Direct virtual photon at STAR

Chi Yang 杨 驰

Shandong University 山东大学

Direct photons

Direct photons:

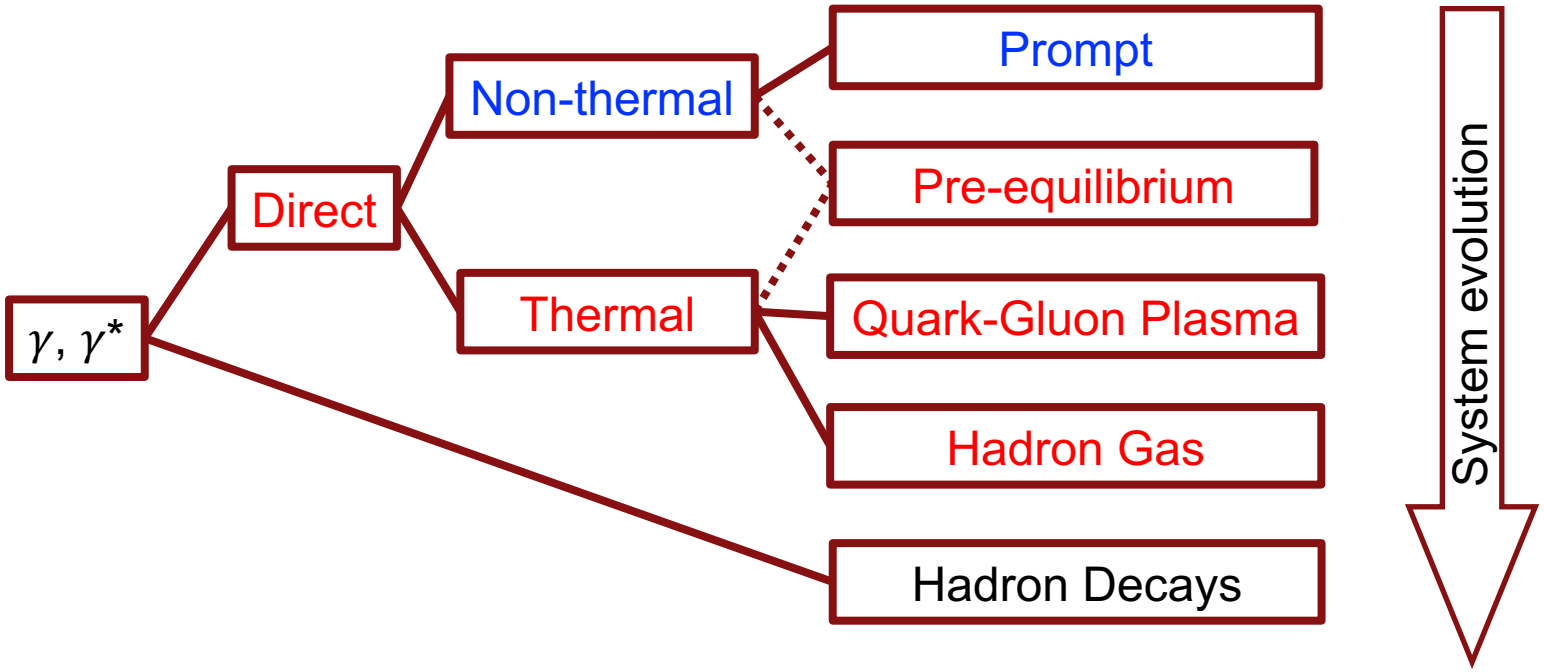
all photons which DO NOT come from hadron decay

Unique probe:

