

QUARK MATTER 2019

Wuhan, China 4-9 November

Thermal photon production in Au+Au collisions

Wenqing Fan for PHENIX

Collaboration

Quark Matter 2019

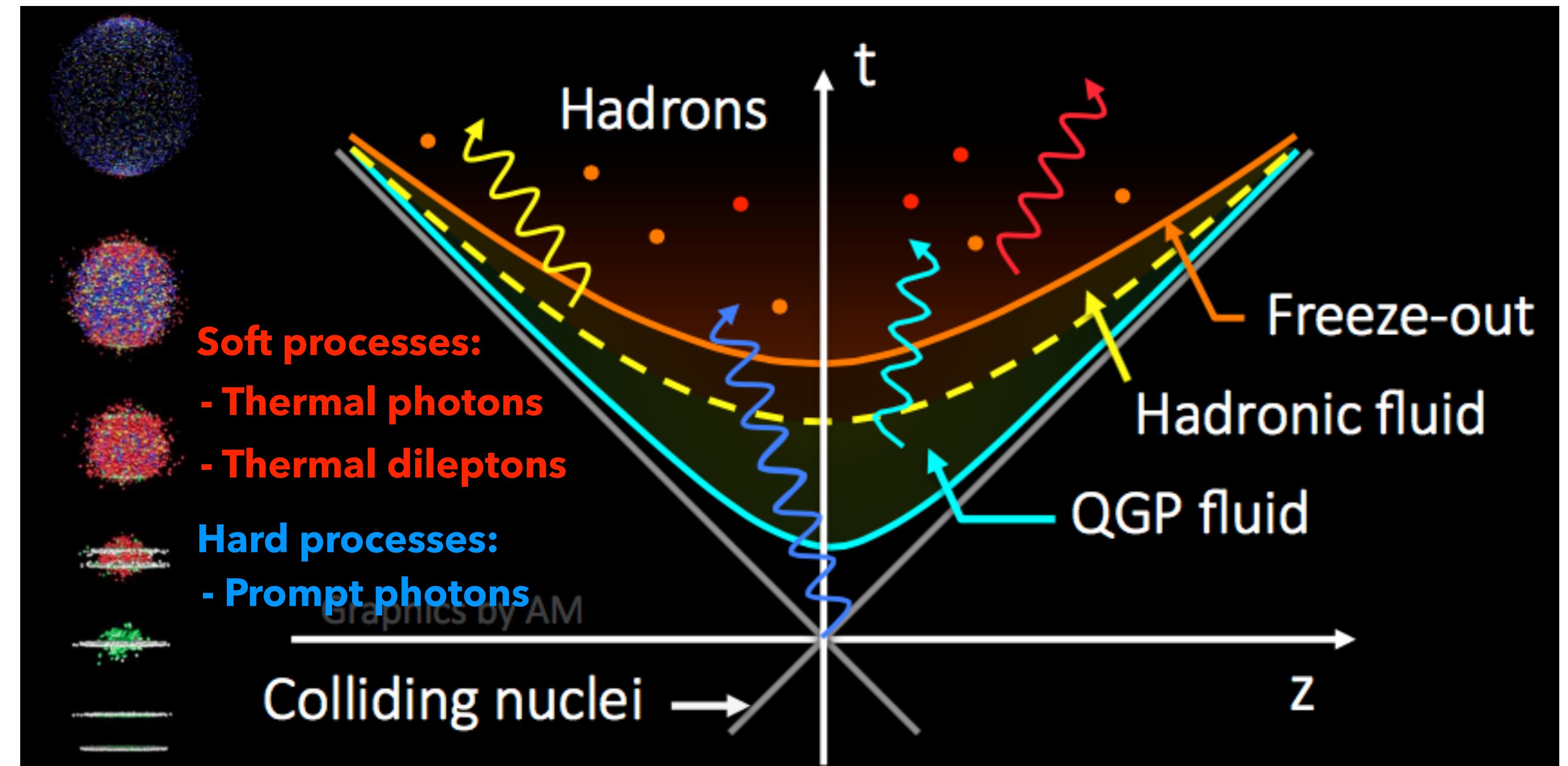


Stony Brook
University

Why photons?

- ▶ Photons are a unique probe for Quark Gluon Plasma (QGP)
- ❖ “Color blind” (do not suffer strong interaction), provide a direct fingerprint of its creation point
- ❖ All thermal mediums emit thermal radiation in the form of photons or low mass lepton pairs

**Direct γ =
Inclusive γ -
hadronic decay γ**

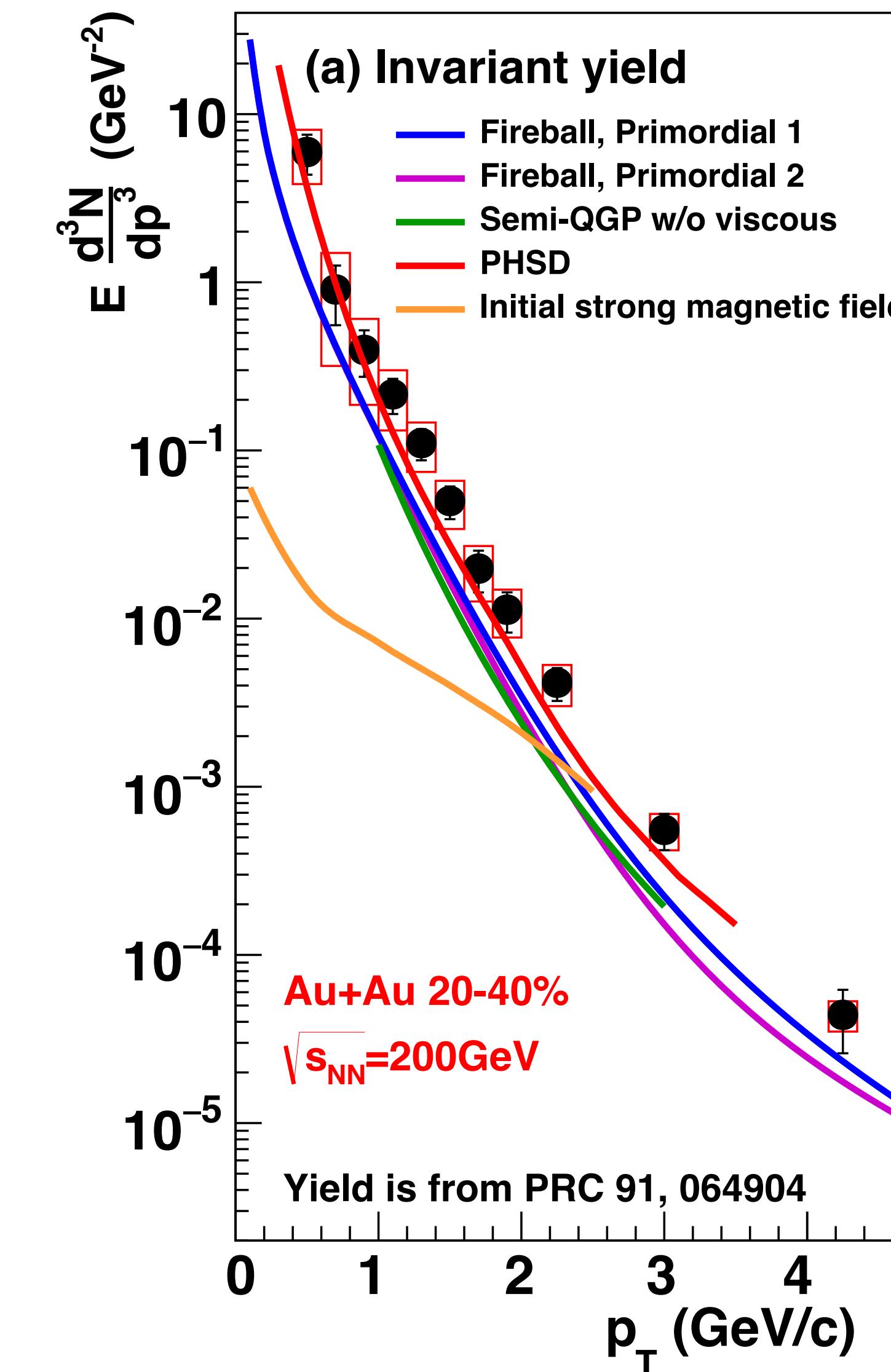


Direct photon puzzle

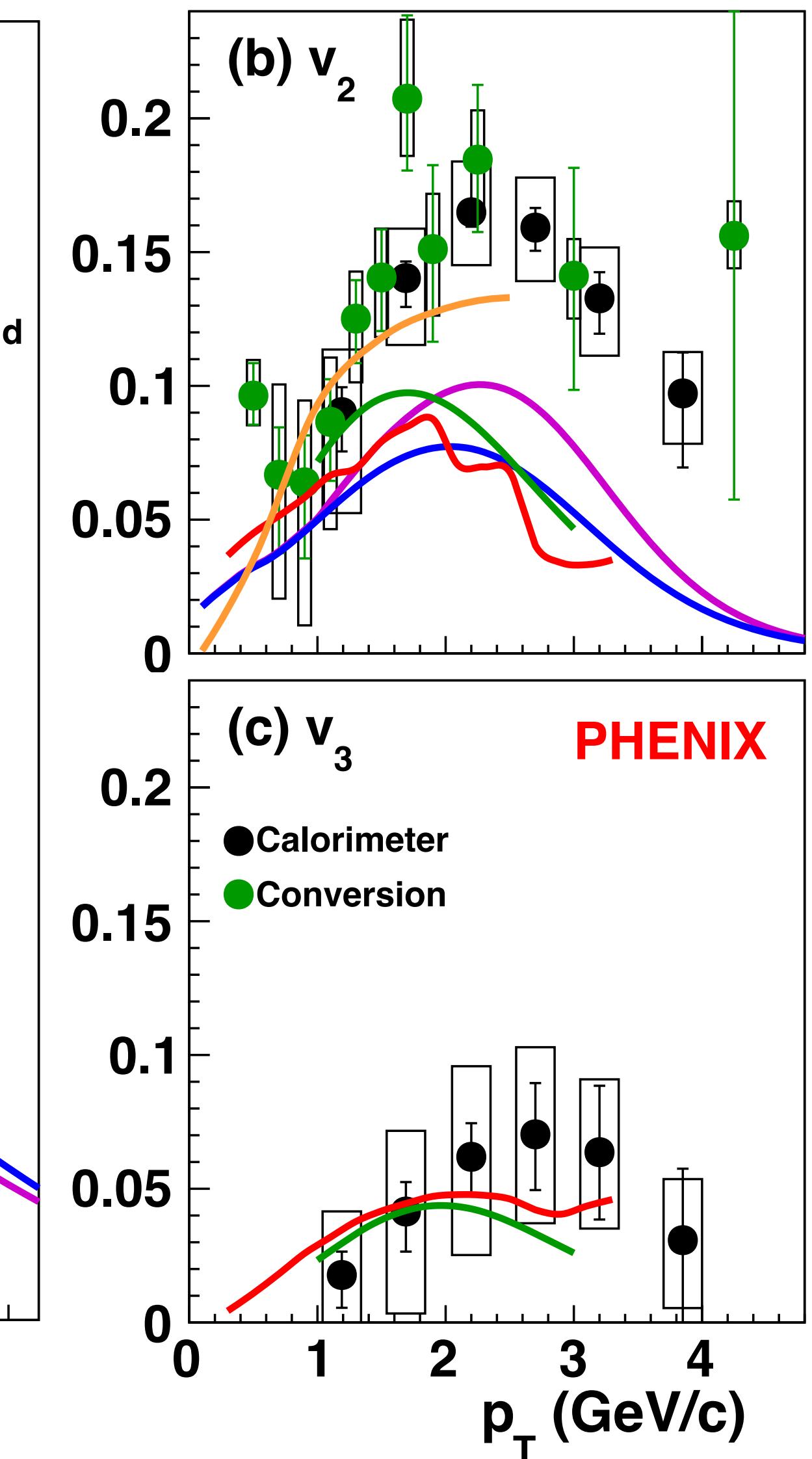
► Large yield & large v_2

- ❖ 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!



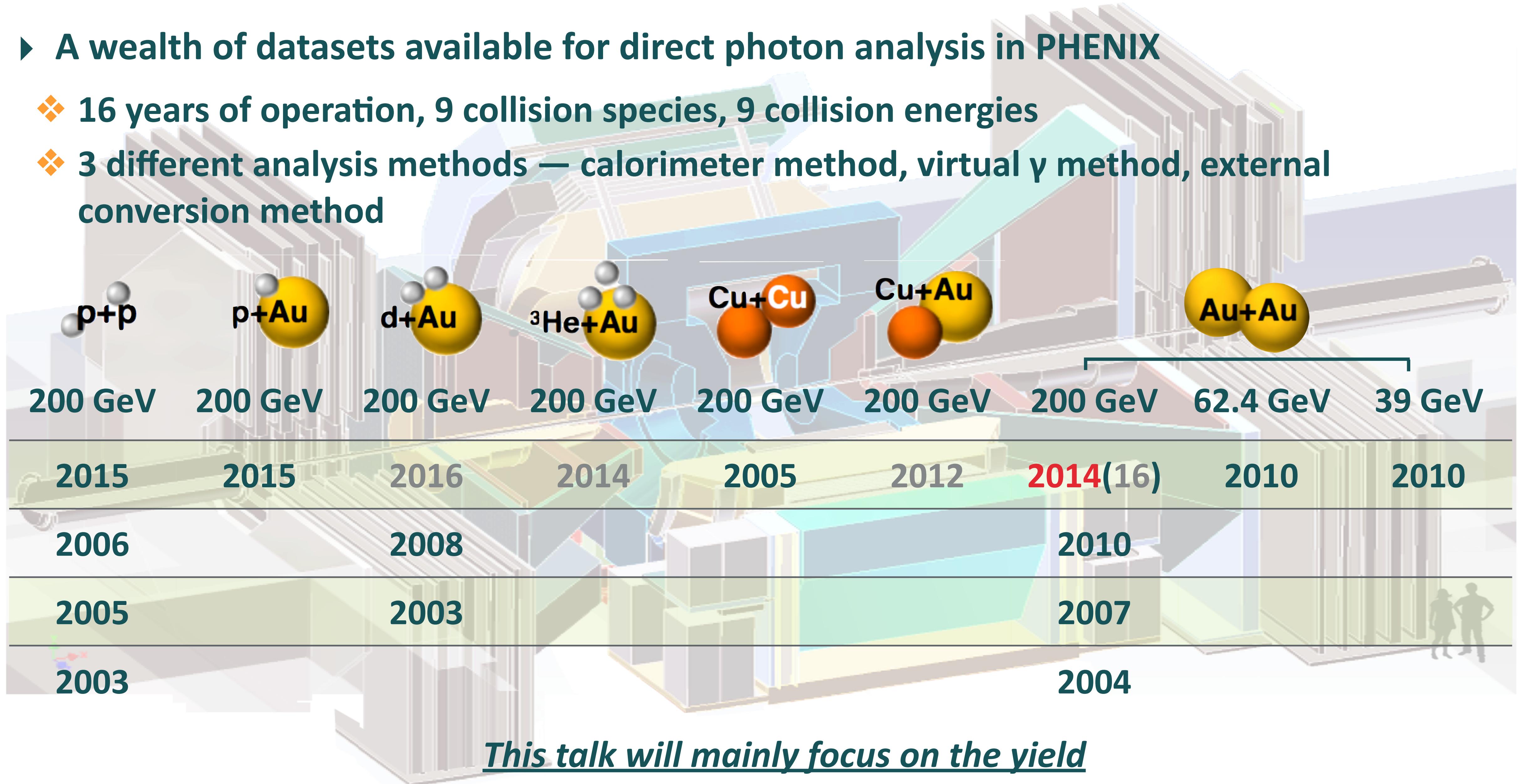
PRC 94, 064901 (2016)



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



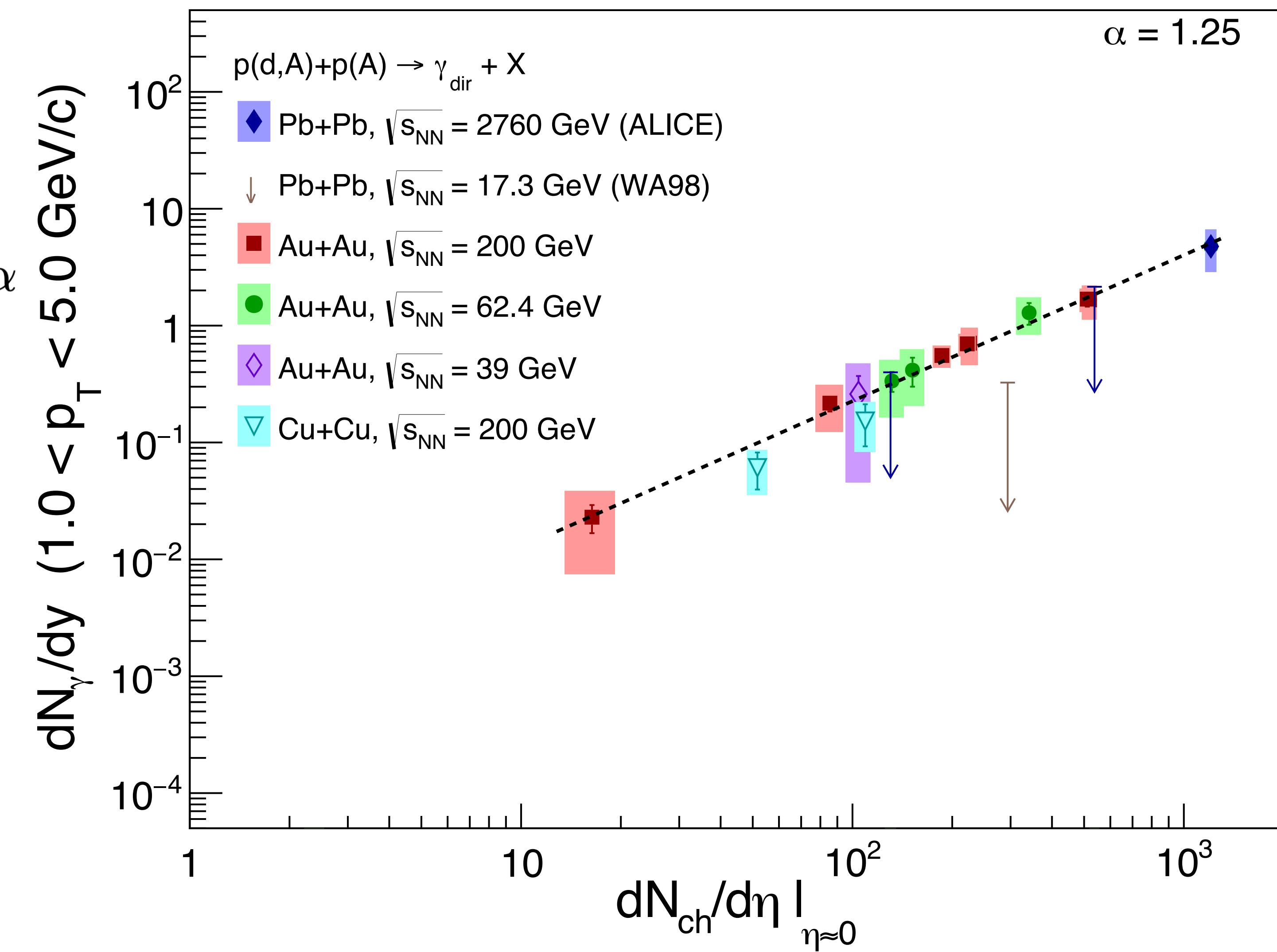
- Integrate the low p_T direct photons and use $dN_{ch}/d\eta$ to compare data from different beam energies, collisions species, and collision centralities

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



- 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

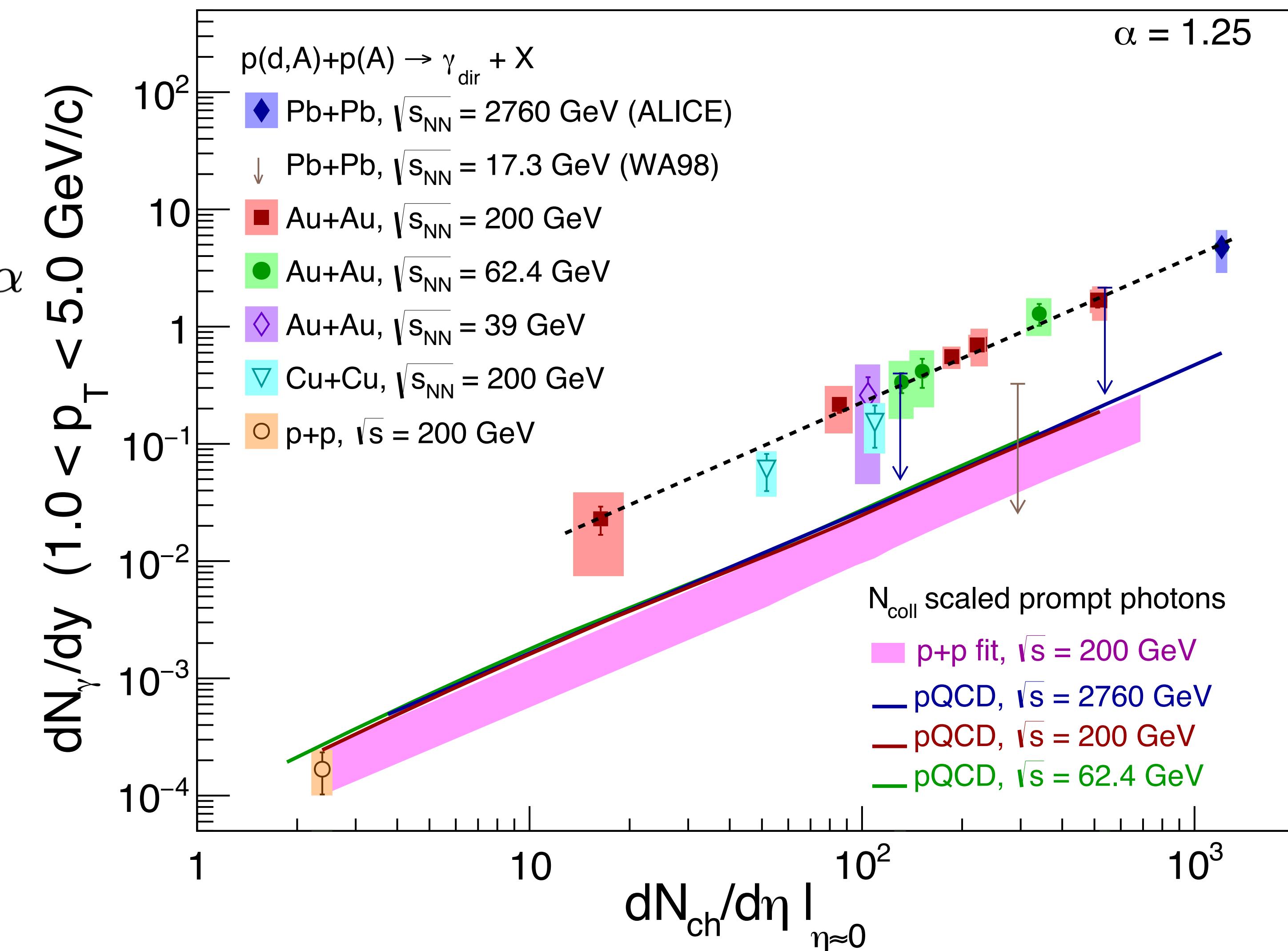
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Universal scaling behavior in all A+A systems

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

Source of photons must be similar

$N_{coll} \times pQCD$ and $N_{coll} \times p+p$ follow same scaling at 0.1 of yield



Integrated low p_T direct photon yield – universal scaling

4

- 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

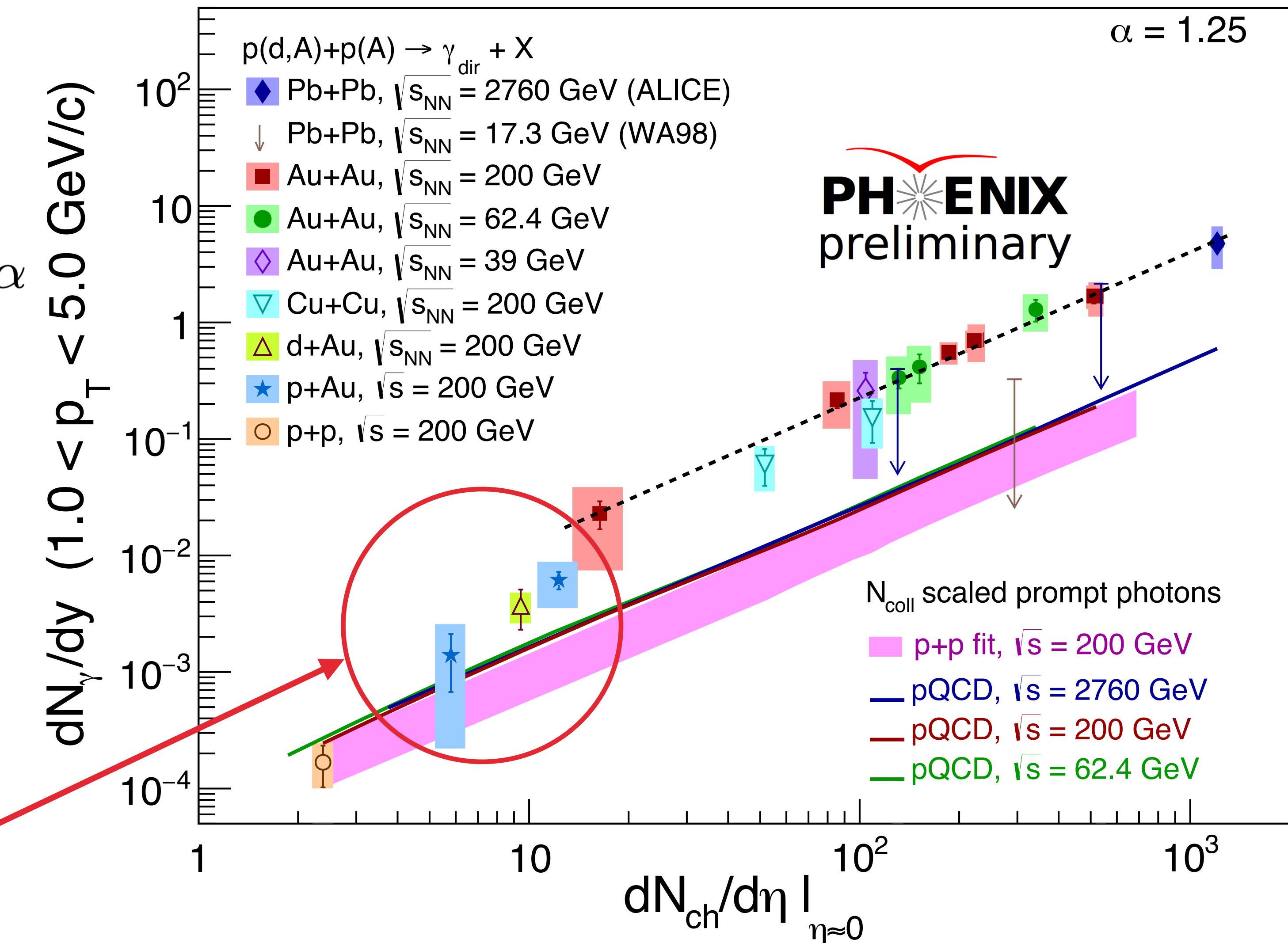
Universal scaling behavior in all A+A systems

