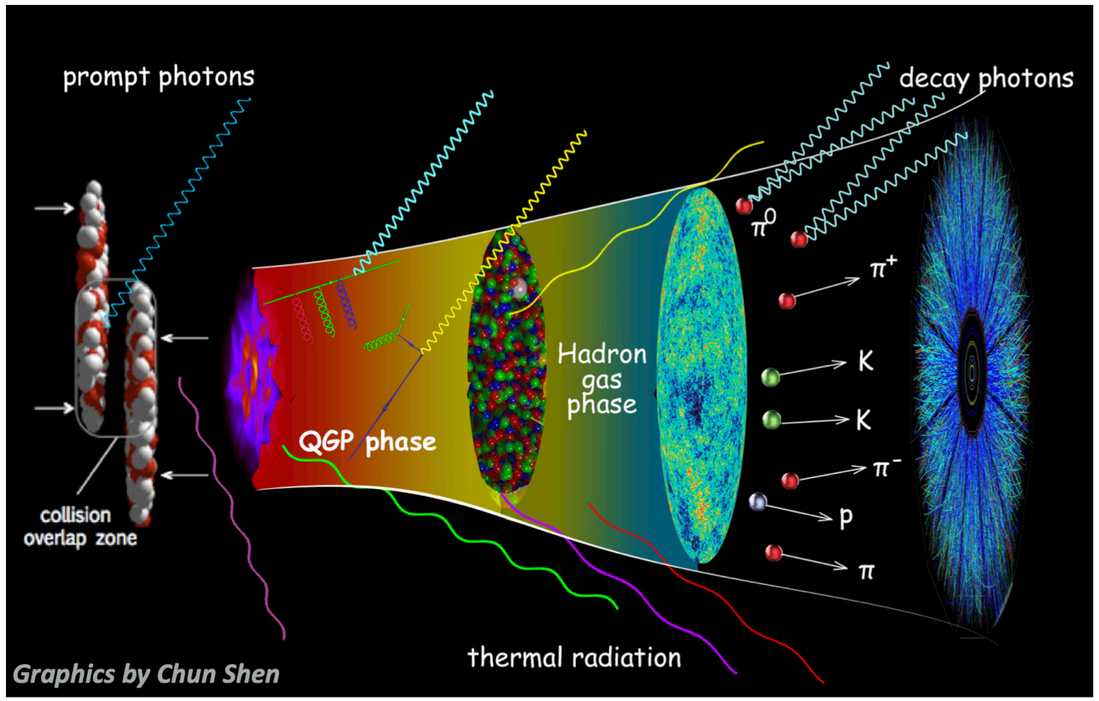
From RHIC to EIC

Roli Esha

Measurement of low p_T direct photons with PHENIX

Introduction



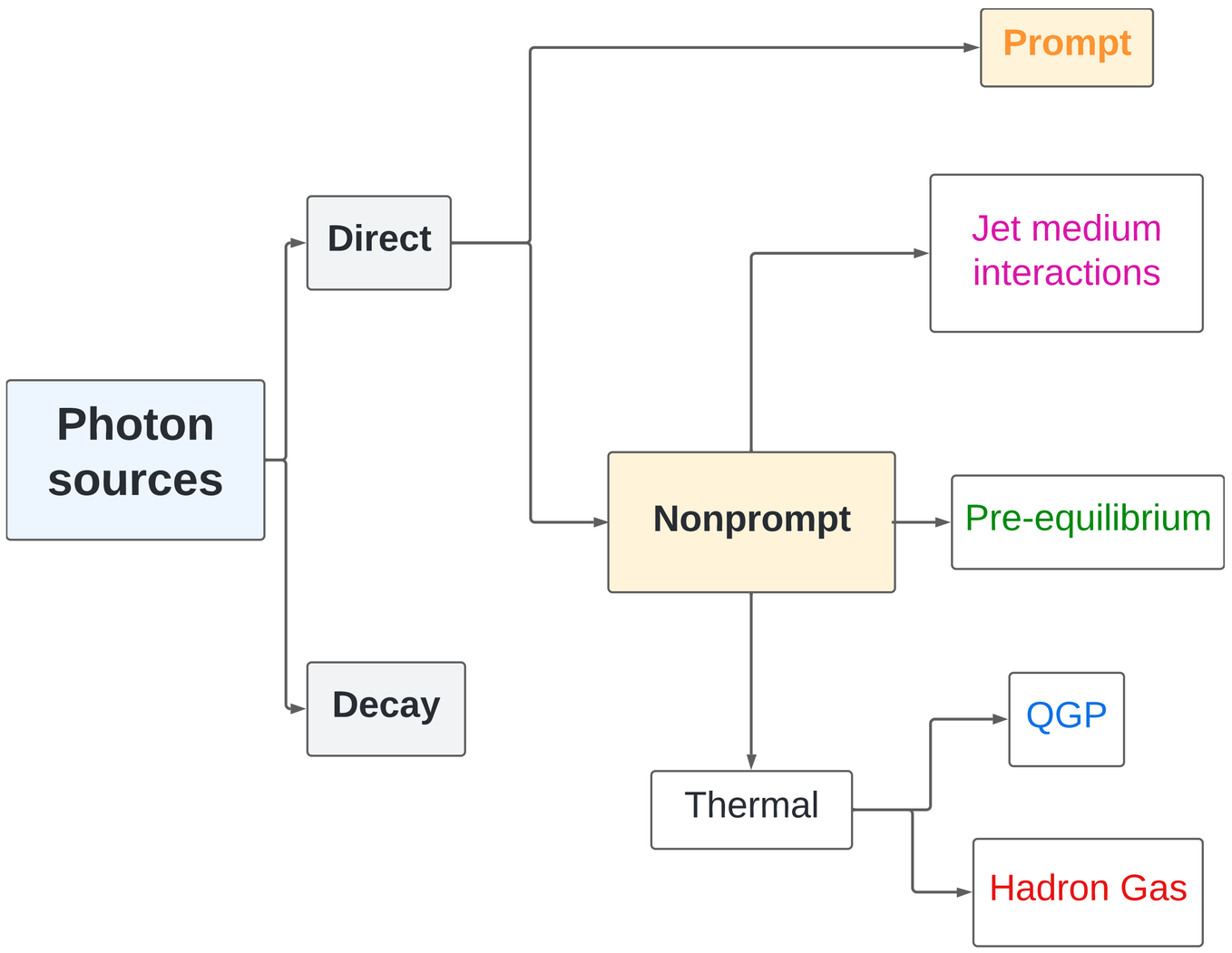
Photons are "color blind" probe of Quark Gluon Plasma

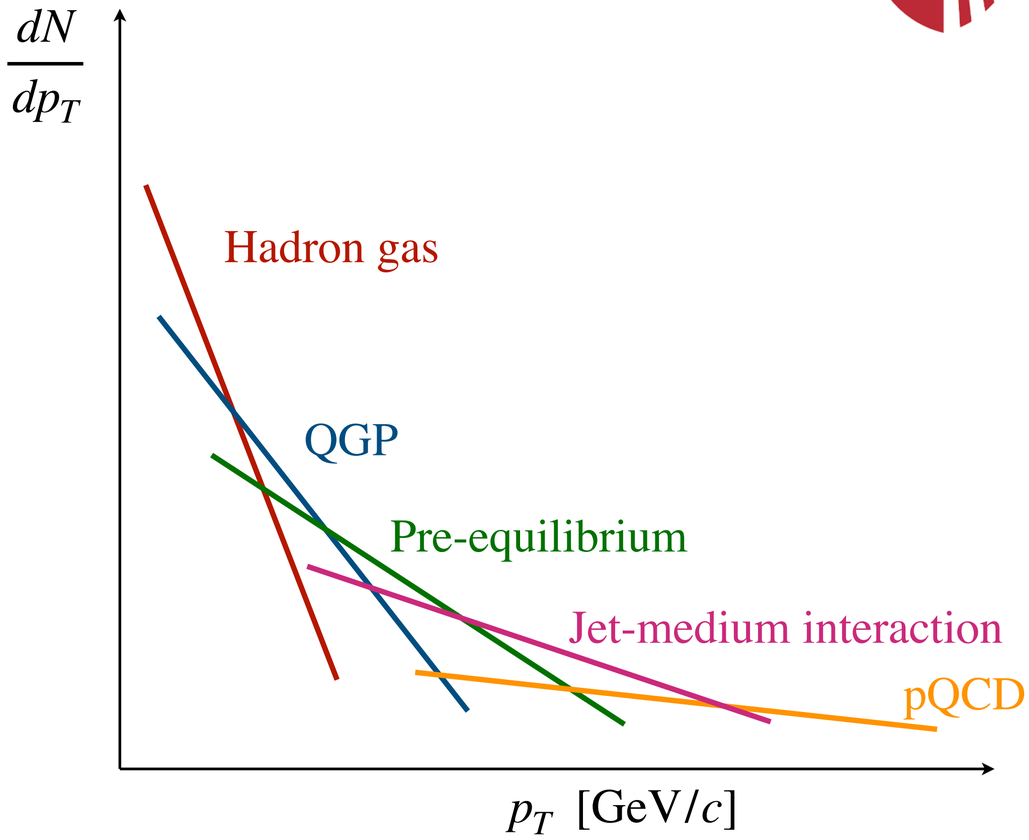
$$\text{Direct photons} = \text{Inclusive photons} - \text{Hadronic decay photons}$$

