Experimental overview: PHENIX

EMMI RRTF "Direct photon flow puzzle"

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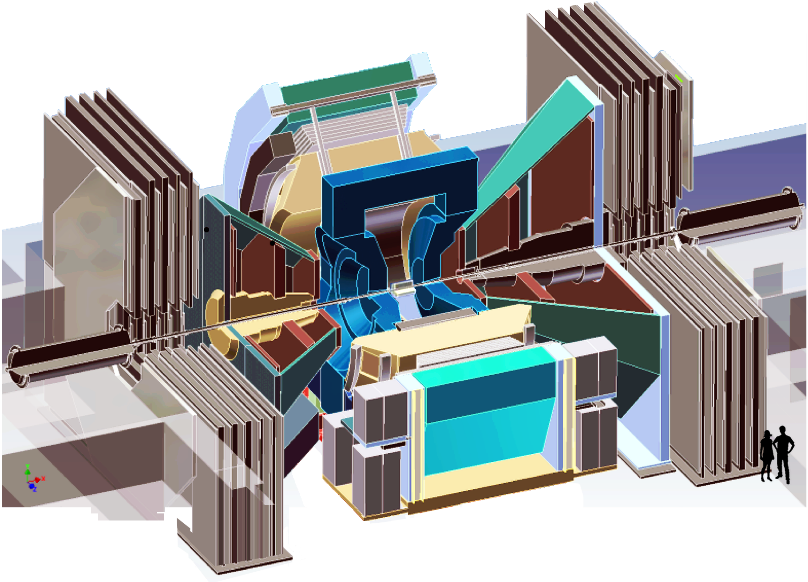


Direct photons in PHENIX

Measurements

- direct photon yield ($\mathrm{d}N/\mathrm{d}p_T$, R_γ, f), and
- v_2 as a proxy for correlation with event topology

Techniques

Electromagnetic calorimeter	$p_T \geq 1\,\mathrm{GeV}/c$
Internal conversions to e^+e^- pairs	$p_T \geq 1\,\mathrm{GeV}/c$
External conversions to e^+e^- pairs	$p_T \geq 0.4\,\mathrm{GeV}/c$

- different methods have differing advantages & disadvantages
- in the soft regime limits from systematics or sample size

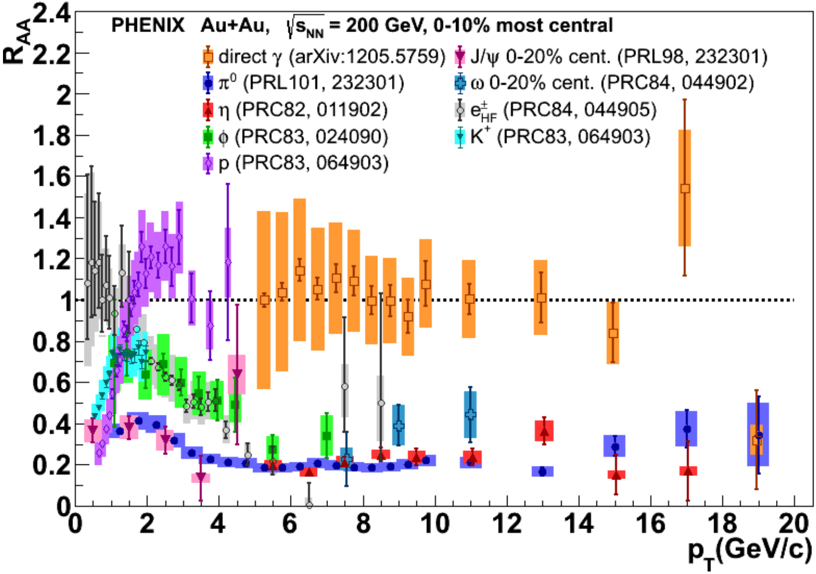
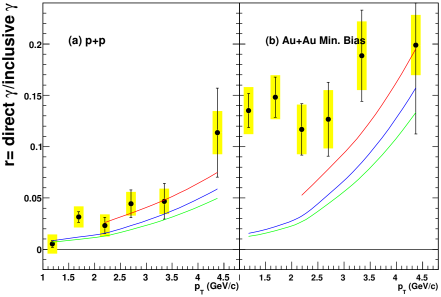


