Search for strange quark matter

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We present results of a search for charged and neutral strangelets produced on collisions of 11.6 A GeV/c *Au* beams with *Pt* or *Pb* targets. Yields of light nuclei and hypernuclei produced by coalescence were measured. Penalty factors were measured for the addition to a fragment of a nucleon or strange hadron. These are useful in planning future searches for strange quark matter.

1. INTRODUCTION TO STRANGE QUARK MATTER

Quark matter can be thought of as color singlet hadronic states with B>1 allowed by the standard model but unstable if composed only of u and d quarks. Strange quark matter composed of u, d and s quarks has several stabilizing factors that could result in quasistable states. The presence of s quarks lowers the Pauli energy and the most stable configurations would have roughly equal numbers of u, d and s quarks thus minimizing the surface and Coulomb energies. A major destabilizing factor is the large mass of the s quark. Thus the most stable varieties of strange quark matter should have a low value of Z/A and increase in stability with mass number.

In 1979, based on QCD and MIT bag models, Chin and Kerman [1] predicted that strange matter with A$\leq$10 might be metastable with lifetime$\geq 10^{-4}$s. Witten[2] studied strange matter and Fahri and Jaffe postulated that low mass strange matter with B$\geq$6 may be metastable and coined the term strangelet[3].

To produce strangelets, processes that generate large numbers of s quarks such as relativistic heavy ion collisions are needed. Strangelets can be formed by coalescence of strange baryons or by the formation of a quark-gluon plasma droplet followed by $\overline{s}$ distillation and cooling. Decay modes of strangelets have been studied by Berger and Jaffe[4] and indicate that strangelets decaying by radiative weak or semi-leptonic modes might have half-lives long enough for direct observation.

2. THE E864 SPECTROMETER

E864 uses an open geometry, large acceptance spectrometer to search for strangelets. It measures particle production near CM rapidity to minimize production model dependence. The quartz Cerenkov beam counters[5] define zero time and targets are typically Pt or Pb with interaction lengths between 10% and 60%. Central collisions are defined by gating the highest 10% of the pulse height distribution of pulses from the multiplicity counter.

Two dipole analyzing magnets measure the rigidity from the slope of the track in the bend plane. Three hodoscopes measure position, time and charge. Two straw tube arrays allow more accurate tracking. The hadronic calorimeter consists of 13x58 identical towers of Pb/scintillating fiber construction.[6] The calorimeter provides a second mass measurement.

A late energy trigger (LET)[7] is used to select massive objects with TOF long relative to v$\simeq$c particles. Enhancement factors of 50 to 100 were obtained for strangelets. Typical mass resolutions were about 3% for particles with β <0.97.

3. SEARCH FOR STRANGE QUARK MATTER

Tracks of charged particles were reconstructed and track momenta and TOF along with appropriate cuts were used to establish a set of high mass candidates. Large numbers of candidates were observed. This was due to charge exchange scattering of neutrons in the magnet exit window producing tracked protons with large reconstructed momenta. Most of these gave m$\simeq$m(p^+) in the calorimeter. The requirement of tracking and calorimeter mass agreement leaves no candidates with M>5 GeV/c^2.

A search was made for neutral strangelets by identifying hits in the calorimeter that fired the LET and represent local maxima in energy. Energy was determined from a 3x3 array of towers surrounding the peak tower. Charged tracks were reconstructed and energy clusters with matching tracks were discarded. Details of the analysis and preliminary strangelet limits have been published[8].

Limits for strangelet production were determined by calculating 90% confidence level (CL) upper limits in the 10% most central Au+Pt(Pb) interactions at an Au momentum of 11.6 GeV/c. We assume the strangelet production model below:

$$\frac{d^2\sigma}{dp_\perp\, dy} \propto \left[p_\perp \exp\left(\frac{-2p_\perp}{< p_\perp >}\right)\right] \left[\exp\left(\frac{-(y-y_{cm})^2}{2\sigma_y^2}\right)\right]$$

where $\sigma_y = 0.5$ and $< p_\perp > = 0.6\sqrt{A}$.

