Di-electron Measurements in STAR

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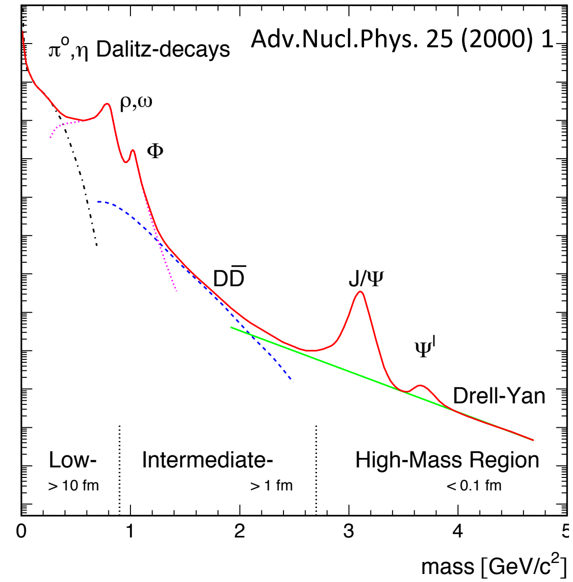
for the STAR Collaboration

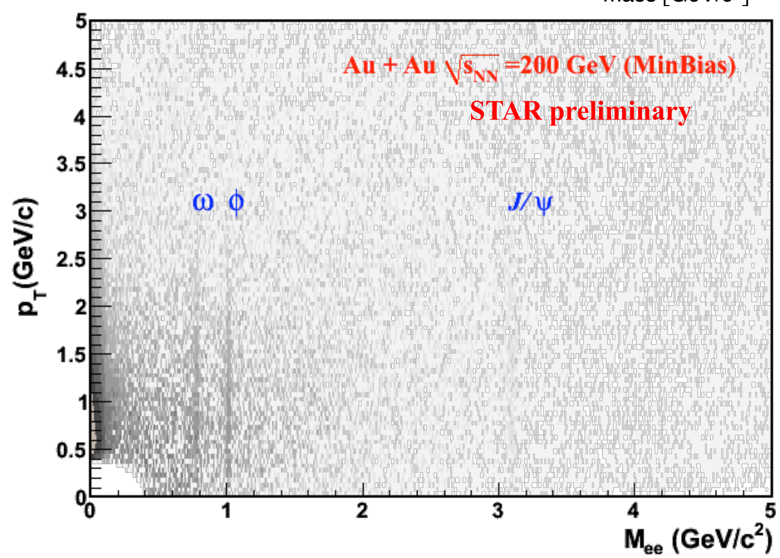
Outline

- Di-electrons in heavy-ion collisions
- STAR: data sample & electron identification
- Background estimates
- Results for p+p and Au+Au at $\sqrt{s_{NN}}$=200GeV
- Di-electrons at lower energies (BES)
- Di-electron elliptic flow
- Future
- Summary

Motivation

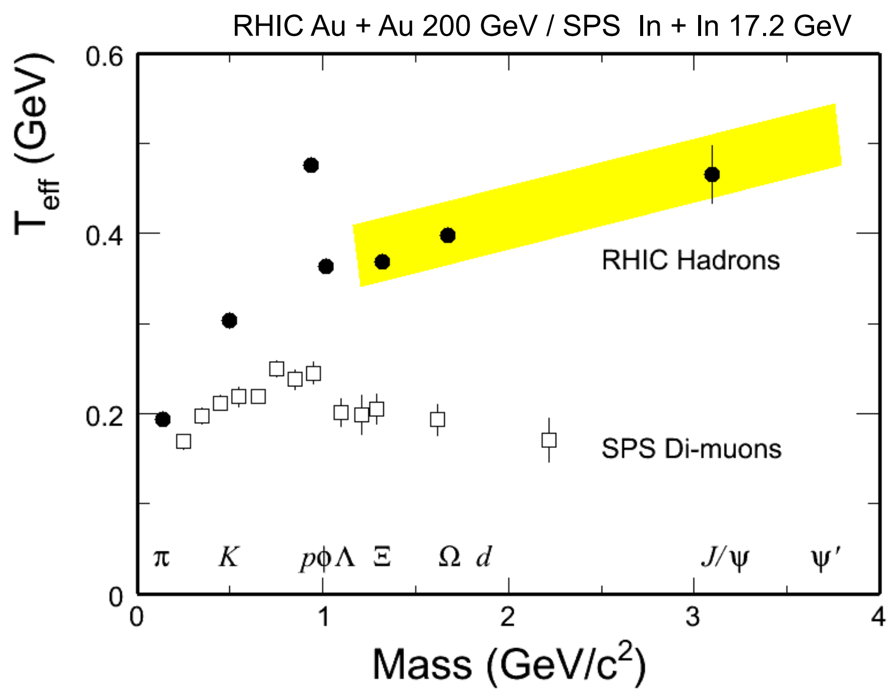
- Di-lepton spectra cover a wide range of physics that may bare signatures from the QGP
  - Leptons are emitted throughout the evolution of the system
  - Leptons practically do not interact with the hot & dense medium
- Low Mass Range (LMR)
  - $m_{ee} < 1.1$ GeV/c^2
  - In-medium modification of vector mesons
  - Possible link to chiral symmetry restoration
- Intermediate mass range (IMR)
  - $1.1 < m_{ee} < 3$ GeV/c^2
  - QGP thermal radiation
  - Heavy Flavor modification
- High Mass Range (HMR)
  - $m_{ee} > 3$ GeV/c^2
  - Primordial emission, J/Ψ and ϒ suppression, Drell-Yan





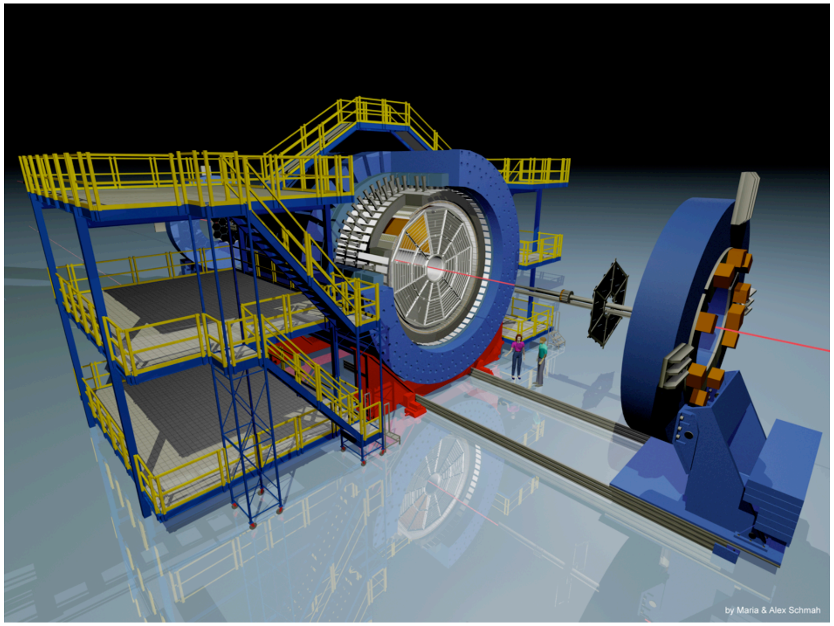
Motivation (cont'd)

- At SPS: different slopes in m_T spectra in low and intermediate masses
  - hint of partonic thermal dileptons
- How about at RHIC?
  - measure production cross sections
  - measure elliptic flow



NA60, PRL 100, 022302 (2008)
STAR, NPA 757,102 (2005)
PHENIX, PRL 98, 232301 (2007)

