Direct photon production in Au+Au collisions at RHIC-PHENIX

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for the PHENIX Collaboration

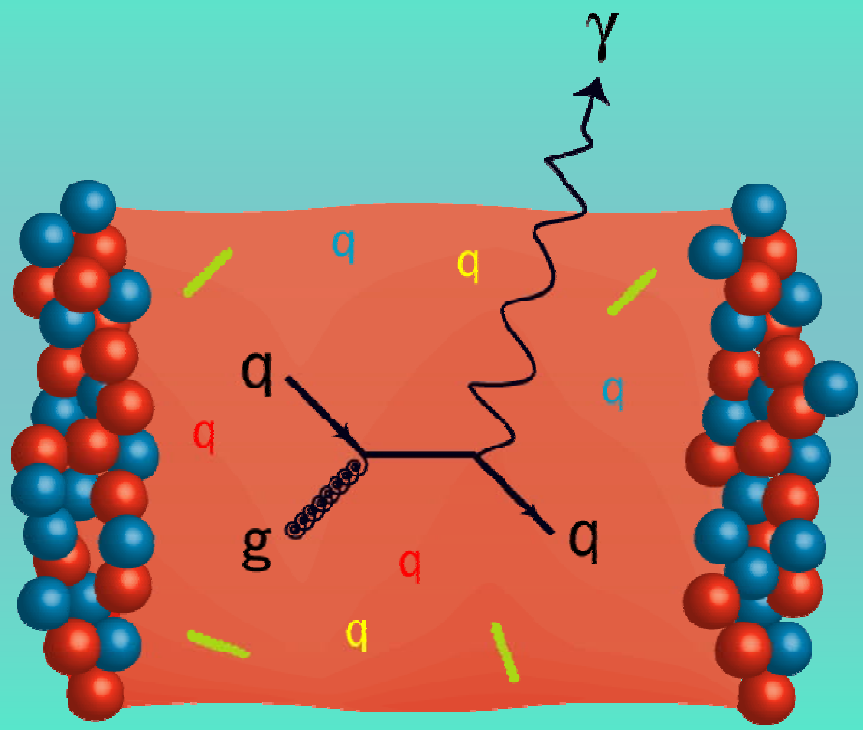
Hard Probes 2006 at Asilomar, CA

Outline

- Motivations for direct photon measurement
- Direct photon measurement at PHENIX
- Measurement at high-pT region
  - Direct photon as a hard probe
- Measurement at mid-pT region
  - Search for thermal emission from QGP
- Azimuthal anisotropy of direct photon
- Summary

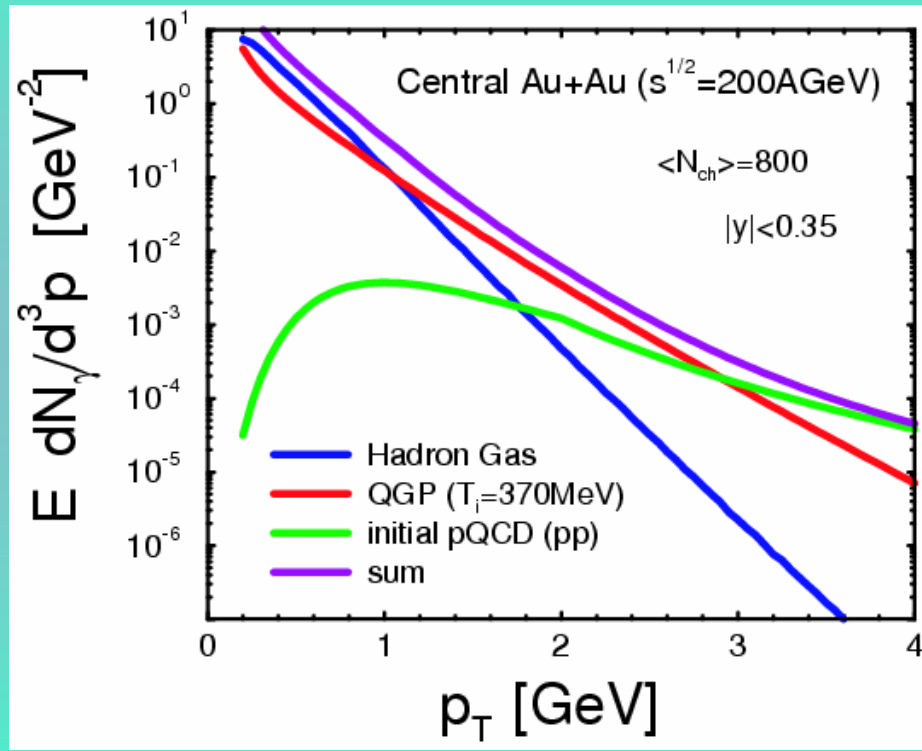
Motivation of direct photon measurement

- **For study of the hot and dense matter created in relativistic HIC**
- Direct photon: non-hadronic photon
- Penetrating probe for the bulk matter produced by Au+Au collision
  - Doesn't interact strongly
  - Long mean free path



Thermal radiation from QGP

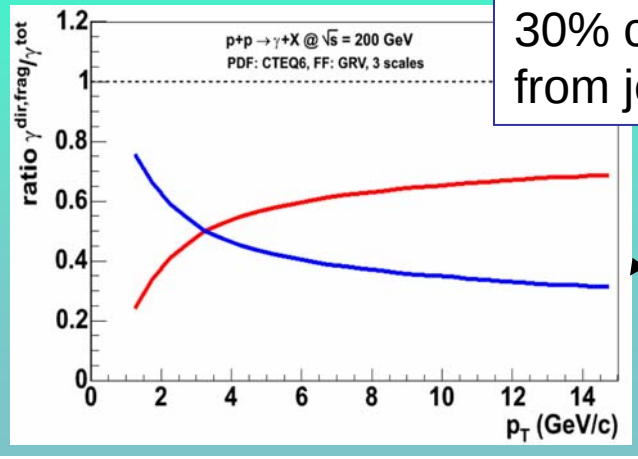
- Expected to be dominant at mid-pT region
  - 1GeV/c<pT<3GeV/c
- Strong signature of the existence of QGP
- Carry information on thermo-dynamical state of medium (temp., degrees of freedom)
- There are also contributions from hadron gas interaction
  - dominant at pT<1GeV/c



S. Turbide *et al.* PRC 69(2004)014903

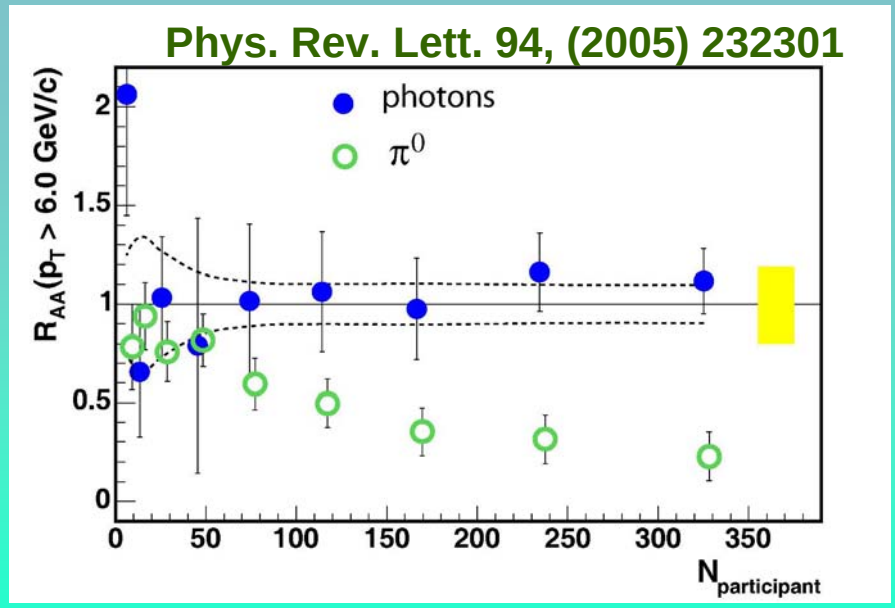
High-pT direct Photon as hard probe

- **pQCD** (hard scattering)
  - p+p data agree with NLO pQCD at high-pT
  - 70% prompt photon + 30% jet fragmentation at high-pT(pT>8-10GeV)
    - Fragmentation photons are suppressed by jet-quenching effect in HIC?
    - High-pT direct photon consistent with *Ncoll* scaled pQCD
    - Compensated by other contribution?



