PHENIX beam energy and centrality dependence of direct photon emission in heavy ion collisions

Vlad Khachatryan* for PHENIX Collaboration
Department of Physics and Astronomy, Stony Brook University, Stony Book, 11794 NY, USA
* presented by Axel Drees

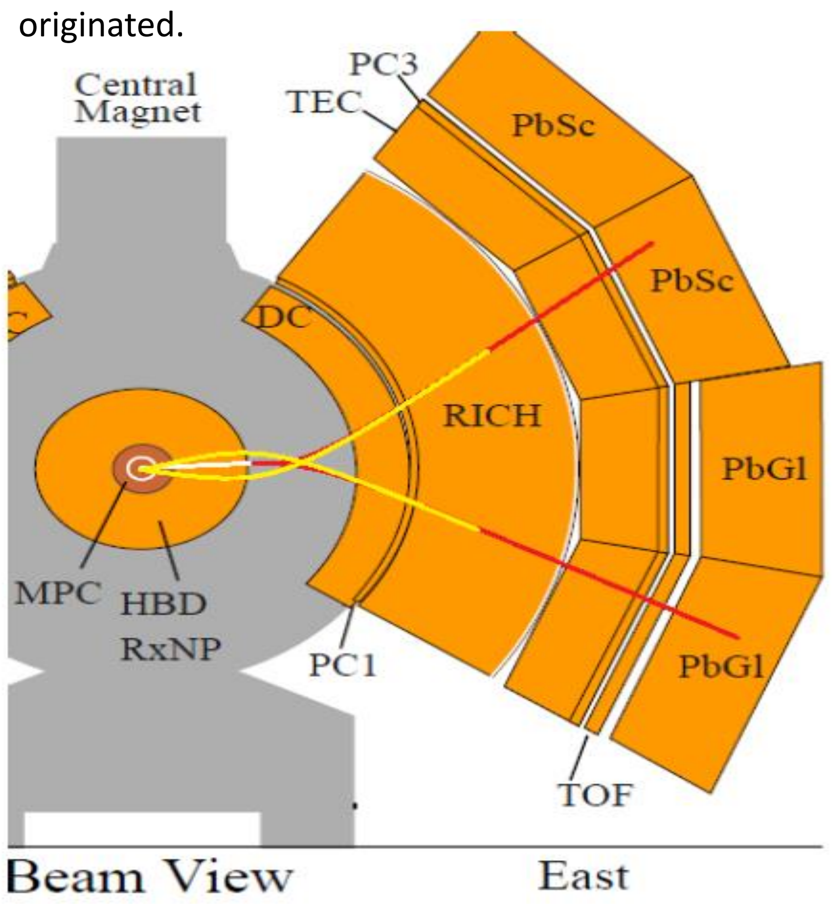
Abstract ①

Direct photon measurements provide a unique tool to study the strongly coupled QGP produced in heavy ion collisions and its evolution to hadron resonance matter. PHENIX has observed that a large number of direct photons are radiated during the evolution of the system created in Au+Au collision at 200 GeV, and that the photons are emitted with a large azimuthal anisotropy. PHENIX presents new data from 39, 62.4, and 200 GeV Au+Au collisions and from Cu+Cu collisions at 200 GeV. We find that the direct photon yield $dN_\gamma/d\eta$ is proportional to $(dN_{ch}/d\eta)^\alpha$. This new scaling behavior holds for beam energies measured at RHIC and LHC, for centrality selected samples, as well as for different collision systems.

