WPCF2018

PHENIX measurements of low momentum direct photon radiation from large and small systems: Direct photon scaling

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PHENIX

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Content

- Introduction: *thermal photon puzzle, PHENIX γ measurements*
- Large systems: *direct photon p_T spectra and scaling*
- Small systems: *direct photon R_γ, p_T spectra, R_{pA}*
- γ connection between large and small systems
- Summary

Introduction: Thermal Photon Puzzle

- Large yield and large anisotropy have been observed in Au+Au at 200 GeV by PHENIX
- It is challenging to describe the large yield and anisotropy simultaneously
- In order to help resolving this puzzle, PHENIX has measured low momentum γ in

large systems:

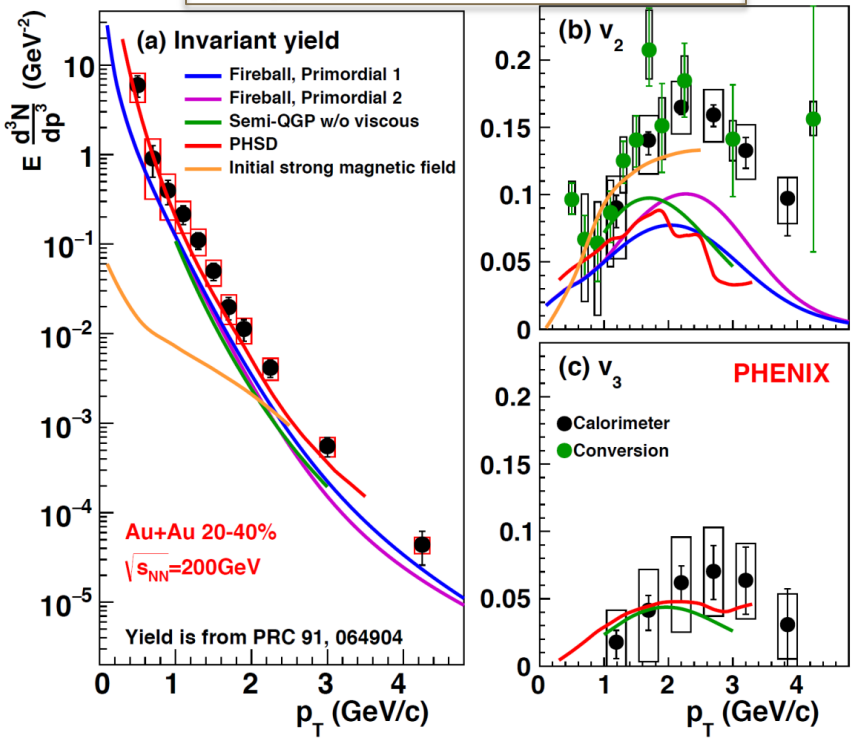
- Au+Au at 200, 62.4, 39 GeV, Cu+Cu at 200 GeV
- **direct photon scaling independent of center-of-mass energy, centrality, system**

small systems

- p+p, d+Au, p+Au at 200 GeV
- **direct photon excess in central p+Au is consistent with QGP droplets' formation**

Large yield from early emission ?
Large v_2 from late emission ?

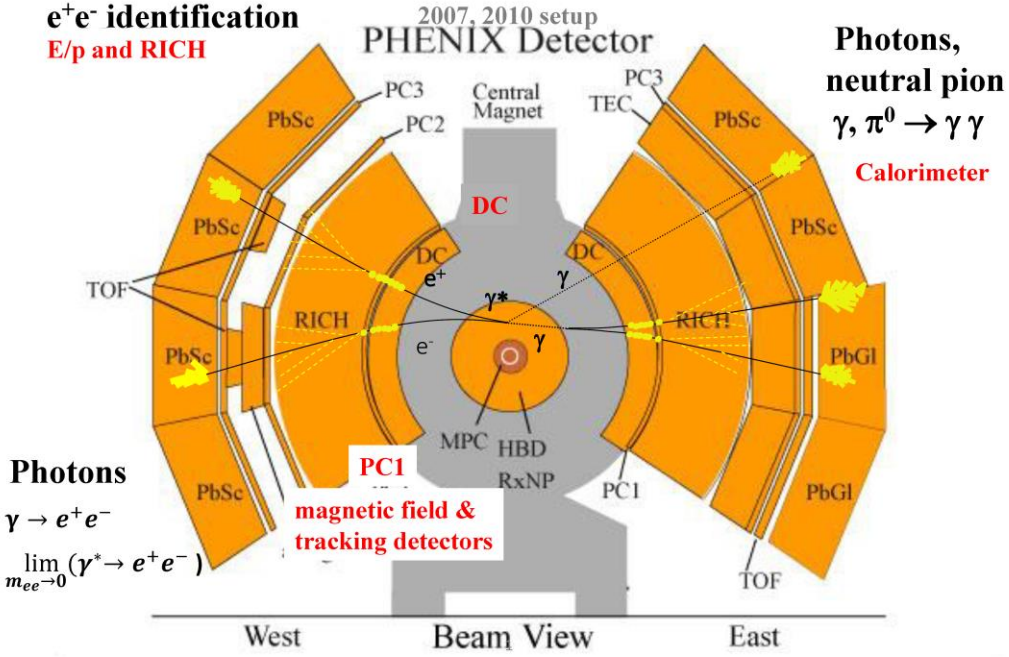
The plots are from PRC 94, 064901



Introduction: Direct Photon Measurements in PHENIX

- Photon measurement techniques include
  - photons that directly deposit energy into electromagnetic calorimeters:
  - virtual photons that internally convert into e^+e^- pairs:
  - real photons that externally convert into e^+e^- pairs in a selected detector material:

- The new results on low momentum direct photons with conversion methods based on photon conversions in
  - Readout plane of Hadron Blind Detector (HBD)
  - Layers of Silicon Vertex Tracker (VTX)

