

Recent Results From E866 and Scaling Between K^+ and Protons in E802

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ABSTRACT

E866 is designed to study Au+Au reactions at 11.6 A-GeV/c with two spectrometers, one upgraded from E802 and another built to cope with the large multiplicity in central Au+Au collisions at forward angles in the laboratory frame. Furthermore, new global detectors have been implemented to gain insight into the reaction dynamics and enable studies of possible collective effects. The first half of this report presents the recent preliminary results for rapidity distributions of protons and produced mesons in central Au+Au collisions. The shape of m_T -spectra of pions is discussed. The second half of this report discusses some insight into K^+ production in conjunction with proton production in reactions induced by light ion beams, namely from proton to Si beams.

1. Experimental Setup

Figure 1 shows the top view of the current setup of E866. The Henry Higgins spectrometer (the upper arm) is used to measure particle spectra between 14 and 54 degrees for Au+Au reactions. It is upgraded from the E802 setup with additions of 2 multiwire tracking chambers TRF1 and TRF2 in front of the magnet. The forward spectrometer arm consists of 2 dipoles, M1 and M2, and two tracking stations indicated in the figure as FT1+TPC1+FT2 and FT3+TPC2+FT4, each equipped with two drift chambers and one TPC of 6 rows. The new time-of-flight wall (FTOF) has good timing resolution (<80 ps) for particle identification.

A forward hodoscope consisting of 40 X-slats and 40 Y-slats is placed in front of the zero degree calorimeter (ZCAL) to measure projectile fragments by their charge deposition in each slat. A so-called reaction plane can be defined by searching for the centroid of the charge distribution in both X and Y directions relative to nominal beam positions. A new multiplicity array (NMA) has been constructed and surrounds the target region.

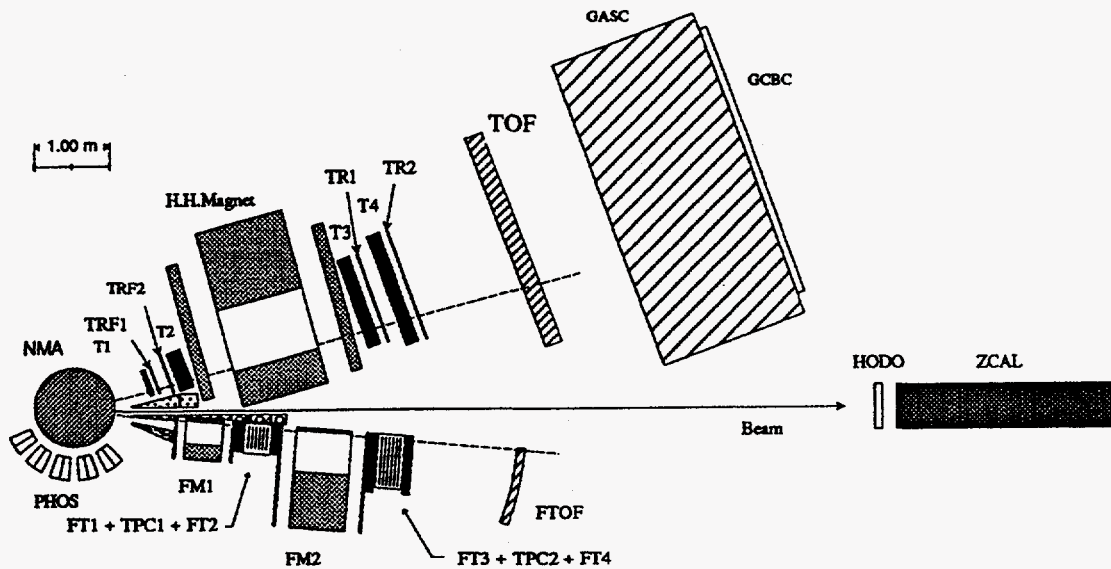


Figure 1. Top view of E866 experimental setup.

