STAR TPC Tracking Capability in High Multiplicity Events

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ABSTRACT

The performance of the STAR TPC has been studied in events of unusually high charged multiplicity, corresponding to $\times 1, \times 2$ and $\times 4$ pseudorapidity density, central ($b < 1fm$), HIJING events. The capability of tracking in this environment has been determined by using the track following method TPT, and is expressed in terms of both tracking efficiency and reconstructed momentum resolution.

Introduction

Considerable uncertainty prevails in the estimates of the charge particle multiplicity that will be encountered in central Au+Au collisions at RHIC. The question arises whether the models that are currently used to explain particle yields at AGS and CERN energies ($\sqrt{s} = 20GeV$) can be extrapolated to RHIC ($\sqrt{s} = 200GeV$). New models for this high energy regime, such as the Parton Cascade approach of Klaus Geiger [1], predict an enhancement of particle production at central rapidity. This enhancement leads to a per nucleon rapidity density of $dN^{AA}/d\eta \sim 2.4 \times dN^{pp}/d\eta$, including those effects such as nuclear shadowing; parton fusion and absoption; the Landau-Pomeranchuk effect and soft gluon interference which actually decrease the central rapidity yield. This corresponds roughly to a central pseudorapidity density of $dN/d\eta = 1000$–4000 primary charged tracks, over the range where all or none of the above effects are included in the calculation.

Analysis

The main issue as it pertains to STAR, is whether the TPC is able to cope with charge particle densities that exceed $dN/d\eta = 1000$ charged tracks. In this study, events up to approximately $dN/d\eta = 4000$ have been generated by overlapping multiple central HIJING events [1]. These events have been filtered by the STAR GEANT program and the TPC Fast Simulator, TFS, with full accounting for secondary interactions and particle decays. Both gas options (P-10 and He-Ethane(50:50)) have been considered. TFS merges close GEANT hits on the basis of a parameterization of the spatial charge distribution along the padrow and in the time direction [2]. The simulation accounts for the smaller longitudinal diffusion expected with the He-Ethane gas mixture and the effect of doubling the number of time samples from 512 to 1024 for the slower gas.

Single events, corresponding to $\times 1, \times 2$ and $\times 4$ pseudorapidity density HIJING central Au+Au, have been tracked using the TPT track following algorithm [3]. Evaluation of the reconstructed tracks was undertaken using

[1] In the simulation no distinction was made between primary and secondary tracks. This number therefore includes charged secondaries produced by decay or interaction in material before the TPC.

the TTE package. Currently, only particles leaving 5 or more space points can form a reconstructed track. Hence the reconstruction efficiency has been defined using variables from the *tp_mctrk* table as,

$$efficiency = \frac{ntfs > 4\,.and.\,vid = 1\,.and.\,nseg = 1}{ntfs > 4\,.and.\,vid = 1} \quad (1)$$

which requires that there be at least 5 space points available to a track, that the track be primary (or secondary $vid > 1$) and that a given Monte-Carlo track is a dominant contributor to one and only one reconstructed track segment. This last requirement prevents would-be double-counting in the case that a given track is fragmented (forms two or more track segments) in reconstruction. The efficiency thus calculated is a lower limit, bearing in mind that no attempt is yet made to join tracks fragmented in the process of reconstruction.

Results

The results are grouped into two parts. Those pertaining to hit merging as a function of TPC pad row [2] and those pertaining to track reconstruction efficiency, for the $\times 1$, $\times 2$ and $\times 4$ density events.

Hit Merging

The effect of lost information due to hit merging as the track density in the TPC increases, is best seen by comparing the number of GEANT track-row crossings with the number of resolved hits determined by TFS. This is shown in Figure 1-2, as a function of the TPC pad row number, for the two gas options. The solid histogram is the number of GEANT track-row crossings; the dashed histogram is the number of reconstructed space points (from both

[2] In this context hit is synonymous with space point since the precise shape of the cluster charge distribution is not known. Conventionally, each pad-time bin above threshold constitutes a hit, but here we do not deal with elemental pixels. Rather, two close tracks are deemed to be unresolved when the GEANT track-row crossings are separated by less than the sum of the two cluster widths (sigma of the pad response function) plus a pad width. In the time direction it is the width (sigma of the time response), plus two time bins. Thus a merged hit is meant to represent an unresolved charge cluster resulting from two or more charged tracks.

unmerged and merged clusters of charge) and the dotted histogram is the distribution of surviving merged hits [3]. The number of unmerged hits is the difference between the dashed and dotted histograms. This is shown in Figure 3-4 as a fraction of the original GEANT track-row crossings. From the profile of unmerged hits it was decided to ignore the inner sector completely in the tracking procedure for the $\times 4$ event. This was a somewhat arbitrary decision, and in fact Figure 4 shows that hit resolution improves on the outer part of the inner sector (as expected due to the smaller pad size). An alternative choice would have been to track through all rows whose efficiency is greater than that of the first row of the outer sector (row 14). In practice therefore, it might be possible to track to row 7 without further degradation of the reconstruction efficiency, but with some marginal improvement in momentum resolution.

Track Reconstruction Efficiency

In Figures 5-7, tracking efficiency is summarized for primary tracks in the TPC utilizing a P-10 gas mixture for each of the $\times 1, \times 2$ and $\times 4$ events. Figures 8-9 show the same information for the He-Ethane gas mixture. Each figure consists of 4 separate plots which together provide all the information used to characterize the quality of track reconstruction.

a) Accepted and reconstructed track length. The solid histogram is the number of available unmerged hits per track, the dashed histogram is the number of reconstructed hits per track.

b) Ratio of reconstructed to generated tracks (efficiency) as a function of the transverse momentum, p_T, of the *generated* track.

c) The difference between the reconstructed and generated transverse momentum, divided by the *generated* transverse momentum (momentum resolution).

