Centrality Dependence of Low Momentum Direct Photon Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200 GeV$ Measured with the PHENIX Detector

Richard Petti (for the PHENIX Collaboration)
Department of Physics and Astronomy
Stony Brook University
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Outline

- Motivation
- Open questions
  - Is the radiation dominated by thermal radiation?
  - Is the radiation dominated by late or early time emission?
- New results
- Summary

Direct Photons are an Important Probe of Heavy Ion Collisions

- Definition: direct photons = inclusive photons – hadron decay photons
  - include photons produced from the initial collision and photons produced from the medium itself
- Direct photons probe the entire space-time evolution of the collision
  - do not interact strongly with the medium
  - escape unmodified
  - carry information about the system at the time of production
- In the context of low momentum (below ~3GeV/c)
  - thermometer
  - constraints on thermalization time
  - constraints on electrical conductivity
  - evidence of strong background magnetic fields

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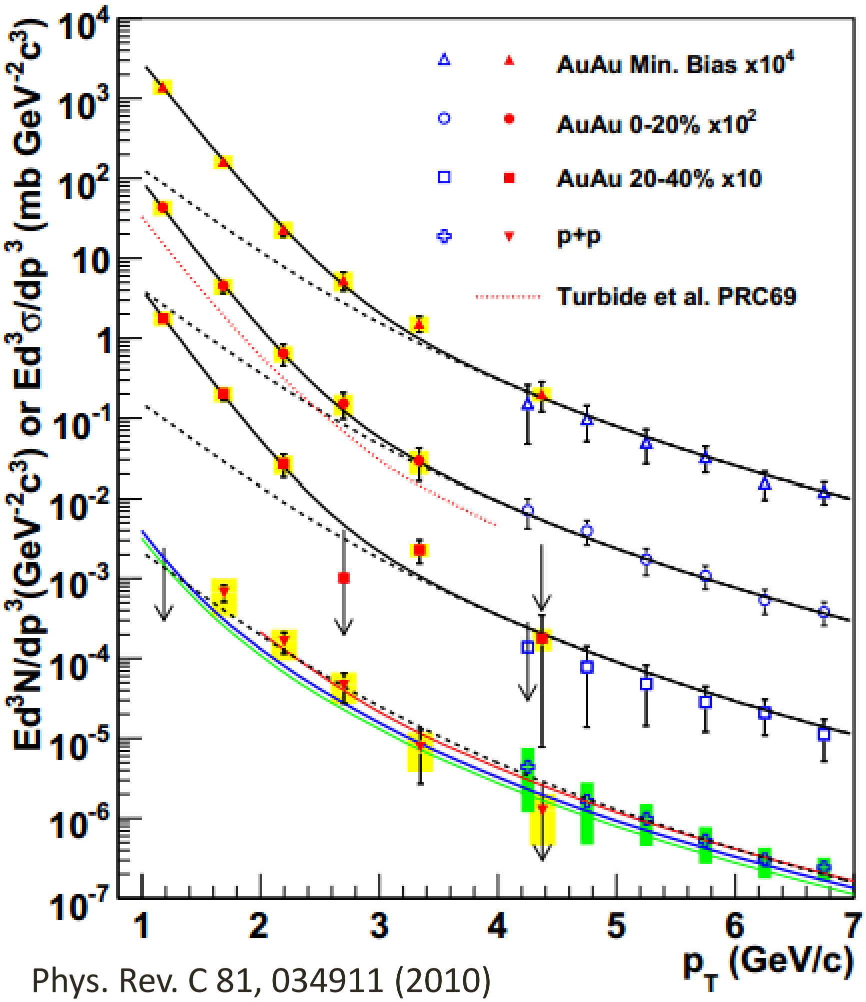
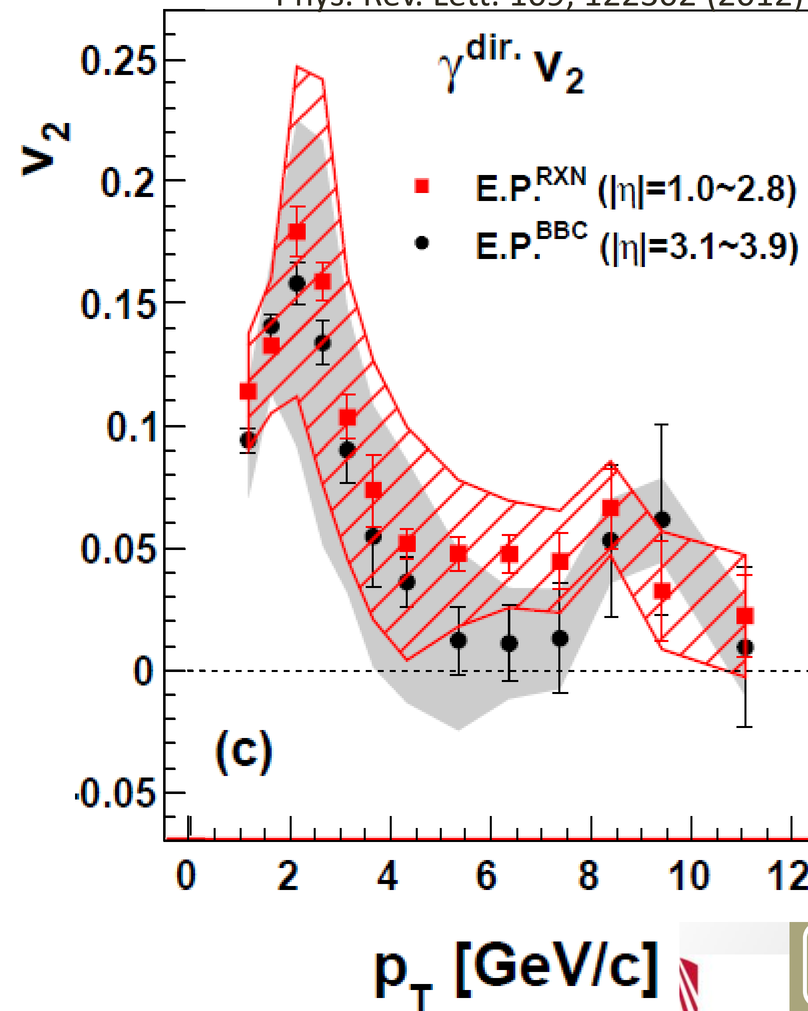
We Have Measurements of Direct Photons



Phys. Rev. C 81, 034911 (2010)

Phys. Rev. Lett. 109, 122302 (2012)



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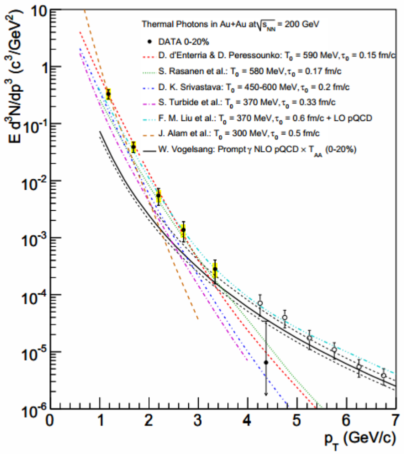

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- Old hydro calculations consistent with yield indicate photons come from a hot medium
- indicate $300 < T_{initial} < 600 MeV$ and $0.6 < \tau_0 < 0.15 fm/c$
- But wait, see next slide!

