Electromagnetic probes at RHIC

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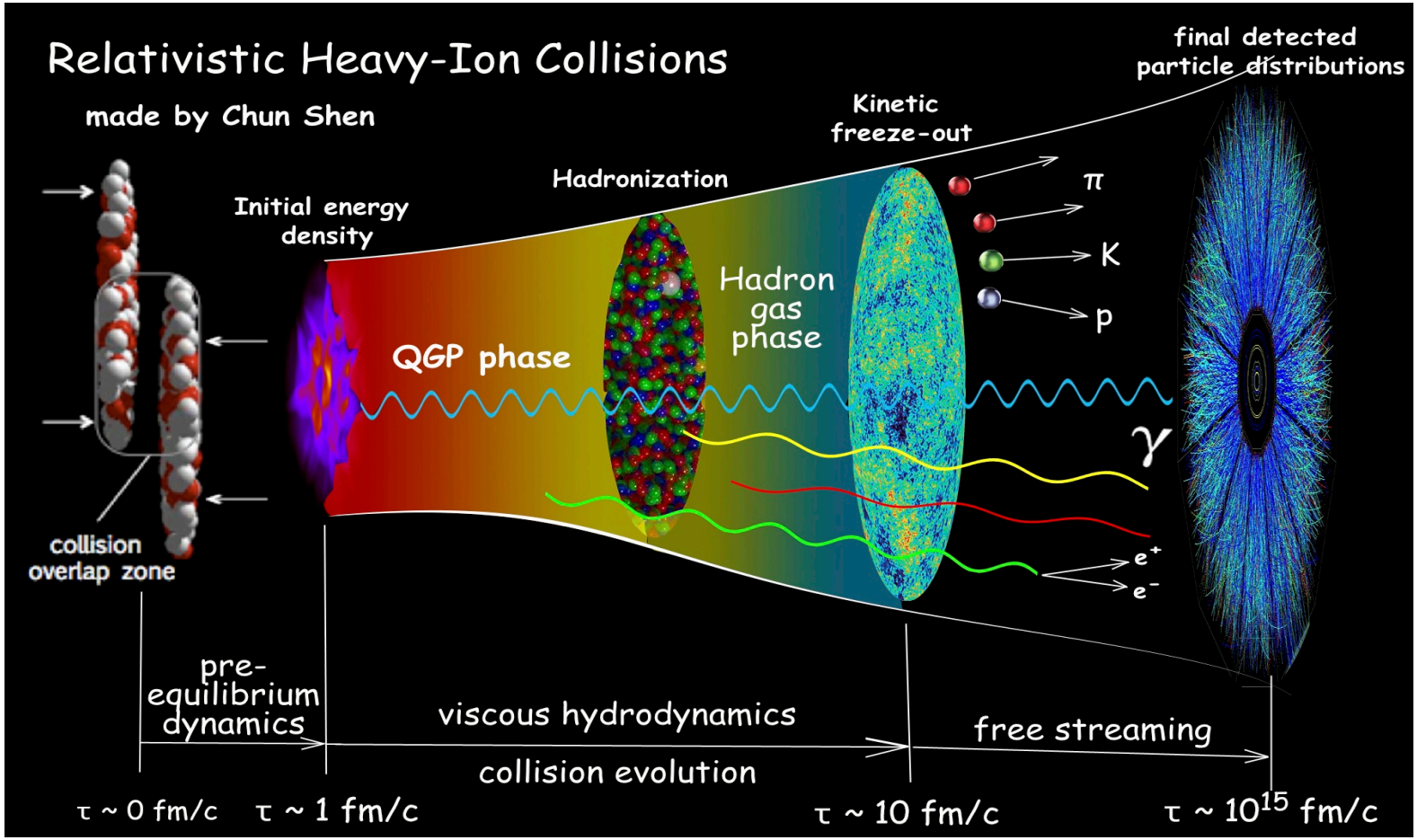
Outline

- ✓ Introduction on EM probes
- ✓ Direct photon results
- ✓ Dilepton results
- ✓ Summary

Electromagnetic probes in HIC



Dileptons and real photons —— idea electromagnetic probes

- ✓ Little interaction with the medium
- ✓ Produced at all stages of the system evolution
- ✓ Bring production information to “Lab”
- ✓ Sensitive to electromagnetic force

Outline

- ✓ Introduction on EM probes
- ✓ **Direct photon results**
- ✓ Dilepton results
- ✓ Summary

Direct photons

Direct photons:

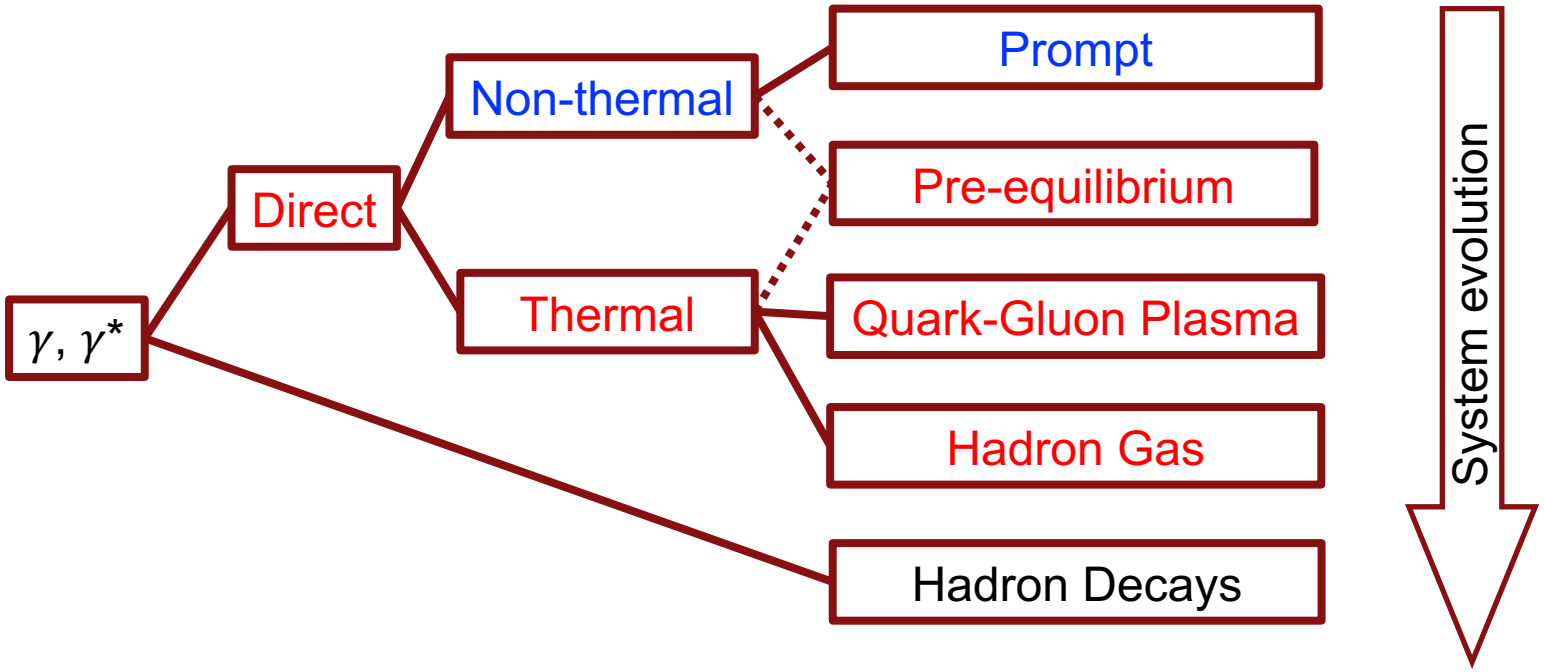
all photons which DO NOT come from hadron decay

Unique probe:

