# Di-electron differential cross section in Au+Au collisions at different beam energies at STAR


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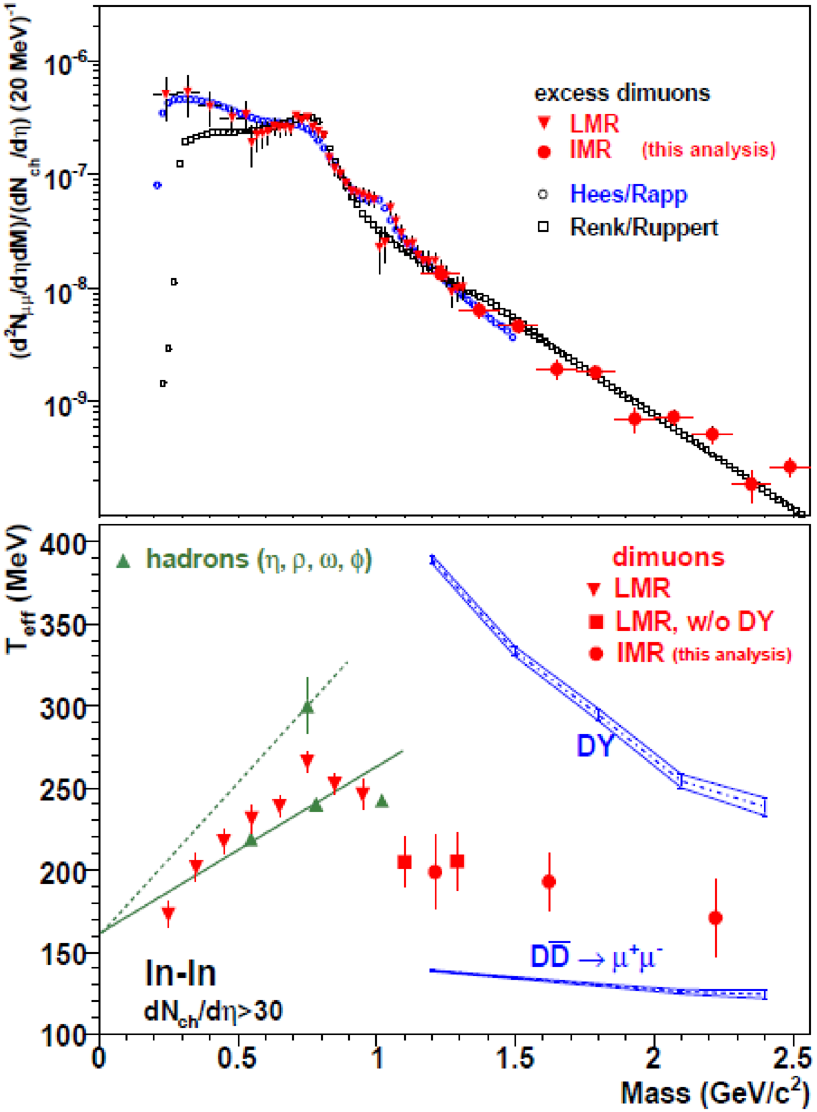
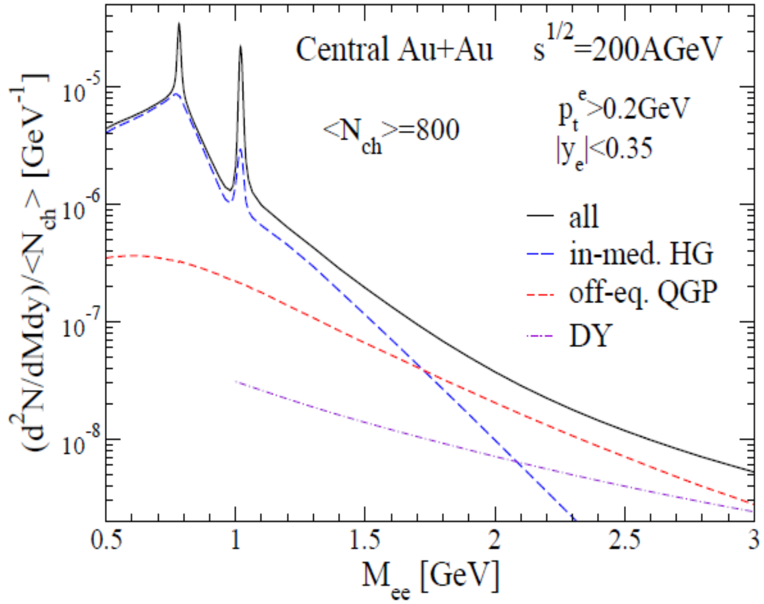
# Outline

- Motivation
- Analysis
- Results in Au+Au at 200 GeV
  - Centrality dependence of di-electron production
  - Ellipitic flow $v_2$ of di-electron
- Di-electron production in Au+Au at 62.4, 39, 19.6 GeV
- Summary

# Motivation




*NA60: Eur.Phys.J.C59:607-623,2009*




***R. Rapp***
*Phys.Rev. C63 (2001) 054907.*

**Low mass range (LMR):**

In-medium modifications of vector mesons.

Possible link to chiral symmetry restoration.

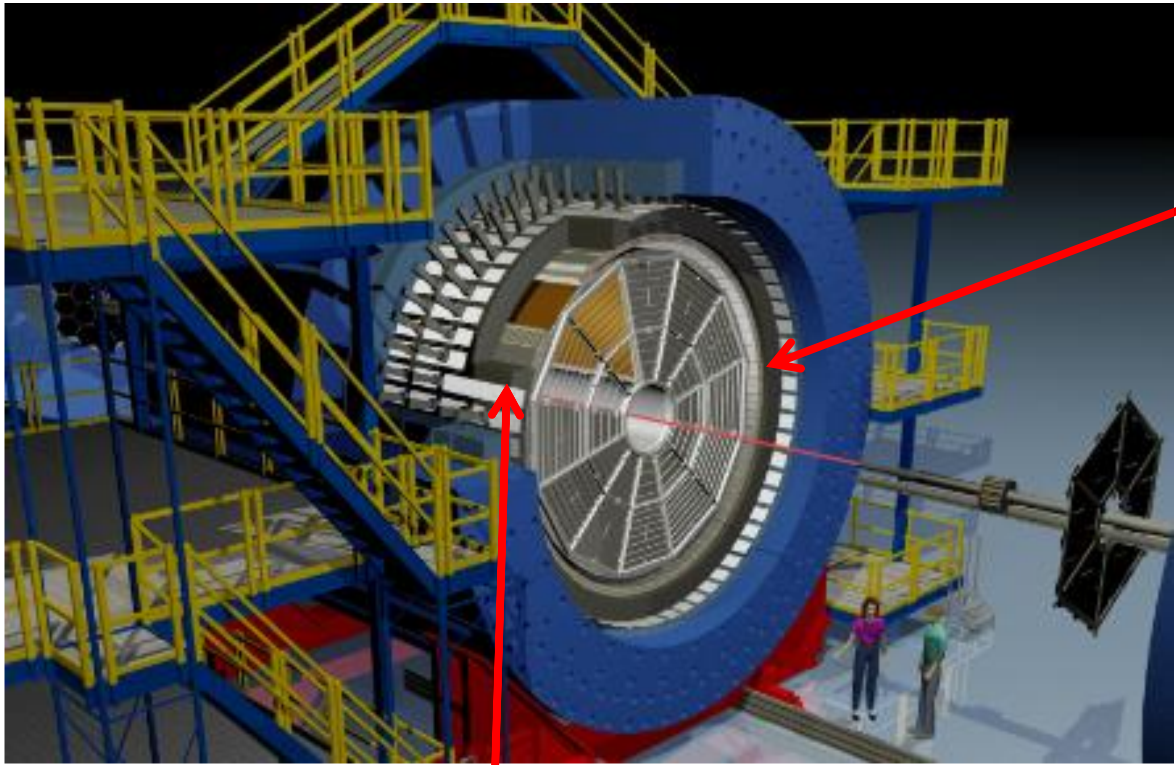
**Intermediate mass range (IMR):**

QGP thermal radiation.

Heavy flavor modification.

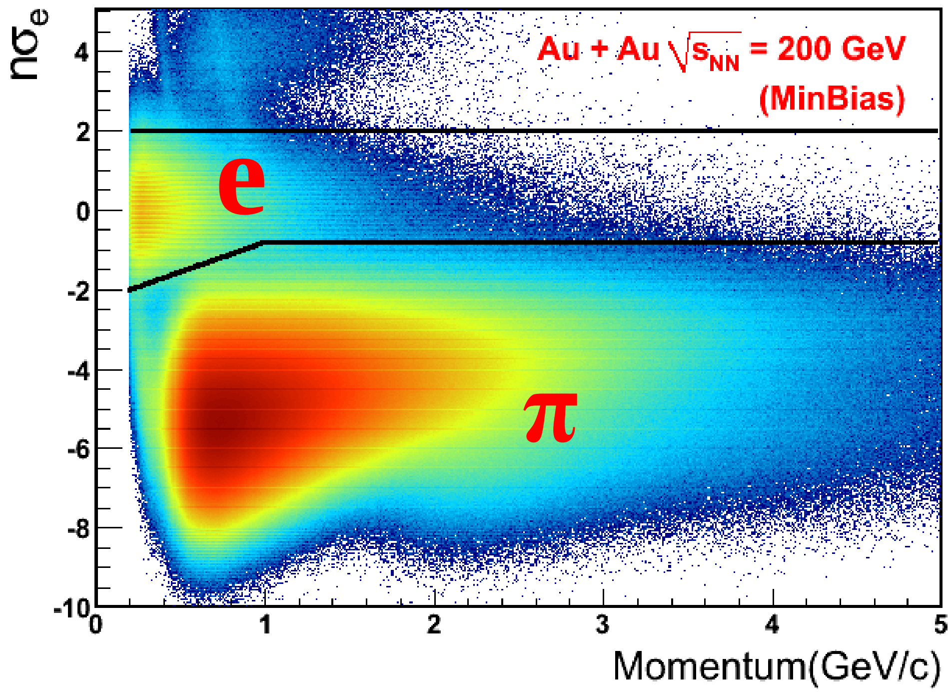
- Di-electron production from QGP thermal radiation increases from low to high beam energy.
- STAR Beam Energy Scan program enables us to systematically study it at different beam energies.