2. Hadronic distributions

Figure 2 shows the proton distributions for different A+A collisions as a function of normalized rapidity with respect to beam rapidity. It is important to measure the rapidity distribution for baryons in order to determine the number of participating nucleons in the reaction and the degree to which the projectile and target nucleons are stopped in the c.m. system in central collisions. The measurements of the proton distribution, of course, constitute only part of the total baryons. E866 data in Figure 2 for Au+Au reactions are a combined analysis of the two spectrometers, and are obtained for a 4% centrality cut corresponding to 210 mb cross section. It is noted that in the E866 setup almost all protons arising from the decay of $\Lambda \rightarrow p + \pi^-$ survive the experimental cuts and are included in the measured spectra. Some additional protons are bound in composite fragments mainly deuterons and should be included when comparing with models. Data from central and peripheral Si+Al collisions [1] at 14.6 GeV/c are also shown in Figure 2 together with the inelastic pp data of Blobel [2]. In pp collisions, only a small amount of stopping is observed with an average rapidity shift of 0.7. The data from peripheral Si+Al is similar to pp collisions. The situation starts to change for the central reactions in Si+Al, and more stopping is observed with a fairly wide and flat rapidity distribution for protons. In central Au+Au reactions, the data exhibits a clear peak at mid-rapidity, indicating that a large fraction of the participating nucleons are indeed stopped at the mid-rapidity.

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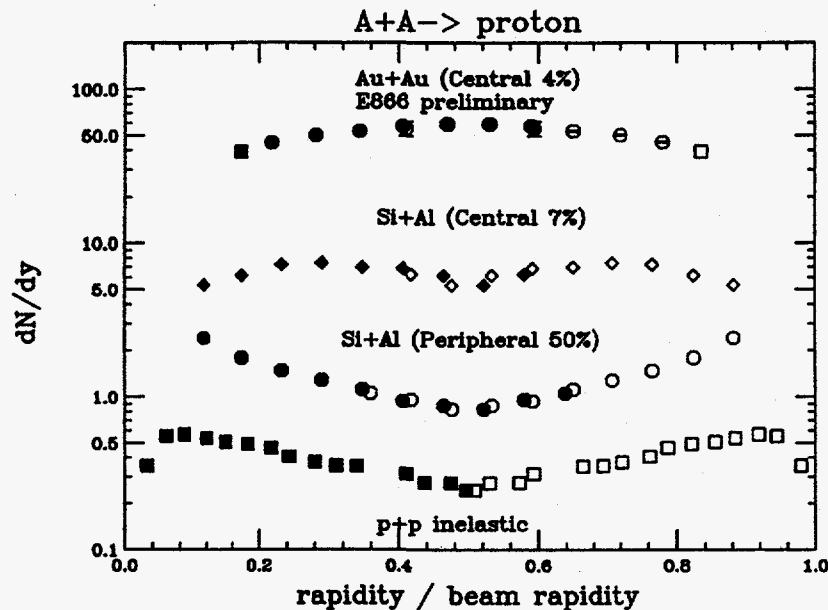


Figure 2. Proton distributions for different AA collisions. Then dn/dy is plotted versus the normalized rapidity y/y_{beam} . The Si+Al data are from [1], the pp data from Blobel [2]. The filled symbols are the measured data while the open symbols represents the data reflected about y_{nn} .

Figure 3 shows the rapidity distribution of the produced mesons, namely π^+ , π^- , K^+ and K^- in central Au+Au collisions. The π^- data are multiplied by a factor of 10 for display. The maximum value of dn/dy reaches 55 for π^+ and 70 for π^- when a low m_t component (discussed below) is included and if we assume that this component is independent of rapidity. Assuming a Gaussian distribution in rapidity the total yield for charged pion production is deduced to be $N^+=115$ for π^+ and $N^-=160$ for π^- . Under the assumption that the neutral pion yield is $N^0=(N^++N^-)/2$, the total pion yield in central Au+Au collisions is about 420. For completeness, we also include kaon distributions in the figure. The data are those presented in [3] except two data points near mid-rapidity. They are all consistent, and yield an overall K^+/π^+ ratio of about 0.21.

