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FIRST LOOK AT NA52 DATA ON Pb-Pb INTERACTIONS AT 158 GeV/c PER NUCLEON

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We have searched for strange matter particles, so-called *strangelets,* in Pb-Pb interactions at $p_{\rm lab} = 157.7\,\mathrm{GeV}/c$ per nucleon. The NA52 apparatus is also ideally suited to measure production yields and rapidity distributions of $\pi^{\pm}, K^{\pm}, p, \bar{p}, d, \bar{d}, \ldots$ near 0° production angle. Some preliminary results are shown.

INTRODUCTION

The discovery of strangelets has long been advertised as an ultimate signature for the quark gluon plasma (QGP) formation in ultrarelativistic heavy ion collisions [1–3]. Strangelets could be formed from the QGP via the "strangeness distillation" [3–5] process. Their discovery would have profound implications beyond the confirmation of QGP formation. It would establish the existence of strange quark matter (SQM) [6–8] in nature, thus lending strong support to astrophysical and cosmological hypotheses on the role of SQM in our universe. If SQM were absolutely stable, it would represent a new, as yet unobserved ground state of matter.

Several experimental searches for strangelets produced in heavy ion collisions have been carried out [9] at the AGS in Brookhaven, or are ongoing at present [10] using Au-ions accelerated to 11.6 GeV/c per nucleon. At CERN, where higher beam energies are available, a search with sulphur ions [11] was completed in 1992. Preliminary results from the recent run with lead ions are presented in this paper.

APPARATUS

NA52 uses the H6 beam line in the North Experimental Area of the SPS at CERN as a spectrometer for secondary charged particles produced in Pb-Pb collisions at a beam momentum of 157.7 GeV/c per nucleon. The H6 beam line is a double-bend, double-focussing spectrometer with a total length of 524 m from the production target. It can be operated to transport secondary particles within the momentum acceptance $\Delta p/p = 3\%$ at any rigidity in the range $5\,\mathrm{GeV}/c \leq p/Z \leq 200\,\mathrm{GeV}/c$. The solid angle acceptance of the spectrometer is $\Delta\Omega = 2.3\,\mu\mathrm{sr}$. The incident Pb beam may be steered to reach production angles in the range $0 \leq \bar{\theta} \lesssim 40\,\mathrm{mrad}$, but all data presented here were obtained at $\bar{\theta} = 0$.

Table 1 lists the equipment installed in the H6 beam line for the NA52 experiment. Distances along the beam line are measured relative to the position of the production target in the T4 target box. A 40 mm lead target was installed there for the strangelet search. A new, second target assembly was squeezed into a tiny space, only 45 mm long in beam direction, just upstream of the T4 target box. It holds a 0.4 mm thick quartz Čerenkov counter to detect incident beam particles, a remote-controlled target ladder supporting targets up to 16 mm thickness, and a scintillator with a ø 5 mm hole in the center. The scintillator measures the number of secondary particles (i.e. multiplicity) produced in individual interactions, which can be used to distinguish central and peripheral collisions. The thin quartz Čerenkov counter detecting the incident beam ions is also used as a "time-zero" counter.

Five time of flight scintillator hodoscopes, TOF1 – TOF5, were positioned along the beam line to measure the particle velocity and charge. Each hodoscope is made of 8 vertical scintillator slats with a thickness of either 1 cm or 0.5 cm. The thicker scintillators are used in TOF1, TOF3 and TOF5, and yield typical, intrinsic time resolutions of

Table 1

H6 Beam Line Equipment for NA52

Distance [m]	Element	Description
−1.08	TOF0	Quartz Čerenkov Counter
−1.06	TGT1	0.5, 2, 4, 16 mm Lead Targets
−1.04	MULT	Multiplicity Scintillator
0.	TGT2	40 mm Lead Target in T4 Target Box
144.	TOF1 / W1T	Scintillator Hodoscope / Wire Chamber
226.	TOF2 / W2T	Scintillator Hodoscope / Wire Chamber
239.	W2S	Spectrometer Wire Chamber
257.	B1 / Č1	Trigger Scint. / Čerenkov Veto Counter
354.	W3S	Spectrometer Wire Chamber
367.	TOF3 / W3T	Scintillator Hodoscope / Wire Chamber
440.	CEDAR	Differential Čerenkov Counter
445.	TOF4 / W4T	Scintillator Hodoscope / Wire Chamber
494.	B2 / Č2	Trigger Scint. / Čerenkov Veto Counter
524.	TOF5 / W5T	Scintillator Hodoscope / Wire Chamber
538.	CALO	Hadron Calorimeter

