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The STAR Time-of-Flight System

W.J. Llope for the STAR Collaboration

Rice University, Houston, TX, 77005

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 tracked charged hadrons is however limited to "low" hadron momenta. Approximately half 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 is presently constructing a large-area (50 m^2) Time-Of-Flight (TOF) system. This system is based on Multi-gap Resistive Plate Chambers (MRPCs). Prototype TOF systems based on this technology were operated in STAR during RHIC Runs 3 through 5, and the first 5 final system trays were operated in the recent Run 8. A new start detector for this system has also been constructed and operated in STAR. The performance of these detectors in STAR, and an update on the status of the construction of the full system, is discussed.

Keywords: Particle Identification; Time of flight; Multigap Resistive Plate Chambers, 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 rather interesting matter. It is dense enough to quench jets, and its viscosity to entropy ratio appears to be close to the theoretical lower limit, leading some to call it a partonic "perfect fluid" [1]. Of the two RHIC experiments now carefully studying this matter, 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, important "blind spots." STAR cannot efficiently particle-identify (PID) the charged hadrons π & K (p) if their momentum is above $\sim$0.7 (1.0) GeV/c. Roughly half of the total number of charged hadrons in any given event thus cannot be directly identified. To fill in these gaps in its PID capabilities, STAR operated prototype Time-Of-Flight (TOF) systems in RHIC Runs 3 through 5, and is now constructing a large-area system. These TOF systems naturally extend upwards the momentum limits at which one can directly identify charged hadrons. A TOF system with a total timing resolution of 100 ps in the STAR geometry, and for the tracking resolution of the STAR TPC, allows π:K:p direct PID up to a momenta of $\sim$1.7-1.9 GeV/c and (π+K):p identification up to $\sim$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 $\sim$98% of the hadron spectra, as well as cross-checks between the different PID techniques. The use of TOF to exclude "slow" tracks also allows a clean separation of electrons and pions based on the track energy loss, "dE/dx," in the TPC.

These TOF systems are based on the relatively new technology called the Multi-gap Resistive Plate Chamber (MRPC) [2,3]. Prototype "trays" of TOF were built and operated in Runs 3 through 5 and the first five "final" trays were operated during the recent Run 8. We intend to instrument the entire cylindrical surface ($\sim$50 m^2) of the STAR TPC with a total of 120 trays in time for RHIC Run 10.

The dramatically enhanced PID is expected to improve the signal-to-background ratios for ρ, $K^*(892)$, f^0, $\phi(1020)$, Δ, $\Sigma(1385)$, $\Lambda(1520)$, D^0 , D^+, and D_s^+ particles by significant factors, in some cases allowing the measurement of complete spectra for these particles in single RHIC running periods for the first time. The TOF system is seen as a particularly crucial component of STAR for the beam energy scan expected to occur in RHIC Run 10 towards the location of the Quantum Chromodynamic critical point. All observables of interest there are improved by the presence of the TOF system. For example, the measurement of the π^+/K^+ ratio and its fluctuations event-by-event is improved by the suppression of both the π and K misidentification, and the otherwise large contributions to the dynamical fluctuations resulting from the finite counting statistics due to the low efficiency of the TPC dE/dx PID.

The STAR MRPCs are discussed in Section 2, and the prototype and final trays are discussed in Section 3. A new start detector for the TOF system is described in Section 4, and the conclusions are presented in Section 5.

2. The Multi-gap Resistive Plate Chambers for STAR

The Multi-gap Resistive Plate Chamber (MRPC) technology was first developed by the CERN ALICE group [2,3]. Working closely with this group, we developed and tested a variant for STAR [4]. Our MRPC is basically a stack of resistive plates (0.54 mm-thick float glass) with a series of uniform 220 m 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 ($\sim 10^{13}$ Ω/cm volume and 10^5 Ω surface, respectively), they are transparent to the 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 SF_6 improve the timing resolution and suppress the probability for very large avalanches called "streamers," respectively. In STAR, we use 95% R-134a and 5% isobutane, but avoid SF_6 since the performance of the STAR TPC would be degraded if SF_6 leaked into it even at concentrations as low as 2 ppb [5]. The typical voltage difference applied across the electrodes is $\sim$14 kV. The resulting signals are extremely small ($\sim$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 typically $\sim$1 Hz per square centimeter of pad area (i.e. $\sim$20 Hz/pad).