Figure: High p_T photons behave like in $p + p$, e.g. no supression observed, PRL 109, 152302 (2012)



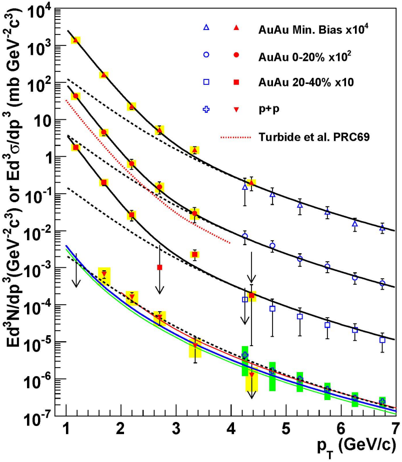
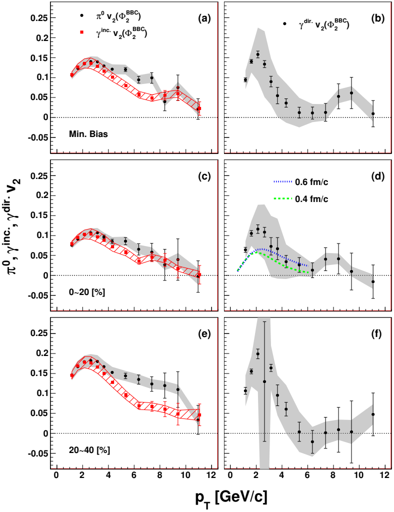


Figure: Direct photons from internal conversion pairs in $m_{ee} > m_{\pi^0}$ and $p_{T,ee} > 1\,\mathrm{GeV}/c$, PRL 104, 132301 (2010).



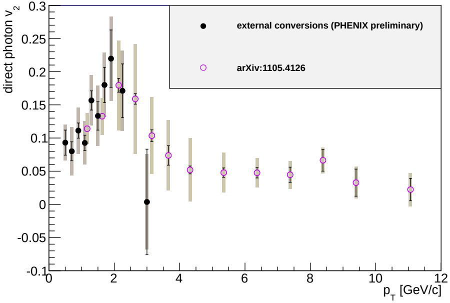
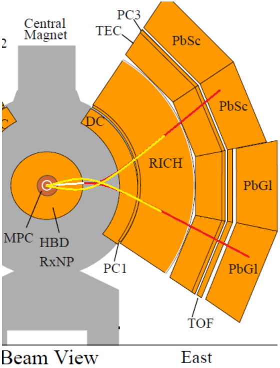
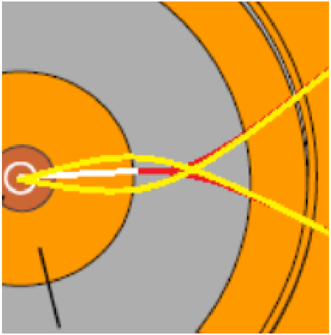


Figure: Direct photon v_2 from calorimeter (*left*, PRL 109, 122302 (2012)) and external conversion photons (*right*, PHENIX prelim HP2012).

