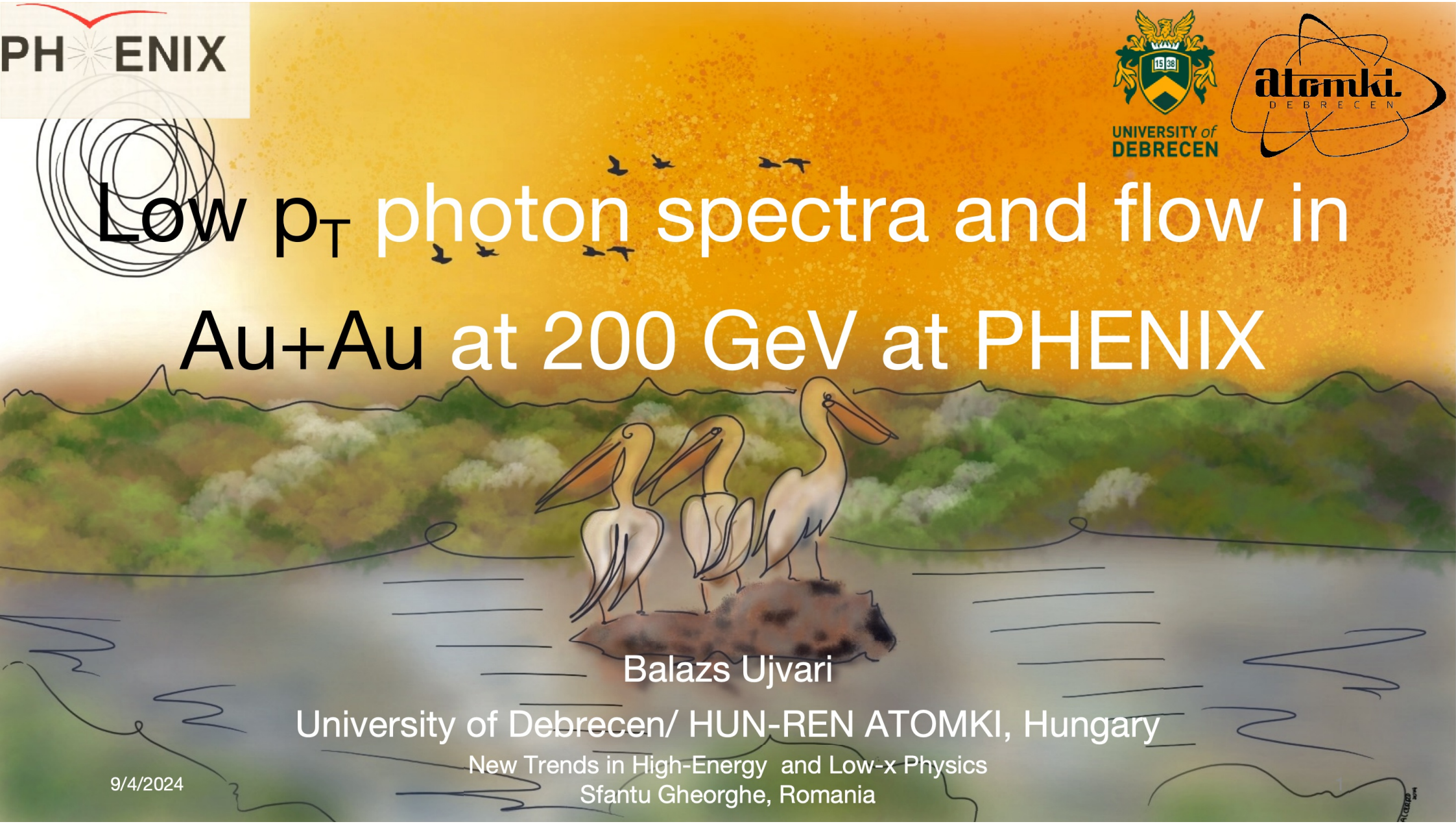
Low p_T photon spectra and flow in Au+Au at 200 GeV at PHENIX



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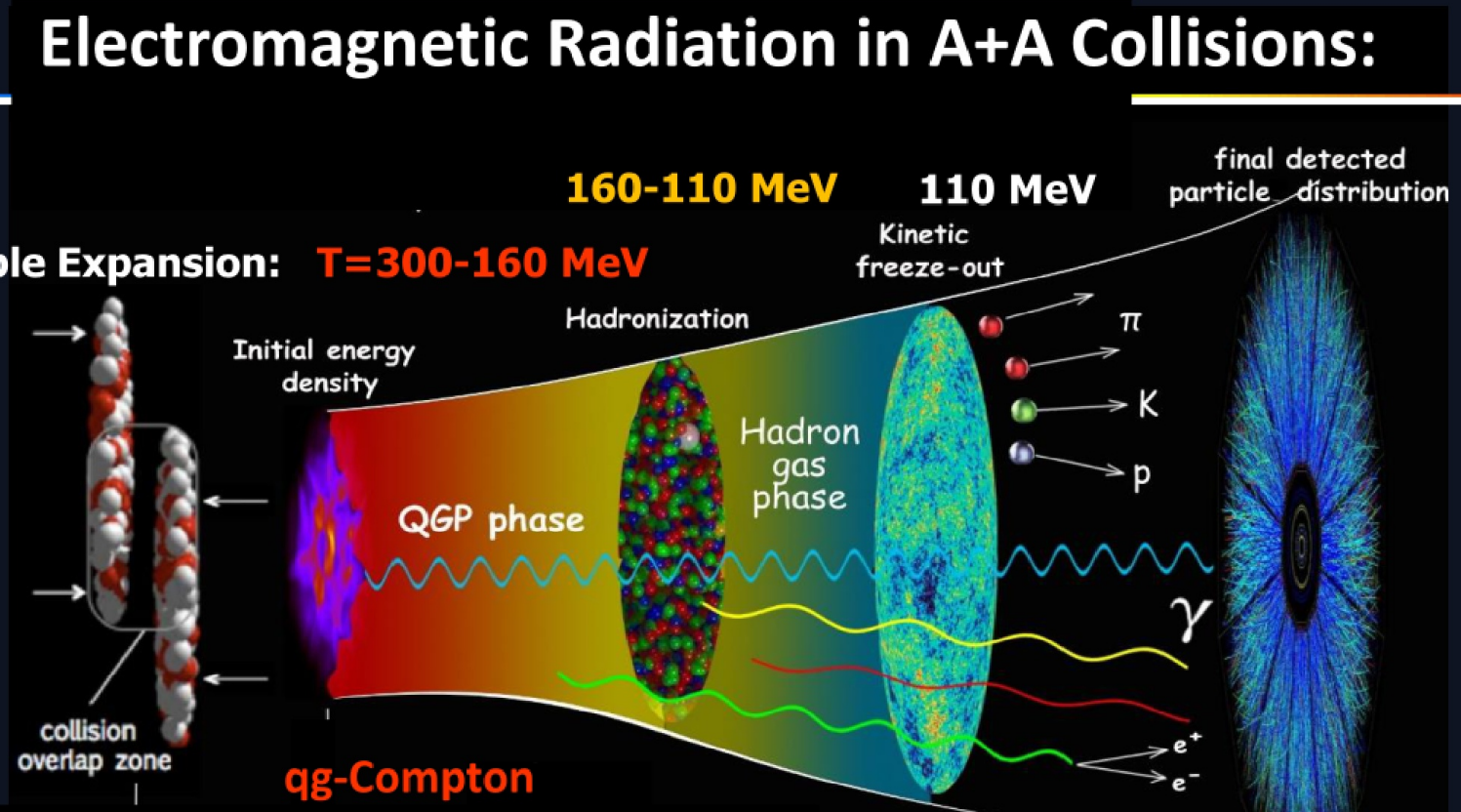
New Trends in High-Energy and Low-x Physics
Sfantu Gheorghe, Romania

