Dielectron and Direct Virtual Photon Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200$GeV at STAR

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for the STAR Collaboration

Outline:

- Motivation
- STAR detector
- Dielectron production
- Direct virtual photon production
- Summary and outlook

XXIV QUARK MATTER
DARMSTADT 2014

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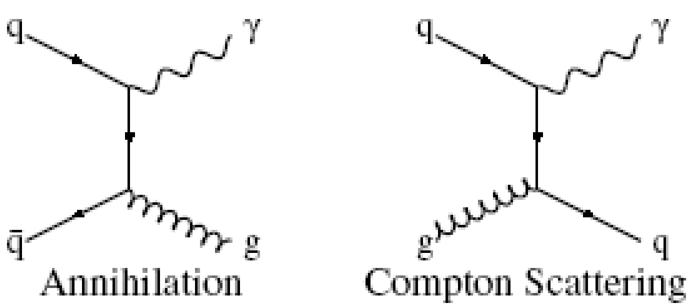
Motivation

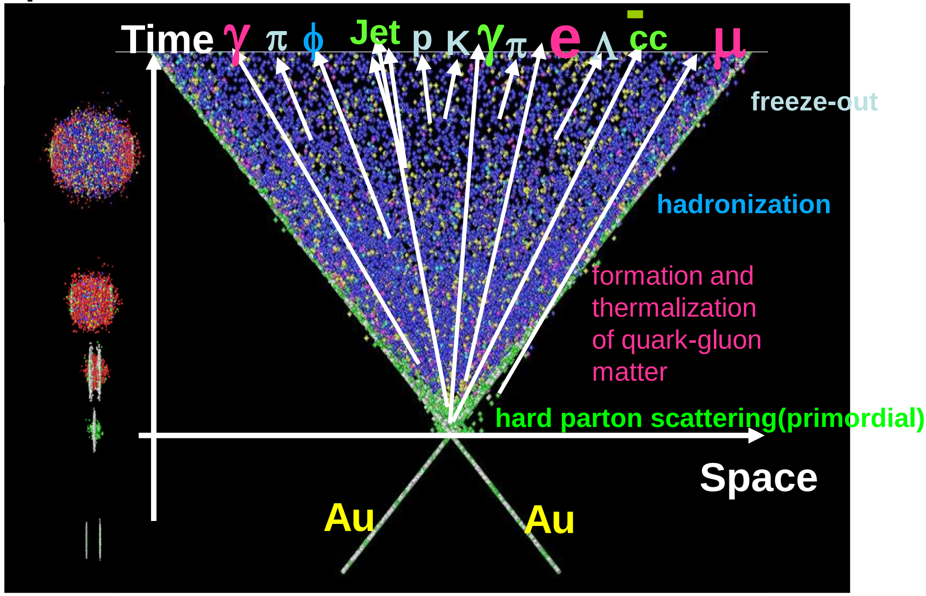
Direct photon and dielectron
------ ideal electroweak probes

- ✓ suffer no strong interaction, traverse the medium with minimum interaction
- ✓ produced throughout all stages of the evolution of the system

Direct photon:

- ✓ high p_T photons (>5GeV/c) : initial hard scattering
- ✓ low p_T photons (1-5GeV/c) : access QGP production





Similar process for virtual photon production, which could convert into e^+e^- pair.

$\gamma^* \rightarrow e^+e^-$

Motivation

Dielectron:

- *higher invariant mass => earlier production*

➢ Low Mass Region

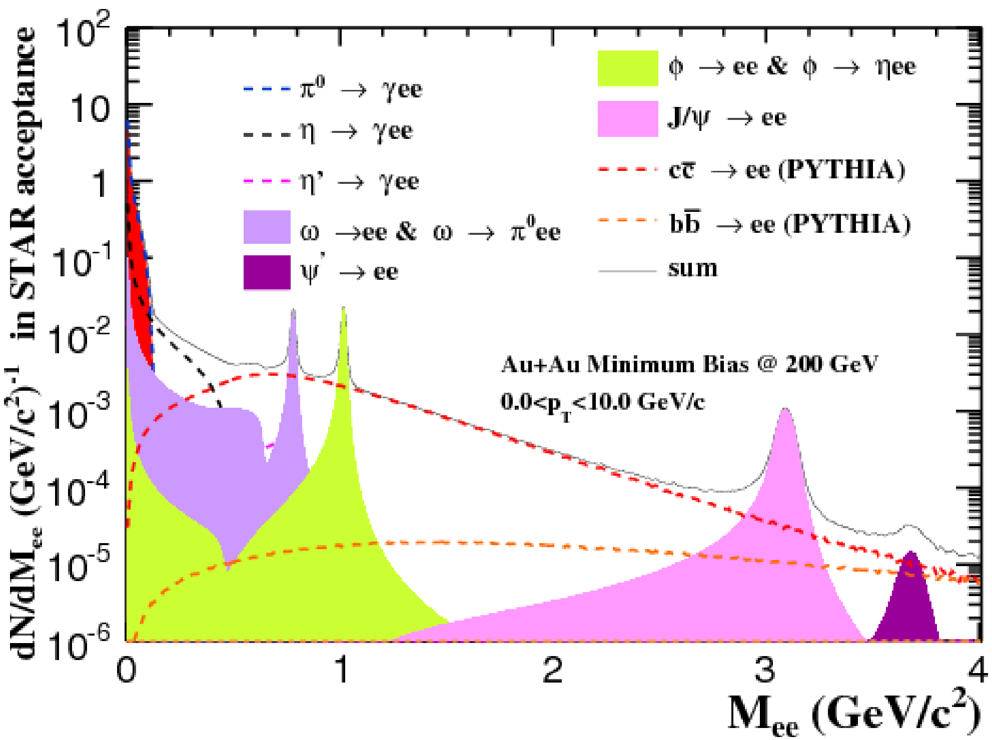
- ✓ In-medium modification of vector mesons

➢ Intermediate Mass Region

- ✓ QGP thermal radiation
- ✓ Semi-leptonic decay of correlated charm: charm modification in Au+Au

➢ High Mass Region

- ✓ Heavy quarkonia
- ✓ Drell-Yan process



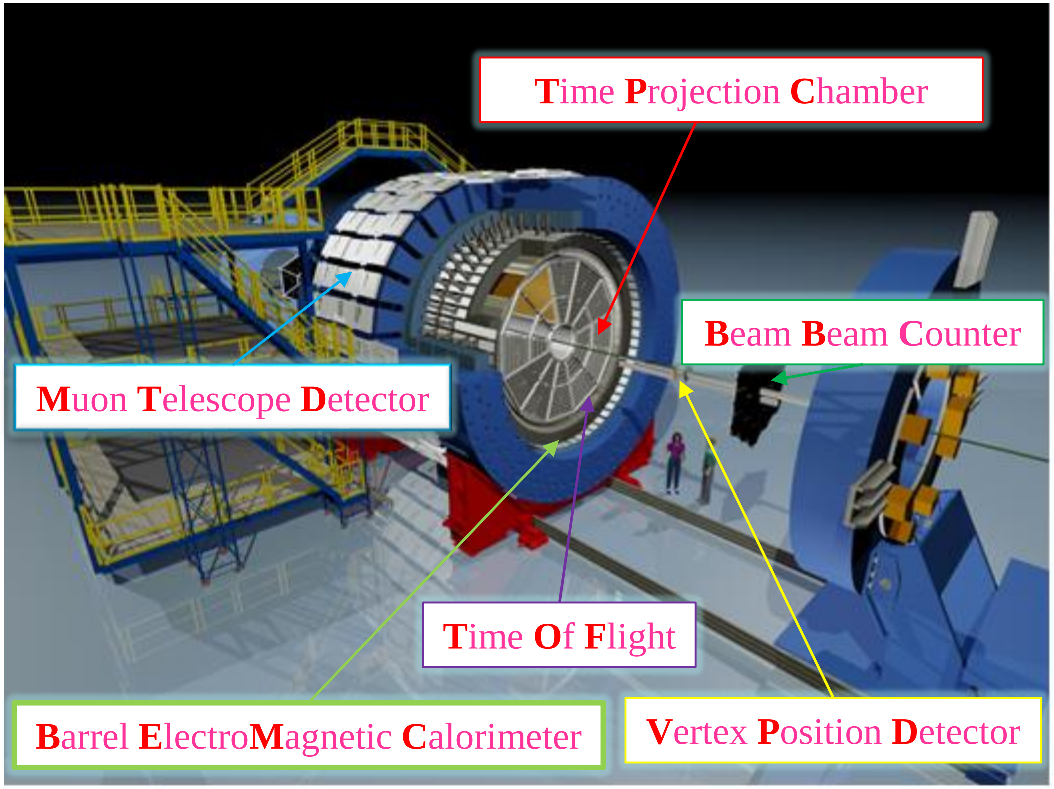
STAR detectors

Key detectors used in the analysis:

Time Projection Chamber:
- $|\eta| < 1 \quad 0<\Phi<2\pi$
- Main tracking detector: track, momenta, ionization energy loss (dE/dx)

Time Of Flight:
- $|\eta| < 0.9 \quad 0<\Phi<2\pi$
- Intrinsic timing resolution ~ 75 ps
- Time-of-flight measurement

