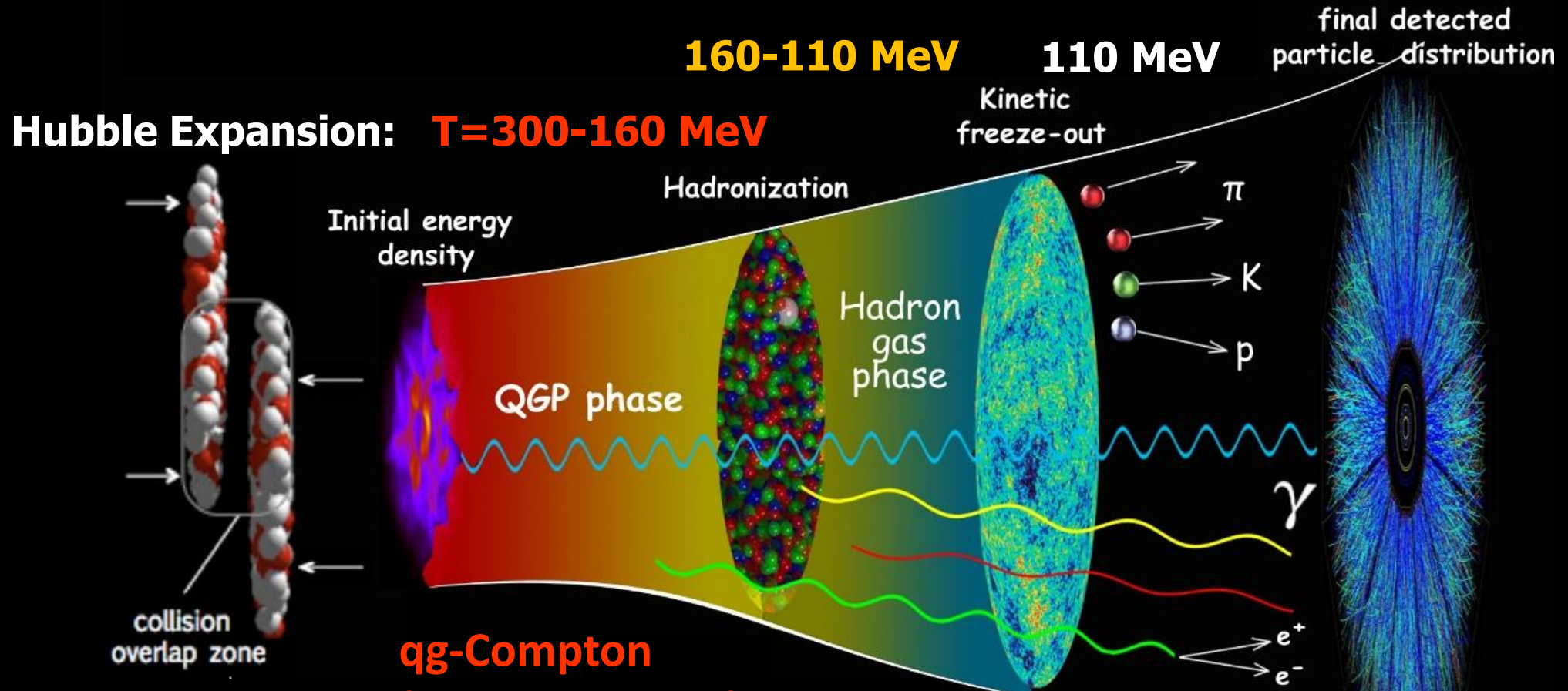


Direct-photon production in heavy ion collisions at RHIC

Axel Drees, ICHEP 2024, July 2024, Prague, Czech Republic

- Introduction
- Direct Photon Production in Au+Au at 200 GeV
 - Direct photon spectra
 - Direct photon flow
- Dilepton continuum in p+p at 200 GeV
- Summary/Outlook

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 $\propto N_{ch}^\alpha$ $\alpha \leq 2$

