Chapter 1

RESULTS FROM THE E917 EXPERIMENT AT THE AGS

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Abstract  Collisions of Au+Au have been studied at beam kinetic energies of 6, 8, and 10.8 GeV/nucleon at the AGS facility at Brookhaven National Laboratory. Particles emitted from the collisions were momentum analyzed and identified in a magnetic spectrometer system. Measurements were made at spectrometer angles in the range 14° - 59°. m_t-spectra of protons from central collisions were analyzed to derive integrated rapidity distributions and inverse slope as a function of rapidity. The results are compared with a thermal model and it is concluded that there is either substantial transparency or longitudinal expansion at all three beam energies.

Keywords: AGS, Protons, Rapidity distributions, Thermal models

1. INTRODUCTION

One of the expected ways of achieving the Quark Gluon Plasma phase of hadronic matter is to increase the matter density to 5-10 times that of normal nuclear matter. It has been thought that these high densities may be achieved in central collisions of heavy nuclei at AGS energies, provided that the relative motion is stopped. The question of the degree of stopping in head-on collisions is thus of central importance at these energies. Direct information pertaining to this issue may be obtained by studying the transverse mass spectra of protons, the majority of which are primordial, over a wide rapidity range to assess whether the observed rapidity distribution is consistent with the initial momentum of the projectile being converted to isotropic emission from a source at rest in the center-of-mass system. We find that complete stopping, defined in this way, is not achieved for the central Au-Au collisions at any of the energies studied in the E917 experiment.

2. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is illustrated in Fig. 1.1. Beams of $^{197}$Au with momenta of 6.84, 8.86 and 11.69 GeV/c per nucleon corresponding to kinetic energies of 6.0, 8.0 and 10.8 GeV per nucleon were obtained from the AGS at Brookhaven National Laboratory and focused onto a Au-target of 1 mm thickness, which corresponds to ~ 3% interaction probability in the target. The trajectory of each beam particle was determined by a beam vertex detector consisting of four planes of scintillating fibers read out by position sensitive photo-multiplier tubes arranged in orthogonal pairs and located at 5.84 m and 1.72 m upstream from the target position. Further beam characterization was performed using beam-time-zero and halo counters also placed upstream from the target. Triggers for beam interactions with the target were obtained by
requiring that a signal of less than 75% of that expected for the full energy loss of a Au-beam nucleus was registered in a circular “bulls-eye” Čerenkov detector placed 11 m downstream from the target.

The centrality of each beam-target interaction was derived from the multiplicity of particles (mostly pions) registered in a multiplicity detector array subtending a solid angle of about 6.85 sr around the target and/or by the total energy of the projectile remnant measured in the zero degree calorimeter.

In order to determine the reaction plane orientation in peripheral collisions a hodoscope consisting of two orthogonal planes of 1 cm wide plastic scintillator slats was placed in front of the zero degree calorimeter. The azimuthal angle of the reaction plane determined from the average position of the charged projectile remnants in the hodoscope, relative to the beam axis will be used to study collective flow characteristics of peripheral collisions and the reaction plane dependence of the apparent source size obtained in a Hanbury-Brown Twiss analysis of pion pairs. Such an analysis is the subject of B. Holzman’s talk at this workshop [1].

Particle spectra were obtained by momentum analysis in a movable magnetic spectrometer consisting of a 0.4-Tesla magnet (Henry Higgins) and a number of multi-wire ionization chambers used to determine the straight line trajectories of particles entering and exiting the magnetic field. In addition, a plastic scintillator wall located behind the spectrometer provided particle identification by time-of-flight measurements relative to the Čerenkov start detector located in front of the target.

This arrangement is capable of identifying charged pions, kaons, protons, anti-protons and heavier nuclei. The separation of pions and kaons

\textbf{Figure 1.1} Experimental arrangement.
is effective up to an energy of $\sim 1.75$ GeV. Protons are separated from pions up to $\sim 3.4$ GeV, although there is a negligible kaon contamination above $\sim 2.9$ GeV.

The acceptance of the spectrometer is also sufficient to detect correlated decay products of $\Phi \rightarrow K^+K^-$, $\Lambda \rightarrow p\pi^-$, and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$. The analysis of $\Phi$-mesons and $\Lambda$ is the subject of W.-C. Chang’s talk at this workshop[2].

The present talk will concentrate on the proton spectra obtained at the three beam kinetic energies of 6, 8, and 10.8 GeV/nucleon, and an analysis to the resulting rapidity distributions and fitted inverse slopes obtained from the measured $m_\pi$-spectra.

Figure 1.2 Proton $m_\pi$-spectra for central (<5%) Au-Au collisions at a beam kinetic energy of 10.8 GeV/nucleon for different rapidity bins (laboratory system). Curves are Boltzmann distributions fitted to the data. Spectra for adjacent rapidity bins are offset by factors of ten to avoid overlapping.
3. RESULTS

In Fig. 1.2, spectra of the invariant probability for proton emission per trigger event are plotted for the 10.8 GeV/nucleon beam energy as a function of the transverse mass $m_t - m_0$ for the 5% most central collisions as determined from the energy deposition in the zero-degree calorimeter. The spectra are shown for different rapidity bins as indicated. Only statistical error bars are shown. Note that adjacent spectra are offset by factors of ten to avoid overlapping. The range in $m_t$ reflects the acceptance of the spectrometer in the different rapidity bins ranging from backwards to near mid-rapidity at $y_{pp} = 1.613$. The curves represent the best fits to the spectra using a Boltzmann distribution, i.e.

$$
\frac{1}{2\pi m_t} \frac{d^2N}{dy dm_t} = C m_t \exp(-m_t/T),
$$

(1.1)

where $C$ is a normalization constant and $T$ is the inverse slope of the spectrum, both of which are determined from the fit to the data. We observe that the experimental $m_t$-spectra are in excellent agreement with this shape although they could also be described almost equally well by a pure exponential function.

