

DIRECT PHOTON RESULTS FROM PHENIX AT RHIC

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for the PHENIX collaboration

ICNFP2018

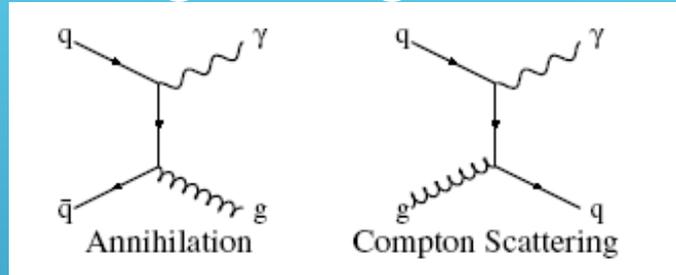
July 7, 2018



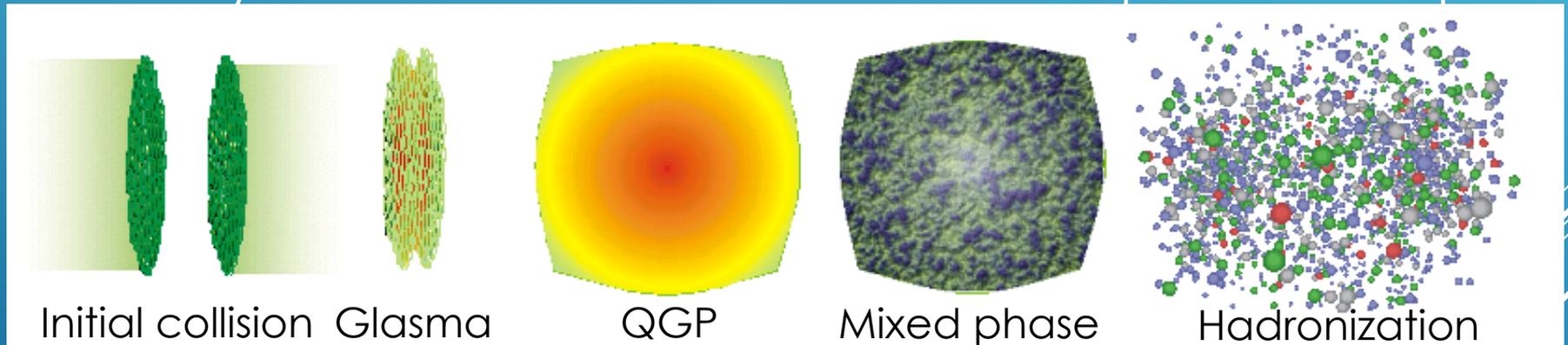
DIRECT PHOTON

- Definition: photons NOT originating from hadron decays

Major production processes:



- Penetrating probe w/o strong interaction in QCD medium
 - ✓ Carry the medium information at the production point



Hard photon

Thermal photon

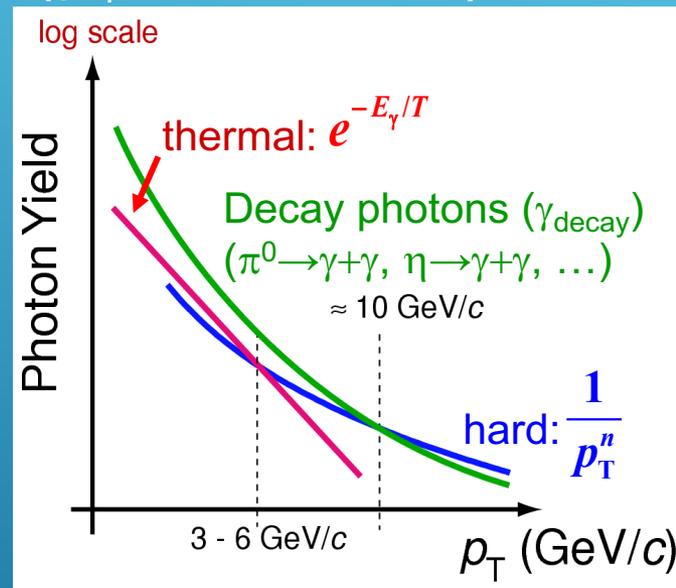
Hadron decay photon

- Produced throughout the collision history

✓ γ_{thermal} yield : $N_{\gamma} = \int_{\tau_0}^{\tau_c} R_{\gamma} \times V dt$, R_{γ} : rate, V : volume

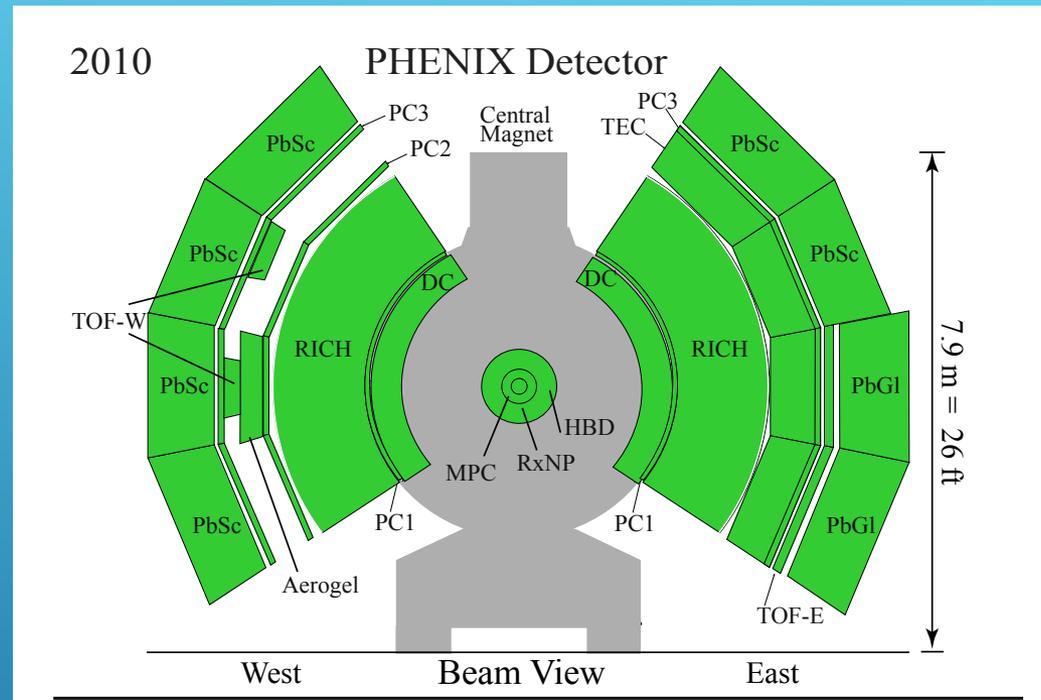
THERMAL PHOTON MEASUREMENT

- Experimental data = Integral of all photon production
 → Need “ p_T -window” to measure target photons
 - ✓ Low p_T region ($p_T < 3-4 \text{ GeV}/c$) for thermal photons



- γ_{decay} always makes γ_{dir} measurements challenging
 - ✓ $\sim 80\%$ from π^0 & $\sim 10\%$ from η of inclusive photon yield
 - ✓ γ_{dir} = Reminder after γ_{decay} subtraction
- Importance of p+p & p+A data as a baseline
 - ✓ Hard photon production & nuclear effects@low p_T