# Electron identification



**Tracking: TPC**

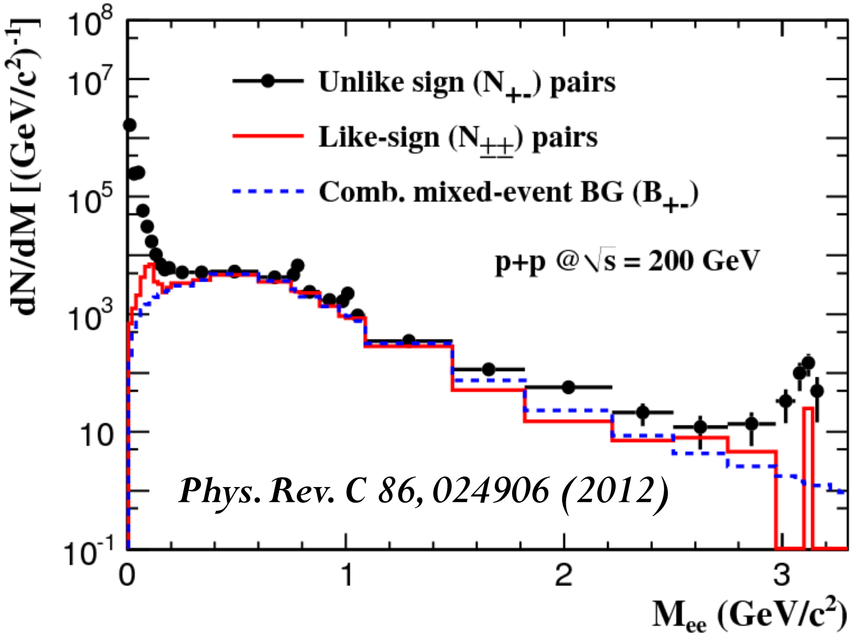
Time Projection Chamber
1. Tracking
2. Ionization energy loss (dE/dx PID)
3. Coverage $-1<\eta<1$

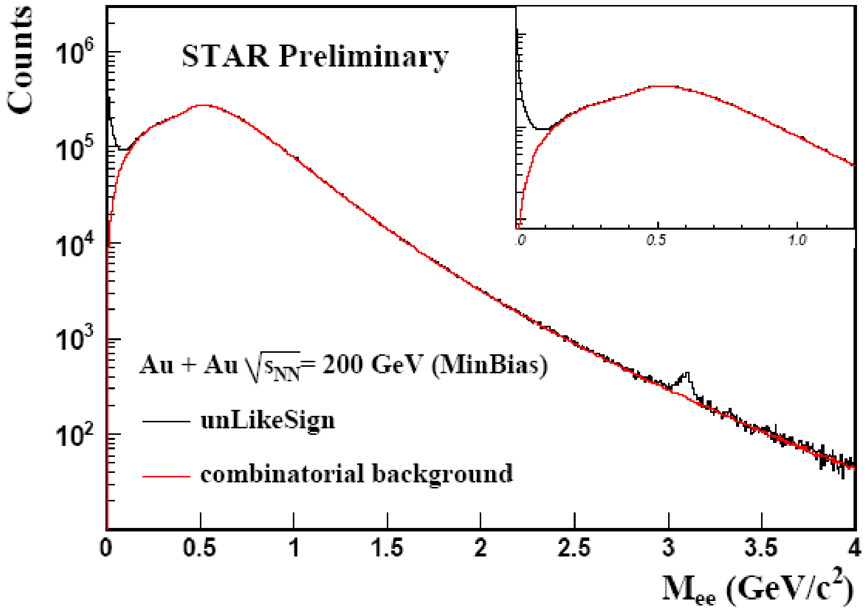



**Particle ID: TOF**

Time Of Flight ----
1. Timing resolution (<100ps)
2. Coverage: $-0.9<\eta<0.9$
3. Completed in 2010 (72% in 2009)

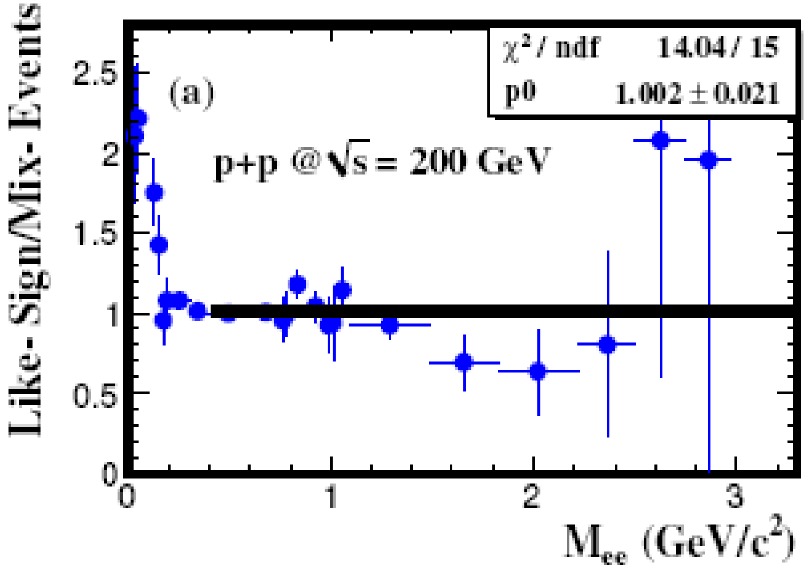
# Background subtraction

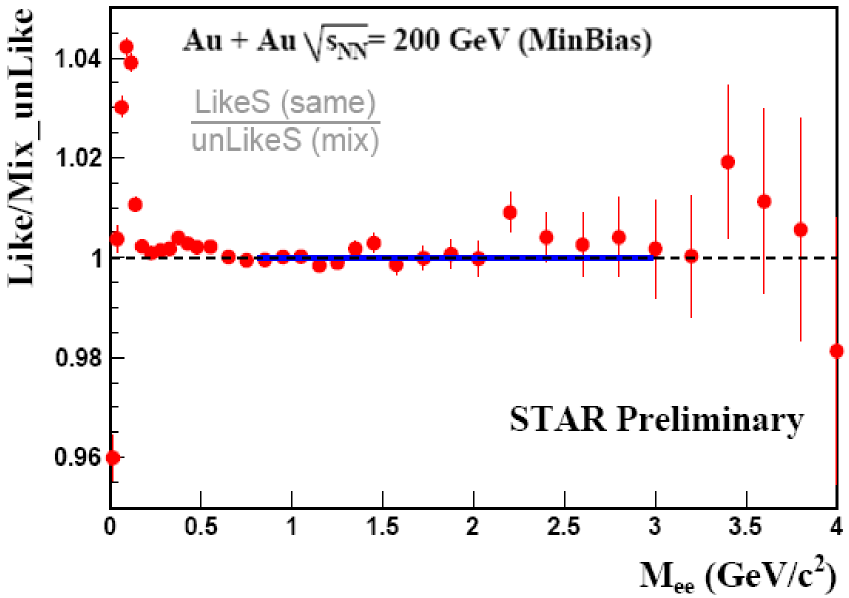



Like-sign background has been corrected by acceptance factor:

$$\frac{B_{+-}^{Mix}}{2\sqrt{B_{++}^{Mix}B_{--}^{Mix}}}$$



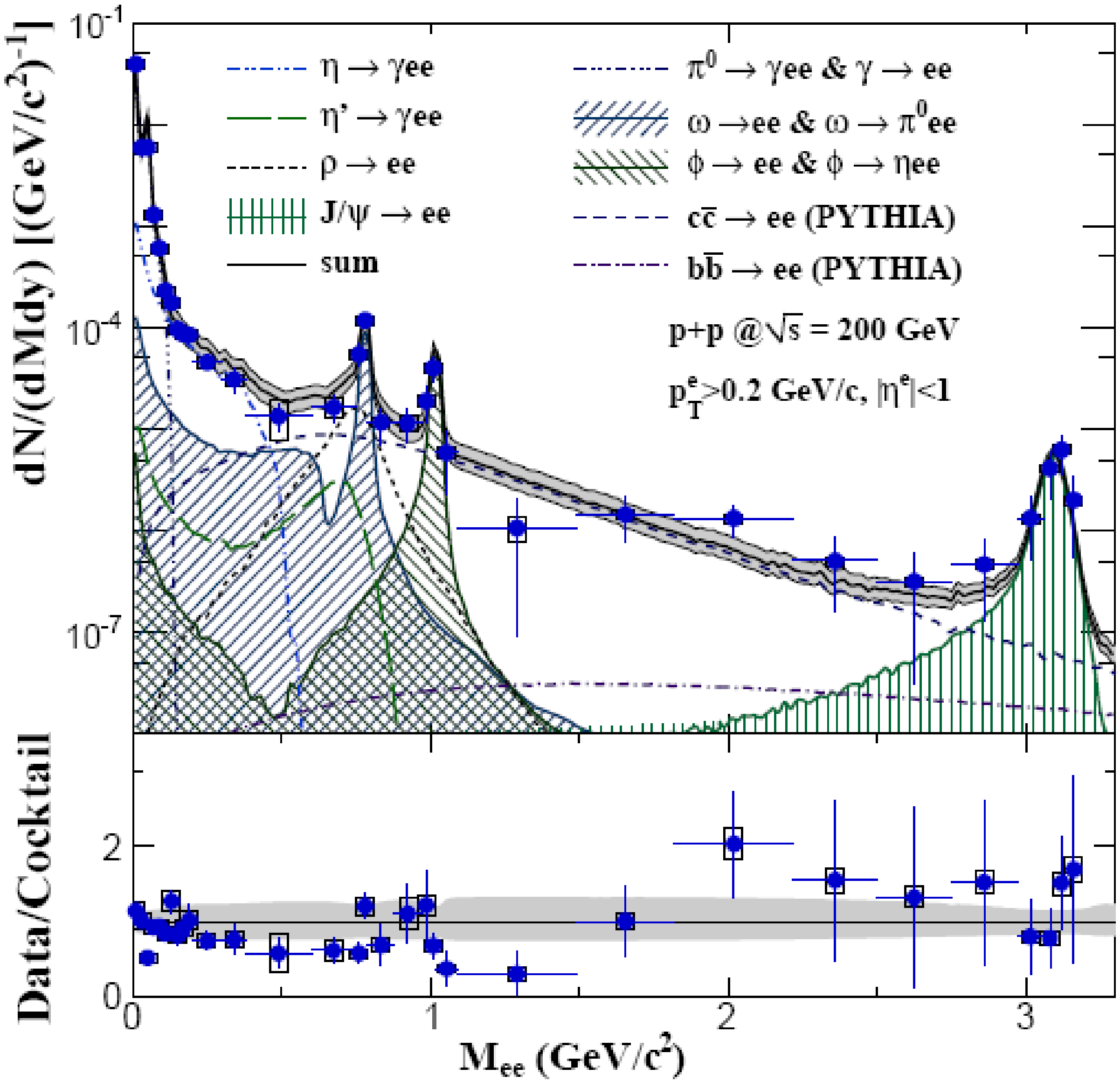

Normalization range of $M_{ee}$:

p+p : (0.4,1.5) GeV/$c^2$

Au+Au: (0.7,3)GeV/$c^2$

Mixed-event BG subtraction range: $M_{ee}$>0.4 GeV/$c^2$ for p+p and $M_{ee}$>0.75 GeV/$c^2$ for Au+Au 200 GeV.