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

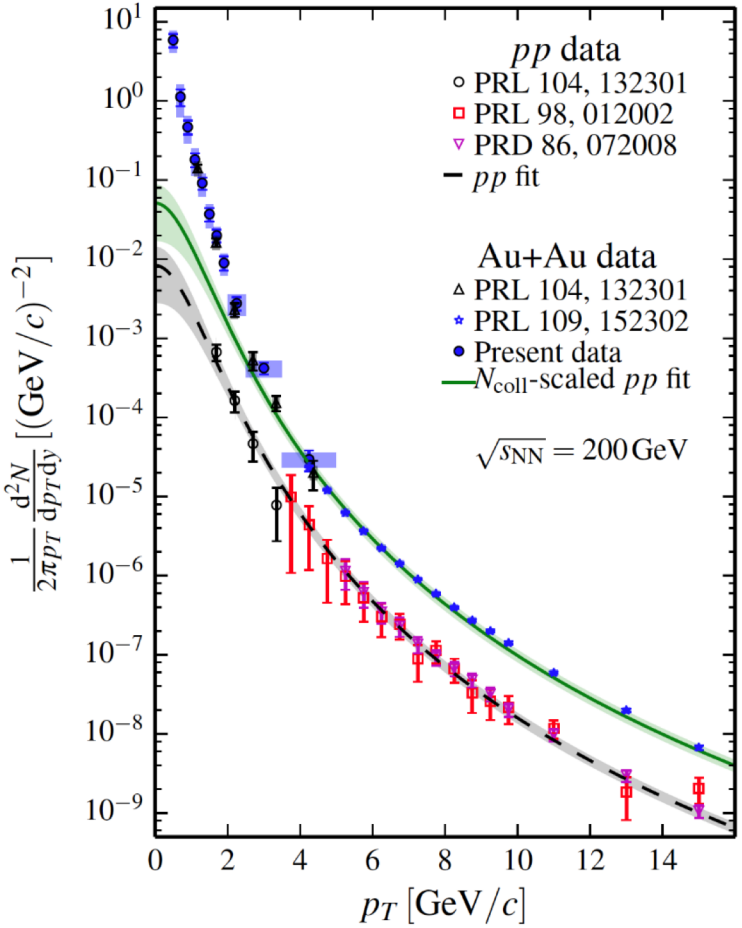
Higher p_T -> Earlier produced

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

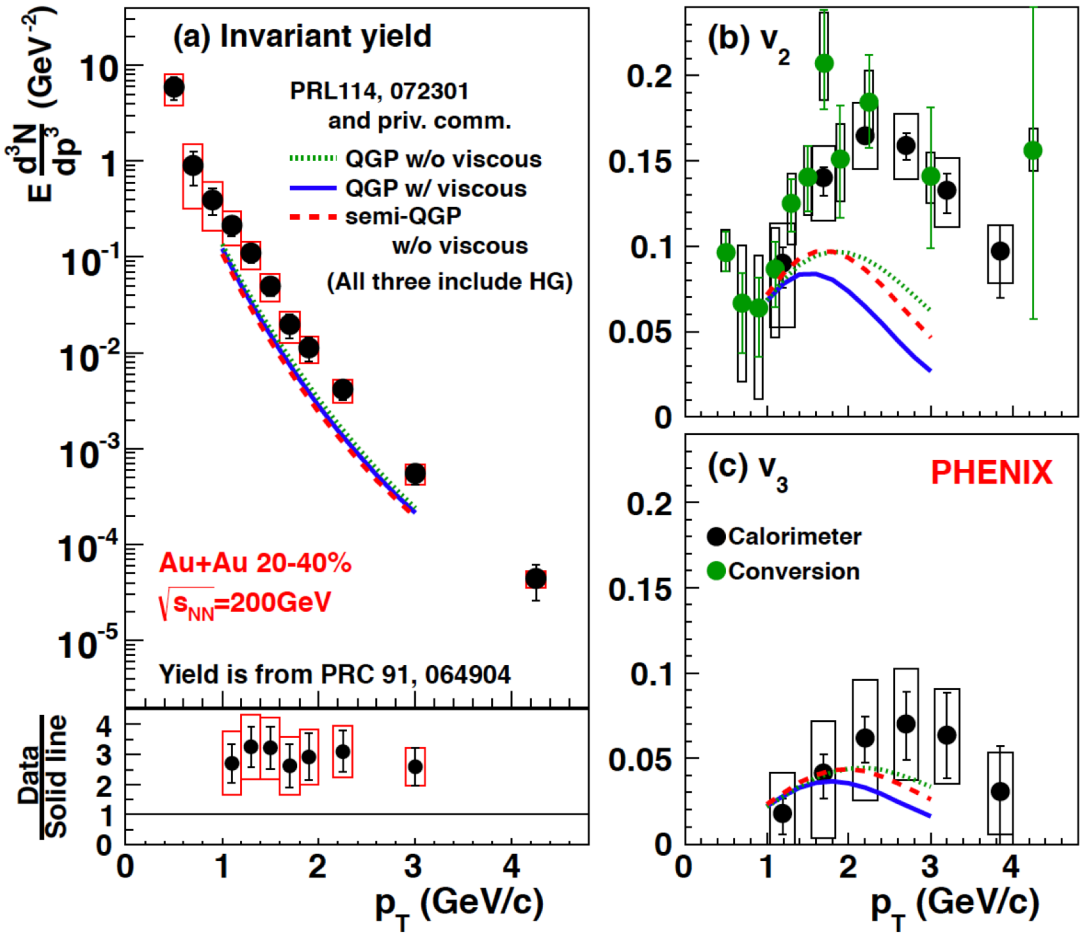


Direct photon at PHENIX

PHENIX, PRC, 91(2015) 064904



PHENIX, PRC, 94(2016) 064901



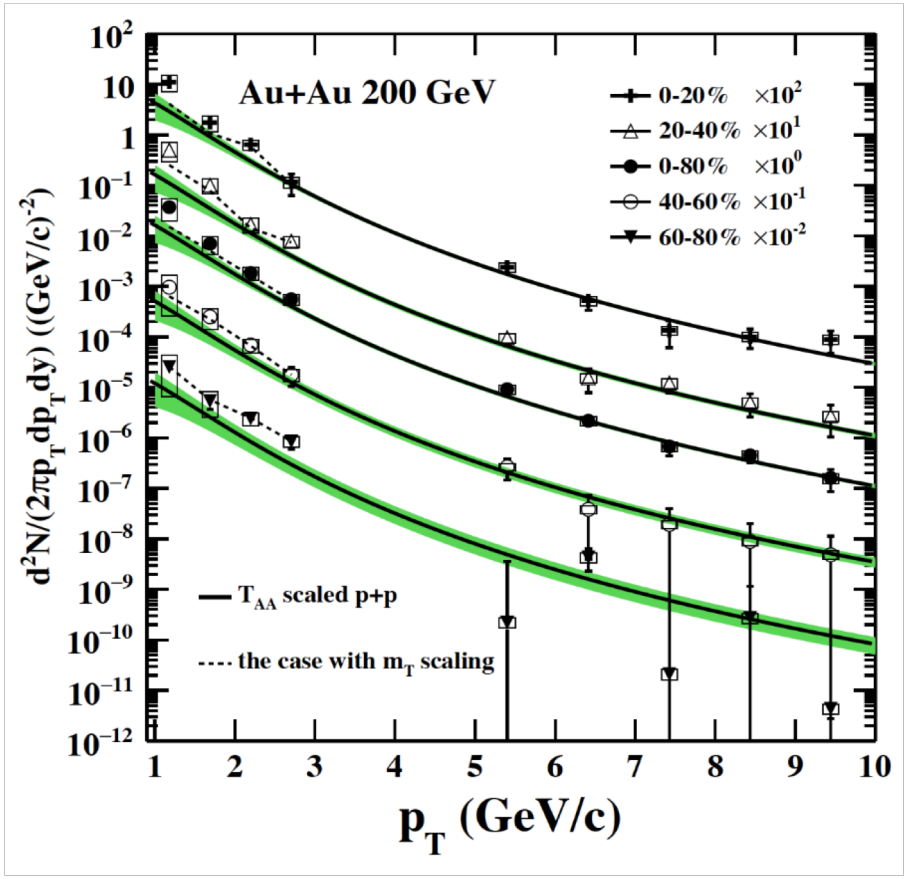
Compared to pp reference, thermal photons can be observed

Large yield and v_n challenge understanding of sources, emission rates and space-time evolution

Photon puzzle is still there!

Direct photon at STAR

STAR, PLB, 770 (2017) 451-458



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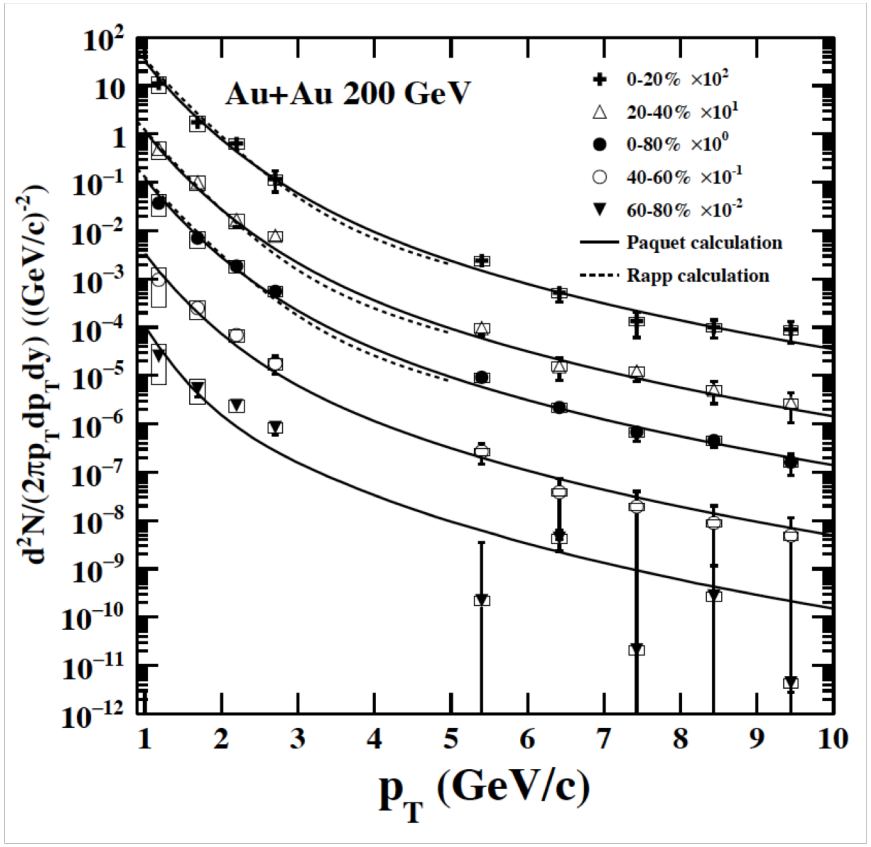
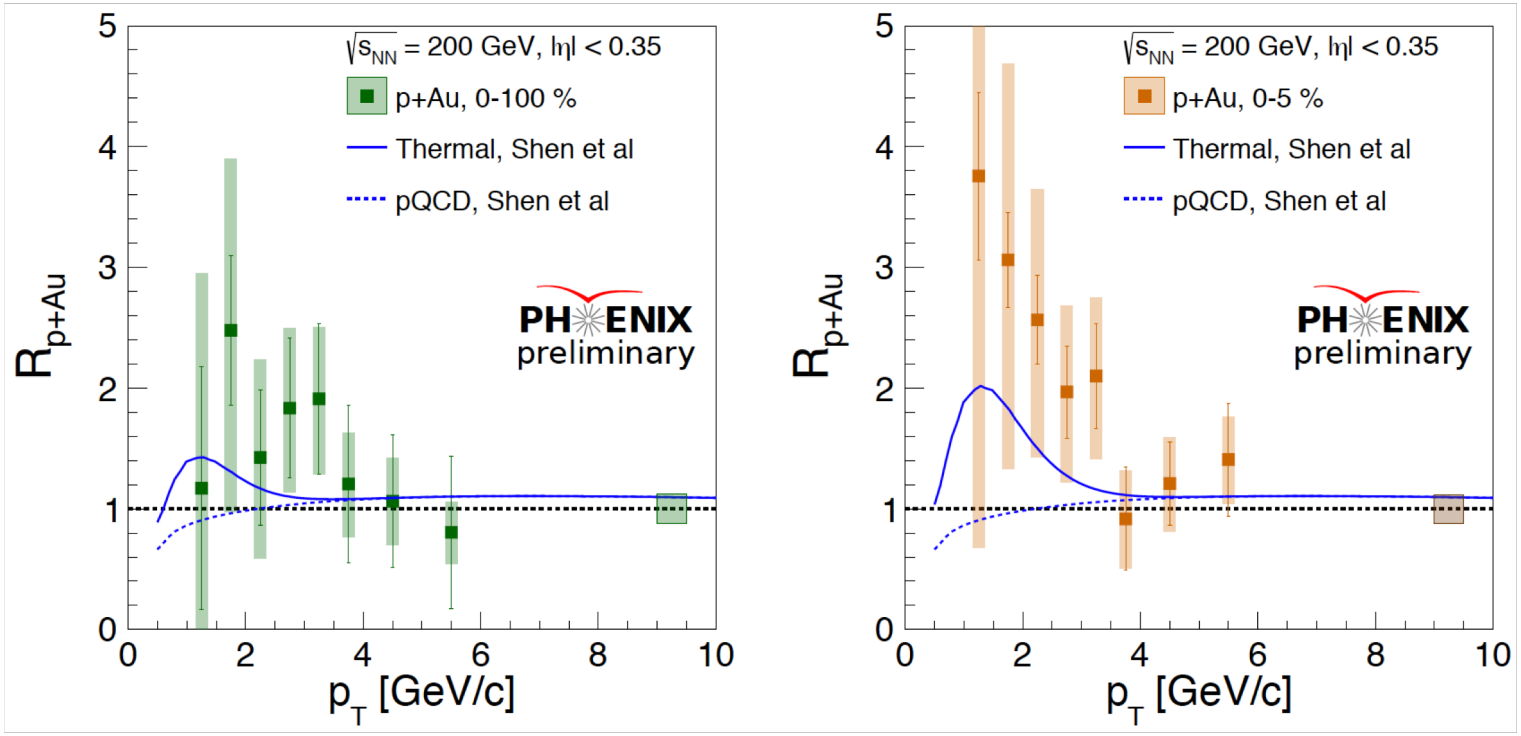


Model predictions considering thermal radiation are consistent with the yield within uncertainties except some bins in 60-80%