$\pi\rho$ 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

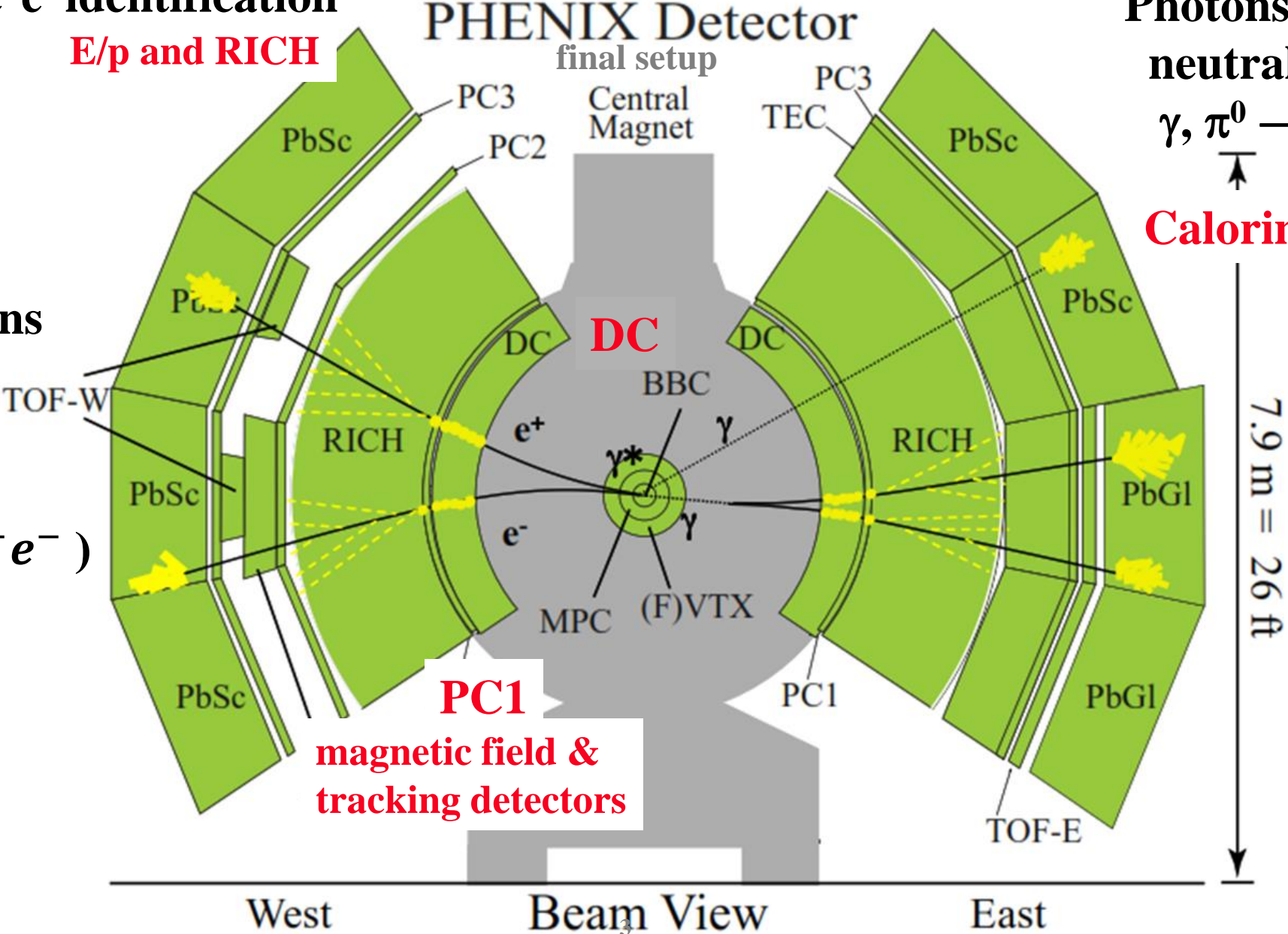
Photon Measurements with PHENIX

e^+e^- identification
E/p and RICH

Photons,
 neutral pion
 $\gamma, \pi^0 \rightarrow \gamma\gamma$
Calorimeter

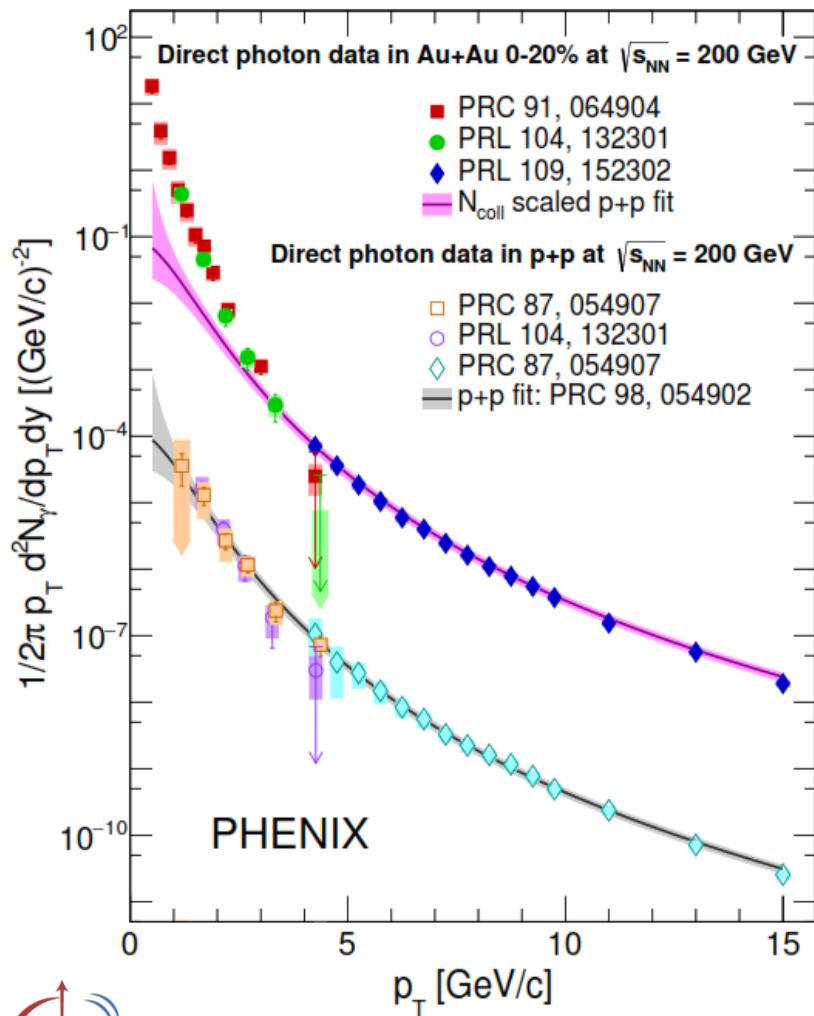
Virtual Photons
 $\gamma^* \rightarrow e^+e^-$

Photons
 $\lim_{m_{ee} \rightarrow 0} (\gamma^* \rightarrow e^+e^-)$
 $\gamma \rightarrow e^+e^-$



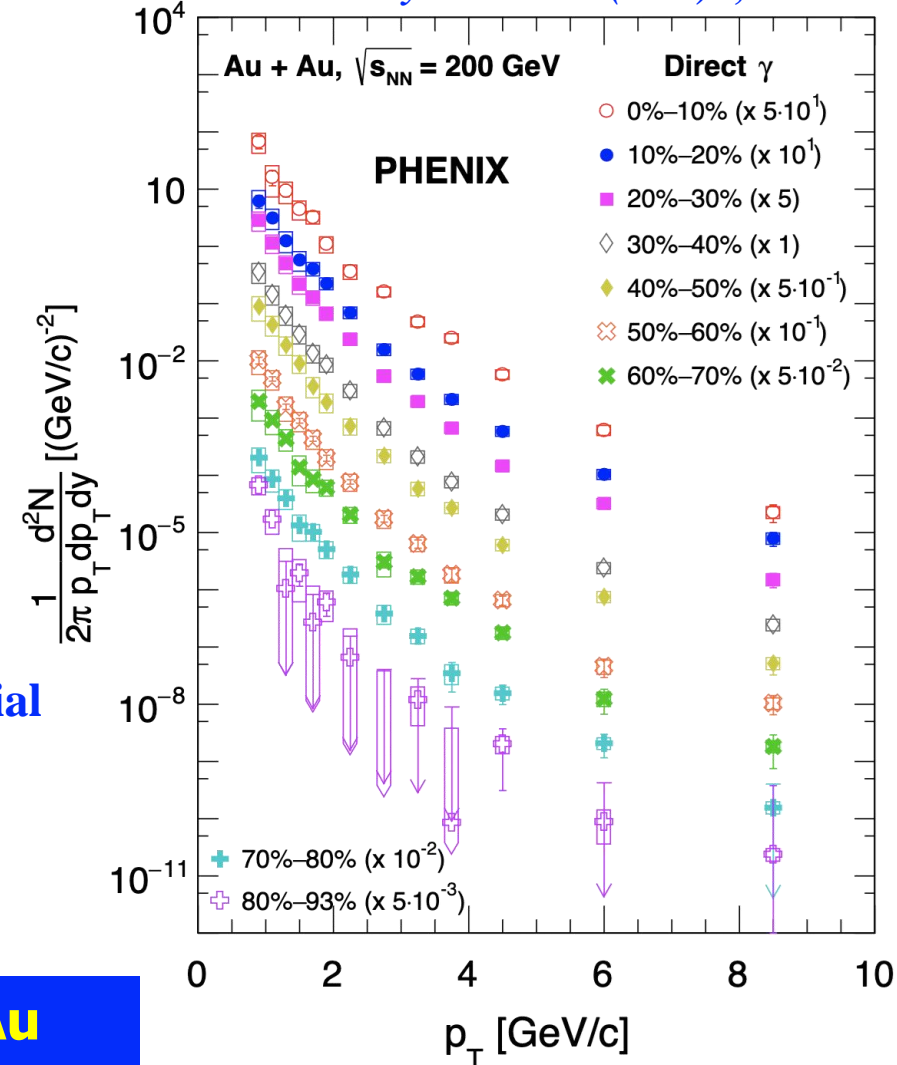
Direct Photons in p+p and Au+Au at $\sqrt{s_{NN}} = 200$ GeV

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



- **Direct photon yield well established**
 - pp consistent with pQCD
 - AuAu follows N_{coll} scaled pp above 4 GeV
 - Significant excess below 3 GeV in AuAu
 - Excess has close to exponential shape with $T_{eff} \sim 240$ MeV