$\sigma_{\mathrm{TOF}} = 75 \pm 3\,\mathrm{ps}^1$ for minimum ionizing particles. TOF2 and TOF4 were built with thinner scintillators to keep the amount of material in the spectrometer as low as possible. They give time resolutions of $105 \pm 5\,\mathrm{ps}$. The energy loss, dE/dx, of a particle traversing a TOF scintillator is obtained from the pulse height measurement. A clean charge determination results from the combination of all dE/dx measurements from the five TOF hodoscopes.

Multiwire proportional chambers just downstream of every TOF hodoscope measure the transverse coordinates of the traversing particles with a precision of $\pm 1.5\,\mathrm{mm}$. This information is used for background and pile-up rejection. Furthermore, with the proportional wire chambers W2T, W2S, W3S, and W3T, the beam spectrometer yields a momentum resolution $p/Z < 0.8 \cdot 10^{-3}$ for particles with $p > 50\,\mathrm{GeV}/c$.

A segmented uranium-scintillator calorimeter with a total depth of $7.1\lambda_{\mathrm{int}}$ is located at the end of the spectrometer. The total energy information obtained with the calorimeter is somewhat redundant with the charge and momentum measurements described above, and is thus a useful instrument for background and pile-up rejection. The longitudinal and lateral segmentation of the calorimeter allows to effectively separate electrons, muons and hadrons.

In order to calculate the acceptance and sensitivity for strangelets one must assume a certain phase space distribution for the produced strangelets. This has been described recently in ref. [12]. Additional information concerning the experimental method, and more technical details about the detectors can also be found there.

TRIGGER

Two independent trigger signals, TRIGA and TRIGB, are obtained at 257 m and 494 m downstream of the target. TRIGA is derived from a coincidence of a signal from beam counter B1 and a signal from any of the scintillators in TOF2. TRIGB is setup identically, but uses B2 and TOF4. Č1 and Č2 are 10 m long threshold Čerenkov counters filled with nitrogen gas. They are used to veto fast particles:

$$\mathrm{TRIGA} = (\mathrm{B1} \cdot \mathrm{TOF2}) \cdot \overline{\check{\mathrm{C}}1}; \qquad \mathrm{TRIGB} = (\mathrm{B2} \cdot \mathrm{TOF4}) \cdot \overline{\check{\mathrm{C}}2}.$$

However, a special pre-scale logic removes the veto requirements $\overline{\check{\mathrm{C}}1}$ resp. $\overline{\check{\mathrm{C}}2}$ from TRIGA and TRIGB at a rate of ~90 Hz. The resulting events triggered by fast particles are used for continuous calibration and monitoring of the TOF system.

Each of the two triggers is associated with its own read-out and data acquisition system. The upstream system, driven by TRIGA, reads out all detectors up to TOF3; all equipment farther downstream is serviced by the system associated with TRIGB. The two systems are synchronized by TRIGC (Trigger Controller), which ensures that a local trigger in either system is accepted only if it does not fall within a dead-time period of the other.

TRIGC allows two operating modes: In the first, events are required to have triggered both TRIGA and TRIGB. In the second, only TRIGA is required, and the downstream detectors are read out only if TRIGB fired as well. In order to maximize the detection

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[1] Intrinsic time resolutions of $74 \pm 1\,\mathrm{ps}$ were obtained [12] with a narrow test beam by measuring the time difference of the signals from two photomultipliers viewing the same scintillator.

efficiency for decaying particles, the latter mode was always used when the resulting trigger rate was not too large.

