THERMAL PHOTON PRODUCTION IN AU+AU COLLISIONS OBSERVED BY PHENIX

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For PHENIX collaboration
Photons are a unique probe for Quark Gluon Plasma (QGP)

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

Direct $\gamma = \text{Inclusive } \gamma$

- Hadronic decay $\gamma$

**Downside:**
- Small production rate
- Very large background from hadron decays
Extracting thermal photon requires the systematic uncertainty of decay photons and prompt photons subtractions much less than 10%.
NEW INSIGHTS

A wealth of datasets available for direct photon analysis in PHENIX

- 16 years of operation, 9 collision species, 9 collision energies
- 3 different analysis methods — calorimeter method, virtual γ method, external conversion method

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Measuring energy deposited by photons in Calorimeter

- Good resolution at high $p_T$
- Low $p_T$ contaminated by hadrons

Internal photon conversions

- Measure virtual photons
- Reduction in background from hadron decay by a factor of 5
- Low $p_T$ reach is limited (~1 GeV) as well as high $p_T$

External conversions

- Measure real photons
- Extends $p_T < 1$ GeV and good resolution
- High $p_T$ reach is limited
Large yield and large anisotropy observed at PHENIX poses a challenge to theoretical models:

- Large yield → Early emission
- Large $v_2$ → Late emission

Challenging for current theoretical models to describe large yield and $v_2$ simultaneously!
Direct photon "puzzle"

Large yield and large anisotropy observed at PHENIX poses a challenge to theoretical models:

Large yield → Early emission
Large v2 → Late emission

In order to understand this, PHENIX has measure data in:

- Large systems:
  Au+Au 200, 62, 39 GeV and Cu+Cu at 200 GeV
- Small systems:
  p+p, p+Au, d+Au (MB) at 200 GeV

PRC94, 064901 (2016)
Direct photon spectra normalized by \((dN_{\text{ch}}/d\eta)^{1.25}\)

Lower energies

![Graph showing direct photon spectra normalized by \((dN_{\text{ch}}/d\eta)^{1.25}\)]
Direct photon spectra normalized by \((dN_{\text{ch}}/d\eta)^{1.25}\)

Lower energies  Different centralities

10/6/2020  Iu. Mitrankov for PHENIX at ICPPA2020
Direct photon spectra normalized by \((dN_{ch}/d\eta)^{1.25}\)

**Lower energies**

**Different centralities**

**Higher energies**

**Other A+A systems**

Similar low \(p_T\) photon yield when scaled by \((dN_{ch}/d\eta)^{1.25}\), independent of energy, centrality, or system size.

PHENIX

PRL123, 022301 (2019)
Integrate 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
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  \[ dN_\gamma/dy = A \times (dN_{ch}/d\eta)^\alpha \]

- Source of photons must be similar

- $N_{coll} \times pQCD$ and $N_{coll} \times p+p$ follow same scaling at 0.1 of yield

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**PRL 123, 022301 (2019)**

- $p(d,A)+p(A) \rightarrow \gamma_{d\bar{d}} + X$
- $\text{Pb+Pb, } \sqrt{s_{NN}} = 2760 \text{ GeV (ALICE)}$
- $\text{Pb+Pb, } \sqrt{s_{NN}} = 17.3 \text{ GeV (WA98)}$
- $\text{Au+Au, } \sqrt{s_{NN}} = 200 \text{ GeV}$
- $\text{Au+Au, } \sqrt{s_{NN}} = 62.4 \text{ GeV}$
- $\text{Au+Au, } \sqrt{s_{NN}} = 39 \text{ GeV}$
- $\text{Cu+Cu, } \sqrt{s_{NN}} = 200 \text{ GeV}$
- $p+p, \sqrt{s} = 200 \text{ GeV}$
- $p+p, \sqrt{s} = 62.4 \text{ GeV}$

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10/6/2020

Iu. Mitrankov for PHENIX at ICPPA2020
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- Onset of low $p_T$ radiation excess at $dN_{ch}/d\eta \sim 10$?
Comparison with STAR

Discrepancy with STAR Au+Au results

STAR data shows the scaling behavior also

The magnitude is lower comparing to PHENIX results
**R_γ via external conversion method**

