# The STAR Dilepton Program


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for the STAR Collaboration

Office of Science
U.S. DEPARTMENT OF ENERGY

# Outline

- Introduction & Motivation
- Electron Identification in STAR
- Dielectron Production at $\sqrt{s_{NN}}$= 200 GeV
  - p+p and Au+Au results
  - elliptic flow of dielectrons
- Results from Beam Energy Scan Program
- STAR Dilepton Present & Future
- Summary

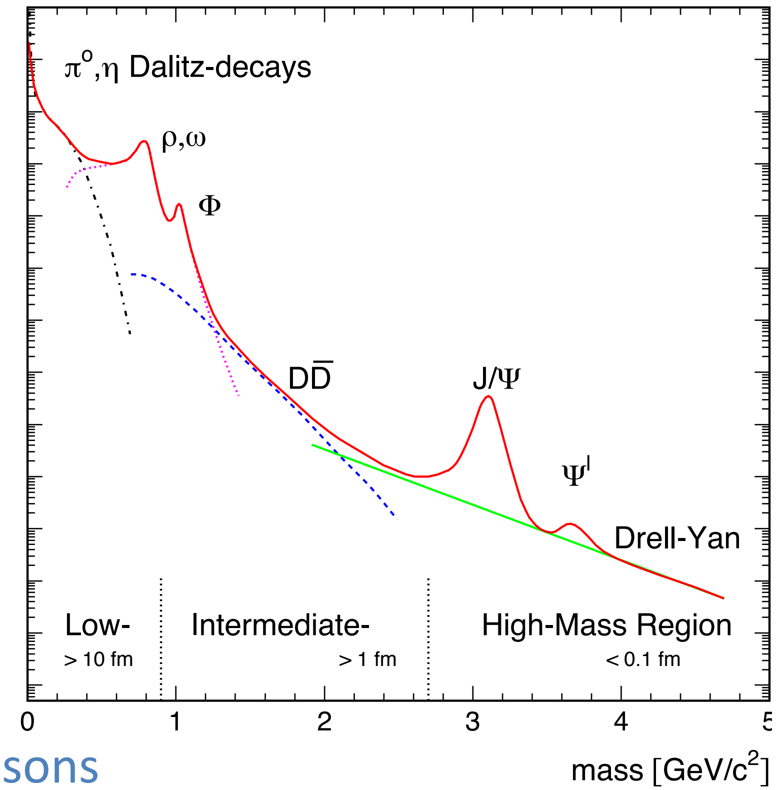
# Dilepton Physics

## Dileptons are excellent penetrating probes

- very low cross-section with QCD medium
- created throughout evolution of system

## Chronological division:

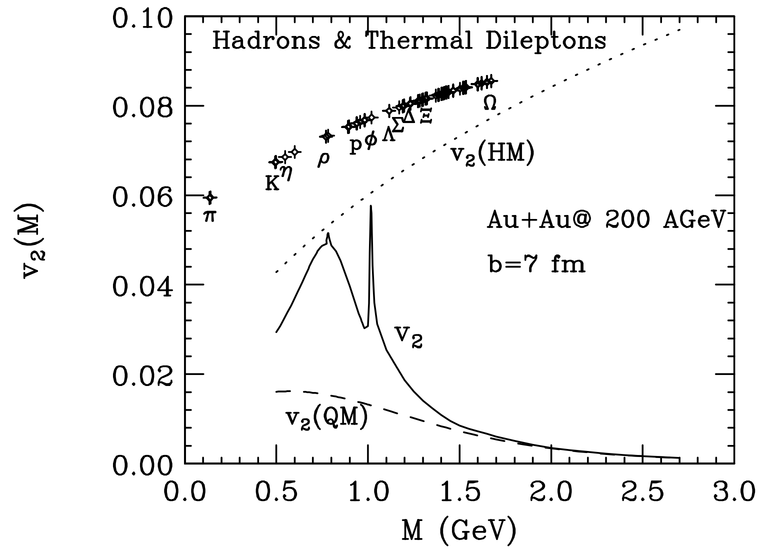
- High Mass Range (HMR)
  $M_{ee} > 3$ GeV/$c^2$
  - primordial emission, Drell-Yan
  - J/Ψ and ϒ suppression
- Intermediate Mass Range (IMR)
  $1.1 < M_{ee} < 3$ GeV/$c^2$
  - QGP thermal radiation
  - heavy-flavor modification
- Low Mass Range (LMR)
  $M_{ee} < 1.1$ GeV/$c^2$
  - in-medium modification of vector mesons
  - possible link to chiral symmetry restoration



# Dilepton Elliptic Flow

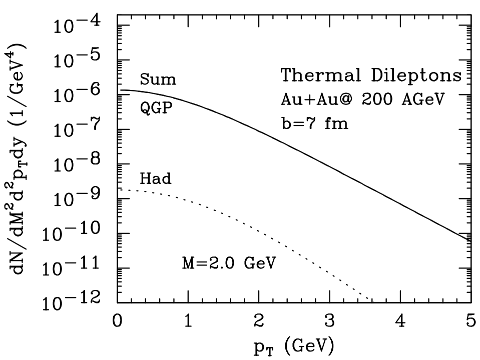
Elliptic flow is generated very early stage

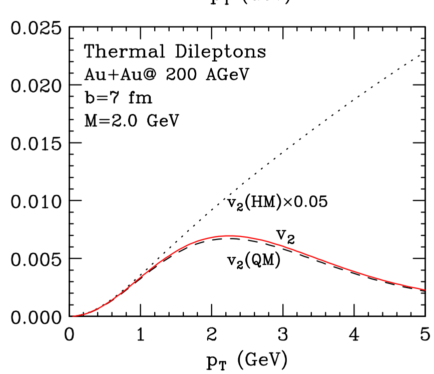
- dileptons can further probe this early stage
- possibly constrain QGP EoS




Combination of $p_T$ and $M_{ll}$ can set observational windows on specific stages of the expansion

Chatterjee *et al.*, Phys Rev. C 75 (2007) 054909



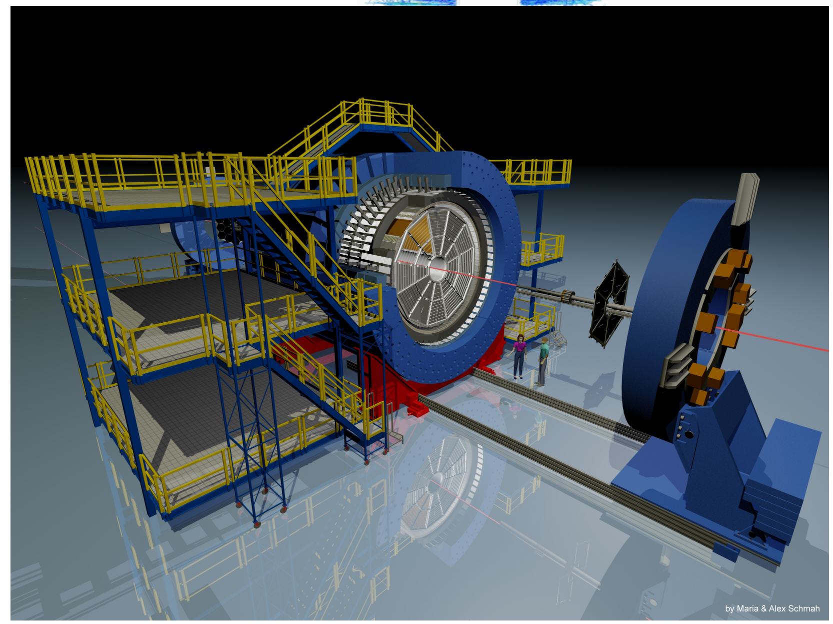

Expect interesting structures in $p_T$-integrated $v_2(M)$:

- high-mass dileptons
  - hot early stage
  - flow is still weak
- low-mass dileptons
  - flow strong, temperature low
- modulations from the contributions of vector mesons
  - strong variations of relative weights on/off resonances

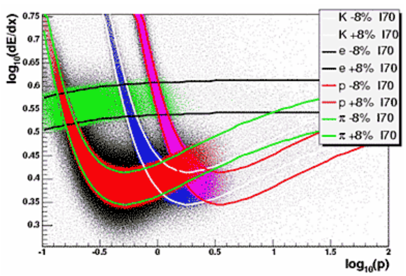
# The STAR Detector

Large acceptance electron ID

- Time Projection Chamber
- Time-of-Flight detector
  - 2009: 72% completed (p+p)
  - 2010: fully commissioned
- Electromagnetic Calorimeter




Poster: K. Jung (125)




