Low p_T Direct Photon Measurements at PHENIX

Vassu Doomra (for the PHENIX collaboration)
Stony Brook Univeristy

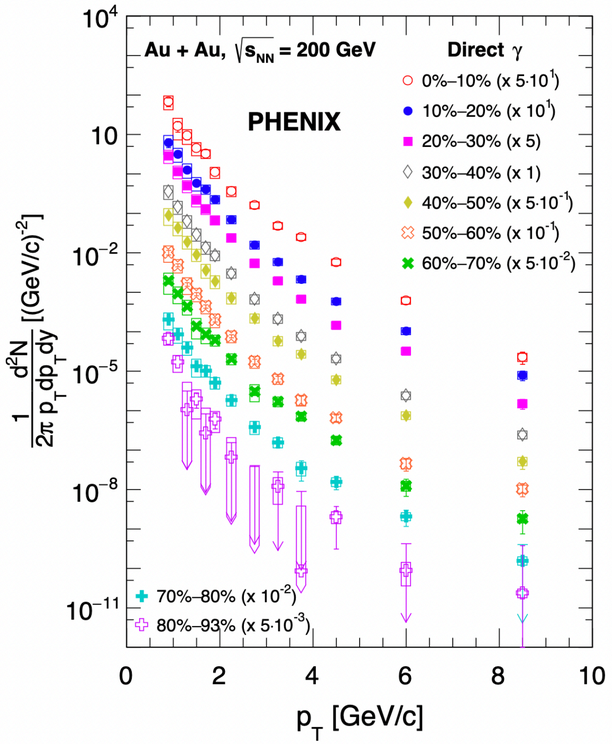
Stony Brook University

PHENIX

2023

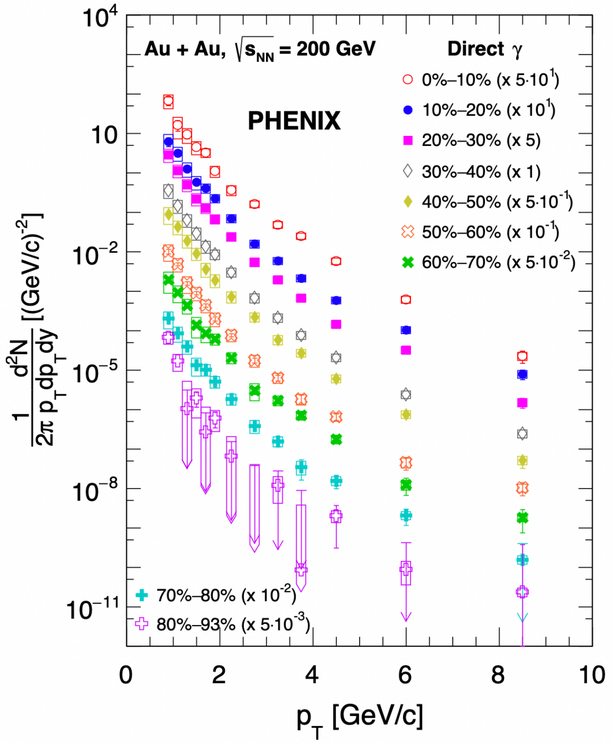
Outline

(A)
Direct Photon Spectra

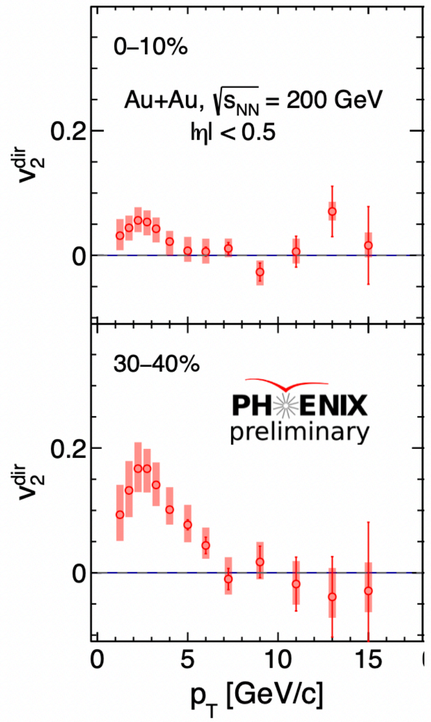


Outline

(A)
Direct Photon Spectra

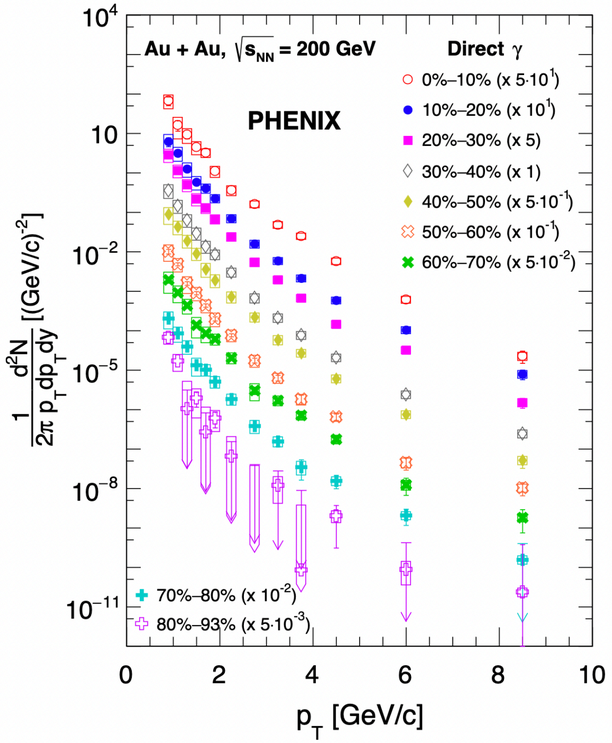


(B)
Direct Photon Flow

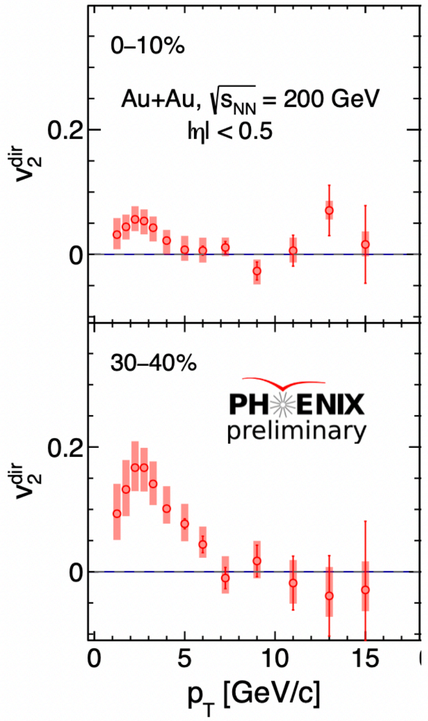


Outline

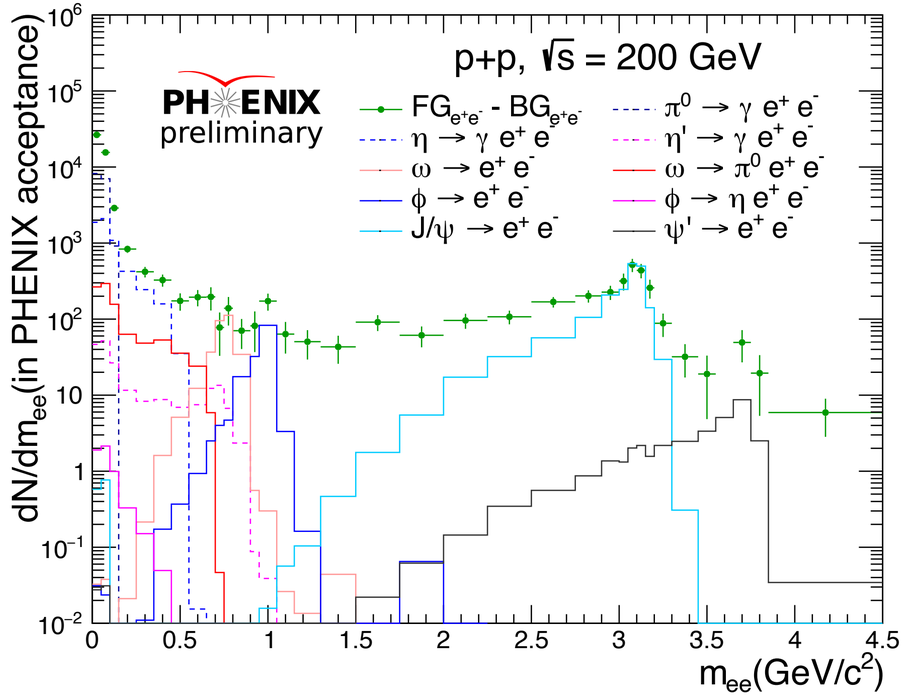
(A)
Direct Photon Spectra



(B)
Direct Photon Flow

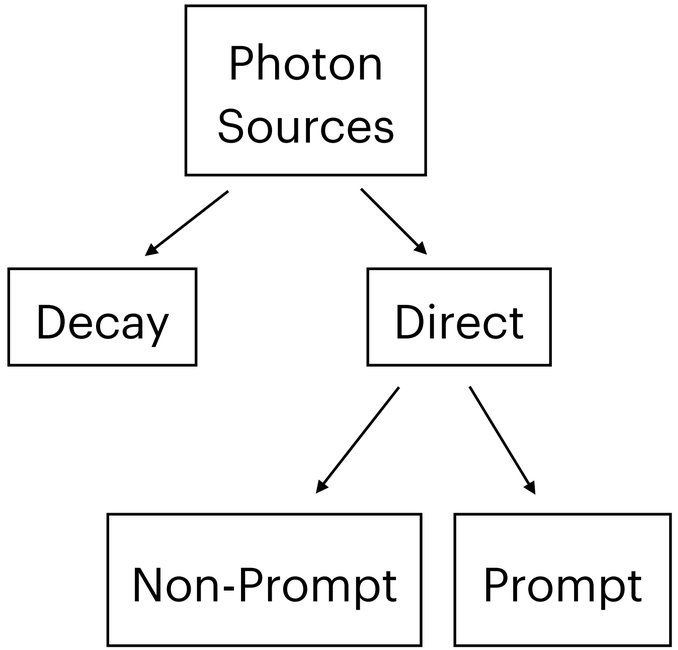


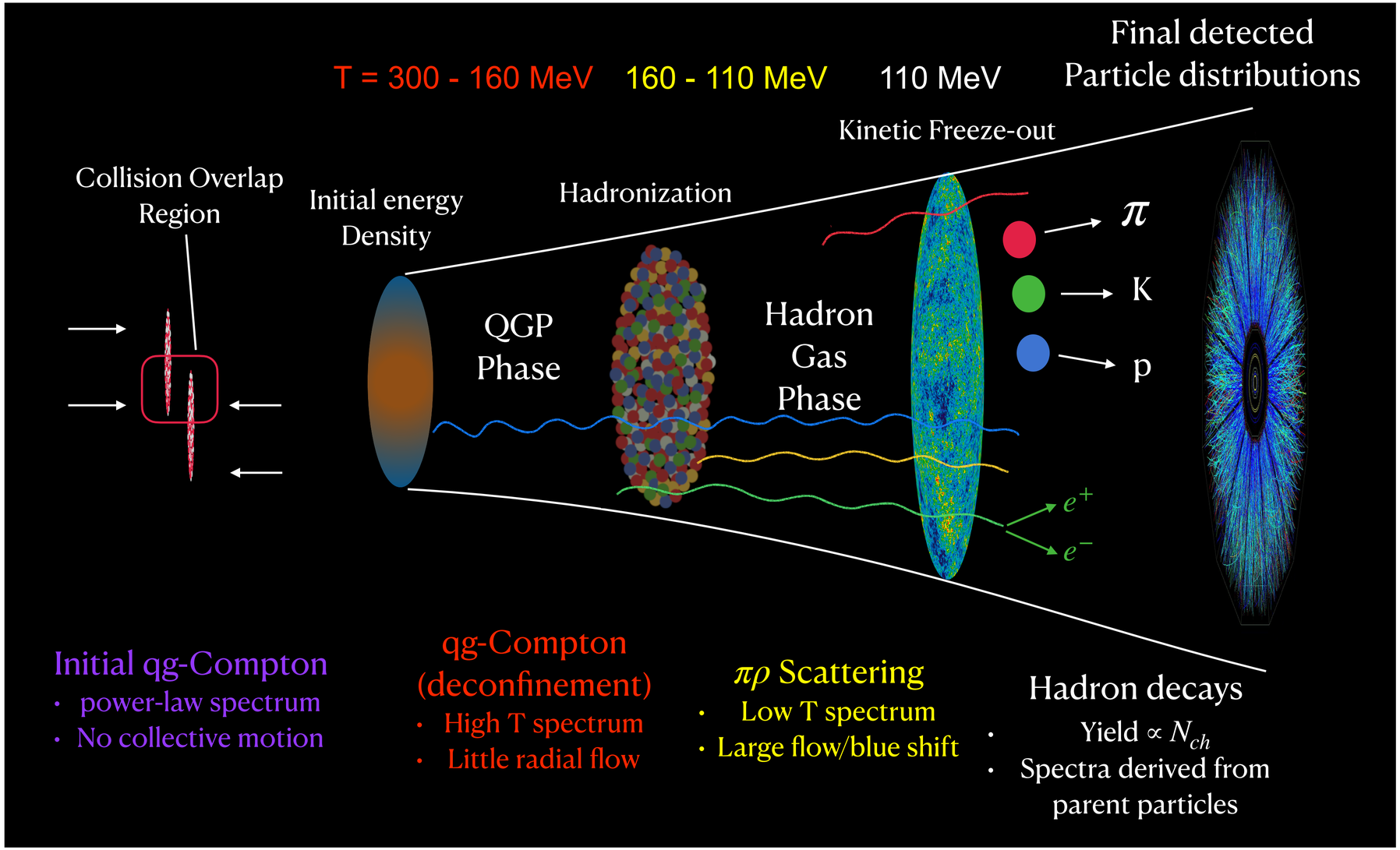
(C)
Dilepton Continuum



Introduction

- Photons are color blind probes of Quark Gluon Plasma.





Photon Measurements with PHENIX

Calorimeter Method → Photons that directly deposit energy into EMCals.

Phys. Rev. Lett. 109, 152302 (2012)

External Conversion Method → Photons that convert into e^+e^- pairs in the detector material.

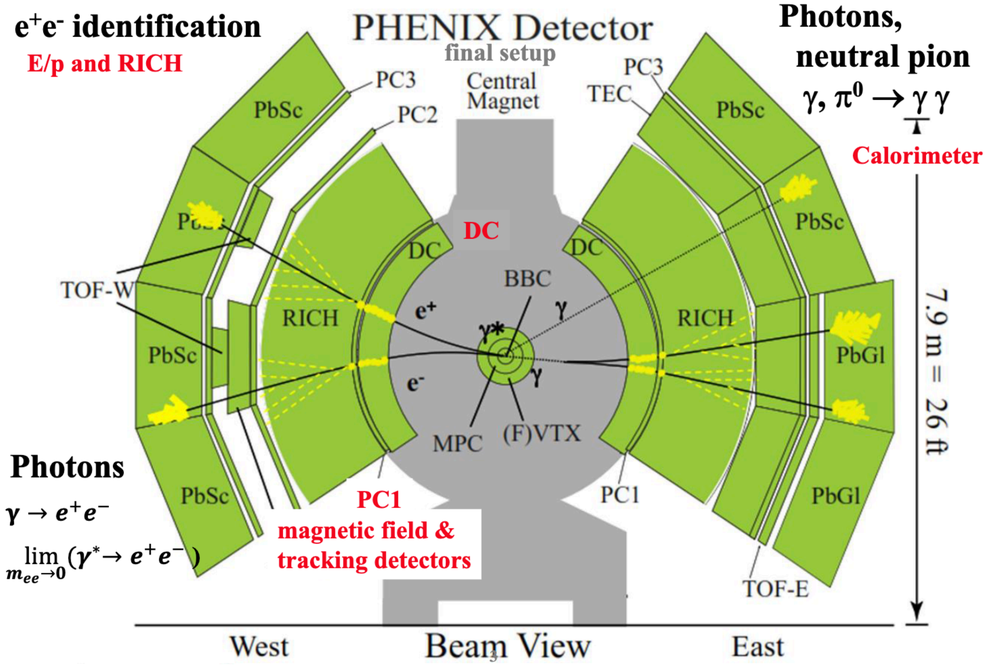
arXiv:2203.17187
Phys. Rev. C 107, 024914 (2023)
Phys. Rev. C 91, 064904 (2015)

Internal Conversion Method → Virtual photons that internally convert into e^+e^- pairs.

