Thermal Photon Yield and Elliptic Flow in 200 GeV Au+Au Collisions from PHENIX

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Stony Brook University
Thermal Radiation Workshop
Brookhaven National Lab
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Talk Overview

- Motivation for study
- Experimental Techniques at PHENIX
- Observation of Direct Photons
  - Direct Photon Elliptic Flow
  - Direct Photon Invariant Yield
- Summary and Future Outlook

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Motivation for Study

- Important global properties of the collision can be characterized by thermal photons
  - temperature
    - thermal photon p_T spectra
  - τ_0
    - thermal photon v_2
- A thermal photon puzzle
  - thermal photons expected to dominate at low p_T
  - direct photon spectra indicate thermal photons are emitted early
  - large direct photon v_2 indicate thermal photon emission is late
  - difficult to reconcile both with the current understanding of the evolution
  - possibly another source of low p_T photons other than thermal?

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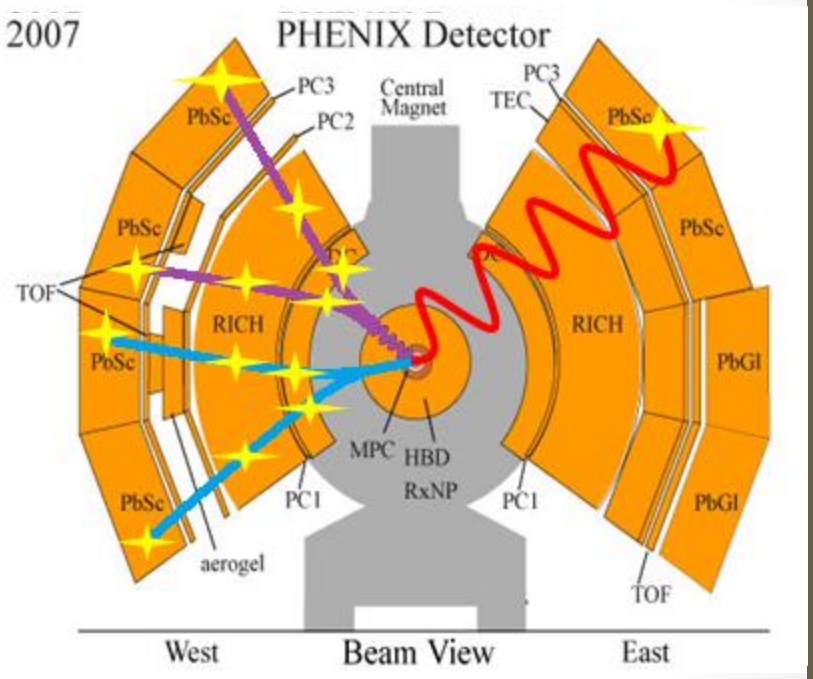
Experimental Techniques at PHENIX

- Large background from hadron decays makes analysis difficult
- 3 techniques at PHENIX
  - photons deposit energy into emcal
    - best at high momentum
  - external photon conversions
    - measure real photons
    - greatly reduce hadron contamination
  - internal photon conversions
    - measure virtual photons
    - reduce background from π^0 Dalitz decays



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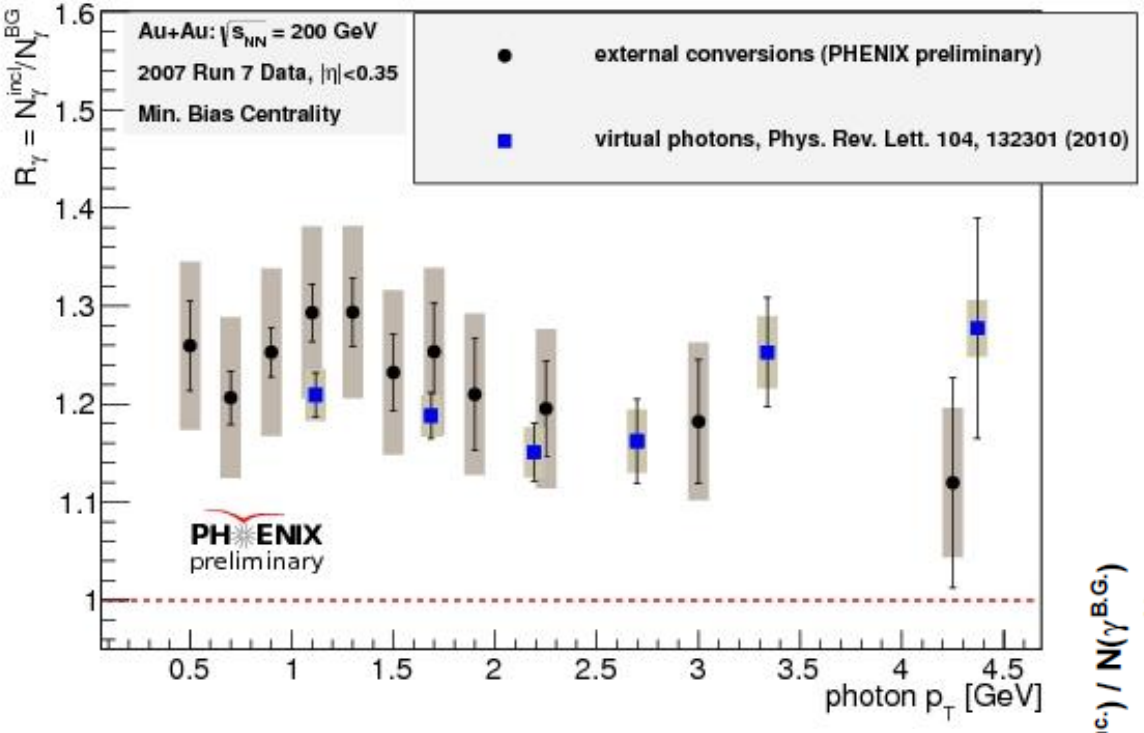
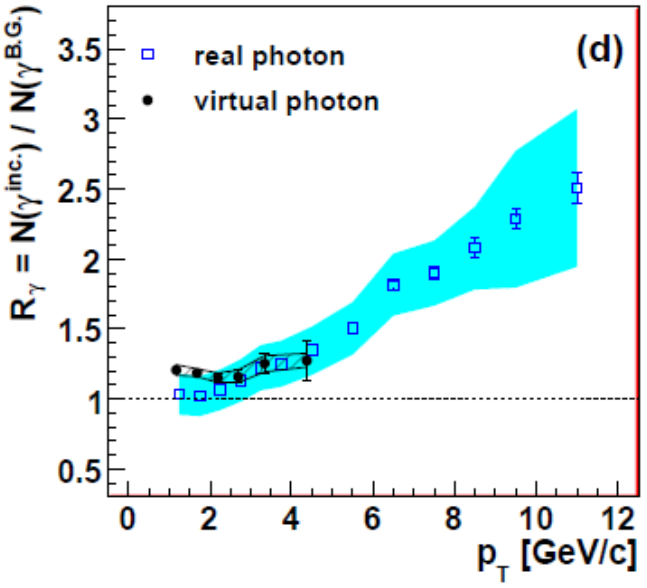
We See Direct Photons in Collisions at RHIC: R_γ Via External and Internal Conversions