[3] Merged hits whose response is greater than 10 pads $\times$ 20 time bins have been rejected as they are deemed too large to be deconvolved. Merged clusters smaller than this cut-off survive to the output. The centroid of the merged clusters is the geometric center charge distribution, albeit smeared by the pad (time) resolution $\sim$ 700 μm. No weight is given to tracks which contribute more energy deposition, dE/dx to a given cluster.

d) Ratio of reconstructed to generated tracks (efficiency) as a function of the pseudorapidity of the *generated* track.

A summary of the results of this study have been collected in Tables 1-4. Some work was also done to look at the efficiency of track reconstruction for secondaries. This may be expected to be different from that for primary tracks due to the fact that in particular the momentum distribution and track length distribution differ. The reconstruction efficiency for secondaries was indeed found to be somewhat lower than for primary tracks by perhaps as much as 10%. These results are not shown here, but the reader may refer to the Minutes of the STAR collaboration meeting held in January–February 1994 [4]. A higher statistics study should be performed to confirm this result.

Conclusions

It has been shown that as the track density increases the number of available unmerged hits decreases significantly. However, the distribution in the number of hits on reconstructed tracks follows this distribution quite closely. It would appear that only the unmerged hits (close to the true track trajectory) ultimately reside on reconstructed tracks. This is not unreasonable, since merged hits will in general appear shifted from the track in the direction toward a neighboring track. Such hits often do not lie on either track (in the case of two-track merged clusters).

At this point some knowledge of the process of hit rejection in pattern recognition is useful, in order to understand where most time is spent during track reconstruction. In the task of fitting each track segment to a helix outliers are removed. This is undertaken on the outcome of a χ^2 probability cut, whereby if the cut is exceeded the largest contributor to the χ^2 will be removed and the track refitted [4]. This is an iterative procedure which stops only when the probability becomes higher than the cut value, or when the maximum number of iterations is exceeded. In the latter case the track is discarded completely. This accounted for a great loss in efficiency when $\times 2$ and $\times 4$ events were first considered. In this case a large number of merged hits had become assigned to tracks. When the tracks were fitted, the merged

[4]The helix fit is factorized into a separate circle fit and straight line fit. There is a χ^2 probability cut for each fit.

	×1	×2	×4
P-10	87	82	74
He-Ethane	91	84	81

Table 1: Track reconstruction efficiency [%] (equation 1) for primary tracks weighted by the transverse momentum distribution in the range $p_T > 200MeV/c, \mid \eta \mid < 1$.

	×1	×2	×4
P-10	1.5	1.6	4.0
He-Ethane	1.0	1.0	3.4

Table 2: Sigma of the momentum resolution [%] for primary tracks . Note that the gaussian shape of the distribution is only approximate, so these numbers are just a figure of merit for comparison. In detail, the momentum resolution is itself a function of momentum and so should ideally be calculated in small bins of momentum.

	×1	×2	×4
P-10	189	845	677
He-Ethane	151	672	603

Table 3: SGI cpu-time [seconds] for track reconstruction. Note (see text) that most of the cpu time goes toward outlier removal in the high track density events. (See also Table 4.)

	×1	×2	×4
P-10	82	228	-
He-Ethane	-	-	-

Table 4: SGI cpu-time [seconds] for track reconstruction with *no* oultier removal.

hits were rejected as outliers - and rightly so. However, where there were more merged hits on a track than allowed iterations for outlier removal then the whole track was lost. To safeguard against this problem, the maximum number of iterations was increased to 20. The price paid was a significant increase in the CPU time required to reconstruct the event (see Table 3–4). An improved mechanism for outlier removal is therefore highly desirable.

On the basis of the tabulated results shown it might be argued that the benefits of the He-Ethane gas mixture do not outweigh the cost of the implementing its use in practice. However, some attention should be given to the assumptions employed in TFS, especially those dealing with hit merging. A slow simulation which carefully accounts for the charge cluster distribution is required to confirm the parametrization used here. Furthermore, it could also be argued that even a slight improvement in track quality may yield significant improvements in the speed of track reconstruction. The point here being that better data quality in general requires less sophisticated methods of reconstruction. Savings in execution time are clearly important when processing large volumes of data.

References

[1] K. Geiger, *Phys. Rev. D.* **47** 133 (1993).

[2] P.G. Jones and G. Rai, *STAR note* # 33 (1992).

[3] I.M. Sakrejda, *STAR note* # xx (1993).

[4] P.G. Jones, *Minutes of the STAR collaboration meeting*, January 29 – February 4, 1994.

