FD5: The Large-Area Time-Of-Flight Upgrade for STAR

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Abstract: The STAR experiment at RHIC concentrates on the tracking of charged hadrons via ionization in gas- and silicon-based detectors, and the detection of electrons and photons via calorimetry, in a wide and azimuthally complete acceptance that's unique at RHIC. STAR's ability to directly identify the species of the tracked charged hadrons is however limited to "low" hadron momenta. Approximately 30% of the charged particles in the event at higher momenta cannot be directly identified, which hampers the physics reach of STAR in a number of key areas. To address this blind spot, STAR aims to surround the entire cylindrical surface of the tracking detectors with a large-area (~50 m^2) Time-Of-Flight (TOF) system based on the relatively new technology called the Multi-gap Resistive Plate Chamber (MRPC). Prototype TOF systems based on this technology were operated in STAR throughout the last two RHIC running periods. The design and operation of STAR's MRPCs, the performance of the two prototype systems, and an overview of the design of the planned large-area system, will be discussed.

PACS: 06.60.Jn; 07.50.Ek; 29.40.Mc
Keywords: Particle Identification; Time of flight; Multigap Resistive Plate Chamber, STAR

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1. Introduction

When it collides two ^{197}Au nuclei at the highest available energy of 100 GeV/c/N, the RHIC facility at Brookhaven generates, for fleeting instants, the hottest and densest matter ever before seen in the laboratory. Of the four RHIC Heavy-Ion experiments now carefully studying these collisions, the STAR experiment is unique in its wide and azimuthally complete acceptance about the collision zone defined by its Time Projection Chamber (TPC). STAR has, however, some important “blind spots.” STAR cannot efficiently particle-identify (PID) the charged hadrons π & K (p) if their momentum is above ~0.7 (1.0) GeV/c. Approximately 30% of the total number of charged hadrons in any given event thus cannot be identified. To fill these gaps in the PID capabilities of STAR, our group has been building and operating prototype Time-Of-Flight (TOF) systems in STAR over the last several RHIC runs. Such systems naturally extend upwards the momentum limits at which we can directly identify charged hadrons. A TOF system with a total timing resolution of 100ps in the STAR geometry, and for the tracking resolution of the STAR TPC, would allow π:K:p direct identification up to a momenta near 1.7-1.9 GeV/c and (π+K):p identification up to 2.9-3.1 GeV/c. Combining the particle identification capabilities of the TOF with those from dE/dx in the TPC allows high efficiency particle identification over ~98% of the hadron spectra, as well as cross-checks between the different PID techniques in the momentum regions where there is overlap.

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These prototype TOF systems are based on the relatively new technology called the Multi-gap Resistive Plate Chamber (MRPC) [1,2]. Two generations of small-area prototype systems based on MRPCs have been operated in STAR in the last two RHIC runs, and a third-generation MRPC TOF system has just recently been built for the upcoming run. Over the coming years, we intend to instrument the entire cylindrical surface (~50m^2) of the STAR TPC with these detectors. The design and operation of the MRPC detectors for STAR, the prototype TOF systems, and the full system to come, are discussed below.

2. The Multigap Resistive Plate Chambers for STAR

The Multi-gap Resistive Plate Chamber (MRPC) technology was first developed by the CERN ALICE group [1,2]. Working closely with this group, we developed and tested a variant for STAR [3]. The side and end views of this design are shown in Figure 1. The upper (lower) view in this figure shows the long (short) edges; the two views are not at the same scale. Our MRPC is basically a stack of resistive plates (0.54 mm-thick float glass) with a series of uniform 220 μm gas gaps in between. Graphite electrodes are applied to the outer surface of (wider) outer glass plates. A strong electric field is thus generated in each gap by applying high voltage across these electrodes. All the inner glass plates float electrically. A charged particle going through the glass stack generates primary ionization along its path inside the gaps, and the strong electric field there produces Townsend amplification avalanches. Because both the electrodes and the glass plates are resistive (~10^{13} Ω/cm volume and 10^5 Ω surface, respectively), they are transparent to this avalanche charge. Thus, the induced signal on the copper readout pads (outside the electrodes) is the sum of the avalanches in all of the gas gaps. Each pad layer is a single row of six 3.5×6.1 cm^2 pads read-out on one edge by traces that connect to twisted-pair signal cables which bring the signals to the electronics for pre-amplification and digitization.

