A Novel and Compact Muon Telescope Detector at STAR for Midrapidity Di-lepton Physics at RHIC

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Abstract:

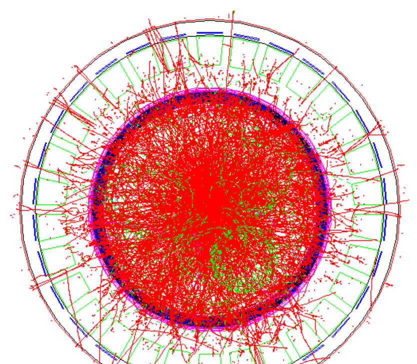
Data taken over the last decade have demonstrated that RHIC has created a hot, dense medium with partonic degrees of freedom. One of the physics goals for the next decade is to study the fundamental properties of this medium such as temperature, density profile, and color screening length via electro-magnetic probes such as di-leptons. Muons have a clear advantage over electrons due to reduced Bremsstrahlung radiation in the detector material. This is essential for separating the ground state (1S) of the Upsilon from its excited states (2S+3S) which are predicted to melt at very different temperatures. We propose a novel and compact Muon Telescope Detector (MTD) in the Solenoidal Tracker at RHIC (STAR) at mid-rapidity to measure different Upsilon states, J/psi over a broad transverse momentum range through di-muon decays to study color screening features, and muon-e correlations to distinguish heavy flavor correlations from initial lepton pair production. In this poster, we present the physics cases for the proposed MTD. We report the R&D results including simulations and MTD prototype performance at STAR.

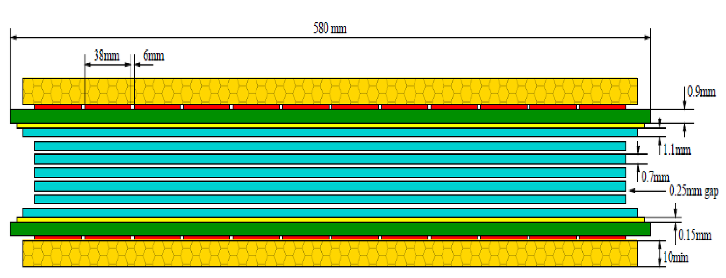
Physics motivation

A large area of MTD at mid-rapidity, allows for the detection of

- di-muon pairs from QGP thermal radiation, quarkonia, light vector mesons, resonances in QGP, and Drell-Yan production
- single muons from the semi- leptonic decays of heavy flavor hadrons
- advantages over electrons: no γ conversion, much less Dalitz decay contribution, less affected by radiative losses in the detector materials, trigger capability in Au+Au
- trigger capability for low to high p_T J/ψ in central Au+Au collsions
  excellent mass resolution, separate different upsilon states
  e-muon correlation to distinguish heavy flavor production from initial lepton pair production

Concept of design



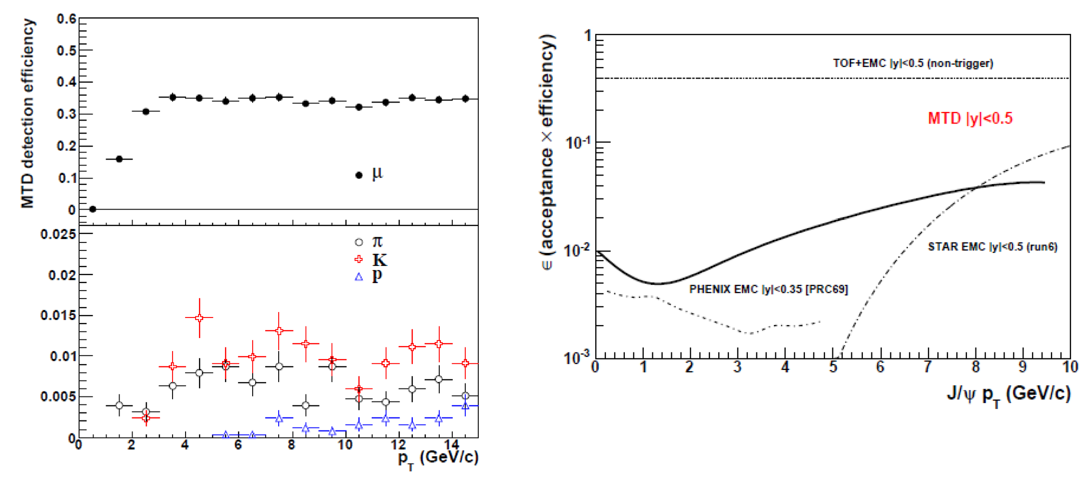


A detector with long-MRPCs covers the whole iron bars and leave the gaps in-between uncovered. Acceptance: 45% at $|\eta|<0.5$

