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RESULTS FROM THE BNL E802 SPECTROMETER FOR 14.5 GEV/C PER NUCLEON SILICON BEAMS

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ABSTRACT

We present selected results of measurements of inclusive π, K, proton, and deuteron spectra from 14.5 A GeV/c Si collisions with various targets. Results of neutral energy and charged particle $dN/d\eta$ measurements are also discussed. Large K to π ratios are observed in Si + Au collisions. Results are compared to the Lund-Fritiof model.

1. INTRODUCTION

The E802 experiment is a collaboration of 60 scientists from 13 institutions working at the BNL AGS. The principle goal of the experiment is to explore the behaviour of nuclear matter under high temperature and pressure using collisions of 14.5 A GeV/c O and Si projectiles with various nuclear targets . The experiment is intended to provide a survey of inclusive and semi-exclusive particle spectra in order, for example, to extract information on strange particle production, inclusive particle slope parameters, $\pi\pi$ and KK correlations, and antiparticle production[1]. In order to perform this task, the experiment has been designed with particle identification (PID) sufficient to separate π's, K's, and protons from 0.5 to 5.0 GeV/c and with segmentations and multihit capabilities sufficient to handle the high charged particle multiplicities associated with these collisions[2]. The particle momenta distributions are correlated with event characterization information provided by a lead glass array (PBGL), zero degree calorimeter (ZCAL), and large solid angle target multiplicity array (TMA) detector.

At the QM87 conference, we reported evidence for complete stopping in collisions of O beams with various targets[3,4], and presented first results for large K to π ratios observed in the spectrometer using Si beams[5]. At this time, we present results from the PBGL, ZCAL, and TMA counters for Si beams, but concentrate on some of the extensive new spectrometer data on π, K, proton, and deuteron momentum distributions. This talk is organized as follows: in section 2 the experiment is briefly reviewed, in section 3 results from the event characterization counters are presented and samples of some of the measured inclusive particle spectra are given. In section 4, discussion focuses on kaon yields and comparisons between the data and the Fritiof event generator. Conclusions are stated in section 5.

2. EXPERIMENT

Figure 1 gives an overview of the E802 apparatus. The beam passes through an evacuated beam line striking targets of 1 to 3% of a nuclear interaction length before being dumped in a zero degree calorimeter (ZCAL). Typical beam rates for the data presented here were less than 10^5 Hz, and the beam was counted with an array of plastic scintillators. A plastic scintillator located just upstream of the ZCAL (not shown in Fig. 1.) provided the interaction trigger. Surrounding the target is the TMA counter consisting of an array of streamer tubes (operating in the proportional mode) with 3,500 pad readouts. This counter was used to provide a first level central trigger which was typically adjusted to count the upper ~ 7% of the multiplicity distribution. For this talk, spectrometer data for the central trigger only will be presented. A large lead glass array, located on the opposite side of the beam from the spectrometer, is centered roughly at midrapidity for nucleon-nucleon collisions (~ 20° at the AGS) and is about one unit of rapidity wide, with π azimuthal angular coverage. The small lead glass array located just upstream of PBGL will be used primarily for π^0 detection but was not in place for the data presented here.

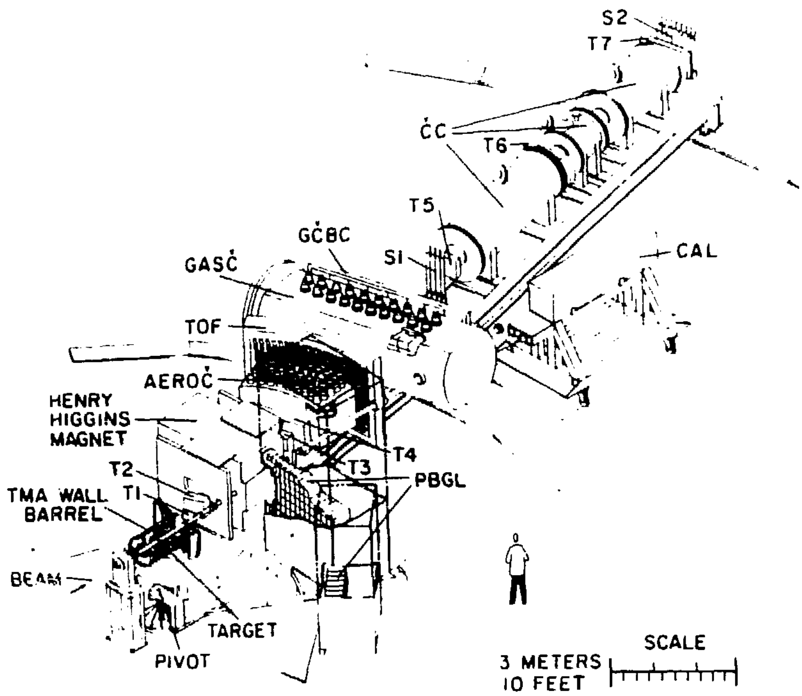

Fig. 1: E802 single arm spectrometer with 25 msr solid angle and associated event characterization detectors.