Figure 4 shows the m_t distribution of pions for different rapidities of bin size $\delta y = 0.2$. The π^- spectra show the well known low m_t enhancement below 200 MeV/c. We can extract the pion yield using a two-component exponential fit, and the dn/dy values are about 10 units higher than those extracted using a single exponential fit (shown with star symbols in Fig.3). The low m_t component constitutes roughly 25% of the rapidity density value. The π^+ spectra, on the other hand, do not show a clear low m_t enhancement although at some rapidities a description using two-components is significantly better. We

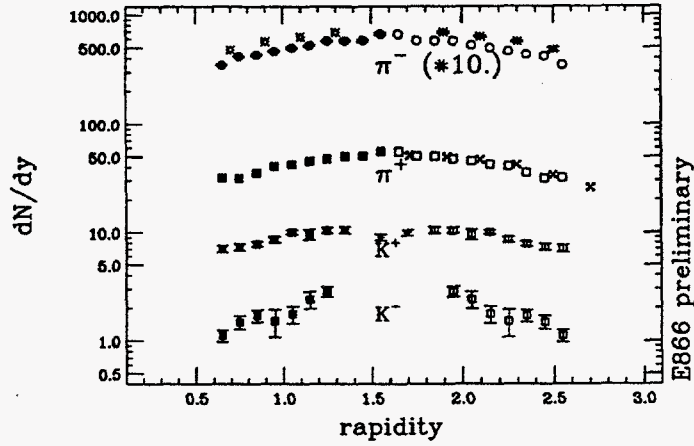


Figure 3. Rapidity distribution for π^+ , π^- , K^+ and K^- , in central Au+Au collisions. The π^- data have been multiplied by 10 before plotting. The data with crosses are the recent analysis [6], while the other data are from [3]. The full drawn symbols are the measured data and the open circles the data reflected around y_{mid} .

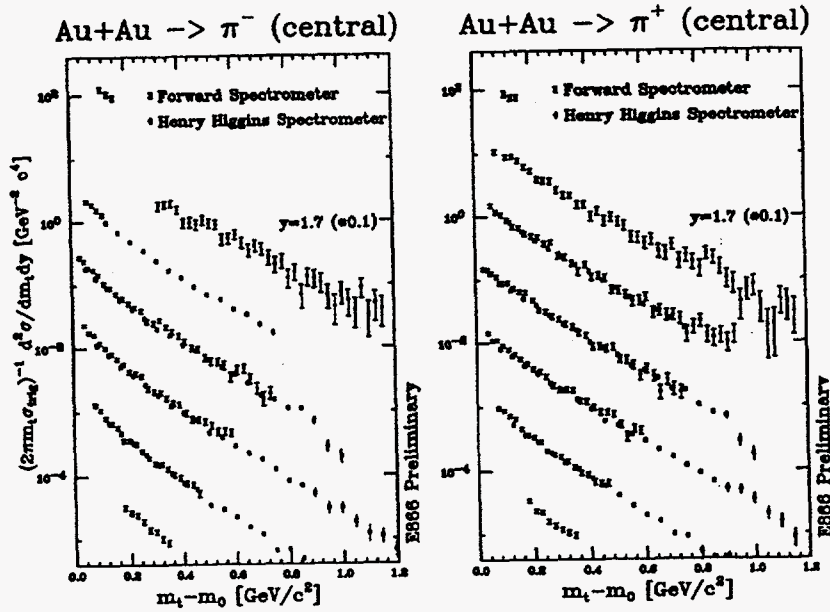


Figure 4. Invariant spectra for π^+ and π^- for transverse mass. The data are shown for rapidity bins $y=1.5$ and 2.7 with a bins size of 0.2 . For each subsequent bin in rapidity the cross section has been multiplied by 0.1 before being plotted.

will in the future settle this issue with more statistics and a better understanding of systematic errors.

