Center for Frontiers in Nuclear Science

Stony Brook University

Low p_T direct photon production at RHIC measured with PHENIX

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PHENIX

QM QUARK MATTER KRAKÓW 2022

Preview

arXiv : 2203.12345

Low p_T direct — photon production in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV

The measurement of direct photons from Au+Au collisions at $\sqrt{s_{NN}}$ and 62.4 GeV in the transverse momentum range $0.4 < p_T < 3$ GeV/c is presented by the PHENIX collaboration. A significant direct photon yield is observed in both the systems. A universal scaling is observed when the direct photon p_T spectra for the different center of mass energies and for different centrality selection at $\sqrt{s_{NN}} = 62.4$ GeV is scaled with $(dN_{\rm ch}/d\eta)^{\alpha}$ with $\alpha = 1.21 \pm 0.04$. This scaling also holds true for direct photon spectra from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV measured by PHENIX, as well as the spectra from Pb+Pb at $\sqrt{s_{NN}} = 2760$ GeV published by ALICE. It is also demonstrated that the scaling power α seem to be independent of p_T, center of mass energy, and collision centrality. The spectra from different collision energies, have a similar shape up to p_T of 2 GeV/c. They have a local inverse slope T_{eff} increasing with p_T that is 0.174 ± 0.018 GeV/c in the range $0.4 < p_T < 1.3$ GeV/c and increases to 0.289 ± 0.024 GeV/c for $0.9 < p_T < 2.1$ GeV/c. The observed similarity of low p_T direct photon production from $\sqrt{s_{NN}} = 39$ GeV to 2760 GeV suggests a common source of direct photons for the different collision energies and event centrality selections, and that the possible differences in the space time evolution do not alter direct photon emission significantly.

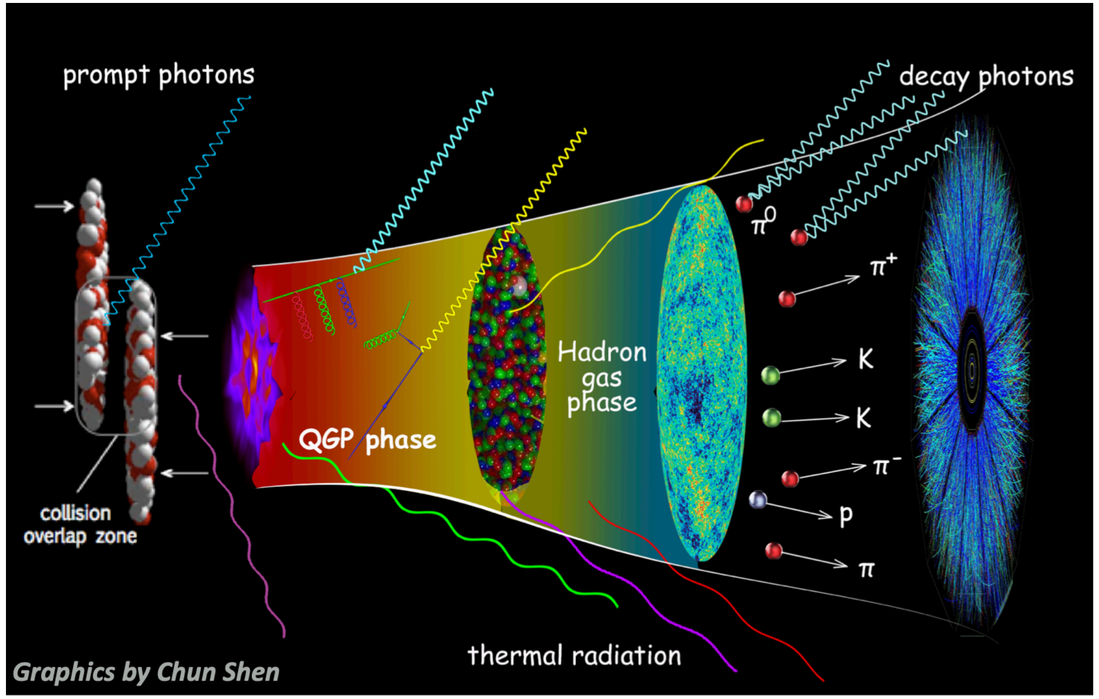
arXiv:2203.17187

Nonprompt direct — photon production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

The measurement of the direct-photon spectrum from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is presented by the PHENIX collaboration using the external-photon-conversion technique for 0%–93% central collisions in a transverse-momentum (p_T) range of 0.8–10 GeV/c. An excess of direct photons, above prompt-photon production from hard-scattering processes, is observed for $p_T < 6$ GeV/c. Nonprompt direct photons are measured by subtracting the prompt component, which is estimated as $N_{\rm coll}$-scaled direct photons from p+p collisions at 200 GeV, from the direct-photon spectrum. Results are obtained for $0.8 < p_T < 6.0$ GeV/c and suggest that the spectrum has an increasing inverse slope from ≈0.2 to 0.4 GeV/c with increasing p_T, which indicates a possible sensitivity of the measurement to photons from earlier stages of the evolution of the collision. In addition, like the direct-photon production, the p_T-integrated nonprompt direct-photon yields also follow a power-law scaling behavior as a function of collision-system size. The exponent, α, for the nonprompt component is found to be consistent with 1.1 with no apparent p_T dependence.

Double differential analysis of the shape of the momentum spectra of direct and non-prompt direct photons and the rapidity density, dN_γ/dy, in p_T and $dN_{ch}/d\eta$

Introduction



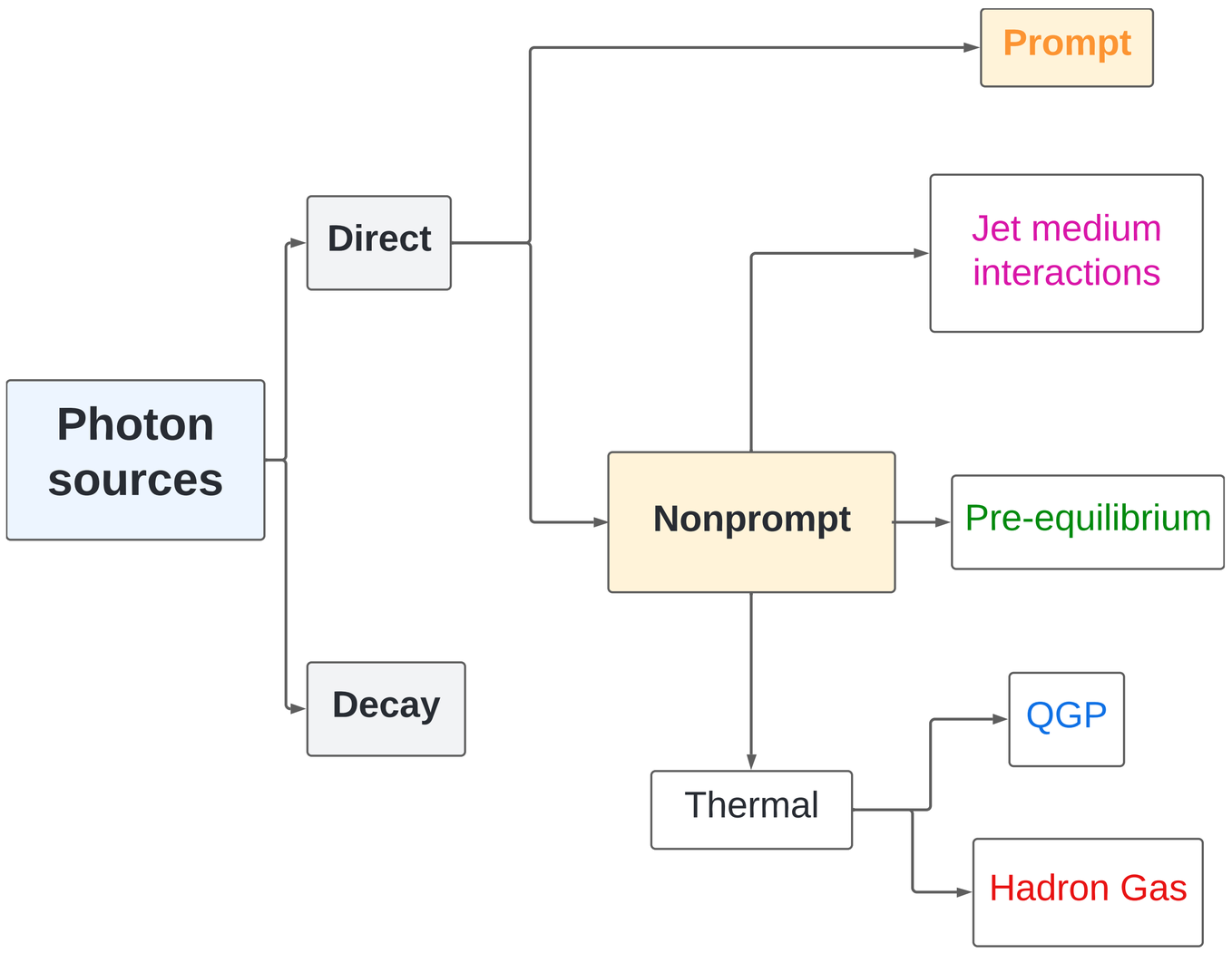
Photons are "color blind" probe of Quark Gluon Plasma

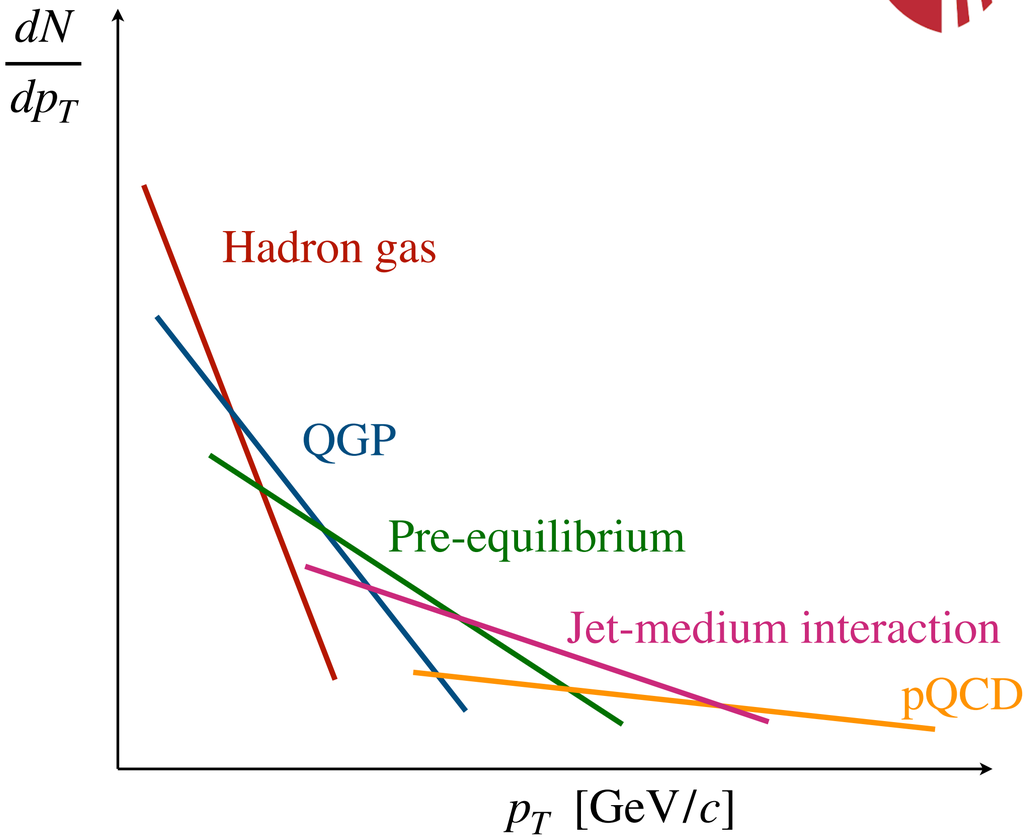
$$\text{Direct photons} = \text{Inclusive photons} - \text{Hadronic decay photons}$$

- Sensitive to **space-time evolution** and **temperature** of matter produced in relativistic heavy-ion collisions
- Evidence of thermal radiations from QGP and Hadron Gas
- 80-90% photons are decay photons

Measurement of yield constrains initial conditions, sources, emission rates and space-time evolution

Introduction





Measurement of the nonprompt direct photons possible due to large statistics

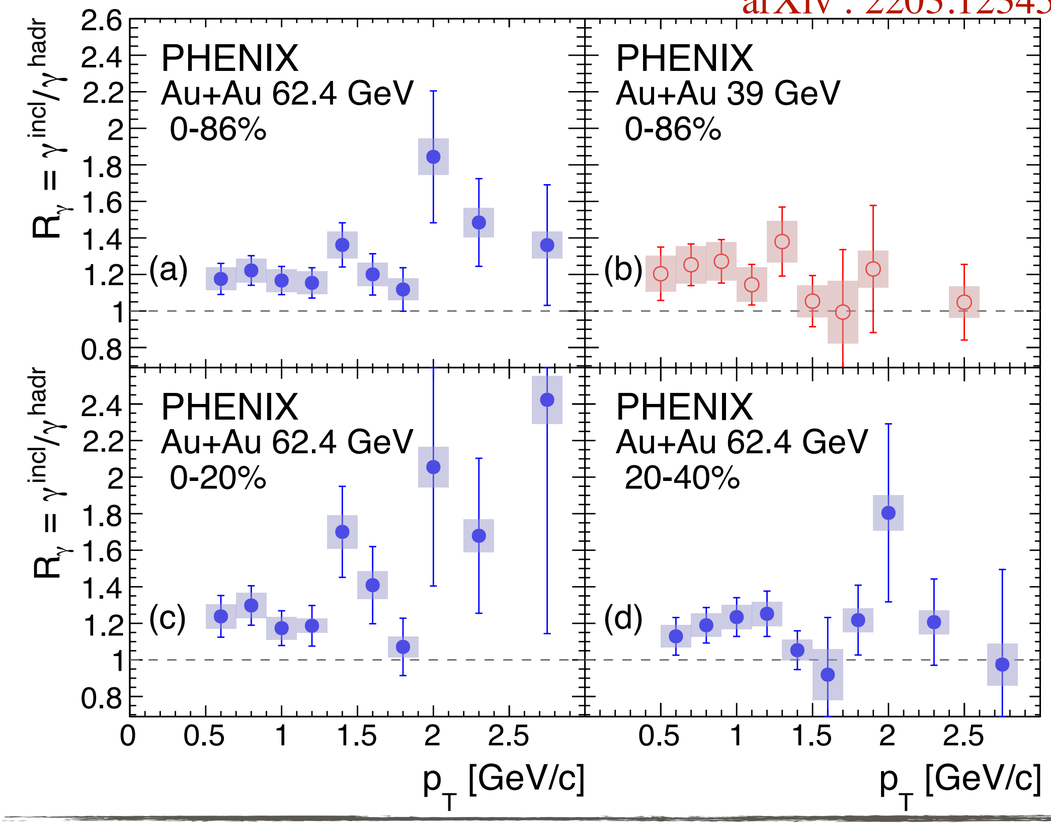
Photon measurements from PHENIX

$\sqrt{s_{NN}}$ [GeV] →	200	200	200	200	200	200	39	62.4	200
Calorimeter	2003		2003						2004
Virtual $\gamma^\star \longrightarrow e^+ + e^-$	2005/6		2008		2005				2004
Conversion $\gamma \longrightarrow e^+ + e^-$	2015	2015	2016	2014		2012	**2010**	**2010**	2007/10 **2014**

