Wuhan HP2016

Direct Photon Production and Azimuthal Anisotropy at Low Transverse Momentum Measured in PHENIX

Wenqing Fan for PHENIX Collaboration

Hard Probes 2016

PHENIX

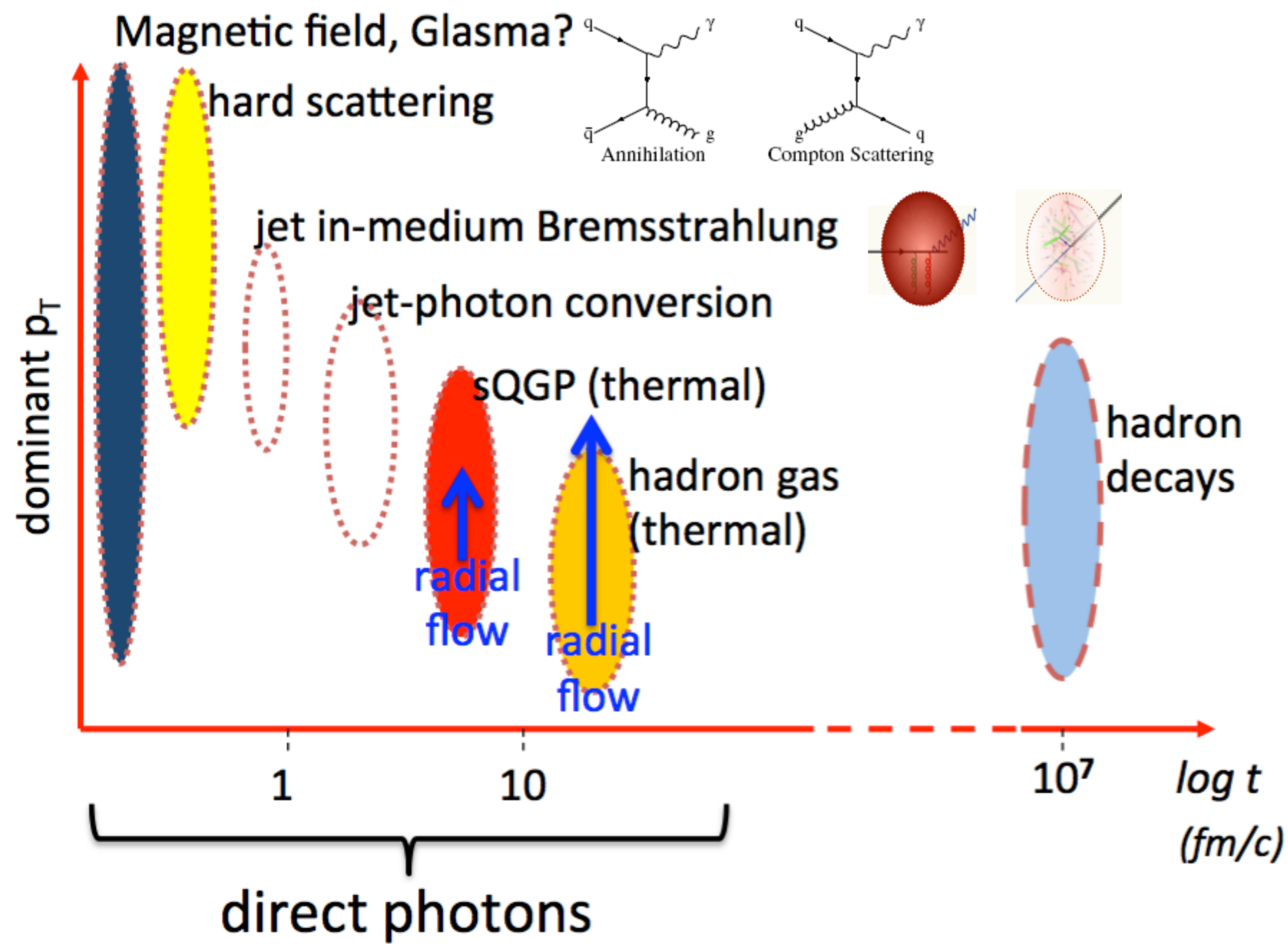
Stony Brook University

Outline

- Direct photons and motivation
- Measurement of photons in PHENIX
- Result: direct photon v_2 and v_3
- New Conversion Photon Reconstruction Technique
- Summary and outlook

Photon Production in Heavy Ion Collision

- Direct photon
  - color blind probes (leave the medium without further interaction)
  - info of the entire evolution of the colliding system (integrated over space and time)



- More differential measurement would disentangle the photon production sources

Measurement at PHENIX — 3 Methods

- calorimetric measurement
  - γ
  - good resolution at high pT
  - low pT is contaminated by hadrons

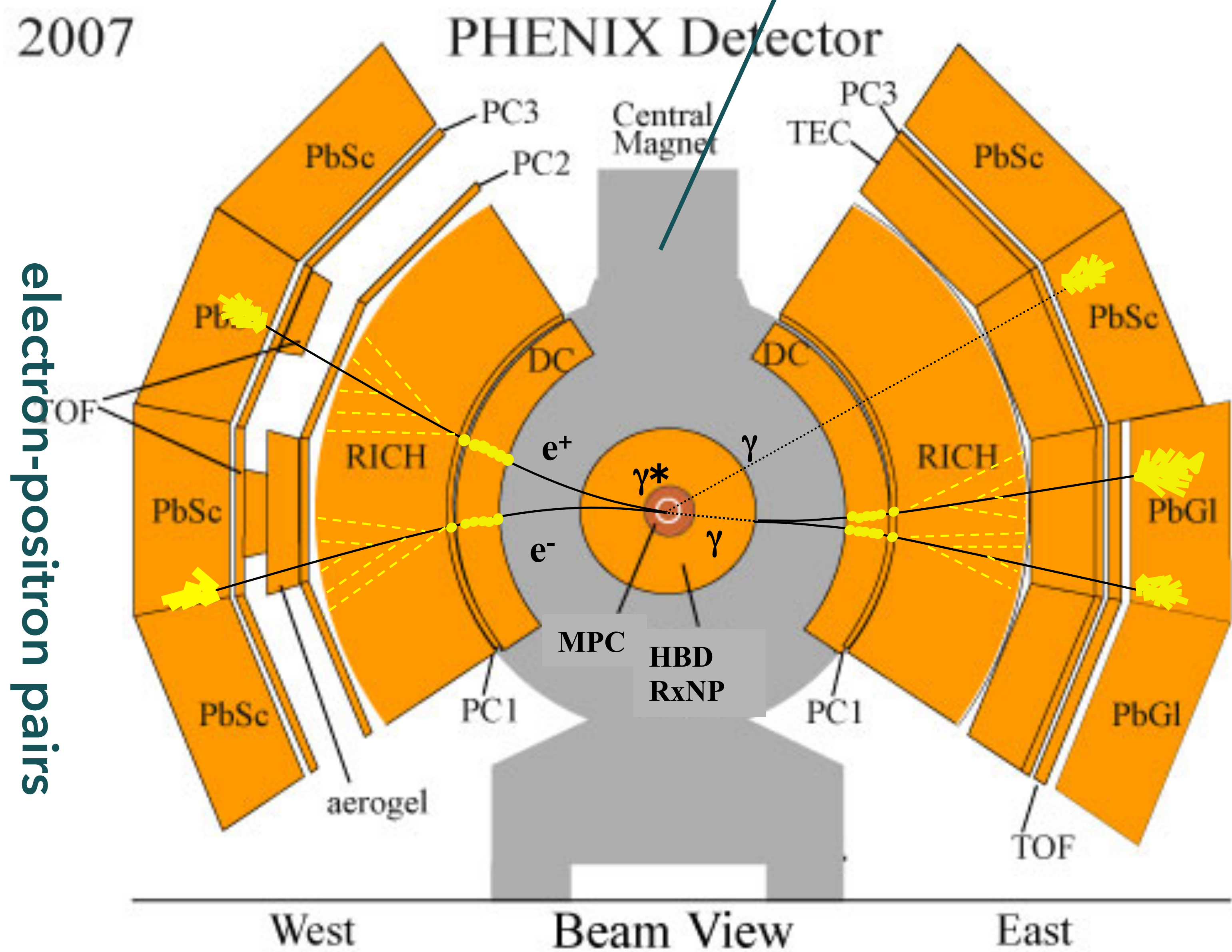
photons

- internal conversions
  - $\gamma^* \rightarrow e^+ + e^-$
  - bkg from hadron decay photon reduced by a factor of 5 (small bkg)
  - 1/1000 signal reduction

- external conversions
  - $\gamma \rightarrow e^+ + e^-$
  - more statistics compared to internal conversion
  - good resolution at low pT

electron-positron pairs

magnetic field (almost along z)



