# Low Momentum Direct Photons in Au+Au collisions at 200 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**

***33rd Winter Workshop on Nuclear Dynamics, 2017***

# Outline

1. Introduction and physics motivation
2. Measurement details of Low Momentum Direct Photons
3. The direct photon results at 200 GeV (2007, 2010 datasets) and 62.4 GeV (2010 dataset) collision energies
4. Summary

# 1. Introduction and physics motivation

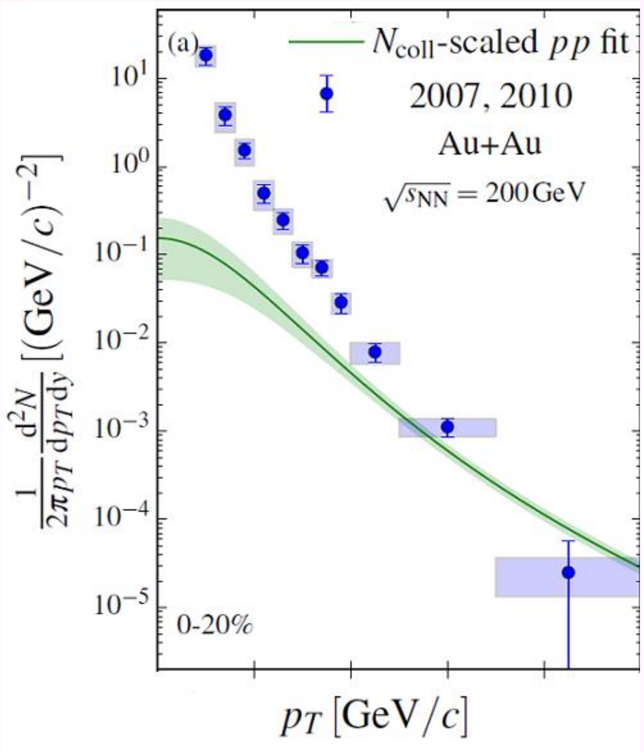
- Direct photons are an important probe of the matter produced in heavy ion collisions, and they
  - are produced during all stages of a heavy-ion collision
  - have long mean free path and escape a heavy ion collision region unmodified with almost no final state interaction
  - carry information about 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

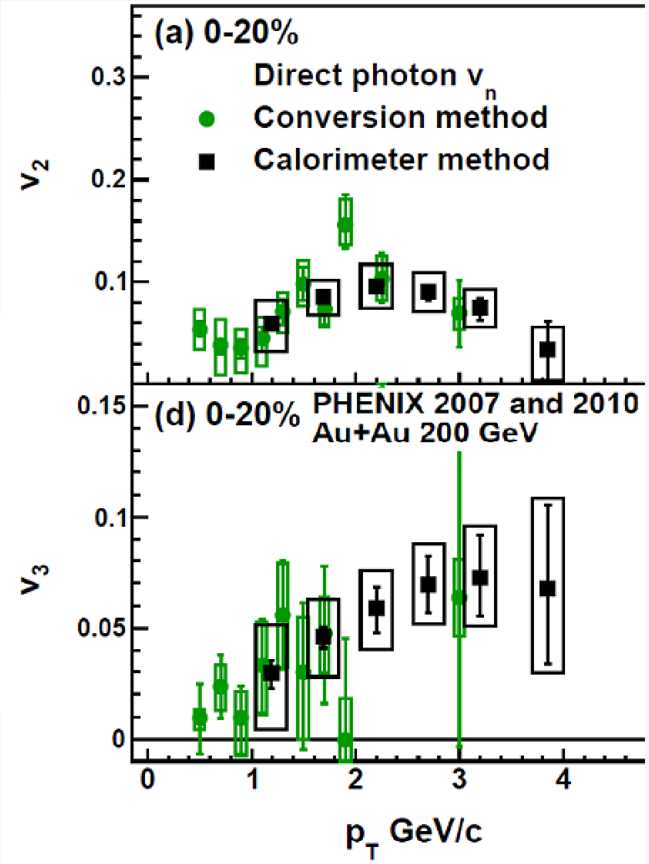
- By definition
  - direct photons = inclusive photons – hadronic decay photons

    (inclusive photons are all the photons which are measured)

- The large yield and large anisotropy observed at 200 GeV collision energy pose a significant challenge to theoretical models

→ *Phys.Rev. C 91, 064904 (2015)*




← *Phys.Rev. C 94, 064901 (2016)*

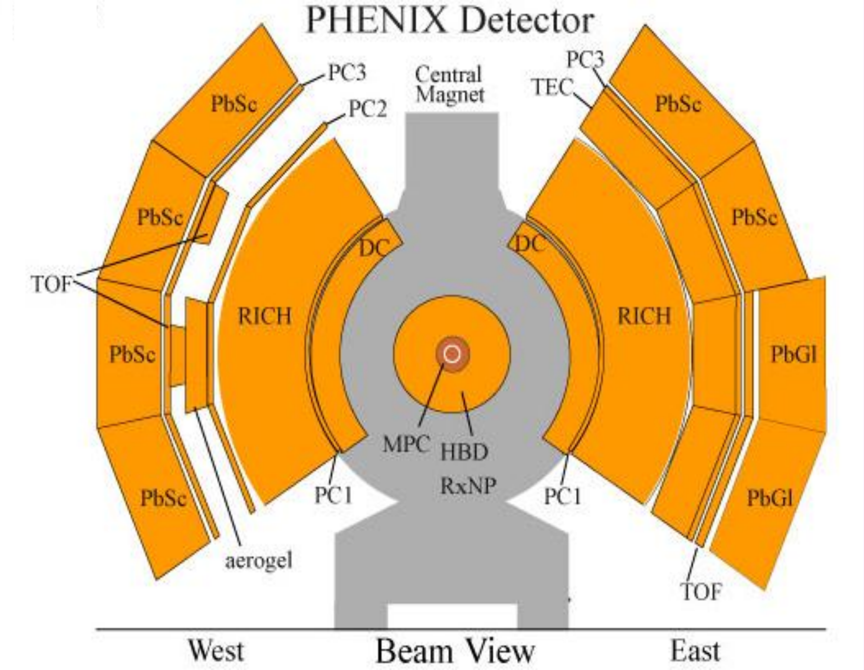
- Measurements at low collision energies, such as 62.4 GeV, on the other hand may provide new insight on the origin of the low momentum direct photons

# 2. Measurement details of Low Momentum Direct Photons

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

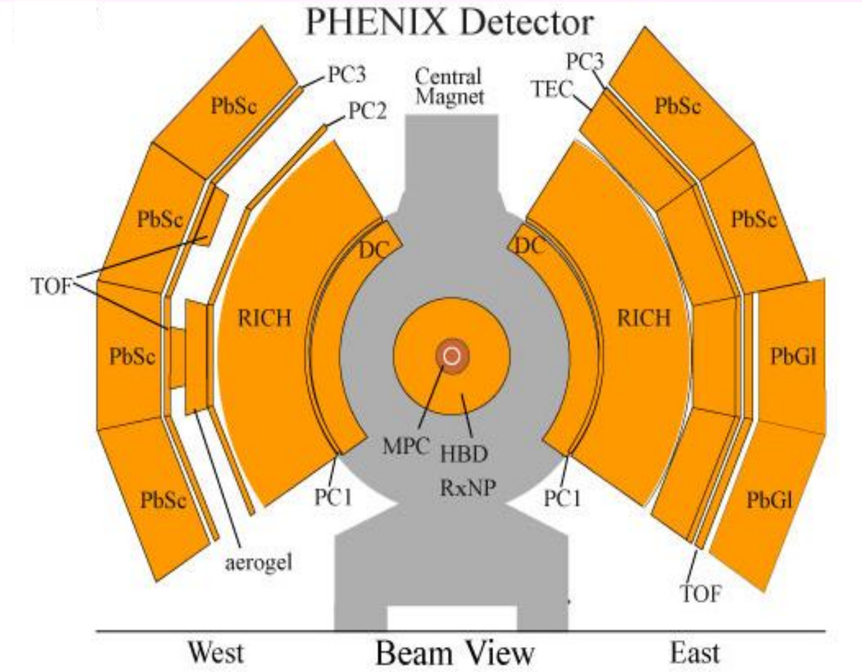
- The measurements of photons that directly deposit energy into the EMCal works best at higher momentum

- The measurements at low $p_T$ are difficult with the EMCal because of
  - hadron and minimal ionizing particle contamination
  - worsening calorimeter resolution




The PHENIX detector at RHIC

- Virtual photons that internally convert into $e^+e^-$ pairs
  - allow a clean $p_T$ measurement
- 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
- The yield of virtual photons is related to that of real photons