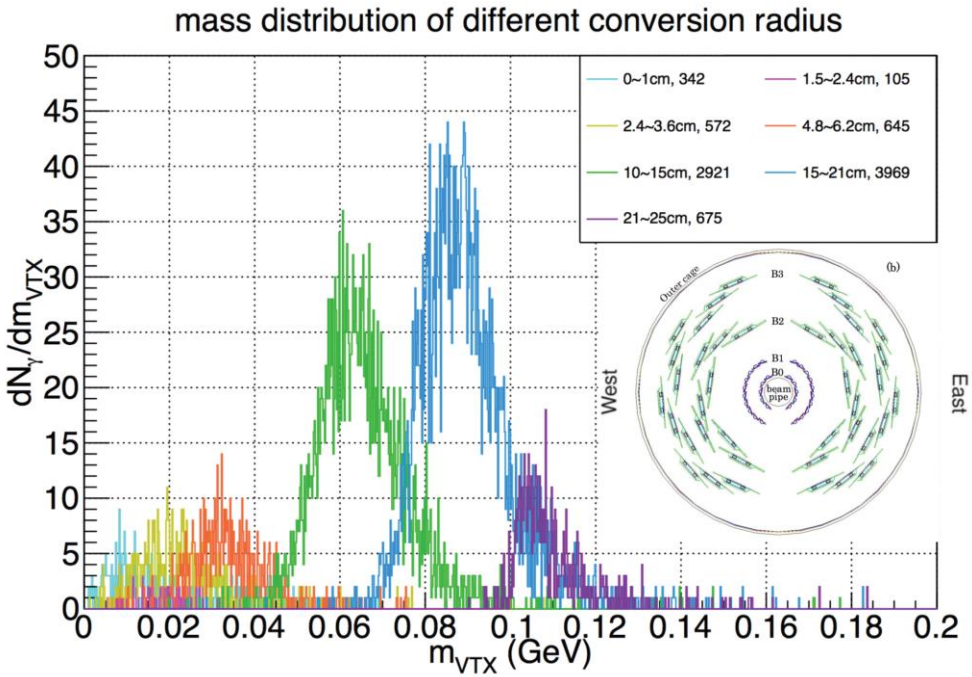


Conversions with the HBD backplane

Introduction: Direct Photon Measurements in PHENIX

Identify and reconstruct photons via external conversions to e^+e^- pairs

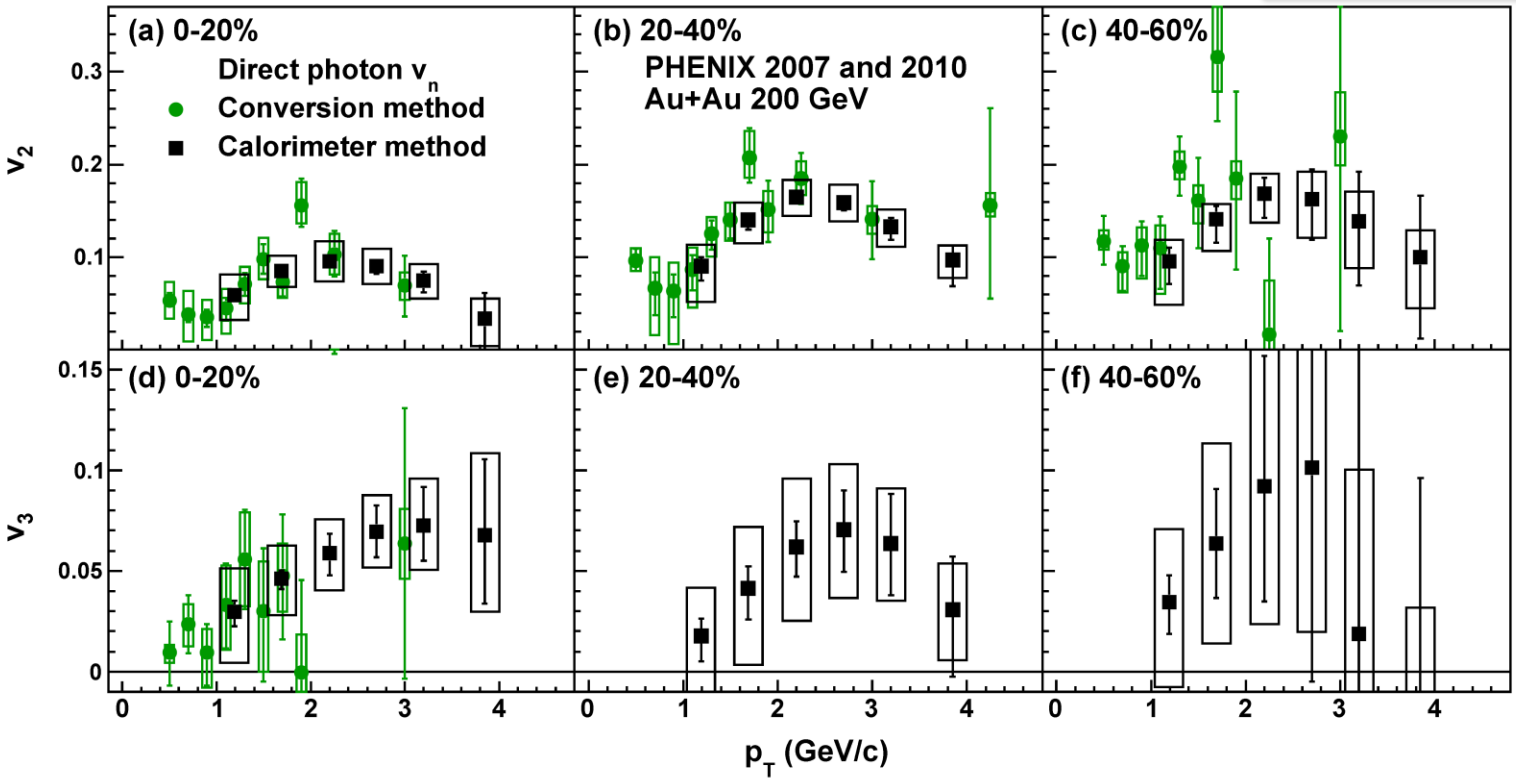
- HBD backplane (Run 2010)
  - Conversions at fixed radius: 60 cm from the event vertex
  - Single e^+/e^- tracks used
  - Radiation thickness ~ 3%
- VTX layers (> Run 2011)
  - Conversions at any material (VTX 3rd 4th layers)
  - e^+e^- pairs used
  - Radiation thickness ~ 10%



Conversions with the VTX layers

Large Systems: Direct Photon v_n

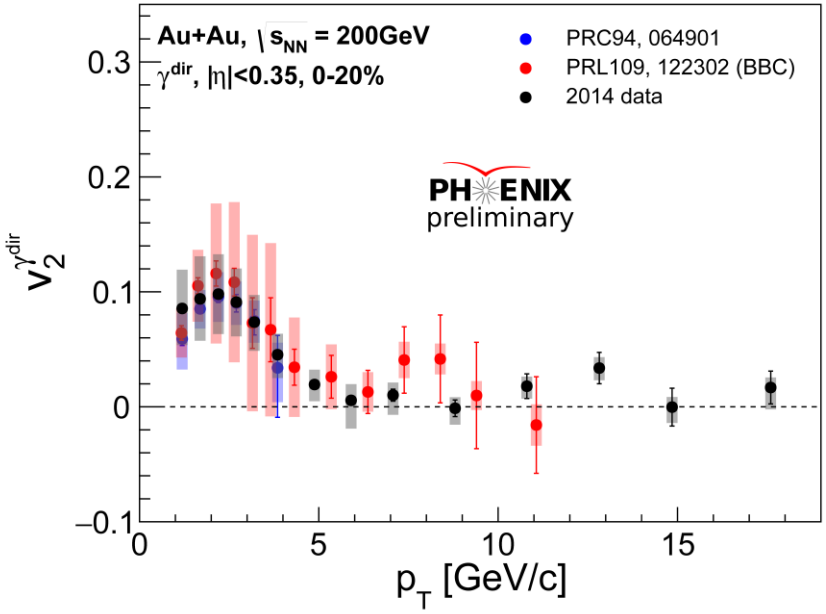
The plots are from PRC 94, 064901

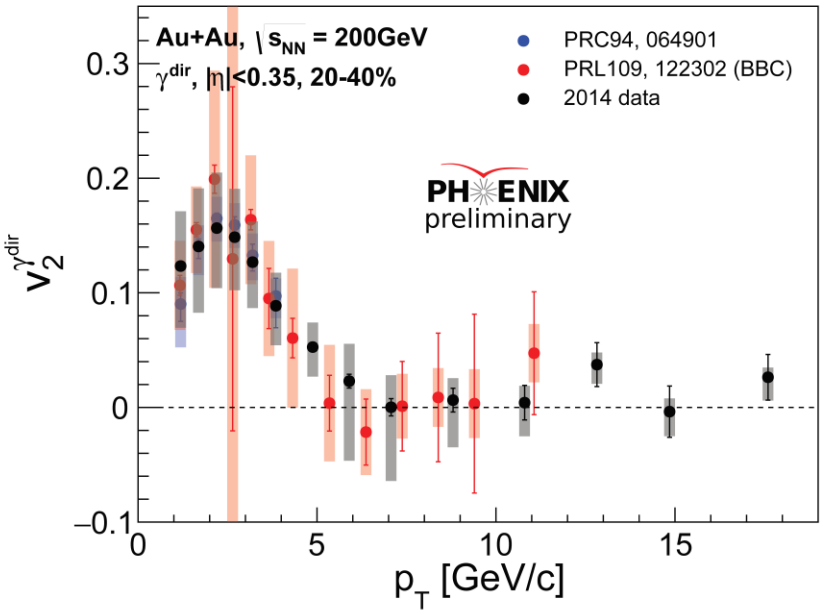


PHENIX v_n results

Large Systems: Direct Photon Preliminary v_2

v_2 in Au+ Au 0-20% centrality bin at 200 GeV	v_2 in Au+ Au 20-40% centrality bin at 200 GeV

