Direct Photon Analyses with PHENIX detector

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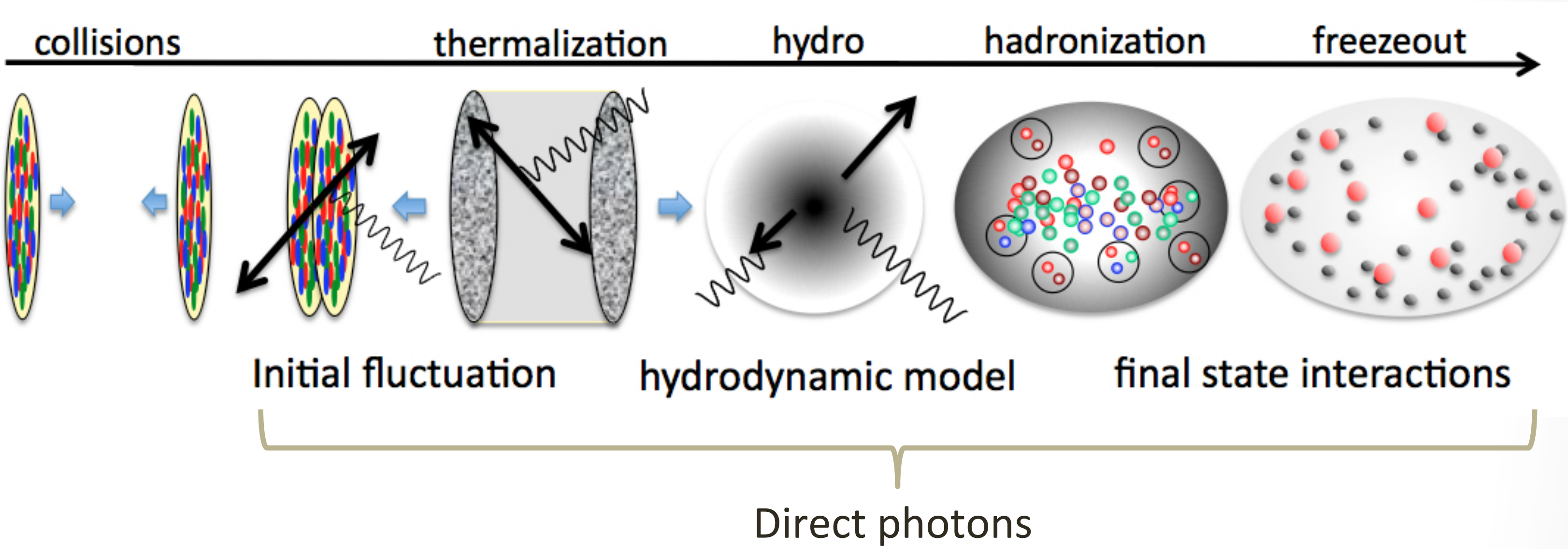
Heavy Ion Collisions

The goal is to melt protons and neutrons into quark-gluon plasma (QGP)



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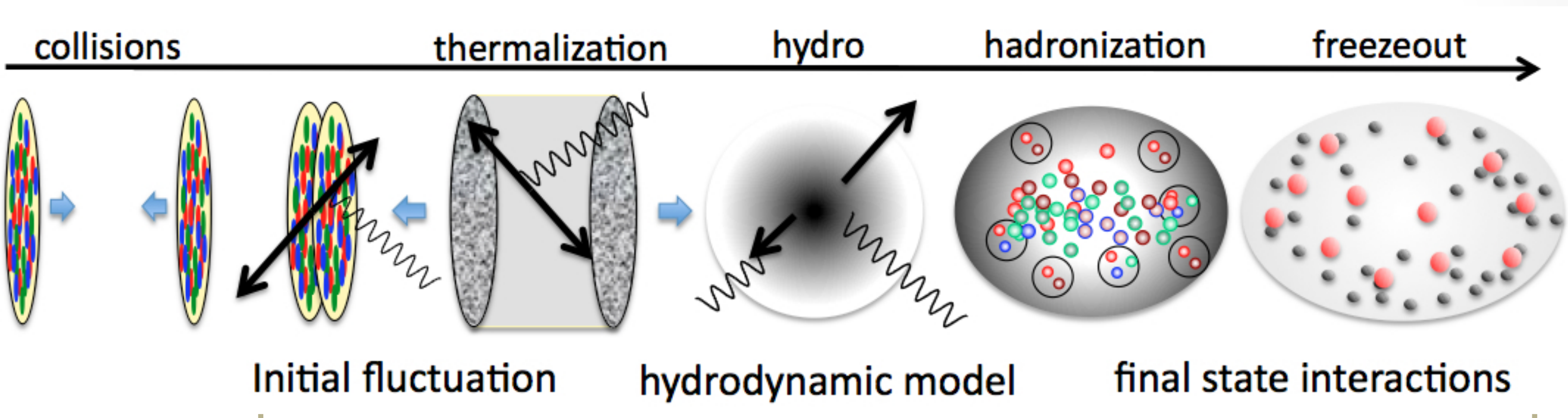
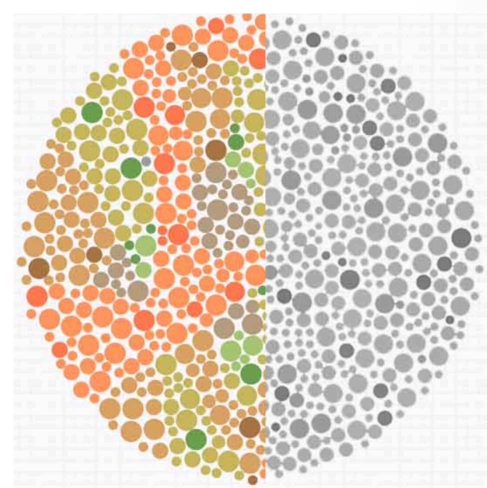


Direct photons

Photons (contrary to partons) are **color blind probes -** they leave the medium without further interaction

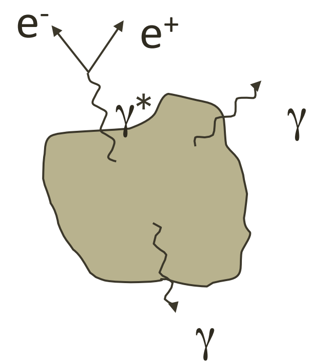


All thermal media emit thermal radiation in form of photons.

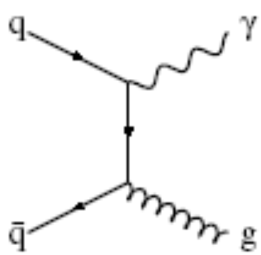
Thermal Radiation

Black Body Radiation

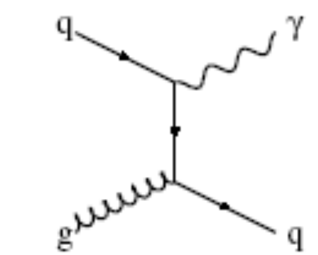
- Real or virtual photons
- Spectrum and yield sensitive to temperature
  Avg. inv. slope $\propto T_{eff}$, Yield $\propto T^3$
- Space-time evolution of matter collective motion:
  → Doppler shift
  → anisotropy



Thermal photons from QGP:

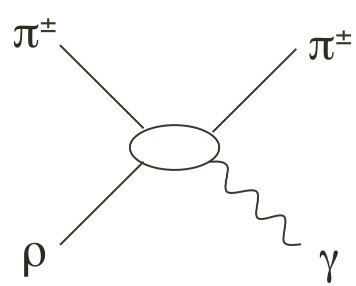


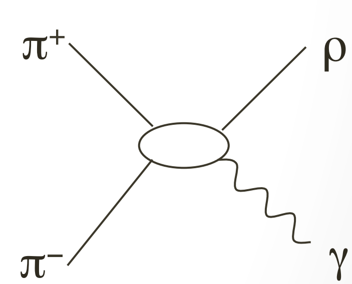
Annihilation



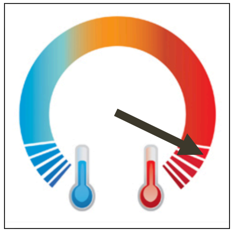
Compton Scattering

Thermal photons from HG:

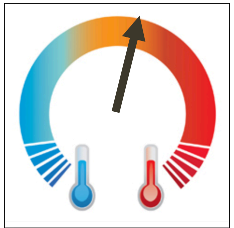




Naïve:



Hot medium
Large yield



Warm medium
Moderate yield

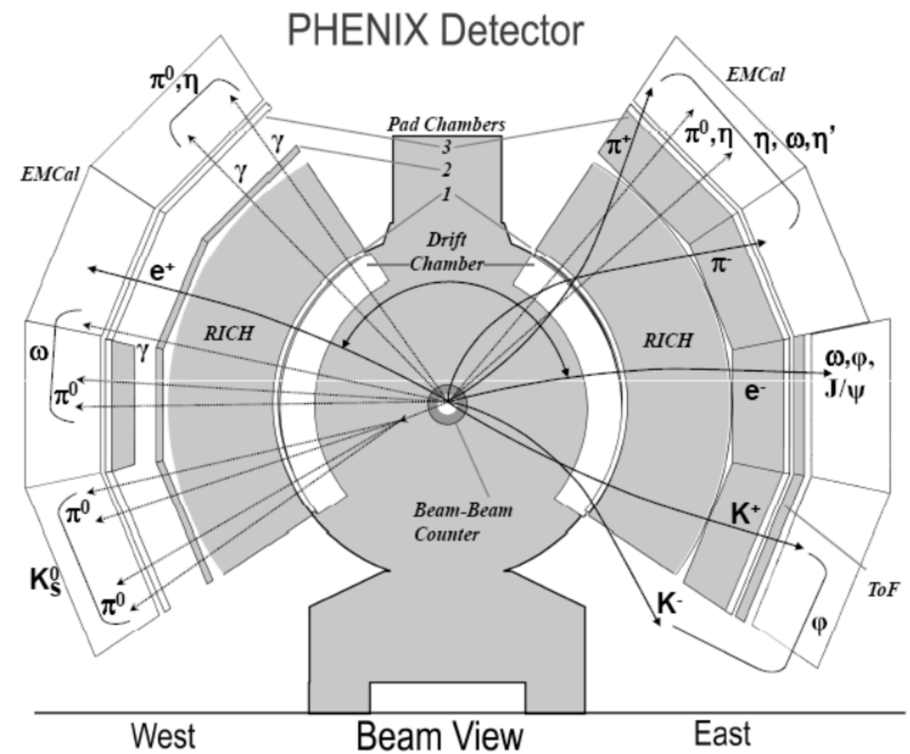
PHENIX detector

Central Arm, $|\eta| < 0.35$:

- **Tracking:**
  - Drift Chambers (DC)
    $\delta p/p = 0.7\,\% + 1.1\%p$
  - Pad Chambers (PC)
    $\sigma = \pm 1.7$ mm

- **Electromagnetic Calorimeter:**
  - 2 PbGl: $0.8\,\% + 5.9\,\%/\sqrt{E}$
  - 6 PbSc: $2.1\,\% + 8.1\,\%/\sqrt{E}$

- **Particle Identification:**
  - RICH – $e^{\pm}$
  - TOF East and TOF West:
    - $\sigma_T \cong 100$ps
    - π/K $p_T < 2.5$ GeV/c
    - K/p $p_T < 4.0$ GeV/c
  - EMCal timing:
    - $\sigma_T \cong 600$ps



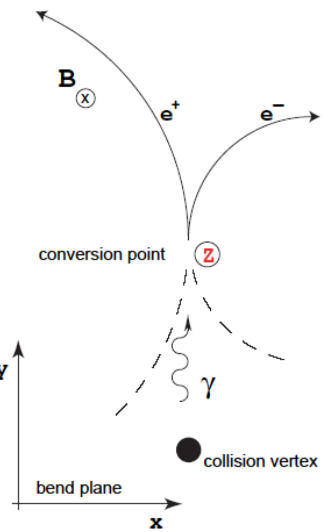
Acceptance: $-0.35 < \eta < 0.35$, $\Delta\varphi$ – 2 x 90°

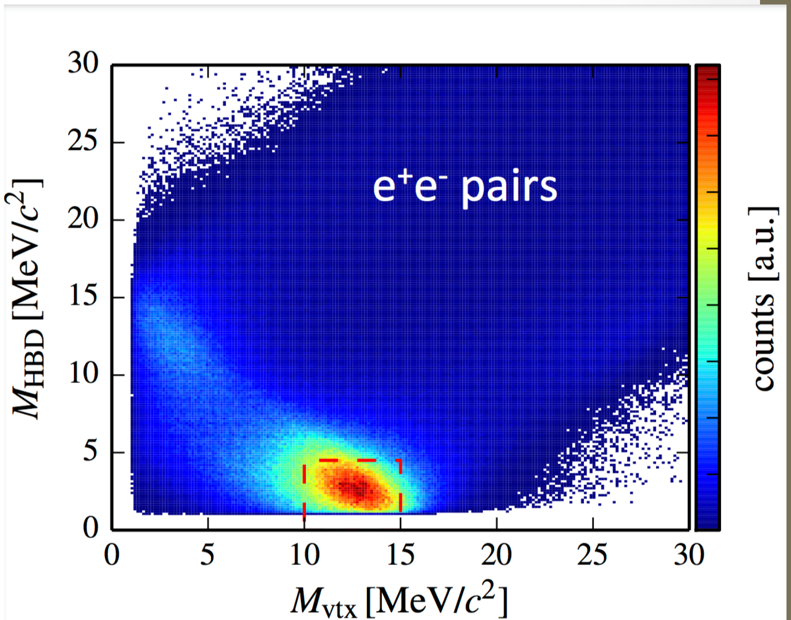
Forward detectors:

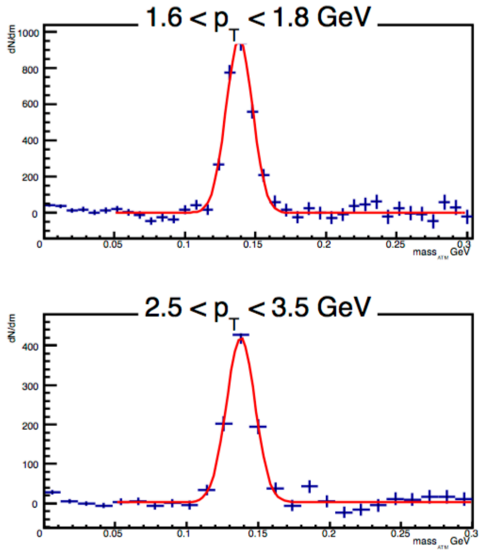
- Muon Tracking, Muon ID
- Forward Electromagnetic Calorimeter (MPC)

External photon conversion

- Method uses **single e^+/e^- tracks** (2010):
  - thick conversion radius ~2.5X_0% at 60cm
  - conversion point is assumed (Alternative Tracking Model = ATM)