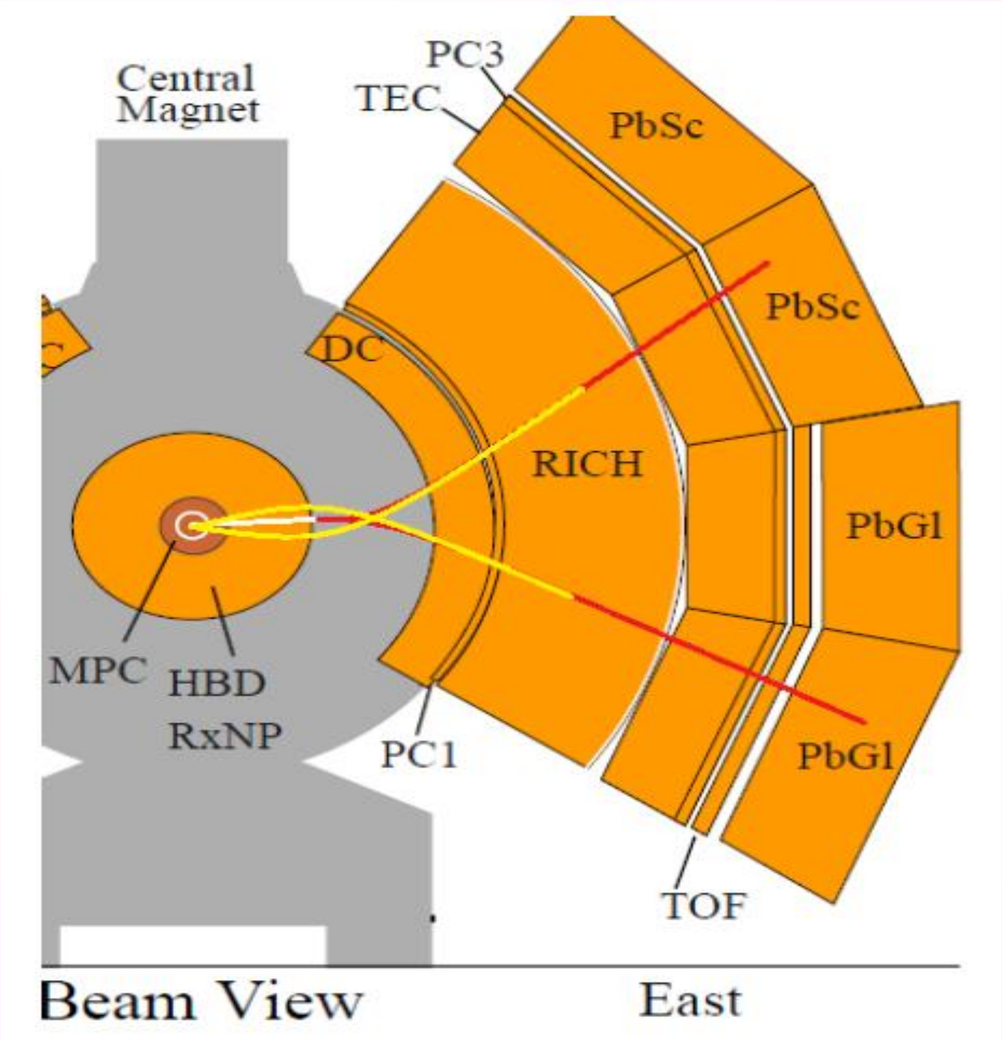



The PHENIX detector at RHIC

# External conversions:



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

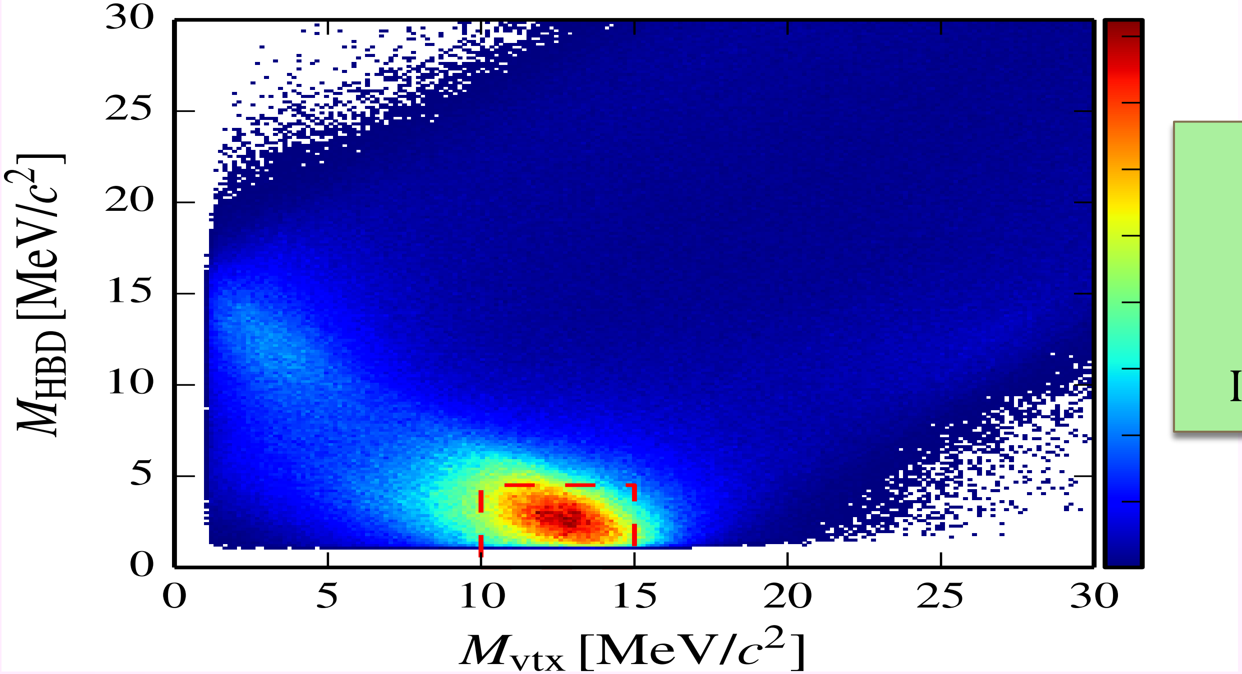



← A cartoon illustrating the effect of the assumption of the track origin

- 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 is very accurate
- The purity of the photon sample is 99%

2.

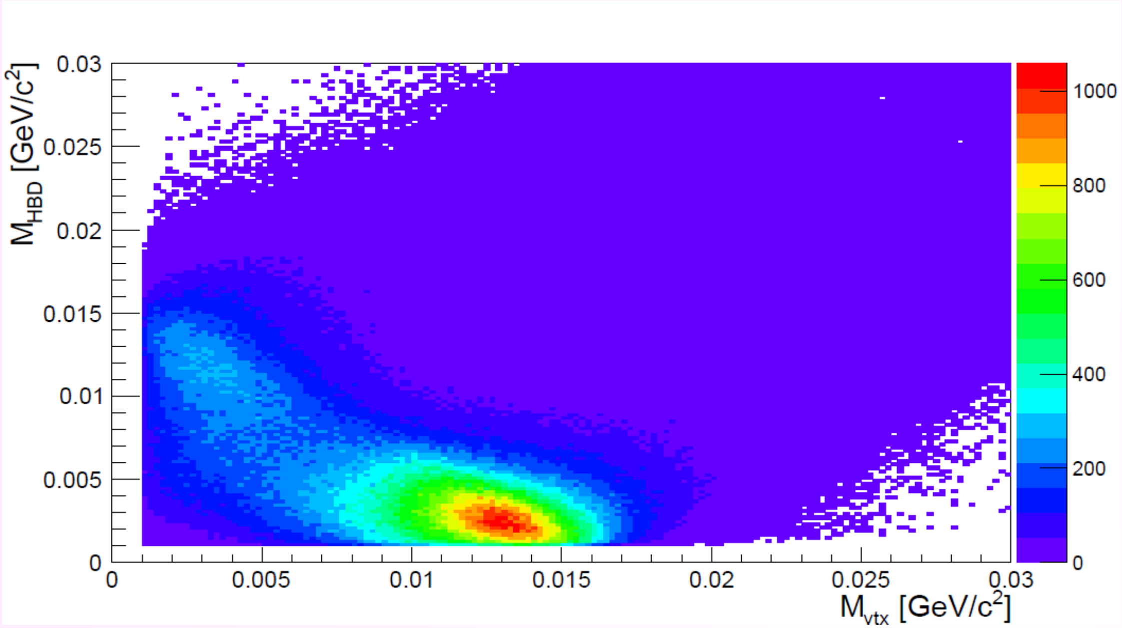
- In the standard PHENIX momentum reconstruction algorithm the $e^+e^-$ pair tracks originate from the event vertex ("vtx")
  - The momenta of the HBD converted photons are initially mis-measured
  - It gives pairs an artificial opening angle, which leads to an apparent mass
- In the Alternate Track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




A view of the cut space used for the conversion photon identification at 200 GeV

In the red box: $N_{\gamma}^{incl} = 7.6 \cdot 10^6$

*Phys.Rev. C 91, 064904 (2015)*




2.

A view of the cut space used for the conversion photon identification at 62.4 GeV

With the same cuts: $N_{\gamma}^{incl} = 3.3 \cdot 10^5$

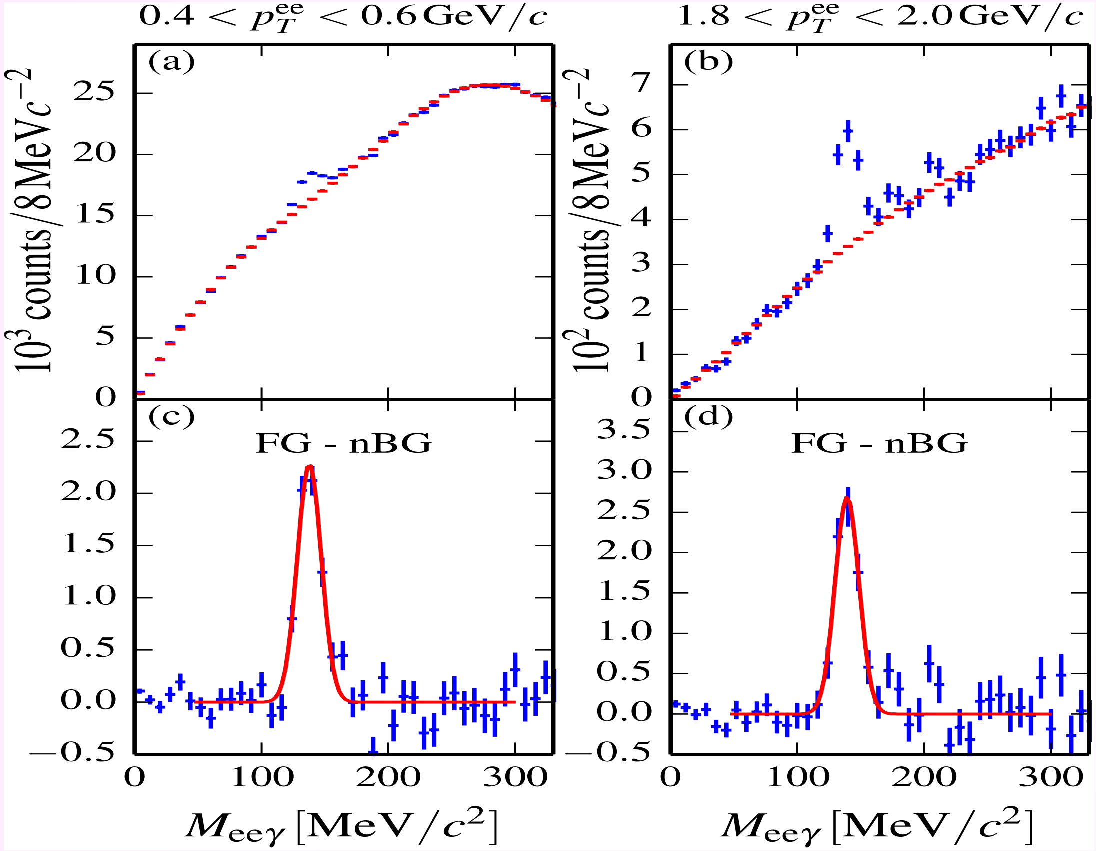
- In a given $p_T^{ee}$ bin the true number of inclusive photons, $\gamma^{incl}$, is given as follows:

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

- The factor $\varepsilon_{ee}$ – 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, $N_{\gamma}^{incl}$, is tagged as photons from $\pi^0$ decays if they reconstruct the $\pi^0$ mass with a second, photon-like shower from the PHENIX EMCal

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






***Phys.Rev. C 91, 064904 (2015)***

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 $\pi^0$ decay photons, $\gamma^{\pi^0}$, 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 $R_\gamma$ 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**

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

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

Conversion factor

Photon efficiency

f: Conditional acceptance of second decay photon

**SIMULATION**

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

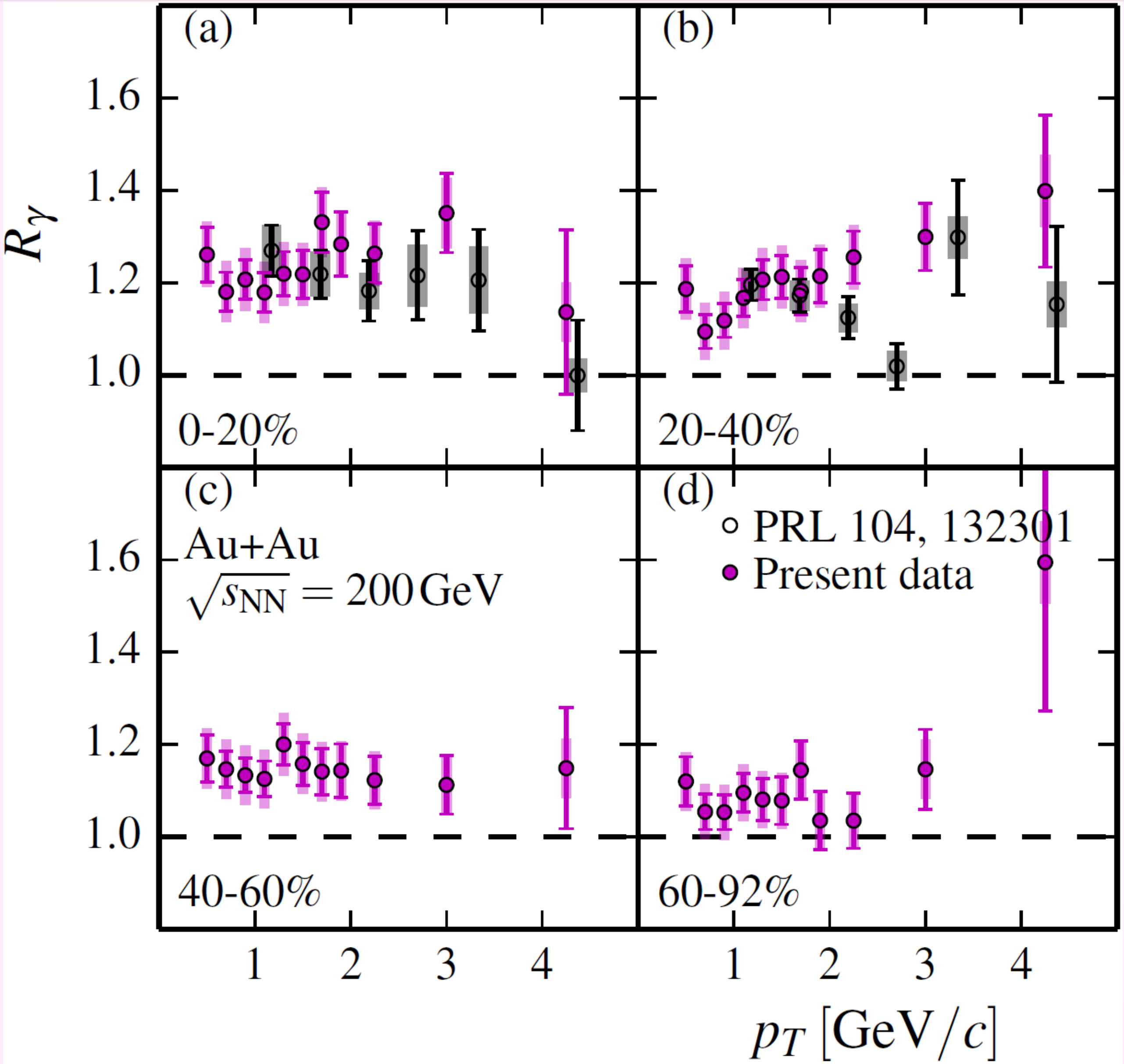
$$N_\gamma^{\pi^0,tag}(p_T) = f N_\gamma^{\pi^0} = a_{ee} f \gamma^{\pi^0}(p_T)$$

**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. The direct photon results at 200 GeV (2007, 2010 datasets) and 62.4 GeV (2010 dataset) collision energies

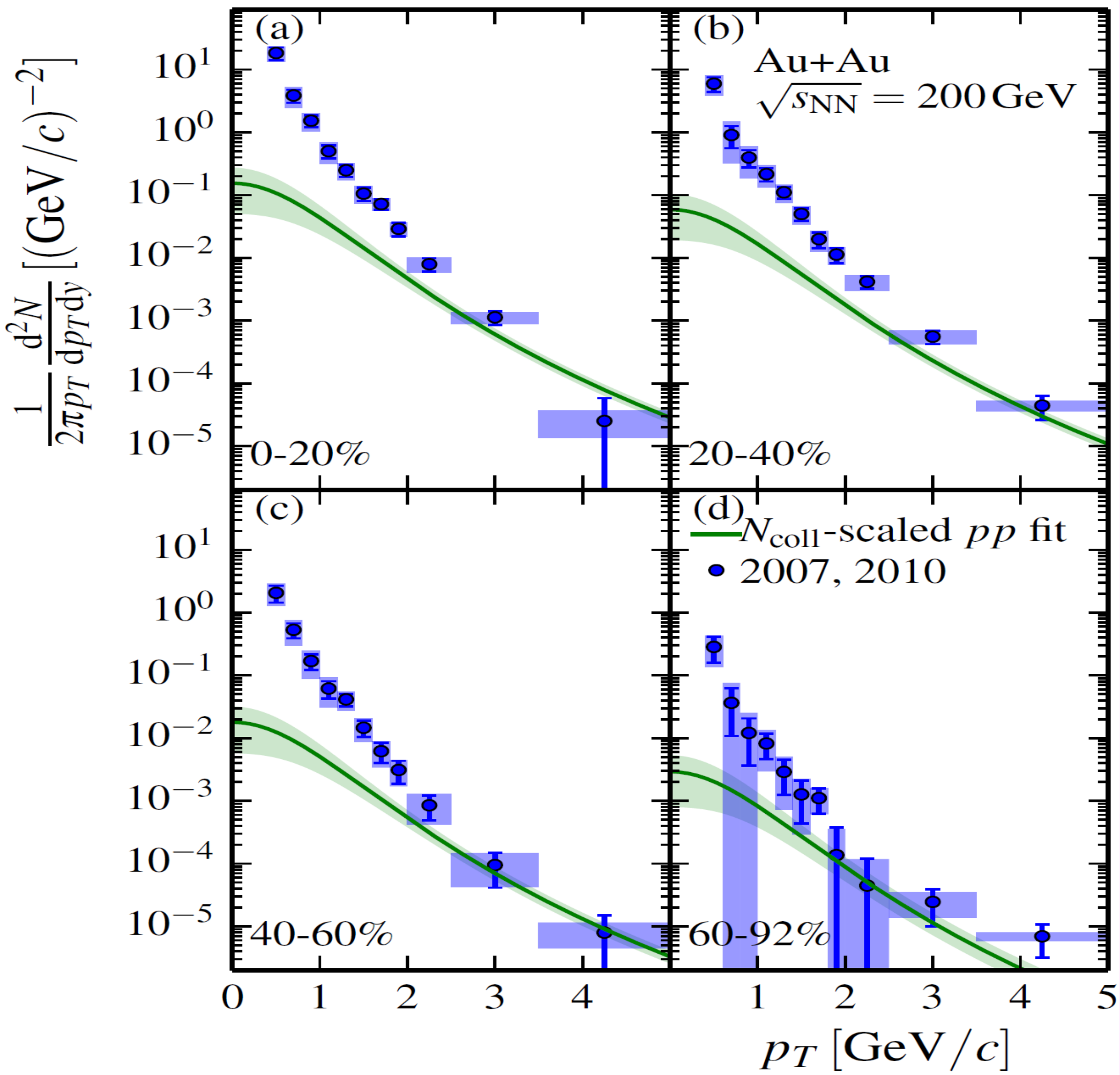



$R_\gamma$ at 200 GeV, for the combined 2007 and 2010 datasets in centrality bins 0-20%, 20-40%, 40-60% and 60-92%

Statistical uncertainties are plotted as vertical lines, systematic uncertainties are shown as filled boxes

