

## TRANSVERSE ENERGY MEASUREMENT IN $\sqrt{s_{NN}} = 62.4$ GeV Au+Au COLLISIONS AT RHIC

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*Abstract.* The transverse energy distributions ( $E_T$ ) have been measured for Au + Au collisions at  $\sqrt{s_{NN}} = 62.4$  GeV by the STAR experiment at RHIC. They have been obtained from two measurements, the hadronic transverse energy ( $E_T^{had}$ ) and the electromagnetic transverse energy ( $E_T^{em}$ ).  $E_T^{had}$  has been measured from the tracks obtained by Time Projection Chamber (TPC) excluding the electrons and positrons.  $E_T^{em}$  has been obtained by the STAR Barrel Electromagnetic Calorimeter (BEMC) which measures the energy of electrons, positrons and photons. The measure of transverse energy gives an estimate of the energy density of the fireball produced in heavy ion collisions.  $E_T$  per participant pair gives information about the production mechanism of particles.

*Key words:* transverse energy, quark gluon plasma, energy density.

### 1. INTRODUCTION

The quest for understanding of the possible formation and existence of the quark-gluon plasma (QGP), the deconfined phase of quarks and gluons, has been a major area of heavy-ion research during the last couple of decades. The study of high energy nuclear collisions at the Relativistic Heavy Ion Collider (RHIC) [1] has opened a new domain in the exploration of strongly interacting matter at very high energy density. High temperature and densities may be generated in the most central nuclear collisions at RHIC, creating conditions in which a phase of deconfined quarks and gluons may exist [2, 3]. The understanding of the early phase of the fireball produced in nuclear collisions requires the study of observables like the energy and momentum, produced transversely to the beam direction viz  $E_T$  and  $p_T$ . The number of charge particles produced and  $E_T$  are

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closely related to the collision geometry and are of importance in understanding the global properties of the system during the collision. Scattering of the partonic constituents of the incoming nuclei in the initial phase added to the rescattering of the produced partons and hadrons results in generation of  $E_T$  [4, 5]. If the fireball of produced quanta breaks apart quickly without significant reinteraction, the observed  $dE_T/dy$  will be the same as that produced by the initial scattering. However, with interaction among the produced quanta, the system can achieve equilibrium at a very early state, after which it can expand resulting in a lowering of  $dE_T/dy$  [6, 7]. To some extent this will be compensated by any transverse hydrodynamic flow [8]. Gluon saturation can delay the onset of the above hydrodynamic flow reducing the effective pressure and thereby reducing the difference in the initially produced and the observed  $E_T$  [9].

Here, we present preliminary results on  $E_T$ , produced in 62.4 GeV Au+Au collisions at RHIC. We present both the hadronic and the electromagnetic components of  $E_T$ , which were measured independently by the STAR detector using the Time projection Chamber (TPC) and the Barrel Electromagnetic Calorimeter (BEMC). A brief description of the STAR experiment with the detectors used together with the data analysis methods employed is given in Section 2. In Section 3 we present the results (STAR Preliminary) with conclusion presented in Section 4.

## 2. STAR EXPERIMENT AND DATA ANALYSIS

STAR[10], is an azimuthally symmetric, large acceptance solenoidal detector comprising of several detector subsystems. The subsystems relevant for this analysis are a large TPC located inside a 0.5 T solenoidal magnet, the BEMC and two zero-degree calorimeters (ZDCs) for event selection. The BEMC[11] is a lead-scintillator sampling electromagnetic calorimeter with equal volumes of lead and scintillator. The full Barrel corresponds to 120 modules. Each module is composed of 40 towers (20 towers in  $\eta$  by 2 towers in  $\phi$ ), constructed to project to the center of the STAR detector. For the 2004 run, only half of the Barrel was instrumented, corresponding to a pseudorapidity coverage of  $0 < \eta < 1$  with full azimuthal symmetry. The transverse dimensions of a tower are approximately  $10 \times 10 \text{ cm}^2$ , which at the radius of the front face of the detector corresponds to a phase space interval ( $\Delta\eta, \Delta\phi$ ) of (0.05, 0.05). Each tower has a depth of 21 radiation lengths ( $X_0$ ) corresponding to one interaction length for a hadron. The BEMC with a radius of 2.3 m sits inside the STAR solenoidal magnet. The electromagnetic energy resolution of the BEMC is  $\delta E/E \sim 16\% / \sqrt{E(\text{GeV})}$ .