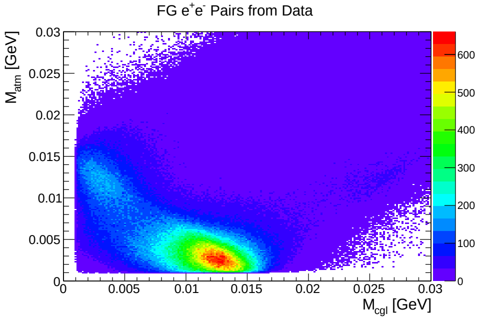
External conversion method in PHENIX

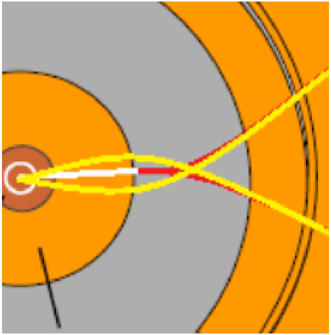




- in PHENIX reconstructed pair mass direct consequence of production vertex

External conversion method in PHENIX





- in PHENIX reconstructed pair mass direct consequence of production vertex
- testing pair against two hypotheses – production at vertex and at well-defined conversion location allows a $> 99\%$ purity inclusive photon sample: $\boxed{N^{\gamma}_{\text{incl.}} = Y^{\gamma}_{\text{incl.}} p_{\text{conv}} a_{ee} \varepsilon_{ee}}$

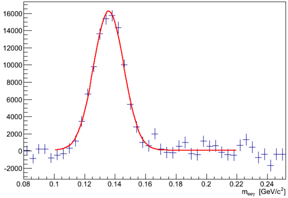
Direct photon fraction R_γ

Fraction of photons from hadron decays is also measured with *same photon sample*:

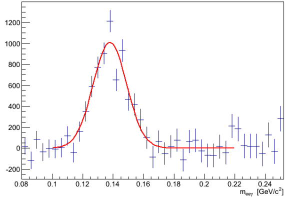
- measure the $\pi \to \gamma\gamma \to (ee)\gamma$ with a calorimeter γ with minimal cuts: *high efficiency, small systematic uncertainty*, benchmark for cuts in S/B

$$\boxed{N^{\gamma}_{\pi^0} = Y^{\gamma}_{\pi^0} p_{\text{conv}} a_{ee} \varepsilon_{ee} \times \langle \varepsilon f \rangle}$$

- tagging efficiency $\langle \varepsilon f \rangle$ can be determined accurately MC



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



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

We now have measured

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

If all yields are measured as *a function of photon p_T* all conversion-related detector quantities *cancel*.

For $\boxed{R_\gamma = \frac{Y^{\gamma}_{\text{incl.}}}{Y^{\gamma}_{\text{hadrons}}}}$ we only need $\frac{Y^{\gamma}_{\text{hadrons}}}{Y^{\gamma}_{\pi^0}}$ with the known yield ratios of other photon sources (η, $\eta\prime$, ω) to π^0, again as a function of photon p_T $\rightarrow$ cocktail simulation.

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

Centrality-dependence of R_γ in $Au + Au$, $\sqrt{s_{NN}} = 200$ GeV

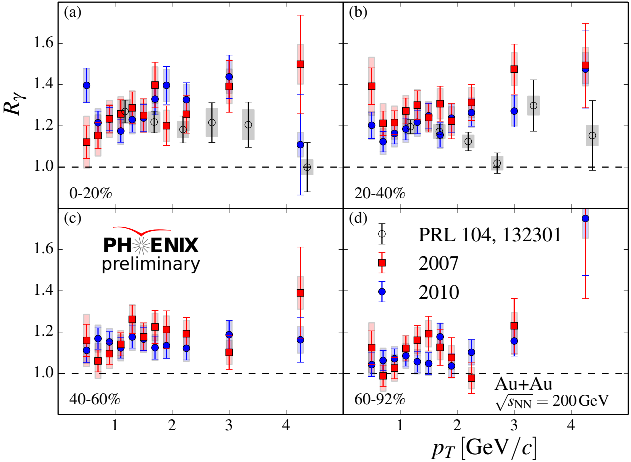


Figure: R_γ from **virtual** and real photons (red, blue) in 0-20%, 20-40%, 40-60% and 60-92% more central collisions.