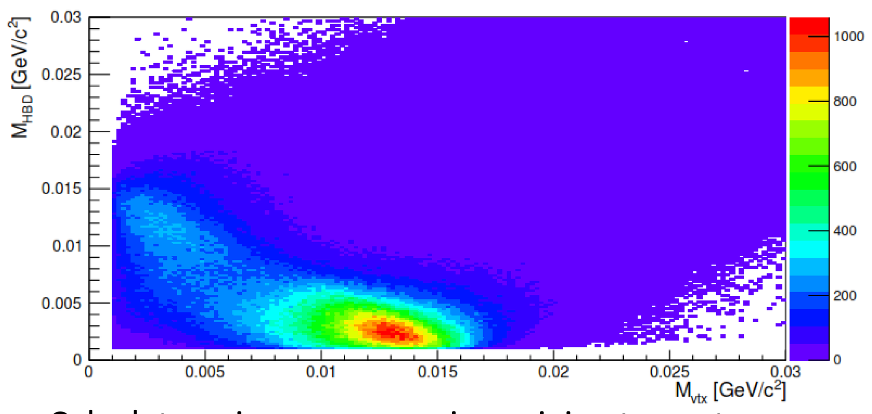
Direct Photon Measurement Techniques in PHENIX ②

Raw inclusive photon yield N_γ^{incl} measured through photon conversions to e^+e^- pairs.

External conversion in HBD:
Illustration of tracking assuming where the e^+e^- pair originated.

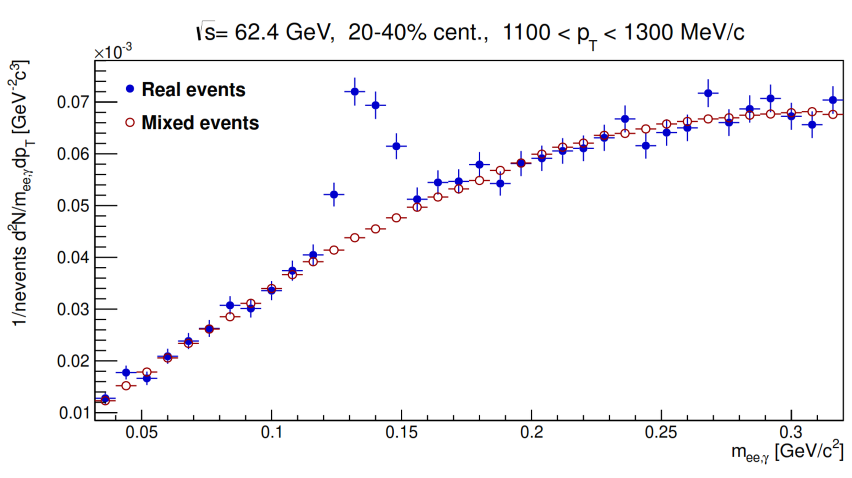


Use conversions that occurred in the readout boards (backplane) of Hadron Blind Detector (HBD) located at a radius of about 60 cm from the event vertex.



Calculate pair mass assuming origin at event vertex (M_{vtx}) and HBD readout boards (M_{HBD}). 2D cut creates photon sample with 99% purity.

Subset of e^+e^- pairs is tagged as π^0 ($N_\gamma^{\pi^0 tag}$) with photon measured in EMCal.



Example of invariant $e^+e^-\gamma$ mass distribution.

Measuring R_γ with the Double Ratio for Au+Au Direct Photon Data at 200 GeV, 62.4 GeV, 39 GeV ③

Cancelation of systematic uncertainties in R_γ

$R_\gamma > 1$ if the direct photons are present in data sample.
$R_\gamma = 1$ if all the photons originate from hadronic decays.

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

From DATA

e^+e^- pair efficiency — e^+e^- pair acceptance

$$N_\gamma^{incl}(p_T) = \varepsilon_{ee} a_{ee} c\, \gamma^{incl}(p_T)$$
$$N_\gamma^{\pi^0,tag}(p_T) = \varepsilon_{ee} a_{ee} c \langle \varepsilon_\gamma f\rangle \gamma^{\pi^0}(p_T)$$

Probability (conversion) factor — Photon efficiency — Conditional acceptance

From SIMULATION

$$N_\gamma^{had}(p_T) = a_{ee}\gamma^{had}(p_T)$$
$$N_\gamma^{\pi^0,tag}(p_T) = f N_\gamma^{\pi^0} = a_{ee} f \gamma^{\pi^0}(p_T)$$

The ratio in the denominator of the R_γ formula is called *cocktail ratio*, and it is the ratio of hadronic decay photons to those from π^0 decays.