Published **Recently submitted** Ongoing

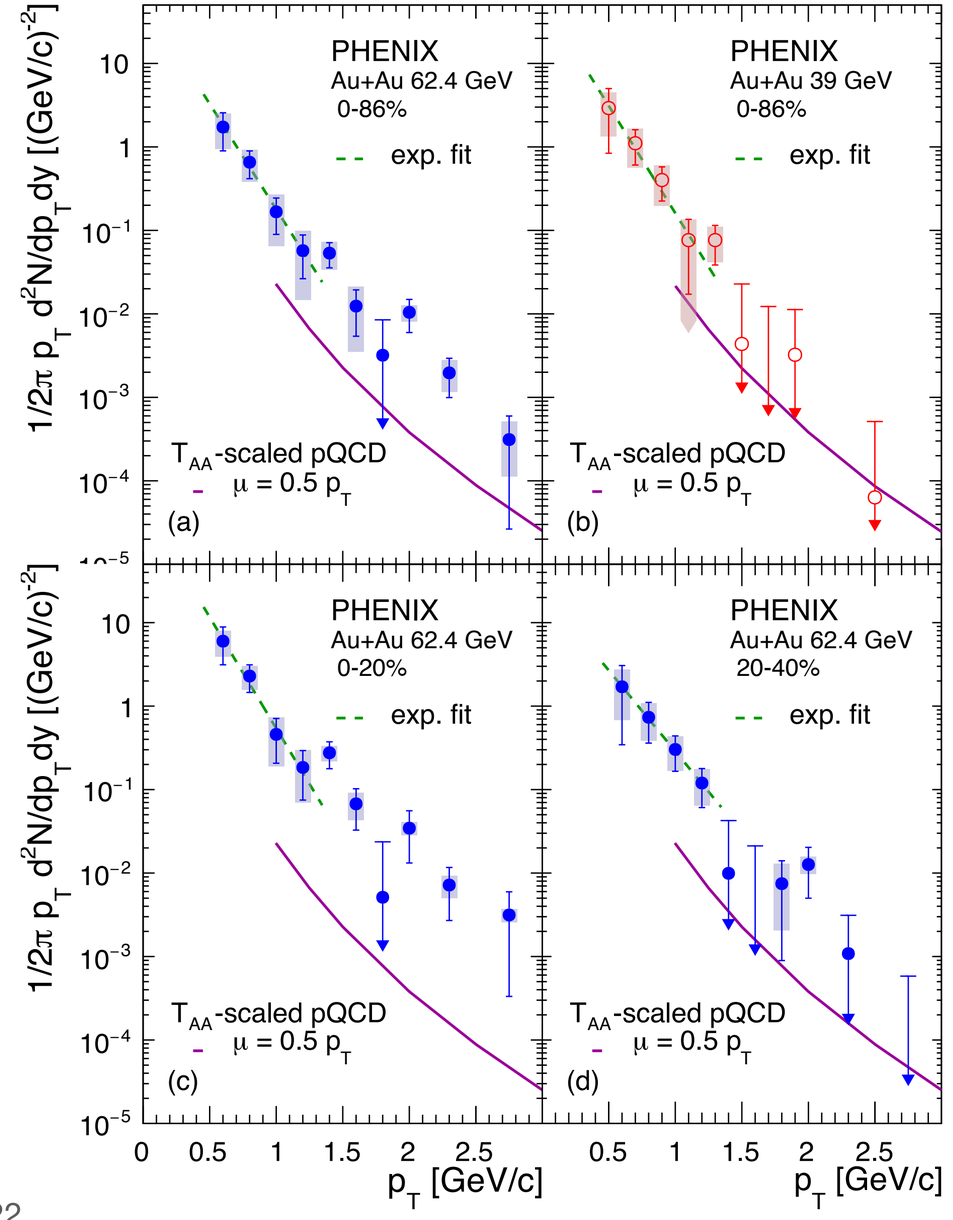
Direct γ for Au+Au at 39 and 62.4 GeV

arXiv : 2203.12345



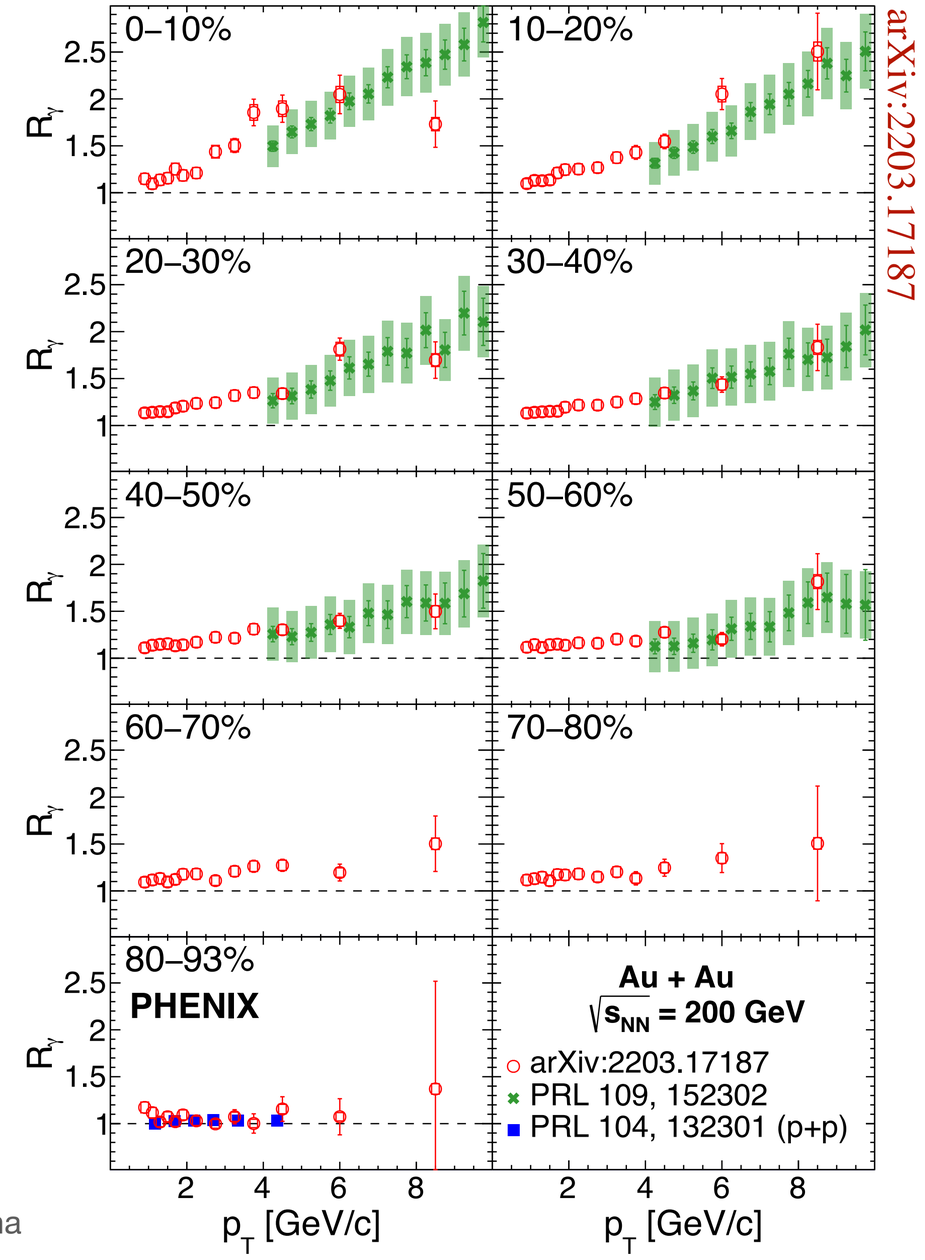
Conversions on the backplane of Hadron Blind detector

Significant direct photon component relative to those from hadron decays

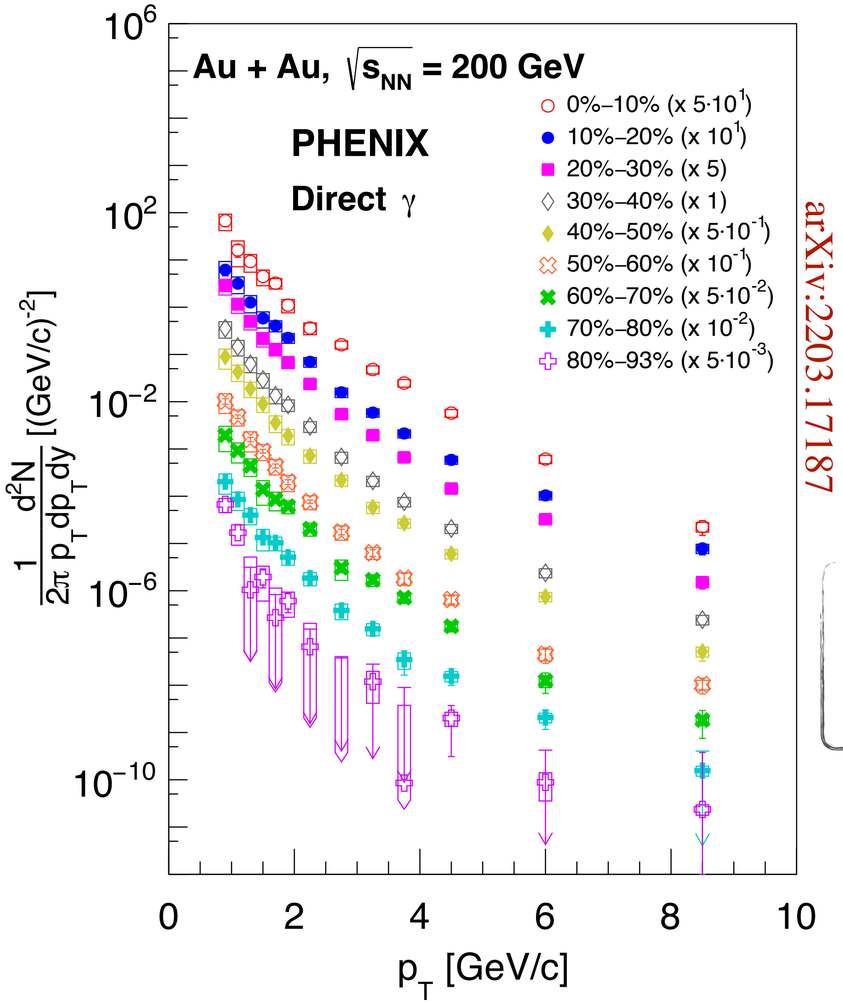


arXiv : 2203.12345

Direct γ for Au+Au at 200 GeV



arXiv:2203.17187



arXiv:2203.17187

Poster by **Wenqing Fan**
Session 2
T13

Conversions in the layers of the Silicon Vertex detectors

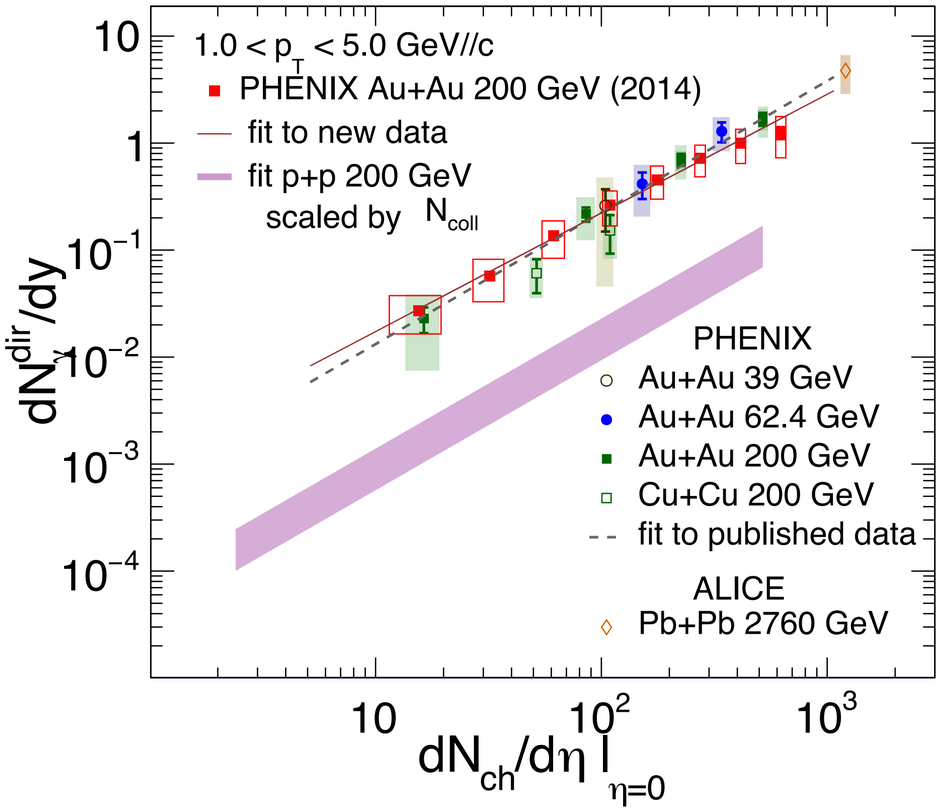
Significantly higher statistics for a more differential measurement