$$R_\gamma = N^{incl}/N^{BG}$$

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



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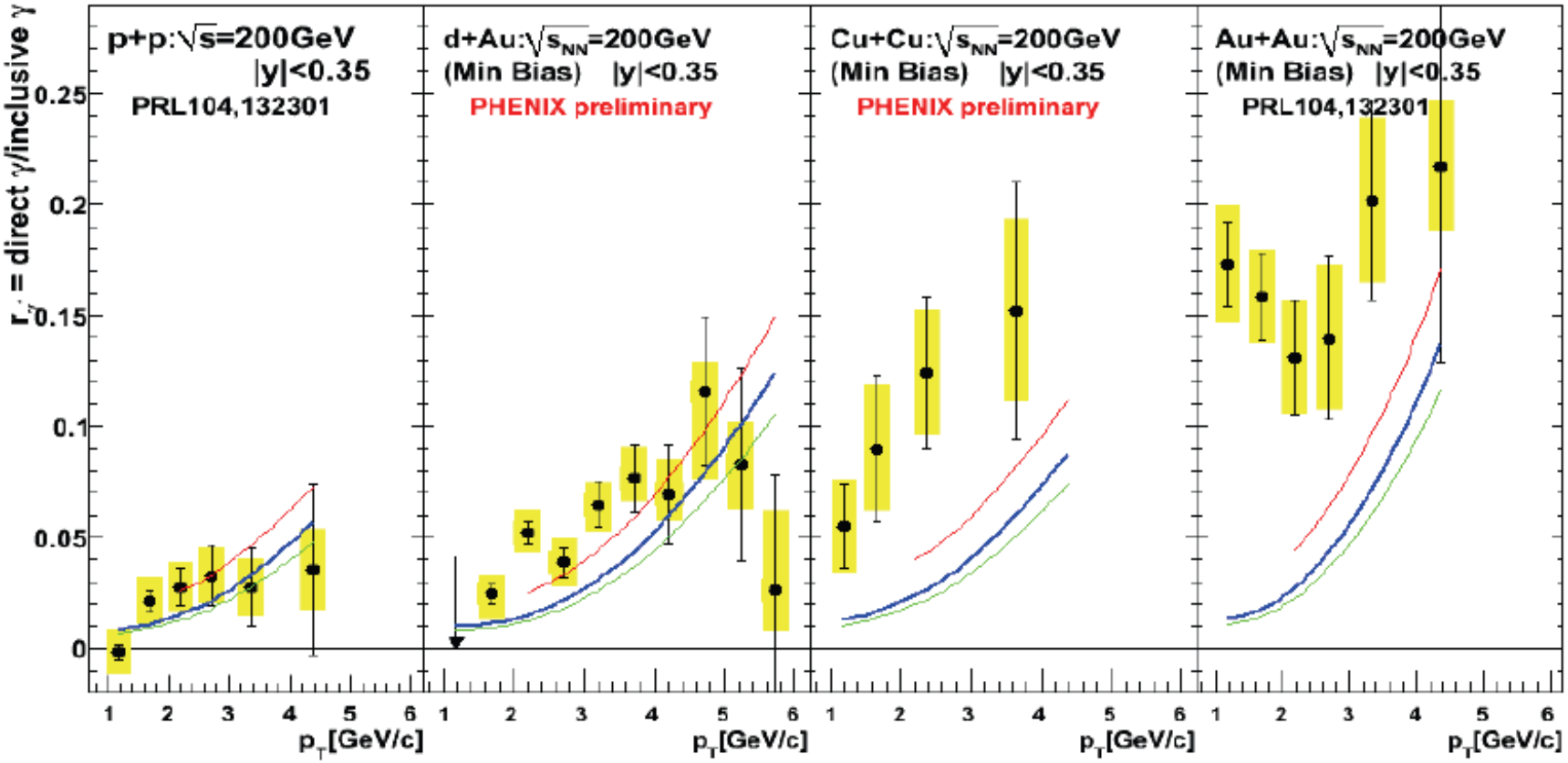
Direct Photons In Different Systems

- PHENIX has measured low p_T direct photon ratio in various collision systems, showing clear enhancement in A+A
- From virtual photon (internal conversion) analysis

$$r = 1 - 1/R_\gamma$$



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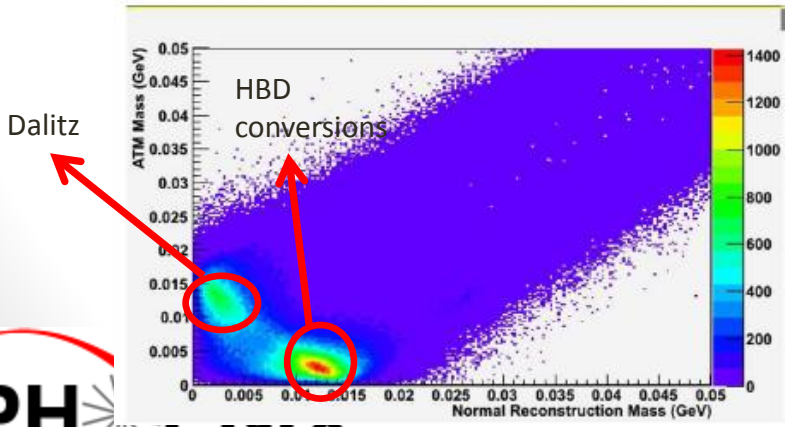
R_γ From Dilepton Techniques

- **External Conversions**
  - measure through a double ratio

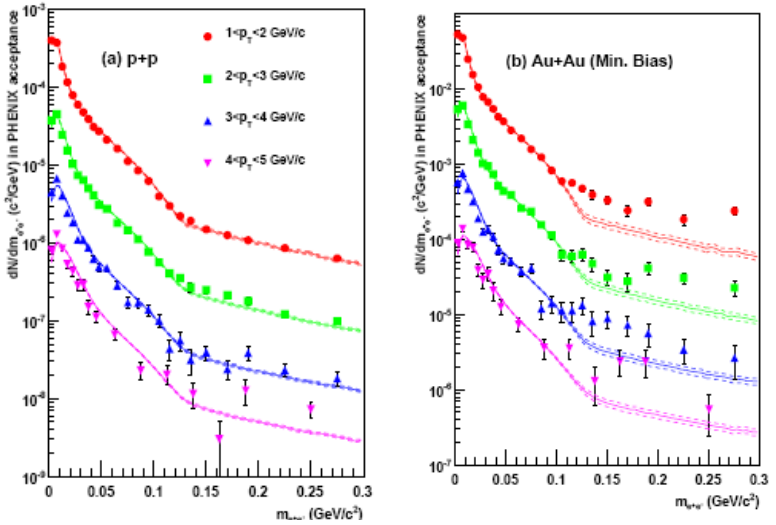
$$R_\gamma = \frac{\gamma^{incl}(p_T)}{\gamma^{hadr}(p_T)} = \frac{\varepsilon_\gamma(p_T) f(p_T) \cdot \left(\frac{N_\gamma^{incl}(p_T)}{N_\gamma^{\pi^0 tag}(p_T)} \right)_{Data}}{\left(\frac{N_\gamma^{hadr}(p_T)}{N_\gamma^{\pi^0}(p_T)} \right)_{Sim}}$$

  - tag photons as coming from π^0 decays
  - other decays accounted for with a cocktail (as in the internal analysis)



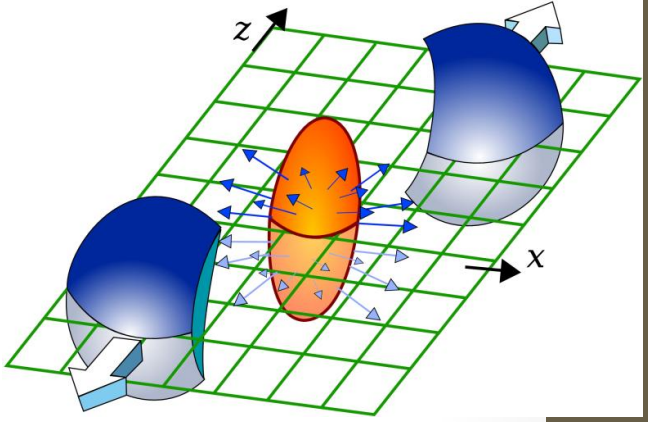
- **Internal Conversions**
  - observed excess in dilepton mass distribution attributed to virtual photons (at $p_T \gg m_{ee}$)
  - fit mass distribution with a two component fit
    - r is a floating fit parameter

$$f(m_{ee}; r) = (1 - r) f_c(m_{ee}) + r f_{dir}(m_{ee})$$



Phys. Rev. Lett. 104, 132301 (2010)

Direct Photon Elliptic Flow



- PHENIX has measured the elliptic flow of direct photons using combinations of all three techniques

$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

- R_γ is the fraction of direct photon, $\gamma^{incl}/\gamma^{hadron}$
- v_2^{BG} is the v_2 of photons from hadron decays
- v_2^{inc} is the measured v_2 of all photons