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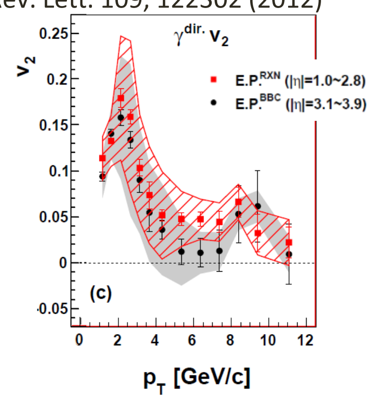
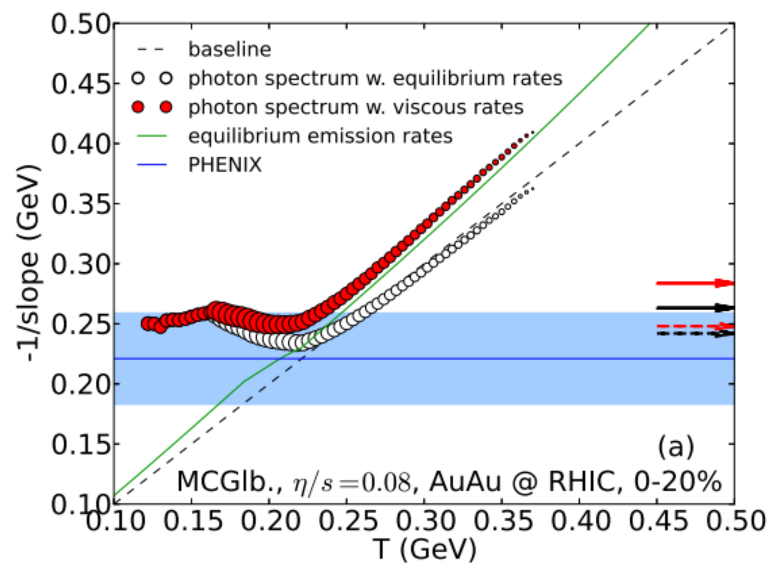
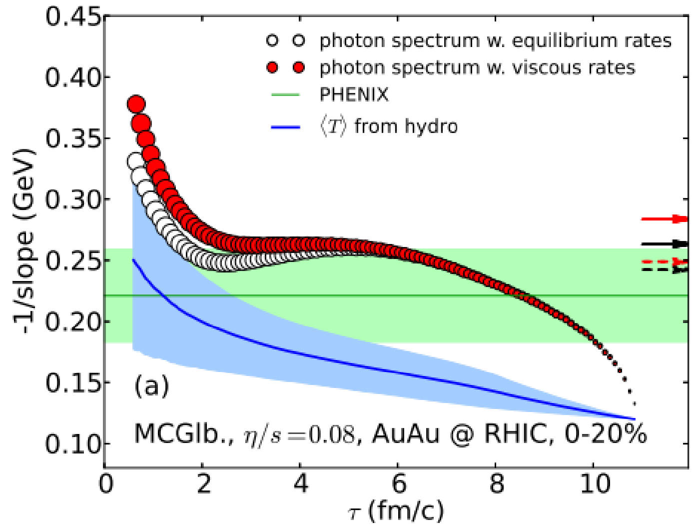


- Large v_2 indicates photons originate later in the collision
  - flow is small early in collision and grows as a function of time
- Possible scenarios:
  - photons are produced late
  - new production mechanisms

Radial Flow Significantly Distorts the Thermal Spectrum

- reasonable description of the yield
- authors find that most of the photons do not come from the hot QGP
  - most come from the cooler periphery
  - look hotter because blue shifted by radial flow





arXiv:1308.2440v3 [nucl-th]

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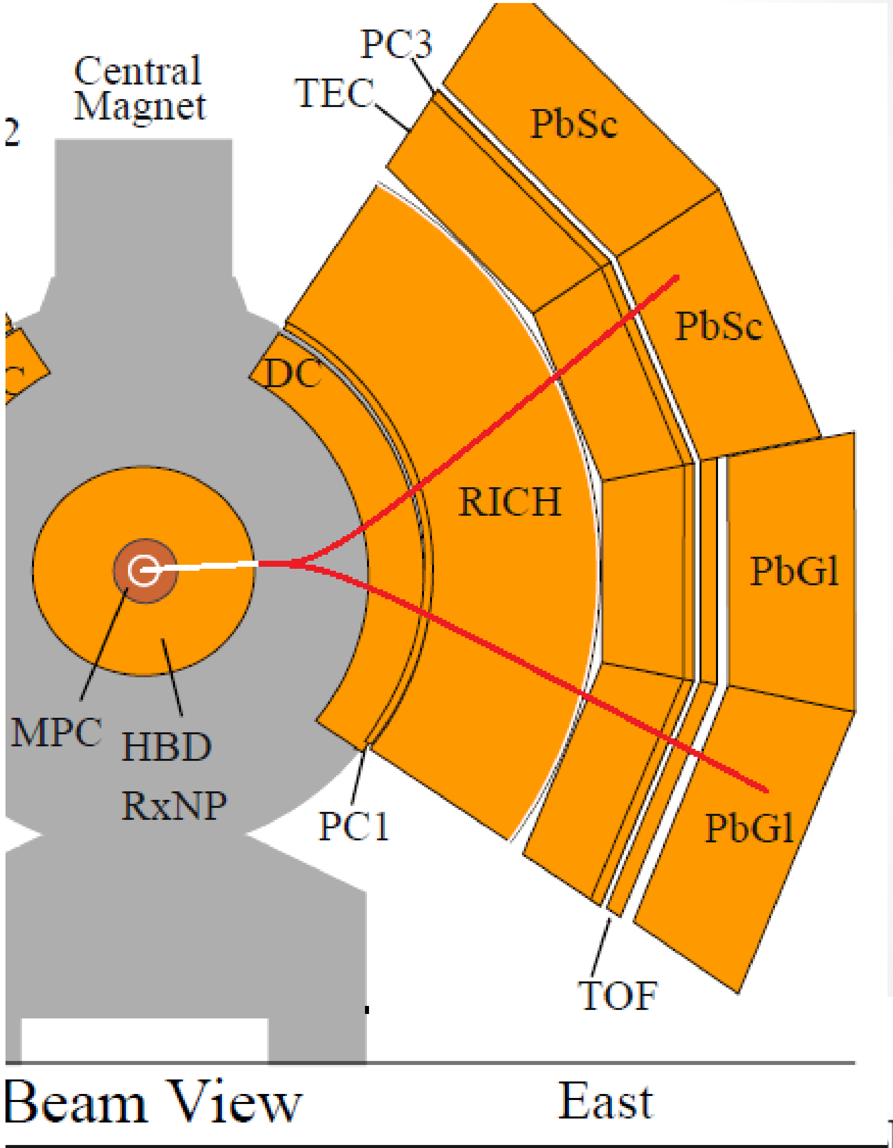
New Measurement of Direct Photons

- measure real direct photons at low p_T to complement the virtual photon analysis
- push to lower p_T
- identify photons via their external conversion in material
  - specifically the back plane of the HBD (R≈60cm)
  - tracks are assumed to come from the event vertex
  - HBD conversions are miss-measured
  - obtain an apparent mass
  - we correct for this



