CENTRALITY AND E_T FLUCTUATIONS 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. The shapes of E_T distributions are observed to vary systematically with the size of the $\delta\eta$ interval, like multiplicity. By plotting the E_T distributions for a given $\delta\eta$ interval scaled by the measured $\langle E_T(\delta\eta)\rangle_{\mathrm{p+Au}}$ on the same interval for p+Au collisions, the distributions become nearly universal in the physically meaningful units of 'number of average p+Au collisions', effectively Wounded Projectile Nucleons. This shows that the centrality characterization remains valid even in relatively small mid-rapidity pseudo-rapidity intervals.

1 Midrapidity E_T distributions and Nuclear Geometry

E_T distributions play an important role in Relativistic Heavy Ion (RHI) collisions to 'characterize' the 'nuclear geometry' of a reaction—the smaller the impact paramter, the larger the overlap of the two nuclei, so more nucleons interact and more particles are produced. The typical '4π' hadron calorimetry of high energy physics [1,2,3] 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. Since 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 pseudorapidity interval, $\delta\eta$, around mid-rapidity would still give a meaningful characterization of the 'nuclear geometry' of a reaction.

The systematics of mid-rapidity multiplicity distributions as a function of $\delta\eta$ has been extensively studied in the 'intermittency' phenomenology in which Normalized Factorial Moments, $F(\delta\eta)$, and Cumulants, $K(\delta\eta)$, were observed to vary systematically with $\delta\eta$. Without belaboring too many pages of

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previous Multiparticle Conference Proceedings,[4,5] the large observed variation of the $K(\delta\eta)$ for central collisions of relativistic heavy ions (^{16}O+A) means that the shapes of multiplicity distributions 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 $0.1 \leq \delta\eta \leq 1.0$. The directly measured shapes of the charged multiplicity distributions for central ^{16}O+Cu collisions (see Fig. 1:Top) were well fit by Negative Binomial Distributions (NBD) and simply characterized by the NBD parameter $k(\delta\eta)$. The shape of the charged multiplicity distribution varies from nearly exponential for $\delta\eta = 0.1$ to nearly gaussian for $\delta\eta = 1.0$. 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, but would likely be different in detail. This additional fluctuation might then complicate the nuclear geometry characterization.

2 Measurements of E_T distributions versus $\delta\eta$

Systematic measurements of mid-rapidity E_T distributions as a function of $\delta\eta$ were made using the E802 electromagnetic (EM) calorimeter (PbGl) which covered half the azimuth ($\Delta\phi = \pi$), with a total pseudorapidity acceptance of $1.22 \leq \eta \leq 2.50$ (where mid-rapidity for these energies is $y_{cm}^{NN} \simeq 1.6 - 1.7$ depending the species). It is important to note that the PbGl EM calorimeter accurately measures elctromagnetic energy deposited by photons (typically produced by $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow$ neutral decays), but also responds to the cerenkov radiation from relativistic charged hadrons.[6,7] The overall response of the detector may be simply represented as:

$$E_T \equiv \sum_{\text{photons}} E_\gamma \ \sin\theta \ \ + \sum_{\text{charged, } \beta \geq 0.8} (0.45 \text{ GeV}) \times \sin\theta$$

No correction is made for the average charged hadron signal since an unknown model dependent systematic error would accrue. Thus, E_T is a composite but precisely measured quantity which has linear response for multiple collisions.

The pseudorapidity distributions, $dE_T/d\eta$ for fixed E_T, have already been published.[6,7] In the present study, the η-acceptance of the half-azimuth calorimeter, $1.22 \leq \eta \leq 2.50$, is subdivided into 8 nominally equal bins of 0.16 in pseudorapidity, i.e. $1.22 \leq \eta \leq 1.38$, $1.38 \leq \eta \leq 1.54$, $\ldots 2.34 \leq \eta \leq 2.50$. The acceptance ($\Delta\eta \times \Delta\phi$) of each bin varies compared to the ideal $0.16 \times \pi$, and is corrected by quoting an effective $\Delta\eta$ rather than simply the difference of the boundaries of the interval. The E_T distributions (in $\Delta\phi = \pi$) are then measured for $\delta\eta$ intervals composed of groups of 1,2,4,6,8 bins centered (except for the smallest) on $\eta|_0 = 1.86$: $\delta\eta = 1.30$, the full η-acceptance of the calorimeter (actually $1.22 \leq \eta \leq 2.50$); $\delta\eta = 0.966$ ($1.38 \leq \eta \leq 2.34$); $\delta\eta = 0.624$

