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An "In Acceptance" Comparison of Si + Au Data and RQMD Predictions

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1. *Introduction*

The following comparison of E-802 (Ref. 1) Si + Au spectra and RQMD predictions is based on the 802 data from November 1987, published in Refs. 2 and 3, and the RQMD calculations described in Refs. 4 and 5. The data presented here often have been binned differently compared to Refs. 1, 2 to facilitate the comparison with the theoretical data. The systematic errors[6] are estimated as less than ±20%. The RQMD data consists of listings of 203 complete events, all with an incident kinetic energy T=14.5*28 GeV and an impact parameter of b=1 fm. The output listings contain 4-vectors of all outgoing particles, and have been sorted into spectra of invariant cross section (normalized per event) versus transverse mass for definite rapidity bins, in the same way as the data. It has been assumed that the RQMD output obeys Poisson statistics.

The RQMD data differ from the experiment in two important ways. The experiment was triggered on high overall charged multiplicity and therefore contains events with a distribution over central impact parameters, whereas the theory uses but one impact parameter (1 fm). The incident momentum in the experiment was p_{802}=28*14.6 GeV/c, while the RQMD calculation used p_{RQMD}=15.4*28 GeV/c, i.e. a difference of 22.4 GeV/c, or 5%.

2. *Overall Multiplicities*

Figure 1 shows the apparent multiplicity distribution as measured by the E-802 target multiplicity array[1] (TMA, filled squares) for Si+Au. "Apparent" stands for the fact that no corrections for acceptance, gamma conversions, multihits or delta rays have been made. The open squares show the simulated result using the RQMD output listings and a GEANT modelling of the TMA, beam tube, target and target-holder arrangement. Only delta ray production from the beam was omitted in the simulation. The average apparent multiplicity for the RQMD input is 215 as compared to 201 for E-802. While this 7% increase may indeed reflect the two major differences between the experimental and theoretical parameters mentioned above, it is barely significant considering the uncertainties involved in the simulation and the systematic errors on the data.

3. *Spectra*

Invariant spectra $(1/(2\pi m_t))d^2n/(dm_t dy)$ versus m_t-m (where y denotes rapidity) are shown in Figs. 2 and 3, again with filled symbols indicating E-802 data and open symbols RQMD results. The E-802 data are from the rapidity bin 0.8<y<1.05 and all the data have been multiplied by 1.23, to enforce agreement between the π^+ E-802 and RQMD spectra. The RQMD spectra cover a slightly broader interval 0.75<y<1.05 to obtain statistics comparable to the experiment. The overall agreement between theory and experiment in overlapping m_t-m intervals is excellent. Some minor differences can be detected: the E-802 protons have a flatter slope than do the RQMD protons, while the latter intercept m_t-m=0 at a larger value. The E-802 K^+ are systematically above the RQMD points (~ one σ level) and vice versa for K^-. The trends for y=0.9 are typical of all intervals near midrapidity and are reflected in the integrals discussed below. It is worth noting that the RQMD $\pi^\pm$ spectra outside the E-802 acceptance, at very low m_t-m (low p_t) curve up. The RQMD π-spectra cannot be well fitted by a single exponential; they require two components, a steep one at low m_t-m and one that would agree with E-802 above m_t-m ~ 0.2 GeV. The steep RQMD pion component can be traced back to delta decays.[7]

4. *Rapidity Densities*

Following the usual E-802 analysis procedure, the spectra are fitted to an exponential

$$(1/(2\pi m_t))\, d^2n/(dm_t dy) = A(y) \exp(-(m_t-m)/B(y)) \qquad (1)$$

from which the rapidity density is derived,

$$dn/dy = 2\pi A\, e^{m/B}\, (B^2 + mB) \qquad (2)$$

by integration. Equation (2) represents an extrapolation outside the acceptance, and is only correct to the extent Eq. (1) is a true representation. The dn/dy from E-802, following Eq. (2), are shown in Figs. 4 and 5 as filled symbols, still multiplied by *1.23. The rapidity intervals Δy were 0.2 for $\pi^\pm$, p and K^+ and 0.3 for K^-. The open symbols in the figures are from the RQMD spectra, fitted according to Eq. (1) in the same acceptance as the E-802 data, using always Δy=0.3. For $K^\pm$ and p, Eq. (2) gives an excellent representation of the true dn/dy, which can also be obtained for the model by counting the particles in the output listing for all m_t. For $\pi^\pm$ the low m_t-m rise is of course missed as it is outside the E-802 acceptance and the true RQMD dn/dy is larger by ≈30%, varying somewhat from rapidity bin to rapidity bin and from π^+ to π^-.

