How CERN’s Documents Contradict its Safety Assurances:

Plans for ‘Strangelet’ Detection at the Large Hadron Collider

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> *‘Negatively charged strange matter, either as strangelets or in bulk, does not exist on earth. If it is stable and could be created it could react exothermically with ordinary matter, converting everything it touched into more of itself.’*
>
> E. Farhi and R.L. Jaffe, *Phys. Rev.* **D30** (1984) p. 2390

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This is the 5th revision of ‘How CERN Documents Contradict the Bases of Its Own Safety Assurances’.

I Strangelets and the LHC

What is a strangelet?

So first, what exactly is a strangelet? A single sphere or 'bag' can be said to contain a proton or neutron. The term strangelet was coined [1] in 1984, for the case of such a 'bag' that would surround a greater number, than so far known, of the fundamental subnuclear particles called 'quarks' by further including an additional of type of quark. This larger bag, would then include a mixture of the more normal 'up' quarks and 'down' quarks along with the heavier 'strange' quarks. It has been shown that strange quarks are included in many of the particles that are produced in high-energy particle collisions.

... a dangerous strangelet?

The following quotes set the criteria for what would be a 'dangerous strangelet' and elaborate upon the potential catastrophic implications for the transforming of surrounding matter. This is from a paper that is repeatedly referred to – and relied upon – within CERN's own safety analysis. The paper, 'Review of Speculative "Disaster Scenarios" at RHIC' [2] (the 'Relativistic Heavy Ion Collider' – 'RHIC' – operated before CERN's Large Hadron Collider), was produced shortly before RHIC's operation in 2000. On pages 11 and 20 of [2] by Jaffe et al. (pp. 1130 and 1136 of physics journal version) it is stated:

> '*In light of the possible consequences of production of a stable negatively charged strangelet, we shall refer to such an object as a "dangerous" strangelet.'* [1] [Ref. 2, p. 11 ► Exhibit 2]

> *'A strangelet growing by absorbing ordinary matter would have an electric charge very close to zero. If its electric charge were negative, it would quickly absorb (positively charged) ordinary matter until the electric charge became positive. At that point absorption would cease until electron capture again made the quark charge negative. As soon as the quark charge became negative the strangelet would absorb a nucleus. Thus the growing strangelet's electric charge would fluctuate about zero as it alternately absorbed nuclei and captured electrons. Even though the typical time for a single quark to capture an electron might be quite long, the number of participating quarks grows linearly with A, so the baryon number of the strangelet would grow exponentially with time, at least until the energy released in the process began to vaporize surrounding material and drive it away from the growing strangelet.* ***This process would continue until all available material had been converted to strange matter. We know of no absolute barrier to the rapid growth of a dangerous strangelet, were such an object hypothetically to exist and be produced.****'* [Emphasis added.][Ref. 2, p. 20 ► Exhibit 3]

In November 2015, heavy ion (lead-lead) collisions are scheduled to take place at the LHC at nearly double the energy of colliding nucleons reached previously for this type of experiment. Within this context – the question of strangelet production has been raised. What does CERN tell the public about the prospect of strangelets being produced at the LHC?

According to CERN's safety page: '*Strangelet production at the LHC is therefore less likely than at RHIC, and experience there* [at RHIC] *has already validated the arguments that strangelets cannot be produced.'* [2] [3] ► Exhibit 4]

Strangelets at the LHC?

In 2008, the LHC Safety Assessment Group (LSAG) produced a report [4] claiming that: '*The previous arguments about the impossibility to produce strangelets at the LHC are confirmed'*[2] [Ref. 4, p. 13 ► Exhibit 5]

But it can now be shown that claims in the safety report about the non-production of strangelets – are in clear contradiction with two experimental research projects for the LHC. Theoretical or technical articles, presentations and online material relating to LHC detector work have been identified, stating that the production of strangelets is either a likely prospect or a serious possibility at the LHC. Those theorists and experimental researchers working on these projects – affiliated[3] ([5]) with CERN at the time of writing this report – outnumber by at least thirty eight to ten, those affiliated[3] ([5]) with CERN, who had made up the entirety of both LSAG and the CERN Scientific Policy Committee (SPC) (the SPC essentially validated [4] – see [6]). Only one of the latter groups[4] (and from the SPC, not LSAG) has, according to 'Google Scholar' [7], authored or co-authored a paper, other than the LSAG or SPC Reports, that makes any reference to 'strangelet(s)'. But two LSAG members – including its chair – have been involved[4] with the Large Hadron Collider Committee' (LHCC), and the minutes from that committee's meetings imply their familiarity with these CERN strangelet detection projects. In 1996 the later LSAG's chair was a 'referee'assigned[4] to the ALICE detector that was associated at that time with both these projects when they were proposals. In fact, four out of five of the LSAG report authors, for the final version, were at that time members of CERN's Theory Division [4].

One of these projects is in fact, a self-contained detector subsystem that is presently installed and operational as part of one of the LHC's four main detector systems – the Compact Muon Solenoid (CMS). This detector is called CASTOR, short for 'Centauro And STrange Object Research'. Another strangelet search project is associated with the ALICE detector.

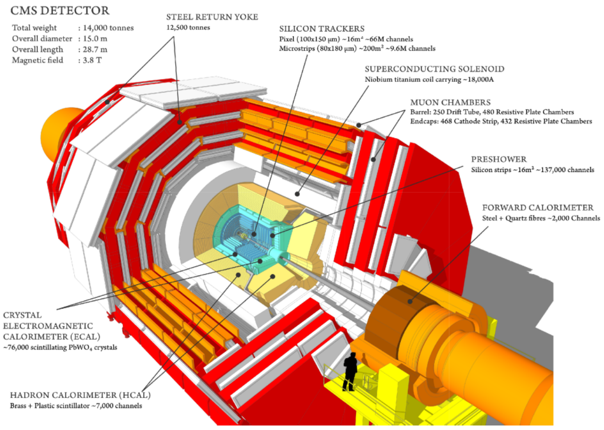
… fulfilling this dangerous criteria?

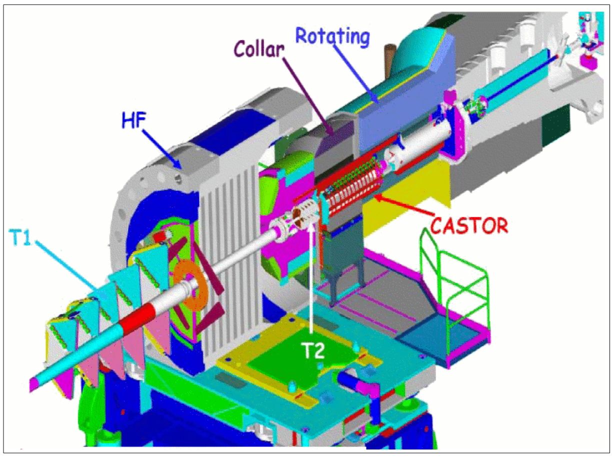
Moreover, these projects indicate that the criteria given above for a catastrophic process can be met by strangelets produced at the LHC. This report shows that many official statements and arguments from CERN, about the possibility for the production of strangelets at the LHC, are contradicted by CERN's own researchers who are directly involved in this research. It is not claimed here that these researchers state that there are dangers, nevertheless, the bases for CERN's remaining safety assurances are also shown to be doubted or contradicted by the published statements or model projections of several physicists.

II Strangelet Searches with the CASTOR Detector of CMS

The CASTOR detector

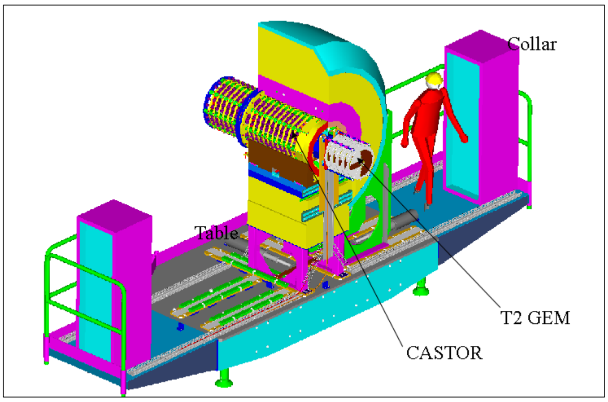
Within the 'Detector' part [8] of the relevant CMS public website, there is no information displayed about the CASTOR detector subsystem. It is not included there within the CMS detector diagram [9] (diagram shown on the right). Like the CMS site, the ALICE detector site [10] is associated with CERN’s main site. The ALICE site however does include subsystem detectors in its diagram, and has its own 'Subdetectors' tab (only the ALICE detector has a comparable number of these subsystem detectors). Though also absent from within the diagram on the right, the ‘TOTEM’ detector (‘T1’ and 'T2' in the diagram below), unlike CASTOR, has a separate 'Experiment' tab even at CERN’s main page [11]. The 'ZDC' detector also isn't included in the diagram, but then it is 140 metres from the main CMS detector.

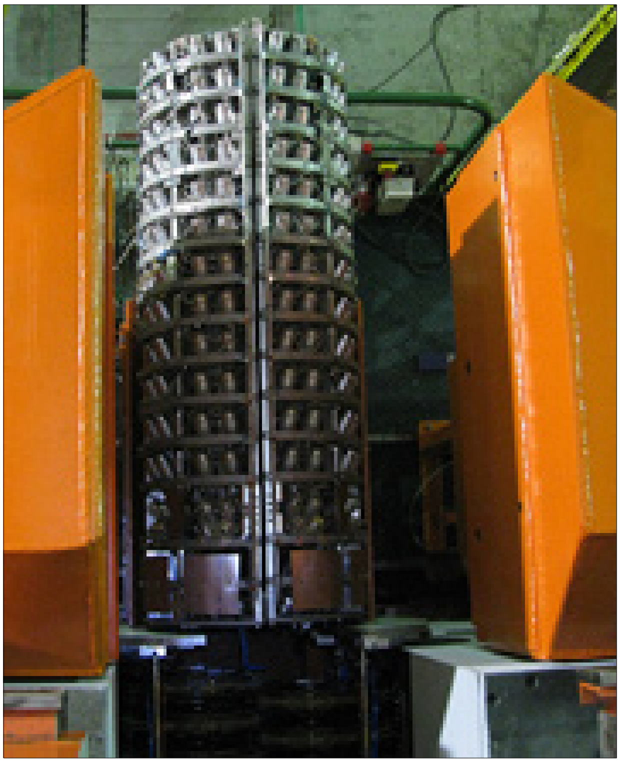




This image though (left), from a CMS newsletter article about CASTOR [12], shows that the detector is installed at the end of the main CMS detector system next to the 'HF' or forward part of HCAL (that is shown above):

Its size is significant (below [13], right [14]):

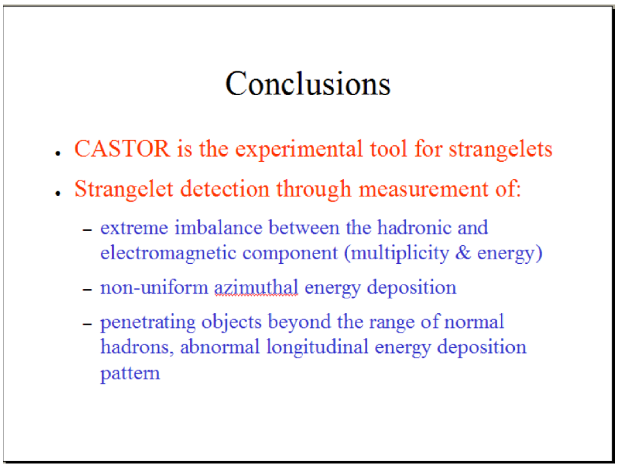




Without prior knowledge of this detector, information about it from CERN would only be traced with difficulty, from within the extended resources of the ‘CERN Document Server’ [15] or deep within the CMS website (such as with the results within the newsletter archives of *CMS Times* [16]) – or from the CMS website for CASTOR [17] that is given in a reference from an article [18]). For casually expressed evidence of its operation in 2009 see [19] ► Exhibit 6].

Aside from those sources, various CERN documents and other physics papers have been found concerning the theory behind the CASTOR detector, and which provide further disclosures (see the listing given on pages 24-26). From CERN's main website [11], no results[3] appear with 'CASTOR' for the detector, and the CASTOR site isn't linkable from it.

The CASTOR website itself shows the prospect of long lived, negative or neutral strangelets is accepted [17]. Yet in CERN's official safety report [4] only unstable (ie short-lived) or positively charged strangelets have been relied upon - similarly with [2] - as having no potentially dangerous implications (though both reports also rely on an astrophysical argument reviewed in Section V).



Conclusions

- CASTOR is the experimental tool for strangelets
- Strangelet detection through measurement of:
  - extreme imbalance between the hadronic and electromagnetic component (multiplicity & energy)
  - non-uniform azimuthal energy deposition
  - penetrating objects beyond the range of normal hadrons, abnormal longitudinal energy deposition pattern

As shown above from this CASTOR presentation slide [Ref. 20,slide 32], the main purpose of the CASTOR detector is the detection of strangelets.

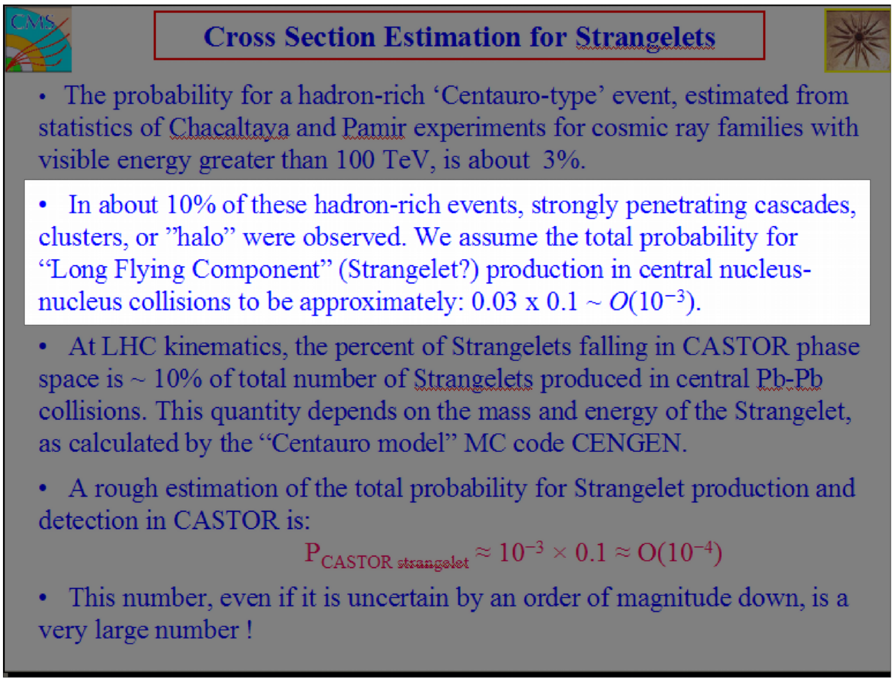
Strangelets *'are likely to be produced'*

The 3rd December 2007 issue of the *CMS Times* reveals the aspirations of a representative of the CASTOR Team:

> *'I work as an experimental physicist for the CASTOR forward calorimeter of CMS and my main area of interest is the study of exotic events in heavy ion collisions, especially the identification of strangelets, which are likely to be produced.'* [21 ► Exhibit 7]

For the podcast associated with this newsletter, the last three minutes appear to have been edited, so that the speaker is neither moving nor audible.

Shown below is a CASTOR theory estimate of the likelihood per collision for strangelet production of around one in three hundred (with the likelihood of detection by CASTOR estimated further below) [Ref. 22, slide 30].



Cross Section Estimation for Strangelets

- The probability for a hadron-rich 'Centauro-type' event, estimated from statistics of Chacaltaya and Pamir experiments for cosmic ray families with visible energy greater than 100 TeV, is about 3%.
- In about 10% of these hadron-rich events, strongly penetrating cascades, clusters, or "halo" were observed. We assume the total probability for "Long Flying Component" (Strangelet?) production in central nucleus-nucleus collisions to be approximately: 0.03 x 0.1 ~ $O(10^{-3})$.
- At LHC kinematics, the percent of Strangelets falling in CASTOR phase space is ~ 10% of total number of Strangelets produced in central Pb-Pb collisions. This quantity depends on the mass and energy of the Strangelet, as calculated by the "Centauro model" MC code CENGEN.
- A rough estimation of the total probability for Strangelet production and detection in CASTOR is:

$$P_{\text{CASTOR strangelet}} \approx 10^{-3} \times 0.1 \approx O(10^{-4})$$

- This number, even if it is uncertain by an order of magnitude down, is a very large number !

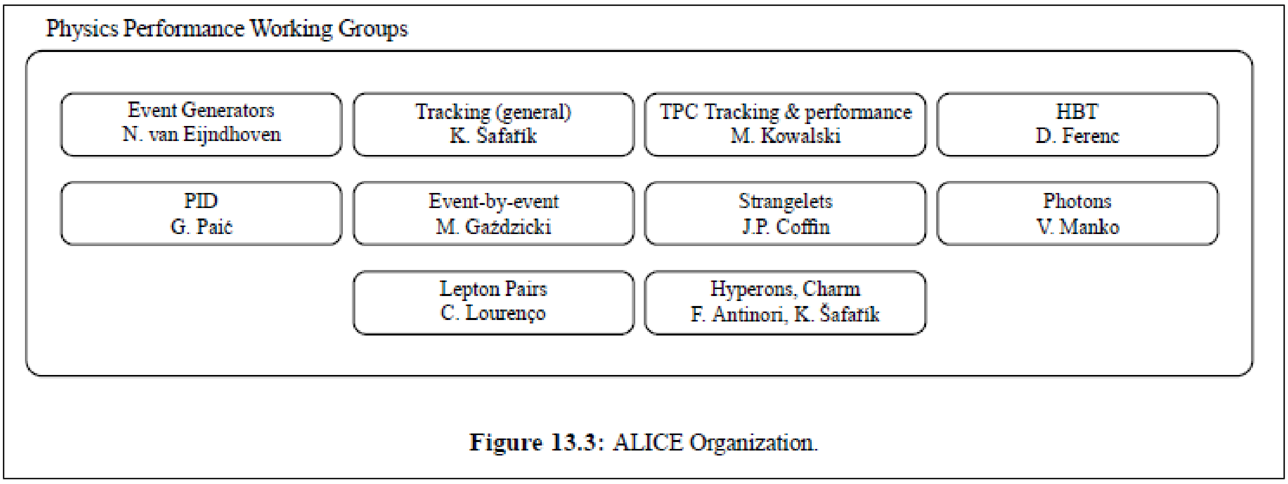
The CASTOR theory of strangelet production is based on the view that there are good indications that strangelets, associated with unusually large showers ('Centauros') of standard particles emerging from cosmic ray collision, have actually been tracked already ([23], contradiction ‘2’) – at an average of slightly above the energies correlated to that of the earlier RHIC (heavy ion) collider (the most similar collider to LHC). These interpretations were based on analyses of mountain-based cosmic ray detector results of the 70's.

These views concerning detected strangelets, themselves contradict two claims of the LSAG report [4] – that there is no evidence for the existence of strangelets and that strangelet production likelihoods decrease with collision energy (see contradictions ‘6’ and ‘2’ respectively in the table below). In relation to the naturally occurring cosmic rays, CASTOR theory argues that the emerging strangelets were increasingly disrupted [23] by subsequent collision with the nuclei of the cosmic ray detector.

CASTOR theorists have also indicated that both stable and negative or neutrally charged strangelets are feasible (as shown in the contradiction ‘4’ of table below), thus fulfilling the criteria above for dangerous strangelets (see also table related comment).

III Strangelet Searches with the ALICE Detector

This chart below from the ‘ALICE Technical Proposal’ [Ref. 25, p. 224] shows the Strangelets Physics Performance Working Group at ALICE, led by J.P. Coffin:



Physics Performance Working Groups

Event Generators
N. van Eijndhoven

Tracking (general)
K. Šafařík

TPC Tracking & performance
M. Kowalski

HBT
D. Ferenc

PID
G. Paić

Event-by-event
M. Gaździcki

Strangelets
J.P. Coffin

Photons
V. Manko

Lepton Pairs
C. Lourenço

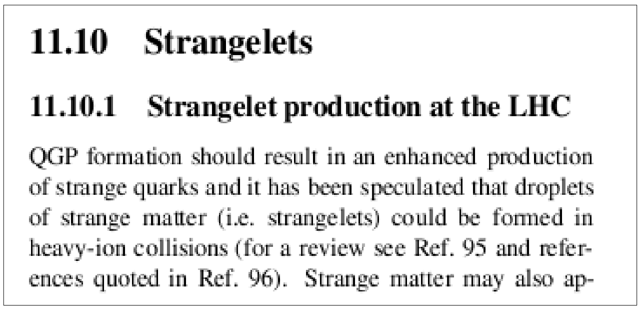
Hyperons, Charm
F. Antinori, K. Šafařík

Figure 13.3: ALICE Organization.

Chapter 11 of this document considers the physics that will apply for the ALICE detector. Strangelets are analysed for how they would be detected [Ref. 25, pp. 189-192: see text on right]. This relies upon the theoretical arguments enabling strangelet production for this context, described as involving ‘fluctuations in net baryon number’[6] [Ref. 26, p. 1776]. These issues – entirely neglected by the LSAG report [4] – have been put forward to explain how strangelets could emerge so as to be detected by the central parts of the ALICE detector.

For this scenario of so called ‘midrapidity’[6] production, it is clear that the strangelets produced could be moving slowly enough not to be subsequently destroyed by collisions with surrounding matter, as the given location of their detection range in ALICE would correlate to this slower ‘rapidity’ prospect. (‘Rapidity’ is an alternative measure for the component of velocity along the beam direction.) In this regard, Jaffe et al. state: ‘*Since strangelets produced at high rapidity are likely to be destroyed by subsequent collisions, . . .*’ [Ref. 2, p. 20 ► Exhibit 8]. So any such sufficiently stable midrapidity LHC strangelets would therefore survive collision.

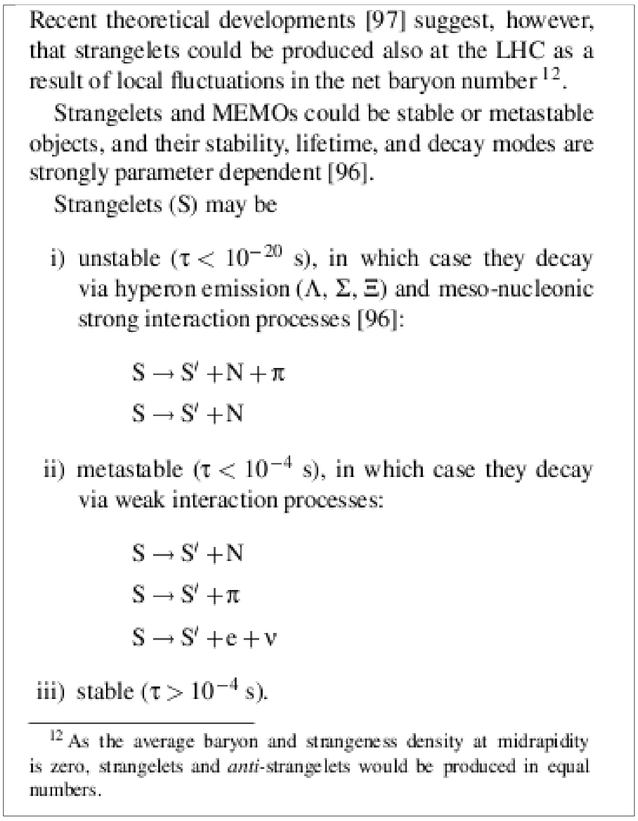
This Jaffe et al. paper, indicates that a negative strangelet lasting over one 10 millionth of a second (10^{-7}s), so as to traverse the detector [Ref. 2, p. 20 ► Exhibit 9], could be potentially dangerous. But durations well beyond this are seriously considered (see text on right) [Ref. 25, p. 189], while negative or neutral strangelets are allowed (see contradiction ‘4’ in the table).



11.10 Strangelets

11.10.1 Strangelet production at the LHC

QGP formation should result in an enhanced production of strange quarks and it has been speculated that droplets of strange matter (i.e. strangelets) could be formed in heavy-ion collisions (for a review see Ref. 95 and references quoted in Ref. 96). Strange matter may also ap-



Recent theoretical developments [97] suggest, however, that strangelets could be produced also at the LHC as a result of local fluctuations in the net baryon number[12].

Strangelets and MEMOs could be stable or metastable objects, and their stability, lifetime, and decay modes are strongly parameter dependent [96].

Strangelets (S) may be

i) unstable ($\tau < 10^{-20}$ s), in which case they decay via hyperon emission (Λ, Σ, Ξ) and meso-nucleonic strong interaction processes [96]:

$$S \rightarrow S' + N + \pi$$
$$S \rightarrow S' + N$$

ii) metastable ($\tau < 10^{-4}$ s), in which case they decay via weak interaction processes:

$$S \rightarrow S' + N$$
$$S \rightarrow S' + \pi$$
$$S \rightarrow S' + e + \nu$$

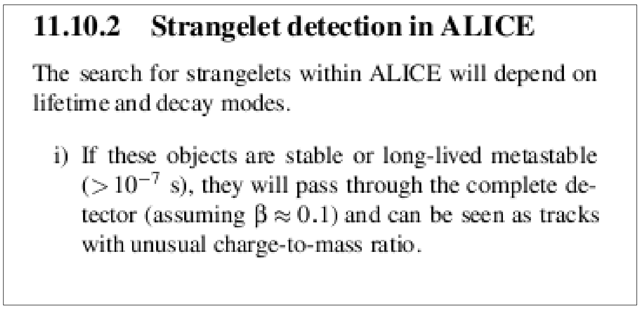
iii) stable ($\tau > 10^{-4}$ s).

