Development of MRPC technology for STAR-TOF

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Abstract A prototype of multi-gap resistive plate chamber (MRPC) modules with 6 gas gaps of 220 μm used for the time-of-flight (TOF) detectors has been developed by STAR TOF group. A tray (TOFr) composed of 28 MRPC modules was constructed and operated in STAR for the d+Au collisions and Au+Au collisions during 2003 RHIC and 2004 RHIC run. Results show its time resolution is 85 ps with the average efficiency of 95% and clear identification of K/π up to 1.6 GeV and proton/ K up to 3.0 GeV.

Key words Multi-gap resistive plate chamber (MRPC), Time of flight(TOF), Particle identification(PID), Solenoidal tracker, Relativistic heavy ion collider (RHIC)

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1 Introduction

The solenoidal tracker at RHIC (STAR) is a detector system constructed at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL). The Multi-gap resistive plate chamber (MRPC) detector was first developed by CERN ALICE TOF group to provide a cost-effective solution for large-area TOF coverage.[1] The STAR experiment plans to construct a 64 m^2 TOF system, which consists of 3840 MRPC modules, housed in 120 trays. Each tray covers about 0.9 unit of pseudo rapidity and 1/60th of the azimuth.[2] The STAR TOF group in collaboration with the CERN ALICE group has manufactured and tested several prototypes of MRPC at CERN PS-T10 area since 2000.[3] The 6-gap MRPC module is a suitable candidate for STAR TOF system due to its time resolution of 60—80 ps with efficiencies in excess of 95% that meet the demand of hadronic particle identification in the STAR experiment. In order to gain a further view of the function of TOF system to the physics research and feasibility of installation in STAR environment, a tray (TOFr) for STAR TOF with 28 MRPC modules was constructed by University of Science and Technology of China (USTC) and Rice University and then installed into STAR. Shown in Fig.1 is a photograph of the TOFr tray first operating in the d+Au collisions during RHIC 2003 physics run.

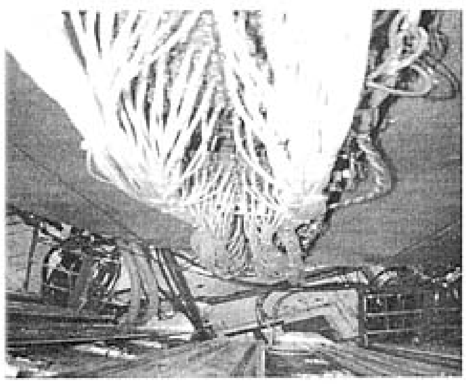

Fig.1 The TOFr tray operating in the STAR experiment at RHIC.

2 MRPC module's design and test

The MRPC module appropriate for STAR has 6 signal pickup pads with size of 61 mm×30 mm which

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cover the active area of 61 mm×195 mm. The cross section view of the module is shown in Fig.2. The five inner glass plates have a thickness of 0.54mm and two outer plates are 1.1 mm. They are kept parallel by 0.22 mm diameter nylon fishing line as spacer. Graphite resistive (~10^5 Ω/square) electrodes applied to the surface of outer glass provide a ~20 kV/mm electrical field in each sub-gap. A charged particle going through the chamber generates avalanche in gas gaps. Because all the internal glass plates are electrically floating, they are transparent to charge induction from avalanches in the gas. Typical resistivity for the glass plates is of the order 10^{13}Ω/cm. Thus the induced signal on the pads is the sum of possible avalanches from all gas gaps. The signal is read out by an array of copper pickup pads, which is separated from the outer electrodes by 0.35 mm of Mylar. The PC board of pickup pads for the present MRPCs is shown in Fig.3.

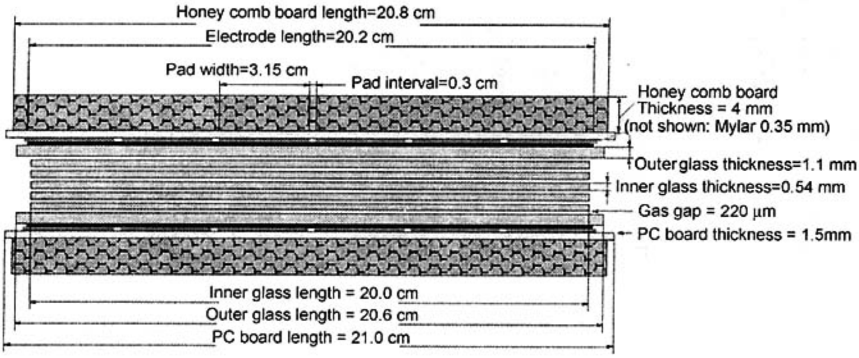

Fig.2 The cross section view of an MRPC module with 6 gaps of 0.22mm.

