Dielectron production in 200 GeV p+p and Au+Au collisions at STAR

Yi Guo[1,2]
for the STAR Collaboration

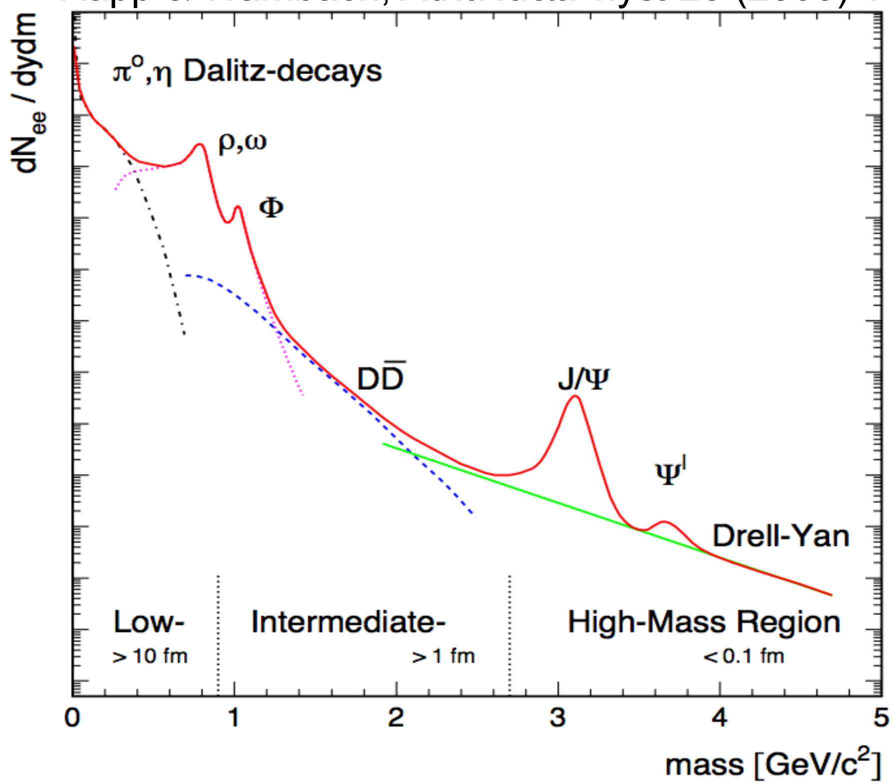
1. Lawrence Berkeley National Laboratory
2. University of Science and Technology of China

Outline

- Motivation
- STAR detector
- Physics results
  - p+p baseline.
  - Low mass enhancement.
  - Possible Charm modification.
- Summary and Outlook

Motivation

Rapp & Wambach, Adv.Nucl.Phys. 25 (2000) 1



- Di-leptons – *a bulk penetrating probe*

  do not suffer strong interactions

  bring us the direct information of the medium in heavy-ion collisions

Interesting topics:

- **Low mass region (LMR):**

  in-medium modifications of vector meson.

- **Intermediate mass region (IMR):**

  QGP thermal radiation.

  semi-leptonic decays of correlated charm : charm modification in Au+Au.

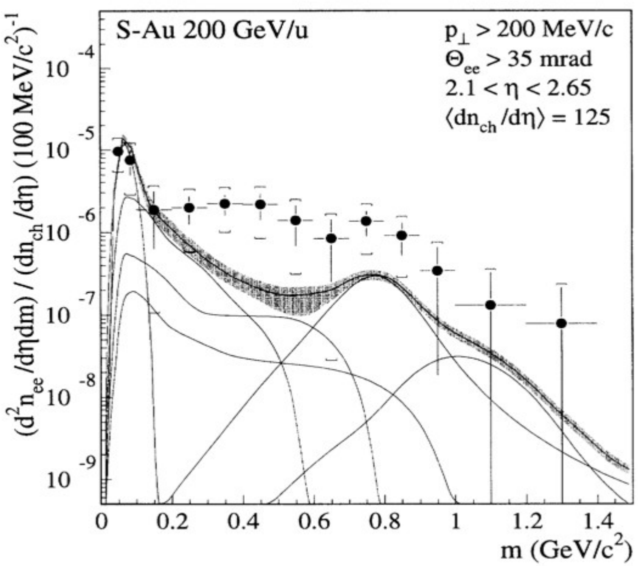
- **High mass region (HMR):**

  heavy quarkonia.

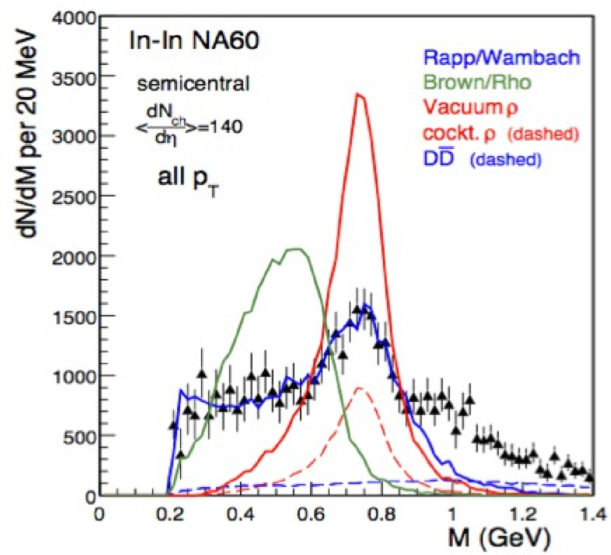
  Drell-Yan process.

Previous measurement – low mass enhancement

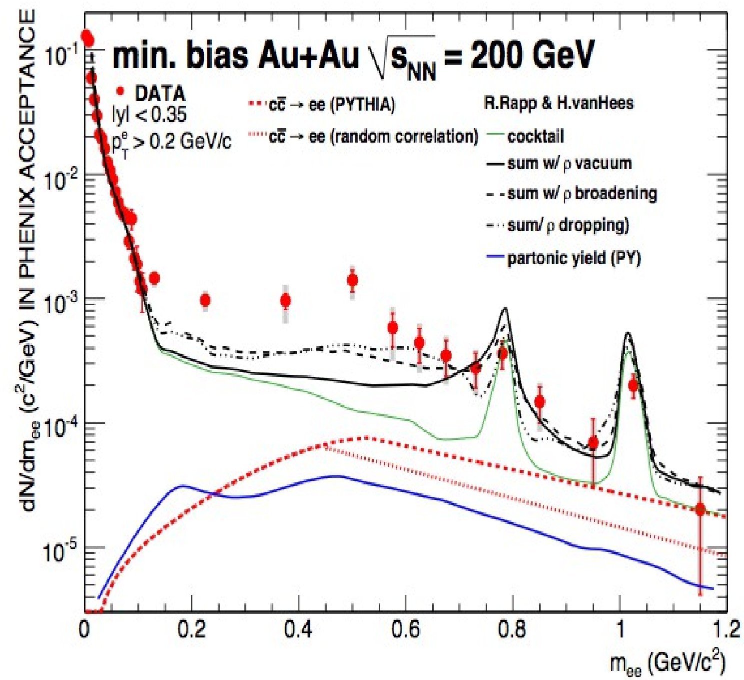
CERES, PRL 75(1995), 1272.



NA60, PRL 96 (2006) 162302, PRL 100 (2008) 022302
Di-muon excess



PHENIX PRC 81 (2010) 034911

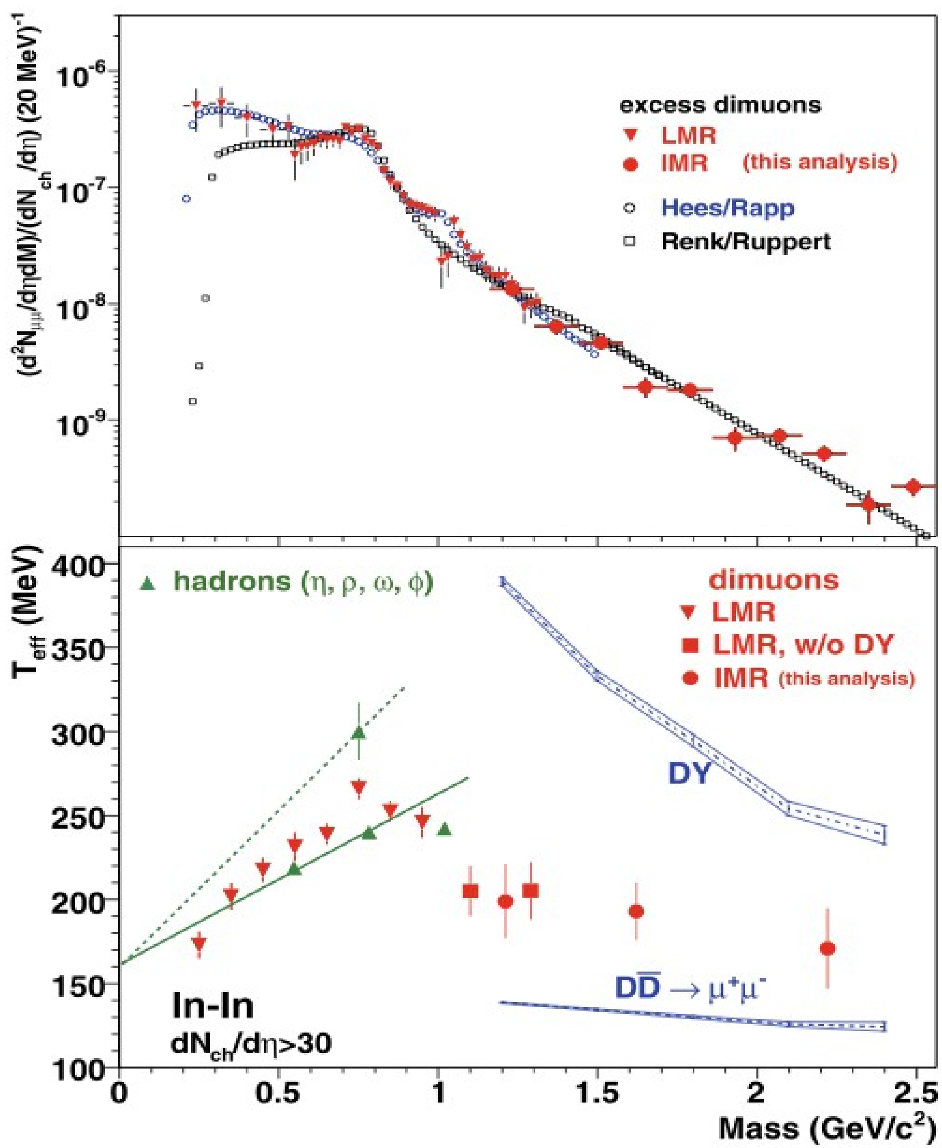


Low mass enhancement:

CERES: observed a significant enhancement at LMR.
NA60: ρ broadening can explain the enhancement.
rules out the Dropping-Mass scenario.
PHENIX: Huge enhancement at LMR, but can not be explained by any model.

Motivation – thermal radiation

NA60, Eur. Phys. J. C 59 (2009) 607



Dimoun spectra at SPS:

LMR : dominanted by hadronic source

IMR : from HG and/or QGP

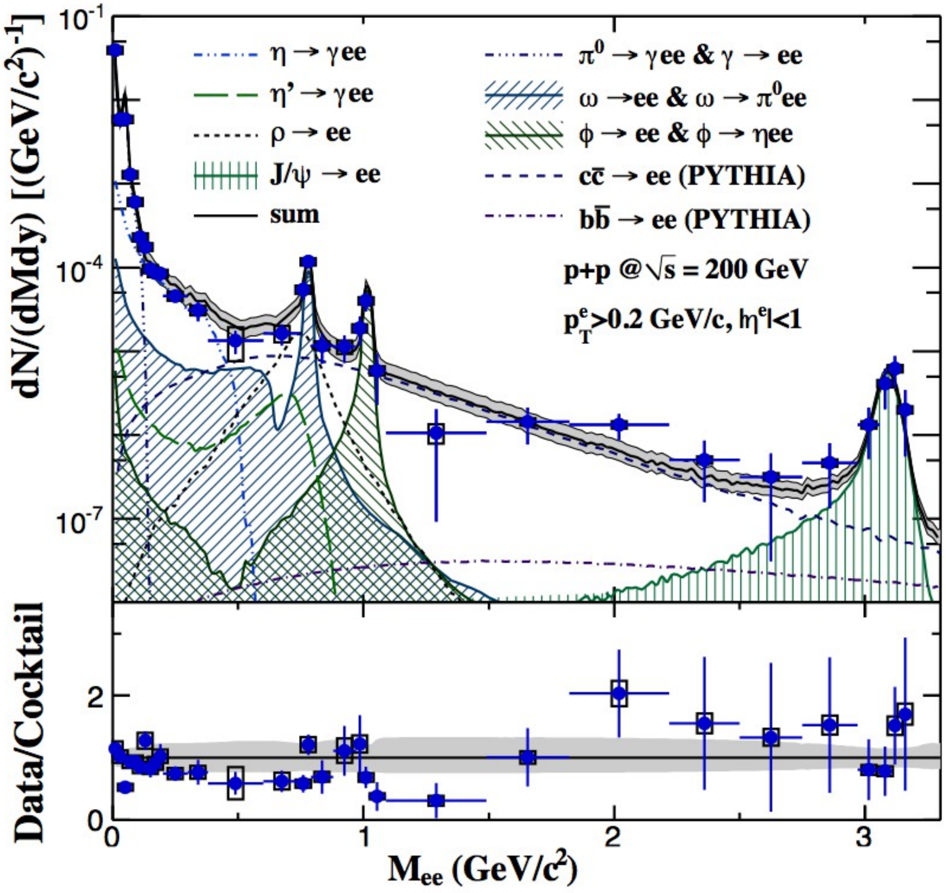
- HG: $\pi a_1 \rightarrow \mu^+\mu^-$ (Hees/Rapp)
- QGP: $qq \rightarrow \mu^+\mu^-$ (Renk/Ruppert)

Inverse slope of m_T spectra (T_{eff})

