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Heavy Ion Reaction Measurements with the EOS TPC (Looking for Central Collisions with Missing Energy)

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Heavy Ion Reaction Measurements with the EOS TPC
(Looking for Central Collisions with Missing Energy)

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ABSTRACT

The EOS TPC was constructed for complete event measurements of heavy ion collisions at the Bevalac. We report here on the TPC design and some preliminary measurements of conserved event quantities such as total invariant mass, total momentum, total A and Z.

1. Introduction

The EOS TPC does a very complete measurement of relativistic heavy ion reactions. Nearly all of the charged particles in a central collision are identified and their momenta are accurately measured. This provides a new, unique way to study heavy reactions. By measuring the total invariant mass of all the charged particles in an event, we can search for events with missing energy to look for exotic phenomena. Clearly, the chances of discovering interesting physics are remote, but, in any case, the measurement of conserved quantities, such as invariant mass and total event momentum, provide an excellent check of detector performance. If exotic events should appear, the highly redundant nature of TPC measurements allows easy rejection of false signals.

2. Experimental Setup

The arrangement of the detectors in the EOS experiment is shown in Figure 1. The central detector is the EOS TPC, followed by MUSIC, a multisampling ionization detector for detecting fragments with Z>6, and a time of flight wall (TOF). There is also a neutron detector called "muffins". This report will, however, be limited to the TPC portion of the experiment. The target is located just inside of the HISS dipole magnet, 10-20 cm upstream from the TPC. The TPC provides true 3D tracking in the magnetic field for most of the particles exiting the downstream side of the target. The active tracking region in the TPC is a rectangular box 1.5 m long in the beam direction and ~1 m in the directions perpendicular to the beam. The beam passes directly through the center of the TPC volume. This arrangement provides excellent coverage for scattered particles in the forward half of the lab frame. The tracking in the magnetic field of 13 kG measures particle rigidity and the multisampling of dE/dx along the track provides particle ID.

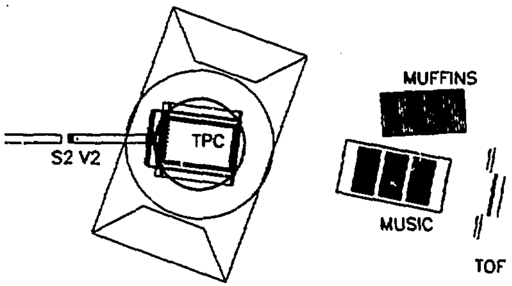

Fig. 1: Detector setup for EOS experiment. The beam enters from the left and the target is located at the entrance to the TPC.

The TPC is constructed with a rectangular field cage sitting over a multiwire proportional chamber (MWPC)-pad plane structure. Electron tracks left by the charged particles passing through the TPC gas of Ar 90% + CH_4 10% drift down to the pad plane where they are amplified by the MWPC and recorded as a function of time. The MWPC pad plane provides a full 2D readout and the drift time provides the third dimension. The MWPC pad plane system is composed of 20 μm anode wires on a 4 mm pitch located 4 mm above a continuous rectangular array of 8 mm by 12 mm pads. The electrons create avalanches as they drift to the anode wires. The positive ions created in the avalanche induce signals in the pads as they drift from the anode region. The induced signal is spread over 2 to 3 pads allowing accurate (600 μm) position determination through centroid reconstruction. The TPC volume is divided up into a 2.5 million pixel volume (15360 pads X 160 time buckets). The high pixel density is necessary to isolate and record the 200 tracks that can result from heavy ion collisions at Bevalac energies.

There are additional wires in the MWPC for field shaping and there is a gating grid that only passes tracks for amplification from triggered events. This gate also prevents avalanche-generated positive ions from entering the drift volume where their space charge field can distort the drift path of the electrons left by the particles of interest. This gate is essential in our configuration where heavy ion beams pass through the drift volume and leave ionization densities up to 6000 times minimum ionizing tracks. If left ungated, the beam load would quickly lead to wire aging and possible sparking and glow discharge. Using the gate we routinely operate the TPC with Au beams in excess of 1000 beam particles per spill with no observable degradation in performance. A summary of the TPC characteristics are listed in Table 1.

HISS TPC Characteristics	
Pad Plane Area	1.5m × 1.0m
Number of Pads	15360 (120 × 128)
Pad Size	12mm × 8mm
Drift Distance	75 cm
Time Sampling Freq.	10 MHz
Signal Shaping Time	250 ns
Electronic Noise	700 e
Gas Gain	3000
Gas Composition	$90\% Ar + 10\% CH_4$
Pressure	1 Atmosphere
B Field	13 kG
E Field	120 V/cm
Drift Velocity	5cm/μ s
Event Rate	10-80 events/ 1 sec spill
dE/dx range	Z = 1-8, $\Lambda, \pi, p, d, t, He, Li - O$
Two Track Resolution	2.5cm
Multiplicity Limit	≈ 200

Table 1: TPC detector specifications.