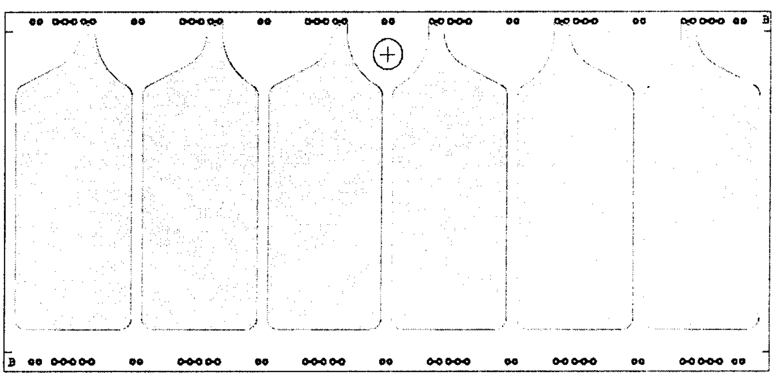

Fig.3 A PC board of pickup pads for the MRPC module.

The design of 6-gap modules is based on the R&D of several prototype MRPCs in USTC together with Rice University.[4-6] It is operated in avalanche mode with a gas mixture composed of 90% freon134a ($C_2H_2F_4$), 5% isobutene (iso-C_4H_{10}) and 5% SF_6. The basic characteristic of each module was measured with the test bench of cosmic rays before built in TOFr tray, which includes:

- leakage current for a module should be <10nA at 15 kV using the regular operating gas mixture;
- noise rate should be < 50Hz/pad at 14.5kV;
- probability for ADC values larger than 3σ above of the mean ADC value should be less than 10% at 14.5 kV, where σ is the standard deviation of Gauss distribution.

Fig.4 is a group of test results of 6-gap modules for cosmic rays. The ADC spectrum is shown on upper left in frame. The typical Time-to-Amplitude (T-A) correlation is shown on upper right in frame. To get the correction coefficients, a six-polynomial is used to fit the T-A distribution at small amplitude area and a linear function is used to fit large one.[7] After Time-to-Amplitude (T-A) correction, the time resolution (lower right frame) is 107.5 ps, which including both of the start time jitter of 62.9 ps (lower left frame) from the telescope trigger system and the time difference of signal transfer when cosmic rays hit the different position on one readout pad.

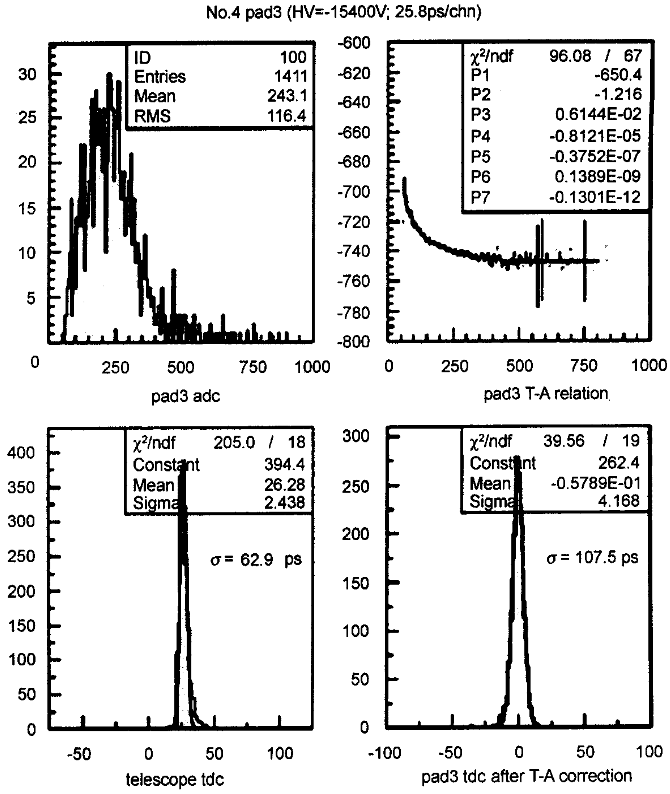

Fig.4 Test results of 6-gap modules from cosmic rays. (TDC: 25.8ps/chn, ADC: 0.25pc/chn).