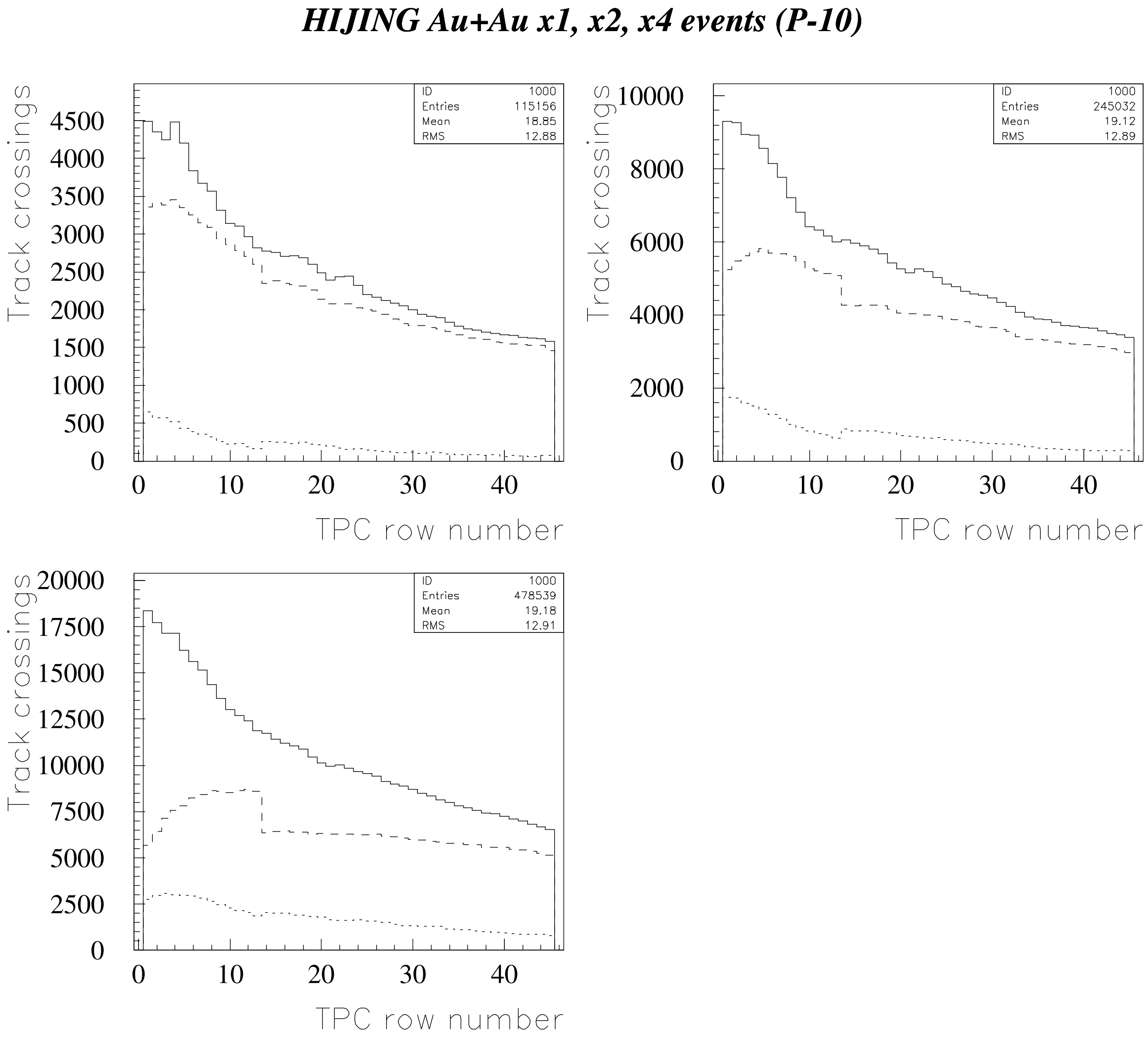

Figure 1: The number of GEANT track-row crossings as a function of the TPC row number (solid histogram), the number of surviving TFS hits including merged hits (dashed) and the number of merged hits (dotted), for $\times 1$, $\times 2$ and $\times 4$ pseudorapidity density events and a P-10 gas mixture.