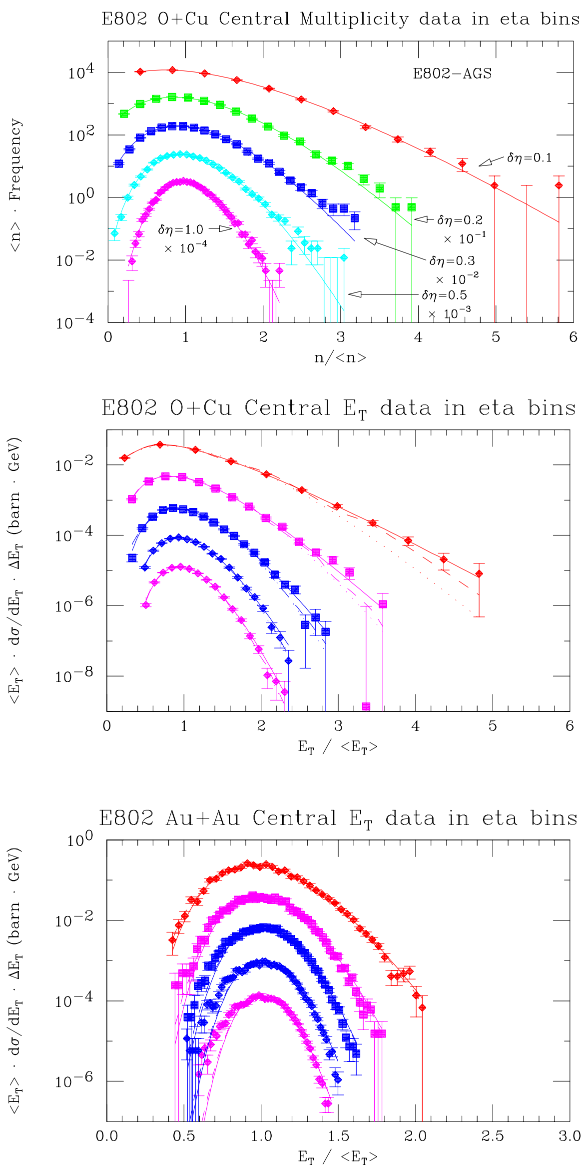

Figure 1: Multiplicity (Top) and E_T (Middle) distributions measured in ^{16}O+Cu central collisions; (Bottom) E_T distributions measured in Au+Au central collisions. Measurements are shown for 5 $\delta\eta$ intervals, scaled by $\langle n\rangle$ or $\langle E_T\rangle$ on the interval.

$(1.54 \le \eta \le 2.18)$; $\delta\eta = 0.378$ $(1.70 \le \eta \le 2.02)$; $\delta\eta = 0.170$ $(1.70 \le \eta \le 1.86)$. The results for ^{16}O+Cu and for ^{197}Au+Au are shown in the Middle and Lower panels of Fig. 1. Evidently, the shapes of the upper edges of E_T distributions change with $\delta\eta$, similarly to multiplicity.

The multiplicity and E_T distributions for ^{16}O+Cu in Fig. 1 come from exactly the same data set [8] where the centrality is defined by the absence of any projectile spectators [2] in a Zero Degree Calorimeter (ZCAL), indicating that all 16 projectile nucleons have interacted. For the ^{197}Au+Au data, the centrality is defined by an 8%-ile cut in the projectile spectator distribution [9] corresponding to collisions with less than 37 projectile spectators (out of 197). Still referring to Fig. 1, the solid lines (Top) are NBD fits to the multiplicity distributions and (Middle, Bottom) Gamma distribution [10,11] fits to the E_T distributions.

The Gamma distributions provide excellent fits to the ^{16}O+Cu E_T data, to the upper edges of the Au+Au data and to the p+Au and p+Be data (not shown). [12] The $p(\delta\eta)$ parameters (see Fig. 2, circles) vary systematically with

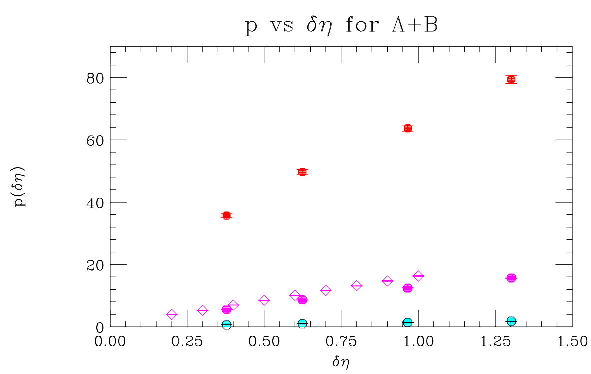

Figure 2: Gamma distribution fit parameters p as a function of $\delta\eta$ for E_T distributions (filled circles) from Au+Au (ZCAL), O+Cu (ZCAL) central collisions, and p+Au collisions. The open diamonds are $p(\delta\eta)$ from Gamma distribution fits [8] to O+Cu (ZCAL) multiplicity distributions.