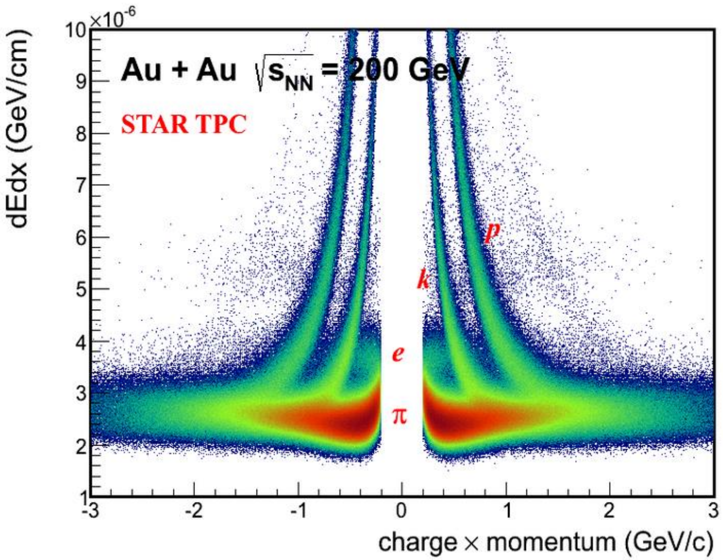
Barrel Electro-Magnetic Calorimeter:
- $|\eta| < 1 \quad 0<\Phi<2\pi$
- Trigger on and measure high-p_T processes

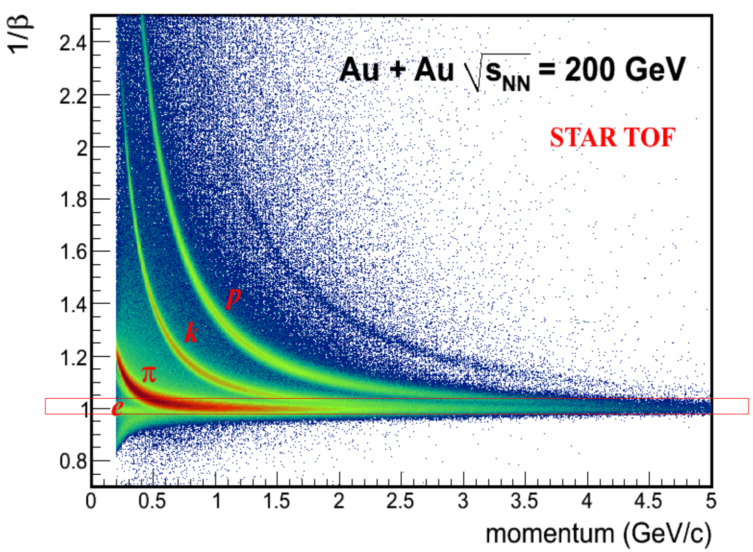


Type	Year	Central	Min.Bias	EMC trigger (energy threshold 4.3GeV)
Au+Au 200GeV	2010	220M	240M	
	2011		490M	39M
p+p 200GeV	2012		375M	

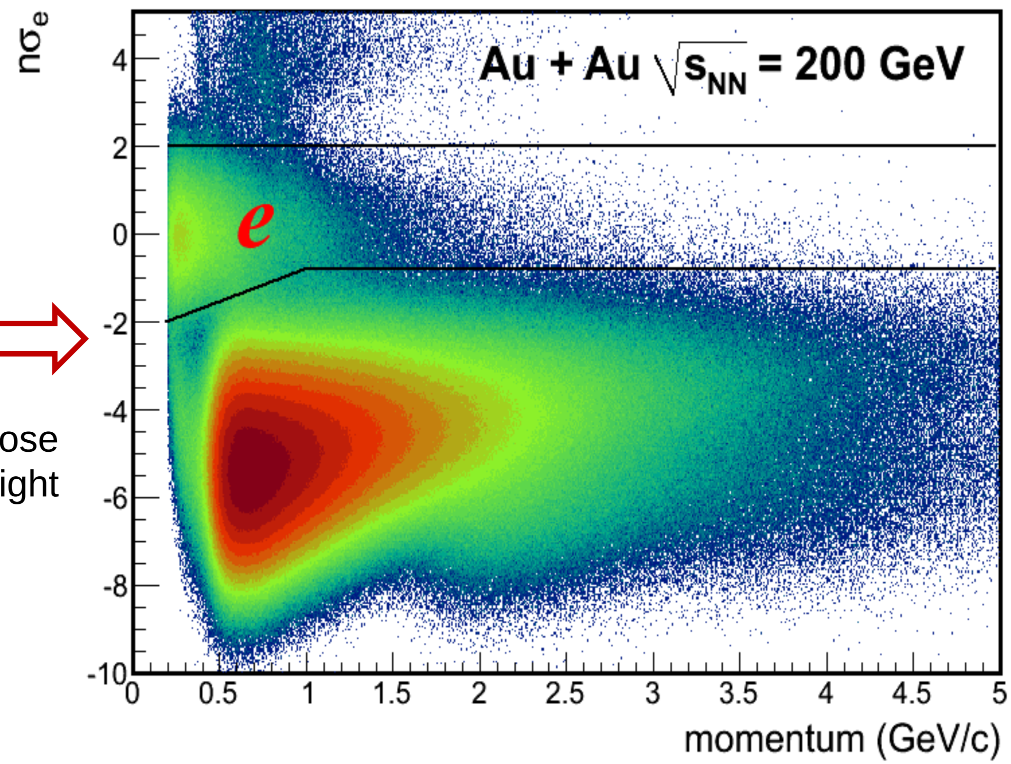
Electron identification

Time-Of-Flight provides clean electron identification from low to intermediate p_T which enables the dielectron measurements.





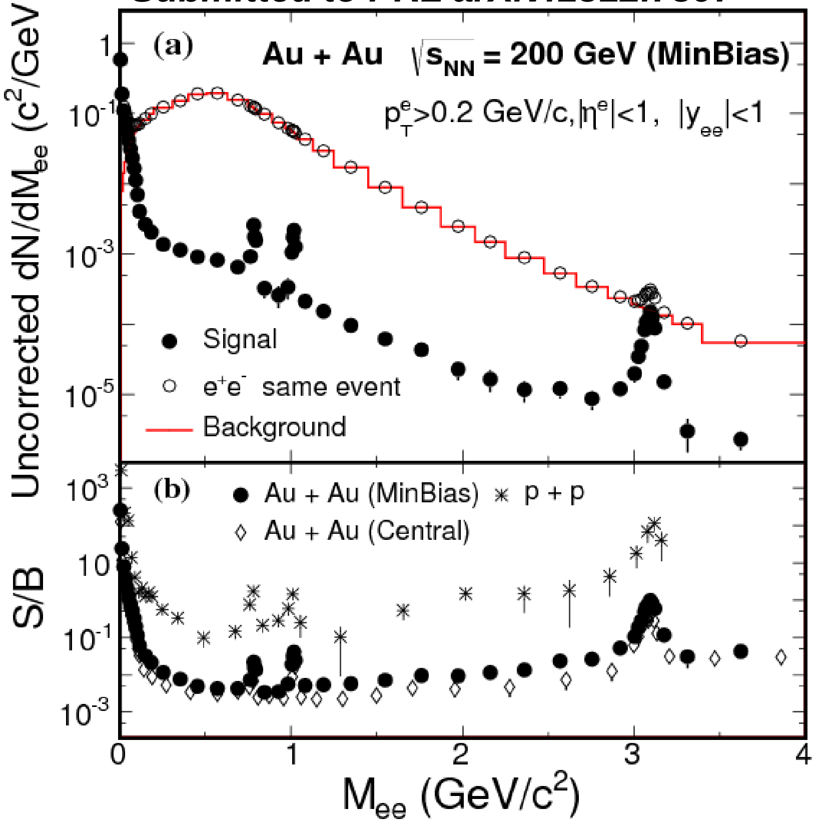
Require β close to speed of light



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%

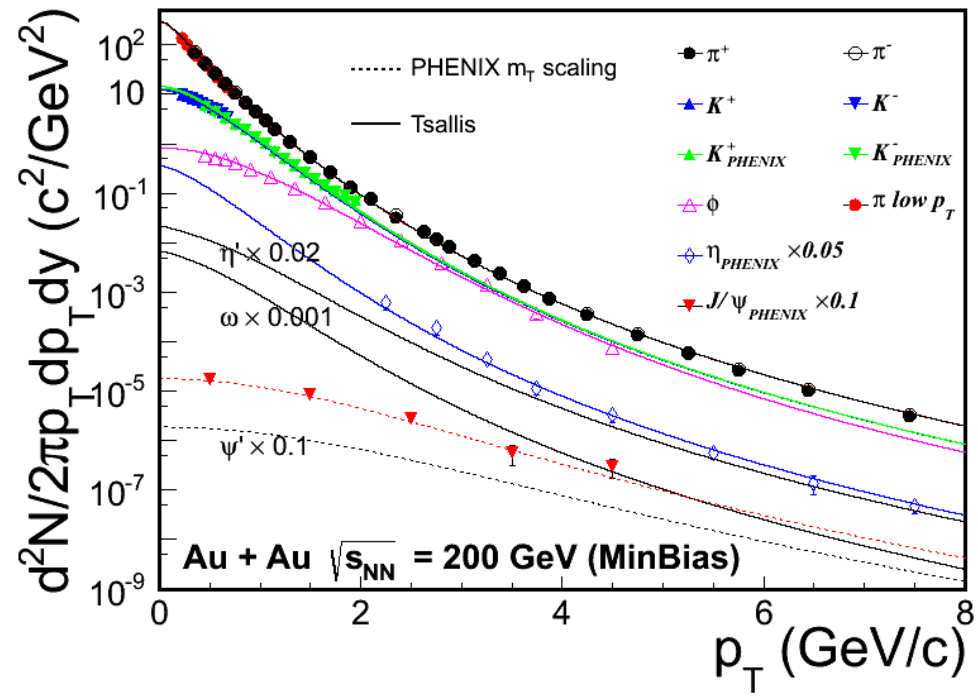
Invariant mass distribution and cocktail input

Submitted to PRL arXiv:1312.7397



p + p S/B : STAR Collaboration, Phys.Rev. C 86, 024906 (2012).

