Physics Analysis with the PHENIX Electromagnetic Calorimeter

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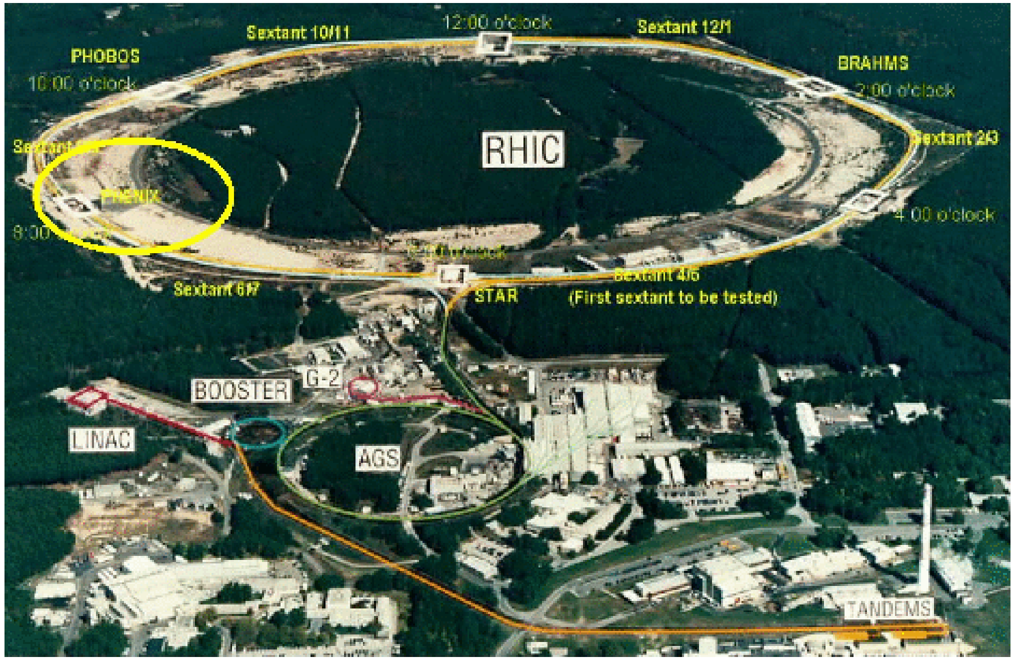
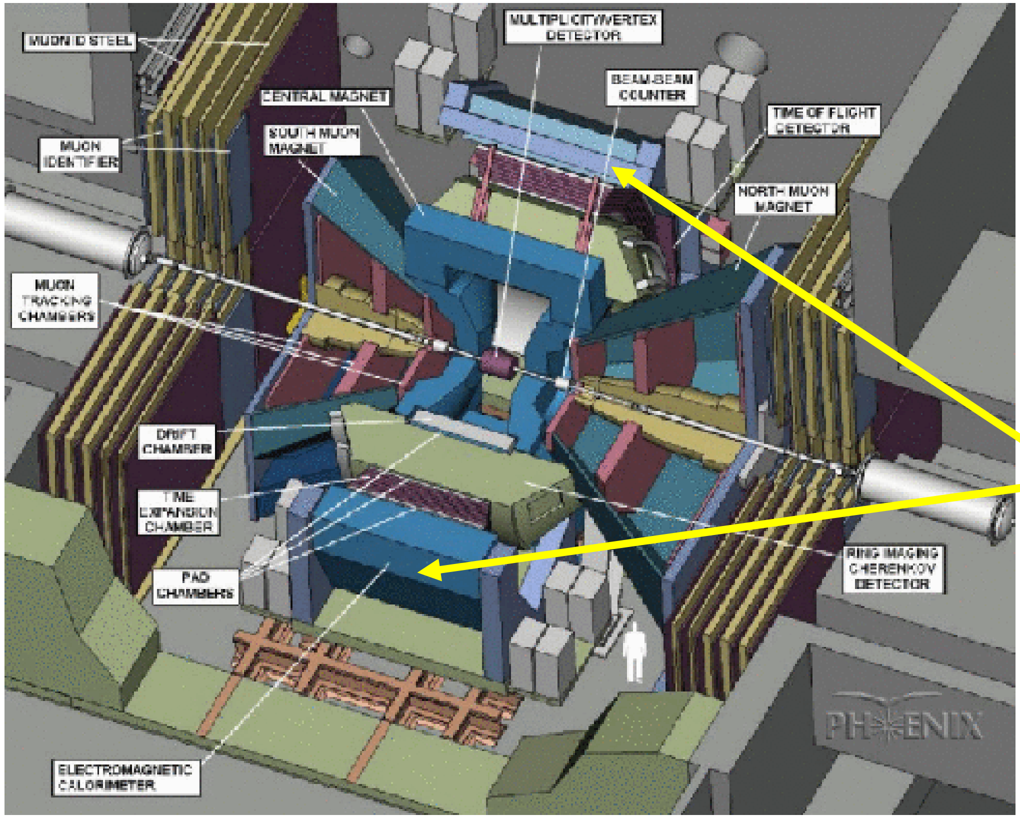
PHENIX: Pioneering High Energy Nuclear Interactions eXperiment

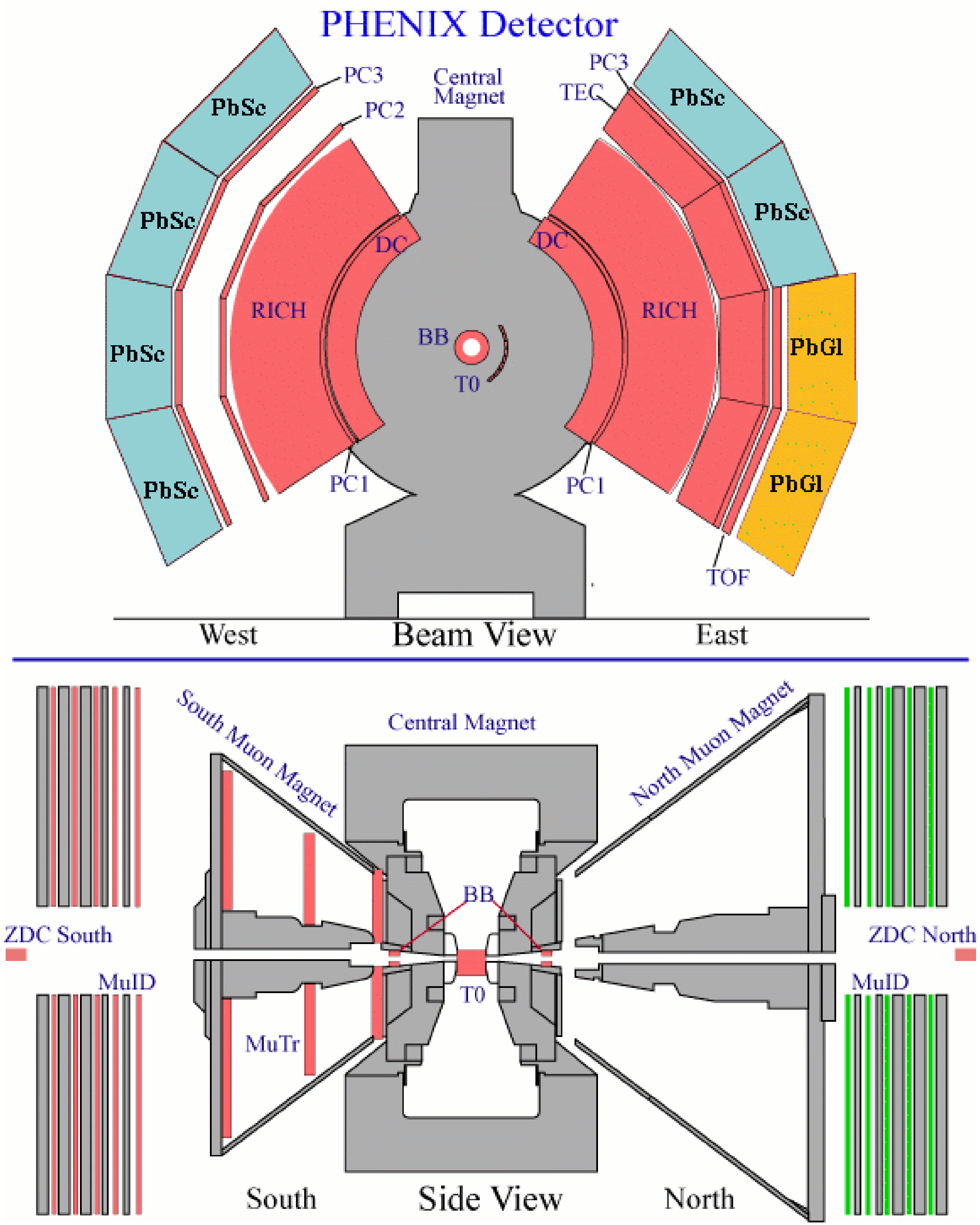
RHIC: Relativistic Heavy Ion Collider
(Brookhaven National Lab):
collides nuclei or (polarized!) protons

4 experiments: STAR, PHENIX, BRAHMS, PHOBOS





- PHENIX looks for rare processes in heavy ion collisions at high data rates; heavy **emphasis** on **photons** and **leptons**.
- PHENIX consists of a large number of subsystems of different operating principles in two central spectrometer arms and two muon spectrometer arms.
- The Electromagnetic Calorimeter (EMCal) is the final stage of the central arm spectrometers.

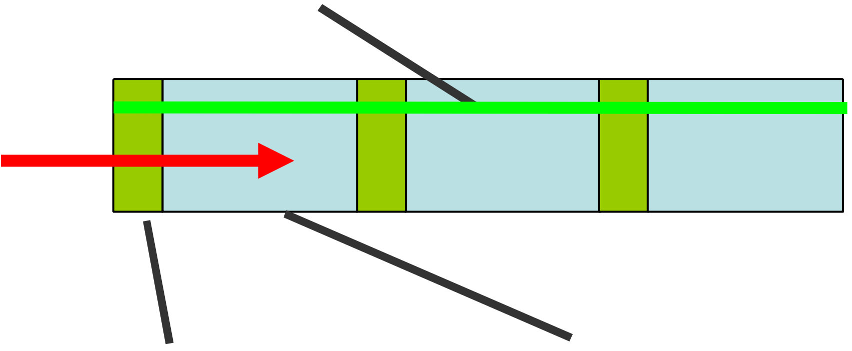


The PHENIX EMCal...

...measures position, energy and time of flight (however, the energy information is inaccurate for hadrons);
...is at a radial distance of 5m from the beam axis to provide low occupancy;
...covers 0.7 units of pseudo-rapidity and 2·90º in azimuth;
...consists of two different detector subsystems, with different detection principles:

- 6 sectors use the sampling principle, with alternating layers of lead and scintillating material (PbSc);
- 2 sectors consist of lead-glass (PbGl) Cherenkov modules.

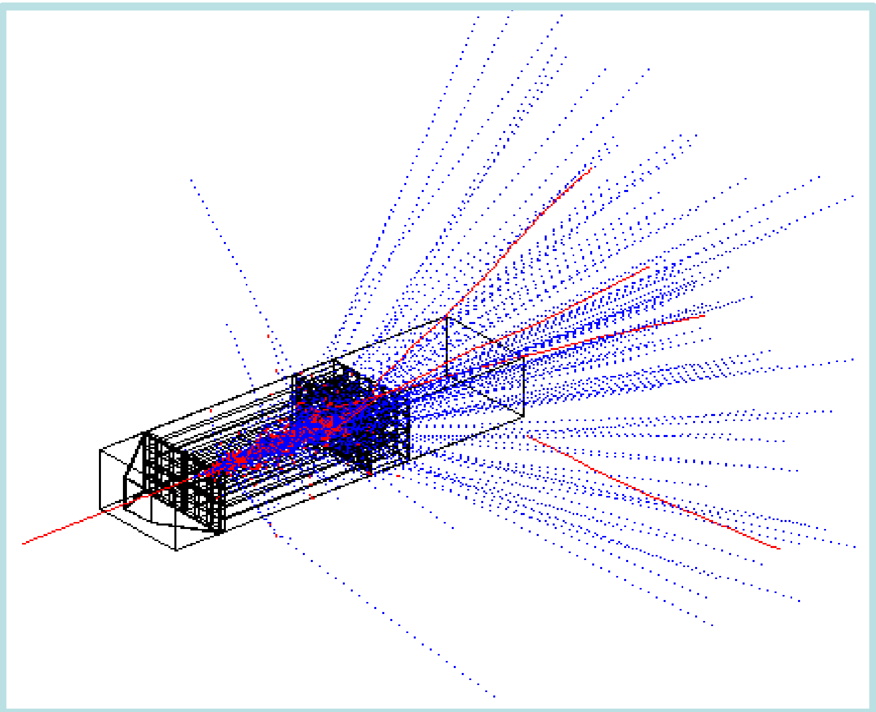
PbSc and PbGl



PbSc

66 layers, each layer consists of

- 1.5 mm of Pb
- 4 mm of scintillator (1.5% PTP/0.01% POPOP)
- 18 wavelength-shifting fibers woven through 36 holes
- PMTs at the back end of the calorimeter

