Low Momentum Direct Photons in Au+Au collisions at 39 GeV and 62.4 GeV measured by the PHENIX Experiment at RHIC

Vladimir Khachatryan

For the PHENIX Collaboration

Department of Physics and Astronomy

Stony Brook University

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Outline

1. Introduction and physics motivation
2. Measurement details of Low Momentum Direct Photons
3. Direct photon results at 62.4 GeV and 39 GeV collision energies from the PHENIX Run 10 datasets
4. The scaling of direct photons
5. Summary

1. Introduction and physics motivation

- Direct photons are an important probe of the matter produced in heavy ion collisions, and they
  - are produced during all stages of a heavy-ion collision
  - have long mean free path and escape a heavy ion collision region unmodified with almost no final state interaction
  - carry information about the system at the time of production and directly probe the conditions of their production environment
  - can tell us something about the evolution of the temperature and collective motion of the matter

- By definition
  - direct photons = inclusive photons – hadronic decay photons

    (inclusive photons are all the photons which are being measured in a given measurement)

1.

- The large yield and large anisotropy observed at 200 GeV collision energy pose a significant challenge to theoretical models
- We know that it is difficult to get the large yield and flow simultaneously

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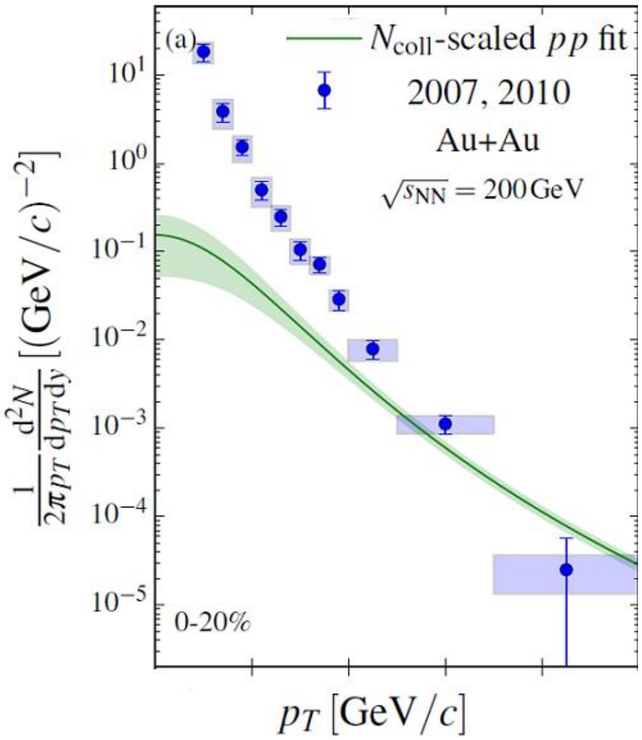
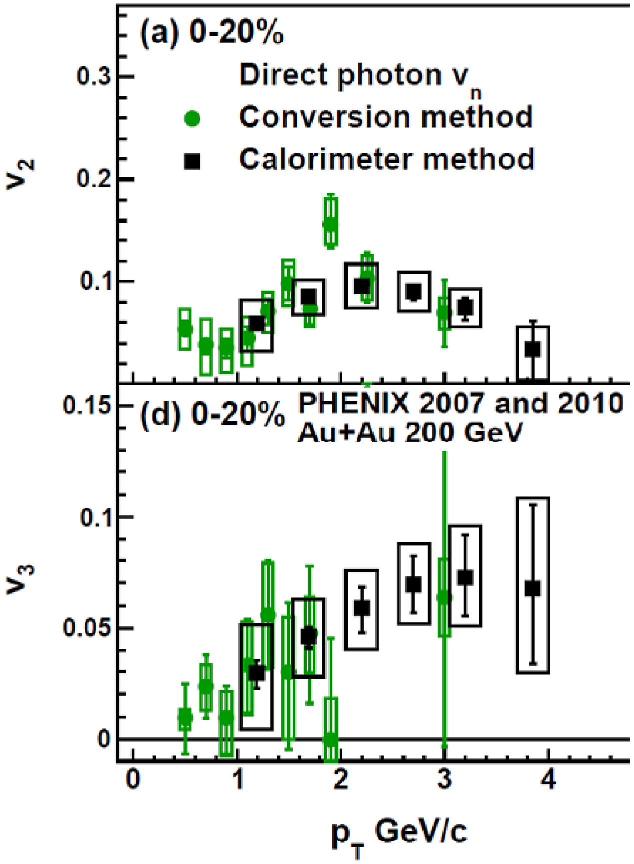
Phys.Rev. C 91, 064904 (2015)





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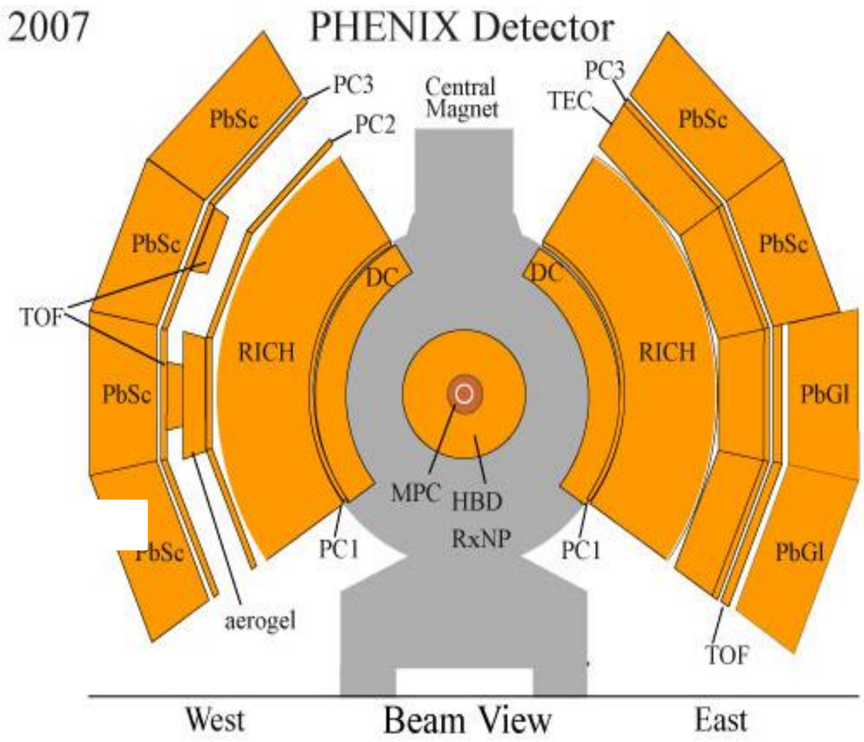
Phys.Rev. C 94, 064901 (2016)

- Measurements at low collision energies, such as 62.4 GeV and 39 GeV, on the other hand may provide new insight on the origin of the low momentum direct photons

2. Measurement details of Low Momentum Direct Photons

- The photon measurement techniques include
  - measuring photons that directly deposit energy into the EMCal
  - virtual photons that internally convert into e^+e^- pairs
  - real photons that externally convert into e^+e^- pairs in a selected detector material

- The measurements of photons that directly deposit energy into the EMCal works best at higher momentum
- The measurements at low p_T are difficult with the EMCal because of
  - hadron and minimal ionizing particle contamination
  - worsening calorimeter resolution
- Virtual photons that internally convert into e^+e^- pairs allow a clean p_T measurement

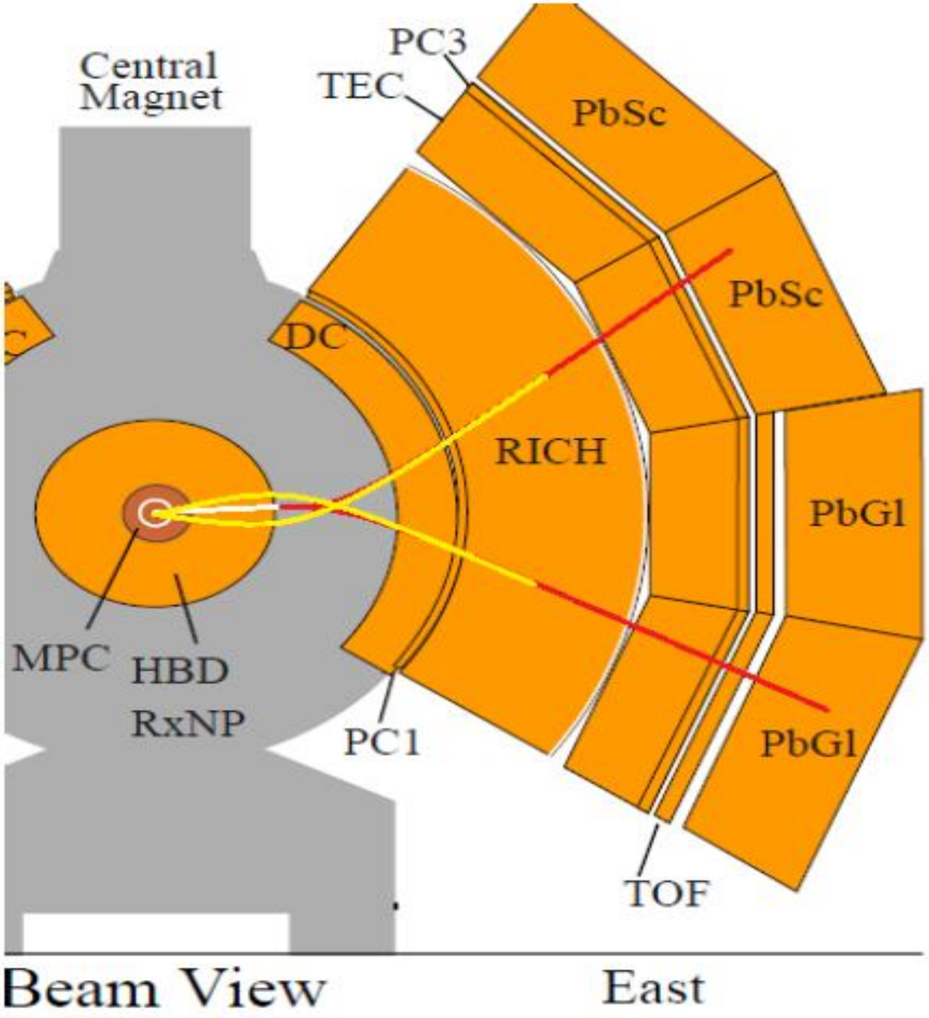


The PHENIX detector at RHIC

- Real photons that externally convert in a selected detector material into e^+e^- pairs
  - allow a clean low p_T measurement
  - minimize the combined statistical and systematic uncertainties that limit direct photon measurements

External conversions:

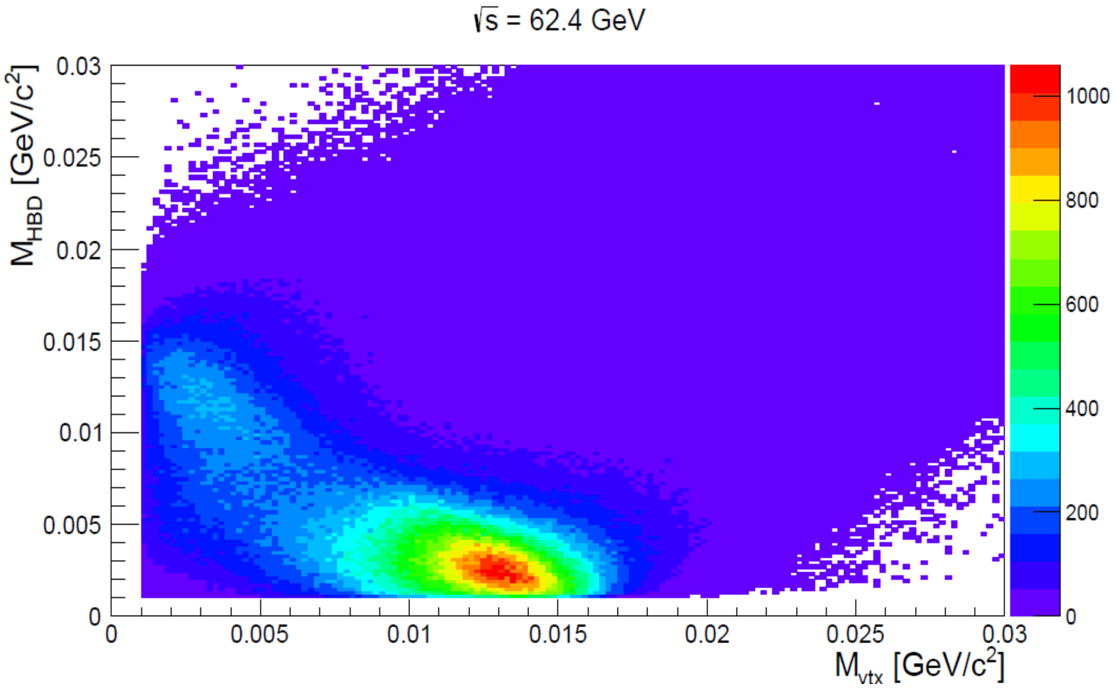
- So the raw inclusive photon yield N_{γ}^{incl} is being measured through photon conversions to $e^{+}e^{-}$ pairs



← A cartoon illustrating the effect of the assumption of the track origin

- The selected detector material for conversions is the backplane of the Hadron Blind Detector (HBD)
- It sits at a radius of about 60 cm from the event vertex
- The identification of the converted photons with HBD is very accurate
- The purity of the photon sample is 99%

- In the standard PHENIX momentum reconstruction algorithm the e^+e^- pair tracks originate from the event vertex ("vtx")
  - The momenta of the HBD converted photons are initially mis-measured
  - It gives pairs an artificial opening angle, which leads to an apparent mass
- In the Alternate Track Model (ATM), the momenta of the conversion electrons are recalculated under the assumption that the conversion takes place at the HBD backplane, and in this case the mass is reconstructed faithfully



A view of the cut space in 2D mass plot, used for the conversion photon identification at 62.4 GeV.

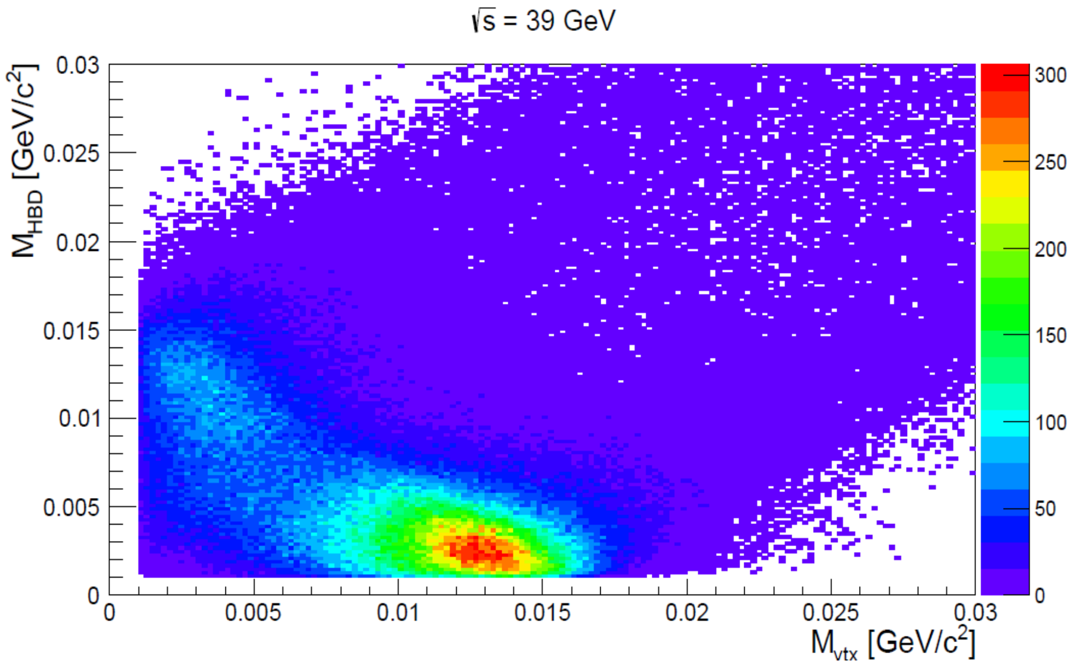
The mass cuts are

$$10\ \mathrm{MeV}/c^2 < M_{vtx} < 15\ \mathrm{MeV}/c^2,$$

$$M_{HBD} < 4.5\ \mathrm{MeV}/c^2$$

$$N_\gamma^{incl} = 3.28\cdot 10^5$$

2.



A view of the cut space used for the conversion photon identification at 39 GeV

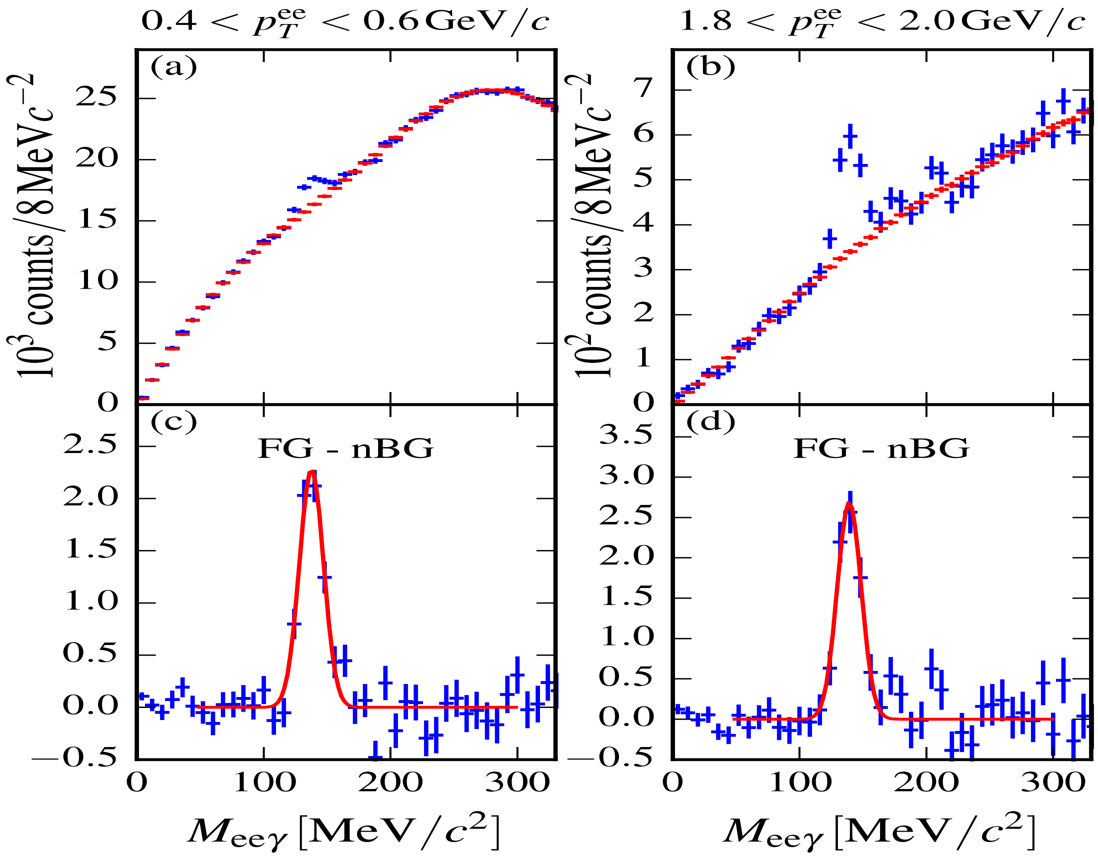
with the same cuts: $N_{\gamma}^{incl} = 9.42 \cdot 10^4$

- In a given p_T^{ee} bin the observed number of inclusive photons is related to the true number of inclusive photons, γ^{incl}, given as follows:

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

- The factor ε_{ee} is the conversion pair reconstruction efficiency; a_{ee} – the pair geometrical acceptance; c – probability for a photon to undergo a conversion
- A subset of the inclusive conversion photon sample, N_{γ}^{incl}, is tagged as photons from π^0 decays if they reconstruct the π^0 mass with a second, photon-like shower from the PHENIX EMCal

- In each p_T^{ee} bin the number of π^0 tagged photons, $N_\gamma^{\pi^0,tag}$, is specified by integrating the $e^+e^-\gamma$ mass distribution
  - $N_\gamma^{\pi^0,tag}$ is measured in terms of p_T^{ee} bins of the converted photon



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Some examples of histograms of the $e^+e^-\gamma$ invariant mass distributions for two different p_T^{ee} bins at 200 GeV.

- In a given p_T^{ee} bin the true number of π^0 decay photons, γ^{π^0}, is given as

$$N_\gamma^{\pi^0,tag} = <\varepsilon_\gamma f> N_\gamma^{\pi^0} = \varepsilon_{ee} a_{ee} c <\varepsilon_\gamma f> \gamma^{\pi^0}$$

Measuring R_γ with the Double Ratio:

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

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

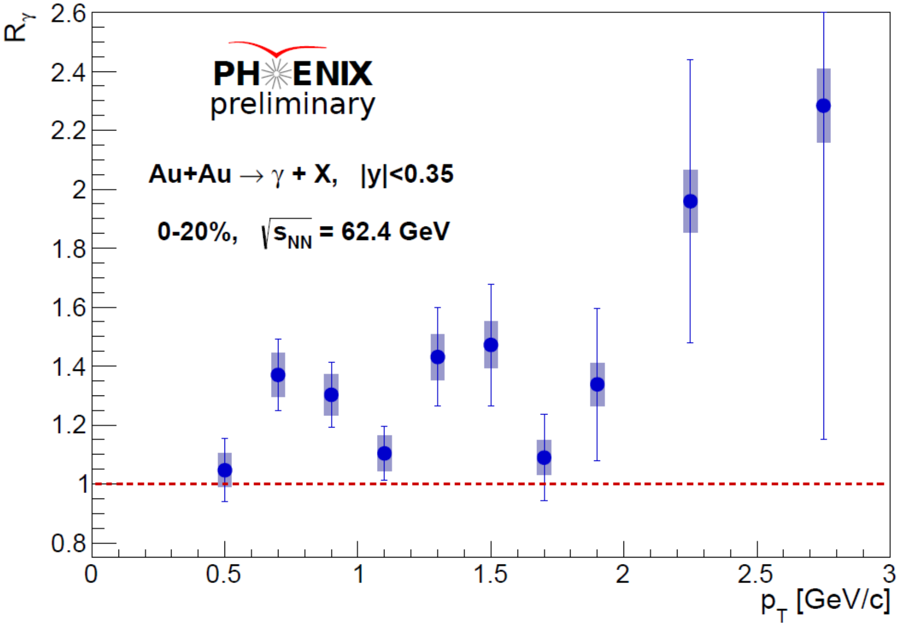
f: Conditional acceptance of the second decay photon in the EMCal