---

[12] As the average baryon and strangeness density at midrapidity is zero, strangelets and *anti*-strangelets would be produced in equal numbers.

Included under section 11.10.2 [Ref. 25, pp. 190-192] is a detailed study of the ALICE detector indications for long lived or stable strangelets, produced by collision and passing through the detector. This is given after the text partly shown to the right [Ref. 25, p. 190].

Again, the potential for enabling strangelet detection – and for strangelets to meet the criteria for being classified as dangerous – are satisfied.



11.10.2 Strangelet detection in ALICE

The search for strangelets within ALICE will depend on lifetime and decay modes.

i) If these objects are stable or long-lived metastable ($> 10^{-7}$ s), they will pass through the complete detector (assuming $\beta \approx 0.1$) and can be seen as tracks with unusual charge-to-mass ratio.

IV The Contradictions between CERN’s Safety Report and the Statements of the CASTOR Team and ALICE Collaboration

CERN's Safety Report	**Statements from CASTOR Physicists**	**Statements from ALICE Physicists**
1. Likelihood of strangelet production at the LHC		
‘The previous arguments about the impossibility to produce strangelets at the LHC are confirmed and reinforced by the analysis of the RHIC data.’ [2] [Ref. 4, p. 13 ► Exhibit 5] — *‘Our conservative estimate for the thermal production of a normal $A = 10$ nucleus at the LHC was 3 x 10^{-25} times the rate of nucleon production. Taking the latter rate to lie in the hundreds, we arrive at a probability of 10^{-13} that a single normal nucleus of size $A = 10$* [10 proton masses] *is produced during the entire LHC program as a result of the essentially thermal dynamics in a heavy ion collision. So, if LHC would run for the entire lifetime of the universe, the probability of producing such a single nucleus via thermal production would be 1/1000*[Note]*.* *We note that the above is an estimate for the thermal production of a normal $A = 10$ nucleus from a hadron gas of temperature $T = 165$ MeV. The production of normal nuclear matter provides an extremely conservative upper bound on the production of strange quark matter.’* [2] [Ref. 4, p. 19 ► Exhibit 10] — Note: MeV is one million ‘electron volt’ units of energy.	*‘We assume the total probability for “Long Flying Component” (Strangelet?) production in central nucleus-nucleus collisions to be approximately: 0.03 x 0.1 ~ $O(10^{-3})$’* [Ref. 22 slide 30 ► Exhibit 11] Note: For each collision, a chance of around one in three hundred. The LHC expects to have up to 10 billion central heavy ion collisions. [Ref. 4, p. 19 ► Exhibit 12]. This number of collisions would be expected to produce about 10 million strangelets. — “Strangelet” Cosmic Rays LHC *Mass 7 - 15 GeV 10- 80 GeV* [Ref. 27, tab. 1, p. 6 ► Exhibit 13] — Comments: In 2010-11 two CASTOR theorists, Onel and Norbeck, gave a brief talk [63] and co-authored papers [64,65] suggesting that these strangelets couldn't be produced for detection by CASTOR or ALICE Nonetheless, these physicists are only 2 out of the 38 CASTOR theorists or experimental researchers. However, the details given under the CASTOR website [17], within six other CASTOR papers produced since [44] (see list on p. 24 including [66] of 2011) and in the 2012 revision of [23(v2)] indicate that the potential applicability of the CASTOR theory for strangelet production is still largely accepted by the team. (See also first comment of this table under contradiction ‘3’). In fact Onel and Norbeck suggest that strangelets, or more recently [65], strange hypernuclei objects ('MEMO's), could be produced – but largely outside of the impact of the collision.	*‘The distillation of very small strangelets of $A_B \leq 10$ . . . cannot be excluded for the midrapidity region at colliders.’* [Ref. 26, p. 1779 ► Exhibit 14] Note: A_B=A; so A_B= 10 is equivalent to the mass of 10 protons. The ‘midrapidity region’ enables slow moving strangelets to be produced.

CERN's Safety Report	Statements from CASTOR Physicists	Statements from ALICE Physicists
2. Likelihood of strangelet production at LHC compared to previous accelerators or colliders		
'We conclude on general physical grounds that heavy-ion collisions at the LHC are less likely to produce strangelets than the lower-energy heavy-ion collisions already carried out in recent years at RHIC, just as strangelet production at RHIC was less likely than in previous lower-energy experiments carried out in the 1980s and 1990s' [Ref. 4, p. 11 ▸ Exhibit 15]	*Other Centauro properties* • *Centauros are observed in the very high energy region. The energy threshold for their production is about 1000 TeV* [total neclei-nuclei energy]. . . . [Ref. 23(v2), tab. 4.1, p. 16] — *"Centauro" event* . . . *Total interaction energy in N-N c.m.* $\sqrt{s_{N\text{-}N}} \geq 233$ *GeV* [Ref. 23(v1), tab. 4.1, p. 84 ▸Exhibit 16] — Note: Associated with the CASTOR theory of strangelet production, the post-collision 'Centauro' particle shower; the threshold given is for a different reference frame from LHC/ RHIC collisions: one could roughly estimate this to correlate to the region of 100GeV per colliding nucleon pair. The energy (per nucleon pair) for these Centauro observations averages slightly above the energies of RHIC collision (√sNN = 200 GeV) at √sNN (233 GeV) – higher again than previous heavy ion colliders. Also note that according to [Ref. 66, pp. 1383-4] RHIC's non strangelet detection results can be explained by its limited detection ranges – here only close to the tangential direction of the beam, far from the collision point.	*'. . . we have to consider that the overall conditions for QGP* [quark gluon plasma] *formation and existence should be better at RHIC and even more at LHC than at all other accelerators. Consequently, if a strangelet really needs a QGP to be created, its production probability could be enhanced at the new colliders.'* [Ref. 28, p. 1055 ▸ Exhibit 17]; also [Ref. 29, pp. 1709-1710]
3. Production of strangelets through 'strangeness distillation'		
'So, there is no evidence for a distillation mechanism capable of strangelet production at RHIC, and this suggestion for strange particle production has been abandoned for the LHC.'[7] [Ref. 4, p. 19 ▸ Exhibit 18]	*'Strangelet formation via a mechanism of strangeness distillation is possible .'* [Ref. 18, p. 2 ▸ Exhibit 19] Note: Details of this mechanisms are given the CASTOR site [17], from [Ref. 20, slide 14 ▸ Exhibit 20] or [CASTOR Pres, slide 5]. — Comment: Onel and Norbeck argue in [65] that in the basic strangeness distillation theory outlined by Greiner and Stöcker [67], the temperatures reached (at 'chemical freeze out') from collider collisions needed to be around 100MeV for stable strange quark matter (strangelets) to be produced.	*'Moreover some calculations* [ref.] *indicate that, even at LHC where* μ_B *is expected to be almost zero, there might be non-negligible fluctuations of different rapidity bins in the central region. Hence distillation could take place locally.'* [Ref. 28, p. 1055 ▸ Exhibit 22] — *'The formation of exotic multistrange objects may proceed as strangelet distillation out of a QGP droplet or as clustering of (anti)hyperons.'* [Ref. 26, p. 1779 ▸ Exhibit 23] —

CERN's Safety Report	Statements from CASTOR Physicists	Statements from ALICE Physicists
	However this value relates specifically to another attribute of the strangelet according to [67] which is known as the 'bag constant'. So higher values for the bag constant than given in [65,67] (<150MeV) would allow for higher temperatures. Stable strangelets have since been allowed at a significantly higher value for the bag constant (170MeV) [Ref. 62, fig. 4, p. 3]. Also note that according to [30], this particular mechanism is not necessarily the only one needed by CASTOR theory to enable strangelet production. [Ref. 30, p. 10 ► Exhibit 21]	Note: 'Clustering' here refers to the alternative 'coalescence' mechanism. — See also the entry for this column in contradiction '1'.

4. Negatively charged or neutral strangelets

'It is generally expected that any stable strangelet would have a positive charge, in which case it would be repelled by ordinary nuclear matter, and hence unable to convert it into strange matter[ref.]*.'* [Ref. 4, p. 9 ► Exhibit 24] — *'Unreasonably low values of the bag constant* [with lower energy density around the quarks] *are necessary to compensate for a large repulsive gluonic interaction energy, which is why negatively charged strangelets are regarded as extremely unlikely.'* [Ref. 4, p. 15 ► Exhibit 25]	*"Strangelet" Cosmic Rays LHC* *. . .* *Z [charge] ≤ 0 ≤ 0* [Ref. 31, tab. 1, p. 3 ► Exhibit 27]. [Ref. 23(v1), tab. 6.3, p. 112 ► Exhibit 26] See also: [17], [Ref 64, p. 2], [Ref. [23(v2), tab.13, p. 83] — *'Generally, for higher bag parameter values* [higher energy density between the quarks] *there are less long–lived strangelets and they are shifted towards higher values of baryon number A, strangeness factor fs and towards higher negative charges.'* [Ref. 23(v1), pp. 76-77 ► Exhibit 28] — Comment: [Ref 27, p.8] (2002) – though a talk by only Gladysz-Dziadiuś – could appear to suggest that various CASTOR theorists had by this time abandoned negative strangelets at LHC, though this isn't stated directly, the detail referring to those of intermediate size. As noted the CASTOR website still includes the negative strangelet prospect and the above-mentioned [23(v2),64] (2012, 2010) CASTOR theorists appear to accept the negative strangelet prospect. This post 2002 situation could relate to a perhaps clearer acceptance of possible stable negative strangelets given [62], which itself supersedes the papers relied on by [27] that criticises the negative strangelet scenario.	*'In heavy-ion reactions strangelets and MEMOs might be found in the final state as objects with baryon number A ≈ 2–40* [between 2-40 proton masses]*, Z/A ratio ranging from ~-0.5 up to +0.5'* [Ref. 25, p. 189 ► Exhibit 29] Note: A Z/A ratio ranging from -0.5 up to +0.5 implies a charge that is negative, neutral, or positive.

CERN's Safety Report	Statements from CASTOR Physicists	Statements from ALICE Physicists
5. Stability of strangelets with masses below that of 10 protons		
'Finite size effects make it very unlikely that small strangelets ($A < 10$) can be stable or long-lived.'[8] [Ref. 4, p. 14 ▸ Exhibit 30] Note: $A < 10$ is a mass less than that of 10 protons.	*'There are also predictions that quite small strangelets might gain stability due to shell effects* [refs.]*. They are called "magic strangelets". However, due to the lack of theoretical constraints on bag model parameters and difficulties in calculating colour magnetic interactions and finite size effects, experiments are necessary to help answer the question of the stability of strangelets.* [Ref. 23(v1), p. 77 ▸ [Exhibit 31], [Ref. 23(v2), p. 58]	*'Special (meta)stable candidates for experimental searches are the quark alpha* [ref.] *with $A_B = 6$ and the Hdibaryon with $A_B = 2$* [ref.].*'* [Ref. 26, p. 1779 ▸ Exhibit 32] Note: A_B=A (atomic mass units). — *'There is a mass range, below 2055 MeV (the mass of a lambda and a neutron), where it [Hdibaryon] could only decay by a doubly weak decay into two neutrons. This is a $\Delta S = 2$ reaction and leads to a predicted lifetime of the order of days.'* [Ref. 29 p. 1708 ▸ Exhibit 33] — *'Strangelets and MEMOs could be stable or metastable objects and their stability, lifetime, and decay modes are strongly parameter dependent [ref.]'* [Ref. 25, p. 189 ▸ Exhibit 34] — under *'Stable or long-lived strangelets'*: *'As an example, we consider strangelets with $Z = 1$ and $Z = 2$ and a mass between 6 and 15 GeV (i.e. $\lvert Z/A \rvert < 0.3$)'* [Ref. 25, p. 190 ▸ Exhibit 35]
6. Existing observational data and the existence of strangelets		
'More recently, additional direct upper limits on strangelet production have been provided by experimental searches at RHIC [ref.] *and among cosmic rays* [ref.]*, which have not yielded any evidence for the existence of strangelets.'* [Ref. 4, p. 9 ▸ Exhibit 36]	*'The simulations show that transition curves, produced by strangelets during their passage through the* [cosmic ray detector] *chamber, resemble the experimentally detected long many-maxima.'* [Ref. 18, p. 3 ▸ Exhibit 37] — *'The old* [comic ray detection] *experimental results are also worth to recalling. Anomalous massive (A=75...1000) and relatively low charged objects (Z=14...46), which could be interpreted as strangelets, have been observed.'* [Ref. 23(v1), p. 79 ▸ Exhibit 38] [Ref. 23(v2), p. 60] —	

<table>
<tr><th>CERN's Safety Report</th><th>Statements from CASTOR Physicists</th><th>Statements from ALICE Physicists</th></tr>
<tr><td></td><td><i>'. . . two SQM candidates have been found during the AMS prototype flight.'</i>
[Ref. 66, p. 1383]
Note: SQM (strange quark matter) here refers to a strangelet and AMS was the 'Alpha Magnetic Spectrometer' prototype flown on the Columbia Space Shuttle.
—
Note: For the above quotes each refers to a different set of data – the second itself referring to several.</td><td></td></tr>
<tr><td colspan="3">7. Comparison of LHC with cosmic-ray collisions*</td></tr>
<tr><td><i>‘. . . This is because cosmic rays have a significant component of heavy ions, as does the surface of the Moon.’</i>
[Ref. 4, p. 12 ► Exhibit 39]</td><td><i>‘It is assumed that cosmic ray showers are caused by nuclei, protons through iron, hitting the atmosphere. If CASTOR does not find events that can be identified with the anomalous cosmic-ray events, this assumption may need to be reconsidered. Pb-Pb collisions with the LHC will have an energy 28 times that of Au-Au collisions studied at RHIC. With this huge increase in energy a wealth of new phenomena is almost assured. Because of the much larger mass number, Pb-Pb events can be expected to show exotic phenomena that is beyond the reach of cosmic rays.’</i>
[Ref. 18, p. 1 ► Exhibit 40]
—
* The intended meaning of this quote is unclear – so this isn't necessarily a contradiction as such. The quote may argue that at or above LHC correlated energies, cosmic ray showers are not <i>only</i> ‘caused by nuclei, protons through iron’, but as ‘only’ is not stated it could mean ‘not any’. (There are no direct detections of primary cosmic rays at such energies). Similarly, given the word ‘phenomena’, the last sentence of the quote may be referring only to detectable or observable indications of cosmic rays – but without the closing word ‘detection’ this isn't clear.</td><td></td></tr>
</table>

V Published Physicists' doubts or counter indications concerning further Safety Arguments given by CERN Physicists

Below, CERN's remaining safety assurance arguments, and the critiques or counter indications of them provided from physicists, are given. The first case concerns astrophysical assurance arguments of the LSAG report [4] and mentioned by Gladysz-Dziaduś for the CASTOR team [27]. The second relates to an argument of both CERN's earlier LHC report [32] and [27]. The third case relates to a specific argument of [27] and the fourth to a further argument raised by two CASTOR theorists [65].

1. Survival of the Moon.

The LSAG report [4] relies here upon the analysis of Jaffe et al. (2000) [2] that was quoted near the beginning of this report. In this argument, enough emerging strangelets from cosmic ray to lunar collision would be slow moving enough to survive collisions with subsequent nuclei. This would then have led to a lunar catastrophe if there was to be a strangelet danger at LHC, yet clearly this lunar catastrophe hasn't occurred. So the survival of the Moon is presented as a reassurance argument against strangelet risks from LHC.

However, this argument is itself questioned by theoretical physicist Kent [33] and the nuclear physicist Calogero [34]. In fact, the equivalent argument had been judged by three physicists from CERN's Theory Department as not completely reliable in a 1999 paper [35]. They stated: *'But, alas, there is a potential flaw in the argument.'* Their counter-argument concerned cosmic ray collisions only producing strangelets in the region of 'midrapidity' – which only means slow moving in relation to the centre of momentum reference frame of the collision system. So for this case, such midrapidity strangelets would be so fast moving that they would anyway be destroyed by subsequent collision. But such midrapidity strangelets from the LHC can be too slow moving to be destroyed from subsequent collision. This Dar et al. paper, [35], is referenced by LSAG, but no acknowledgement is given of that criticism, or of other questions as to the reliability of Jaffe et al.'s astrophysical safety argument, in the LSAG's report. The LSAG report claims that the argument is strengthened by existing data from RHIC and supposedly concerns a sufficiently wide rapidity range of strange baryon production. But no reference is provided for this claim. In fact, relevant RHIC data [56,57] appears insufficient[9] to support it. The conditions for inapplicability of this safety argument need not be so specific as given above by Dar et al. in [35], and a broader version (a) below) of this counter-argument, along with further doubts (b – e)) about this astrophysical reassurance are elaborated in detail by Kent. These concern uncertainties in relation to: a) Jaffe et al.'s presumptions [2] of the feasible range of speeds for any strangelets emerging from lunar collisions, b) the strangelet speed at which it is at least partly destroyed by collisions with subsequent nuclei, c) the extent of slowing by momentum, resulting from the previous collision with nuclei, upon any surviving strangelet fragments and d) the comparability of the much heavier gold or lead ions of high energy colliders, to the iron nuclei which are expected to frequently occur in higher energy cosmic rays.

In the CASTOR theory version [27] of this argument, from a talk for the CASTOR team by Gladysz-Dziaduś, it is added that the CASTOR theory explanation of certain cosmic ray detections as involving strangelets or of actual (primary) cosmic ray strangelets as the cause would imply that safety argument a) would become more particularly applicable. But clearly this is only relevant if the arguments in favour of the disputed a) apply.

Despite Gladysz-Dziaduś' application [27] of this safety argument, the paper does not really consider whether the cosmic ray induced strangelets of CASTOR theory could in fact be too fast moving to survive disruption. While clearly the following argument is not being made by the CASTOR theorists themselves, it is also apparently not considered by them. An indication from a CASTOR theory graph[10] [Ref. 36, fig. 9, p. 13 ► Exhibit 41], either reinforces or makes relevant the risk implied doubts a) - c). This relates to the differing configuration of LHC's two-way collisions to the one-way collisions at the Moon. One consideration from the graph is associated with doubt a), as the graph suggests that no such dangerously slow moving strangelets would occur at the correlated energy when considered for the Moon case[10]. As discussed above and in Section III, emerging strangelets – the type which could be identified by the main ALICE detector – can be slow moving enough to survive and so potentially grow catastrophically. The further safety doubts of astrophysical assurance implied by d), refer to the comparability of the unusually high atomic mass of RHIC or LHC's heavy ions with the much less frequently expected lead cosmic ray nuclei (too infrequent for reassurance in the Moon collision case). But this suggestion of incomparability of iron cosmic rays, is also effectively relied on in Dar et al.'s [35] construction of a different type of safety argument, which involves predictions not of iron nuclei, but of the much lower frequencies – if any – of lead nuclei cosmic rays (though this safety argument of [35] is itself disputed [2,33,34] for only considering fully stable strangelets, not long-lived 'metastable' ones). This doubt d) may perhaps be further extended to the possibility of no heavy ion high energy cosmic rays, given the statement of CASTOR theorists quoted in contradiction '7' of the table, but, as previously indicated, this depends on intention of the authors of [18].

A further doubt, e), that is implied elsewhere, [23,35,29] and not contradicted by Kent, concerns the potential irrelevance of lower than RHIC or LHC correlated cosmic ray energies for enabling strangelet production, and the related diminishing number of cosmic rays at these higher energies. Doubt e) is also supported by another feature within the basis of Dar et al.'s safety argument, where it conservatively assumes a minimum of either RHIC or LHC correlated energies, to enable strangelet production from cosmic ray collision – an argument compatible with both CASTOR and ALICE theory (as discussed in Sect. II and quoted in contradiction '2' of the table). Furthermore, the view that higher than RHIC related energies are required to produce strangelets from cosmic rays is given by [29], also under ALICE related contradiction '2'.

2. Charge of growing strangelets when reaching intermediate mass

A further argument (not in fact included in the LSAG report itself) was emphasised in the earlier 2003 CERN safety paper [32]. This entails that intermediate mass strangelets – such as initially negative LHC strangelets after subsequent growth through catalysis – would be unstable and (presumably) decay into positively charged strangelets, due to predicted effects upon strange quarks near the edge. But the arguments on which this on which this relies, based upon [68,69] ([69] potentially applying to all negatively charged 'colour flavour locked' (CFL) strangelets), is subsequently put into doubt by Peng et al. [62], in 2006, for the candidate CFL strangelets. This latter paper is neglected by the LSAG report [4] – despite that it refers to another recent strangelet paper [37] that shares two out of three of its authors. In [62], Peng et al. indicate that, for a range of parameters, the stability of negative (or neutral) strangelets can apply without such restrictions for the intermediate mass strangelets. While the LSAG cited [37] of Wen et al. doesn't specify stable negative strangelets, as the parameter values chosen for its calculations are limited (most relevantly in respect to '$D^{1/2}$') such that the impression of 'no stable negative strangelets' for [37] might be taken. It is such an impression that is here relied on by LSAG in [4] to again undermine the viability of stable negative strangelets in particular, but no such statement is given [37] about the impossibility of stable negative strangelets at the end of their paper Wen et al. [37] acknowledge their limited exploration of parameter values[11] and mention uncertainties about their application of this model. In Gładysz-Dziaduś' version of this safety argument, [27], [68,69] are also cited in support. Further papers, written after [68,69], suggest further bases for strangelet stability, for example [70], or even of negative strangelets having greater stability than other types [71] – though this not discussing [68,69]).

3. Lower rate of 'midrapidity' strangelets than CASTOR theory strangelets

The last reassurance given in [27] is the much lower rate of strangelet production from the midrapidity range than of the high rapidity strangeletsrelated to CASTOR theory. In the latter case, supposedly, safety argument '1.' would thereby more specifically apply with strangelets according CASTOR theory and would then have led to a lunar catastrophe. But even a much lower rate of midrapidity strangelet production can still present danger where the above-mentioned criticisms of safety argument '1.' are applicable. To clarify, as mentioned above, safety reviews have assumed that for the cosmic ray to moon case, midrapidity strangelets would be so fast moving that they would anyway be destroyed by subsequent collision. However, as was also recognised by these reviews, such midrapidity strangelets at the LHC, such as those according ALICE theory, can be too slow moving to be destroyed from subsequent collision.

4. Simultaneous decays processes required for growth of strangelet implies no danger

In the 2011 paper [65] Onel and Norbeck make the argument that any sufficiently stable LHC strangelet would take too long to catalyse surrounding matter to lead to a continuously growing strangelet because in order for the requisite lower energy state to be attained, all of the decay processes – for the attached ordinary nuclei to reach the new larger strangelet – would have to occur simultaneously. This issue is mentioned in it [2,35] though not relied on there as a formal safety argument. Yet it is well established[12] that catalysis from neutron stars to 'strange stars' (also known as 'quark stars') is plausible [71,72]. A period of days for this catalysis to occur has recently been proposed to explain astronomical data [73]. No explanation is offered as to how this could happen if there would be such a decay barrier. See also end of quote on 1st page of this report for the relevant Jaffe et al. safety review statement [Ref. 2, p. 20 ► Exhibit 3].

VI Conclusion and Recommendation

It is has been shown that regarding strangelet production at the LHC, CERN presents us with two sides. The LHC research side looks more inward, fulfilling CERN's functional role. For it, free of a concern to reassure the public, the viability of producing long-lived strangelets that can be negatively charged or neutral, is accepted. The other looks more outward, as if bearing the responsibility for continuing LHC's heavy ion project. This side assures us that this could not occur and, largely as a result, that LSAG's most emphasised and direct criteria for danger don't apply.

For the remaining safety reassurances that CERN has discussed, various published works of physicists demonstrate the insufficient and unsatisfactory nature of them. So particularly, if cosmic ray induced strangelets would have been already occasionally observed – as suggested by CASTOR theory – and that furthermore ALICE strangelet theory is applicable, then the more rare ALICE theory related LHC strangelets can dangerously survive whilst the analogous ones – CASTOR or ALICE – from cosmic rays would be too fast to survive disruptions from subsequent collision.

CERN's withholding of relevant information and negligence from its safety assessments is particularly significant given the magnitude of what is at stake. CERN has misled the public to the extent that its mandate to conduct heavy ion collisions comes under question.

Under such circumstances with the continuation of heavy ion collisions from November 2015, at an energy approaching the LHC design energy, the prospect of a continual increase in the accumulated rate of overall growth for increasing numbers of dangerous, catalysing strangelets appears a real possibility. So the safety of the public needs to be addressed. We recommended that no further heavy ion collisions be permitted at the LHC prior to the conclusion of an independent multi-disciplinary safety review. This panel should be fully independent of CERN, and conduct a thorough and transparent review of all LHC risks. It should consider LSAG's neglected issues associated with these collisions and review publicly submitted critiques of LHC safety.

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Further Notes and Comments

1. The use of quotes here appears to relate to the uncertainties expressed in the paper [2] about whether or not the results of these strangelets would *necessarily* be catastrophic, and to the astrophysical assurance argument given in that paper. However, given that the word is used in the paper elsewhere without quotes for this context and that the astrophysical reassurance arguments are themselves criticised or questioned by other physicists I refer to dangerous strangelets without quotes.