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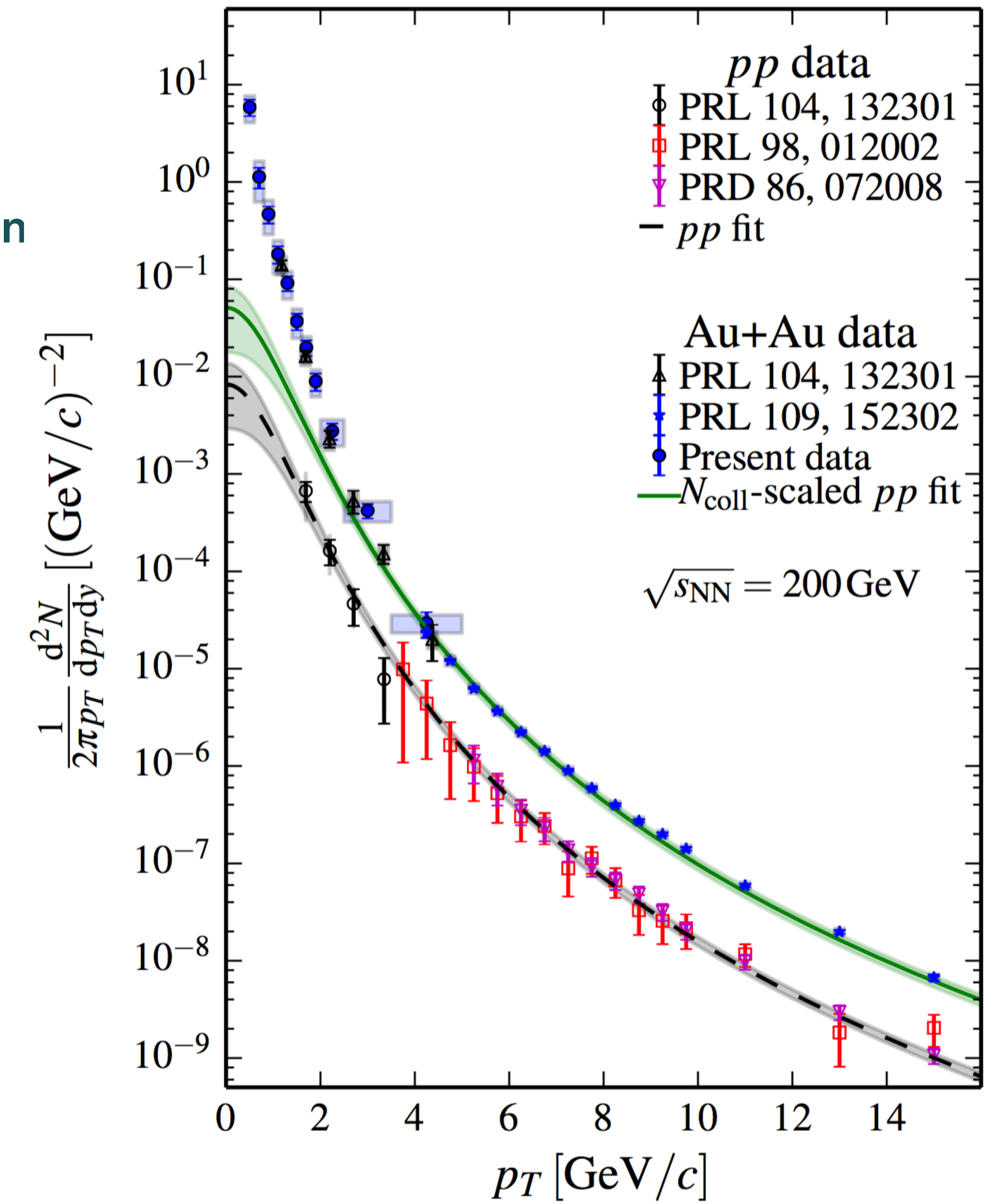

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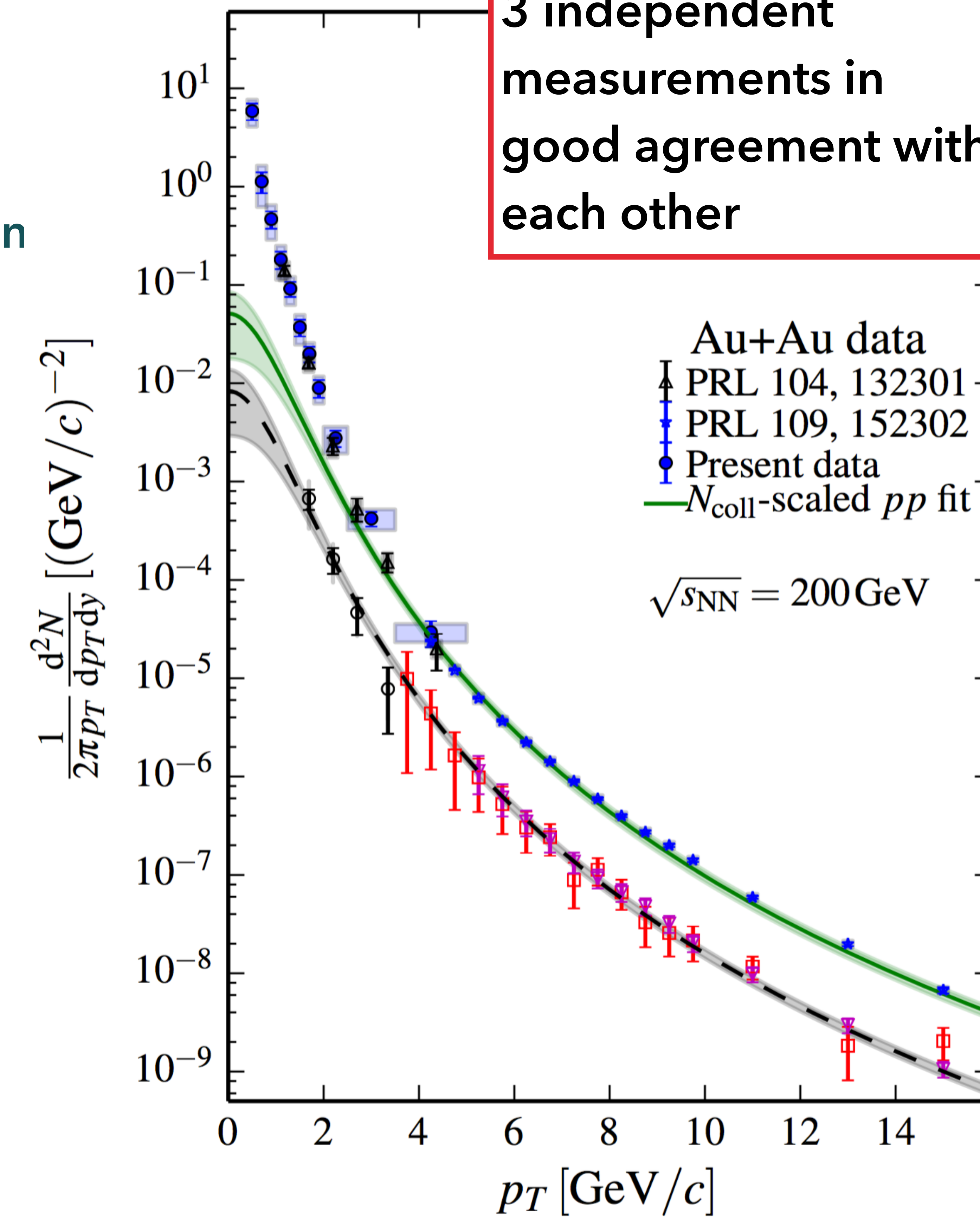
3 independent measurements in good agreement with each other