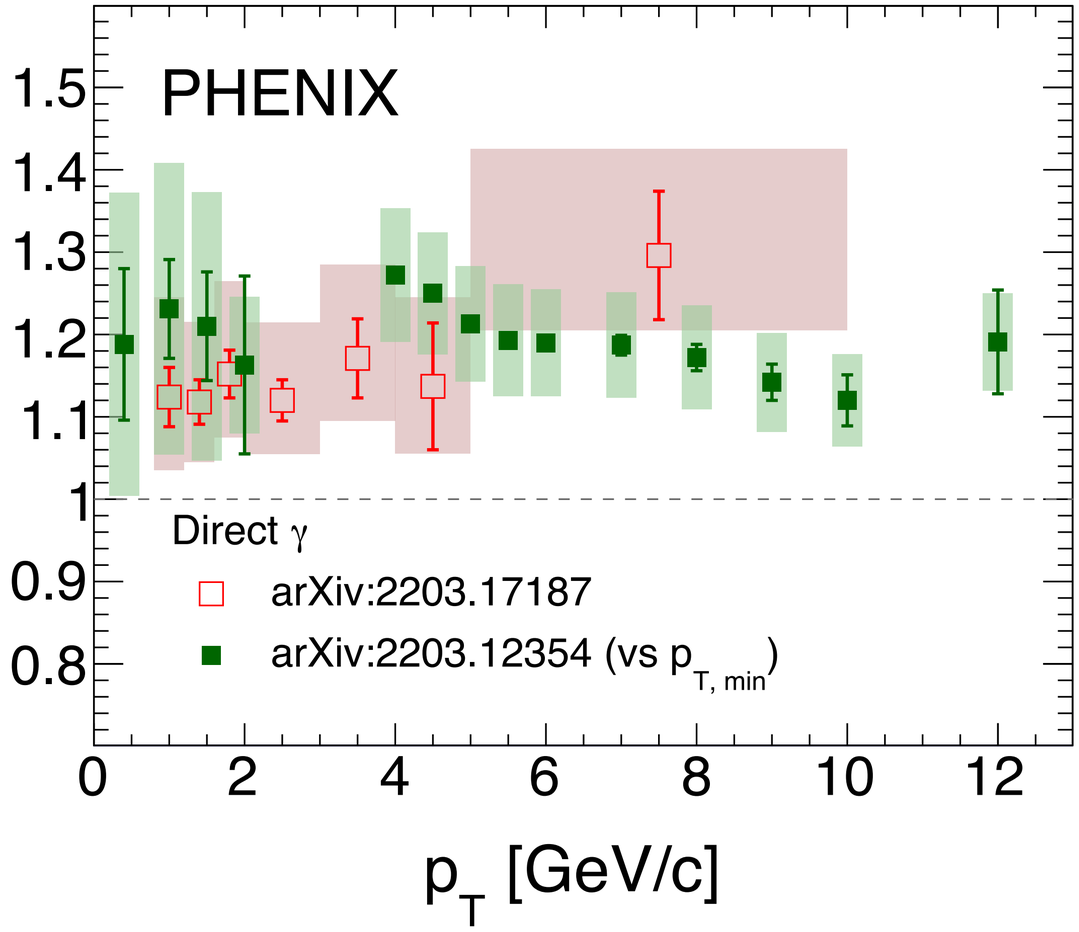
Universal scaling of direct γ yields

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

Universal scaling behavior in all A+A systems

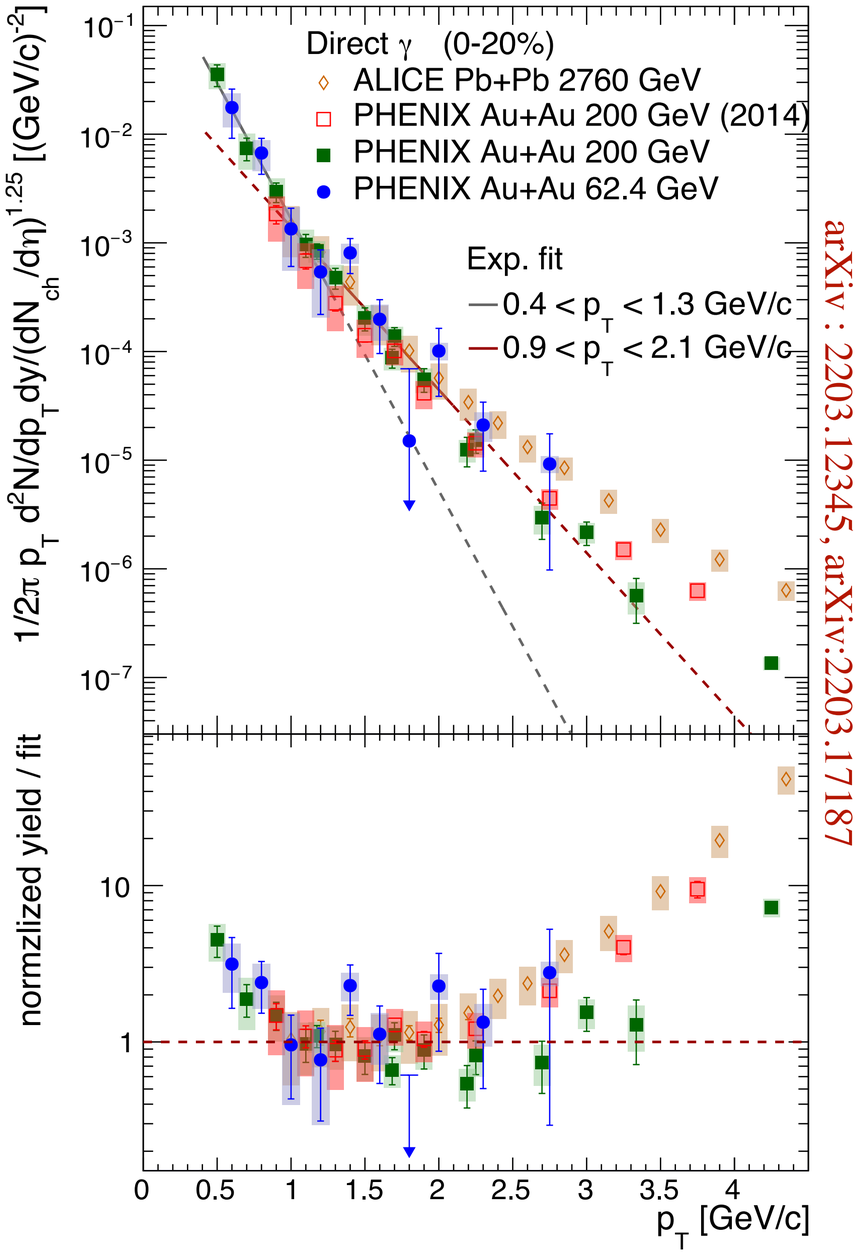
arXiv:2203.17187

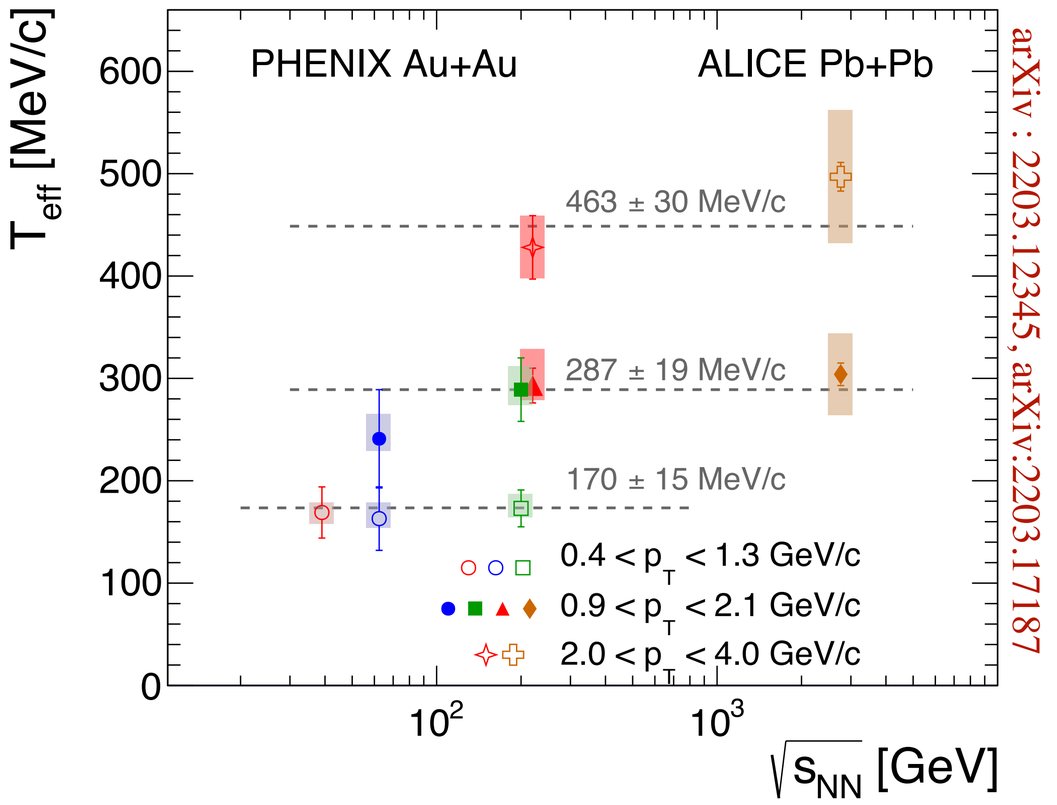




$\alpha > 1$ and independent of p_T

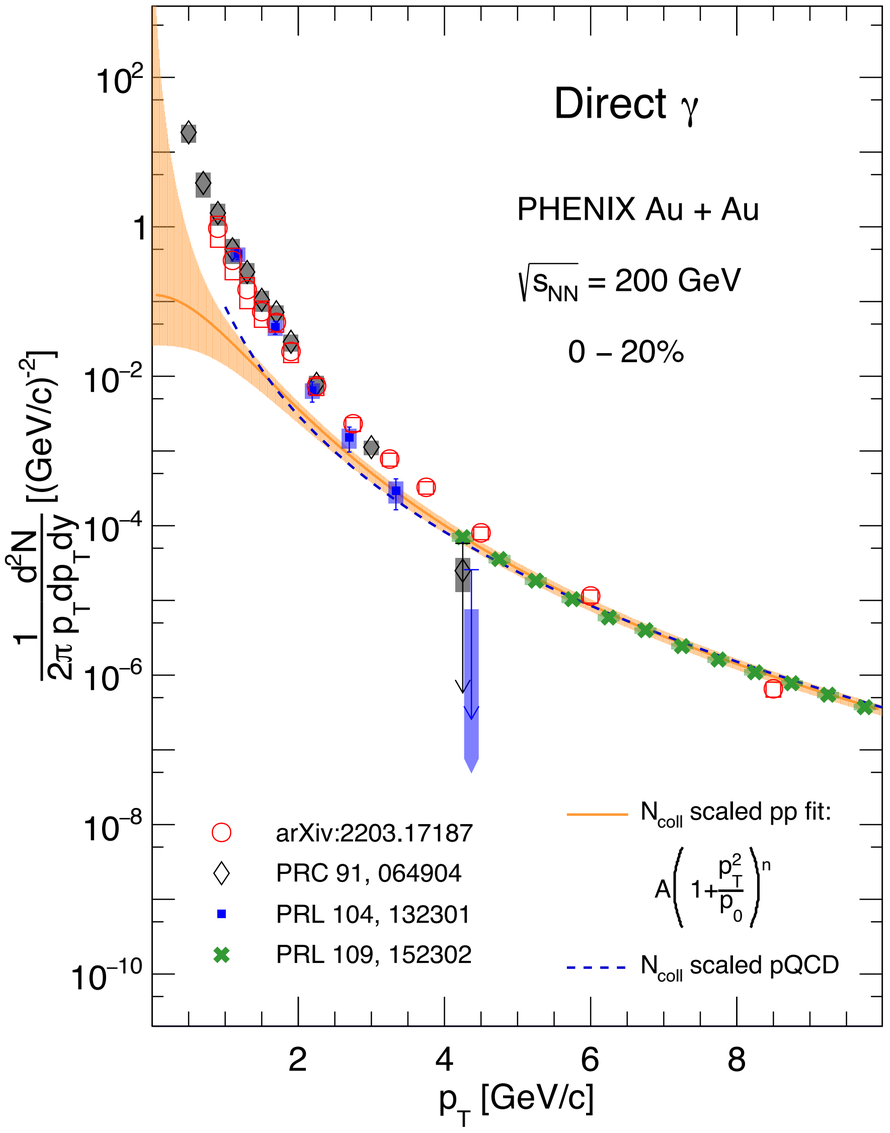
T_{eff} from direct γ





Similar spectra around 2 GeV/c — common source of photon production independent of $\sqrt{s_{NN}}$