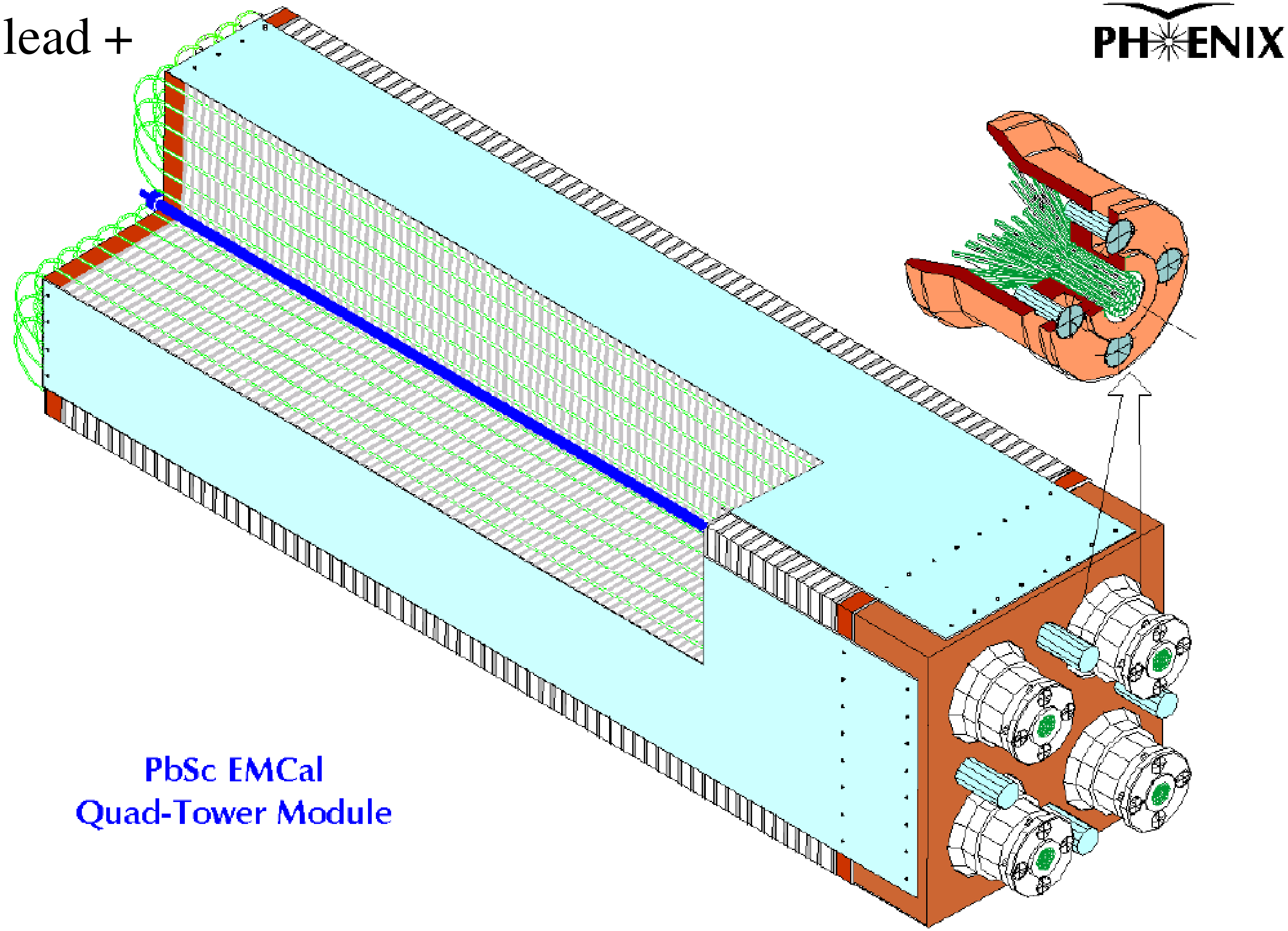


PbGl

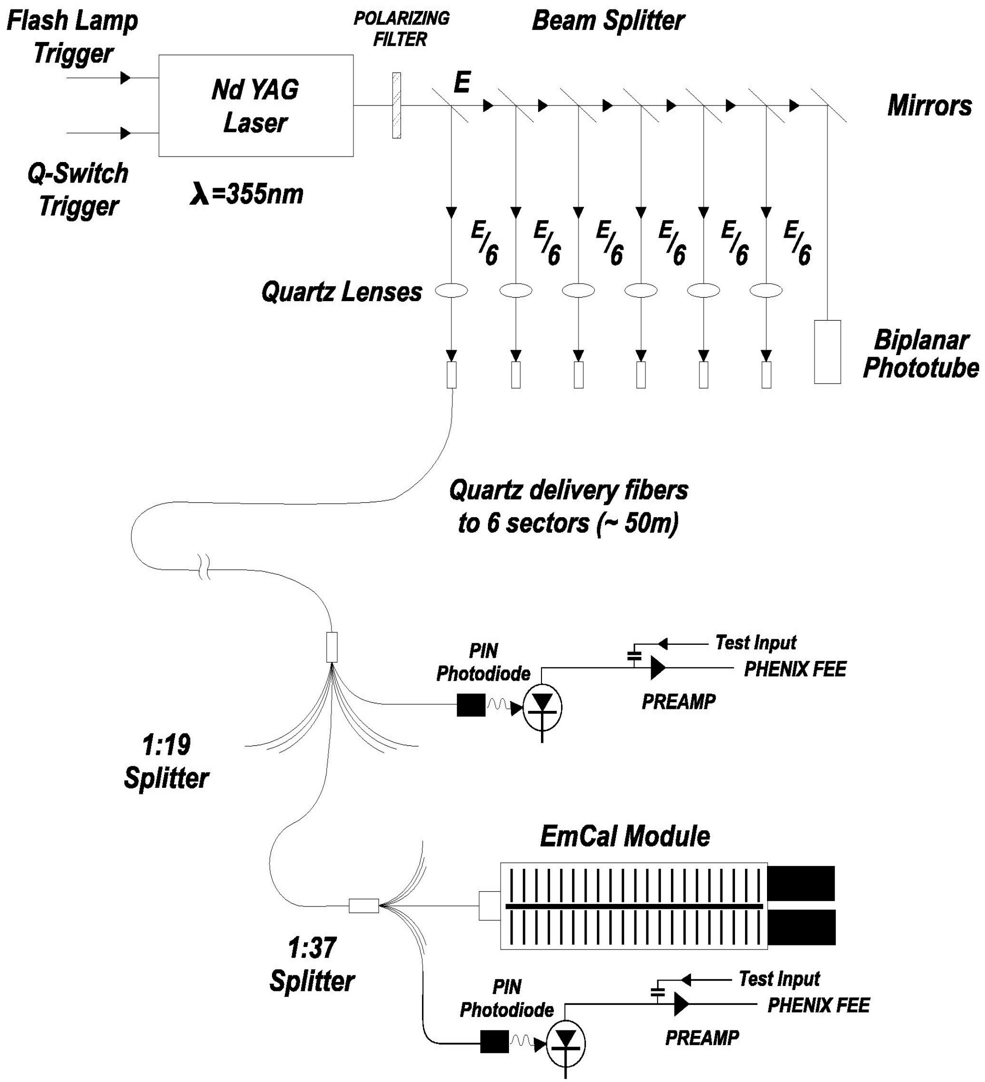
- Homogeneous Cherenkov calorimeter (n = 1.647)
- # of photons proportional to particle energy
- PMTs at the back end

PbSc Structure

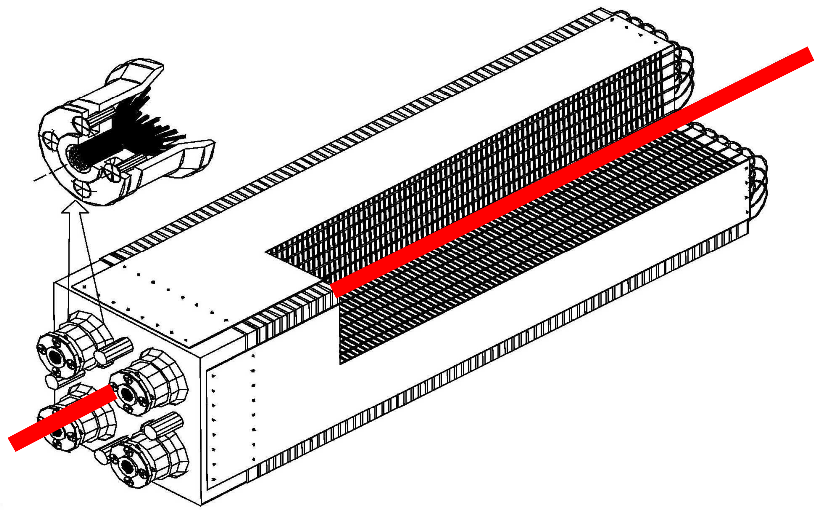
- PbSc tower: $5.52x5.52x33cm^3$ ($18X_0$)
- 15552 towers total (6 sectors x2592 towers/sector)
- 66 layers of 1.5mm lead + 4mm scintillator.



Reference System

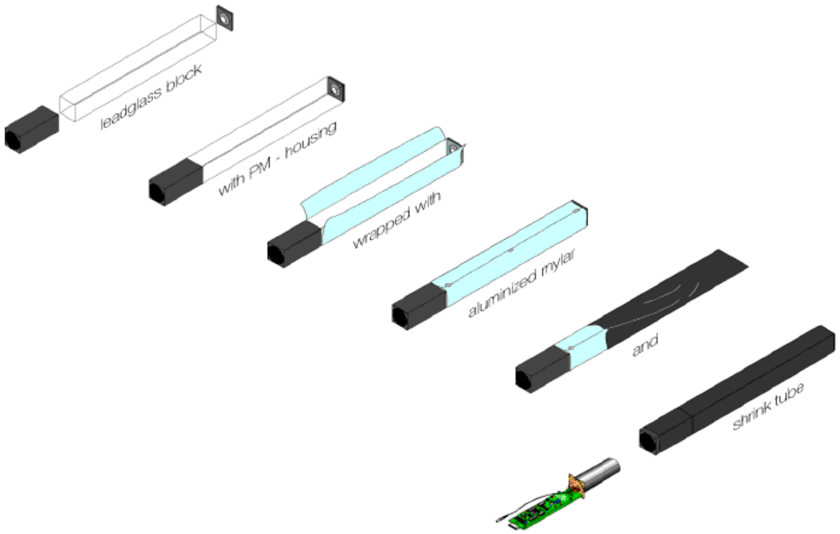


A Nd:YAG laser fires between physics events. Its light is split multiple times and carried to the calorimeter by fibers. Leaking fibers go through quad-tower modules, the leaked light imitates the shower depth profile of a 1 GeV EM shower.