Direct Photon v_n Measurement in Au+Au

- Event plane method $dN/d\phi = 1 + \sum 2v_n \cos(n(\phi - \Psi_n))$

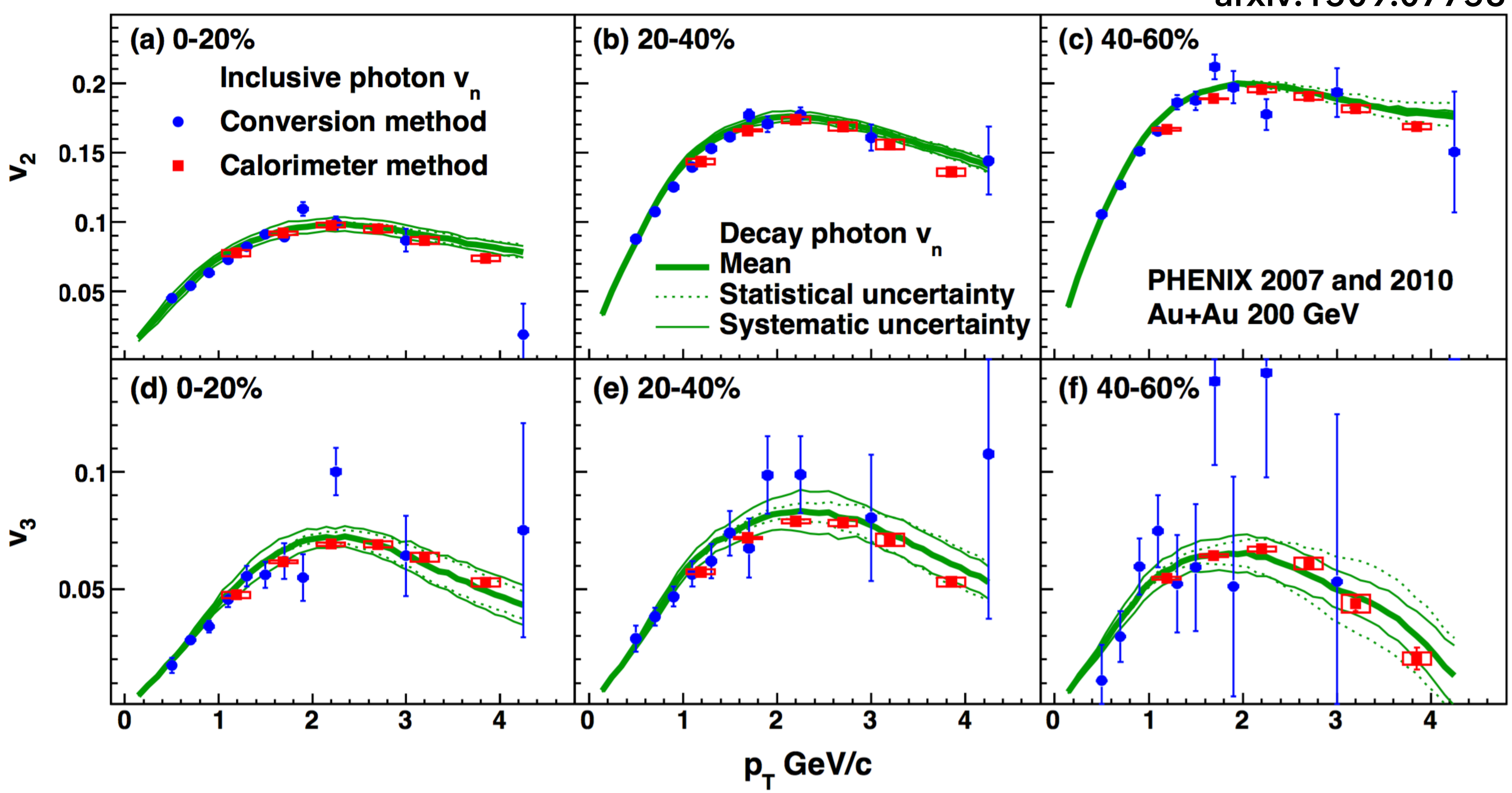
  Measure azimuthal distributions of photons with respect to event plane

- To determine direct photon v_2, v_3 $v_n^{dir} = \frac{R_\gamma v_n^{inc} - v_n^{dec}}{R_\gamma - 1}$

- Inclusive photon v_2, v_3

  external conversions / calorimetric method

arxiv:1509.07758



Decay Photon v_n

- Estimate decay photon v_n
  - Use measured yield and anisotropy of charged and neutral pions
  - v_n for heavier mesons estimated by KE_T

$$v_n^{meson}(KE_T) = v_n^{\pi}(KE_T) \quad \text{with} \quad KE_T = m_T - m = \sqrt{p_T^2 + m^2} - m$$

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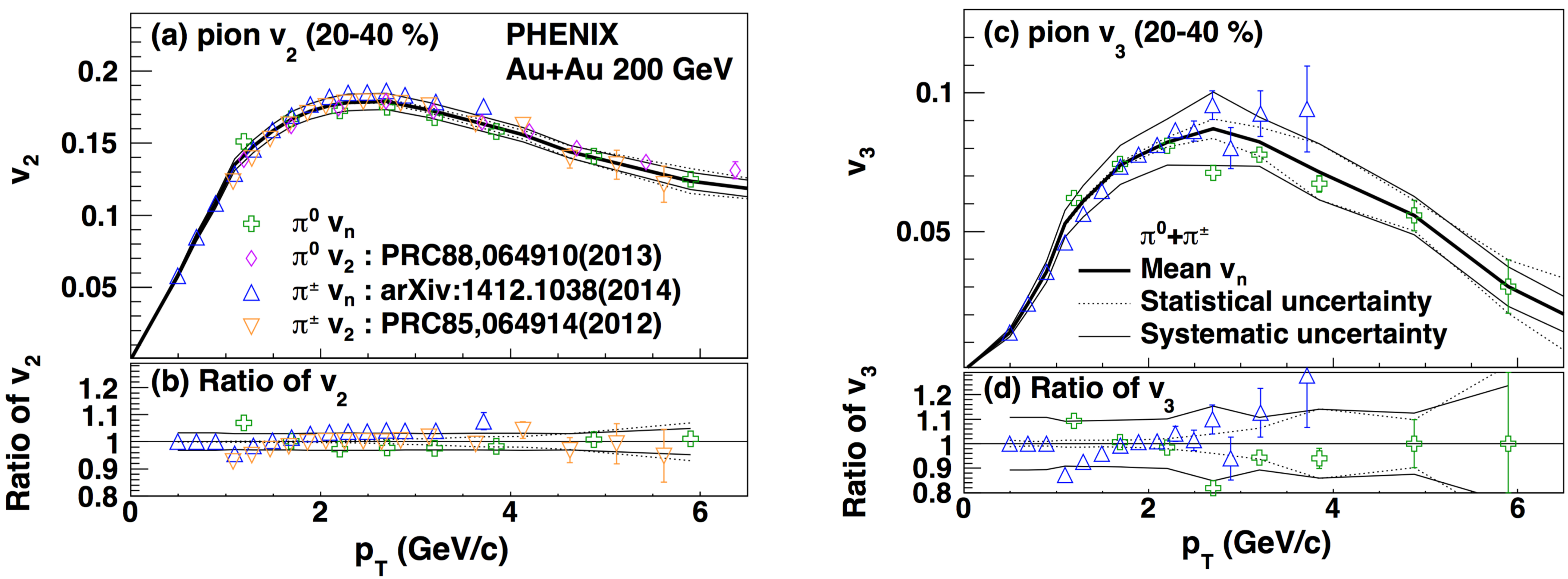


- Use the meson yields and v_n in MC, process them through all decay chains including photons ⟶ calculate the decay photon v_n