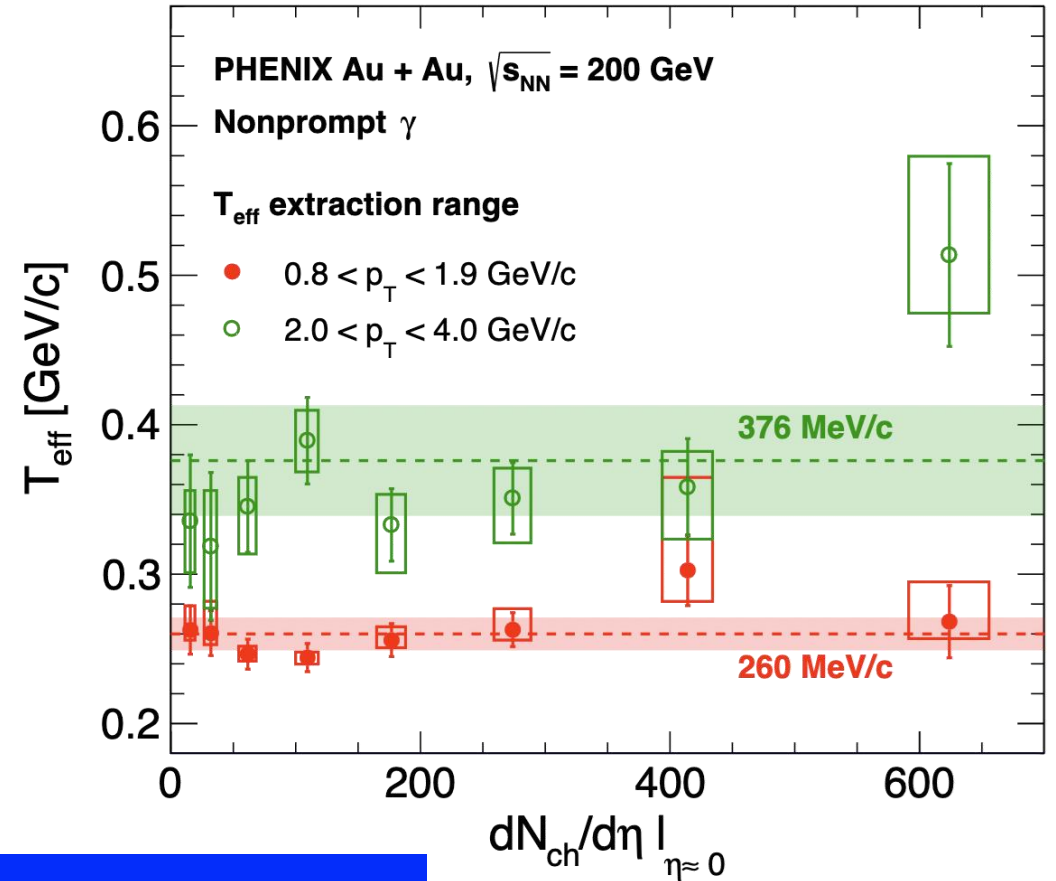
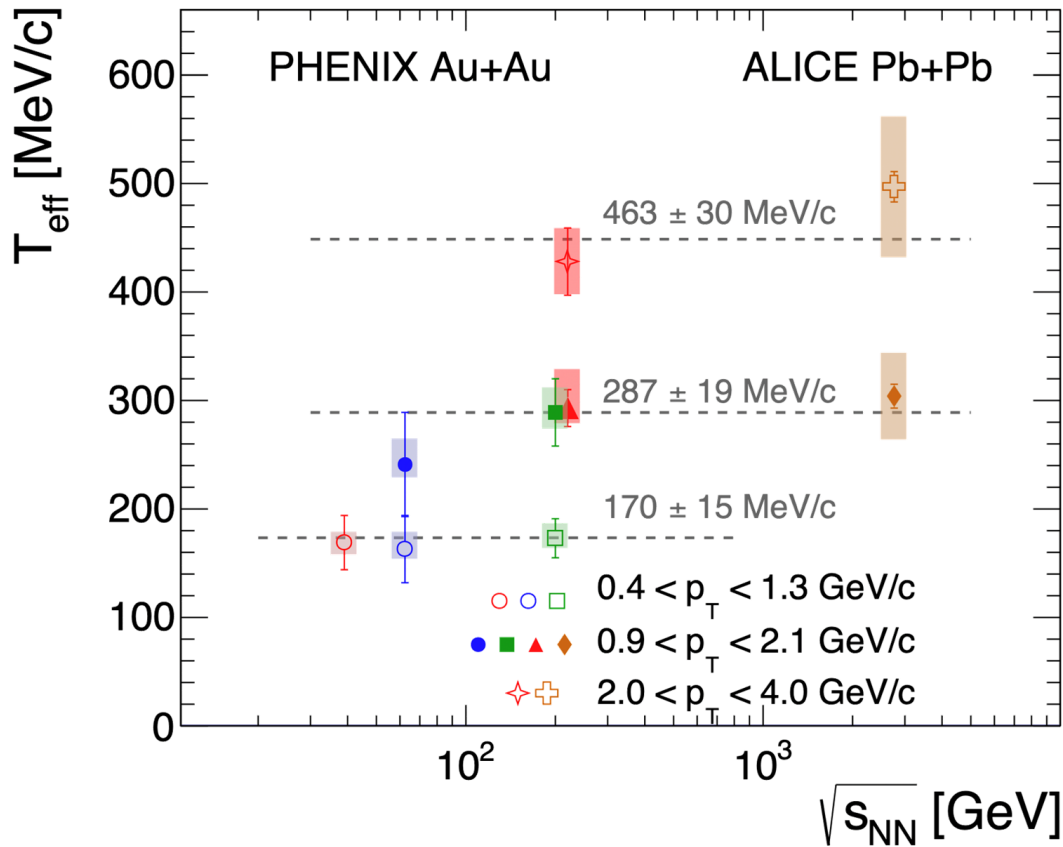
PHENIX: Phys. Rev. C 109 (2024) 4, 044912



New high statistics Au+Au results reveal universal features

System Size and Energy Dependence of Spectral Shape

PHENIX: Phys. Rev. C 109 (2024) 4, 044912
 PHENIX: Phys. Rev. C 107 (2023) 2, 024914
 ALICE: Phys. Lett. B 754 (2016) 235-248

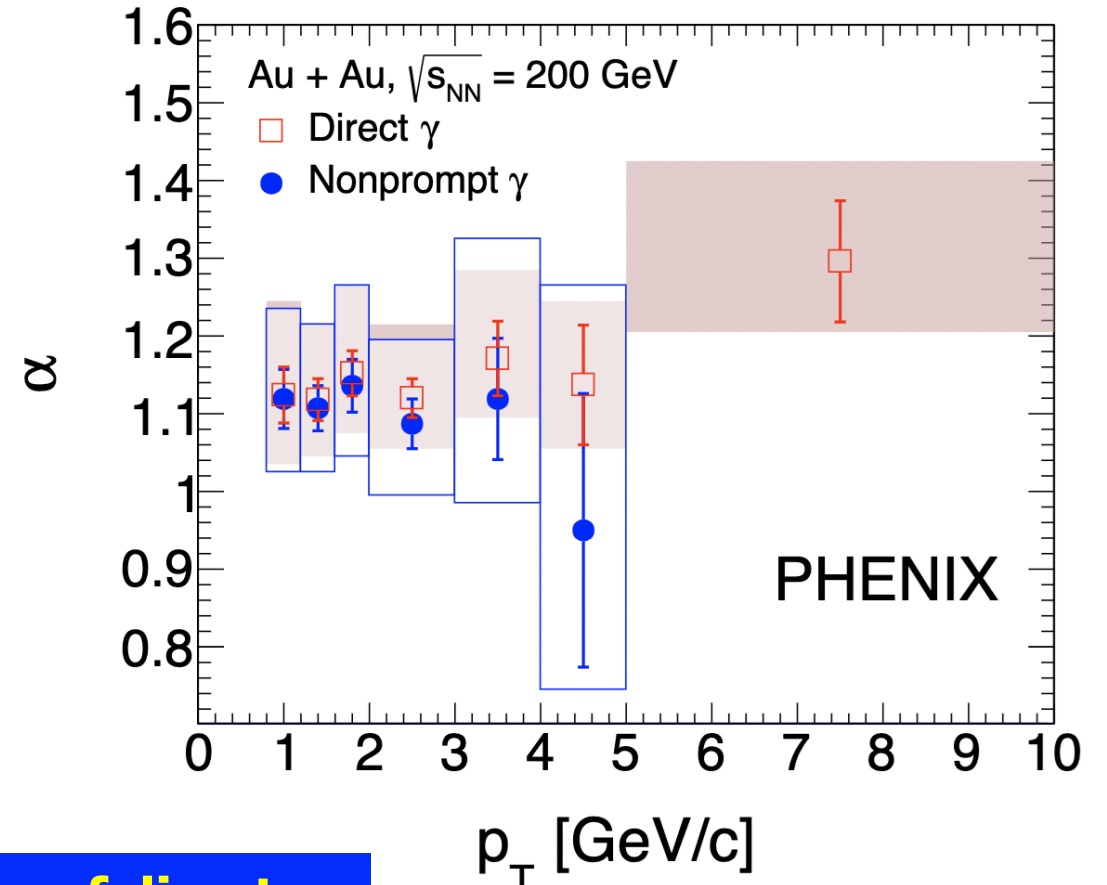
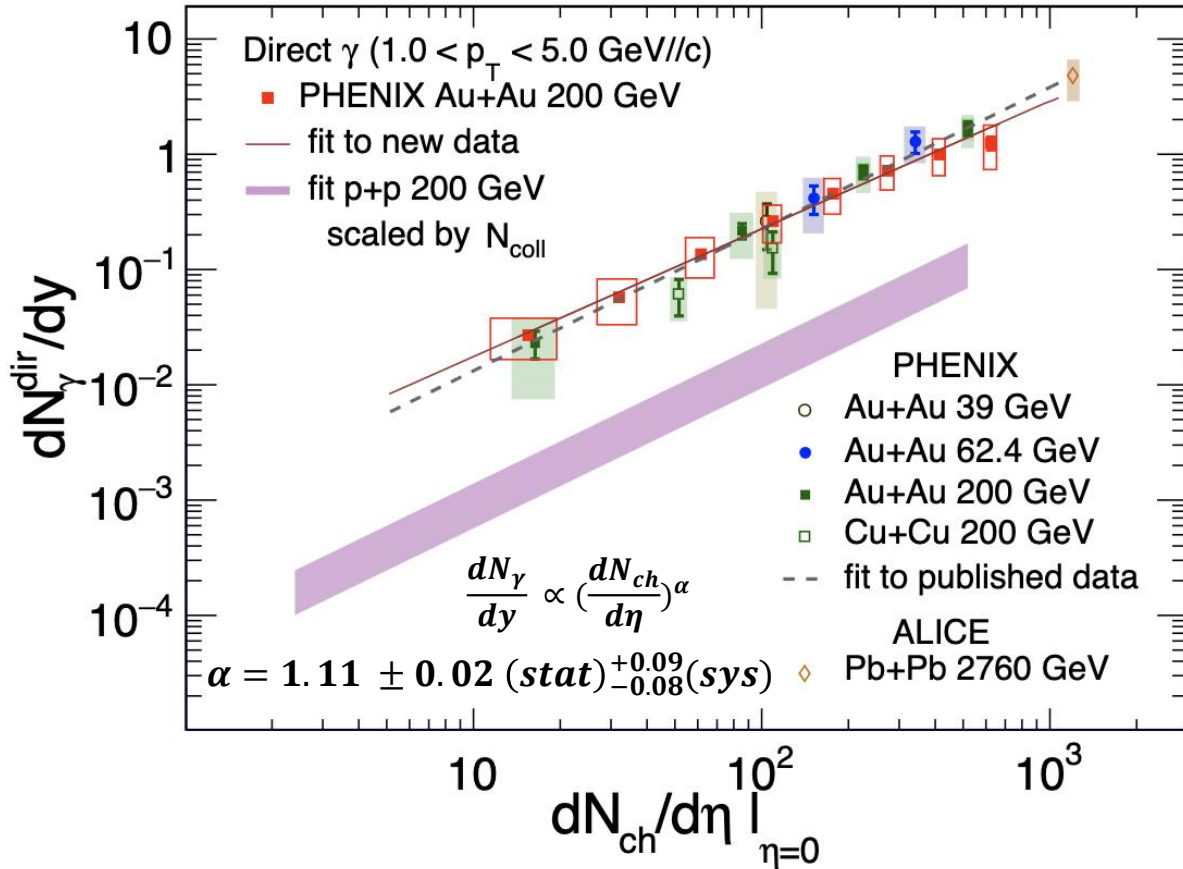


