π^0 reconstruction in PHOS and EMCAL

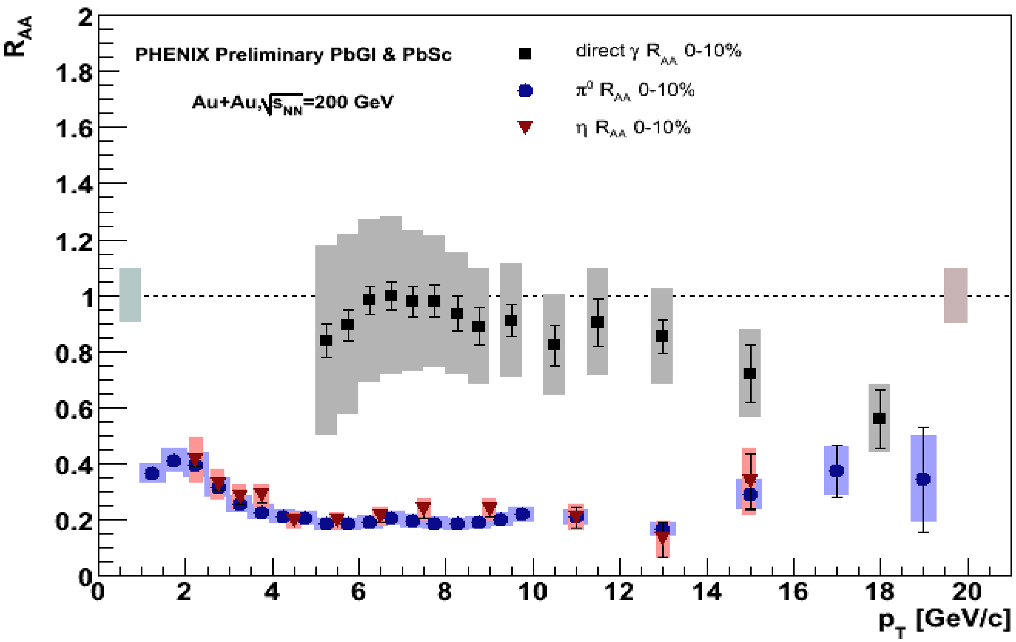
Yuri Kharlov
IHEP, Protvino
EMCAL offline meeting
19-21.05.2008

Physics motivation

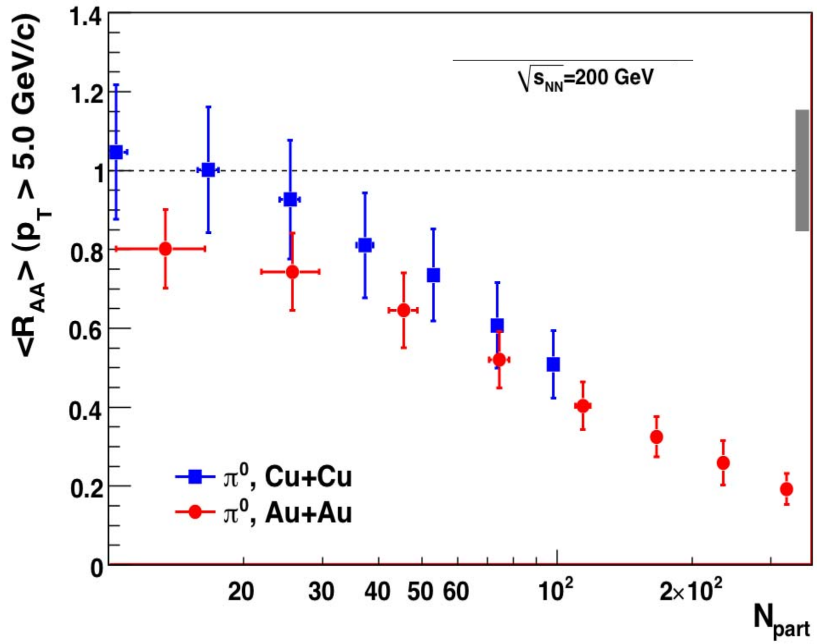
- Cross section of inclusive production of $pp \rightarrow \pi^0 X$ at 10 (0.9) TeV
  - Validation of pQCD calculations, constraints on PDF and FF
  - Reference for future AA collisions to measure R_{AA}: π^0 spectrum was the first evidence of jet quenching at RHIC
- Study the π^0 production in pp collisions at high multiplicity: insight on thermalization in pp
- π^0 spectrum is the easiest measurement in calorimeters, therefore it used for calibration purposes

Direct photons and π^0 in AA collisions

[PHENIX, QM2008]



R_{AA} scales with N_{part}

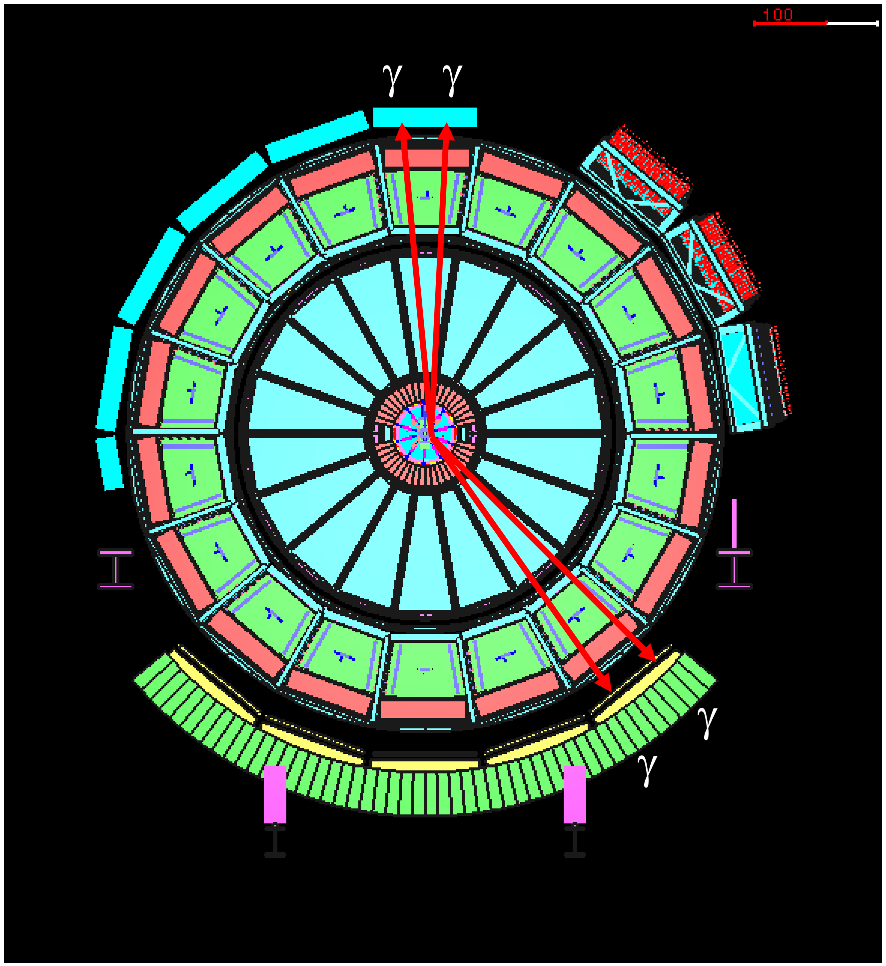


π^0 detection in ALICE

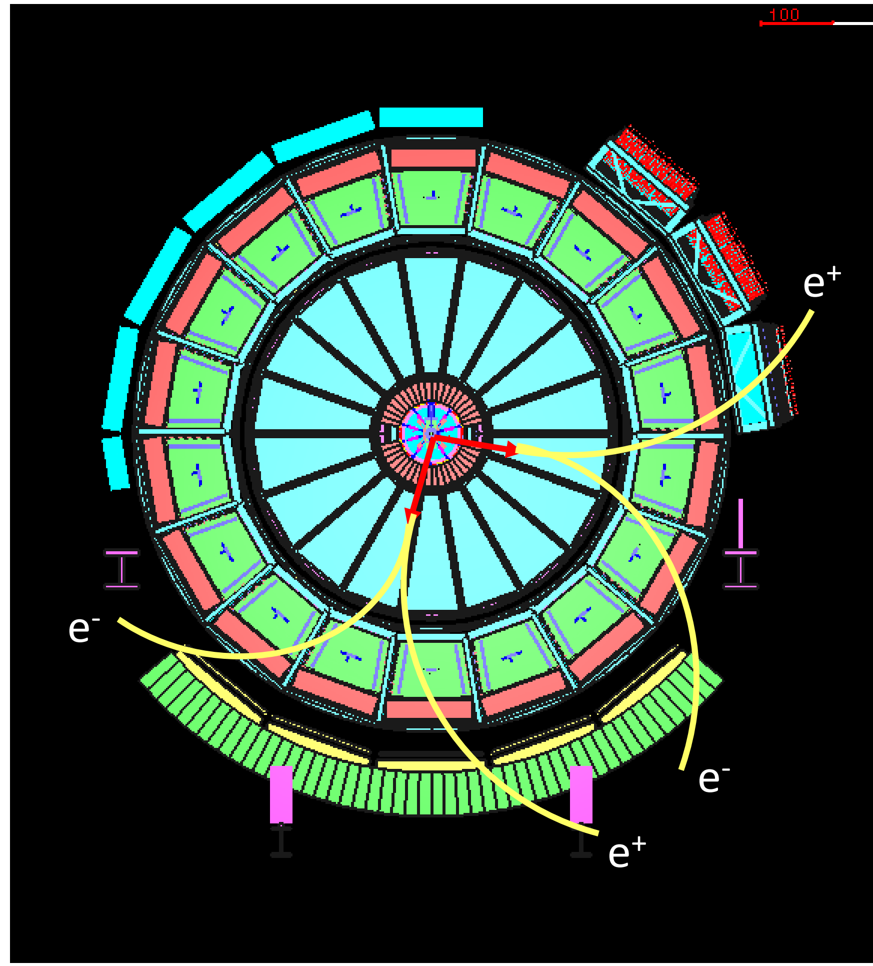
- $\pi^0 \to \gamma\gamma$, where γ's are detected in PHOS or EMCAL
  - High efficiency, but limited acceptance
- $\pi^0 \to \gamma\gamma$, $\gamma \to e^+e^-$, where are detected in e^+e^- TPC (TRD)
  - Low photon conversion probability is compensated by a large TPC acceptance