3 TOFr tray construction

The TOFr tray containing 28 6-channel MRPC modules, 24 of which produced by USTC and 4 by CERN, was constructed at Rice University and pre-tested in a radiation area near the E949 experiment at the AGS of BNL before operating in STAR. The dimensioned side view of the module geometry of the TOFr tray is shown in Fig.5. The mechanical support of the MRPC modules in the aluminum box (241.3 cm long, 21.6 cm wide, 8.9 cm high) was accomplished using so-called "sawtooths". The sawtooths are 48 differently-shaped pieces of honeycomb board of 1/4" (0.64 cm) thick. The 28 modules in the TOFr tray are connected to one of two interior HV bus, A and B. The 28×6 short twisted -pair cable that carry the signals from modules were connected to pins on the underside of the feed-through plates. Once gas was flowing through the sealed gas box of TOFr tray without leaks, the readout electronics boards were mounted on the top of the feed-through plate. Shown in Fig.6 is the fully constructed TOFr tray under test in Rice Lab. Fig.7 summarizes the results from the first power-up of the TOFr tray.

Since SF_6 has much higher global warming potential and other gas detectors such as TPC are also undesirable to use in STAR environment, one of the important tests at the AGS is to determine the optimum gas mixture before operating in STAR. The beam is not actually a test beam but rather a radiation on the floor of the AGS near Experiment 949.[8] The tested results of TOFr tray operating with three kinds of gas mixtures are presented in Fig.8. The results showed that the TOFr system could be operated without SF_6 at particle fluxes of less than 100 Hz/cm^2, and a reduced voltage of 14 kV and 95% efficiency.

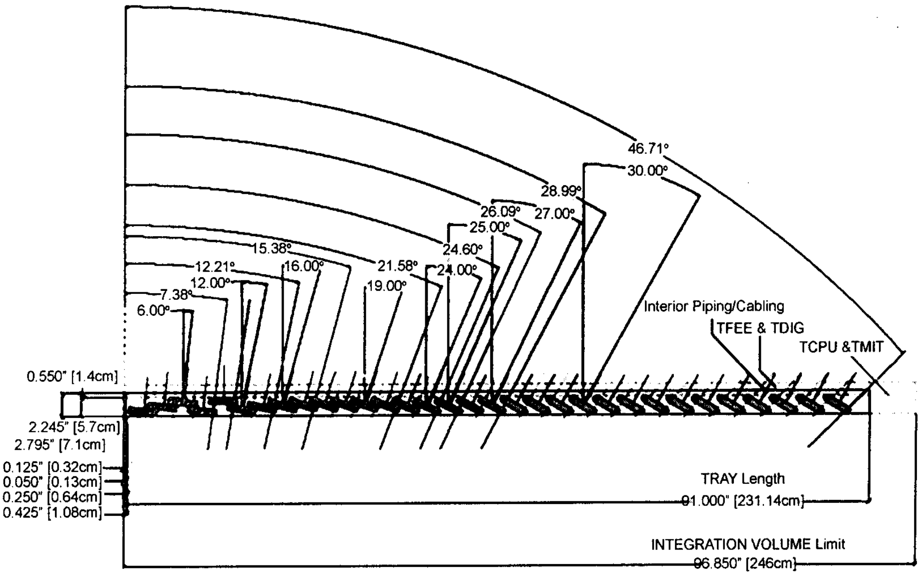

Fig.5 A dimensioned side view of the TOFr tray indicating the module's position.

Fig.6 The completed TOFr tray with all FEE boards installed.