Phys. Rev. Lett. 104, 132301 (2010)

Au+Au dataset at $\sqrt{s_{NN}} = 200$ GeV (2014)

With the Silicon Vertex Detector (~ 13% X_0)



Direct γ for Au+Au at 200 GeV

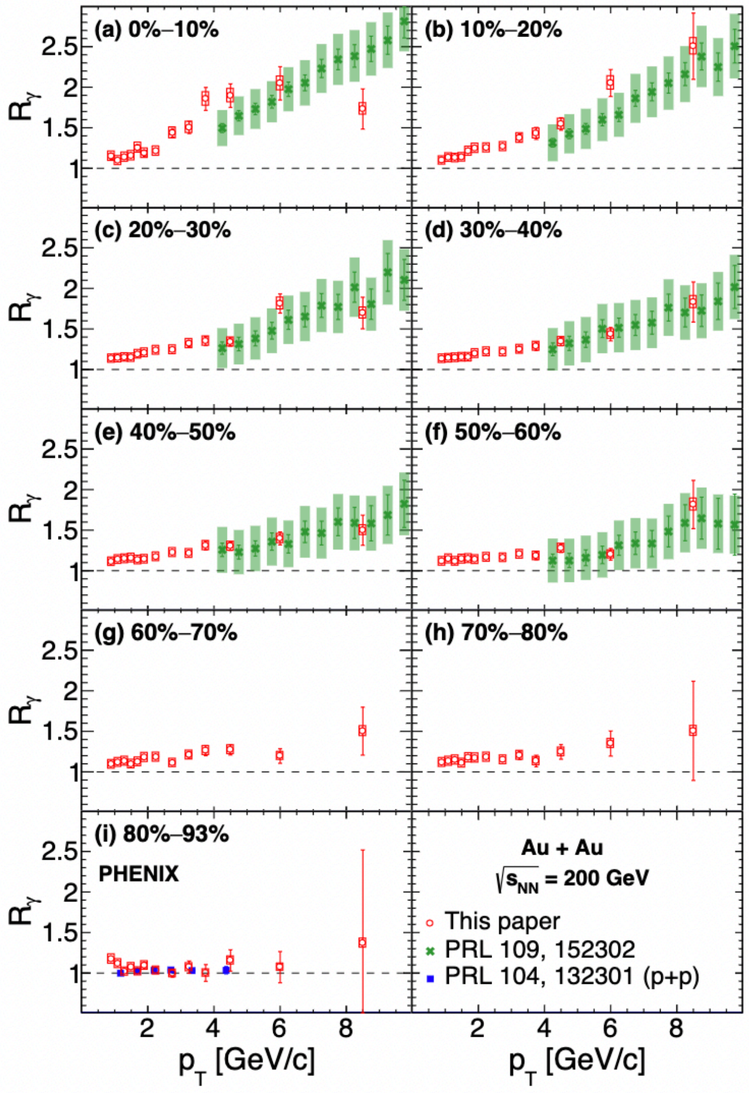
The quantity of interest is

$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{decay}}$$

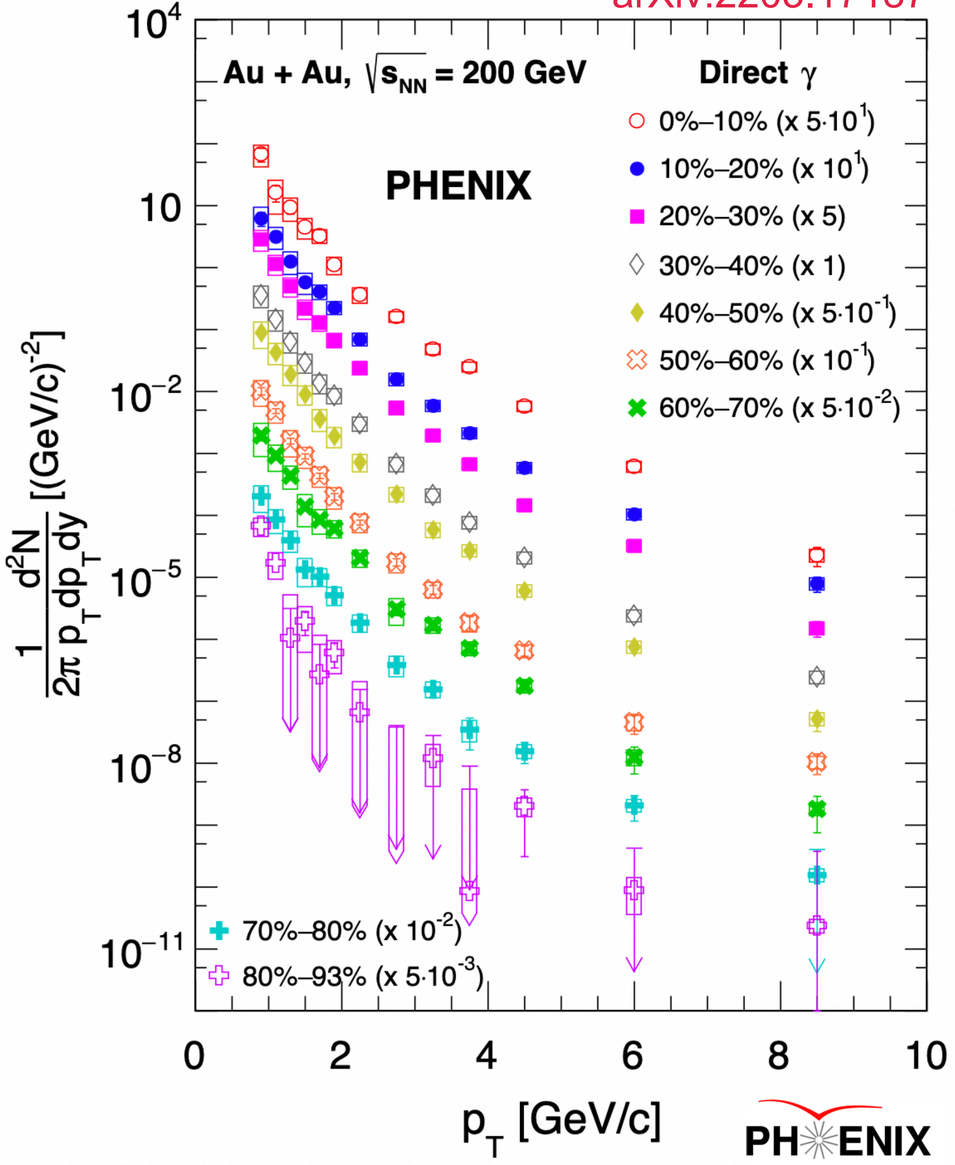
$$\gamma^{dir} = (R_\gamma - 1)\ \gamma^{hadron}$$

About 20% direct photon component is seen in more central collisions.

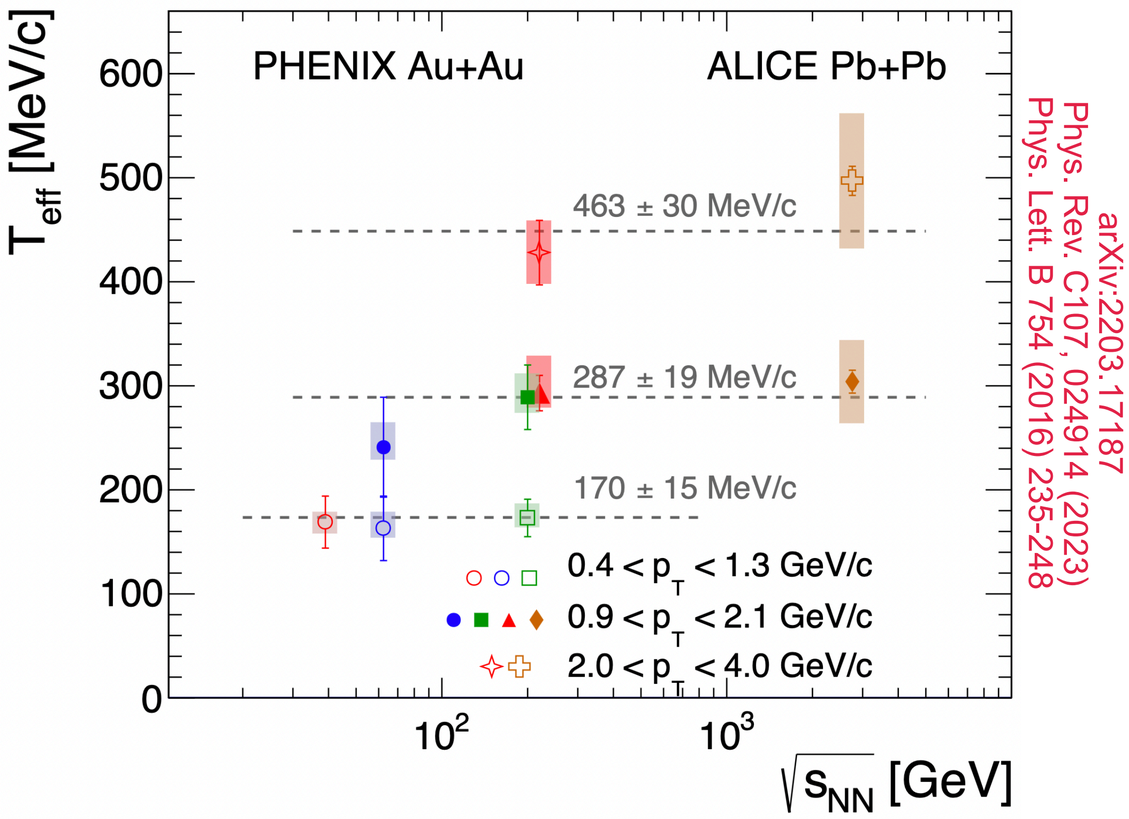
arXiv:2203.17187



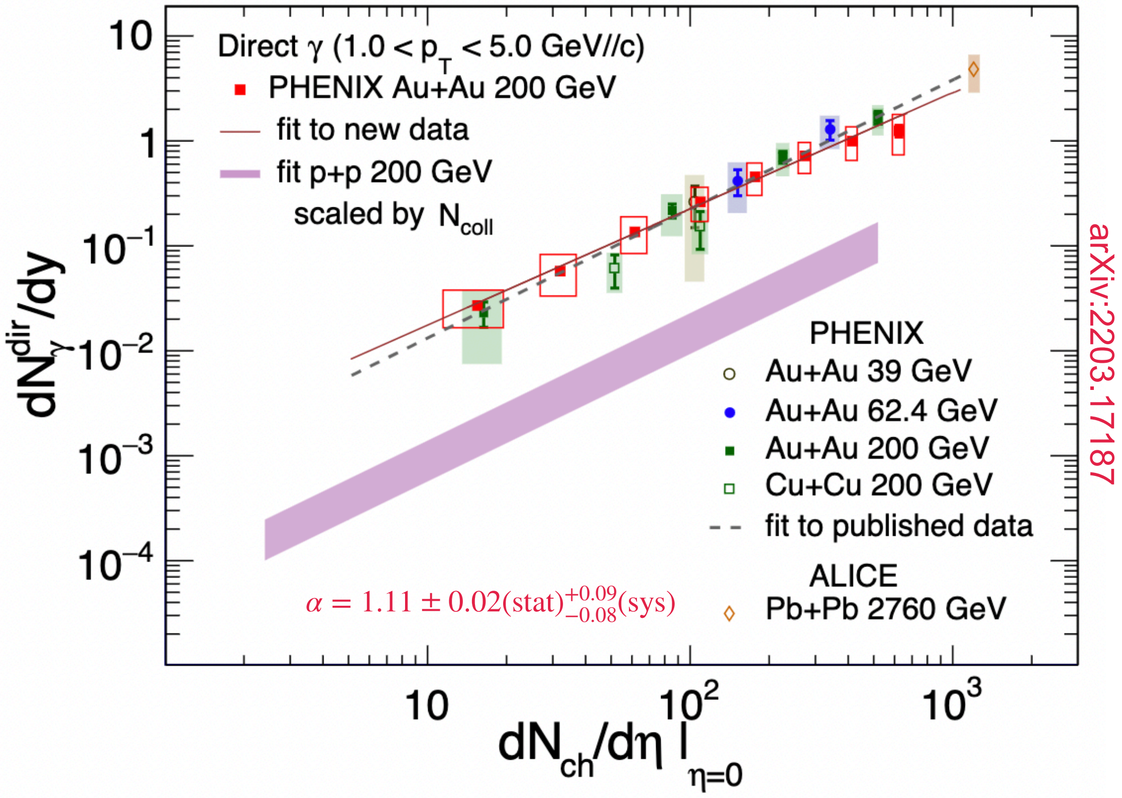
arXiv:2203.17187



Direct γ for Au+Au at 200 GeV



arXiv:2203.17187
Phys. Rev. C107, 024914 (2023)
Phys. Lett. B 754 (2016) 235-248



arXiv:2203.17187

- T_{eff} increases with p_T
- No obvious variation of T_{eff} with $\sqrt{s_{NN}}$

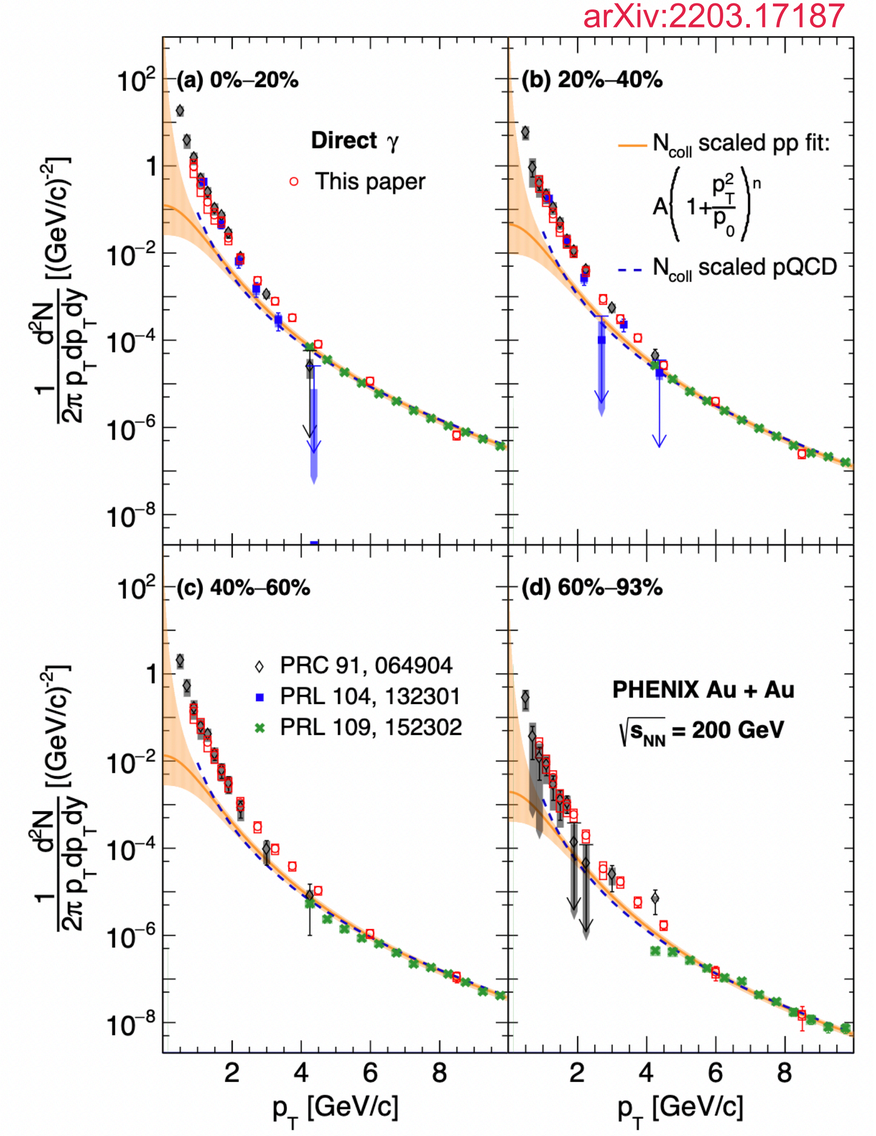
$$\frac{dN_\gamma}{dy} = A \times \left(\frac{dN_{ch}}{d\eta}\right)^{\alpha}$$

Universal scaling behaviour of direct photon yields in all A+A systems.