π^0 detection in ALICE

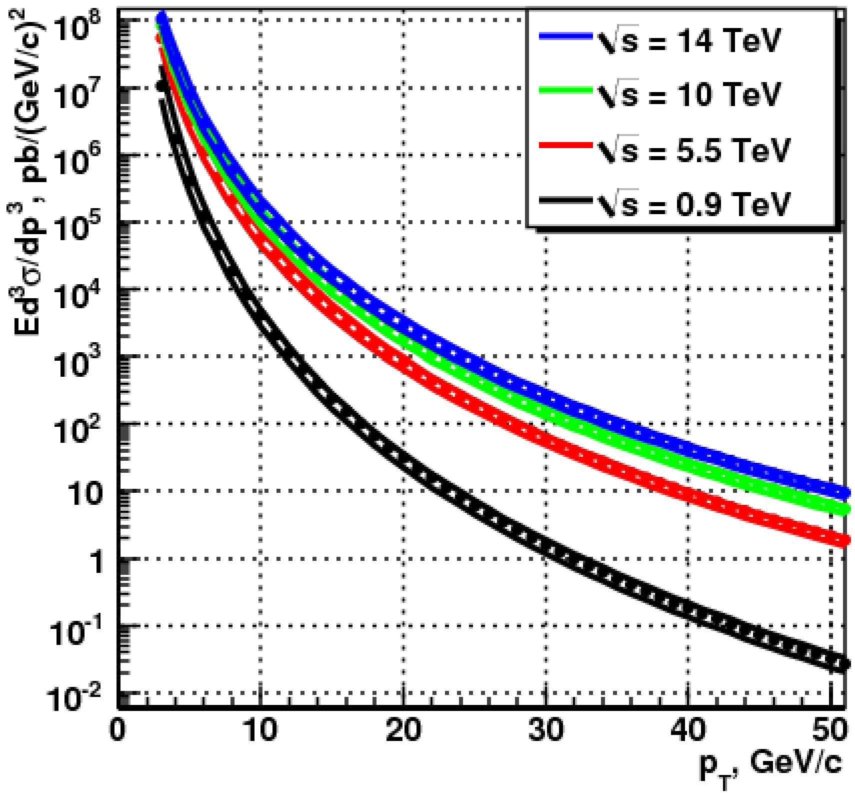
$\pi^0 \to \gamma\gamma$ in PHOS and EMCAL



$\pi^0 \to \gamma\gamma$, $\gamma \to e^+e^-$ in TPC



Production cross section



NLO pQCD + CTEQ5M + KPP
Bands indicate possible uncertainties in QCD scale
[P. Aurenche, et al., Eur. Phys. J. C 13,347 (2000)]

From inclusive π^0 spectrum to event rate

$$E\frac{d^3\sigma}{dp_T^3} = \frac{1}{2\pi p_T \Delta p_T} \cdot \frac{1}{LT} \cdot \frac{1}{Br} \cdot C_{\text{trig}} \cdot C_{\text{geom}} \cdot C_{\text{rec}} \cdot C_{\text{offvtx}} \cdot N^{\pi^0}$$

$N^{\pi 0}$: number of detected π^0 in selected p_T-bin (raw spectrum)

L: luminosity

T: run time

Br: branching ratio

C_{trig} : trigger bias correction

C_{geom} : geometrical acceptance

C_{rec} : reconstruction efficiency

C_{offvtx} : correction due to off-vertex background

LHC run scenarios

Nominal LHC scenario for ALICE:

- pp collision energy: 14 TeV
- luminosity: $3{\cdot}10^{30}$ $cm^{-2}s^{-1}$

First LHC run scenario:

- pp collisions at 10 TeV (?)
- luminosity: $5{\cdot}10^{28}$ $cm^{-2}s^{-1}$ (?)
- Data taking time: from days to months

If PHOS/EMCAL are triggered by the ALICE minimum bias trigger, then event rate is limited by 200 Hz: $L_{eff} = 5{\cdot}10^{27}$ $cm^{-2}s^{-1}$

If PHOS/EMCAL are triggered by their standalone L0 trigger on high p_T, event rate is defined by p_T spectrum only

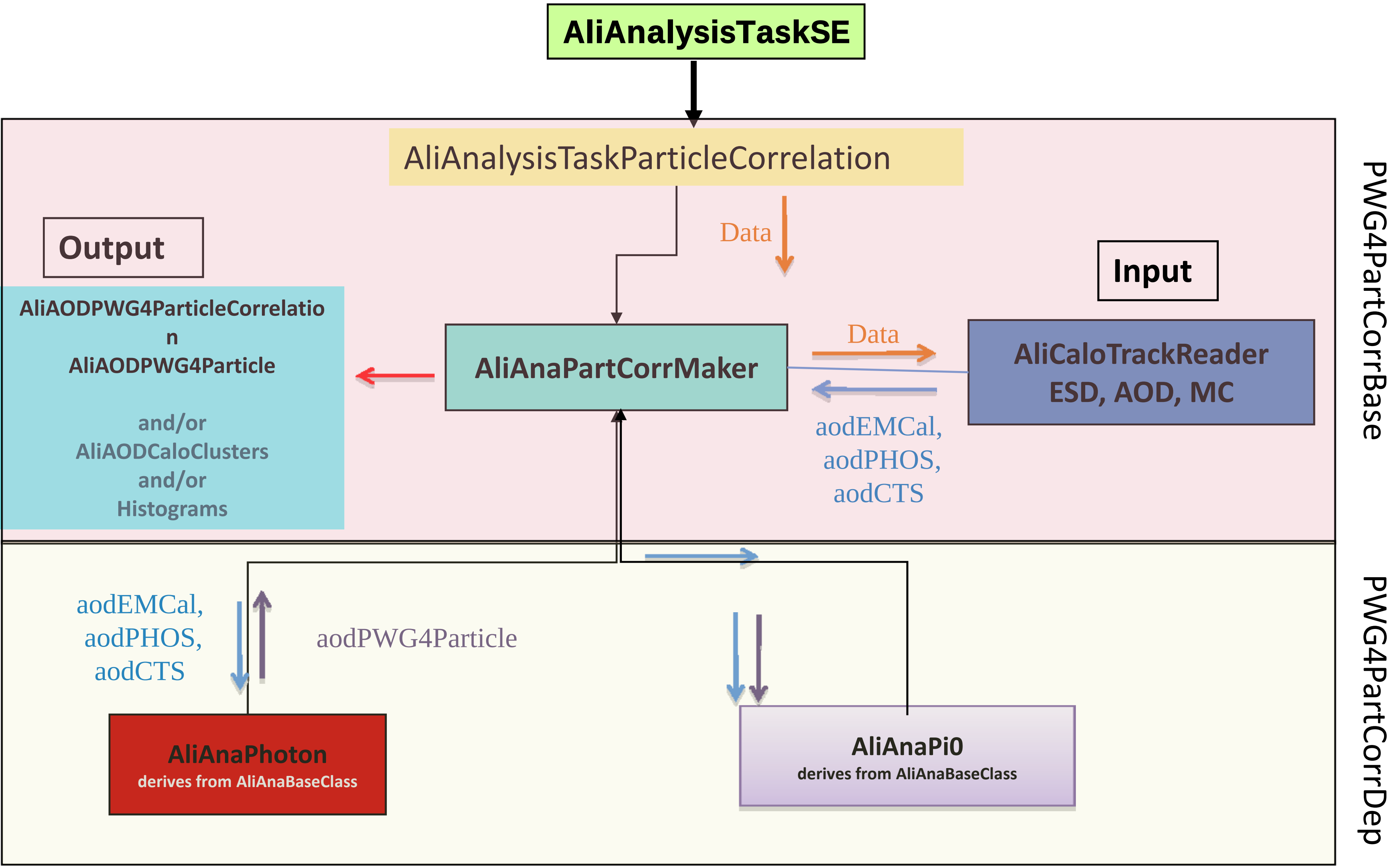
Integrated luminosity, nb^{-1}			
Run time T	L, $cm^{-2}s^{-1}$		
	$5{\cdot}10^{27}$	$5{\cdot}10^{28}$	$3{\cdot}10^{30}$
3 days	1.3	13	780
1 month	13	130	7800
3 months	39	390	22000

