Probing the Quark Gluon Plasma : Photons and Dileptons as Messengers

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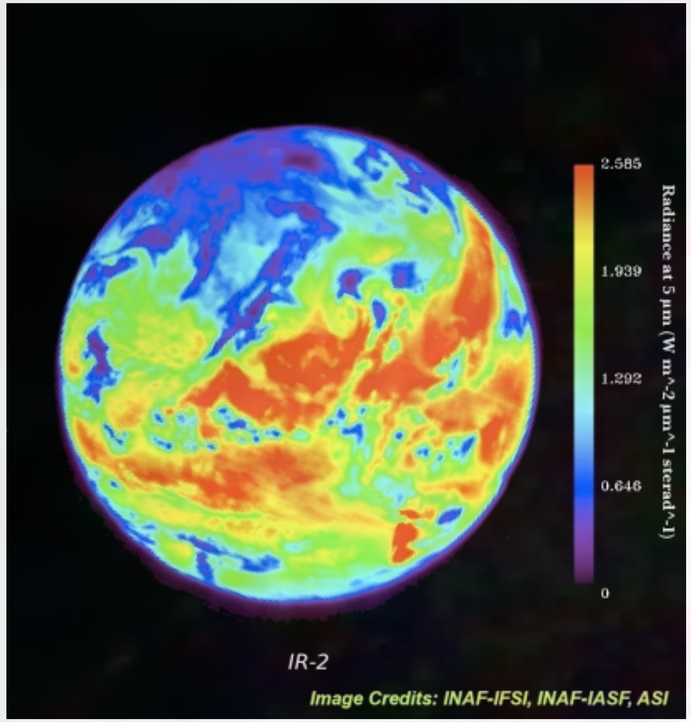
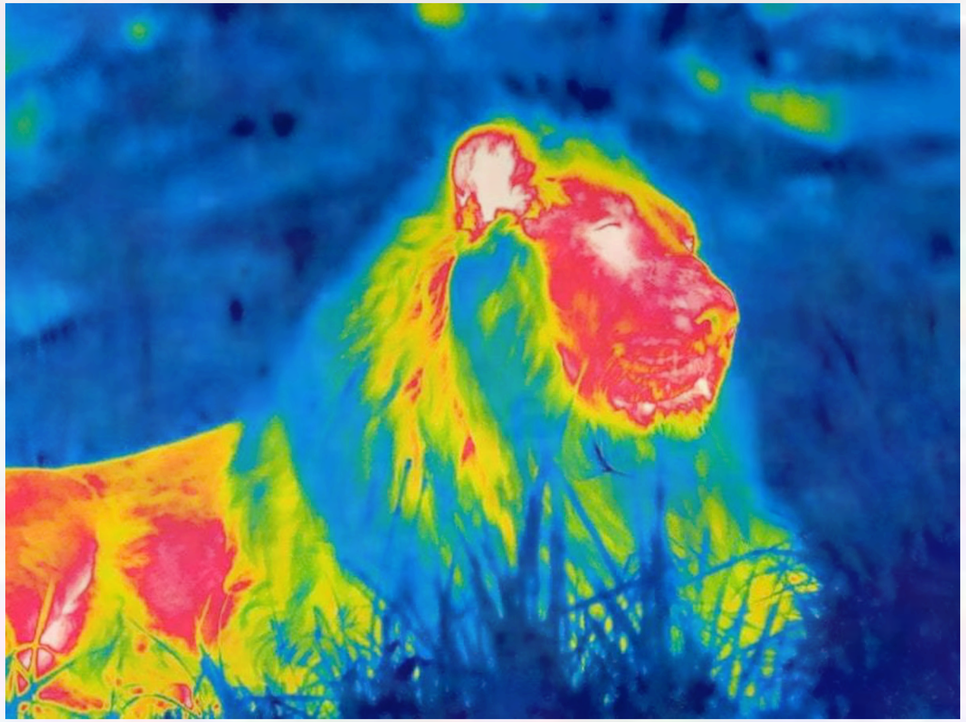
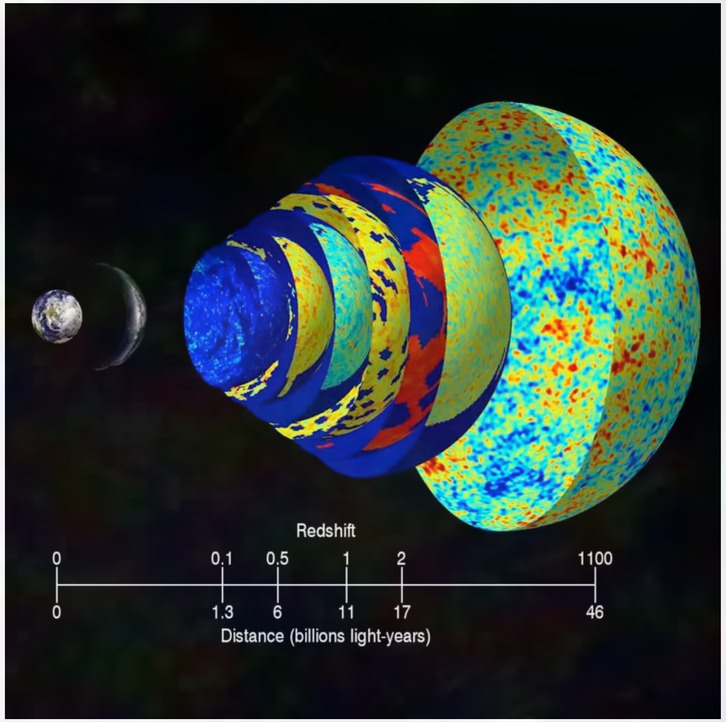
Electromagnetic radiations

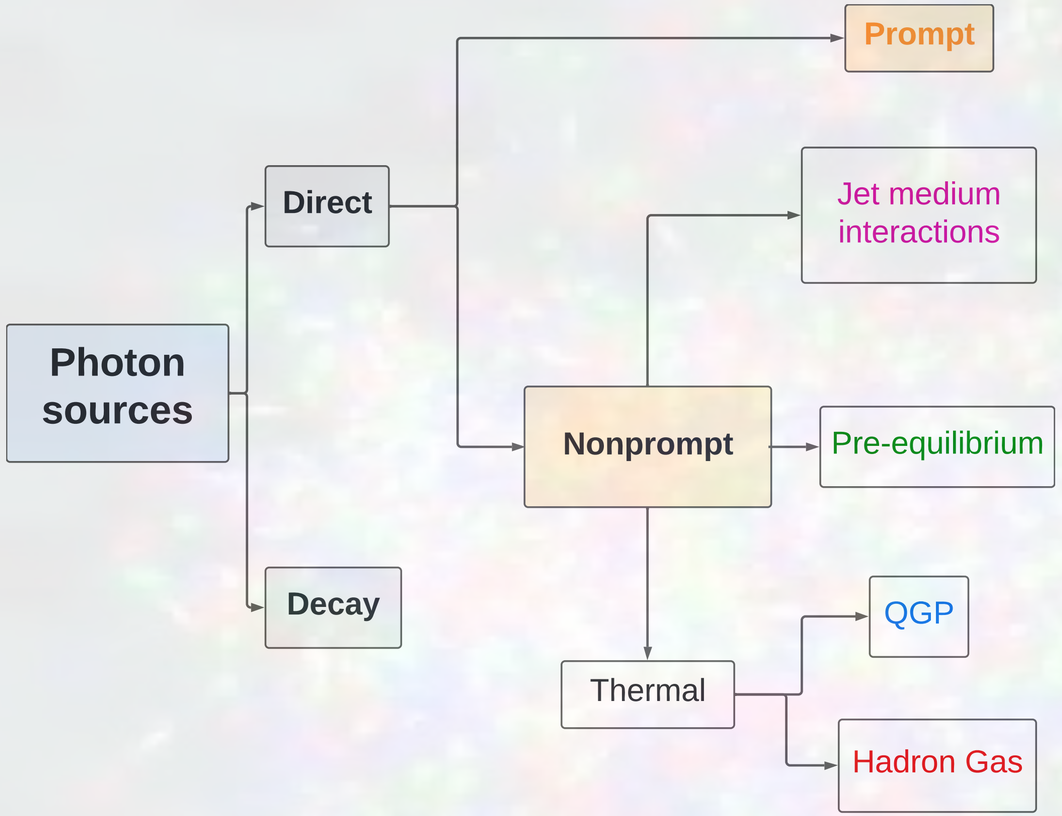




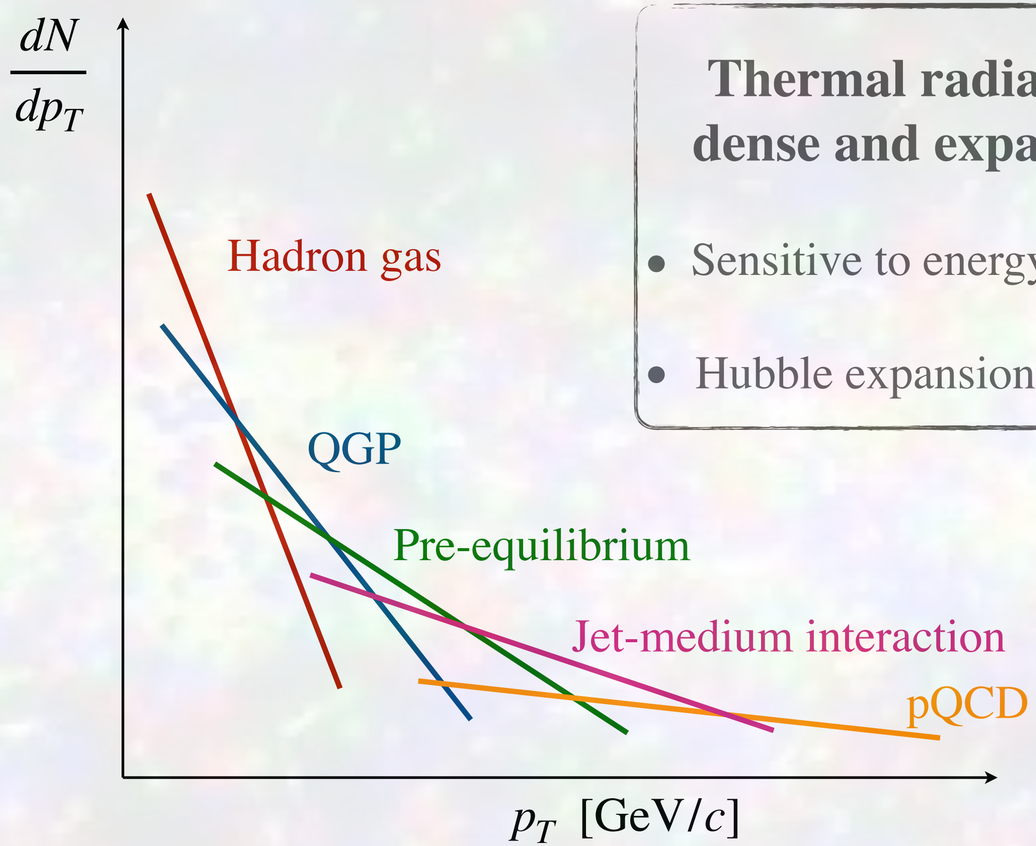


All object emit electromagnetic radiations, characterized by their temperature

Electromagnetic radiations in A+A collisions



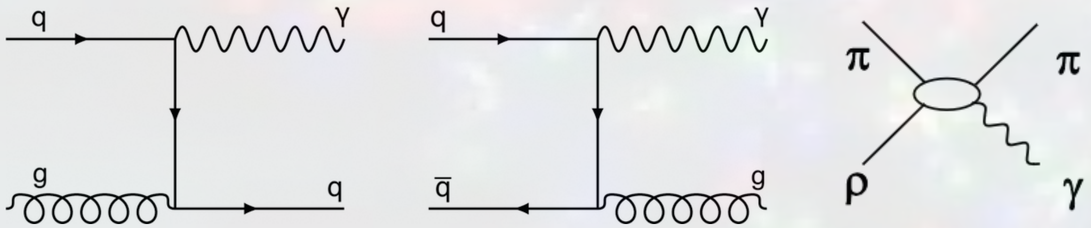
Photons are "color blind" probe of Quark Gluon Plasma



Thermal radiation from hot, dense and expanding medium

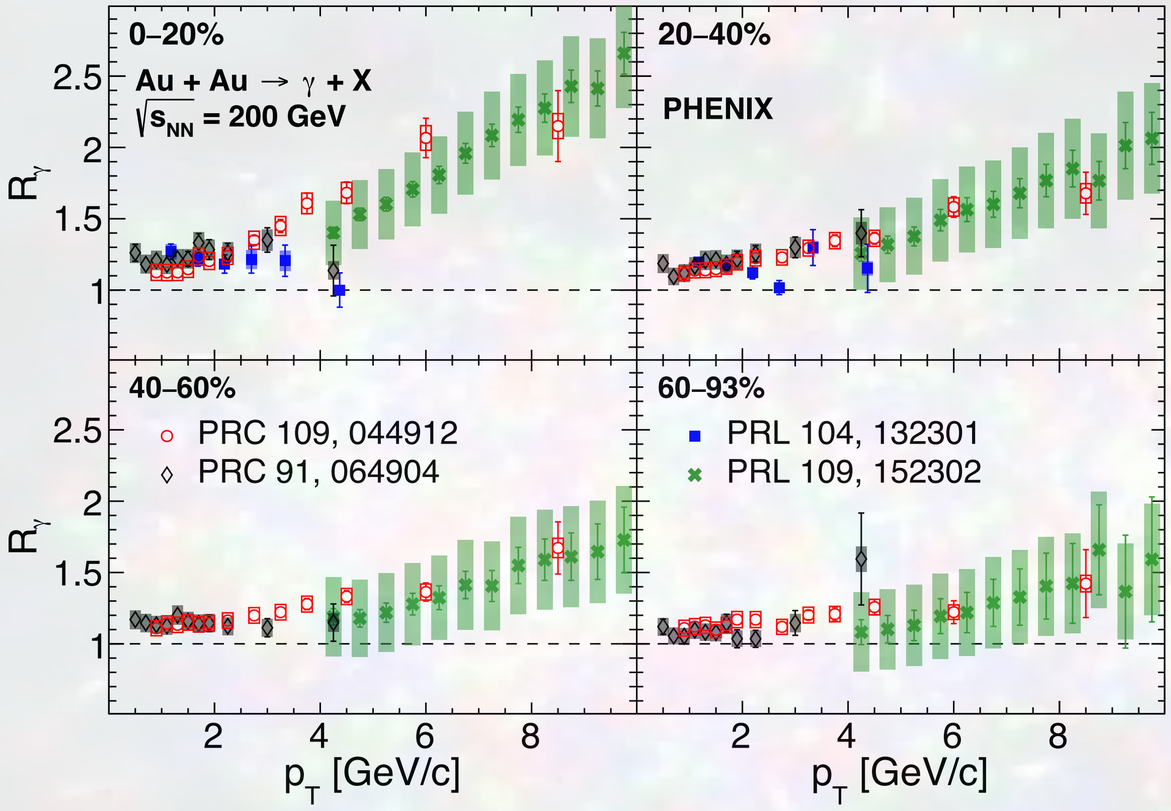
- Sensitive to energy density ($\propto T^4$)
- Hubble expansion $\Longrightarrow$ Doppler shift