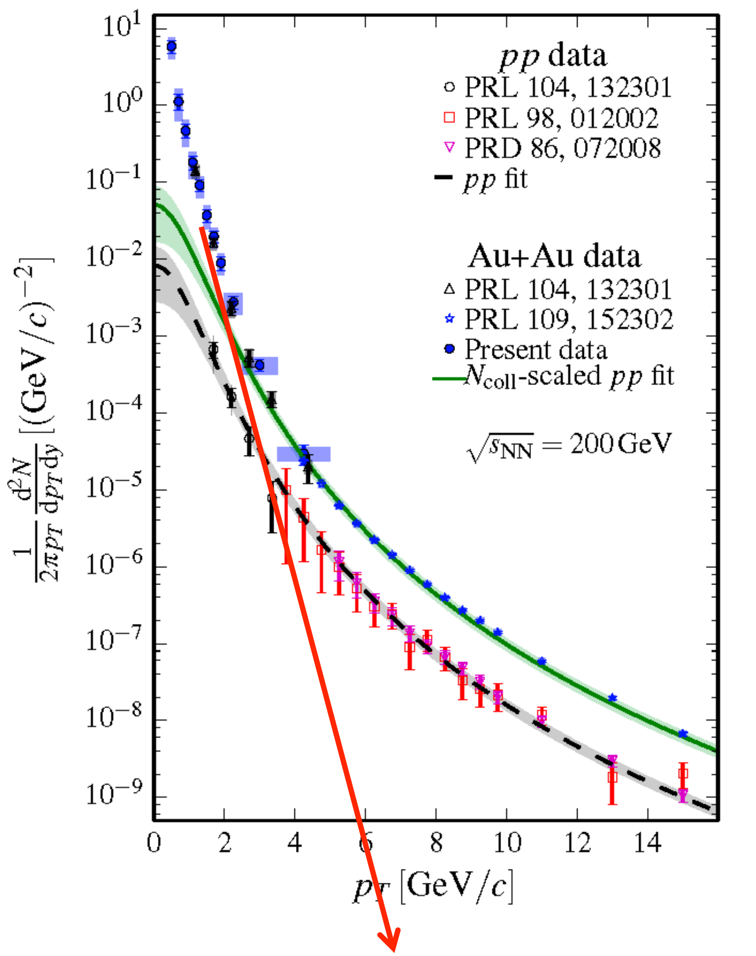




The π^0 is reconstructed with one converted photon and one photon from EMCal.

- Combinatorial background is subtracted
- π^0 photons are estimated subtracted from inclusive photons

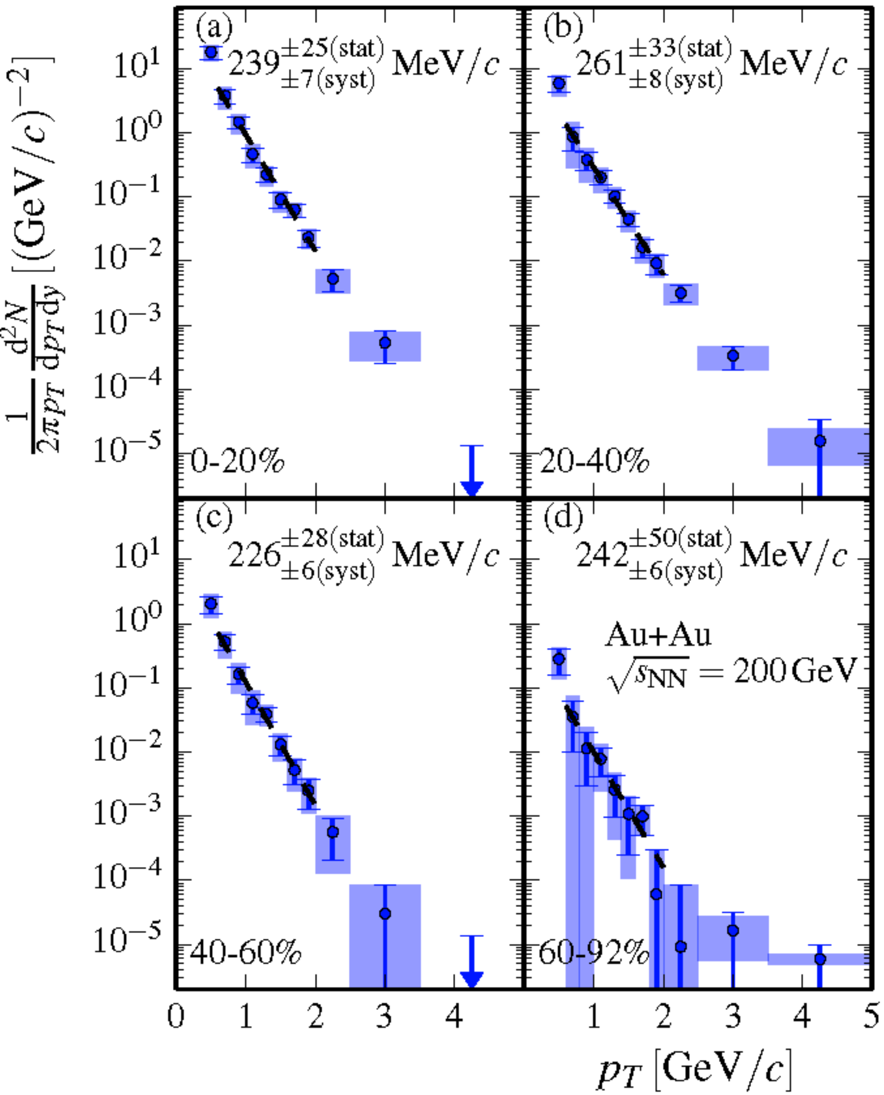
Direct Photon Yield – PHENIX



Exponential fit over the low-p_T excess
T_{inv} = 221 ± 19(stat) ± 19 (syst) MeV

- External conversion technique
- PRL104, 132301: p+p and AuAu from virtual photon (Run4 data)
- PRL 98, 012002: pp in EMCal (Run2003 data)
- PRD 86, 072008: pp in EMCal (Run2006 data)
- PRL 109, 152302: AuAu in EMCal (Run2004 data)
- Using external photon conversion method achieved good agreement with previous results.

Thermal yield

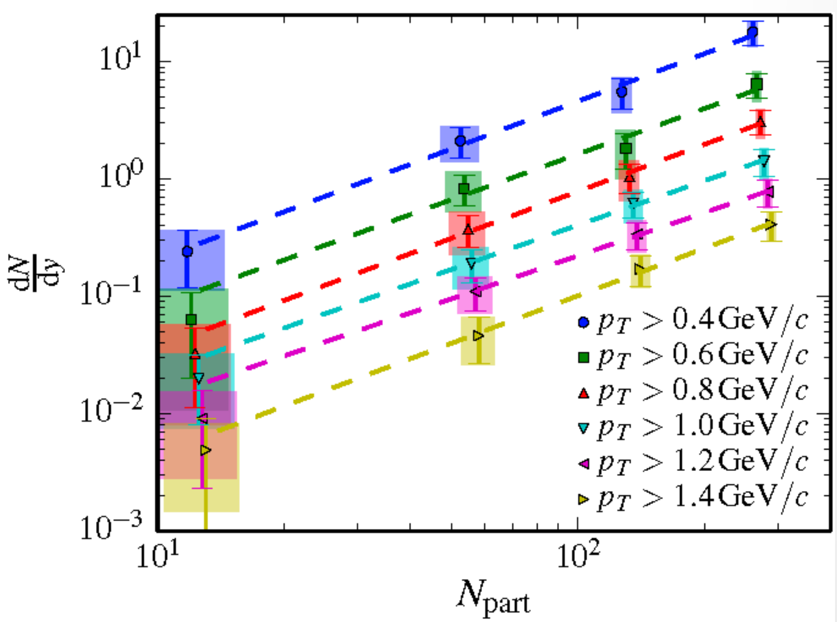


Thermal photon spectra are extracted by subtracting the N_{coll} scaled p+p photon cross section:

- The inverse slope is ~220-260 MeV and comparable within errors in all centralities.