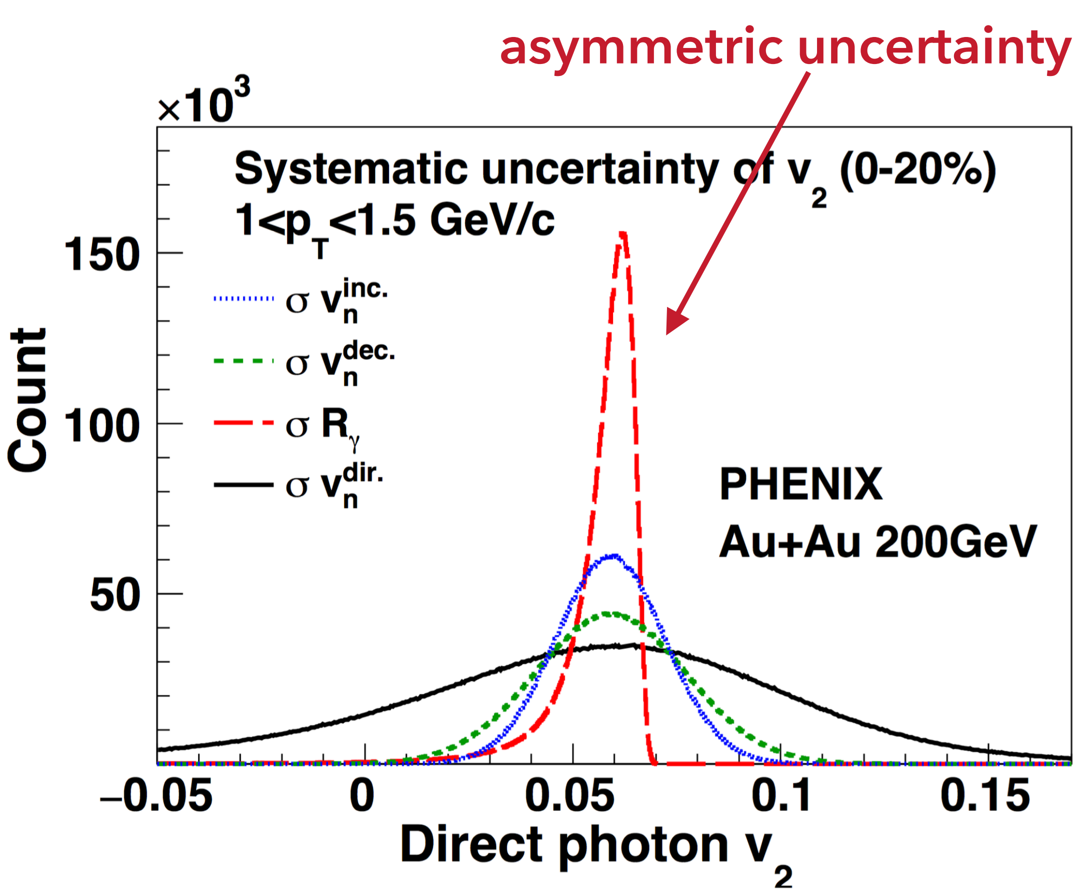
Systematic Uncertainty on v_n

- Using Gaussian error propagation

$$v_n^{dir} = \frac{R_\gamma v_n^{inc} - v_n^{dec}}{R_\gamma - 1}$$

$$\sigma^2_{v_n^{dir}} = \left(\frac{R_\gamma}{R_\gamma - 1}\right)^2 \times \sigma^2_{v_n^{inc}} + \left(\frac{1}{R_\gamma - 1}\right)^2 \times \sigma^2_{v_n^{dec}} + \left(\frac{v_n^{dec} - v_n^{inc}}{R_\gamma - 1}\right)^2 \times \sigma^2_{R_\gamma} + \sigma^2_{EP}$$

- Non-linear dependence of uncertainty on R_γ
  - Modeling the probability distribution of possible values of v^{dir}
  - Assuming the individual statistical and systematic uncertainties follow Gaussian probability distributions



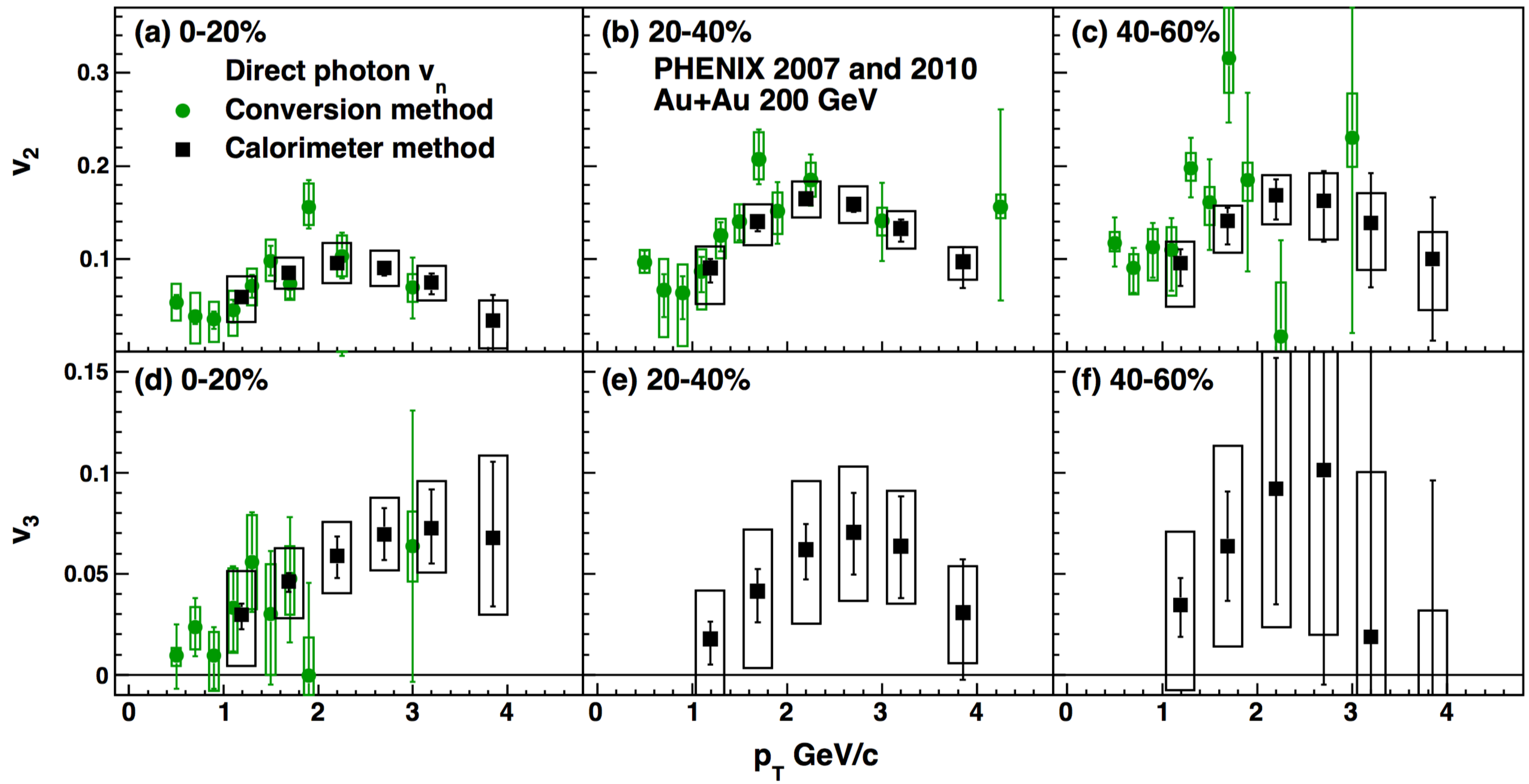
Systematic Uncertainties for v_2

Sources	0~20%
R_γ	5.5%
v_2^{inc}	4%
v_2^{dec}	5%
Event plane	3%

Direct Photon v_n

- To determine direct photon v_2, v_3

$$v_n^{dir} = \frac{R_\gamma v_n^{inc} - v_n^{dec}}{R_\gamma - 1}$$



arxiv:1509.07758

- Large v_2 observed (comparable to hadron v_2 in low pT region)
- Strong centrality dependence
- Showing trend to 0 toward high pT
- Unclear $v_2 \rightarrow 0$ for pT $\rightarrow 0$

- Sizable v_3 observed ($\sim v_2/2$)
- Independent of centrality

Comparison with Theoretical Models

- Thermal photons (HG+QGP), pQCD with fireball scenario

- H.van Hees, C. Gale, R. Rapp PRC 84 054906 (2011)
- Include finite initial flow at thermalization
- Include resonance decays and hadron-hadron scattering
- Blue shift of HG spectrum included

- Microscopic transport (PHSD)