In the measured ratio of $N_\gamma^{incl}/N_\gamma^{\pi^0,tag}$ the p_T-dependent factors c, ε_{ee} and a_{ee} cancel explicitly at each p_T^{ee} bin, except for the conditional acceptance $\langle\varepsilon_\gamma f\rangle$.

From SIMULATION

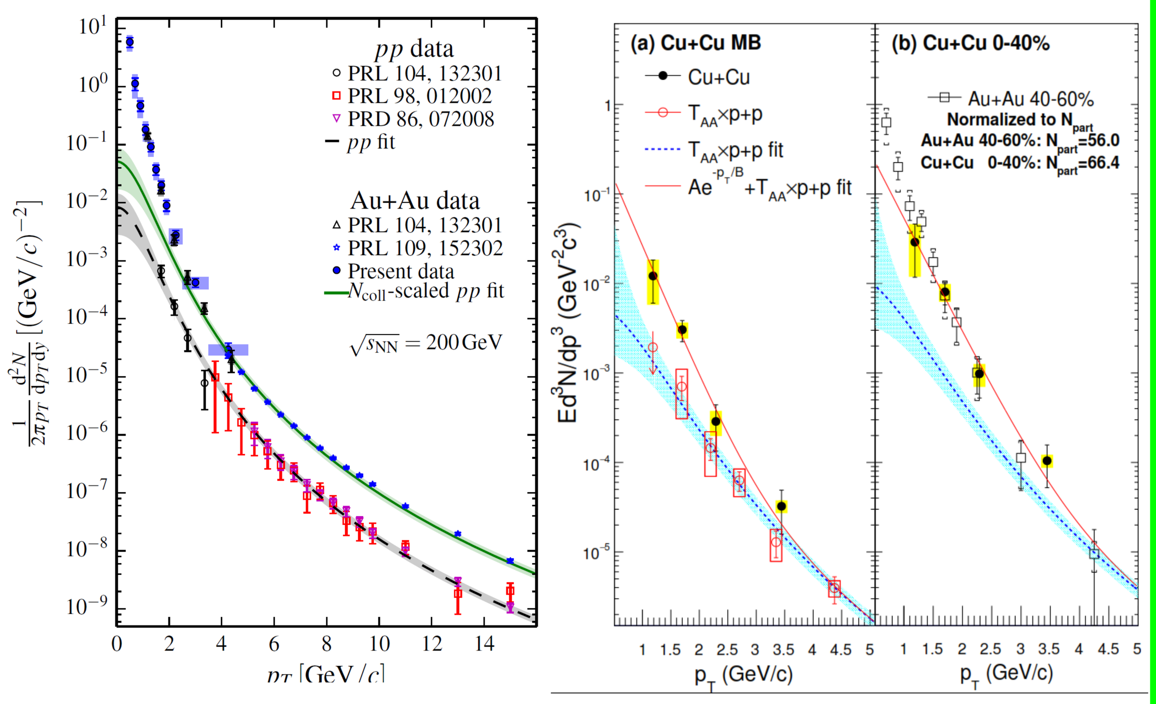
$\langle \varepsilon_\gamma(p_T) f(p_T)\rangle$

