AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

Presented at DPF '94
Albuquerque, NM
August 2-6, 1994

RECEIVED

SEP 19 1994

OSTI

BNL-60732

Conf-940816--4

**PROTON AND PRODUCED PARTICLE DISTRIBUTIONS
FROM Au+Au COLLISIONS AT 11.6 A GeV/c ***

BRUCE MOSKOWITZ

*Physics Department, Brookhaven National Laboratory,
Upton, New York 11973 U.S.A.*

for the E802/E866 Collaboration

ABSTRACT

The highest net baryon density possible in the laboratory – up to ten times normal nuclear density – is expected in the central region of collisions of heavy nuclei ($A \approx 200$) at energies near 10 GeV per nucleon. The transverse energy (E_T) distribution, as well as yields of identified particles (π^+ , K^+ and protons), from $^{197}\text{Au}+^{197}\text{Au}$ at 11.6A GeV/c are presented. Two key observations are a large degree of proton “stopping”, indicating multiple scatterings of the incident nucleons, and a proportional relationship of the pion production to the number of participating nucleons. Strangeness enhancement, a proposed signature of the quark-gluon plasma, is studied via the K^+/π^+ ratio, which achieves the value of 21% without a strong centrality dependence. Comparisons to similar data taken with a 14.6A GeV/c beam of ^{28}Si are made.

1. Introduction

Very heavy relativistic $A+A$ collisions, where $A \approx 200$, offer perhaps the best opportunity of observing new phenomena due to the expected creation of a relatively large and long-lived high-density region.¹ It is believed that the highest possible baryon density should be achieved at AGS energies of approximately 10 GeV per nucleon. To better understand the conditions actually produced by these collisions, we now report on measurements made by E-866 of global transverse energy (E_T) spectra as well as semi-inclusive distributions of protons, pions and kaons.

2. Global Transverse Energy

Figure 1 shows the global transverse energy spectrum for produced particles at midrapidity.² The detector consisted of lead-glass blocks covering pseudorapidity $1.3 < \eta < 2.4$ and azimuthal angles $0 \leq \phi < 2\pi$. The distribution from Au+Au at 11.6A GeV/c is compared to that of the smaller (essentially) symmetric system Si+Al at 14.6A GeV/c. (Also shown is Si+Au.) The Au+Au and Si+Al spectra clearly have different shapes and comparing the two in terms of the magnitude of E_T on the tail

*This research was supported by the U.S. Department of Energy, Division of Basic Energy Sciences under contract no. DE-AC02-76CH00016.

MASTER

depends on the criterion for the cut. The Au+Au/Si+Al ratio for different centrality cuts is listed in Table 1. Given along with the E866 data of Fig. 1 are E877 data³ for a hadron calorimeter covering $0.83 < \eta < 4.7$.

Fig. 1. The differential cross-section versus the transverse energy, E_T^{PbLR} , for lead-glass covering $1.3 < \eta < 2.4$ and $0 \leq \phi < 2\pi$ for Si+Al,Au at 14.6A GeV/c and Au+Au at 11.6A GeV/c.

Two simple models which represent opposite extremes of the nucleon-nucleon collision picture are also given in Table 1. In the Isotropic Fireball Model (IFM) all the projectile and target nucleons collectively “stick together” and convert all of their kinetic energy in the center-of-mass system, E^* , to particle production.⁴ This represents the limit in which the nucleon-nucleon collision time is much less than the de-excitation time following each collision. The IFM predicts a ratio Au+Au/Si+Al=6.1, which is considerably less than the data indicate.

The Wounded Nucleon Model (WNM) code is a Glauber calculation which uses a Woods-Saxon potential and allows reinteractions.⁵ In this model the nucleon-nucleon collision time is much greater than the de-excitation time, and each collision is an elementary one. The results for the total number of nucleon participants, N_{part}^{tot} , which is a purely geometric quantity, are given in the table; the ratio Au+Au/Si+Al includes a 13% beam energy correction which is based on the $\sqrt{s}$ -dependence of the multiplicity of $\pi^+ + \pi^-$ from p+p collisions.⁶ The WNM ratios closely follow those from the actual measurements and we conclude that this independent nucleon-nucleon collision model adequately describes the general features of the transverse energy spectra.