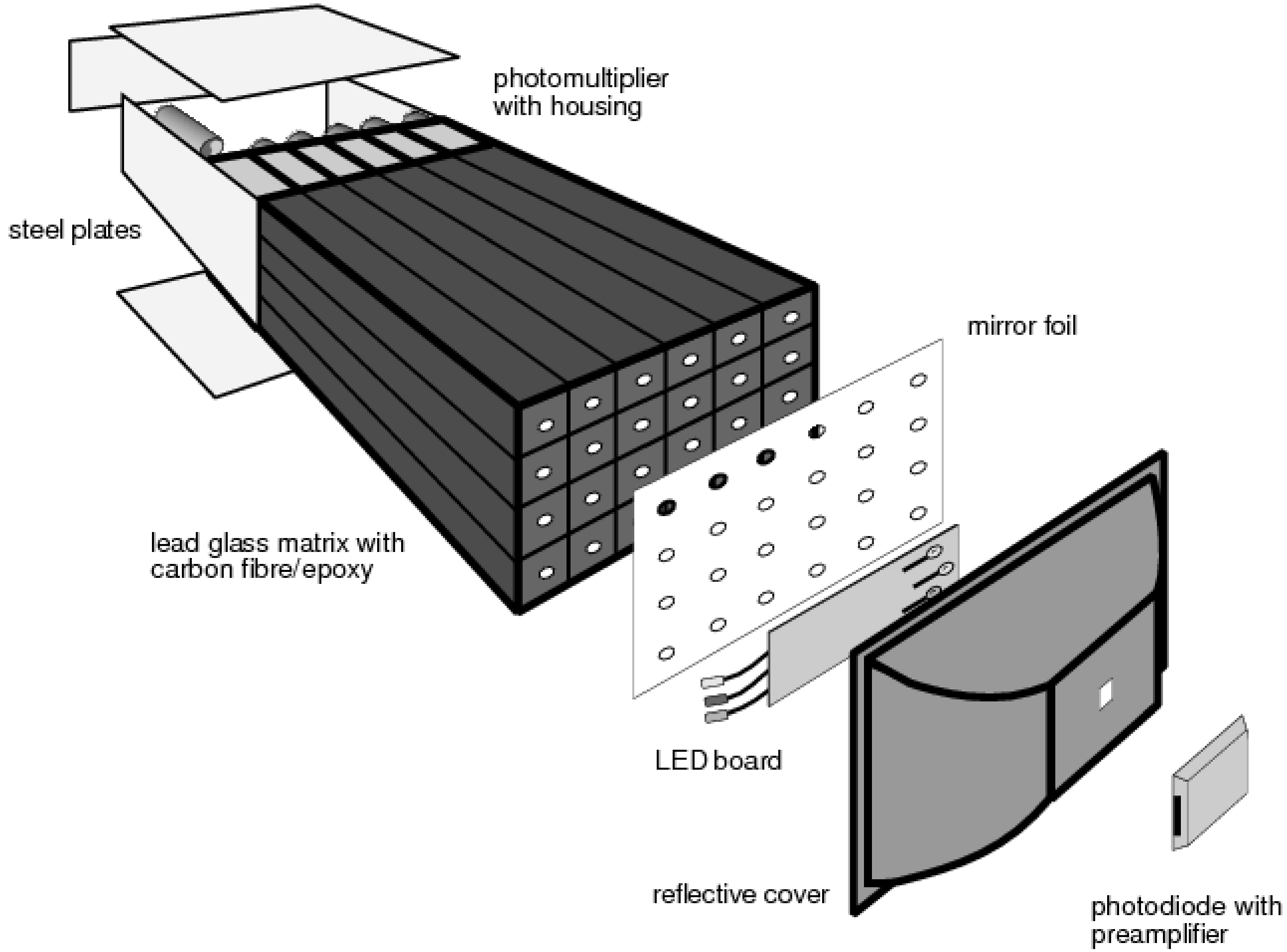


WA98 LEDA

PbGl structure

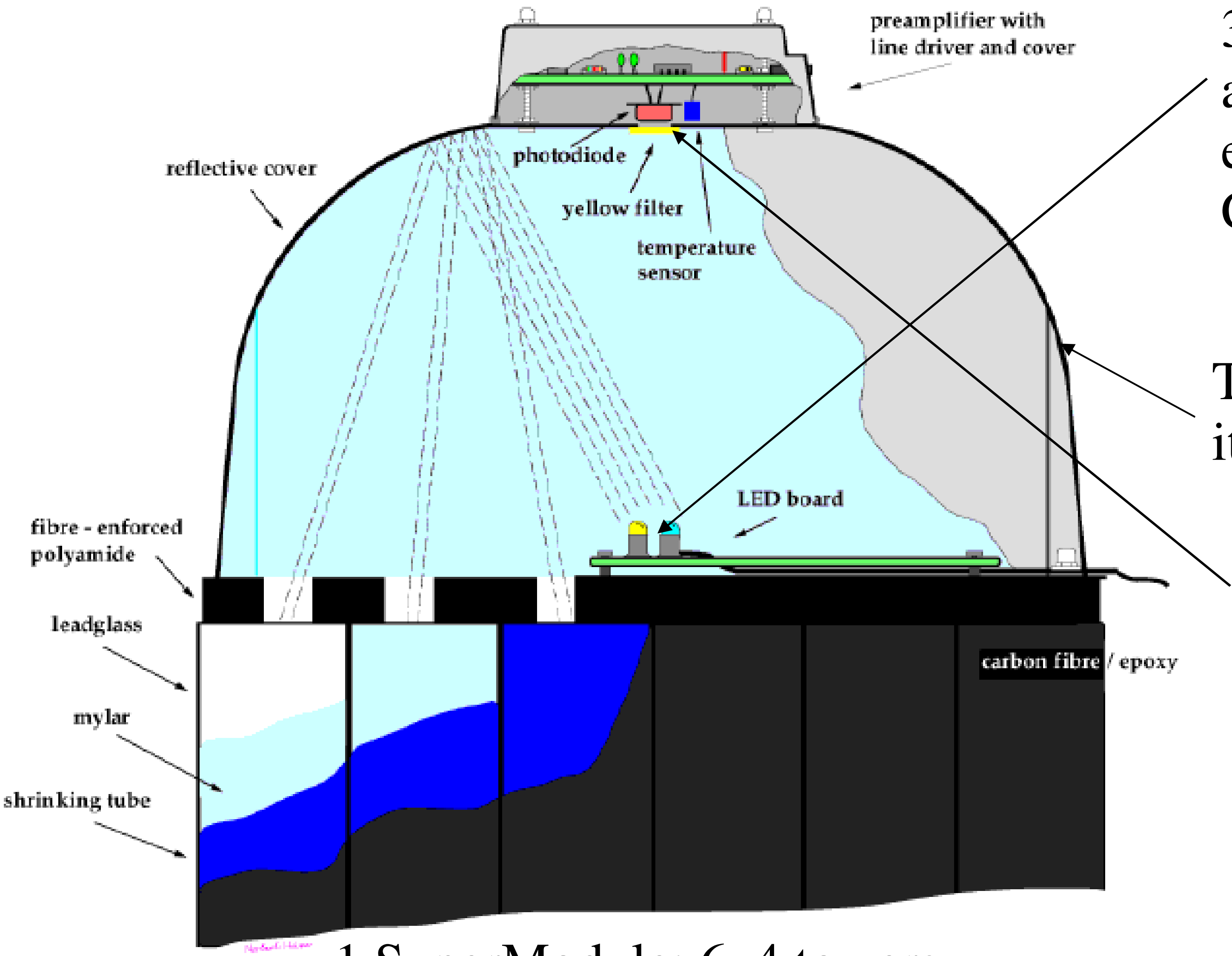


9216 tower total (2 sectors x 4608 towers/sector)



Towers are grouped into supermodules (SMs): each SM is a 6x4 array of towers and has a separate reference system

Reference System



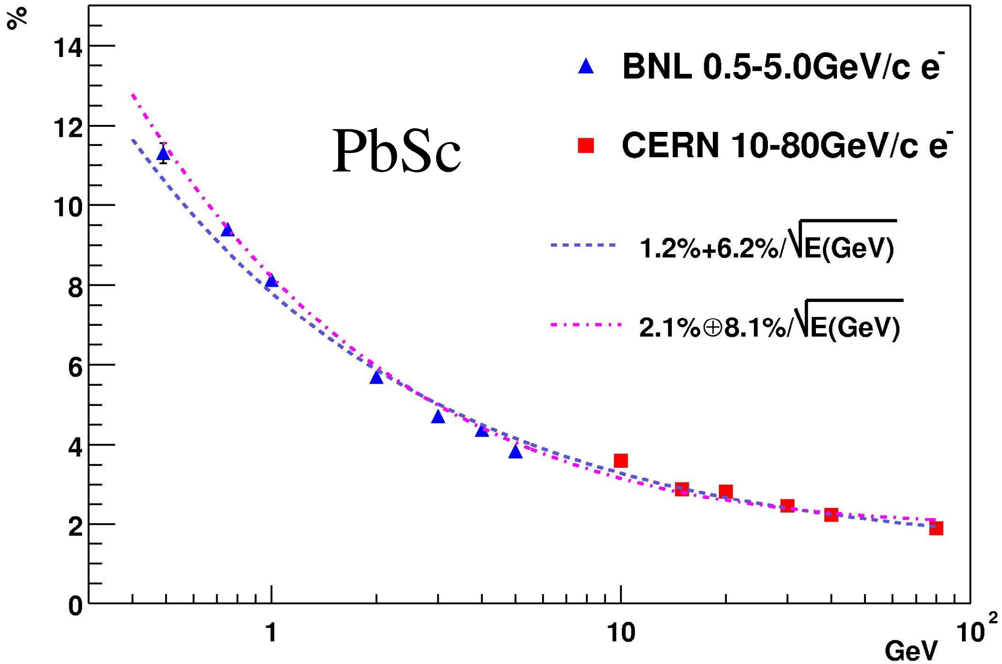
3 LEDs (blue, yellow, avalanche yellow) emit light (imitate Cherenkov photons)

The "dome" reflects it back to the towers

PIN diode used for normalization

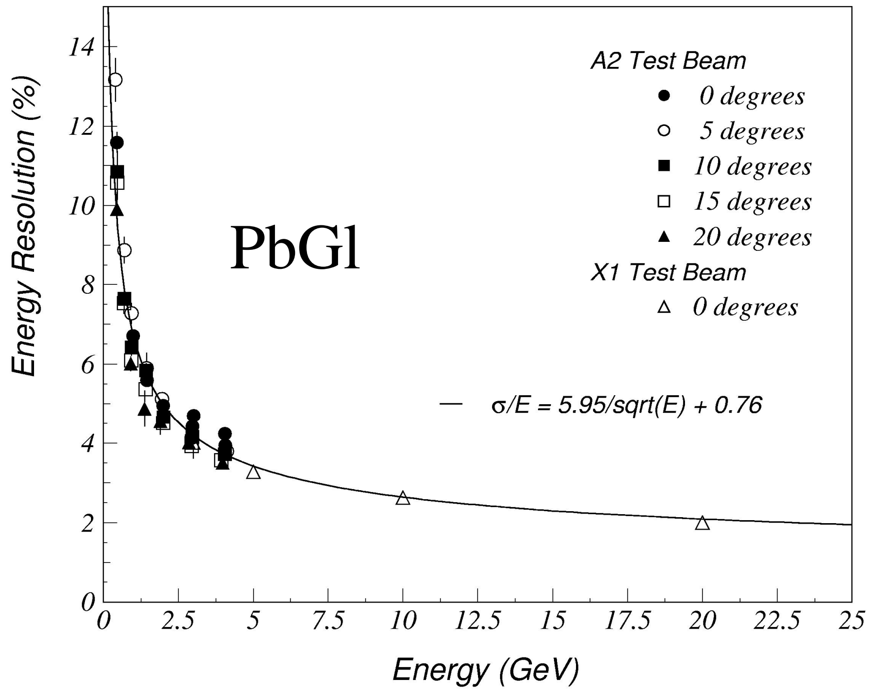
1 SuperModule: 6x4 towers

Energy resolution



$$\frac{\sigma_E}{E} = \frac{8.1\,\%}{\sqrt{E}} \oplus 2.1\,\%$$

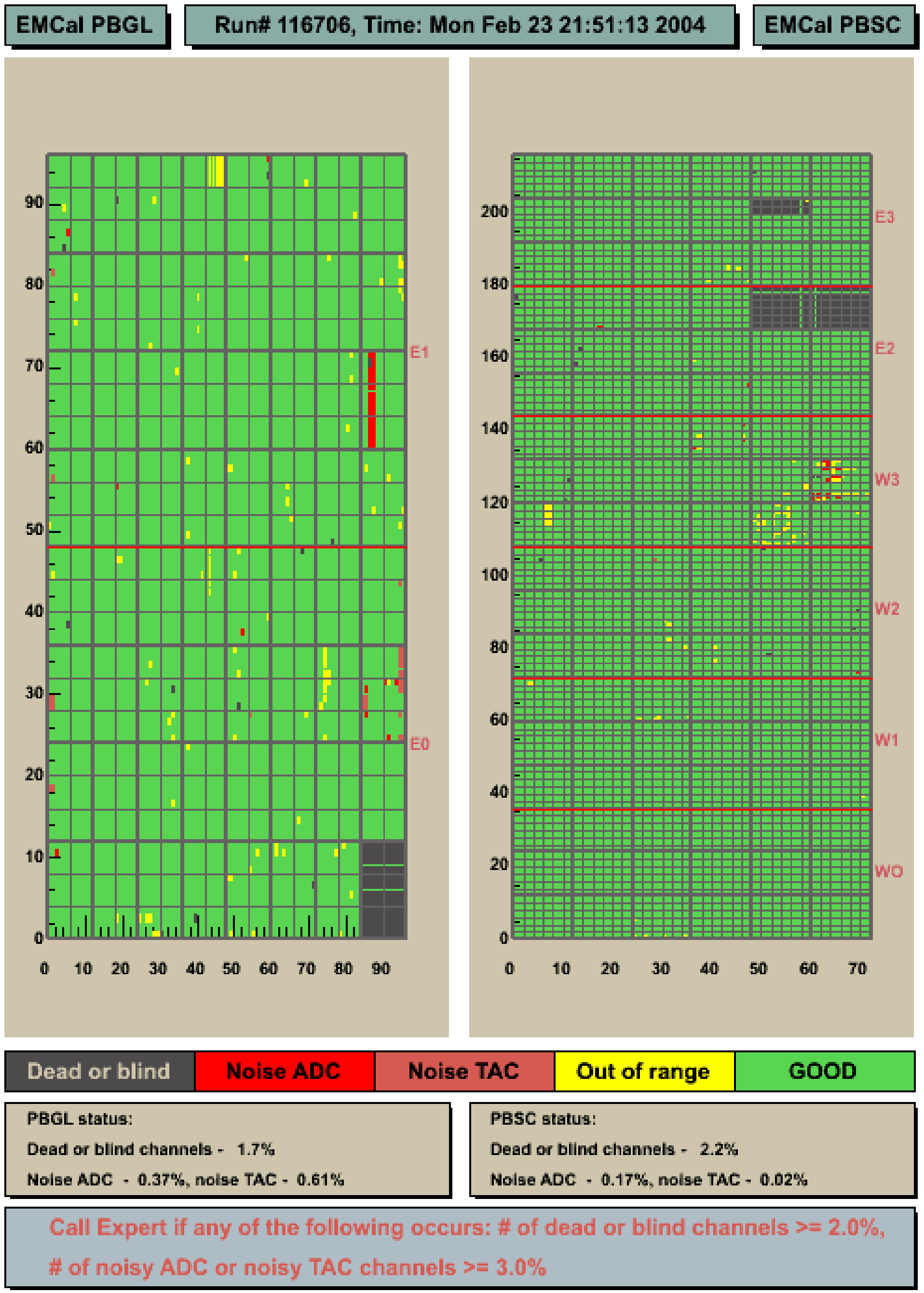
$$\frac{\sigma_E}{E} = \frac{5.95\,\%}{\sqrt{E}} \oplus 0.76\,\%$$



