Measurements of low-momentum thermal photons in Au+Au collisions with the PHENIX detector

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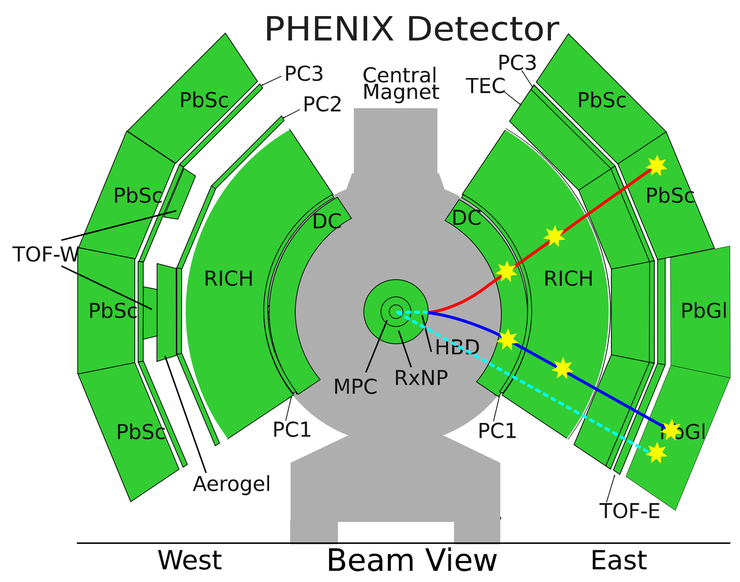
Motivation

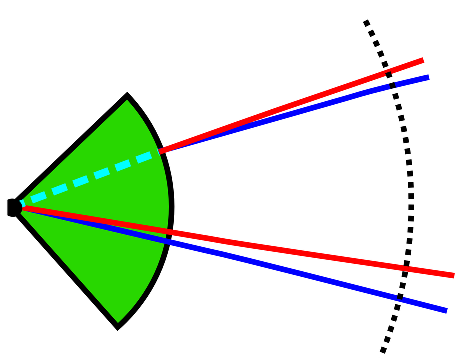
Photons are produced at all stages of a nuclear collision.
Because of their extremely small interaction rate with the hadronic medium any information they carry about their production environment is accessible nearly undistorted in their final state.
Photons are produced in hadronic decays, hard scatterings of initial state partrons, jet-photon conversions and from thermal radiation of the medium. At their lowest momenta hadronic ($p_T < 3 - 4\,\text{GeV}/c$) decays and thermal production are the dominant sources.

