POLYTECH
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THERMAL PHOTON PRODUCTION IN AU+AU COLLISIONS OBSERVED BY PHENIX

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For PHENIX collaboration

MOTIVATION

Photons are a unique probe for Quark Gluon Plasma (QGP)

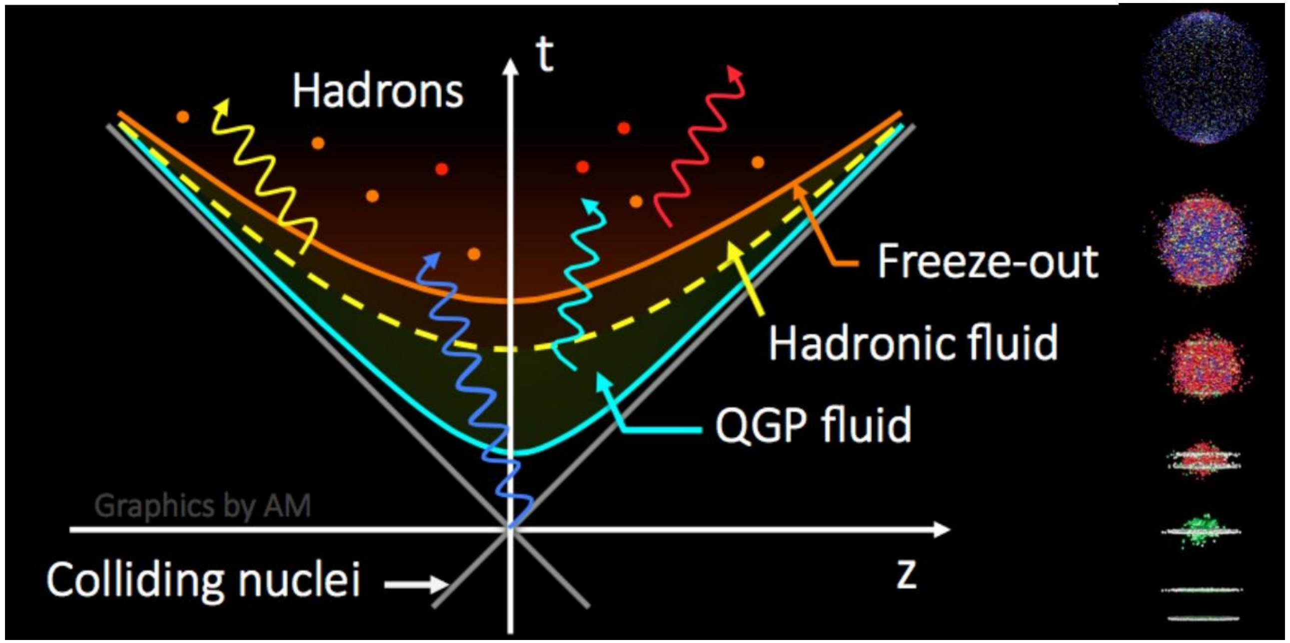
- Emitted from all the stages after the collision
- All thermal mediums emit thermal radiation in the form of photons or low mass lepton pairs
- "Color blind" (do not suffer strong interaction), provide a direct fingerprint of its creation point

Direct γ = Inclusive γ

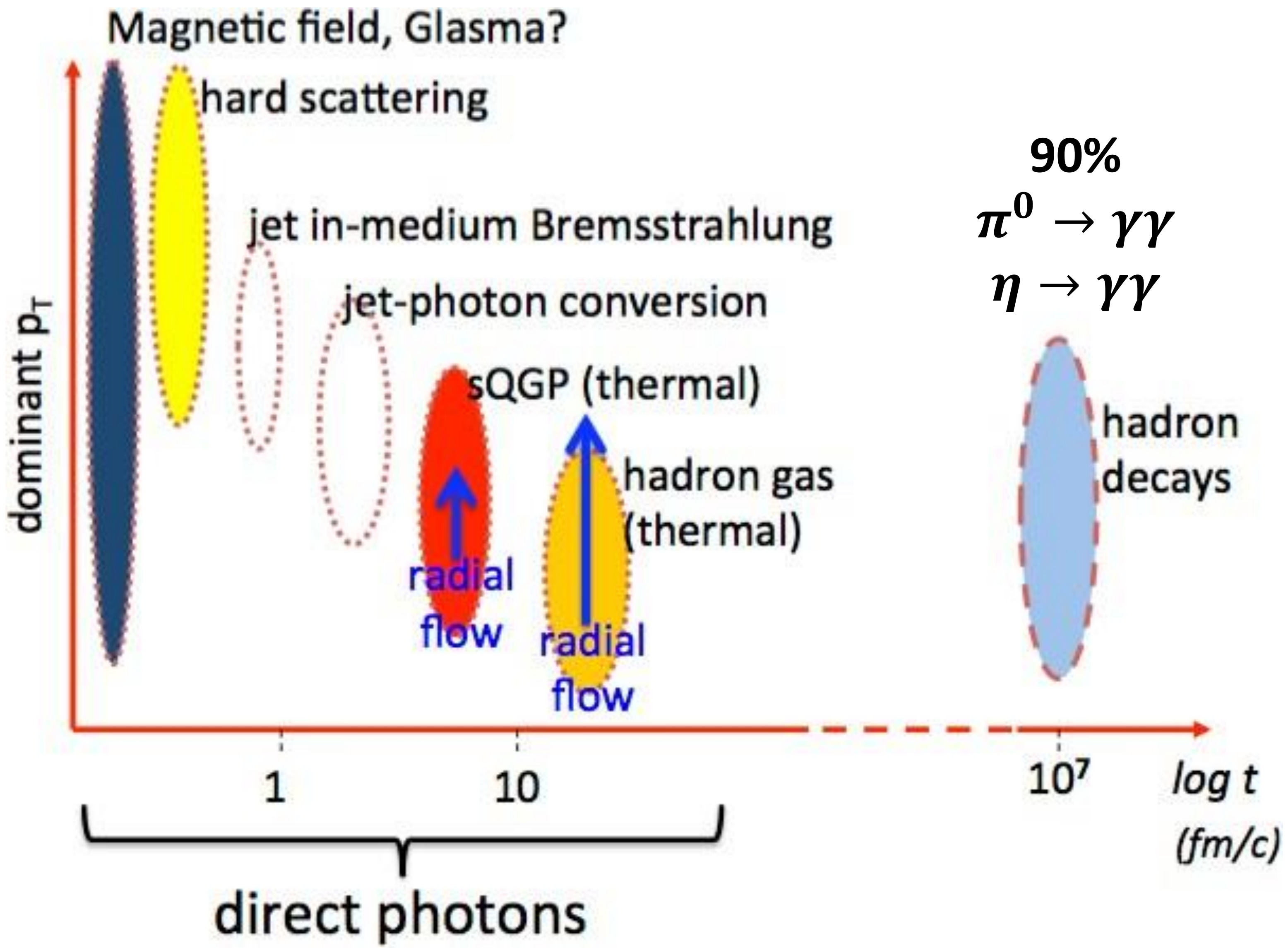
\- Hadronic decay γ

Downside:

- Small production rate
- Very large background from hadron decays



PHOTON SOURCES IN HEAVY ION COLLISIONS

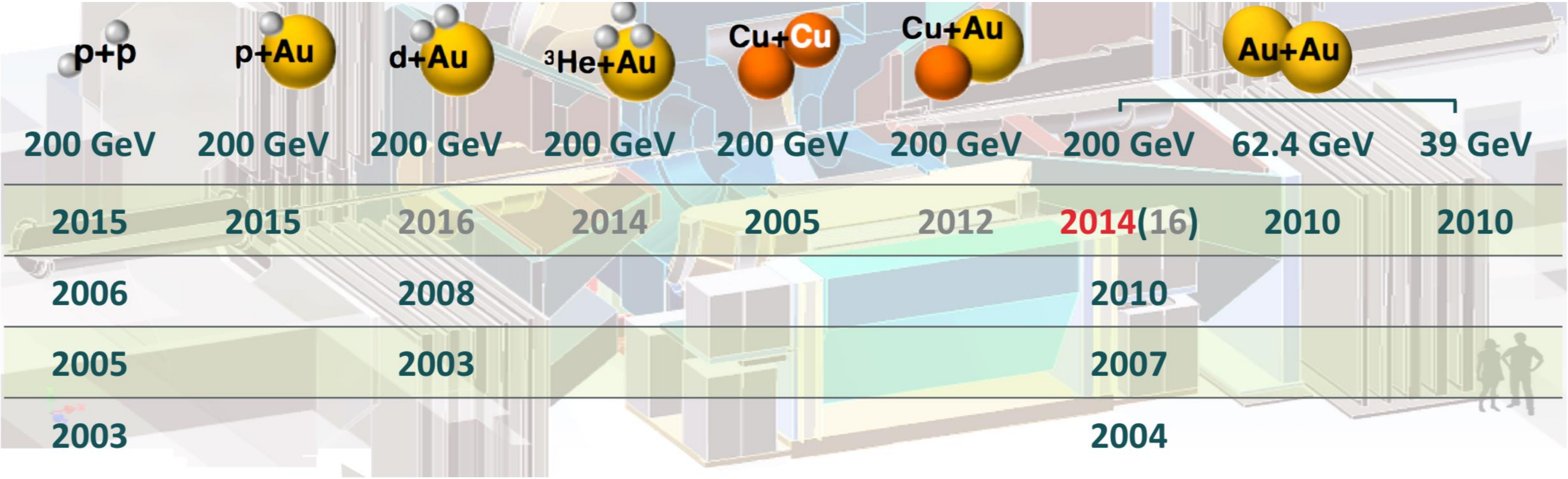


Extracting thermal photon requires the systematic uncertainty of decay photons and prompt photons subtractions much less than **10 %**

NEW INSIGHTS

A wealth of datasets available for direct photon analysis in PHENIX

- 16 years of operation, 9 collision species, 9 collision energies
- 3 different analysis methods — calorimeter method, virtual γ method, external conversion method



p+p	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au		
200 GeV	200 GeV	200 GeV	200 GeV	200 GeV	200 GeV	200 GeV	62.4 GeV	39 GeV
2015	2015	2016	2014	2005	2012	2014(16)	2010	2010
2006		2008				2010		
2005		2003				2007		
2003						2004		

Photon measurement techniques in PHENIX

Measuring energy deposited by photons in Calorimeter

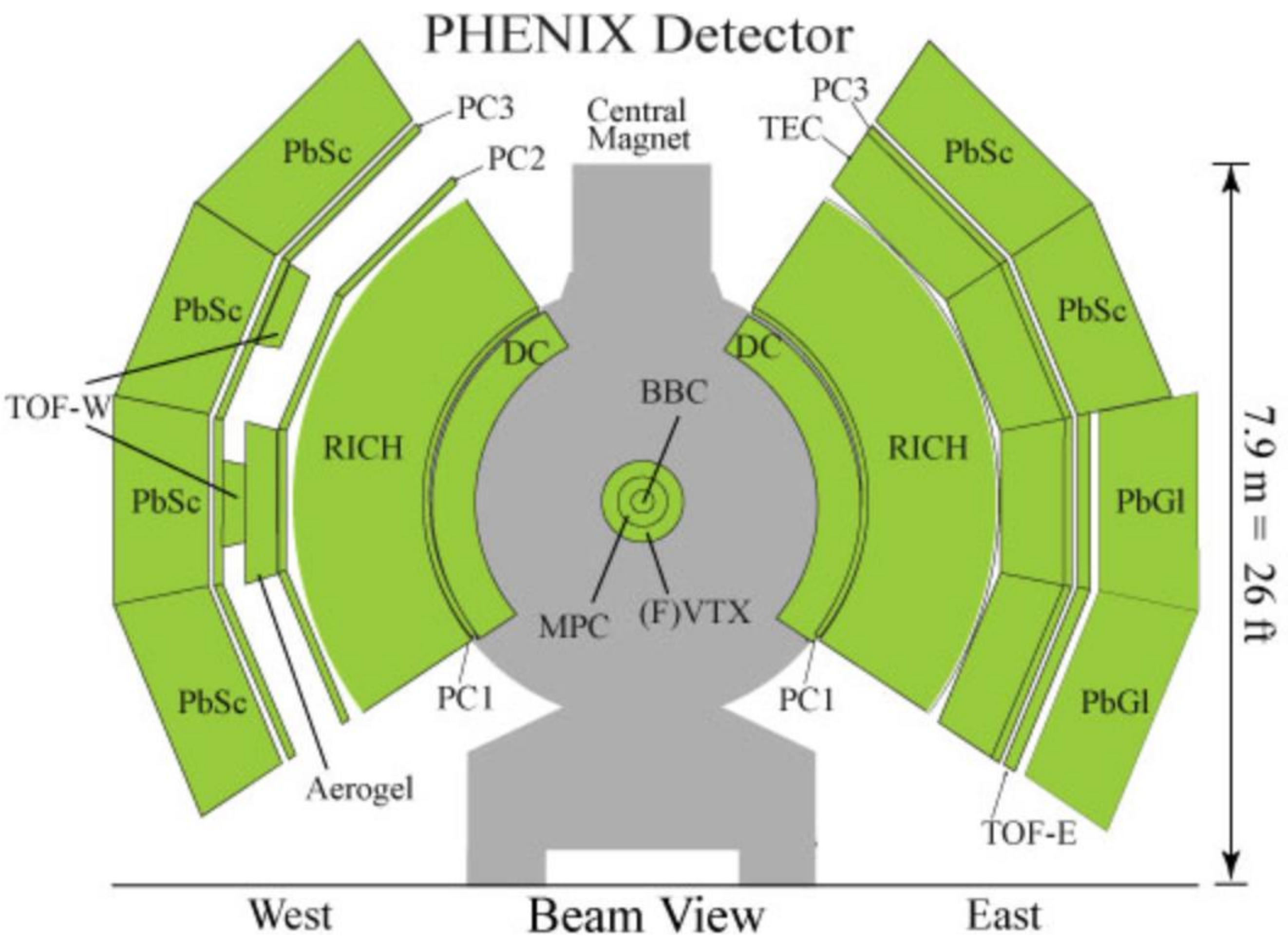
- Good resolution at high p_T
- Low p_T contaminated by hadrons