2. **Concerning likelihood of strangelet production:**
LSAG's likelihood estimates disregard calculation for producing smaller strangelets, on the basis that these wouldn't be stable enough to be hazardous – a claim itself disputed (see contradiction '5' of the table) by CASTOR or ALICE related theories. For smaller mass strangelets, likelihoods would then become significant over the operational lifetime of the LHC (see above), even with LSAG's supported production models. This is much more greatly the case for the particular possibility of long lived A=2 Hdibaryon that is mentioned in contradiction '5' of the table and below. The LSAG report quote given in Section I continues: *'. . . and reinforced by the analysis of the RHIC data.'* This 'confirmation' refers to the two models accepted by CERN in relation to likelihood of strangelet production at LHC are the coalescence and thermal models. The thermal model relies on overall unlike particle correlation data to reconstruct what the results would be for specific particle ratios under the model. But it is acknowledged even by papers promoting the thermal model, that it involves problems reproducing the range of results at certain energy levels [38]. The thermal model is disputed as needed for explaining various results, according to Schaffner-Bielich et al. [39], as the differing model that his own group used was successful for a further set of data, whilst this model [39] was itself incompatible with a projection of the thermal model. This other model itself involved a notion ('colour glass condensate') for which further indications of validation have been shown by [40] and [41]. The coalescence model yields give a much greater range of values for strangelet production probabilities than does the thermal model. The LSAG Report production estimates for the thermal or coalescence model are based only on data for the 'midrapidity range', though it has been shown in [42] how a wider rapidity range selection can increase the likelihood significantly, or enhance the factors that would effect this likelihood ([44]). Also neglected is CERN's previous LSSG report [32] claim that strangelet production prospects increase if the mechanism known as 'colour-flavour-locking' (CFL) applies – a form of strange matter that is explored in [62].

3. This means 'at the time of writing the original version of this report'. The CASTOR and CASTOR website search attempt, though, was checked for the current version of the report. In relation to CERN affiliation, proof can be supplied if necessary by contacting the author.

4. P. Braun-Munzinger of the SPC is listed for the ALICE collaboration within the ALICE Technical Proposal and is listed [5] for ALICE at the time of writing the original version of this report. LSAG's I. Tkachev is listed for CMS. The two LSAG members are M. Mangano and J. Ellis. Before becoming LSAG chair, J. Ellis, presented at a conference in 1999 where a CASTOR talk was held with its title referring to 'strangelets from LHC', while a further one was CASTOR theory related [43]. Such facts would have at least been apparent from the programme. Note that the earlier CERN documents from 1996 in the 'List of CASTOR Papers' (p. 24 of this report), were made available during the time that J. Ellis was an ALICE referee (as shown by the first document given in [43]).

5. Also, the CMS website's search function hasn't been functioning up to the time of writing the first version of this report.

6. Net baryon number refers to the net surplus of bayonic matter above baryonic antimatter (baryons are made up of quark triplets bound together by 'gluons'). The context for this argument is – 'midrapidity' – is the circumstance for emitted particles within the slowest category, for their component of velocity along the beam direction. The LSAG report several times refers to the paper [44], which details the thermal model that CERN accepts. Here it is stated: '*In this description, the net value of a given charge (e.g. electric charge, baryon number, strangeness, charm, etc.) fluctuates from event to event.*' [Ref 44, p. 33].

7. **Concerning doubts over 'strangeness distillation':**
The cosmic ray data suggesting collision induced strangelets at around or above RHIC energy is, irrespective to the unlike particle ratios results at RHIC, a central issue about what could be different features of collision results at energies above previous heavy ion colliders. More generally though, near the end of sect. 3.1 [45] it is

indicated that particle yield ratio results (like those relied on by LSAG to support the thermal model) – for stable or metastable strnagelets – could yet be explained by strangeness distillation models, once 'lattice gauge' theory is taken into account. LSAG refers to RHIC data to claim that the QGP is too short lived to enable strangeness distillation. However the collision detectors are unable to directly measure the duration of this assumed QGP state so a 'blast wave' model is relied on for the estimates LSAG cites for the 'too short-lived' claim. The LSAG referenced paper for this estimate [46], cites [47] for the relevant calculations. The following is stated about this model [Ref. 47, pp. 2-3] – '*With eight freely tunable parameters, it is a toy model with little predictive power'*. The paper [48] dismisses the concept relied on for this estimate – 'boost invariance' – as demonstrably inapplicable. As the blast wave model involves 'radial flow', it thereby according to [39] becomes doubted and not needed to explain results (like with the thermalised model[2] above) as for some data at least, this can be alternatively achieved. LSAG's 'net nucleon density is small' claim [4] for RHIC results neglects the potential for 'fluctuations of net baryon number', as discussed in [26] for the relevant midrapidity. Three papers [49-51] of 2000-2005 consider strangeness distillation as a way to explain an anomaly of thermal model data present at that time – one of those authors (Redlich) had previously co-authored the main thermal model paper [44]. As given by [52] of 2008 and [53] of 2009, strangeness distillation still has been an considered a candidate mechanism. The need for modelling with 'lattice gauge' theory for furtther consideration of applicability, as mentioned by [45], is repeated in [52]. A more meaningful test of strangeness distillation, that could yet be applied for existing RHIC or LHC data is given in [D1]. This model is still supported, since the LSAG report, in several sentences within the CASTOR teams' Gladysz-Dziaduś 2012 update of [23(v2)] as an explanation for several cosmic ray detected events. Irrespectively, whilst strangeness distillation is highlighted by CASTOR and ALICE theories, it is not relied upon entirely for their suggestions of strangelet production (presumably because they both allow for strangelets at below 10 proton mass equivalent (A=10)).

8. **Strangelet mass less than that of 10 protons (A<10):**
As shown by Jaffe et al. [2] the papers that this assurance relies upon are [1] or [54]. [1] only disputes strangelet stability for <=6, but then with the noted potential exception of A=2. Actually [54] is referenced within the CASTOR quote in contradiction '5' of above table because this paper refers to the potential stability (or metastability) of A=6 strangelets. Furthermore, the paper [55] also elaborates on the potential for a (meta)stable neutral strangelet of A=6.

9. **High rapidity data:**
The relevant criteria would be strange baryon production and net baryon number at extreme rapidity. Evidence at RHIC of non-negligible values at this rapidity range for either are not demonstrated, as follows. In the 2009 paper [56] and for strange baryon yields at the higher rapidities in particular, only projections but not data are included, suggesting that no actual relevant data is available. Furthermore, for net baryon number at rapidity, the data plots at extreme rapidities are not available [Ref. 57, figs. 3-4, pp. 3-4] while the 'mongaus' projection of fig. 4 inset, indicates negligible net baryon number at the extreme RHIC rapidity range. For the predictions [Ref. 26, fig.1, p. 1776], [Ref. 58, fig. 6, p. 7] for LHC, the net baryon number can be negligible at the relevant highest rapidity range, again in contradiction to the claim of the LSAG report.

10. **CASTOR theory graph of strangelet rapidity distribution**:
This concerns [Ref 36, fig. 9, p. 13 ► Exhibit 41]. The units of 'multiplicity' – or production likelihood – in the figure are yields after many collisions for increases of a rapidity value of 1. Here for the cosmic ray configuration, will be considered the mirrored-inversion of this graph (i.e. here negative rapidities), then the posiive values combined together to give rapidities up to double the graph value. In relation to a negligibly low strangelet production likelihood against rapidity, and, for example, with the theoretical case (3) from the graph, the 2.5 rapidity difference for negligible strangelet production between rapidities 6.4 and 8.9 (8.9 is maximum possible rapidity for emitted baryons) implies that where the given CASTOR model were applied for relevant existing cosmic ray detections, after an estimated appropriate scaling down of the rapidity values, the minimum speed of cosmic ray produced strangelets would be over .91 of the speed of light at √sNN = 233GeV (energy per nucleon-nucleon in centre of mass of collision system) – where 233GeV is the average cosmic ray collision energy to enable strangelet production according to CASTOR theory (for which see contradiction '2' of above table). This graph would also imply a speed beyond .99c (.99 of light speed) for cosmic ray induced strangelets at LHC correlated energies per nucleon pair (√sNN= 5.5TeV). Either of these values (.91c or .99c) is well above the value .1c expected by [2] or [35] for strangelet disruption from subsequent collision with nuclei. Furthermore, for the limiting case given in [Ref. 59, p. 5] or as given in [60], when applied to the graph here discussed, the minimum strangelet speed from LHC appears to be .98c, which is slower than the .99c that can be calculated for the case of LHC collision energy where correlated for cosmic ray collision. However, this speed would not be slower than the cosmic ray case of √sNN=233GeV of .91c. This is based only on model projections however, so may not be conclusive for safety – as similarly for the applicability of the .1c

destructibility threshold from nuclei to the denser strangelet. But still in this case CASTOR theory can still involve risk if the cause of the relevant cosmic ray collision detections (for √sNN≥ 233GeV) related to only non-nuclei cosmic rays – a possibility also given by CASTOR theory [23,27,66], whilst the CASTOR theory still applied given the high combined mass numbers that could be particular to LHC Pb-Pb collisions. More clearly though, if ALICE strangelet theories were also to apply alongside CASTOR theories, then these models would together imply that some – ALICE theory related – LHC strangelets dangerously survive whilst analogous ones from cosmic rays would be too fast to survive disruption (as implied by ALICE theory and by [Ref. 36, fig. 9, p. 13] of CASTOR theory).

11. While the Peng et al. [62] paper claims that risk isn't implied by their arguments, they here neglect to take into account their acknowledged uncertainties about their own model. The first of their arguments concerns the greater stability of positive compared to negative strangelets for the same parameter values. This second concerns where maximal strangelet size constraints are introduced within the catalysis process (related to the strangelet reaching the electron Compton wavelength). But this doesn't consider either the catalysing potential from the remaining smaller stable strangelet surviving after decay – potentially leading to a chain reaction involving increasing numbers of such decay result negative strangelets. Note here that ALICE theory itself allows for the decay products of strangelets to be strangelets ([Ref. 25, p. 189 ► Exhibit 34]). The related quotes here express the uncertainties as were later given within a particular version of this model involving some further considerations by Wen et al. [37] (emphasis added): *'Although there are multiple solutions for a fixed baryon number, it is necessary to declare that the positively charged slet-1* [solution '-1'] *is more stable than and the other two* ***if the density dependence of the pairing parameters is not considered****.' 'It should be emphasized that the common Fermi momentum "pF " is only a fictional intermediate parameter in CFL matter.' 'When two paired quarks have a very small momentum* [this is relevant to stable negative strangelets]*, their global behavior may looks* [sic] *like a boson. Therefore, the new solution may indicate that boson condensation or diquark condensate appears to some extent, and* ***the*** [CFL/condensate] ***formation mechanism needs further investigations in the future****. '..'.. present results depend on the parameter choice, and so, further studies are needed.'* It should also be noted that according to the LSAG Report ([4]) the following is accepted: *'However, there is no rigorous proof that the charge of a stable strangelet must be positive, nor that a negatively- charged strangelet cannot be metastable, i.e., very long-lived.'* See also end of quote on 1st page of this report, [Ref. 2, p. 20 ► Exhibit 3].

12 In [72] Italian physicist G. Plagiara is quoted as saying "*We all agree that if quark stars exist, then the conversion of normal, ordinary matter into a quark star will be a very exothermic process, a lot of energy will be released, . . .* ". Furthermore [71] provides indications that quark stars (strange stars) actually exist.

Acronyms

ALICE	A Large Ion Collider Experiment
CASTOR	Centauro And STrange Object Research
CERN	European Organization for Nuclear Research (originally: Conseil Européen pour la Recherche Nucléaire)
CMS	Compact Muon Solenoid
LHC	Large Hadron Collider
LSAG	LHC Safety Assessment Group
LSSG	LHC Safety Study Group
MEMO	Metastable Exotic Multi-hypernuclei Objects
SPC	(CERN's) Scientific Policy Committee

References

[1] E. Farhi and R.L. Jaffe, 'Strange matter', *Phys. Rev.* **D30**(11) (1 Dec 1984) 2379-2390, doi: 10.1103/PhysRevD.30.2379.

[2] R.L. Jaffe, W. Busza, F. Wilczek and J. Sandweiss, 'Review of speculative "disaster scenarios" at RHIC', *Rev. Mod. Phys.* **72**(4) (2000) 1125-1140, doi: 10.1103/RevModPhys.72.1125; arXiv: hep-ph/9910333v3 (2000).

[3] <http://public.web.cern.ch/public/en/lhc/safety-en.html>.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] (2008).

[5] <http://user.web.cern.ch/user/AcceleratorServices/OnSiteServices/Directory/Directory.html>, <https://cds.cern.ch/?ln=en&as=1>.
Note: As directory results show, such people are necessarily based at the CERN location. Results are from entering surname into above site. Alternatively enter surname on site below it to find associations with the respective CMS (for CASTOR) or ALICE Collaborations.

[6] G. 't Hooft, P. Braun-Munzinger, B. Webber, F. Zwirner and M. Cavalli-Sforza, 'SPC Report on LSAG Documents', <http://cdsweb.cern.ch/record/1113558/files/cer-002766289.pdf>.

[7] <http://scholar.google.co.uk/>.

[8] <http://cms.web.cern.ch/news/cms-detector-design>.

[9] <https://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2007/11_12/index.html>.

[10] <http://aliceinfo.cern.ch/Public/en/Chapter2/Chap2Experiment-en.html>.

[11] <http://home.web.cern.ch/about>.

[12] A. Panagiotou, K. Borras and D. d'Enterria, 'Looking forward with the CASTOR Calorimeter', *CMS Times* (12 Nov 2007), <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2009/07_06/index.html>, <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2009/07_06/pdf/CMS%20Times.pdf>.

[13] E. Norbeck, Y. Onel, A. Panagiotou and M. Murray, 'Physics at Very Small Angles with CASTOR at CMS', for the 22nd Winter Workshop On Nuclear Dynamics (13 Mar 2006), <https://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2007/11_12/index.html>.

[14] A.D. Panagiotou, 'CASTOR's installation in CMS', *CMS Times* (6 Jul 2009), <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2009/07_06/index.html>, <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2009/07_06/pdf/CMS%20Times.pdf>.

[15] <http://cdsweb.cern.ch/>
Note: Enter title or document code (replacing '/' with a space) into the above CERN Document Server.

[16] <http://cmsinfo.web.cern.ch/cmsinfo/Resources/archive.html>.

[17] <http://cmsdoc.cern.ch/cms/castor/html/>.
Note: For negative strangelets, follow the tabs: 'Motivation', 'phenomenological model', followed by either 'Description of the Model' or 'Predictions of the Model'. The nature of the strangeness distillation and its relevance is outlined under the tab 'Description of Model'.

[18] E. Norbeck, Y. Onel, E. Gładysz-Dziaduś, A.D. Panagiotou and P. Katsas, 'Exotic Physics at the LHC with CASTOR in CMS', CMS Conference Report 2007/013, *Int. J. Mod. Phys.* **E16**(7-8) (2007) 2451-2456, doi: 10.1142/S0218301307008082, <http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2007&files=CR2007_013.pdf>.

[19] <http://cmsinfo.web.cern.ch/cmsinfo/News/e-commentary/cms-e-commentary09a.htm>.

[20] P. Katsas, 'Strangelet hunt at CMS' [slides], QCD at Cosmic Energies II Workshop, Skopelos, Greece, 25 Sep - 1 Oct 2005, <http://cmsdoc.cern.ch/cms/castor/html/files/Strangelets_hunt_v3.ppt> or 2nd to last transparency from: <http://indico.cern.ch/event/a056703>.

[21] D. Barney and M. Lapka, Eds., 'The University of Athens (Greece) in CMS', *CMS Times* (3 Dec 2007), <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2007/12_03/index.html>, <http://cmsinfo.web.cern.ch/cmsinfo/Media/Publications/CMStimes/2007/12_03/pdf/CMS%20Times.pdf>.

[22] P. Katsas, A.D. Panagiotou and E. Gładysz-Dziaduś for the CMS/CASTOR Group, 'Searching for Strange Quark Matter with the CMS/CASTOR Detector at the LHC', CMS-HI meeting, (23 Sep 2006) <http://cmsdoc.cern.ch/cms/castor/html/files/strangelet_cmsweek230906.ppt>. Also: A.D. Panagiotou, P. Katsas for the CMS collaboration, 'Searching for Strange Quark Matter with the CMS/CASTOR Detector at the LHC', Proc. 5th Int. Conf. on Perspectives in Hadron Physics, Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies, Trieste, Italy, 22-26 May 2006, *Nucl. Phys.* **A782**(1-4) (2007) 383-391, doi: 10.1016/j.nuclphysa.2006.10.020.

[23] E. Gładysz-Dziaduś, 'Are Centauros exotic signals of the QGP?', *Phys. Part. Nucl.* **34** (2001) 285-347; see also *Fiz. Elem. Chast. Atom. Yadra* **34** (2003) 565-678; arXiv: hep-ph/0111163v1 (2001). Revised version: arXiv: hep-ph/0111163v2 (2012).

[24] J.S. Lange, 'Au+Au collisions at RHIC and implications for ultra-relativistic astrophysical A+A collisions', *Nucl. Phys. B (Proc. Suppl.)* **151**(1) (2006) 183-190, doi: 10.1016/j.nuclphysbps.2005.07.033.

[25] ALICE Collaboration, 'ALICE: Technical Proposal for A Large Ion Collider Experiment at the CERN LHC', CERN document code: CERN/LHCC/95–71, LHCC/P3, (1995), ISBN: 9789290830771 and ISBN: 9290830778; abstract: <http://consult.cern.ch/alice/Documents/1995/01/abstract>, available as download at: <http://cdsweb.cern.ch/record/293391?ln=en>.
Note: My thanks to Alam Rahman for finding this vital information in the above source and distributing it to members of the LHC critic network like myself.

[26] C. Spieles, L. Gerland, H. Stöcker, C. Greiner, C. Kuhn and J.P. Coffin, 'Creation of Strange Matter at Low Initial μ/T', *Phys. Rev. Lett.* **76**(11) (1996) 1776–1779, doi: 10.1103/PhysRevLett.76.1776.

[27] E. Gładysz-Dziaduś for the CASTOR group, 'CASTOR: Centauro and Strange Object Research in nucleus-nucleus collisions at LHC', talk given at the Int. Workshop on Nuclear Theory, 10-15 Jun 2002, Rila Mountains, Bulgaria, arXiv: hep-ex/0209008v2 (2002).

[28] J.P. Coffin, C. Kuhn, B. Hippolyte, J. Baudot and I. Belikov, 'Multi-strange-quark states at ultra-relativistic heavy-ion collisions', *Pramana* **60**(5) (2003) 1055-1058, <http://www.ias.ac.in/pramana/v60/p1055/fulltext.pdf>, doi: 10.1007/BF02707030.

[29] C. Kuhn, B. Hippolyte, J.P. Coffin, J. Baudot, I. Belikov, D. Dietrich, M. Germain and C. Suire, 'Search for strange dibaryons in STAR and ALICE', *J. Phys.* **G28**(7) (2002) 1707-1714, doi: 10.1088/0954-3899/28/7/323.

[30] E. Gładysz-Dziaduś, 'Black Holes versus Strange Quark Matter', arXiv: hep-ph/0405115v3 (2005); see also: E. Gładysz-Dziaduś and Z. Włodarczyk, 'Black Holes versus Strange Quark Matter' in *Trends in Black Hole Research*, Ed. P.V. Kreitler (Nova Science, New York, 2006) 163-180.

[31] A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'CASTOR: A Forward Detector for the Identification of Centauros and Strangelets in Nucleus-Nucleus Collisions at the LHC', arXiv: hep-ex/9901038v1 (1999). Also: Proc. Int. Symp. on Multiparticle Dynamics, Delphi, 6-11 Sep (1998).

[32] J.-P. Blaizot, J. Iliopoulos, J. Madsen, G.G. Ross, P. Sonderegger, H.-J. Specht, 'Study of Potentially Dangerous Events During Heavy-Ion Collisions at the LHC: Report of the LHC Safety Study Group', CERN Theoretical Physics Division, Document code: CERN 2003–001, (2003), <http://www.inr.ac.ru/ads_icons/history/8/cern_p1.pdf>.

[33] A. Kent, 'Problems with empirical bounds for strangelet production at RHIC', arXiv: hep-ph/0009130v2 (2000).

[34] F. Calogero, 'Might a laboratory experiment destroy planet earth?', *Interdisciplinary Science Reviews* **25**(3) (2000) 191-202, doi: 10.1179/030801800679224.

[35] A. Dar, A. De Rújula and U. Heinz, 'Will relativistic heavy-ion colliders destroy our planet?', *Phys. Lett.* **B470**(1-4) (1999) 142-148, doi: 10.1016/S0370-2693(99)01307-6; arXiv: hep-ph/9910471v1 (1999).

[36] S.A. Sadovsky, Yu. V. Kharlov, A.L.S. Angelis, E. Gładysz-Dziaduś, V.L. Korotkikh, G. Mavromanolakis and A.D. Panagiotou, 'Model for describing the production of Centauro events and strangelets in heavy-ion collisions', *Phys. At. Nucl.* **67**(2) (2004) 396-405, doi: 10.1134/1.1648929; see also: *Yad. Fiz.* **67** (2004) 414-424; arXiv: nucl-th/0301003v1 (2003).

[37] X.J. Wen, G.X. Peng and P.N. Shen, 'Color-flavor locked strangelets in a quark mass density-dependent model', *Int. J. Mod. Phys.* **A22**(8-9) (2007) 1649-1661, doi: 10.1142/S0217751X07035276; arXiv: hep-ph/0612253v1 (2006).

[38] A. Andronic, P. Braun-Munzinger, J. Stachel, 'Hadron production in central nucleus-nucleus collisions at chemical freeze-out', *Nucl. Phys.* **A772** (2006) 167-199, doi: 10.1016/j.nuclphysa.2006.03.012; arXiv: nucl-th/0511071v3 (2006).

[39] J. Schaffner-Bielich, D. Kharzeev, L. McLerran and R. Venugopalan, 'Scaling properties of the transverse mass spectra', Proc. 30th International Workshop on Gross Properties of Nuclei and Nuclear Excitation, Hirschegg, Austria, 13-19 Jan 2002, <http://www.bnl.gov/isd/documents/24816.pdf>; arXiv: nucl-th/0202054v1 (2002).

[40] B. K. Srivastava , 'Forward-Backward Multiplicity Correlations in Au+Au Collisions at √sNN = 200 Gev', *Int. J. Mod. Phys.* **E16** (2008) 3371-3378; arXiv: nucl-ex/0702054v1 (2007).

[41] T. Lappi, L. McLerran, 'Long range rapidity correlations as seen in the STAR experiment', *Nucl. Phys.* **A832** (2010) 330-345.

[42] T.A. Armstrong *et al.*, 'Measurements of light nuclei production in 11.5AGeV/c Au+Pb heavy-ion collisions', *Phys. Rev.* **C61** (2000) id. 064908.

[43] For CERN 'Large Hadron Collider Committee' minutes referring to 'CASTOR' (detector) the CERN document codes are:
LHCC 062, LHCC 089, LHCC 091, LHCC 095, LHCC 096, LHCC 097, LHCC 099, LHCC minutes referring to (ALICE) 'Technical Proposal': CERN LHCC 95-41, CERN LHCC 94-25, CERN LHCC 97-053 rev., CERN LHCC 96-044 , CERN LHCC 96-028, CERN LHCC 96-031 , CERN LHCC 96-024 , CERN LHCC 97-048, CERN LHCC 96-011.
Note: Enter code into [15].

For conference J. Ellis presented at:
'26th International Cosmic-ray Conference', 17 - 25 Aug 1999, Salt Lake City, UT, USA.
<http://cdsweb.cern.ch/search?sysno=000279424CER>

Note: If necessary, contact this report author for evidence of above.

[44] P. Braun-Munzinger, K. Redlich and J. Stachel, 'Particle Production in Heavy Ion Collisions', arXiv: nucl-th/0304013v1 (2003); Also P. Braun-Munzinger *et al.*, 'Particle Production in Heavy Ion Collisions', Quark Gluon Plasma 3, Eds. R.C. Hwa and X.-N. Wang (World Scientific, Singapore, 2004) 491.

[45] C. Greiner, 'Physics of Strange Matter', *J. Phys.* **G25**(2) (1999) 389-401, doi: 10.1088/0954-3899/25/2/028.

[46] M.A. Lisa, S. Pratt, R. Soltz and U. Wiedemann, ‘Femtoscopy in Relatvistic Heavy Ion Collisions: Two Decades of Progress’, *Ann. Rev. Nucl. Part. Sci.* **55** (2005) 357-402, doi: 10.1146/annurev.nucl.55.090704.151533.

[47] F. Retière and M.A. Lisa, ‘Observable implications of geometrical and dynamical aspects of freeze-out in heavy ion collisions’, *Phys. Rev.* **C70**(4) (2004) id. 044907 (33pp.), doi: 10.1103/PhysRevC.70.044907; arXiv: nucl-th/0312024v3 (2004).

[48] R.M. Weiner, ‘Surprises from the search for quark-gluon plasma? When was quark-gluon plasma seen?’, *Int. J. Mod. Phys.* **E15**(1) (2006) 37-70, doi: 10.1142/S0218301306004004; arXiv: hep-ph/0507115v2 (2006).

[49] J. Letessier, J. Rafelski, ‘Observing Quark-Gluon Plasma with Strange Hadrons’, *Int. J. Mod. Phys.* **E9** (2000) 107-147, doi: 10.1142/S0218301300000076; arXiv: nucl-th/0003014v1 (2000).

[50] A.S. Khvorostukhin, V.V. Skokov, V.D. Toneev, K. Redlich ‘Lattice QCD Constraints on the Nuclear Equation of State’, *Eur. Phys. J.* **C48** (2006) 531-543.

[51] V.D.Toneev, A.S.Parvan, ‘Canonical Strangeness and Distillation Effects in Hadron Production’ *J. Phys.* **G31** (2005) 583-598 doi: 10.1088/0954-3899/31/7/005; arXiv: nucl-th/0411125v2 (2005).

[52] T.S. Biro, ‘Present and future challenges for quark matter theorists’, *J. Phys.* **G35**(4) (2008) id. 044056, doi: 10.1088/0954-3899/35/4/044056.