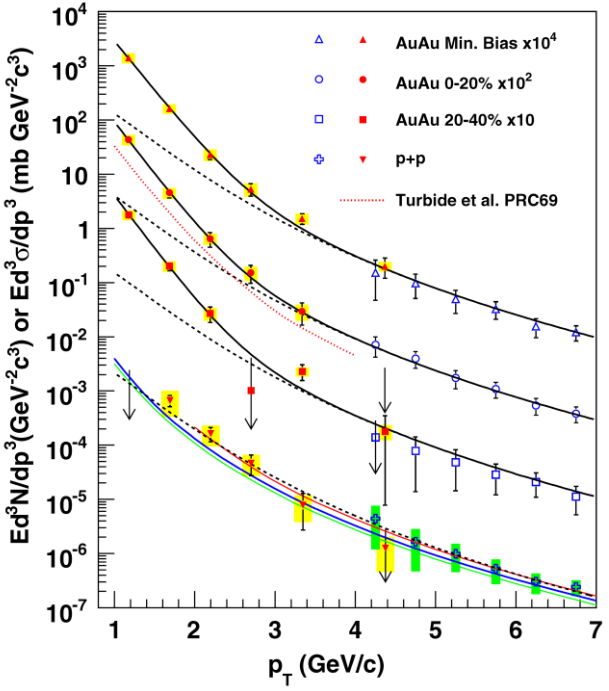




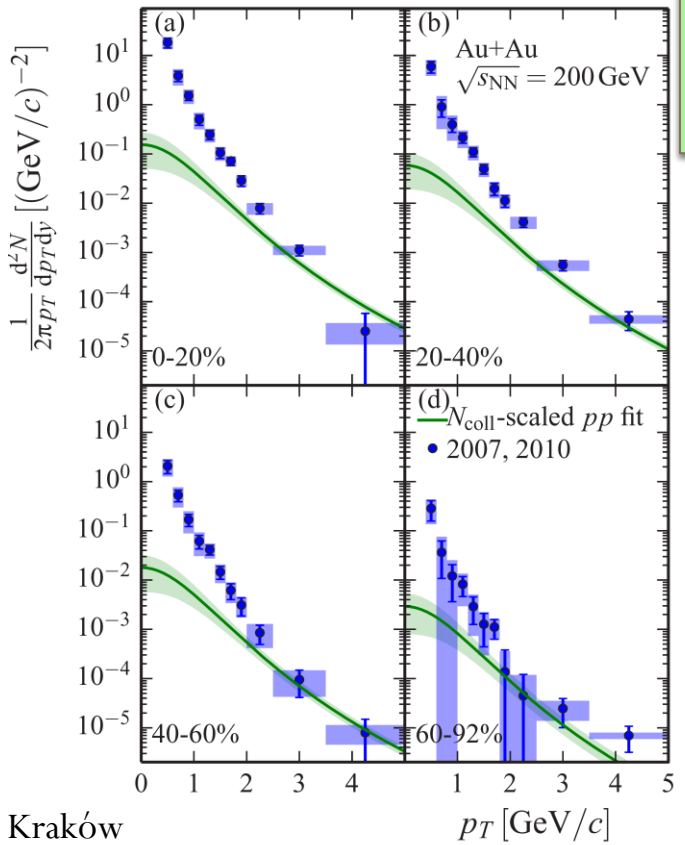
- Higher p_T reach is accessible as compared to the previous v_2 results

Large Systems: Direct Photon p_T Spectra

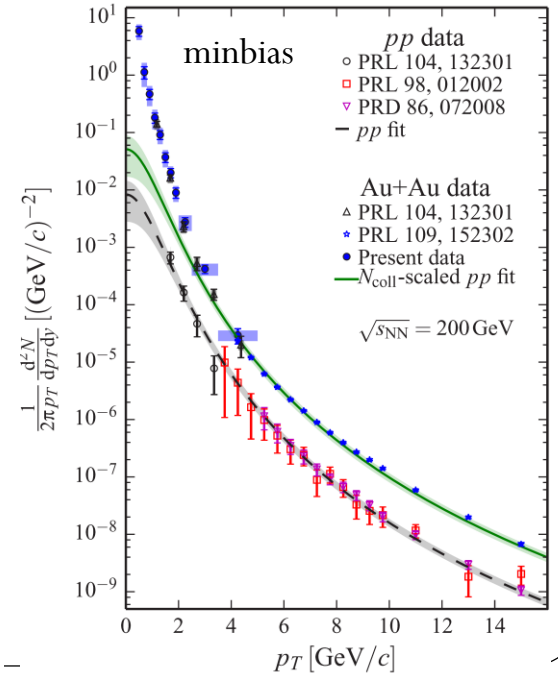
The plot is from PRL 104, 132301



The plots are from PRC 91, 064904



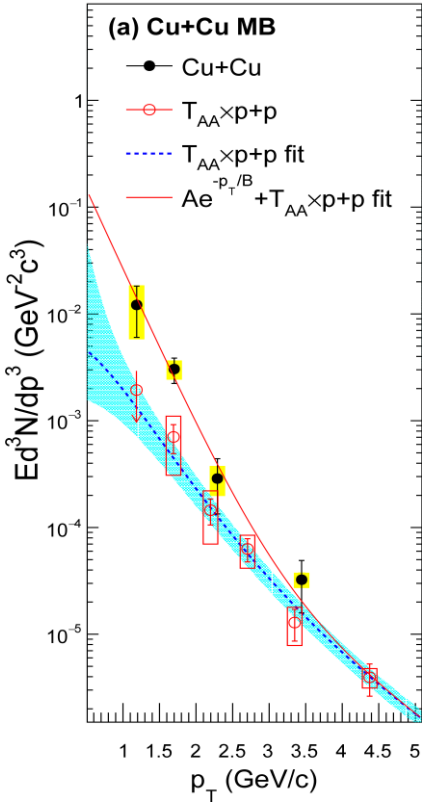
Three PHENIX independent measurements are in good agreement with each other

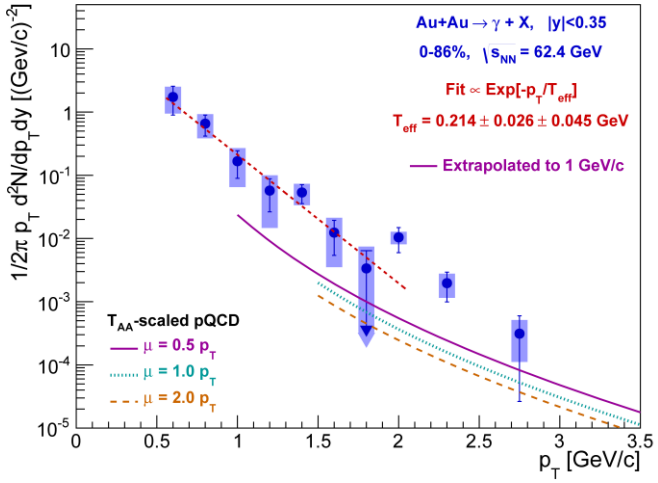


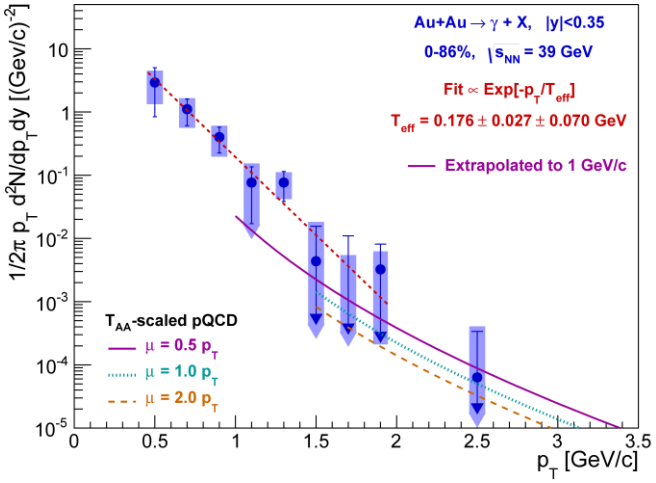
Large Systems: Direct Photon p_T Spectra

p_T spectra in minbias

- We have new direct photon data
  - from Au+Au at 62.4 GeV and 39 GeV
  - from Cu+Cu at 200 GeV