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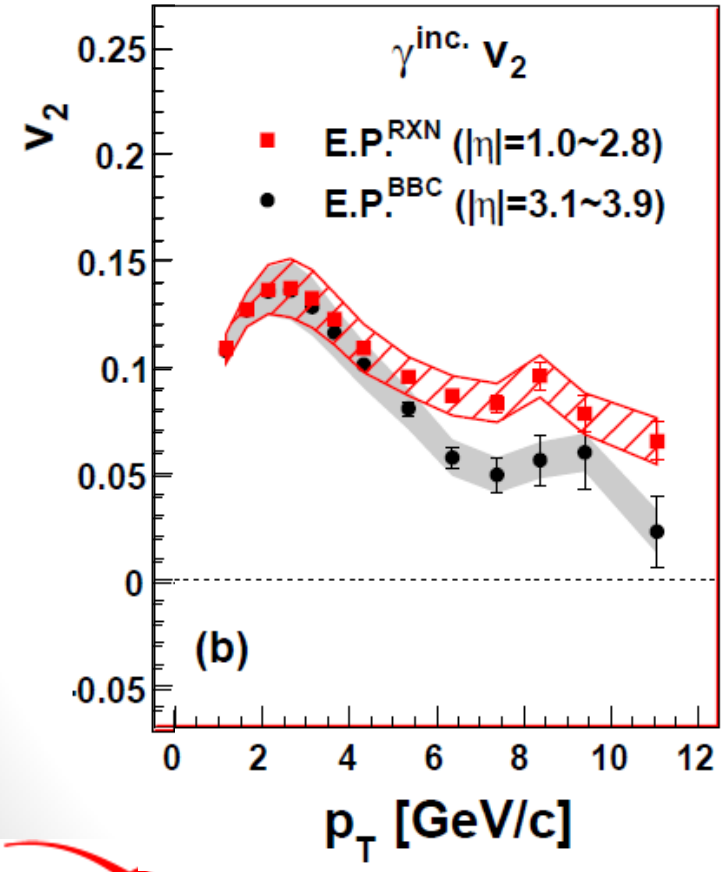
Inclusive photon v_2

$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

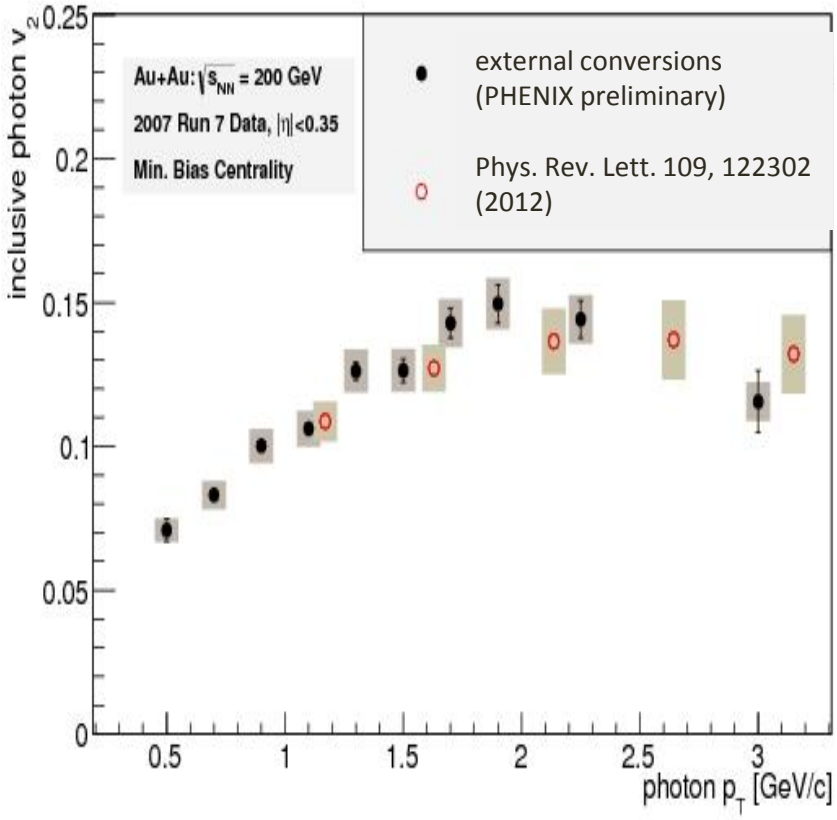


- Photons measured in the EMCal
- PID consists of
  - Shower shape cut
  - Charged track veto with PC
- Significant number of hadrons pass cuts below 6 GeV
  - up to 20% below 2 GeV deposited energy
  - Correct for this with GEANT sim

$$v_2^{\gamma,obs} = \frac{v_2^{\gamma,meas} - (N^{hadr}/N^{meas})v_2^{hadr}}{1 - N^{hadr}/N^{meas}}$$

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

Hadron contamination check



- Hadron contamination can be significant
- Check with an external conversion analysis
  - Identify photons via external conversions
  - No hadron contamination
- Two measurements are consistent
- Hadron contamination in the real photon (EMCal) measurement well understood

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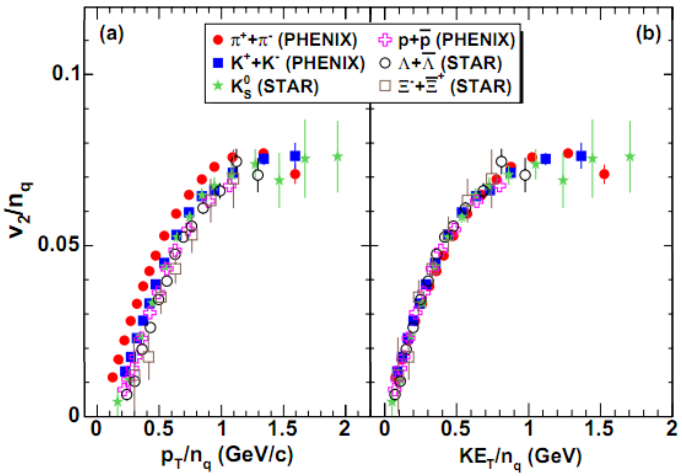
Hadron Decay Photon v_2

- We only measure π^0 v_2
  - about 80% of BG
- Assume v_2 of other hadrons from KE_T scaling
- v_2 modulation put into cocktail
- cocktail gives the total BG v_2 from decay photons

$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

Phys.Rev.Lett.98:162301,2007



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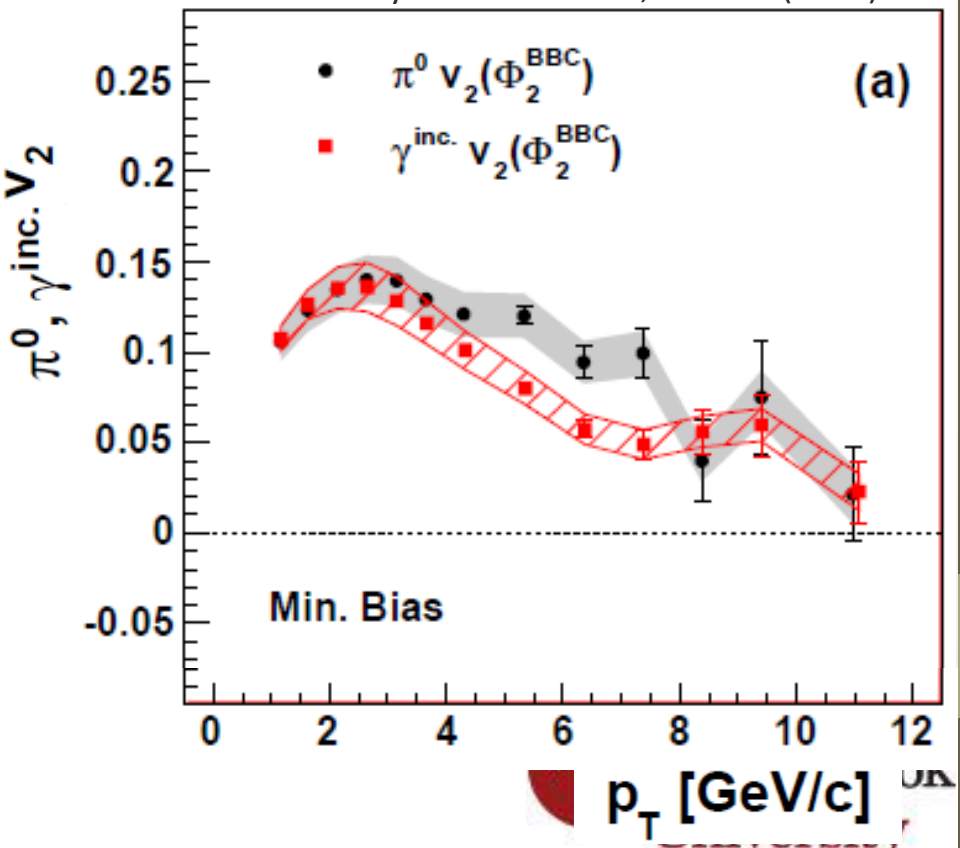
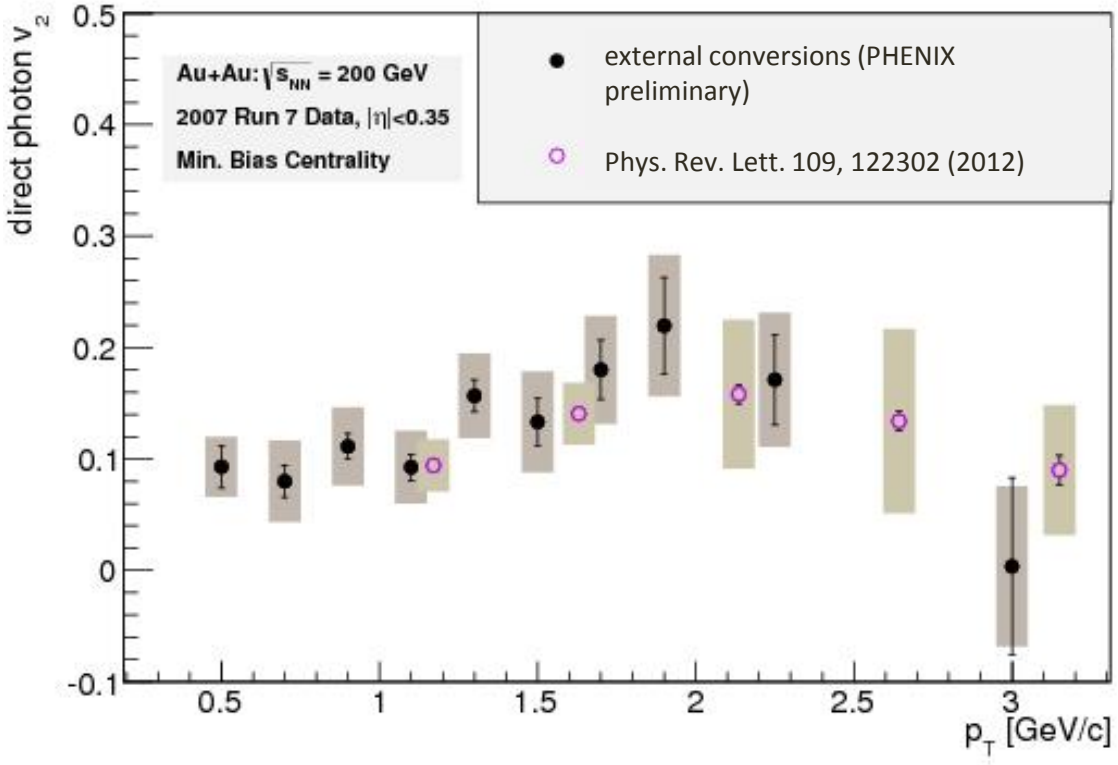


