Direct photons in p+p and p+Au collisions

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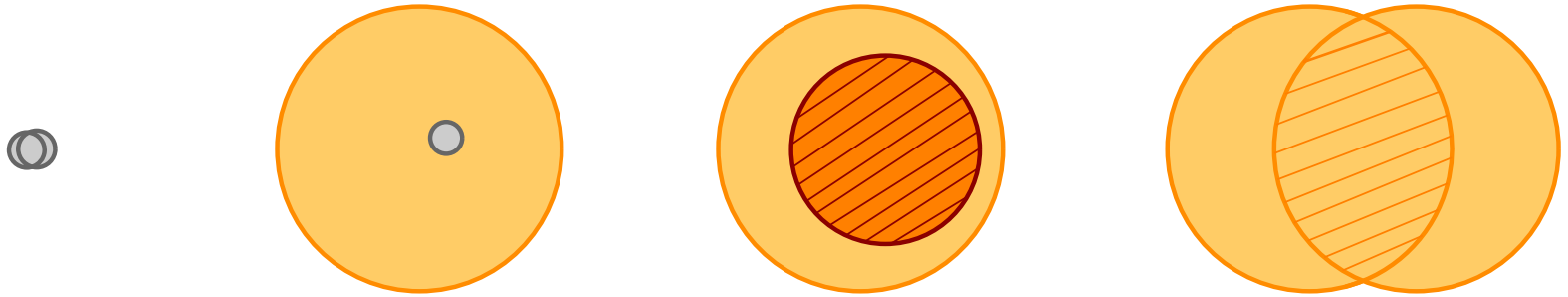
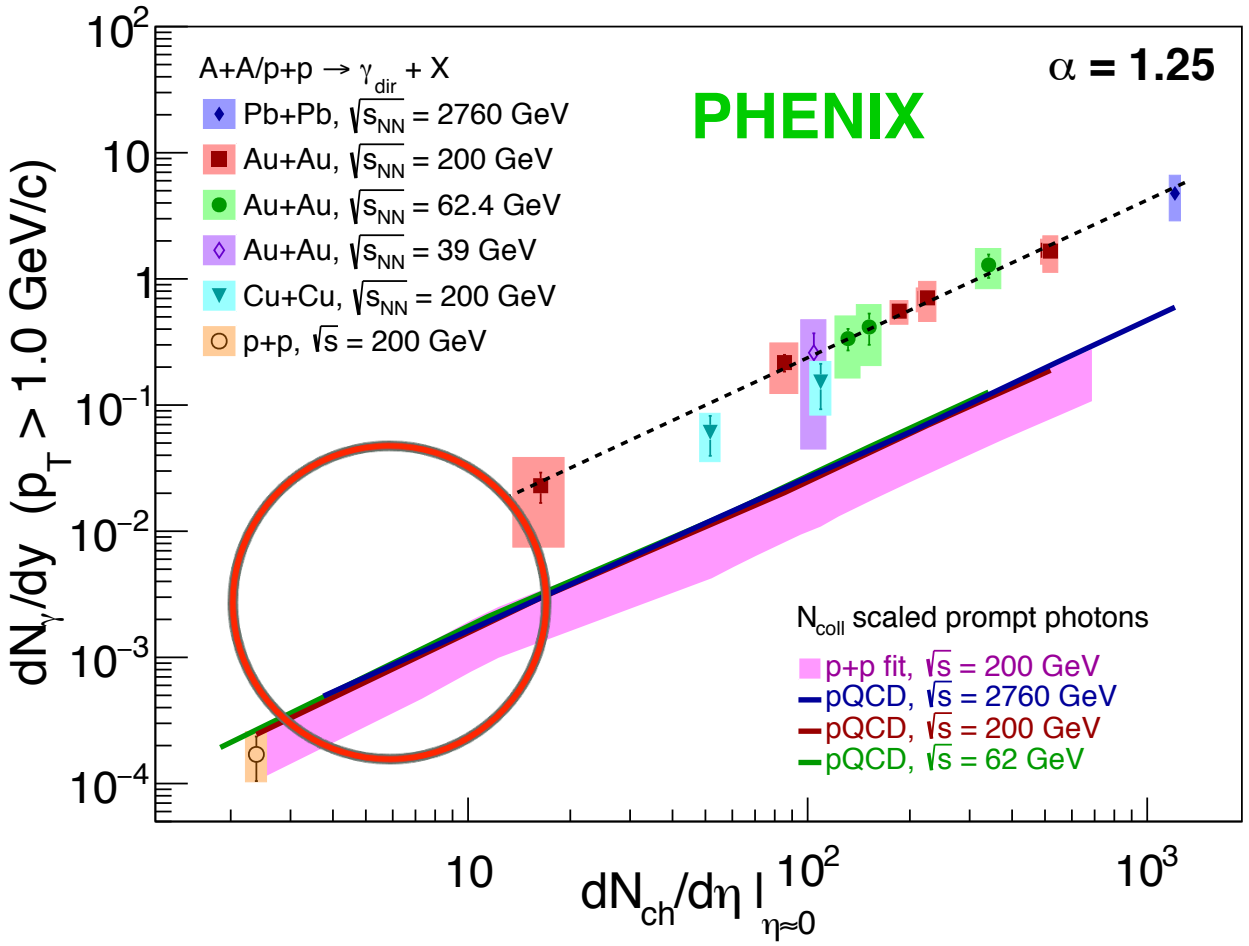
Remaining questions?



pp **pAu** **CuAu** **AuAu**

- What is the direct photon spectrum shape in low p_T for p+p?
- Is there hot medium created in p+Au collisions?
- What is the p_T dependence of v_2 for Cu+Au most central collision? (magnetic field effect)
- What is the p_T dependence of v_3, v_4 for Au+Au collision? (compare with theoretical models)

Scaling of photon yield p_T>1 GeV/c



Observed scaling behavior in all A+A collisions.

The N_{coll}-scaled p+p data and pQCD calculations show the similar scaling behavior

The A+A yield is factor of 10 larger than expected from pQCD

Transition region expected in the 2-20 multiplicities

Virtual photon conversion

The relation between γ production and the associated e^+e^- production can be written:

$$\frac{d^2N_{ee}}{dm_{ee}dp_T} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}L(m_{ee})S(m_{ee},p_T)\frac{dN_\gamma}{dp_T}$$

Form factors: $L(m_{ee}) = \sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)$

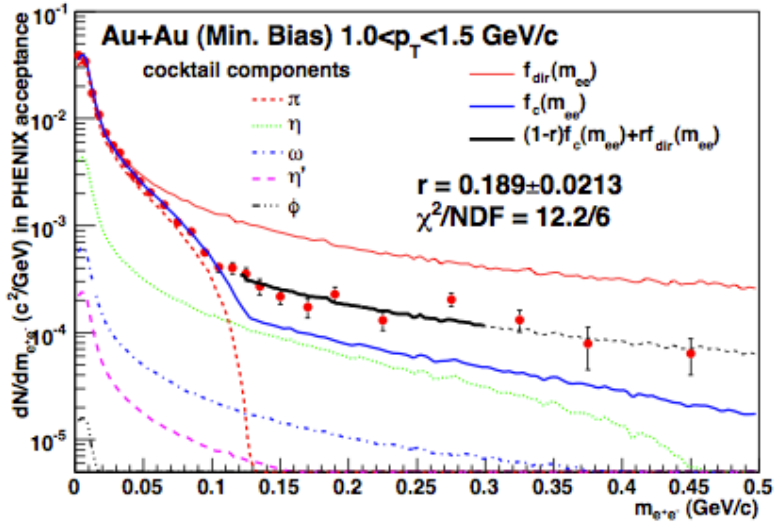
$m_{ee} >> m_e$

1

Virtual/Real photons $S(m_{ee},p_T) = dN_{\gamma^*}(m_{ee}) \Big/ dN_\gamma$

$p_T >> m_{ee}$

1



The virtual photons convert to e^+e^- pairs.
f_{dir} = direct photon contribution
$f_{cocktail}$ = all hadron contribution

The functions are normalized for $m_{ee} < 30$ MeV/c^2: in both $L(m_{ee})/m_{ee}$ is dominant (independent of r).

The function of the $(1-r)f_{cocktail}+rf_{direct}$ is fitted in mass range $0.1 < m_{ee} < 0.3$ MeV/c^2 (only r is fitted).