Figure 5 shows the ratio of π^+/π^- as a function of m_t for two rapidity bins, 2.1 (circles) and 2.3 (squares), for the central Au+Au reactions. The qualitative difference in spectrum shapes between π^+ and π^- can be simulated by the Coulomb interaction with the co-moving matter. The curve in the figure is based on the Gamow correction factors for an effective charge of 10. The assumptions for using the Gamow correction are clearly much too simplistic, but the comparison with data show that large part of the difference can be accounted for this way. Other processes, such as $\Lambda \rightarrow p + \pi^-$, can also give rise to the low m_t enhancement.

3. Scaling Between K^+ and Protons

The following discussion is the second half of the report, and has been based on data of experiment E802. The E-802 collaboration has been interested in hadronic particle production at AGS energies ranging from reactions induced by proton beams to that induced by Si beams. We perform systematically studies of these reactions, measuring charged hadrons with the same magnetic spectrometer a over large area of the phase space [1,4]. From these measurements, distributions of particle yield over rapidity, dn/dy , and their average transverse momentum, $\langle p_t \rangle$, can be extracted.

Among these results, kaon production in heavy ion reactions has attracted considerable attention since an increased K^+/π^+ ratio is observed in Si+Au central reactions (~20%) compared to the same ratio in p-p reactions (~5%) at the same incident momentum per nucleon. Because kaons comprise one strange valence quark, the increased K^+/π^+ ratio could indicate an increased production of strange quarks in heavy ion reactions. One of the early predictions is that the increased strangeness productions might signal the formation of a state where quarks and gluons are no longer confined in the small volumes of hadrons but free, in a simple picture, in the entire, much larger reaction volume, — the so called quark gluon plasma. To evaluate this prediction, a more detailed understanding of kaon production mechanism from both theories and experiments is very important. On the other hand, the measured distribution of protons in the reaction reflects much of the reaction dynamics, because it provides information on the degree of nuclear stopping and the amount of energy available for particle production. At AGS energies, the production of antiprotons is rare, and the measured protons are from both the projectile and the target: they carry the initial momentum before the reaction and are participants during the reaction.

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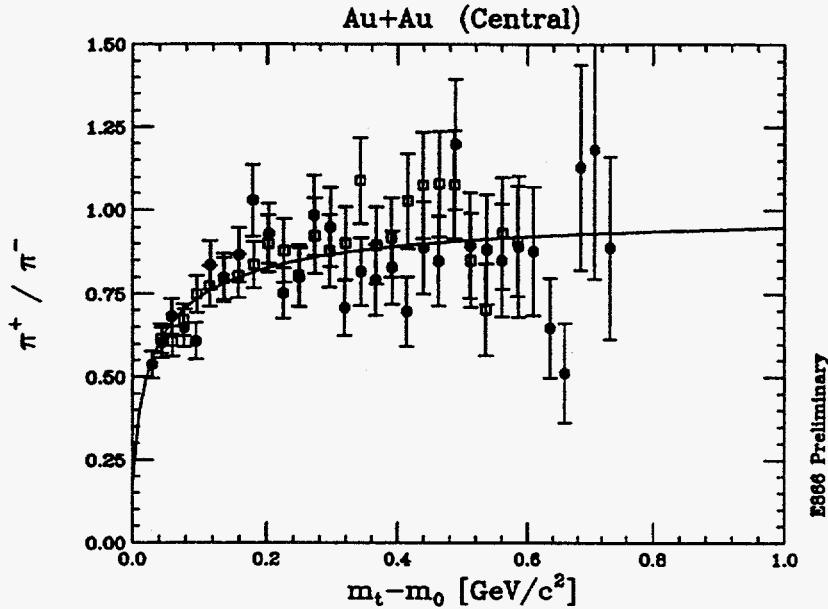


Figure 5. Transverse mass dependence of the π^+/π^- yields. The data are at $y=2.1$ and 2.3 [5]. The full drawn curve is based on a Gamow correction as described in the text.

