Future dilepton measurements from STAR Upgrades

Zhangbu Xu
(Brookhaven National Lab)

- Free Quarks
  - Color Screening of Heavy Quarkonia
- Excited Vacuum
  - Novel symmetries in QCD
  - Dileptons as tool to systematically study Chiral Symmetry Restoration
- Projections from STAR Upgrades
  - Inner TPC Upgrade (iTPC) and Beam Energy Scan (II)
  - Muon Telescope Detector (dimuon and e-μ)
  - Heavy-Flavor Tracker (HFT)

1. FREE QUARKS
2. EXCITED VACUUM

Quark Matter 1995

1. TWO PUZZLES OF MODERN PHYSICS

The status of our present theoretical structure can be summarized as follows:

QCD (strong interaction)
$SU(2) \times U(1)$ **Theory** (electroweak)
General Relativity (gravitation).

However, in order to apply these theories to the real world, we need a set of about 18 parameters, all of unknown origins. Thus, this theoretical edifice cannot be considered complete.

The two outstanding puzzles that confront us today are:

i) Missing symmetries - All present theories are based on symmetry, but most symmetry quantum numbers are *not* conserved.

ii) Unseen quarks - All hadrons are made of quarks; yet, no individual quark can be seen.

These two puzzles have been with us for several decades, beginning with parity nonconservation in the fifties and CP and time reversal violations in the sixties. They are perhaps of an equal profundity as the puzzles which faced our predecessors around the turn of the century.

1. Color Screening of Quarkonia
2. In-medium ρ spectral function

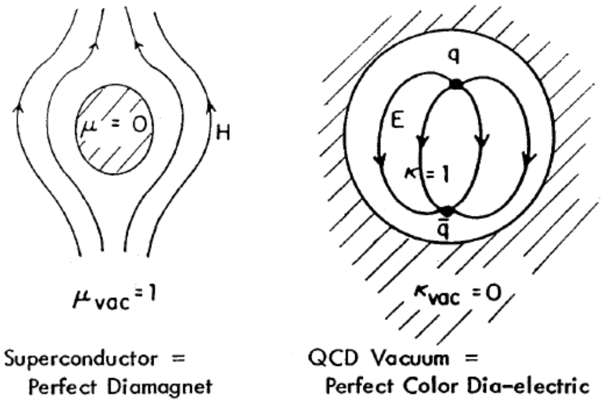


Figure 1. Superconductivity in QED vs. quark confinement in QCD.

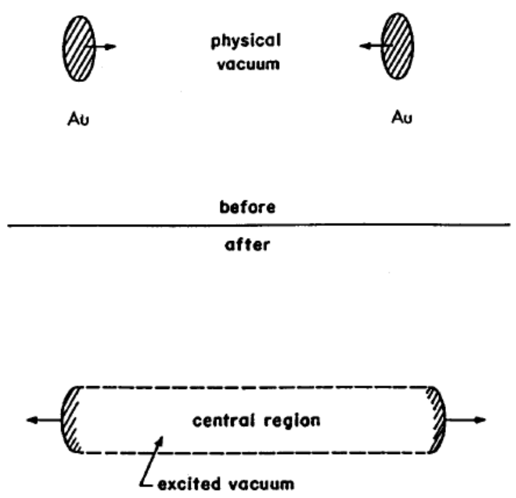
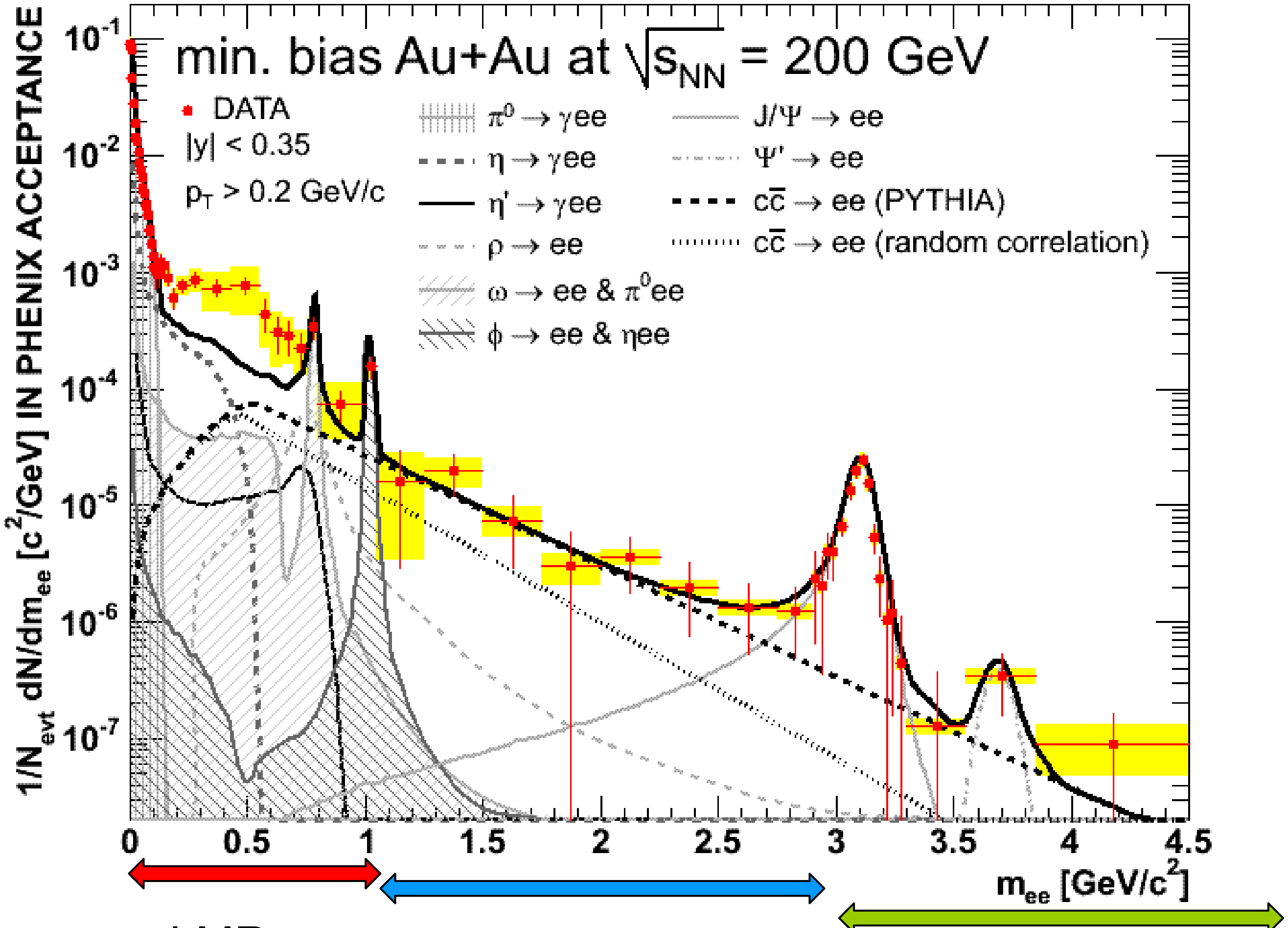


Figure 2. Vacuum excitation through relativistic heavy ion collisions.

Dilepton Mass Ranges



LMR

$\rho \rightarrow e^+e^-$

$\pi\eta\phi\omega$

IMR

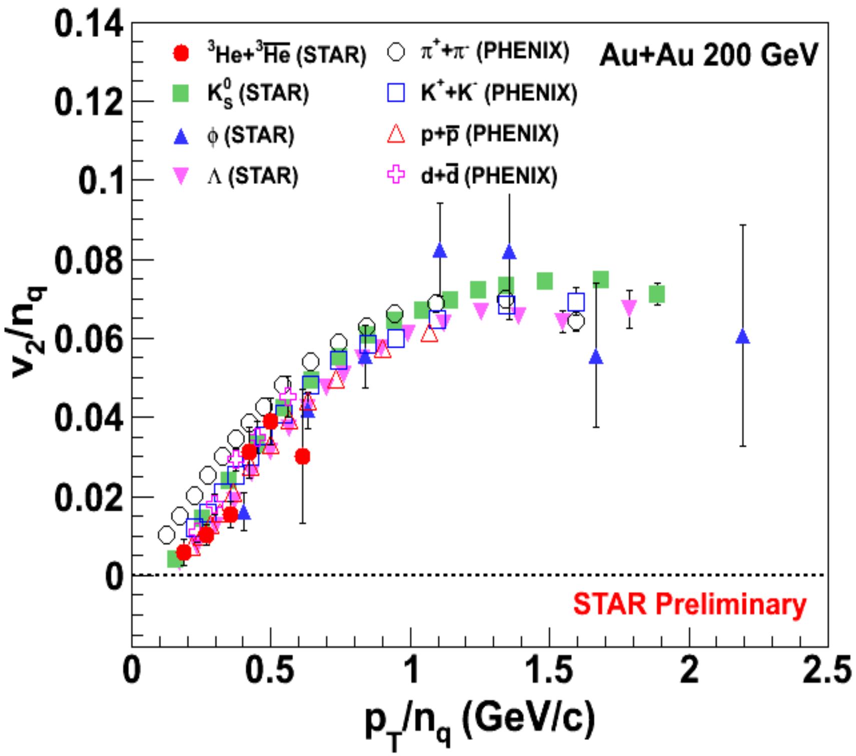
$q\bar{q} \rightarrow l^+l^-$

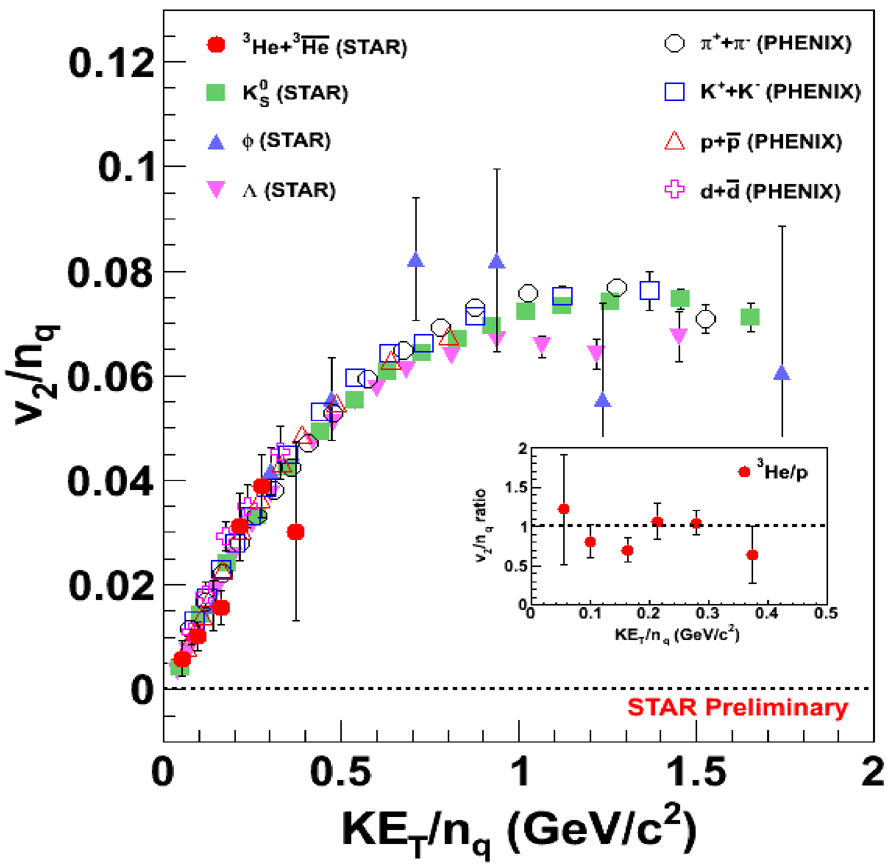
$c \rightarrow l$

HMR

J/Ψ, DY, Υ(1,2,3)

NCQ Scaling





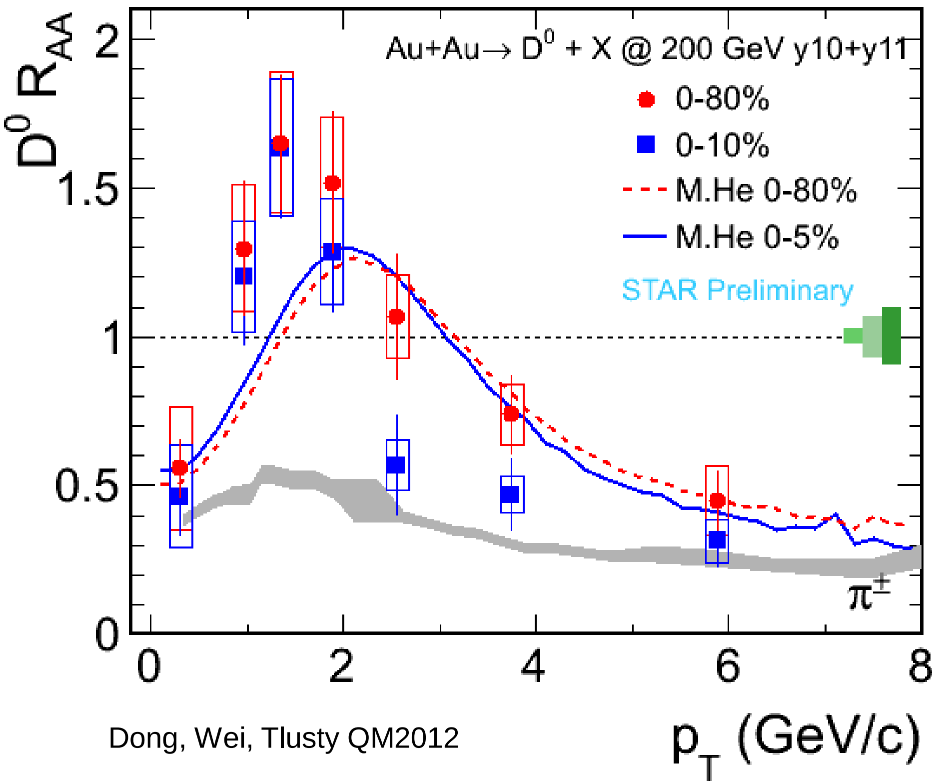
STAR, arXiv:0909.0566 [nucl-ex]

PHENIX, PRL 99, 052301 (2007)

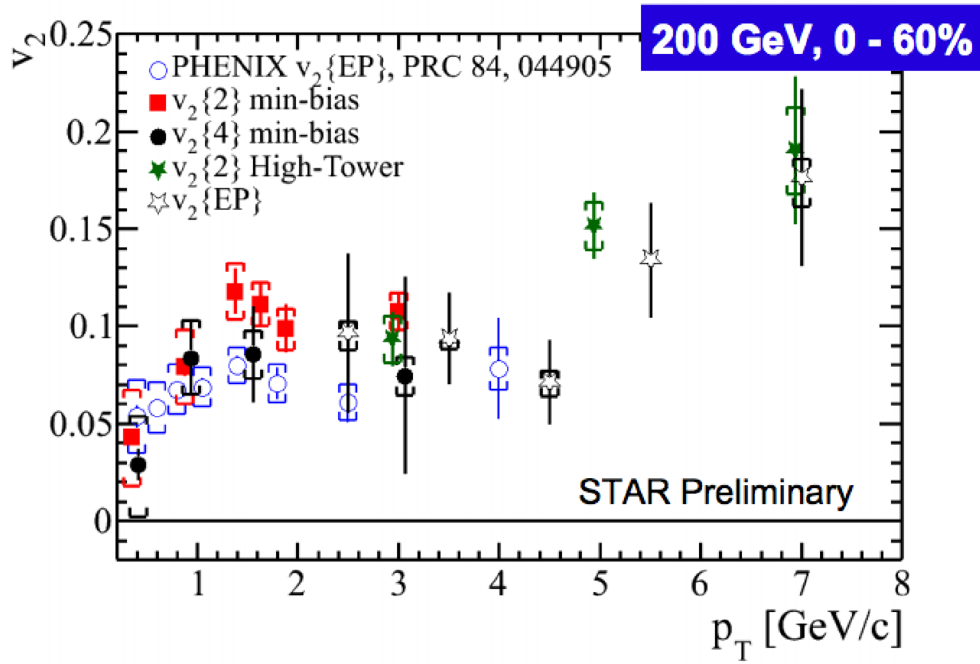
d(p+n) : n_q = 2 x 3 ^{3}He(2p+n) : n_q = 3 x 3

➢Number of **constituent quark** scaling holds well for v_2 of ^{3}He.