The spectrometer system consists of two sets (T1 and T2) of multiplane drift chambers before and two sets (T3 and T4) after a roughly 25 msr window frame dipole magnet (labelled *Henry Higgins* in Fig. 1). The spectrometer platform assembly is moveable and covers laboratory angles from 5 to 60 degrees. Following the last tracking chamber is a 96 segment aerogel Čerenkov detector (AEROČ)[6], followed by 160 time of flight scintillator slats (TOF), and a forty segment 4 atmosphere gas Čerenkov detector (GASČ). The TOF detector independently provides π- K separation to momenta in excess of 2 GeV/c, and the AEROČ and GASČ counters extend particle identification (PID) for π, K, and protons to 4.7 GeV/c. For the data presented here, the GASČ detector was not yet in place, and results for π's and K's are given for momenta up to 2 GeV/c using the TOF counter alone for PID. At the very end of the spectrometer is an array of three Čerenkov vessels with associated time of flight scintillators and tracking chambers. The Čerenkov complex can independently provide PID within a small (0.5 msr) solid angle up to 15

GeV/c. Figure 2 summarizes the acceptance for the spectrometer and delineates the region of acceptance for which Si beam spectrometer data is presented at this conference[2].

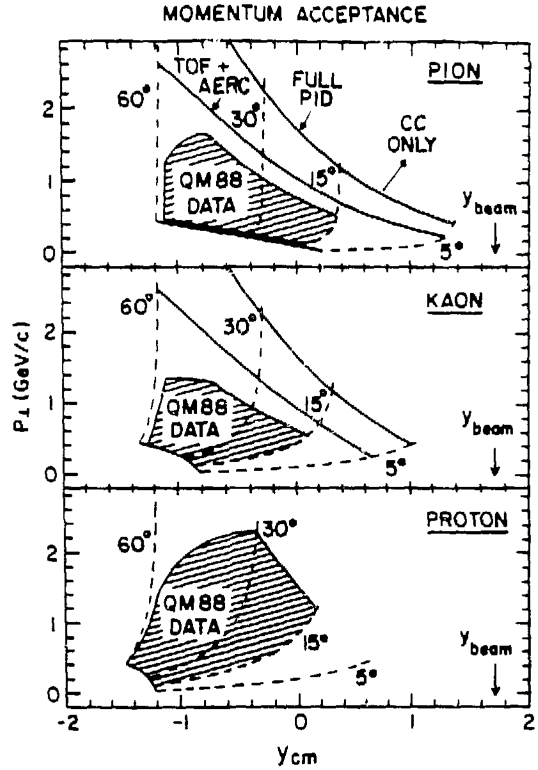

Fig. 2: Acceptance in rapidity vs. $p_\perp$ plane. The cross hatched regions indicate phase space where data is presented at this conference. Particle identification limits are indicated in the upper panel.

3. SELECTED RESULTS

Figure 3 shows results for energy deposition in PBGL for Si beam collisions with various targets (left panel) and the correlation between PBGL and ZCAL (right panel) for Al and Au targets. The PBGL spectrum exhibits the characteristic shape typical of calorimeter energy distributions in heavy ion collisions, which largely reflects nuclear geometry[4,7]. Examination of the high energy part of the distributions shows that cross sections for the production of PBGL energy above 40 GeV increase strongly with target mass up to Ag targets. However, there is very little difference in the spectral distributions for Ag and Au targets. These results suggest that Ag nuclei are sufficiently thick to completely stop Si projectiles in central collisions at AGS energies and are consistent with results presented at the QM87 conference for O beams[3]. This complete stopping hypothesis is confirmed by the correlation between PBGL and ZCAL (right panel Fig. 3). Large PBGL energies are associated with small energy deposition in the zero degree calorimeter and, for the case of the Au target, events with maximum PBGL energy are correlated with the complete lack of energy in the beam direction.