In Figure 6, the dn/dy is shown for minimum biased p+Be, p+Au, and central Si+Au reactions at the same incident momentum of $14.6 \text{ A}\cdot\text{GeV}/c$ per nucleon. The spectra for central Si+Au are accordingly scaled down by a factor of 28, the mass number of Si. Detailed discussions on the spectra have been made extensively in Ref. [1,4]. In p+Be reactions, the distribution of protons is more or less symmetric around the nucleon-nucleon center-of-mass rapidity, $y_{nn}=1.74$. This indicates that p+Be reactions are mostly a single violent nucleon-nucleon collision. The yields of protons in p+Au reactions are greatly increased in rapidities lower than y_{nn} . There are a factor of 4 more protons at $y=0.7$ in p+Au reactions than there are in p+Be reactions. After being scaled down by a factor of 28, the proton yields in Si+Au are somewhere between the yields in p+Be and p+Au.

Intuitively it is a temptation to explore any possible relationships between the created particles, pions and kaons, and participants, protons, of the reaction. Figure 7 displays the π^+/p and K^+/p ratios as a function of rapidity for all the targets in the proton induced reaction [4]. The vertical scale is calculated as $(dn/dy)_{\text{meson}}/(dn/dy)_p$ where meson is either pions or kaons. The π^+/p ratios, as indicated in the upper row of the figure, decrease systematically with increasing target mass at backward rapidity ($y < y_{nn}$), and are approximately constant in the rapidity region forward of y_{nn} .

In spite of all the changes in the shape and magnitude of the individual kaon and proton rapidity distributions for the different reactions, the K^+/p ratios exhibit a remarkable target mass independence, and the rapidity dependence of K^+/p is just as strong as that for

π^+/p . This target mass independence is in marked contrast to the ratio for pions and may provide a clue for the different production mechanisms of these particles. Stated in another way, for every proton observed at a given rapidity in the collision, there is a definite probability of finding a K^+ at the same rapidity regardless of the target. It is important to realize that the yields involved in the ratio are inclusive, and the majority of the protons comes from reactions where no K^+ is produced since there are about 10 times more protons than K^+ (the average number of protons for each collision in p+Be is about 1). It is the inclusive yield of K^+ , hence the average probability of producing K^+ , which is related to that of protons at the same rapidity.

In the lower panel of Figure 8, the K^+/p ratio for central Si+Au reaction is put on the same scale as those for p+Be and p+Au with minimum bias trigger. In general, the K^+/p ratio for central Si+Au is higher than those in p+Be and p+Au reactions, and in the forward rapidity the ratio for p+Au might also be higher than that for p+Be. For comparison, rapidity distributions of average transverse momentum for the protons, $\langle p_t \rangle_p$, are also plotted in the upper panel of Figure 8 for the three reactions. Surprisingly, these two quantities have very good correlation: larger K^+/p ratio is measured at a rapidity where the protons are produced with larger average transverse momentum in the reaction. This observation leads to the following discussion.

In Figure 9, the meson yields are divided by the proton yields and the average transverse momentum of the protons at the same rapidity, $(dn/dy)_{\text{meson}}/(dn/dy \cdot \langle p_t \rangle_p)$. The denominator, by definition, is the total transverse momentum carried by protons at the given rapidity. For K^+ , this ratio exhibits a striking scaling behavior from p+Be, which is similar to p-p reactions, to the central Si+Au reactions, which is so far the largest system at incident momentum 14.6 A·GeV/c. Because of this independence over such a large range of projectile and target combinations, it may suggest that the same mechanism for K^+ production is responsible for all the systems regardless of the size of the projectile or the target. Naively, $(dn/dy)_p$ represents the number of participating nucleons in the reaction at the given rapidity and $\langle p_t \rangle_p$ increases with the average number of violent collisions. Empirically, the yields of K^+ are proportional to the product of the two.