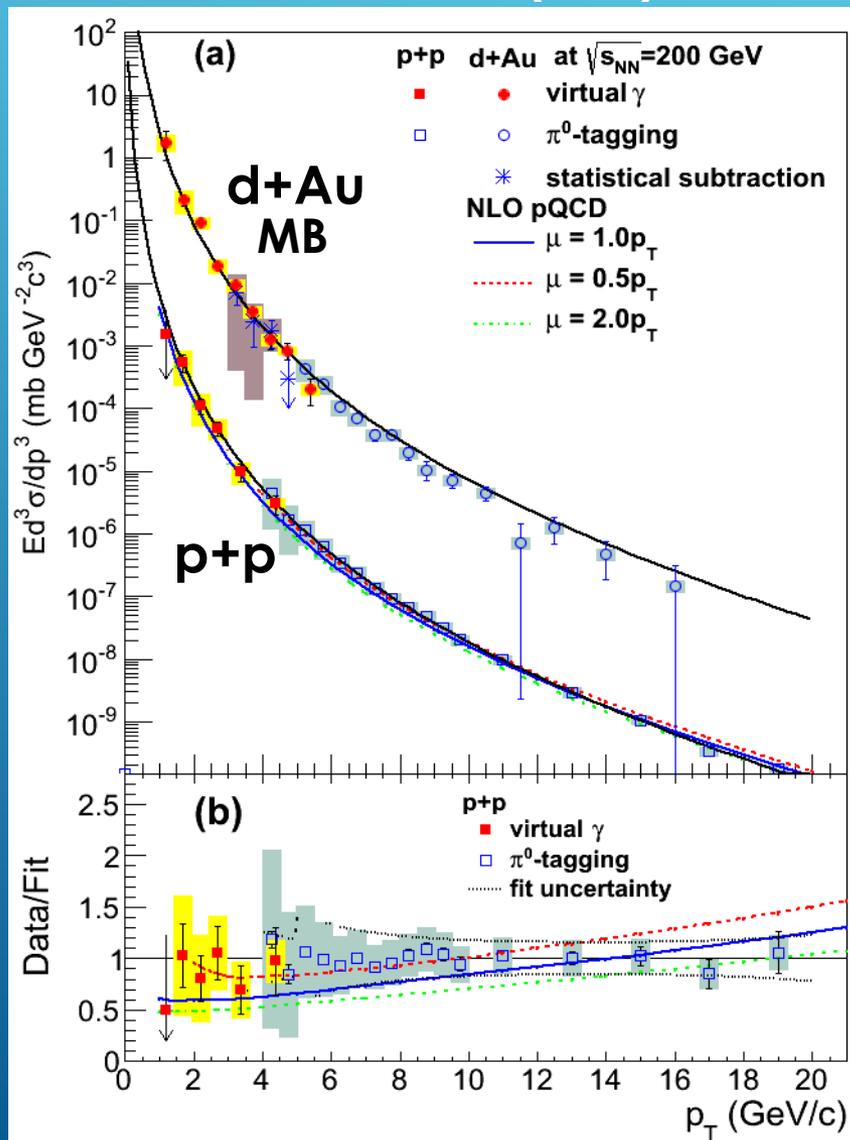
PHOTON MEASUREMENTS AT PHENIX



- 3 independent measurements at PHENIX
 1. EMCal method: Suitable for high p_T ($>4\text{GeV}/c$)
 2. Conversion photon method: Utilizing photon conversions and covering a wide p_T range from less than $1\text{GeV}/c$
 3. Virtual photon method: Measuring $\gamma_{\text{dir}}^* \rightarrow e^+e^-$ with reduced BG and works for $1 < p_T < 5-6\text{GeV}/c$

BASELINE: p+p & d+Au AT $\sqrt{s_{NN}}=200\text{GeV}$

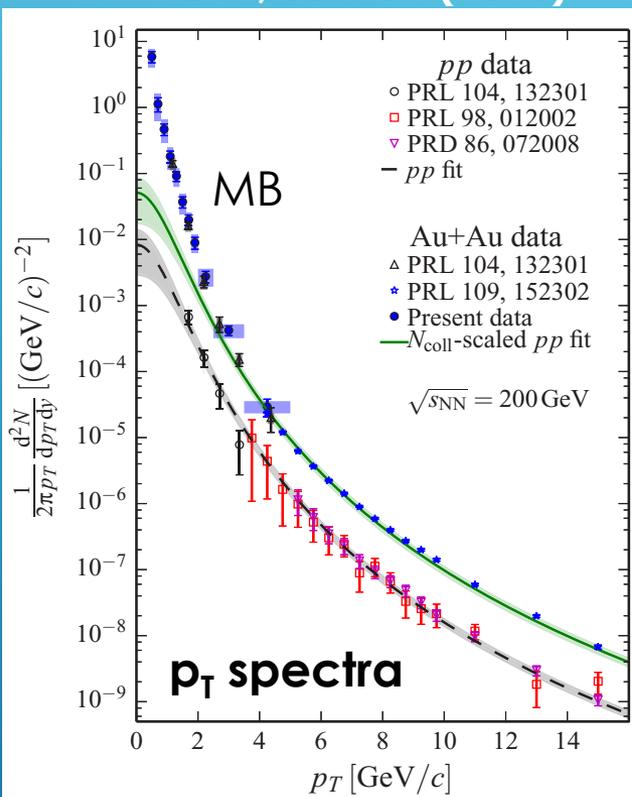
PRC87, 054907 (2013)



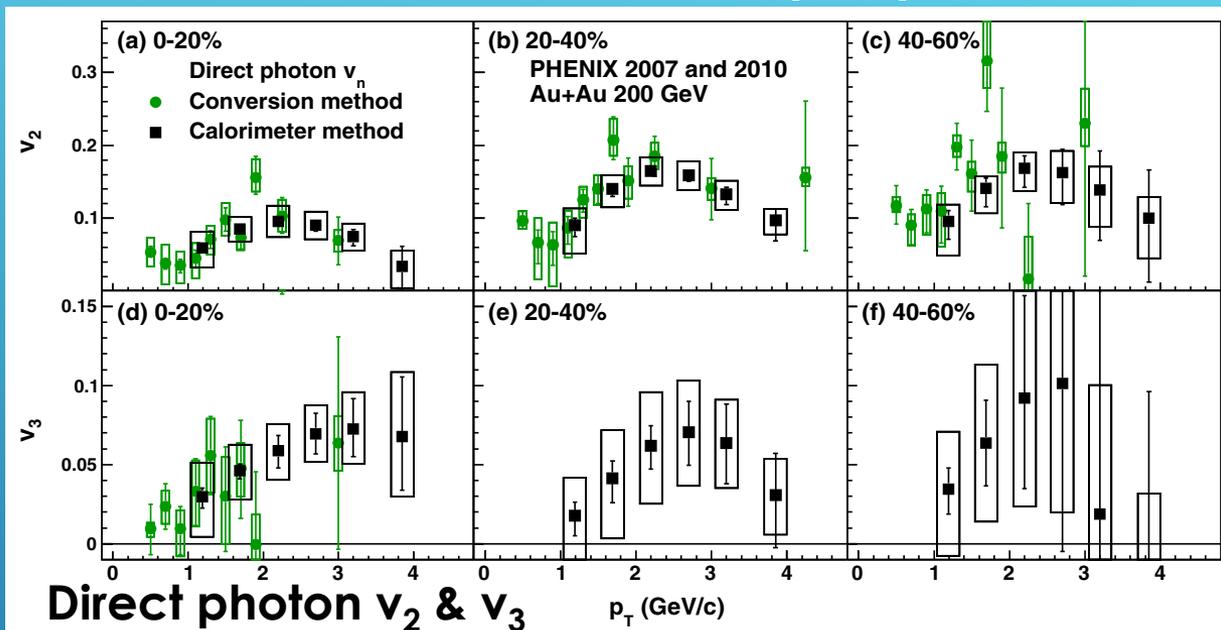
- Successful direct photon measurements for p+p & d+Au at PHENIX
 - ✓ **p+p:** Consistent with pQCD calculations for 1-20 GeV/c → binary scaled p+p result = hard photons in A+A
 - ✓ **d+Au (MB):** Consistent with binary-scaled p+p result → Very small nuclear effects