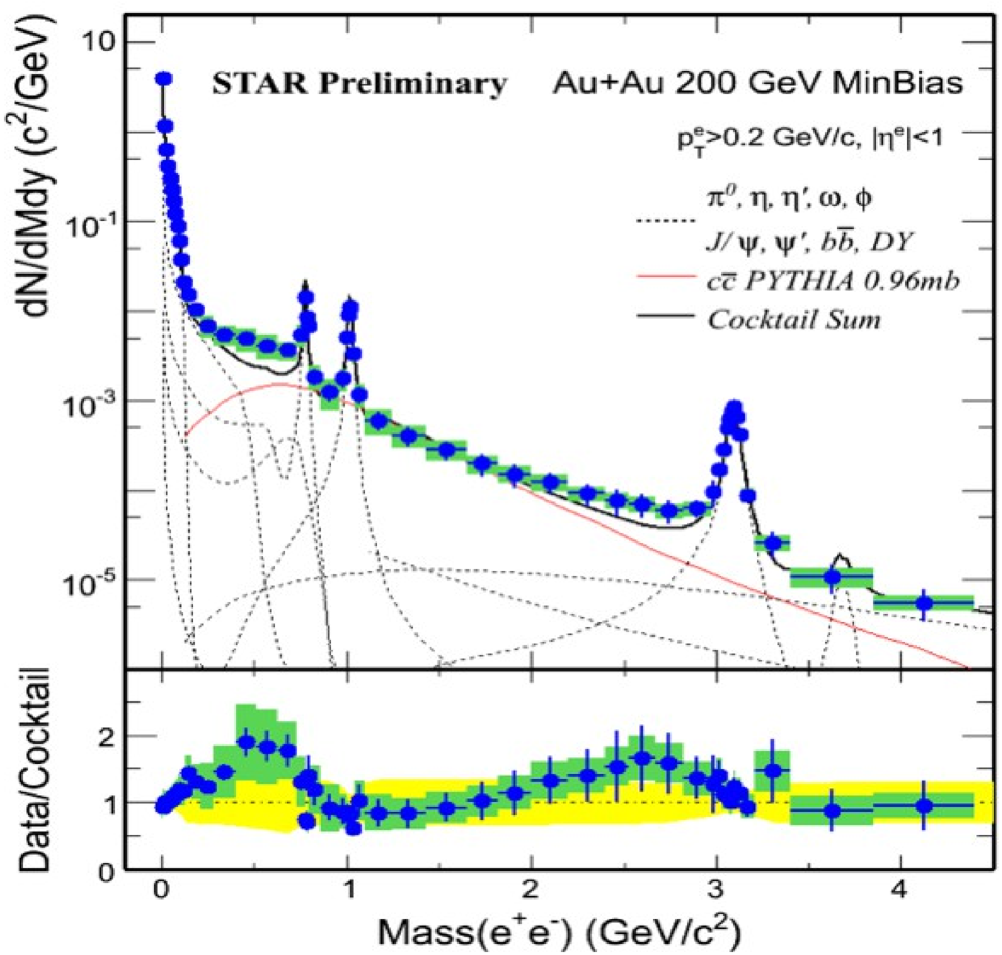
- **LMR : increasing with mass.**
  - radial flow of hadronic source.
- **IMR : drop around 1 GeV/c^2.**
  - thermal radiation from partonic source.

Previous results from STAR

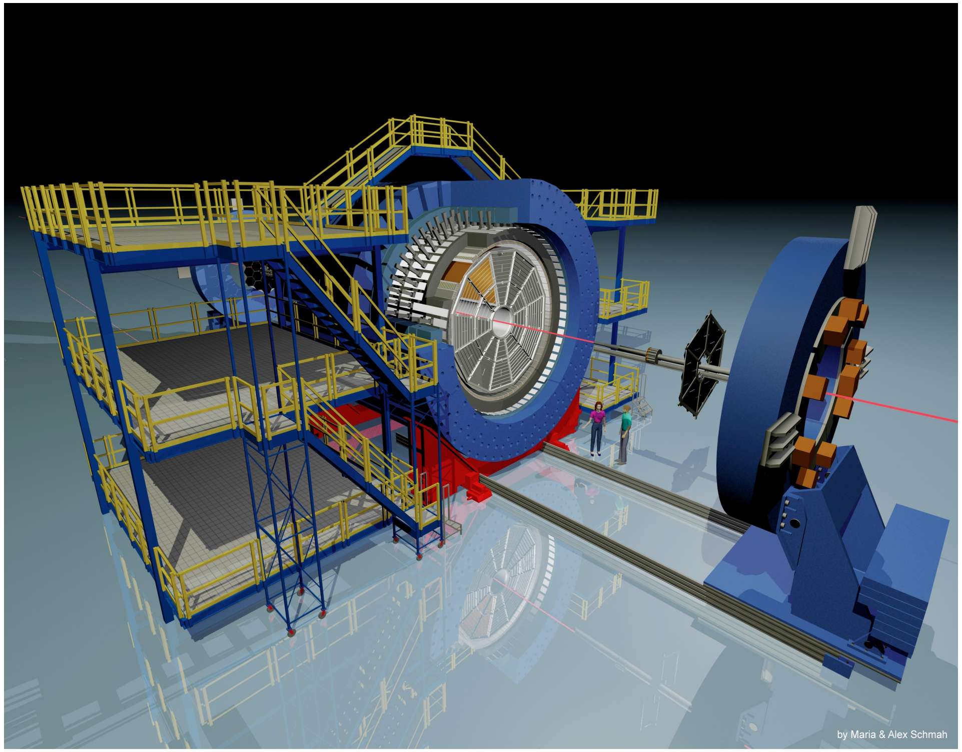
p+p 200GeV from year 2009:
Phys. Rev. C 86, 024906 (2012)



Au+Au 200GeV from year 2010:
QM2012



STAR detectors



Detectors used in dielectron analysis:

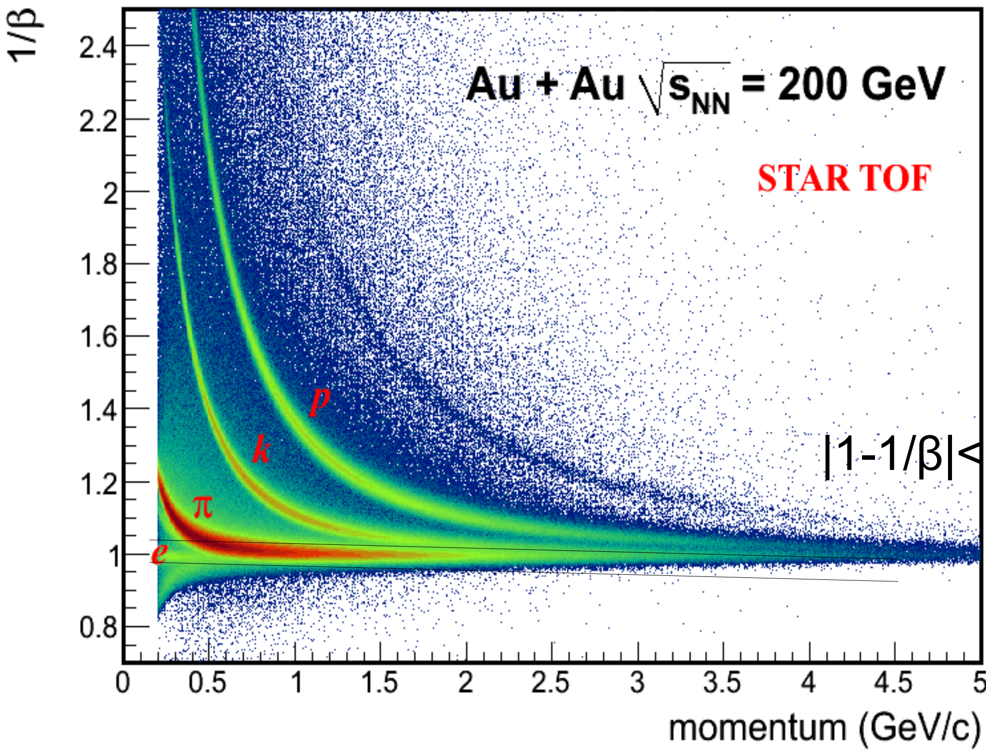
- **Time Projection Chamber**
  (0<Φ<2π, |η|<1)
  Tracking – momentum
  Ionization energy loss – dE/dx
  (particle identification)

- **Time Of Flight detector**
  (0<Φ<2π, |η|<1)
  Time resolution < 100ps – significant improvement for PID

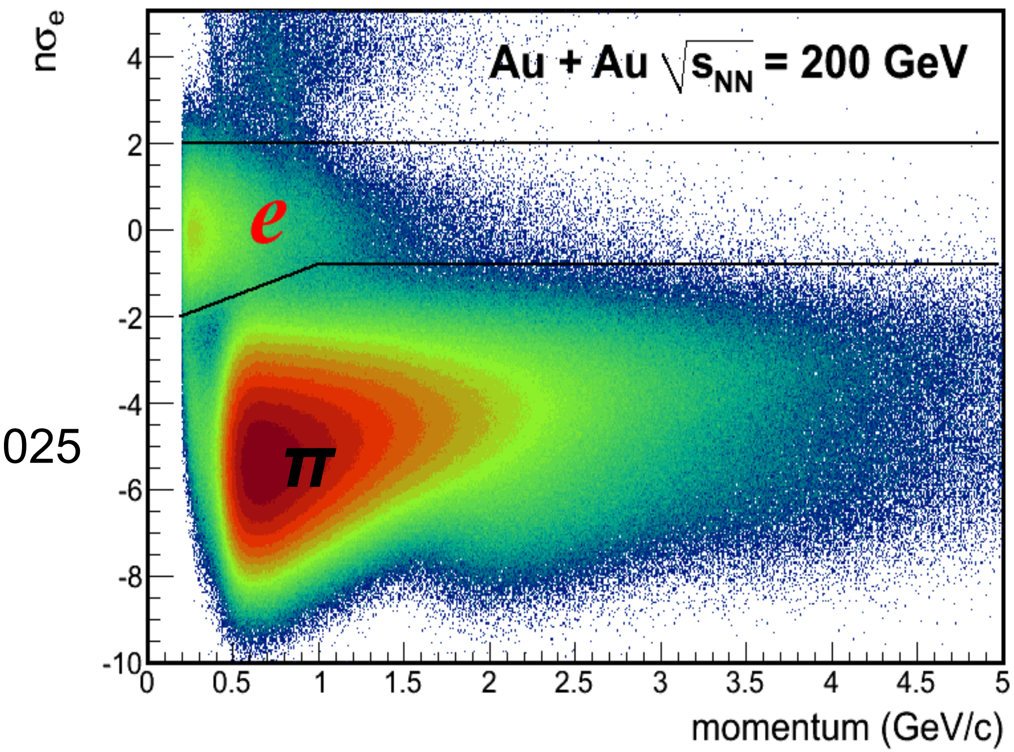
Data Set:

Run Type	Year	Central	Minbias
AuAu200GeV	2010	150M	270M
	2011	N/A	580M
pp200GeV	2012	N/A	375M

Electron identification



|1-1/β|<0.025



➢**Clean electron PID in p+p and Au+Au collisions with a combination of TPC *dE/dx* and TOF velocity**

- **Electron purity: (0.2-2.0GeV/c)**

AuAu 200GeV	MinBias	~95%
	Central	~93%
pp 200GeV	MinBias	~98%

nσ_e normalized dE/dx

Background

- **Background**

  a. Low mass region

  Like Sign – acceptance corrected

  ✓ *can reproduce both the combinatorial and correlated background.*

  ✗ *but lack of statistics and need correct acceptance factor*

$$B_{LikeSign} = 2\sqrt{N_{++}\cdot N_{--}}\cdot\frac{B^{Mix}_{+-}}{2\cdot\sqrt{B^{Mix}_{++}\cdot B^{Mix}_{--}}}$$