Present data = 2007, 2010 datasets

*Phys.Rev. C 91, 064904 (2015)*



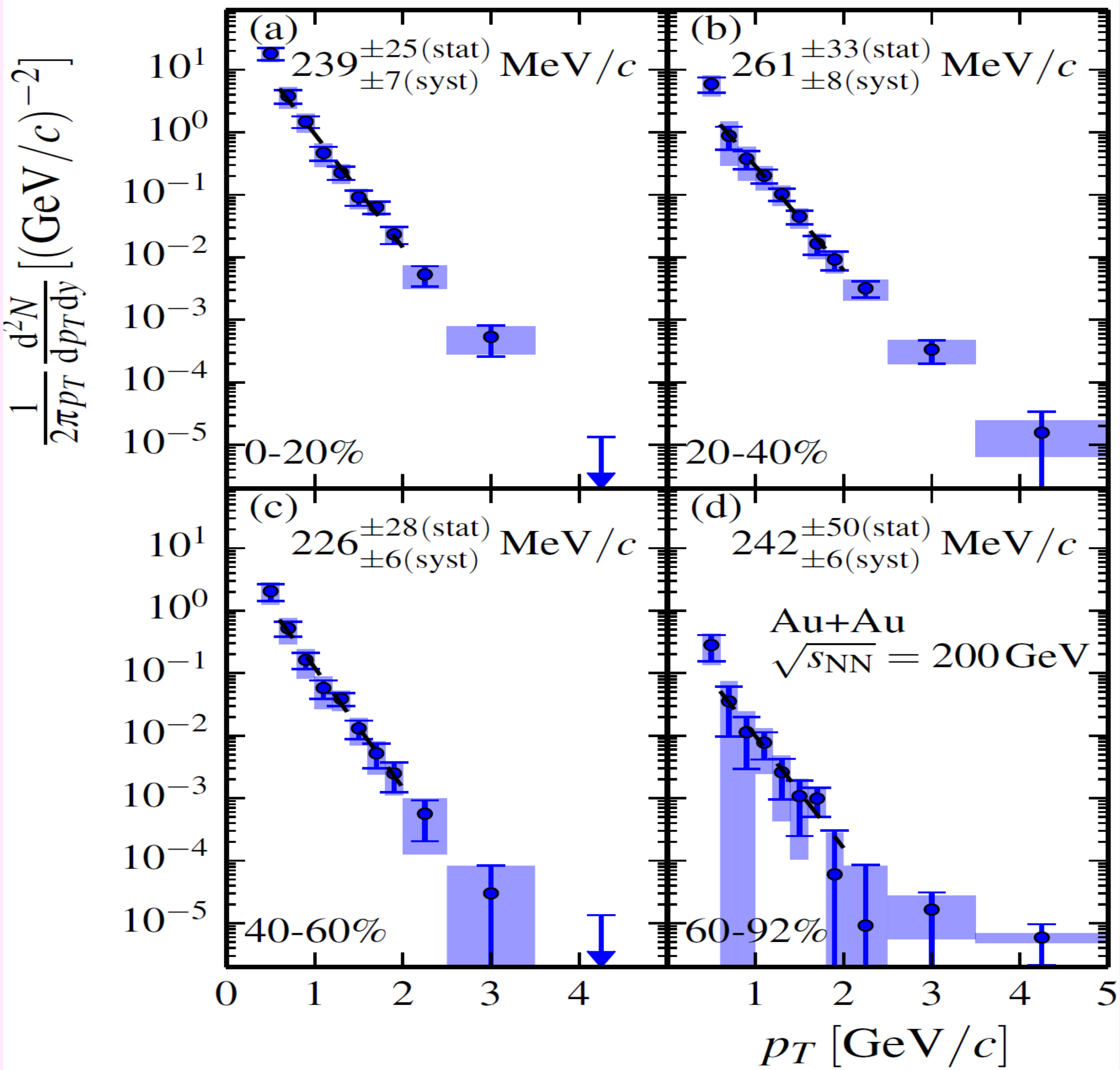

Inv. Yield = $(R_\gamma - 1) \times \gamma^{had}$

Direct photon $p_T$ spectra in centrality bins 0-20%, 20-40%, 40-60% and 60-92%

Widths of filled boxes indicate bin widths of the analysis

The green lines show $N_{coll}$-scaled modified power-law fits to the PHENIX p + p data

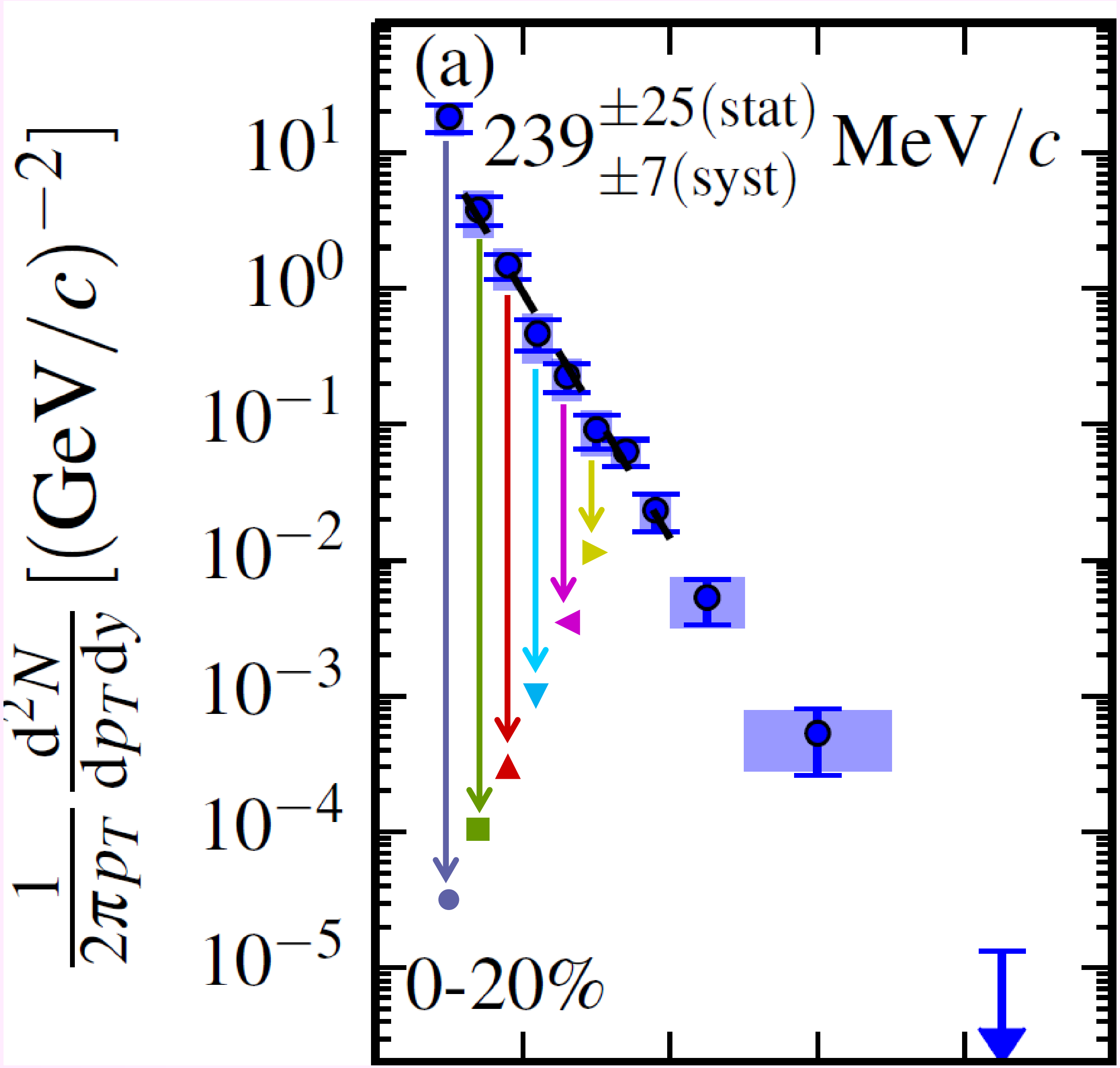
*Phys.Rev. C 91, 064904 (2015)*




Direct photon $p_T$ spectra after subtraction of the pQCD-contribution in centrality bins 0-20%, 20-40%, 40-60% and 60-92%

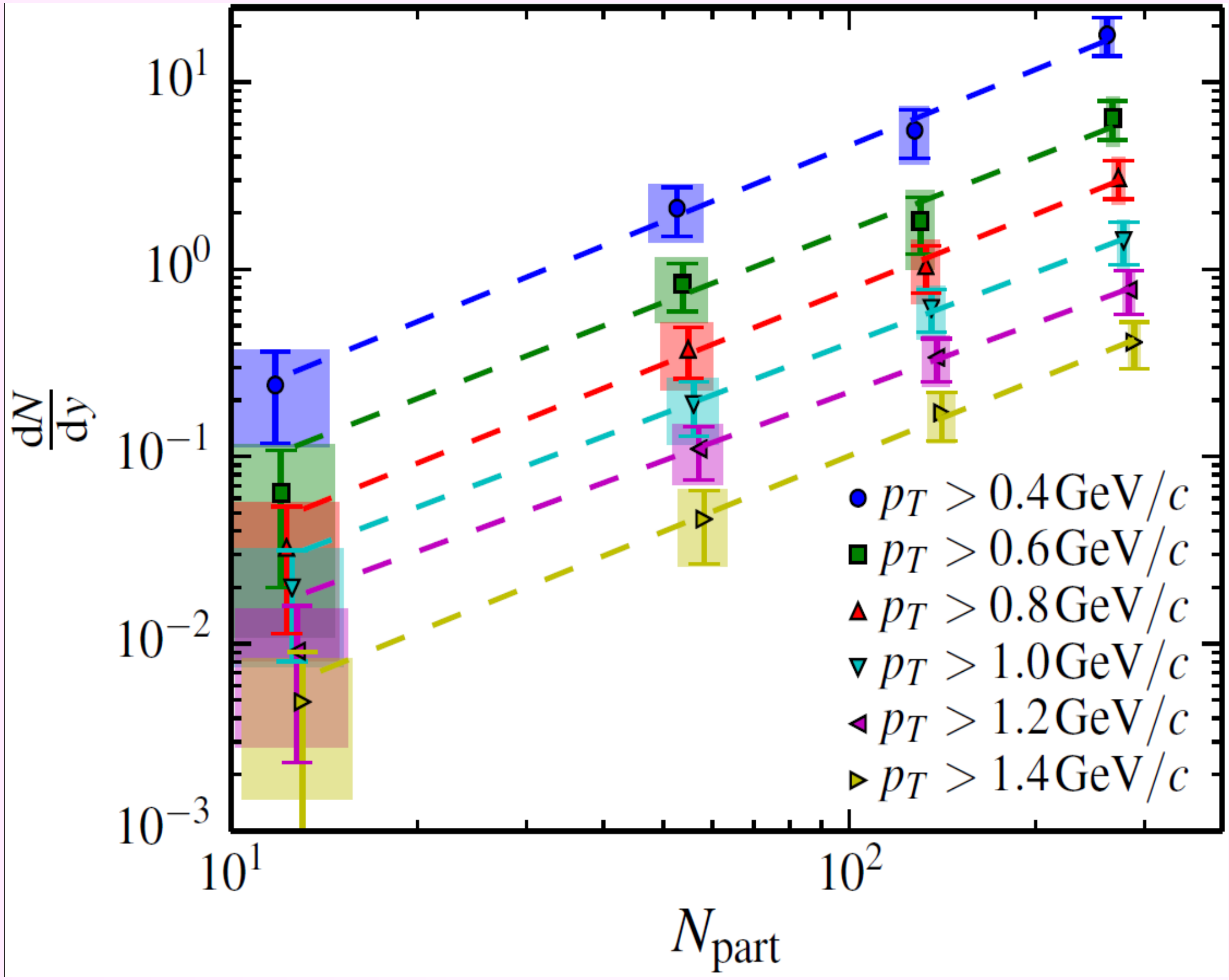
Dashed lines are fits to an exponential in the range 0.6 GeV/c < $p_T$ < 2.0 GeV/c