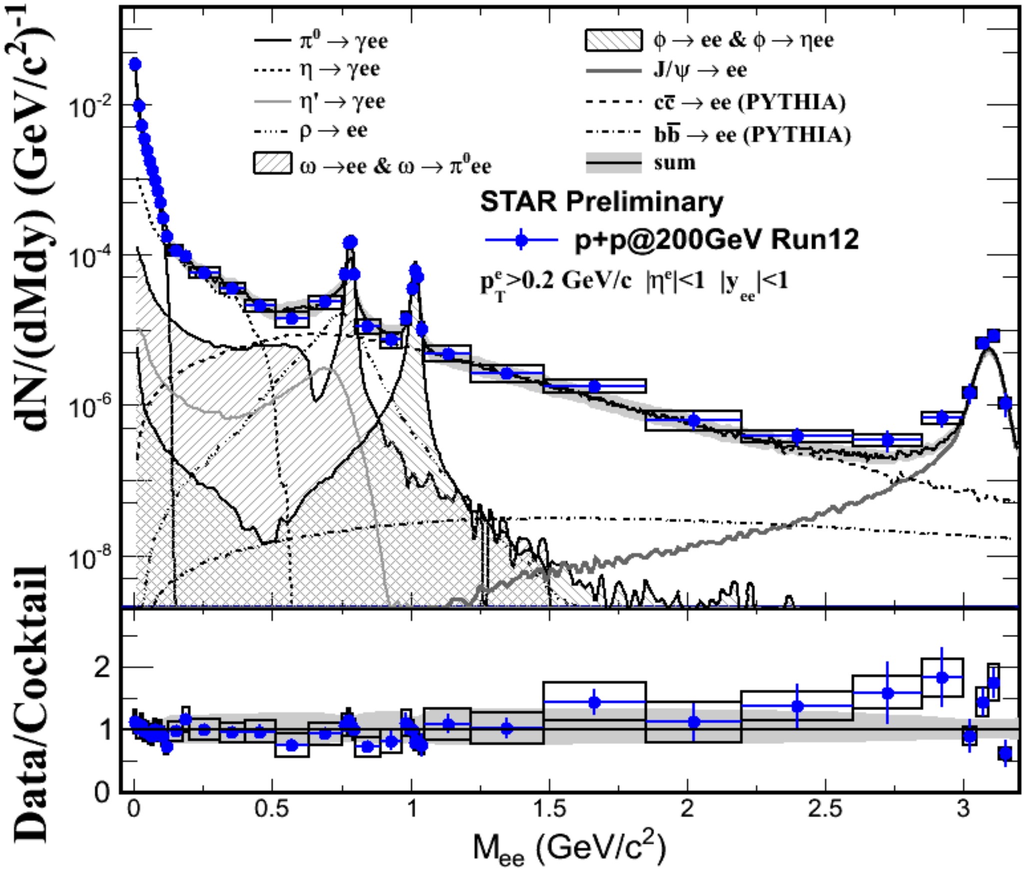
Input p_T spectra

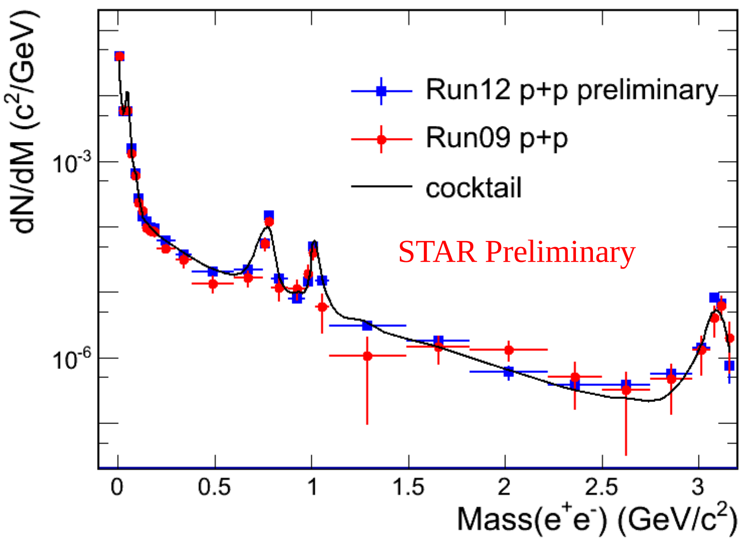


PHENIX Collaboration, Phys. Rev. C 81, 034911 (2010)
STAR Collaboration, Phys. Rev. Lett. 92, 112301 (2004)
STAR Collaboration, Phys. Lett. B 612, 181 (2005).
STAR Collaboration, Phys. Rev. Lett. 97, 152301 (2006)
Z. Tang et al. Phys. Rev. C 79, 051901 (2009)

M_{ee} < 1 GeV/c^2 Like sign background
M_{ee} >= 1 GeV/c^2 Mixed event background

p+p 200GeV results from Run12





Cocktail is taken from ***[Phys.Rev.C. 86, 24906 (2012)]*** with charm cross section changed from 0.96 to 0.80mb (±0.36mb) ***[Phys.Rev.D. 86, 72013 (2012)]*** **(STAR newest measurement)**

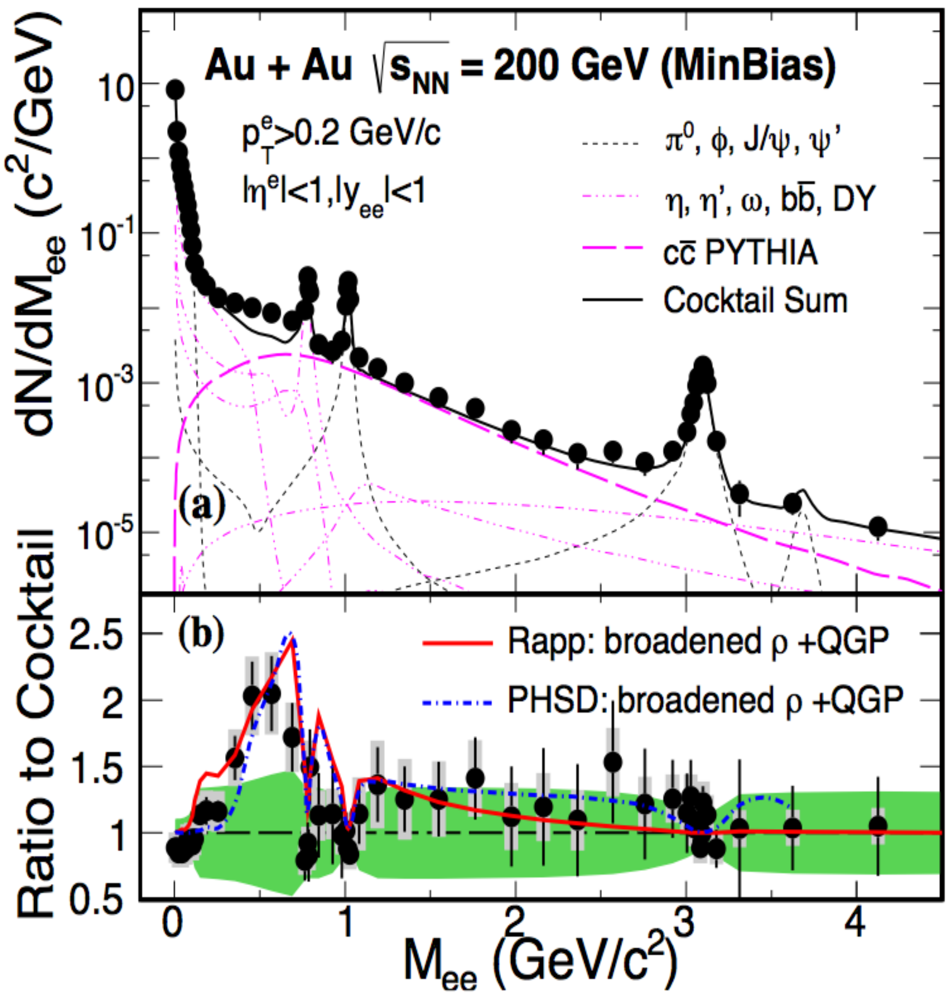
Run9 p+p: ***[Phys.Rev.C. 86, 24906 (2012)]***

Within uncertainty, the cocktail simulation reproduces the data very well.

With a full TOF coverage and more data taken, Run-12 results have greatly improved statistics ~ 7 times more than Run9.

Au+Au 200GeV results from Run10

Submitted to PRL arXiv:1312.7397



Enhancement at ρ-like region(0.30-0.76 GeV/c^2)
1.77 ± 0.11(stat.) ± 0.24 (sys.) ± 0.41 (cocktail) in Min.Bias

Comparison with models based on a ρ-broadening scenario :

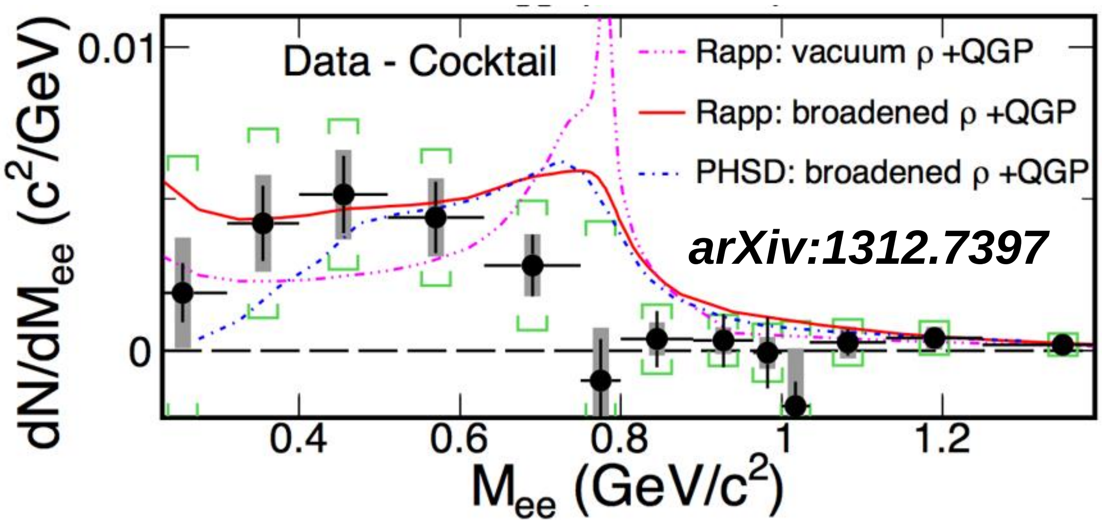
1) Model I : effective many-body model
[*R. Rapp, PoS CPOD2013, 008 (2013)*]

2) Model II : Parton-Hadron String Dynamics (PHSD)
[*O. Linnyk et al., Phys. Rev. C 85, 024910 (2012)*]

Models show good agreement with data within uncertainty.