N_{part} dependence of integrated yield has same slope even as the integration range is varied

- dN/dy ~N_{part}^{α}: α= **1.48**+/- 0.08 (stat)+/- 0.04 (syst)



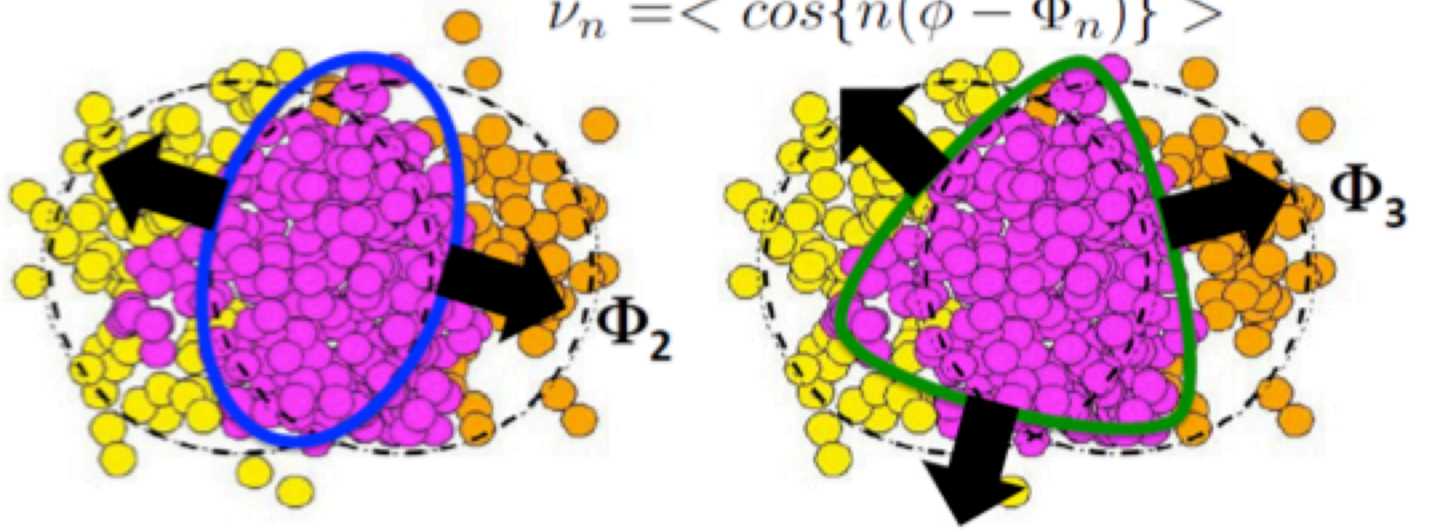
arXiv:1405.3940, PRC91, 064904 (2015)

Collective Motion – Flow

Spatial anisotropy → Large pressure gradient in-plane → Less yield out-of-plane than in-plane

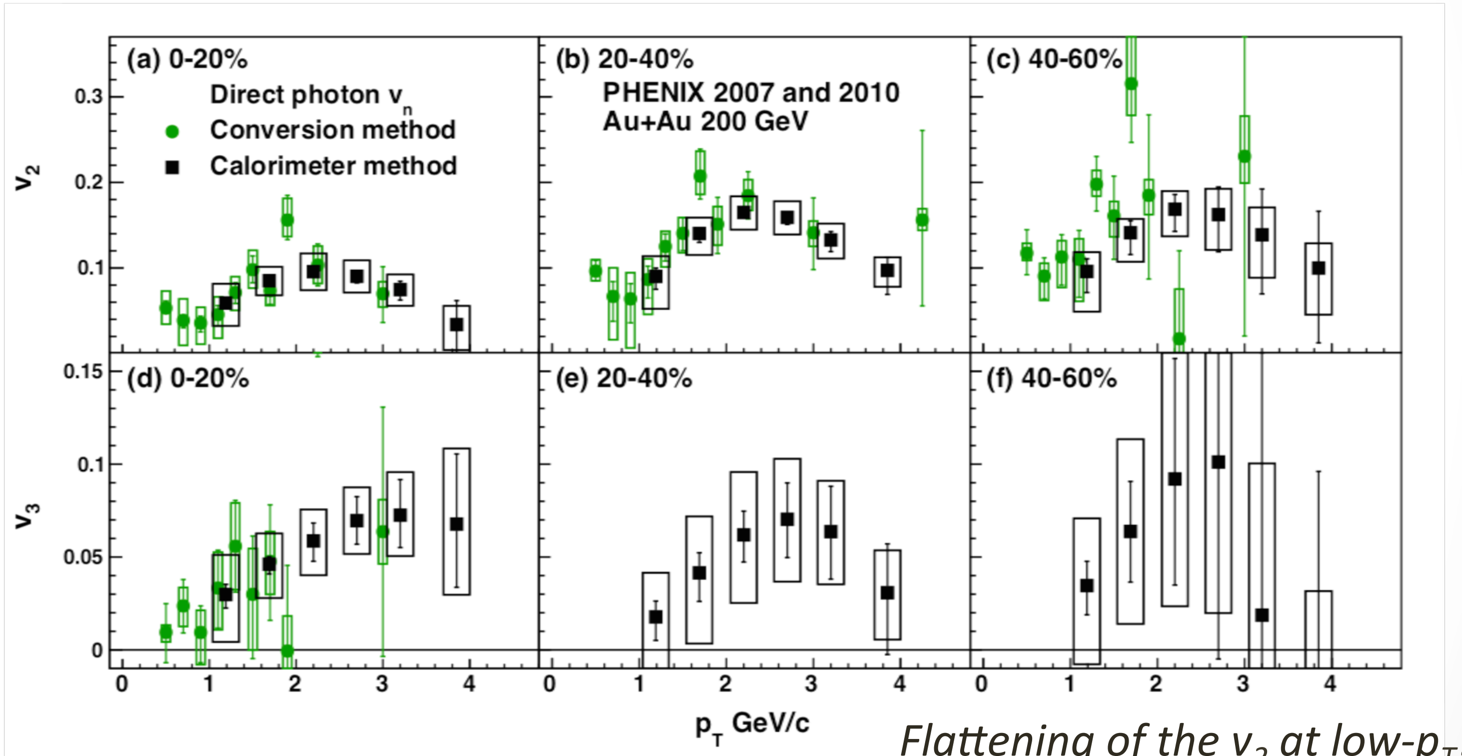
$$\frac{dN}{d(\phi - \Psi_n)} = N_0[1 + 2\sum_{n=1}^{\infty} v_n cos\{n(\phi - \Phi_n)\}]$$

$$\nu_n =< cos\{n(\phi - \Phi_n)\} >$$



Direct Photon Flow

Can we learn about the medium evolution by looking at the direct photon collective motion?



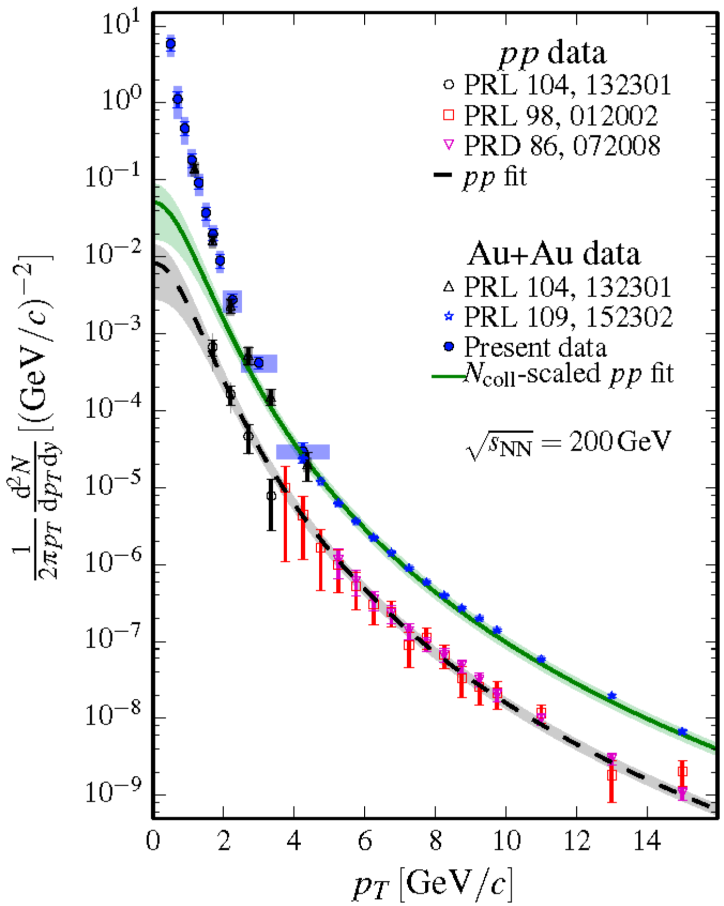
Flattening of the v_2 at low-p_T?