T_{eff} increases with p_{T}

No obvious variation of T_{eff} with $\sqrt{s_{\text{NN}}}$ or centrality

System Size and Energy Dependence of Direct Photon Yield

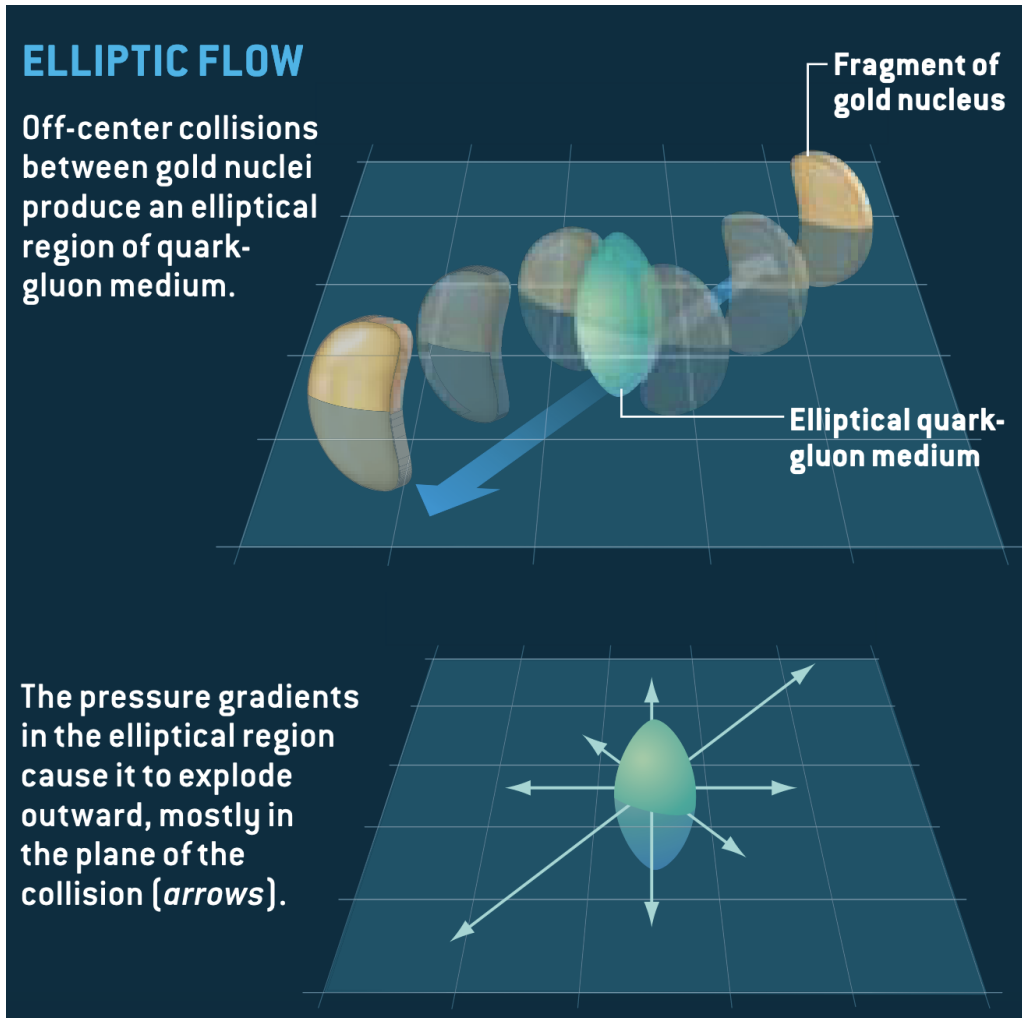
PHENIX: Phys. Rev. C 109 (2024) 4, 044912
 PHENIX: Phys. Rev. C 107 (2023) 2, 024914
 ALICE: Phys. Lett. B 754 (2016) 235-248



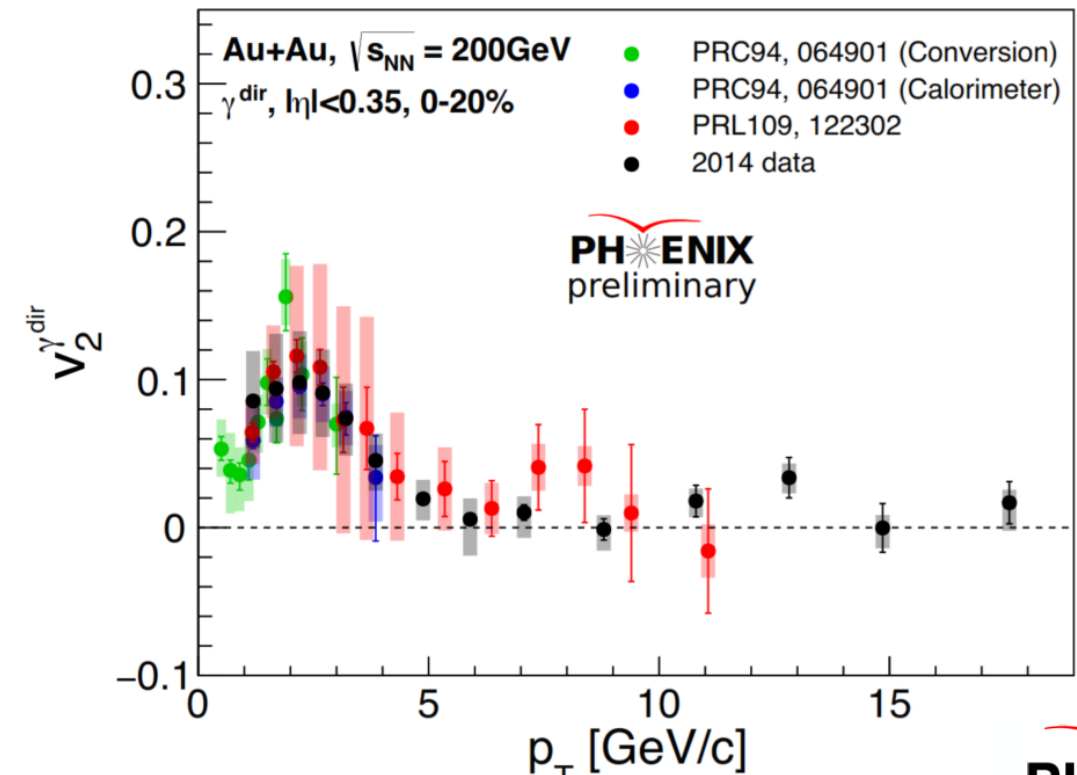
Universal scaling behavior of direct photon yields in all A+A systems.