- 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



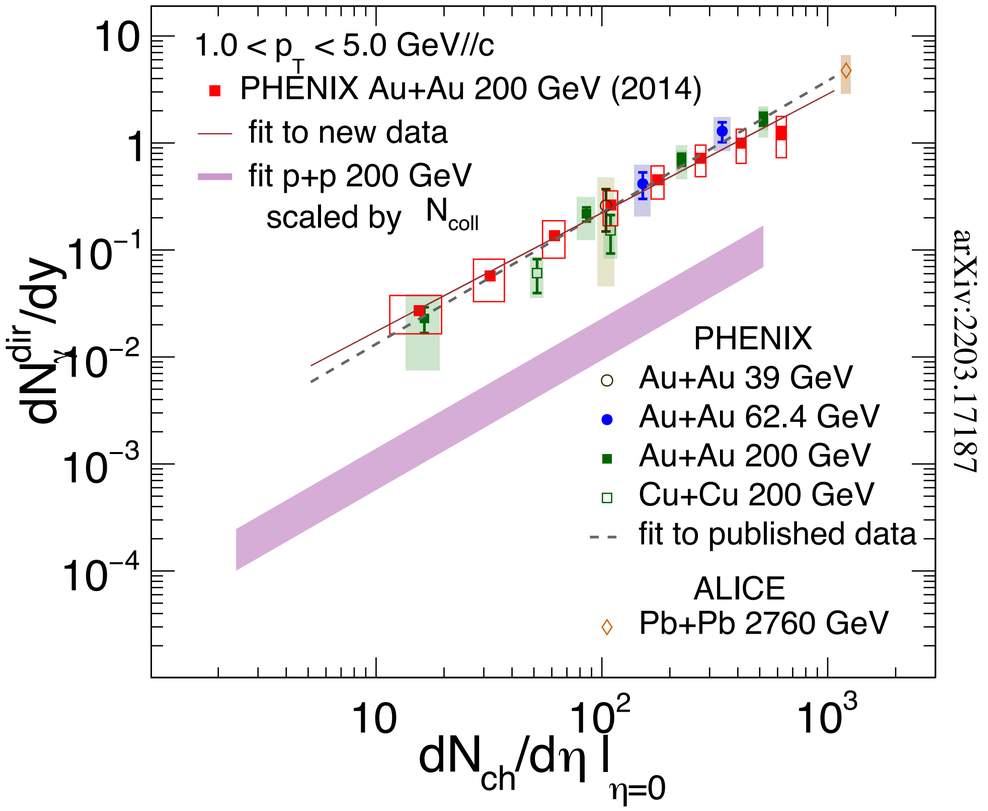


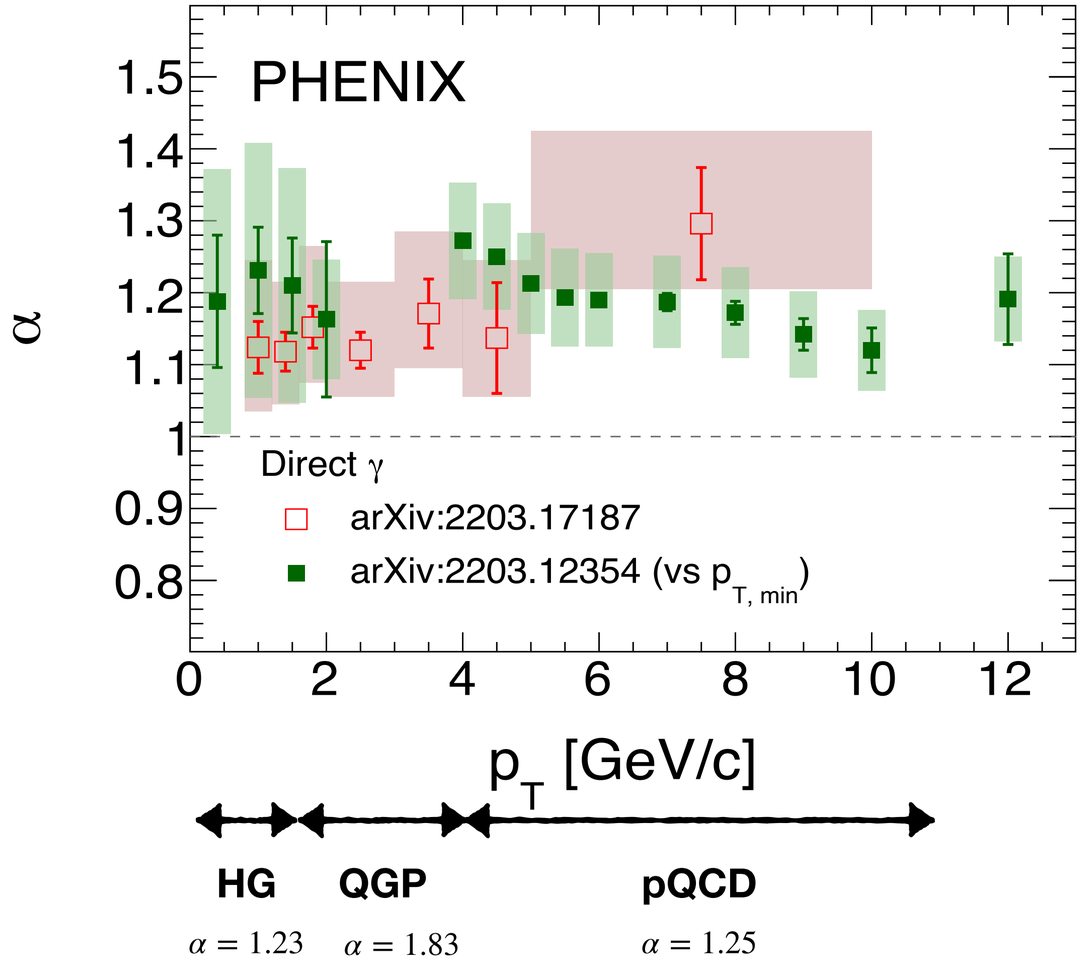
Measurement of the nonprompt direct photons possible due to large statistics

Effective temperature

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

Universal scaling behavior in all A+A systems



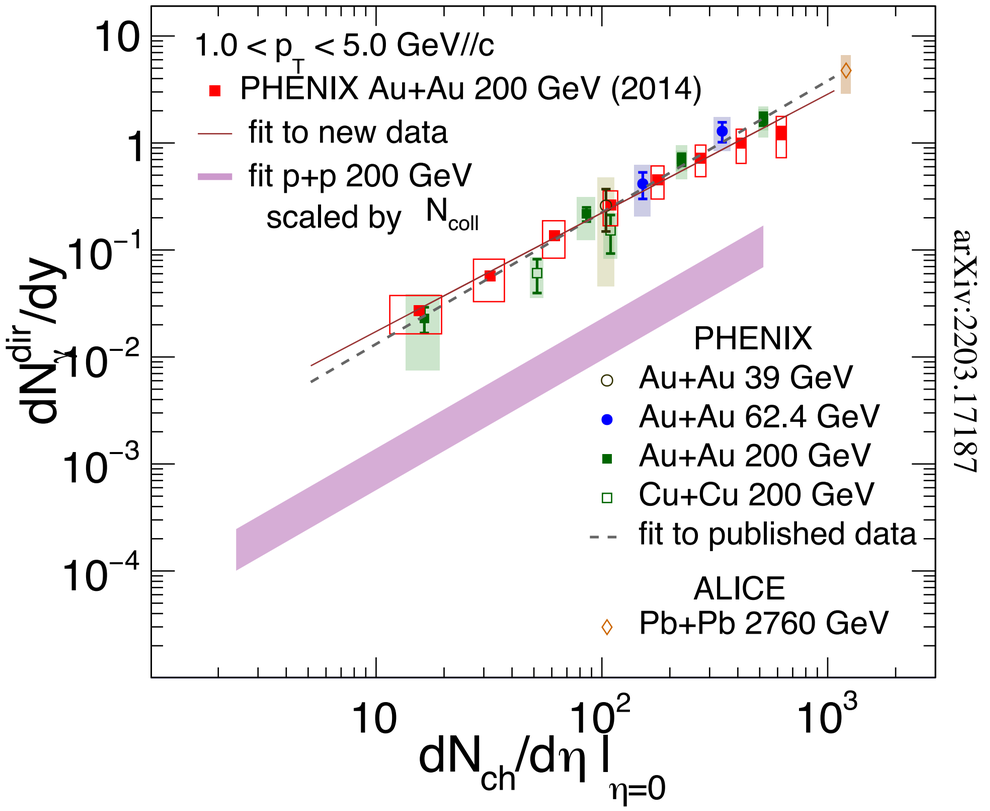


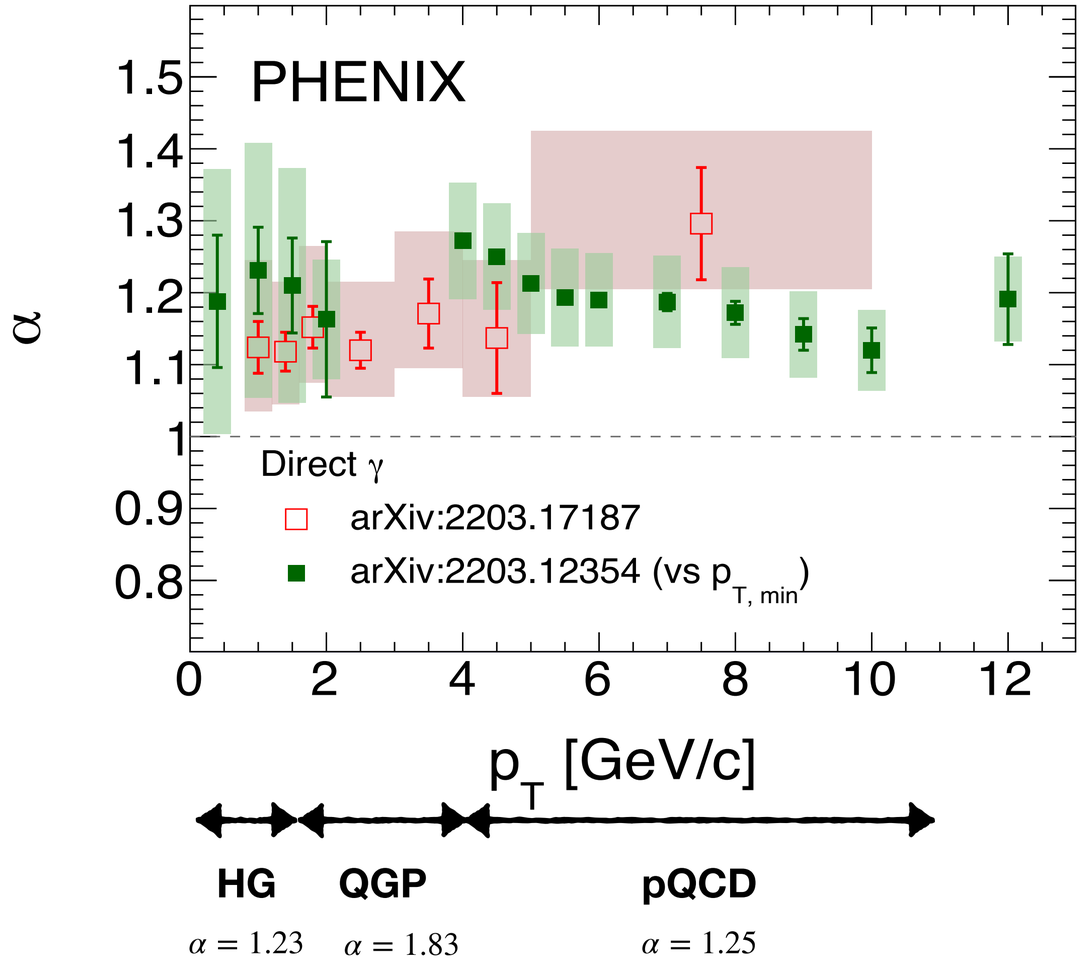
$\alpha > 1$ and independent of p_T

Universal scaling of direct γ yields

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

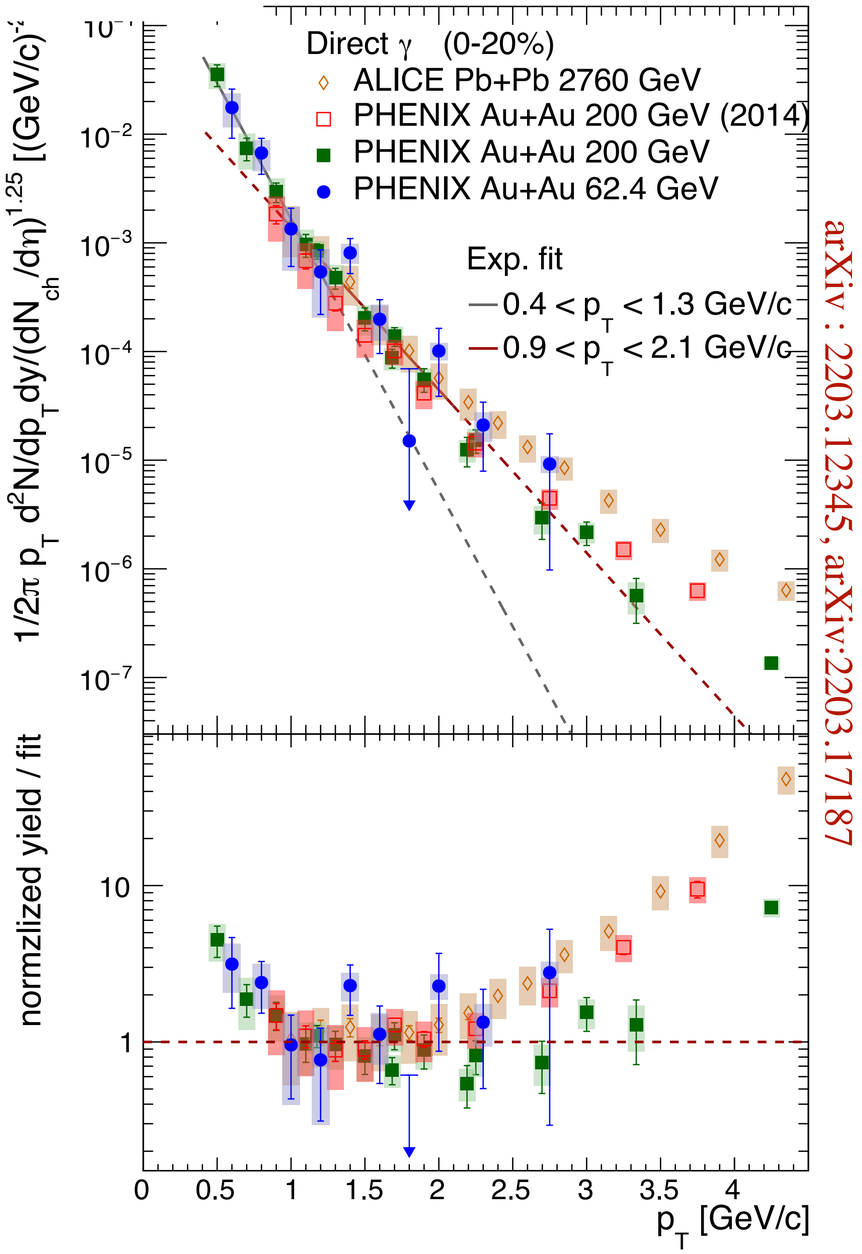
Universal scaling behavior in all A+A systems

