Thermal Photon and Dilepton Results from STAR

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for the STAR Collaboration

- Motivation
- STAR detector
- Physics results
  - Dielectron production results.
  - Direct photon results.
- Summary and Outlook

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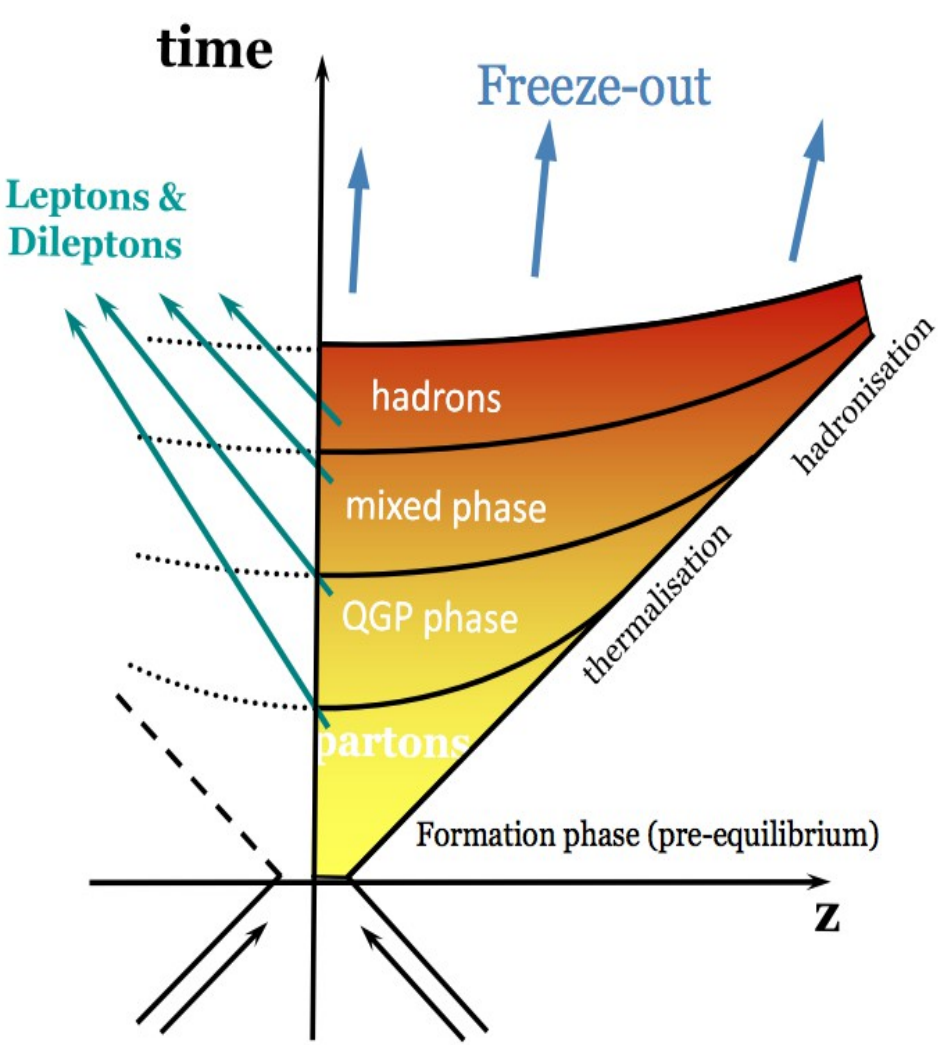
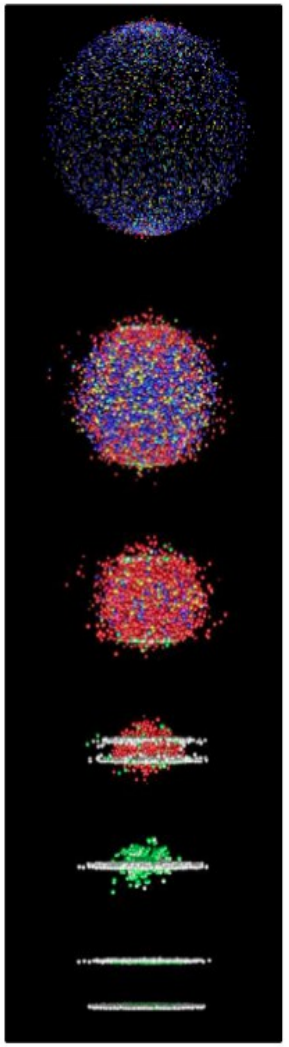
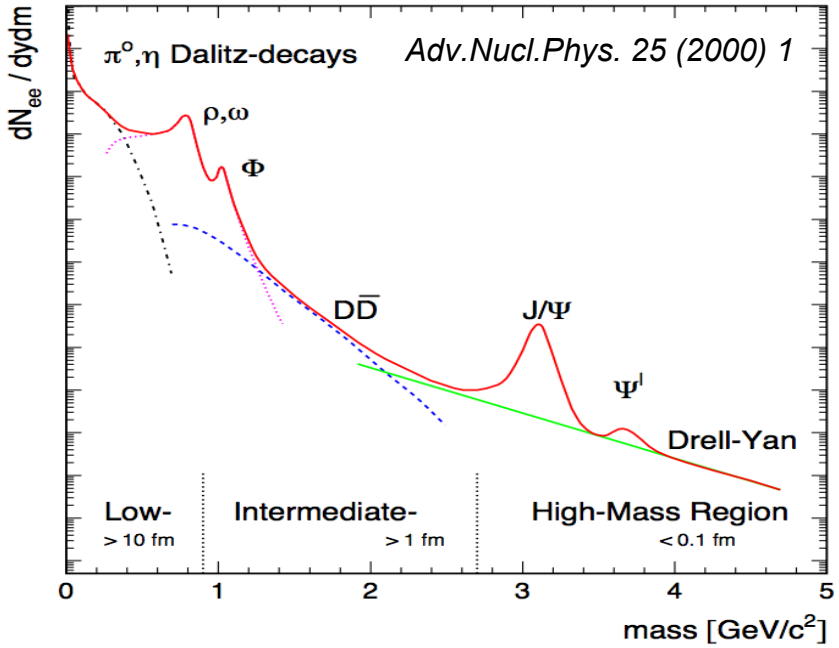
Dilepton in RHIC

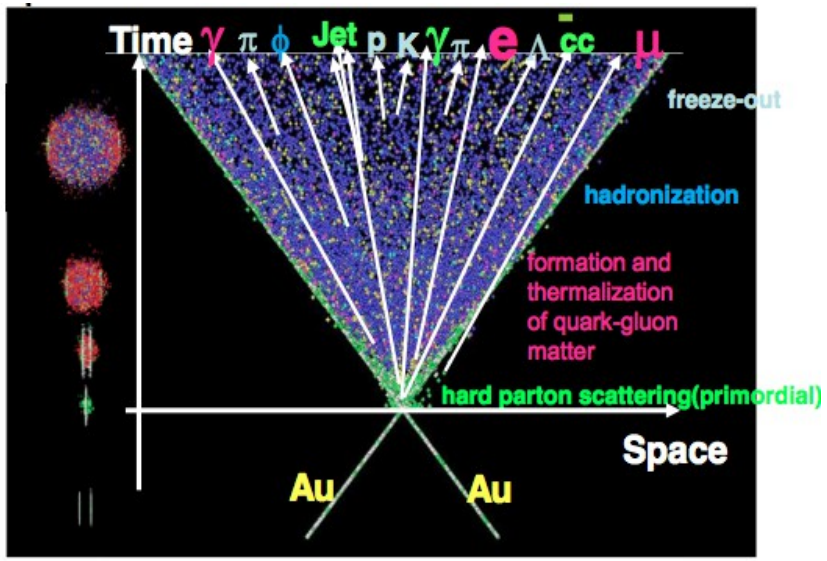
- **Dileptons – a bulk penetrating probe:**
  - Do not suffer strong interaction, penetrating the medium without final state effect.
  - Produced in all stages of the system evolution.
  - Provide direct information of medium.
  - Additional kinematic information (mass vs p_T), sensitive to different dynamics.
- **Challenges:**
  - Production rate is low, especially in higher mass region (M_{ee}>1GeV/c^2).
  - Integrate over time and over many background sources.





Dilepton in RHIC





Interesting topics:

- **Low mass region (LMR):**
  in-medium modifications of vector meson.
  possible hint of chiral symmetry restoration.

- **Intermediate mass region (IMR):**
  QGP thermal radiation.
- semi-leptonic decays of correlated charm : possible charm de-correlation in Au+Au.

- **Direct photon:**
  - ➔ connect to dielectron through internal conversion.
  - ➔ high p_T photons (>5GeV/c) : initial hard scattering
  - ➔ low p_T photons (1-5GeV/c) : access QGP production

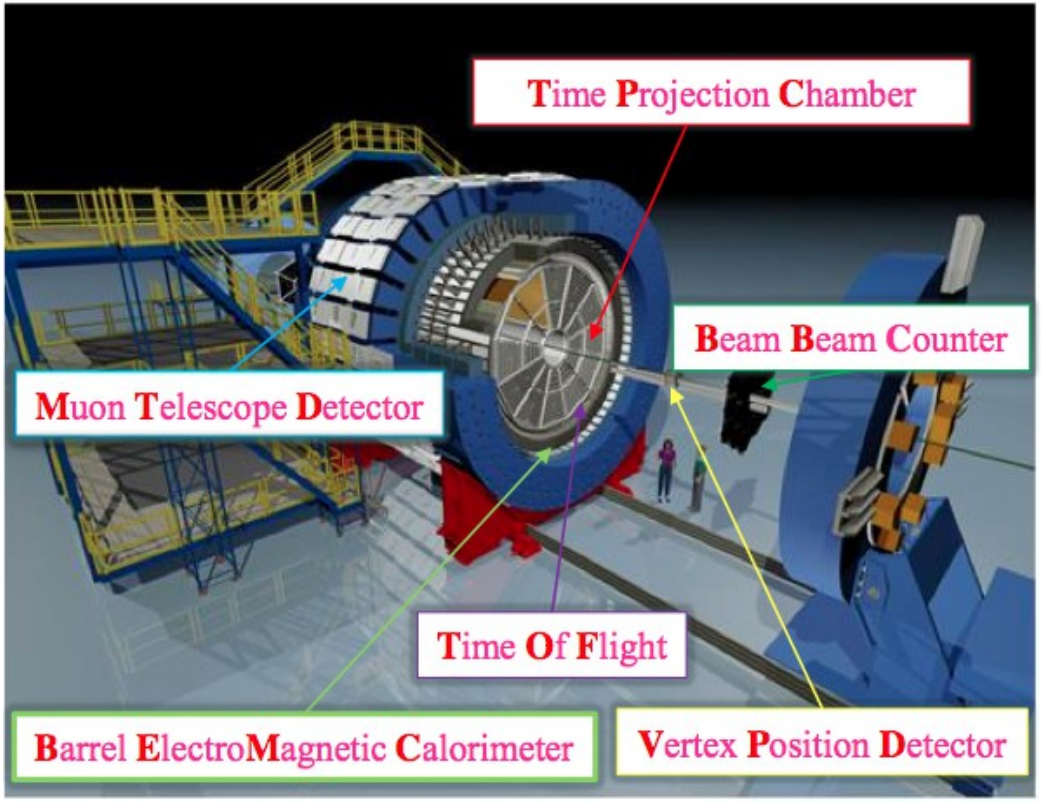
STAR detectors

Key detector used in this analysis:

- Time Projection Chamber:
  - ➔|η|<1, 0<Φ<2π
  - ➔Main tracking detector: track, momenta, ionization energy loss (dE/dx)