The 90% C.L. limits for 10% central collisions for strangelets with proper lifetimes greater than 50 ns are shown in Fig. 1. For the charged and neutral particle searches

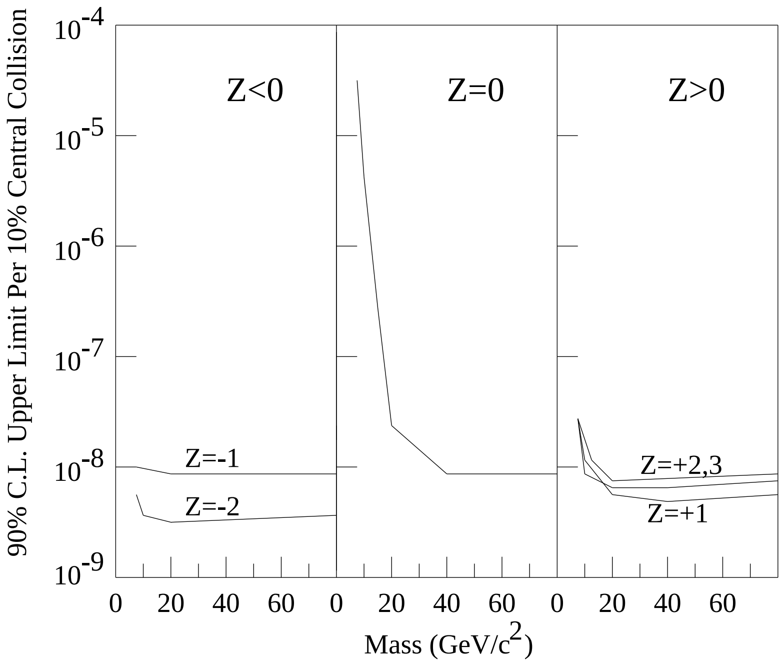

Figure 1. Limits for Charged and Neutral Strangelet Production

approximately 13 and 1.3, billion, respectively, 10% central collisions were sampled. The first results on charged strangelet limits have been published[9].

4. PRODUCTION OF NUCLEI AND HYPERNUCLEI BY COALESCENCE

High-mass strangelets may be created in heavy ion collisions by the coalescence of nucleons and strange baryons. We thus measured the production of light nuclei from A=1 to A=7 around $y \simeq 1.9$ and $p_T/A \leq 300\text{meV}/c$. Also the yields of the strongly decaying nuclei ^5He and ^5Li were measured by observing the α + p(n) decay pairs. In order to determine the additional penalty factor for addition of a strange quark, the yield of $^3_\lambda H$ was measured by observing its decay to $^3He + \pi^-$. The results are shown in Fig. 2. The invariant yields show an exponential dependence which results in a penalty factor of about 48 for adding a nucleon to the fragment[10]. An additional penalty factor for adding a unit of strangeness was extracted by taking the measured yield ratio $Y(^3_\lambda H)/Y(^3He) = 0.031 \pm 0.018$ which gives a penalty factor of about 32.

5. CONCLUSION AND ACKNOWLEDGEMENTS

No strangelets were observed in the analysis of a total of 30 billion 10% most central collisions of 11.6 GeV/c Au nuclei on Pt and Pb targets using the E864 spectrometer at the AGS. Limits for charged strangelet production were typically $\leq 10^{-8}$ at 90% C.L. Limits from the first search for neutral strangelets are given. Penalty factors of 48 for addition of a nucleon to a cluster and 32 for the addition of a unit of strangeness indicate

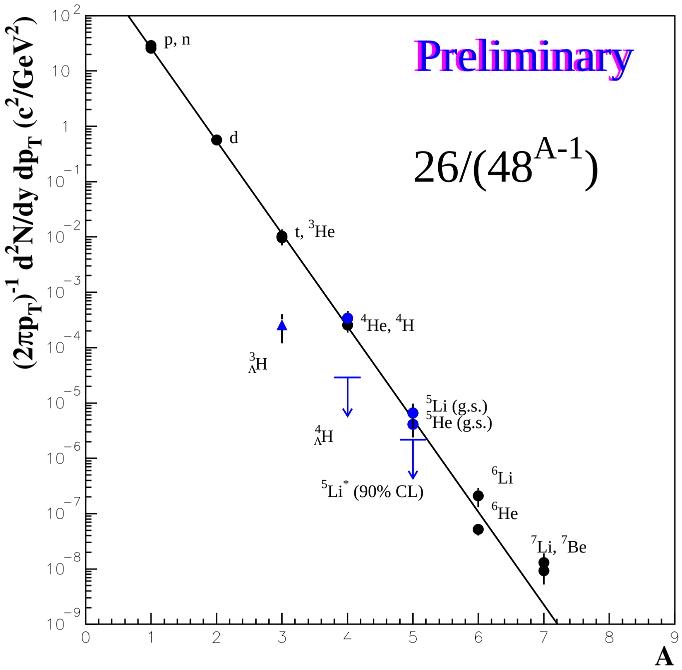

Figure 2. Yields of Nuclei from Coalescence

the difficulty of producing strange quark matter by coalescence and serve as a guide for the design of future searches. This work was supported by grants from the U. S. Dept. of Energy's Nuclear and High Energy Physics Divisions, the U.S. National Science Foundation and the Istituto Nationale di Fisica Nucleare of Italy.

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