# Di-electron results in p+p 200 GeV

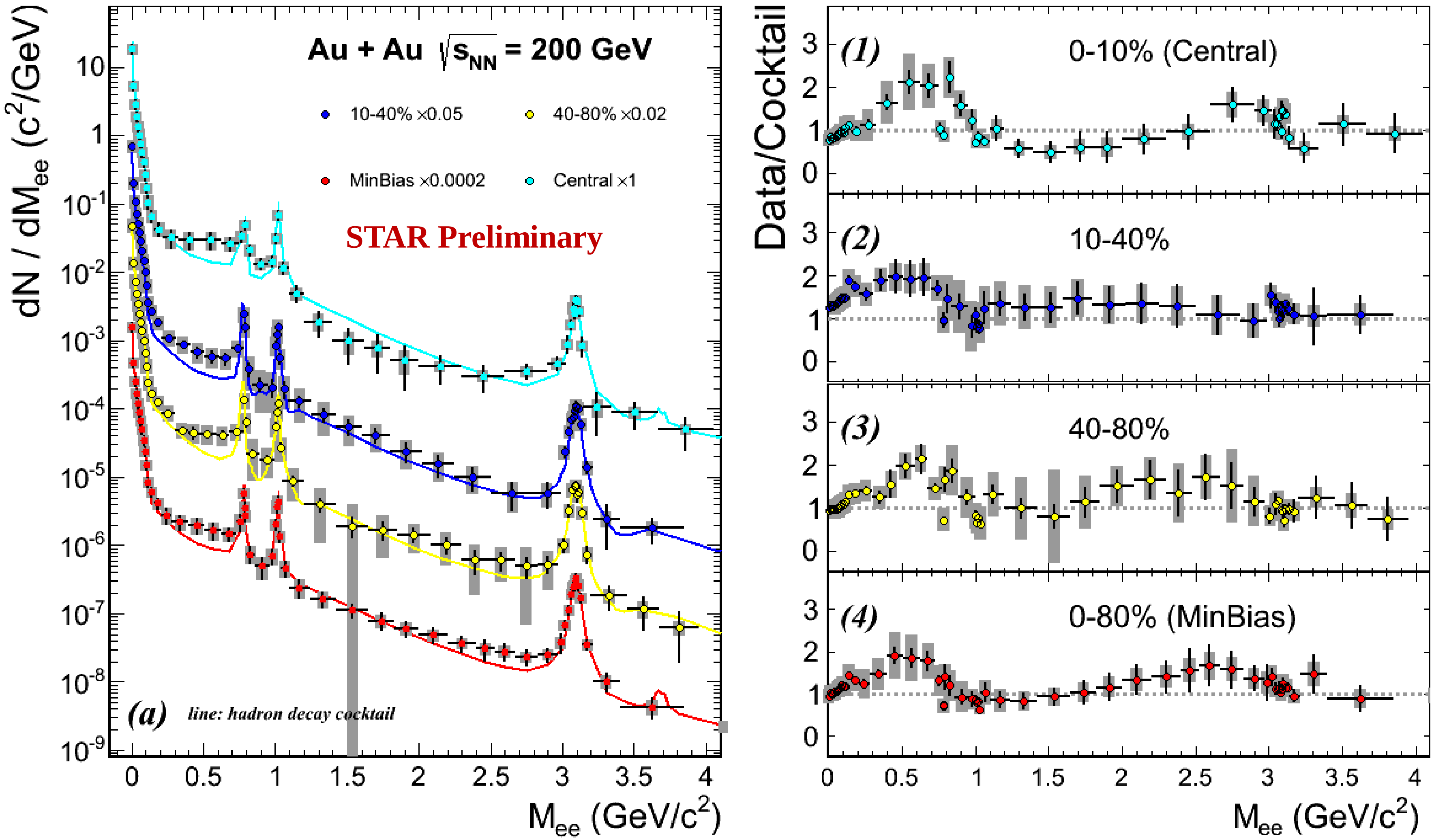



- Cocktail simulation is consistent with di-electron spectrum within quoted uncertainties.
- Intermediate mass region is dominated by charm correlation contribution.

**Phys. Rev. C 86, 024906 (2012)**

# Centrality dependence in Au+Au 200 GeV

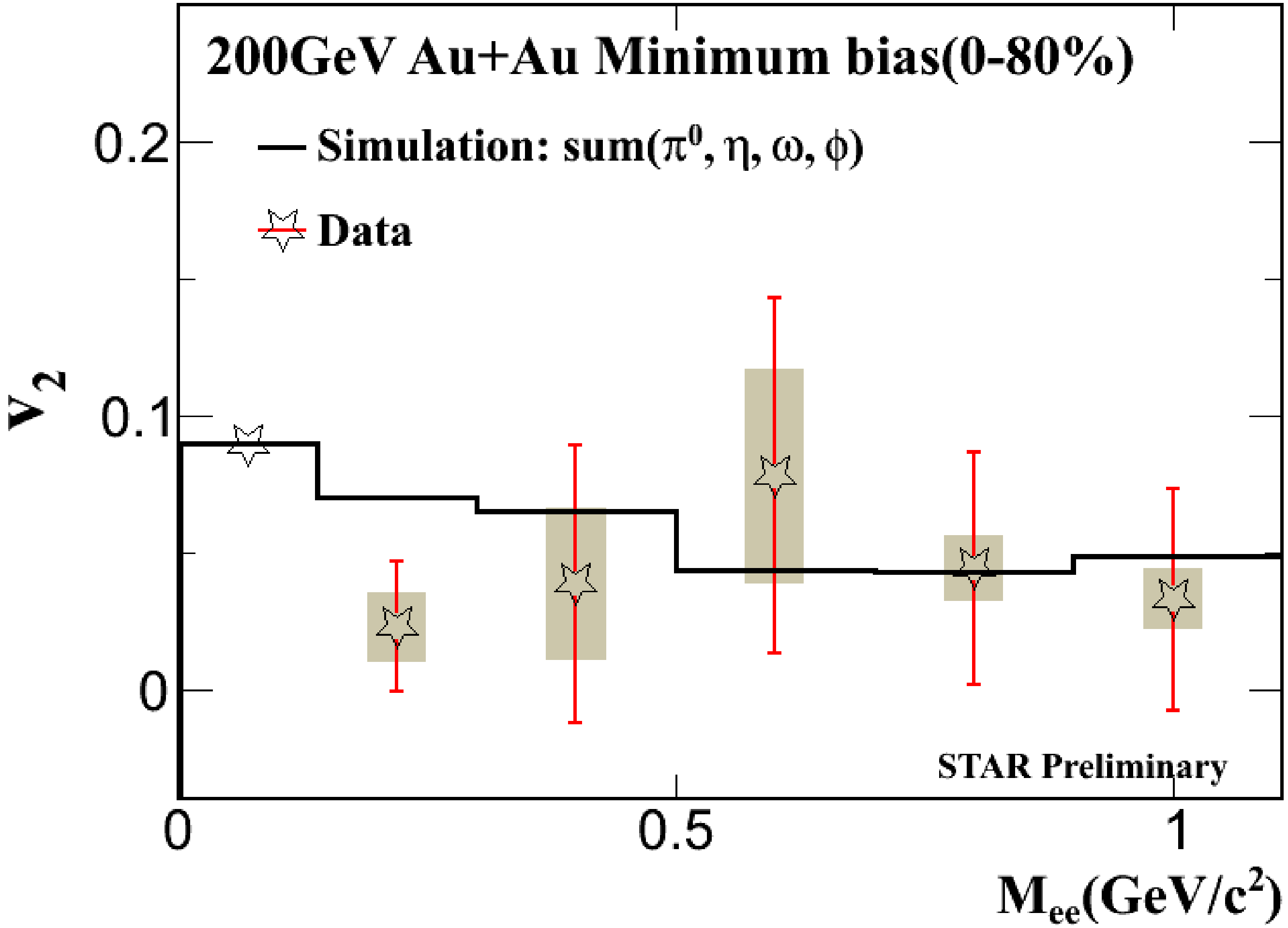
Poster (153) Jie Zhao




➢Low mass enhancement: no significant centrality dependence.