Flow of Heavy Quarks



Dong, Wei, Tlusty QM2012



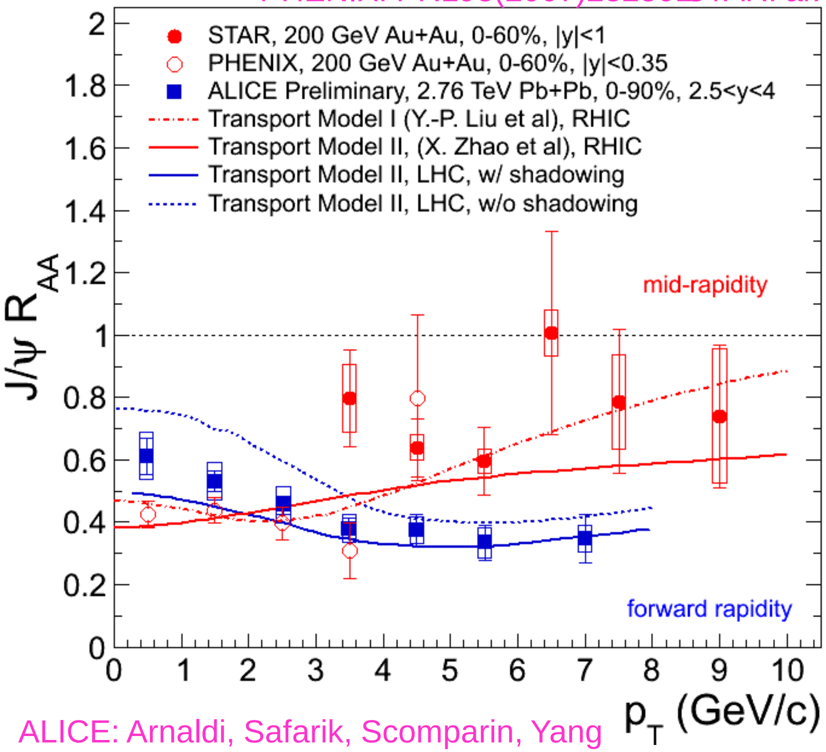
First measurement of directly reconstructed Charmed hadron radial flow at RHIC

Elliptic flow of
Electrons from heavy-flavor hadrons
Different flow methods:
large flow at low pt
Jet contribution at high pt

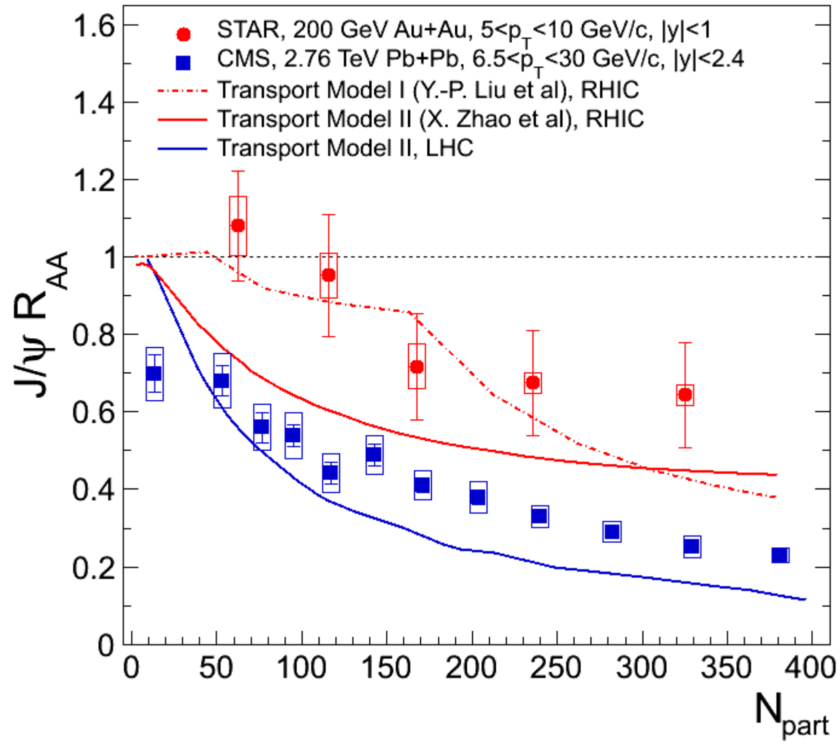
J/ψ p_T dependence in A+A

PHENIX: PRL98(2007)232301 STAR: arXiv: 1208.2736, Trzeciak, Xie

CMS: Mironov, Moon, Roland



ALICE: Arnaldi, Safarik, Scomparin, Yang



J/ψ R_{AA} decreases from low to high p_T at LHC.

J/ψ R_{AA} increases from low to high p_T at RHIC.

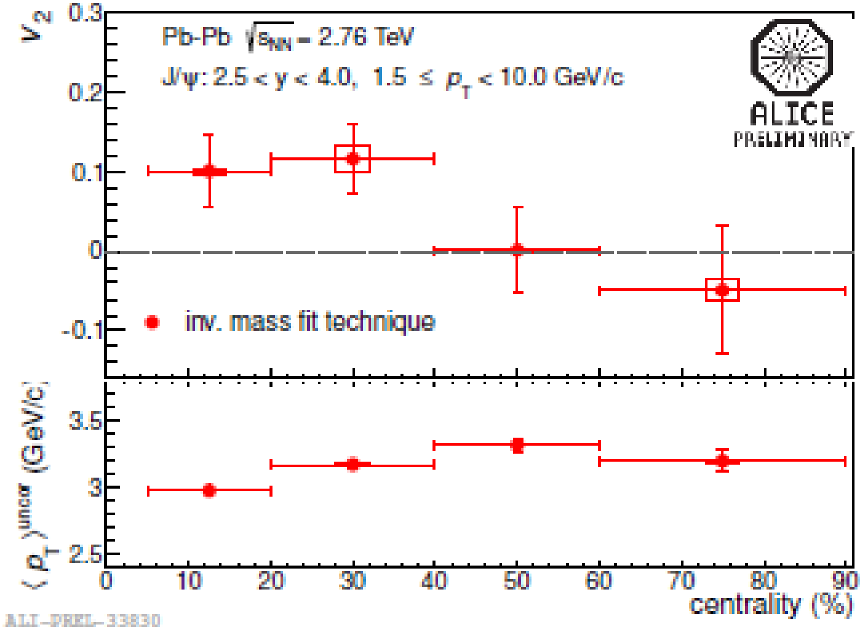
At high p_T, J/ψ more suppressed at LHC.

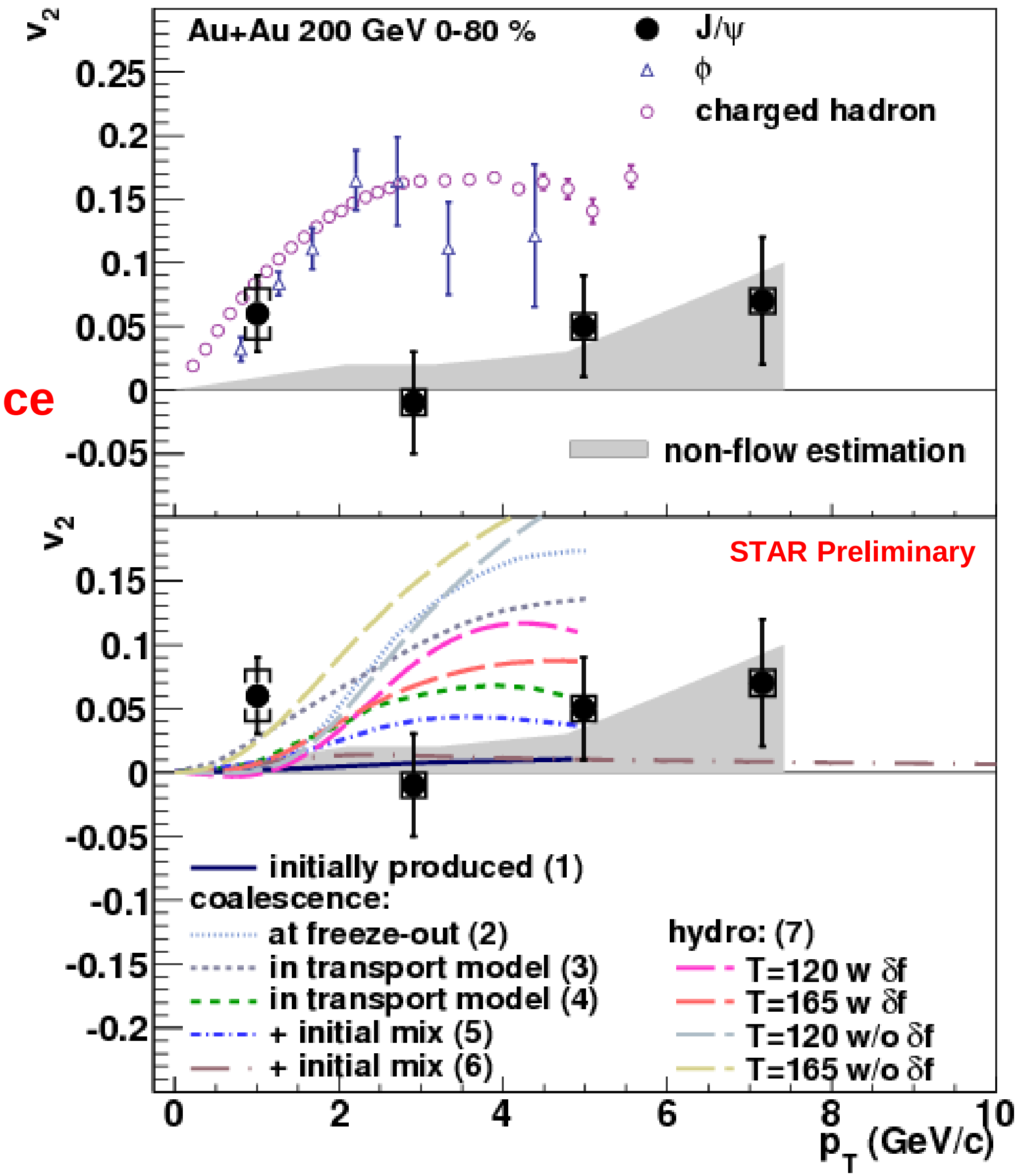
Models incorporating color screening andrecombination can consistently describe the J/ψ suppression pattern and flow measurements.

Suppression without flow

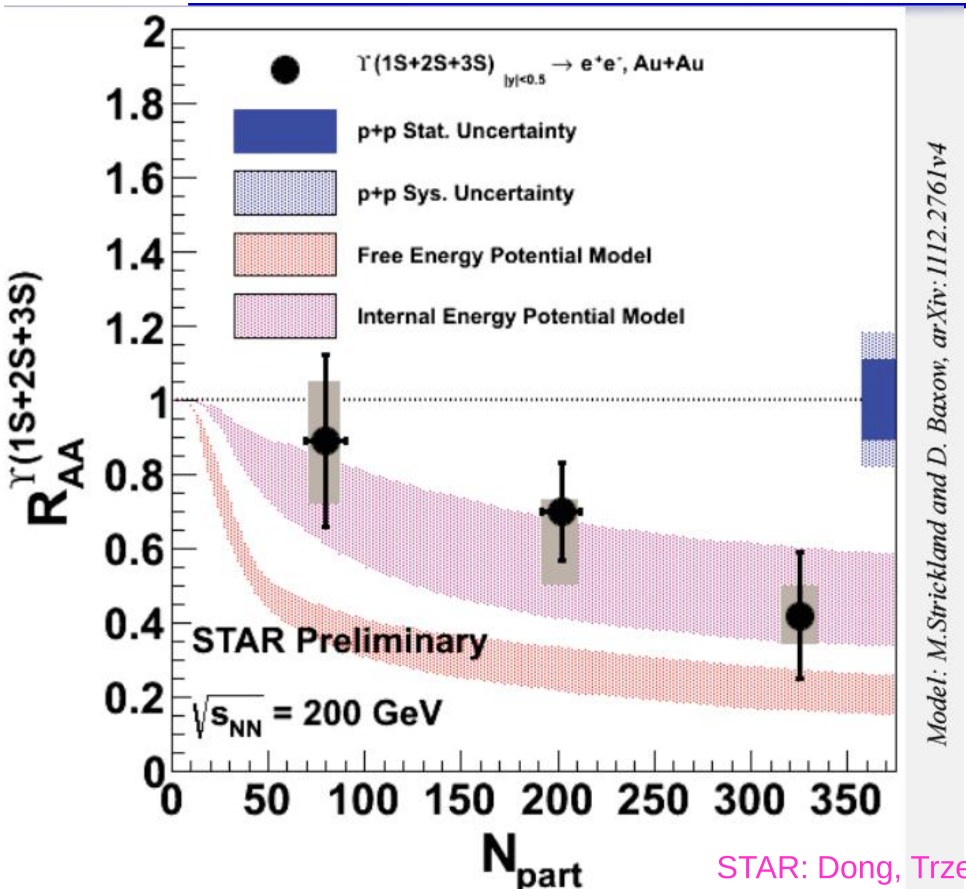
RHIC:
large suppression, zero flow
LHC:
less suppression, hints of flow