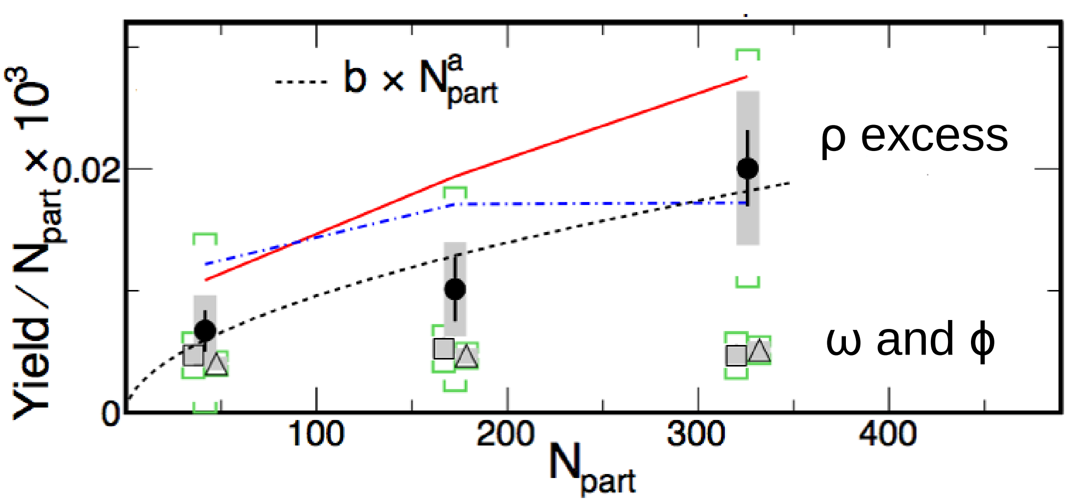
Low-mass excess

1) invariant-mass dependence :



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

ω-like and ϕ-like region (B), (C):
--- Yield shows N_{part} scaling.
ρ-like region (A):
--- Significant excess is observed.

e^+e^- pair from internal conversion

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

$$\frac{d^2N_{ee}}{dM} = \frac{2\alpha}{3\pi}\frac{L(M)}{M}S(M,q)dN_\gamma$$

$$L(M) = \sqrt{1-\frac{4m_e^2}{M^2}}\left(1+\frac{2m_e^2}{M^2}\right)$$

$$S(M,q) = \frac{dN_{\gamma^*}}{dN_\gamma}$$

✓ *pass STAR acceptance*
✓ *normalize to 0-30MeV/c²*

cocktail normalized to 0-30MeV/c²

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

cocktail component

direct virtual photon component

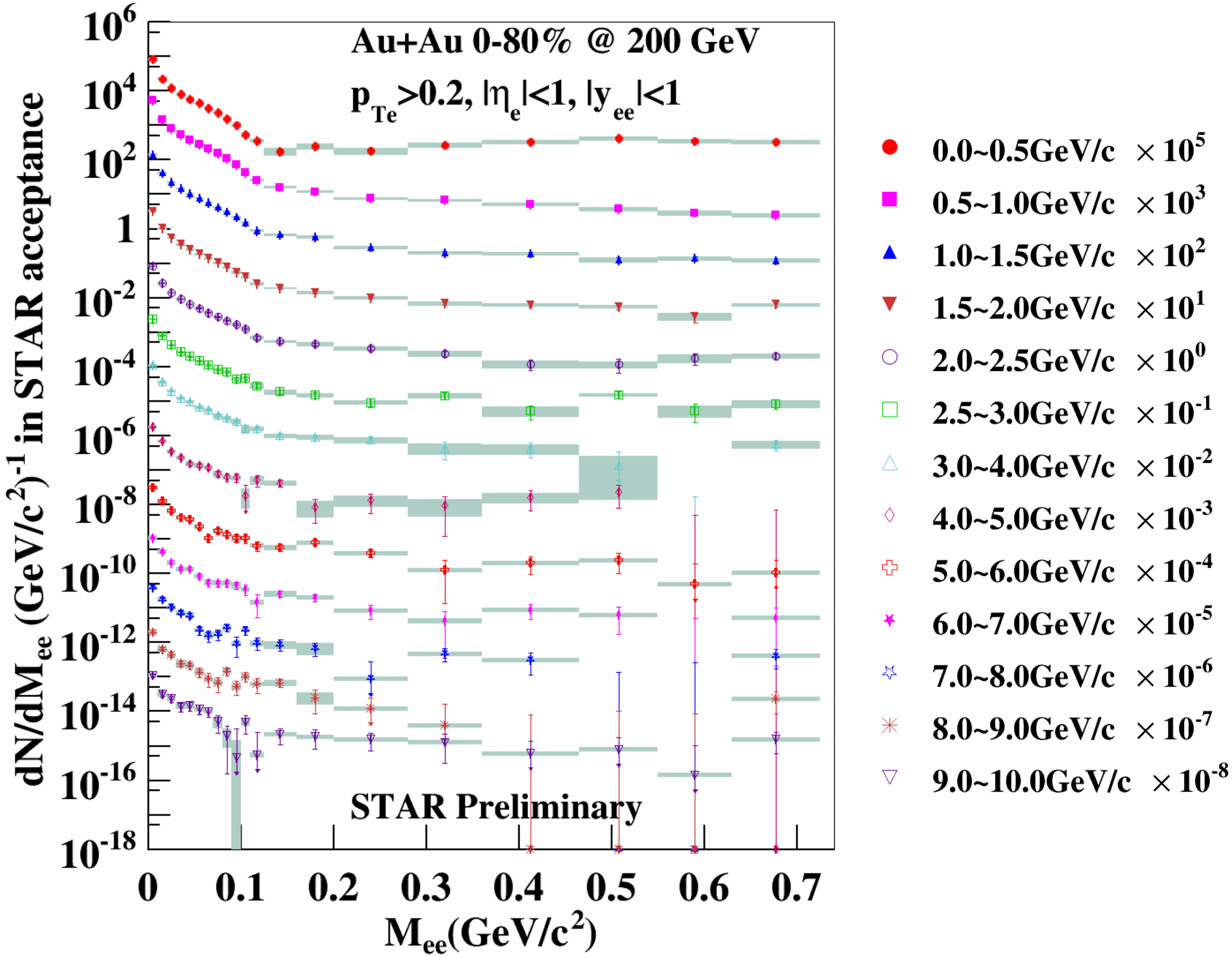
Direct photons can be measured by the associated dielectron production.

S = 1 => direct virtual photon ($p_T \gg M$, $M \gg m_e$)

: two-component fit to dielectron continuum.