[53] J. Steinheimer, M. Mitrovski, T. Schuster, H. Petersen, M. Bleicher and H. Stöcker, ‘Strangeness fluctuations and MEMO production at FAIR’, *Phys. Lett.* **B676**(1-3) (2009) 126-131, doi:10.1016/j.physletb.2009.04.062; arXiv: 0811.4077v2 (2008).

[54] E.P. Gilson and R.L. Jaffe, ‘Very Small Strangelets’, *Phys. Rev. Lett.* **71** (1993) 332-335, doi: 10.1103/PhysRevLett.71.332; arXiv: hep-ph/9302270v1 (1993).

[55] F.C. Michel, ‘Quark Matter or New Particles?’, *Phys. Rev. Lett.* **60**(8) (1988).

[56] J. Song, F.-L. Shao and Q.-B. Xie, ‘The Influence of Net Quarks on Yields and Rapidity Spectra of Identified Hadrons’, *Int. J. Mod. Phys.* **A24**(6) (2009) 1161-1174, doi: 10.1142/S0217751X0904302X.

[57] I.G. Bearden *et al*. (BRAHMS Collaboration), ‘Nuclear Stopping in Au+Au Collisions at $\sqrt{s_{NN}}$=200 GeV’, *Phys. Rev. Lett.* **93**(10) (2004) id. 102301 (5pp.), doi: 10.1103/PhysRevLett.93.102301.

[58] L. Gerland, C. Spieles, M. Bleicher, H. Stoecker, C. Greiner, ‘Baryon Stopping and Strangeness Production in Ultra-Relativistic Heavy Ion Collisions’, Proc. of the Winter Meeting on Nuclear Physics, January 1996, Bormio, Italy; arXiv: nucl-th/9606001v1 (1996).

[59] E. Gładysz-Dziaduś, Yu V. Kharlov, Yu V, A. D. Panagiotou, A D, S.A. Sadovsky, ‘Generator for Centauro Event Simulation’, 3rd International Conference on Physics and Astrophysics of Quark-gluon Plasma Related, 17 - 21 Mar 1997, Jaipur, India. Available[3] as .ps file from CERN Document Server [15].

[60] M.N. Asprouli, A.D. Panagiotou and E. Gładysz-Dziaduś, ‘Interaction length and spontaneous decay of a cosmic ray “Centauro” fireball’, *Astropart. Phys.* **2**(2) (1994) 167-174, doi: 10.1016/0927-6505(94)90039-6.

[61] <http://www.arxiv.org>.

[62] G.X. Peng, X.J.Wen, Y.D. Chen, ‘New solutions for the color-flavor locked strangelets’, *Phys.Lett.* **B633** (2006) 314-318 doi: 10.1016/j.physletb.2005.11.081, arXiv: hep-ph/0512112v1 (2005).

[63] E. Norbeck, Y. Onel, ‘Strangelets at the LHC’, Mini-Symposium: Exotic Phenomena in High Energy Nuclear Collisions, 13-15 Feb 2010, Bulletin of the American Physical Society APS April Meeting 2010 Vol 55, No. 1. Available at http://meetings.aps.org/Meeting/APR10/Event/115561.

[64] E. Norbeck, Y. Onel, ‘CMS (LHC) Measurements and Unusual Cosmic Ray Events’, 26th International Symposium on Very High Energy Cosmic Ray Interactions 2010, Batavia Illinois, USA, 28 Jun – 2 Jul, http://arxiv.org/abs/1010.6017 (2010).

[65] E. Norbeck, Y. Onel, ‘The strangelet saga’, 27th Winter Workshop on Nuclear Dynamics (WWND 2011) *Journal of Physics: Conference Series* **316** (2011) 012034, <http://iopscience.iop.org/1742-6596/316/1/012034/pdf/1742-6596_316_1_012034.pdf>, doi:10.1088/1742-6596/316/1/012034.

[66] E. Gladysz-Dziadus, ‘Cosmic ray inspired searches at the LHC’, Cracow Epiphany Conference on the First Year of the LHC, Cracow, Poland, (10-12 Jan 2011), *Acta Phys. Pol.* **B42** (2011) 1377-1391, <http://www.actaphys.uj.edu.pl/_cur/store/vol42/pdf/v42p1377.pdf>.

[67] C. Greiner, H. Stöcker, ‘Distillation and survival of strange-quark-matter droplets in ultrarelativistic heavy-ion collisions’, *Phys Rev* **D44**(11) (1991) 3517-3529, <http://www.researchgate.net/publication/13275284_Distillation_and_survival_of_strange-quark-matter_droplets_in_ultrarelativistic_heavy-ion_collisions>, doi: 10.1103/PhysRevD.44.3517.

[68] J. Madsen, ‘Intermediate mass strangelets are positively charged’, *Phys. Rev. Lett.* **85** (2000) 4687, arXiv: hep-ph/0008217, doi: 10.1103/PhysRevLett.85.4687.

[69] J. Madsen, ‘Color-flavor locked strangelets’, *Phys. Rev. Lett.* **87** (2001) 172003, doi: 10.1103/PhysRevLett.87.172003, arXiv: hep-ph/0108036.

[70] X-J Wen D-H Yang, S-Z Su Finite-size effects on the strangelets with different coupling strengths J. Phys. G: Nucl. Part. Phys. 38 (2011) 115001 doi:10.1088/0954-3899/38/11/115001.

[71] Y Zhang, R.-K. Su, ‘Stability of strangelet at finite temperature’, Phys.Rev. C67 (2003) 015202, doi: 10.1103/PhysRevC.67.015202, arXiv: nucl-th/0207071.

[72] A. Ananthaswamy, ‘Space Oddity’, *NewScientist* 7 December 2013, 42-45,<http://www.quarknova.org/_include/files/feature_quark_stars.pdf>.

[73] T Gangopadhyay, S Ray, X.-D. Li, J. Dey, M. Dey, ‘Strange star equation of state fits the refined mass measurement of 12 pulsars and predicts their radii’, *Mon. Not. R. Astron. Soc.* **431** (2013) 3216-3221, arXiv:1303.1956.

[74] R. Ouyed, D. Leahy, ‘The peculiar case of the ‘‘double-humped’’ super-luminous supernova SN 2006oz’, *Research in Astronomy and Astrophysics*, **13**(10) (2013) 1202-1206, arXiv: 1202.2400.

[75] L. Martin, B. Erazmus, R. Lednicky, V. Lyuboshitz, K. Mikhailov, J. Pluta, C. Roy, Y. Sinyukov, A. Stavinsky ‘Particle correlations in ultra-relativistic heavy-ion experiments STAR at RHIC and ALICE at LHC’, Talk presented at the IV TAPS Workshop (Mont Sainte Odile, FRANCE, September 14-20, 1997), <http://www.researchgate.net/publication/45162092_Particle_correlations_in_ultra-relativistic_heavy-ion_experiments_STAR_at_RHIC_and_ALICE_at_LHC>.

Note: The quotes and exhibit images are taken from the ‘arXiv’ version where available. The quotes themselves are usually identical in the journal versions, for which the same content is sometimes slightly rephrased. Details of the CERN document versions for the CASTOR papers are given in the subsequent section.

List of CASTOR Strangelet Theory Papers

Those papers available as CERN documents begin with 'ALICE-INT', 'CERN-ALICE', 'CERN-ALI', 'CERN-CMS-CR' or 'CERN-CMS' and should be accessible[3] from the CERN Document Server [15]. As for the subsequent section, the theoretical papers below often also appear in published physics journals or the free online 'arXiv' collection [61] of scientific papers (there are also several other related CERN documents). Note that CASTOR was originally to be installed at ALICE.

As indicated below, there are 26 CASTOR theorists or experimental reserchers. There are also further physicists or engineers involved specifically on the design and testing aspects but their papers not included here. All are[3] affiliated with CERN [5].

—

A. D. Panagiotou, E. Gladysz-Dziaduś, 'Possible Production and Detection of "Centauros" and Strangelets at LHC', CERN document codes: ALICE-INT-1995-18; CERN-ALICE-INT-1995-18, Geneva, CERN (1995).

ALICE Collaboration, 'A Detector for ALICE at very Forward Rapidity Dedicated to the Identification and Study of Centauros and Strangelets', CERN document codes: ALICE-INT-1996-22; CERN-ALICE-INT-1996-22, CERN, Geneva (1996).

Yu V. Kharlov, A.D. Panagiotou, S.A. Sadovsky, 'Simulation of the Centauro events at CASTOR', CERN document codes: ALICE-INT-1997-06; CERN-ALICE-INT-1997-06, Geneva, CERN (1997).

A.D. Panagiotou, 'Particles from Centauro Decay in the CASTOR Detecting System', CERN document codes: ALICE-INT-1997-16; CERN-ALICE-INT-1997-16, Geneva, CERN (1997)

Z. Wlodarczyk, 'Strongly Penetrating Cascades Caused by Strangelets in the Cosmic Ray Chambers and in the Castor Calorimeter', CERN document codes: ALICE-INT-1997-17; CERN-ALICE-INT-1997-17, Geneva, CERN (1997).

E. Gladysz-Dziaduś, Z. Wlodarczyk, 'Is the strongly penetrating component a sign of the strangelet passage through matter?' Presented at the International Symposium on Strangeness in Quark Matter (SQM '97), Thera, Santorini, Greece, 14 - 18 Apr 1997, CERN document codes: CERN-ALI-97-21; CERN-ALICE-PUB-97-21 (1997).

S. N. Filippov, E. Gladysz-Dziaduś, Yu V Kharlov, A. B. Kurepin, A. D. Panagiotou, S. A. Sadovsky, 'Centauro And STrange Object Research: CASTOR' Technical Proposal ('Current Status Report'). CERN document codes: ALICE-INT-1997-07; CERN-ALICE-INT-1997-07, CERN, Geneva (1997).

A.L.S. Angelis and A.D. Panagiotou, 'CASTOR: A dedicated detector for the detection of centauros and strangelets at the LHC', Proc. Int. Symp. on Strangeness in Quark Matter (SQM '97), Thera, Santorini, Greece, 14-18 Apr 1997, *J. Phys.* **G23**(12) (1997) 2069-2080, doi: 10.1088/0954-3899/23/12/032; CERN document codes: CERN-ALI-97-20; CERN-ALICE-PUB-97-20, Geneva, CERN (1997).

J. Bartke, E. Gładysz-Dziaduś and Z. Włodarczyk 'The energy deposition pattern as the unconventional strangelet signature and its relevance to the CASTOR calorimeter', CERN document codes: ALICE-INT-1998-38; CERN-ALICE-INT-1998-38, Geneva, CERN (1998).

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'Formation and identification of Centauro and Strangelets in nucleus- nucleus collisions at the LHC', 10th Int. Symp. on Very High Energy Cosmic Ray Interactions, L'Aquila, Italy, 12 - 17 Jul 1998, pp.203-205; CERN document codes: CERN-ALI-98-27; CERN-ALICE-PUB-98-27, Geneva, CERN (1999).

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'Formation of Centauro in Pb+Pb Collisions at the LHC and their Identification in the ALICE Experiment' Presentation at the International Europhysics Conference on High-Energy Physics, Tampere, Finland, 15-21 Jul 1999, pp.957-958; CERN document codes: CERN-ALI-99-52; CERN-ALICE-PUB-99-52, Geneva : CERN (1999).

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'Formation of Centauro and Strangelets in Nucleus-Nucleus Collisions at the LHC and their Identification by the ALICE Experiment'. Presentation at the 26th International Cosmic-ray Conference, Salt Lake City, UT, USA, 17-25 Aug 1999; CERN document codes: CERN-ALI-99-54; CERN-ALICE-PUB-99-54, Geneva, CERN (1999).

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'Formation and identification of centauro and strangelets in nucleus-nucleus collisions at the LHC', Proc. Int. Symp. on Multiparticle Dynamics, Delphi, 6-11 Sep. 1998, *Nucl. Phys. B (Proc. Suppl.)* **75**(1-2) (1999) 203-205, doi: 10.1016/S0920-5632(99)00243-1; CERN document codes: CERN-ALI-98-27; CERN-ALICE-PUB-98-27, Geneva, CERN (1999).

A.L.S. Angelis, J. Bartke, E. Gładysz-Dziaduś and Z. Włodarczyk, 'The energy deposition pattern as the unconventional strangelet signature and its application to the new accelerator experiments', *EPJ direct* **C9** (2000) 1-18, <http://www.springerlink.com/content/knp6v16151258432/fulltext.pdf>, doi: 10.1007/s1010500c0009; CERN document codes: CERN-ALI-99-55; CERN-ALICE-PUB-99-55, Geneva, CERN (1999).

A.L.S. Angelis, J. Bartke, M. Yu Bogolyubsky, S.N. Filippov, E. Gladysz-Dziaduś, Yu V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski, Z. Wlodarczyk, 'CASTOR : The ALICE forward detector for identification of Centauros and Strangelets in Nucleus-Nucleus Collisions at the LHC' hep-ex/9901038; CERN document codes: CERN-ALI-99-04 ; CERN-ALICE-PUB-99-04, Geneva, CERN (1999), arXiv: hep-ex/9901038v1 (1999).

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'CASTOR: A Forward Detector for the Identification of Centauros and Strangelets in Nucleus-Nucleus Collisions at the LHC', arXiv: hep-ex/9901038v1 (1999); CERN document codes: CERN-ALI-99-14; CERN-ALICE-PUB-99-14, Geneva, CERN (2000).

A.L.S. Angelis, X. Aslanoglou, J. Bartke, M. Yu. Bogolyubsky, K. Chileev, S. Erine, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, M. Lobanov, A.I. Maevskaya, G. Mavromanolakis, N. Nicolis, A.D. Sadovsky, S.A. Panagiotou and Z. Włodarczyk, 'CASTOR detector: Model, objectives and simulated performance', Chacaltaya Meeting on Cosmic Ray Physics, La Paz, Bolivia, 23-27 Jul 2000, *Nuovo Cim.* **C24**(4-5) (2001) 755-760.

A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, 'CASTOR: Centauro and strange object research in nucleus-nucleus collisions at the LHC', Proc. 11th Int. Symp. on Very High Energy Cosmic Ray Interactions, Campinas, Brazil, 17-21 Jul 2000, *Nucl. Phys. B (Proc. Suppl.)* **97**(1-3) (2001) 227-230, doi: 10.1016/S0920-5632(01)01270-1.

E. Gładysz-Dziaduś, 'Are Centauros exotic signals of the QGP?', *Phys. Part. Nucl.* **34** (2001) 285-347; see also *Fiz. Elem. Chast. Atom. Yadra* **34** (2003) 565-678; arXiv: hep-ph/0111163v1 (2001), arxiv.org/ahep-ph/0111163v2

E. Gładysz-Dziaduś for the CASTOR group, 'CASTOR: Centauro and Strange Object Research in nucleus-nucleus collisions at LHC', talk given at the Int. Workshop on Nuclear Theory, 10-15 Jun 2002, Rila Mountains, Bulgaria, arXiv: hep-ex/0209008v2 (2002).

A.L.S. Angelis, X. Aslanoglu, J. Bartke, K. Chileev, E. Gładysz-Dziaduś, M.B. Golubeva, F.F. Guber, T.L. Karavitcheva, Yu.V. Kharlov, A.B. Kurepin, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, V.V. Tiflov and Z. Włodarczyk, 'Formation and detection of centauro in Pb+Pb collisions at the LHC', *J. Phys.* **G28**(7) (2002) 1937-1942, doi: 10.1088/0954-3899/28/7/349.

A.L.S. Angelis, X. Aslanoglu, J. Bartke, K. Chileev, E. Gładysz-Dziaduś, M. Golubeva, F. Guber, T. Karavitcheva, Y.V. Kharlov, A.B. Kurepin, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, V.V. Tiflov and Z. Włodarczyk, 'Formation of Centauro in Pb+Pb collisions at the LHC and their detection with the CASTOR detector of CMS', Proc. 12th Int. Symp. on Very High Energy Cosmic Ray Interactions, CERN, Geneva, Switzerland, 15-20 Jul 2002, *Nucl. Phys. B (Proc. Suppl.)* **122** (2003) 205-208, doi: 10.1016/S0920-5632(03)80379-1.

S.A. Sadovsky, Yu. V. Kharlov, A.L.S. Angelis, E. Gładysz-Dziaduś, V.L. Korotkikh, G. Mavromanolakis and A.D. Panagiotou, 'Model for describing the production of Centauro events and strangelets in heavy-ion collisions', *Phys. At. Nucl.* **67**(2) (2004) 396-405, doi: 10.1134/1.1648929; see also: *Yad. Fiz.* **67** (2004) 414-424; arXiv: nucl-th/0301003v1 (2003).

E. Norbeck, Y. Onel, A.D. Panagiotou and M. Murray, 'Heavy-Ion Reactions at Forward Angles with CMS (LHC)', *Acta Physica Hungarica A) Heavy Ion Physics* **21**(2-4) (2004) 321-327.

E. Gładysz-Dziaduś, 'Black Holes versus Strange Quark Matter', arXiv: hep-ph/0405115v3 (2005); see also: E. Gładysz-Dziaduś and Z. Włodarczyk, 'Black Holes versus Strange Quark Matter' in *Trends in Black Hole Research*, Ed. P.V. Kreitler (Nova Science, New York, 2006) 163-180.

E. Gładysz-Dziaduś, 'CASTOR: Centauro And STrange Object Research - Exotic Aspects of Forward Physics at the LHC', *Acta Phys. Pol.* **B37**(1) (2006) 153-160, <http://th-www.if.uj.edu.pl/acta/vol37/pdf/v37p0153.pdf>.

A.D. Panagiotou, P. Katsas for the CMS collaboration, 'Searching for Strange Quark Matter with the CMS/CASTOR Detector at the LHC', Proc. 5th Int. Conf. on Perspectives in Hadron Physics, Particle–Nucleus and Nucleus–Nucleus Scattering at Relativistic Energies, Trieste, Italy, 22-26 May 2006, *Nucl. Phys.* **A782**(1-4) (2007) 383-391, doi: 10.1016/j.nuclphysa.2006.10.020.

E. Norbeck, Y. Onel, E. Gładysz-Dziaduś, A.D. Panagiotou and P. Katsas, 'Exotic Physics at the LHC with CASTOR in CMS', CMS Conference Report 2007/013, *Int. J. Mod. Phys.* **E16**(7-8) (2007) 2451-2456, doi: 10.1142/S0218301307008082, <http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2007&files=CR2007_013.pdf>; CERN document codes: CMS-CR-2007-013; CERN-CMS-CR-2007-013, Geneva, CERN, (2007), 5 p.

E. Norbeck, Y. Onel (for the CMS Collaboration) 'CMS (LHC) Measurements and Unusual Cosmic Ray Events',16th International Symposium on Very High Energy Cosmic Ray Interactions, Batavia, IL, USA, 28 Jun - 2 (Jul 2010), **C49** (2010). 4 p., arXiv:1010.6017 (2010); CERN document code: CMS-CR-2010-196, (2010), 5 p.

E. Norbeck, Y. Onel, 'The strangelet saga', 27th Winter Workshop on Nuclear Dynamics (WWND 2011) *Journal of Physics: Conference Series* **316** (2011) 012034, <http://iopscience.iop.org/1742-6596/316/1/012034/pdf/1742-6596_316_1_012034.pdf>, doi:10.1088/1742-6596/316/1/012034.

E. Gladysz-Dziadus, 'Cosmic ray inspired searches at the LHC', Cracow Epiphany Conference on the First Year of the LHC, Cracow, Poland, (10-12 Jan 2011), *Acta Phys. Pol.* **B42** (2011) 1377-1391, <http://www.actaphys.uj.edu.pl/_cur/store/vol42/pdf/v42p1377.pdf>.

List of ALICE Strangelet Theory Papers

The first is a CERN document and the five published papers involve CERN's Coffin and Kuhn and up to 8 other CERN-affiliated physicists at this time [3] ([5]).

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ALICE Collaboration, 'ALICE: Technical Proposal for A Large Ion Collider Experiment at the CERN LHC', CERN document codes: CERN/LHCC/95–71, LHCC/P3, (1995) ISBN: 9789290830771 and ISBN: 9290830778 CERN, Geneva; abstract: <http://consult.cern.ch/alice/Documents/1995/01/abstract>, available as download at: http://cdsweb.cern.ch/record/293391?ln=en>.

J.P. Coffin, P. Crochet, P. Fintz, G. Guillaume, F. Jundt, A. Michalon, F. Rami, C. Roy, 'Search for Exotic Forms of Strange Matter in the ALICE Experiment', CERN document codes: ALICE-INT-1995-49; CERN-ALICE-INT-1995-49, Geneva, CERN, (1995).

C. Spieles, L. Gerland, H. Stöcker, C. Greiner, C. Kuhn and J.P. Coffin, 'Creation of Strange Matter at Low Initial μ/T', *Phys. Rev. Lett.* **76**(11) (1996) 1776–1779, doi: 10.1103/PhysRevLett.76.1776.

J.P. Coffin and C. Kuhn, 'Search for exotic strange matter in the ALICE and STAR experiments at the LHC and RHIC heavy-ion colliders', Proc. Int. Symp. on Strangeness in Quark Matter (SQM '97), Thera, Santorini, Greece, 14-18 Apr 1997, *J. Phys.* **G23**(12) (1997) 2117-2125, doi: 10.1088/0954-3899/23/12/037.

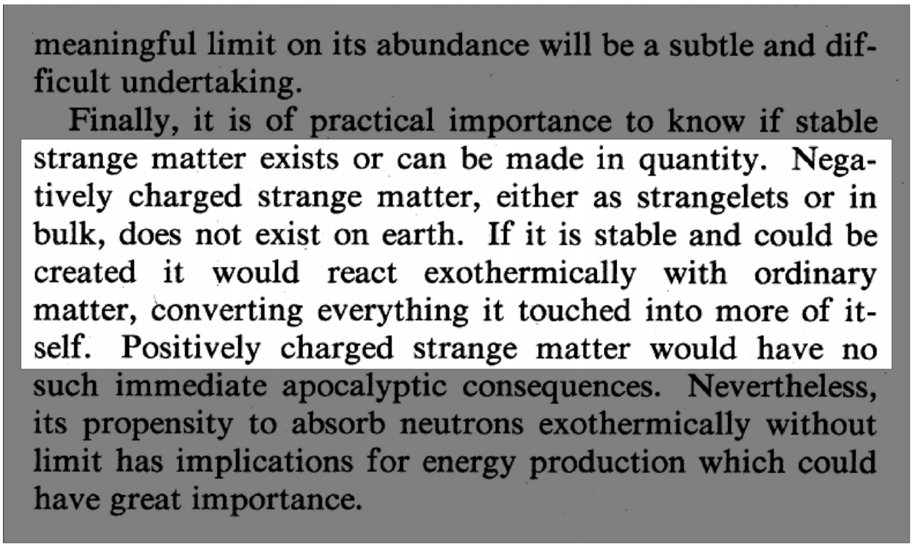
J.P. Coffin, 'Some Aspects of Ultra-Relativistic Heavy-Ion Collisions, Complex Forms of Strangeness', 241st WE-Heraeus Seminar: Symp. on fundamental issues in elementary matter, Bad Hannef, Germany, *Acta Phys. Hung.* **A14**(1-4) (2001) 72-82, doi: 10.1556/APH.14.2001.1-4.9; Also presentation at: <http://www.star.bnl.gov/public/ssd/STAR_documents/BadHonnef00JPC/sld001.htm>.

C. Kuhn, B. Hippolyte, J.P. Coffin, J. Baudot, I. Belikov, D. Dietrich, M. Germain and C. Suire 'Search for strange dibaryons in STAR and ALICE', *J. Phys.* **G28**(7) (2002) 1707-1714, doi: 10.1088/0954-3899/28/7/323.

J.P. Coffin, C. Kuhn, B. Hippolyte, J. Baudot and I. Belikov, 'Multi-strange-quark states at ultra-relativistic heavy-ion collisions', *Pramana* **60**(5) (2003) 1055-1058, <http://www.ias.ac.in/pramana/v60/p1055/fulltext.pdf>, doi: 10.1007/BF02707030.

Exhibits

Exhibit 1

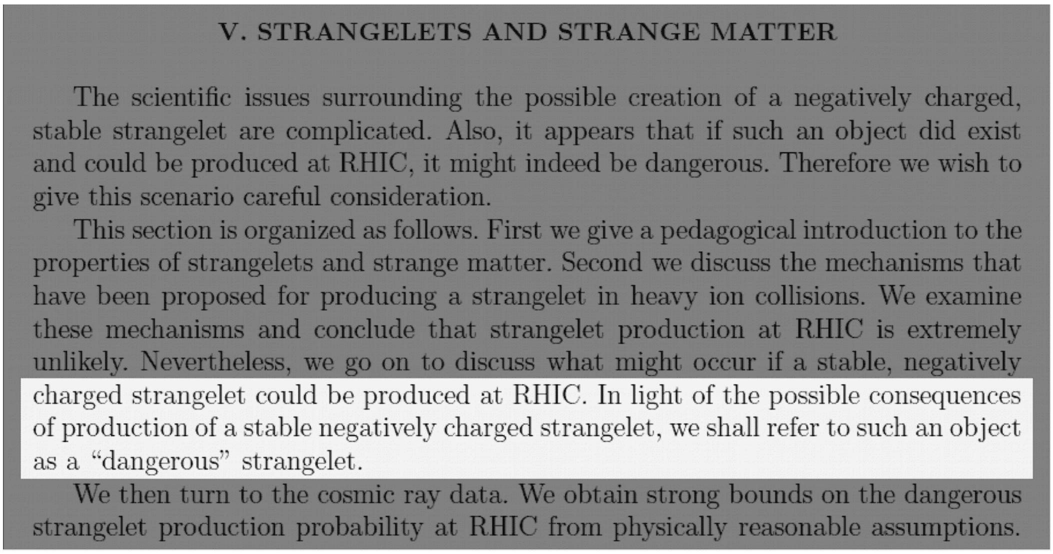


meaningful limit on its abundance will be a subtle and difficult undertaking.