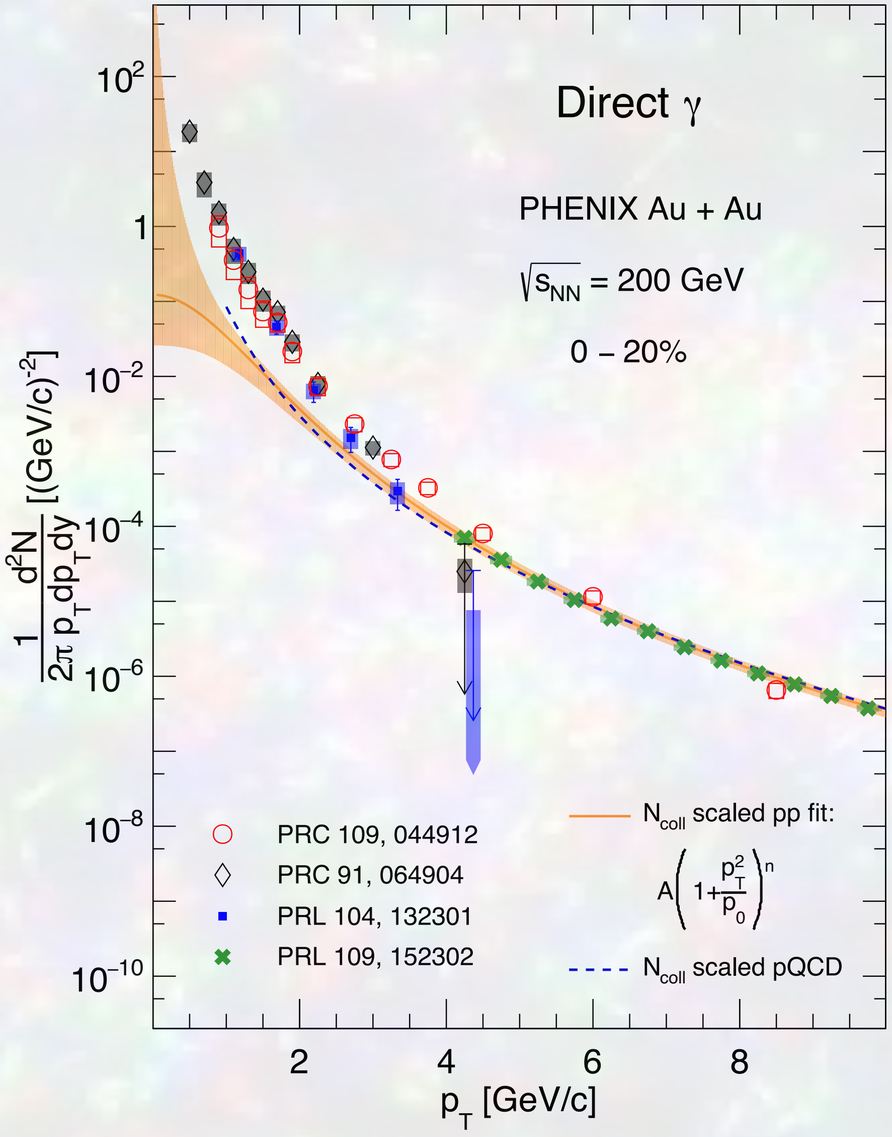
Microscopic processes for photon production



Measurement of yield constrains initial conditions, sources, emission rates and space-time evolution

Thermal radiations from A+A collisions



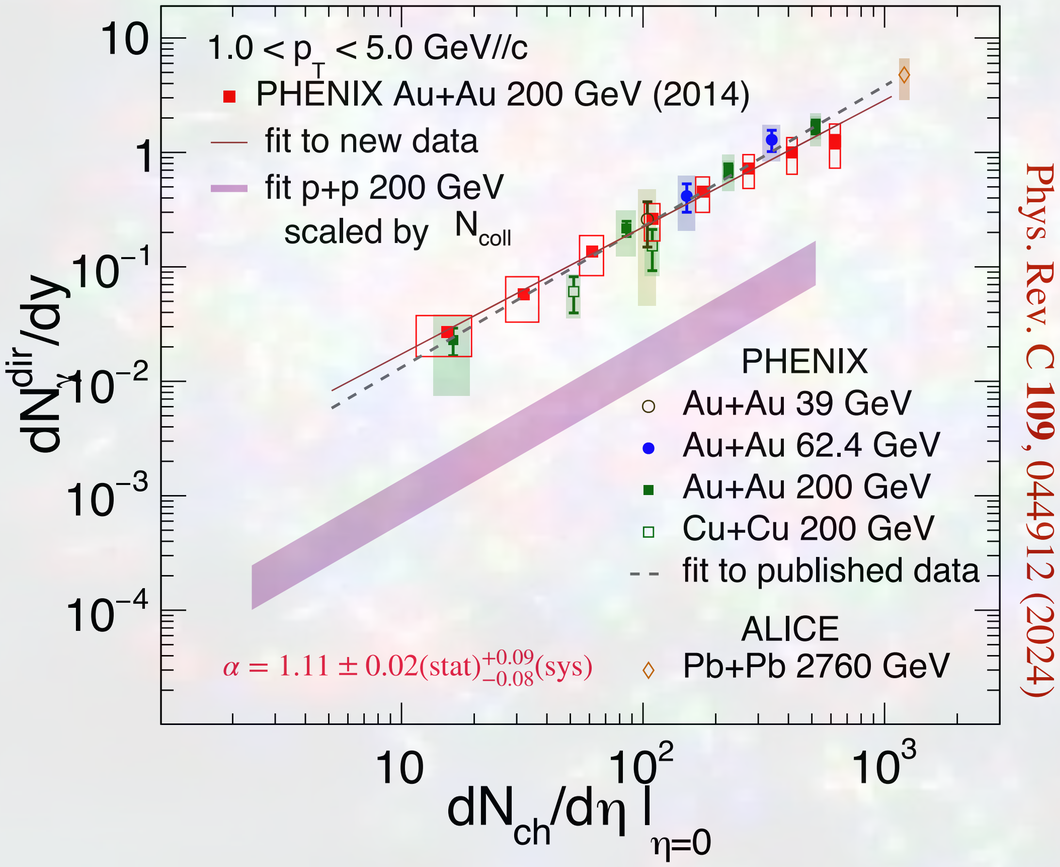


Consistent results with different methods

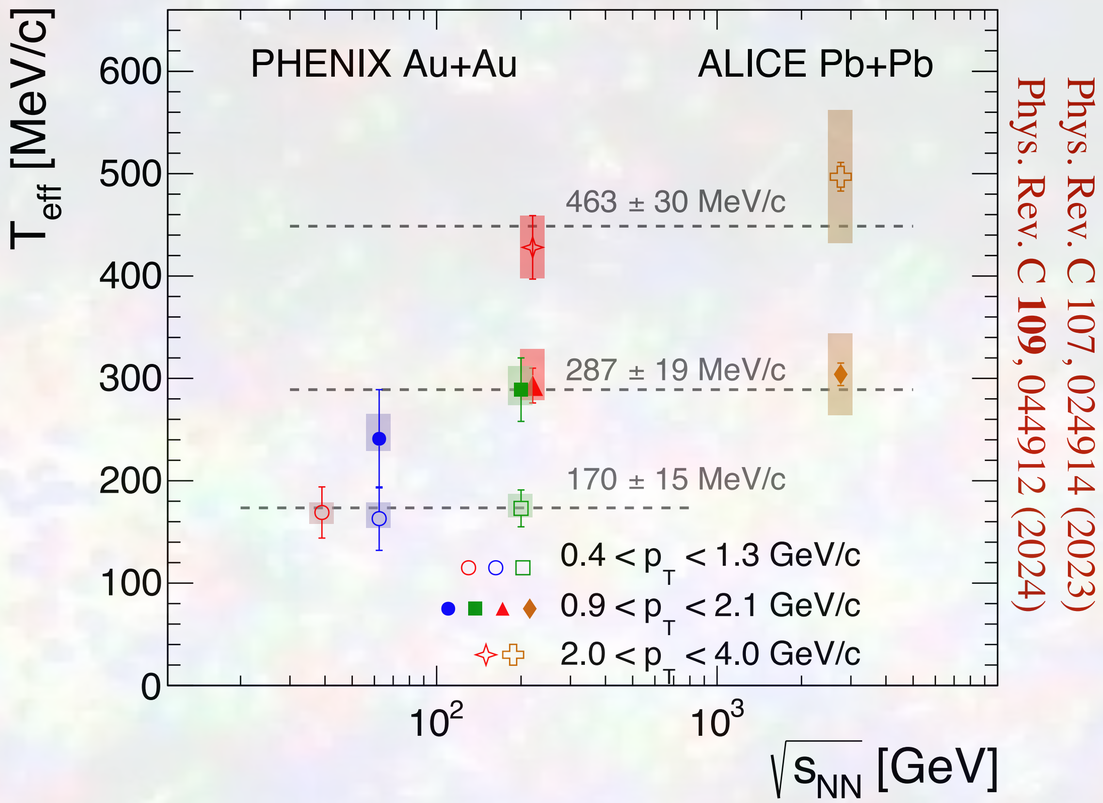
Universal behavior

Universal scaling behavior in all A+A systems :

$$\frac{dN_\gamma}{dy} = A \times \left(\frac{dN_{ch}}{d\eta}\right)^{\alpha}$$



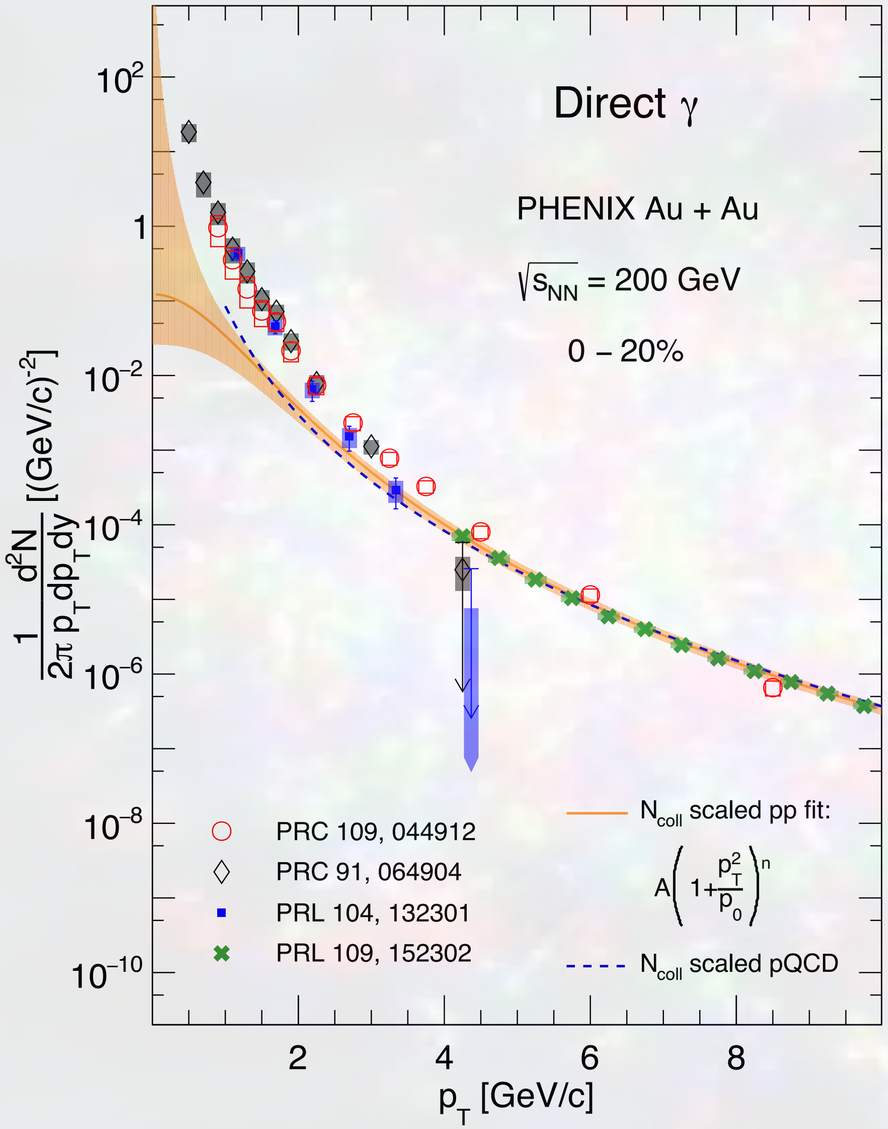
Phys. Rev. C **109**, 044912 (2024)



Phys. Rev. C 107, 024914 (2023)
Phys. Rev. C **109**, 044912 (2024)

Universality suggests common source of photon production independent of collision energy