The TPC[12] is the primary STAR detector used for the event reconstruction. It is a gas chamber, 4.2 m long with inner and outer radii of 50 and 200 cm respectively, placed in an uniform magnetic field of 0.5 T. The particles passing through the active gas medium release secondary electrons that drift to the readout end caps at both ends of the chamber. The readout system is based on multiwire proportional counters, with readout pads. There are 45 pad rows between the inner and outer radii of the TPC. The induced charge from the electrons is shared over several adjacent pads. The TPC provides up to 45 independent spatial and specific ionization  $dE/dx$  measurements. The  $dE/dx$  measurements, along with the momentum measurement from the bending of the tracks inside the magnetic field, determine the particle mass within limited kinematic regions. The TPC covers a pseudorapidity region with  $|\eta| < 1.8$  with full azimuthal coverage.

The event trigger consisted of the coincidence of signals from two ZDCs, located at  $\theta < 2$  mrad about the beam down stream of the 1st accelerator dipole magnet and sensitive to spectator neutrons. These calorimeters provide a minimum bias trigger which, after collision vertex reconstruction, corresponds to  $97 \pm 3\%$  of the geometric cross section  $\sigma_{geom}^{Au+Au}$ . The events are analyzed in centrality bins based on the TPC charged particle multiplicity in  $|\eta| < 0.5$ .

The present analysis is based on the minimum bias Au+Au collisions data at  $\sqrt{s_{NN}} = 62.4$  GeV, taken by STAR in the 2004 RHIC run. Here the TPC acceptance is limited by the BEMC. The TPC track quality cuts include a) z-coordinate (longitudinal axis) selection of collision vertex within 30 cm of the TPC center and b) a minimum TPC track space point cut of 10.

### 2.1. HADRONIC TRANSVERSE ENERGY, $E_T^{had}$

The hadronic part of the transverse energy as measured from the momentum analysed TPC tracks is defined as

$$E_T^{had} = \sum_{tracks} E_{track} \sin\theta, \quad (1)$$

where the sum runs for all hadrons produced in the collision, except  $\pi^0$  and  $\eta$ .  $\theta$  is the polar angle with respect to the beam axis and the collision vertex position. The Hadronic energy,  $E_{track}$ , is defined as [13, 14]

$$E_{track} = \begin{cases} \sqrt{p^2 + m^2} - m & \text{for nucleons} \\ \sqrt{p^2 + m^2} + m & \text{for anti-nucleons} \\ \sqrt{p^2 + m^2} & \text{for all other particles.} \end{cases}$$

With the above definition,

$$E_T^{had} = C_0 \sum_{tracks} C_1(ID, p) E_{track}(ID, p) \sin\theta \quad (2)$$

where the sum includes all the primary tracks in BEMC acceptance. Here,  $C_0$  is a correction factor defined as

$$C_0 = \frac{1}{f_{acc}} \frac{1}{f_{pT^{cut}}} \frac{1}{f_{neutral}} \quad (3)$$

where  $f_{acc}$  is the acceptance correction,  $f_{neutral}$  is the correction for long-lived neutral hadrons not measured by the TPC,  $f_{pT^{cut}}$  corresponding to the TPC low momentum cutoff. The factor  $C_1(ID, p)$  is defined as

$$C_1(ID, p) = f_{bg}(pT) \frac{1}{f_{notID}} \frac{1}{eff(pT)} \quad (4)$$

which includes the uncertainty in the particle ID determination,  $f_{notID}$ , the momentum dependent tracking efficiency,  $eff(pT)$  and the momentum dependent background,  $f_{bg}(pT)$ . Details of the procedure for finding out the correction factors are given elsewhere [13].

## 2.2. ELECTROMAGNETIC TRANSVERSE ENERGY, $E_T^{em}$

$E_T^{em}$  is measured from the BEMC tower hits corrected for the hadronic contaminations in the calorimeter. It is defined as

$$E_T^{em} = \sum_{towers} E_{tower}^{em} \sin(\theta_{tower}) \quad (5)$$

where  $E_{tower}^{em}$  is the electromagnetic energy measure in an BEMC tower and  $\theta_{tower}$  is the polar angle of the center of the tower relative to the beam axis and the collision vertex position. Experimentally,  $E_T^{em}$  is given by

$$E_T^{em} = \frac{1}{f_{acc}} \sum_{towers} (E_{tower} - \Delta E_{tower}^{had}) \sin(\theta_{tower}) \quad (6)$$

where,  $f_{acc}$  is the acceptance correction,  $E_{tower}$  is the energy measured by an BEMC tower and  $\Delta E_{tower}^{had}$  is the total correction for each tower to exclude the hadronic contributions.  $\Delta E_{tower}^{had}$  is given by