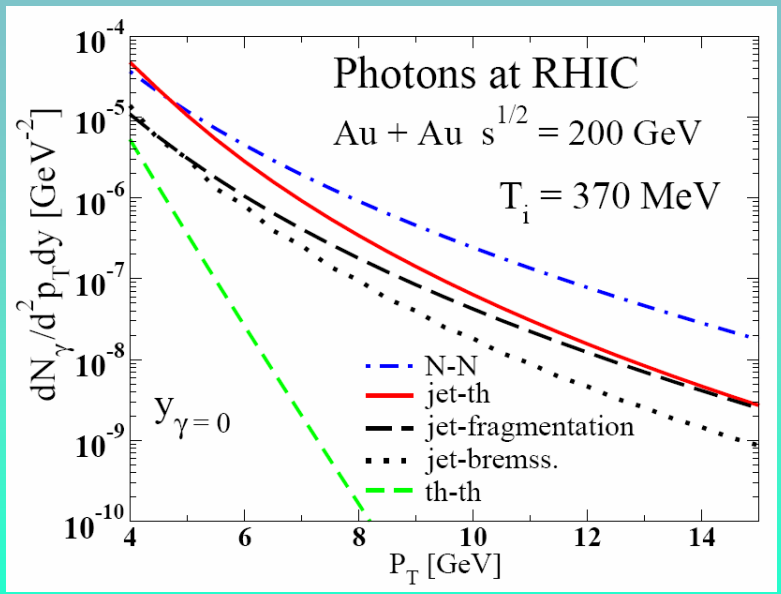
30% contribution from jet frag.

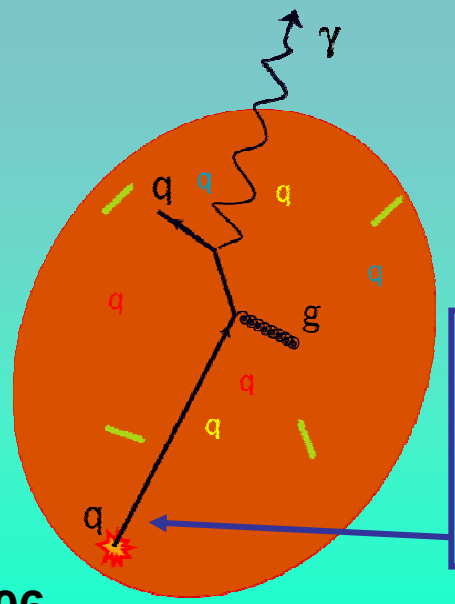
Phys. Rev. Lett. 94, (2005) 232301



Medium induced high-pT direct photon

- **Interaction of hard-scattered parton with dense matter**
  - Compton scattering (jet-photon conv.)
  - Bremsstrahlung
  - may be used as hard probe of bulk matter



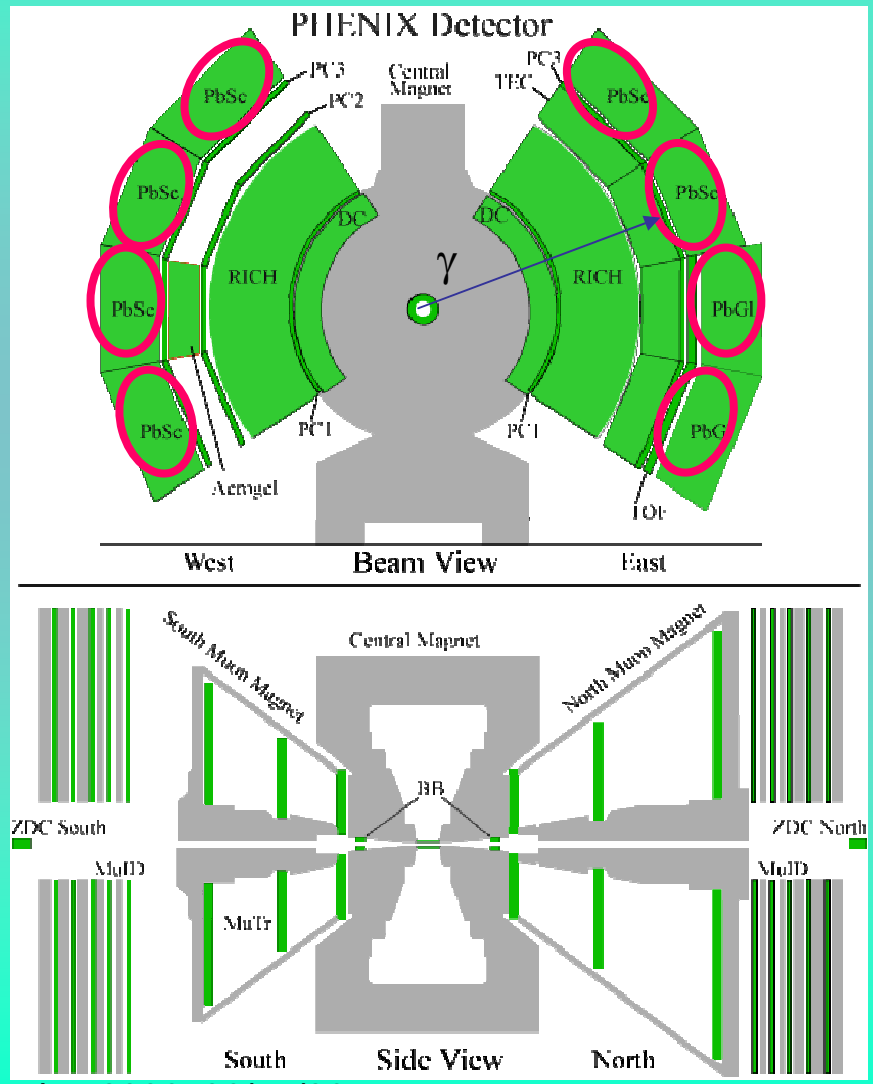


Hard scattered parton Interact with gluon in bulk matter

S. Turbide *et al.* Phys.Rev. C72 (2005) 014906

Direct photon measurement at RHIC-PHENIX

- RHIC-PHENIX Au+Au 200 GeV Run at Year-4
  - Sampled Luminosity 241μb-1
    - 1.5B events
- **Photon measurement using PHENIX- Electromagnetic Calorimeter (EMCal)**
  - Lead Scintillator Type (PbSc, $18X_0$)
  - Lead Glass Type (PbGl, $14.4X_0$)
- **Min. Bias trigger from BBC-ZDC coincidence**
  - Also used for Centrality determination
    - 0%: central, 100%: peripheral collision



method for direct photon measurement

- **Subtraction method**

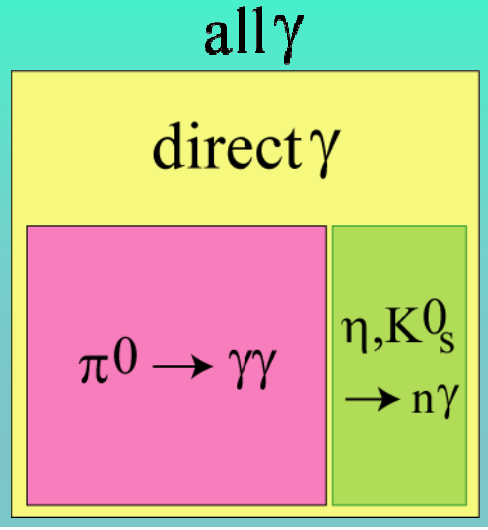
$$N^{\gamma}_{all} = N^{\gamma}_{decay} + N^{\gamma}_{direct}$$