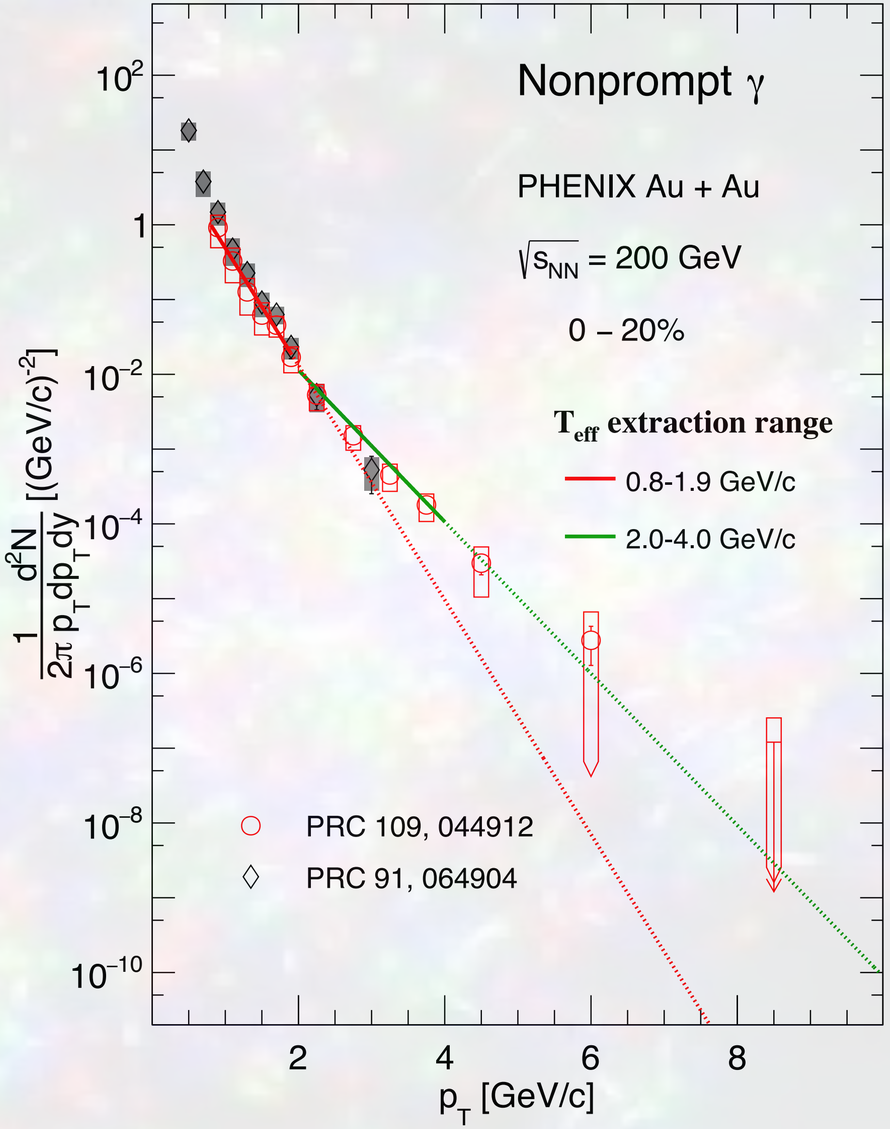
Non-prompt direct photons



Direct photon

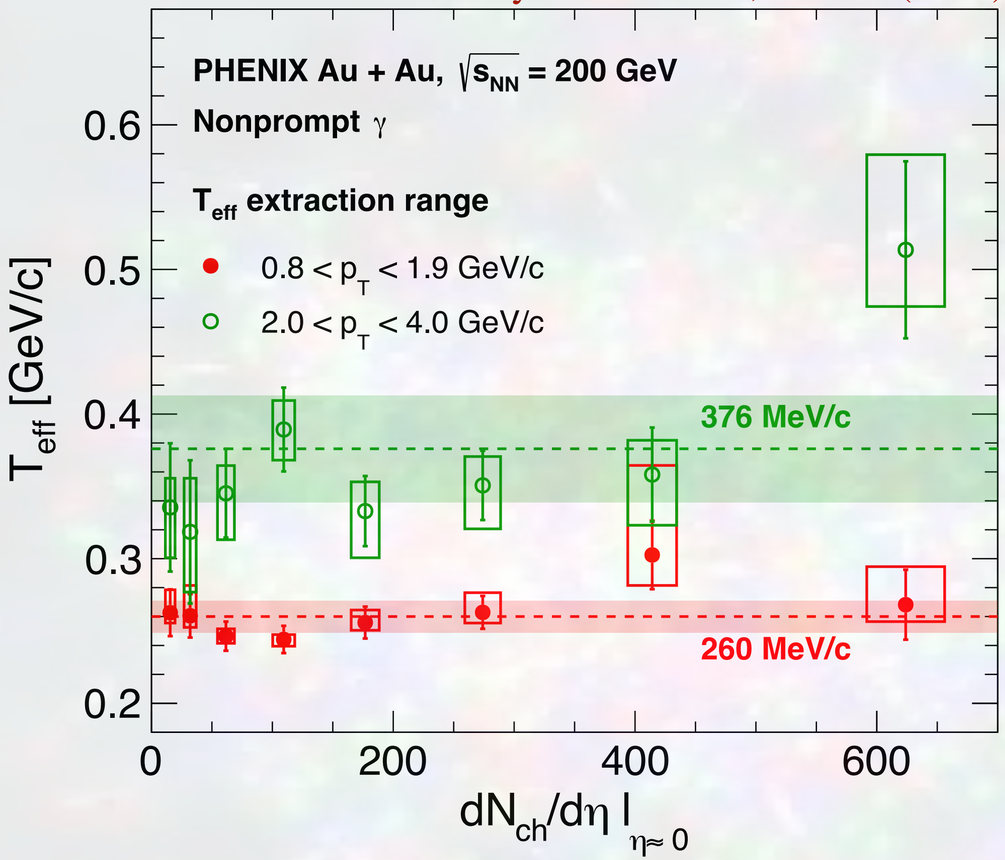
— N_{coll} **scaled p+p fit**

Non-prompt direct photon

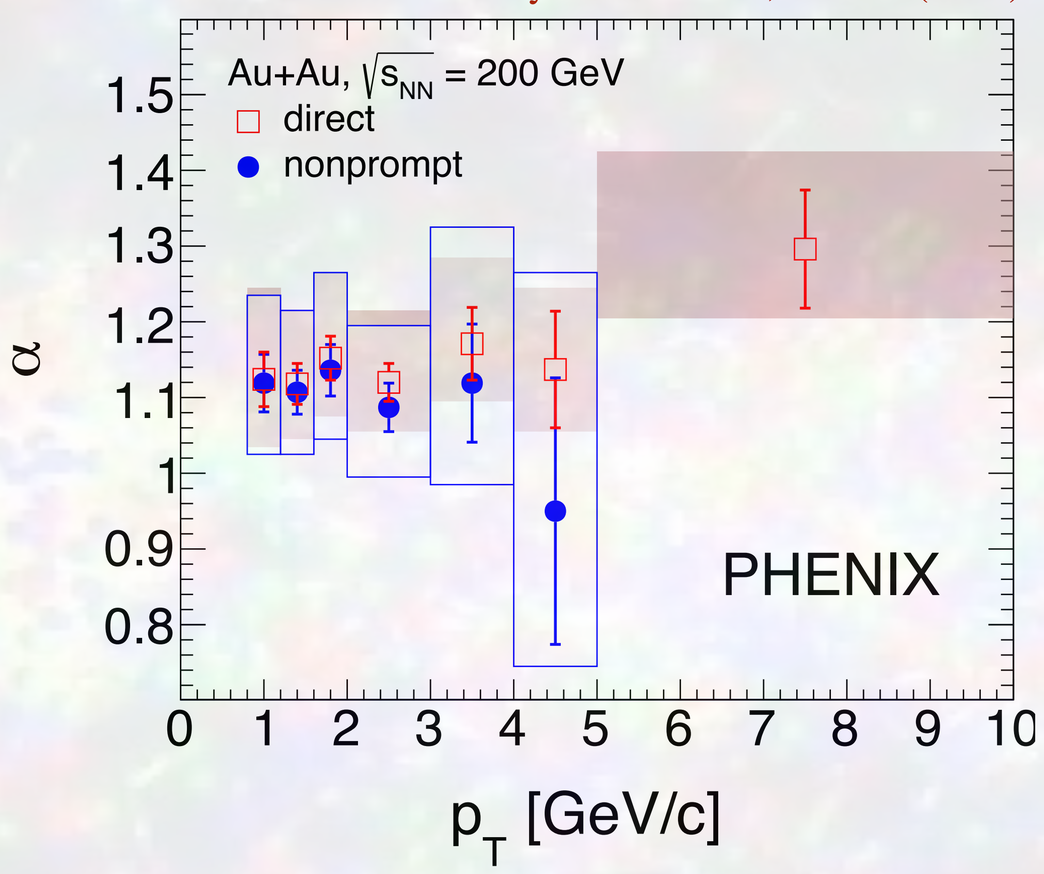


Non-prompt direct photons

Phys. Rev. C **109**, 044912 (2024)



Phys. Rev. C **109**, 044912 (2024)



Increasing inverse slope with p_T to above 350 MeV/c suggests contributions from sources beyond those from Hadron Gas

α independent of p_T for direct and nonprompt photons

Azimuthal anisotropy

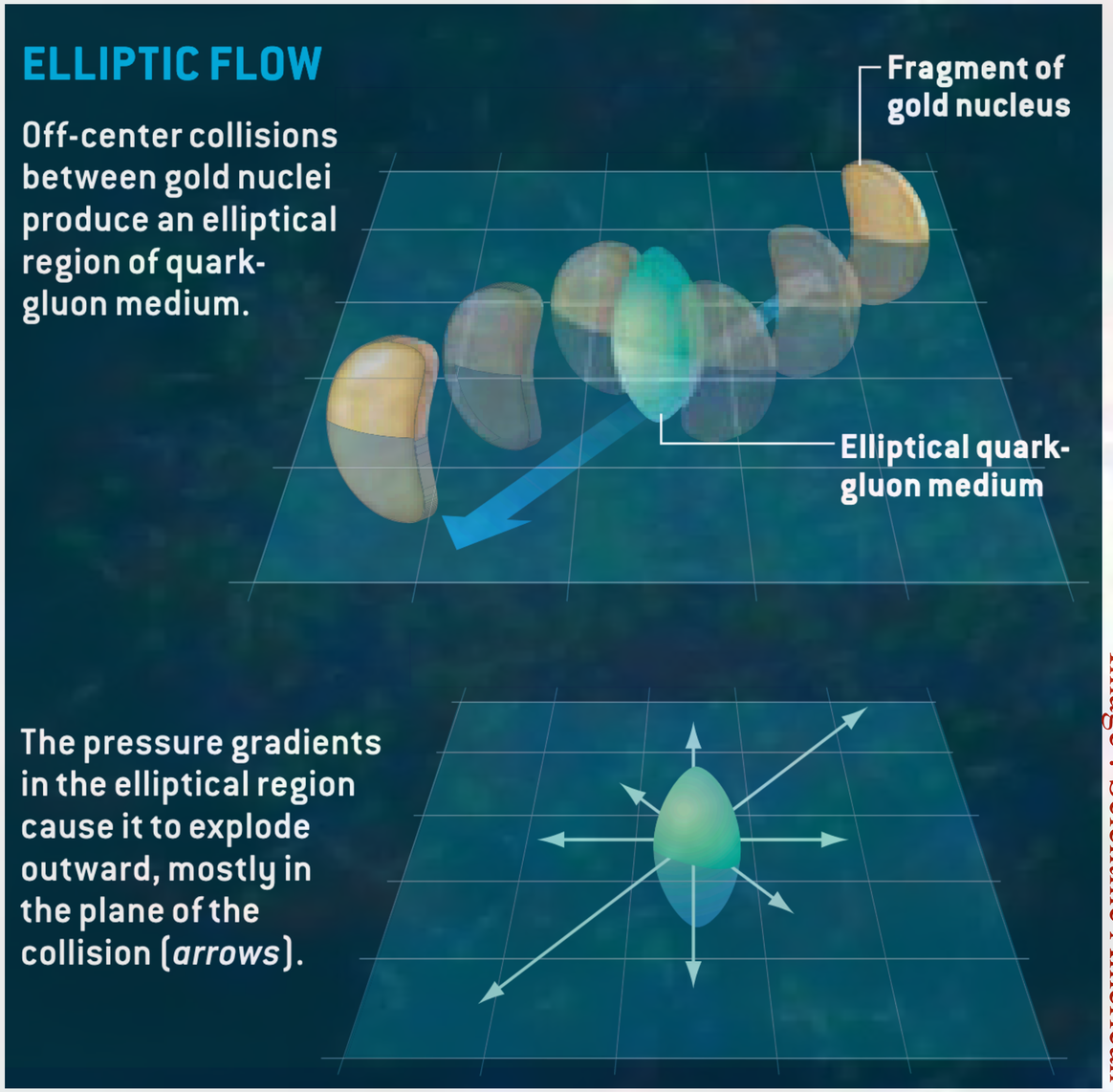


Image : Scientific American

$$\frac{dN}{d\varphi} = N_0\,(1 + 2v_2\cos(2\varphi))$$

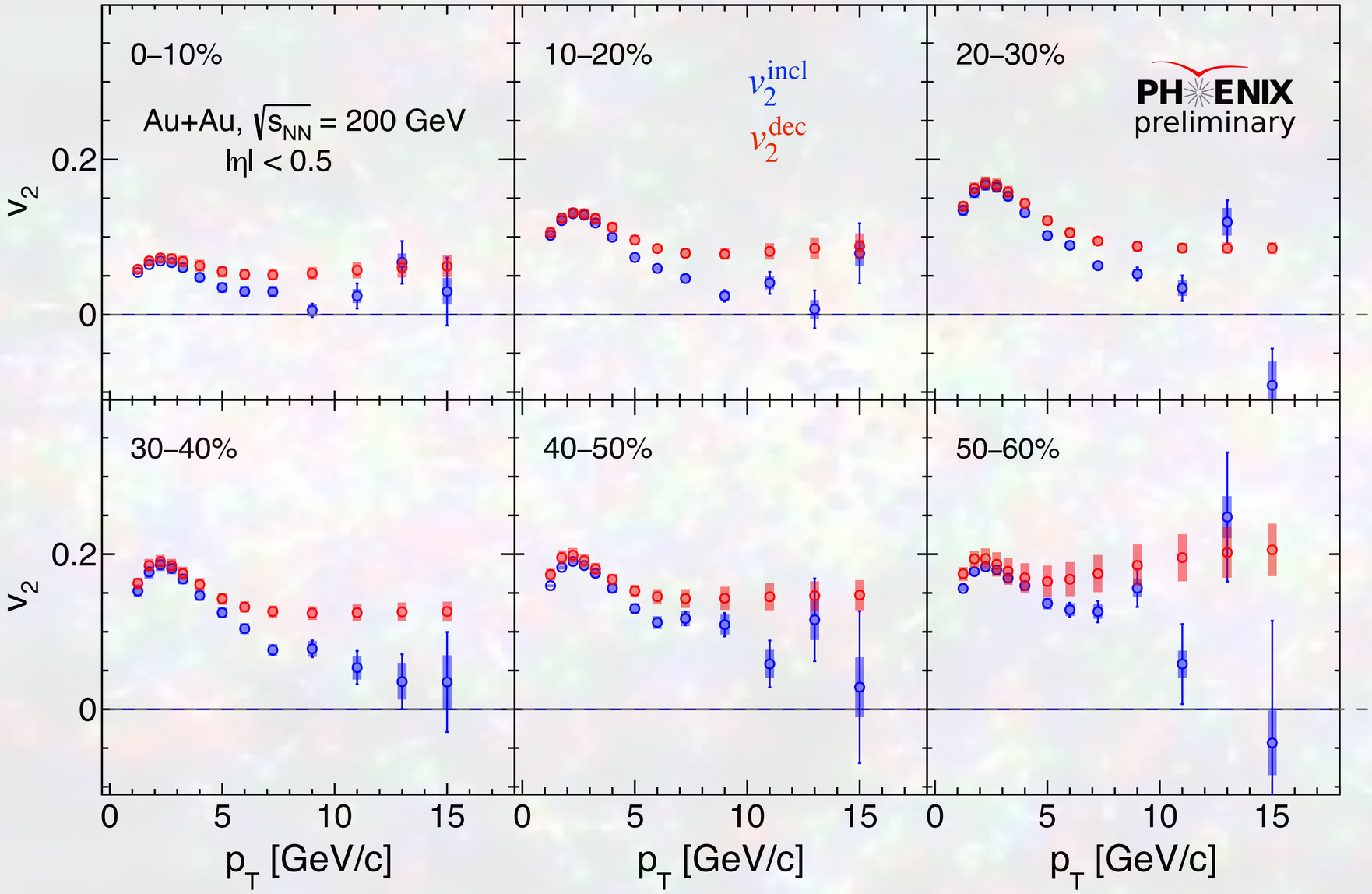
v_2^{incl} of all the photons measured by the EMCal (measured from data)

v_2^{dec} of all the photons coming from hadron decays (comes from cocktail)