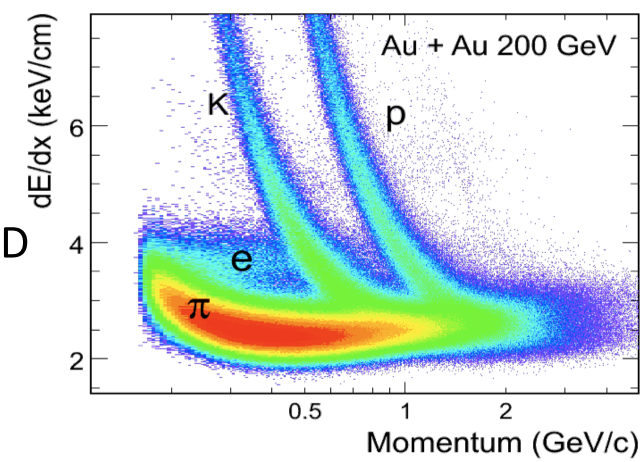
The STAR detector



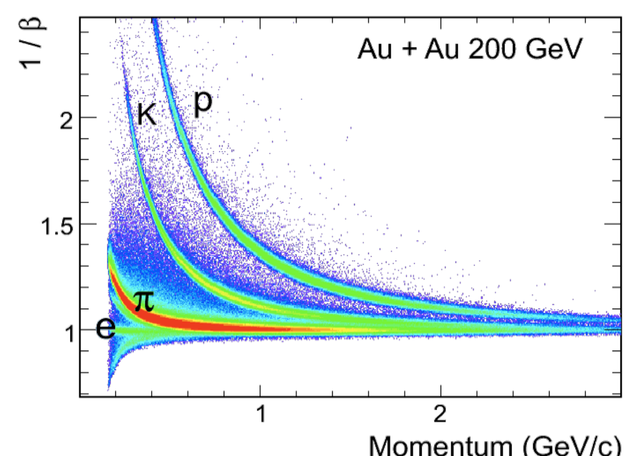
Relevant Sub-Detectors:

- Time Projection Chamber
  $0<\phi<2\pi$, $|\eta|<1$
  - Tracking
  - dE/dx PID
- Time-of-Flight detector
  $0<\phi<2\pi$, $|\eta|<0.9$
  - Time resolution < 100ps
  - Significantly improves PID
  - Fully commissioned 2010

TPC PID

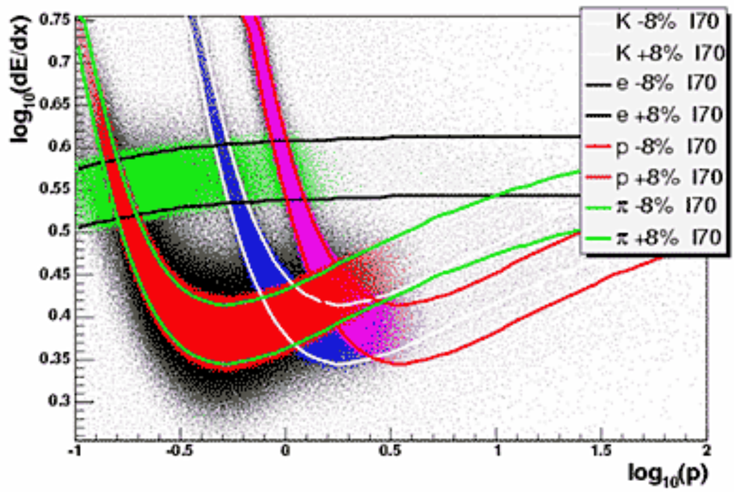


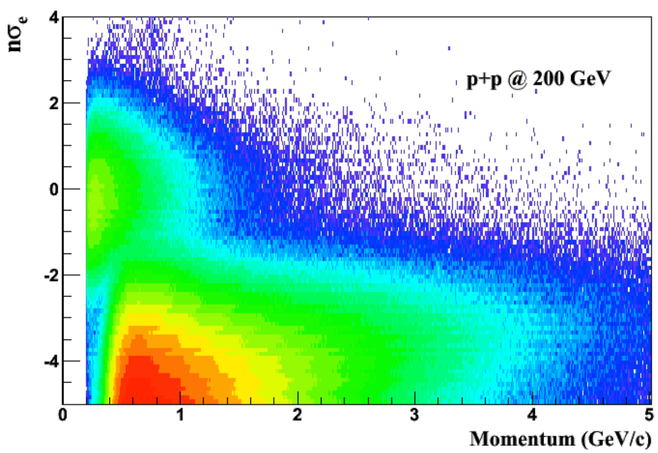
TOF PID



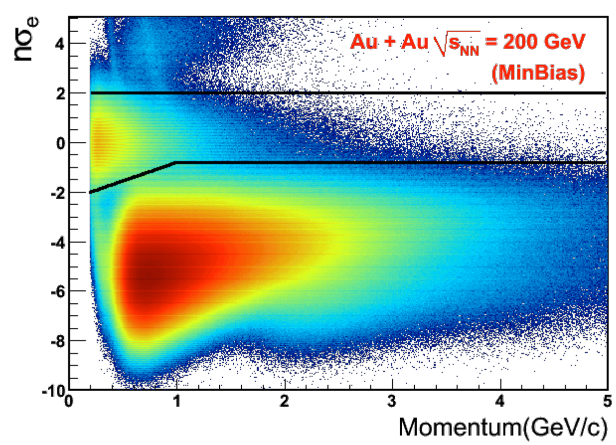
Electron Identification

- dE/dx PID only: significant hadron contamination
- TOF velocity cut removes “slow” hadrons
  - purity ~99% in p+p, ~97% in Au+Au (min-bias)



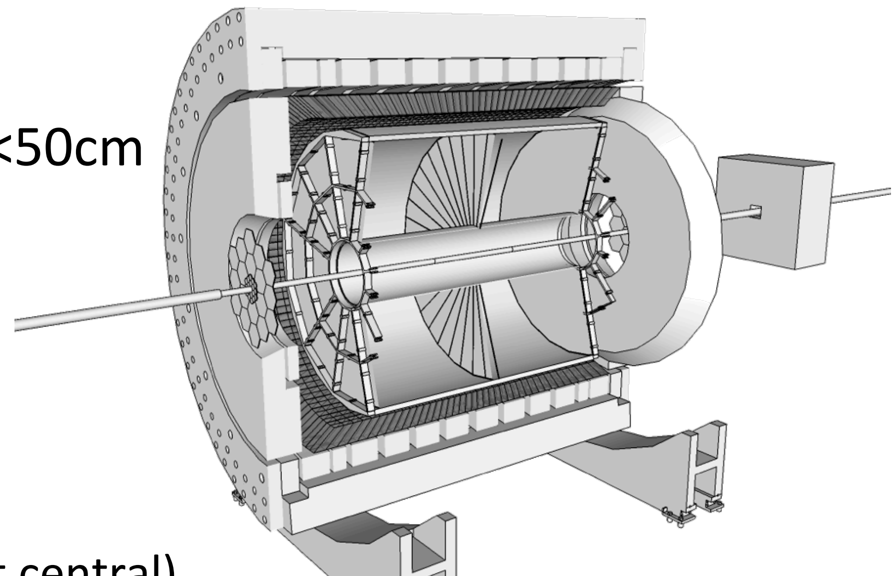


$$n\sigma_e = \frac{\log\left(\frac{dE/dx}{B_e}\right)}{\sigma_e}$$



Event Selection & Data Sample

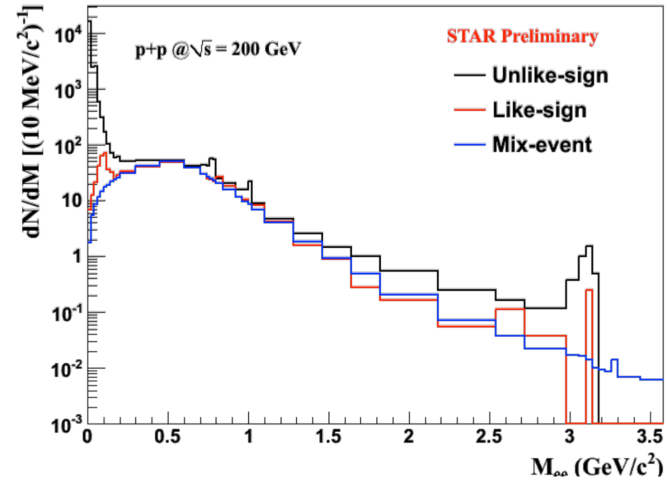
- p+p at $\sqrt{s}$=200GeV
  - RHIC Run 9
    - 107M minimum-bias events
  - Collision vertex selection |Vz|<50cm
  - 72% TOF coverage

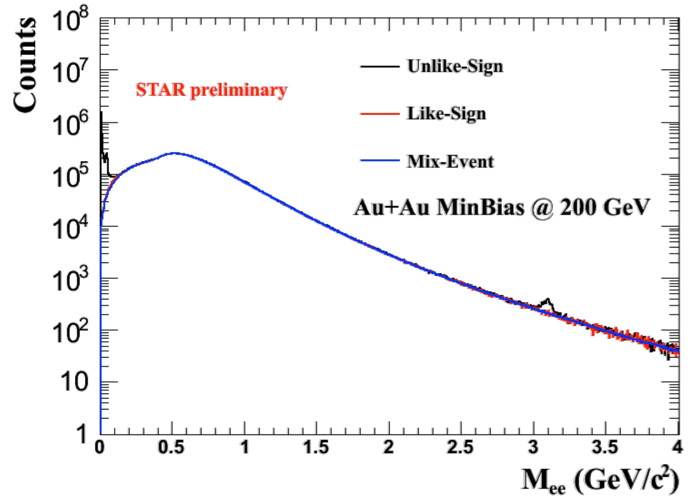


- Au+Au at $\sqrt{s_{NN}}$=200GeV
  - RHIC Run 10
    - 270M minimum-bias events
    - 150M central events (10% most central)
  - Collision vertex selection |Vz|<30cm
  - 100% TOF coverage