4 TOFr tray in STAR

The TOFr prototype tray was installed in STAR and run continuously throughout 2003 RHIC run for d+Au, p+p in 200 GeV, and 2004 RHIC run for Au+Au in 62 GeV and 200 GeV collisions. Since the acceptance of TOFr subtends about 1/300th of the outer cylindrical surface of the time projection chamber (TPC), a special STAR Level-0 trigger was setup to trigger on events with TOFr hits and valid pseudo-vertex position detector (pVPD) coincidence between east and west parts.[9] Also included in the logic was simple primary vertex cut based on maximum allowable values of the timing difference of the pVPD East and West signals. The TPC offers information of particle momentum, dE/dX, and path length within the magnetic field and collision vertex after special algorithms.[10] The pVPD was specially designed to present the reference start time for TOF while the TOFr itself records the stop time. The start timing resolution of pVPDs is different for d+Au, Au+Au and p+p collisions used in the test and calibration of TOFr, respectively.

The time of flight of a particle between the collision vertex and the hit point on a pickup pad on an MRPC is calculated by the difference between the start time (T0) and stop time recorded by the corresponding channel. The delay by each connecting cable was measured and subtracted. A typical T-A slewing from ADC and TDC measured is shown in Fig.9. Similar corrected methods as in cosmic rays test were used. Since all the pickup pads are readout from positive z direction, the different hit position along z-axis on a pickup pad will cause a time difference in the signal transfer on the pad. This effect is shown in Fig.10. After the T-A and z position correction, the overall time resolution of TOFr is 85 ps in 200 GeV Au+Au and 110 ps in 62 GeV Au+Au collisions, as shown in Fig.11 and 12, respectively. To subtract the quota from pVPD, the average TOFr timing resolution is 80 ps and 85 ps in 200 GeV and 62 GeV Au+Au collisions, respectively. This still includes contribution from the electronics jitter and the influence of TPC track resolution.

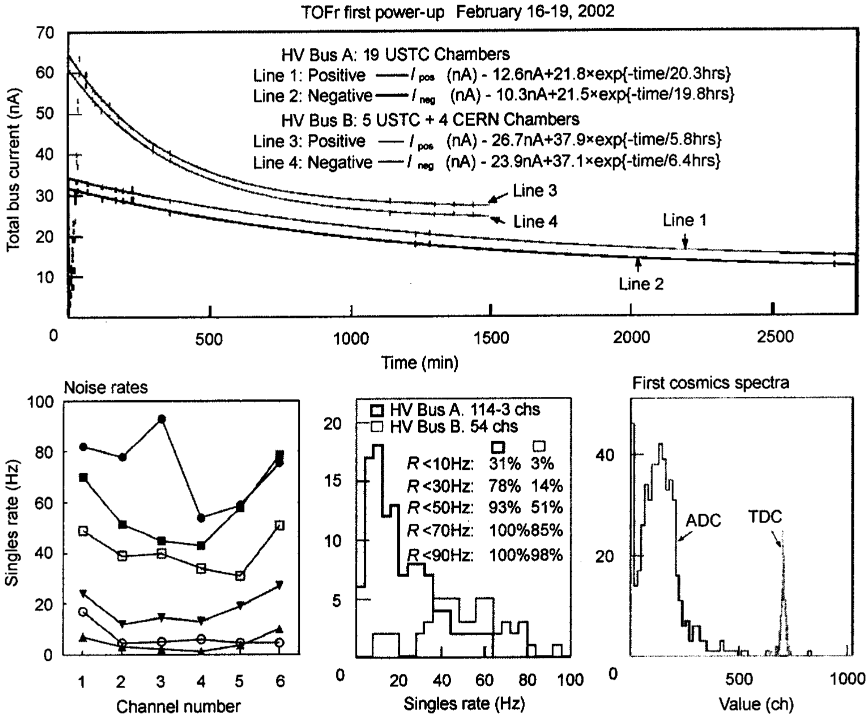

Fig.7 Results on the noise rate, bus current and cosmic spectra from first power-up of the TOFr tray.