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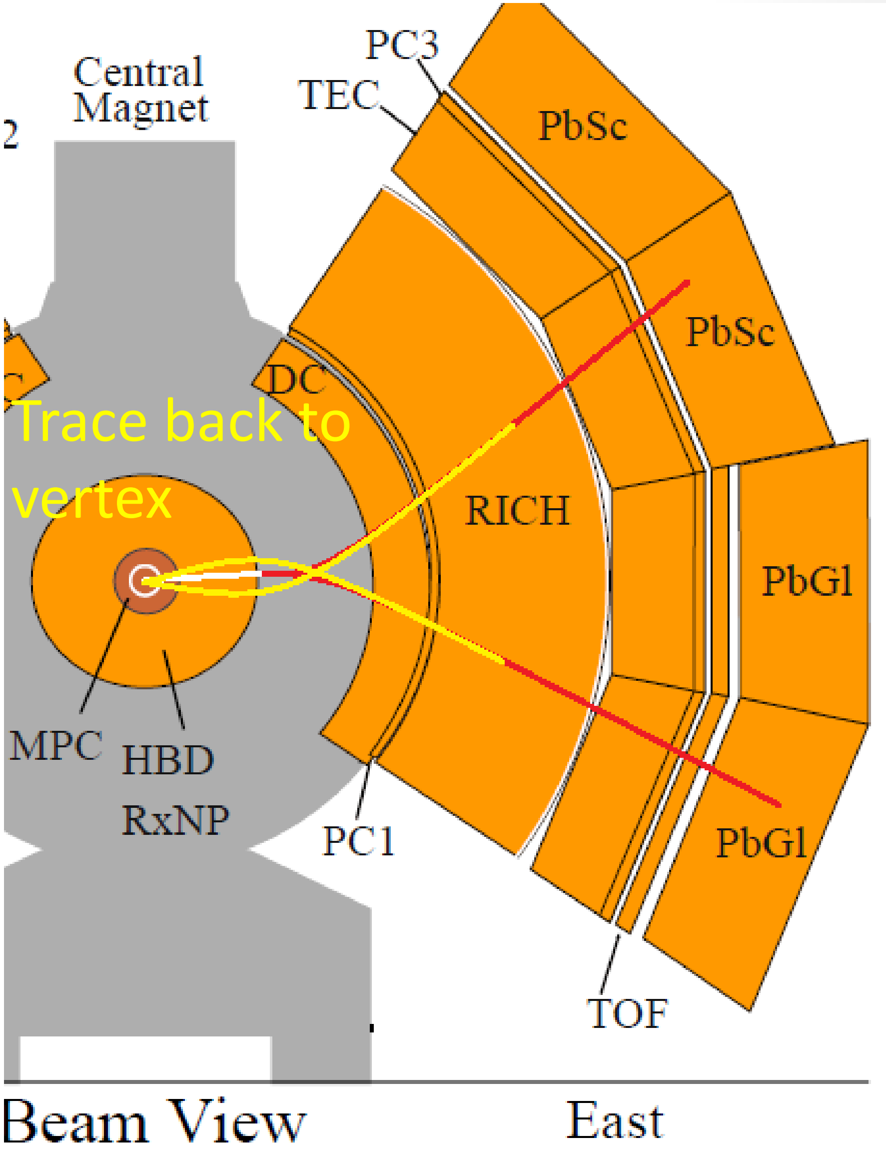

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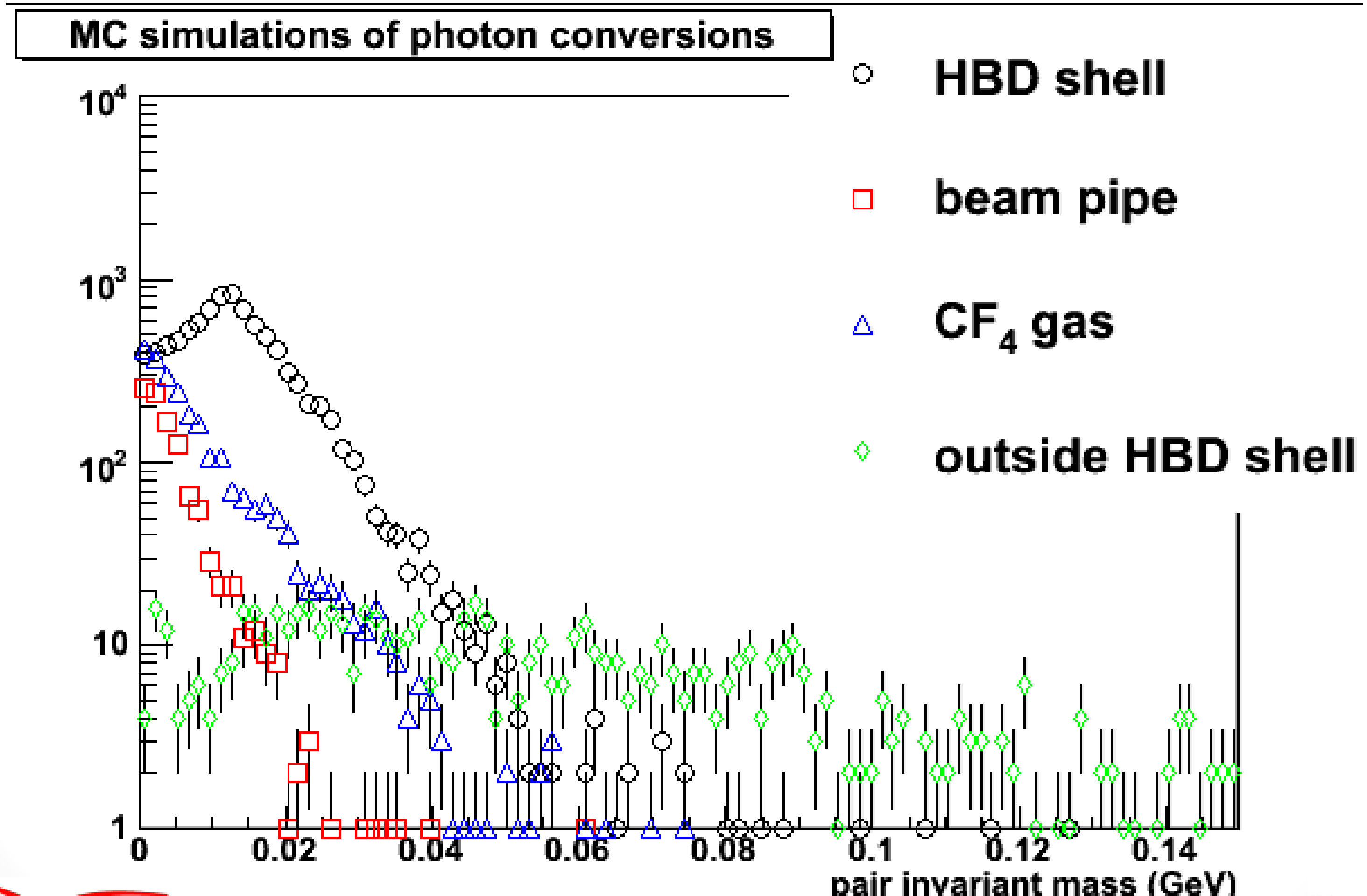
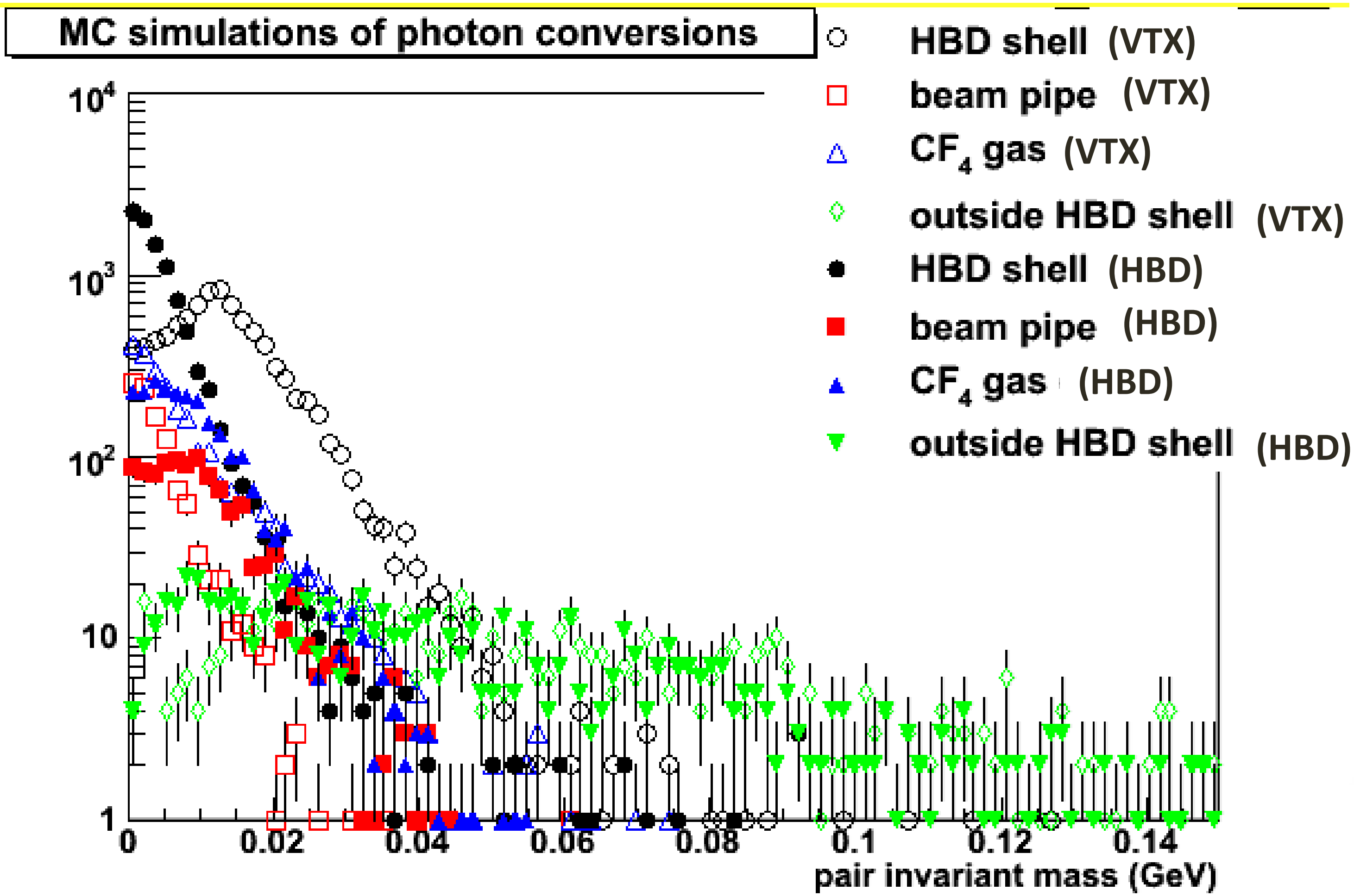
Some Simulations of Conversions

