ZIMÁNYI SCHOOL 2020

J.E.: Borura derü! (From Darkness, the Light)

Direct Photon Measurements at PHENIX

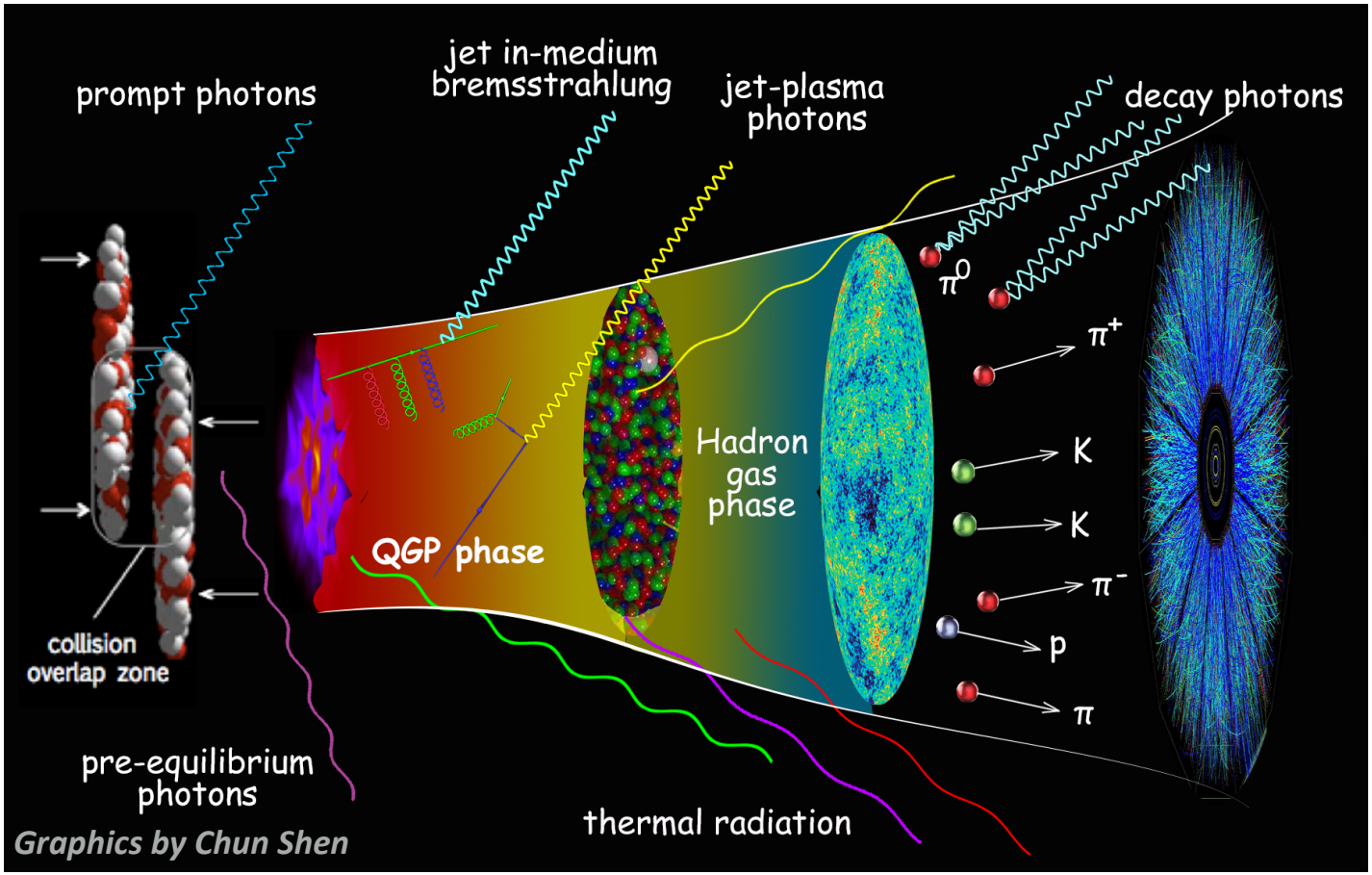
Wenqing Fan for the PHENIX Collaboration

PHENIX

Stony Brook University

Why photons?

- **Photons are a unique probe for QGP**
  - **"Color blind" (do not experience strong interaction), provide a direct fingerprint of its creation point**
  - **All thermal mediums emit radiation in the form of photons or low mass lepton pairs**



80-90% of the photons are decay photons!

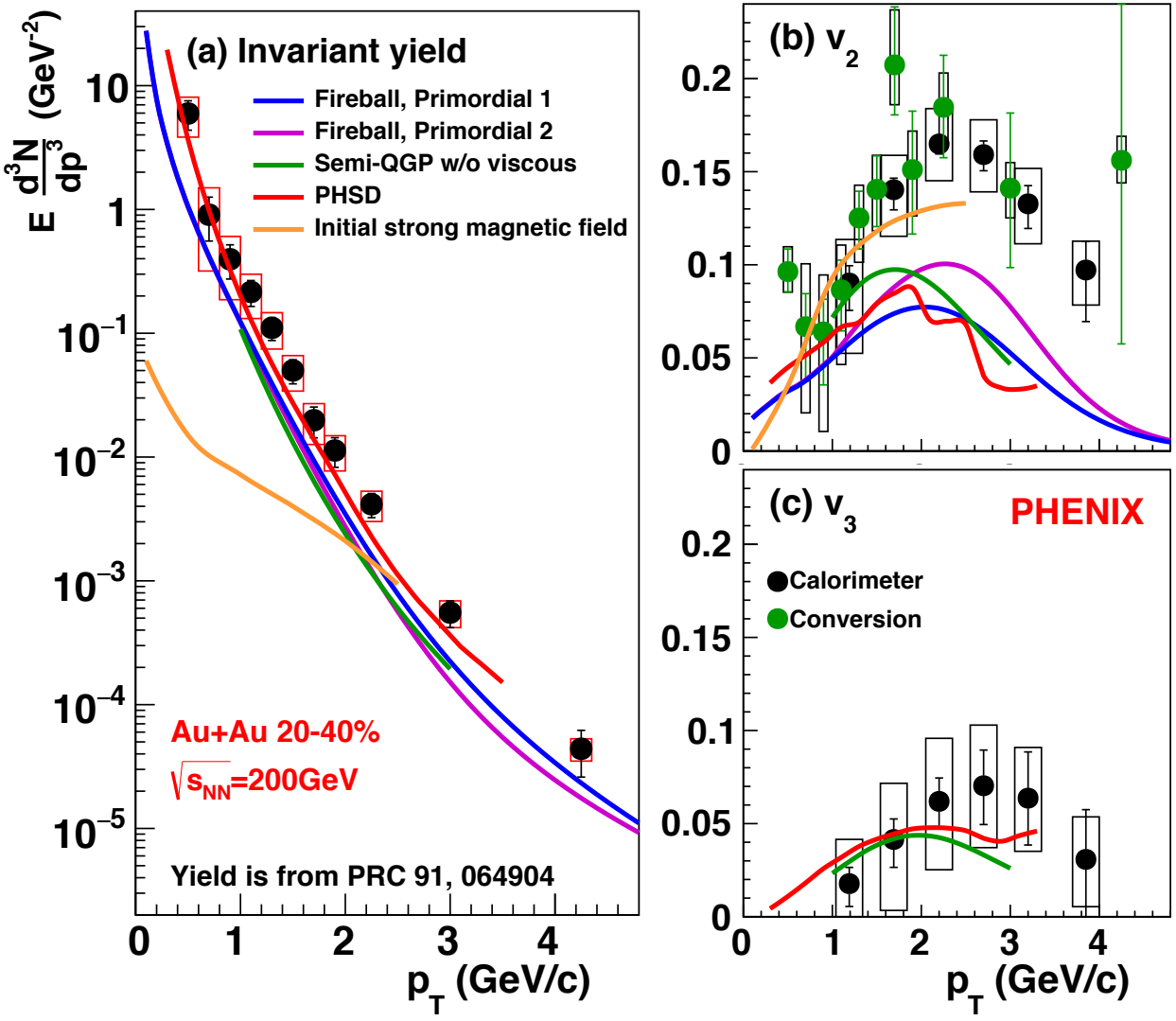
Direct photon = Inclusive photon - decay photon

Early vs late emissions?