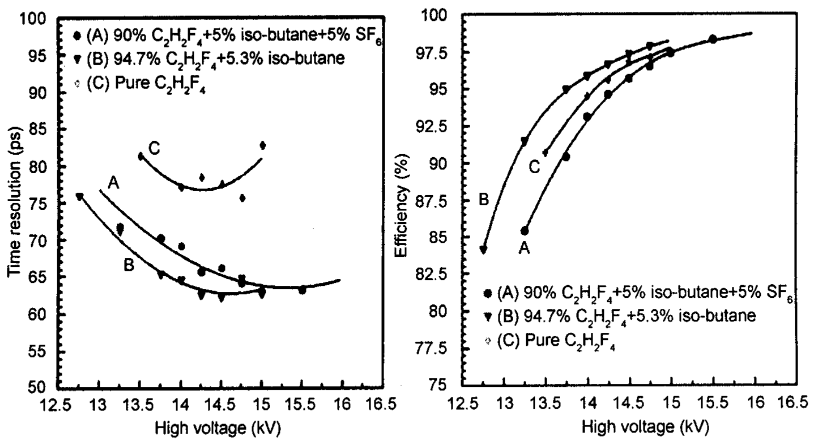

Fig.8 The time resolution and detection efficiency with different gas mixture in TOFr tested at AGS.

Fig.13 shows TOFr detection efficiency as a function of particle transverse momentum. The track sample with well-defined characteristics in TPC is selected. This means that the track must be a TPC primary track with more than 25 hits and the reconstructed vertex of the track is within the range of −50cm<Z<50cm. The average detection efficiency is around 95% after counting the absorption effect in detectors.

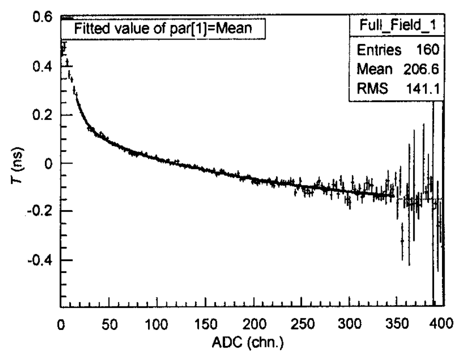

Fig.9 The time amplitude slewing correction in Au+Au (200GeV) collisions.

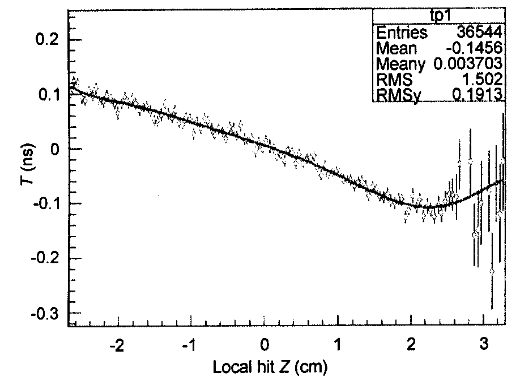

Fig.10 Correction due to different hit position on a pad in Au+Au (200GeV) collisions.

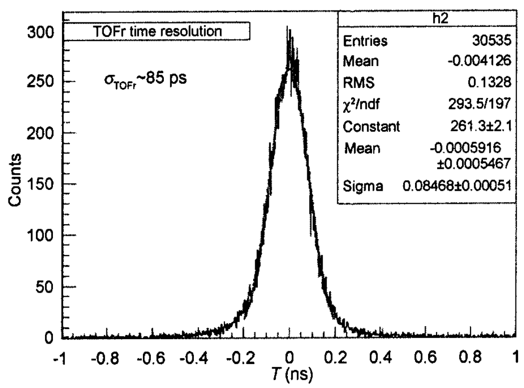

Fig.11 Overall time resolution in Au+Au (200GeV) collisions.

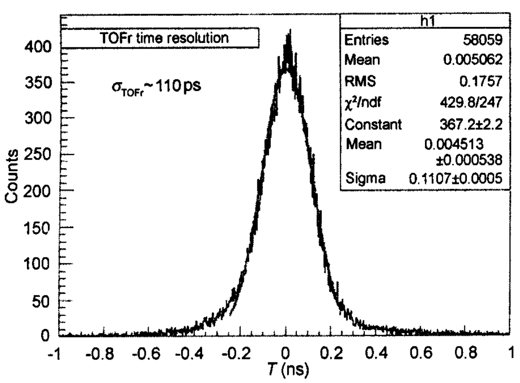

Fig.12 Overall time resolution in Au+Au(62GeV) collisions.