SIMULATION

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

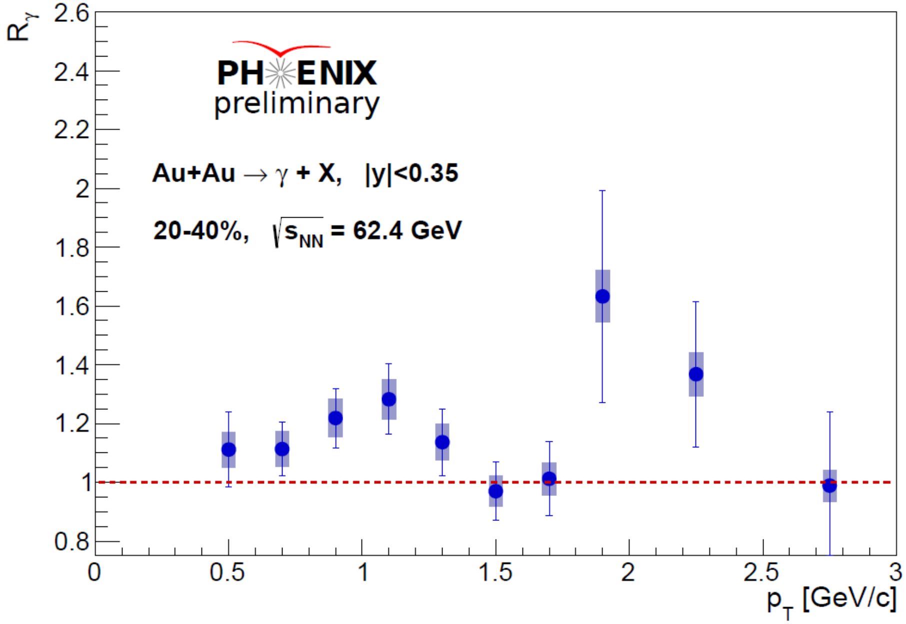
- Pair acceptance and efficiency cancel in the ratios as well as the conversion factor

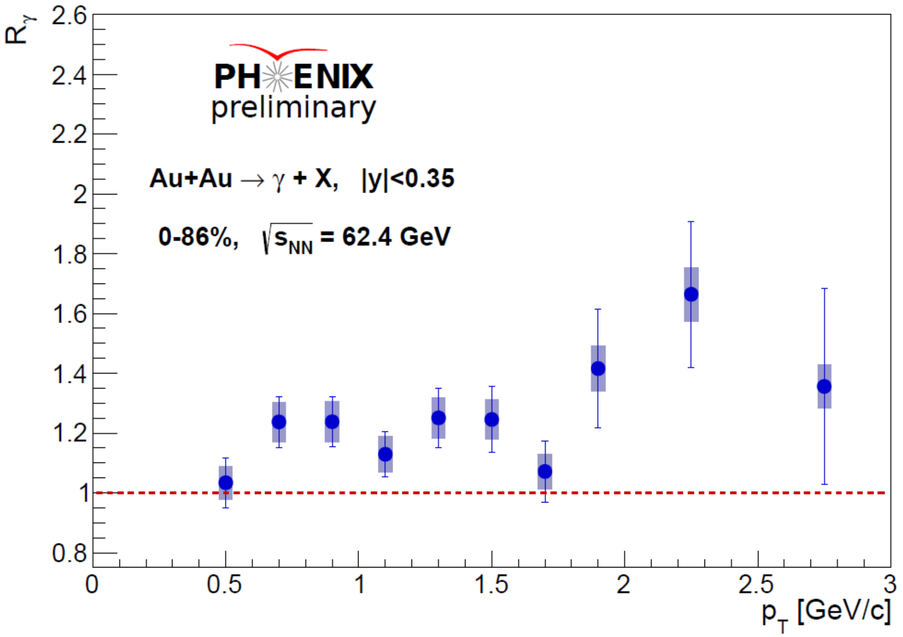
3. Direct photon results at 62.4 GeV and 39 GeV



R_γ of direct photons in 0-20% centrality bin at 62.4 GeV collision energy

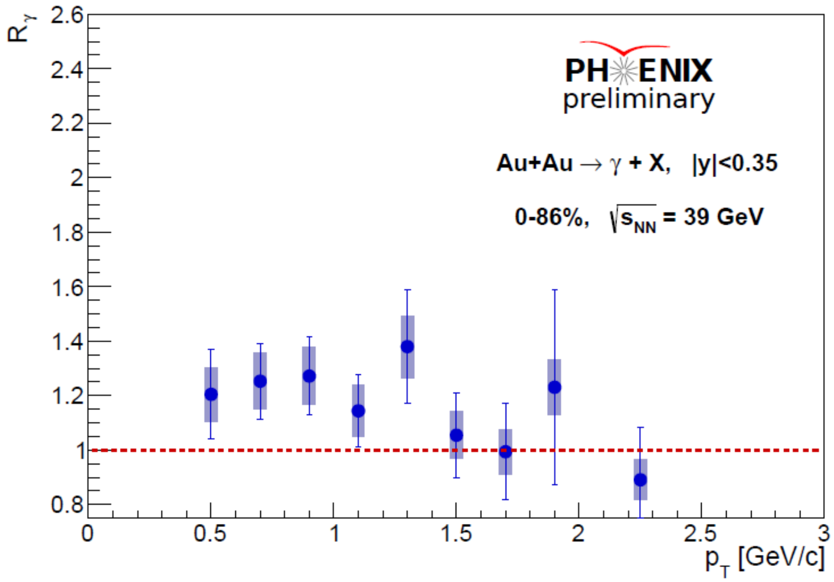
R_γ of direct photons in 20-40% centrality bin at 62.4 GeV collision energy





← R_γ of direct photons in min bias 0-86% at 62.4 GeV collision energy

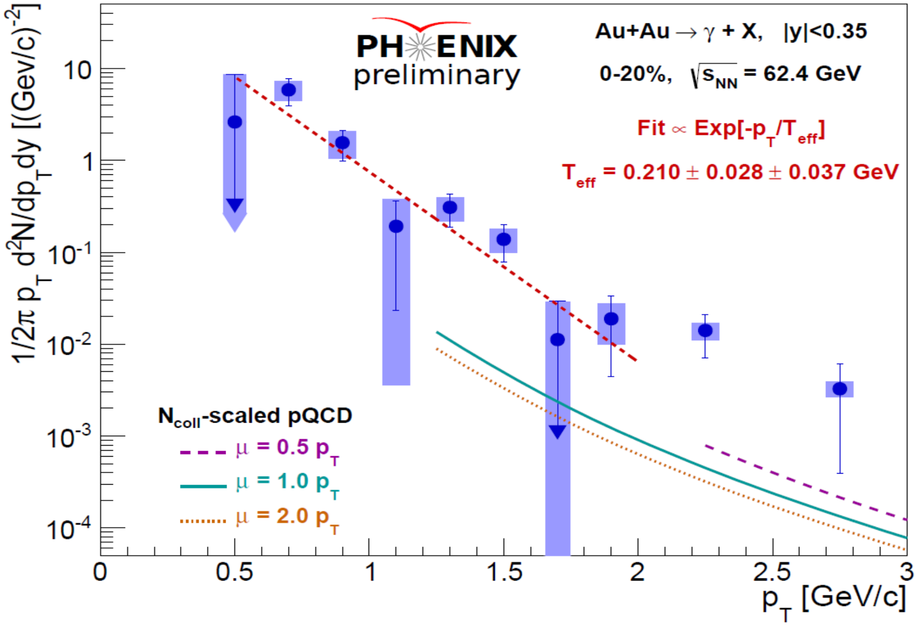
R_γ of direct photons in min bias 0-86% at 39 GeV collision energy →



3.

The invariant yield is calculated by

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



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The invariant yield of direct photons in 0-20% centrality bin at 62.4 GeV collision energy

The invariant yield of direct photons in 20-40% centrality bin at 62.4 GeV collision energy

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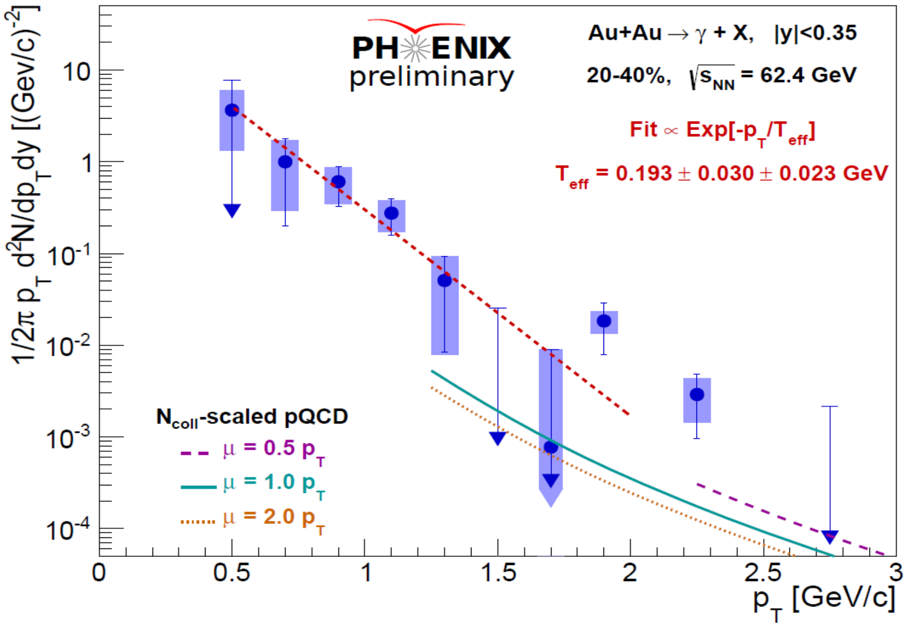

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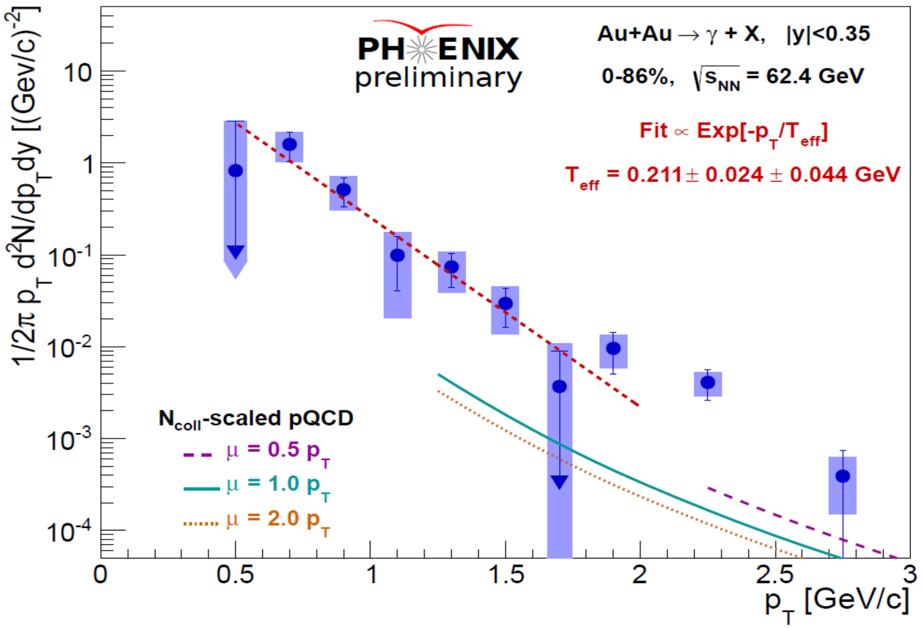