Internal photon conversions

- Measure virtual photons
- Reduction in background from hadron decay by a factor of 5
- Low p_T reach is limited(~1 GeV) as well as high p_T

External conversions

- Measure real photons
- Extends p_T<1 GeV and good resolution
- High p_T reach is limited



Direct photon "puzzle"

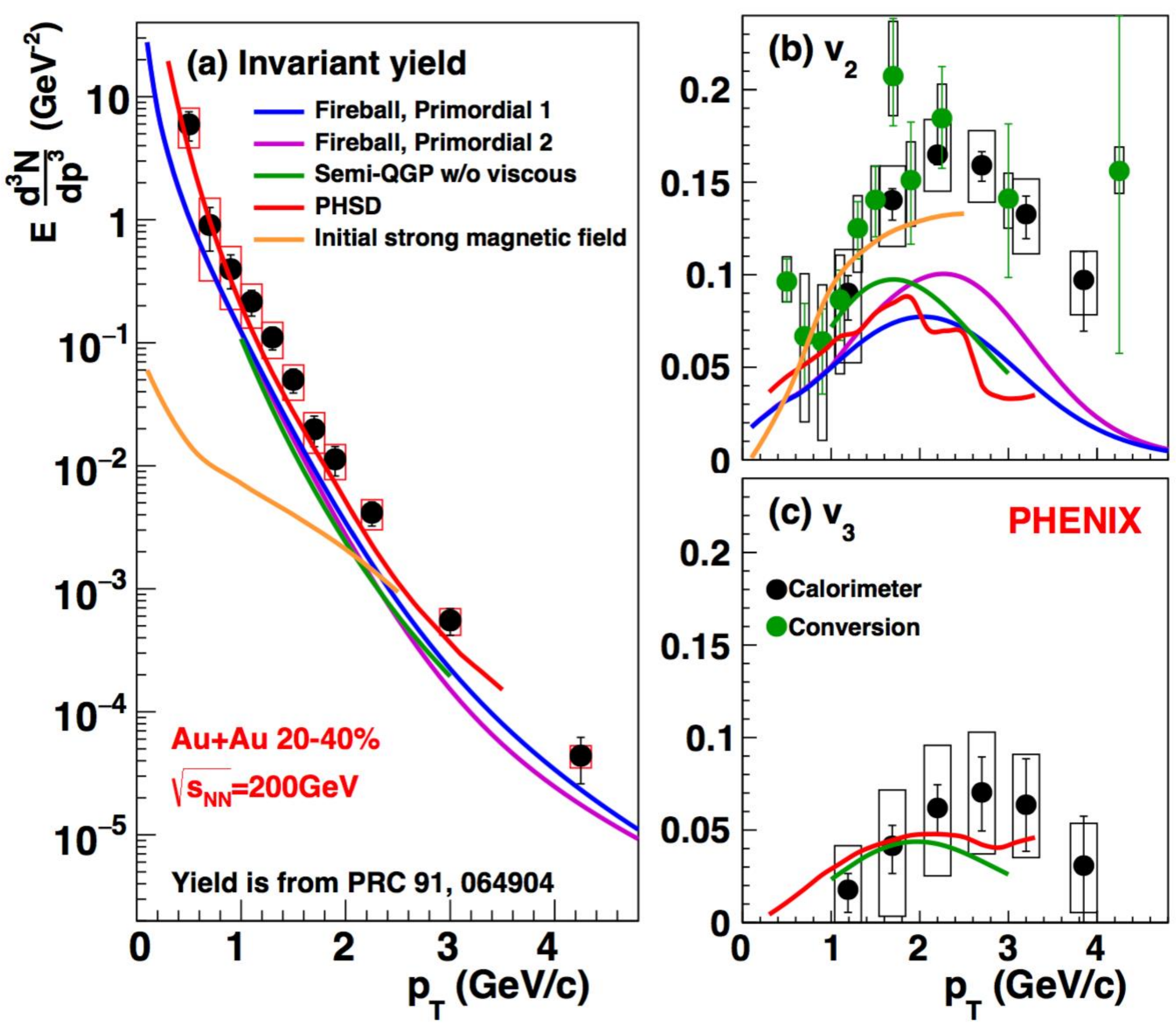
Large yield and large anisotropy observed at PHENIX poses a challenge to theoretical models:

Large yield → Early emission

Large v2 → Late emission

Challenging for current theoretical models to describe large yield and v_2 simultaneously!

PRC94, 064901 (2016)



Direct photon "puzzle"

Large yield and large anisotropy observed at PHENIX poses a challenge to theoretical models:

Large yield → Early emission

Large v2 → Late emission

In order to understand this, PHENIX has measure data in:

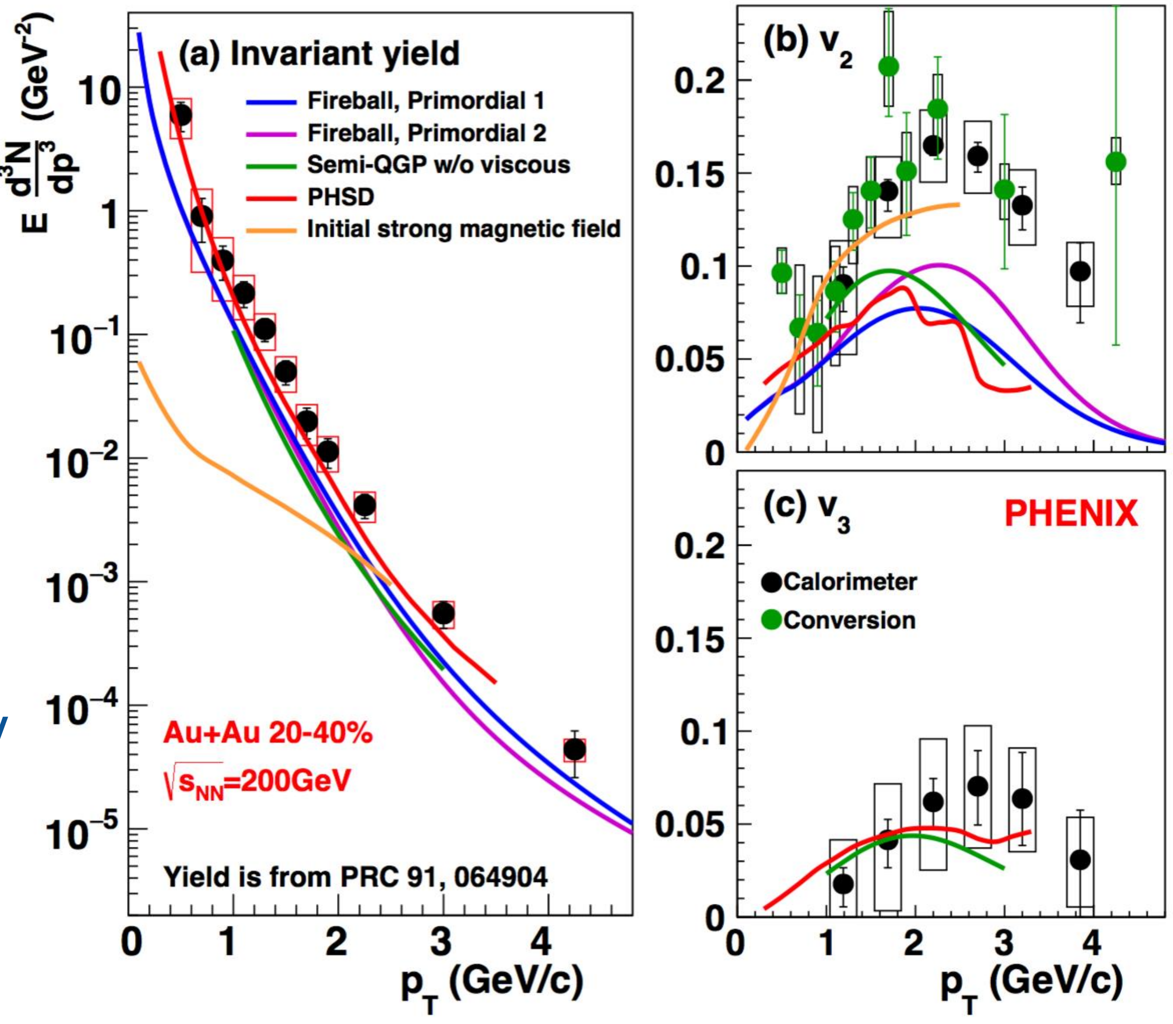
- Large systems:

Au+Au 200, 62, 39 GeV and Cu+Cu at 200 GeV

- Small systems:

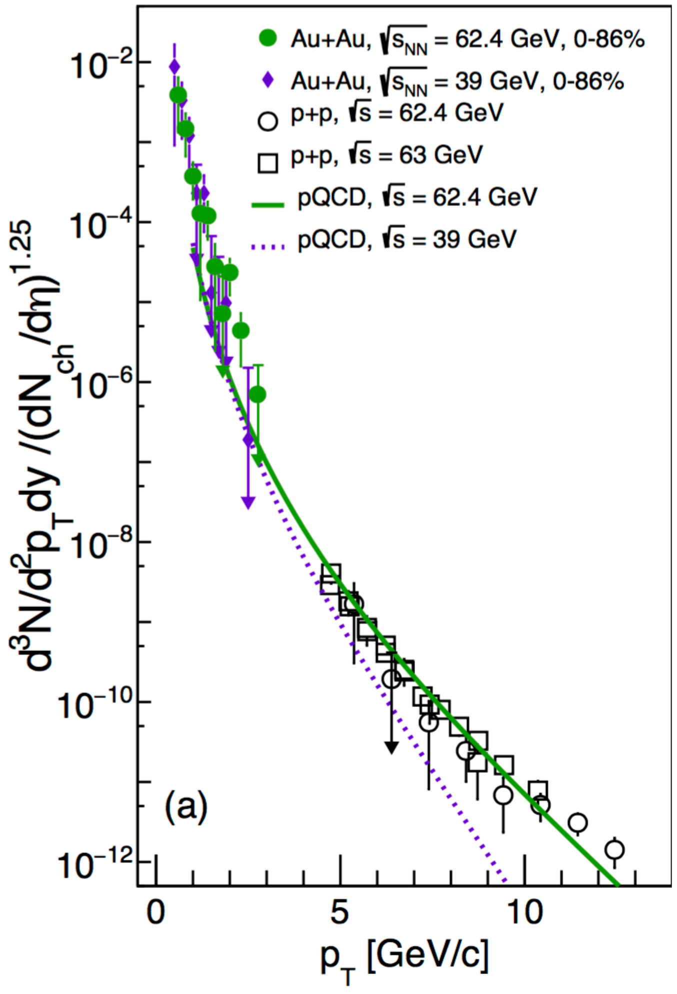
p+p, p+Au, d+Au (MB) at 200 GeV

PRC94, 064901 (2016)