Time Projection Chamber

$0<\phi<2\pi$, $|\eta|<1$

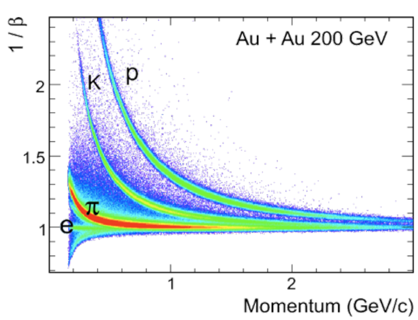
- Tracking
- dE/dx PID

TOF cut removes "slow" hadrons

- improves electron purity

  central events ~92%

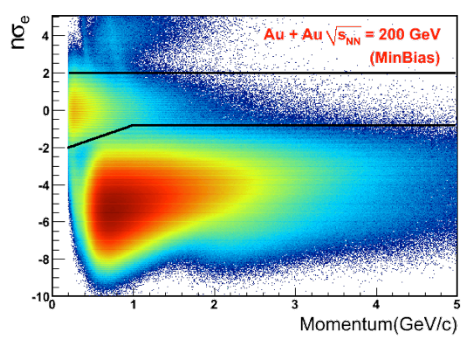
  min-bias events ~95%



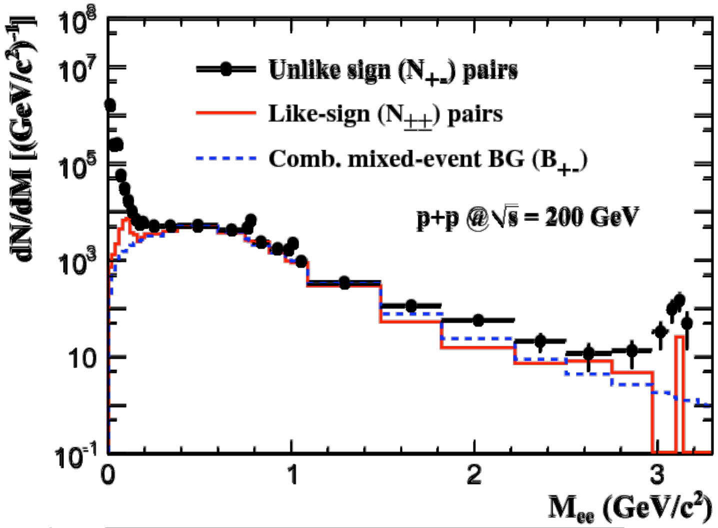

Time-of-Flight Detector

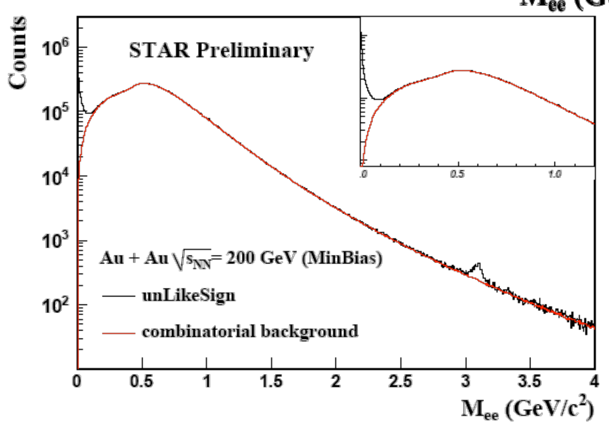
$0<\phi<2\pi$, $|\eta|<0.9$

- Time resolution < 100ps
- Significantly improves PID



# $e^+e^-$ Invariant Mass & Background




Combine both methods:

p+p: LS < 0.4 GeV/$c^2$ < ME

Au+Au: LS < 0.75 GeV/$c^2$ < ME×LS

carefully normalized using overlap in $M_{ee}$

## Background sources

- combinatorial background (non-physical)
- correlated background
  - *e.g.* double Dalitz decay, jet correlation.

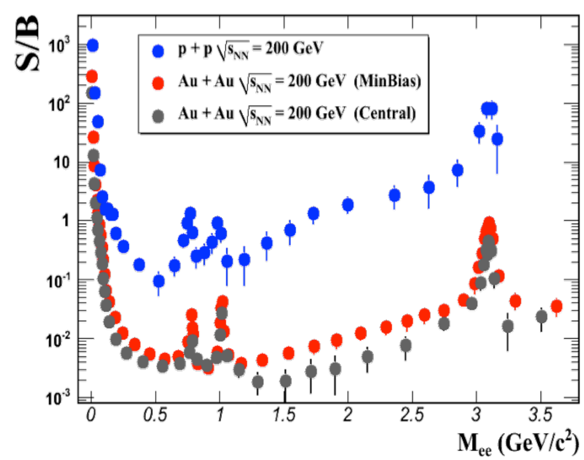
## Background methods

- mixed-event method: combinatorial only
  - improve statistics
- like-sign method: combinatorial & correlated BG
  - correct for acceptance differences
- pair cuts remove photon conversions

## Other signals (meson decays)

Remove by comparing real data with simulations for hadron contamination

- Hadron Simulation Cocktail

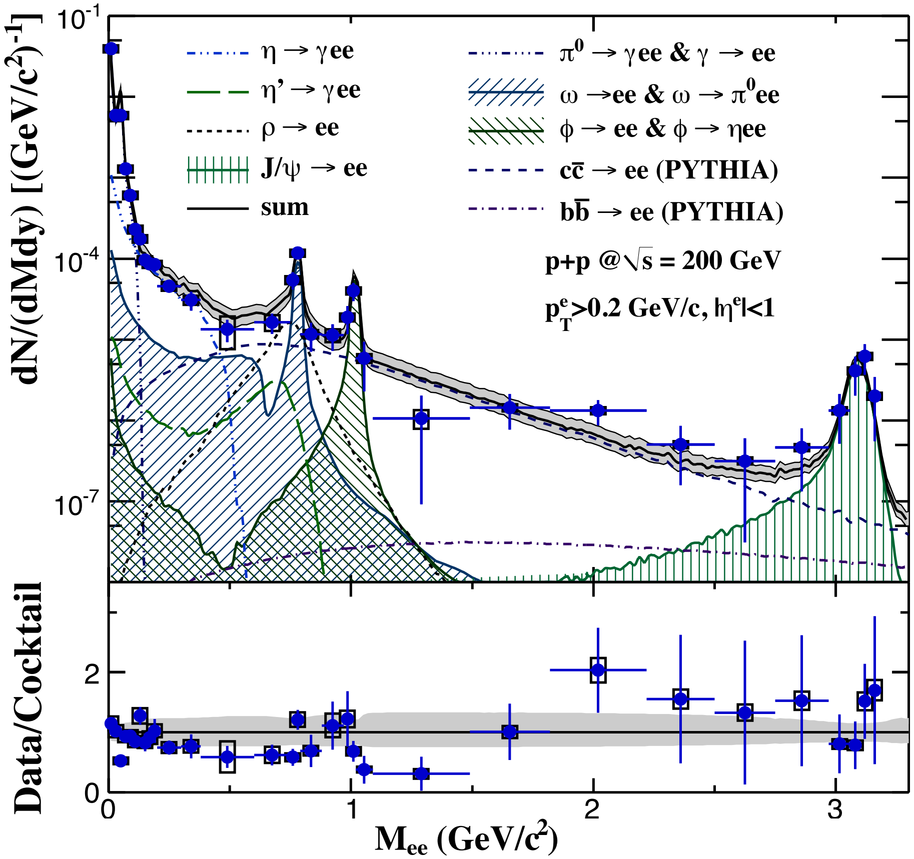



S/B @ $M_{ee}$~ 0.5 GeV/$c^2$:

- ➢ 1/10 for p+p
- ➢ 1/250 for Au+Au central

# Production in p+p at 200 GeV

Phys. Rev. C 86, 024906 (2012)




➢ Understand the p+p reference

Cocktail simulation consistent with data

L. Ruan (STAR), Nucl. Phys. A855 (2011) 269

Charm contribution dominates IMR

– scaled with STAR charm cross-section

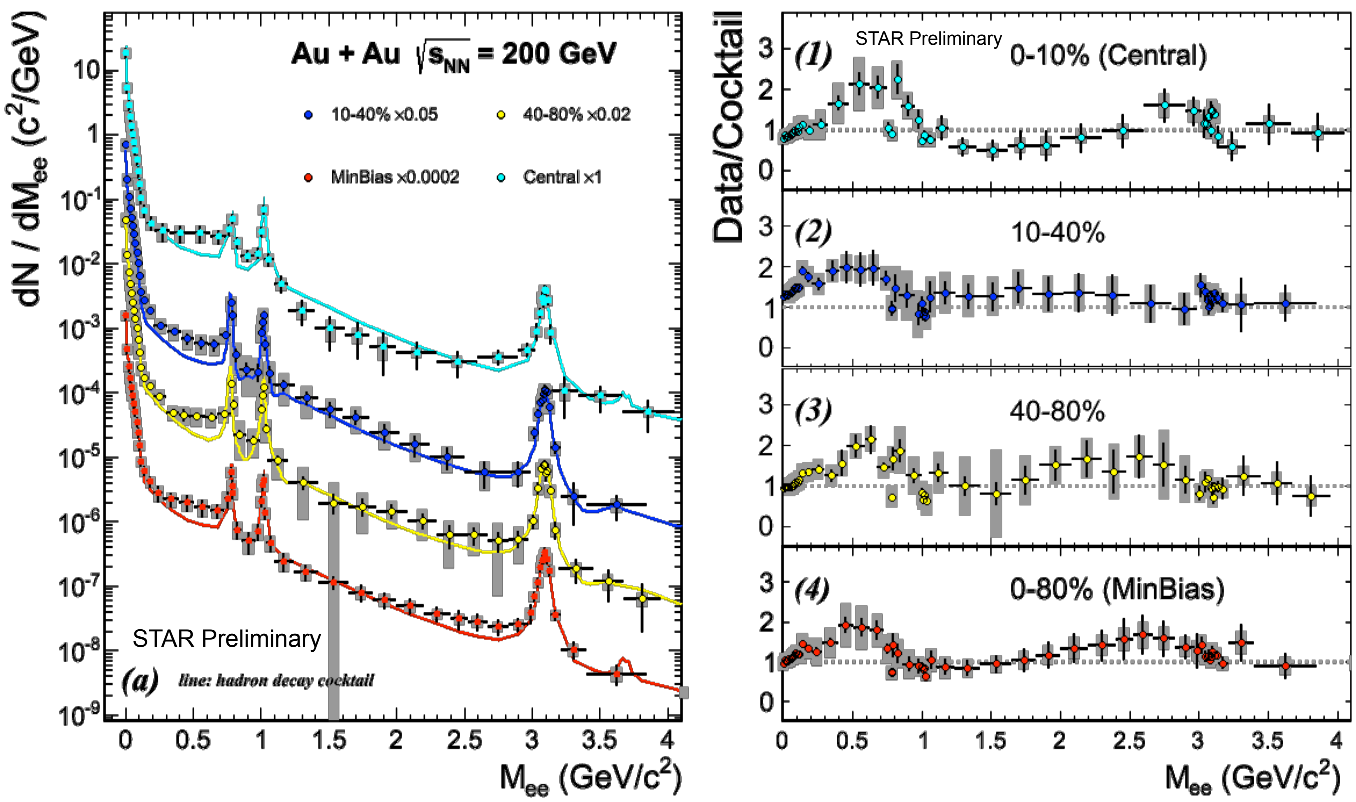
Adams et al (STAR), Phys. Rev. Lett. 94 (2005) 062301

Uncertainties:

- vertical bars: statistical
- boxes: systematic
- grey band: cocktail simulation systematic
- not shown: 11% normalization

# Production in Au+Au at 200 GeV

STAR ☆




## Low Mass:

- ➢ enhancement

when compared to cocktail (w/o ρ meson)

little centrality dependence

## Intermediate Mass:

cocktail "overshoots" data in central collisions

but, consistent within errors

modification of charm?