STRANGELET SEARCH

The ion beam intensity delivered to NA52 in 1994 varied between $2 \cdot 10^7$ and $6 \cdot 10^7$ Pb-ions / burst. We have searched for positively and negatively charged strangelets at spectrometer rigidities of $\pm 100\,\mathrm{GeV}/c$ and $\pm 200\,\mathrm{GeV}/c$. Data from $2 \cdot 10^{11}$ to $3 \cdot 10^{11}$ Pb-ions were accumulated at each of these four settings. The targets and trigger conditions used are summarized in table 2, together with the maximum rates of particles observed in the spectrometer. Under equal conditions, the particle flux at $+200\,\mathrm{GeV}/c$ is about 10 times larger than at $+100\,\mathrm{GeV}/c$. This large rate increase is due to projectile fragments, which are moving with $|y - y_{\mathrm{proj.}}| \simeq 0.2$ very close to the projectile rapidity. The trigger rate induced by these fast particles was effectively reduced by the vetoes of the threshold Čerenkov counters Č1 and Č2.

The data analysis was carried out with the calibration and reconstruction programs running in the data acquisition environment. Preliminary results were obtained for about 1/3 (1/4) of the strangelet search data samples collected at $p/Z = +100\,\mathrm{GeV}/c$ ($+200\,\mathrm{GeV}/c$). Out of $5 \cdot 10^5$ events at $+100\,\mathrm{GeV}/c$, about 100 appeared to have masses in the range $30 - 50\,\mathrm{GeV}/c^2$ and charge $Z = 1$. All these events were registered only in the upstream part of the spectrometer and were found to be affected by pile-up. When extending the TOF fit to include the timing information from the quartz Čerenkov counter detecting incident beam ions, all such events – with the exception of one – could be removed. The surviving event is characterized by $Z = 1$ and $m = 33\,\mathrm{GeV}/c^2$; the other remaining events were found to obey $(m/Z)^2 < (5.3\,\mathrm{GeV}/c^2)^2$. The $+100\,\mathrm{GeV}/c$ data sample analysed so far corresponds to $\sim 6.3 \cdot 10^{10}$ Pb-Pb interactions.

No background due to pile-up was found in the data collected at $p/Z = +200\,\mathrm{GeV}/c$. The trigger condition TRIGA · TRIGB, requiring that each particle is seen to travel down the full length of the spectrometer, makes the TOF analysis robust against pile-up effects, even in the presence of a higher particle flux. The result is that no particles with $(m/Z)^2 > (11\,\mathrm{GeV}/c^2)^2$ were detected in a data sample corresponding to $\sim 2.6 \cdot 10^{10}$ Pb-Pb interactions.

The full line in figure 1 shows the sensitivity for strangelet production reached with the data sample analysed so far. The broken line indicates the sensitivity, which will be reached when the complete data sample taken in 1994 will be analysed. Further analysis will be able to exploit additional, as yet unused experimental information (multiple hits in

Table 2

Summary of running conditions in the strangelet search

Rigidity, p/Z	[GeV/c]	−200	−100	+100	+200
Thickness of Pb Target	[mm]	40	40	40	16
Max. Particle Flux[1]	$[10^3/\mathrm{sec}]$	0.1	2	55	150
Trigger		TRIGA	TRIGA	TRIGA	TRIGA·TRIGB

[1] observed at $6 \cdot 10^7$ Pb-ions/burst ($= 1.2 \cdot 10^7$ ions/sec).