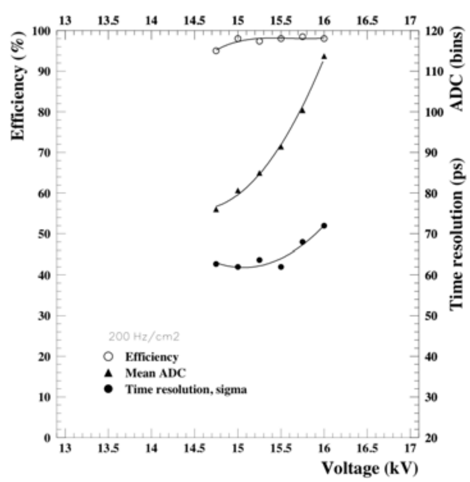

Fig. 1. *The performance of the STAR MRPCs measured at a CERN test beam.*

The technology has proved to be very inexpensive and easy to build, yet capable of the necessary timing resolution. The detection efficiency (open circles), time resolution (solid circles), and average signal area (triangles) versus the voltage obtained from the CERN test-beam running is shown in Figure 1. The hit rate for these data was 200 Hz/cm, which is the maximum rate expected for TOF in STAR during the RHIC-II era. One notices a wide voltage plateau leading to >95% efficiency, and a (pure-stop) timing resolution below 75 ps, both of which are well suited for STAR.

3. The STAR Prototypes & the Full System

With the MRPC design finalized in 2001, we then tested the technology in STAR by building full-scale prototype "trays." The first, "TOFr," was used in Run 3, the second "TOFr'," was used in Run 4, and the third, "TOFr5," was used in Runs 5 and 6. Both TOFr and TOFr' were digitized in CAMAC by the existing STAR TOFp subsystem [6] using TOFp's start detector called the pVPD. Each of these prototypes were built "from the ground up" and included incremental improvements to the mechanical and electronic design to simplify the construction, improve the mechanical tolerances, and improve the overall performance. A few MRPCs were used in all three prototypes to search for possible aging effects - none were seen. The stop-timing resolution of these prototypes was consistent across runs and was near 80-90 ps [7]. TOFr was also tested extensively in an AGS radiation area [8].

These systems were thus the first to prove that MRPCs are viable for TOF systems in a modern collider experiment following their successful operation in STAR. The data taken during Run 3 also resulted in the first physics results [9] ever obtained from an MRPC-based TOF system.

The major difference between TOFr5 and TOFr' was that the digitization was done on-board instead of over long-signal cables in CAMAC [6]. This new digitization approach, based on the HPTDC chip [10] developed at CERN, is the only feasible way to efficiently read out the 23,040 channels in the large-area STAR TOF system [11]. The full system will consist of 120 TOFr5-like trays and is presently under construction.

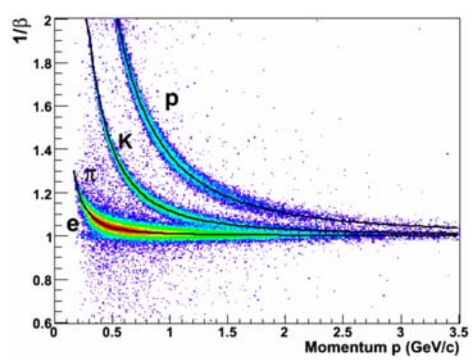

Fig. 2. *The PID performance of the final trays during Run 8 based on a preliminary calibration of a very small fraction of the available data set.*

The first five final trays ran stably throughout Run 8. Only two of the 960 total channels were dead. A very preliminary calibration was performed using the data from the p+p phase. As ∼1% of the data was available at the time, the calibration procedure added together read-out channels in groups of 24. The tracking data was crude "fast-offline" information from the as-yet uncalibrated TPC. The results [13], shown in Figure 2, are encouraging and will improve once the full data set and a calibrated TPC is used.

As of the time of this write-up, forty-six final trays have been fabricated. Twenty-three of these have been fully tested. All hold voltage and draw the proper currents, and there are no dead channels. All trays are leak-tested for at least 24 hours with respect to a known leakless tray and any that show a measurable leak rate are fixed (only one so far). We are aiming to have 90 trays (3/4 of the full system) installed in advance of Run 9. The system will be fully installed in advance of Run 10.

