Photons at RHIC

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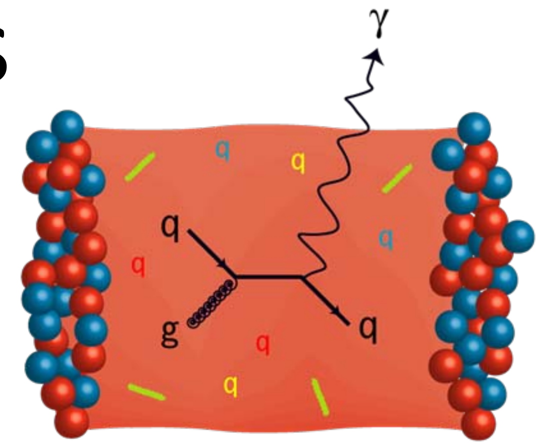
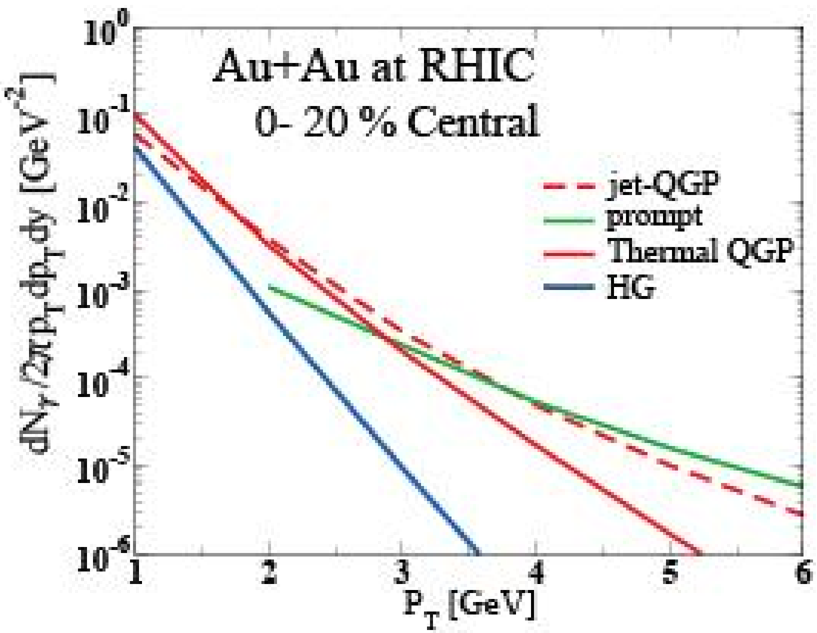
Direct photons



- ☐ Sensitive and direct probe for all stages of a collision
  - ☐ Generated in every stage of the collision
  - ☐ Leave a medium without a strong interaction
  - → Provide key inputs (T_{init} & τ_0) to describe evolution of the matter
- ☐ Their p_T are characterized by their origin.



S. Turbide et al., PRL77,024909(2008)

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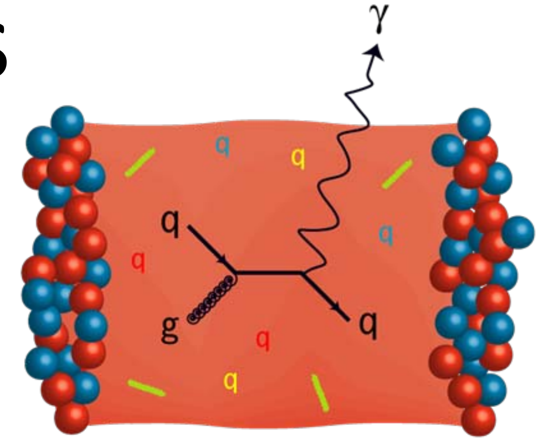

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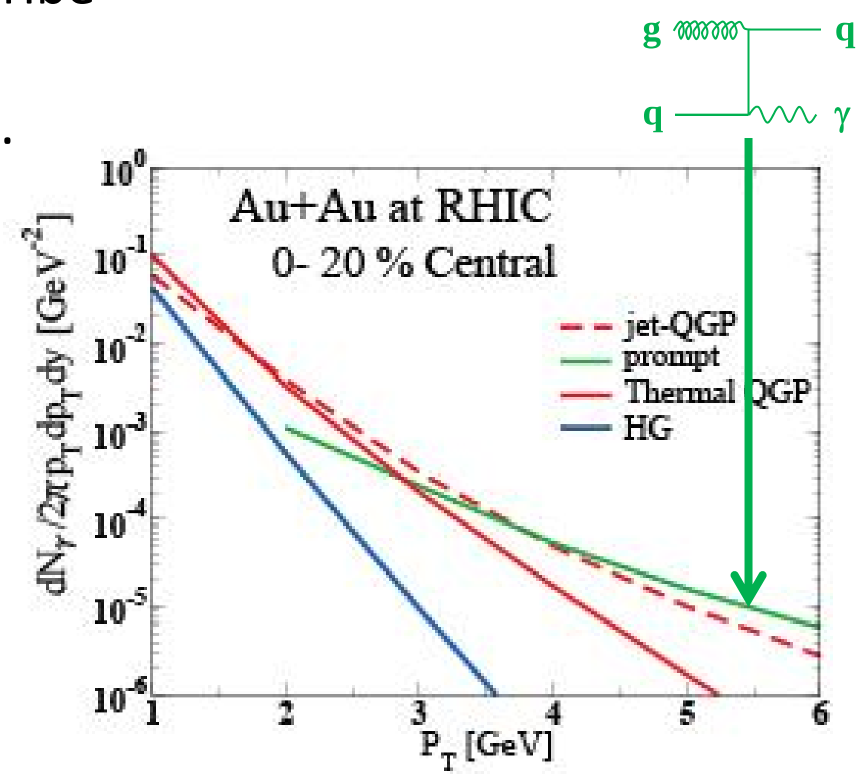

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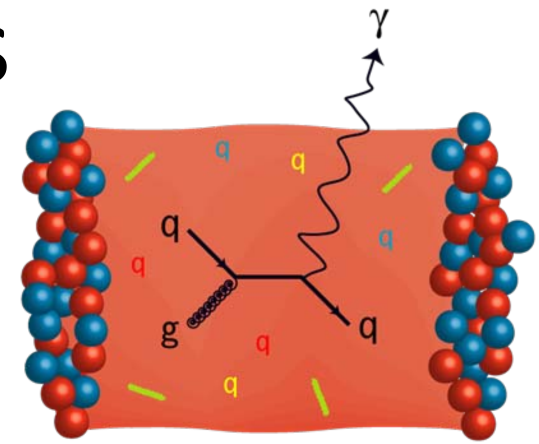

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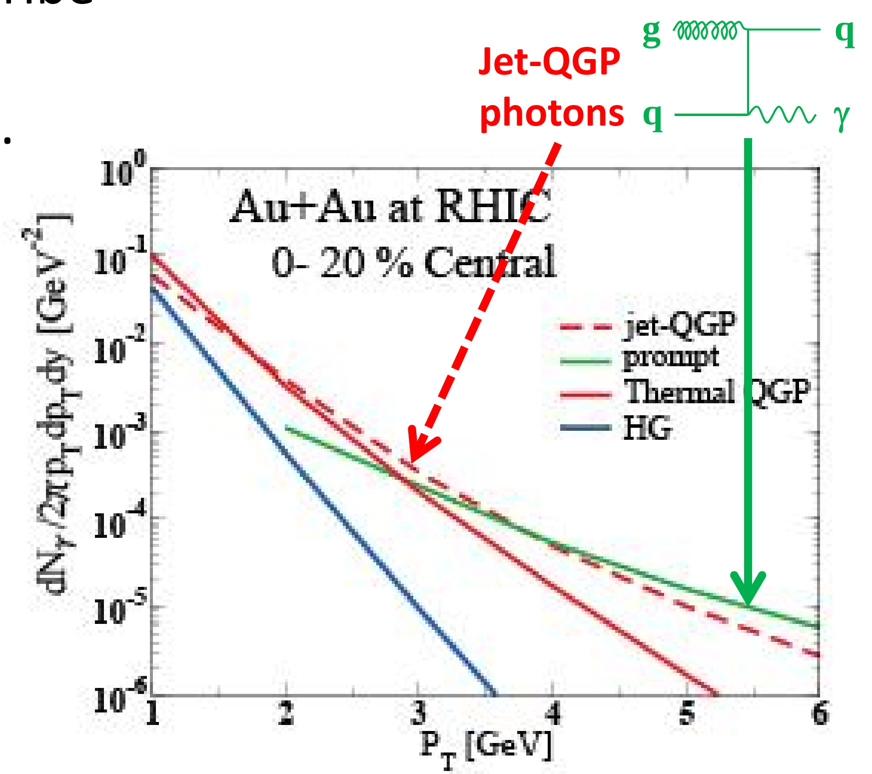

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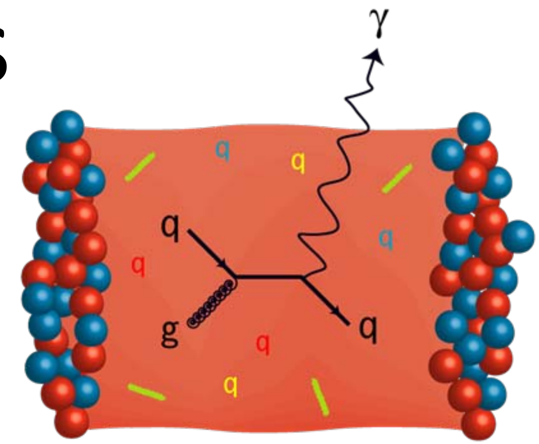

