Thermal photons and n_q-scaling

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RHIC/AGS User's Meeting

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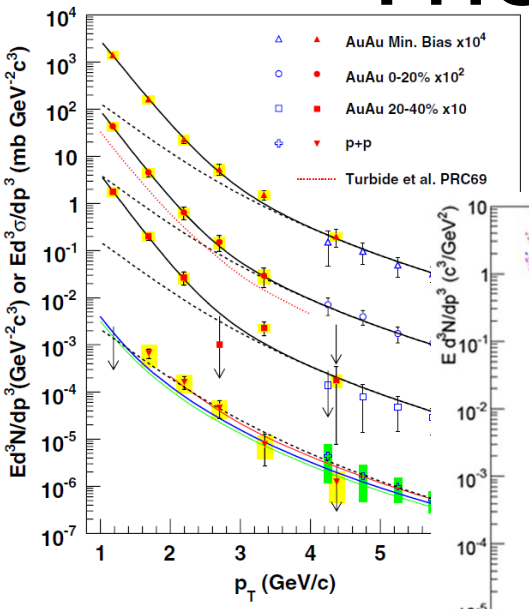
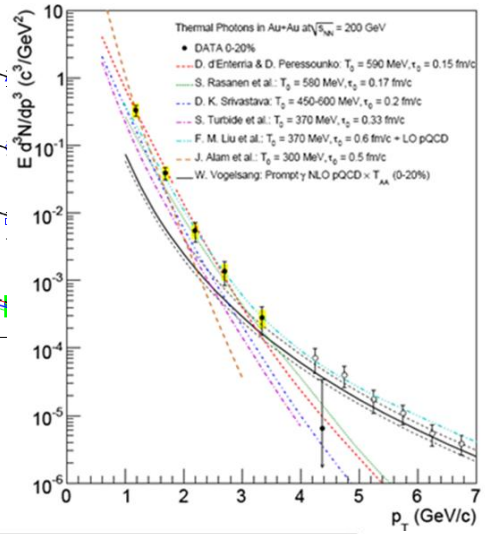
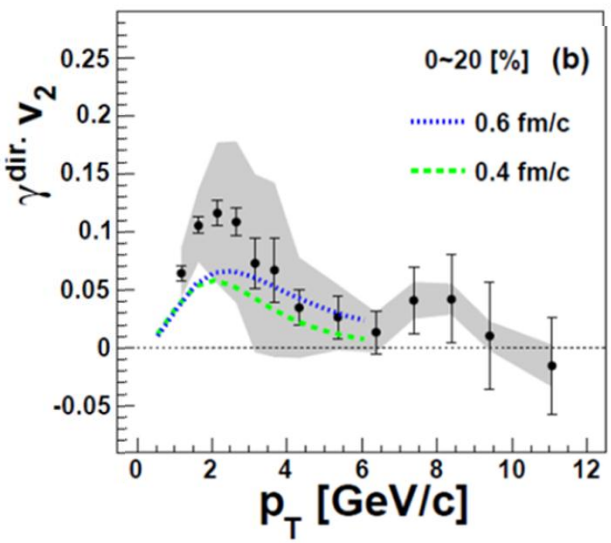
Thermal photon puzzle



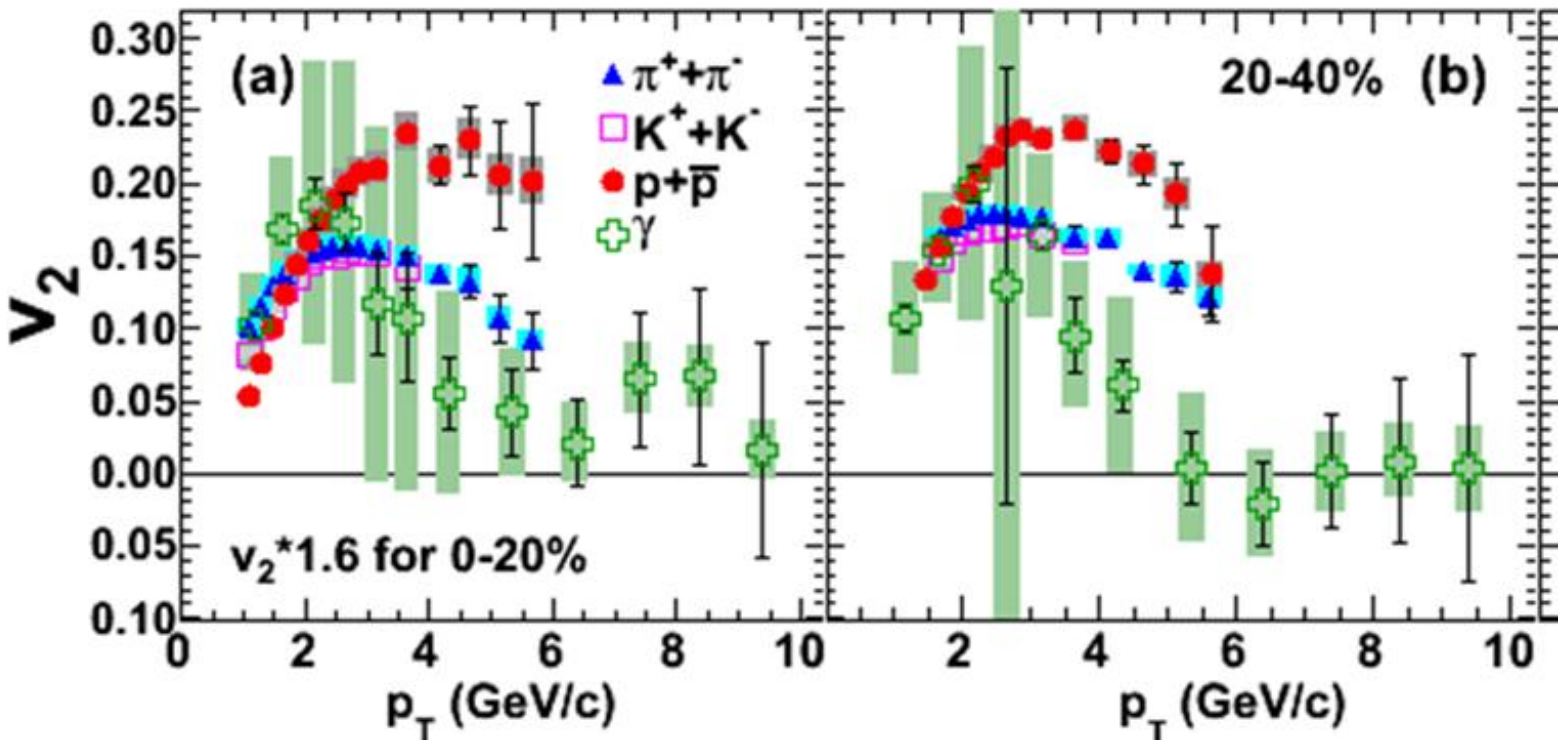


Looks like partonic emission
T_{init} ~ 300 to 600 MeV
τ_0 ~ 0.15 - 0.5 fm/c



Looks like hadronic emission
Direct photon v_2 ~ pion v_2

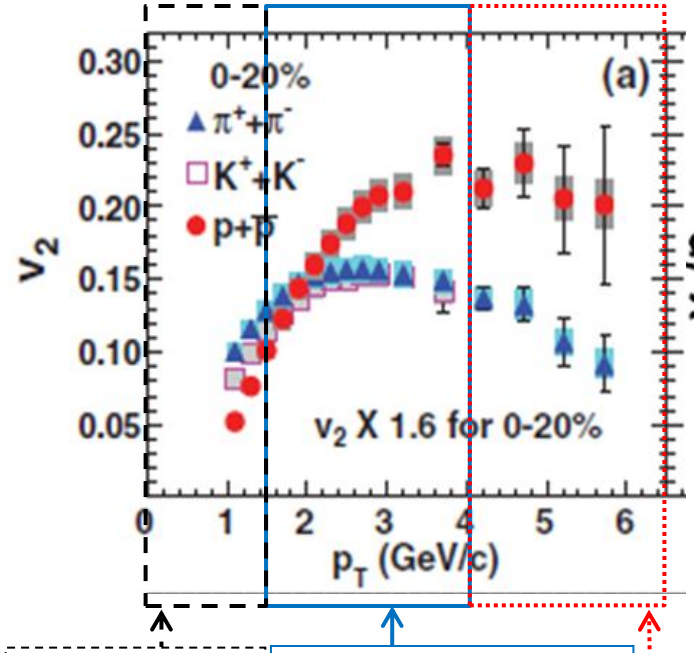
"Thermal photon v_2 is as large at the pion v_2"

