Different Methods of Photon Identification in the Electromagnetic Calorimeter of PHENIX and the Systematic Errors on Photon Spectra

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Introduction

Photon measurements are notoriously difficult.
Systematic errors quoted by WA98 (2000): 5.7-8.9% depending on energy.

There are two types of electromagnetic calorimeters in PHENIX: a lead-glass (Cherenkov) calorimeter (PbGl) and a lead-scintillator sampling calorimeter (PbSc). This presentation concentrates on Year-1 (130 GeV AuAu) photon measurements in the PbSc and gives a preview of the Year-2 (200 GeV) photon measurements.

There are usually a few dominant and several minor sources of systematic errors in an inclusive photon measurement. Typical dominant sources are the photon identification/efficiency itself, contamination from misidentified hadrons and the uncertainties of the energy scale. Typical minor sources are conversions in material in front of the detector, photons not coming from the vertex, energy deposit from other neutral particles.

In case of a direct photon search an additional source is the uncertainty on the spectrum of mesons that have photon decay channels.

Shape of Electromagnetic Showers

The basic idea:

- using electron beam of different momenta and impact angles establish a 3-dimensional parametrization of electromagnetic showers (expected energy deposit in the i-th calorimeter tower and its variance)

$$f(E_i, E_0, sin(\Theta)) \qquad \sigma_i(E_i/E_0, sin(\Theta))$$

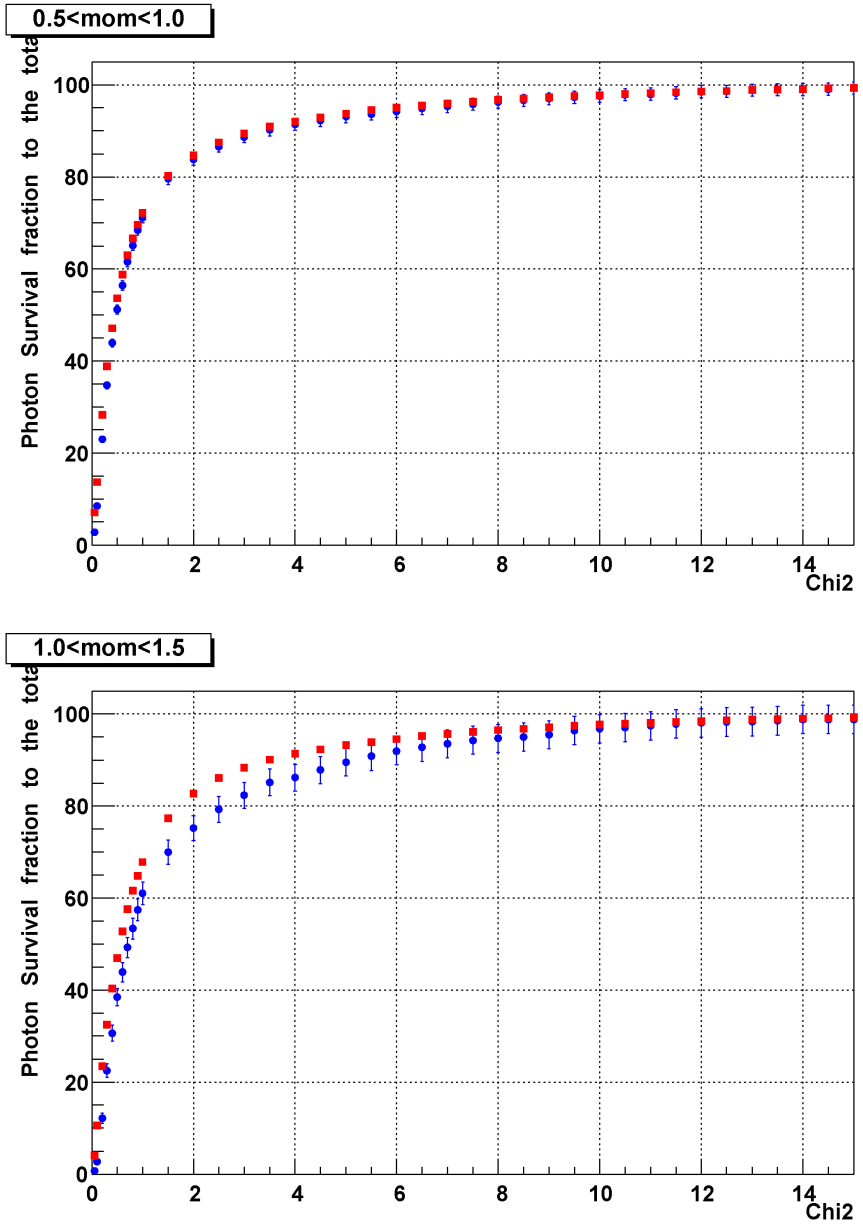
In the data analysis test each shower against the assumption that it's photon

- calculate the energy in each tower predicted by the model
- compare it to the energy measured in each tower

$$\chi^2 = \Sigma_i \frac{(E_i^{pred} - E_i^{meas})^2}{\sigma_i^2}$$

Electromagnetic showers are very compact
Hadron showers are diffuse

Photon efficiency of the shower shape cut



Efficiency of the shower shape cut for different energy photons in simulations (red points) and identified, clean electron showers in data (blue points)