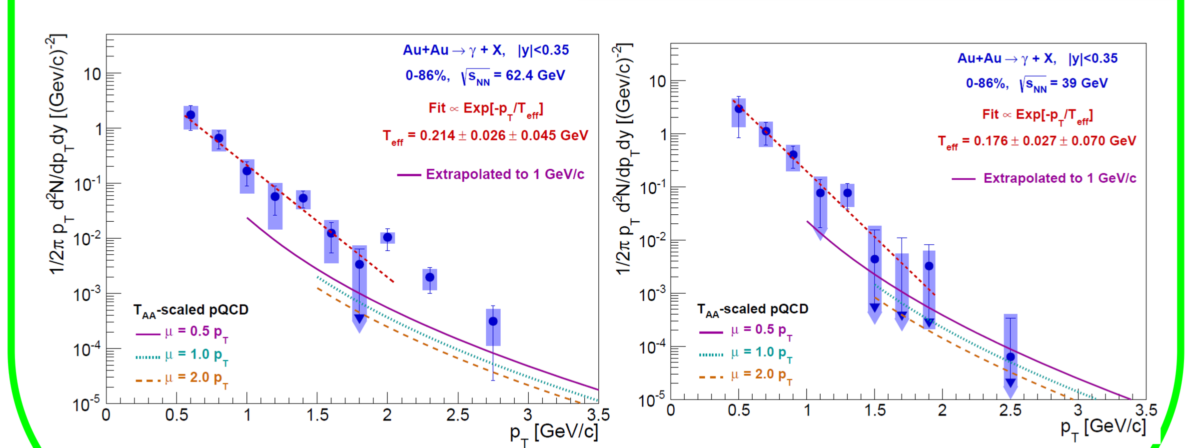
$\langle\varepsilon_\gamma f\rangle$: f is the *conditional acceptance* of having the second photon from a π^0 decay in the EMCal acceptance, given that the e^+e^- is reconstructed. The probability to reconstruct the second photon is ε_γ. The product $\varepsilon_\gamma f$ is averaged over all possible p_T values of the second photon.

Direct Photon p_T Spectra in PHENIX ④

Au+Au min. bias at 200 GeV, 62.4 GeV, and 39 GeV
Cu+Cu min. bias and 0-40% centrality at 200 GeV