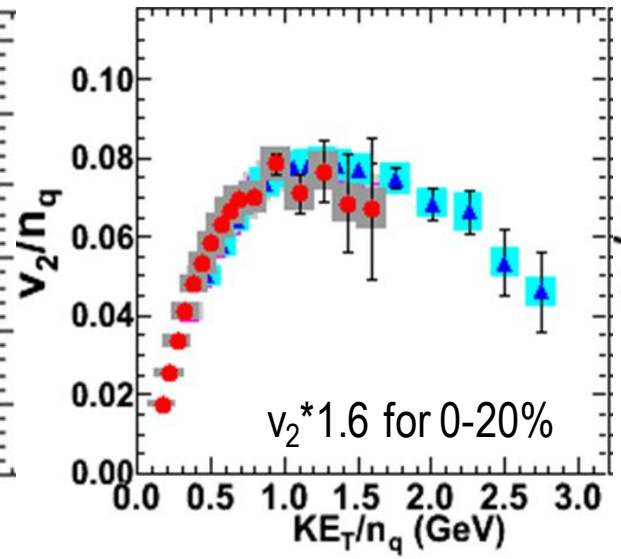


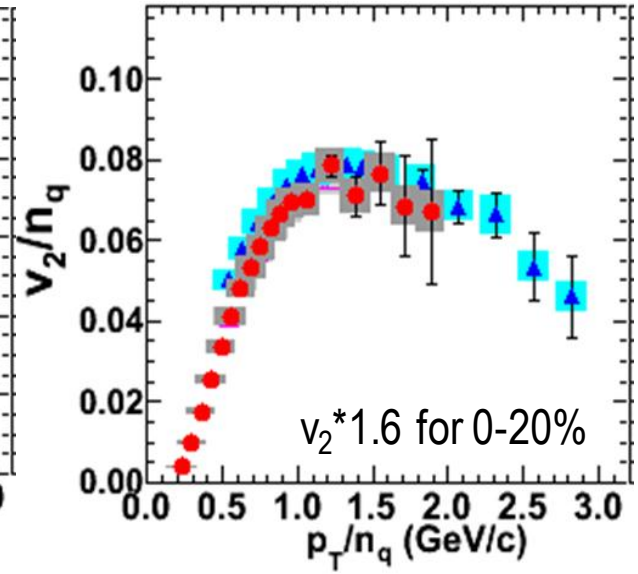
PRC 85 064914 (2012)

PRL 109 122302 (2012)

Hadronic flow and n_q-scaling







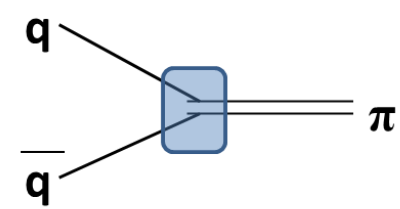
PRC 85 064914 (2012)

Bulk expansion

Recombination n_q-scaling

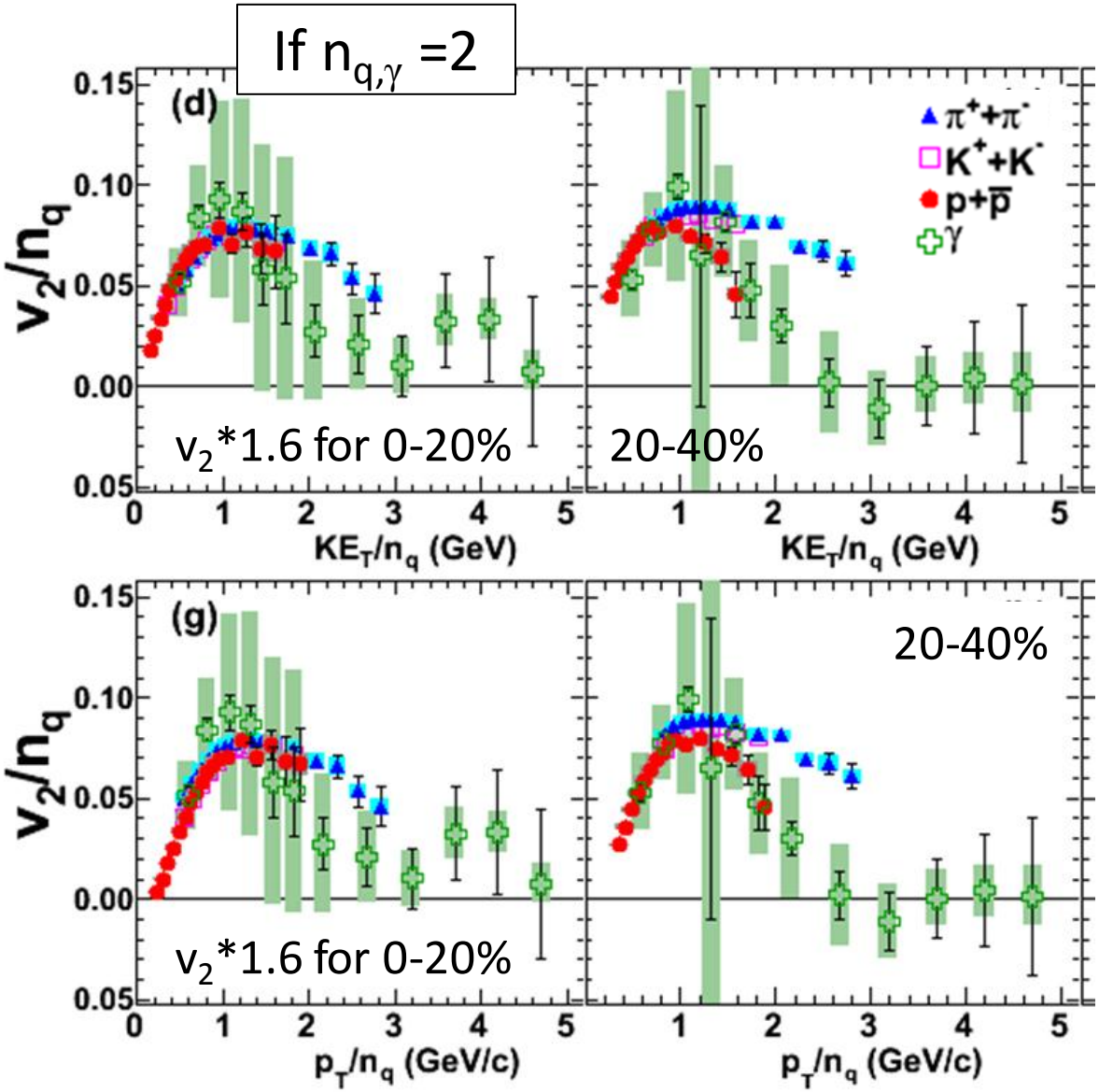
Jets

Coalescence model

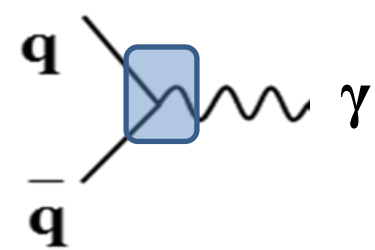


- Quarks: $\frac{dN}{d\phi} \approx 1 + 2v_{2,q}(p_{T,q})\cos(2\phi)$
- Mesons: $p_{T,M} \rightarrow 2p_{T,q}$ and $v_{2,M}(p_{T,M}) \rightarrow 2v_{2,q}(p_{T,M}/2)$
- Baryons: $p_{T,B} \rightarrow 3p_{T,q}$ and $v_{2,B}(p_{T,B}) \rightarrow 3v_{2,q}(p_{T,B}/3)$

Mechanism for photon production?



Could similar soft gluon interactions lead to an increase in the $q - \bar{q}$ annihilation cross section as the system moves toward confinement?