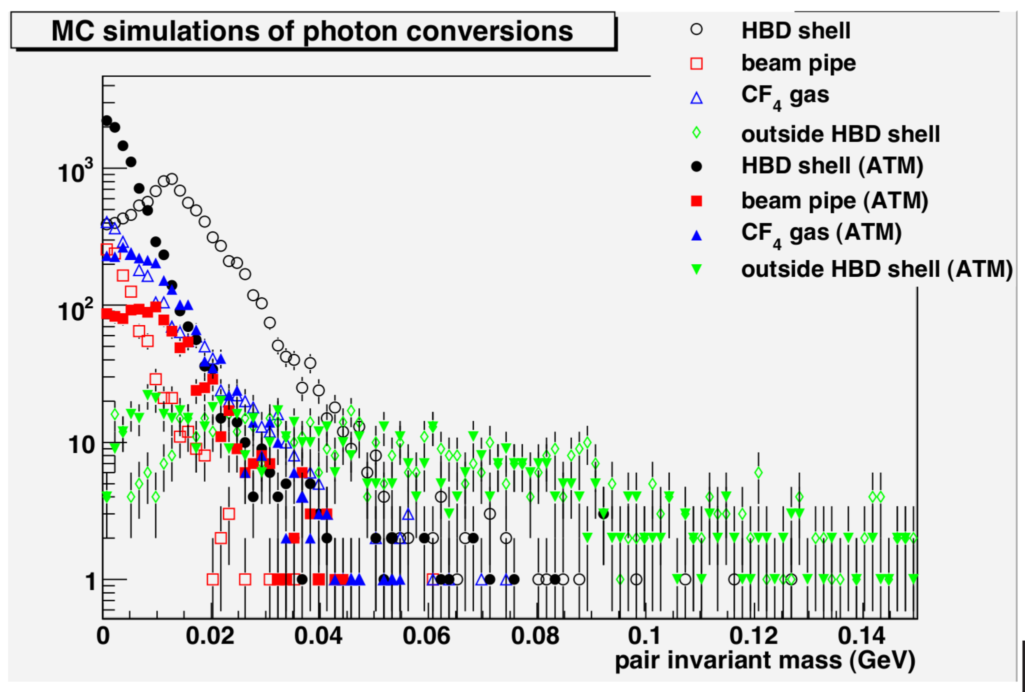
Method

Any direct observation of low-momentum photons is challenging in an electromagnetic calorimeter due to a large contamination from misidentified hadrons and a deteriorating energy resolution.
Instead we measure photons with external conversion pairs coming from a well-defined radius in the PHENIX detector, the shell of the HBD detector ($X/X_0 \approx 1.8\%$ [2]).
Since charged tracks with low momenta curve more in the PHENIX solenoidal magnetic field, their momentum resolution improves towards lower p_T.



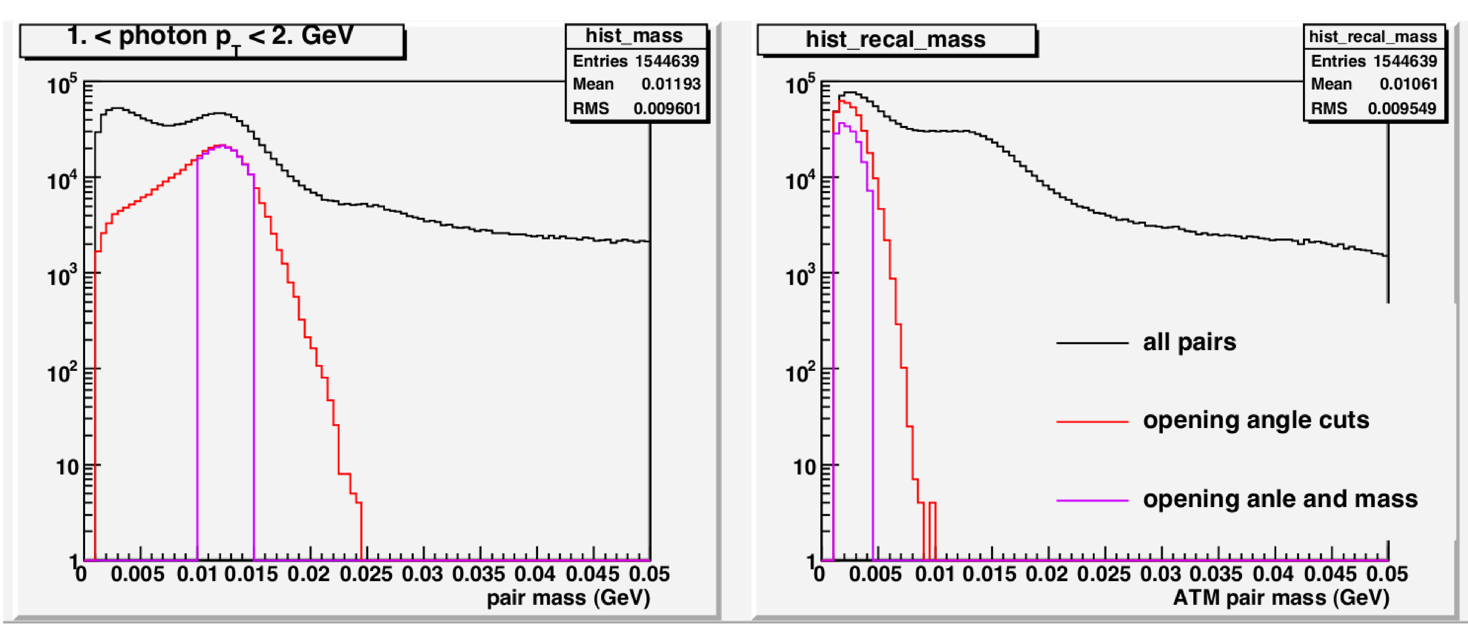
Conversion pairs are identified by a characteristic apparent pair mass (opening angle) at the vertex and at the HBD shell and by track proximity on the HBD shell.