Finally, it is of practical importance to know if stable strange matter exists or can be made in quantity. Negatively charged strange matter, either as strangelets or in bulk, does not exist on earth. If it is stable and could be created it would react exothermically with ordinary matter, converting everything it touched into more of itself. Positively charged strange matter would have no such immediate apocalyptic consequences. Nevertheless, its propensity to absorb neutrons exothermically without limit has implications for energy production which could have great importance.

[1] E. Farhi and R.L. Jaffe, ‘Strange matter’, Phys. *Rev.* **D30**(11) (1 Dec 1984) 2379-2390, doi: 10.1103/PhysRevD.30.2379. ► p. 2390 (no link) [Back to the text]

Exhibit 2



V. STRANGELETS AND STRANGE MATTER

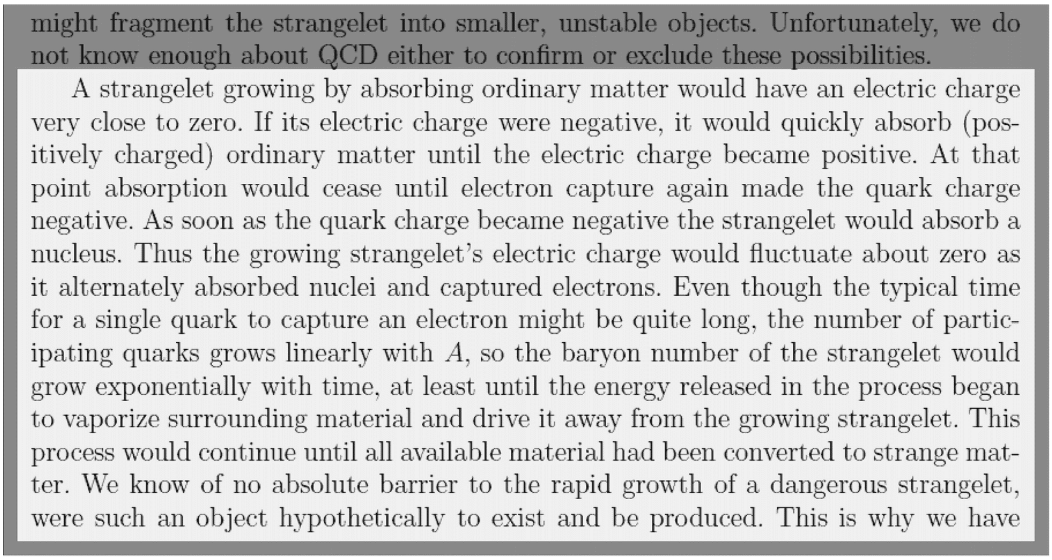
The scientific issues surrounding the possible creation of a negatively charged, stable strangelet are complicated. Also, it appears that if such an object did exist and could be produced at RHIC, it might indeed be dangerous. Therefore we wish to give this scenario careful consideration.

This section is organized as follows. First we give a pedagogical introduction to the properties of strangelets and strange matter. Second we discuss the mechanisms that have been proposed for producing a strangelet in heavy ion collisions. We examine these mechanisms and conclude that strangelet production at RHIC is extremely unlikely. Nevertheless, we go on to discuss what might occur if a stable, negatively charged strangelet could be produced at RHIC. In light of the possible consequences of production of a stable negatively charged strangelet, we shall refer to such an object as a “dangerous” strangelet.

We then turn to the cosmic ray data. We obtain strong bounds on the dangerous strangelet production probability at RHIC from physically reasonable assumptions.

[2] R.L. Jaffe, W. Busza, F. Wilczek and J. Sandweiss, ‘Review of speculative “disaster scenarios” at RHIC’, *Rev. Mod. Phys.* **72**(4) (2000) 1125-1140, doi: 10.1103/RevModPhys.72.1125; arXiv: hep-ph/9910333v3 14 Jul 2000. ► p. 11 [Back]

Exhibit 3

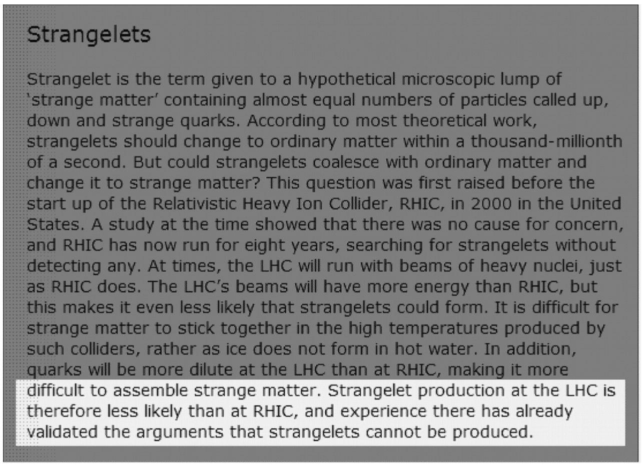


might fragment the strangelet into smaller, unstable objects. Unfortunately, we do not know enough about QCD either to confirm or exclude these possibilities.

A strangelet growing by absorbing ordinary matter would have an electric charge very close to zero. If its electric charge were negative, it would quickly absorb (positively charged) ordinary matter until the electric charge became positive. At that point absorption would cease until electron capture again made the quark charge negative. As soon as the quark charge became negative the strangelet would absorb a nucleus. Thus the growing strangelet's electric charge would fluctuate about zero as it alternately absorbed nuclei and captured electrons. Even though the typical time for a single quark to capture an electron might be quite long, the number of participating quarks grows linearly with A, so the baryon number of the strangelet would grow exponentially with time, at least until the energy released in the process began to vaporize surrounding material and drive it away from the growing strangelet. This process would continue until all available material had been converted to strange matter. We know of no absolute barrier to the rapid growth of a dangerous strangelet, were such an object hypothetically to exist and be produced. This is why we have

[2] R.L. Jaffe, W. Busza, F. Wilczek and J. Sandweiss, 'Review of speculative "disaster scenarios" at RHIC', *Rev. Mod. Phys.* **72**(4) (2000) 1125-1140, doi: 10.1103/RevModPhys.72.1125; arXiv: hep-ph/9910333v3 14 Jul 2000. ► p. 20 [Back]

Exhibit 4

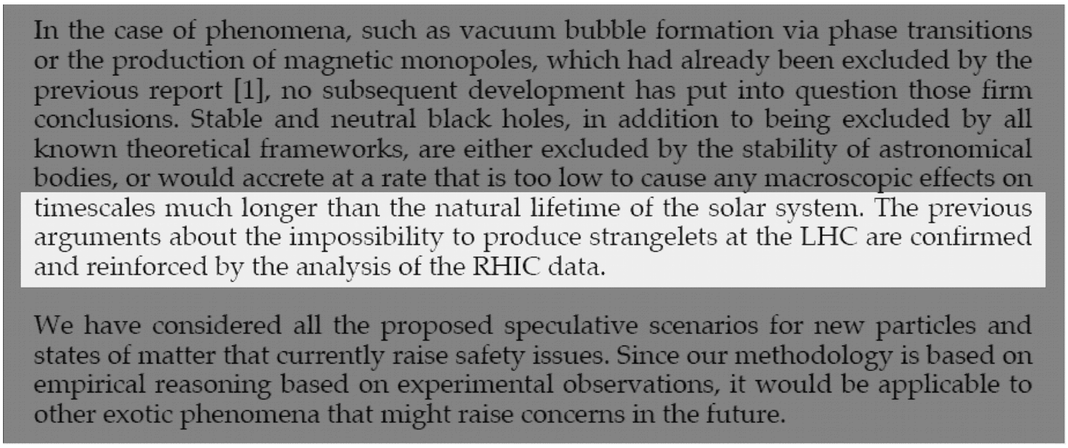


Strangelets

Strangelet is the term given to a hypothetical microscopic lump of 'strange matter' containing almost equal numbers of particles called up, down and strange quarks. According to most theoretical work, strangelets should change to ordinary matter within a thousand-millionth of a second. But could strangelets coalesce with ordinary matter and change it to strange matter? This question was first raised before the start up of the Relativistic Heavy Ion Collider, RHIC, in 2000 in the United States. A study at the time showed that there was no cause for concern, and RHIC has now run for eight years, searching for strangelets without detecting any. At times, the LHC will run with beams of heavy nuclei, just as RHIC does. The LHC's beams will have more energy than RHIC, but this makes it even less likely that strangelets could form. It is difficult for strange matter to stick together in the high temperatures produced by such colliders, rather as ice does not form in hot water. In addition, quarks will be more dilute at the LHC than at RHIC, making it more difficult to assemble strange matter. Strangelet production at the LHC is therefore less likely than at RHIC, and experience there has already validated the arguments that strangelets cannot be produced.

[3] <http://public.web.cern.ch/public/en/lhc/safety-en.html> [Back]

Exhibit 5

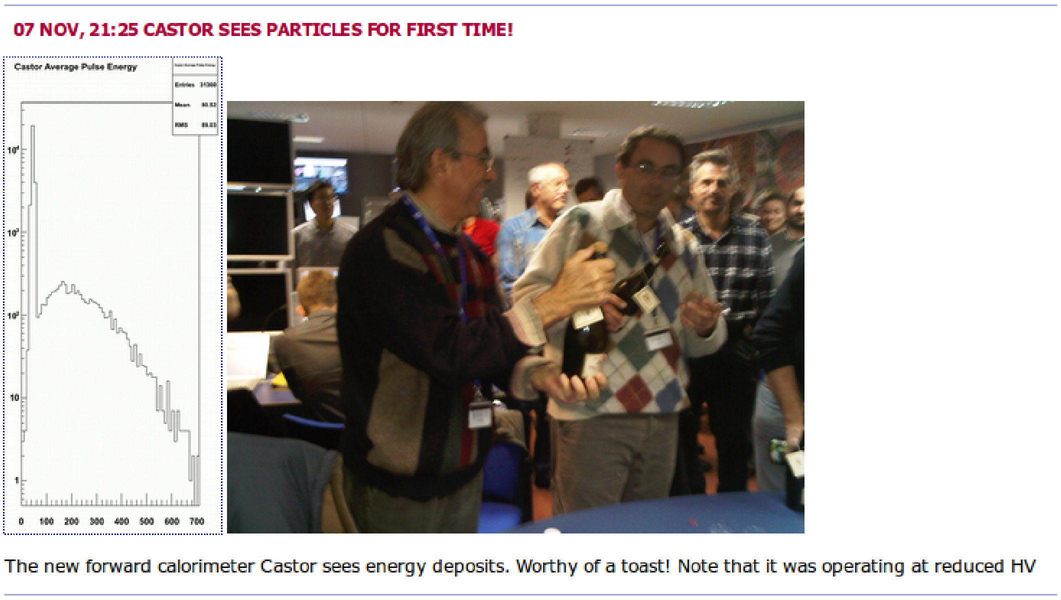


In the case of phenomena, such as vacuum bubble formation via phase transitions or the production of magnetic monopoles, which had already been excluded by the previous report [1], no subsequent development has put into question those firm conclusions. Stable and neutral black holes, in addition to being excluded by all known theoretical frameworks, are either excluded by the stability of astronomical bodies, or would accrete at a rate that is too low to cause any macroscopic effects on timescales much longer than the natural lifetime of the solar system. The previous arguments about the impossibility to produce strangelets at the LHC are confirmed and reinforced by the analysis of the RHIC data.

We have considered all the proposed speculative scenarios for new particles and states of matter that currently raise safety issues. Since our methodology is based on empirical reasoning based on experimental observations, it would be applicable to other exotic phenomena that might raise concerns in the future.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), ‘Review of the safety of LHC Collisions’, *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 13 [Back to text] [Back to table]

Exhibit 6



07 NOV, 21:25 CASTOR SEES PARTICLES FOR FIRST TIME!

The new forward calorimeter Castor sees energy deposits. Worthy of a toast! Note that it was operating at reduced HV

[19] <http://cmsinfo.web.cern.ch/cmsinfo/News/e-commentary/cms-e-commentary09a.htm> [Back]

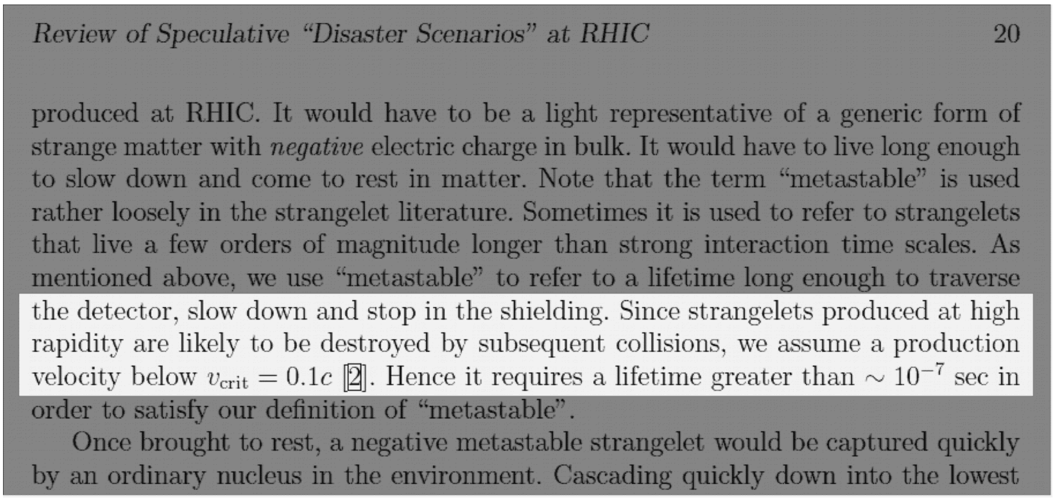
Exhibit 7

Panos Katsas

My name is **Panos Katsas**. I am a Ph.D student at the Nuclear & Particle Physics department of the University of Athens, where I also obtained my bachelor and MSc degree. I work as an experimental physicist for the CASTOR forward calorimeter of CMS and my main area of interest is the study of exotic events in heavy ion collisions, especially the identification of strangelets, which are likely to be produced. I am currently also involved in the software development for CASTOR and analysis of the calorimeter's 2007 test beam.

[7] D. Barney and M. Lapka, Eds., ‘The University of Athens (Greece) in CMS’, *CMS Times* (3 Dec 2007), <http://cms.web.cern.ch/cms/Media/Publications/CMStimes/2007/12_03/index.html>, <http://cms.web.cern.ch/cms/Media/Publications/CMStimes/2007/12_03/pdf/CMS%20Times.pdf> [Back]

Exhibit 8



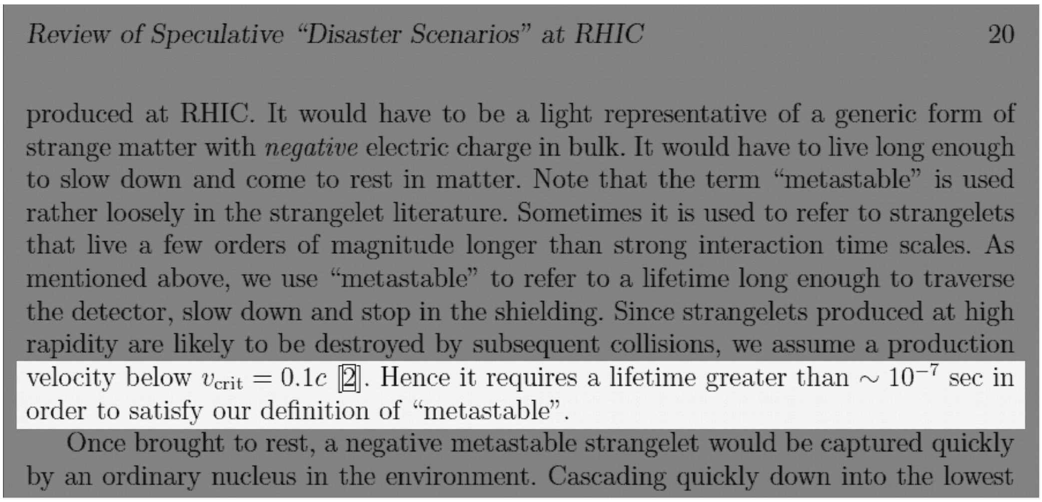
Review of Speculative “Disaster Scenarios” at RHIC 20

produced at RHIC. It would have to be a light representative of a generic form of strange matter with *negative* electric charge in bulk. It would have to live long enough to slow down and come to rest in matter. Note that the term “metastable” is used rather loosely in the strangelet literature. Sometimes it is used to refer to strangelets that live a few orders of magnitude longer than strong interaction time scales. As mentioned above, we use “metastable” to refer to a lifetime long enough to traverse the detector, slow down and stop in the shielding. Since strangelets produced at high rapidity are likely to be destroyed by subsequent collisions, we assume a production velocity below $v_{\rm crit} = 0.1c$ [2]. Hence it requires a lifetime greater than $\sim 10^{-7}$ sec in order to satisfy our definition of “metastable”.

Once brought to rest, a negative metastable strangelet would be captured quickly by an ordinary nucleus in the environment. Cascading quickly down into the lowest

[2] R.L. Jaffe, W. Busza, F. Wilczek and J. Sandweiss, ‘Review of speculative “disaster scenarios” at RHIC’, *Rev. Mod. Phys.* **72**(4) (2000) 1125-1140, doi: 10.1103/RevModPhys.72.1125; arXiv: hep-ph/9910333v3 14 Jul 2000. ► p. 20 [Back]

Exhibit 9



Review of Speculative "Disaster Scenarios" at RHIC 20

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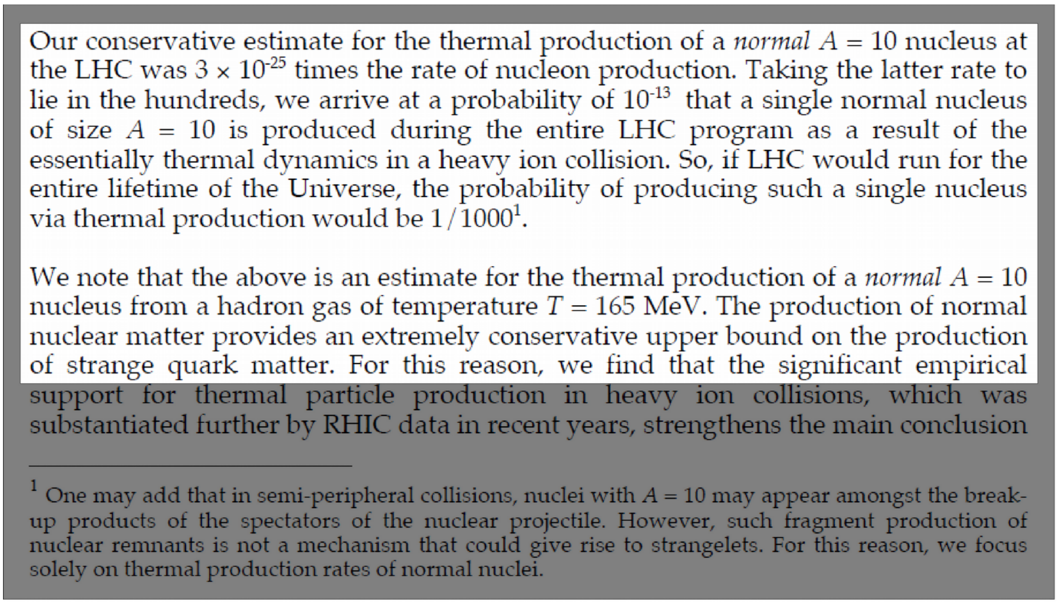
Exhibit 10



Our conservative estimate for the thermal production of a *normal* $A = 10$ nucleus at the LHC was 3×10^{-25} times the rate of nucleon production. Taking the latter rate to lie in the hundreds, we arrive at a probability of 10^{-13} that a single normal nucleus of size $A = 10$ is produced during the entire LHC program as a result of the essentially thermal dynamics in a heavy ion collision. So, if LHC would run for the entire lifetime of the Universe, the probability of producing such a single nucleus via thermal production would be 1/1000[1].

We note that the above is an estimate for the thermal production of a *normal* $A = 10$ nucleus from a hadron gas of temperature $T = 165$ MeV. The production of normal nuclear matter provides an extremely conservative upper bound on the production of strange quark matter. For this reason, we find that the significant empirical support for thermal particle production in heavy ion collisions, which was substantiated further by RHIC data in recent years, strengthens the main conclusion

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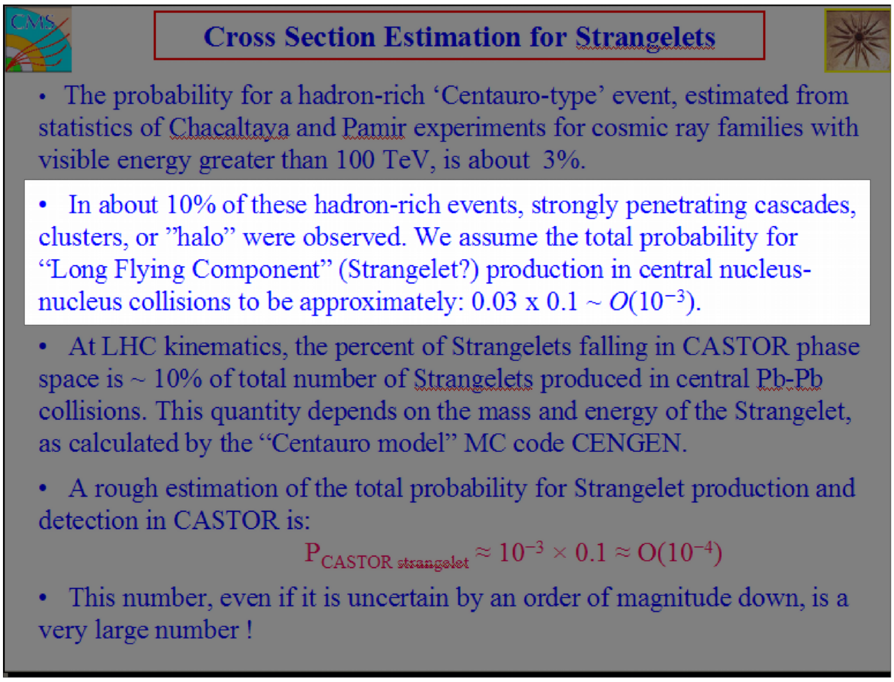
[1] One may add that in semi-peripheral collisions, nuclei with $A = 10$ may appear amongst the break-up products of the spectators of the nuclear projectile. However, such fragment production of nuclear remnants is not a mechanism that could give rise to strangelets. For this reason, we focus solely on thermal production rates of normal nuclei.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 19 [Back]

Exhibit 11



Cross Section Estimation for Strangelets

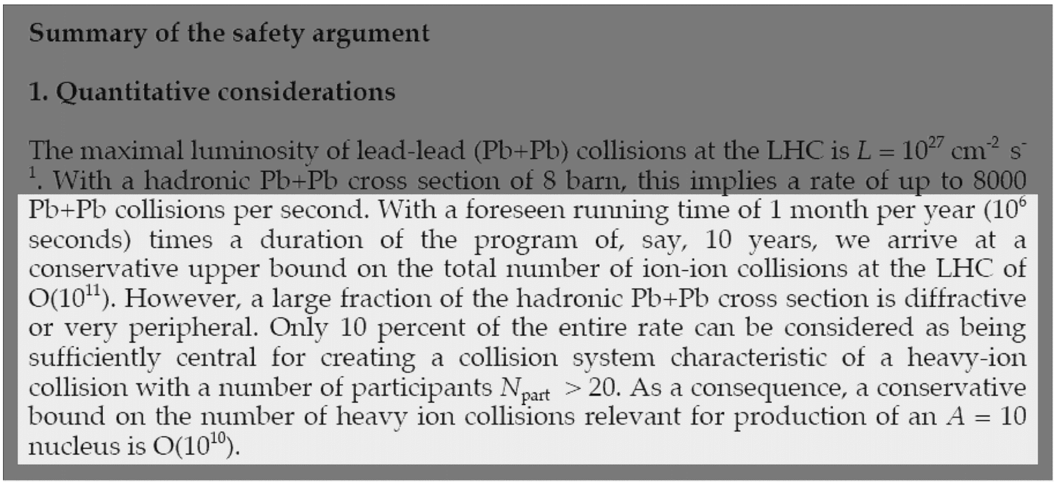
- The probability for a hadron-rich 'Centauro-type' event, estimated from statistics of Chacaltaya and Pamir experiments for cosmic ray families with visible energy greater than 100 TeV, is about 3%.
- In about 10% of these hadron-rich events, strongly penetrating cascades, clusters, or "halo" were observed. We assume the total probability for "Long Flying Component" (Strangelet?) production in central nucleus-nucleus collisions to be approximately: 0.03 x 0.1 ~ $O(10^{-3})$.
- At LHC kinematics, the percent of Strangelets falling in CASTOR phase space is ~ 10% of total number of Strangelets produced in central Pb-Pb collisions. This quantity depends on the mass and energy of the Strangelet, as calculated by the "Centauro model" MC code CENGEN.
- A rough estimation of the total probability for Strangelet production and detection in CASTOR is:

$$P_{\mathrm{CASTOR\ strangelet}} \approx 10^{-3} \times 0.1 \approx O(10^{-4})$$

- This number, even if it is uncertain by an order of magnitude down, is a very large number !