$\delta\eta$, similarly to the $k(\delta\eta)$ from multiplicity distributions. [8] In contrast to the situation for multiplicity distributions where the shape as characterized by the NBD parameter $k(\delta\eta)$ can be related to the 2-particle short-range correlation length, there is at present no theoretical framework to relate the systematic variation in the Gamma distribution parameters $p(\delta\eta)$ to other physical quantities. However, Gamma distribution fits to ^{16}O+Cu multiplicity distributions [8] (open diamonds on Fig. 2) give $p(\delta\eta)$ in excellent agreement with the E_T results.

3 A new way to plot E_T distributions

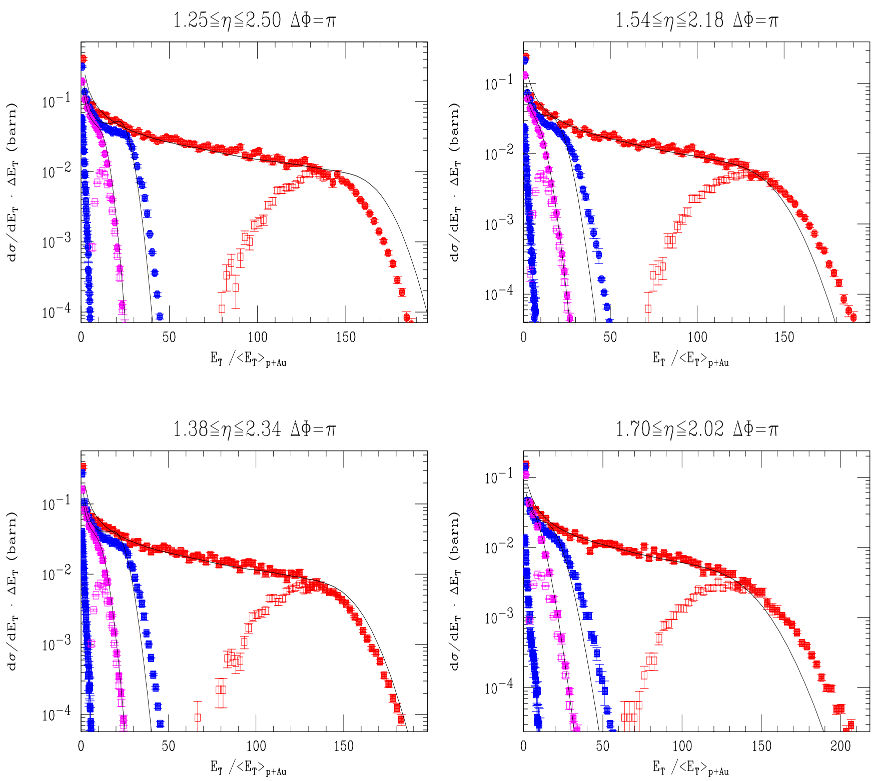

Figure 3: E_T distributions ($\Delta\phi = \pi$) for the four $\delta\eta$ intervals indicated, for p+Au, O+Cu, O+Cu (ZCAL), Si+Au, Au+Au, Au+Au (ZCAL), where the E_T scale is normalized by the measured $\langle E_T(\delta\eta)\rangle_{\rm p+Au}$ on the interval. The Au+Au E_T has been scaled up by a factor of 1.155 to correspond to 14.6 A GeV/c beam momentum. [7] The solid lines are Wounded Projectile Nucleon Model calculations. [12]

One problem with the limited aperture EM calorimeter E_T distributions in comparison to '4π' hadron calorimeters is the difficulty in relating the endpoints of the E_T spectra to the total available energy for the reaction. However, when the energy scale for each aperture is normalized by the measured $\langle E_T\rangle$ in the same aperture for p+Au collisions (or p-p, if available), the situation changes dramatically (see Fig. 3). The dynamics of the reaction, in terms of projectile (or total) participants, can now be read directly from Fig. 3—e.g. the knees of the ^{16}O+Cu and ^{28}Si+Au E_T distributions for all $\delta\eta$ intervals occur at roughly 16 and 28 times the $\langle E_T \rangle_{\rm p+Au}$, corresponding to the A of the projectiles; but the knee of the Au+Au distribution is at roughly 150, clearly not $A_{\rm Au} = 197$, apparently indicating some 'shadowing.'