Raw π^0 spectrum

- π^0 analysis is implemented as a part of the Particle identification and Hadron/Jet correlations analysis framework
  – $ALICE_ROOT/PWG4PartCorrDep, $ALICE_ROOT/PWG4PartCorrBase
  – Documentation in: http://aliceinfo.cern.ch/Offline/Activities/Analysis/PWGDocumentation/PWG4/PartCorr.html
- Requirements to run π^0 analysis:
  1. Root installed
  2. Data ESD, AOD or MC
  3. A ".par" files or analysis libraries with your analysis class inside

     To produce a ".par" file the user should execute :
     - cd $ALICE_ROOT
     - make XXX.par

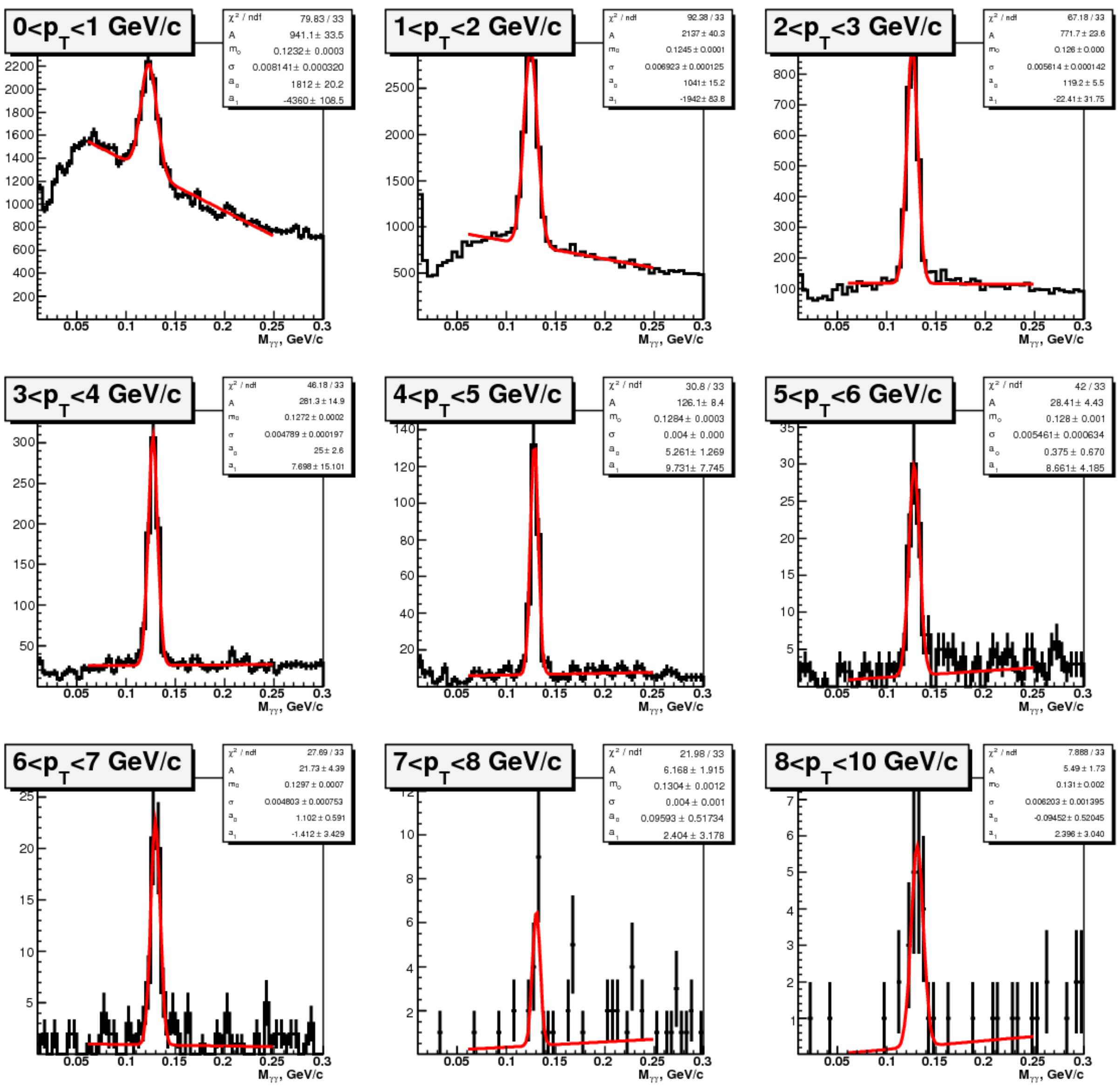
     AOD.par, ESD.par, ANALYSISalice.par, ANALYSIS.par, STEERBase.par, PWG4PartCorrBase.par, PWG4PartCorrDep.par.
  4. Analysis configuration file (for example ConfigAnalysisPi0.C)
  5. Analysis macro ana.C
- If the five conditions are satisfied and everything is well written the user has just to execute by : root -q –b –l ana.C
- It is running in the analysis train.


AliAnalysisTaskSE
AliAnalysisTaskParticleCorrelation
Data
Output
Input
AliAODPWG4ParticleCorrelatio
n
AliAODPWG4Particle
and/or
AliAODCaloClusters
and/or
Histograms
AliAnaPartCorrMaker
Data
AliCaloTrackReader
ESD, AOD, MC
aodEMCal,
aodPHOS,
aodCTS
PWG4PartCorrBase
aodEMCal,
aodPHOS,
aodCTS
aodPWG4Particle
AliAnaPhoton
derives from AliAnaBaseClass
AliAnaPi0
derives from AliAnaBaseClass
PWG4PartCorrDep

AliAnaPi0 Class

- Analyze ESD and AOD
  - Extraction of 2γ inv mass spectrum, Real and Mixed
  - Invariant mass is filled in 3D histogram (p_T, asymmetry, mass)
  - In one pass it should be able to
    - Evaluate centrality dependence
    - Evaluate PID dependence
    - Evaluate dependence on distance to bad modules
    - Evaluate dependence on asymmetry cut
  - Produce as flat Re/Mi ratio around peak as possible