$$\Delta E_{tower}^{had} = \frac{1}{f_{neutral}} \sum_{tracks} \frac{f_{elec}(pT)}{eff(pT)} \Delta E(p, \eta, d), \quad (7)$$

where,  $\Delta E(p, \eta, d)$  is the energy deposited by a track projected on a BEMC tower as a function of it's momentum  $p$ , pseudorapidity  $\eta$  and distance  $d$  from the center of the tower to the track hit point.  $f_{elec}(pT)$  is the correction to exclude electrons that are misidentified as hadrons.  $eff(pT)$  is the track reconstruction efficiency and  $f_{neutral}$  is the contribution to exclude the long-lived neutral hadron contribution.

### 3. RESULTS

Assuming the correction factors used in this analysis, to be the same as those obtained for 200 GeV Au+Au collisions [13], we have determined the minimum bias distributions of the total transverse energy,  $E_T$  and it's components ( $E_T^{had}$  and  $E_T^{em}$ ) separately. These are shown in Fig. 1 (a)–(c).

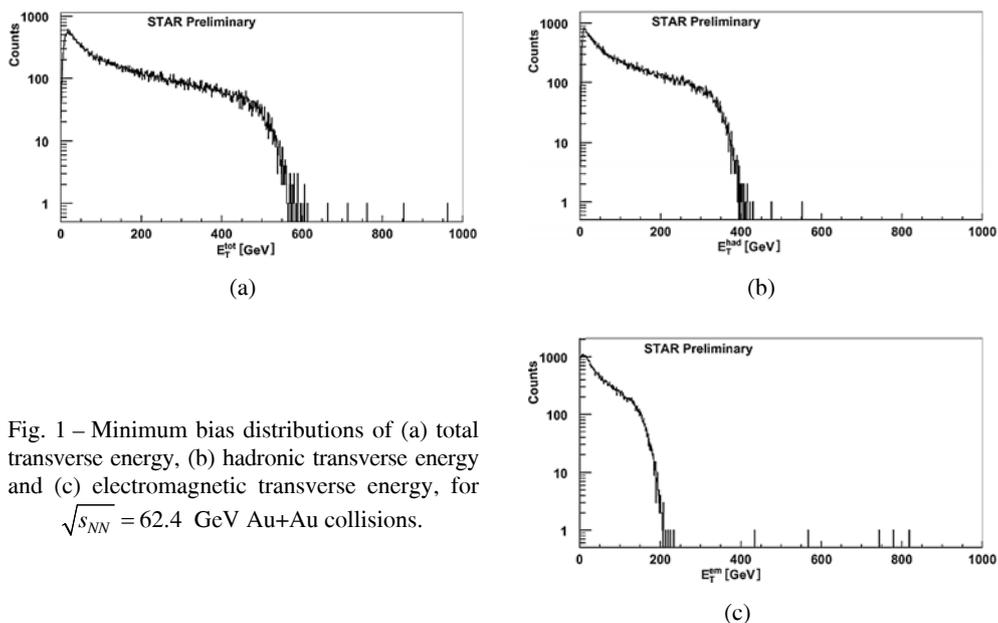


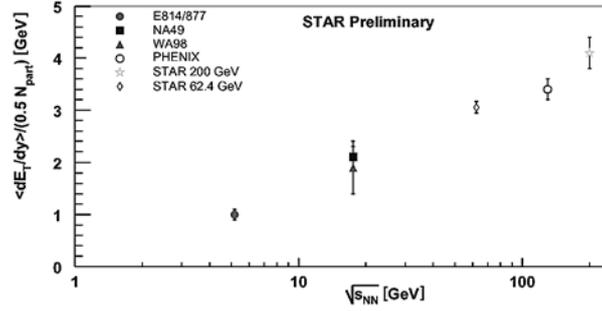
Fig. 1 – Minimum bias distributions of (a) total transverse energy, (b) hadronic transverse energy and (c) electromagnetic transverse energy, for  $\sqrt{s_{NN}} = 62.4$  GeV Au+Au collisions.