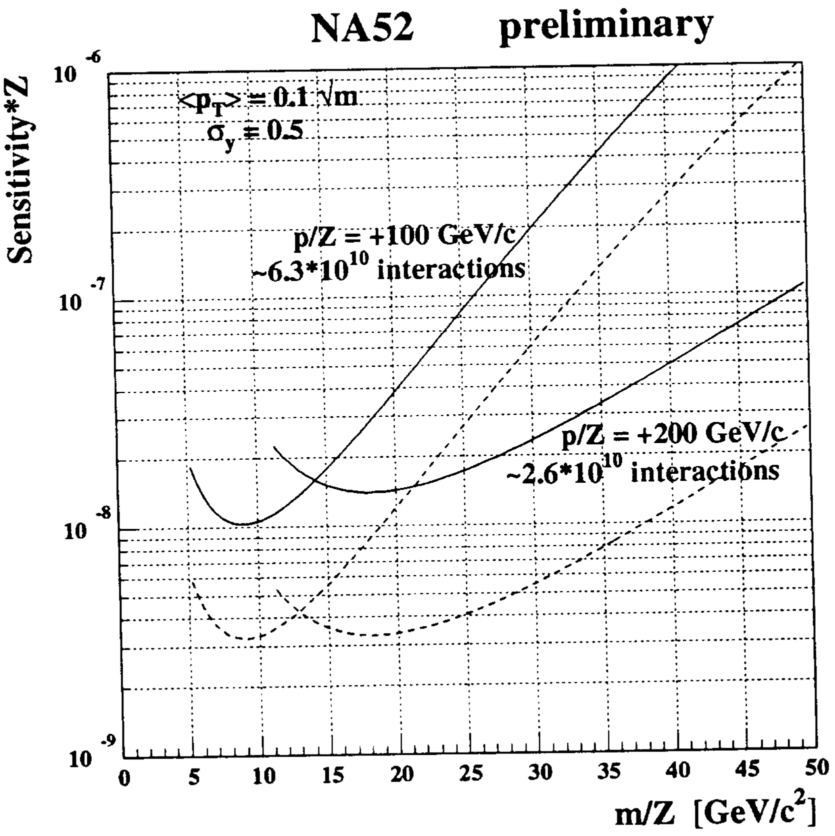

Figure 1. Sensitivity · Z for strangelet production obtained in this preliminary analysis of data taken at $p/Z = +100\,\mathrm{GeV}/c$ and $+200\,\mathrm{GeV}/c$. The broken lines indicate the sensitivity reach of the full data samples collected in 1994. Similar sensitivities will also be reached for negative strangelets from the 1994 data samples.

the wire chambers, future/past registers of the TOF counters) to improve the recognition and elimination of pile-up effects.

In future runs, at higher beam intensities, we hope to improve the sensitivity by about one order of magnitude.

PARTICLE PRODUCTION MEASUREMENTS

A beam line spectrometer equipped with time of flight and Čerenkov counters, as described above, is an ideal tool for particle production studies. To illustrate this, we show in Fig. 2 the mass spectra obtained at $p/Z = \pm 20\,\mathrm{GeV}/c$. The $K^{\pm}/\pi^{\pm}$ separation is achieved with the help of the threshold Čerenkov counter Č1, while the heavier particles are unambiguously identified by the TOF measurement. The contamination of the π^+ and π^- peaks with electrons and muons can be measured, and corrected, by exploiting the shower profile information from the segmented calorimeter.