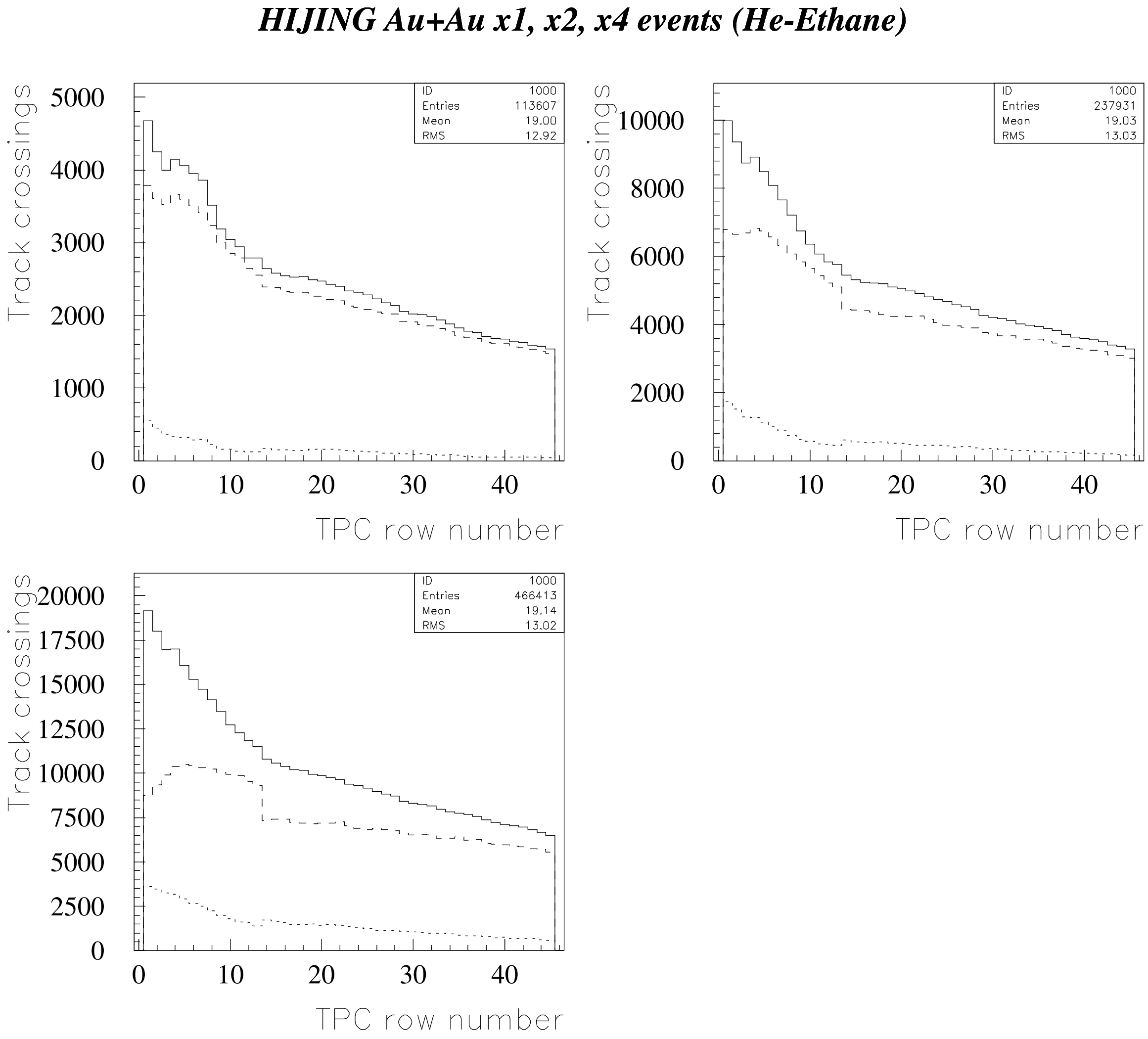

Figure 2: The number of GEANT track-row crossings as a function of the TPC row number (solid histogram), the number of surviving TFS hits including merged hits (dashed) and the number of merged hits (dotted), for $\times 1$, $\times 2$ and $\times 4$ pseudorapidity density events and a He-Ethane (50:50) gas mixture.

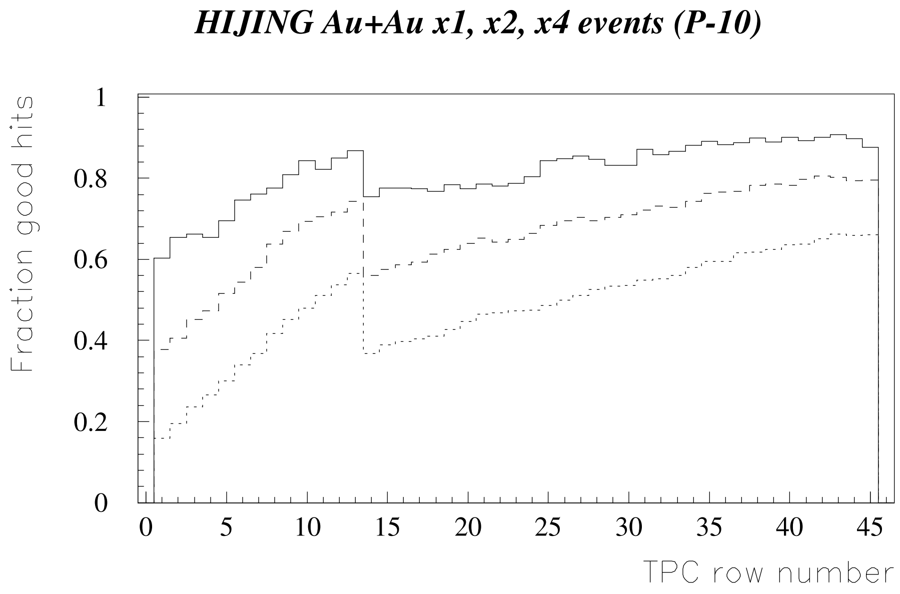

Figure 3: The fraction of unmerged hits as a function of the TPC row number, for $\times 1$ (solid), $\times 2$ (dashed) and $\times 4$ (dotted) pseudorapidity density events and a P-10 gas mixture.

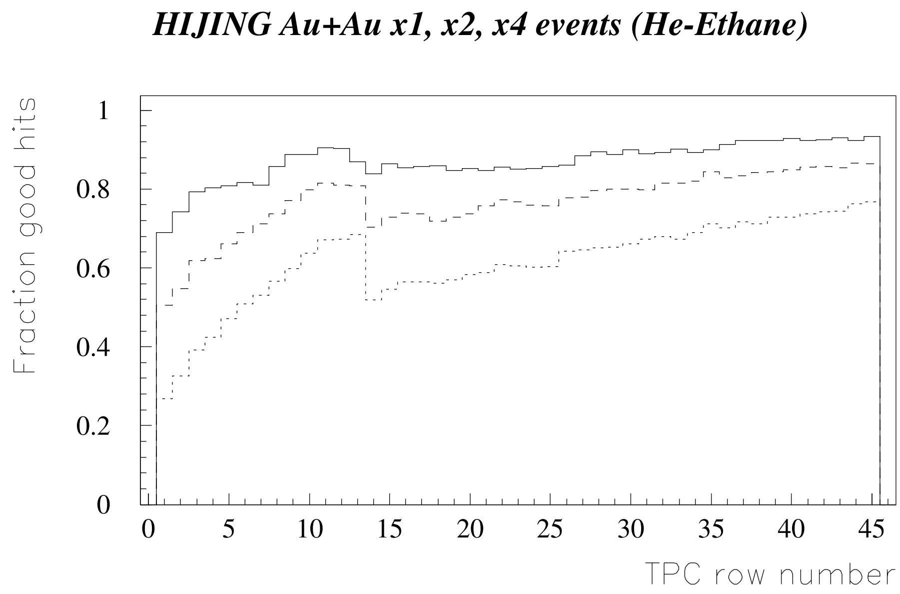

Figure 4: The fraction of unmerged hits as a function of the TPC row number, for $\times 1$ (solid), $\times 2$ (dashed) and $\times 4$ (dotted) pseudorapidity density events and a He-Ethane(50:50) gas mixture.