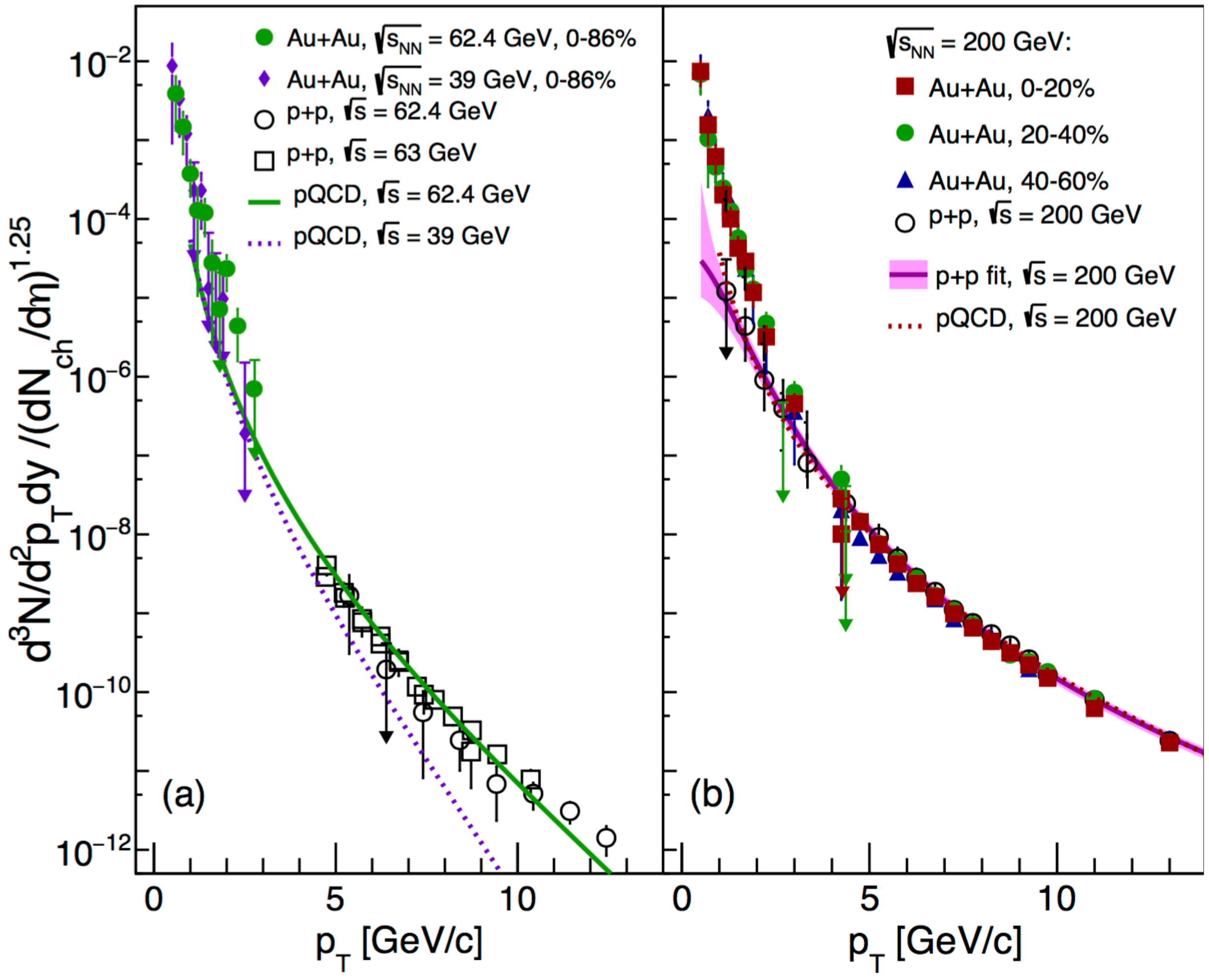
Direct photon spectra normalized by $(dN_{ch}/d\eta)^{1.25}$

Lower energies



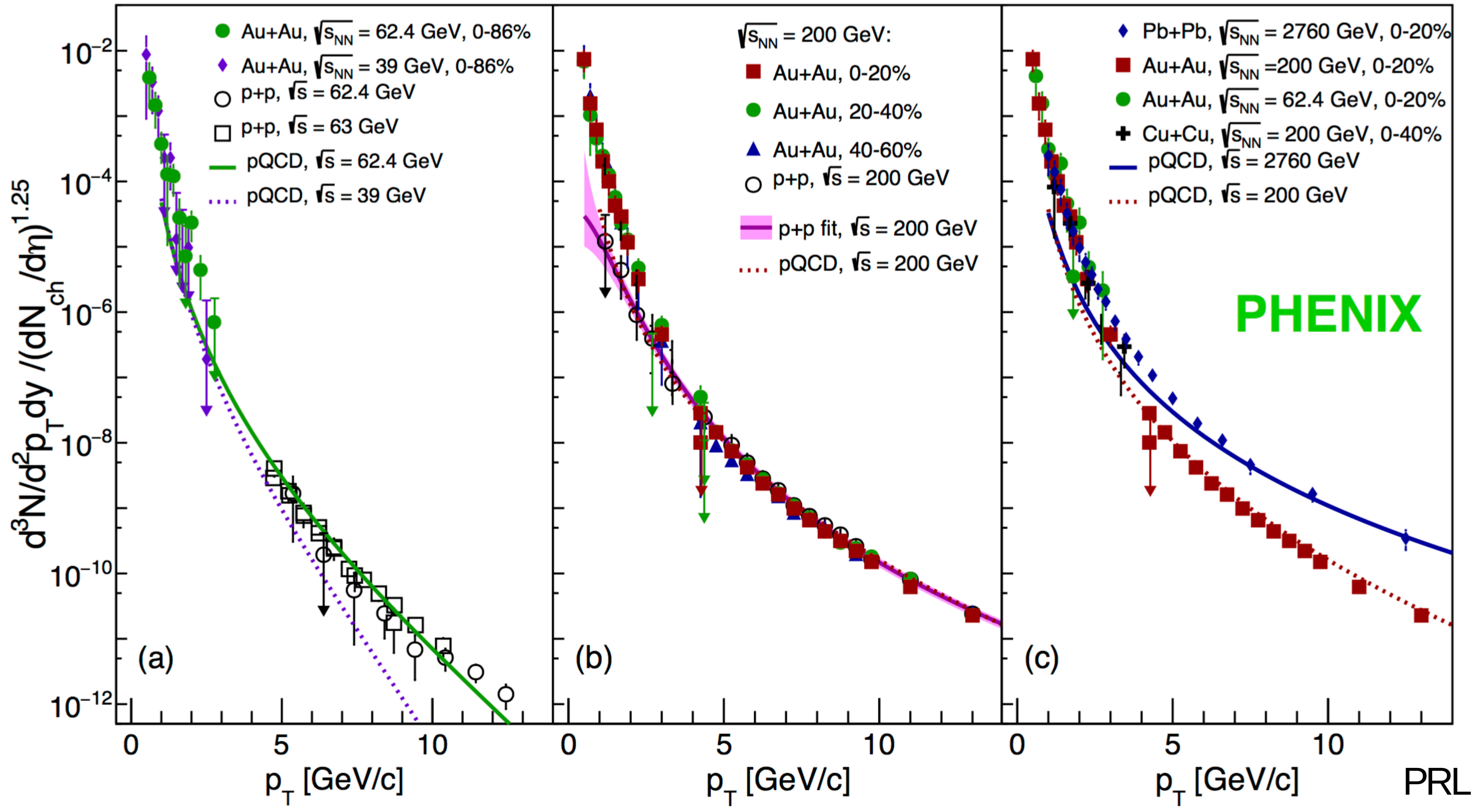
Direct photon spectra normalized by $(dN_{ch}/d\eta)^{1.25}$

Lower energies   Different centralities



Direct photon spectra normalized by $(dN_{ch}/d\eta)^{1.25}$

Lower energies Different centralities Higher energies Other A+A systems



Similar low p_T photon yield when scaled by $(dN_{ch}/d\eta)^{1.25}$, independent of energy, centrality, or system size

PRL123, 022301 (2019)

Integrated low p_T direct photon yield — universal scaling

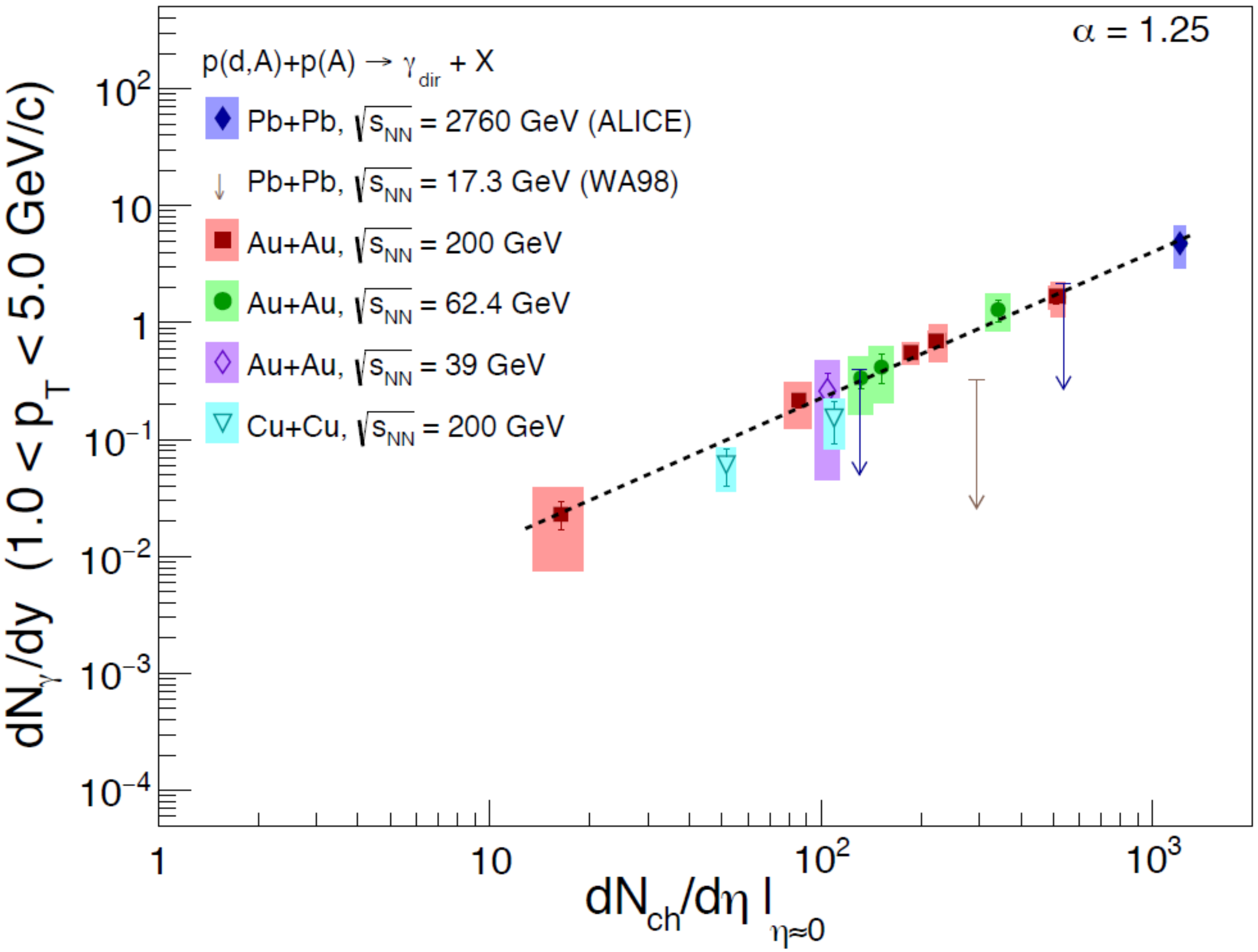
Integrate the low p_T direct photons and use $dN_{ch}/d\eta$ to compare data from different beam energies, collisions species, and collision centralities

PRL 123, 022301 (2019)