Is there a strong magnetic effect?

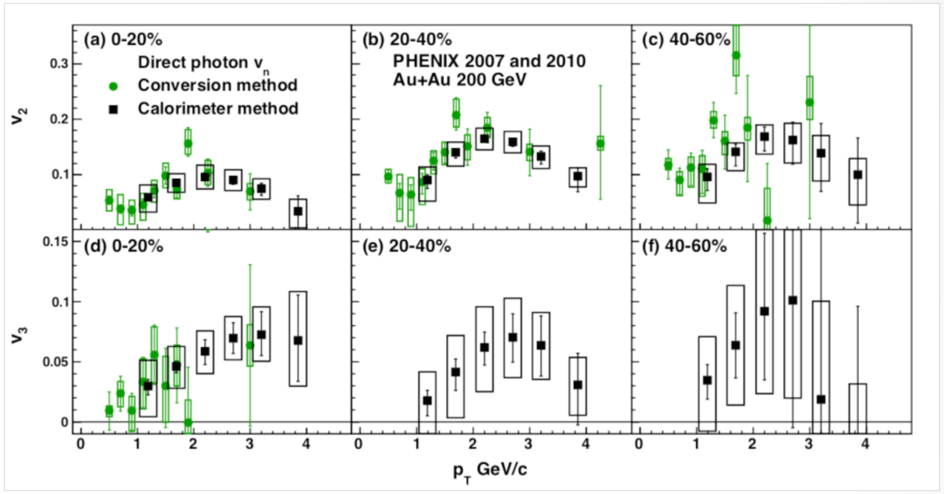
- Significant direct photon v_2 was measured.
- General trend to note: $\mathbf{v_3 \sim v_2/2}$

Direct Photon Puzzle

PRC91, 064904 (2015)



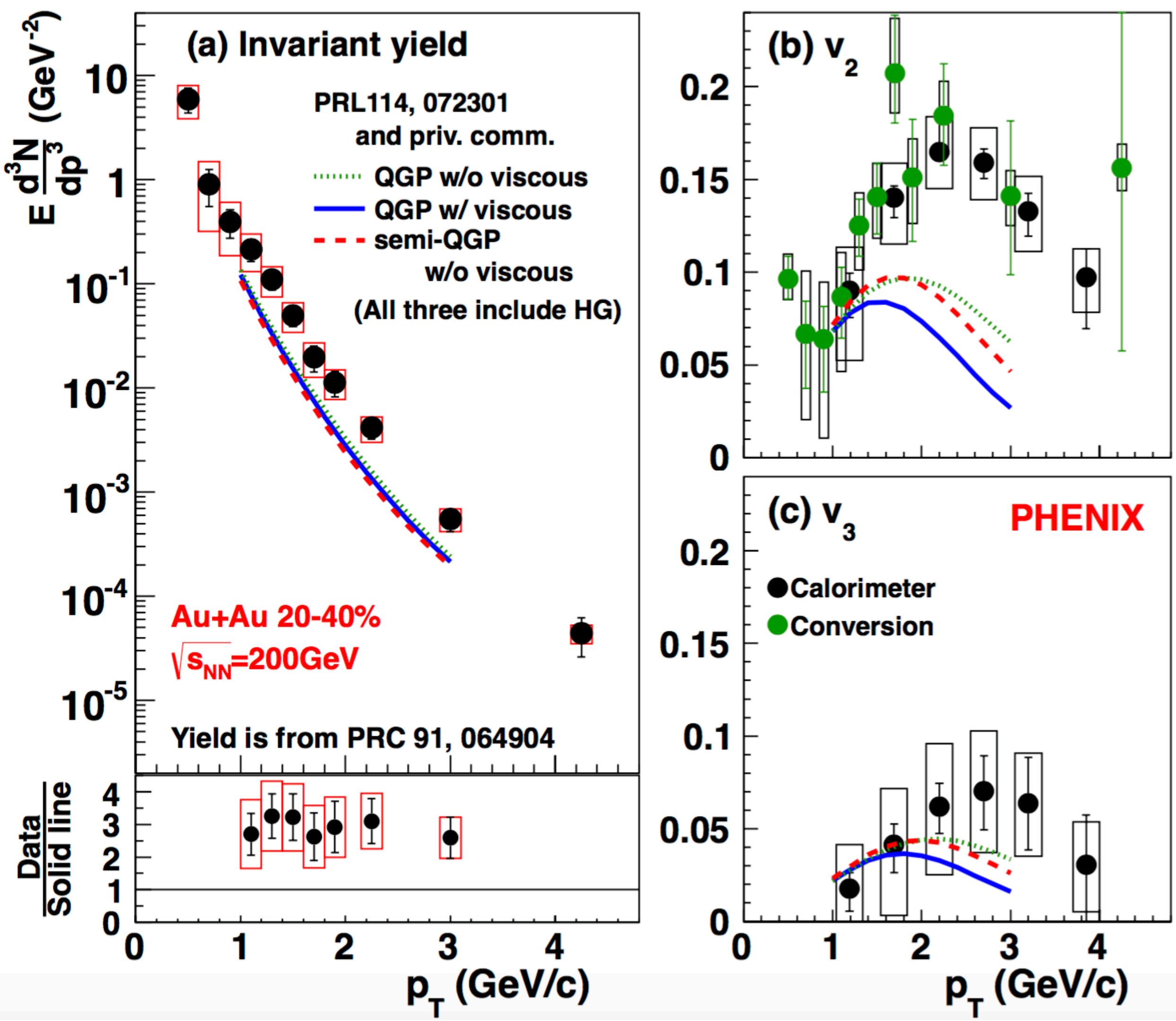
arXiv:1509.07758



- **Large yield**
  - Emission from the early stage where temperature is high
- **Large elliptic flow (v_2)**
  - Emission from the late stage where the collectivity is sufficiently built up

Theoretical models struggle to understand the direct photon data in Au+Au collisions at 200 GeV

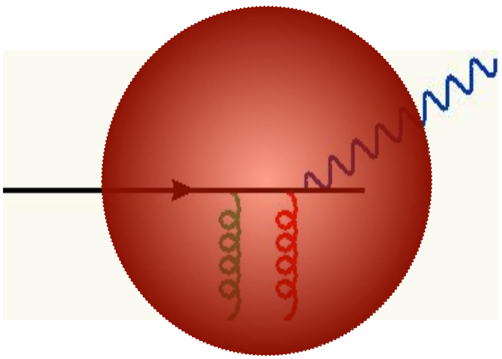
Theoretical Model



Comparison to three hydrodynamical model calculation (C. Gale et al):

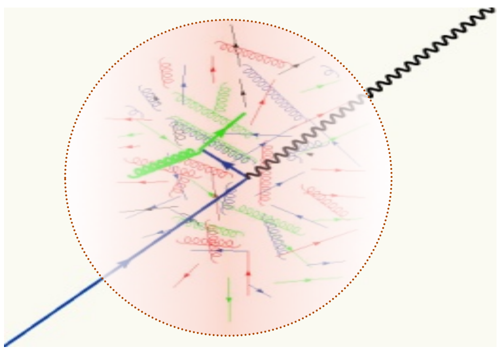
- QGP, w/o viscous
- QGP, w viscous – including bulk and shear viscosity
- semi-QGP, w/o vis-cous - confinement on the photon emission rate
- All calculations also include HG phase emission with blue shift correction

Jet-Medium interactions

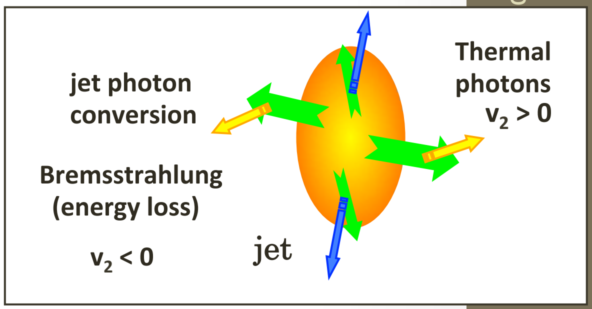


Jets and photons in the created medium:

- Medium induced bremsstrahlung
- Jet-photon conversion – hard quark scatters on thermal gluon, leaving a hard photon and thermal quark.