4. The Upgraded Start Detector

The MRPC-based trays provide half of the Time-of-Flight equation - the "stop time". During Runs 2 through 5, the other half of the equation - the "start time" - was provided by the pVPD [6]. This detector consisted of two equivalent assemblies of 3 Pb+scintillator+PMT-based detectors. Each assembly was positioned very close to the beam pipe on each side of STAR. Its high-precision measurement of very forward-going photons provides both the event start-time for TOF as well as the location of the primary collision vertex along the beam-pipe via timing differences. The pVPD worked well in Au+Au collisions, but was only ∼10% efficient for p+p and d+Au collisions. To improve the efficiency, as well as the resolution via the averaging effect, the 2×3 channel pVPD was replaced by the 2×19 channel "upVPD" before Run 7.

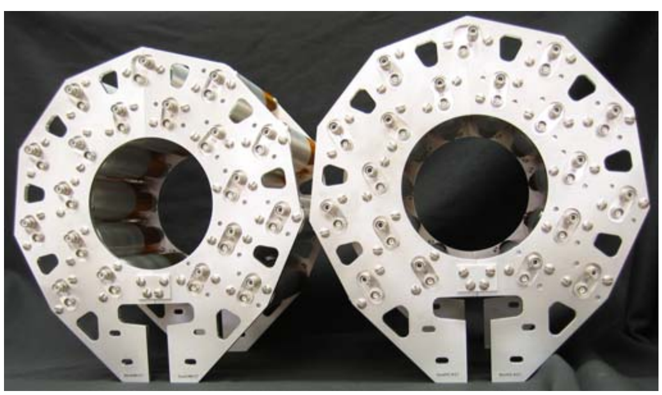

Fig. 3. *The upgraded start detector, "upVPD," assemblies.*

The two upVPD assemblies are shown in Figure 3. Each of the thirty-eight detectors are also Pb+scintillator+PMT-based detectors that use the mesh-dynode PMTs once part of the TOFp tray [6]. The upVPD signals were digitized by the STAR Trigger system and, beginning in Run 8, also the HPTDC-based TOF electronics. This detector was the primary input to the minimum bias trigger STAR ran nearly exclusively in Run 7, and was also used for triggering in Run 8.

The single detector resolution obtained from the TOF electronics in Run 8 was ∼140 ps in both the d+Au and p+p phases. In the d+Au phase, the mean multiplicity of lit PMTs on the east(west) was ∼10(2). In events with these multiplicities, the start-time resolution for TOF is $(41 \oplus 92)/2$, or ∼54 ps. In Au+Au collisions where all 19 chs/side are lit, the start-time resolution should be $32 \oplus 32/2$, or 23 ps.

5. Conclusions

The large-area STAR TOF system is presently under construction. Approximately one-third of the trays have been built and appear to work well. The construction is expected to be compete, and the system fully-installed, in advance of RHIC Run 10.

Acknowledgments

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References

1. http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=05-38
2. E. Cerron Zeballos, *et al.*, Nucl. Inst. and Methods A **374**, 132 (1996).
3. M.C.S. Williams, Nucl. Phys. **A698**, 464 (2002).
4. B. Bonner, *et al.*, Nucl. Inst. and Methods A **478**, 176 (2002).
5. http://rjd.home.cern.ch/rjd/Alice/frac_SF6.html.
6. W.J. Llope, *et al.*, Nucl. Inst. and Methods A **522**, 252 (2004).
7. J. Wu, *et al.*, Nucl. Inst. and Methods A **538**, 243 (2005).
8. F. Geurts, *et al.*, Nucl. Inst. and Methods A **533**, 60 (2004).
9. J. Adams, et al. (STAR Collaboration), Phys. Lett. B **616**, 8 (2005);
   J. Adams, et al. (STAR Collaboration), Phys. Rev. Lett. **94**, 062301 (2005).
10. http://micdigital.web.cern.ch/micdigital/hptdc.htm.
11. "Proposal for a Large-Area Time-Of-Flight System for STAR,",
    http://wjllope.rice.edu/∼TOF/TOF/Documents/TOF_20040524.pdf.
12. J.H. Zhou, Master's Thesis, adv. W.J. Llope, Rice U., unpublished (2005).
13. Z. Tang, private communication.