*Phys.Rev. C 91, 064904 (2015)*




One can integrate the thermal photon yield over $p_T$ as a function of $N_{part}$

In the analysis of 200 GeV it has been calculated for six different lower $p_T$ integration limits shown in this plot



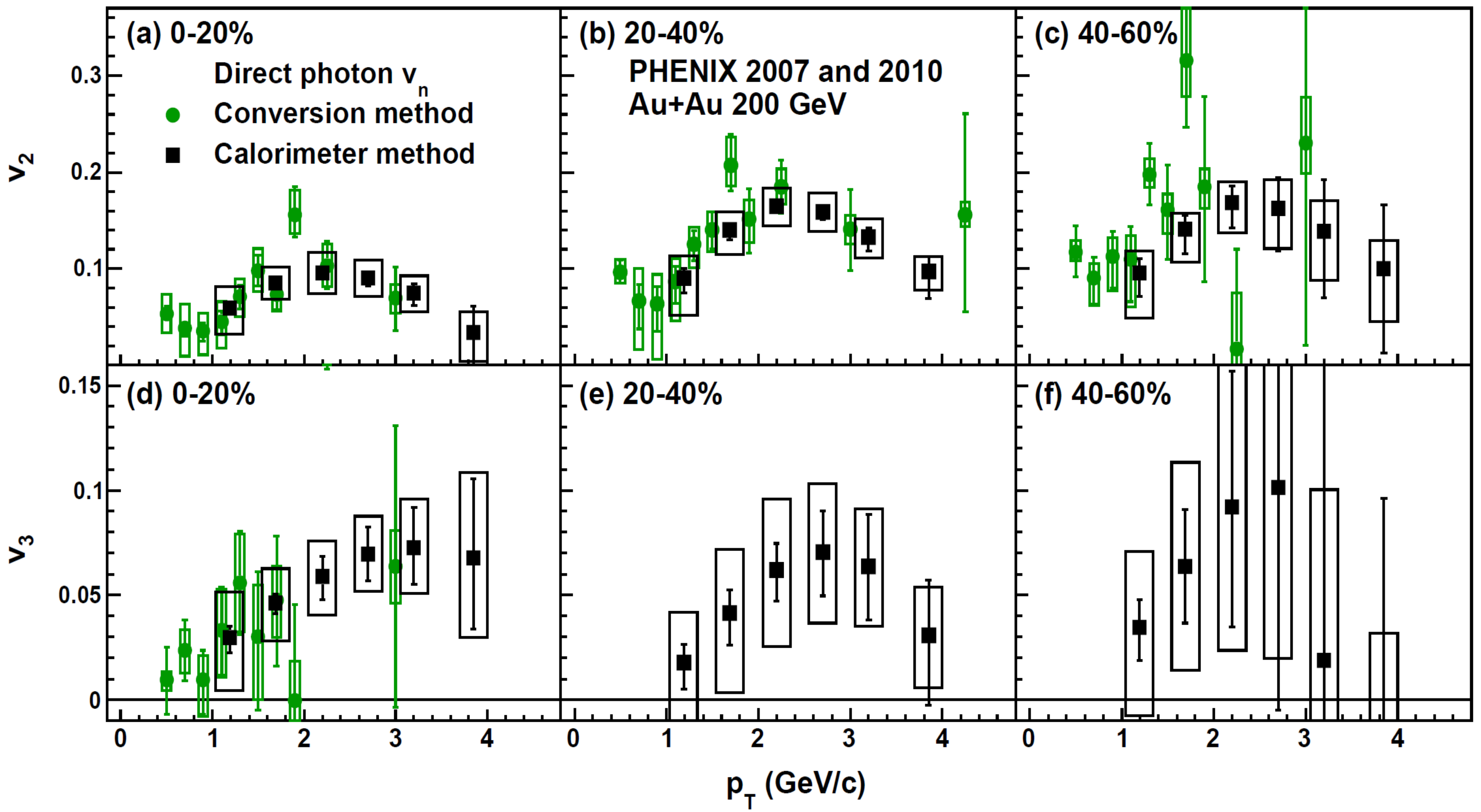

Integrated thermal photon yields as a function of $N_{part}$ for different lower $p_T$ integration limits

The dashed lines are independent fits to a power-law $A \times (N_{part})^{\alpha}$

The six points in the top-right corner are the integrals for 0-20% centrality bin.

The yield increases rapidly with increasing centrality, scaling approximately with $(N_{part})^{\alpha}$, where $\alpha = 1.48 \pm 0.08(\mathrm{stat}) \pm 0.04(\mathrm{sys})$