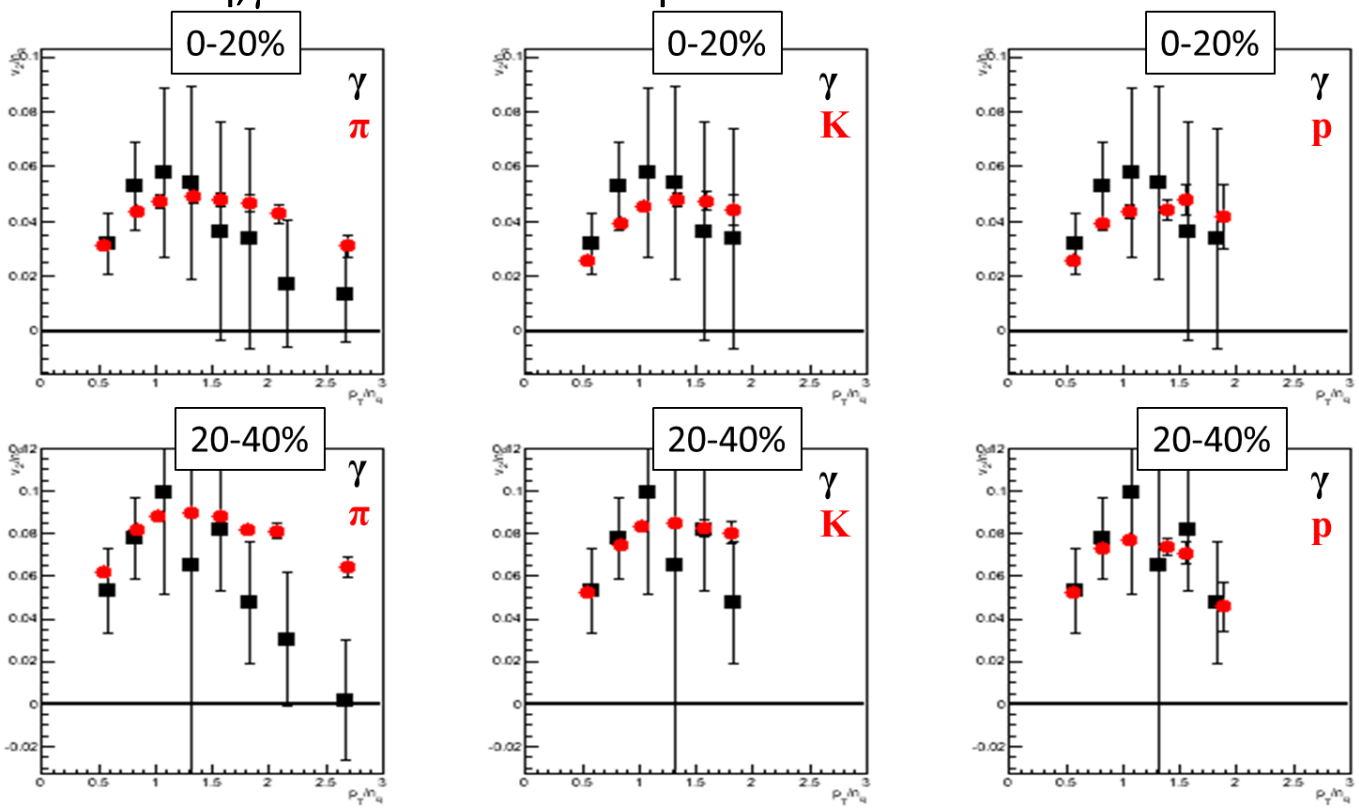
If yes, then should see n_q-scaling with $n_{q,\gamma}$ = 2

PRC 85 064914 (2012)

PRL 109 122302 (2012)

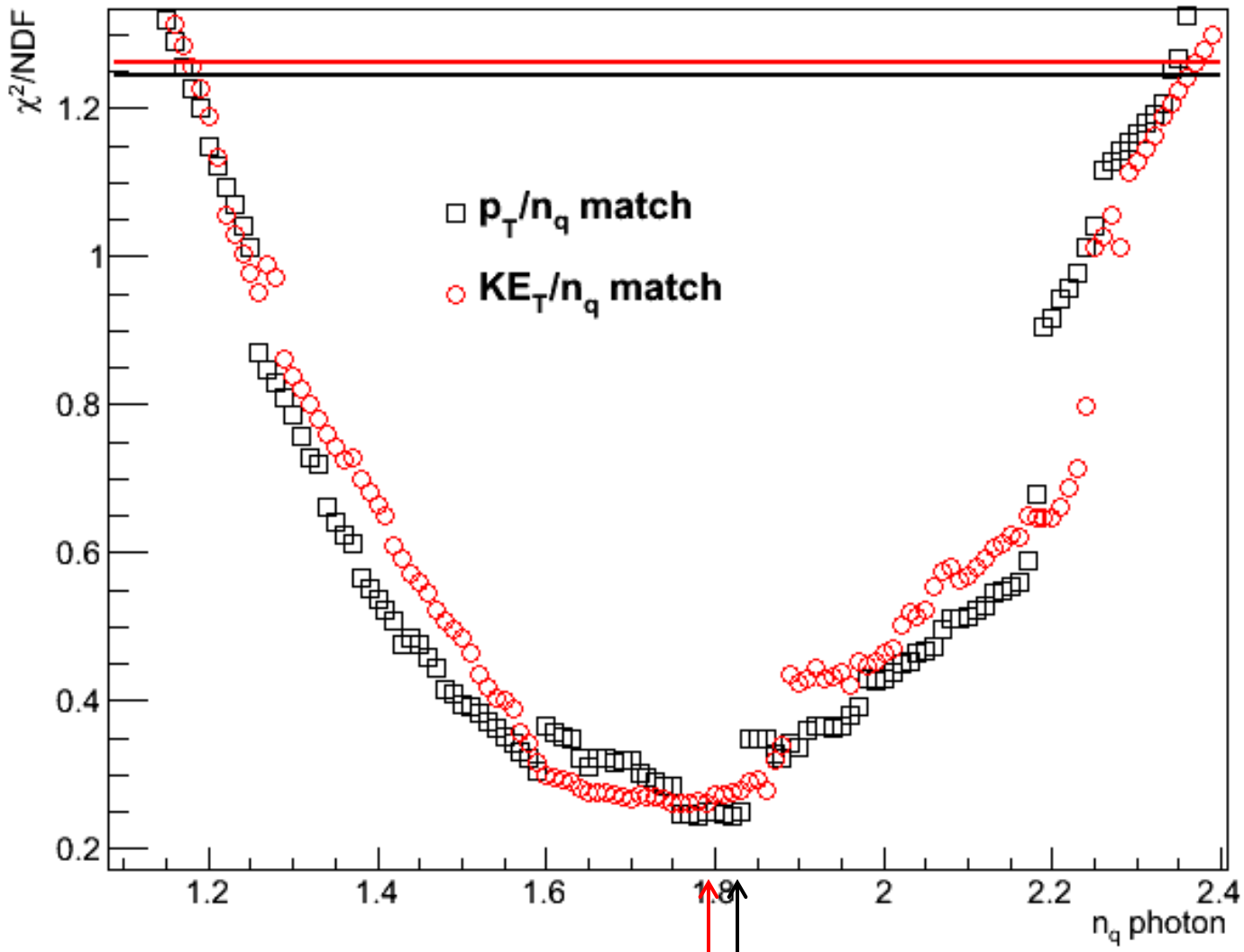
Compare n_q-scaled v_2 for γ and hadrons

- $\chi^2 = \sum_{c,h,pT/nq} (v_{2,\gamma}/n_{q,\gamma} - v_{2,h}/nq_{,h})^2/(\sigma_\gamma^2 + \sigma_h^2)$
  - Sum over centrality, hadron for each γ data point in p_T/n_q
- Example $n_{q,\gamma}$=2 with p_T/n_q match:



- χ^2 = 16.739 NDF = 39 χ^2 /NDF = 0.429

χ^2/NDF space in $n_{q,\gamma}$



$n_{q,\gamma}$ ranges:

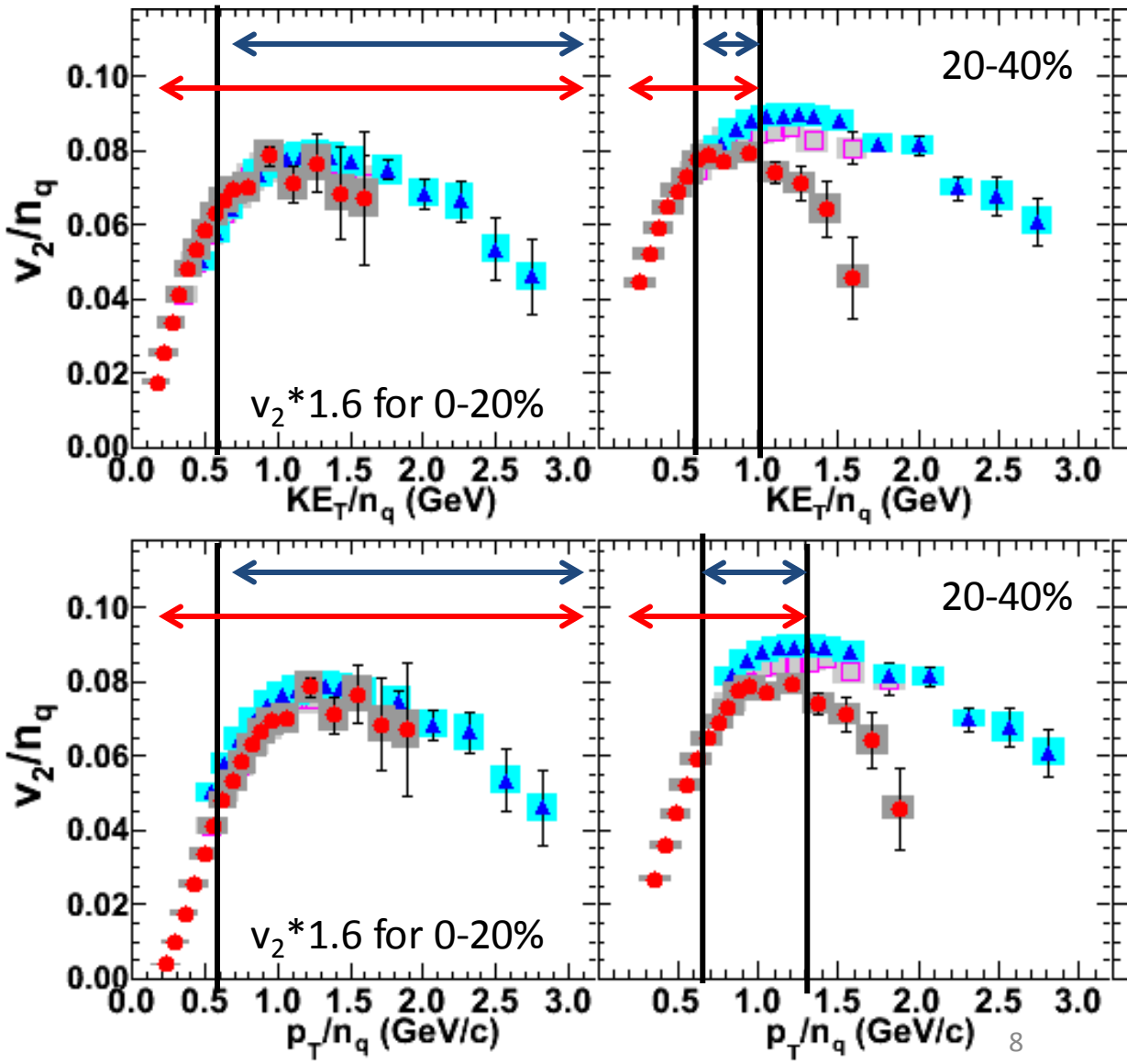
1.19-2.38
1.17-2.34

p_T/n_q and KE_T/n_q are consistent

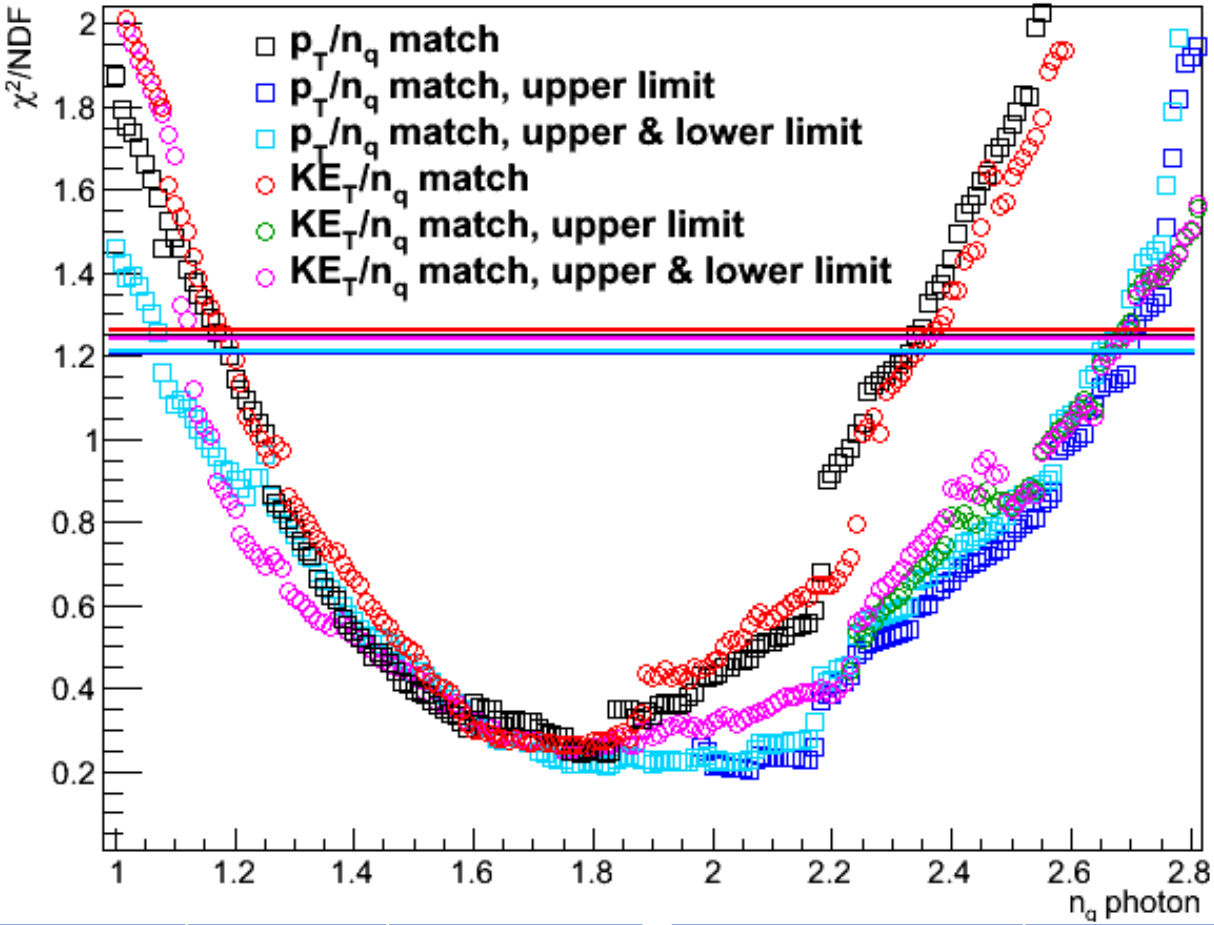
$n_{q,\gamma}$ minima: 1.79 1.82

Limit to regions where hadrons n_q-scale

- Upper limit:
  - $KE_T/n_q < 1$ for 20-40%
  - $p_T/n_q < 1.3$ for 20-40%
- Lower Limit:
  - $KE_T/n_q > 0.6$
  - $p_T/n_q > 0.6$



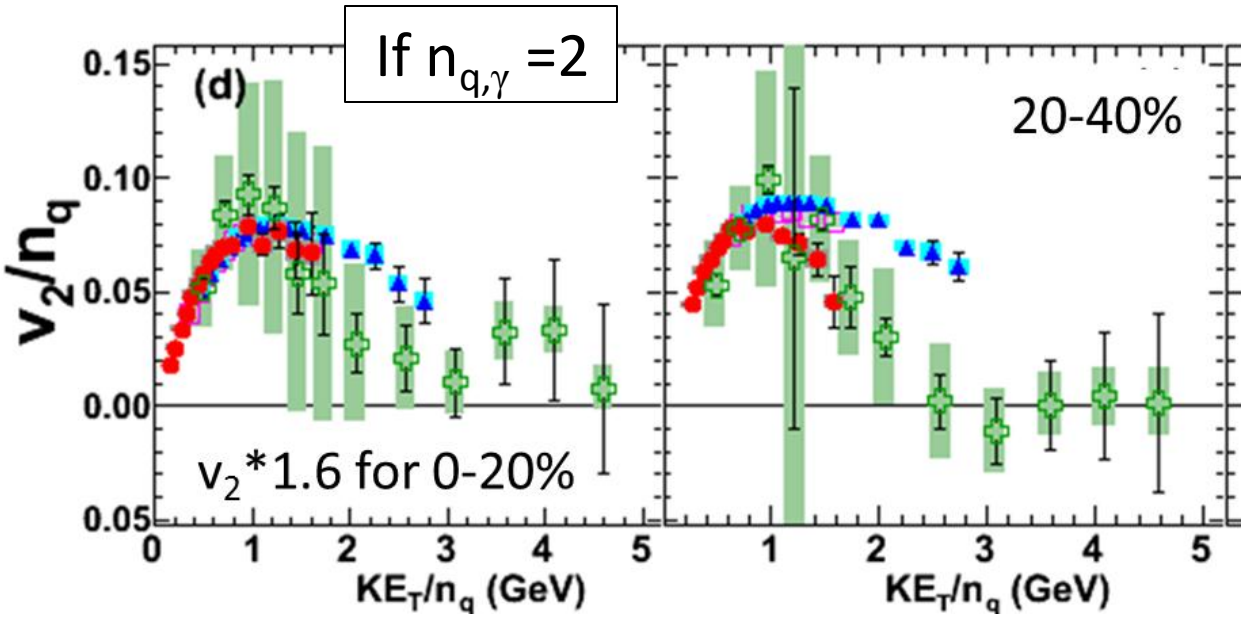
χ^2/NDF space with limits



p_T/n_q range	Min. $n_{q,\gamma}$	Range of $n_{q,\gamma}$
Whole range	1.82	1.17-2.34
Upper limit	2.06	1.07-2.70
Upper & lower limit	1.82	1.06-2.66