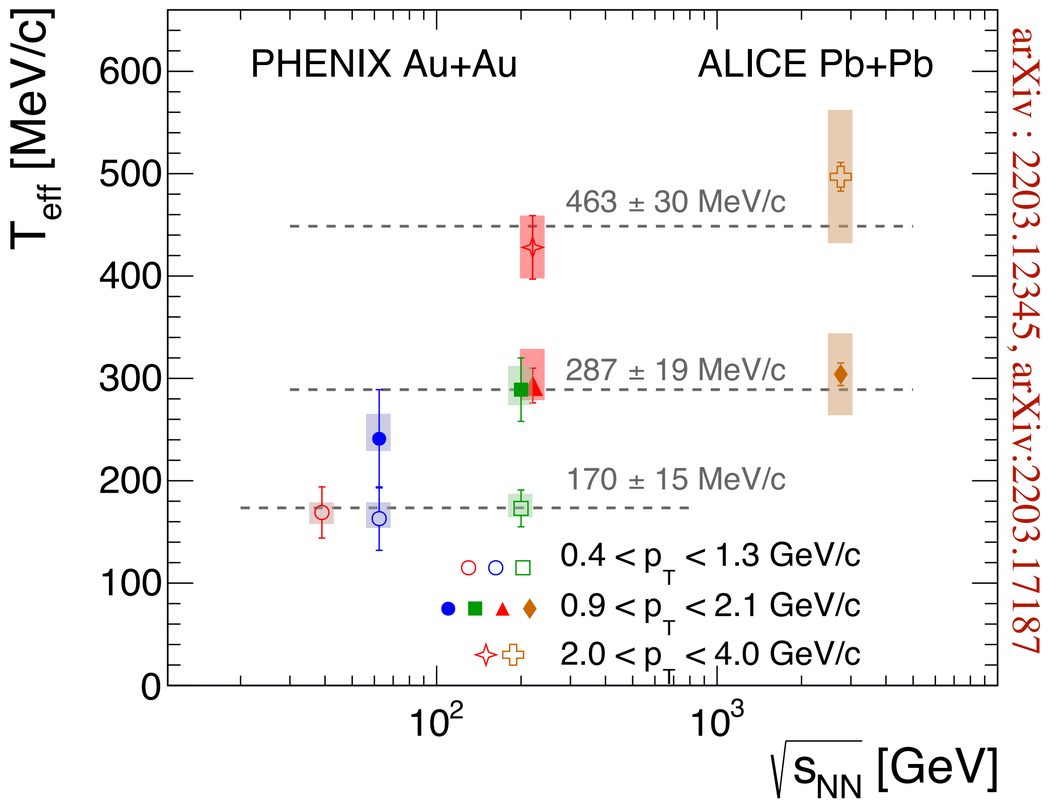




$\alpha > 1$ and independent of p_T

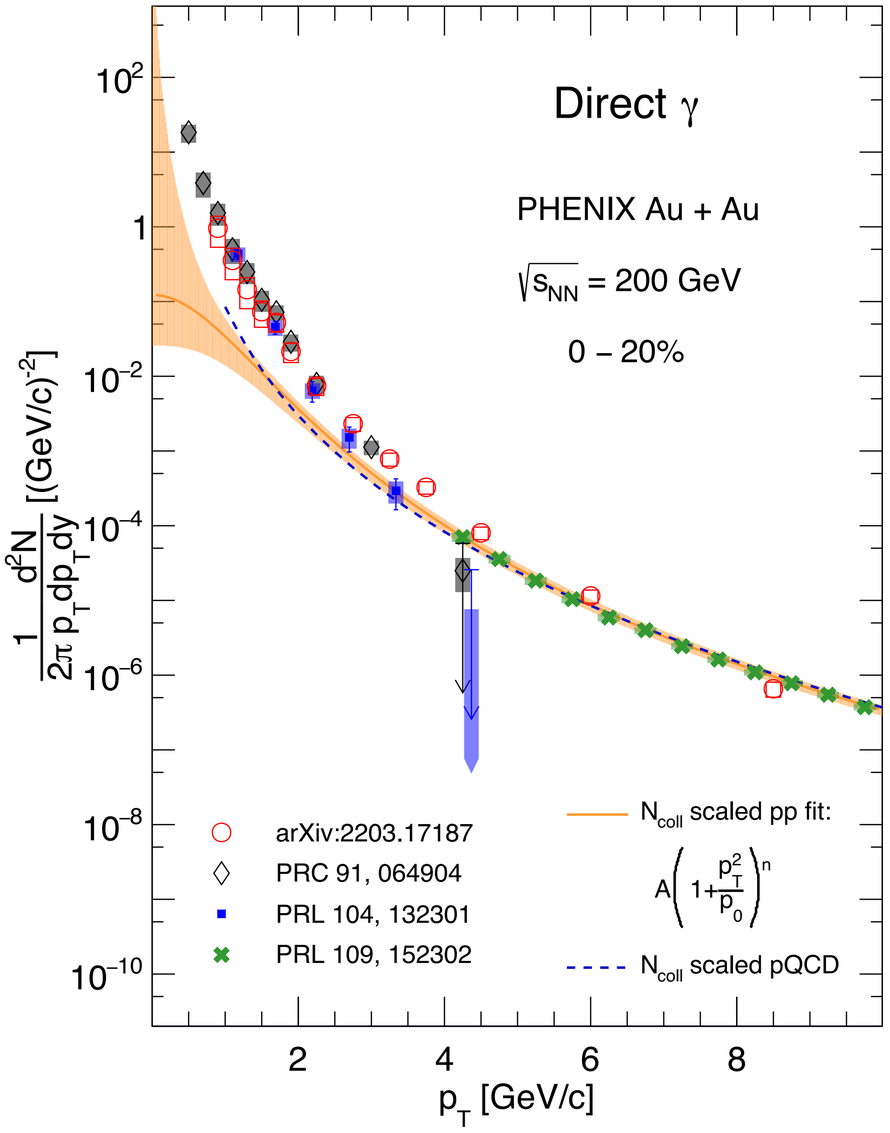
T_{eff} from direct γ





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

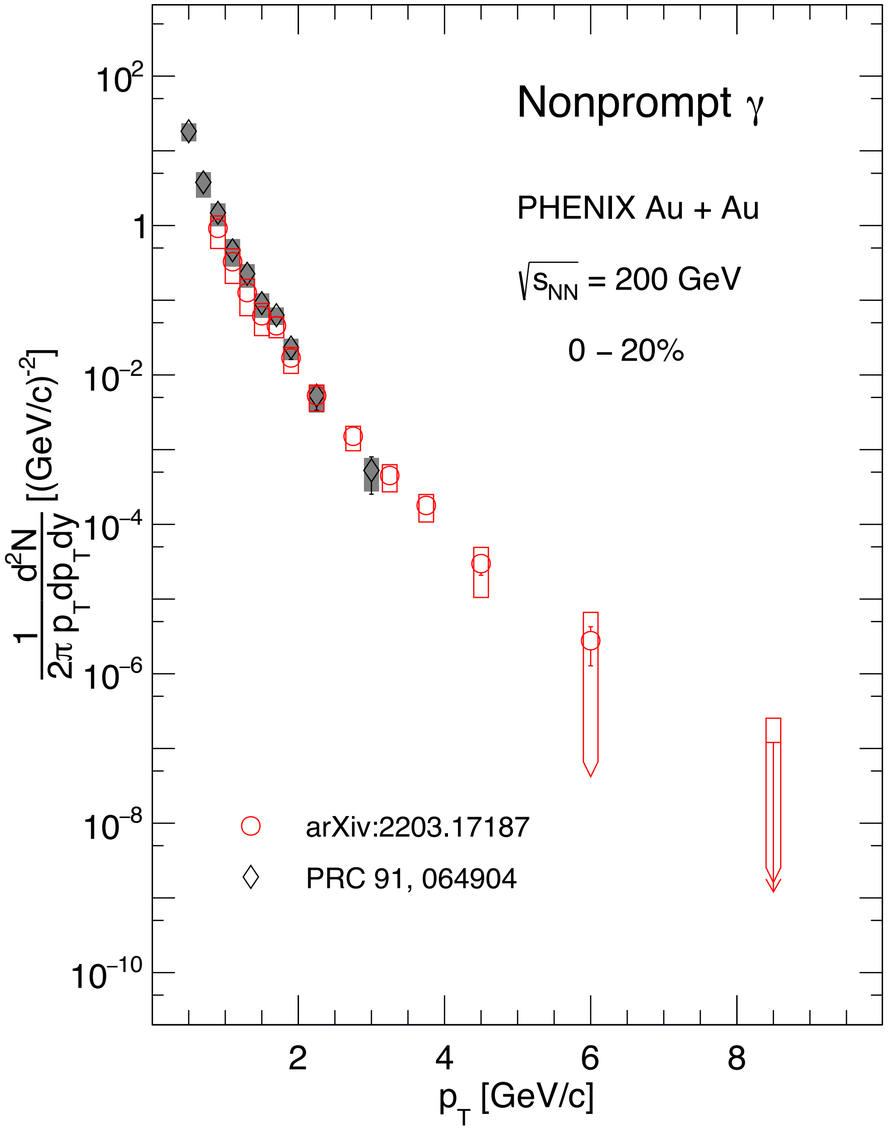
Nonprompt direct photons



Direct photon

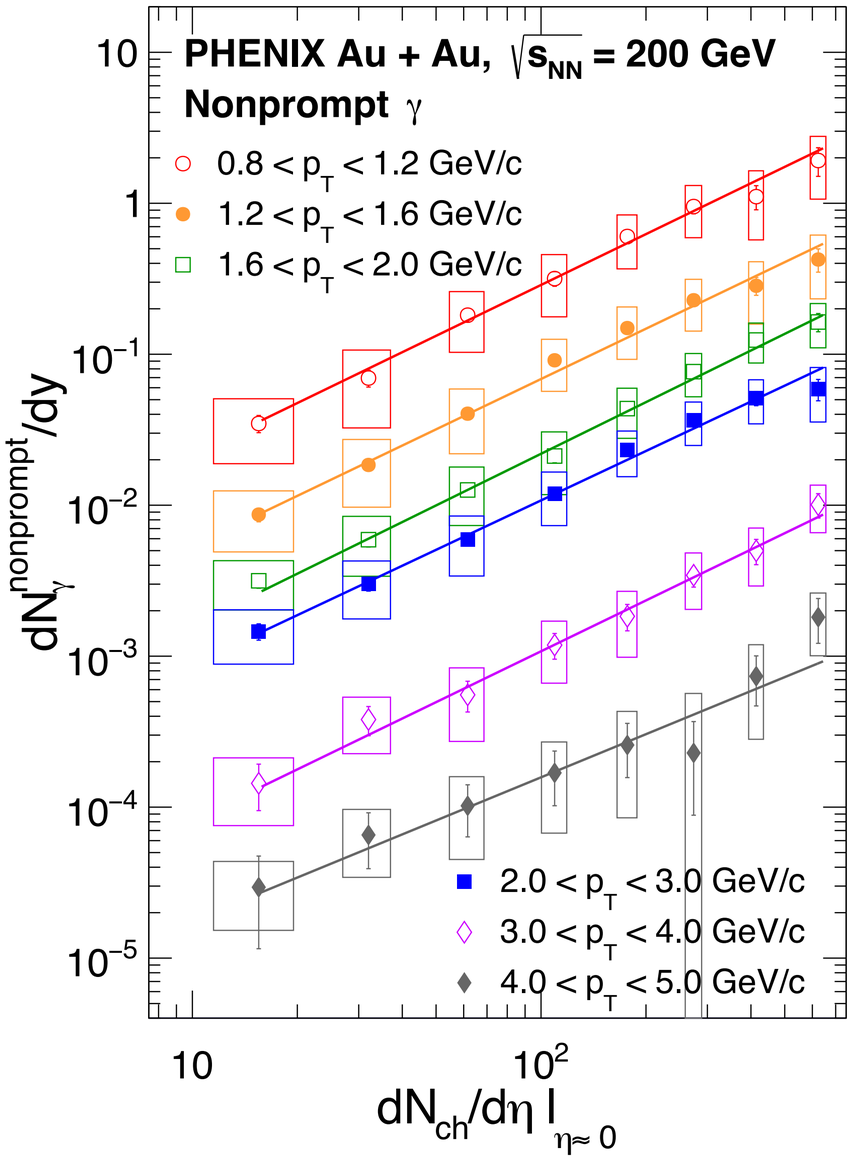
— N_{coll} **scaled p+p fit**

Non-prompt direct photon