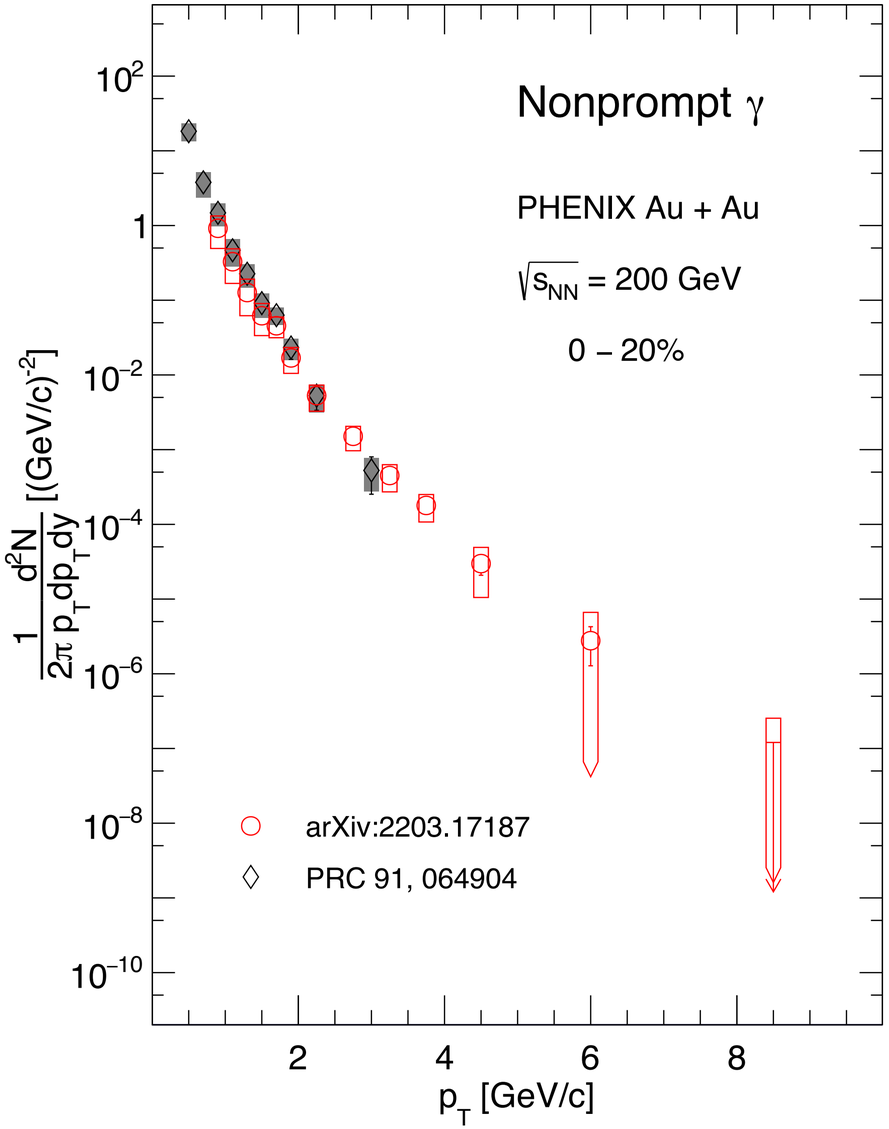
Nonprompt direct photons



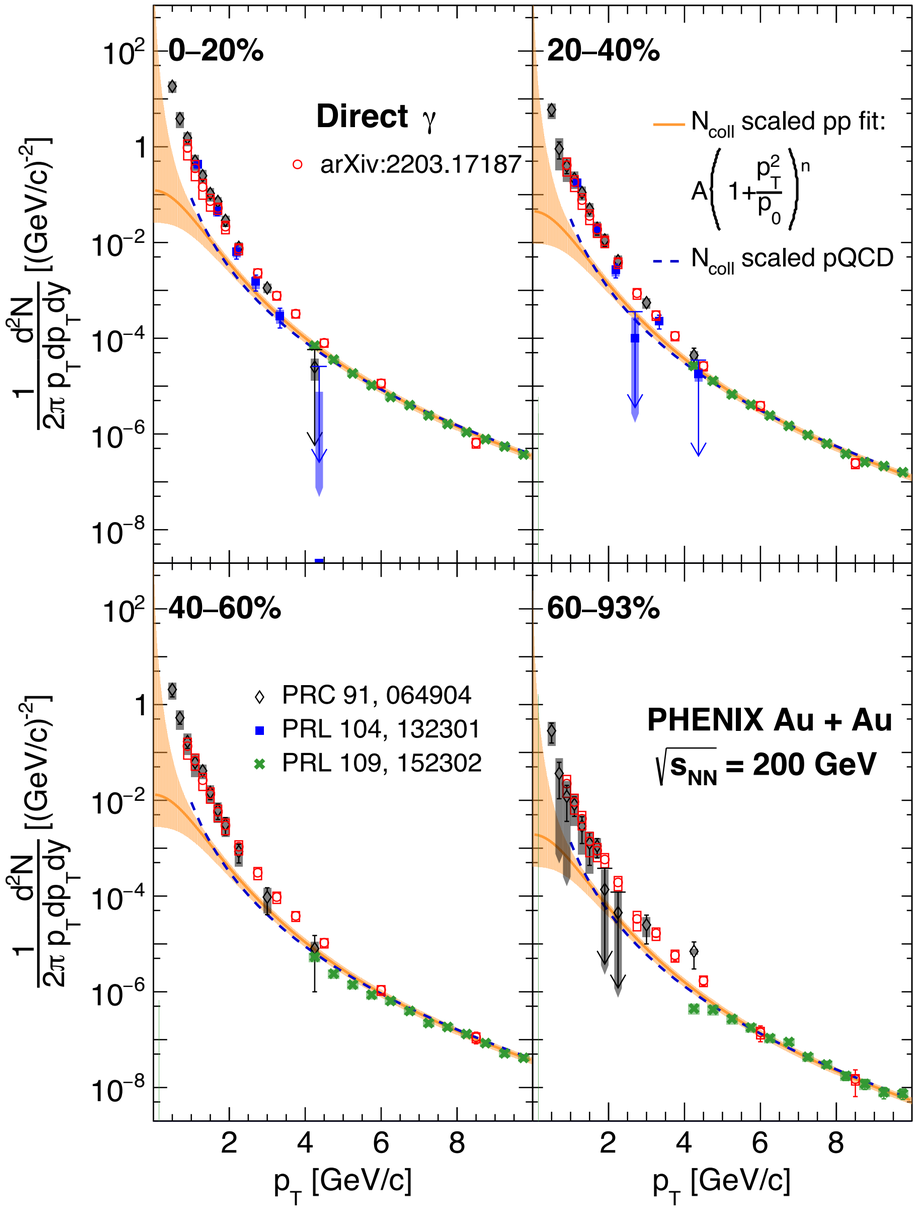
Direct photon

— N_{coll} **scaled p+p fit**

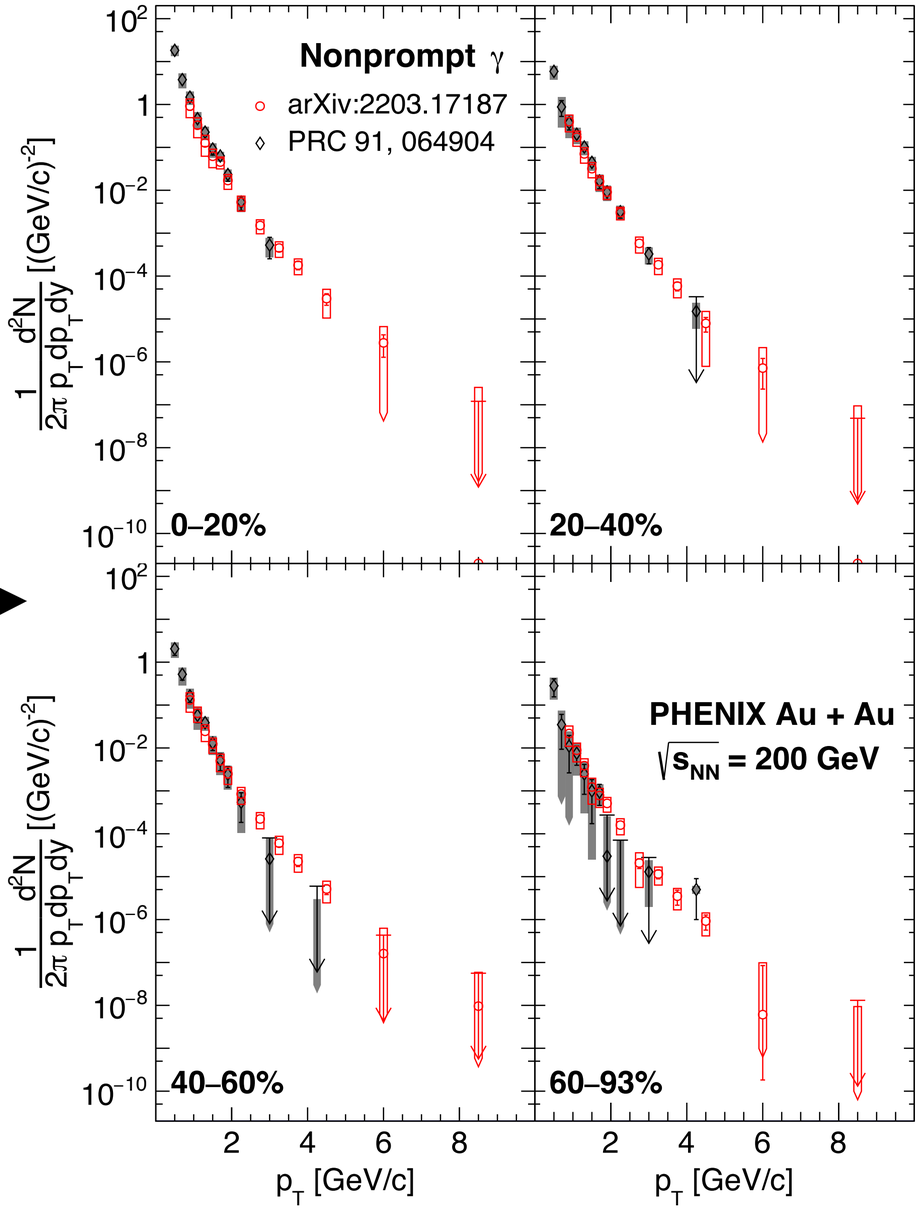
Non-prompt direct photon



Nonprompt direct photons

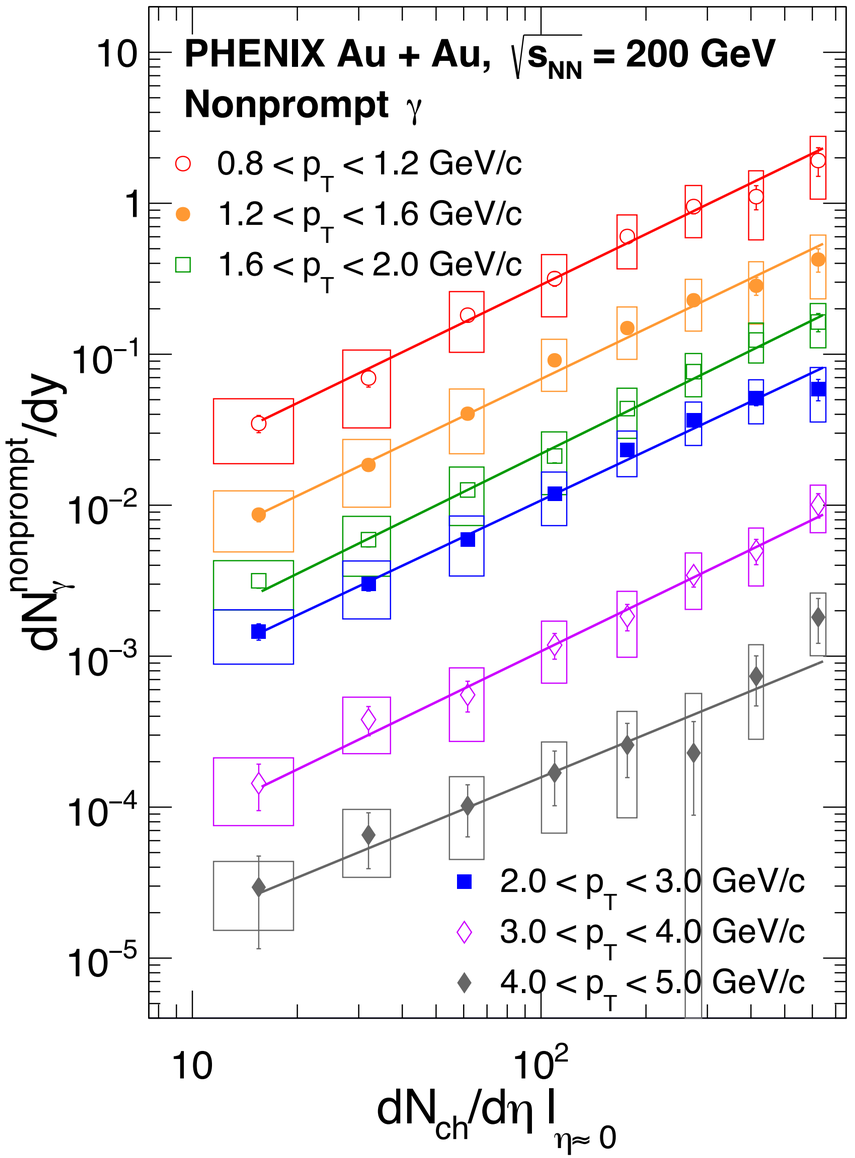


— N_{coll} scaled p+p fit →

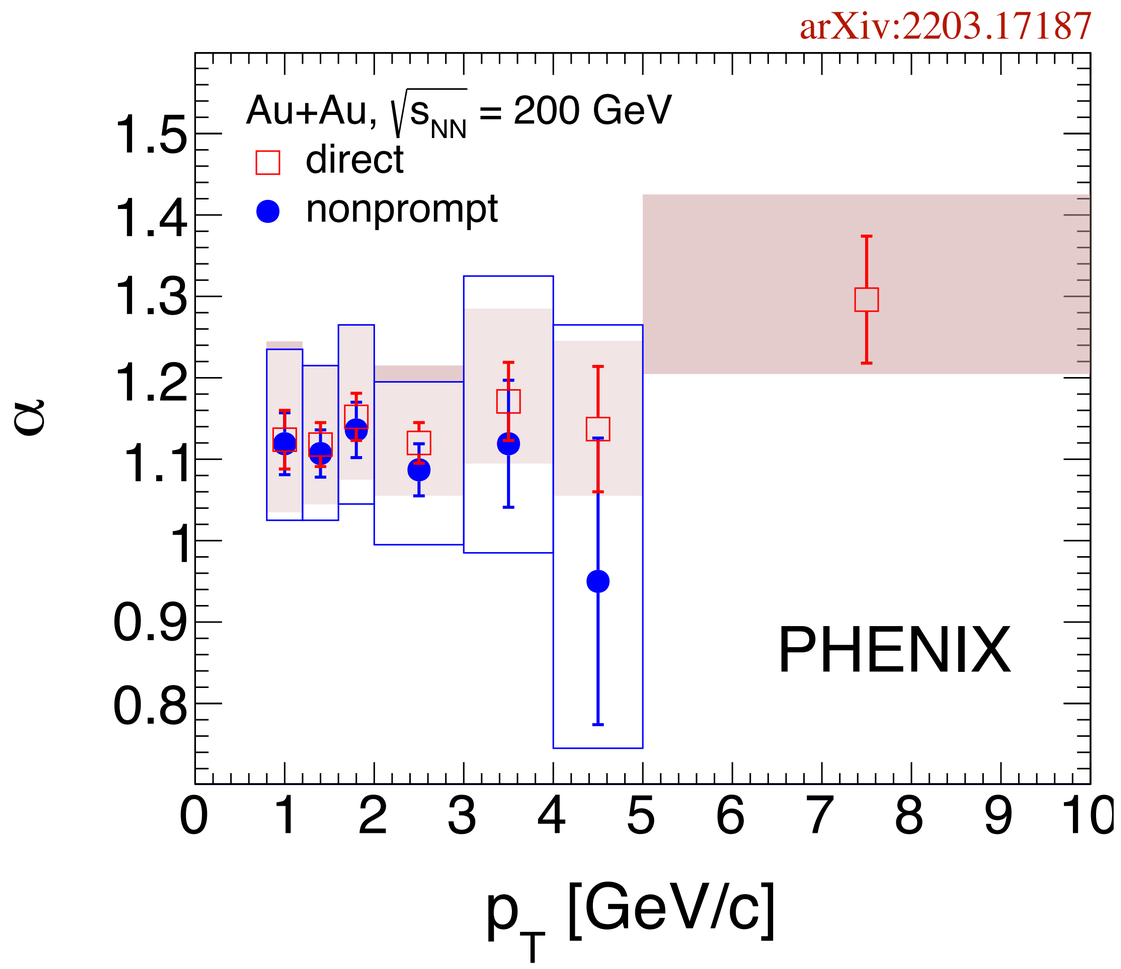


Scaling of nonprompt direct γ with $dN_{ch}/d\eta$

arXiv:2203.17187

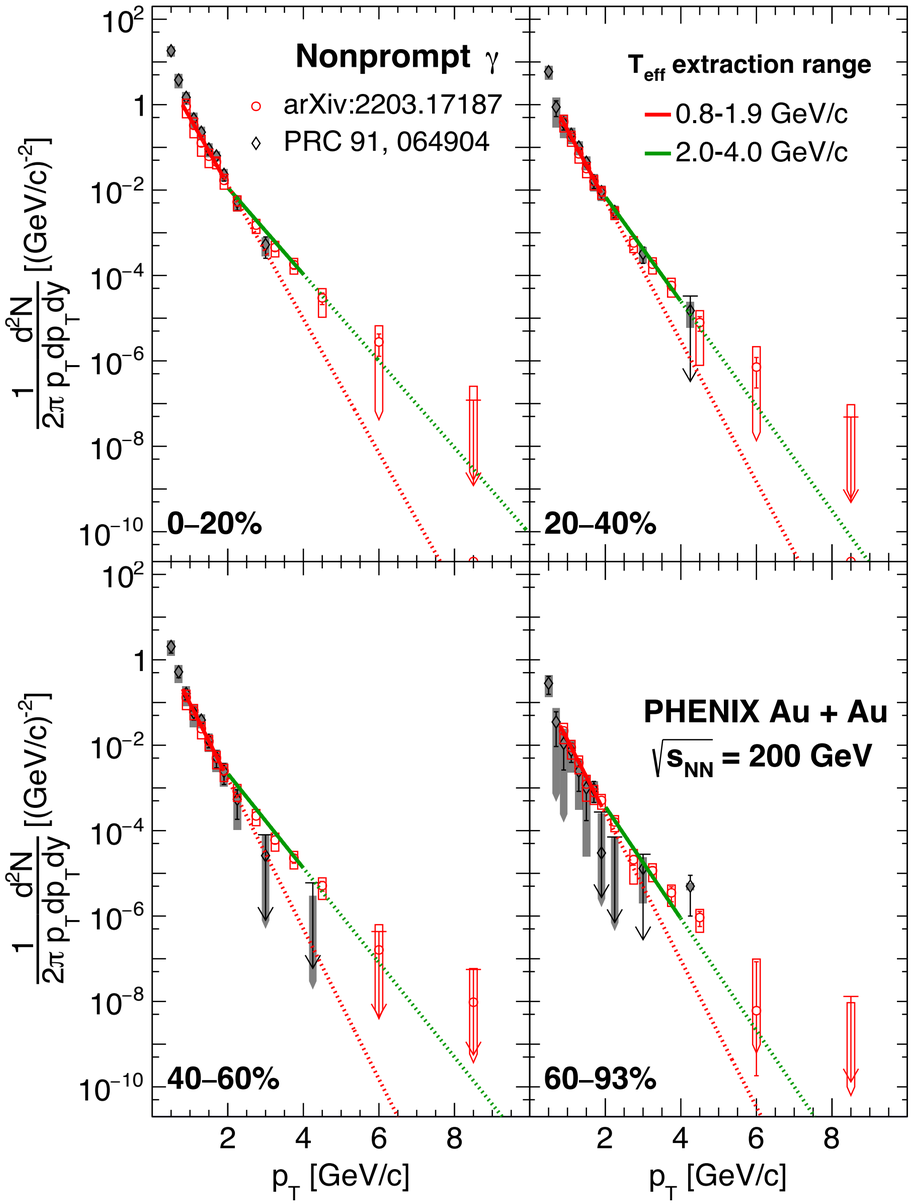


arXiv:2203.17187



α independent of p_T for direct and nonprompt photons

T_{eff} for nonprompt direct γ