- ✓ Charge neutral
- ✓ Can probe the whole time evolution

Higher p_T -> Earlier produced

- ✓ high p_T : initial hard scattering
- ✓ low p_T : QGP thermal + hadron gas

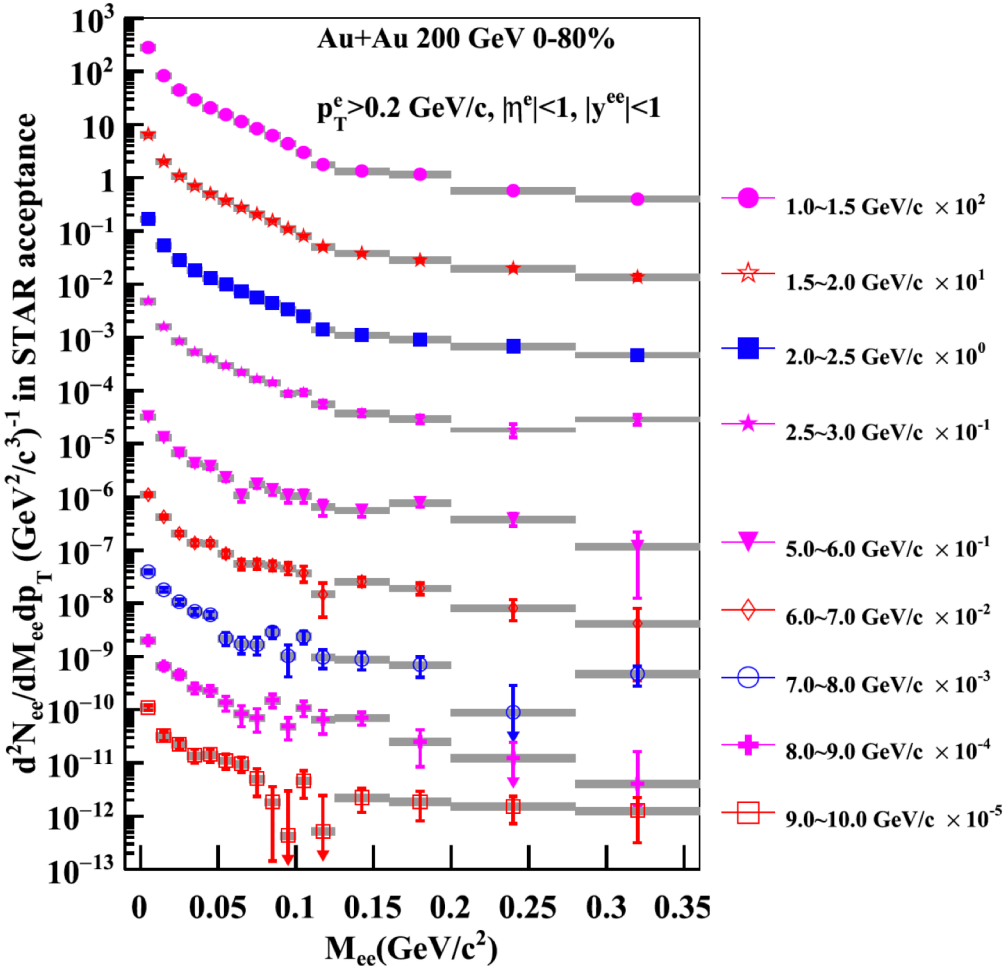


Data set

- Run10 and Run11 200 GeV Au+Au collisions
- 258 M and 488 M events after event selection
- Dielectron continuum reconstruction details and hadronic cocktail simulation details can be found in the papers:

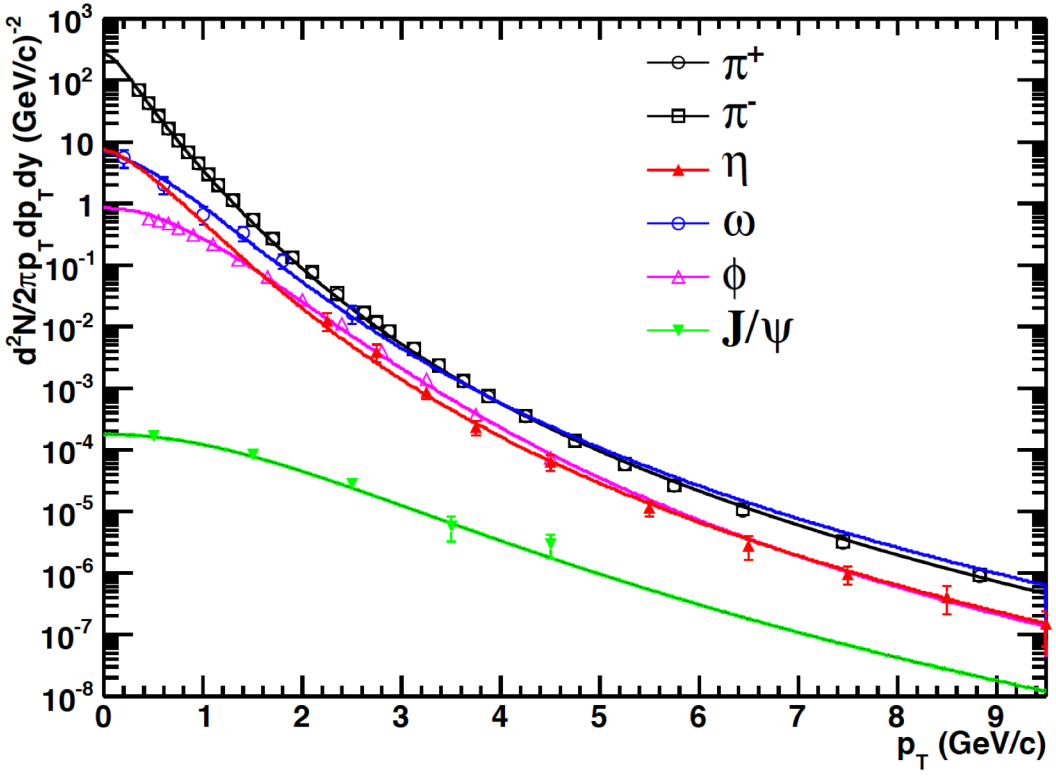
  [STAR Collaboration, Phys. Rev. C 92 (2015) 024912]
  [STAR Collaboration, Phys. Rev. C 90 (2014) 064904]