Direct photon in small system

PHENIX, arXiv: 1805.04084

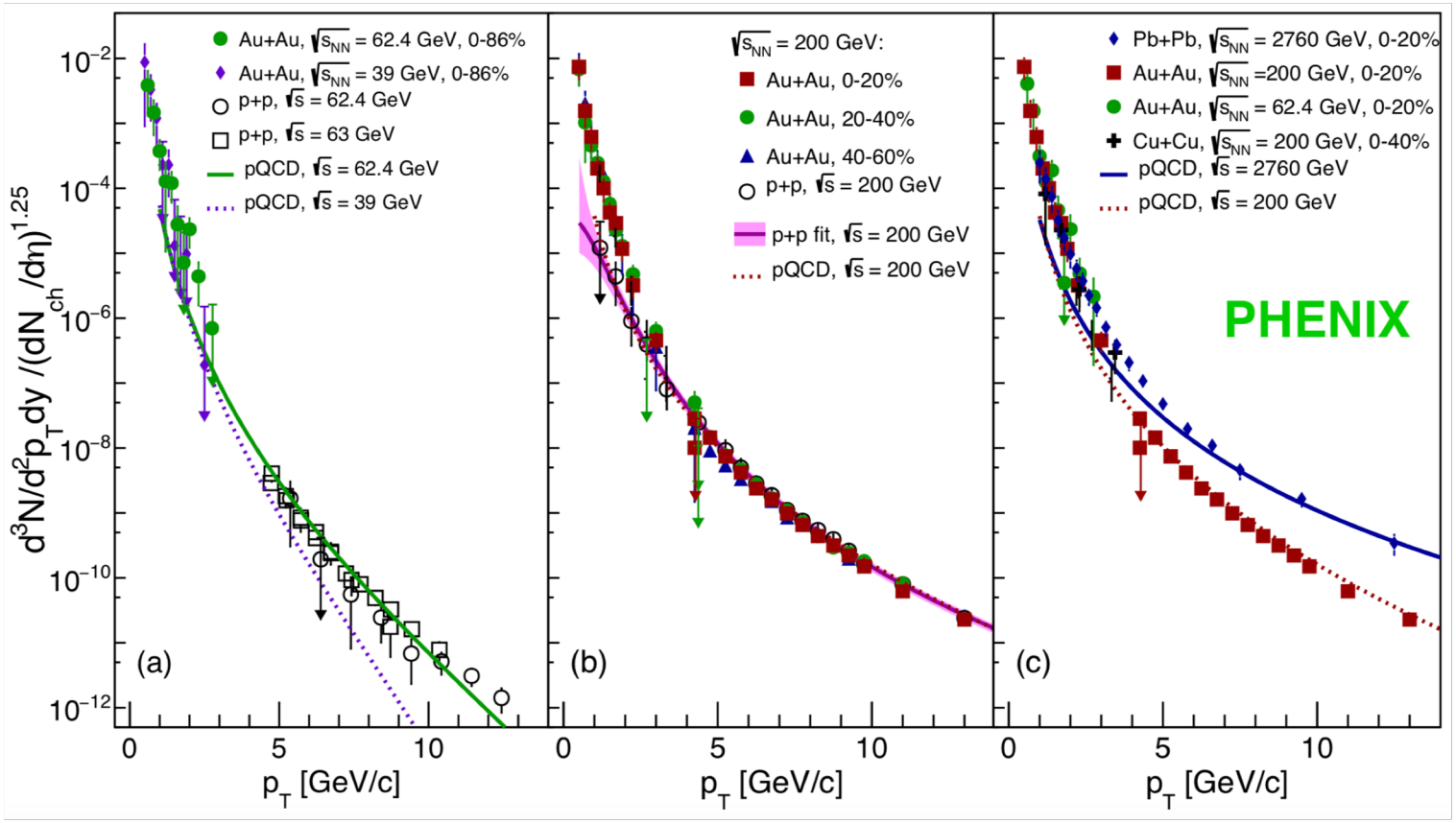


Scan on small systems, hint enhancement in the high multiplicity collisions

Thermal photons in small system with high multiplicity?

Direct photon beam energy dependence

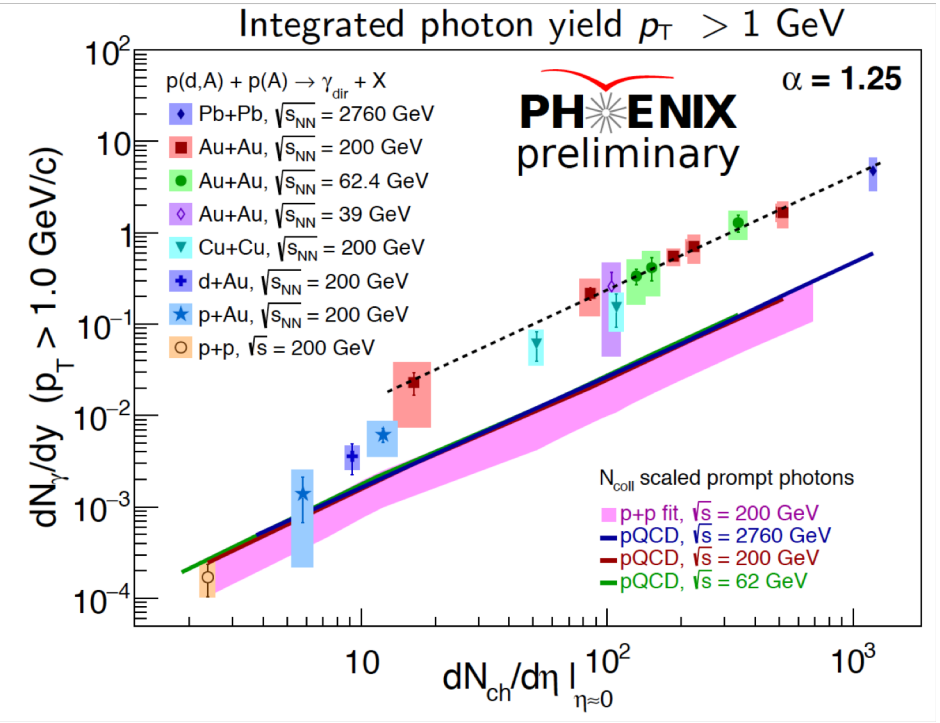
PHENIX, arXiv: 1805.04084



✓ Scan over beam energies

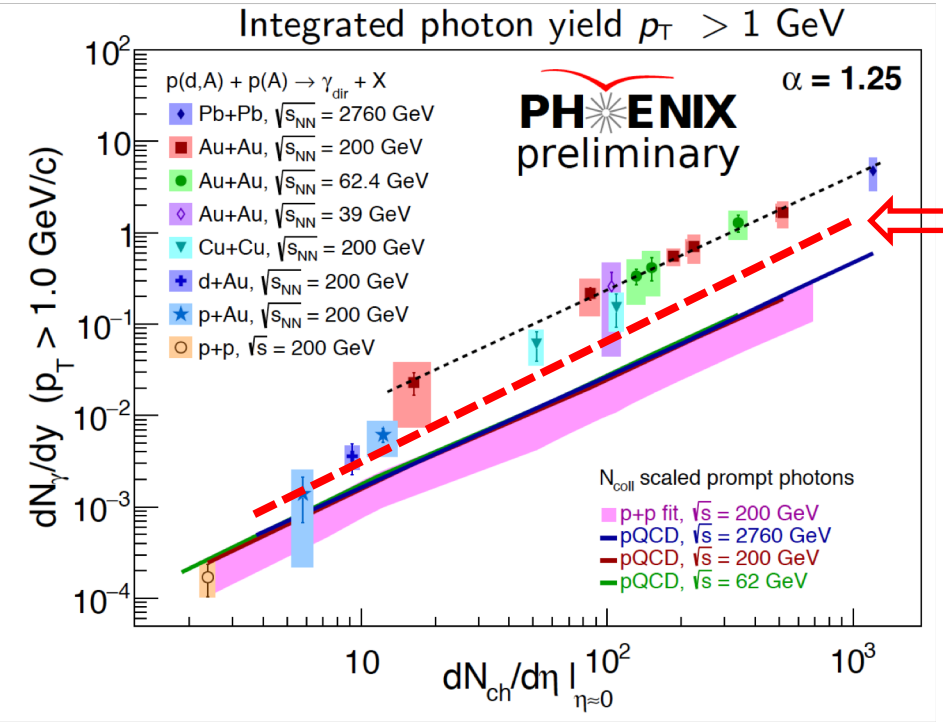
✓ **Similar scaling over different collision energies and different centralities**

Direct photon $dN_{ch}/d\eta$ scaling

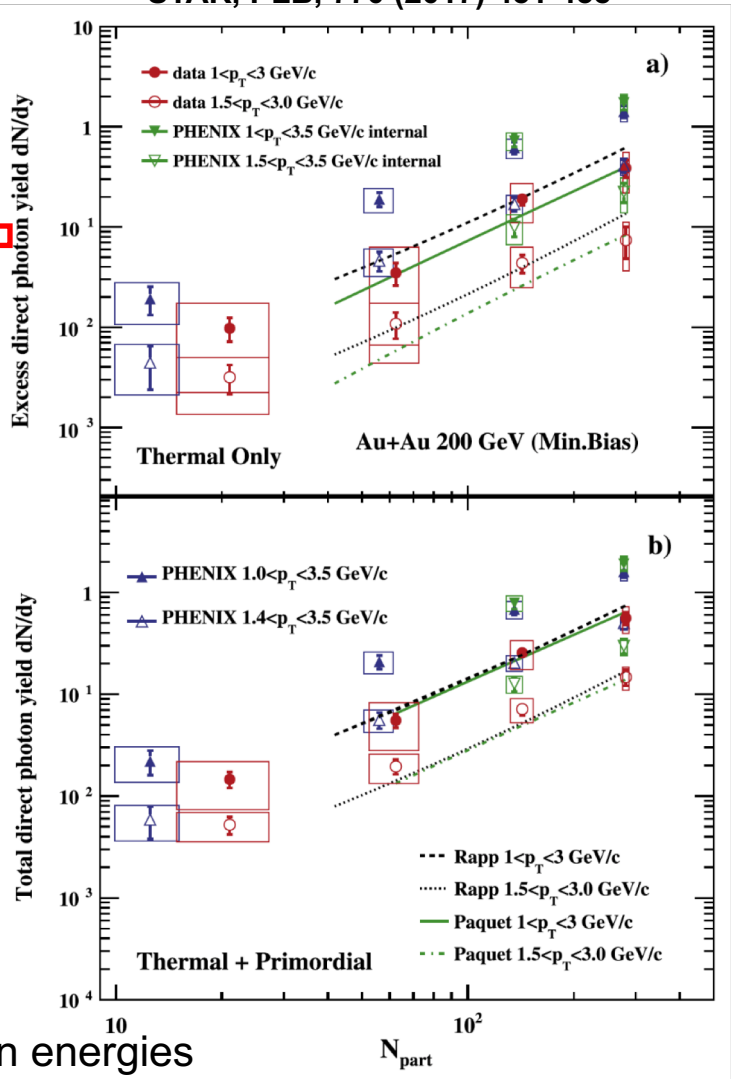


- ✓ Universal scaling across different collision energies
- ✓ Similar source of photons in low p_T range across beam energy

Direct photon $dN_{ch}/d\eta$ scaling



STAR, PLB, 770 (2017) 451-458



Follow different scalings but not quite visible?
Link between small system and Au+Au?