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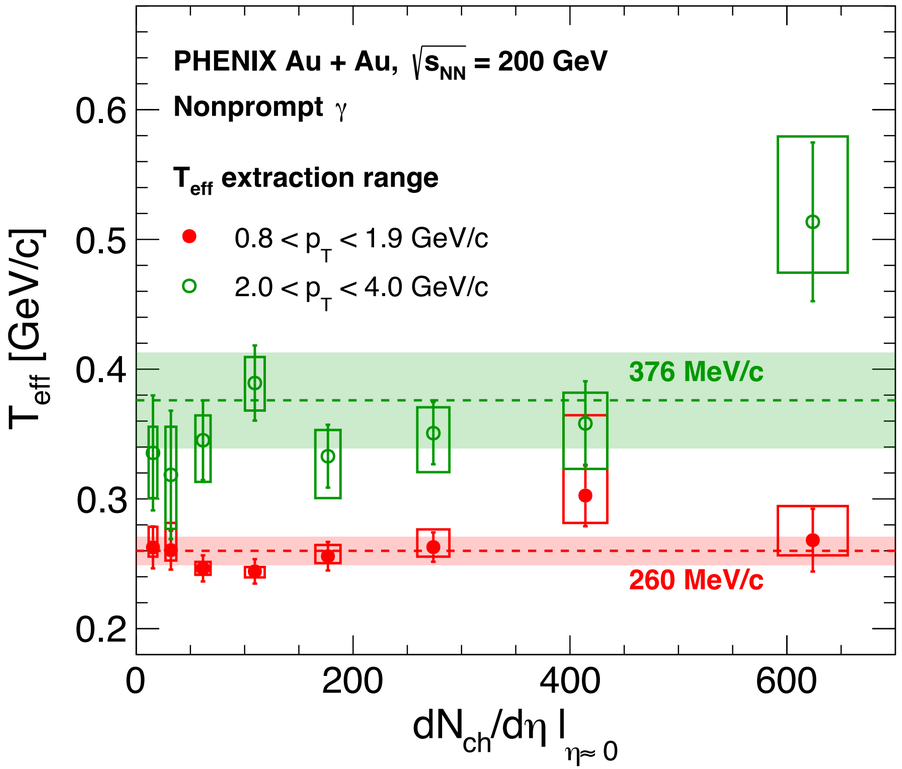
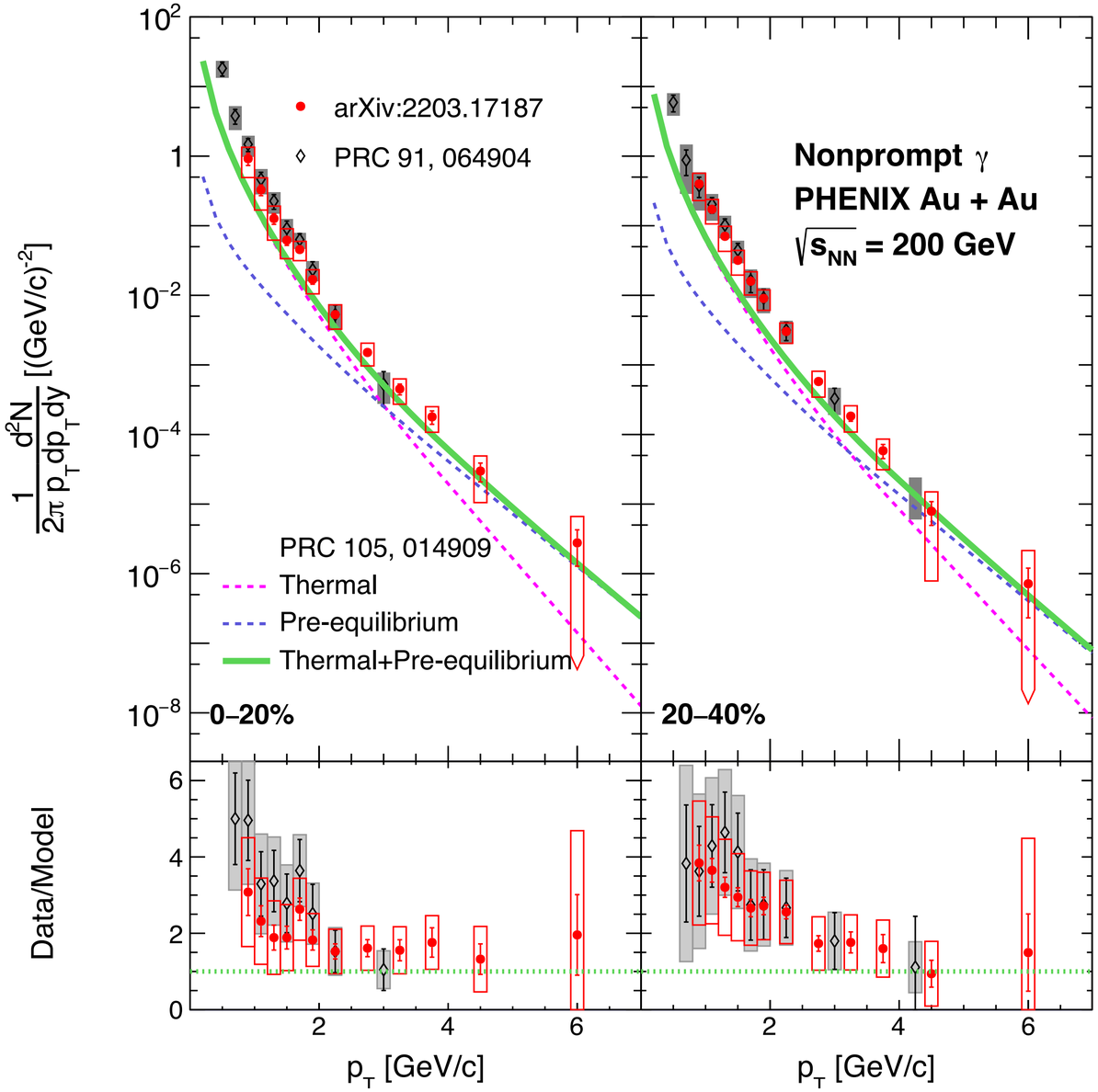


Increasing inverse slope with p_T to above 350 MeV/c suggests contributions from sources beyond those from Hadron Gas

Comparison with theory



C. Gale, J.-F. Paquet, B. Schenke & C. Shen,
Phys. Rev. C **105** (2022) 014909

Multi-messenger heavy-ion physics

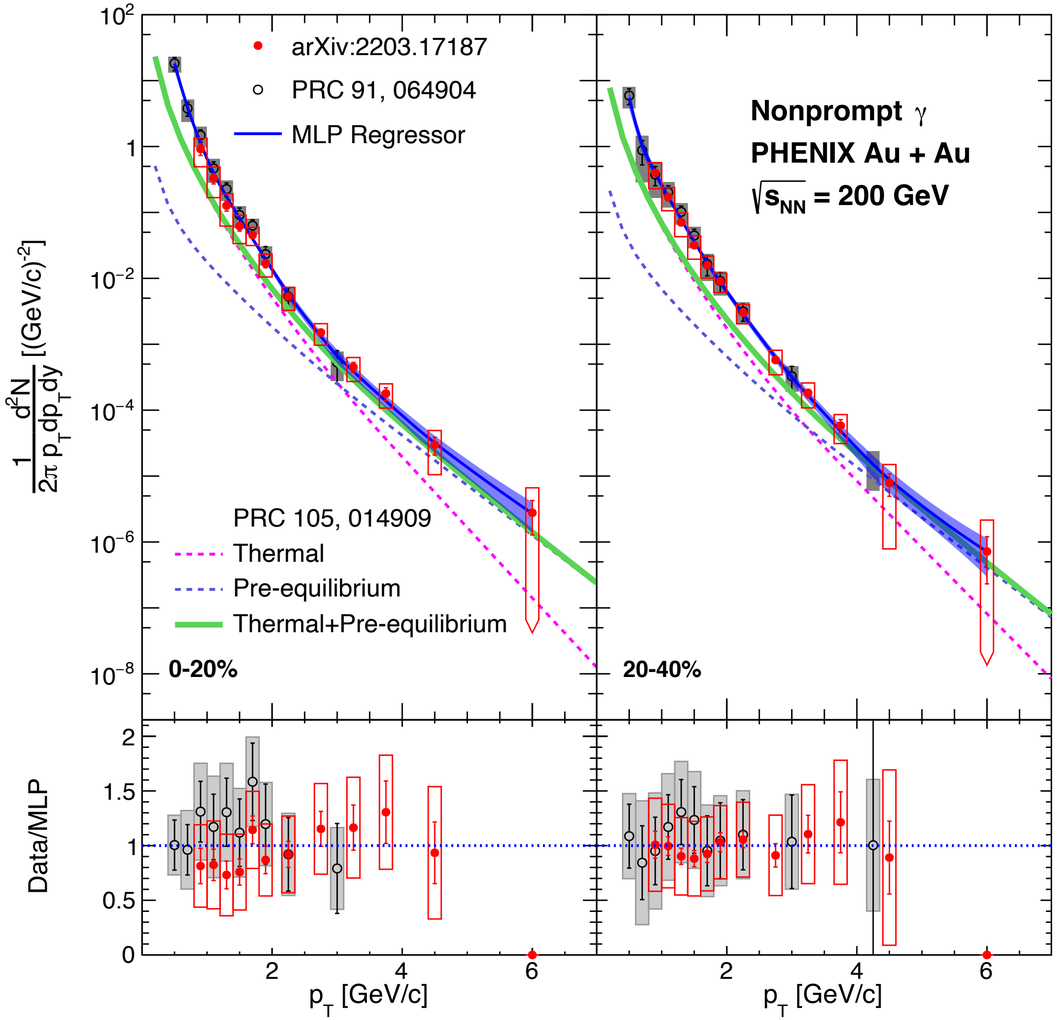
- Hybrid model that describes all stages of relativistic heavy-ion collisions
- Effect of the pre-equilibrium phase on both photonic and hadronic observables highlighted