- Large yield & large v_2
  - Large yield: emissions from the early stage when temperature is high
  - Large v_2: emissions from the late stage when the collective flow is sufficiently built up

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

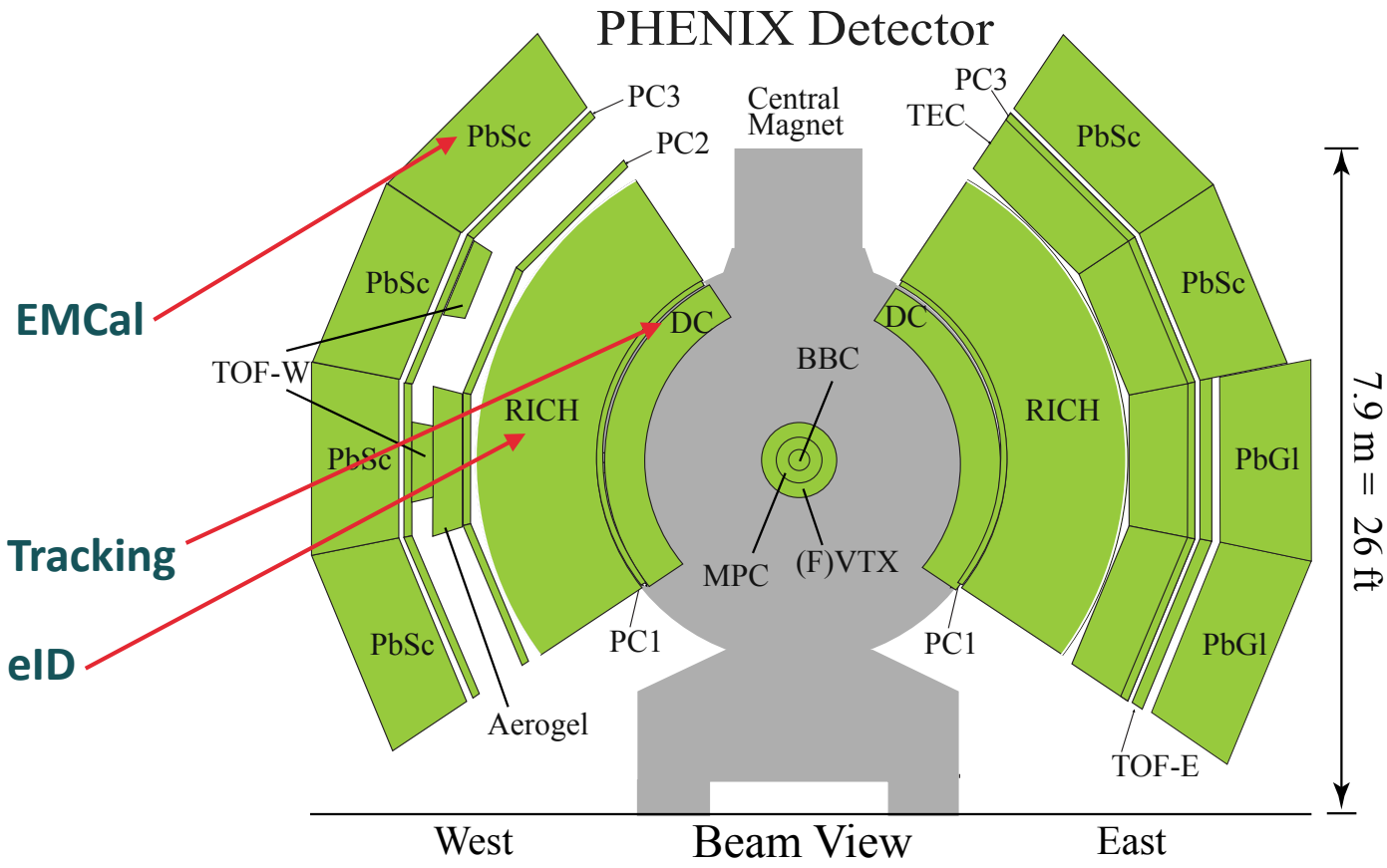
PRC 91, 064904 (2015)



New insights — direct photon in different systems

- A wealth of datasets available for direct photon analysis in PHENIX
  - 16 years of operation, 9 collision species, 9 collision energies

System	p+p	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au		
$\sqrt{s_{NN}}$ [GeV]	200	200	200	200	200	200	200	62.4	39



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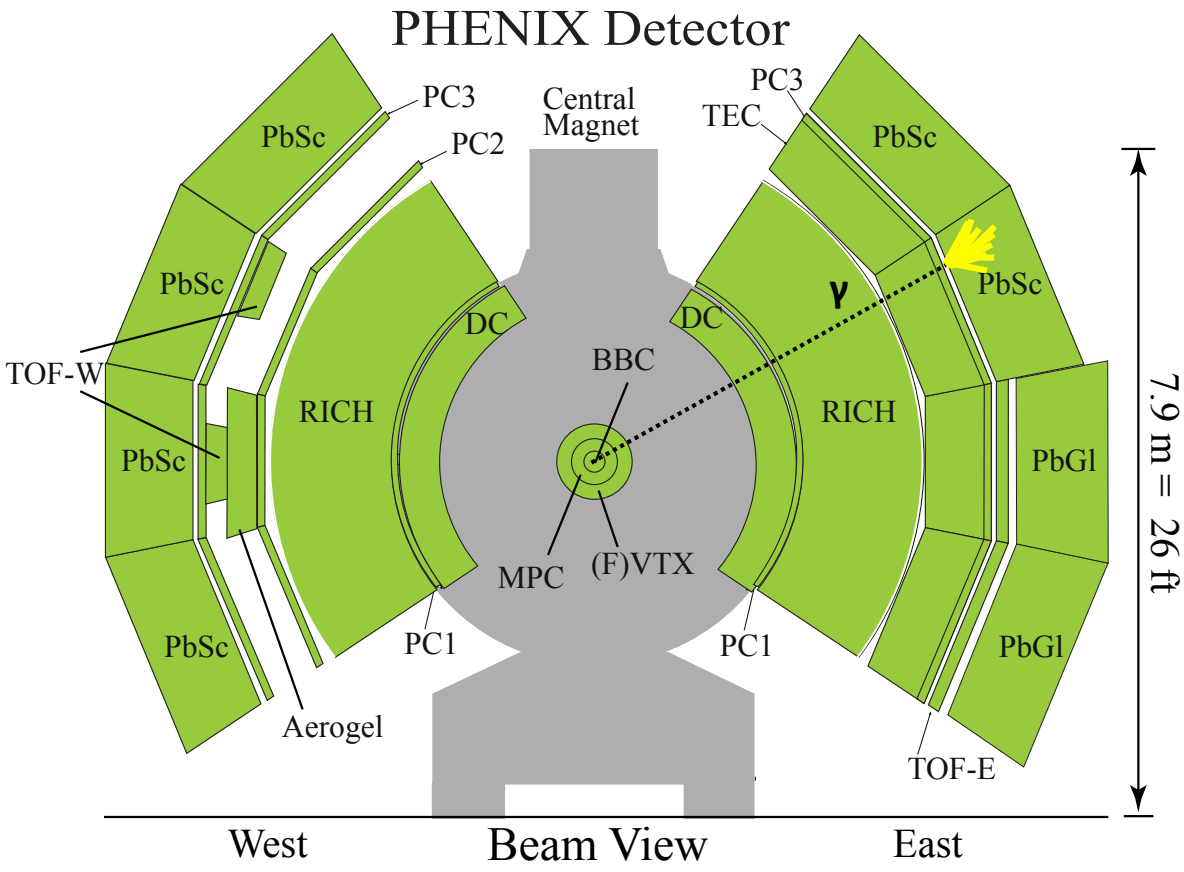
- 3 different methods to measure photons
  - calorimeter method

γ — EMCal

Tracking

eID



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- 3 different methods to measure photons
  - calorimeter method
    γ
  - virtual γ method
    $\gamma^* \rightarrow e^+ + e^-$
  - external conversion method
    $\gamma \rightarrow e^+ + e^-$

EMCal

Tracking

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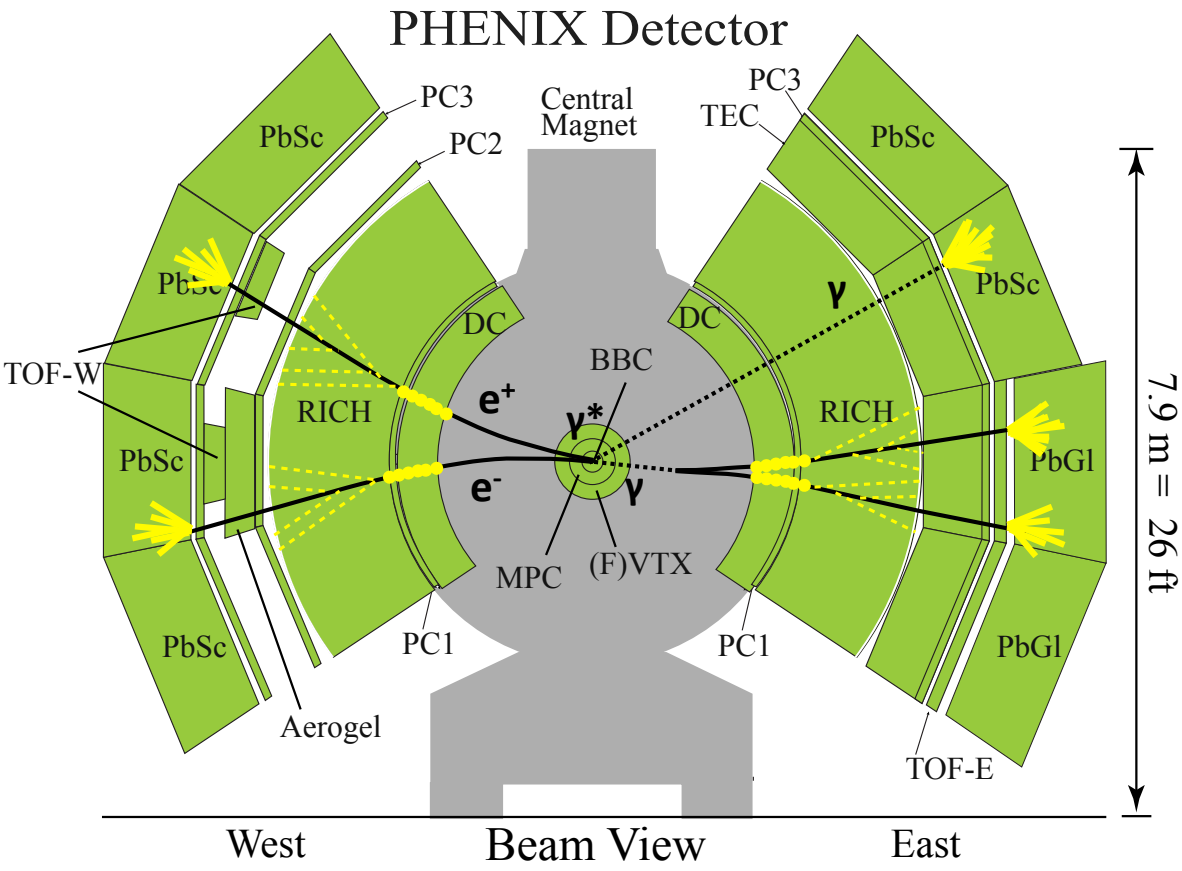