The ratios for pions change with the systems. Generally, the ratio becomes smaller for heavier system, consistent with increasing K^+/π^+ ratios. From p+Be to central Si+Au reactions, the ratio decreases by a factor of 2-3. Interestingly, reactions of the same projectile seem to have similar values for this ratio at rapidity close to the projectile, and so are reactions of the same target at rapidity close to the target.

The environment in p+Be and Si+Au reactions is very different. Most of the time, the projectile and one nucleon experience one violent collision in p+Be reactions, whereas nucleons in both the projectile and the target have several collisions in Si+Au reactions. The amount of rescattering or absorption for produced particles is very small in p+Be, and the largest in Si+Au central reactions. In spite of the differences between these reactions, the relationship between K^+ and protons are the same. From these observations, it seems that the final distribution of protons and their average transverse momentum depend on the sizes of the projectile and target, but the dynamics of the collisions is such that the probability of producing K^+ at a given rapidity is determined by the total inclusive transverse momentum of protons there. It is reasonable to hypothesize that initially after

the impact of the projectile and the target, a primordial distribution of K^+ exist that is solely governed by the distribution of protons, namely,

$$\left(\frac{dn}{dy}\right)_{K^+} = \alpha(y) \cdot \left(\frac{dn}{dy} \cdot \langle pt \rangle\right)_P$$

where $\alpha(y)$ depends on the rapidity. Again this relation does not suggest that K^+ is produced on one-by-one basis with protons, rather it means that the probability of producing K^+ in a reaction depends on the inclusive transverse momentum of protons at the same rapidity. This dependency is the same for all reactions discussed. Since the cross section for K^+ interacting with surrounding matter is small, the subsequent evolution of rescattering and absorption does not change this relationship appreciably. Hence the relationship between K^+ and protons is preserved as observed. Due to their large interaction cross sections, even if a similar primordial relationship exists for pions, it will be modified differently in the subsequent evolution of rescattering and absorption, depending on the amount of surrounding matter. The possible indication for such process is that the ratios for pions in Figure 9 are lower when heavier projectile and/or target are involved and they converge to the same value toward projectile (target) rapidity for systems with the same projectile (target). This is presumably because heavier projectile and/or target introduce more rescattering and absorption. Preliminary result from central Au+Au at 11.6 A-GeV/c indicates a violation of this scaling between K^+ and protons, which is established at 14.6 A-GeV/c up to Si beams.

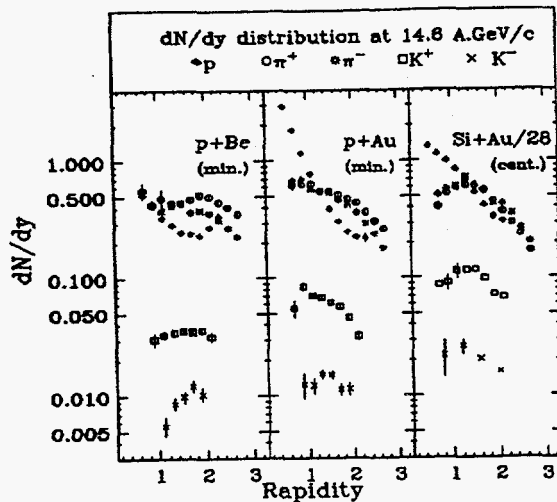


Fig.6 Rapidity distribution dn/dy for π^\pm , K^\pm , and protons in p+Be, p+Au, and central Si+Au collisions [1,4] at 14.6 A-GeV/c.

