Direct Photon Measurements at PHENIX

Wenqing Fan for the PHENIX Collaboration
Photons are a unique probe for QGP

- “Color blind” (do not experience strong interaction), provide a direct fingerprint of its creation point
- All thermal mediums emit radiation in the form of photons or low mass lepton pairs

Why photons?

- 80-90% of the photons are decay photons!
- Direct photon = Inclusive photon - decay photon
Early vs late emissions?

- Large yield & large $v_2$
  - Large yield: emissions from the early stage when temperature is high
  - Large $v_2$: emissions from the late stage when the collective flow is sufficiently built up

Challenging for current theoretical models to describe large yield and $v_2$ simultaneously!
New insights — direct photon in different systems

- A wealth of datasets available for direct photon analysis in PHENIX
  - 16 years of operation, 9 collision species, 9 collision energies

| System | p+p | p+Au | d+Au | $^3$He+Au | Cu+Cu | Cu+Au | Au+Au |
|--------|-----|------|------|-----------|-------|-------|-------|
| $\sqrt{s_{NN}}$ [GeV] | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 62.4 | 39 |

12/08/2020
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- 3 different methods to measure photons
  - calorimeter method
    - EMCal
  - Tracking
  - eID

PHENIX Detector

- West
- Beam View
- East

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- 3 different methods to measure photons
  - calorimeter method
    - $\gamma$
  - virtual $\gamma$ method
    - $\gamma^* \rightarrow e^+ + e^-$
  - external conversion method
    - $\gamma \rightarrow e^+ + e^-$

PHENIX Detector

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Integrated low $p_T$ direct photon yield — universal scaling

- Integrate the low $p_T$ direct photons and use $dN_{ch}/d\eta$ to compare data from different beam energies, collisions species, and collision centralities

Universal scaling behavior in all A+A systems

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

Source of photons must be similar

PRL 123, 022301 (2019)
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More central collision, higher beam energy, heavier nuclei $A$.
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Onset of low $p_T$ radiation excess at $dN_{\text{ch}}/d\eta \sim 10$?

PRL 123, 022301 (2019)

more central collision
higher beam energy
heavier nuclei A
Direct photon puzzle

- Experimental observations
  - Large yield of low $p_T$ direct photons
  - Large anisotropic emission
  - Universal scaling with $\alpha \sim 5/4$
- Challenging to explain by thermal source

What is the main source for low $p_T$ direct photons?
Towards precision measurement with the “golden dataset”

- Theoretically
  - Modification in thermal photon emission?
  - Modification in prompt photon emission?
  - Other sources of photons? (pre-equilibrium? hadronization? B field)

- Experimentally (to confirm and to study in more detail)
  - Experimental data needs more statistics
  - 2014 Au+Au dataset
  - More conversions at the PHENIX silicon vertex detector (VTX) \((X/X_0 \sim 14\%)\)
External conversion method

- Double ratio tagging method (\(R_\gamma > 1\) indicating direct photon signal)

\[
R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\gamma^{incl}}{\gamma^{\pi^0}} = \frac{\langle \epsilon_f \rangle \left( \frac{N^{incl}_\gamma}{N^{\pi^0}_\gamma} \right)_{\text{Data}}}{\left( \frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{\text{Sim}}}
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Reduce systematics!
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**Raw counts**

- $N^{incl}/N^{tag}$ from real data: # of conversion photons/# of conversion photons tagged as coming from $\pi^0$

**Conversions from $\pi^0$ tagged**

**Conversions from inclusive photons**

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Correct for detector effects

- Conditional acceptance and efficiency: the acceptance for the second photon in the EMCal from $\pi^0$ decay given that we already reconstructed the first photon from a conversion pair

Correct for other background sources

- Cocktail ratio (other sources of decay photons)
External conversion method

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Conversions from direct photons

- Conversions from hadronic decay photons

Conversions from inclusive photons

Reduce systematics!
Direct photon results in Au + Au collisions at 200 GeV

A new measurement with improved statistical precision
Direct photon results in Au + Au collisions at 200 GeV

A new measurement with improved statistical precision

Consistent with previous published results using conversion method, virtual γ method, calorimeter method

Full overlap with the published low $p_T$ and high $p_T$ measurements
Direct photon results in Au + Au collisions at 200 GeV

\[ \gamma_{\text{direct}} = (R\gamma - 1)\gamma_{\text{hadron}} \]

At high \( p_T \), Au+Au data consistent with \( N_{\text{coll}} \) scaled \( p+p \) → the dominant photon source is hard scattering
Direct photon results in Au + Au collisions at 200 GeV

At high $p_T$, Au+Au data consistent with $N_{\text{coll}}$ scaled p+p → the dominant photon source is hard scattering

At low $p_T$, Au+Au data shows a clear enhancement w.r.t. $N_{\text{coll}}$ scaled p+p below 3GeV
New Au+Au result consistent with the observed scaling behavior in A+A systems
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More peripheral Au+Au measurements can fill in the “transition region”
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More PHENIX data varying system size and geometry to be finalized/analyzed

Summary and Outlook

- New Au+Au result consistent with the observed scaling behavior in A+A systems
- More peripheral Au+Au measurements can fill in the “transition region”
- More PHENIX data varying system size and geometry to be finalized/analyzed
THANKS!