Invariant Mass & Background

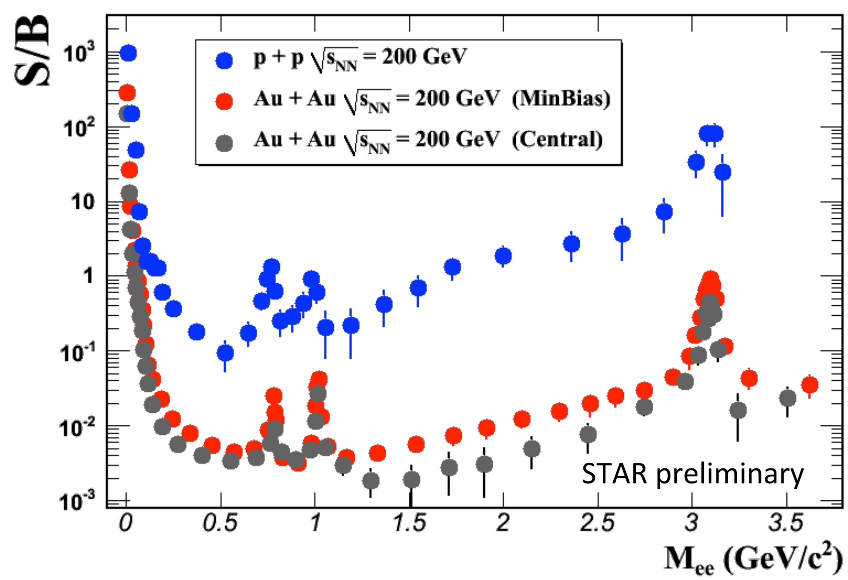
- Background sources
  - Combinatorial background (non-physical)
  - Correlated background, e.g. double Dalitz decay, jet correlation.
- Background methods
  - Combinatorials: mixed-event and/or like-sign method
  - Correlated background: like-sign method
  - Pair cuts that remove photon conversions
- Other signals
  - Meson decays (photon background, hadron contamination)
  - Remove by comparing real data with simulations for hadron contamination





Signal to Background Ratios

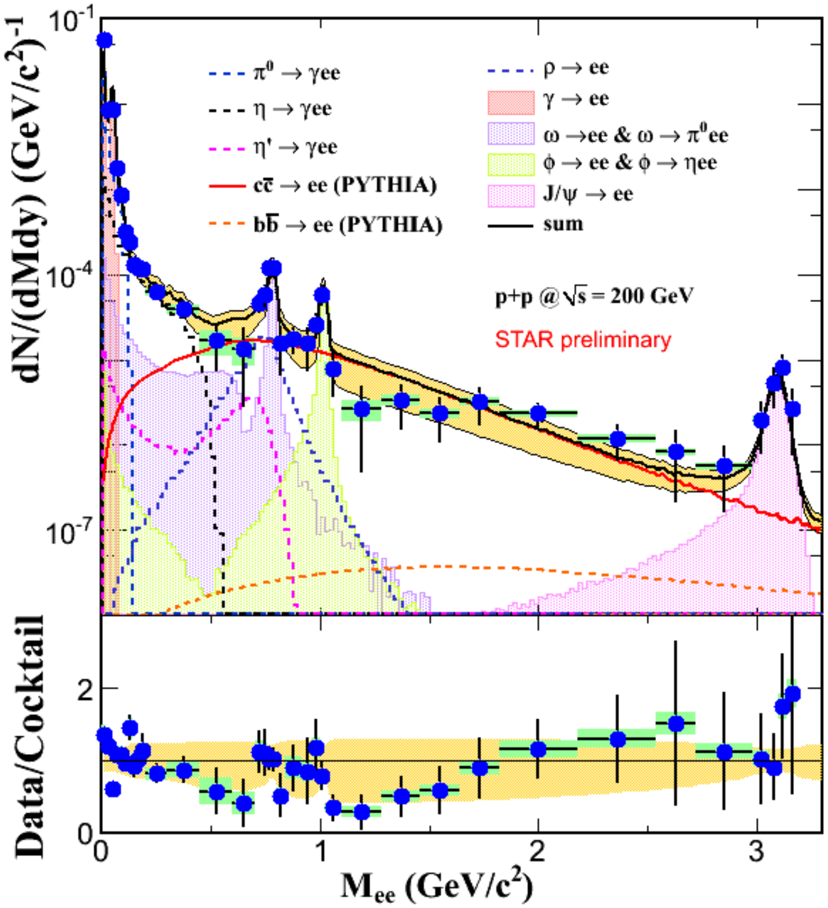
- Mixed-Event Method
  - Combinatorial only
  - Statistics can be made significantly large
  - No acceptance difference between unlike-sign and mixed-event
- Like-Sign Method
  - Same event: combinatorial + correlated background
  - Statistics comparable to Unlike-Sign, i.e. original raw spectra
  - Acceptance differences between unlike-sign and like-sign
- Combine both methods, carefully normalized using an overlap region in inv. mass m_{ee}
  - p+p: LS < 0.4 GeV/c^2 < ME
  - Au+Au: LS < 0.75 GeV/c^2 < ME×LS



Signal/Background @ m_{ee}~ 0.5GeV/c^2
- 1/10 for p+p
- 1/(200-250) for Au+Au min-bias, central

Di-electrons in p+p

QM/SQM/CPOD2011



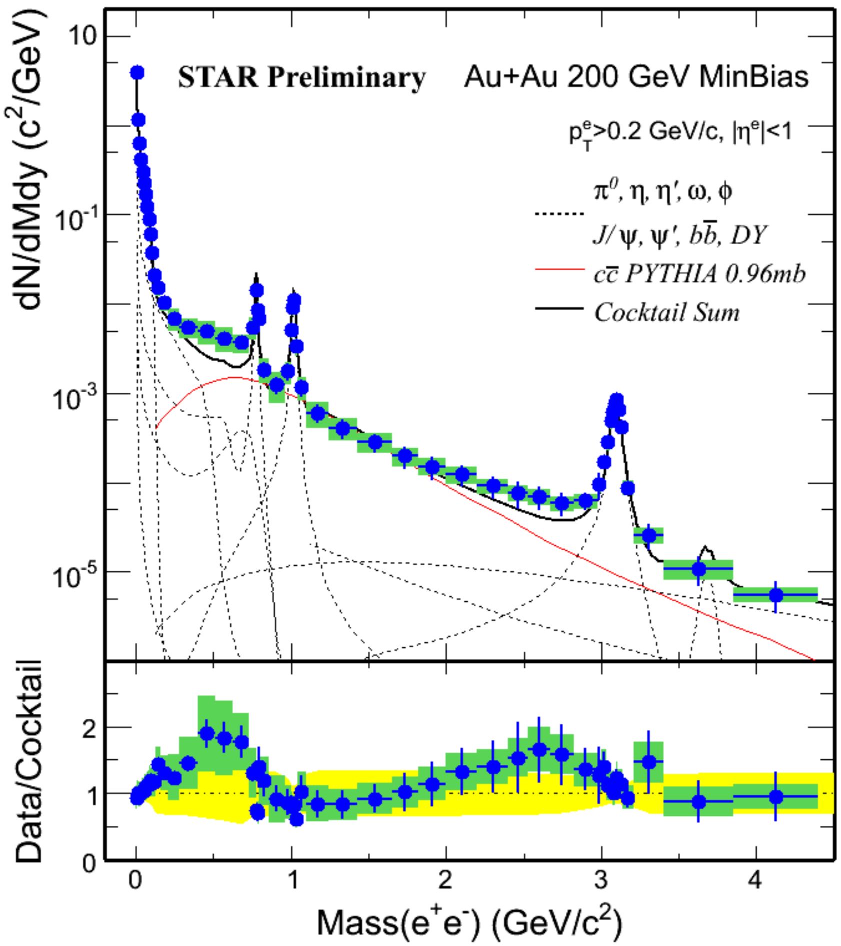
- LMR and IMR in p+p min-bias
  - efficiency corrected
- Hadron cocktail simulation consistent with data
  - NPA 855(2011)269
- Charm contribution dominates IMR
  - scaled with STAR charm cross-section
  - PRL 94(2005)062301