As anticipated above, the π^- agreement is good (the π^+ is even better), while RQMD underpredicts the K^+ yield by ≈10% on average and overpredicts the K^- yield by ≈50%. The protons (Fig. 5) agree below y=1.1, whereas for larger y, RQMD increasingly is above the experimental points, by ≈50% towards y=2. Thus, if the E-802 data are increased by 23%, a very acceptable, though not perfect, agreement is obtained within the experimental acceptance, with the RQMD prediction.

5. *Parallel Momentum and Total Energy*

The amount of parallel momentum p_z contained, for a given final particle within a phase space acceptance, $y_1<y<y_2$, $m_{t1}<m_t<m_{t2}$, can be estimated from the exponential fits (Eq. (1)) to the data as

$$p_z\,(y_1, y_2, m_{t1}, m_{t2}, \mathrm{PID}) =$$

$$\sum_{y=y_1}^{y_2} \Delta y\, \sinh(y)\, A(y)\, e^{m/B(y)} \int_{m_{t1}}^{m_{t2}} (m_t)^2\, e^{-m_t/B(y)}\, dm_t \qquad (3)$$

where PID is the particle specie, and the integral is elementary. The RQMD numbers were obtained directly from the output listings. The phase space acceptance was chosen as a rectangle in y-m_t space (see Table 1) which avoids most of the low m_t extrapolations of the data as well as the low m_t rise in the RQMD pions, while the rapidity interval is as wide as allowed by the experimental data. The experimental entries in the table have been multiplied by 1.23 as in the previous paragraph, and no attempt to correct for the too high RQMD incident energy has been made.

TABLE 1

Comparison of p_t and E for E-802 and RQMD in a Common Acceptance[a)]

Particle	y_1 *to* y_2	m_{t1}-*m to* m_{t2}-*m*	*Ratio* (p_z)	*Ratio* (*E*)
π^+	0.6-1.80	0.24- 1.32	0.86	0.87
π^-	0.6-2.20	0.24- 1.32	0.69	0.71
K^+	0.6-1.60	0.10- 0.94	1.24	1.28
K^-	0.6-1.80	0.10- 0.94	0.74	0.75
P	0.6-2.00	0.041-1.83	0.87	0.89
Sum			0.84	0.86

The last line, called "sum", is evaluated on the momenta (energies) summed over the particles, 67.11 GeV/c and 81.82 GeV for E-802 times 1.23. Ratio is E-802/RQMD.

The total energies E were evaluated by substituting cosh(y) for sinh(y) in Eq. (3). Two thirds of the p_t or E is supplied by the protons, so the summed values in Table 1 are close to the proton value. The ratio numbers do not depend strongly on the choice of the m_t interval.

6. *Conclusions*

RQMD, to a first conclusion, gives a good overall account of the E-802 data. RQMD seems to overpredict the dn/dy extrapolated from spectra by a little over 20%. To some extent this may be caused by too high a beam energy in the calculations and a different "trigger" condition. The deviation is just within the estimated systematic errors of the experiment. With regard to p_z and E, the theory overpredicts the experiment by a somewhat larger amount, ≈45%, reflecting that the main discrepancy between E-802 and RQMD is in the forward protons.

Our conclusion is that there is no drastic disagreement between E-802 and RQMD, nor between E-802 and momentum and energy conservation, the discrepancies are essentially within the systematic errors of the experiment and the effects of incorrect input parameters of the theory (beam energy and trigger condition). Reference 8 asserts that transparency in central Si+Au collisions must be high in order to reconcile the E-802 data with energy and momentum conservation. The reconciliation is achieved by postulating a large number of baryons at rapidities between 2.5 and 3.0. This, on the other hand disagrees with data[9,10] from E-810 and E-814, leading to the conclusion[8] that E-802 needs an upwards renormalization of nearly a factor 2 for all dn/dy. We disagree with this conclusion, which largely comes about because the authors of Ref. 8 used extrapolations of the E-802 data, and did not compare theory and experiment in a consistent manner within the experimental acceptance. Reference 11 states that the "missing" energy-momentum in E-802 still remains a puzzle. The above analysis demonstrate that the puzzle is of a size comparable to the systematic errors in experiment and in the theory.

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Figure Captions

Fig. 1: Comparison of overall apparent charged particle multiplicity distributions from E-802 and RQMD. For details, see the text.

Fig. 2: Invariant cross sections normalized per event for π^+ (top), protons (middle), and π^- (bottom). Filled symbols are E-802 data multiplied by *1.23 and open symbols are RQMD results. For more details, see the text.