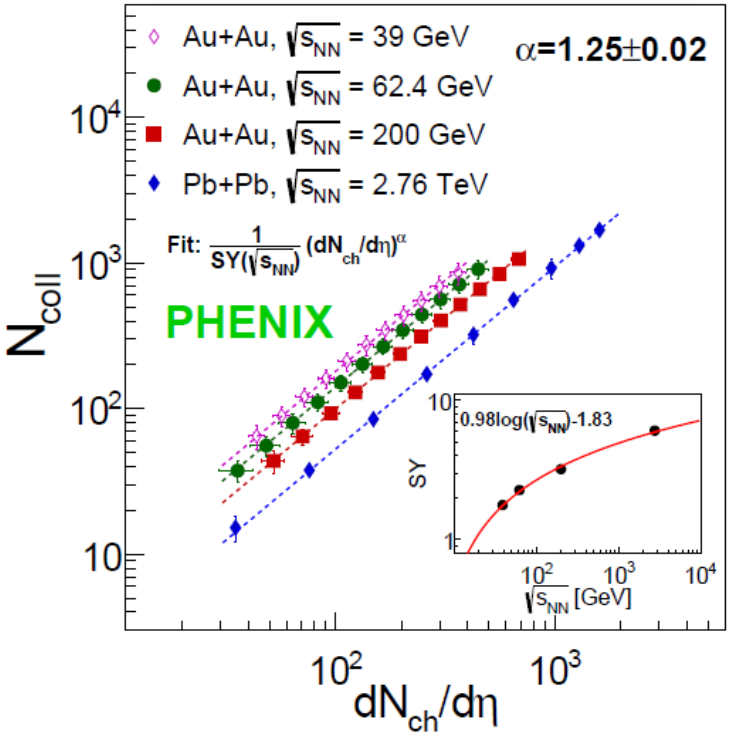






Large Systems: Direct Photon Scaling

arXiv:1805.04084 [hep-ex]



- N_{coll} scales like $(dN_{ch}/d\eta)^{1.25}$ for all center-of-mass energies with a logarithmic increasing constant (specific yield)

N_{coll} scales with $dN_{ch}/d\eta$ as

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

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

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

Large Systems: Direct Photon Scaling

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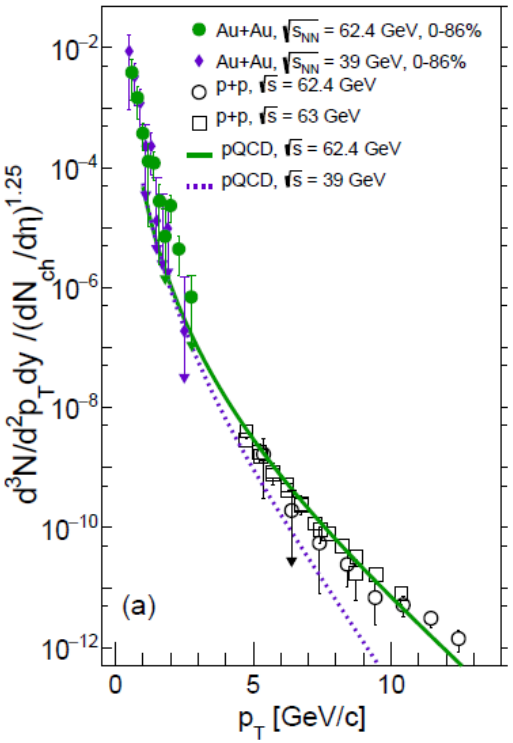


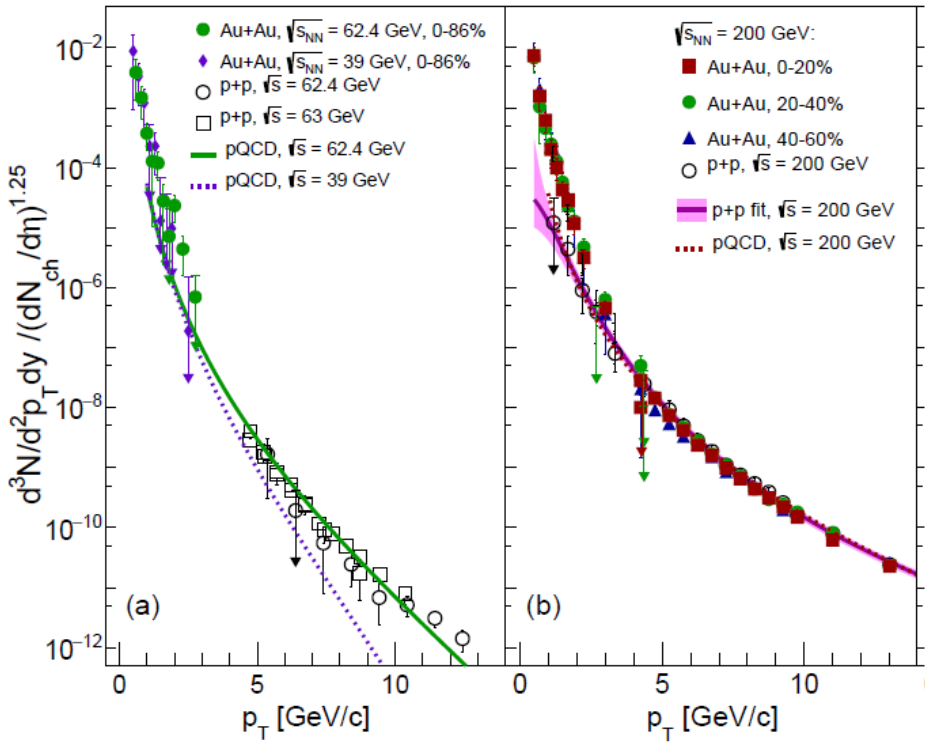
- PHENIX low energy 62.4/39 GeV data are above $p_T = 0.4$ GeV/c
- The data at 62.4/39 GeV falls on top of each other
- At high-p_T the 62.4 GeV pQCD is consistent with ISR data

Direct photon p_T spectra normalized by $(dN_{ch}/d\eta)^{\alpha}$, where $\alpha = 1.25$

The pQCD curves are also normalized

Large Systems: Direct Photon Scaling

arXiv:1805.04084 [hep-ex]



- All Au+Au data are on top of each other at low- and high-p_T at 200 GeV
- At low-p_T they are distinctly above the p+p data/fit/pQCD

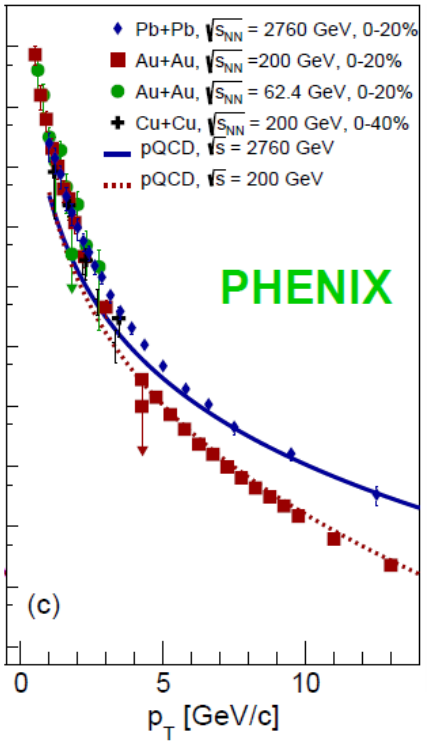
Direct photon p_T spectra normalized by $(dN_{ch}/d\eta)^{\alpha}$, where $\alpha = 1.25$

The pQCD curves and p+p fit are also normalized

Large Systems: Direct Photon Scaling

- Now we compare different energies from 39 GeV to 2760 GeV
- Again all data coincides at low-p_T
- We see the expected difference with the energy and N_{coll} scaling at high-p_T

arXiv:1805.04084 [hep-ex]