[22] P. Katsas, A.D. Panagiotou and E. Gładysz-Dziaduś for the CMS/CASTOR Group, 'Searching for Strange Quark Matter with the CMS/CASTOR Detector at the LHC', CMS-HI meeting, (23 Sep 2006) <http://cmsdoc.cern.ch/cms/castor/html/files/strangelet_cmsweek230906.ppt>.
► slide 30 [Back]

Exhibit 12



Summary of the safety argument

1. Quantitative considerations

The maximal luminosity of lead-lead (Pb+Pb) collisions at the LHC is $L = 10^{27}$ cm^{-2} s^{-1}. With a hadronic Pb+Pb cross section of 8 barn, this implies a rate of up to 8000 Pb+Pb collisions per second. With a foreseen running time of 1 month per year (10^6 seconds) times a duration of the program of, say, 10 years, we arrive at a conservative upper bound on the total number of ion-ion collisions at the LHC of $O(10^{11})$. However, a large fraction of the hadronic Pb+Pb cross section is diffractive or very peripheral. Only 10 percent of the entire rate can be considered as being sufficiently central for creating a collision system characteristic of a heavy-ion collision with a number of participants $N_{\mathrm{part}} > 20$. As a consequence, a conservative bound on the number of heavy ion collisions relevant for production of an $A = 10$ nucleus is $O(10^{10})$.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 19 [Back]

Exhibit 13

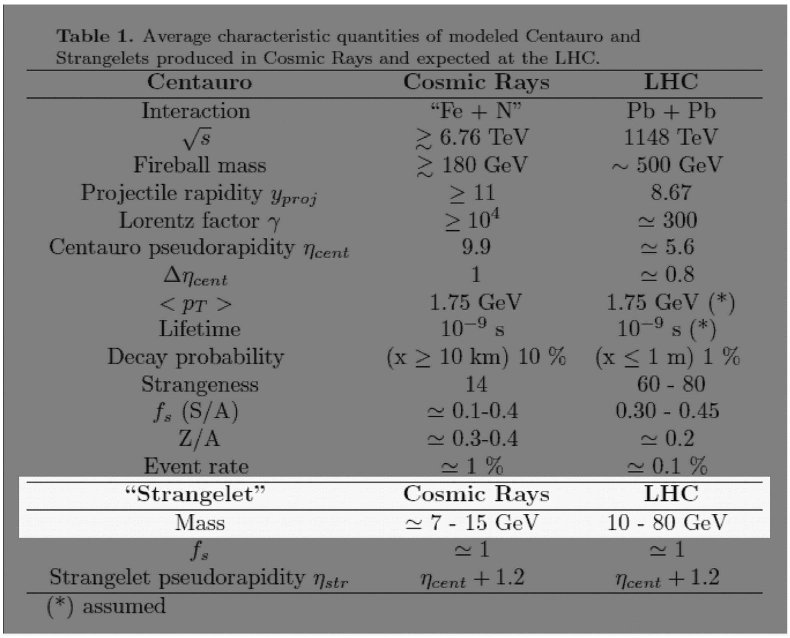


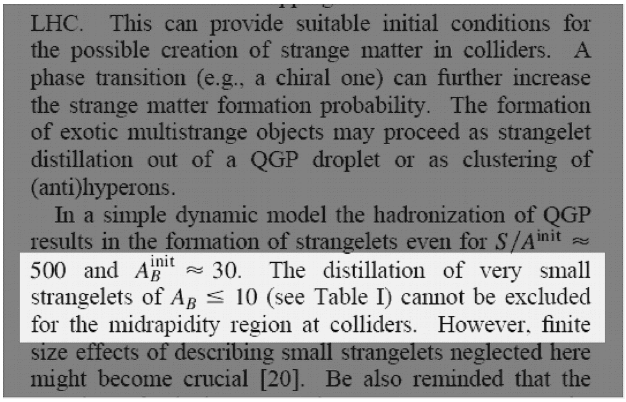
Table 1. Average characteristic quantities of modeled Centauro and Strangelets produced in Cosmic Rays and expected at the LHC.

Centauro	Cosmic Rays	LHC
Interaction	"Fe + N"	Pb + Pb
$\sqrt{s}$	$\gtrsim$ 6.76 TeV	1148 TeV
Fireball mass	$\gtrsim$ 180 GeV	$\sim$ 500 GeV
Projectile rapidity y_{proj}	≥ 11	8.67
Lorentz factor γ	$\geq 10^4$	$\simeq 300$
Centauro pseudorapidity η_{cent}	9.9	$\simeq 5.6$
$\Delta\eta_{cent}$	1	$\simeq 0.8$
$< p_T >$	1.75 GeV	1.75 GeV (*)
Lifetime	10^{-9} s	10^{-9} s (*)
Decay probability	(x $\geq$ 10 km) 10 %	(x $\leq$ 1 m) 1 %
Strangeness	14	60 - 80
f_s (S/A)	$\simeq$ 0.1-0.4	0.30 - 0.45
Z/A	$\simeq$ 0.3-0.4	$\simeq 0.2$
Event rate	$\simeq$ 1 %	$\simeq$ 0.1 %
"Strangelet"	**Cosmic Rays**	**LHC**
Mass	$\simeq$ 7 - 15 GeV	10 - 80 GeV
f_s	$\simeq 1$	$\simeq 1$
Strangelet pseudorapidity η_{str}	$\eta_{cent} + 1.2$	$\eta_{cent} + 1.2$

(*) assumed

[27] E. Gładysz-Dziaduś for the CASTOR group, 'CASTOR: Centauro and Strange Object Research in nucleus-nucleus collisions at LHC', talk given at the Int. Workshop on Nuclear Theory, 10-15 Jun 2002, Rila Mountains, Bulgaria, arXiv: hep-ex/0209008v2 (2002). ► tab. 1, p. 6 [Back]

Exhibit 14

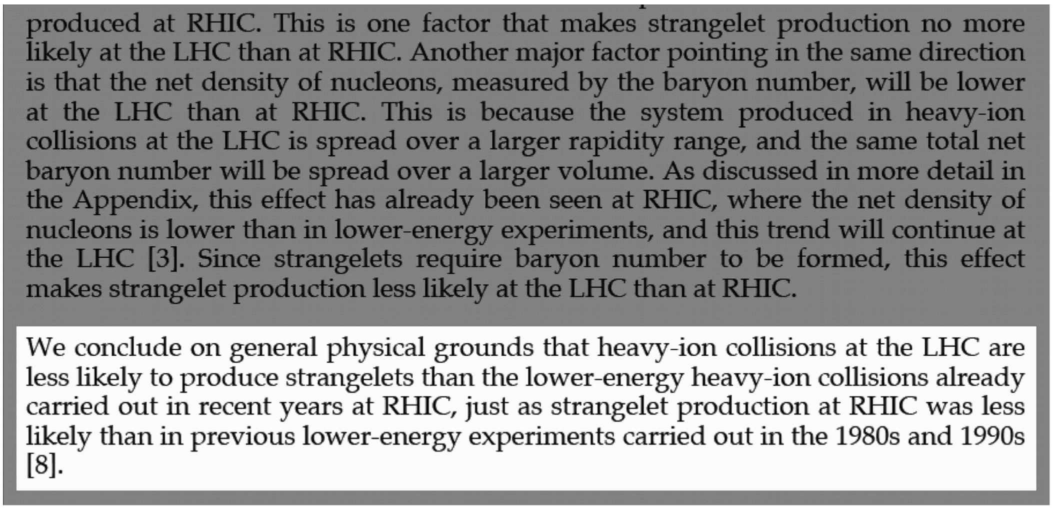


LHC. This can provide suitable initial conditions for the possible creation of strange matter in colliders. A phase transition (e.g., a chiral one) can further increase the strange matter formation probability. The formation of exotic multistrange objects may proceed as strangelet distillation out of a QGP droplet or as clustering of (anti)hyperons.

In a simple dynamic model the hadronization of QGP results in the formation of strangelets even for $S/A^{\text{init}} \approx 500$ and $A_B^{\text{init}} \approx 30$. The distillation of very small strangelets of $A_B \lesssim 10$ (see Table I) cannot be excluded for the midrapidity region at colliders. However, finite size effects of describing small strangelets neglected here might become crucial [20]. Be also reminded that the

[26] C. Spieles, L. Gerland, H. Stöcker, C. Greiner, C. Kuhn and J.P. Coffin, 'Creation of Strange Matter at Low Initial μ/T', *Phys. Rev. Lett.* **76**(11) (1996) 1776–1779, doi: 10.1103/PhysRevLett.76.1776. ► p. 1779 (no link) [Back]

Exhibit 15

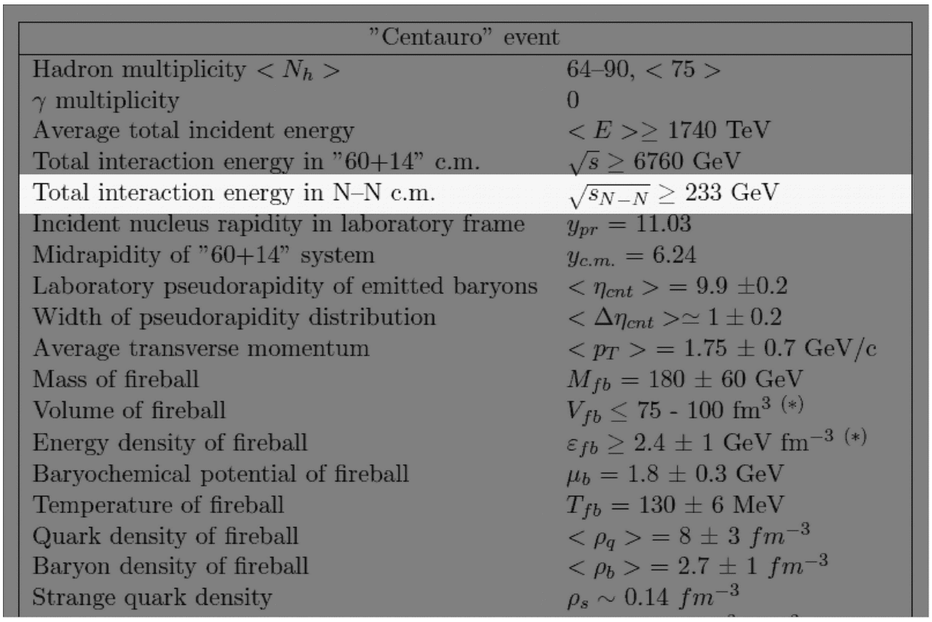


produced at RHIC. This is one factor that makes strangelet production no more likely at the LHC than at RHIC. Another major factor pointing in the same direction is that the net density of nucleons, measured by the baryon number, will be lower at the LHC than at RHIC. This is because the system produced in heavy-ion collisions at the LHC is spread over a larger rapidity range, and the same total net baryon number will be spread over a larger volume. As discussed in more detail in the Appendix, this effect has already been seen at RHIC, where the net density of nucleons is lower than in lower-energy experiments, and this trend will continue at the LHC [3]. Since strangelets require baryon number to be formed, this effect makes strangelet production less likely at the LHC than at RHIC.

We conclude on general physical grounds that heavy-ion collisions at the LHC are less likely to produce strangelets than the lower-energy heavy-ion collisions already carried out in recent years at RHIC, just as strangelet production at RHIC was less likely than in previous lower-energy experiments carried out in the 1980s and 1990s [8].

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), ‘Review of the safety of LHC Collisions’, *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 11 [Back]

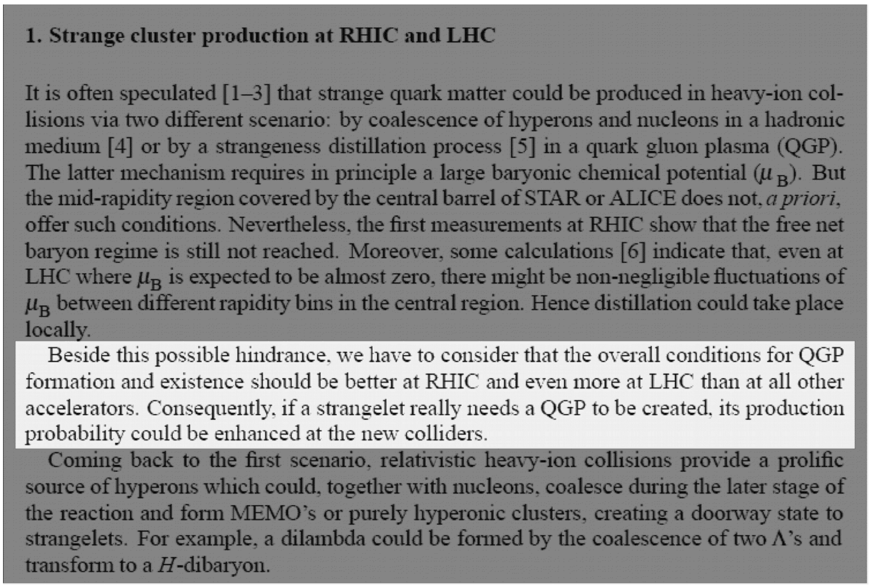
Exhibit 16



”Centauro” event	
Hadron multiplicity $< N_h >$	64–90, $< 75 >$
γ multiplicity	0
Average total incident energy	$< E >\geq$ 1740 TeV
Total interaction energy in ”60+14” c.m.	$\sqrt{s} \geq$ 6760 GeV
Total interaction energy in N–N c.m.	$\sqrt{s_{N-N}} \geq$ 233 GeV
Incident nucleus rapidity in laboratory frame	$y_{pr} = 11.03$
Midrapidity of ”60+14” system	$y_{c.m.} = 6.24$
Laboratory pseudorapidity of emitted baryons	$< \eta_{cnt} > = 9.9 \pm 0.2$
Width of pseudorapidity distribution	$< \Delta\eta_{cnt} > \simeq 1 \pm 0.2$
Average transverse momentum	$< p_T > = 1.75 \pm 0.7$ GeV/c
Mass of fireball	$M_{fb} = 180 \pm 60$ GeV
Volume of fireball	$V_{fb} \leq$ 75 - 100 fm^3 $^{(*)}$
Energy density of fireball	$\varepsilon_{fb} \geq 2.4 \pm 1$ GeV fm^{-3} $^{(*)}$
Baryochemical potential of fireball	$\mu_b = 1.8 \pm 0.3$ GeV
Temperature of fireball	$T_{fb} = 130 \pm 6$ MeV
Quark density of fireball	$< \rho_q > = 8 \pm 3\ fm^{-3}$
Baryon density of fireball	$< \rho_b > = 2.7 \pm 1\ fm^{-3}$
Strange quark density	$\rho_s \sim 0.14\ fm^{-3}$

[23] E. Gładysz-Dziaduś, ‘Are Centauros exotic signals of the QGP?’, *Phys. Part. Nucl.* **34** (2001) 285-347; arXiv: hep-ph/0111163v1 (2001). ► tab. 4.1, p. 84 [Back]

Exhibit 17



1. Strange cluster production at RHIC and LHC

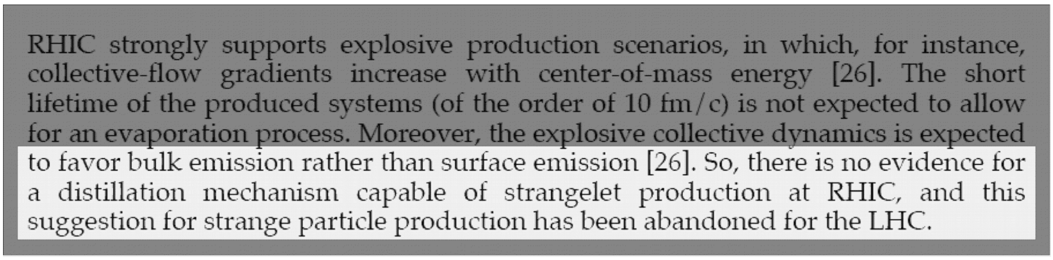
It is often speculated [1–3] that strange quark matter could be produced in heavy-ion collisions via two different scenario: by coalescence of hyperons and nucleons in a hadronic medium [4] or by a strangeness distillation process [5] in a quark gluon plasma (QGP). The latter mechanism requires in principle a large baryonic chemical potential (μ_B). But the mid-rapidity region covered by the central barrel of STAR or ALICE does not, *a priori*, offer such conditions. Nevertheless, the first measurements at RHIC show that the free net baryon regime is still not reached. Moreover, some calculations [6] indicate that, even at LHC where μ_B is expected to be almost zero, there might be non-negligible fluctuations of μ_B between different rapidity bins in the central region. Hence distillation could take place locally.

Beside this possible hindrance, we have to consider that the overall conditions for QGP formation and existence should be better at RHIC and even more at LHC than at all other accelerators. Consequently, if a strangelet really needs a QGP to be created, its production probability could be enhanced at the new colliders.

Coming back to the first scenario, relativistic heavy-ion collisions provide a prolific source of hyperons which could, together with nucleons, coalesce during the later stage of the reaction and form MEMO's or purely hyperonic clusters, creating a doorway state to strangelets. For example, a dilambda could be formed by the coalescence of two Λ's and transform to a H-dibaryon.

[28] J.P. Coffin, C. Kuhn, B. Hippolyte, J. Baudot and I. Belikov, 'Multi-strange-quark states at ultra-relativistic heavy-ion collisions', *Pramana* **60**(5) (2003) 1055-1058, <http://www.ias.ac.in/pramana/v60/p1055/fulltext.pdf>, doi: 10.1007/BF02707030. ► p. 1055 [Back]

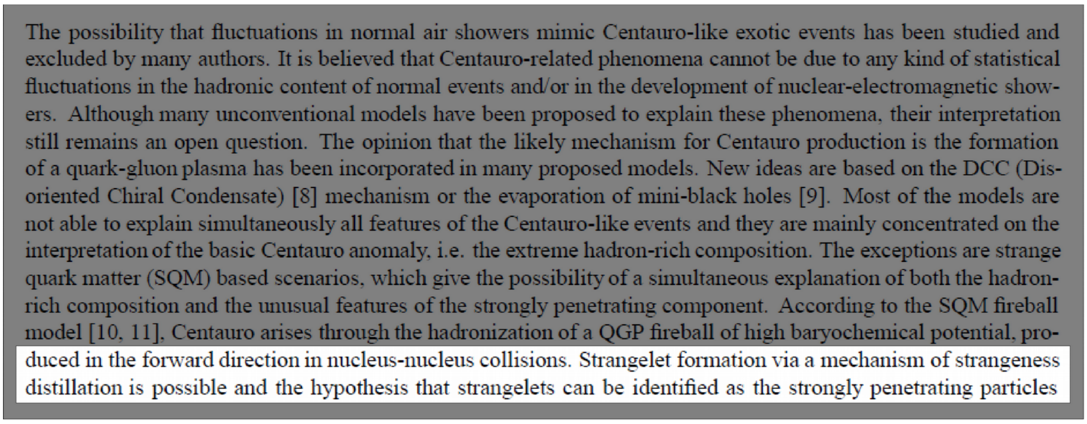
Exhibit 18



RHIC strongly supports explosive production scenarios, in which, for instance, collective-flow gradients increase with center-of-mass energy [26]. The short lifetime of the produced systems (of the order of 10 fm/c) is not expected to allow for an evaporation process. Moreover, the explosive collective dynamics is expected to favor bulk emission rather than surface emission [26]. So, there is no evidence for a distillation mechanism capable of strangelet production at RHIC, and this suggestion for strange particle production has been abandoned for the LHC.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 19 [Back]

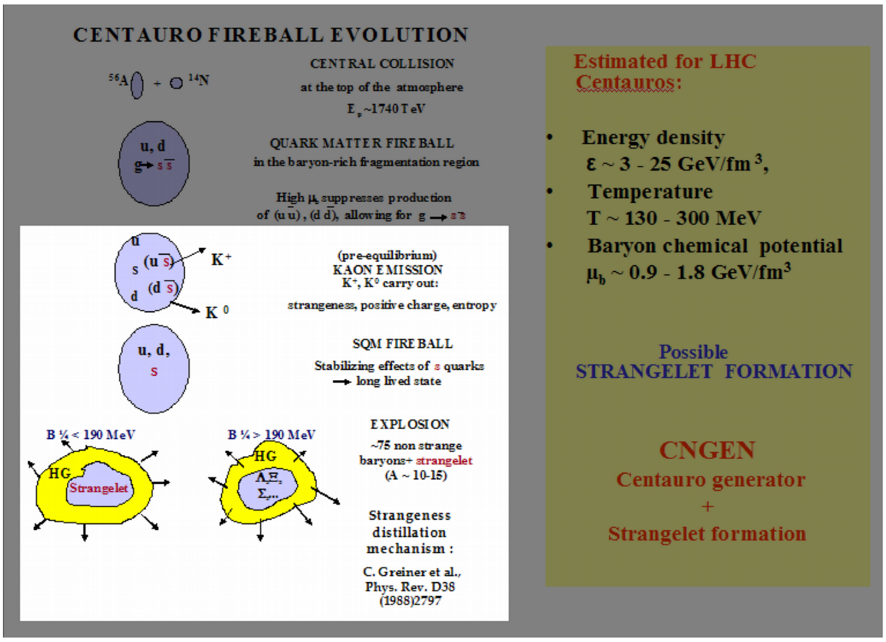
Exhibit 19



The possibility that fluctuations in normal air showers mimic Centauro-like exotic events has been studied and excluded by many authors. It is believed that Centauro-related phenomena cannot be due to any kind of statistical fluctuations in the hadronic content of normal events and/or in the development of nuclear-electromagnetic showers. Although many unconventional models have been proposed to explain these phenomena, their interpretation still remains an open question. The opinion that the likely mechanism for Centauro production is the formation of a quark-gluon plasma has been incorporated in many proposed models. New ideas are based on the DCC (Disoriented Chiral Condensate) [8] mechanism or the evaporation of mini-black holes [9]. Most of the models are not able to explain simultaneously all features of the Centauro-like events and they are mainly concentrated on the interpretation of the basic Centauro anomaly, i.e. the extreme hadron-rich composition. The exceptions are strange quark matter (SQM) based scenarios, which give the possibility of a simultaneous explanation of both the hadron-rich composition and the unusual features of the strongly penetrating component. According to the SQM fireball model [10, 11], Centauro arises through the hadronization of a QGP fireball of high baryochemical potential, produced in the forward direction in nucleus-nucleus collisions. Strangelet formation via a mechanism of strangeness distillation is possible and the hypothesis that strangelets can be identified as the strongly penetrating particles

[18] E. Norbeck, Y. Onel, E. Gładysz-Dziaduś, A.D. Panagiotou and P. Katsas, ‘Exotic Physics at the LHC with CASTOR in CMS’, CMS Conference Report 2007/013, *Int. J. Mod. Phys.* **E16**(7-8) (2007) 2451-2456, doi: 10.1142/S0218301307008082, <http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2007&files=CR2007_013.pdf>. ► pp. 2-3 [Back]

Exhibit 20



CENTAURO FIREBALL EVOLUTION

CENTRAL COLLISION
at the top of the atmosphere
E_p~1740 TeV

QUARK MATTER FIREBALL
in the baryon-rich fragmentation region

High μ_b suppresses production
of $(u\bar{u})$, $(d\bar{d})$, allowing for $g \rightarrow s\bar{s}$

(pre-equilibrium)
KAON EMISSION
K^+, K^0 carry out:
strangeness, positive charge, entropy

SQM FIREBALL
Stabilizing effects of s quarks
→ long lived state

EXPLOSION
~75 non strange baryons+ strangelet
(A ~ 10-15)

Strangeness distillation mechanism :
C. Greiner et al., Phys. Rev. D38 (1988)2797

Estimated for LHC Centauros:

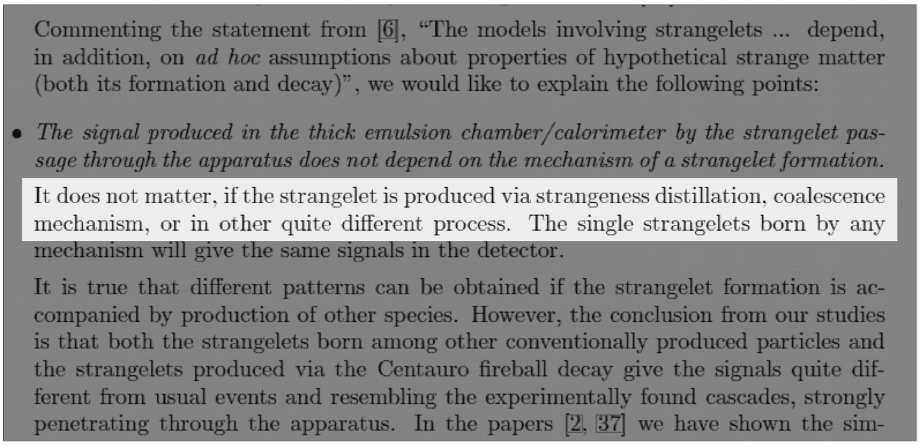
- Energy density
  $\varepsilon \sim 3 - 25$ GeV/fm ^{3},
- Temperature
  T ~ 130 - 300 MeV
- Baryon chemical potential
  $\mu_b \sim 0.9 - 1.8$ GeV/fm^3

Possible
STRANGELET FORMATION

CNGEN
Centauro generator
+
Strangelet formation

[20] P. Katsas, ‘Strangelet hunt at CMS’ [slides], QCD at Cosmic Energies II Workshop, Skopelos, Greece, 25 Sep - 1 Oct 2005, <http://cmsdoc.cern.ch/cms/castor/html/files/Strangelets_hunt_v3.ppt> or 2nd to last transparency from: <http://indico.cern.ch/event/a056703>. ► slide 14 [Back]

Exhibit 21



Commenting the statement from [6], “The models involving strangelets ... depend, in addition, on *ad hoc* assumptions about properties of hypothetical strange matter (both its formation and decay)”, we would like to explain the following points:

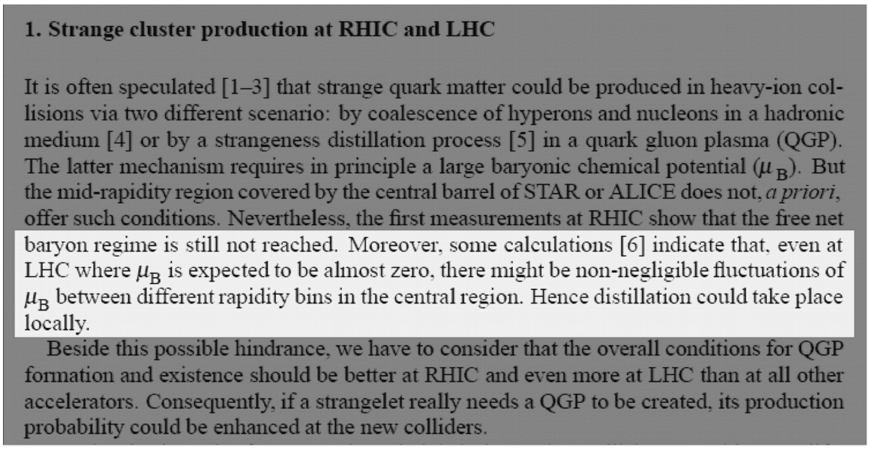
- *The signal produced in the thick emulsion chamber/calorimeter by the strangelet passage through the apparatus does not depend on the mechanism of a strangelet formation.*

It does not matter, if the strangelet is produced via strangeness distillation, coalescence mechanism, or in other quite different process. The single strangelets born by any mechanism will give the same signals in the detector.