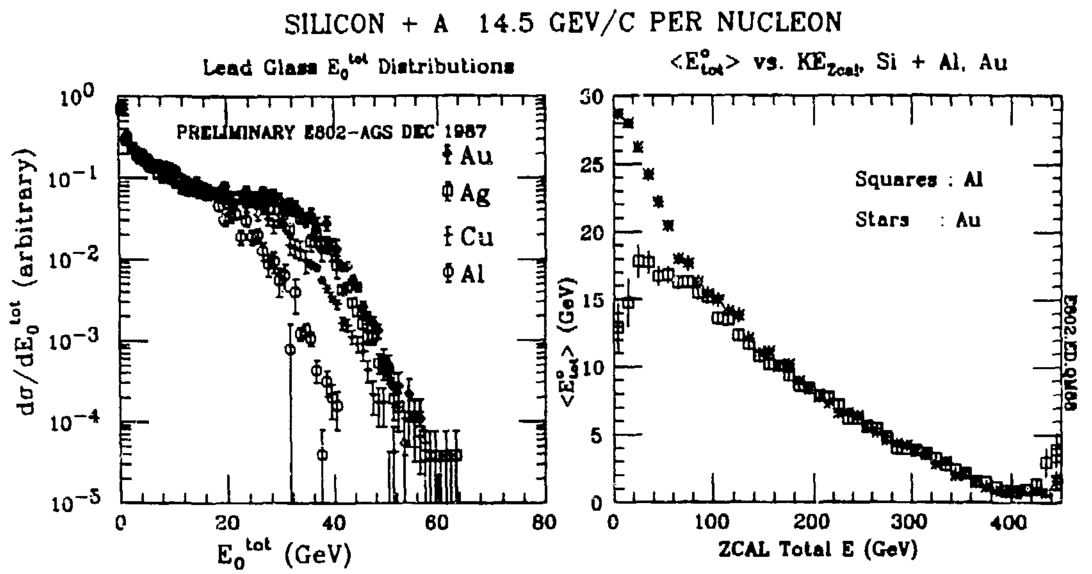

Fig. 3: Left panel: PBGL energy distributions for Si + Au, Ag, Cu, and Al collisions. Right panel: correlation between PBGL and ZCAl energies for Si + Al, Au systems.

In Figure 4, results for TMA $dN/d\eta$ distributions are plotted for central Si beam collisions with Au, Ag, Cu, and Al targets. Multiplicities of 100 charged particles per unit pseudorapidity are seen in Au target encounters. For illustrative purposes, the pseudorapidities corresponding to 90 degrees in the nucleon-nucleon and Si + Au central collision fireball center of mass systems are indicated. For the symmetric Si+Al collisions, the $dN/d\eta$ distribution peaks near zero in the nucleon-nucleon center of mass system. A systematic shift in the peak of the distributions is observed in going from the Al to the Au target, and the peak in the Si + Au distribution is near zero in the center of mass system given by the geometric overlap of the Si projectile with a tube of participant Au nucleons. The kink in the distributions seen at $\eta = 0$ is an experimental artifact associated with the positioning of the target and its frame perpendicular to the beam direction. Further discussion of these results and comparisons to predictions of the Fritiof model will be given in section 4.

Figures 5 and 6 show examples of momentum distributions for π's, K's, protons, and deuterons for central Si + Au collisions. In Fig. 5, the invariant cross sections versus $M_\perp = \sqrt{p_\perp^2 + m^2}$ for π^+ and K^+ (left panel) and π^- and K^- (right panel) are given within the rapidity range indicated on the figures. Note that there is one common arbitrary overall normalization factor in the data of Figures 5 and 6 and error bars are statistical only. There are additional systematic errors in the shapes of the spectra reflecting current uncertainties in acceptance corrections and run to run normalizations. At the present time, these errors are estimated to be less than 10% and are under further investigation. The pion and kaon invariant cross sections of Fig 5 are roughly exponential in $M_\perp$ and have similar slopes ($M_\perp$ scaling). The exponential lines drawn in Fig. 5 are illustrative only and are not fits to the data. Slope parameters on the order of 170 MeV are seen.