Integrated low p_T direct photon yield — universal scaling

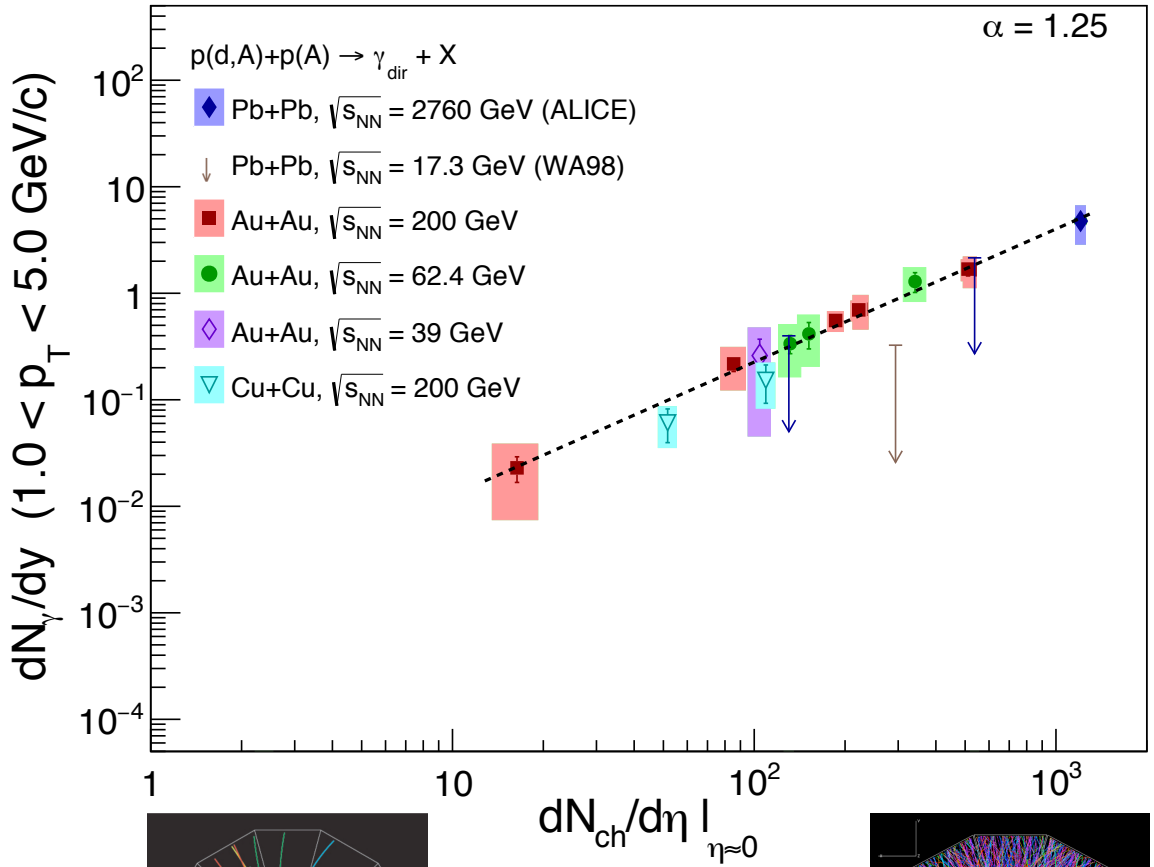
- Integrate the low p_T direct photons and use $dN_{ch}/d\eta$ to compare data from different beam energies, collisions species, and collision centralities

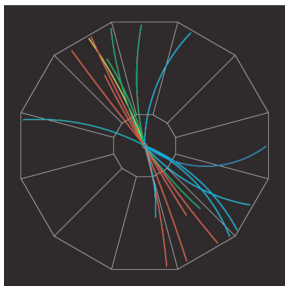
Universal scaling behavior in all A+A systems

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

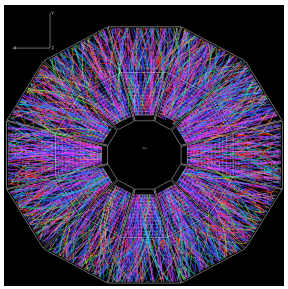
Source of photons must be similar

PRL 123, 022301 (2019)





more central collision
higher beam energy
heavier nuclei A



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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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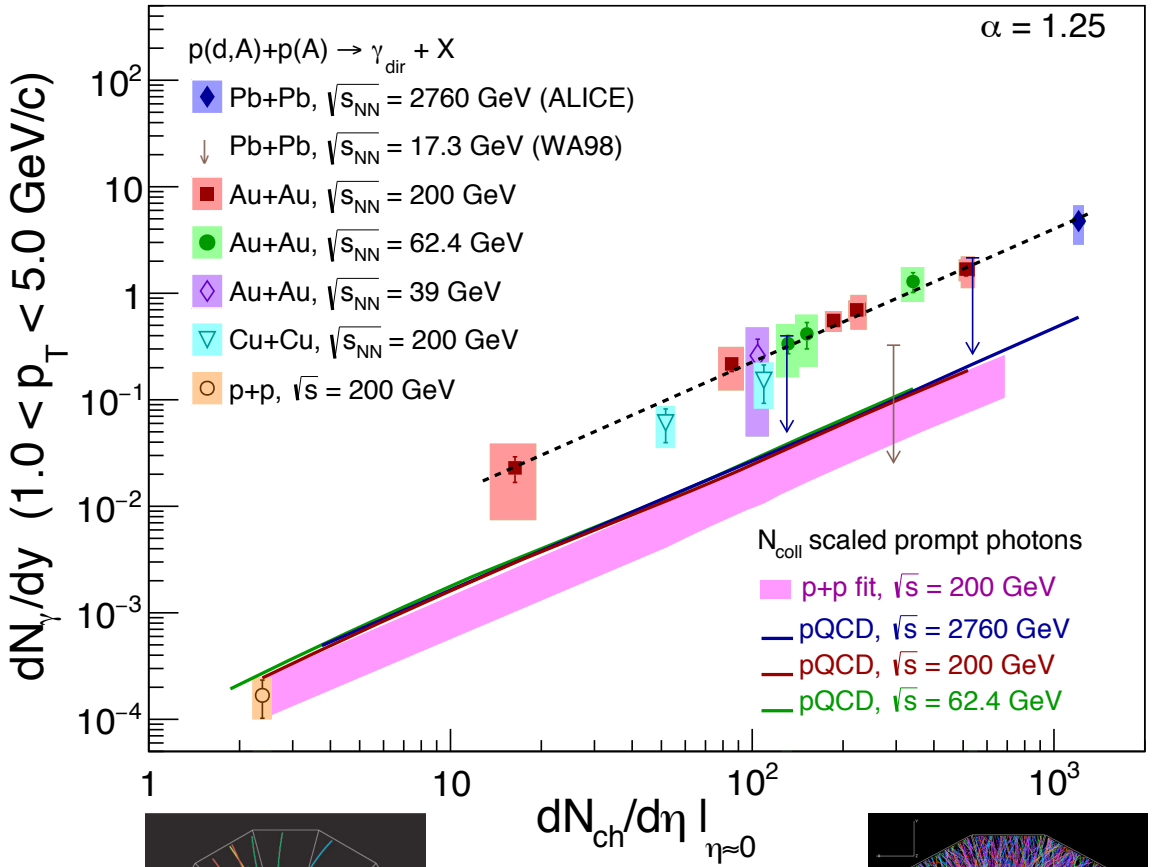

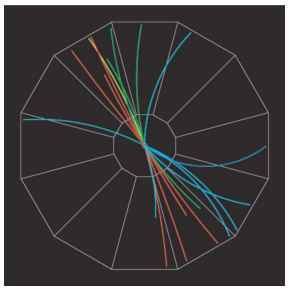

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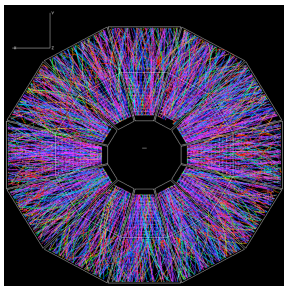