KE_T/n_q range	Min. $n_{q,\gamma}$	Range of $n_{q,\gamma}$
Whole range	1.79	1.19-2.38
Upper limit	1.79	1.12-2.68
Upper & lower limit	1.79	1.12-2.69

Conclusion

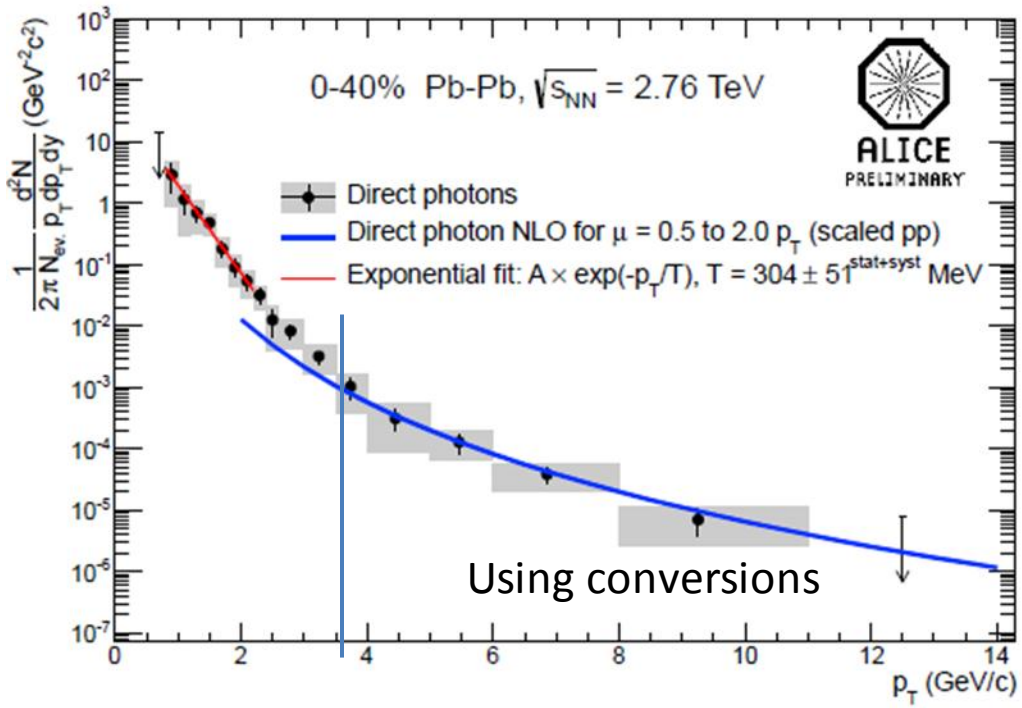


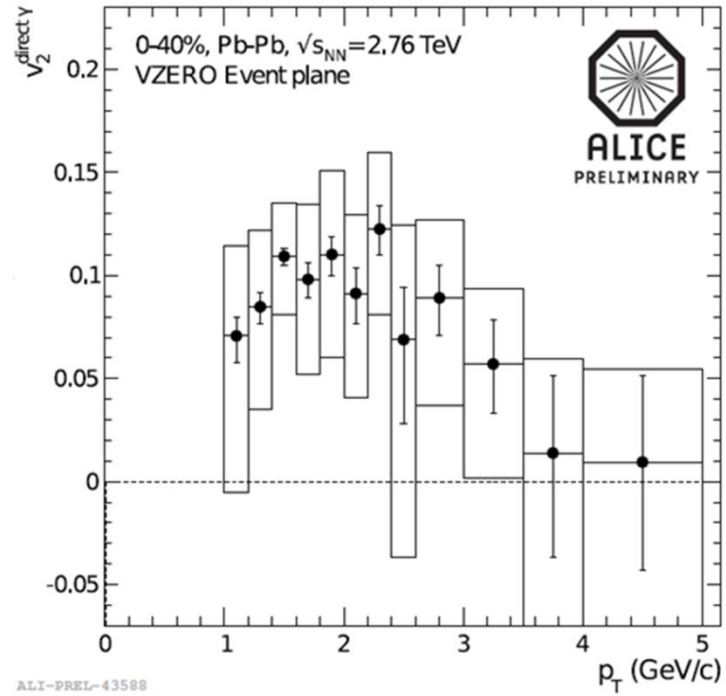
- Consistent with late-stage photon production from $q - \bar{q}$ annihilation.