During operation, the MRPCs are bathed in a gas that is predominantly (90-95%) Freon R-134a. Admixtures of isobutane and SF6 improve the timing resolution and suppress the probability for very large avalanches called “streamers,” respectively. In STAR, we use 95% R134a and 5% isobutane, but avoid SF6 since the performance of the STAR TPC would be degraded if SF6 leaked into it even at concentrations as low as 2 ppb [4]. The typical voltage difference applied across the electrodes is ~14 kV. The resulting signals are extremely small (~25 fC/hit). Thus, careful pre-amplification in the front-end electronics, and careful shielding from external radio-frequency interference in the mechanical design, is crucial. The thermionic emission of electrons from the glass plates causes a finite rate for MRPC signals even in the absence of particles traversing the glass stack. For our MRPCs, this rate is low, being typically ~1 Hz per square centimeter of pad area (*i.e.* ~20 Hz/pad).

The technology has proved to be very inexpensive, easy to build, and capable of the necessary timing resolution. The detection efficiency, time resolution, and average signal area versus the voltage obtained from CERN test-beam running is shown in figure 2. One notices a wide voltage plateau leading to >95% efficiency, and a timing resolution below 70ps, both of which are well suited for STAR.

With the MRPC design finalized in 2001, we then built a full-scale prototype TOF system for STAR based on MRPCs. This system, called TOFr, was tested extensively in an AGS radiation area [5], and then installed in STAR in advance of RHIC Run-3 (2002-2003). Here, TOFr's signals were digitized in CAMAC by the existing STAR TOFp subsystem [6] using TOFp's start detector called the pVPD. Shown in figure 3 is the inverse velocity versus the momentum for charged hadrons in STAR obtained from the pVPD & TOFr detectors in d+Au collisions [7]. Going vertically in this plot, the strong bands correspond to directly-identified charged pions, Kaons, and protons, respectively, and the momenta at which the bands merge indicates the system is performing to expectations (stop resolution ~80-90 ps). The TOFr system was thus the first to prove that MRPCs are viable for TOF systems in a modern collider experiment. The data taken during this run also resulted in the first physics result [8] ever obtained from an MRPC-based TOF system.

For the following RHIC Run-4 (2003-2004), another full-sized MRPC-based TOF tray, TOFr', was constructed and installed in STAR. It ran stably throughout the run. The stop-timing resolution of the TOFr and TOFr' systems has been consistent across runs and near 80-90 ps. For the upcoming RHIC Run-5 (2004-2005), a third full-sized system, TOFr5, was constructed and will be installed in STAR in a few weeks. For both TOFr' and TOFr5, improvements to the mechanical and electronic design were made both to simplify the construction and improve the overall performance. Photographs of TOFr5 are shown in figure 4. On the left, one sees the interior of the gas volume and the 32 MRPCs in position, and on the right is the tray closed up and ready for operation.

The major difference between TOFr5 and TOFr' is that the digitization is now done on-board instead of over long-signal cables in CAMAC [6]. This new digitization approach, based on the HPTDC chip [9] developed at CERN, is the only feasible way to efficiently read out the 23,040 channels in the future large-area STAR TOF system [10]. This full system will consist of 120 TOFr5-like trays and will cover the entire cylindrical surface of STAR's TPC. The system is presently under U.S. D.O.E. review, but we are optimistic for a construction start in late 2005 and completion in advance of RHIC Run-9 (2008-2009). Present R&D is focused on commissioning the TOFr5 system for STAR, and continuing to improve the mechanical and electronic design towards the large-area system to come.

This work is supported by the U.S. Department of Energy under the Grant DE-FG03-96ER40772.