9/4/2024

Outlines

- Introduction
- Direct photon spectra
- Direct photon flow
- Summary

Electromagnetic Radiation in A+A Collisions:



Initial qg-Compton

- powerlaw spectrum
- $\propto N_{coll}$
- no collective motion

qg-Compton (deconfinement)

- high T spectrum
- little radial flow
- yield $\propto N_{ch}^{\alpha}$ $\alpha \leq 2$

πρ Scattering

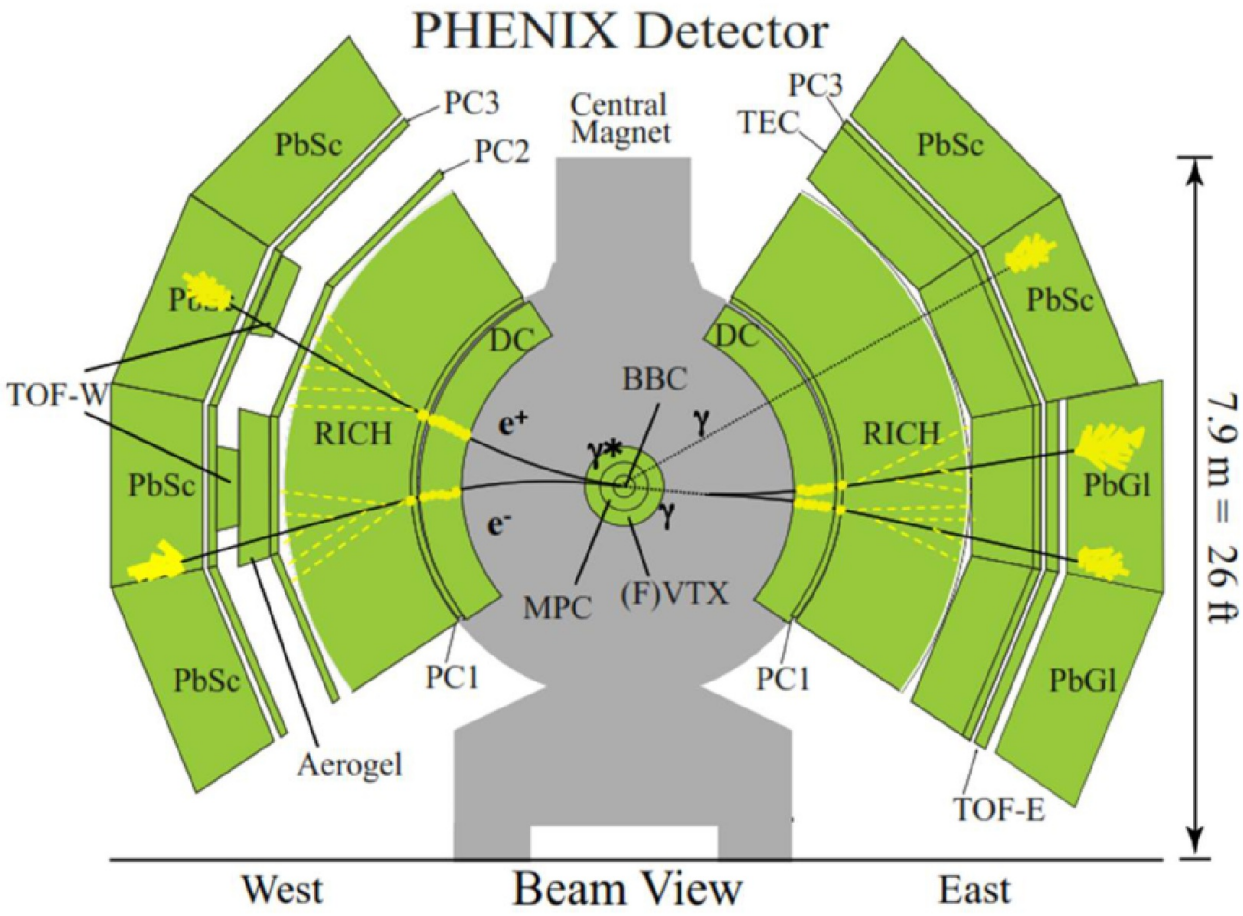
- Low T spectrum
- Large flow/ blue shift
- yield $\propto N_{ch}^{\alpha}$ $\alpha > 1$