Direct Photon Flow



$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

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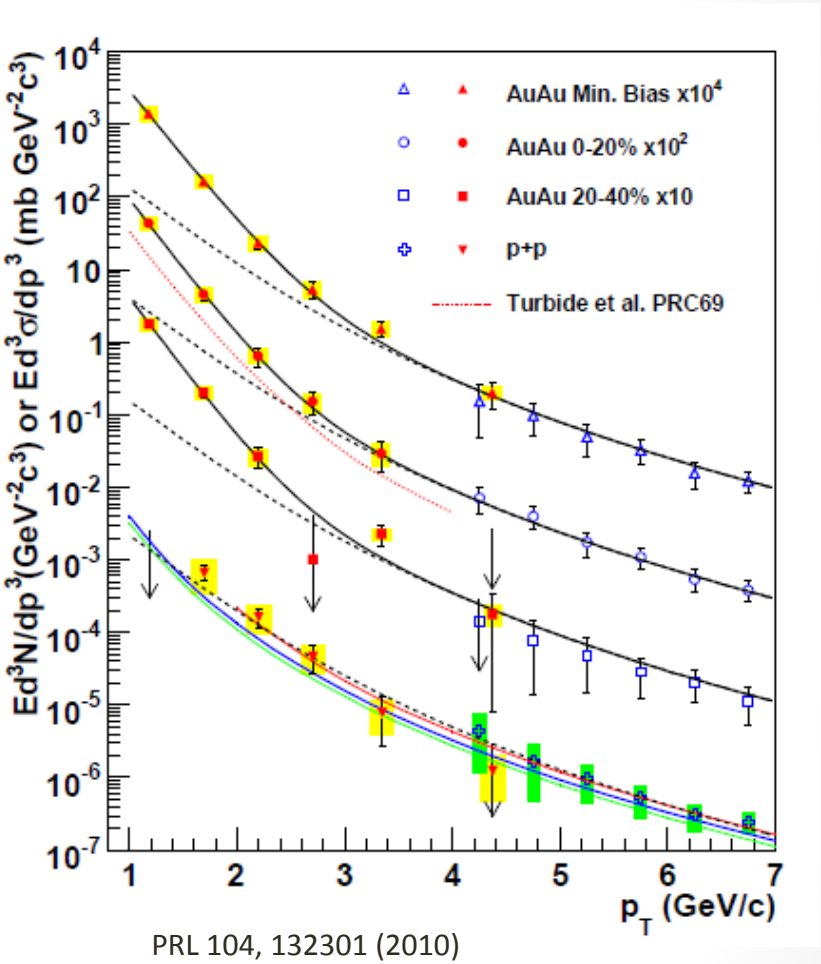
Direct Photon Invariant Yield

$$\gamma^{direct} = r\gamma^{incl}$$

- significant excess in low pT region compared to pQCD
- shape consistent with thermal emission
- fit yield with a two component function
  - pQCD power law
  - exponential
- Extract inverse slope parameter which is related to the temperature
  - T = 233±14±19 MeV in MB



PRL 104, 132301 (2010)

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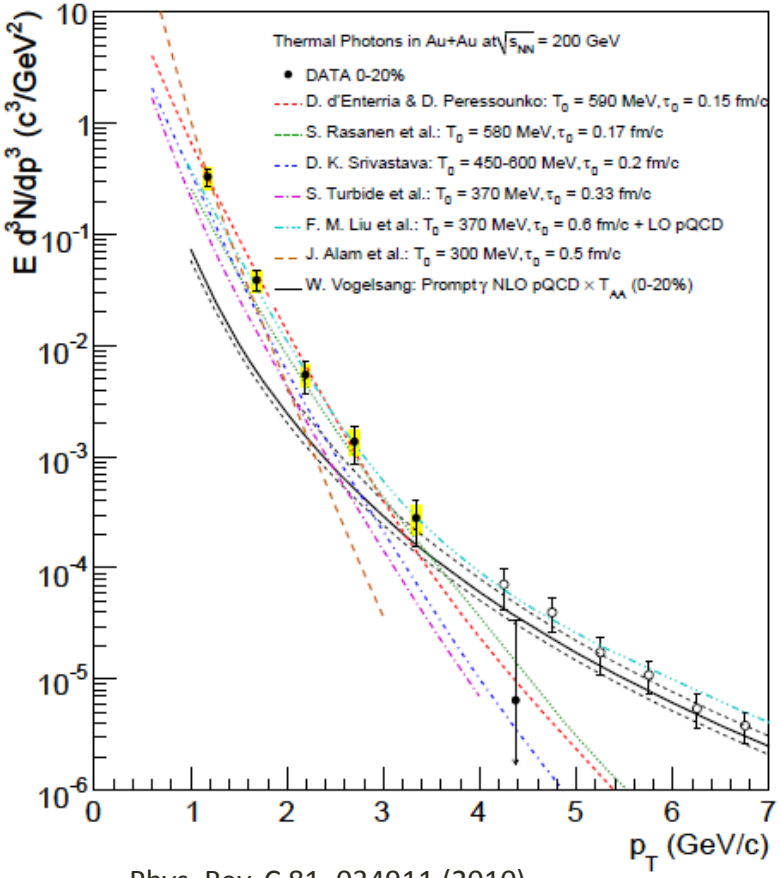
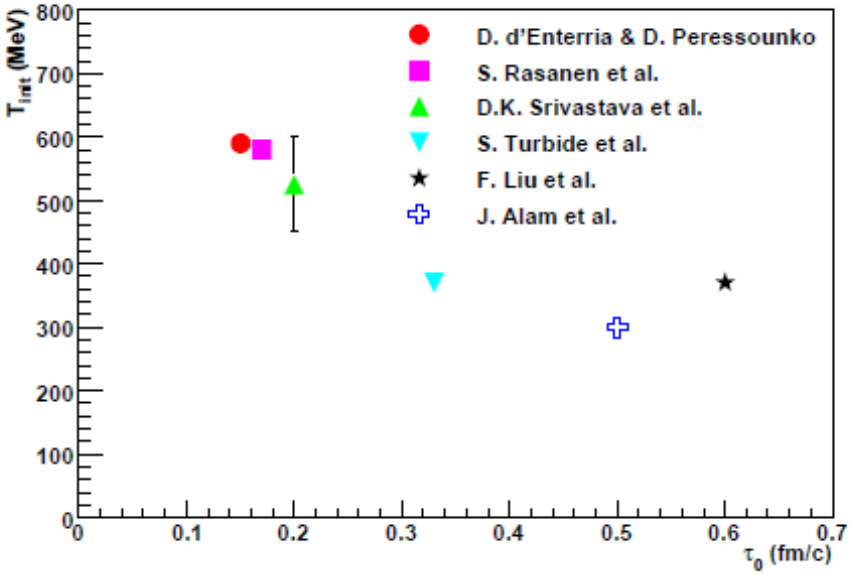
Comparing the Yield to Theory