Incl. stat. + syst. errors:

- green -- syst. error on data
- yellow -- syst. error on cocktail

Di-electron in Au+Au (minbias)

QM/SQM/CPOD2011



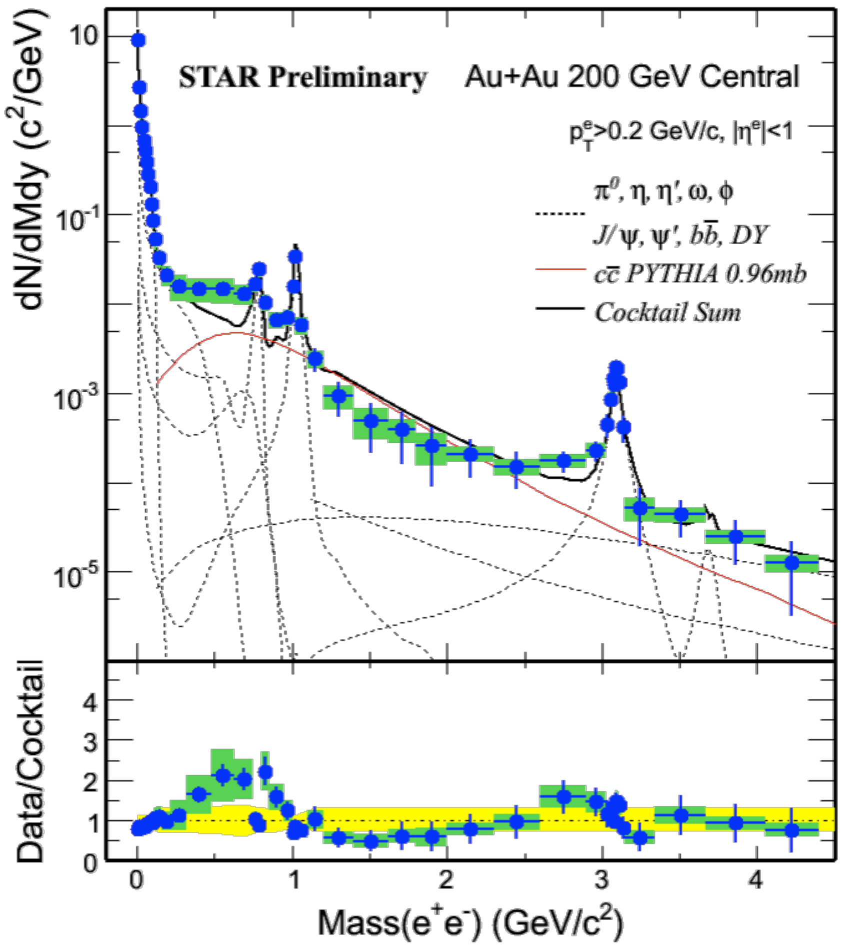
- A hint of enhancement at LMR between 150 - 750 MeV/c^2:
  - 1.53 ± 0.07 (stat) ± 0.41 (syst)
    - PHENIX: 4.7 ± 0.4 ± 1.5
  - compared to hadron cocktail without ρ

- Hadron cocktail
  - ρ contribution not included
  - charm contribution based on N_{bin}-scaled PYTHIA simulation (0.96mb)

Incl. stat. + syst. errors:
- green -- syst. error on data
- yellow -- syst. error on cocktail

Di-electron in Au+Au (central)

QM/SQM/CPOD2011



Compared with min-bias ...

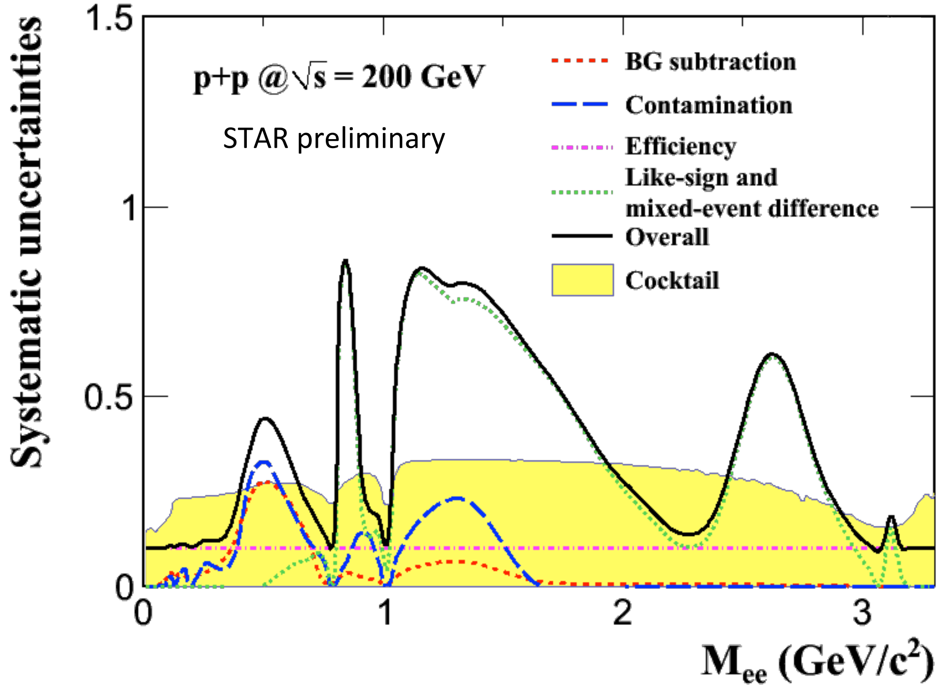
- LMR: more pronounced enhancement
  between 150 – 750 MeV/c^2
  - 1.72 ± 0.10(stat) ± 0.50(syst)
    - PHENIX: 7.6 ± 0.5 ± 1.3
  - compared to cocktail without ρ
- IMR: cocktail overshoots data
    - but consistent within uncertainties
  - modification of charm?
  - further study needed (HFT,MTD)

Incl. stat. + syst. errors:

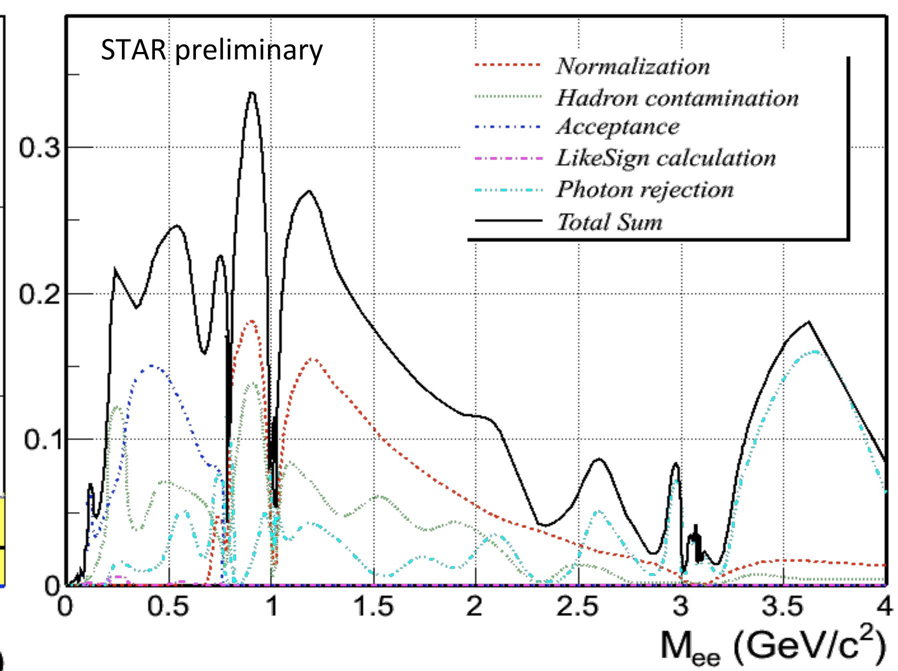
- green -- syst. error on data
- yellow -- syst. error on cocktail