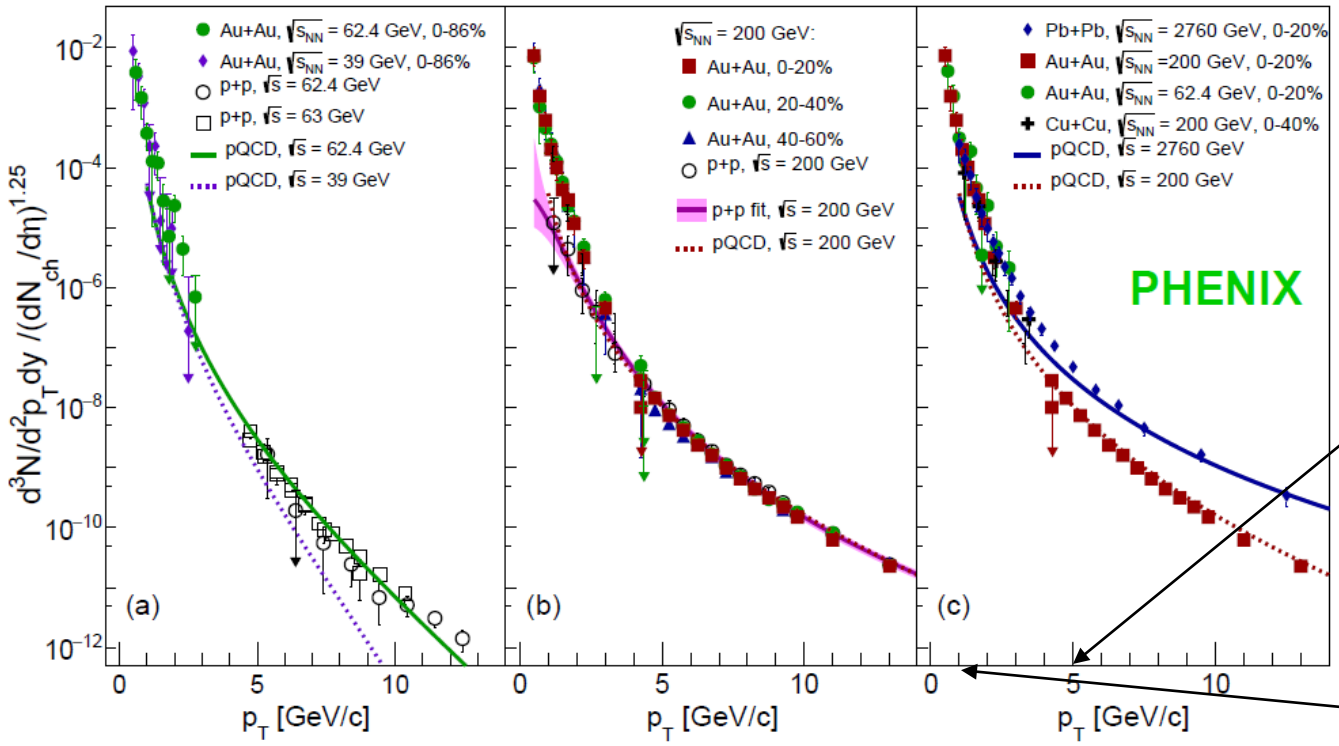
Direct photon p_T spectra normalized by $(dN_{ch}/d\eta)^{\alpha}$, where $\alpha = 1.25$

ALICE data from Pb+Pb at 2760 GeV and ISR data from p+p at 62.4 GeV are included

The pQCD curves and p+p fit are also normalized

Large Systems: Direct Photon Scaling

- Direct photon p_T spectra -- quantified by integrating the invariant yield from some p_T value



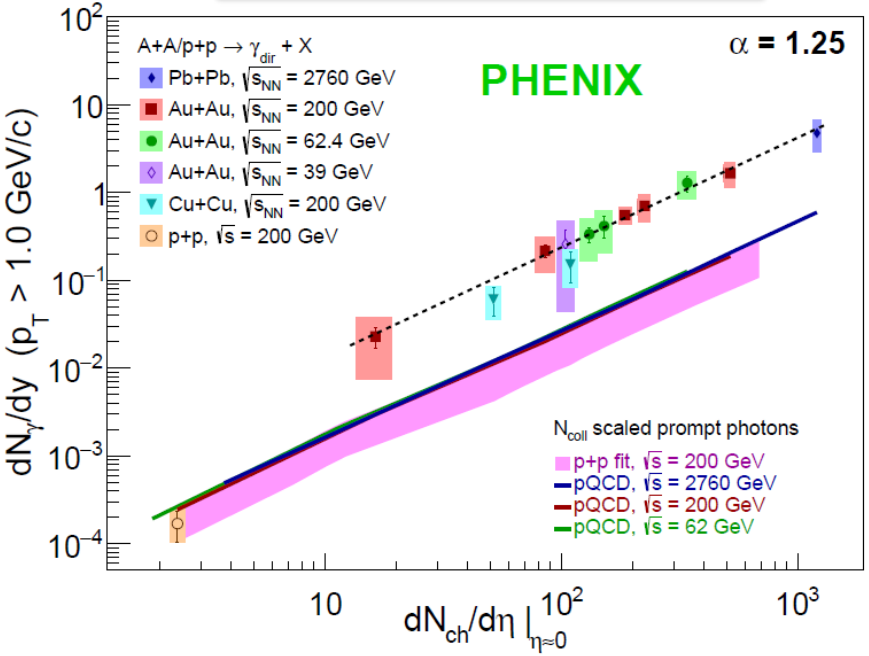
Integrate from 5.0 GeV/c

Integrate from 1.0 GeV/c

Large Systems: Direct Photon Scaling

Integrated direct photon yield above $p_T = 1.0$ GeV/c

arXiv:1805.04084 [hep-ex]

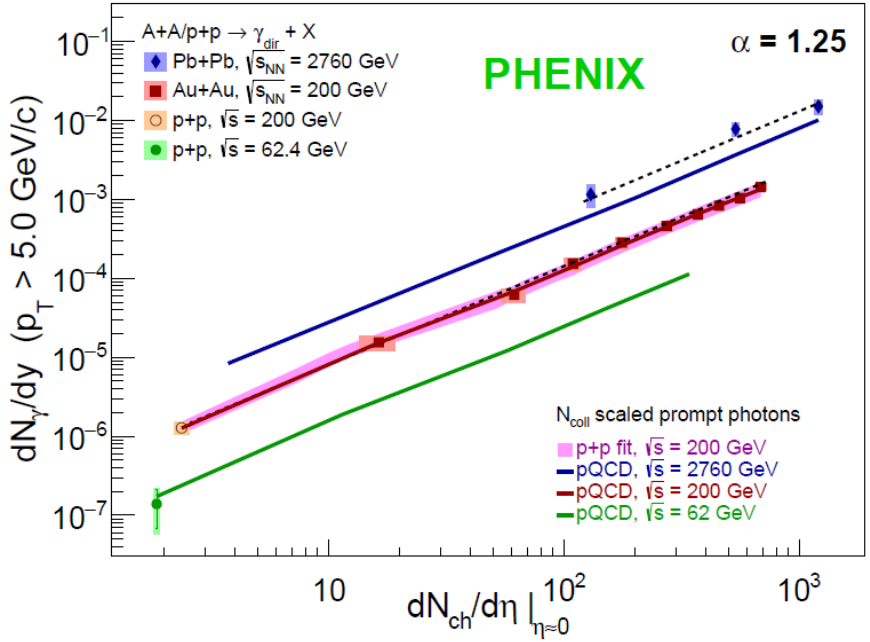


- Another representation of the direct photon scaling
- The integrated yield grows faster than the multiplicity
- The prompt photons described by the purple band and integrated pQCD curves have nearly the same slopes

Large Systems: Direct Photon Scaling

Integrated direct photon yield above $p_T = 5.0$ GeV/c

arXiv:1805.04084 [hep-ex]

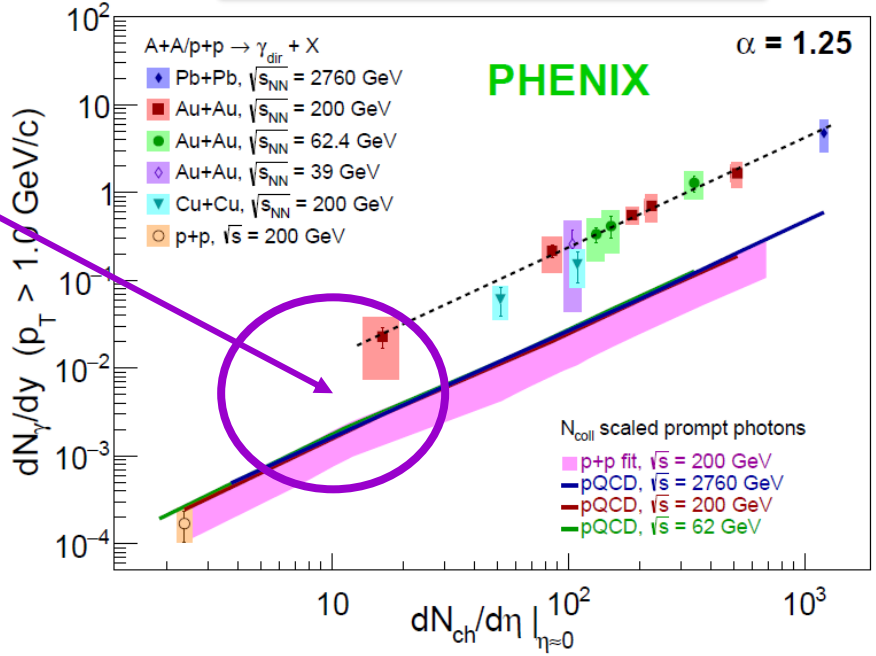


Large Systems: Direct Photon Scaling

Integrated direct photon yield above $p_T = 1.0$ GeV/c

arXiv:1805.04084 [hep-ex]

