Strangelets, strangeness and antimatter: results from the experiment NA52 at CERN

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ABSTRACT: We present results of the CERN experiment NA52 which measures Pb+Pb collisions at 158 A GeV. The topics we address are: 1. strangelet search, 2. nuclei and antinuclei production and 3. strangeness production. No strangelets have been found. We set upper limits which stretch down to the minimal values of $\sim 2\ 10^{-10}$ for negatively and $3\ 10^{-9}$ for positively charged strangelets. We observed 5 $\overline{^3He}$ near midrapidity. Nuclei and antinuclei cross sections suggest production mainly through coalescence, out of a thermalised particle source, at the time of the thermal freeze-out as witnessed by their temperature of 100-120 MeV. Charged kaons per participant nucleon (N_p) show an onset of enhancement followed by saturation at $N_p \sim 80$, corresponding approximately to an initial energy density of $\epsilon_i \sim 1.3$ GeV/fm^3. This onset may be connected to the onset of the QCD phase transition.

KEYWORDS: Quark gluon plasma, strangelets, strangeness, antimatter.

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1. Introduction

NA52 is a fixed target experiment at the CERN SPS with the main goal to search for strangelets in 158 A GeV/c Pb-Pb collisions. For a description of the experiment and of the used methods for particle identification see [1, 2, 3, 4]. Besides the dedicated search for strangelets [1, 5, 6, 7, 8] we measure (anti)particle and (anti)nuclei over a wide range of rapidity (y) and near zero transverse momentum (p_T) [1, 9, 10, 11, 12, 13, 14, 15, 2, 3]. In the present paper we focus on new results of NA52 on the strangelet search, and (anti)particle and (anti)nuclei production cross sections in Pb+Pb collisions at 158 A GeV. Strangelets are exotic hadrons made up by more than 3 quarks, stabilized by a high s-quark content. Particle and antiparticle production, and in particular antimatter and strange particle production, are important for searches for the onset of the QCD phase transition in nuclear reactions [16, 17]. All results correspond to a minimum bias trigger, unless differently stated.

2. Strangelet search

No charged strangelets have been found in the full set of data. The results we present here, include the data from the last NA52 run in 1998, and are the final NA52 results [18]. Figure 1 shows the upper limits for negatively charged strangelets that we set. For the positively charged see reference [1].

3. Particle and Antiparticle cross sections

Figure 2 shows the production cross sections for negatively charged particles as a function of rapidity [18]. The filled colored dots are from data taken in 1998. We observed in total 5 $\overline{^3He}$ antinuclei. As shown in figure 2 of [9] the cross sections of nuclei and antinuclei at

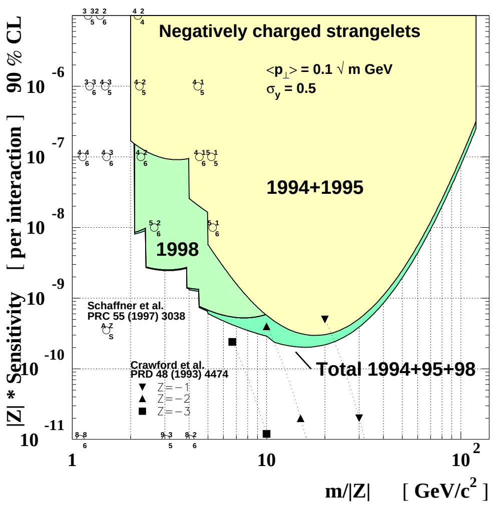

Figure 1: Upper limits set for the production of negatively charged strangelets in Pb+Pb collisions at 158 A GeV.

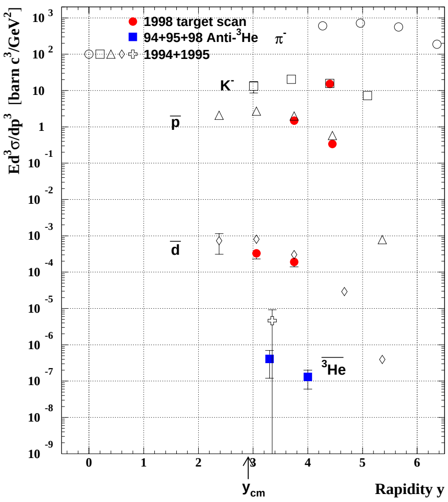

Figure 2: Invariant cross section of antiparticles and antinuclei in Pb+Pb collisions at 158 A GeV at $p_T \sim 0$, as a function of rapidity.