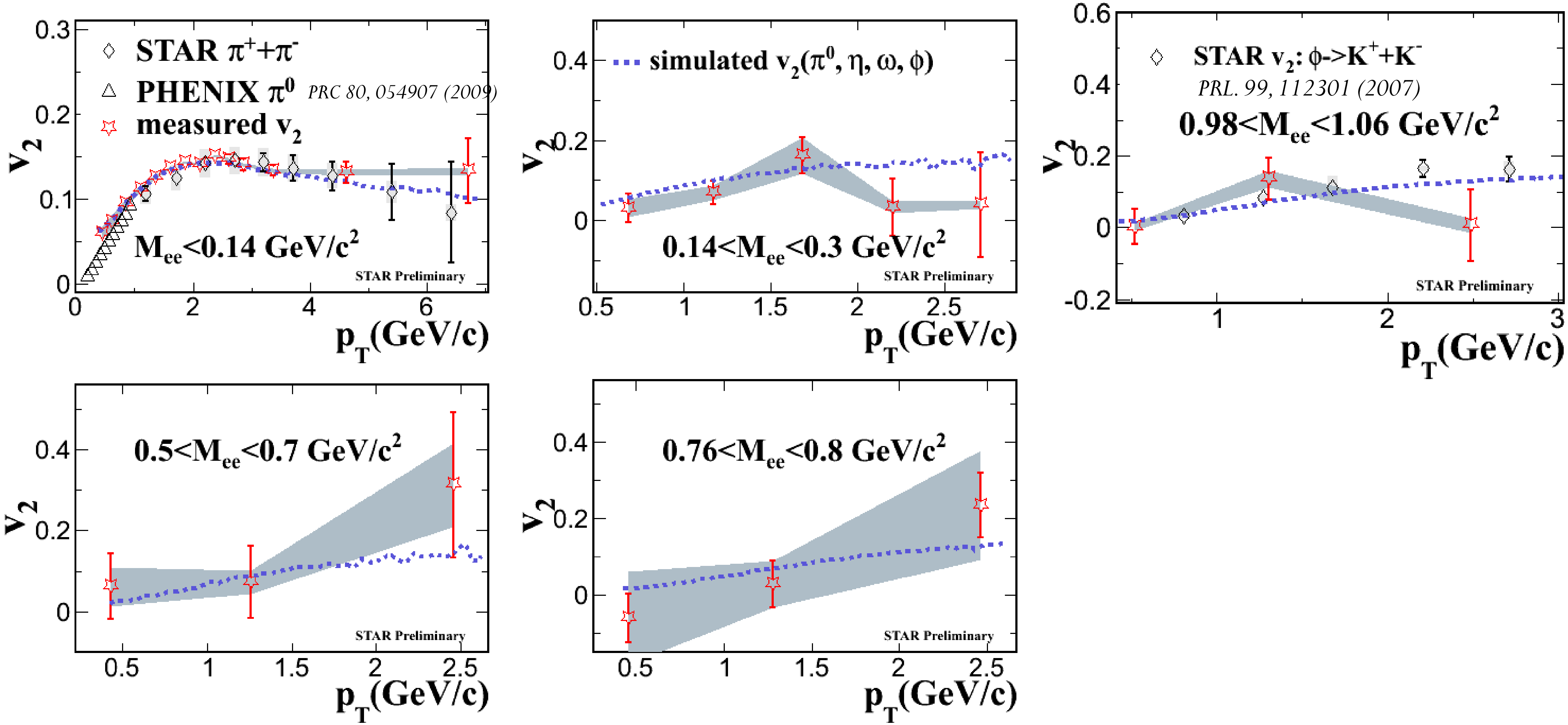
# Elliptic flow $v_2$ in Au+Au 200 GeV

Poster (322) Xiangli Cui



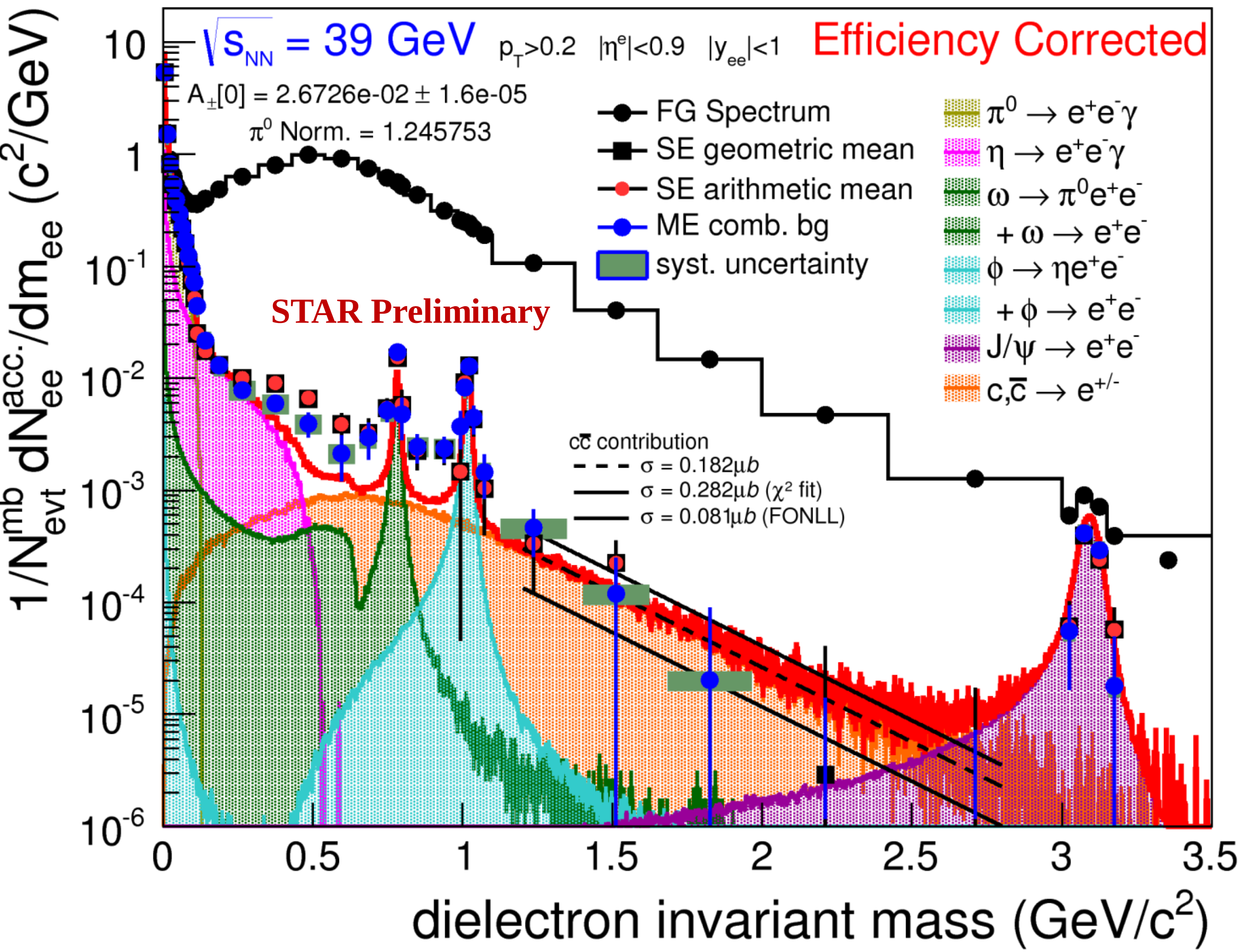

➢Di-electron $v_2$ is consistent with simulation using the measured meson $v_2$ as input in Au+Au at 200 GeV.

# $p_T$ dependence of $v_2$ in Au+Au 200 GeV




- Simulated $v_2$ is consistent with measured di-electron $v_2$ within uncertainties in 0-80% Au+Au collisions.

# Di-electron in Au+Au at 39 GeV




**Poster (113) Patrick Huck**

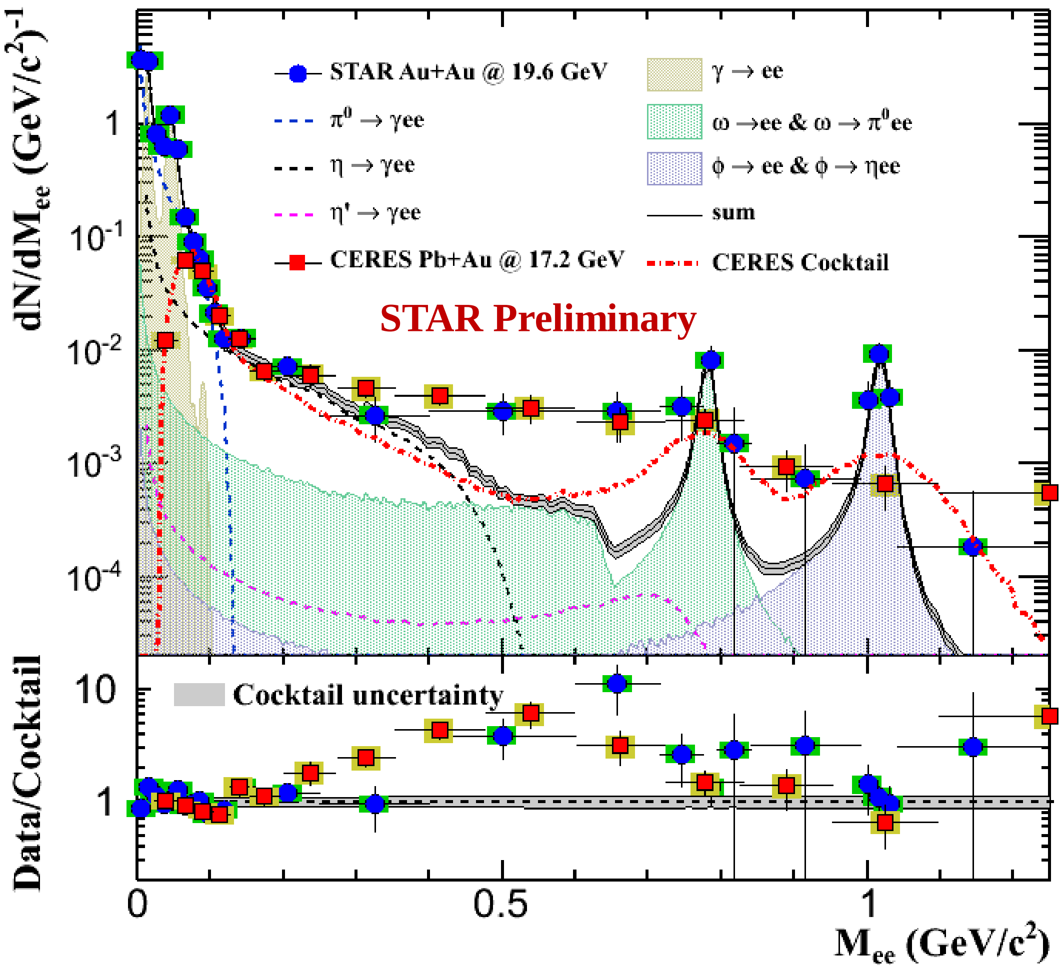
## Cocktail simulation:

- Unknown $p_T$ distributions are taken from AMPT model calculations. The according dN/dy is extrapolated from measurements at 200 GeV based on the energy dependence given by AMPT.
- Correlated charmed hadron contribution are simulated using PYTHIA and scaled to Au+Au by the number of binary collisions.
- Charm cross sections are used as center value between $\chi 2$ fits to the IMR data and FONLL prediction.

ME subtraction $M_{ee}$>0.9 GeV/$c^2$, LS subtraction $M_{ee}$<0.9 GeV/$c^2$.