Hadron Decays

- yield $\propto N_{ch}$
- Spectra derived from parent particles

Introduction

- Direct photons have long been considered a golden probe to understand of the evolution of relativistic heavy-ion collisions – from the quark-gluon plasma (QGP) phase to the hadron-gas (HG) phase.
- Direct photons traverse the medium unmodified due to the small cross section of electromagnetic interaction
- These penetrating photons encode information about the environment
- High transverse momentum p_T direct photons –→ dominated by photons created from initial hard-scattering processes
- Low p_T is dominated by radiation from the evolving partonic/hadronic medium –→ earlier terminology: thermal photons
- Current measurements –→ additional sources and mechanisms of direct-photon production –→ new name: non-prompt photons



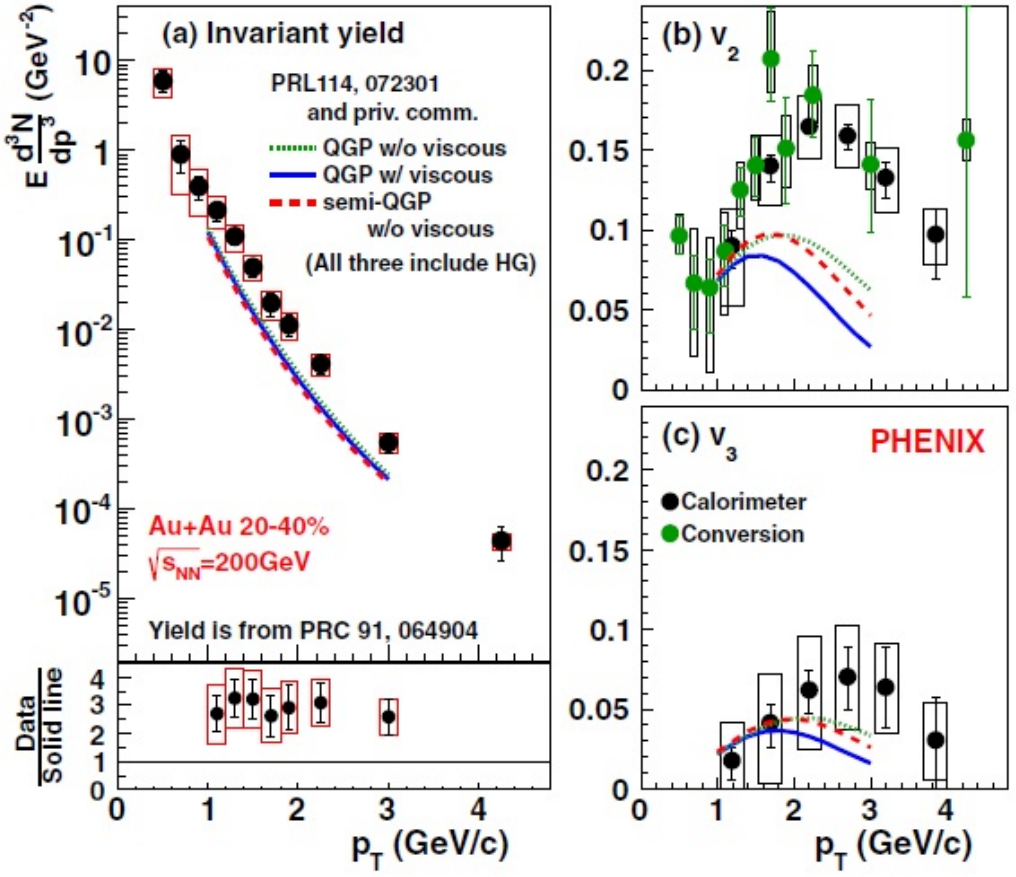
"calorimetry"

"external conversion"

"internal conversion"

Direct photon puzzle

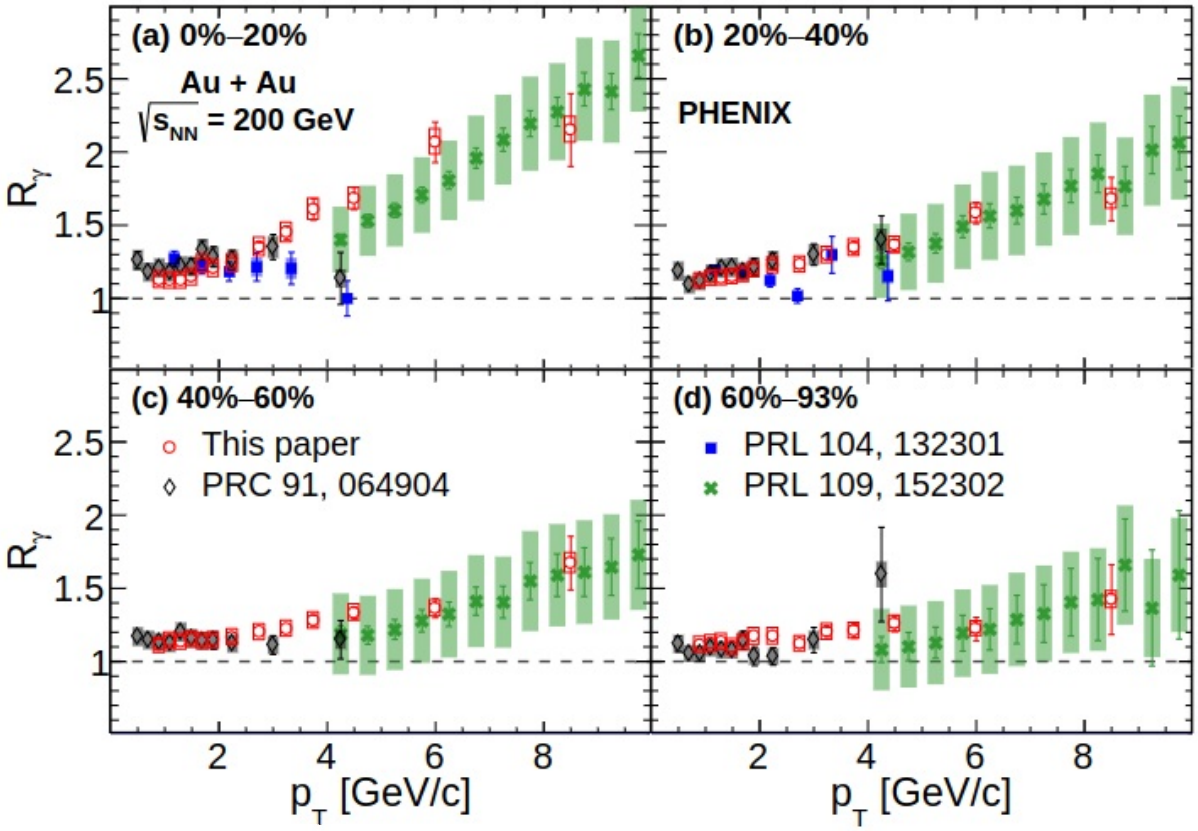
- Several theoretical models have been developed
- Most of the models qualitatively ✓
- For quantitatively ø
- What was seen earlier?
- high yield and high v2 at the same time
- ↔ old paradigm will not work
- high yields means high T (early emission) ↔ high v_2 means late emission, where T is low
- Theoretical curves are below the yield and flow