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

arXiv:2203.17187



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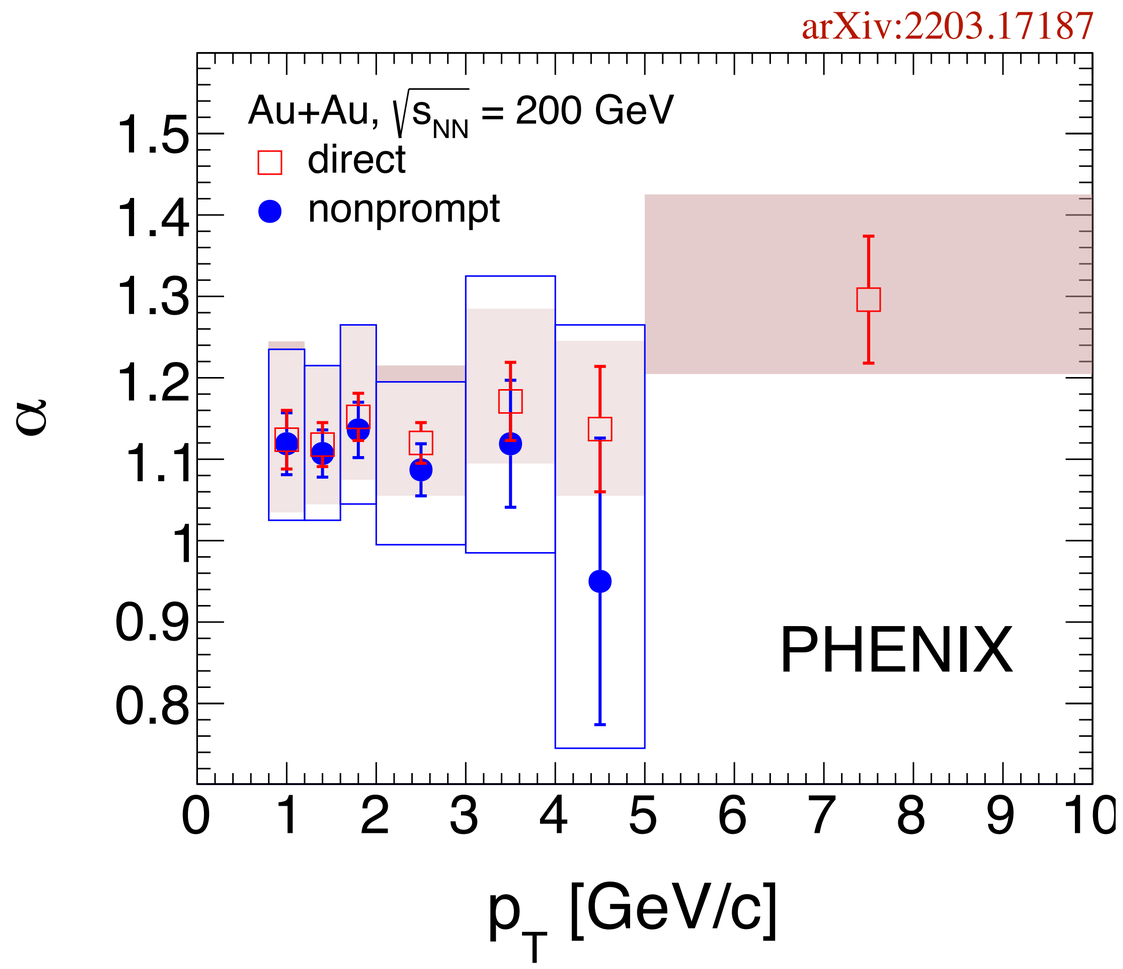
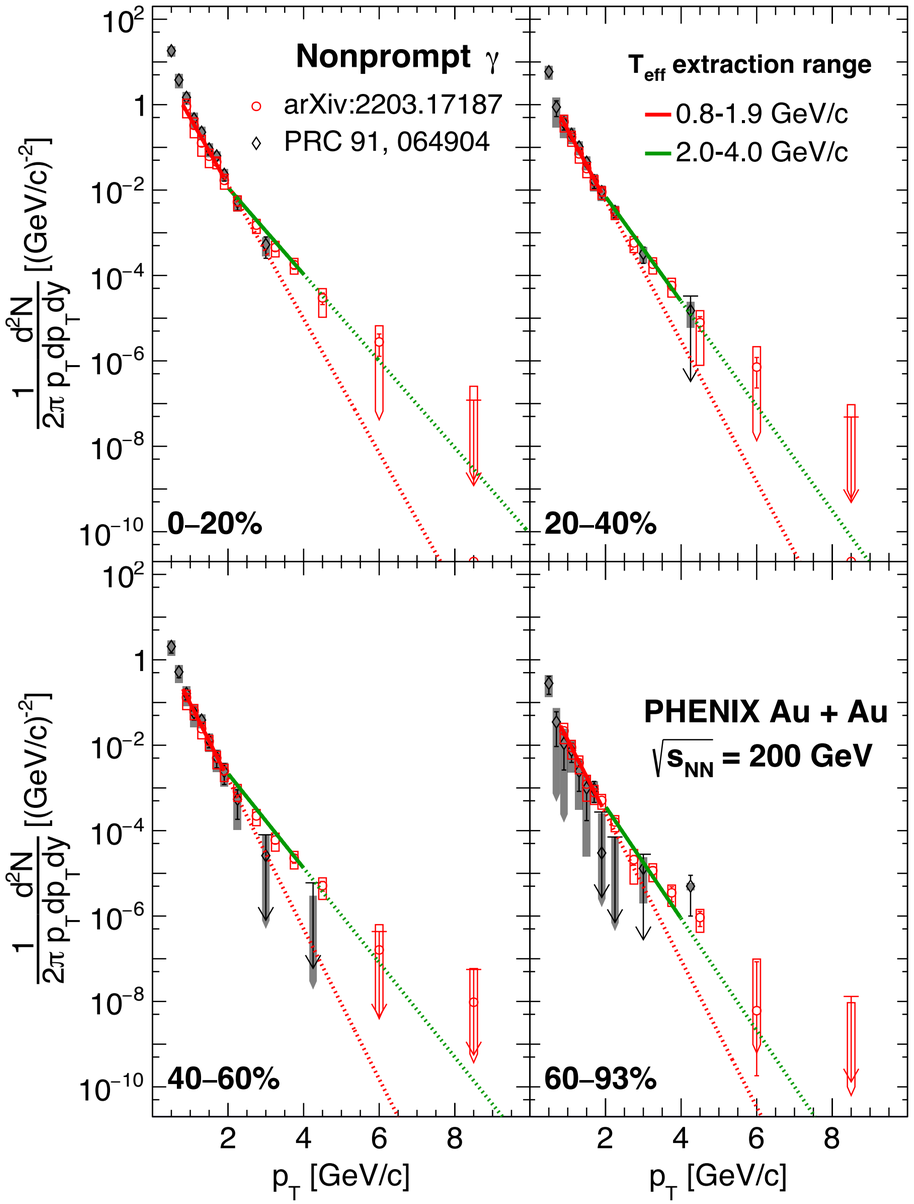


α independent of p_T for direct and nonprompt photons

T_{eff} for nonprompt direct γ



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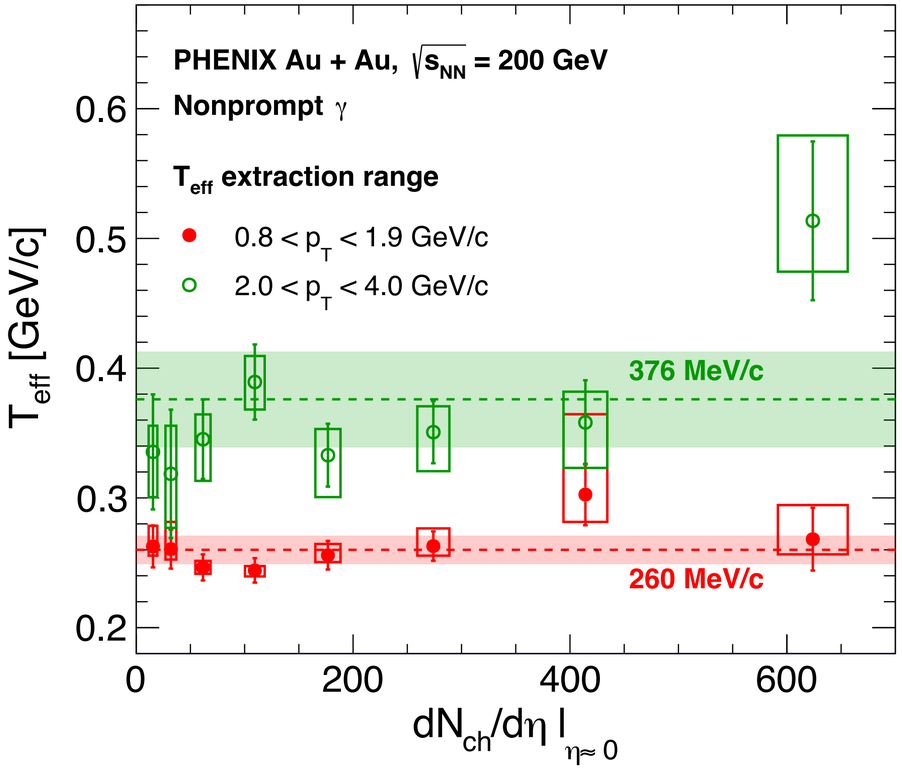
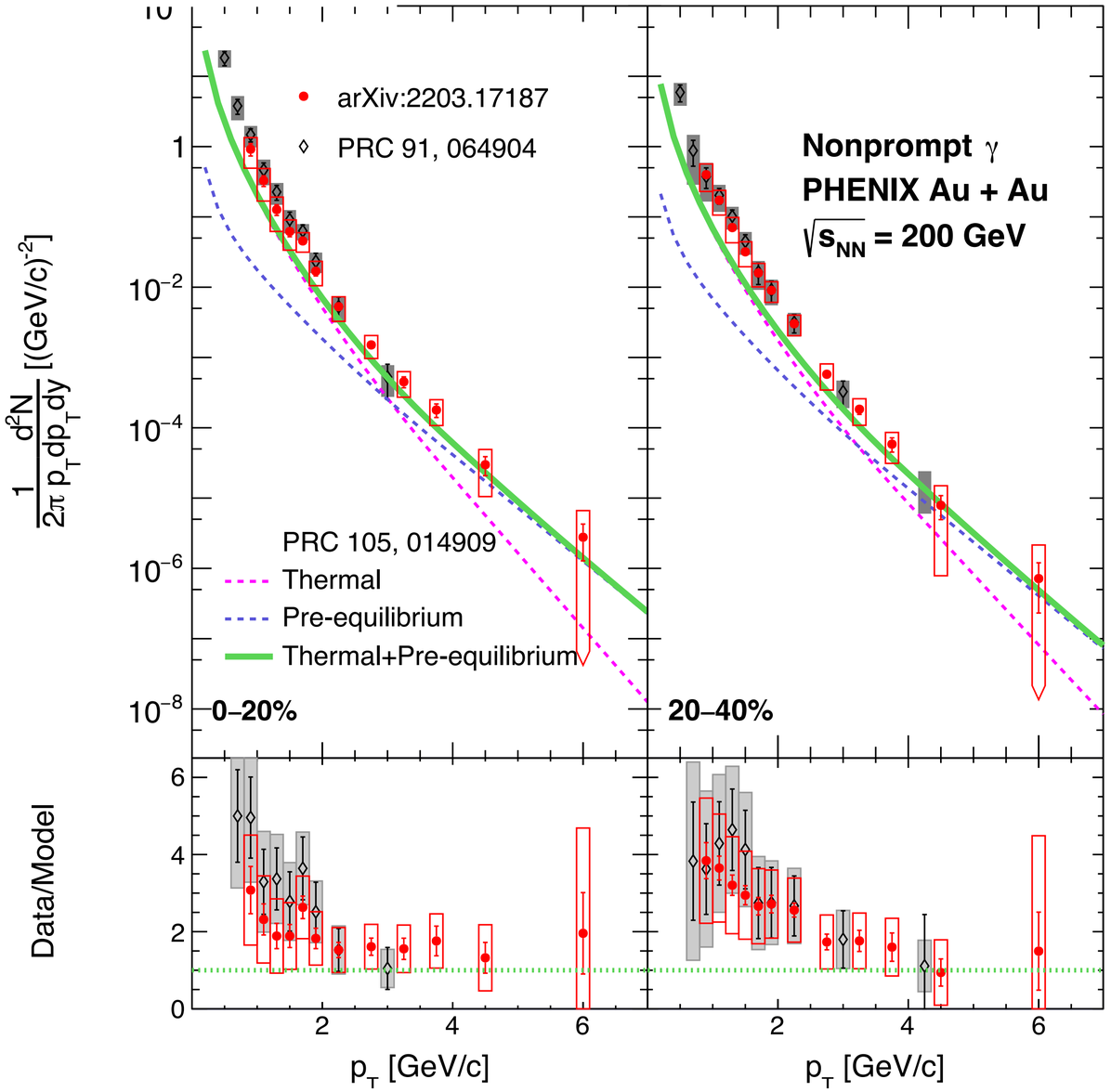