# Di-electron in Au+Au at 19.6 GeV


**Poster (269) Bingchu Huang**



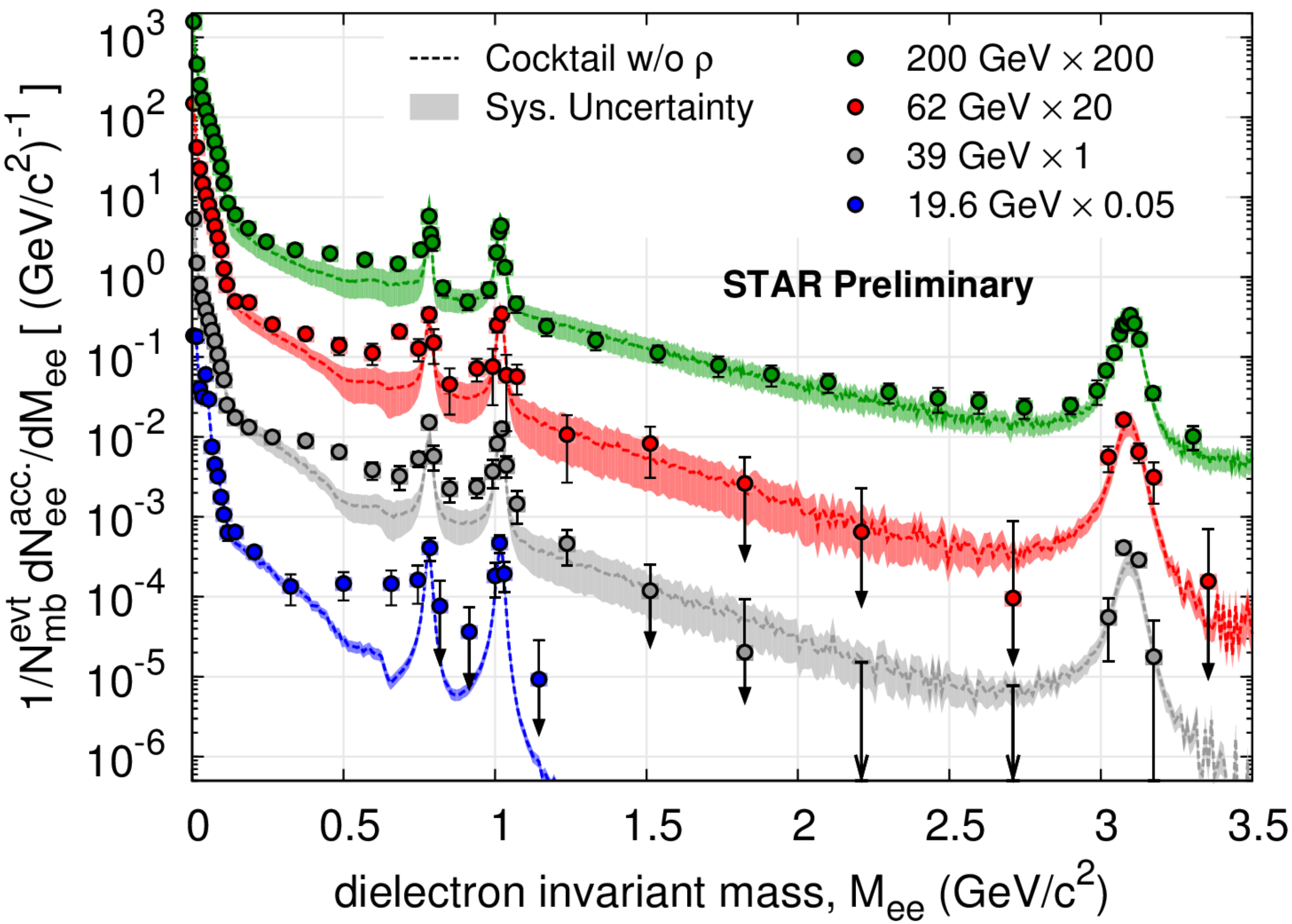

• π yield is from STAR $\pi^{+-}$ measurement, other meson yields derived from SPS meson/$\pi^0$ ratio.

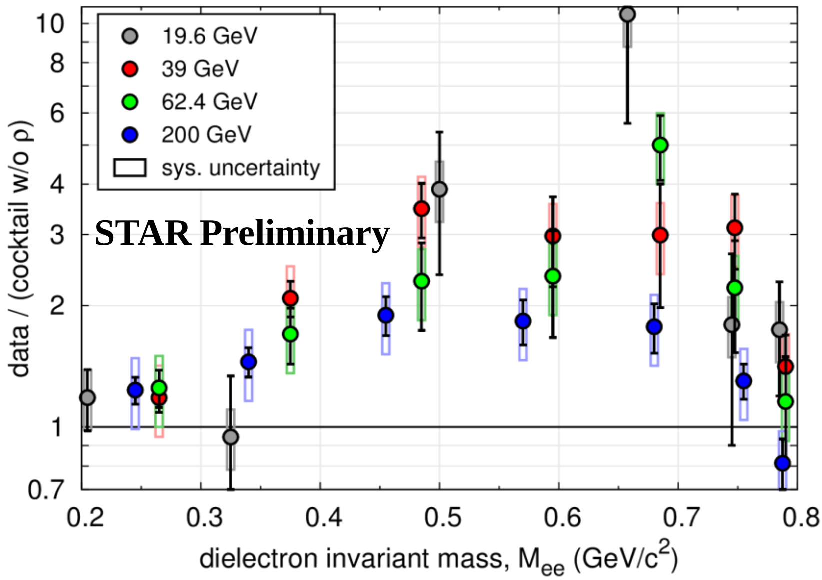
STAR Au+Au: 0-80% centrality, $p_T$>0.2 GeV/c, $|\eta|$<1, $|y_{ee}|$<1.
CERES Pb+Au: 0-28% centrality. $p_T$>0.2 GeV/c, 2.1<η<2.65, $\theta_{ee}$>35mrad.

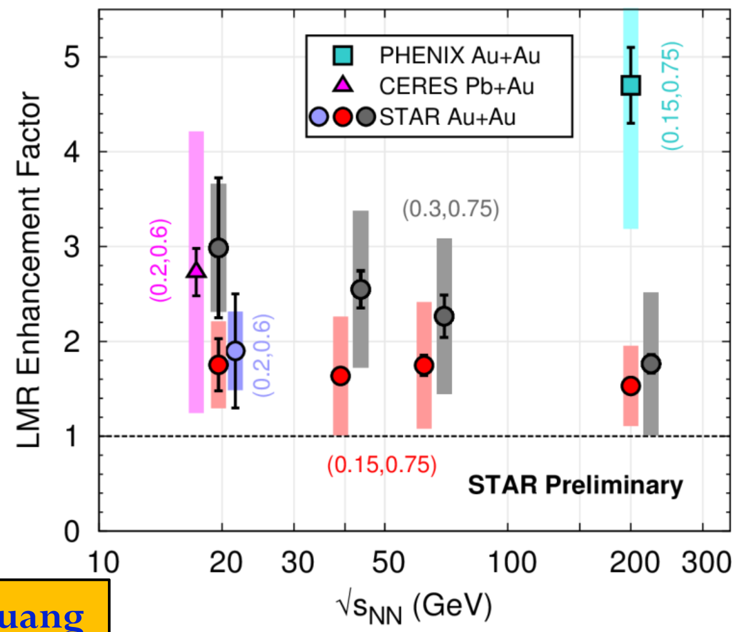
| Enhancement factor | $0.2<M_{ee}<0.6$ GeV/$c^2$ |
|---|---|
| STAR | 1.9 ± 0.6± 0.4 |
| CERES | 2.73 ± 0.25±0.65±0.82[decays] |

➢ Low mass enhancement comparable to CERES.

# Di-electron beam energy dependence



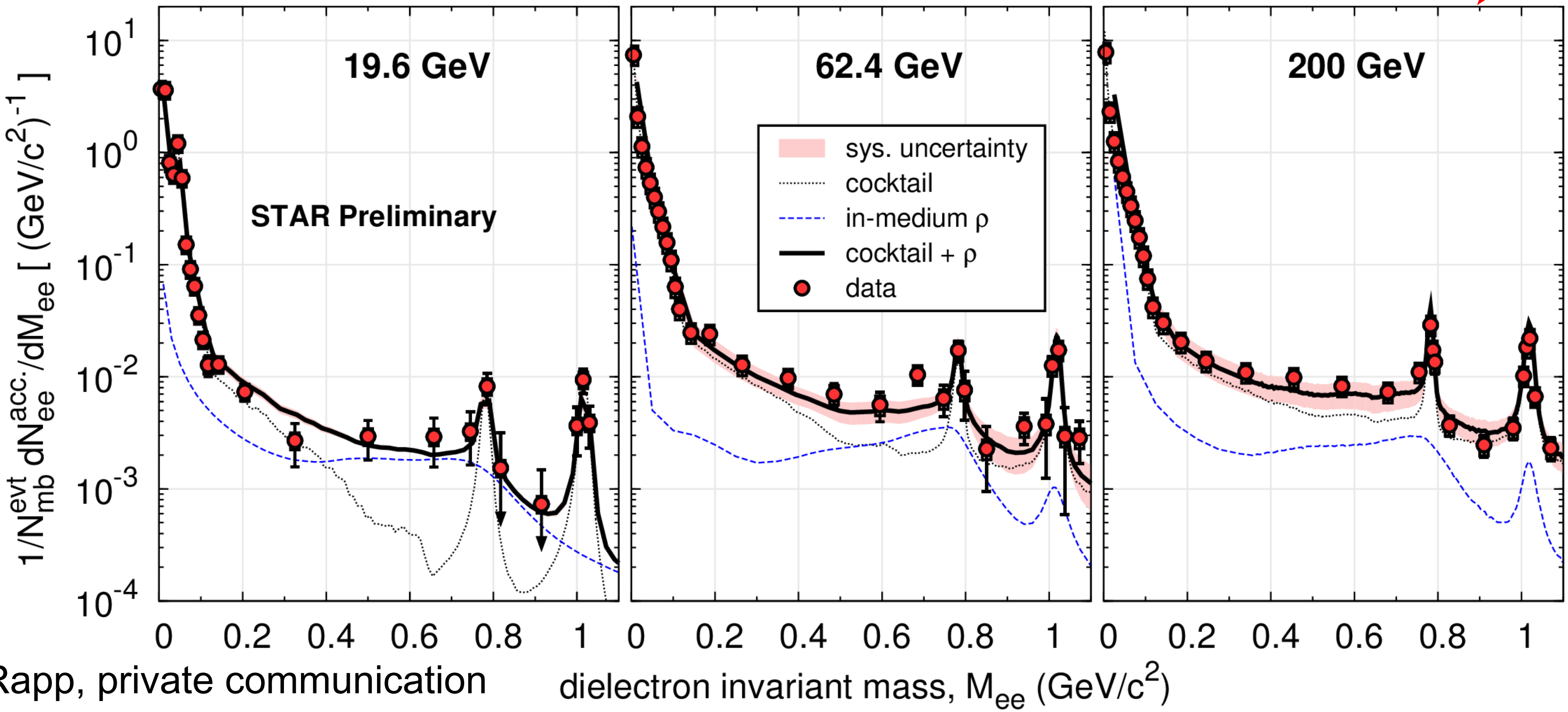




Au+Au 200 GeV: **Poster (153) Jie Zhao**

Au+Au 62 & 39 GeV: **Poster (113) Patrick Huck**

Au+Au 19.6 GeV: **Poster (269) Bingchu Huang**

# Comparison with theory calculations




R. Rapp, private communication

R.Rapp Adv. Nucl.Phys. **25, 1** (2000), arXiv:nucl-th/0204003v1

➢A broadened ρ spectral function scenario can consistently describe the low mass enhancement observed from 19.6 to 200 GeV.