$$r = \frac{yield\ of\ direct\ virtual\ photon}{yield\ of\ inclusive\ photon}$$

Low mass dielectron continuum



- *0-5 GeV/c*

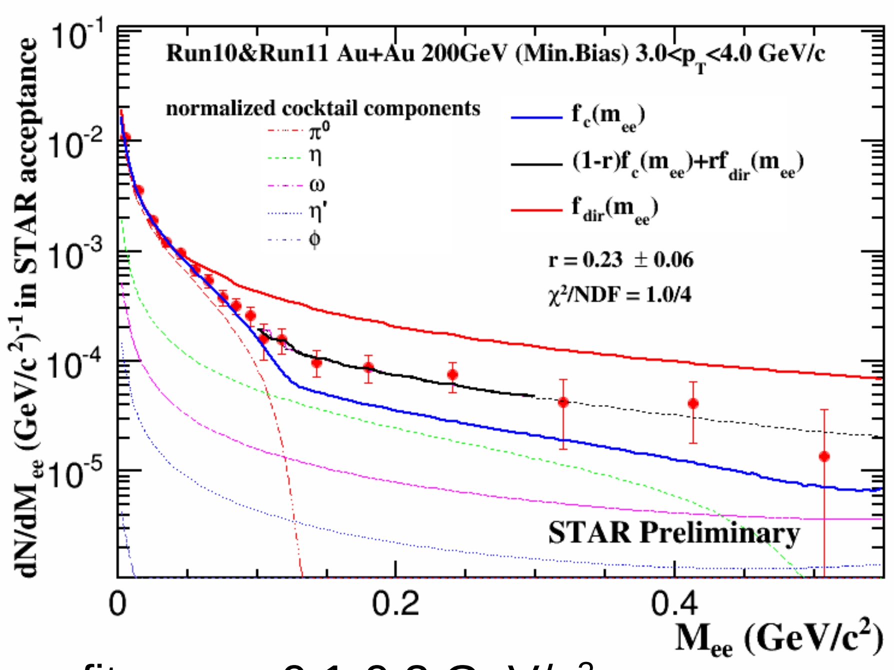
Run10+Run11 MB data

- *5-10 GeV/c*

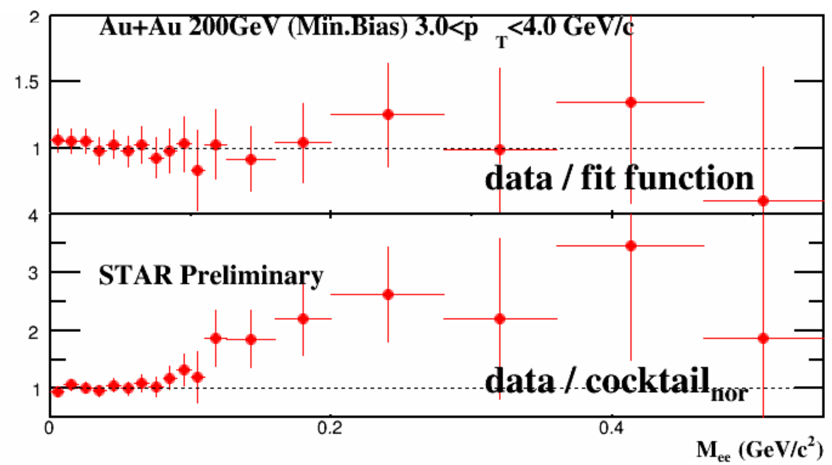
Run11 EMC triggered data

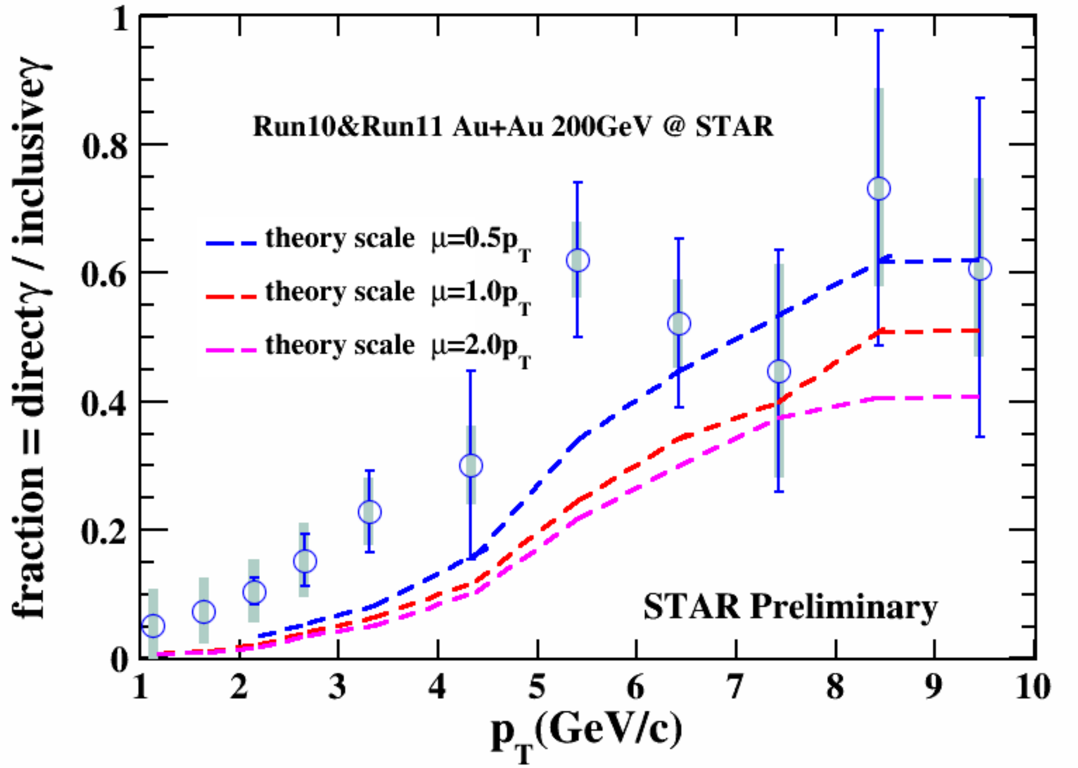
The statistical and systematic uncertainties are shown by the bars and bands, respectively.

Fraction of direct virtual photon



fit range: 0.1-0.3 GeV/c^2



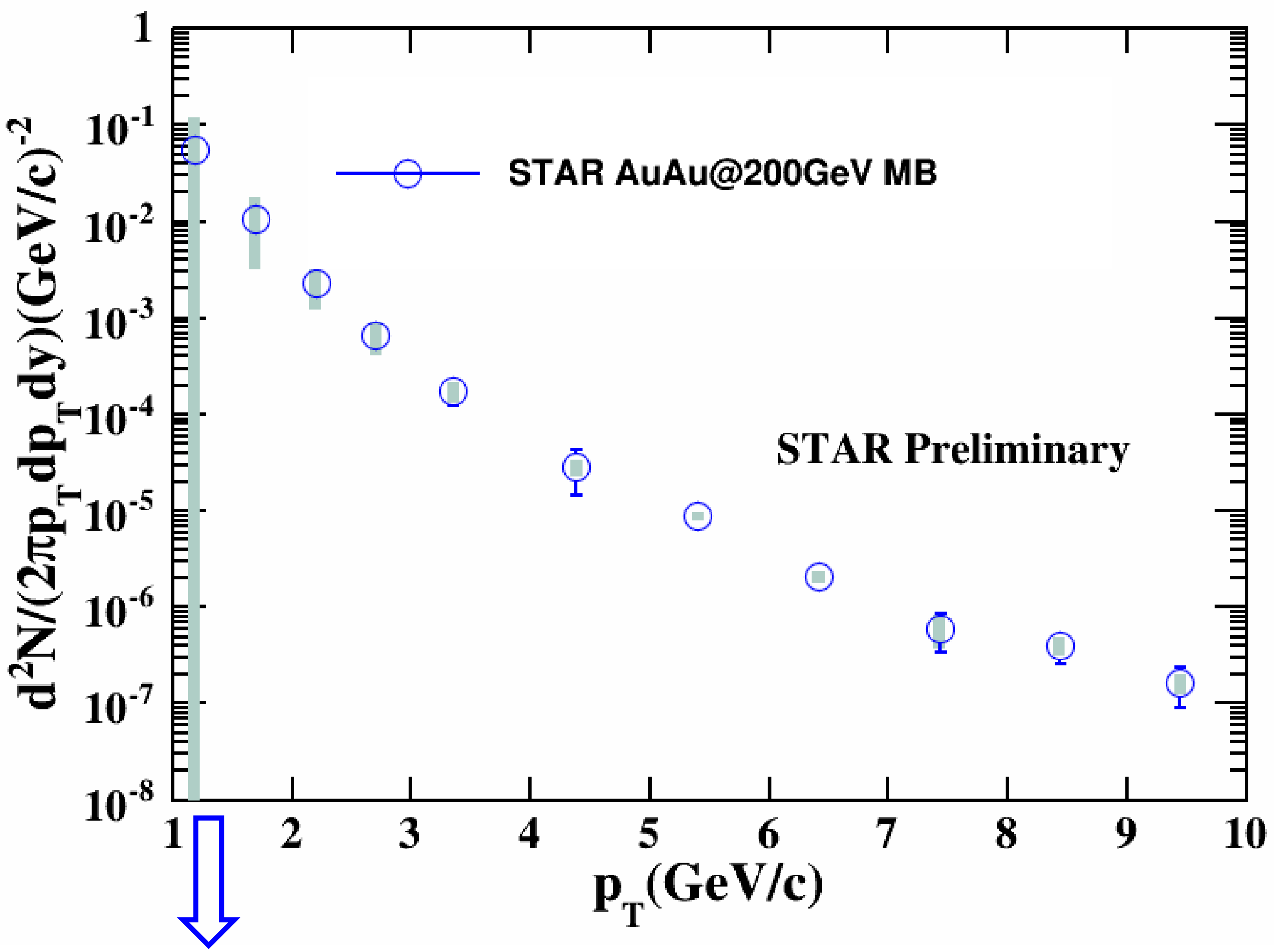


The curves represent NLO pQCD prediction: $\frac{T_{AA} d\sigma_\gamma^{NLO}(p_T)}{dN_\gamma^{inclusive}(p_T)}$

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).