difficult to disentangle (modified) charm from thermal QGP contributions

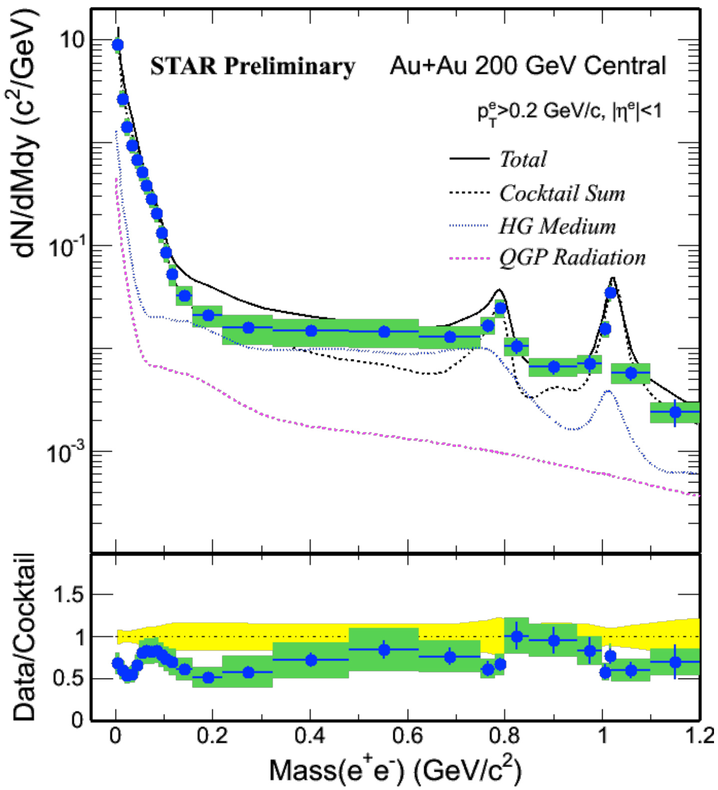
- ➢ future detector upgrades required

B. Huang (3C, 268)

Poster: Y. Guo (153)

H. Huang (6C - 142)

# Compare to Rapp, Wambach, v. Hees




- STAR central 200 GeV Au+Au
- hadronic cocktail (STAR)

Ralf Rapp (priv. comm.)

R. Rapp, Phys.Rev. C 63 (2001) 054907

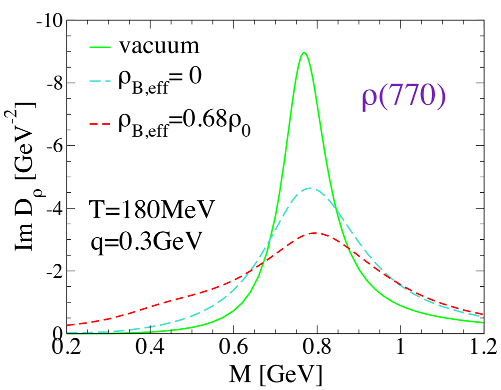
R. Rapp & J. Wambach, EPJ A 6 (1999) 415

Complete evolution (QGP+HG)

cocktail + HG + QGP:

➢ Agreement w/in uncertainties

Rapp, Wambach, van Hees
arXiv:0901.3289

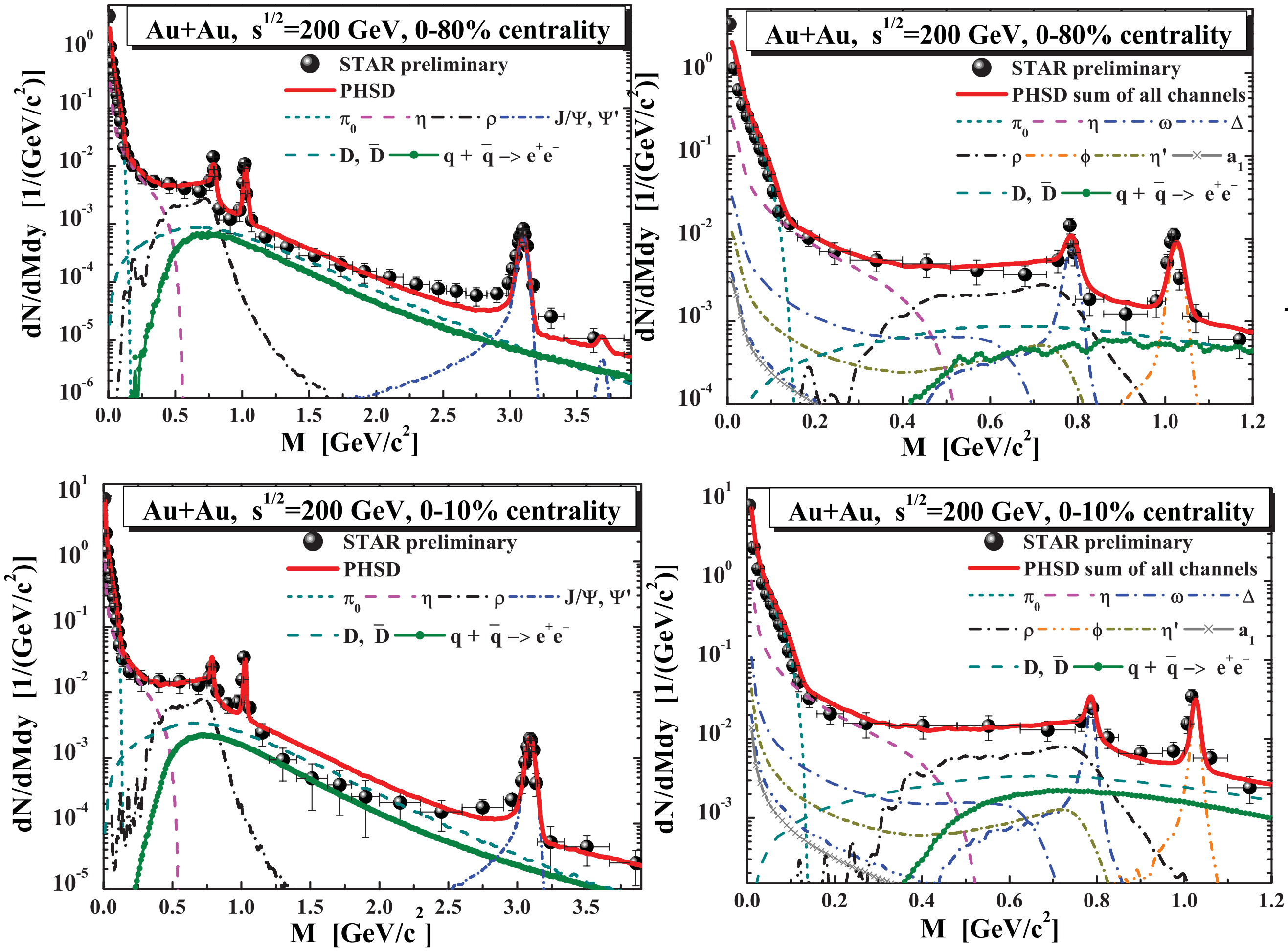



➢ hadronic phase: ρ "melts" when extrapolated close to phase transition boundary
  - total baryon density plays the essential role
➢ top-down extrapolated QGP rate closely coincides with bottom-up extrapolated hadronic rates