Dielectron continuum in 0-80%



- Combination of Run10 and Run11 data
- ~1% difference between Run10 and Run11 dielectron continuum in pion region (good statistics)

TBW inputs for cocktail simulation



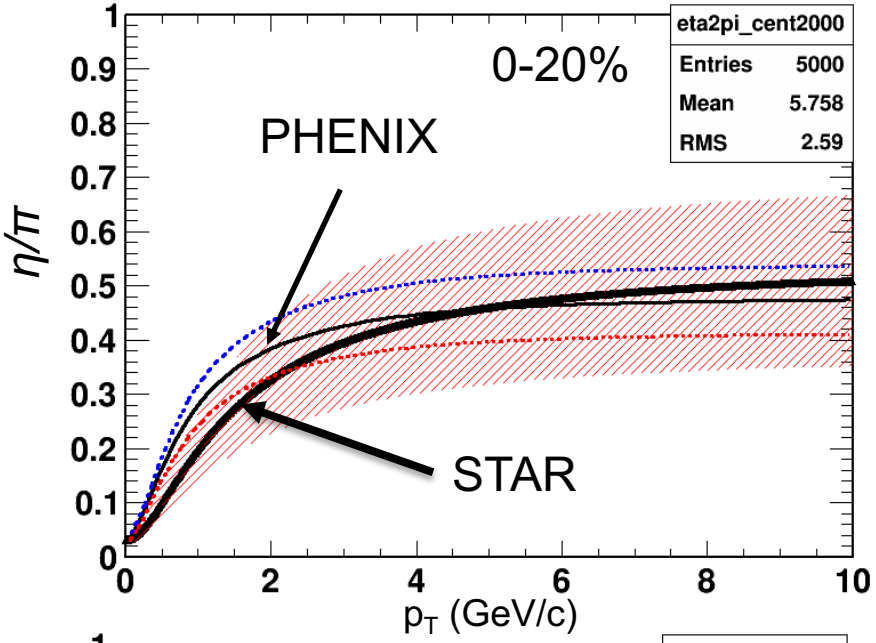
- TBW: simultaneous fit the spectra from many particle species
- Limit eta measurement in low p_T