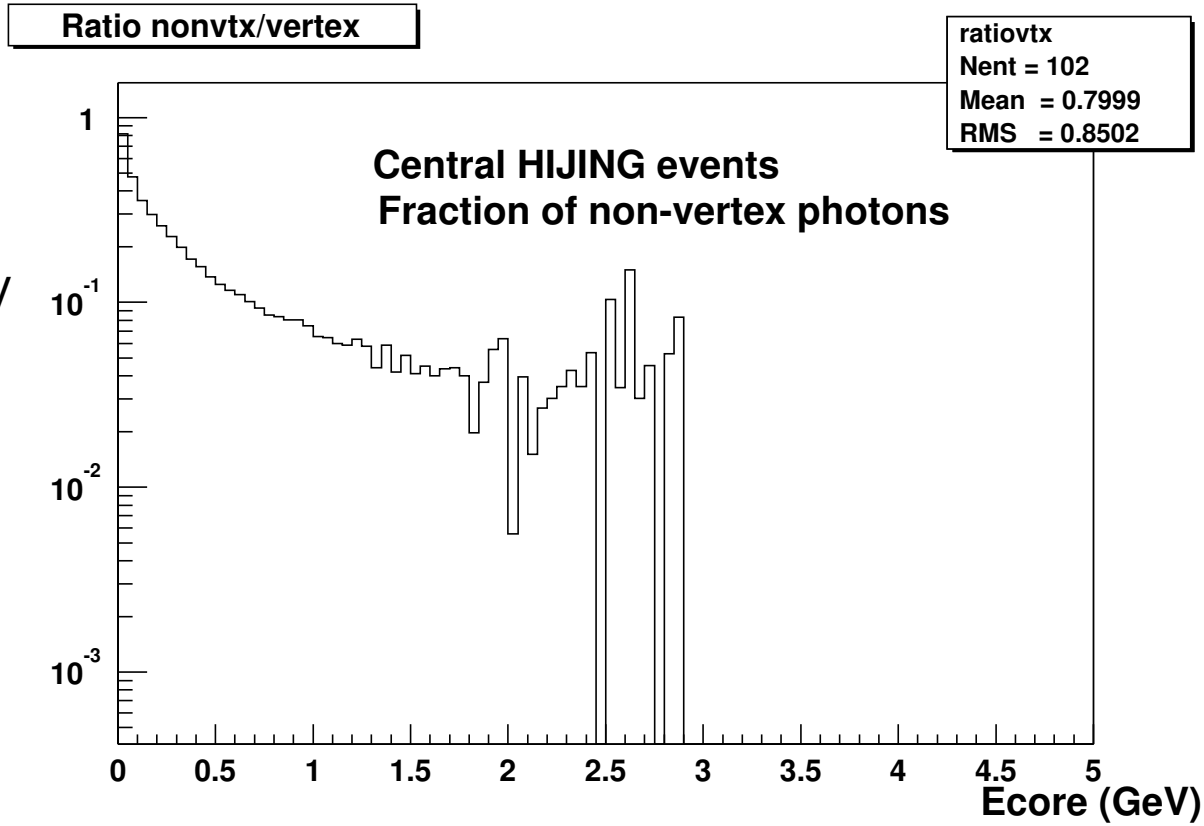
The deviation is momentum-dependent and it is part of the systematic error.

Photons not coming from the vertex

There are two sources of non-vertex photons reaching the calorimeter
- late decays of particles produced in the collision
- secondaries produced when a particle hits some piece of the experimental equipment (by far the most abundant source is the magnet yoke)

Both the spectrum and the yield of non-vertex photons is known only from simulations. Therefore, they are a significant source of systematic errors.