# Compare to Theory: PHSD Model

O. Linnyk et al., Phys. Rev. C 85 024910 (2012)
H. Xu et al., Phys. Rev. C 85 024906 (2012)

## Parton-Hadron String-Dynamics




1. Collisional broadening of vector mesons
2. Radiation from QGP

**Minimum bias collisions (0-80%):**

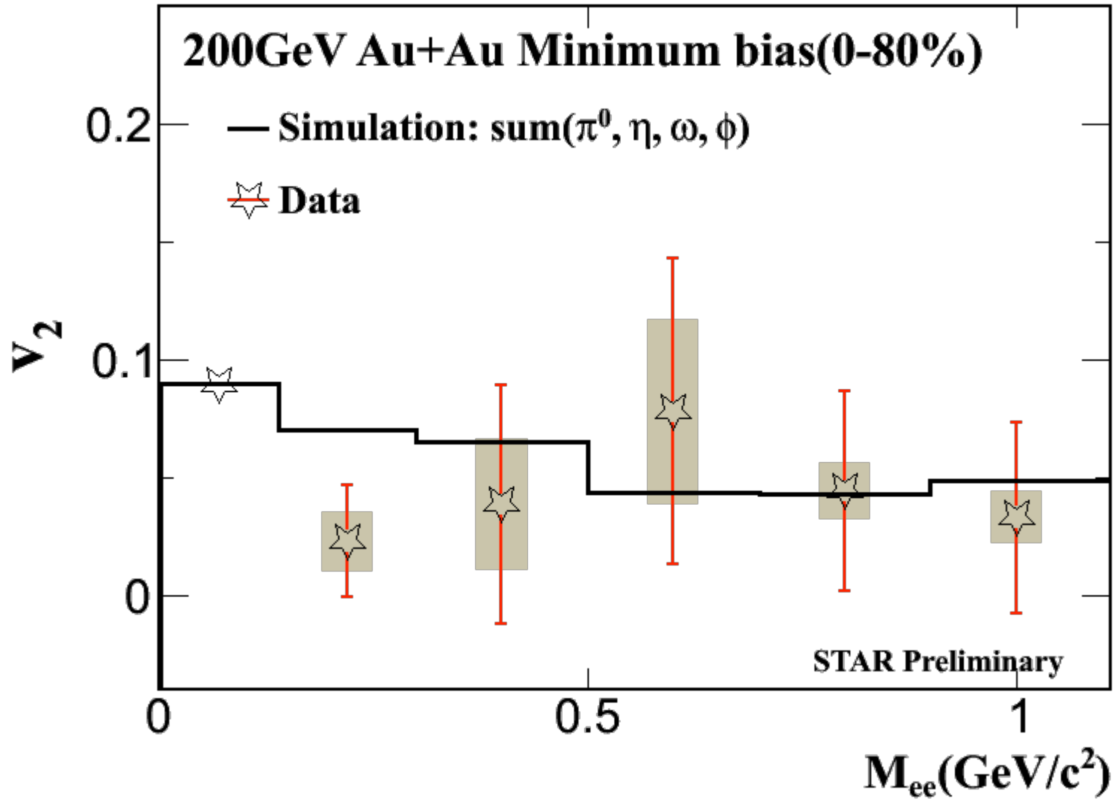
- Generally good agreement

**Central collisions (0-10%):**

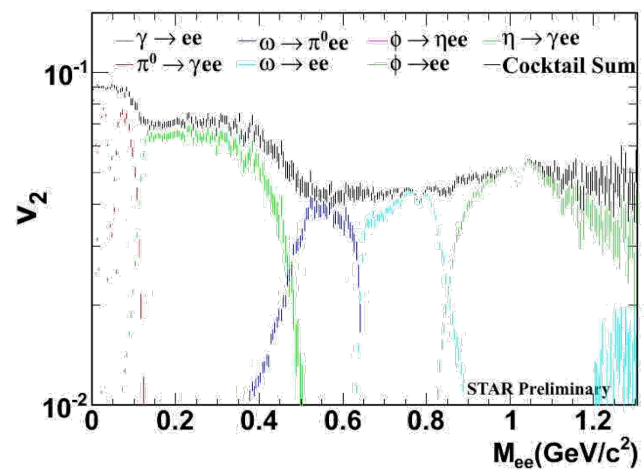
- PHSD roughly in line with LMR region

# Elliptic Flow in Au+Au at 200 GeV

First measurements from STAR




- 700M min-bias events
  - combined 2010/2011
- Background:
  - Like-Sign $M_{ee}$<0.7 GeV/$c^2$
  - Mixed-Event $M_{ee}$>0.7 GeV/$c^2$
- Event-Plane method: TPC
- Cocktail contributions:




➢ dielectron $v_2(M_{ee})$: data and simulations consistent

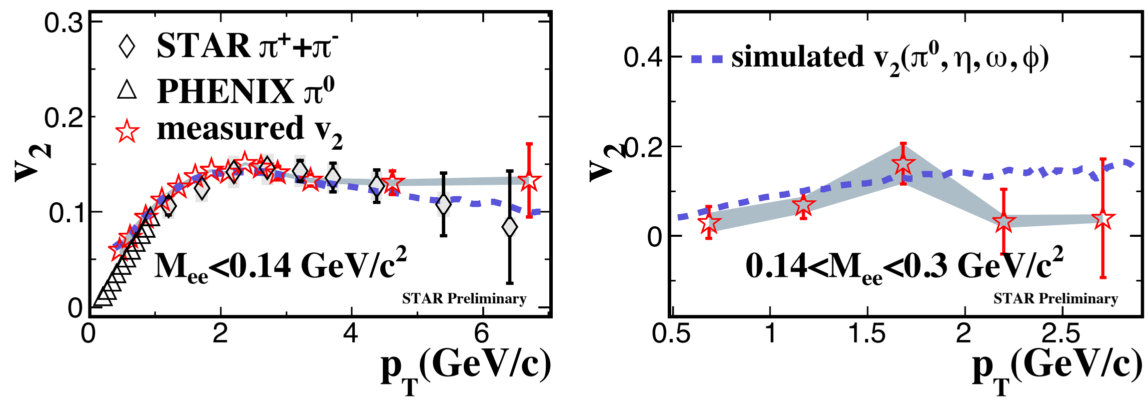
- work in progress to include IMR $v_2$

Poster: X. Cui (322)

# Dielectron $v_2$ $p_T$ Dependence

Poster: X. Cui (322)

Au+Au $\sqrt{s_{NN}}$= 200GeV 0-80% centrality




## Comparison with measured $v_2(p_T)$

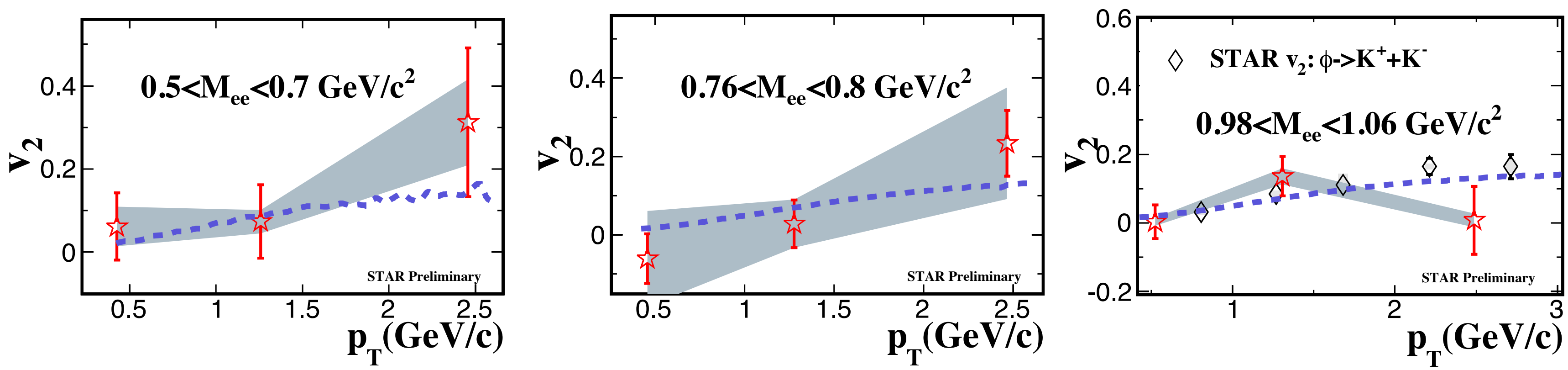
$\pi^{\pm}$ (STAR) and $\pi^0$ (PHENIX)

$M_{ee} < 0.14$ GeV/$c^2$

PHENIX, PRC 80 (2009) 054907

$\phi \rightarrow K^+K^-$ (STAR)

$0.98 < M_{ee} < 1.06$ GeV/$c^2$



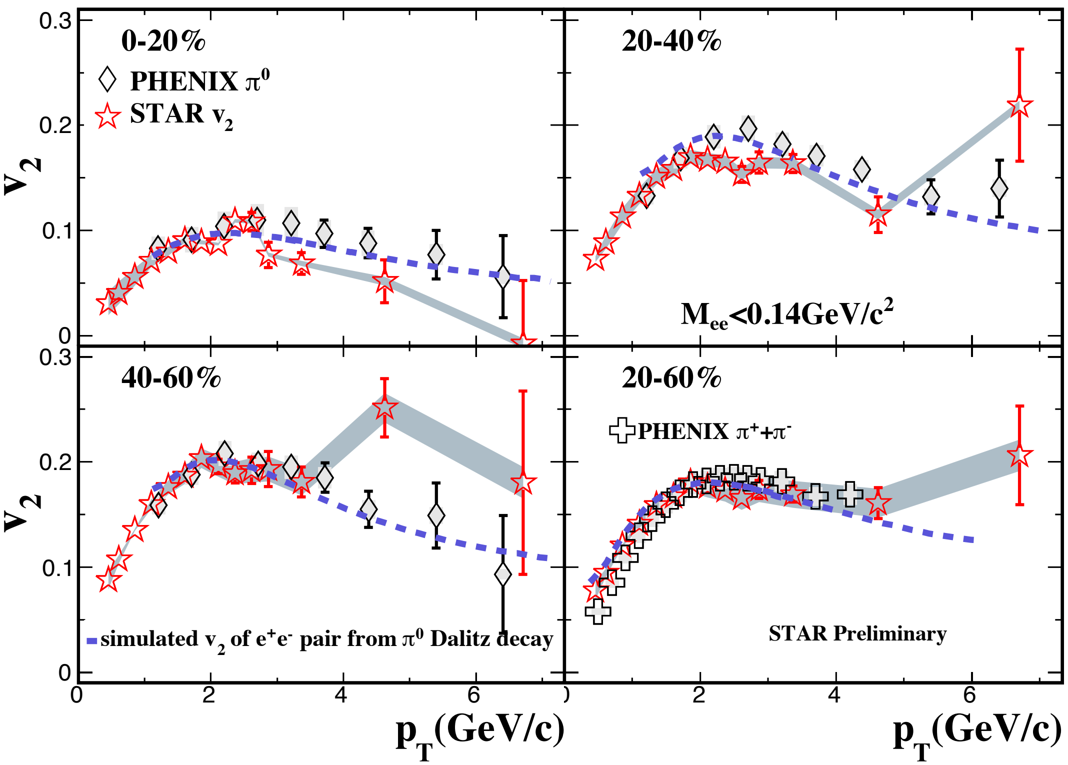

- $v_2(p_T)$ consistent with simulations & measurements

# Dielectron $v_2$ Centrality Dependence

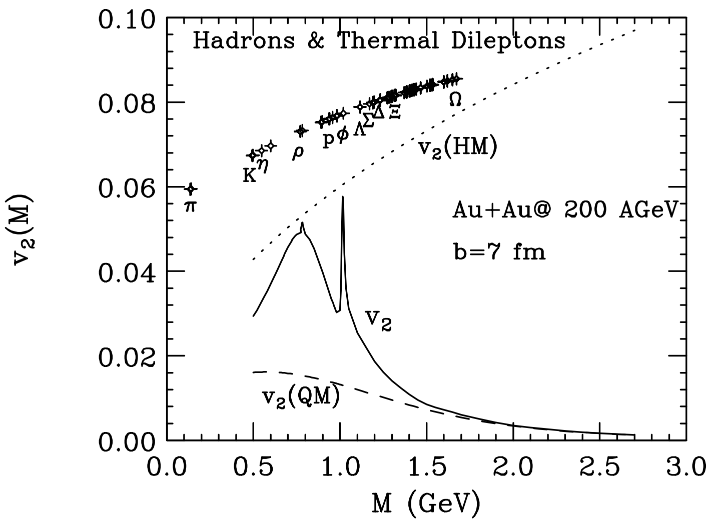
Centrality dependence $v_2(p_T)$

$M_{ee}$<0.14 GeV/$c^2$

- consistent with simulations
- consistent with measurements




Can we distinguish between HG and QGP $v_2$ contributions?




Recall: need uncertainties to be <4%
(compared with model differences) … no, not yet.