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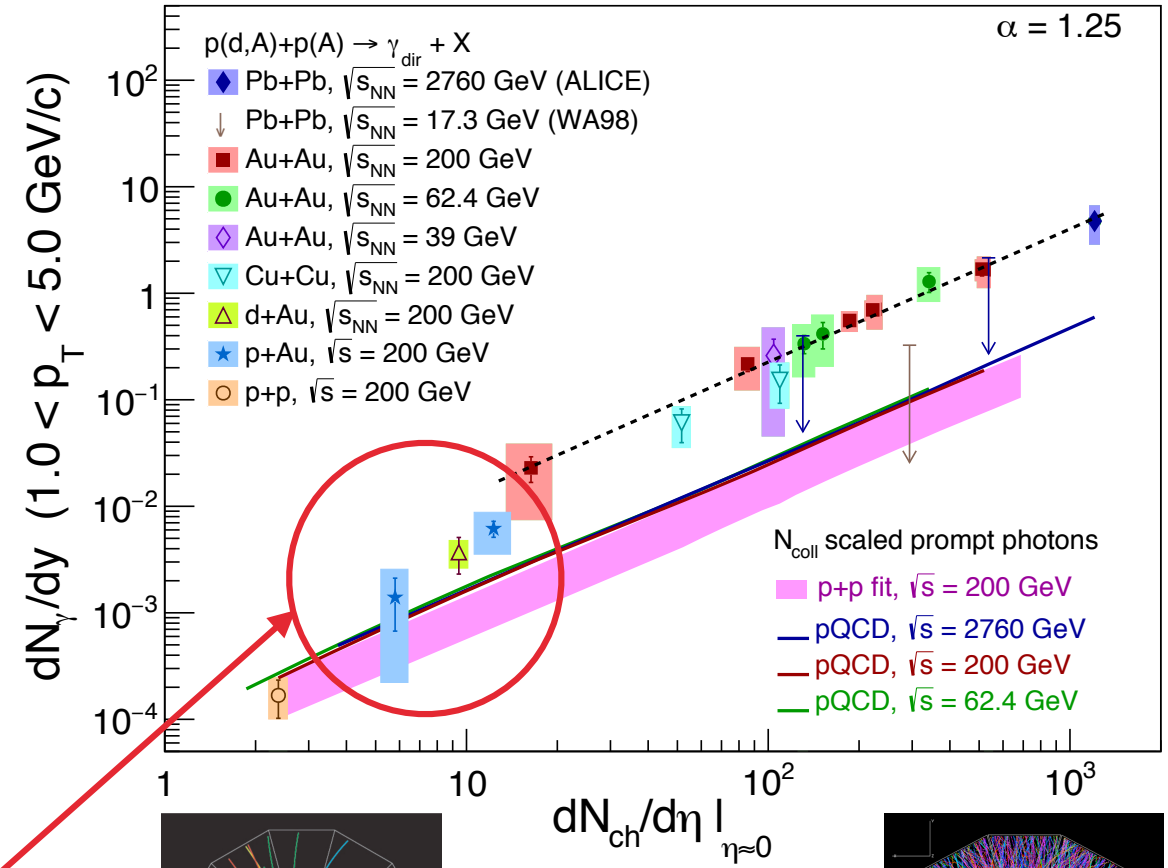
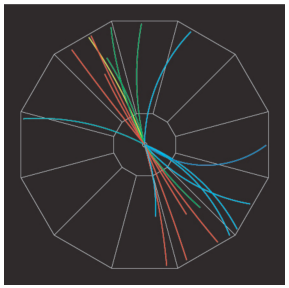
Onset of low p_T radiation excess at $dN_{ch}/d\eta$ ~10?

PRL 123, 022301 (2019)





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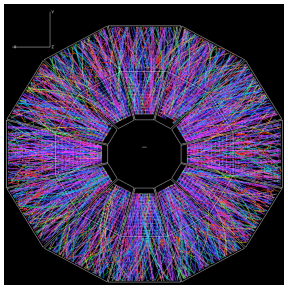
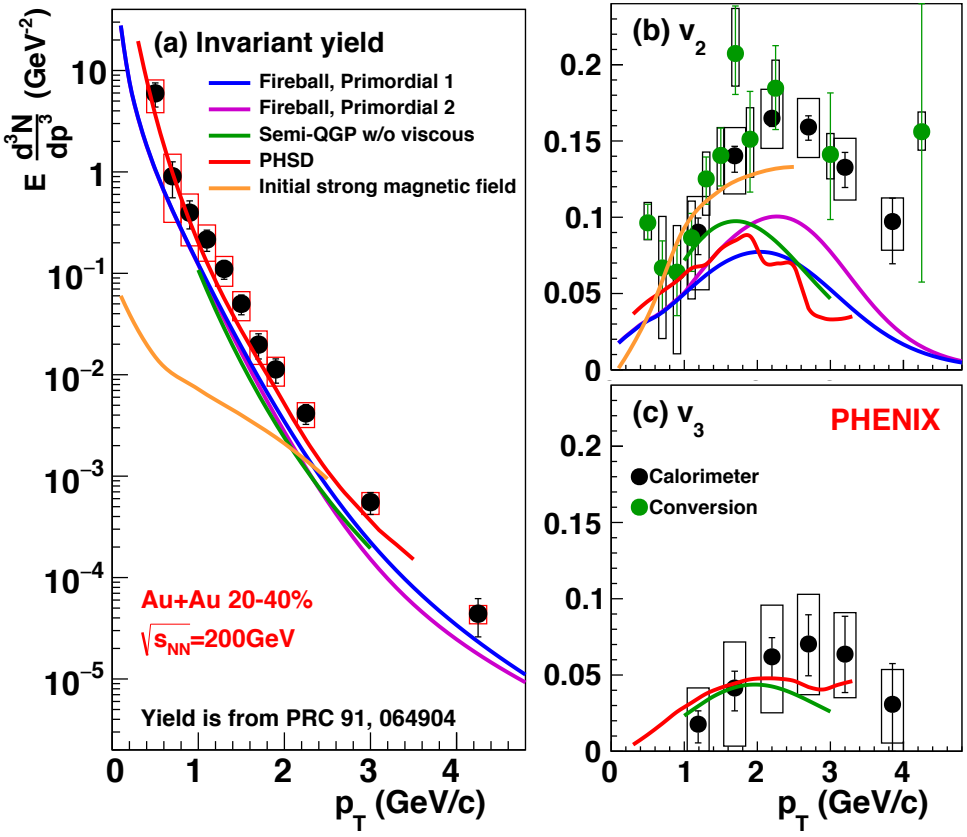
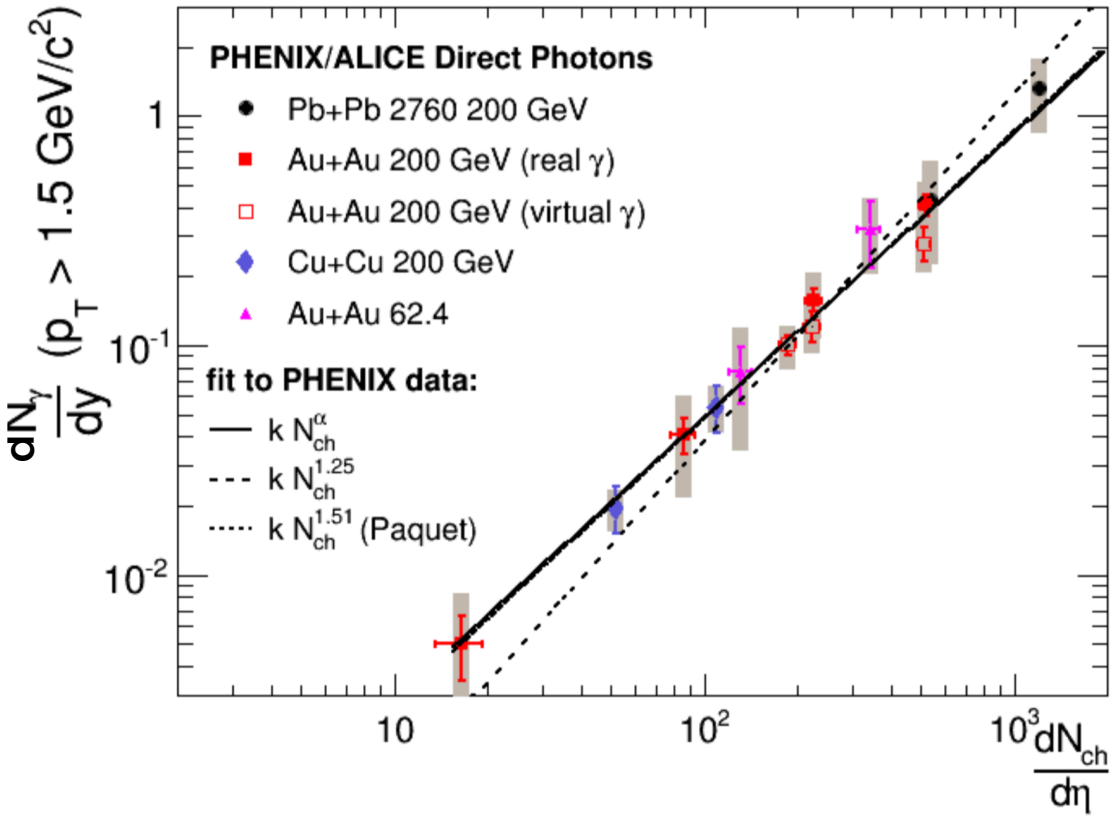


Direct photon puzzle

- Experimental observations
  - Large yield of low p_T direct photons
  - Large anisotropic emission
  - Universal scaling with α ~5/4
- Challenging to explain by thermal source