118 modules, 1416 readout strips, 2832 readout channels

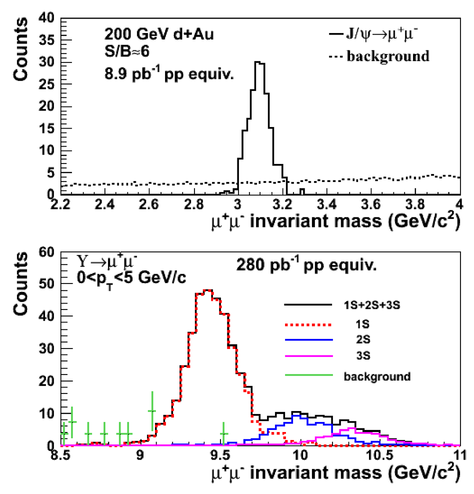
Long-MRPC detector technology, HPTDC electronics (same as STAR-TOF)

Simulation: single muon and J/psi efficiency



1. muon efficiency at $|\eta|<0.5$: 36%, pion efficiency: 0.5-1% at $p_T>2$ GeV/c
2. muon-to-pion enhancement factor: 50-100
3. muon-to-hadron enhancement factor: 100-1000 including track matching, tof and dE/dx
4. dimuon trigger enhancement factor from online trigger: 40-200 in central Au+Au collisions

High mass di-muon capability



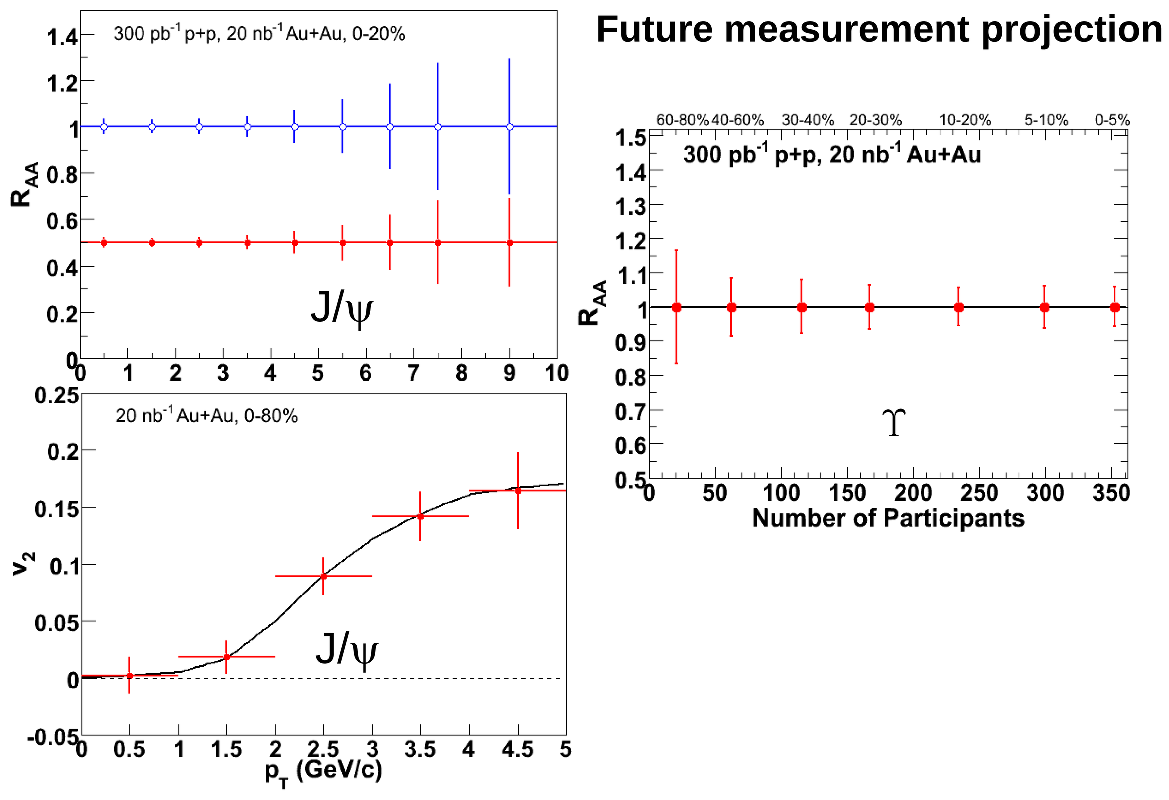
1. J/ψ: S/B=6 in d+Au and S/B=2 in central Au+Au
2. With HFT, study B→J/ψ X; J/ψ→$\mu\mu$ using displaced vertices
3. Excellent mass resolution: separate different upsilon states