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The invariant yield of direct photons in min bias 0-86% at 62.4 GeV collision energy

The invariant yield of direct photons in min bias 0-86% at 39 GeV collision energy

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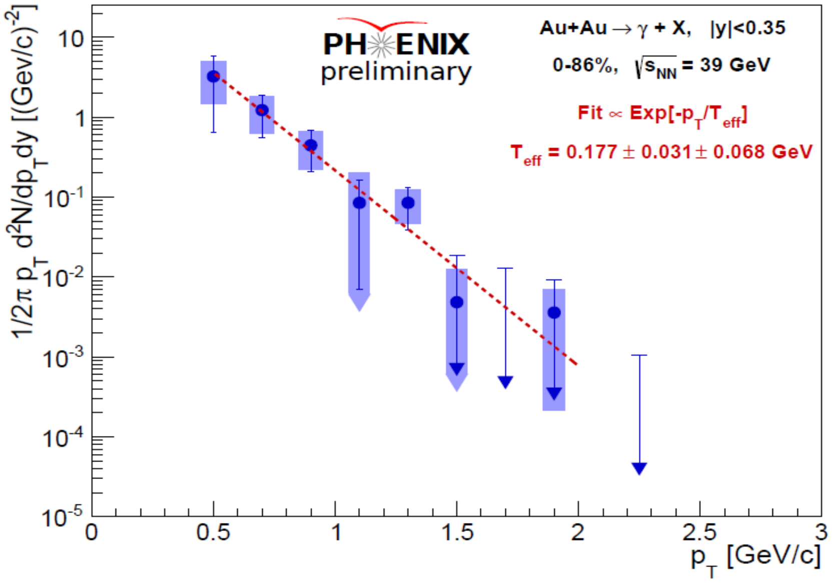
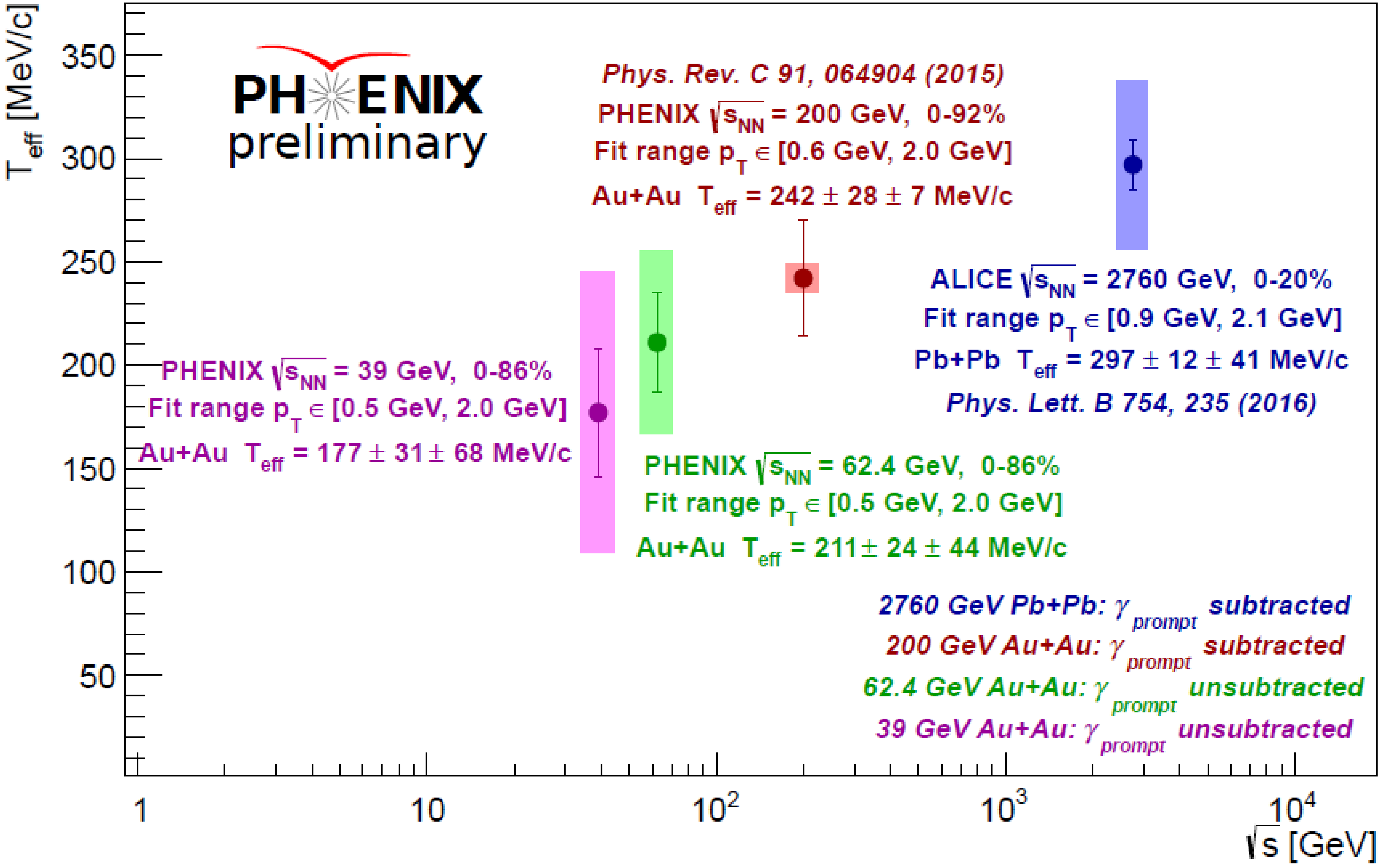