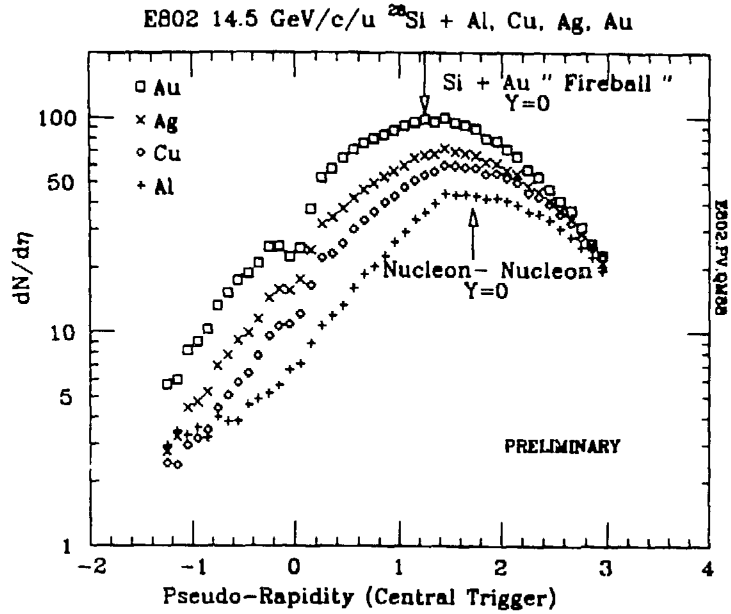

Fig. 4: TMA charged particle multiplicity $dN/d\eta$ distributions for central Si collisions with various targets.

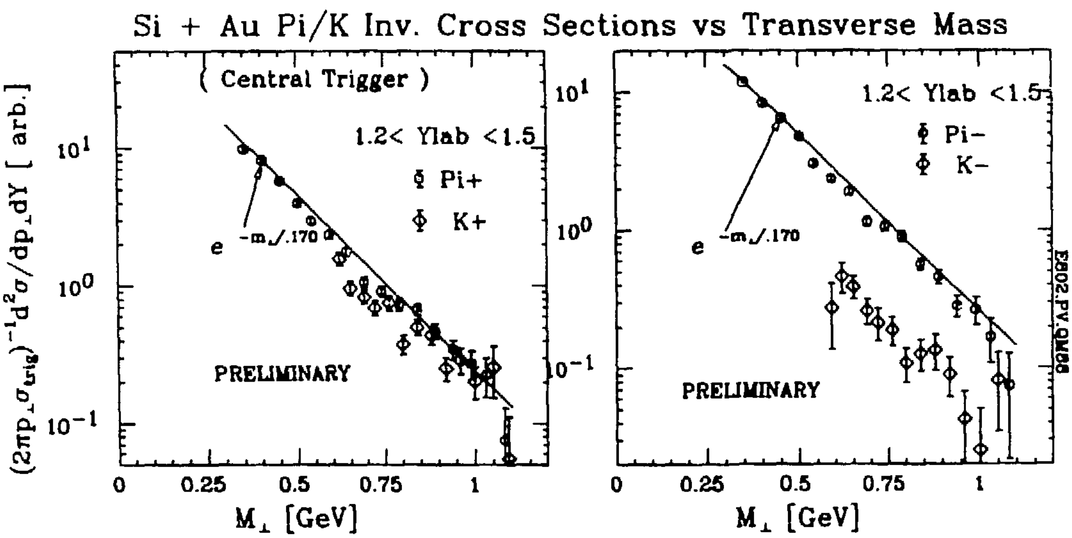

Fig. 5: Si + Au invariant cross sections vs. transverse mass for pions and kaons (central trigger). Exponential lines guide the eye and are not fits.

Results for protons and deuterons are shown in Fig. 6. Note that the rapidity range for protons ($1.2 < Y_{lab} < 1.5$) is the same as that for the π's and K's of Fig. 5, but somewhat different than that of the deuterons. The proton distributions are nearly exponential in shape and exhibit larger slope parameter values than the pion and kaon data. The deuteron distributions exhibit slopes at low values of $M_\perp$ similar to that of the protons, but then appear to flatten off at higher $M_\perp$. Note that the coalescence model for deuteron production[8] predicts that, if the proton slope is exponential in $M_\perp$, then the deuteron spectra (in the same or similar rapidity interval) should also be exponential with a similar slope. Further analysis of these results within the context of hydrodynamic and coalescence models is in progress.