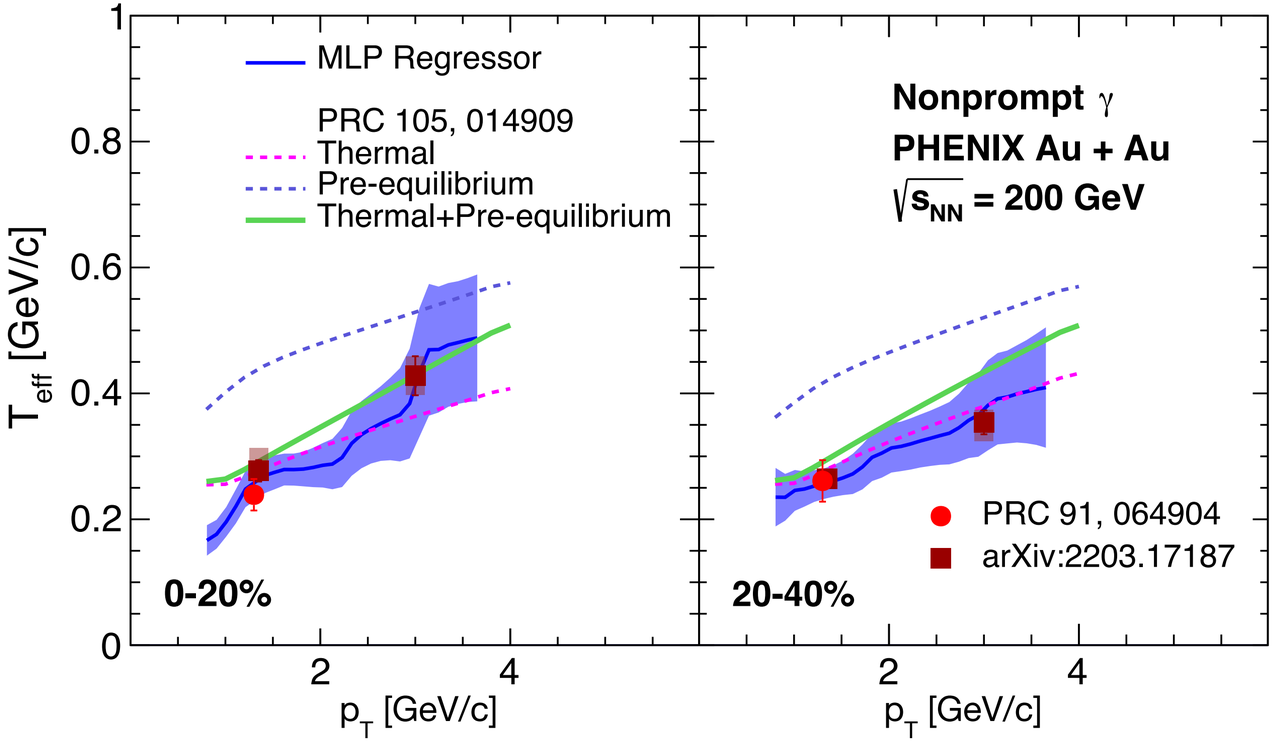
Dominant contribution from pre-equilibrium above 3 GeV/c in the model seems to align well with the data

Overall yield falls short, especially below 2 GeV

Comparison of local inverse slopes

Multi-Layer Perceptron (MLP) — a machine learning based regression algorithm

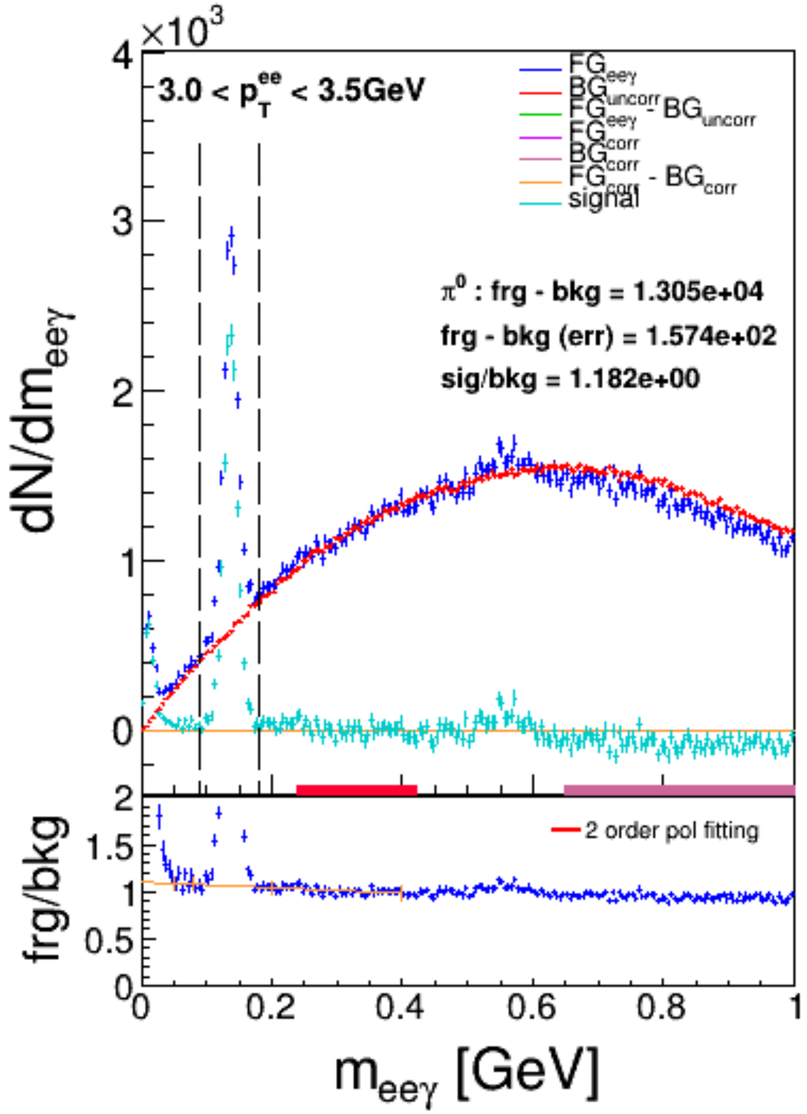


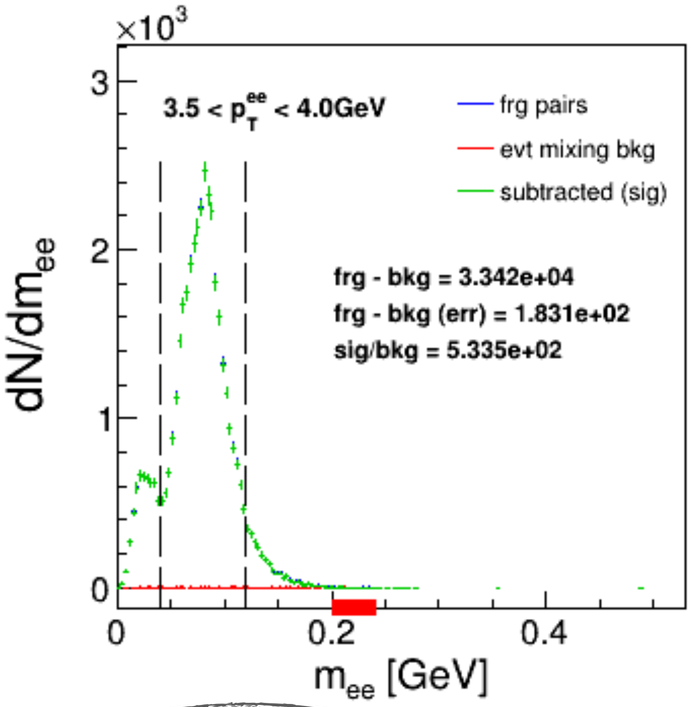


Contributions from pre-equilibrium may be important at intermediate p_T

Cu+Au - coming soon

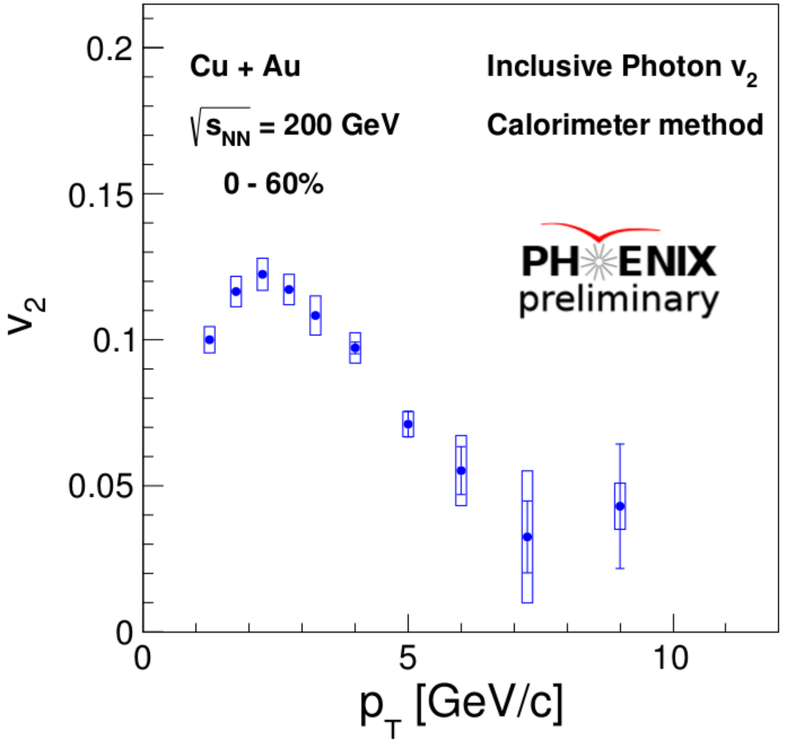
Spectrum — underway





Poster by **Vassu Doomra**
Session 1
T05

Azimuthal anisotropy — ongoing



Poster by **Michael Giles**
Session 1
T06/07

Summary and outlook

Recently published Au+Au measurements for $\sqrt{s_{NN}} = 39, 62.4$ and 200 GeV

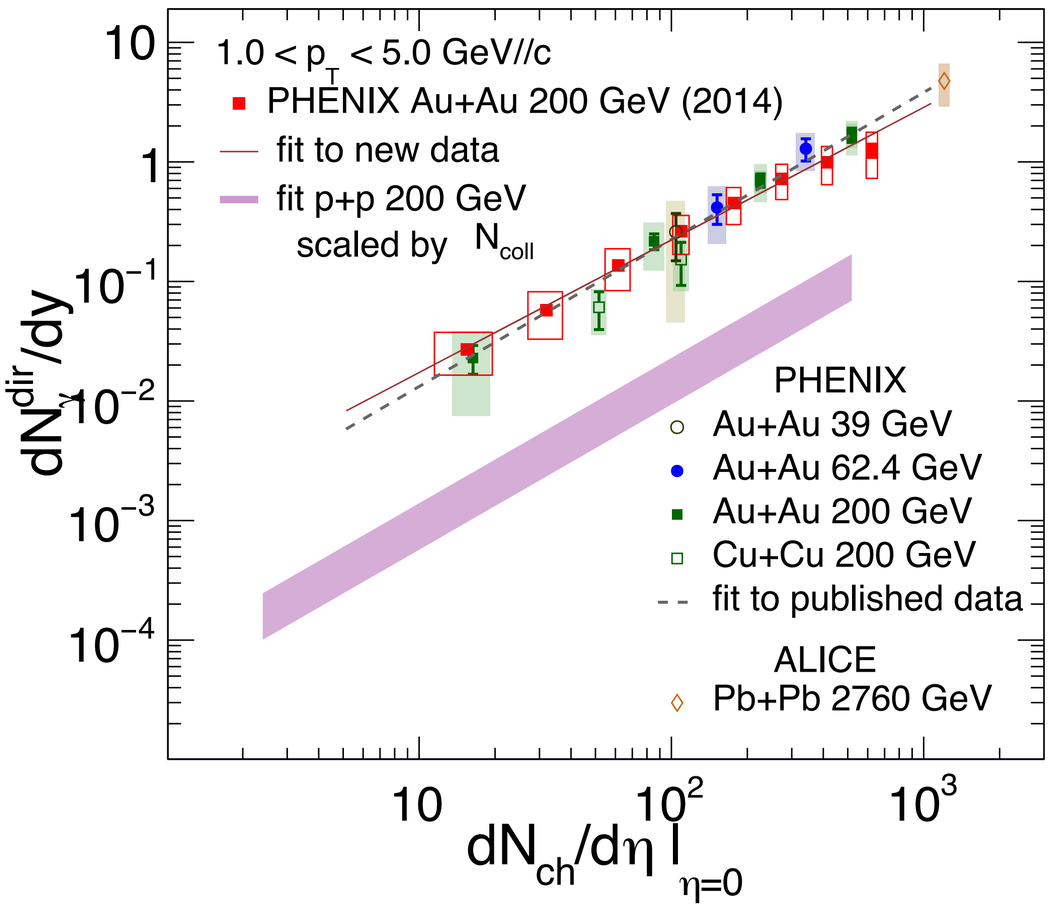
Universal scaling, $N_\gamma^{dir} \propto (dN_{ch}/d\eta)^\alpha$ — α **independent of** p_T for direct and nonprompt direct photons

Direct and nonprompt direct photon spectra exhibit **increasing inverse slope** with p_T

Nonprompt direct photon spectra **sensitive to pre-equilibrium emissions** for $p_T > 2$ GeV/c