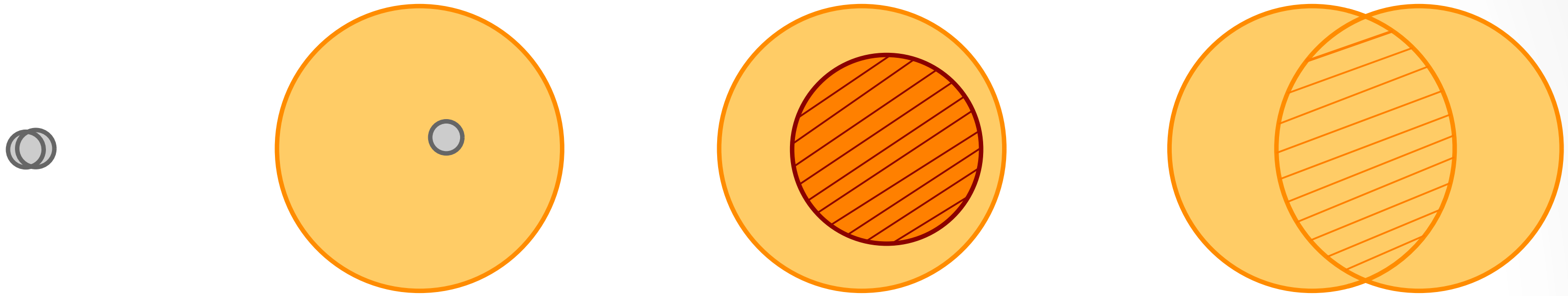
Photon sources	v_2	
Jet medium induced bremsstrahlung	negative	non-isolated
Jet-photon conversion	negative	isolated
Thermal photons	positive	



For prompt photons: v_2~0

There is no clear observation of photon from these processes, but it would provide new constraints for the medium

Some of the remaining questions



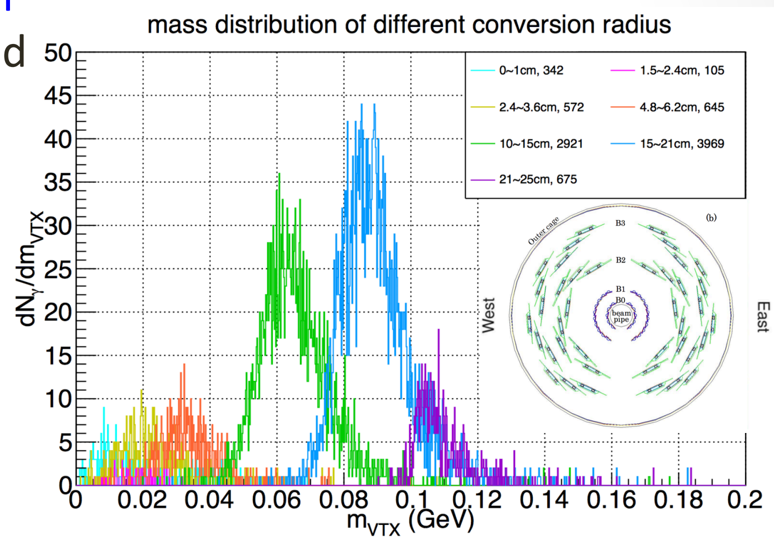
pp **pAu** **CuAu** **AuAu**

- What is the direct photon spectrum shape in low p_T for p+p?
- Is there hot medium created in p+Au collisions?
- What is the p_T dependence of v_2 for Cu+Au most central collision? (magnetic field effect)
- What is the p_T dependence of v_3, v_4 for Au+Au collision? (compare with theoretical models)
- What is the collision energy dependence of the photon production?

New photon-conversion reconstruction method

- Identify and reconstruct photons via external conversions to e^+e^- pairs. The method depend on the conversion geometry.
- Old method uses **single e^+/e^- tracks** (2010):
  - Fixed conversion point at 60cm
- New method uses **e^+e^- pairs** (>2011):
  - Reconstruction of the true conversion radius

simulation result



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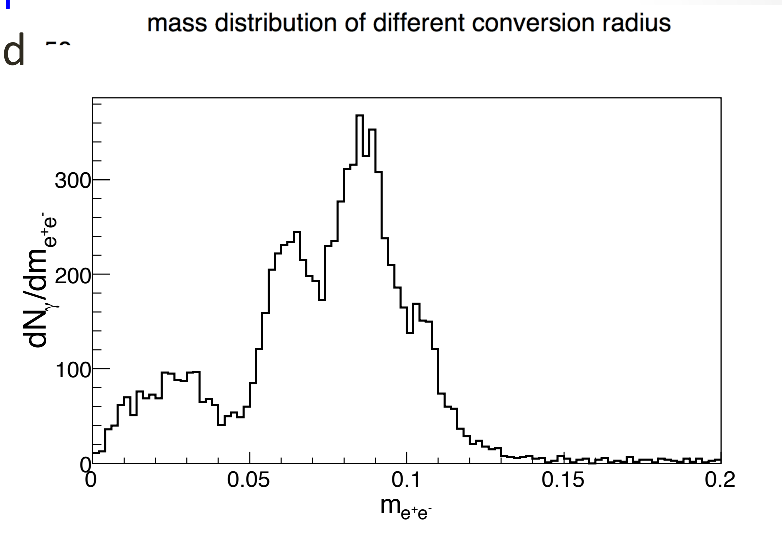
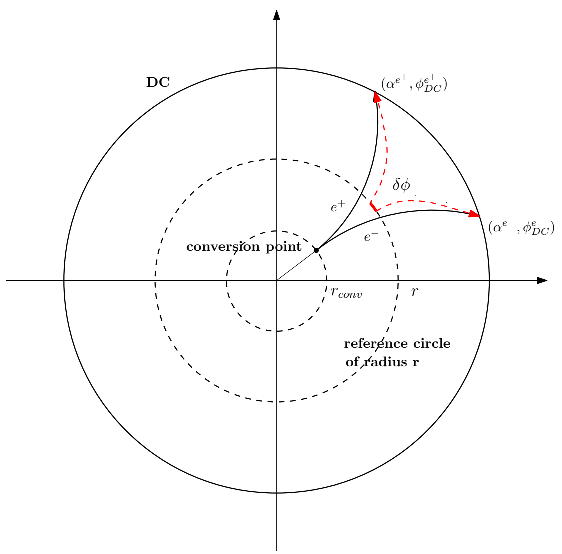
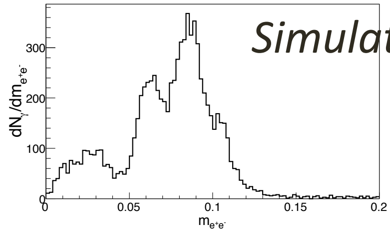
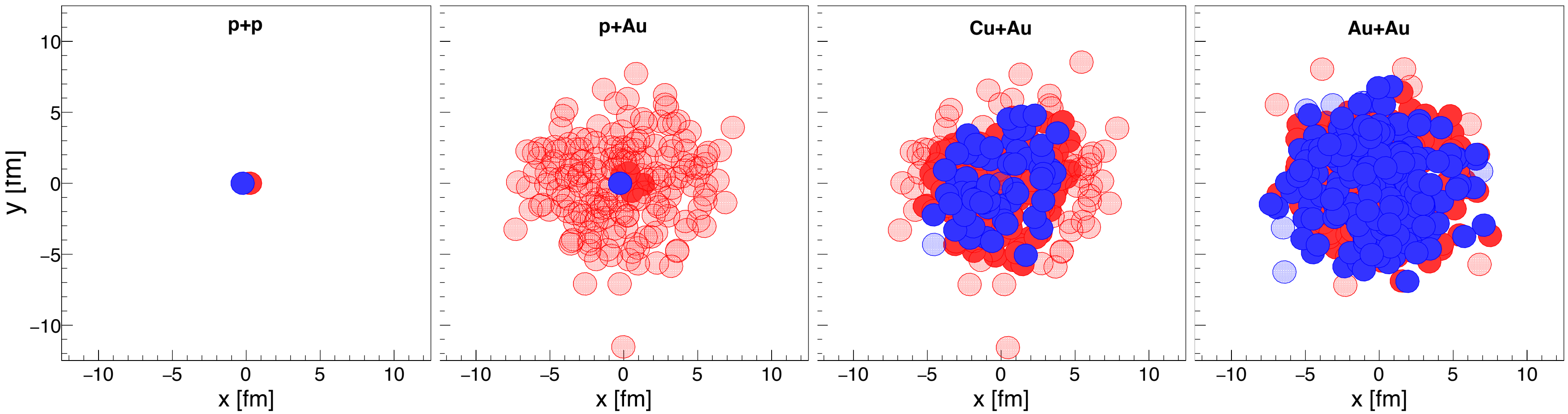