Direct photon yield in d+Au

PHENIX Phys.Rev.Lett 104 (2010) 132301

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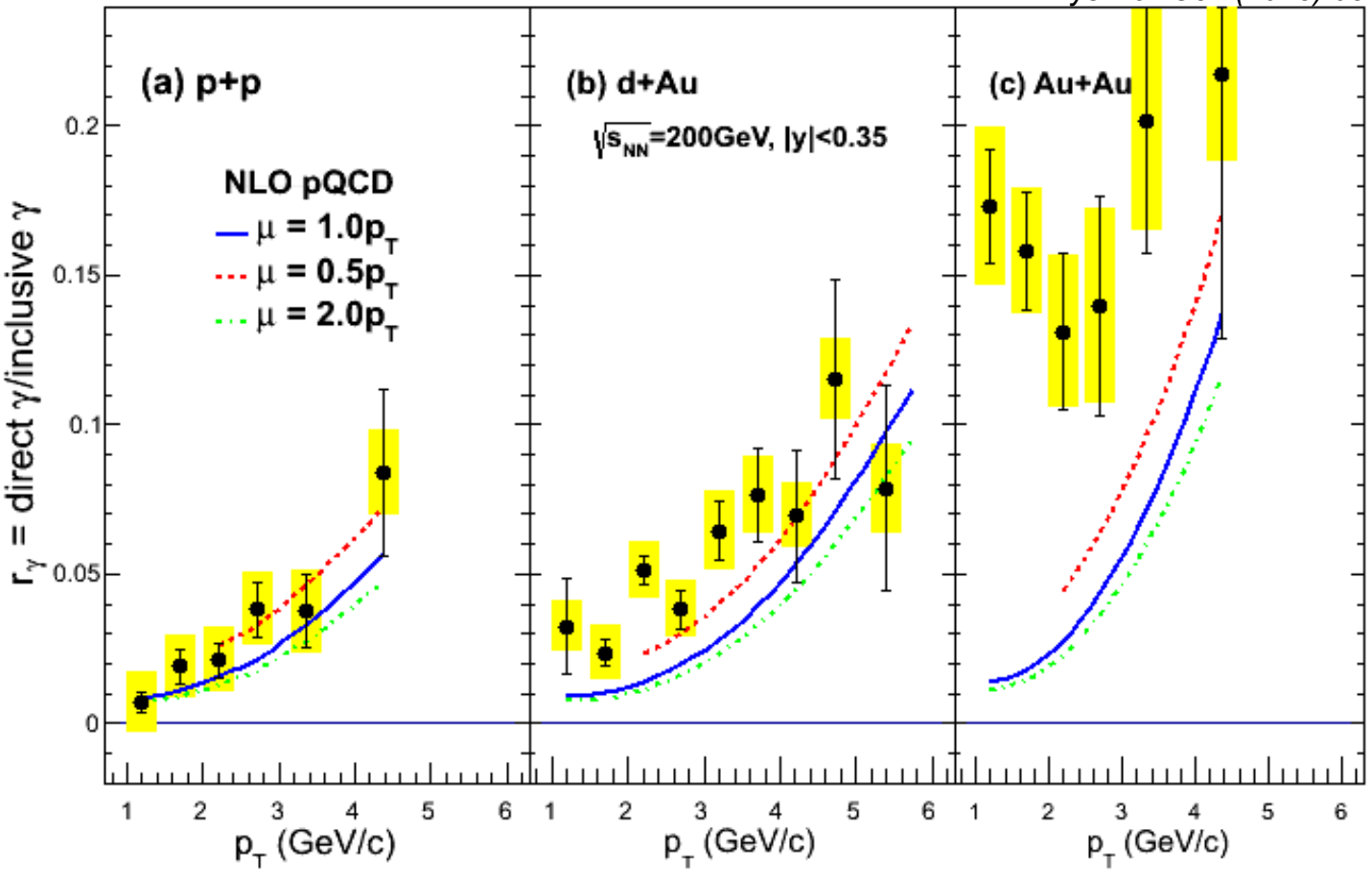

The direct photon yield is measured in p+p, d+Au and Au+Au collisions.
Very small signal in p+p and d+Au collisions

Direct photon yield in d+Au

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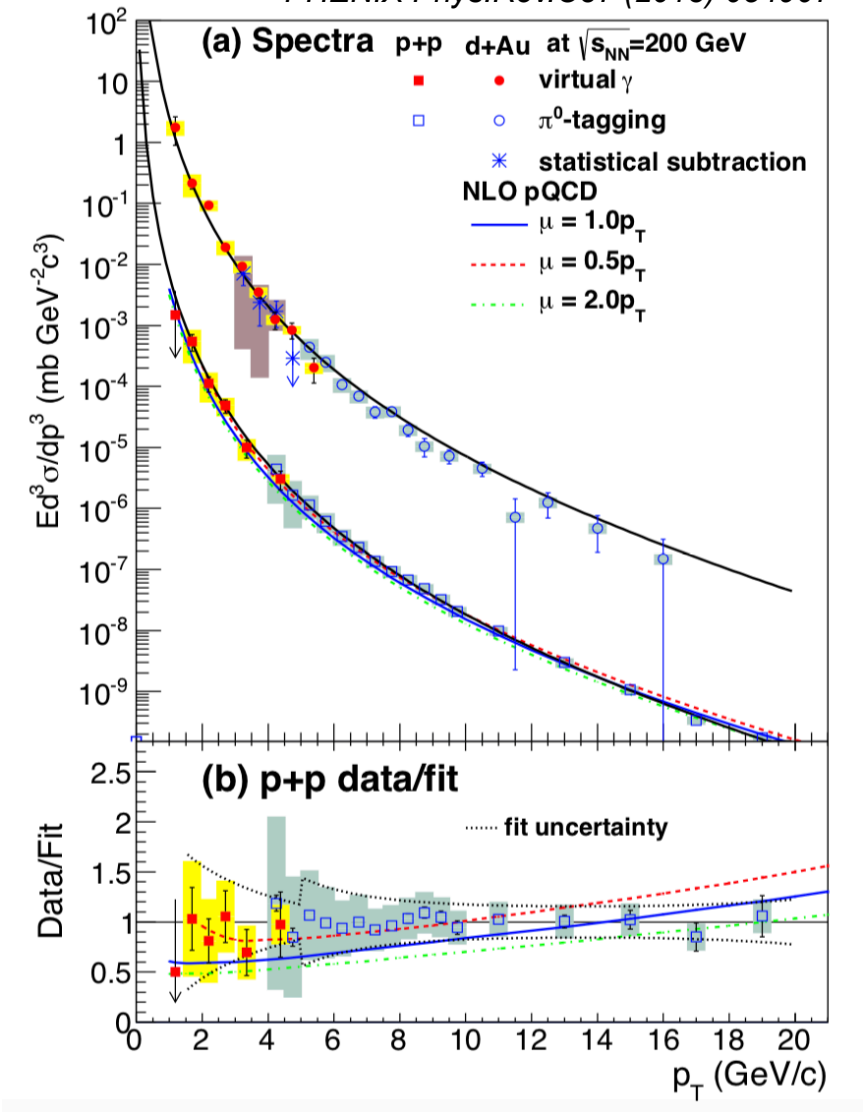