Small systems



Large Systems: Direct Photon Scaling

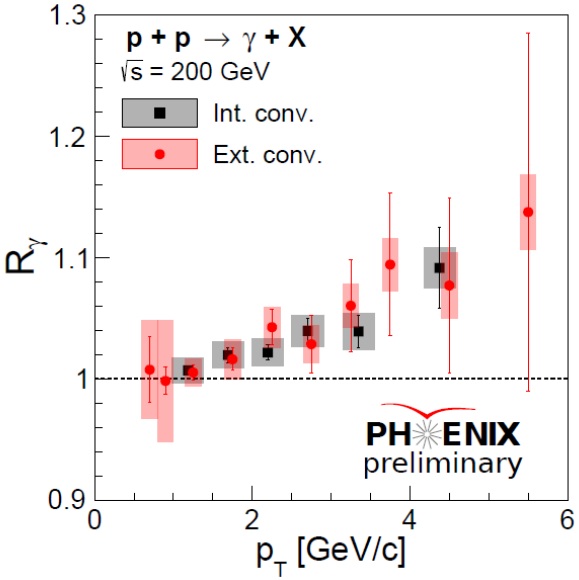
- At a given center-of-mass energy the direct photon invariant yield in A+A collisions scales with N_{coll} down to below 1 GeV/c in p_T

- The scaling at low-p_T can be generalized to different center-of-mass energies and centrality/collisions systems if the yield is scaled by $(dN_{ch}/d\eta)^{1.25}$ instead of N_{coll}.

- The low-p_T scaling suggests the main photon sources contributing to it, could be similar across beam energies

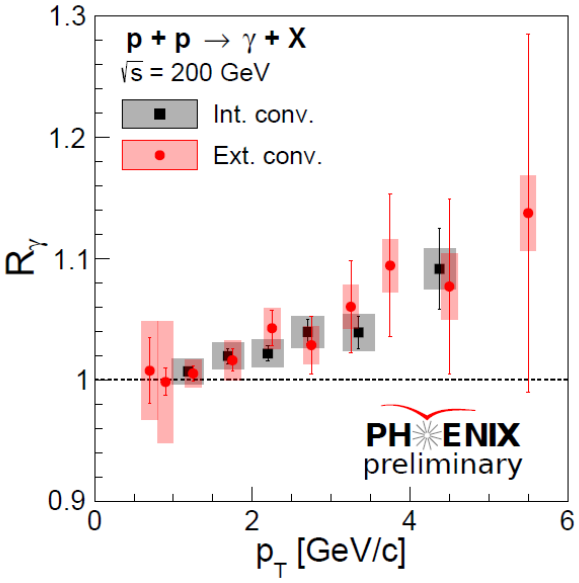
Small Systems: Direct Photon Preliminary R_γ

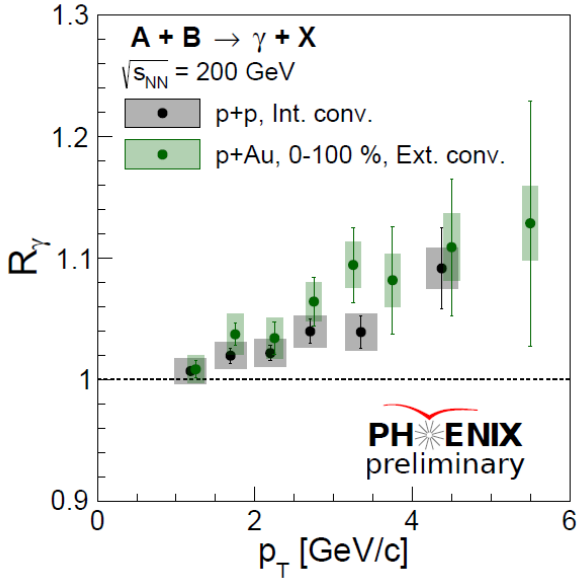
- R_γ from p+p collisions: The new data are in red, the published data are in black



Small Systems: Direct Photon Preliminary R_γ

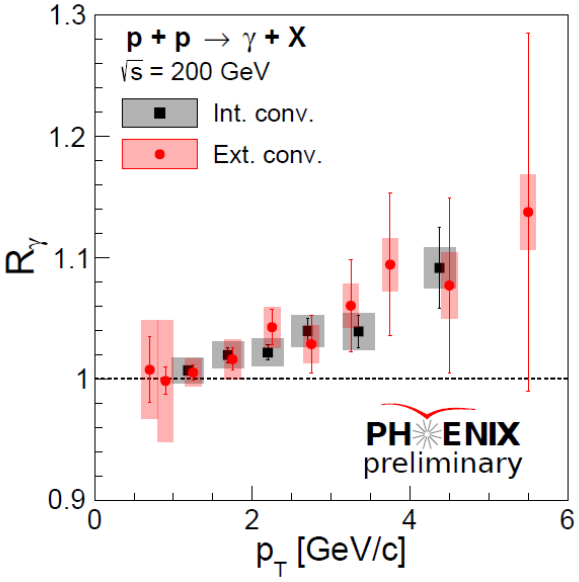
- R_γ from p+p collisions: The new data are in red, the published data are in black
- R_γ from p+ Au collisions in minbias

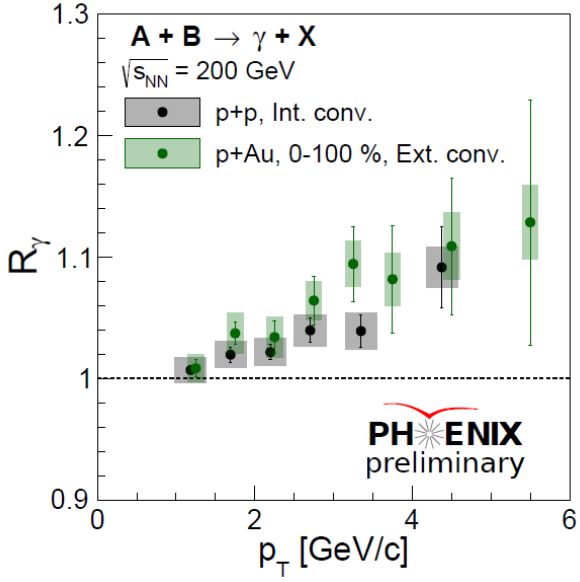


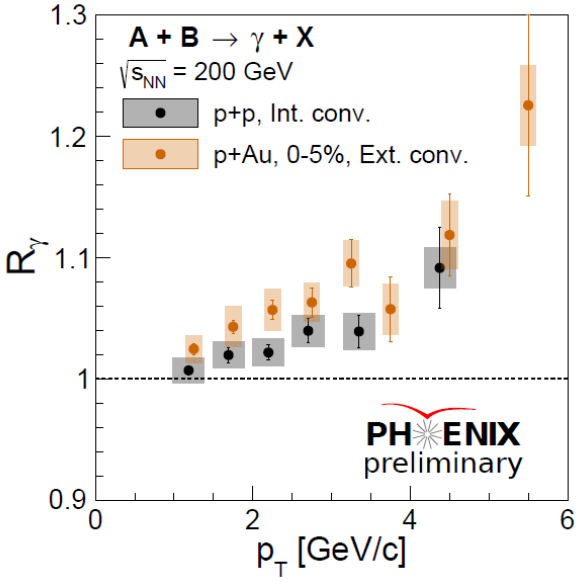


Small Systems: Direct Photon Preliminary R_γ

- R_γ from p+p collisions: The new data are in red, the published data are in black
- R_γ from p+ Au collisions in minbias
- R_γ from p+ Au collisions in 0-5% centrality bin