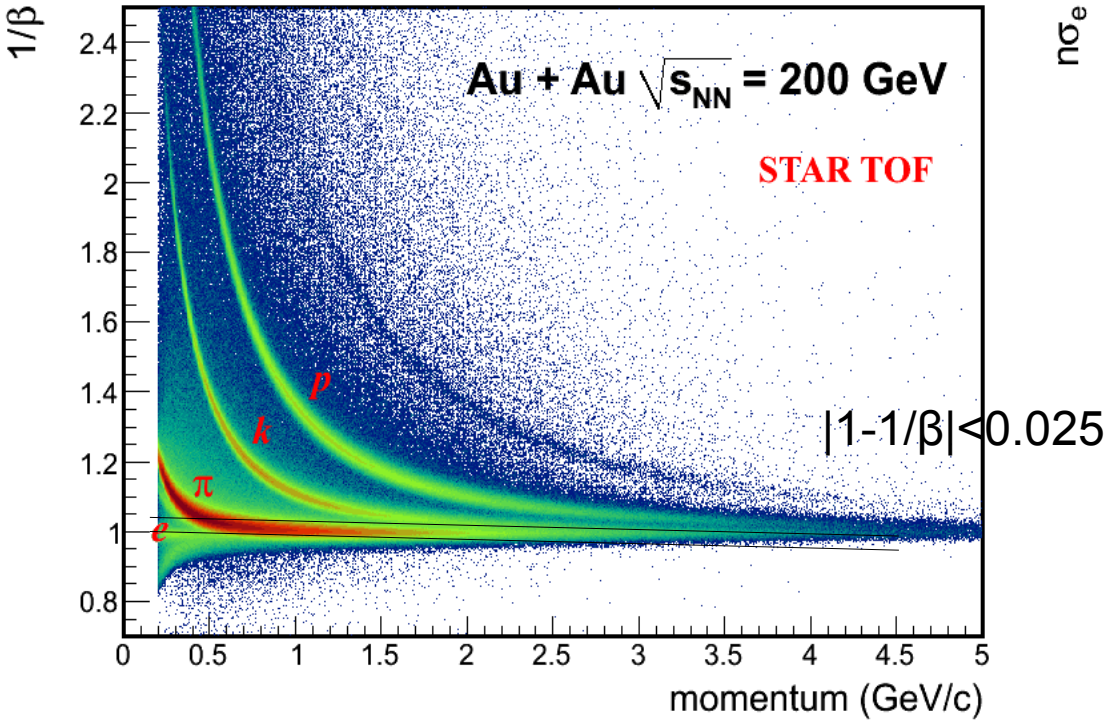
- Time Of Flight:
  - ➔|η|<0.9, 0<Φ<2π
  - ➔Intrinsic timing resolution ~ 75 ps
  - ➔Significant improvement for PID

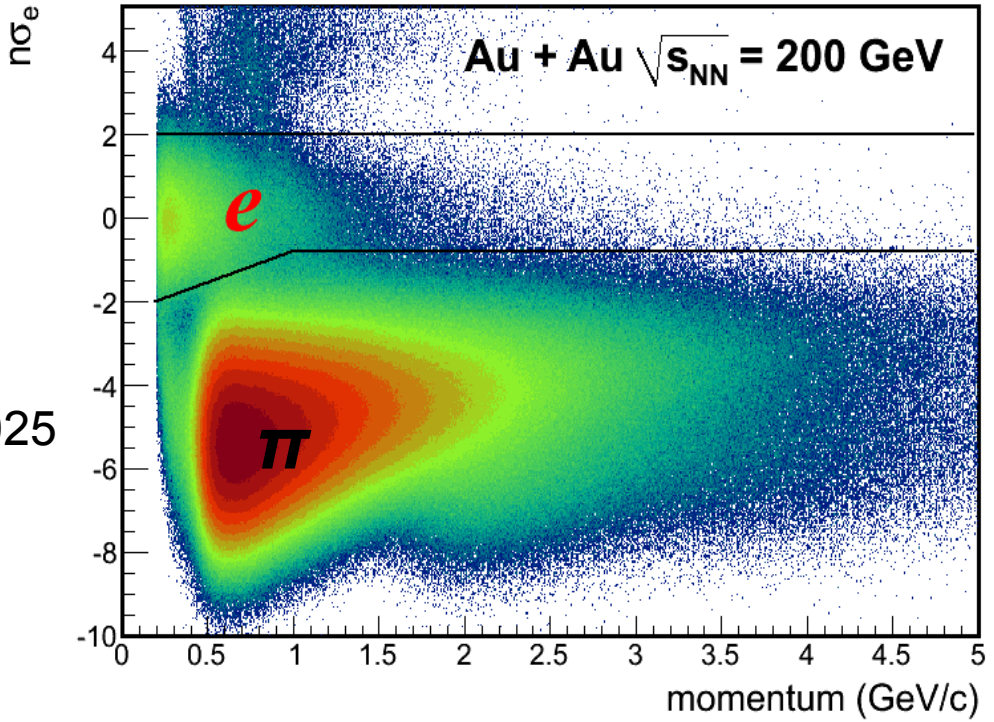
- Barrel Electro-Magnetic Calorimeter:
  - ➔|η|<1, 0<Φ<2π
  - ➔Trigger and measure high-p_T particles



Type	Year	Central	Min.Bias	EMC trigger (energy threshold 4.3GeV)
Au+Au 200GeV	2010	220M	240M	
	2011		490M	39M
p+p 200GeV	2012		375M	

Electron identification





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

$n\sigma_e$ normalized dE/dx

Collision system	Trigger	Momentum range	Purity
Au+Au 200GeV	Min.Bias	0.2 – 2.0 GeV/c	~95%
	Central	0.2 – 2.0 GeV/c	~93%
	EMC trigger	3.5 – 6.0 GeV/c	~80%
p+p 200GeV	Min.Bias	0.2 – 2.0 GeV/c	~98%

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

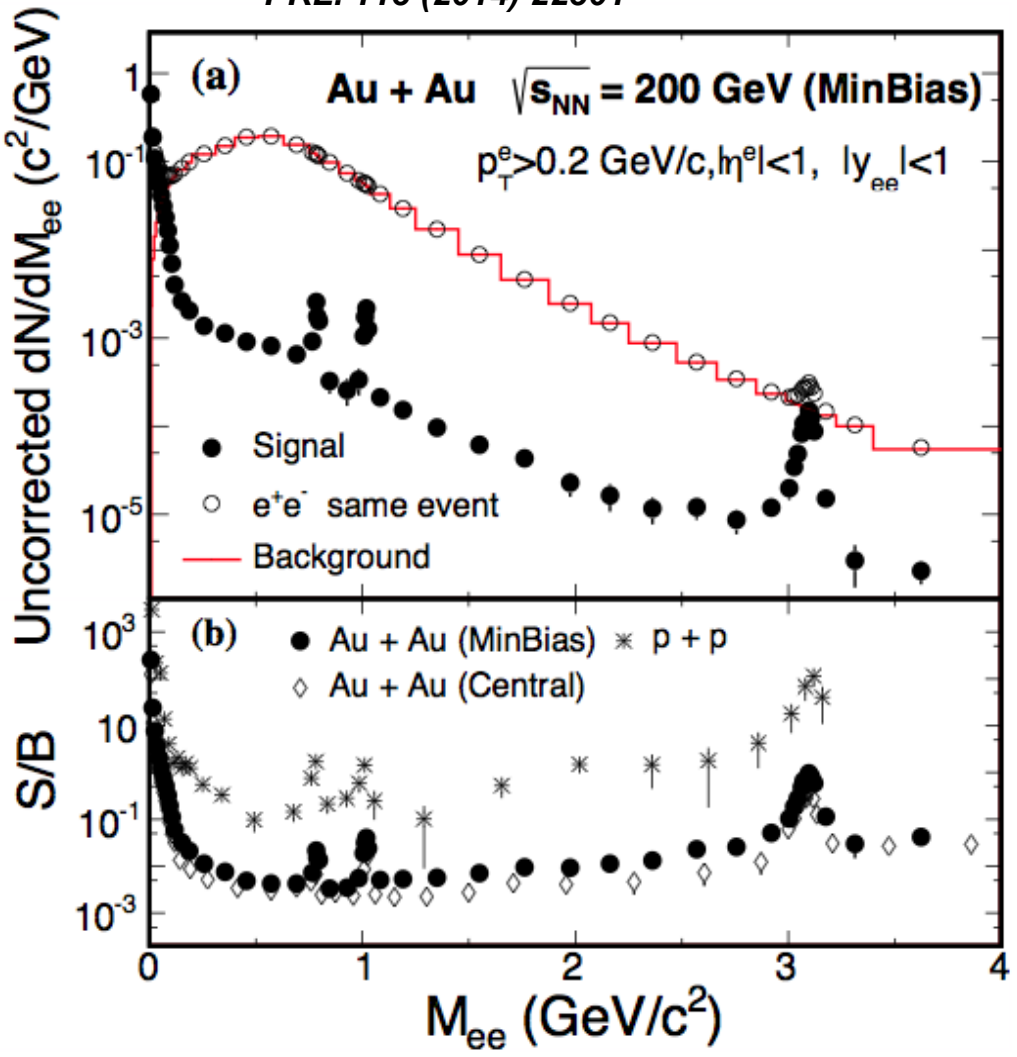
  b. Mass>0.75GeV/c²

  Mixed Event – normalized to Like Sign in mass region [1,2] GeV/c²

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

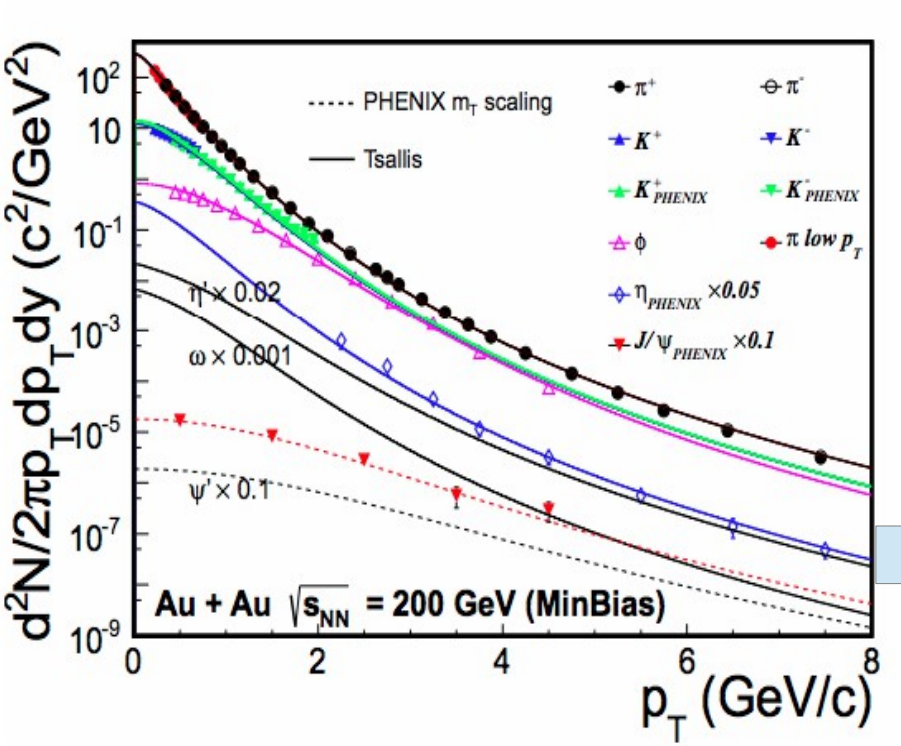
  ✗ *but can't reproduce correlated background*