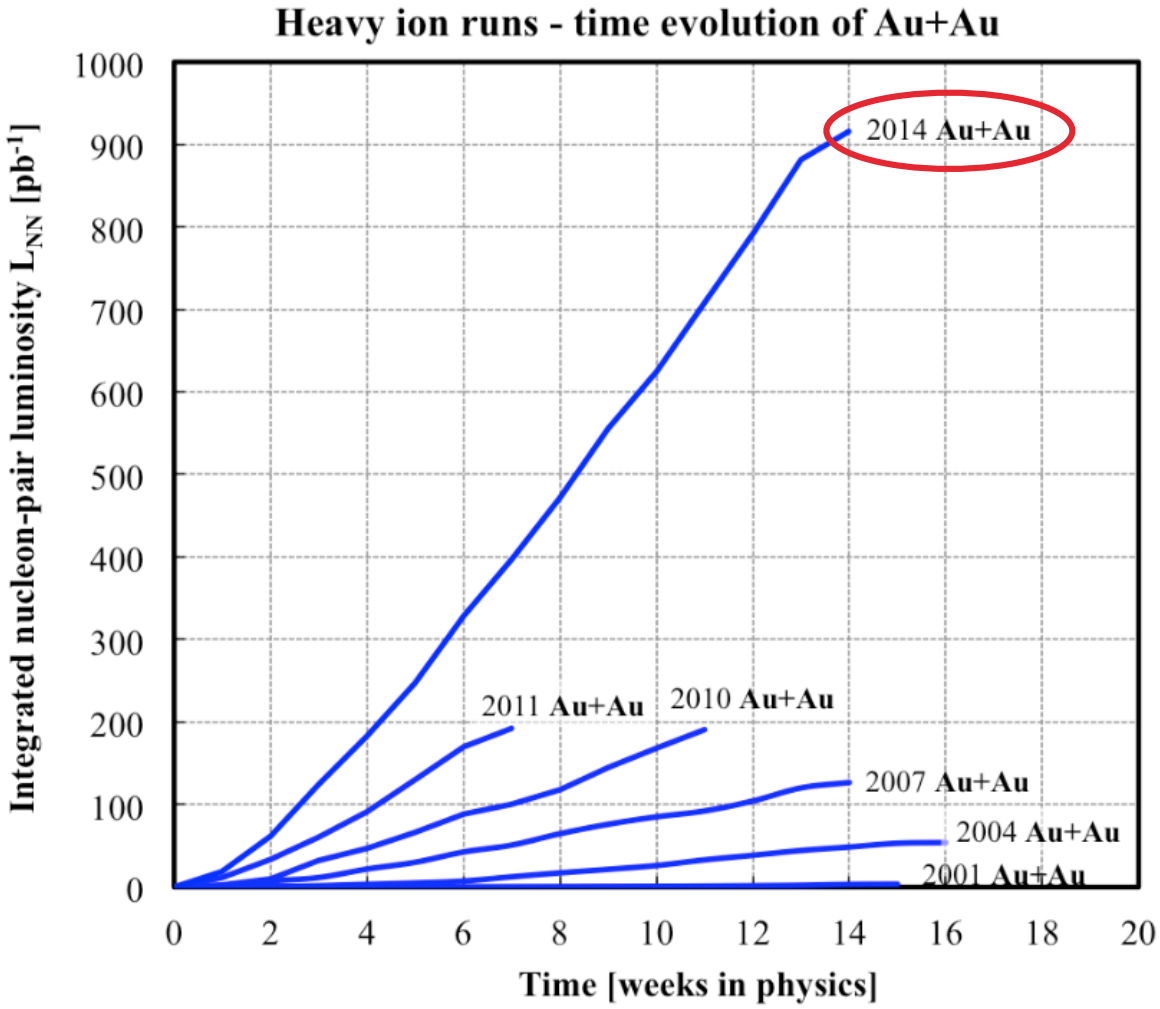
What is the main source for low p_T direct photons?





Towards precision measurement with the “golden dataset”

- Theoretically
  - Modification in thermal photon emission?
  - Modification in prompt photon emission?
  - Other sources of photons? (pre-equilibrium? hadronization? B field)
- **Experimentally (to confirm and to study in more detail)**
  - **Experimental data needs more statistics**
  - **2014 Au+Au dataset**
  - **More conversions at the PHENIX silicon vertex detector (VTX) ($X/X_0 \sim 14\%$)**



External conversion method

- Double ratio tagging method ($R_\gamma > 1$ indicating direct photon signal)

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

Reduce systematics!

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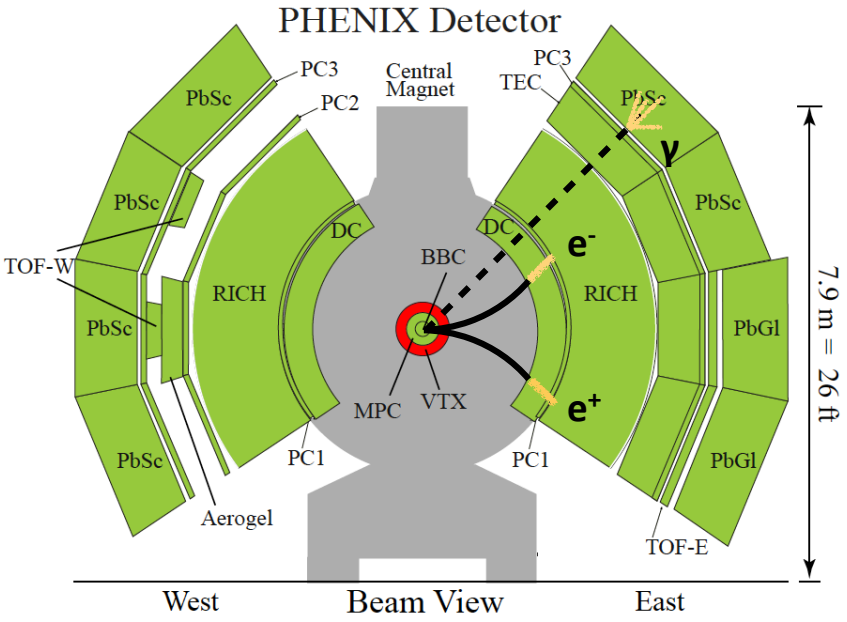
Raw counts

❖ N^{incl}/N^{tag} from real data: # of conversion photons/# of conversion photons tagged as coming from π^0



Conversions from π^0 tagged

Conversions from inclusive photons

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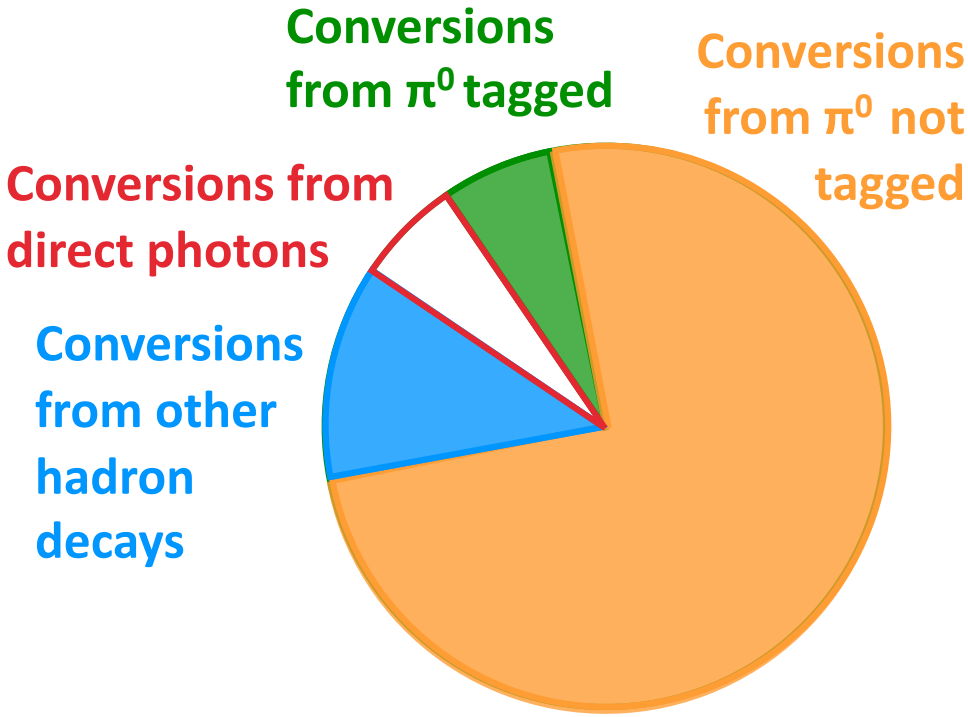
Correct for detector effects

❖ Conditional acceptance and efficiency: the acceptance for the second photon in the EMCal from π^0 decay given that we already reconstructed the first photon from a conversion pair

Correct for other background sources

❖ Cocktail ratio (other sources of decay photons)