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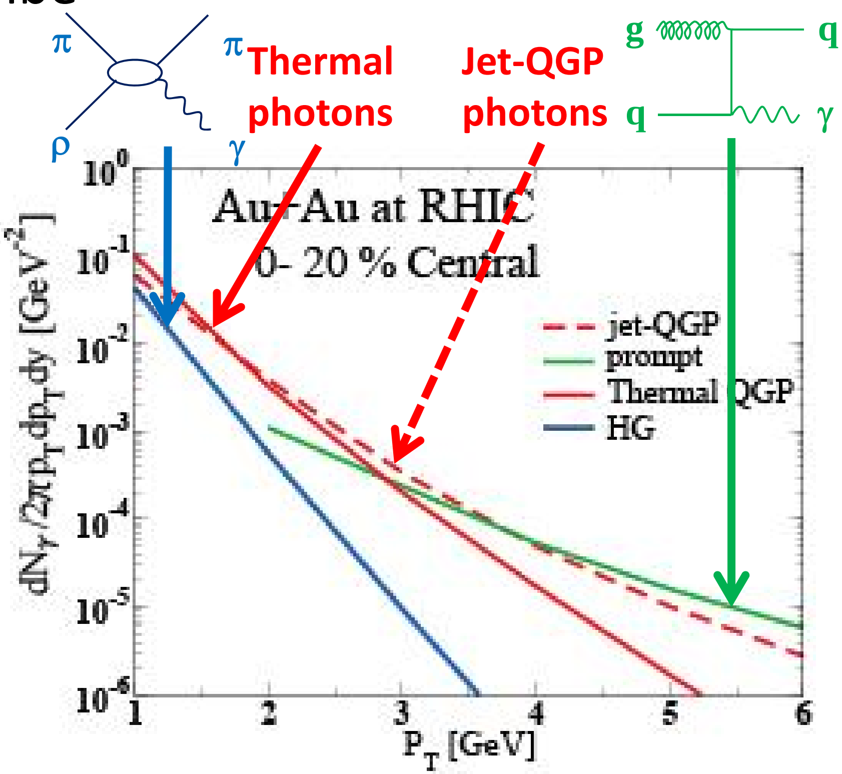

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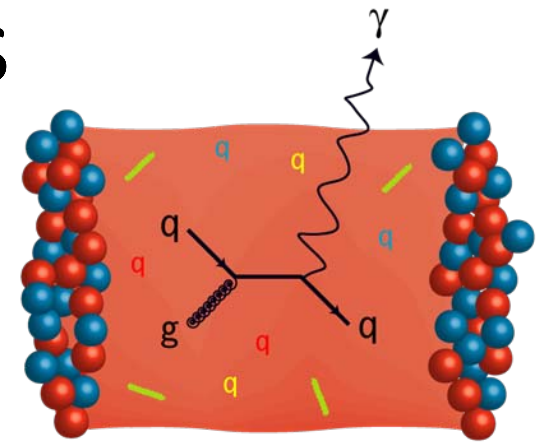

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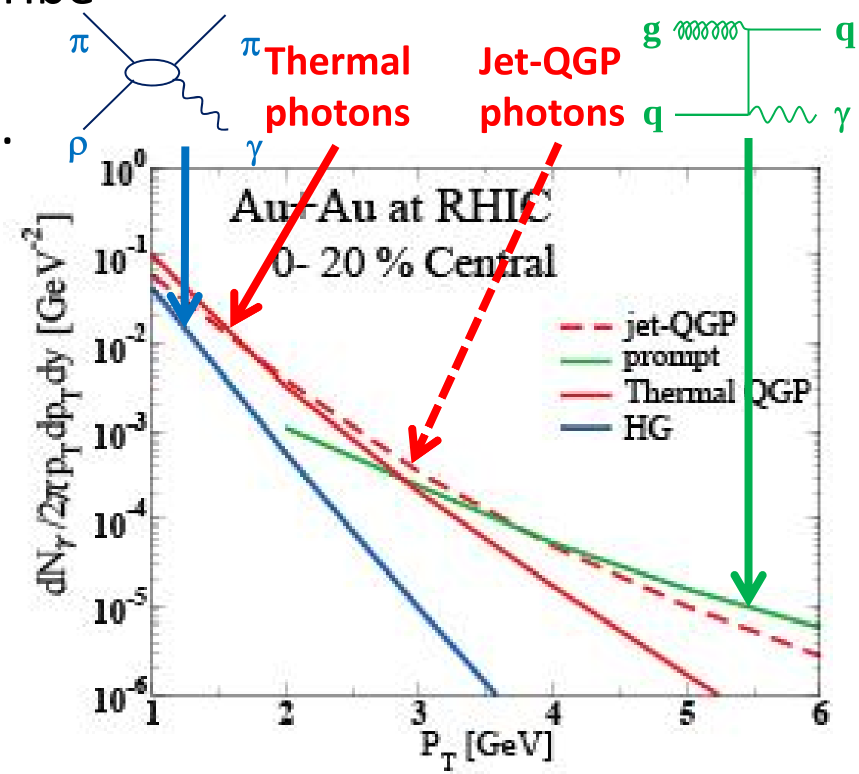

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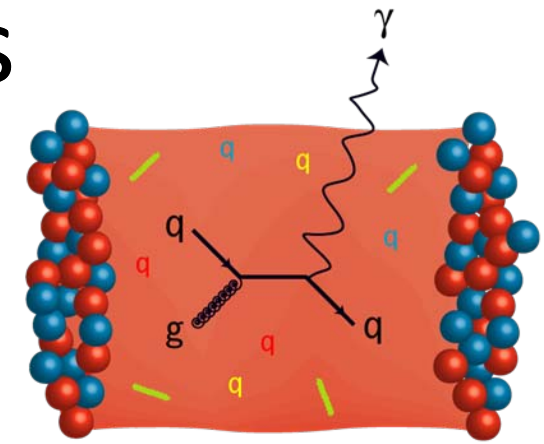
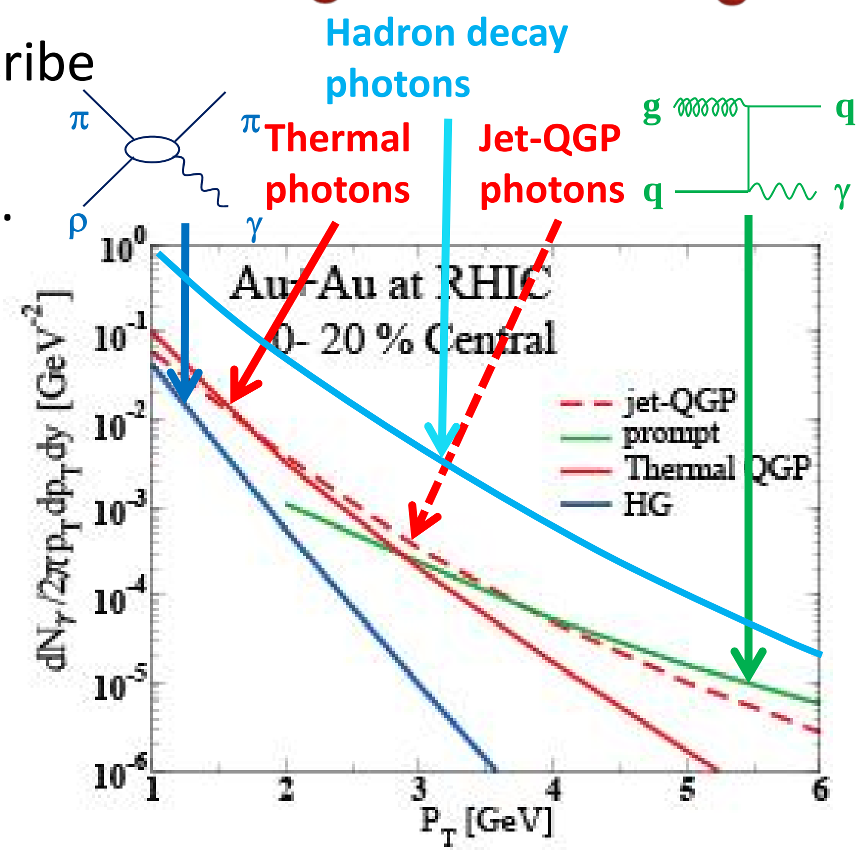
- Elliptic flow, v_2 of direct photons can disentangle their production processes.
- Direct photon measurements are very challenging due to a large background from hadron decays.



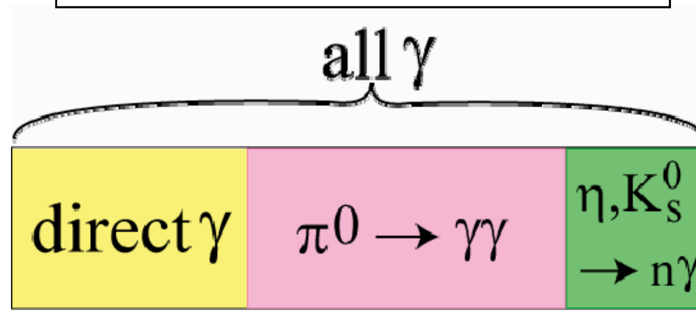


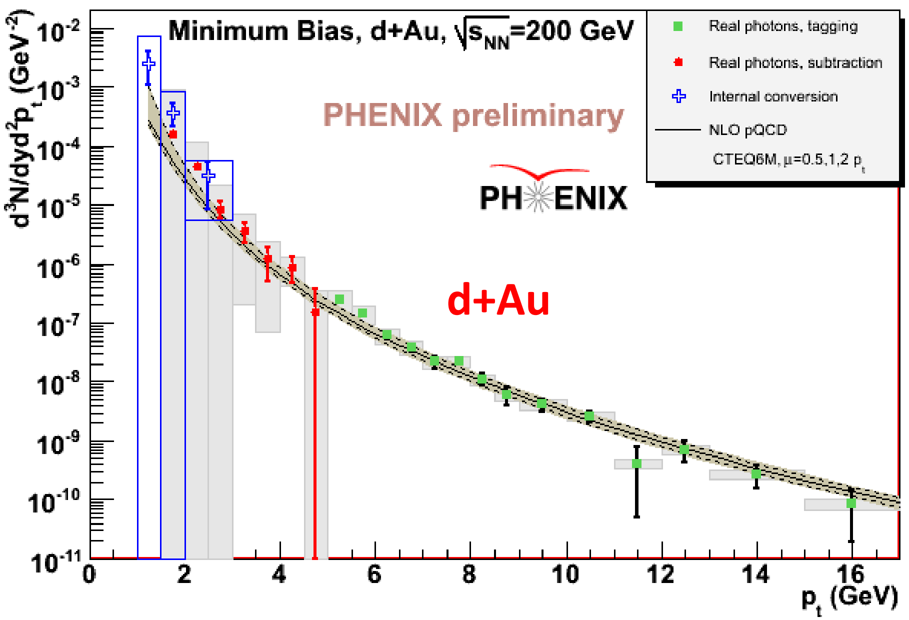
S. Turbide et al., PRL77,024909(2008)