rapidity y=3.3 follow the predictions of a simple coalescence model. Additionally a function of the form $constant_1/constant_2^{A-1}$, fits the dependence of particle cross sections on A (see EPS2001 talk) respectively on m (see figures 6 and 7 in [9]) at rapidities y=3.3 and 5.4. The $constant_2$ can be interpreted as 'coalescence penalty factor' [19]. However as can be seen in the above pictures we find $constant_2$ factors which are different for positively and negatively charged particles at y=3.3. To understand the origin of this difference, we compare the same data with the predictions of a thermal model. Figures 3, 4 and 5 demonstrate that the invariant cross sections as a function of m_T are well described by a thermal model fit. The fit function is an approximation of the Boltzman equation, where we substitute A by (mass/GeV): $E\frac{d^3\sigma}{dp^3}/E(2S+1) = c\ e^{-m_T(coshy+(\frac{\mu_B}{T})T/GeV)/T}$. We fix the ratio $\mu_B(proton)/T$ to its value extracted from the $\overline{p}/p$ ratio, namely 1.4 for y=3.3 and 6.3 for y=5.4. We use in the fit $+|\mu_B/T|$ for the positive and $-|\mu_B/T|$ for the negative particles. Notably, the temperature which can be obtained from the yields of both positively and negatively charged particles at y=3.3 comes out to be T $\sim$ 120 MeV. Therefore, the difference in the slopes of positively and negatively charged particles at the same rapidity y=3.3, as seen in the figures 3 and 4, can be explained as due to the different sign of the baryochemical potential for positively and negatively charged particles. Note that these temperatures are affected by the presence of p_T dependent dynamic phenomena like the transverse flow. The thermal and the coalescence interpretations are both valid. After the thermal freeze-out of p, $\overline{p}$, n and $\overline{n}$ at a T of $\sim$ 170 MeV, they can coalesce to form nuclei and antinuclei. However newly formed nuclei and antinuclei are weekly bound and can break up due to interaction and annihilation processes in the hadron dense environment before they finally freeze out at a T of $\sim$ 120 MeV. The resulting T of $\sim$ 120 MeV at y=3.3

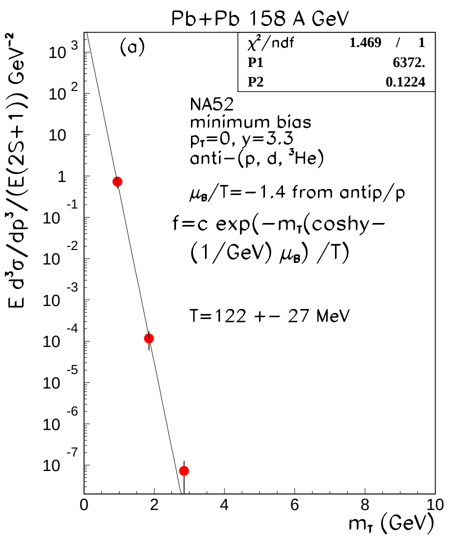

Figure 3: Invariant cross section as a function of m_T ($m_T = m$ for $p_T = 0$) for negatively charged particles at y=3.3 and $p_T \sim 0$ in Pb+Pb collisions at 158 A GeV.

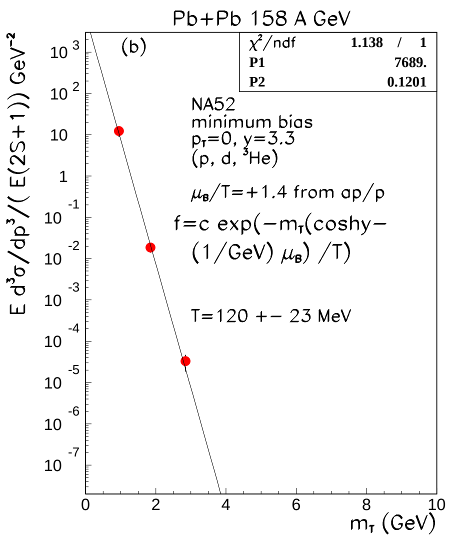

Figure 4: Invariant cross section as a function of m_T ($m_T = m$ for $p_T = 0$) for positively charged particles at y=3.3 and $p_T \sim 0$ in Pb+Pb collisions at 158 A GeV.