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

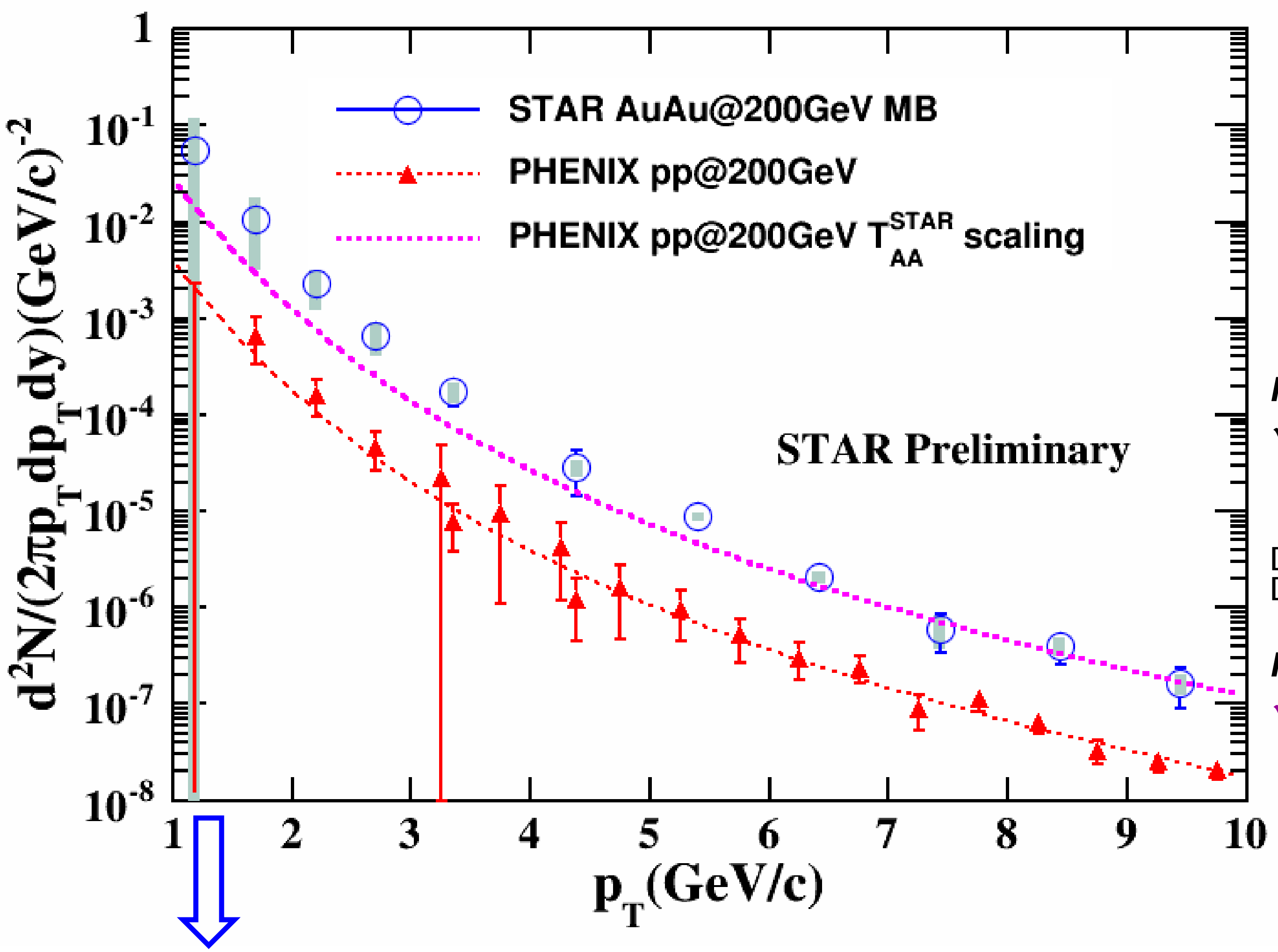
Direct virtual photon invariant yield



no η measurement in $p_T < 2$ GeV/c

Most uncertainty comes from the difference between TBW model prediction and m_T scaling

Direct virtual photon invariant yield



no η measurement in $p_T < 2$ GeV/c

Most uncertainty comes from the difference between TBW model prediction and m_T scaling

In the high p_T range (5~10GeV/c):

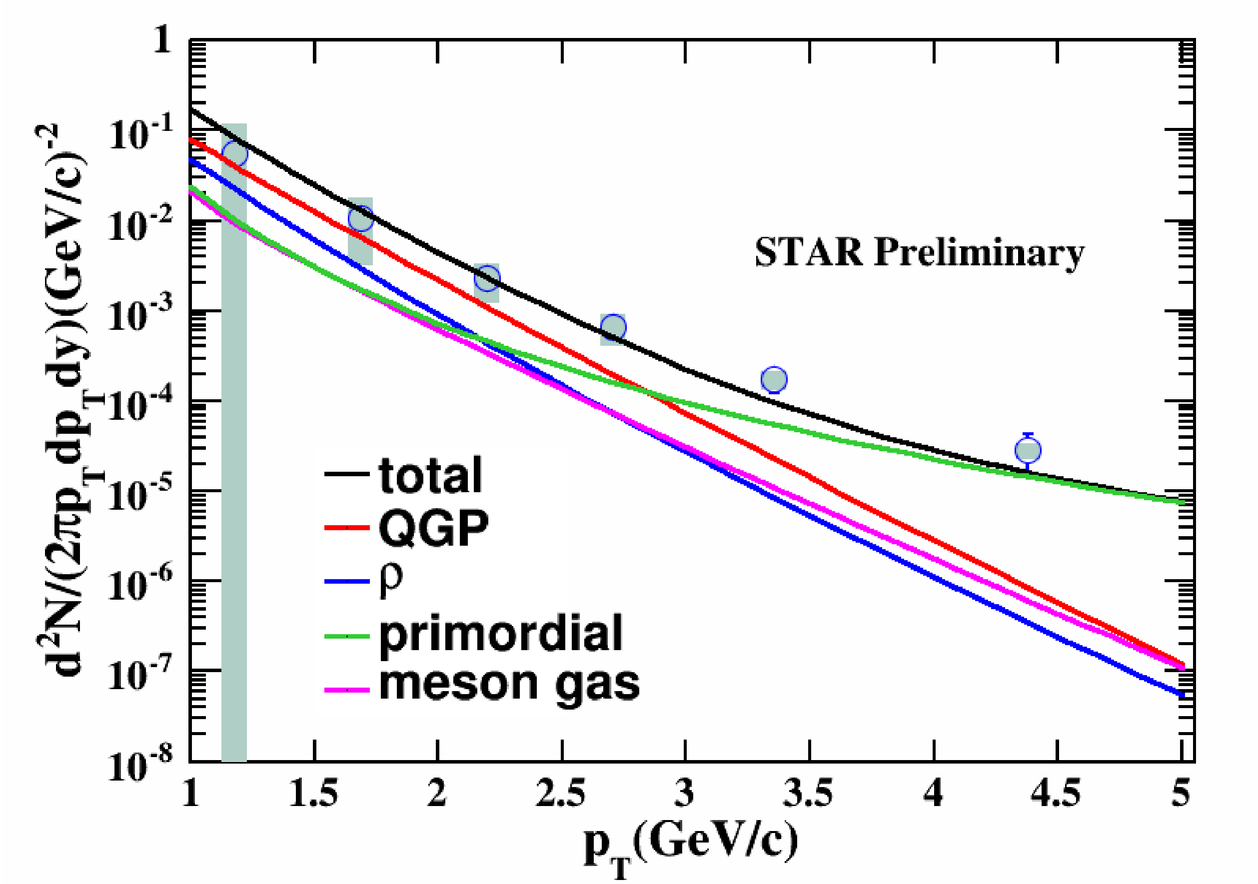
- ✓ **the yield is consistent with a T_{AA} scaled fit function to PHENIX pp data.**

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

In the p_T range 1~5GeV/c:

- ✓ **Compared to the pp reference, an excess is observed.**

Low p_T range



Rapp's model prediction[1] including QGP, ρ, meson gas, and primordial production contributions is consistent with the invariant yield at $1<p_T<5$ GeV/c within our uncertainty.

1 : from private communication with Ralf 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*]

Summary

- **Dielectron production:** ***(Yi Guo's poster 548 @ Board #: G-13)***
  - *Measured dielectron production in Au+Au collisions at STAR at $\sqrt{s_{NN}}$=200GeV.*
  - *An enhancement is observed with a data/cocktail ratio 1.77$\pm$0.49 at ρ-like region in Min.Bias.*
  - *Within uncertainties, broadening of ρ model calculations can explain the enhancement.*
- **Direct virtual photon production:**
  - *Presented the direct virtual photon measurement (1-10 GeV/c) in Au+Au collisions at STAR at $\sqrt{s_{NN}}$=200GeV.*
  - *An enhancement compared to PHENIX p+p results is observed for 1-5 GeV/c 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:

- To measure eta meson in 1-2 GeV/c.
- Get the direct virtual photon reference measurements in p+p from STAR Run12 results.
- Improve the charm contributions.

Backup

Background

Like sign background:

- can reconstruct both the combinatorial and correlated background.
- low statistics
- need to correct acceptance difference between unlike sign and like sign ee pair

$$B_{likesign} = 2\sqrt{N_{++}N_{--}}\frac{B_{+-}}{2\sqrt{B_{++}B_{--}}}$$

$$for\ EMC\ triggered\ events\ in\ p_T > 5GeV/c\ \ B_{likesign} = (N_{++}+N_{--})\frac{B_{+-}}{2\sqrt{B_{++}B_{--}}}$$

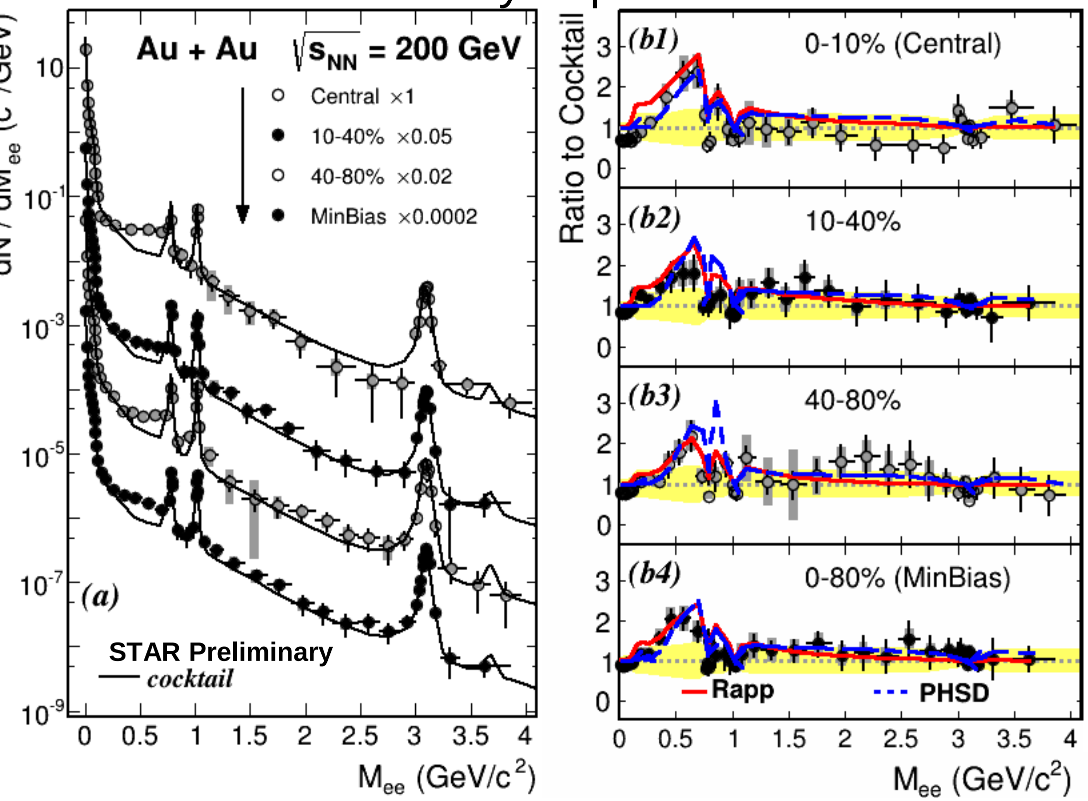
N: same event B: mixed event

Mixed event background:

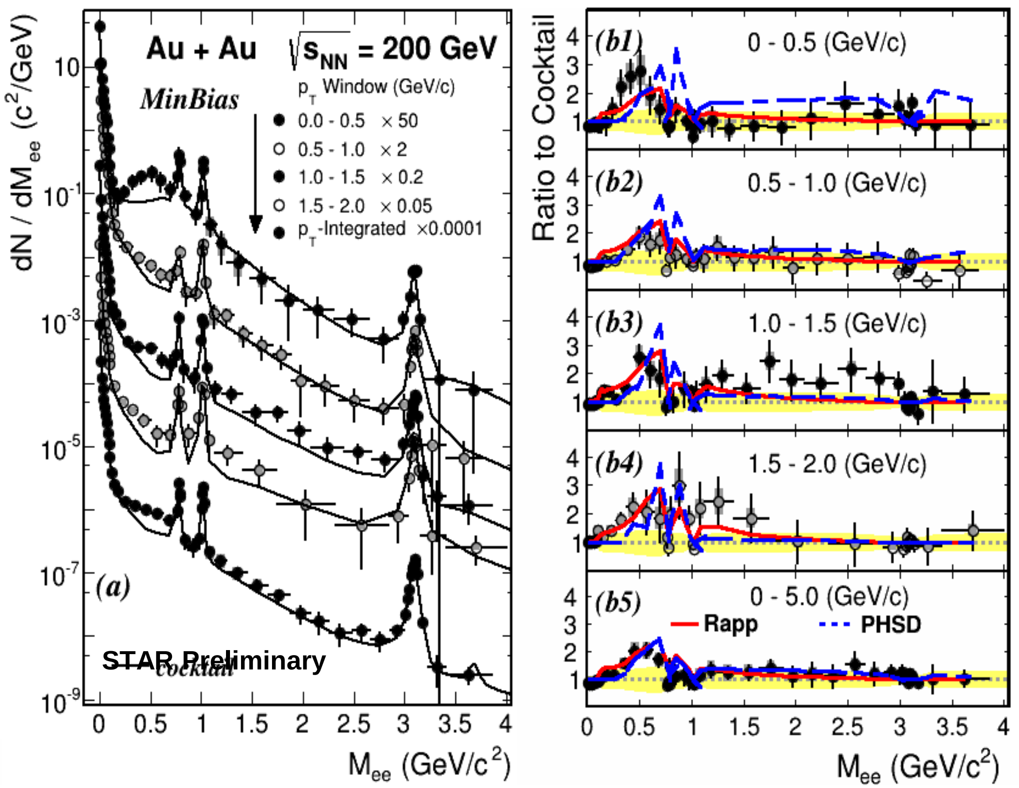
- High statistics
- Do not need to correct acceptance
- Can't reconstruct correlated background
- normalized to Like Sign in mass region [1,2] GeV/c^2

Centrality and p_T dependence (Run10)

Centrality dependence



p_T dependence



Two models show good agreement with data within uncertainty.

Φ_V cut for photon conversion rejection

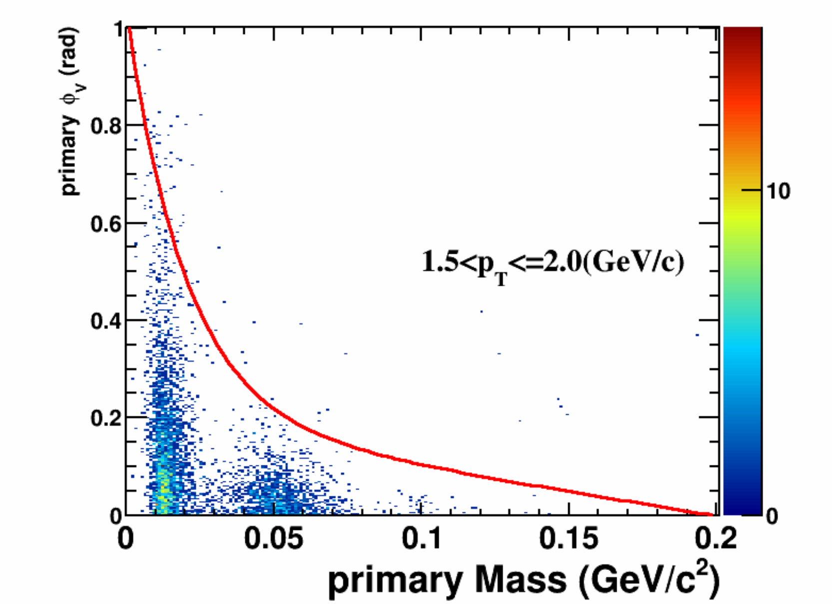
Φ_V definition:

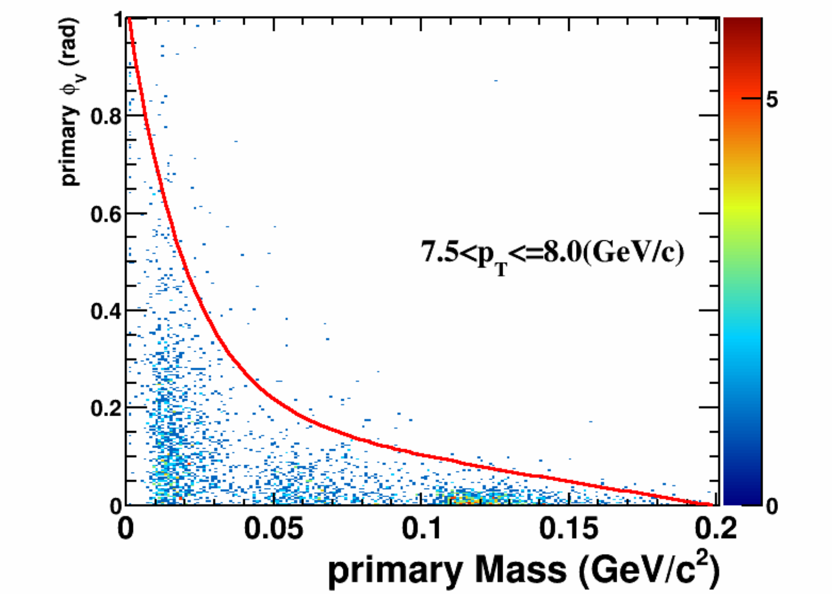
$$\hat{u} = \frac{\vec{p}_+ + \vec{p}_-}{|\vec{p}_+ + \vec{p}_-|}, \hat{v} = \vec{p}_+ \times \vec{p}_-$$

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

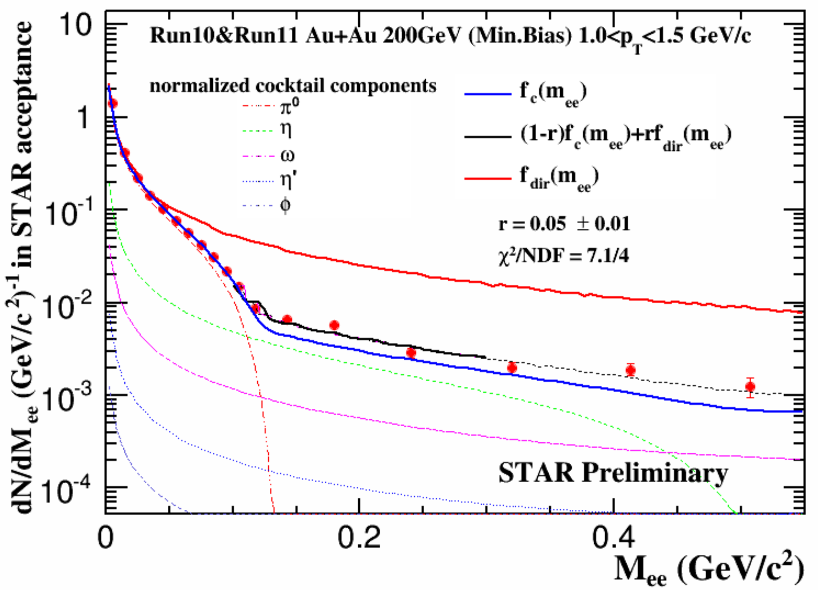
$$\cos\phi_V = \hat{w} \cdot \hat{w}_c$$

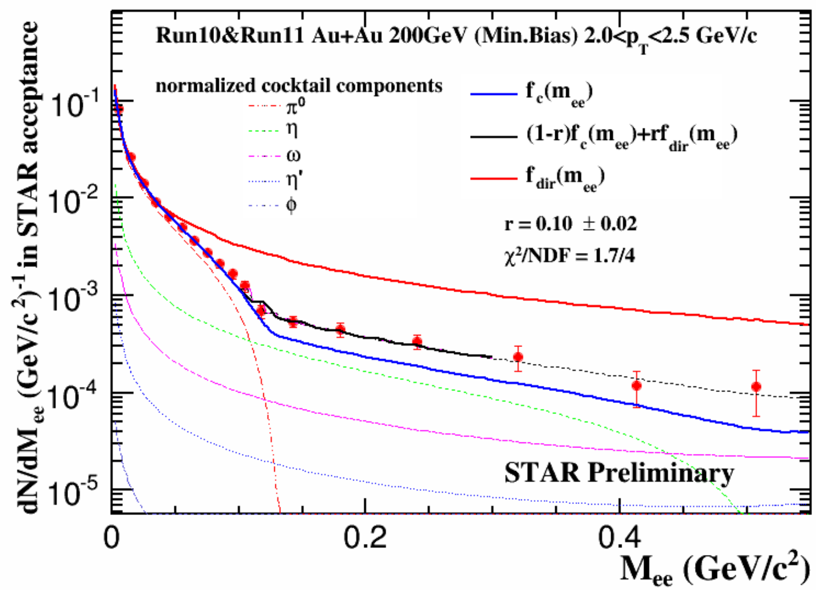
- *GEANT simulation*：
- Red line is the cut
- ~99% conversion electrons are rejected