Invariant Yield = $(R_\gamma - 1)\cdot\gamma^{had}$

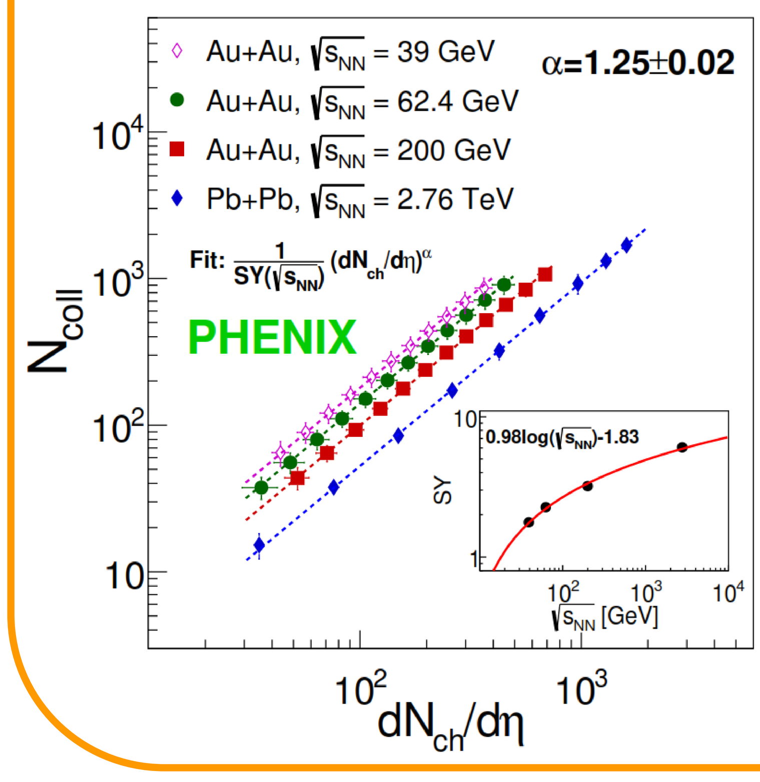




Summary ⑦

- The low p_T photon excess in A+A compared to p+p, which is often associated with thermal radiation, scales with N_{coll} at a given $\sqrt{s_{NN}}$ for all centrality selections.
- This scaling at low p_T can be generalized to $\sqrt{s_{NN}}$ from 39 to 2760 GeV if the yield is scaled by the charge particle density to the ~5/4 instead of N_{coll}.
- At p_T below 2 GeV/c we find a universal direct photon spectrum with common slope and yield/Nch independent of $\sqrt{s_{NN}}$, centrality and collision system.
- The rapidity density of charged particles, and with it the number of quark participants, is proportional to Ncoll to a power ~4/5 with a proportionality constant that increases logarithmically with center of mass energy.

Scaling of Number of Binary Collisions with Charged Hadron Multiplicity ⑤



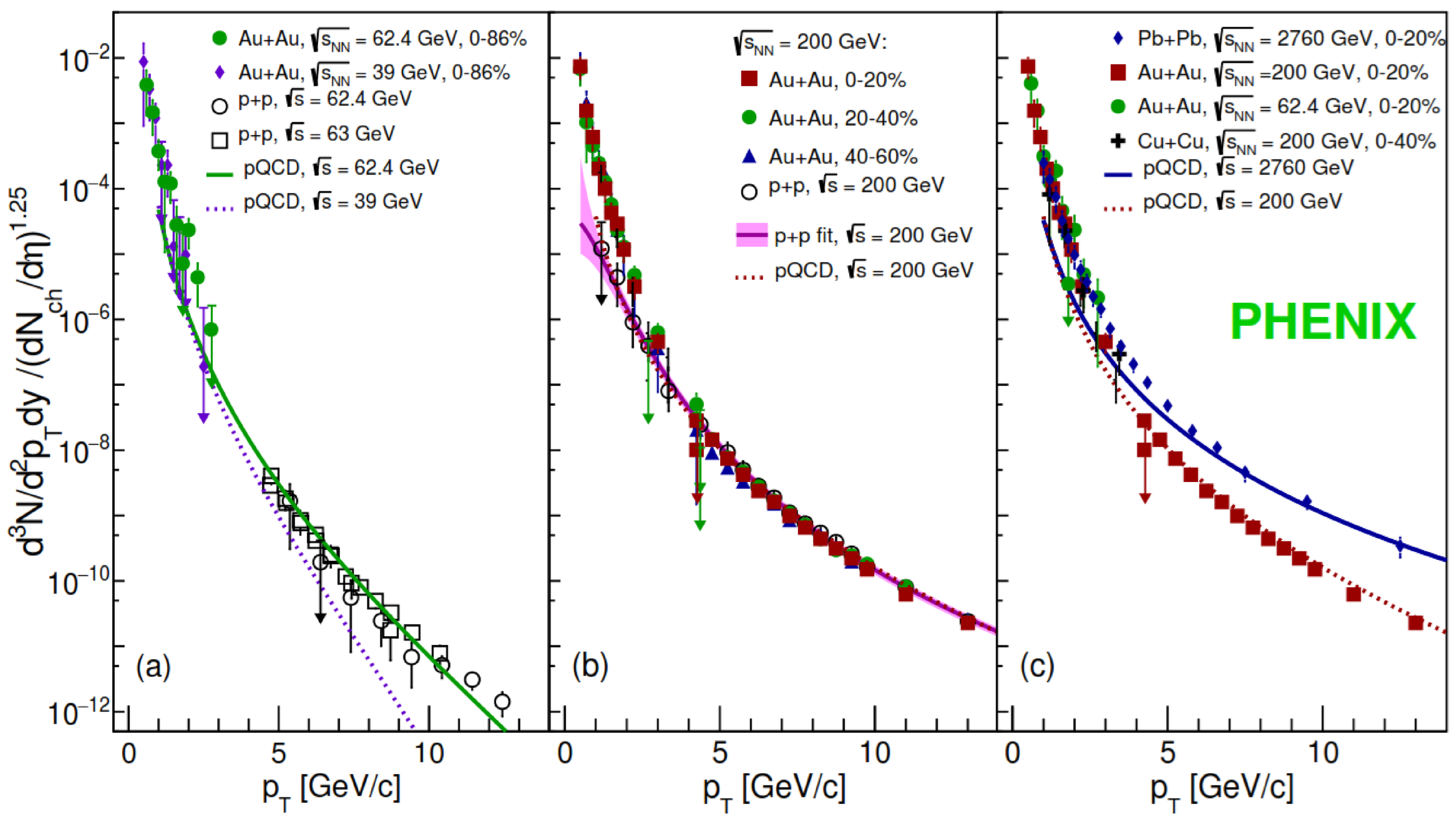
$$N_{coll} = \frac{1}{SY(\sqrt{s_{NN}})}\left(\frac{dN_{ch}}{d\eta}\right)^\alpha$$