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

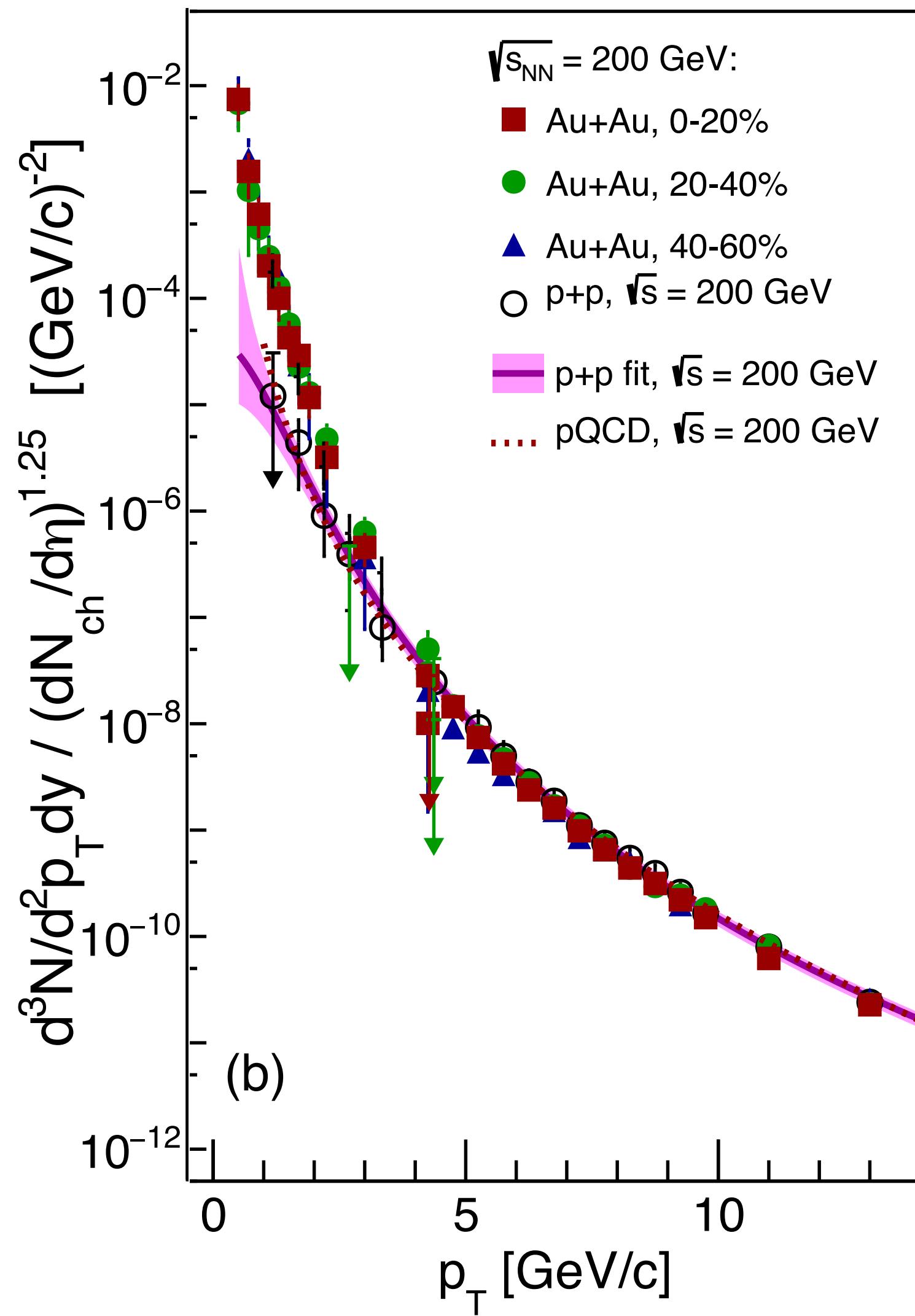
Source of photons must be similar

$N_{coll} \times pQCD$ and $N_{coll} \times p+p$ follow same scaling at 0.1 of yield

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



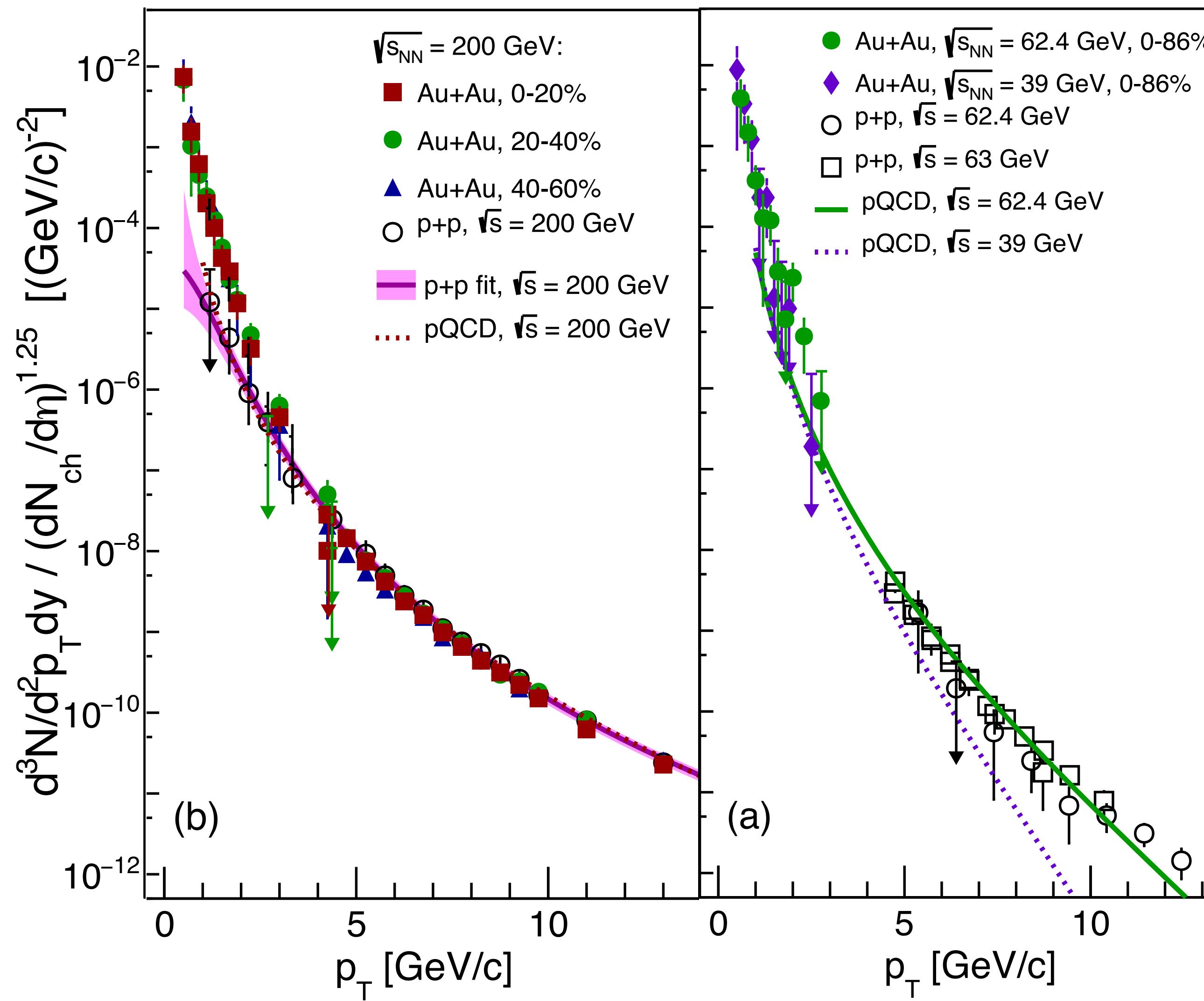
Different centralities



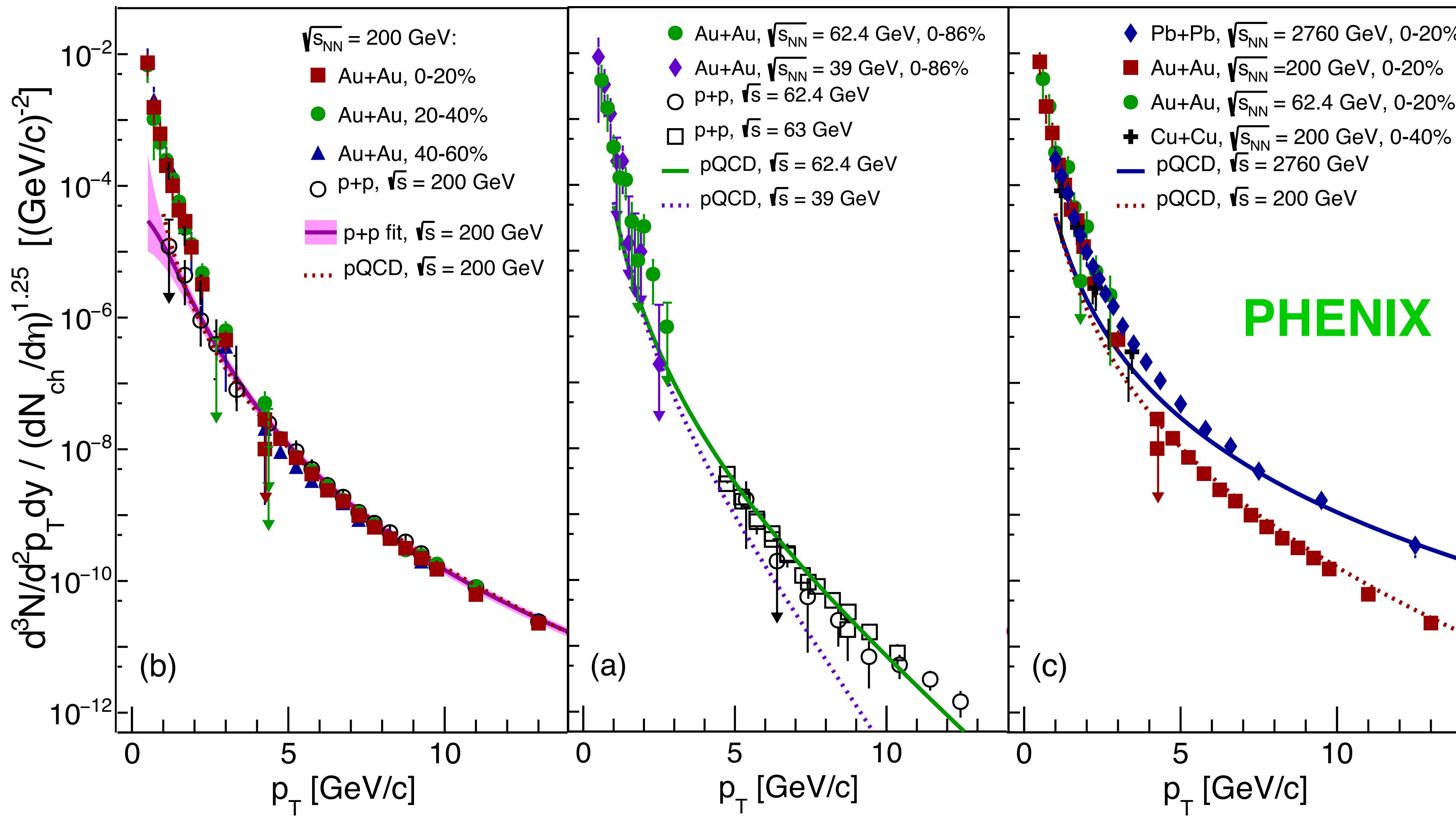
Direct photon spectra normalized by $(dN_{ch}/d\eta)^{1.25}$

Different centralities

Lower energies



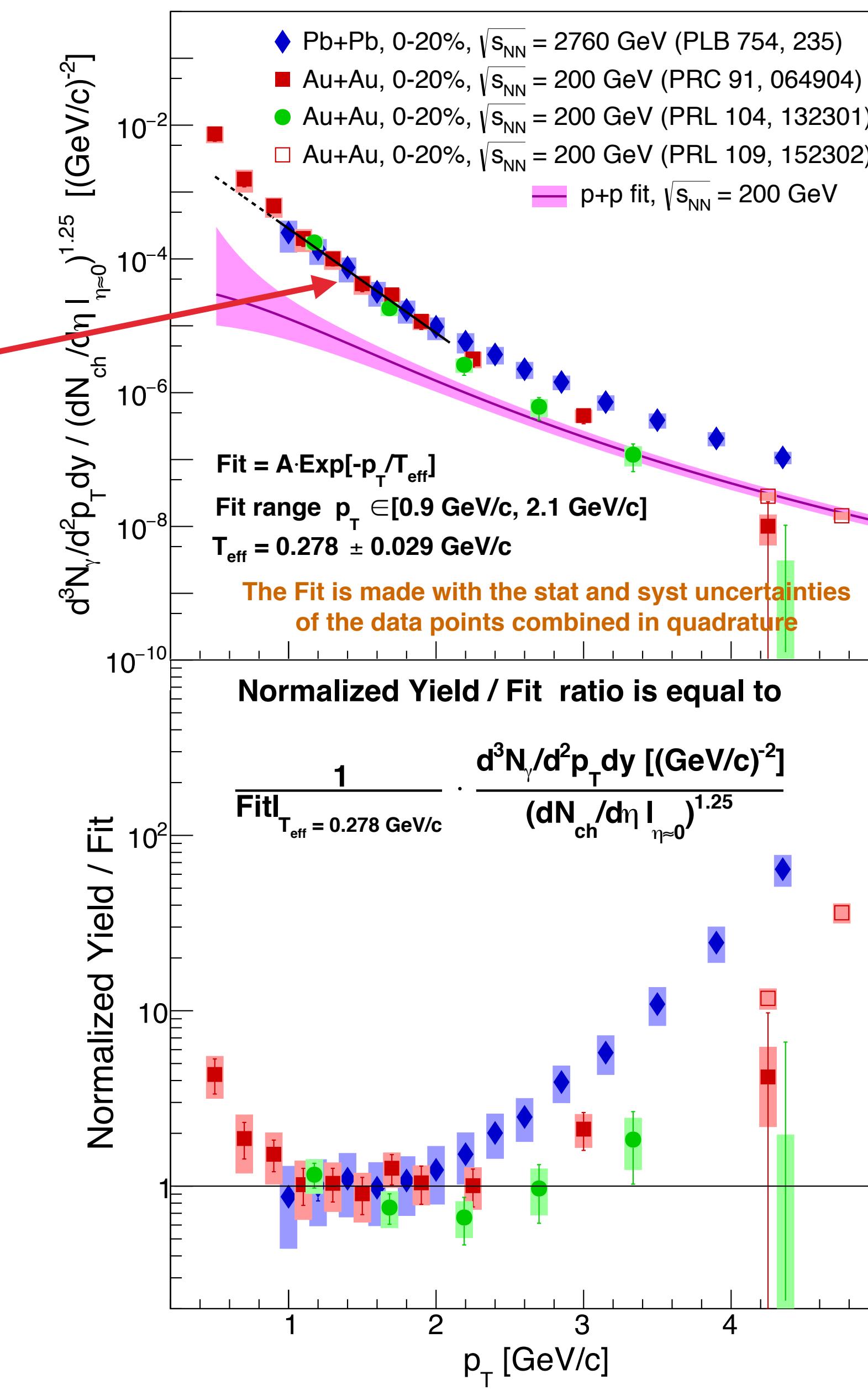
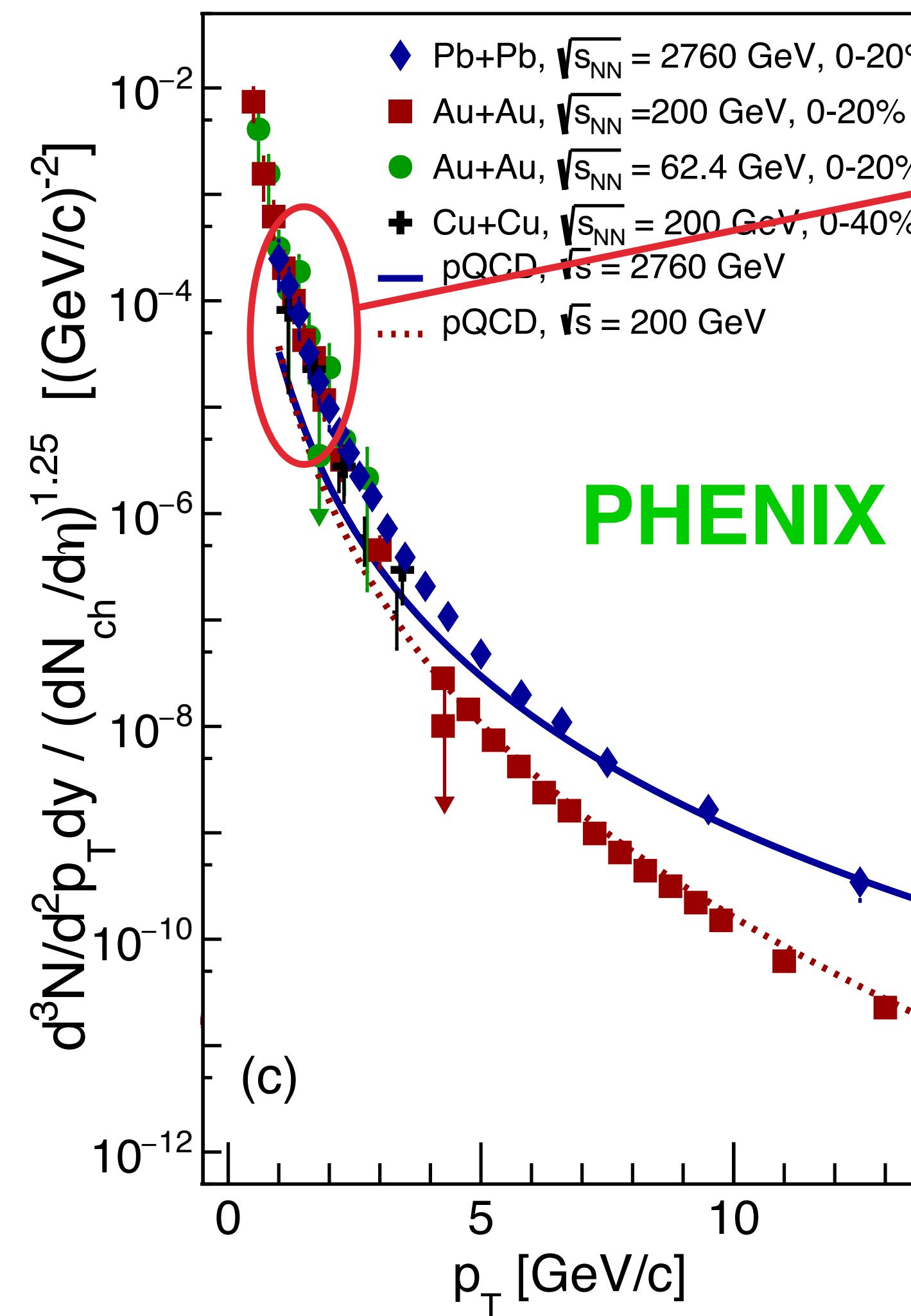
Different centralities Lower energies Higher energies Other A+A systems



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

Closer look into the low p_T range

Fit exponential to scaled PHENIX 200 GeV Au +Au centrality selected and ALICE 2.76 TeV data in range of 0.9 to 2.1 GeV