- Universal scaling behavior in all A+A systems

$$dN_\gamma/dy = A \times (dN_{ch}/d\eta)^\alpha$$

- Source of photons must be similar



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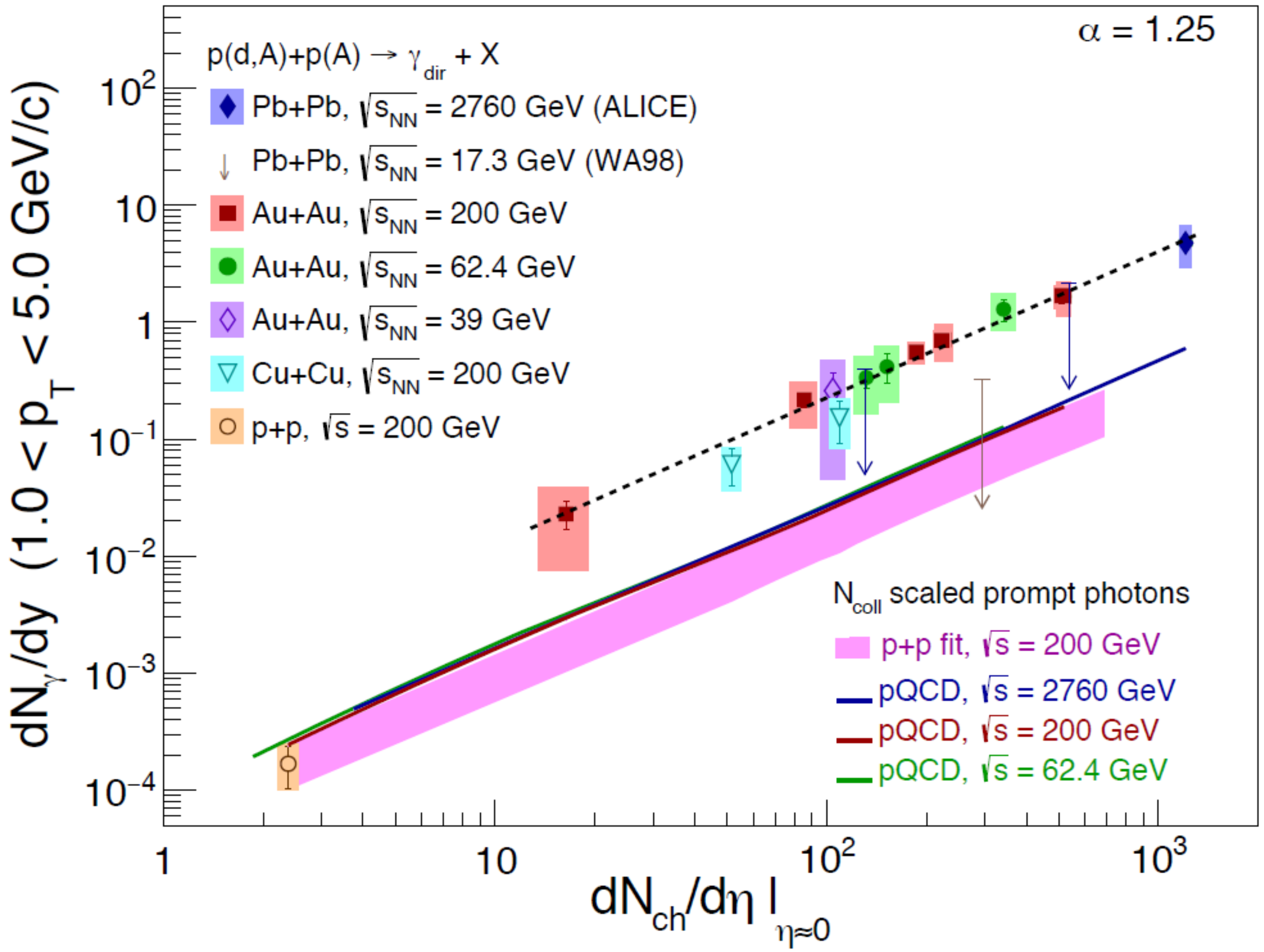
- N_{coll} x pQCD and N_{coll} x p+p follow same scaling at 0.1 of yield



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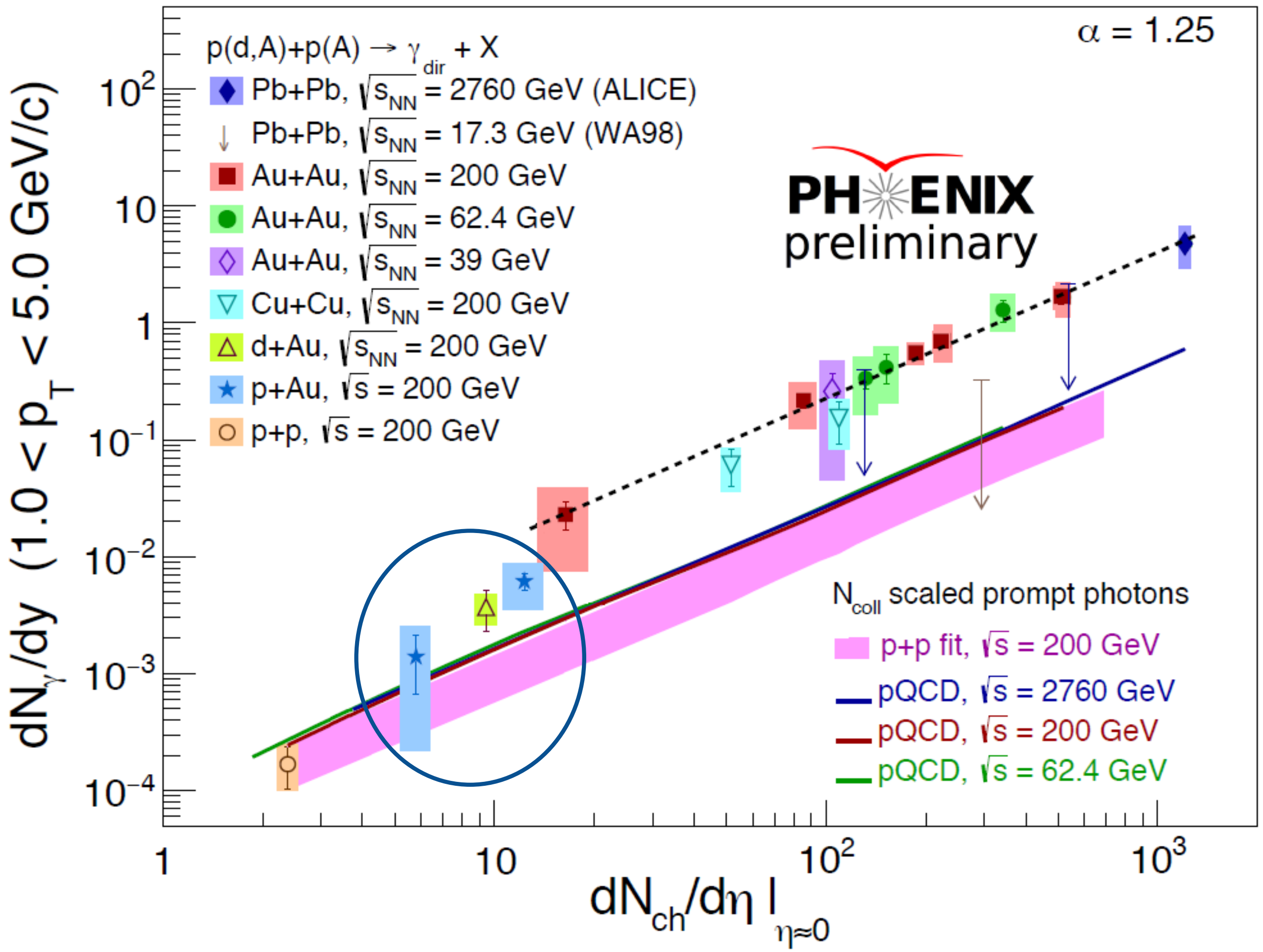
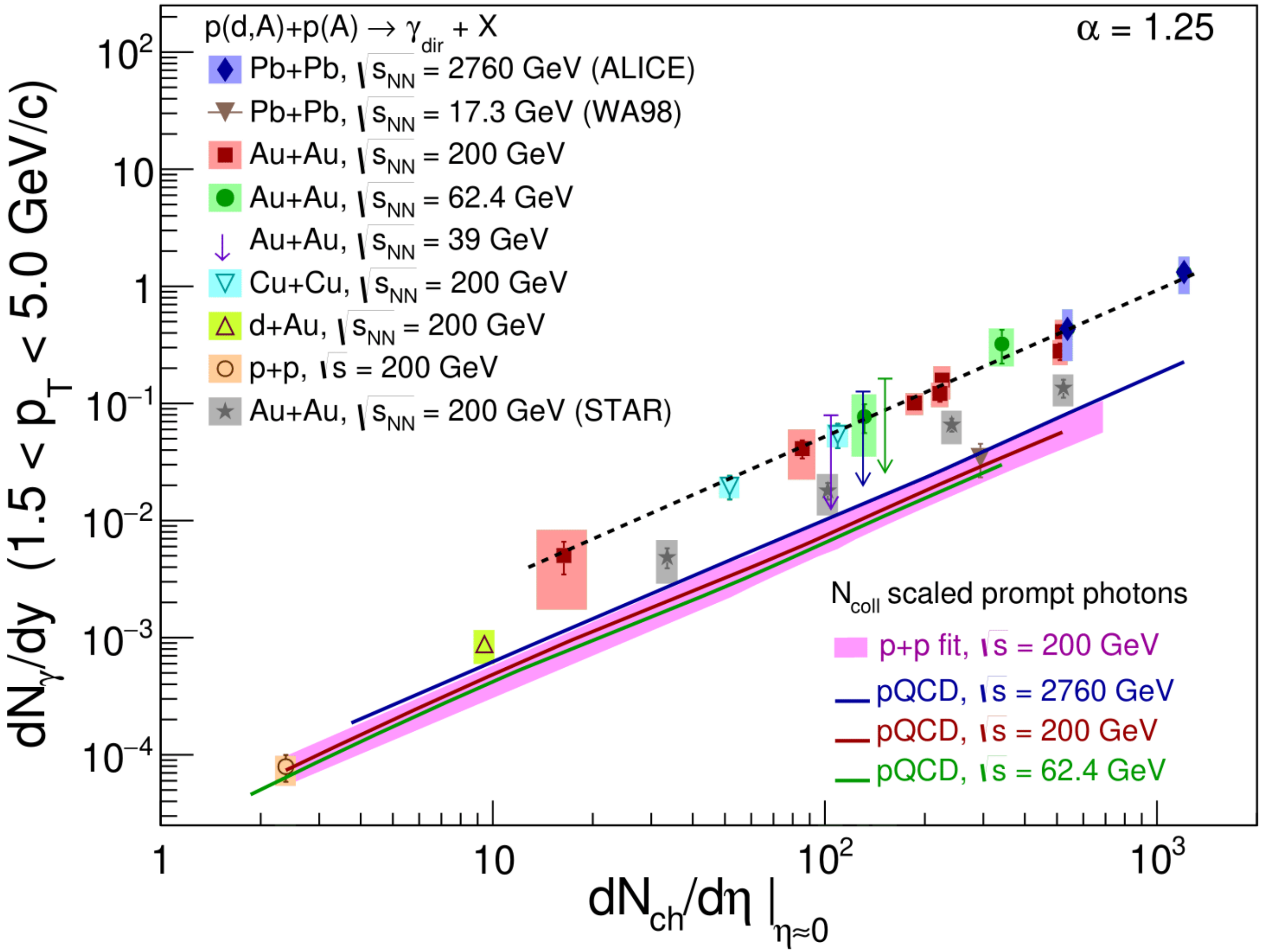
- Source of photons must be similar
- N_{coll} x pQCD and N_{coll} x p+p follow same scaling at 0.1 of yield
- Onset of low p_T radiation excess at $dN_{ch}/d\eta$ ~10?



Comparison with STAR

Discrepancy with STAR Au+Au results



STAR data shows the scaling behavior also

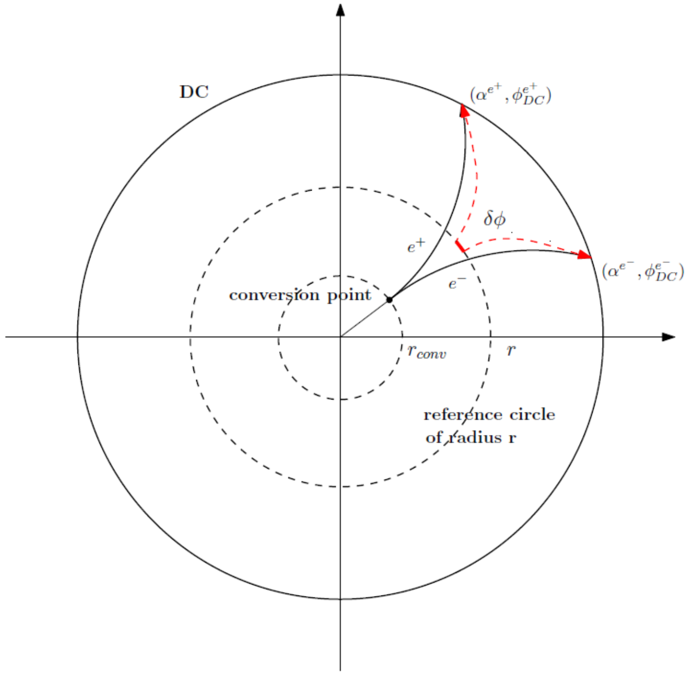
The magnitude is lower comparing to PHENIX results

R_γ via external conversion method

A new measurement with 2014 Au+Au dataset

via external conversion method

- 10 fold statistics
- Photons convert in VTX layers.
- Reconstruction conversion position using e^+e^- and the B map, origin of the conversion
- Double ratio tagging method: cancelation of systematics