Special electronics were developed for the TPC to read out the 15360 pads. The electronics design was driven by the need for low noise (700 e rms), high dynamic range, high density and low cost. The first amplifier stage had to be located on the chamber to reduce the noise (low noise is required for position resolution). Since space is at a premium in the magnetic field volume, it was decided to design a highly multiplexed system with local, on-chamber, digitization to avoid potentially impossible cabling problems. The first element of the electronics chain is a 4 channel, integrated CMOS preamp circuit developed at LBL for this project by Michael Wright. This is followed by a shaper amplifier built with surface mount technology. The shaper signal is time sampled with a custom integrated analog storage circuit, also developed at LBL for this project. This circuit, a switched capacitor analog transient waveform recorder (SCA), was developed by Stuart Kleinfelder. The SCA has 16 channels with 256 sampling capacitors per channel. The signals are written into the SCA at 10 MHz and they are readout and digitized at a lower rate with a commercial 12 bit ADC chip. The number of time buckets is selectable, and most of our data was recorded with 160 time buckets. One ADC reads out the up to 256 time samples for 60 channels and the digital output from two ADC's is transmitted off the chamber over an optical fiber serial data link. There are a total of 128 boards with one fiber each on the chamber. A time of 10 ms is required to digitize and transfer the data off the chamber. The data is passed to a receiver card where pedestal subtraction, gain factor multiplication and zero suppression take place. Pedestal subtraction is done with a separate pedestal value for each time bucket to remove transient background effects that arise from opening the gating grid and from clock signal pickup. During the time that data is recorded into the SCA, the electronics operation is fully synchronous to maintain event independent pedestals. The zero suppressed and gain corrected data from the receiver card is collected by the event builder and written to Exabyte tape.

The TPC is also equipped with a Nd-Yag laser system that generates 17 straight ionized tracks in the tracking volume for checking the distortion corrections. This distortion correction is applied to correct for the non-uniform B field. The Nd-Yag laser is frequency quadrupled to produce 5 ns wide pulses of 266 nm UV light. The UV pulses produce tracks through 2 photon-ionization of contaminants in the drift gas.

The MWPC is constructed with tight mechanical tolerances and operated at low gas gain to provide good energy resolution for dE/dx. Particle identification is obtained from the truncated mean of multiple energy loss samples along the ionization track. Under ideal conditions with low multiplicity, the full track length through the TPC (160 cm) is available with 128 samples for the truncated mean determination. In practice, the available track length is somewhat less due to track overlap in the high track density region near the target. A measured dE/dx spectrum is shown as a function of rigidity for high multiplicity events of 0.8 GeV Au on Au in Figure 2.

Good isotopic identification is achieved for charge 1 and 2 baryons and the pions are clearly identified. At higher momentum the isotopes merge and require the time of flight wall for proper identification. Charge is identified in the TPC for the heavier elements from Li through O, but without isotopic identification.

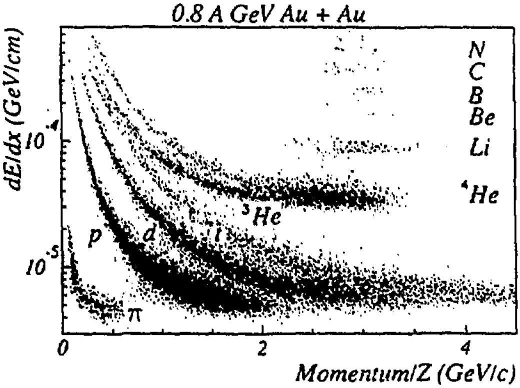

Fig. 2: Measured dE/dx truncated mean with the EOS TPC as a function of particle rigidity

3. Measurements With the TPC

A summary of the large number of beam target systems measured at the Bevalac by the EOS collaboration is shown in Figure 3. This lego plot shows the number of events recorded for each system. The preliminary measurements to be shown here are for only two systems, 800 MeV*A La + La and 1000 MeV*A Au + C. We have constructed several conserved quantities for the events from the TPC measurements. The total invariant mass minus the rest mass, the total momentum, the total charge and the total mass were determined for the baryons detected in the TPC. For the most central collisions, there are few heavy ion remnants with Z>8. Almost all of the charged baryon matter appears as either hydrogen or helium isotopes so we expect the TPC to lose very little when constructing these totals for the event. The free neutrons should account for the only significant loss in the total momentum, total invariant mass and total mass. The pions can and will be included in future analyses.

