Measurements of direct photons in $Au + Au$ collisions with PHENIX

Hard Probes 2013

Benjamin Bannier for the PHENIX collaboration

Stony Brook University

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PHENIX

Outline

Low momentum direct photons: $0.4\,\text{GeV}/c < p_T < 5.0\,\text{GeV}/c$

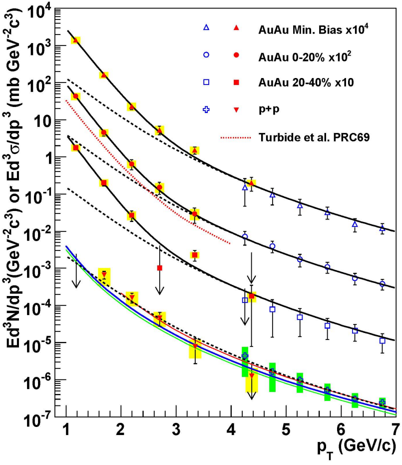
How are low momentum real photons measured in PHENIX?

Spectra and centrality dependence of the low momentum real photons from RHIC

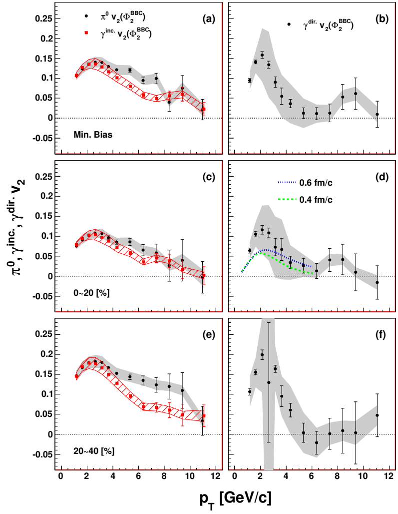
Low momentum direct photons

- long mean free path, escape heavy ion collision with almost no final state interaction
- produced at all stages of the collision in scatterings of constituents of each other or the medium
- probe complete temperature and flow evolution of the collision
- experimentally characterized by momentum-dependent yields and angular correlations with event planes

Low momentum direct photons (experiment)



(a) PRL 104, 132301 (2010)



(b) PRL 109, 122302 (2012)

Low p_T photons via external conversions in PHENIX

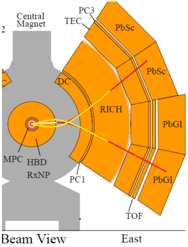
$$R_\gamma = \frac{Y^\gamma_{\text{incl.}}}{Y^\gamma_{\text{hadron}}} = \boxed{\frac{\langle \varepsilon f \rangle \frac{N^\gamma_{\text{incl.}}}{N^\gamma_{\pi^0}}}{\frac{Y^\gamma_{\text{hadron}}}{Y^\gamma_{\pi^0}}}}$$

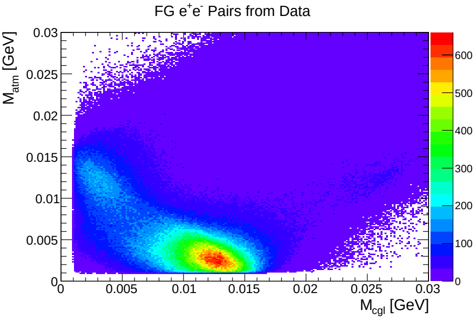
Requirements:

- clean photon sample
- high π^0-tagging efficiency $\langle \varepsilon f \rangle$

Photon sample

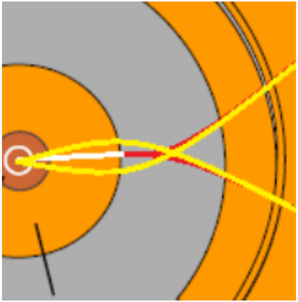
- measurement of low momentum photons in electromagnetic calorimeters is difficult due to e.g. MIPs
- PHENIX has good electron reconstruction capability down to $p_T = 200\,\text{MeV/c}$
- reconstruct real photons down to 400 MeV/c from e^+e^- pairs $\rightarrow$ no hadron contamination