Acceptance factor

N : same Event , B^{mix} : mixed Event

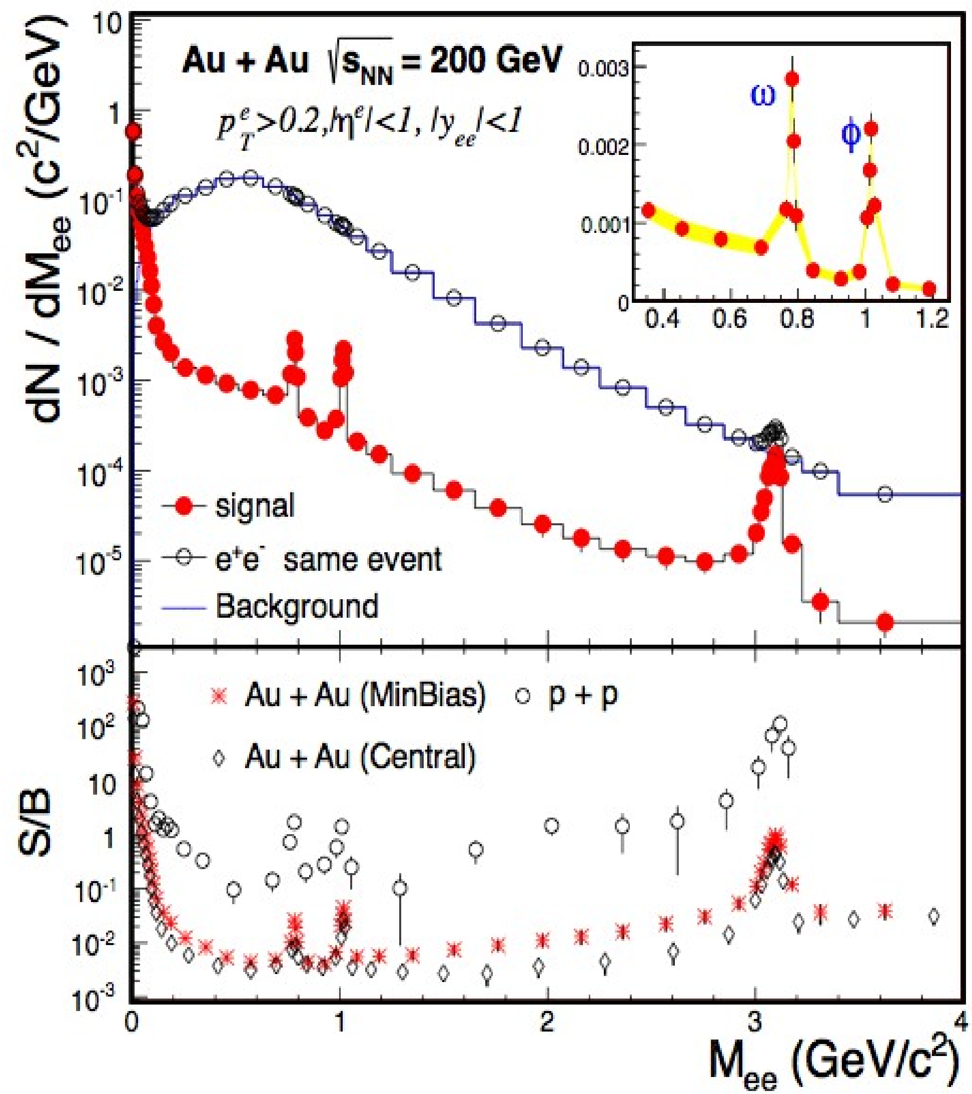
  b. Mass>0.75GeV/c^2

  Mixed Event – normalized to Like Sign in mass region [1,2] GeV/c^2

  ✓ *large statistics and no need to correct acceptance.*

  ✗ *but can't reproduce correlated background*

STAR preliminary

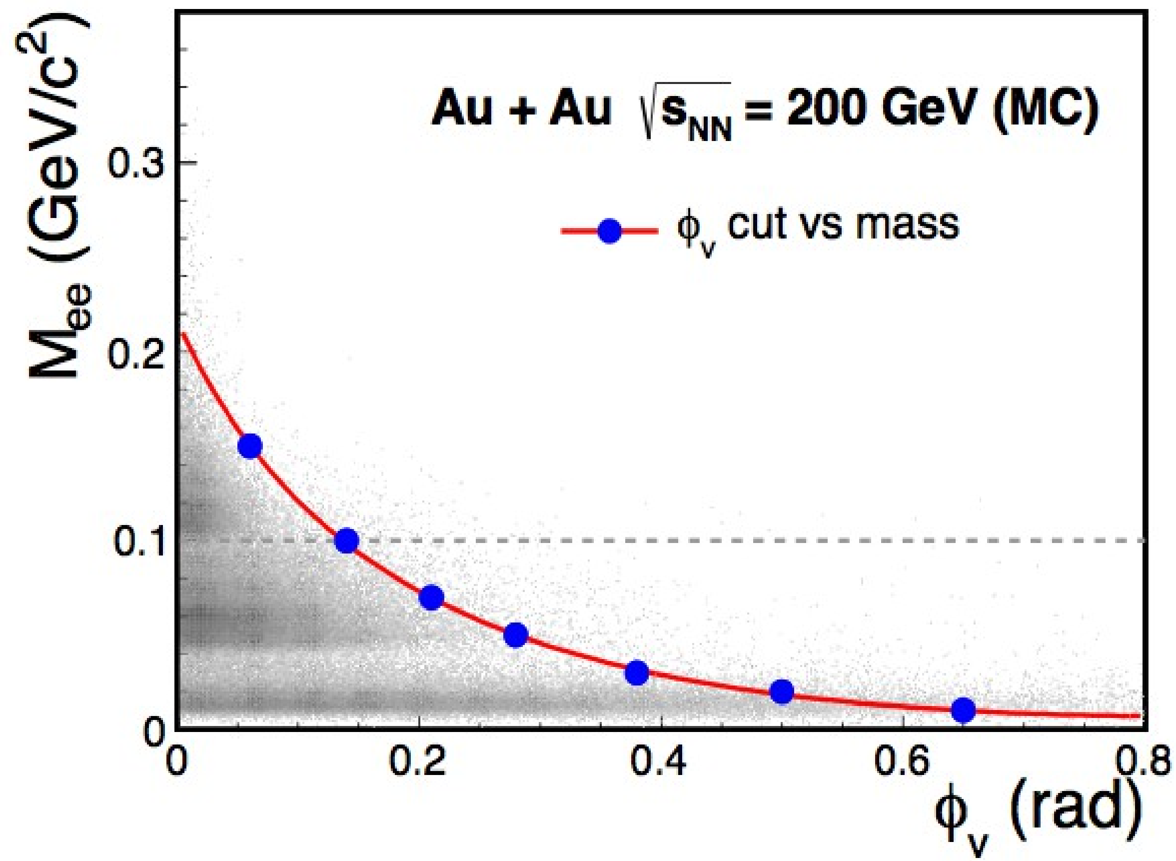


Background – photon conversion

We use φ_V angle cut method to remove the photon conversion background as described in:

***[PHENIX Collaboration], Phys. Rev. C 81, 034911 (2010)*.**

Geant simalution :
– red line is the cut:
remove 95%
conversion electrons.



Definition of φ_V angle :

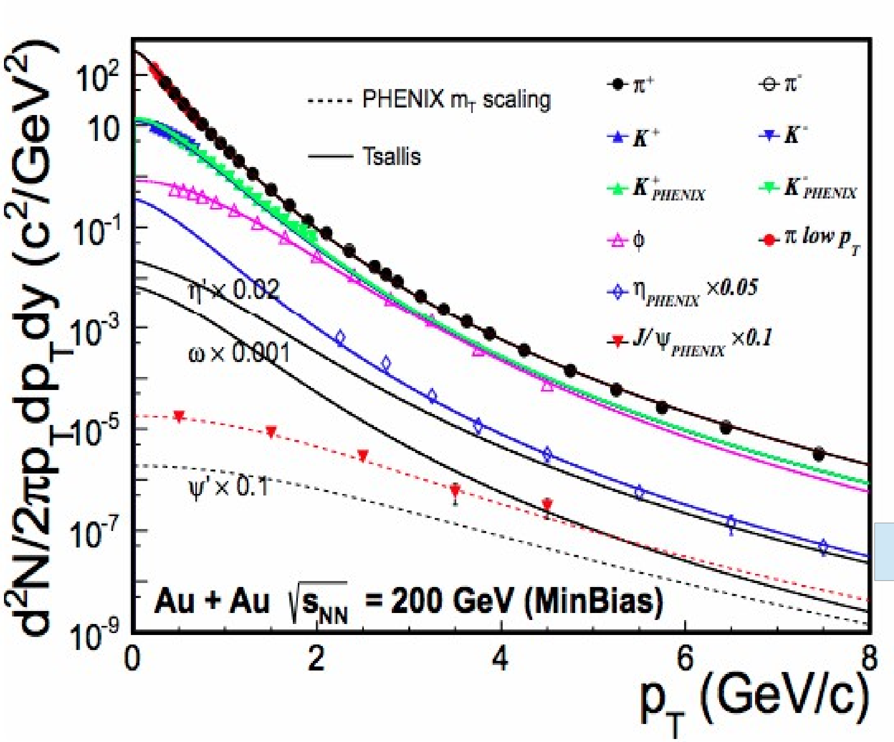
$$\hat{u} = \frac{\vec{p}_+ + \vec{p}_-}{|\vec{p}_+ + \vec{p}_-|}, \hat{v} = \vec{p}_+ \times \vec{p}_-$$

$$\hat{w} = \hat{u} \times \hat{v}, \hat{w}_c = \hat{u} \times \hat{z}$$

$$\cos\phi_V = \hat{w} \cdot \hat{w}_c$$

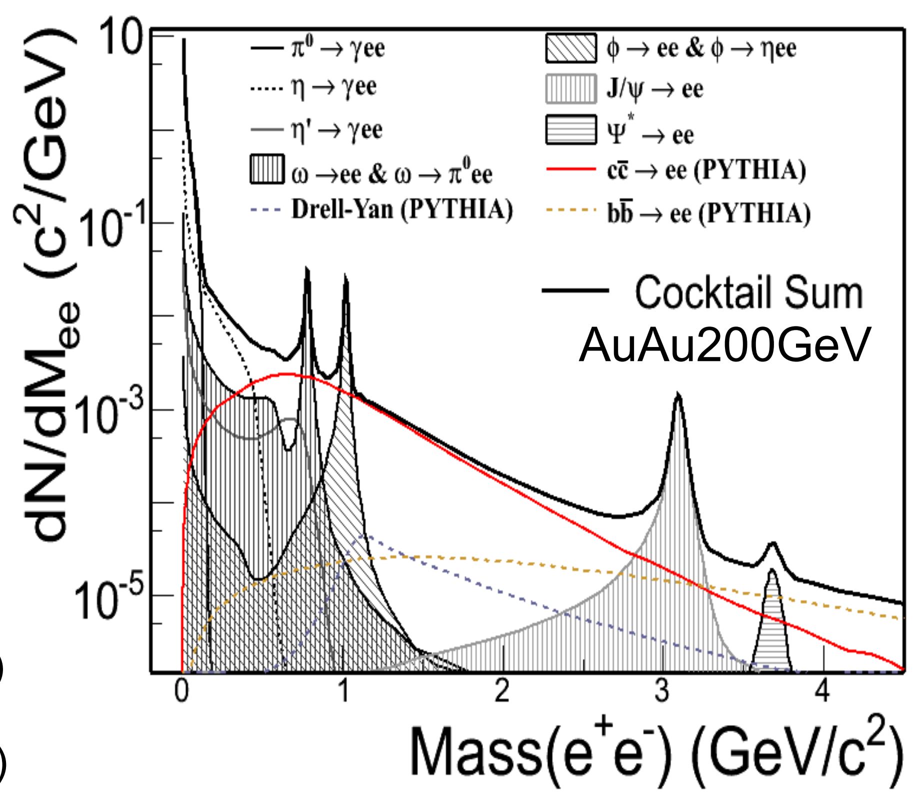
Cocktail simulation

Input p_T spectra

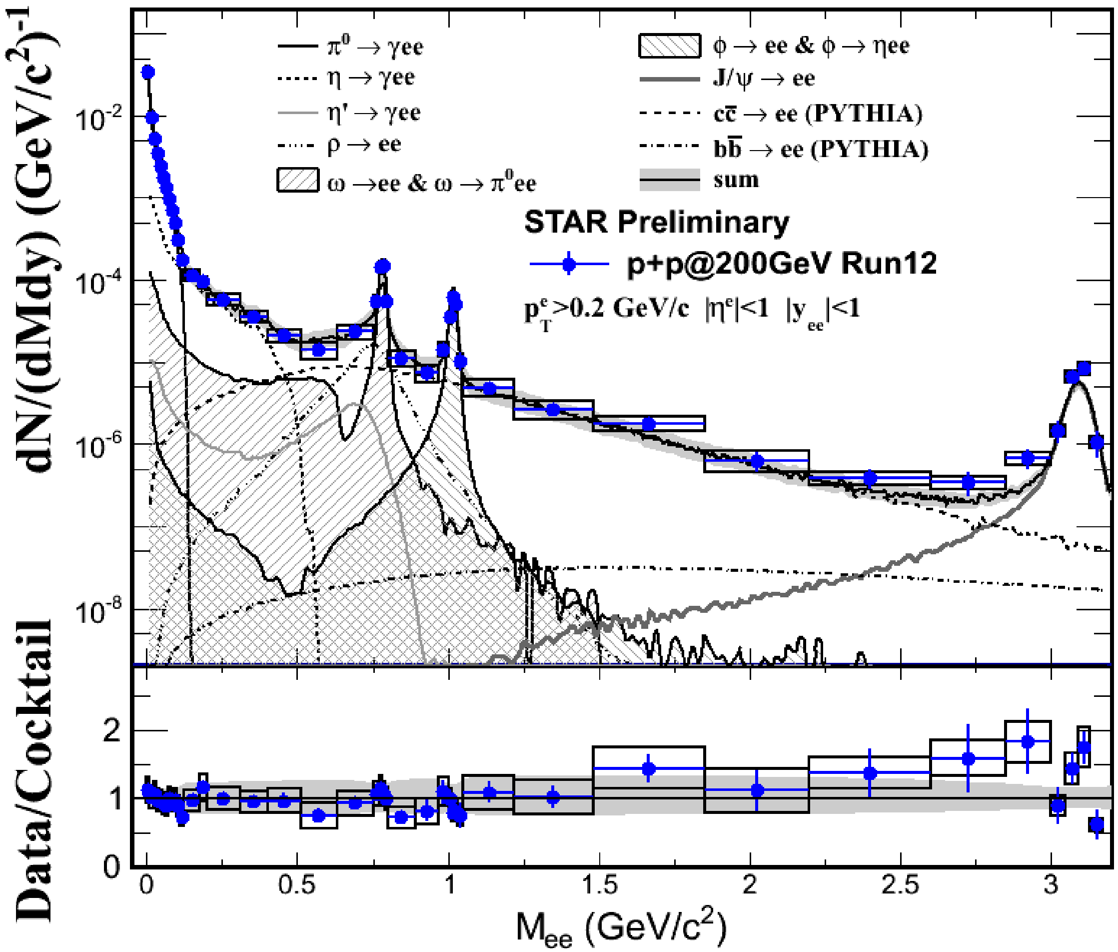


PHENIX Collaboration, Phys. Rev. C 81, 034911 (2010)
STAR Collaboration, Phys. Rev. Lett. 92, 112301 (2004)
STAR Collaboration, Phys. Lett. B 612, 181 (2005).
STAR Collaboration, Phys. Rev. Lett. 97, 152301 (2006)
Z. Tang et al. Phys. Rev. C 79, 051901 (2009).

Contributions from decays of hadrons after they freeze out, usually called hadronic cocktails.



pp 200GeV result from year 2012

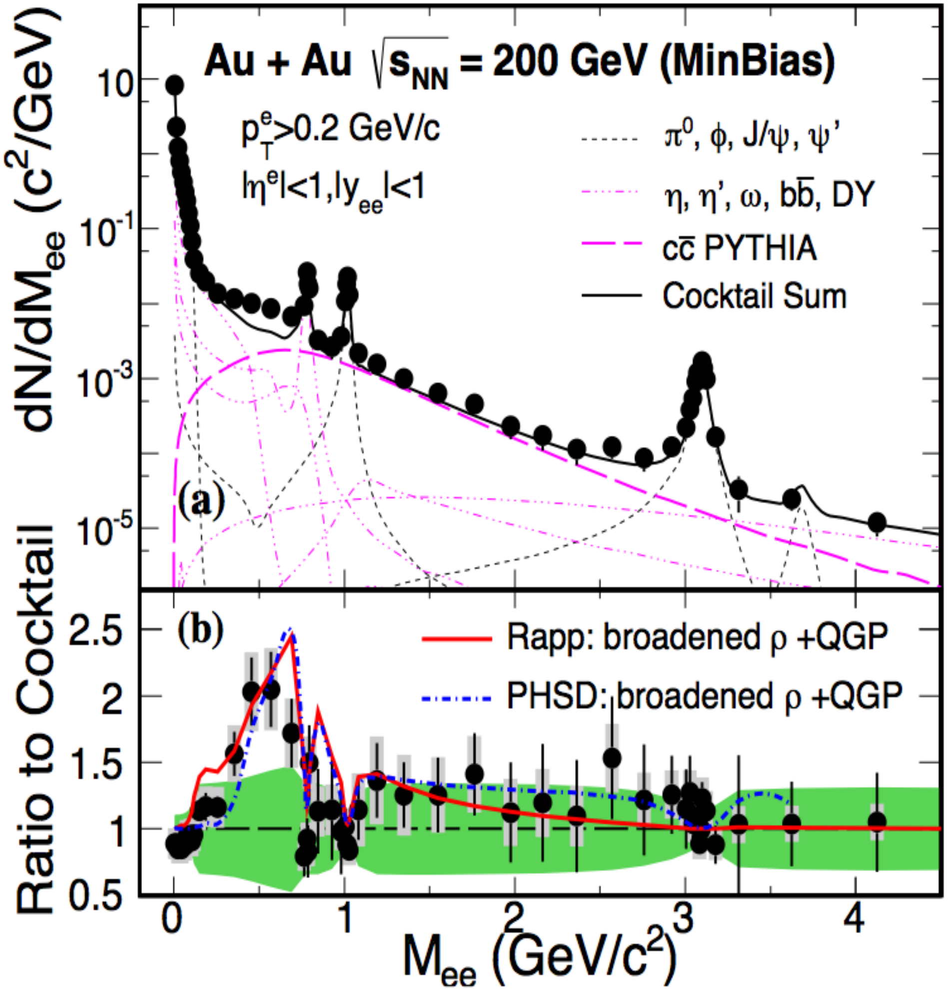


Photon conversion background are removed with φ_V cut.