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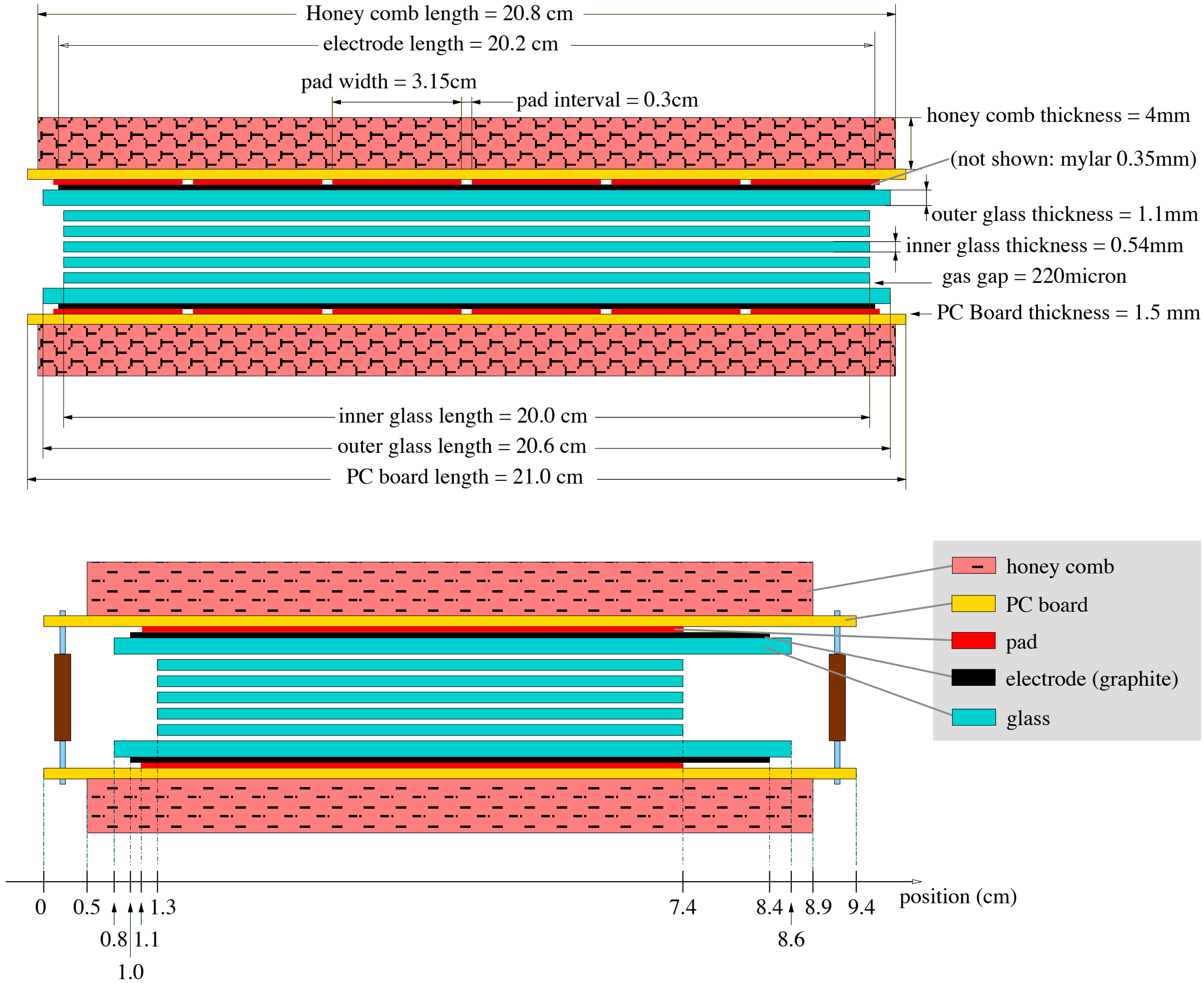

Figure 1: Side and End views of the MRPC modules developed for STAR.