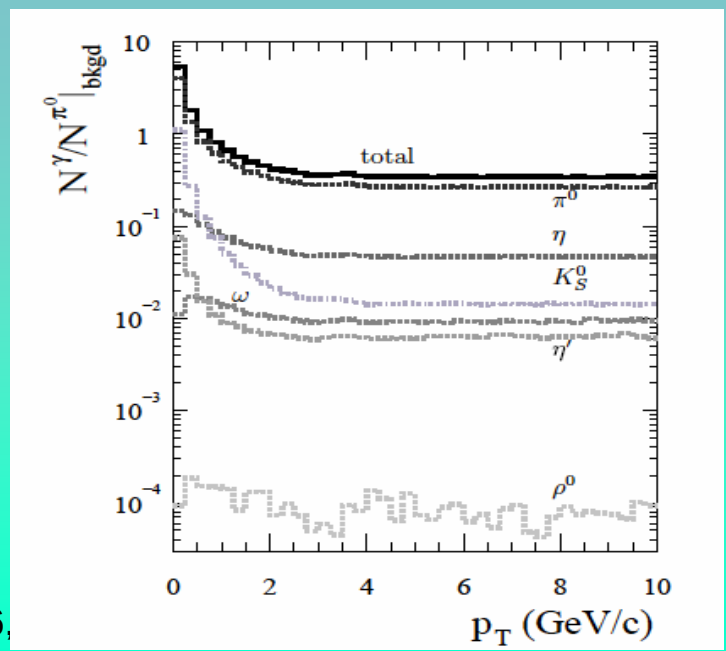
  - Pi0-> 2gamma
  - Eta, K0s, omega..
    - Reconstruct the slope with mT scaling and for eta using the eta/pi0 ratio measured in PHENIX

- **Direct photon excess ratio**

$$\frac{N^{\gamma}{}_{all}}{N^{\gamma}{}_{decay}} = \frac{(N^{\gamma}{}_{all} / N^{\pi^0})_{measured}}{(N^{\gamma}{}_{decay} / N^{\pi^0})_{MC}}$$