PRL. 113 (2014) 22301

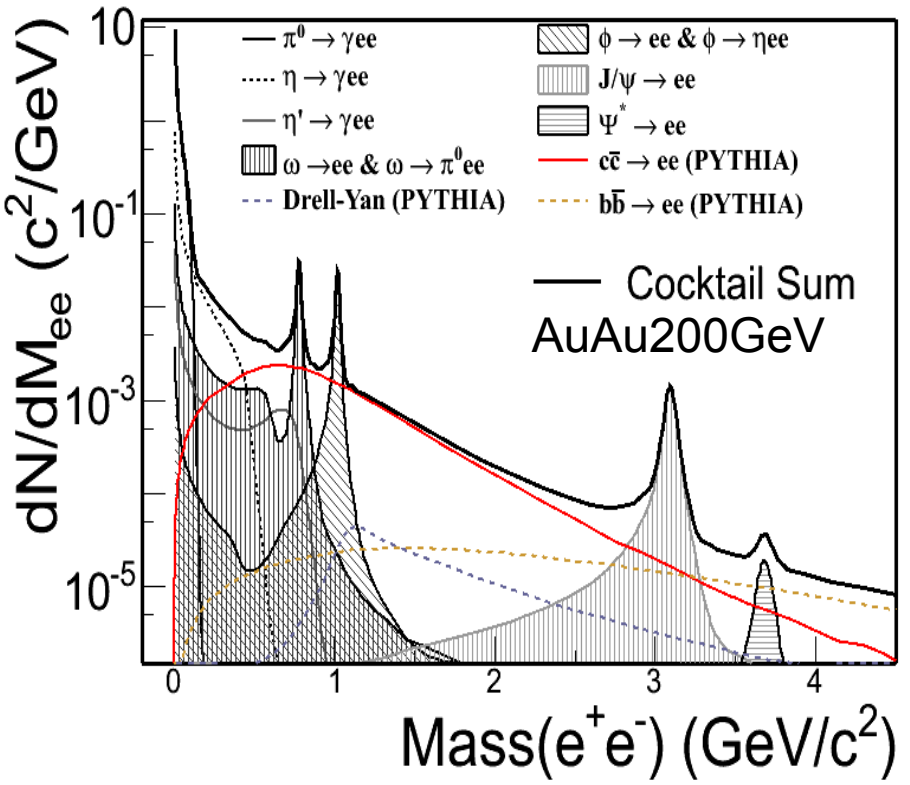


Cocktail simulation

Input p_T spectra



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



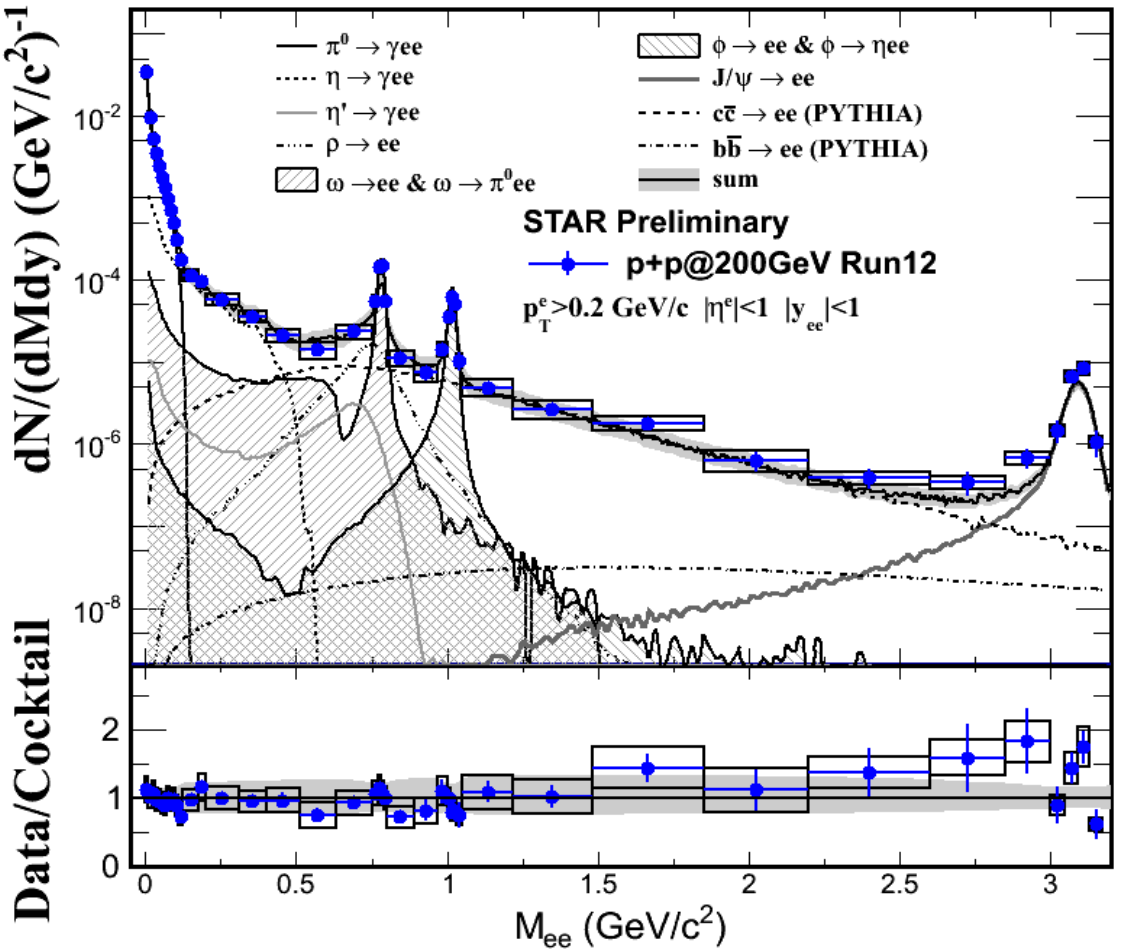
Data Points:

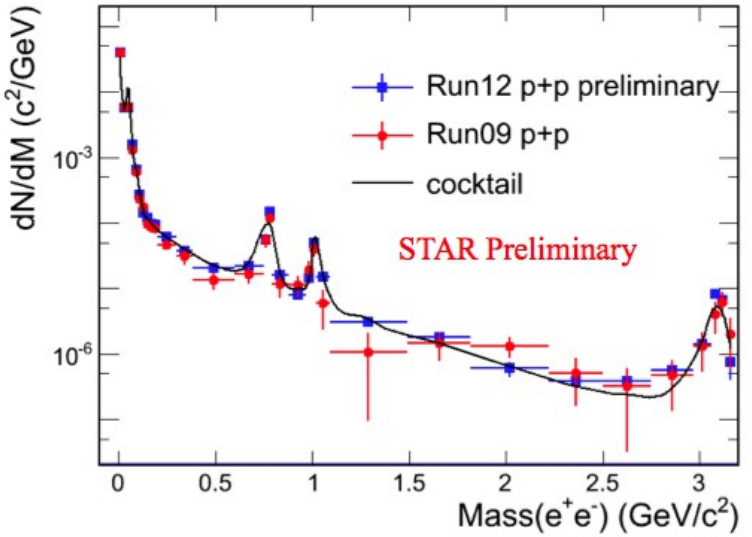
PHENIX Collaboration, Phys. Rev. C 81, 034911 (2010)
STAR Collaboration, Phys. Rev. Lett. 92, 112301 (2004)
STAR Collaboration, Phys. Lett. B 612, 181 (2005).
STAR Collaboration, Phys. Rev. Lett. 97, 152301 (2006)

TBW Fit:

Z. Tang et al. Phys. Rev. C 79, 051901 (2009).

pp 200GeV result from year 2012



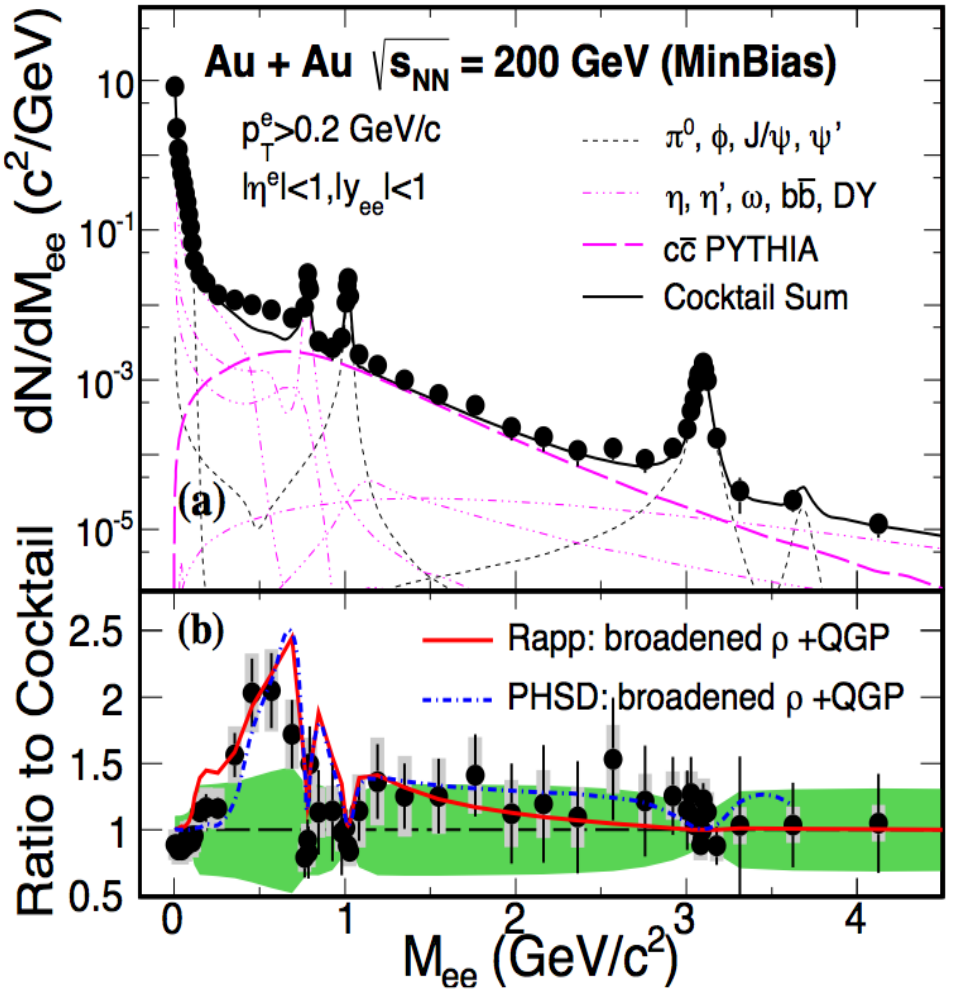


Cocktail is taken from ***[STAR, Phys. Rev. C 86, 024906 (2012)]*** with charm cross section changed to 0.797+0.3/-0.36mb ***[STAR, Phys. Rev. D. 86, 072013(2012)]***

Run9 p+p: [STAR, Phys.Rev.C. 86, 24906 (2012)]

Within uncertainty, the cocktail simulation reproduces the data very well.
Greatly improved statistics ~ 7 times more than year 2009.