PHENIX PRC 94, 064901 (2016)

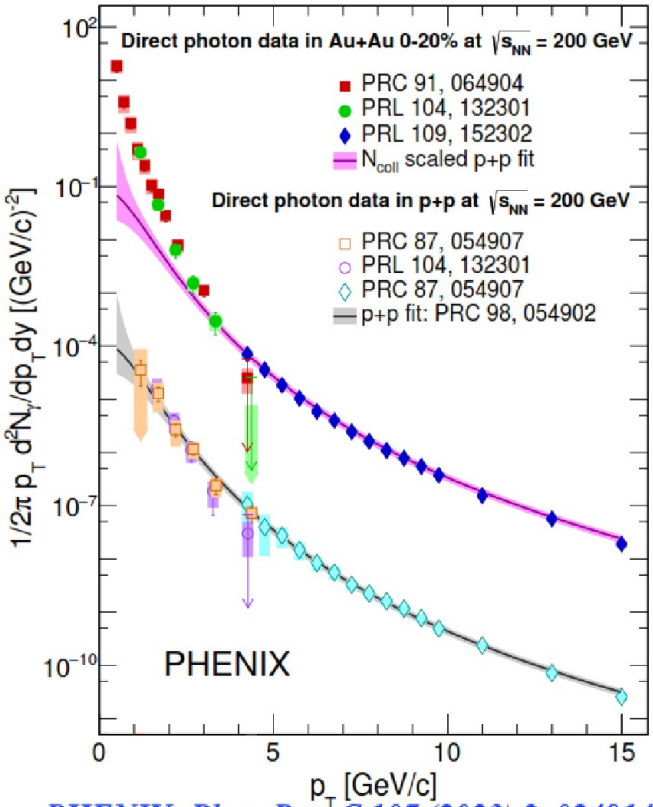
Result - four different R_γ PHENIX measurment

- Internal conversion (PRL 104, 132301)
- External conversion far from vertex (PRL 91, 064904)
- Real photons in calorimeter (PRL 109, 152302)
- External conversion close to the vertex (arXiv:2203.17187)



The new results are compared with all other published PHENIX results –→ different methods + independent systematic uncertainties.

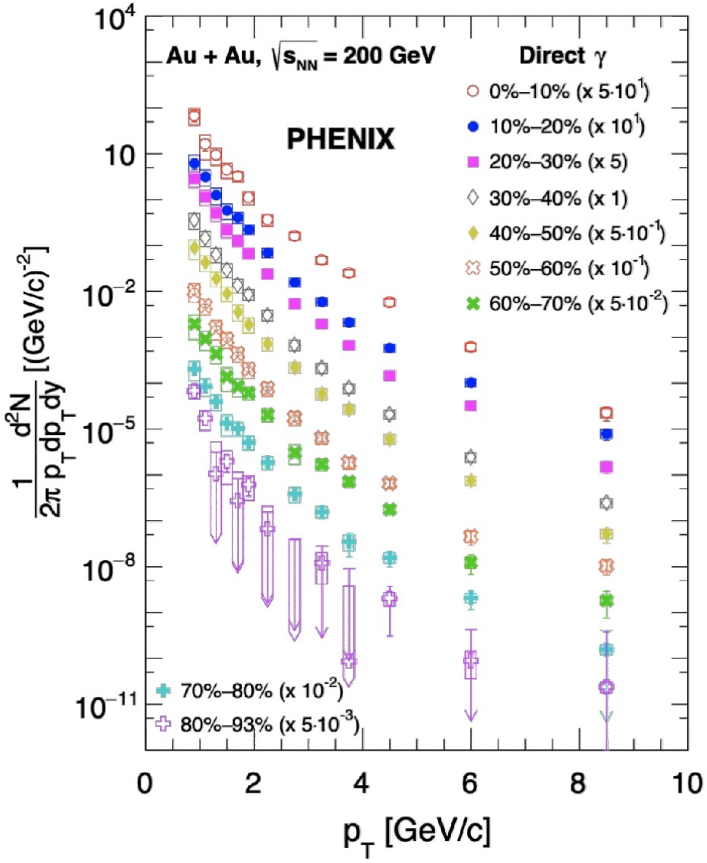
Yield of direct photons in p+p and Au+Au at 200GeV



PHENIX: Phys. Rev. C 107 (2023) 2, 024914

- pp consistent with pQCD
- AuAu follows N_{coll} scaled pp above 4 GeV
- Significant excess below 3 GeV in AuAu
- Excess has close to exponent

New !