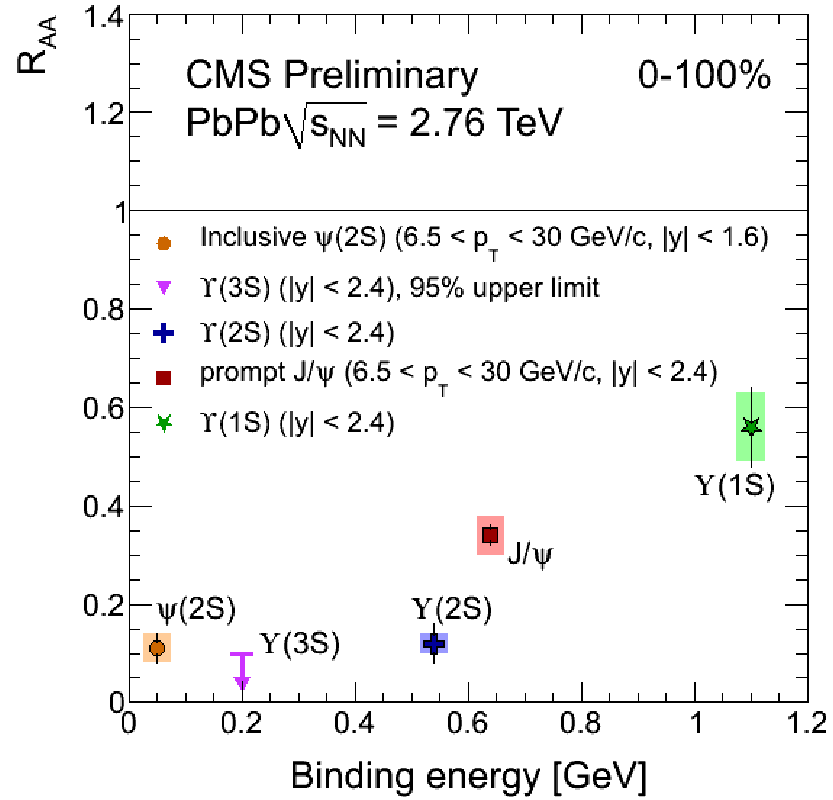
Color Screening and quark coalescence





ϒ Suppression in A+A





STAR: Dong, Trzeciak, Xie (QM2012)
CMS: arXiv: 1208.2826, Mironov, Rangel, Roland

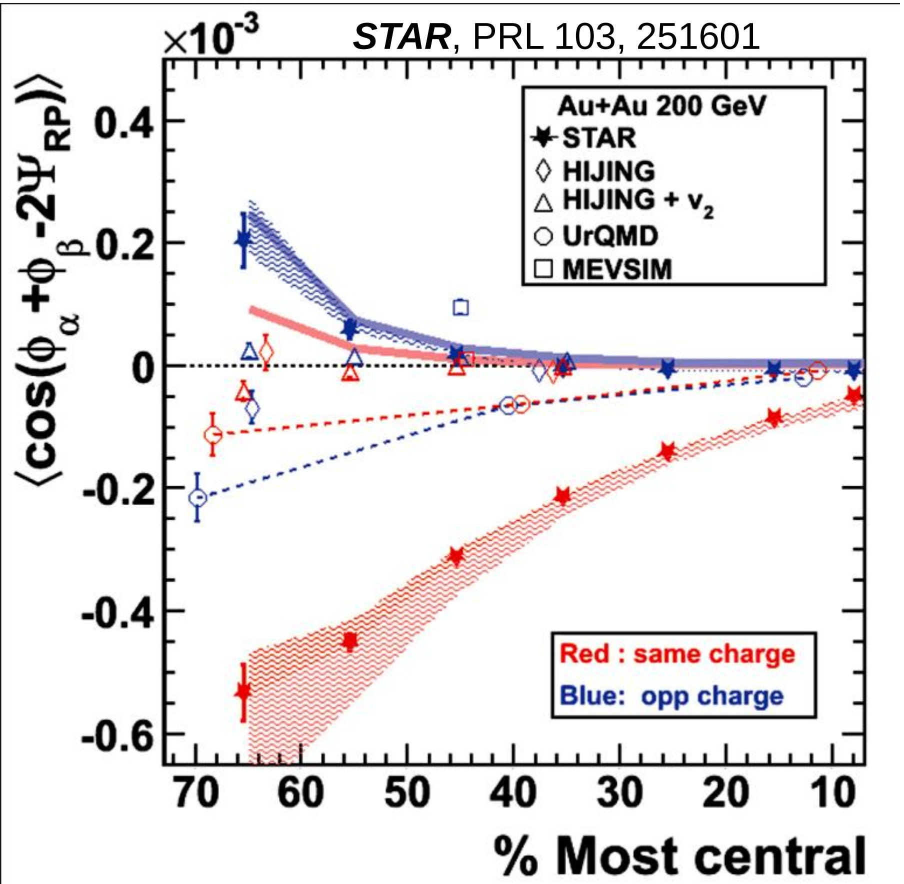
ϒ(1s) suppression magnitude consistent with excited states suppression.

ϒ(2S) strongly suppressed, ϒ(3S) completely melted.

Last piece of convincing evidence: color screening features of hot, dense medium in light of RHIC and LHC precise quarkonium measurements.

Novel Symmetries

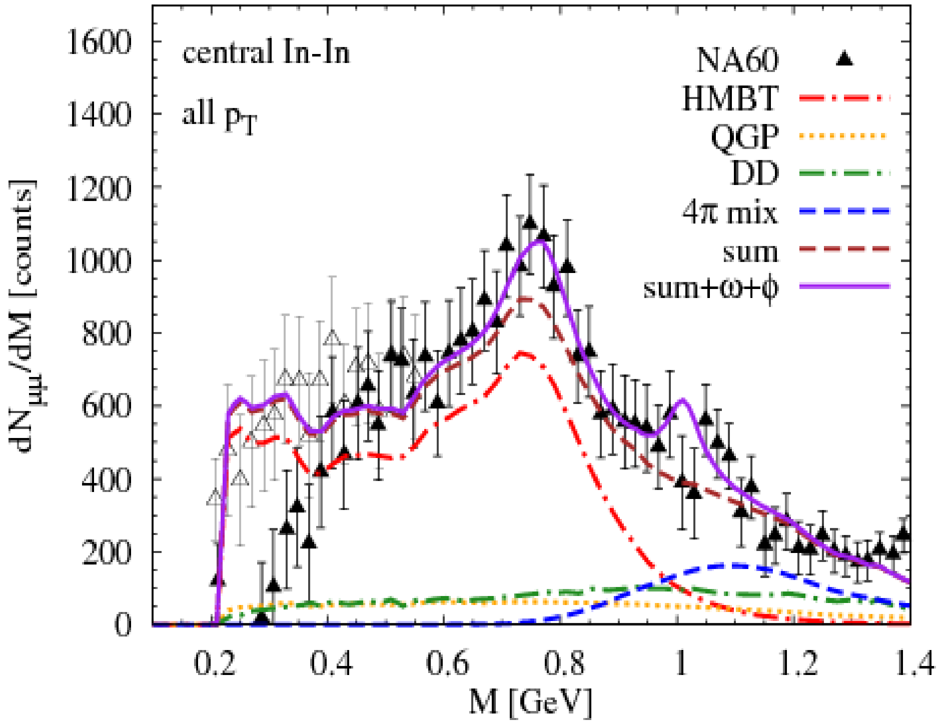
Local Parity Violation



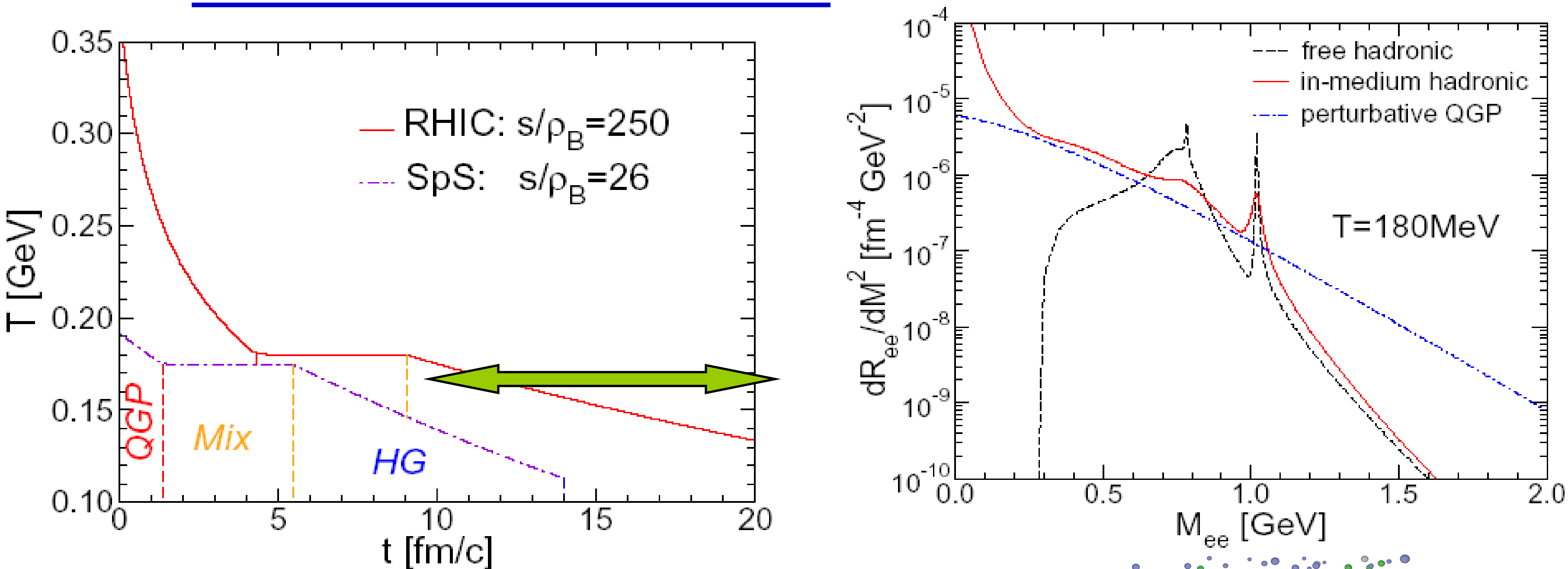
Crucial to verify if parity violation is the **correct explanation**

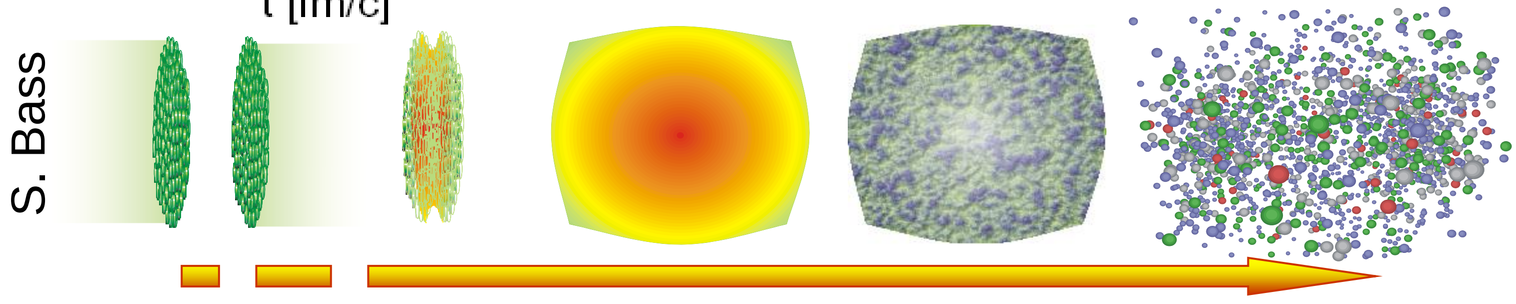
U+U collisions: collisions with **more v_2** and **less B field** than Au+Au