With no obvious dependence on p_T

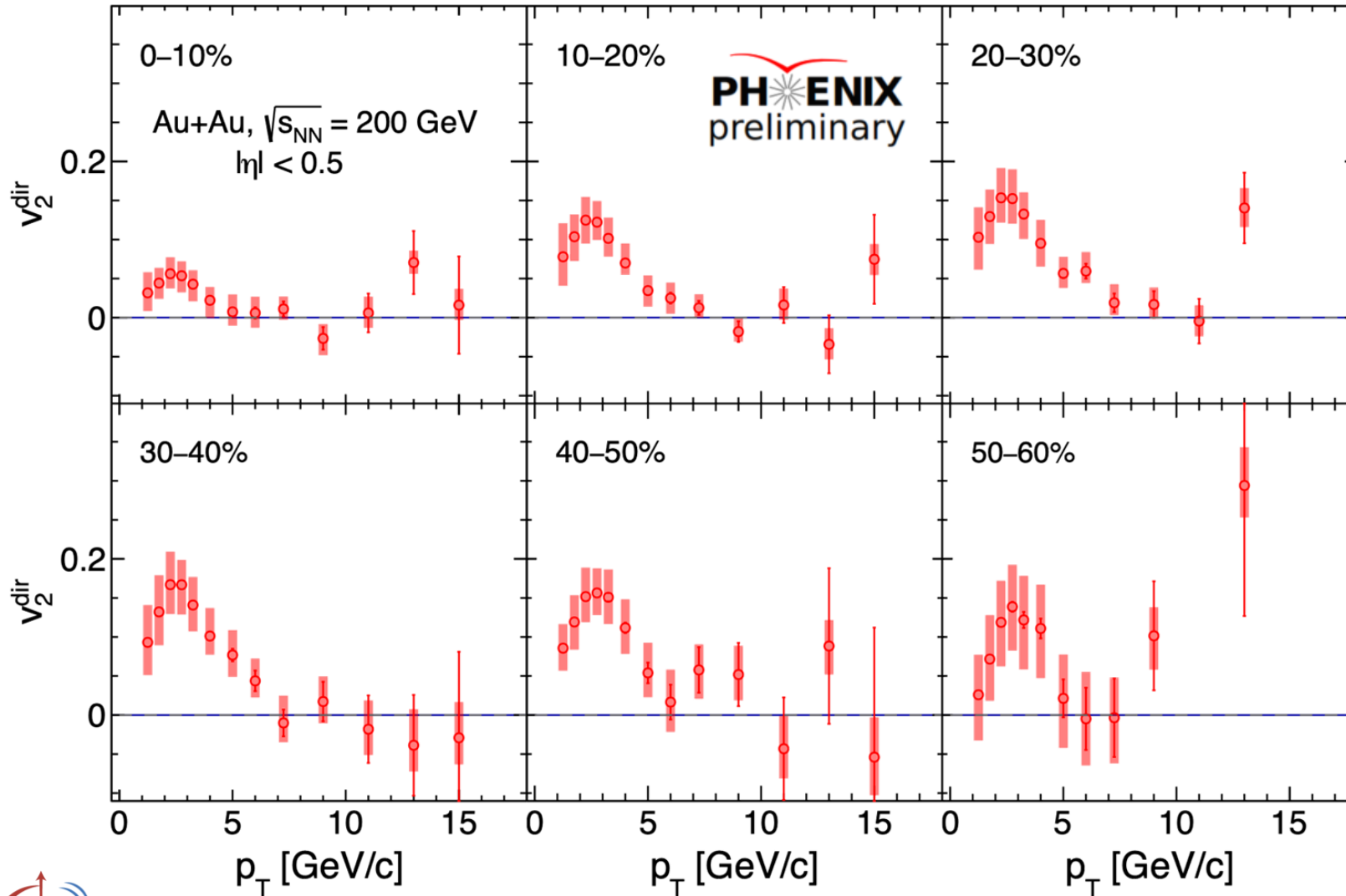
Azimuthal Anisotropy of Direct Photon Production



- 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



Direct Photon Azimuthal Anisotropy

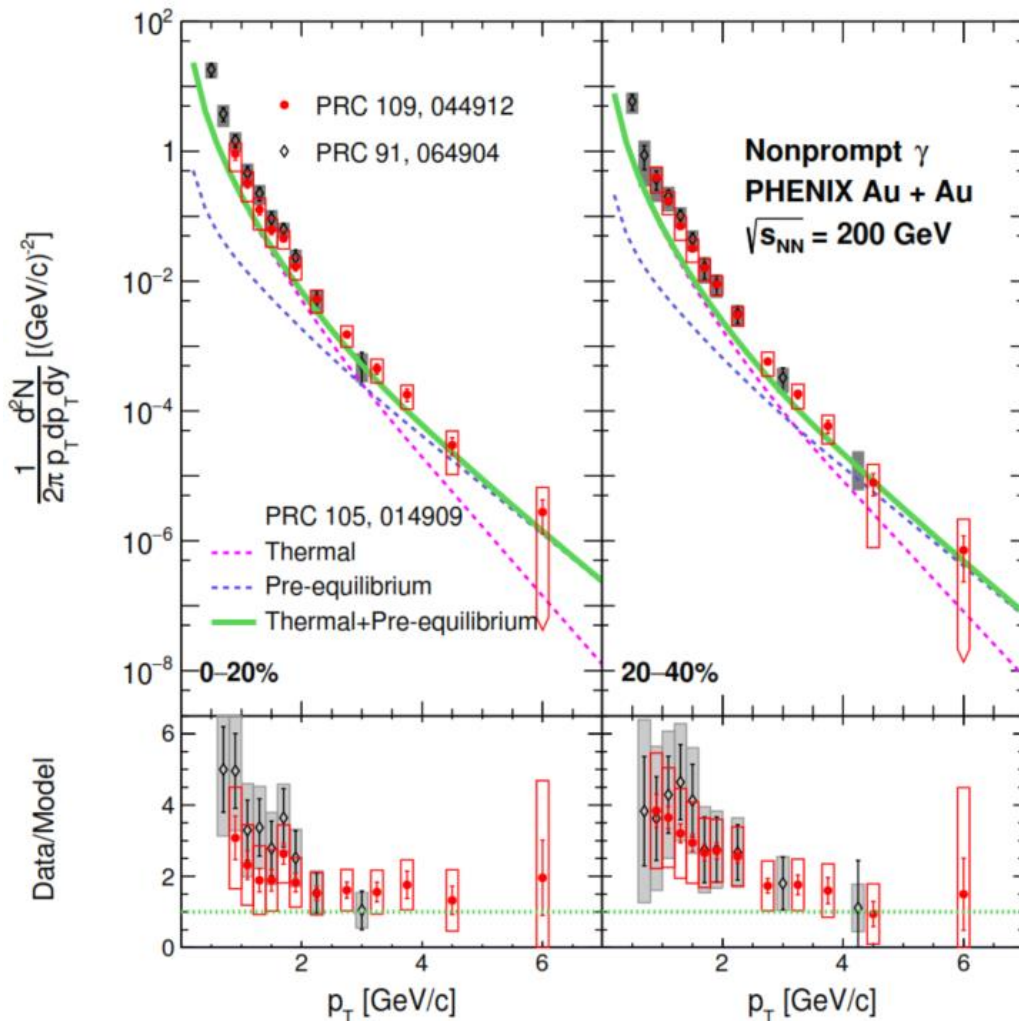


- Significant anisotropy for $p_T < 5$ GeV/c
 - Similar to hadrons
 - Maximum around 2-3 GeV/c
 - Clear centrality dependence