The specific yield SY is a function of $\sqrt{s_{NN}}$:

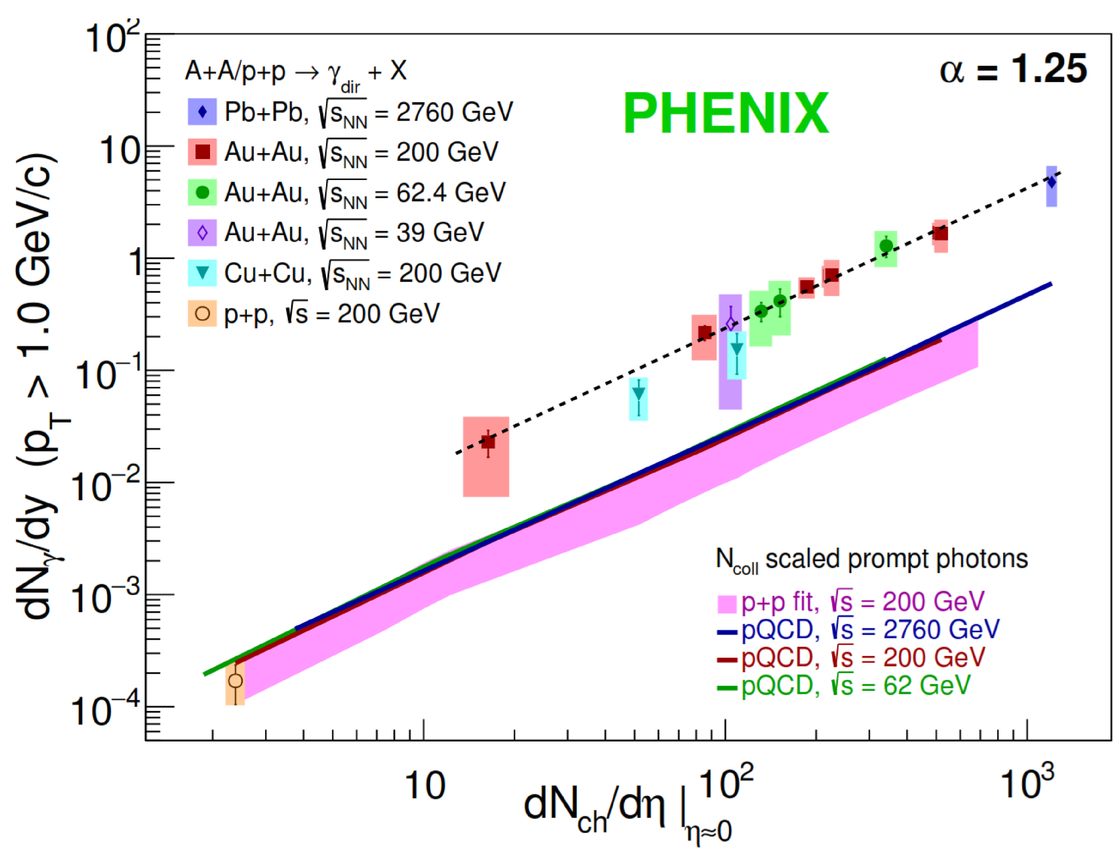
$$SY(\sqrt{s_{NN}}) = c_1\log(\sqrt{s_{NN}}) - c_2$$