AuAu 200GeV results



STAR, PRL. 113 (2014) 22301

Enhancement w.r.t cocktail at ρ like region(0.30-0.76 GeV/c^2):

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:

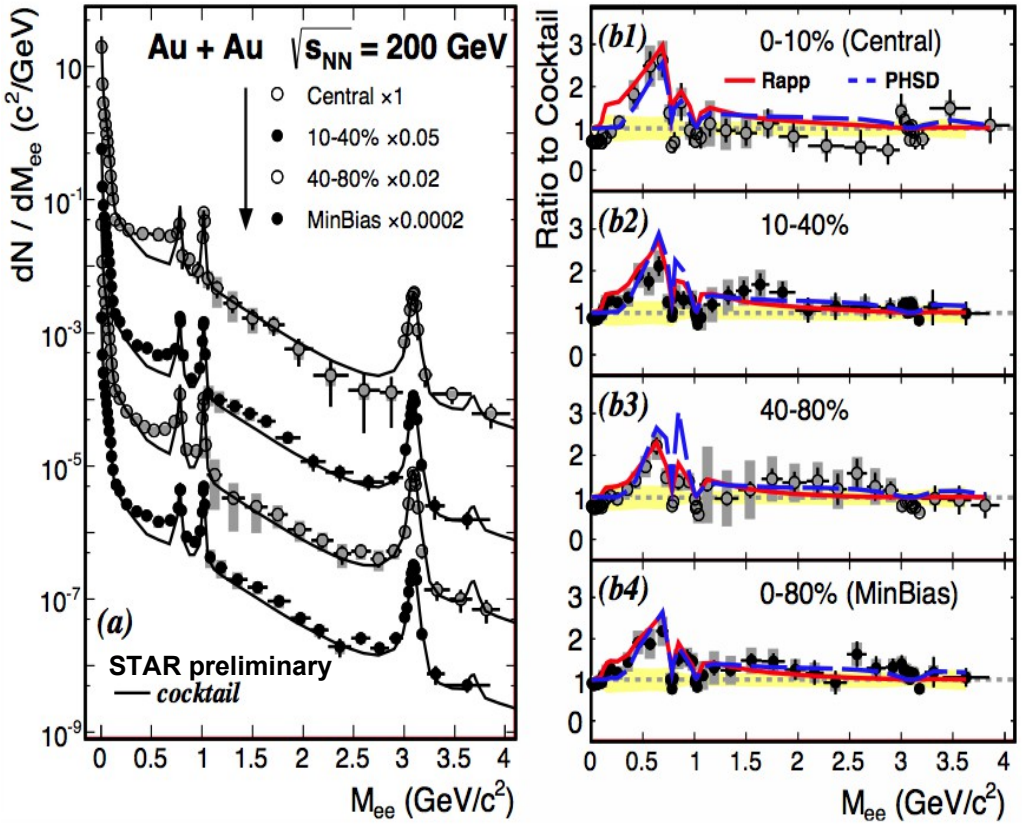
1) Model I by Rapp et al. is an effective many-body model.[*R. Rapp, PoS CPOD2013, 008 (2013)*]

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

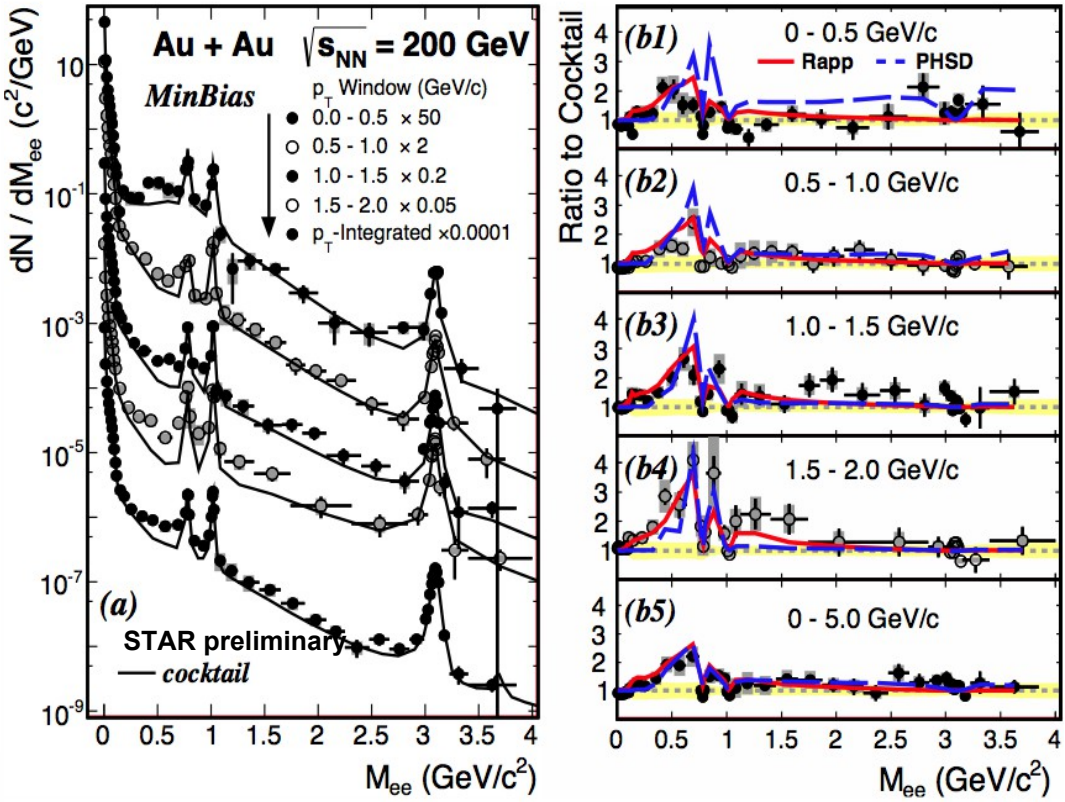
Both models show good agreement with data within uncertainty.

Centrality and p_T dependence

Centrality dependence



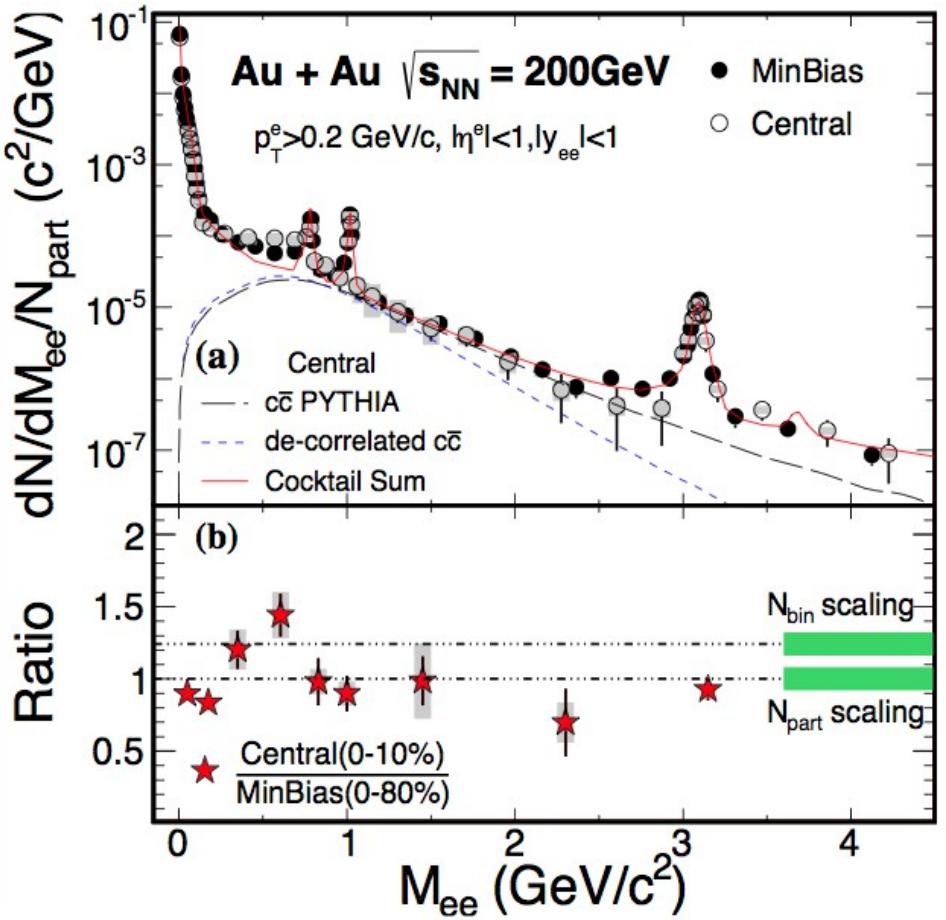
p_T dependence



STAR, PRL. 113 (2014) 22301, arXiv:1504.01317

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

Possible charm de-correlation

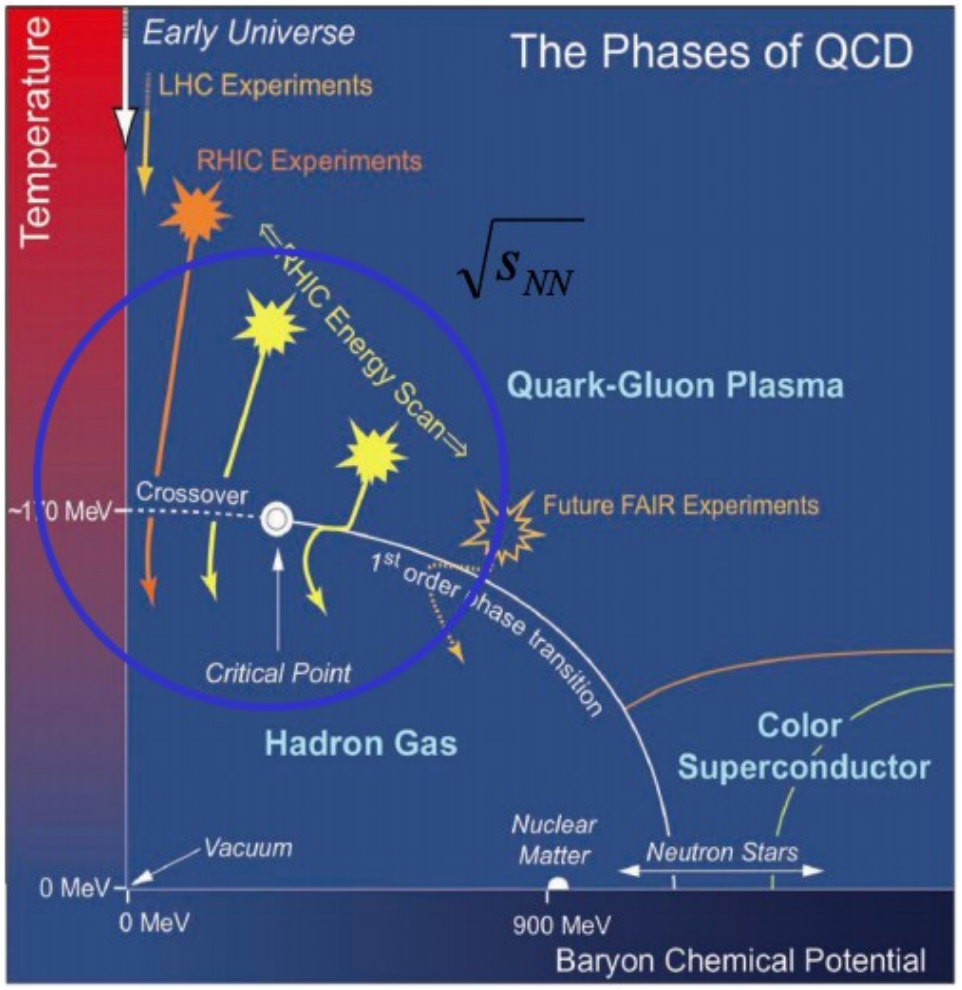


STAR, PRL. 113 (2014) 22301,
arXiv: 1504.01317

Ratio(*Central/MinBias*) shows 2.0σ deviation from the N_{bin} scaling in 1.8<M_{ee}<2.8GeV/c^2.

Possible charm de-correlation in Au+Au collision or other source from thermal radiation?

Beam Energy Scan at RHIC



NSAC Long Range Plan 2007

- ✔**Turn-off of the sQGP signature**
- ✔**Search for the phase boundary.**
- ✔**Search for the critical point.**

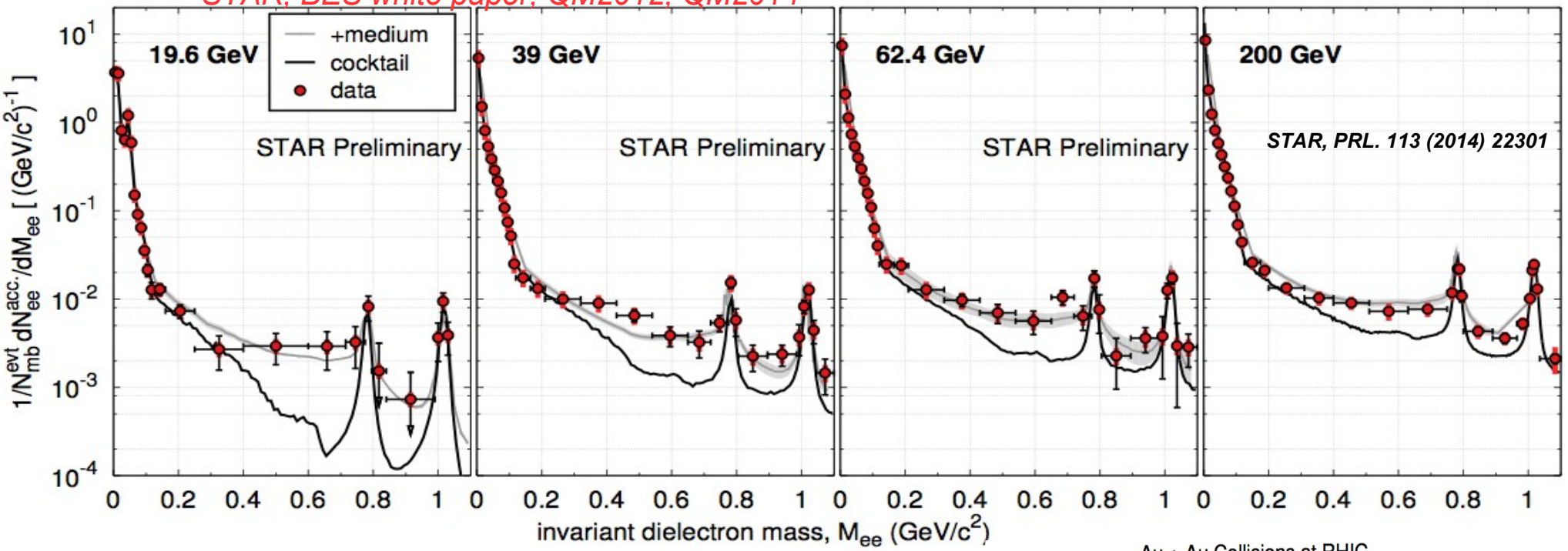
Dielectron production in BES:

LMR: in medium modification of vector meson. Study the chiral property of the medium.