Cocktail is taken from ***[Phys. Rev. C 86, 024906 (2012)]*** with charm cross section changed to 0.797+0.3/-0.36mb ***[Phys. Rev. D. 86, 072013(2012)]***

Within uncertainty, the cocktail simulation reproduces the data very well. With a full TOF coverage and more data taken, year 2012's result has greatly improved statistics ~ 4 times more than year 2009.

AuAu 200GeV results



Submited to PRL arXiv:1312.7397

Enhancement at ρ like region(0.30-0.76 GeV/c²):

1.77±0.11(stat.)±0.24(sys.)±0.41(cocktail) in MinBias.

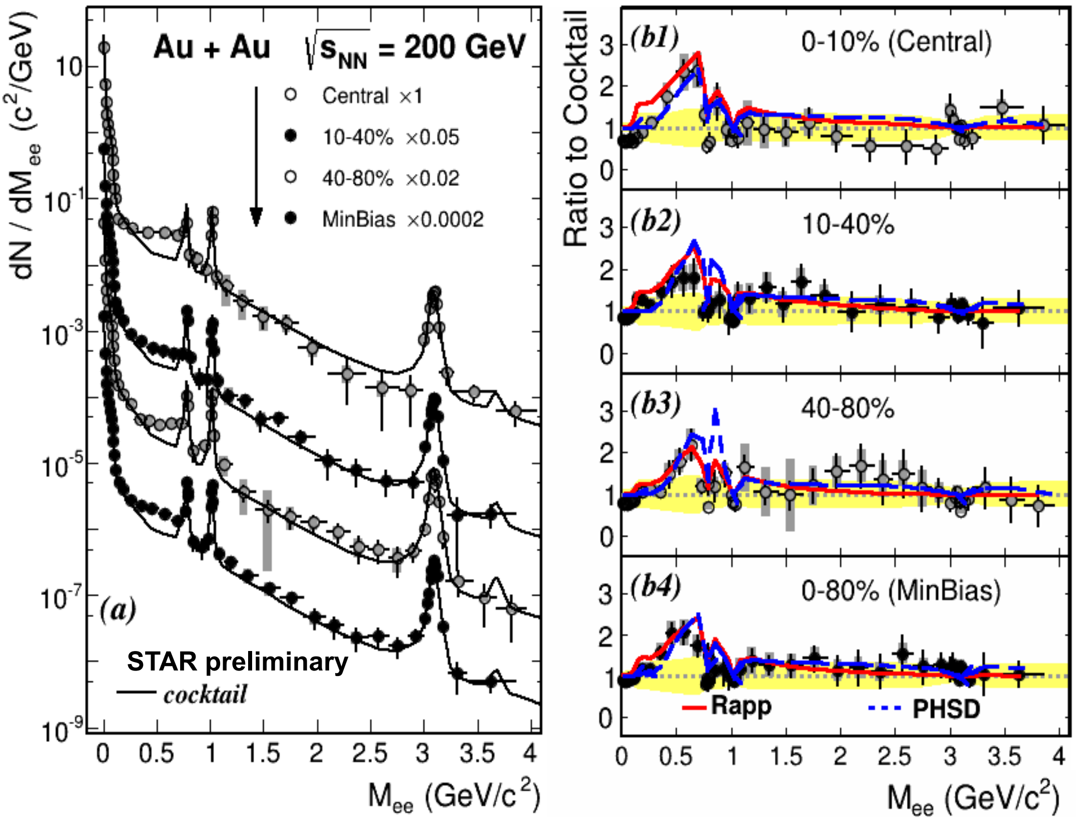
Data is compared with two models both based on a ρ broadening scenario:
1) Model I by Rapp et al. is an effective many-body model. ***[R. Rapp, PoS CPOD2013, 008 (2013)]***

2) Model II is a microscopic transport model – Parton-Hadron String Dynamics (PHSD). ***[O. Linnyk et al., Phys. Rev. C 85, 024910 (2012)]***

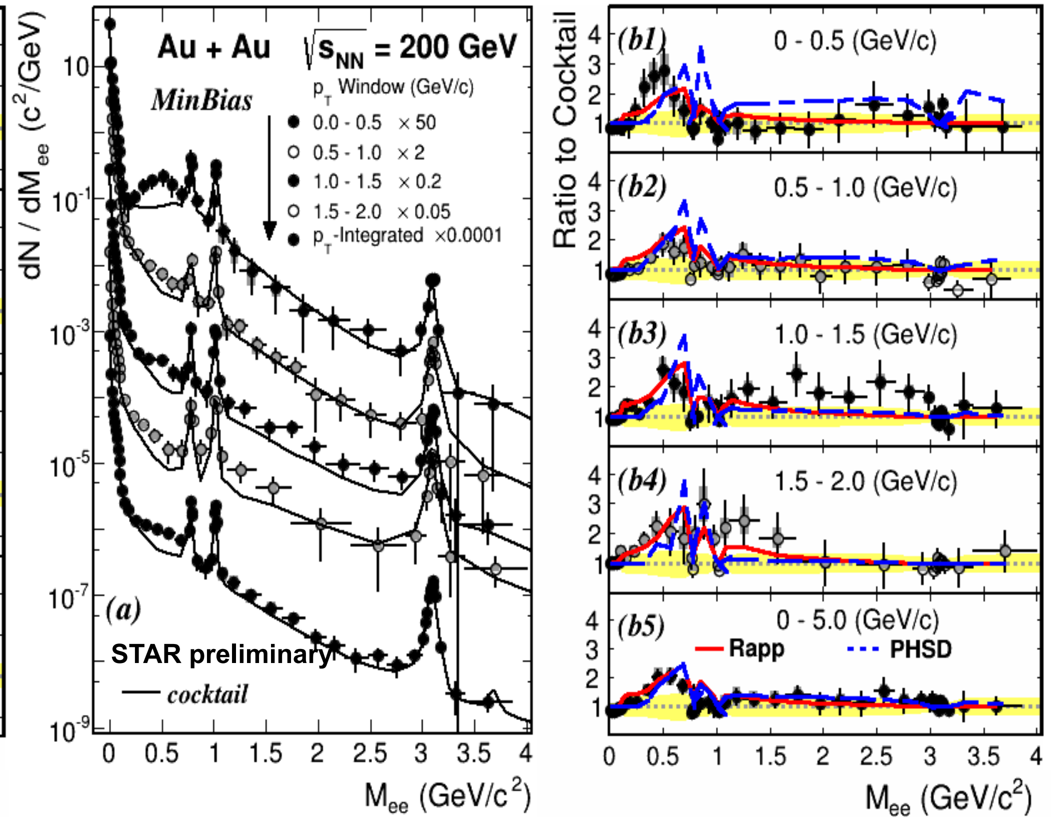
Models show good agreement with data within uncertainty.

Centrality and p_T dependence

Centrality dependence

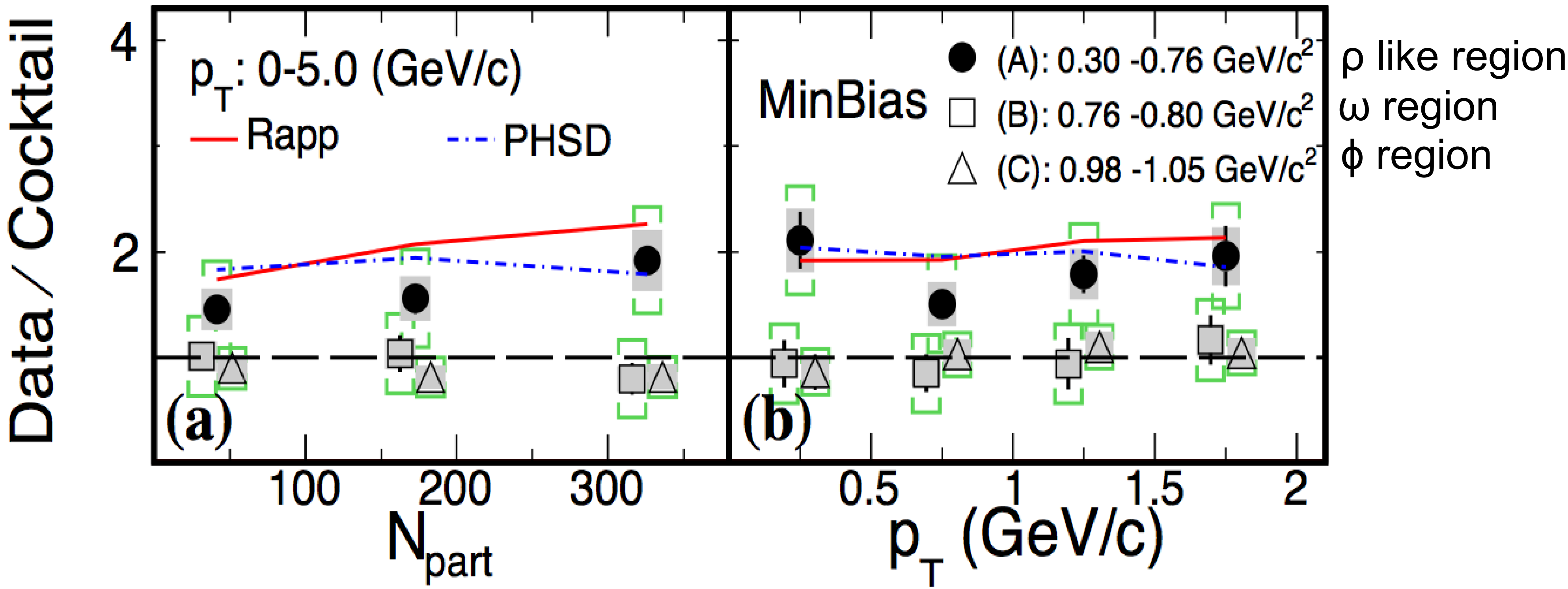


p_T dependence



The two model calculations show good agreement with data within uncertainty.

Low mass enhancement



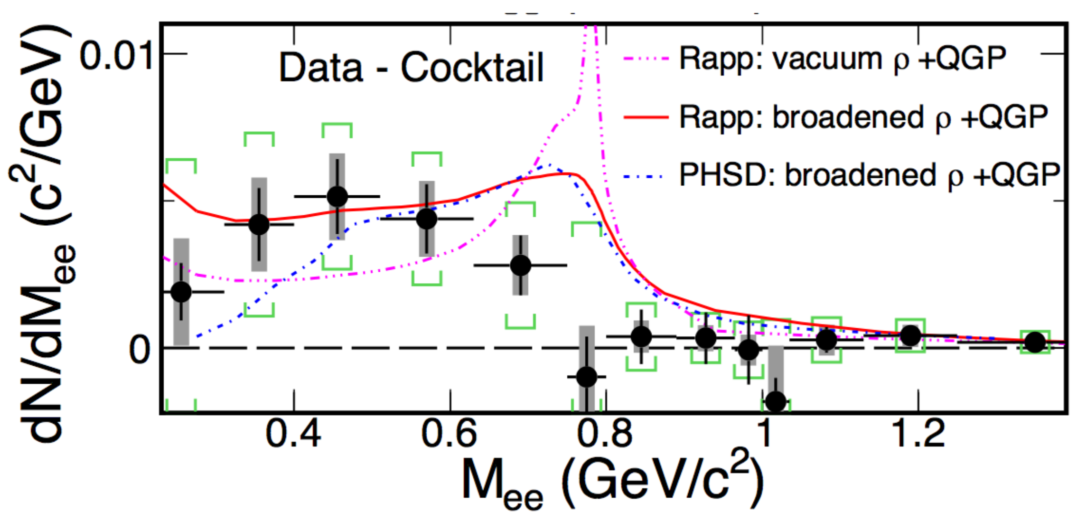
arXiv:1312.7397

- ρ like region (A):
  - --- The enhancement shows weak dependence on centrality and p_T.
- ω and ϕ region (B), (C):
  - --- Cocktail can reproduce the yield.

Low mass excess

1) excess in LMR (MinBias) :

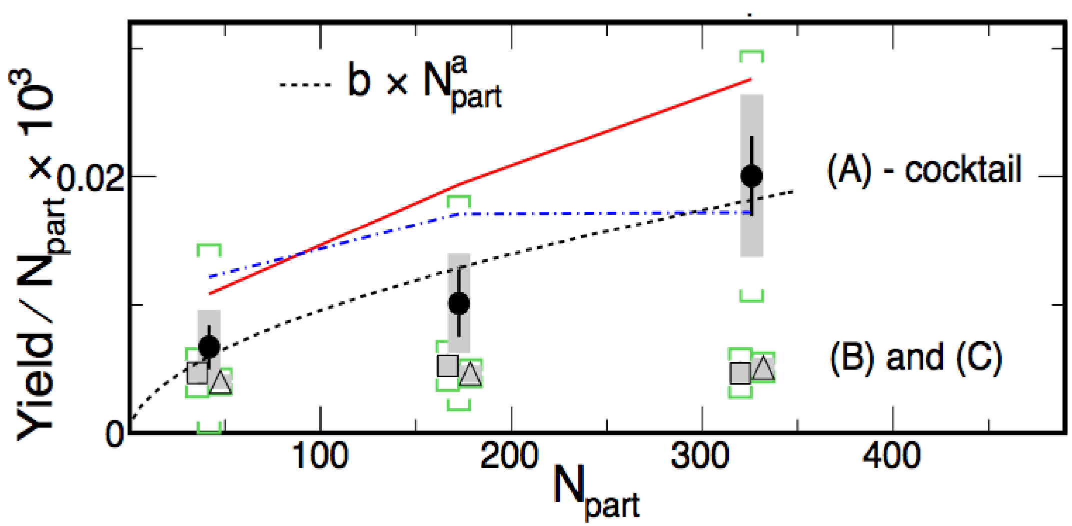
arXiv:1312.7397



Broadened ρ model calculations can explain STAR data within uncertainties.