Monitoring

Optical monitoring system

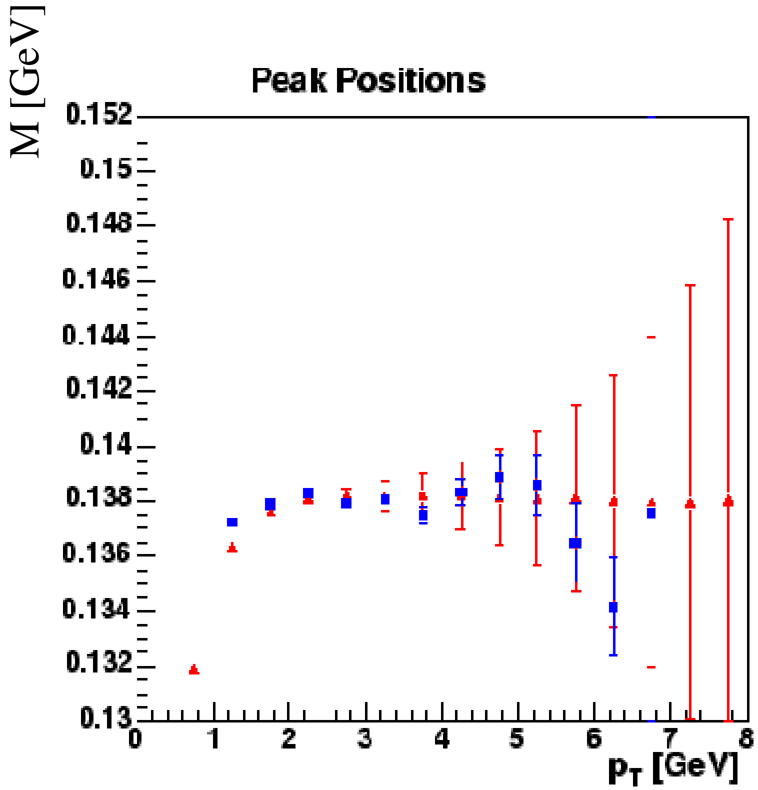
- ❑ continuously tracks gains of towers
- ❑ laser/LEDs fire between physics events
- ❑ monitoring events are saved in the data stream
- ❑ this info can be used for online monitoring or calibration
- ❑ can insure long-term stability, crucial when analyzing rare processes



Calibration

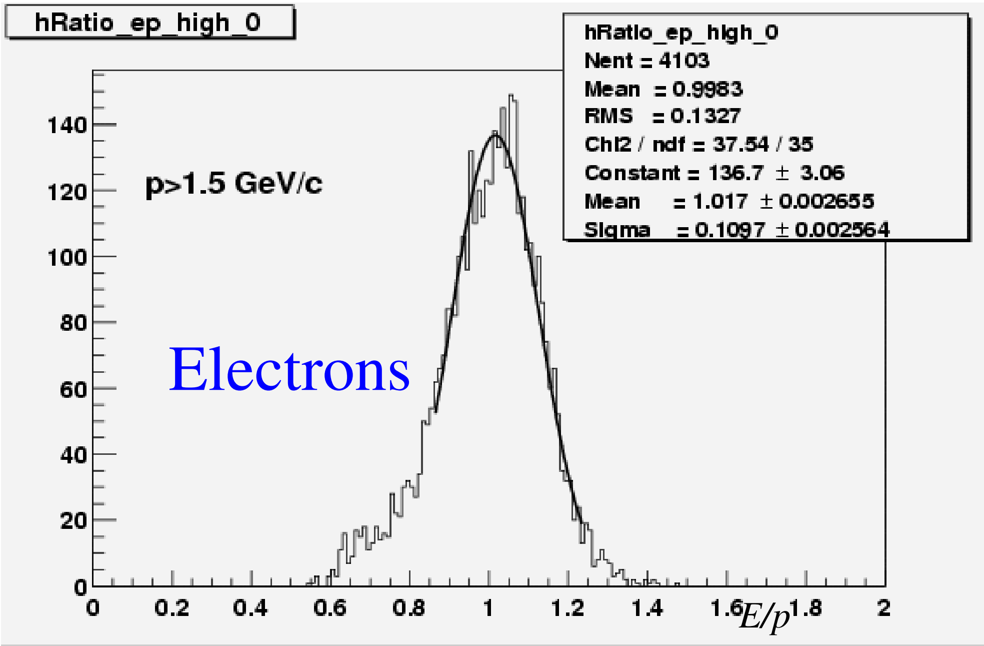
We have to calibrate energy and time and find dead and hot towers - a plethora of methods:

- test beam (CERN, BNL)
- calibration inherited from WA98 (PbGl)
- reference system:
  - laser/LEDs track gain changes of PMTs, PIN diodes track laser/LEDs, test pulse tracks amplifier, etc...
  - track timing shifts (problem: cross-talk in electronics)
- physics data:
  - MIP, π^0, electron...
  - photons, charged pions, kaons, protons...

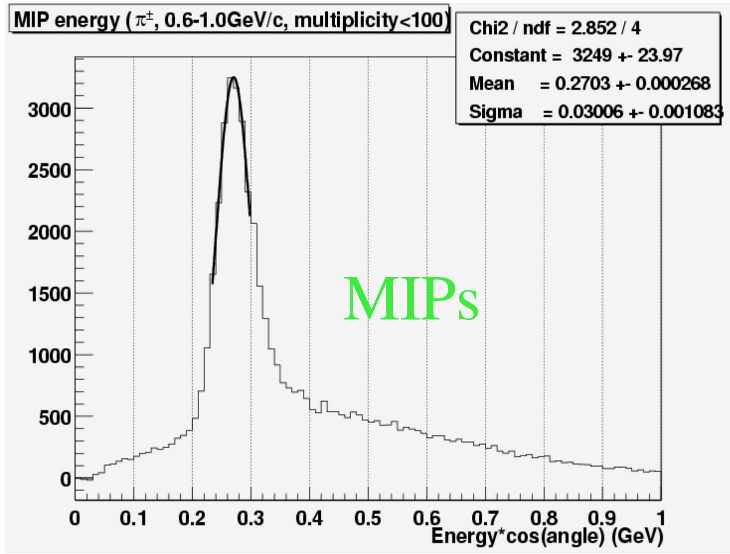


A check of the absolute energy scale:
neutral pion mass vs transverse momentum.
red: MC
blue: real data
taken at 62.4 GeV

Some physics-based energy calibration methods



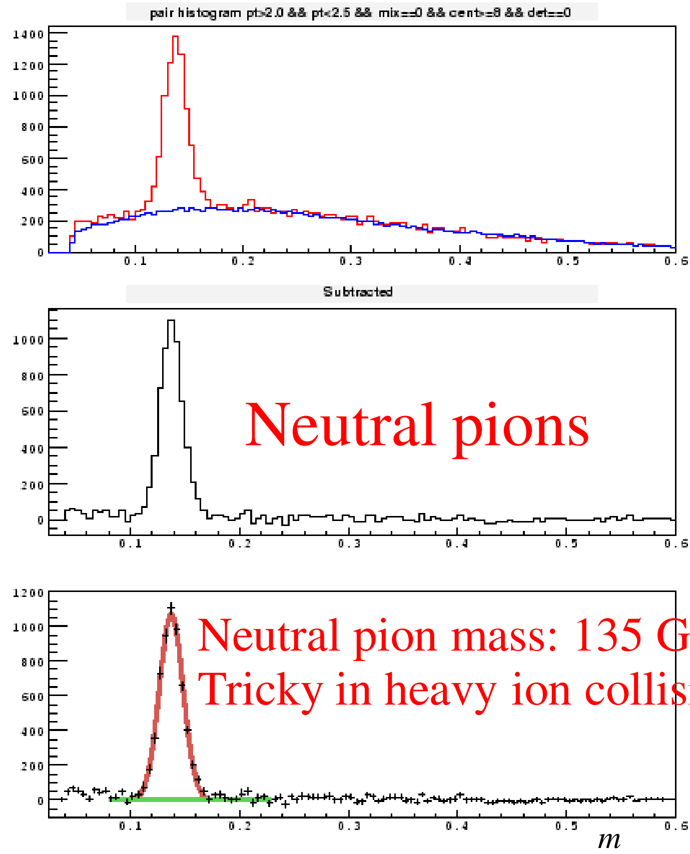
Minimum Ionizing Particles deposit about 270 MeV in PbSc



Electrons are relativistic!

- Identify electrons in Ring Imaging Cherenkov counter
- Measure their momenta in tracking detectors
- Measure their energies in the calorimeter

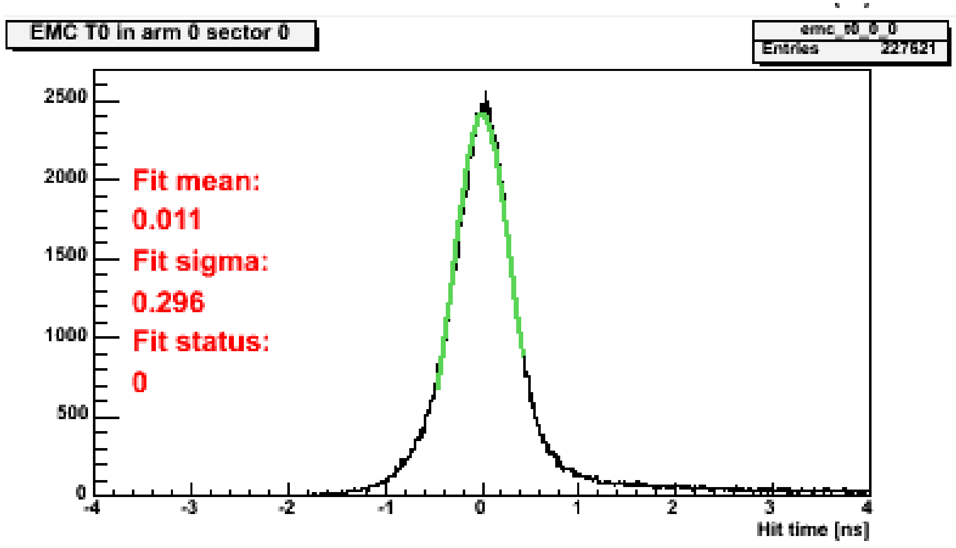
E/*p* should peak at 1. Problem: very low statistics, lots needed!