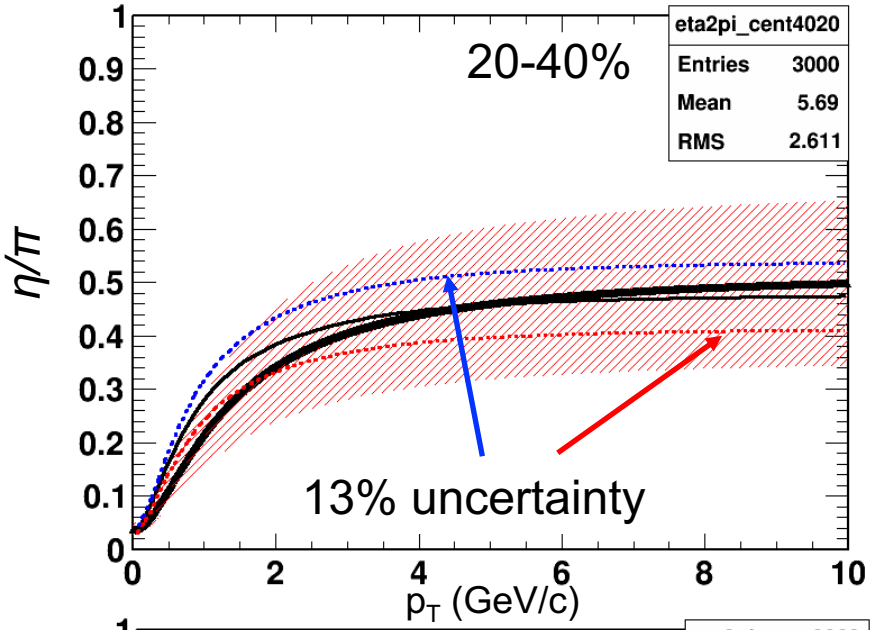
Cocktail uncertainty from η

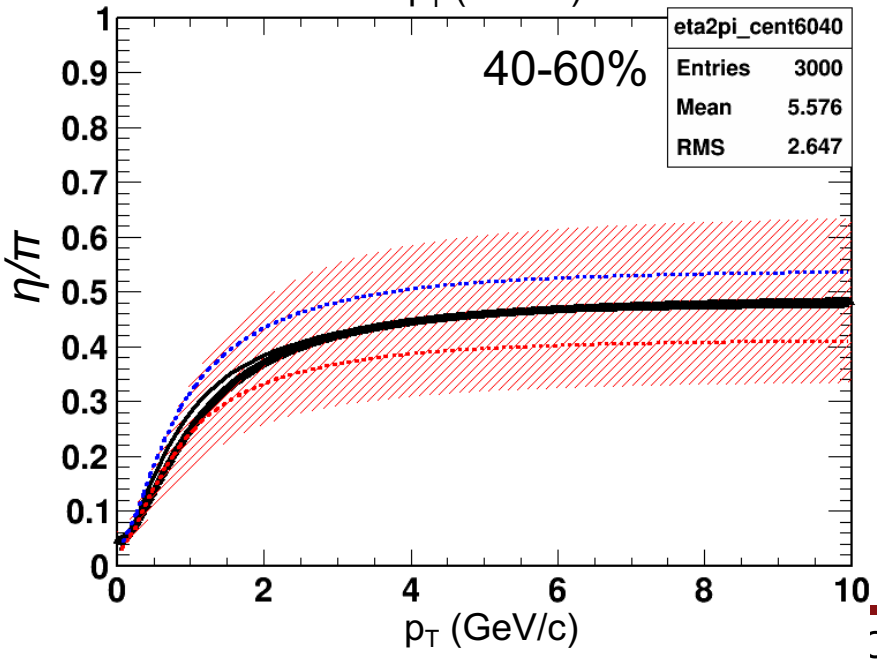
- η/π ratio affect the direct photon results significantly
- Calculate the η/π ratio as a function of p_T (Tsallis blast-wave model prediction)
- Match it to the η/π ratio value measured by PHENIX at p_T = 5 GeV/c
- The ratio uncertainty is quoted as 13%

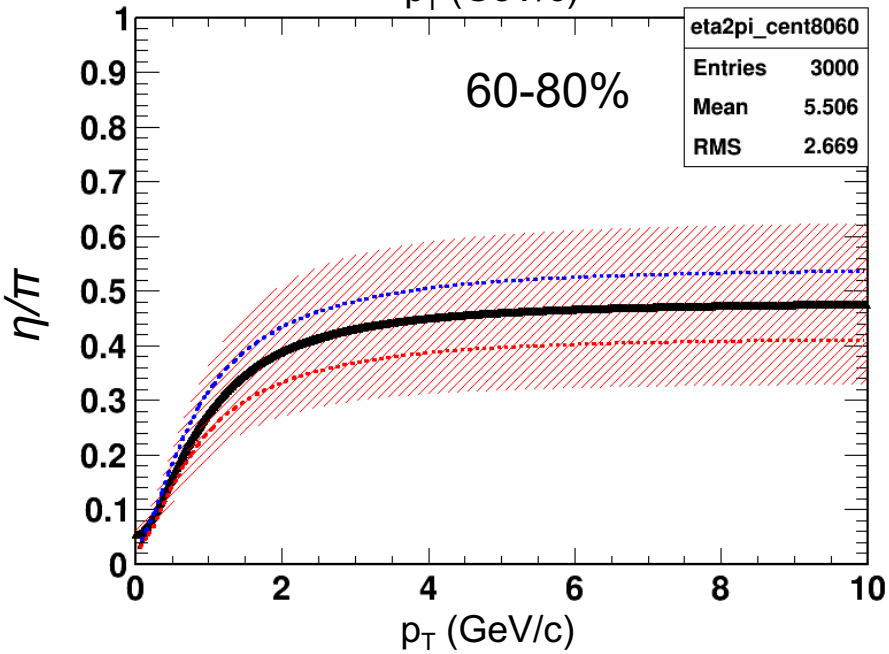
[PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301]
[PHENIX Collaboration, Phys. Rev. C 75 (2007) 024909]

η/π versus p_T


eta2pi_cent2000
Entries 5000
Mean 5.758
RMS 2.59
0-20%
PHENIX
STAR
η/π
p_T (GeV/c)