Our measurements disfavor a pure vacuum ρ model with a $\chi^2/NDF = 25/8$ in 0.3~1 GeV/c^2.

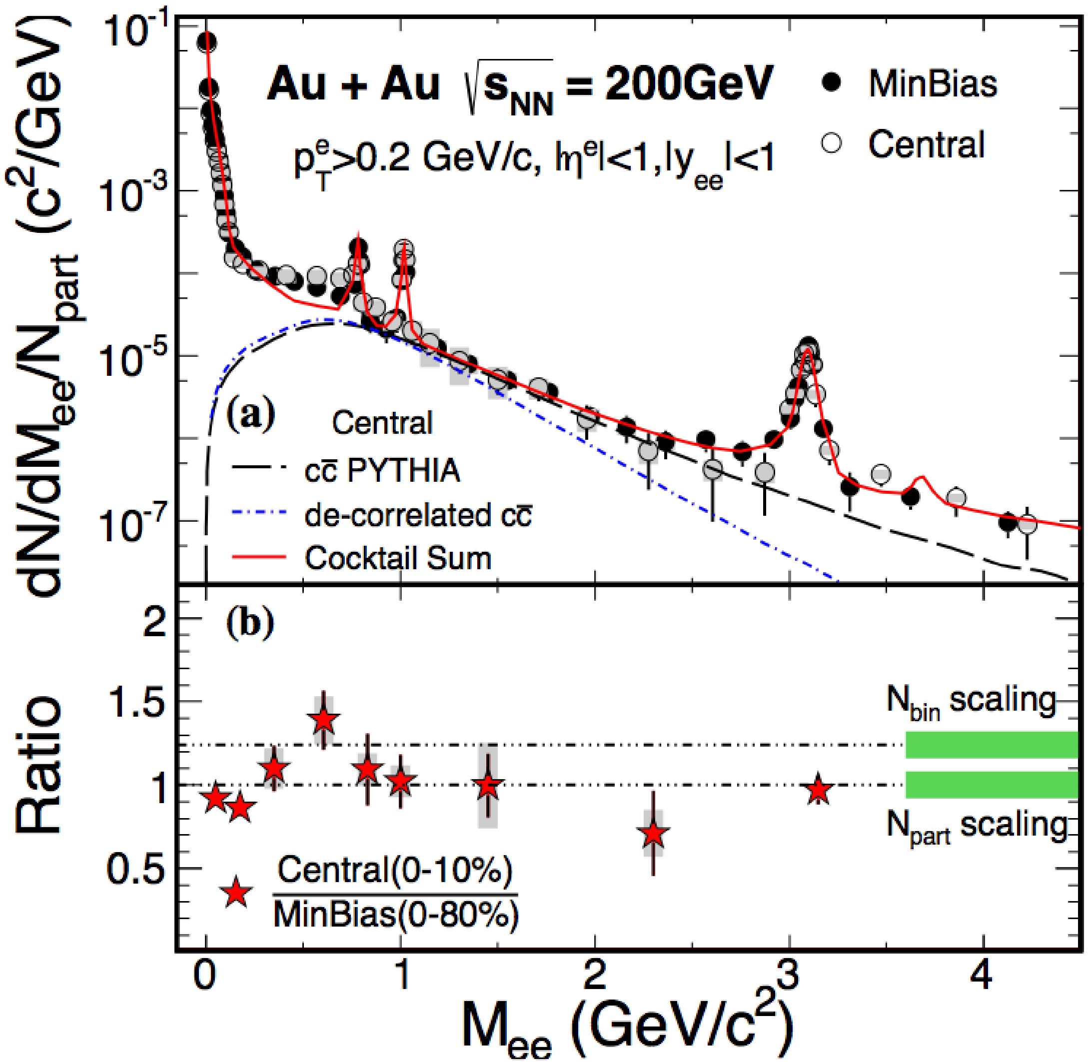
2) N_{part} dependence of excess yield:



(A) ρ like region : 0.3~0.76GeV/c^2
(B) ω region: 0.76~0.80GeV/c^2
(C) ϕ region: 0.98~1.05GeV/c^2

- ω and ϕ region (B), (C):
  --- Yield shows N_{part} scaling.
- ρ like region (A):
  --- Significant excess. Sensitive to the QCD media dynamics. A power fit shows: $Y^{\rho}_{excess} \propto N^{1.54\pm0.18}_{part}$

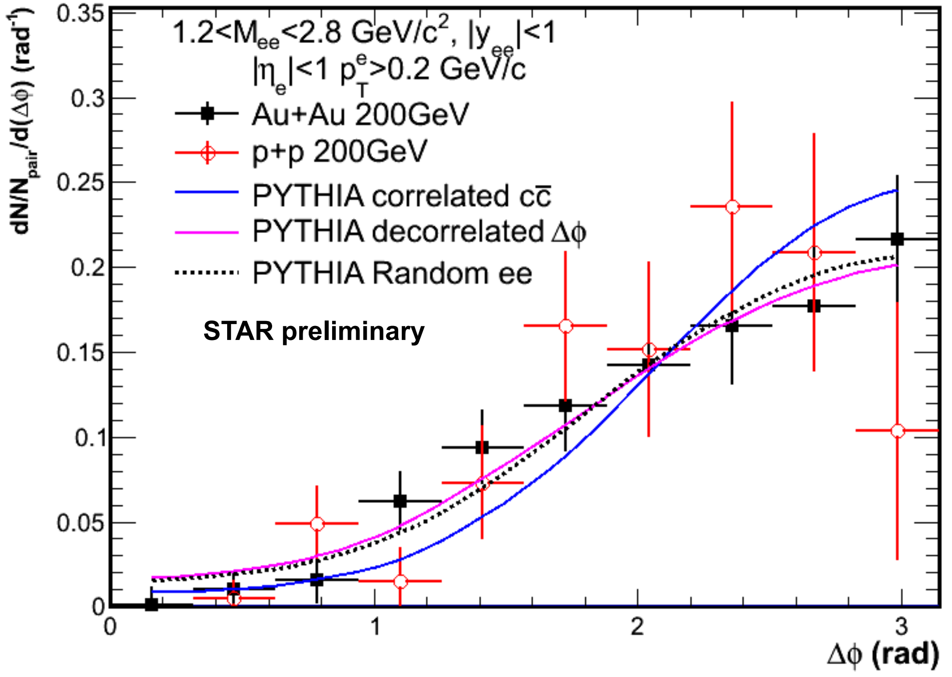
Possible charm de-correlation



arXiv:1312.7397

Ratio(*Central/MinBias*) shows 2.0σ deviation from the N_{bin} scaling in $1.8<M_{ee}<2.8\mathrm{GeV}/c^2$. Possible charm de-correlation in Au+Au collision or other source from thermal radiation.

Dielectron azimuthal correlation

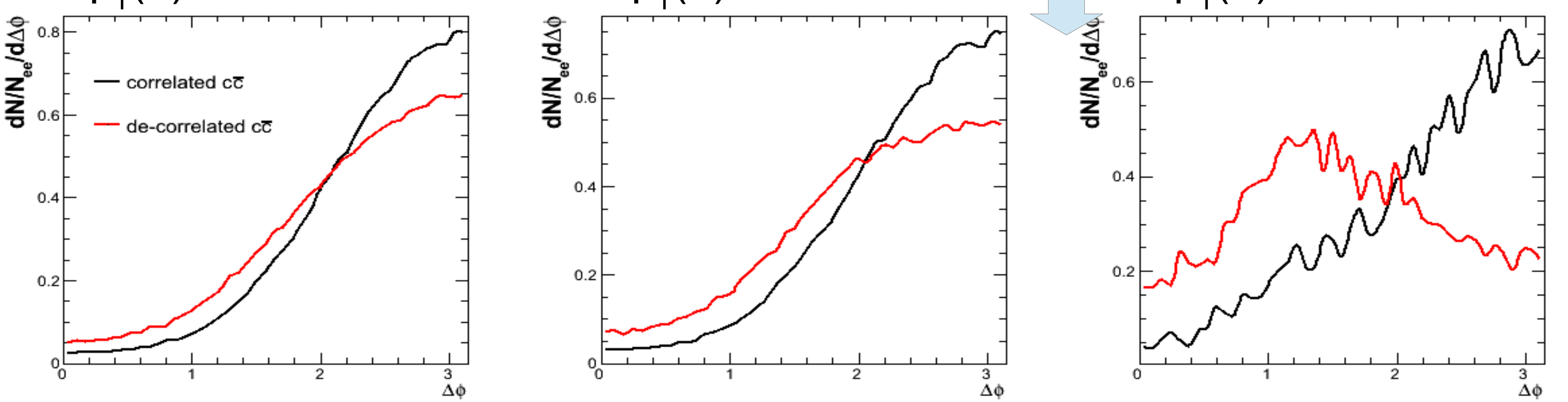


e-e correlation in IMR ($1.2<M_{ee}<2.8 GeV/c^2$) :
Au+Au 200GeV from year 2011
p+p 200GeV from year 2012
Both results need more statistics.

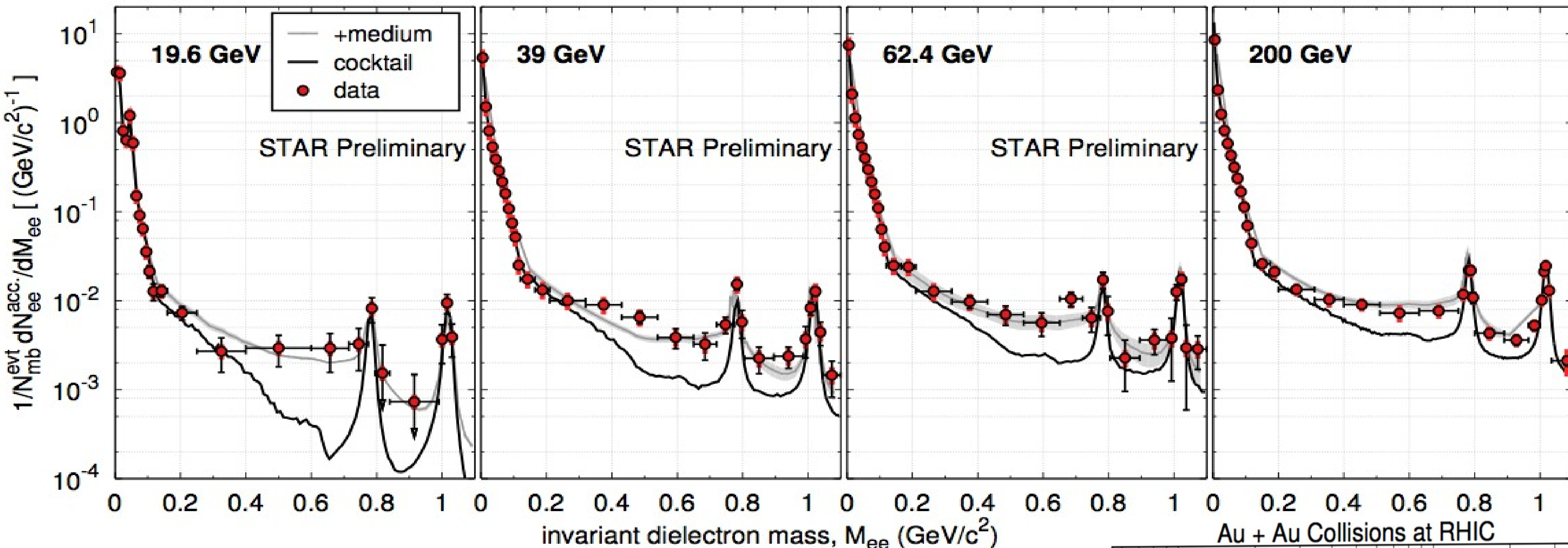
Higher electron p_T – more distinguish power.