Neutral pion mass: 135 GeV
Tricky in heavy ion collisions

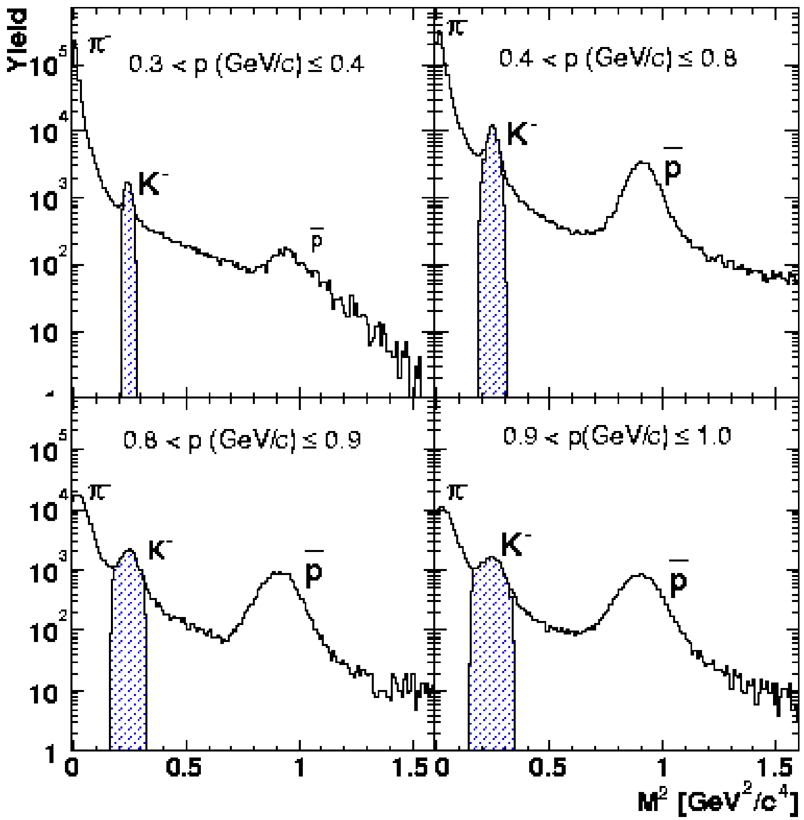
The accuracy of the energy scale is very important with steep spectra!

Physics-based timing calibration methods



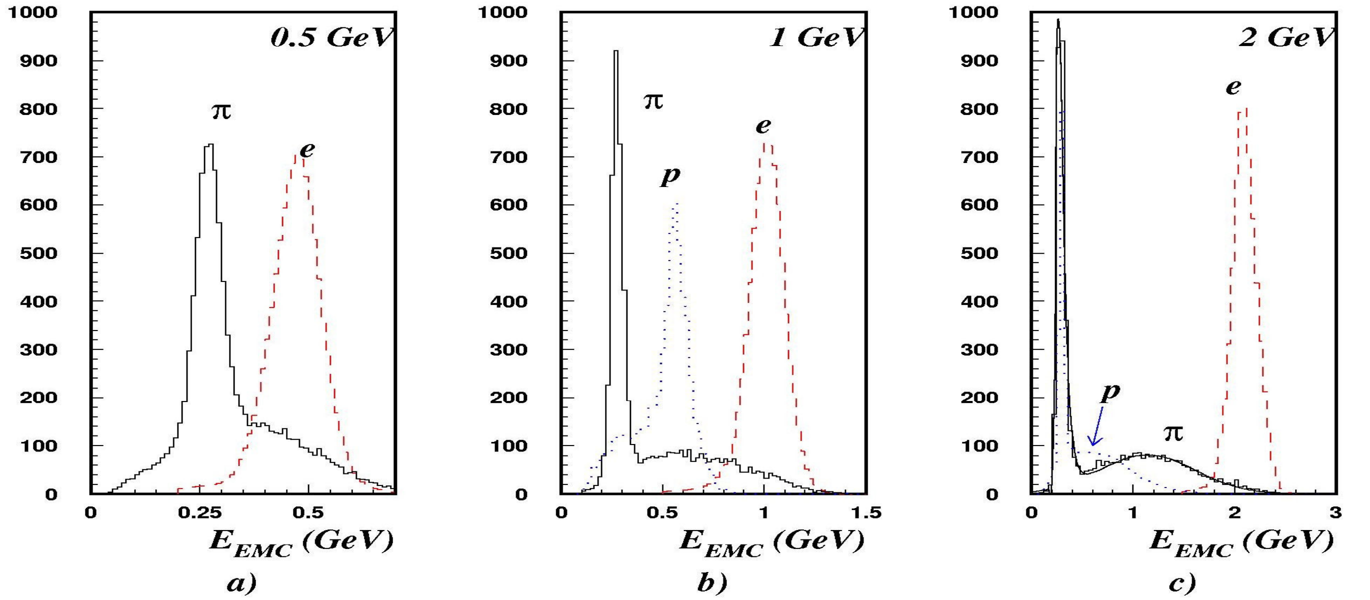
Calibration with **photons**:

- Time scale is fixed by TDC count to ns conversion factor
- The origin of the time axis can be chosen freely
- Our choice: 0 is chosen to be the time when photons arrive at the calorimeter



Calibration with **charged hadrons:**

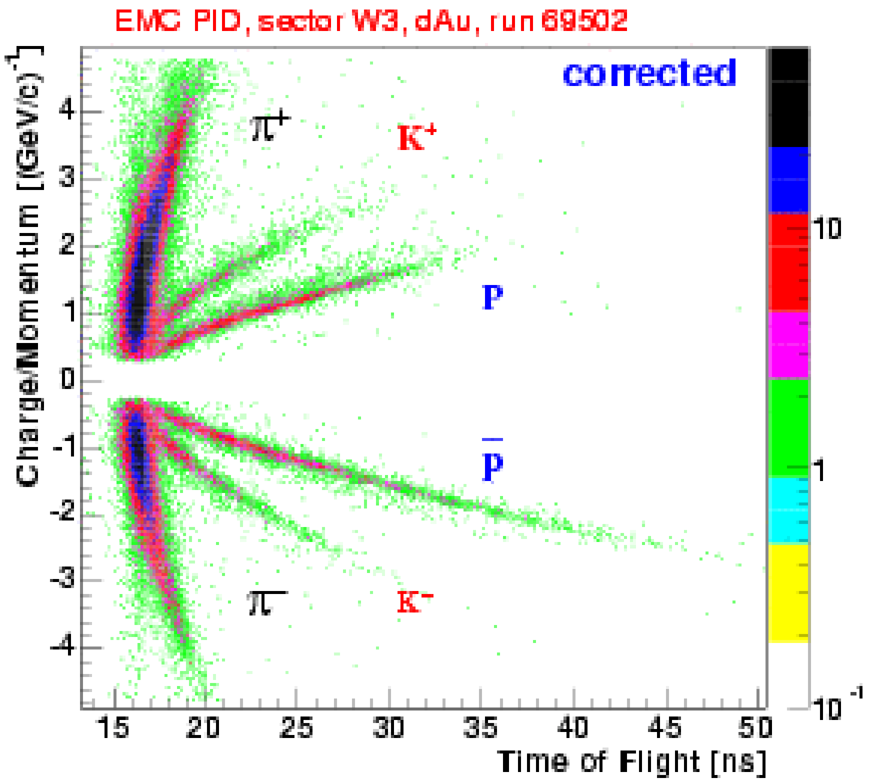
Squared mass is calculated from momentum (tracking detectors), path length (tracking detectors), time of arrival (TOF or EMCal)



Hadrons

Problem with hadrons: no hadron calorimeter! Charged hadrons are MIPs in the EMCal, full energy can't be measured. But we can:

- tell apart hadronic and EM showers from shower shape;
- identify charged pions, kaons and protons.



Run2 timing calibration

Problems with laser tracking:

- shower shape and penetration depth do not depend on laser amplitude (unlike photons)
- occupancy ~100%, crosstalk

Need physics-based calibration.

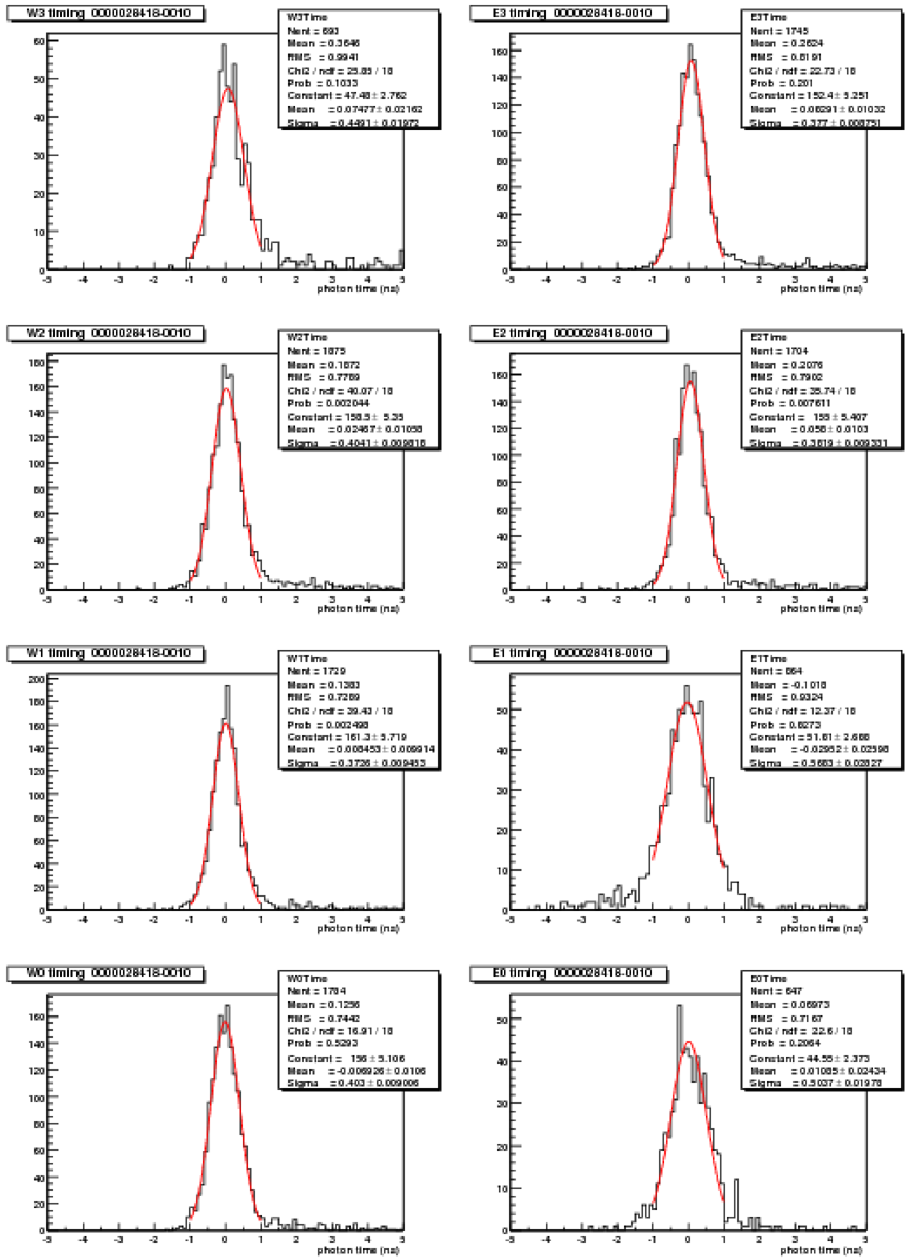
Goal: move photon peaks to 0 in every EMCal tower; track changes.

