STRANGELET SEARCH AND PARTICLE PRODUCTION STUDIES IN Pb + Pb COLLISIONS

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Abstract

We have searched for long-lived strange quark matter particles, so-called *strangelets*, and studied particle and antiparticle production in Pb + Pb collisions at 158 GeV/c per nucleon at zero degree production angle. We give upper limits for the production of strangelets covering a mass to charge ratio up to 120 GeV/c^2 and lifetimes $t_{\rm lab} > 1.2\mu$s and plot invariant differential production cross sections as a function of rapidity for a variety of particles. The shown results are based on the full analysed statics obtained during the lead beam periods at CERN-SPS in 1994 and 1995.

1. Introduction

In order to study nuclear matter under extreme conditions (high temperatures and/or high densities) ultra-relativistic heavy ion beams have been made available at CERN and BNL. The study of particle and antiparticle production in such heavy ion collisions gives insight into the collision dynamics and space time evolution of the reactions [1–3]. There is hope that in these collisions a new phase of hadronic matter, the so-called quark-gluon plasma (QGP), can be formed. The production of strange quark matter, strangelets, is regarded as a possible signature for the formation of a QGP. By virtue of the large s-quark content, the charge to mass ratio of strangelets is expected to be small ($|Z|/A < 0.1$), which is used as a prominent experimental signature. Another good signature for the phase transition would be an enhanced antibaryon production. See [4–6] and references therein.

2. Apparatus

The NA52 experiment [7] uses the 524 m long H6 beam line as a secondary particle spectrometer. The experimental setup is shown in Fig. 1. The incident lead flux is monitored by a

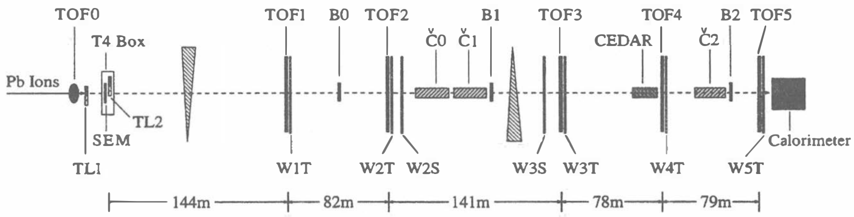

Figure 1. The experimental set-up consists of the target region (TOF0, TL1, TL2, SEM) and the H6 beam line which is equipped with scintillation counters (TOF1-5, B0-2), Čerenkov counters (Č0-2, CEDAR), multiwire proportional chambers (W1T-W5T, W2S, W3S) and a hadronic calorimeter. B0 and Č0 have been added for the 1995 data taking period.

0.4 mm thick quartz Čerenkov counter (TOF0). The target ladder TL1 contains lead targets of 4 mm and 16 mm thickness and TL2 one with a thickness of 40 mm. The produced secondaries are identified by measuring their charge and velocity and by the spectrometer rigidity. The double-bend focusing spectrometer with its momentum bite of 2.8% and its solid angle acceptance of 2.2 μsr was operated at zero degree production angle and at rigidities p/Z of ± 5, ± 10, ± 20, ± 40, ± 100 and ± 200 GeV/c. The charge of a particle is determined through the energy loss measurements ($\mathrm{d}E/\mathrm{d}x$) in scintillation counters: five eightfold segmented time of flight hodoscopes (TOF1-5), two trigger counters (B1, B2) and one beam counter (B0). Its velocity is derived from the time information available from these scintillation counters and the quartz Čerenkov counter (TOF0). A differential (CEDAR) and three threshold (Č0, Č1, Č2) Čerenkov counters provide additional particle identification capabilities where the time of flight measurement is not sufficient to separate the particles (cf. Fig. 2). Seven sets of multiwire proportional chambers (W1T-W5T, W2S, W3S) are used for particle tracking.

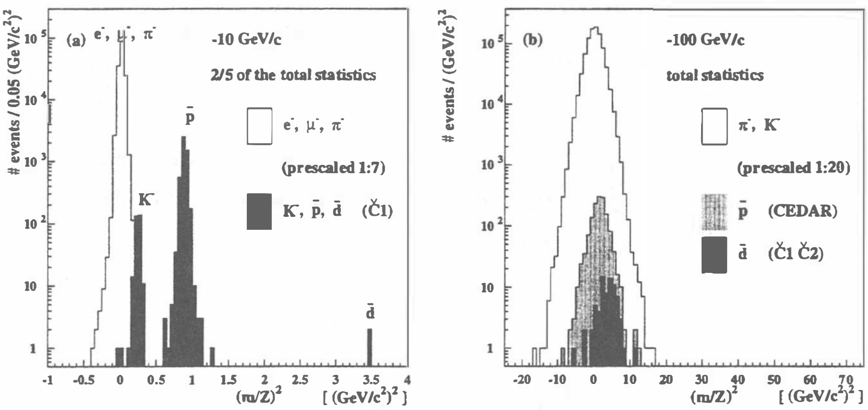

Figure 2. Particle identification capabilities with the aid of time of flight measurements and Čerenkov counters at $p/Z = -10$ GeV/c (a) and -100 GeV/c (b) are shown.