Au+Au AT $\sqrt{s_{NN}}=200\text{GeV}$

PRC91, 064904 (2015)



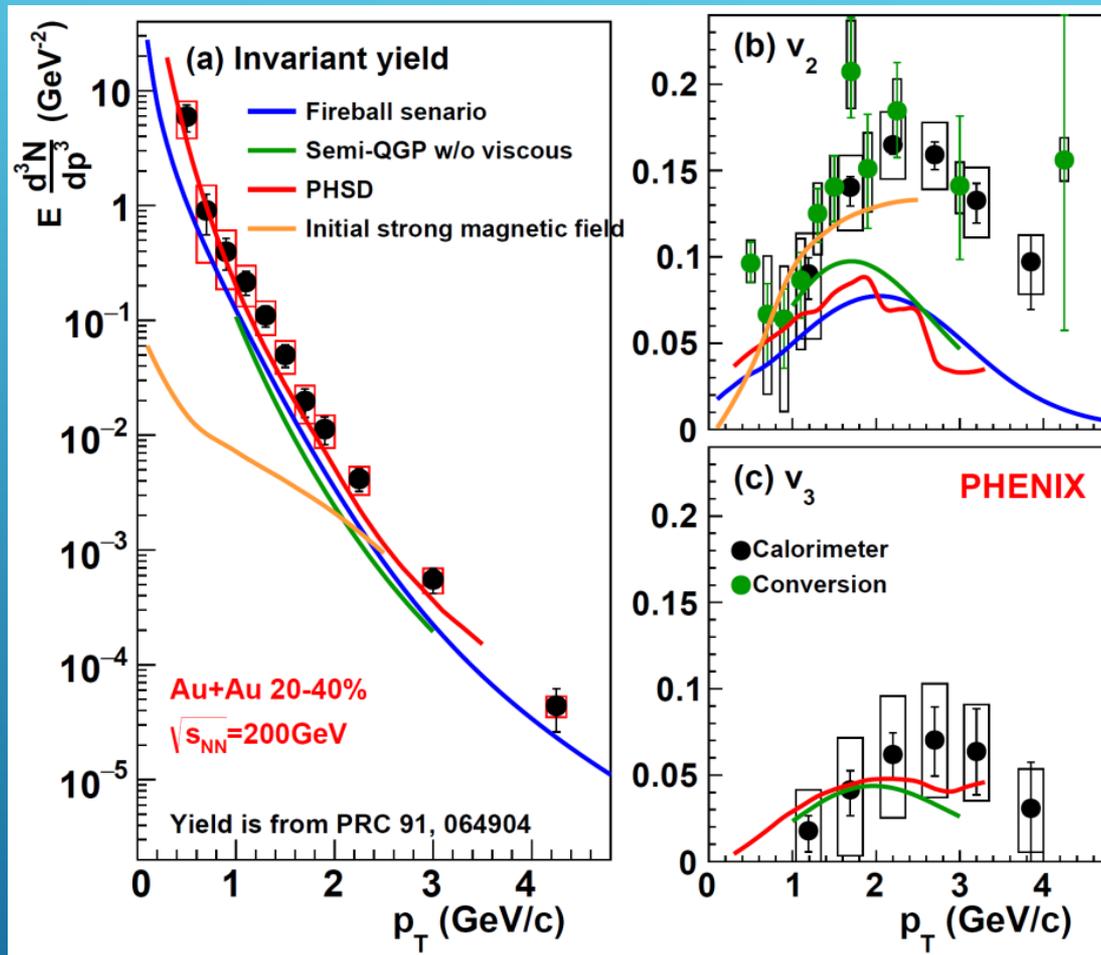
PRC94, 064901 (2016)



- $p_T > 4\text{ GeV}/c$: Consistent with the binary scaled p+p
- $p_T < 4\text{ GeV}/c$: Enhanced yield over the binary scaled p+p
 - ✓ Thermal photons from the medium
- However, observation of a surprisingly large v_2 as well
 - ✓ Sensitive to production process & production time

DIRECT PHOTON PUZZLE

PRC94, 064901 (2016)

