FORWARD ENERGY AND MULTIPLICITY IN AU-AU REACTIONS AT $\sqrt{S_{NN}} = 130GEV$

MICHAEL MURRAY
Cyclotron Institute, Texas A&M University

I. G. BEARDEN[1], D. BEAVIS[2], Y. BLYAKHMAN[3], J. BRZYCHCZYK[4], B. BUDICK[3], H. BØGGILD[1], C. CHASMAN[2], P. CHRISTIANSEN[1], J. CIBOR[5], R. DEBBE[2], J. J. GAARDHØJE[1], K. GROTOWSKI[4], J. I. JORDRE[6], F. JUNDT[7], K. HAGEL[8], O. HANSEN[1], A. HOLM[1], C. HOLM[1], A. K. HOLME[9], H. ITO[10], E. JACOBSEN[1], A. JIPA[11], C. E. JØRGENSEN[1], E. J. KIM[12], T. KOSIC[4], T. KEUTGEN[8], T. M. LARSEN[9], J. H. LEE[2], Y. K. LEE[12], G. LØVHOIDEN[9], Z. MAJKA[4], A. MAKEEV[8], B. MCBREEN[2], M. MURRAY[8], J. NATOWITZ[8], B. S. NIELSEN[1], K. OLCHANSKI[2], D. OUERDANE[1], J. OLNESS[2], R. PLANETA[4], F. RAMI[7], D. ROEHRICH[6], B. SAMSET[9], S. SANDERS[10], R. A. SHEETZ[2], P. STACZEL[1], T. F. THORSTEINSEN[6+], T. S. TVETER[9], F. VIDEBÆK[2], R. WADA[8], F. RAMI[7], A. WIELOCH[4], I. S. ZGURA[11]
THE BRAHMS COLLABORATION

[1] *Niels Bohr Institute,* [2] *Brookhaven National Laboratory,* [3] *New York University,* [4] *Jagiellonian University, Krakow,* [5] *Institute of Nuclear Physics, Krakow* [6] *University of Bergen,* [7] *IReS and Université Louis Pasteur, Strasbourg* [8] *Texas A&M University,* [10] *University of Kansas,* [9] *Fysisk Institutt, University of Oslo,* [11] *University of Bucharest,* [12] *John Hopkins University,* [+]*Deceased*

For relativistic heavy ion collisions the energy flow in the collision reveals information on the equation of state of matter at high density. The BRAHMS experiment has studied the relation between multiplicity in the side-wards direction and zero degree energy using our Tile Multiplicity Array and Zero Degree Calorimeters. To understand this spectrum requires a knowledge of the coalescence of nucleons that are close in phase space. We have also studied electromagnetic collisions and compared our results to lower energy data. As the center of mass energy increases, each nucleus sees a stronger electromagnetic field resulting in more energy being absorbed. This in turn causes an increase in the neutron multiplicity.

1 The Experimental Setup

The BRAHMS experiment consists of two movable spectrometers and four detector systems to measure global variables for each event,[1]. The spectrometers allow BRAHMS to measure particles yields over a very wide range of p_T and rapidity. In this paper only details of the global detectors used in the present analysis are given.

The Tile Multiplicity Array, TMA, consists of an hexagonal barrel 96cm long placed around the beryllium beam pipe. The array is made up of square tiles that are 12cm long and 0.5cm thick. For collisions at the nominal interaction point the pseudo-rapidity range is $|\eta| < 2.2$. Four tiles in front of each of the two spectrometers have been removed to minimize multiple scattering of particles heading into the spectrometers. The multiplicity is measured by counting the energy deposited in each ring and dividing by the mean energy lost per particle.

The Beam-Beam counter consists of two sparsely populated arrays of Cerenkovs (made from Ultra Violet Transmission plastic) coupled to photomutiplier tubes. They are ± 2.3m from the nominal interaction vertex and subtend the pseudo-rapidity regions $3.0 < |\eta| < 3.5$. The left array has eight 2 inch tubes and 36 3/4 inch ones arranged symmetrically around the beam pipe. In order to allow the forward spectrometer to move to small angles the right array is asymmetric. It consists of 30 small tubes and 5 large ones.

Finally two zero degree calorimeters (ZDCs) at ± 18m measure the energy of forward going neutral particles[2]. Almost all of this energy is from non interacting neutrons. They are used for finding the interaction vertex and for centrality determination. The ZDCs are also very useful to study peripheral electromagnetic interactions and provide a measure of the luminosity for the accelerator and experiment,[3].