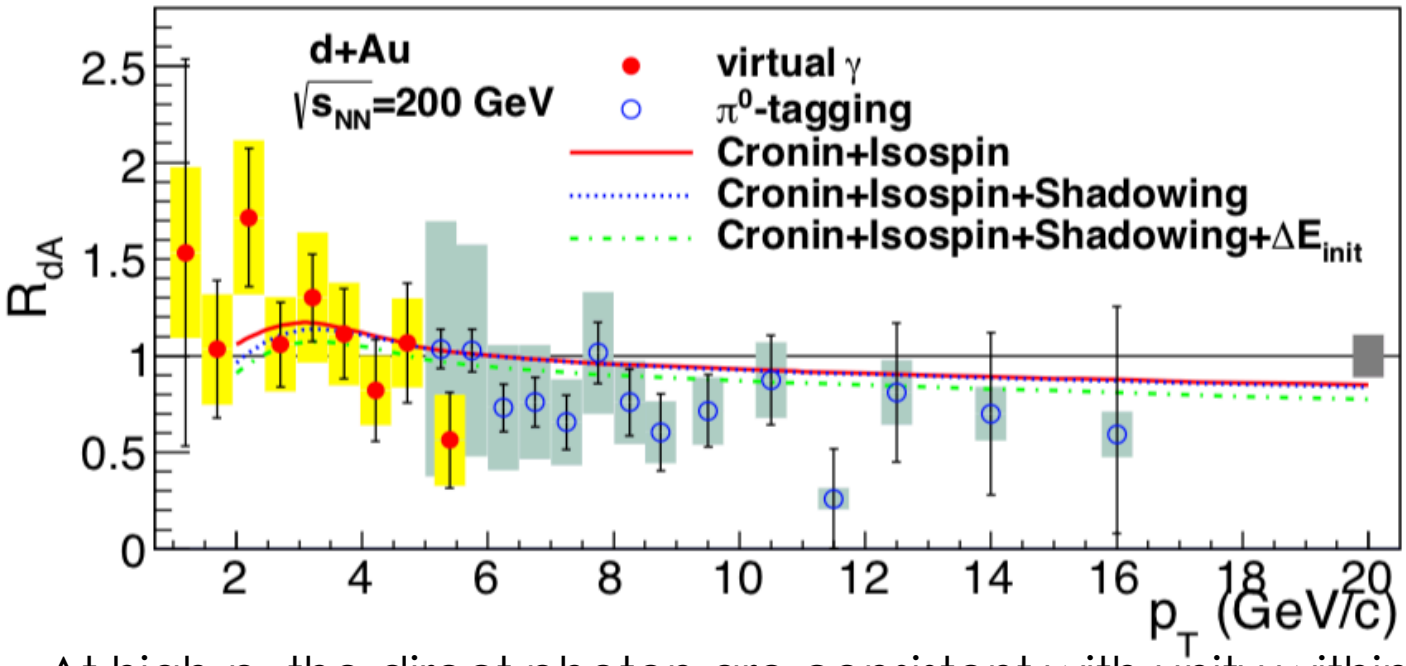
The direct photon yield is measured with two methods:

- low-p_T with the virtual photon conversion method
- high-p_T with the real photon measurement (EMCal)
- p+p direct photon yield is fitted with a pQCD inspired function:

$$E\frac{d^3\sigma}{dp^3} = a \cdot p_T^{-(b+c\cdot\ln x_T)} \cdot \left(1 - x_T^2\right)^n$$

- The d+Au yield is crosschecked with the N_{coll}-scaled function

What we learned from R_{dAu}



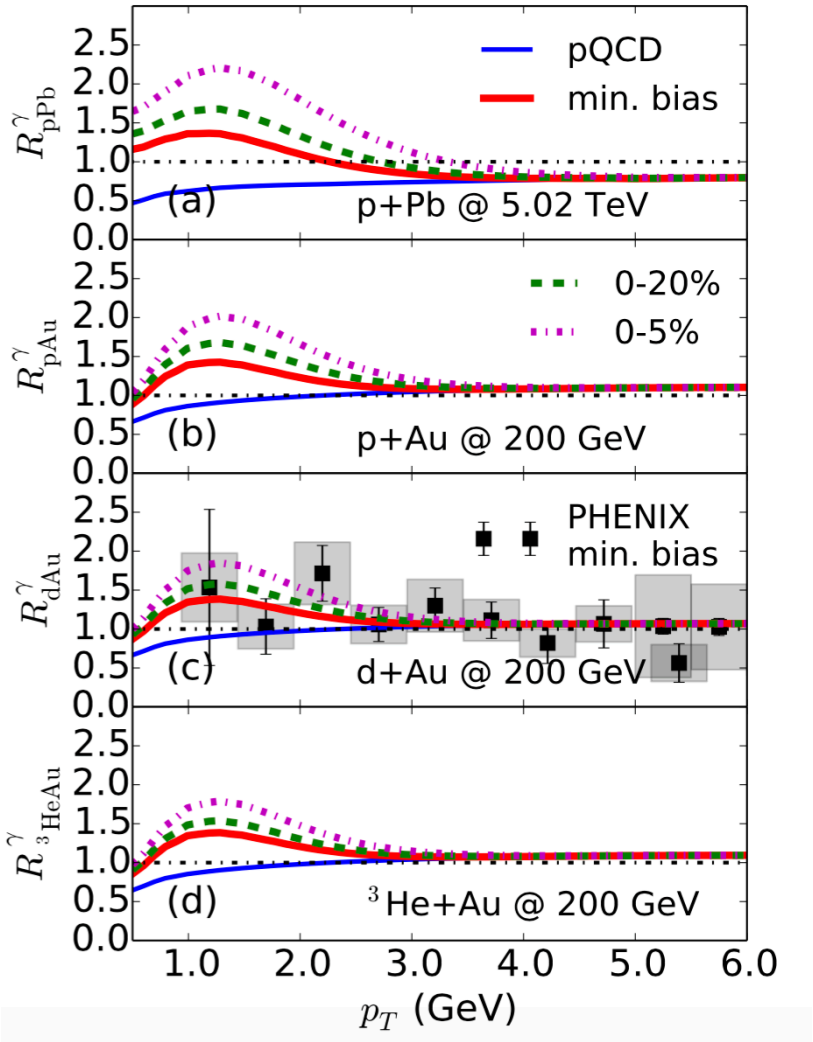
At high-p_T the direct photon are consistent with unity within the uncertainties:

- However, all the points are systematically lower than 1, around ~0.85
  → this could indicate a bit different N_{coll} (consequences also in the 'energy loss' measurements)

At low-p_T the yield shows good agreement with the unity, there is also room for a small enhancement

Theory prediction of thermal radiation in small systems

Phys. Rev. C **95**, 014906



Collectivity is observed in all 'small systems' from high multiplicity p+p to p+A collisions.

Question: Is there a **QGP** formed in these collisions?

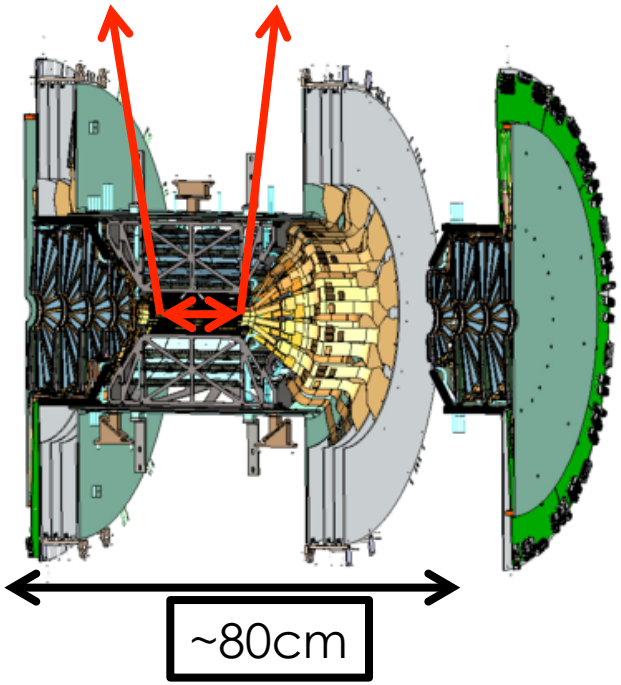
Theory model predicts also a thermal enhancement in the low-p_T direct photons:

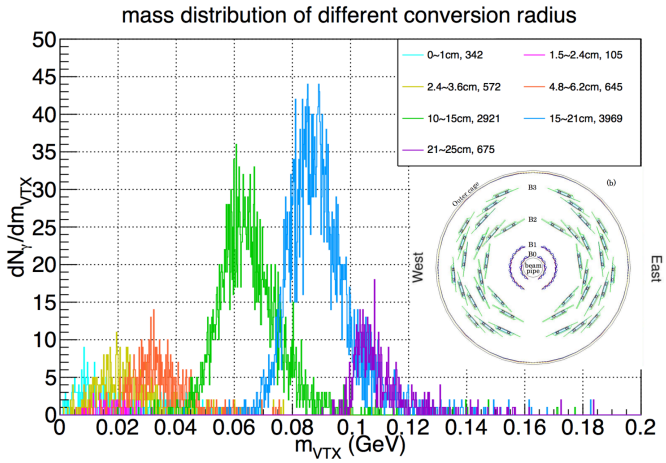
- Largest at LHC, less visible in the larger 'small systems' $R_{pPb}>R_{pAu}>R_{dAu}>R_{HeAu}$