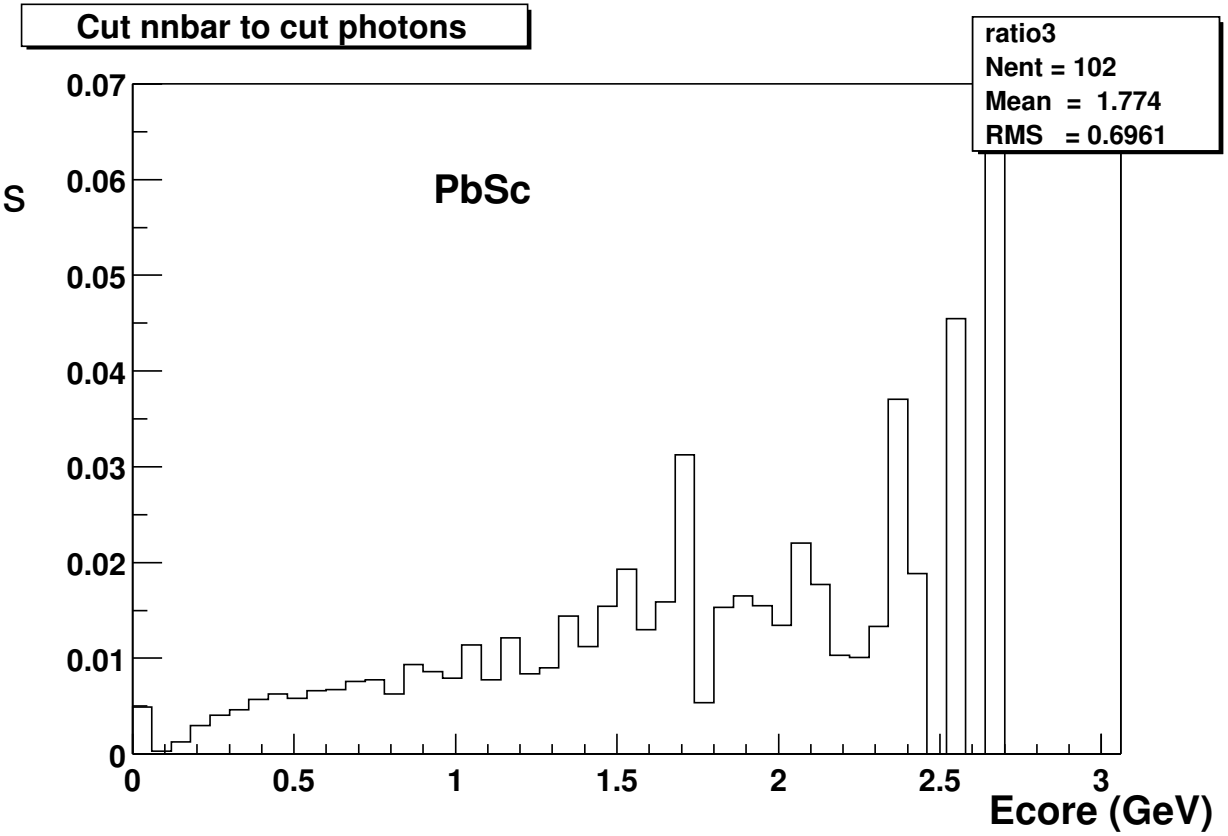
Simulations are limited in statistics. We extrapolate the yield of non-vertex photons at higher energies as a constant 6%.



Neutrons and antineutrons

The majority of neutrons and antineutrons are rejected by a timing and showershape cut. However, those that pass form an irreducible background to the photon measurement. Their contribution is known only from simulations. Stopped antineutrons – depositing twice their rest mass energy – are a very strong contributor to the neutral spectrum around 2 GeV.

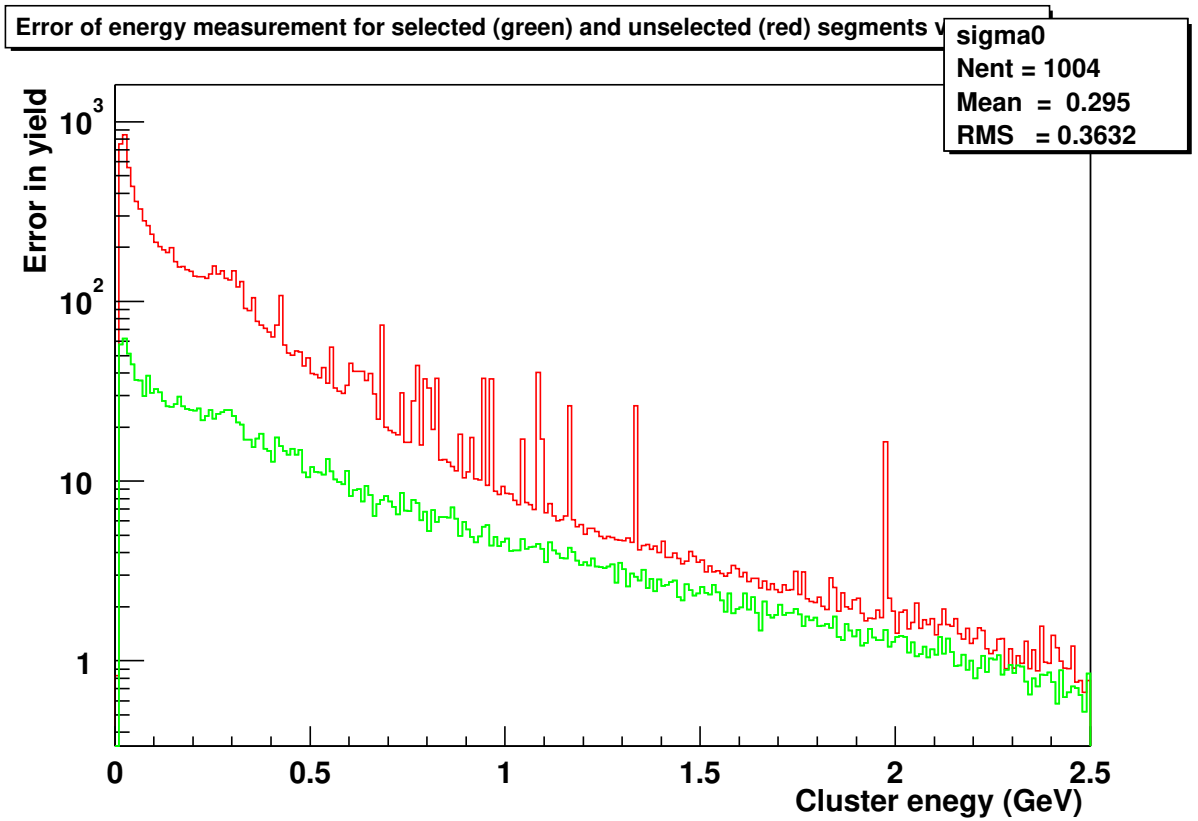
Simulated contribution of neutrons and antineutrons to the photon spectrum as a function of measured cluster energy (after photon PID cuts). The ratio stays below 2%, when using HIJING, but baryon spectra at high pt are ill-described.