In the first example we measured the total invariant mass minus the rest mass ($M_{inv} - M_0$) for 800 MeV*A La + La. This quantity is simply the total kinetic energy in the center of mass reference frame, but it can be calculated without transforming to the center of mass frame. We can compare this with the total available invariant mass less rest mass calculated with just the beam nucleus and the target nucleus:

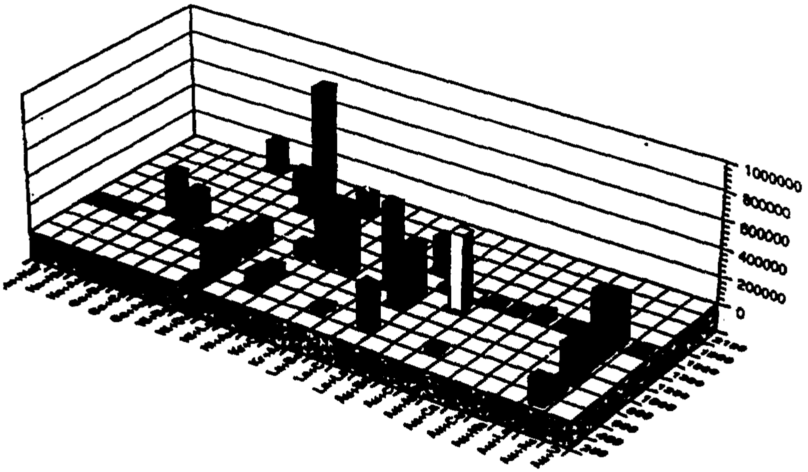

Fig. 3: Summary of beam-target systems measured with EOS at the Bevalac.

$\sqrt{(E_{beam} + E_{target})^2 - P_{beam}^2} - M_{0beam} - M_{0target}$. At the highest multiplicity the measured $(M_{inv} - M_0)$ accounts for 37% of the total available for the 800 MeV*A La + La system. The missing 63% is carried by the undetected particles and the energy required to break up the projectile and target. We have also looked at $(M_{inv} - M_0)/A_{measured}$. We can compare this directly with the total available kinetic energy in the CM frame divided by the mass of the target and the projectile. This will normalize out the effect of the undetected neutrons if the neutrons carry the same energy per nucleon as the rest of the baryons. One could expect this if the expansion is totally hydrodynamic. If it is strictly thermal expansion, then the lighter neutrons will carry more energy per nucleon than the heavier isotopes and the measured ratio will be lower than the total ratio calculated from the beam energy and mass and target mass. At the highest multiplicity, $(M_{inv} - M_0)/A_{measured}$ is 68% of the total expected value (0.18 GeV/A). This measurement is low for the system chosen because the geometric acceptance of the TPC misses some of the target rapidity nucleons. This is clear when viewing pperp vs rapidity plots.

To correct for the missing target rapidity particles, we have done the same analysis using only the data in the forward half of the CM frame by reflecting all detected particles in the forward half to the back half before computing $(M_{inv} - M_0)/A_{measured}$ for the event. This result is shown in Figure 4. The measured ratio in this case is now 89% of the total available for a symmetric target - beam system with a beam energy of 800 MeV*Abeam. This now leaves only 20 MeV/nucleon missing. Part of this missing energy goes into breaking up the nucleus. Total disintegration of the La nuclei into free protons and neutrons is 8.5 MeV/nucleon. This is an upper limit since there are many deuterons, tritons and helium isotopes. In a future, more careful analysis, we can calculate this quantity directly because we have complete particle ID for Z=1 and 2. However, using the number of 8.5 MeV/nucleon, this leaves 11.5 MeV/nucleon unaccounted for, or a total of 3.2 GeV, enough for 23 pions. In order to pursue this analysis more thoroughly, we must now include the pions and small affects such as energy loss in the target to get a more precise accounting of the total available kinetic energy in the CM. It is clear at this point that the detector is coming close to a complete measurement in the forward half of the CM frame and that, in a complete analysis, we will have a sensitive indicator for special events with missing energy. It should also be possible to compare $(M_{inv} - M_0)/A_{measured}$ for different mass fragments to distinguish between thermal expansion and collective expansion just has been done previously [1] with single particle kinetic energy spectra.

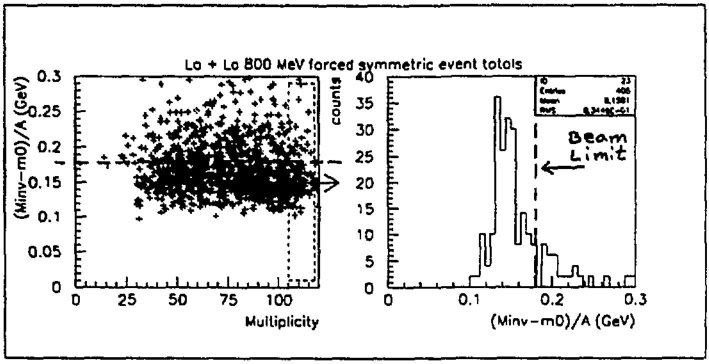

Fig. 4: The quantity $(M_{inv} - M_0)/A_{measured}$ as a function of the event multiplicity. Only the particles in the forward half of the CM frame have been used and reflected into the back half to create a full event. The right hand frame shows a histogram of the highest multiplicity portion of the scatter plot projected onto the $(M_{inv} - M_0)/A_{measured}$ axis.

