Direct photons measurements with PHENIX experiment at RHIC

Ilia Ravinovich
for the PHENIX Collaboration
Weizmann Institute of Science

ICNFP, Kolymbari, Crete, Greece, 2014
Published PHENIX results

New external conversion analysis method

Extracted direct photons $p_T$ spectra

Anisotropic flow of thermal photons

Discussion and summary
Why the direct photons measurements are so important?

- What are the direct photons:
  - all photons excluding those that originate from the hadron decays
- They are created during all stages of the collision
- Since they penetrate the QGP it is a very good probe
- Previous direct photons measurements created a puzzle:
  - Yield enhancement
  - Large elliptic flow ($v_2$)
Published PHENIX results

1. A large excess wrt scaled p+p
2. A very large flow in the \( p_T \) region of 1-4 GeV/c

PRL 104, 132301 (2010)

PRL 109, 122302 (2012)
Why the new measurements were needed?

- Try to resolve this puzzle
- And understand the photon production mechanisms
- What is needed to perform above:
  - More complete centrality dependence
  - Higher order azimuthal anisotropy
  - Extend the $p_T$ spectra as low as possible
- Since PHENIX EMCal can not measure the real photons below 1 GeV/c the new external conversion analysis method has been developed
The momentum can be reconstructed assuming production at the nominal event vertex or at defined radius.

In the first case the reconstructed invariant mass of the $e^+e^-$ pairs will be wrong because the standard vertex reconstruction algorithm assumes that each track originates from the primary vertex.

In the second case the correct $e^+e^-$ vertex can be assigned using alternate track model.

$I. Ravinovich$
How does it work?

- Cut to select 60 cm conversion pairs
- These are low $p_T$ photon candidates
\( \pi^0 \)-decay photon tagging

- A second photon measured with very loose cuts in the calorimeter is paired with converted photons in order to see whether they reconstruct the pion mass.
- The combinatorial background is modeled with a mixed-event sample of uncorrelated converted and calorimeter photons.

\[ R_\gamma = \frac{N_{inc.}}{N_{dec.}} \]
The yields from $p+p$ data are fitted by

$$a(1 + \frac{p_T^2}{b})^c$$

extrapolated below 2 GeV/c

$$T_{AA} = \frac{<N_{coll}>}{\sigma_{pp}}$$

Compared with a green line (extrapolation from $p+p$ data) the enhancements are observed in all centrality bins

arXiv: 1405.3940
Excess photons yields

\[ A e^{-p_T/T_{\text{eff}}} \]

Excess yield (above expectation from scaled p+p) fitted with an exponential. The slopes are comparable within uncertainties.
Excess of photon yield increases with power-law function, 
\[ \alpha = 1.48 \pm 0.08 \text{(stat.)} \pm 0.04 \text{(sys.)} \approx 3/2 \]

The centrality dependence is not an artifact of the very low \( p_T \) points:
- same slope as we increase lower limit of integration
  (upper limit is always 2 GeV/c).
- The shape of direct photon \( p_T \) spectra doesn’t depend on centrality.
The magnitude of the direct photon $v_2$ is comparable to the hadron (and hadron decay photon) $v_2$.

Therefore, $R_\gamma$ is a crucial component.

\[ v_n^{\text{dir.}} = \frac{R_\gamma v_n^{\text{inc.}} - v_n^{\text{dec.}}}{R_\gamma - 1} \]

I. Ravinovich

ICNFP 2014
R\textsubscript{\gamma} for virtual and real photons

\begin{itemize}
  \item \textbf{R\textsubscript{\gamma} for virtual and real photons}
  
  \begin{figure}[h]
    \centering
    \includegraphics[width=\textwidth]{figure.png}
    \caption{Graph showing \( R\gamma \) as a function of \( p_T \) for different pseudorapidity intervals.
    
    (a) 0-20\% pseudorapidity interval.
    (b) 20-40\% pseudorapidity interval.
    (c) 40-60\% pseudorapidity interval.
    (d) 60-92\% pseudorapidity interval.
    
    \textbf{Error Bars and Data Points:}
    
    \begin{itemize}
      \item \textbf{Arrows:} Error bars representing uncertainties.
      \item \textbf{Data Points:} Observed data points.
    \end{itemize}
    
    \textbf{Significance:}
    
    \begin{itemize}
      \item \textbf{Arrows:} Error bars indicating statistical uncertainties.
      \item \textbf{Data Points:} Experimental data.
    \end{itemize}
  \end{figure}

  \textbf{Reference:}
  
  I. Ravinovich

  \textbf{ArXiv: 1405.3940 for real photons}

  \textbf{PRL 104, 132301 (2010) for virtual photons}

  \textbf{R\textsubscript{\gamma} measured with real (conversion) photons is consistent with the earlier virtual photon measurement.}
\end{itemize}
Higher order azimuthal anisotropy

\[ \frac{dN}{d(\phi - \Psi_n)} = N_0 \left[ 1 + 2 \sum_{n=1}^{\infty} \nu_n \cos \{ n(\phi - \Phi_n) \} \right] \]

\[ \nu_n = \langle \cos \{ n(\phi - \Phi_n) \} \rangle > \]

Dominant component is \( \nu_2 \); \( \nu_3 \) comes from participant fluctuations. Viscosity dampens higher order terms.
The magnitude of $\gamma^{\text{dir.}} v_3$ is similar to $\pi^0$, a similar trend as seen in case of $v_2$. Photon azimuthal asymmetries may be affected by expansion of QGP.
η range of RxN(I+O) is from 1.0 to 2.8.
Non-zero, positive $v_3$ is observed in all centrality bins.
No strong centrality dependence: similar tendency as for charged hadrons (PRL 107, 252301 (2011)) and $\pi^0$. 
Direct photons and $\pi^0$ comparison

The centrality (in)dependence of $\gamma_{\text{dir.}} v_3$ is also observed for $\pi^0 v_3$. 
The soft photons are expected to help us to constrain the photon production mechanisms.

They should also provide the information about a medium properties including viscosity.

The centrality dependence has been measured:

- No strong centrality dependence of the $p_T$ spectra shapes
- The excess of yield increases with centrality like $N_{\text{part}}^{\alpha}$

The third order azimuthal anisotropy has been measured:

- Direct photon has as large $v_3$ as hadrons, which is similar to $v_2$
- Non-zero, positive direct photon $v_3$ is observed in all centrality bins