Systematic Uncertainties

p+p at √s=200 GeV



Au+Au at $\sqrt{s_{NN}}$=200 GeV

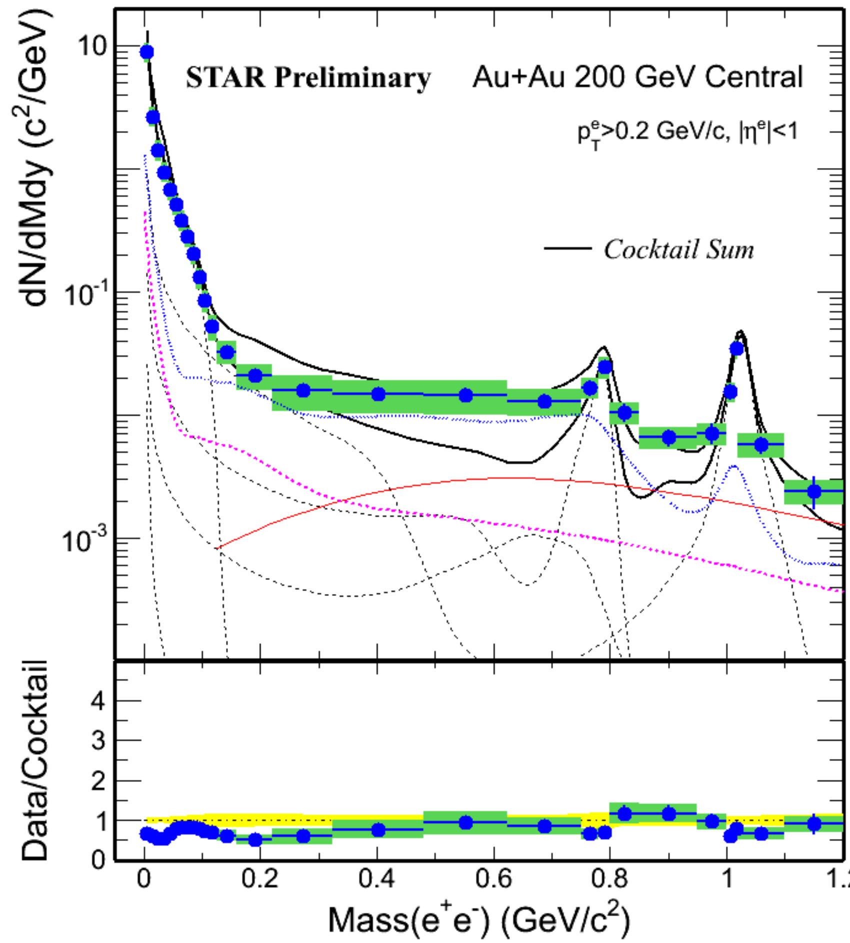


Comparison to Theoretical Calculations

SQM2011

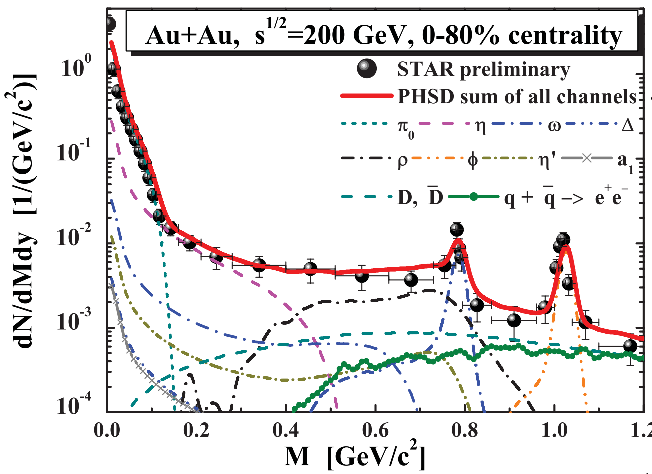
by Ralf Rapp (priv. comm.)

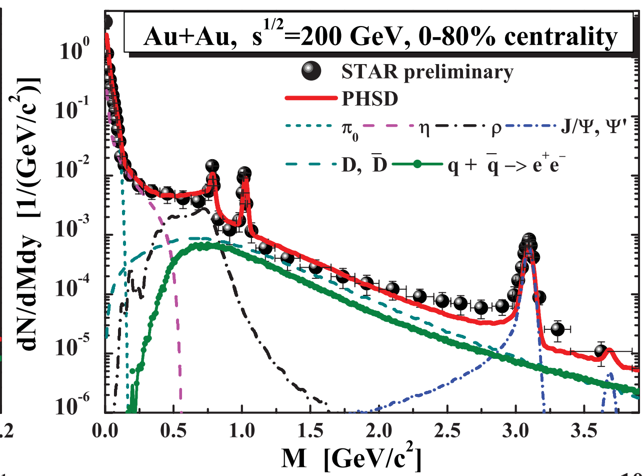
- blue dotted line
  contribution from hadron gas
- pink dotted line
  contribution from QGP
- upper solid line
  cocktail + HG + QGP
- lower solid line
  cocktail only



Comparison to Theoretical Calculations (2)

PHSD model, Phys. Rev. C85 0249010 (2012)



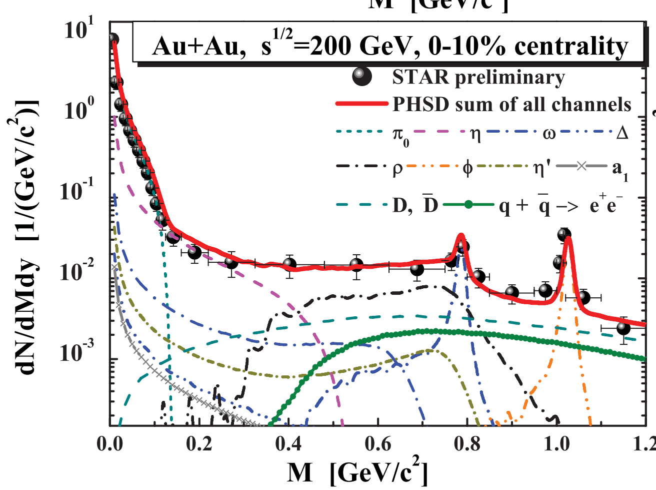


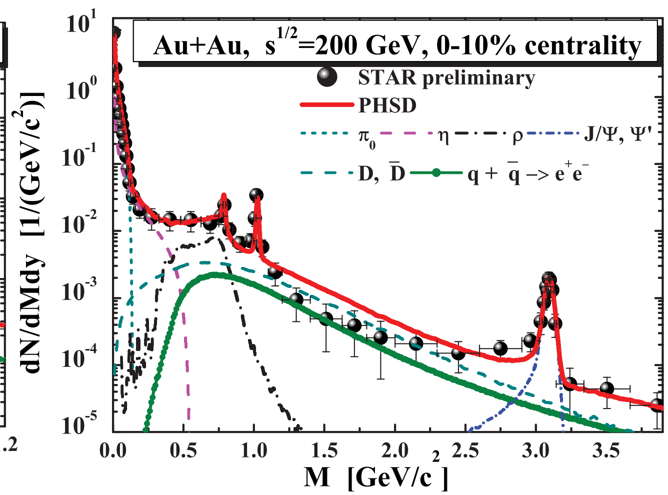
Minimum bias collisions (0-80%):

- Generally good agreement

Central collisions (0-10%):

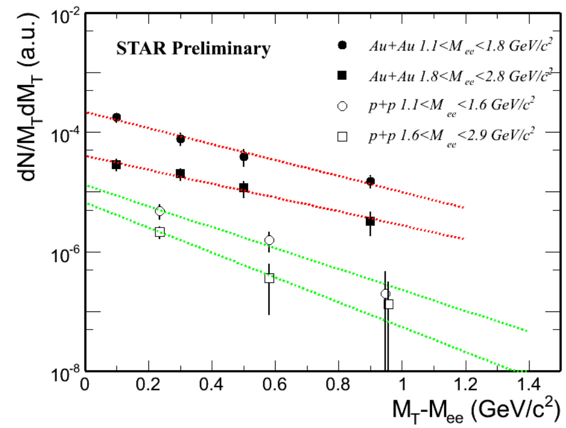
- PHSD roughly in line with LMR region
- overestimation in IMR region
  - further study charm contributions