- Full GEANT simulation of photon conversions



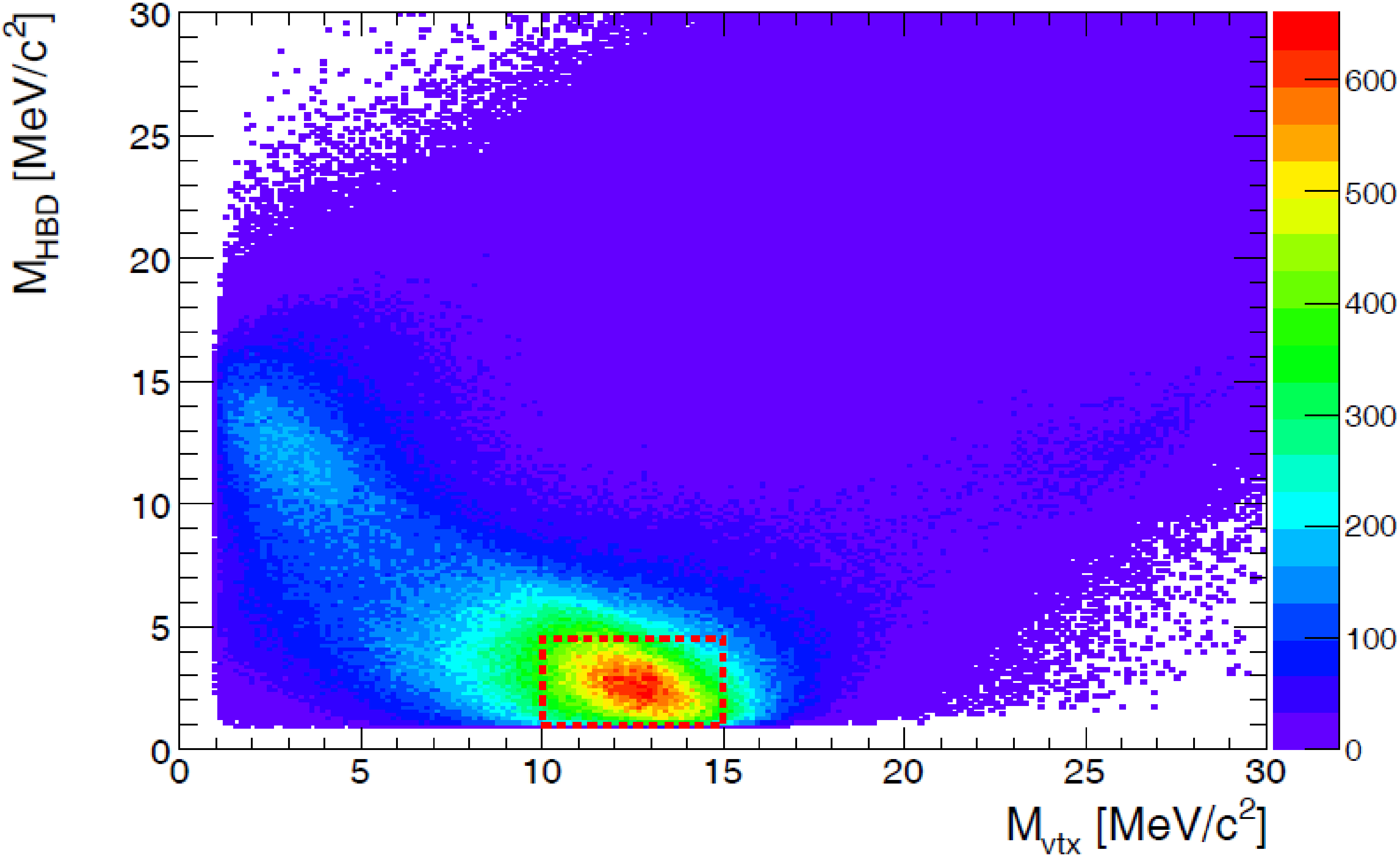
Some Simulations of Conversions

- Full GEANT simulation of photon conversions
- Assume all particles come from a radius of 60cm (HBD) (solid points)



Conversion Recalibrator in 2D: Data

- excellent electron id + mass cuts = very clean photon sample
- photon sample purity 99%



Measuring a Direct Photon Signal, R_γ - The Double Ratio

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

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DATA

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

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e+/e- Pair efficiency

e+/e- Pair acceptance

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Conversion factor

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Photon efficiency

f: Conditional Acceptance of second decay photon

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- Pair acceptance and efficiency cancels in the ratio
- Conversion factor cancels