Conditional tagging efficiency

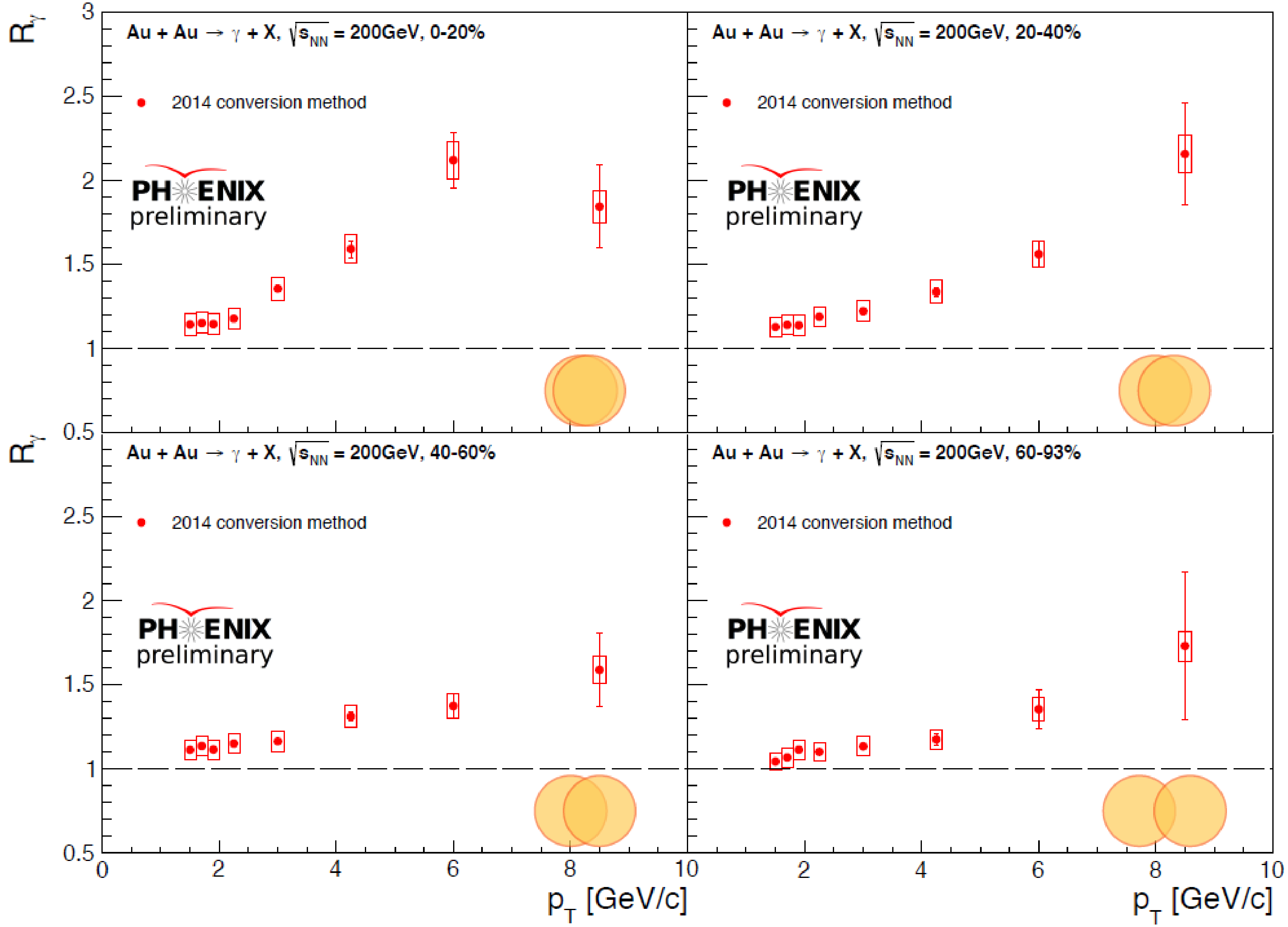
Measured raw yields

$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\boxed{\langle \varepsilon_\gamma f \rangle} \boxed{\left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}}\right)}_{Data}}{\boxed{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}}\right)}_{Sim}}$$

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

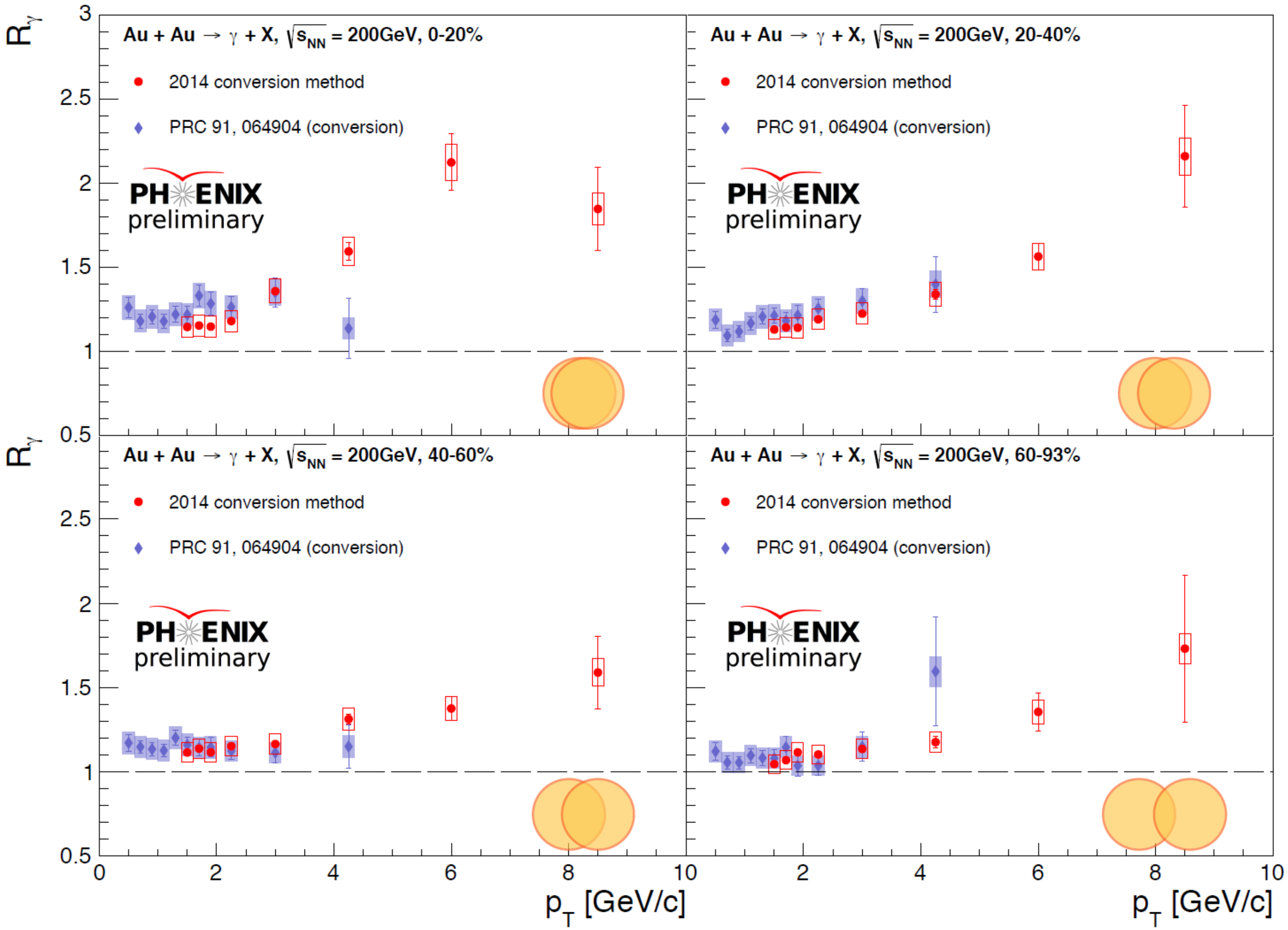
Simulated based on hadron data

R_γ in Au + Au collisions at 200 GeV



New result

R_γ in Au + Au collisions at 200 GeV



New result consistent with previous published results using:

- conversion method

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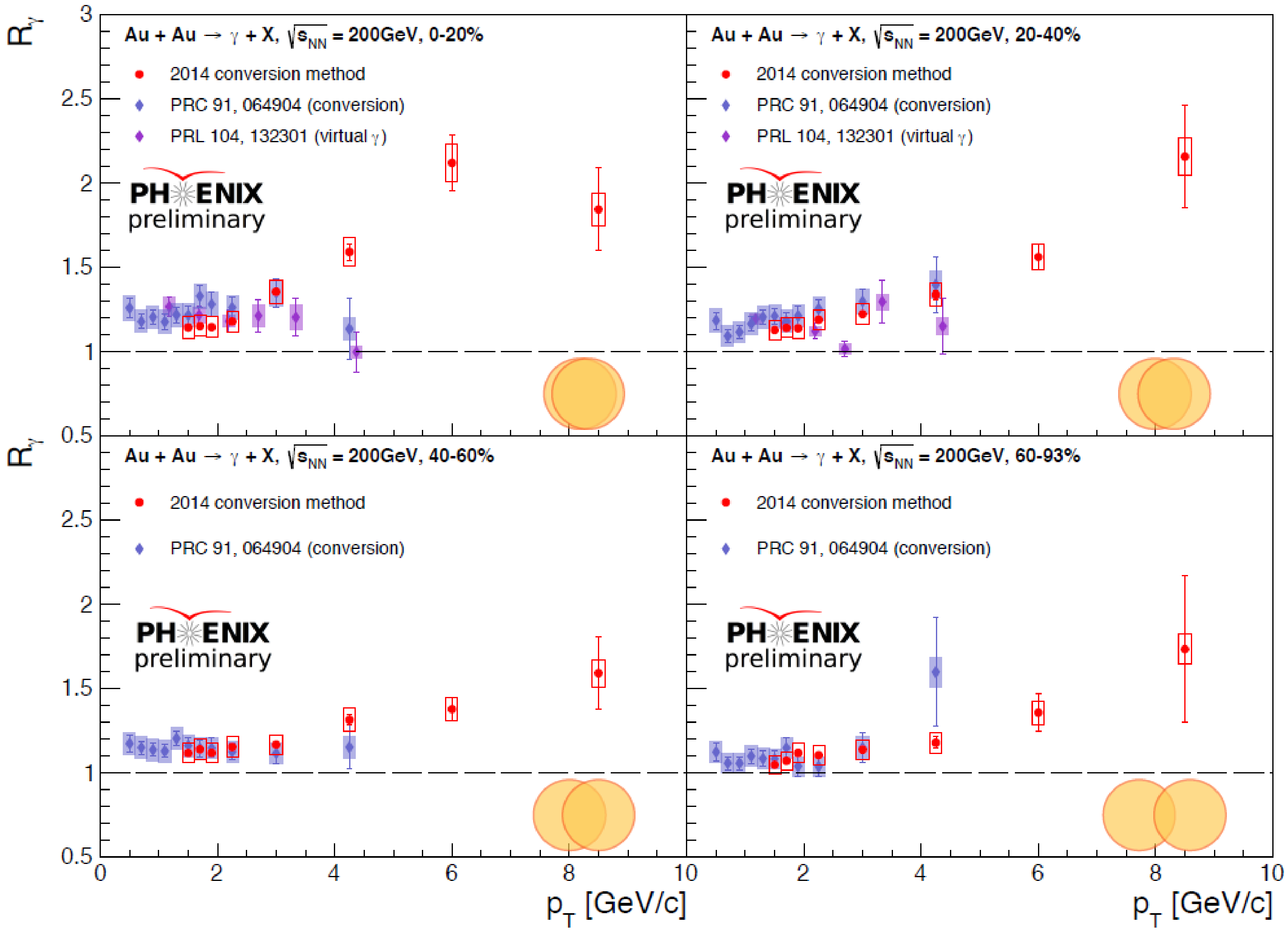
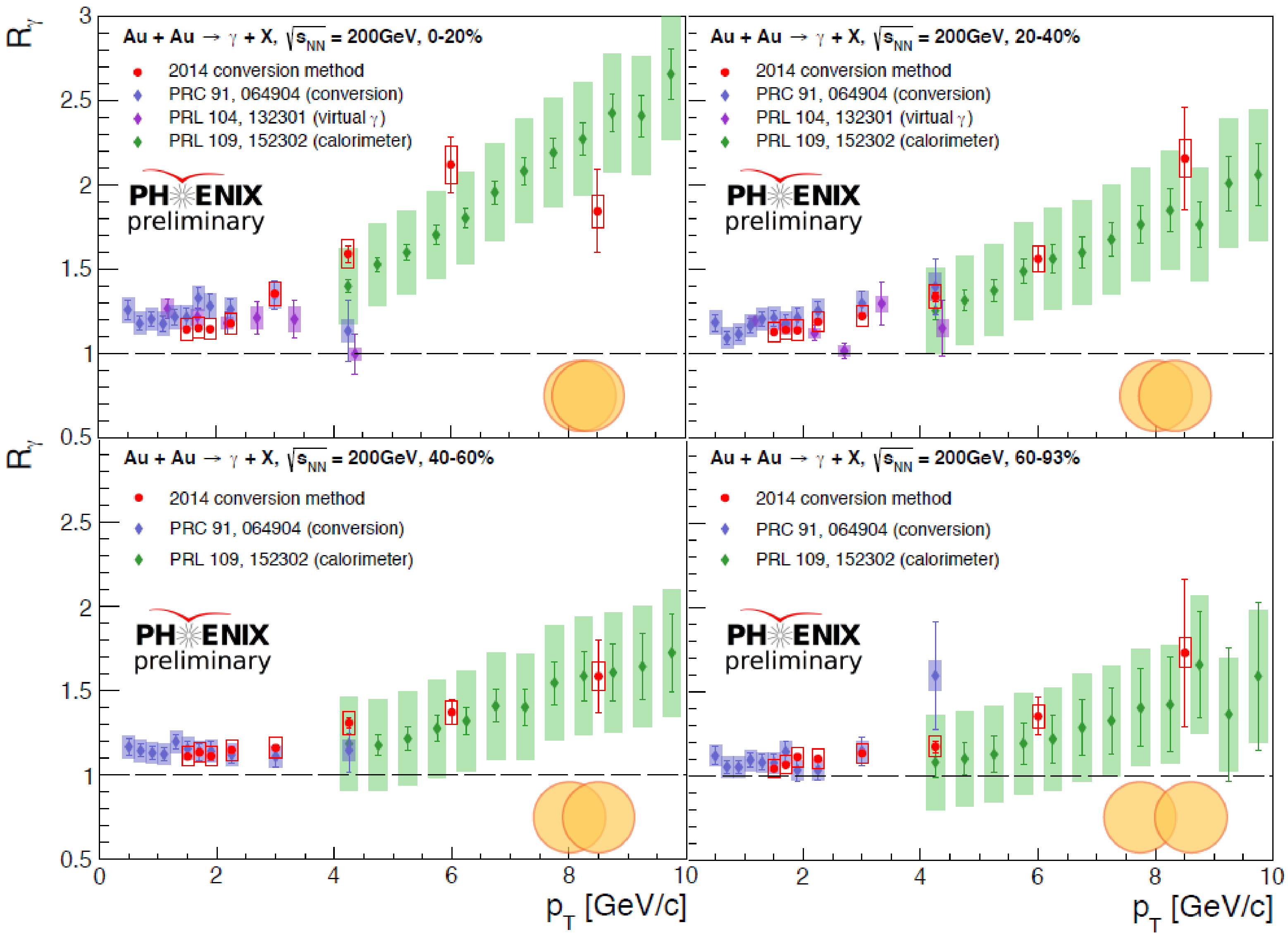