Increasing inverse slope with p_T to above 350 MeV/c suggests contributions from sources beyond those from Hadron Gas

Comparison with theory



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

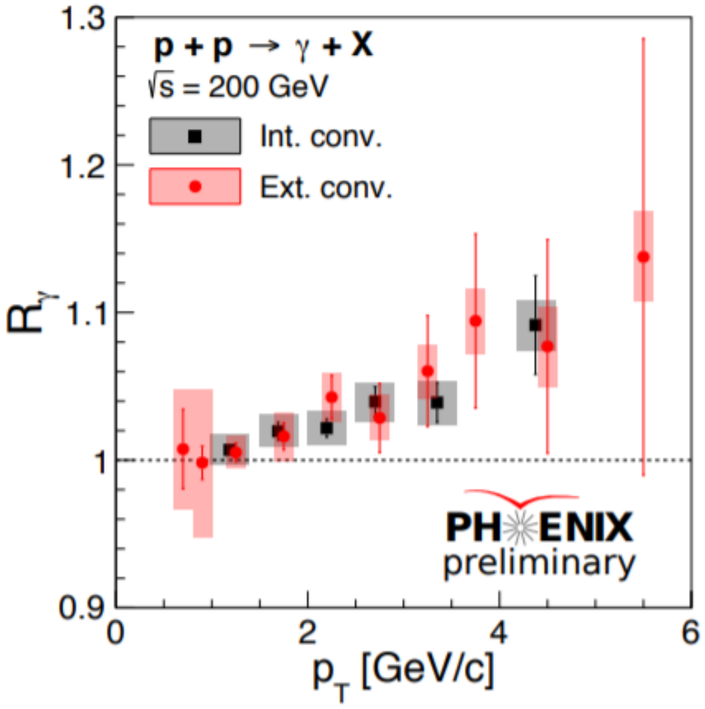
Multi-messenger heavy-ion physics

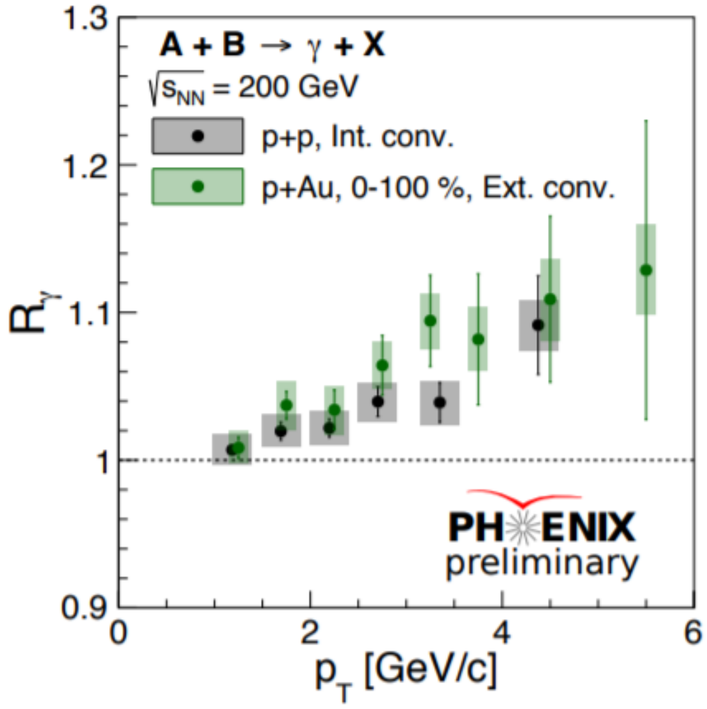
- Hybrid model that describes all stages of relativistic heavy-ion collisions
- Effect of the pre-equilibrium phase on both photonic and hadronic observables highlighted

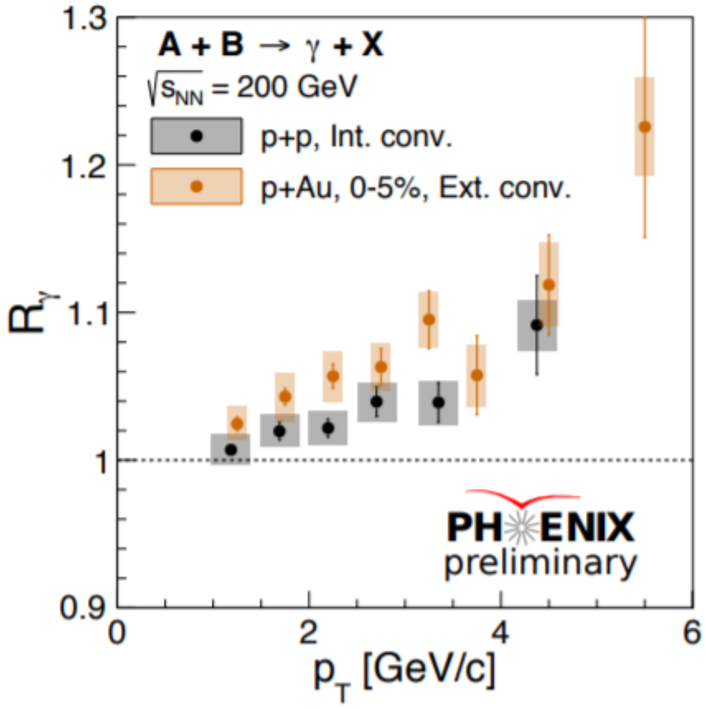
Dominant contribution from pre-equilibrium above 3 GeV/c in the model seems to align well with the data