Pythia simulation
$1.2<M_{ee}<2.8GeV/c^2$

$p_T(e)>0.2GeV/c$ $p_T(e)>0.5GeV/c$ $p_T(e)>1.0GeV/c$



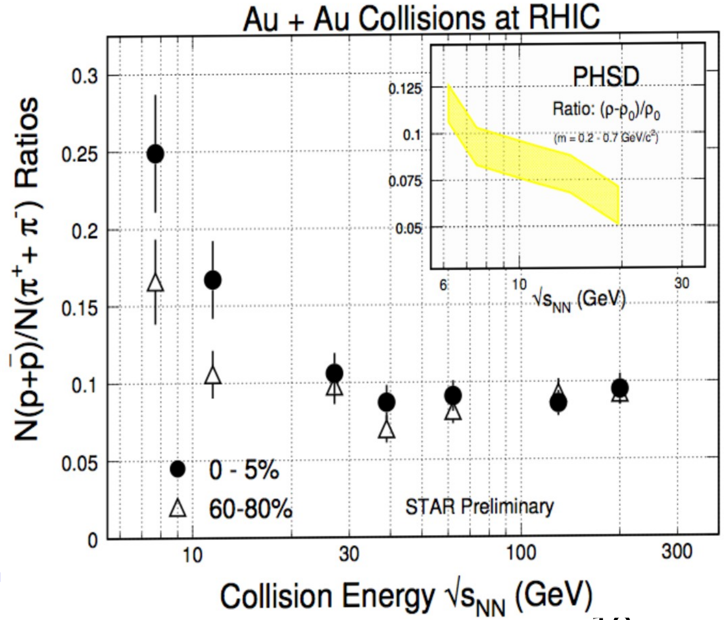
Dielectron from RHIC BES-I



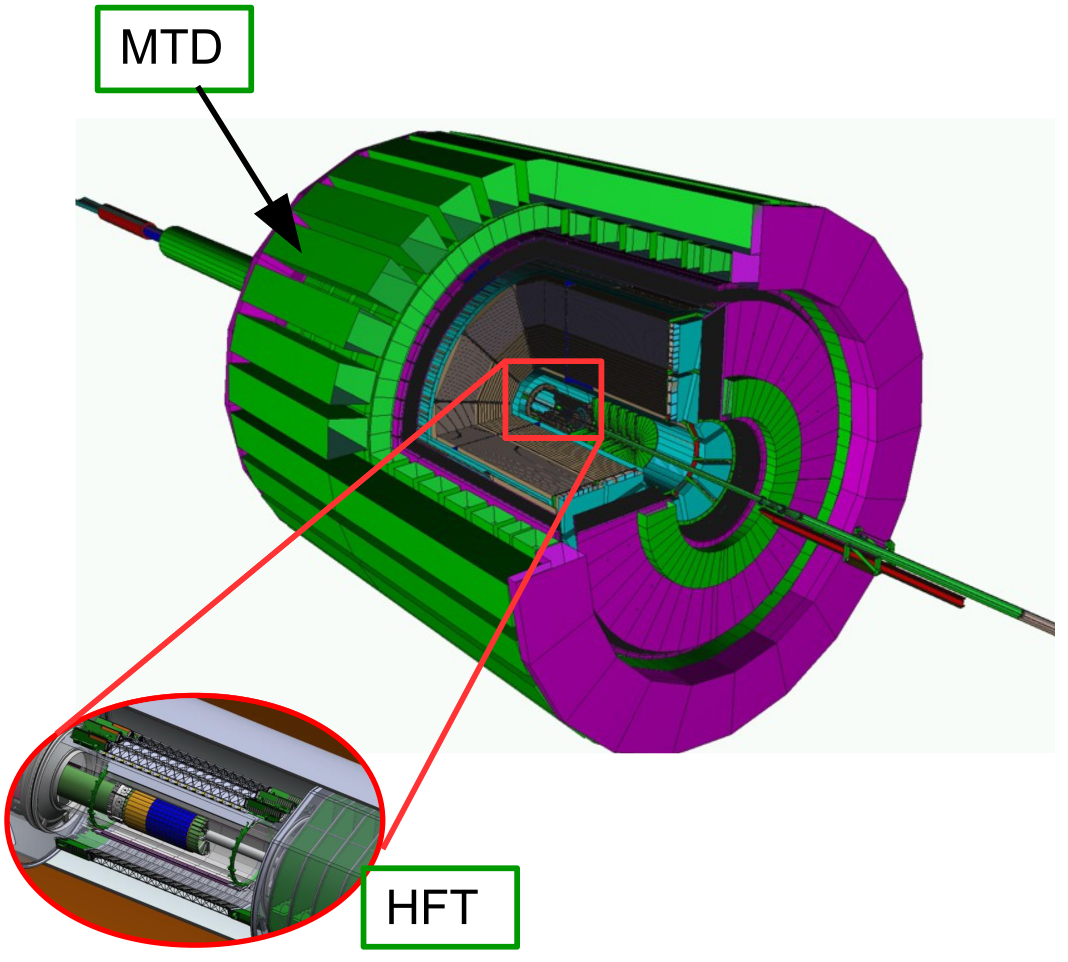
Model calculations robustly describe the data from 200GeV to 20 GeV:

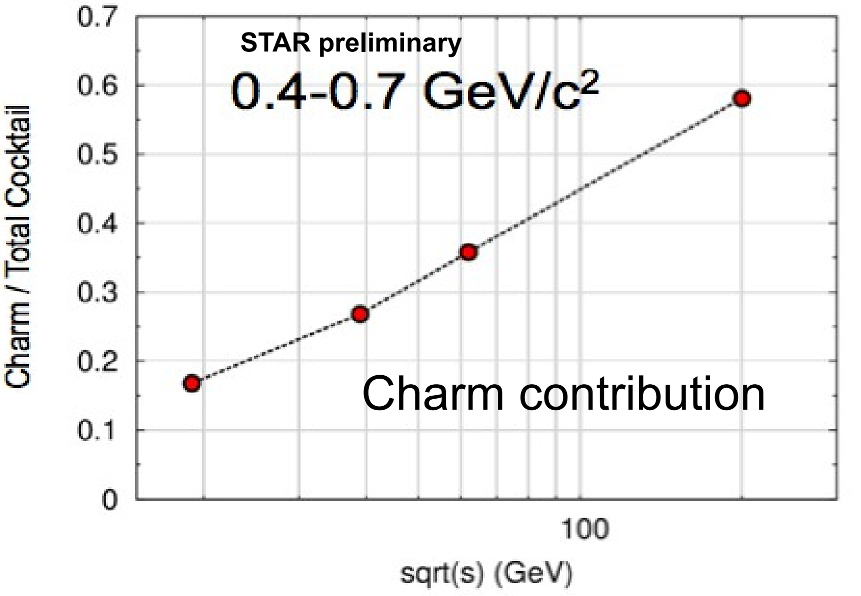
– model calculations by Rapp, based on in-media broadening of ρ spectra function, expected to depend on total baryon density.

– almost constant baryon density from 20-200GeV.



Outlook – Measure correlated charms





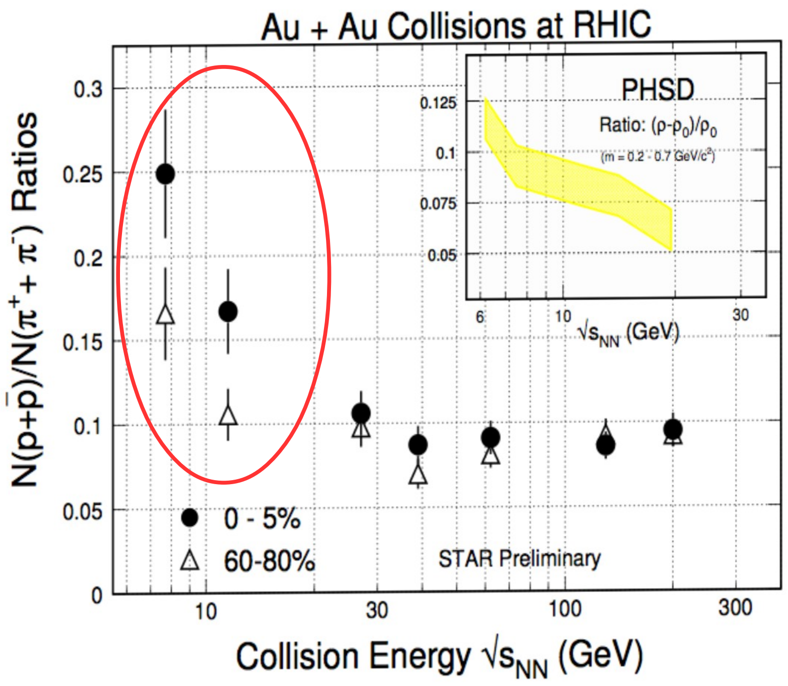
STAR Upgrade
MTD : Full Installed.
HFT : Full installed.
STAR Run14: They are taking data now!!

- **HFT - topologically reconstructs D mesons from hadronic decays and identifies electrons from charm decays.**
- **MTD - measurement of e-μ correlation – clean to correlated charm.**
- **HFT+MTD - help to understand the correlated charm contribution.**

Outlook - RHIC BES-II

BES Phase 2 (2018-2019):

- Revisit lower energies.
- Improve statistics – extend to IMR.
- Systematically study dielectron continuum from $\sqrt{s}$ = 7.7-19.6GeV. LMR enhancement vs.increasing total baryon density.



Estimation for event statistics needed:

Energy	7.7GeV	9.1GeV	11.5GeV	14.6GeV	19.6GeV
MB events	100M	160M	230M	300M	400M

Summary

➢ Low-mass region:

➔ An enhancement is observed in LMR, with a data/cocktail ratio about 1.77±0.11(stat.)±0.24(sys.)±0.41(cocktail) in MinBias. The enhancement shows weak centrality and p_T dependence.

➔ Within uncertainties, broadening of ρ model calculations can explain the enhancement in data from 200 GeV down to 19.6 GeV at RHIC.

➢ Intermediate-mass region:

➔ Data gives hint for possible charm de-correlate effect in Au+Au collision.

➔ Need more precise measurement to constrain charm and QGP thermal radiation contributions. HFT, MTD!!

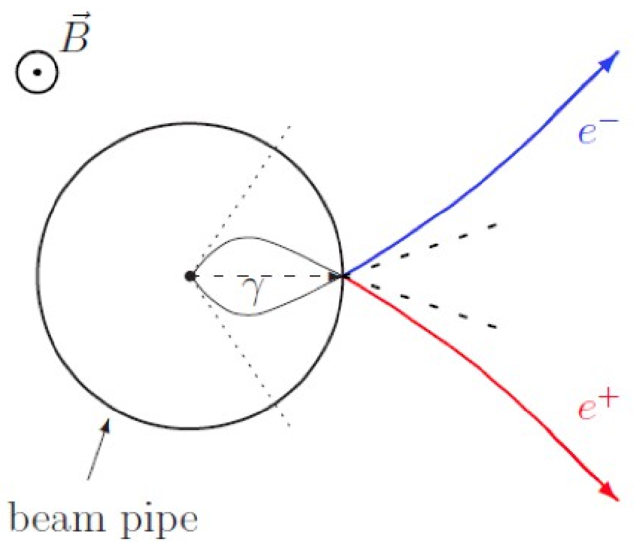
Work underway to combine Au+Au at 200GeV statistics of year 2010 and year 2011.

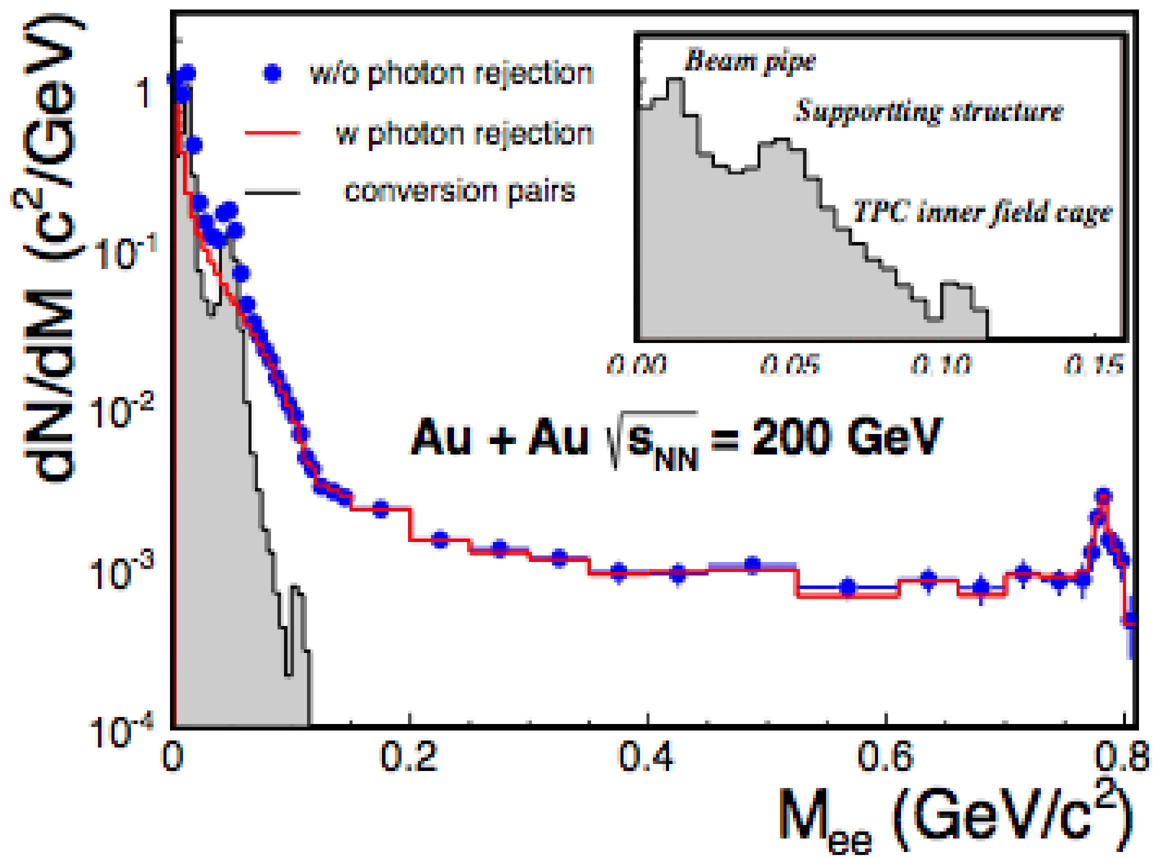
Proposed BES Phase-2 will significantly improve the dielectron LMR and IMR statistics

Thank you !!!