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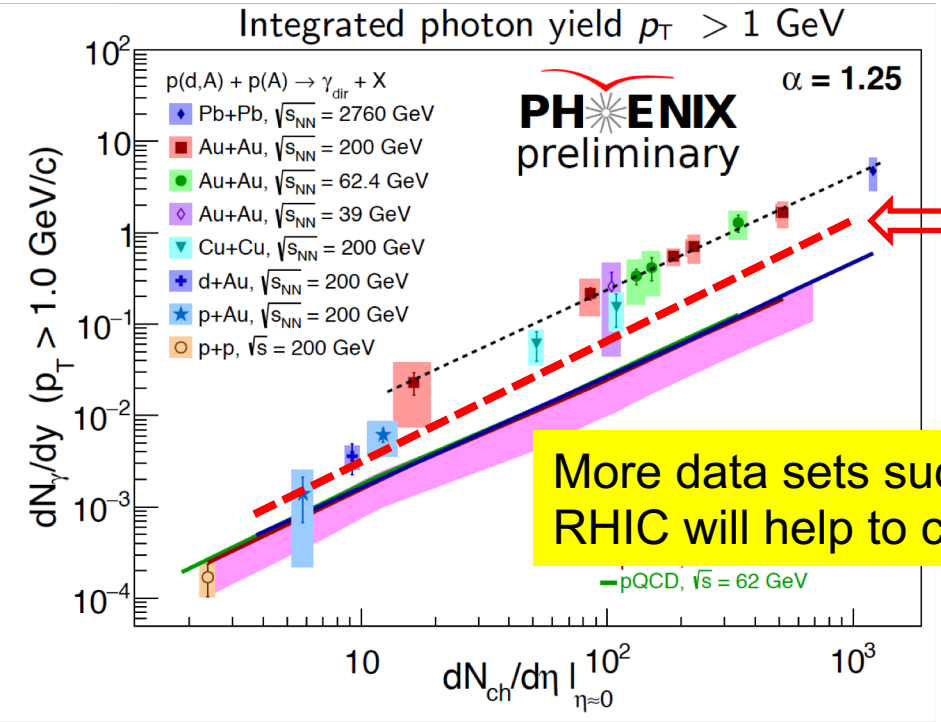
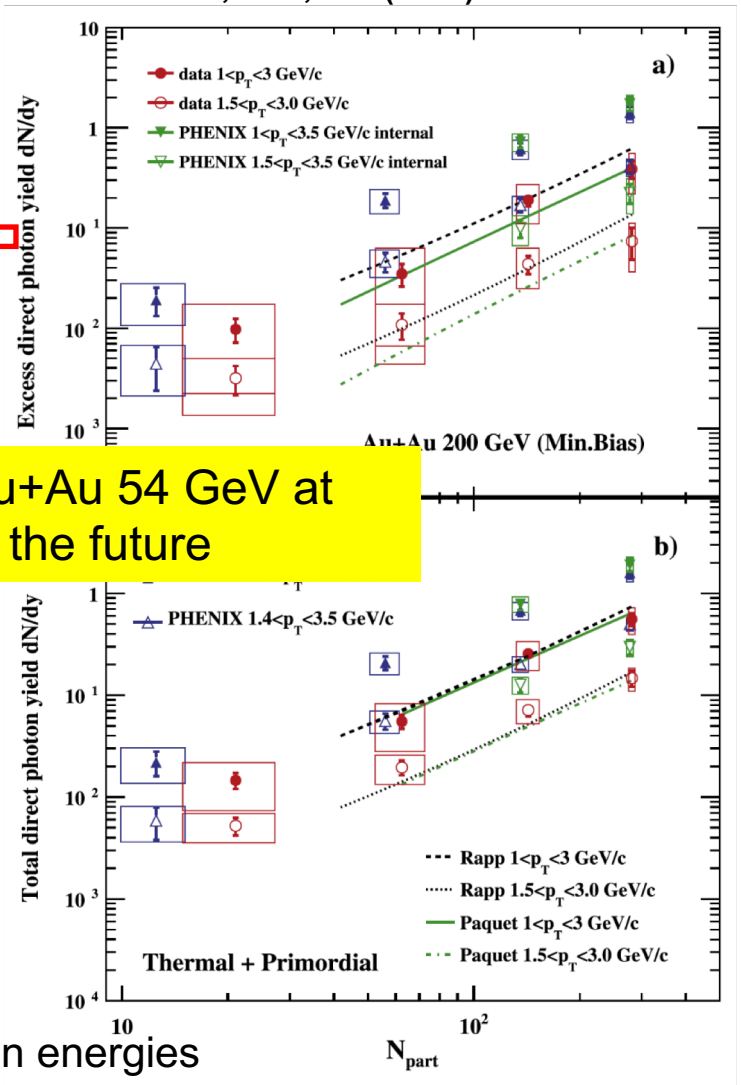
STAR, PLB, 770 (2017) 451-458





More data sets such as Au+Au 54 GeV at RHIC will help to check in the future

Follow different scalings but not quite visible?
Link between small system and Au+Au?

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Outline

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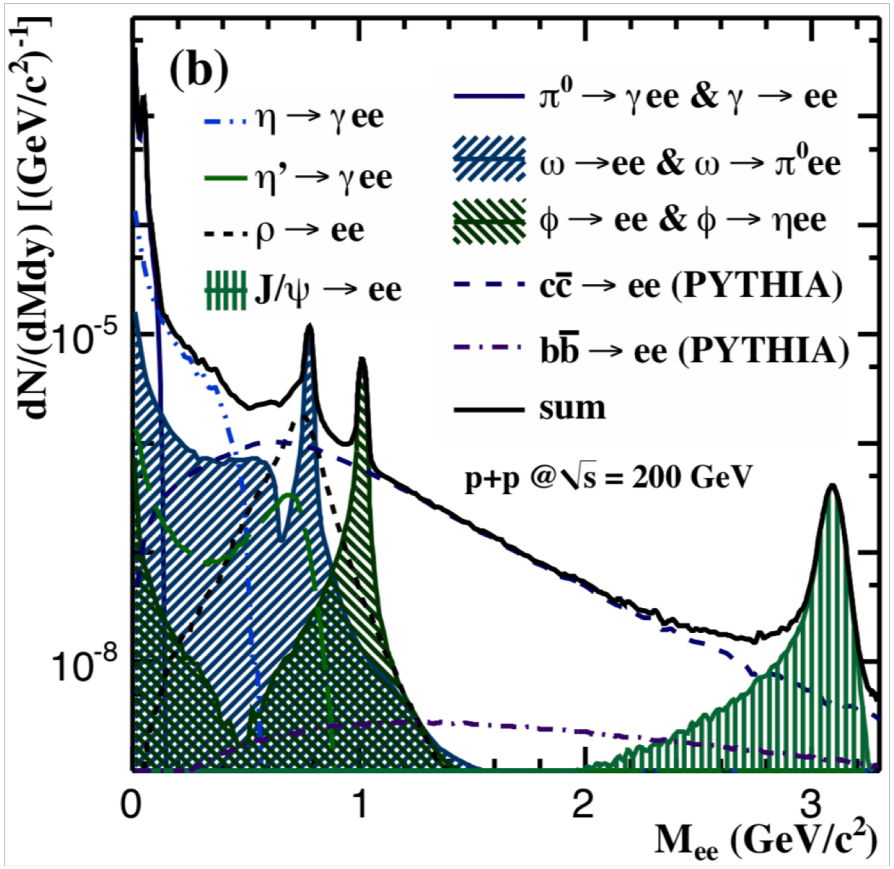
- ✓ Direct photon results
- ✓ **Dilepton results**
- ✓ Summary

Dileptons

Higher M_{ll} -> Earlier produced

STAR, PRC, 86 (2012) 024906



Low Mass Region (<1.1 GeV/c^2):

- ✓ vector meson in-medium modification
- ✓ link to chiral symmetry restoration

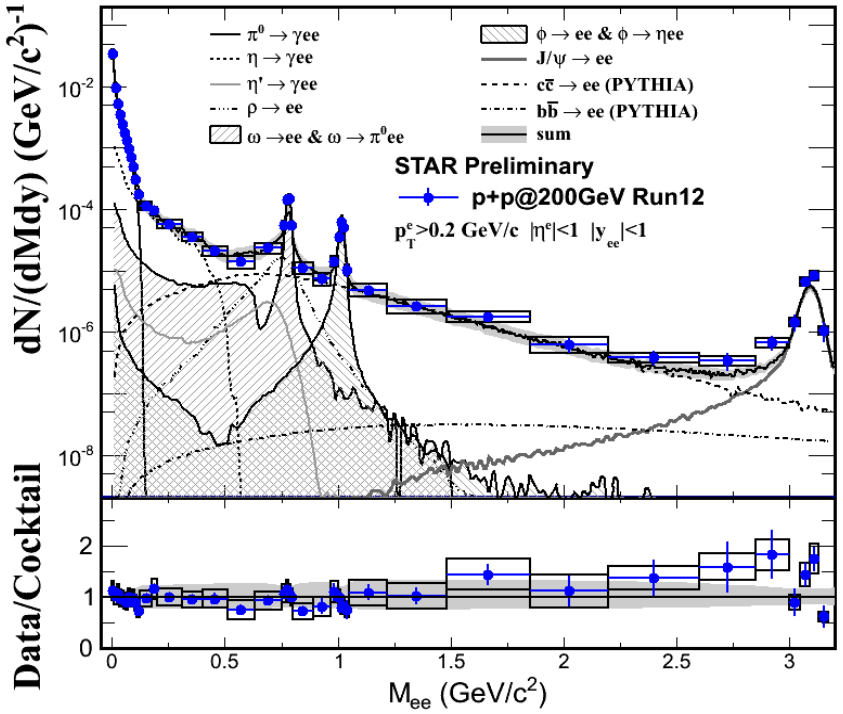
Intermediate Mass Region (1.1-3.0 GeV/c^2):

- ✓ thermal probe of QGP $dN/dm_{ee} \sim e^{-m/T}$
- ✓ dominant contribution from semi-leptonic decays

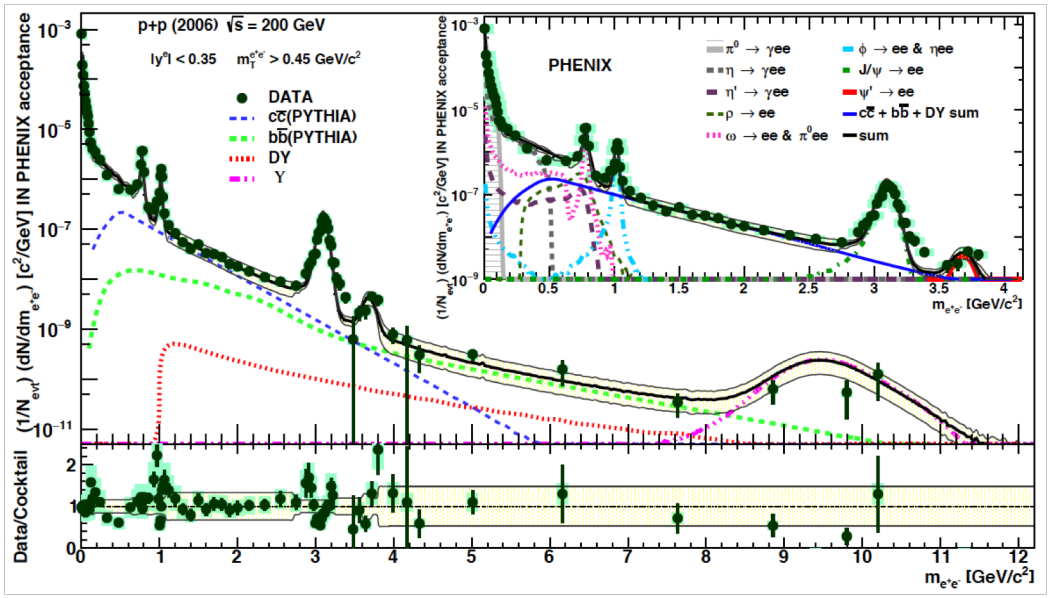
High Mass Region (>3.0 GeV/c^2)