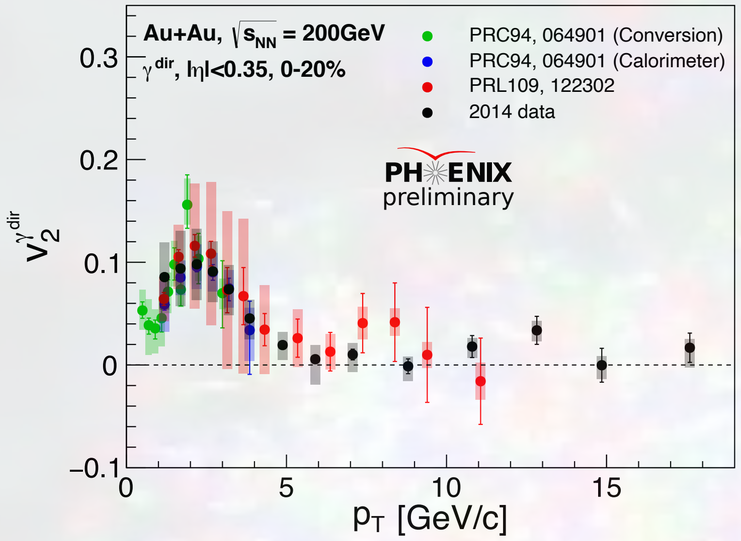
$$v_2^{dir} = \frac{R_\gamma v_2^{incl} - v_2^{dec}}{R_\gamma - 1}$$

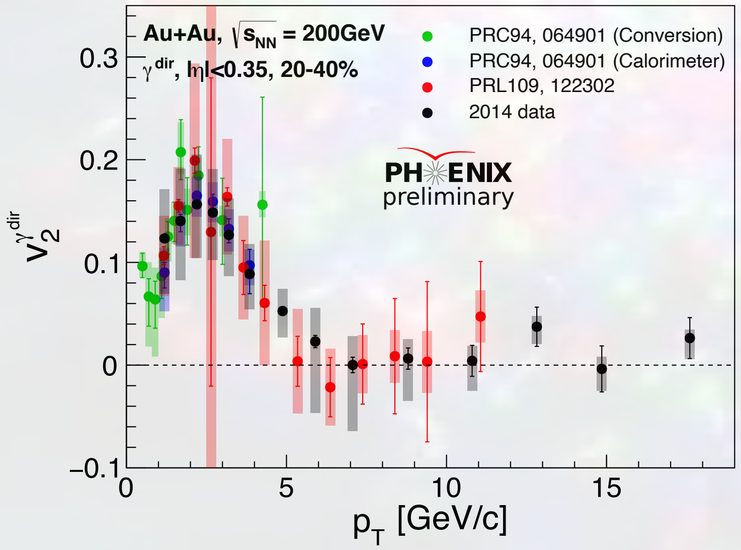
R_γ of direct photons (measured from data)

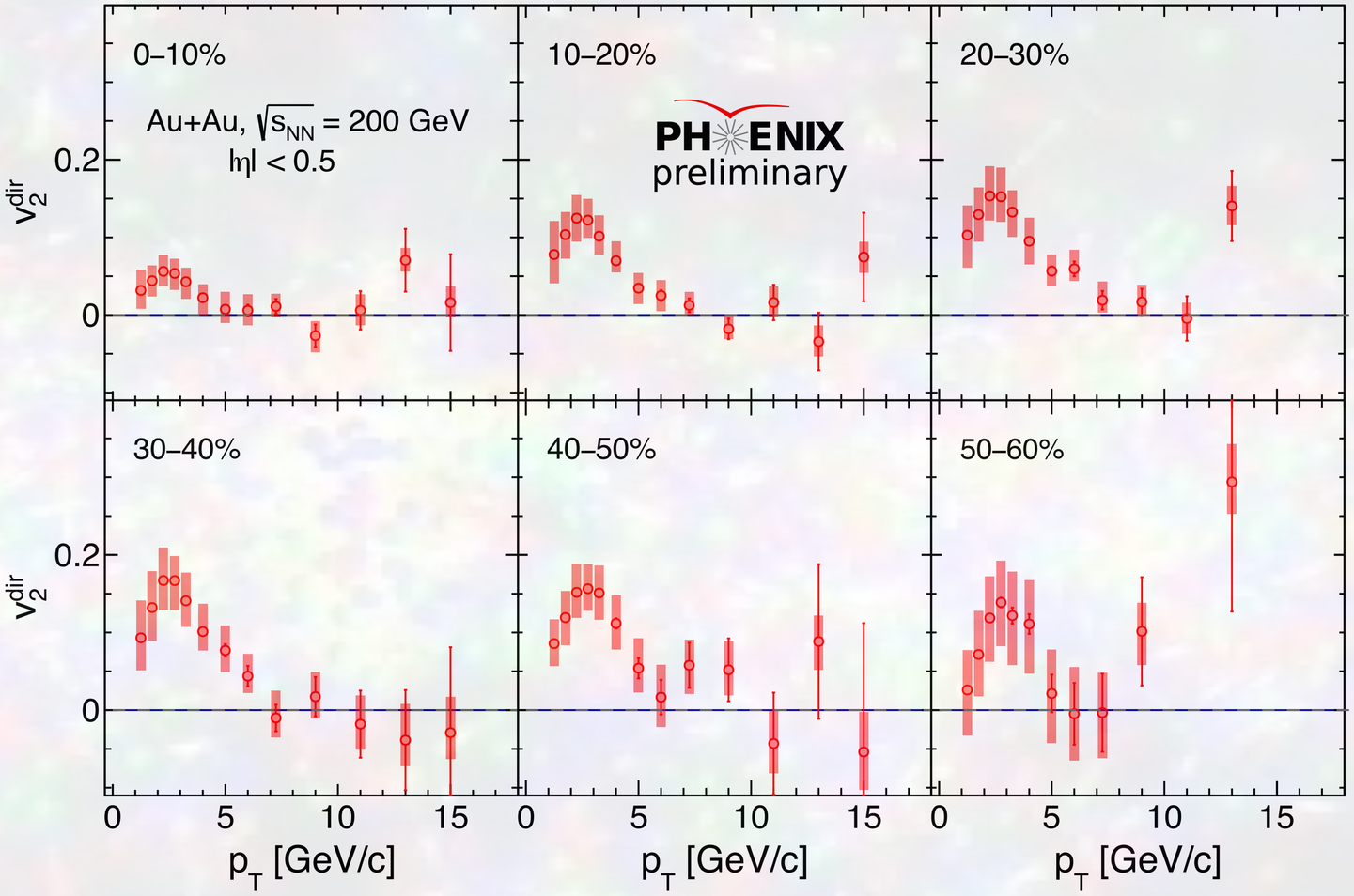
Azimuthal anisotropy



Azimuthal anisotropy



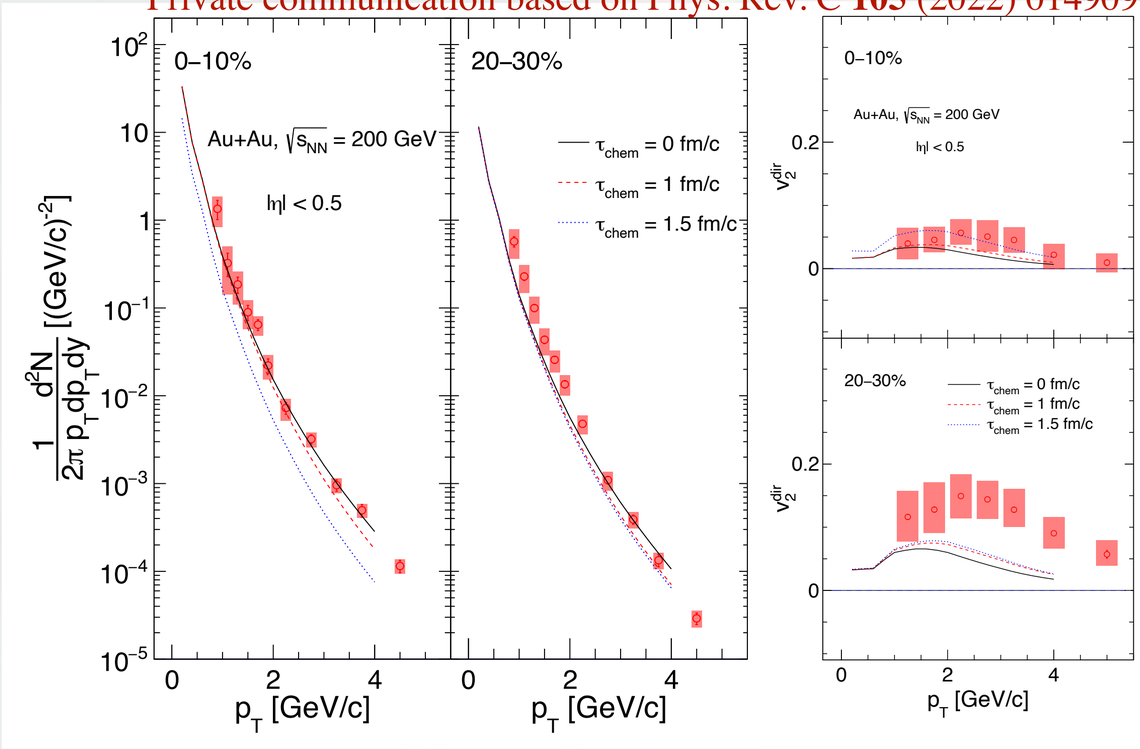




v_2^{dir} in the high p_T region is consistent with ZERO

Direct Photon Puzzle

Private communication based on Phys. Rev. C **105** (2022) 014909



Multi-messenger heavy-ion physics

- Hybrid model that describes all stages of relativistic heavy-ion collisions
- Effect of the pre-equilibrium phase on both photonic and hadronic observables highlighted

Dominant contribution from pre-equilibrium above 3 GeV/c in the model seems to align well with the data

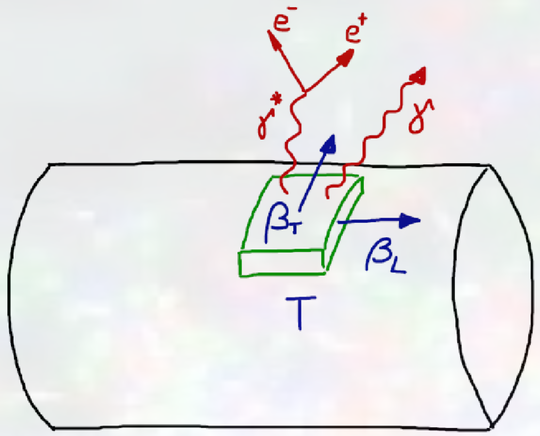
Overall yield falls short, especially below 2 GeV/c

Describes flow at low p_T but missed at high p_T

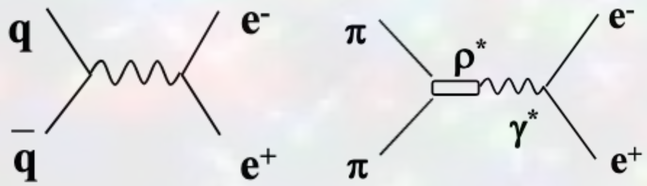
Qualitative agreement with thermal source

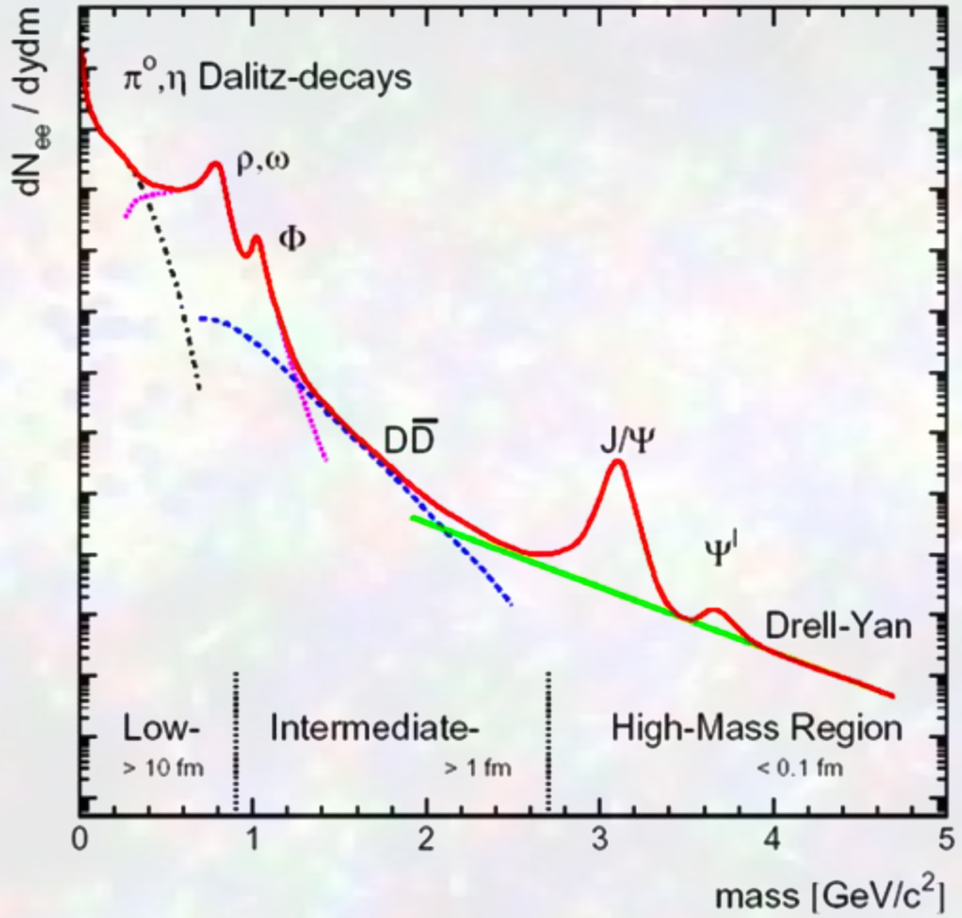
Quantitative tension with model predictions