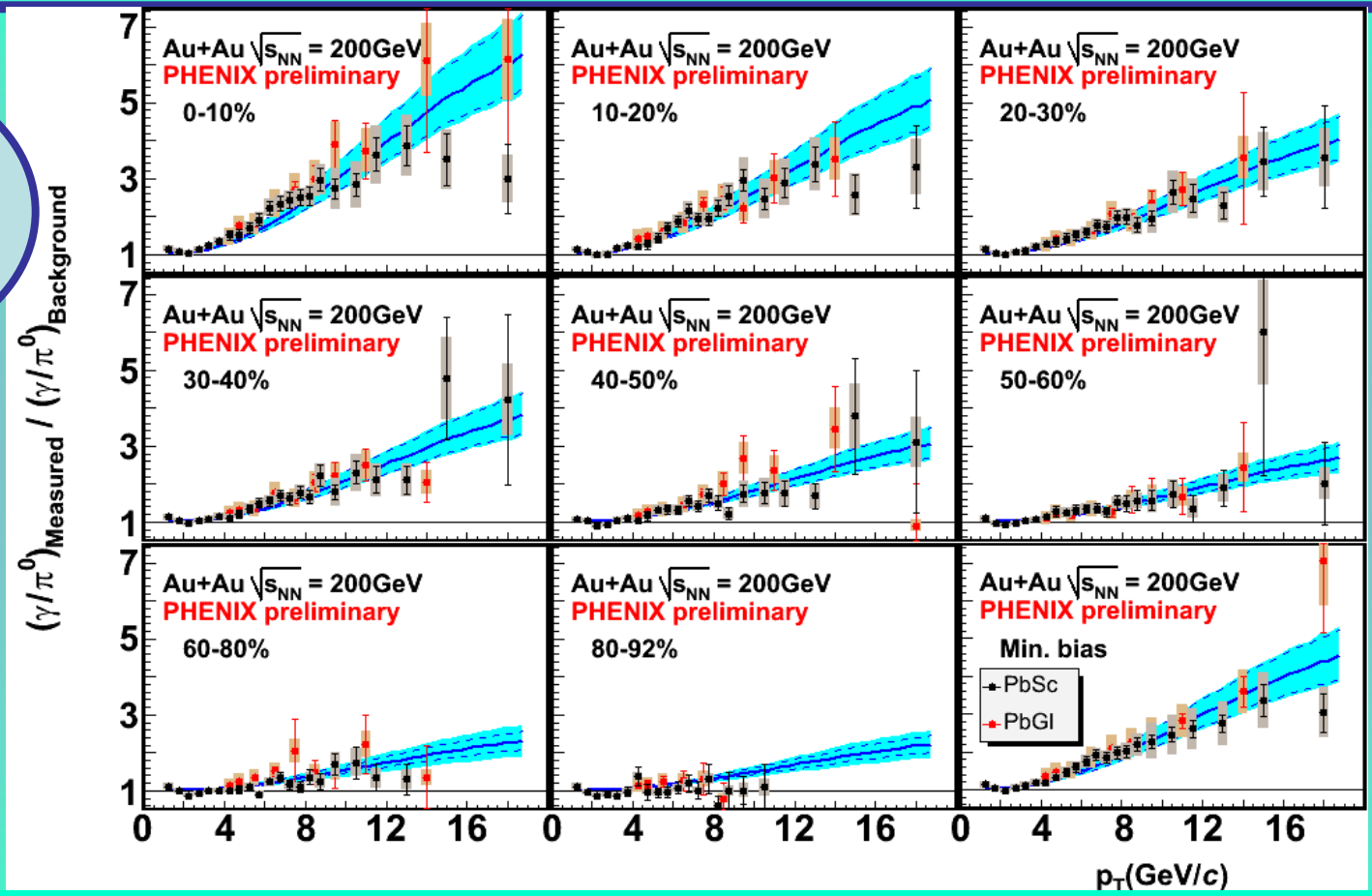
  - Part of systematic errors cancel





Direct photon excess ratio

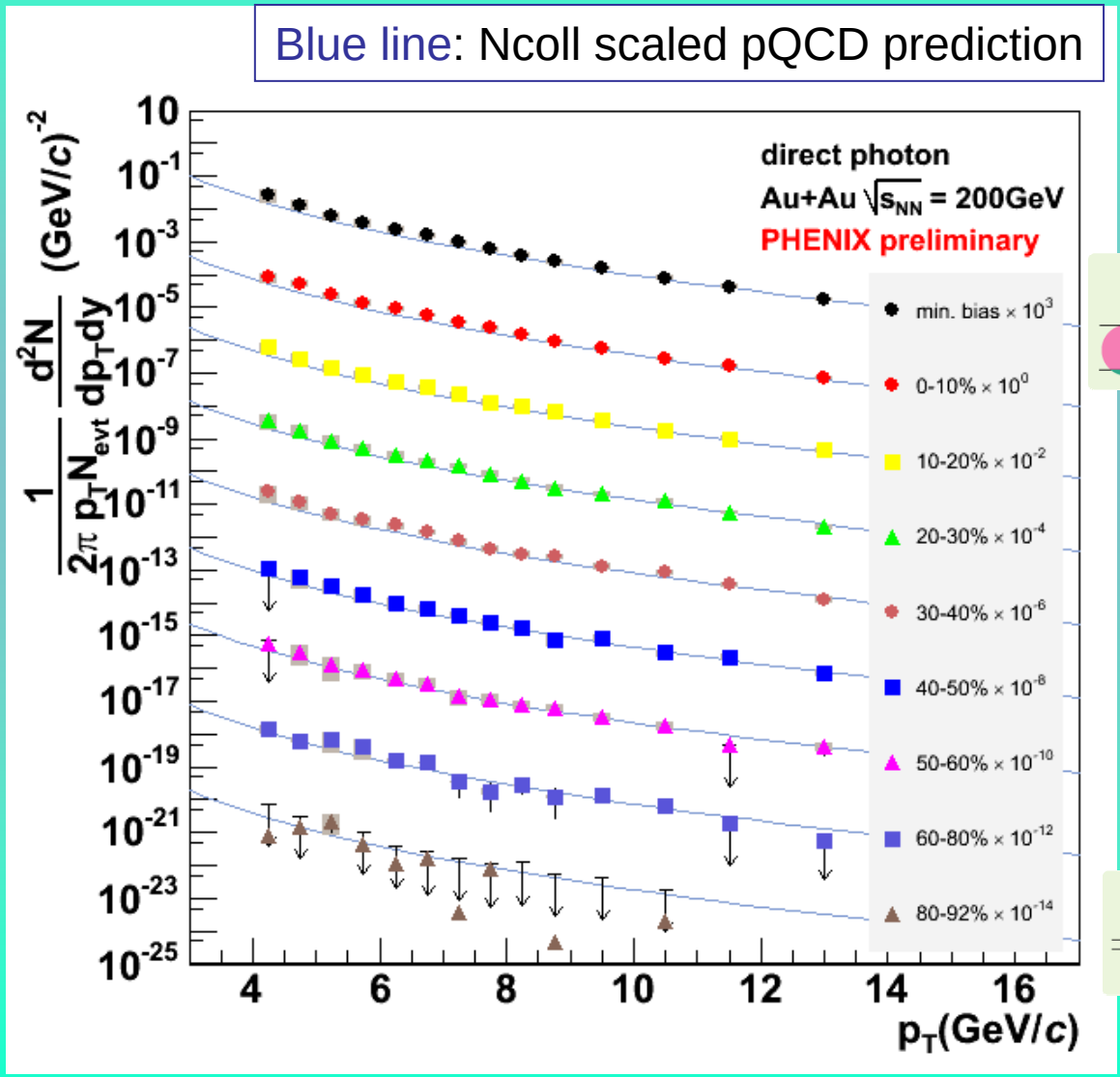
PHENIX
Run4
New data



- Strong suppression of neutral mesons makes possible the clear extraction of direct photon signal
- Compared with pQCD calculation (Phys. Rev. D48, 3136 (1993))
  - (theoretical uncertainty: dashed lines, blue bands: dashed+Ncoll error)

Direct photon spectra

- PbSc/PbGl combined result
  - Run4 new result
- Good agreement with Ncoll scaled pQCD at high-pT

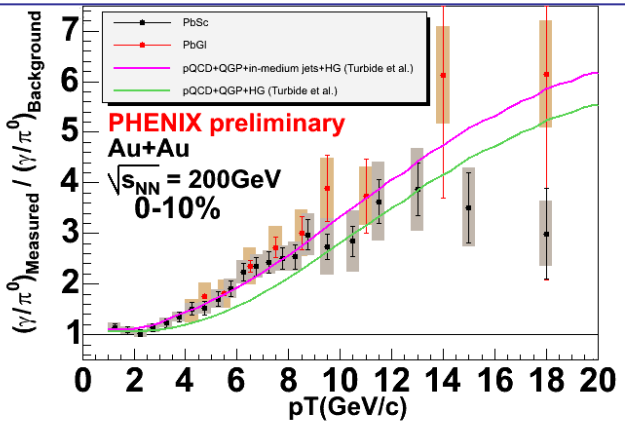


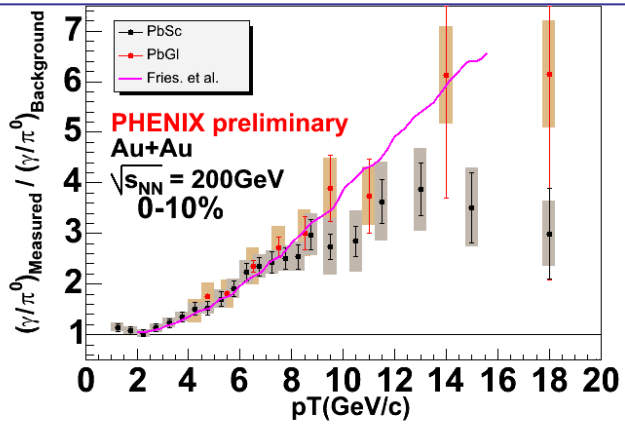
Comparison with Theory

pQCD+Jet-photon+HG, Turbide et al., Phys.Rev. C72 (2005) 014906

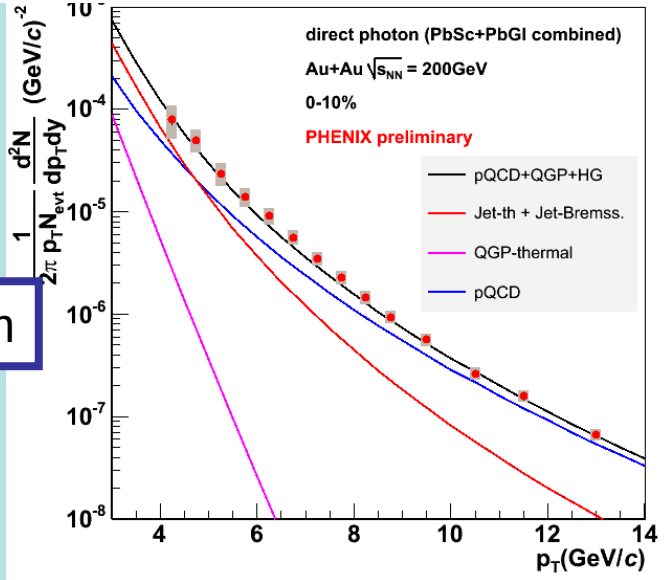
pQCD and Jet-photon, Fries et al., Phys.Rev. C72 (2005) 041902