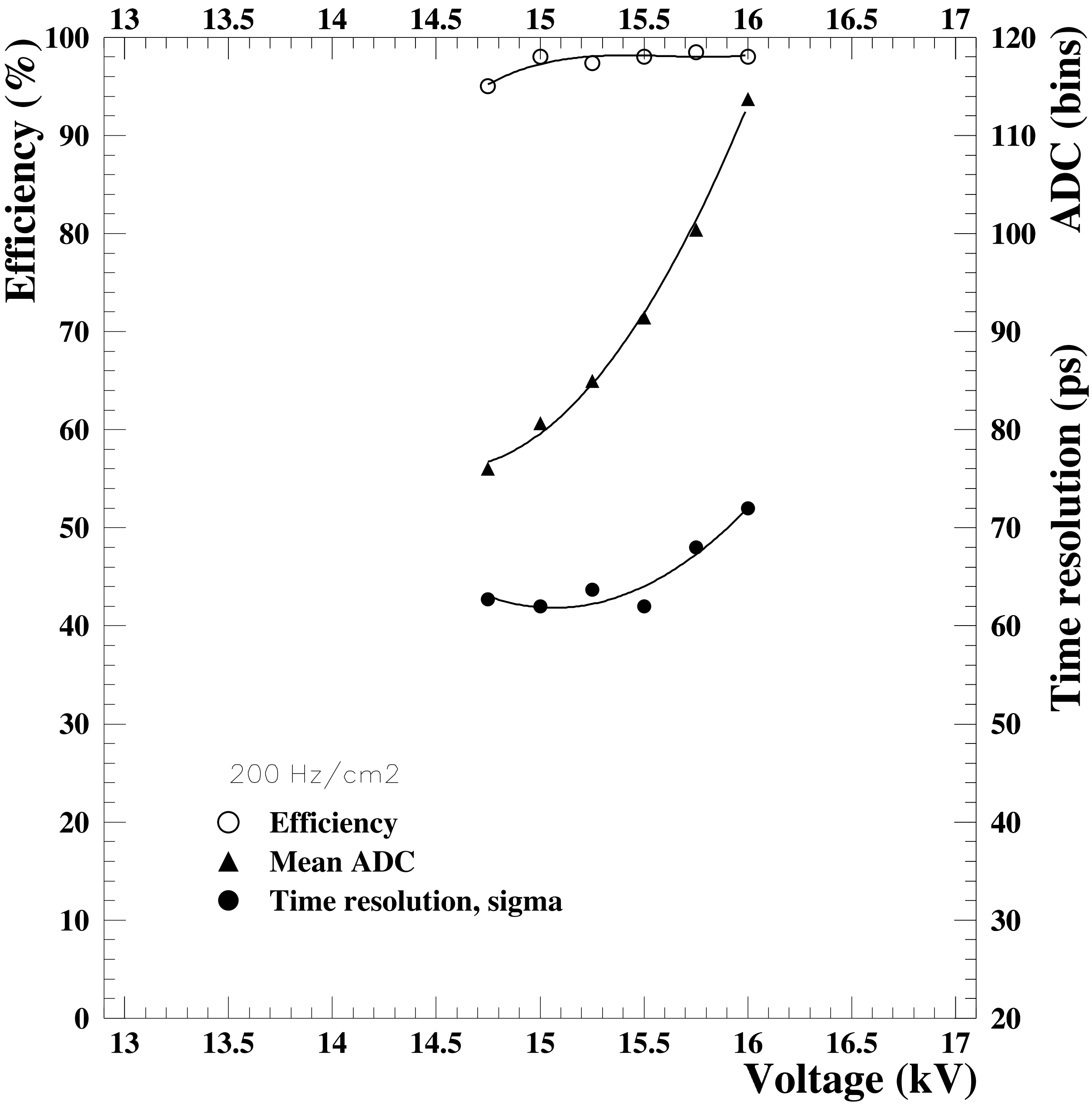

Figure 2: The efficiency (percent, open circles), time resolution (in ps, solid circles), and average signal total charge (ADC bins with 0.25pC/bin, triangles) versus the voltage for the STAR MRPCs at an instantaneous beam rate of 200 Hz/cm^2.