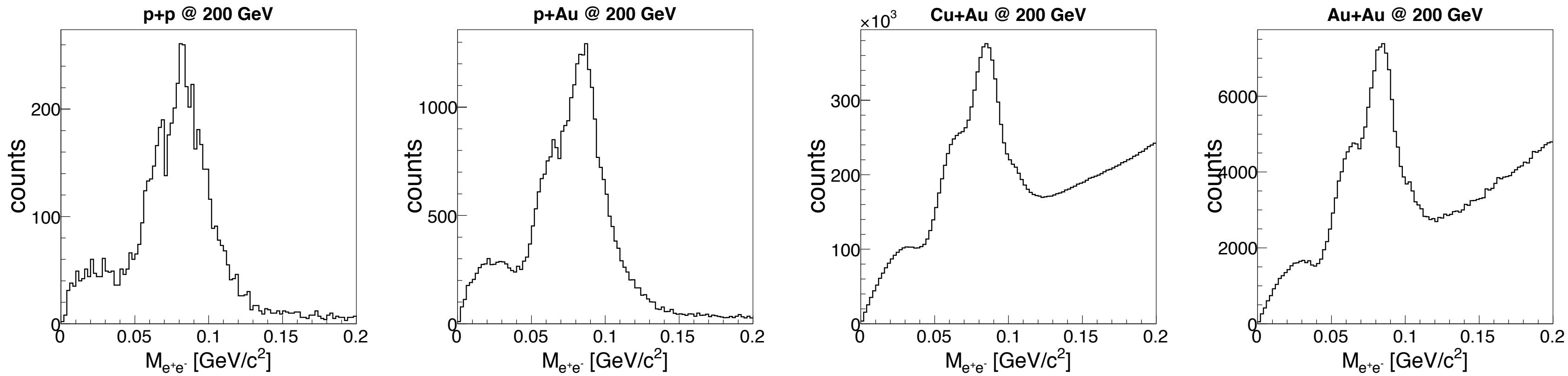
- Solve the equation of motions for both tracks to the their intersection (4D lookup table, 2 -> 2 operator)
- Once the conversion radius is found, reconstruct the true momentum of the photon

First look at the data





$2.0 < p_T < 2.5$ GeV/c



Signal is clearly visible in all systems

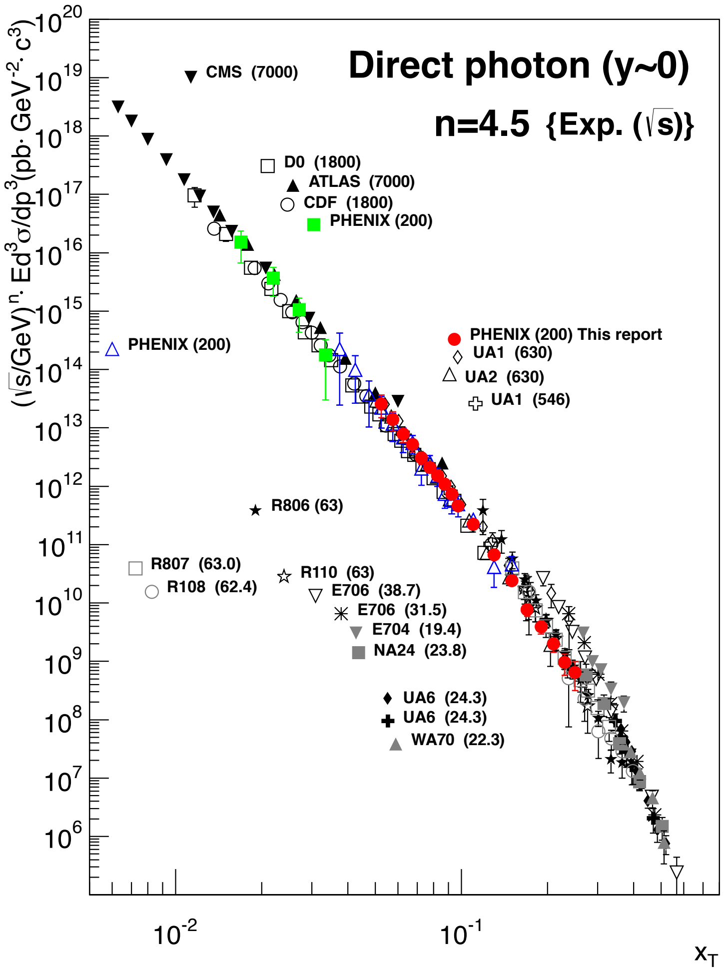
Summary

- Direct photons are excellent probes to study the properties of the Quark Gluon Plasma
- The measurement of the large yield and large flow of the direct photons is a challenge to theoretical models
- Extend the measurement to 62.4 and 39 GeV Au+Au collisions
- A new reconstruction method was needed due to the change in detector setup
  - Larger statistics from 2014 Au+Au will provide accurate measurement of v_n (v_2, v_3, v_4) at low p_T
  - v_n measurement in most central Cu+Au will provide useful input in understanding of chiral magnetic field effect, if any
  - p+Au results will help to understand properties of the medium created in small systems
  - New p+p results will extend the measurement to lower p_T

BACKUP

Prompt photon production

PhysRevD 86 072008

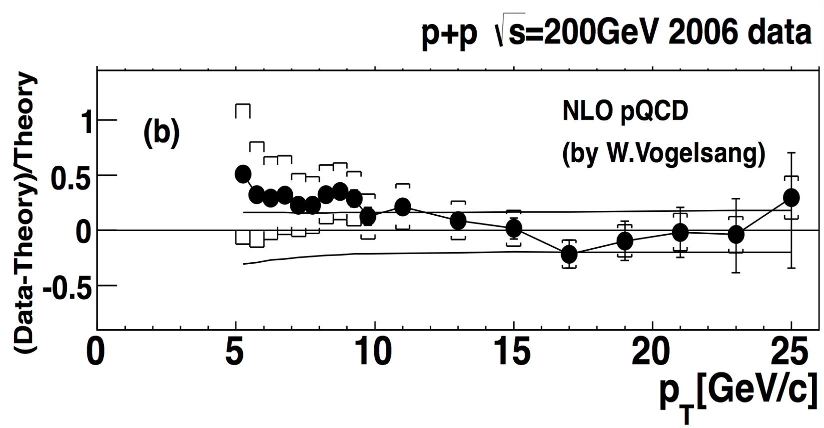


The invariant cross of direct photon production in p+p collisions (from 20 GeV to 7 TeV) factorizes in dimensional and dimensionless parts, as

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{\,n_{eff}(x_T,\sqrt{s})}}G(x_T)$$

Phys.Rev. D4, 3388 (1971).