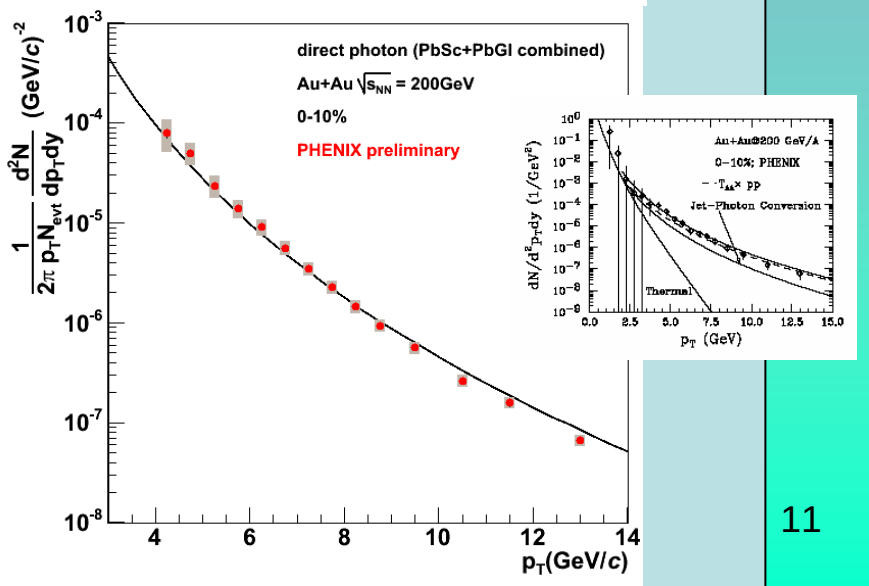
excess raito





spectrum





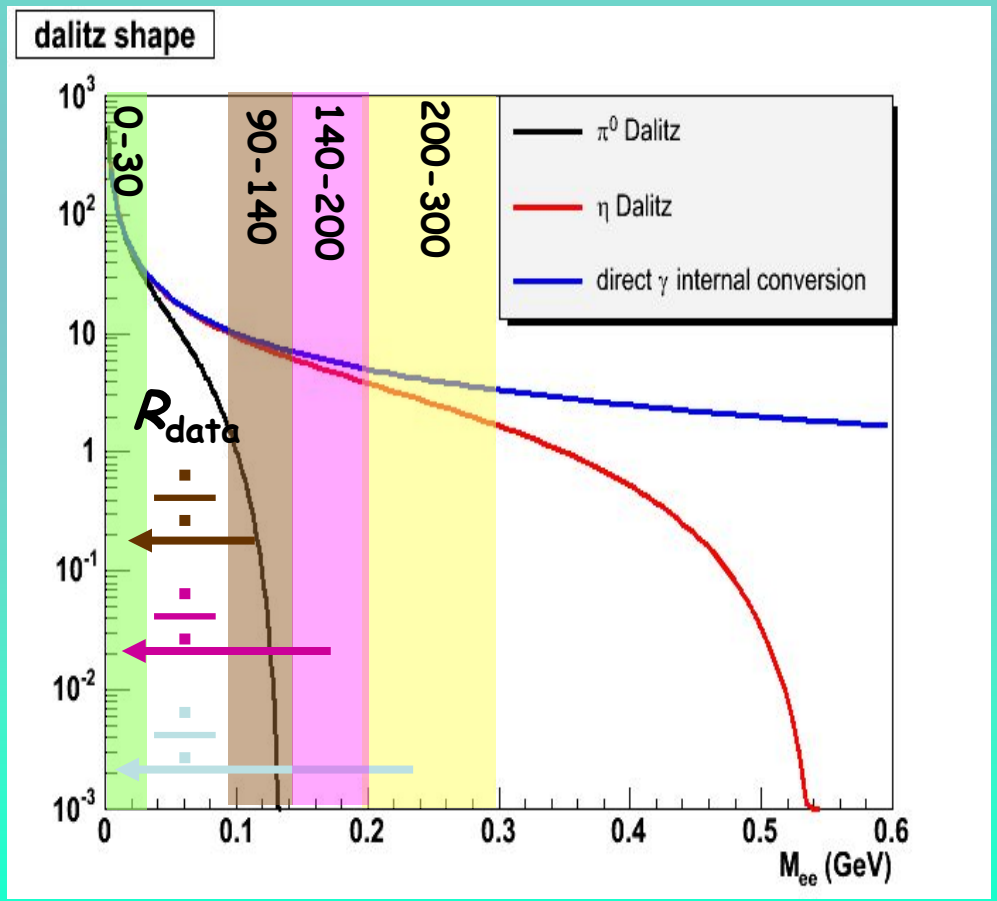
Focus on mid-pT region

New Approach "internal conversion"

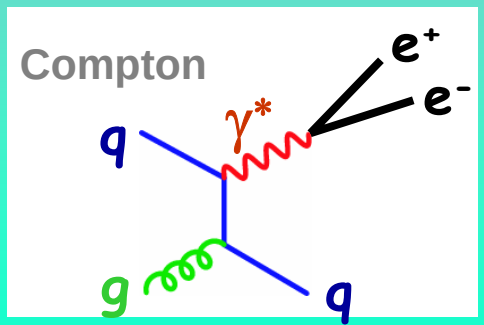
$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}\left|F(m_{ee}^2)\right|^2\left(1-\frac{m_{ee}^2}{M^2}\right)^3$$

Kroll-Wada Formula

phase space factor 1 for high p_T γ



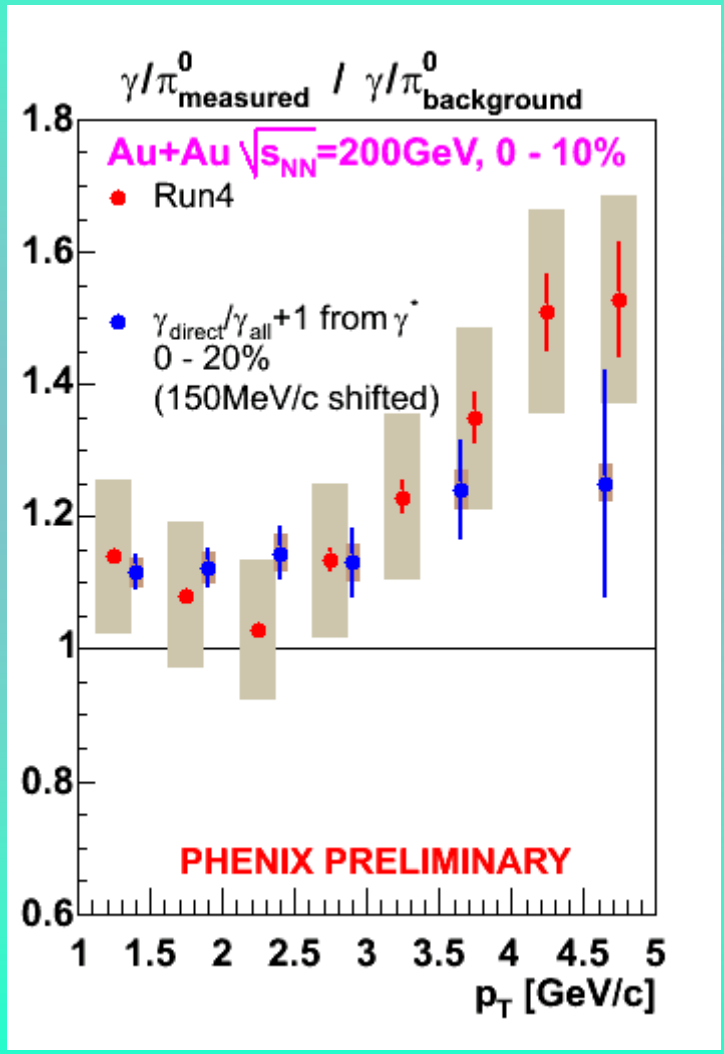
- any source of real photons produces virtual photons with very low invariant mass
- Ratios of M_{inv} bins to lowest one (R_{data})
- If no direct photons: the ratios become exactly what can be calculated from Dalitz decay formulae above
- If excess over calculation: direct photons