Dileptons as direct radiations



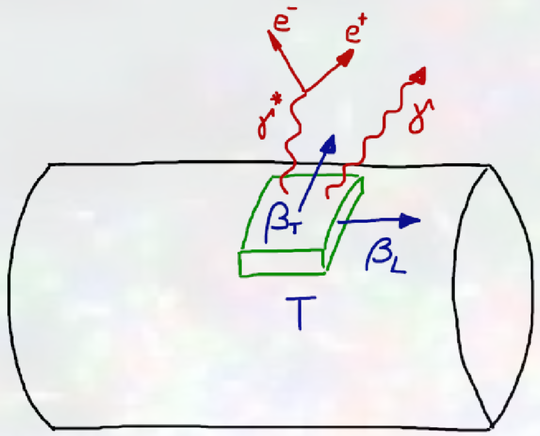
- Momentum — Doppler shifted
- Mass — Lorentz invariant





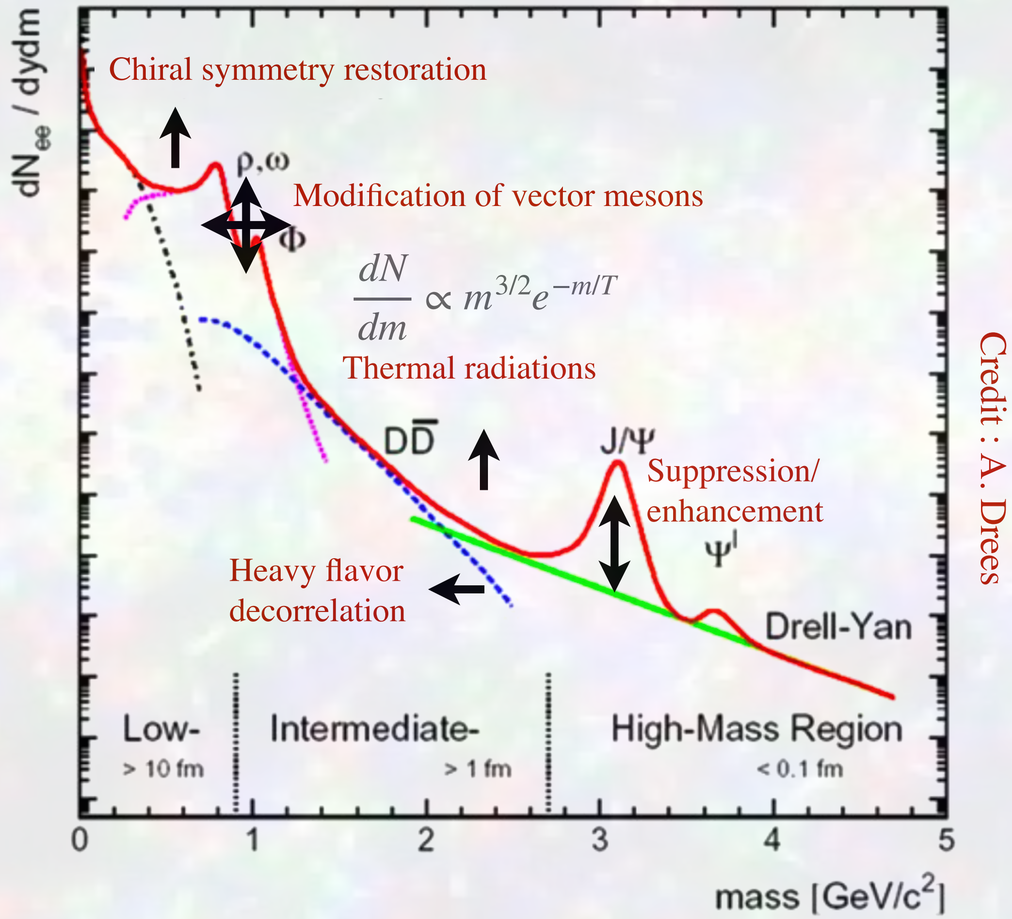
Credit : A. Drees

Dileptons as direct radiations



- Momentum — Doppler shifted
- Mass — Lorentz invariant
- In $1 < m_{ee} < 3$ GeV, the only significant physics background is open heavy flavor

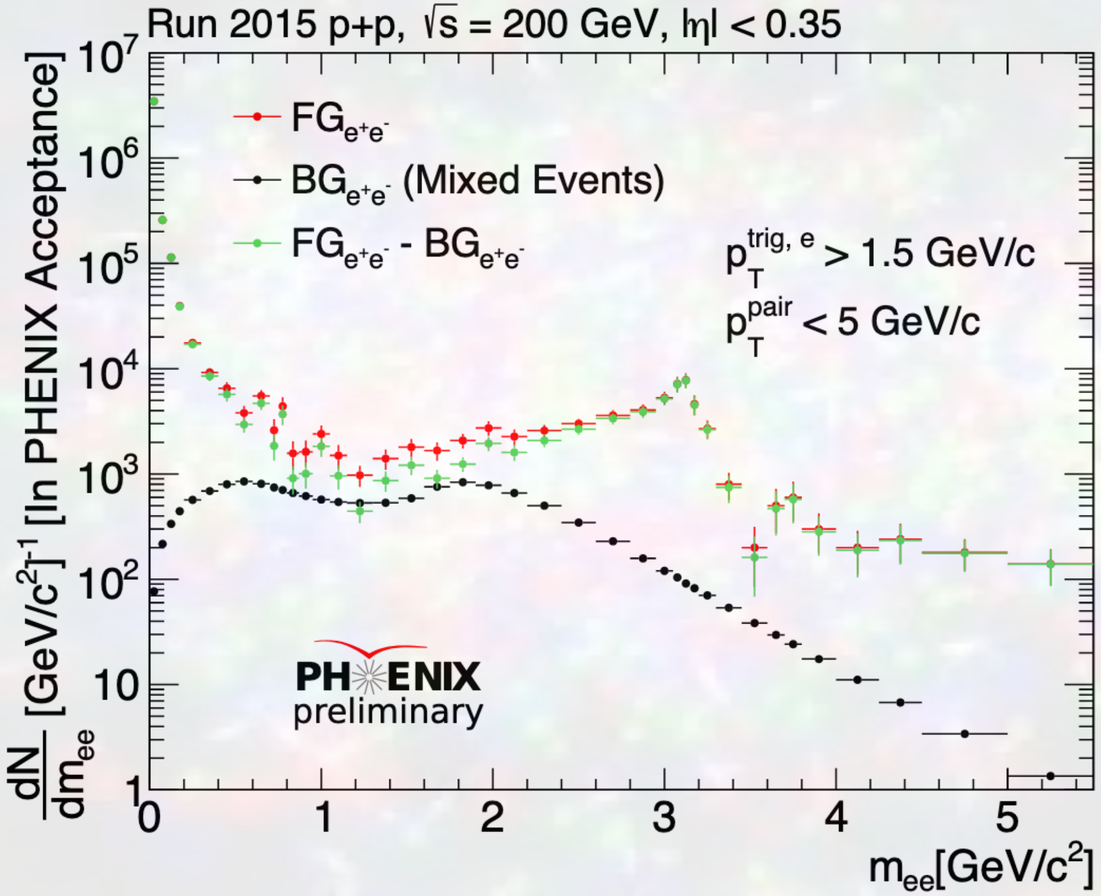
Modifications due to medium interactions



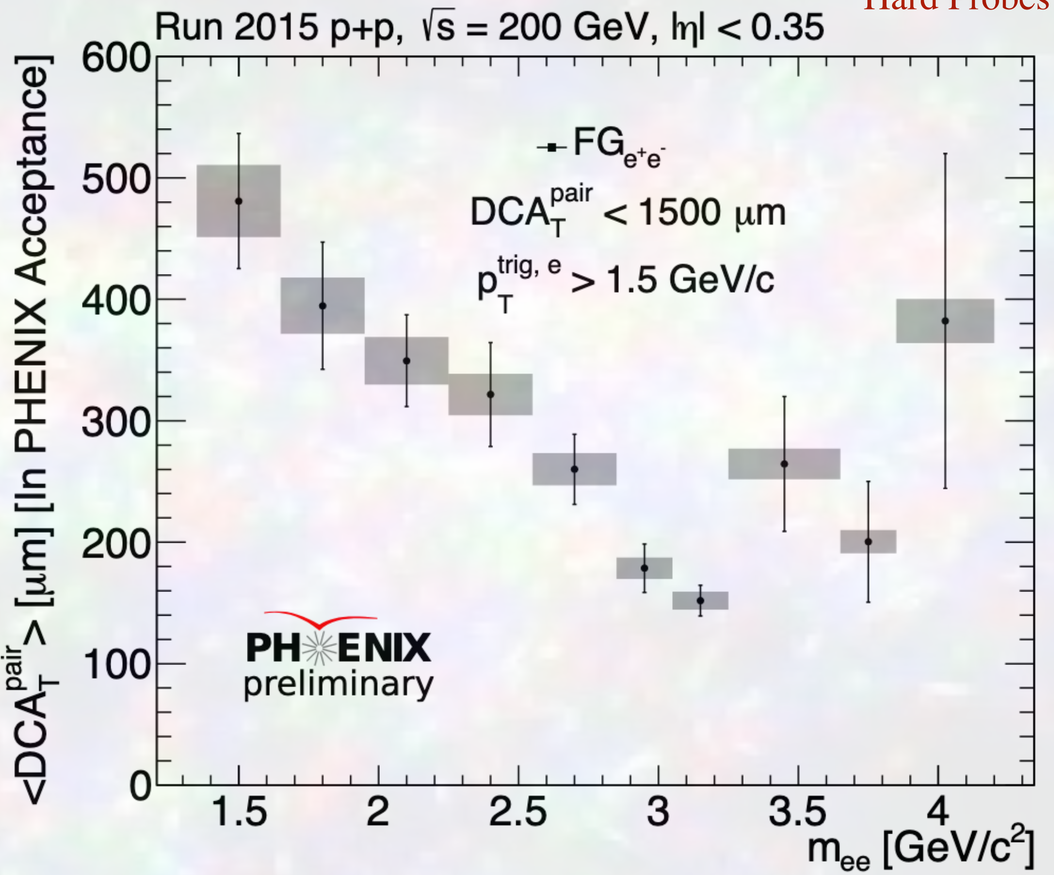
Credit : A. Drees

The $c\bar{c}$ correlation

First attempt at measuring the dielectron correlation due to semileptonic decay of charm at RHIC