Fig. 3: Invariant cross sections for K^+ (top) and K^- (bottom). See also caption Fig. 2.

Fig. 4: dn/dy as deduced from exponential fits to the spectra within the experimental acceptance for p^+, K^+, and K^-, displayed as a function of laboratory rapidity. Full symbols are E-802 data times 1.23, open symbols for RQMD.

Fig. 5: dn/dy for protons. See also caption Fig. 4.

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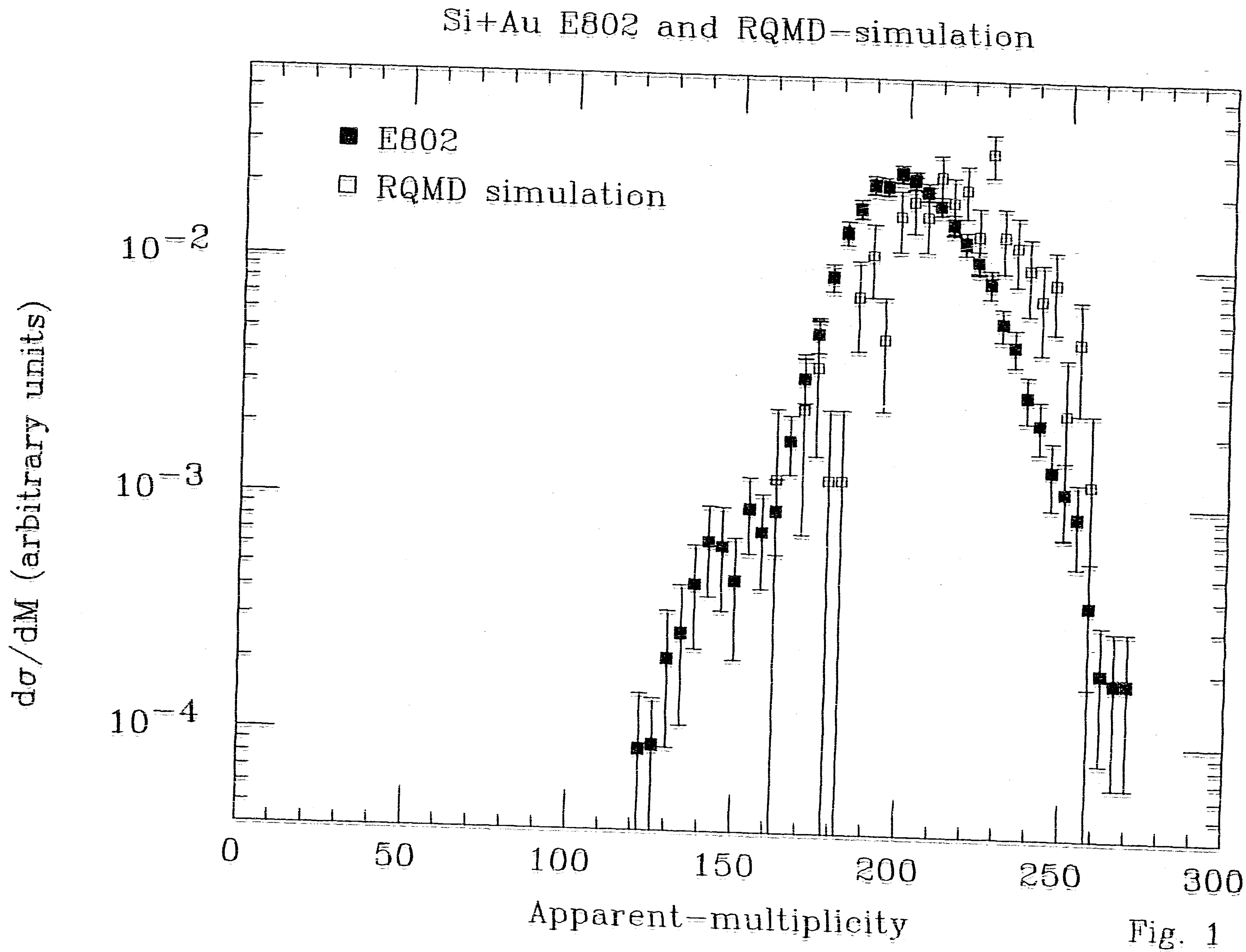
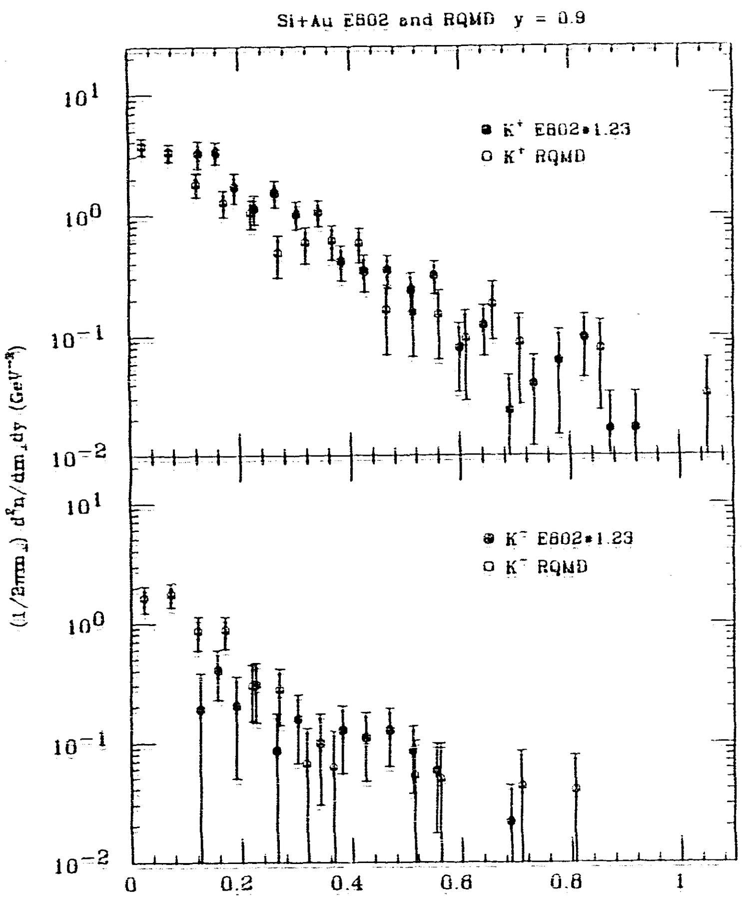
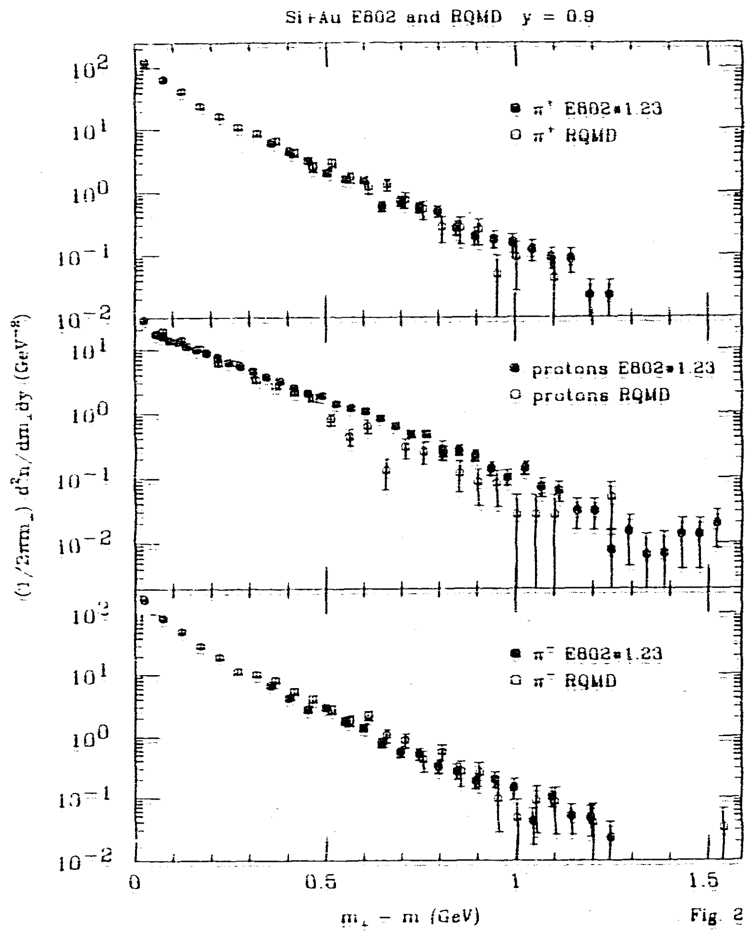


Si+Au E802 and RQMD-simulation
E802
RQMD simulation
10−2
10−3
10−4
dσ/dM (arbitrary units)
0
50
100
150
200
250
300
Apparent-multiplicity