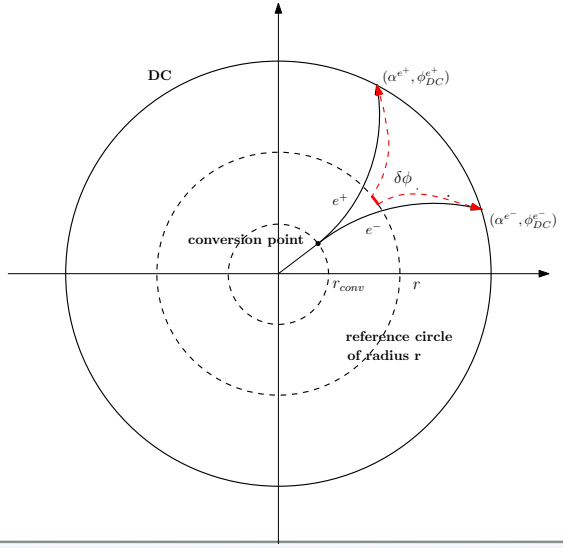
Currently had only the d+Au minimum bias data and it was not conclusive. Data is consistent with the enhancement and with unity.

Conversion photon on detector material

VTX detector (+ FVTX detector):
Here we have more complicated geometry. Also, we consider conversion analysis only in the very middle of the detector, +/- 10cm.
Conversion material is also changing by layers: 1.28X_0 2.6cm, 1.28X_0 5.1cm, 5.43X_0 11.8cm, 5.43X_0 16.7cm.







R_γ extraction

The calculation of the relative yield:

$$R_\gamma = \frac{\gamma_{Inc}}{\gamma_{Decay}} \longrightarrow R_\gamma = \frac{\langle \varepsilon f \rangle \left(N_{Inc} / N_{Tag} \right)_{Data}}{\left(N^{\gamma}_{had} / N^{\gamma}_{\pi} \right)_{MC}}$$

N_{Inc}/N_{Tag}:

- Extracted from the data. The inclusive photon yield and the tagged (from π^0) photon yield

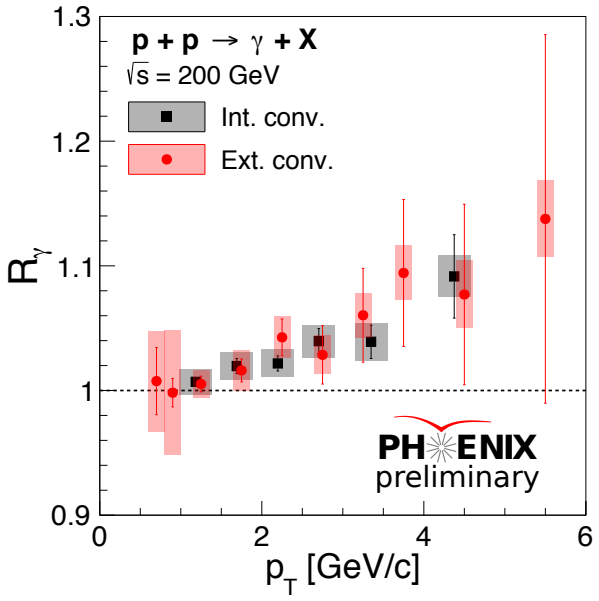
$<\varepsilon f>$:

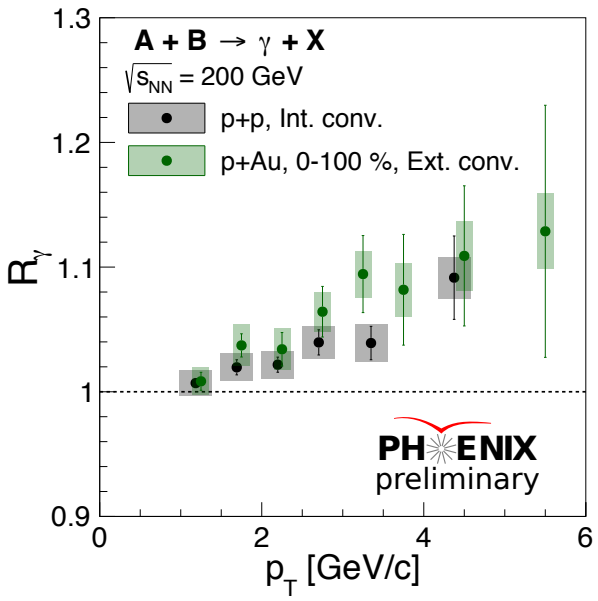
- The conditional efficiency and acceptance in order to reconstruct a π^0 via one converted photon and one calorimeter photon

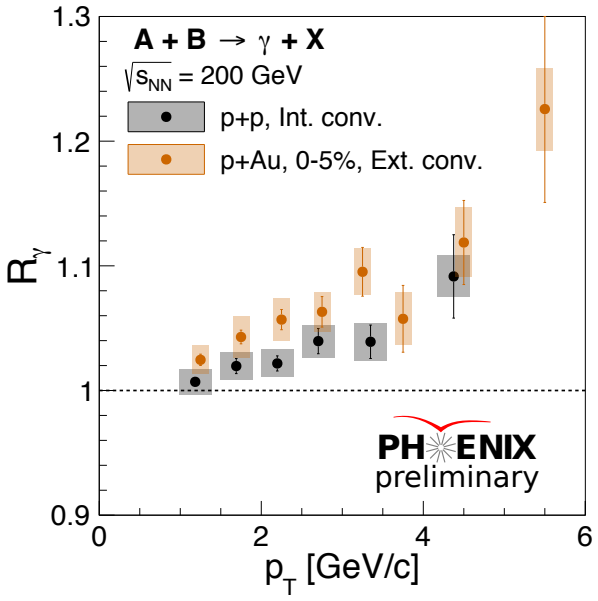
$N^{\gamma}_{had}/N^{\gamma}_{\pi 0}$:

- Obtained from the cocktail simulation

R_γ at p+p and p+Au







The R_γ was measured with the new method in p+p and p+Au collisions:

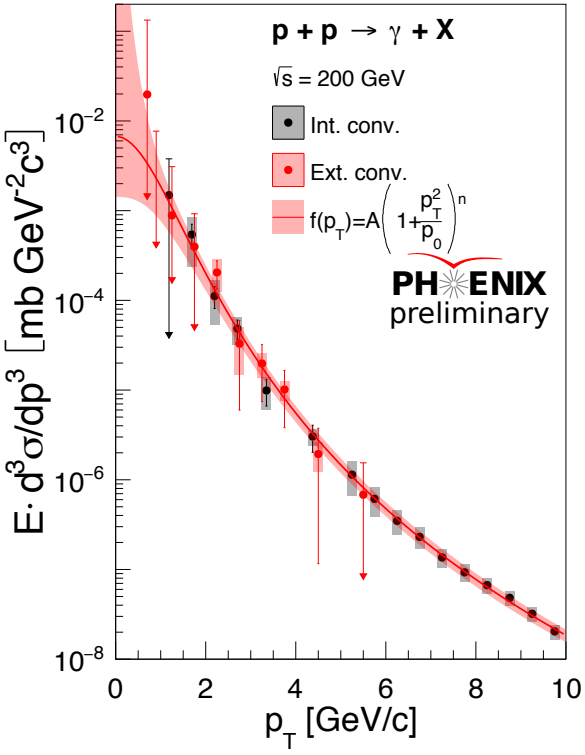
- Very small signal at low-p_T, consistent with the previous p+p result
- A small enhancement is possible in the central p+Au result.