It is true that different patterns can be obtained if the strangelet formation is accompanied by production of other species. However, the conclusion from our studies is that both the strangelets born among other conventionally produced particles and the strangelets produced via the Centauro fireball decay give the signals quite different from usual events and resembling the experimentally found cascades, strongly penetrating through the apparatus. In the papers [2, 37] we have shown the sim-

[30] E. Gładysz-Dziaduś, ‘Black Holes versus Strange Quark Matter’, arXiv: hep-ph/0405115v3 (2005). ► p. 10 [Back]

Exhibit 22



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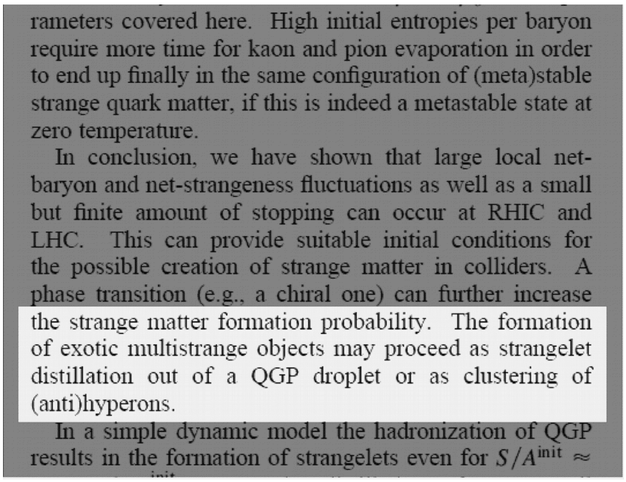
Beside this possible hindrance, we have to consider that the overall conditions for QGP formation and existence should be better at RHIC and even more at LHC than at all other accelerators. Consequently, if a strangelet really needs a QGP to be created, its production probability could be enhanced at the new colliders.

[28] J.P. Coffin, C. Kuhn, B. Hippolyte, J. Baudot and I. Belikov, ‘Multi-strange-quark states at ultra-relativistic heavy-ion collisions’, *Pramana* **60**(5) (2003) 1055-1058, <http://www.ias.ac.in/pramana/v60/p1055/fulltext.pdf>, doi: 10.1007/BF02707030. ► p. 1055 [Back]

Exhibit 23



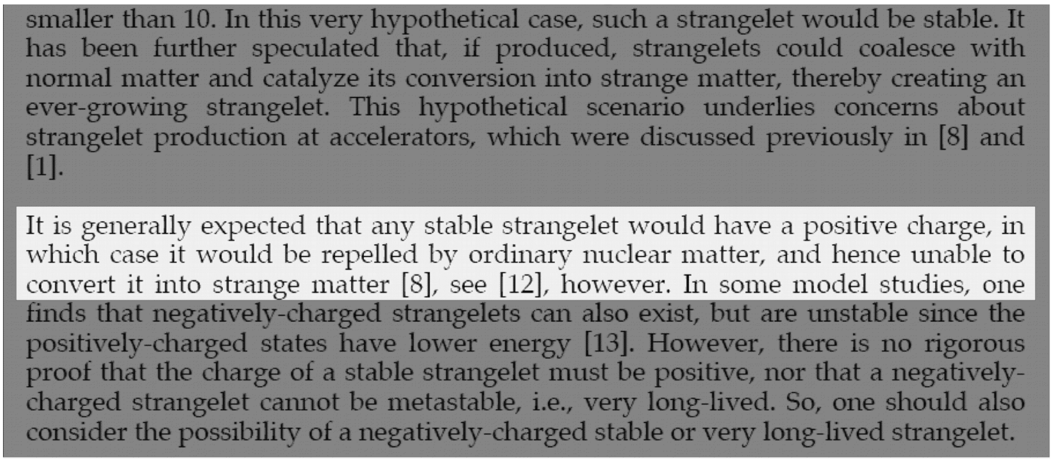
rameters covered here. High initial entropies per baryon require more time for kaon and pion evaporation in order to end up finally in the same configuration of (meta)stable strange quark matter, if this is indeed a metastable state at zero temperature.

In conclusion, we have shown that large local net-baryon and net-strangeness fluctuations as well as a small but finite amount of stopping can occur at RHIC and LHC. This can provide suitable initial conditions for the possible creation of strange matter in colliders. A phase transition (e.g., a chiral one) can further increase the strange matter formation probability. The formation of exotic multistrange objects may proceed as strangelet distillation out of a QGP droplet or as clustering of (anti)hyperons.

In a simple dynamic model the hadronization of QGP results in the formation of strangelets even for $S/A^{\text{init}} \approx$

[26] C. Spieles, L. Gerland, H. Stöcker, C. Greiner, C. Kuhn and J.P. Coffin, 'Creation of Strange Matter at Low Initial μ/T', *Phys. Rev. Lett.* **76**(11) (1996) 1776–1779, doi: 10.1103/PhysRevLett.76.1776. ► p. 1779 (no link) [Back]

Exhibit 24

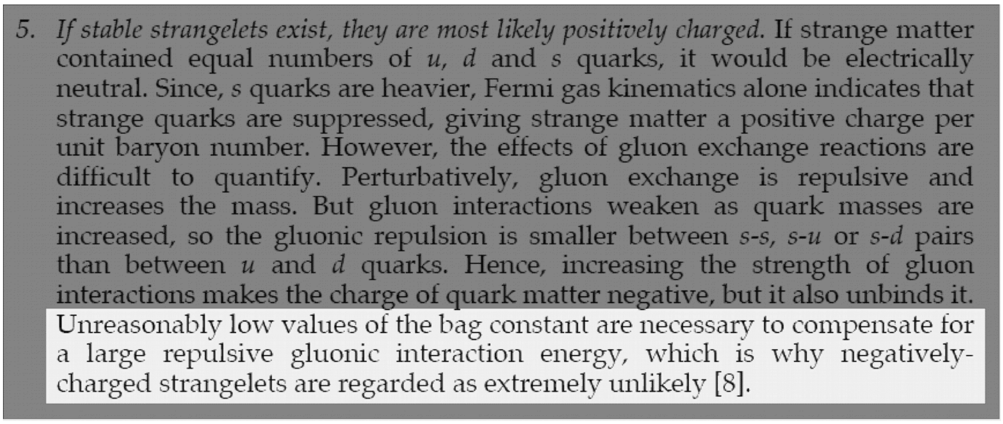


smaller than 10. In this very hypothetical case, such a strangelet would be stable. It has been further speculated that, if produced, strangelets could coalesce with normal matter and catalyze its conversion into strange matter, thereby creating an ever-growing strangelet. This hypothetical scenario underlies concerns about strangelet production at accelerators, which were discussed previously in [8] and [1].

It is generally expected that any stable strangelet would have a positive charge, in which case it would be repelled by ordinary nuclear matter, and hence unable to convert it into strange matter [8], see [12], however. In some model studies, one finds that negatively-charged strangelets can also exist, but are unstable since the positively-charged states have lower energy [13]. However, there is no rigorous proof that the charge of a stable strangelet must be positive, nor that a negatively-charged strangelet cannot be metastable, i.e., very long-lived. So, one should also consider the possibility of a negatively-charged stable or very long-lived strangelet.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 9 [Back]

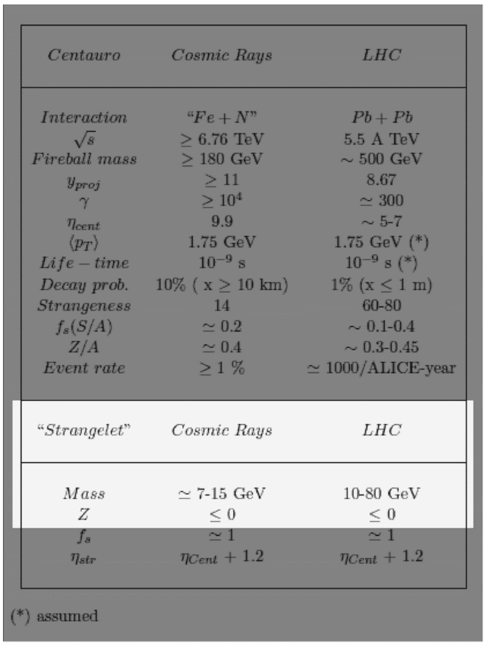
Exhibit 25



5. *If stable strangelets exist, they are most likely positively charged.* If strange matter contained equal numbers of *u*, *d* and *s* quarks, it would be electrically neutral. Since, *s* quarks are heavier, Fermi gas kinematics alone indicates that strange quarks are suppressed, giving strange matter a positive charge per unit baryon number. However, the effects of gluon exchange reactions are difficult to quantify. Perturbatively, gluon exchange is repulsive and increases the mass. But gluon interactions weaken as quark masses are increased, so the gluonic repulsion is smaller between *s*-*s*, *s*-*u* or *s*-*d* pairs than between *u* and *d* quarks. Hence, increasing the strength of gluon interactions makes the charge of quark matter negative, but it also unbinds it. Unreasonably low values of the bag constant are necessary to compensate for a large repulsive gluonic interaction energy, which is why negatively-charged strangelets are regarded as extremely unlikely [8].

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), ‘Review of the safety of LHC Collisions’, *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 15 [Back]

Exhibit 26



Centauro	*Cosmic Rays*	*LHC*
Interaction	“Fe + N”	Pb + Pb
$\sqrt{s}$	≥ 6.76 TeV	5.5 A TeV
Fireball mass	≥ 180 GeV	~ 500 GeV
y_{proj}	≥ 11	8.67
γ	$\geq 10^4$	$\simeq 300$
η_{cent}	9.9	$\sim$ 5-7
$\langle p_T \rangle$	1.75 GeV	1.75 GeV (*)
Life − time	10^{-9} s	10^{-9} s (*)
Decay prob.	10% ($x \geq 10$ km)	1% ($x \leq 1$ m)
Strangeness	14	60-80
$f_s(S/A)$	$\simeq 0.2$	$\sim$ 0.1-0.4
Z/A	$\simeq 0.4$	$\sim$ 0.3-0.45
Event rate	≥ 1 %	$\simeq$ 1000/ALICE-year

“Strangelet”	*Cosmic Rays*	*LHC*
Mass	$\simeq$ 7-15 GeV	10-80 GeV
Z	≤ 0	≤ 0
f_s	$\simeq 1$	$\simeq 1$
η_{str}	$\eta_{Cent} + 1.2$	$\eta_{Cent} + 1.2$

(*) assumed

[23] E. Gładysz-Dziaduś, ‘Are Centauros exotic signals of the QGP?’, *Phys. Part. Nucl.* **34** (2001) 285-347; see also *Fiz. Elem. Chast. Atom. Yadra* **34** (2003) 565-678; arXiv: hep-ph/0111163v1 (2001). ► tab. 6.3, p. 112 [Back]

Exhibit 27

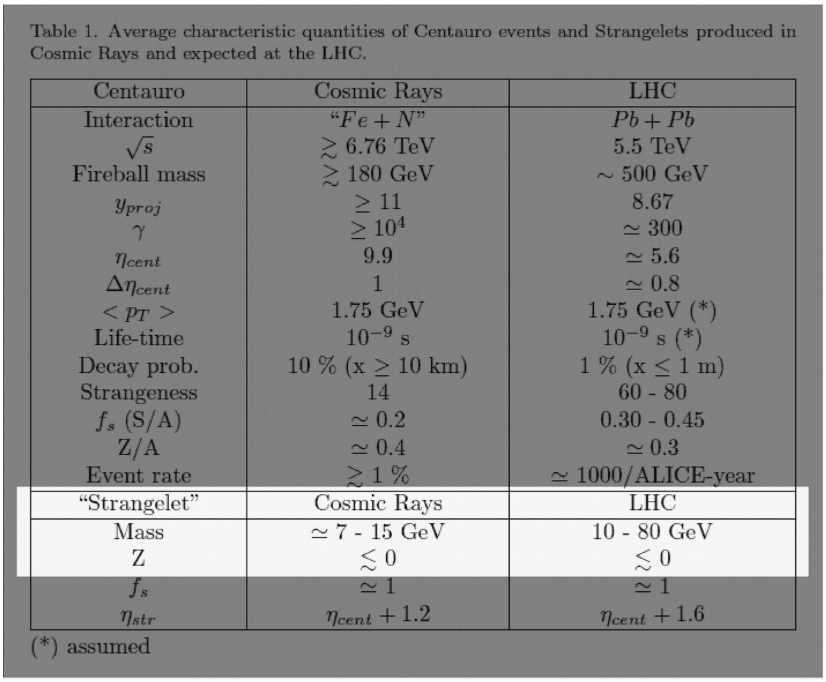


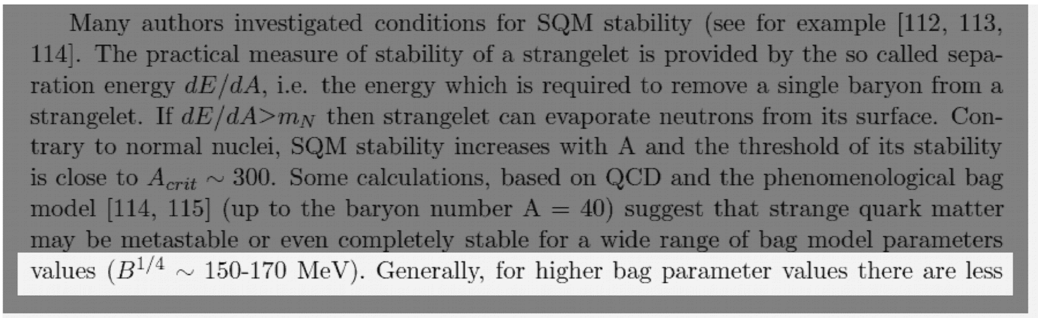
Table 1. Average characteristic quantities of Centauro events and Strangelets produced in Cosmic Rays and expected at the LHC.

Centauro	Cosmic Rays	LHC
Interaction	“$Fe+N$”	$Pb+Pb$
$\sqrt{s}$	$\gtrsim$ 6.76 TeV	5.5 TeV
Fireball mass	$\gtrsim$ 180 GeV	$\sim$ 500 GeV
y_{proj}	≥ 11	8.67
γ	$\geq 10^4$	$\simeq 300$
η_{cent}	9.9	$\simeq 5.6$
$\Delta\eta_{cent}$	1	$\simeq 0.8$
$< p_T >$	1.75 GeV	1.75 GeV (*)
Life-time	10^{-9} s	10^{-9} s (*)
Decay prob.	10 % (x $\geq$ 10 km)	1 % (x $\leq$ 1 m)
Strangeness	14	60 - 80
f_s (S/A)	$\simeq 0.2$	0.30 - 0.45
Z/A	$\simeq 0.4$	$\simeq 0.3$
Event rate	$\gtrsim$ 1 %	$\simeq$ 1000/ALICE-year
“Strangelet”	Cosmic Rays	LHC
Mass	$\simeq$ 7 - 15 GeV	10 - 80 GeV
Z	$\lesssim 0$	$\lesssim 0$
f_s	$\simeq 1$	$\simeq 1$
η_{str}	$\eta_{cent}+1.2$	$\eta_{cent}+1.6$

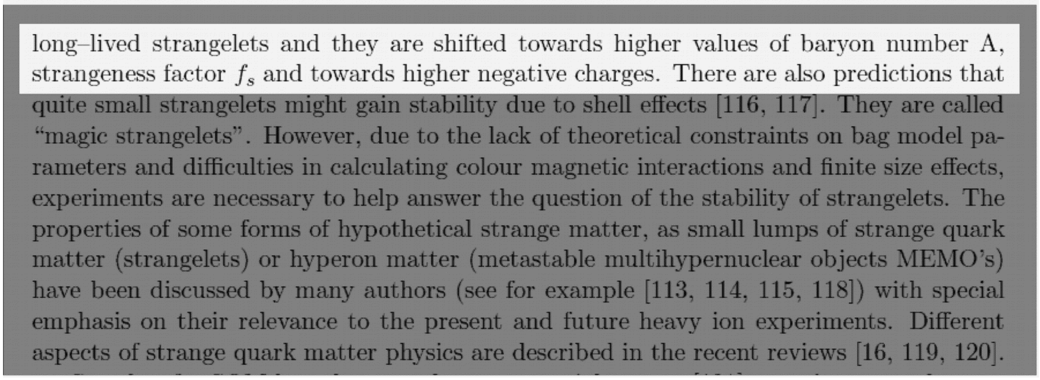
(*) assumed

[31] A.L.S. Angelis, J. Bartke, M.Yu. Bogolyubsky, S.N. Filippov, E. Gładysz-Dziaduś, Yu.V. Kharlov, A.B. Kurepin, A.I. Maevskaya, G. Mavromanolakis, A.D. Panagiotou, S.A. Sadovsky, P. Stefanski and Z. Włodarczyk, ‘CASTOR: A Forward Detector for the Identification of Centauros and Strangelets in Nucleus-Nucleus Collisions at the LHC’, arXiv: hep-ex/9901038v1 (1999). Also: A.L.S. Angelis *et al.*, ‘Formation and identification of centauro and strangelets in nucleus-nucleus collisions at the LHC’, *Nucl. Phys. B (Proc. Suppl.)* **75**(1-2) (1999) 203-205, doi: 10.1016/S0920-5632(99)00243-1; also: Proc. Int. Symp. on Multiparticle Dynamics, Delphi, 6-11 Sep. 1998. ► tab. 1, p. 3 [Back]

Exhibit 28



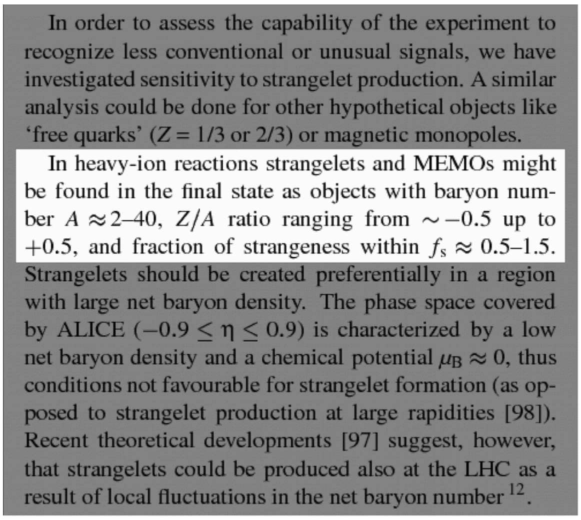
Many authors investigated conditions for SQM stability (see for example [112, 113, 114]. The practical measure of stability of a strangelet is provided by the so called separation energy dE/dA, i.e. the energy which is required to remove a single baryon from a strangelet. If $dE/dA > m_N$ then strangelet can evaporate neutrons from its surface. Contrary to normal nuclei, SQM stability increases with A and the threshold of its stability is close to $A_{crit} \sim 300$. Some calculations, based on QCD and the phenomenological bag model [114, 115] (up to the baryon number A = 40) suggest that strange quark matter may be metastable or even completely stable for a wide range of bag model parameters values ($B^{1/4} \sim$ 150-170 MeV). Generally, for higher bag parameter values there are less



long–lived strangelets and they are shifted towards higher values of baryon number A, strangeness factor f_s and towards higher negative charges. There are also predictions that quite small strangelets might gain stability due to shell effects [116, 117]. They are called "magic strangelets". However, due to the lack of theoretical constraints on bag model parameters and difficulties in calculating colour magnetic interactions and finite size effects, experiments are necessary to help answer the question of the stability of strangelets. The properties of some forms of hypothetical strange matter, as small lumps of strange quark matter (strangelets) or hyperon matter (metastable multihypernuclear objects MEMO's) have been discussed by many authors (see for example [113, 114, 115, 118]) with special emphasis on their relevance to the present and future heavy ion experiments. Different aspects of strange quark matter physics are described in the recent reviews [16, 119, 120].

[23] E. Gładysz-Dziaduś, 'Are Centauros exotic signals of the QGP?', *Phys. Part. Nucl.* **34** (2001) 285-347; arXiv: hep-ph/0111163v1 (2001). ► pp. 76-77 [Back]

Exhibit 29

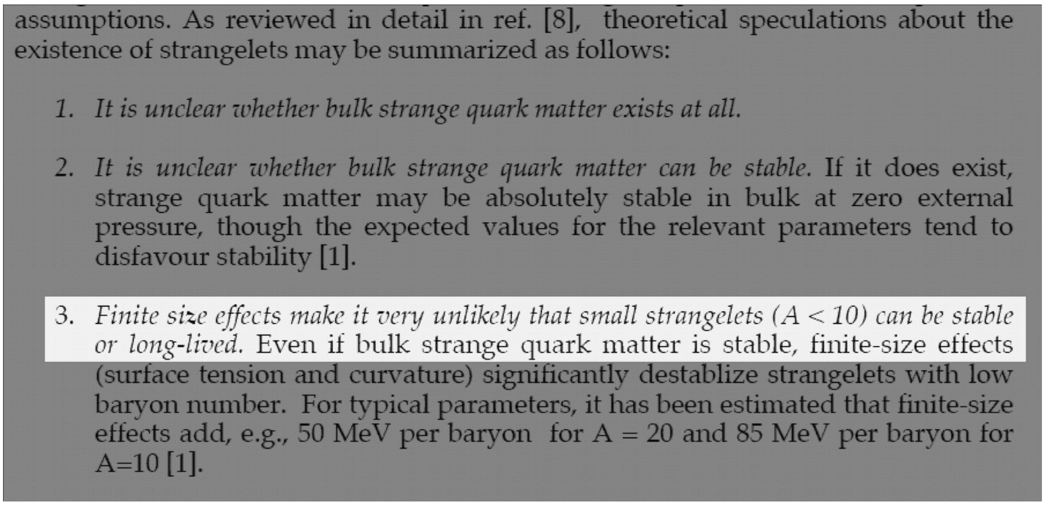


In order to assess the capability of the experiment to recognize less conventional or unusual signals, we have investigated sensitivity to strangelet production. A similar analysis could be done for other hypothetical objects like ‘free quarks’ ($Z = 1/3$ or $2/3$) or magnetic monopoles.

In heavy-ion reactions strangelets and MEMOs might be found in the final state as objects with baryon number $A \approx 2$–40, Z/A ratio ranging from ~ -0.5 up to $+0.5$, and fraction of strangeness within $f_s \approx 0.5$–1.5. Strangelets should be created preferentially in a region with large net baryon density. The phase space covered by ALICE ($-0.9 \le \eta \le 0.9$) is characterized by a low net baryon density and a chemical potential $\mu_B \approx 0$, thus conditions not favourable for strangelet formation (as opposed to strangelet production at large rapidities [98]). Recent theoretical developments [97] suggest, however, that strangelets could be produced also at the LHC as a result of local fluctuations in the net baryon number[12].

[25] ALICE Technical Proposal for A Large Ion Collider Experiment at the CERN LHC Document code: CERN /LHCC / 95–71 LHCC / P3, (1995),. Chapter 11 ‘Physics performance’, Chapter 13 ‘Planning and organization’: 13.4 ‘Organization’. ► p. 189 [Back]

Exhibit 30

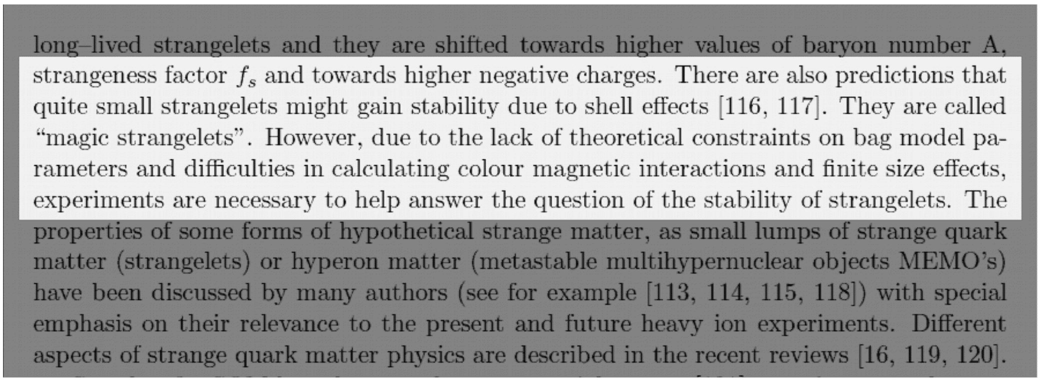


assumptions. As reviewed in detail in ref. [8], theoretical speculations about the existence of strangelets may be summarized as follows:

1. *It is unclear whether bulk strange quark matter exists at all.*
2. *It is unclear whether bulk strange quark matter can be stable.* If it does exist, strange quark matter may be absolutely stable in bulk at zero external pressure, though the expected values for the relevant parameters tend to disfavour stability [1].
3. *Finite size effects make it very unlikely that small strangelets ($A < 10$) can be stable or long-lived.* Even if bulk strange quark matter is stable, finite-size effects (surface tension and curvature) significantly destablize strangelets with low baryon number. For typical parameters, it has been estimated that finite-size effects add, e.g., 50 MeV per baryon for A = 20 and 85 MeV per baryon for A=10 [1].

