Centrality Definition Using Mid-Rapidity E_T distributions from p+Be to Au+Au at AGS Energies

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Measurements by the E802 Collaboration of the A-dependence and pseudorapidity interval ($\delta\eta$) dependence of mid-rapidity E_T distributions in a half-azimuth electromagnetic calorimeter are presented for p+Be, p+Au, O+Cu, Si+Au and Au+Au collisions at the BNL-AGS. The issues addressed are 1) whether the shapes of the upper edges of the E_T distributions vary with $\delta\eta$ similarly to the variation in shapes of mid-rapidity charged particle distributions and 2) how small a $\delta\eta$ interval would still give a meaningful characterization of the 'nuclear geometry' of a reaction. A new way of plotting E_T distributions was found from which the reaction dynamics could be read directly.

1. MIDRAPIDITY E_T DISTRIBUTIONS AND NUCLEAR GEOMETRY

E_T distributions play an important role in RHI collisions to 'characterize' the 'nuclear geometry' of a reaction, typically by a certain upper percentile of the distribution, e.g. 5%. The typical '4π' hadron calorimetry of high energy physics is not necessarily the best method for event characterization since it combines baryons and mesons, produced particles and participating nucleons, the projectile, midrapidity and target fragmentation regions into one number, E_T. More restrictive quantities might be better.

As the projectile dependence of a reaction is emphasized by measurements in the projectile fragmentation region, while the target dependence is emphasized by measurements in the target fragmentation region, it is possible that mid-rapidity measurements might represent a reasonable global average. An important issue to address is how small a $\delta\eta$ interval around mid-rapidity would still give a meaningful characterization of the 'nuclear geometry' of a reaction.

1.1. The shapes of multiplicity distributions vs $\delta\eta$—'Intermittency'

It is well known, by now, that the shapes of multiplicity distributions for central collisions of relativistic heavy ions, which are well described by Negative Binomial Distributions (NBD), change with the size of the region of phase space in which they are measured—even for relatively 'small' changes of pseudorapidity interval in the range $0.1 \leq \delta\eta \leq 1.0$. [1] This phenomenon, originally developed in terms of the normalized factorial moments of the multiplicity distributions and dubbed 'intermittency', has been explained by the dramatic reduction of the two-particle short-range rapidity correlation

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length ξ in central RHI collisions to a value, $\xi \sim 0.2$, derived from the NBD fits, which is much shorter than the value $\xi \sim 1-3$ in nucleon-nucleon collisions. [2]

One assumes that the same effect, the variation in shape as a function of the pseudorapidity interval $\delta\eta$, must occur with E_T distributions. This additional fluctuation might then complicate the nuclear geometry characterization and the centrality definition.

2. MEASUREMENTS OF MIDRAPIDITY E_T DISTRIBUTIONS VS $\delta\eta$

Systematic measurements of the projectile A dependence of mid-rapidity E_T distributions as a function of the $\delta\eta$ interval were made using the E802 electromagnetic calorimeter (PbGl) which covered half the azimuth with a pseudorapidity acceptance $1.25 \leq \eta \leq 2.50$ (where mid-rapidity for these energies is $y_{cm}^{NN} \simeq 1.6 - 1.7$ depending the species). The pseudorapidity distributions, $dE_T/d\eta$ for fixed E_T, have already been published. [3,4] In the present study, the η-acceptance of the calorimeter is subdivided into 8 nominally equal bins of 0.16 in pseudorapidity. The E_T distributions (in $\Delta\phi = \pi$) are then measured for 8,6,4,2,1 of these bins, i.e. in successively smaller $\delta\eta$ intervals centered (except for the smallest) on $\eta|_0 = 1.86$: $\delta\eta = 1.28$, the full η-acceptance of the calorimeter (actually $1.25 \leq \eta \leq 2.50$); $\delta\eta = 0.96$ ($1.38 \leq \eta \leq 2.34$); $\delta\eta = 0.64$ ($1.54 \leq \eta \leq 2.18$); $\delta\eta = 0.32$ ($1.70 \leq \eta \leq 2.02$); $\delta\eta = 0.16$ ($1.70 \leq \eta \leq 1.86$). The results for ^{16}O+Cu and for ^{197}Au+Au central collisions are shown in Fig. 1. Evidently, the shapes of the upper edges of E_T distributions change with $\delta\eta$, similarly to multiplicity. For the ^{16}O+Cu data, the shapes of the upper tails represent the actual fluctuations of the distributions for the case when all the projectile nucleons have interacted, while for the ^{197}Au+Au data, acceptance effects due to the limited aperture play the dominant role ($\epsilon^{197} \ll 1$ for any reasonable ϵ). Gamma distribution fits shown for ^{16}O+Cu provide a reasonable description of the spectra; however, in contrast to the NBD fits for multiplicity, no theoretical framework was found in the literature to help further interpret this observation.