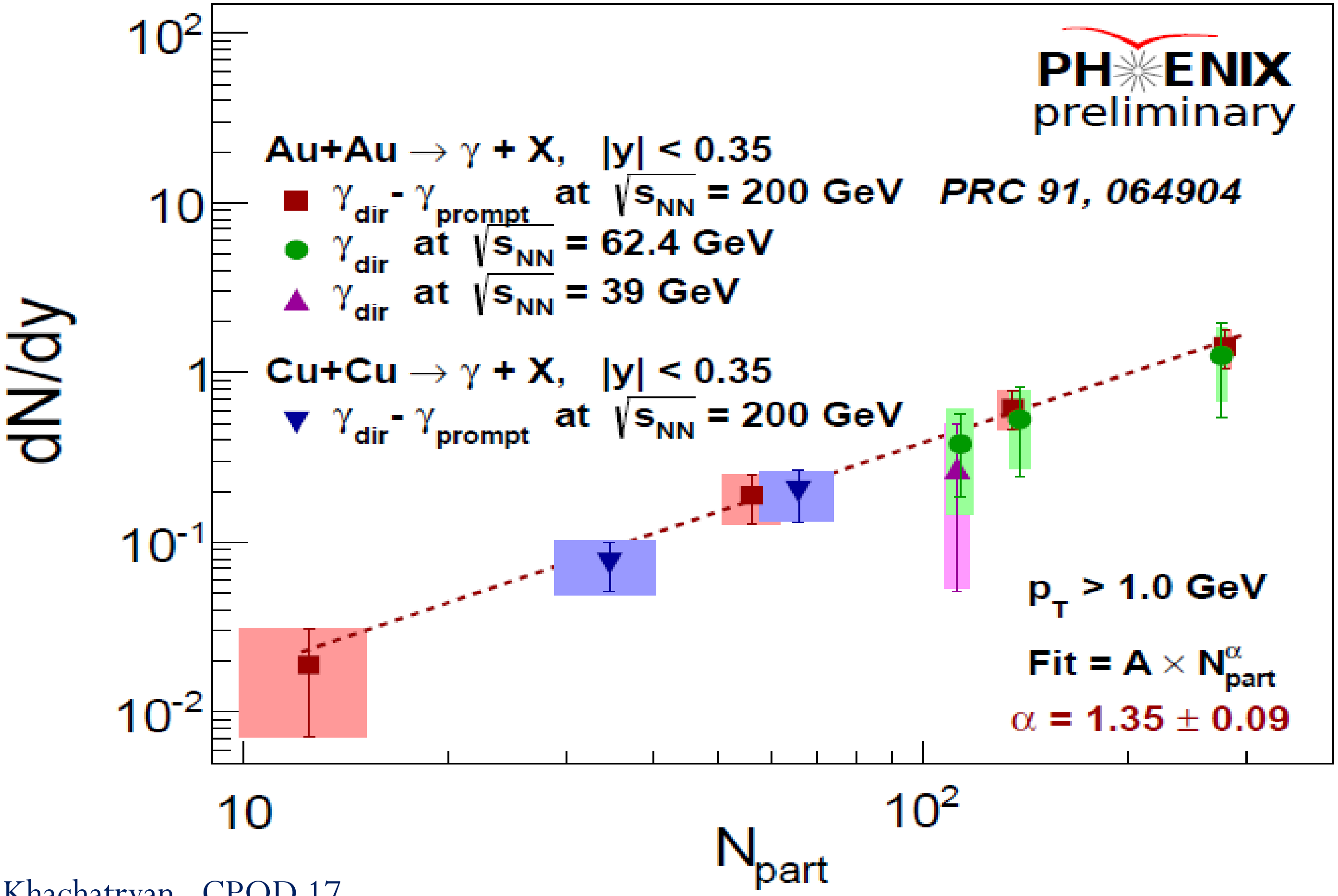
T_{eff} vs. collision energy



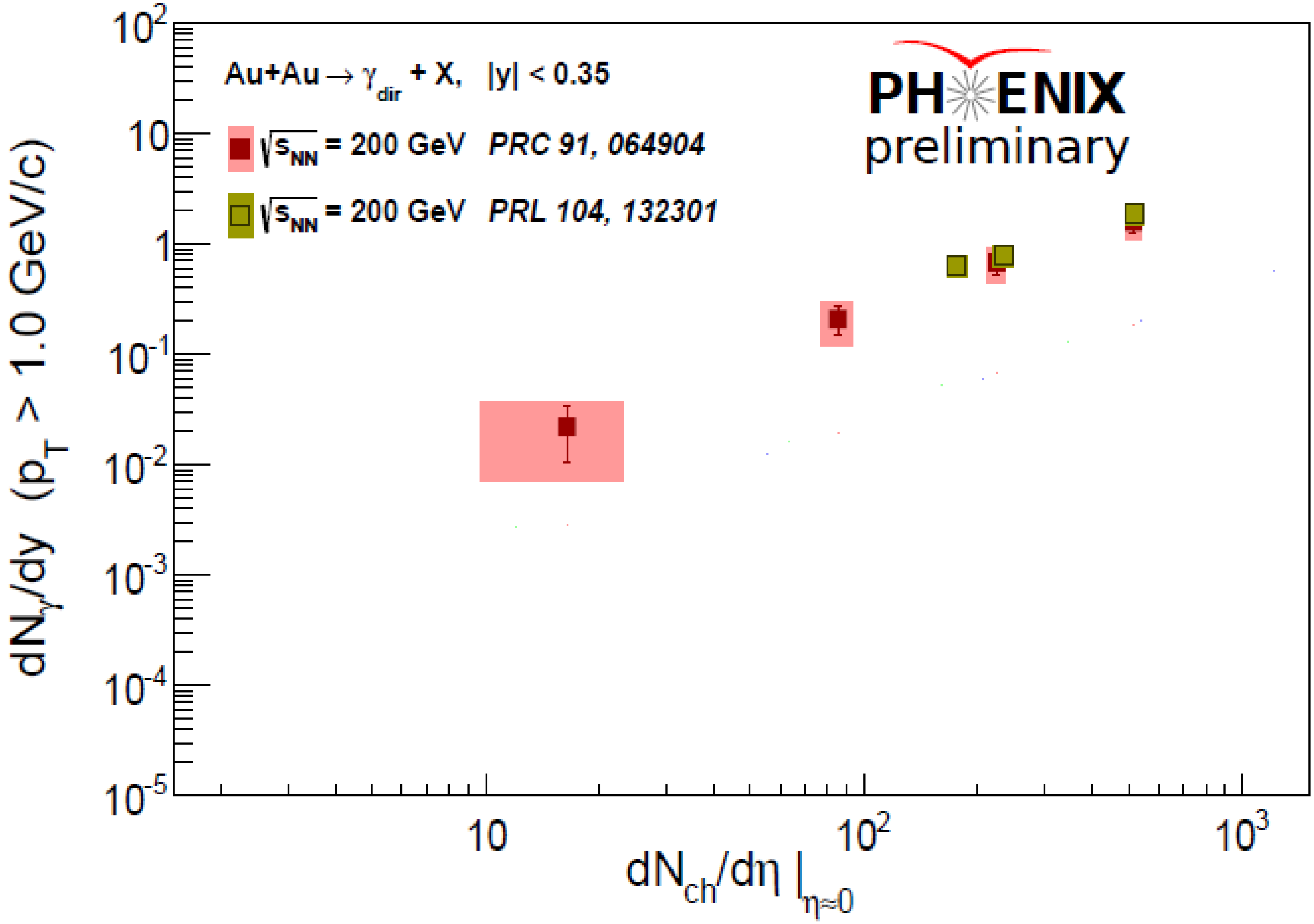
The extracted T_{eff} at four collision energies: 2760 GeV, 200 GeV, 62.4 GeV and 39 GeV

4. The scaling of direct photons

- In this plot we can see the integrated yield for four systems vs. N_{part}
  - where for two of them the integrated yield is prompt photon subtracted
  - and for the other two the yield is prompt photon unsubtracted

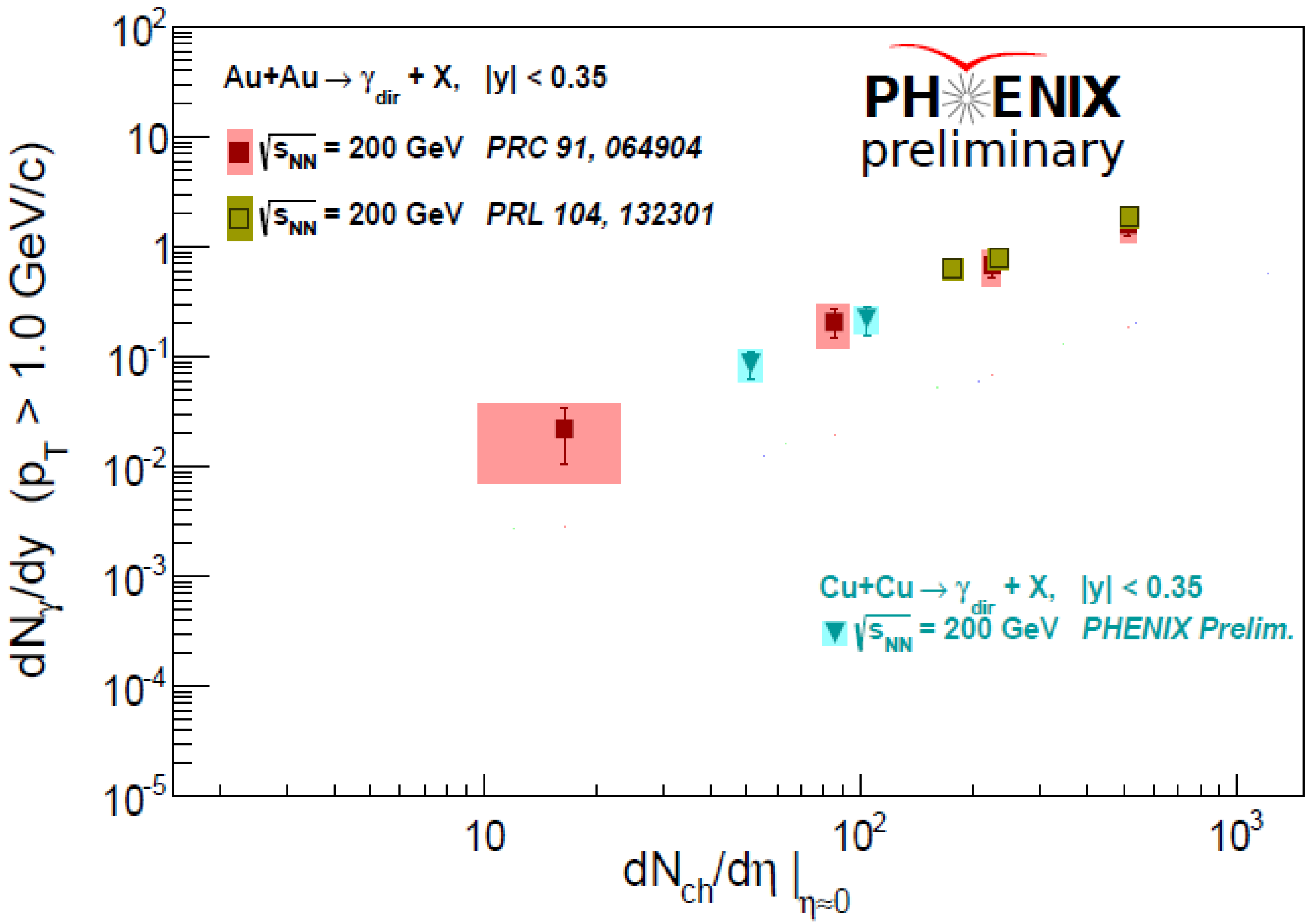


The integrated yield for Au+Au 200 GeV (PHENIX)

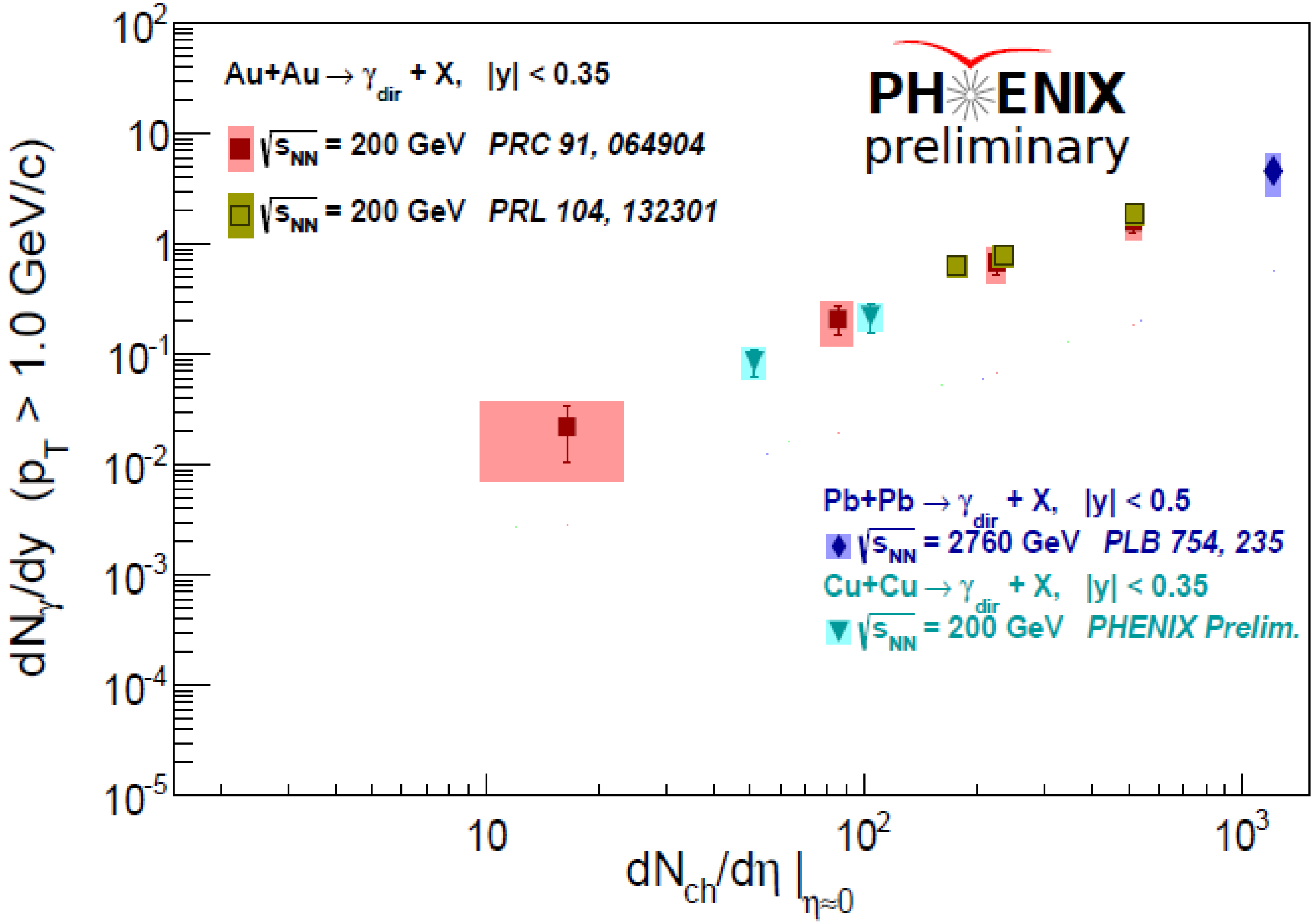


- Here is the integrated yield, which is prompt photon unsubtracted (integrated from 1.0 GeV/c)