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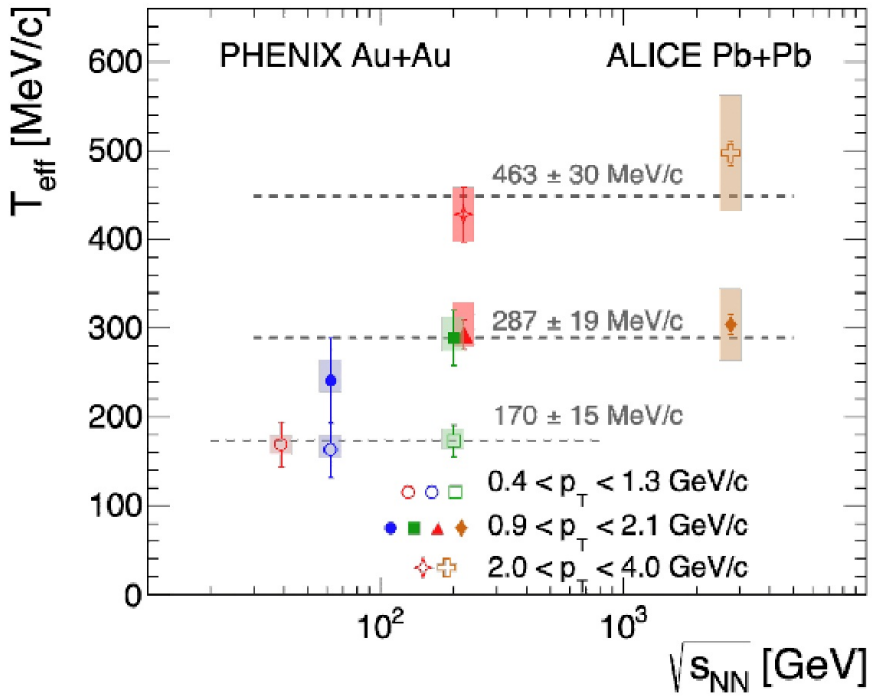
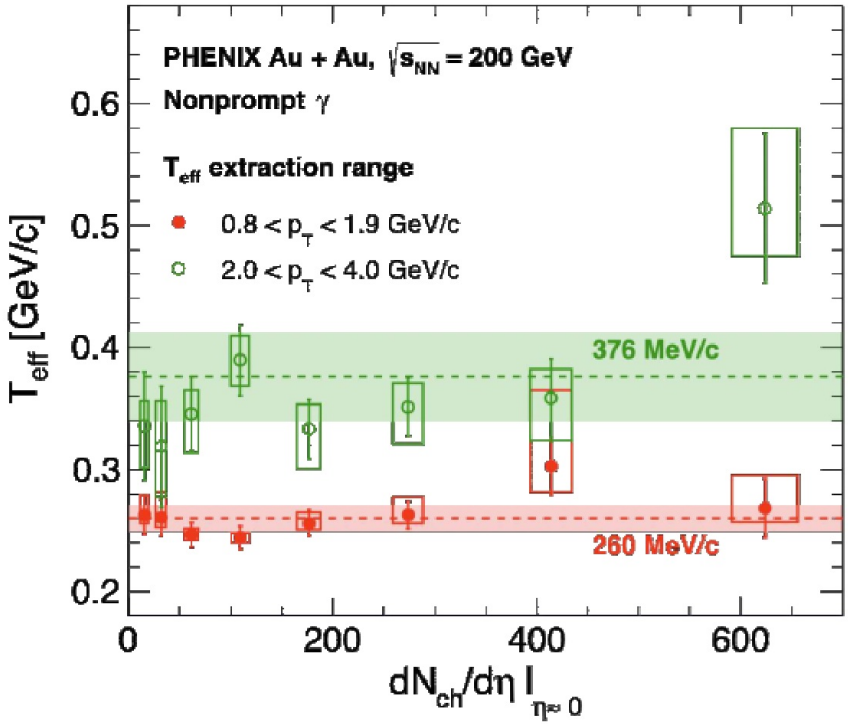
Effect of System size and Collision Energy





T_{eff} inverse slope of an exponential fit over a given range

T_{eff} depends on the fitted p_T range,
but almost no dependence on centrality

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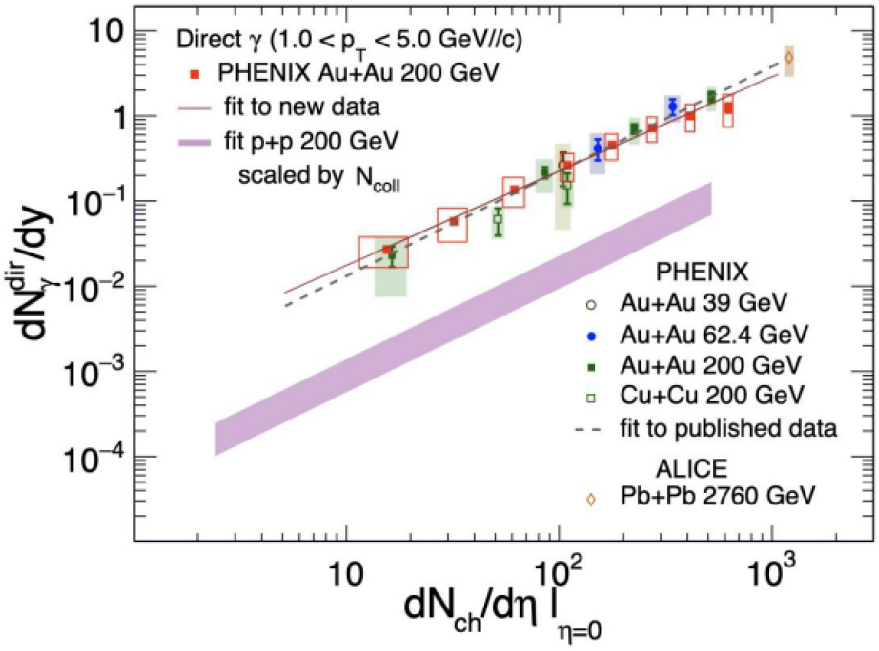
ALICE: Phys. Lett. B 754 (2016) 235-248