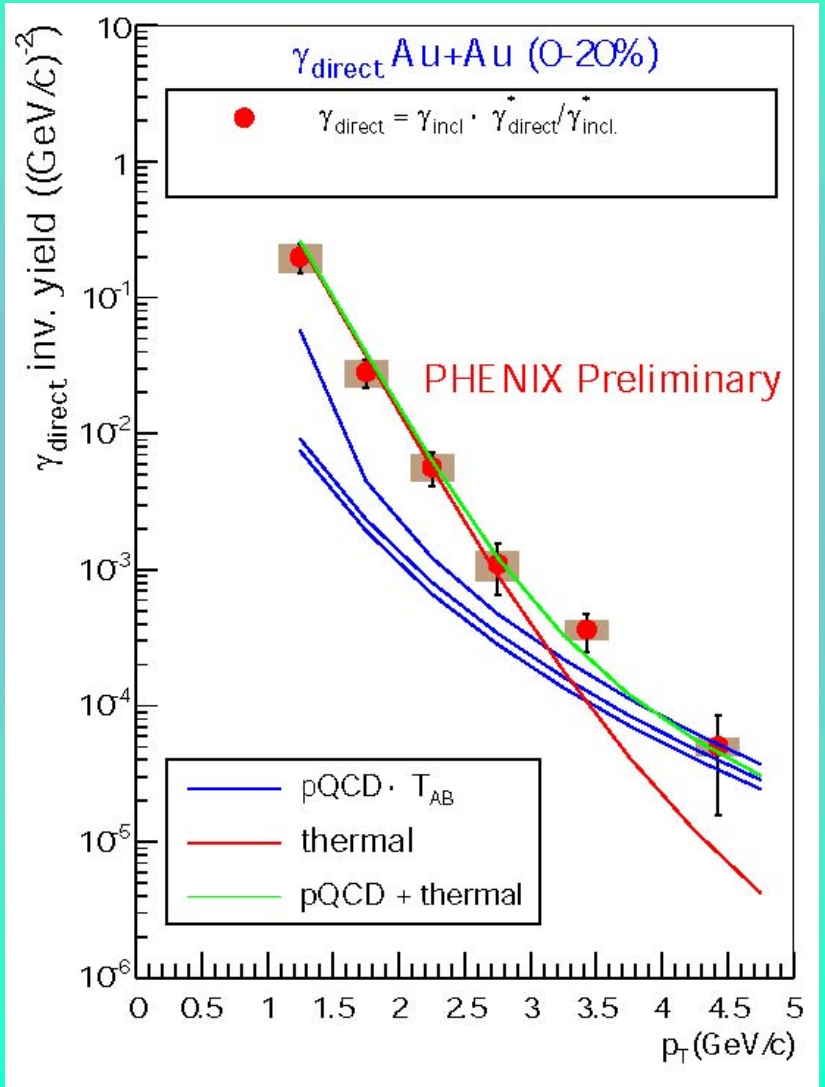
Result in mid. pT region

- Run4 low p_T result from conventional method (Red points)
- the result from the method through internal conversion (Blue points)
  - smaller errors

$$\frac{\gamma_{direct}}{\gamma_{incl.}} = \frac{\gamma^*_{direct}}{\gamma^*_{incl.}} = \frac{R_{data} - R_{\pi^0+\eta}}{R_{direct} - R_{\pi^0+\eta}}$$



The Direct photon spectrum



- Inclusive photon come from EMCal measurement

$$\gamma_{direct} = \gamma_{incl.} \cdot \frac{\gamma^*_{direct}}{\gamma^*_{incl.}}$$

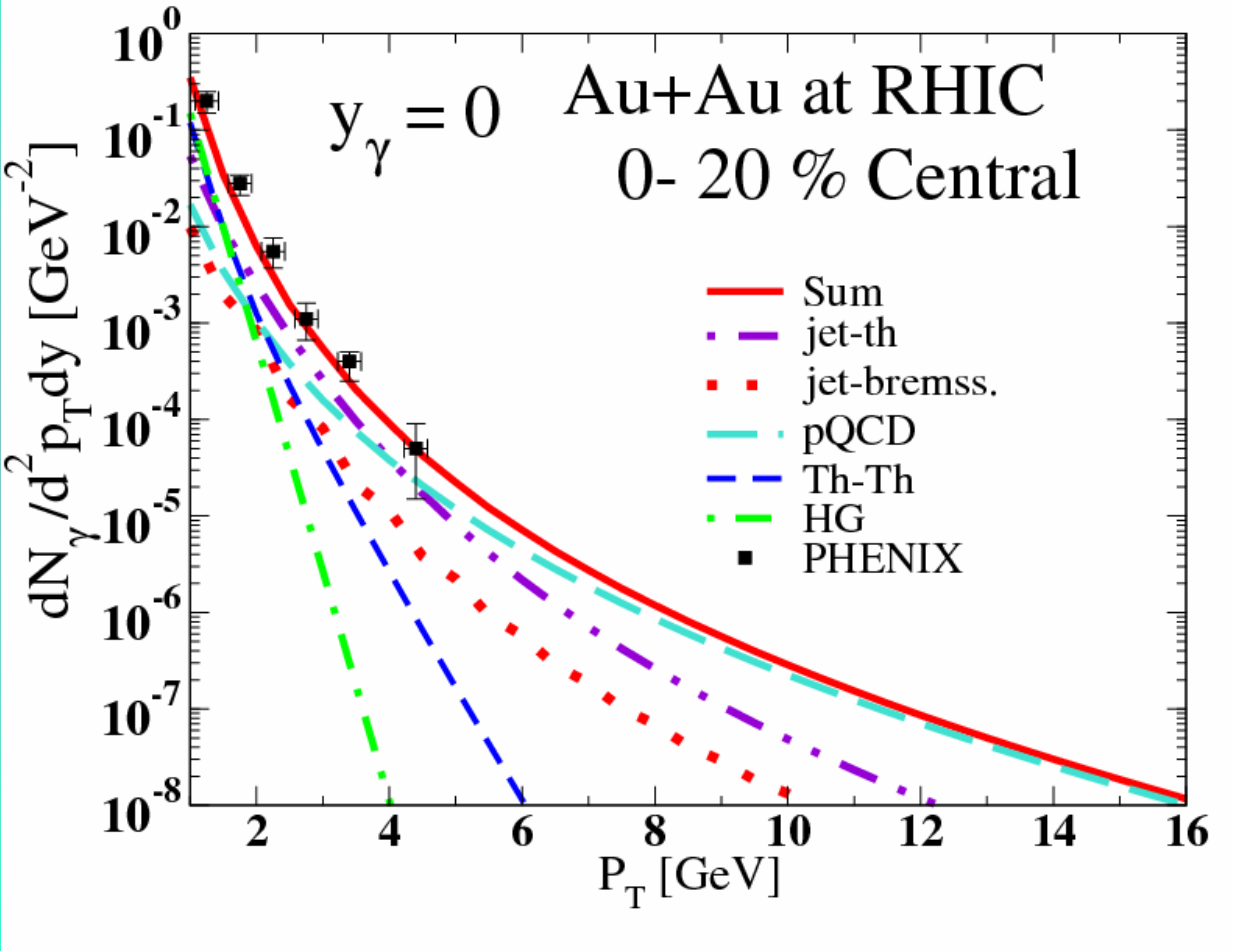
- NLO pQCD

  L.E. Gordon, W. Vogelsang
  Phys. Rev. D48, 3136 (1993)

- A particular thermal Model
  - 2+1 hydro, τ_0=0.15 fm/c
  - T_0^{ave}=360 MeV(T_0^{max}=570 MeV)

  D. d'Enterria, D. Peressounko
  nucl-th/0503054
  - The data are consistent with thermal + pQCD
  - pQCD questionable down to low pT
  - needs confirmation from analysis of p+p data

Medium induced photon is still dominant at mid-pT



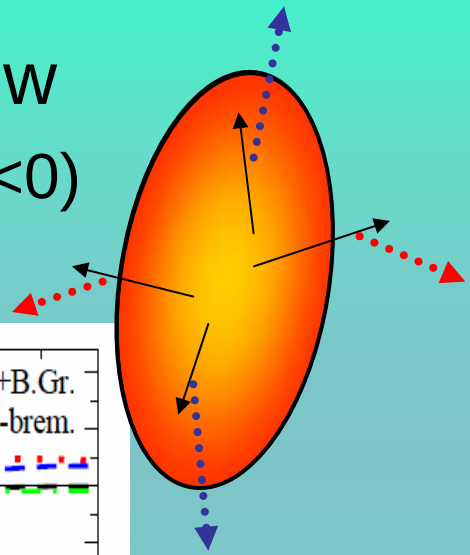
- A prediction: jet-conversion is dominant at mid-pT region