IMR: Searching for the onset of QGP thermal radiation.

Dielectron from RHIC BES-I

STAR, BES white paper, QM2012, QM2014

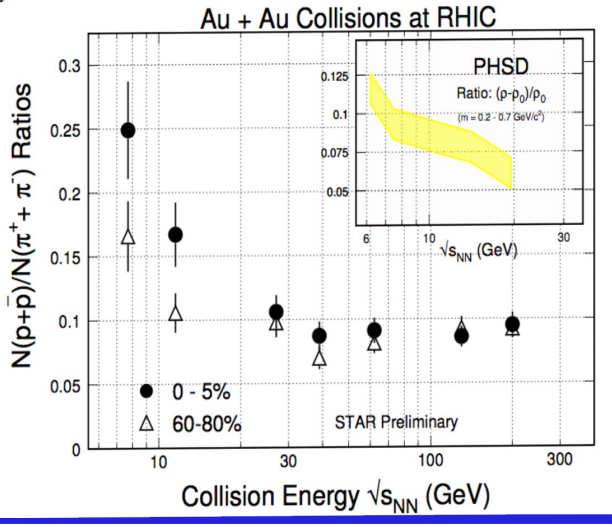


Model calculations† robustly describe the data from 200GeV to 20 GeV:

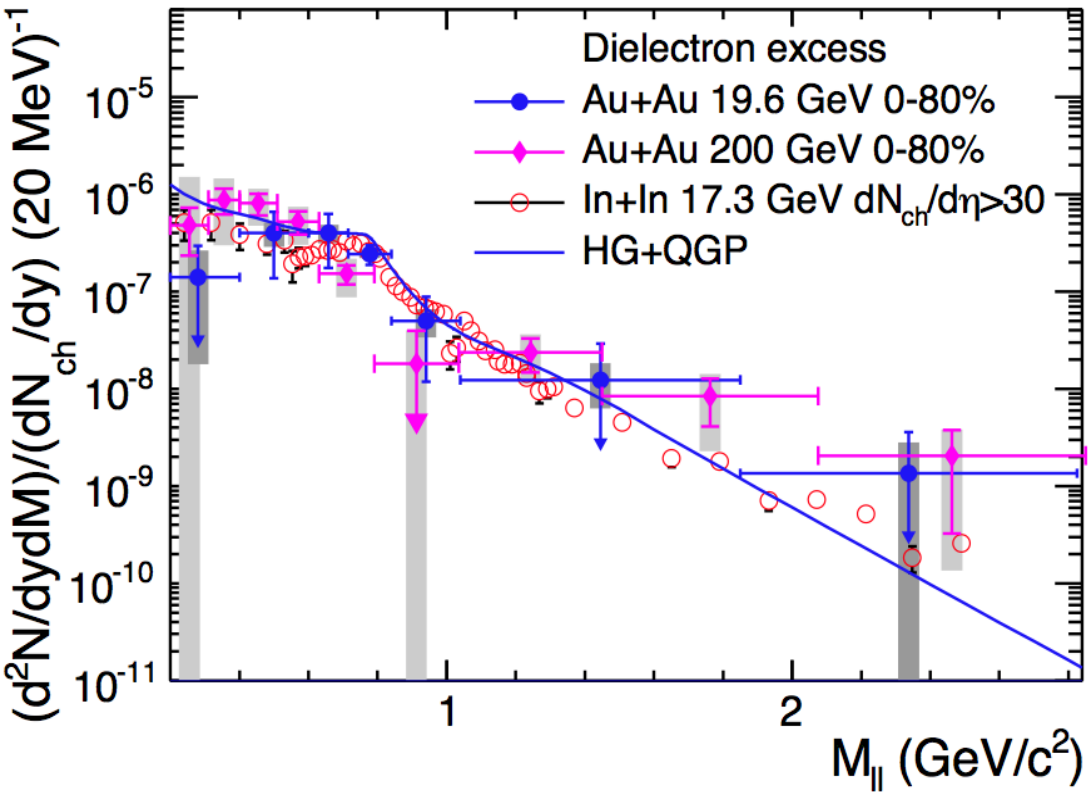
– model calculations by Rapp, based on in-media broadening of ρ spectra function, expected to depend on total baryon density.

– almost constant baryon density from 20-200GeV.

†**Model:** Rapp & Wambach, priv. communication;
Adv. Nucl.Phys. 25, 1 (2000) Phys. Rept. 363, 85 (2002)



Acceptance corrected excess spectra



arXiv:1501.05341

Spectra is corrected for STAR detector acceptance.

Normalized to mid-rapdity dN_{ch}/dy.

NA60 Data:

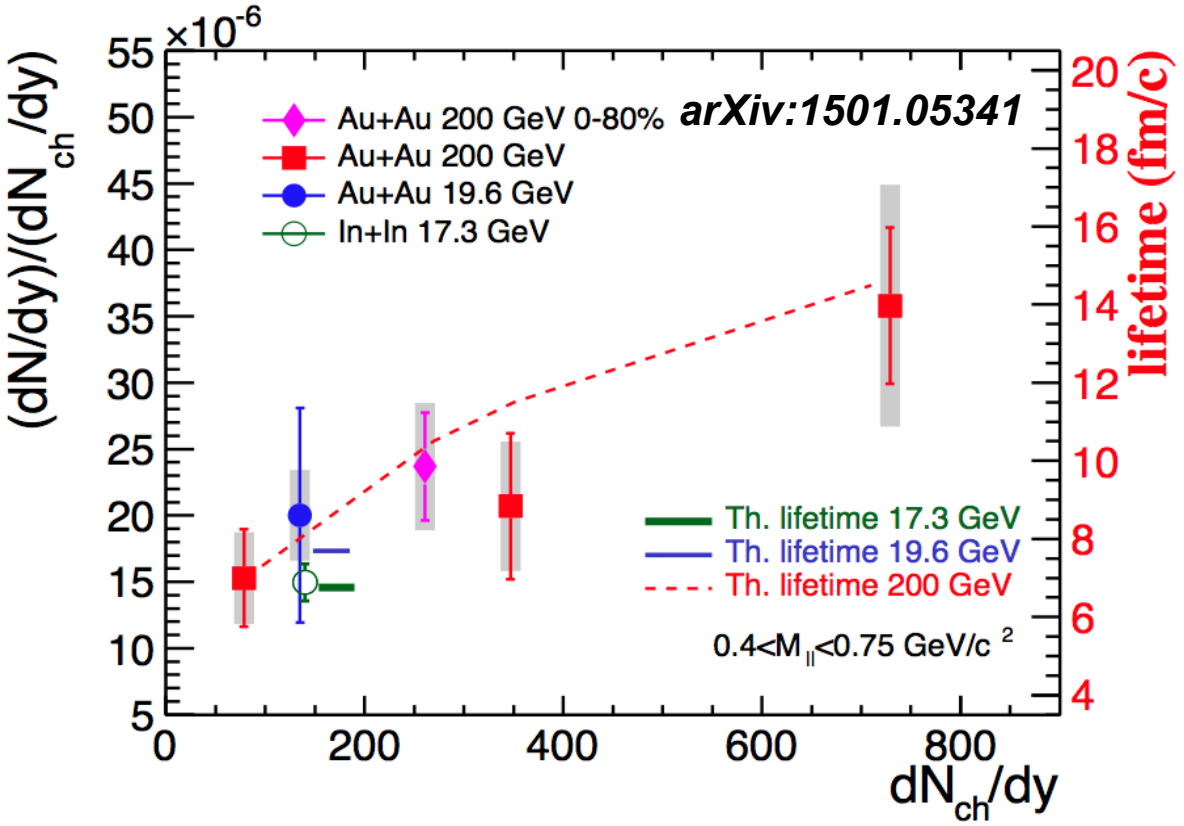
R. Arnaldi et al., PRL. 96, 162302 (2006);
R. Arnaldi et al., PRL. 100, 022302 (2008);
R. Arnaldi et al., EPJ. C 59, 607 (2009).

Blue line Rapp's model calculation, including a broadened spectral function and QGP thermal radiation

Excess spectra:

- The model calculation from R. Rapp is consistent with acceptance corrected excess spectra of AuAu 19.6 GeV.

Low mass excess



Integrated excess yield within mass region 0.4~0.75 GeV/c^2 :

- **AuAu 19.6 GeV:**
  - ➔consistent with In+In 17.3 GeV.
- **AuAu 200 GeV:**
  - ➔centrality dependence on the excess yield.
  - ➔higher excess yield in central collision than In+In 17.3 GeVs indicates a longer life time of medium.

Dielectron from internal conversion

- Relation between real photon yield and the associated e+e- pairs:

$$\frac{d^2N_{ee}}{dM} = \frac{2\alpha}{3\pi}\frac{L(M)}{M}S(M,q)dN_\gamma \qquad L(M) = \sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right) \qquad S(M,q) = \frac{dN_{\gamma^*}}{dN_\gamma}$$