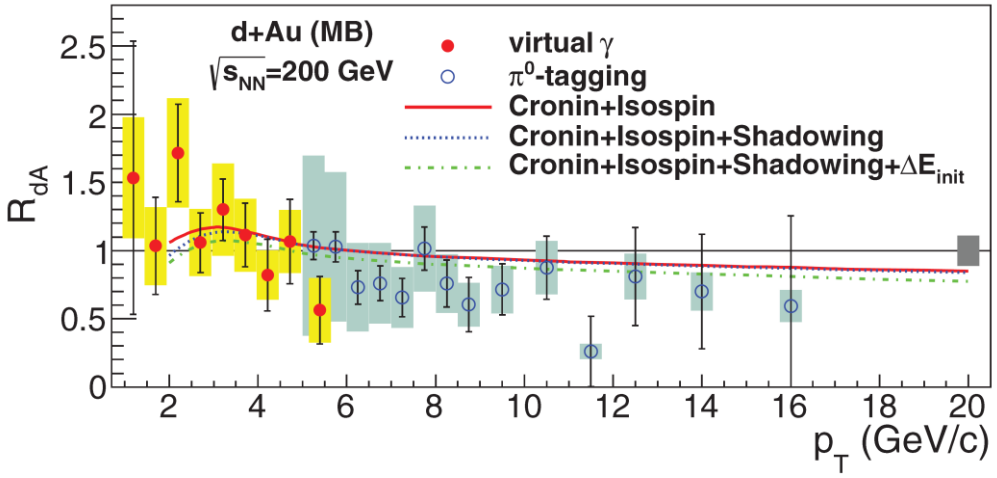


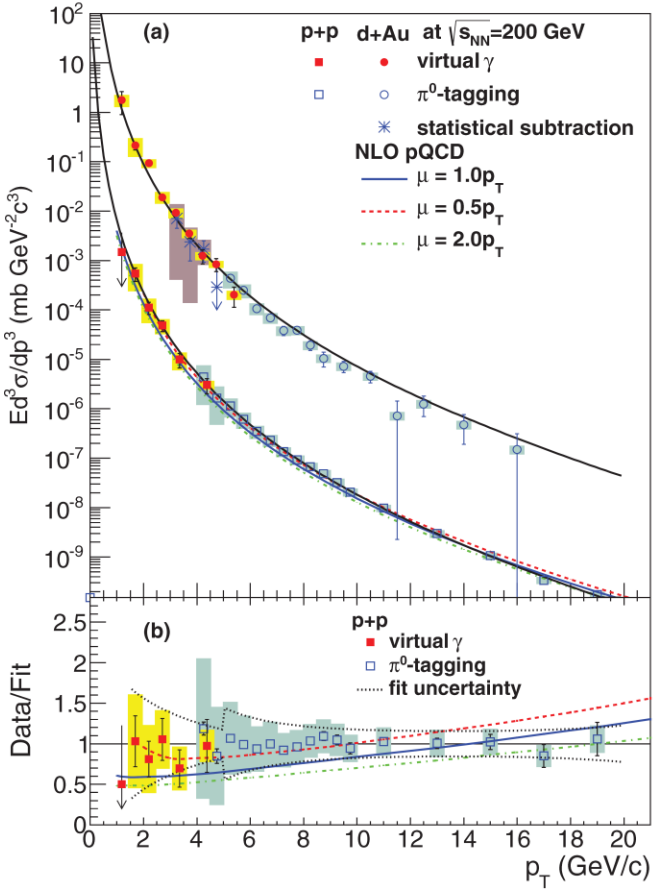




Small Systems: Direct Photon p_T Spectra

The plots are from PRC 87, 054907

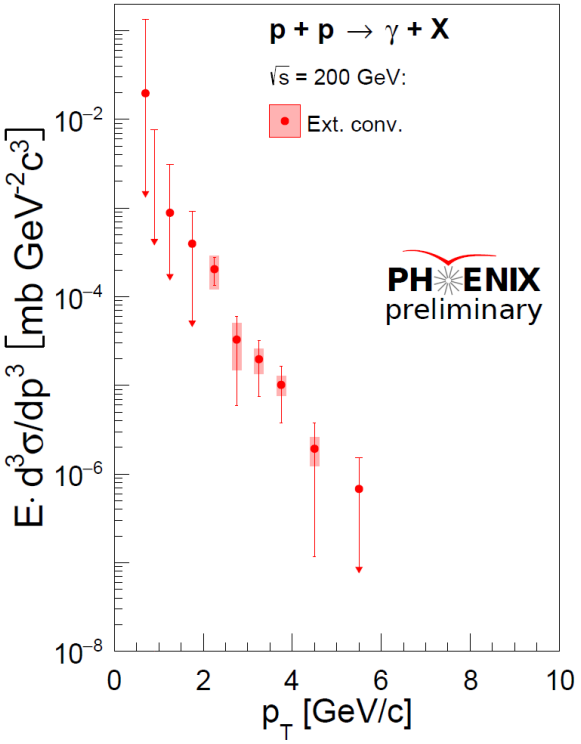




Small Systems: Direct Photon Preliminary p_T Spectra

- After R_γ is constructed, we can get the invariant cross section

$$\text{Inv. Yield} = (R_\gamma - 1) \times \gamma^{had}$$



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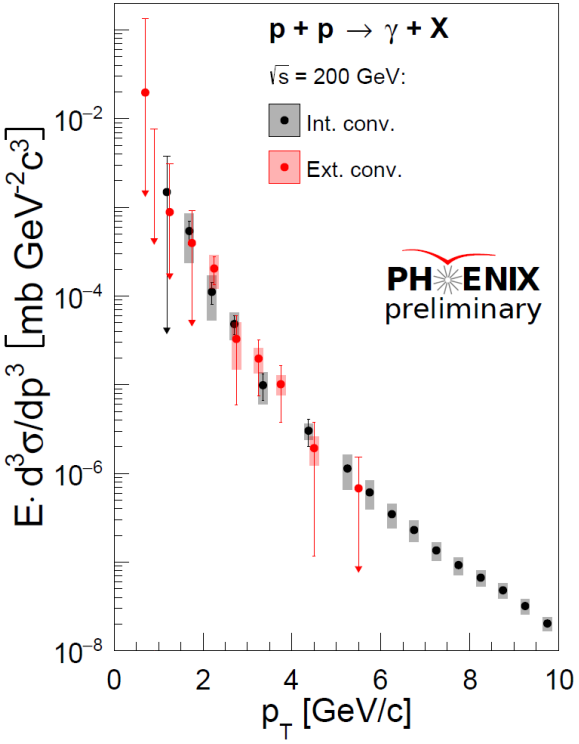

Above p_T =5.0 GeV/c the published p+p data are from calorimeter measurements: PRL 109, 152302

Small Systems: Direct Photon Preliminary p_T Spectra

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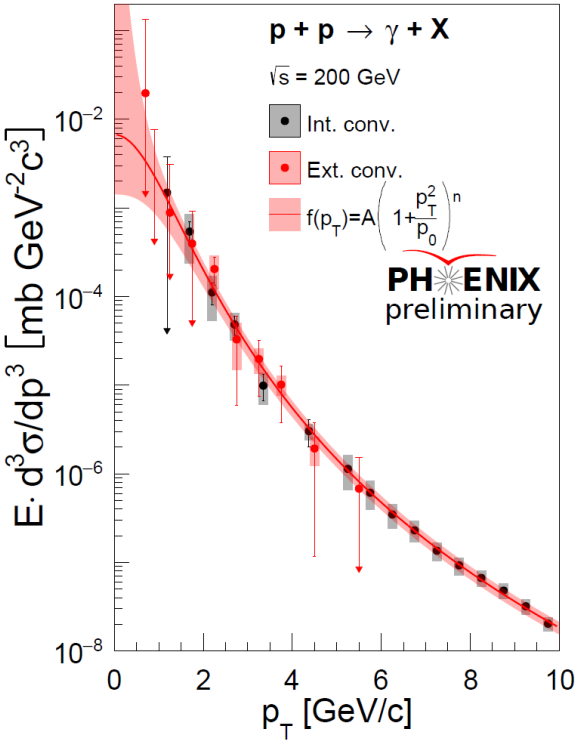