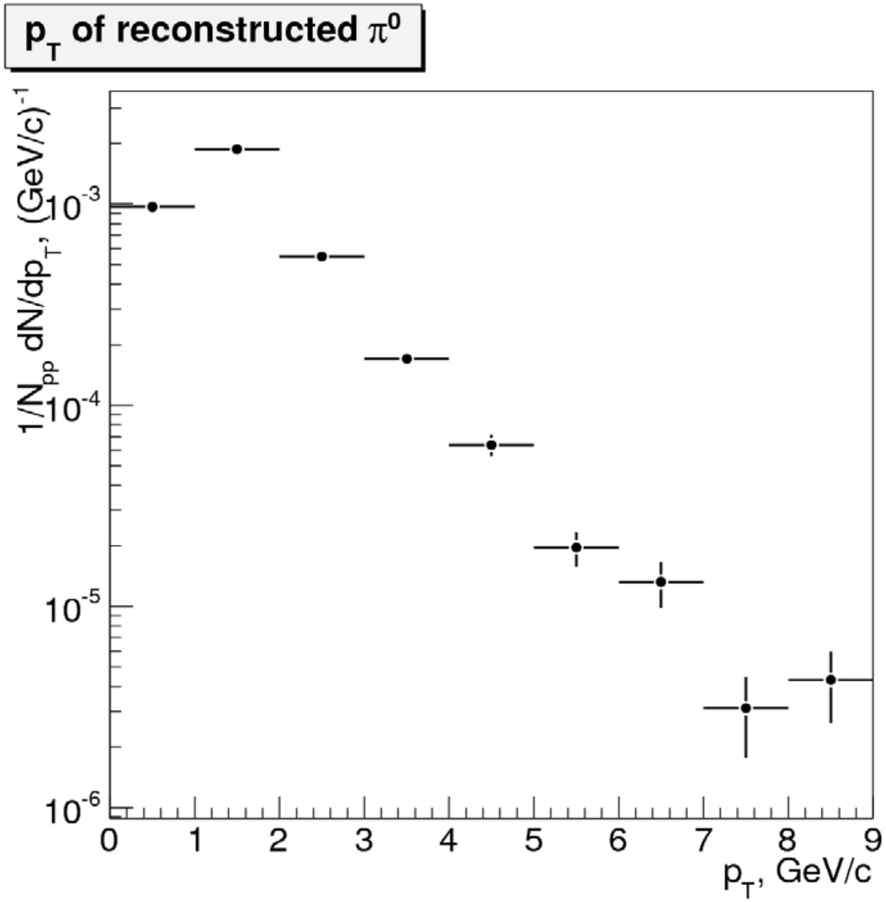
Invariant mass

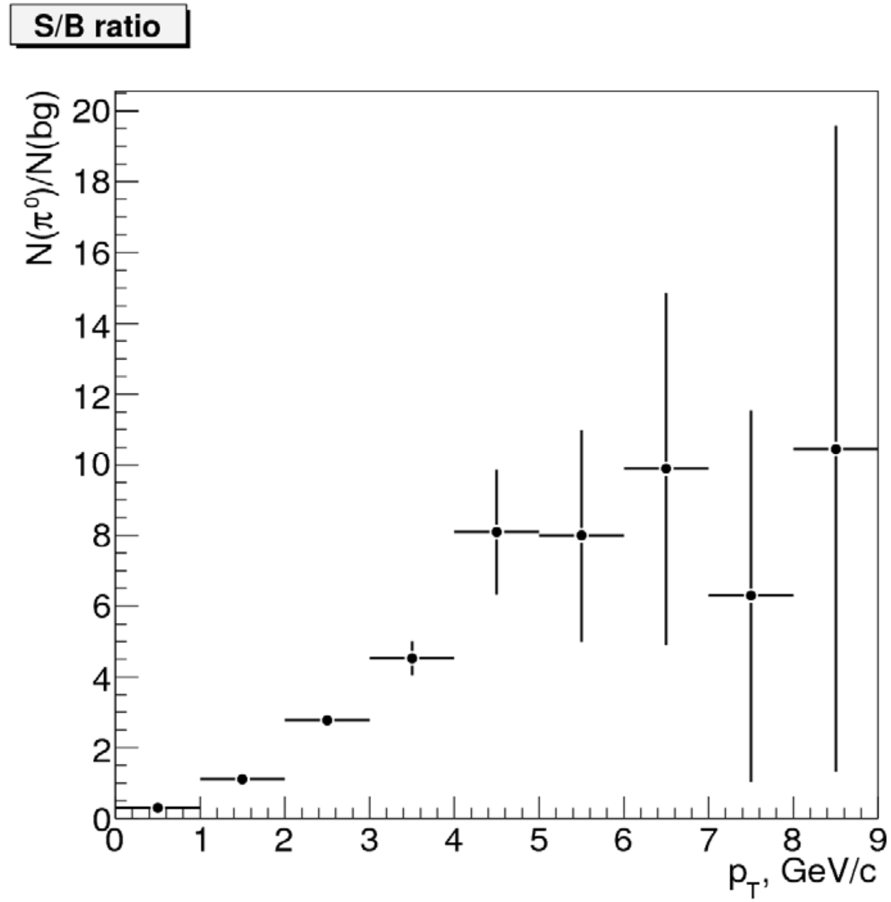


4M pp min.bias events in PHOS

Fit by gaus+pol1

Raw π^0 spectrum and S/B ratio

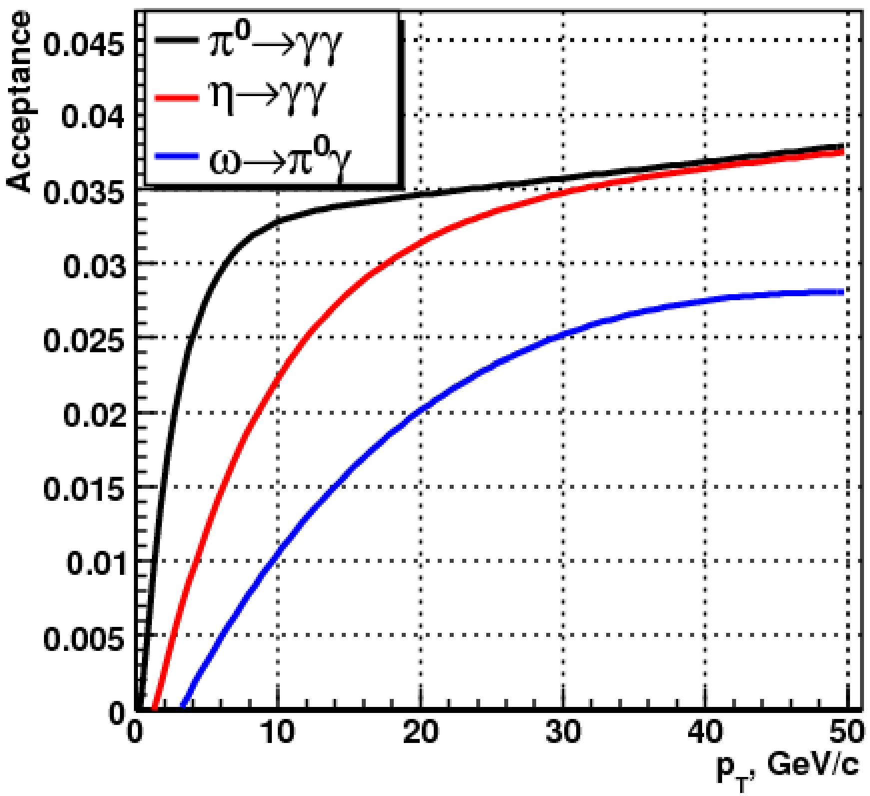




Acceptance parameterization for 3 PHOS modules

Acceptance is normalized per |y|<0.5, Δφ=2π:

$$A = \frac{N(\text{all decay prod's in PHOS})}{N(\text{gen'ed in } |y| < 0.5, \Delta\varphi = 2\pi)}$$

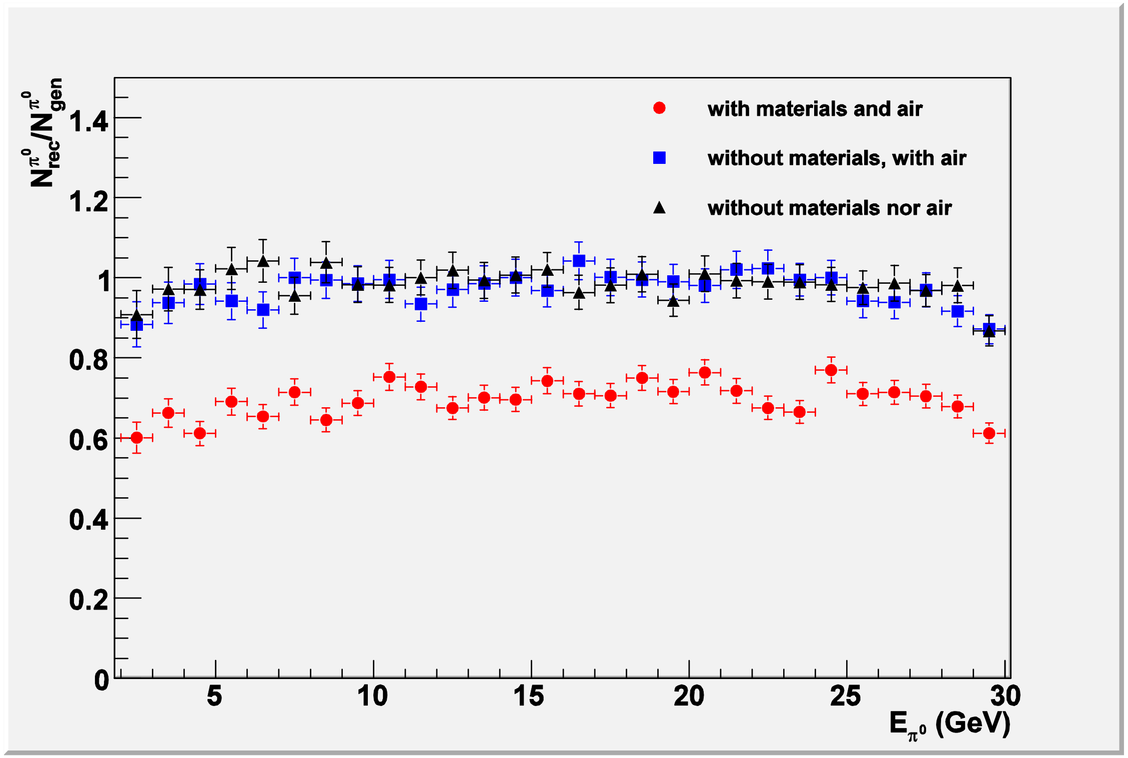


$$A(p_T) = (a + bp_T)\left[1 - \exp\left(\frac{c - p_T}{d}\right)\right]$$

	a	b	c	d
π^0	0.032	$1.1\cdot10^{-4}$	0.355	2.51
η	0.033	$9.1\cdot10^{-5}$	1.33	8.10
ω	0.183	$2.0\cdot10^{-3}$	2.37	120

Reconstruction efficiency × conversion probability

$$\varepsilon_{\text{rec}} = \frac{N(\text{reconstructed } \pi^0)}{N(\pi^0 \to \gamma\gamma \text{ in PHOS})}$$



Spectrum recovery for converted π^0

- If a photon from π^0 decay converts to e^+e^- far from a calorimeter, a π^0 can be detected as 3 clusters, and π^0 will be lost at invariant mass spectrum.
- If a photon from π^0 decay converts to e^+e^- close to a calorimeter, a π^0 can be detected as 2 clusters, and π^0 will not be lost.
- If we rely on the material description of central ALICE detectors, a recovery factor due to converted π^0 can be evaluated in simulations:

$$c_{\mathrm{conv}} = \frac{\varepsilon_{\mathrm{rec}}(\text{real material})}{\varepsilon_{\mathrm{rec}}(\text{no interactions})}$$

Spectrum correction due to p_T smearing

- π^0 has a finite p_T resolution in a calorimeter $K(p_T^{true}-p_T^{meas})$
- Measured pT spectrum has a steep slope
- As a result of a finite p_T and a slopy spectrum, a distribution of a measured p_T $f'(p_T^{meas})$ is not the same as a distribution of a true p_T $f(p_T^{true})$.

