Direct Photon Measurement by the PHENIX Experiment at RHIC

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Extracting thermal photon requires the systematic uncertainty of decay photons and prompt photons subtractions less than 10%
Direct photon yield is well established

- pp consistent with pQCD
- AuAu follows Ncoll scaled pp above 4 GeV
- Significant excess below 3 GeV in Au+Au 200 GeV
- Excess has nearly exponential shape

Direct photon challenge

- Large yield and large anisotropy is observed -> challenge to theoretical models:
  - Large yield -> Early emission
  - Large $v_2$ -> Late emission
- We need new data from:
  - Large systems: Au+Au, Cu+Cu,
  - Asymmetric system: Cu+Au
  - Small systems: p+Au, d+Au, He+Au
Photon measurement techniques in PHENIX

- **Measuring energy deposited by photons in Calorimeter**
  - Good resolution at high pt
  - Low pt contaminated by hadrons

- **Internal photon conversions**
  - Measure virtual photons
  - Reduction in background from hadron decay by a factor of 5
  - Low pt reach is limited (~1 GeV) as well as high pt

- **External conversions**
  - Measure real photons
  - Extends pt < 1 GeV and good resolution
  - High pt reach is limited
Internal conversion method

\[ \frac{d^2 N_{ee}}{dm_{ee} dp_T} \simeq \frac{2\alpha}{3\pi} \frac{1}{m_{ee}} \frac{dN_{\gamma}}{dp_T} \]

\[ f_{incl}(m_{ee}) = (1-r)f_c(m_{ee}) + rf_{dir}(m_{ee}) \]

- All hadron contribution
- Direct photon contribution

\[ r = \frac{\gamma^*_{dir}}{\gamma^*_{incl}} = \frac{\gamma_{dir}}{\gamma_{incl}} \]

\[ dN^{dir}(p_T) = r \times dN^{incl}(p_T) \]

- Direct $\gamma^*$ yield fitted in range [120, 300] MeV
  - -> insensitive to $\pi^0$ yield
• Clear direct photon signal in Cu+Cu data at 200GeV
• Inverse slopes consistent within large uncertainty with Au+Au
External conversion method

- Conversions at Hadron Blind Detector (HBD) backplane (~60 cm)

\[ \gamma \rightarrow e^+ e^- \]

- Standard method assumes the origin in the event vertex -> Now momentum reconstruction with origin in HBD

- Sample purity 99 %

- Double ratio tagging method

\[ R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\langle \epsilon_{\gamma} f \rangle}{\frac{N_{\gamma}^{incl}}{N_{\gamma}^{\pi^0 \text{tag}}}} \]

- Condiciona tagging efficiency
- Measured raw yields
- Simulated based on hadron data

\[ \gamma^{direct} = (R_\gamma - 1) \gamma^{hadron} \]
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\[
R_\gamma = \frac{\gamma_{incl}}{\gamma_{hadron}} = \frac{\left( \frac{N_\gamma^{incl}}{N_\gamma} \right)}{\left( \frac{\gamma_{hadron}}{\gamma_{\pi^0}} \right)}_{Data}
\]

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• Clear direct photon signal in Au+Au at 62.4 GeV and 39 GeV
Possible increase of $T_{\text{eff}}$ with increasing beam energy
• Similar increase with $N_{\text{part}}$ for different systems
• Yield increases faster than reaction volume
Integrated yield vs $N_{\text{charge}}$

$Au+Au \rightarrow \gamma_{\text{dir}} + X, \ \mid y \mid < 0.35$

$\sqrt{s_{NN}} = 200 \text{ GeV} \quad PRC 91, 064904$

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$\sqrt{s_{NN}} = 62.4 \text{ GeV} \quad PHENIX Prelim.$

$\sqrt{s_{NN}} = 39 \text{ GeV} \quad PHENIX Prelim.$

$Pb+Pb \rightarrow \gamma_{\text{dir}} + X, \ \mid y \mid < 0.5$

$\sqrt{s_{NN}} = 2760 \text{ GeV} \quad PLB 754, 235$

$Cu+Cu \rightarrow \gamma_{\text{dir}} + X, \ \mid y \mid < 0.35$

$\sqrt{s_{NN}} = 200 \text{ GeV} \quad PHENIX Prelim.$
Integrated yield vs N\_charge

- Scaling direct photon yield with multiplicity in heavy ion collisions, $a \sim 1.2$
Scaling direct photon yield with multiplicity in heavy ion collisions, $\alpha \approx 1.2$
Integrated yield vs $N_{\text{charge}}$

- Scaling direct photon yield with multiplicity in heavy ion collisions, $a \sim 1.2$
- Similar scaling in pQCD contribution
Forward rapidity
Physics Motivation

- **An experimental door to gluon saturation:**
  - Using lower transverse momentum
  - Greater advantage at forward measurements
    - Tool -> nuclear modification factor
- **MPC_EX detector** capability to reconstruct direct photon (separate from decays) at forward rapidities. **Why real photons?**:
  - Sensitivity to gluons at LO
  - Clear kinematic relation

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![Diagram showing direct-gamma, Compton (LO) and EIC at 140 GeV]
MPC-EX detector

• Array of PbWO4 Crystal both sides
  (-3.8< eta <-3.1 and 3.1<eta<3.9 )

• Preceded by a pre-shower stage:

  - 8 layers of 24 SiW micro modules.

  - Each micro module has 2mm W plate+128 Si minipads (2x15 mm2) -> suitable for direct photon identification

• Data from d+Au collision at 200 GeV from 2016
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Summary and Outlook

• Well established measurements of low $p_T$ direct photons in Au+Au at 200 GeV:
  - Large yield above expected in the low $p_T$ region
  - Large anisotropy $v_2$ observed for the direct photons

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

• New results from Cu+Cu at 200 GeV and Au+Au at 62.4GeV & 39GeV
  - Possible increase of $T_{\text{eff}}$ with beam energy
  - Scaling of direct photon yield with multiplicity in heavy ion collisions

• Future measurements from PHENIX:
  - Data from different collision geometry Cu+Au (2012)
  - Low momentum measurement of p+p (2015)
  - At forward rapidities direct photons and RdAu for d+Au(2016)