To achieve that: calibration corrections:

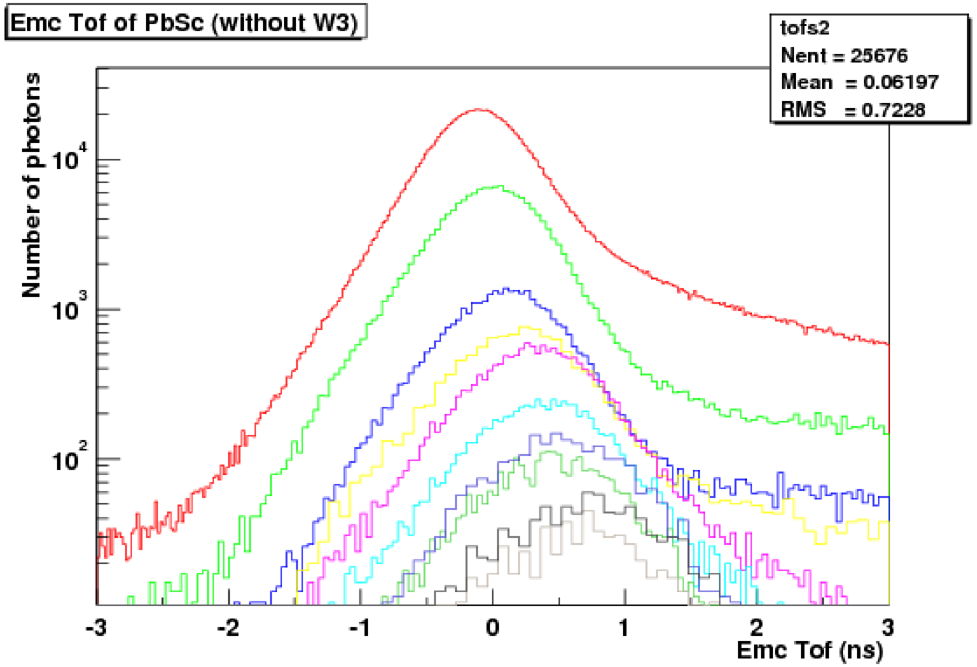
- time-independent tower-by-tower (statistics-intensive) to “balance” the EMCal
- time-dependent sector-by-sector to track changes

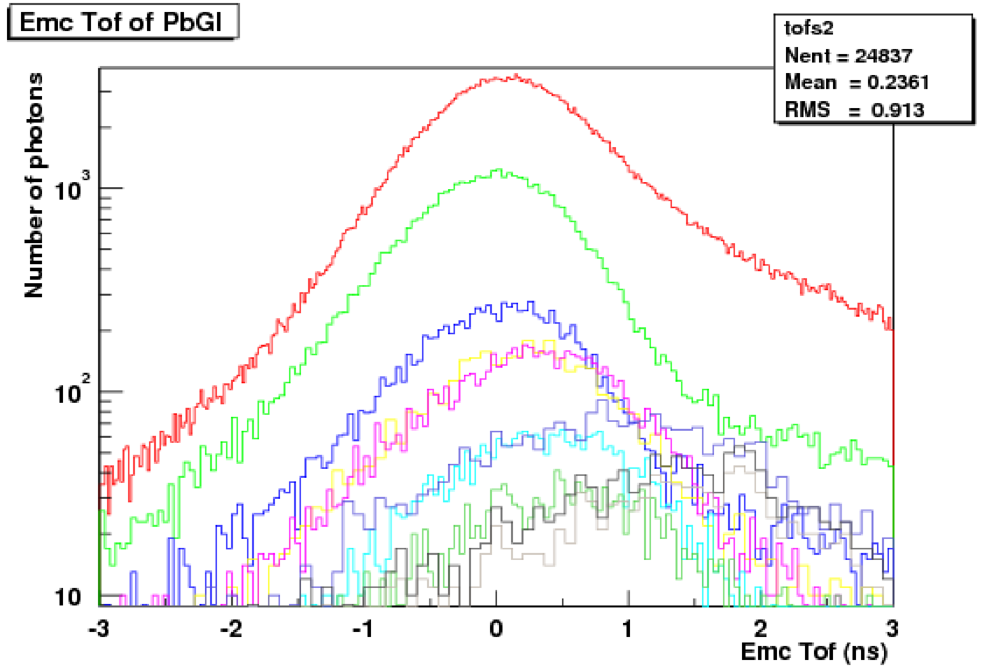
Both sets of corrections come from fitting the photons’ time of arrival peak with a Gaussian.

After corrections: photon peak within 100ps of 0; width ~400ps.



ToF energy-dependence





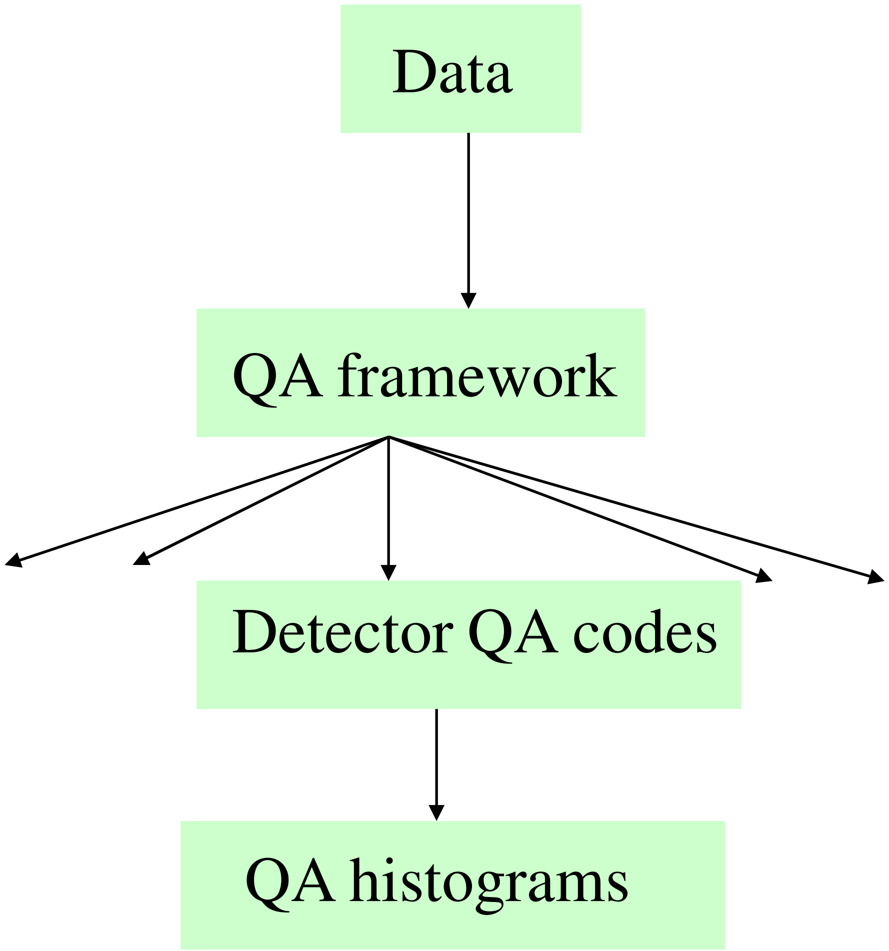
Problem: photon ToF depends on the energy?! (red: lowest energy, gray: highest)

Dependence is expected (EMCal “tachyons” ☺) but direction is counter-intuitive.

Cause: overcompensated slewing.

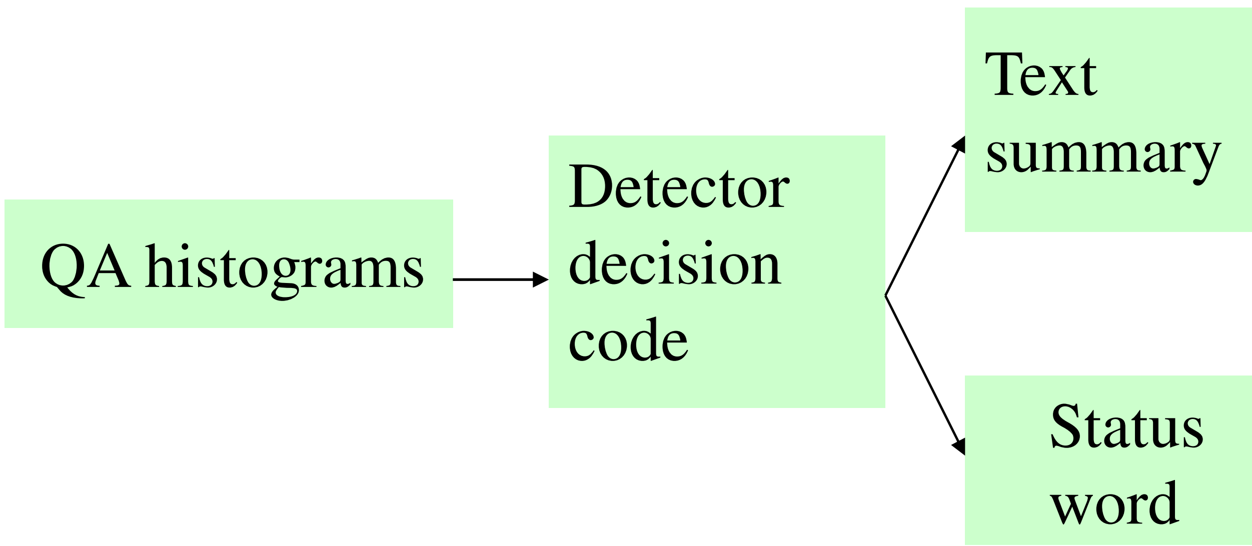
Analyses need to take it into account.

Quality Assurance



Goals:

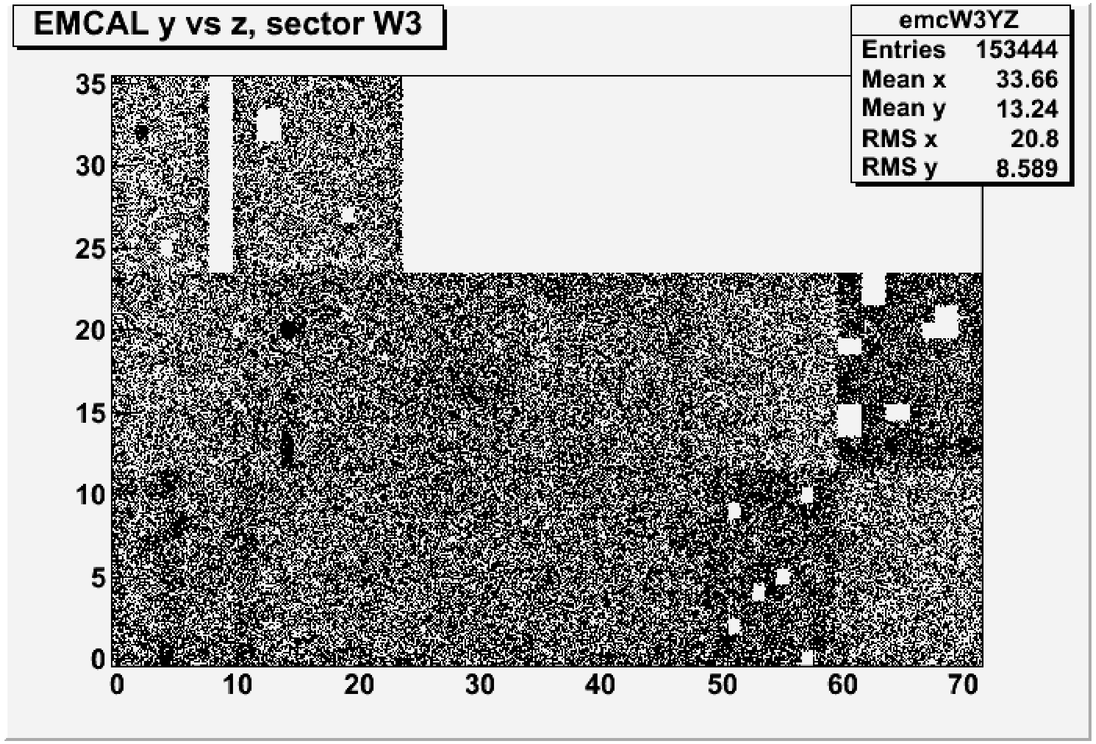
- identify misbehaving detector parts
- identify and correct miscalibrations