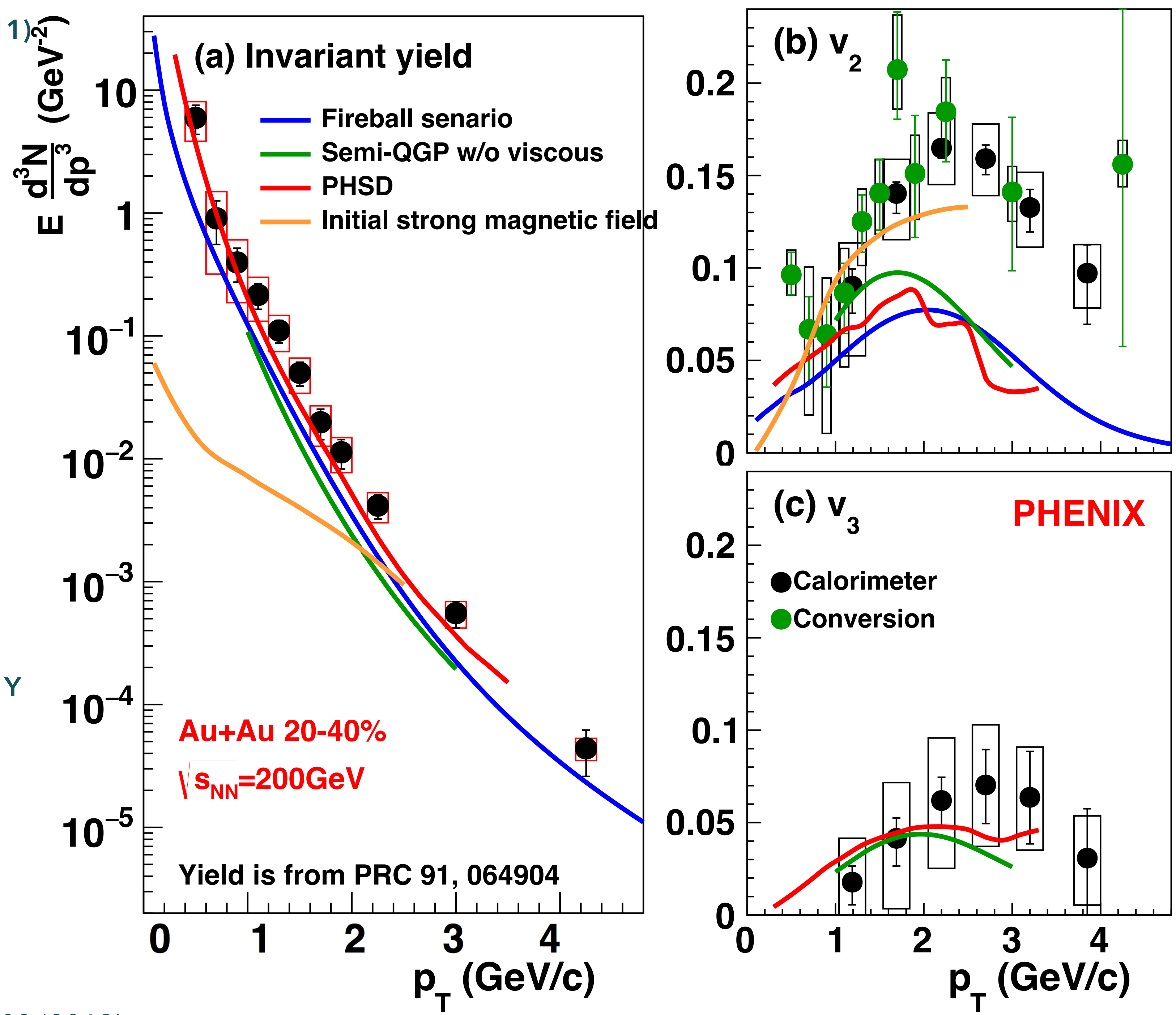
- O. Linnyk, W. Cassing, E.L. Bratkovskaya, PRC 89, 034908 (2014)
- Parton-Hadron-String dynamics
- Include large contribution from hadron-hadron interaction in HG using Boltzmann transport
- Include thermal photons from QGP

- Enhanced non-equilibrium effects (glasma, etc.)

- C. Gale et al., PRL114, 072301 + priv.comm. with Y Hidaka and J-F. Paquet
- Semi-QGP is the QGP near T_c
- Annihilation and Compton processes around hadronization time are naturally included

- Enhanced early emission from magnetic field

- G. Basar, D. E. Kharzeev, V. Skokov, PRL 109 202303 (2012)
- Initial strong magnetic field produces anisotropy of photon emission
- magnetic field + thermal photons (lattice QCD)

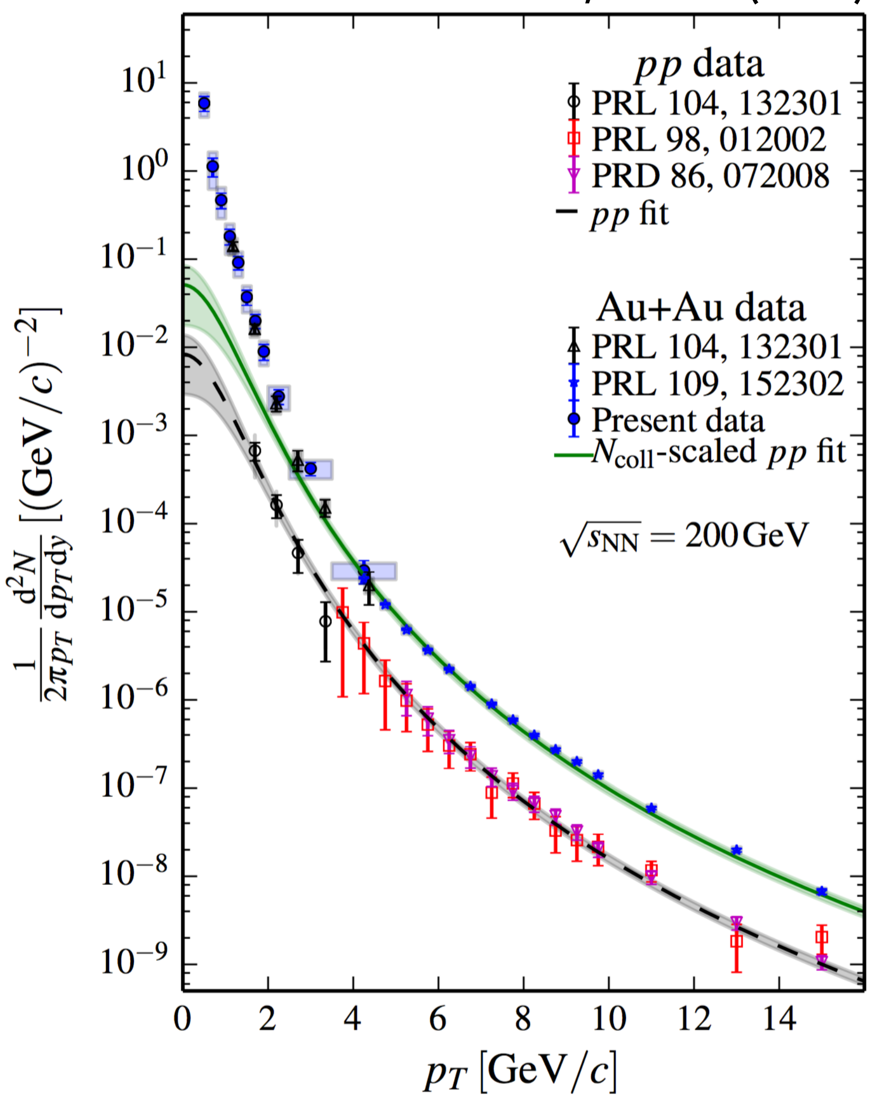


Direct Photon Puzzle

- **Large yield & large v_2**
  - Large yield: emission from the early stage when temperature is high
  - Large v_2: emission from the late stage when the collective flow is sufficiently built up

Challenge for theoretical model to describe large yield and v_2 simultaneously!

PRC 91, 064904 (2015)



