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Prototype Performance of Novel Muon Telescope Detector at STAR

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Abstract. Research on a large-area, cost-effective Muon Telescope Detector (MTD) has been carried out for RHIC and for next generation detectors at future QCD Lab. We utilize state-of-the-art multi-gap resistive plate chambers with large modules and long readout strips in detector design [1]. The results from cosmic ray and beam test will be presented to address intrinsic timing and spatial resolution for a Long-MRPC. The prototype performance of a novel muon telescope detector at STAR will be reported, including muon identification capability, timing and spatial resolution.

Keywords: Muon Telescope Detector, long-MRPC, intrinsic timing and spatial resolution, muon identification capability
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1. Introduction

A large-area muon detector at mid-rapidity for RHIC collisions will be crucial for advancing our knowledge of Quark-Gluon Plasma (QGP) properties. It directly addresses many of the open questions and long-term goals proposed in STAR white papers [2]. Since muons do not participate in strong interactions, they provide penetrating probes for the strongly-interacting QGP. A compact detector identifying muons with momentum of a few GeV/c at mid-rapidity, allows for the detection of di-muon pairs from QGP thermal radiation, quarkonia, light vector mesons, possible correlations of quarks and gluons as resonances in QGP, Drell-Yan production, as well as the measurement of heavy flavor hadrons through their semi-leptonic decays into single muons [3]. Some of these topics can also be studied using electrons or photons or a combination of both. However, they have large backgrounds from hadron decays at the interaction, π^0 and η Dalitz decay and gamma conversions in the detector material. These backgrounds prevent an effective trigger in central nucleus-nucleus collisions in a detector with large coverage. In addition to an effective trigger and cleaner signal-to-background ratio, electron-muon correlation can be used to distinguish lepton pair production and heavy quark decays ($c+\bar{c} \rightarrow e+\mu(e)$, $B \rightarrow e(\mu)+c \rightarrow e+\mu(e)$). Besides, muons are less affected than electrons by radiative losses in the detector materials, thus providing excellent mass resolution of vector mesons. For example, different Upsilon states ($\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$) can be separated through dimuon decay channel in the invariant mass distribution.

Conventional muon detectors rely heavily on tracking stations while this new detector proposes to use good timing (< 100 ps) and coarse spatial (~ 1 cm) resolution to identify muons with momentum of a few GeV/c [1]. The multi-gap resistive plate chamber technology with large modules, long strips and double-ended readout (Long-MRPC) was used for this research. Similar technology but with small pads is being built for STAR as a Time-of-Flight Detector [4].

2. Simulation

The simulation of a full HIJING central Au+Au collisions is shown in Fig. 1 using STAR year 2003 geometry with full configuration of the detectors and a complete material budget. We created a muon-detector (MTD) (in blue) covering the full magnet steel within $|\eta| < 0.8$ and left the gaps in-between uncovered, which corresponds to 56.6% of 2π in azimuth. Fig. 1 shows that most of the particles are stopped before passing the Barrel Electromagnetic Carolimeter and most of the escaping particles (primary or secondary) come through the gaps in the magnet steel (in green). Further simulation with STAR geometry indicates that for a muon track at $p_T > 2$ GeV/c generated in the center of the Time Projection Chamber (TPC), the detection efficiency of the MTD including acceptance effect is about 40-50% while for a pion track, the efficiency is 0.5-1%. A matched MTD hit, a precise time of flight measurement from the MTD and the current ionization energy loss (dE/dx) identification capability from the TPC, will give us a muon-to-hadron enhancement factor of 100-1000. Also, requiring two MTD hits in the trigger will enhance the di-muon spectra by a factor of 10-50. This together with data acquisition at >1000 Hz will greatly enhance the capability of J/Ψ and other dilepton programs in RHIC II and future QCD Lab [1, 5].