New result consistent with previous published results using:

- conversion method,
- virtual γ method

R_γ in Au + Au collisions at 200 GeV



New result consistent with previous published results using:

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- virtual γ method,
- calorimeter method

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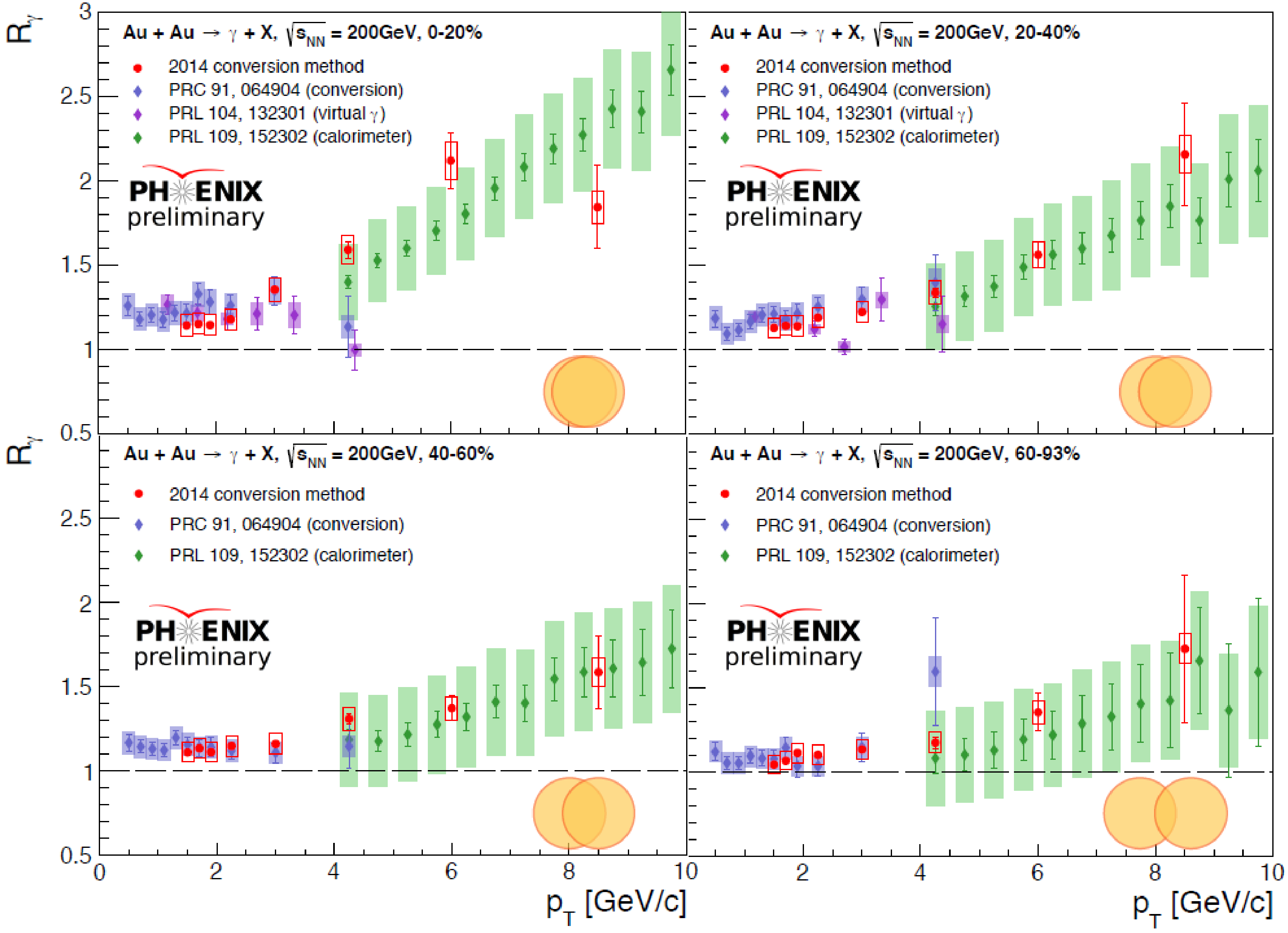

New result consistent with previous published results using:

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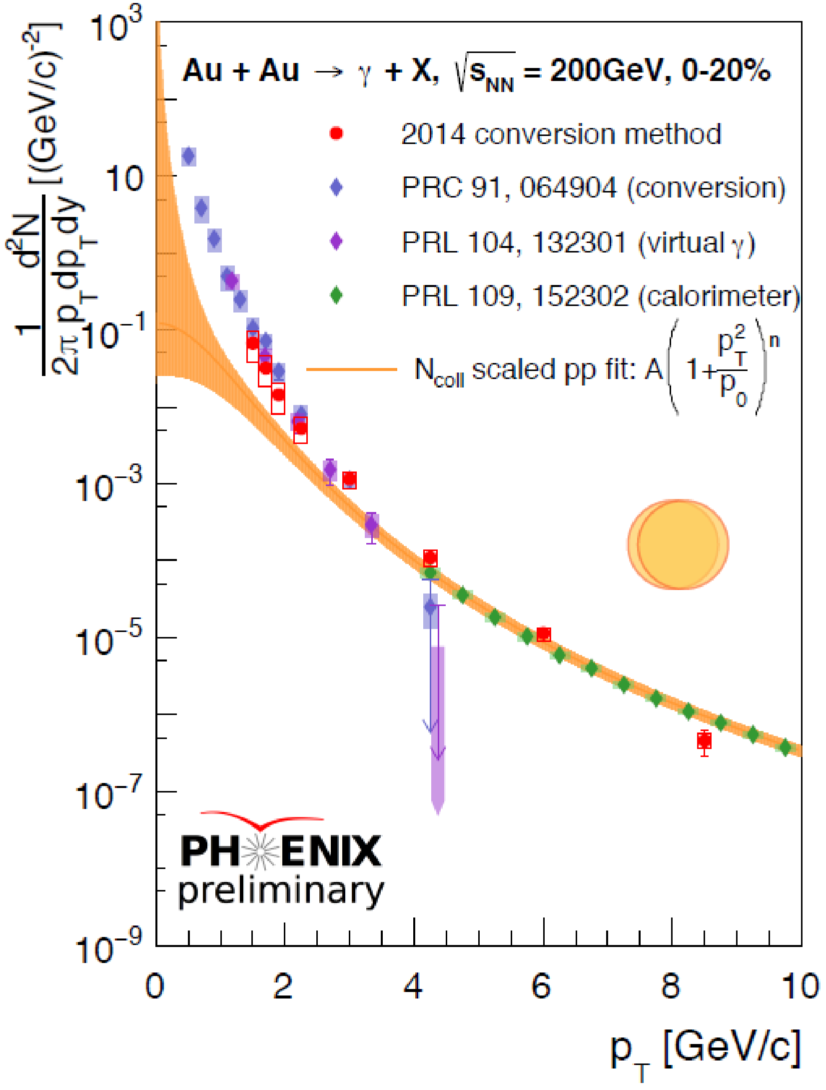
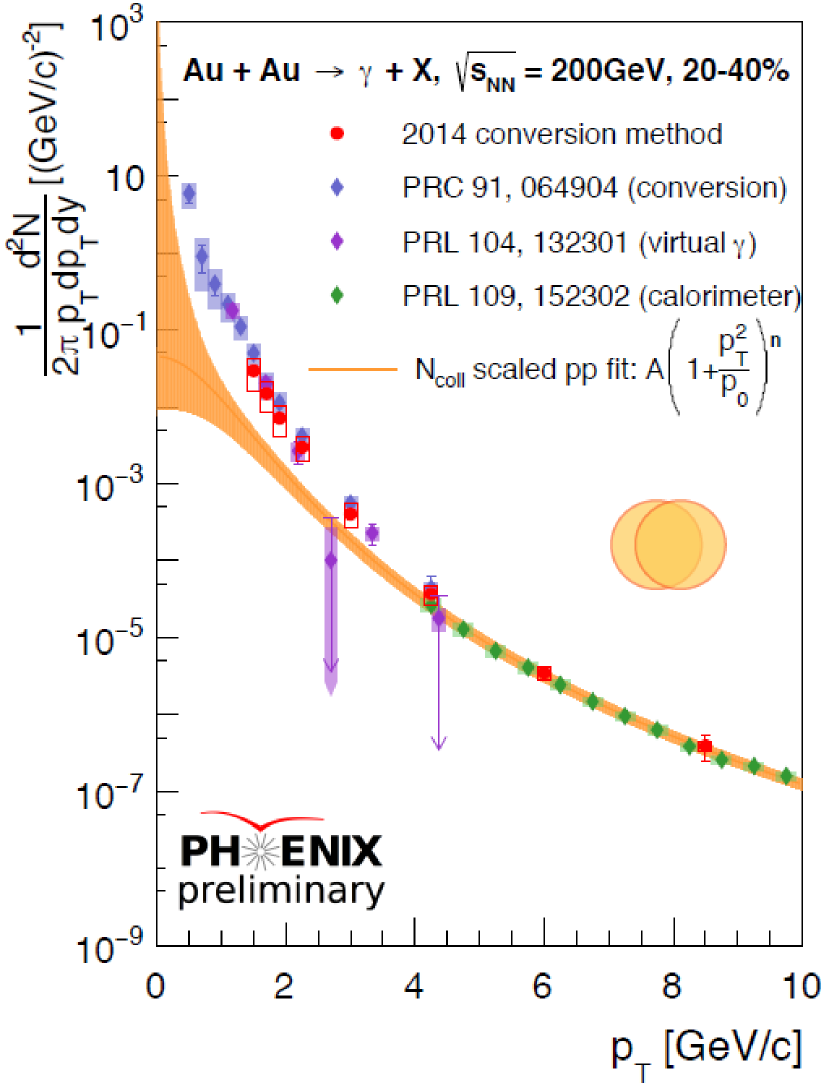
4 independent measurements from independent datasets shown here!