S~1 @ p_T >> M, M>>m_e

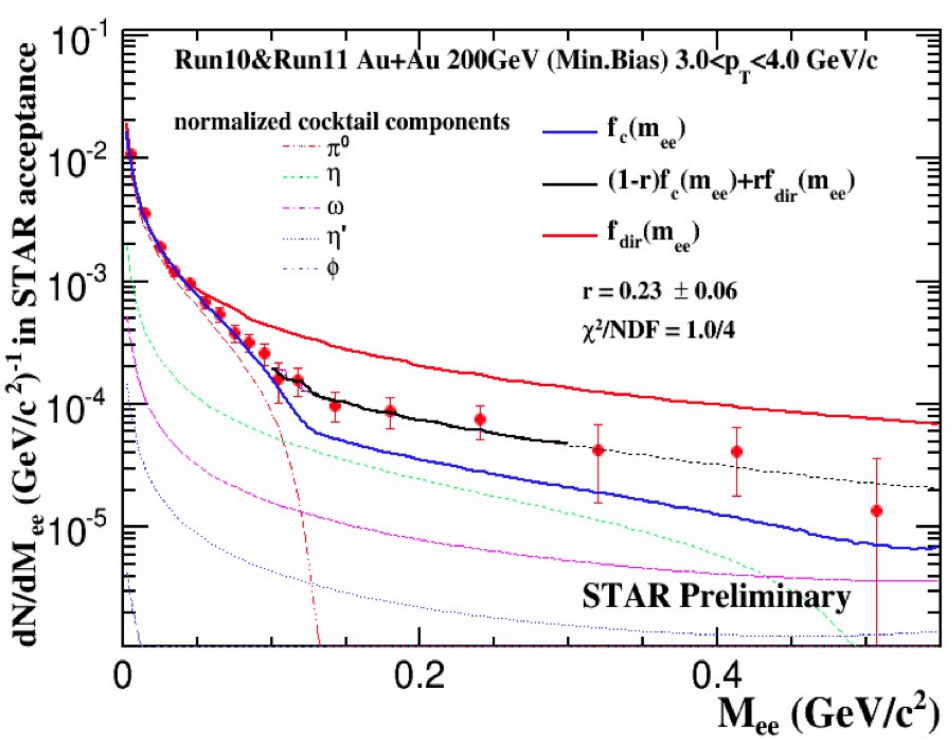
- Two component fit in mass region 0.1~0.3 GeV/c^2:

$$(1-r)f_c + r f_{dir}$$

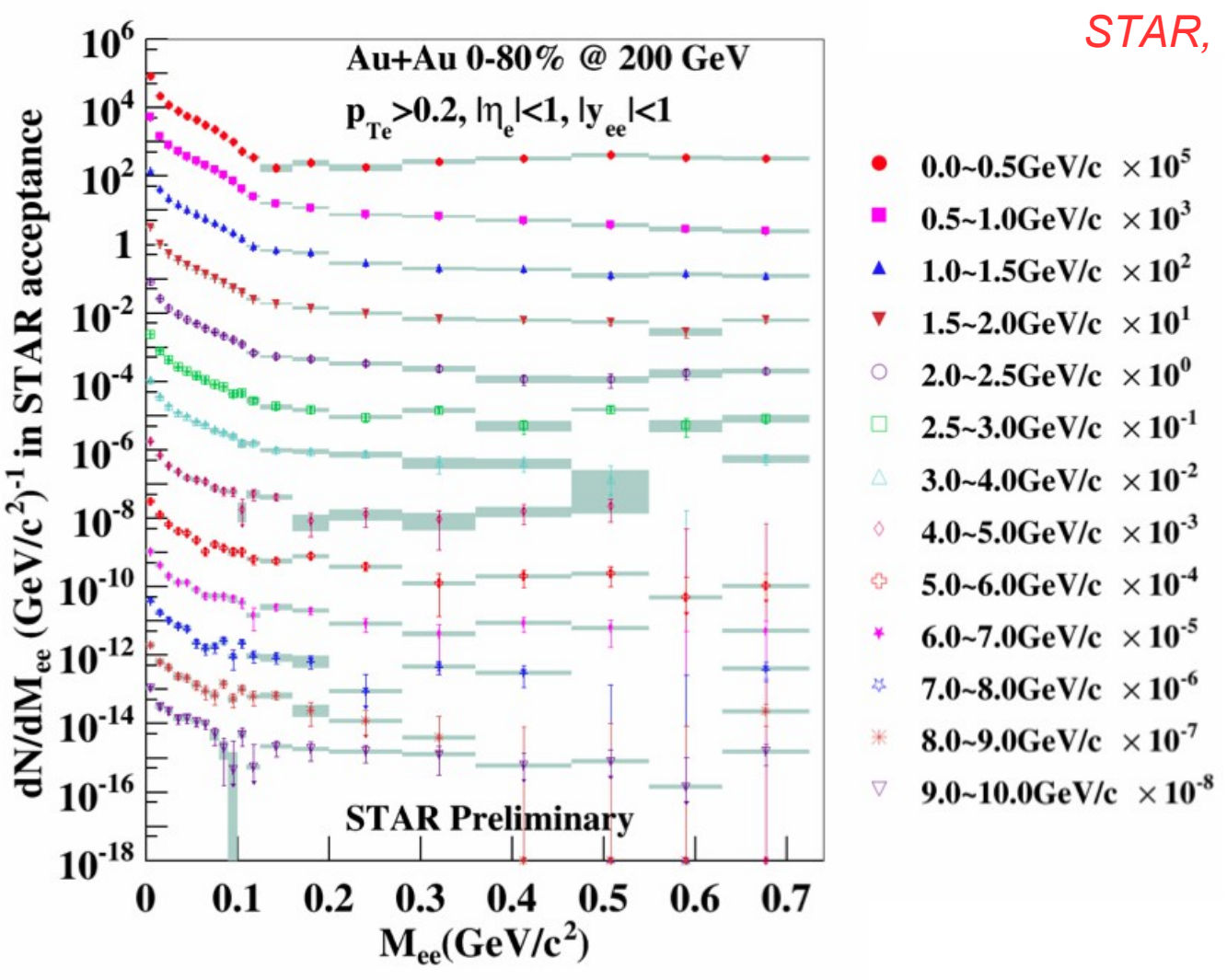
➔ f_c *:* cocktail normalized to 0~30 MeV/c^2

➔ f_{dir} *:* direct virtual photon component normalized to 0~30 MeV/c^2.

➔ r : ratio of the yield of direct virtual photon over the yield of inclusive photon



Low mass dielectron continuum

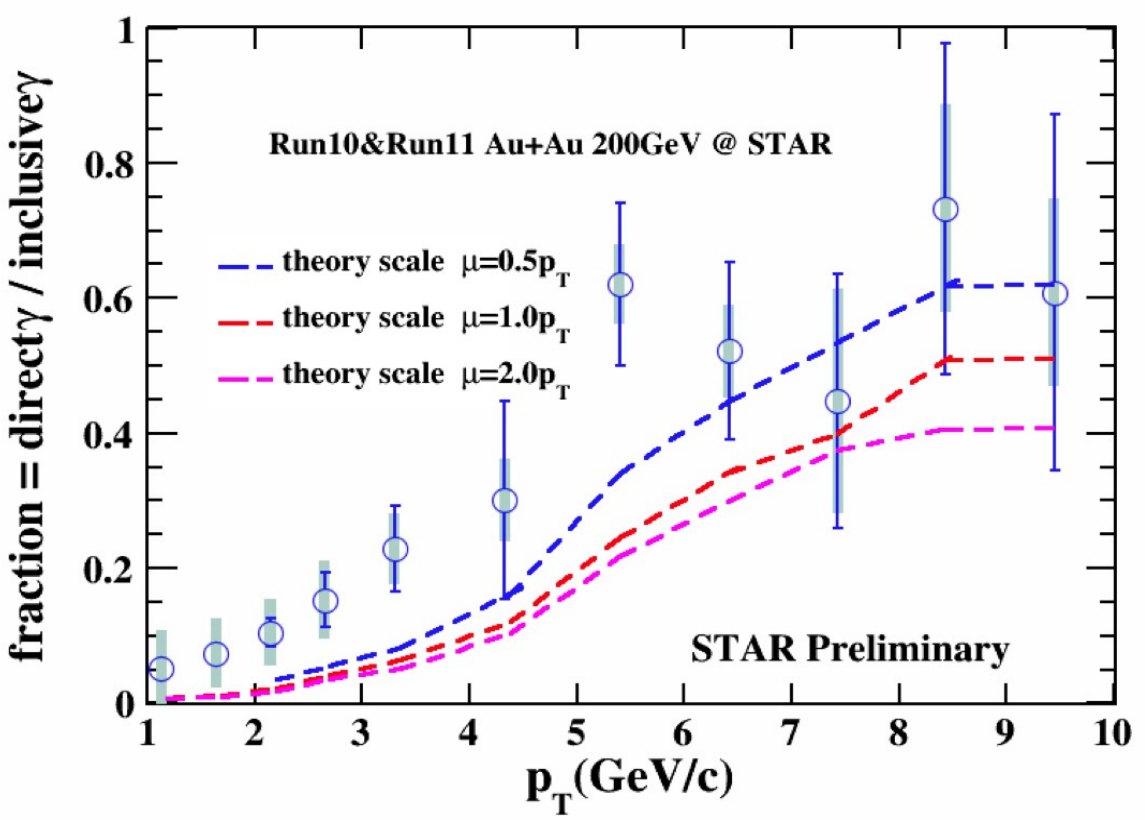


STAR, QM2014

- *0-5 GeV/c*
  Run10+Run11 MB data
- *5-10 GeV/c*
  Run11 EMC triggered data

Fraction of direct virtual photon

STAR, QM2014



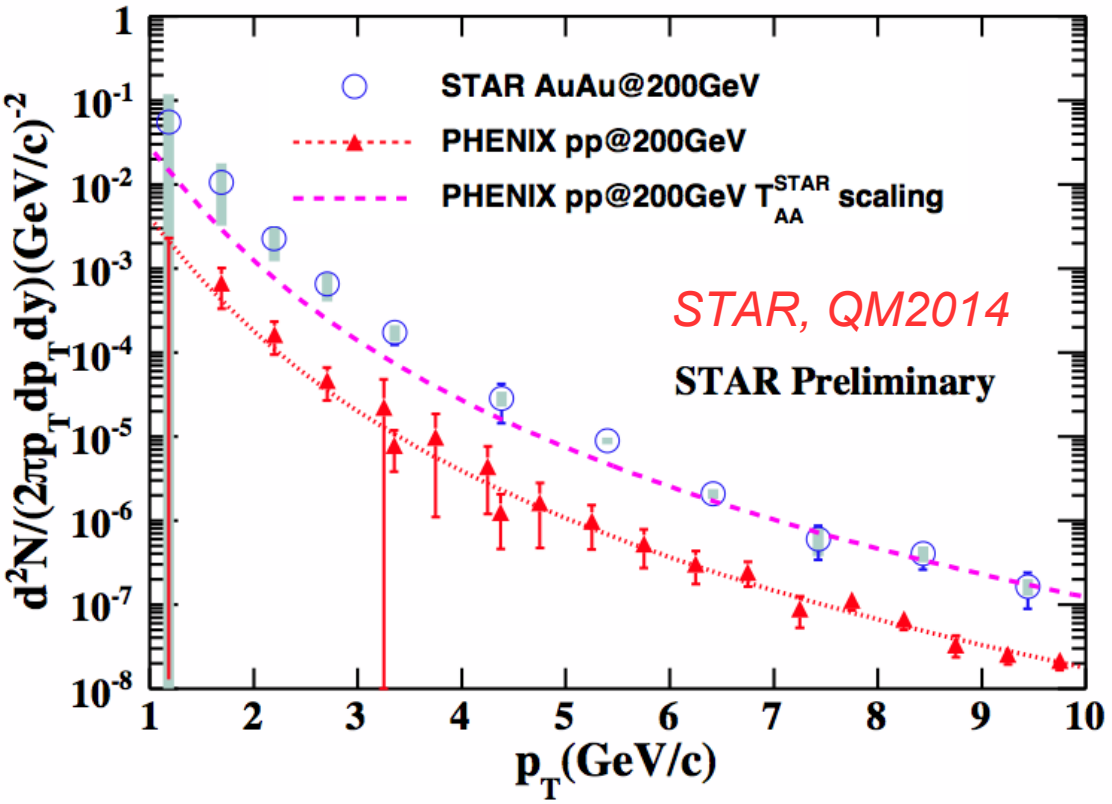
The curves represent NLO pQCD prediction:

$$\frac{T_{AA} d\sigma_{\gamma}^{NLO}(p_T)}{dN_{\gamma}^{inclusive}(p_T)}$$

L. E. Gordon and W. Vogelsang, Phys. Rev. D 48, 3136 (1993).
PHENIX Collaboration, Phys.Rev.L 98, 012002 (2007).
PHENIX Collaboration, Phys.Rev.L 104,132301(2010).

Compare to the p+p reference, an excess is observed up to 4GeV/c.