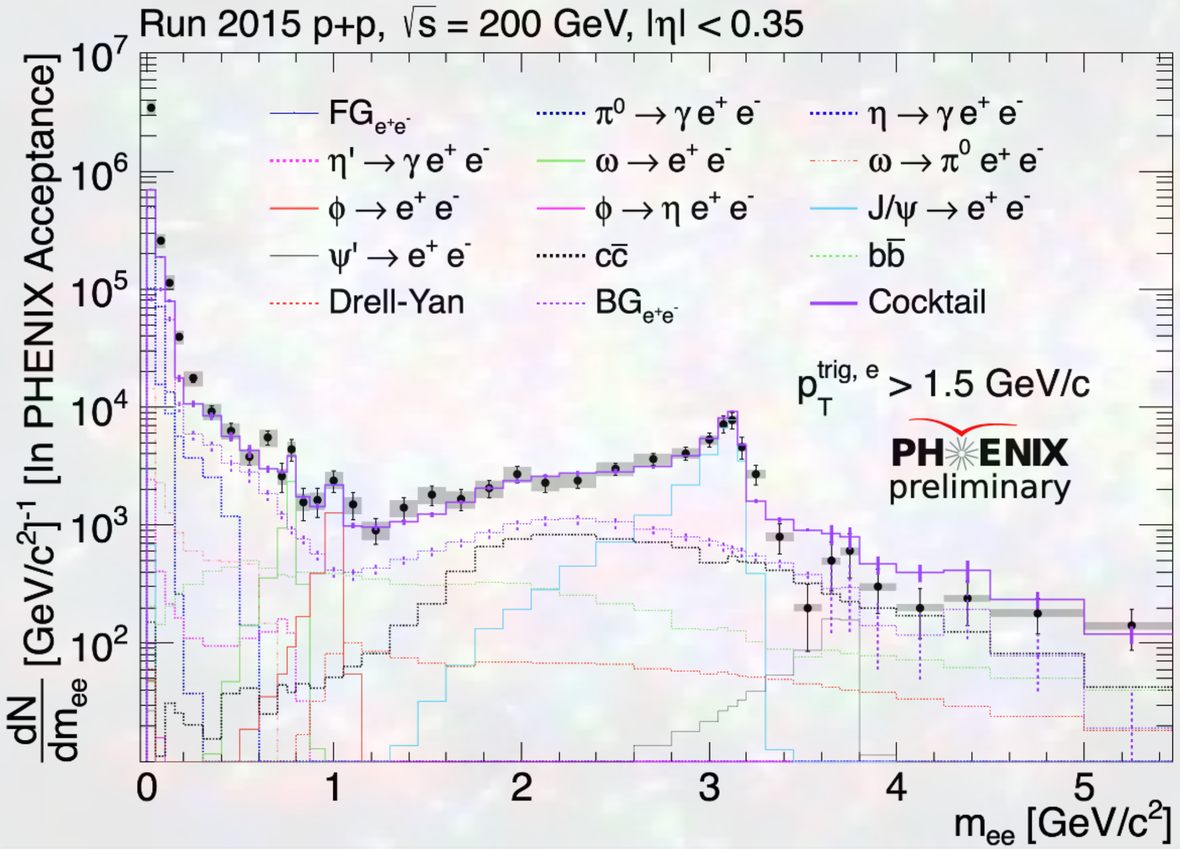
Hard Probes 2024



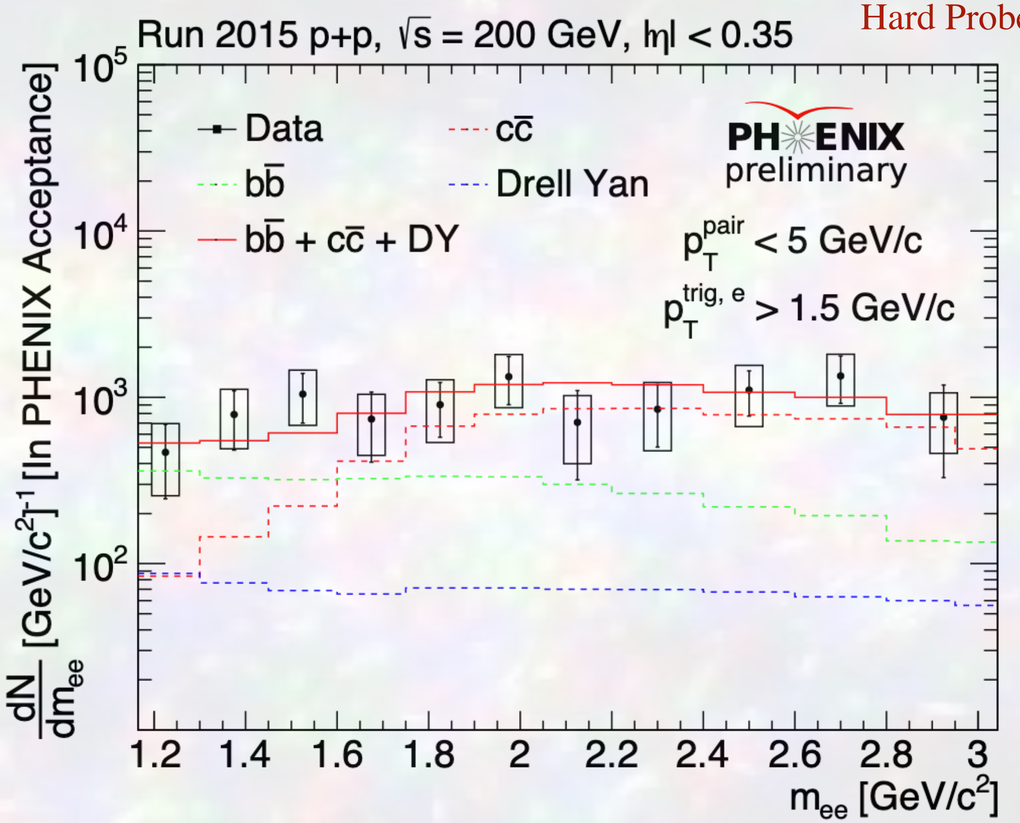
$$DCA_T^{pair} = \sqrt{|DCA_{e^-}^2 - DCA_{e^+}^2|}$$

The $c\bar{c}$ correlation

First attempt at measuring the dielectron correlation due to semileptonic decay of charm at RHIC

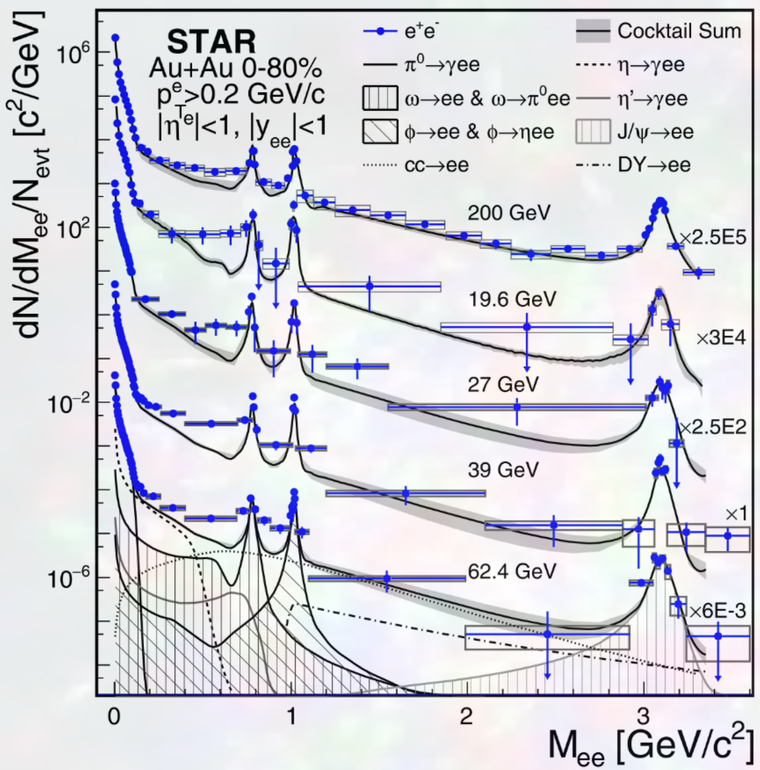


Hard Probes 2024

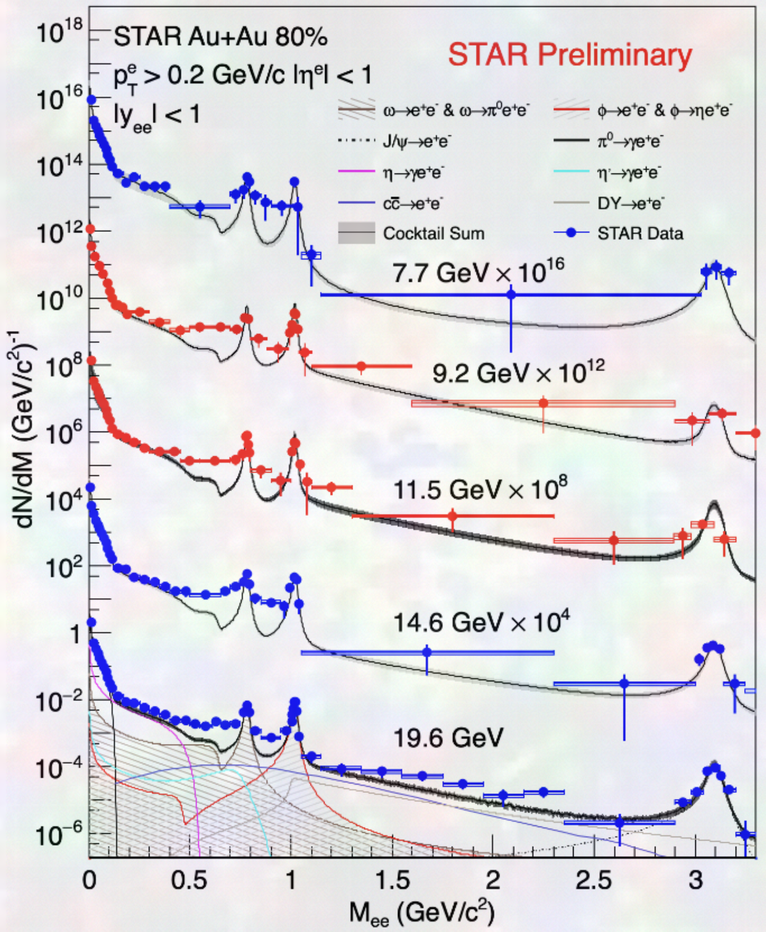


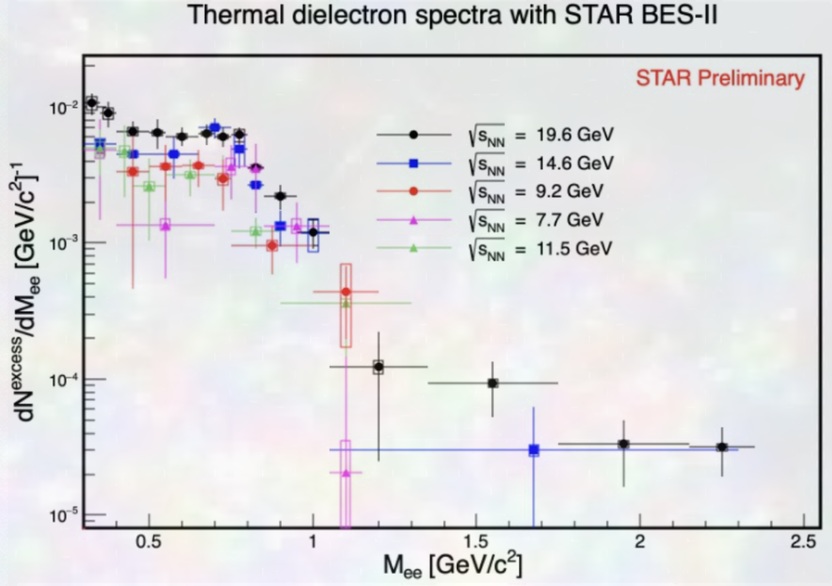
Thermal dileptons from BES

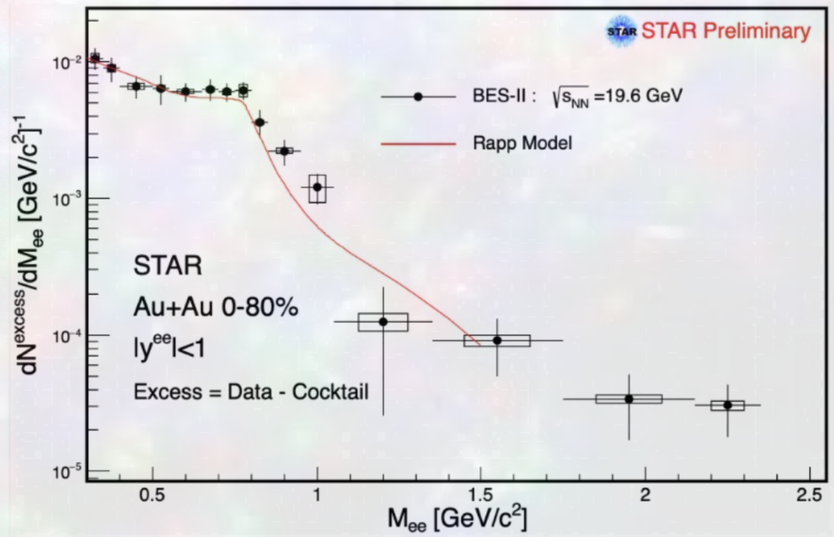
Phys. Rev. C 107, L061901 (2023)