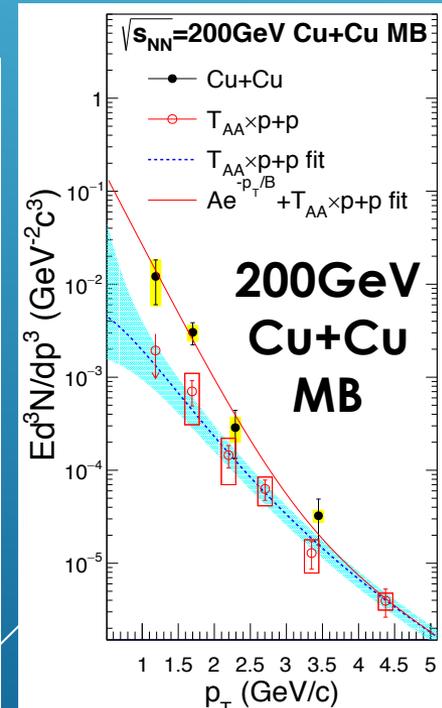
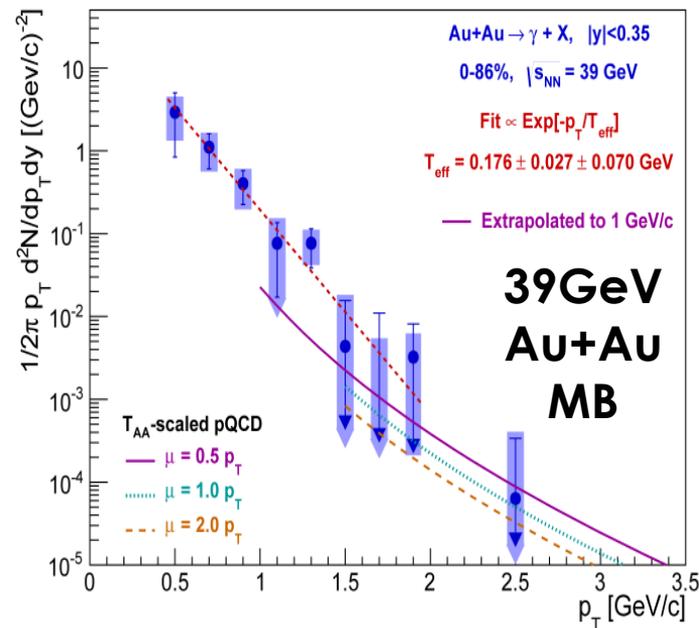
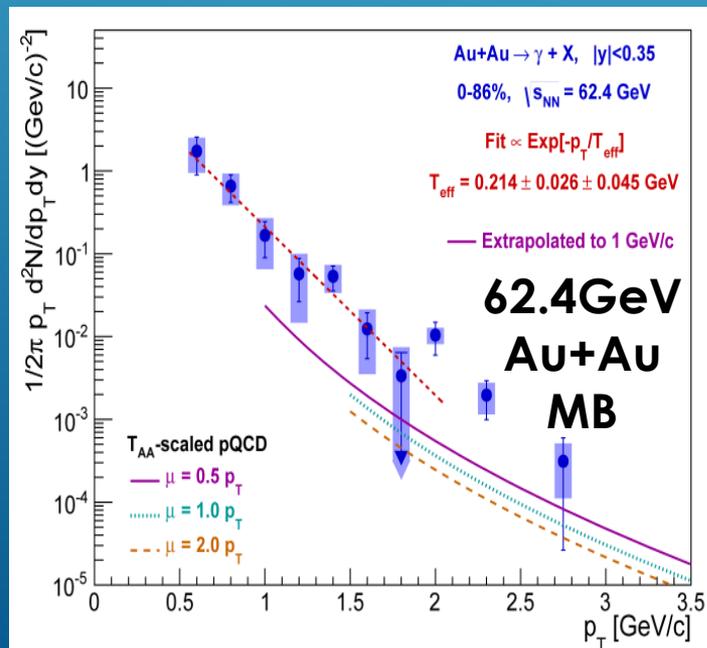


- No simultaneous description for both large yield & v_2
- Need more systematic study on photon production
 - ✓ Collision system & energy

NEW RESULTS

- **Cu+Cu 200GeV(MB, 0-40%)**
 - ✓ Different collision species
 - ✓ Covering small N_{part} region
- **Au+Au 39(MB) & 62.4GeV(0-20%, 20-40%, MB)**
 - ✓ Study of $\sqrt{s_{NN}}$ dependence
 1. Direct photon yield
 2. Inverse slope of exp. fit (T_{eff})

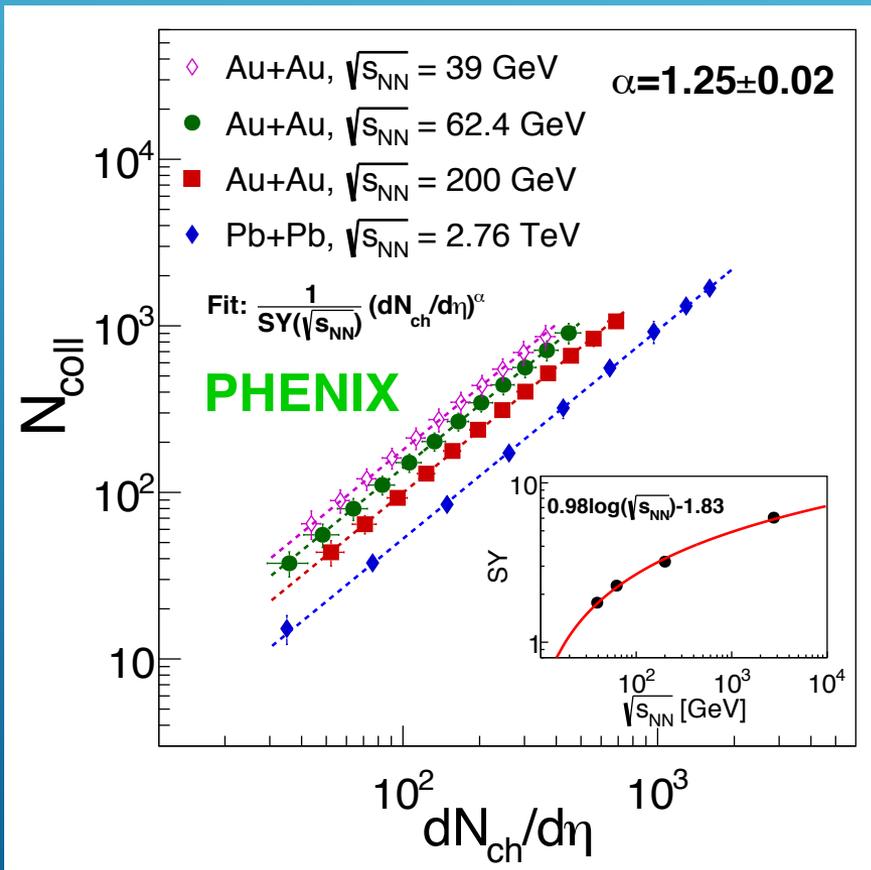
arXiv: 1805.04066



TRANSLATION OF N_{coll} TO $dN_{\text{ch}}/d\eta$

- $dN_{\text{ch}}/d\eta$: Useful measured observable for study of direct photon production across a wide range of $\sqrt{s_{NN}}$ systems