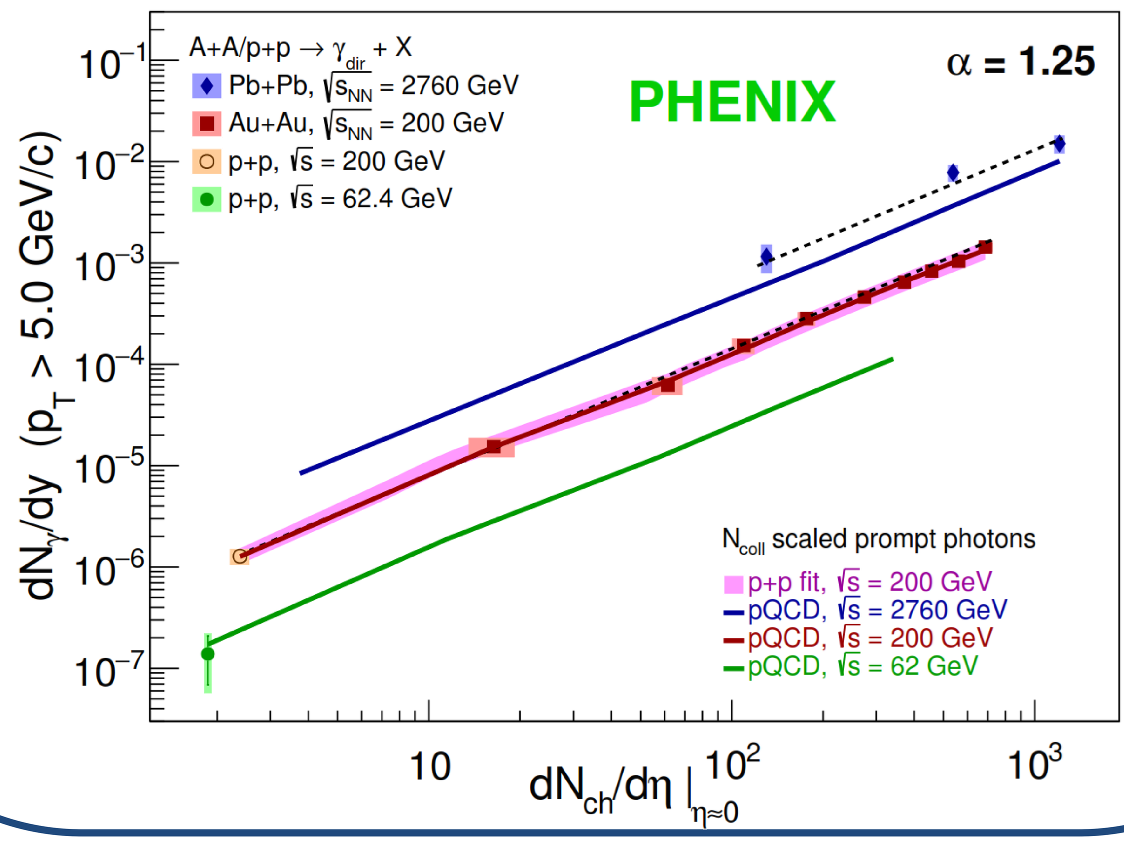
Direct Photon Scaling ⑥

PHENIX direct photon p_T spectra normalized by $(dN_{ch}/d\eta)^\alpha$, where α= 1.25
ALICE data of Pb+Pb at 2760 GeV and ISR data of p+p at 62.4 GeV
pQCD calculations are from Jean-Francois Paquet



Integrated direct photon PHENIX data above p_T = 1.0 GeV/c and p_T = 5.0 GeV/c





Vladimir.Khchatryan@stonybrook.edu