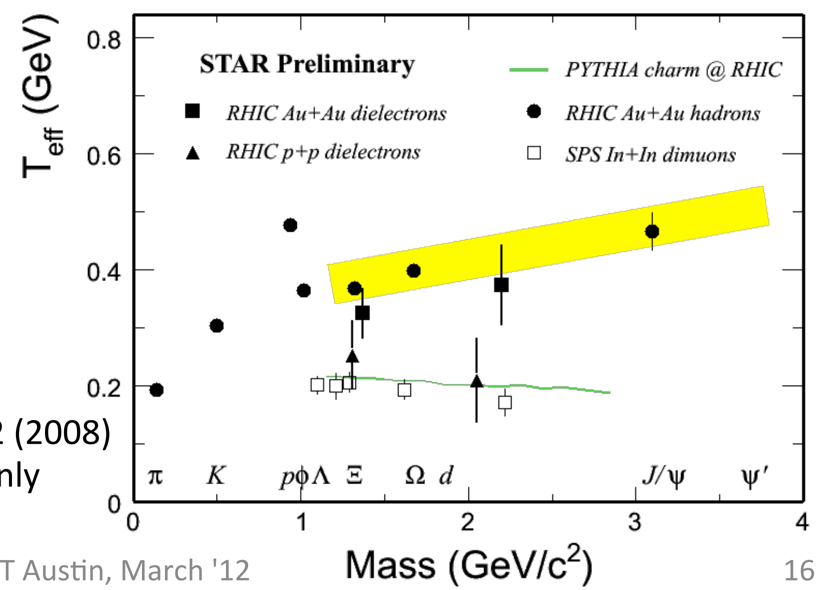
Transverse Mass Spectra

QM2011



- p+p results consistent with PYTHIA charm
- m_T slope parameter Au+Au higher than p+p
  - hint of thermal di-lepton production and/or charm modification
- Inclusive di-lepton slope for Au+Au (RHIC) higher than NA60 measurement
  - NA60 data has charm/DY subtracted

RHIC Au + Au 200 GeV / SPS In + In 17.2 GeV



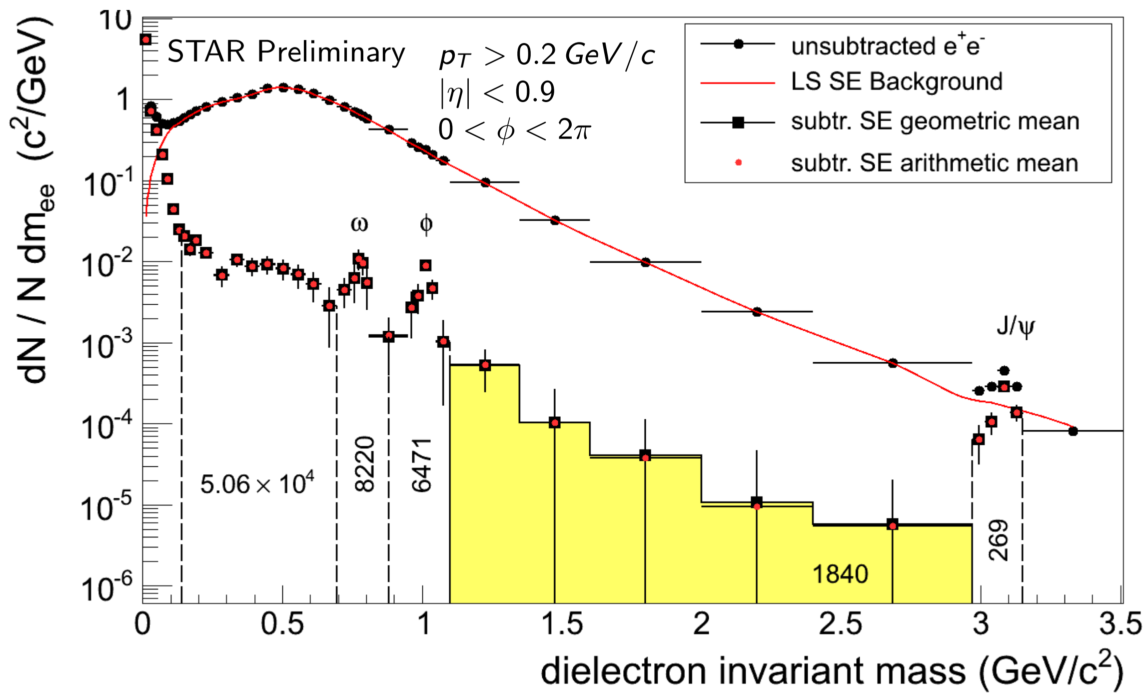
SPS (NA60): PRL 100, 022302 (2008)
STAR: di-electron, stat.err. only

Di-electrons in BES ($\sqrt{s_{NN}}$=39GeV)

- Beam Energy Scan: explore QCD phase diagram
  - di-electrons can serve as an additional probe
- RHIC Run 10: low material budget, high statistics
  - 39GeV data set: 115M MB events, |Vz|<30cm
  - but, only 20% with one or more e^+e^- pairs

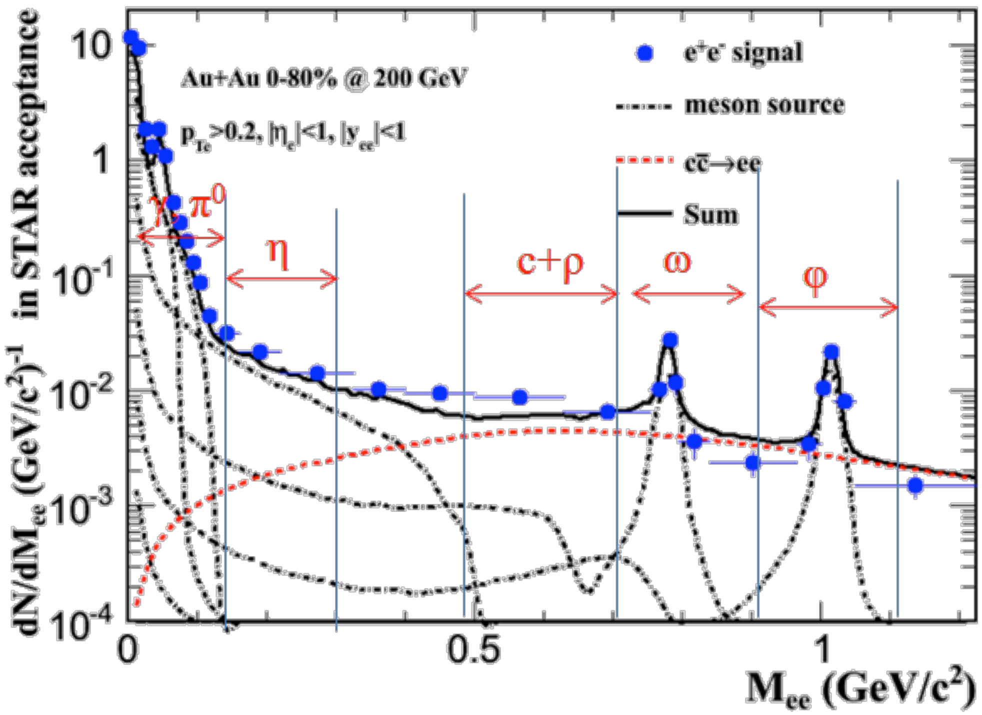
CPOD2011

Raw m_{ee} spectrum ➔



- work underway to determine background & hadron cocktail
- involve more energies, such as $\sqrt{s_{NN}}$=62GeV

LMR: di-electron flow



Dominant sources in LMR

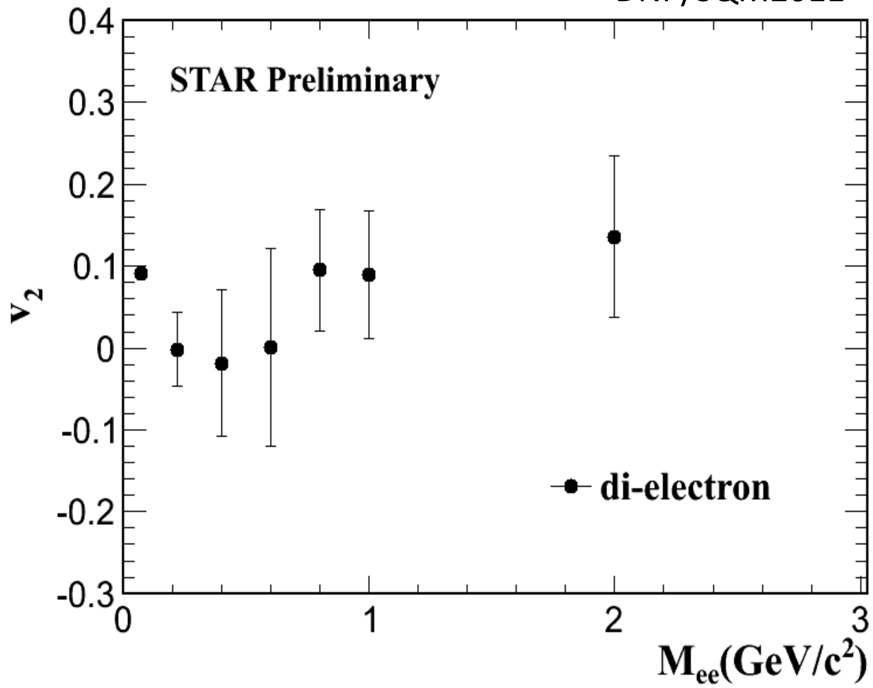
- m_{ee} [0-0.14 GeV/c^2]: $\pi^0 + \gamma$
- m_{ee} [0.14-0.3]: η
- m_{ee}[0.5-0.7] : charm + ρ
- m_{ee}[0.7-0.9]: ω
- m_{ee}[0.9-1.1]: φ
- m_{ee}[1.1-2.9]: charm