Overall yield falls short, especially below 2 GeV

Direct γ in small system collisions

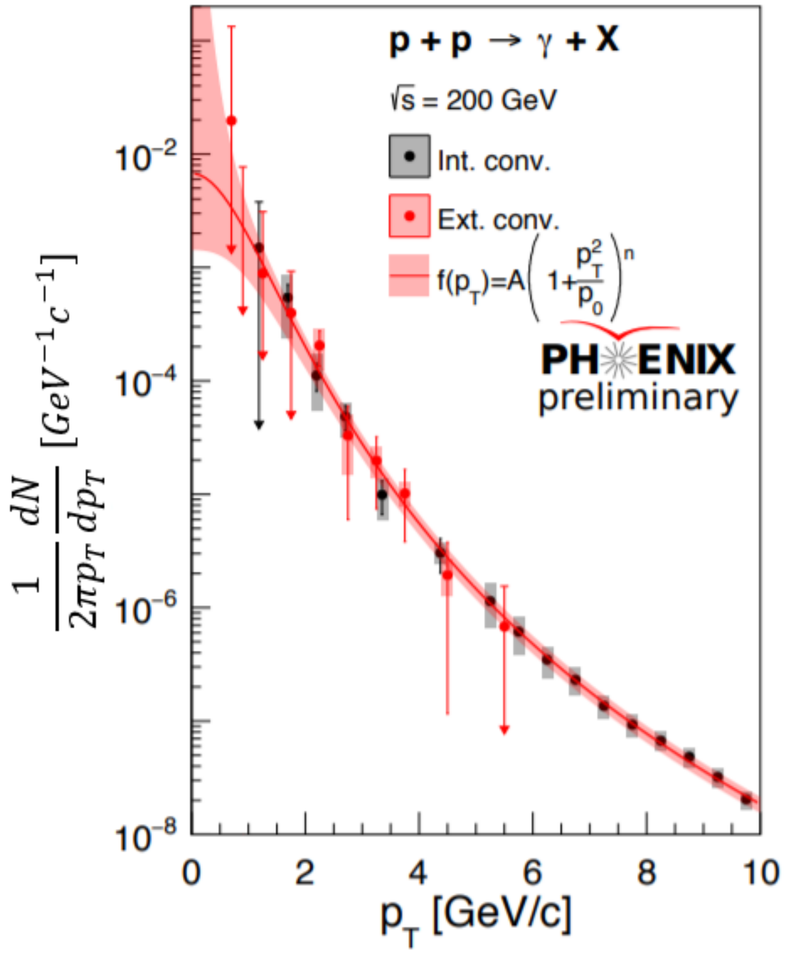


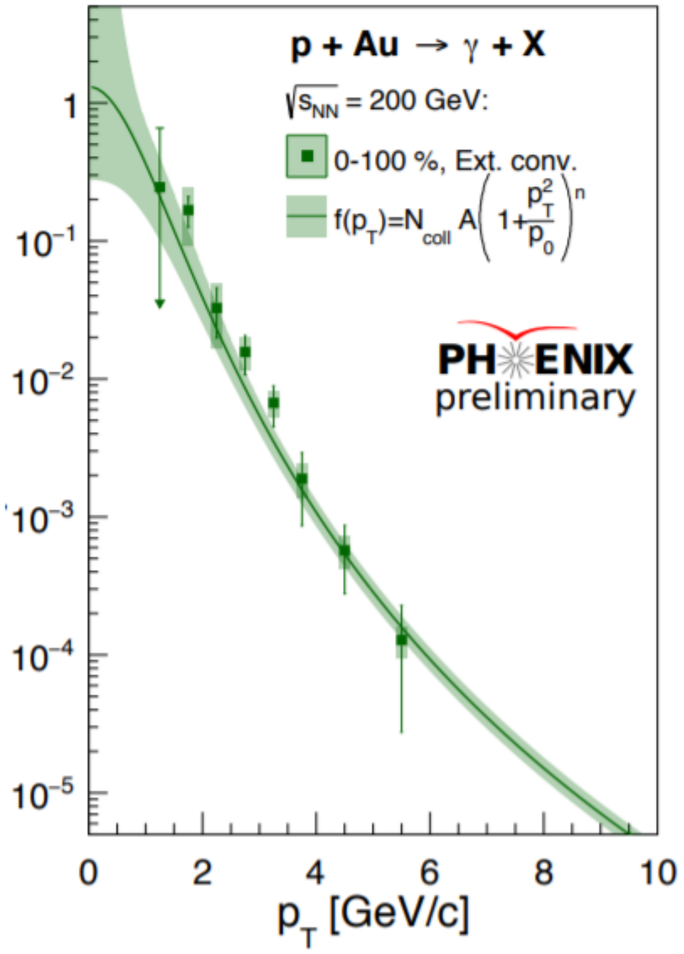


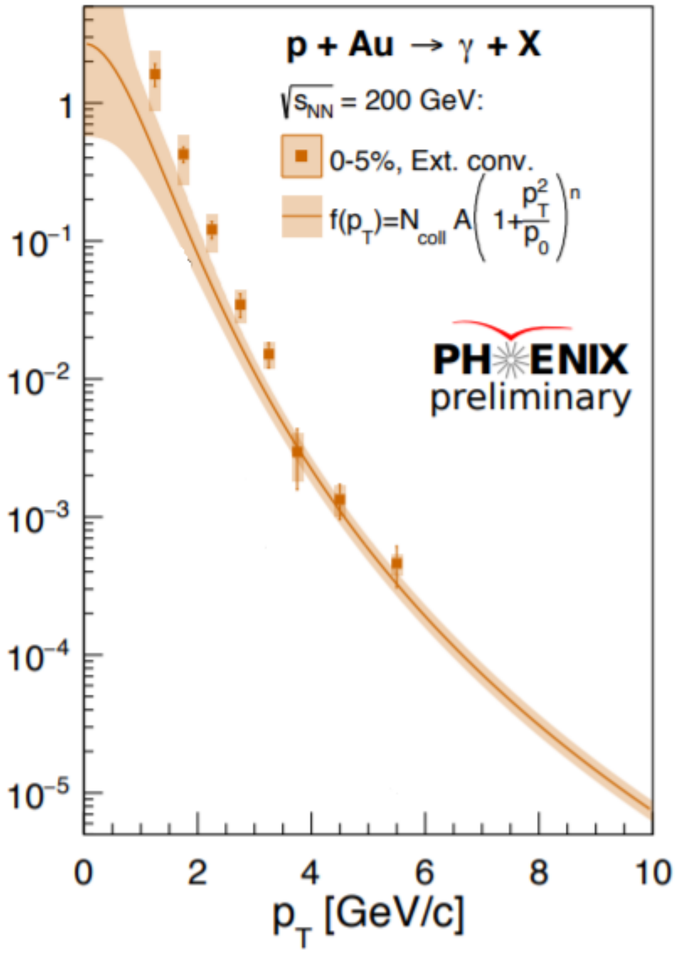


Direct γ in small system collisions

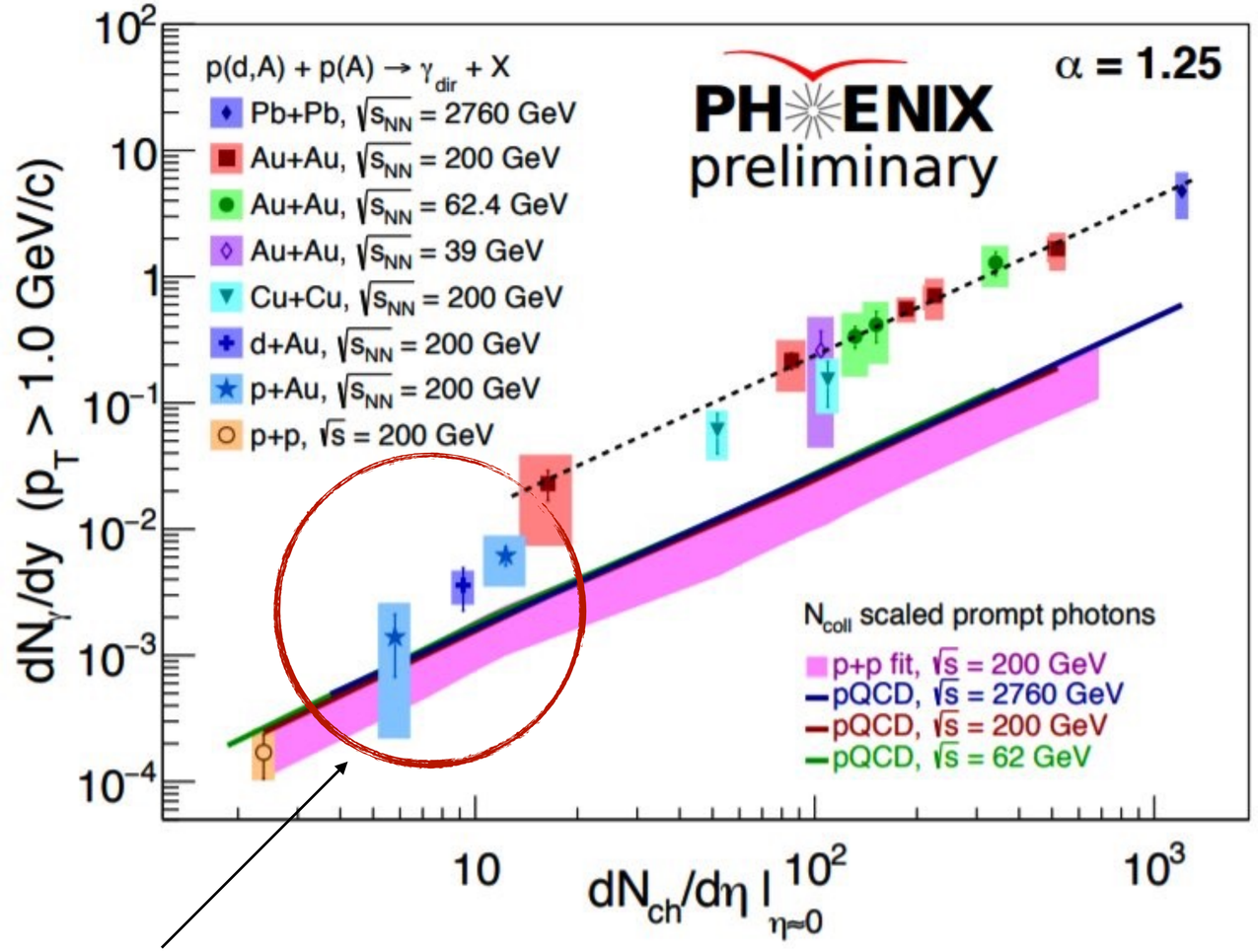
$$\gamma_{direct} = (R_\gamma - 1) * \gamma_{hadron}$$







Bridging the gap



Onset of QGP (?)

Jet anisotropy and jet shape at the future Electron-Ion Collider

Introduction

Azimuthal anisotropy has been the cleanest experimental indication of collective flow, an observable that provides experimental information on the transport properties and the equation of state of the Quark-Gluon Plasma in heavy-ion collisions

As the result of the finite size and anisotropic shape of the initial energy density distribution of the partons inside the colliding proton/ion, measurement of anisotropic flow harmonics is interesting for electron-proton/ion collisions

$$e(l) + N(P) \to e(l') + J_q(p_J) + X$$

$$\frac{d\sigma^{e+p\to e+\text{jet}+X}}{d^2p_T dy_J d\boldsymbol{q}_T} = \hat{\sigma}_0 \sum_q e_q^2 H(Q,\mu) \int \frac{d^2\boldsymbol{b}}{(2\pi)^2} \exp(i\boldsymbol{b}\cdot\boldsymbol{q}_T)\, x\tilde{f}_1(x,\boldsymbol{b},\mu,\zeta/\nu^2)$$

$$\times \tilde{S}^{\text{global}}(\boldsymbol{b},\mu,\nu) \left(\tilde{\mathcal{S}}_c(\boldsymbol{b},R,\mu) J_q(p_T,R,\mu)\right)$$

$\cos(n(\phi_J - \phi_q))$

dependence

Soft function

Has a jet radius dependence

For unpolarized proton/ion, and under the condition that the electron and jet are back-to-back

Introduction

$$\frac{d\sigma}{d^2p_T dy_J d\phi_J d^2q_T} = \frac{d\sigma}{2\pi d^2p_T dy_J q_T dq_T}\left[1 + 2\sum_{n=1}^{\infty} v_n(p_T, y_J)\cos(n(\phi_q - \phi_J))\right]$$