3. Strangelet Search

The recorded number of interactions at the spectrometer settings most relevant for the strangelet search (± 40, ± 100 and ± 200 GeV/c) are shown in Table 1. It is based on the full analysed statistics obtained in 1994 and 1995.

As an example of the strangelet search the $(m/Z)^2$ distribution obtained with a rigidity setting of -100 GeV/c is discussed. Fig. 3 shows all events which satisfy two requirements. First, the event had to be consistently identified by the two threshold Čerenkov counters Č0 and Č1 as a slow particle (i.e. heavier than antiprotons) which, secondly, had to reach at least TOF3. As can be seen from Fig. 3 no particle with $m/|Z| > 5$ GeV/c^2 has been found. Since all of them are singly charged particles, they are $\bar{\mathrm{d}}$ and $\bar{\mathrm{t}}$ candidates.

Table 1
Overview of the accumulated statistics. The employed targets, the numbers of sampled Pb + Pb interactions and the covered mass to charge ranges for the strangelet search are shown.

p/Z [GeV/c]	Pb target [mm]	interactions [10^{11}]	$m/\lvert Z\rvert$ range [GeV/c^2]	p/Z [GeV/c]	Pb target [mm]	interactions [10^{11}]
−5	4	0.09		+5	4	0.03
−10	4	0.17		+10	4	0.06
−20	4	0.35		+20	4	0.05
−40	4	0.38	2...24	+40	4	0.02
−100	40	1.1	4...60	+100	40	2.1
				+100	4	0.002
−200	40	21.2	5...120	+200	16	1.1
				+200	4	0.003

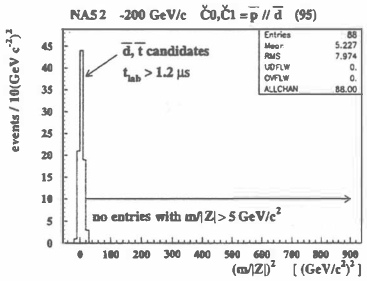

Figure 3: The mass distribution at −200 GeV/c obtained with the aid of the time of flight system. Only the events not tagged by the Čerenkov counters Č0 and Č1 are shown.

However the two particle species cannot be further distinguished from each other. Similar distributions could be shown for the other rigidity settings — with the same result: No strangelet candidate with $m/\,|Z|$ larger than 5 GeV/c^2 and a lifetime $t_{\rm lab} > 1.2\,\mu$s has been found.

Based on these results upper limits for the production of long-lived strangelets have been calculated. In terms of an invariant differential production cross section the upper limit for the production of strangelets is about $10^{-7}\,\frac{\rm barn}{\rm GeV^2}c^3$ for positively and $10^{-8}\,\frac{\rm barn}{\rm GeV^2}c^3$ for negatively charged strangelets. In order to quote an upper limit for the absolute production probability of strangelets a factorized strangelet phase space distribution is assumed [8]:

$$\frac{\mathrm{d}^2N}{\mathrm{d}y\,\mathrm{d}p_\perp} = \frac{4p_\perp}{\langle p_\perp\rangle^2}\exp\left(-\frac{2p_\perp}{\langle p_\perp\rangle}\right)\frac{1}{\sqrt{2\pi}\,\sigma_y}\exp\left(-\frac{(y-y_{\rm cm})^2}{2\sigma_y^2}\right) \tag{1}$$

Here, y is the rapidity of the strangelet, $y_{\rm cm}$ is the rapidity of the c.m.s. of the nucleons participating in the interaction ($y_{\rm cm}$= 2.9 for Pb + Pb at 158A GeV/c), σ_y is the width of the rapidity distribution which was taken to be $\sigma_y = 0.5$, and $\langle p_\perp\rangle$ is the mean transverse momentum of the strangelet. The absolute values of the sensitivity strongly depend on the assumed model parameters, in particular on the mean transverse momentum $\langle p_\perp\rangle$ of the strangelets which is unknown. The shape of the sensitivity curves is determined by the assumed Gaussian rapidity distribution, while their absolute values reflect the overlap between the assumed transverse momentum range of the strangelets and the angular acceptance of the beam line. The resulting upper limits are shown in Fig. 4 assuming various values of $\langle p_\perp \rangle$. Crawford et al. calculated