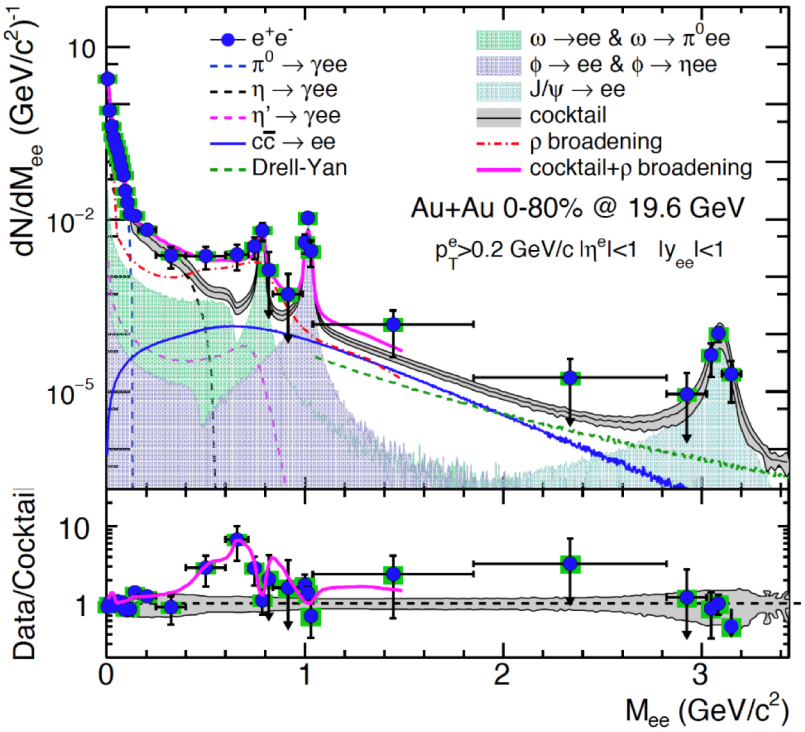

eta2pi_cent4020
Entries 3000
Mean 5.69
RMS 2.611
20-40%
13% uncertainty
η/π
p_T (GeV/c)


eta2pi_cent6040
Entries 3000
Mean 5.576
RMS 2.647
40-60%
η/π
p_T (GeV/c)


eta2pi_cent8060
Entries 3000
Mean 5.506
RMS 2.669
60-80%
η/π
p_T (GeV/c)

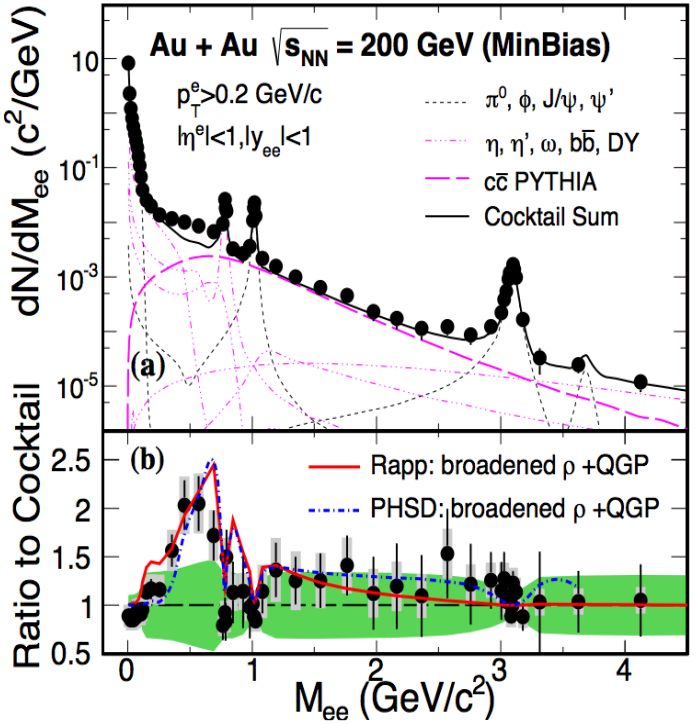
Dielectron in Au+Au at STAR

Au+Au 19.6GeV



STAR, PLB, 750 (2015) 64-71

Au+Au 200GeV



STAR, PRL, 113 (2014) 022301

- ✓ In ρ-like region, clear excesses are observed from RHIC top energy to low energy
- ✓ Consistent with ρ broadening scenario
- ✓ Self consistent picture from 200, 62.4, 39, 27 and 19.6 GeV

e^+e^- pairs from internal conversion

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

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

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

cocktail normalized to 0-30MeV/c²

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

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

Direct photons can be measured by the associated dielectron production.