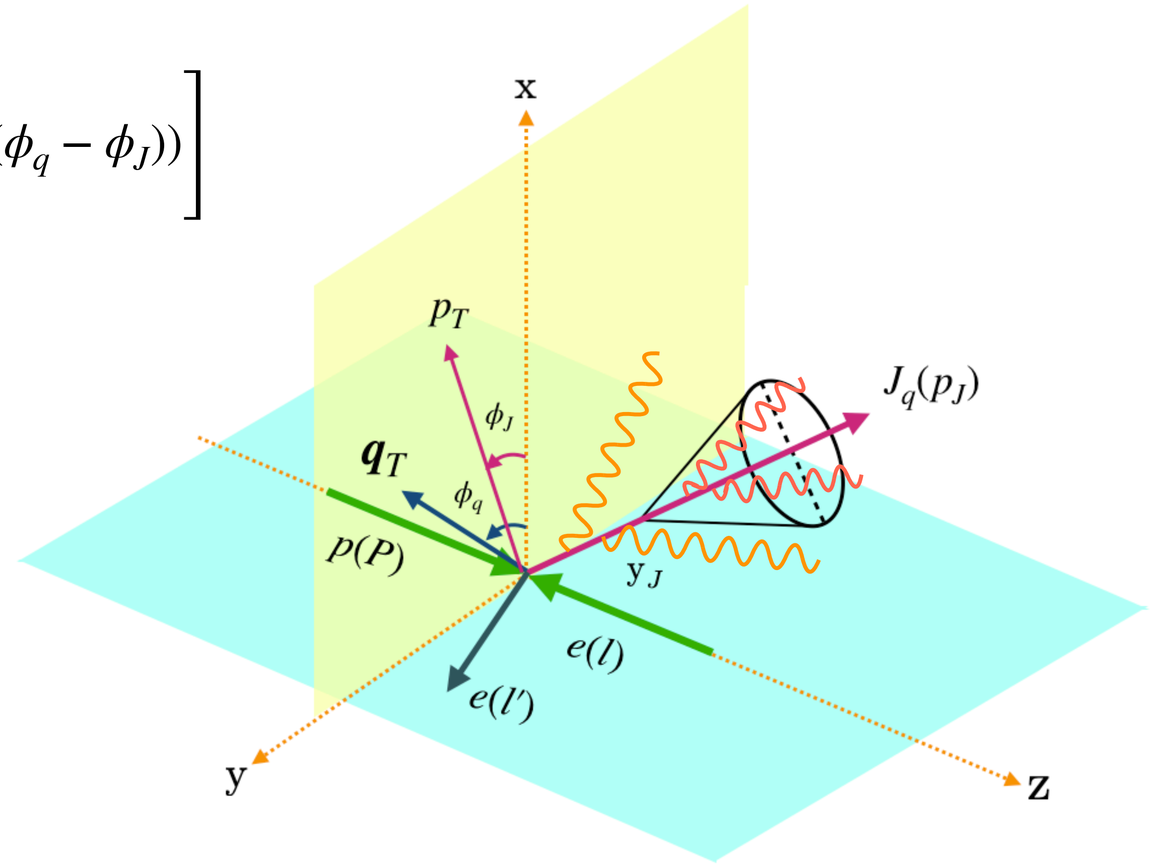
q_T : transverse momentum imbalance

p_T : jet transverse momentum

y_J: jet rapidity

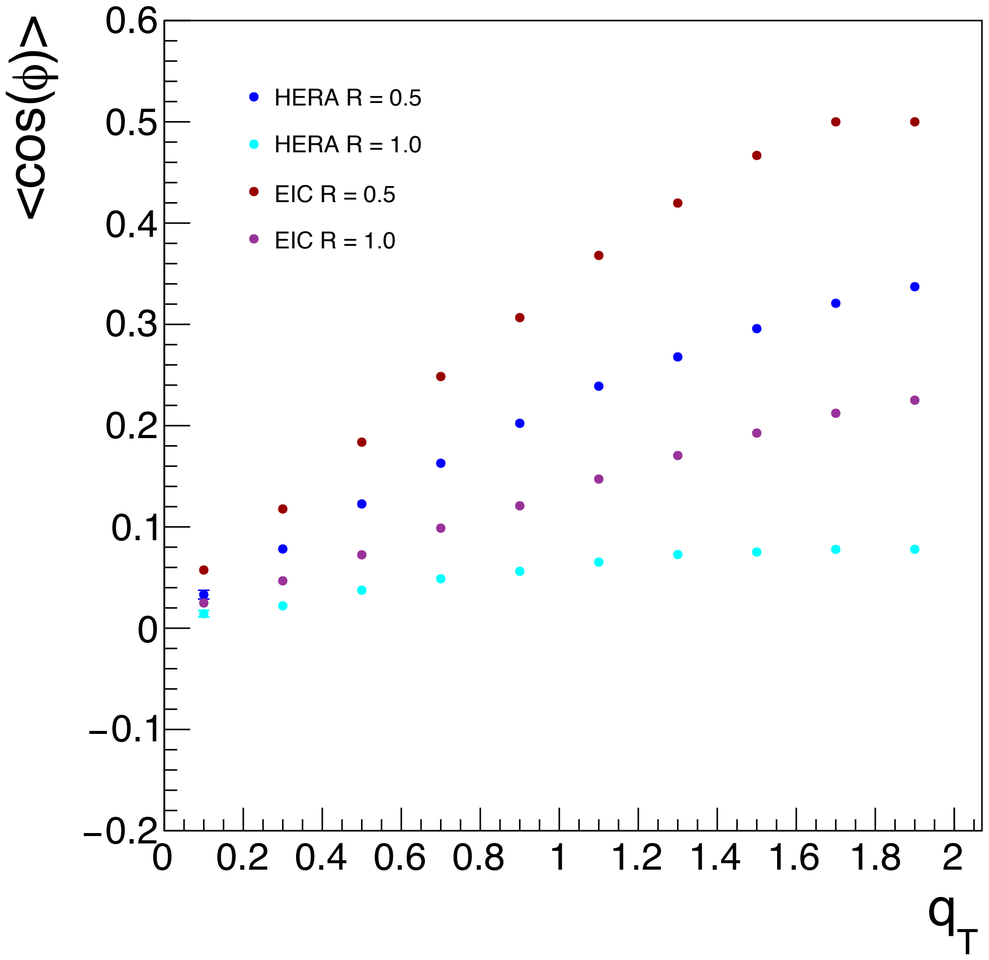
ϕ_q : azimuthal angle of transverse momentum imbalance

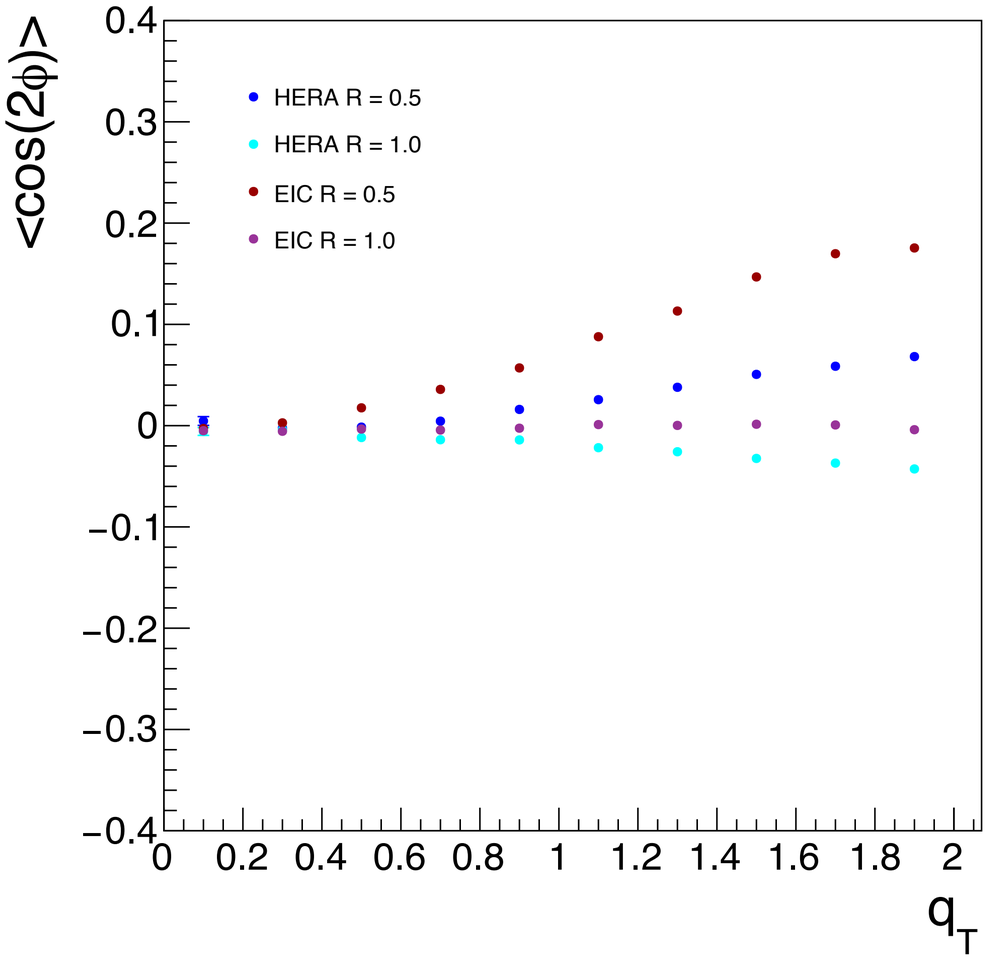
ϕ_J : azimuthal angle of jet transverse momentum



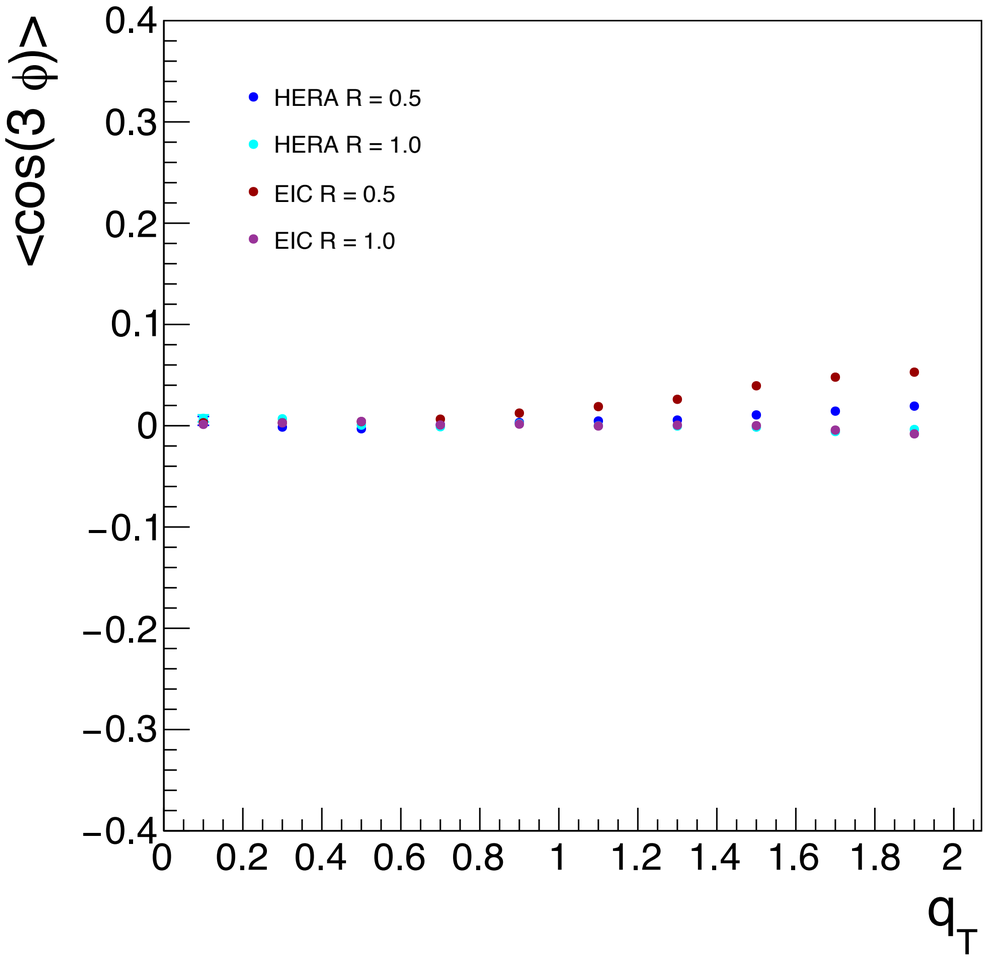
The back-to-back lepton-jet production from $e + p$ collisions provides insights into transverse momentum dependent (TMD) studies, where the jet observables are expected for probing the three-dimensional nucleon structure encoded in transverse-momentum-dependent parton-distribution functions (TMD PDFs)