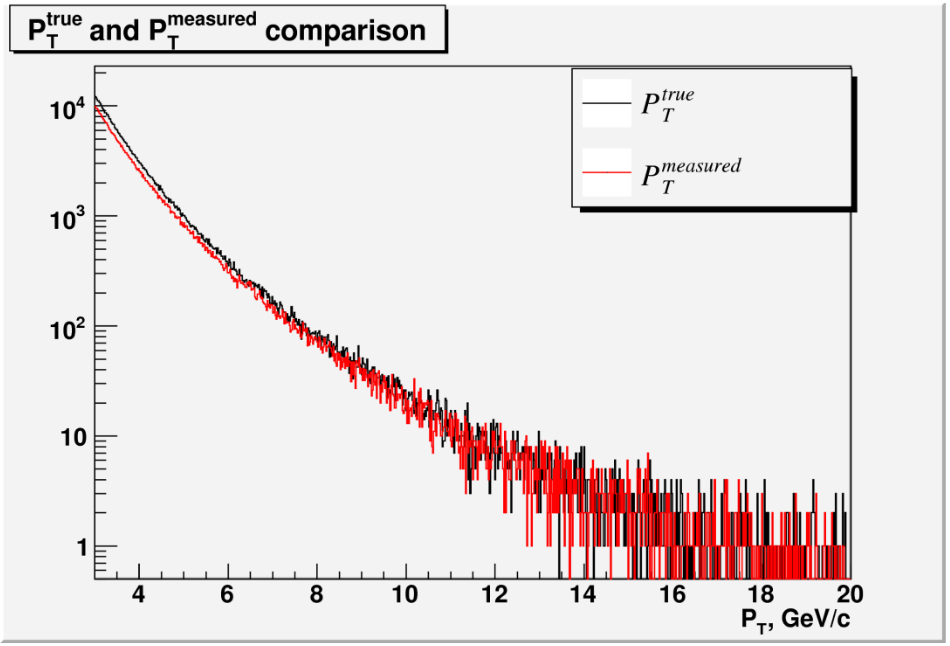
$$f'(p_T^{meas}) = \int_0^\infty f(p_T^{true}) K(p_T^{meas} - p_T^{true}) dp_T^{true}$$

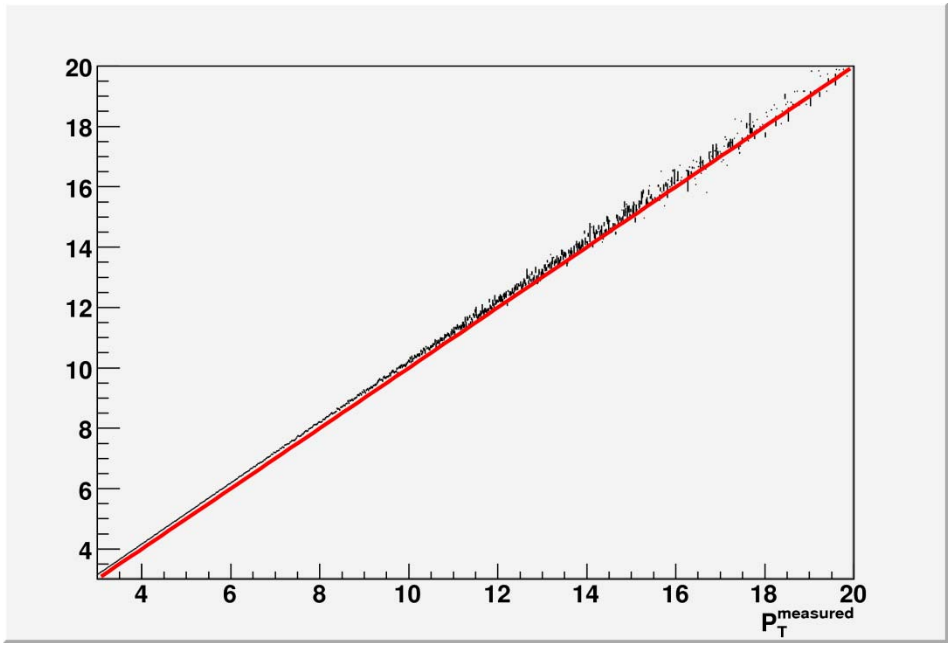
- $f'(p_T^{meas})$ is measured experimentally
- $K(p_T^{true}-p_T^{meas})$ can be evaluated in MC simulations
- $f(p_T^{true})$ has to be defined as a solution of integral equation

Smearing effect in "toy" model

$$f(p_T^{\mathrm{true}}) = \frac{\exp(-4/p_T)}{p_T^6}$$

$$K(p_T^{\mathrm{meas}} - p_T^{\mathrm{true}}) = A\exp\left(-\frac{(p_T^{\mathrm{meas}} - p_T^{\mathrm{true}})^2}{\sigma^2}\right)$$





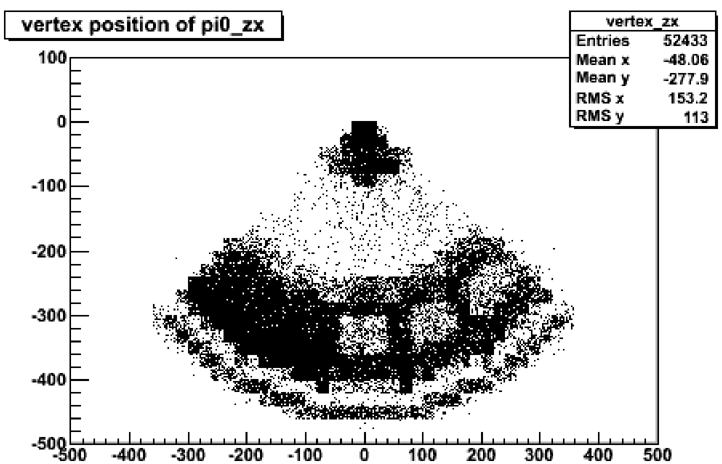
Measured p_T is always softer than true p_T.

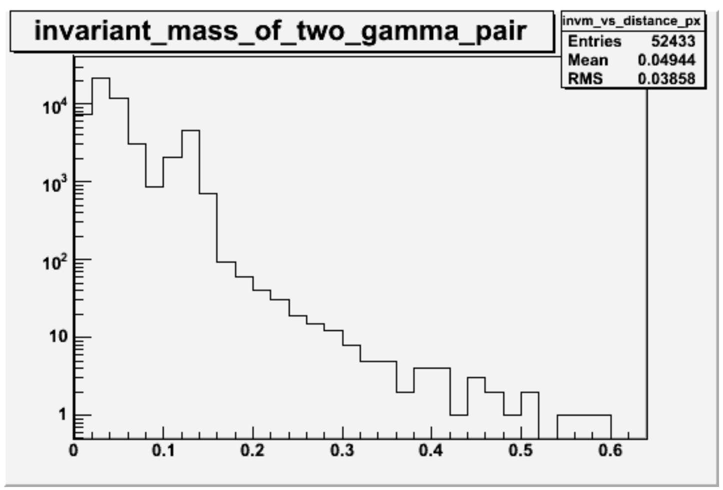
Measured spectrum of measured p_T is always lower that a true spectrum of true p_T