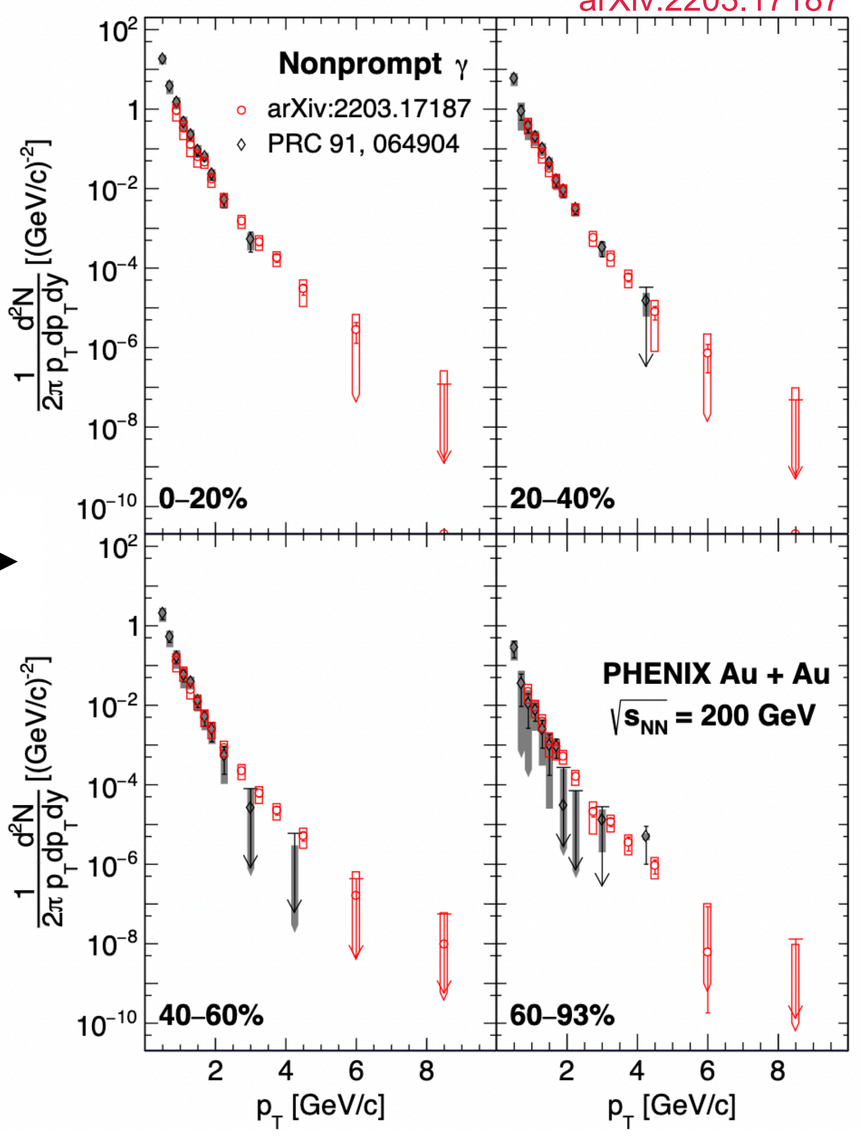
PHENIX

Non-Prompt Direct γ for Au+Au at 200 GeV

arXiv:2203.17187

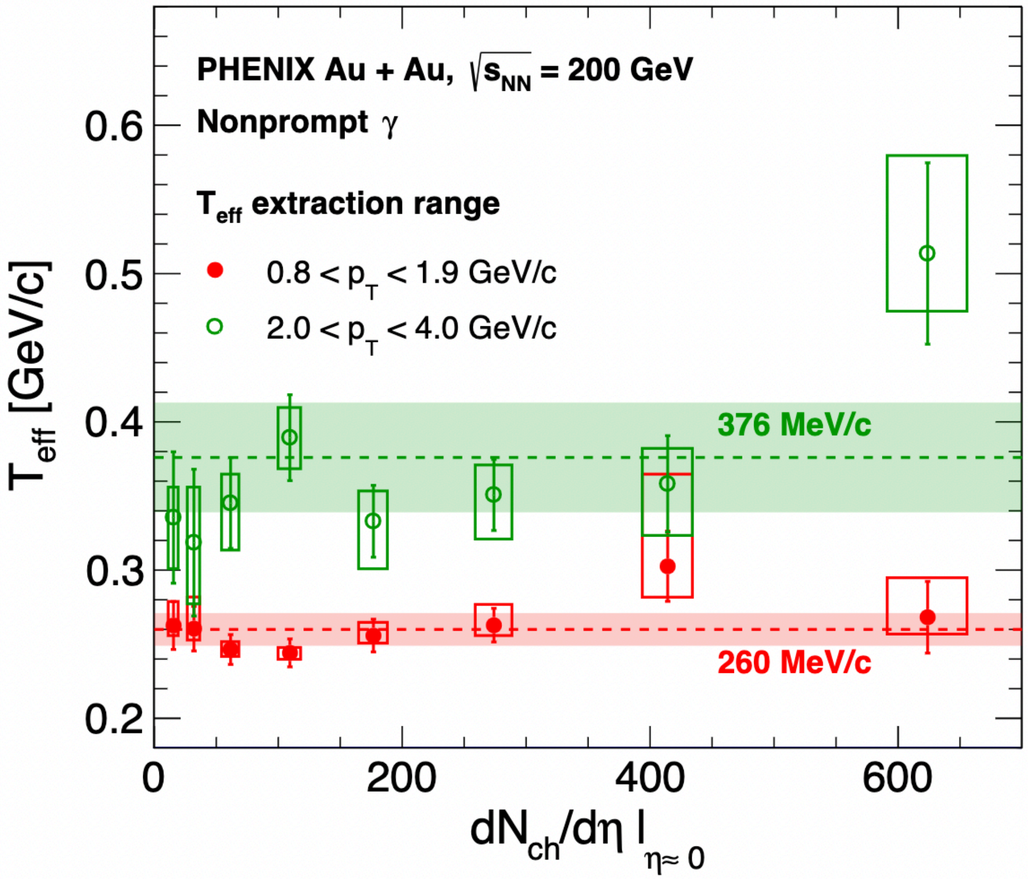


— N_{coll} scaled p+p fit



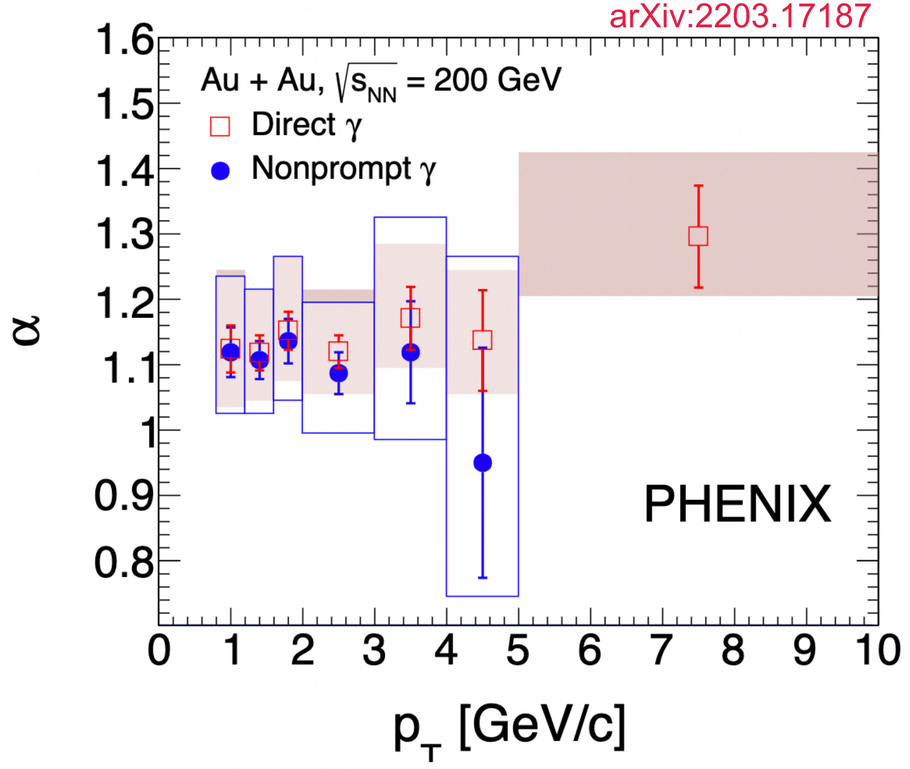
T_{eff} and scaling behaviour of non-prompt direct γ

arXiv:2203.17187



No obvious system size dependence of T_{eff}

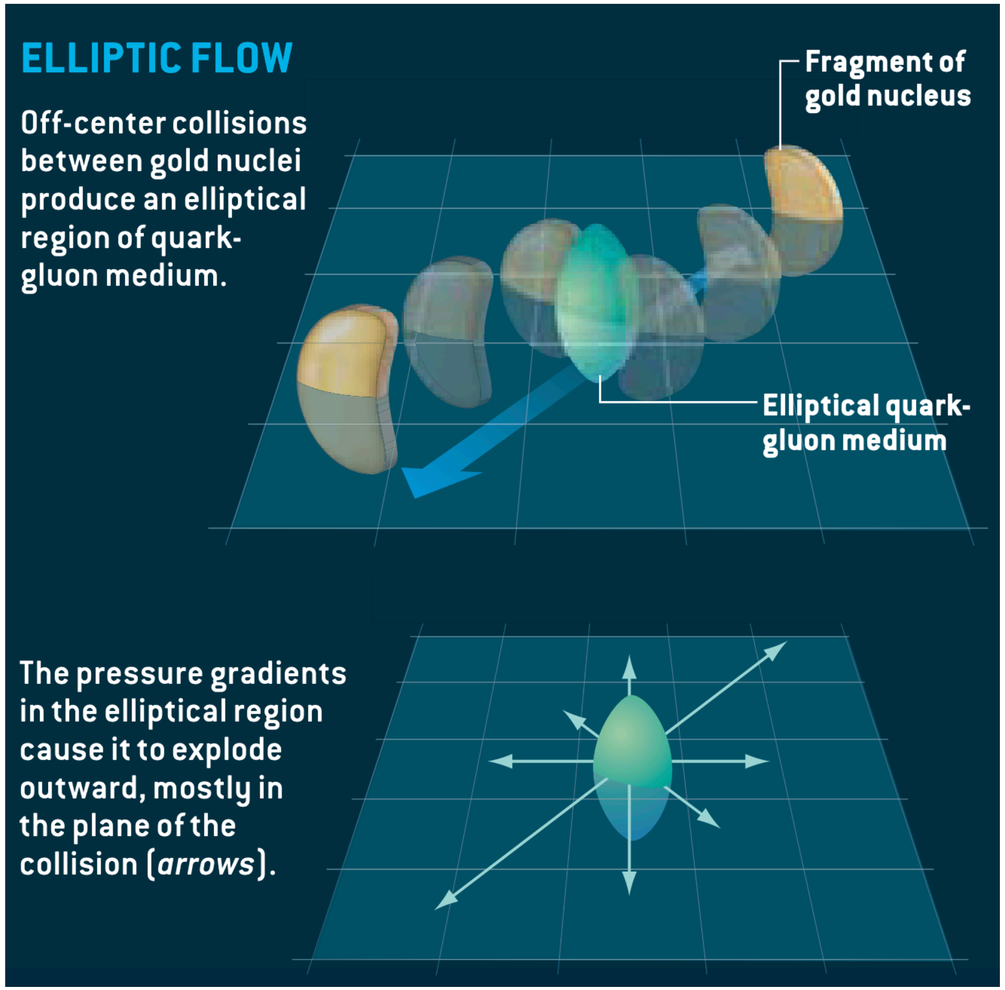
arXiv:2203.17187



Data: α independent of p_T

Hydro Model: Different dependence on $dN_{ch}/d\eta$ for QGP, HG and prompt component.

Elliptic flow of direct photons



Quantified by the second Fourier moment of the particle azimuthal distribution with respect to the reaction plane.

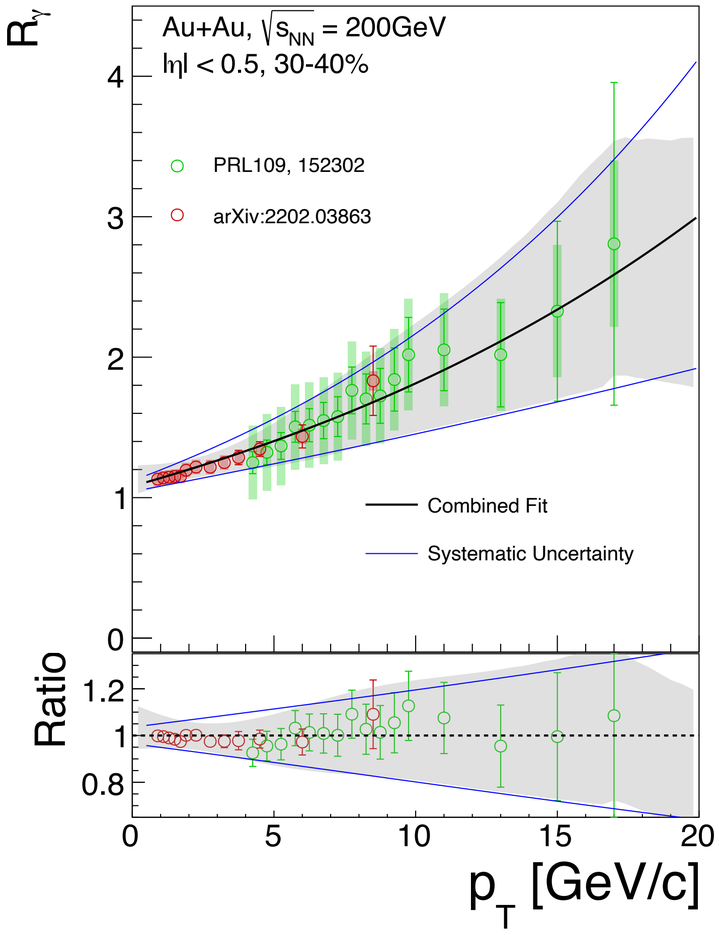
$$\frac{dN}{d\phi} = N_0[1 + 2v_2 \cos(2\phi)]$$

In the analysis, v_2 is calculated using the following equation

$$v_2^{dir} = \frac{R_\gamma v_2^{incl} - v_2^{dec}}{R_\gamma - 1}$$

We measure the anisotropy in the azimuthal distribution of photons with respect to the reaction plane determined by the forward vertex detector $1.5 < |\eta| < 2.9$.