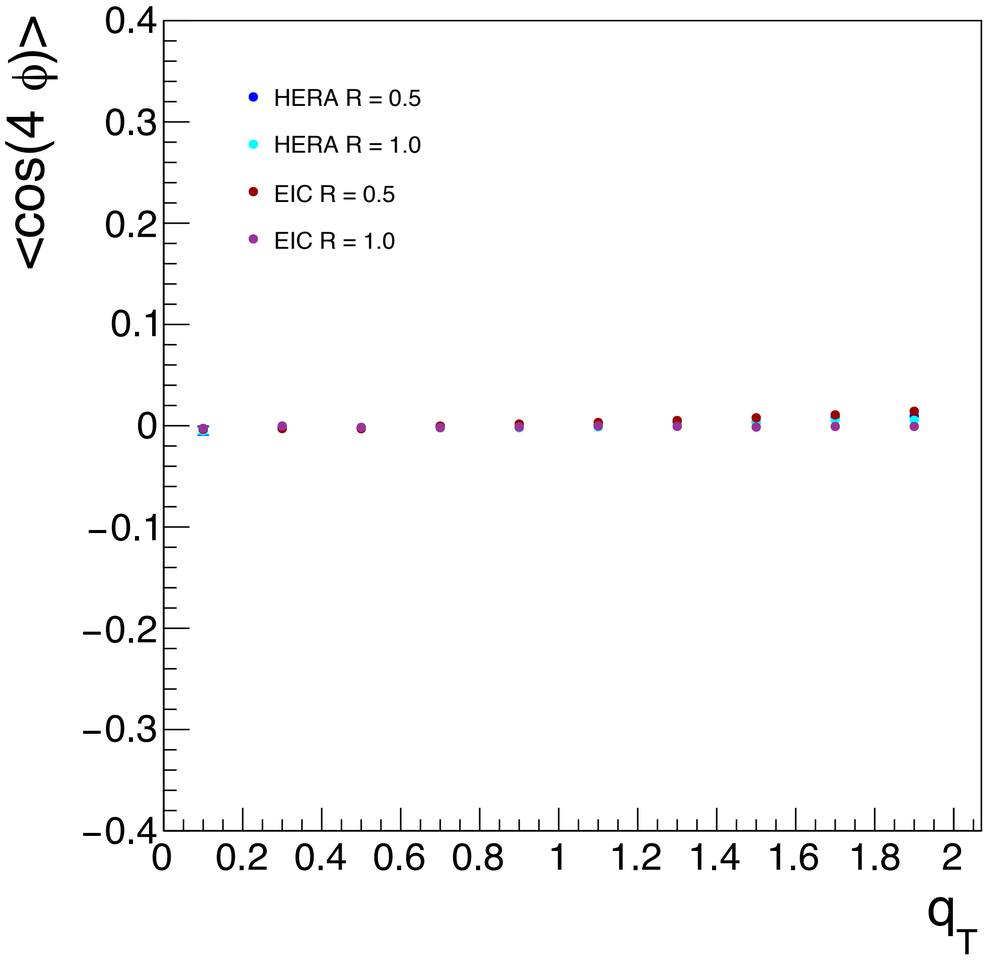
Jet anisotropy





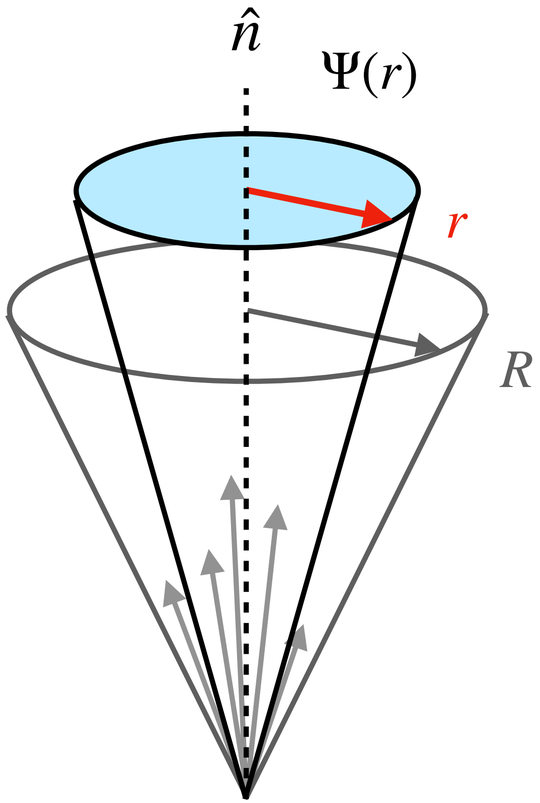
Jet anisotropy





Integrated jet shape

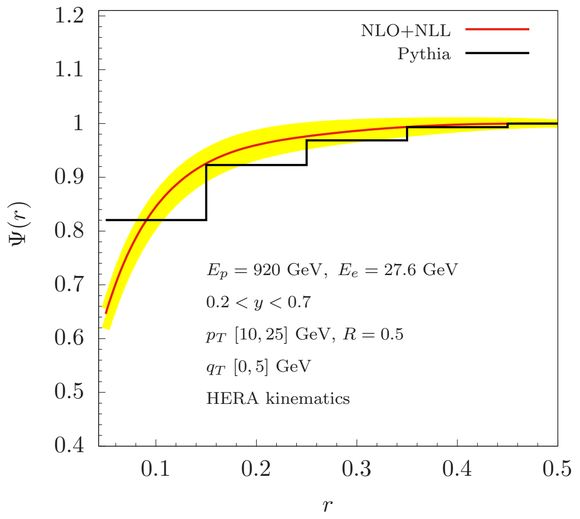
$$\psi(r) = \frac{\int dz_r \, z_r \dfrac{d\sigma}{d^2\boldsymbol{p}_T dy_J d^2\boldsymbol{q}_T dz_r}}{\dfrac{d\sigma}{d^2\boldsymbol{p}_T dy_J d^2\boldsymbol{q}_T}}$$

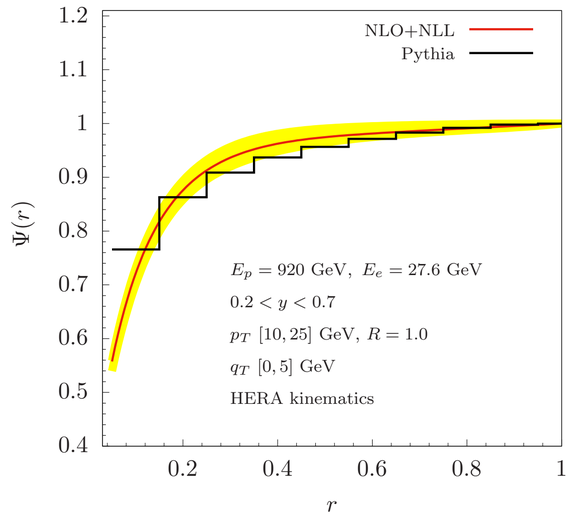


R = 0.5

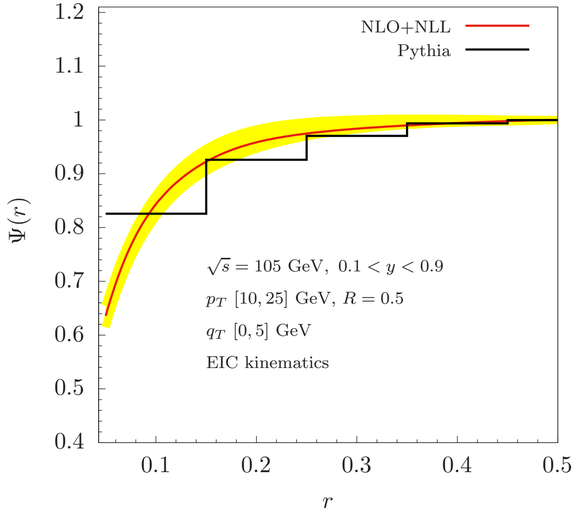
R = 1.0

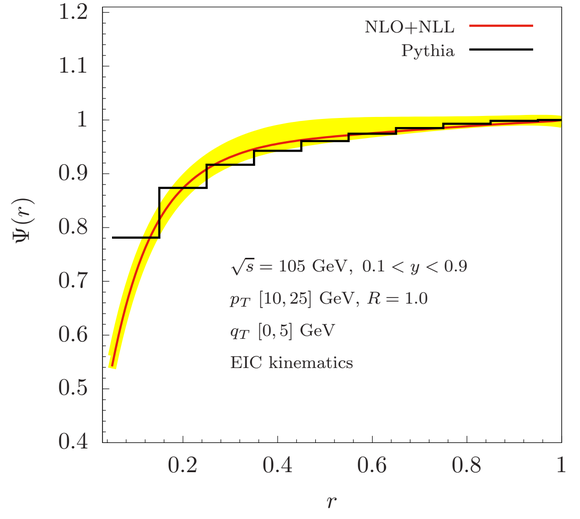
HERA





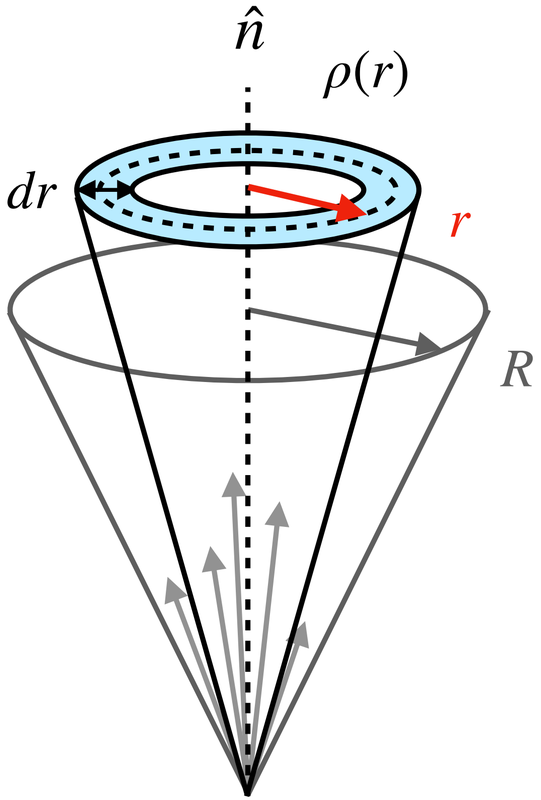
EIC





Differential jet shape

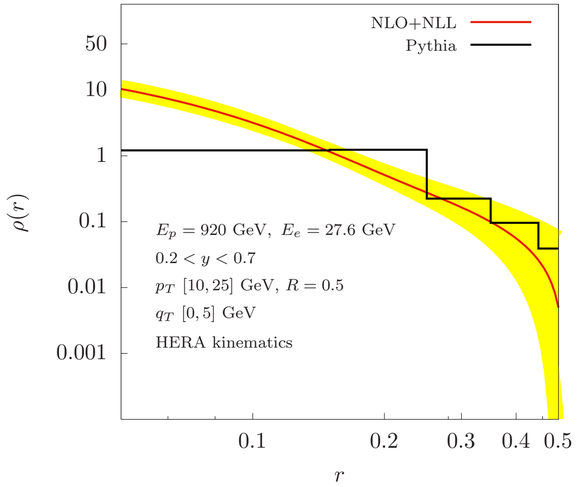
$$\rho(r) = \frac{d\psi(r)}{dr}$$

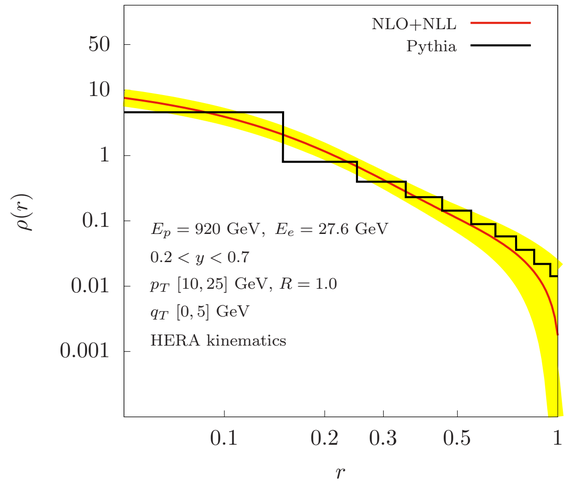


R = 0.5

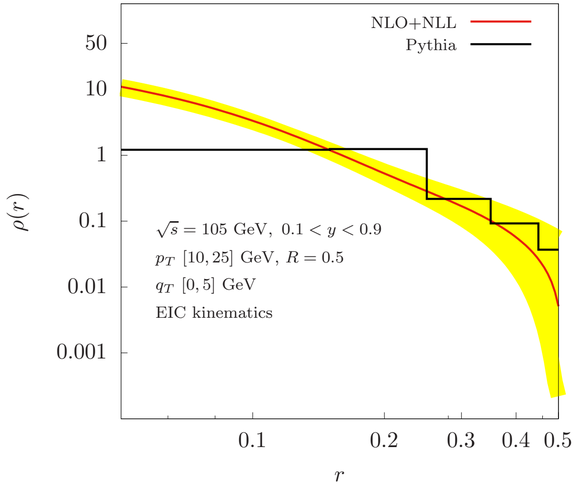
R = 1.0

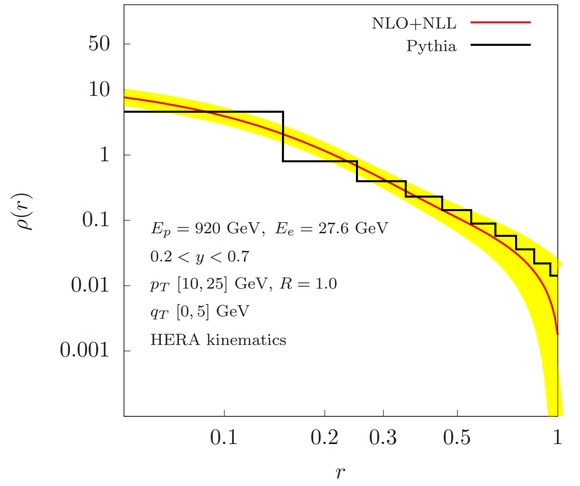
HERA





EIC





Thank you for your attention!