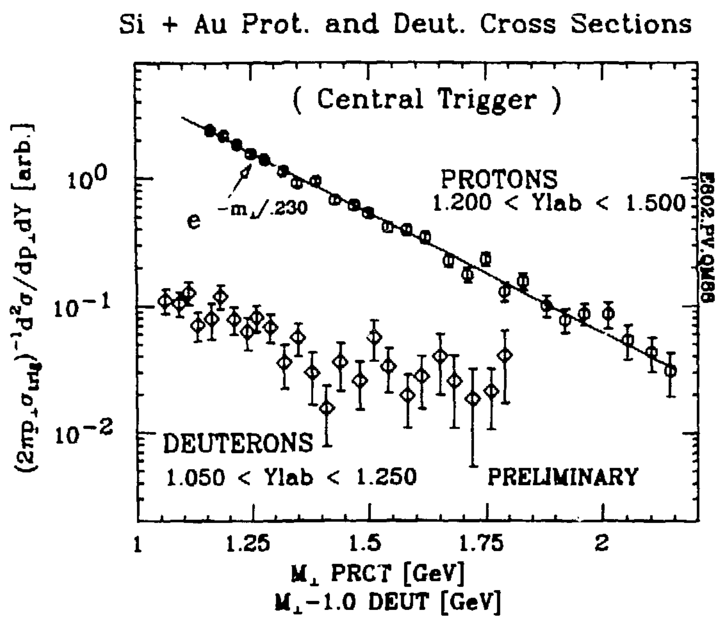

Fig. 6: Si + Au proton and deuteron invariant cross sections in central collisions. Note the different offsets in the abscissa scales for protons and deuterons. Exponential lines guide the eye and are not fits.

4. DISCUSSION OF SELECTED RESULTS

4.1 Comparison of K/π Ratios to p-p and p-A Data

At QM87, we presented results for integrated K to π ratios in Si + Au central collisions measured in our spectrometer[5] (in the rough angular range from 14° to 28°) of $K^+/\pi^+ = 24 \pm 5\%$ and $K^-/\pi^- = 4^{+4}_{-2}\%$. We pointed out that the K^+/π^+ yields were in excess of typical values obtained at AGS energies in p-p and p-A collisions, whereas the K^-/π^- yields agreed, to within the large experimental errors, with typical values measured in lighter collisions. These results included only preliminary acceptance corrections. In addition, the low statistics in the K^- channel precluded a definitive comparison to existing p-p and p-A data.

Figure 7 compares K to π ratios versus $p_\perp$ extracted from the data of Fig. 5 to a compilation of published p-p and p-Pb data at AGS energies[9]. The Si + Au ratios are the ratios of invariant cross sections at $1.2 < Y_{lab} < 1.5$, and the compilation of p-p and p-A data includes both ratios of invariant cross sections at central rapidities as well as ratios of laboratory cross sections at laboratory angles above 5°. Studies show the ratios to be nearly independent of laboratory angle and insensitive to whether the ratio of laboratory or invariant cross sections are taken *except* for laboratory angles below $\sim 5°$, which are not included in Figure 7. The compilation ratios have not been assigned error bars in the Figure, but such uncertainties are dominated by systematic errors among the various experiments and are reflected in fluctuations in the points of Fig. 7 at similar $p_\perp$.

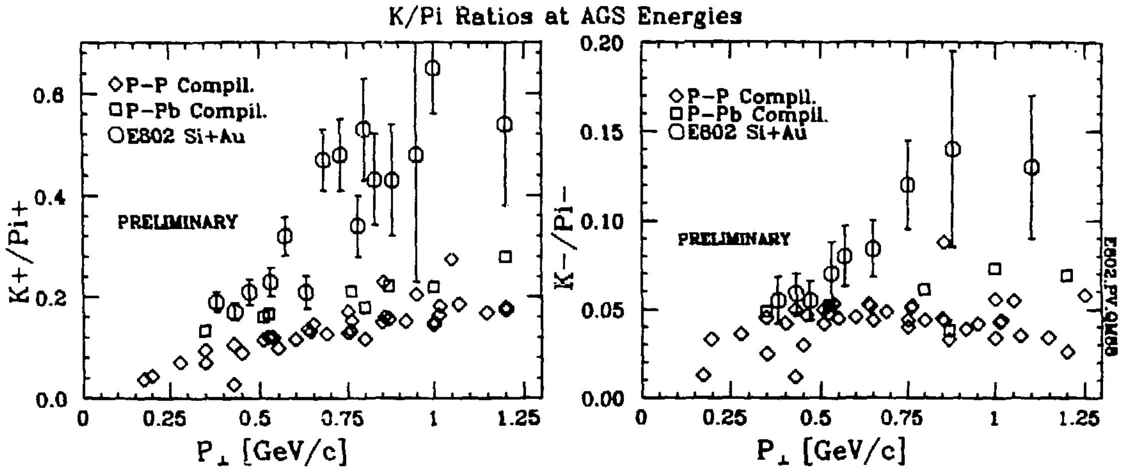

Fig. 7: Compilation of K/π ratios vs. $p_\perp$ in p-p and p-A collisions at AGS energies compared to Si + Au.