Phys. Rev. C 81, 034911 (2010)



- model range in initial T is 300 to 600 MeV
- thermalization time range from about 0.6 to 0.15 fm/c

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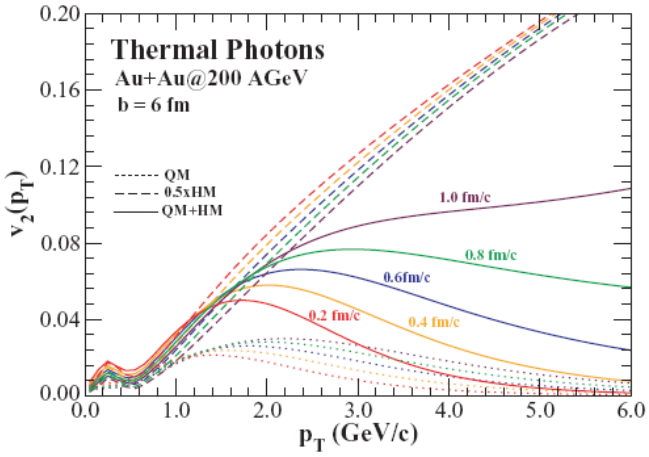
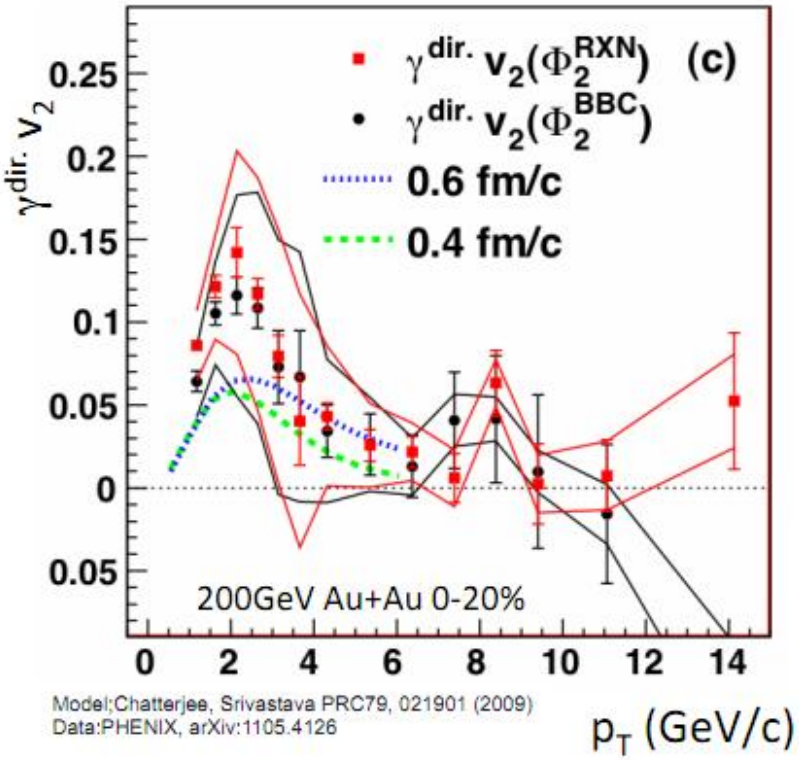
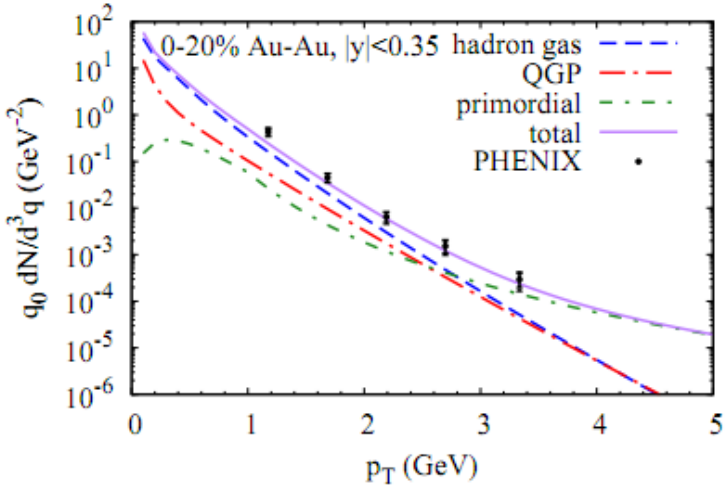
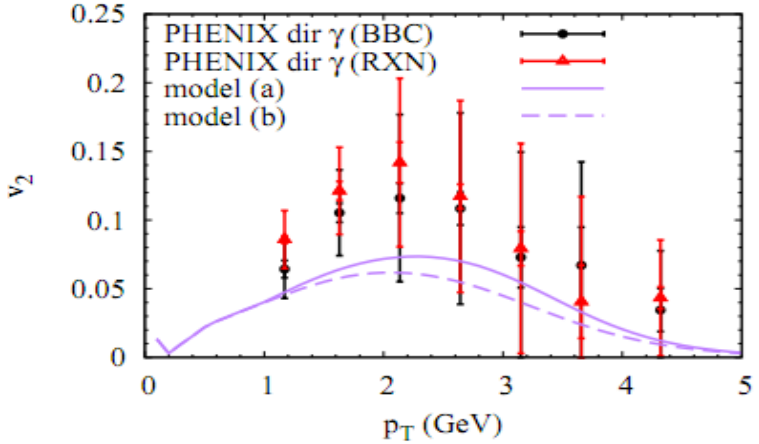
Comparison To Theory for 0-20% Centrality v_2





H. van Hees, C. Gale, R. Rapp
Phys. Rev. C 84, 054906 (2011)





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Summary

- Direct photons have a v_2 similar to that of hadrons at low p_T
- An excess of direct photons is found at low p_T and is unique to heavy ion collisions
  - This excess is thermal in shape and indicates a high temperature
- These two results are seemingly at odds with our standard picture of the heavy ion collision at RHIC

Outlook

- Improved data on the direct photon invariant yield a la external conversions
  - more points at low p_T
  - lower p_T reach

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References

Theory curves on direct photon yield:

- D. d'Enterria and D. Peressounko, Eur. Phy. J. C46, 451 (2006).
- S. Turbide, R. Rapp, and C. Gale, Phys. Rev. C 69, 014903 (2004).
- P. Huovinen, P. V. Ruuskanen, and S. S. Rasanen, Phys. Lett. B535, 109 (2002).
- D. K. Srivastava and B. Sinha, Phys. Rev. C 64, 034902 (2001).
- Jan-e Alam, S. Sarkar, T. Hatsuda, T.K. Nayak, and B. Sinha Phys. Rev. C 63, 021901(R) (2001).
- F. M. Liu, T. Hirano, K.Werner, and Y. Zhu, Phys. Rev. C 79, 014905 (2009).