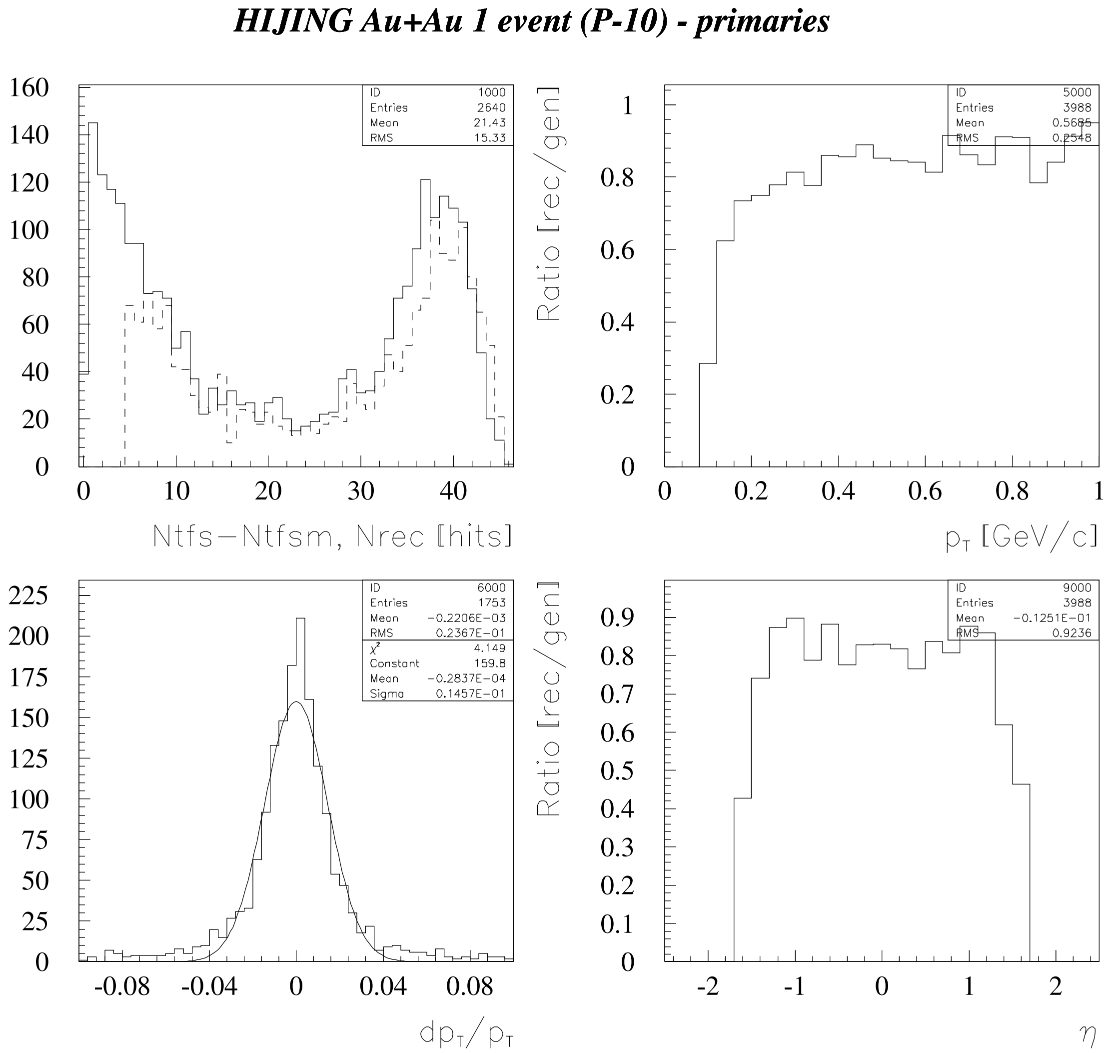

Figure 5: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 1$ pseudorapidity density event and a P-10 gas mixture.