3. Intrinsic timing and spatial resolution of long-MRPC

Each long-MRPC module consists of two stacks of resistive glass plates with ten uniform gas gaps with gap widths of 250 μm. High voltage is applied to electrodes on the outer surfaces of the outer plates of each stack. A charged particle traversing a module generates avalanches in the gas gaps which are read out by six copper pickup strips with strip dimensions of 870×25 mm^2. The MRPC modules were operated at 12.6 kV with a mixture of 95% $C_2H_2F_4$ and 5% iso-butane at 1 atmosphere. Fig. 2 shows the efficiency and intrinsic timing resolution as a function of half of applied high voltage (HV) from the cosmic ray test. In the high voltage range

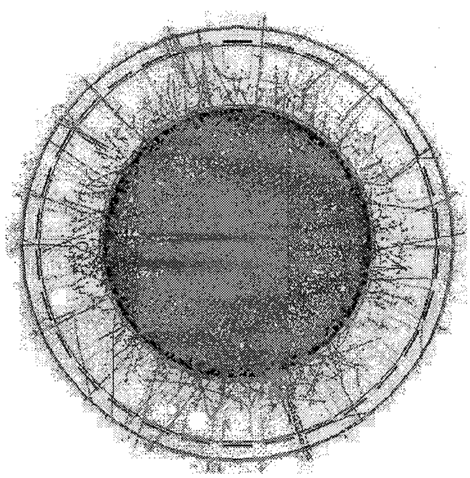

Fig. 1. (in color online) A full HIJING central Au+Au collisions simulated in STAR.

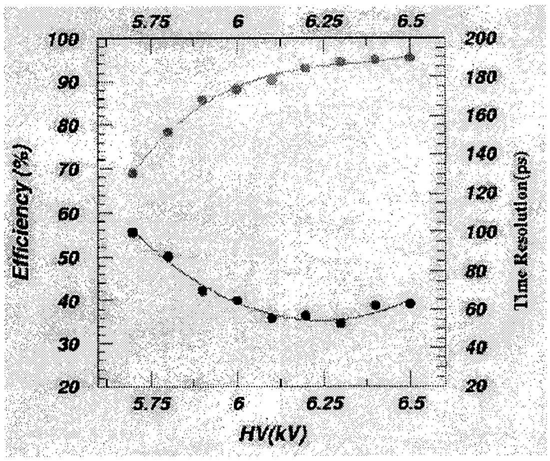

Fig. 2. (in color online) Efficiency and intrinsic timing resolution, from the cosmic ray tests, as a function of half the applied high voltage.

$12.5 < HV < 13.0$ kV, the efficiency is above 95% and timing resolution is about 60-70 ps. In additional to the cosmic ray test, a beam test named T963 was carried out in the MTEST beam line at Fermi National Accelerator Laboratory (FNAL) in May 2007. The results from beam tests using prototype front-end electronics show timing resolution and efficiency consistent with those from the cosmic ray tests. The spatial resolution of the long-MRPC along the long strip is about 0.6-1 cm. This satisfies the needs for a large-area muon detector. The details of the long-MRPC construction and its performance in the cosmic ray and beam tests can be found in this paper [6].

4. Prototype performance of muon detector at STAR

The prototype of the MTD, covered $\pi/60$ in azimuth and $-0.25 < \eta < 0.25$ in pseudo-rapidity at a radius of $\sim$ 400 cm during the 2007 run in 200 GeV Au+Au collisions. It contained two long-MRPC modules. The prototype was placed outside of the magnet steel that serves as hadron absorber. The prototype successfully triggered the data acquisition system. Fig. 3 shows azimuthal angle distribution of particles from the TPC extrapolated to a radius of 400 cm in Au+Au collisions at transverse momentum $p_T > 4$ GeV/c. The peak shows an enhancement of particle yield at the angle where MTD is positioned. This indicates that offline tracking of particles from the TPC was able to match hits from the Long-MRPC. The tracks of the TPC were extrapolated to the MTD barrel, resulting in position information from tracking. The time difference from two-end readout of the hit strip gave us a position measurement along the long strip of the long-MRPC. The difference of these two position values in the z direction (Δz) is shown in Fig. 4, where the z direction is the beam direction. Two components were observed in the Δz distribution. A double Gaussian function was used to fit the distribution. The σ of the narrow Gaussian was found to be $\sim$10 cm by selecting tracks of $p_T > 2$ GeV/c while the other Gaussian is significantly broader. From the GEANT simulation, it shows that muons of $p_T \sim 2.5$ GeV/c generated at the TPC center will result in a Gaussian distribution with a sigma of 9 cm in the z direction in the MTD barrel, after traversing the detector material from the TPC center to the MTD. The simulation also indicates that pions will result in a much broader distribution. Assume the broad distribution is dominated by hadrons and narrow Gaussian is dominated by muons, we obtained the muon to hadron ratio is 1.7 and muon-to-hadron enhancement factor is about 200-300 at $\Delta z < 20$ cm by requiring track matching only. Additional dE/dx and time of flight cuts significantly enhanced the muon-to-hadron ratio.