- Require ~2x more Au+Au min-bias data and e-μ measurements at higher $M_{ee}$ to disentangle charm contributions

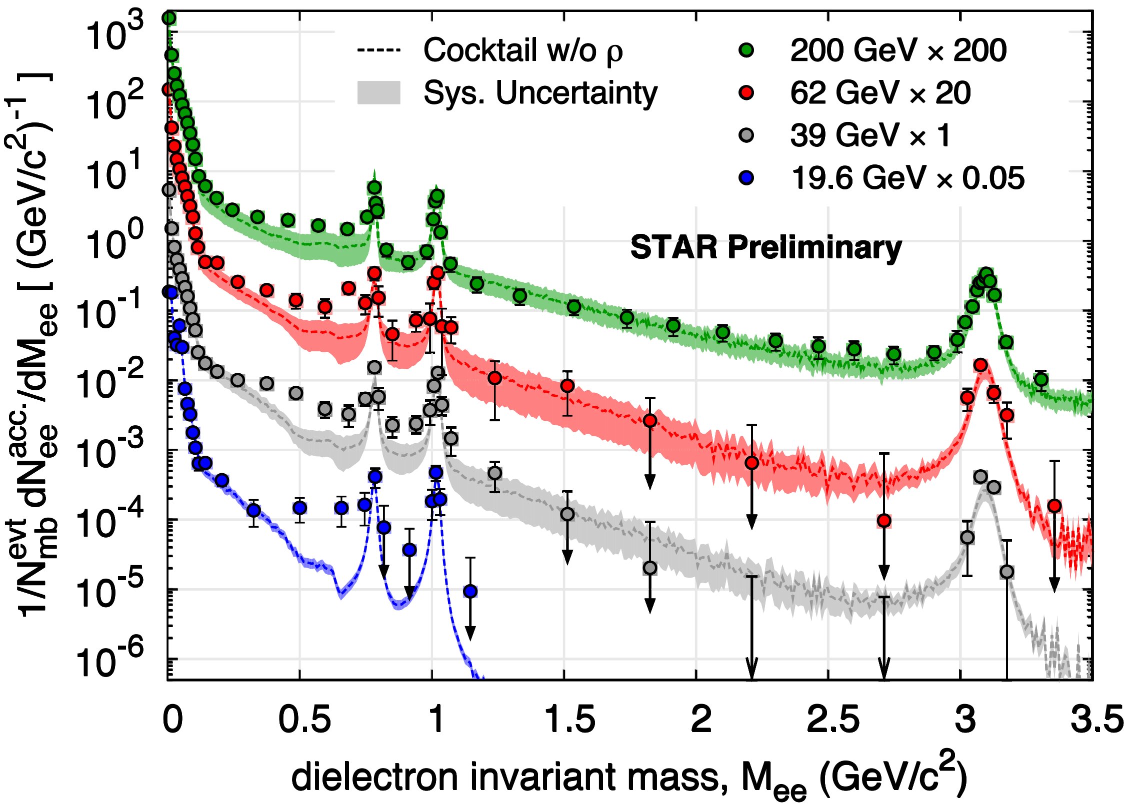
# Dielectron Production at lower $\sqrt{s_{NN}}$

Observed Low-Mass enhancement at top RHIC energy

- in-medium modification effects?
- indication of chiral symmetry restoration?

Explore Low Mass Range down to SPS energies

- possible enhancement, consistent model description?




Beam Energy Scan Dielectrons:

2010 - 2011

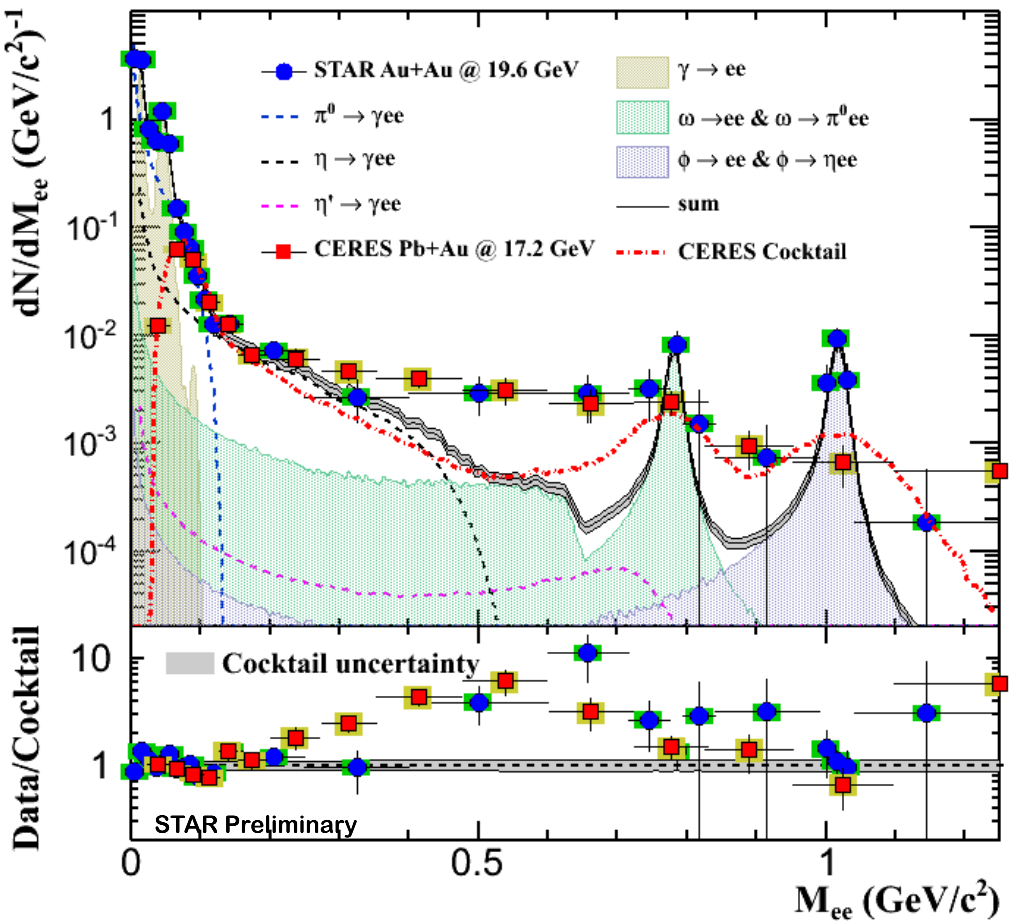
Au+Au at 62.4, 39, and 19.6 GeV

STAR data samples:

55M, 99M, and 34M min-bias events

Posters: P. Huck (113), B. Huang (269)

# Comparison to SPS measurements




STAR Au+Au at 19.6 GeV/c

- min-bias (0 - 80%)
- $p_T$>0.2GeV/*c*, |η|<1, $|y_{ee}|$<1

Cocktail:

- $\pi^0$ yield: STAR $\pi^\pm$
- other mesons: NA49-based, scaled with SPS meson/$\pi^0$ ratio

CERES Pb+Au at 17.2 GeV/c

CERES, Eur.Phys.J. C 41 (2005) 475

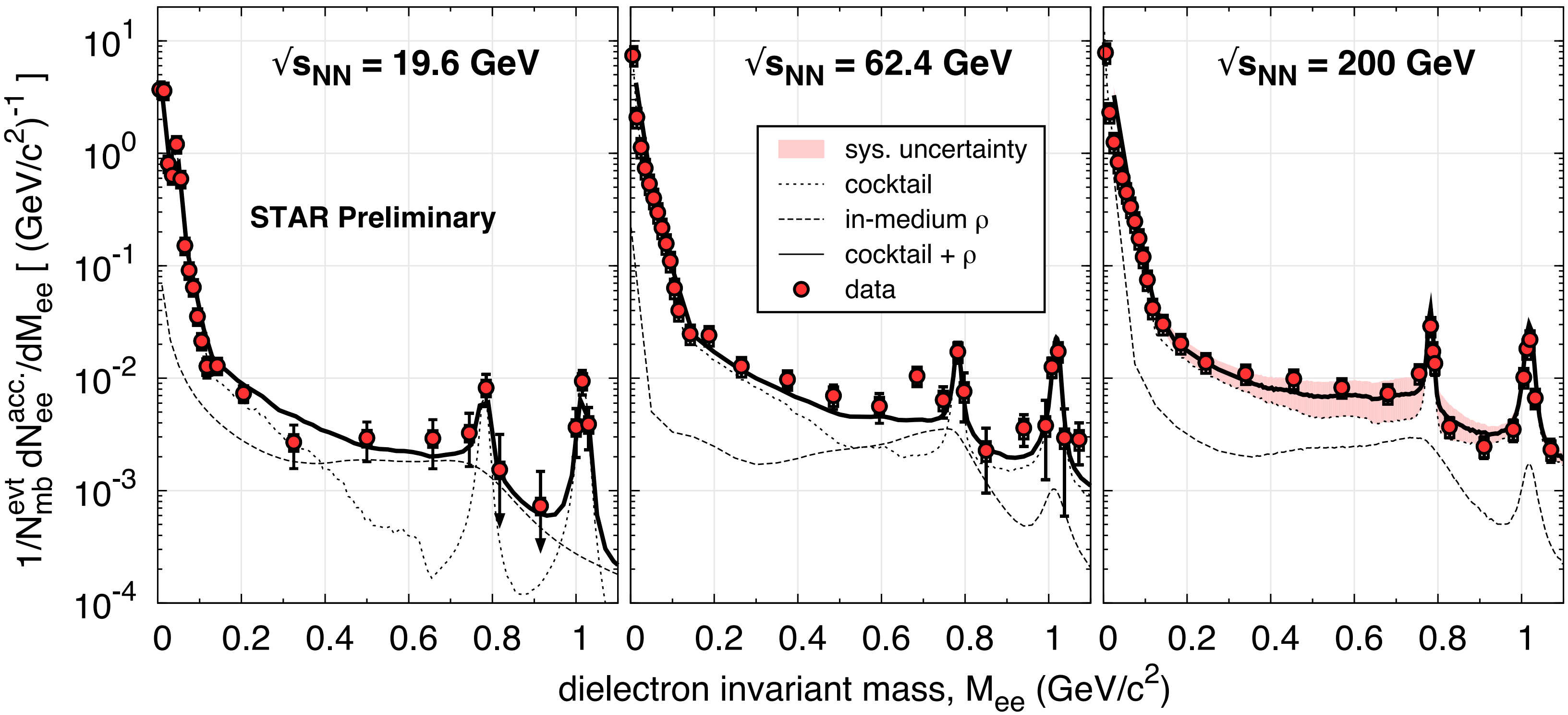
- semi-central (0-28%)
- $p_T$>0.2GeV/*c*, 2.1<η<2.65, $\theta_{ee}$>35mrad