Direct Photons v_2

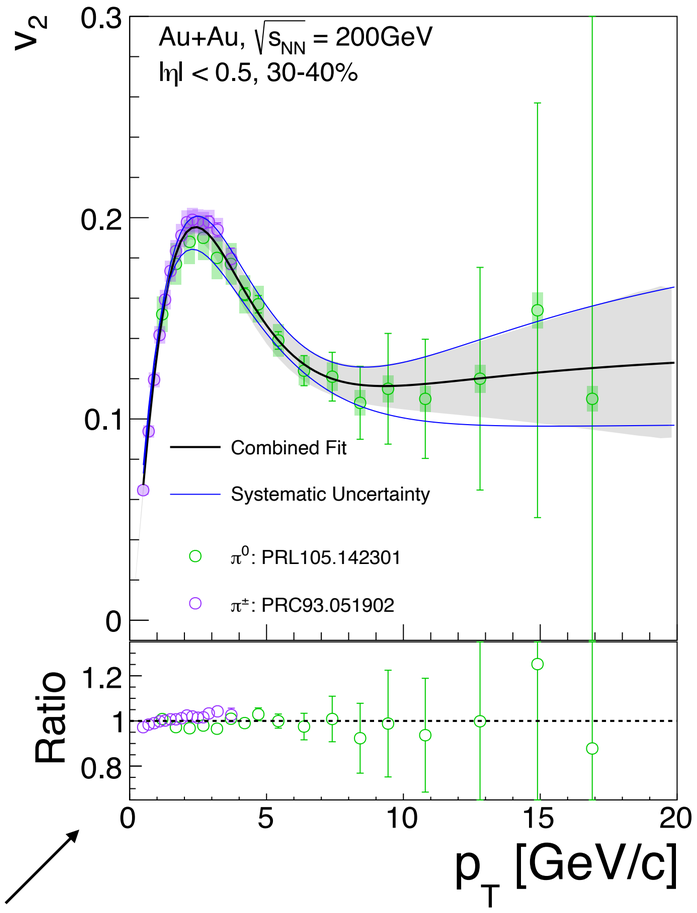


v_2^{incl} of all the photons measured by the EMCal (from data)

v_2^{dec} of all the photons coming from hadron decays (comes from cocktail)

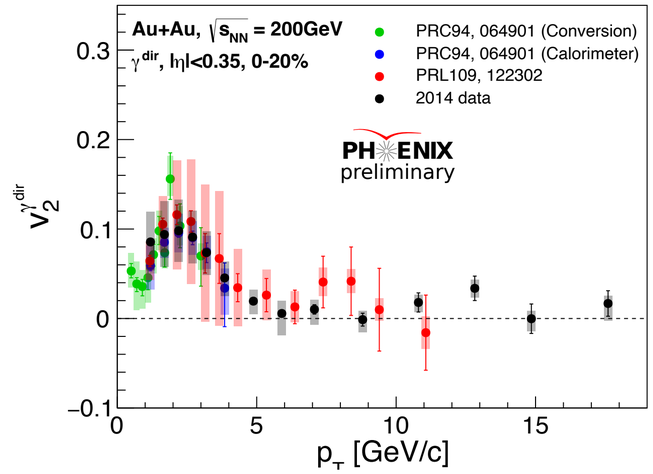
$$v_2^{dir} = \frac{R_\gamma v_2^{incl} - v_2^{dec}}{R_\gamma - 1}$$

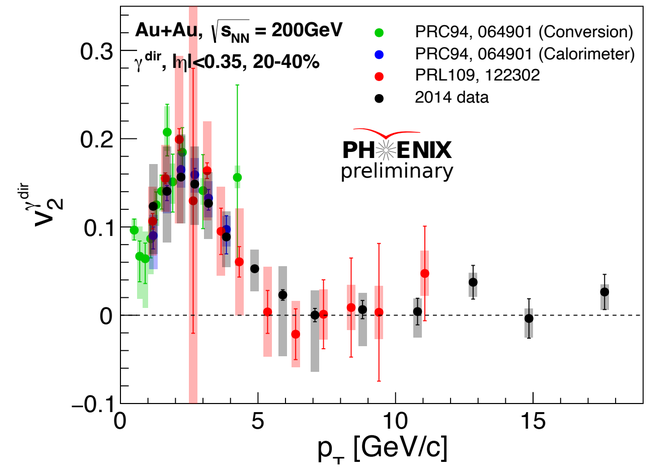
R_γ of direct photons (measured from data)

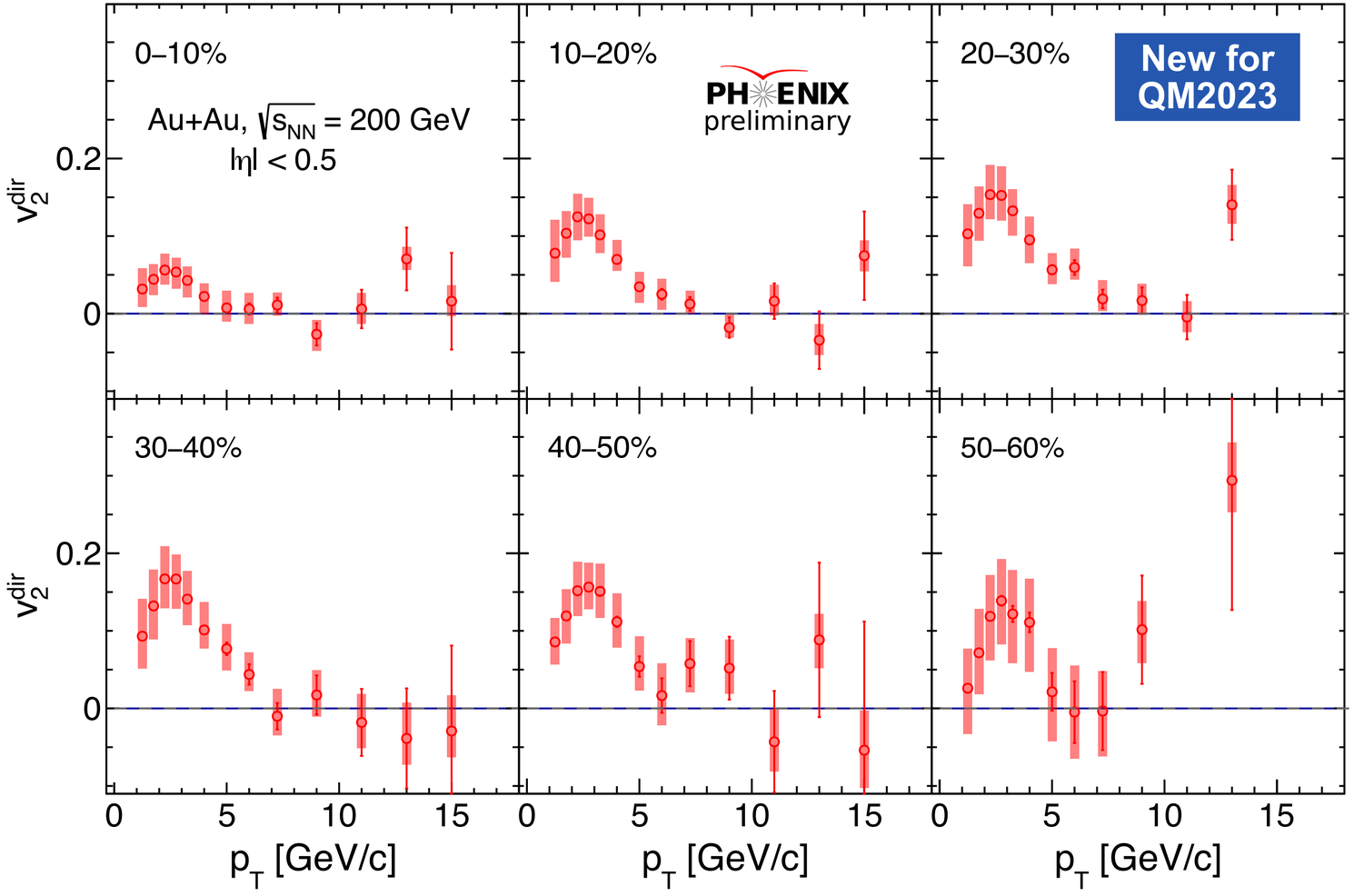


Given as an input for the simulation to calculate v_2^{dec}

Direct Photons v_2



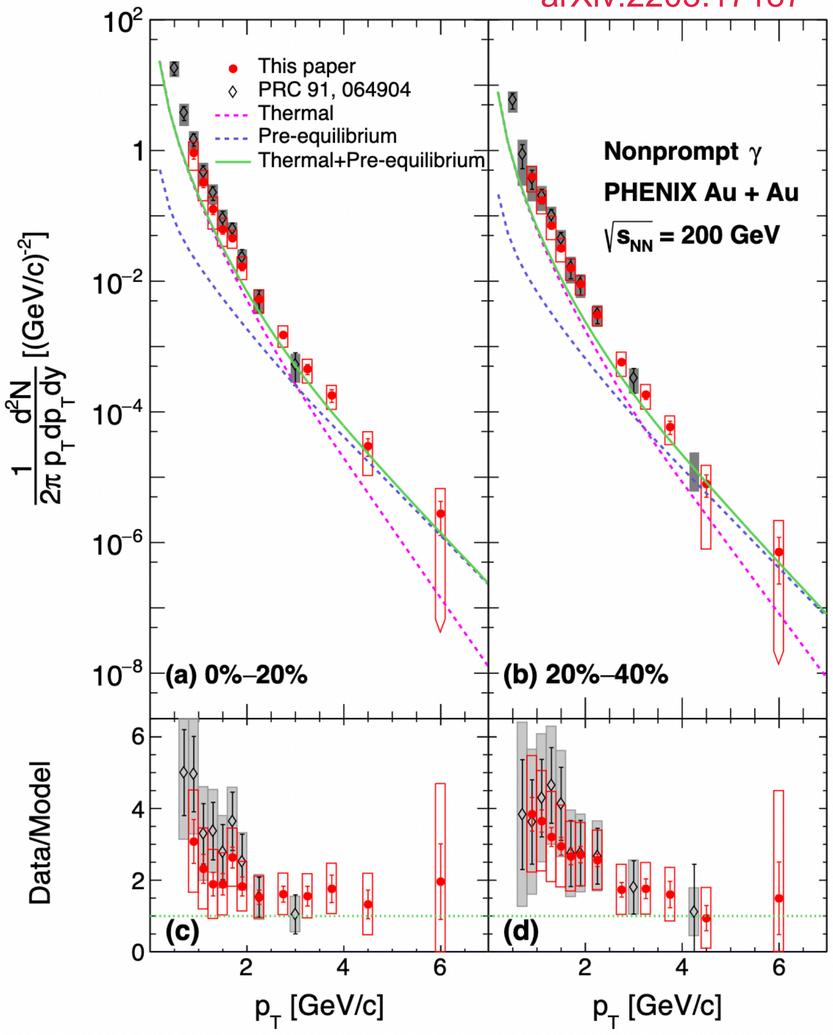




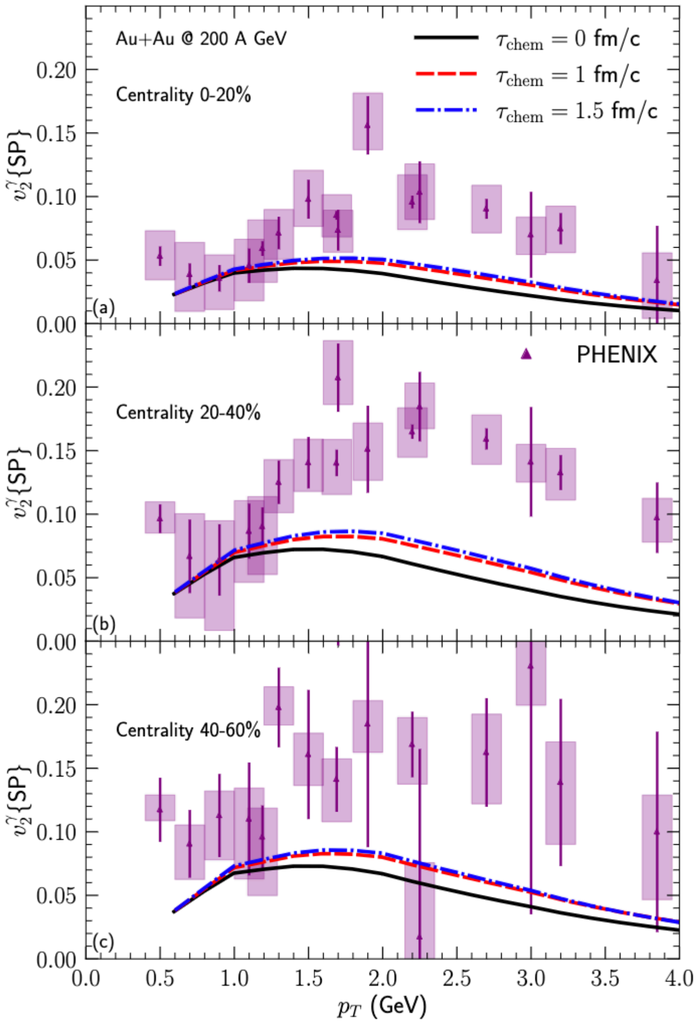
Direct photons v_2 in the high p_T region is consistent with zero within uncertainties.

Model comparison

arXiv:2203.17187



Phys. Rev. C 105 014909 (2022)
C. Gale et. al.



Multi-messenger heavy-ion physics

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

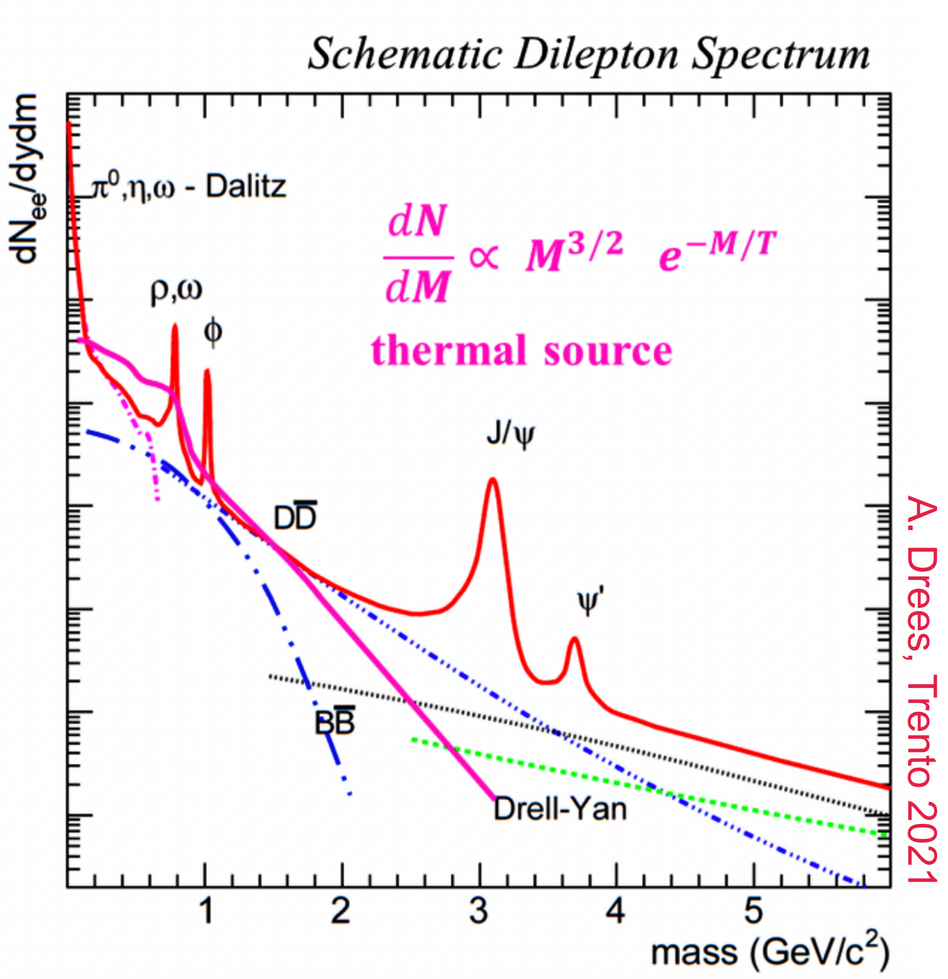
Theoretical models qualitatively reproduce the shape but falls short quantitatively.