2 Forward Energy versus Side-wards Multiplicity

One of the most import things to know about heavy ion collisions is the number of nucleons that participated in the collision, $n_{participants}$. The relationship between the number of participants and the multiplicity and central rapidity is a measure of how much energy each nucleon loses in the collision and how this energy is shared between particle production and particle motion. This is best done by measuring the forward going energy of those nucleons that do not participate using a zero degree calorimeter,[4]. Unfortunately at RHIC the beam focusing magnets sweep all charged particles away from the ZDCs and only the neutrons are measured. This complicates the extraction of the centrality of the collision from the ZDC measurement. Figure 1 shows the correlation between the forward going neutral energy and the multiplicity for $|\eta| < 2.$ as measured in the tiles. For events in the top 70% of the multiplicity distribution there is a steady decrease of neutron multiplicity with energy. While there is certainly a strong correlation between the ZDC energy and the multiplicity at mid-rapidity the distribution is wide. This is due partly to the small number of neutrons observed and to the detectors' resolution. However

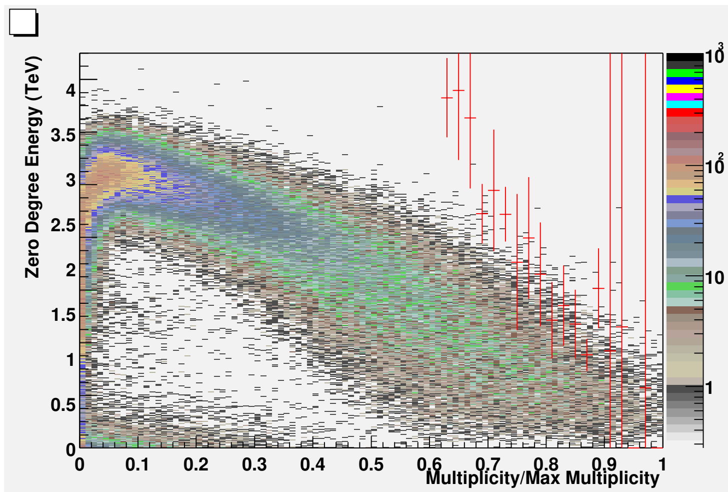

Figure 1. ZDC total energy versus multiplicity in the tile counters. The overlaid histogram represents the prediction of the AMPT [5] model.

it seems likely that intrinsic fluctuations between the number of participants and the multiplicity at mid-rapidity are also important.

The overlaid histogram represents the prediction of the AMPT [5] model. Both AMPT and HIJING[6], overestimate the number of forward going neutrons. This may be because it ignores the possibility that nucleons can coalesce into light clusters such as deuterons or tritons. Any coalescence effect would decrease the number of forward going neutrons. The JAM code includes coalescence of nucleons that are close together in phase space[7]. This does a much better job of reproducing the ZDC spectrum.

3 Electromagnetic Interactions

Peripheral interactions of heavy ions produce intense electromagnetic fields which may be used to probe the structure of the nucleus. At $\sqrt{S_{nn}} = 130GeV$ one nucleus sees the other approaching at a speed corresponding to a Lorenz factor of $\gamma = 9800$. The nucleus may absorb several photons and be excited into the giant dipole or even to multi-phonon resonances. As the nucleus equilibrates and cools it may emit several neutrons, protons and photons.

In order to study electromagnetic interactions we require no hits in either the tiles or the beam-beam counters. From HIJING[6] we estimate that we have

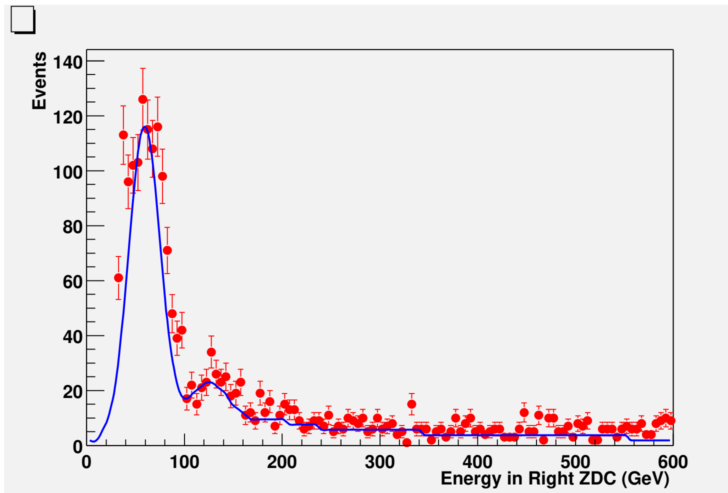

Figure 2. The Zero Degree Calorimeter spectrum for electromagnetic events. The smooth curve shows the prediction of the RELDIS model.