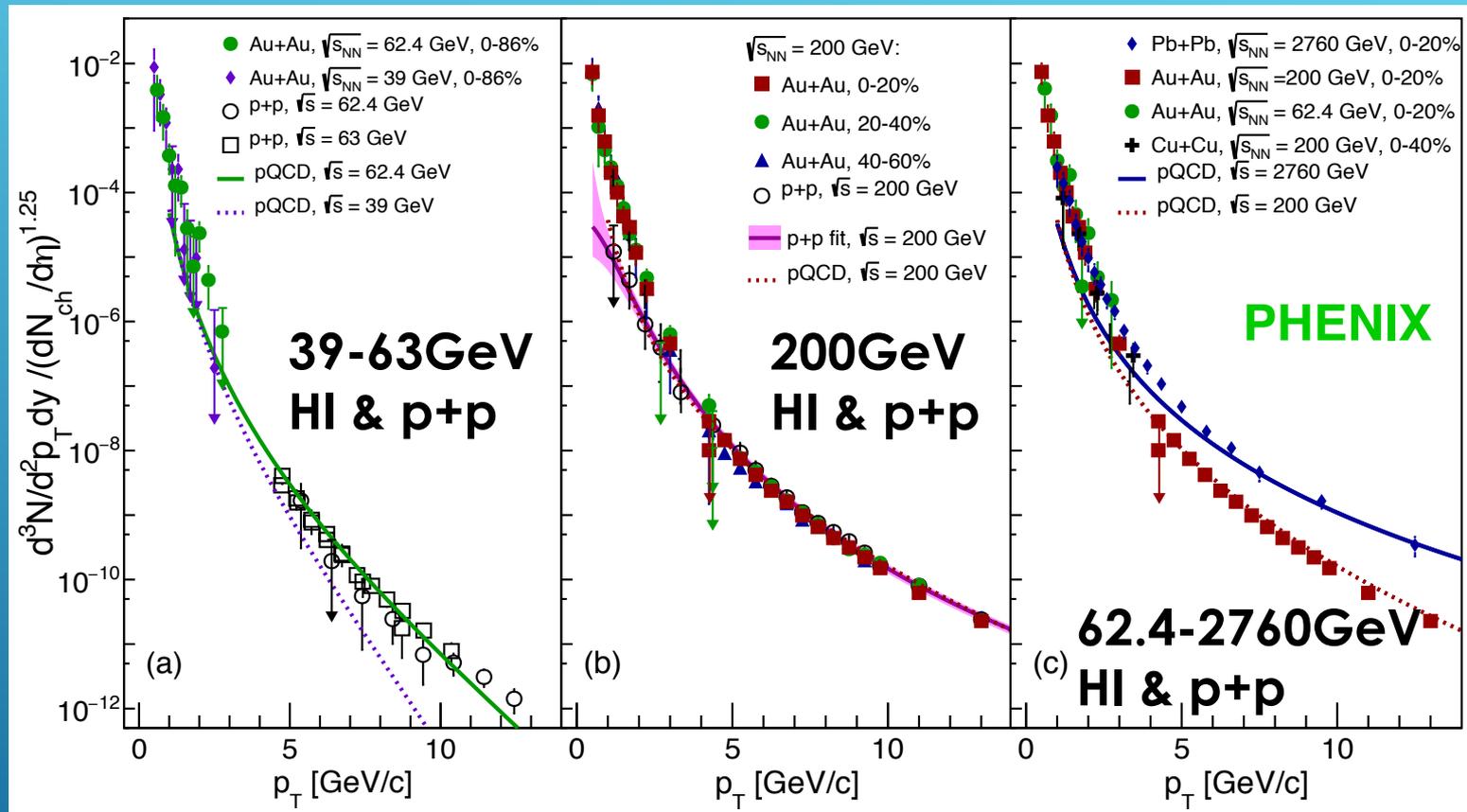
arXiv: 1805.04084



- Observed N_{coll} -scaling for high p_T photons
 - ✓ Dominated by initial hard scatterings
 - Attempt to translate N_{coll} to $dN_{\text{ch}}/d\eta$ for different energy systems
 - ✓ Introduction of $\sqrt{s_{NN}}$ dependent constant
- $\rightarrow N_{\text{coll}}(\sqrt{s_{NN}}) = (dN_{\text{ch}}/d\eta)^{1.25}$

NORMALIZED SPECTRA BY $(dN_{ch}/d\eta)^{1.25}$

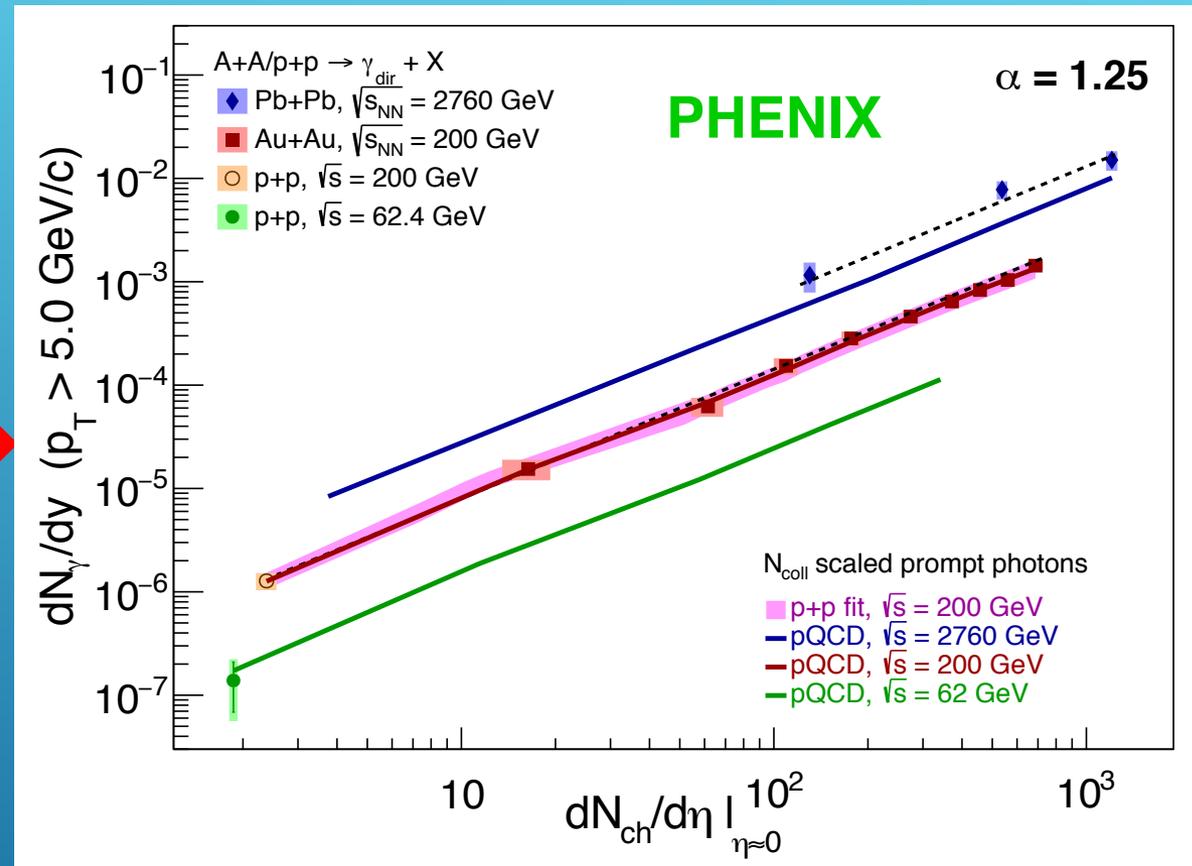
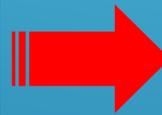
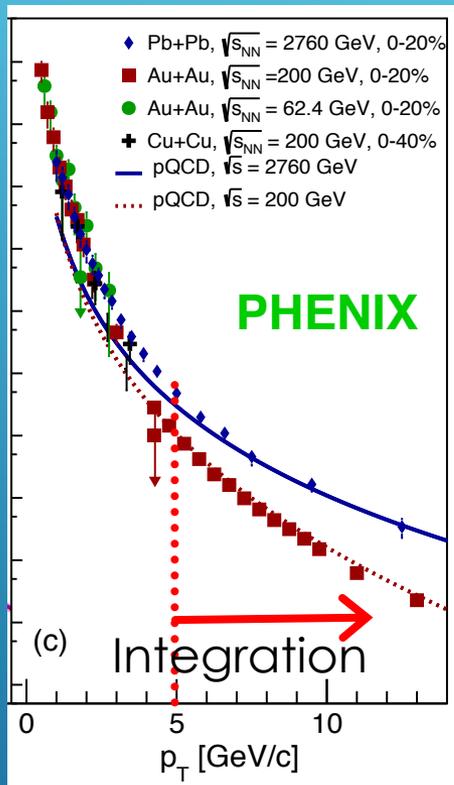
arXiv: 1805.04084