Thermal radiation in dilepton spectra

- In the dilepton invariant mass range from about 1 to 3 GeV/c^2, there is a significant contribution from thermal emission from the QGP.
  - Background from semileptonic decays of open heavy flavor.
  - Small contribution from Drell-Yan.
  - Vertex detector is required to disentangle the thermal and semiletonic components

    (PHENIX installed Silicon Vertex Detector in 2011).

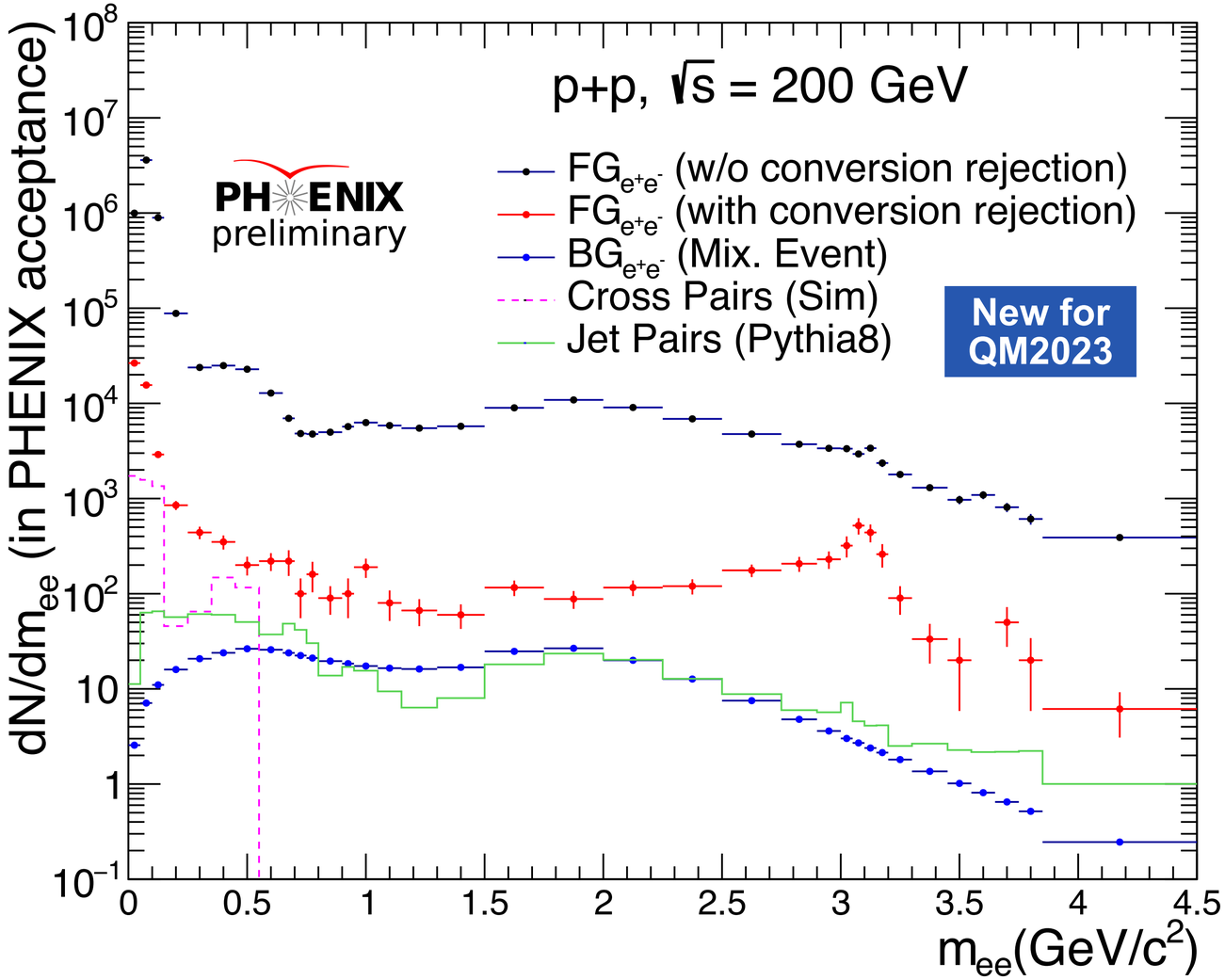
- Silicon Vertex detector presents a huge photon conversion background.

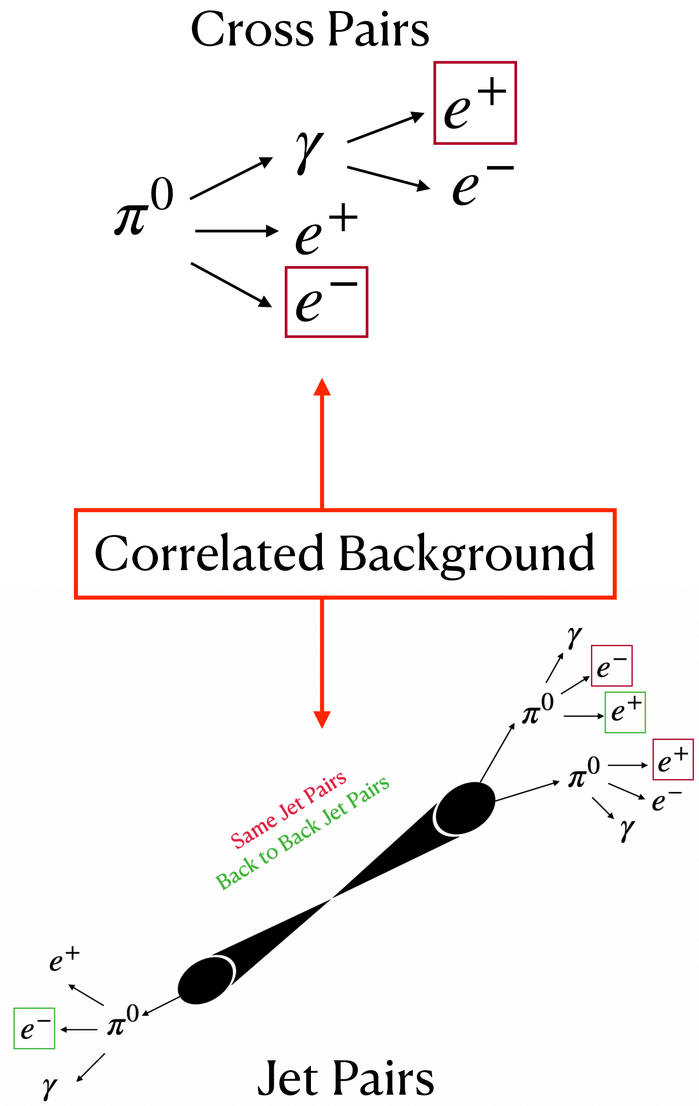


Poster by Roli Esha

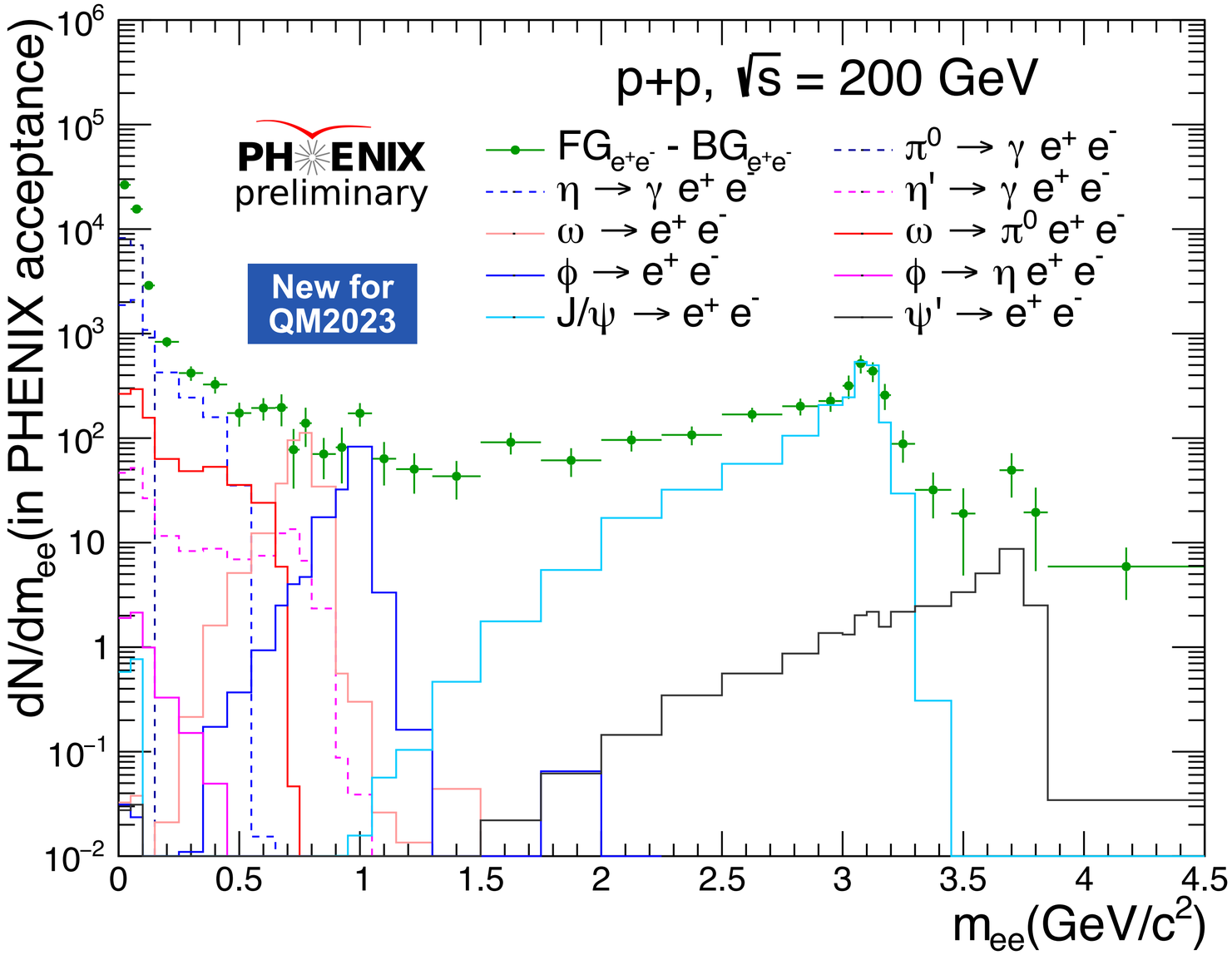
PHENIX

Invariant mass spectrum in p+p at 200 GeV





Comparison to Hadronic Cocktail



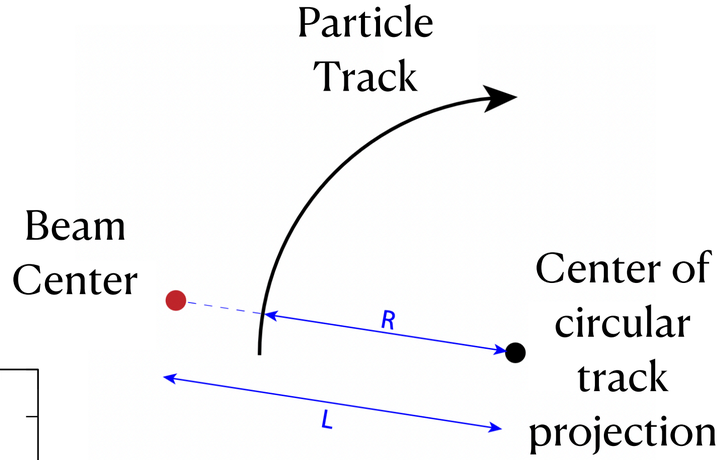
A good agreement between the measured pairs in data and known sources from simulation.

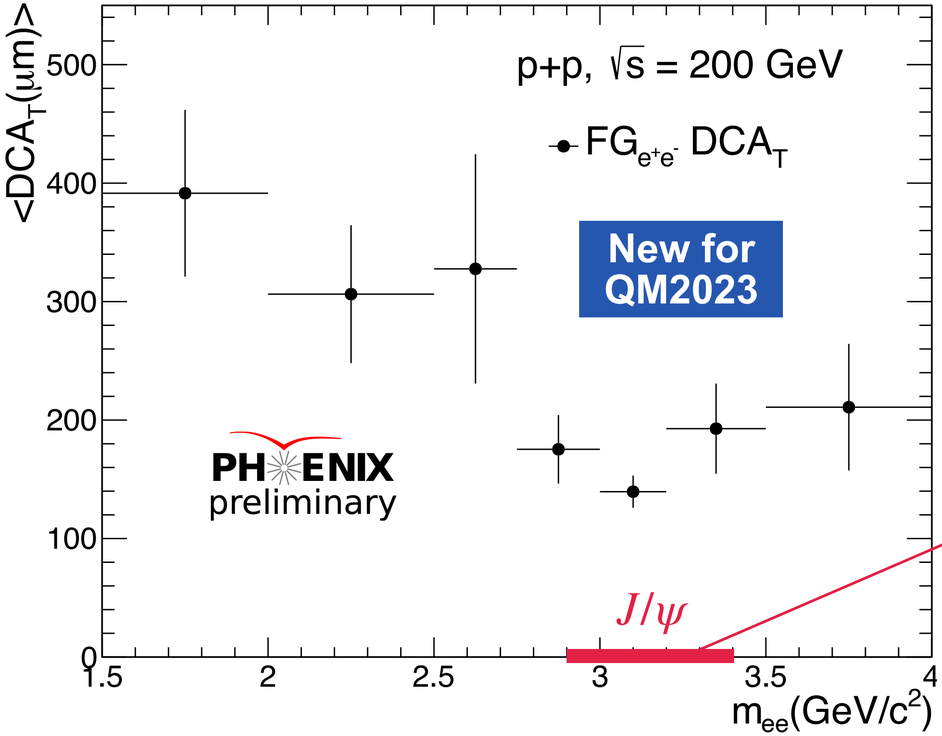
The only missing source here is the open heavy flavor contribution.