- Further work needed…
  - Working on a fast Monte Carlo and/or AMPT calculation

Backup

Also seen at LHC in ALICE

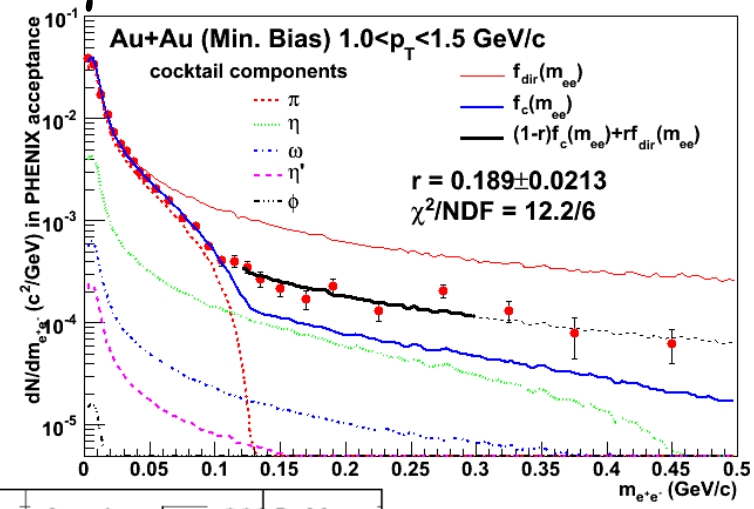




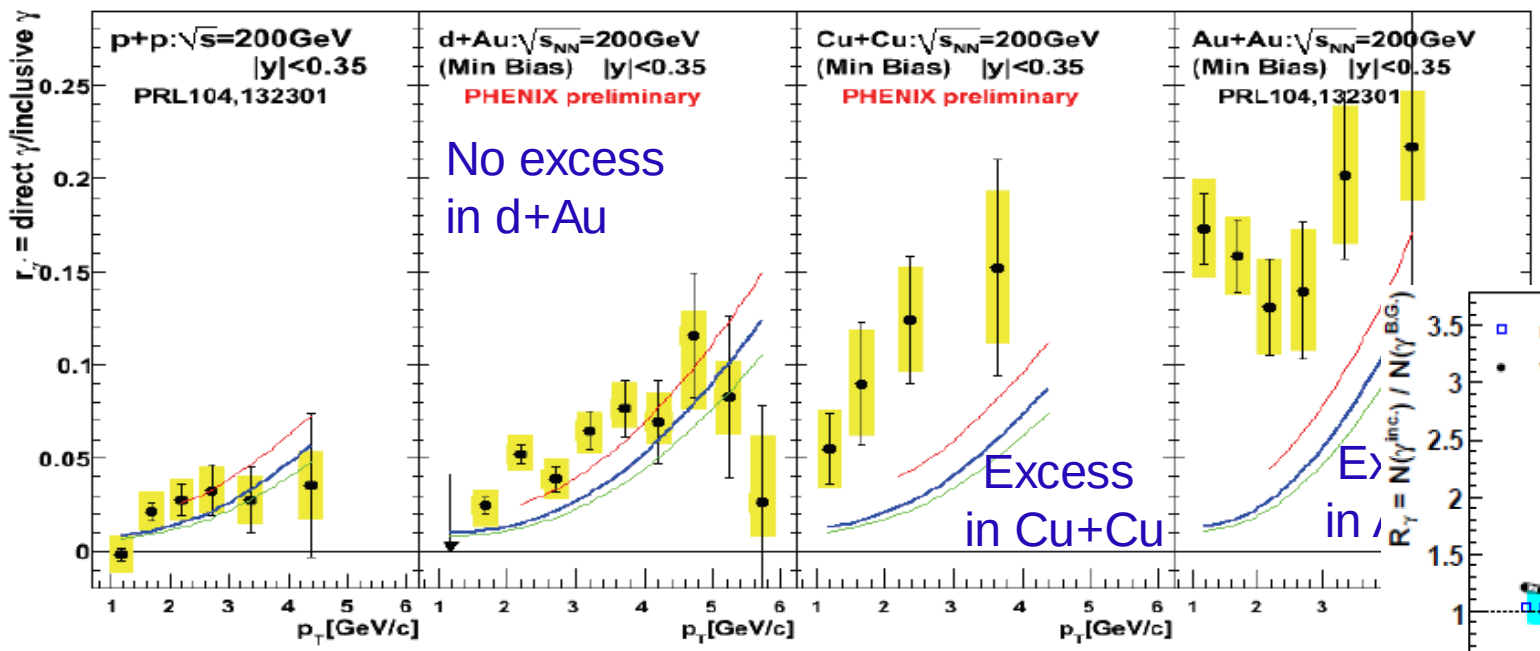
Fit to find r_γ

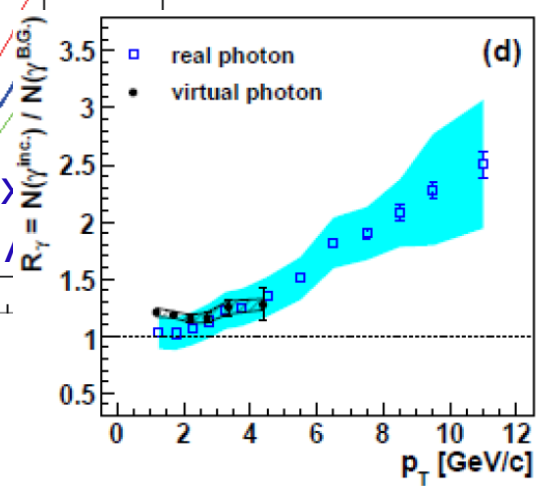
$$f(m_{ee}) = (1 - r_\gamma) f_c(m_{ee}) + r_\gamma f_{dir}(m_{ee})$$

$$r_\gamma = R_\gamma$$



- Fit for m_{ee} in 0.15-0.3 GeV/c^2 in each p_T slice

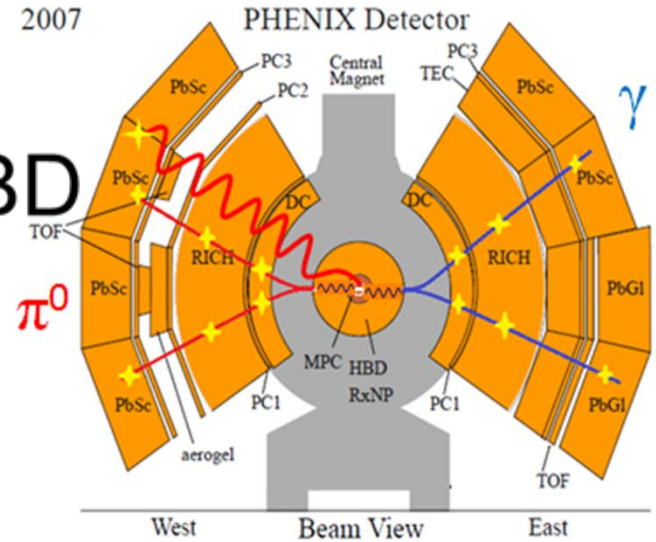


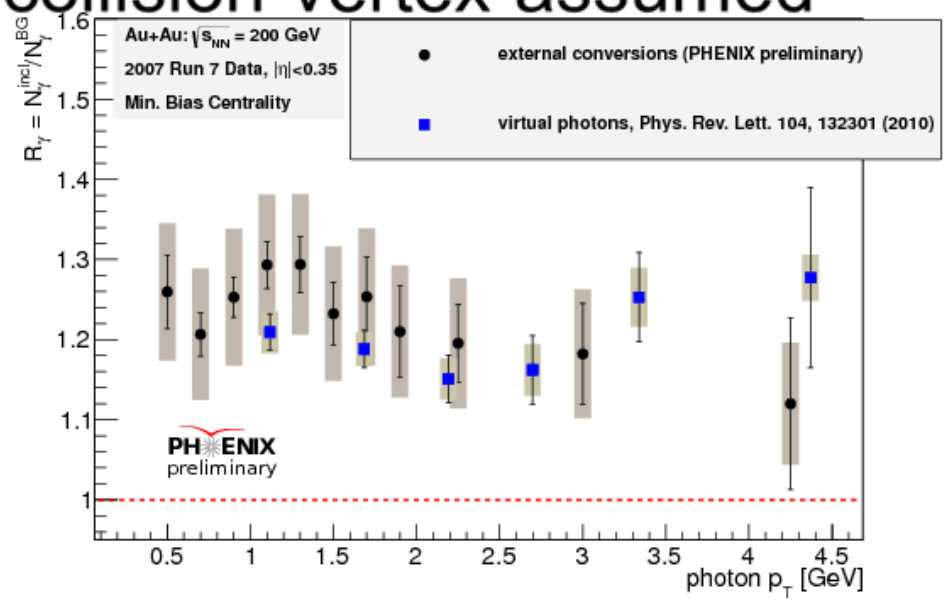


PRL 104 132301 (2010)

Au+Au low p_T photons

- External conversion method
- Photons convert in back of HBD
  - Off-vertex decay (r_{conv} ~ 60 cm)
- Apparent mass from mis-reconstructed momentum
  - In PHENIX 2007 data, collision vertex assumed
  - $m_{ee} \propto r_{conv}$
- R_γ method
  - Measure π^0 by tagging inclusive π^0 photons