- ✓ Primordial emission
- ✓ Drell-Yan process
- ✓ J/ψ and Upsilon

Dilepton in p+p – baseline



PHENIX, PRC, 96 (2017) 024907



- ✓ In p+p collisions, the data are consistent with vacuum ρ distribution
- ✓ Hadronic cocktail simultaneously describe data at all mass regions
- ✓ Consistent with our understanding for p+p collisions – no "hot" contribution
- ✓ Cocktail simulation can be trusted

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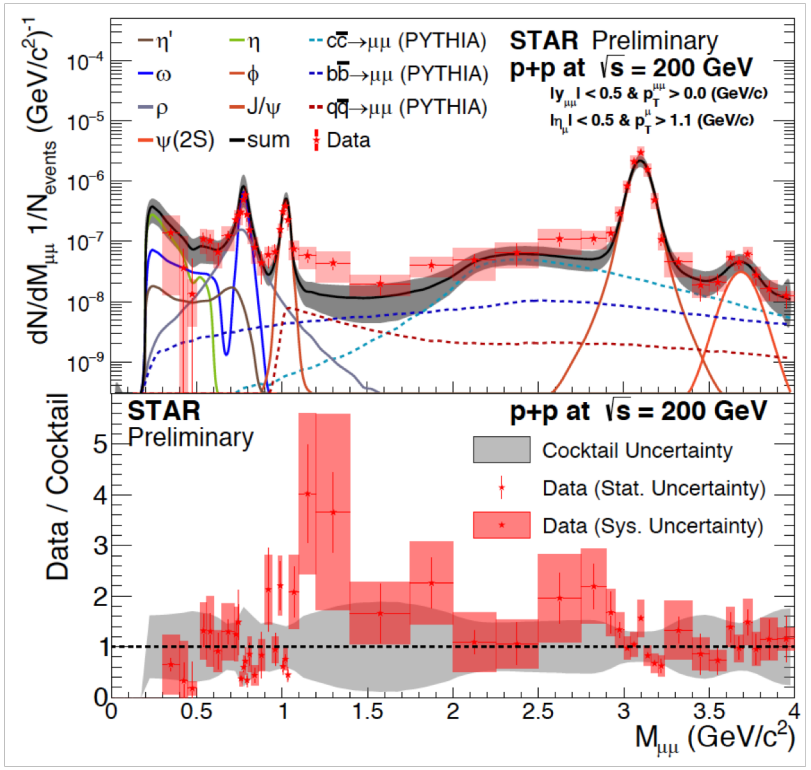
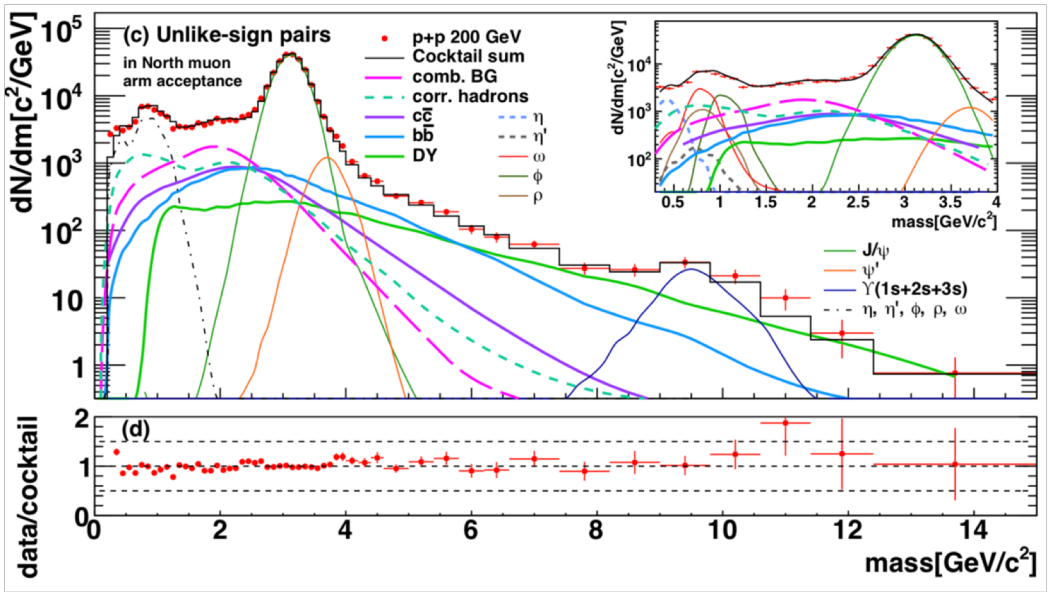


PHENIX, arXiv:1805.02448



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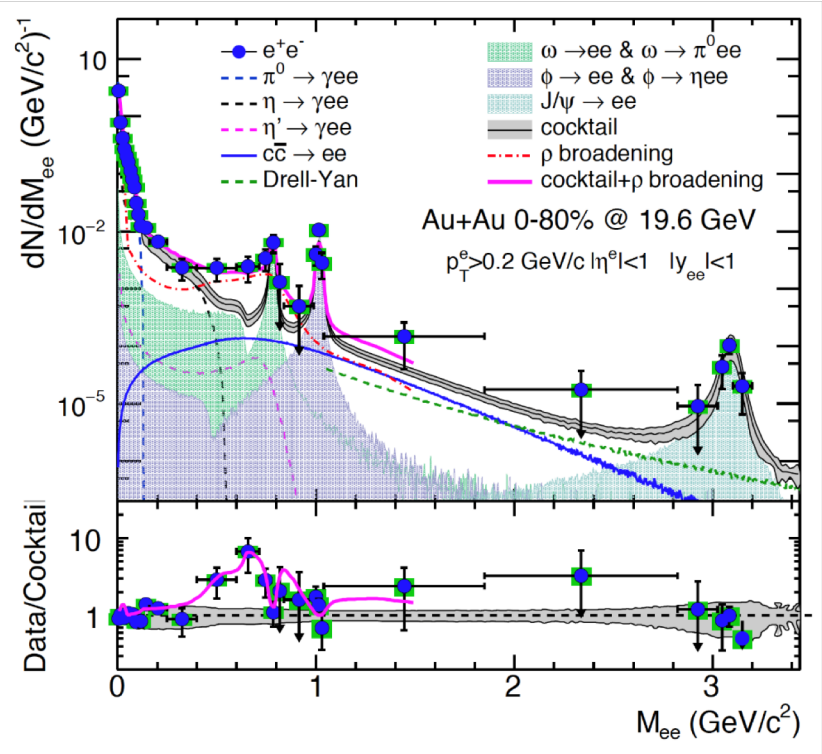
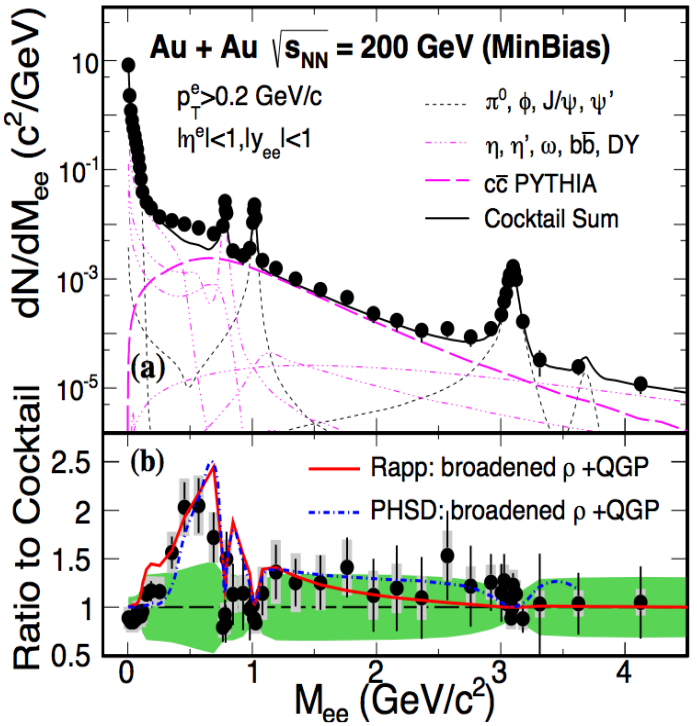
Dielectron continuum at STAR

Au+Au 19.6GeV



STAR, PLB, 750 (2015) 64-71

Au+Au 200GeV

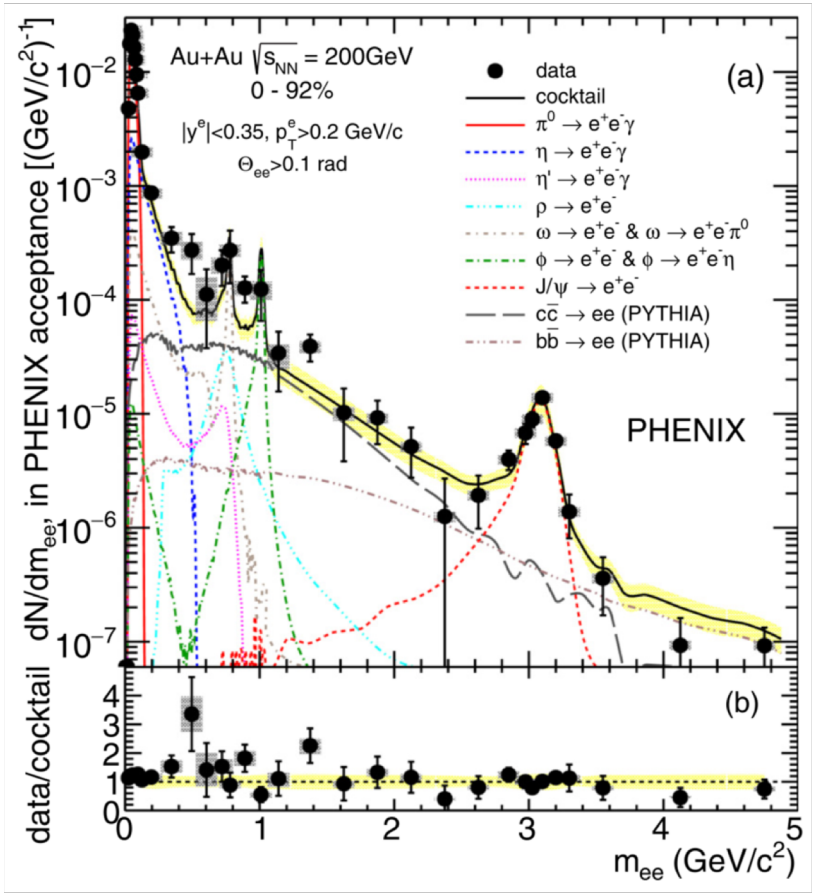


STAR, PRL, 113 (2014) 022301

- ✓ In ρ-like region, clear excesses are observed from RHIC top energy to low energy
- ✓ Consistent with ρ broadening scenario
- ✓ **Simultaneous matched theoretical calculations for both dielectron and direct virtual photon**