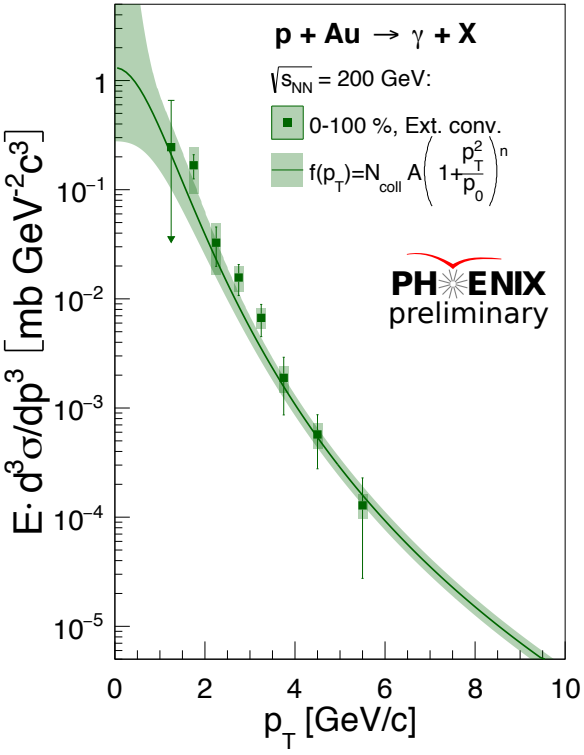
Direct photon invariant yields

Fit function, inspired from pQCD
Systematic errors include the fit errors, different functional forms

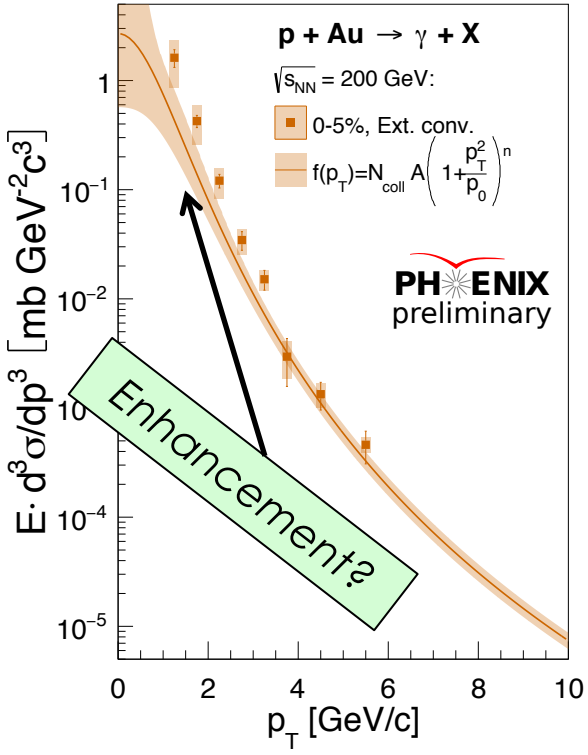
$$f(p_T) = A\left(1+\frac{p_T^2}{p_0}\right)^n$$

A = 6.74e-03
p_0 = 2.1
n = -3.3





N_{coll} = 4.667



N_{coll} = 9.59

Why curving at low-p_T

PRD23, 604

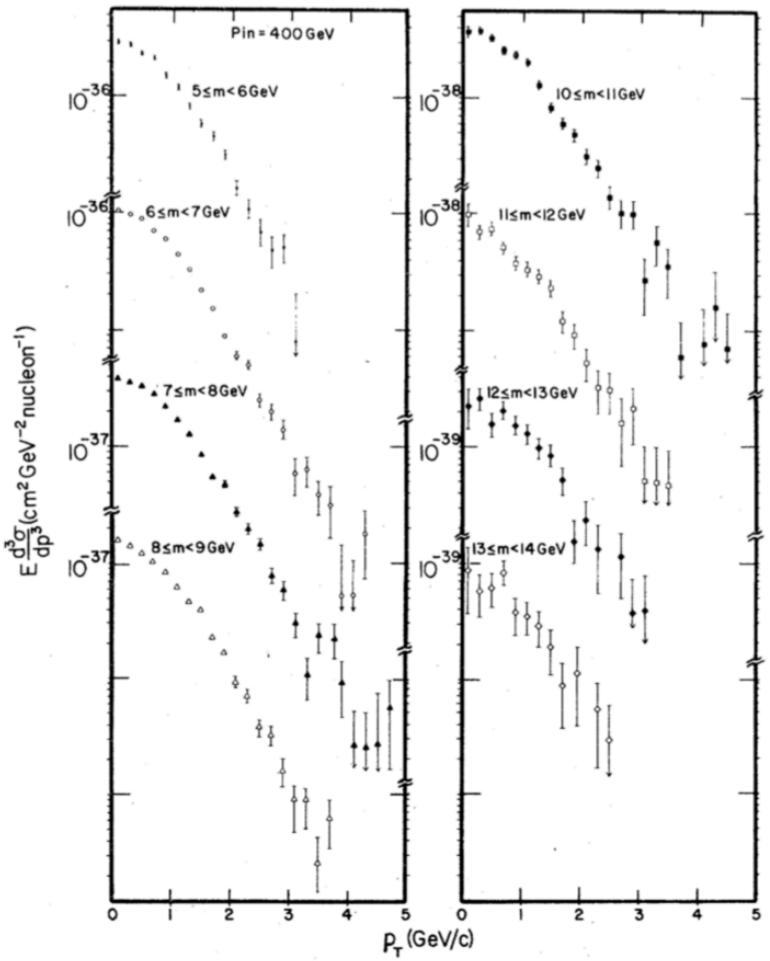


FIG. 12. Invariant yield of dimuons as a function of the transverse momentum p_T of the muon pair for 400 GeV incident protons.

Drell-Yan measurement from the di-muon decays at Fermilab proton-nucleus collisions.

At low-p_T the spectra shows a deviation from a power law behavior, and the curvature is very similar across different mass regions.

It is argued then that the direct photon spectrum in p+p collisions would show similar shape in the low-p_T region.

The function used in p+p from PHENIX

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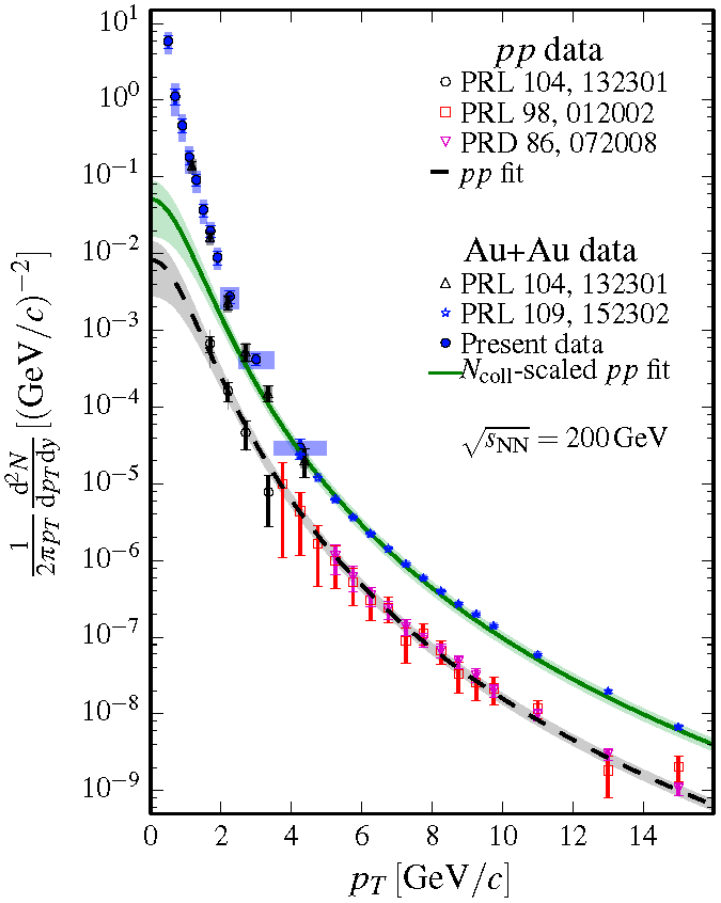