Off-vertex background to π^0 spectrum

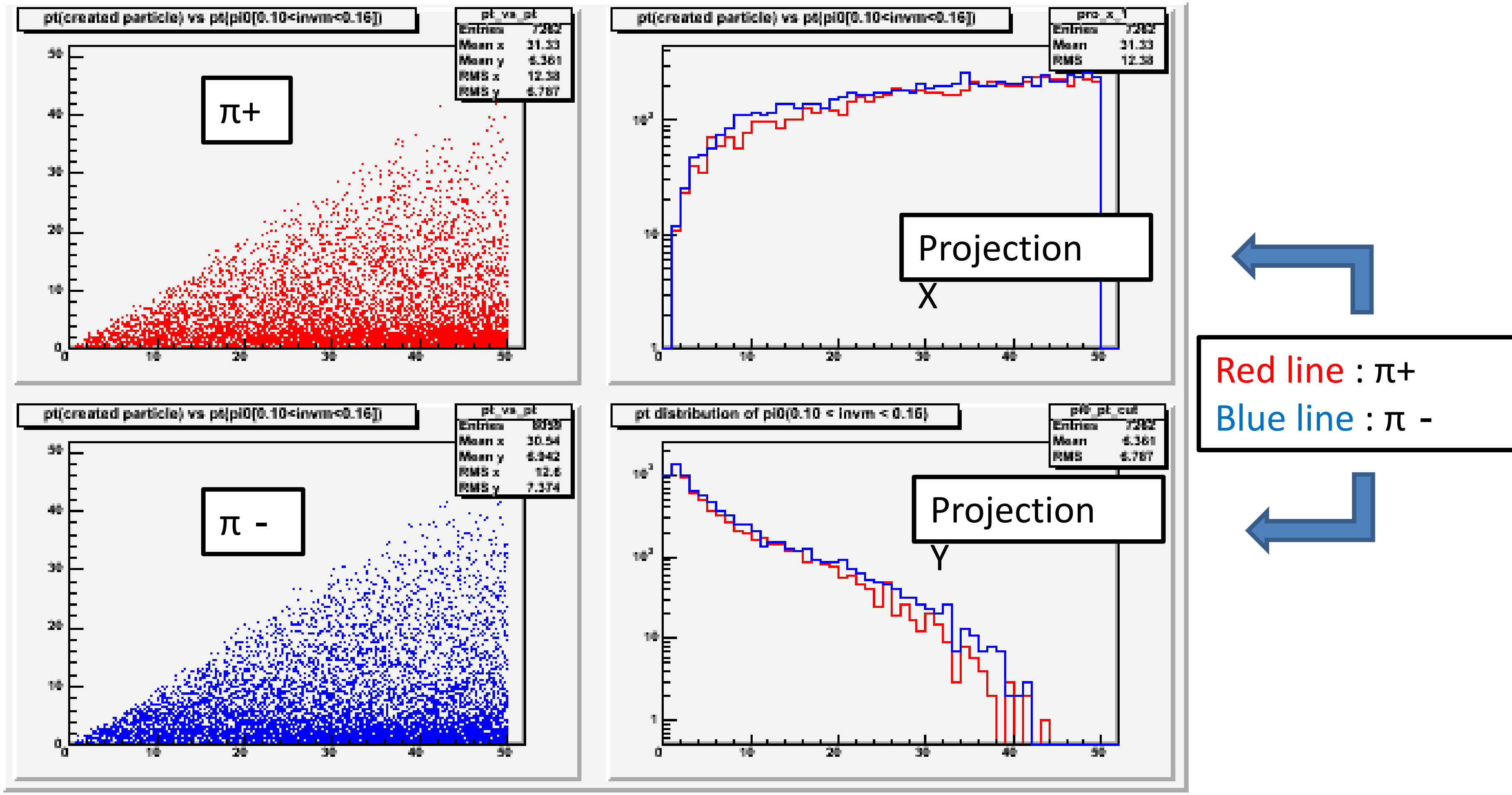
- In 2-photon invariant mass spectrum, some fraction of π^0 are produced off-vertex
- Secondary interactions of hadrons with ALICE medium can produce 2 clusters which will be detected in PHOS with invariant mass around π^0 mass (135 MeV)
- For example, primary π^+ can scatter off medium and produce secondary pi0 in charge-exchange reaction. Reconstructed photons are assigned to a primary vertex.

Example: single π^+ 2.5M events at
$0 < p_T < 50$GeV/c, : 220°$<\phi<$320°, : $-0.3< \eta <0.3$