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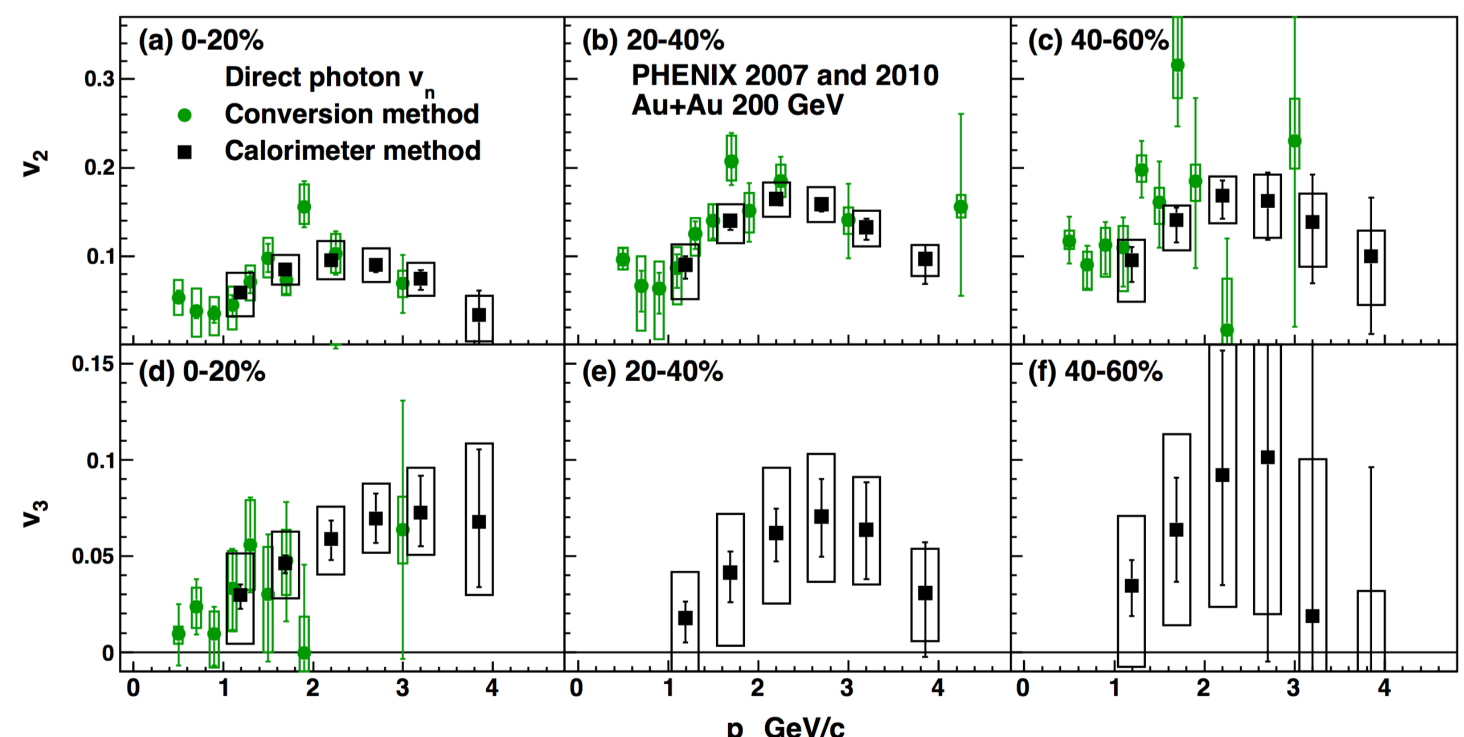
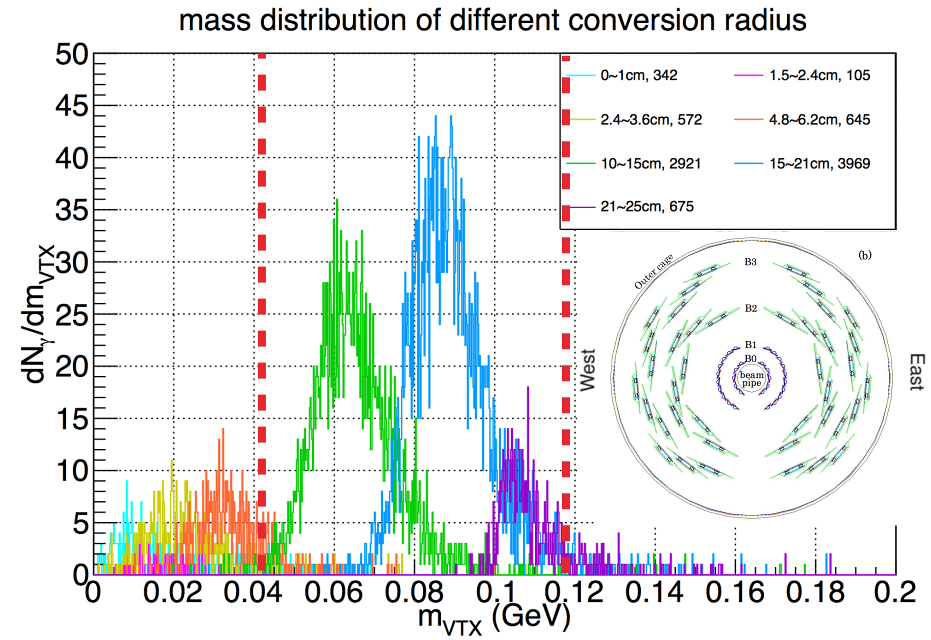


New Conversion Photon Reconstruction Technique

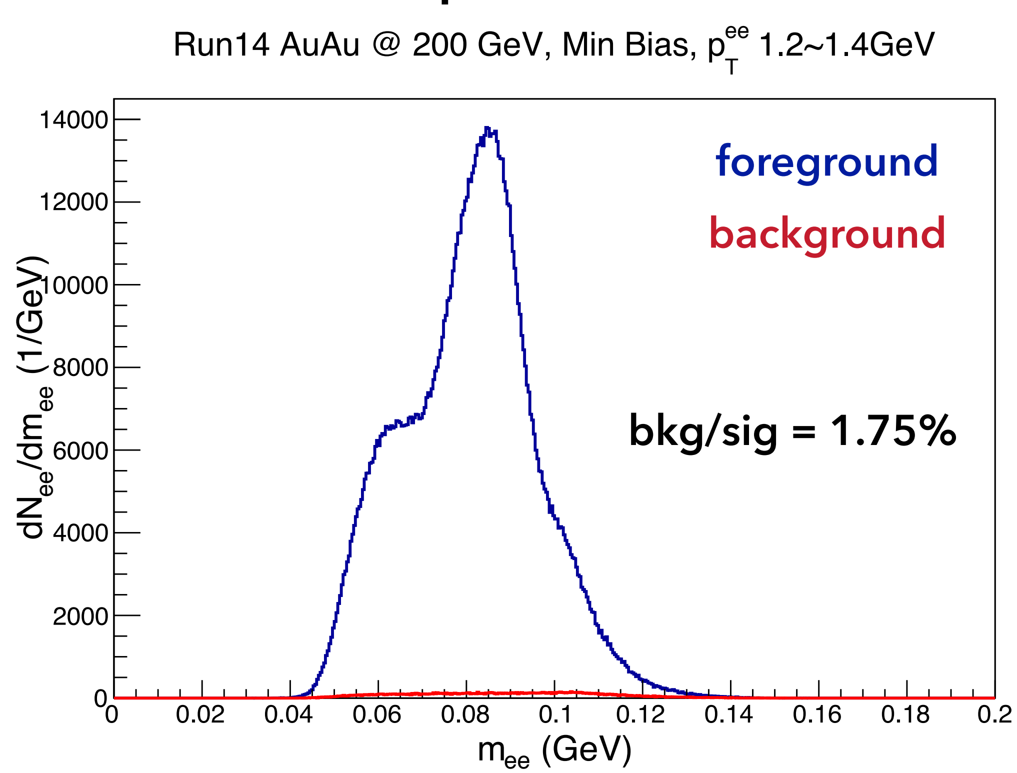
Identify and reconstruct photons via external conversion to e^+e^- pairs

- Previous method used single e^+/e^- tracks (2010)
  - Conversions at fixed radius (Hadron Blind Detector readout plane at 60cm, ~3%)
- New method used e^+e^- pairs (>2011)
  - Conversions at any material (VTX 3rd and 4th layer, ~10%)

