DIRECT PHOTON RESULTS FROM PHENIX AT RHIC

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DIRECT PHOTON

- Definition: photons NOT originating from hadron decays

Major production processes:

- Penetrating probe w/o strong interaction in QCD medium
  - Carry the medium information at the production point

Produced throughout the collision history
  - $\gamma_{\text{thermal}}$ yield: $N_\gamma = \int_{\tau_0}^{\tau_c} R_\gamma \times V dt$, $R_\gamma$: rate, $V$: volume
THERMAL PHOTON MEASUREMENT

- Experimental data = Integral of all photon production
  → Need “$p_T$-window” to measure target photons
  ✓ Low $p_T$ region ($p_T < 3-4\text{GeV/c}$) for thermal photons

- $\gamma_{\text{decay}}$ always makes $\gamma_{\text{dir}}$ measurements challenging
  ✓ ~80% from $\pi^0$ & ~10% from $\eta$ of inclusive photon yield
  ✓ $\gamma_{\text{dir}}$ = Reminder after $\gamma_{\text{decay}}$ subtraction

- Importance of p+p & p+A data as a baseline
  ✓ Hard photon production & nuclear effects@low $p_T$
PHOTON MEASUREMENTS AT PHENIX

3 independent measurements at PHENIX

1. EMCal method: Suitable for high $p_T$ (>4GeV/c)
2. Conversion photon method: Utilizing photon conversions and covering a wide $p_T$ range from less than 1GeV/c
3. Virtual photon method: Measuring $\gamma_{\text{dir}}^* \rightarrow e^+e^-$ with reduced BG and works for 1<$p_T$<5-6GeV/c
• Successful direct photon measurements for p+p & d+Au at PHENIX
  ✓ **p+p**:
  Consistent with pQCD calculations for 1-20GeV/c → binary scaled p+p result
  → hard photons in A+A
  ✓ **d+Au (MB)**:
  Consistent with binary-scaled p+p result
  → Very small nuclear effects
**Au+Au AT \(\sqrt{s_{NN}}=200\text{GeV}\)**

**PRC91, 064904 (2015)**

- **p\_T>4 GeV/c**: Consistent with the binary scaled p\+p
- **p\_T<4 GeV/c**: Enhanced yield over the binary scaled p\+p
  - Thermal photons from the medium
- However, observation of a surprisingly large \(v_2\) as well
  - Sensitive to production process & production time

**PRC94, 064901 (2016)**

**Puzzle**

- Current theoretical scenarios have difficulties investigating the centrality dependence in more detail.
- The enhancement has a significantly smaller inverse slope than the symbol size.
- From each distribution we calculate uncertainties agrees with the calculated central value to better than the symbol size.
- From 0\%–20%, 20\%–40%, 40\%–60%, and 60\%–92%. Widths of filled boxes indicate bin widths in this analysis.
- The green bands show a \(N_{\text{coll}}\)-scaled fit to the data, and the solid line the parametrization of the photon yields measured in 
  - Including new data in the fit
  - Over the past few years, a new data set, \(\sqrt{s_{NN}} = 200\text{GeV}\)
  - Kinematic features observed with the PHENIX experiment
  - \(|\eta|<0.6\) for 
    - Minimum-bias and our previously published Au+Au data
    - Open squares are from 
      - Conversion method
      - Calorimeter method

**Shapes**

- For the generator needs to be included
- At this point a systematic uncertainty of 10\% on the shape of the input pion spectra, as described above.
- As 
  - Using data and the uncertainty in
  - Conversion method
  - Calorimeter method
**DIRECT PHOTON PUZZLE**

PRC94, 064901 (2016)

- No simultaneous description for both large yield & $v_2$
  - Need more systematic study on photon production
  - Collision system & energy
NEW RESULTS

• **Cu+Cu 200GeV(MB, 0-40%)**
  - Different collision species
  - Covering small $N_{\text{part}}$ region

• **Au+Au 39(MB) & 62.4GeV(0-20%, 20-40%, MB)**
  - Study of $\sqrt{s_{NN}}$ dependence
  1. Direct photon yield
  2. Inverse slope of exp. fit ($T_{\text{eff}}$)

ArXiv: 1805.04066
TRANSLATION OF N_{coll} TO dN_{ch}/d\eta

- \textbf{dN}_{ch}/d\eta: Useful measured observable for study of direct photon production across a wide range of \sqrt{S_{NN}} systems

\textbf{Observed N_{coll}-scaling for high p_T photons}
- Dominated by initial hard scatterings

\textbf{Attempt to translate N_{coll} to dN_{ch}/d\eta for different energy systems}
- Introduction of \sqrt{S_{NN}} dependent constant

\rightarrow N_{coll}(\sqrt{S_{NN}}) = (dN_{ch}/d\eta)^{1.25}

\textbf{arXiv: 1805.04084}
Normalization by \((dN_{ch}/d\eta)^{1.25}\) for different centralities & \(\sqrt{S_{NN}}\) data

- High \(p_T\): separation by \(\sqrt{S_{NN}}\)
- Low \(p_T\): surprisingly consistent for all centralities & \(\sqrt{S_{NN}}\)
**dNγ/dy FOR p_T>5GeV/c**

arXiv: 1805.04084

- Integrated yield for p_T>5GeV/c
  - Dominated by hard photons
  - Larger yields with higher \( \sqrt{s_{NN}} \), but same trend with \( dN_{ch}/d\eta \)

![Graph showing dNγ/dy for different collision systems and energies, with a fit to the data for p+p collisions at 200 GeV.](image-url)
dN_\gamma/dy FOR p_T>1GeV/c

- Integrated yield for p_T>1GeV/c
  ✓ Dominated by thermal photons
  ✓ Unique scaling with dN_{ch}/d\eta for all HI data
  → Large contribution near phase transition to HG?
• Theory calculation predicts unique multiplicity scaling of thermal photons as well.
  ✓ Expected transition at $N_\pi < 20$
    – No data point so far
  ✓ Different slopes for thermal and hard photons
    – Same slope in data
QGP FORMATION IN SMALL SYSTEM?

- Experimental results suggesting collective motion in small systems with high multiplicity

→ Possible formation of QGP even in small systems

PRC95, 014906 (2017)

- Thermal photons as an evidence of QGP formation in small systems

- Theoretical prediction of thermal enhancement:
  - $R^\gamma_{XX} = \gamma_{dir}^{XX} / (N_{coll} \times \gamma^{hard})$
  - Less visibility at larger systems
    - $R^\gamma_{pPb} > R^\gamma_{pAu} > R^\gamma_{dAu} > R^\gamma_{HeAu}$

→ Available 0-5% & MB p+Au data at RHIC energy
DIRECT PHOTONS IN p+Au

- Successful measurement for MB & 0-5% in p+Au
  - MB: consistent with binary-scaled p+p baseline
    - Same for d+Au MB
  - 0-5%: enhancement over binary-scaled p+p baseline
• Consistent with theory calculations for both MB & 0-5%, but not conclusive.
✓ Need more data for systematic study in small systems
SUMMARY

- Enhanced yield and a large $v_2$ of the direct photon in the low $p_T$ region
  ✓ Photon puzzle: no model can reproduce both yield & $v_2$ simultaneously so far
- Unique scaling with respect to $dN_{ch}/d\eta$ for all HI results with a wide range of $\sqrt{s_{NN}}$
  ✓ Possible explanation by a large photon production near the phase transition to Hadron
- Observation of enhanced photons in 0-5% p+Au
  ✓ Positive indication for QGP formation in small system