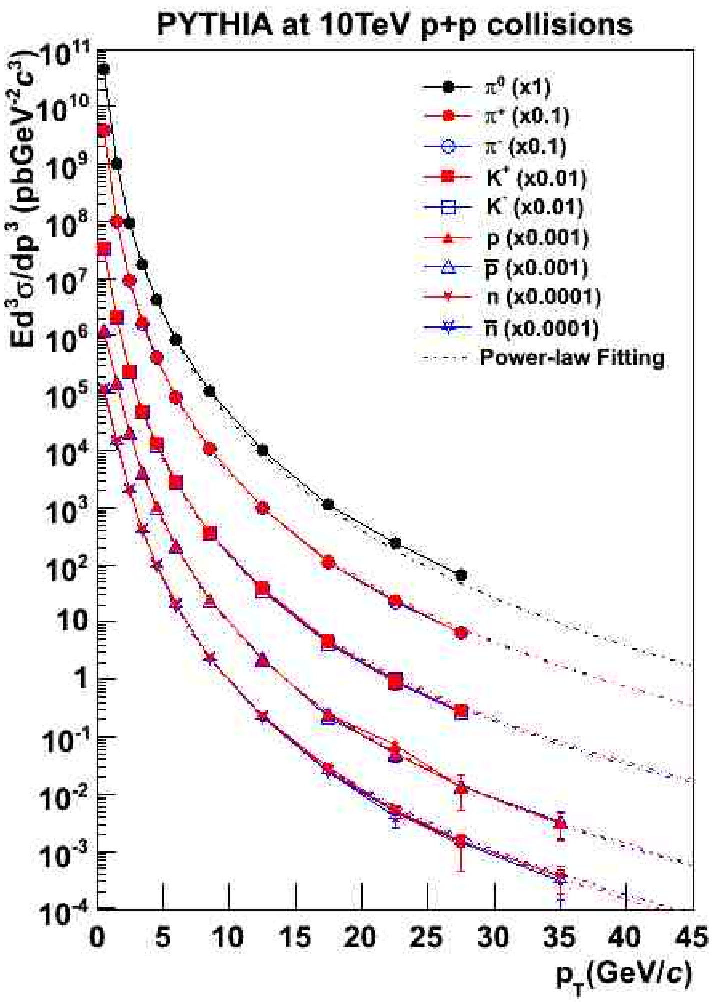


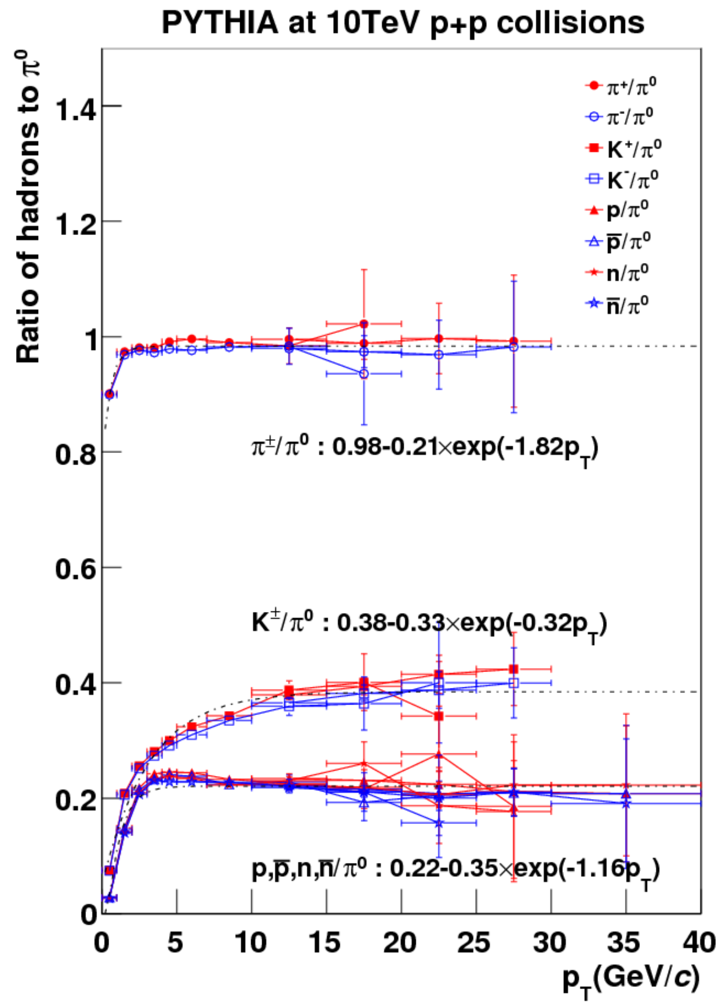
single $\pi^{\pm}$



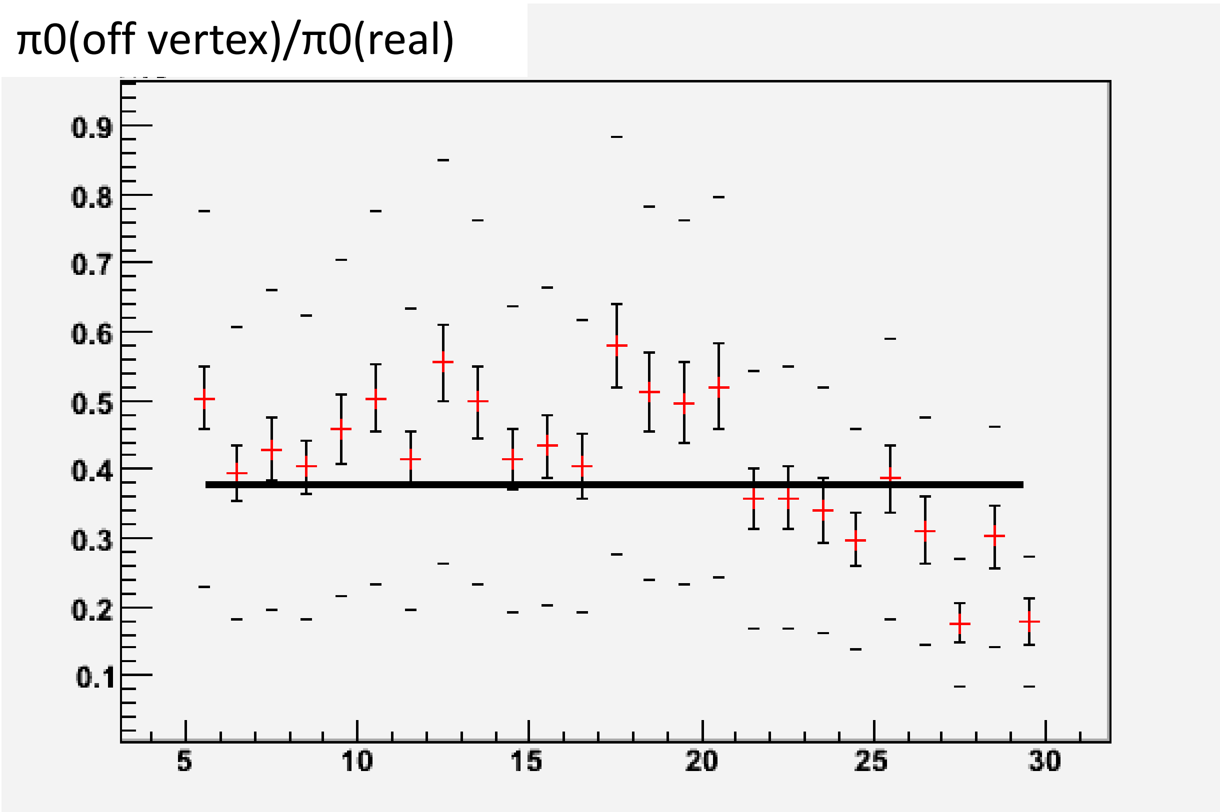
The π^0(off vertex)/ π^0(real) ratio can be calculated as a convolution with hadron/π^0 production yields ratios

Hardon/π^0 ratio in pp @ 10 TeV





π0(off vertex)/π0(real) ratio (π±, K±, K0L, p, anti-p, n, anti-n)



Error bars:
inside: statistic error
outside: systematic error

- systematic error
  - $\pi^{\pm}$: 10%
  - $K^{\pm}$,K^0_L: 30%
  - p,anti-p,n,anti-n: 50%
  - Geant: 50%

Fit the data with statistic error by constant at $5<p_T<30$GeV/c
$3.77\times10^{-4}\pm0.09\times10^{-4}$

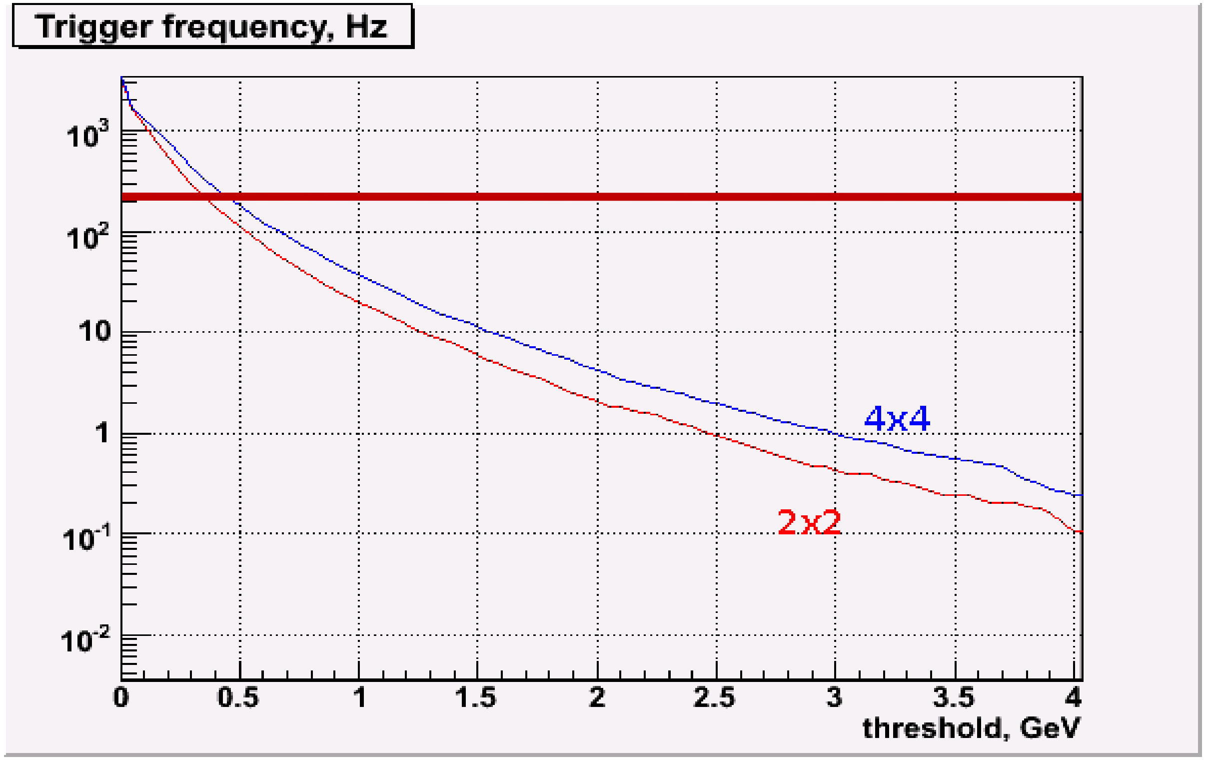
0.04% of off vertex π0 contribute to π0 measurement.

Trigger simulation

- AliPHOSTrigger class: simulation model of PHOS L0 trigger
- AliEMCALTrigger: similar class for EMCAL
- Simulation with 5 PHOS modules, pp min.bias events by Pythia
  - Ideal calibration: all cells provide exact deposited energy (not true in real life!)
  - threshold to keep digit: 0.012 GeV
- LHC luminosity: $L=5\cdot10^{28}$ cm^{-2} $c^{-1} \Rightarrow$ interaction rate: 3.5 kHz

PHOS L0 trigger rate

<u>L0 definition</u>: 2x2 (4x4) cells energy sum above a threshold somewhere in PHOS



Calibration

- PHOS/EMCAL will be pre-calibrated by adjusting APD bias to the same gain, using Hamamatsu datasheets. Decalibration of pre-calibrated PHOS is 10%
- Online DAs will deliver calibration parameters from physics events (pp or AA peripheral):
  - equalization of mean deposited energy per cell
  - equalization of MIP peak per cell
  - these algorithms give 5% accuracy of calibration parameters
- Offline calibration aims to refine calibration parameters to 1% accuracy.
- Offline calibration for ALICE calorimeters was defined: see http://indico.cern.ch/conferenceTimeTable.py?confId=58016

Basics of Calorimeters Offline Calibration

- Calorimeters (PHOS and EMCAL) offline calibration requires the full available statistics:
  - PHOS needs ~10^9 - 10^{10} events estimated from a requirement to have 100-1000 π^0's photons per cell,
  - EMCAL might need less statistics due to a larger ($\times$7.5) cell.
- Calorimeters offline calibration is an iterative procedure, needs 5-10 iterations with the full statistics.
- Objects needed for calorimeter calibration:
  - AODCaloClusters (clusters energy and coordinate)
  - AODCaloCells (cells energy and ID)
  - Vertex V0
  - Tracks (only needed for particular calibration algorithms)
  - Geometry from OCDB GRP
- Since the input for Calo calibration is AOD, the algorithm is implemented as an Analysis Task

Calibration algorithm

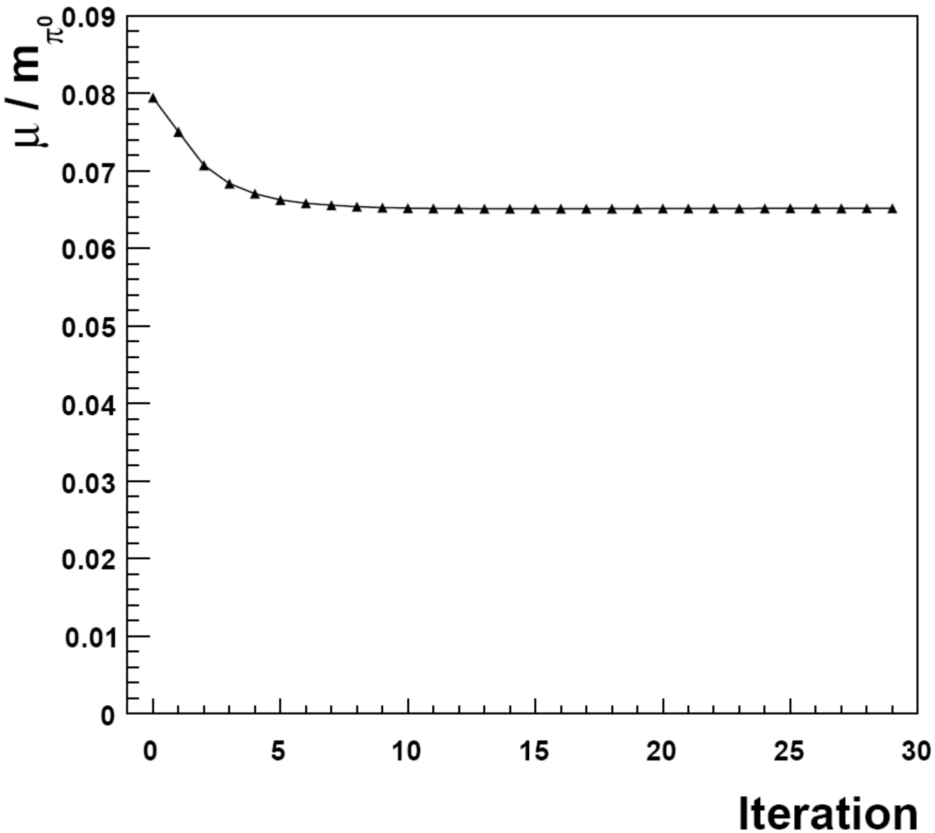
1. Reconstruct invariant masses. For every cell, take all invariant masses which has a cluster with a center in cell and plot those in a “cell histogram”.
2. In each “cell histogram”, find the π^0 mass by fitting the plots by Gaussian+polynomial.
3. Correct calibration parameters by adjusting π^0 mass to 135 MeV
4. Repeat until calibration is achieved, using the new calibration coefficients from step 3 in step 1.