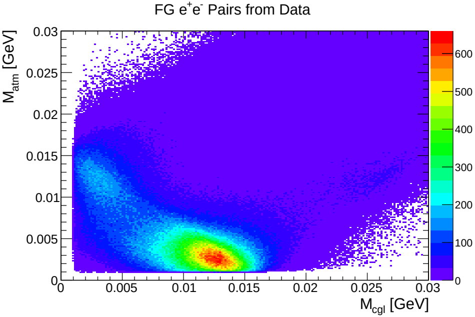




- momentum can be reconstructed assuming production at the nominal event vertex or a defined radius
- conversion pairs can be selected through their invariant mass under hypotheses for production radius

$$\boxed{N^{\gamma}_{\text{incl.}} = Y^{\gamma}_{\text{incl.}} p_{\text{conv}} a_{e^+e^-} \varepsilon_{e^+e^-}}$$





- momentum can be reconstructed assuming production at the nominal event vertex or a defined radius
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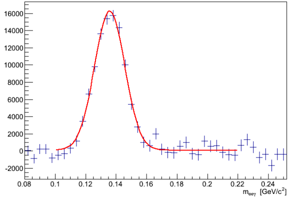
$$\boxed{N^{\gamma}_{\text{incl.}} = Y^{\gamma}_{\text{incl.}} p_{\text{conv}} a_{e^+e^-} \varepsilon_{e^+e^-}}$$

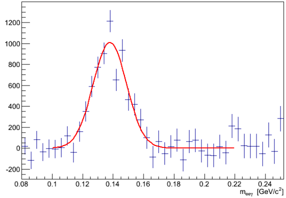
π^0-decay photon tagging

- a second photon measured with very loose cuts in the calorimeter is paired with converted photons
- the combinatorial background is modelled with a mixed-event sample of uncorrelated converted and calorimeter photons

$$\boxed{N^{\gamma}_{\pi^0} = Y^{\gamma}_{\pi^0} p_{\mathrm{conv}} a_{e^+e^-} \varepsilon_{e^+e^-} \times \langle \varepsilon f \rangle}$$

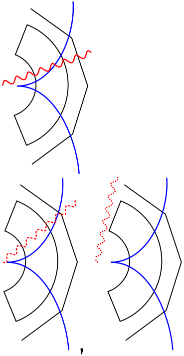


(a) $p_{T,\gamma} = 0.8 - 1.0\,\mathrm{GeV/c}$



(b) $p_{T,\gamma} = 2.0 - 2.5\,\mathrm{GeV/c}$

Tagging efficiency correction $\langle \varepsilon f \rangle$



- 2nd photon in acceptance $\rightarrow \varepsilon$
- 2nd photon lost $\rightarrow f$

The tagging efficiency $\langle \varepsilon f \rangle$ is calculated in a Monte Carlo simulation.

- f can be calculated accurately, $\varepsilon \approx 90\%$

$$\boxed{\frac{N^{\gamma}_{\text{incl.}}}{N^{\gamma}_{\pi^0}} = \frac{Y^{\gamma}_{\text{incl.}} p_{\text{conv}} a_{e^+e^-} \varepsilon_{e^+e^-}}{Y^{\gamma}_{\pi^0} p_{\text{conv}} a_{e^+e^-} \varepsilon_{e^+e^-} \times \langle \varepsilon f \rangle} = \frac{Y^{\gamma}_{\text{incl.}}}{Y^{\gamma}_{\pi^0} \langle \varepsilon f \rangle}}$$

R_γ in $Au + Au$ at $\sqrt{s_{NN}} = 200$ GeV

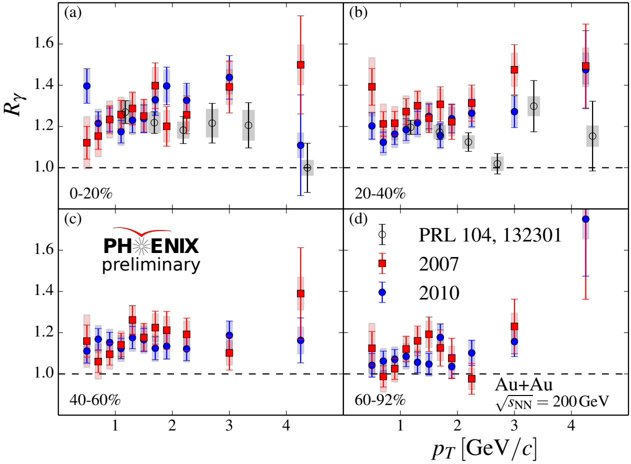


Figure: R_γ from **virtual** and real photons (red, blue) in 0-20%, 20-40%, 40-60% and 60-92% more central collisions.