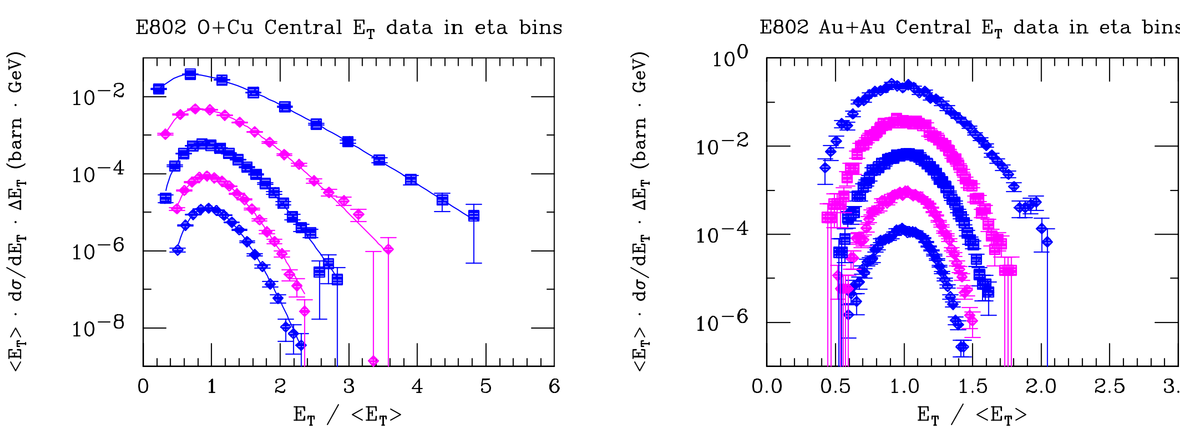

Figure 1. E802 mid-rapidity central (ZCAL) E_T distributions as a function of $\delta\eta$, normalized by $\langle E_T(\delta\eta)\rangle$ on the interval; O+Cu (left), Au+Au (right). The scale corresponds to the top curves ($\delta\eta = 0.16$); the curves for larger $\delta\eta$ are offset by factors of 10 each.

3. REACTION DYNAMICS FROM MID-RAPIDITY E_T DISTRIBUTIONS

The original E802 measurements [5] showed that the mid-rapidity E_T spectra of p+Au, p+Cu, p+Al and p+Be all exhibit the same shape over roughly 5 decades of cross section—no obvious multiple collisions effects were evident at mid-rapidity for p+A at AGS energies. Furthermore, the detailed shape of E_T distributions in B+A collisions, including the shapes of the upper edges, could be represented by the sum of independent p+A collisions weighted according to the 'geometric' probability of the number of projectile participants (Wounded Projectile Nucleons, WPN) in the reaction. Since naive models predict that mid-rapidity for a B+A collision shifts according to hard-sphere kinematics, there was concern [6] that the saturation of the upper edges of these distributions and the success of the WPN model could be an artifact of the limited angular (η) acceptance. In the present measurement (Fig. 2), the $\delta\eta$ interval is further reduced, yet the shapes of the p+Au and p+Be E_T distributions in each $\delta\eta$ interval remain essentially **identical** with each other, while the spectra clearly change shape with $\delta\eta$ for both p+Au and p+Be. Importantly,