Stability of the energy calibration

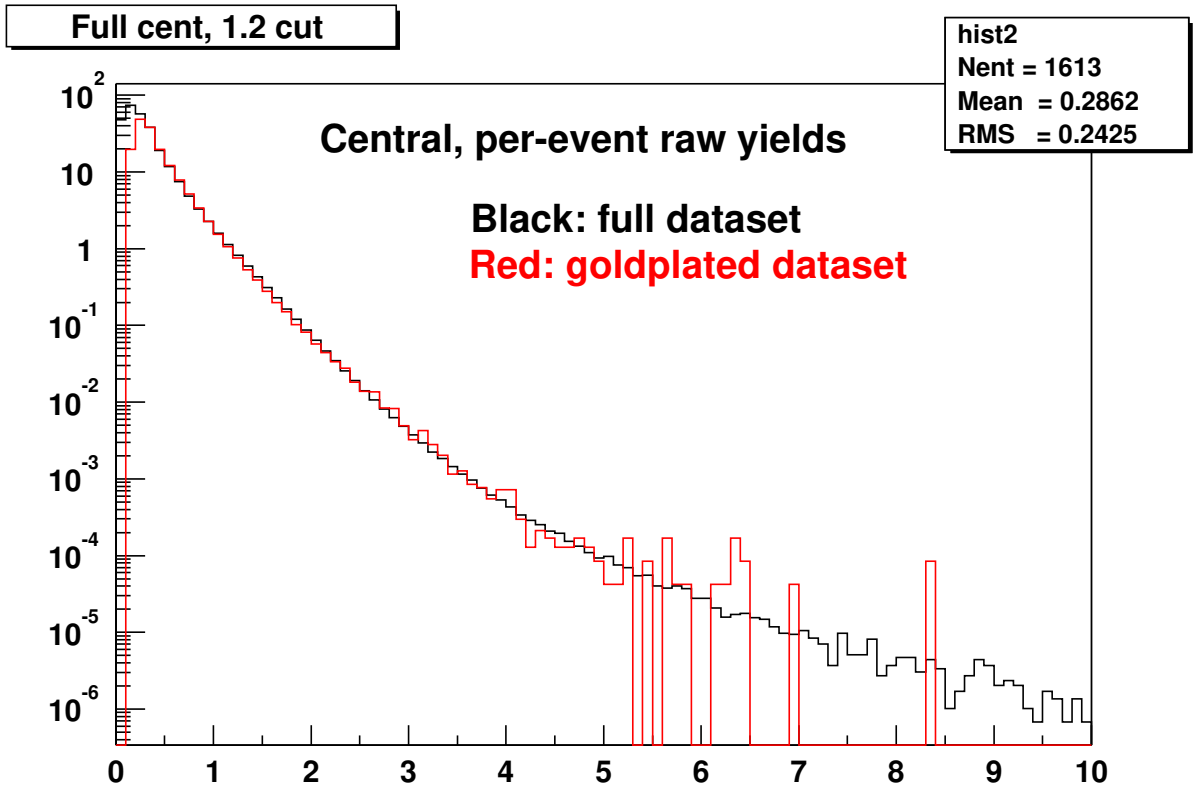
Careful calibration requires a large data sample – but this implicitely assumes that the calibration was stable while those data were collected.
However, this assumption can be tested by comparing variances of the energy distributions in run segments (typically 5-8000 events) to their avarage.
Based upon these variances very stable subsets of data can be selected.

Red histogram:
bin-by-bin variances of the energy distribution w.r.t. its average in randomly selected run segments.
Green histogram:
same quantity for runs passing selection criteria.