Dielectron continuum at PHENIX

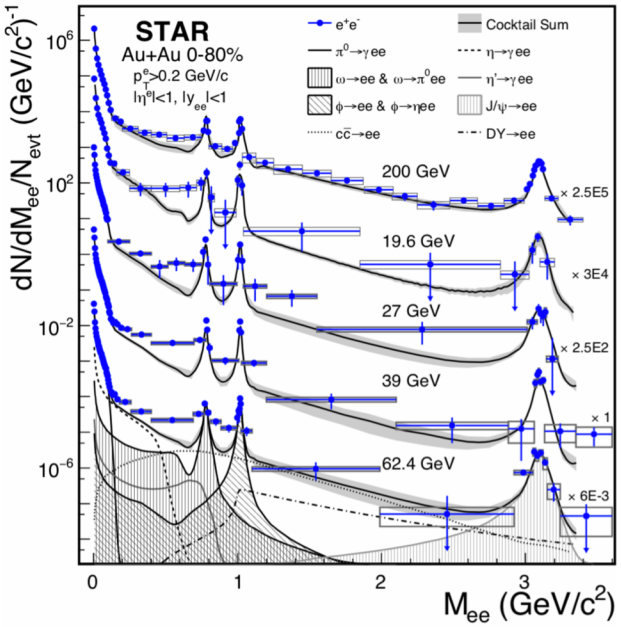
PHENIX, PRC, 93(2016) 014904

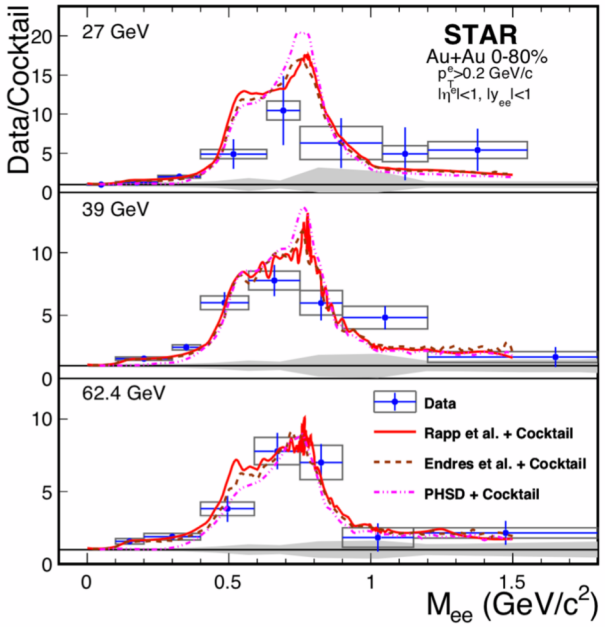


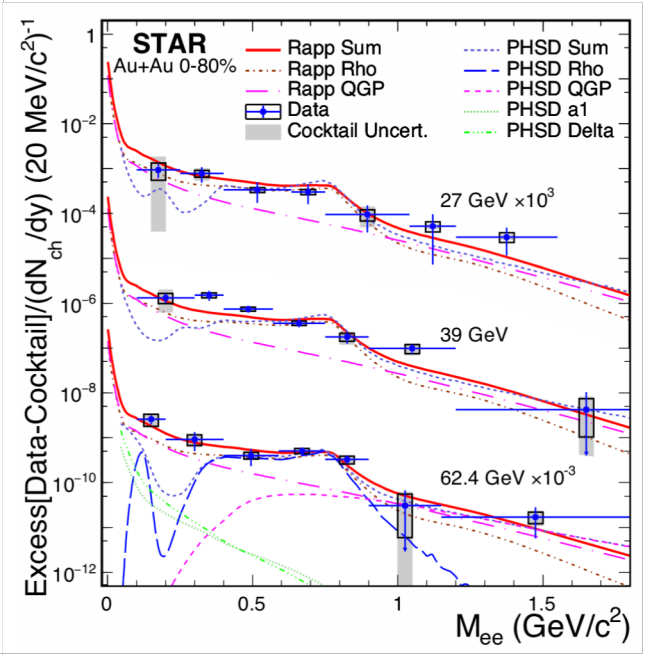
- ✓ New results with HBD are with better precision compared to previous results.
- ✓ The LMR enhancement is consistent with what STAR observed considering the uncertainties.

Dielectron in BES-I

STAR, arXiv:1810.10159

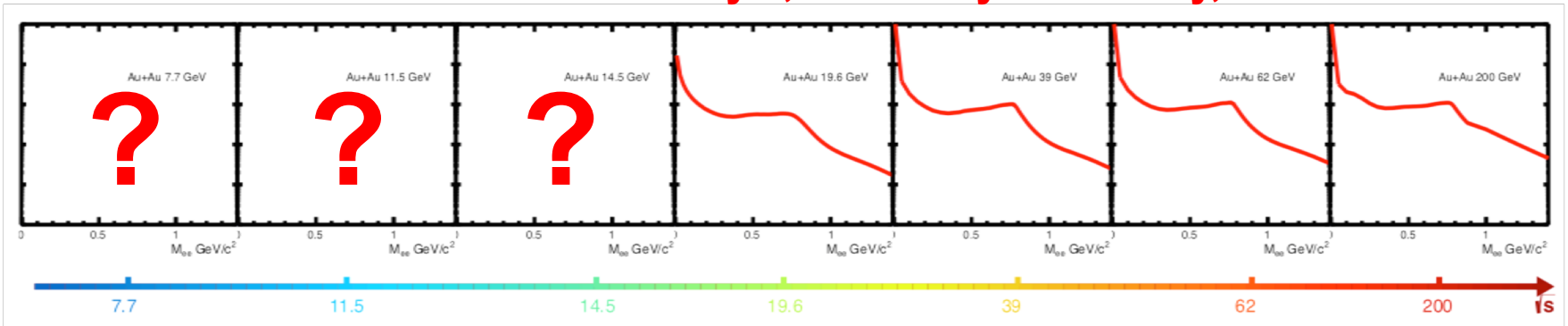






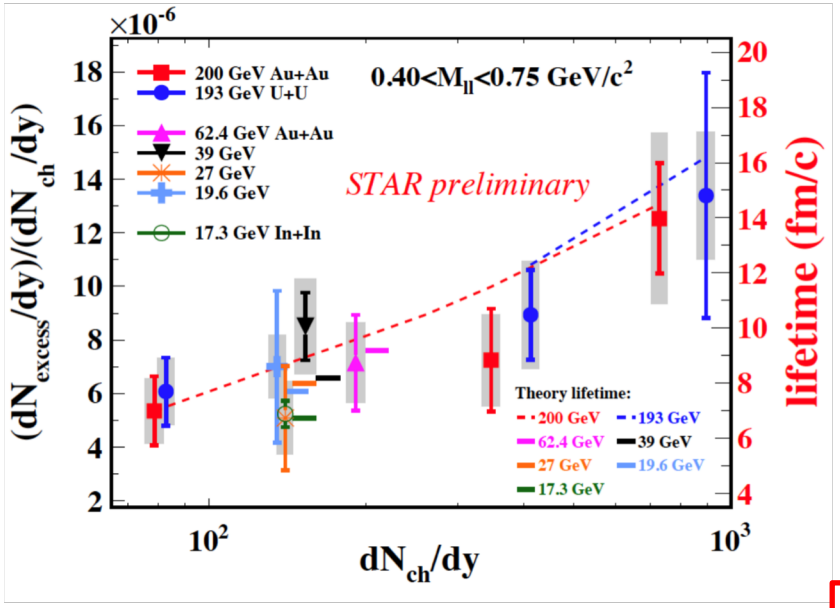
Low mass excesses are consistent with ρ broadening scenario within uncertainties

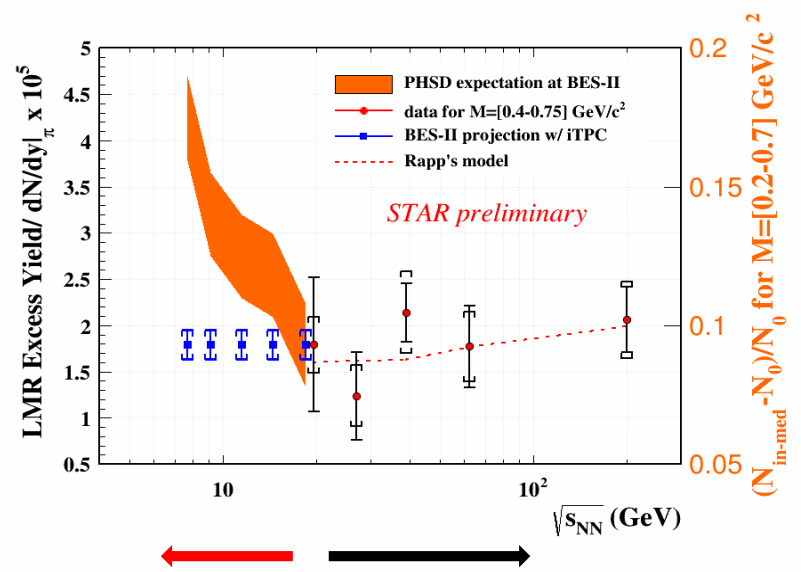
Low-mass e^+e^- emission is effected by T, total baryon density, lifetime



Future In RHIC Beam Energy Scan Phase II

BES-II:
In 2019-2020, scan from 19.6GeV down to 7.7 GeV Au+Au.
Detector upgrades will reduce the systematic uncertainties and extend the acceptance.





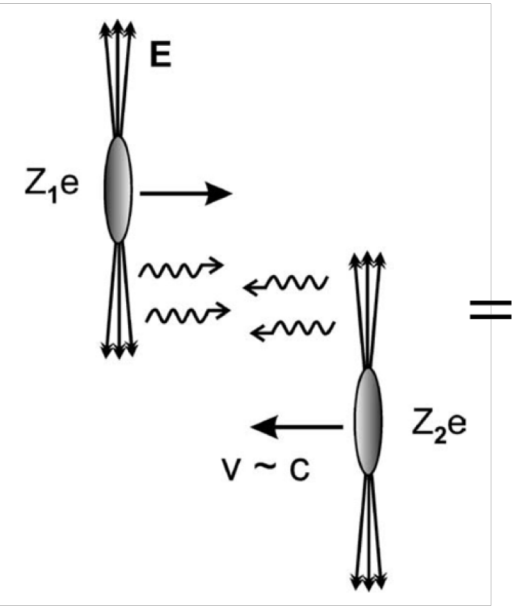
Total baryon density increases

Constant total baryon density

- ✓ Excess yield normalized by dN_{ch}/dy is proportional to lifetime of the medium
- ✓ Constant excess along constant total baryon density
- ✓ More clear pictures of the excess versus lifetime and total baryon density in BES-II

Photon-photon and photon-nucleon interaction –
From Ultra Peripheral Collisions to Hadronic Heavy Ion Collisions

Ann. Rev. Nucl. Part. Sci. 55 (2005) 271
PLB 679 (2009) 321



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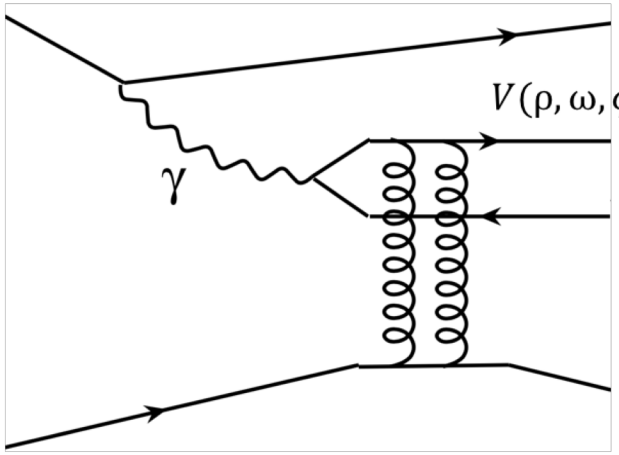