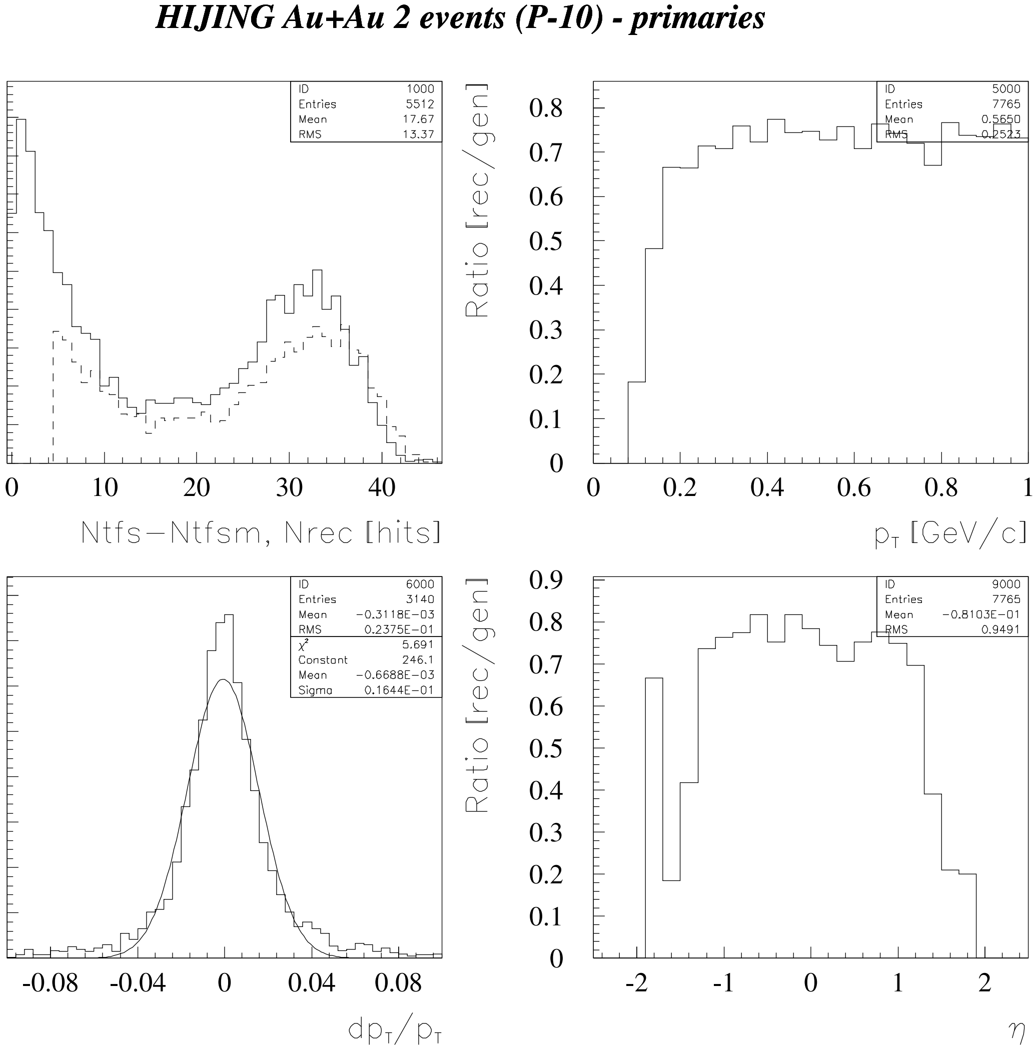

Figure 6: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 2$ pseudorapidity density event and a P-10 gas mixture.

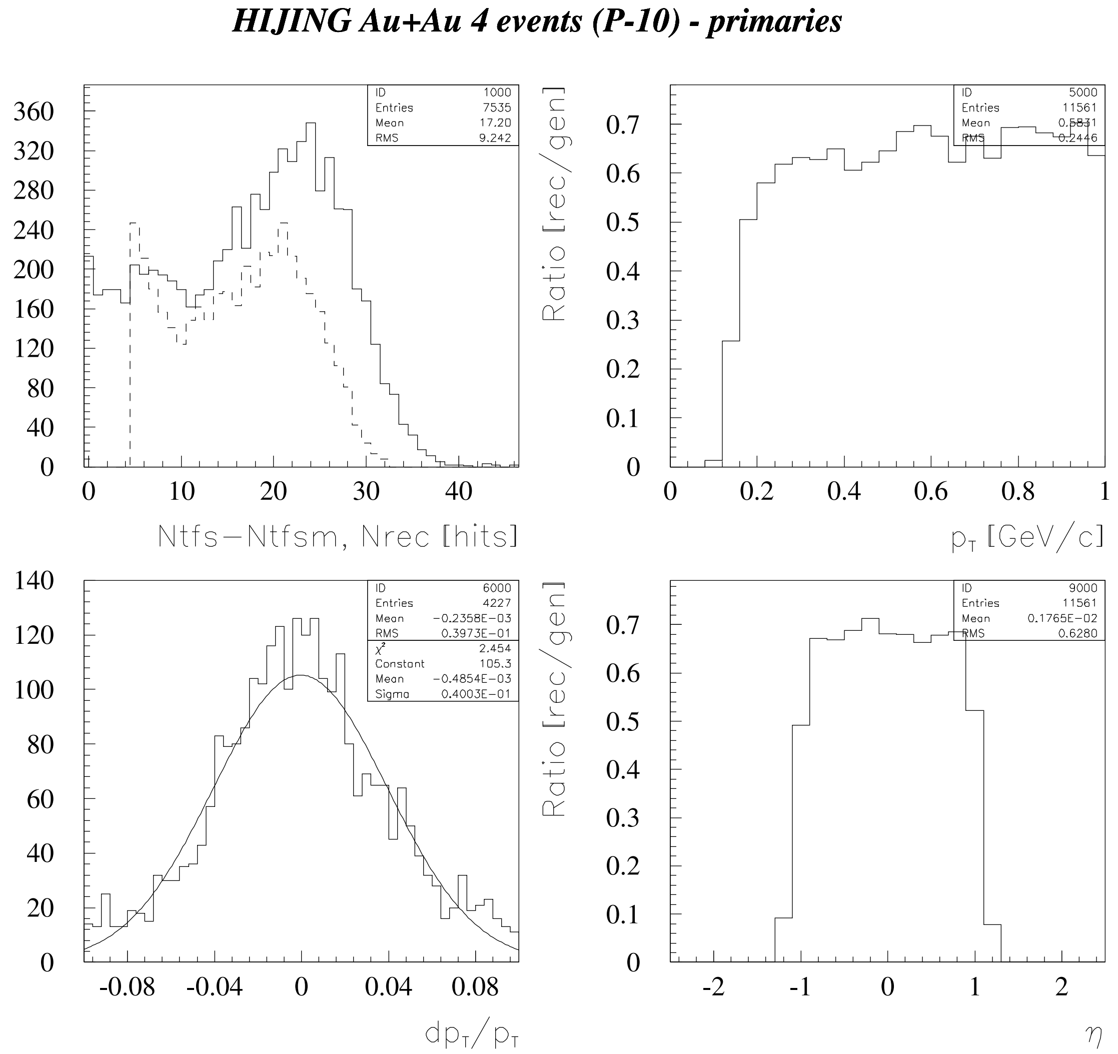

Figure 7: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 4$ pseudorapidity density event and a P-10 gas mixture.