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

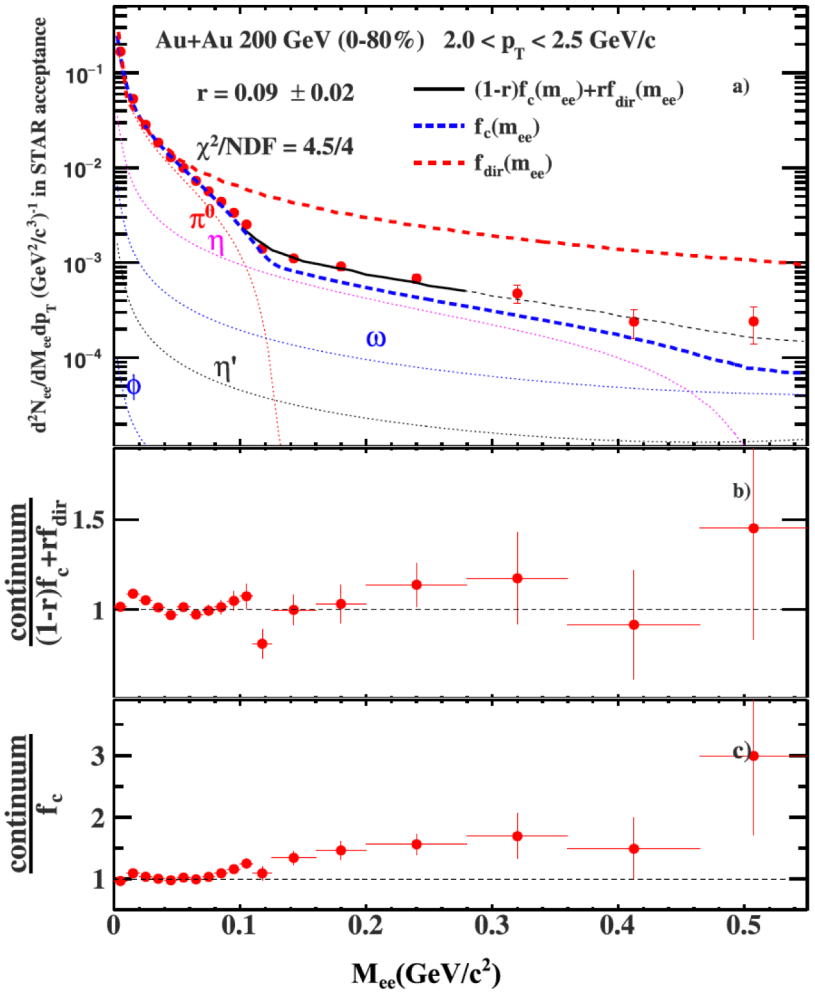
$(1-r)\ f_c$ + $r\ f_{dir}$: two-component fit to dielectron continuum.