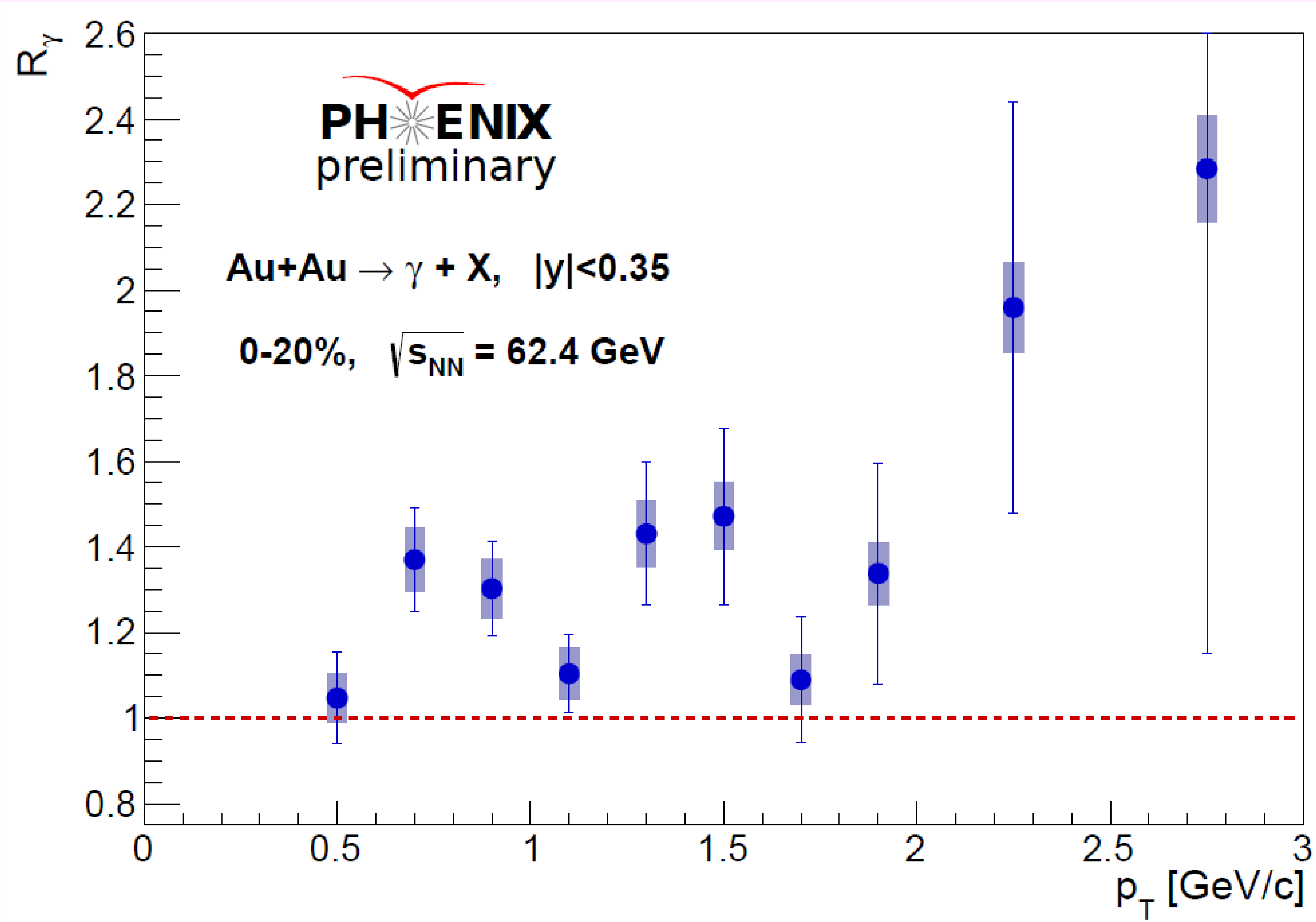
*Phys.Rev. C 91, 064904 (2015)*



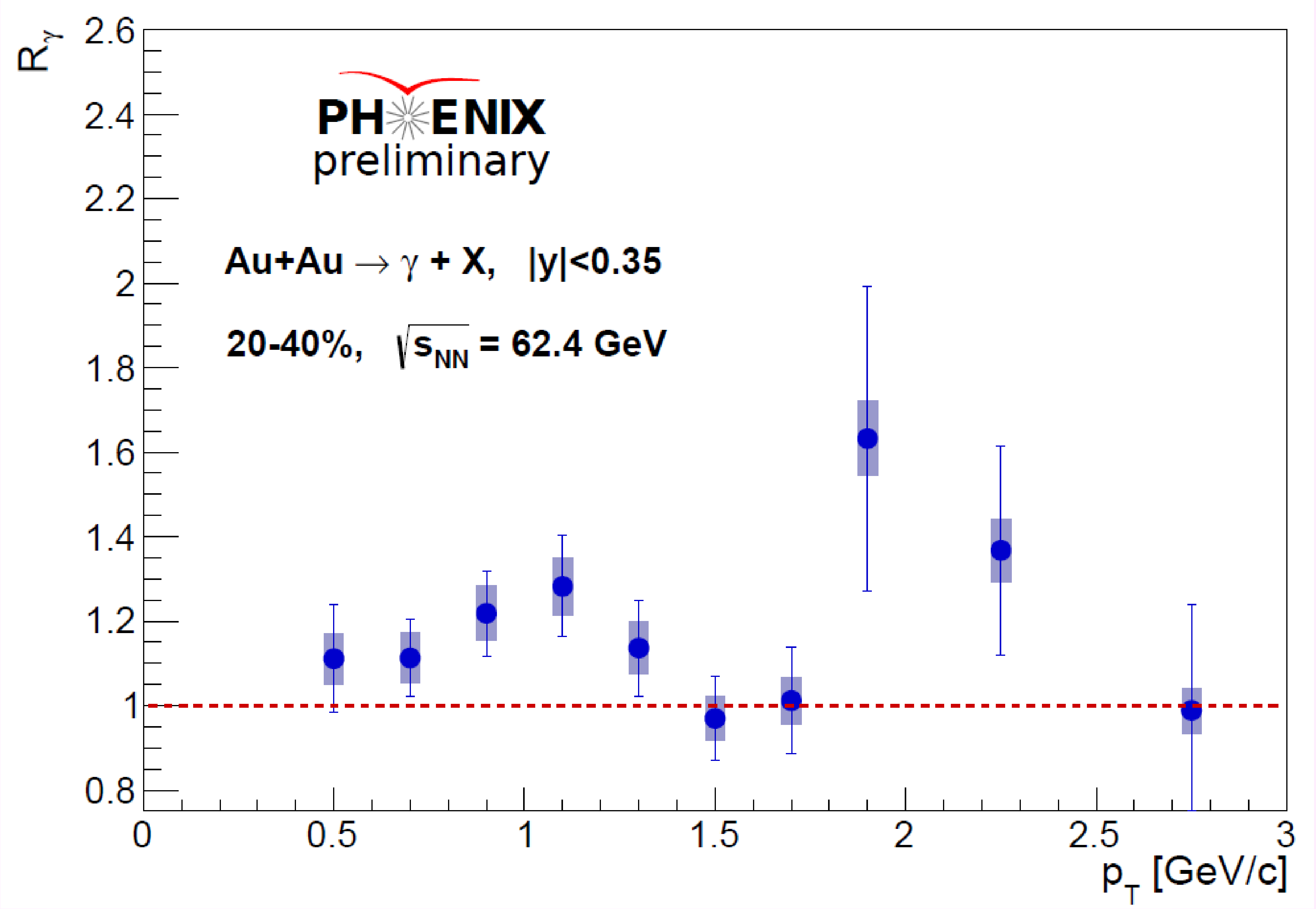

Direct photon $v_2$ and $v_3$ at midrapidity ($|\eta| < 0.35$), for different centralities, measured with the conversion method (solid circles, green) and calorimeter method (solid squares, black). The error bars (boxes) of the data points are statistical (systematic) uncertainties.



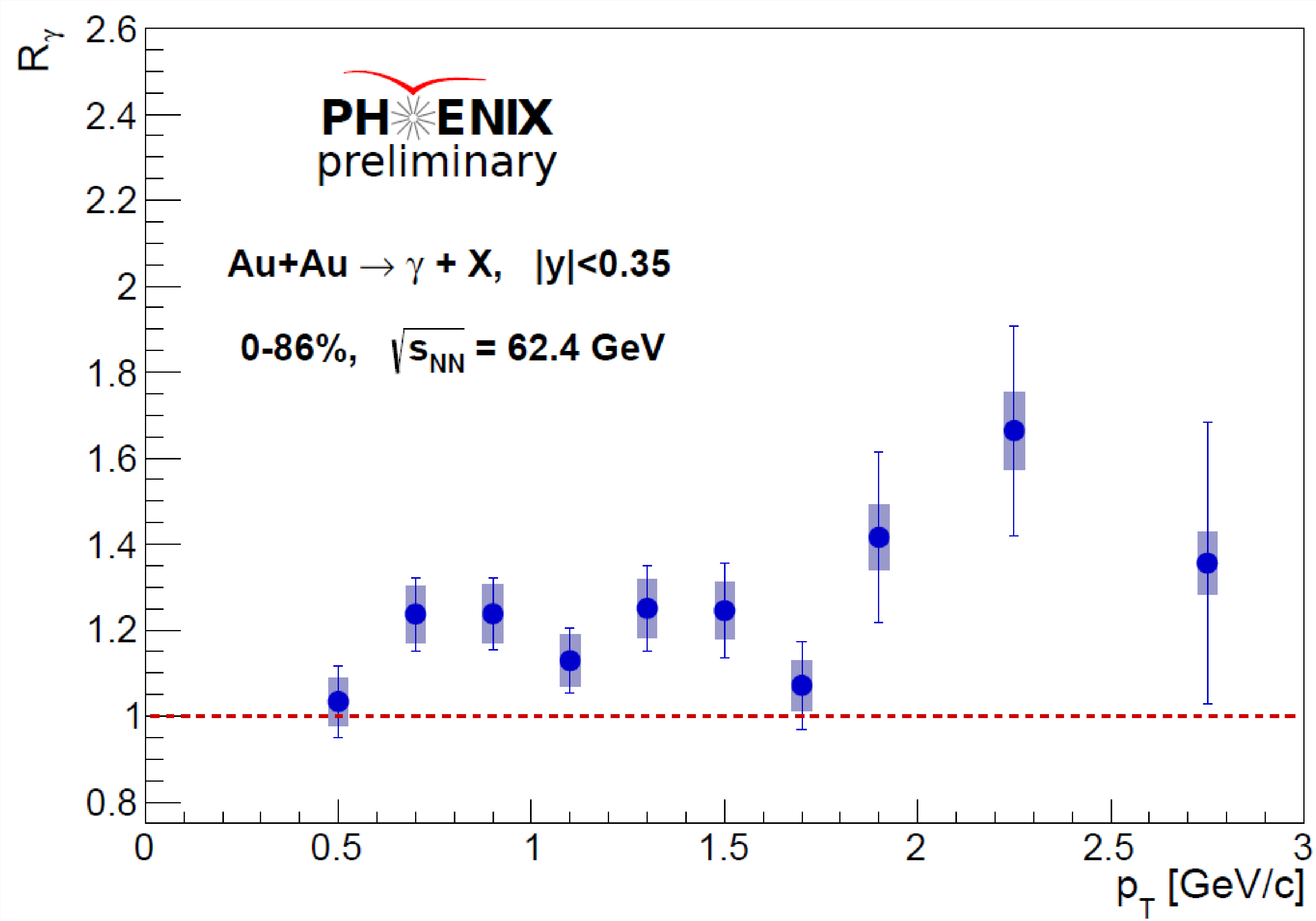
*Phys.Rev. C 94, 064901 (2016)*



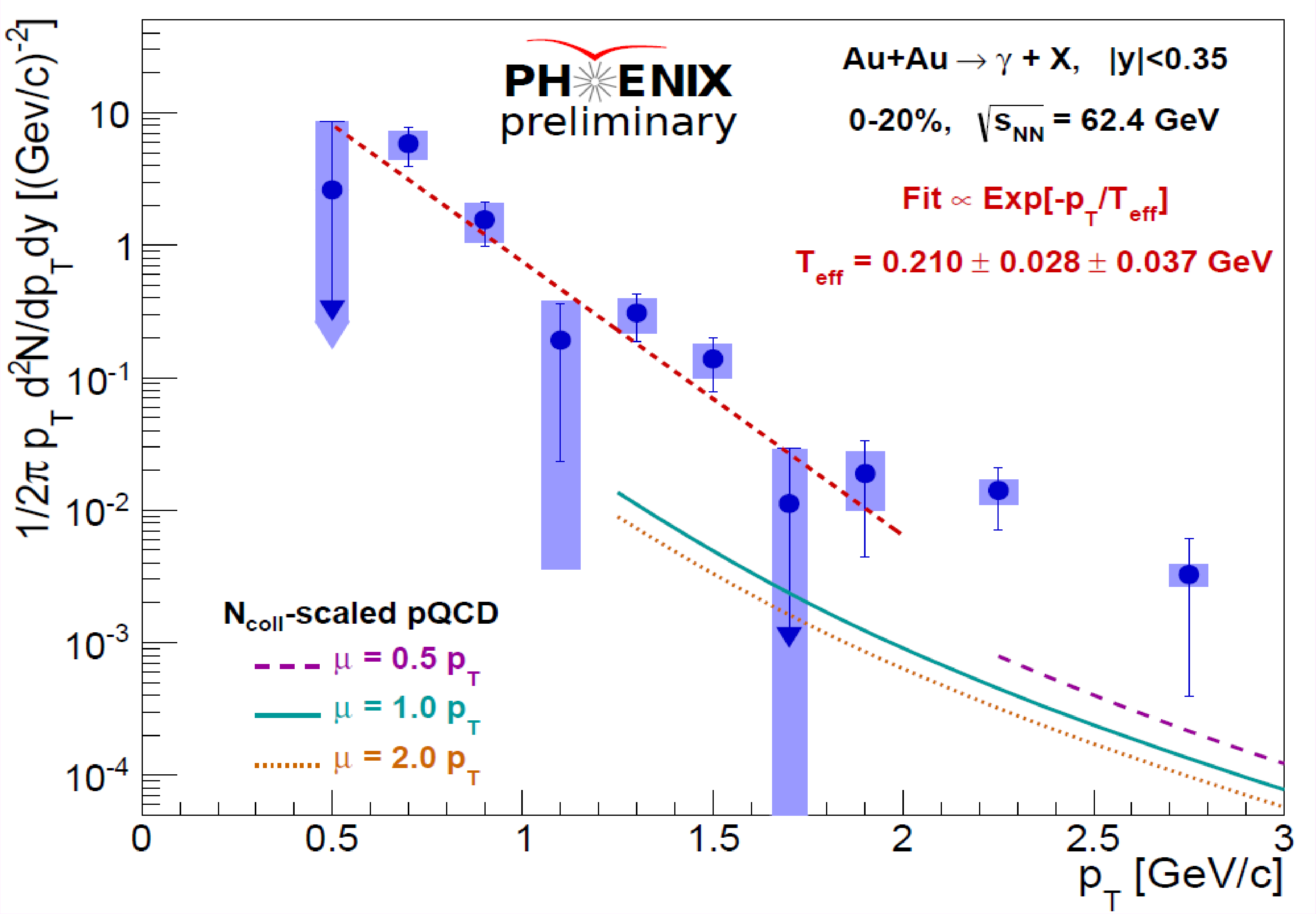

$R_\gamma$ of direct photons in 0-20% centrality bin at 62.4 GeV collision energy