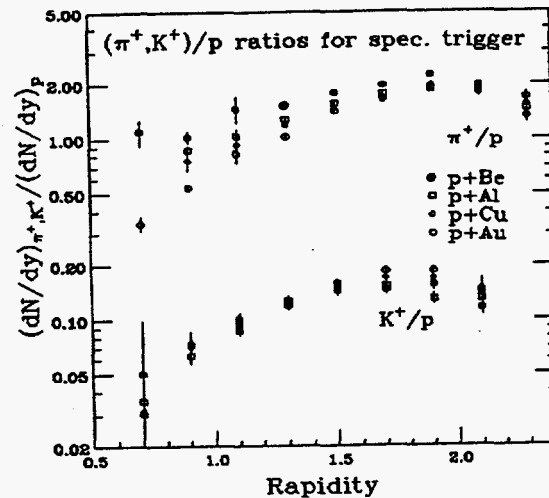


Fig.7 Rapidity distributions of π^+/p and K^+/p ratios for p+Be, p+Al, p+Cu, p+Au collisions at 14.6 GeV/c [4].

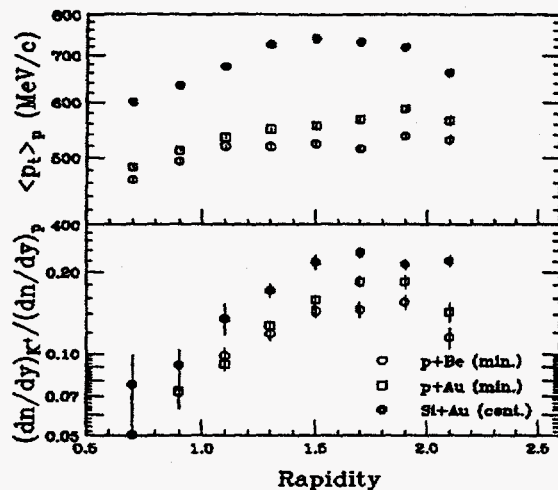


Fig.8 Rapidity distributions of K^+/p ratios and average transverse momentum of protons (upper panel) for minimum biased p+Be, p+Au, and central Si+Au reactions.

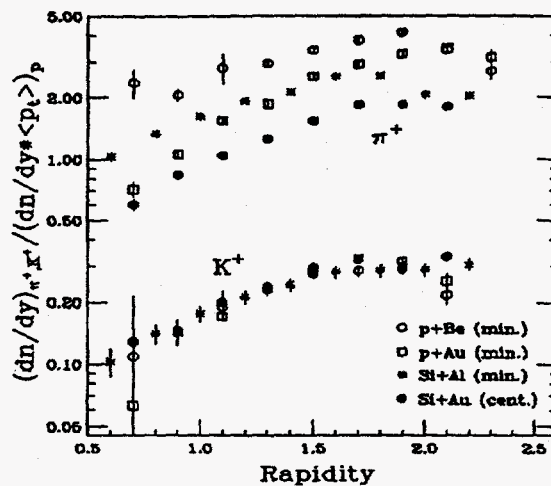


Fig.9 Rapidity distributions of $(dn/dy)_{meson}/(dn/dy)_{proton}$ for minimum biased p+Be, p+Au, and central Si+Au reactions.

4. Summary and Acknowledgment

To summarize, this report is divided into two parts. In the first half, some preliminary results from the forward spectrometer built specifically for the Au beams have been presented. The data together with the previously reported data have allowed us to present dn/dy distributions of protons covering the mid-rapidity region. The large degree of pileup of protons at the center of mass, hence a large degree of stopping, is confirmed for Au+Au central reactions. It is therefore likely that a high baryon density region is formed in such collisions. At low m_t , different shapes are observed for π^+ and π^- , with a clear low- m_t enhancement for π^- near mid-rapidity. This feature is not present in the current model description of the reactions.

In the second half, a scaling has been observed at each rapidity over a large region for the production of K^+ and protons from minimum biased p+Be reaction to the central Si+Au reaction at 14.6 A-GeV/c. The same method applied for pions shows a systematic change with the projectile and target combinations. The scaling may indicate a primordial

distribution for the production of K^+ whose yield is solely determined by the total transverse momentum of protons at the same rapidity.

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5. References

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