Measuring a Direct Photon Signal, R_γ - The Double Ratio

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SIMULATION

DATA

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

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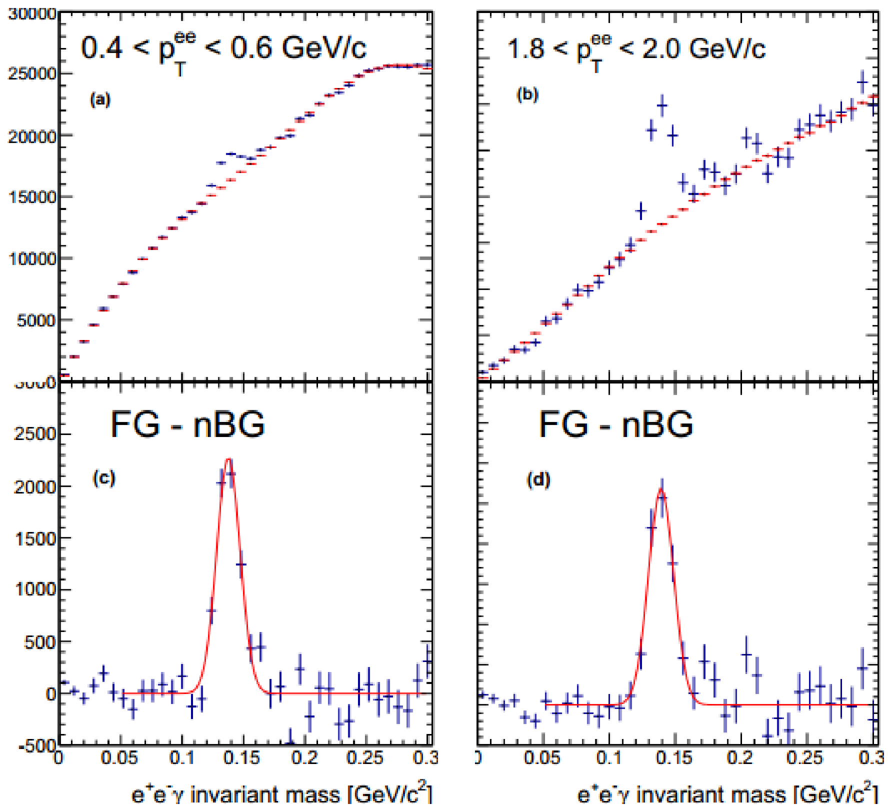
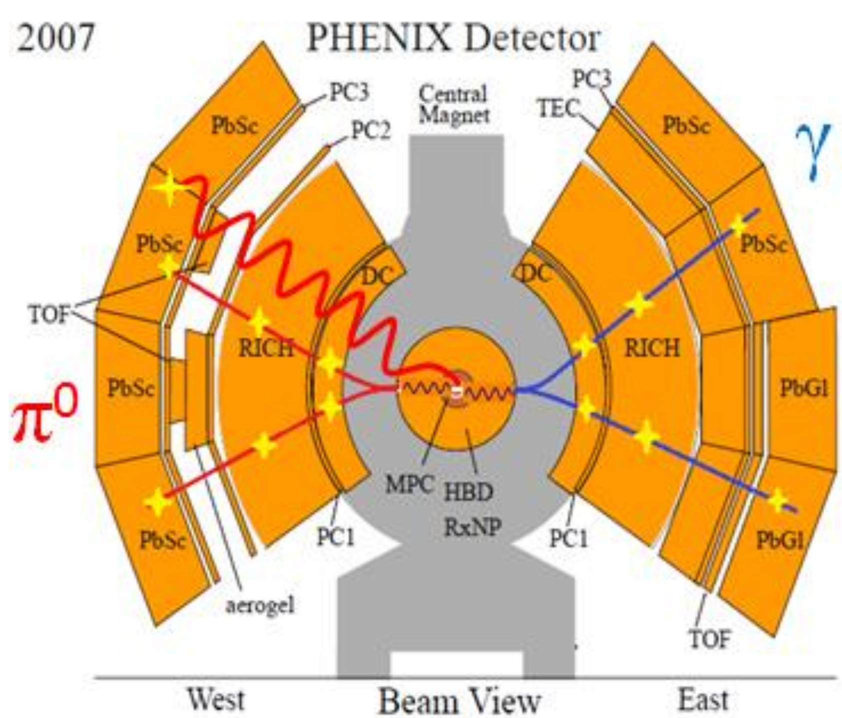
The π^0 Tagged Photon Signal

- Subtract the normalized mixed event background

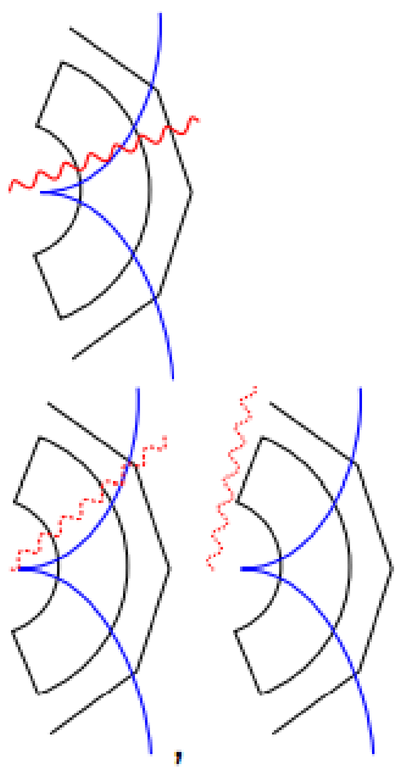
$$R_\gamma = \frac{\langle \varepsilon_\gamma f \rangle \cdot \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadr}}{\gamma^{\pi^0}} \right)_{Sim}}$$





Simulations for Corrections for Pion Tagging Efficiency

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



- calculate from a full GEANT Monte Carlo simulation of π^0 decays
  - $\pi^0 \rightarrow \gamma + e^+e^-$, where one photon, γ converts at a radius of 60cm
- embed simulated events into real data to account for occupancy in the Emcal
- tune the resolution and energy scale of photons in the Emcal to match reconstructed pions in data and simulation
- produce charged track and Emcal dead maps to match in data and simulation

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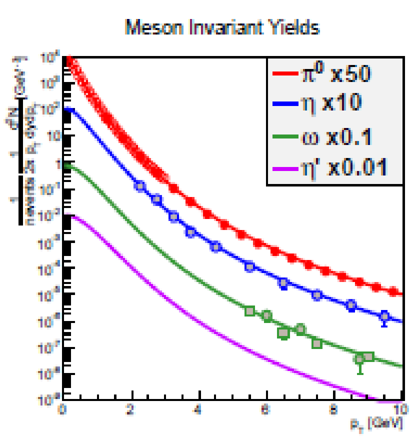
Estimation of non-π^0 Hadronic Sources

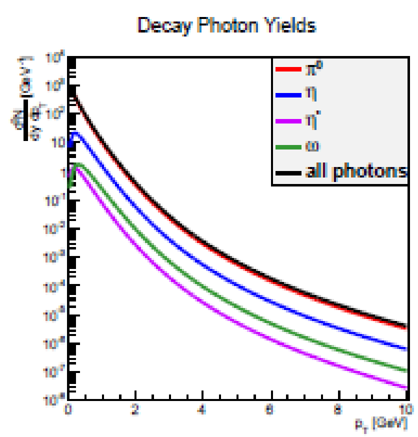
- Calculate the yield of hadron decay photons from our PHENIX decay photon generator (exodus)
- Included species and decays:

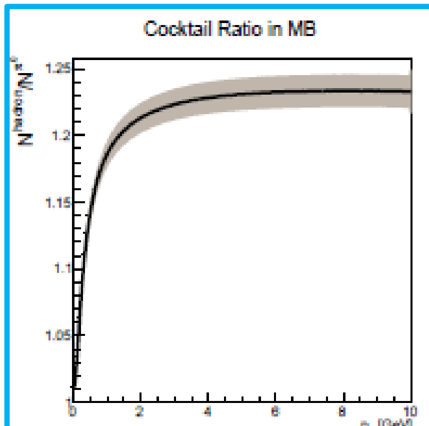
- $\pi^0 \to \gamma + \gamma$ (BR = 0.98)
- $\eta \to \gamma + \gamma$ (BR = 0.39)
- $\eta \to \pi^+ + \pi^- + \gamma$ (BR = 0.046)
- $\eta' \to \gamma + \gamma$ (BR = 0.0218)
- $\eta' \to \pi^+ + \pi^- + \gamma$ (BR = 0.293)
- $\eta' \to \omega + \gamma$ (BR = 0.0275)
- $\omega \to \pi^0 + \gamma$ (BR = 0.0828)

- pion spectral shape parameterized with a modified Hagedorn
- meson/pion ratios taken from measurements