- Normalization by $(dN_{ch}/d\eta)^{1.25}$ for different centralities & $\sqrt{s_{NN}}$ data
 - ✓ High p_T : separation by $\sqrt{s_{NN}}$
 - ✓ Low p_T : surprisingly consistent for all centralities & $\sqrt{s_{NN}}$

dN_γ/dy FOR $p_T > 5 \text{ GeV}/c$

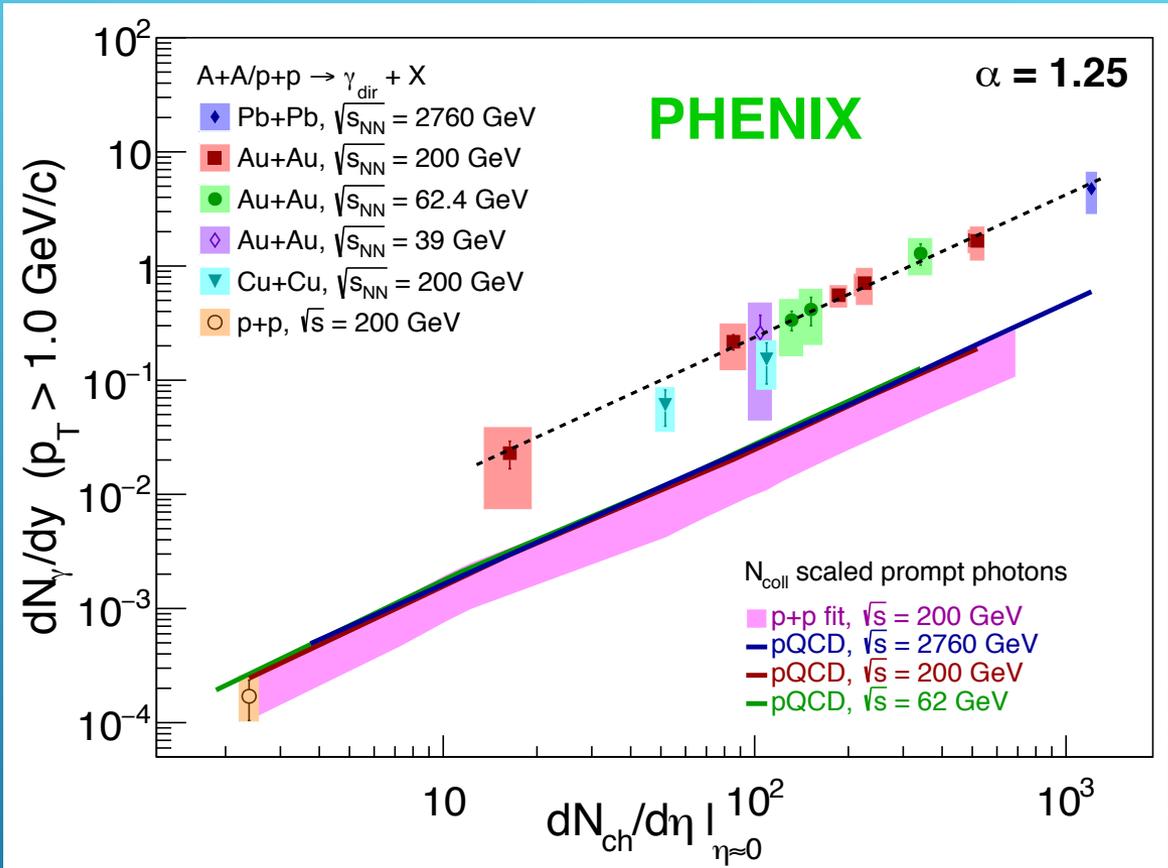
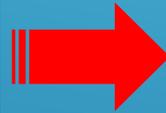
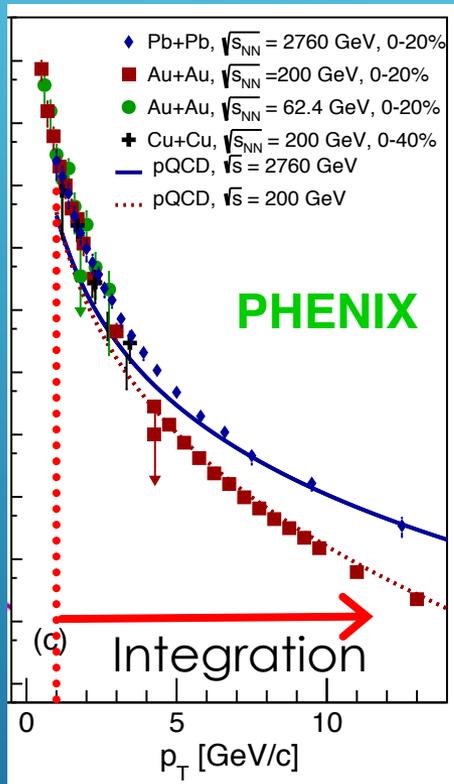
arXiv: 1805.04084



- Integrated yield for $p_T > 5 \text{ GeV}/c$
 - ✓ Dominated by hard photons
 - ✓ Larger yields with higher $\sqrt{s_{NN}}$, but same trend with $dN_{ch}/d\eta$