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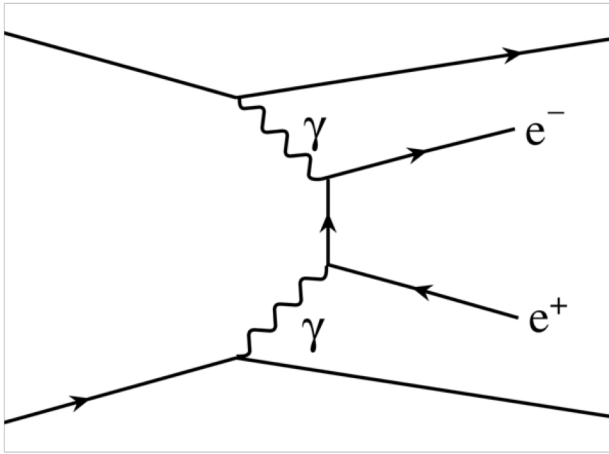


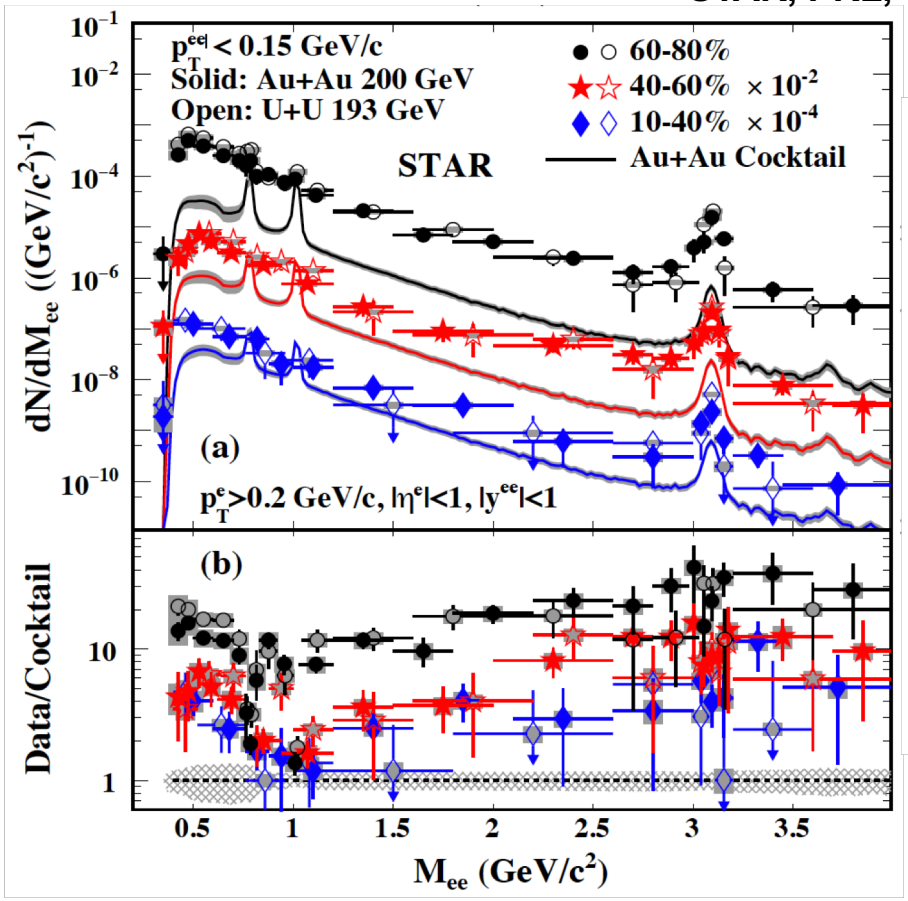
Coherent:

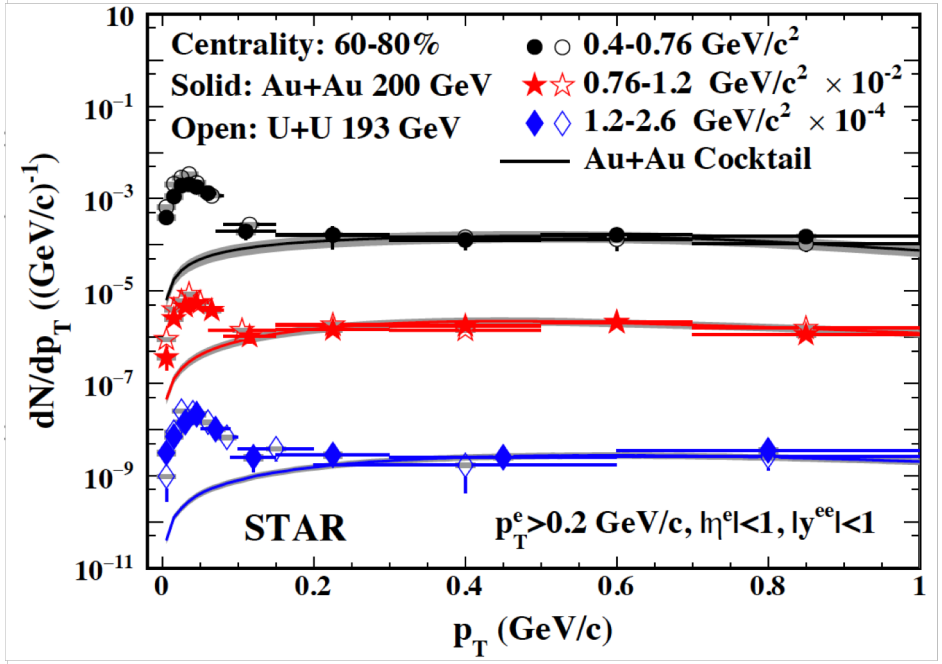
- ✓ Emitted photon/pomeron interacts with the nucleus as a whole
- ✓ Strong coupling results in large cross sections
- ✓ Photon wavelength $\lambda = h/p > R_A$
- ✓ $p_T < h/R_A \sim 30$ MeV/c for heavy ions
- ✓ No overlapping for two collision nucleuses

See Wangmei's talk, Nov. 3rd

Low p_T e^+e^- in Au+Au and U+U at STAR

STAR, PRL, 121 (2018) 132301



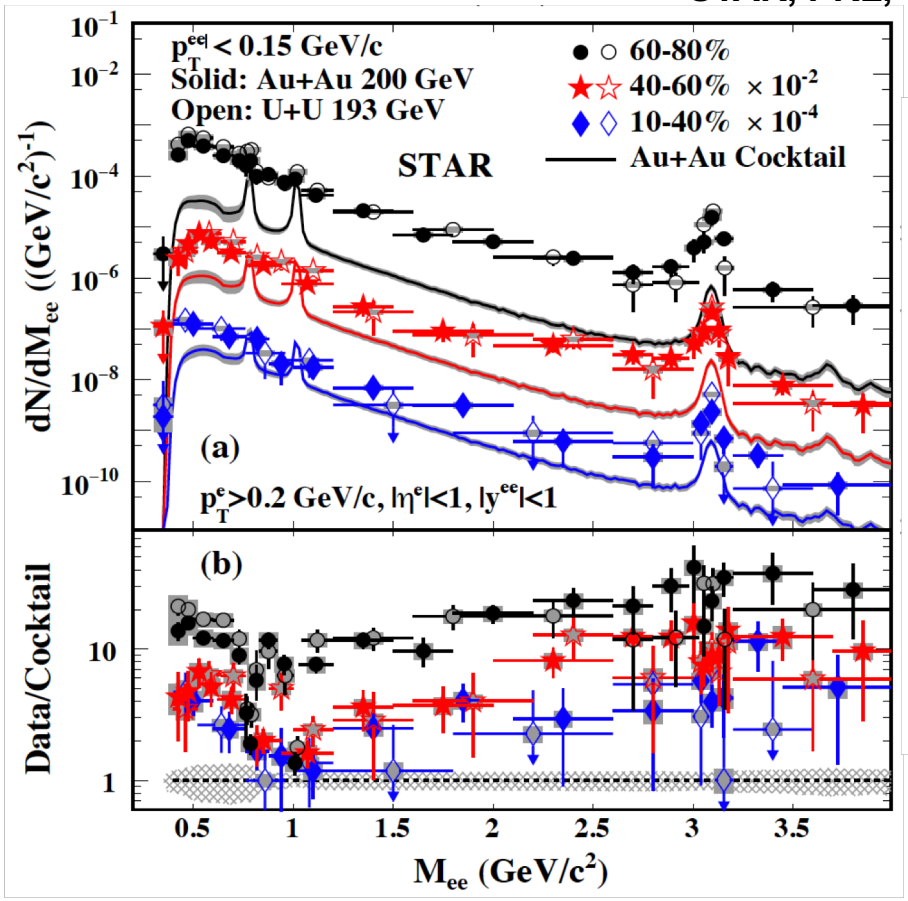


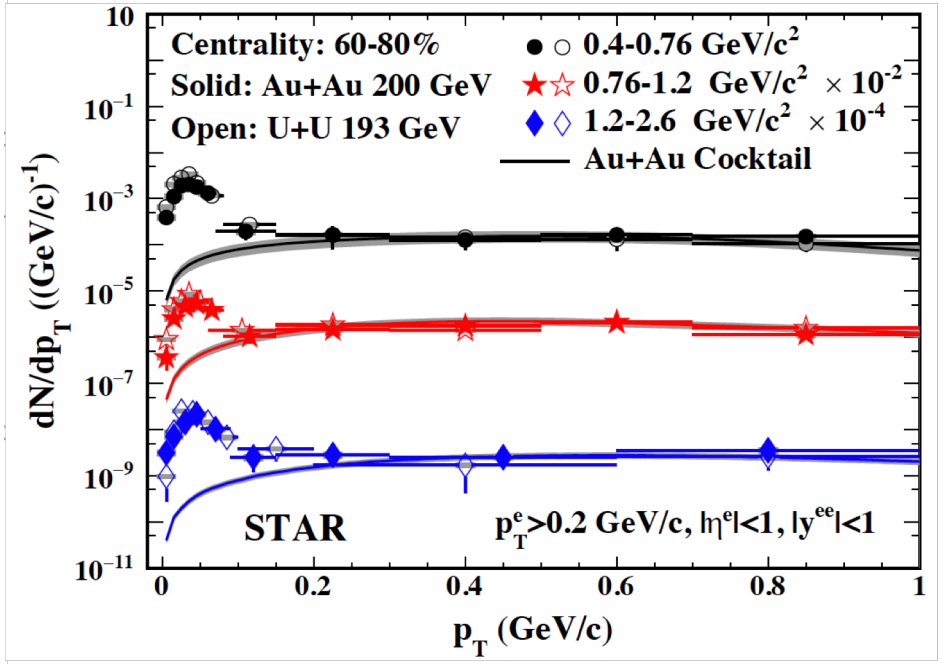
- ✓ Significant enhancement
- ✓ Excess concentrate below $p_T \approx 0.15$ GeV/c
- ✓ Data are consistent with hadronic expectation when $p_T > 0.15$ GeV/c

See Shuai's talk, Nov. 4th

Low p_T e^+e^- in Au+Au and U+U at STAR

STAR, PRL, 121 (2018) 132301





Coherent photon-photon interaction and photon-nucleon interaction in HHIC!
A new topic in dilepton analysis.
May also be observed in dimuon channel