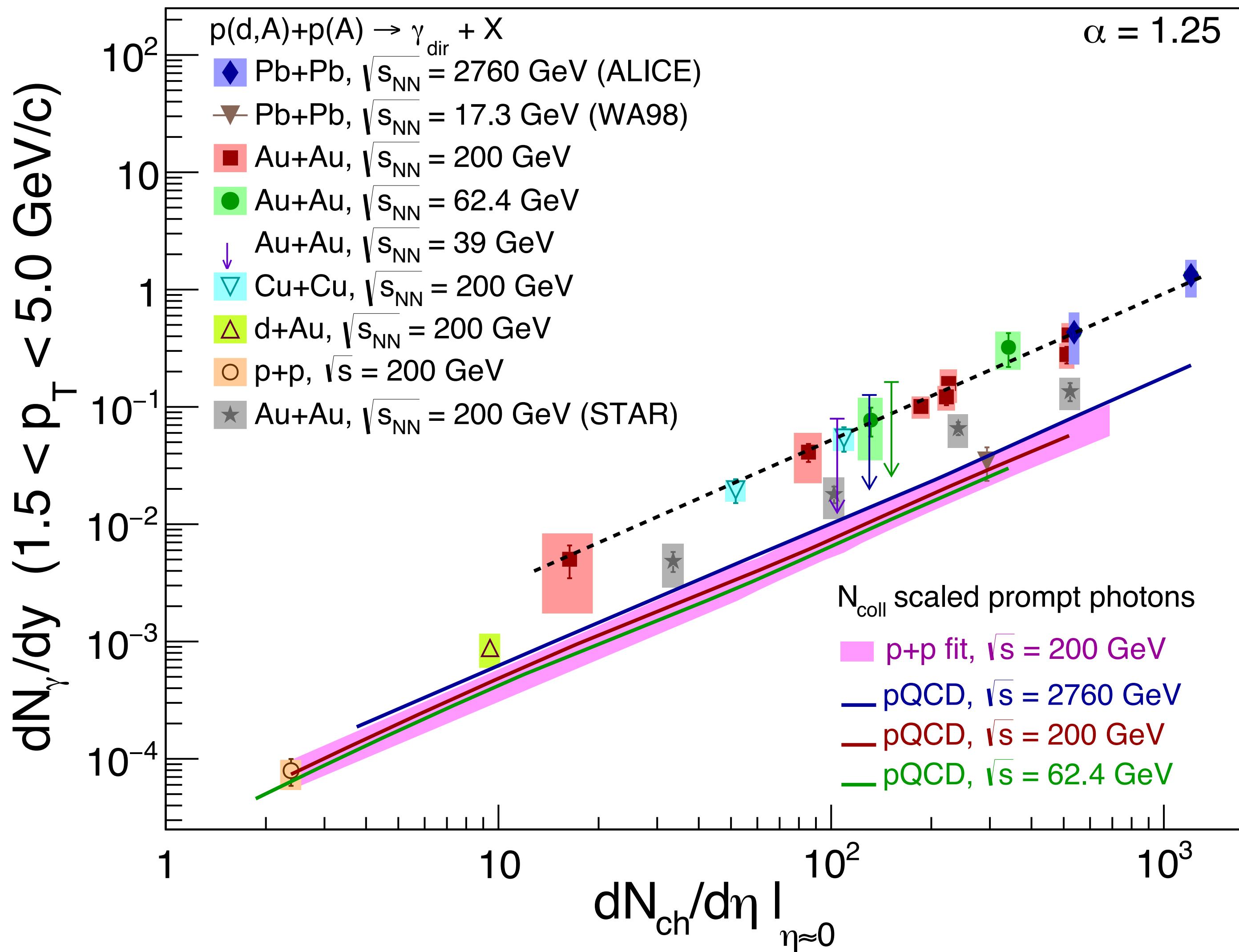


Same slope in
fitted p_T range ~
280 MeV

Spectra are not
exponential over
large p_T range

Comparison with STAR

► Discrepancy with STAR Au+Au results

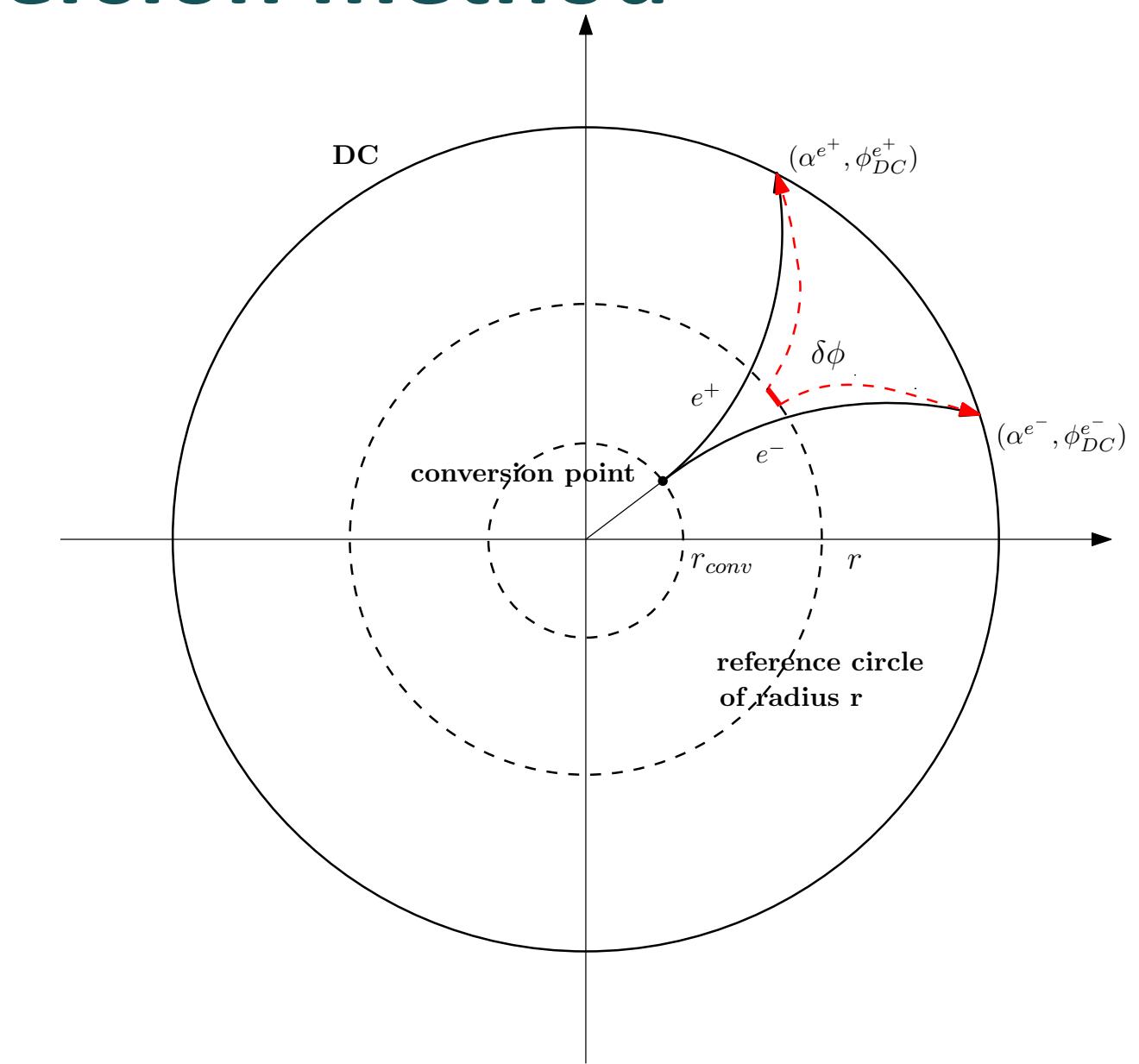
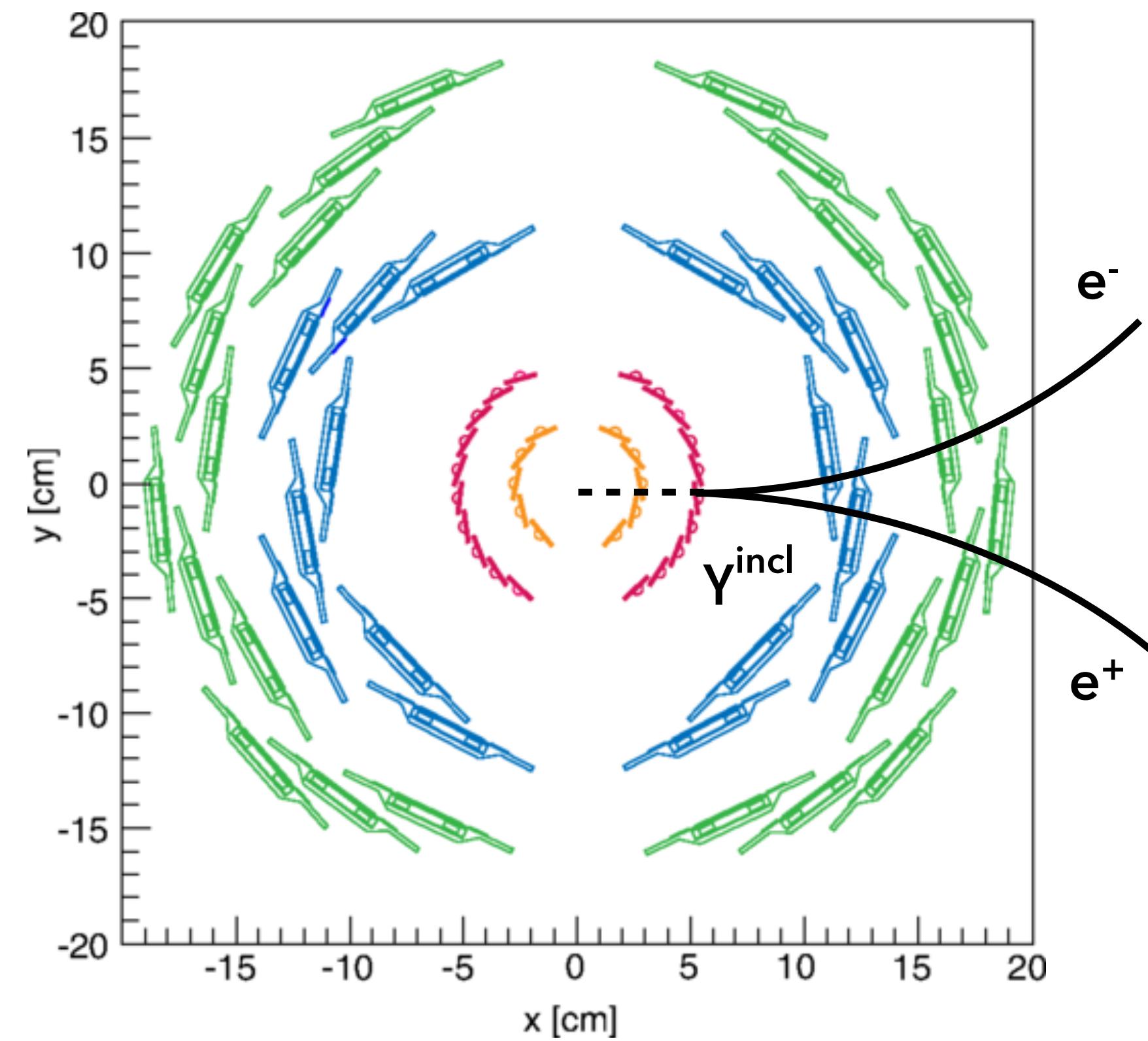


STAR data shows
the scaling
behavior also

The magnitude is
lower comparing to
PHENIX results

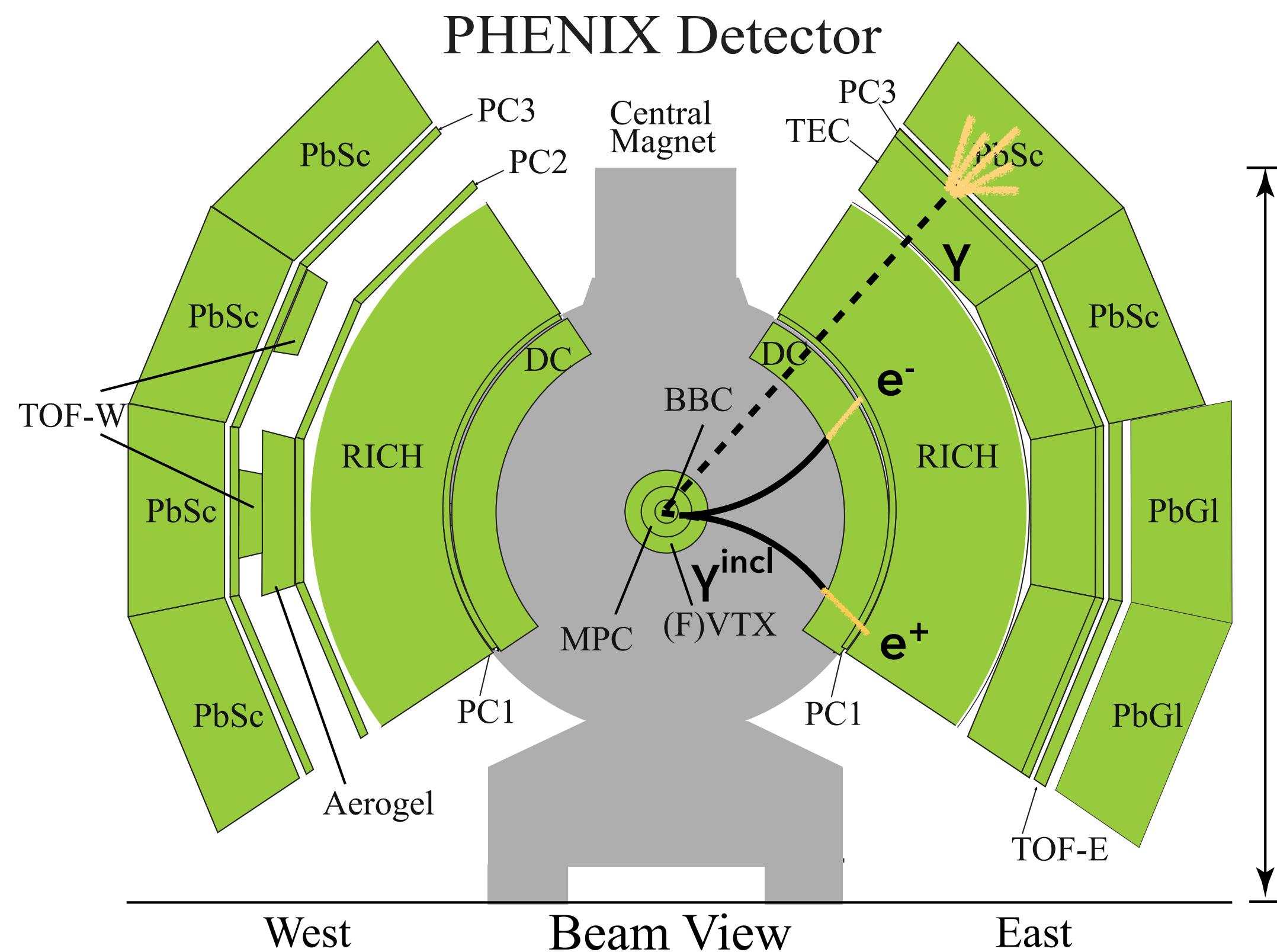
- A new measurement with 2014 Au+Au dataset via external conversion method

- ❖ 10 fold statistics
- ❖ More conversions at silicon vertex detector (VTX) ($X/X_0 \sim 14\%$)
- ❖ Reconstruct conversion position using e^+e^- pair and B field map and track conversions back to its conversion position



- A new measurement with 2014 Au+Au dataset via external conversion method

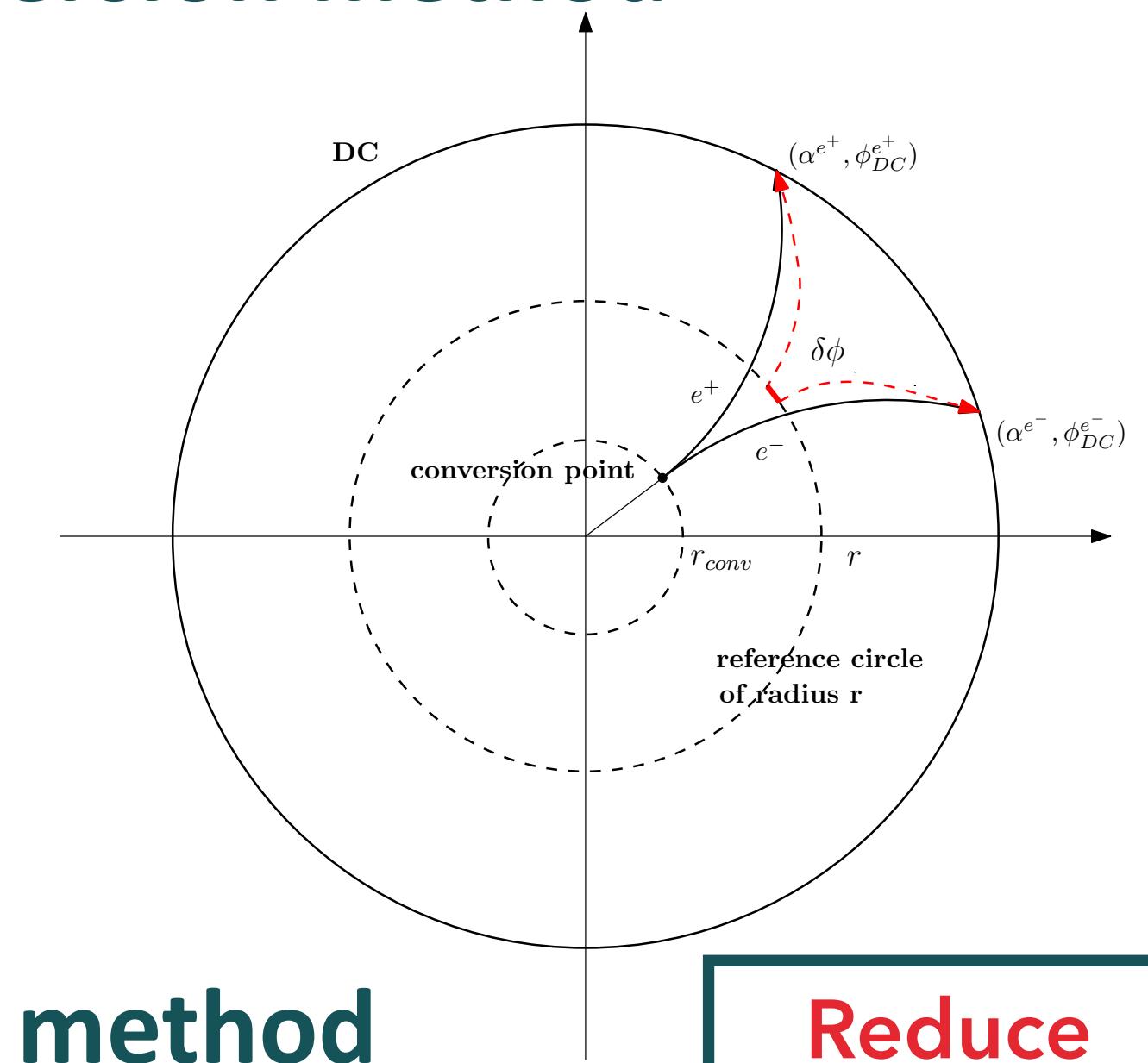
- ❖ 10 fold statistics
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- Double ratio tagging method

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

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

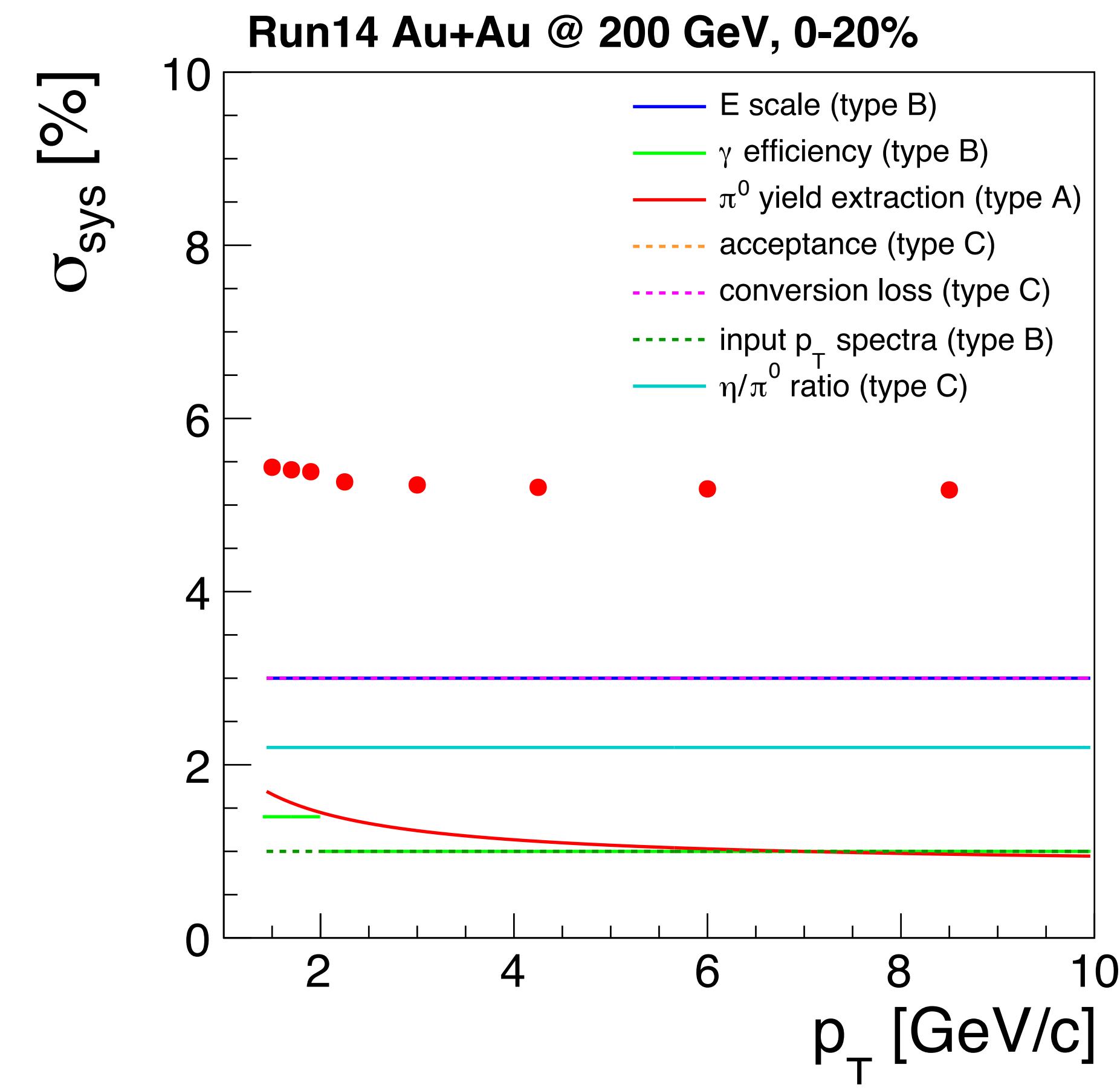


Reduce systematics

Systematic uncertainties

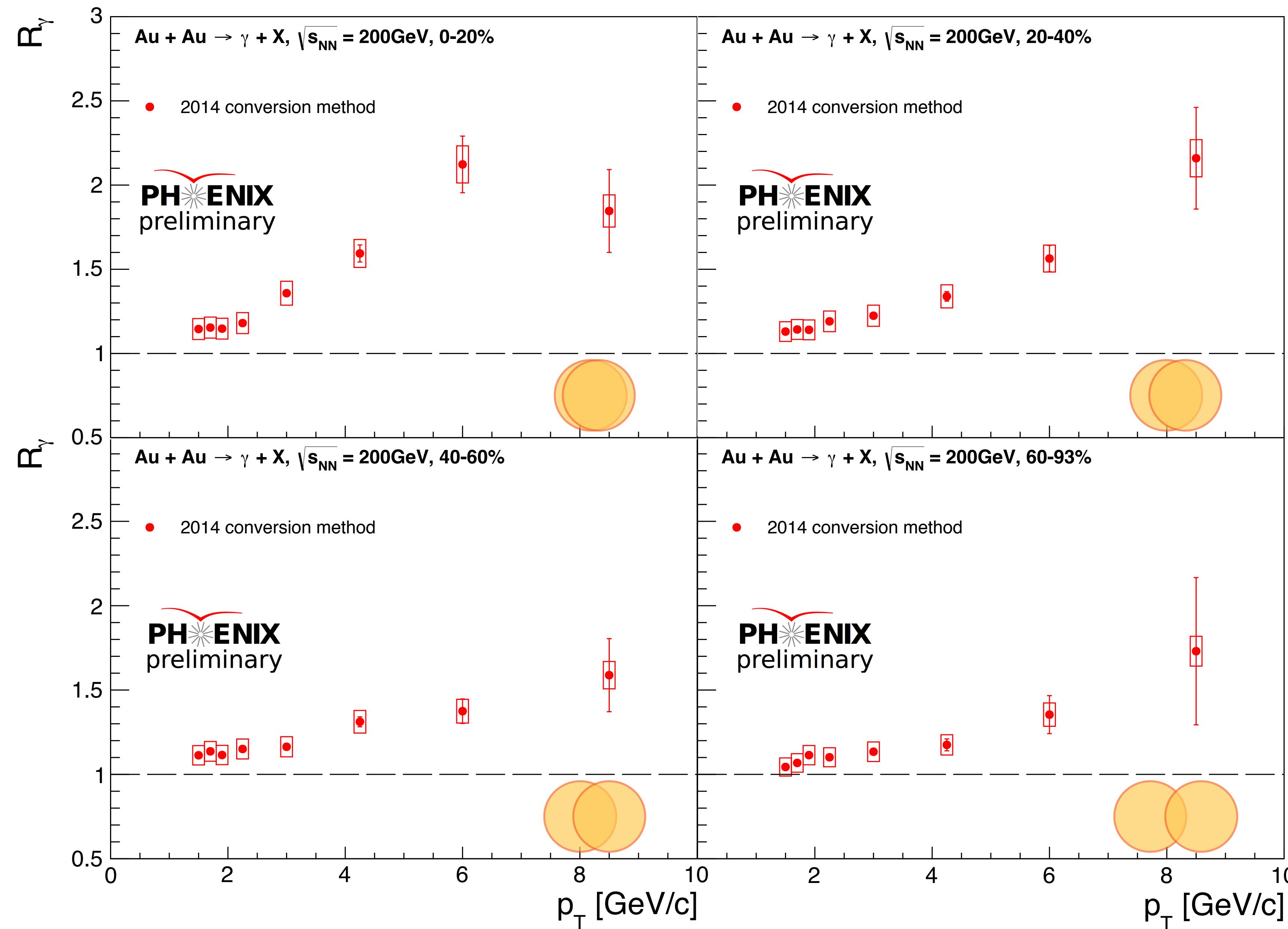
- ▶ $N_\gamma^{\text{incl}}/N_\gamma^{\pi^0}$ from real data
 - ❖ $N_\gamma^{\pi^0}$ extraction ($\sim 2\%$)
 - ❖ Conversion sample purity ($< 1\%$)
- ▶ Conditional acceptance and efficiency
 - ❖ Energy scale/resolution (3%)
 - ❖ Conversion photon loss due to second conversion / material budget (3%)
 - ❖ γ efficiency ($\sim 1\%$)
 - ❖ Active area (1%)
 - ❖ Input p_T spectra (1%)
- ▶ $\gamma^{\text{hadron}}/\gamma^{\pi^0}$
 - ❖ η/π^0 ratio (2%)
 - ❖ Other mesons ($< 1\%$)

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



R_γ in Au + Au collisions at 200 GeV

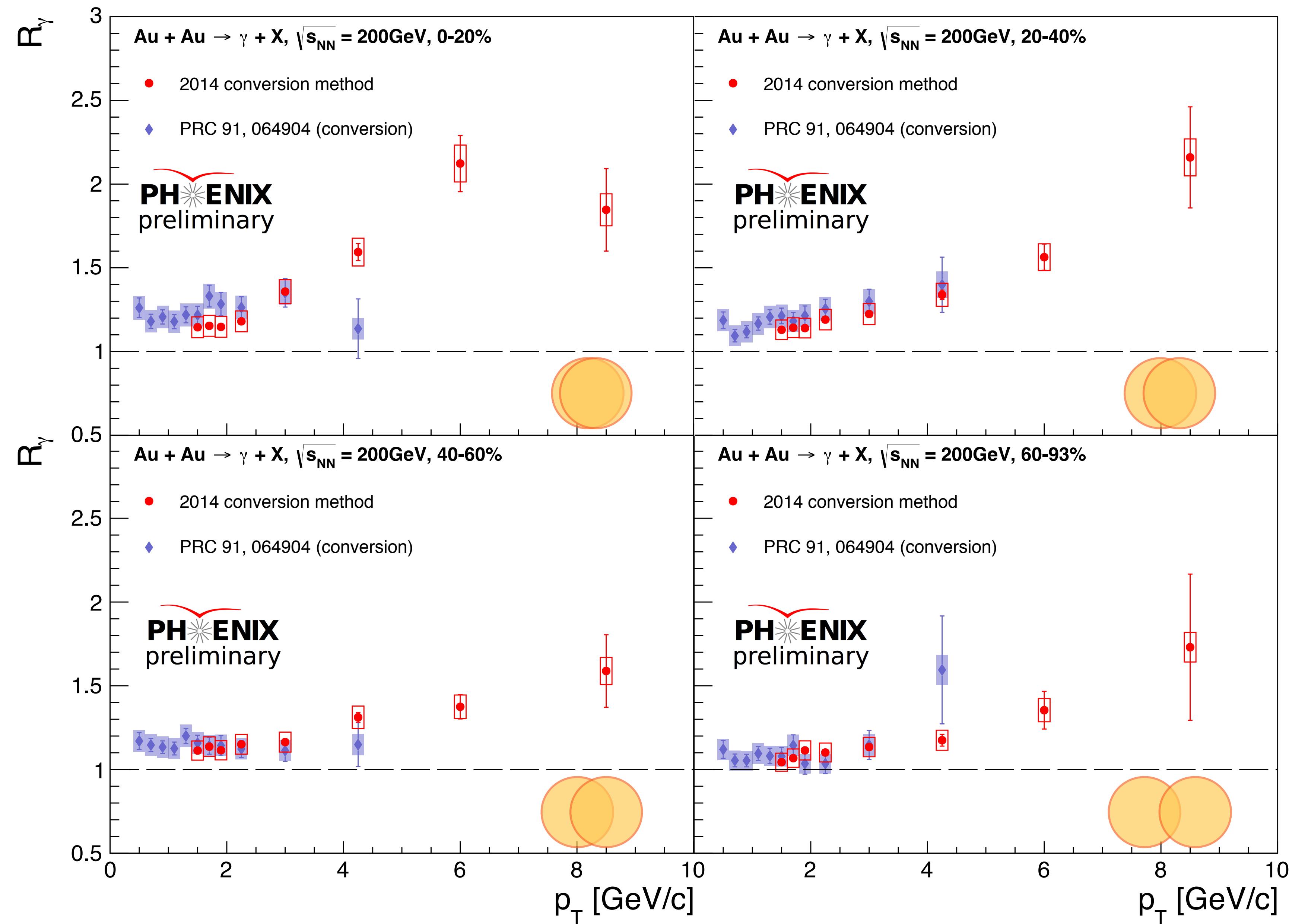
10



New result!