A new measurement with 2014 Au+Au dataset via external conversion method

- 10 fold statistics
- Photons convert in VTX layers.
- Reconstruction conversion position using e^+e^- and the B map, origin of the conversion
- Double ratio tagging method: cancelation of systematics

**Conditional tagging efficiency**

\[
R_\gamma = \frac{\gamma_{incl}}{\gamma^{hadron}} = \frac{\langle \epsilon \gamma f \rangle}{\left( \frac{N_{\gamma}^{incl}}{N_{\gamma}^0_{tag}} \right)}_{Data} \quad \left( \frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}
\]

**Measured raw yields**

\[
\gamma^{direct} = (R_\gamma - 1) \gamma^{hadron}
\]

Simulated based on hadron data

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Iu. Mitrankov for PHENIX at ICPPA2020
$R_γ$ in Au + Au collisions at 200 GeV

New result
New result consistent with previous published results using:
• conversion method
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- conversion method,
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4 independent measurements from independent datasets shown here!

Full overlap with the published low $p_T$ and high $p_T$ measurements
Direct photon yield 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 \( p+p \) result

Clear enhancement observed below 3 GeV in (semi-)central
Au+Au collisions
Direct photon yield in Au + Au collisions at 200 GeV

At high $p_T$ Au+Au data consistent with $N_{coll}$ scaled p+p result

Enhancement persists below 3 GeV in (semi-)peripheral Au+Au collisions
Direct photon scaling with new 2014 results

\[ \frac{d^2N}{dp_T^2 dy} \propto \left( \frac{p_T^2}{1 + p_T^2} \right)^n \]

\[ p(d,A)+p(A) \rightarrow \gamma + X, \sqrt{s_{NN}} = 200 \text{ GeV}, 0-20\% \]

\[ \begin{align*}
\text{2014 conversion method} & \quad \bullet \\
\text{PRC 91, 064904 (conversion)} & \quad \diamond \\
\text{PRL 104, 132901 (virtual \gamma)} & \quad \triangle \\
\text{PRL 109, 152302 (calorimeter)} & \quad \square
\end{align*} \]

\[ N_{coll} \text{ scaled pp fit: } A \left( \frac{p_T^2}{1 + p_T^2} \right)^n \]

\[ \begin{align*}
\text{PHENIX preliminary} & \quad \alpha = 1.25 \\
p(d,A)+p(A) \rightarrow \gamma + X & \quad \text{pQCD, } \sqrt{s} = 2760 \text{ GeV} \quad \text{(ALICE)} \\
\text{Pb+Pb, } \sqrt{s_{NN}} = 2760 \text{ GeV} & \quad \text{(ALICE)} \\
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\text{Au+Au, } \sqrt{s_{NN}} = 39 \text{ GeV} & \quad \text{(STAR)} \\
\text{Cu+Cu, } \sqrt{s_{NN}} = 200 \text{ GeV} & \quad \text{(STAR)} \\
\text{d+Au, } \sqrt{s_{NN}} = 200 \text{ GeV} & \quad \text{(STAR)} \\
\text{p+p, } \sqrt{s} = 200 \text{ GeV} & \quad \text{(STAR)} \\
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\end{align*} \]
Direct photon scaling with new 2014 results

Consistent with the observed scaling behavior in A+A systems
Direct photon scaling with new 2014 results

Consistent with the observed scaling behavior in A+A systems

More peripheral Au+Au measurements can fill in the “transition region”
SUMMARY

PHENIX measured the low pt direct photon yields in Au+Au collisions at 200 GeV for different centrality bins with 2014 dataset

- Consistent with previous published PHENIX results
- Higher statistical precision, a full overlap with the published low pt and high pt measurements

Theoretical picture still incomplete-unable to describe large yield and $v_2$ simultaneously

Observed a scaling behavior on direct photons at large systems:

- At the same center of mass energy, low at high $p_T$ scale with $N_{coll}$
- At all energies, low $p_T$ yield scale with $(dN_{ch}/d\eta)^{1.25}$
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PHENIX measured the low pt direct photon yields in Au+Au collisions at 200 GeV for different centrality bins with 2014 dataset

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THANK YOU FOR ATTENTION!