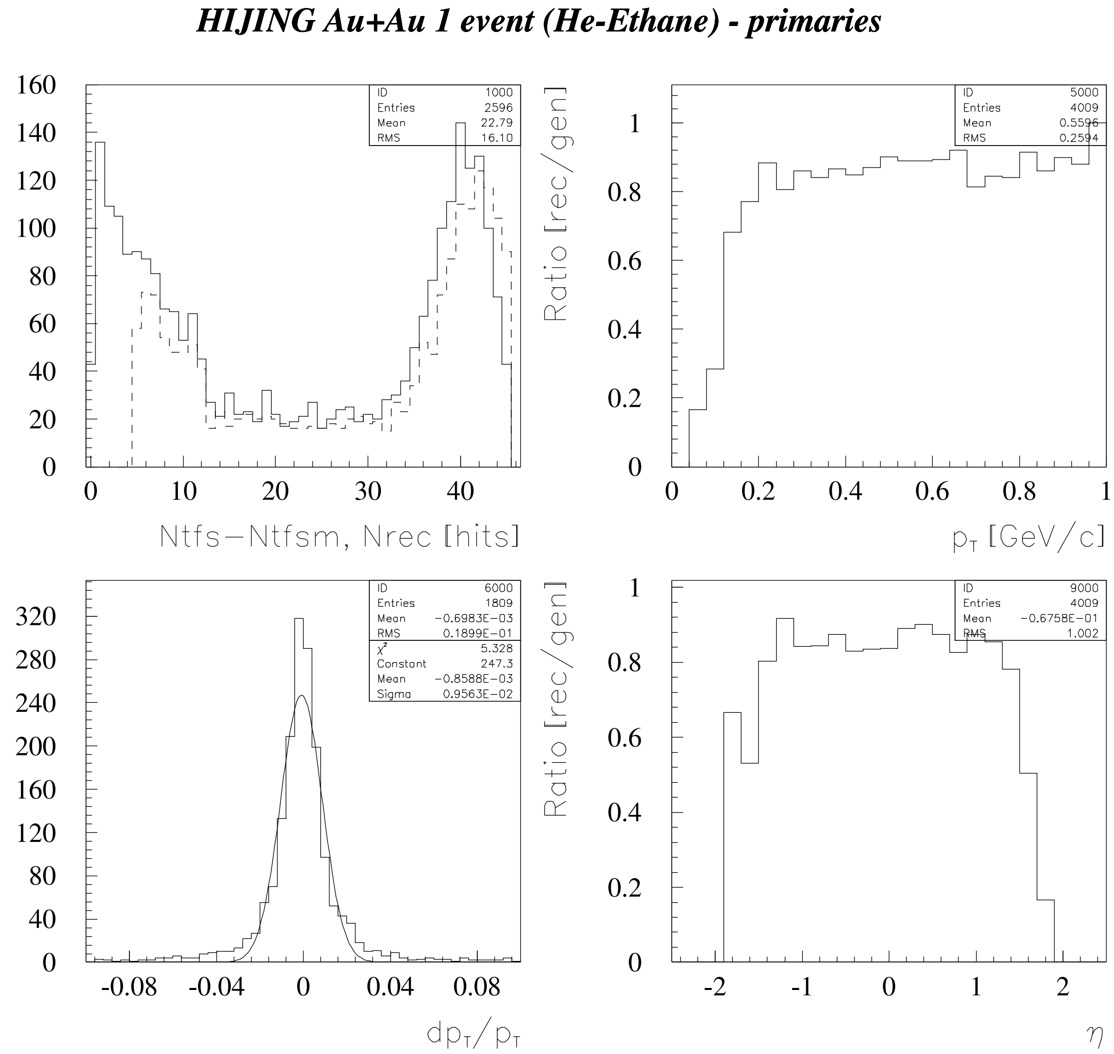

Figure 8: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 1$ pseudorapidity density event and a He-Ethane gas mixture.