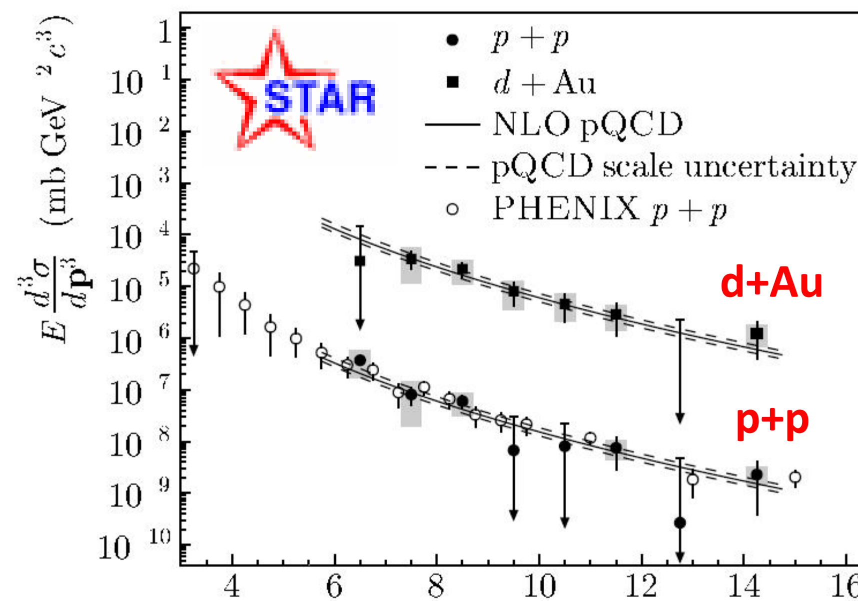
Hard photon measurements

- Statistical subtraction method by EMCals
  - Firstly measure π^0, η
  - Strong suppression of high p_T hadrons helps to measure direct γ for Au+Au
    → Identify remaining γ after subtraction of hadron decay γ as direct γ.

$$\gamma^{Direct} = \gamma^{All} - \gamma^{Hadronic}$$



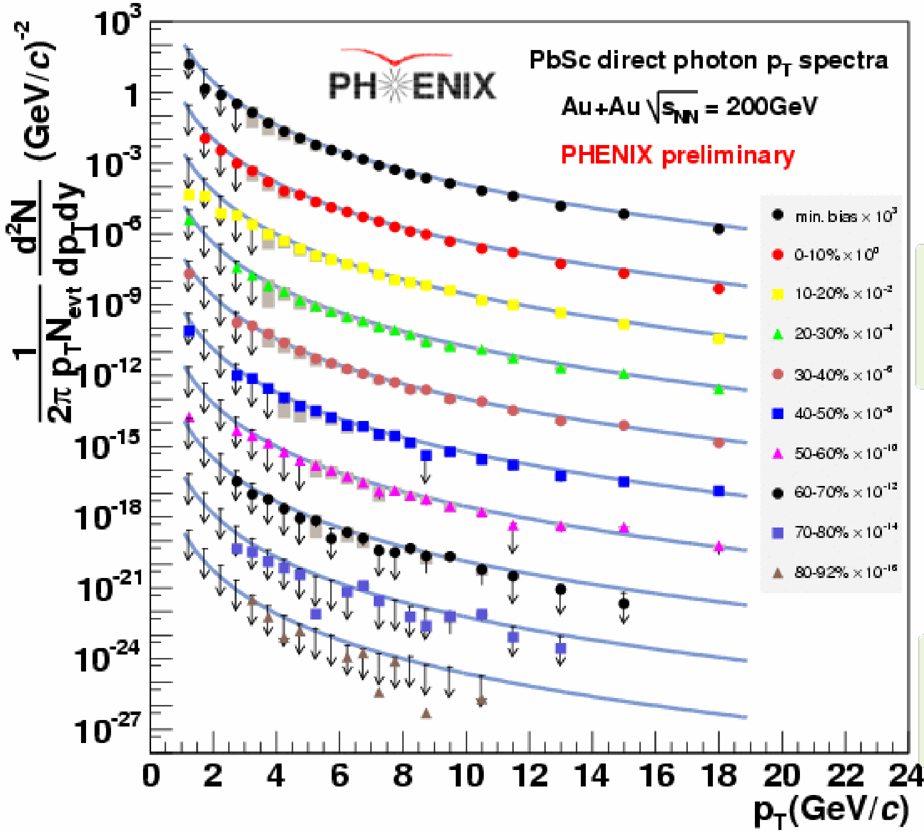


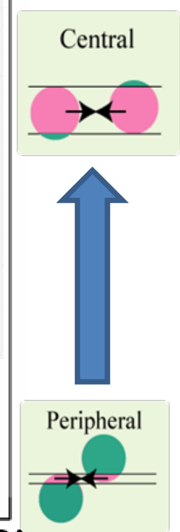


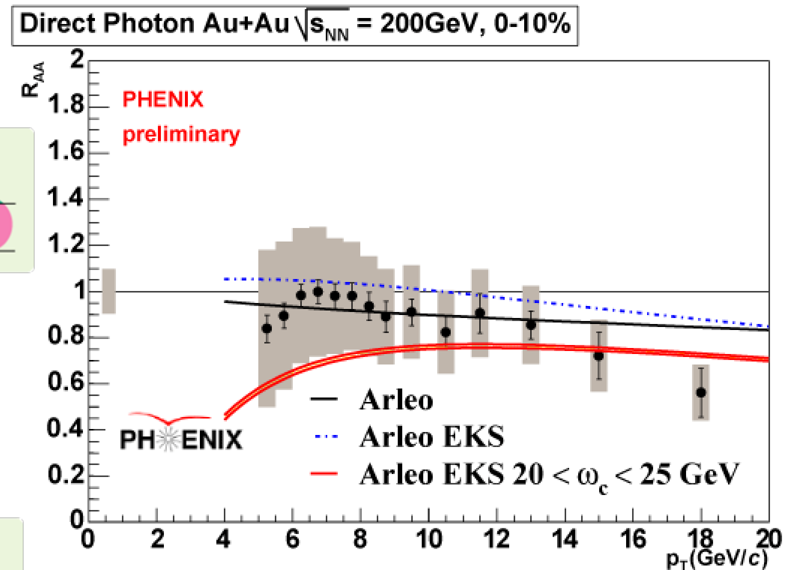
B.I. Abelev et al., PRC81,064904(2010)

- p+p : Consistent with NLO pQCD calculation → Works for pQCD test
- d+Au : Also consistent with N_{coll}-scaled NLO pQCD → Little nuclear effects

Hard photons in Au+Au





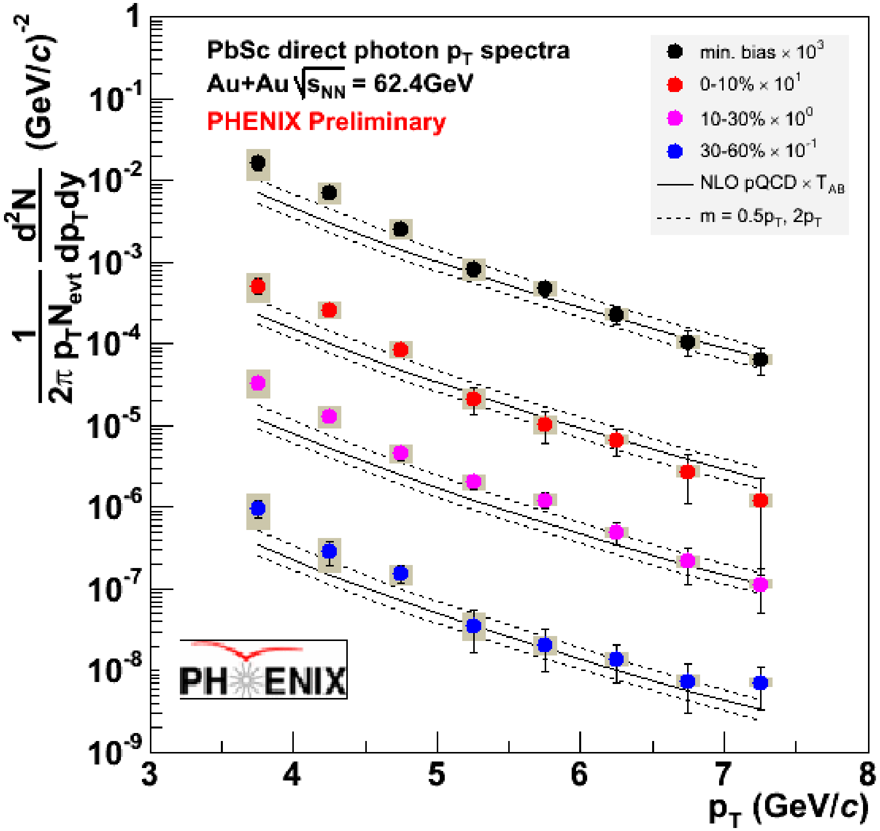


- ☐ Spectra : Also follows N_{coll}-scaled p+p for different centrality bins
- ☐ R_{AA} : Suppression at high p_T (p_T>14GeV/c) due to isospin effect? or due to initial state energy loss?