The K^+/π^+ ratios increase with increasing $p_\perp$ reflecting, at least in part, the influence of approximate $M_\perp$ scaling. However, there is an additional systematic increase in the ratios as the number of nucleons involved in the collisions increases. The Si + Au ratios are substantially larger than typical values observed in either p-p or p-Pb collisions. The ratio at low $p_\perp$ is $\sim 20\%$ which is in agreement with the integral ratio presented at QM87[5].

The K^-/π^- ratios exhibit similar tendencies, but the overall magnitude of the ratios is reduced for all collision systems. There are large discrepancies in values of measured negative K to π ratios for p-p collisions, particularly at low $p_\perp$. The integral ratios are, of course, dominated by the values at low $p_\perp$, with mean values for p-p lying in the $2-4\%$ range, and Si + Au exhibiting somewhat higher values of 5-6%. At high $p_\perp$ the heavy ion data systematically exceed typical values from p-p and p-A.

4.2 Comparison of TMA and Spectrometer Data to Fritiof

In order to compare our results for Si + Au collisions to model predictions, the Lund-Fritiof event generator[10] was tuned to reproduce inclusive pion distributions in p-p and p-Pb collisions at AGS energies. Three parameters were adjusted to obtain best fits. The fragmentation function $f(x, m_\perp) = \frac{(1-x)^a}{x} e^{-bm_\perp^2/x}$ parameters a and b were chosen as 1.0 and 0.4 respectively and the σ parameter governing the transfer momentum exchange between interacting strings was set to 0.55. Good results were obtained for π^+ and π^- spectra and qualitative agreement for proton spectra. No attempt was made to tune parameters for K distributions[11].

Using these parameters, the Fritiof predictions for the $dN/d\eta$ distributions in central Si + Au collisions can be calculated. A comparison between TMA data and the model is given in Figure 8. The agreement between calculation and experiment is good for the case of the symmetric Si + Al collision. For the asymmetric Si + Au system, the data appear shifted to lower pseudorapidities than Fritiof and there is an appreciable excess of experimental yield below $\eta \sim 1.5$. This excess of charged particles in the backward region is in qualitative agreement with additional yields from the target spectators, which are not included in Fritiof. Further discussion of the spectator contribution follows below. Note that the comparison of Figure 8 is absolute in magnitude; no normalization of calculation to the data has been made.

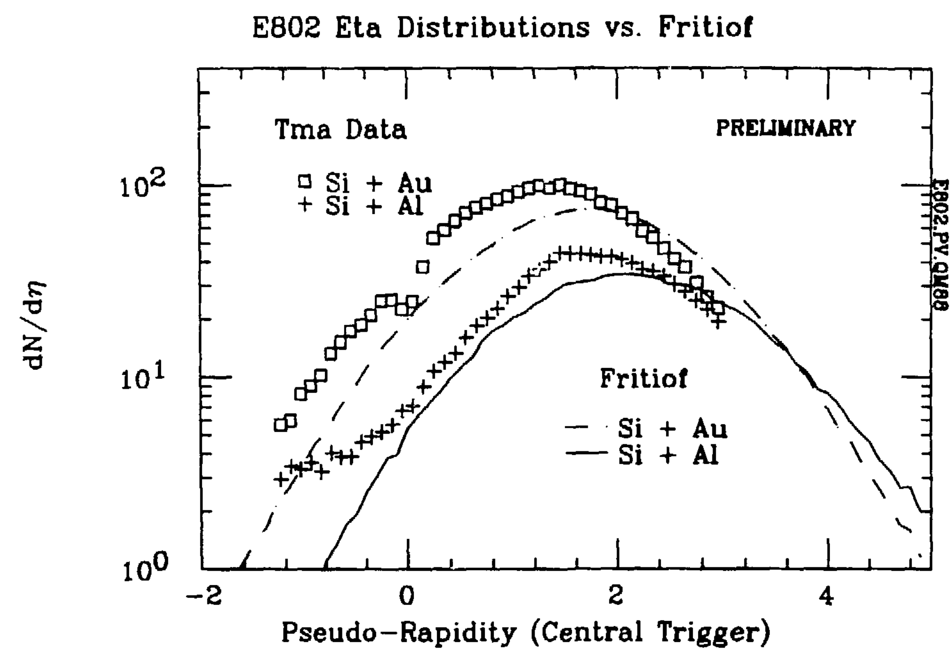

Fig. 8: Comparison between TMA $dN/d\eta$ distributions and Fritiof for central Si + Au and Si + Al collisions.