Heavy flavor collectivity and color screening, quarkonia production mechanisms:
J/ψ R_{AA} and v_2; upsilon R_{AA} …

Z. Xu, BNL LDRD 07-007; L. Ruan et al., Journal of Physics G: Nucl. Part. Phys. 36 (2009) 095001

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

Future measurement projection



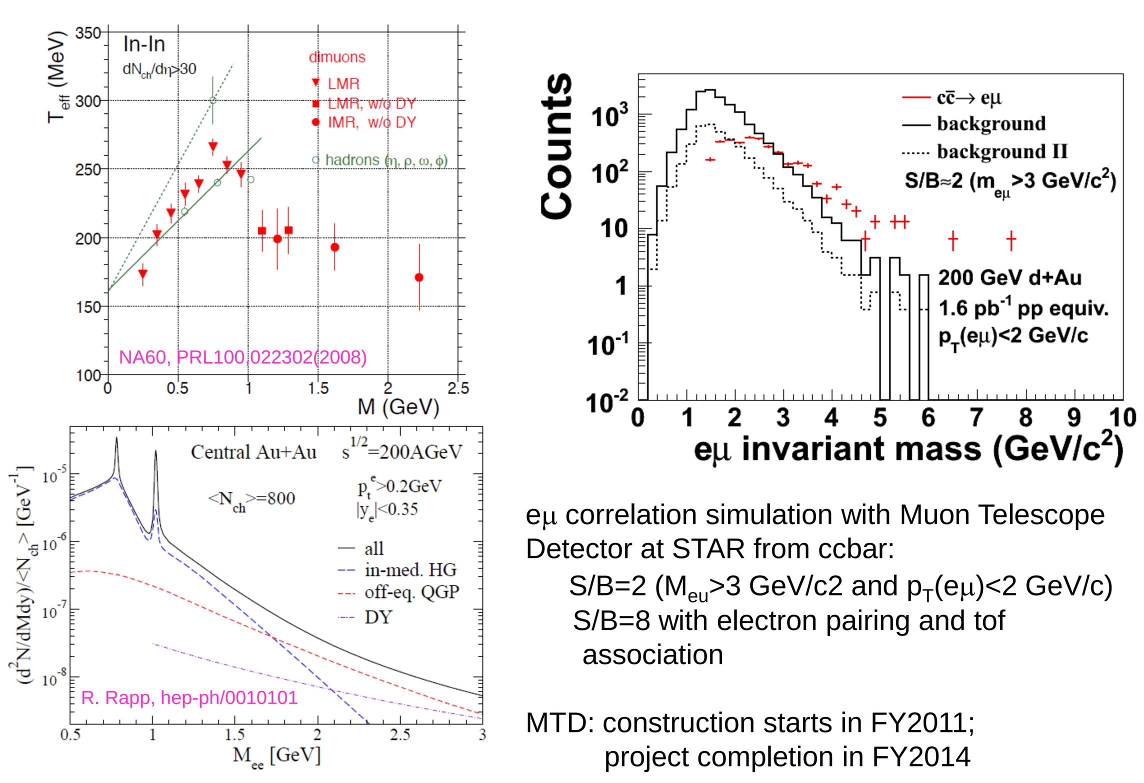
Upsilon statistics

Delivered luminosity: 2013 projected;
Sampled luminosity: from STAR operation performance