Direct photon p_T spectrum

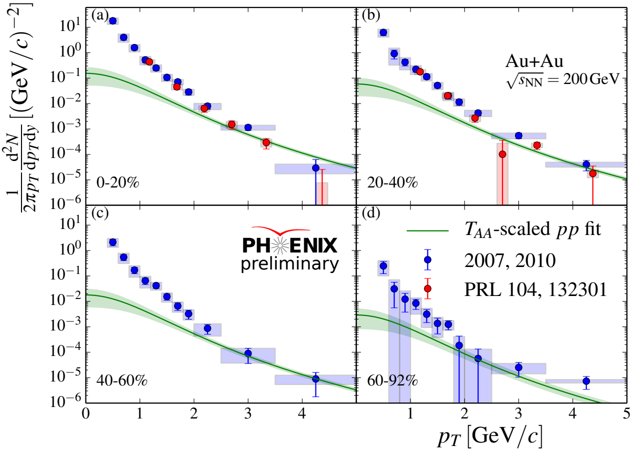


Figure: Direct photon p_T spectra $Y_\gamma = (R_\gamma - 1)\,Y_\gamma^{\text{hadron}}$ in 0-20%, 20-40%, 40-60% and 60-92% more central collisions. A N_{coll}-scaled fit $a\left(1 + p_T^2/b\right)^{-c}$ to RHIC $p + p$ data is shown in green.

Excess photon p_T spectrum

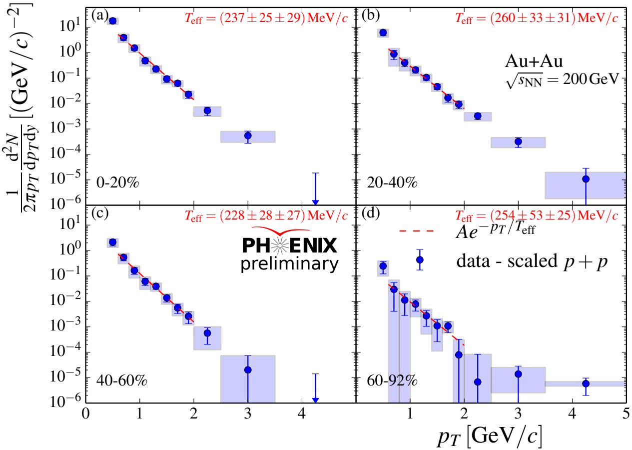


Figure: Excess photon p_T spectra after subtraction of hard-scattering component in 0-20%, 20-40%, 40-60% and 60-92% more central collisions. Red lines are fits of $Ae^{-p_T/T_{\rm eff}}$ in $p_T = 0.6 - 2.0$ GeV/c.

Centrality dependence of excess photon yield

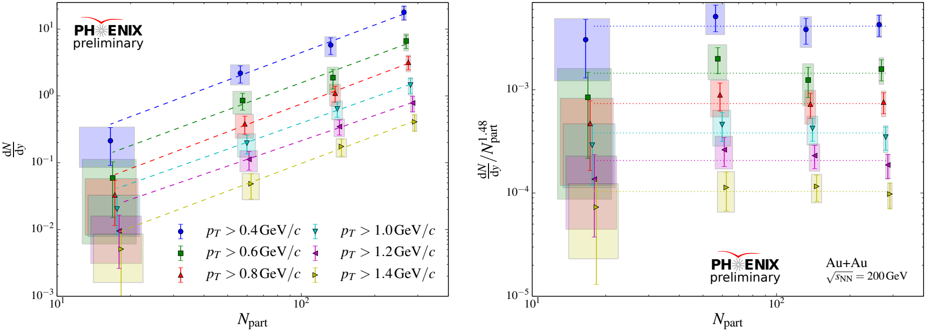


Figure: *Left*: Integrated excess photon yield as a function of Glauber N_{part}. *Right:* Residuals of fits to power laws $AN_{\text{part}}^{\alpha}$ with $\alpha = 1.48 \pm 0.08(\text{stat}) \pm 0.04(\text{sys})$.

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

Summary

- high-p_T photons appear unmodified compared to $p + p$
- enhanced production of low-p_T photons

- yield of excess photons $\sim N_{\text{part}}^{1.5}$ while hadron yield $\sim N_{\text{part}}$
- the shape of the excess p_T spectrum does not change strongly with centrality
- excess photons have elliptic flow v_2 similar to hadrons

- ongoing work to measure the excess photon v_n as a function of centrality across all accessible p_T