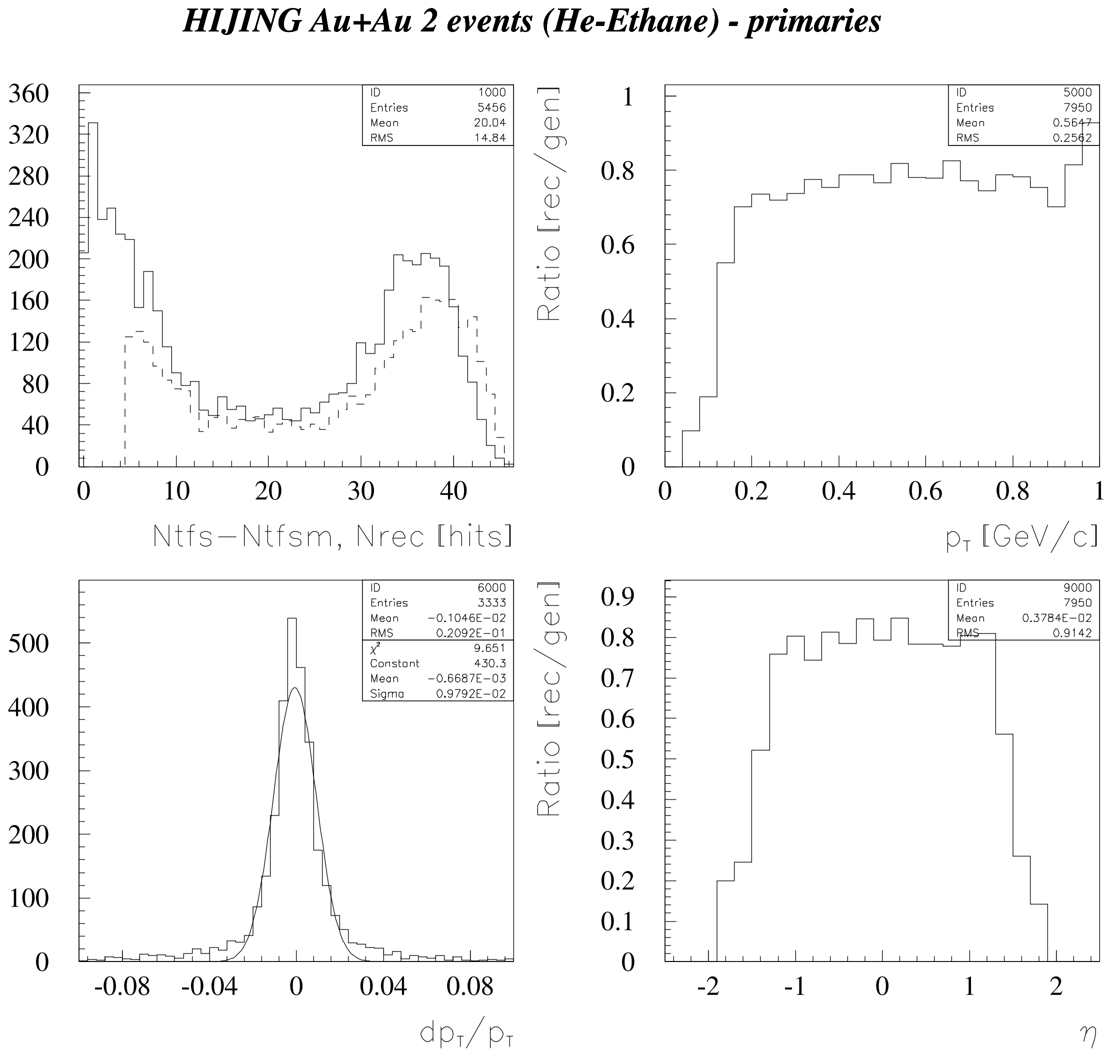

Figure 9: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 2$ pseudorapidity density event and a He-Ethane gas mixture.

HIJING Au+Au 4 events (He-Ethane) - primaries

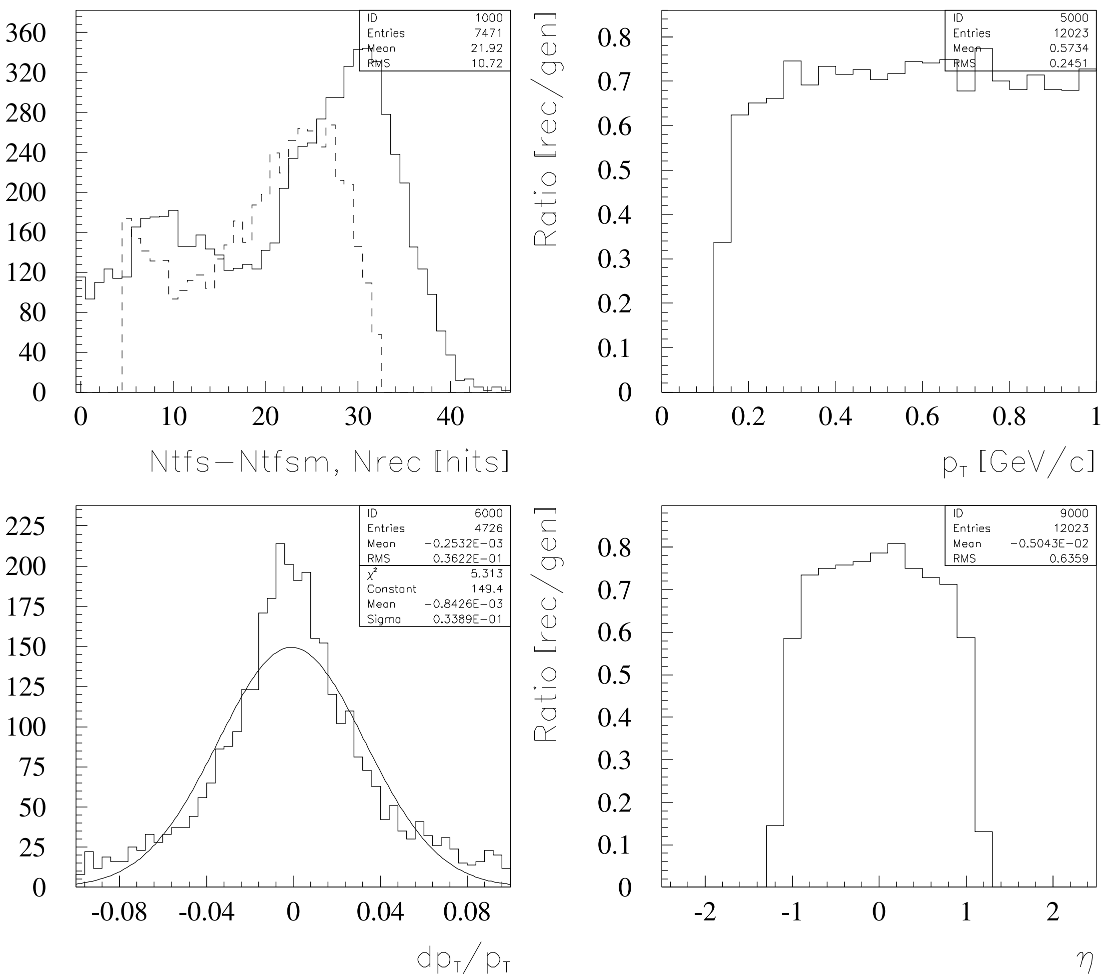

Figure 10: The distribution of available unmerged hits and reconstructed hits on tracks; reconstruction efficiency as a function of p_T; transverse momentum resolution and reconstruction efficiency as a function of pseudorapidity for the $\times 4$ pseudorapidity density event and a He-Ethane gas mixture.