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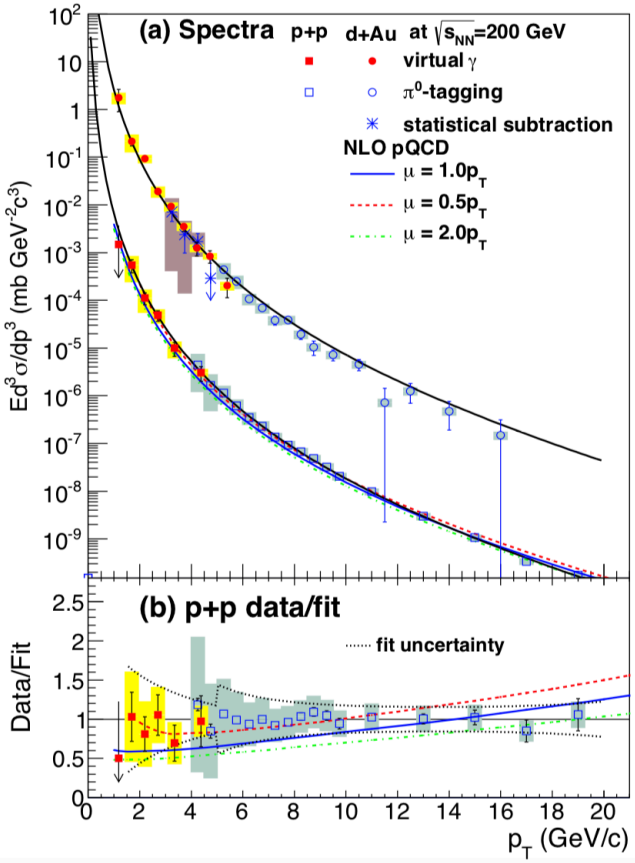
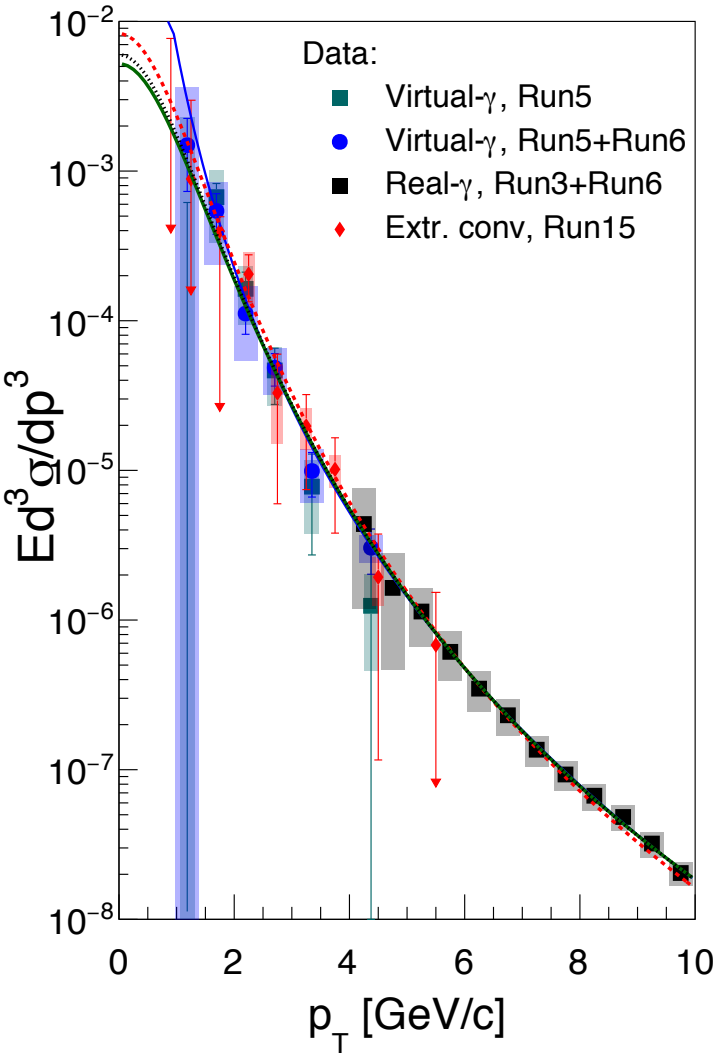


Two different fit functions used in PHENIX to describe the p+p direct photon yield. Both are inspired by the pQCD, but the low-p_T region behaves differently.

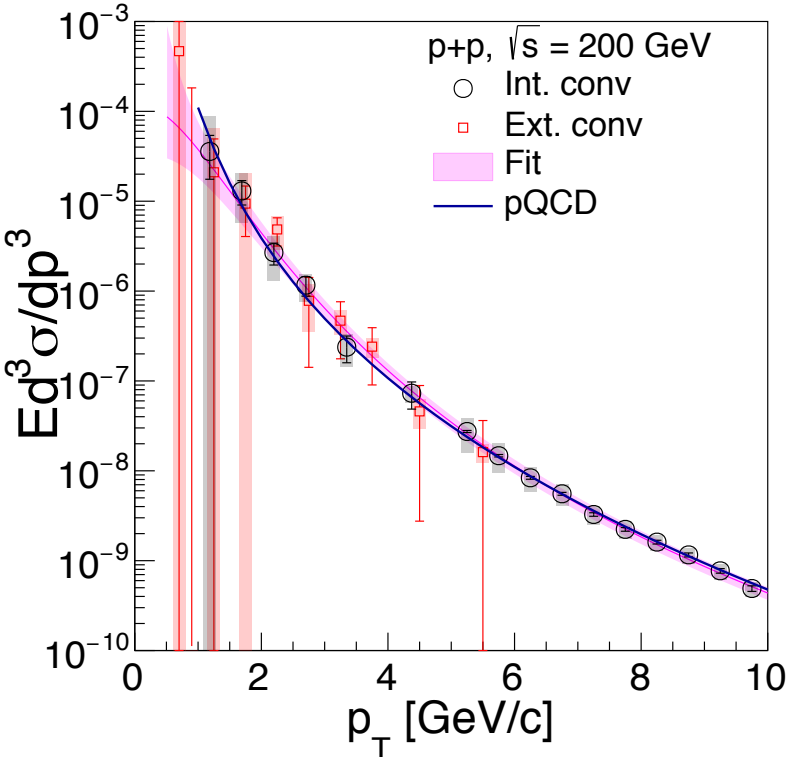
p+p fit

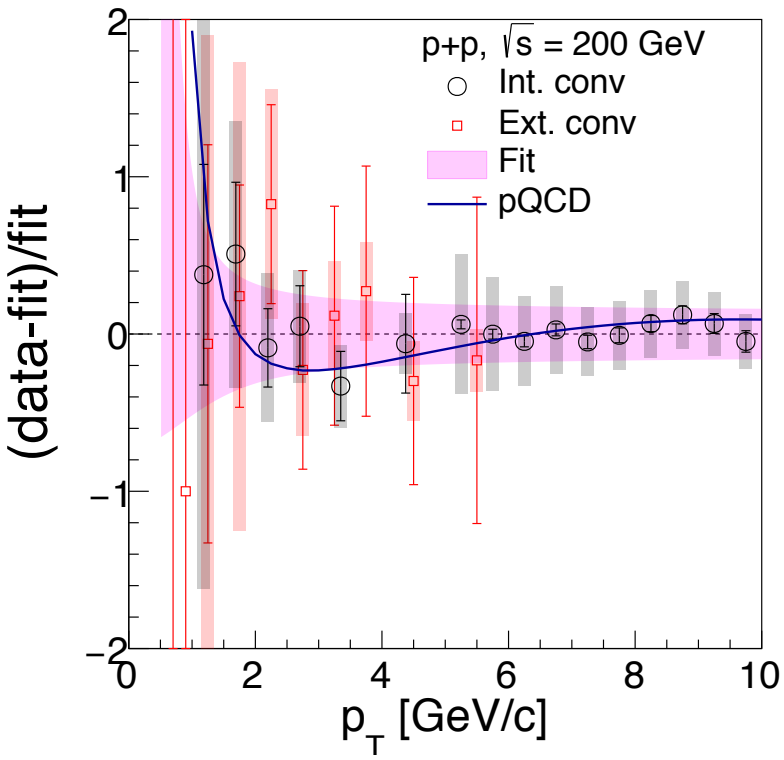


We investigated different fitting methods including and not including data points:

- The first data point is an upper limit with the systematic error (not in stat. error)
- The different fit functions also bring different answer:
  - when the function "curves" down in the p+p?
    → $p_T < 1$ GeV/c? $p_T < 0.2$ GeV/c
- The new data from the external photon measurement is not considered in the fit as of now:
  - It is also not a large effect on the final fit (especially low-p_T)

pQCD function vs fit function

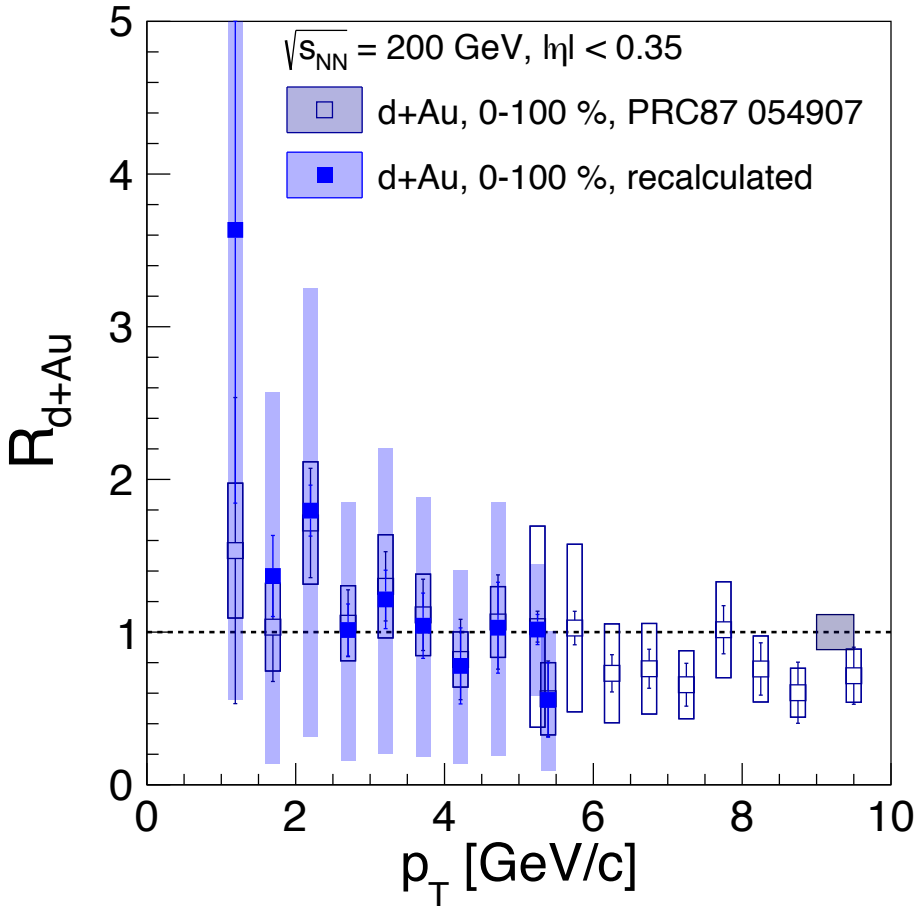




The comparison of the data and two different approaches to describe them:

- The fit function is curving over motivated from the DY measurements
- pQCD calculation with higher scales (up to $8p_T$), normalized to $0.5p_T$ scale

Reconsidering the d+Au

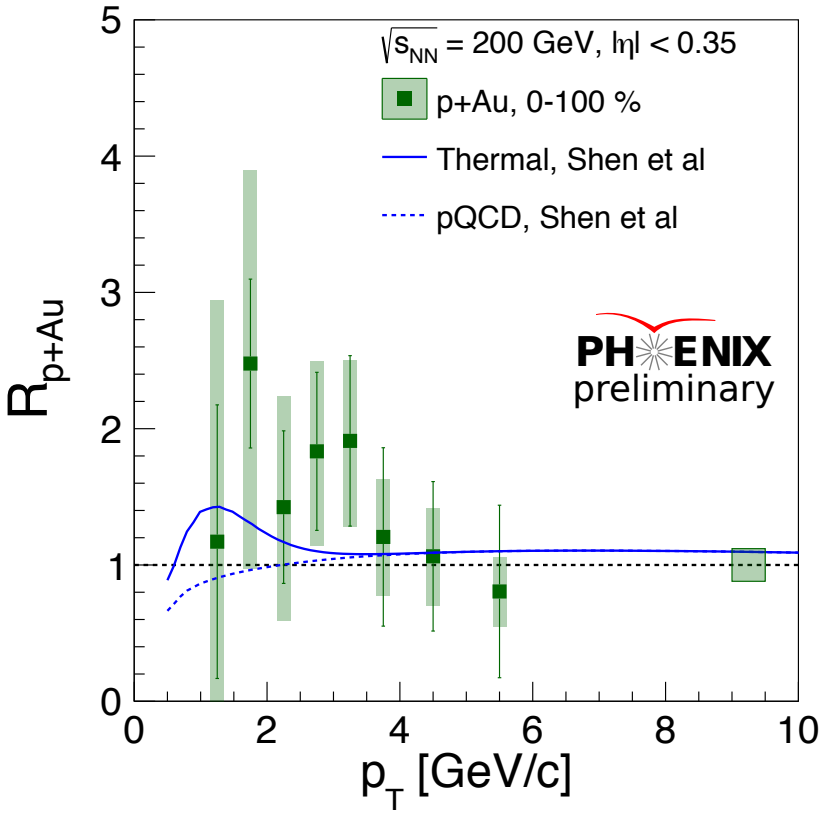


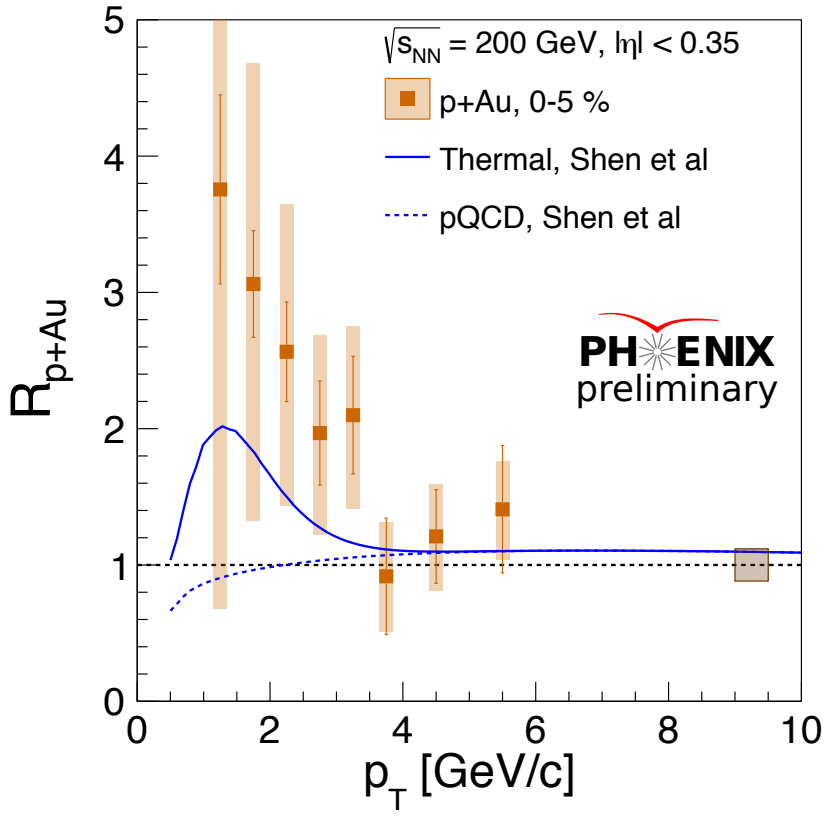
Recalculating the d+Au nuclear modification factor with the new fit function:

- Higher-p_T points are not changed
- The low-p_T points shows higher values, also includes larger systematics.

The baseline is very important, it can change the interpretation a lot!

Excess photon in p+Au collisions?