All other references written directly on the slide

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Backups

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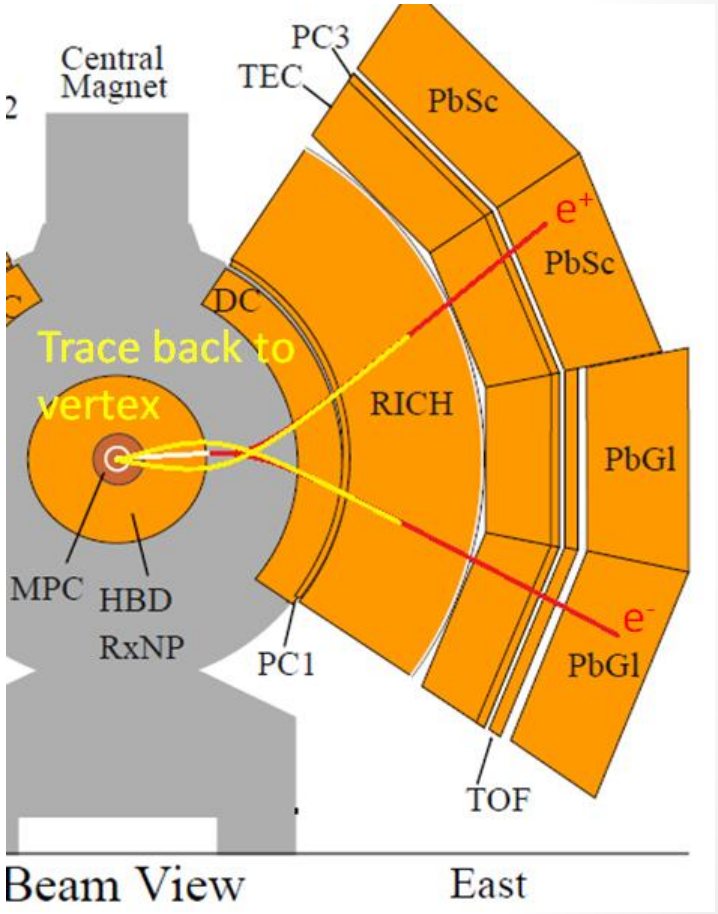
Measuring External Photon Conversions: Identification

- PHENIX tracks outside magnetic field
  - Need to assume the origin
  - Assume particles come from event vertex
- We are interested in conversions in the HBD backplane (radius ≈ 60cm)
  - Now our assumption is incorrect
  - Gives pairs an artificial opening angle
  - Leads to an apparent mass



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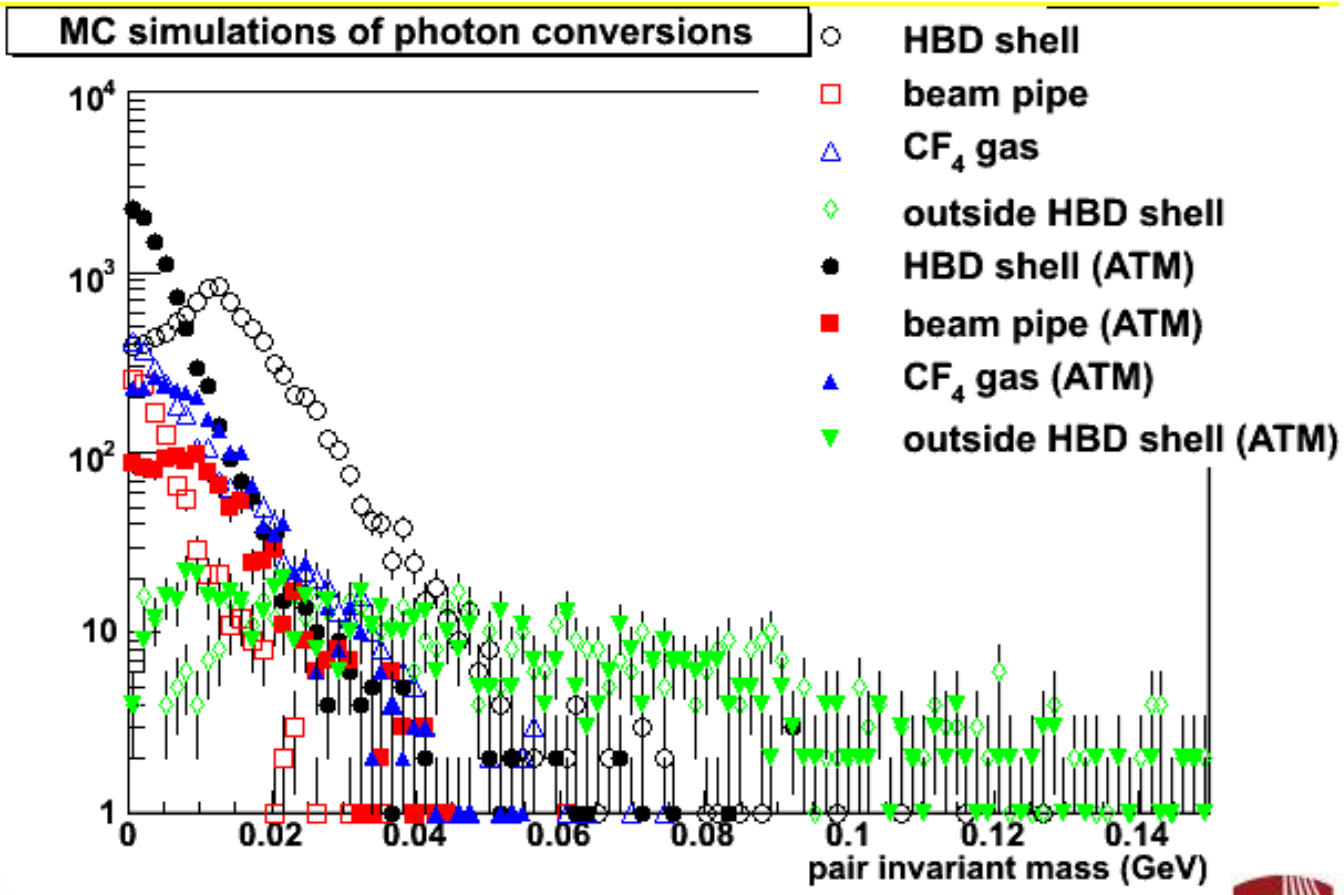
Some Simulations of Conversions

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



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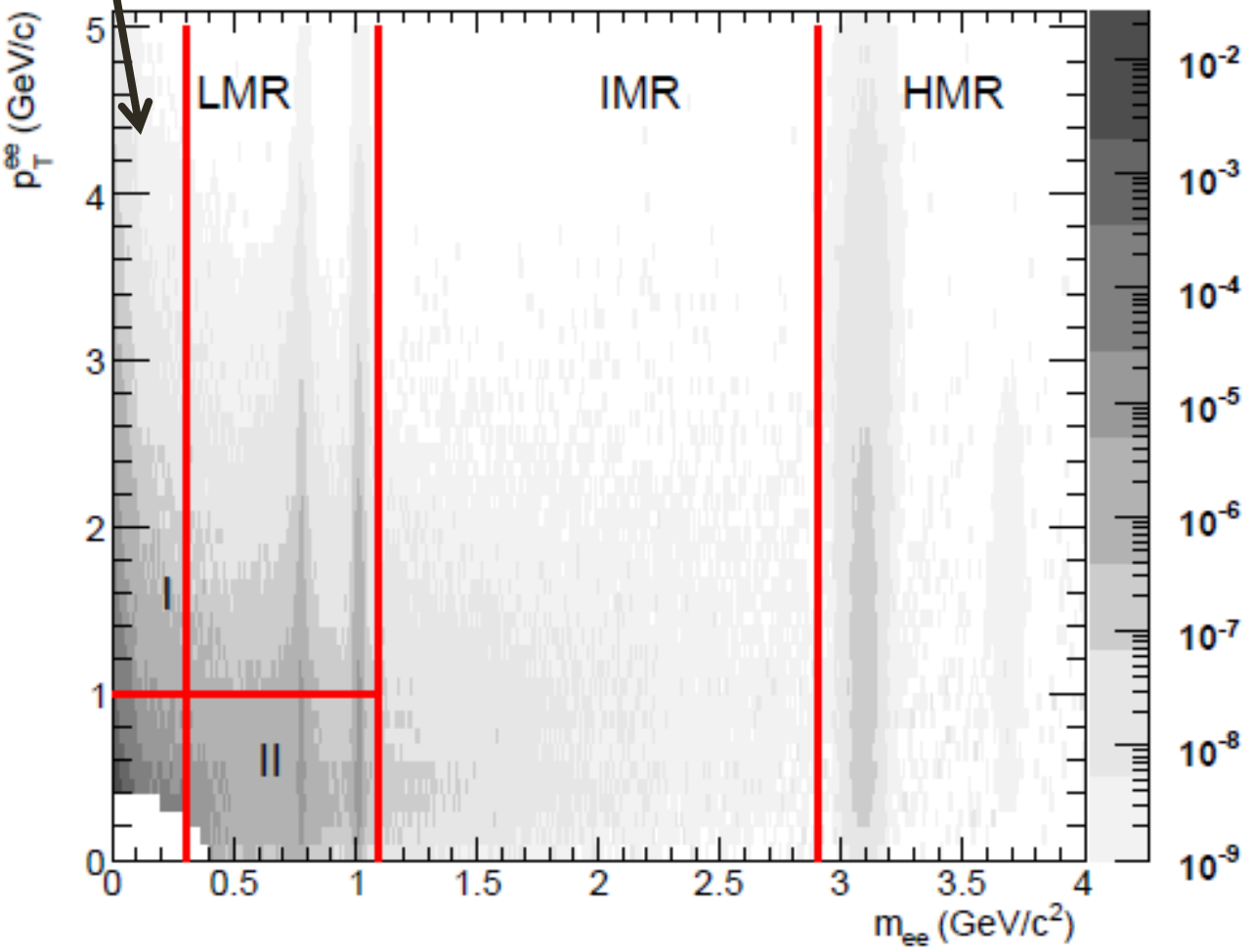
The di-electron spectrum