Fig. 1


Si+Au E802 and RQMD y = 0.9
K⁺ E802*1.23
K⁺ RQMD
K⁻ E802*1.23
K⁻ RQMD
(1/2πm⊥) d²n/dm⊥dy (GeV⁻³)
m⊥ − m (GeV)
Fig. 3


Si+Au E802 and RQMD y = 0.9
π⁺ E802*1.23
π⁺ RQMD
protons E802*1.23
protons RQMD
π⁻ E802*1.23
π⁻ RQMD
(1/2πm⊥) d²n/dm⊥dy (GeV⁻³)
m⊥ − m (GeV)
Fig. 2

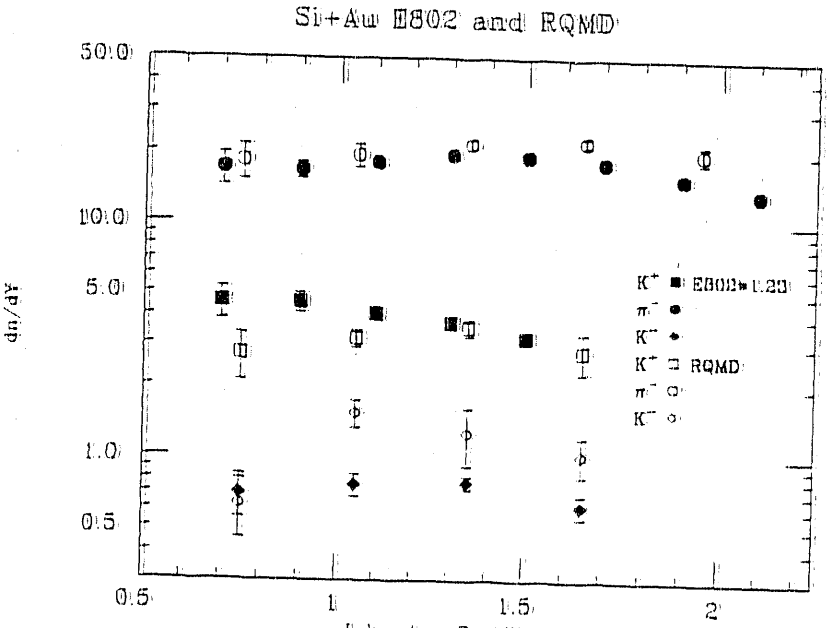

Si+Au E802 and RQMD
dn/dY
50.0
10.0
5.0
1.0
0.5
0.5
1
1.5
2
Laboratory Rapidity
K+ E802*1.23
π−
K−
K+ RQMD
π−
K−

Fig. 4

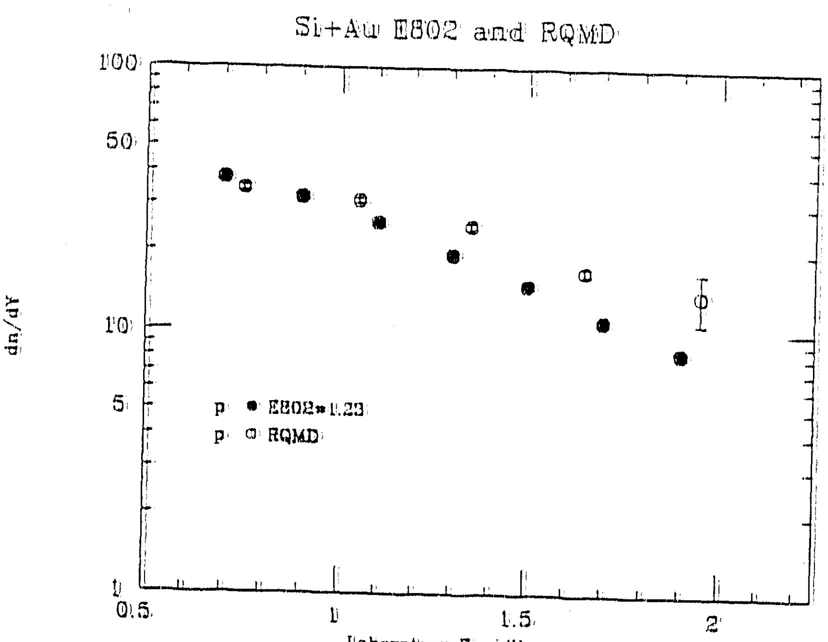

Si+Au E802 and RQMD
dn/dY
100
50
10
5
1
0.5
1
1.5
2
Laboratory Rapidity
p E802*1.23
p RQMD

Fig. 5

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