System Size and Energy Dependence of Direct Photon Yield

The integrated direct photon yield scaling function:

$$\frac{dN_\gamma}{dy} = \int_{p_T,min}^{p_T,max} \frac{dN_\gamma^{dir}}{dp_T dy} dp_T = A \times \left(\frac{dN_{ch}}{d\eta}\right)^\alpha$$

- Agreement with other direct-photon results
- Fit for previously published data: α = 1.23 ± 0.06 ± 0.18
- Fit from the current data: α = 1.11 ± 0.02 ± 0.09
- α smaller than predicted –→ HG = 1.25 and QGP = 1.8
- The same scaling holds over vastly different collision energies (39-2760GeV) and systems (CuCu - PbPb)



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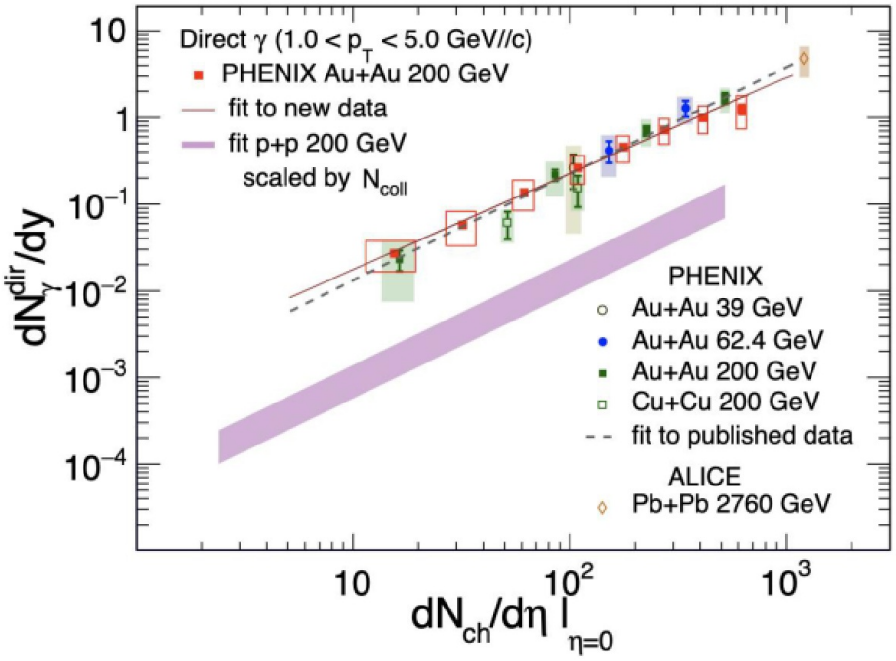

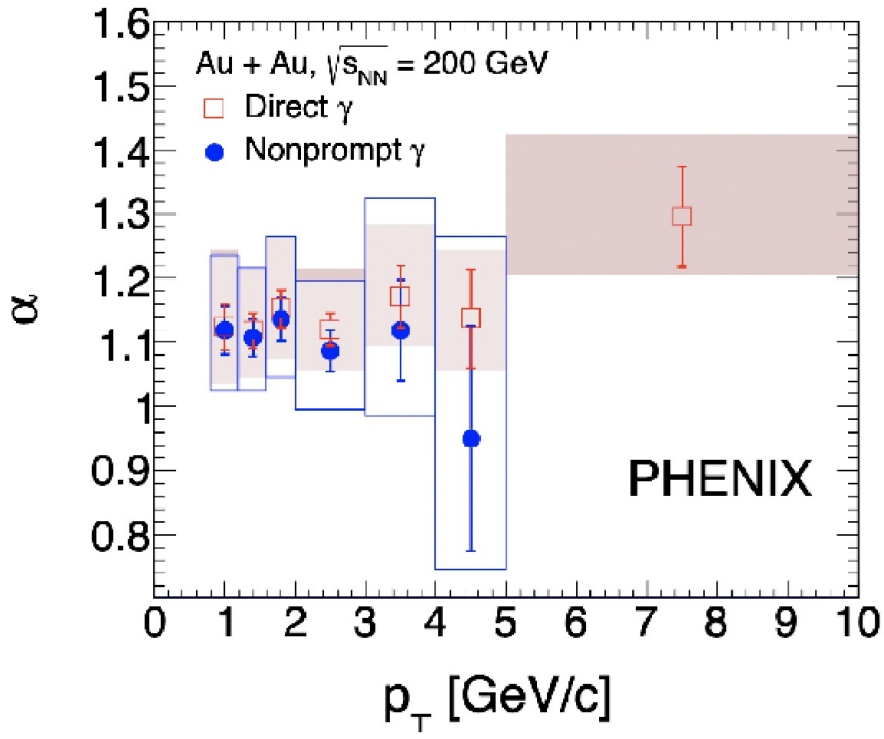

Universal scaling behavior observed in all A+A systems
No obvious p_T dependence observed