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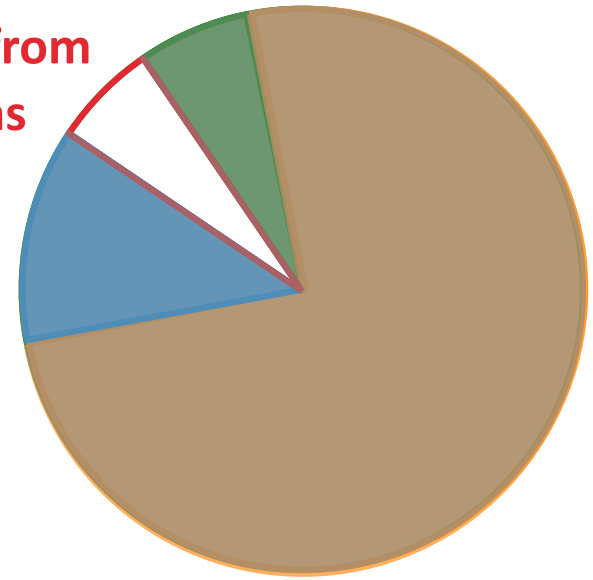
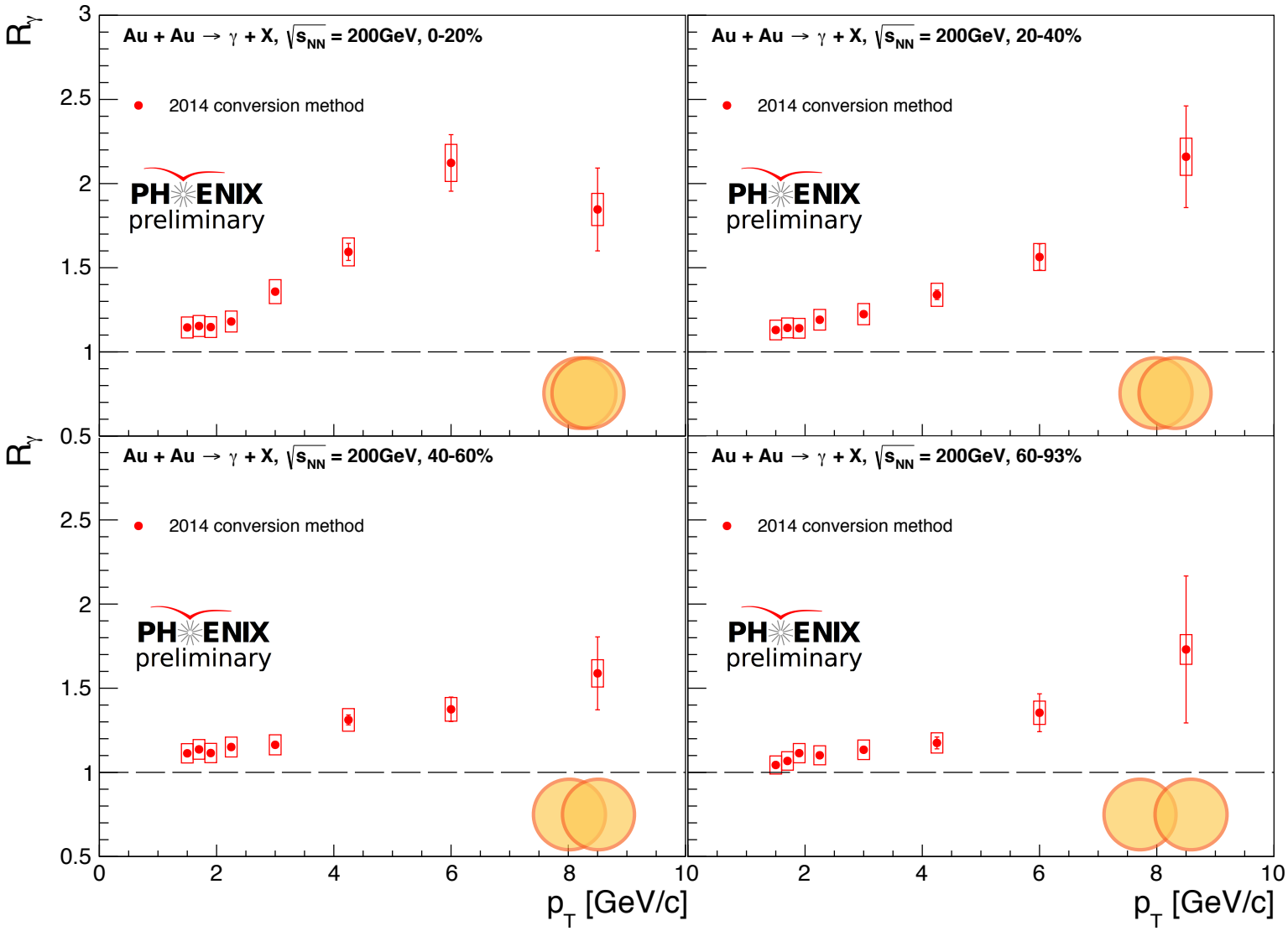


Direct photon results in Au + Au collisions at 200 GeV



A new measurement with improved statistical precision

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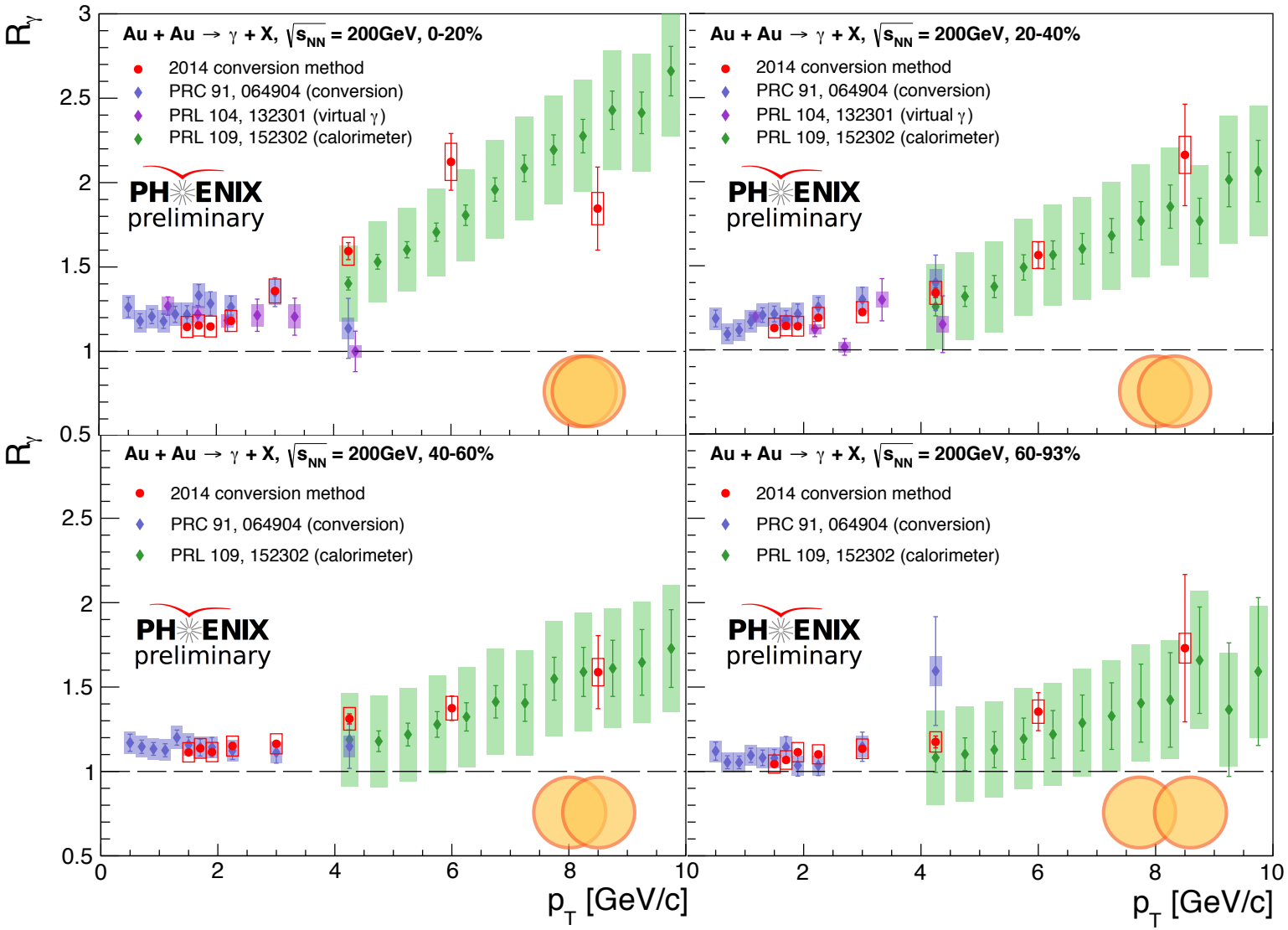

A new measurement with improved statistical precision

Consistent with previous published results using conversion method, virtual γ method, calorimeter method