Figure 9 shows a comparison between the invariant π and K cross sections versus $p_\perp$ and the predictions of Fritiof for central Si + Au collisions. There is one overall normalization factor between the data and calculations. The $p_\perp$ distributions for pions and the π^+/π^- ratios are well reproduced by Lund-Fritiof, although the slopes of the measured π distributions are somewhat flatter than those of the model. If one normalizes to the pions, the calculated kaon yields are substantially lower than the data for both the K^+ and the K^- channels.

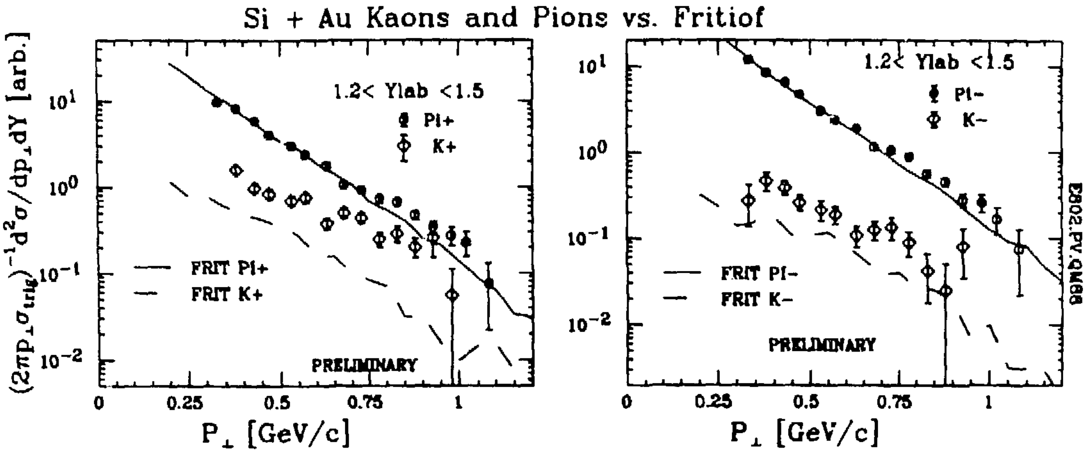

Fig. 9: Invariant cross sections vs. $p_\perp$ for pions and kaons compared to Fritiof.

The results of Figure 9 lead one to ask whether or not Fritiof underpredicts K yields in p-p and p-A collisions as well as in Si + Au encounters. In Figure 10 the experimental K/π ratios presented in Figure 7 are compared to the K/π ratios predicted by the model by constructing the double ratio $\frac{K/\pi_{exp}}{K/\pi_{frit}}$. The calculated ratios were constructed at the same laboratory angles or rapidities as the experiment. Examination of the Figure shows that Fritiof does quite well in predicting the K^+/π^+ ratio in both p-p and p-A collisions, while underpredicting the ratios in Si + Au collisions by factors of 2-5. For the K^-/π^- case, the model tends to *overpredict* the K/π ratio in p-p and p-A collisions. However, despite this tendency to generate too many K^-, the calculation strongly underpredicts the ratios for Si + Au. Therefore, relative to Fritiof p-p and p-A predictions, the Si + Au K^-/π^- yields are as enhanced as those seen in the K^+/π^+ channel.

We note that comparisons up to this time have been made with ratios. A large K/π ratio could therefore reflect either K enhancement or π suppression. This point is addressed in Figure 11 where charged particle $dN/d\eta$ distributions for Si + Au are compared to Fritiof, and to modified model calculations where the kaon yields have been doubled or the pion yields halved. In order to roughly account for the influence of spectators, an isotropic (in the laboratory frame) angular distribution of target spectator protons has been added to the calculated yields. In the central rapidity region, the agreement between Fritiof and the data is good. An enhanced K yield does not change the agreement significantly, but the π suppression scenario is inconsistent with the data. The Figure therefore suggests good agreement between Fritiof and observed yields of charged pions in Si + Au collisions. Good agreement in absolute magnitude between calculation and inclusive charged pion yields in p-p and p-A collisions is also obtained[11]. The large enhancement in K/π ratios observed in Si + Au encounters appears therefore to be caused by enhanced K yields rather than suppressed π intensities.