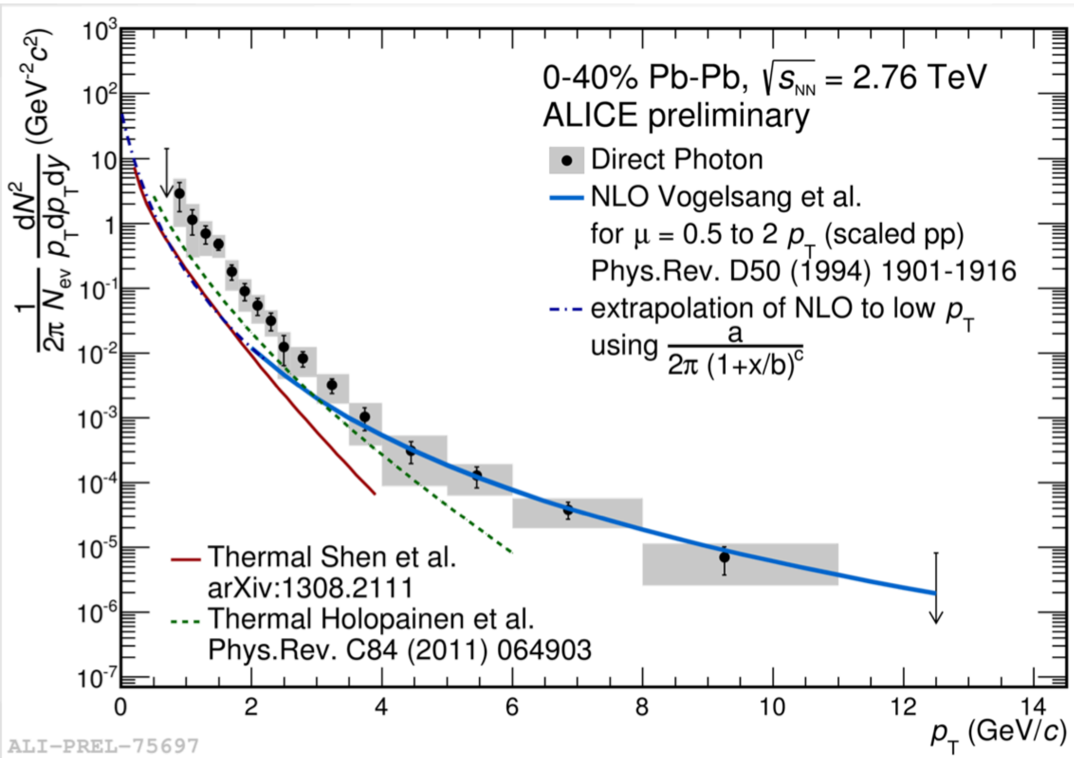
- holds for any scale-free theory.
- n_{eff} = 4 LO, n_{eff} > 4 for NLO

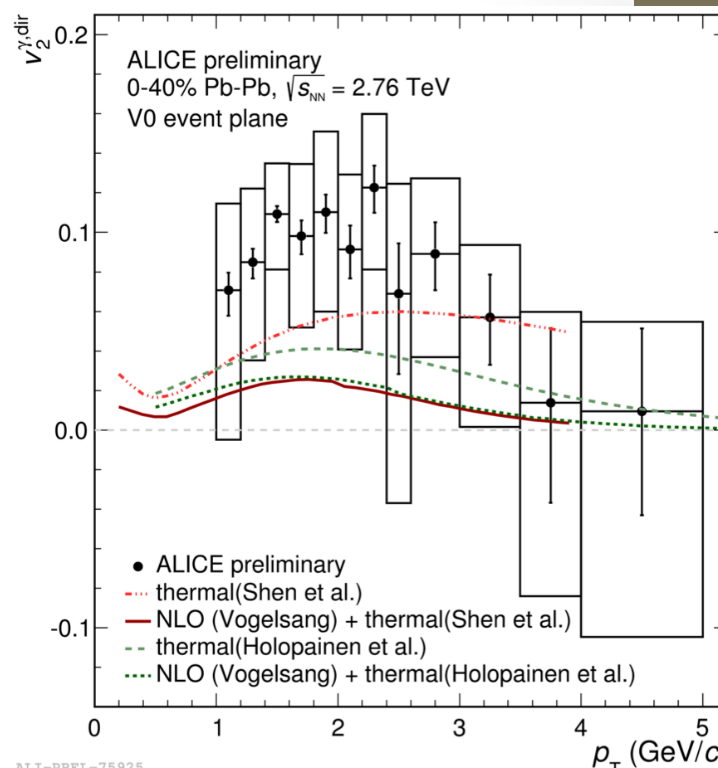


PhysRevD 86 072008

pQCD works in p-p collisions

Thermal photons at LHC energies



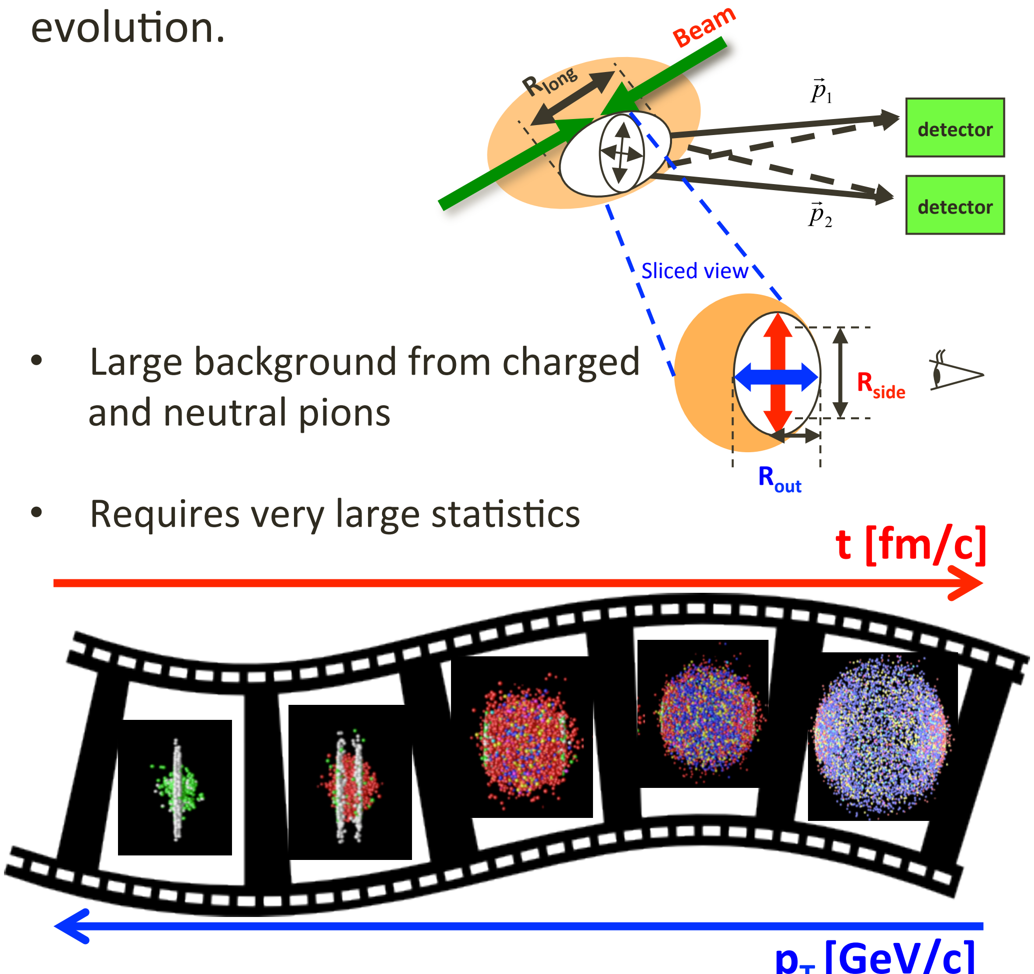


Preliminary results from ALICE exhibited similar tensions with theoretical models trying to describe the yield and flow of photons

Direct photon HBT promise

PRL 93 162301

Direct photon and hadron HBT will shed light on the time-dependent source geometry and flow evolution.



- Large background from charged and neutral pions
- Requires very large statistics