a 2% contamination of peripheral nuclear events in the sample. Figure 2 shows the energy spectrum in the right ZDC. The spectrum shows a strong one neutron peak, a smaller two neutron peak and then a continuum. Figure 2 also shows the energy spectrum from the RELDIS[8] model after smearing with the experimental resolution. RELDIS extends the Weizsacker-Williams method to Mutual Coloumb Dissociation. Photo-neutron cross sections measured in different experiments are used as input for the calculations of dissociation cross sections. The excited nuclei reach thermal equilibrium and then decay according to the statistical evaporation-fission-multi-fragmentation model, (the SMM model) [9]. The data and model have been normalized at the one neutron peak. The real spectrum is consistently higher than the spectrum from the model.

Since only non-interacting nucleons hit the ZDCs their energy spread is set by their Fermi motion in the nucleus. This is negligible compared to the energy resolution of the ZDC which is $\sigma_E = 14GeV$ for one $65GeV$ neutron. Therefore we can fit the spectrum to a series of Gaussians at $n \cdot 65GeV$ with width $\sqrt{n} \cdot \sigma_E$ and extract the multiplicity of 1, 2, 3 etc neutrons. Figure 3 shows the ratio of two to one neutron cross sections as a function of $\sqrt{s_{nn}}$. The probability to emit 2 neutrons rises with $\sqrt{s_{nn}}$, because more energy is absorbed and the multi-phonon resonances are more likely to be excited. Such

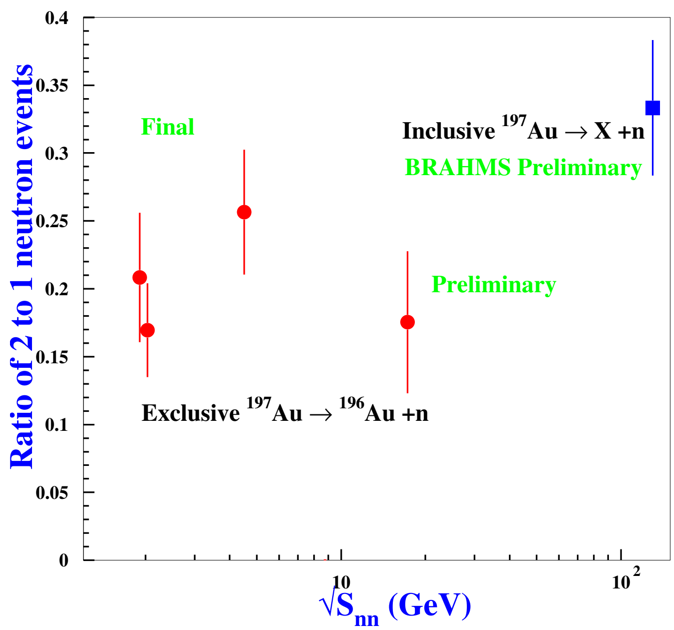

Figure 3. Ratio of two to one neutron cross sections as a function of $\sqrt{s_{nn}}$. The data below $\sqrt{s_{nn}} = 130GeV$ are from [10].

a correlation between the excitation energy of a compound nucleus and the neutron multiplicity has been observed in $CuAu$ collisions at 35A MeV,[11].

4 Conclusions

For nuclear collisions the number of neutrons emitted forward is anti-correlated to the multiplicity observed at central pseudo-rapidity. However the distribution is rather broad. In order to reproduce the number of neutrons observed it is necessary to estimate the number that are removed from the spectrum by coalescence. For electromagnetic collisions the RELDIS model gives a reasonable description of the neutron spectrum at zero degrees. In this model the electromagnetic breakup of two nuclei is mainly due to multiphoton exchange. As the beam energy increases the neutron multiplicity in electromagnetic interactions increases.

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