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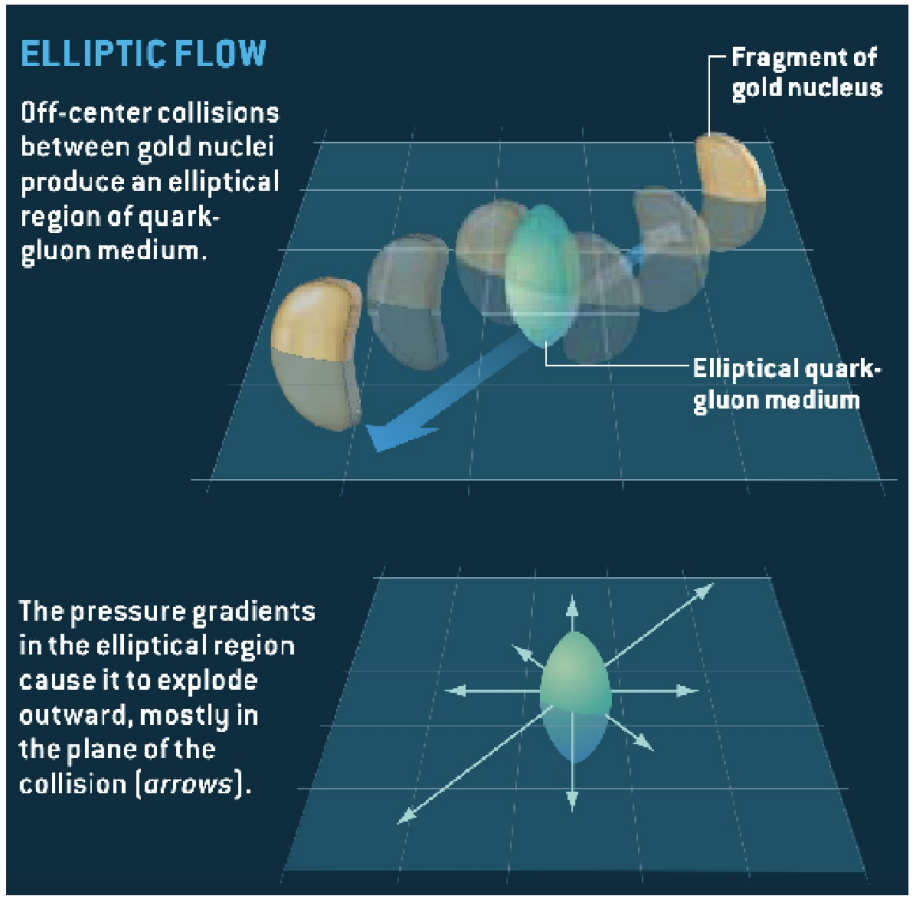
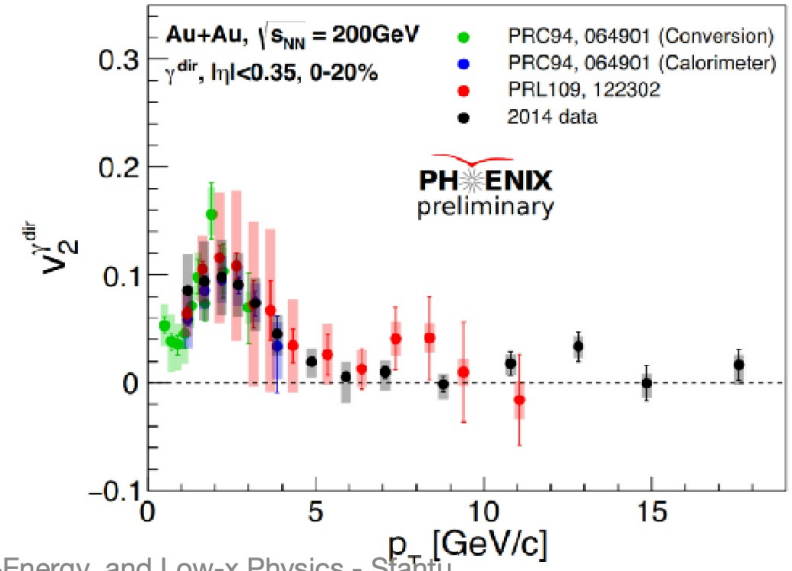
Elliptic flow (v_2) of Direct photons

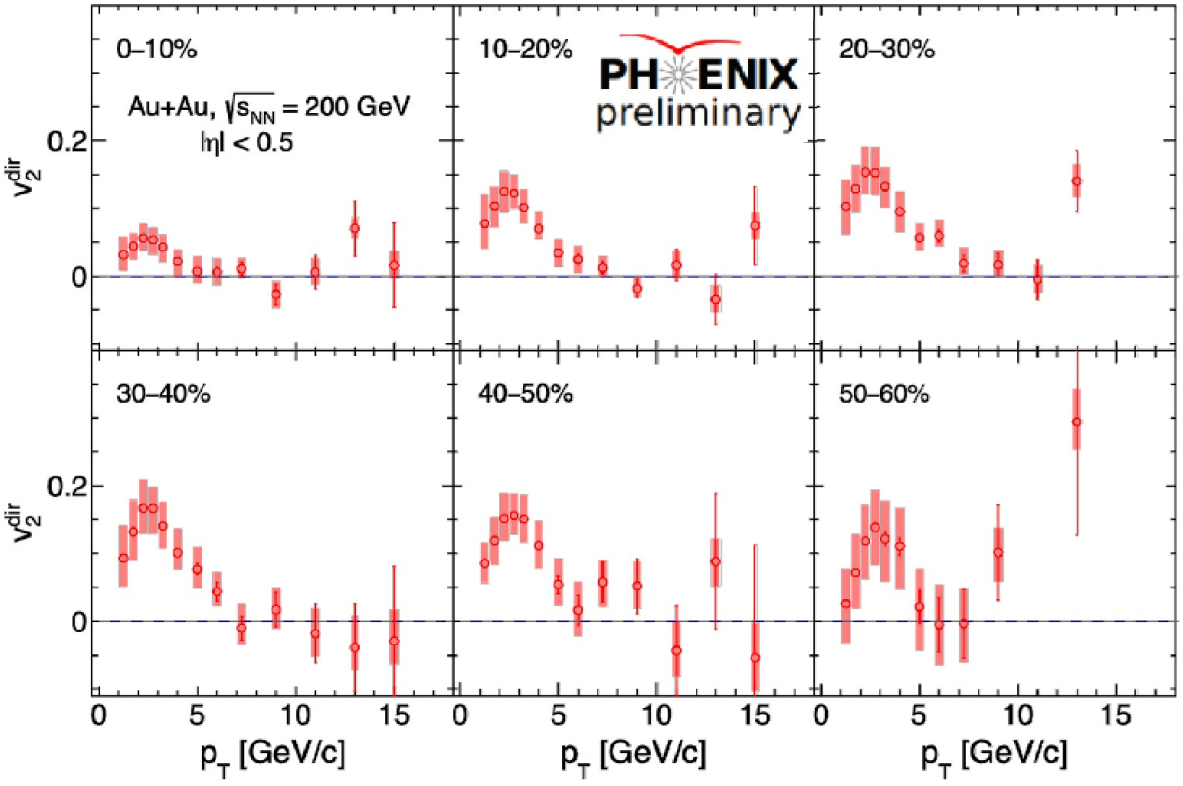


- **Fireball from collision rapidly expands**
  Radial flow with anisotropy with respect to the reaction plane (elliptic flow)
- **Direct photons emitted from collectively expanding matter**
  Anisotropic Doppler shift