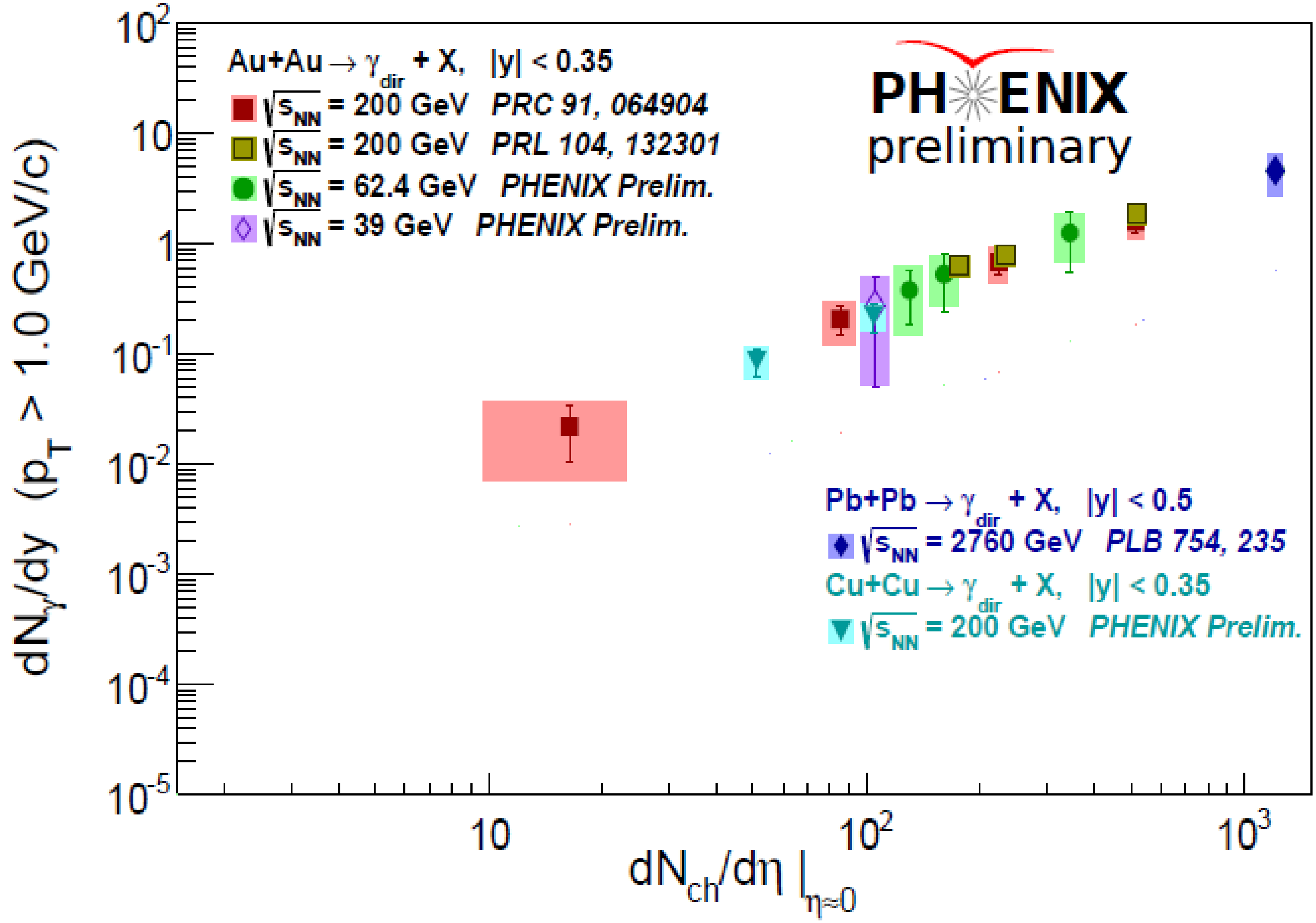
Cu+Cu 200 GeV (PHENIX) added



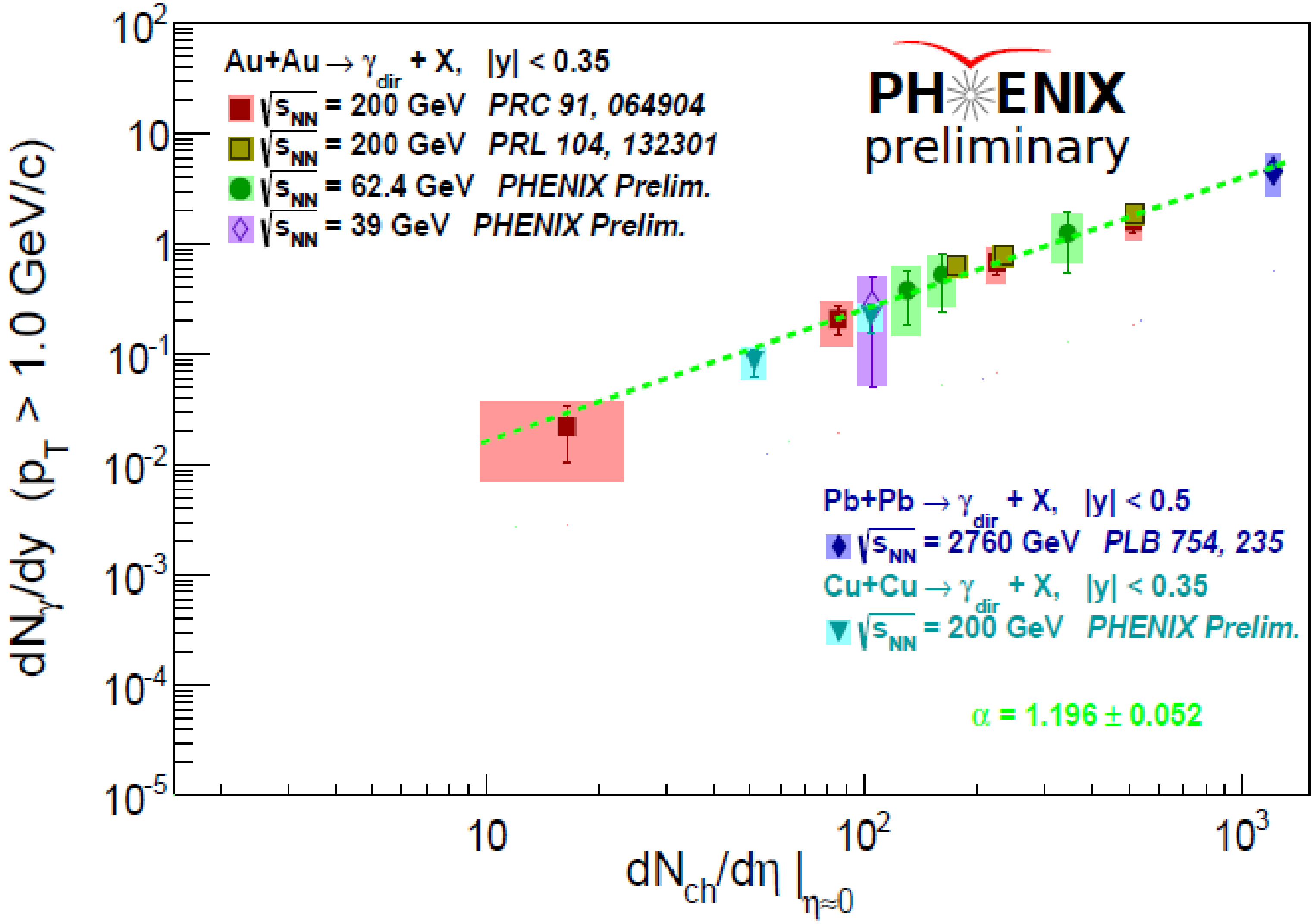
Pb+Pb 2760 GeV (ALICE) added



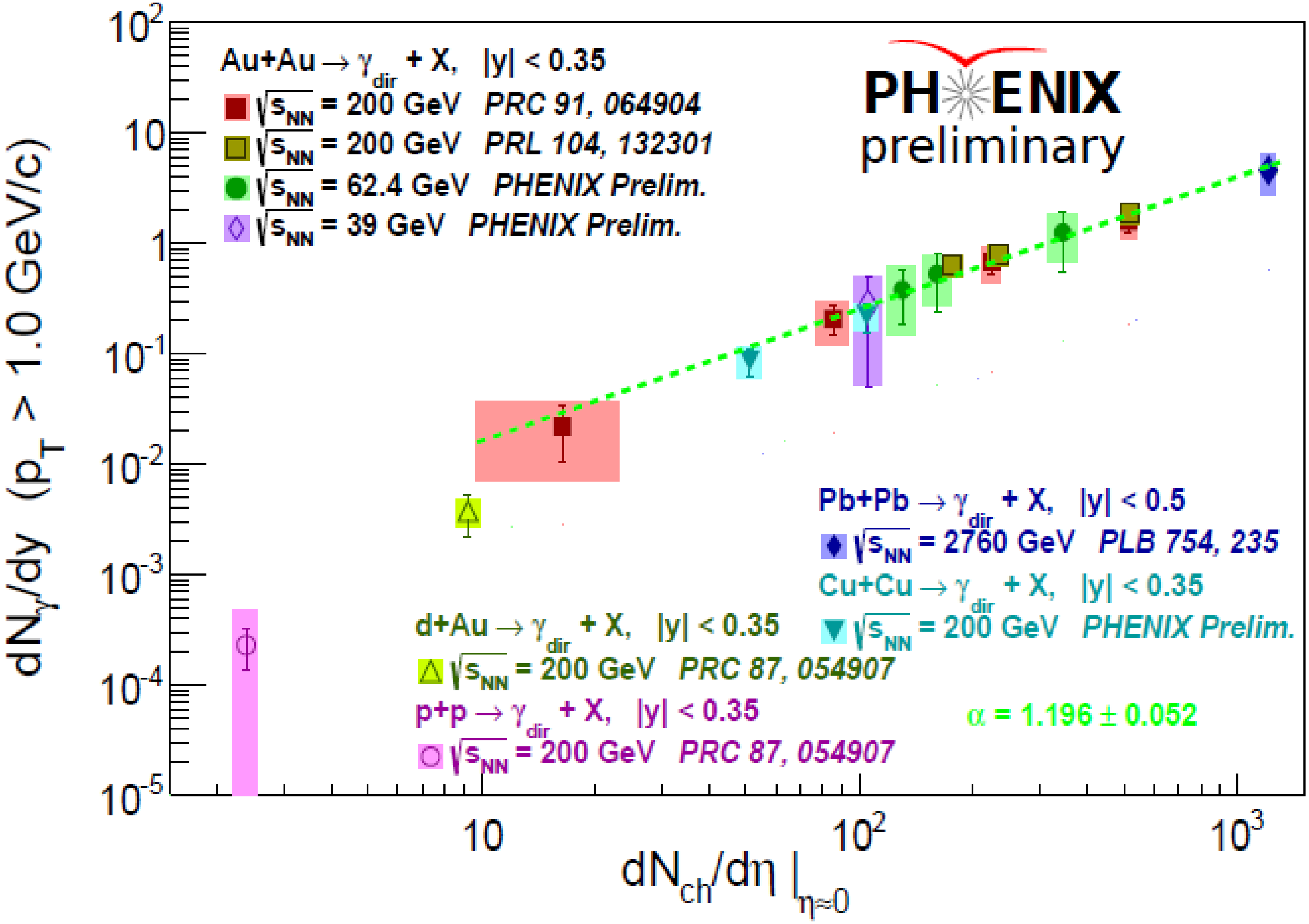
Au+Au 62.4 GeV and Au+Au 39 GeV (PHENIX) added