Centrality cut	Quantity	Source	Si+Al	Au+Au	Au+Au/Si+Al*
0.5%	E_T^{PBLR} (GeV)	E866 ²	10.9	78.0	7.2
"	N_{part}^{tot}	WNM ⁵	44.6	364.8	7.1
2%	E_T^{PBLR} (GeV)	E866 ²	9.6	71.2	7.4
"	N_{part}^{tot}	WNM ⁵	40.9	345.7	7.4
4%	E_T^{PBLR} (GeV)	E866 ²	8.5	64.9	7.6
"	N_{part}^{tot}	WNM ⁵	38.2	321.8	7.3
"E877"***	E_T^{PBLR} (GeV)	E866 ²	10.0	81.1	8.1
"	E_T^0 (GeV)	E877 ³	40.2	318.5	7.9
"	N_{part}^{tot}	WNM ⁵	41.8	369.6	7.6
$b=0$	E^* (GeV)	IFM ⁴	97.0	587.4	6.1

* The ratios from the WNM include a beam energy correction of 13%.

** The E877 cut is 1.5% for Si+Al and 0.22% for Au+Au.

Table 1. The ratio of Au+Au/Si+Al from measured transverse energy distributions and from model calculations. The E866 and WNM values are cut thresholds; those from E877 are mean values.

3. Proton Distributions and "Stopping"

Semi-inclusive single particle distributions for Au+Au were recorded by the E-802 spectrometer which has clean particle identification over a wide range of coverage.⁷ The invariant cross-sections versus transverse mass, $m_t = \sqrt{p_t^2 + m^2}$, were individually fitted to an exponential form and then integrated over all m_t to obtain the rapidity density, dN/dy .

Figure 2 shows preliminary results for dN/dy of protons versus rapidity, y , for five different centrality cuts based on a zero-degree calorimeter⁷ which effectively measured the number of projectile spectators of the collision. The percentages of centrality quoted are relative to an interaction trigger cross-section of $\sigma_{trig}=6250$ mb. The most central cut, identical with the 340 mb "4% ZCAL" cut previously reported,⁸ derives from a high-bias hardware trigger, while the other cuts are from a minimum-bias interaction trigger.⁹ Note that the data points below $y_{NN}=1.6$ are actual measurements and that the points above y_{NN} are reflections in this symmetric projectile-target system.

The distributions show a remarkable trend. For more peripheral collisions the number of protons moved away from projectile and target rapidities is small, with the dN/dy distribution gently sloping down towards midrapidity (y_{NN} .) As the collisions become more violent the opposite behavior is observed: a large number of protons are pushed into midrapidity and dN/dy strongly peaks there. Such collisions exhibit a strong amount of nucleon "stopping" in the sense that incident nucleons undergo multiple scatterings, ultimately creating very high baryon density in the central region.

Fig. 2. The rapidity distribution, dN/dy , for protons from Au+Au for different centrality cuts. The cuts are based on a zero-degree calorimeter and are normalized to an interaction trigger cross-section of $\sigma_{trig}=6250$ mb.

4. Produced Particles

4.1. Yield Per Participant

Results for positive pion and kaon yields integrated over the rapidity interval $y_{NN} - 1.2 \leq y \leq y_{NN} + 1.2$ for both Si+Al (E802 final¹⁰) and Au+Au (E866 preliminary⁹) are shown in Fig. 3. Plotted is the yield per participant versus the total number of participants, N_{part}^{tot} , which is twice the number of projectile participants as measured by the zero-degree calorimeter. Pion production per participant appears to be constant, independent of the centrality of the collision; the systematic difference between Si+Al and Au+Au may be attributed to the different beam energies of the two systems. For K^+ , the yield per participant shows a slight upward trend with N_{part}^{tot} , and, significantly, the Si+Al and Au+Au points at $N_{part}^{tot} \approx 50$ neatly overlap. This contradicts the large $\sqrt{s}$ -dependence expected for direct production of K^+ , and thus lends support to models where the K^+ are formed mainly in rescatterings.