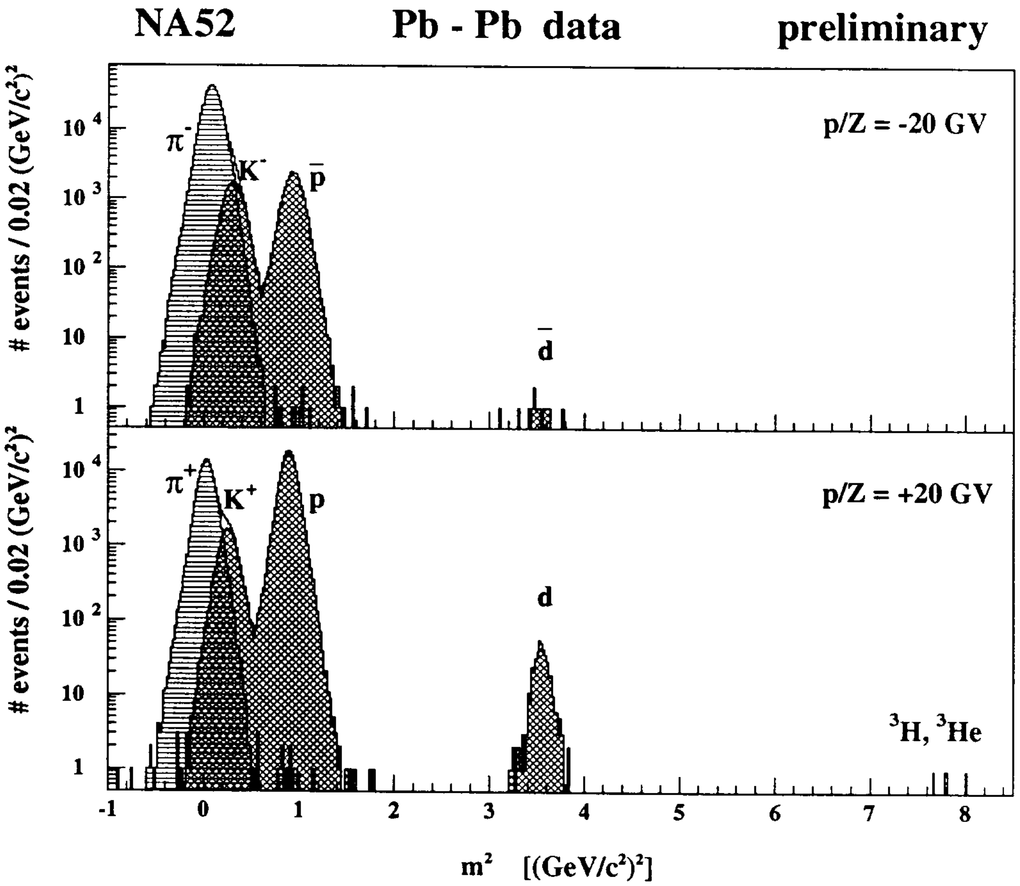

Figure 2. Mass spectra observed at $p/Z = \pm 20\,\mathrm{GeV}/c$.

Similar spectra were also obtained at $p/Z = \pm 5$, ± 10, and $\pm\, 40\,\mathrm{GeV}/c$. These settings were chosen primarily with the goal to measure the production yields, as a function of rapidity near y_{CM}, of protons, anti-protons, deuterons, and anti-deuterons.

The number of particles of each species, obtained from the mass spectra like the one shown in Fig. 2, were corrected for decay and pre-scaling, and normalized to the number of incident beam ions. A rate dependent dead-time correction ($\lesssim 1.5\%$) was also applied. Detailed acceptance calculations, including particle losses due to multiple scattering in the TOF scintillators and other material along the beam line are, however, not yet available. Absolute production yields can therefore not be quoted reliably at the present time. However, acceptance corrections are expected to cancel when forming particle/anti-particle ratios from the data taken at the same absolute rigidity, but opposite polarity. The anti-particle/particle ratios obtained are shown in Fig. 3. Statistical errors are $< 10\%$, except for the $\bar{\mathrm{d}}/\mathrm{d}$ ratios because of the small number of $\bar{\mathrm{d}}$'s observed (0, 3, 14, and 11 $\bar{\mathrm{d}}$'s were detected, respectively, at $p/Z = -5, -10, -20$, and $-\,40\,\mathrm{GeV}/c$).