From these fits we derive the total probability for proton emission per unit of rapidity, $dN/dy$, which is plotted as a function of rapidity in the center-of-mass frame, $y - y_{cm}$, in the left panels of Fig. 1.3. The derived inverse slopes $T$ are shown in the right hand panels. Data are shown for 5% central collisions at all three beam energies, where the centrality for the 6 and 8 GeV/nucleon data are obtained from the the multiplicity array at the target position. The measured points are represented by solid circles, whereas reflection around mid-rapidity results in the open points. Error bars on the fit parameters are purely statistical and do not include possible systematic errors.

We note that all three $dN/dy$ distributions are quite flat over the measured rapidity range. The inverse slopes, $T$, show, however, a distinct peaking at mid-rapidity. The solid curves in Fig. 1.3 represent the expectation for isotropic emission from a thermal source with temperature, $T_0$, at rest in the center-of-mass system. For such a source one expects that the $y$-dependence of the inverse slope is:

$$
T = T_0 / \cosh y
$$

(1.2)

and a $dN/dy$ distribution of [3]

$$
\frac{dN}{dy} \propto T_0 \left( m_0^2 + 2m_0 \frac{T_0}{\cosh y} + 2 \frac{T_0^2}{\cosh^2 y} \right) \exp(-m_0 \cosh y/T_0),
$$

(1.3)
where $m_0$ is the proton rest mass. In the right hand panels of Fig. 1.3 we compare the rapidity dependence of the inverse slope, $T$, with those predicted by this model. The source temperature, $T_0$, was adjusted to account for the observed inverse slope at mid-rapidity. We note that this naive model gives a rather good representation of the observed inverse slopes.

On the other hand, a comparison of the predicted distribution in rapidity $dN/dy$ with the measurements (left hand panels in Fig. 1.3) reveals a discrepancy which clearly demonstrates that the observed proton spectra are inconsistent with isotropic emission from a single source at rest in the center-of-mass system. Rather, we note that the rapidity distributions for protons are flat over a wide range of rapidities indicating a significant degree of either incomplete stopping or longitudinal expansion at all three beam energies.
Of course, the naive model shown here also disregards the possible effects of radial expansion in the fireball. It has been shown\cite{3}, however, that, within a wide range of parameters, there is a strong anti-correlation between the radial expansion velocity, \( v_0 \), and the source temperature, \( T_{\text{source}} \), such that it is impossible to disentangle their relative values from fits to spectra of a single particle species e.g. protons. In the present analysis we have therefore chosen to use only a single parameter, namely the \textit{apparent} source temperature, \( T_0 \), keeping in mind that its value does not necessarily represent the true temperature of the source formed in a central Au-Au collision.

Figure 1.4  Proton rapidity distributions (top) and inverse slopes (bottom) for Au-Au collisions at 10.8 GeV/nucleon beam kinetic energy compared with previously published results from the E866 and E877 experiments at the AGS. The arrows indicate target and beam rapidities.

In Fig. 1.4 we compare the \( dN/dy \) (top panel) and inverse slopes \( T \) (bottom panel) from our experiment to results from the E866 \cite{4} and E877\cite{5} experiments at the AGS. At mid-rapidity there is good agreement between the present data for the \( dN/dy \) distribution and that from
the E866 experiment, but a relatively small discrepancy between the two data sets is apparent at less central rapidities. The source of this discrepancy is presently being investigated. The E877 data were measured in the extreme forward rapidity region but overlap with the present (reflected) data in the rapidity region $y - y_{cm} = 0.8 - 1.1$. Here, there appear to be substantial discrepancies between the data sets. The general trend of the three data sets is, however, clear. There is a wide range $-0.7 < y - y_{cm} < 0.7$ around mid-rapidity, where the $dn/dy$ distribution is essentially flat, followed by a monotonic decrease on either side. We note that this observed range of essentially constant $dN/dy$ is inconsistent with thermal emission from a stopped source (solid curve), as well as early predictions of the Relativistic Quantum Molecular Dynamics model [6] (RQMD v1.08, [5]) (solid histogram), both of which are too sharply peaked at mid-rapidity.

The slopes, however, appear to be in reasonable agreement with the $1/\cosh y$ dependence expected from the thermal model (solid curve) although this may be fortuitous since the rapidity distribution clearly show that there is either a significant amount of transparency or longitudinal expansion at these energies which violates the assumption of a thermal source at rest in the center-of-mass system.

4. CONCLUSION

An analysis of $m_t$-spectra for protons emitted in central Au-Au collisions at beam kinetic energies of 6, 8 and 10.8 GeV/nucleon in terms of Boltzmann distributions has been carried out, and the resulting $dN/dy$ distributions and inverse slopes derived. They are compared to a simple thermal model assuming isotropic emission from a source at rest in the center-of-mass system corresponding to complete stopping of the colliding Au nuclei in central collisions. We find that the rapidity distributions $dN/dy$ are substantially wider and essentially constant around mid-rapidity although the inverse slopes exhibit the expected $1/\cosh y$ dependence on rapidity. We interpret this as a manifestation of incomplete stopping or longitudinal expansion of the entrance channel momenta at all three beam energies.

Acknowledgments

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