Full overlap with the published low p_T and high p_T measurements

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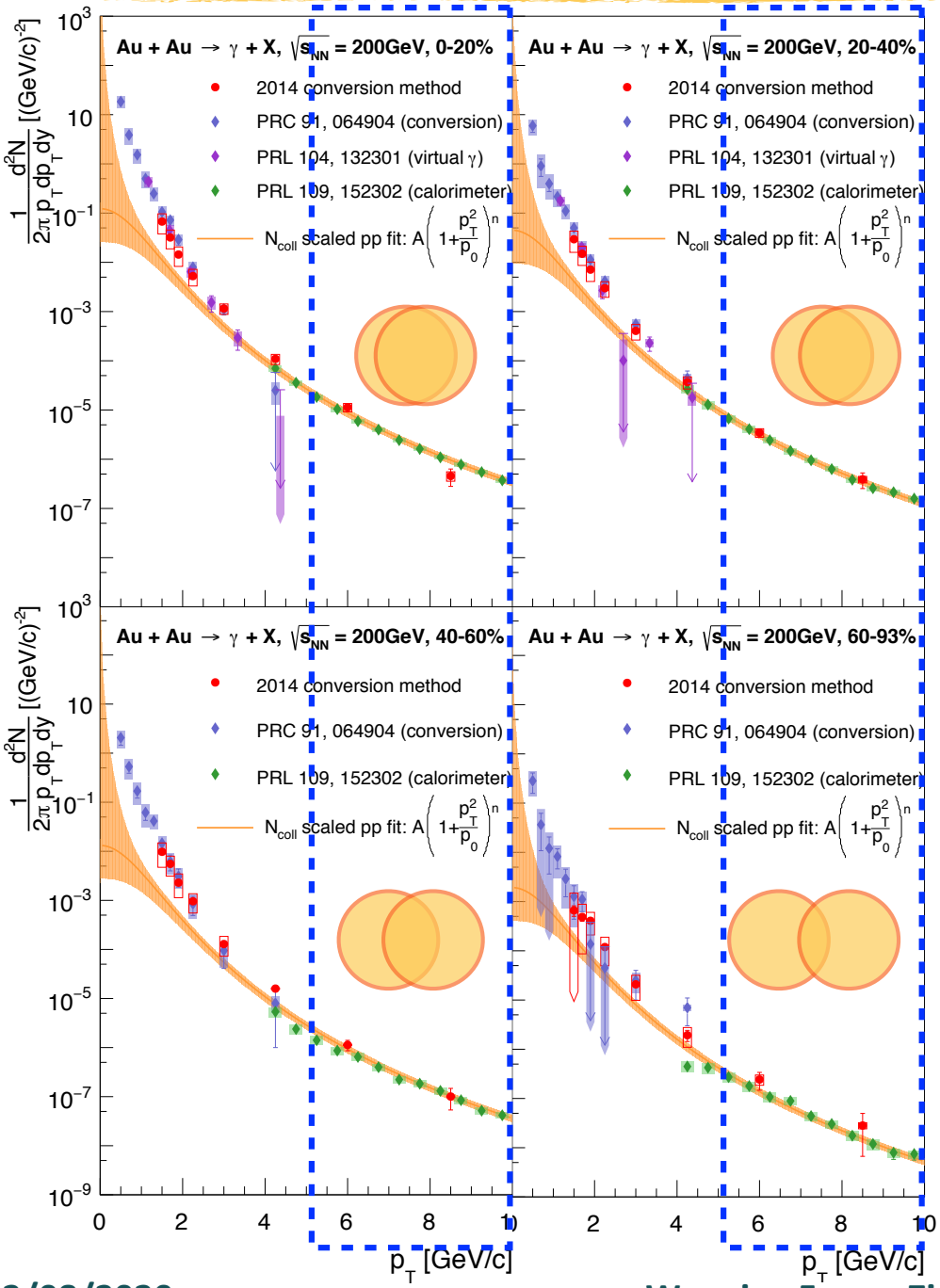

$$\gamma^{\mathrm{direct}} = (R_\gamma - 1)\gamma^{\mathrm{hadron}}$$

At high p_T, Au+Au data consistent with N_{coll} scaled p+p ➜ the dominant photon source is hard scattering

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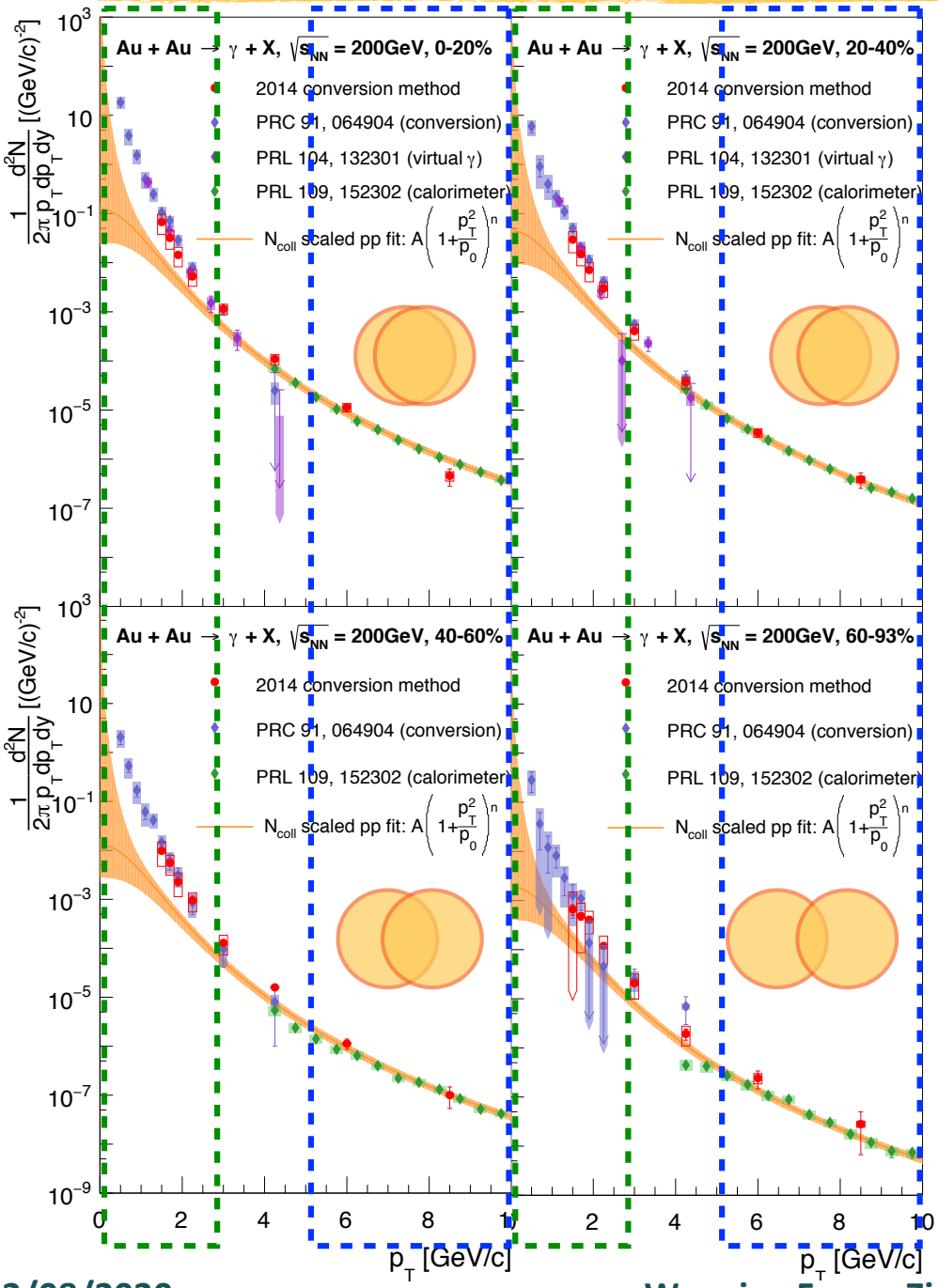
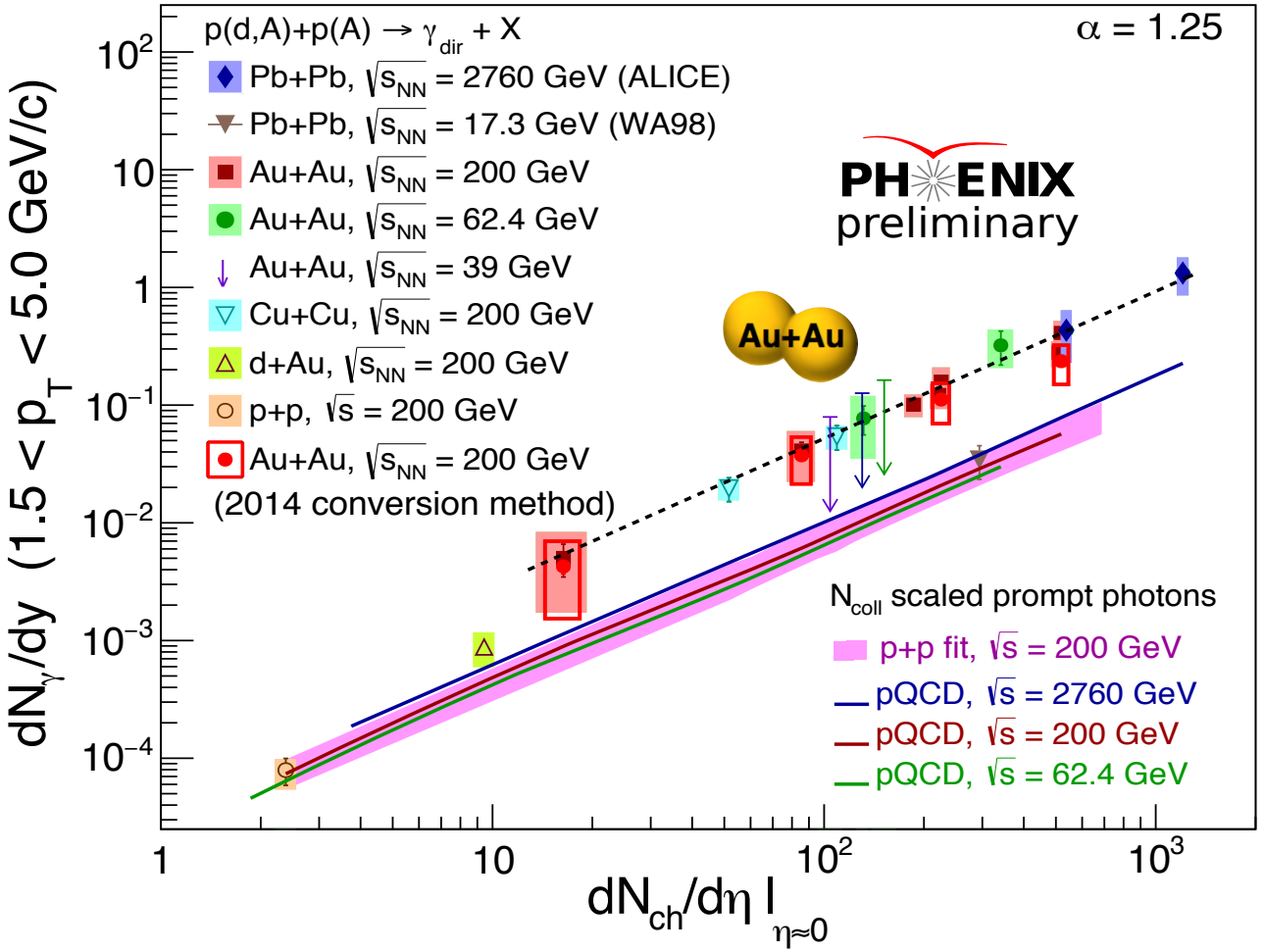