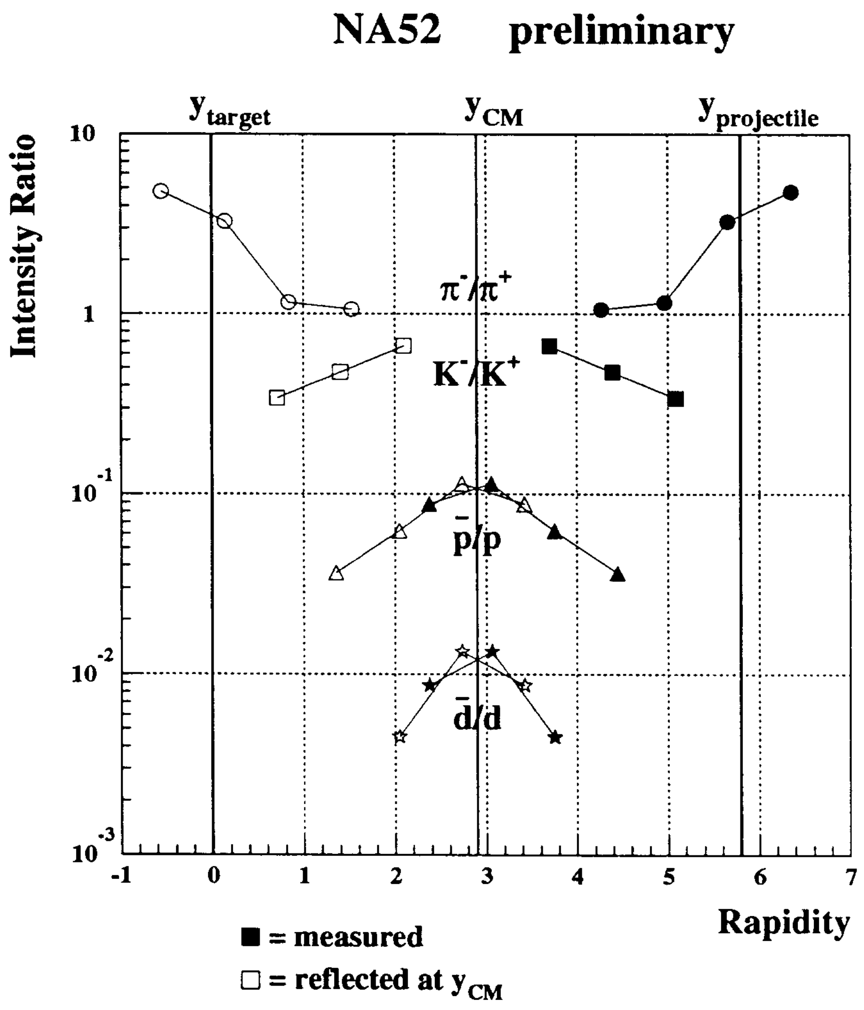

Figure 3. Particle ratios obtained with a 4 mm Pb target at $p_T \approx 0$. Minimum bias data; no centrality cut has been applied.

CONCLUSIONS

With the data from the first, very successful Pb-ion run at CERN, the NA52 experiment will be able to reach sensitivities for the production of positively or negatively charged strangelets well below 10^{-8}/interaction over a wide mass range. The clean particle identification capability makes the NA52 apparatus well suited for particle production measurements. We have shown anti-particle/particle ratios at $p_T \approx 0$ in the mid-rapidity region for protons and deuterons, and at forward rapidities for $\pi^{\pm}$ and $\mathrm{K}^{\pm}$. A careful and thorough analysis of all the data collected has just started. It will provide firm upper limits for the production of strangelets, and establish the rapidity and centrality dependencies for the yields of $\pi^{\pm}, \mathrm{K}^{\pm}, \mathrm{p}, \bar{\mathrm{p}}, \mathrm{d}$, and $\bar{\mathrm{d}}$.

REFERENCES

1. S.A. Chin and A.K. Kerman, Phys. Rev. Lett. **43**, 1292 (1979).
2. H.C. Liu and G. Shaw, Phys. Rev. **D30**, 1137 (1984).
3. C. Greiner, P. Koch and H. Stöcker, Phys. Rev. Lett. **58**, 1825 (1987).
4. C. Greiner, D.H. Rischke, H. Stöcker and P. Koch, Phys. Rev. **D38**, 2797 (1988).
5. C. Greiner and H. Stöcker, Phys. Rev. **D30**, 272 (1984).
6. E. Witten, Phys. Rev. **D30** 2379 (1984).
7. E. Farhi and R.L. Jaffe, Phys. Rev. **D30** 2379 (1984).
8. M.S. Berger and R.L. Jaffe, Phys. Rev. **C35** 213 (1987).
9. For a summary of experimental limits obtained sofar, see e.g. the contribution of B.S. Kumar in "The Physics and Astrophysics of Quark-Gluon Plasmas", proceedings, eds. B. Sinha, Y.P. Viyogi and S. Raha, World Scientific, 63 (1994).
10. F. Rotondo, talk presented at the "Workshop on Strangeness in Hot Hadronic Matter" (S'95), Tucson, Arizona, Jan. 4-6, 1995.
11. K. Borer et al., Phys. Rev. Lett. **72** 1415 (1994).
12. K. Pretzl et al., Bern preprint BUHE-95-1, to be published in the proceedings of the "International Symposium on Strangeness and Quark Matter", Krete, Hellas, Sept. 1-5, 1994.