region of virtual photons



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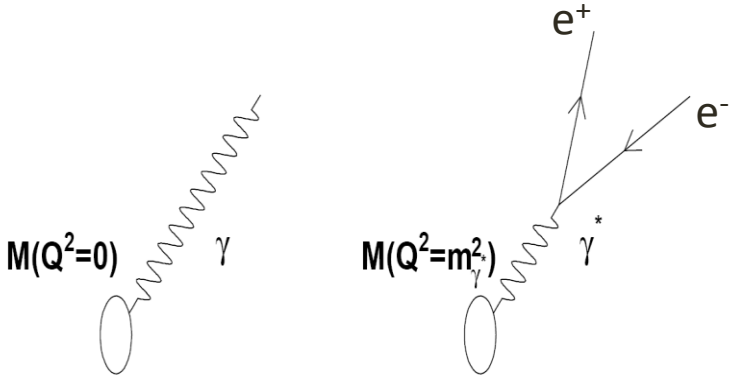
Measuring Virtual Photons



- Processes which produce photons can also produce virtual photons
  - Decay into low-mass e^+e^- pairs
  - The relation between photon and pair production can be written as

$$\frac{d^2n_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)Sdn_\gamma$$

- Measure low mass, high momentum dileptons
  - Correspond to nearly real photons
  - Extrapolate back to zero mass
- Analyze above π^0 mass to remove 90% of hadron background

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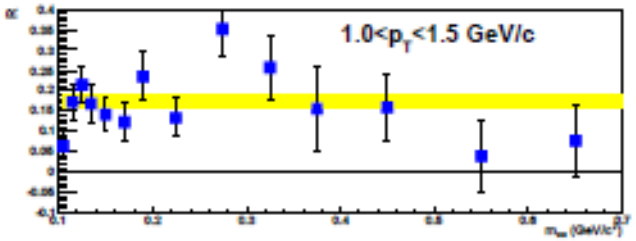
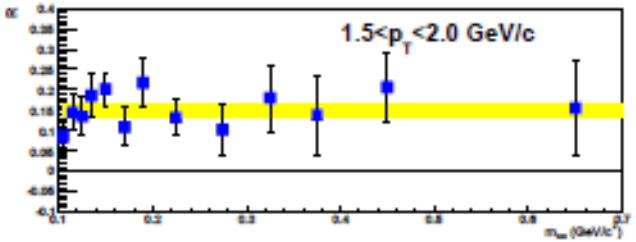
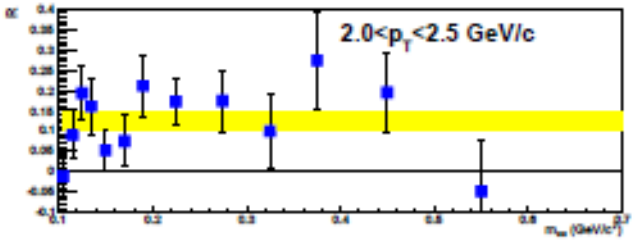
Virtual Photons

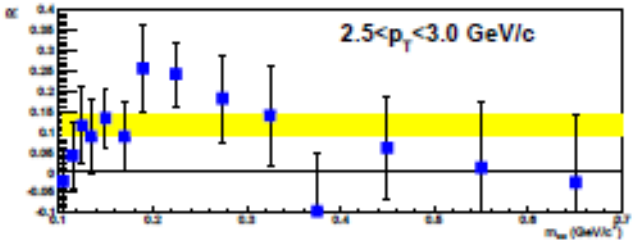
- excess seems to be consistent with the assumption of originating from virtual photons
- S(m, p_T) is constant

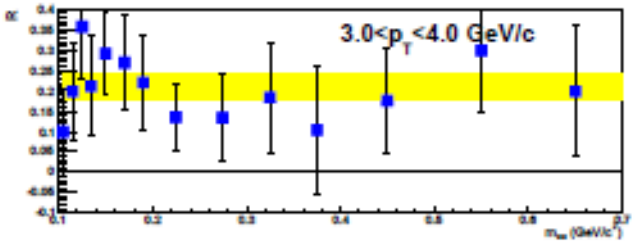
$$R(m,p_T) \simeq \frac{dN_{\gamma^*}^{\rm excess}(m,p_T)}{dp_T} \Big/ \frac{dN_{\gamma}^{\rm incl}(p_T)}{dp_T}$$
$$= S(m,p_T) dN_{\gamma}^{direct}(p_T)/dN_{\gamma}^{\rm incl}(p_T)$$











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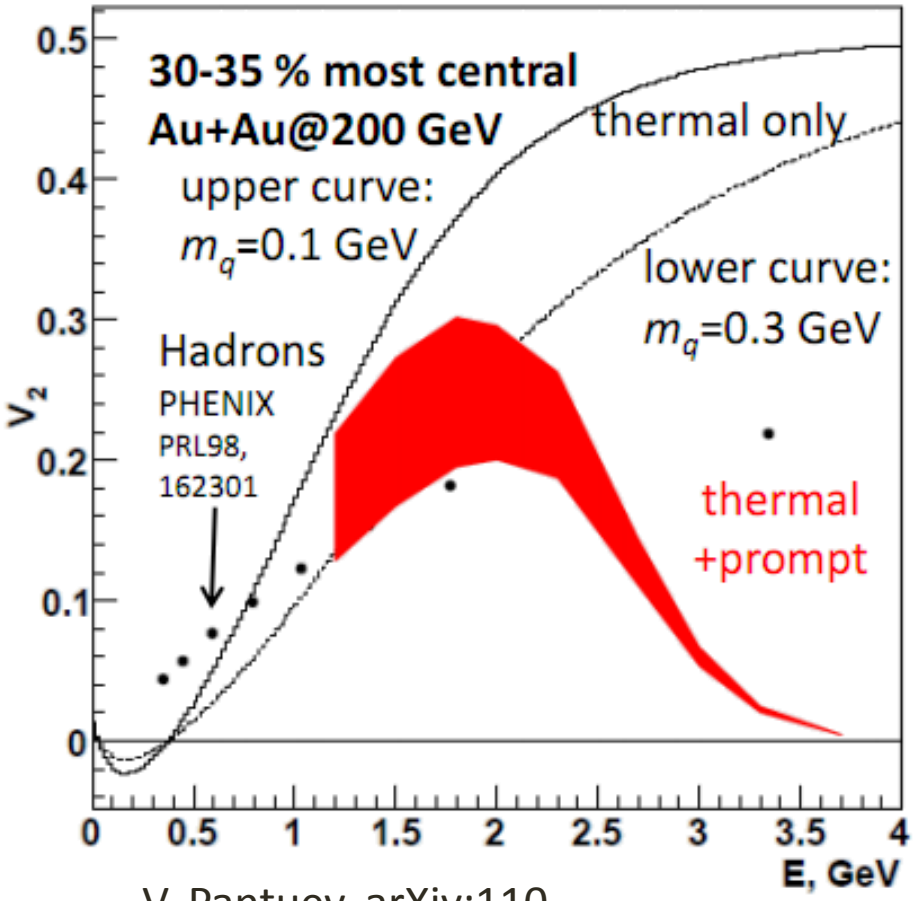
Theory Comparison (III)



V. Pantuev, arXiv:110

- Nothing about photon production included in model
  - Assume thermal shape and normalize to data
  - Describes effect of Doppler shift

$$dN/d\omega_0 = exp(-\omega_0/T),$$

$$\omega = \omega_0 \frac{\sqrt{1-\beta^2}}{1-\beta cos\theta}.$$

$$dN/dE = \frac{1-\beta_T cos\theta}{\sqrt{1-\beta^2}} exp(-\frac{E(1-\beta_T cos\theta)}{T\sqrt{1-\beta^2}}).$$