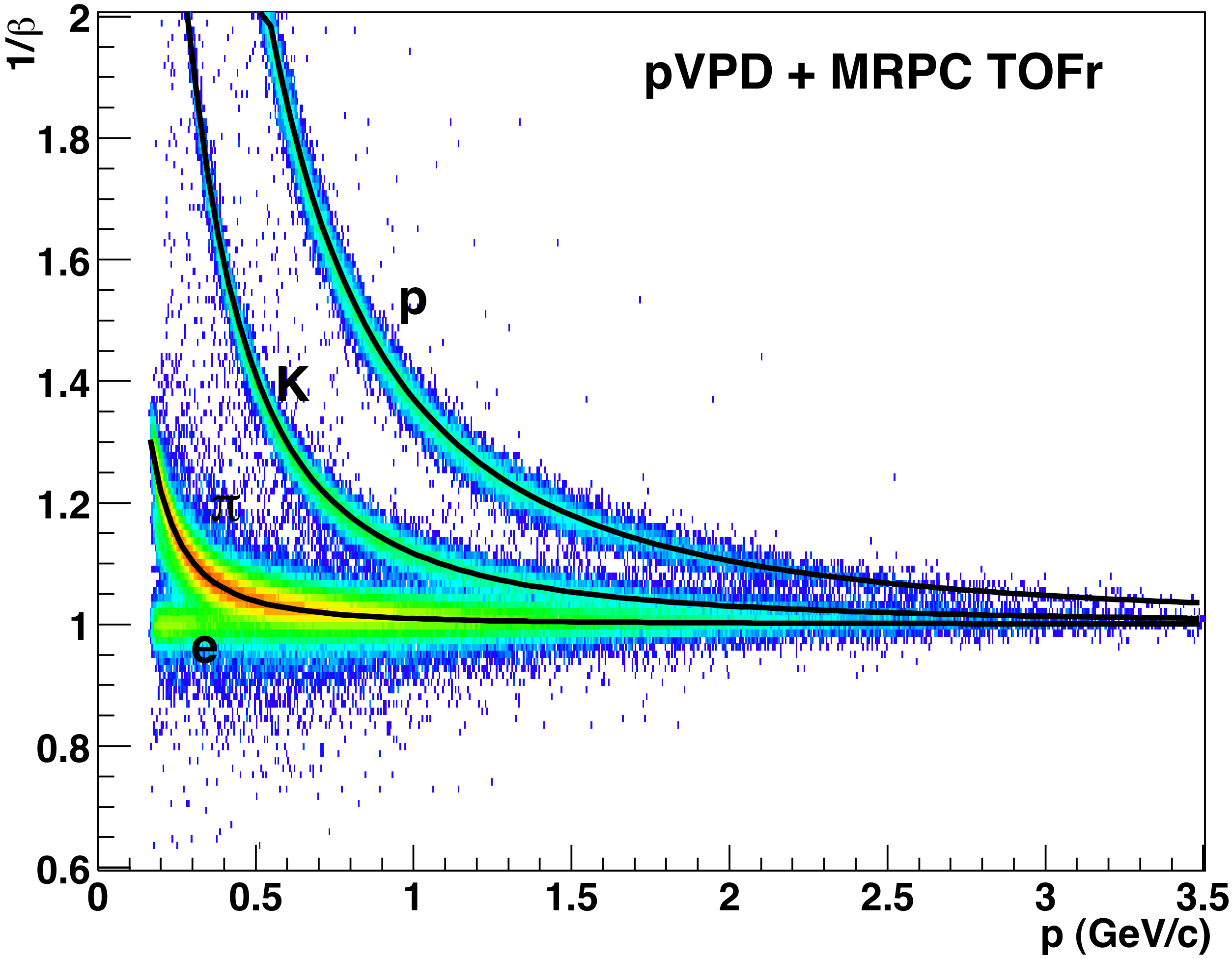

Figure 3: The inverse velocity for charged hadrons in STAR versus the momentum obtained from the pVPD and TOFr systems in RHIC Run-3.

Figure 4: On the left is the interior of the TOFr5 system with 32 MRPC detectors installed, and on the right is the TOFr5 system closed up and ready for installation in STAR.