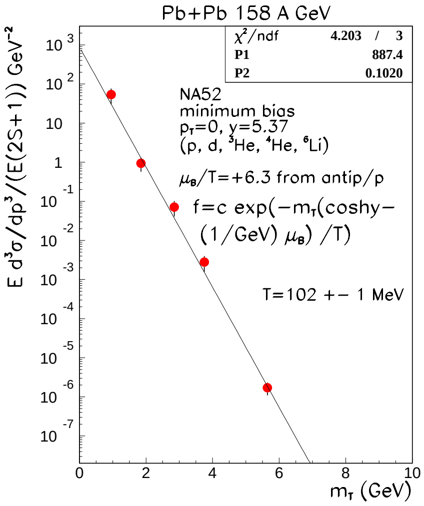

Figure 5: Invariant cross section as a function of m_T for positively charged particles at y=5.4 and $p_T \sim 0$ in Pb+Pb collisions at 158 A GeV.

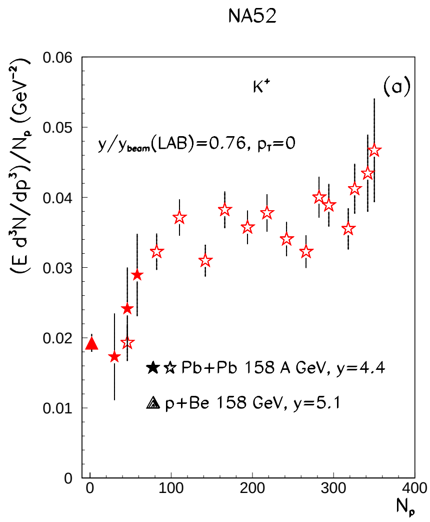

Figure 6: Invariant K^+ yields at y=4.4 and $p_T \sim 0$ in Pb+Pb collisions at 158 A GeV, normalized to the number of participant nucleons (N_p), as a function of the latter.

(see fig. 3 and 4) respectively of $\sim$ 100 MeV at y=5.4 (see fig. 5) are of the same order, which supports the conclusion that nuclei and antinuclei are formed through coalescence just before they thermally freeze out.

4. Strangeness

Figure 6 demonstrates that charged kaon yields show a threshold behaviour at $N_p \sim 80$ [12, 3]. The corresponding initial energy density is $\epsilon_i \sim 1.3$ GeV/fm^3 [21]. A similar behaviour has been seen in Ξ and $\overline{\Xi}$ by NA57 [20]. This threshold is visible not only in Pb+Pb collisions at 158 A GeV but also in other A+A colliding systems at different energies [21]. This is also observed in the temperature and the strangeness suppression factor λ_s when investigated as a function of ϵ_i under conditions of a common chemical potential [22]. These phenomena may be interpreted as due to the onset of the QCD phase transition near $\epsilon_i \sim 1.3$ GeV/fm^3.

5. Conclusions

The NA52 experiment at the CERN SPS searched and found no evidence for multiquark bound states called strangelets in Pb+Pb collisions at 158 A GeV. Upper limits were set, reaching down to a sensitivity of 2 10^{-10} for negatively charged particles. We found evidence that nuclei and antinuclei are produced mainly through coalescence [9]. Their freeze-out temperature extracted from the m_T dependence of nuclei and antinuclei at midrapidity (y=3.3) is $\sim$ 120 MeV, while at forward rapidity (y=5.4) T $\sim$ 100 MeV. The data are in good agreement with both coalescence model and thermal model predictions. The opposite sign of the chemical potential explains the different slopes of positively and negatively charged particles at y=3.3. These results are shown here for the first time. We found evidence that the onset of strangeness enhancement takes place in Pb+Pb collisions at $N_p \sim 80$, respectively at an initial energy density of 1.3 GeV/fm^3. The same behaviour can be found not only in one system (Pb+Pb) as a function of centrality, but also in other A+A data at different energies [21, 22]. This onset may be interpreted as due to the onset of the QCD phase transition, while more data from SPS and RHIC are needed to confirm this interpretation.

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