R_γ in Au + Au collisions at 200 GeV

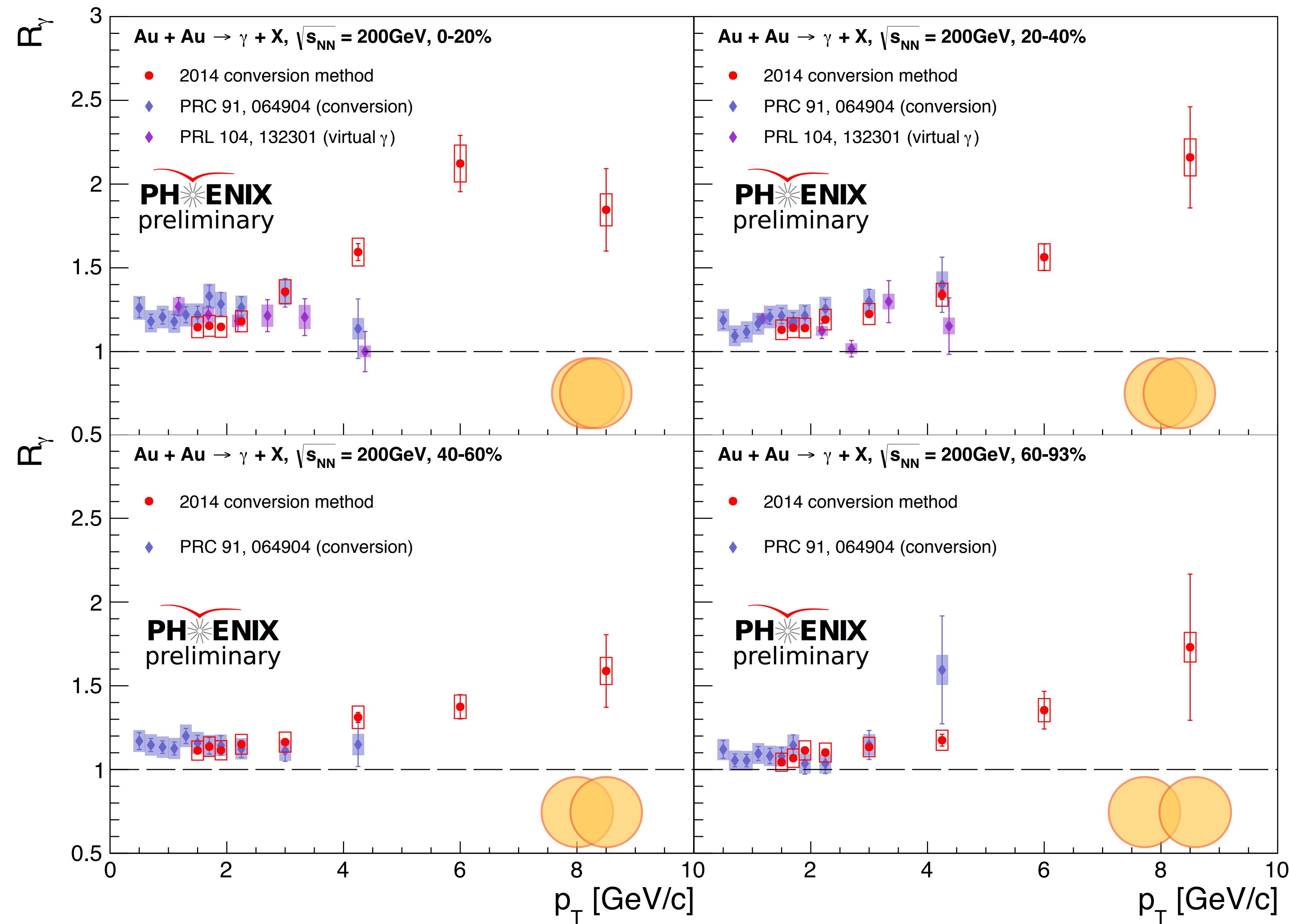
10



New result consistent
with previous published
results using conversion
method

R_γ in Au + Au collisions at 200 GeV

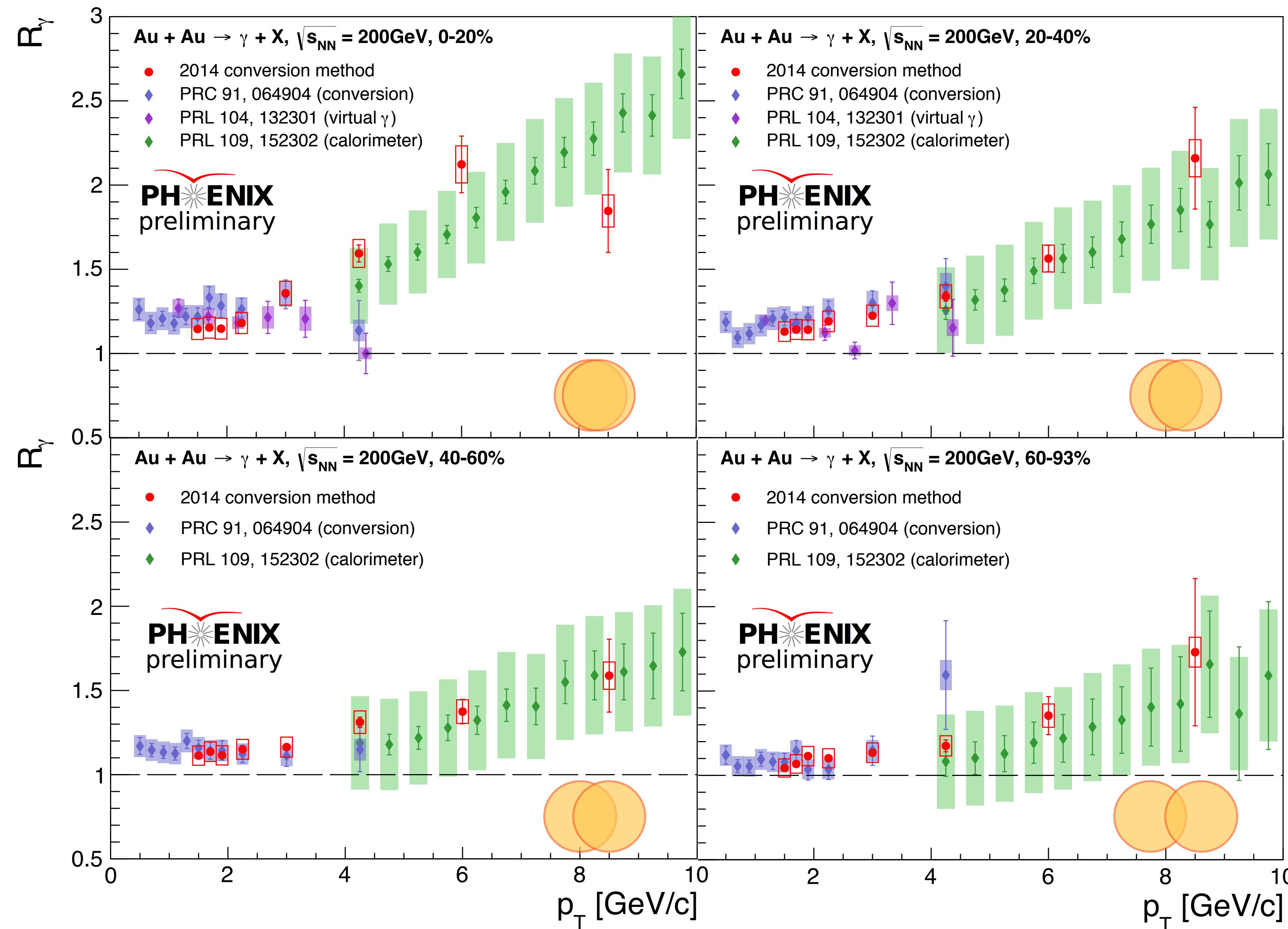
10



New result consistent
with previous published
results using conversion
method, virtual γ method

R_γ in Au + Au collisions at 200 GeV

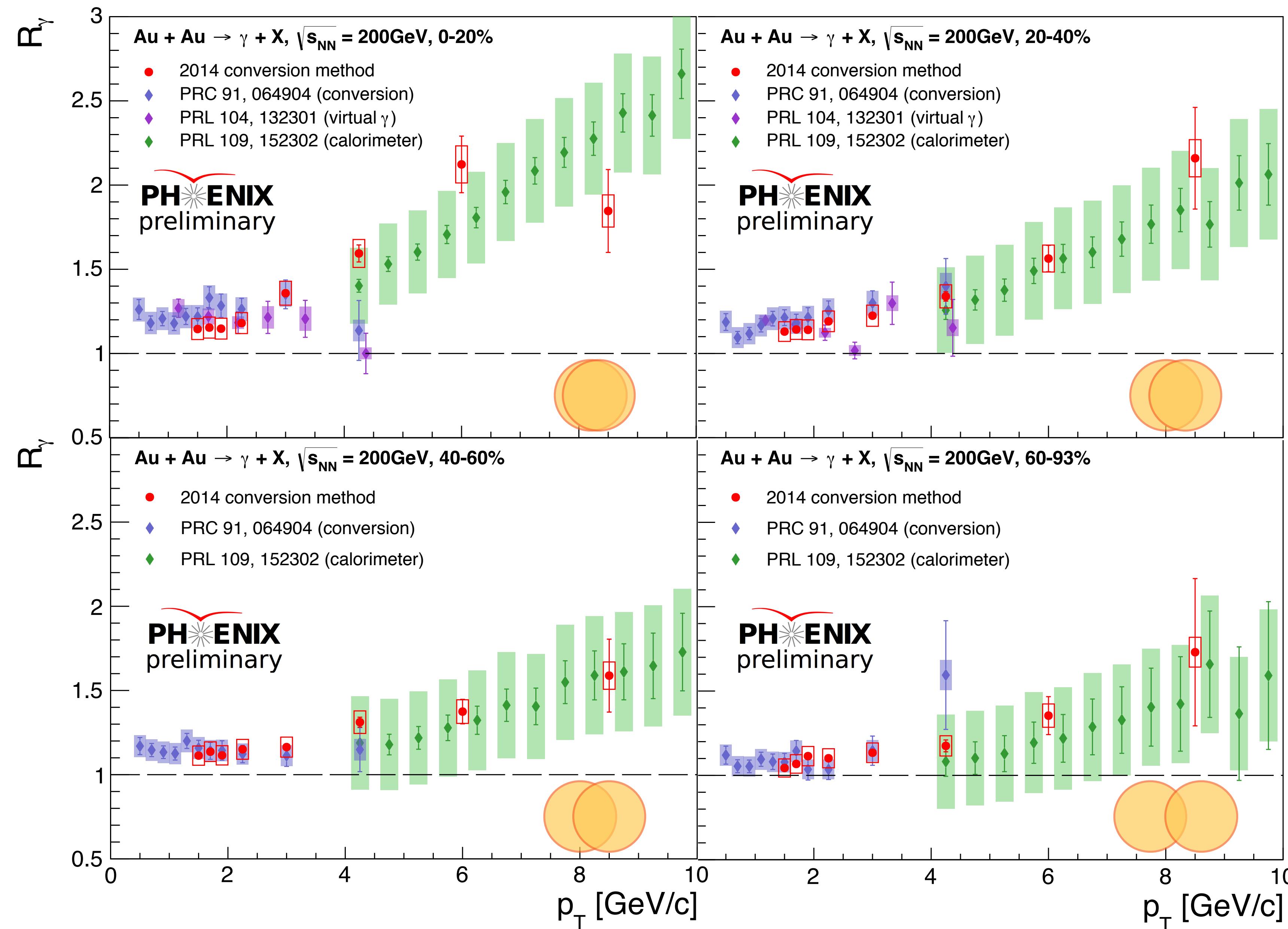
10



New result consistent
with previous published
results using conversion
method, virtual γ method,
calorimeter method

R_γ in Au + Au collisions at 200 GeV

10



New result consistent
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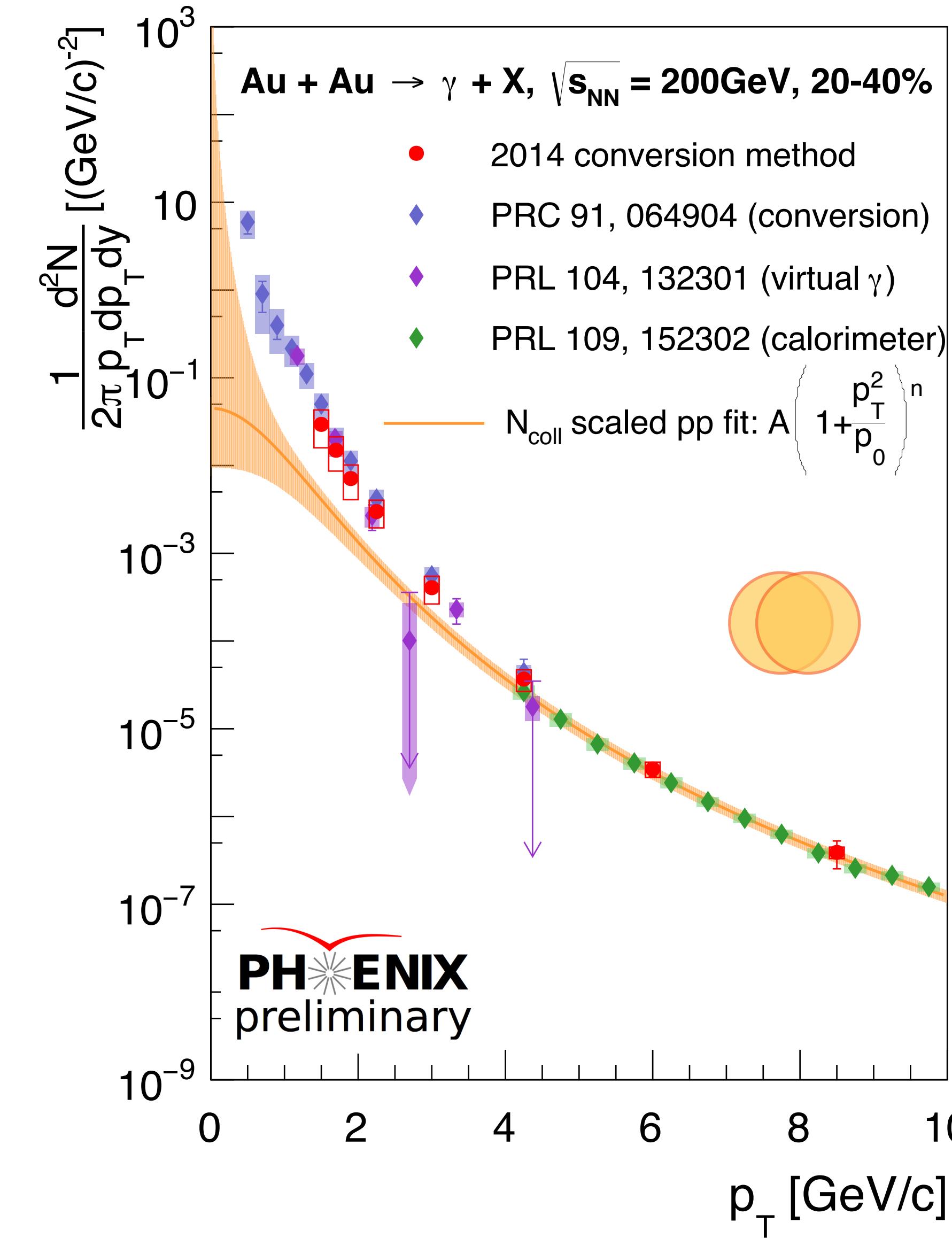
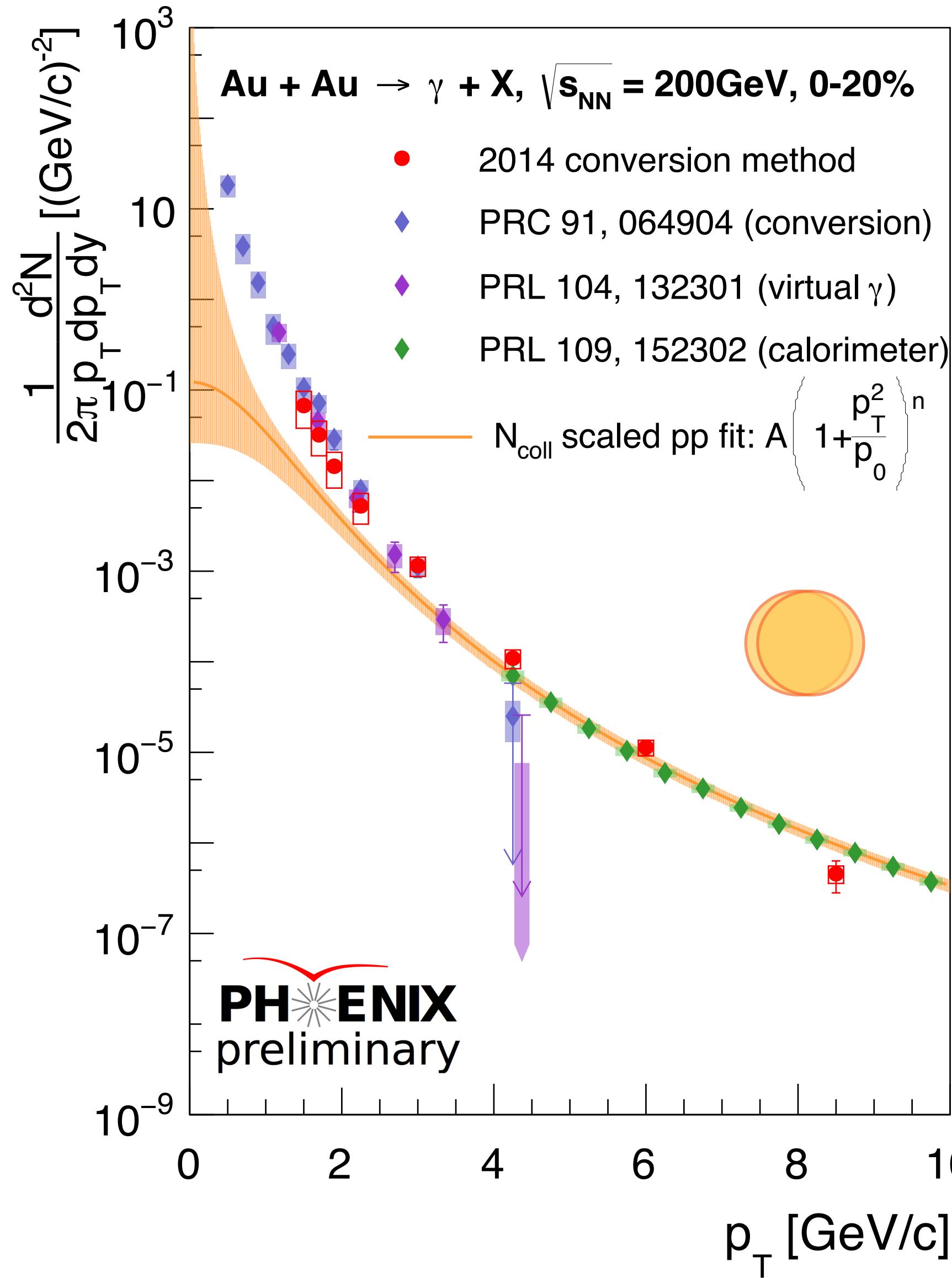
4 independent
measurements from
independent datasets
shown here!

Full overlap with the
published low p_T and high
 p_T measurements

Direct photon yield in Au + Au collisions at 200 GeV

11

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



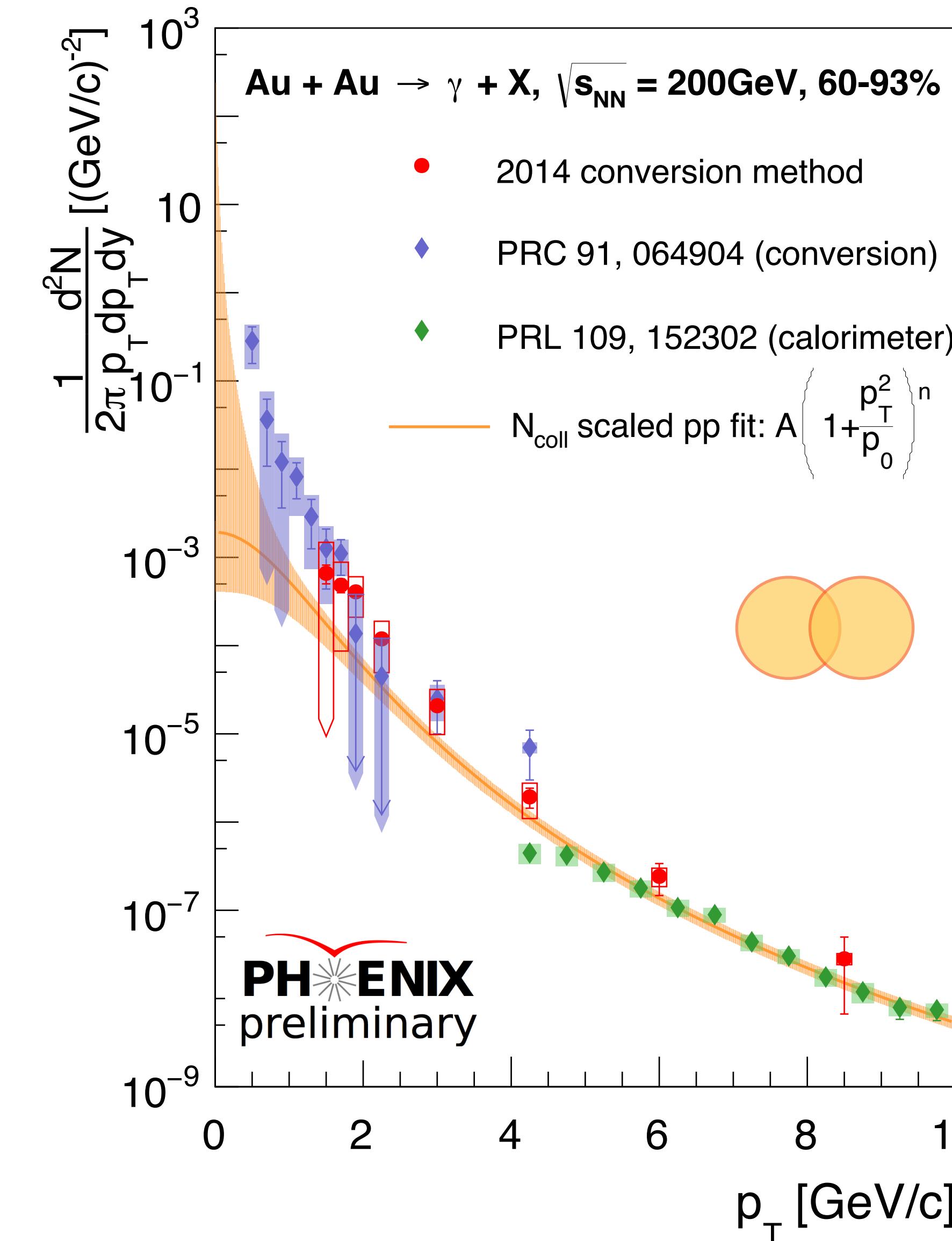
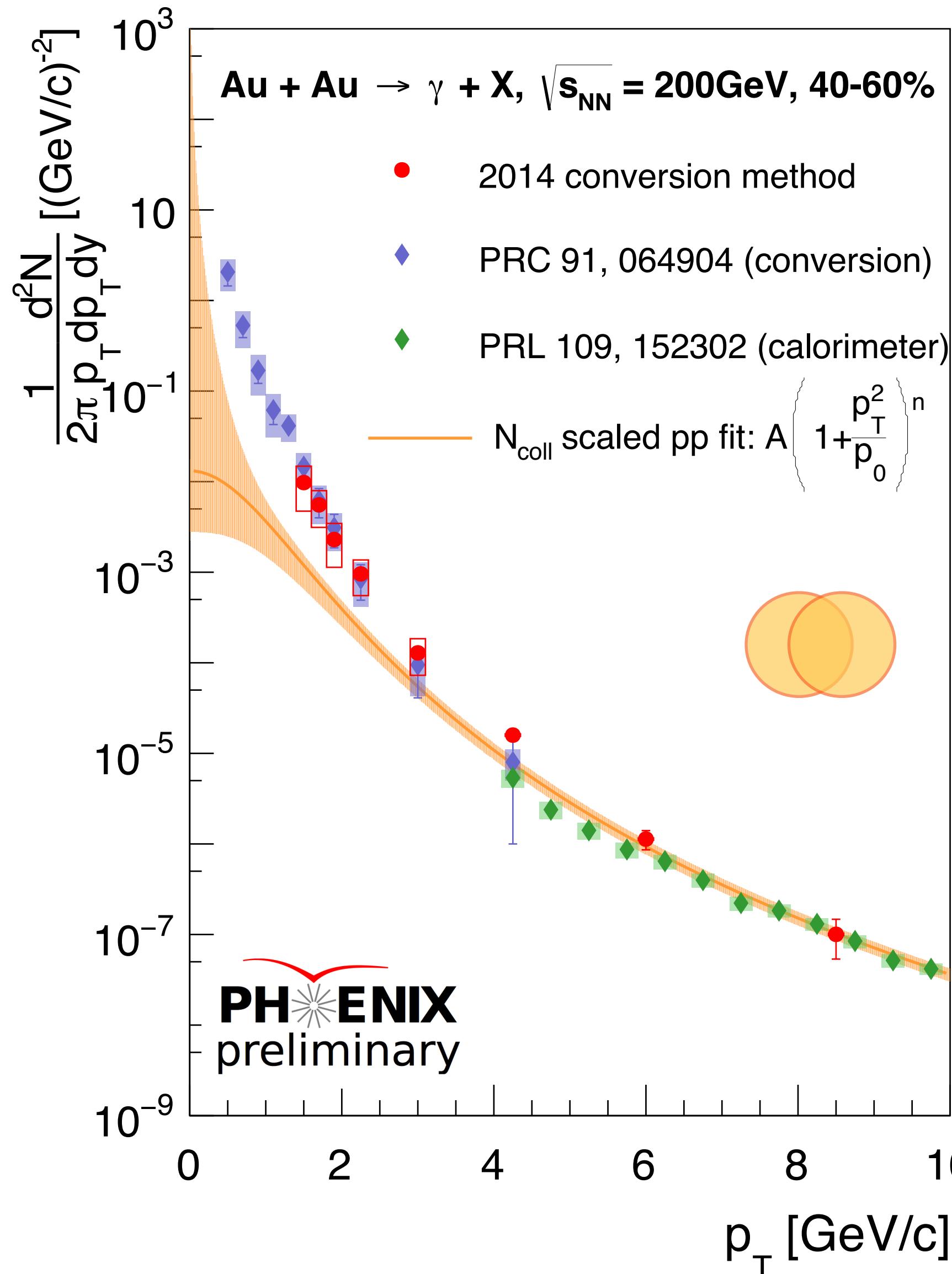
**At high p_T Au+Au
data consistent with
 N_{coll} scaled p+p
result**