cocktail component

direct virtual photon component

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

Two-component fitting



pass STAR acceptance normalize to 0-30MeV/c^2

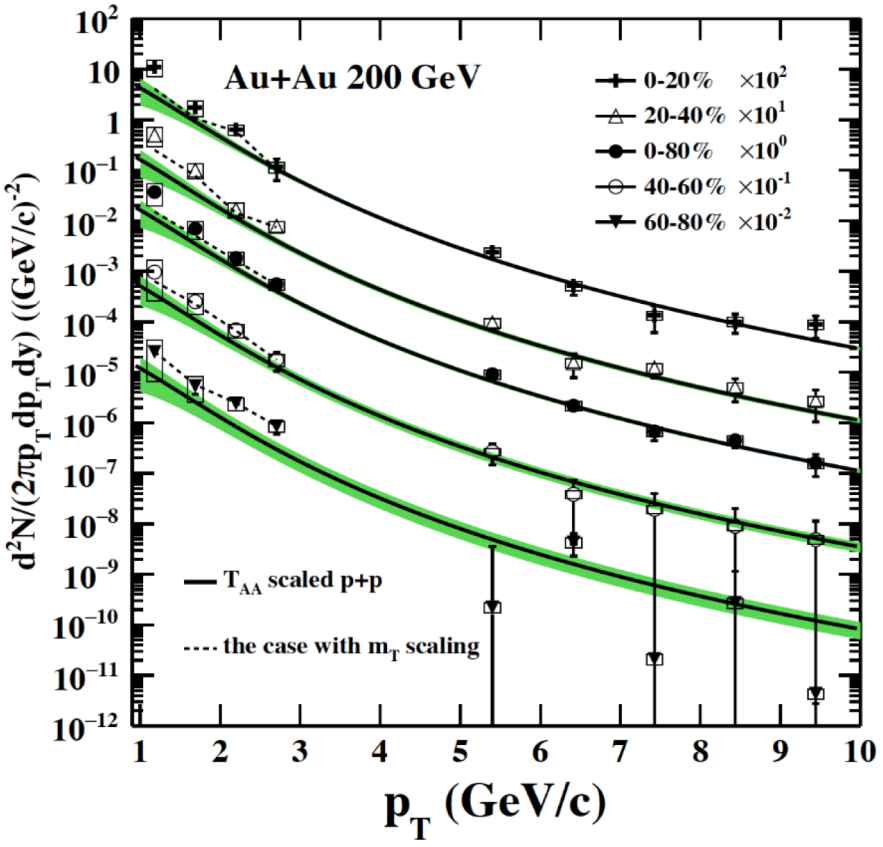
cocktail normalized to 0-30MeV/c^2

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

More fit plots in backup.

Direct virtual photon yield and uncertainties

STAR, PLB, 770 (2017) 451-458



$$\frac{2\alpha dN_\gamma^{dir}(p_T)}{3\pi M_{ee} dp_T} = rF_{dir}\frac{1}{M_{ee}},$$

$$\frac{d^2N_\gamma^{dir}(p_T)}{2\pi p_T dp_T dy} = \frac{3rF_{dir}}{4\alpha p_T dy} = r\frac{d^2N_\gamma^{inc}(p_T)}{2\pi p_T dp_T dy},$$

F_{dir}: f_{dir} normalization factor

Compared to pp reference, thermal photons can be observed

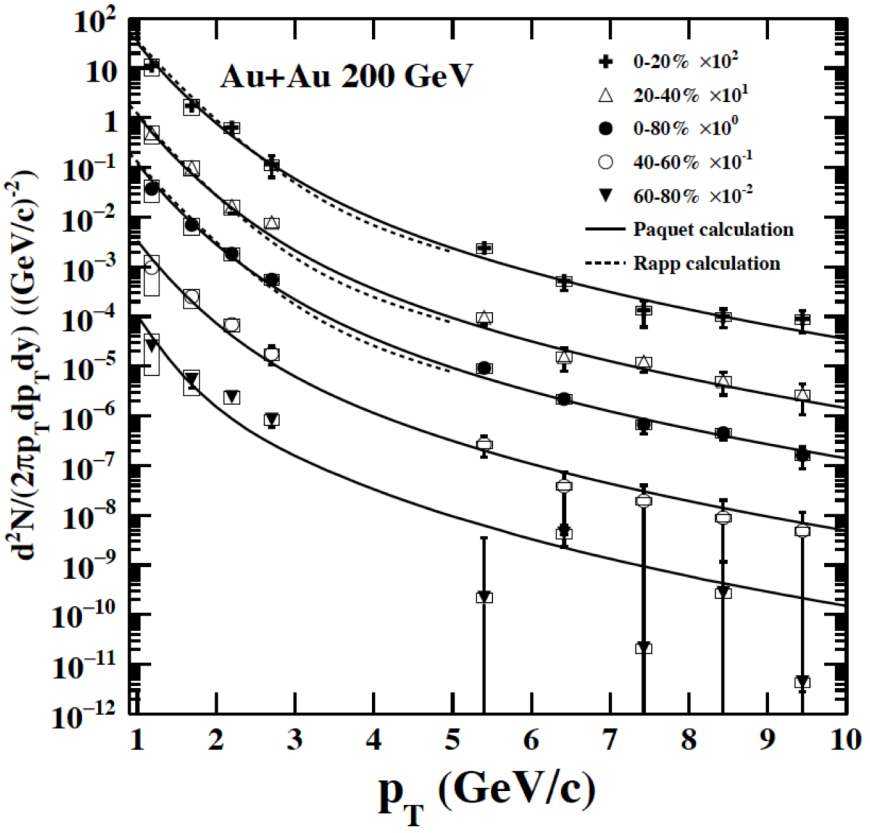
p+p baseline is from PHENIX

~2% run difference

Source	Centrality 0–80%	Centrality 0–20%	Centrality 20–40%	Centrality 40–60%	Centrality 60–80%
Fit range	14%	13%	15%	9%	16%
π^0/η	2–43%	2–31%	1–35%	2–71%	1–70%
$c\bar{c}$	0–6%	0–4%	0–4%	0–6%	0–5%
Global	15%	15%	15%	15%	15%
Normalization	0.2%	0.2%	0.1%	0.2%	0.1%
RunDiff	2.2%	2.7%	0.8%	0.5%	1.2%
Total	20–48%	19–37%	21–41%	17–73%	21–74%