Posters: B. Huang (269)

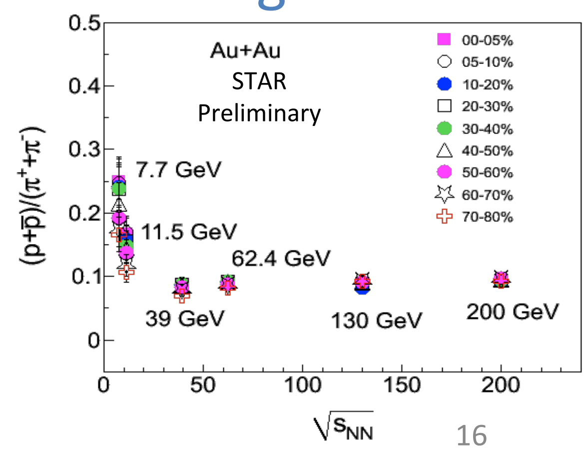
➢ STAR enhancement comparable to CERES

… and with better mass resolution

# Compare to Theory: in-medium ρ




- Robust theoretical description top RHIC down to SPS energies
  - calculations by Ralf Rapp (priv. comm.)
  - black curve: cocktail + in-medium ρ
- Measurements consistent with in-medium ρ broadening
  - expected to depend on total baryon density
  - tool to look for chiral symmetry restoration



# STAR Dileptons: Present & Future

- 2009 – 2011
  - **TPC + TOF + EMC**
    - dielectron continuum
    - dielectron spectra, and $v_2$ ($p_T$)
  - vector meson in-medium modifications
  - LMR enhancement
  - modification in IMR?

- 2012-2013
  - **TPC + TOF + EMC + MTD** (partial)
    - e-μ measurements
  - IMR: Improve our understanding of thermal QGP radiation
  - LMR: vector meson in-medium modifications

- 2014 and beyond
  - **TPC + TOF + EMC + MTD + HFT**
    - dimuon continuum
    - e-μ spectra and $v_2$
  - LMR: vector meson in-medium modifications
  - IMR: measure thermal QGP radiation

➢ More on HMR physics:

Wei Xi – Heavy Flavor Results from STAR (Plenary IIB)

➢ More on MTD and HFT:

Huan Huang – STAR Upgrade Plan for the Coming Decade (Parallel 6C)

Poster: C. Yang (331)

# Summary

- STAR detector very well suited for dilepton physics
  - recent TOF upgrade allows for large acceptance electron ID

- Dielectron in p+p and Au+Au at $\sqrt{s_{NN}}$=200 GeV: centrality and $p_T$ differentials
  - observe low mass enhancement
- Dielectron elliptic flow measurements in Au+Au at $\sqrt{s_{NN}}$=200 GeV
  - $v_2(M_{ee},p_T)$ results consistent with other measurements & cocktail simulations
  - need ~2x increase in statistics to distinguish HG and QGP contributions
- Dielectron measurements in Au+Au at $\sqrt{s_{NN}}$= 19.6 – 62.4 GeV
  - low mass enhancement down to SPS energies, with comparable magnitude
  - consistent with in-medium ρ broadening
  - robust and consistent description for $\sqrt{s_{NN}}$= 19.6, 62.4, and 200 GeV

- Future STAR upgrades enable further exploration of the dilepton continuum
  - upcoming MTD upgrade allows for large acceptance μ ID
  - QGP thermal radiation measurements

# STAR Dilepton Presentations at QM'12

- B. Huang – parallel session 3C (268)
  Di-electron differential cross section in Au+Au collisions at different beam energies at STAR

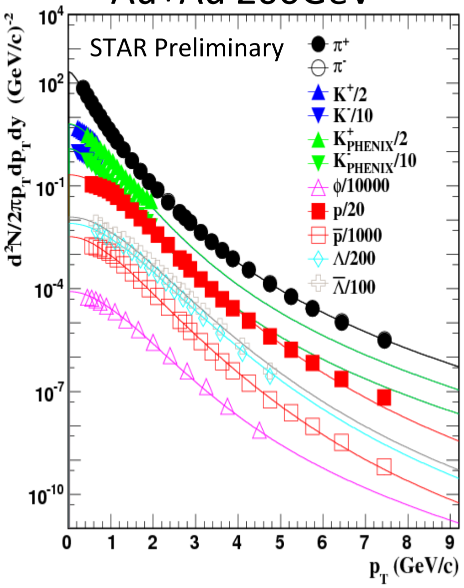
- X. Cui – poster 322
  Centrality, mass and transverse momentum dependence of di-electron elliptic flow in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at STAR
- K. Jung – poster 125
  A Study of High-pT/High-mass Dielectron Production through Trigger Combination in 200 GeV Au+Au Collisions at STAR
- B. Huang – poster 269
  Low mass di-electron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV at STAR
- P. Huck – poster 113
  Dielectron Production in Au+Au-Collisions $\sqrt{s_{NN}}$= 39 & 62.4 GeV at STAR
- M. Wada – poster 110
  ω(782) and ϕ (1020) mesons from di-leptonic decay channels at the STAR experiment
- Y. Guo – poster 153
  Centrality and pT dependence study of Dielectron Production $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at STAR

- H. Huang – parallel session 6C (142)
  STAR Upgrade Plan for the Coming Decade
- C. Yang – poster 331
  Performance of the Muon Telescope Detector in STAR at RHIC