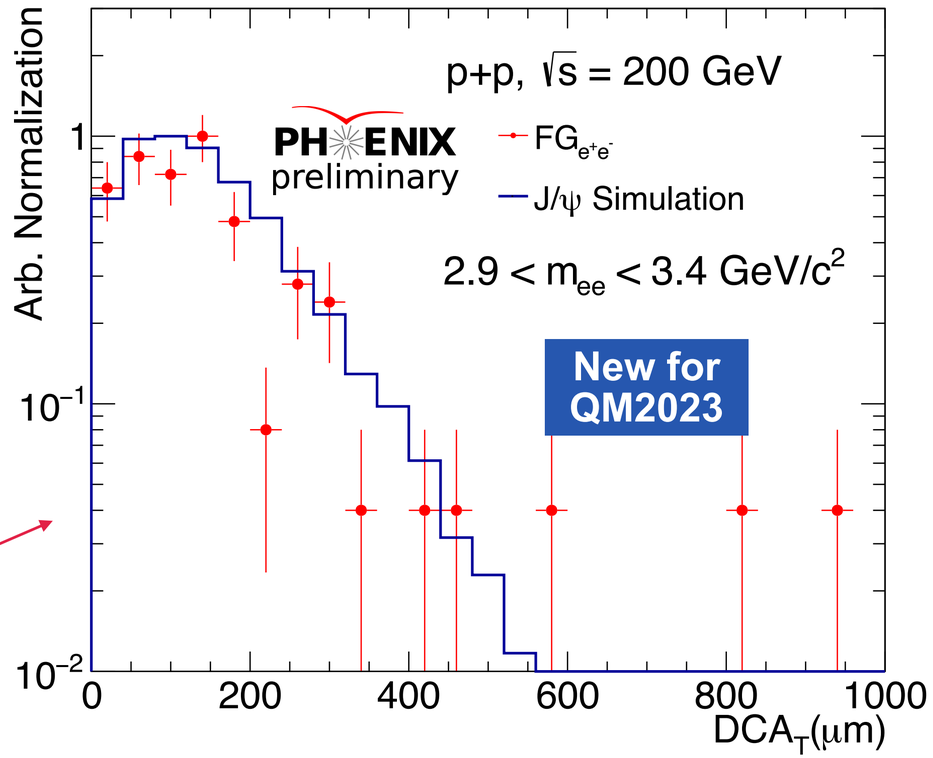
Separating the J/ψ and heavy flavor contributions

We calculate a transverse DCA of the central arm tracks to the interaction vertex determined by the VTX given by

$$DCA_T = L - R$$





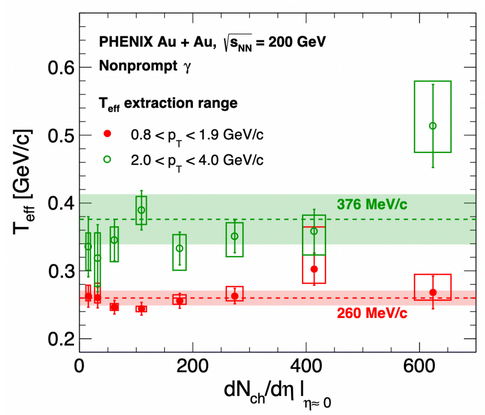


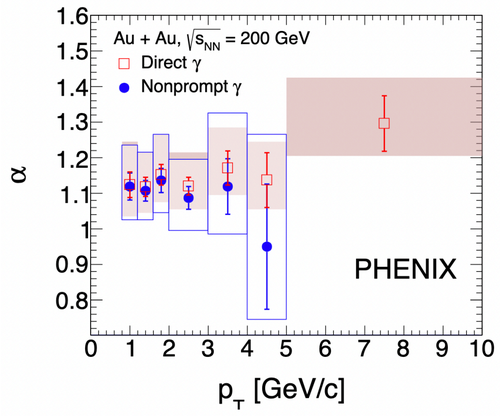
Separation between the two components is indeed possible!

There is a very good match between data and single J/ψ simulation. This is expected as the J/ψ mass region in data has very small background under it.

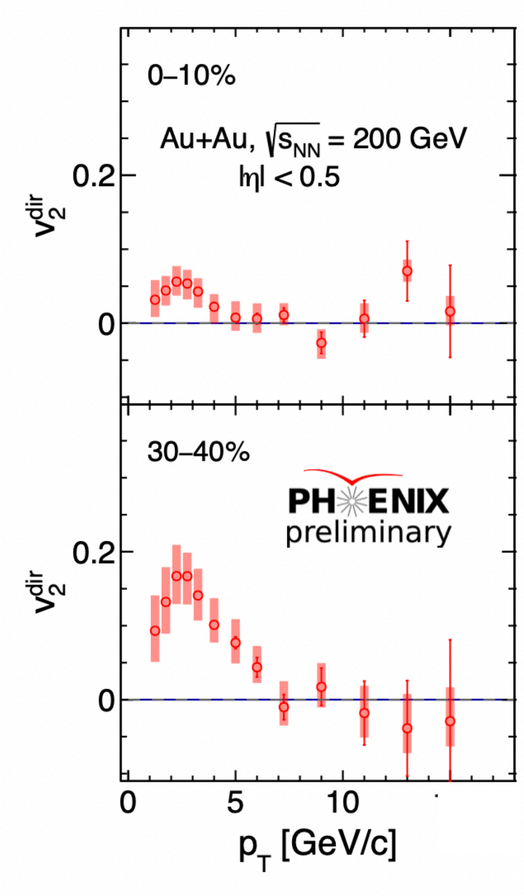
Summary

(A)
Direct Photon Spectra

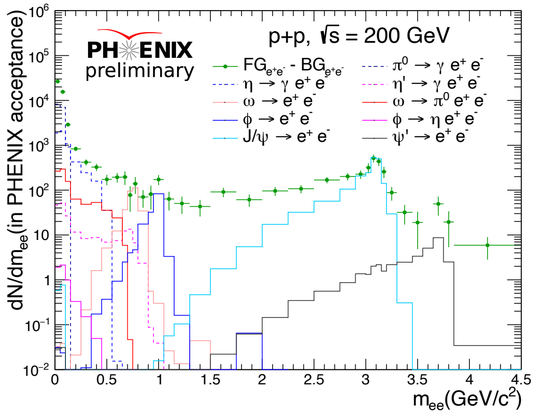


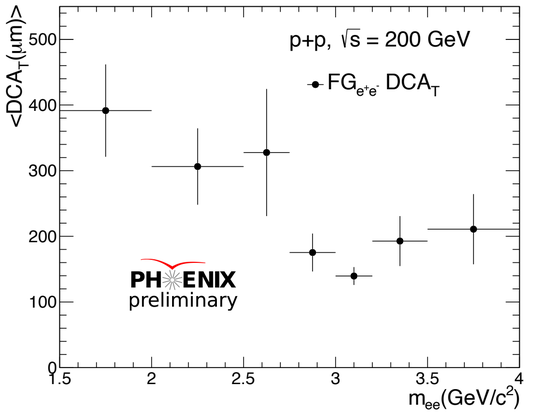


(B)
Direct Photon Flow



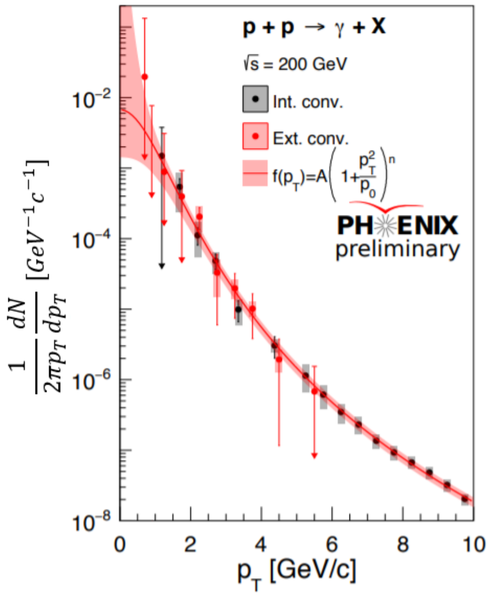
(C)
Dilepton Continuum

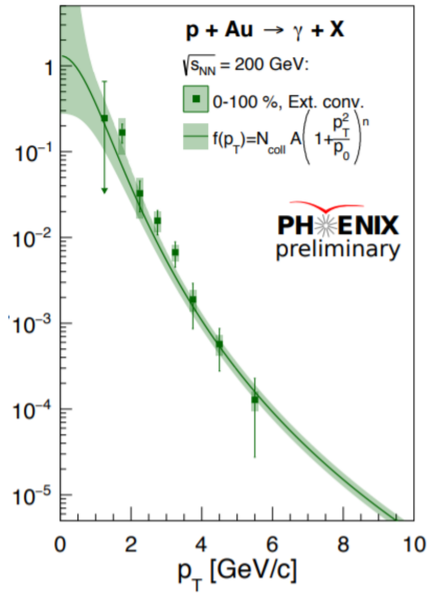


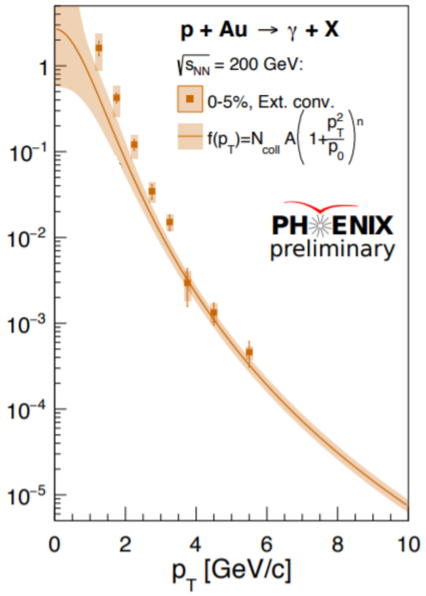


Thank you!

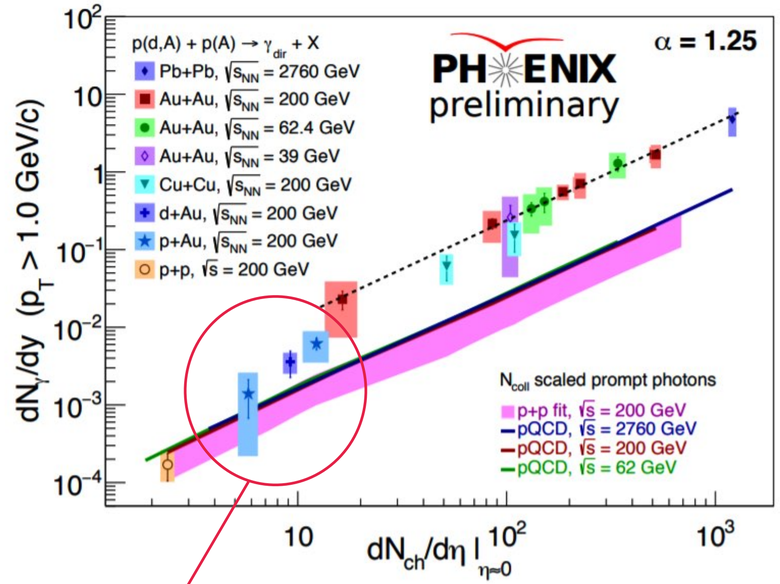
Direct γ in small systems







Bridging the gap



Onset of QGP?

$p+p$ Fit

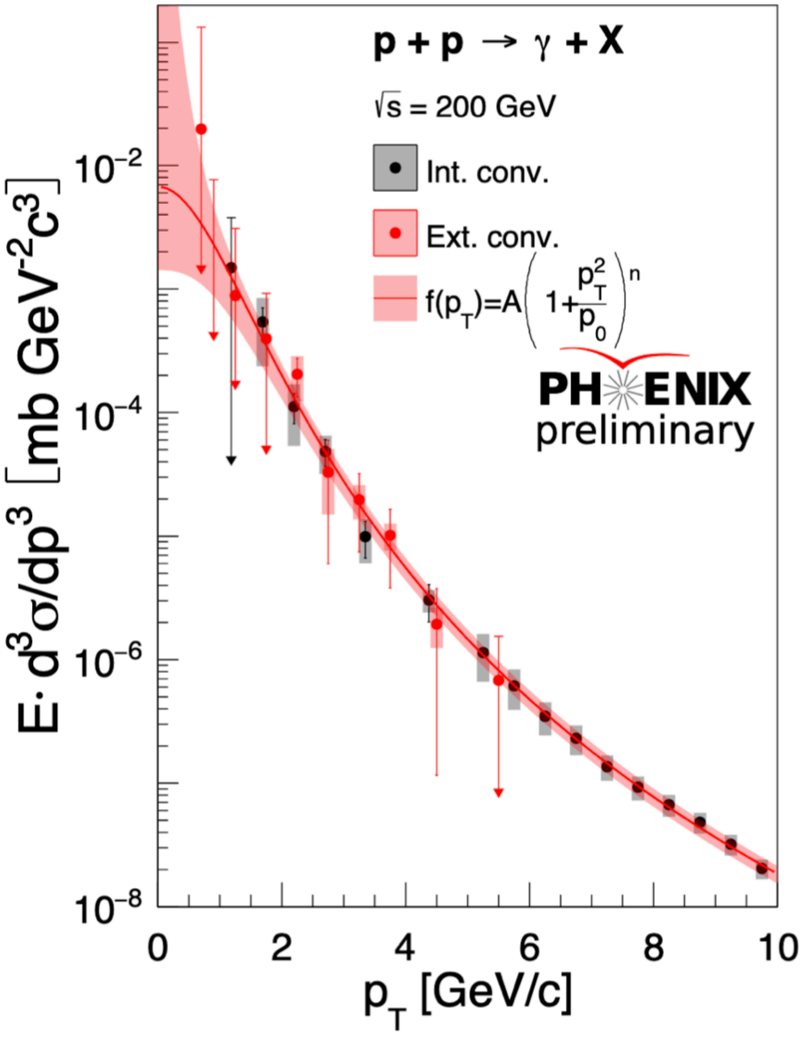
Functional form inspired by pQCD

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

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

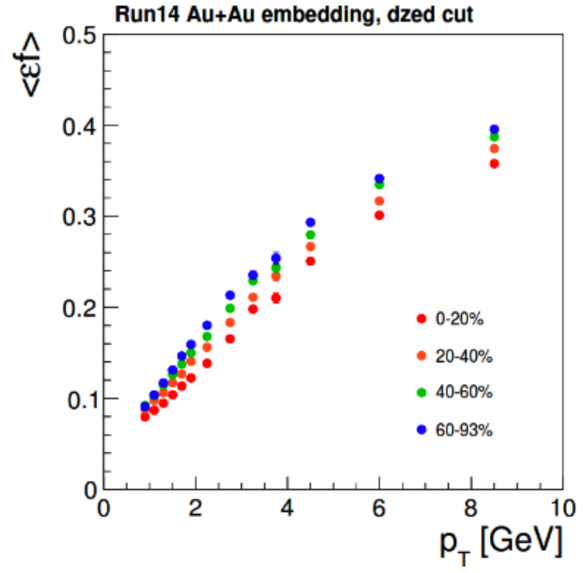
$a = 6.4 \times 10^3$ $b = 1.45$ $c = -3.30$