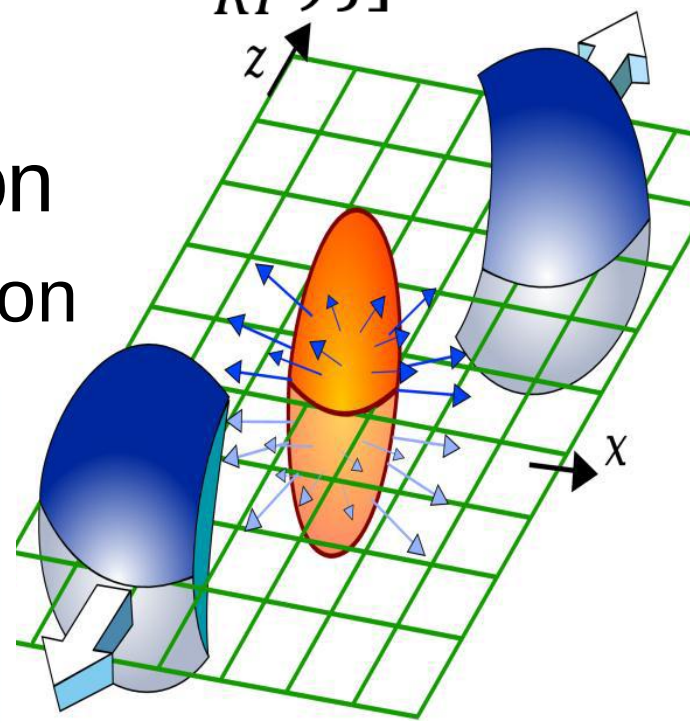


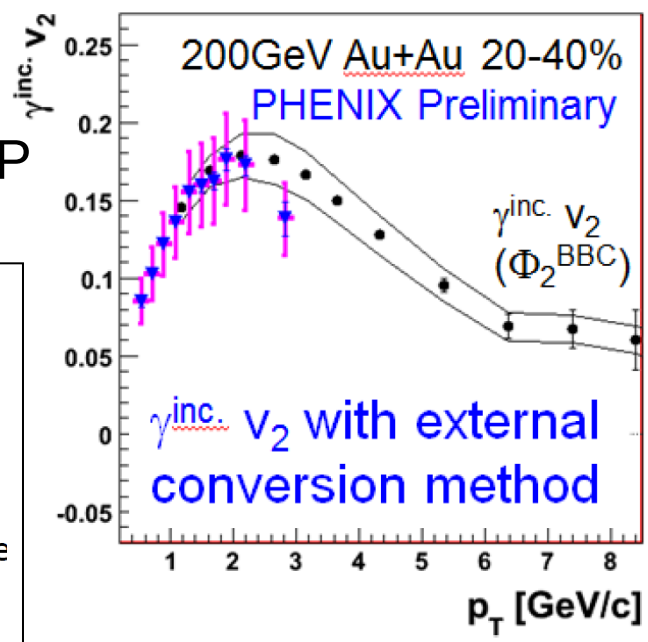


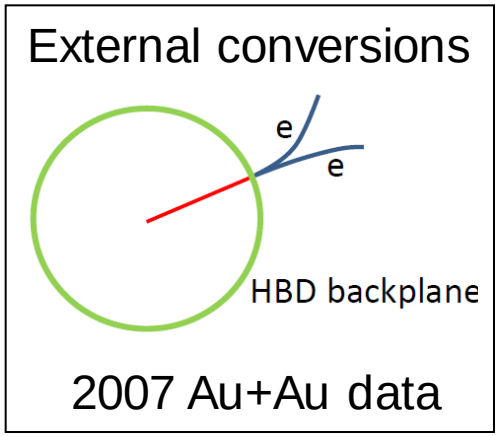
Inclusive photon v_2

$$\frac{dN}{d(\Phi-\Psi_{RP})} \propto N_0[1+2v_2\cos\{2(\Phi-\Psi_{RP})\}]$$

- Remove hadron contamination
  - Confirmed by external conversion method
- Divide by σ_{RP}





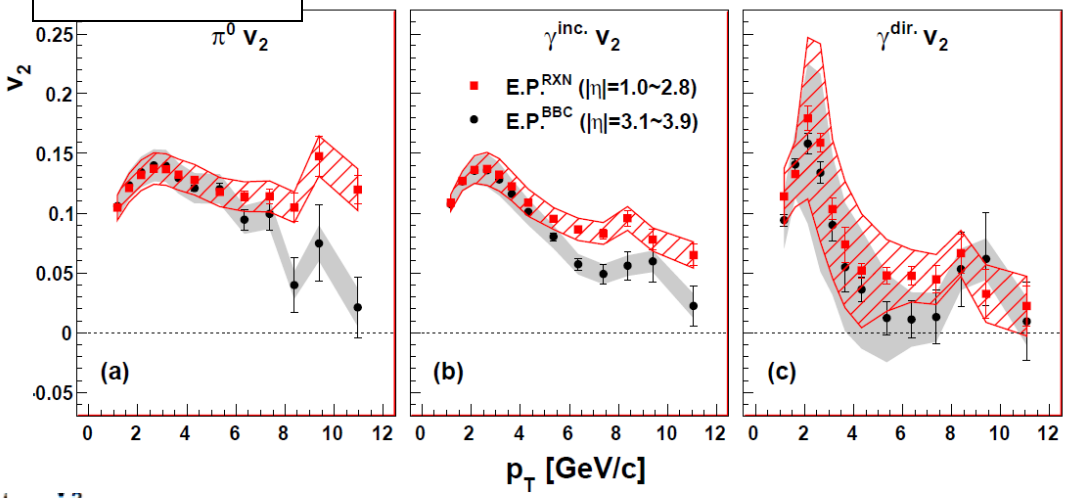


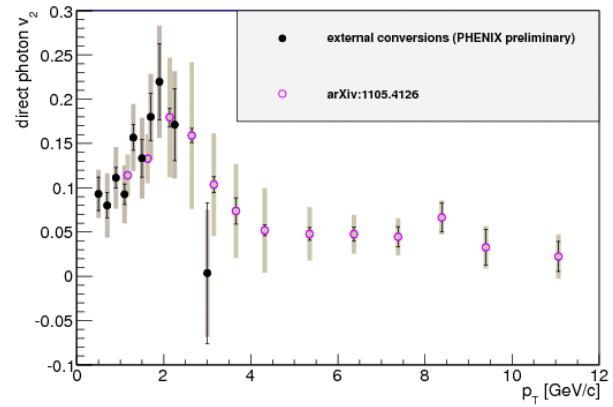
Measuring v_2^{dir}

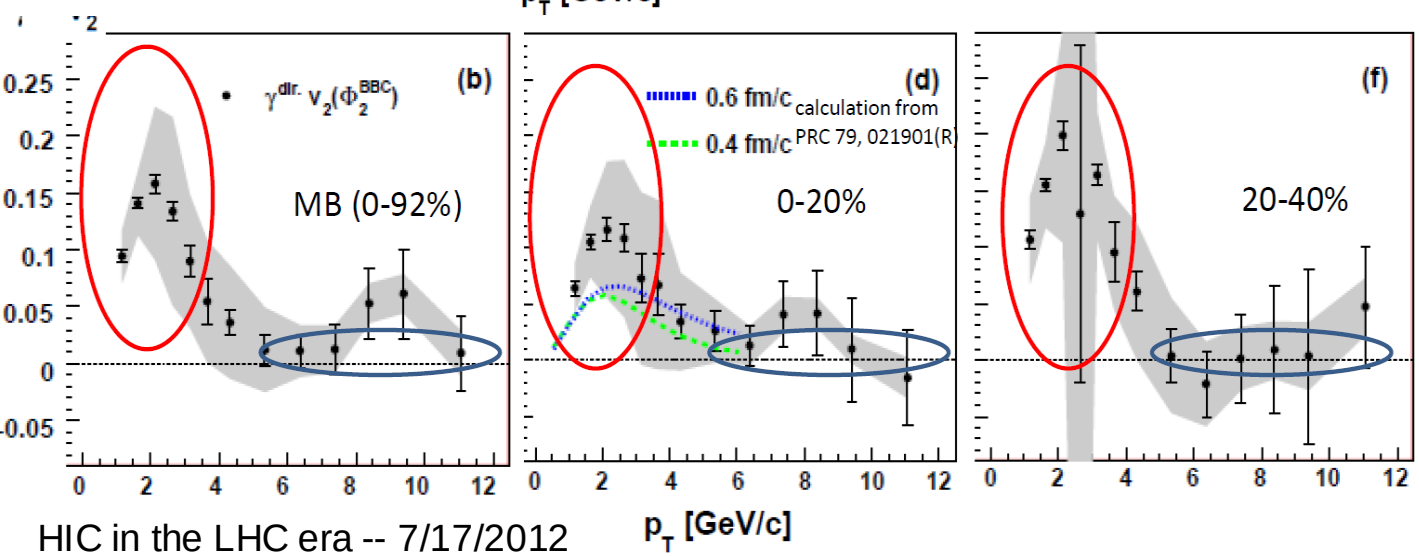
$$v_2^{\gamma,dir} = \frac{R_\gamma(p_T) v_2^{\gamma,incl} - v_2^{\gamma,BG}}{R_\gamma(p_T) - 1}$$

Calculated with a cocktail assuming KE_T and m_T scaling and measured $v_2^{\pi 0}$