At high p_T, Au+Au data consistent with N_{coll} scaled p+p ➜ the dominant photon source is hard scattering

At low p_T, Au+Au data shows a clear enhancement w.r.t. N_{coll} scaled p+p below 3GeV

Summary and Outlook

New Au+Au result consistent with the observed scaling behavior in A+A systems



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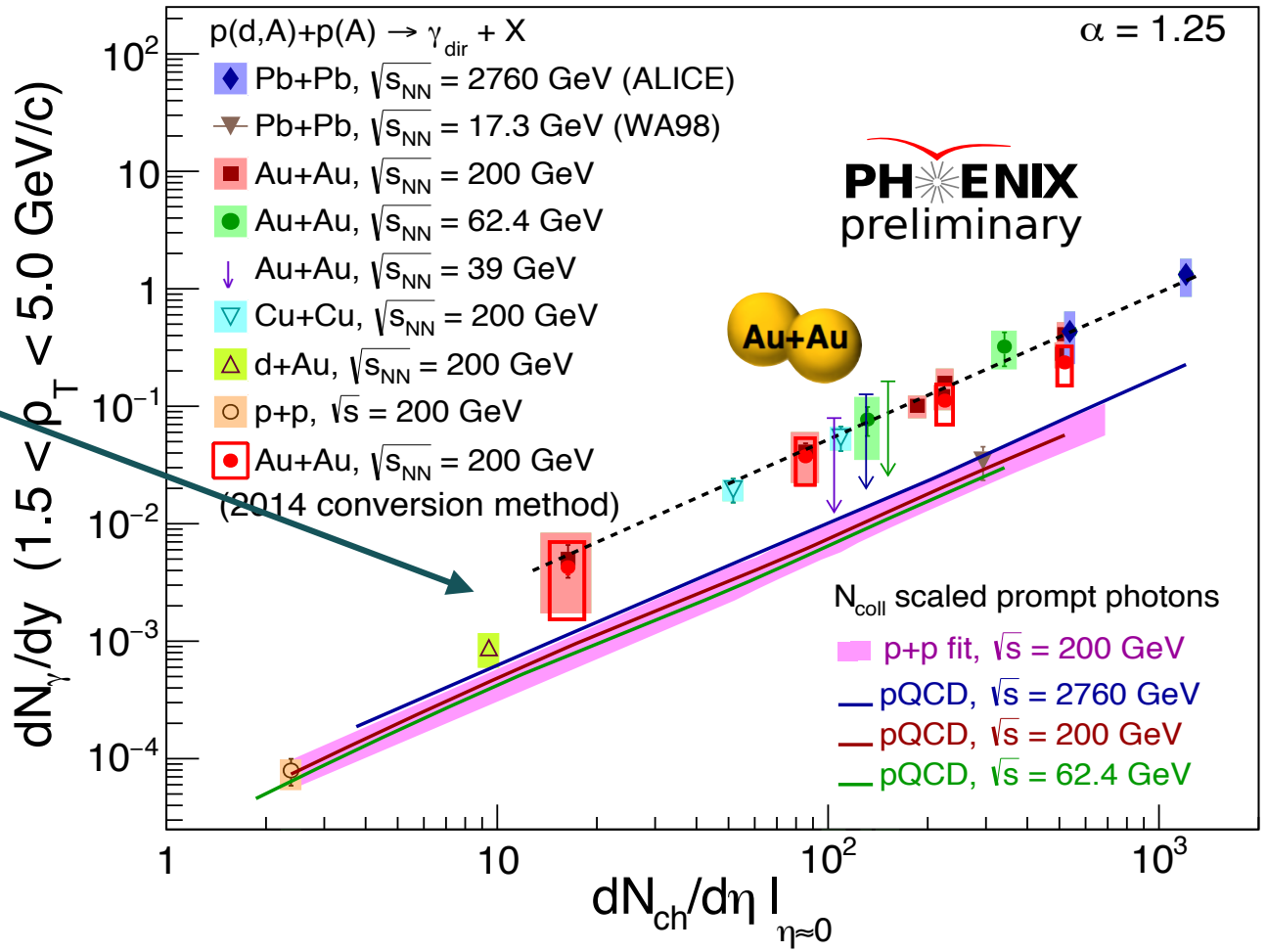
New Au+Au result consistent with the observed scaling behavior in A+A systems

More peripheral Au+Au measurements can fill in the "transition region"



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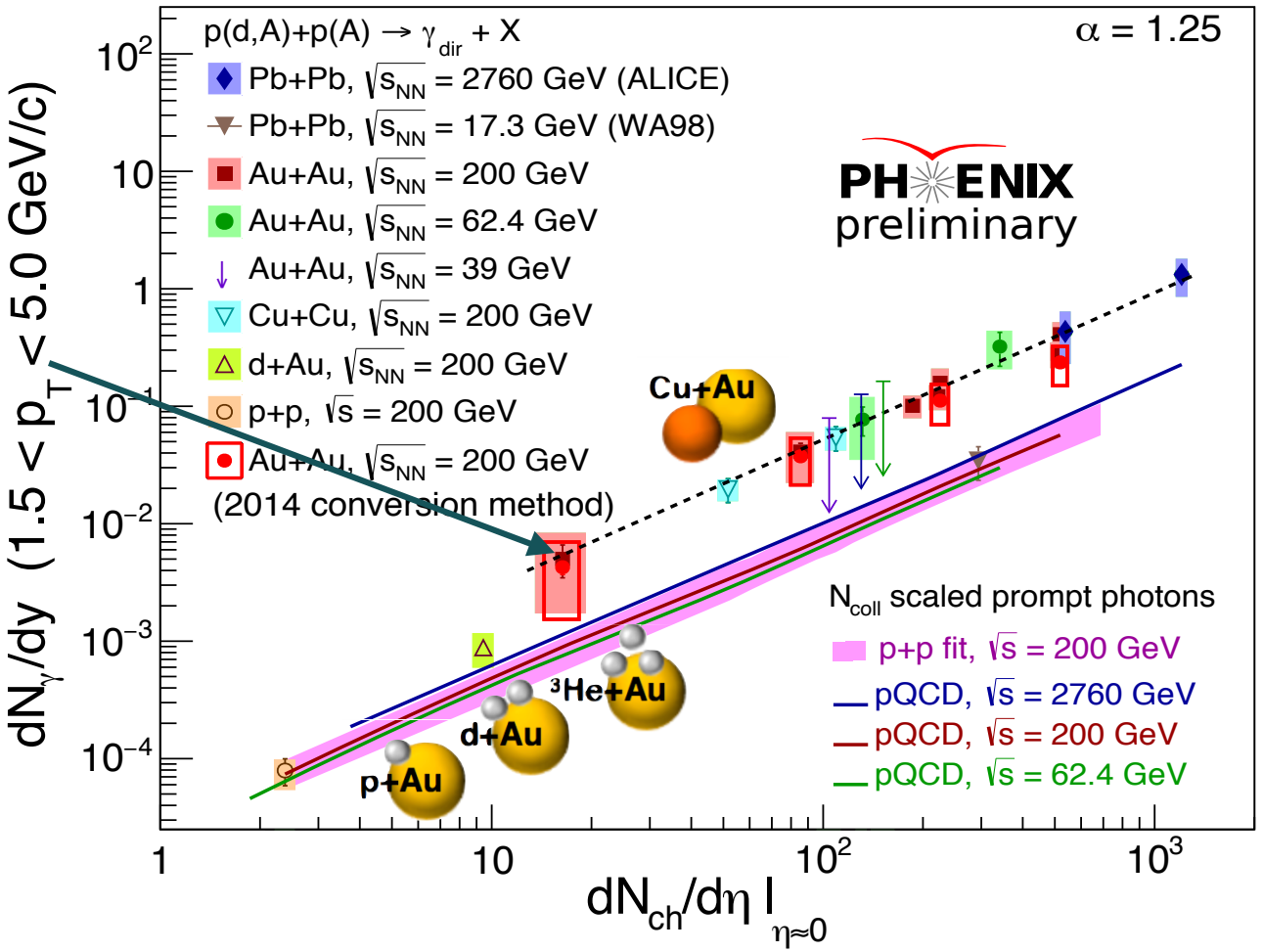
More PHENIX data varying system size and geometry to be finalized/analyzed



THANKS!