Hard Probes 2024





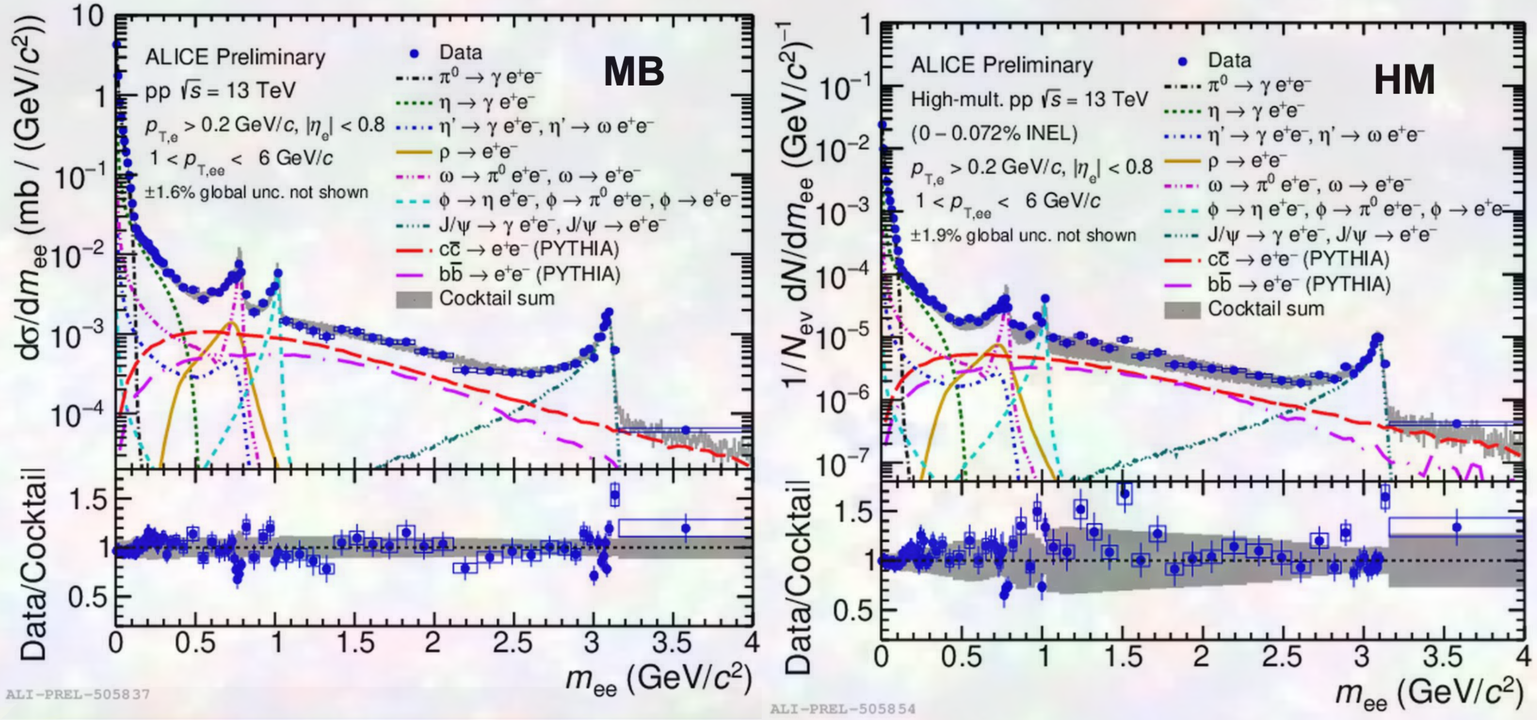


Normalized excess yield shows no significant $\sqrt{s_{NN}}$ dependence

Dilepton excess in good agreement with theoretical expectation

Thermal dileptons from p+p at 13 TeV

Hard Probes 2024



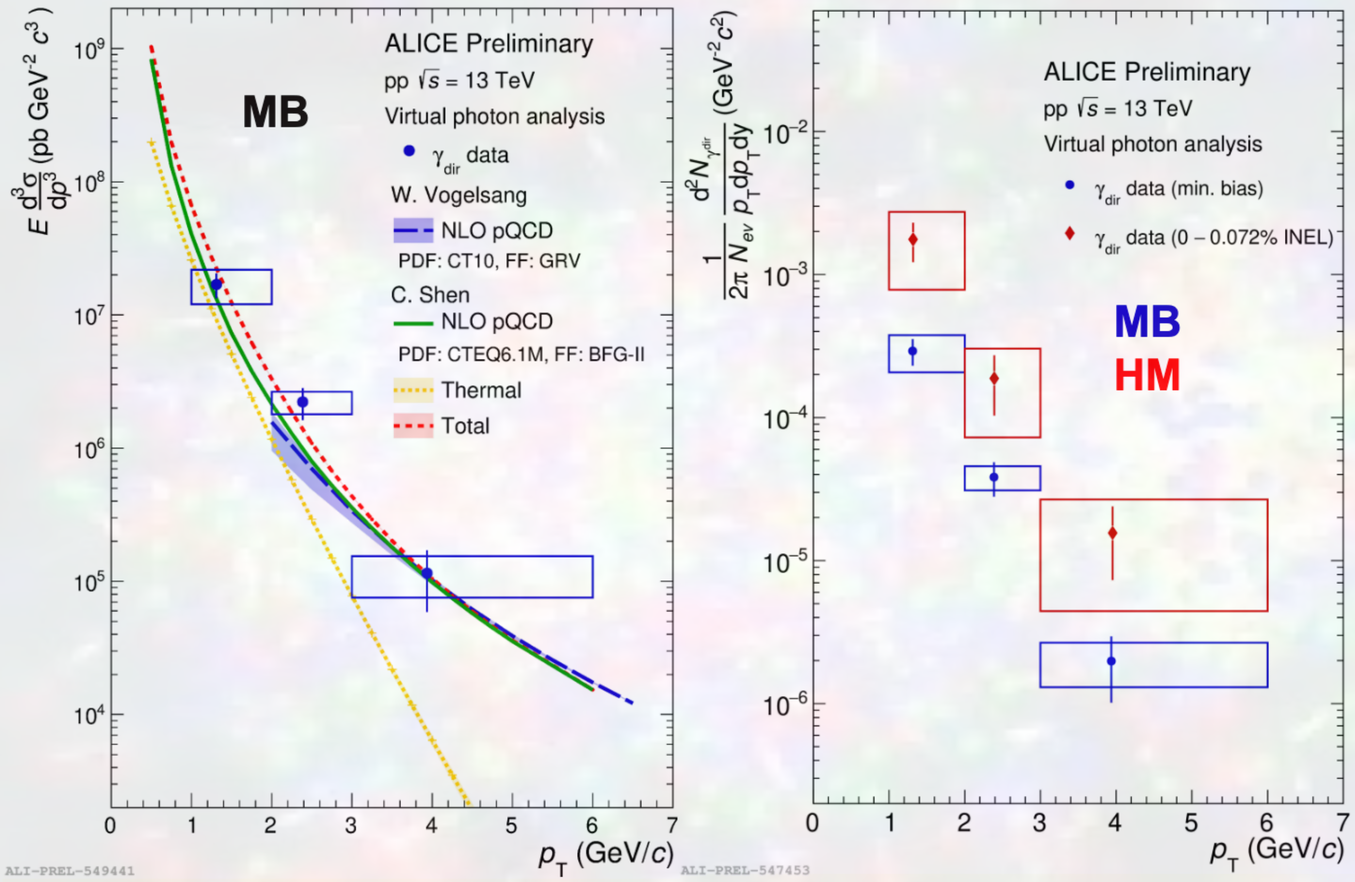
Increased statistics by a factor of ~4 as compared to previous result

MB well described by hadronic sources

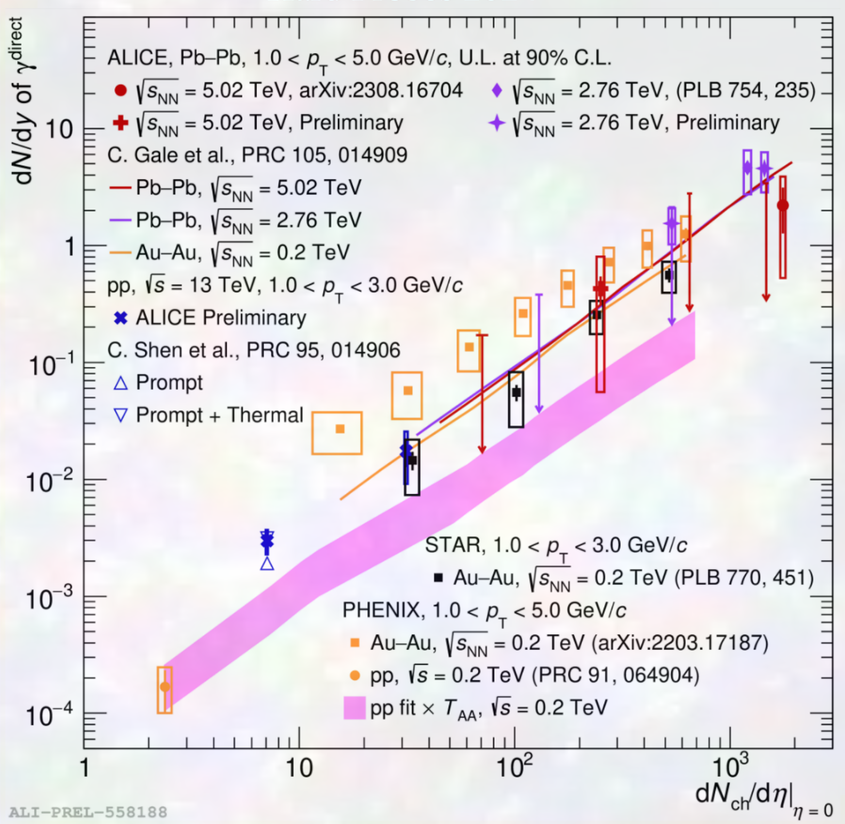
Within uncertainties no sign of thermal radiation in HM events

Thermal dileptons from p+p at 13 TeV

Hard Probes 2024



Hard Probes 2024

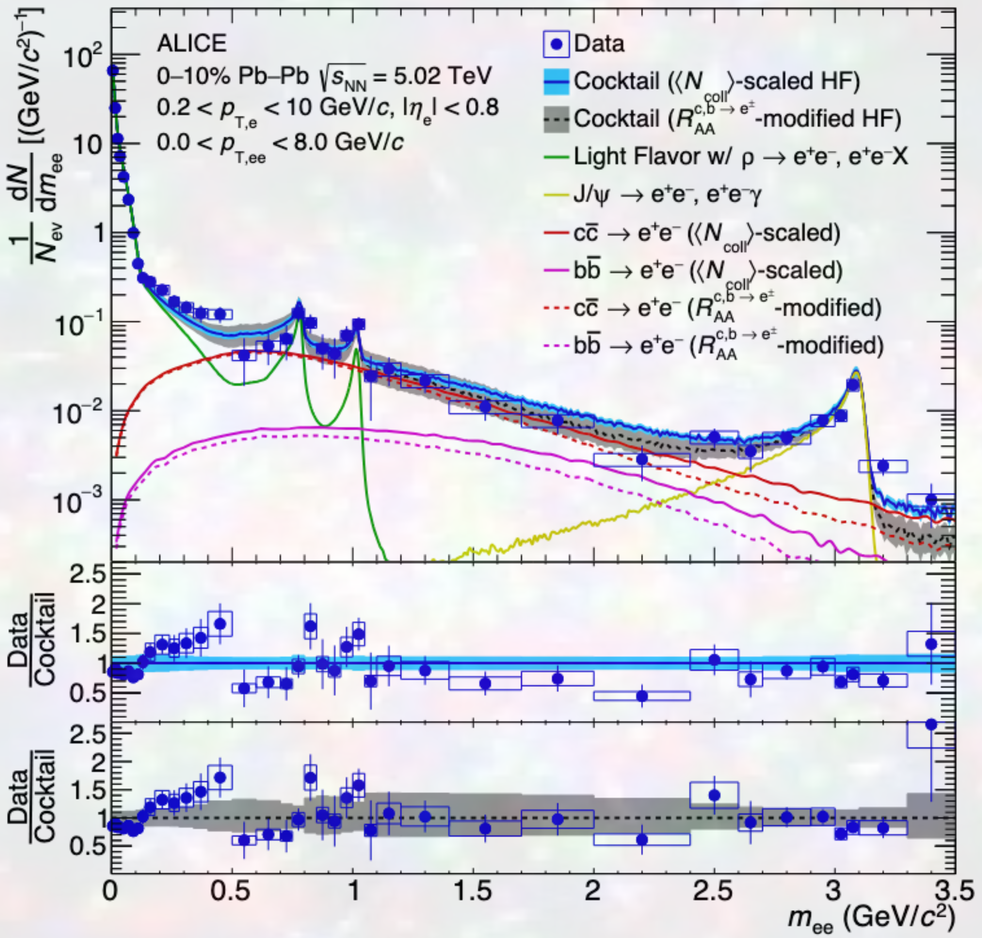


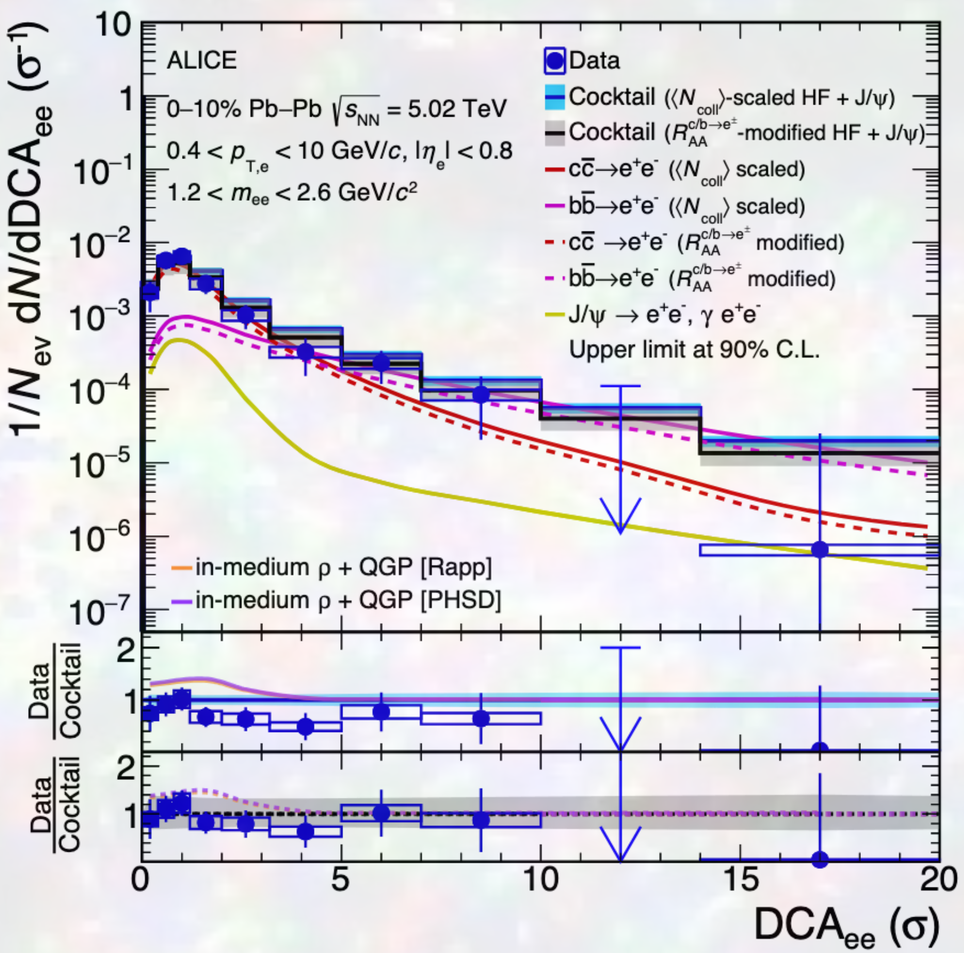
MB can be reproduced by both prompt only or prompt + thermal radiation

Significant increase of direct-photon yield in HM collisions compared to MB collisions

Thermal dileptons from Pb+Pb at 5.02 TeV

arXiv:2308.16704



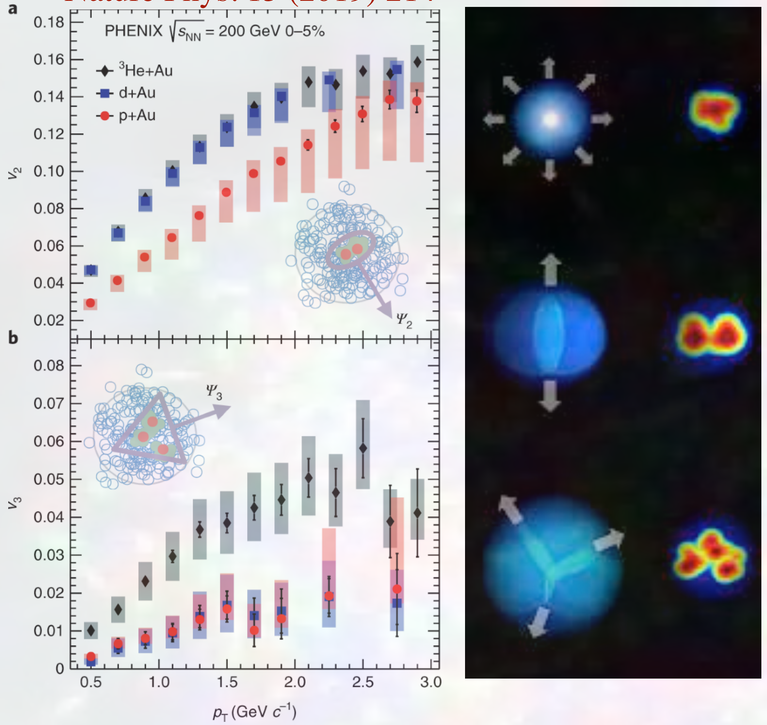


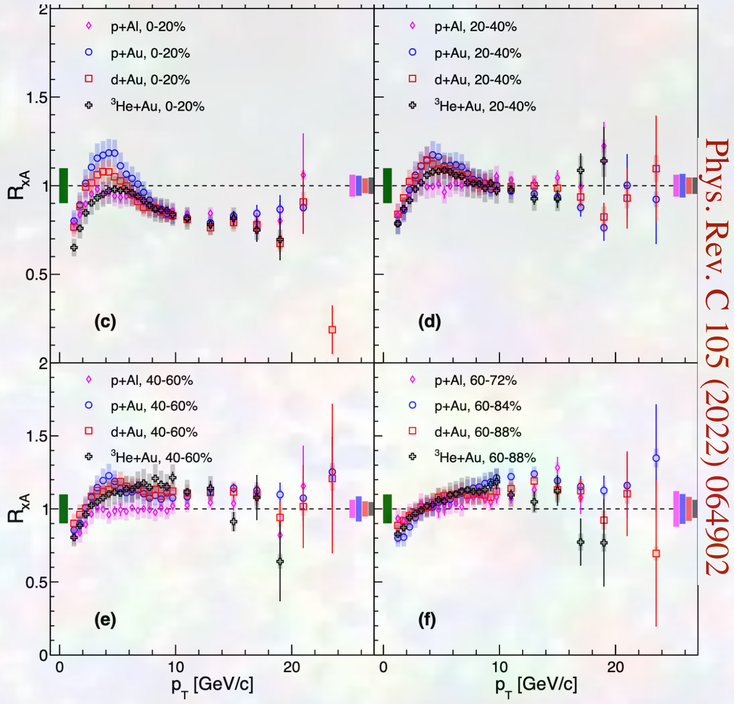
Topological separation technique is used which is independent of hadronic cocktail