More results coming soon from small system collisions and Cu+Au at $\sqrt{s_{NN}} = 200$ GeV

arXiv : 2203.17187



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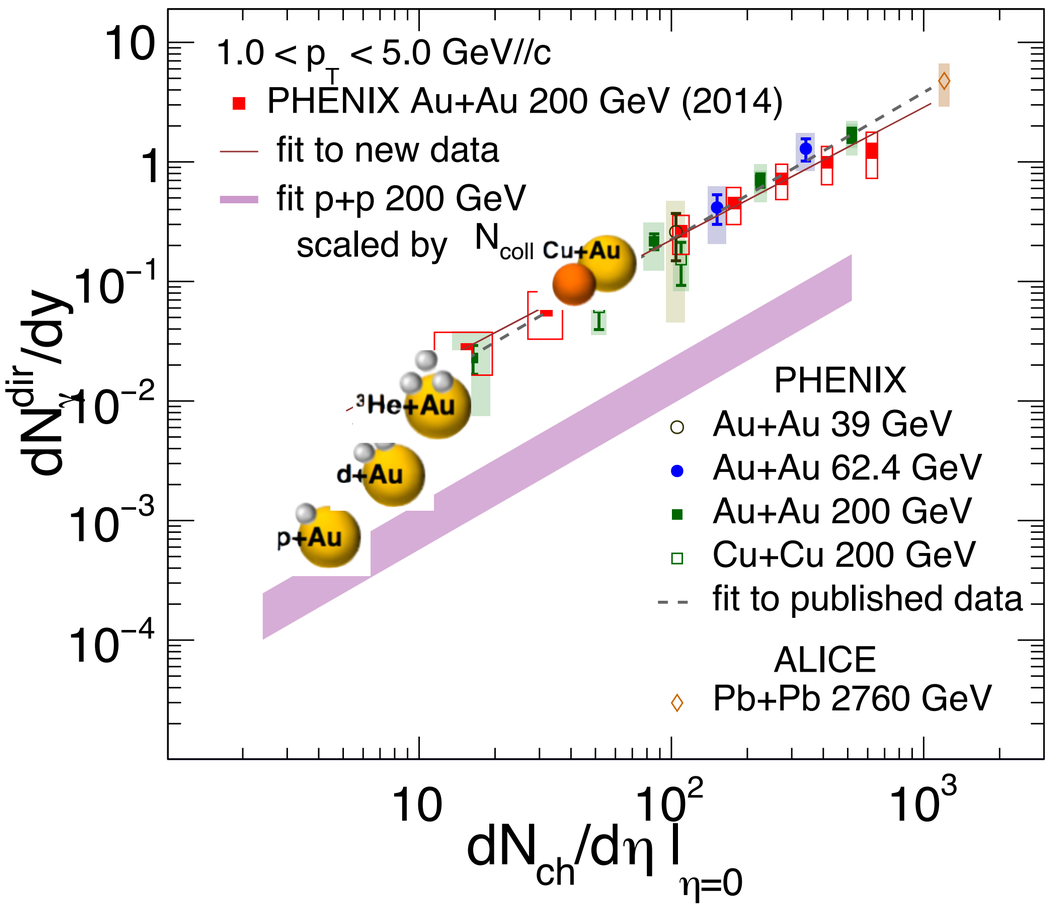


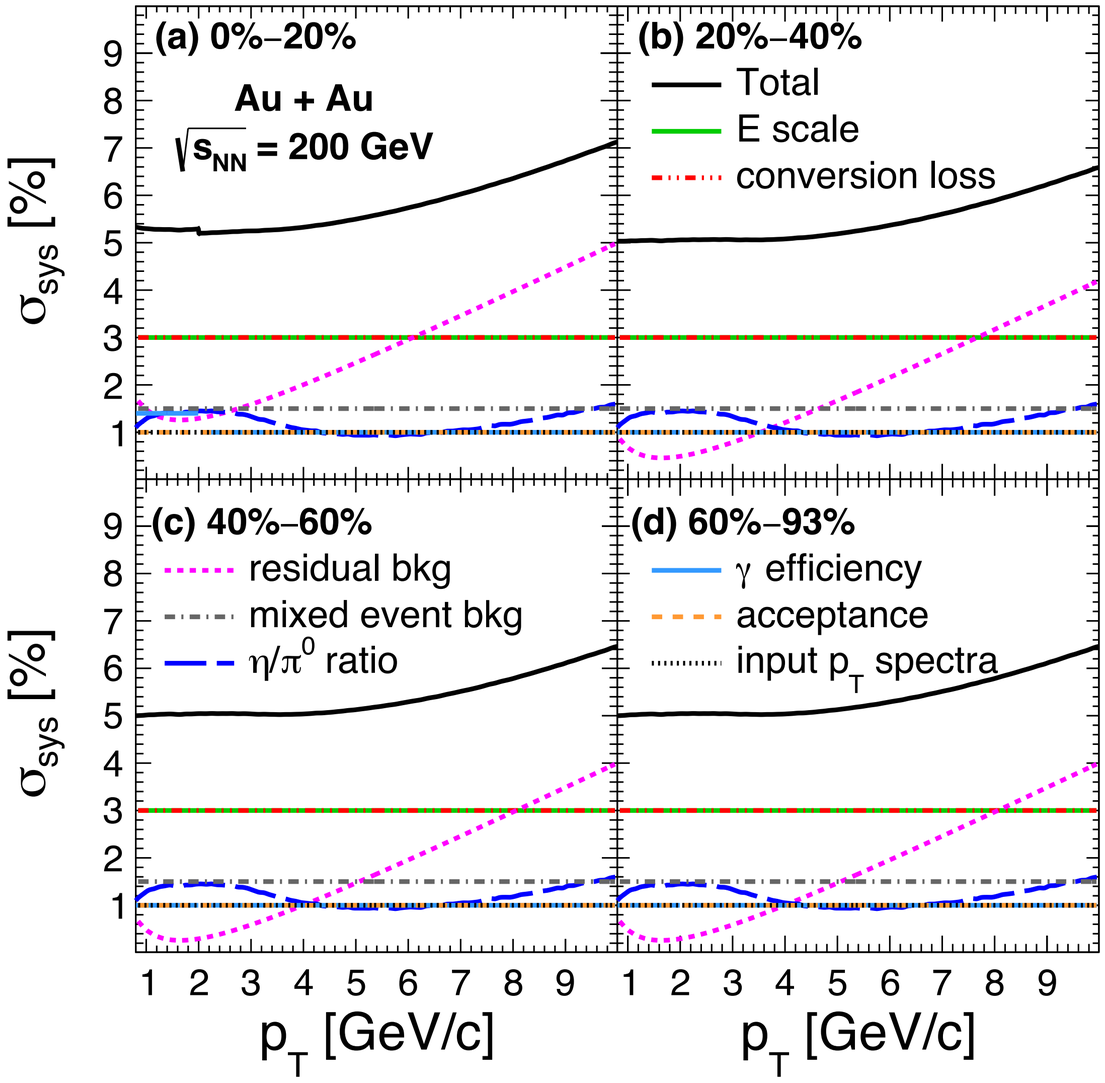

Thank you for your attention!

Back-up

Systematic uncertainties

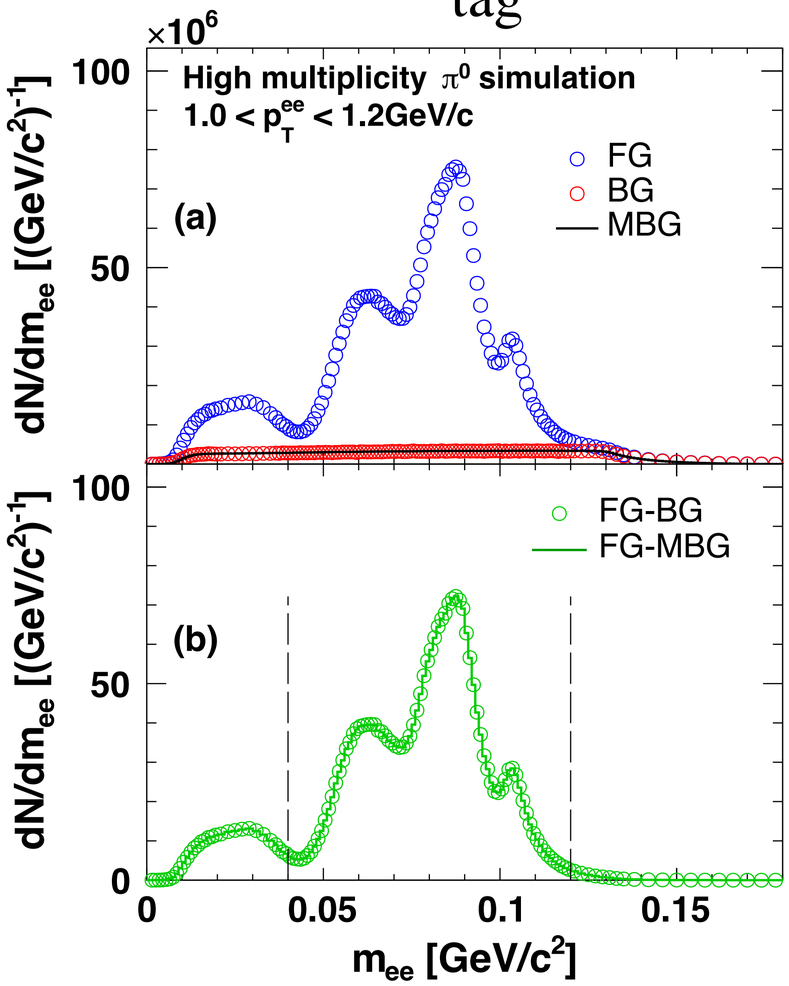
Systematic uncertainty source (39 GeV)	σ_{sys}/R_γ	Type
π^0 *reconstruction*		
tagged photon yield	8%	A
Conditional acceptance		
input Hagedorn p_T spectra and energy scale	8%	B
Cocktail ratio		
γ^{hadron}/π^0	2%	B

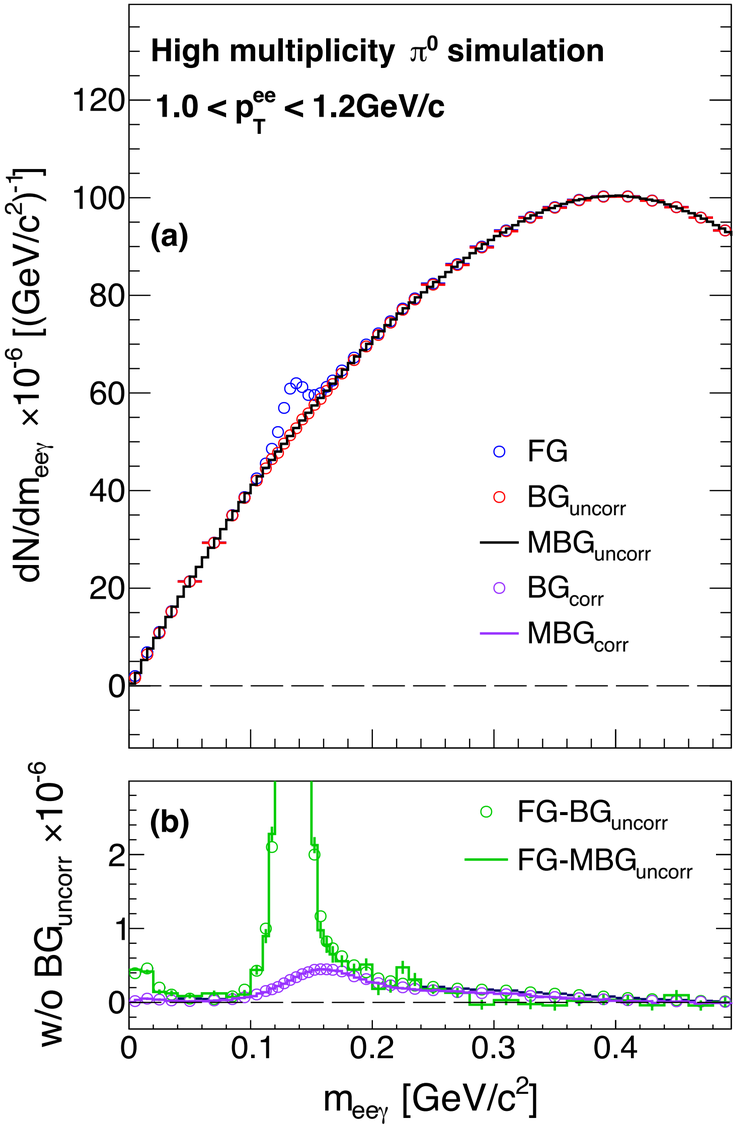
Systematic uncertainty source (62.4 GeV)	σ_{sys}/R_γ	Type
π^0 *reconstruction*		
tagged photon yield	5%	A
Conditional acceptance		
input Hagedorn p_T spectra and energy scale	5%	B
Cocktail ratio		
γ^{hadron}/π^0	2%	B

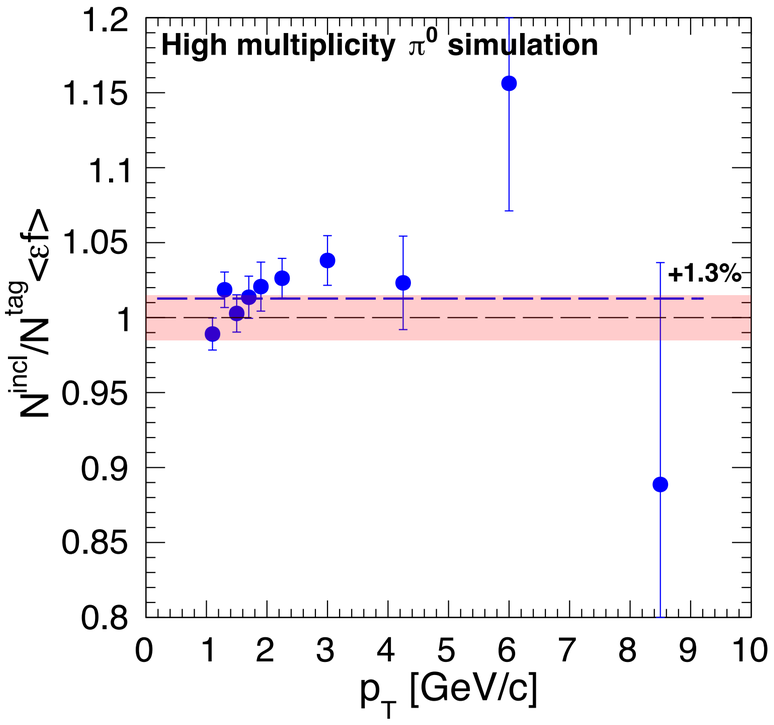


Closure test with high-multiplicity π^0 simulation

$$R_\gamma = \frac{N_{\mathrm{inc}}}{N^{\pi^0}_{\mathrm{tag}}} \langle \varepsilon f \rangle$$