Full overlap with the published low p_T and high p_T measurements

Direct photon yield in Au + Au collisions at 200 GeV



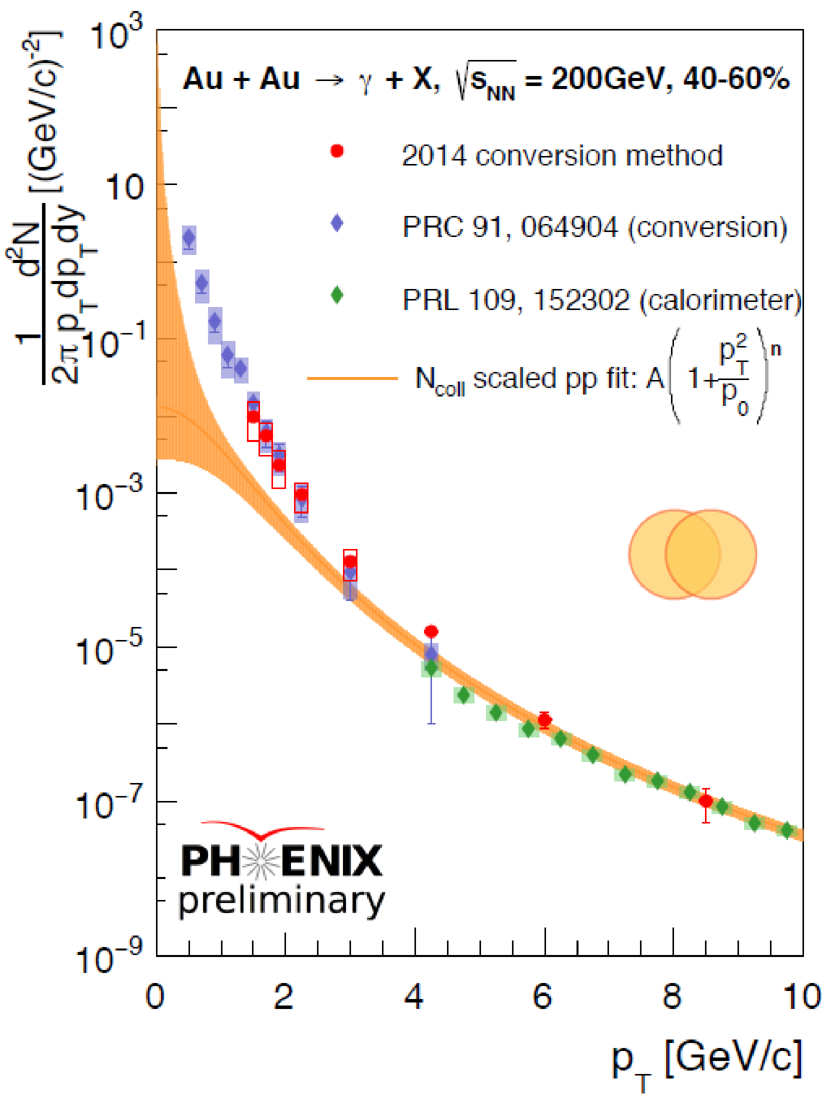


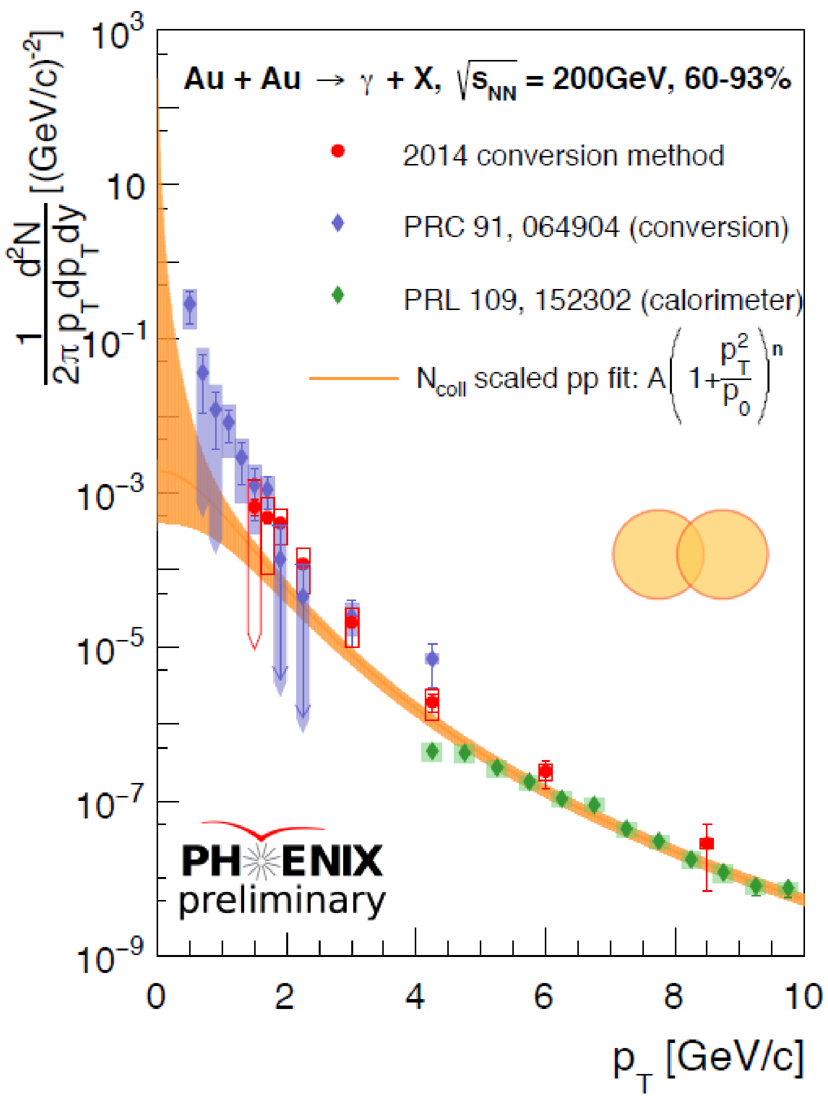
$$\gamma^{\text{direct}} = (R_\gamma - 1)\gamma^{\text{hadron}}$$

At high p_T Au+Au data consistent with N_{coll} scaled p+p result

Clear enhancement observed below 3 GeV in (semi-)central Au+Au collisions

Direct photon yield in Au + Au collisions at 200 GeV



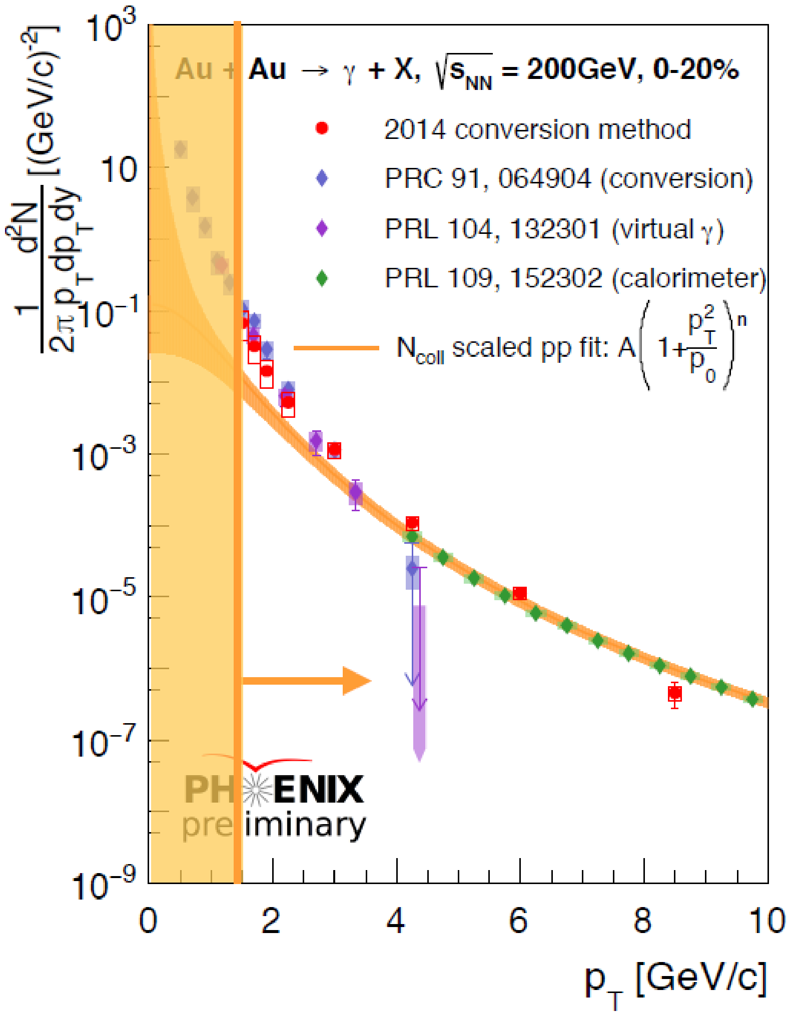


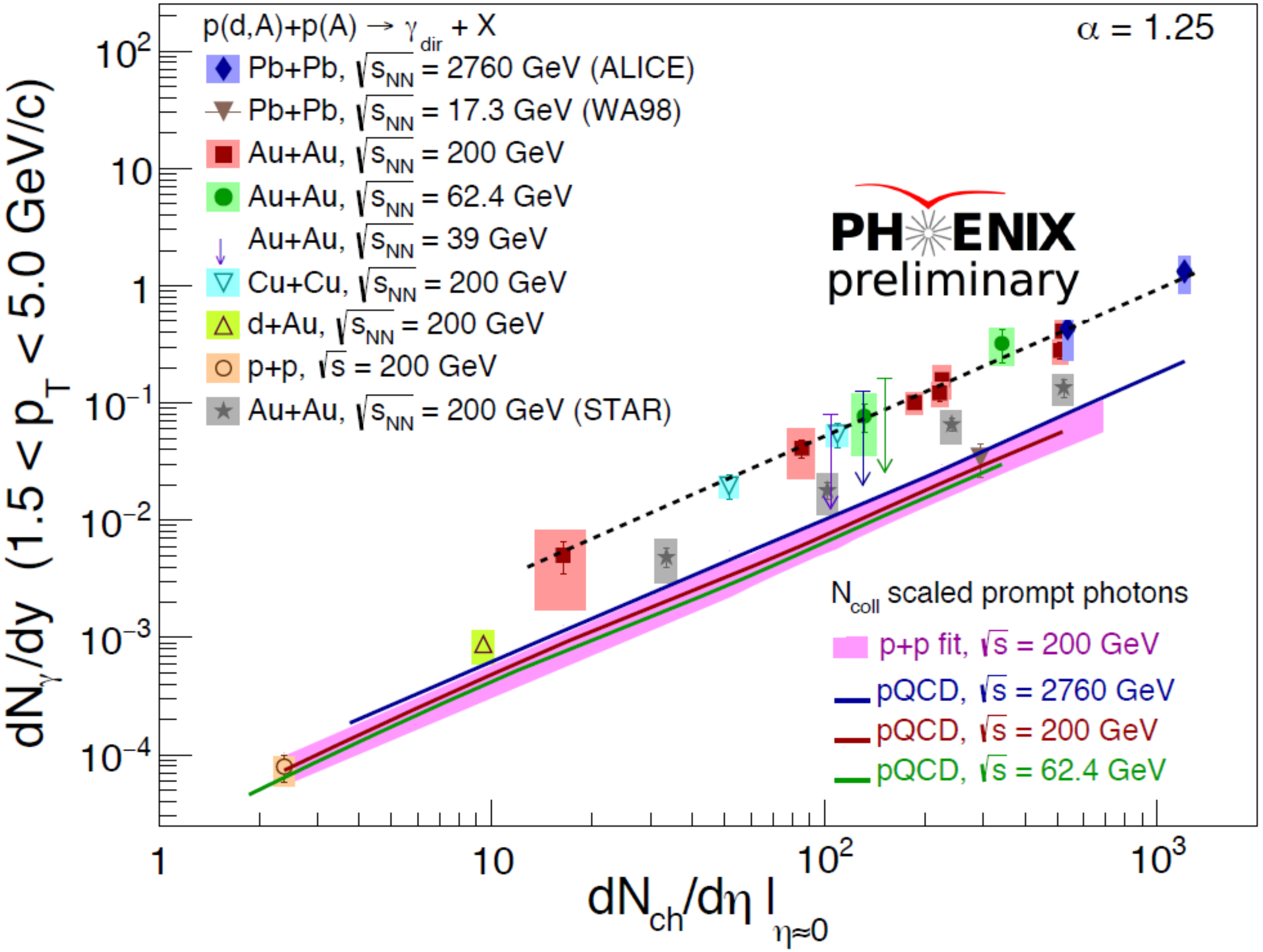
$$\gamma^{\text{direct}} = (R_\gamma - 1)\gamma^{\text{hadron}}$$