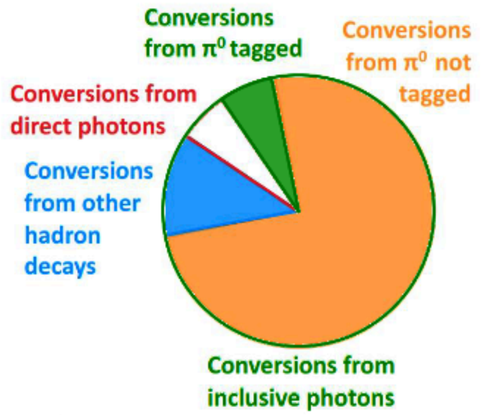


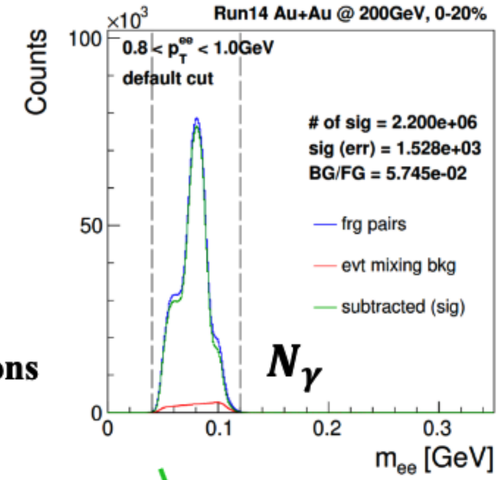
External Conversion Method

Full MC simulation

conditional tagging efficiency





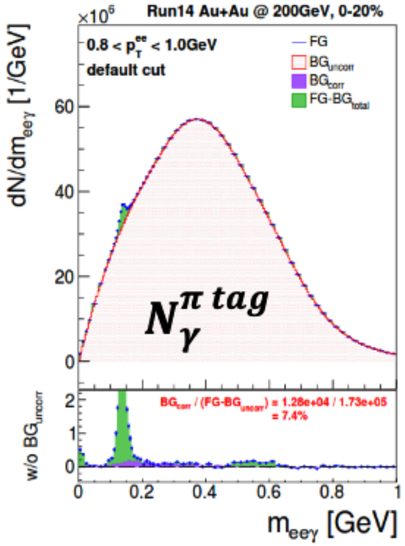


Key contributions

- **Energy cut**
- **Acceptance**
- **Detector material**

measured raw yields

Closure test with full high multiplicity MC simulation



$$\langle \varepsilon f \rangle \times \left(\frac{N_\gamma}{N_\gamma^{\pi^0 tag}} \right)^{Data}$$

$$R_\gamma = \frac{N_\gamma^{incl}}{N_\gamma^{hadr}} = \frac{\langle \varepsilon f \rangle \times \left(\frac{N_\gamma}{N_\gamma^{\pi^0 tag}} \right)^{Data}}{\left(\frac{N_\gamma^{hadr}}{N_\gamma^{\pi^0}} \right)^{MC}}$$

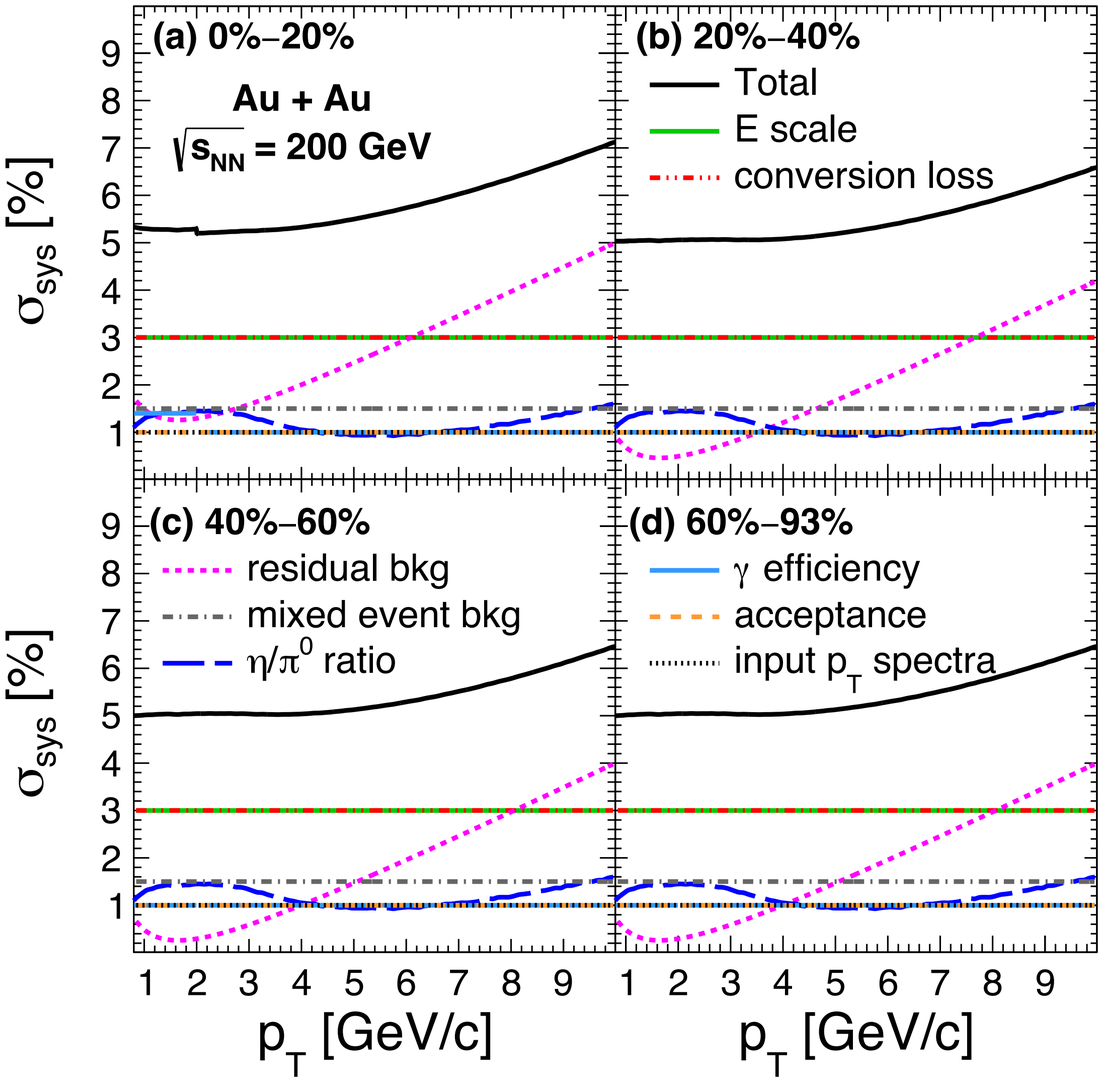
η/π^0 ratio main contribution

Photons from hadron decays

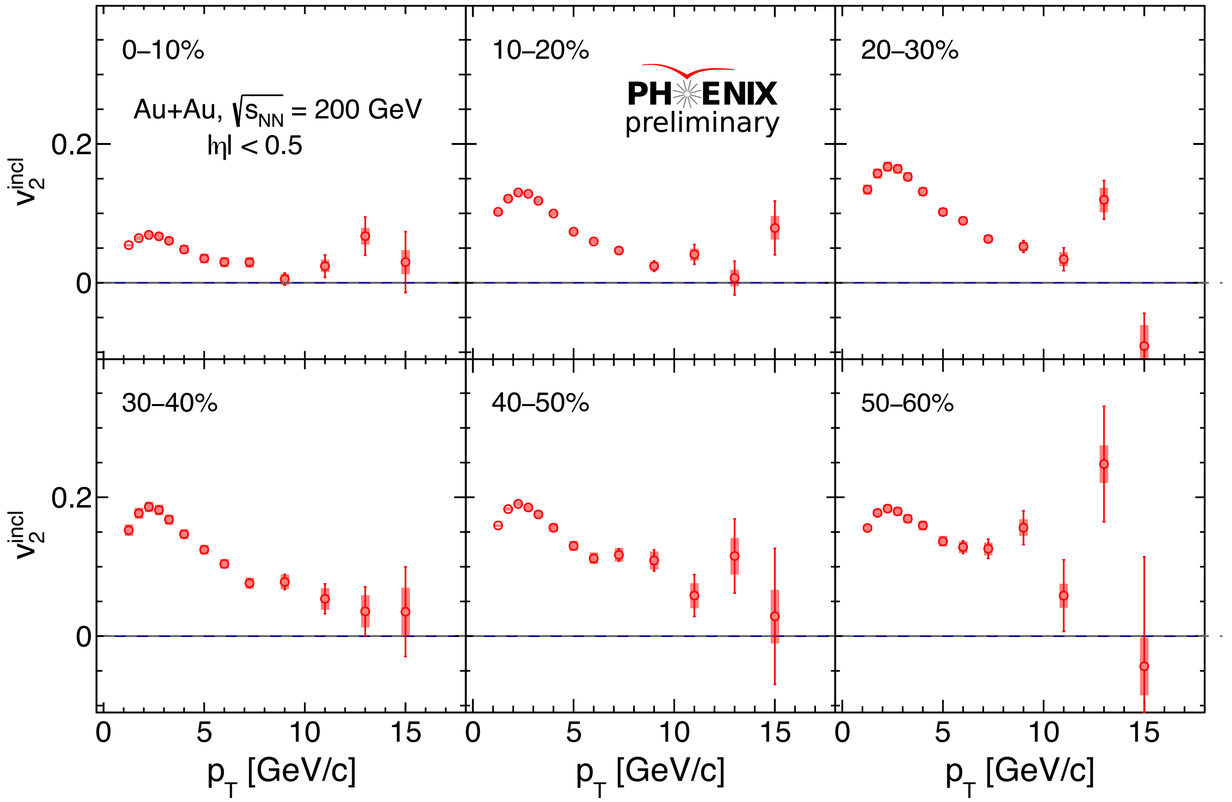
Systematic Uncertainties

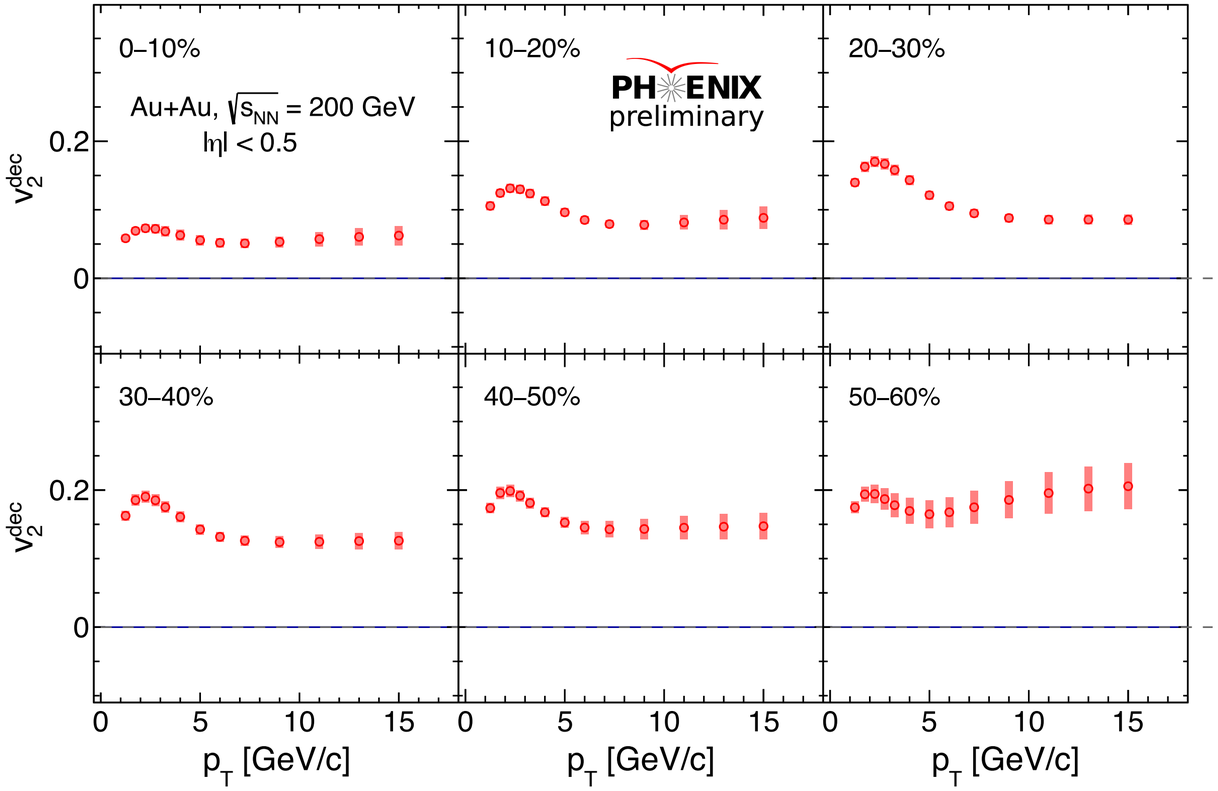
Systematic uncertainty source (39 GeV)	σ_{sys}/R_γ	Type
π^0 *reconstruction*		
tagged photon yield	8%	A
Conditional acceptance		
input Hagedorn p_T spectra and energy scale	8%	B
Cocktail ratio		
γ^{hadron}/π^0	2%	B

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



Inclusive and Decay Photons v_2

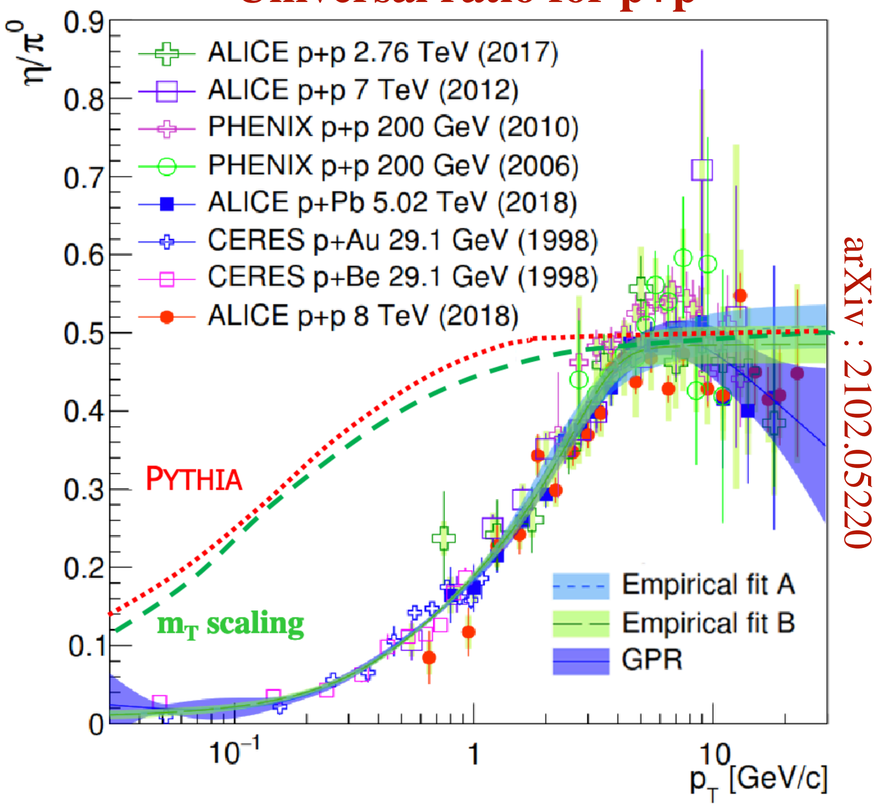




Quantitatively, elliptic flow of both the inclusive and decay photons is very similar!