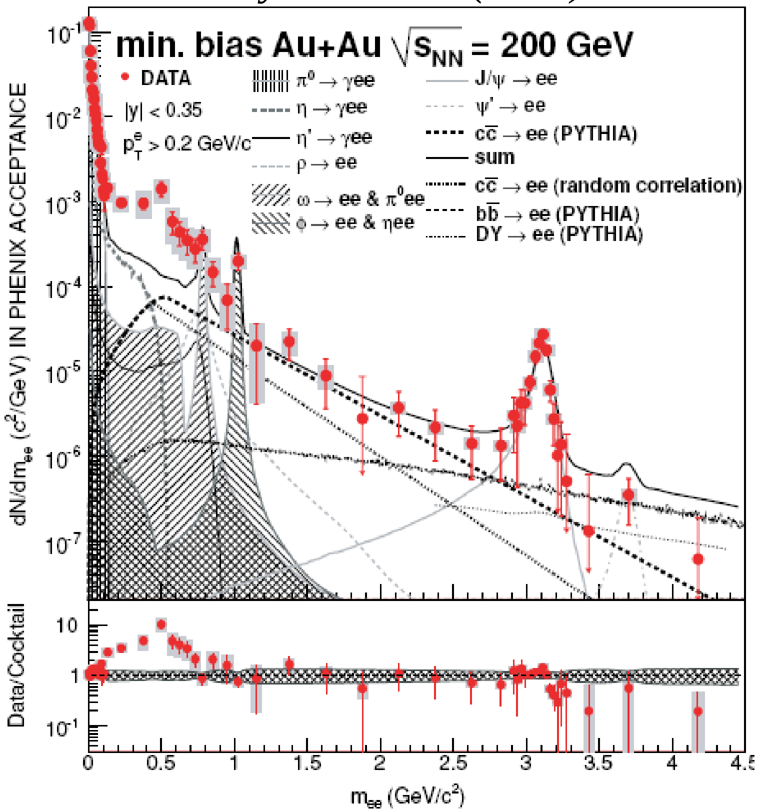
# Summary

- Centrality-dependent di-electron production has been measured in Au+Au at 200 GeV.
  - No significant centrality dependence of LMR enhancement.
- Di-electron elliptic flow $v_2$ has been measured in Au+Au 200 GeV.
  - The simulated cocktail $v_2$ are consistent with the measured di-electron $v_2$ within uncertainties in 0-80% Au+Au collisions.
- Di-electron productions have been measured in Au+Au at 19.6, 39, and 62 GeV.
  - At 19.6 GeV, we observed comparable low mass enhancement as CERES measurements.
- A broadened $\rho$ spectral function scenario can consistently describe the low mass enhancement observed from 19.6 to 200 GeV.

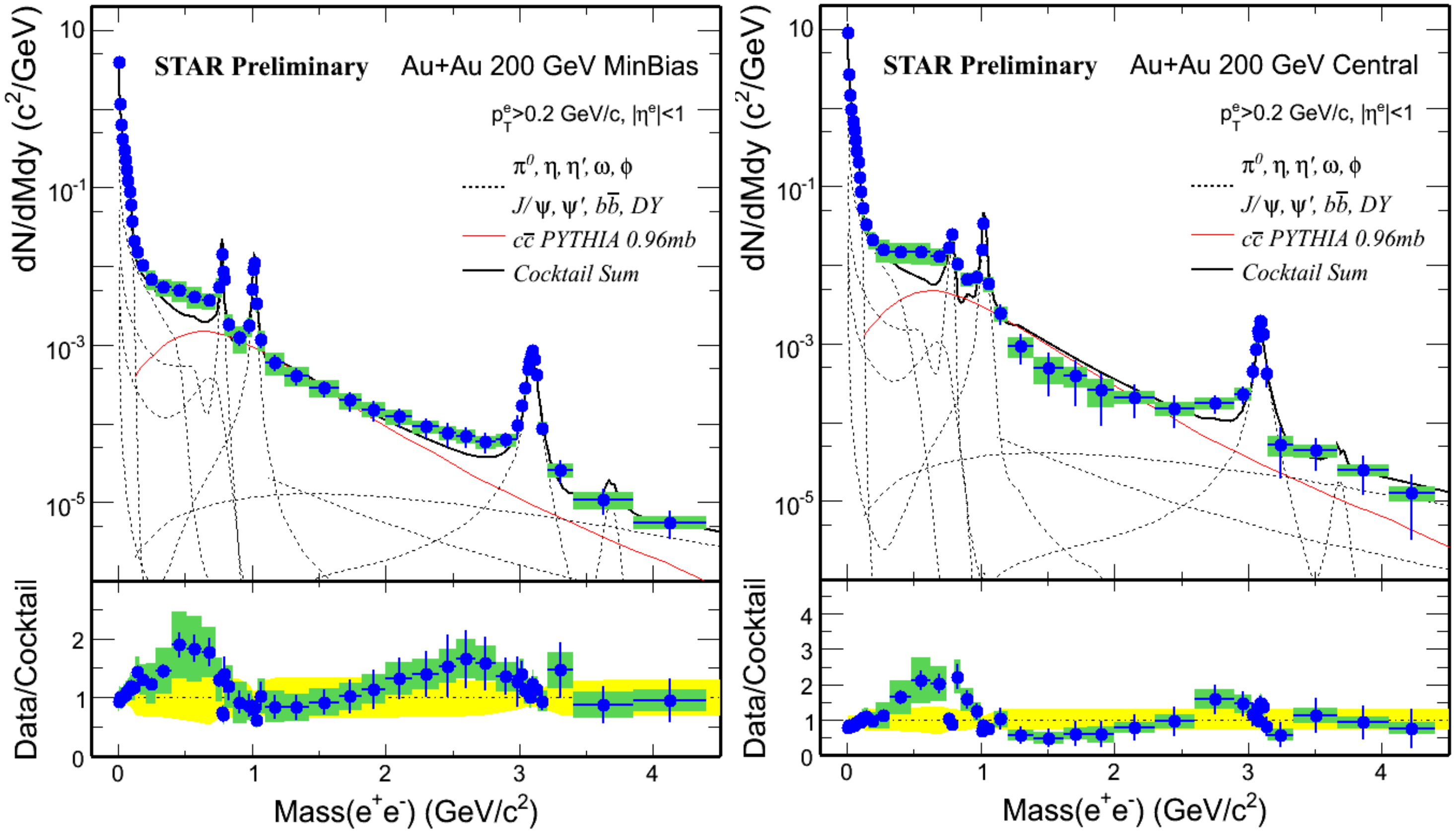
**Thank you !**

# Backup

**PHENIX** *Phys.Rev. C81 (2010) 034911*




**STAR QM2011:** *J. Phys. G:38 124134*



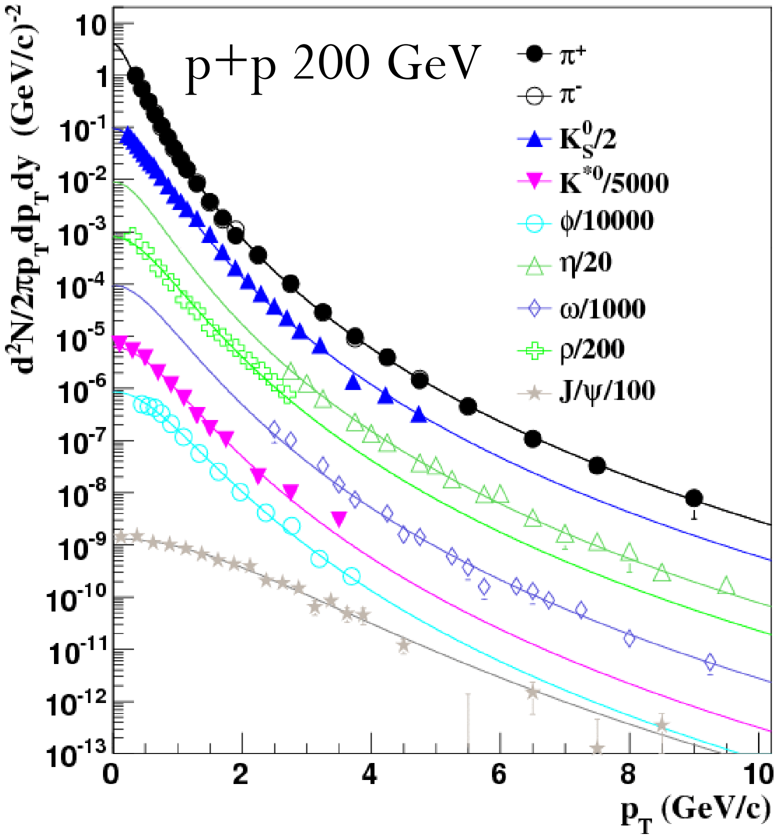

**Enhancement factor in $0.15<M_{ee}<0.75$ Gev/$c^2$**

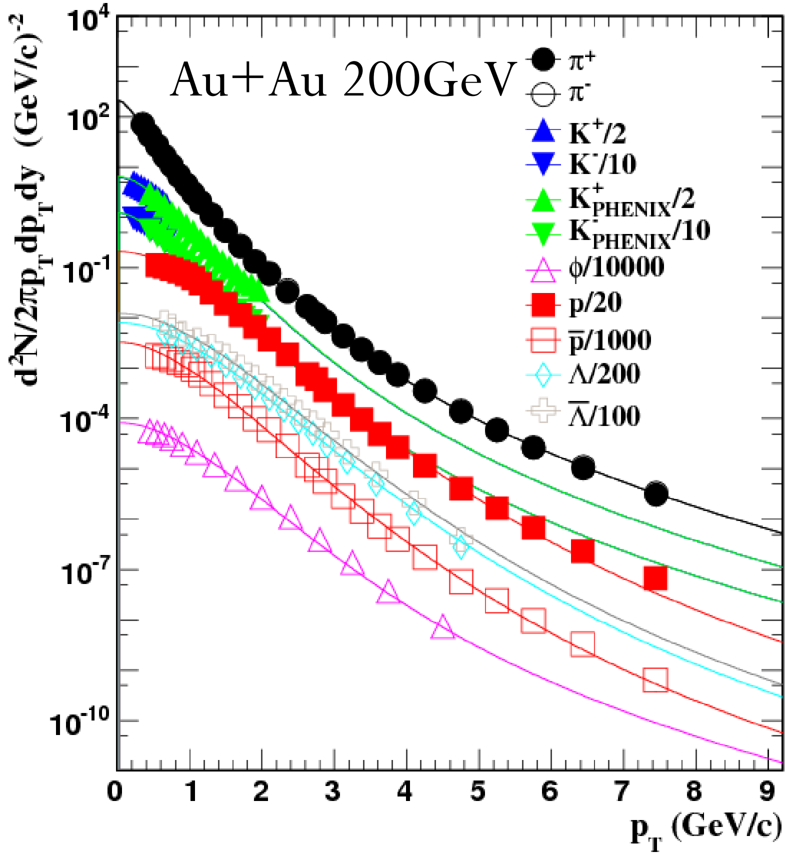
| | Minbias (value ± stat ± sys) | Central (value ± stat ± sys) |
|---|---|---|
| STAR | 1.53 ± 0.07 ± 0.41 (w/o ρ)<br>1.40 ± 0.06 ± 0.38 (w/ ρ) | 1.72 ± 0.10 ± 0.50 (w/o ρ)<br>1.54 ± 0.09 ± 0.45 (w/ ρ) |
| PHENIX | 4.7 ± 0.4 ± 1.5 | 7.6 ± 0.5 ± 1.3 |
| Difference | 2.0 σ | 4.2 σ |

# Simulation

## Inputs:

- Flat rapidity (-1,1) , flat Φ (0, 2π), $p_T$: use Tsallis function fit for all measured particles.
- Hadron sources: using form factors from measurements.
- Heavy flavor sources: using PYTHIA.