Chiral Symmetry



Medium Effect on Vector Meson

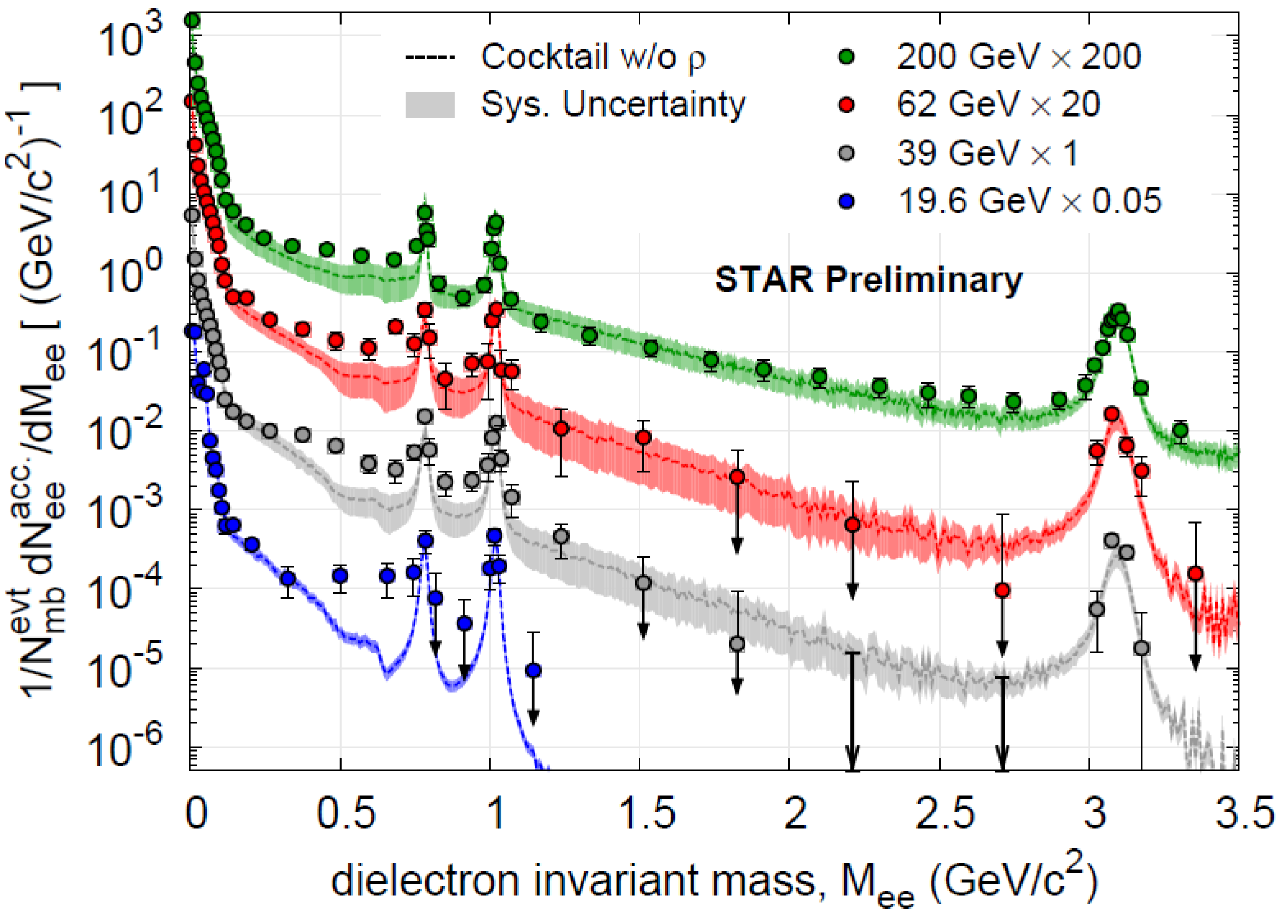




- Vector Meson Properties
- Thermal Dileptons

R. Rapp, hep-ph/0010101

Energy dependence of di-electron spectra

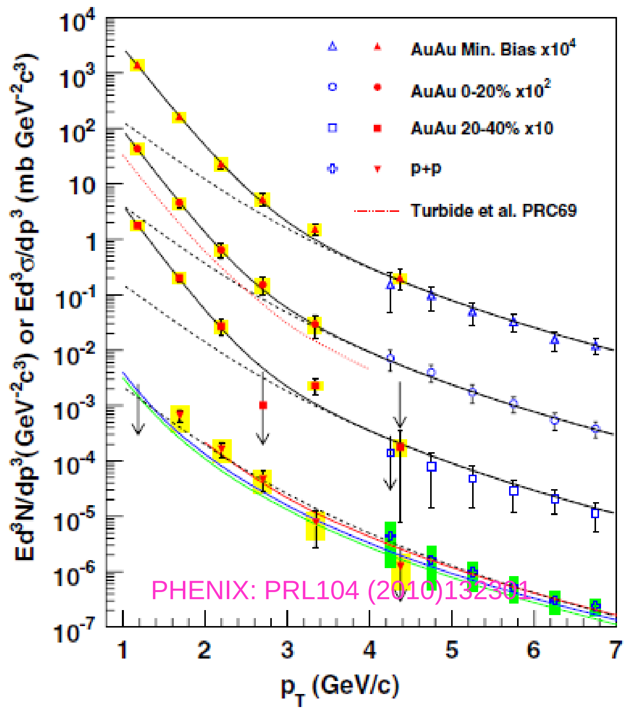


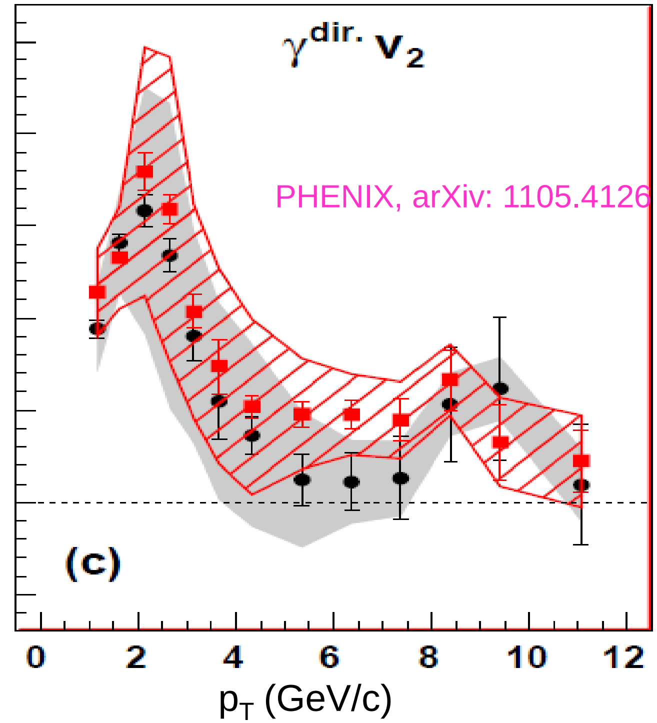
QM2012 STAR: Dong, Geurts, Huang, Huck

systematically study the di-electron continuum from 19.6, 39, 62.4 and 200 GeV.

Observe enhancement above cocktails in low mass range (~0.5 GeV/c²)

Direct photon spectra and elliptic flow

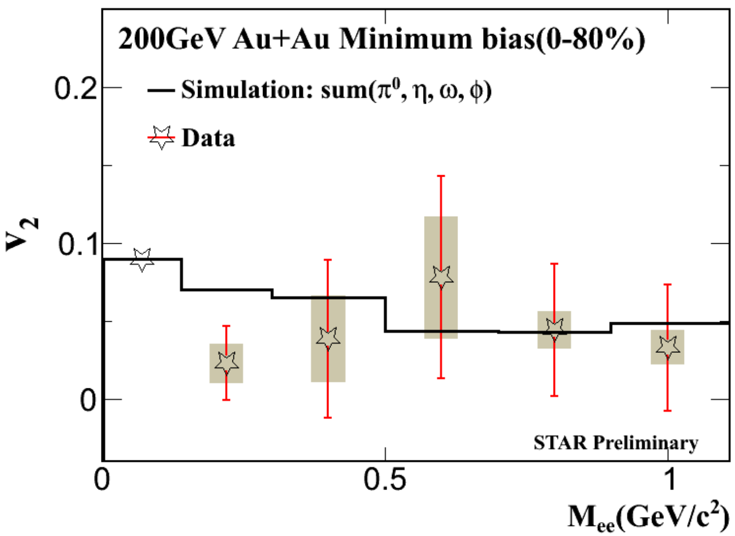




- Low p_T direct photon elliptic flow measurement could provide direct constraints on QGP dynamics (η/s, T, t_0…).
- Excess of direct photon yield over p+p: T_{eff}=221 ± 19 ± 19 MeV in 0-20% Au+Au; substantial positive v_2 observed at p_T<4 GeV/c.
- Di-lepton v_2 versus p_T & M_{ll}: probe the properties of the medium from hadron-gas dominated to QGP dominated. (R. Chatterjee, D. K. Srivastava, U. Heinz, C. Gale, PRC75(2007)054909)

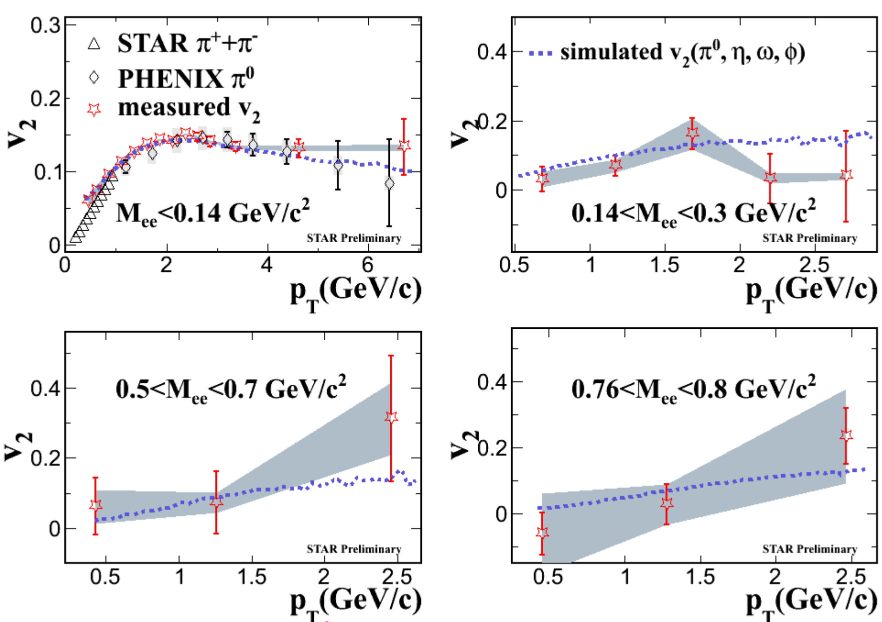
Gale, Ruan, Tserruya, QM2012

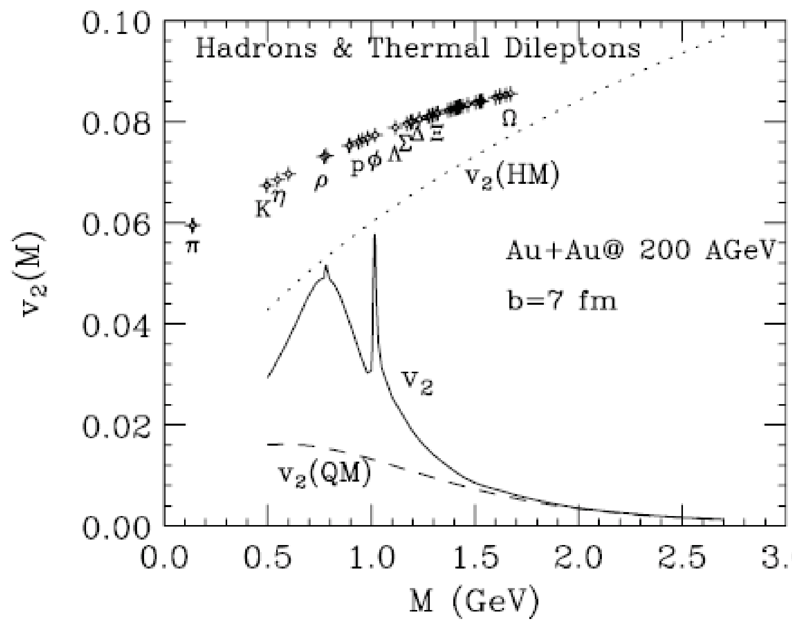
Di-electron v_2 at 200 GeV Au+Au



Cocktail simulation is consistent with the measured di-electron v_2 at M_{ee}<1.1 GeV/c2.

Need a factor of two more data to be sensitive to hardon gas and QGP contribution, in addition to independent measurements to disentangle ccbar correlation contribution





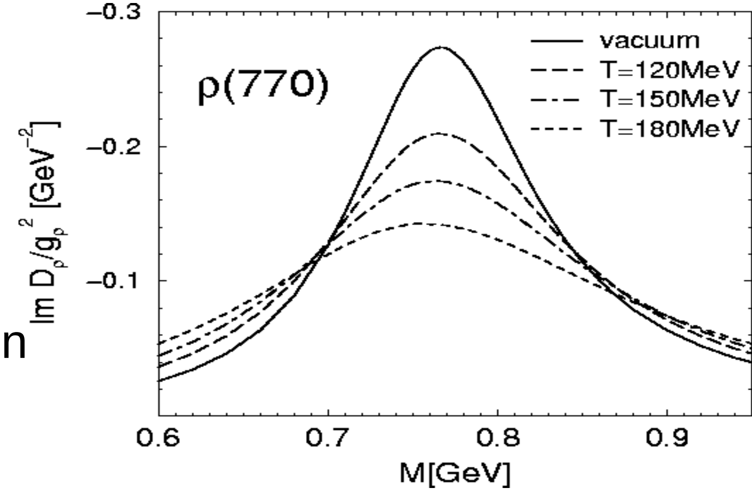
R. Chatterjee, D. K. Srivastava, U. Heinz, C. Gale, PRC75(2007)054909)

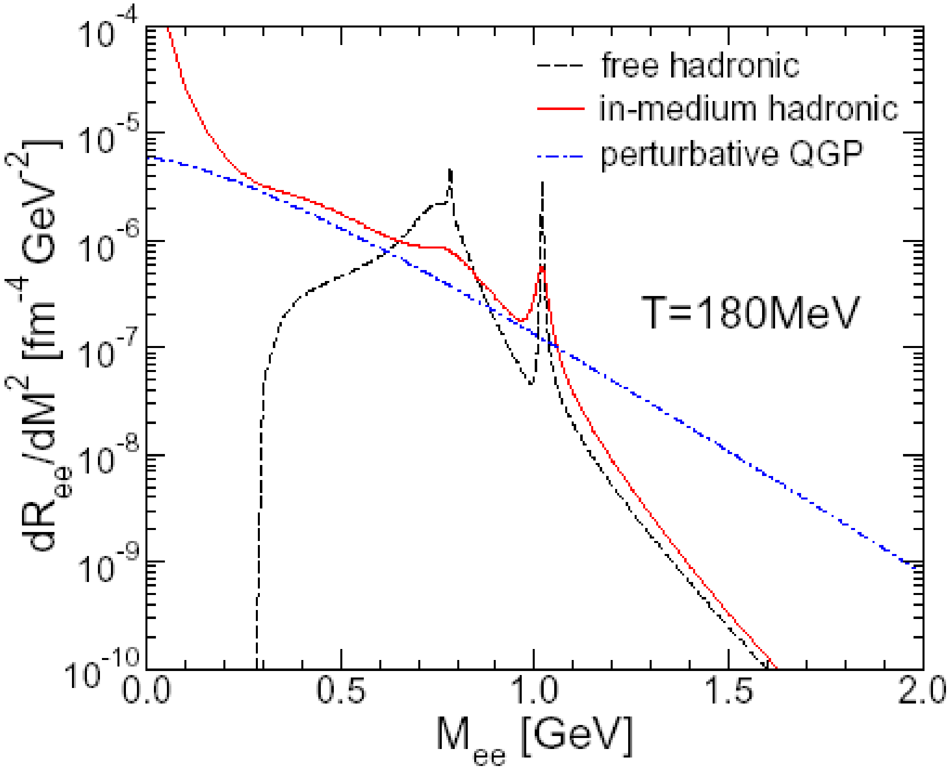
STAR: Cui, Geurts, Huang QM2012

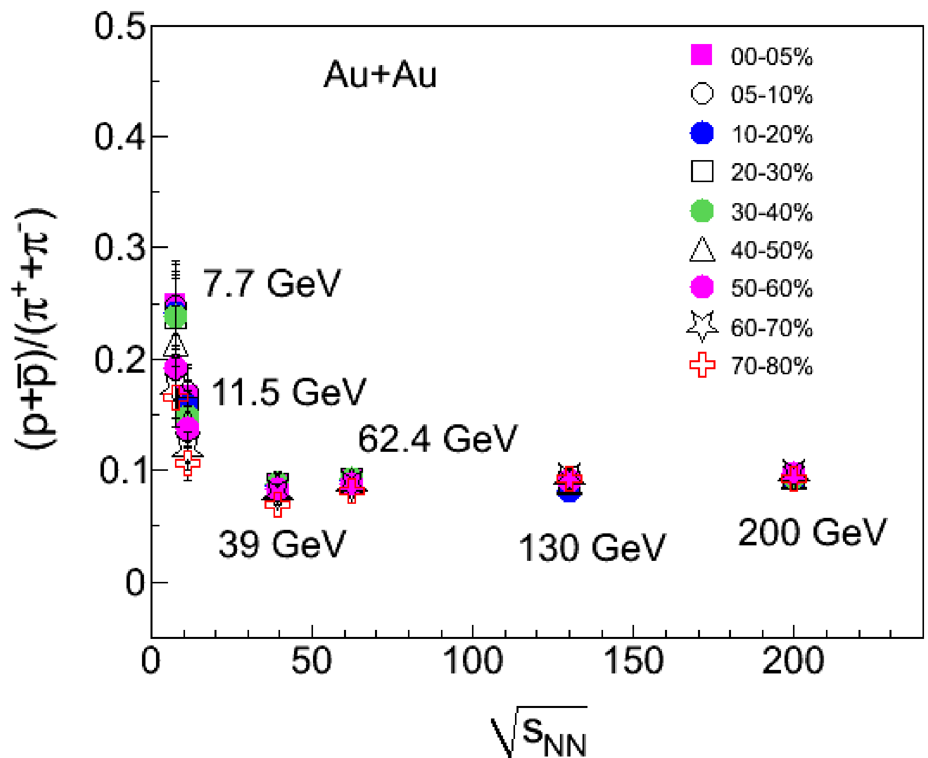
Quantify the Enhancements

Temperature dependence of rho spectral function

1. Beam energy range where final state is similar
2. Initial state and temperature evolution different
3. Density dependence by Azimuthal dependence (v_2)
4. Use centrality dependence as another knob
5. Direct photon results should match with extrapolation