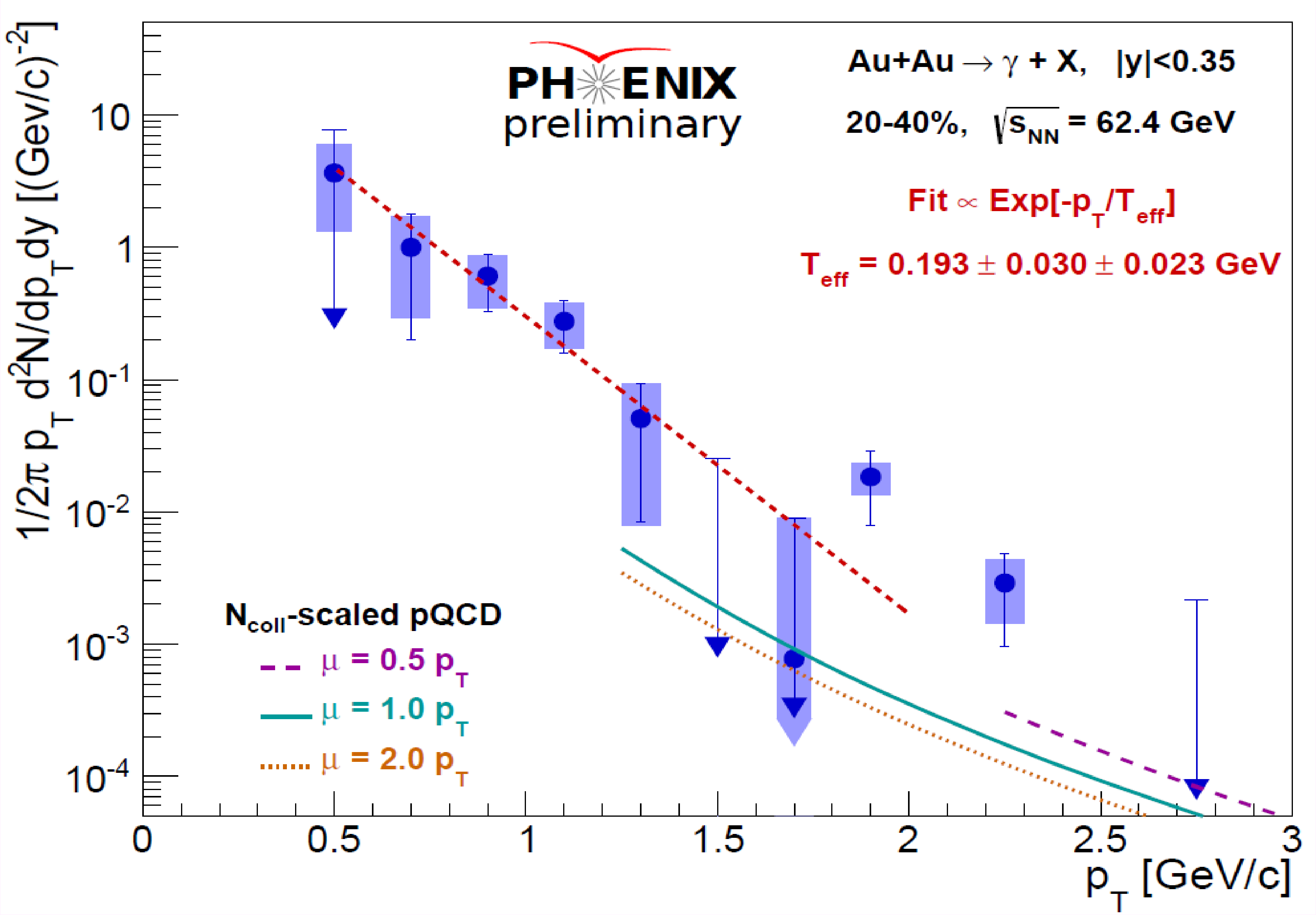

$R_\gamma$ of direct photons in 20-40% centrality bin at 62.4 GeV collision energy