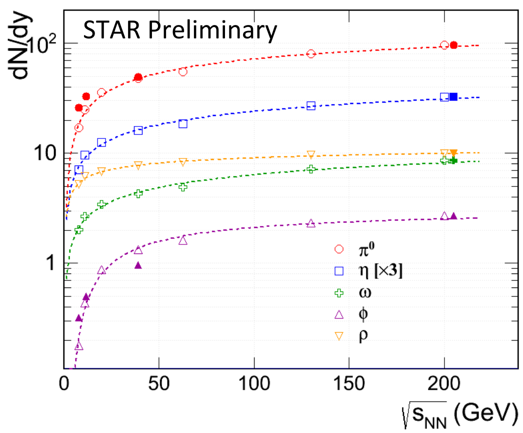
# BACKUP

# Hadronic Background Simulation

Au+Au 200GeV

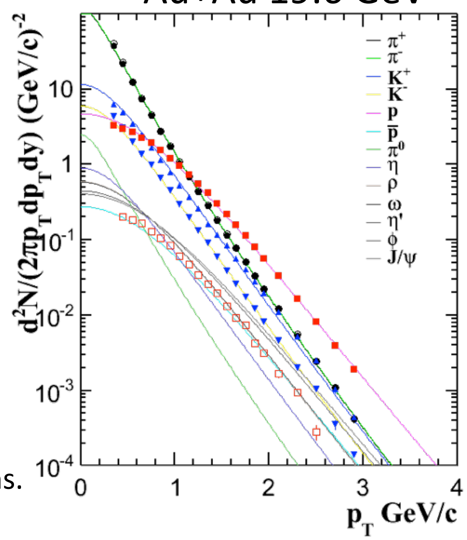



Au+Au 39 & 62GeV



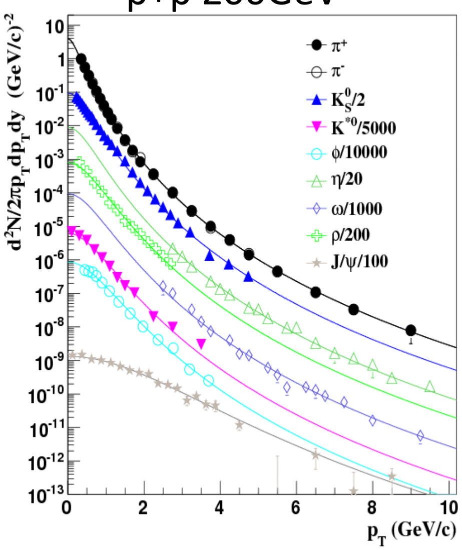

- Extrapolated from AMPT calculations.
- Scaled to measurements at 200GeV

Au+Au 19.6 GeV

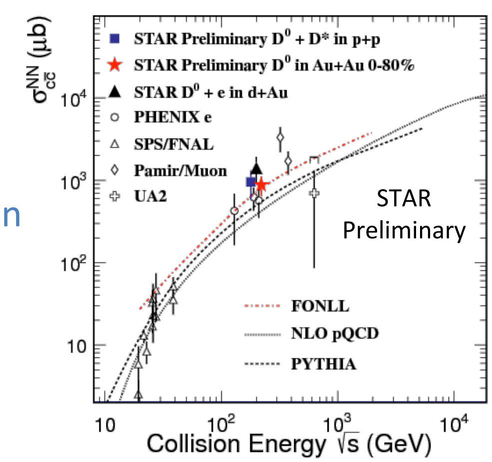



- TBW fit from NA49 data
- π yield from STAR

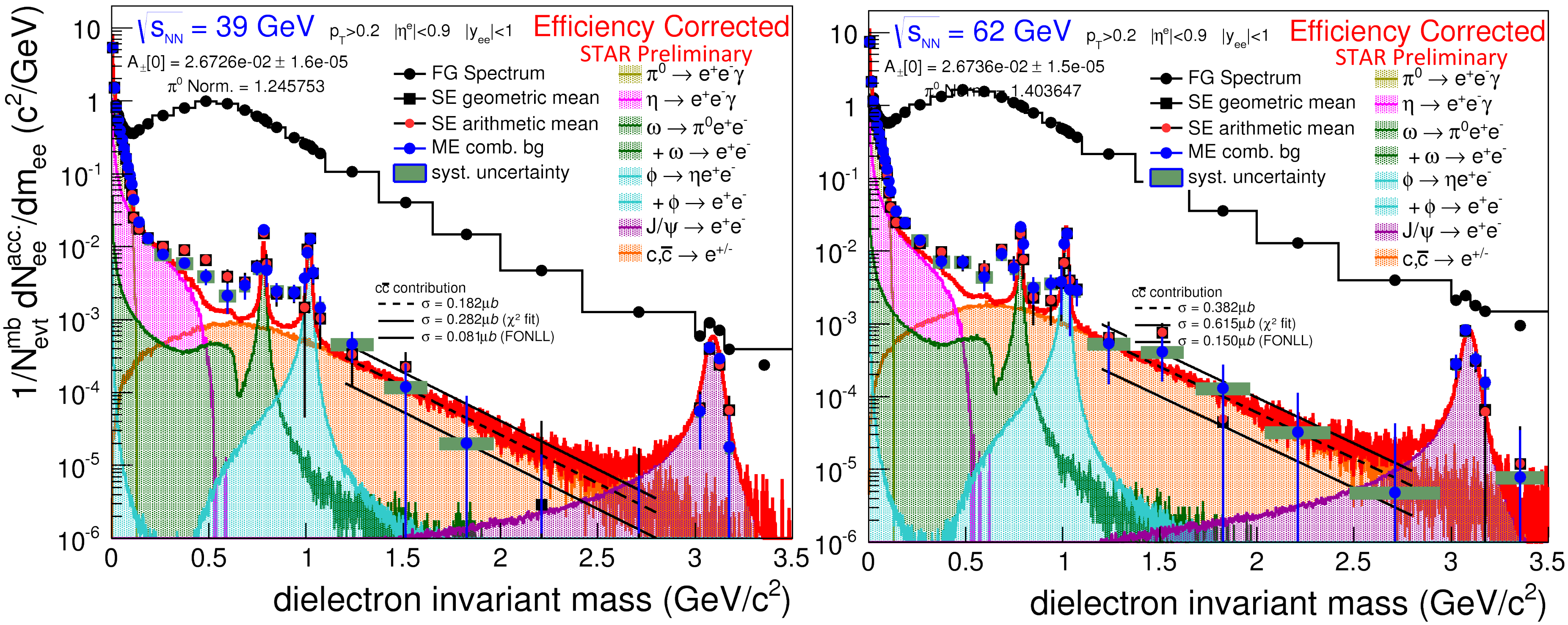
p+p 200GeV




- Hadrons: flat |y|<1.0, and flat full azimuthal input distribution
  - $p_T$ distribution from Tsallis blast-wave fit to measured particle spectra
- Heavy flavor sources:
  - STAR measurements, and PYTHIA simulation
  - $N_{bin}$ scaled in Au-Au
  - at low energy: FONLL



# Dielectron $M_{ee}$ for 39 and 62GeV

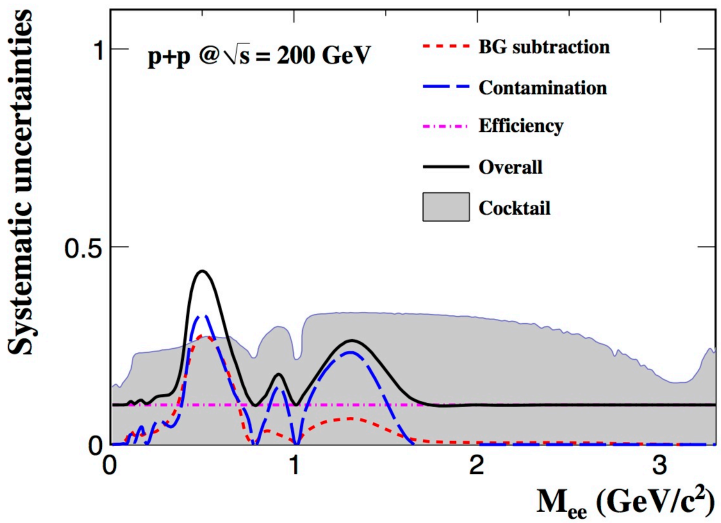



Poster: P. Huck (113)

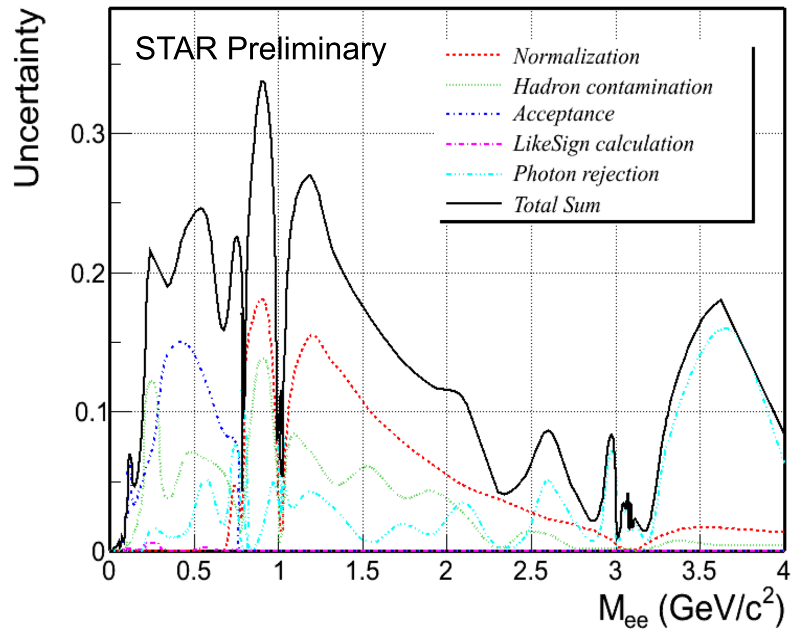
# Systematic Uncertainties

**p+p@200GeV**

- Background subtraction 0 - 27%
- hadron contamination 0 - 32%
- efficiency ~10%




**Au+Au@200GeV**




**Au+Au@19.6GeV**

Tracking efficiency 7%

TOF matching 5%

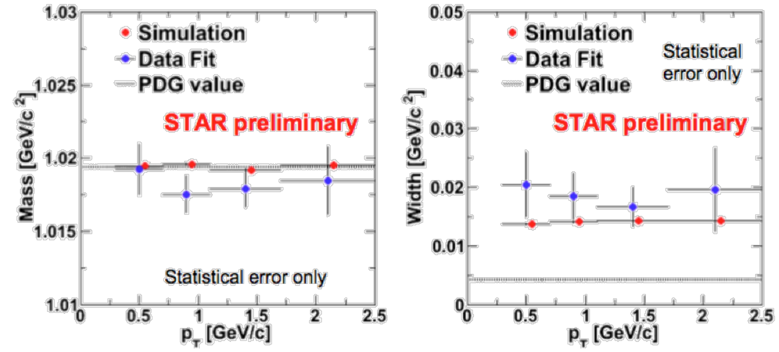
Pair uncertainties (summed) 17%

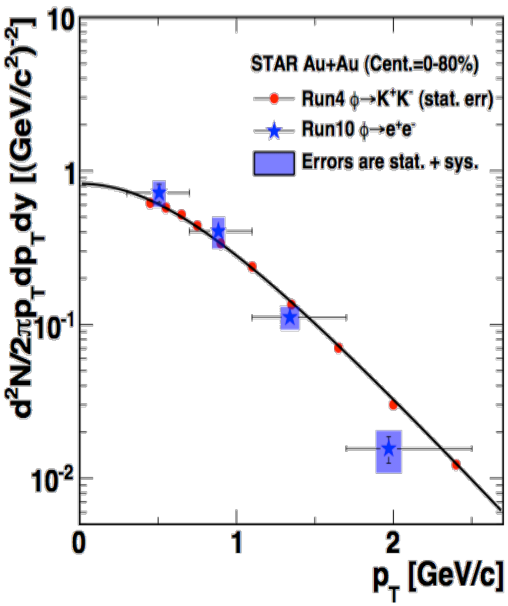
cocktail uncertainties 12-20%

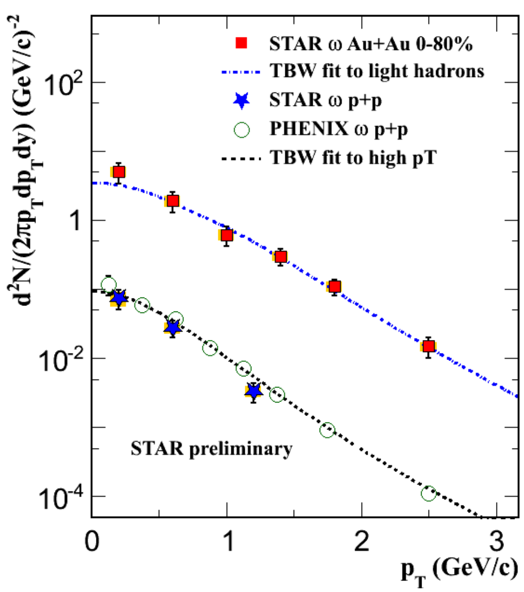
# Leptonic Decay of ϕ and ω Mesons

## Lifetimes comparable to fireball

- hadronic decay daughters interact with hadronic medium
  - sensitive to lifetime of that medium
- leptonic decay daughters do not interact with QCD medium
  - look for medium modifications to resonance mass & width
  - sensitive to chiral phase transition
  - small branching ratio



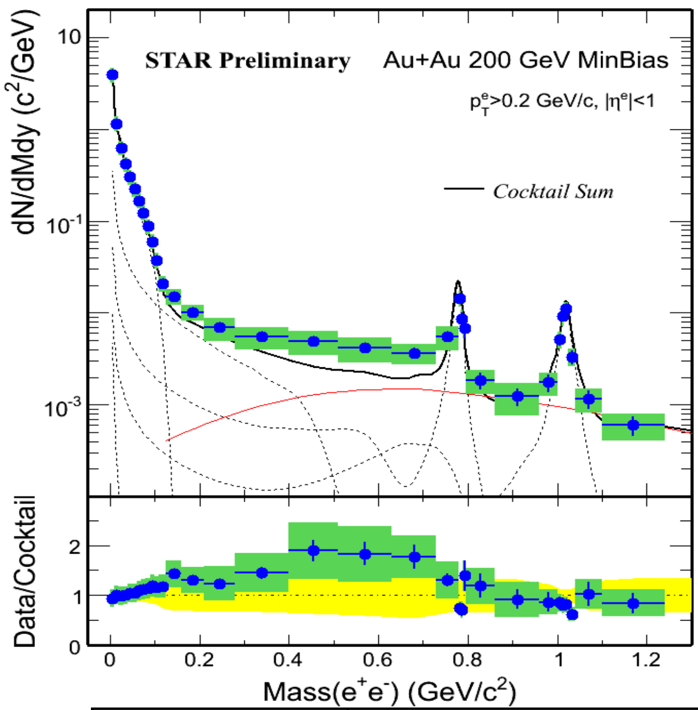

- ➢ No evidence of ϕ mass shift or width broadening
  - beyond known detector effects
- ➢ ϕ yield in dilepton decay channel consistent with hadronic channel