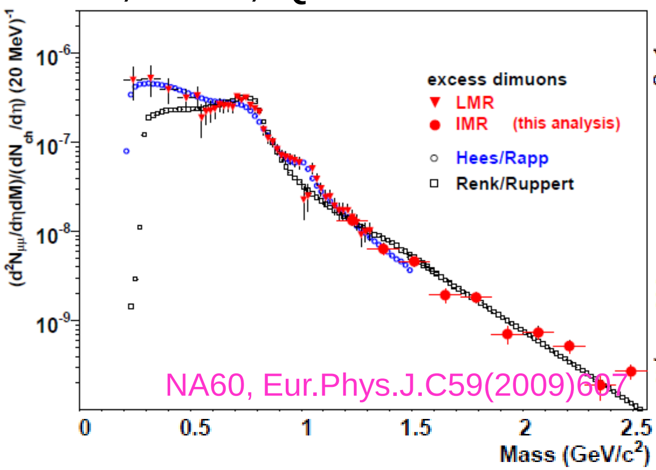




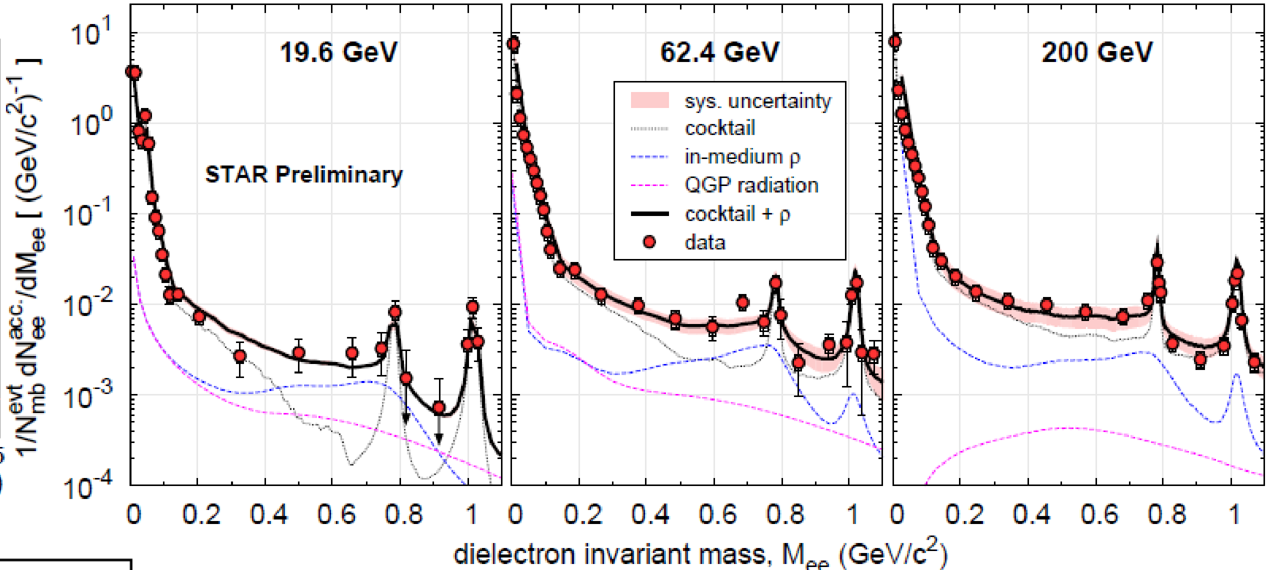


A tool to study Chiral Symmetry Restoration

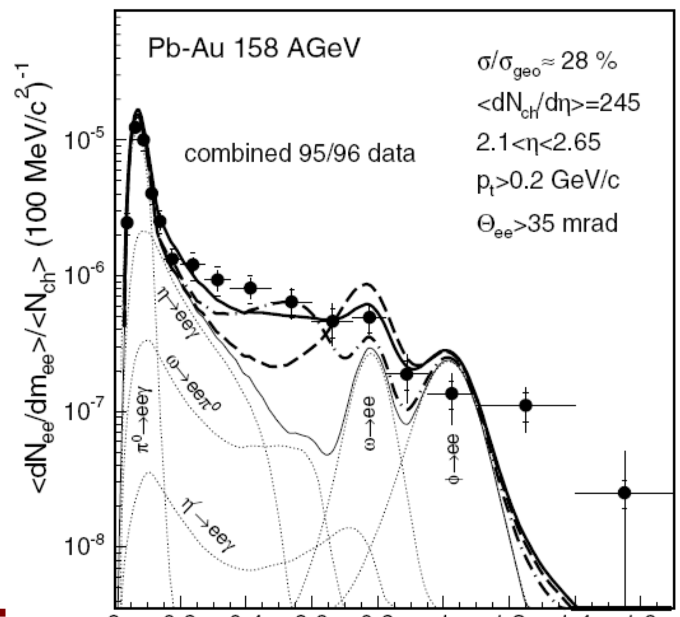
Gale,Ruan, QM2012



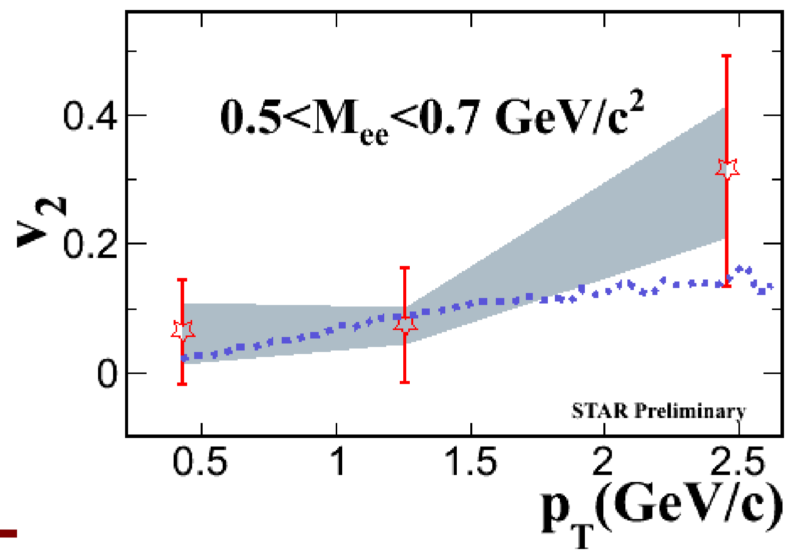
NA60, Eur.Phys.J.C59(2009)607



STAR: Cui, Dong, Geurts, Huang, Huck

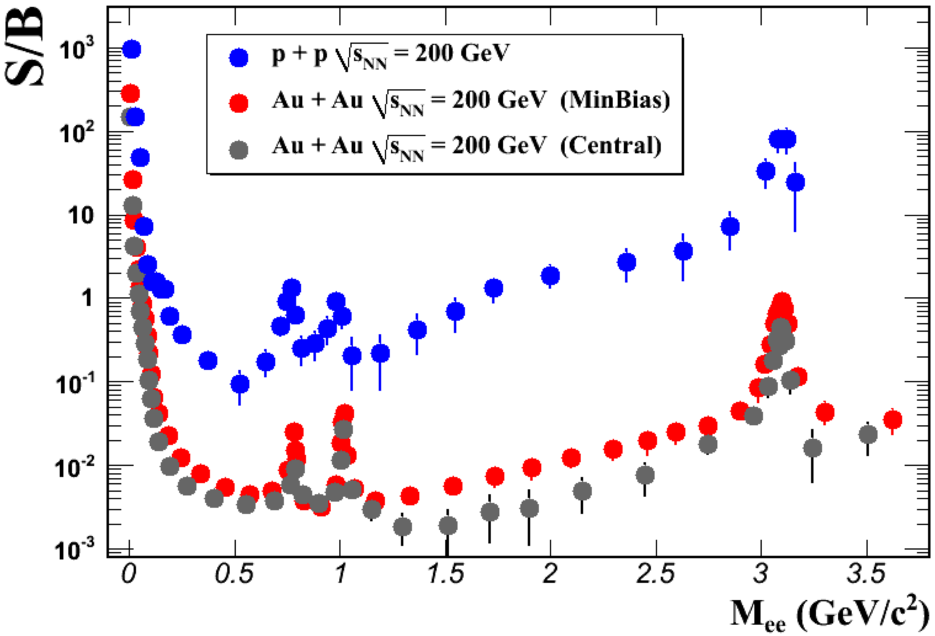


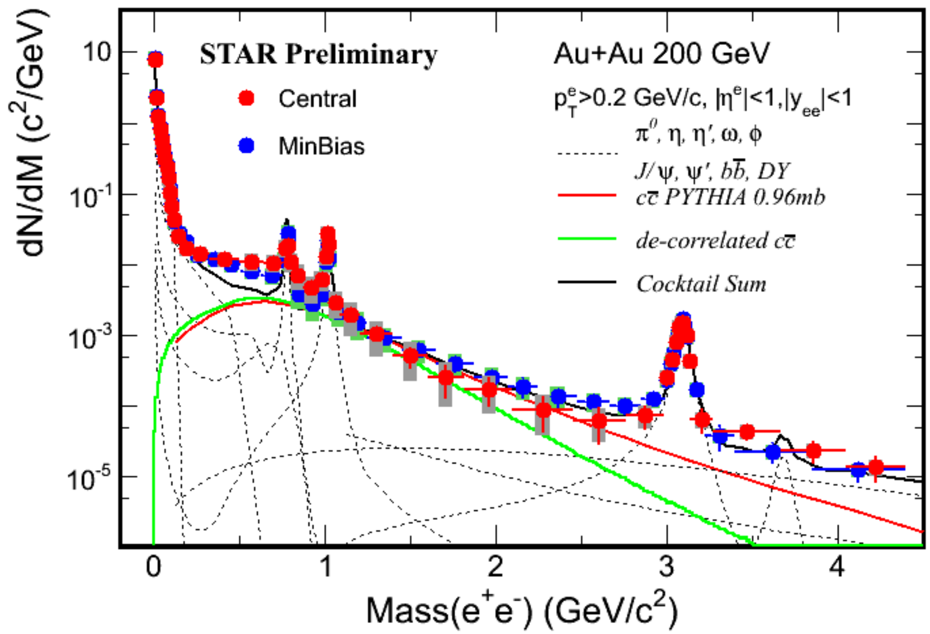
CERES: Eur.Phys.J.C41(2005)475



Issues and Solutions

Low signal to background ratio at LMR
Charm semileptonic decay (“irreducible background”)





PHENIX:
Cherenkov+EMC for electron ID
Hadron Blind Detector (HBD)
reduce Dalitz decay electron pairs

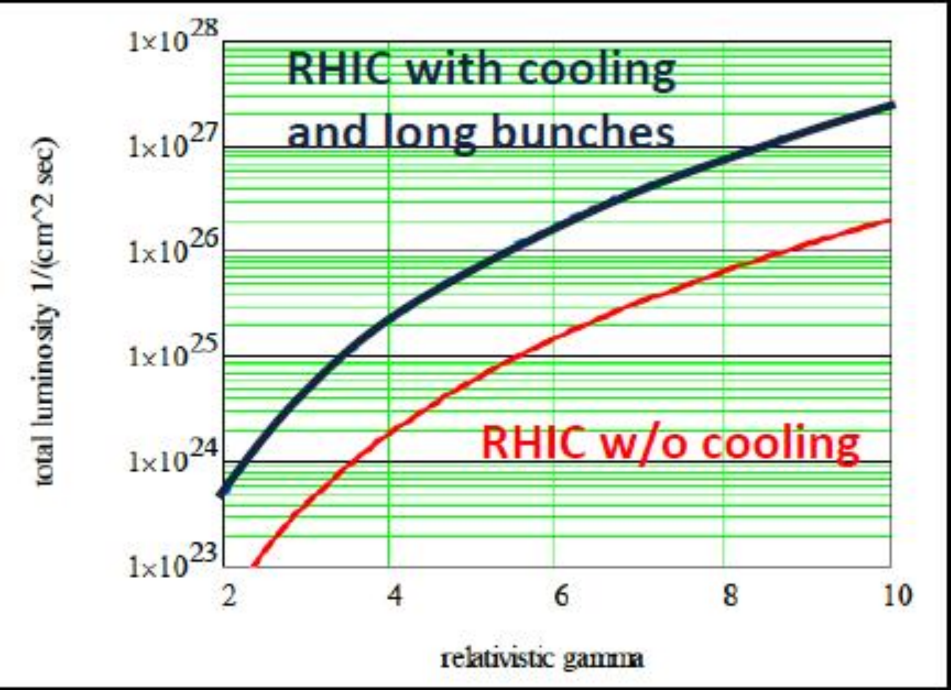
STAR:
TPC dE/dx+TOF for electron ID
BES dilepton at SPS energy
Unique μ+e pair from MTD+EMC
Same rapidity and kinematics

Must move from "Hints" → "Definitive Answers"

Beam Energy Scan (BES) Phase II

e-cooling for low energy RHIC operation

Increased acceptance for STAR and PHENIX

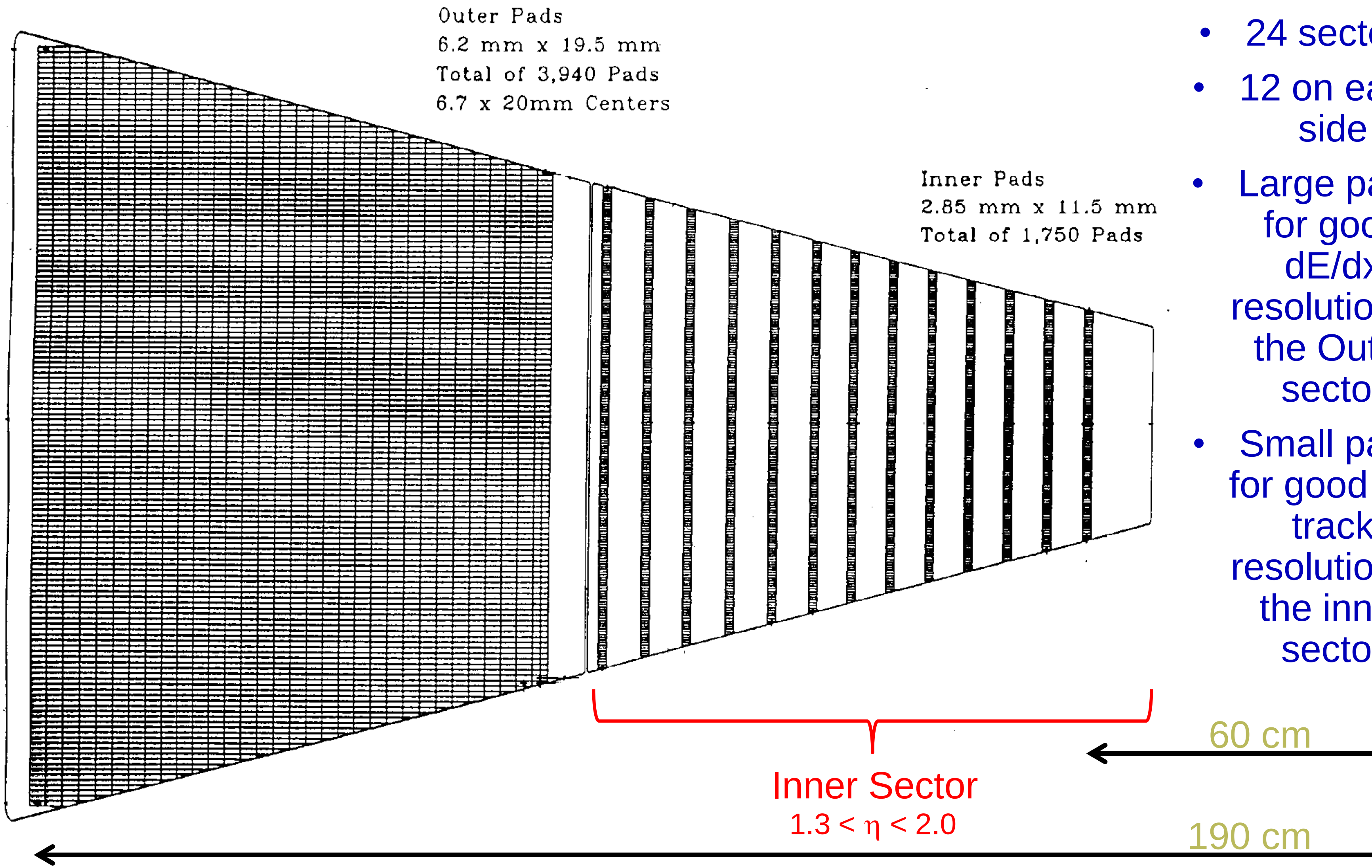


High brightness SRF electron gun or Fermilab Pelletron for 10x L

STAR Inner TPC Readout
Improved tracking and dE/dx PID
Extend η coverage 1.0-1.7

Nagle, "RHIC Future", QM2012

What is the upgrade?