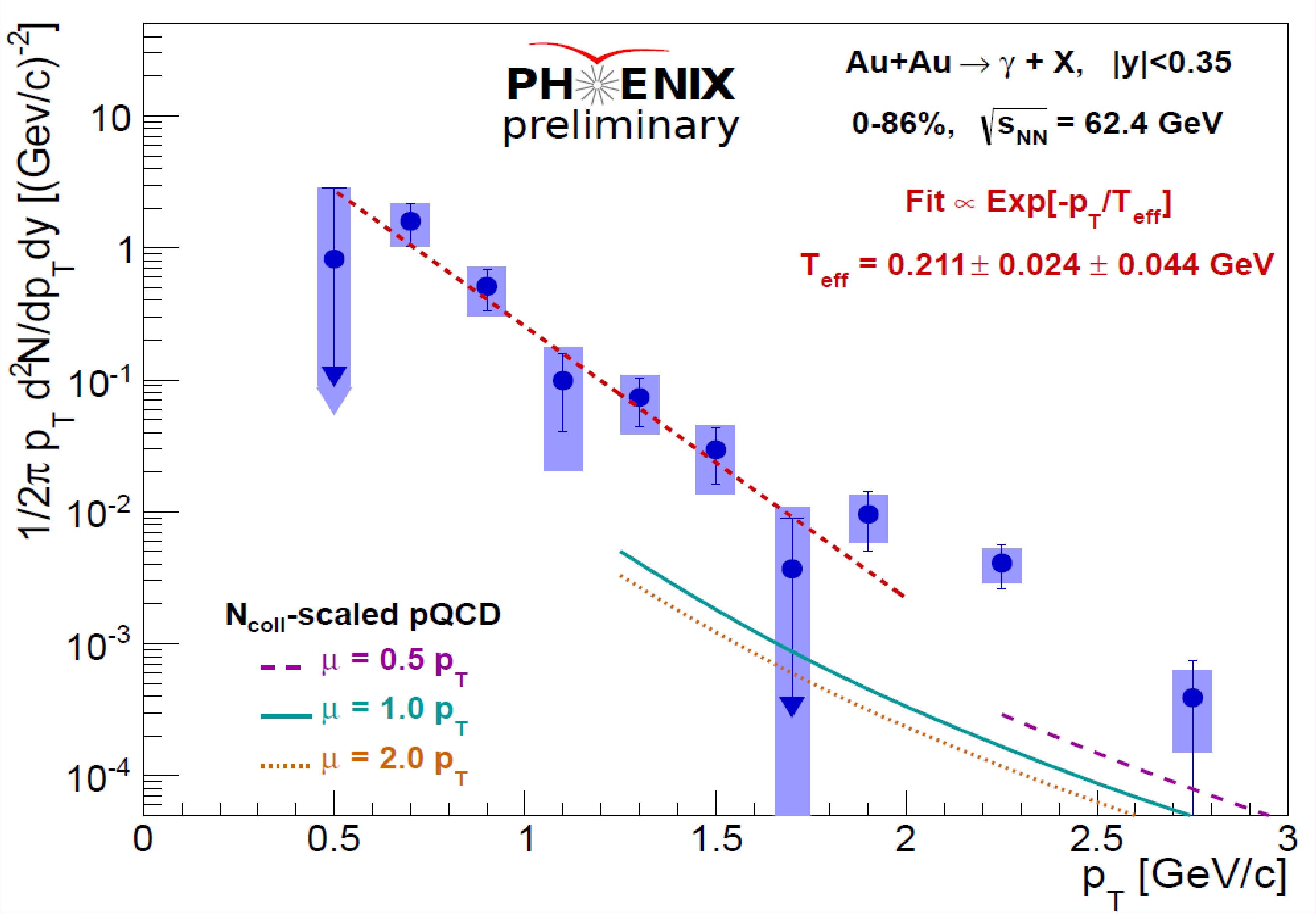

$R_\gamma$ of direct photons in the minbias 0-86% at 62.4 GeV collision energy



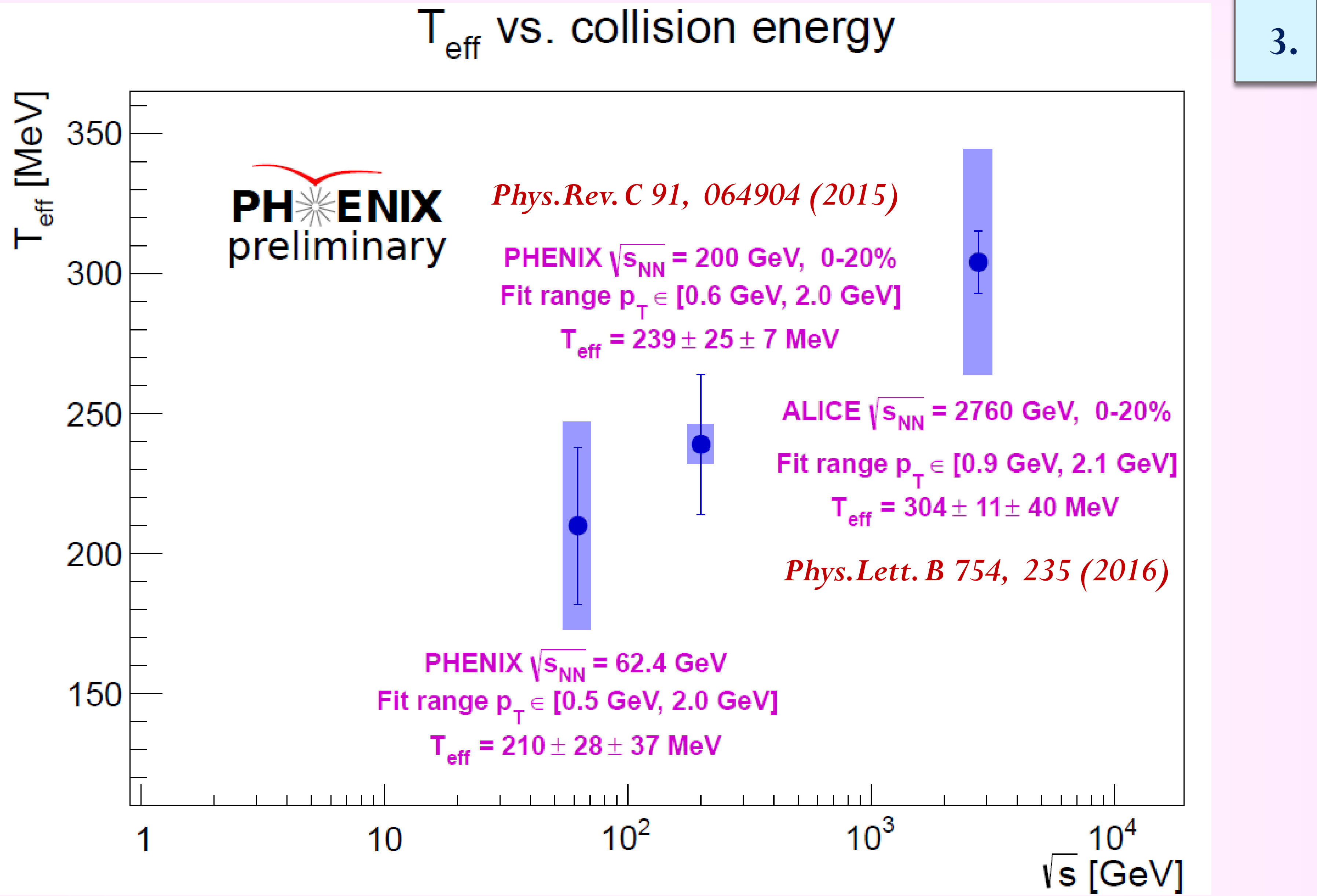

The invariant yield of direct photons in 0-20% centrality bin at 62.4 GeV collision energy




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




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




The extracted $T_{eff}$ at three collision energies, 2760 GeV, 200 GeV and 62.4 GeV

# 4. Summary

1. We have measured $R_\gamma$ and $p_T$ spectra for real photons at 200 GeV and 62.4 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 also show significant excess yield at least for the most central collisions

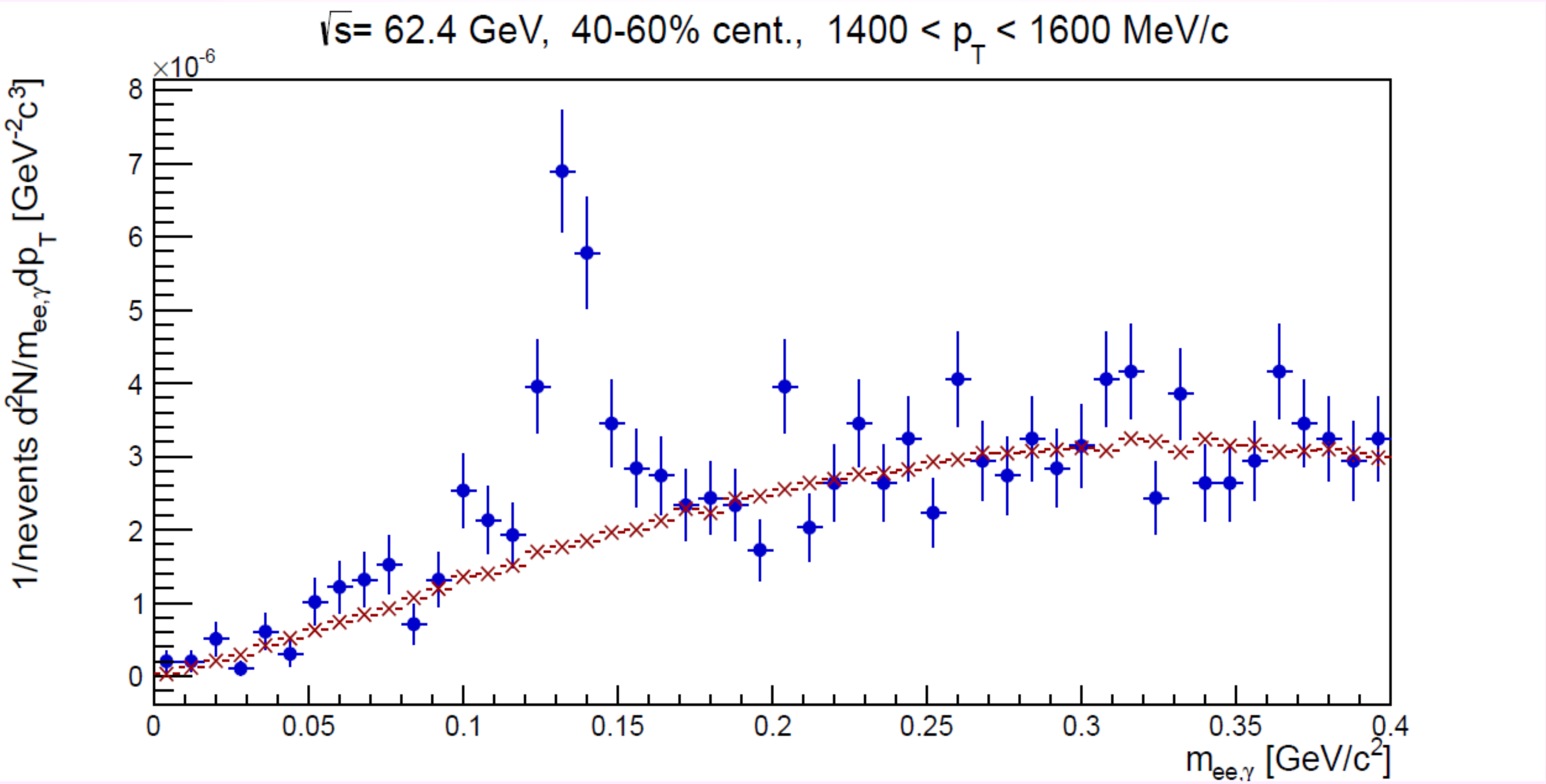
4. Similar results from 39 GeV measurements will be shown in the upcoming Quark Matter conference

**Thank You !**

# Backups

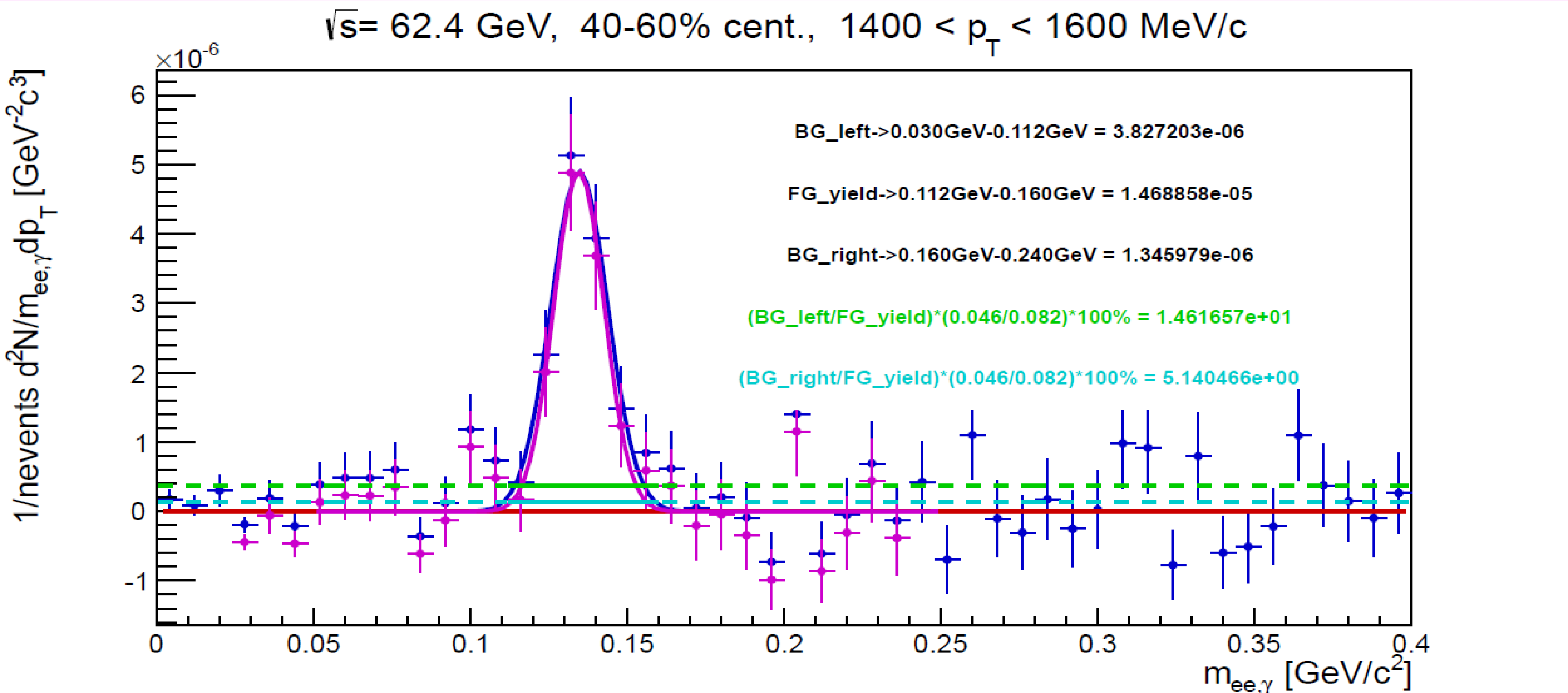
**An example of a histogram of the $e^+e^-\gamma$ invariant mass distribution for 1.4-1.6 GeV/c $p_T^{ee}$ bin and 40-60% centrality at 62.4 GeV**

- **The diphoton foreground distribution is in blue**
- **The normalized background distribution from the mixed events is in red**



An example below shows an isolated pion peak after subtraction of the normalized background from the foreground

- The residual background is assumed to be described by averaging the sum of the green and cyan colored lines
- Then it is used to correct the original blue colored subtraction
- It results in shifting the blue points up or down, represented by the purple points and fitted by a purple Gaussian



The integration of the pion peak goes to the $\pi^0$ tagged photon yield, which along with the inclusive yield give the numerator ratio in the $R_\gamma$ formula