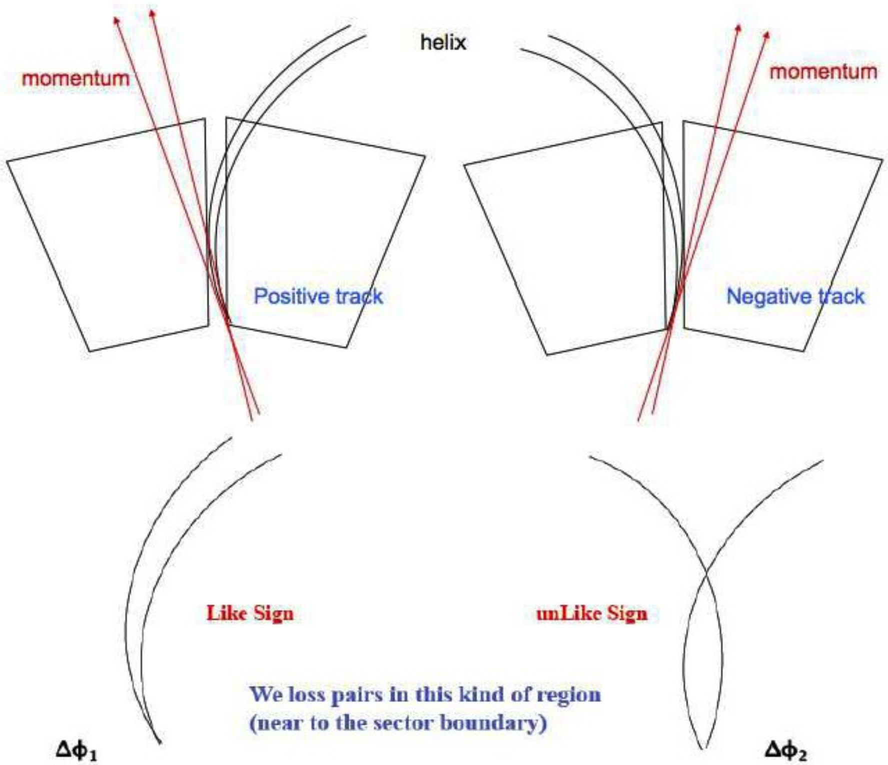
Backup

Photon conversion



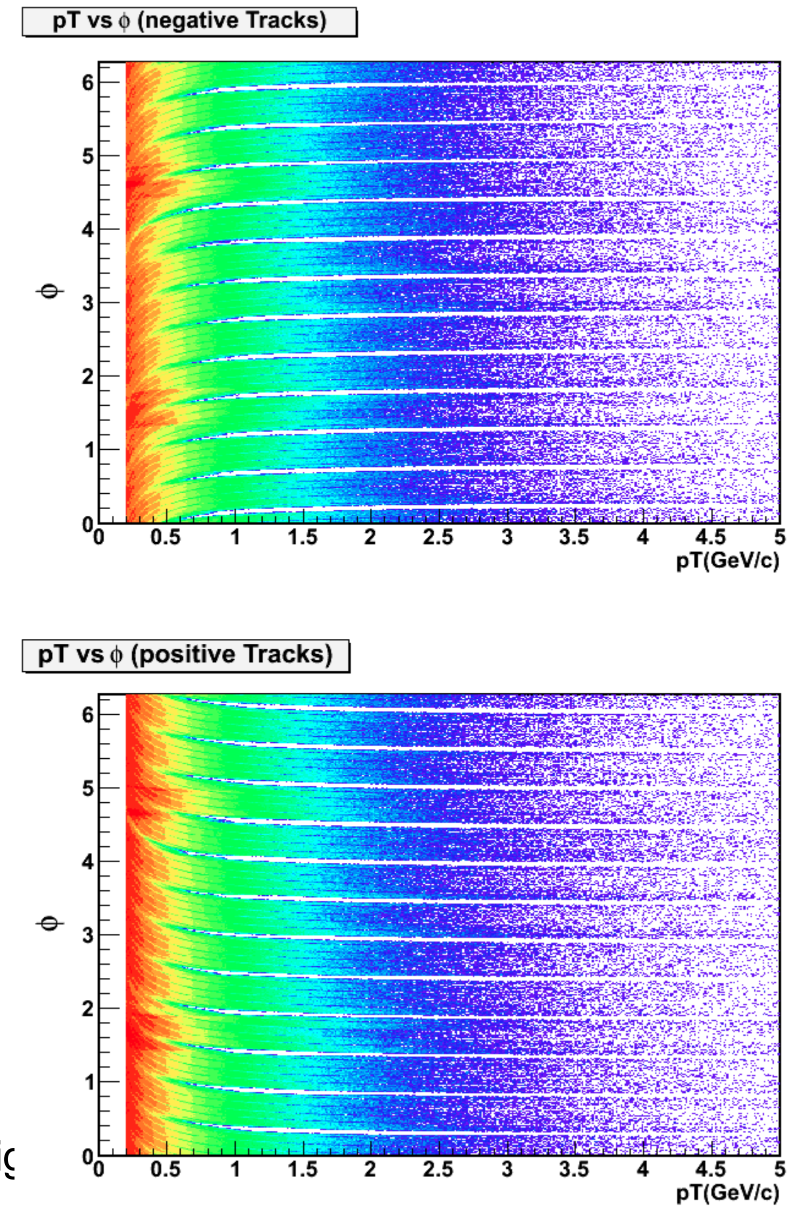


Acceptance correction



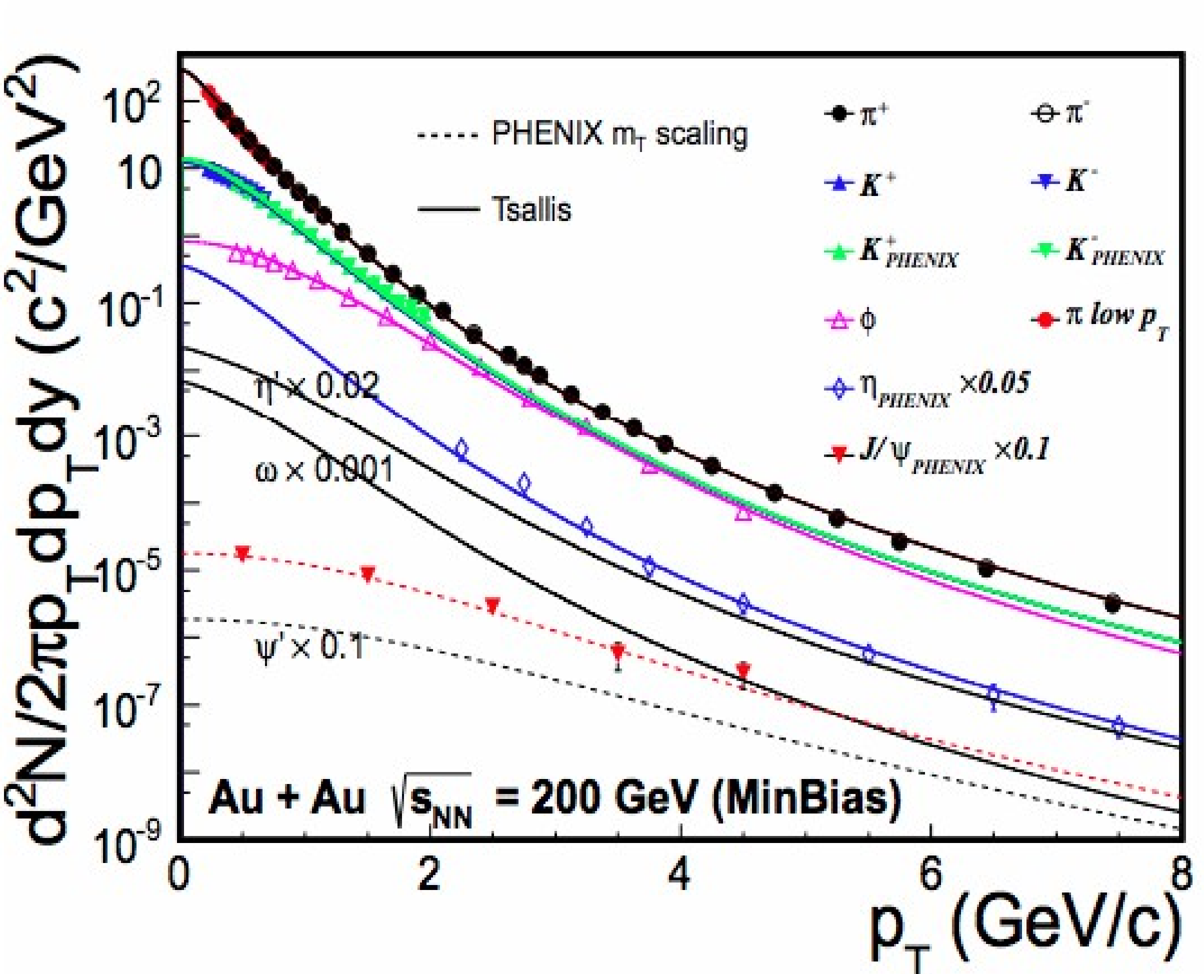
$$mass = \sqrt{(mass_1^2 + mass_2^2 + 2E_1E_2 - 2p_1p_2\cos(\Delta\phi))}$$

$\Delta\phi_1 < \Delta\phi_2$ → Loss like Sign pair in low mass ($\Delta\phi_1$) 0.2GeV
Loss unlike Sign pair in high mass ($\Delta\phi_2$) 0.2-0.5GeV



positive and negative tracks: - TPC sector boundary
lost in different phi region, especially in low pT region.
loss Like Sign pair in mass(<0.2 GeV/c2), loss unLike Sig
GeV/c2).

Cocktail simulation



Phys. Rev. C 81, 034911 (2010)
Phys. Rev. Lett. 92, 112301 (2004)
Phys. Rev. Lett. 97, 152301 (2006)
Phys. Rev. C 79, 051901 (2009).

Cocktail input :
Tsallis Blast-Wave (TBW) model fits to parameterize data and predicts the p_T spectra for particles without measurements.

J/ψ is taken from the measurement by the PHENIX collaboration.

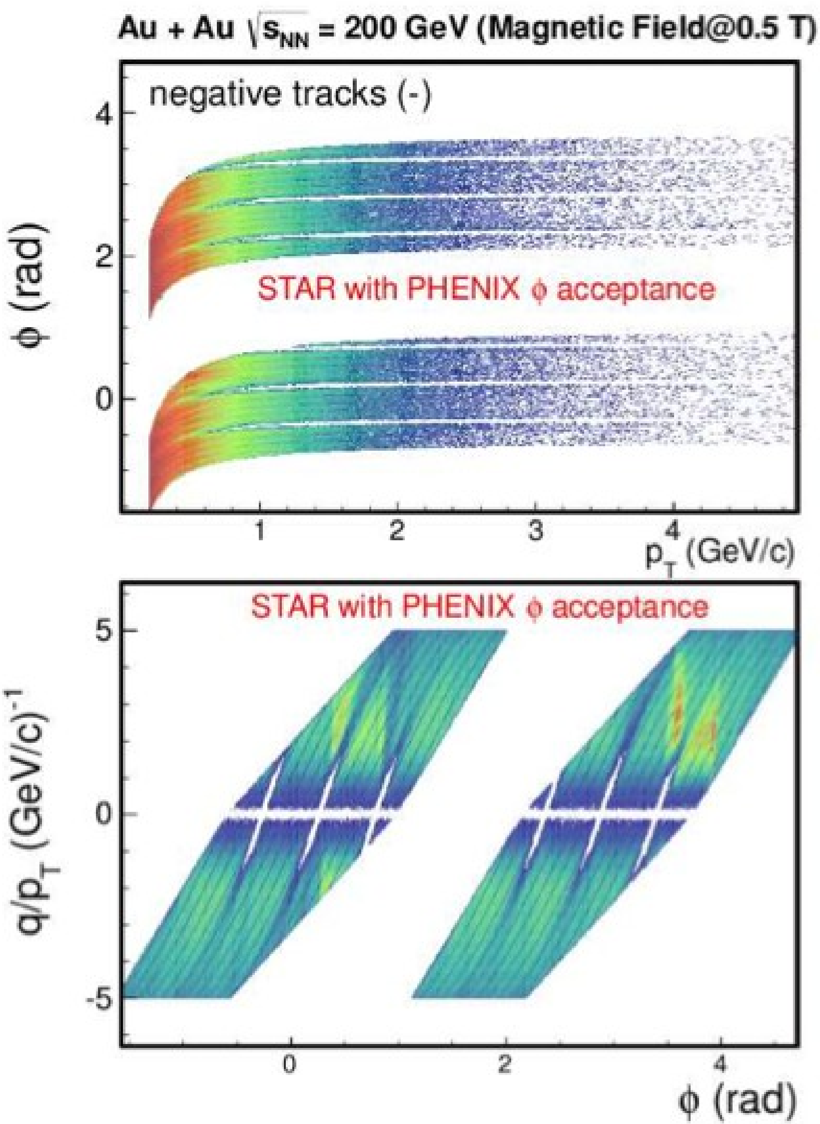
The correlated charm, bottom and Drell-Yan contributions are obtained from PYTHIA calculations.

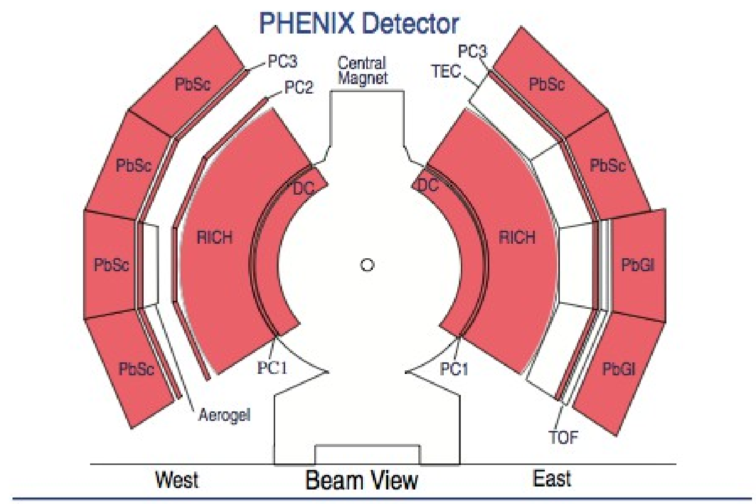
ρ meson is not included in the cocktail simulation for AuAu 200GeV.

Cocktail input for AuAu200

source	B.R.	dN/dy or σ	Uncertainty	Reference
$\pi^0 \rightarrow \gamma ee$	1.174×10^{-2}	98.5	8%	STAR [29, 30]
$\eta \rightarrow \gamma ee$	7×10^{-3}	7.86	30%	PHENIX [15]
$\eta' \rightarrow \gamma ee$	9×10^{-4}	2.31	100%	PHENIX [15]
$\rho \rightarrow ee$	4.72×10^{-5}	9.88	42%	STAR [41]
$\omega \rightarrow ee$	7.28×10^{-5}			
$\omega \rightarrow \pi^0 ee$	7.7×10^{-4}	9.87	33%	STAR [34]
$\phi \rightarrow ee$	2.95×10^{-4}			
$\phi \rightarrow \eta ee$	1.15×10^{-4}	2.43	10%	STAR [35]
$J/\psi \rightarrow ee$	5.94×10^{-2}	2.33×10^{-3}	15%	PHENIX [36]
$\psi\prime \rightarrow ee$	7.72×10^{-3}	3.38×10^{-4}	27%	PHENIX [38, 39]
$c\bar{c} \rightarrow ee$	1.03×10^{-1}	$d\sigma^{c\bar{c}}/dy = 170\mu b$	35%	STAR [37]
$b\bar{b} \rightarrow ee$	1.08×10^{-1}	$\sigma_{pp}^{b\bar{b}} = 3.7\ \mu b$	30%	Pythia[40]
$DY \rightarrow ee$	3.36×10^{-2}	$\sigma_{pp}^{DY} = 42$ nb	30%	Pythia[40]

Understand the enhancement in LMR





PHENIX ϕ acceptance:

$$\phi_{min} \leq \phi + q\frac{k_{\ DC}}{p_T} \leq \phi_{max}$$

$$\phi_{min} \leq \phi + q\frac{k_{RIHC}}{p_T} \leq \phi_{max}$$

k_{DC} and k_{RICH} represent the effective azimuthal bend to DC and RICH (k_{DC} = 0.206 rad GeV/c and k_{RICH} = 0.309 rad GeV/c).