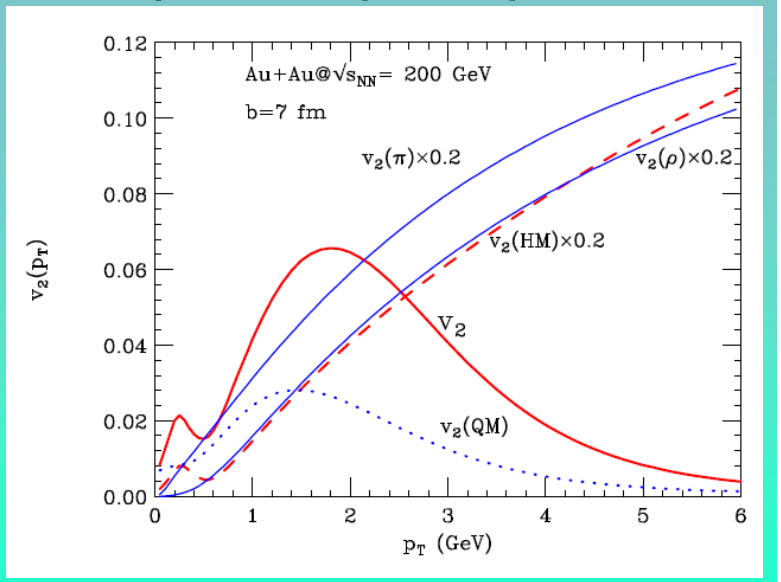
C. Gale (QM05) hep-ph/0512109

Azimuthal anisotropy

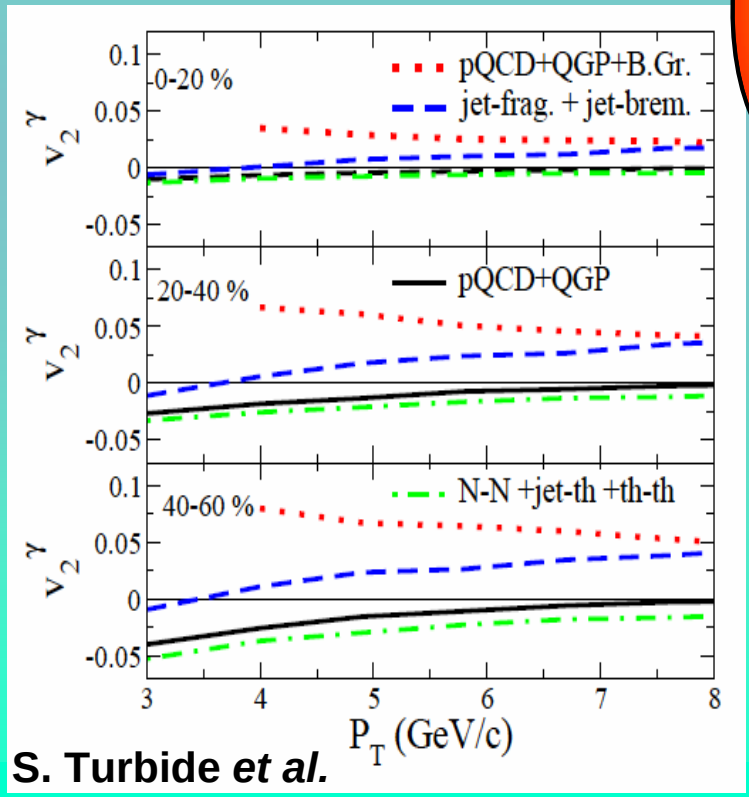
Other approach to extract medium induced photon

- Measurement of direct photon elliptic flow
  - Jet-photon conversion, Bremsstrahlung (v2<0)
  - Jet-fragmentation (v2>0)
  - Thermal photon
  - pQCD (v2=0)





Thermal photon (HG+QGP): 6% v2
R. Chatterjee *et al.* nucl-th/0511079

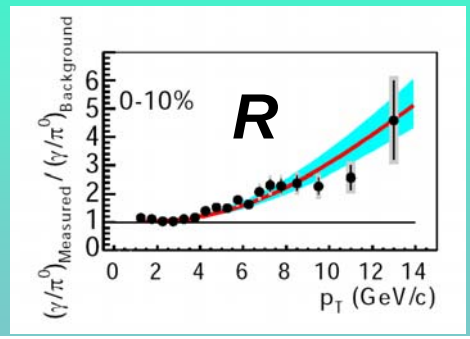


S. Turbide *et al.*
Phys.Rev.Lett. 96 (2006) 032303

v2 measurement at PHENIX

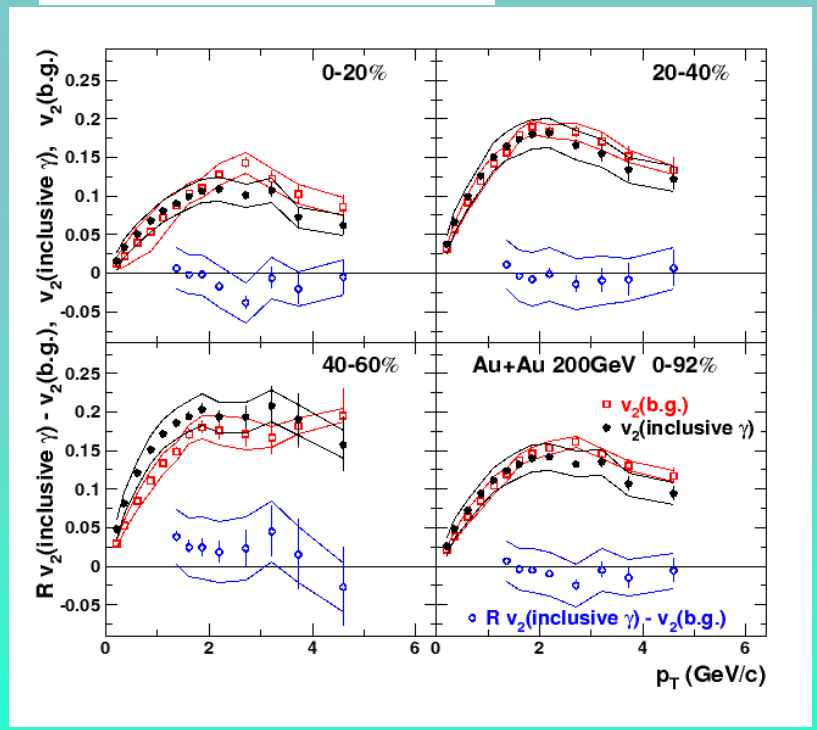
- Standard reaction plane method

$$v_2^{direct} = \frac{R \cdot v_2^{inclusive} - v_2^{hadronic}}{R - 1}$$



PRL 94, 232301

- **Direct gamma v2 is consistent with 0**
  - large error due to the large systematic error on direct photon excess ratio "*R*"
- New Run4 PHENIX result may extend the pT
  - improvement of S/N may reduce the error
- New reaction plane detector improve RP resolution
  - will be installed for RHIC Year-7 run