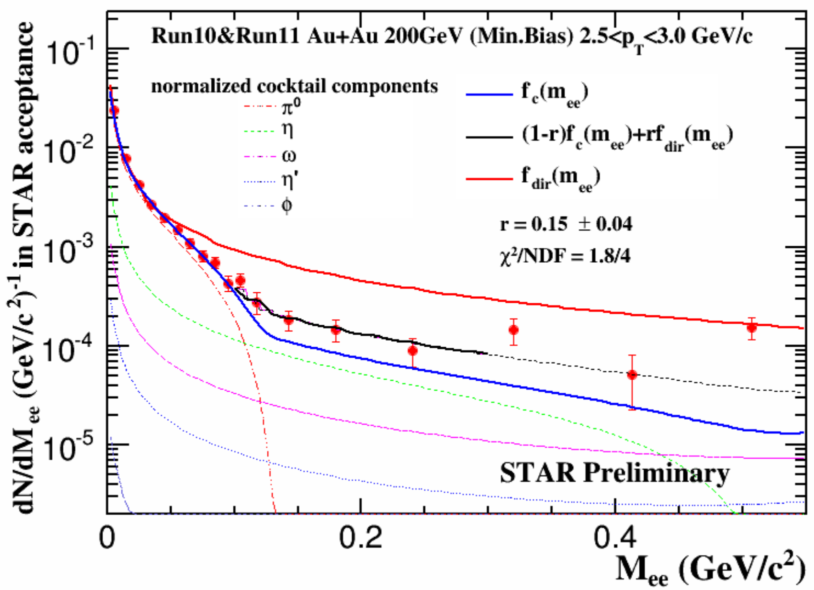


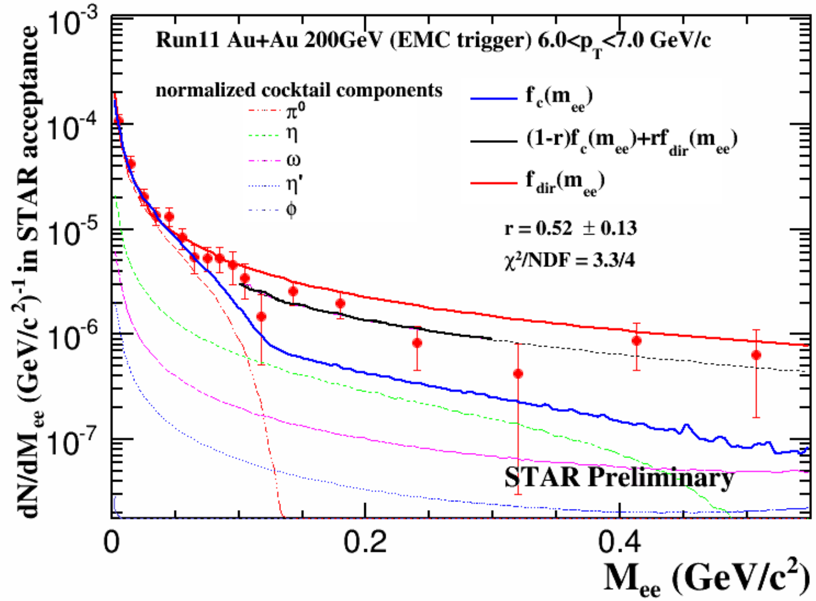


Fitting in other p_T slices



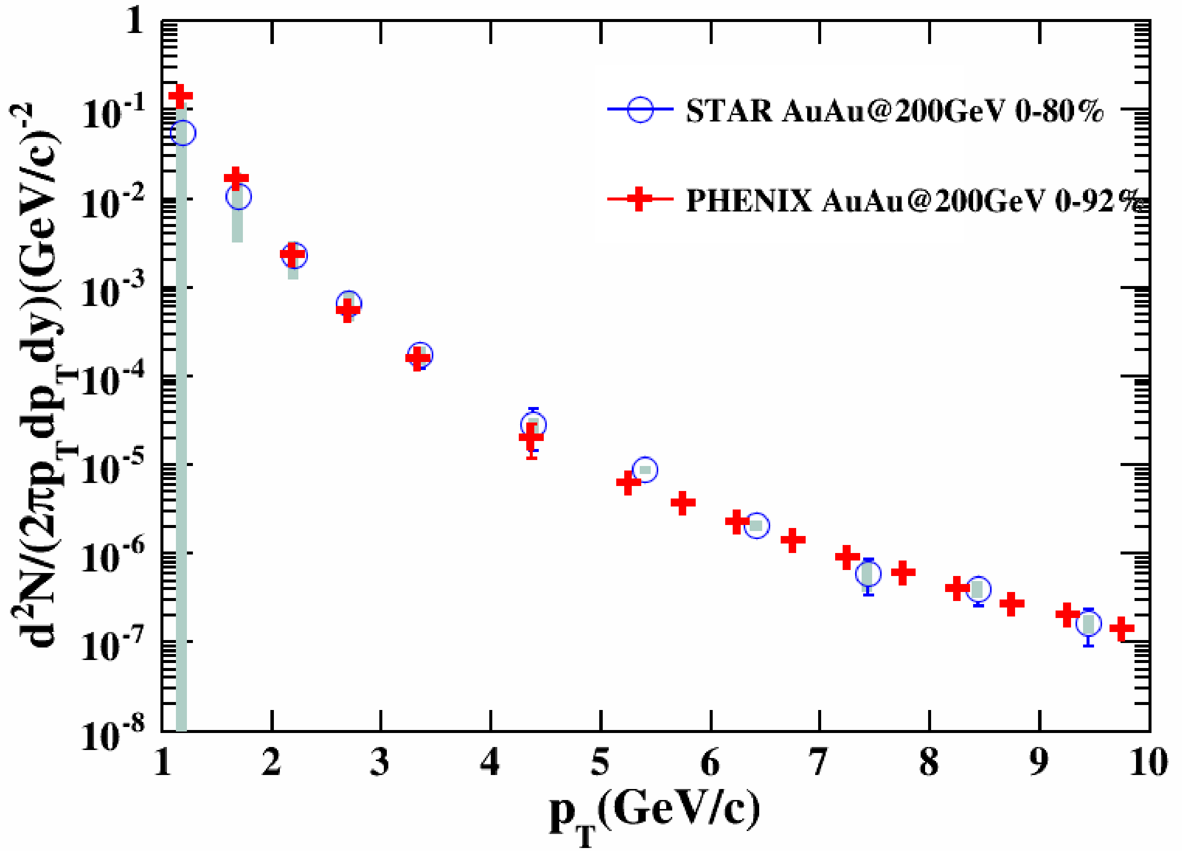






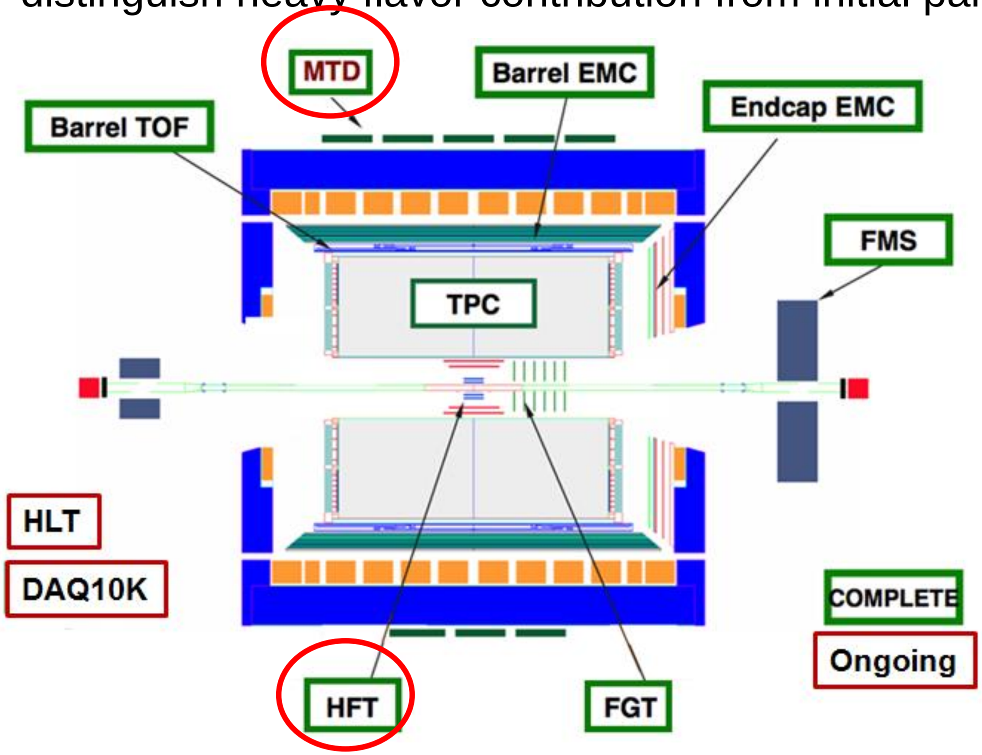
Compare to PHENIX results

1. To measure eta meson in 1-2 GeV/c ($\eta \rightarrow \gamma + \gamma$).
2. Get the p+p reference from STAR Run12 data.
3. To obtain the inverse slope parameter.



Outlook- STAR Upgrade

- Fully installed Muon Telescope Detector in Run14 will significantly enhance di-lepton related analysis.
  - di-μ will provide another way to study direct virtual photon.
  - e-μ correlation – distinguish heavy flavor contribution from initial pair production.



Heavy Flavor Tracker: fully installed.
Topologically reconstructs D mesons from hadronic decays and identifies electrons from charm decays