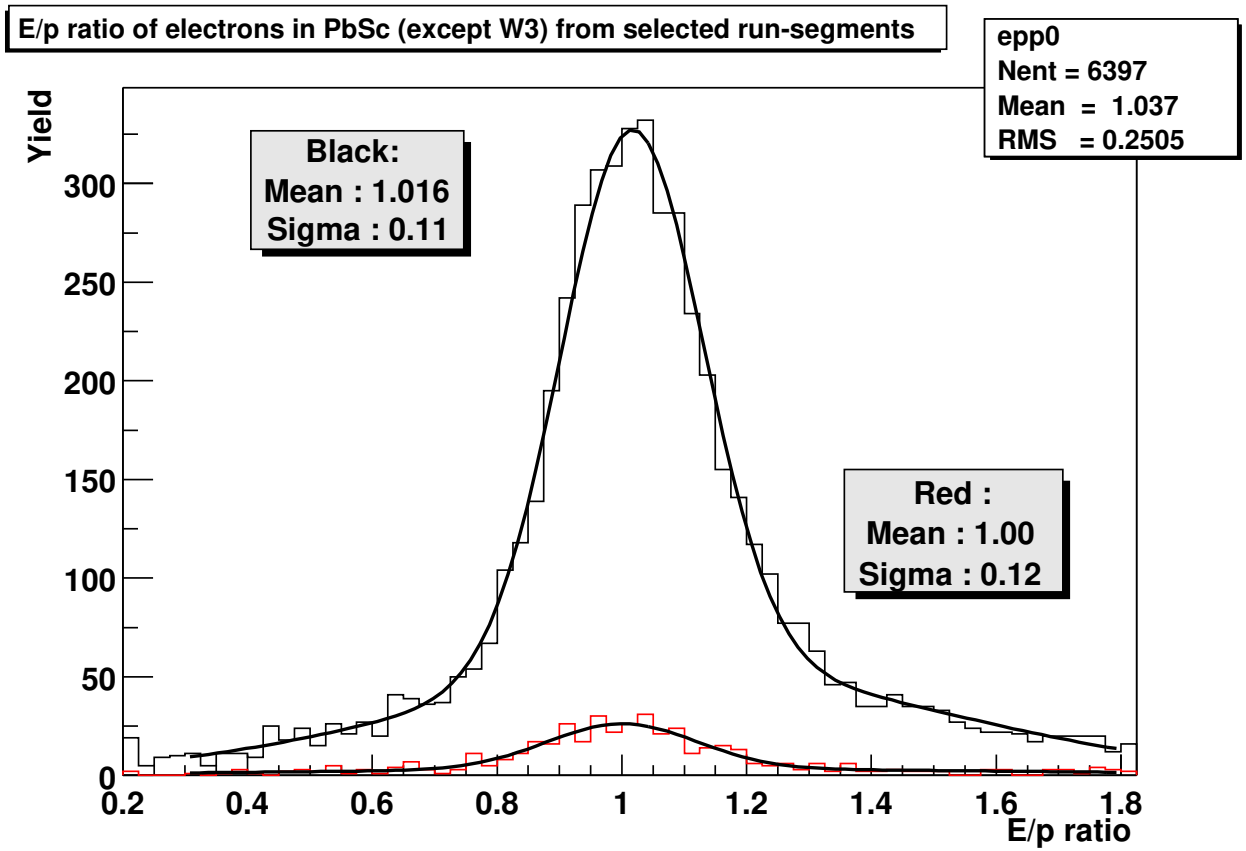
Cluster spectra from two different datasets

Per-event raw yields for an arbitrary set of runs and for a small, very stable subset. The differences at 1-2 GeV are statistically significant, but above 2 GeV the “goldplated” set runs out of statistics.



Cross-check of the energy scale

One way to check the energy scale in PHENIX is to compare the measured energy and reconstructed momentum of identified electrons (E/p ratio). Results are shown for two different set of runs. The momentum range is 08-1.2 GeV/c in both cases. The observed widths are in good agreement with the energy resolution assumed in the neutral pion and photon analyses.

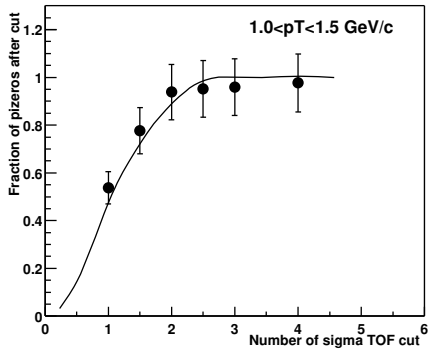


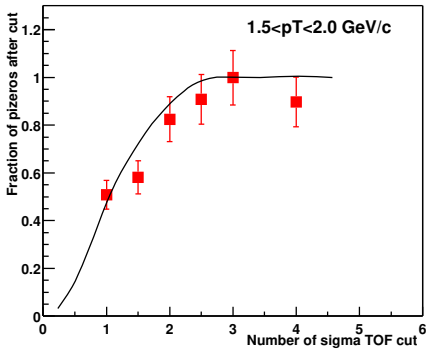
Timing cuts

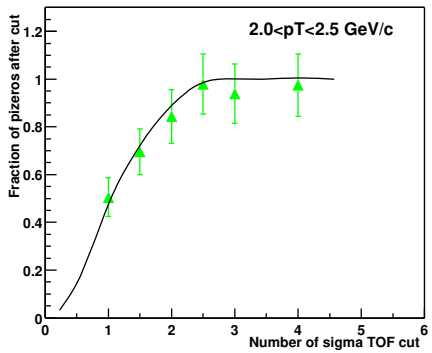
Time-of-flight resolution of the PbSc calorimeter for photons was between 420-530 ps, although it exhibited a significant shift at very high energies (>3 GeV) beyond ordinary slewing effects.

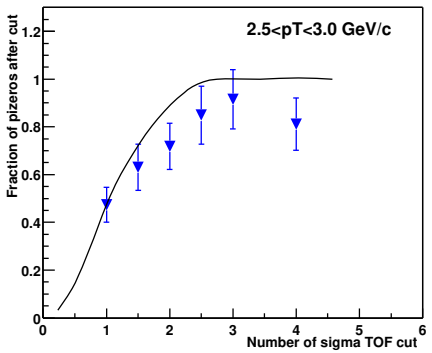
This series of plots shows how good is the assumption that the timing is truly Gaussian. The horizontal scale is in units of TOF s. The points are neutral pion yields extracted with the corresponding TOF window. The curves indicate what one would expect if the timing distribution is a perfect Gaussian.