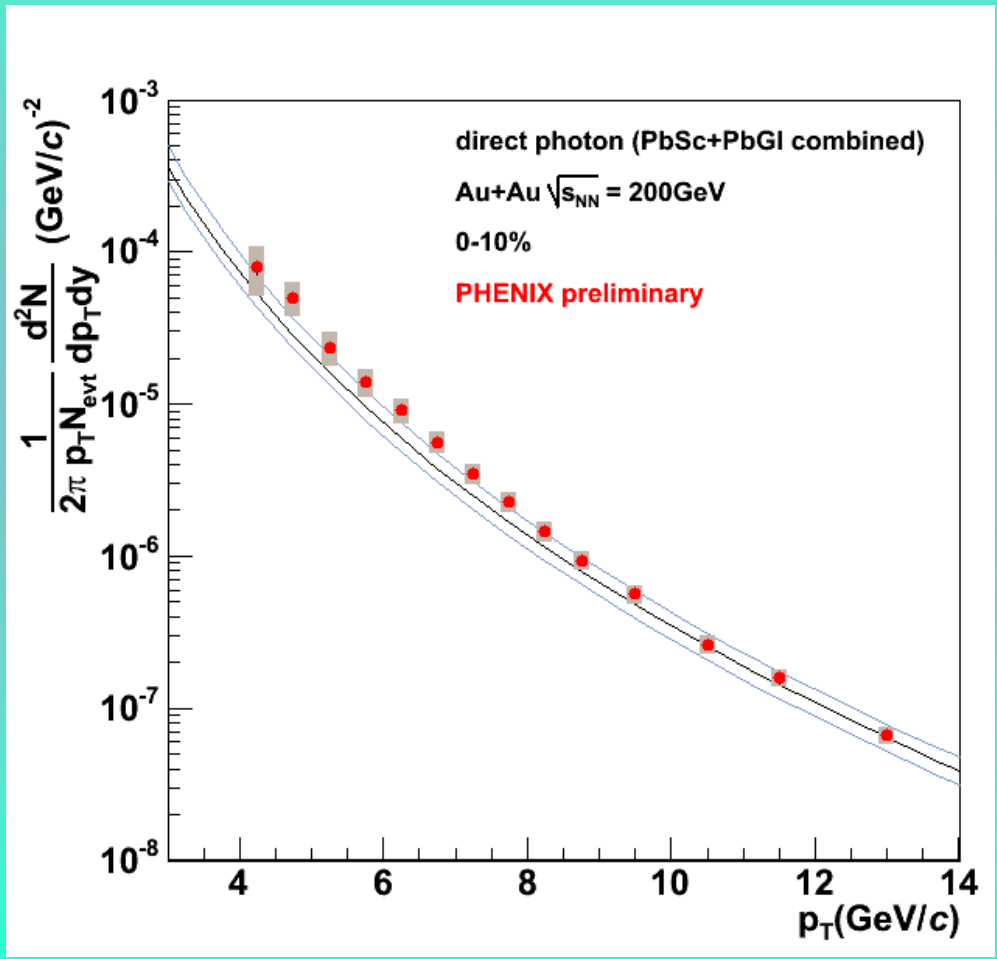
Phys. Rev. Lett. 96, (2006) 032302

Summary

- Measurement of direct photon using PbSc/PbGl
  - Clear signal of direct photon at high-pT due to the strong suppression of neutral hadrons
  - Extend up to 18GeV/c
- Measurement for high-pT region
  - The theoretical calculation taking jet-conversion into account agree with data well at pT<15GeV
- Measurement for mid-pT region
  - new technique for measuring direct photons in HI collisions through internal conversion
- Azimuthal anisotropy of direct γ
  - Consistent with v2=0

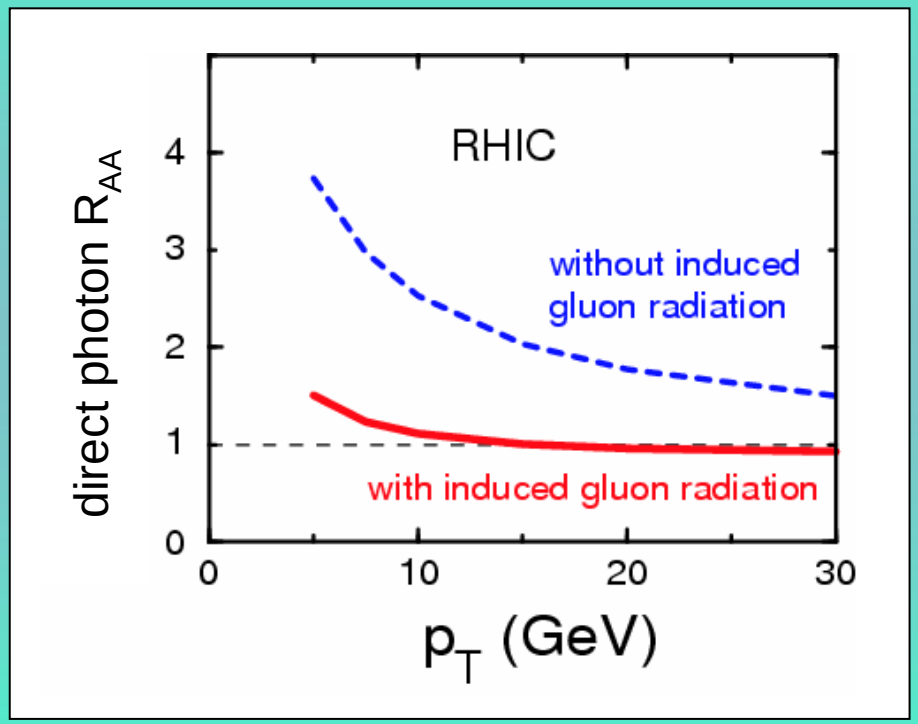
backup

Comparison with pQCD



Direct photon source

Zakharov, hep-ph/0405101



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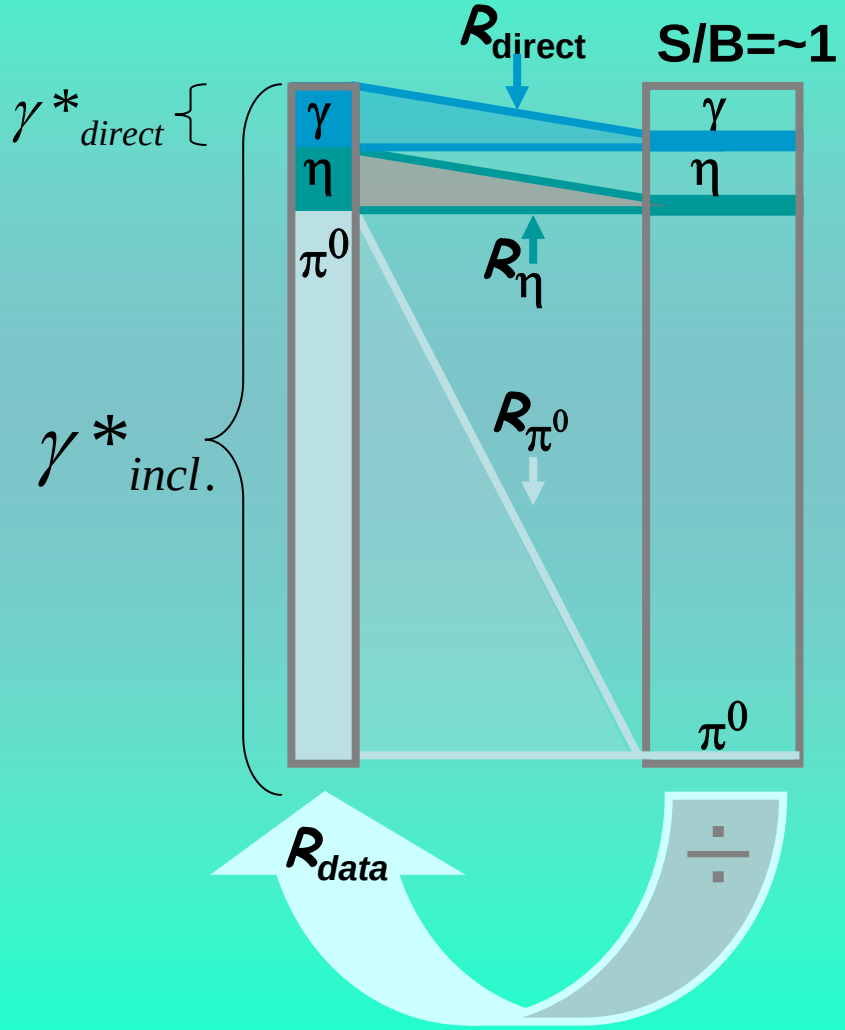

$$R_{data} = \frac{\gamma^*_{direct} \cdot R_{direct} + (\gamma^*_{inclusive} - \gamma^*_{direct}) \cdot R_{\pi^0+\eta}}{\gamma^*_{inclusive}}$$

$$\frac{\gamma^*_{direct}}{\gamma^*_{incl.}} = \frac{R_{data} - R_{\pi^0+\eta}}{R_{direct} - R_{\pi^0+\eta}}$$