Goals:

- Study integral elliptic flow for the dominant particles
- Study p_T dependence in different mass ranges

Di-electron Elliptic Flow

DNP/SQM2011



First measurements from STAR

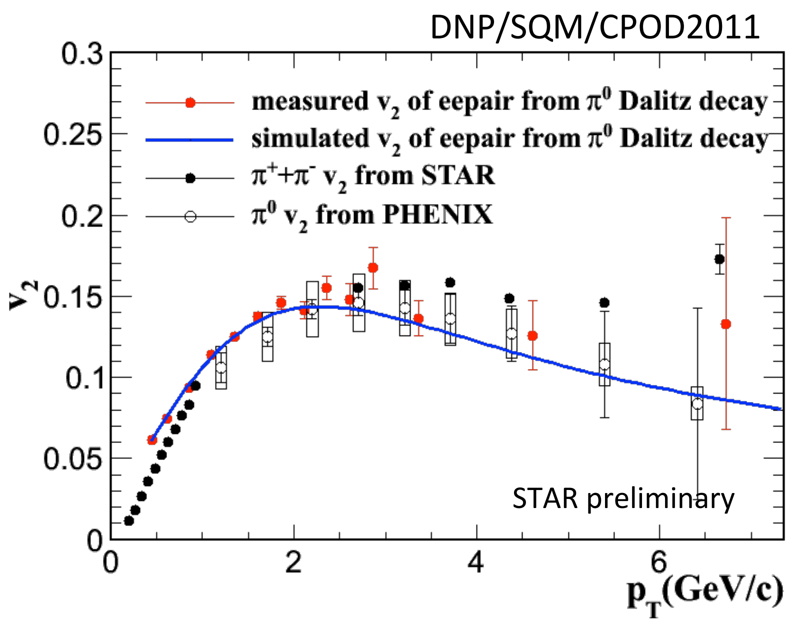
Dataset: Au+Au @200GeV
- 220M minbias events
- statistical error only

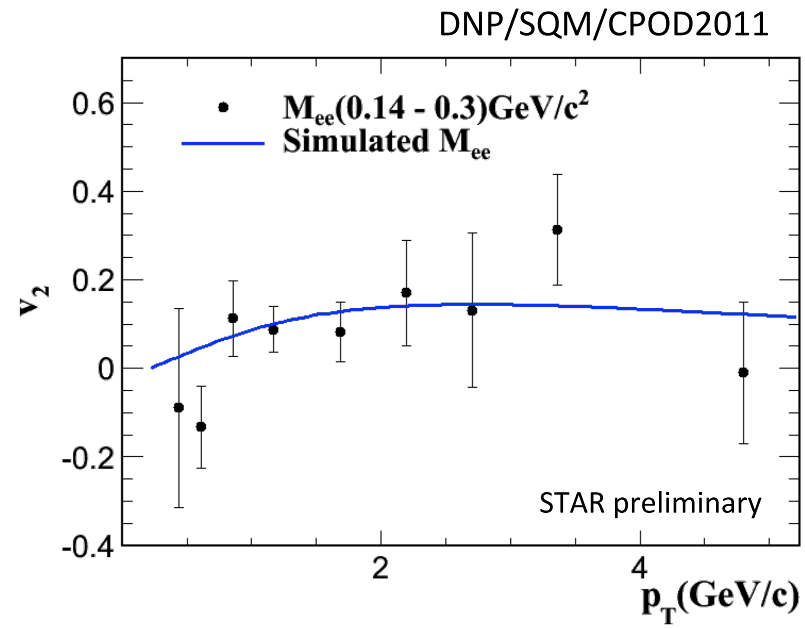
Background determination
- like-sign $m_{ee}<0.7GeV/c^2$
- mixed-event $m_{ee}>0.7GeV/c^2$

Work underway to determine systematic uncertainties

$$v_2^{\text{total}}(m_{ee}) = v_2^{\text{signal}}\left[\frac{N_S}{N_B+N_S}\right](m_{ee}) + v_2^{\text{background}}\left[1-\frac{N_S}{N_B+N_S}\right](m_{ee})$$

Di-electron Elliptic Flow



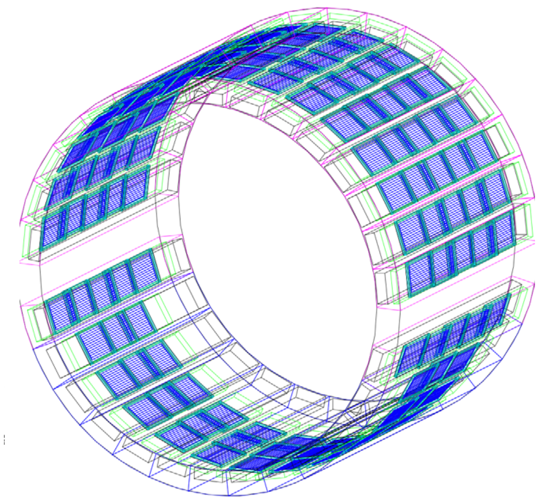


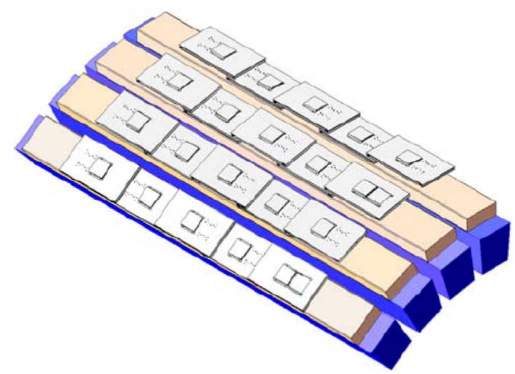
- Measured flow in π^0 mass range is consistent with simulations of the v_2 of "Dalitz decayed" charged pions
  - input parameterized STAR $\pi^\pm$ spectra
- For η mass range simulation similar procedure
  - assume similar v_2 as K_S
- This is still work in progress …
  - estimate systematical uncertainties, study other inv. mass regions

Muon Telescope Detector

- A large area muon detector, located outside STAR magnet steel
  - based on proven technologies used in STAR TOF
- muons versus electrons:
  - no γ conversion
  - significantly less Dalitz decay
  - less affected by radiative losses in detector materials
- single-muon measurements:
  - look for e-μ correlations to distinguish heavy flavor production from initial lepton pair production
- di-muon measurements
  - QGP thermal radiation
  - Quarkonia (ϒ separation), light vector mesons, resonances
  - Drell-Yan production

- Installation schedule: Run 12 – 10%, Run 13 – 43%, Run 14 – 80%, completion March 2014.