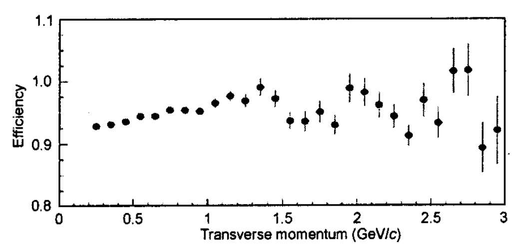

Fig.13 TOFr detection efficiency as a function of particle transverse momentum in Au+Au (200GeV) collisions.

5 TOFr PID performances

RHIC 2003 run and 2004 run provided significant TOF data for full energy d+Au and Au+Au collisions, such as the STAR collected ~7.2M Au+Au 62 GeV events with minimum-bias triggers approximately 2.2M total events matched TOFr. These data are sufficiently larger to allow detailed analysis of the PID performance for the TOFr performance. With the calibration parameters from the pion sample, the time of flight in formation of TOFr are combined with path length and momentum of TPC to identify charged particles. Fig.14 shows the $1/\beta$ from the TOFr measurement as a function of the momentum measured from the TPC tracking in the minimum-bias Au+Au 62 GeV collisions. A 2σ separation of 3.0 GeV/c and 1.6 GeV/c for the proton/ kaon and kaon/pion was obtained, respectively. Under the figure is the reconstructed squared mass distribution for proton, pion and kaon within the transverse momentum range of 1.4—1.6 GeV/c and 2.5—3.0 GeV/c. The same results were got from the 200 GeV d+Au collisions in 2003 RHIC run.[11]

6 Conclusions

We have successfully developed a new, low-cost MRPC technology for STAR experiment. For the 6-gap MRPC module, a series of test results shows that the time resolution and detection efficiency are good enough to meet the requirement of TOF measurement. A 28×6 channel MRPC prototype tray was operated in STAR for two years. Stable performance and strong PID capability have been demonstrated in the STAR experiment. A proposal for a full barrel STAR TOF detector upgrade has been submitted based on these R&D results. The full TOF systems will double STAR's particle identification capability to 95% of all charged particles within the acceptance of the TOF detector.

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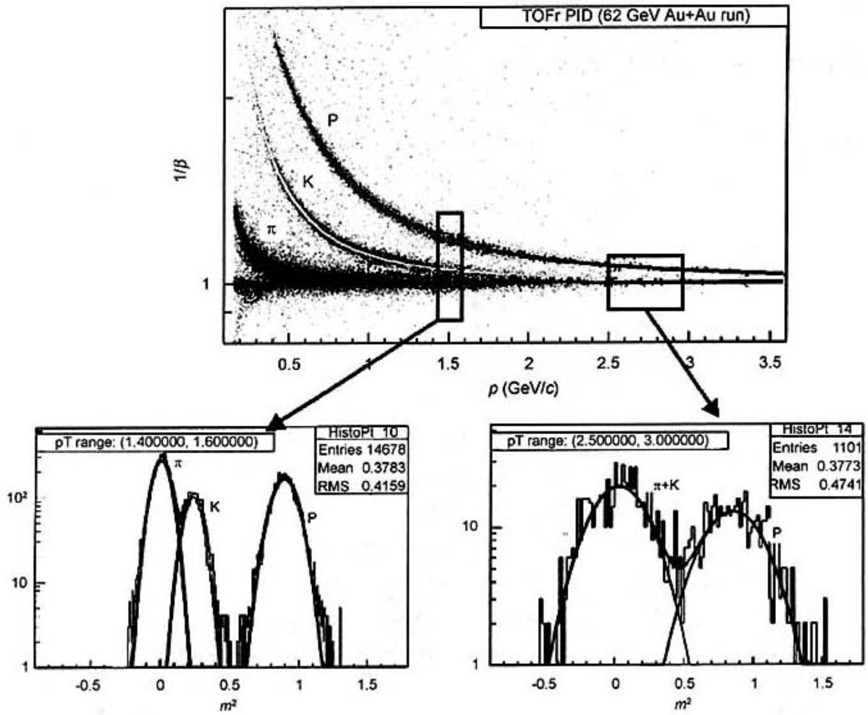

Fig.14 Inverse velocity vs momentum from 2.2 million TOFr+pVPD triggered events in Au+Au 62 GeV collisions.

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