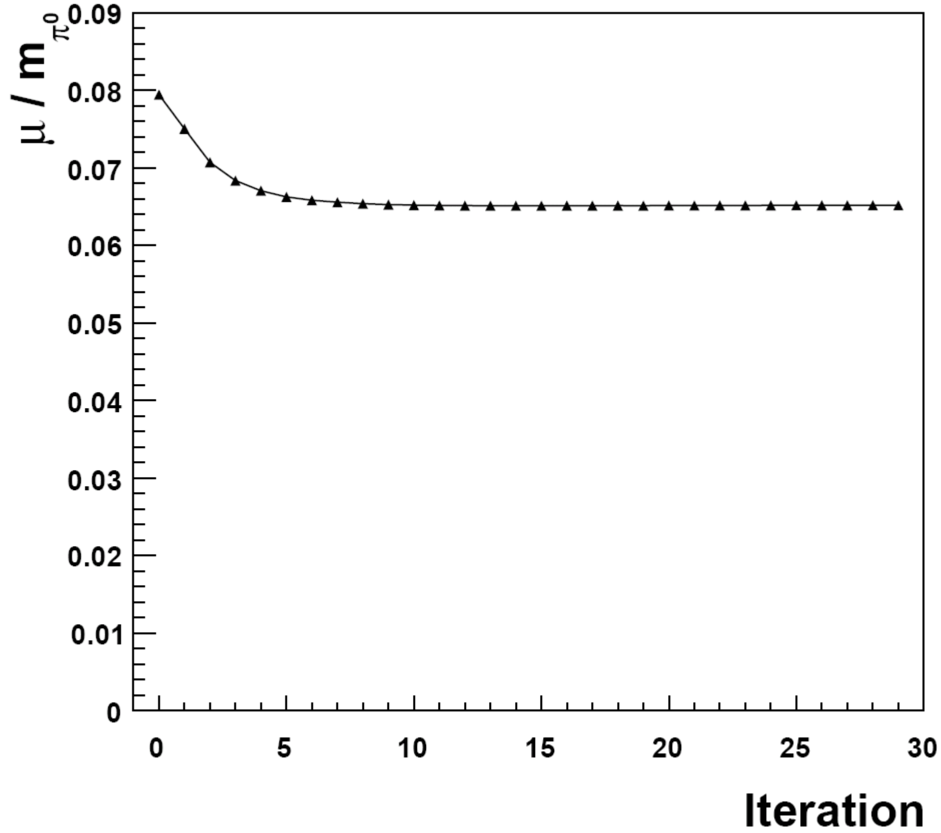
Simple converging function

$$c^{i+1} = c^{i} \times \left[1 + \left(\frac{135\,\mathrm{MeV}}{\mathrm{M}_{\pi^0}} \right)^2 \right] / 2$$

Convergence of iterations

Single π^0 at pT=10 GeV/c: H.Qvigstad





Each (i-th) iteration does:

1. Opens ESD/AOD, reads calibration parameter corrections calculated from (i-1)th iteration
2. Writes the output of the Calibration Analysis Task as a set of N histograms TH1 (N is a number of cells, N=18k for PHOS and N=11k for EMCAL)
3. Calibration analysis task analyzes data of several chunks in parallel (GRID jobs). Output histograms from all chunks should be merged to create an accumulated set of N histograms. Some bookkeeping is required to mark the merged chunks, in order to avoid double merging and missed chunks.
4. As soon as enough statistics is accumulated, the histograms are analyzed to calculate the new set of calibration parameters corrections
5. The output histograms and calibration parameters corrections are transient objects:
   - no need to store them in a persistent mass storage system.
   - Should survive until the i-th iteration processes the full statistics and full merging is completed

End of iterative calibration

- Criteria of the calibration procedure convergence:
  - Variation of the calibration parameters corrections in the (i-1)th and i-th iteration is less then ε_1;
  - Variation of the π_0 mass distribution width in the (i-1)th and i-th iteration is less then ε_2.
- After the final iteration, a new set of calibration parameters is calculated as a product of the initial calibration parameters from OCDB and the calibration parameters corrections.
  - Note that calculation of the new set of calibration parameters may require manual intervention.
- The new set of calibration parameters should be submitted to production managers to register to OCDB

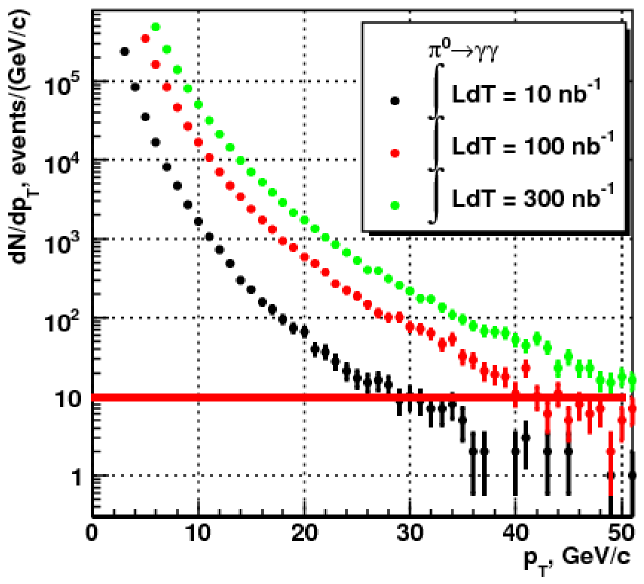
A step after offline calibration

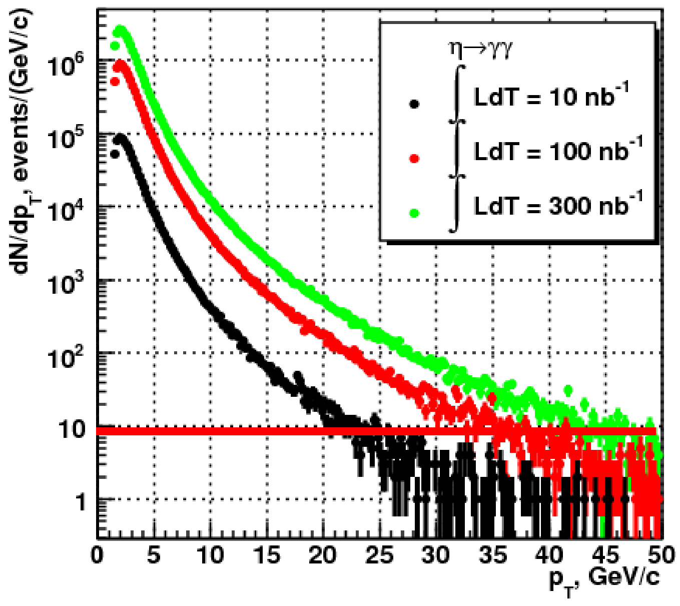
- Besides creating the new OCDB object, we aim to recalibrate the ESD created after the first reconstruction pass. For this, this first ESD should pass through another filter, and parameters of the CaloClusters (energies, coordinates, shower shape) should be recalculated with the use of corrections to the cell amplitudes found by recalibration procedure.
  - As a result of this filtering, a new AOD will be created with better calibrated CaloClusters. This new AOD should be used for the official physics analysis.

Summary

- π^0 analysis in both ALICE calorimeters PHOS and EMCAL is unified.
- All steps to achieve the final goal - π^0 inclusive spectrum can be adapted from PHOS to EMCAL:
  - Acceptance$\times$reconstruction efficiency
  - Raw spectrum extraction
  - Corrections due to photon conversion
  - Corrections due to off-vertex background
  - Trigger efficiency
  - Calibration
- Materials of the PHOS analysis WG can are available in http://indico.cern.ch/categoryDisplay.py?categId=662
- Simultaneous measurement of π^0 spectrum in PHOS and EMCAL is important for systematic error estimations
- Joining the efforts looks natural

Expected detection rate in PHOS





What will EMCAL provide?