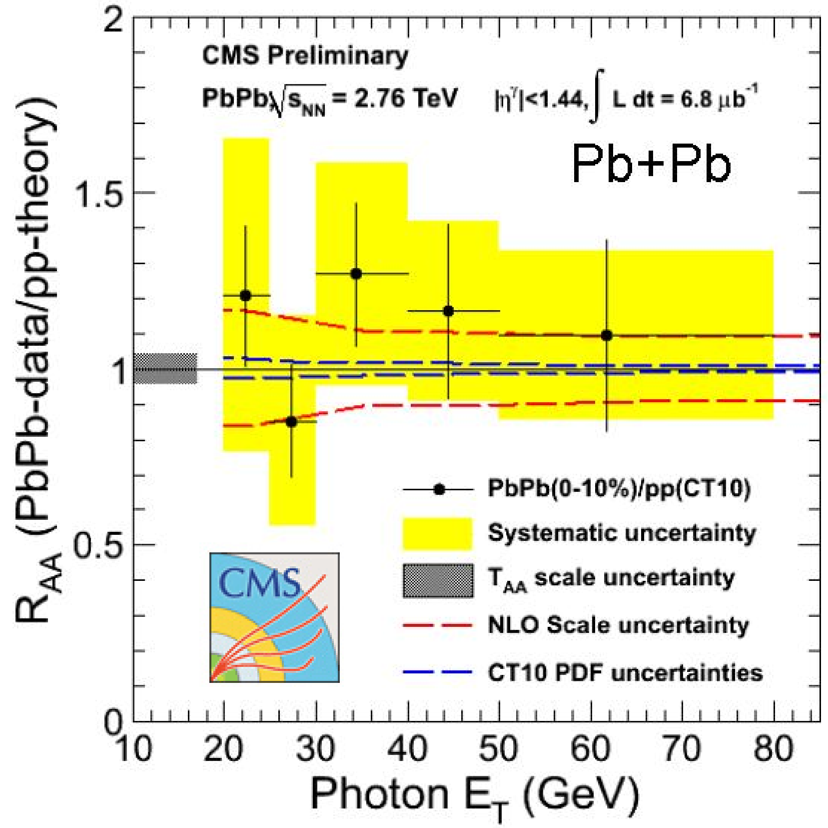
→ Experimentally challenging due to merging effect for decay photons.

Different collision energy

Au+Au : 62.4GeV



Pb+Pb : 2.76TeV



- ☐ 62.4GeV : Isospin effect would be at lower p_T → Consistent NLO pQCD
- ☐ 2.76TeV : CMS measured isolated photons → No suppression

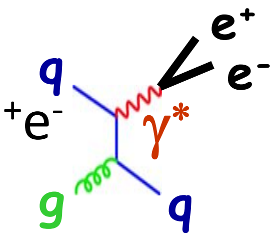
→ Inconsistent with 200GeV Au+Au, but efforts to finalize the 200GeV Au+Au result are ongoing.

How to measure low pT photons

- Hard to measure by EMCals due to a finite energy resolution

→ Alternative method has been developed : "Virtual photon method"

Virtual photon method

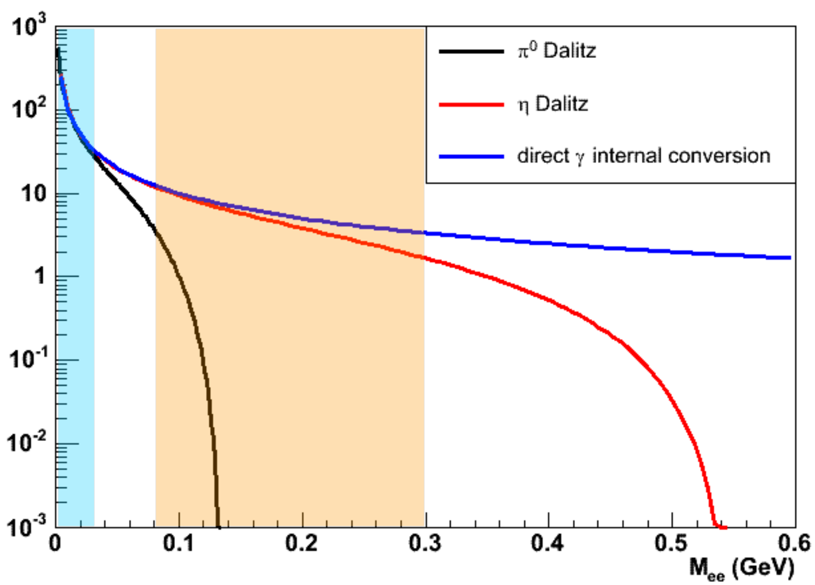


- Basic idea : Any source of γ can emit γ^*, convert to low mass e^+e^-
- How to identify direct $\gamma^* \rightarrow e^+e^-$:

Relation between γ and associated $\gamma^* \rightarrow e^+e^-$ emission rates

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

Process dependent factor



- Direct γ^* : If $p_T^2 \gg m_{ee}^2$, $S(m_{ee}) \sim 1$
- Dalitz decay : $S(m_{ee}^2) = \left|F(m_{ee}^2)\right|^2 \left(1-\frac{m_{ee}^2}{m_h^2}\right)^3$

→ Extraction of direct $\gamma^* \rightarrow e^+e^-$ can be made by utilizing m_{ee} shape difference between direct γ^* and hadrons.

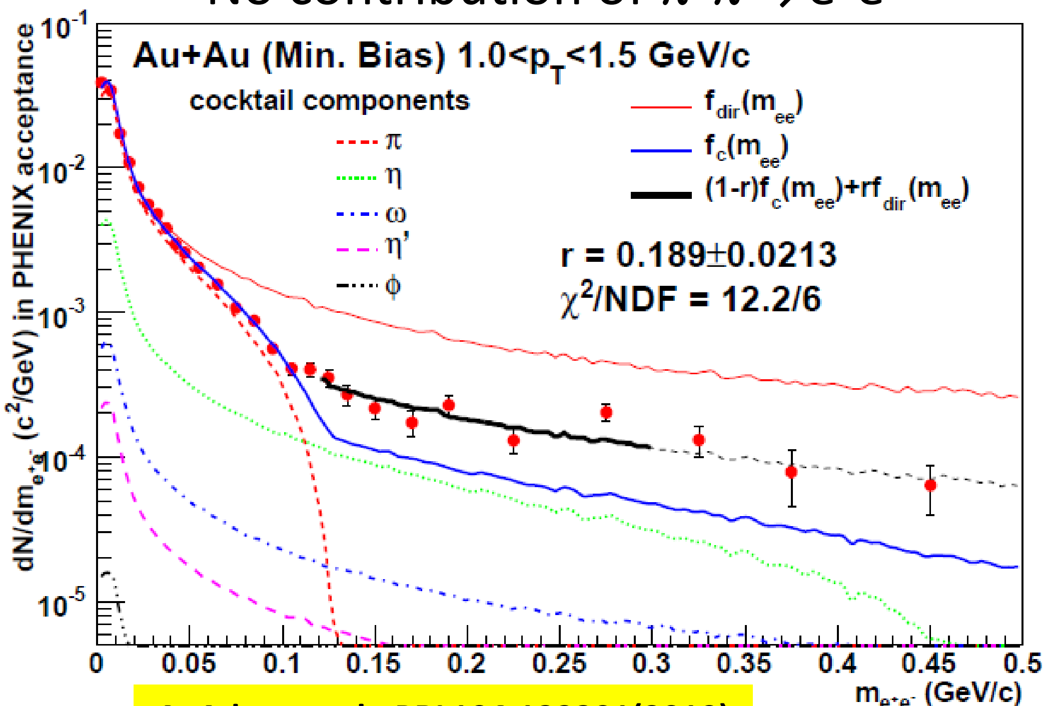
Determination of direct γ fraction

$$f_{data}(m_{ee}) = (1-r)\cdot f_c(m_{ee}) + r\cdot f_{dir}(m_{ee})$$

r **: direct γ/inclusive γ**

Hadrons ($f_c(m_{ee})$) **Direct γ*** ($f_{dir}(m_{ee})$)

- Determination of direct γ fractions in 0.1-0.3GeV/c^2 for p_T>1GeV/c
  - ✓ Negligible contribution of $\pi^0 \rightarrow \gamma e^+e^-$
  - ✓ Satisfy an important assumption of $p_T^2 \gg m_{ee}^2 \rightarrow S(m_{ee}) \sim 1$
  - ✓ No contribution of $\pi^+\pi^- \rightarrow e^+e^-$



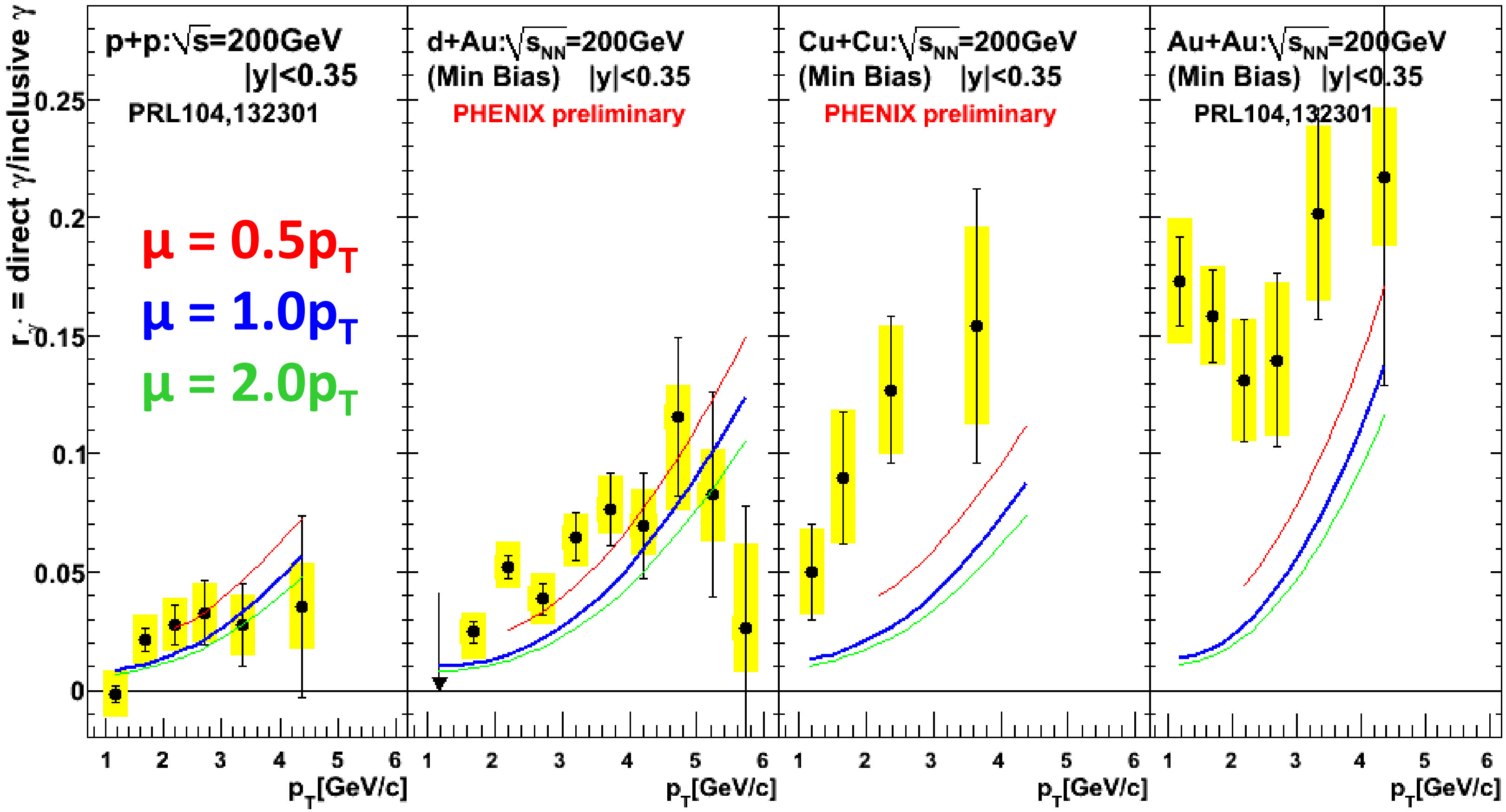
A. Adare et al., PRL104,132301(2010)

- Enhanced e^+e^- yield over known hadron contributions is clearly seen due to direct $\gamma^* \rightarrow e^+e^-$.