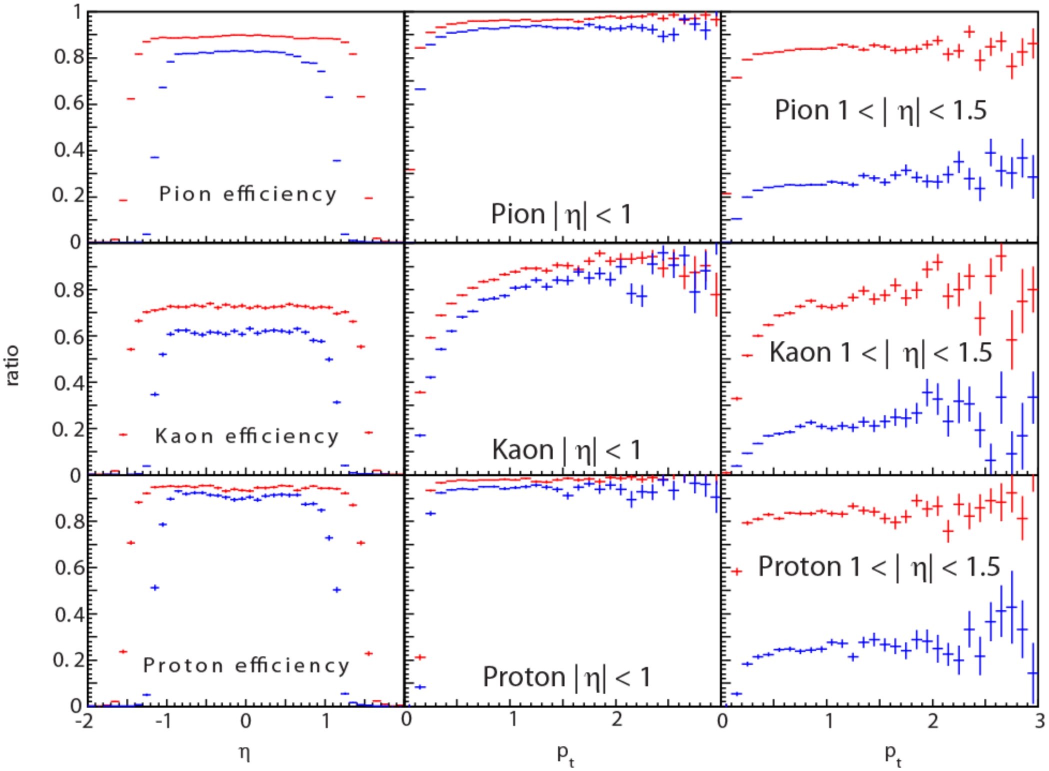
- 24 sectors
- 12 on each side
- Large pads for good dE/dx resolution in the Outer sector
- Small pads for good two track resolution in the inner sector

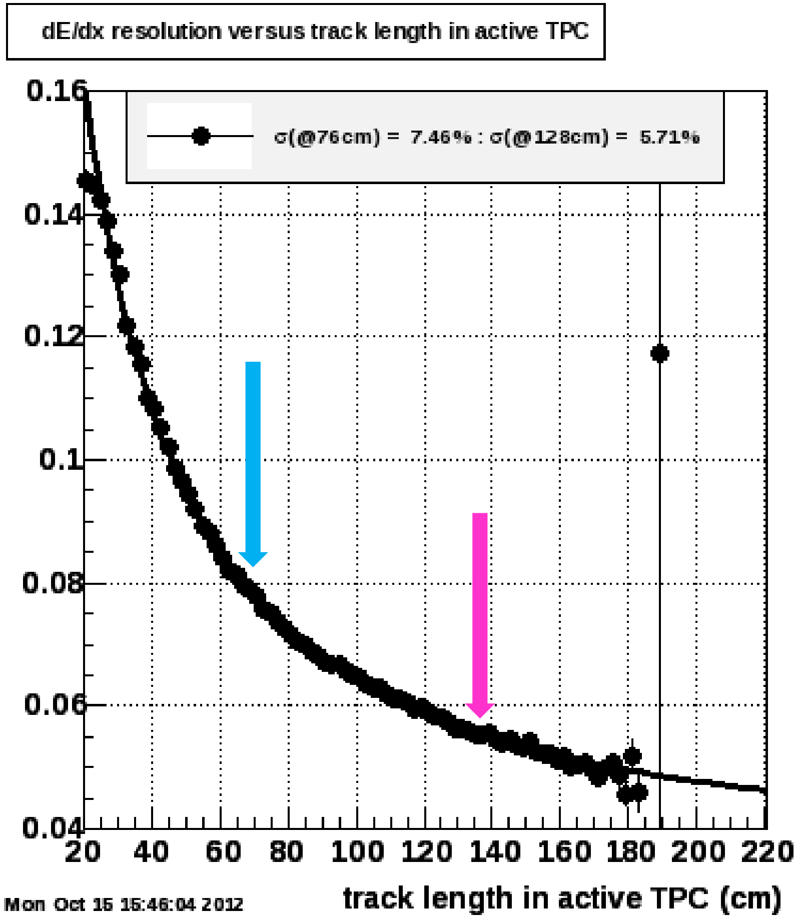
More pad rows and larger pads in the inner sector

Why do it?

- Physics Motivations
  - Study of the QCD phase diagram (Beam Energy Scan Phase II)
    1. Increase eta coverage for hadron acceptance and correlations
    2. Improve low-pt coverage for hyperon reconstruction
    3. Increase dE/dx resolution for particle identification
    4. High eta coverage for fixed-target datasets
  - Study of the QGP Properties
    1. A tool to systematically map chiral symmetry restoration
    2. Improve low-pt coverage for weak-decay reconstruction
    3. Heavy-Flavor physics by improving acceptance and dE/dx
    4. Identified high-pt hadron spectra and correlation for understanding jet properties
  - Spin structure in polarized p+p collisions
    1. Improved forward tracking with FGT+EEMC
    2. Interference Fragmentation Functions at high x
    3. Rapidity dependence of Lambda hyperon polarization
- Reduce space charge distortion induced by charge leak from the Gating Grid
- Eliminate the concern about issues related to wire aging

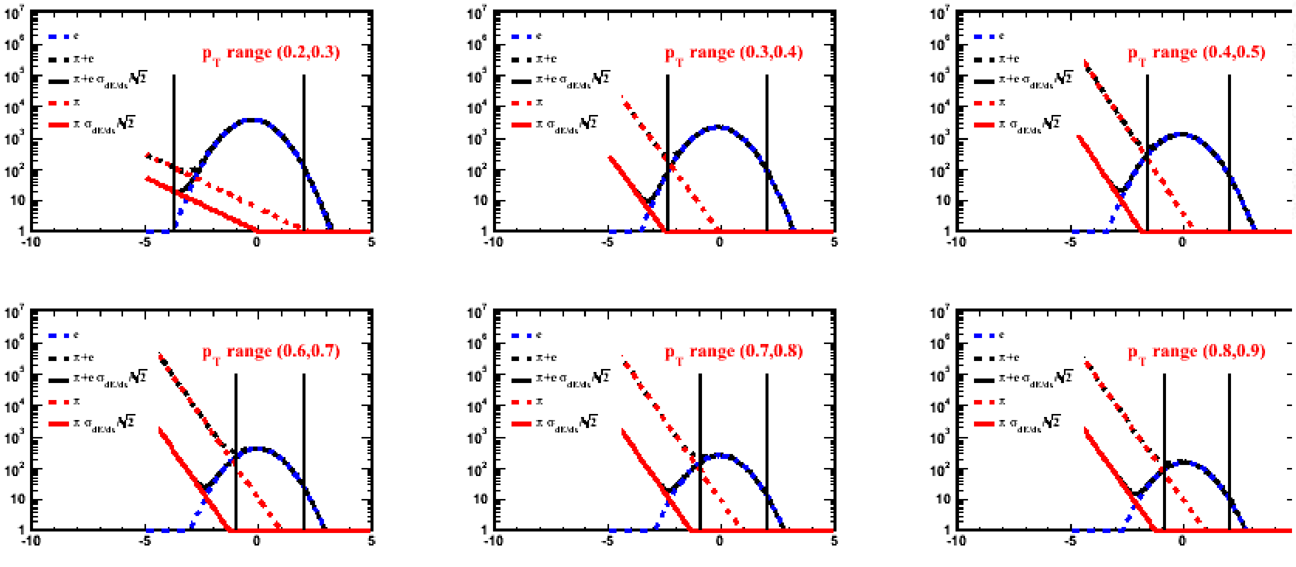
Benefit to dilepton in a nutshell

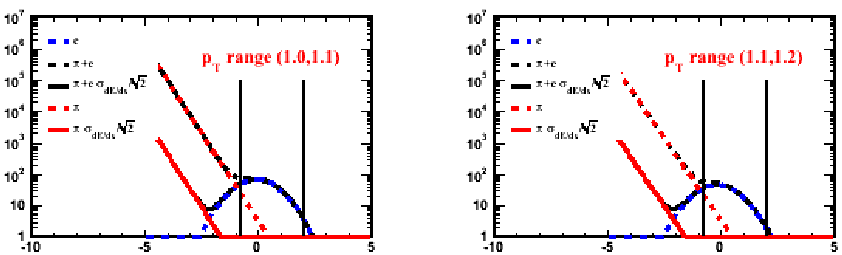


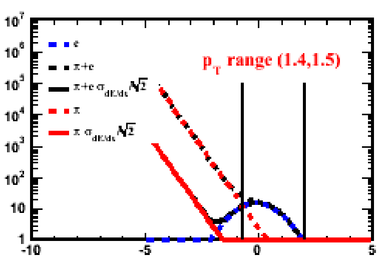


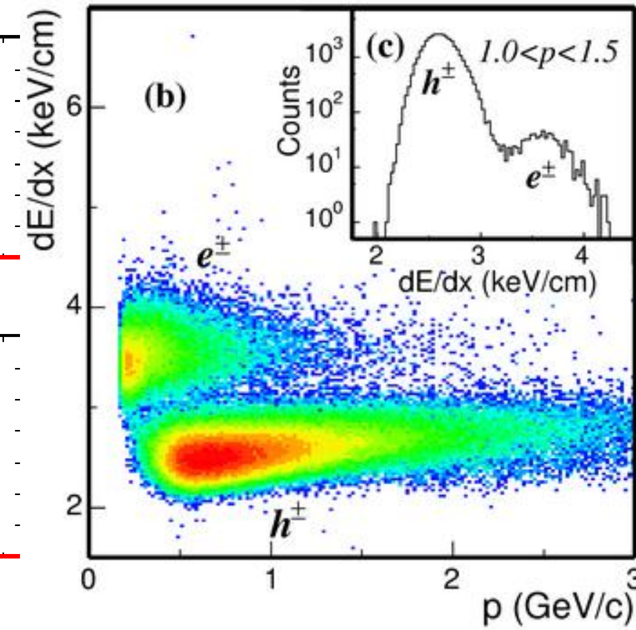
Improve dE/dx resolution and acceptance

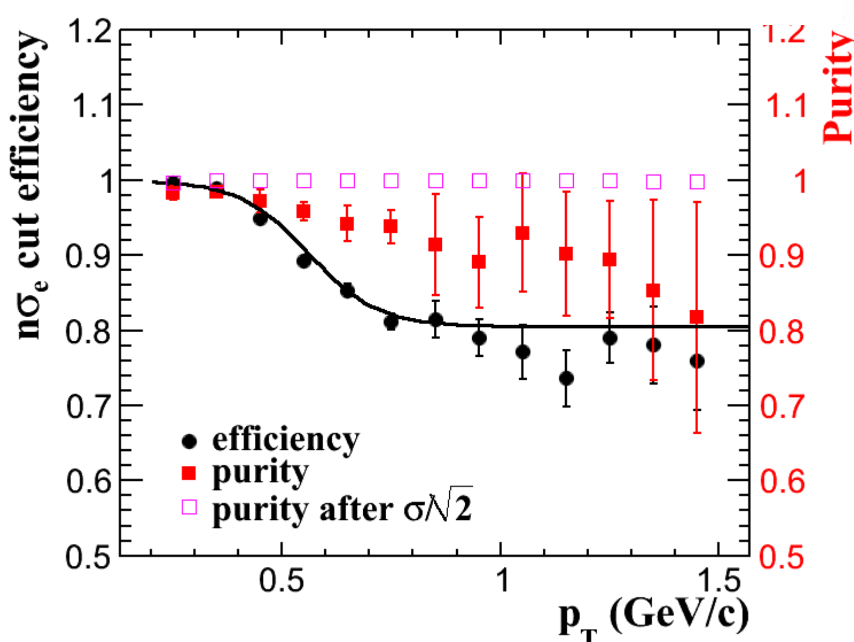
Improve electron PID for dilepton program