Direct photon p_T spectrum

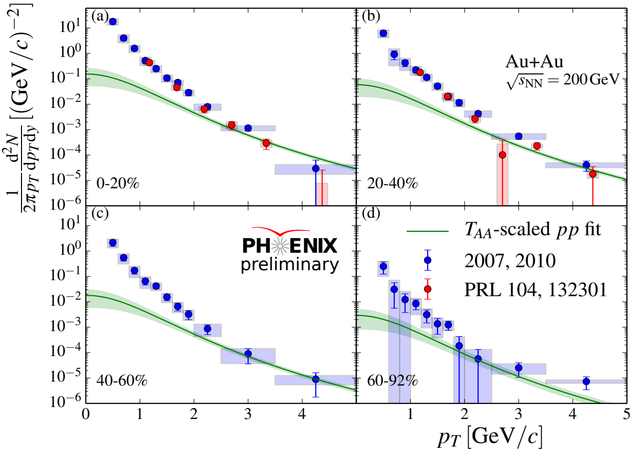


Figure: Direct photon p_T spectra $Y_\gamma = (R_\gamma - 1)\,Y_\gamma^{\text{hadron}}$ in 0-20%, 20-40%, 40-60% and 60-92% more central collisions. A N_{coll}-scaled fit $a\left(1 + p_T^2/b\right)^{-c}$ to RHIC pp data is shown in green.

Excess photon p_T spectrum

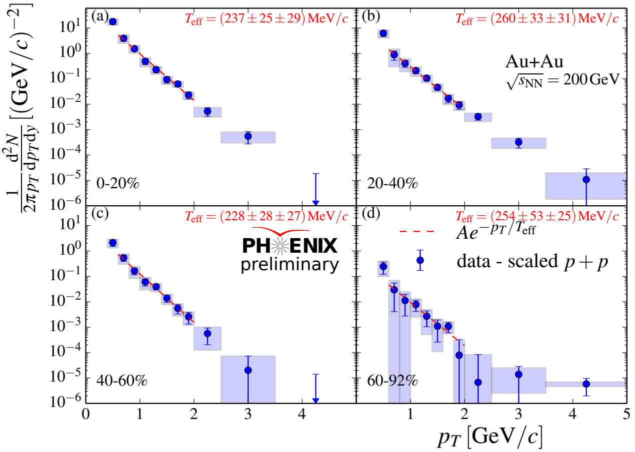


Figure: Excess photon p_T spectra after subtraction of hard-scattering component in 0-20%, 20-40%, 40-60% and 60-92% more central collisions. Red lines are fits of $Ae^{-p_T/T_{\rm eff}}$ in $p_T = 0.6 - 2.0\,\text{GeV/c}$.

Centrality dependence of excess photon yield

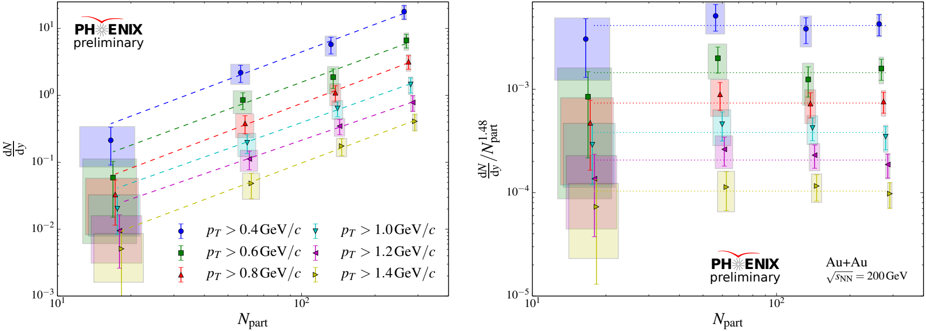


Figure: *Left*: Integrated excess photon yield as a function of Glauber N_{part}. *Right:* Residuals of fits to power laws AN_{part}^x with $x = 1.48 \pm 0.08(\mathrm{stat}) \pm 0.04(\mathrm{sys})$.

$$\frac{dN}{dy}(p_T) = \sum_{p_T^{(i)}=p_T}^{5\,\mathrm{GeV}/c} 2\pi p_T^{(i)} \Delta p_T^{(i)} \left(\frac{1}{2\pi p_T} \frac{d^2 N}{dp_T dy} \right) \Bigg|_{p_T^{(i)}}$$

Summary

We have measured R_γ and p_T spectra for real photons.

Real and virtual photons show similar R_γ.

An excess yield of photons is seen across all centralities.

No change in the shape of the photon p_T spectra is seen between centralities outside uncertainties.

The excess photon yield grows stronger than N_{part} in the p_T window $0.6 - 2.0\text{GeV}/c$ and is described by a power law with $x = 1.48 \pm 0.08(\text{stat}) \pm 0.04(\text{sys})$.