The PHENX new p+p fit made by using three p+p data sets

Small Systems: Direct Photon Preliminary p_T Spectra

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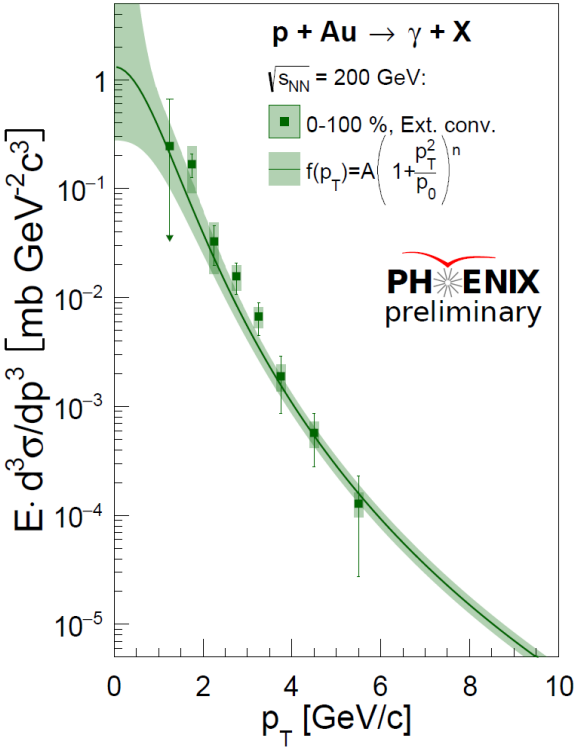

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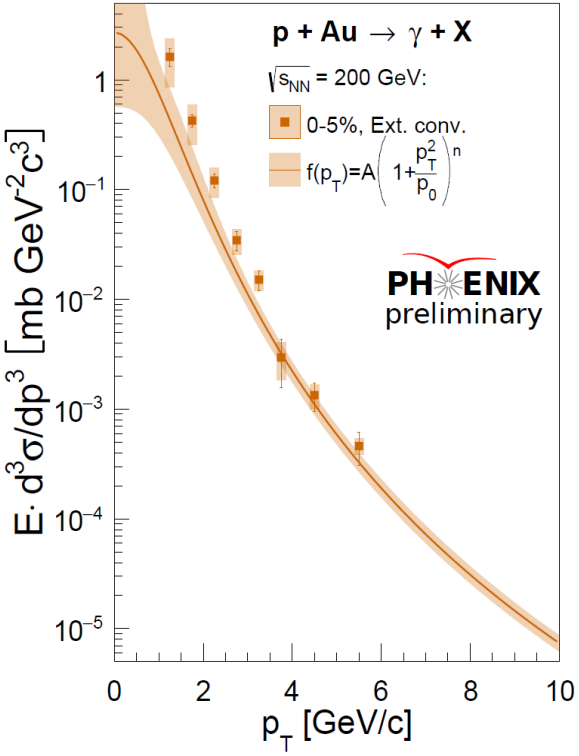
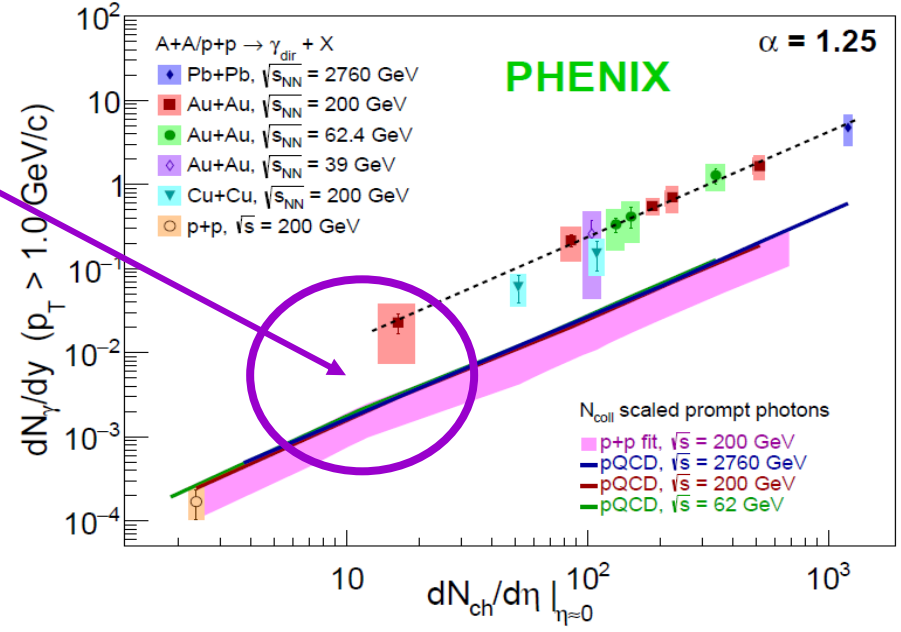


- One can see a clear enhancement of the direct photon yield above the N_{coll} scaled p+p

Direct Photon Connection Between Large and Small Systems

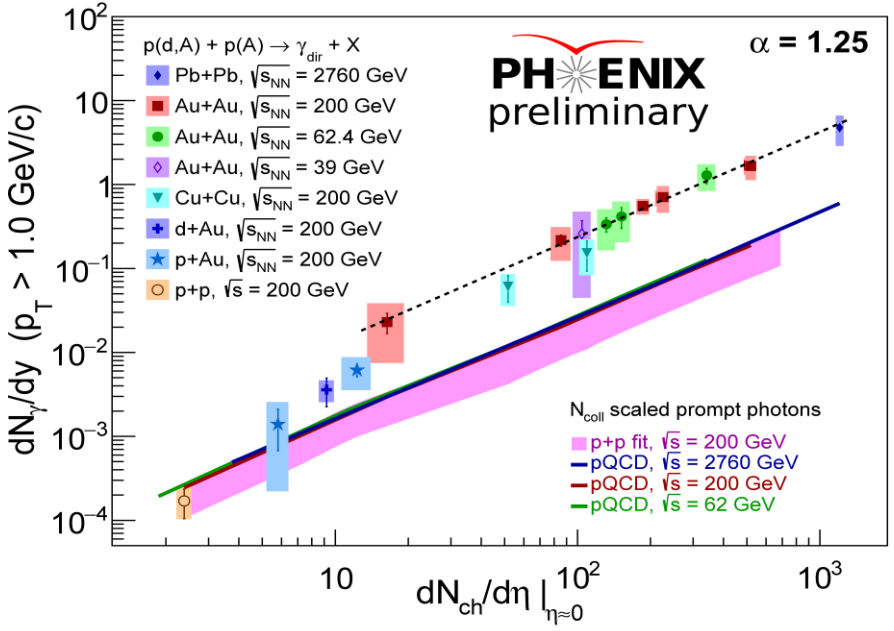
- Let's now go back to the plot of the integrated direct photon yield above $p_T = 1.0$ GeV/c

Small systems



Direct Photon Connection Between Large and Small Systems

- There seems to be another trend from small systems, different from that of large systems
- Both trends suggest an "intersection region" or "intersection point"
- p+Au 0-5% data point shows a sign of existence of QGP small droplet



Summary

- New PHENIX direct photon data from Au+ Au 39, 62.4 GeV; Cu+Cu 200 GeV, p+p, p+Au at 200 GeV
- Discovered a new scaling behavior in large systems
  - at a given center-of-mass energy, the low and high-p_T yields scale with N_{coll}
  - across energies, N_{coll} is proportional to $(dN_{ch}/d\eta)^{1.25}$
  - for all energies, the low-p_T yield scales like $(dN_{ch}/d\eta)^{1.25}$
- Discovered excess of direct photons in central p+Au
  - above N_{coll} scaled p+p
  - consistent with the formation of QGP droplets
  - data suggests transition from p+p to A+A like scaling

Back-Ups

Measuring Direct Photon R_γ with the Double Ratio

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

e^+e^- pair efficiency

e^+e^- pair acceptance

DATA

$$N_\gamma^{incl}(p_T) = c\varepsilon_{ee} a_{ee} \gamma^{incl}(p_T)$$

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

SIMULATION

$$N_\gamma^{had}(p_T) = a_{ee} \gamma^{had}(p_T)$$

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

Conversion factor

Photon efficiency

f: Conditional acceptance of the second decay photon in the EMCal

SIMULATION

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

- Pair acceptance, efficiency and conversion probability factors cancel in the ratios