4 Studies of the upper edges for Au+Au

The details of the upper edge of the Au+Au distribution can be studied (see Fig. 4) in the context of the Wounded Projectile Nucleon Model (WPNM).[12] The steep fall-off above the upper 'knee' of the Au+Au distribution is largely due to the steep fall-off of the contributions above 150 WPN, as shown in the lower left panel. This is apparently an acceptance effect in the limited aperture—e.g. $(1 - p_0)^{197}$ tends to be considerably less than unity for most reasonable values of p_0, where p_0 is the measured probability for a WPN (a p+Au interaction) to produce zero signal on the $\delta\eta$ interval.[12] The sensitivity of the upper edge to p_0 can be studied by setting $p_0 = 0$ in the WPNM calculation (top right); and to the shape of the underlying p+Au E_T distribution by varying p and b, keeping $\langle E_T \rangle|_{\rm p+Au} = p/b$ fixed (bottom right). The shape of upper edge is preserved as p_0 varies, but the position of the knee moves. For fixed $\langle E_T \rangle|_{\rm p+Au}$, the upper edge flattens as b flattens (decreases), but the 'knee' remains unchanged. Thus, the upper edges of Au+Au E_T distributions integrate over many WPN but retain their sensitivity to the nuclear geometry and to the underlying fundamental fluctuations on the interval.

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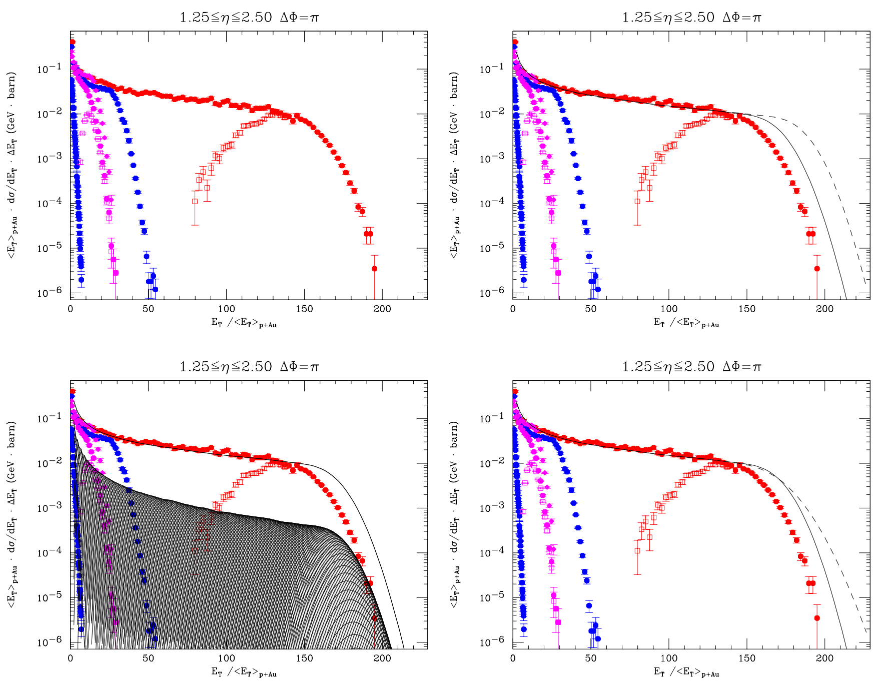

Figure 4: Top left: E_T distributions ($\Delta\phi = \pi$) in $1.25 \leq \delta\eta \leq 2.50$ for p+Au, O+Cu, O+Cu (ZCAL), O+Au, Si+Au, Au+Au, Au+Au (ZCAL). Bottom left: the same with WPNM calculation for Au+Au, with individual WPN components shown. Top right: WPNM calculation (dashes) with $p_0 \to 0$, Bottom right: WPNM calculation (dashes) with underlying p+Au $\Gamma(p, b)$ parameters changed keeping $\langle E_T \rangle|_{\text{p+Au}}$ fixed ($p \to p/2$, $b \to b/2$). Solid curve on all panels is the correct WPNM calculation.

Scientific, Singapore, 1985)

11. The Gamma distribution, normalized on $0 \leq x \leq \infty$, is defined as:

$$f(x) = \frac{b}{\Gamma(p)}(bx)^{p-1}e^{-bx} \quad ,$$

where $p > 0$, $b > 0$, $\Gamma(p) = (p-1)!$ for integer p.

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