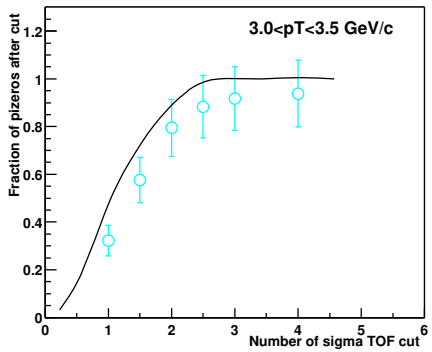
However, there is a hint of shitfts at high pt. Further studies confirmed that and it became a major source of photon PID error.

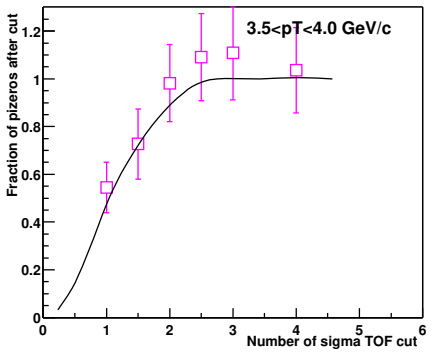












Prerequisite to direct photon search: neutral meson spectra

Basic idea:

- measure the spectrum of mesons that have photon decay channels
- set an upper limit of the photon contribution of those you can not measure
- calculate the photon distribution you expect from meson decays only
- compare that distribution to the observed distribution of photons

Very often only neutral pions are measured, the rest is implied by mt scaling

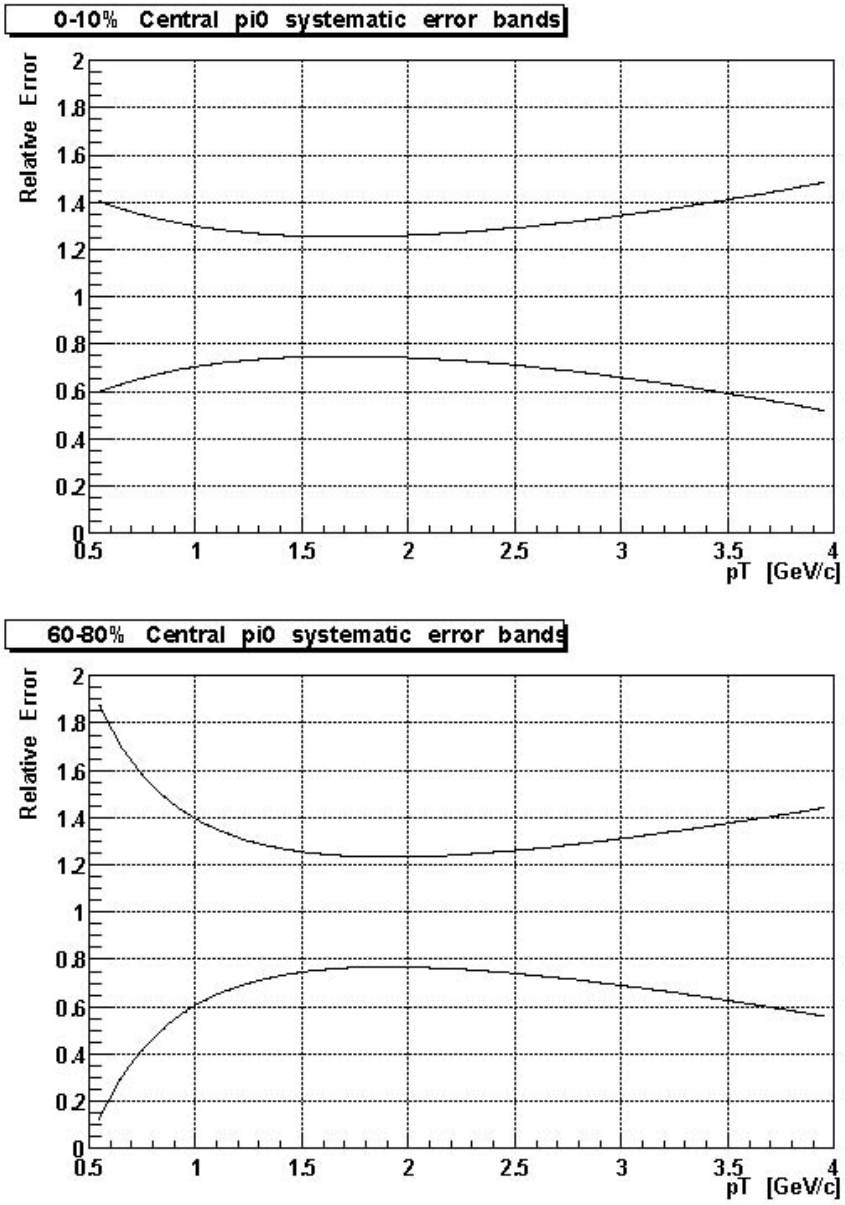
State	Mass (MeV/c^2)	$R_{X/\pi^0}(p_T \to \infty)$	Decay Branch	Branching Ratio
π^0	134.98		$\gamma\gamma$	98.798 %
			$e^+e^-\gamma$	1.198 %
η	547.3	0.55	$\gamma\gamma$	39.21 %
			$\pi^+\pi^-\gamma$	4.77 %
			$e^+e^-\gamma$	4.9×10^{-3}
			$\pi^0\gamma\gamma$	7.1×10^{-4}
			$\mu^+\mu^-\gamma$	3.1×10^{-4}
ρ^0	770.0	1.0	$\pi^+\pi^-\gamma$	9.9×10^{-3}
			$\pi^0\gamma$	7.9×10^{-4}
ω	781.9	1.0	$\pi^0\gamma$	8.5 %
			$\eta\gamma$	6.5×10^{-4}
η'	957.8	0.25	$\rho\gamma$	30.2 %
			$\omega\gamma$	3.01 %
			$\gamma\gamma$	2.11 %
K^0_s	497.7	0.4	$(\pi^0\pi^0)$	(31.39 %)
Σ^0	1192.6	1.0	$\Lambda\gamma$	100.0 %