In Fig. 2(a), we present  $dE_T/dy$  per participant pair for the top 5% central collisions, together with results from other experiments from AGS to RHIC [15–18]. The  $dE_T/dy$  values for this analysis, were calculated from  $dE_T/d\eta$  using a factor of 1.18 obtained from HIJING simulation to convert  $\eta$  to  $y$  phase space. We obtained a value of  $3.05 \pm 0.05$  (stat) GeV, consistent with an overall logarithmic growth of  $dE_T/dy/(0.5N_{part})$  with  $\sqrt{s_{NN}}$ . For the same top 5% central events,

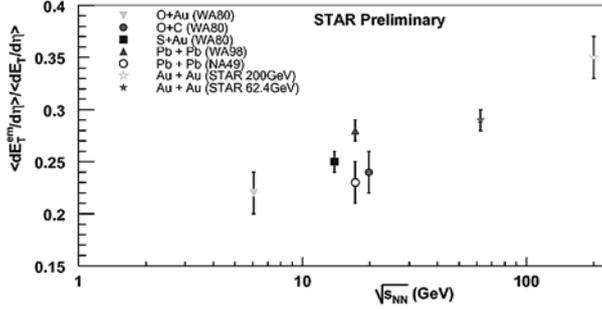
$\langle E_T \rangle_{5\%}$  as obtained from  $\langle dE_T/d\eta|_{\eta=0.5} \rangle$  for full azimuthal coverage and one unit  $\eta$  interval, is found to be  $450 \pm 6$  (stat) GeV. Further, we have also determined the spatial energy density produced in the collision using the Bjorken formula [19]

$$\epsilon_{Bj} = \frac{dE_T}{dy} \frac{1}{\tau_0 \pi R^2} \quad (8)$$

where,  $dE_T/dy$  is the primordial rapidity density of transverse energy,  $R$  is the transverse system size given by  $R = R_0 A^{\frac{1}{3}}$  and  $\tau_0$  is the formation time. Assuming  $\tau_0 = 1$  fm/c, we get  $\epsilon_{Bj} = 3.46 \pm 0.05$  GeV/fm<sup>3</sup>. This energy density is significantly higher than the energy density  $\sim 1$  GeV/fm<sup>3</sup> as required for the transition to a deconfined quark gluon plasma, predicted by lattice QCD [20]. This estimate is based on the assumption that local equilibrium has been achieved at  $\tau \sim$  fm/c and then the system expands hydrodynamically.



(a)



(b)

Fig. 2 – (a)  $(dE_T/dy)/(0.5N_{part}) Vs \sqrt{s_{NN}}$  for central events, (b) Collision energy dependence of electromagnetic fraction of total  $E_T$  as given by  $\langle dE_T^{em}/d\eta \rangle / \langle dE_T/d\eta \rangle$  for a number of systems from SPS to RHIC for central events.

In Fig. 2(b), we have shown the electromagnetic fraction of the total transverse energy for the top 5% central events, as a function of the center of mass energy from SPS [21, 22] to RHIC. This is seen to increase slowly when we go from AGS to RHIC. At 62.4 GeV this value is  $0.29 \pm 0.01$  (stat). As discussed in ref. [13], the observed electromagnetic fraction of the total transverse energy is strongly dependent on the baryon to meson ratio. At very high energy it is expected that virtually all the  $E_T$  will be carried by mesons, as an almost baryon free region is expected to be created in the central rapidity region, while at lower SPS energies, baryon dominance results in a much smaller electromagnetic fraction. A very high value of the electromagnetic fraction of total transverse energy is expected in case of a long-lived deconfined phase, due to an excess yield of photons [23]. Based on the present ratio of  $0.29 \pm 0.01$  (stat) it is very difficult to conclude anything regarding the formation of a deconfined QGP phase.

#### 4. CONCLUSIONS

In the present work we have reported preliminary STAR results on  $E_T$  within  $0 < \eta < 1$  for Au+Au collisions at  $\sqrt{s_{NN}} = 62.4$  GeV. For top 5% central events  $\langle E_T \rangle$  has been estimated to be  $450 \pm 6$  (stat) GeV. The value of  $\langle dE_T/dy \rangle / (0.5N_{part})$  has been found to be  $3.05 \pm 0.05$  (stat) GeV. Knowing that the observed  $E_T$  is lower than the initial values [6, 9, 24], the present value of  $3.05 \pm 0.05$  (stat) GeV may be considered as a lower bound only. The initial energy density estimated within the framework of boost-invariant hydrodynamics, as given by  $\epsilon_{Bi}$ , has been found to be  $3.46 \pm 0.05$  (stat) GeV/fm<sup>3</sup> which is well above that required for the deconfinement phase transition as predicted by lattice QCD [20]. The electromagnetic fraction of the total transverse energy for central events is found to be  $0.29 \pm 0.01$  (stat), consistent with the fact that the final state is dominated by mesons. Finally, this method of independent measurement of  $E_T^{em}$  and  $E_T^{had}$  gives an unique opportunity to study event by event fluctuations in these observables and in their ratios. The correction factors and the systematic errors are yet to be calculated for this analysis.

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