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

Direct photon yield in Au + Au collisions at 200 GeV

12

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

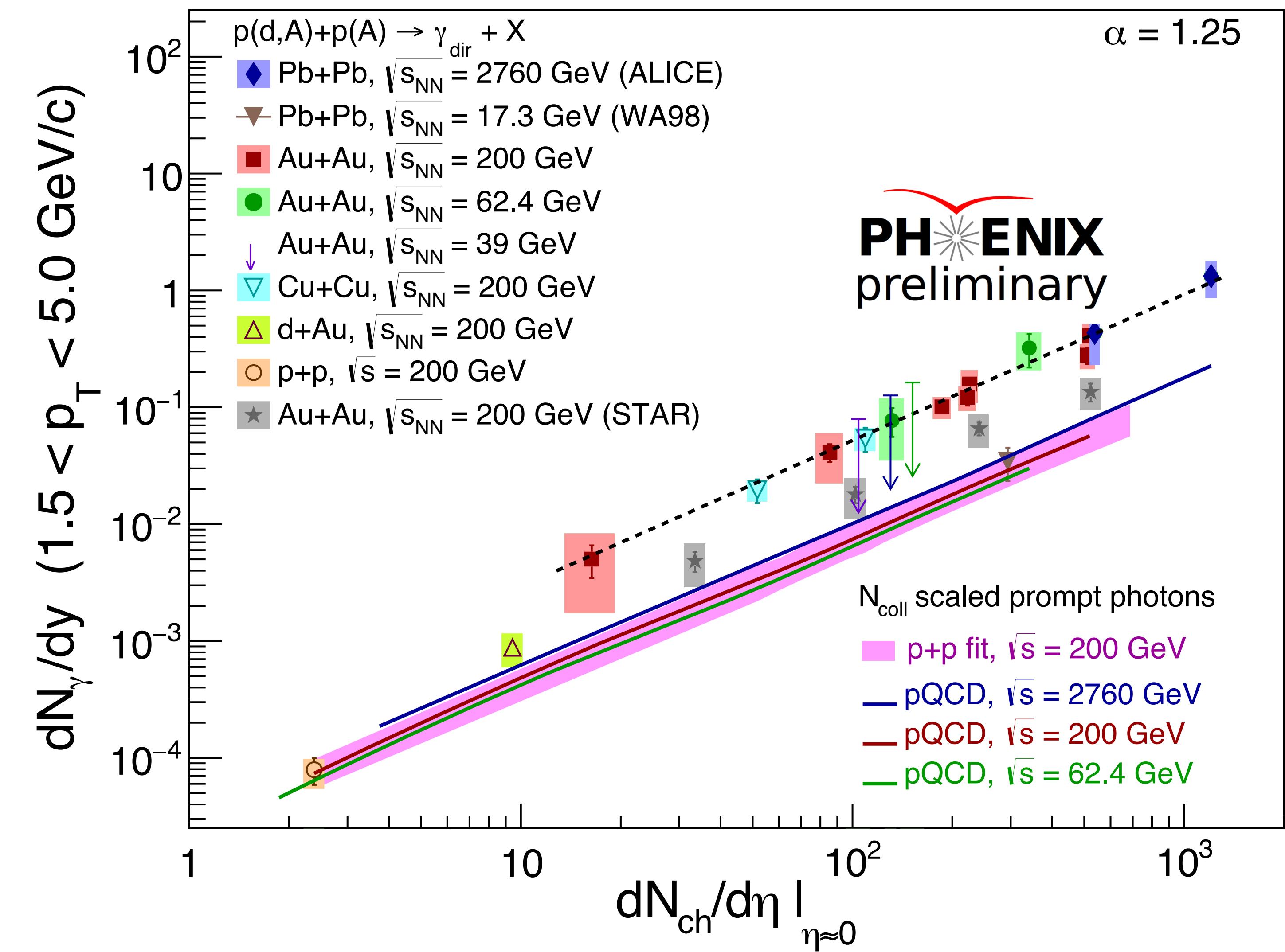
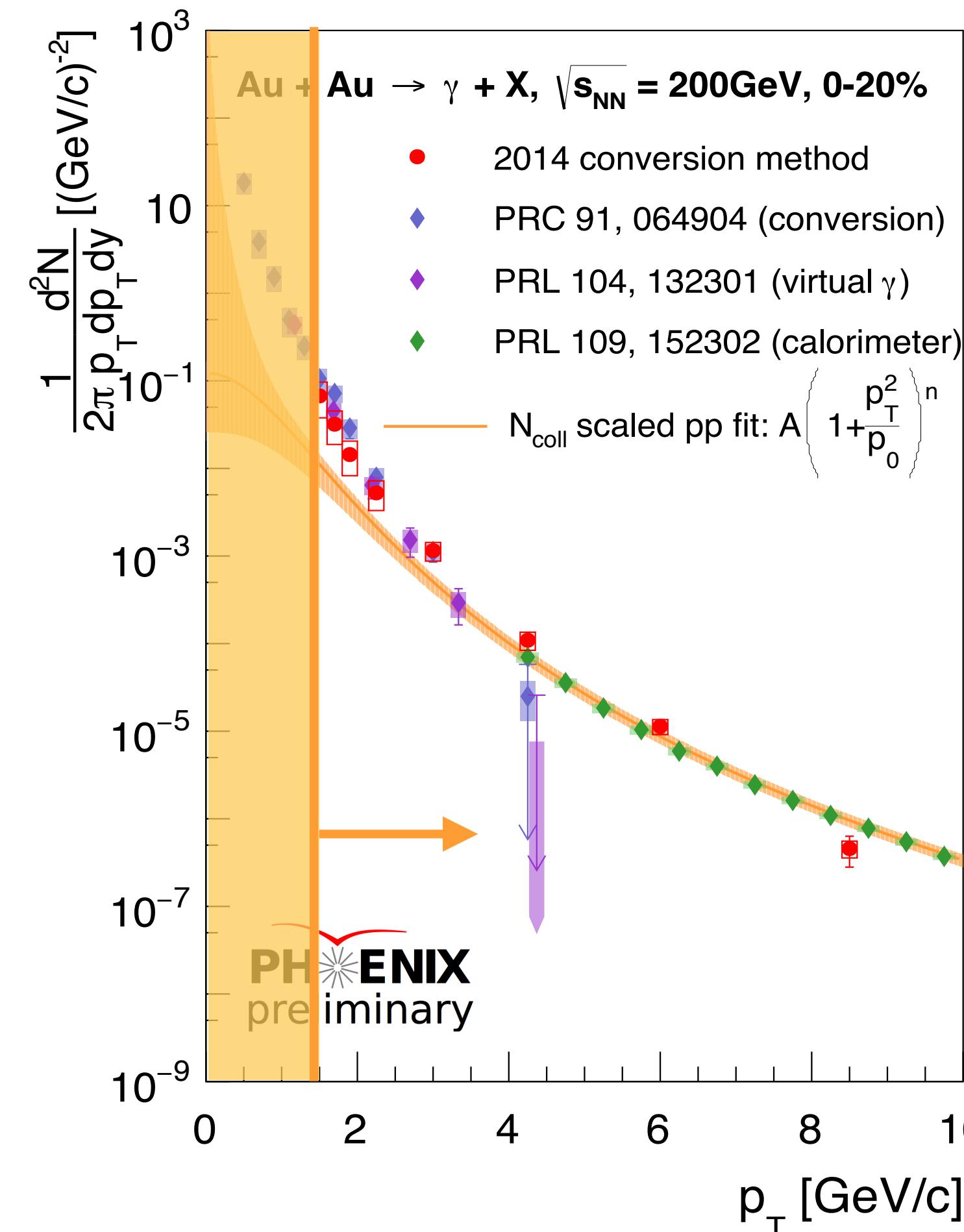


**At high p_T Au+Au
data consistent with
 N_{coll} scaled p+p
result**

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

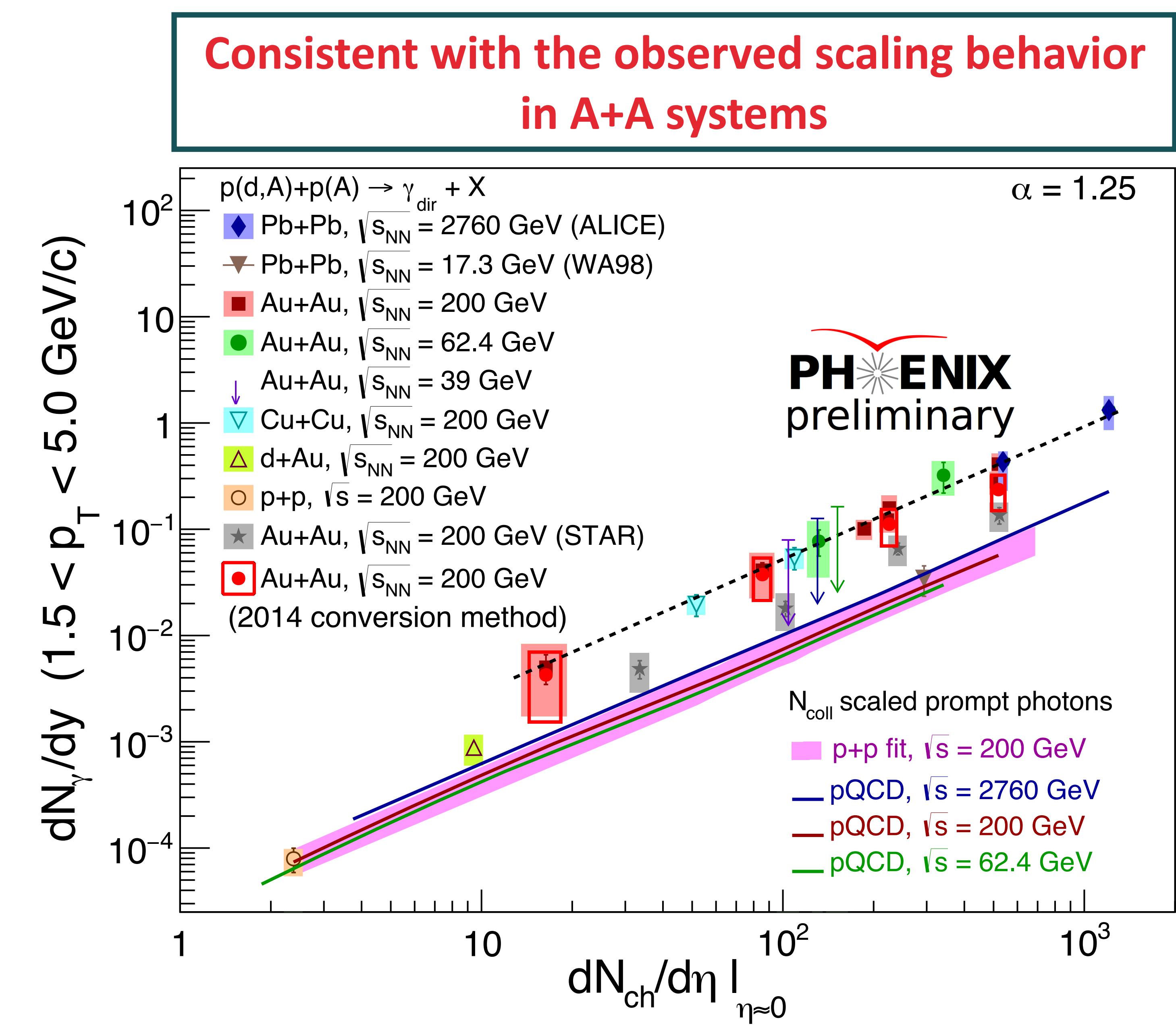
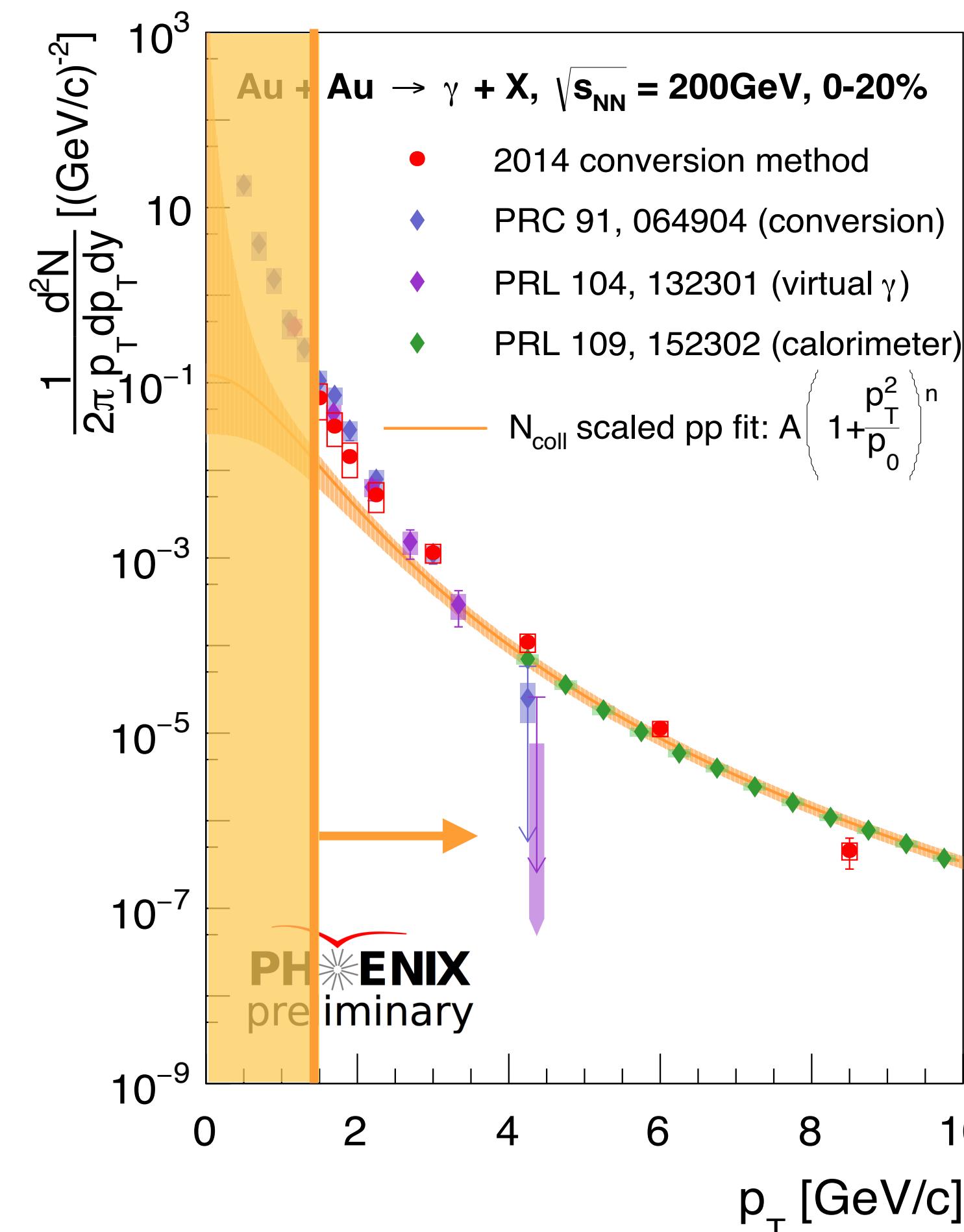
Direct photon scaling with new 2014 results

13



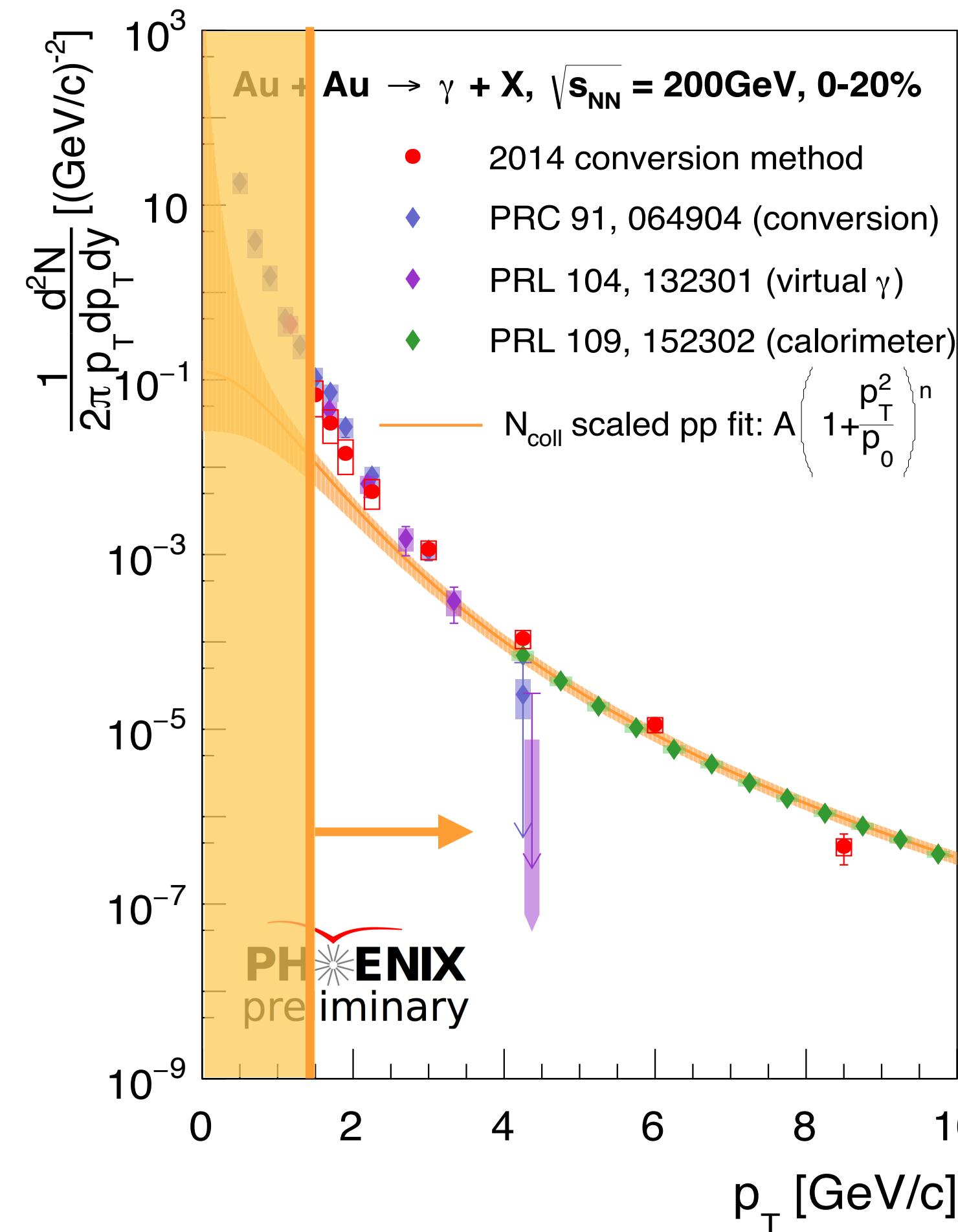
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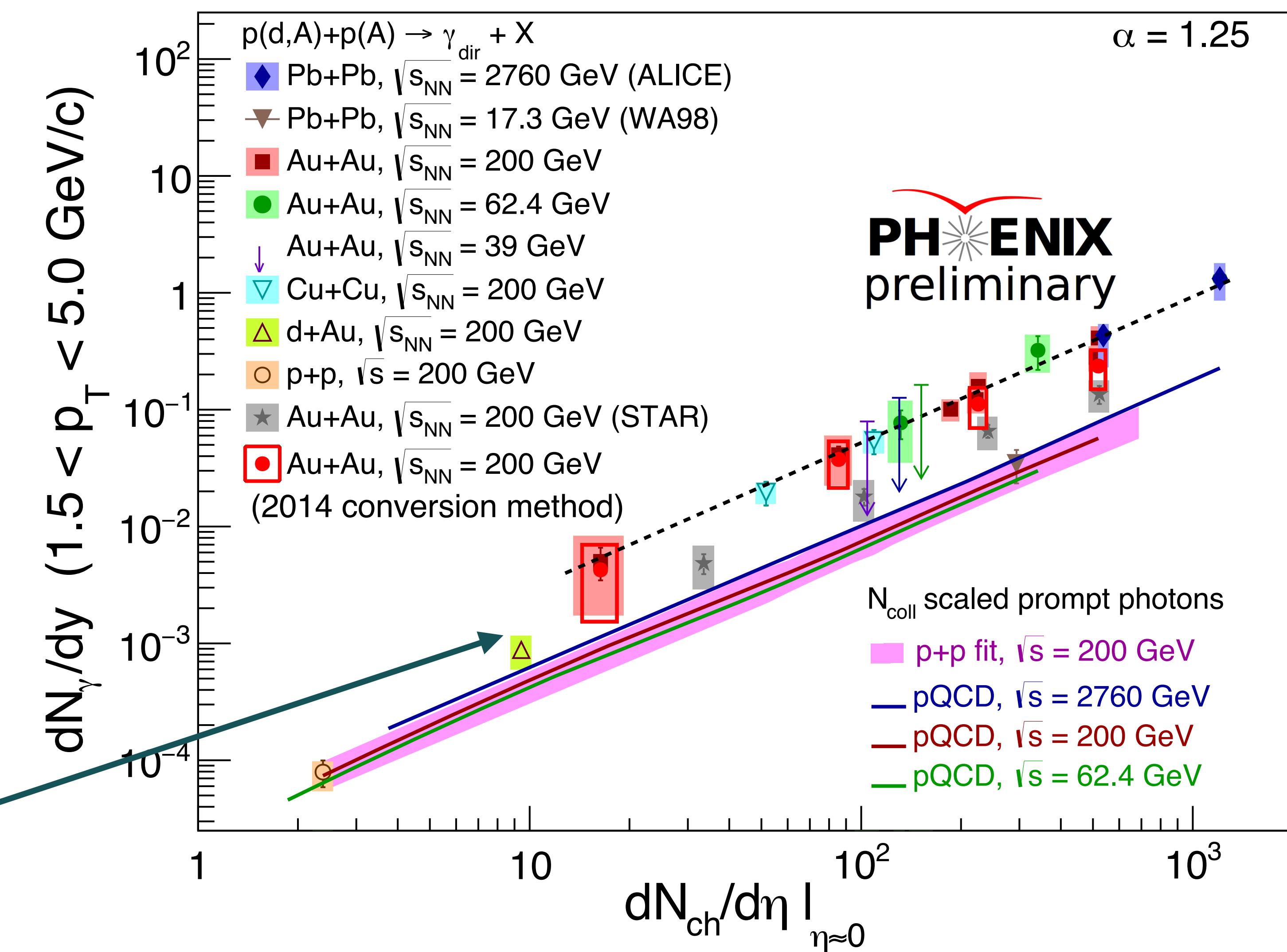
Direct photon scaling with new 2014 results

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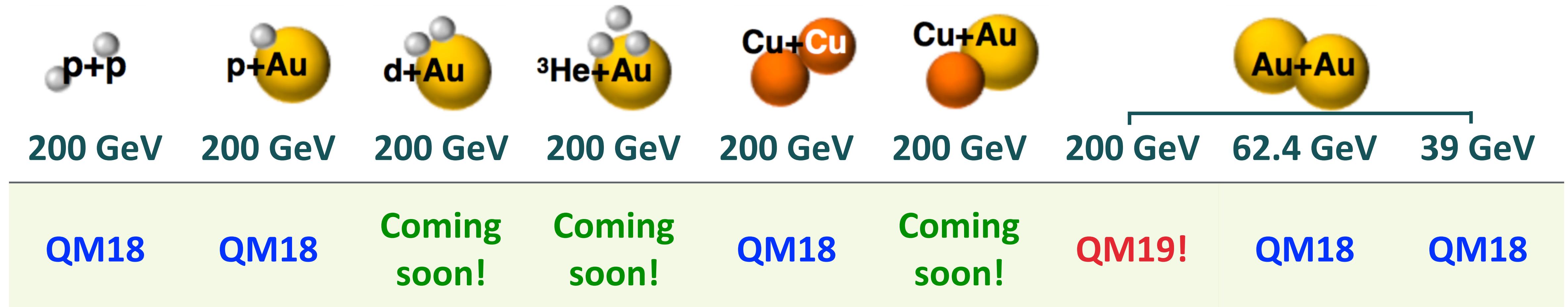


More peripheral Au+Au measurements can fill in the “transition region”

Consistent with the observed scaling behavior in A+A systems



- ▶ PHENIX measured the low p_T 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 p_T and high p_T measurements
- ▶ More PHENIX data varying size and geometry to be finalized/analyzed