- Extended fit result can also describe the data well in m_{ee}>0.3GeV/c^2.

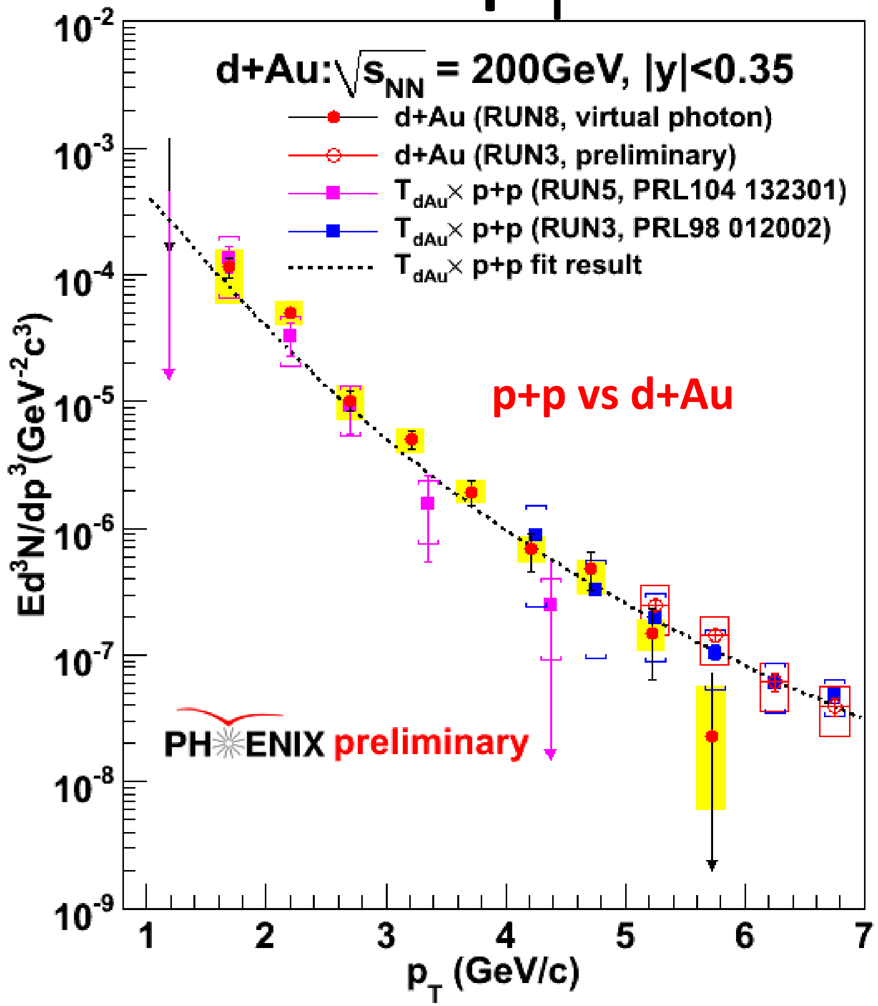
Direct γ fractions

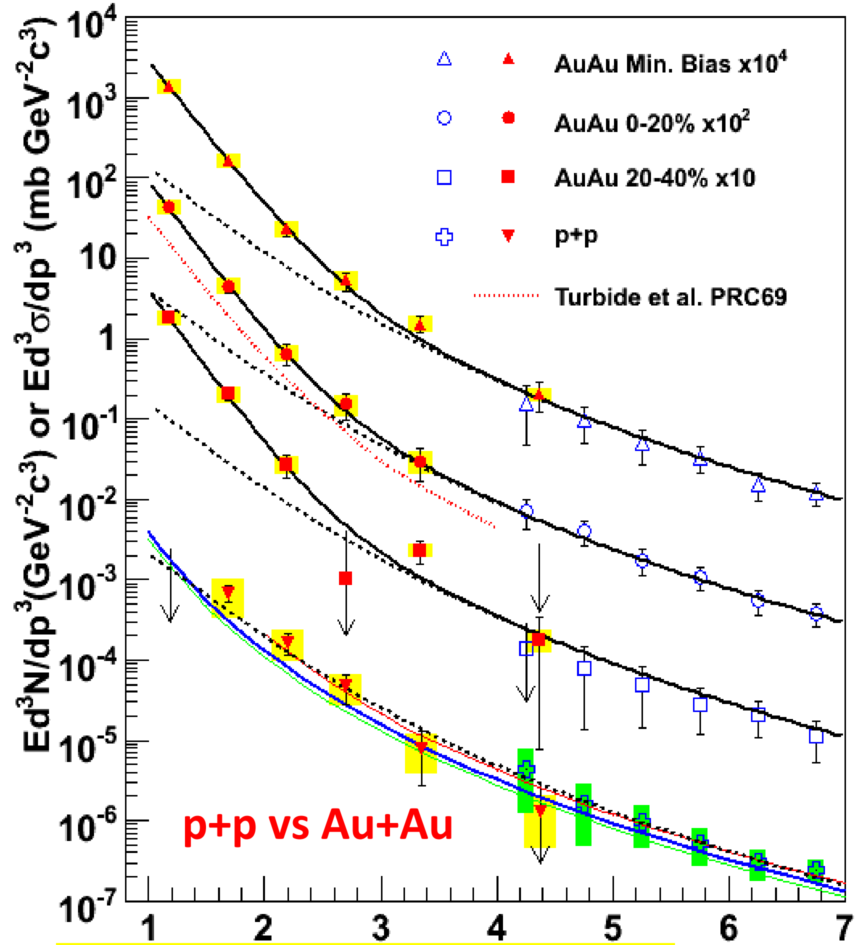
NLO pQCD expectations are calculated as : $\frac{d\sigma_\gamma^{NLO}}{dp_T} \Big/ \left(\frac{d\sigma_\gamma^{NLO}}{dp_T} + \frac{d\sigma_\gamma^{hadron}}{dp_T} \right)$



- Direct γ fractions from virtual photon method plays an important role on determination of direct photon v_2 in low p_T region.

Low p_T direct photon results



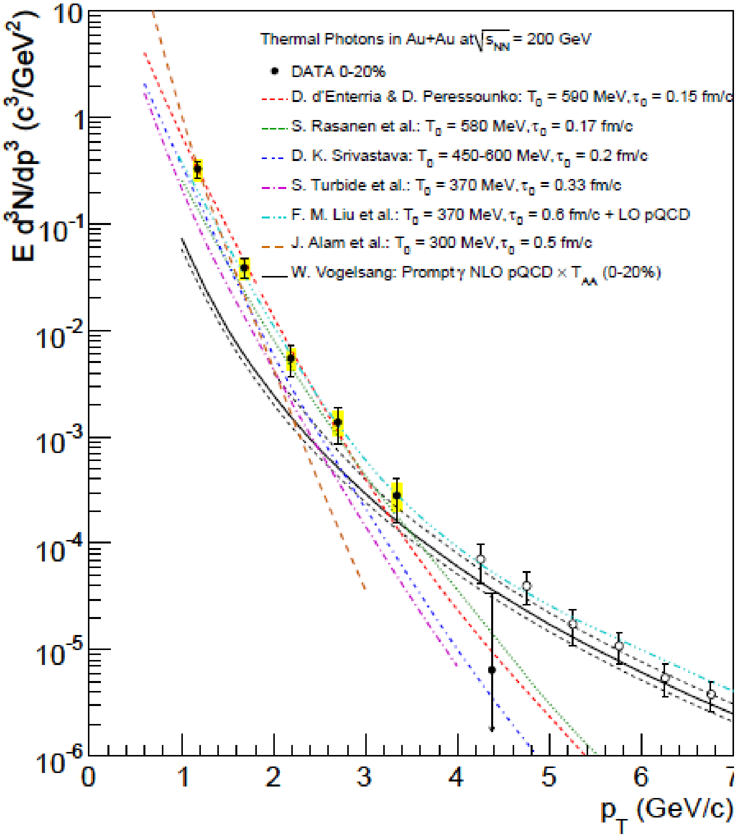


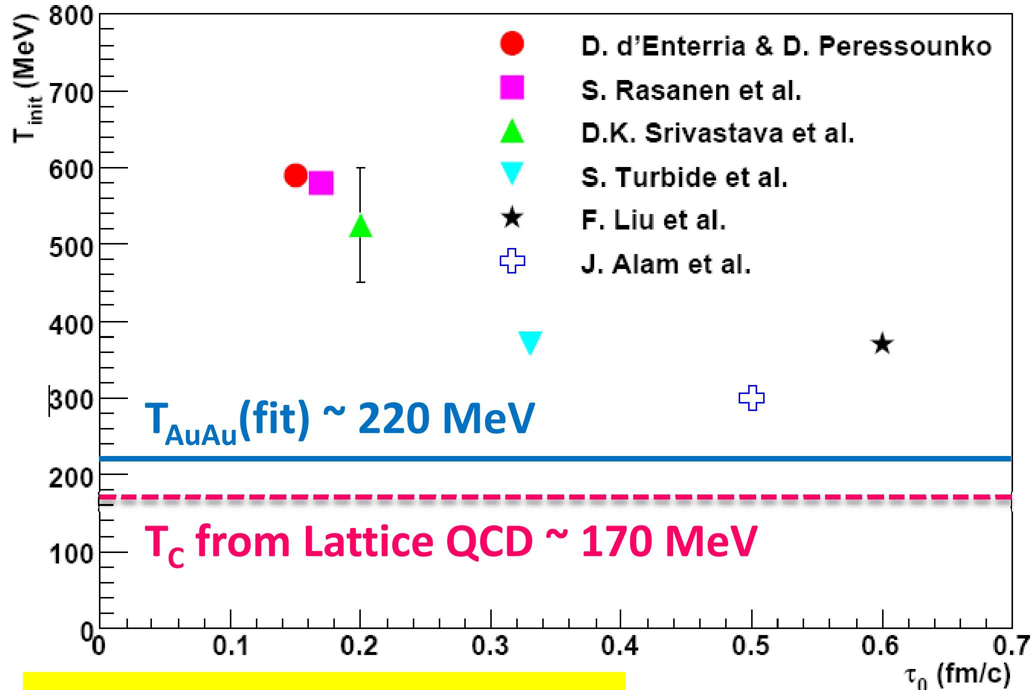
A. Adare et al., PRL104,132301(2010)

- p+p vs d+Au : Consistent → Little nuclear effects
- p+p vs Au+Au : Observation of a clear excess in p_T<3GeV/c

→ Exponential fit gives inverse slope of T = 221±19^{stat}±19^{syst}MeV (Central).