We have also looked at several other conserved event quantities. As an example, we show (see Figure 5) $p_{lab}/A_{measured}$ as a function of multiplicity for the 800 MeV*A La + La system. At the highest multiplicity $p_{lab}/A_{measured}$ is 107% of the beam $p_{labbeam}/(A_{beam} + A_{target})$. This a little high due to missing target rapidity particles. But this agreement to within 7% is close and, as a consistency check, shows that the TPC is correctly measuring Z , A and momentum.

We also studied another system, 1000 MeV*A Au + C. In this case the CM velocity

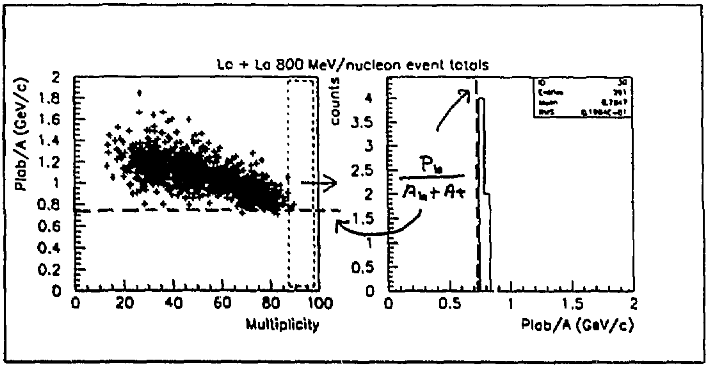

Fig. 5: The measured quantity, $p_{lab}/A_{measured}$ is shown as a function of multiplicity. The limiting value, $p_{labbeam}/(A_{beam} + A_{target})$, that would be seen if all the particles were detected is shown for comparison.

is larger so that the TPC has better geometric acceptance, but isotope resolution is not as good for the highest momentum particles. Figure 6 shows $(M_{inv} - M_0)/A_{measured}$ for the Au + C measurement. This measurement of $(M_{inv} - M_0)/A_{measured}$ is 138% of the initial value defined by the beam and target. The high value of 138% may be due to isotope mis-identification. Including the TOF wall in the analysis will improve the isotope identification at high momentum and possibly resolve this problem. A summary of the various measurements, selected on high multiplicity, are given in Table 2 as a fraction of the totals available in the reaction. The quantity, n, gives the fraction of the total neutrons bound in the measured fragments.

	La + La 800 MeV/A	La + La 800 MeV/A (forward half)	Au + C 1000 MeV/A
	% detected	% detected	% detected
M_{inv} -m_0	37	62	82
plab	59	73	60
A	55	73	65
Z	85	109	87
n	36	48	50
(M_{inv} -m_0)/A	68	89	128
plab/A	107	98	91

Table 2: Summary of total event quantity measurements for the most central, highest multiplicity events. The "forward half" column shows results for events constructed from forward half particles in the CM plus their reflection to the back half. The quantity "n" is the number of bound neutrons in the detected isotopes.

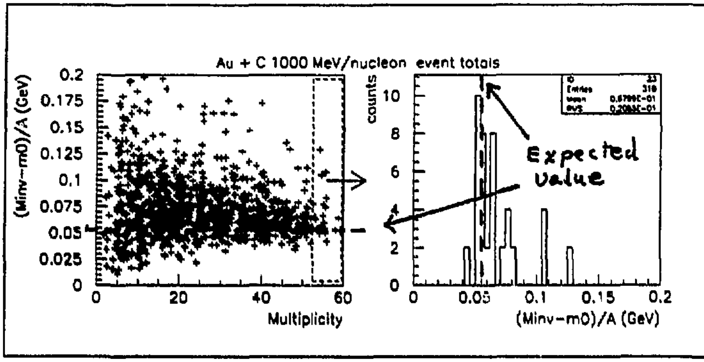

Fig. 6: The quantity, $(M_{inv} - M_0)/A_{measured}$, is shown as a function of multiplicity for the 1000 MeV*A Au + C system. The expected value, if all the energy is accounted for, is shown for comparison.

4. Conclusion

Measurements of total event quantities such as $(M_{inv}-M_0)/A_{measured}$ and $p_{lab}/A_{measured}$ show that the TPC provides very good coverage and could be useful for searching for exotic missing energy events. The $(M_{inv} - M_0)/A_{measured}$ analysis for different isotopes may be an interesting tool for studying the collective versus thermal expansion issue.

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