The average long-MRPC timing resolution for the two modules used in this analysis was measured to be $\sim$ 300 ps in Au+Au collisions. The "start" timing was provided by two identical upgraded pseudo-vertex position detectors (upVPD), each 5.4 m away from the TPC center along the beamline [4]. After subtracting the start timing jitter and detector material effect contribution, the timing resolution from the MTD was found to be not as good as those from cosmic and beam tests.

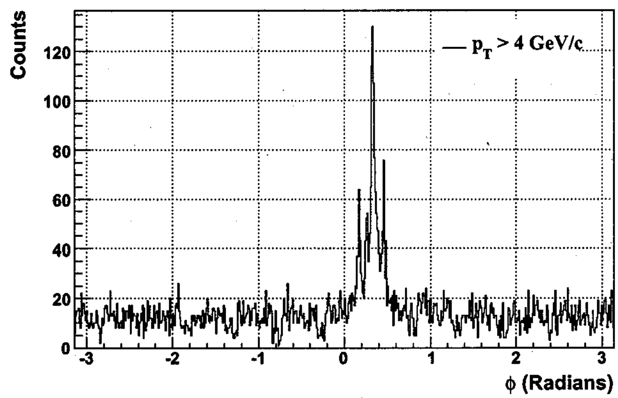

Fig. 3. (in color online) Azimuthal angle distribution of particles of $p_T > 4$ GeV/c in Au+Au collisions, extrapolated from the TPC to a radius of 400 cm.

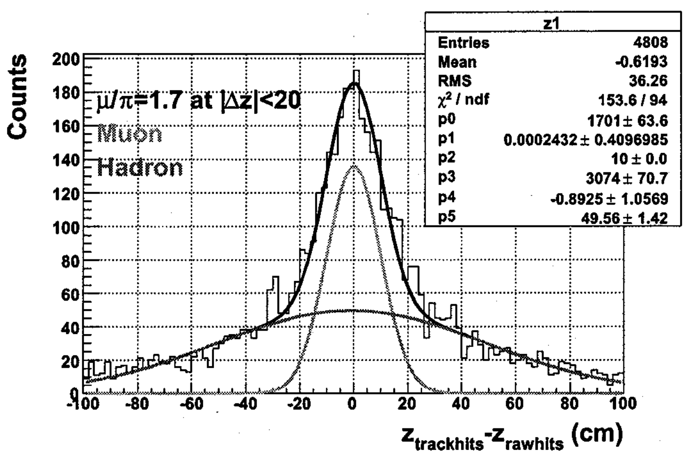

Fig. 4. (in color online) Δz distribution between extrapolated hits and MTD hits in the MTD barrel.

This is understood by the fact that the electronics we are currently using are not designed for precise time measurement. With the proposed full scale detector, we will improve our electronics.

5. Conclusions

In summary, research on a large-area, cost-effective muon telescope detector has been carried out for STAR and for next generation detectors at a future QCD Lab from state-of-the-art multi-gap resistive plate chambers with large modules and long strips. Cosmic ray and beam tests show the intrinsic timing resolution of the long-MRPC is about 60-70 ps and spatial resolution is better than 1 cm. The MTD triggered data at STAR show that offline tracking of particles from the TPC was able to match hits from the Long-MRPC. A clear muon peak was observed. The hadron rejection power is found to be a few hundreds by requiring track matching only.

In the year 2008 run, we took MTD triggered data in d+Au and p+p collisions. Possible physics topics such as electron muon correlations, muon spectra and elliptic flow will be pursued in d+Au, p+p and Au+Au collisions. For the year 2009 run, we plan to install another prototype tray, which will be equipped with the same electronics as the time of flight system at STAR, to further address the timing resolution of the Long-MRPC at STAR. We plan to optimize the detector configuration and write a proposal for full-coverage muon telescope detector at STAR.

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