Direct photon at STAR

STAR, PLB, 770 (2017) 451-458

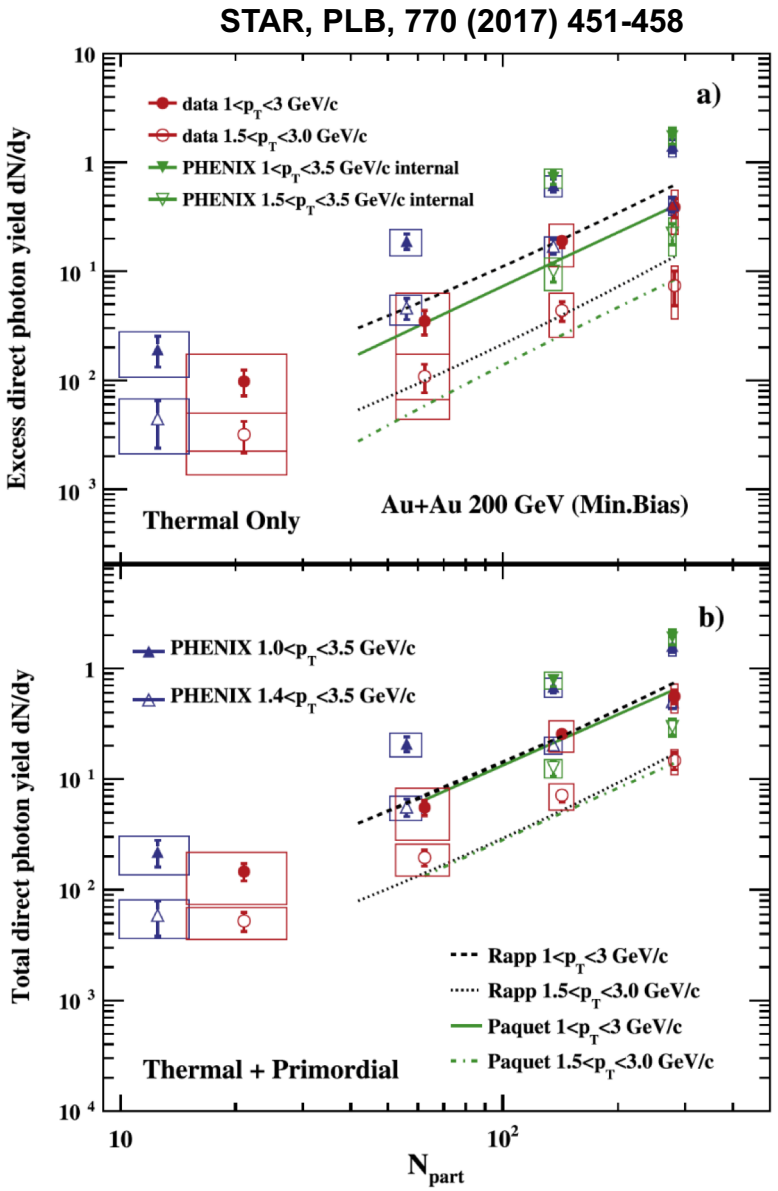


Model predictions considering –

- thermal radiation
- in-medium ρ meson
- other mesonic interactions in the hadronic gas
- primordial contributions from the initial hard parton scattering

- Model calculations are consistent with the yield within uncertainties except some bins in 60-80%
- In most peripheral, hydrodynamic calculations might not be applicable
- Uncertainty in peripheral centrality bin definition

Direct photon dN/dy



Since the *p* + *p* references have a large uncertainty, we also compare the total direct photon yield to the sum of thermal and primordial contributions in the models

PHENIX data are from:
[PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301]
[PHENIX Collaboration, Phys. Rev. C 91 (2015) 064904]

Future measurement

- **Different collision energies:** 54GeV Au+Au data taken in Run17 ~ 1.2 B
- **Different collision systems:** 200GeV Zr+Zr, 200GeV Ru+Ru -- Isobaric data taken in Run18 ~3.1B (1.5B in proposal), daily switch to minimize the systematic uncertainty
- **Beam Energy Scan Phase II at RHIC:**
  - ✓ 7.7, 9.1, 11.5, 14.5 and 19.6 GeV in 2019 and 2020
  - ✓ 10 times more statistics compared to BES-I
  - ✓ May provide direct virtual photon yield in low energies

Current and future STAR data provide good opportunity to study the collision energy and collision system dependence

Summary

- ✓ **Thermal photons observed in Au+Au collisions**
- ✓ **Run10 and Run11 results are consistent with each other within ~ 2%**
- ✓ **Model calculation simultaneously describe dielectron and direct virtual photon results**
- ✓ **More results expected based on current and future data collected at STAR**

Thank you for your attention!