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



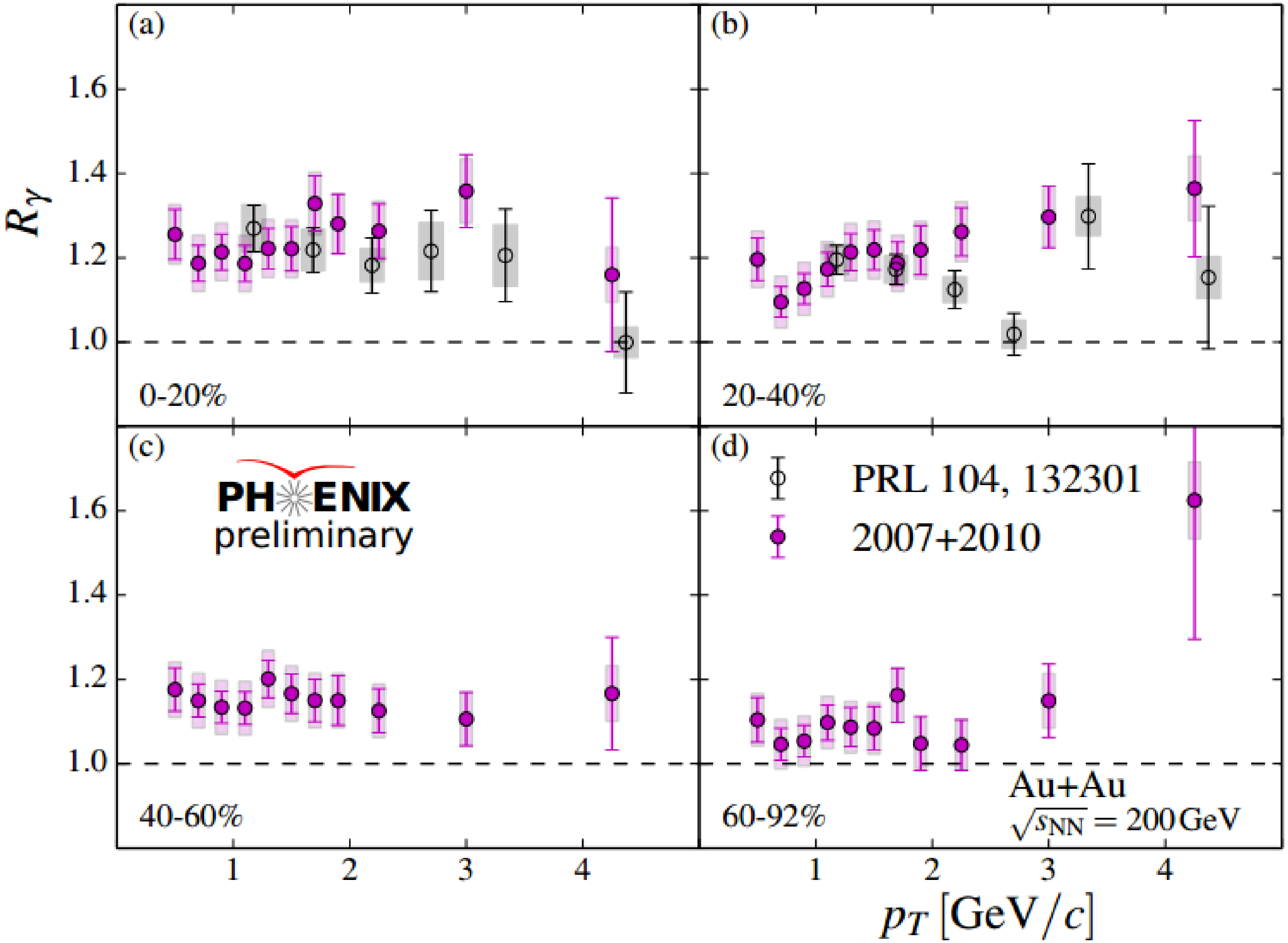




Results: R_γ

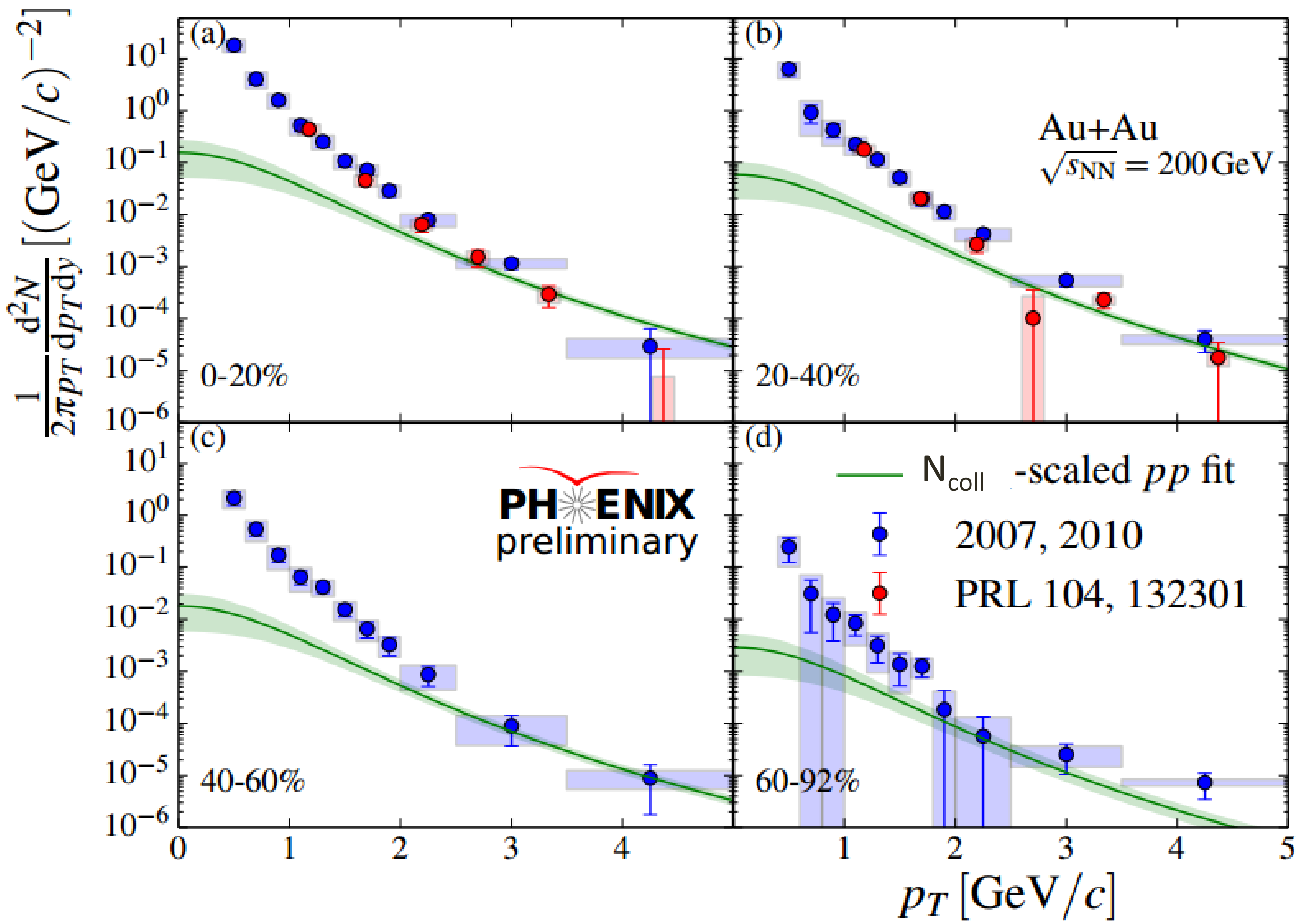
$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadr}} \frac{\langle \varepsilon_\gamma f \rangle \cdot \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadr}}{\gamma^{\pi^0}} \right)_{Sim}}$$