Collision system	Delivered lumi. 12 weeks	Sampled lumi. 12 weeks (70%)	Υ counts	Min. lumi. precision on Υ (3s) (10%)	Min. lumi. precision on Υ (2s+3s) (10%)
200 GeV p+p	200 pb^{-1}	140 pb^{-1}	390	420 pb^{-1}	140 pb^{-1}
500 GeV p+p	1200 pb^{-1}	840 pb^{-1}	6970	140 pb^{-1}	50 pb^{-1}
200 GeV Au+Au	22 nb^{-1}	16 nb^{-1}	1770	10 nb^{-1}	3.8 nb^{-1}

Upsilon in 500 GeV p+p collisions can also be measured with good precision.

e-muon correlations



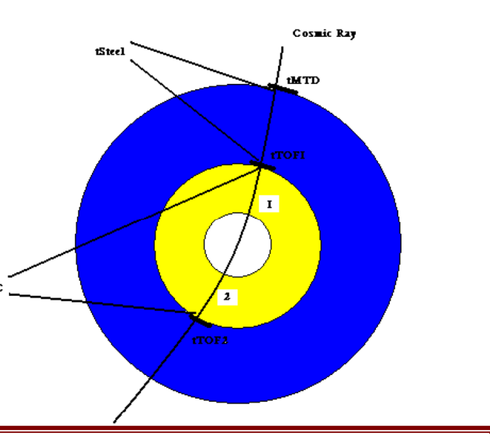
eμ correlation simulation with Muon Telescope Detector at STAR from ccbar:
S/B=2 ($M_{e\mu}$>3 GeV/c2 and $p_T(e\mu)$<2 GeV/c)
S/B=8 with electron pairing and tof association

MTD: construction starts in FY2011;
project completion in FY2014

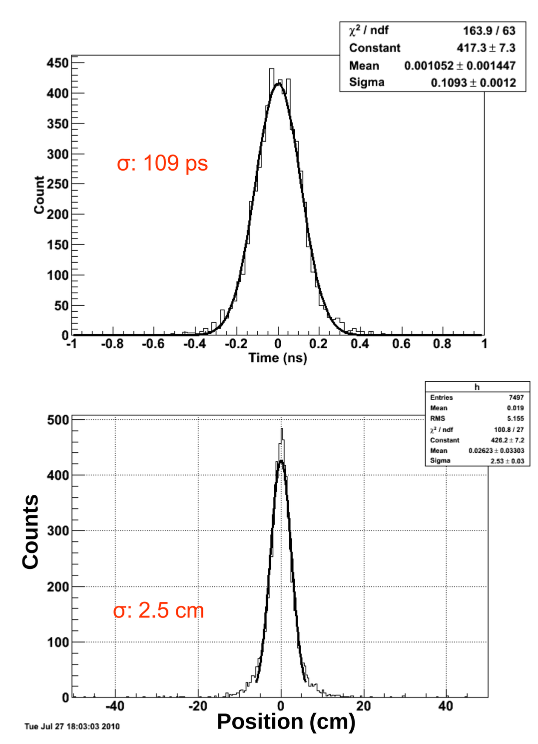
R&D summary table

Conditions	Modules and readout
Cosmic ray and Fermi-lab T963 beam tests	double stacks, module size: 87(z)×17(ϕ) cm^2, Performance: 60 ps, ~0.6 cm at HV ± 6.3 kV
Run 7: Au+Au Run 8: p+p, d+Au	double stacks, 2 modules in a tray, module size: 87(z)×17(ϕ) cm^2, Readout: trigger electronics, Time resolution: 300 ps
Run 9: p+p Run 10: Au+Au, cosmic ray	double stacks, 3 modules in a tray, module size: 87(z)×17(ϕ) cm^2, Readout: TOF electronics; trigger electronics for trigger purpose.
Run 11	single stack, 1 module in a tray, module size: 87(z)×52(ϕ) cm^2, Readout: TOF electronics; trigger electronics for trigger purpose, Cosmic ray test performance: <100 ps