[1]

The momenta of electrons and positrons can be recalculated under the assumption that they came from the HBD shell (**A**lternate **T**rack **M**odel), and their mass (opening angle) at the vertex and the HBD shell can be compared. This allows a clean separation of electron-positron pairs from Dalitz-decays and external photon conversions.



[1]

Relative photon yield

We measure a relative photon yield in which the acceptance and efficiency of converted photons cancel.

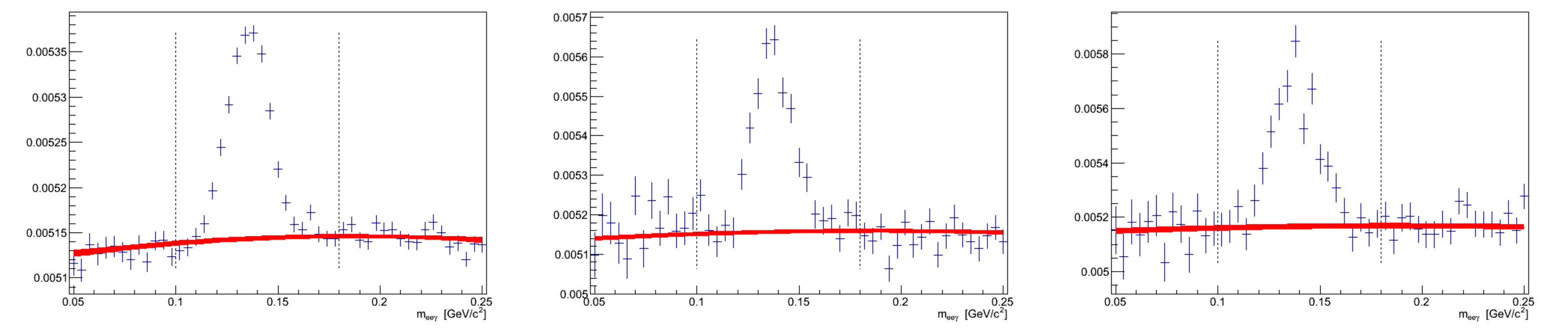
$$R_\gamma = \frac{Y_{\gamma\ \text{inclusive}}}{Y_{\gamma\ \text{from hadron decays}}} = \boxed{\frac{\varepsilon_\gamma f \frac{N_{\gamma\ \text{incl.}}}{N_{\gamma\ \text{from}\ \pi^0}}}{\frac{Y_{\gamma\ \text{hadron decays}}}{Y_{\gamma\ \text{from}\ \pi^0}}}} \qquad (1)$$

- The measured quantities are an inclusive photon yield $N_{\gamma\ \text{incl.}}$ and a photon yield from decays $\pi^0 \to \gamma\gamma$, $N_{\gamma\ \text{from}\ \pi^0}$.
- The efficiency to tag genuine converted photons from π^0 decays $\varepsilon_\gamma f$ is determined from a fast Monte Carlo.
- The p_T-dependent "cocktail" ratio $\frac{Y_{\gamma\ \text{hadron decays}}}{Y_{\gamma\ \text{from}\ \pi^0}}$ is calculated from measured hadron yields[3].