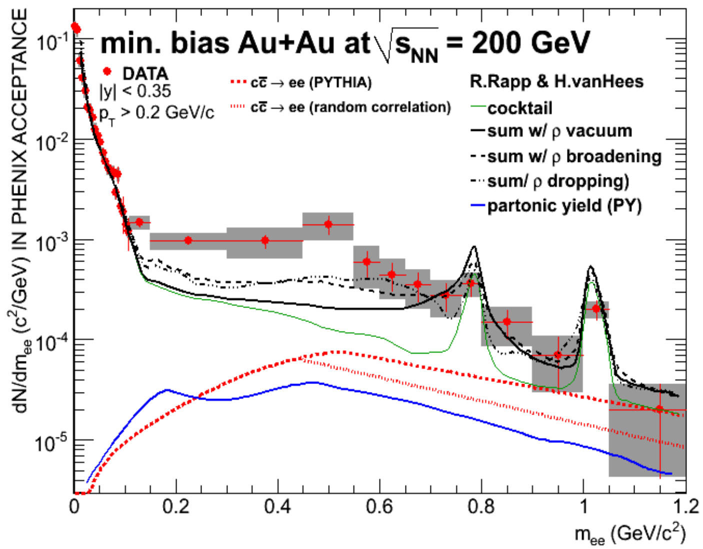
ω $p_T$ shapes agree with light hadrons

ω mass and width are under study

Poster: M. Wada (110)

# PHENIX & STAR Enhancement Factor



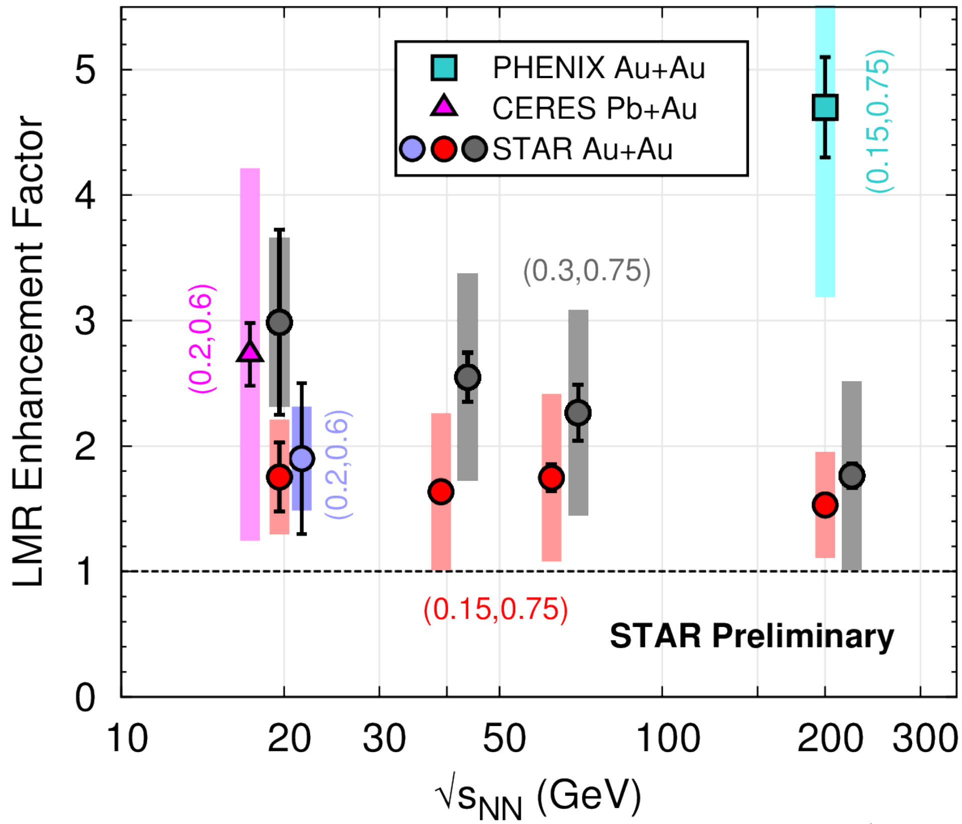

QM/SQM2011

**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)**<br>**1.40 ± 0.06 ± 0.38 (w/ ρ)** | **1.72 ± 0.10 ± 0.50 (w/o ρ)**<br>**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** |

# Dielectron Enhancement *vs.* √$s_{NN}$

STAR ☆




Systematic measurements of enhancement factor *vs.* √$s_{NN}$

- STAR data shows no evident beam-energy dependence
  - 150-750 MeV/$c^2$ range
- – low energy: comparable with CERES
- – high energy: discrepancy with PHENIX

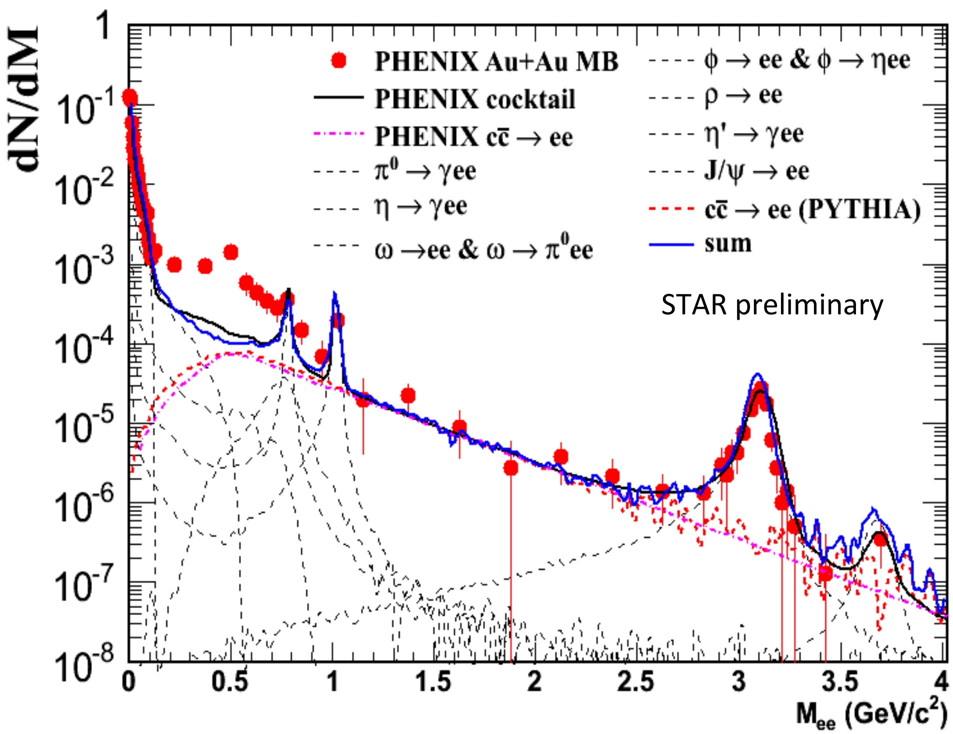
- <u>200 < $M_{ee}$ < 600 MeV/$c^2$ range</u>

STAR: 1.9 ± 0.6 ± 0.4

CERES: 2.73 ± 0.25 ± 0.65 ± 0.82 [decays]

B. Huang (3C, 268) Poster: P. Huck (113)

# Reproducing the PHENIX Cocktail

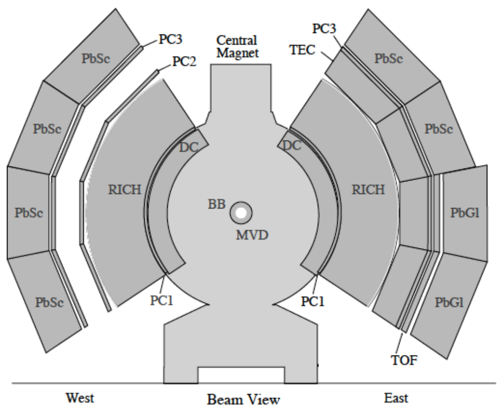


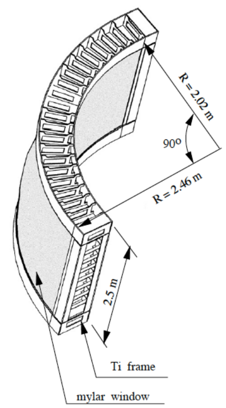

SQM2011

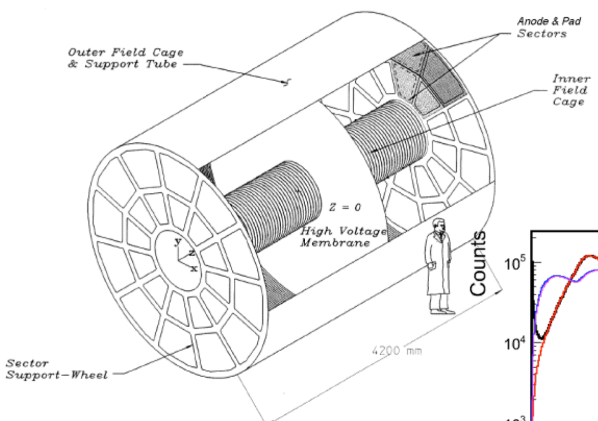
- Reproduce the cocktail within PHENIX acceptance by our method.
- The momentum resolutions are still from STAR.

Scaled by all the yields from PHENIX paper[1], STAR reproduces the PHENIX cocktail.
[1]. Phys. Rev. C 81, 034911 (2010).

# STAR with PHENIX Acceptance




- STAR
  - 12 sectors east and west barrel
  - 2π coverage, |η|<1
- PHENIX
  - 20 sectors east and west arm
  - π coverage, |η|<0.35