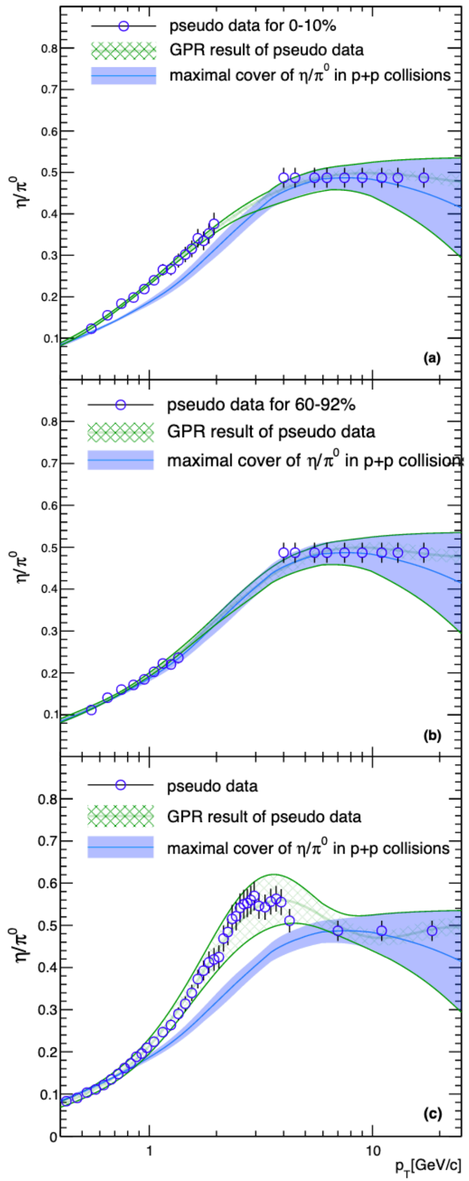
η/π^0 from world data

Universal ratio for p+p

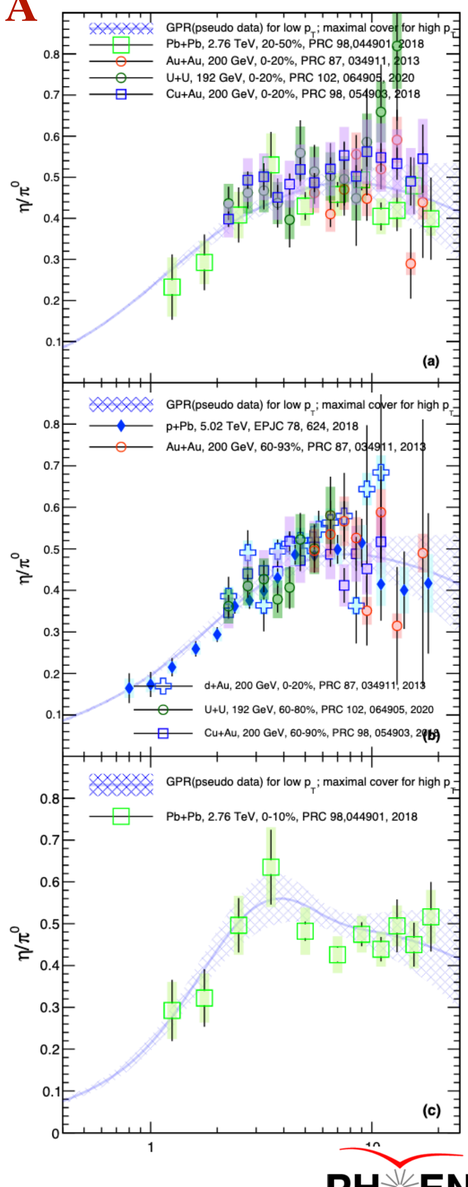


arXiv : 2102.05220

Accounting for effects of radial flow

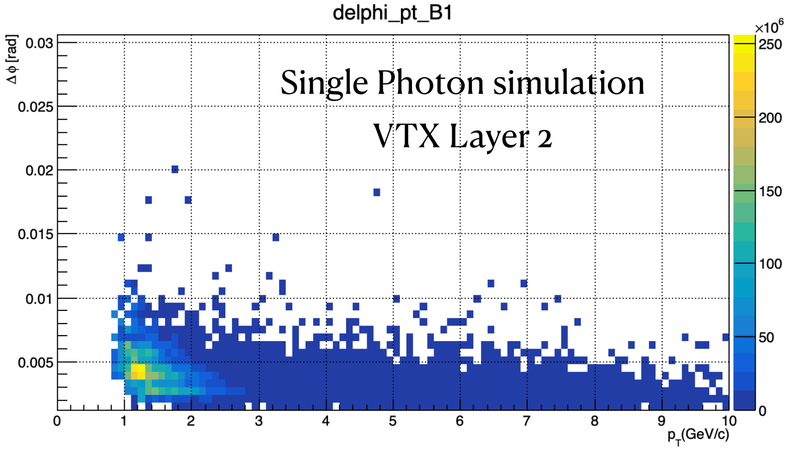


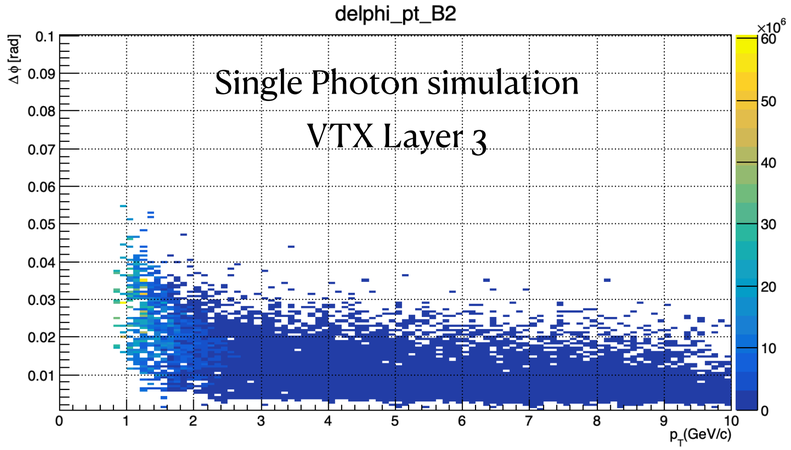
A + A

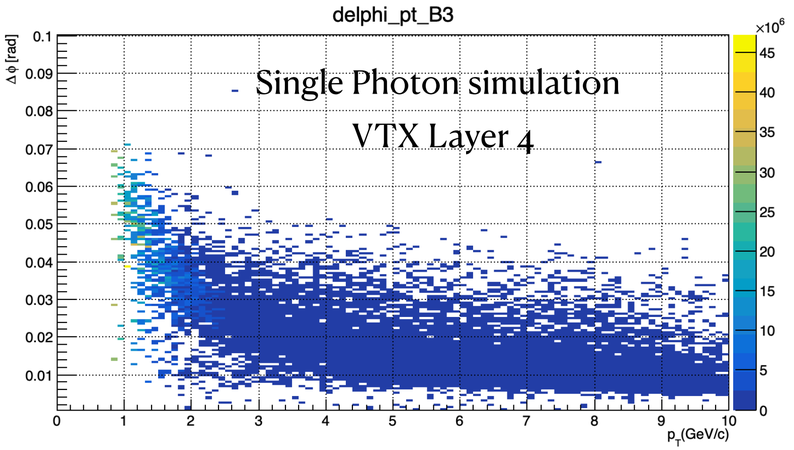


PHENIX

Using the track-hit association to remove conversions: Conversion Veto







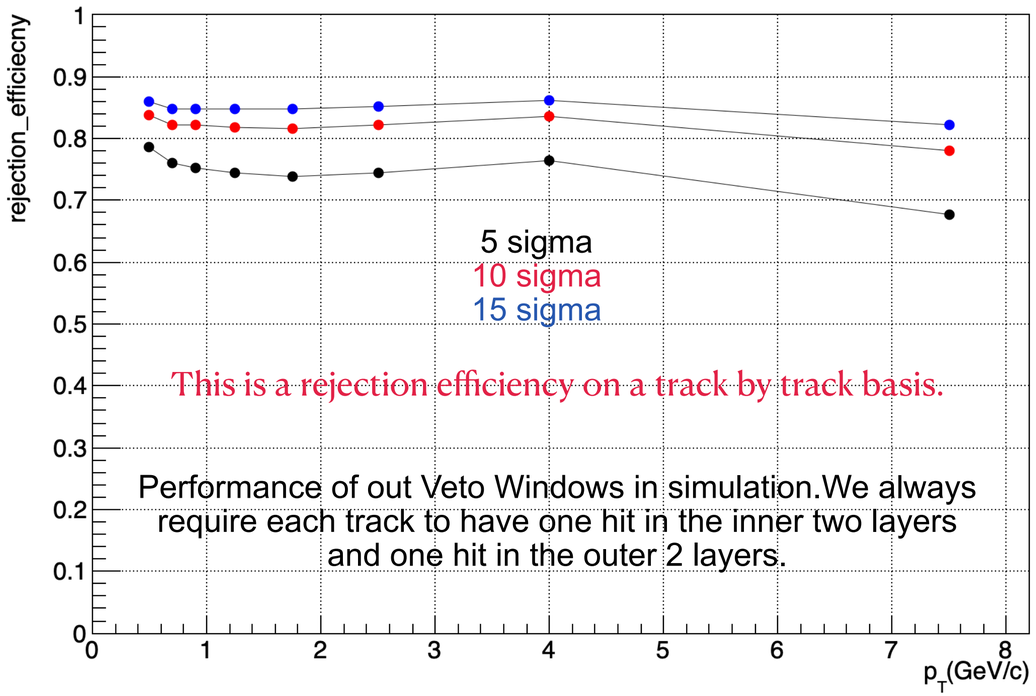
Opening angle as a function of the parent photon pT between the electron and the positron track for conversions happening at the beam pipe and the innermost VTX Layer.

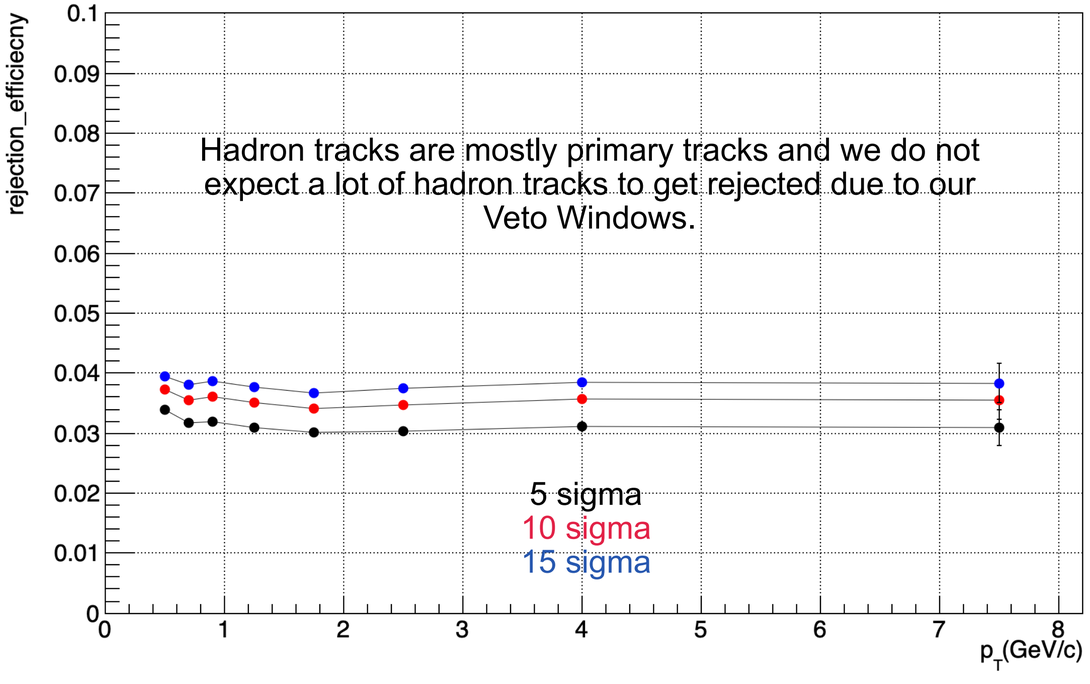
p_T (GeV/c)	B1 [mrad]	B2 [mrad]	B3 [mrad]
1.00	4.09	30.97	51.53
5.00	2.36	8.68	13.19

ϕ extent of the sensor for VTX L2: ~ 1 mrad
ϕ extent of the sensor for VTX L3 and L4: ~ 0.7 mrad

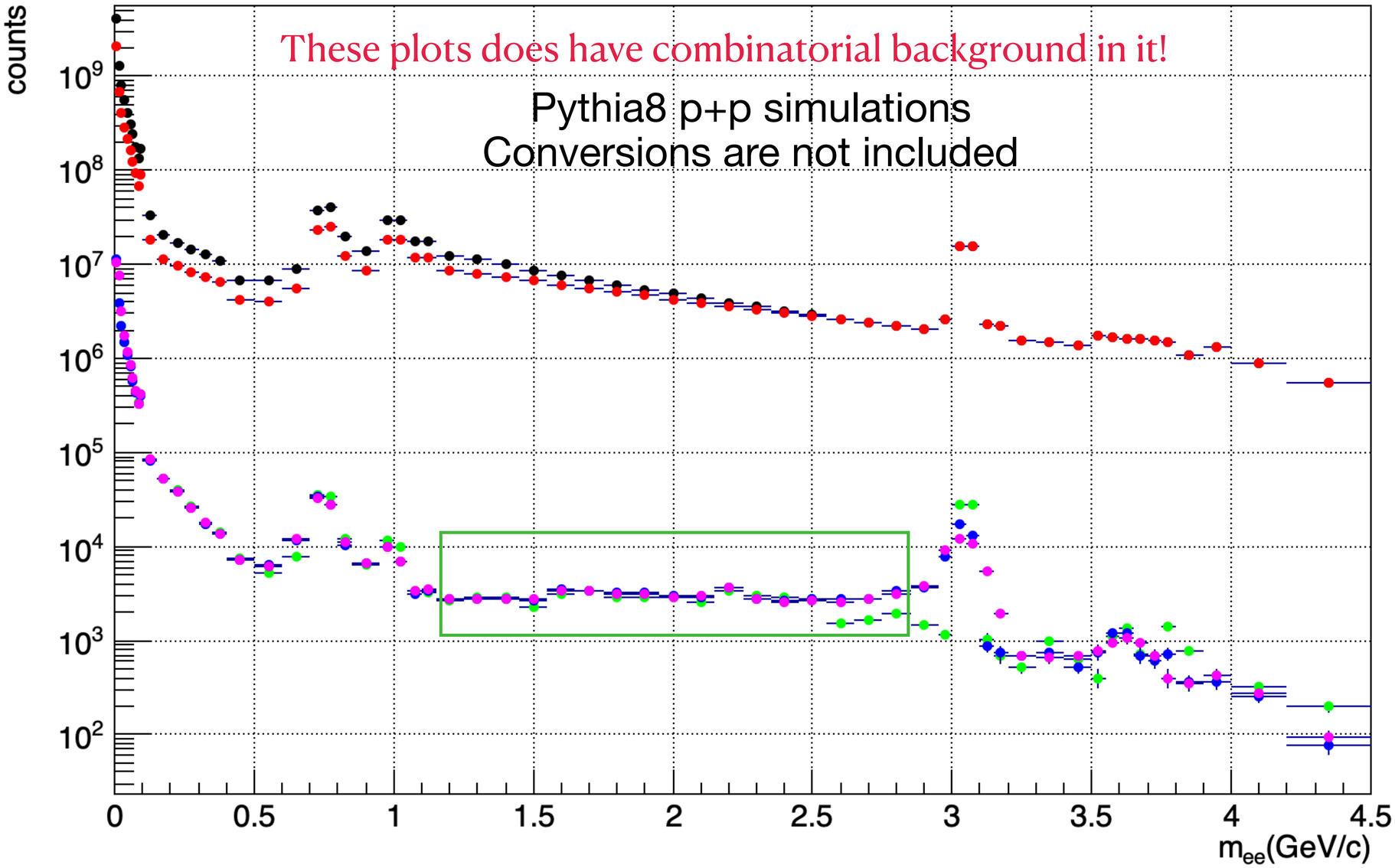
Even if only one of the conversion tracks is reconstructed by the DC we will always find a hit in the vicinity of a conversion track!

Performace of our rejection techniques





Understanding the important aspects of the spectra using Pythia8 Simulations



MinBias (4π Acceptance)

MinBias + ERT (4π Acceptance)

MinBias + ERT (PHENIX Acceptance)

MinBias + ERT + PHENIX Acceptance + Bremstruhlung

MinBias + ERT + PHENIX Acceptance + Bremstruhlung + pT Smearing

In the intermediate mass region, the combination of acceptance and ERT trigger flattens out the curve.

PHENIX