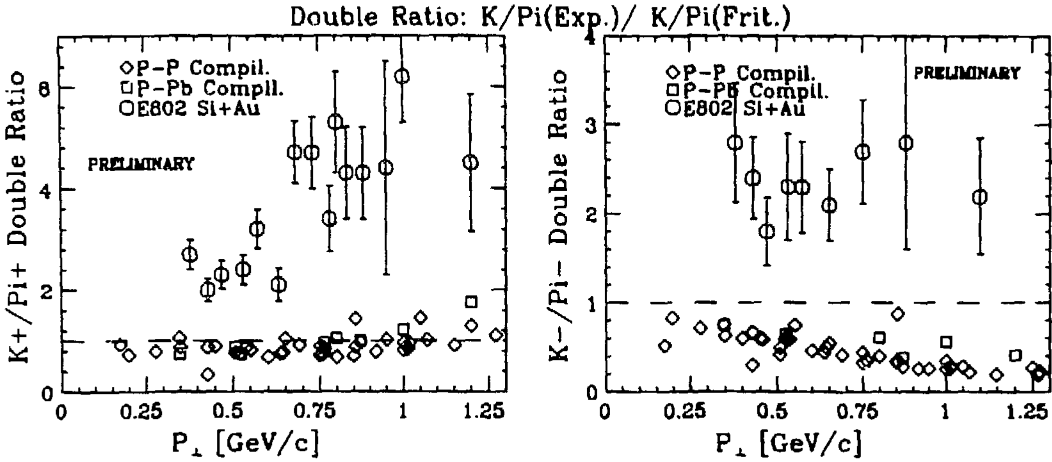

Fig. 10: Double ratio of experimental K/π to that of Fritiof versus $p_{\perp}$.

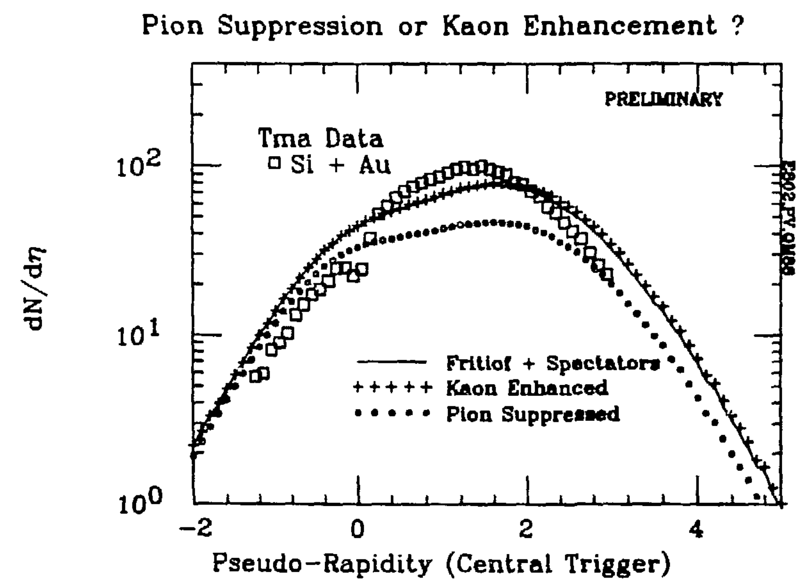

Fig. 11: Effect of pion suppression (rather than kaon enhancement) on the TMA versus Fritiof comparison. An isotropic distribution of target spectators has been added to the model calculations.

5. CONCLUSIONS

Results from studies of event topology using the PBGL detector provide evidence for complete stopping of Si in Ag at AGS energies. These results are confirmed by correlations between PBGL and ZCAL. The TMA $dN/d\eta$ distributions indicate multiplicities up to 100 charged particles per unit of η, and display a characteristic shift in the peak of the $dN/d\eta$ yields which follows the shift in the geometric participant center of mass.

Only a small sample of the available data for inclusive particle spectra was shown. The π and K spectra exhibit approximate $M_{\perp}$ scaling. The proton and deuteron distributions show a characteristic increase in slope parameter as the mass of the observed particle increases. Comparisons of observed K/π ratios to p-p and p-A data and to Fritiof indicate large ratios for both $K^+/\pi^+ and\ K^-/\pi^-$.

The proton projectile data used in this talk have ambiguities and in order to clearly determine the projectile mass dependence of the observed K/π enhancement, proton beam measurements in the E802 spectrometer must be carried out. These measurements are now in progress, and will be available for presentation in the near future. Analysis of $\pi\pi$ correlations is proceeding and results should be available for presentation at the next Quark Matter conference. Hopefully, there will be other new interesting surprises to report as well!

ACKNOWLEDGEMENTS

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