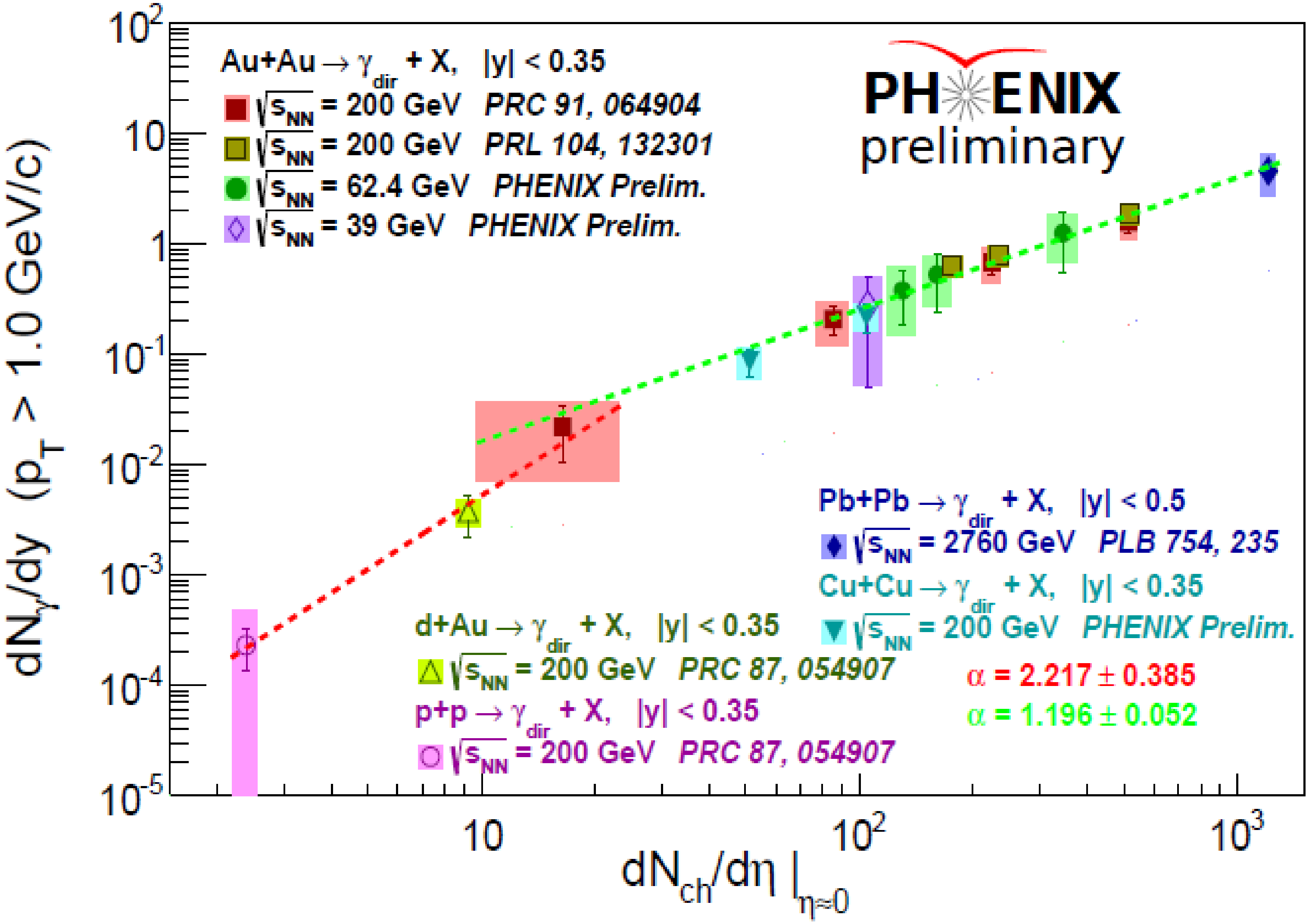
Add a fit to A+A systems



d+Au 200 GeV (PHENIX) and p+p 200 GeV (PHENIX) added

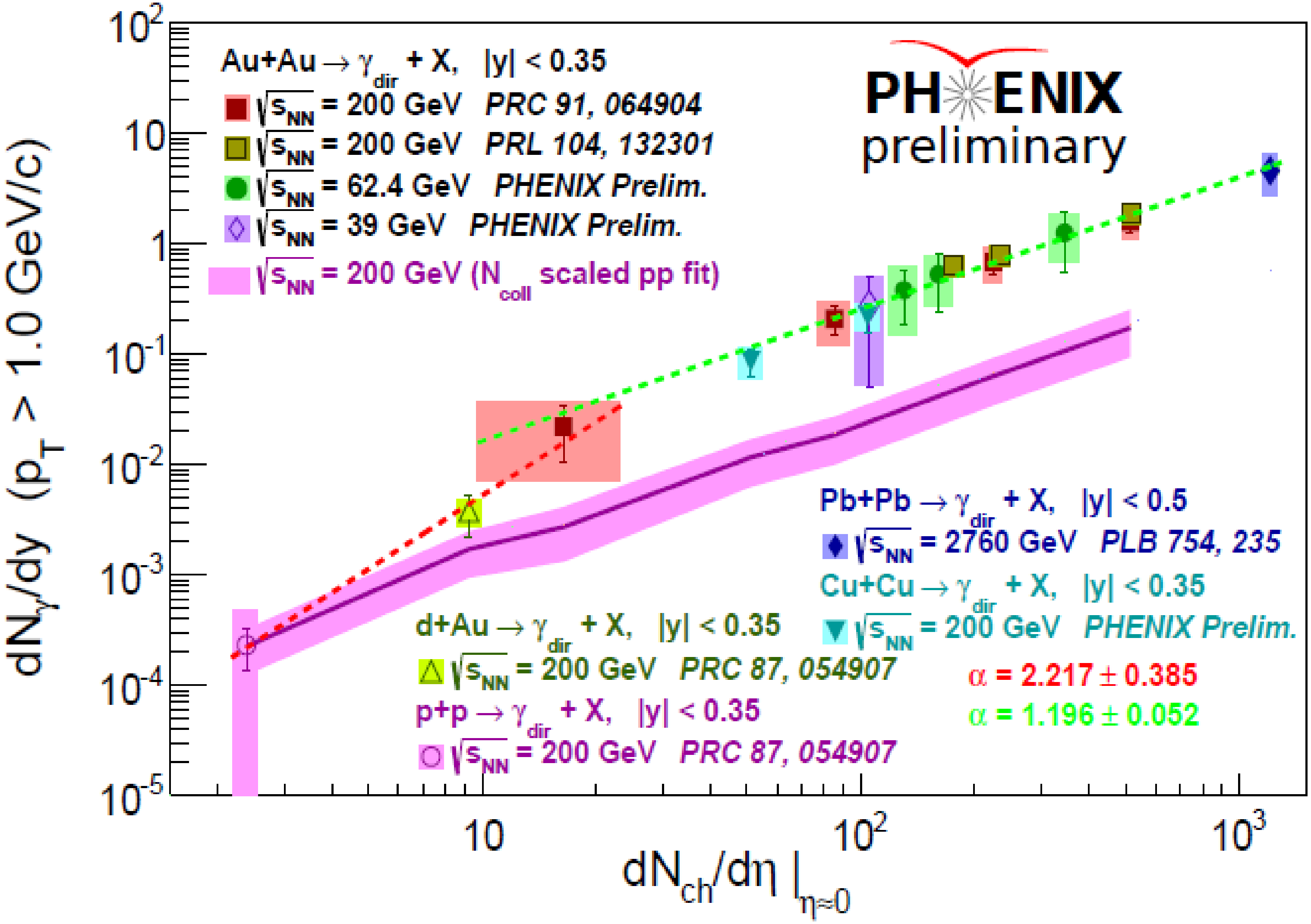


Add a fit to small systems

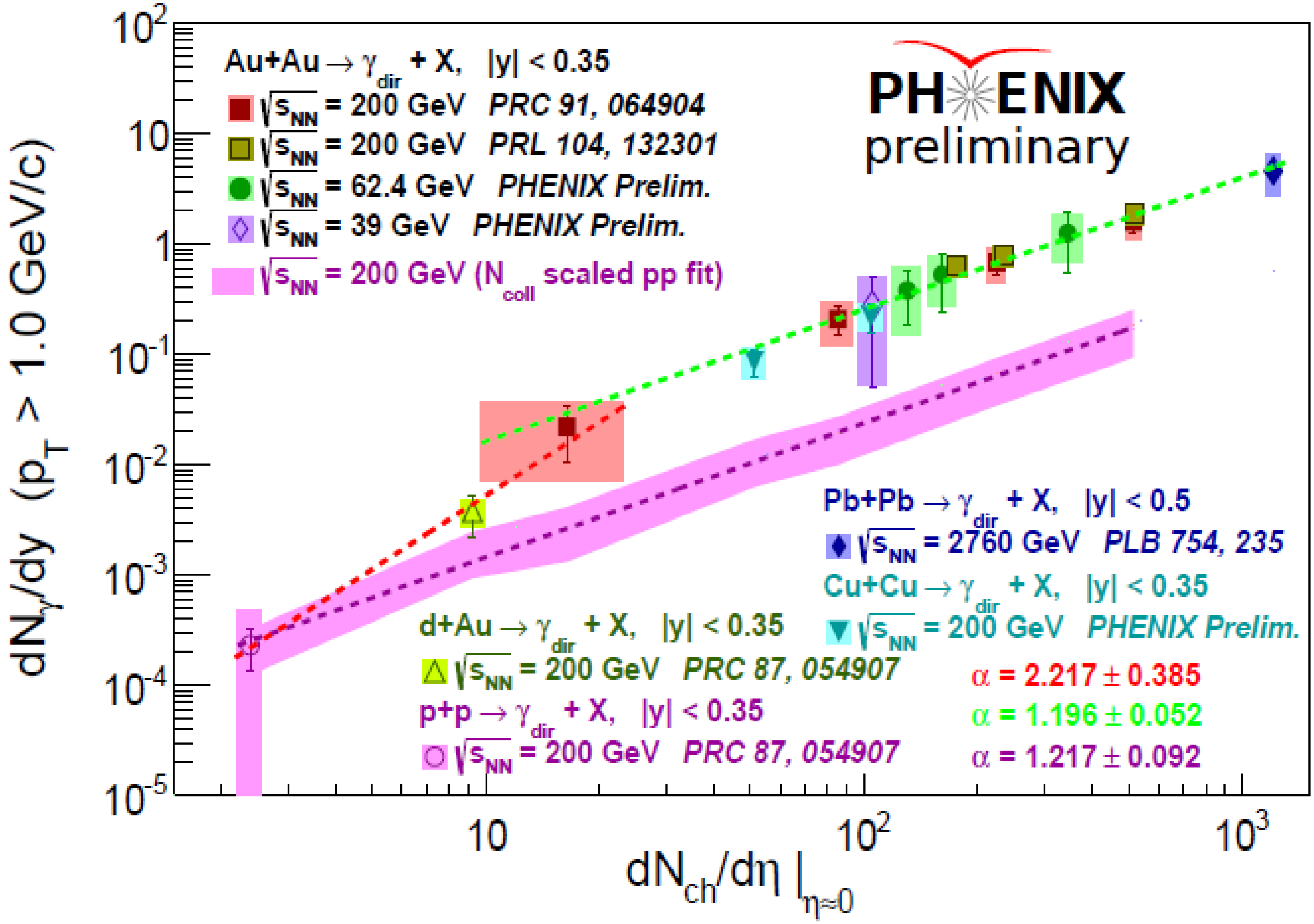


4.