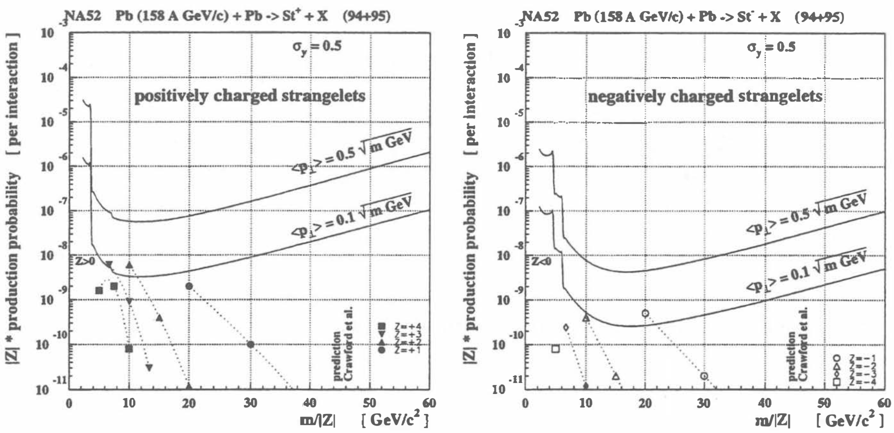

Figure 4. Upper limits of the absolute production probability for positively (left figure) and negatively (right figure) charged strangelets.

production probabilities for long-lived strangelets ($\tau > 2 \cdot 10^{-7}$ sec) of masses $A = 20$, 30 and 40 in Pb+Pb collisions [9]. Some of those points ($-4 \leq Z \leq +4$) are also marked in Fig. 4. Assuming low values of $\langle p_\perp \rangle$ the experimental upper limits begin to overlap the predictions.

4. Particle and Antiparticle Production

Some additional data have been recorded at lower rigidity settings: ± 5, ± 10, and ± 20 GeV/c (cf. Table 1). These settings together with the strangelet search settings allow us to measure invariant differential particle and antiparticle production cross sections over a wide range in rapidity. Fig. 5 shows the invariant differential production cross sections of negatively and positively charged particles as a function of rapidity (closed symbols). The open symbols are data points reflected at midrapidity y_{cm}. We have observed one $^3\overline{\mathrm{He}}$.

5. Conclusions and Outlook

The data we took during the 1994 and 1995 Pb periods at CERN-SPS did not reveal any charged particle with $m/|Z| > 5$ GeV/c^2 and $t_{\mathrm{lab}} > 1.2\,\mu$s. In terms of invariant differential

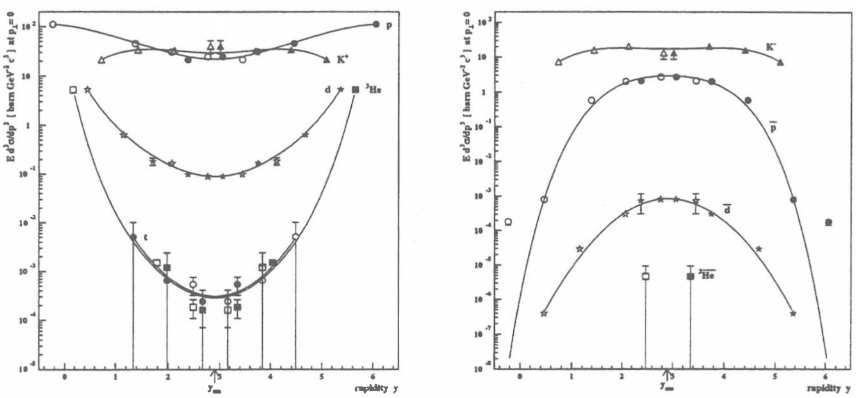

Figure 5. Rapidity distribution of positively (left figure) and negatively (right figure) charged particles.

production cross sections at zero degree the upper limits are $10^{-7}\,\frac{\text{barn}}{\text{GeV}^2}c^3$ for positively and $10^{-8}\,\frac{\text{barn}}{\text{GeV}^2}c^3$ for negatively charged strangelets.

There is still some potential in our data which can be explored by reducing the life time requirement of particles to $t_{\text{lab}} > 0.85\,\mu\text{s}$ (up to B1). There we have found one strangelet candidate with a mass of 7.4 GeV/c^2 and charge number -1 in the $p/Z = -100$ GeV/c rigidity setting. This event is suggestive to explore the kinematical region of this candidate with much more statistics in the forthcoming Pb period at CERN in 1997.

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