4.2. The K^+/π^+ Ratio

The K^+/π^+ yield ratio versus N_{part}^{tot} is plotted in Fig. 4 for p+Be minimum bias,¹¹ Si+A for Al, Cu and Au targets¹² and Au+Au.^{8,9} For consistency, the rapidity interval $0.6 \leq y \leq 1.4$ is used throughout. The K^+/π^+ ratio appears to follow a universal

Fig. 3. Integrated π^+ and K^+ yields per participant versus the total number of nucleon participants, based on zero-degree calorimeter measurements. The rapidity interval used is $[0.5, 2.9]$ for Si+Al and $[0.4, 2.8]$ for Au+Au.

curve which begins at the value 7% for elementary collisions, rises to a final value of $K^+/\pi^+ = 21\%$. For Au+Au there is not a strong centrality dependence and the ratio may be saturated.

5. Conclusions

To summarize, we learn from the proton distributions that as the Au+Au collisions become more violent, the incident nucleons tend to increasingly pile up at midrapidity, indicating that a region of high baryon density is indeed produced. Comparing the produced particle E_T spectra of Si+Al and Au+Au, the Isotropic Fireball Model of collective de-excitation is ruled out; however, the Wounded Nucleon Model of independent elementary collisions does an adequate job. Pion production is proportional to the number of participating nucleons, with some beam energy dependence. Finally the K^+/π^+ ratio follows a universal curve which rises from 7% for elementary collisions to a maximum of 21% for Au+Au central.

References

1. See, e.g., *Proc. Quark Matter '93*, *Nucl. Phys.* **A566** (1994), as well as proceedings of earlier Quark Matter conferences.
2. E802 Collaboration, L. Ahle et al., *Phys. Lett. B* (1994) in press.
3. E814/E877 Collaboration, J. Barrette et al., *Phys. Rev. Lett.* **70** (1993) 2996.
4. See, e.g., S. Das Gupta and A.Z. Mekjian, *Phys. Rep.* **72** (1981) 131.

Fig. 4. The K^+/π^+ ratio for the rapidity interval $[0.6, 1.4]$ versus the total number of nucleon participants for several projectile-target systems. The beam momentum is at $14.6A$ GeV/c, except for Au+Au which is at $11.6A$ GeV/c.

5. H. Brody et al., *Phys. Rev.* **D28** (1983) 2334. The code was run with a 0.4 fm core and a 30 mb nucleon-nucleon cross-section.
6. A.M. Rossi et al., *Nucl. Phys.* **B84** (1975) 269.
7. E802 Collaboration, T. Abbott et al., *Nucl. Instrum. Meth.* **A290** (1990) 41.
8. M. Gonin (E802 Collab.), *Nucl. Phys.* **A566** (1994) 601c; H. Hamagaki (E802 Collab.) *Nucl. Phys.* **A566** (1994) 27c; B. Moskowitz and M. Gonin (E802 Collab.) *Proc. PANIC '93*, A. Pascolini, ed., (World Scientific, 1994) in press.
9. D.S. Zachary, Ph.D. thesis, Massachusetts Institute of Technology (1994).
10. E802 Collaboration, T. Abbott et al., *Phys. Rev. C* (1994) in press.
11. E802 Collaboration, T. Abbott et al., *Phys. Rev.* **D45** (1992) 3906.
12. E802 Collaboration, T. Abbott et al., *Phys. Lett.* **B291** (1992) 341.

**DATE
FILMED**

10/17/94

END