Direct virtual photon invariant yield

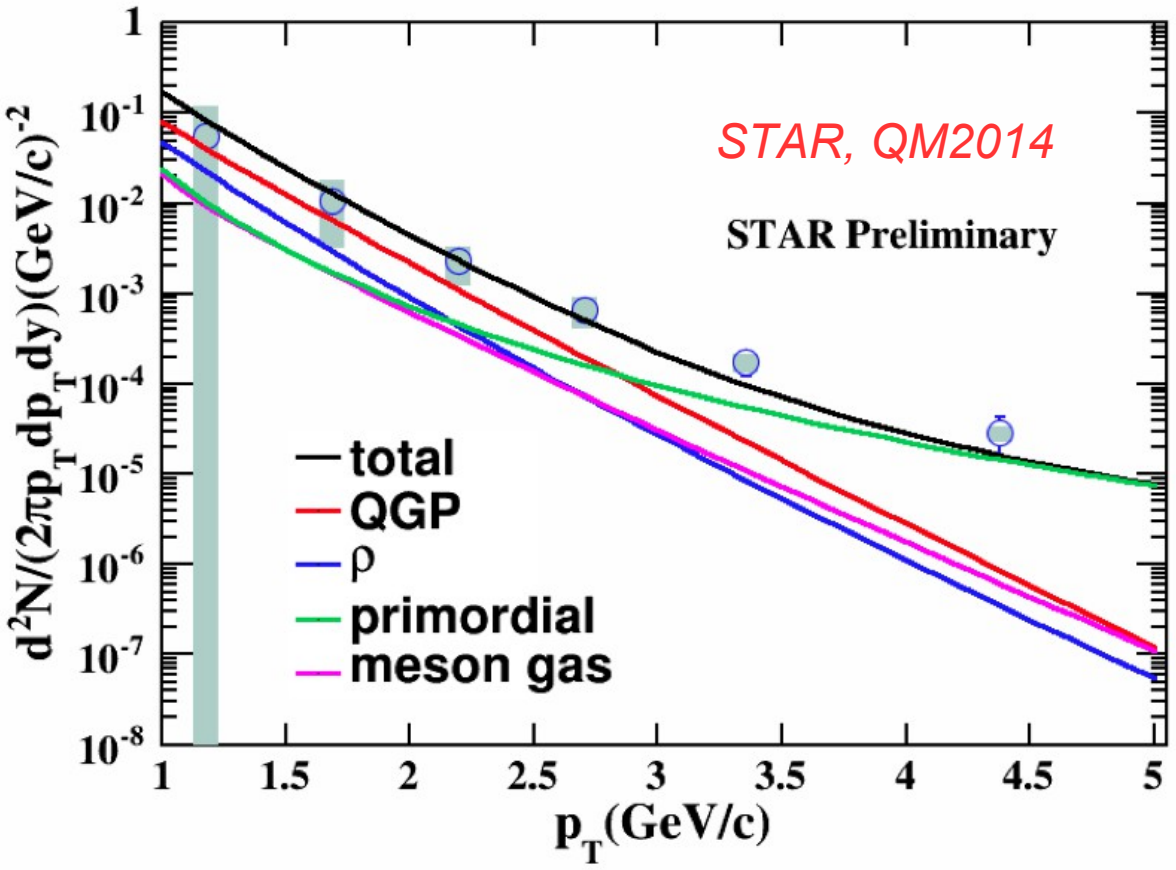


Data are compared with T_{AA} scaled function fit to PHENIX p+p data.

PHENIX data ref:
[A. Adare et al. Phys.Rev.C.81:034911, (2010)]
[S.S. Adler et al. Phys.Rev.Lett., 98:012002, (2007)]

- In high p_T region (5~10 GeV/c):
  - consistent with T_{AA} scaled function fit to PHENIX p+p data.
- In low p_T region:
  - an excess is observed in p_T range 2~4 GeV/c.

Low p_T excess



†from private communication with R. Rapp for Min.Bias.

0-20%: initial temperature ~320MeV at 0.36fm/c, fireball life time ~10fm/c.

[Van Hees, Gale, and Rapp, Phys. Rev. C 84, 054906]

Rapp's model prediction†:

- Including *QGP, ρ, meson gas, and primordial production contributions.*
- Well describing the low p_T excess in our data within uncertainty.

Summary

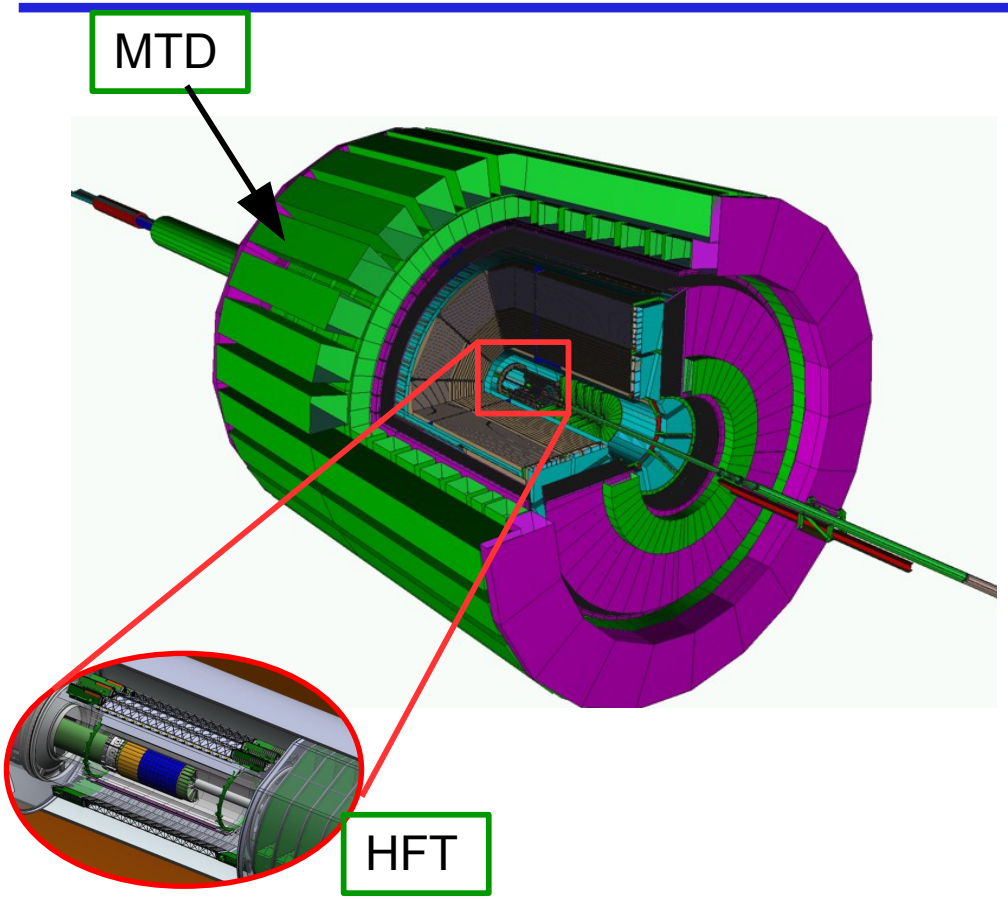
➢ Dielectron production :

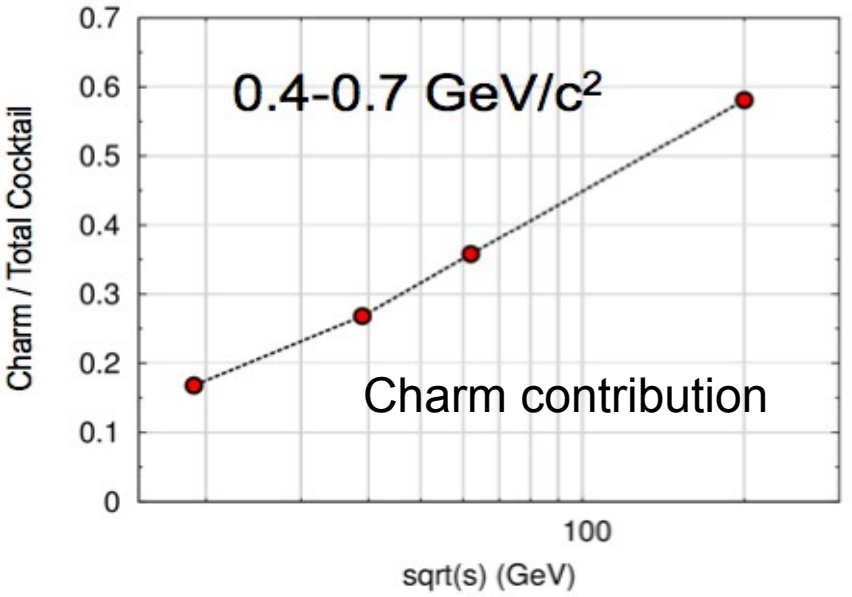
- ➔ A clear excess is observed in LMR from 200 GeV to 19.6 GeV.
- ➔ The excess yields (in mass range 0.4~0,75 GeV/c^2) show centrality dependence in 200 GeV Au+Au collisions.
- ➔ Within uncertainties, broadening of ρ model calculations can explain the excess in data from 200 GeV down to 19.6 GeV at RHIC.
- ➔ Comparing to In+In 17.3 GeV, higher excess yield in LMR at 200 GeV central Au+Au collisions indicates a longer life time of the medium.

➢ Direct photon production :

- ➔ An excess is observed in (p_T range 2~4 GeV/c) when compared to p+p reference and the invariant yield is consistent with model prediction.
- ➔ For p_T range 5~10 GeV/c, the invariant yield follows a T_{AA} scaled p+p results.

Outlook – Measure correlated charms





STAR Upgrade HFT+MTD :

Understand the correlated charm.

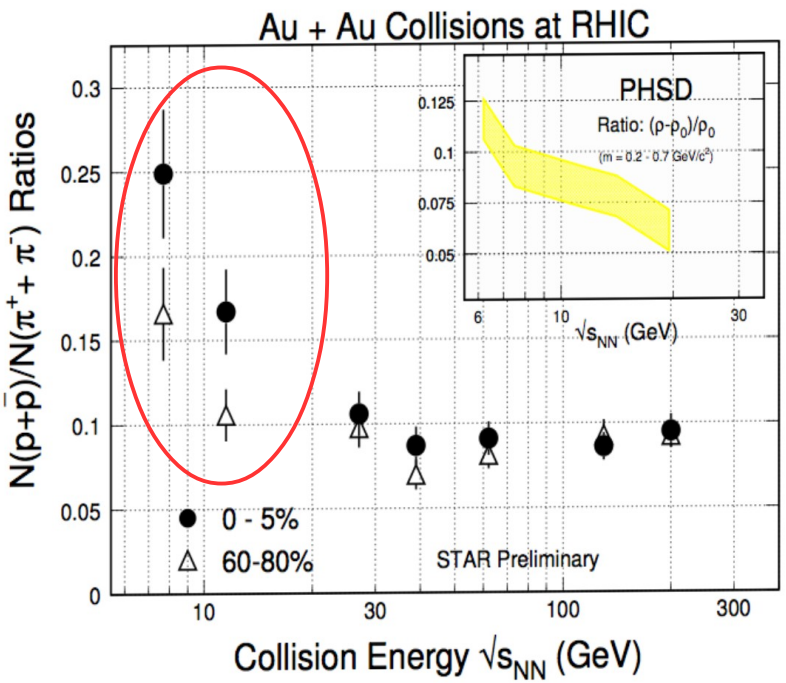
Clear the way to access the thermal radiation.

- **Heave Flavor Tracker - topologically reconstructs D mesons from hadronic decays and identifies electrons from charm decays.**
- **Muon Telescope Detector - measurement of e-μ correlation – clean to correlated charm.**

Outlook - RHIC BES-II

BES Phase 2 (2018+):

- 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.