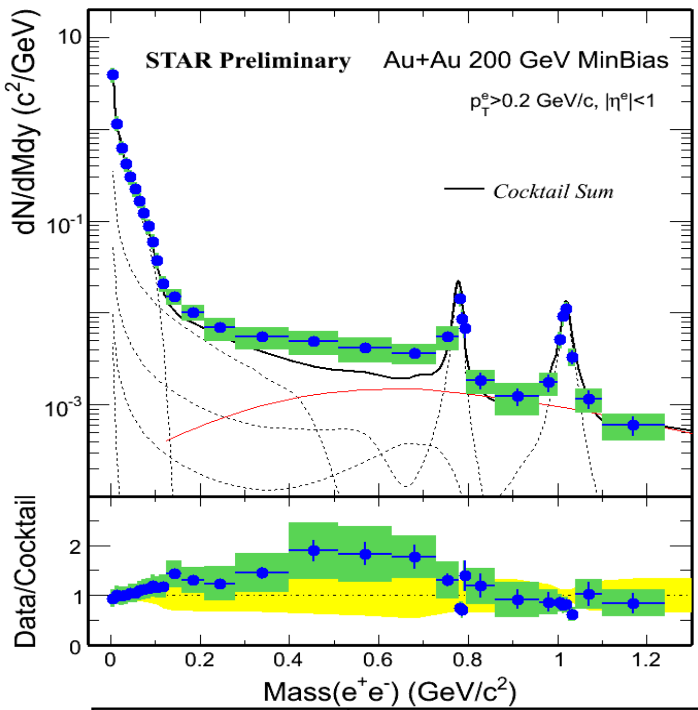


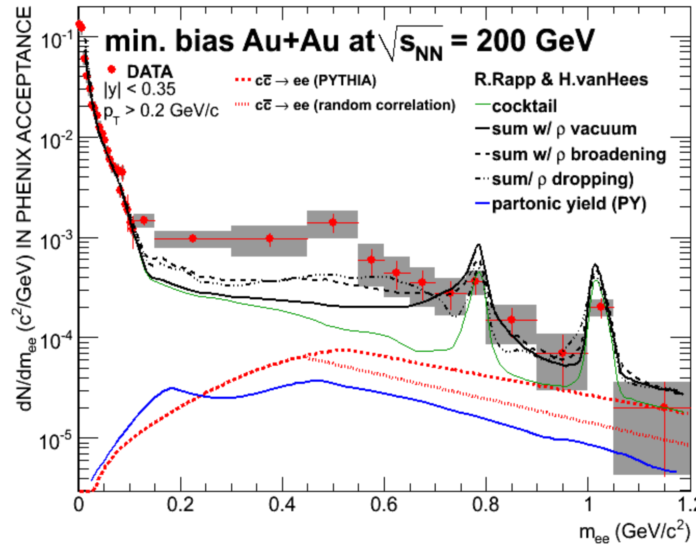
Summary

- STAR has measured di-electron spectra in p+p and Au+Au at $\sqrt{s_{NN}}$=200 GeV
  When compared to hadron cocktail:
  – p+p: consistent with hadron cocktail; charm contribution dominates IMR
  – Au+Au (min-bias): hint of enhancement in LMR
  – Au+Au (central): more pronounced enhancement in LMR, hint of charm modification in IMR
- STAR has measured di-electron spectra in BES data. Work in progress.
- STAR has measured di-electron elliptic flow. Work in progress.
  – proof of principle established
- STAR is constructing the MTD and HFT detectors
  – scheduled for 2014
  – expect significant improvements in di-lepton measurements, e-μ correlations, etc.

Backup Slides

LMR Enhancement



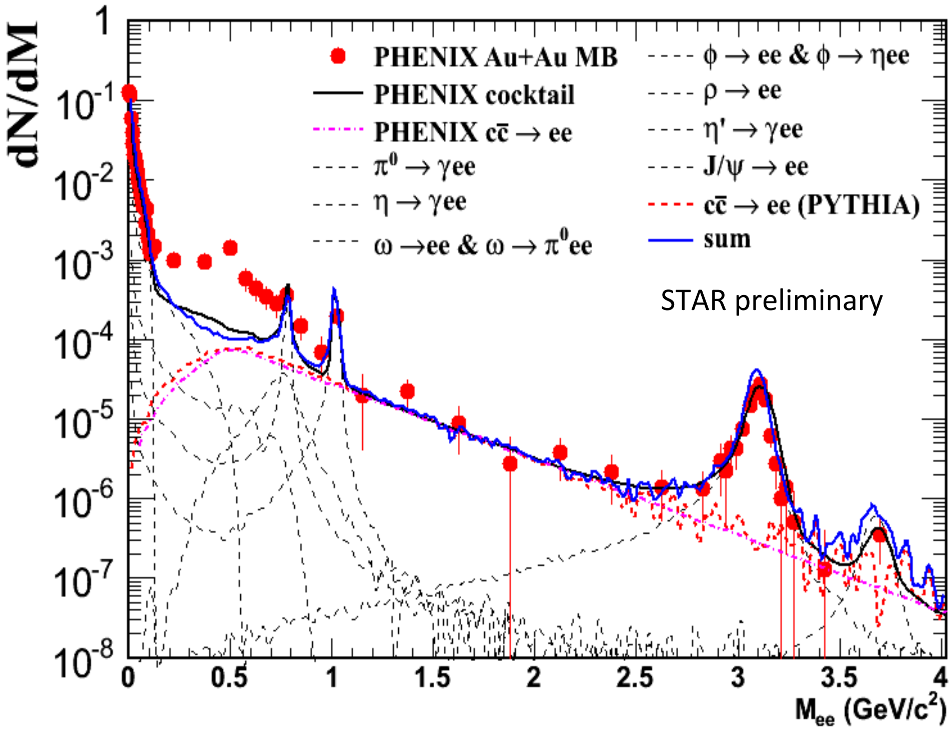


QM/SQM2011

Enhancement factor in $0.15<M_{ee}<0.75$ Gev/c^2

	Minbias (value ± stat ± sys)	Central (value ± stat ± sys)
STAR	1.53 ± 0.07 ± 0.41 (w/o ρ) 1.40 ± 0.06 ± 0.38 (w/ ρ)	1.72 ± 0.10 ± 0.50 (w/o ρ) 1.54 ± 0.09 ± 0.45 (w/ ρ)
PHENIX	4.7 ± 0.4 ± 1.5	7.6 ± 0.5 ± 1.3
Difference	2.0 σ	4.2 σ

Reproduce PHENIX cocktail



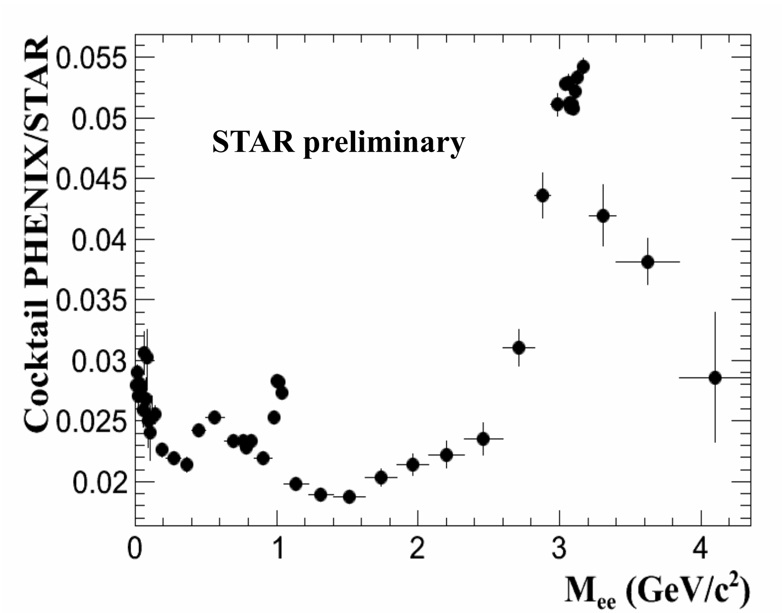
SQM2011

- Reproduce the cocktail within PHENIX acceptance by our method.
- The momentum resolution are still from STAR.

Scaled by all the yields from PHENIX paper[1], we can reproduce the PHENIX cocktail.

[1]. Phys. Rev. C 81, 034911 (2010).

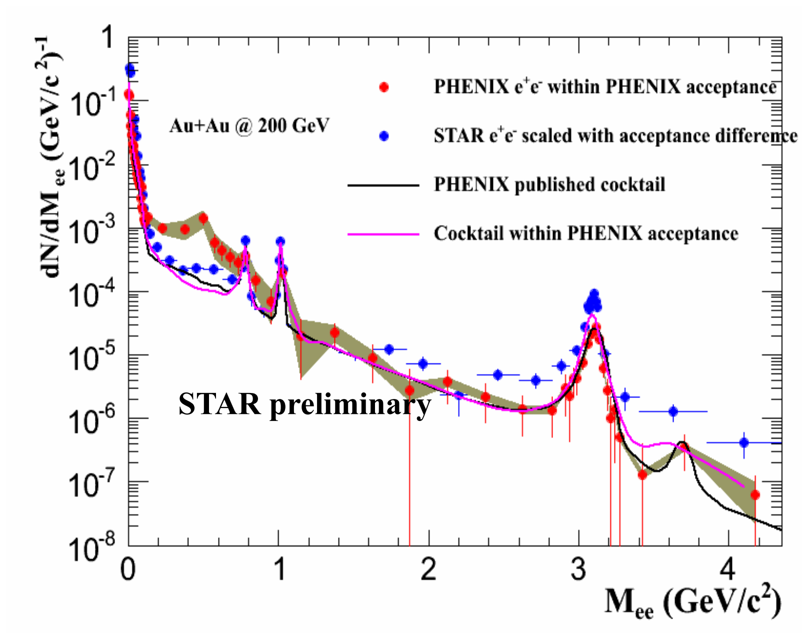
Check with acceptance difference



Acceptance difference:

$$\frac{\text{Cocktail in PHENIX acceptance}}{\text{Cocktail in STAR acceptance}}$$

Scaled by same meson and charm yields.



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Scaled by the acceptance difference.