T_{init} & τ_0



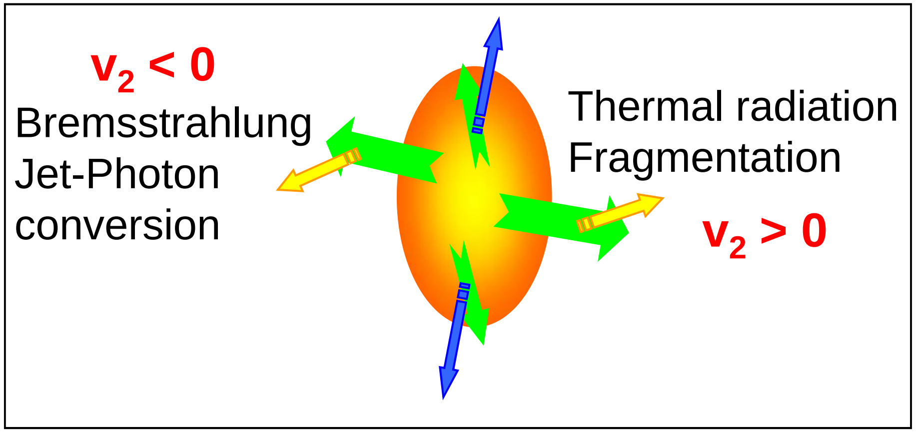


A. Adare et al., PRC81,034911(2010)

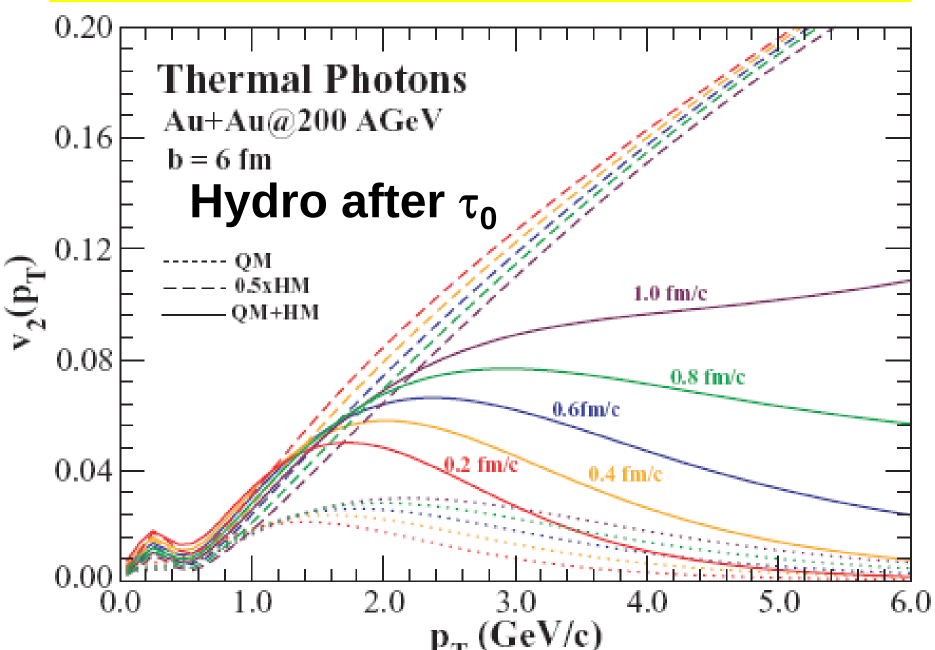
- Hydrodynamic models agree with the data within a factor of 2
- Uncertainty on T_{init} (300-600MeV) is still large.
  - ✓ Depending on thermalization time τ_0 (0.1-0.6fm/c)

→ Need sensitive observable to further constrain T_{init}

Further constraint of T_{init} & τ_0 by v_2



R. Chatterjee & D. K. Srivastava, **PRC 79**, **021901 (2009)**



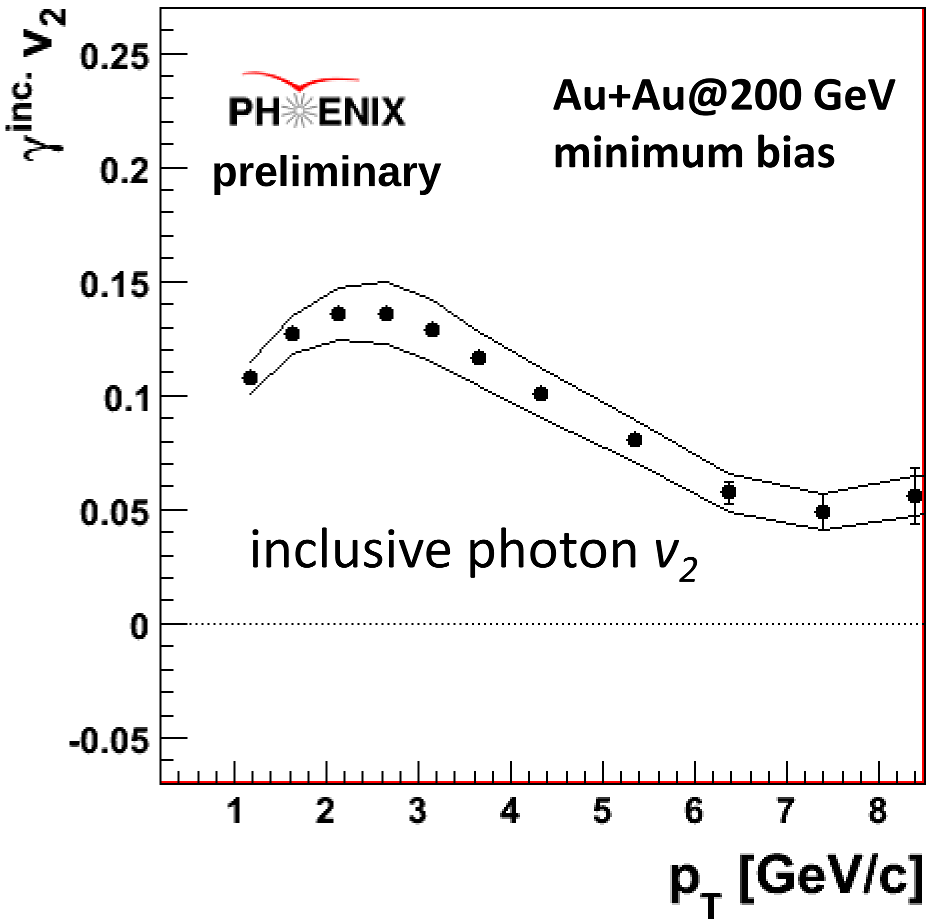
- Different direct photon production processes have different behavior of v_2.
  - ✓ Initial hard scattering → v_2=0
  - ✓ Thermal radiation & Fragmentation → v_2>0
  - ✓ Bremsstrahlung & JPC → v_2<0

→Helps to disentangle compositions of direct photon spectrum

- Direct photon v_2 is also sensitive to thermalization time τ_0.
  - ✓ Early thermalization
    → Small thermal photon v_2
  - ✓ Late thermalization
    → Large thermal photon v_2

How to obtain direct photon v_2

A. Adare et al., arXiv:1105.4126



Statistical subtraction method

$$v_2^{direct} = \frac{r_\gamma v_2^{inclusive} - v_2^{hadron}}{r_\gamma - 1}$$

1. Measure inclusive γ v_2 using EMCals

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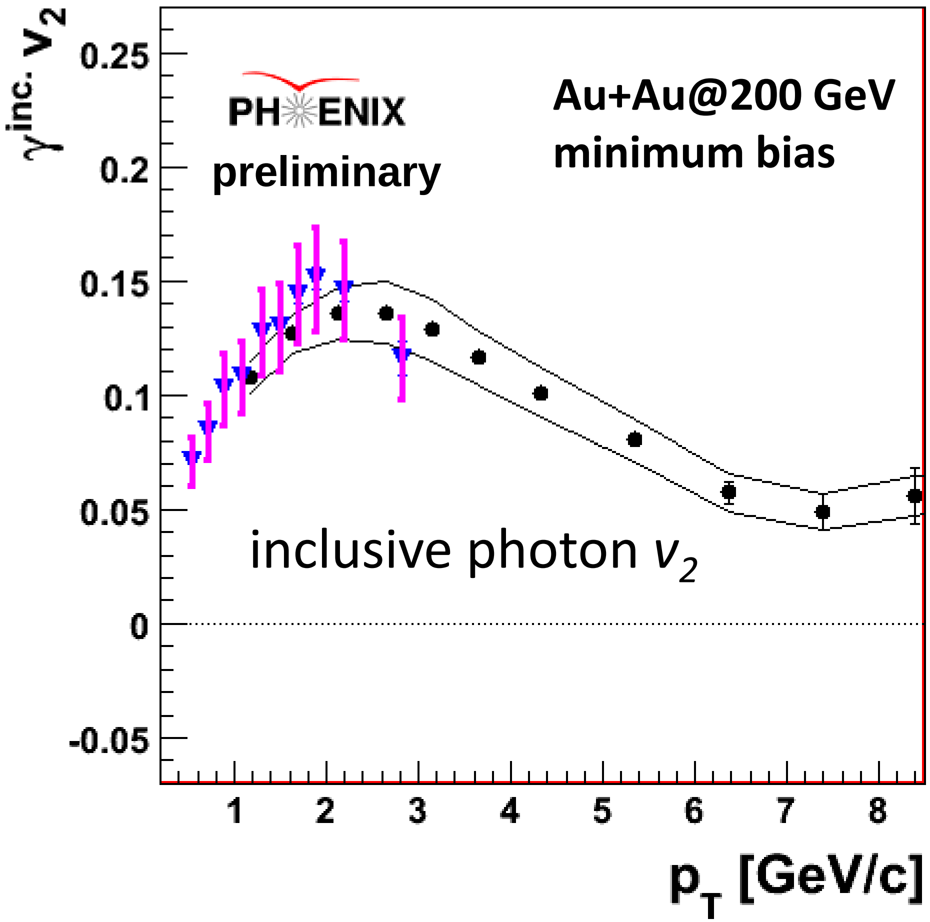