PHENIX, Year-1 neutral pions

In Year-1 (130 GeV data) the PHENIX measurement of neutral pions consisted only of 6 points for central, 5 points for peripheral events, all with significant errors. This allows for a wide range of fits to the spectra, which in turn allows large variations in the number of photons attributed to meson decays.

The figure shows the error band on the measurable photon excess – due to the insufficient knowledge of the pion spectra.

This is the dominant source of error in Year-1 (130 GeV AuAu data)



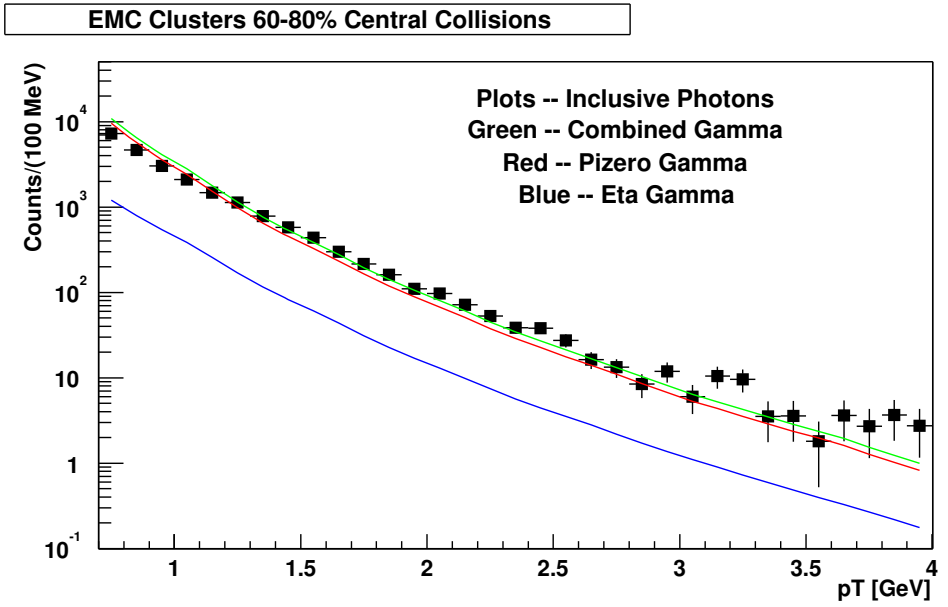
Year-1 (130 GeV AuAu) photons – peripheral data

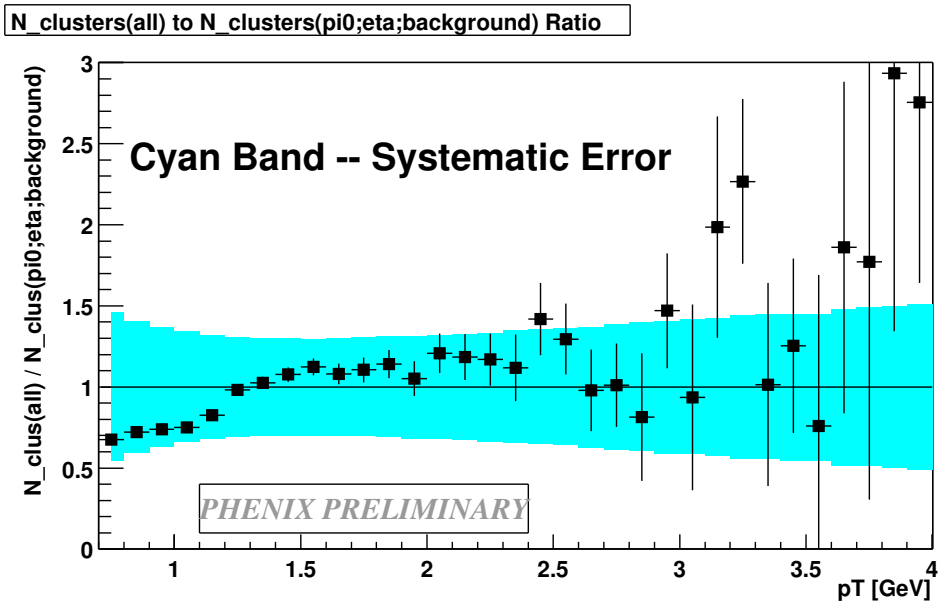
60-80% most peripheral collisions

Ratio of observed photons to photons attributable to meson decays as a function of photon transverse momentum in 130 GeV AuAu peripheral collisions.