Zebo Tang et al, PRC 79, 051901(R) (2009)

# Cocktail simulation

**Kroll-Wada Formula:**

$$\frac{dN}{dm_{ee}} \propto \sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\cdot\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\cdot\frac{1}{m_{ee}}\cdot\left(1-\frac{m_{ee}^2}{M_h^2}\right)^3 |F(m_{ee}^2)|^2$$

QED | Phase Space | Form Factor

*N.M. Kroll, et al., Phys Rev, 98 (1955) 5.*

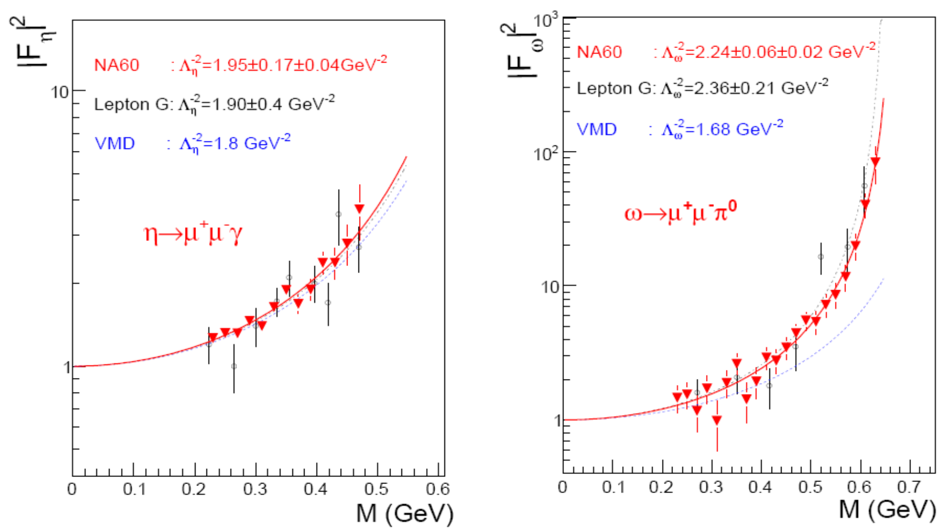
Twobody: Breit-Wigner

Dalitz: Kroll-Wada

FF: parameterized from measurement.

Phase Space term for ω, ϕ:

$$(1-\frac{m_{ee}^2}{m_h^2})^3 \Rightarrow ((1+\frac{m_{ee}^2}{m_\omega^2-m_{\pi^0}^2})^2-\frac{4m_\omega^2 m_{ee}^2}{(m_\omega^2-m_{\pi^0}^2)^2})^{\frac{3}{2}}$$




NA60: PLB677 (2009) 260.

$$|F(m_{ee}^2)|^2=\frac{1}{(1-m_{ee}^2\cdot\Lambda^{-2})^2+\Gamma_0^2\cdot\Lambda^{-2}}$$

ρ line shape:

$$\frac{dN}{dm_{ee}dp_T} \propto \frac{m_{ee}M_\rho\Gamma_{ee}}{(M_\rho^2-m_{ee}^2)^2+M_\rho^2(\Gamma_{\pi\pi}+\Gamma_{ee}\Gamma_2)^2} \times PS,$$

P-wave of ππ channel: $\Gamma_{\pi\pi}=\Gamma_0\frac{M_\rho}{m_{ee}}(\frac{m_{ee}^2-4M_\pi^2}{M_\rho^2-4M_\pi^2})^{3/2},$

S-wave of ee channel: $\Gamma_{ee}=\Gamma_0\frac{M_\rho}{m_{ee}}(\frac{m_{ee}^2-4m_e^2}{M_\rho^2-4m_e^2})^{1/2},$

$$PS=\frac{m_{ee}}{\sqrt{m_{ee}^2+p_T^2}}e^{-\frac{\sqrt{m_{ee}^2+p_T^2}}{T}}.$$

*PRC 78, 044906 (2008)*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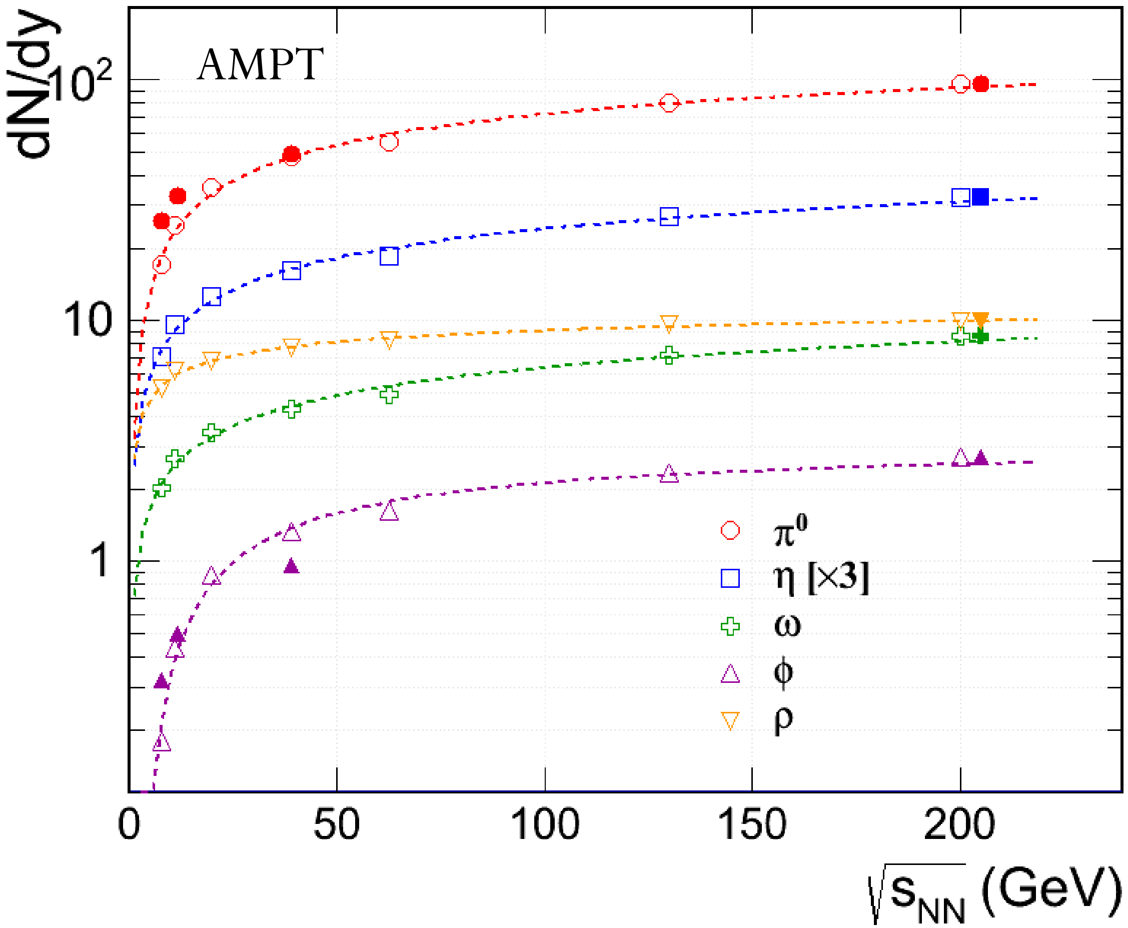
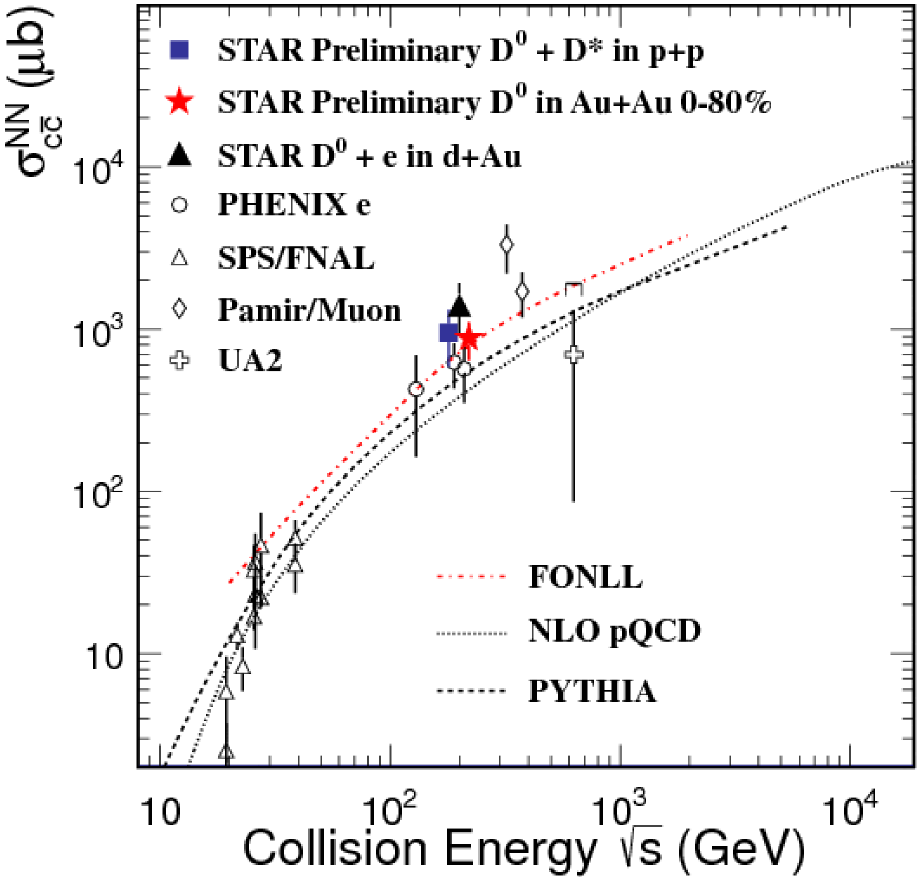
# Extrapolation to lower energies