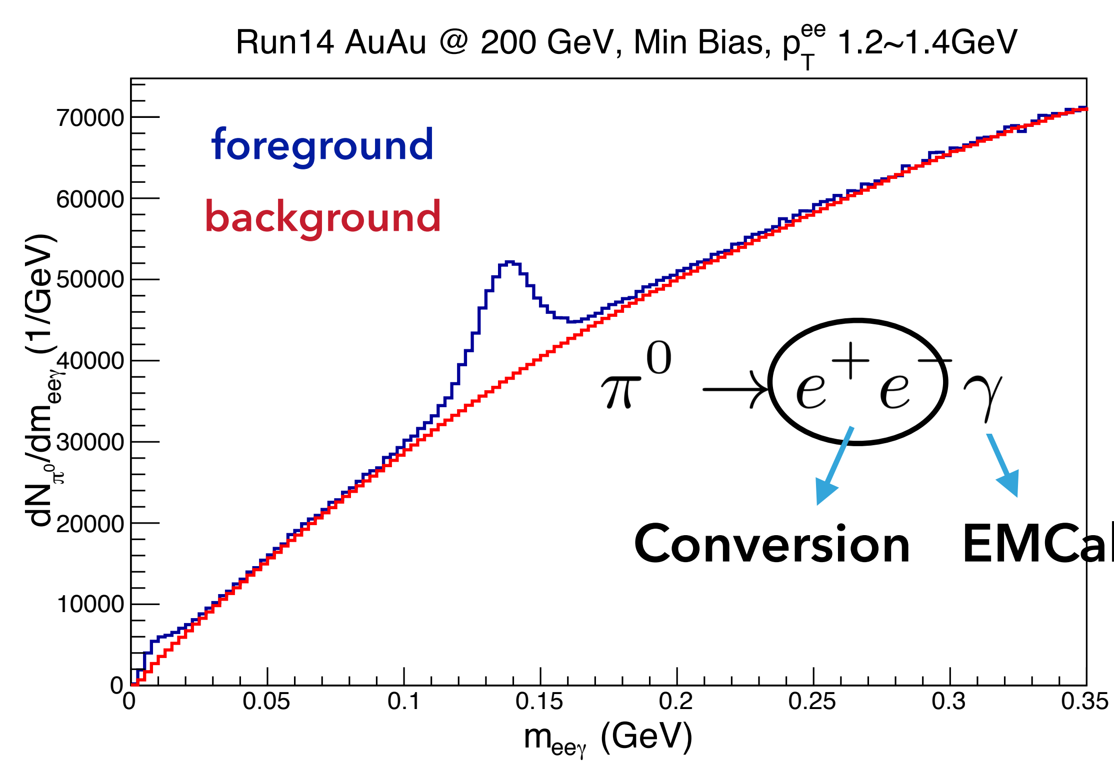


MC simulation

inclusive photon (e^+e^-) mass

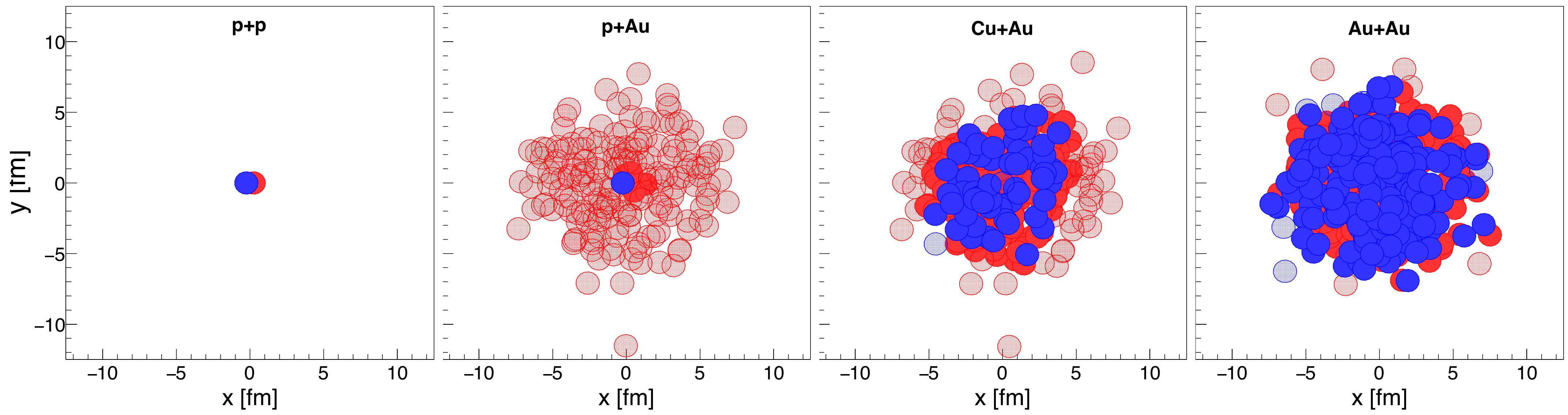


π^0 ($e^+e^-\gamma$) mass



- Other systems: AuAu, CuAu, He3Au, pp, pA, dAu

Future Measurements



- Run10 AuAu at 39GeV and 62GeV will provide more insight in direct photon production (with the previous published method)
- Larger statistics from Run14 AuAu will provide accurate measurement of v_n (v_2, v_3, v_4) at low p_T
- v_n measurement in most central CuAu will provide useful input in understanding of chiral magnetic field effect, if any
- pA, He3Au, dAu results will help to understand properties of the medium created in small systems
- New pp results will extend the measurement to lower p_T

Summary & Outlook

- Conclusions

  - PHENIX has detailed measurements of the direct photon v_2, v_3 in $\sqrt{s}$ = 200GeV Au+Au collisions

  - A sizable v_2 and v_3 are observed for direct photons, provide constrains to theoretical model

  - Theoretical picture still incomplete to describe large yield and v_2 simultaneously

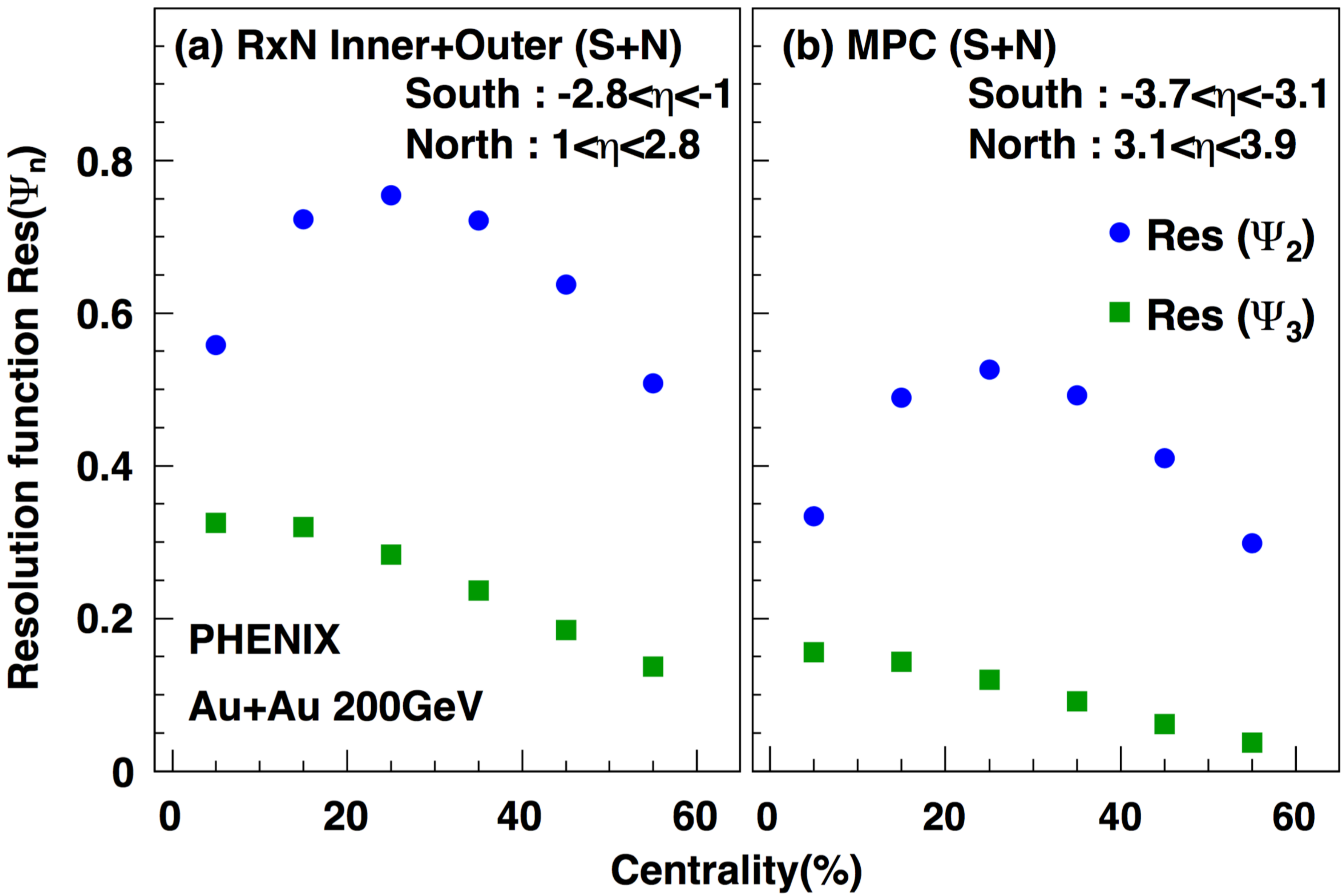
  - More future measurements from PHENIX are coming

THANKS!