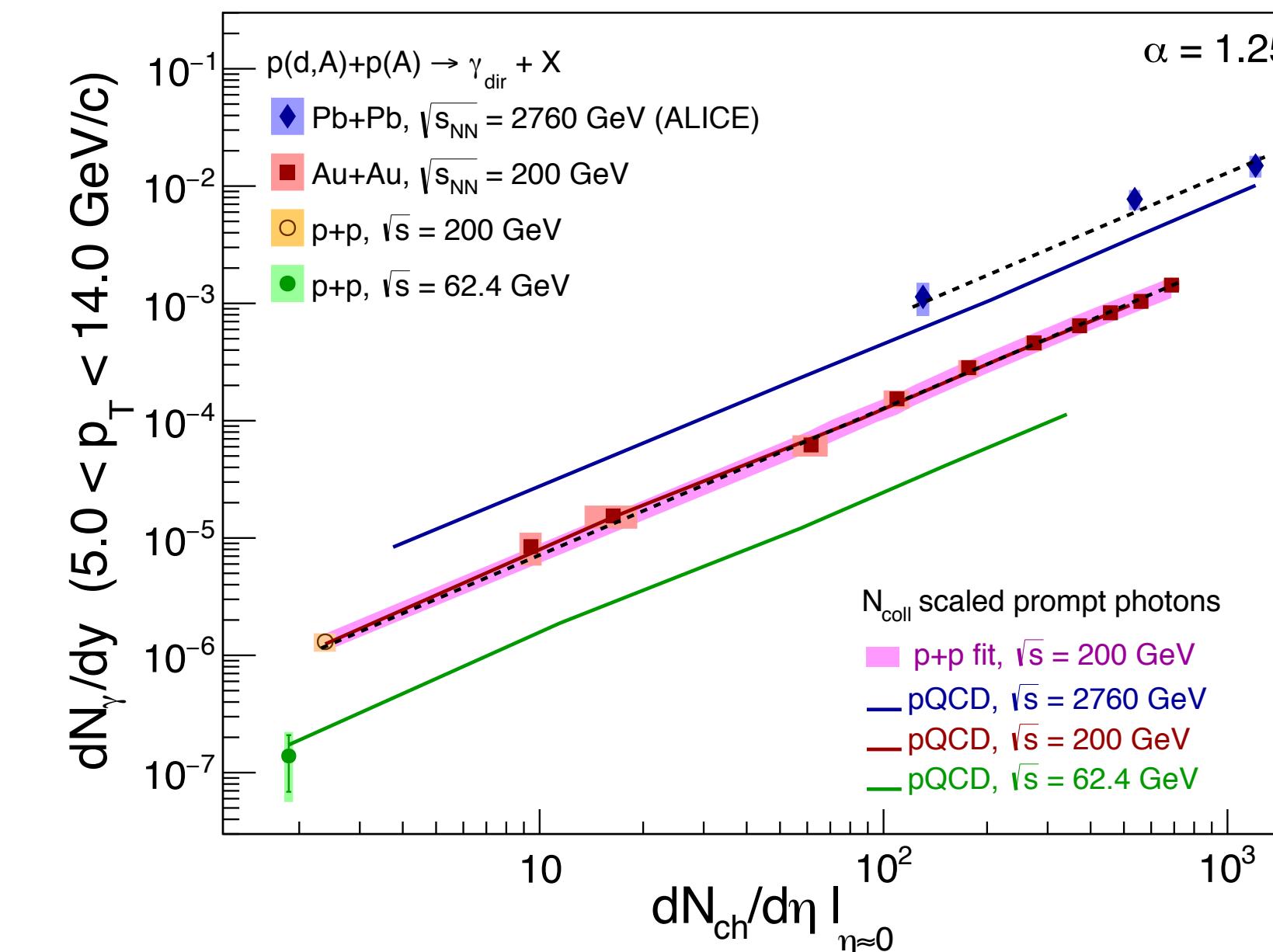
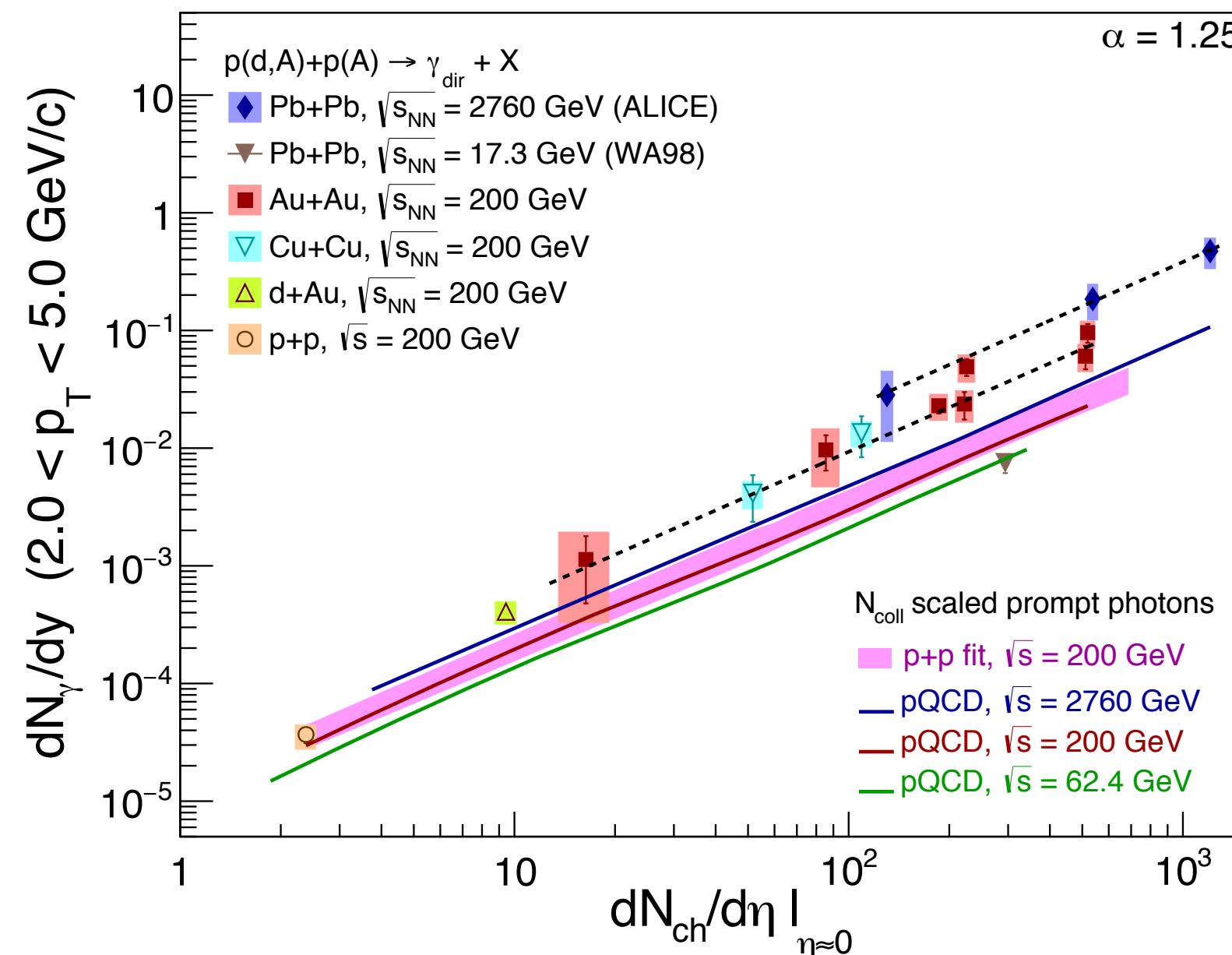
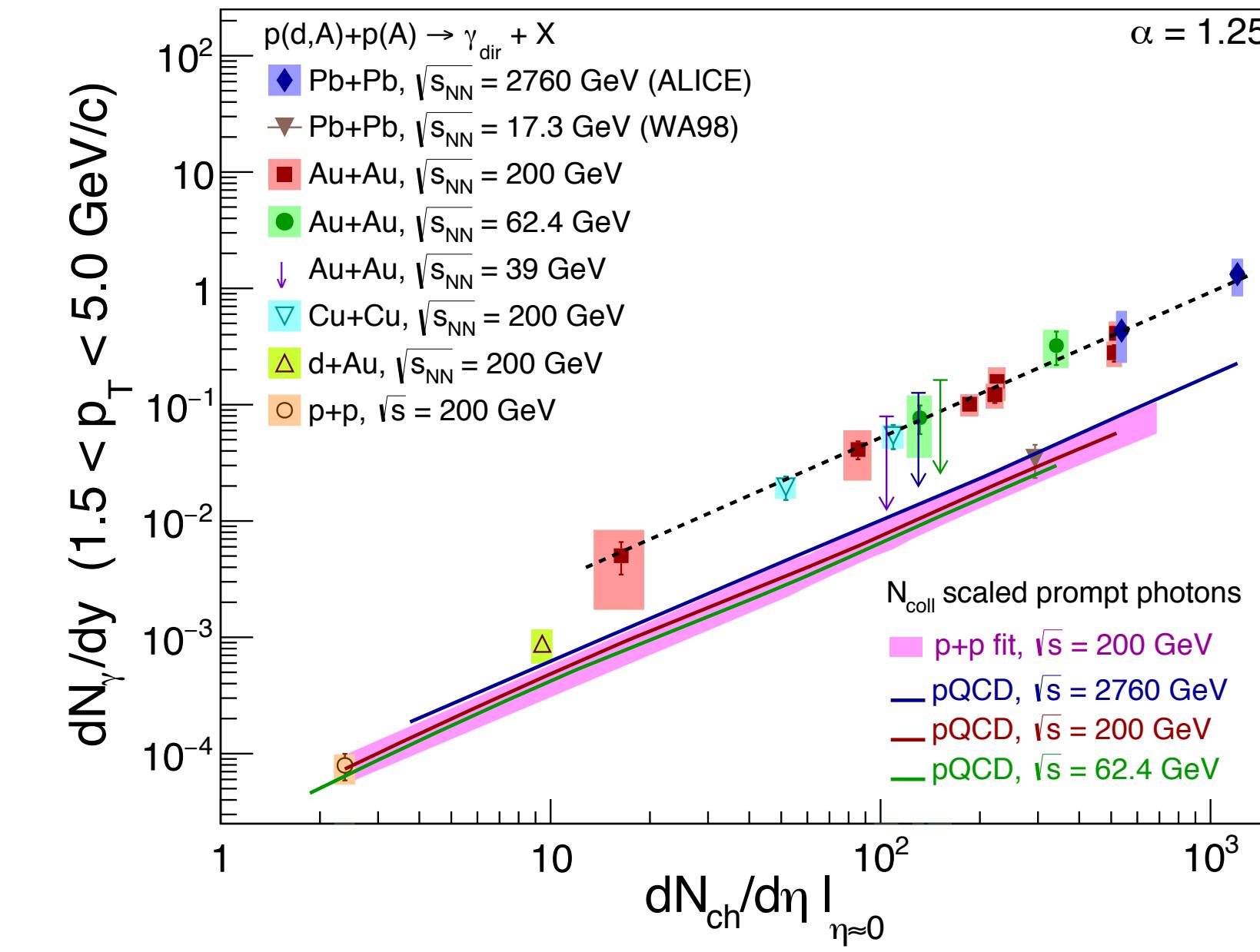
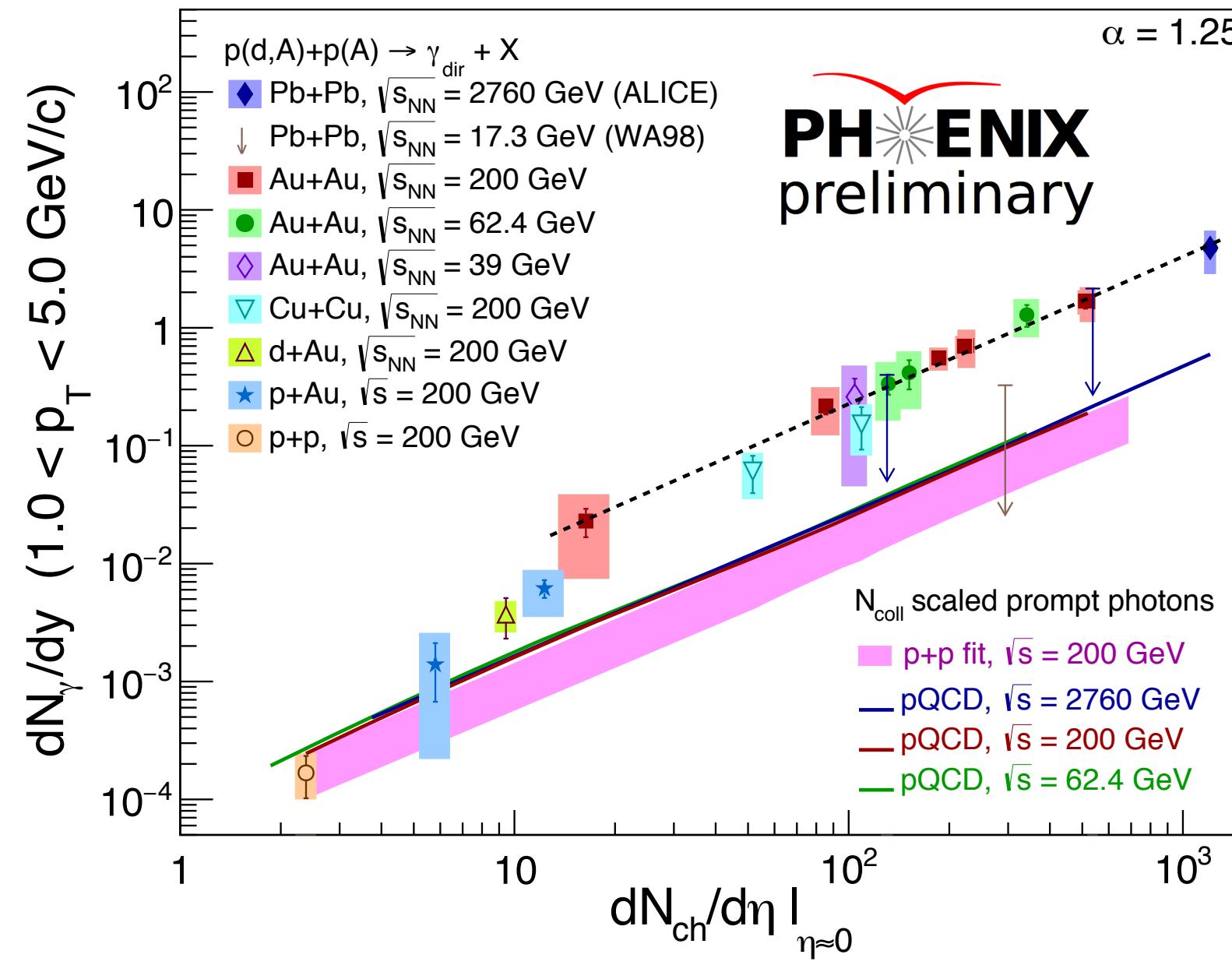
Poster by Norbert Novitzky (scaling behavior of direct photons)

Poster by Zhandong Sun (high p_T direct photon in pAu)



THANKS!

Integrated direct photon yield over different p_T ranges

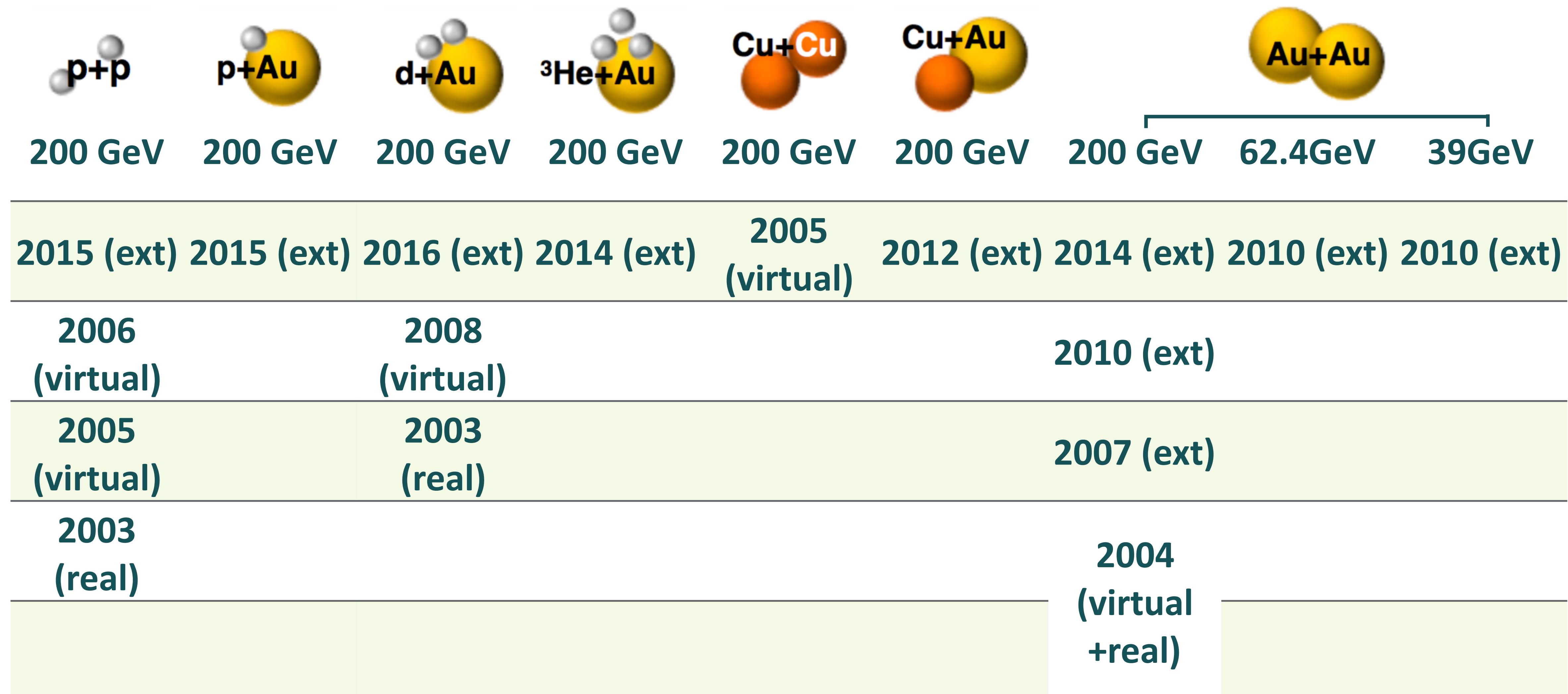


The main sources contributing to photons $< 2 \text{ GeV}$ are similar for different beam energies

Hard scattering dominates $> 5 \text{ GeV}$

New insights

- A wealth of datasets available for direct photon analysis in PHENIX



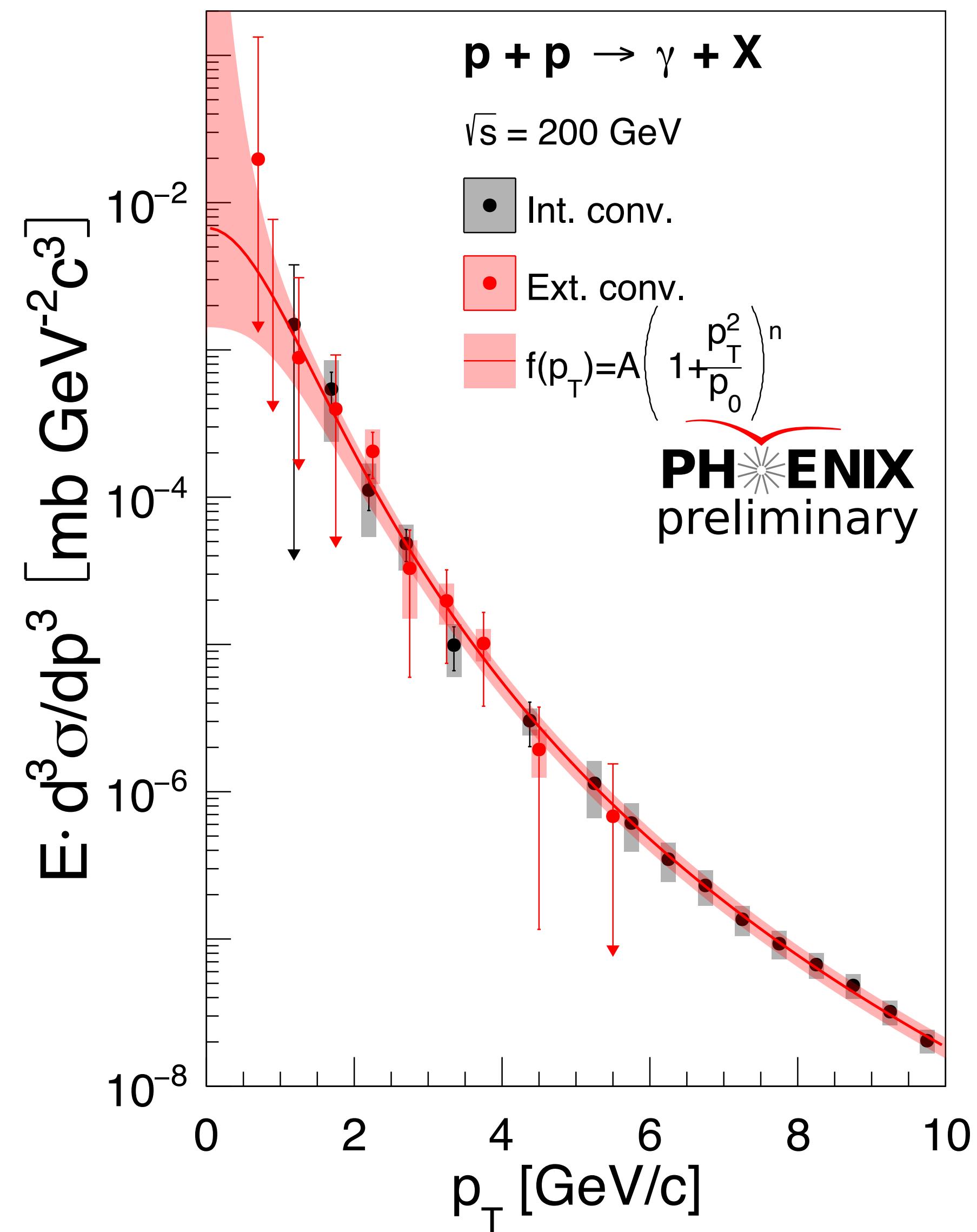
p+p fit

► Fitting function

$$\frac{dN}{dy} = a \left(1 + \frac{p_T^2}{b} \right)^c$$

a	b	c
6.74×10^3	2.10	-3.30

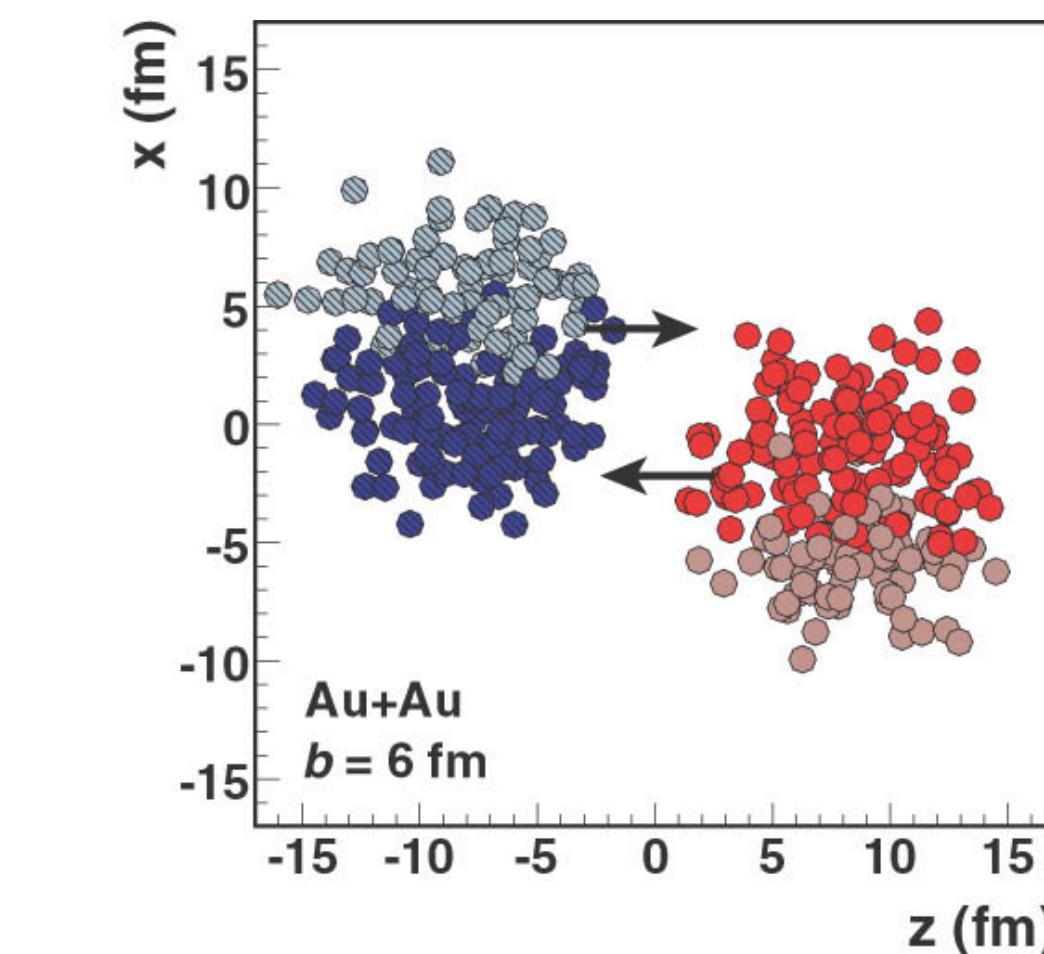
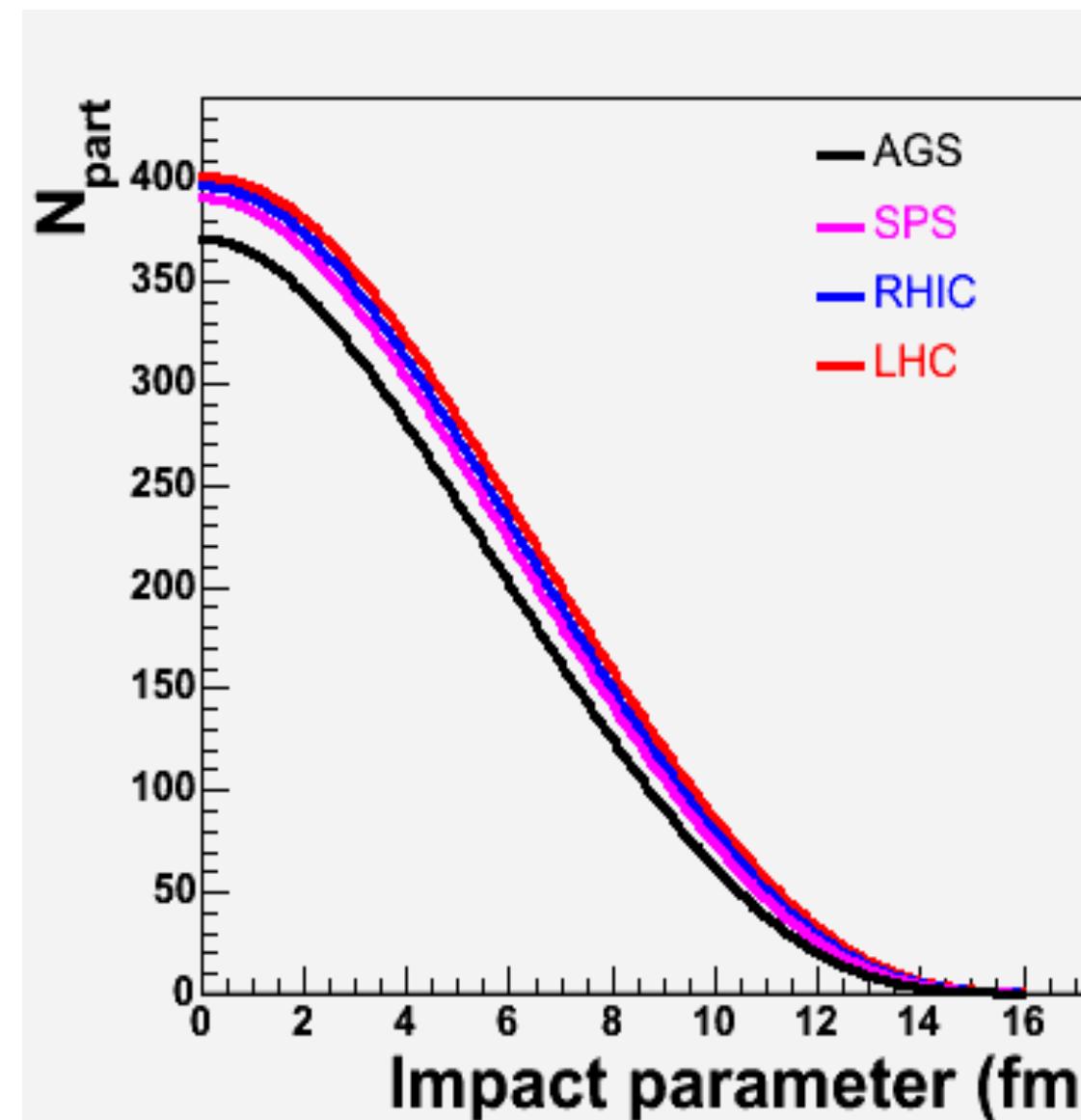
- ❖ pQCD inspired function
- ❖ The fit <1GeV is motivated by Drell-Yan measurement [Ito, et al, PRD23, 604 (1981)]
- ❖ Systematic errors include the fit errors, different functional forms