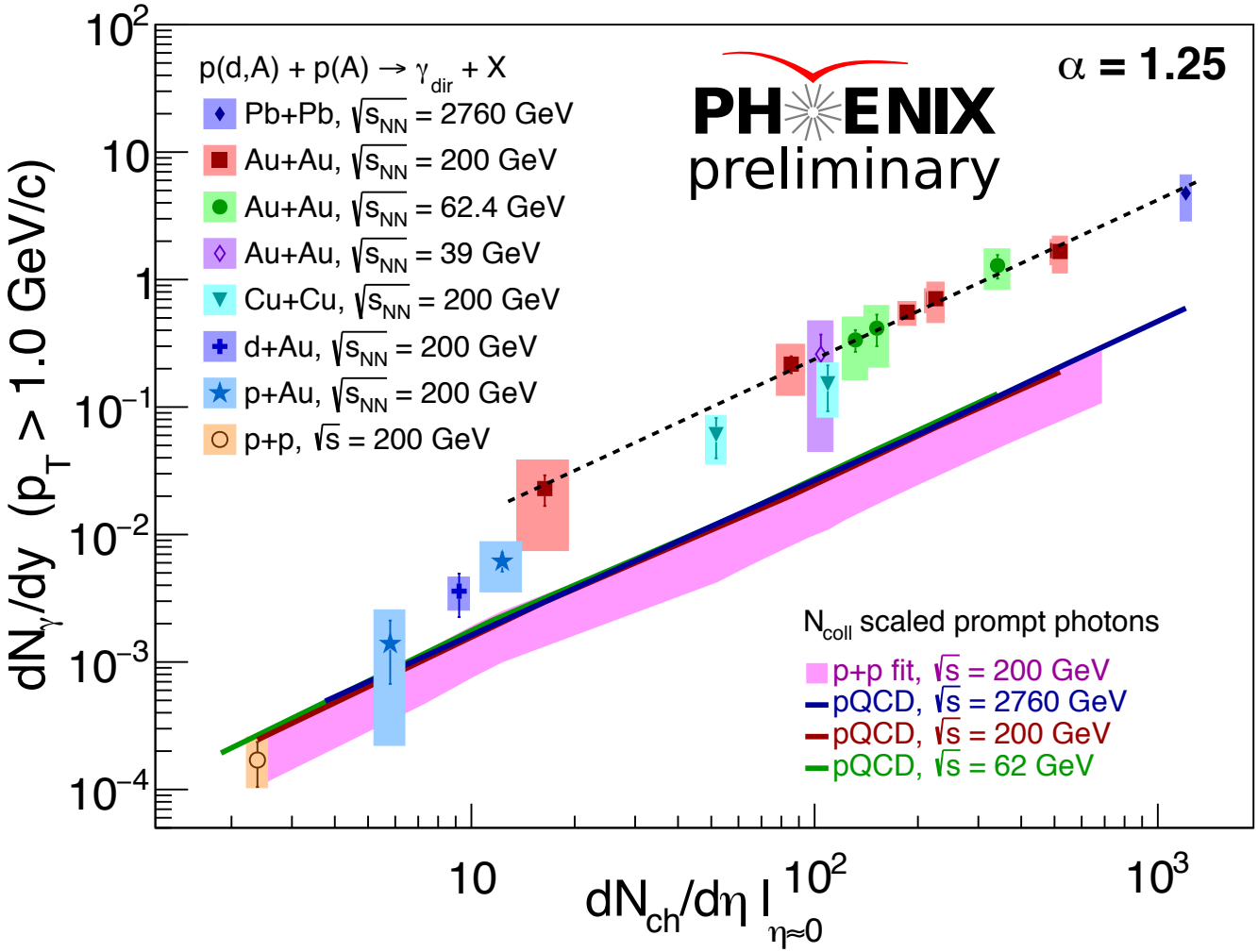




The direct photon R_{p+Au} is consistent with unity in the minimum bias collisions and shows a hint of small enhancement in the high multiplicity collisions.

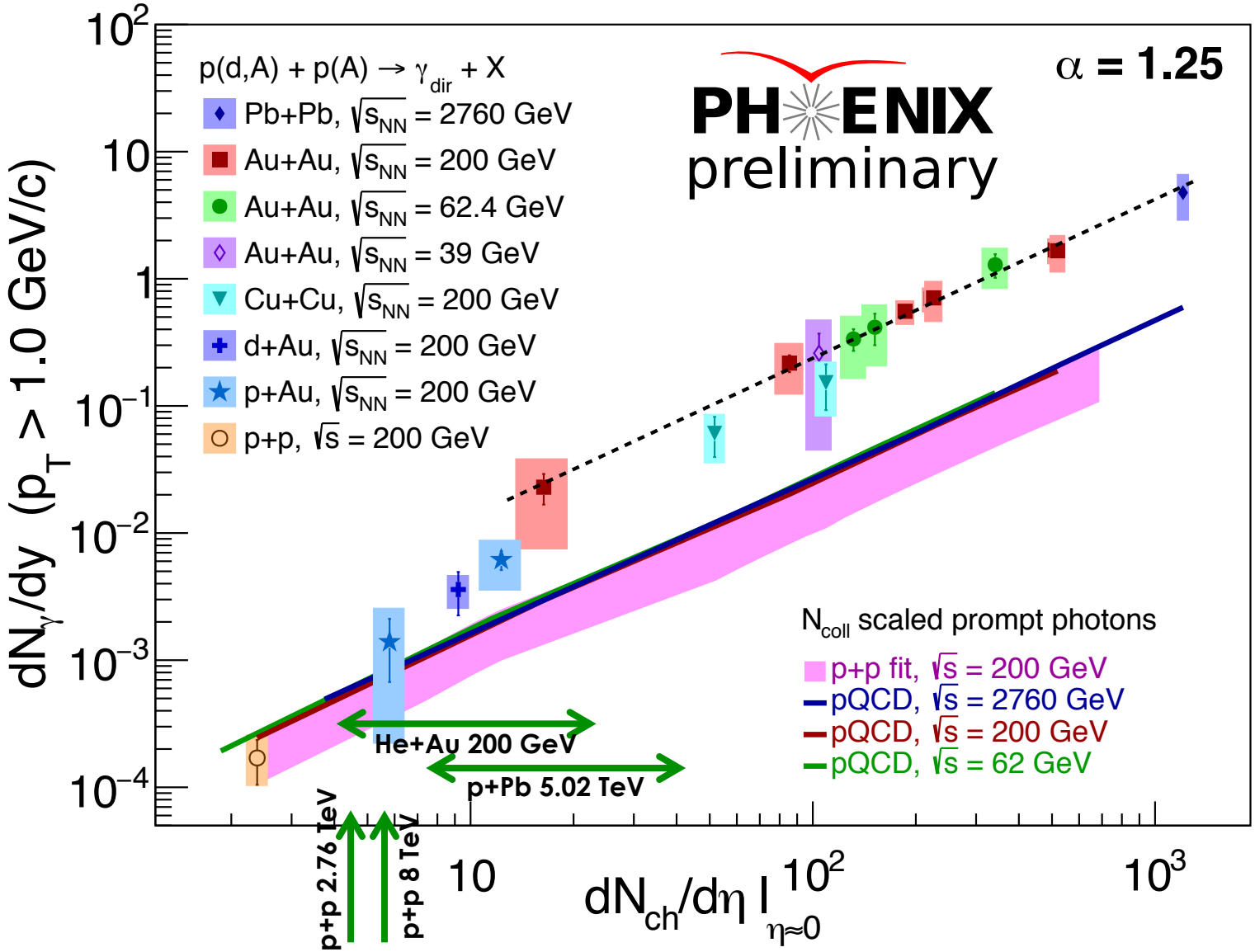
Hint of small enhancement in high multiplicity events

Filling up the multiplicity gap



The new data fill up the gap!

Outlook


p(d,A) + p(A) → γ dir + X
Pb+Pb, √sNN = 2760 GeV
Au+Au, √sNN = 200 GeV
Au+Au, √sNN = 62.4 GeV
Au+Au, √sNN = 39 GeV
Cu+Cu, √sNN = 200 GeV
d+Au, √sNN = 200 GeV
p+Au, √sNN = 200 GeV
p+p, √s = 200 GeV
PHENIX
preliminary
α = 1.25
Ncoll scaled prompt photons
p+p fit, √s = 200 GeV
pQCD, √s = 2760 GeV
pQCD, √s = 200 GeV
pQCD, √s = 62 GeV
He+Au 200 GeV
p+Pb 5.02 TeV
p+p 2.76 TeV
p+p 8 TeV
dNγ/dy (pT > 1.0 GeV/c)
dNch/dη |η≈0

Summary

- New method implementation:
  - Using the VTX detector as a convertor material
- The photon measurement in p+p collisions at 200 GeV:
  - Consistent with the previous measurement
  - Extend the lower $p_T > 0.6$ GeV/c
  - Fit with a pQCD inspired function
- Measurement of the direct photon yield in p+Au collisions:
  - R_γ is consistent with the p+p measurement
  - R_{p+Au} in min bias collisions is consistent with unity, in most central collisions is a hint of enhancement?
    - Very important to have a correct baseline
  - Integrated yield fills the gap in the 2-20 charge multiplicity region