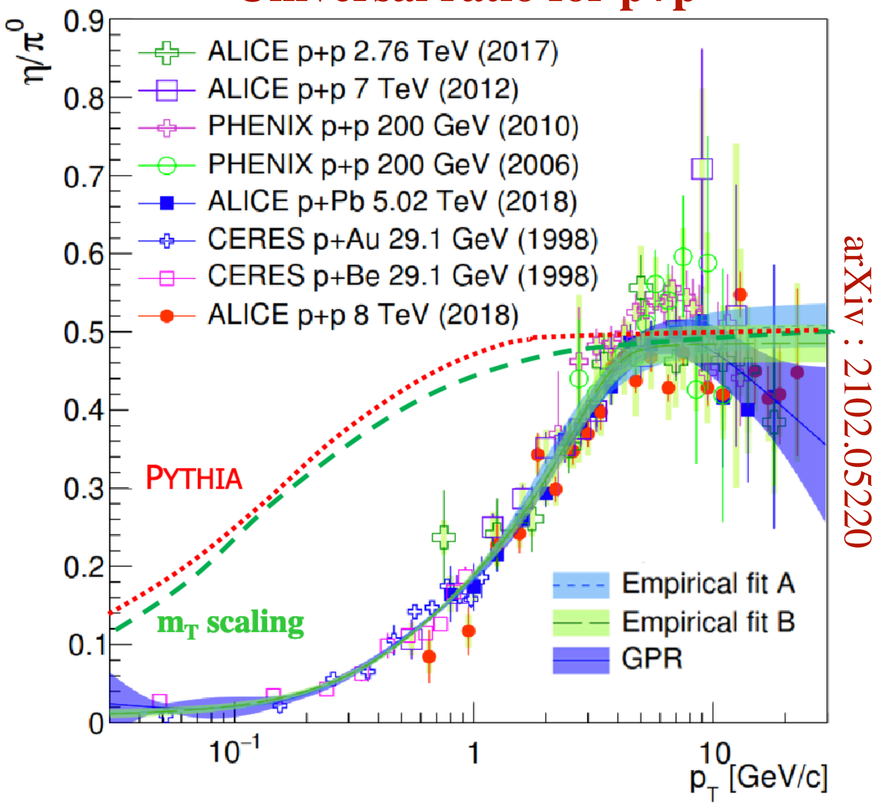




Simulating 280 π^0 per event through the PHENIX reconstruction and analysis framework

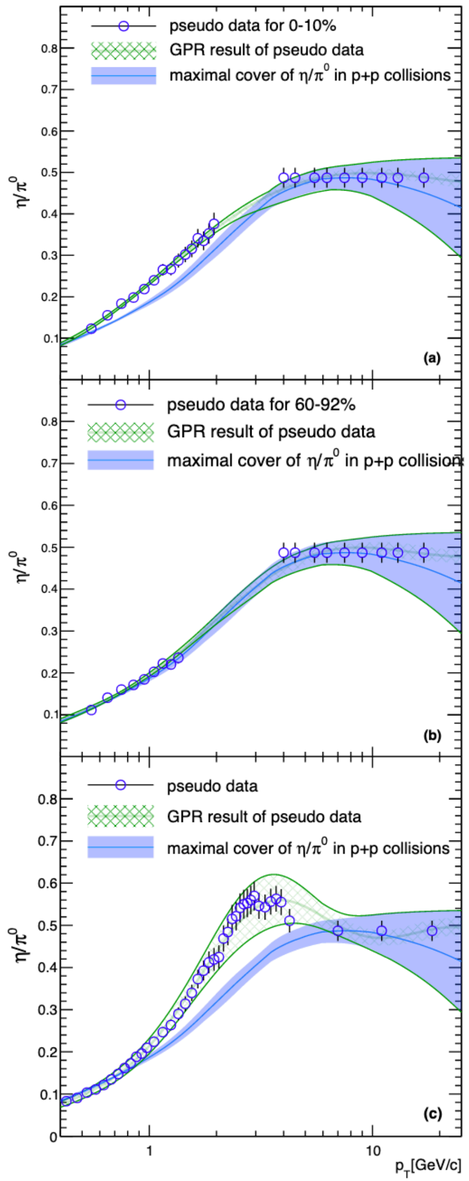
η/π^0 from world data

Universal ratio for p+p

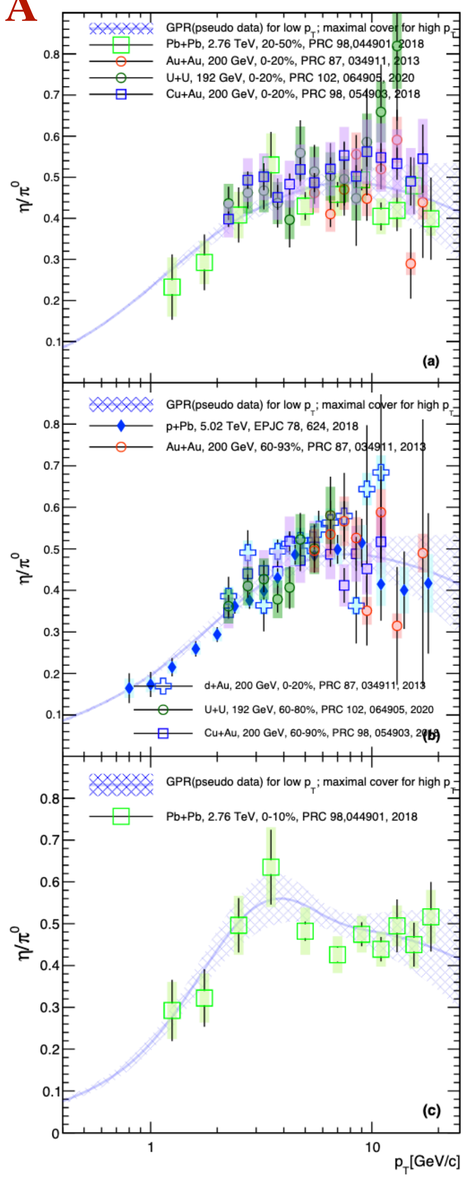


arXiv : 2102.05220

Accounting for effects of radial flow



A + A



p+p – fit

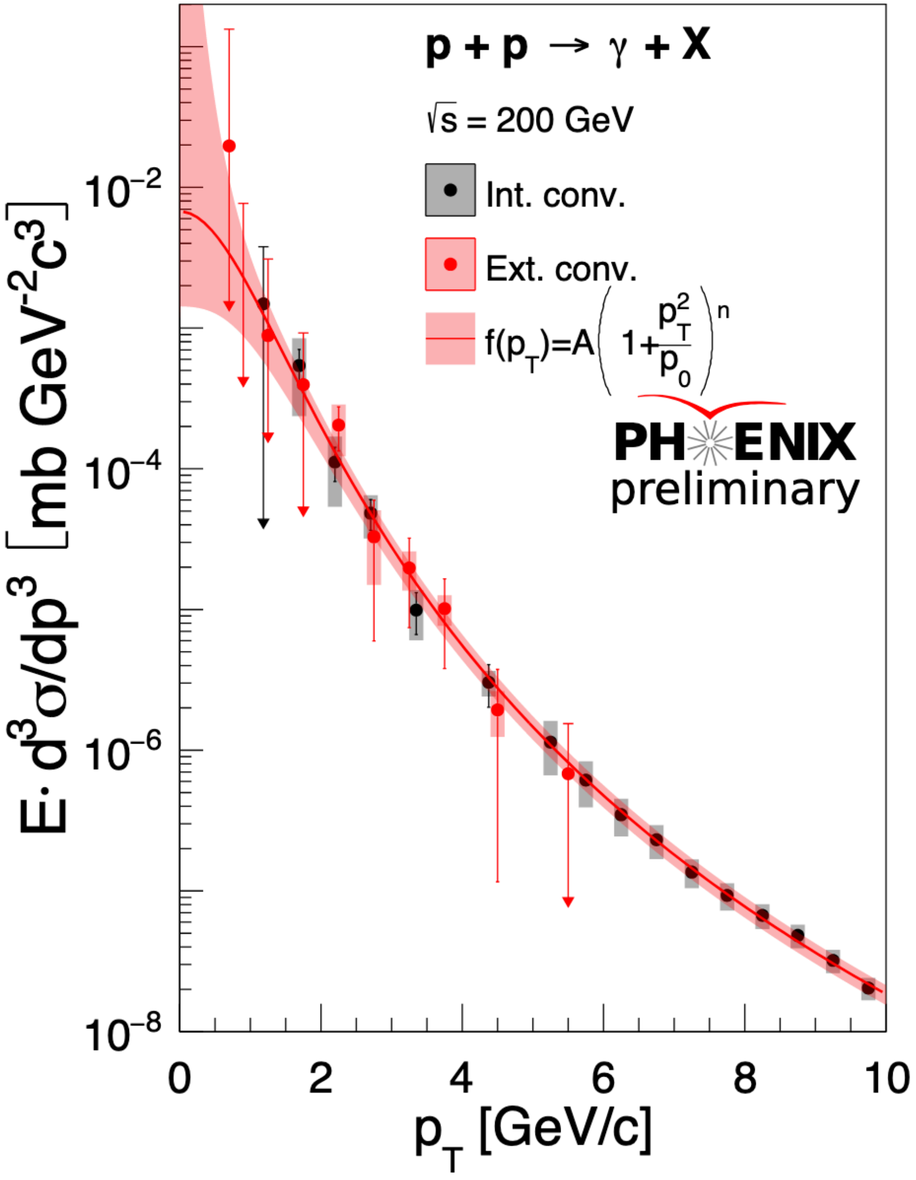
Functional form inspired by pQCD

Fit below 1 GeV/c motivated by Drell Yan measurements [Ito, et al, PRD23, 604 (1981)]

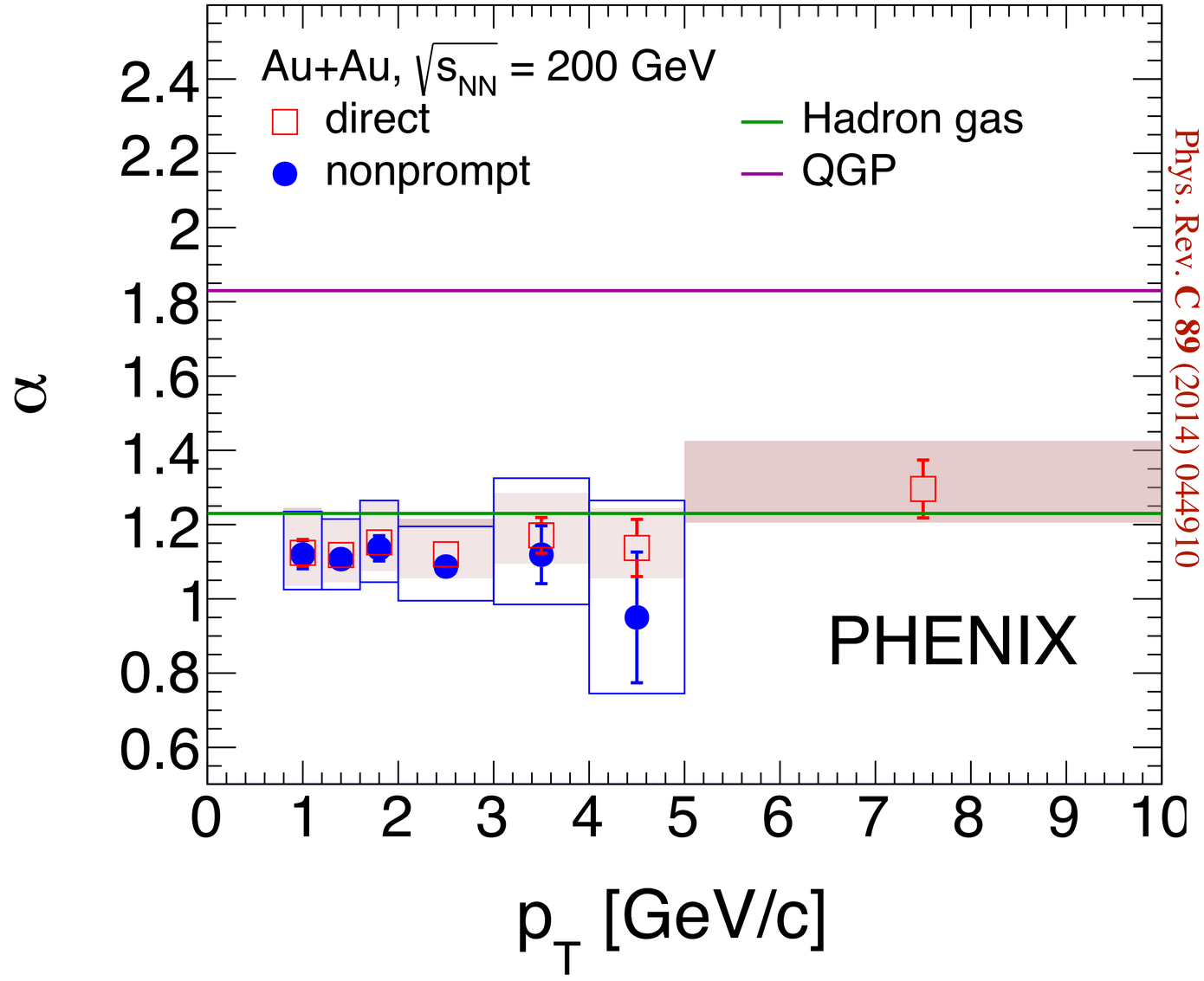
Systematic errors include the fit errors, different functional forms

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

$a = 6.4 \times 10^3$ $b = 1.45$ $c = -3.30$



Theoretical comparisons



Universal scaling of direct γ