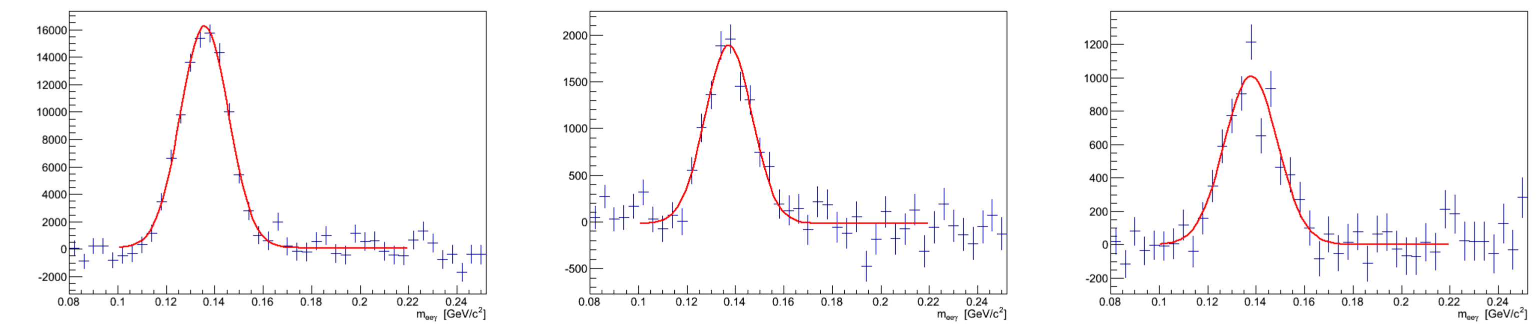
Photons from π^0 decays

To measure converted photons from π^0 decays, conversion pairs are paired with photons reconstructed directly in the PHENIX electromagnetic calorimeter.
The combinatorial background is estimated using event-mixing techniques.

Background description



π^0 yield extraction



Tagging efficiency correction $\varepsilon_\gamma f$

Not every converted photon from a decay $\pi^0 \to \gamma\gamma$ can be identified because the corresponding second photon might be emitted outside of the acceptance or not be reconstructed.

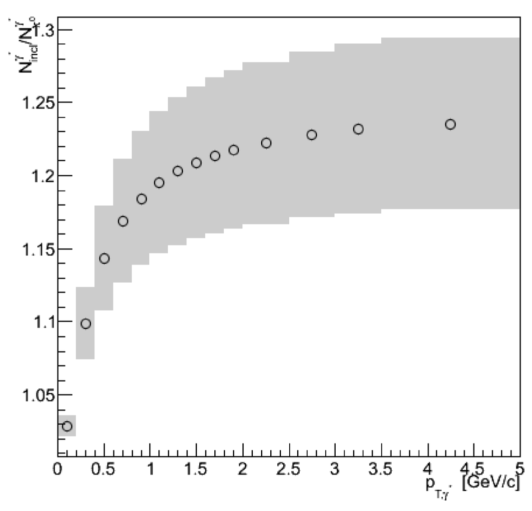
Since the converted photon is opened in the magnetic field the conversion electrons are typically well-separated from the unconverted photon in the electromagnetic calorimeter, their measurements become largely uncorrelated.
The determination of εf is split into two steps:

i. ε_γ is determined in a full single photon Monte Carlo simulation of an idealized detector.
ii. The combined $\varepsilon_\gamma f$ is then measured in a fast Monte Carlo simulation of $\pi^0 \to \gamma\gamma \to \gamma ee$.

This approach allows to e.g. change detector configurations more easily to model realistic data taking and study systematic effects. Generating a large statistics sample is always possible.

Another approach is used for the analysis of our 2007 data: There the full process $\pi^0 \to \gamma\gamma$ with subsequent conversion $\gamma \to ee$ is simulated in a full Monte Carlo. The systematic uncertainties in these two methods are largely independent.

The "cocktail" ratio



A realistic cocktail[3] of all relevant photon sources is simulated in a fast Monte Carlo.

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

Systematic uncertainties are dictated by the uncertainties in the measured meson yields.

Method performances and experimental challenges

- We have developed a method to reliably measure low-momentum photons in Au+Au collisions.
- With two independent methods to determine εf we are able to reduce the associated systematic uncertainty .
- The quality of the available data on meson yields for our system currently poses a upper limit on how well R_γ can be determined (only on the order of 5%).

Results and Outlook

- This method has been successfully applied to measure R_γ for low-momentum photons and the elliptic flow of direct photons (*see R. Petti's poster*).
- The analysis of the 2010 data set is ongoing. It should have both less statistical uncertainties and systematic uncertainties largely independent of the 2007 data set analysis.

References

- R. Petti, arXiv:1107.5379v1, 2011.
- W. Anderson *et al.*, 1103.4277v1, 2011.
- S. S. Adler *et al.*, Phys. Rev. Lett. **96**, 032301 (2006).

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