The points fluctuate within the systematic error band: no excess is observed within syst. errors.

Also, the non-statistical fluctuations of the points at lower pt indicate that the errors are truly 1σ errors.





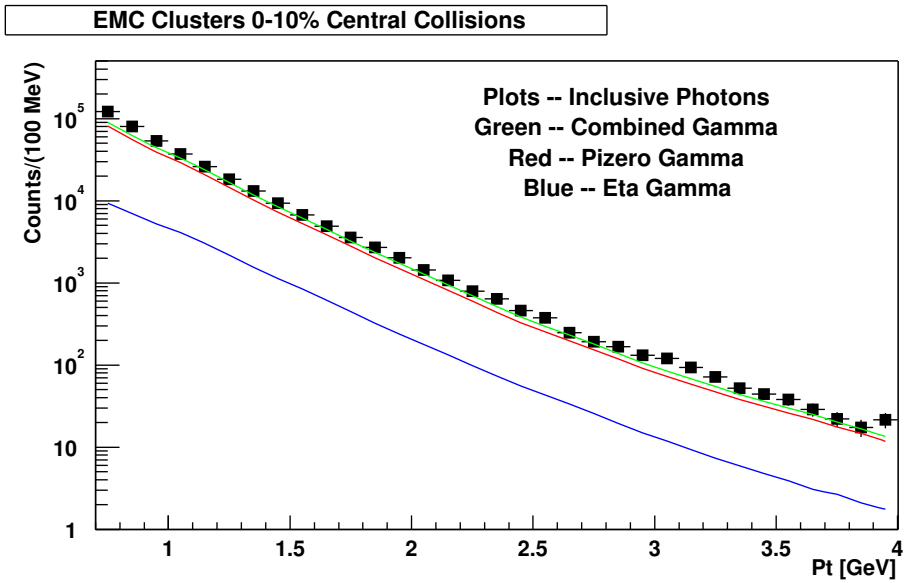
Year-1 (130 GeV AuAu) photons – central data

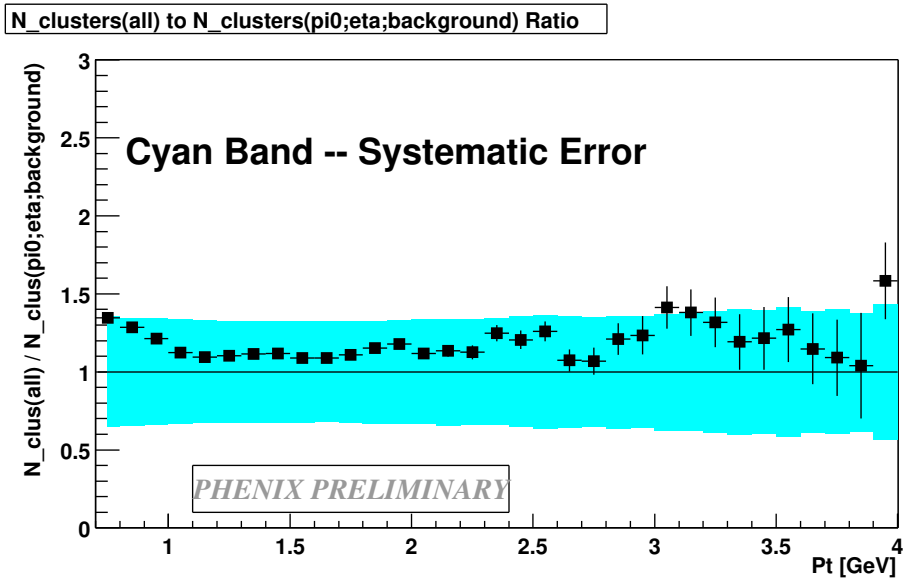
0-10% most central collisions

Ratio of observed photons to photons attributable to meson decays as a function of photon transverse momentum in 130 GeV AuAu peripheral collisions.

The points fluctuate within the systematic error band: no excess is observed within syst. errors.

Also, the non-statistical fluctuations of the points at lower pt indicate that the errors are truly 1σ errors.





Summary of errors on PbSc inclusive photons in Year-2

Source	pt dep?	Correction (1 – 6+ GeV)	Error (% of γ yield)	Remark
n, nbar	yes	0.5-2%	+4%	HIJING lower than data
timing shift	yes	0.5-15%	0.5-10%	sim <-> data (instr. eff)
$\varepsilon(\gamma)$ of χ cut	yes	90-73%	4-6%	diff. of sim. and identified
misid. hadrons	yes	46-20%	2-10%	HIJING<-> data at high pt
conversion	no	4%	2%	no loss if past magn. Field
offvtx photons	yes	12-6%	10-3%	only from simulations
mesons $\|\eta\|>0.5$	yes	4-2%	4-2%	unidirectional, upper lim
calib. Variations	yes	1-10%	1-10%	subset vs full sample
energy scale	yes	2%	8%	not well known at high pt

Sum: 14.8% at 1 GeV, 20.8% at and above 5 GeV

This is from the first, quick analysis. Expect significant improvement soon!