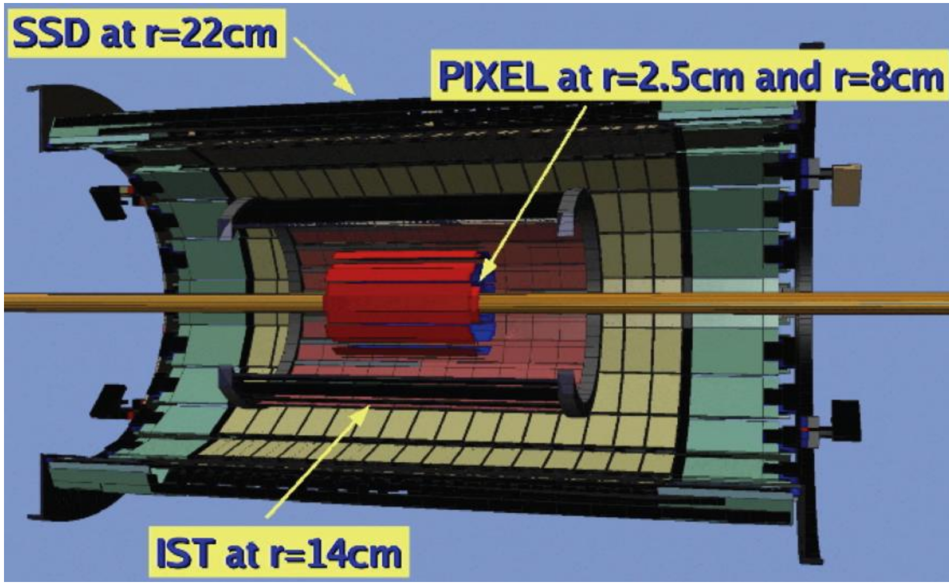
Purity, Efficiency, acceptance

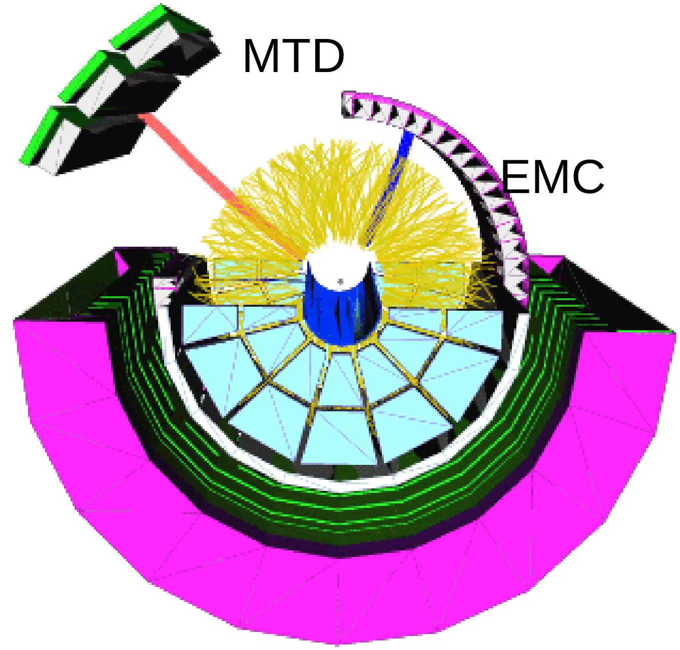
Bingchu Huang

Summary of iTPC upgrade event timeline

- Discuss the necessary tracking upgrade between -2<eta<-1 for eSTAR (2011)
- Identify iTPC as a crucial step for eSTAR upgrade (10/11)
- Discussion of possible iTPC upgrade before eRHIC
  http://drupal.star.bnl.gov/STAR/system/files/UclaUpgrade_jt.pdf
  Jim Thomas (LBL)
  UCLA Upgrade Workshop, December 2011
- iTPC Upgrade group discussions/talks at BNL (02/01/2012)
  http://drupal.star.bnl.gov/STAR/event/2012/02/14/estar-task-force-biweekly-meeting
- iTPC session at BNL upgrade workshop (06/11/2012)
  decision to move toward an iTPC project
  outline the necessary steps
- Upgrade Session at STAR Collaboration Meeting (08/07/2012)
  Establish iTPC geometry for simulation, possible collaboration institutes
  http://drupal.star.bnl.gov/STAR/system/files/iTPC_Collaboration_Upgrade2012_0.pdf
- Establish simulation/tracking framework (09/12)
- Cost Estimates and Technical Driven Schedule
  to Steve Vigdor and Tribble Committee (09/12)
- Possible Chinese group involvements (10/12)
- STAR R&D Review (10/12)
- Upgrade Workshop (11/12)
- Draft Proposal to upgrade group (2013) Proposal to Collaboration
- Electronics R&D prototype and engineer drawings (2013)
- Prototype Sector (2013—2014)

Future STAR HFT and MTD





PIXEL:

- high hit resolution: 20.7μm X 20.7μm pitch
- low thickness: 0.4% X_0

- ❑ Muon identification
- ❑ Muon trigger

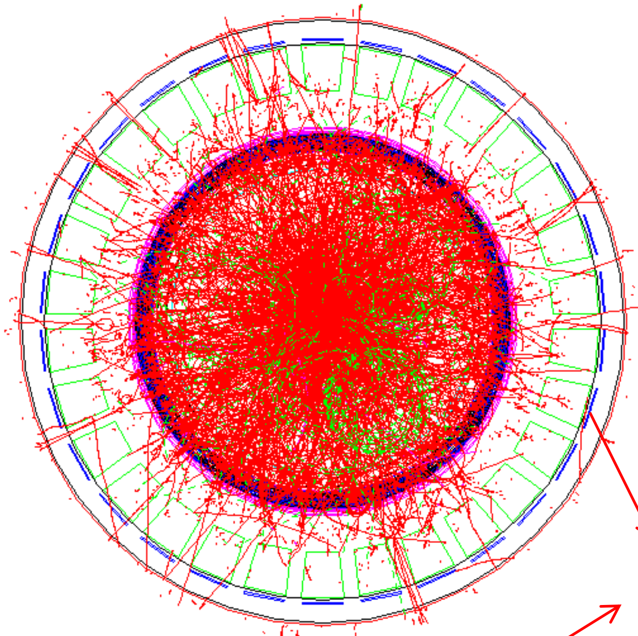
❑ **significantly enhance STAR capability on measuring heavy flavor production at RHIC**

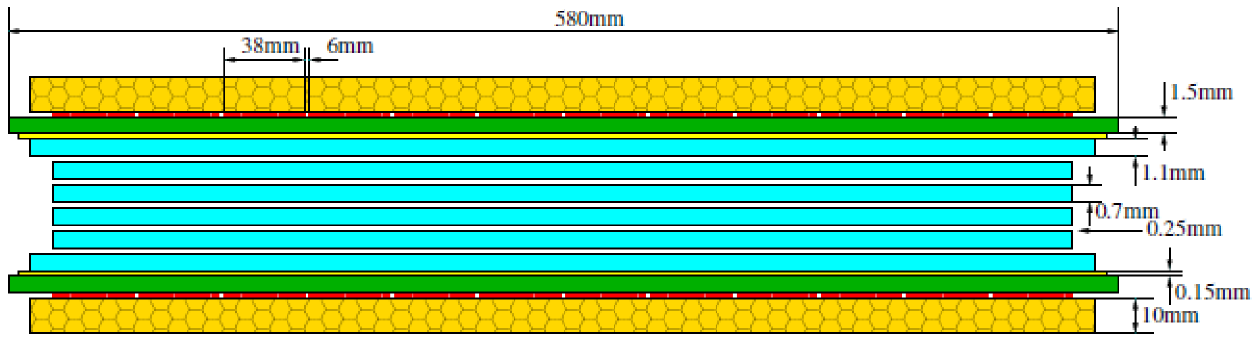
- Direct reconstruction of D mesons at both low p_T and high p_T
- B→J/ψ→μμ +X, disentangle upsilon ϒ(1S/2S/3S).

❑ **Study QGP thermal dilepton radiation**

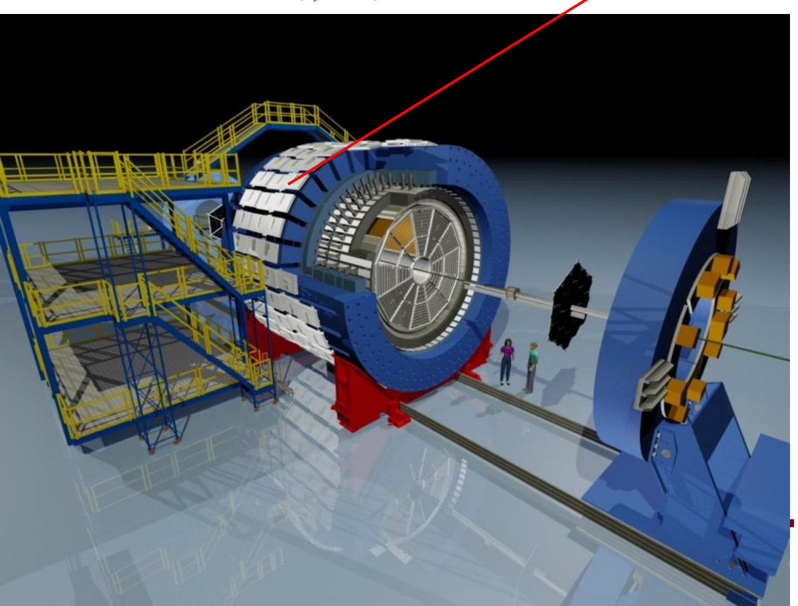
- Understanding background charm decorrelation through e-muon correlation.

Concept Design of the STAR-MTD





MTD



Multi-gap Resistive Plate Chamber (MRPC): gas detector, avalanche mode

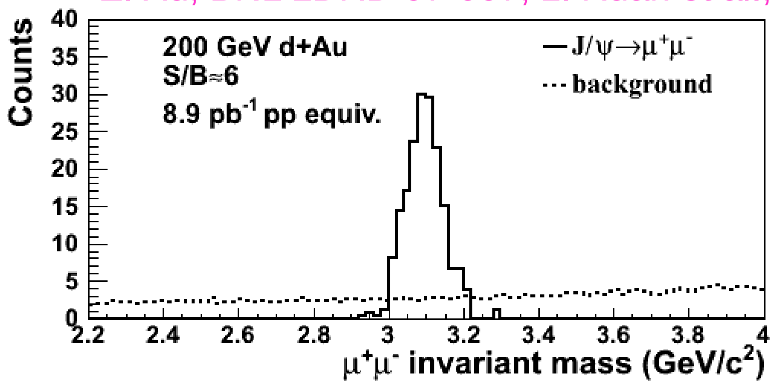
A detector with long-MRPCs covers the whole iron bars and leave the gaps in-between uncovered. Acceptance: 45% at $|\eta|<0.5$

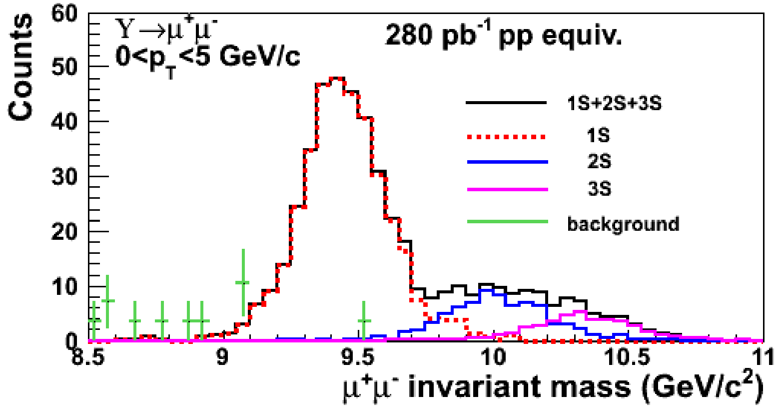
118 modules, 1416 readout strips, 2832 readout channels

Long-MRPC detector technology, electronics same as used in STAR-TOF

High Mass Di-muon Capabilities

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





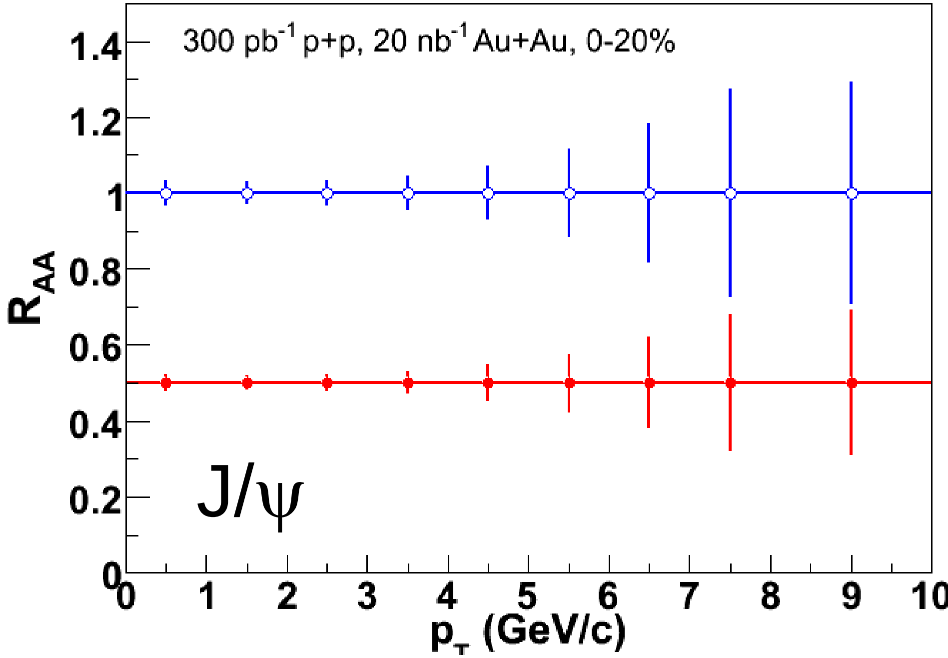
1. J/ψ: S/B=6 in d+Au and S/B=2 in central Au+Au
2. With HFT, study B→J/ψ X; J/ψ→μμ using displaced vertices
3. Excellent mass resolution: separate different upsilon states

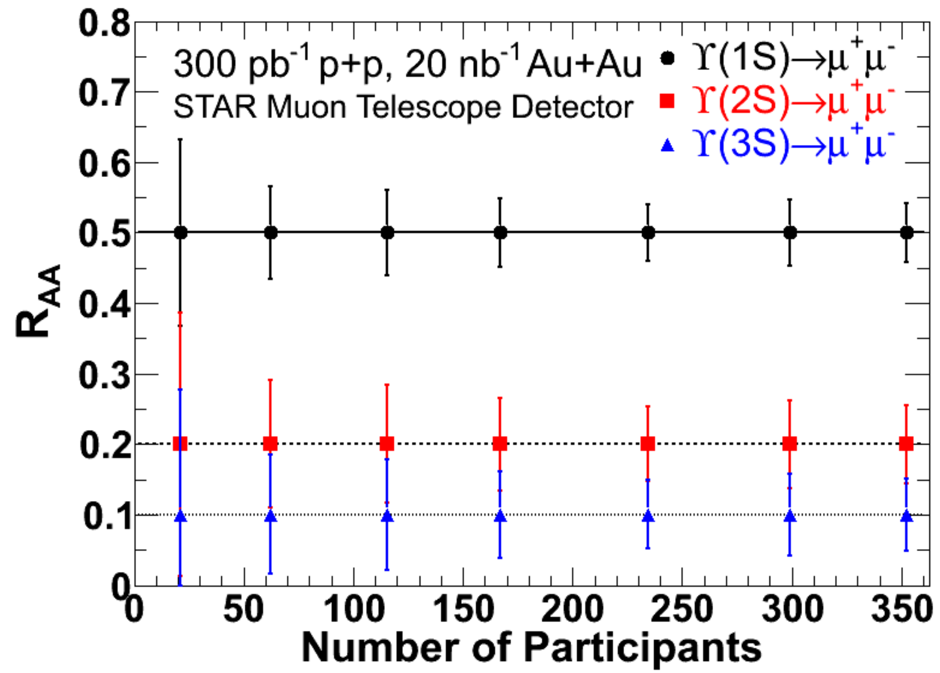
Heavy flavor collectivity and color screening, quarkonia production mechanisms:
J/ψ R_{AA} and v_2; upsilon R_{AA} …