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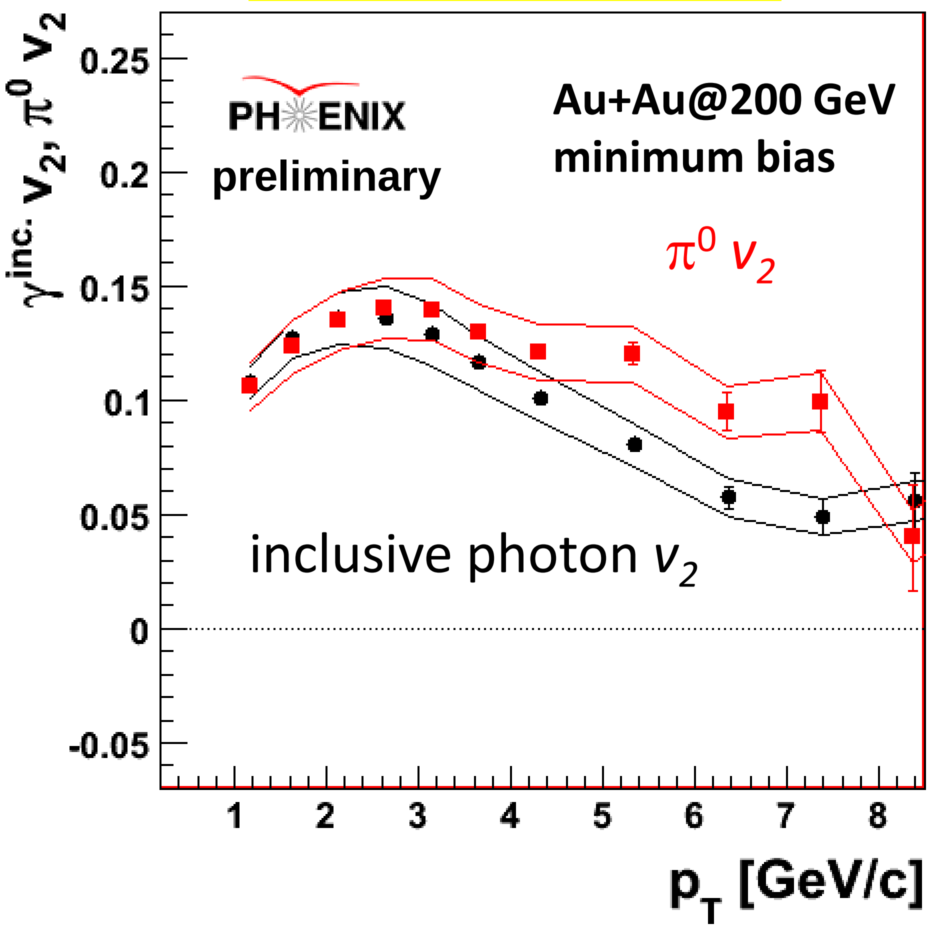

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✓ π^0 v_2 looks similar to inclusive γ v_2

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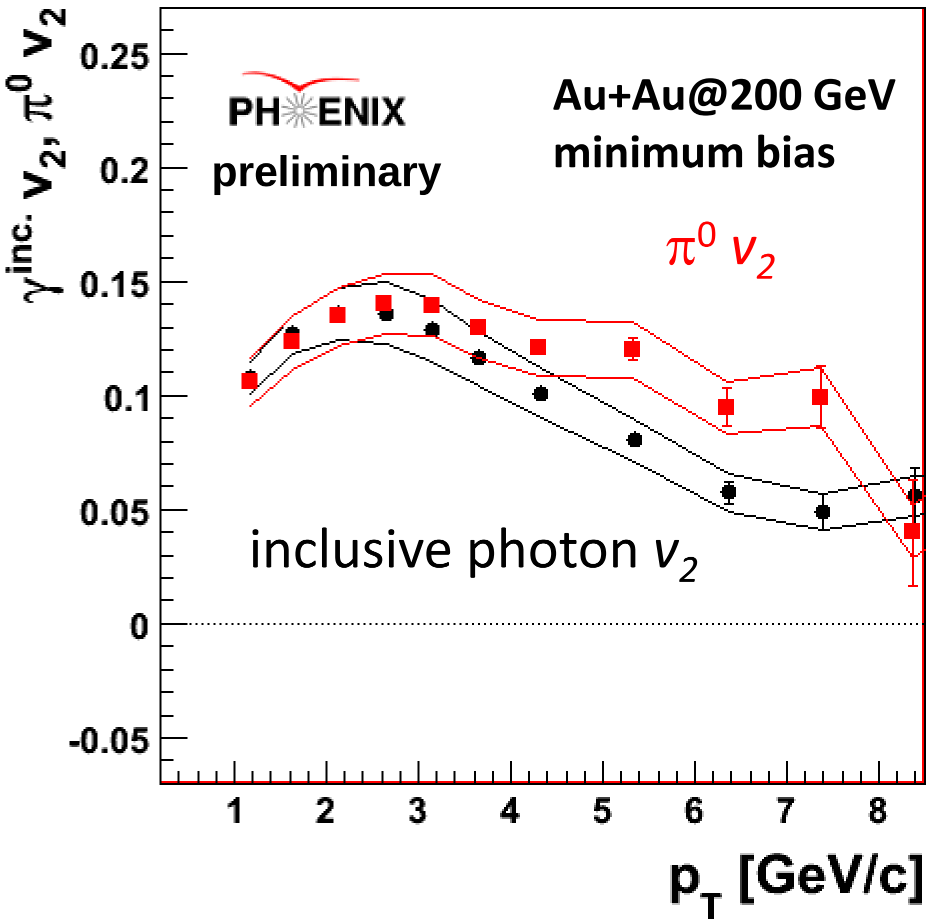

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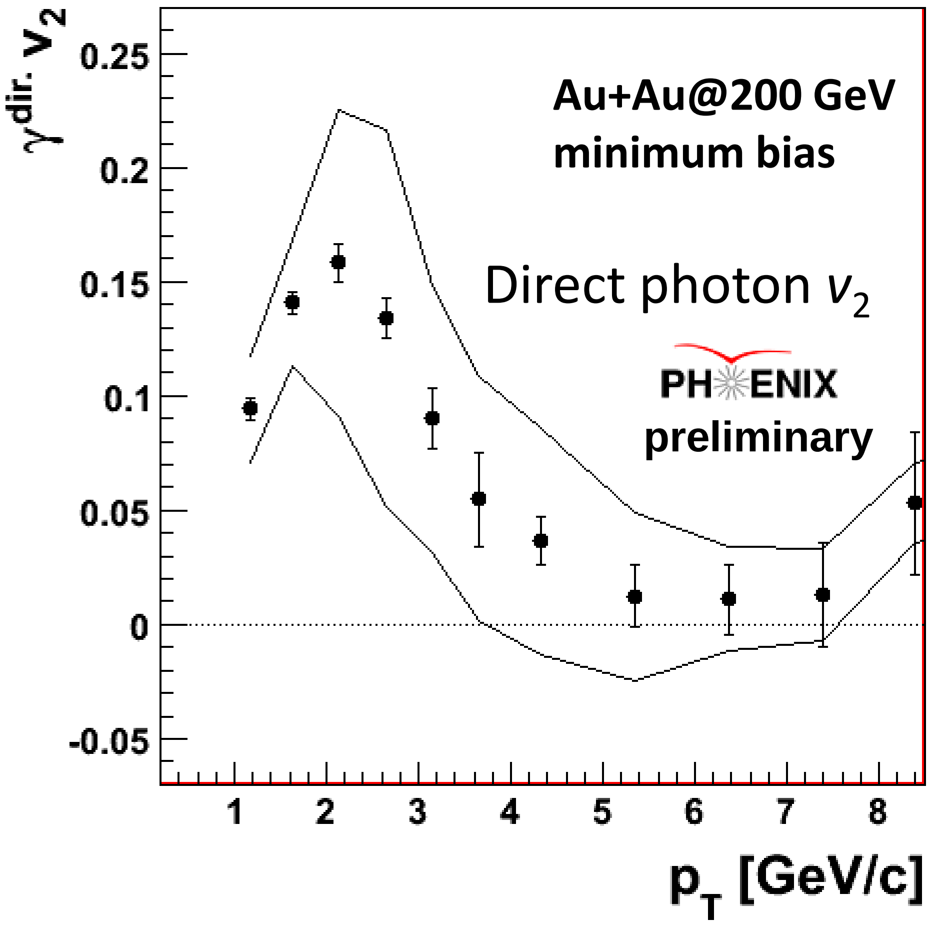
3. Subtract hadron v_2 from inclusive γ v_2 with direct γ fractions from virtual photon method