- ✓ Significant enhancement
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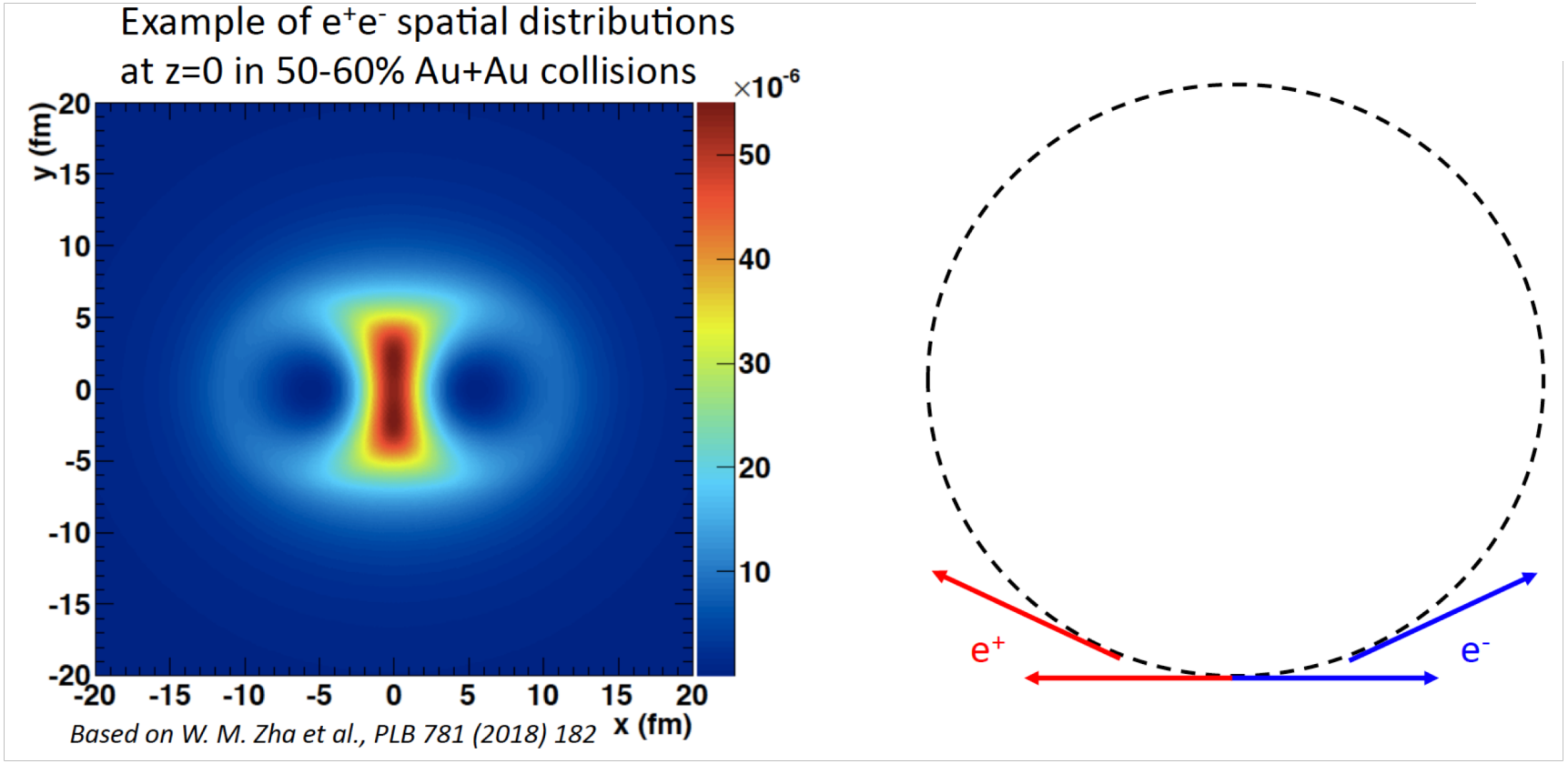
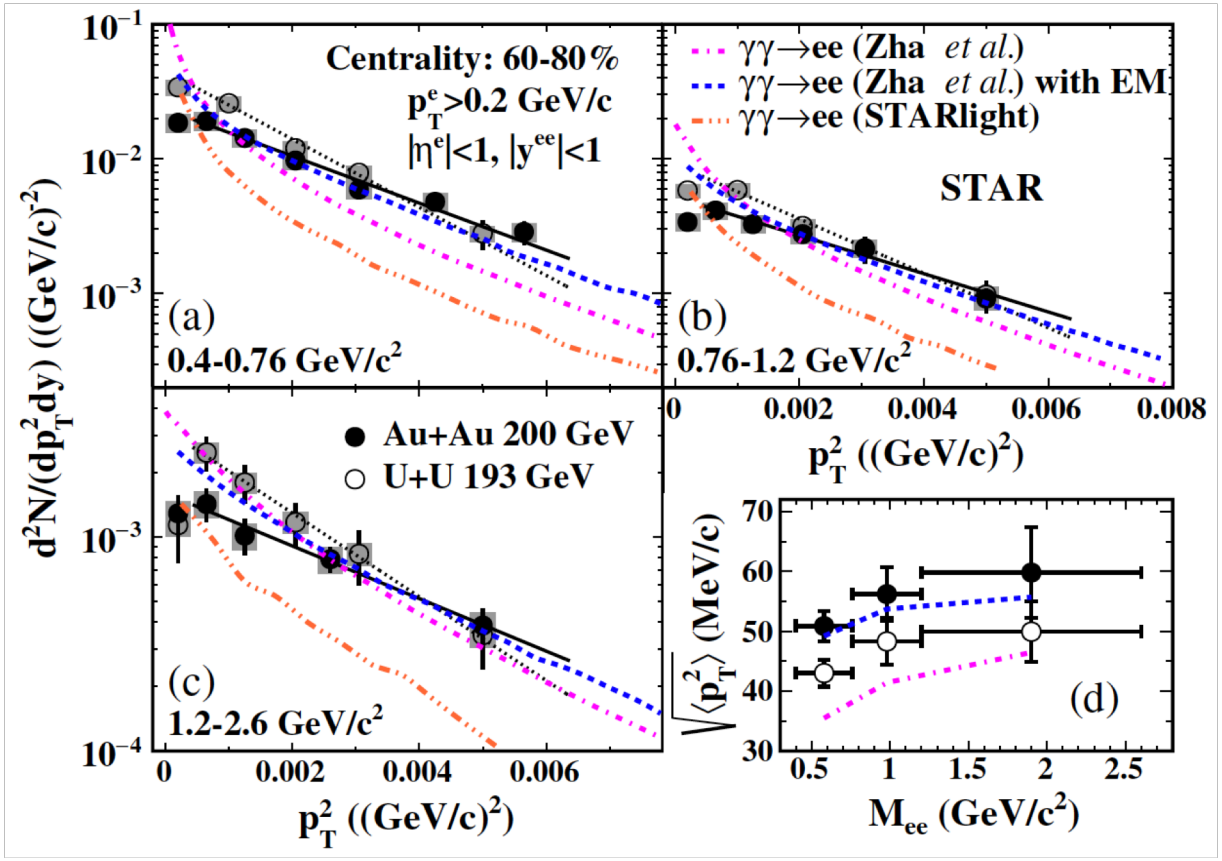
Sensitive probe to residual EM field



- ✓ Initial produced dilepton can be bent by the EM field
- ✓ The effect is large enough to see, if magnetic field last long (trapped in QGP)

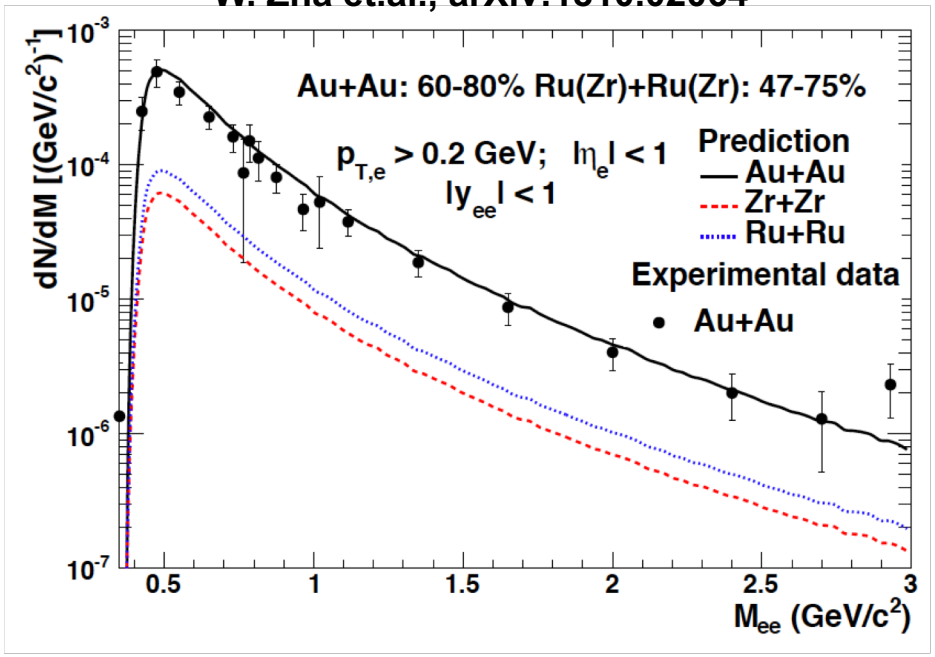
p_T^2 distribution for low p_T dielectron



- ✓ $\langle p_T^2 \rangle$ is sensitive to p_T broadening
- ✓ Theoretical calculation with EM field effect matches data better
- ✓ The model assumes that all the e^+e^- pairs traverse 1 fm through a magnetic field of 10^{14} T perpendicular to the beam line, the net effect of this approach is like $\int eB(t)cdt = e\bar{B}L = 30\ MeV/c$ for one track

Future low p_T dilepton in isobaric collisions

W. Zha et.al., arXiv:1810.02064



- ✓ Same A, different Z
- ✓ Huge statistics: 3.1B vs. 1.5B (goal) minimum-bias events
- ✓ Daily switching between Zr and Ru to minimize systematic uncertainty

60-80% Au+Au vs. 47-75% Isobar

- ✓ Similar hadronic contribution but different yields from two photon Interactions
- ✓ 60-80% Au+Au: ~180M : 47-75% Isobar ~840M

Yield ratio in 0.40-0.76 GeV/c^2

- ✓ Au : Ru : Zr ≈ 7.9 : 1.5 : 1.0
- ✓ Difference between Ru+Ru and Zr+Zr: ~ 3.7σ

Summary

Electromagnetic probes provide unique ways to study the hot and dense medium over the whole evolution

Direct photons – Thermal photons observed in Au+Au collisions

- ✓ **Photon puzzle still exists, large v_2 versus large yield**
- ✓ **New results from different collision systems (200GeV p+Au, 200GeV d+Au, 62GeV Au+Au, 39GeV Au+Au), need further study on the current finding scaling behavior over collision energies and hint thermal photon in small systems**

Dilepton – consistent pictures at RHIC, rho broadening scenario describes the excesses in LMR

- ✓ **New measurements on dimuon continuum in p+p and p+Au**
- ✓ **Coherent low p_T dielectron production joins dilepton "club" – link to EM fields**

Future RHIC operation plan provides excellent opportunity to continue the research on EM probes.

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Thank you for your attention!