dN_γ/dy FOR $p_T > 1 \text{ GeV}/c$

arXiv: 1805.04084

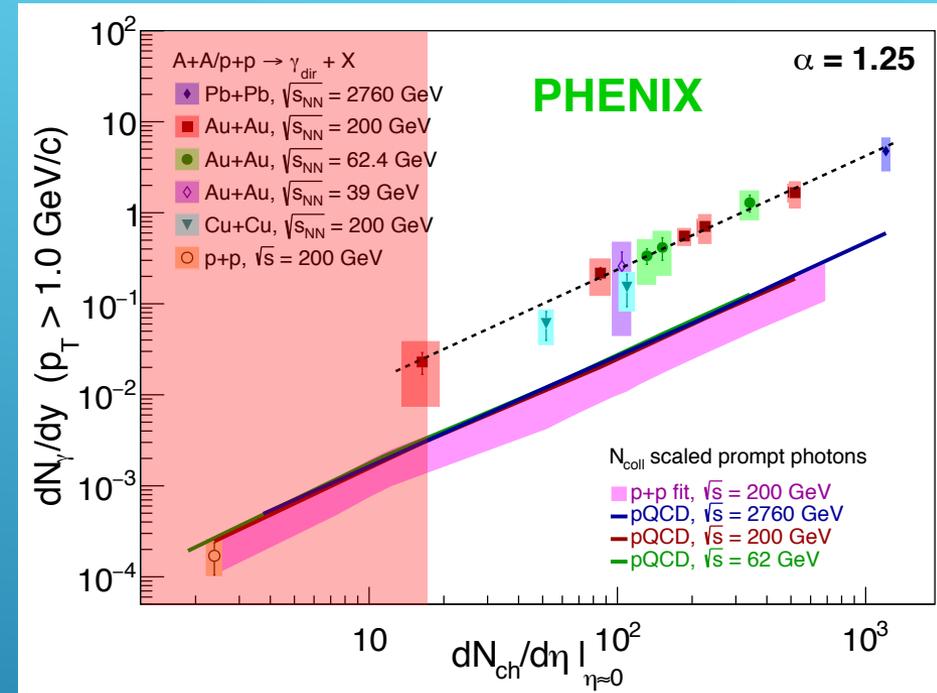
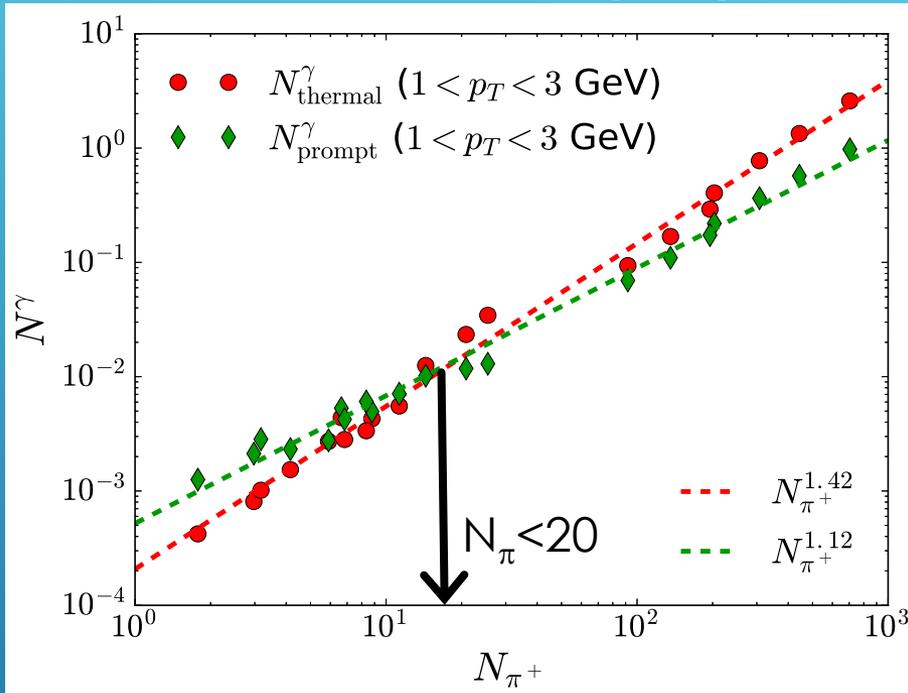


- Integrated yield for $p_T > 1 \text{ GeV}/c$
 - ✓ Dominated by thermal photons
 - ✓ Unique scaling with $dN_{ch}/d\eta$ for all HI data
 - Large contribution near phase transition to HG ?

DOES TRANSITION POINT EXIST?

PRC95, 014906 (2017)

arXiv: 1805.04084

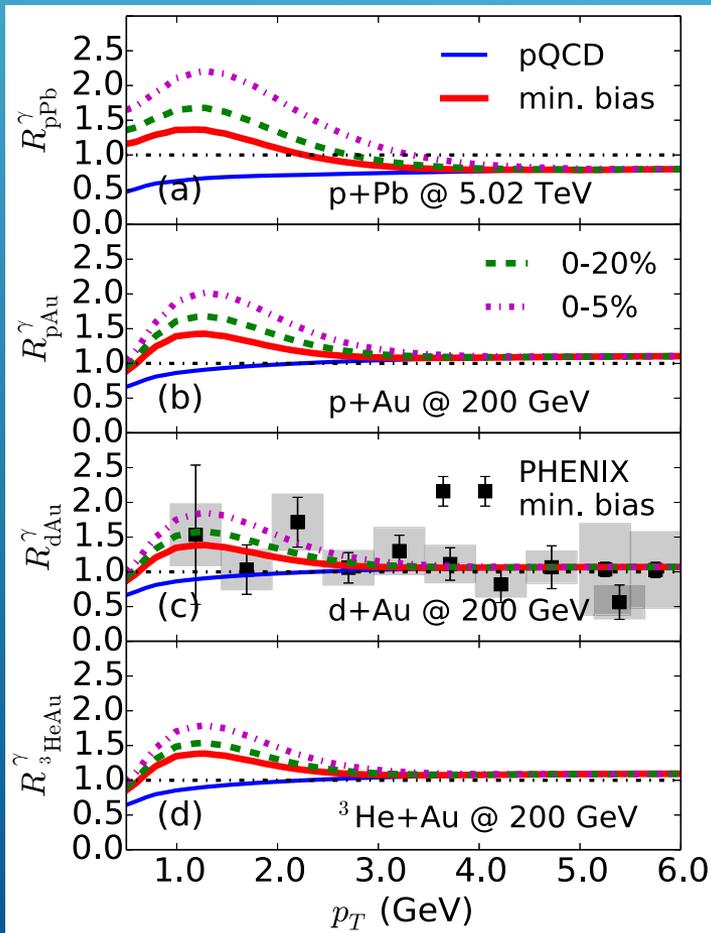


- Theory calculation predicts unique multiplicity scaling of thermal photons as well.
 - ✓ Expected transition at $N_{\pi^+} < 20$
 - No data point so far
 - ✓ Different slopes for thermal and hard photons
 - Same slope in data

QGP FORMATION IN SMALL SYSTEM?

- Experimental results suggesting collective motion in small systems with high multiplicity
- Possible formation of QGP even in small systems

PRC95, 014906 (2017)



- Thermal photons as an evidence of QGP formation in small systems
- Theoretical prediction of thermal enhancement:

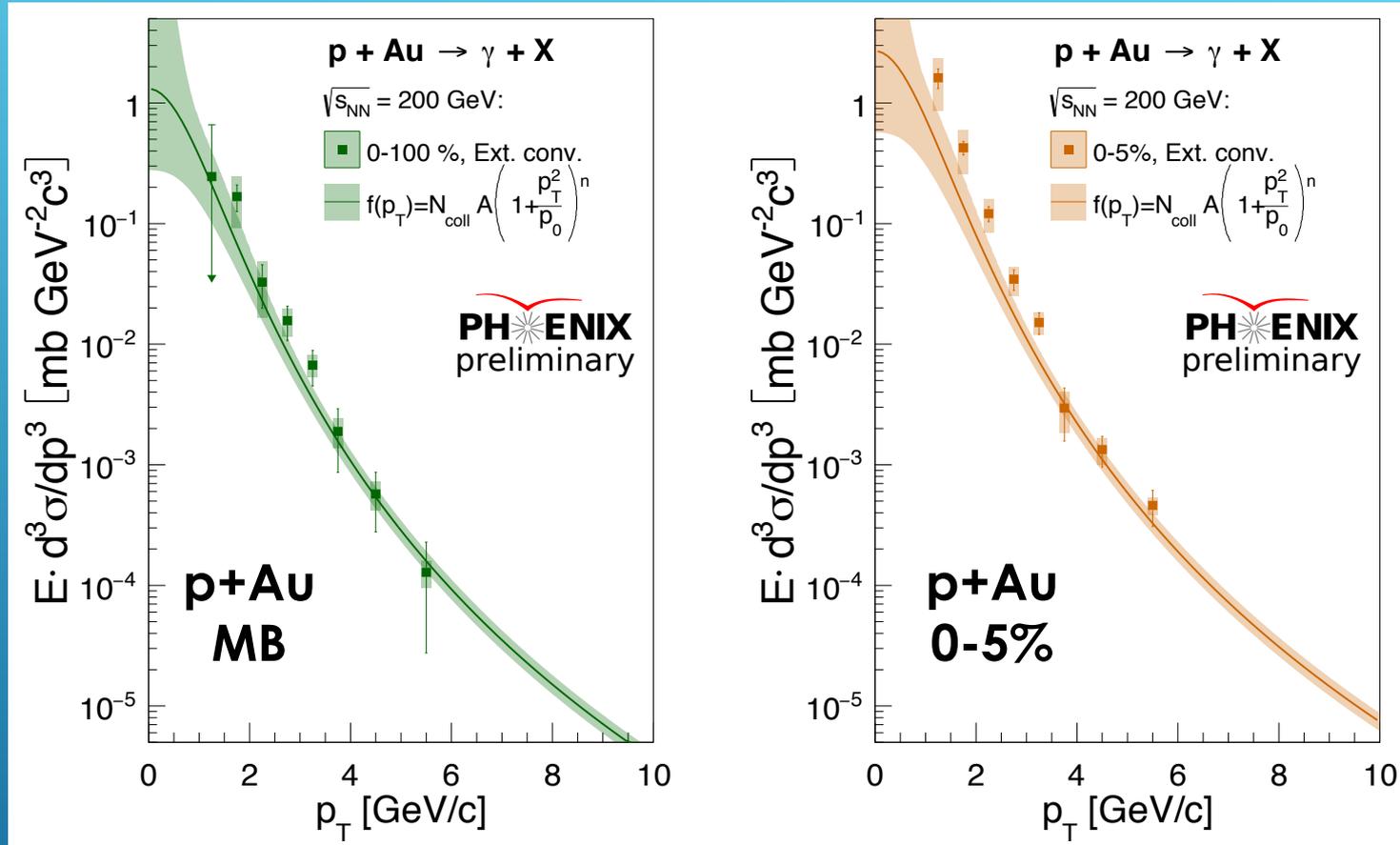
$$\checkmark R_{\gamma_{XX}}^{\gamma} = \gamma_{XX}^{\text{dir}} / (N_{\text{coll}} \times \gamma^{\text{hard}})$$

- Less visibility at larger systems

$$- R_{\gamma_{\text{pPb}}}^{\gamma} > R_{\gamma_{\text{pAu}}}^{\gamma} > R_{\gamma_{\text{dAu}}}^{\gamma} > R_{\gamma_{\text{HeAu}}}^{\gamma}$$

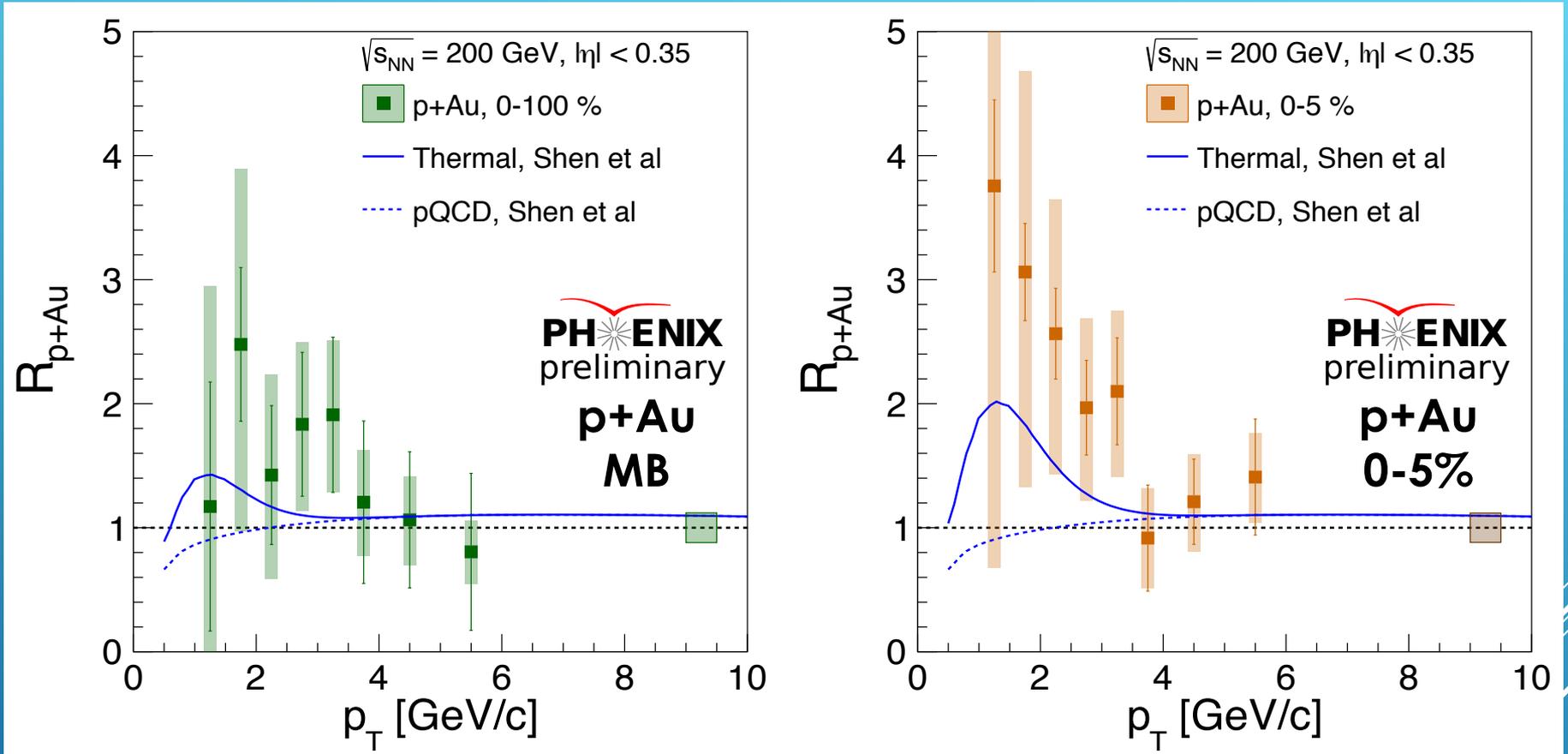
- Available 0-5% & MB p+Au data at RHIC energy

DIRECT PHOTONS IN p+Au



- Successful measurement for MB & 0-5% in p+Au
 - ✓ MB: consistent with binary-scaled p+p baseline
 - Same for d+Au MB
 - ✓ 0-5%: enhancement over binary-scaled p+p baseline

THEORY COMPARISON OF p+Au PHOTONS



- Consistent with theory calculations for both MB & 0-5%, but not conclusive.
 - ✓ Need more data for systematic study in small systems

SUMMARY

- Enhanced yield and a large v_2 of the direct photon in the low p_T region
 - ✓ Photon puzzle: no model can reproduce both yield & v_2 simultaneously so far
 - Unique scaling with respect to $dN_{ch}/d\eta$ for all HI results with a wide range of $\sqrt{s_{NN}}$
 - ✓ Possible explanation by a large photon production near the phase transition to Hadron
 - Observation of enhanced photons in 0-5% p+Au
 - ✓ Positive indication for QGP formation in small system
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