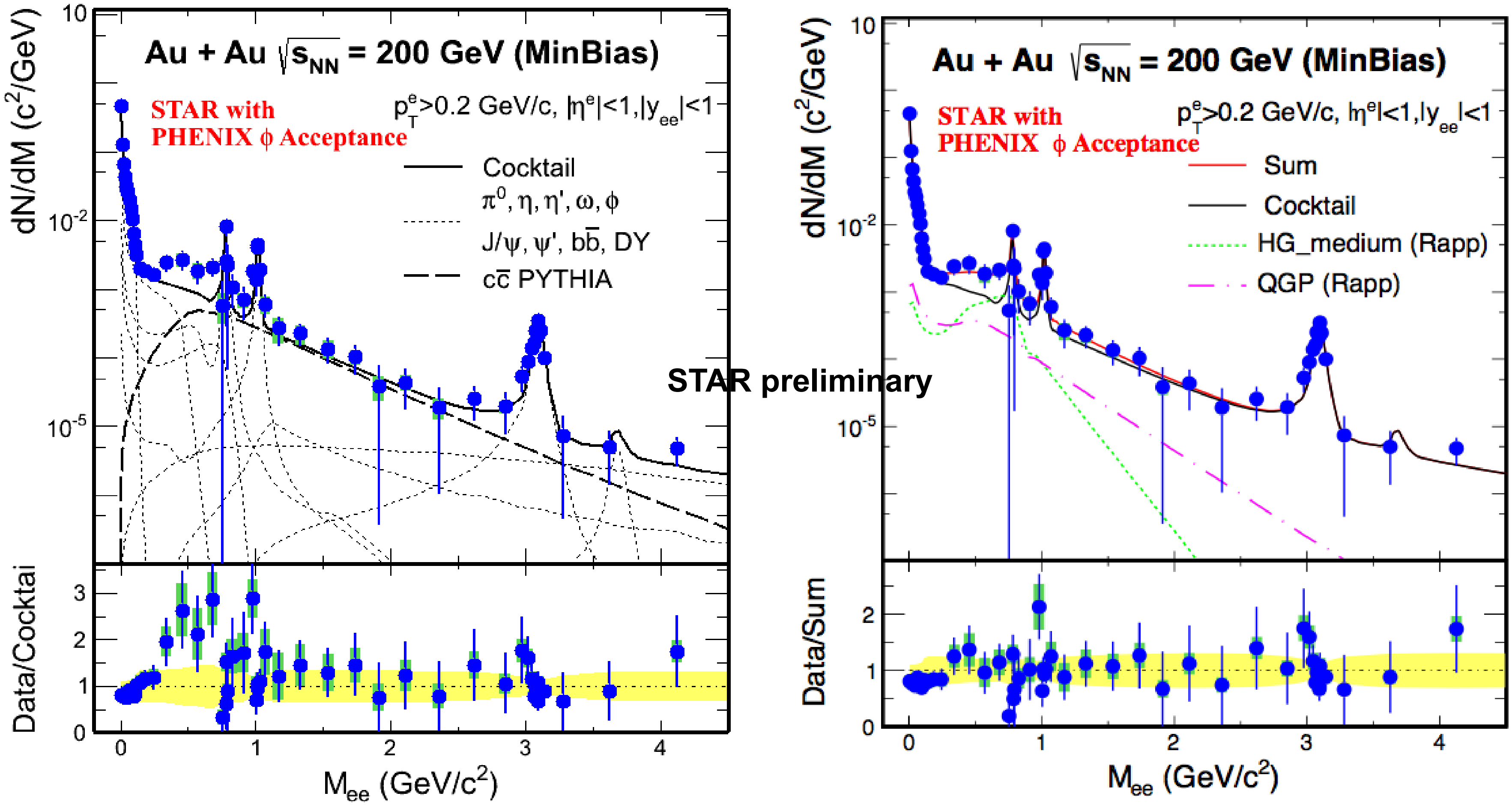
One arm covers : ϕ_{min} = *-3π/16 to* ϕ_{max} = *5π/16*

The other covers : ϕ_{min} = *11π/16 to* ϕ_{max} = *19π/16*

STAR in PHENIX φ acceptance

Compare with cocktail

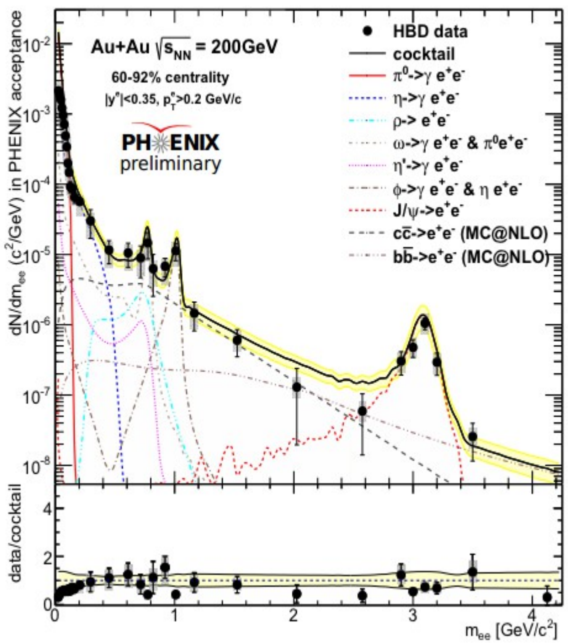
Compare with Rapp's model calculation



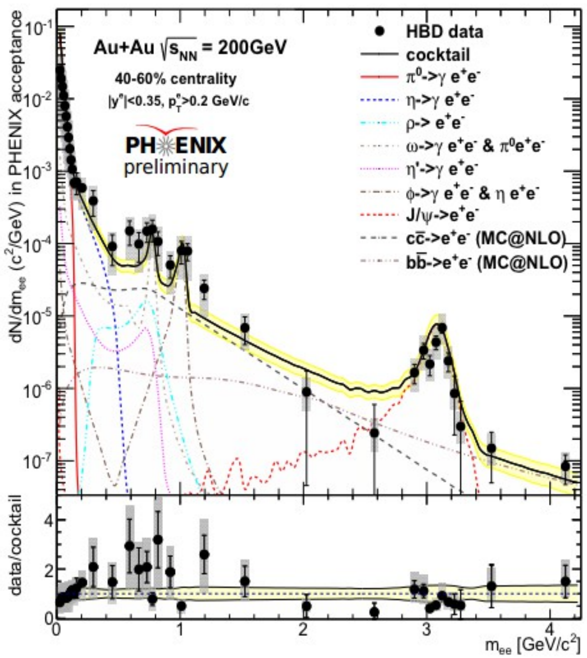
In PHENIX acceptance, the enhancement is about 2, consistent with the result from STAR's full acceptance and the ρ broadening model can explain the data.

Phenix with HBD

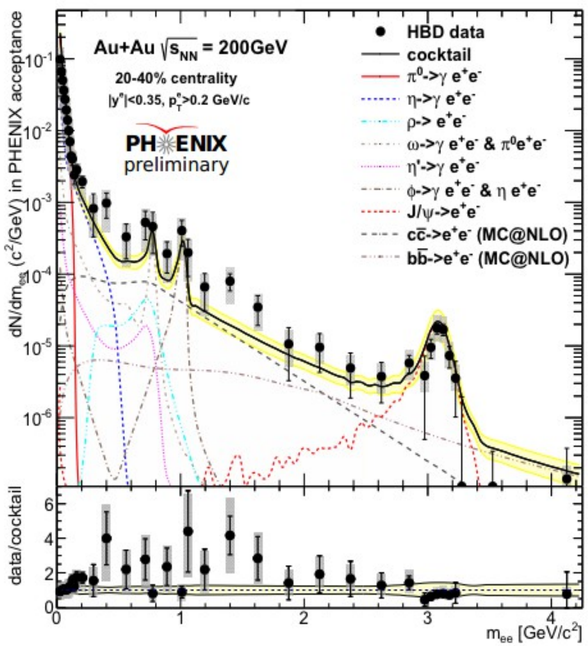
60%~92%



40%~60%

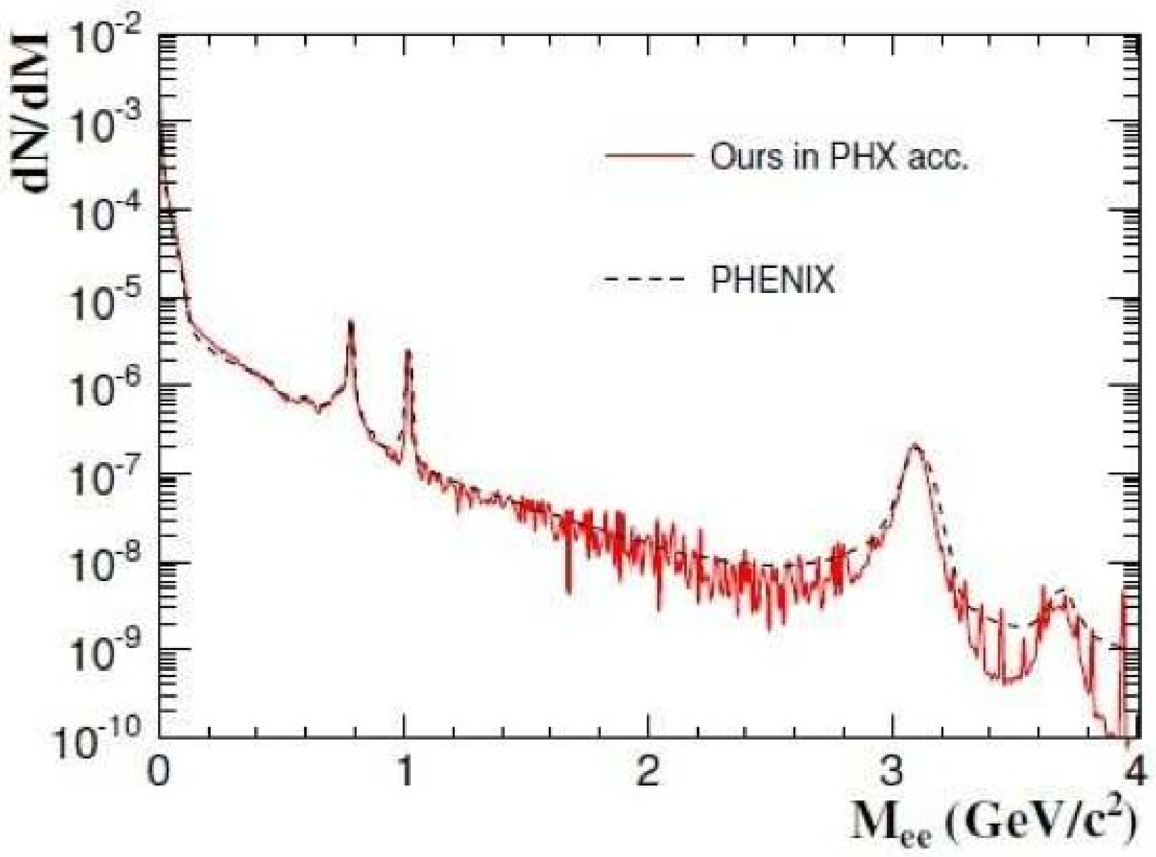


20%~40%

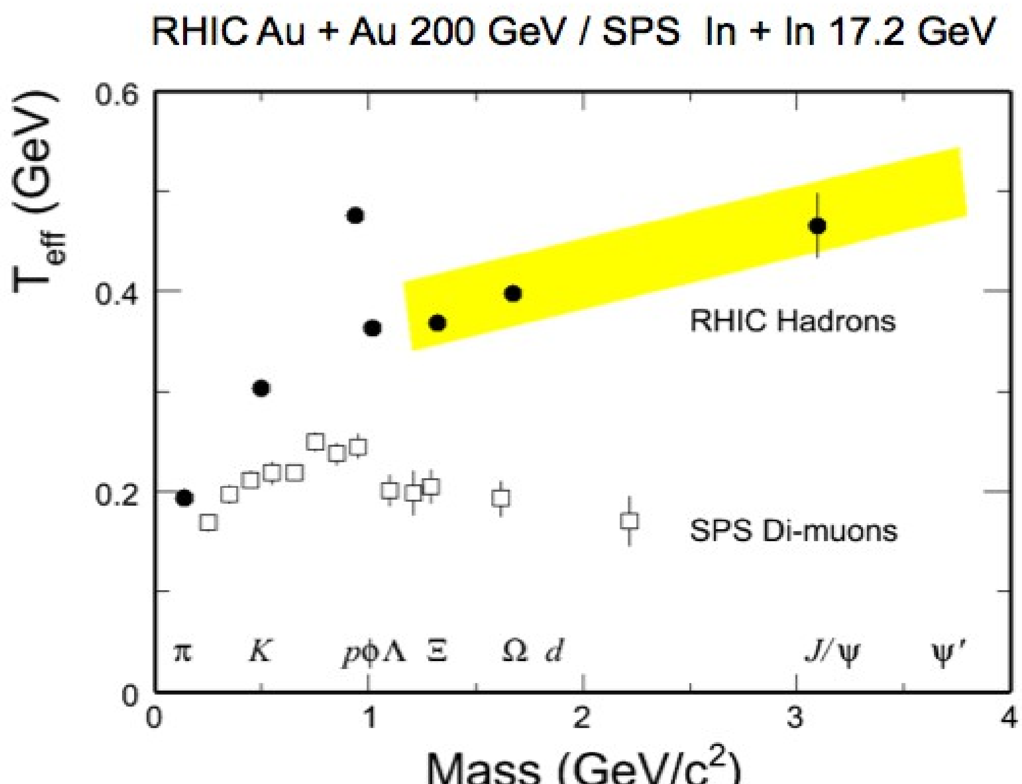


PHENIX, QM12 Preliminary results report in 20-40%, 40-60%, 60-92%.

Cocktail in Phenix acceptance



Motivation – thermal radiation



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

Different slope in m_T spectra in low and intermediate mass at SPS energy.
- m<1 GeV/c^2: hadronic contributions dominant.
- 1<m<3 GeV/c^2: partonic contributions dominant.

What about at RHIC energy?
Observables: production cross section vs (mass, p_T).
elliptic flow, polarization et al.