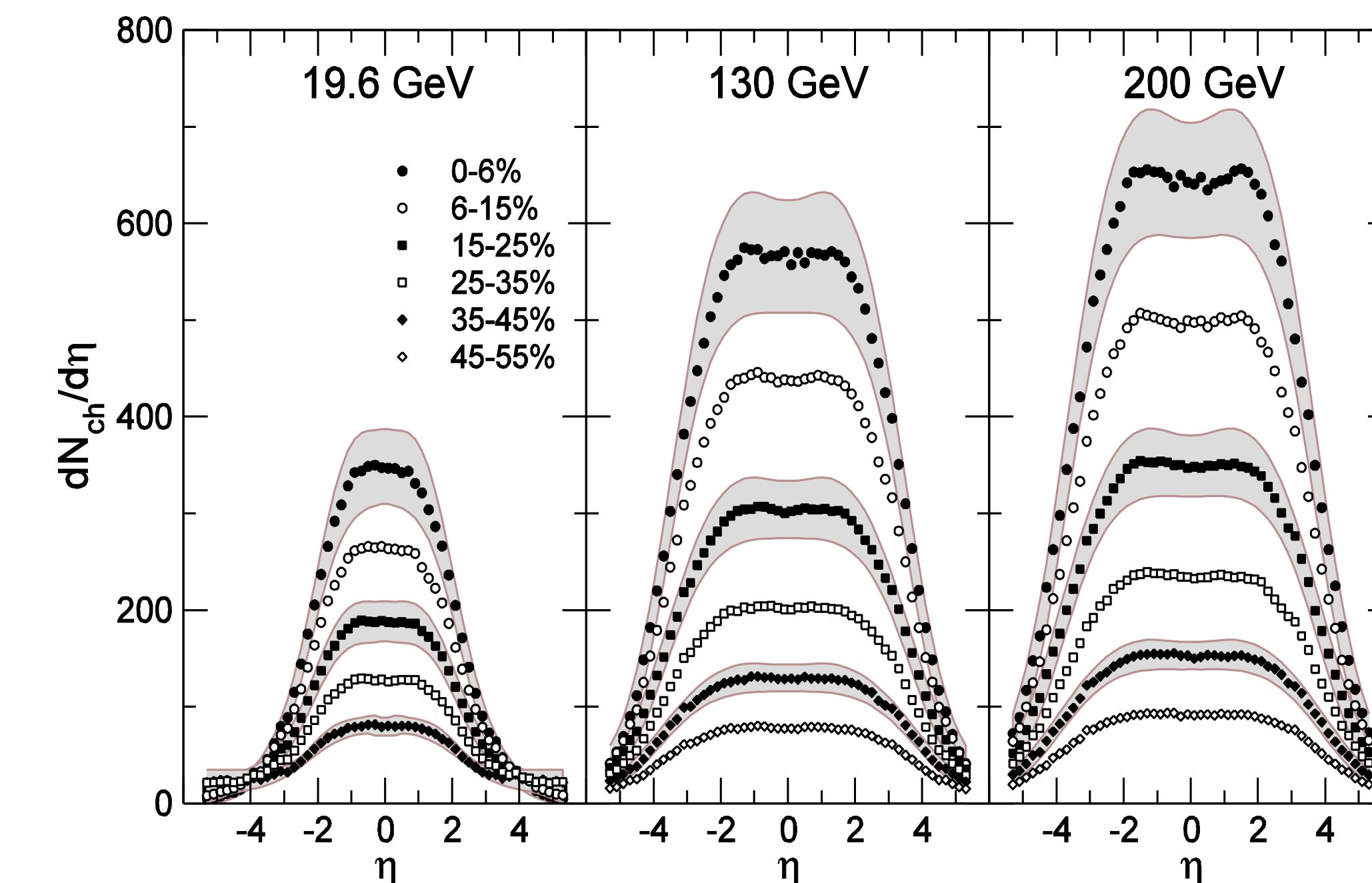
Characterize System Size via $dN_{ch}/d\eta$

- ▶ Use $dN_{ch}/d\eta$ to compare data from different beam energies, collisions species, and collision centralities
 - ❖ $dN_{ch}/d\eta$ is an experimental observable
 - ❖ At fixed \sqrt{s} $dN_{ch}/d\eta \sim N_{part} \sim$ volume
 - ❖ Comparing different \sqrt{s} :

N_{part} saturates at same value for similar size systems at different beam energies

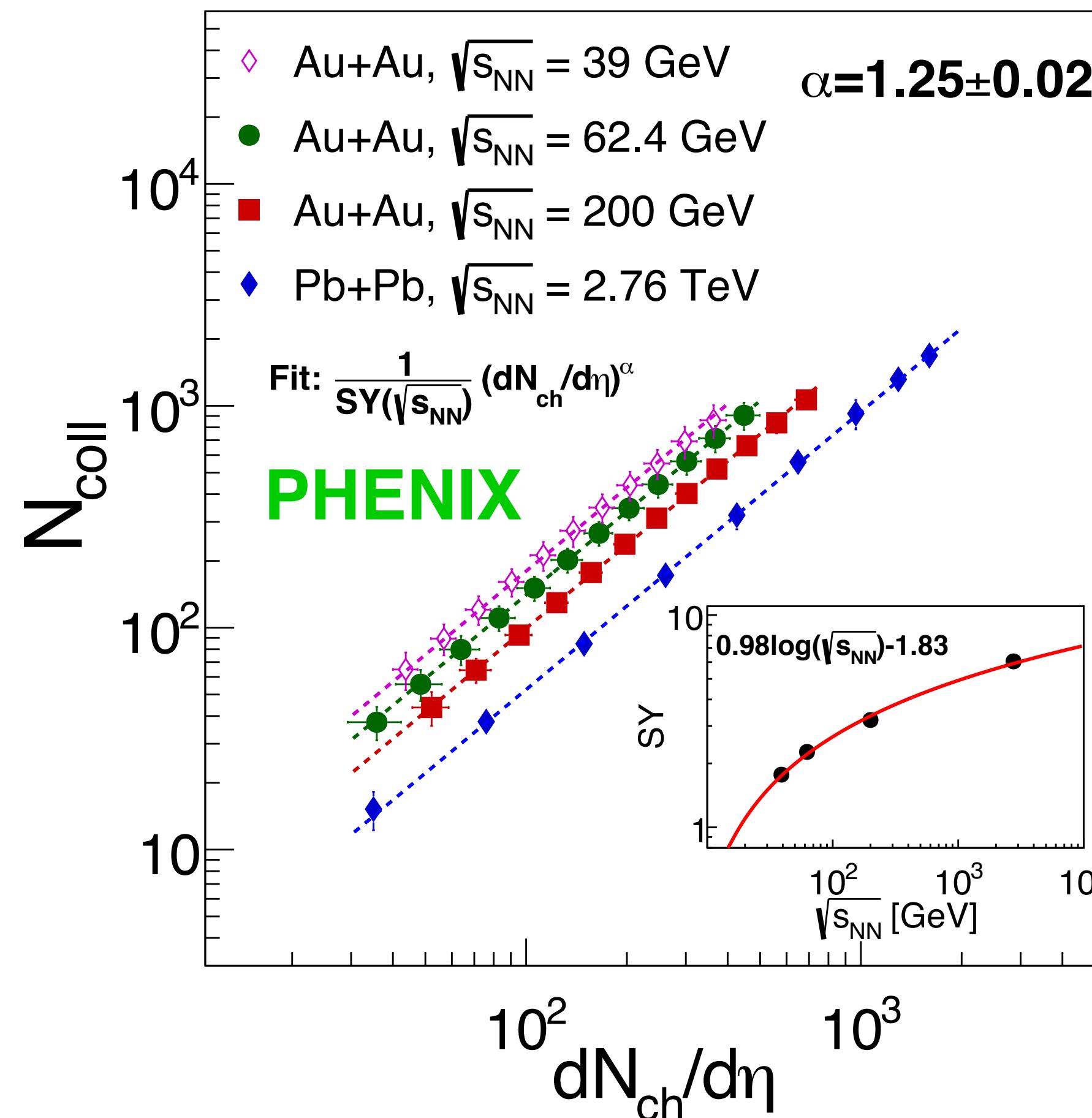


$dN_{ch}/d\eta \sim$ energy density \times volume



N_{coll} vs $dN_{\text{ch}}/d\eta$

- ▶ Compare system size and number of binary collisions: empirical scaling relation across $\sqrt{s_{\text{NN}}}$



energy dependent term

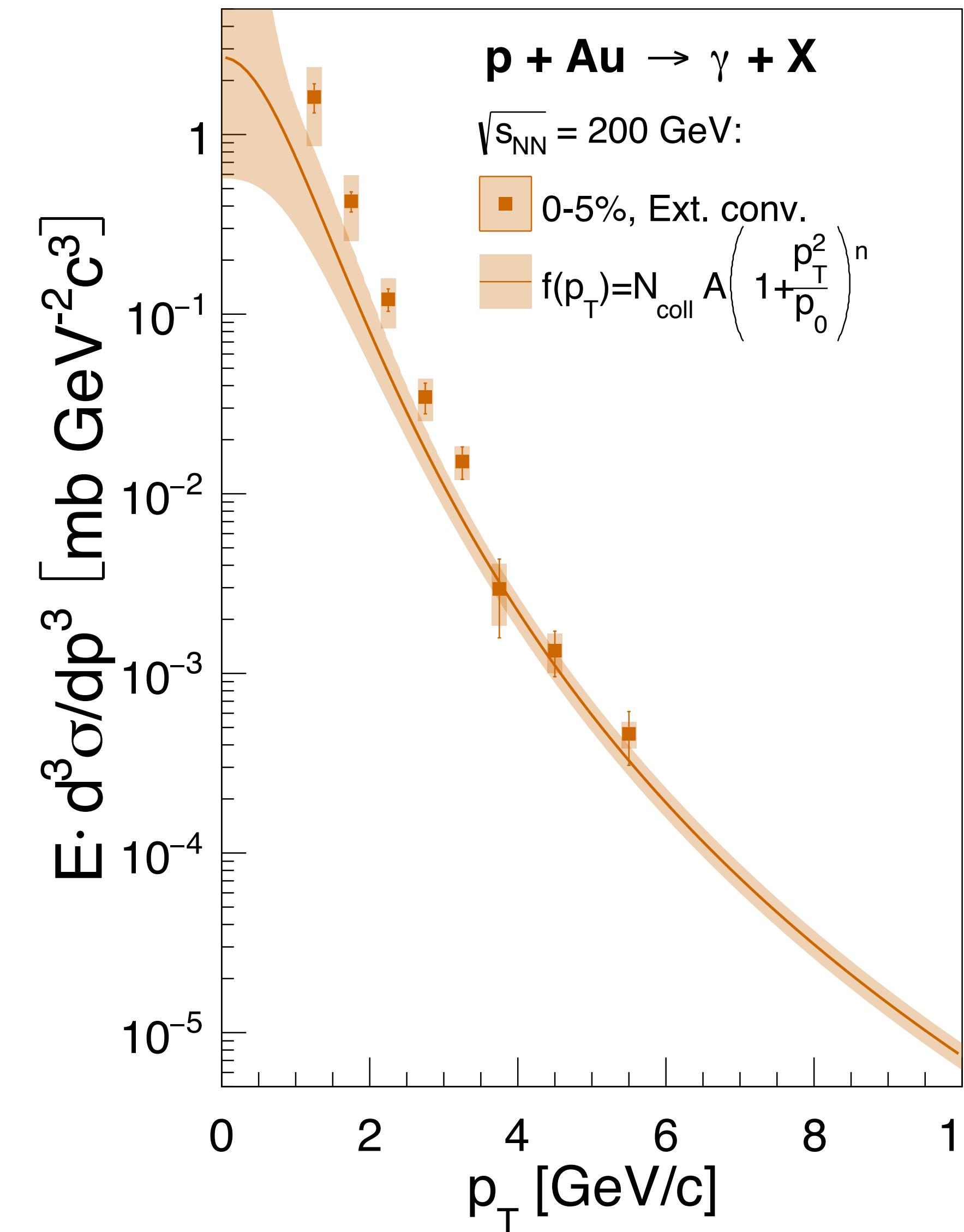
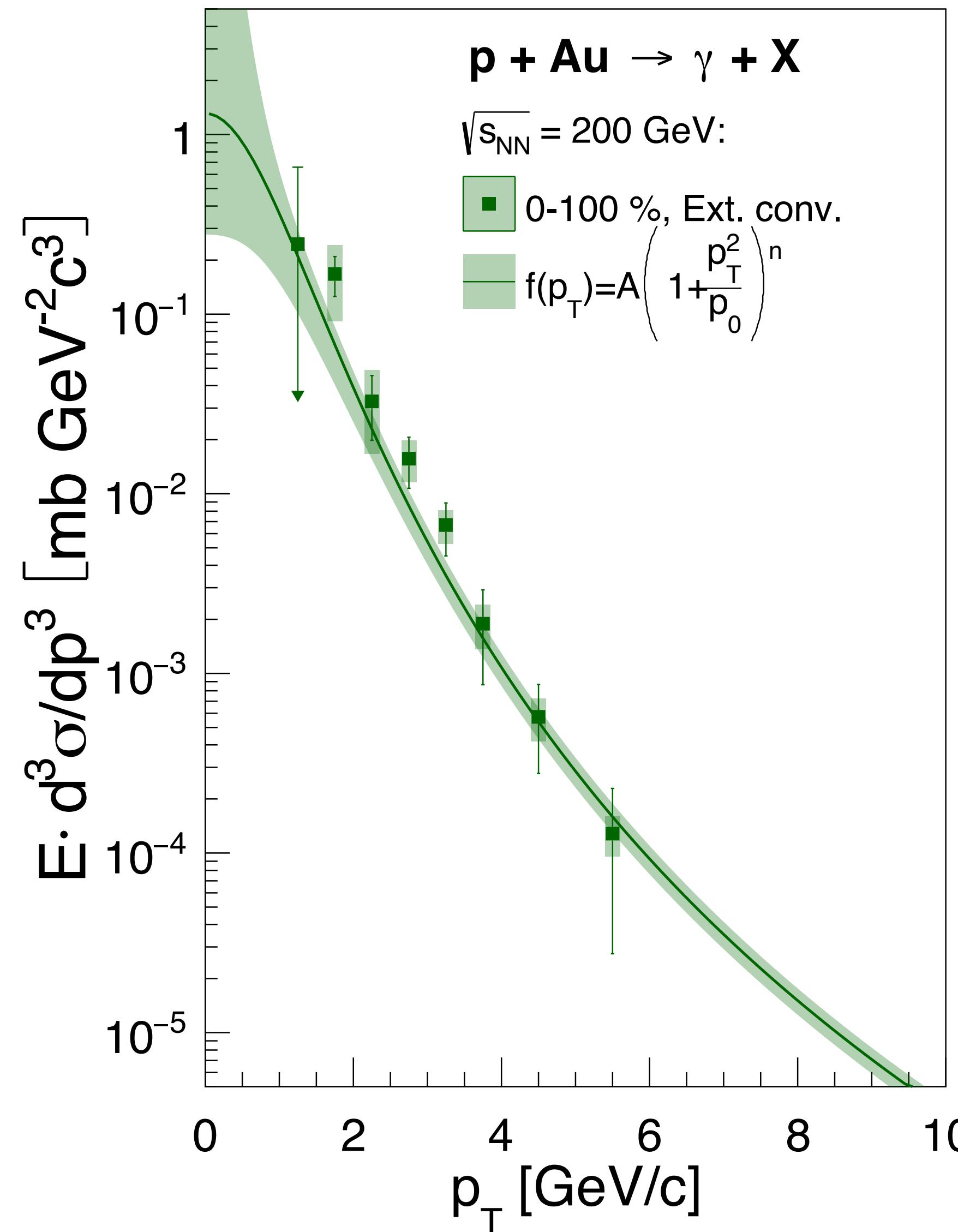
$$N_{\text{coll}} = \frac{1}{SY(\sqrt{s_{\text{NN}}})} \times \left(\frac{dN_{\text{ch}}}{d\eta} \right)^\alpha$$

"hard scattering" term

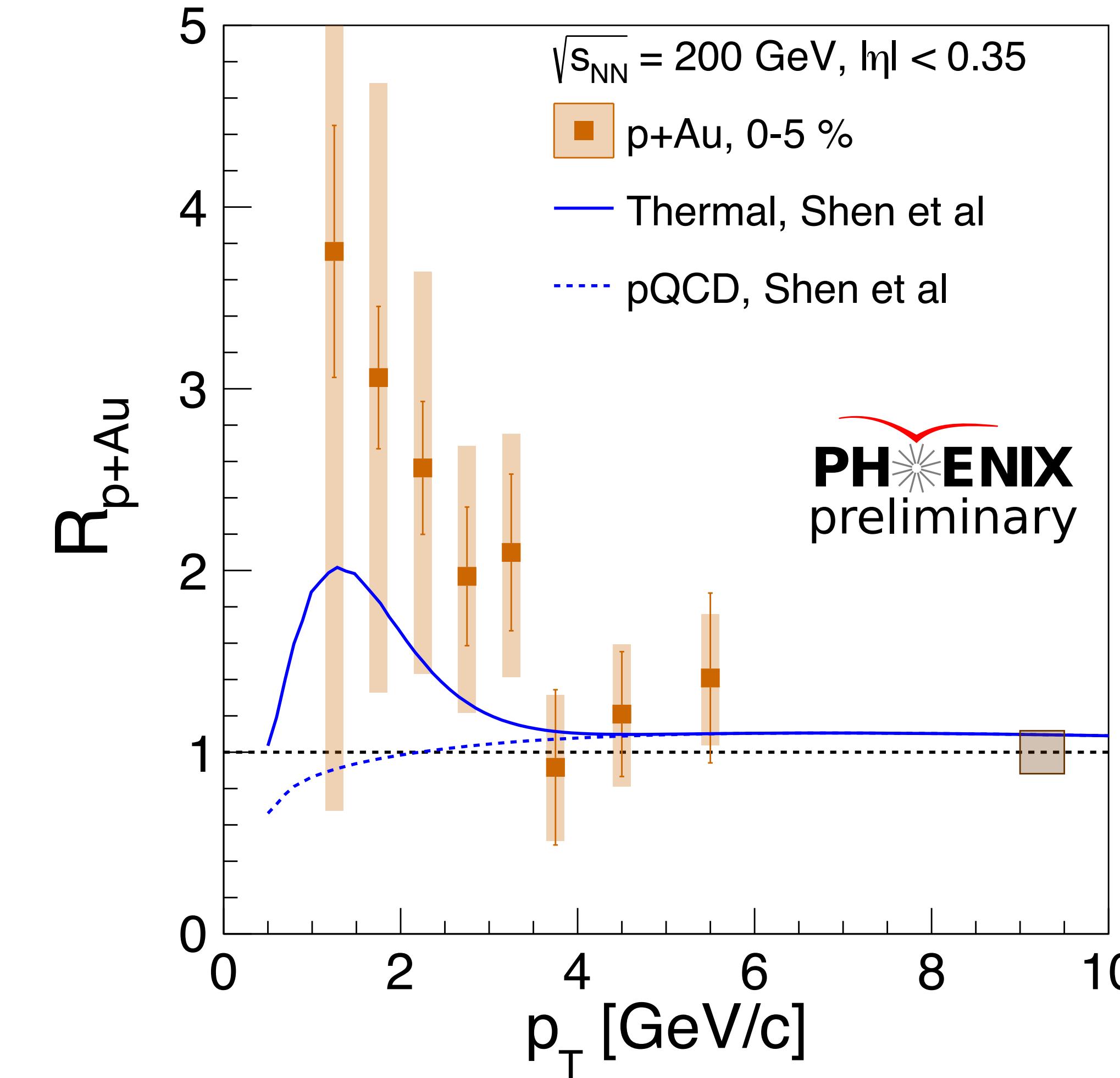
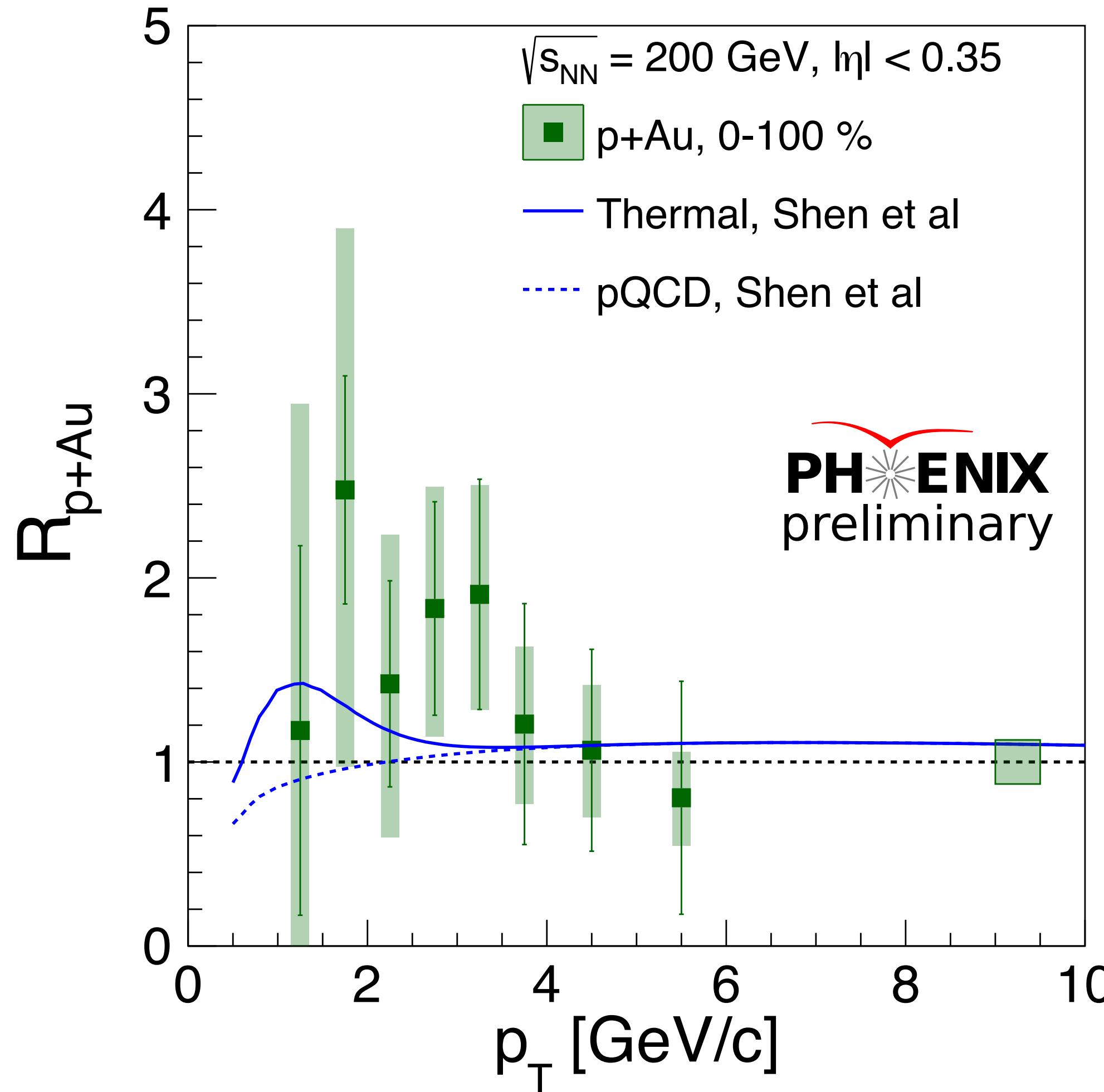
charged particle multiplicity term

What is the origin of the scaling?