BACKUPS

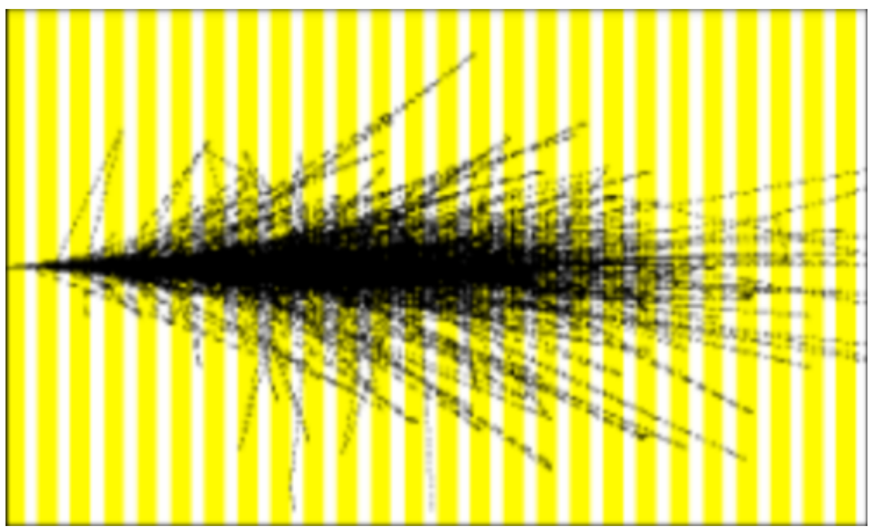
Reaction Plane Resolution

- $Res(\Psi_n)$ is measured with 2-subevent method

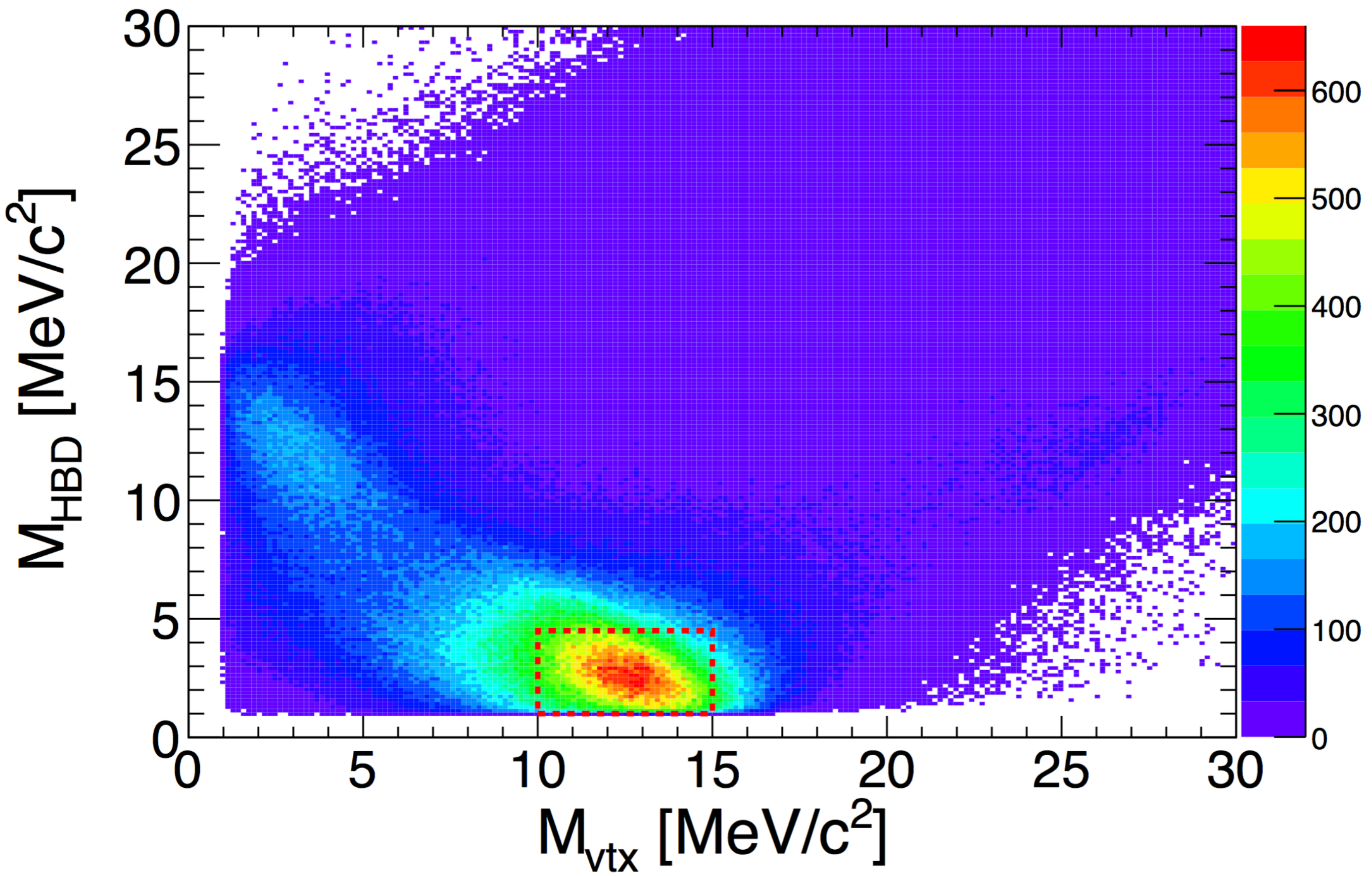


Photon Identification

- **EMCal method: measure photons that deposit energy in the EMCal**
  - Shower shape cut
  - Charged track veto cut

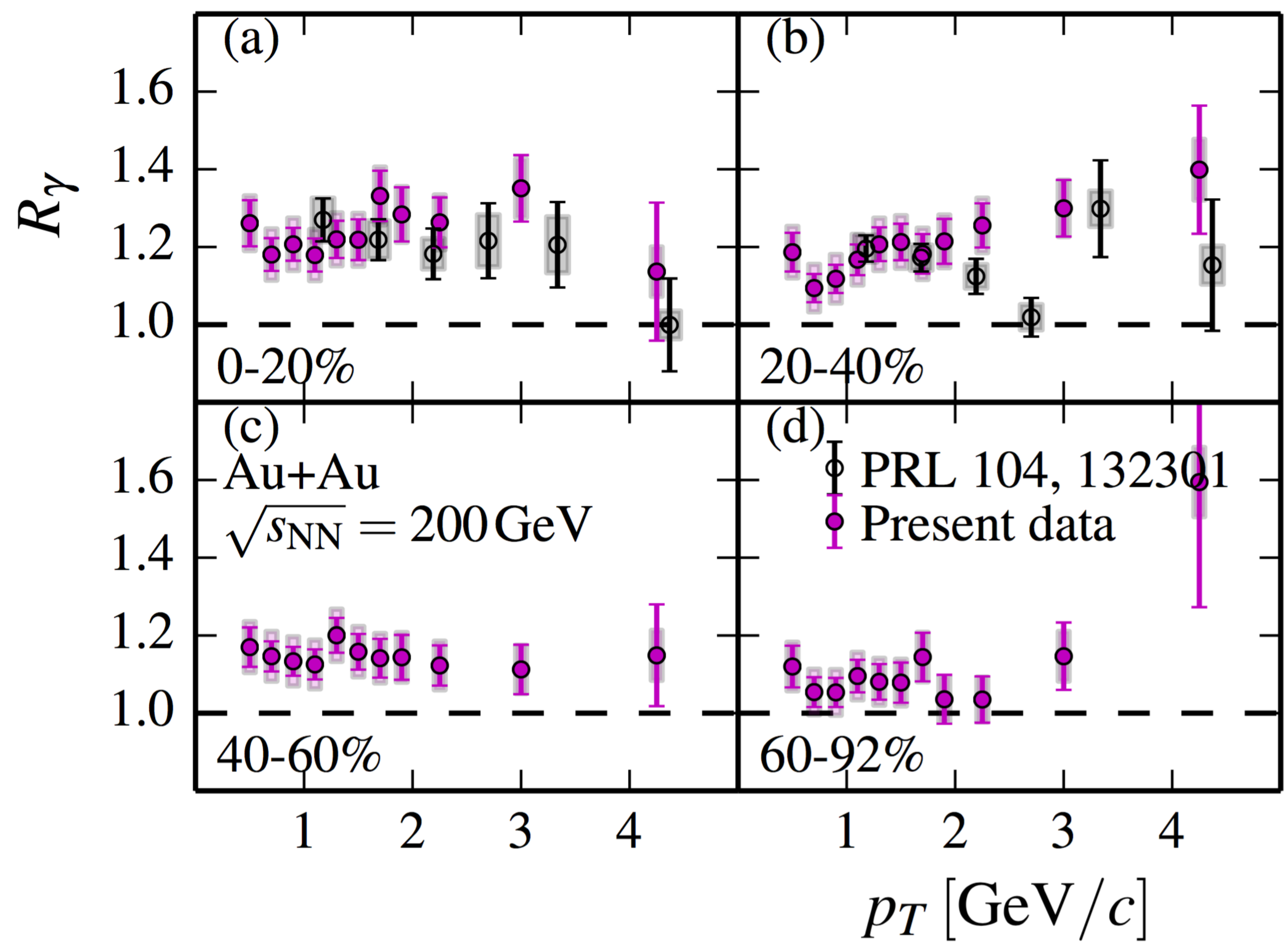


- **External conversion method: measure photons that convert in detector material**
  - Focus on conversions at HBD backplane (~60cm)
  - Identified by the invariant mass of the e+e- pairs
    - Artificial mass due to vertex origin assumption when reconstructing momentum
    - Calculate momentum both assuming vertex origin and true origin



- Ratio of the inclusive photon to decay photon yield
  - Using external conversion method

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



Disentangling different photon sources

- **More differential measurement would disentangle the photon production sources**

Sources	p_T	v_2	v_3	v_n t-dep.
Magnetic field	All p_T	Positive down to p_T=0	Zero	→
Primordial (jets)	High p_T	~zero	~zero	→
QGP (thermal)	Mid p_T	Positive and small	Positive and small	↗
Jet-Brems.	Mid p_T	Positive	?	↘
Jet-photon conversion	Mid p_T	Negative	?	↘
Hadron-gas (thermal)	Low p_T	Positive and sizable	Positive and sizable	→

pp fit

- Fitting function $$\frac{dN}{dy} = a\left(1 + \frac{p_T^2}{b}\right)^c$$

a	b	c
$(8.3\pm7.5)\times10^3$	2.26±0.78	-3.45±0.08

- The actual lowest data point in the fit is 1GeV

- The fit <1GeV is motivated by Drell-Yan measurement