- We show the 2007 and 2010 analysis results combined



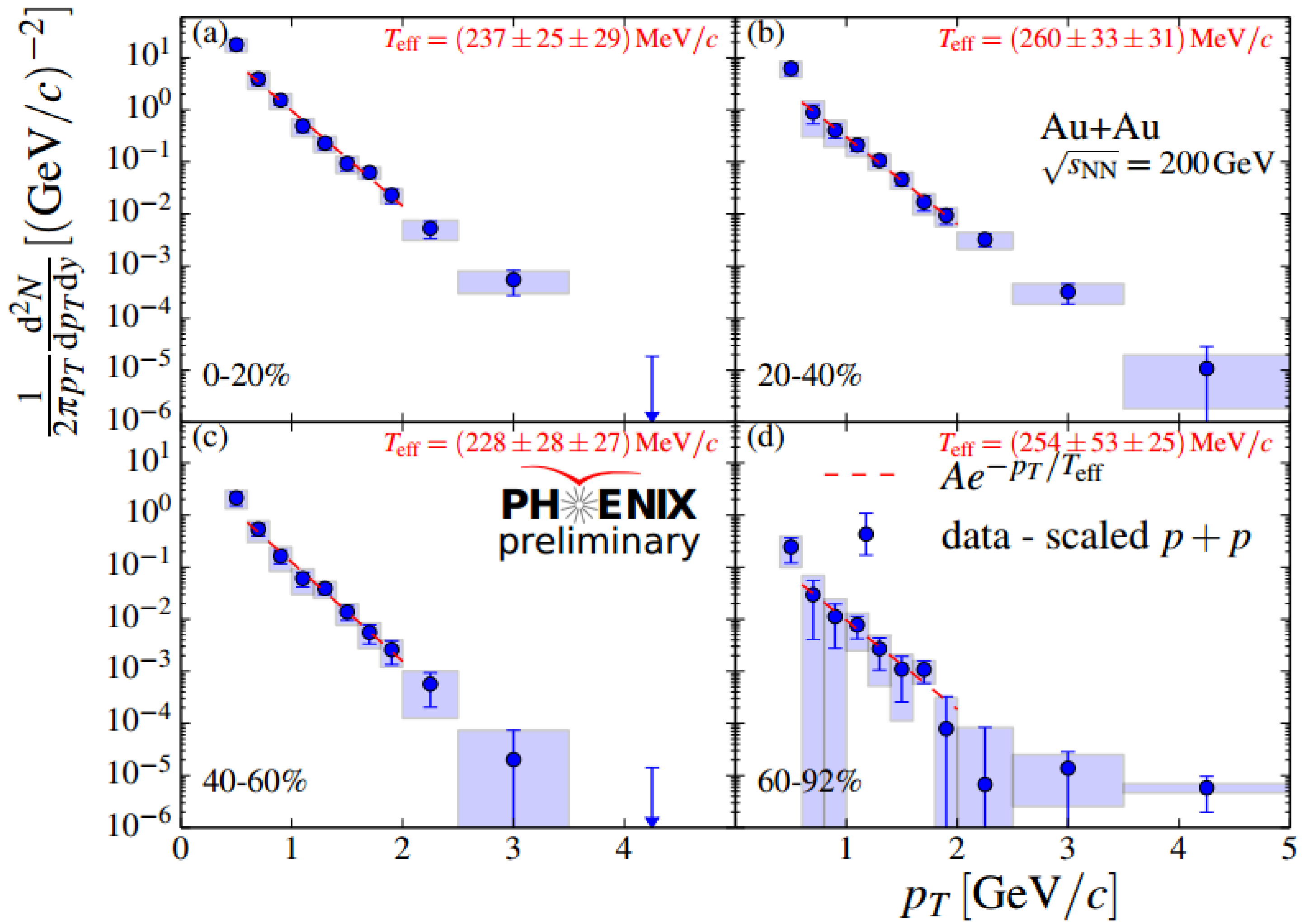
More Results: Invariant Yield of Direct Photons

- 2007 and 2010 dataset results are combined for one result
- prompt contribution estimated from N_{coll} scaled p+p yield
- yield calculated as $\gamma^{direct} = (R_\gamma - 1)\gamma^{hadron}$



More Results: Isolate the non-prompt direct photon contribution

- 2007 and 2010 dataset results are combined for one result
- subtract the N_{coll} scaled p+p yield to isolate the "thermal" yield



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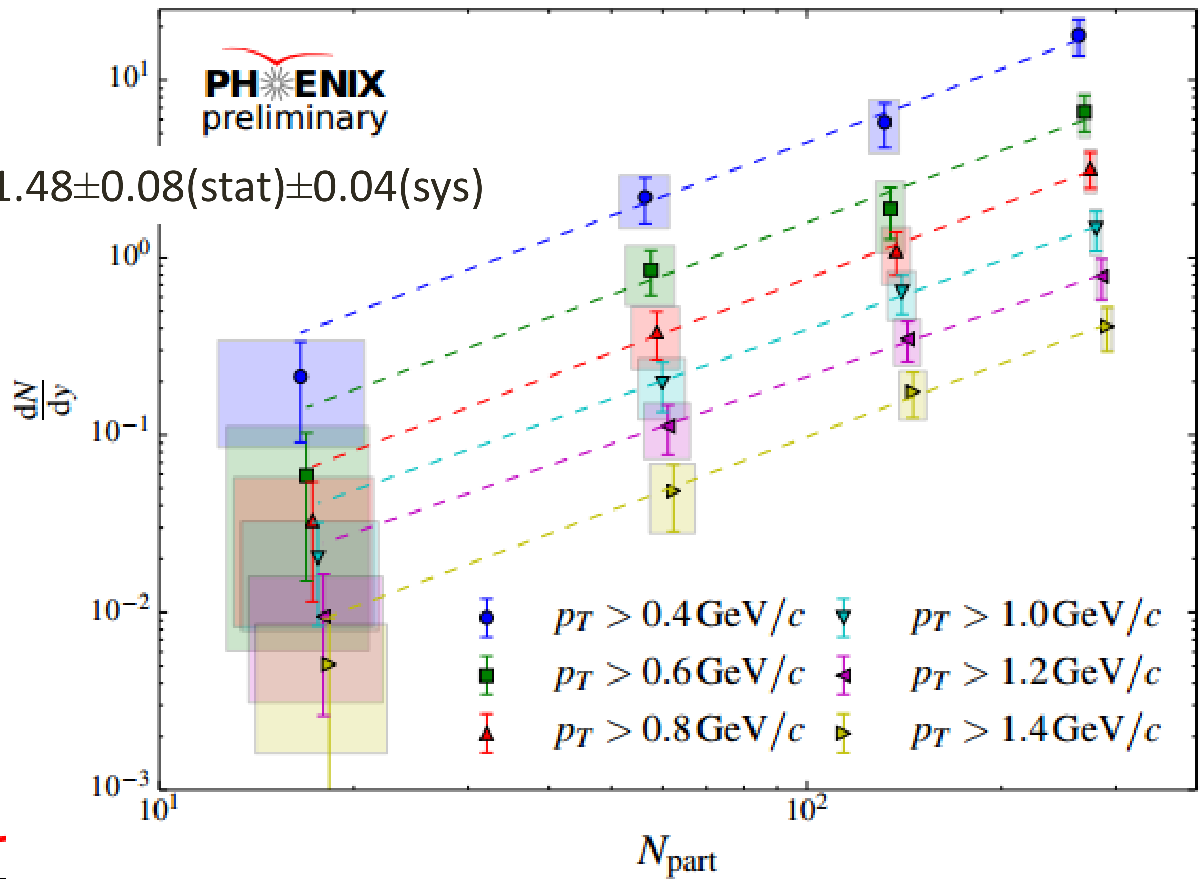
Detailed Centrality Dependence

- Integrate yield with different low p_T cutoffs
- same shape for each integration region
- roughly follows power law as a function of N_{part}

α = 1.48±0.08(stat)±0.04(sys)



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Summary

- Novel technique applied to measure (real) direct photons in the range $0.4 < p_T < 5$ GeV/c
  - extremely clean photon id via external conversions in HBD
  - double ratio method for R_γ allows for explicit cancelation of systematic uncertainties
- Real and virtual photons analyses display similar R_γ
- An excess of photon yield above scaled p+p yield is seen in all centralities
- Shape of photon spectra is independent of centrality within uncertainties
- Excess photon yield grows stronger than N_{part}
  - described by a power law with power = 1.48±0.08(stat)±0.04(sys)
- New measurement offers constraints on model calculations of exotic production mechanisms