Results consistent with charm suppression and thermal contribution in IMR

High p_T direct photons

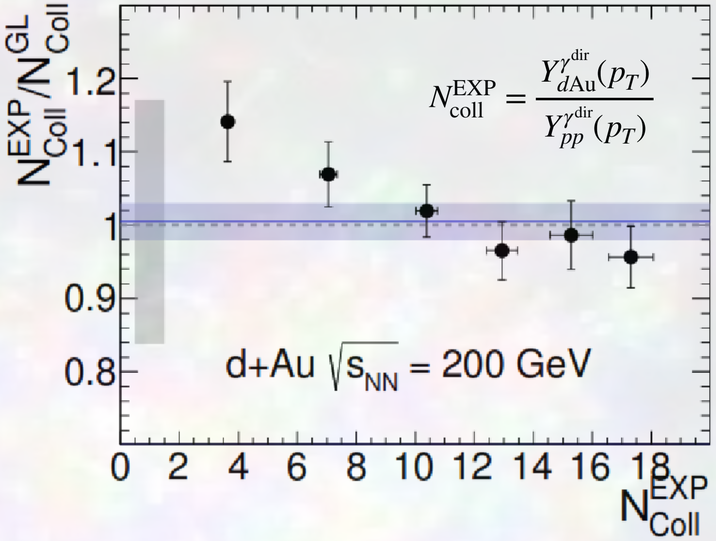
Nature Phys. 15 (2019) 214



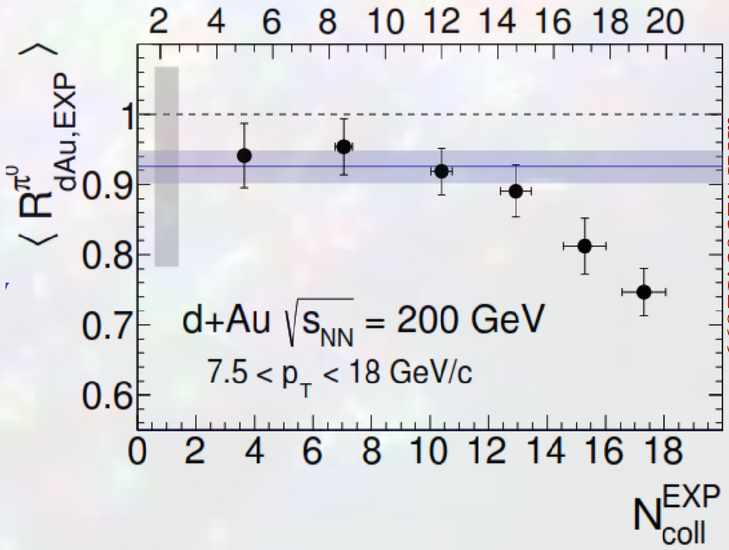


Phys. Rev. C 105 (2022) 064902

Accepted in PRL



arXiv:2303.12899



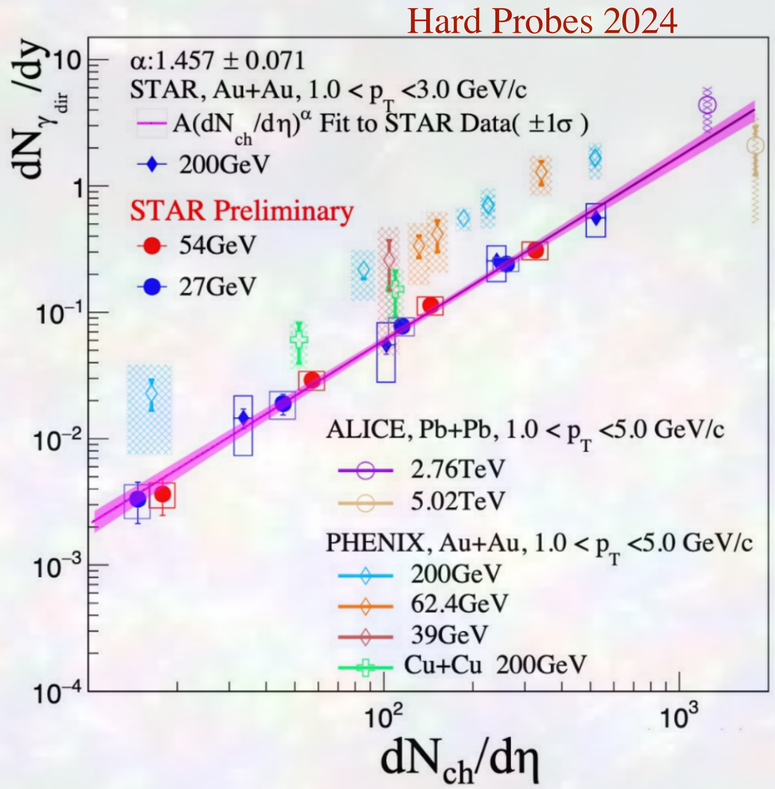
arXiv:2303.12899

20% suppression at high p_T with a 4.5σ significance in 0-5% central d+Au collisions at 200 GeV

Ongoing efforts to establish with *p*+Au and ^{3}He+Au

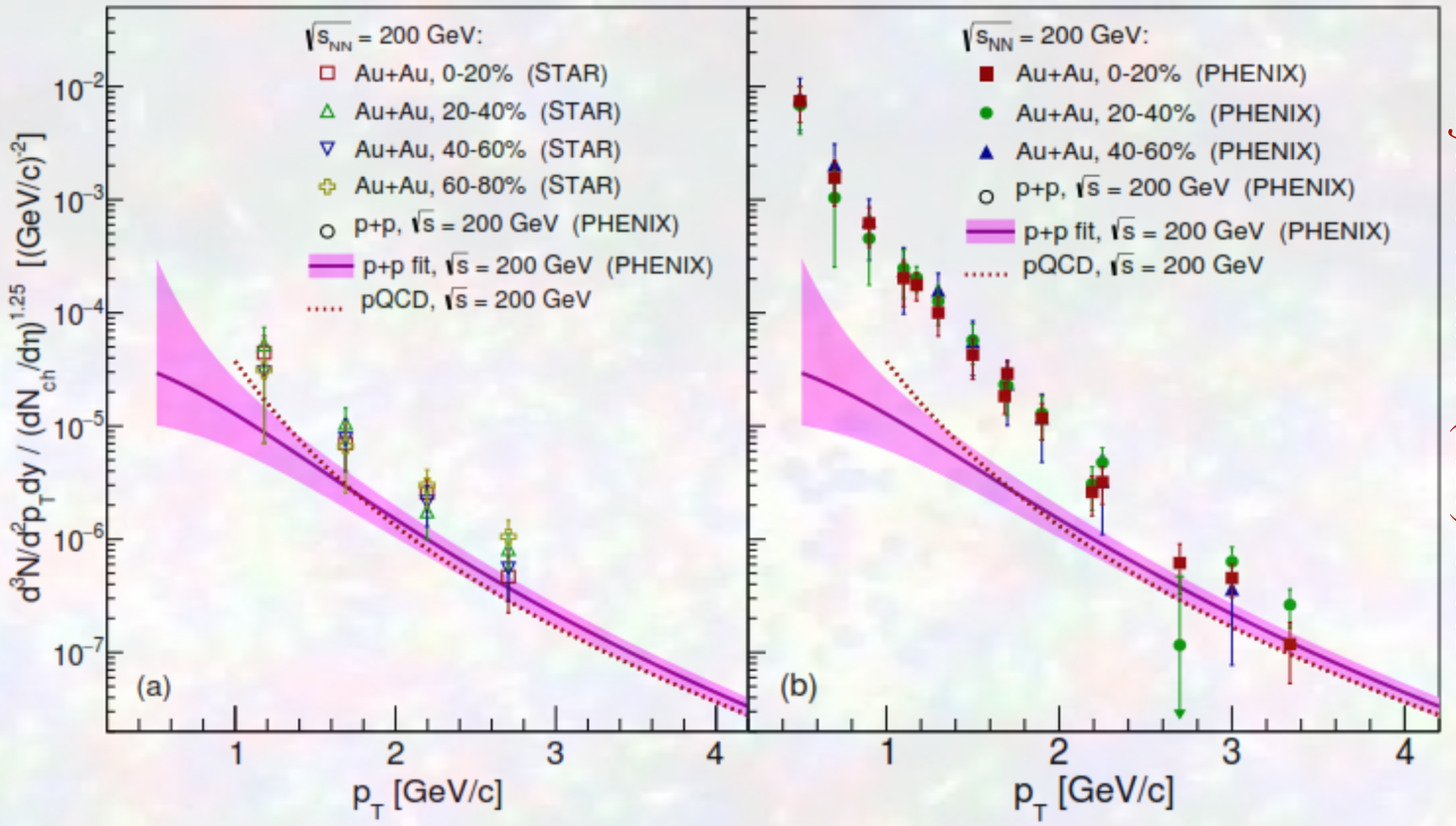
Summary

- Plethora of exciting new measurements with different methods for different systems and collision energies
- Direct photon puzzle still stands at RHIC
- Experimental measure of hard scattering
- Direct photons still have a lot to offer!



Thank you for your attention!

Comparing PHENIX and STAR



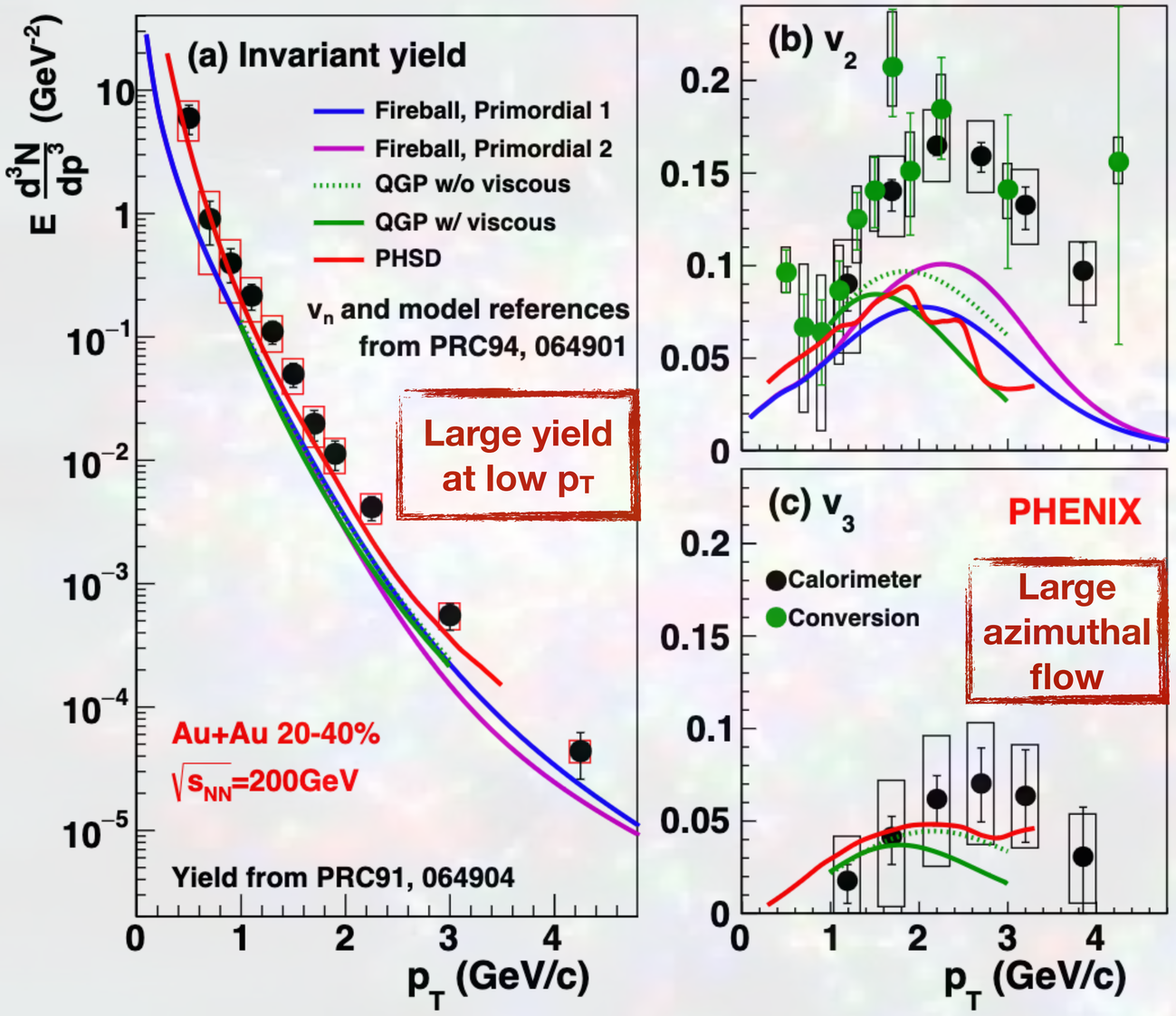
Phys. Lett. B 770 (2017) 451–458
Phys. Rev. C 93 (2016) 1, 014904
Phys. Rev. Lett. 104 (2010) 132301

- PHENIX data is consistent among several measurements using different techniques
- STAR data is significantly lower

The discrepancy is not yet resolved

Direct photon puzzle

Phys. Rev. C 94 (2016) 064901



- Large contribution from hadron gas and QGP
  - Thermal rates with hydro (viscous/non viscous) or blastwave evolution
  - Microscopic transport (PHSD)
- Early contributions
  - Non-equilibrium effects (glasma, etc.)
  - Enhanced thermal emission in large B-fields
  - Modified formation time and initial conditions
- Effects at phase boundary
  - Extended emission
  - Emission at hadronization

Qualitative agreement with thermal source

Quantitative tension with model predictions