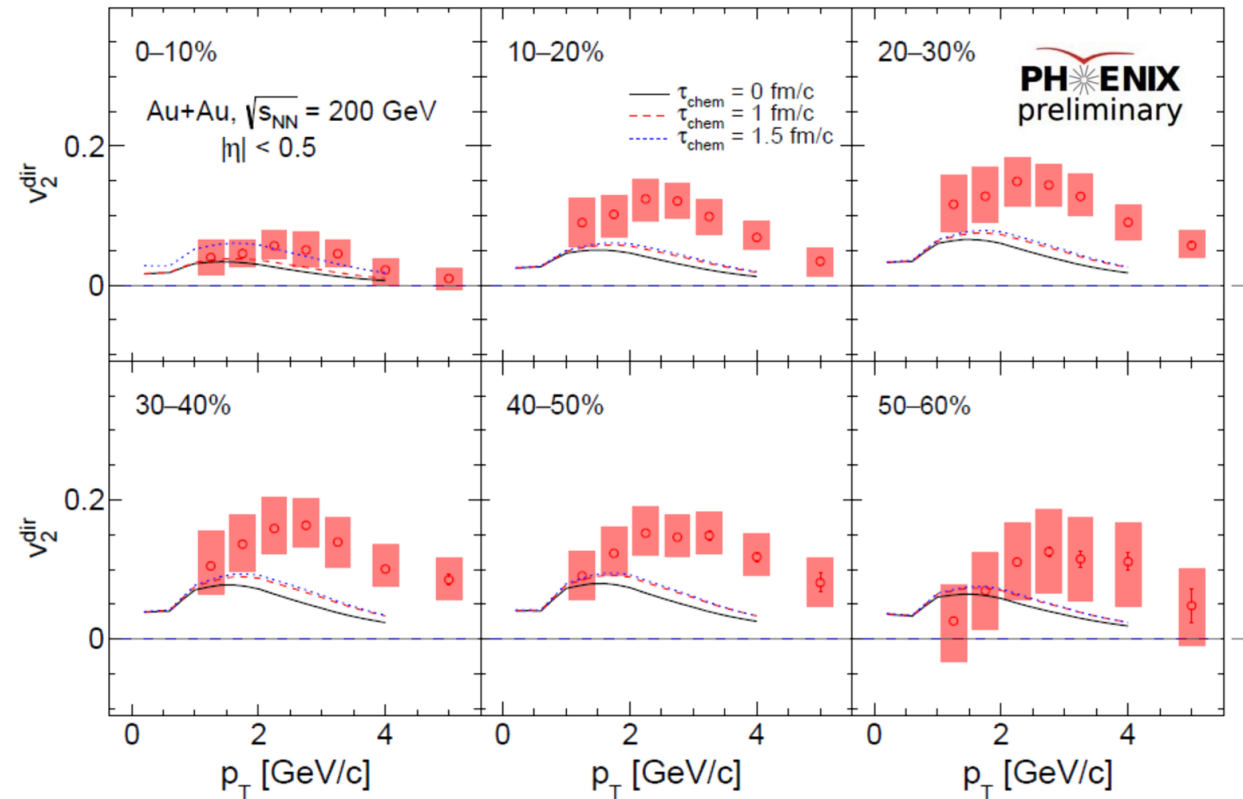
- High p_T dominated by prompt photon emission
 - v_2 consistent with zero
 - No centrality dependence

Thermal Photon Model Calculations

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



- **Multi-messenger heavy-ion physics**
 - Hybrid model for all stages of heavy-ion collisions
 - Effect of pre-equilibrium phase for photons and hadrons

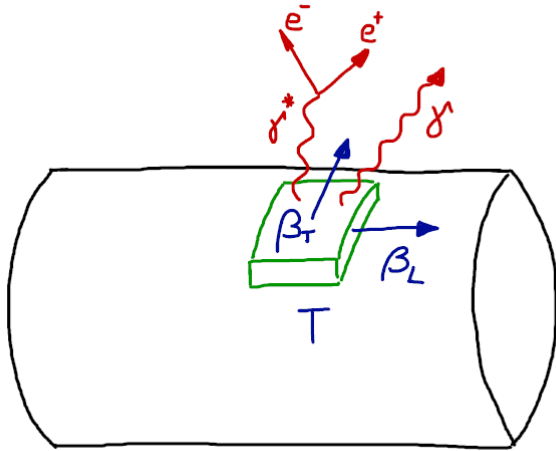


Model calculations qualitatively reproduce shape but falls short quantitatively

Virtual Photon (e^+e^- Pair) Continuum Measurement in PHENIX

Requires high statistics and simultaneous measurement of open heavy flavor pairs

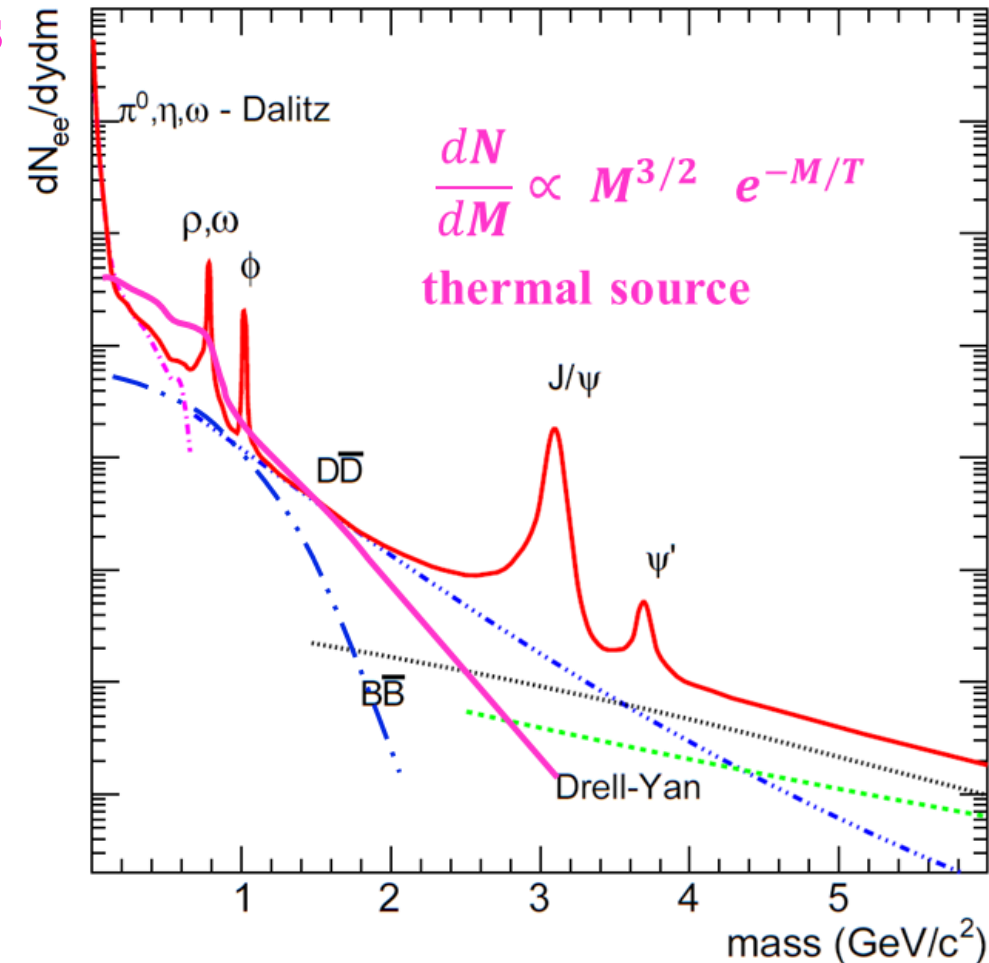
PHENIX 2014 + 2016 datasets
15 nb⁻¹ or 34B Au+Au events