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), ‘Review of the safety of LHC Collisions’, *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 14 [Back]

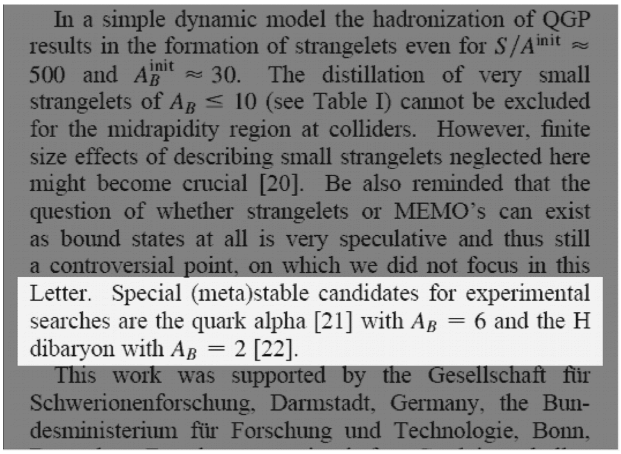
Exhibit 31



long–lived strangelets and they are shifted towards higher values of baryon number A, strangeness factor f_s and towards higher negative charges. There are also predictions that quite small strangelets might gain stability due to shell effects [116, 117]. They are called "magic strangelets". However, due to the lack of theoretical constraints on bag model parameters and difficulties in calculating colour magnetic interactions and finite size effects, experiments are necessary to help answer the question of the stability of strangelets. The properties of some forms of hypothetical strange matter, as small lumps of strange quark matter (strangelets) or hyperon matter (metastable multihypernuclear objects MEMO's) have been discussed by many authors (see for example [113, 114, 115, 118]) with special emphasis on their relevance to the present and future heavy ion experiments. Different aspects of strange quark matter physics are described in the recent reviews [16, 119, 120].

[23] E. Gładysz-Dziaduś, 'Are Centauros exotic signals of the QGP?', *Phys. Part. Nucl.* **34** (2001) 285-347; arXiv: hep-ph/0111163v1 (2001). ► p. 77 [Back]

Exhibit 32

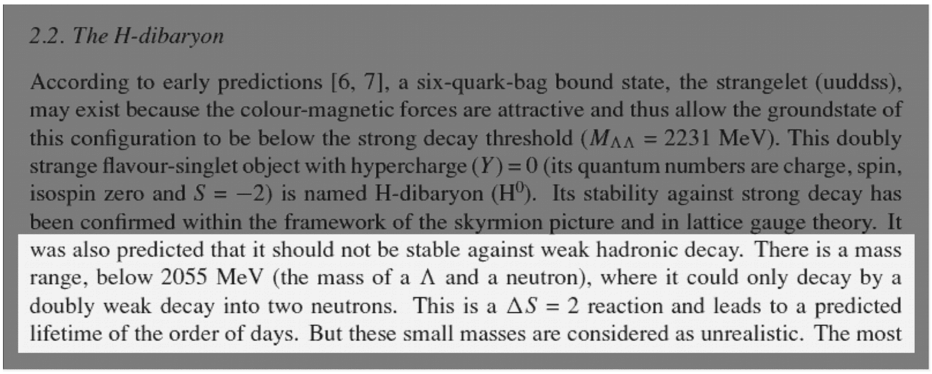


In a simple dynamic model the hadronization of QGP results in the formation of strangelets even for $S/A^{\mathrm{init}} \approx 500$ and $A_B^{\mathrm{init}} \approx 30$. The distillation of very small strangelets of $A_B \leq 10$ (see Table I) cannot be excluded for the midrapidity region at colliders. However, finite size effects of describing small strangelets neglected here might become crucial [20]. Be also reminded that the question of whether strangelets or MEMO's can exist as bound states at all is very speculative and thus still a controversial point, on which we did not focus in this Letter. Special (meta)stable candidates for experimental searches are the quark alpha [21] with $A_B = 6$ and the H dibaryon with $A_B = 2$ [22].

This work was supported by the Gesellschaft für Schwerionenforschung, Darmstadt, Germany, the Bundesministerium für Forschung und Technologie, Bonn,

[26] C. Spieles, L. Gerland, H. Stöcker, C. Greiner, C. Kuhn and J.P. Coffin, 'Creation of Strange Matter at Low Initial μ/T', *Phys. Rev. Lett.* **76**(11) (1996) 1776–1779, doi: 10.1103/PhysRevLett.76.1776. ► p. 1779 (no link) [Back]

Exhibit 33

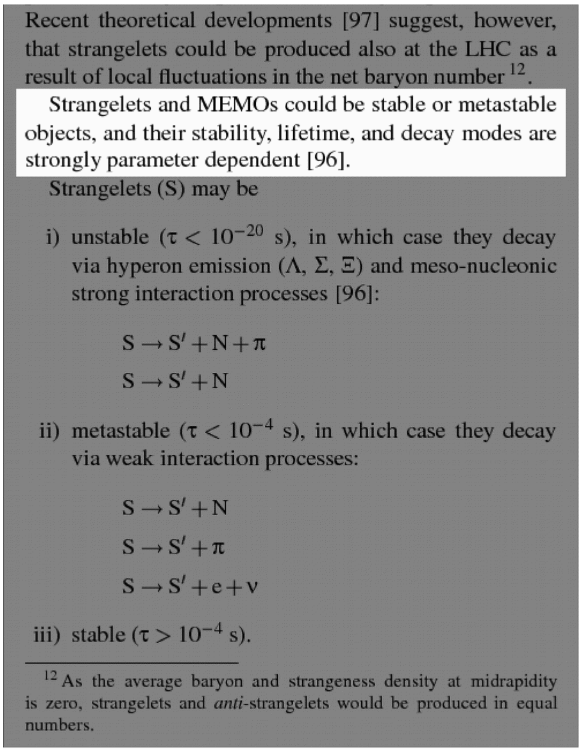


2.2. The H-dibaryon

According to early predictions [6, 7], a six-quark-bag bound state, the strangelet (uuddss), may exist because the colour-magnetic forces are attractive and thus allow the groundstate of this configuration to be below the strong decay threshold ($M_{\Lambda\Lambda}$ = 2231 MeV). This doubly strange flavour-singlet object with hypercharge $(Y) = 0$ (its quantum numbers are charge, spin, isospin zero and $S = -2$) is named H-dibaryon (H^0). Its stability against strong decay has been confirmed within the framework of the skyrmion picture and in lattice gauge theory. It was also predicted that it should not be stable against weak hadronic decay. There is a mass range, below 2055 MeV (the mass of a Λ and a neutron), where it could only decay by a doubly weak decay into two neutrons. This is a $\Delta S = 2$ reaction and leads to a predicted lifetime of the order of days. But these small masses are considered as unrealistic. The most

[29] C. Kuhn, B. Hippolyte, J.P. Coffin, J. Baudot, I. Belikov, D. Dietrich, M. Germain and C. Suire, 'Search for strange dibaryons in STAR and ALICE', *J. Phys.* **G28**(7) (2002) 1707-1714, doi: 10.1088/0954-3899/28/7/323. ► p. 1708 (no link)   [Back]

Exhibit 34



Recent theoretical developments [97] suggest, however, that strangelets could be produced also at the LHC as a result of local fluctuations in the net baryon number[12].

Strangelets and MEMOs could be stable or metastable objects, and their stability, lifetime, and decay modes are strongly parameter dependent [96].

Strangelets (S) may be

i) unstable ($\tau < 10^{-20}$ s), in which case they decay via hyperon emission (Λ, Σ, Ξ) and meso-nucleonic strong interaction processes [96]:

$$S \rightarrow S' + N + \pi$$
$$S \rightarrow S' + N$$

ii) metastable ($\tau < 10^{-4}$ s), in which case they decay via weak interaction processes:

$$S \rightarrow S' + N$$
$$S \rightarrow S' + \pi$$
$$S \rightarrow S' + e + \nu$$

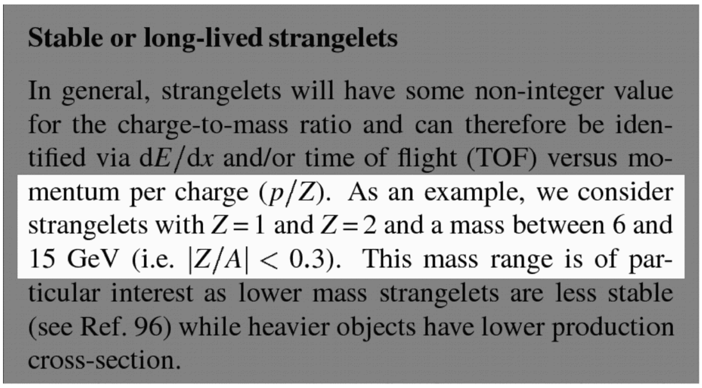
iii) stable ($\tau > 10^{-4}$ s).

---

[12] As the average baryon and strangeness density at midrapidity is zero, strangelets and *anti*-strangelets would be produced in equal numbers.

[25] ALICE Technical Proposal for A Large Ion Collider Experiment at the CERN LHC Document code: CERN /LHCC / 95–71 LHCC / P3, (1995),. Chapter 11 'Physics performance', Chapter 13 'Planning and organization': 13.4 'Organization'. ► p. 189 [Back]

Exhibit 35

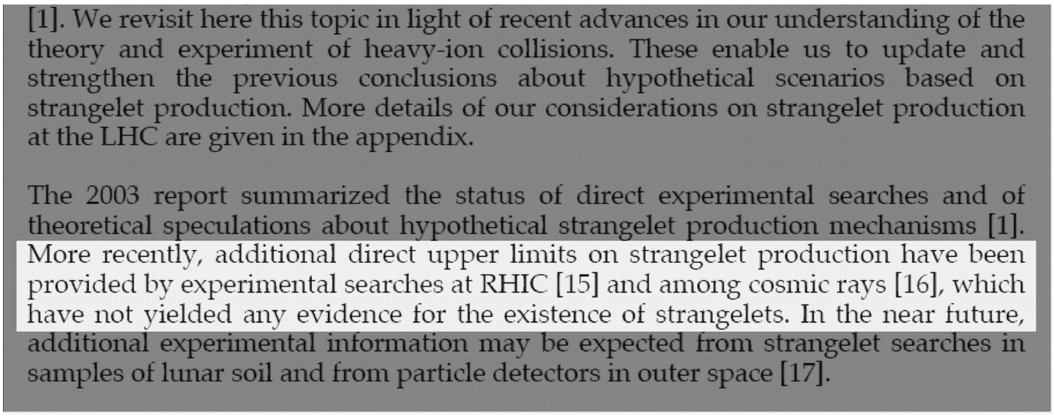


Stable or long-lived strangelets

In general, strangelets will have some non-integer value for the charge-to-mass ratio and can therefore be identified via $\mathrm{d}E/\mathrm{d}x$ and/or time of flight (TOF) versus momentum per charge (p/Z). As an example, we consider strangelets with $Z=1$ and $Z=2$ and a mass between 6 and 15 GeV (i.e. $|Z/A| < 0.3$). This mass range is of particular interest as lower mass strangelets are less stable (see Ref. 96) while heavier objects have lower production cross-section.

[25] ALICE Technical Proposal for A Large Ion Collider Experiment at the CERN LHC Document code: CERN /LHCC / 95–71 LHCC / P3, (1995),. Chapter 11 'Physics performance', Chapter 13 'Planning and organization': 13.4 'Organization'. ► p. 190 [Back]

Exhibit 36

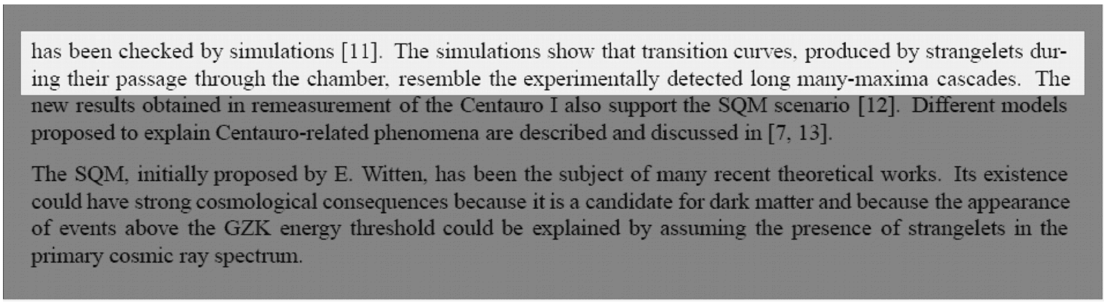


[1]. We revisit here this topic in light of recent advances in our understanding of the theory and experiment of heavy-ion collisions. These enable us to update and strengthen the previous conclusions about hypothetical scenarios based on strangelet production. More details of our considerations on strangelet production at the LHC are given in the appendix.

The 2003 report summarized the status of direct experimental searches and of theoretical speculations about hypothetical strangelet production mechanisms [1]. More recently, additional direct upper limits on strangelet production have been provided by experimental searches at RHIC [15] and among cosmic rays [16], which have not yielded any evidence for the existence of strangelets. In the near future, additional experimental information may be expected from strangelet searches in samples of lunar soil and from particle detectors in outer space [17].

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 9 [Back]

Exhibit 37

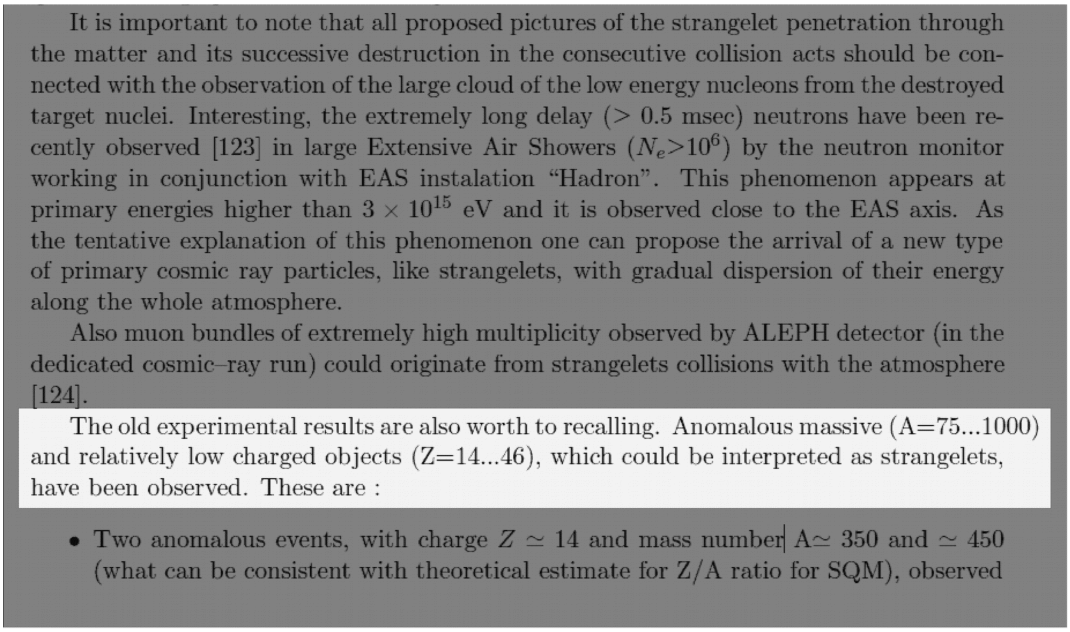


has been checked by simulations [11]. The simulations show that transition curves, produced by strangelets during their passage through the chamber, resemble the experimentally detected long many-maxima cascades. The new results obtained in remeasurement of the Centauro I also support the SQM scenario [12]. Different models proposed to explain Centauro-related phenomena are described and discussed in [7, 13].

The SQM, initially proposed by E. Witten, has been the subject of many recent theoretical works. Its existence could have strong cosmological consequences because it is a candidate for dark matter and because the appearance of events above the GZK energy threshold could be explained by assuming the presence of strangelets in the primary cosmic ray spectrum.

[18] E. Norbeck, Y. Onel, E. Gładysz-Dziaduś, A.D. Panagiotou and P. Katsas, ‘Exotic Physics at the LHC with CASTOR in CMS’, CMS Conference Report 2007/013, *Int. J. Mod. Phys.* **E16**(7-8) (2007) 2451-2456, doi: 10.1142/S0218301307008082, <http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2007&files=CR2007_013.pdf>. ► p. 3 [Back]

Exhibit 38



It is important to note that all proposed pictures of the strangelet penetration through the matter and its successive destruction in the consecutive collision acts should be connected with the observation of the large cloud of the low energy nucleons from the destroyed target nuclei. Interesting, the extremely long delay (> 0.5 msec) neutrons have been recently observed [123] in large Extensive Air Showers ($N_e > 10^6$) by the neutron monitor working in conjunction with EAS instalation “Hadron”. This phenomenon appears at primary energies higher than 3×10^{15} eV and it is observed close to the EAS axis. As the tentative explanation of this phenomenon one can propose the arrival of a new type of primary cosmic ray particles, like strangelets, with gradual dispersion of their energy along the whole atmosphere.

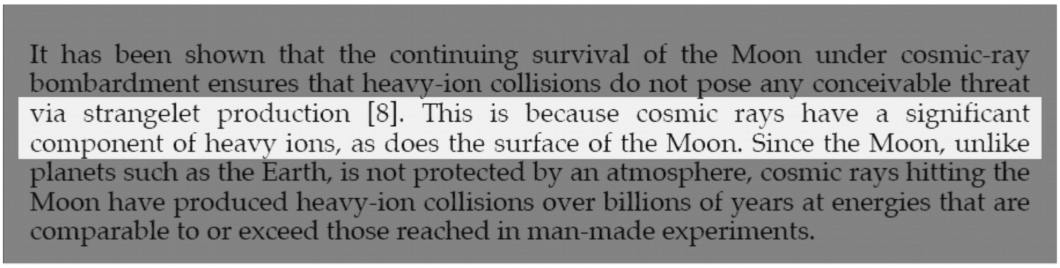
Also muon bundles of extremely high multiplicity observed by ALEPH detector (in the dedicated cosmic–ray run) could originate from strangelets collisions with the atmosphere [124].

The old experimental results are also worth to recalling. Anomalous massive (A=75...1000) and relatively low charged objects (Z=14...46), which could be interpreted as strangelets, have been observed. These are :

- Two anomalous events, with charge $Z \simeq 14$ and mass number A$\simeq$ 350 and $\simeq$ 450 (what can be consistent with theoretical estimate for Z/A ratio for SQM), observed

[23] E. Gładysz-Dziaduś, ‘Are Centauros exotic signals of the QGP?’, *Phys. Part. Nucl.* **34** (2001) 285-347; arXiv: hep-ph/0111163v1 (2001). ► p. 79 [Back 38]

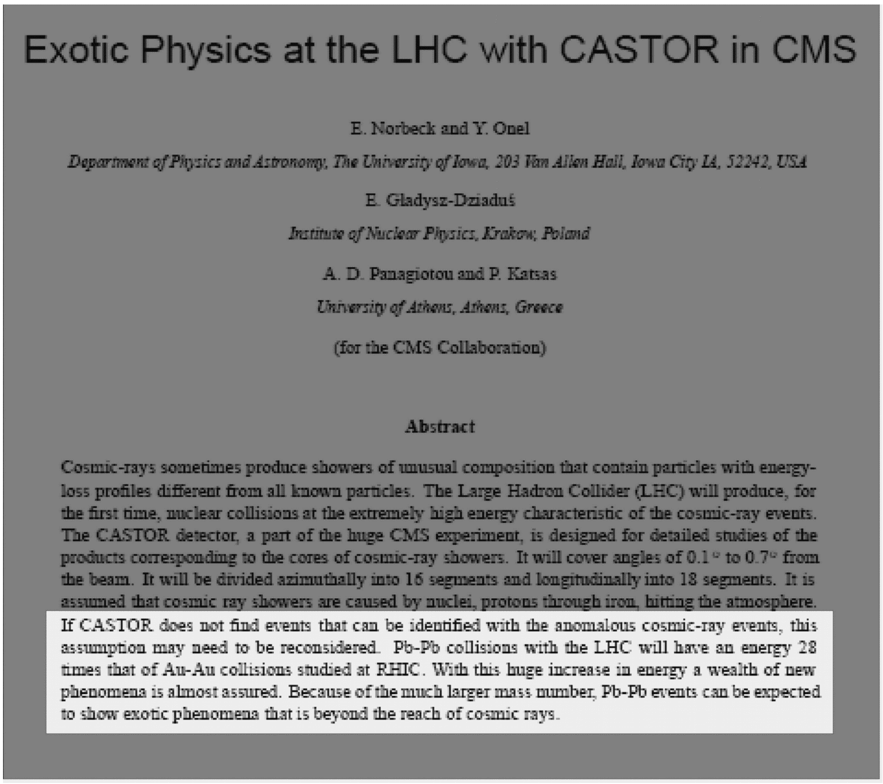
Exhibit 39



It has been shown that the continuing survival of the Moon under cosmic-ray bombardment ensures that heavy-ion collisions do not pose any conceivable threat via strangelet production [8]. This is because cosmic rays have a significant component of heavy ions, as does the surface of the Moon. Since the Moon, unlike planets such as the Earth, is not protected by an atmosphere, cosmic rays hitting the Moon have produced heavy-ion collisions over billions of years at energies that are comparable to or exceed those reached in man-made experiments.

[4] J. Ellis, G. Giudice, M.L. Mangano, I. Tkachev and U. Wiedemann (LHC Safety Assessment Group), 'Review of the safety of LHC Collisions', *J. Phys.* **G35**(11) (2008) id. 115004 (18pp.), doi: 10.1088/0954-3899/35/11/115004; arXiv: 0806.3414v2 [hep-ph] 18 Sep 2008. ► p. 12 [Back]

Exhibit 40



Exotic Physics at the LHC with CASTOR in CMS

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E. Gladysz-Dziaduś
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Abstract

Cosmic-rays sometimes produce showers of unusual composition that contain particles with energy-loss profiles different from all known particles. The Large Hadron Collider (LHC) will produce, for the first time, nuclear collisions at the extremely high energy characteristic of the cosmic-ray events. The CASTOR detector, a part of the huge CMS experiment, is designed for detailed studies of the products corresponding to the cores of cosmic-ray showers. It will cover angles of 0.1° to 0.7° from the beam. It will be divided azimuthally into 16 segments and longitudinally into 18 segments. It is assumed that cosmic ray showers are caused by nuclei, protons through iron, hitting the atmosphere. If CASTOR does not find events that can be identified with the anomalous cosmic-ray events, this assumption may need to be reconsidered. Pb-Pb collisions with the LHC will have an energy 28 times that of Au-Au collisions studied at RHIC. With this huge increase in energy a wealth of new phenomena is almost assured. Because of the much larger mass number, Pb-Pb events can be expected to show exotic phenomena that is beyond the reach of cosmic rays.

[18] E. Norbeck, Y. Onel, E. Gładysz-Dziaduś, A.D. Panagiotou and P. Katsas, 'Exotic Physics at the LHC with CASTOR in CMS', CMS Conference Report 2007/013, *Int. J. Mod. Phys.* **E16**(7-8) (2007) 2451-2456, doi: 10.1142/S0218301307008082, <http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2007&files=CR2007_013.pdf>. ► p. 1 [Back]

Exhibit 41

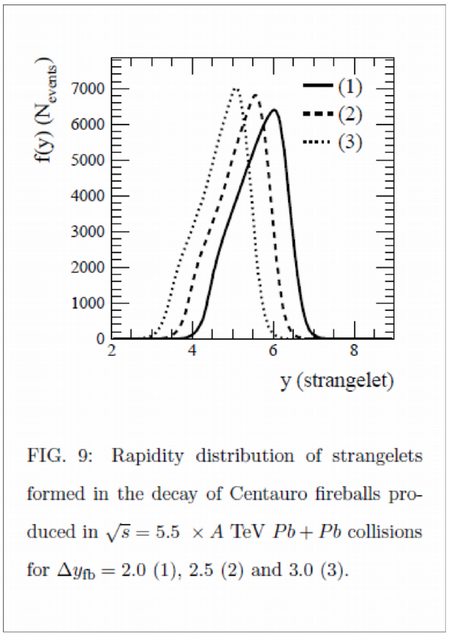

FIG. 9: Rapidity distribution of strangelets formed in the decay of Centauro fireballs produced in $\sqrt{s} = 5.5 \times A$ TeV $Pb + Pb$ collisions for $\Delta y_{\mathrm{fb}} = 2.0$ (1), 2.5 (2) and 3.0 (3).

[36] S.A. Sadovsky, Yu. V. Kharlov, A.L.S. Angelis, E. Gładysz-Dziaduś, V.L. Korotkikh, G. Mavromanolakis and A.D. Panagiotou, 'Model for describing the production of Centauro events and strangelets in heavy-ion collisions', *Phys. At. Nucl.* **67**(2) (2004) 396-405, doi: 10.1134/1.1648929; arXiv: nucl-th/0301003v1 (2003). ► fig. 9, p. 13 [Back to text] [Back to notes]