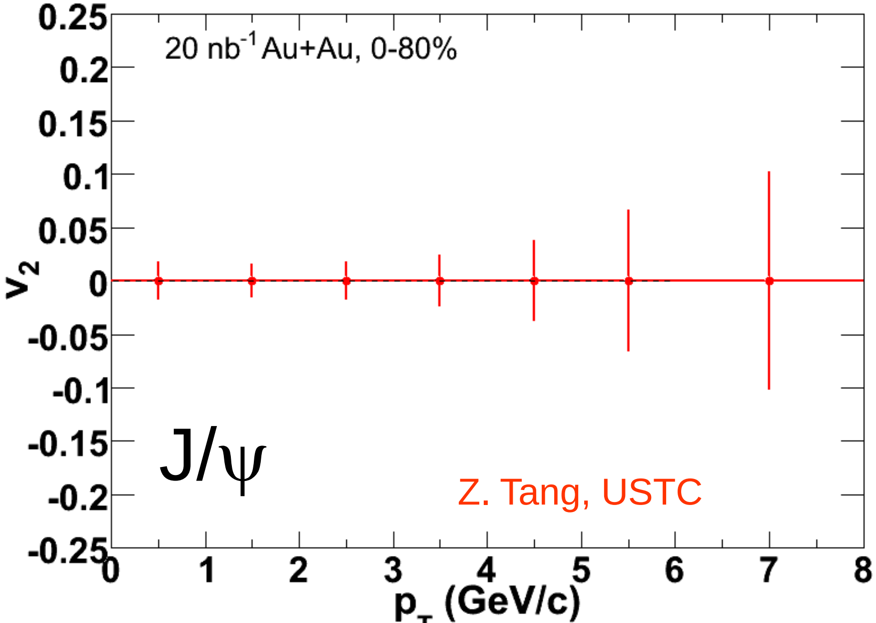
Quarkonium dissociation temperatures – Digal, Karsch, Satz

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



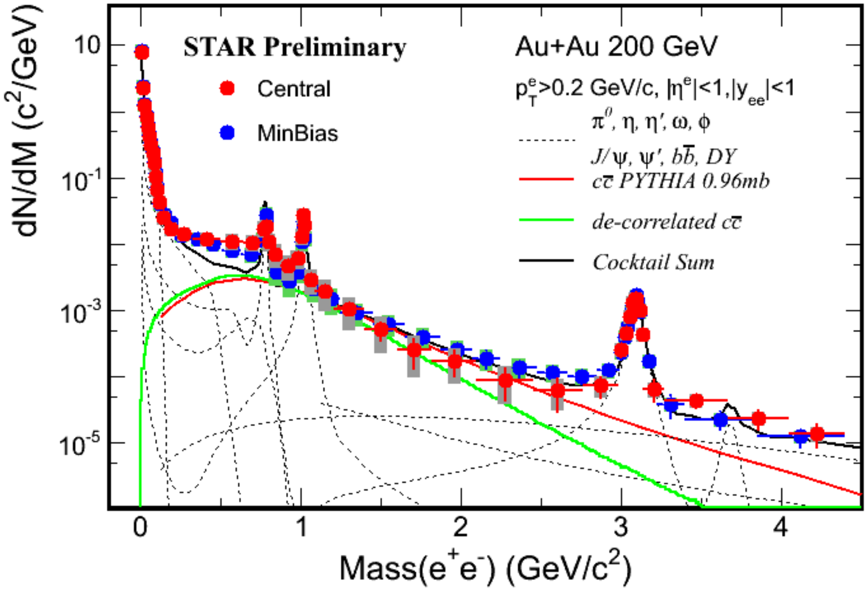


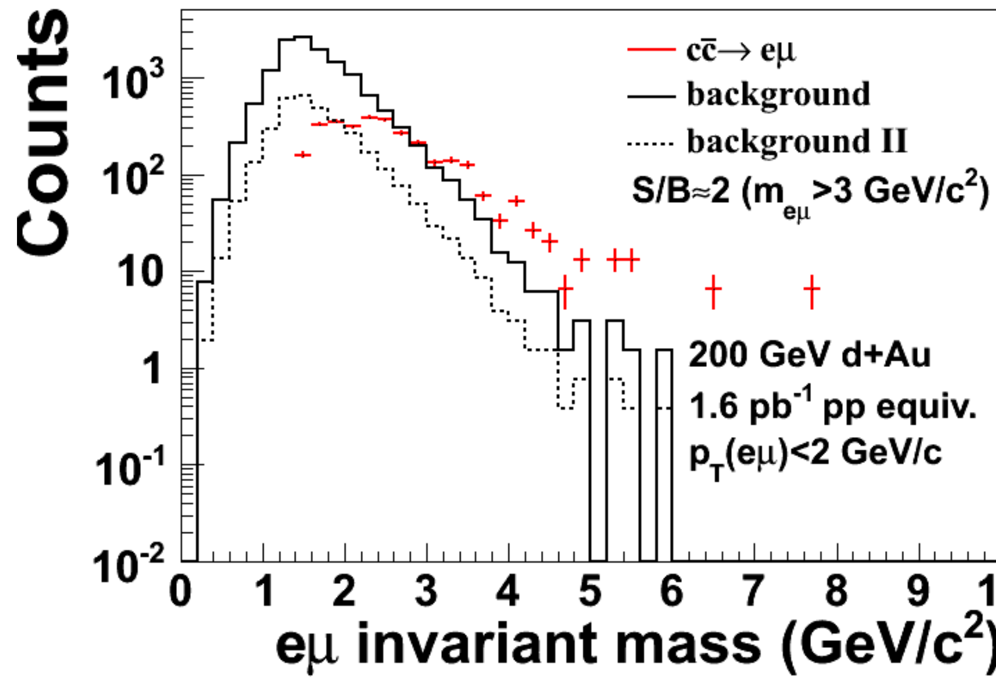


J/ψ R_{AA} and v_2;
Y (1S, 2S, 3S) R_{AA} versus N_{part}…

Different Upsilon states in 500 GeV p+p collisions can be measured with good precision from 12 weeks run.

Distinguish Heavy Flavor and Initial Lepton Pair Production: e-muon Correlation





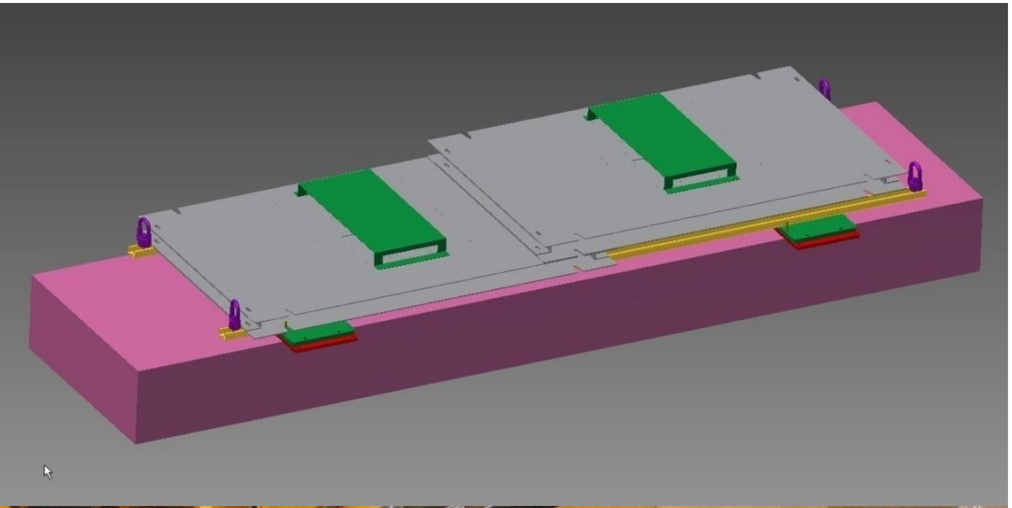
eμ correlation simulation with Muon Telescope Detector at STAR from ccbar:

S/B=2 (M_{eu}>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

MTD in Run12

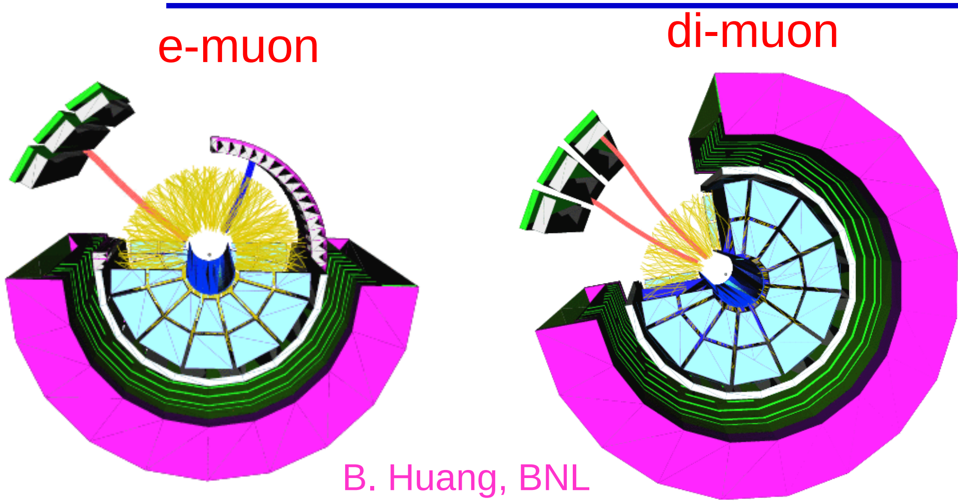


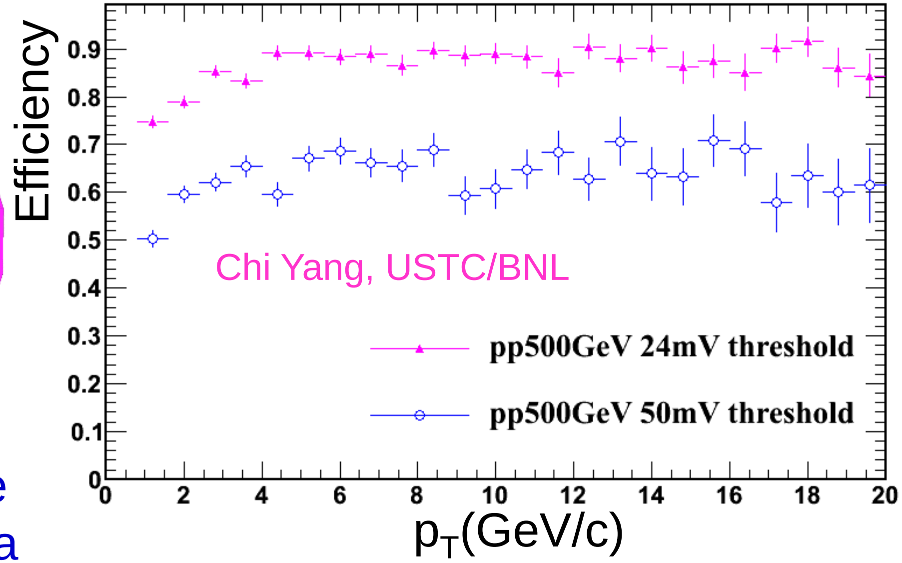
Two-pack system for the installation, designed by B. Llope and J. Scheblein, proven to be successful.

MRPC built at USTC and Tsinghua, trays assembled at UT-Austin.

For Run 12, 13 trays on three backlegs installed by STSG. Fully integrated into STAR Data Acquisition system since Jan. 2012. Successfully took MTD triggered events since Feb. 2012.

MTD Performance from Run 12

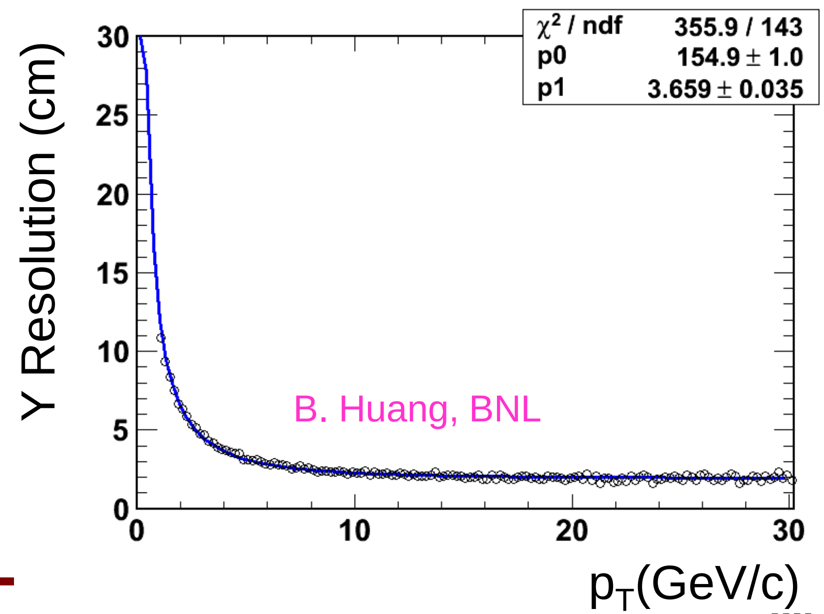




Commissioned e-muon (coincidence of single MTD hit and BEMC energy deposition above a certain threshold) and di-muon triggers, event display for Cu+Au collisions shown above.

Determined the electronics threshold for the future runs, achieve 90% efficiency at threshold 24 mV

Intrinsic timing and spatial resolution: < 100 ps and 1~2 cm, respectively.



MTD for Run 13

L-R: John, Bob, Bill, Matt, Tim, Chris, Chi, Hui, Wangmei, Alex, Anthony
Not shown: Bingchu and Shuai

By Nov. 13th, 63% of the MTD system was installed at STAR for Run 2013, electronics commissioning is on-going.
Superseded the milestone (43%) for Run 2013.

Understanding Symmetry and Degree Of Freedom

- RHIC is the best facility to study novel symmetries and critical point:
  - flexible machine to change conditions beam species (magnetic field), BES (turn on/off QGP)
  - Large Acceptance (good for both LPV and chiral symmetry)
  - Excellent lepton PID (both electrons and muons at midrapidity, who else has that!)
- Since the beginning of physics, symmetry considerations have provided us with an extremely powerful and useful tool in our effort to understand nature. Gradually they have **become the backbone of our theoretical formulation of physical laws**.
  — Tsung-Dao Lee
  Particle Physics and an Introduction to Field Theory (1981), 177

- Novel Symmetries:
  - beam energy: deconfinement, chiral symmetry
  - Beam species: magnetic field
- Medium effect on vector mesons (chiral symmetry, resonant states):
  - beam energy;
  - Spectra and v_2 vs M_{l+l-}
- HFT+MTD upgrade
  - First glimpse of dilepton spectra around ρ_0 and $1<M<3$GeV
  - Heavy-flavor flow
- Future+
  - iTPC+Phase II BES
  - **Detailed studies of DOF**