Direct Measurement of the Temperature

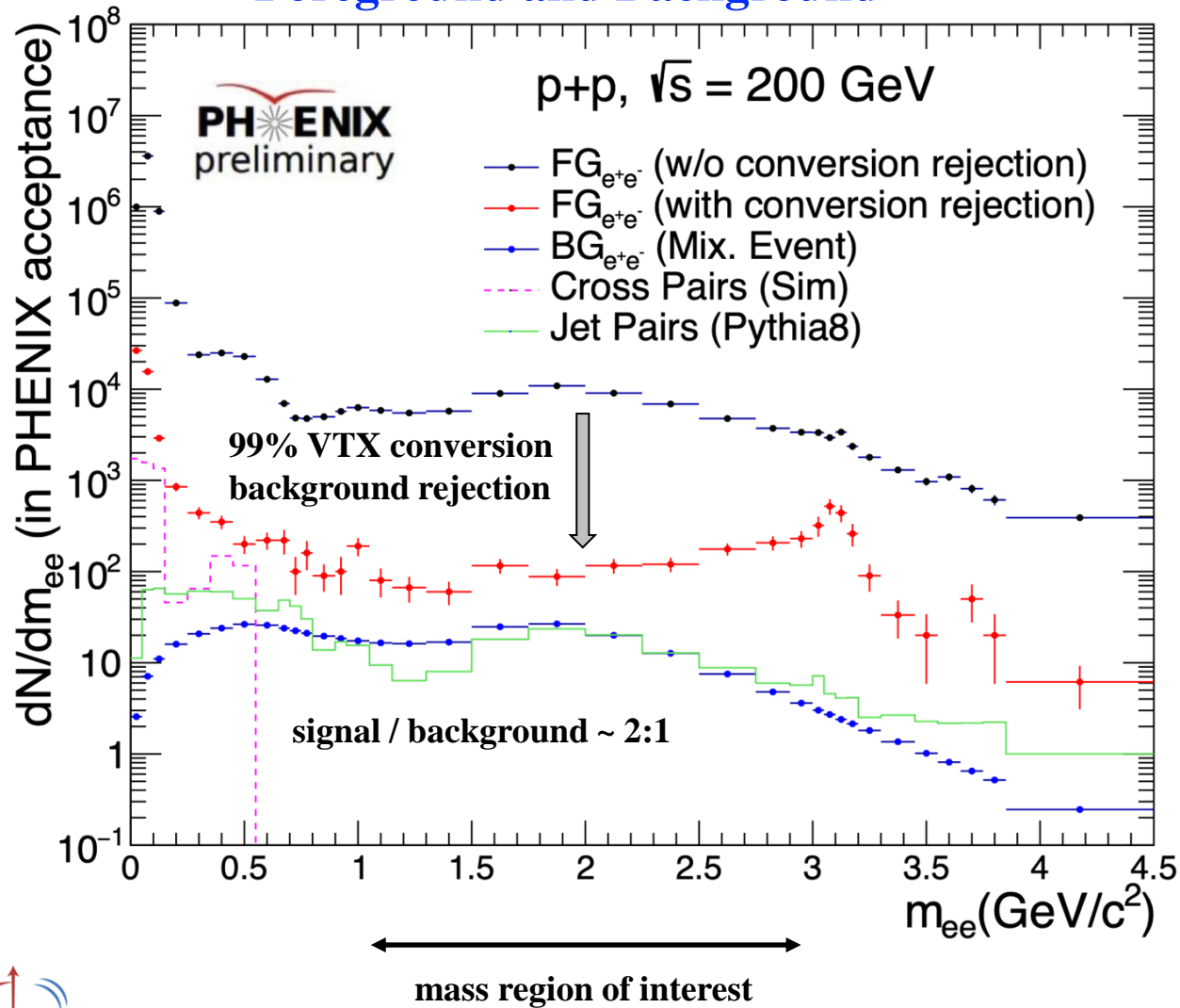
- **Thermal virtual photons: mass and momentum**
 - Momentum Doppler shifted
 - Mass Lorentz invariant
 - Mass directly measures time averaged temperature
- **Mass range 1 – 3 GeV**
 - Only significant physics background open heavy flavor

Schematic Dilepton Spectrum

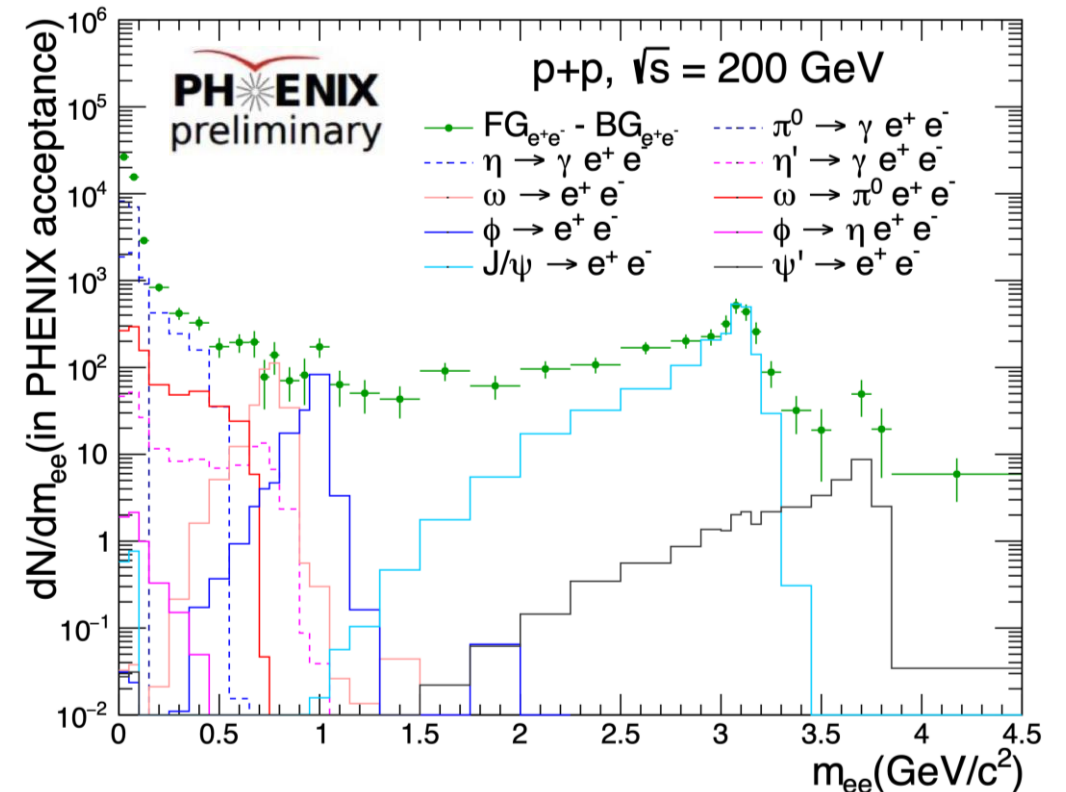


Proof of Principle: p+p Collisions with Vertex Tracker (VTX)