- Cylindrical expanding fireball

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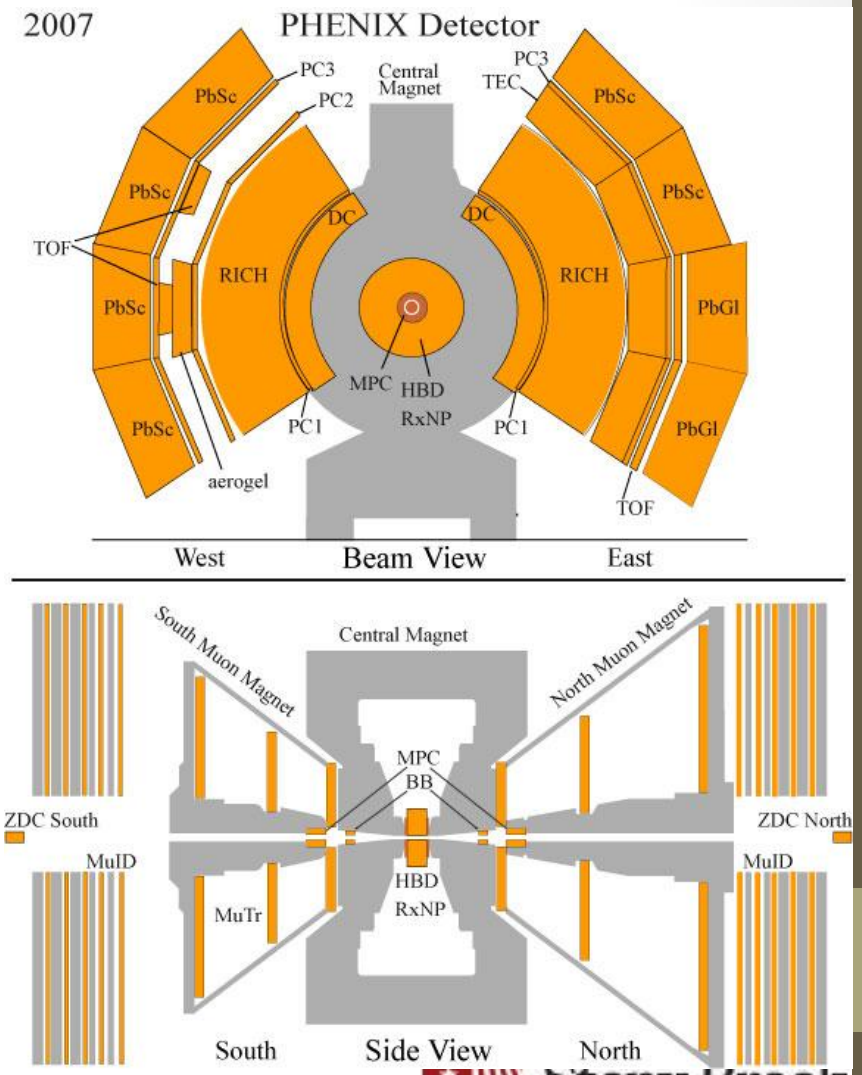
Experimental Techniques at PHENIX (I)

- Beam Beam Counter (BBC)
  - Centrality
  - Z vertex
  - Reaction plane
- Reaction Plane Detector (RxNP)
  - Reaction plane

- Electromagnetic Calorimeter (EMCal)
  - Photon energy and id
- Pad Chamber (PC)
  - Veto charged tracks
- Drift Chamber (DC)
  - Charged tracking
- Ring Imaging Cherenkov detector (RICH)
  - Electron id



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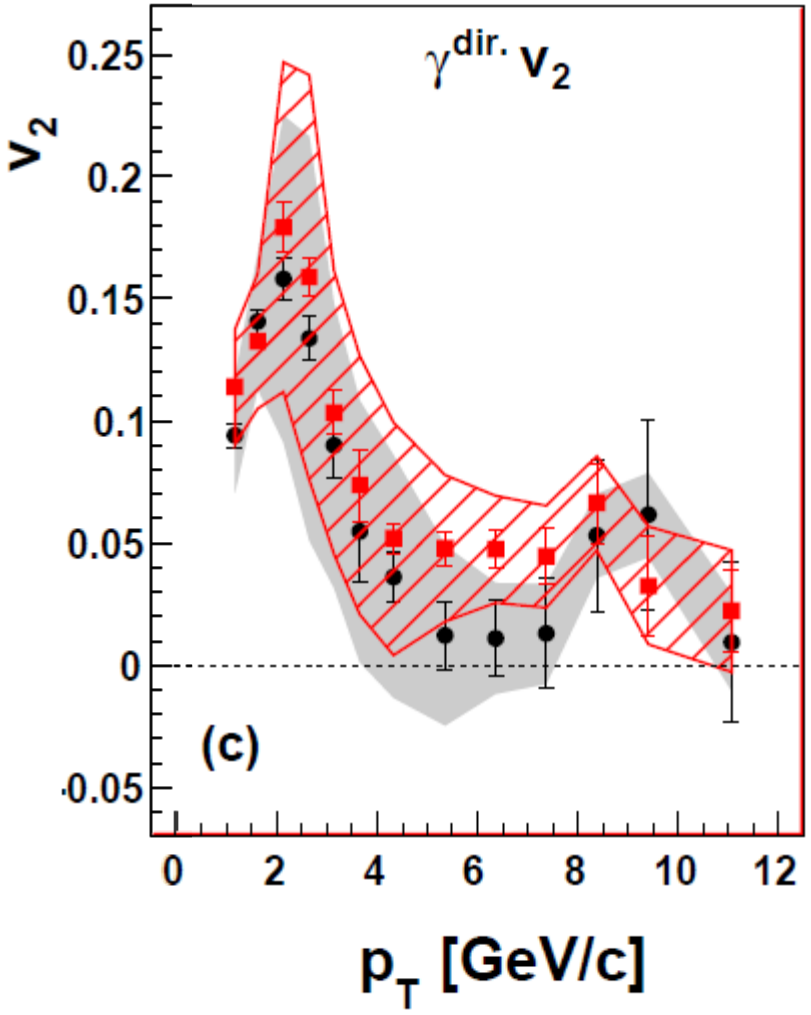
Published Direct Photon Flow

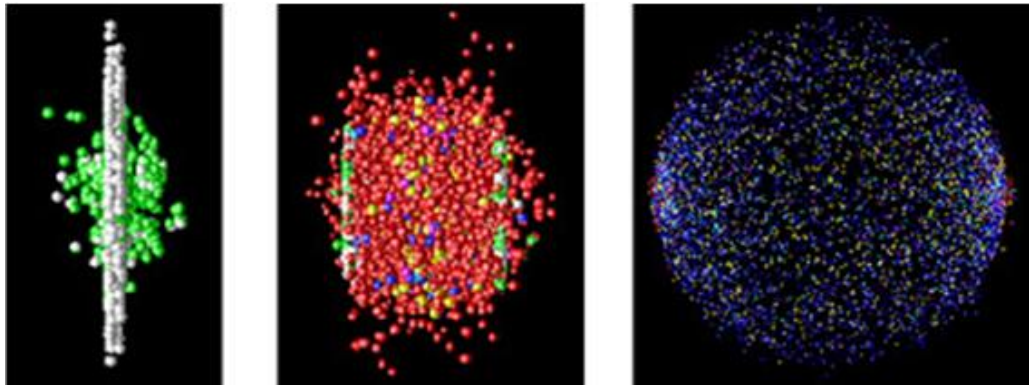


- E.P.^{RXN} ($|\eta|$=1.0~2.8)
- E.P.^{BBC} ($|\eta|$=3.1~3.9)

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

Direct Photons in HIC

- Initial collision
- QGP
- Hadron gas



- Direct photons = (inclusive photons) – (hadron decay photons)
  - Initial collision
    - Hard scattering of partons $v_2 = 0$
    - Pre-thermalized radiation $v_2 = ?$
  - QGP
    - Thermal radiation $v_2 > 0$
    - Jet Fragmentation $v_2 > 0$
    - Bremsstrahlung $v_2 < 0$
    - Jet conversions $v_2 < 0$

} High p_T phenom. Reflective of geometry, not dynamics

  - Hadron Gas
    - Thermal radiation $v_2 > 0$