Direct photon v_2

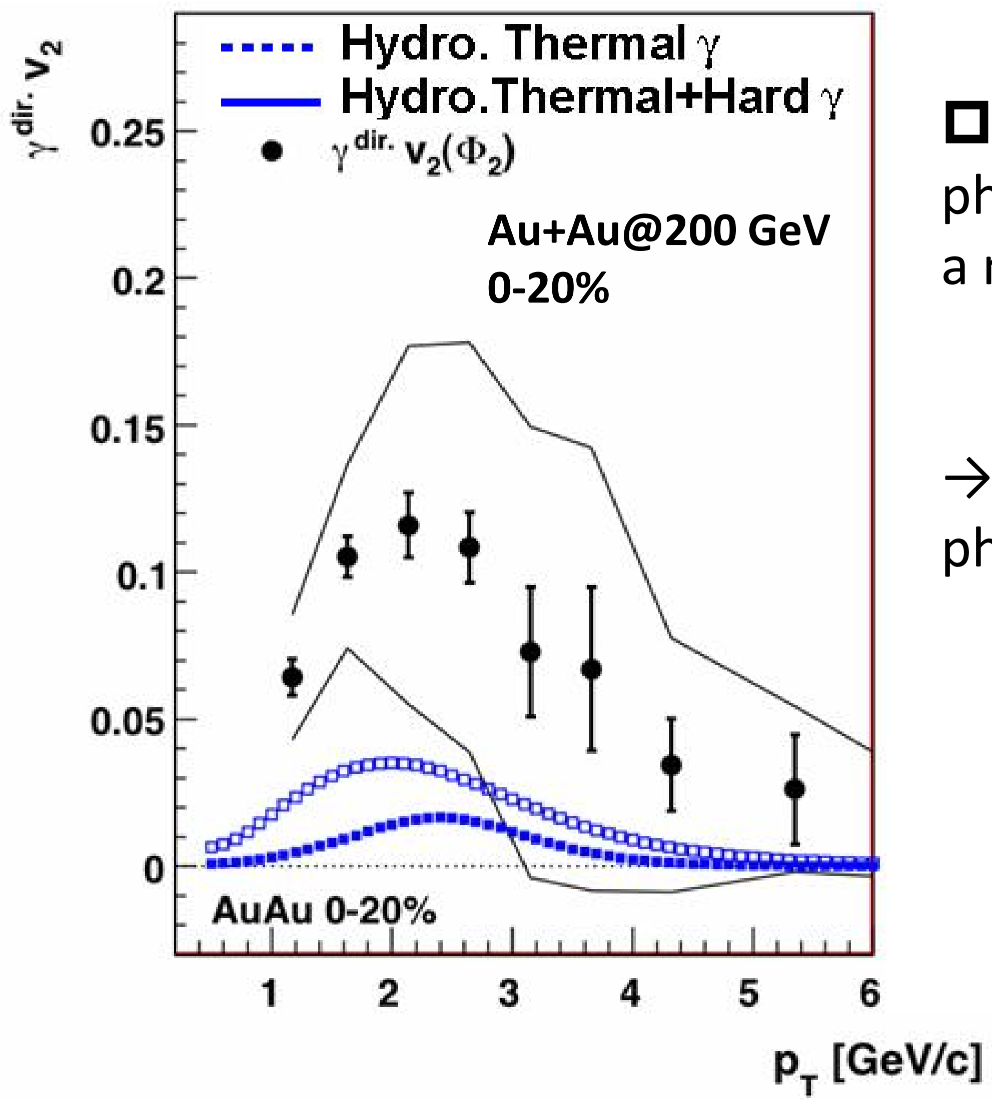
A. Adare et al., arXiv:1105.4126



- Surprisingly, a large direct photon v_2 is observed in p_T<3GeV/c
- Direct photon v_2 →0 indicates prompt photons from initial hard scatterings are dominant in p_T>5GeV/c

Comparison with model

Theory calculation: H. Holopainen et al., arXiv:1104.5371



- ☐ Models predict a shape of direct photon v_2, however they under-predict a magnitude.
  - ✓ T_{init} = 580MeV, τ_0 = 0.17fm/c

→ Need to understand observed direct photon v_2 to further constrain T_{init} & τ_0

Summary & Outlooks

- Direct photons have been successfully measured in a wide-ranging p_T region for different collision systems at RHIC.

  High pT photons

  ✓ Statistical subtraction method (using EMCals)

  ✓ Possible suppression at p_T>14GeV/c is observed in 200GeV Au+Au, but no suppression in different energy Au+Au (62.4GeV & 2.76TeV)

  Low pT photons

  ✓ Virtual photon method ($\gamma^* \rightarrow e^+e^-$)

  ✓ Enhanced yield is observed in Au+Au

- Direct photon v_2 has been also measured.

  ✓ Large v_2 at low p_T → Thermal photons?

  ✓ v_2 = 0 at high p_T → Photons from initial hard scatterings

  → Theoretical challenge to further constrain T_{init} & τ_0

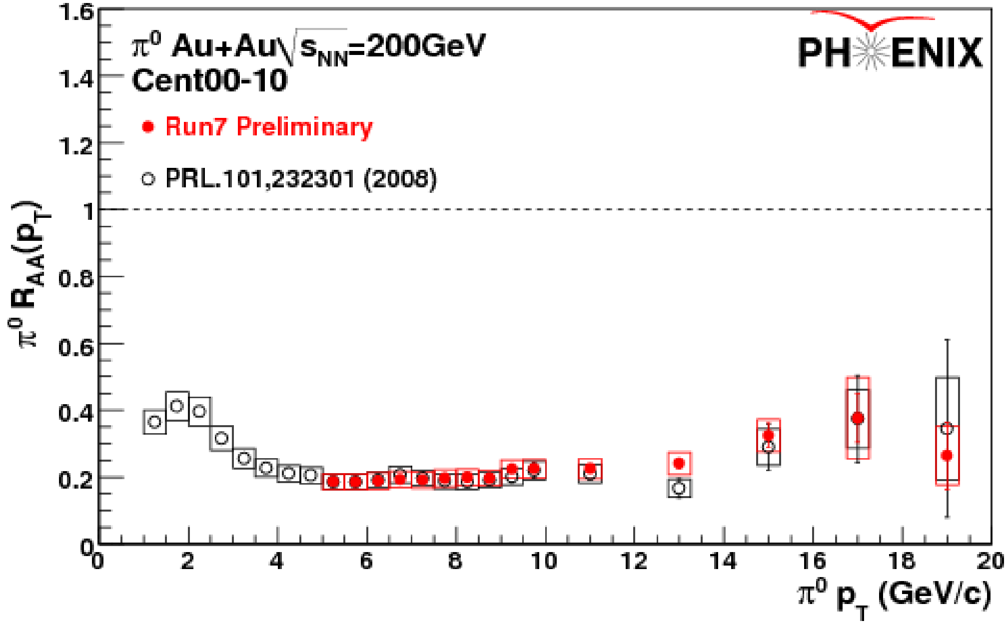
- Direct photons are still one of "hot" probes

  ✓ Low energy scan at RHIC & measurements at LHC

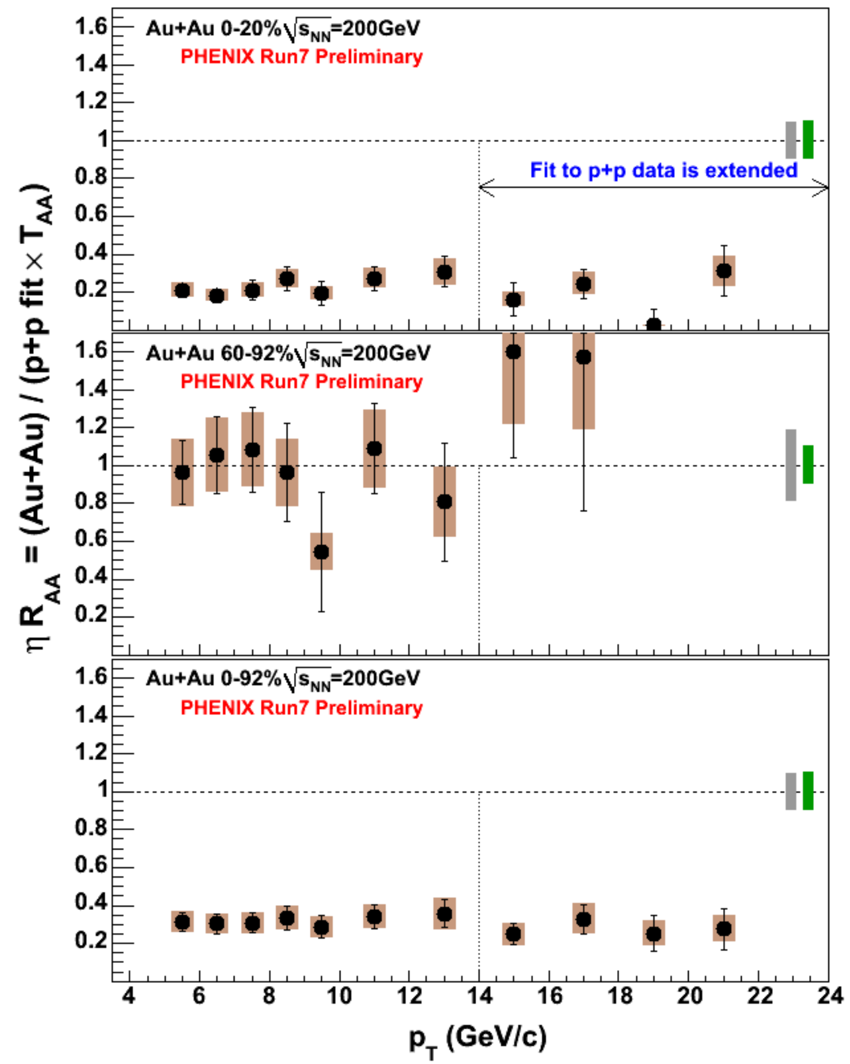
  → Systematic study in wide collision energy

Backup

π^0 & η R_{AA}



π0 Au+Au √sNN=200GeV
Cent00-10
Run7 Preliminary
PRL.101,232301 (2008)
PHENIX
π0 RAA(pT)
π0 pT (GeV/c)



Au+Au 0-20% √sNN=200GeV
PHENIX Run7 Preliminary
Fit to p+p data is extended
Au+Au 60-92% √sNN=200GeV
PHENIX Run7 Preliminary
Au+Au 0-92% √sNN=200GeV
PHENIX Run7 Preliminary
η RAA = (Au+Au) / (p+p fit × TAA)
pT (GeV/c)