Foreground and Background



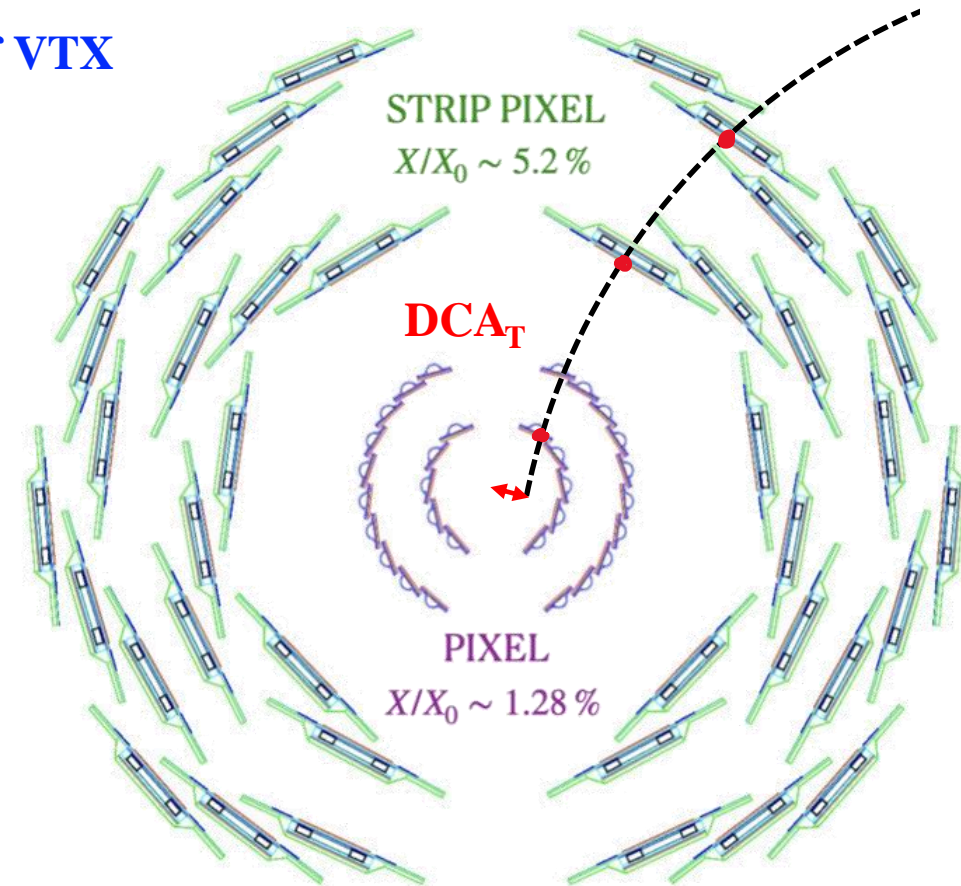
Signal = Foreground - Background



Clear signal
in heavy flavor region

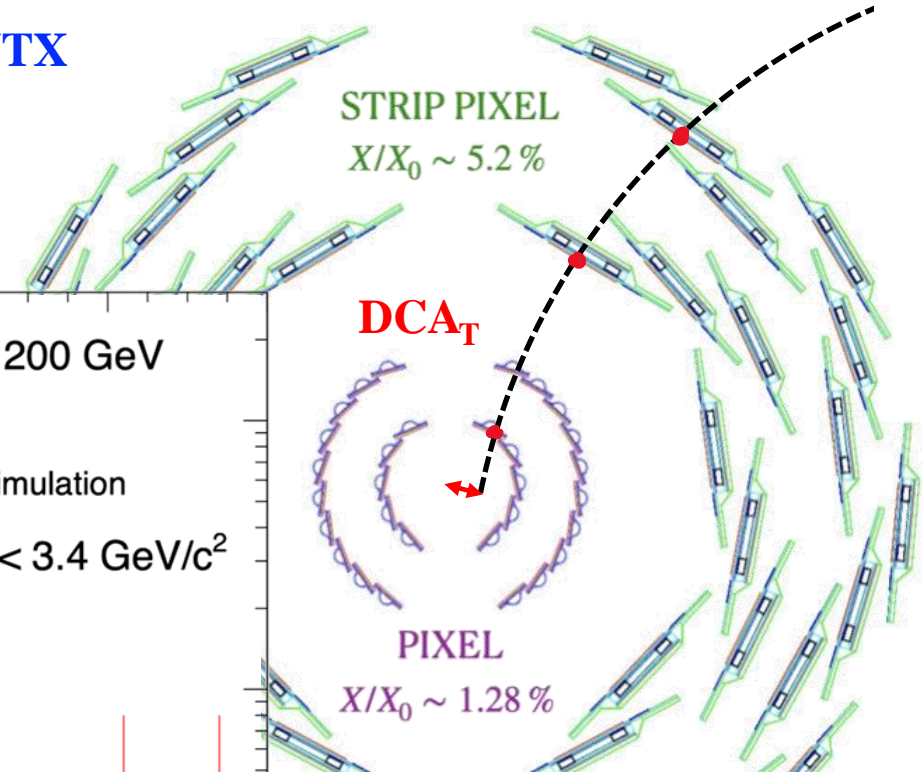
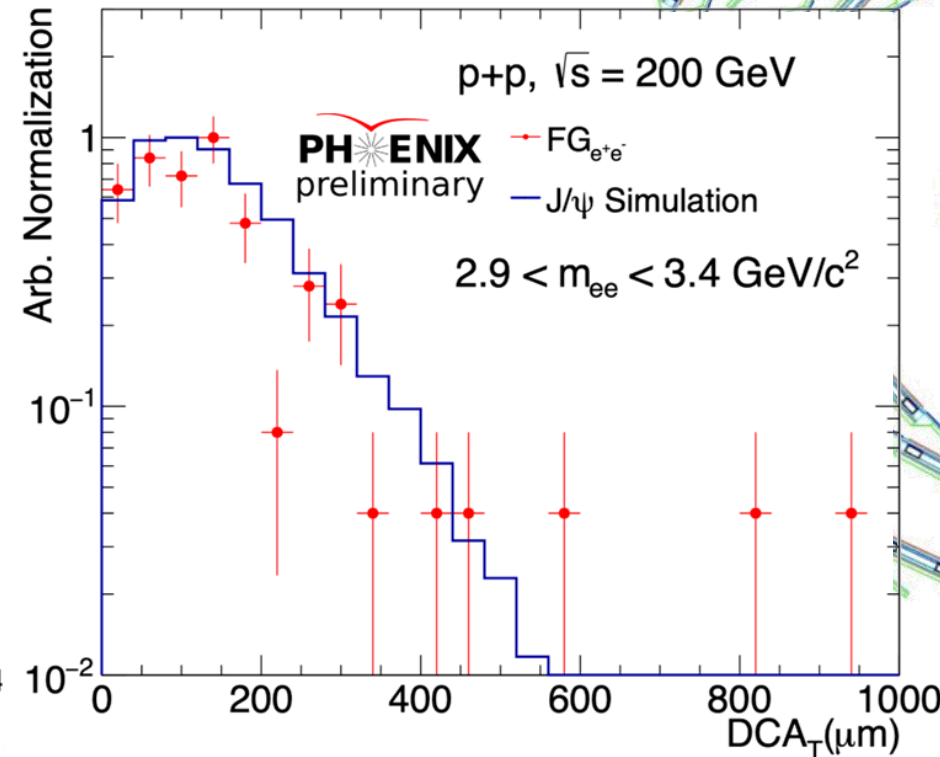
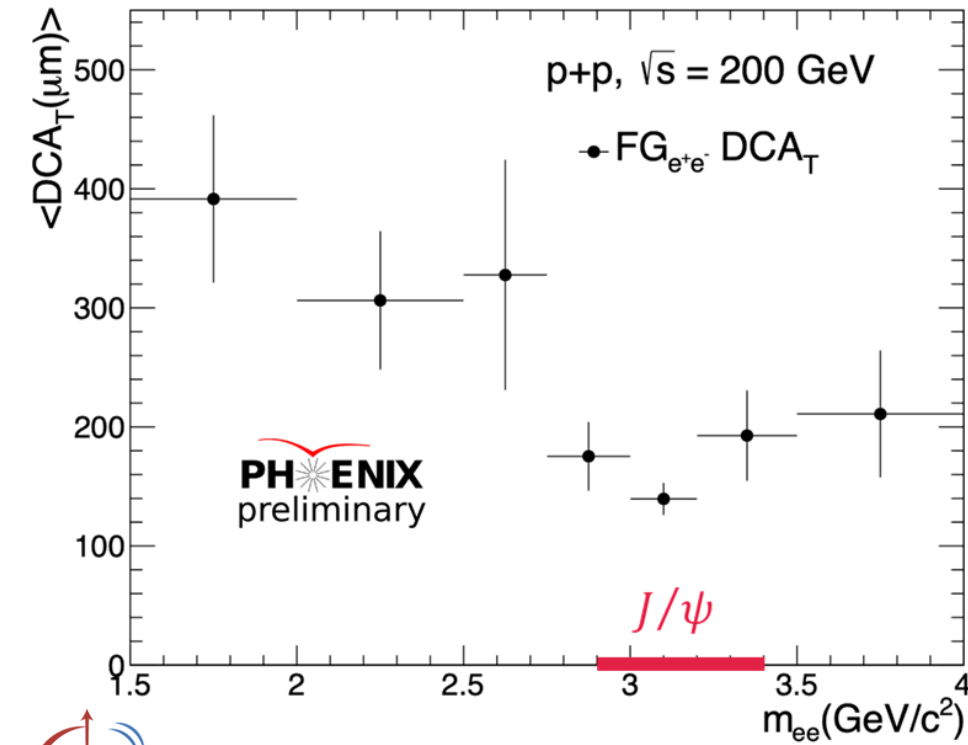
Separating Prompt and Heavy Flavor Signal

- **Transverse Distance of Closest Approach**
 - **Require 2+ hits – PIXEL and STRIP PIXEL layer of VTX**
 - **Momentum measurement from DC/PC1 tracking**
 - **Constant magnetic field**



Separating Prompt and Heavy Flavor Signal

- **Transverse Distance of Closest Approach DCA_T**
 - **Require 2+ hits – PIXEL and STRIP PIXEL layer of VTX**
 - **Momentum measurement from DC/PC1 tracking**
 - **Constant magnetic field**



Separation between prompt and HF components possible

Summary: PHENIX Direct Photon Results

- **New high statistics Au+Au results reveal universal features**
- **Large “thermal” yield for $p_T < 4$ GeV**
 - T_{eff} increases with p_T
 - No obvious variation of T_{eff} with $\sqrt{s_{NN}}$ or centrality
 - $N_{\gamma}^{\text{dir}} \sim (N_{\text{ch}})^{\alpha}$ scaling of direct photon yields in all A+A systems
 - $\alpha=1.1$ independent of p_T
 - Large anisotropy v_2 with max at 2-3 GeV
- **Prompt photon production dominates $p_T > 5$ GeV**
 - No modification of yield beyond N_{coll} scaling of p+p
 - No anisotropy
- **Outlook: measure T through e^+e^- pair continuum in Au+Au**
 - Proof of principle in p+p
 - Separation between prompt and HF components possible