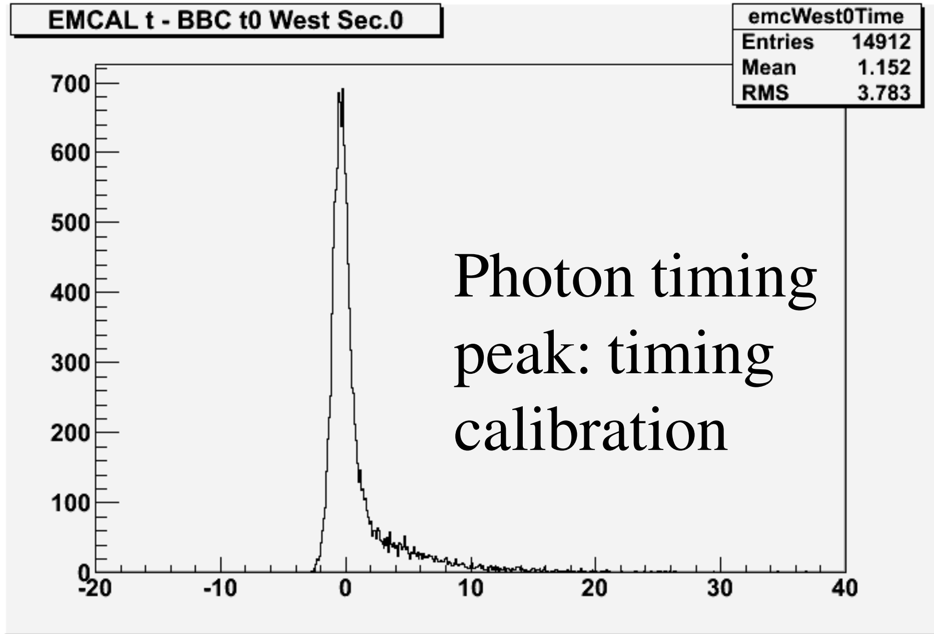


EMCal QA

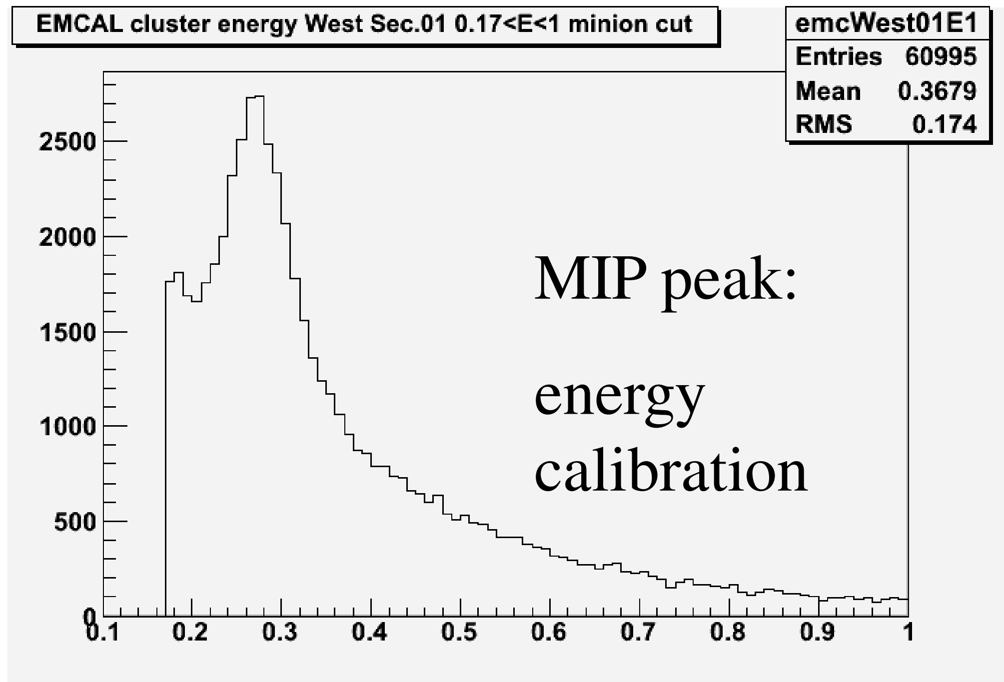
Some EMCal histograms

Sector hit map: hot and dead towers





Photon timing peak: timing calibration

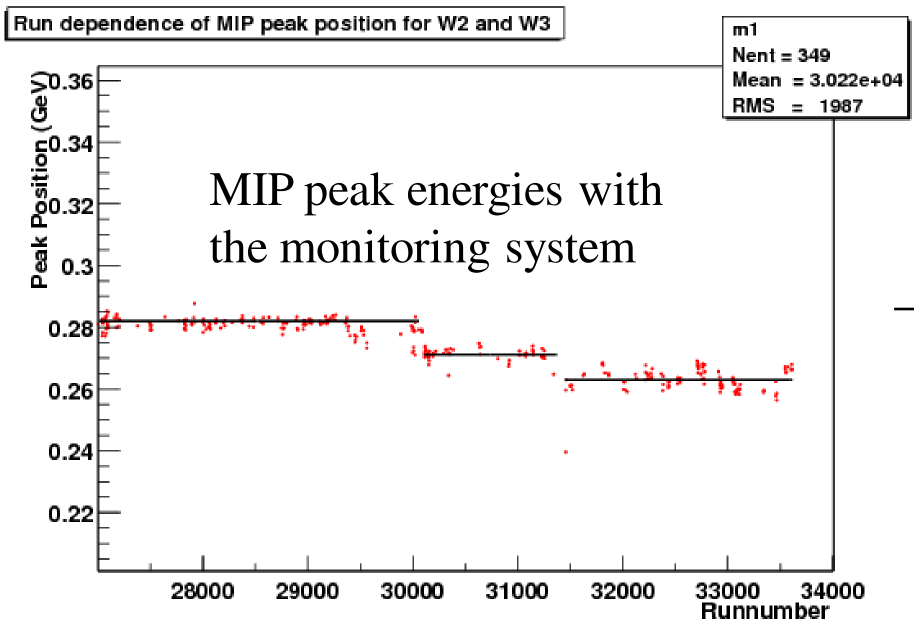


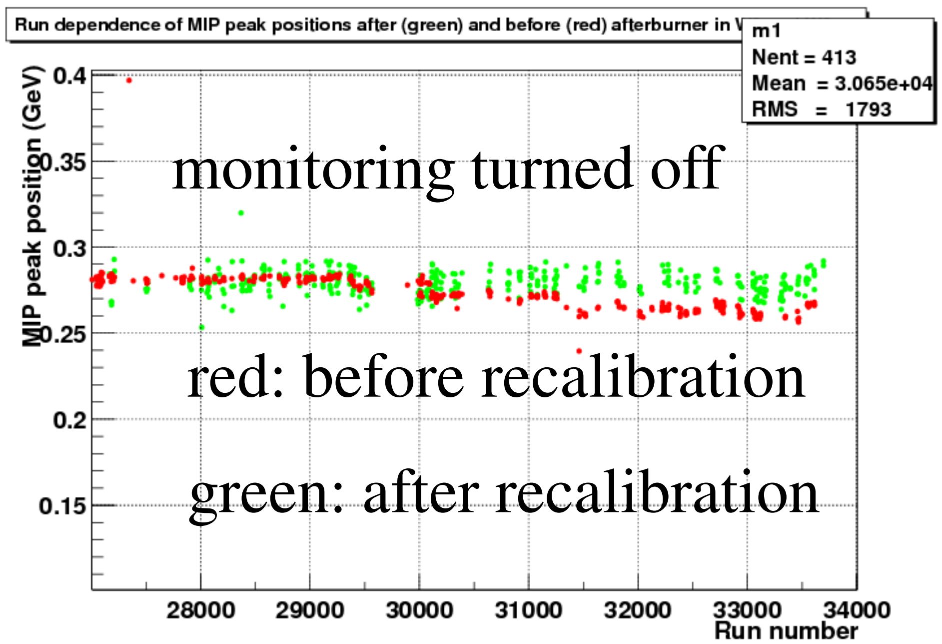
MIP peak:

energy calibration

QA revelations

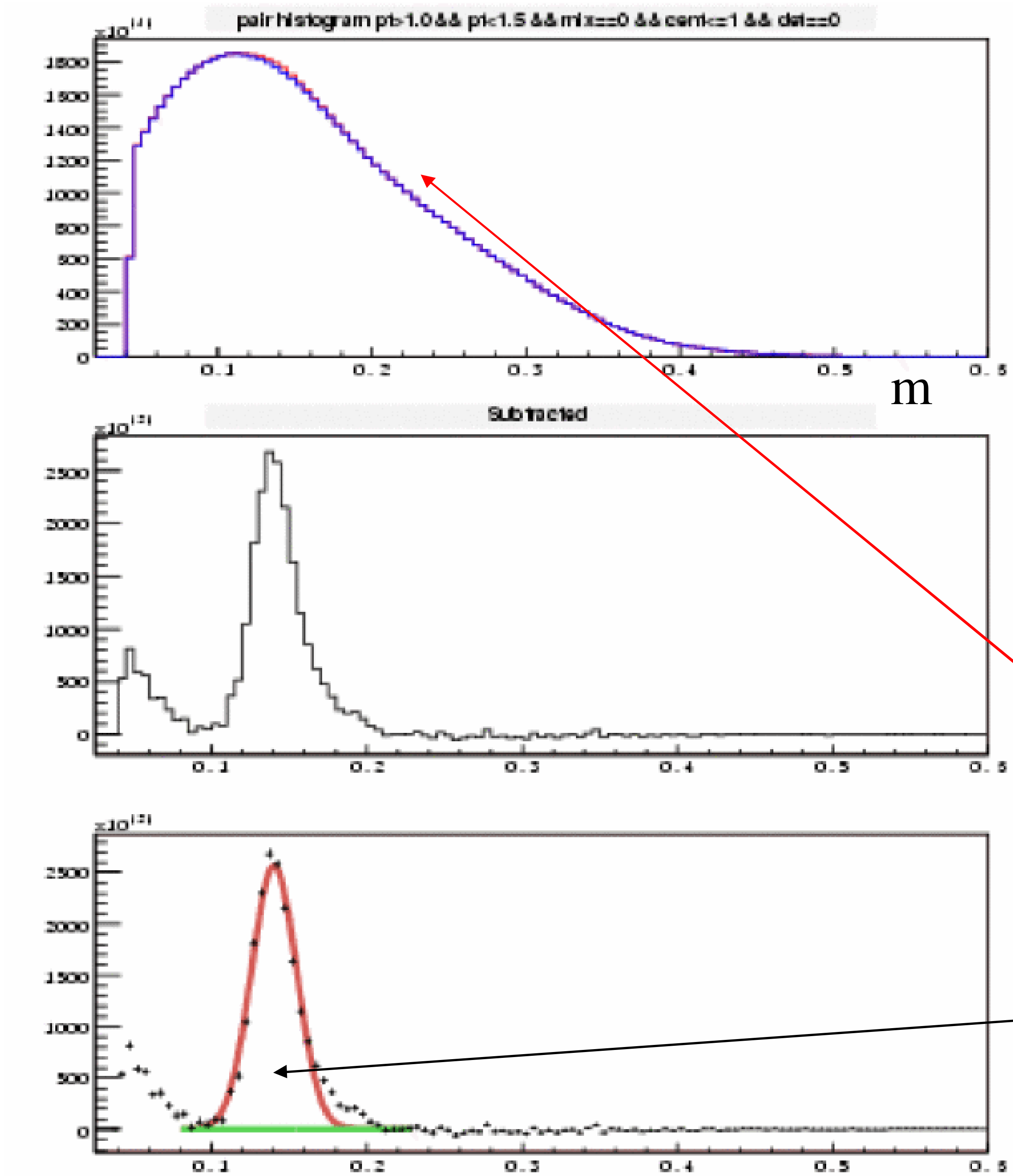
MIP peak energies vs time





Identifying neutral pions

$$\pi \rightarrow \gamma\gamma$$



Neutral pions are reconstructed by calculating the invariant mass of photon pairs.

Many possible photon pair combinations in events, most of them false! → huge background

Background can be estimated and subtracted with the event mixing method.

Integral = # of pions detected under the constraints of the cuts.