The purple line (with the purple error band) describes the integrated yield from N_{coll} scaled pp fit

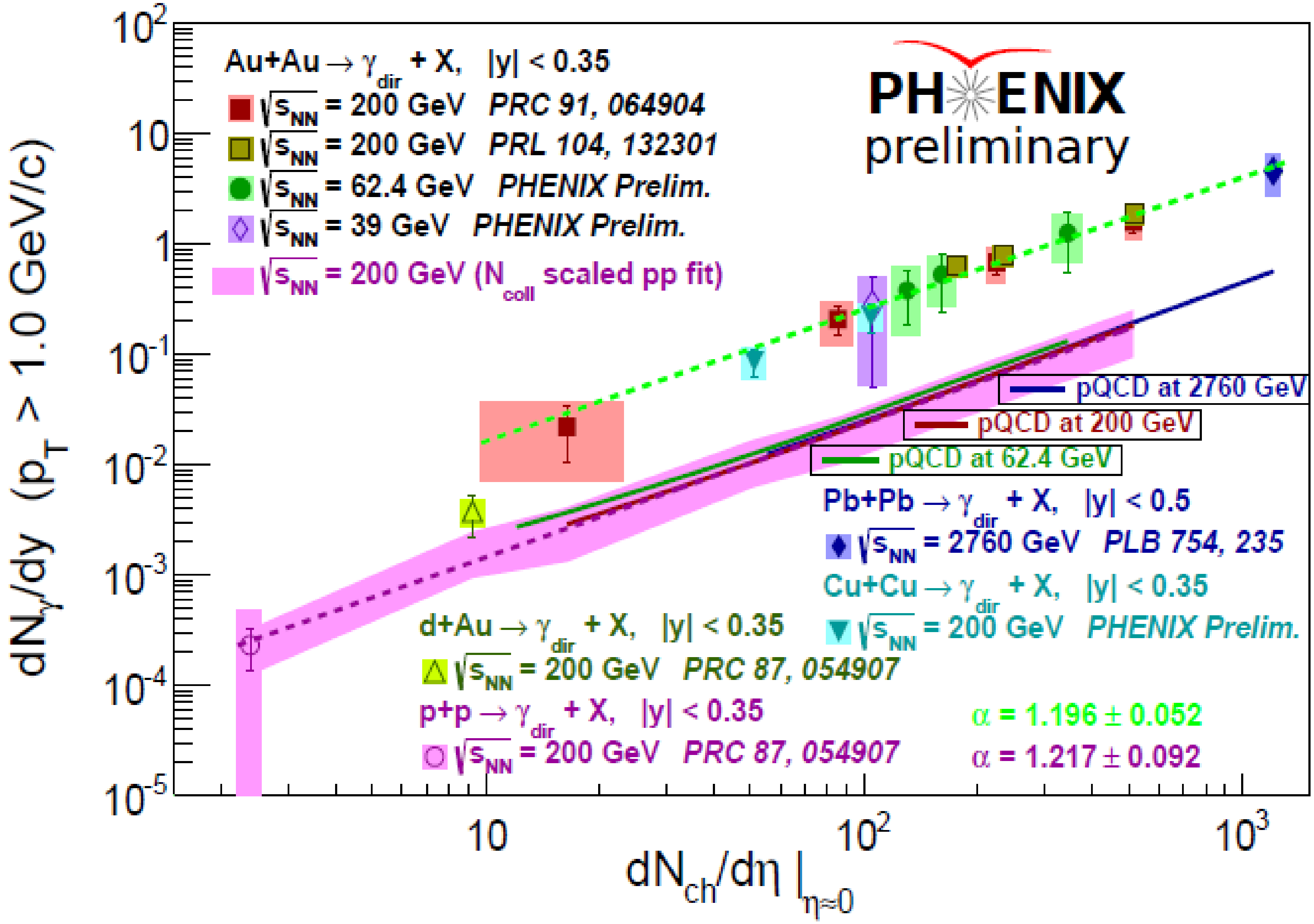


Add a fit to the N_{coll} scaled points described by the purple line in the previous page



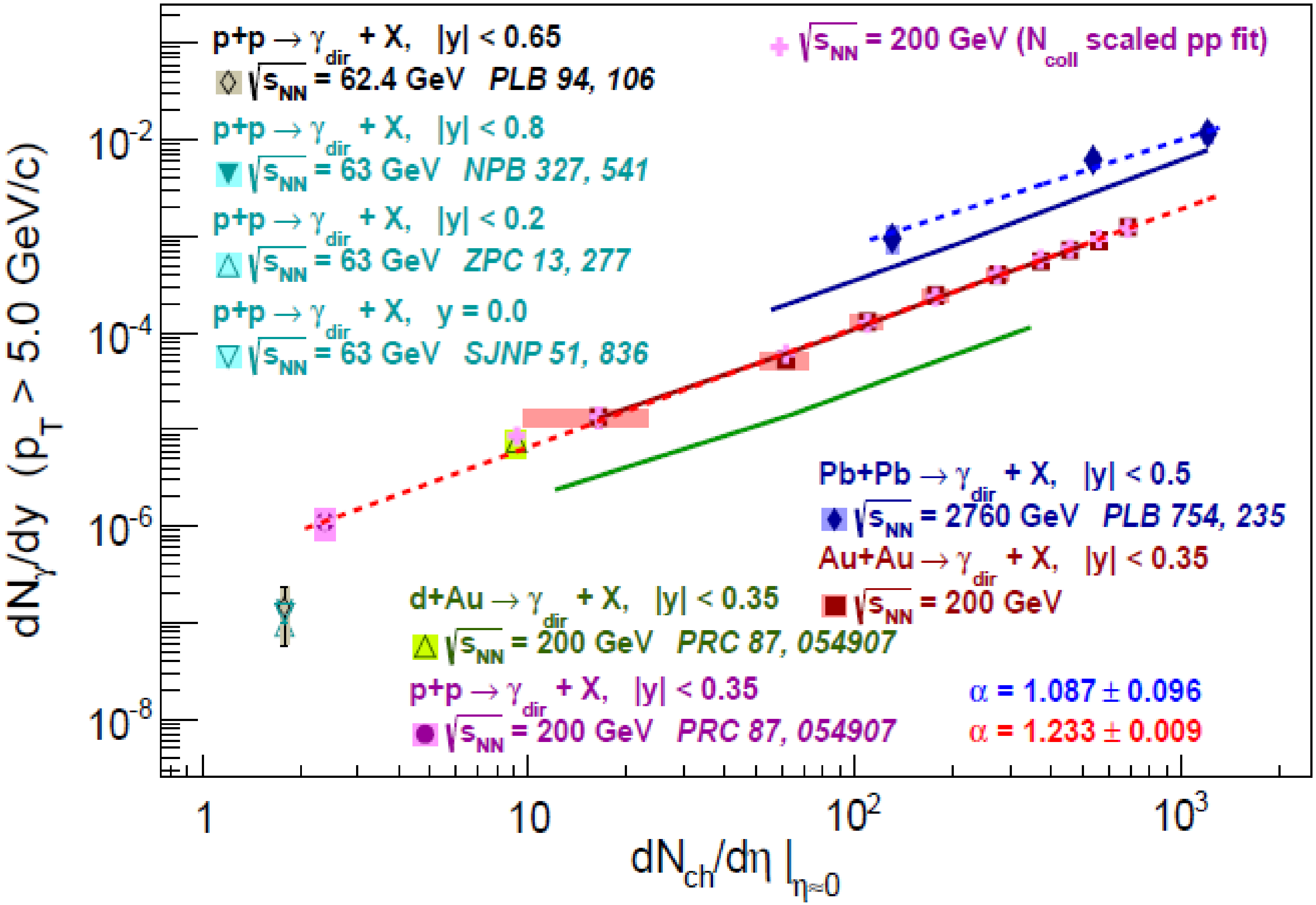
4.

Add the expectation from N_{coll} scaled pQCD



The yield for various systems integrated from 5.0 GeV/c to 8.0 GeV/c

4.



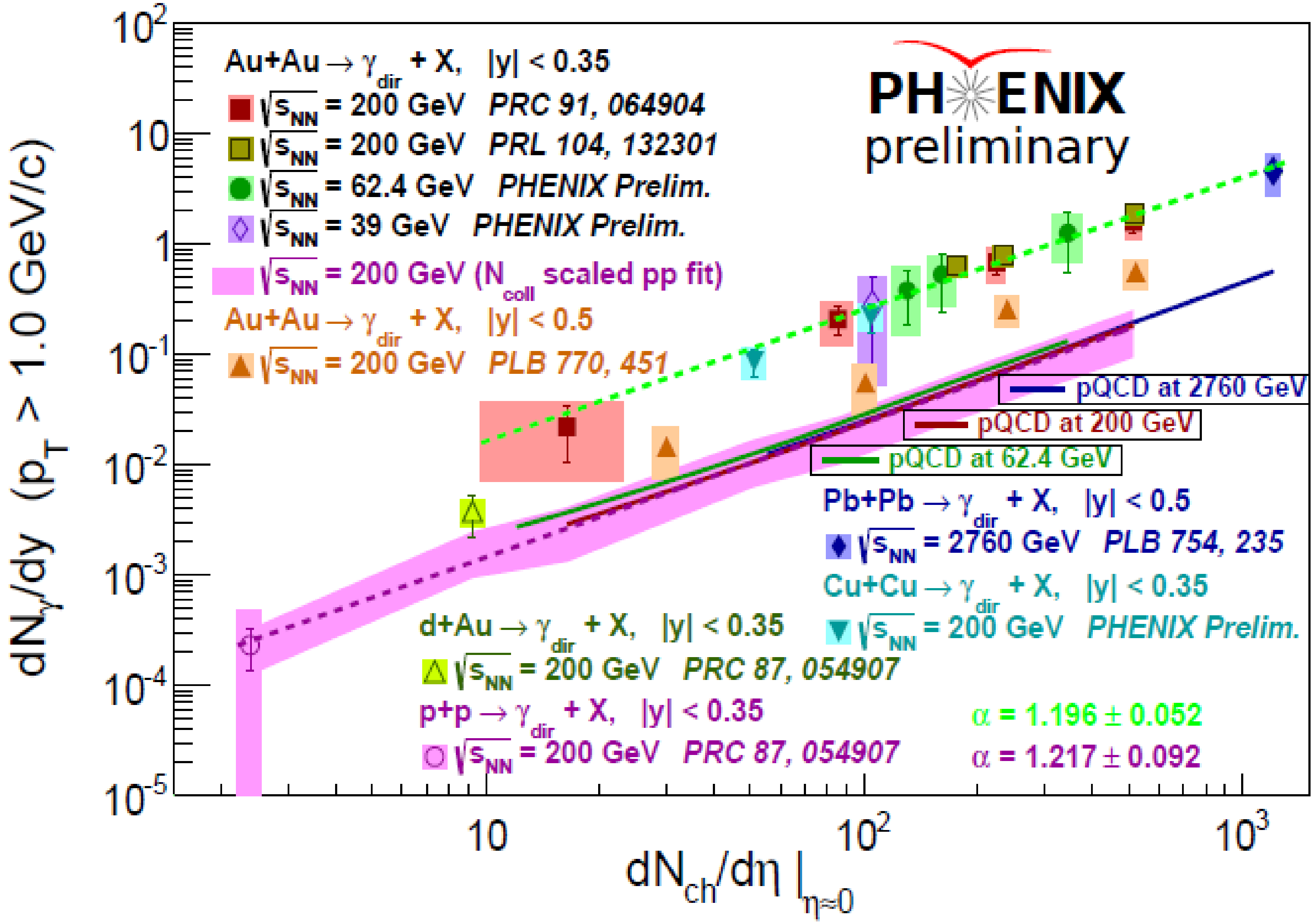
5. Summary

1. We have measured R_γ and p_T spectra for real photons at 200 GeV, 62.4 GeV and 39 GeV as well as v_2 and v_3 at 200 GeV
2. The measurements at 200 GeV show many interesting features like the large excess yield and anisotropy of low momentum direct photons
3. The measurements at 62.4 GeV and 39 GeV also show significant excess yield at least for the most central collisions
4. We also see some scaling behavior of direct photons obtained from different datasets at various collision energies
5. In particular, one can think about the possible existence of a “turning point”, at which the thermal radiation from Quark Gluon Plasma is being “switched on/off”.

Thank You !

Backups

Au+Au 200 GeV (STAR) added



The integration is from 1.5 GeV/c