MB Au+Au







High p_T, $v_2 \sim 0$

- Consistent with hard scattering

Low p_T, v_2 large

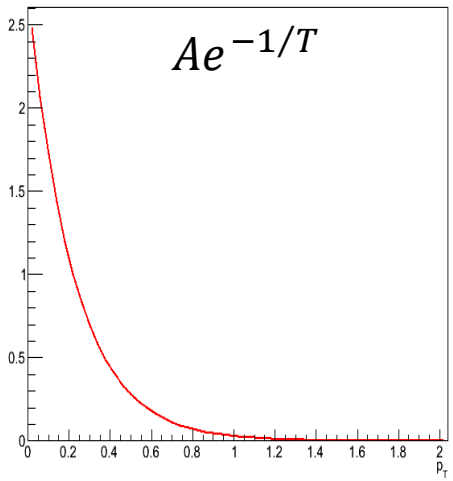
- Larger than theoretical expectations

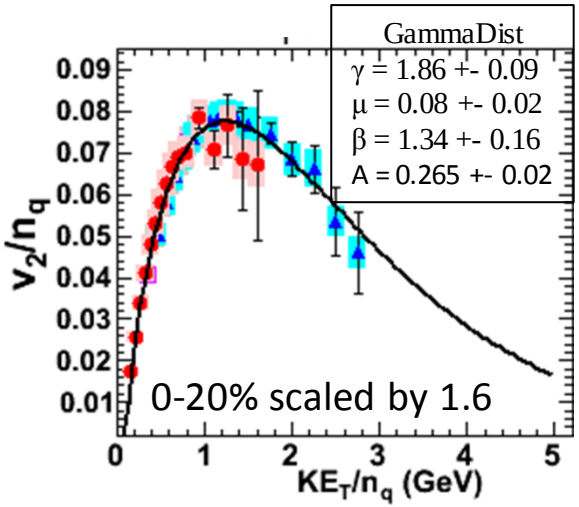
Next step: Simple Monte Carlo

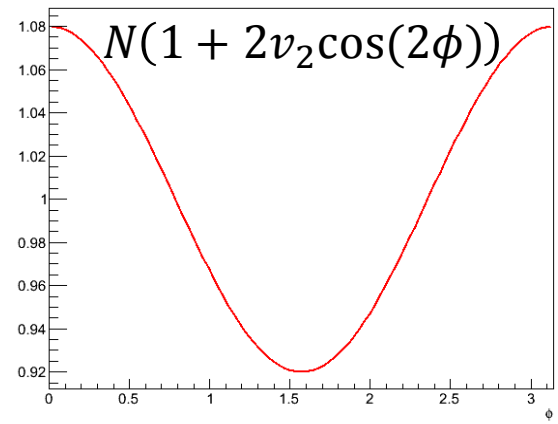
1st quark:

1.) Randomly pick η from a flat distribution

2.) Randomly pick p_T → 3.) Calculate v_2 from p_T → 4.) Randomly pick φ







2nd, 3rd quarks:

5.) Assume at the same φ, η as 1st quark

6.) Randomly pick p_T from conditional prob. distrib.

→ restrict to +/- δp_T around 1st quark's p_T

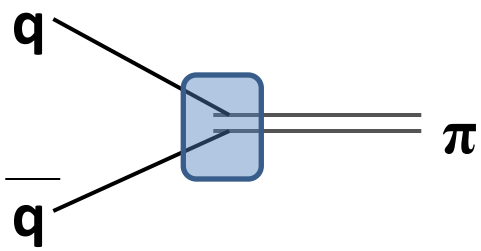
Make pairs:

7.) For pion and proton: conserve p, E or KE

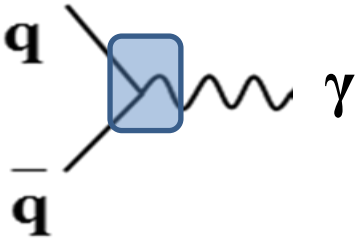
- Parameters: T, γ, μ, β, A, δp_T

Coalescence model

- Quarks: $dN/d\varphi \sim 1 + 2v_{2,q}(p_T)\cos(2\varphi)$
- Mesons: $v_2(p_T) = 2v_{2,q}(p_T/2)$
- Baryons: $v_2(p_T) = 3v_{2,q}(p_T/3)$

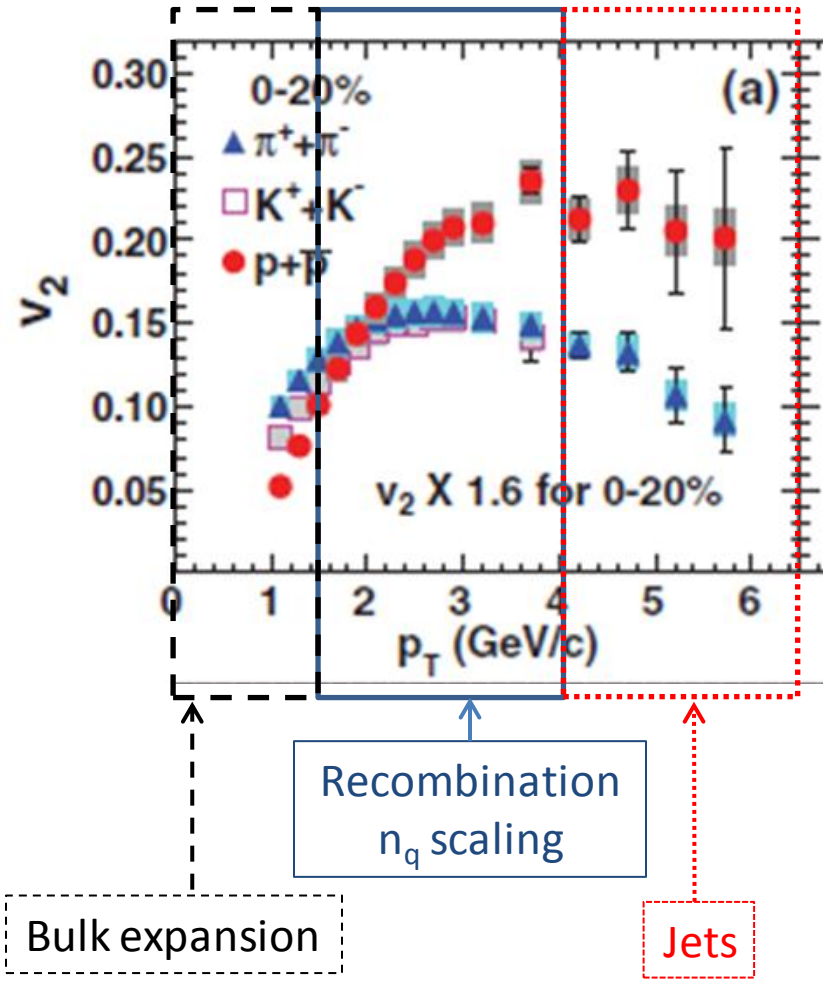


- Assumes co-moving quarks of same momentum
  - $p_{T,M} \rightarrow 2p_{T,q}$ $\quad p_{T,B} \rightarrow 3p_{T,q}$
  - Momentum conservation maintained by mean field interaction
- Quarks close in phase space

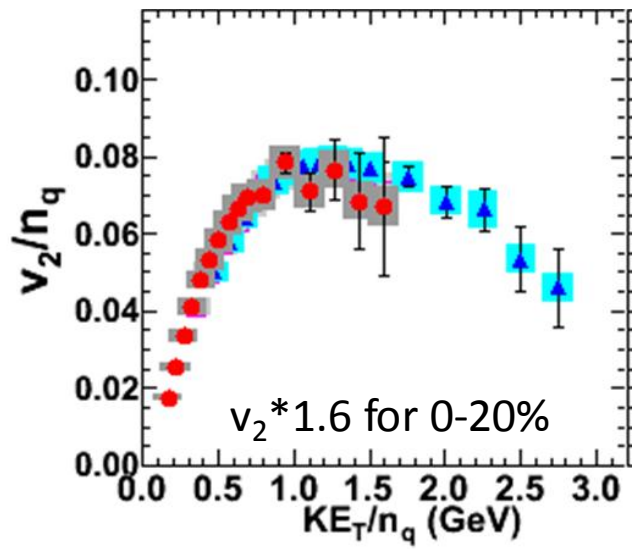


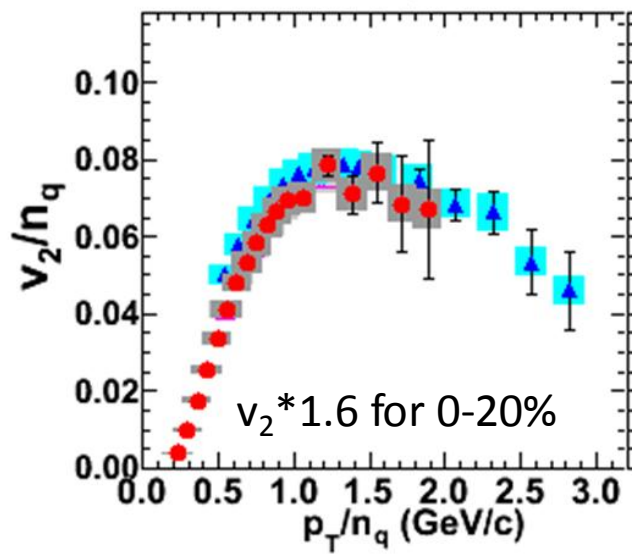
- Why not increase q-qbar annihilation cross-section?
  - Produce more thermal photons during crossover

Hadronic flow



n_q scaling





PRC 85 064914 (2012)