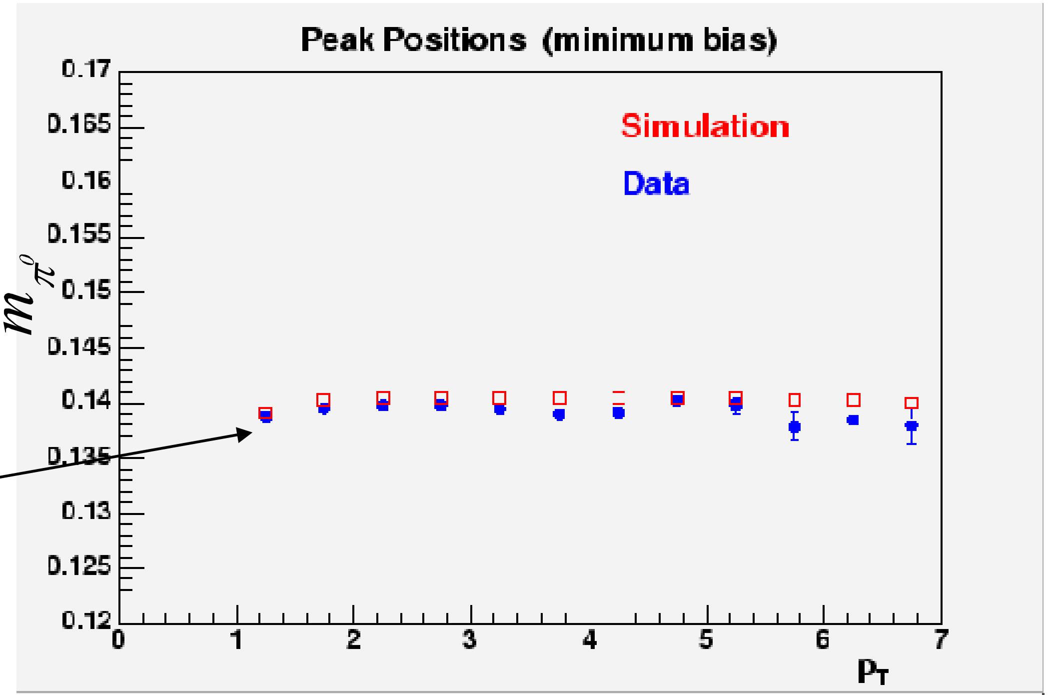
Overlaps and FastMC

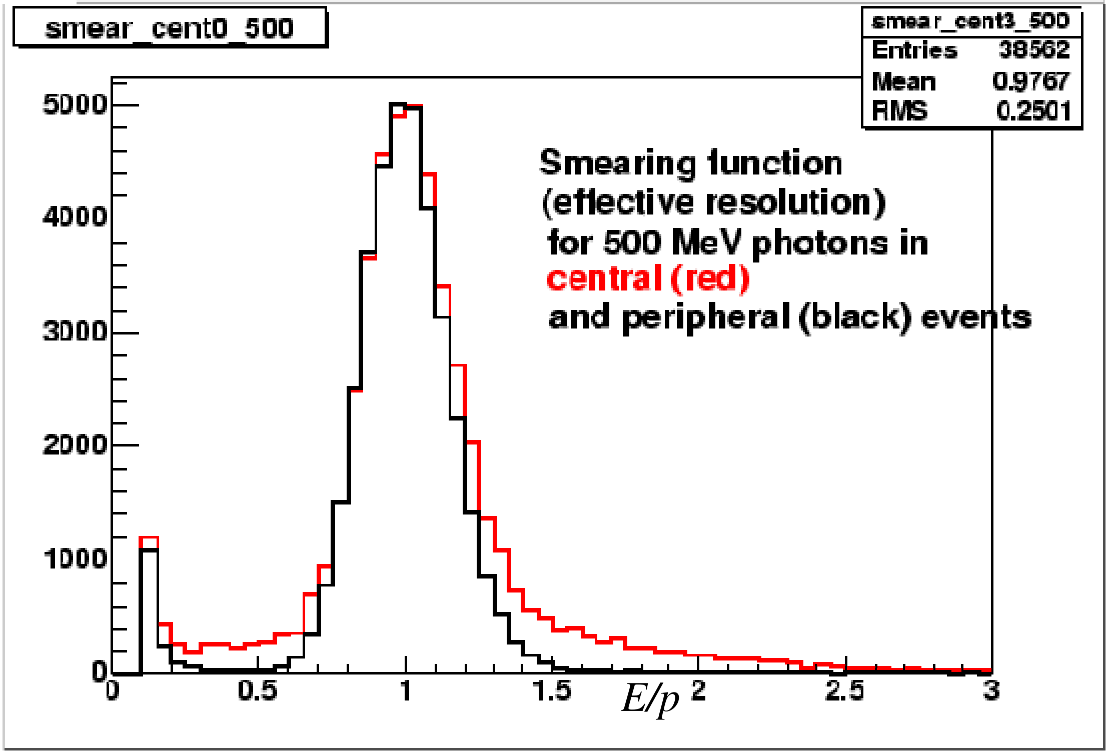
Problem: hundreds of particles in the detector in central events; showers overlap, distorting the energy measurement.

Pion mass seems higher than the nominal 0.135 GeV/c^2

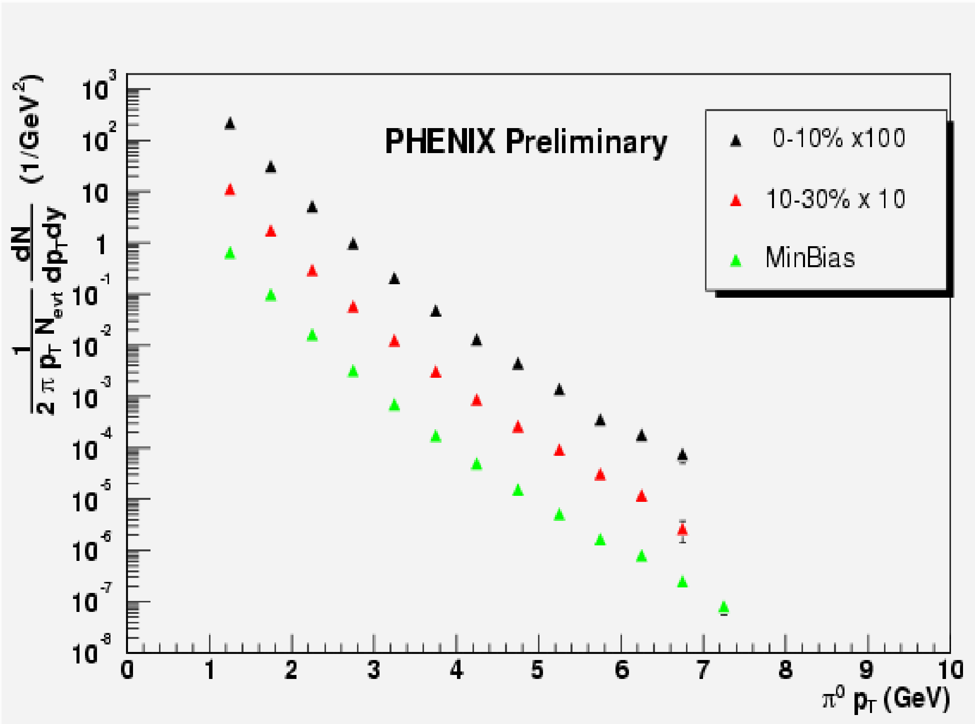
Estimating this and other systematic effects:

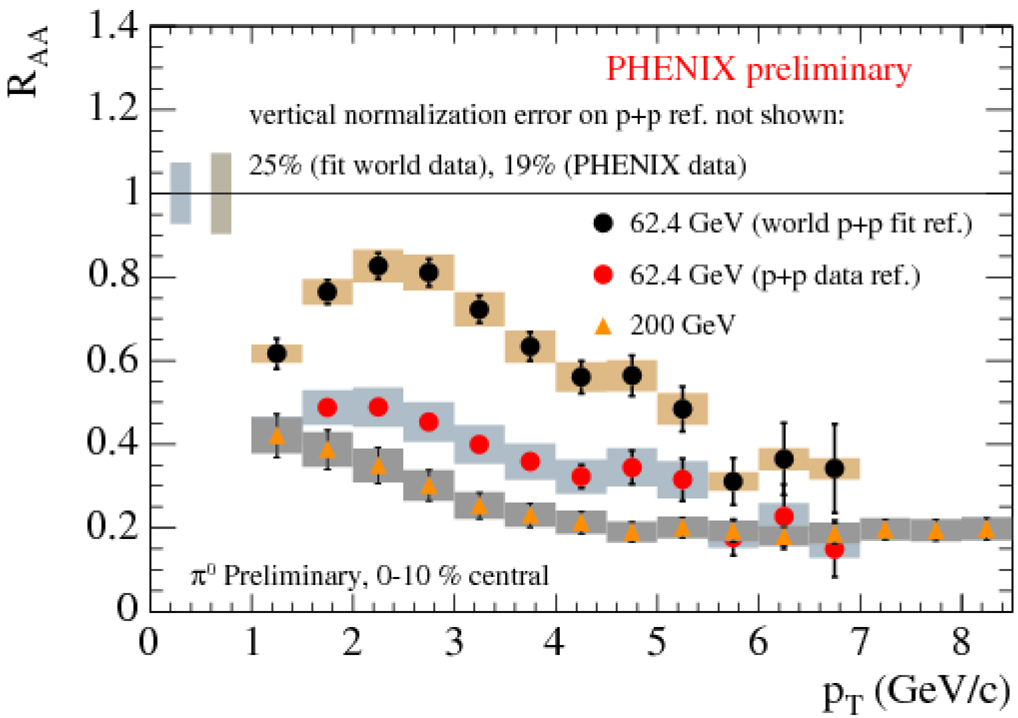
- full detector simulation – too slow
- fastMC





Neutral pion yields in 62.4 GeV Au + Au collisions



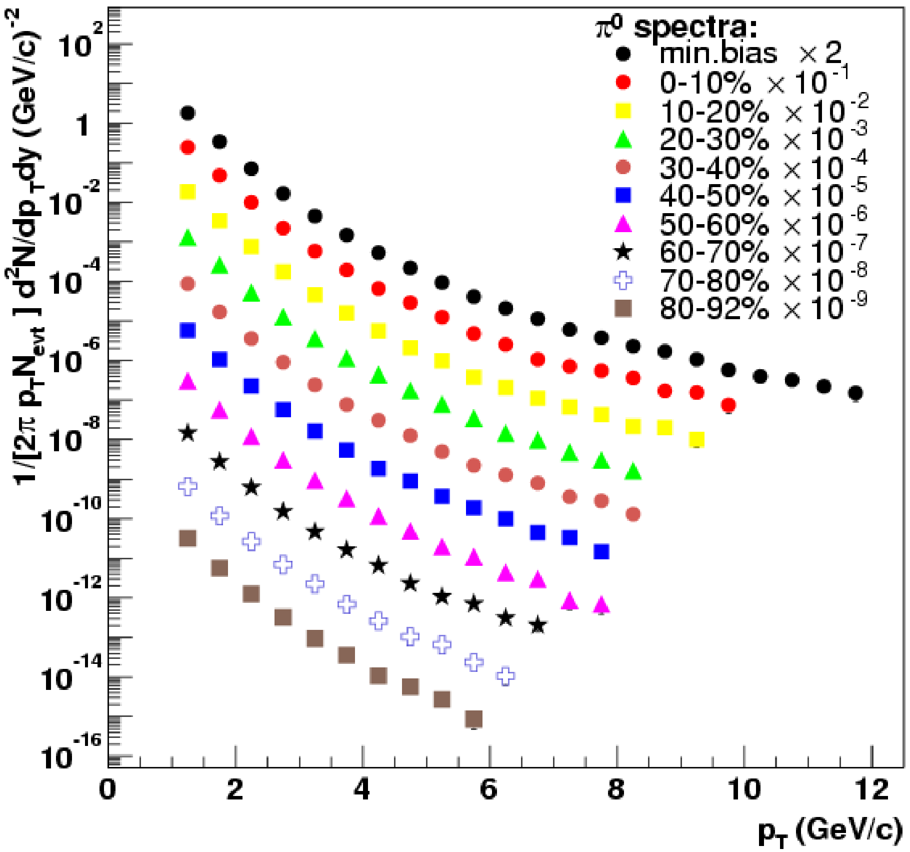


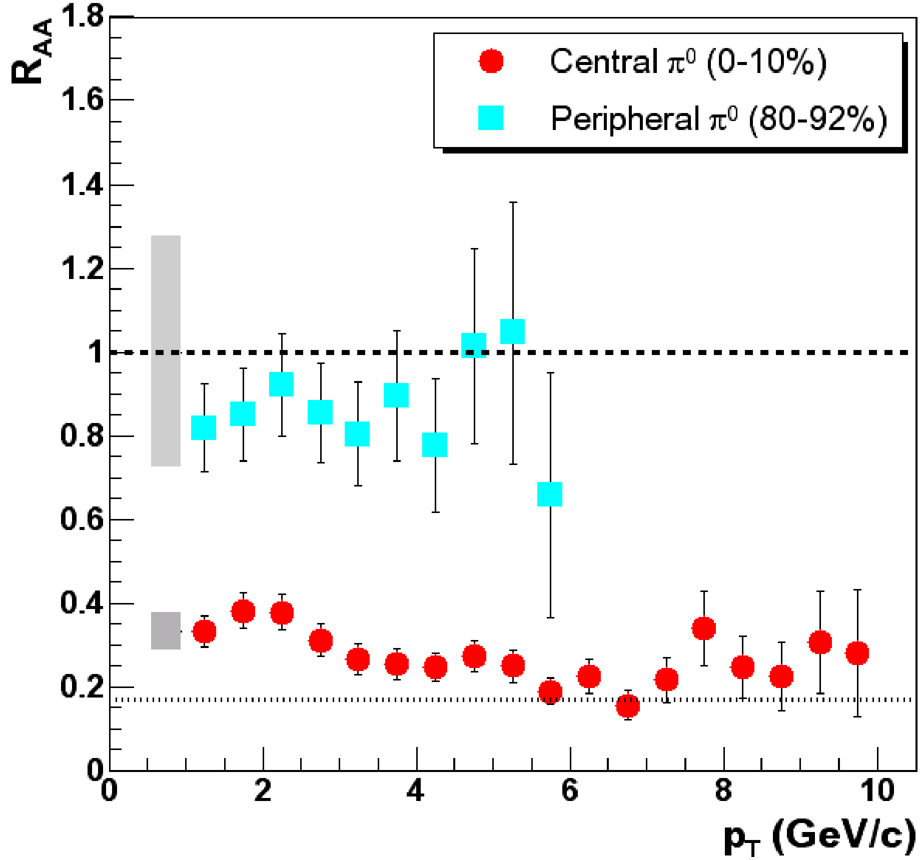
$$R_{AA}(p_T) = \frac{(\text{Yield in Au + Au})}{\langle N_{coll} \rangle (\text{Yield in p + p})}$$

suppression at high transverse momenta:

hot and dense medium in final state?

Neutral pion yields in 200 GeV Au + Au collisions





Peripheral yields: not suppressed (within errors)

Central yields: strongly suppressed – jet quenching in QGP or other explanation?

Summary

Calibration is a tricky business – data quality control by methods complementing one another is essential.

Neutral pion yields are suppressed both in 62.4 AGeV and 200 AGeV central collisions: medium effects?

Suppression sets in at lower than expected energies – impractical to search for transition point with RHIC.