At high p_T Au+Au data consistent with N_{coll} scaled p+p result

Enhancement persists below 3 GeV in (semi-)peripheral Au+Au collisions

Direct photon scaling with new 2014 results





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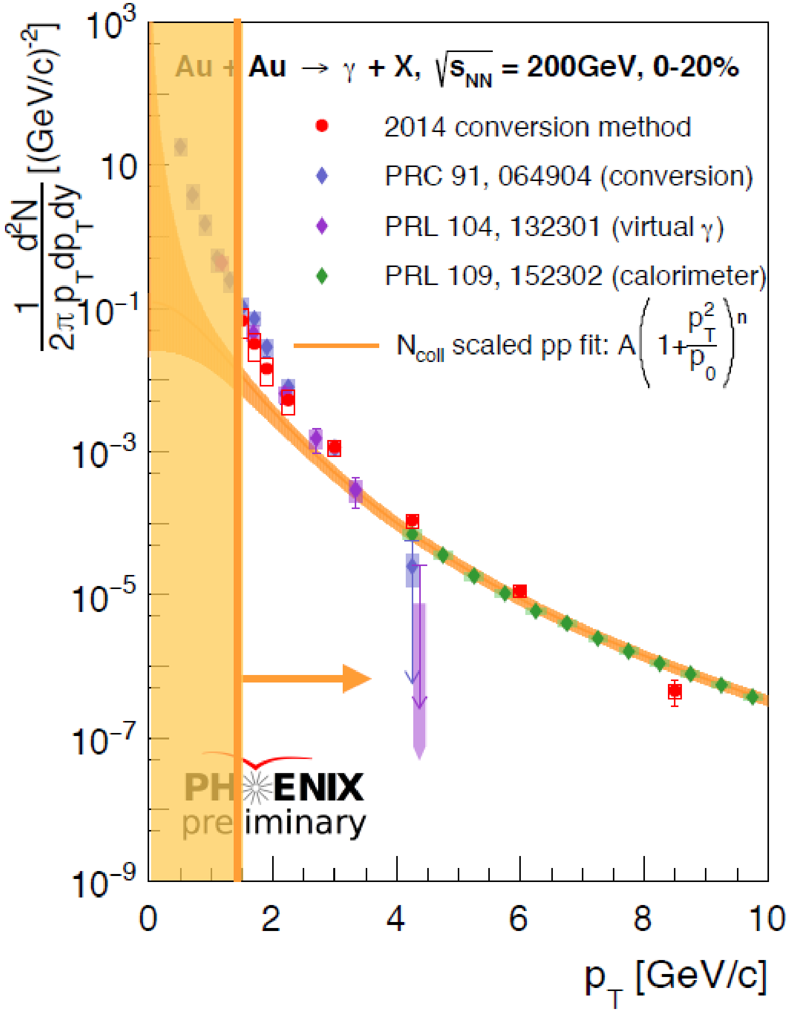
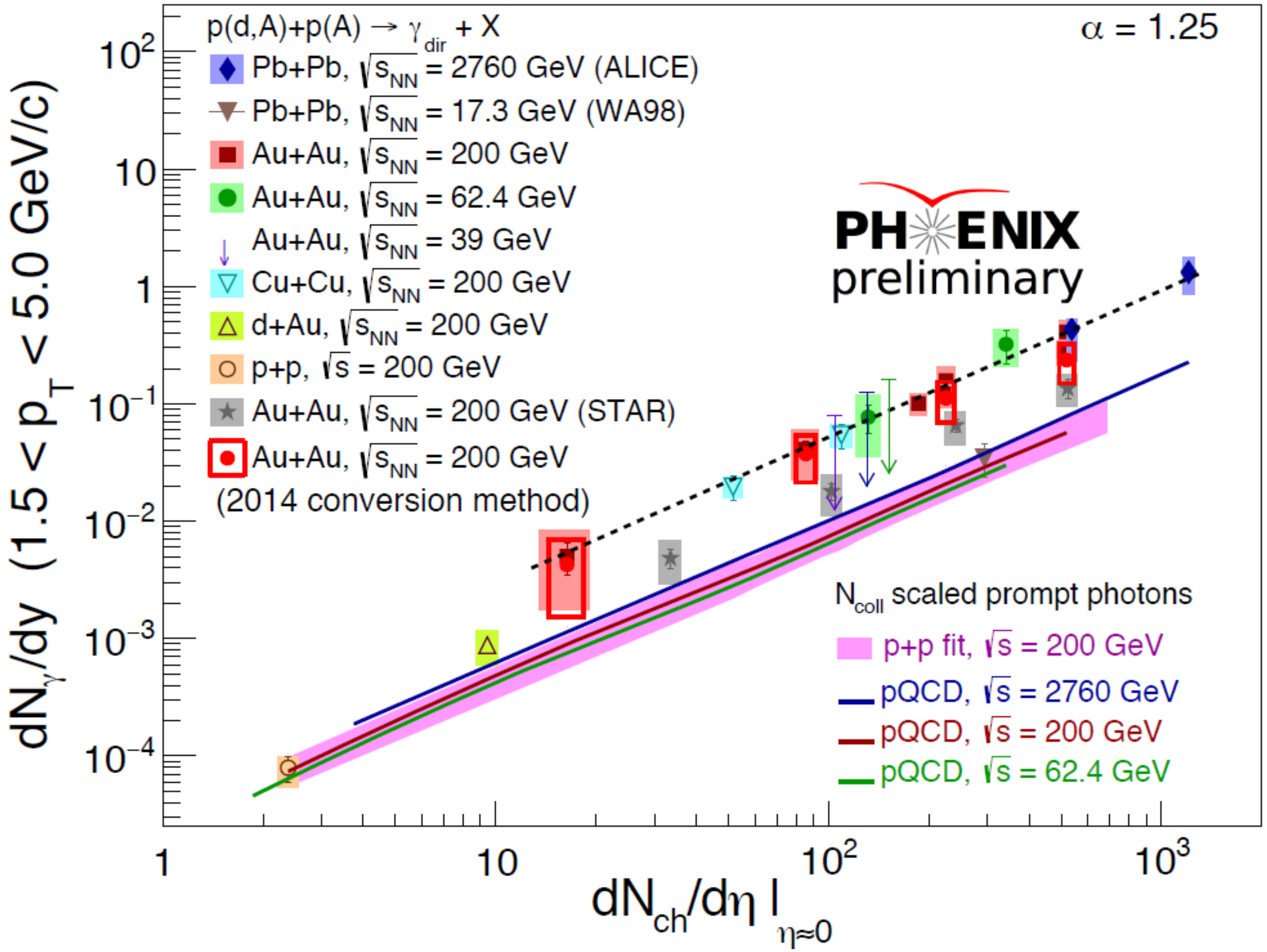


Consistent with the observed scaling behavior in A+A systems



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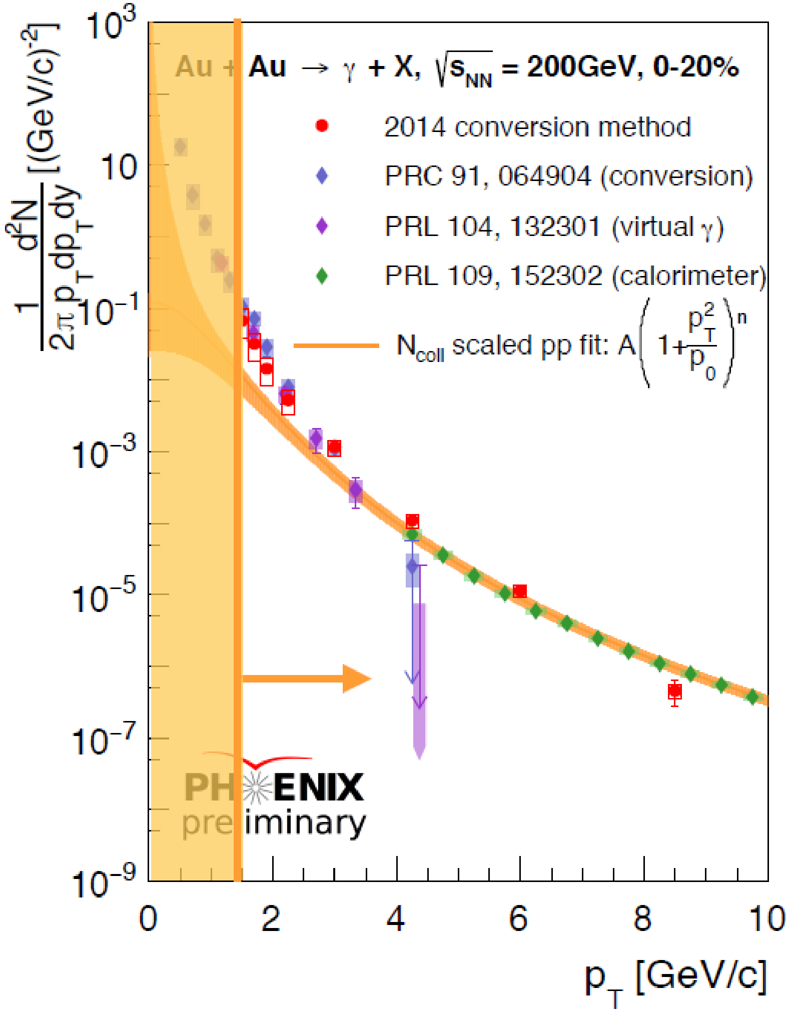

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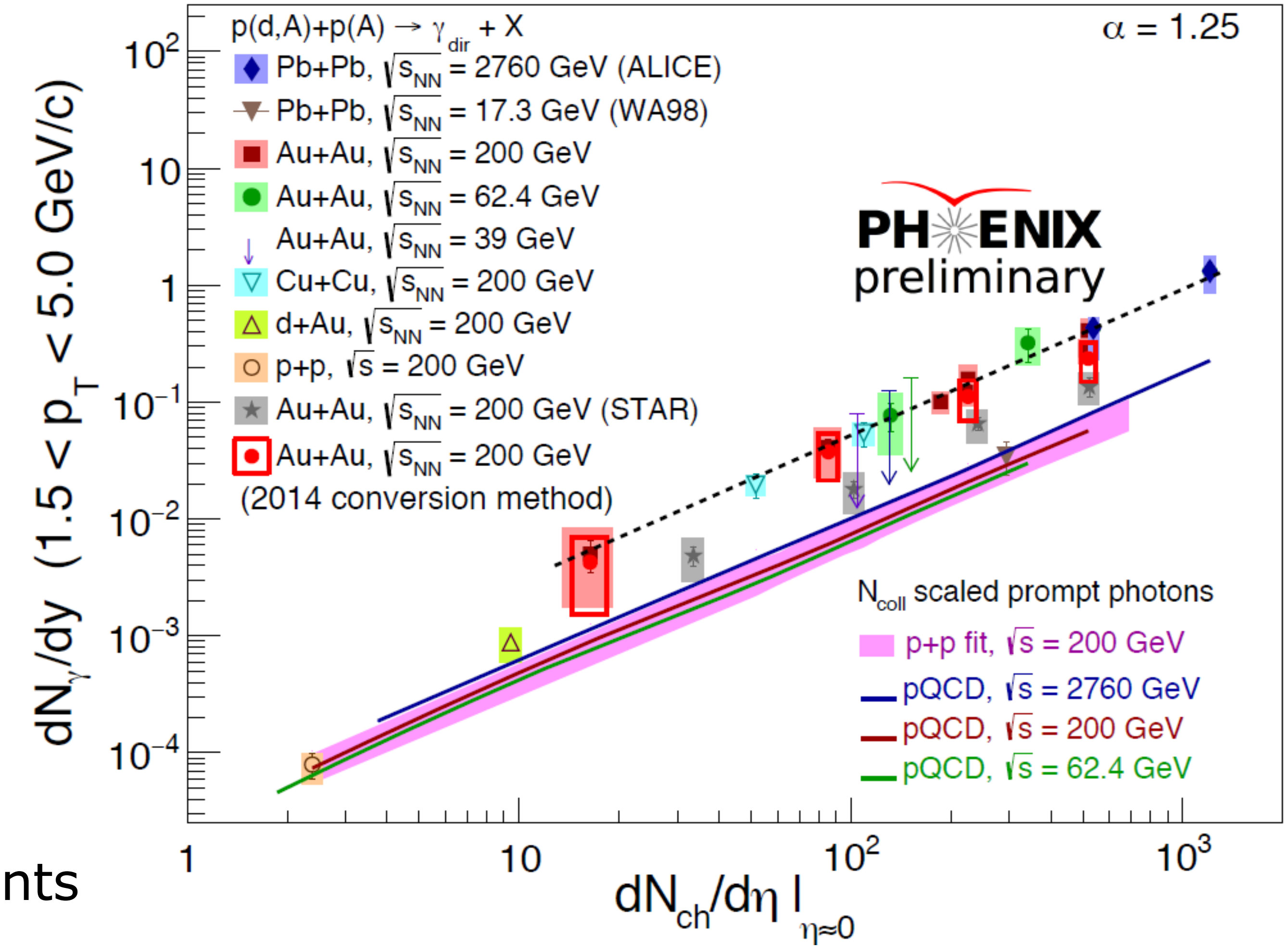

More peripheral Au+Au measurements can fill in the “transition region”

SUMMARY

PHENIX measured the low pt direct photon yields in Au+Au collisions at 200 GeV for different centrality bins with 2014 dataset

- Consistent with previous published PHENIX results
- Higher statistical precision, a full overlap with the published low pt and high pt measurements

Theoretical picture still incomplete-unable to describe large yield and v_2 simultaneously

Observed a scaling behavior on direct photons at large systems:

- At the same center of mass energy, low at high pT scale with Ncoll
- At all energies, low pT yield scale with $(dNch/d\eta)^{1.25}$

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THANK YOU FOR ATTENTION!