Run10 performance: timing and spatial resolution



Cosmic ray trigger
Total resolution: 109 ps
Start resolution (2 TOF hits): 46 ps
Multiple scattering: 25 ps
MTD intrinsic resolution: 96 ps
System spatial resolution: 2.5 cm, dominated by multiple scattering

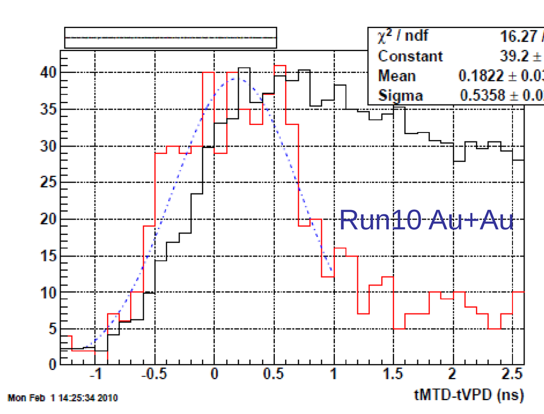


Trigger Capability

RHIC II lumonisity in terms of collision rate: 40 k Hz;
Au+Au projection: based on Run 10 prototype performance.

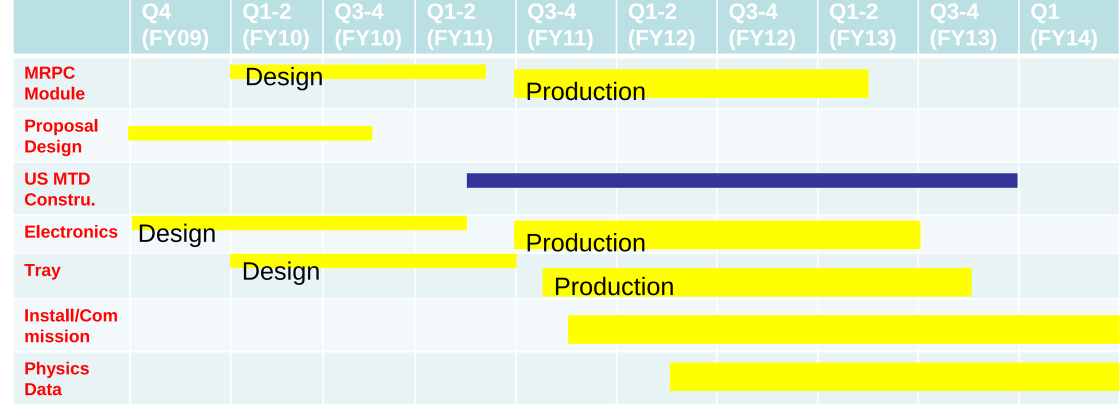
trigger time window	double-hit rejection factor	dimuon L0 trigger rate
2 ns	50	800 Hz
1.5 ns	116	185 Hz
1 ns	509	80 Hz

1 ns trigger window: 80 Hz for dimuon trigger



L0 trigger timing resolution (assumed)	di-muon trigger efficiency of the timing cut
140 ps	±3.6σ (100%)
200 ps	±2.5σ (98%)
300 ps	±1.7σ (80%)

MTD schedule



Finish the project by Mar, 2014 and make 80% of the full system ready for year 2014 run

Summary

MTD will advance our knowledge of Quark Gluon Plasma:

low to high p_T J/ψ in central Au+Au collisions (trigger capability)

separate different upsilon states (excellent mass resolution)

distinguish heavy flavor production from initial lepton pair production (e-muon correlation)

rare decay and exotics
complementary measurements for dileptons (different background contribution) …

The prototype of MTD works at STAR from Run 7 to Run 11. Results published at L. Ruan et al., Journal of Physics G: Nucl. Part. Phys. **36** (2009) 095001; 0904.3774; Y. Sun et al., NIMA 593 (2008) 430.

The details are at http://www.star.bnl.gov/~ruanlj/MTDreview2010/mtd.htm
http://drupal.star.bnl.gov/STAR/system/files/MTD_proposal_v14.pdf

The STAR Collaboration: http://drupal.star.bnl.gov/STAR/presentations