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Backups

Results: R_γ

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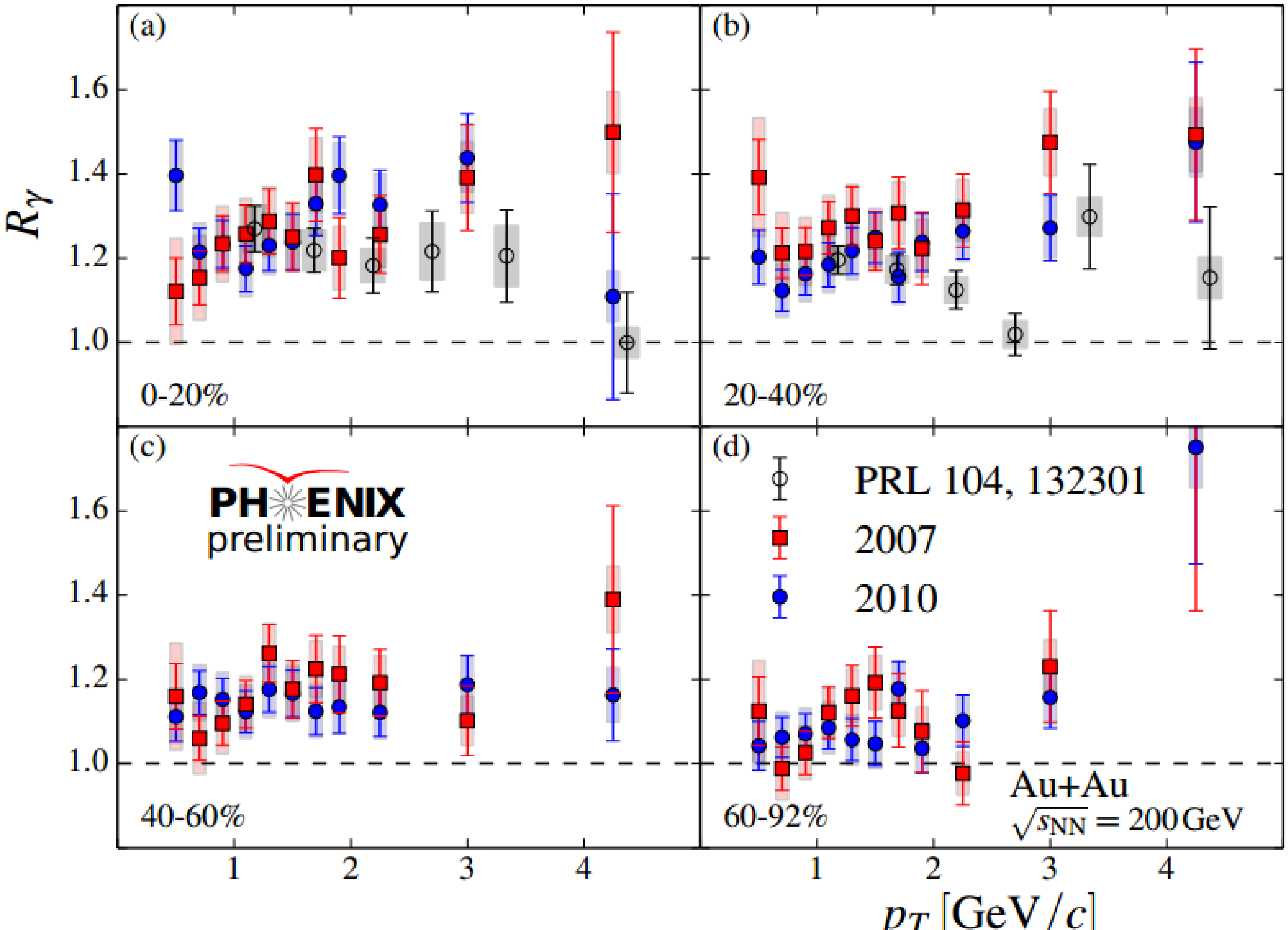

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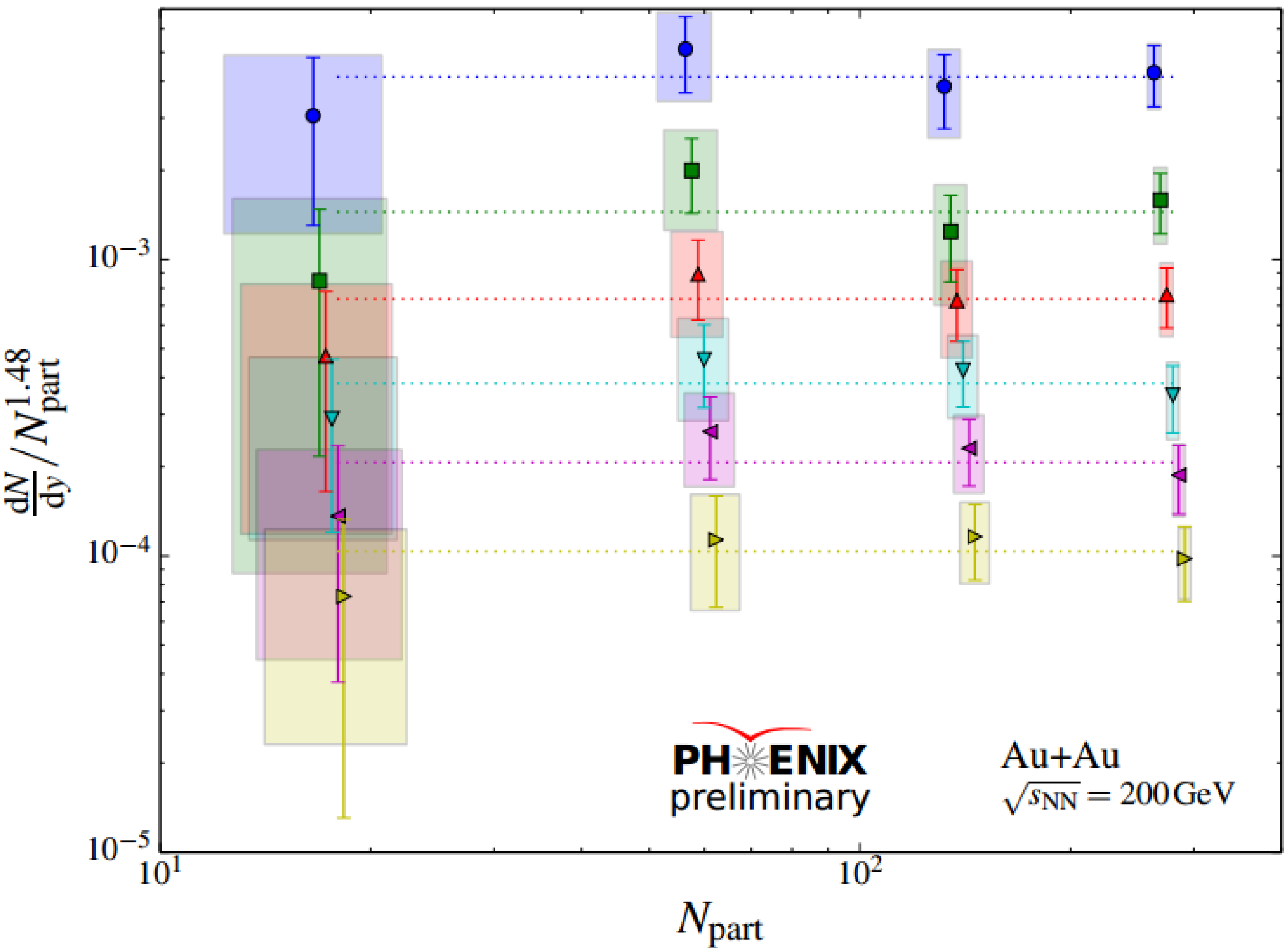
Check the power law scaling on the integrated yields



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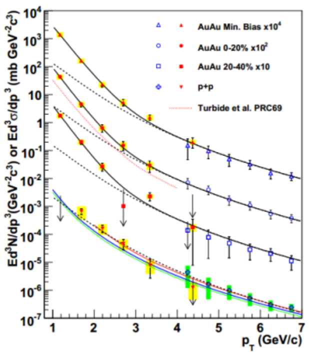

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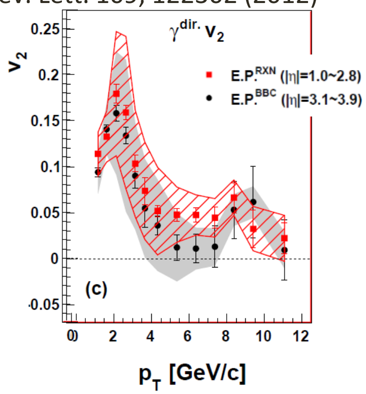

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Direct Photons as a Thermometer

- if thermal in origin, photons follow an exponential, $e^{-\beta p_T}$, where β is inversely related to the temperature
- old calculations from hydrodynamics based calculations indicate $300 < T_{initial} < 600 MeV$ and $0.6 < \tau_0 < 0.15 fm/c$

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BUT WAIT!
ITS NOT SO EASY

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