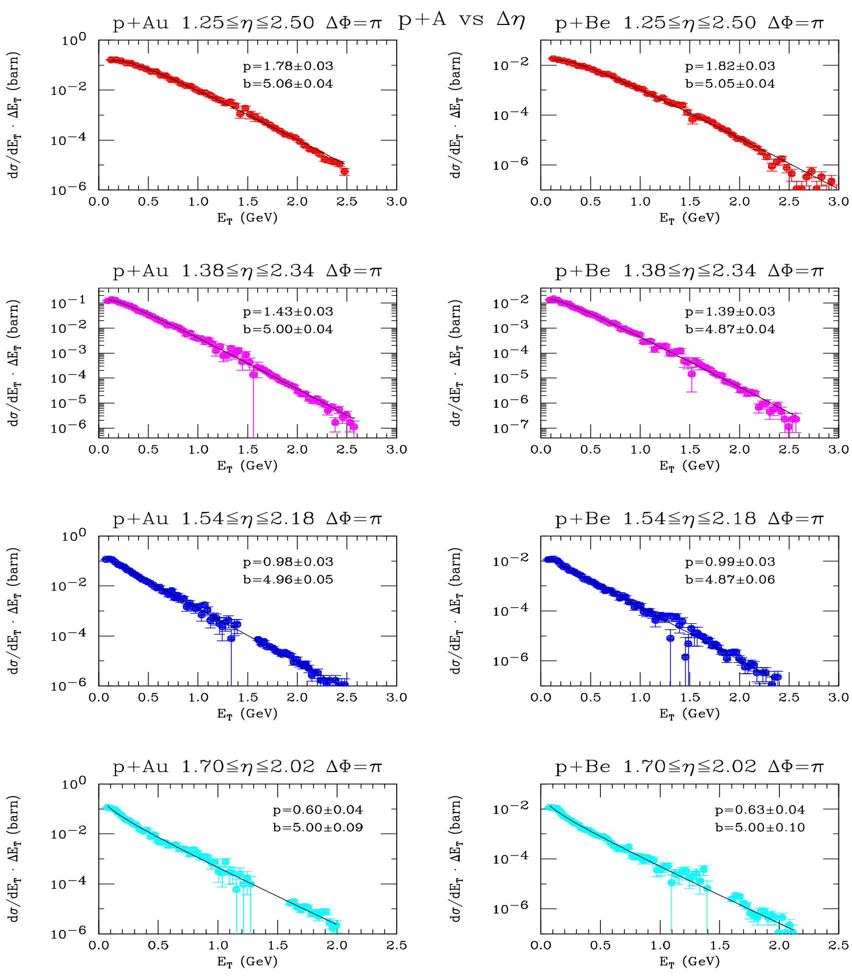

Figure 2. E_T distributions for p+Au (left) and p+Be (right) as a function of decreasing $\delta\eta$ from top to bottom. Adjacent p+Au and p+Be plots have the same $\delta\eta$. The curves are Γ distribution fits with parameters indicated.

the WPN model continues to work reasonably as $\delta\eta$ is reduced (Fig. 3), showing that E_T distributions, even in limited regions of $\delta\eta$, provide an excellent characterization of the 'nuclear geometry' of RHI collisions.

The maximum energies observed for E_T distributions in different $\delta\eta$ depend on the aperture. However, in Fig. 3, the energy scale for each $\delta\eta$ is normalized by the measured $\langle E_T \rangle$ in the same aperture for p+Au collisions. The scales for all 4 intervals are thus in physically meaningful units of 'number of average p+Au collisions', effectively Wounded Projectile Nucleons. The distributions are nearly indistinguishable when plotted this way, again showing that the characterization does not change with aperture.

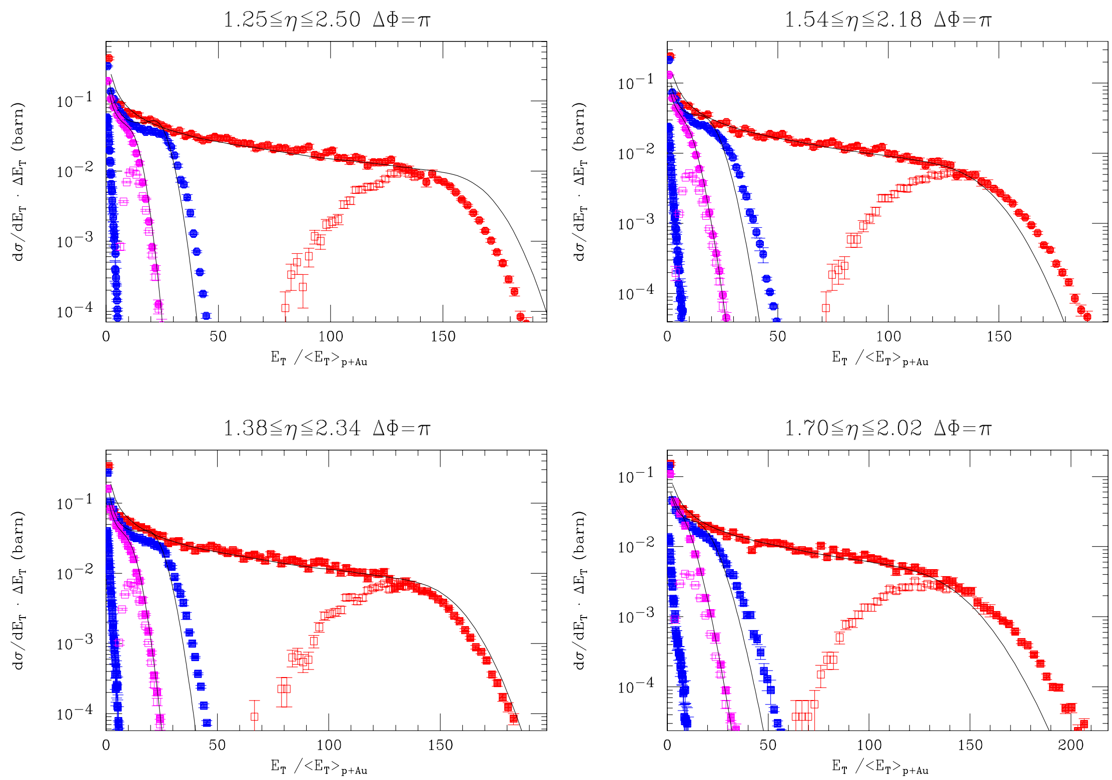

Figure 3. E_T distributions ($\Delta\phi = \pi$) for the four $\delta\eta$ intervals indicated for p+Au, O+Cu, O+Cu (ZCAL), Si+Au, Au+Au, Au+Au (ZCAL), where the E_T scale is normalized by the measured $\langle E_T \rangle_{\text{p+Au}}$ on the interval. The Au+Au E_T has been scaled up by a factor of 1.155 to correspond to 14.6 GeV/c [3]. The curves are the WPN model.

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