Direct Photon Yield in p+Au @ 200GeV

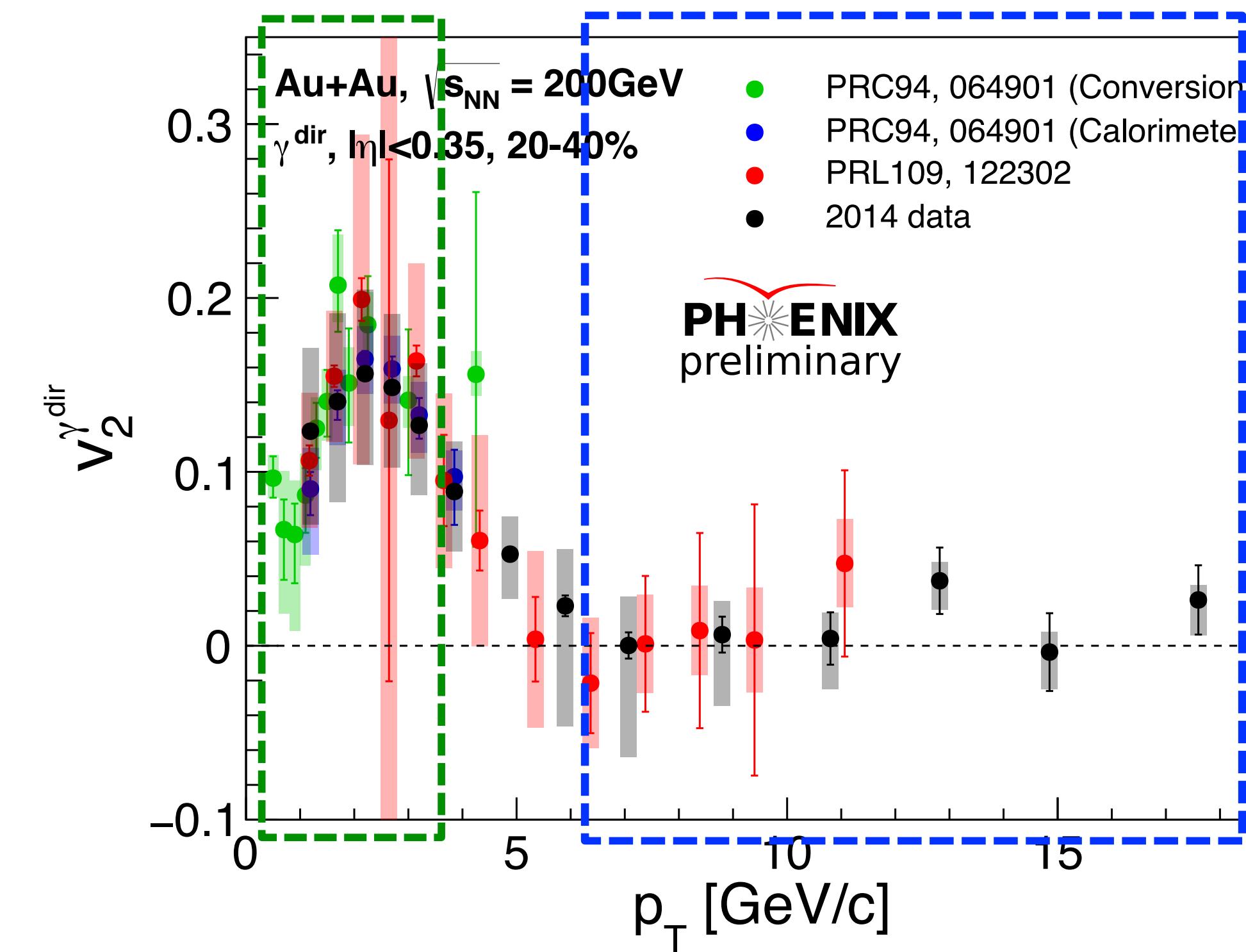
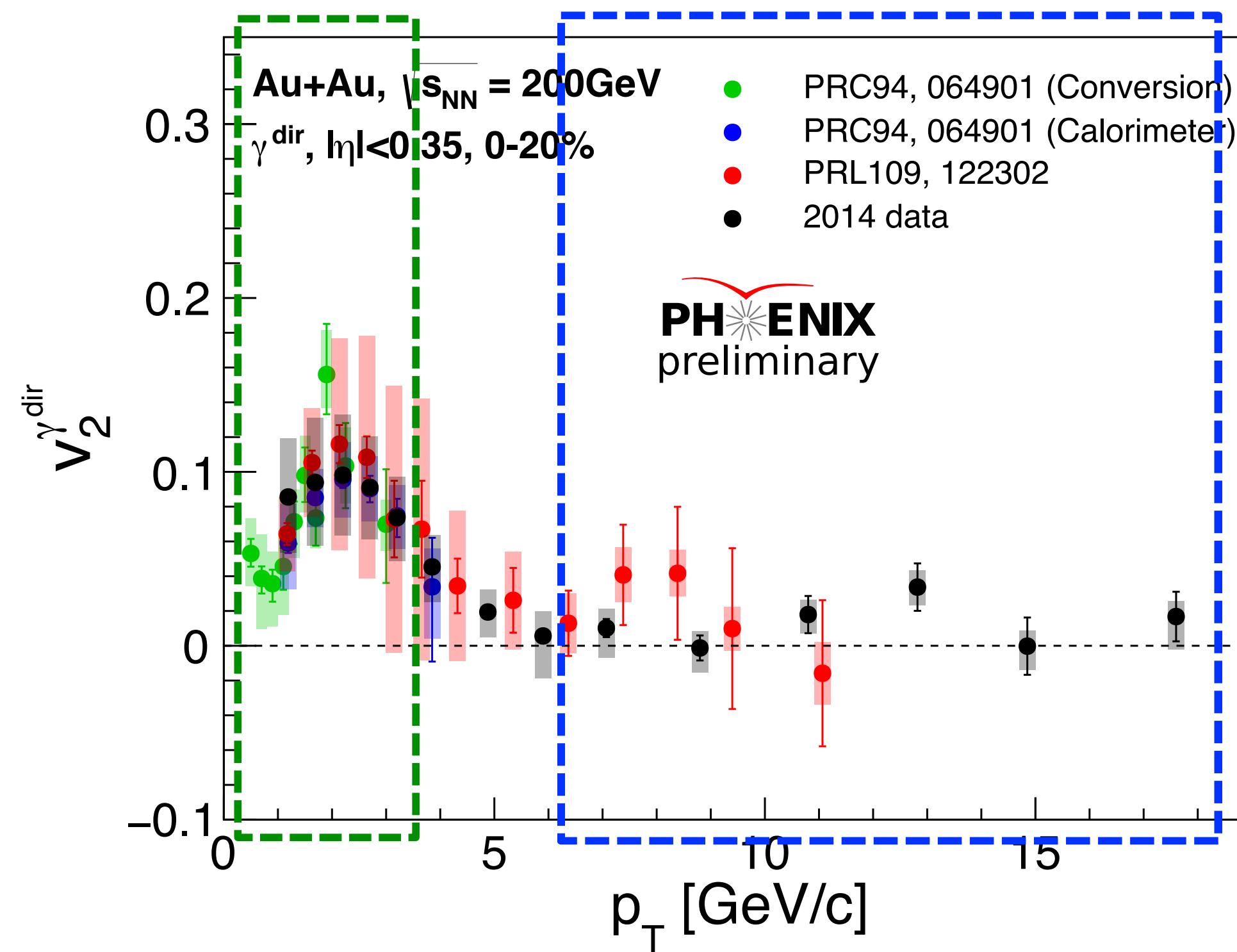


Direct Photon Yield in p+Au @ 200GeV



Direct photon v2 in Au + Au collisions at 200 GeV

- Using R_γ from published results (low p_T : PRC91, 064904; high p_T : PRL109, 152302)



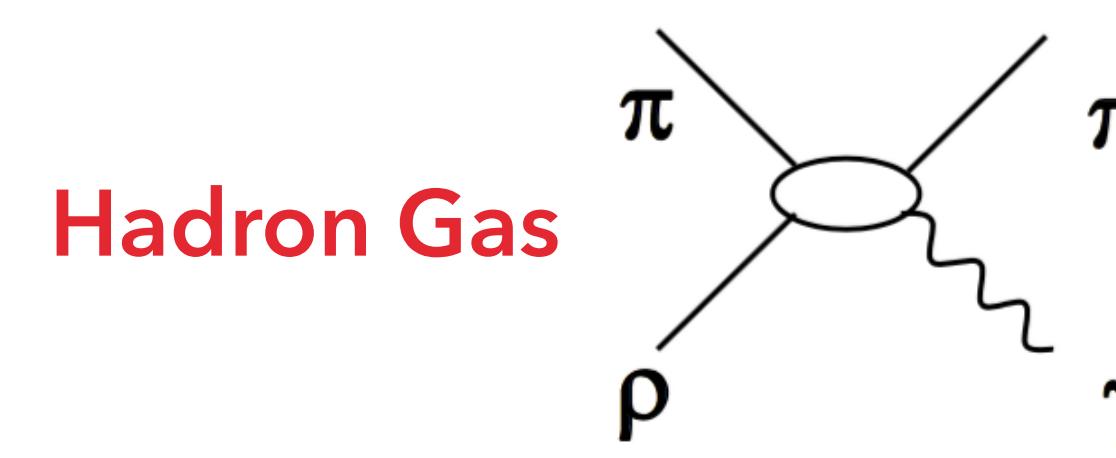
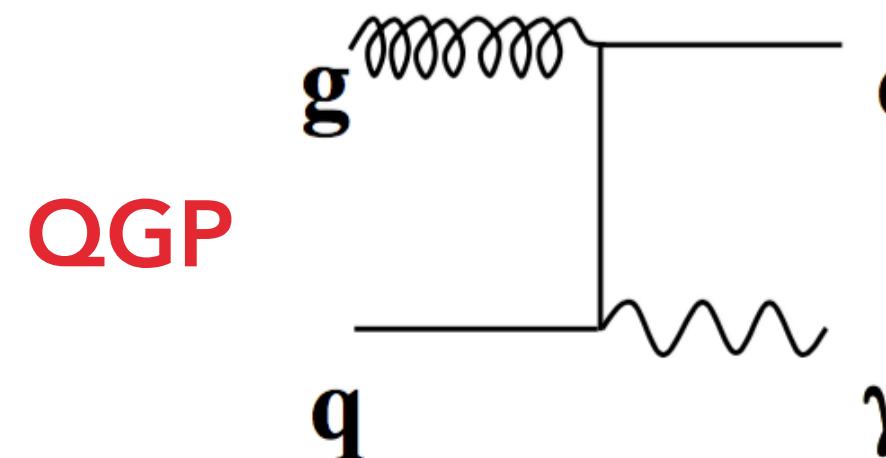
Low p_T : Large azimuthal anisotropy for direct photons (mixture of direct photons from initial scattering and thermal radiation (QGP and HG))

High p_T : ~0 azimuthal anisotropy for the direct photons (dominant source of direct photons is from initial scattering)

What to measure with direct photons?

► Thermal radiation

- ❖ Hot & dense medium: radiate thermal photons



- ❖ Spectrum and yield sensitive to temperature **Avg. inv. slope $\propto T_{\text{eff}}$**

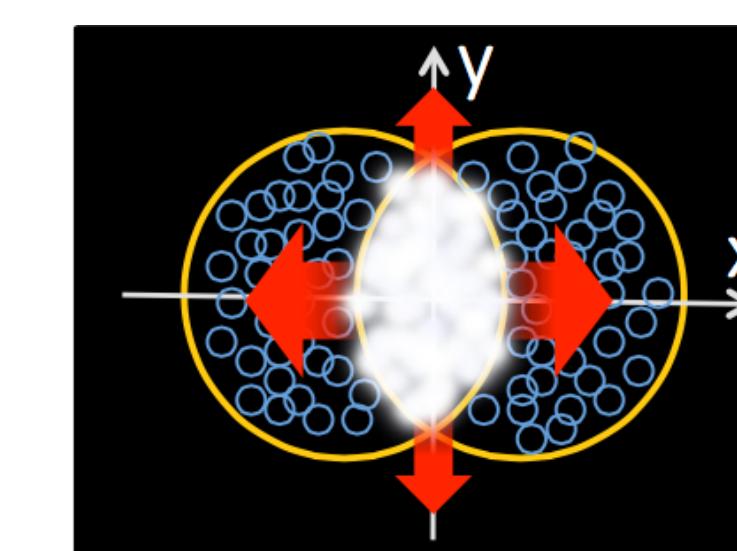
- ❖ Spectrum also affected by the space time evolution of matter **Doppler shift**



Measurements of yield will constrain initial conditions, sources, emission rates and space-time evolution

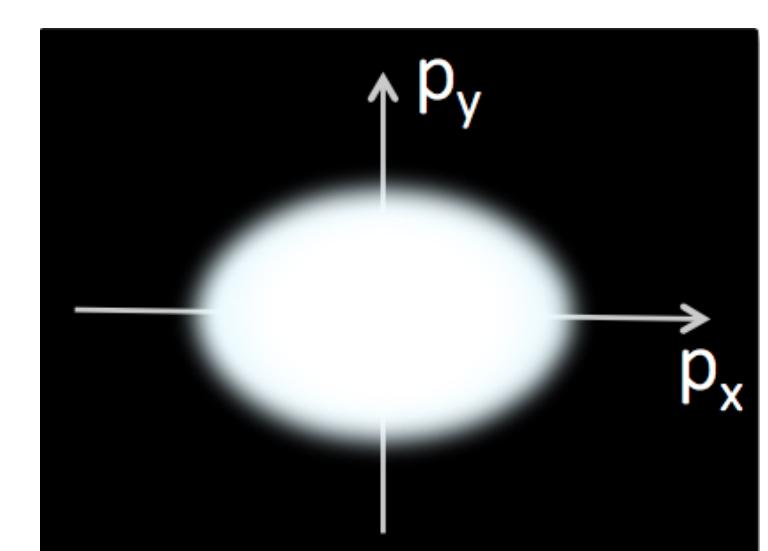
► Collective behavior (Flow)

- ❖ Hydro Model: strongly interacting medium — “perfect fluid”



initial state eccentricity

pressure gradient



final state anisotropy

elliptical flow

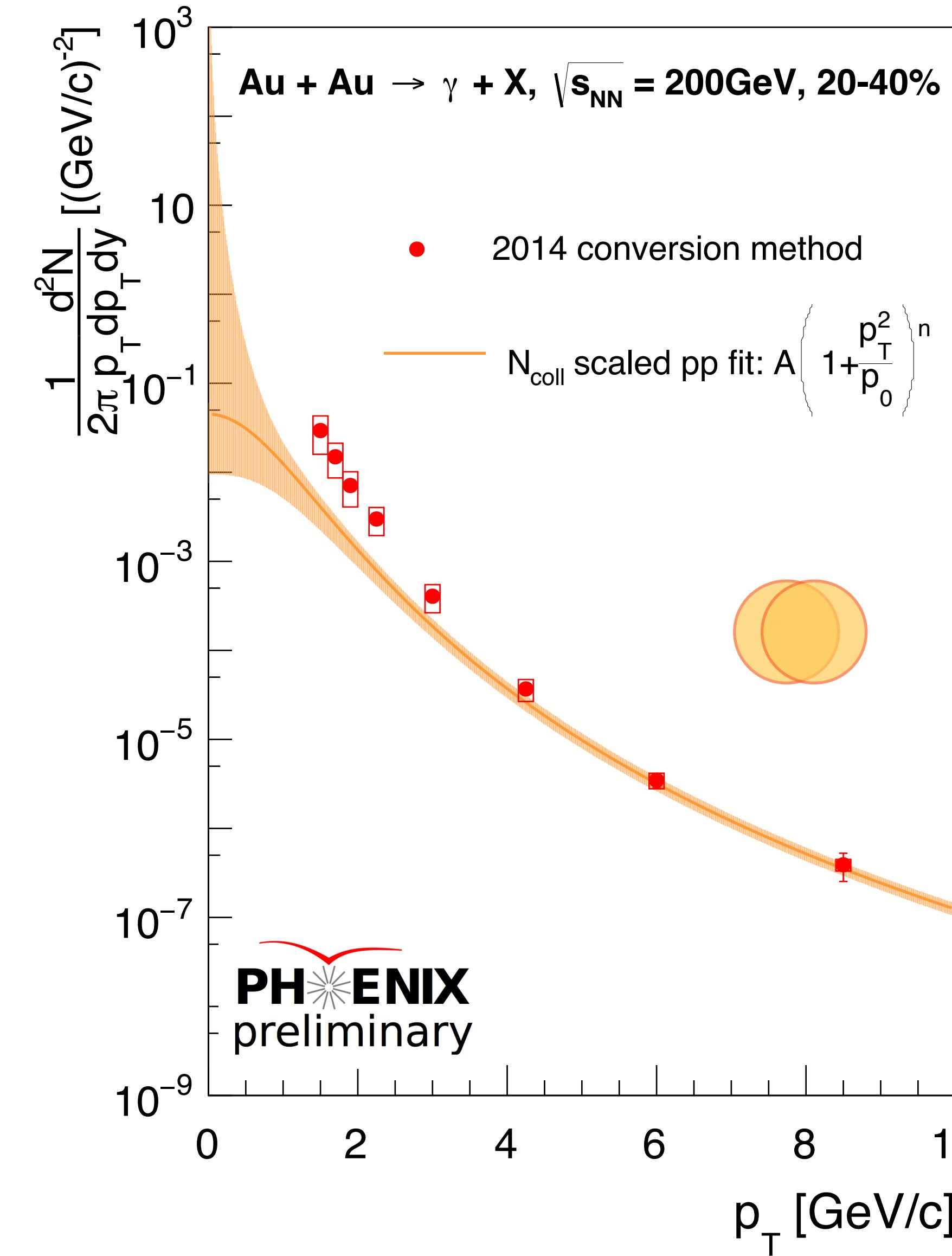
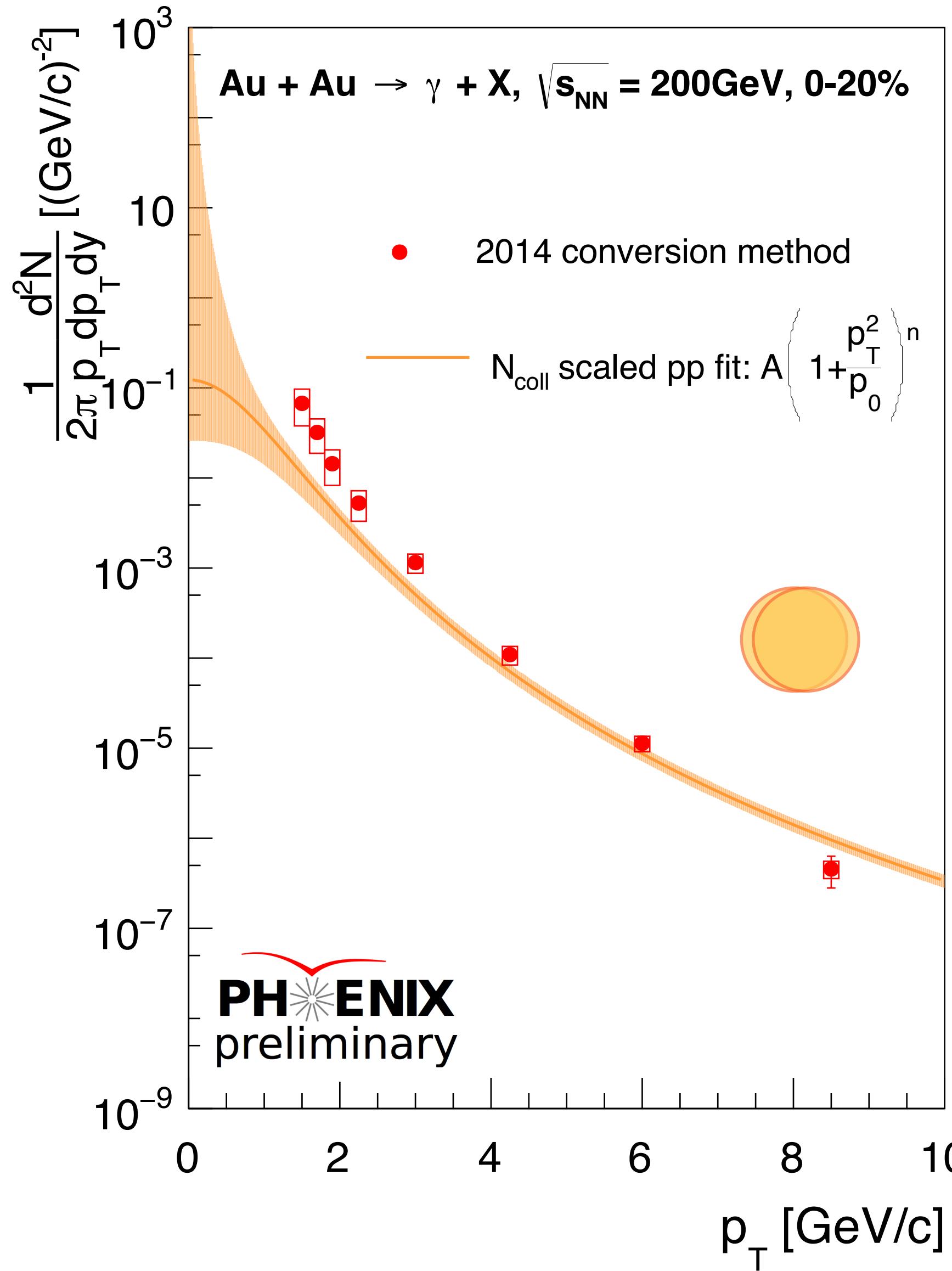
$$\frac{dN}{d(\phi - \Psi_{2,RP})} \propto 1 + 2v_2 \cos 2(\phi - \Psi_{2,RP}) + \dots$$



Measurements of flow will constrain initial conditions, fluctuations and some QGP properties (η/s , partonic level flow)

Direct photon yield in Au + Au collisions at 200 GeV

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

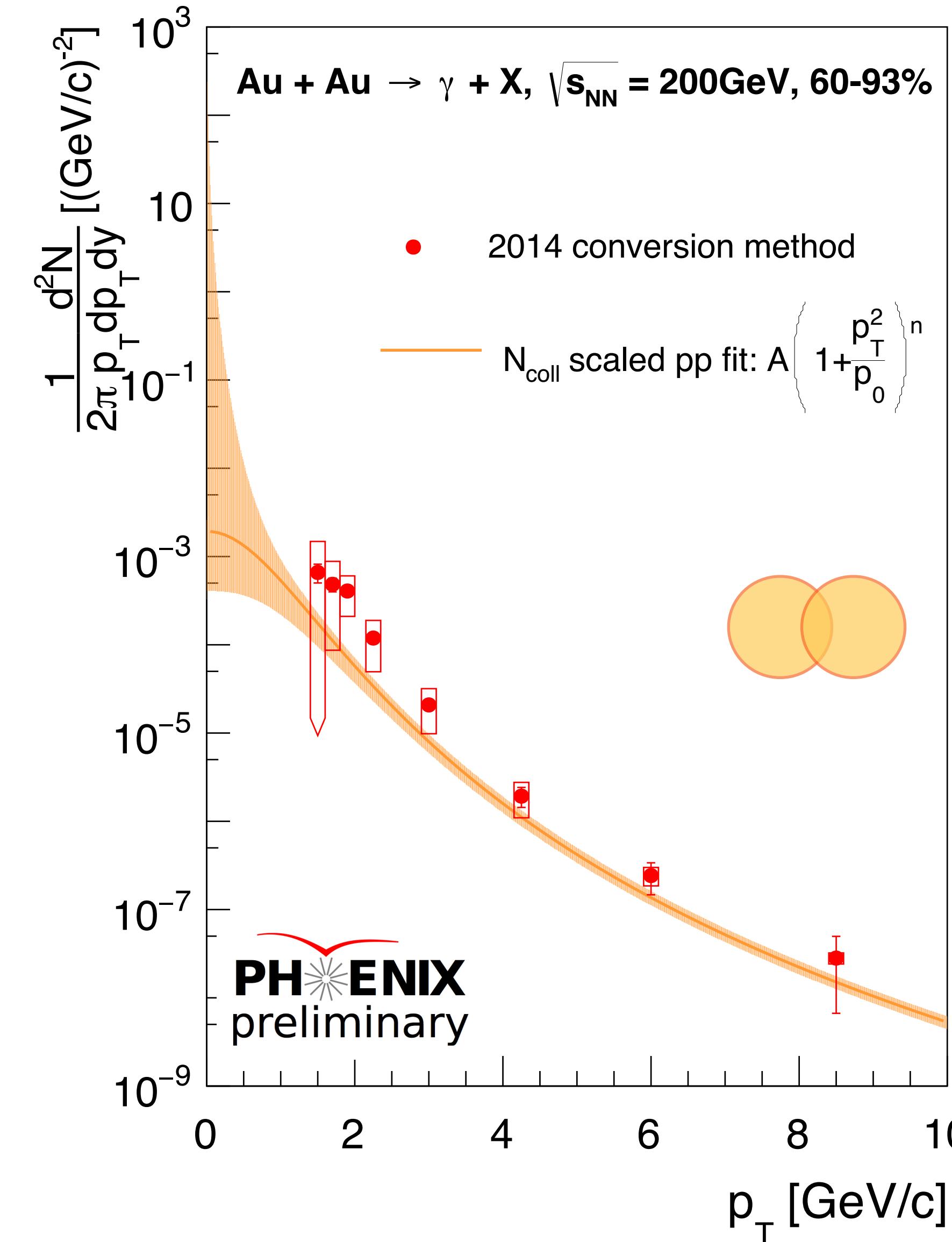
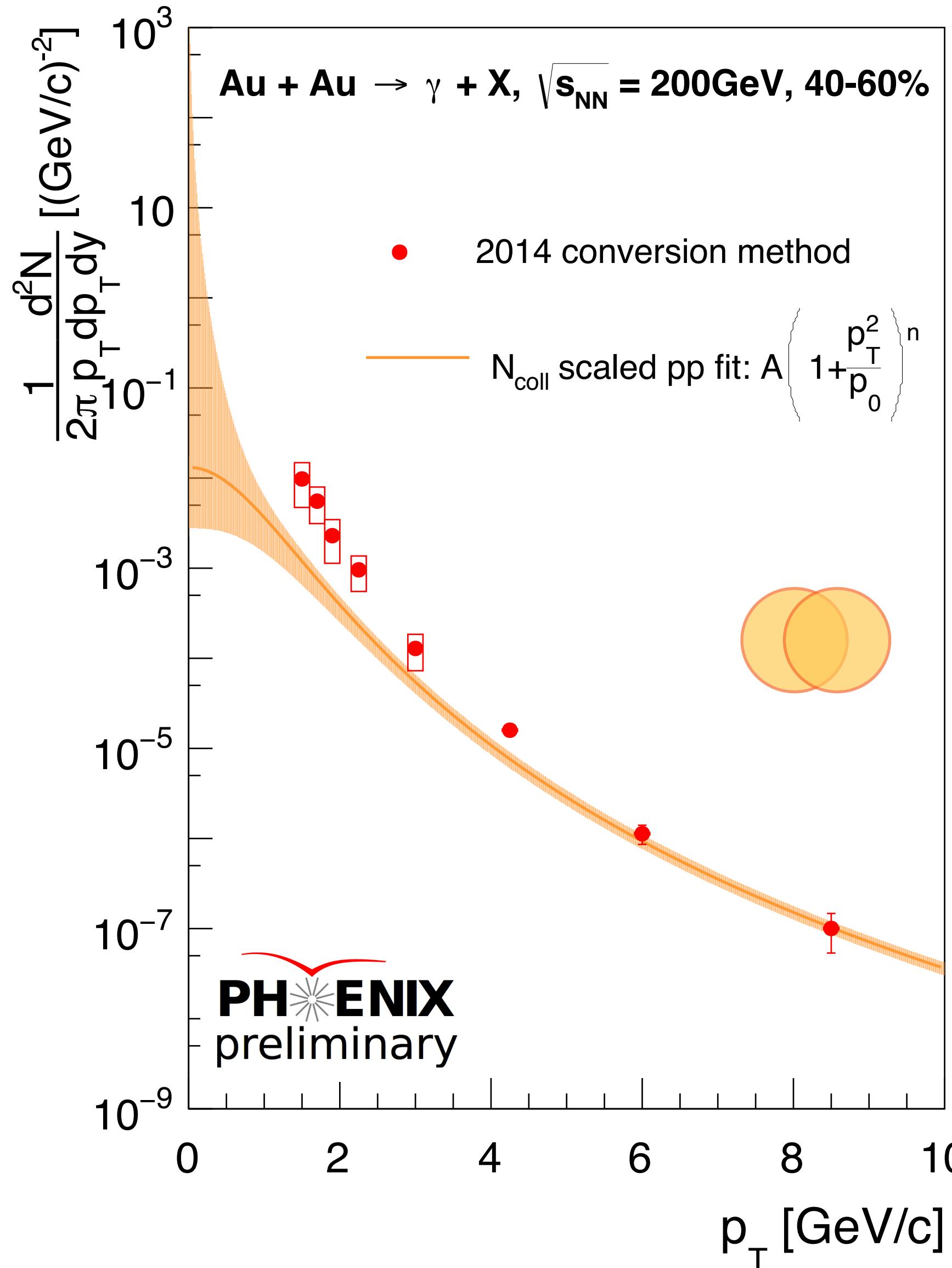


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Direct photon yield in Au + Au collisions at 200 GeV

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

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