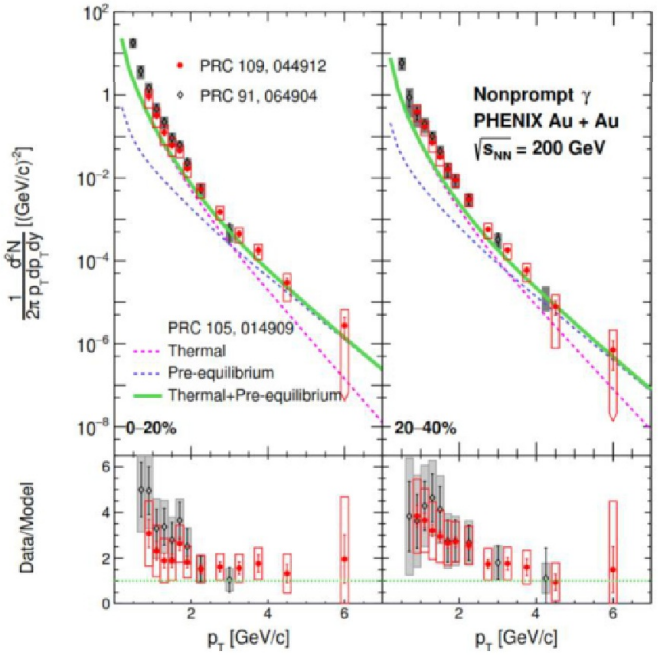
previous results with different analysis techniques

Elliptic flow (v_2) of Direct photons

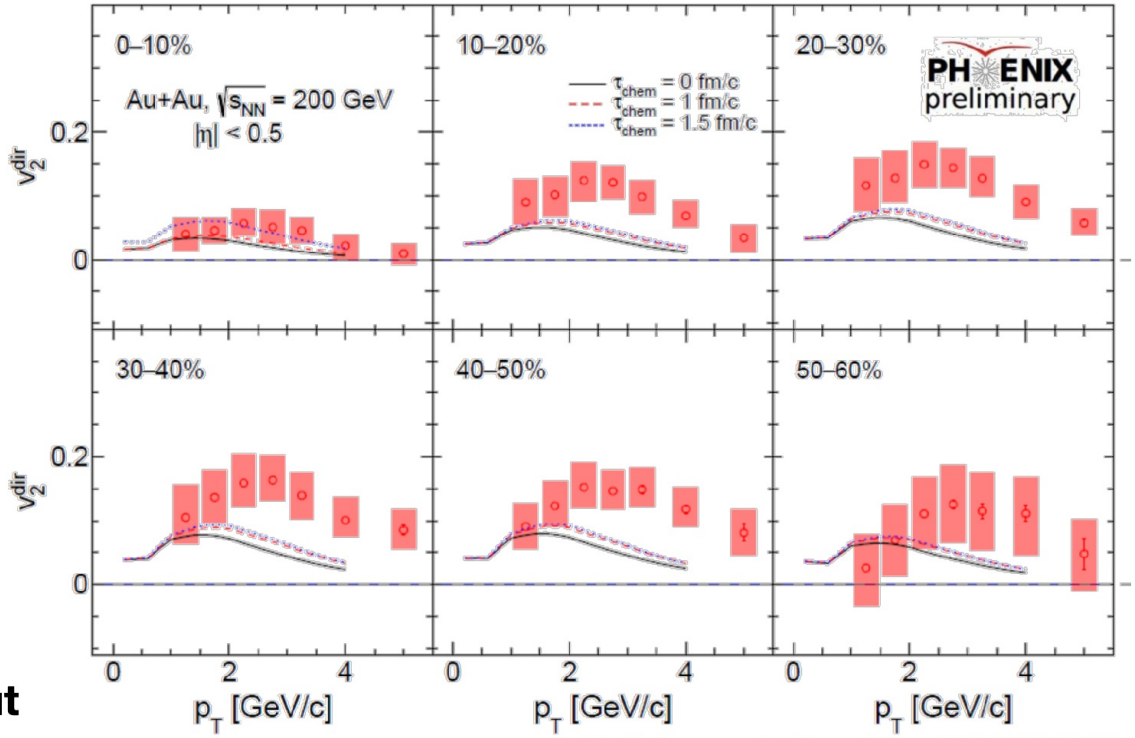


- **Measurement done in finer centrality bins**
- **Significant anisotropy for p_T < 5 GeV/c**
  - ➢ **Similar to hadrons**
  - ➢ **Maximum around 2-3 GeV/c**
  - ➢ **Clear centrality dependence**
- **High p_T dominated by prompt photon emission**
  - ➢ **v_2 consistent with zero**
  - ➢ **No centrality dependence**

Thermal Photon Model Calculations



Model calculations qualitatively reproduce shape but falls short quantitatively



C. Gale et. al. Phys. Rev. C 105 014909 (2022)

- **at low p_T, where the theories describe the flow, they miss the yield completely,**
- **at higher p_T, the yield is well described, but there the theory completely misses the flow**

Summary

- Bigger PHENIX dataset : 10 × more statistic −→ + confirm earlier results + new kind of analysis −→ ”direct photon puzzle” is still alive
- More photons emitted from Au+Au collisions than can be accounted for in model calculations
- Large “thermal” yield at $p_T < 4$GeV
- Prompt photon dominates at $p_T > 5$GeV

- In this p_T range, the yield is larger than what would be expected from a rapidly but anisotropically expanding hadronic fireball