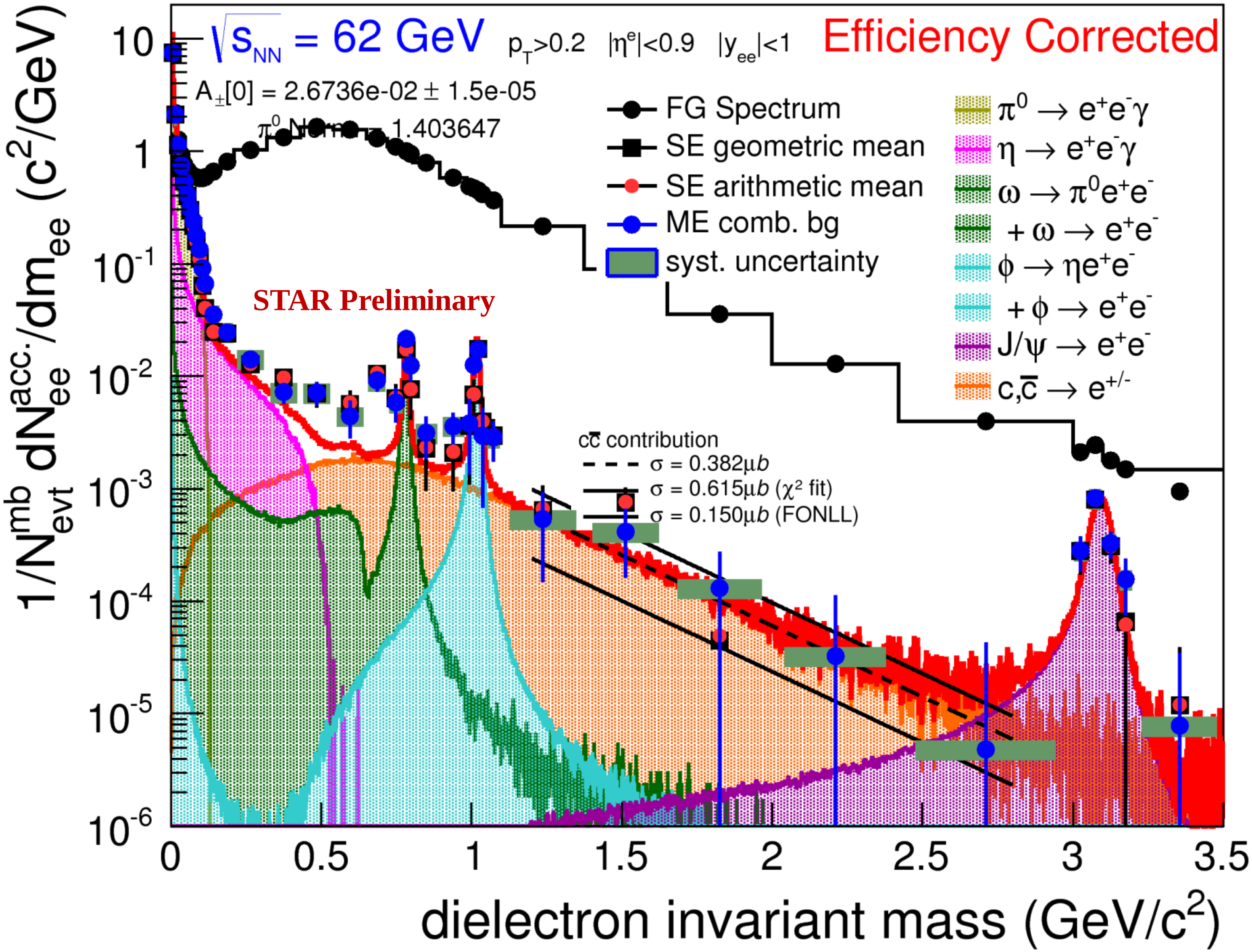
dN/dy and $p_T$ distributions from AMPT calculations.
Charm cross section: NLO calculation for low energies.



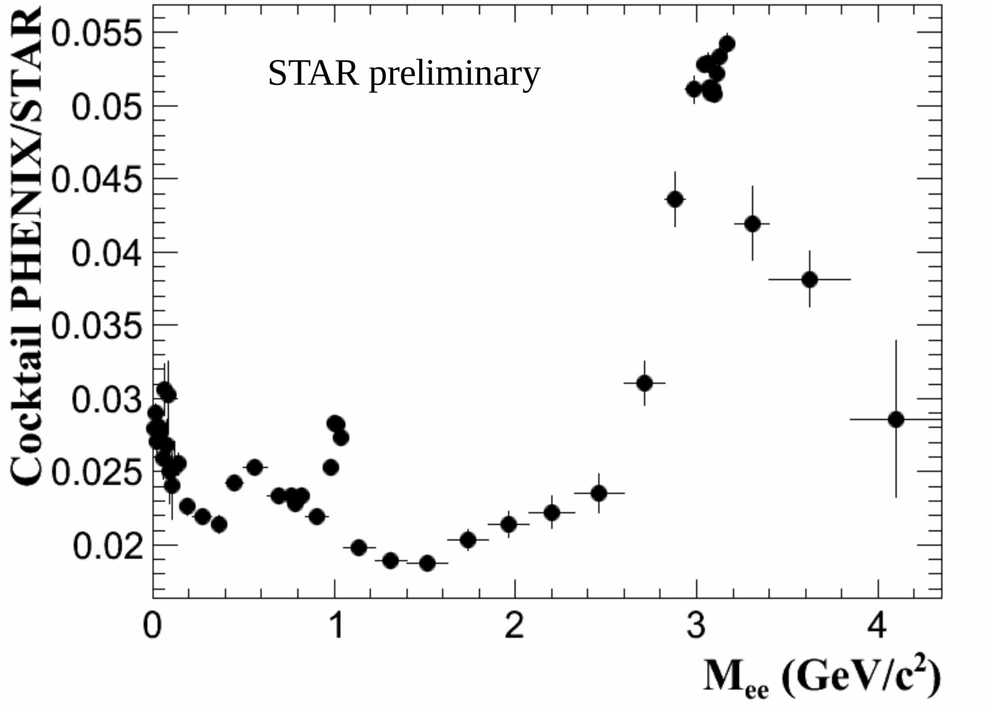

Scale to measurements at 200 GeV (solid symbols), some difference at lower energy.

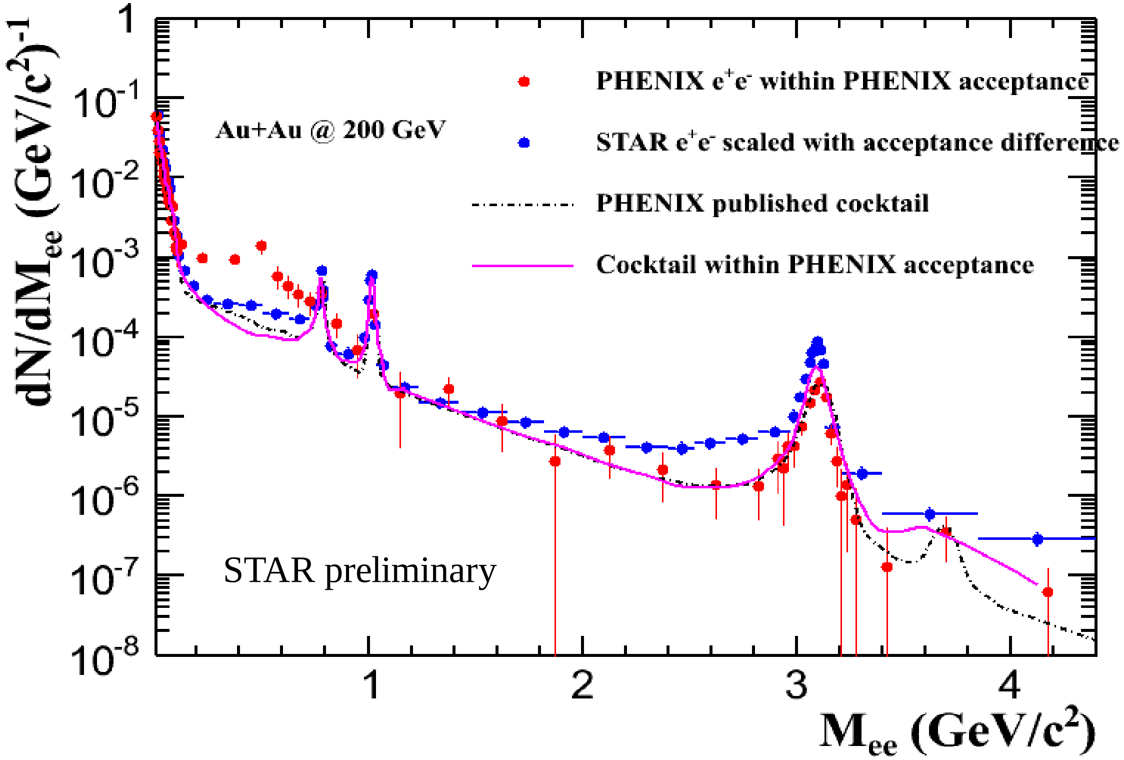
# 62 GeV



$\sqrt{s_{NN}}$ = 62 GeV
$p_T$>0.2 $|\eta^e|$<0.9 $|y_{ee}|$<1
Efficiency Corrected
$A_{\pm}[0]$ = 2.6736e-02 ± 1.5e-05
$\pi^0$ Norm = 1.403647
STAR Preliminary
FG Spectrum
SE geometric mean
SE arithmetic mean
ME comb. bg
syst. uncertainty
$\pi^0 \rightarrow e^+e^-\gamma$
$\eta \rightarrow e^+e^-\gamma$
$\omega \rightarrow \pi^0e^+e^-$
$+\omega \rightarrow e^+e^-$
$\phi \rightarrow \eta e^+e^-$
$+\phi \rightarrow e^+e^-$
$J/\psi \rightarrow e^+e^-$
$c,\bar{c} \rightarrow e^{+/-}$
$c\bar{c}$ contribution
σ = 0.382μb
σ = 0.615μb ($\chi^2$ fit)
σ = 0.150μb (FONLL)
$1/N_{evt}^{mb}\, dN_{ee}^{acc.}/dm_{ee}$ ($c^2$/GeV)
dielectron invariant mass (GeV/$c^2$)

# Check with acceptance difference




Acceptance difference:

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

Scaled by same meson and charm yields.

Scaled by the acceptance difference

Difference at low mass is not from the simulation but from the measurements.

# STAR with PHENIX Φ acceptance