

Study of potentially dangerous events during heavy ion collisions at the LHC

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Commissioned by L. Maiani as a follow-up of the review set up by J. Marberger before the commissioning of RHIC :

“Review of Speculative ‘Disaster Scenarios’ at RHIC”, R.L.Jaffe, W.Busza, J.Sandweiss and F.Wilczek Sept 1999

Heavy Ion collider : Produce large volume over which high energy densities and numbers of quarks can be achieved

- **Black hole (or gravitational singularity) production**
- **New vacuum state**
- **Formation of a stable strangelet that accretes ordinary matter**

Marberger report : catastrophic scenarios “...are firmly excluded by existing empirical evidence, compelling theoretical arguments, or both.”

This study :

•Black hole (and monopole) production $\left\{ M_{Planck}^{4+d} \geq 1TeV \right.$

(•New vacuum state)

•Formation of a stable strangelet



....Implications for LHC in light of new development, both in theoretical studies and experimental results :

➡ **Stability** : New stability study excludes unbroken range of stable negative strangelets from $A=6$ to $A=\infty$

➡ **Production** : Estimates in the light of recent experimental results

Black Holes

$$ds^2 = dt^2 (1 - 2V(r)) - \frac{dr^2}{(1-2V(r))} - r^2 d\Omega$$

In 4D $V(r) = \frac{GM}{r} \implies R_{Schwarzschild} = 2GM = 10^{-33} \left(\frac{M}{M_P} \right)$

LHC energy deposited in $(1\text{TeV})^{-1} \rightarrow 10^{-17} \text{ cm}$

Production $\implies \left(\frac{M}{M_P} \right) > 10^{16} \equiv 10^{32}$ nucleons at 1 TeV

No LHC production

Black Holes

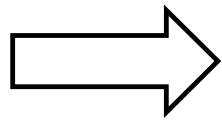
$$ds^2 = dt^2 (1 - 2V(r)) - \frac{dr^2}{(1-2V(r))} - r^2 d\Omega$$

In (4+d)D $V(r) = \frac{KM}{M_*^{2+d}} \frac{1}{r^{1+d}}, \quad r < R$

$$= \frac{KM}{M_*^{2+d}} \frac{1}{R^d} \frac{1}{r} \equiv \frac{GM}{r}, \quad r > R$$

Extreme $M_* = 1\text{TeV}$ $R \leq 0.7\text{mm}$, $d \geq 2$

$$R_{\text{Schwarzschild}} = \text{TeV}^{-1} \left(\frac{M}{M_*} \right)^{1/(1+d)}$$



Copious production at LHC

But macroscopic BH will decay :

Decay \propto Area

$$\Gamma_{\text{Decay}} = T_{BH} \cdot R_s^{2+d}$$

$$\text{Accretion } \Gamma_A = \pi R_s^2 \rho$$

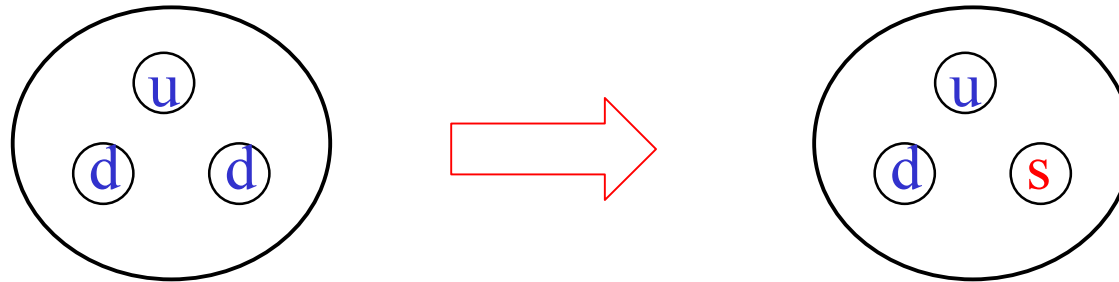
Stable $M > 10^3 \cdot 10^{7(1+d)} \text{ GeV} > 10^{21}$ nucleons

No LHC production



Strangelets

Pauli exclusion



...overcomes (?) $\delta m = m_s - m_d$

Disaster scenarios : Stable -ve strangelets $A \approx 6$ to $A = \infty$

...unlimited accretion of normal matter

Stable -ve strangelets $\Lambda \approx 6$ to $\Lambda = \infty$???

- Abundance of **s** quarks < **u,d** quarks due to mass

⇒ Q +ve

- One gluon exchange attractive for massive nonrelativistic quarks

⇒ Q -ve for large α_s ?

- Finite size (surface) effects reduces **s** quark abundance

⇒ $Q_{\Lambda < 10^7}$ +ve

J. Madsen

Suppression follows from simple quantum mechanical arguments...robust

Constraints from cosmic rays and astrophysics

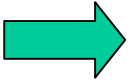
Most robust...cosmic rays incident on the moon

$$\int_{Moon} collisions \gg \int_{LHC} collisions$$

Strangelets fragile ...survive only if not moving rapidly through matter

LHC...zero rapidity,

Moon....target fragmentation region

Rapidity distribution $\frac{d\Pi}{dy} = Npy^\alpha e^{-by}$  LHC Safe

(c.f. $\frac{d\Pi}{dy} = p\delta(y - Y/2)$ (Dar, de Rujula, Heinz))

Strangelet production

Yield nucleus A

Coalescence

$$Y_A = B_A (Y_N)^A$$

$$B_A \sim 1/V_{A-1}$$

Coalescence factor

Data $P_F = Y_A / Y_{A-1}$

AGS, SPS, RHIC

...good description

$$N_A \approx 100 \cdot P_F^{A-1}$$

Number nuclei A
per collision

$$\approx 10^{-54} \quad \text{RHIC}$$

$$\approx 10^{-55} \quad \text{LHC}$$

$$A=20, Z=-1, S=22$$

c.f. 10^{11} collisions 10 year LHC operation. i.e. $A \leq 6$ production at most

Conclusions

- **Disaster scenarios** : Stable –ve strangelets $A \approx 6$ to $A = \infty$

All stability studies exclude this possibility

- Coalescence mechanism reliable. All accumulated evidence implies that LHC will be no more efficient at producing strangelets than RHIC.

Marberger report : catastrophic scenarios “...are firmly excluded by existing empirical evidence, compelling theoretical arguments, or both.”

We endorse this conclusion