Backup

Characterization of excess photon p_T spectra

Excess photon spectra are roughly exponential in low p_T range.

The shape of the spectra doesn't change outside uncertainties across centralities.

0-20%	20-40%	40-60%	60-92%	[T_{eff}]
$237 \pm 25 \pm 29$	$260 \pm 33 \pm 31$	$228 \pm 28 \pm 27$	$254 \pm 53 \pm 25$	MeV/c

Integrated yields

To quantify the centrality-dependence of the yield we can calculate

$$\frac{\mathrm{d}N}{\mathrm{d}y}(p_T) = \sum_{p_T^{(i)}=p_T}^{5\,\text{GeV}/c} 2\pi p_T^{(i)} \Delta p_T^{(i)} \left(\frac{1}{2\pi p_T} \frac{\mathrm{d}^2 N}{\mathrm{d}p_T \mathrm{d}y} \right) \Bigg|_{p_T^{(i)}}$$

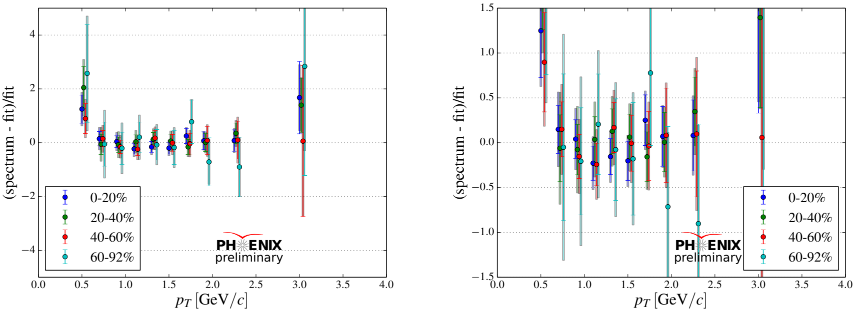


Figure: Normalized fit residuals for fits of the excess photon spectra to an exponential in $p_T = 0.6 \ldots 2.0\,\mathrm{GeV/c}$ (*left*) and zoomed (*right*).

Hadron decay photon simulation

To calculate $R_\gamma$the efficiency-corrected ratio needs to be scaled by the expected ratio of photons yields from hadron and π^0 decays $Y^\gamma_{\text{hadron}}/Y^\gamma_{\pi^0}$.

We implement a cocktail including

- $\pi^0 \to \gamma\gamma$
- $\eta \to \gamma\gamma$, $\pi^+\pi^-\gamma$
- $\eta' \to \gamma\gamma$, $\pi^+\pi^-\gamma$, $\omega\gamma$
- $\omega \to \pi^0\gamma$

using experimental π p_T spectra and m_T scaling for other mesons with experimental meson/π^0 ratios.

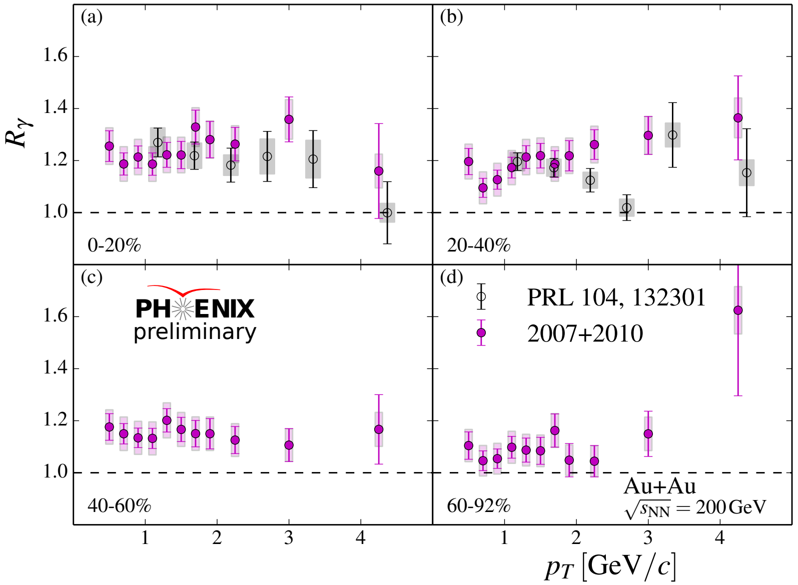


Figure: R_γ from **virtual** and real photons in 0-20%, 20-40%, 40-60% and 60-92% more central collisions.