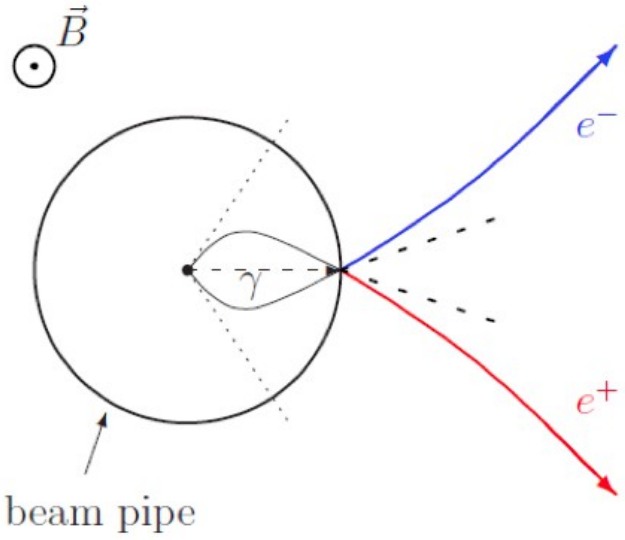
Estimation for event statistics needed:

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

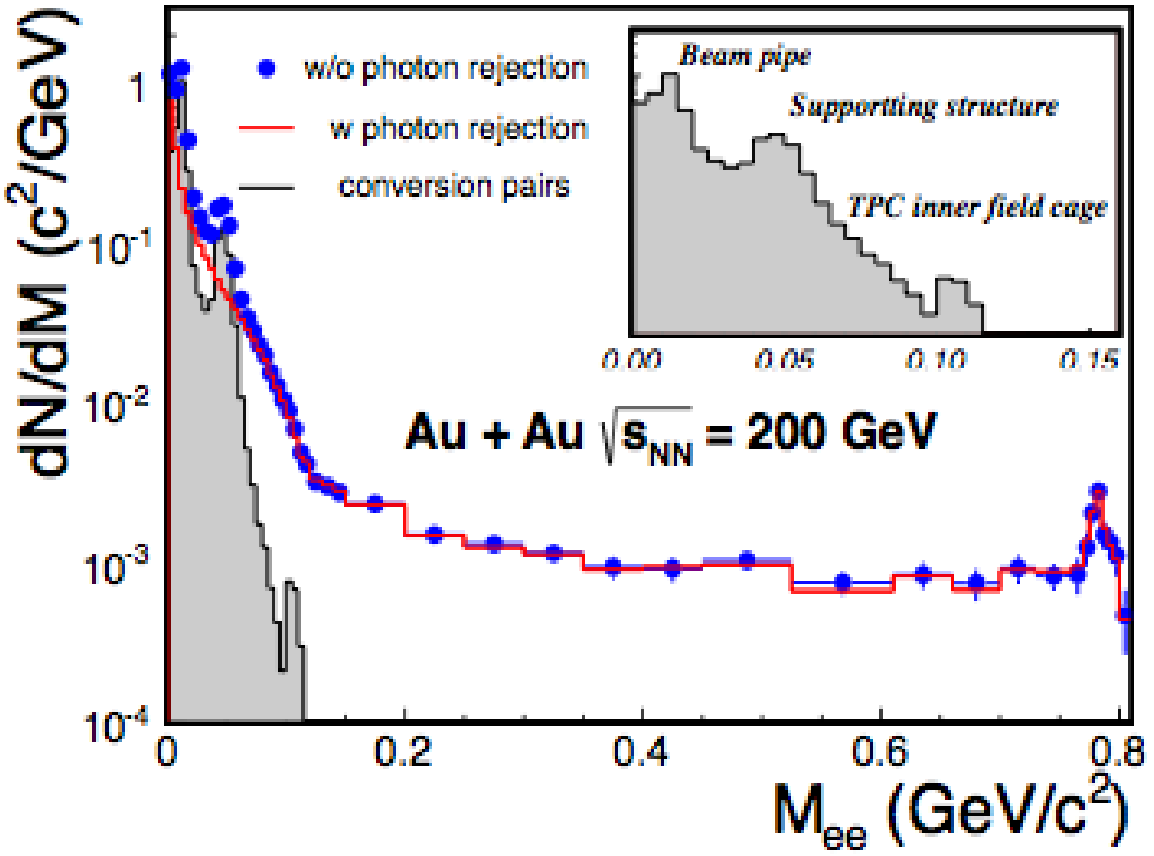
Thank you !!!

Backup

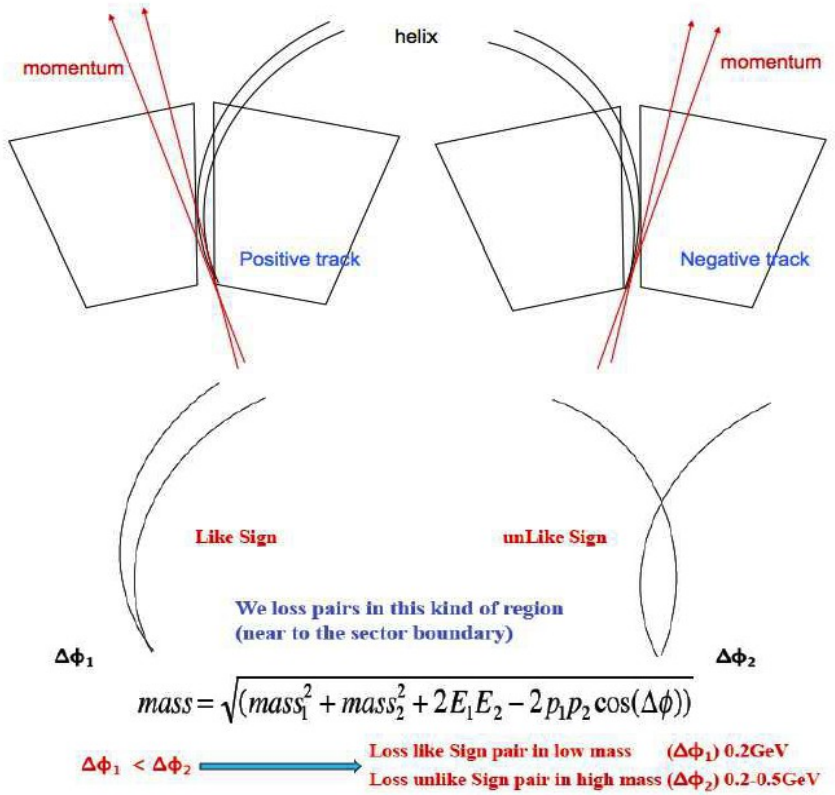
Photon conversion

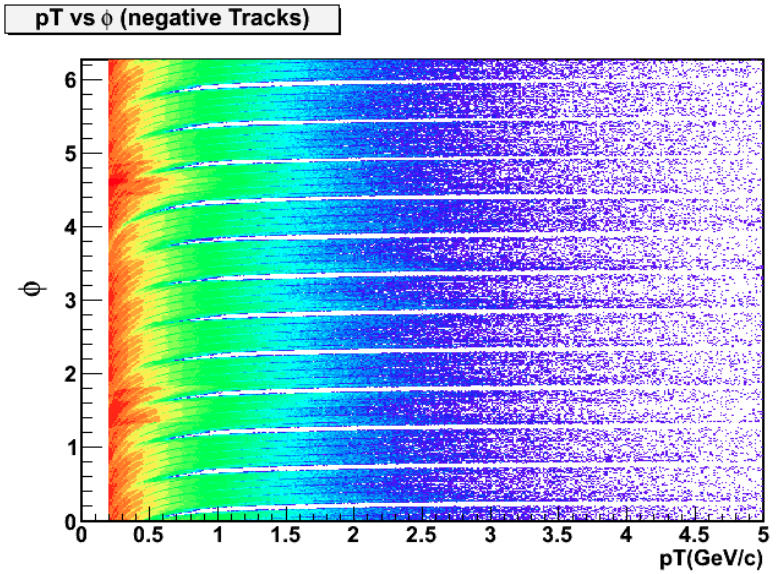


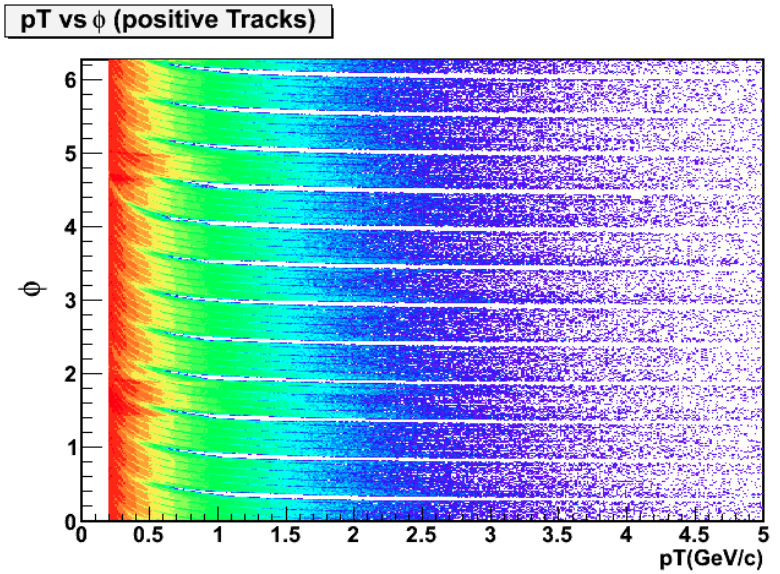
arXiv: 1504.01317



Acceptance correction







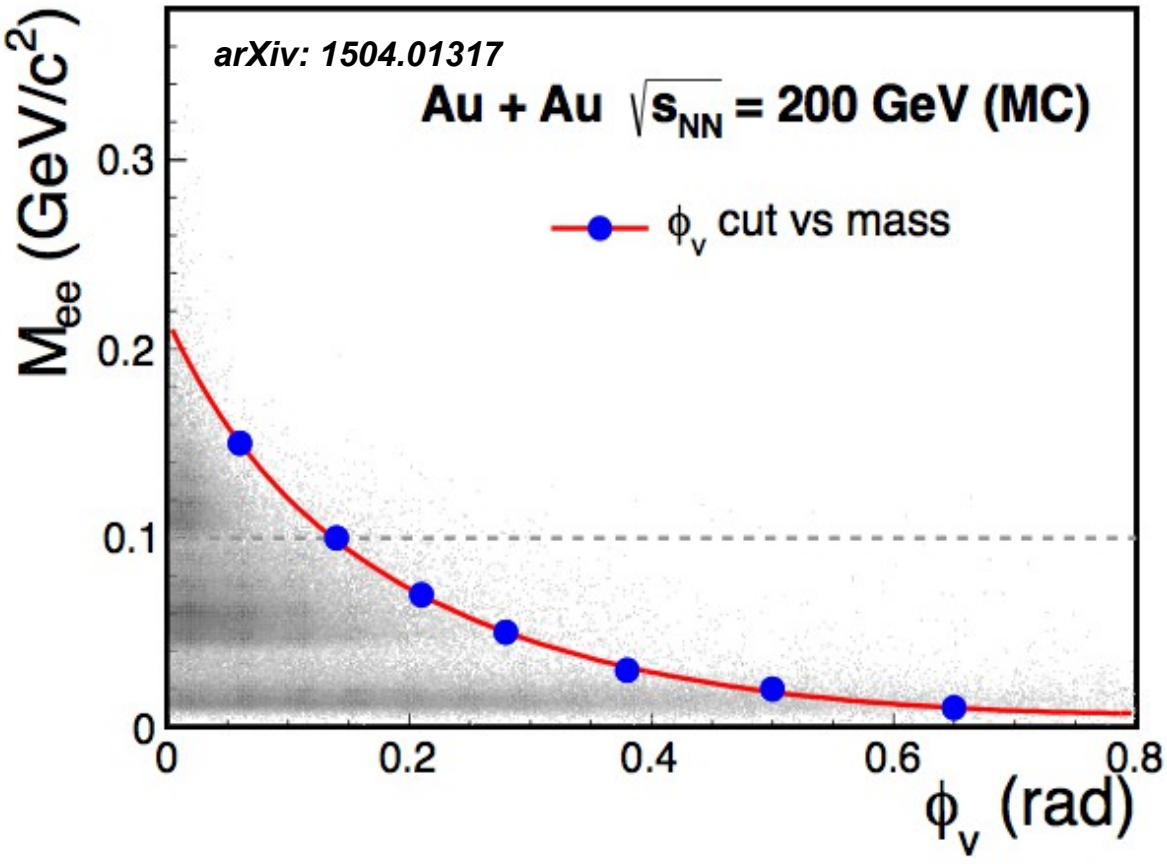
positive and negative tracks: - TPC sector boundary lost in different phi region, especially in low pT region. loss Like-Sign pair in mass(<0.2 GeV/c^2), loss unLike-Sign pair in mass(0.2-0.5 GeV/c^2).

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 :

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

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

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