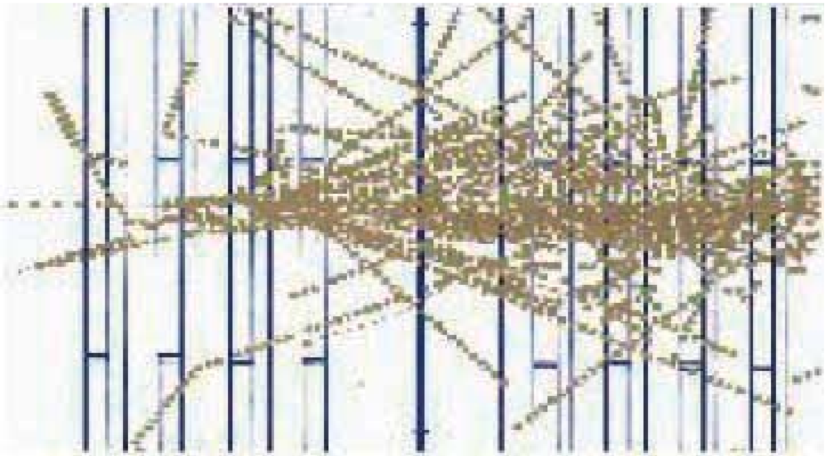
Test beam study of the PANDA Shashlyk calorimeter prototype



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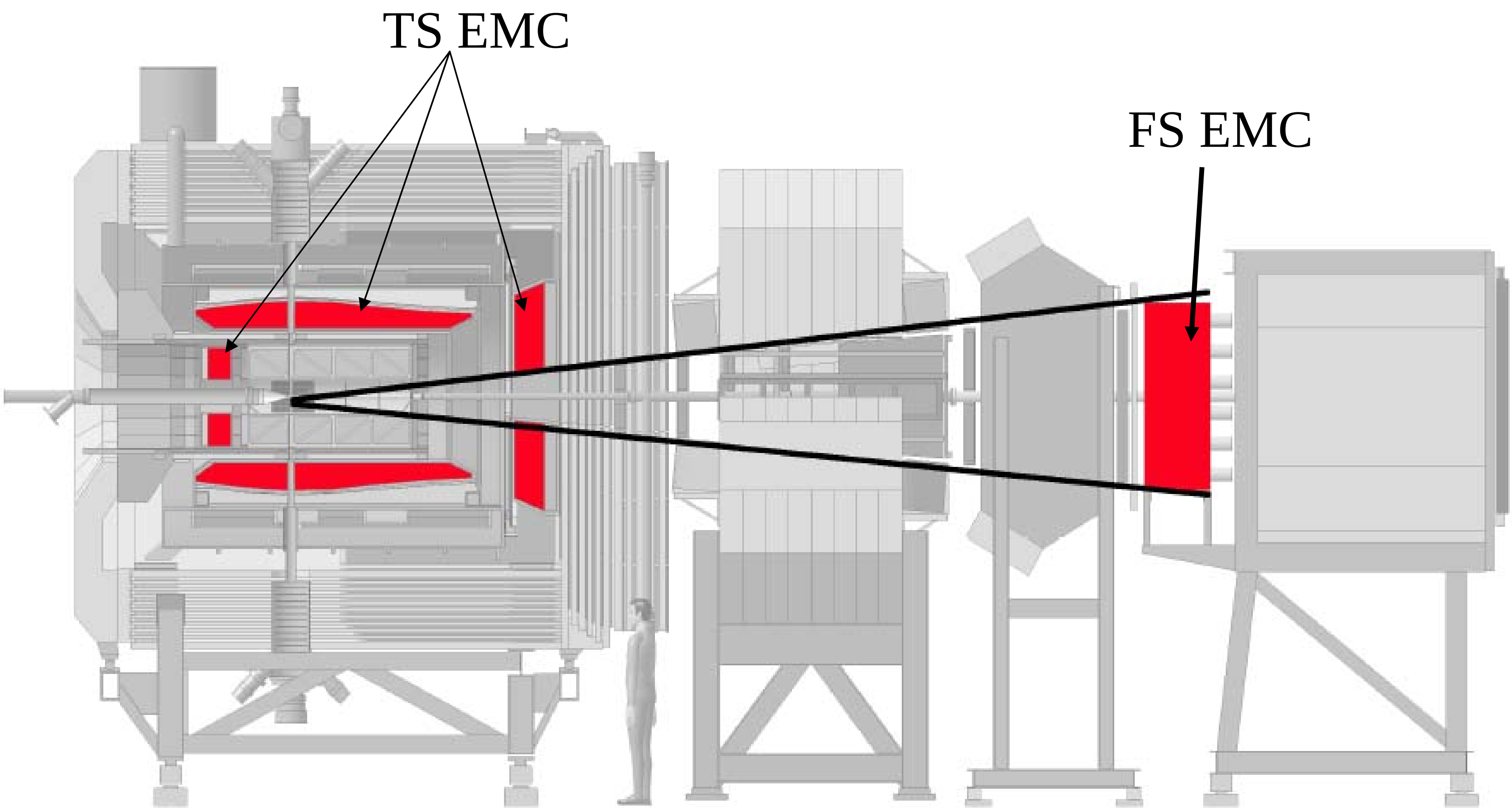
Outline

- PANDA detector overview and motivation
- Test beam setup and Shashlyk prototype
- Monte-Carlo simulation parameters
- Energy/Position resolution results
- Light output measurements
- Detection inefficiency due to mechanical inhomogenieties
- Plans for the near-term future
- Conclusions

Motivation

- The physics program of the PANDA (FAIR, GSI Germany) is based on a state-of-the-art universal detector for strong interaction studies at high intensity cooled antiproton beam with an energy up to 15 GeV. This program relies heavily on the capability to measure photons with excellent energy and position resolution. For this purpose PANDA has proposed to employ electromagnetic calorimeters using two different technologies:
  - a compact calorimeter around the target based on lead tungstate crystals
  - a fine-segmented Shashlyk-type calorimeter in the forward region covering area about 4 m^2
- Recently the improved electromagnetic calorimeter modules with a very fine sampling and an energy resolution of about $3\%/\sqrt{E}$ (GeV) for 50−1000 MeV photons have been developed for KOPIO project at BNL, and a prototype tested
- It is critical for PANDA to study parameters of the fine-sampling calorimeter in the wide energy region, significantly bigger than the one with the existing data – i.e. up to 15 GeV
- We tested parameters in the energy range from 1 to 19 GeV

PANDA detector overview

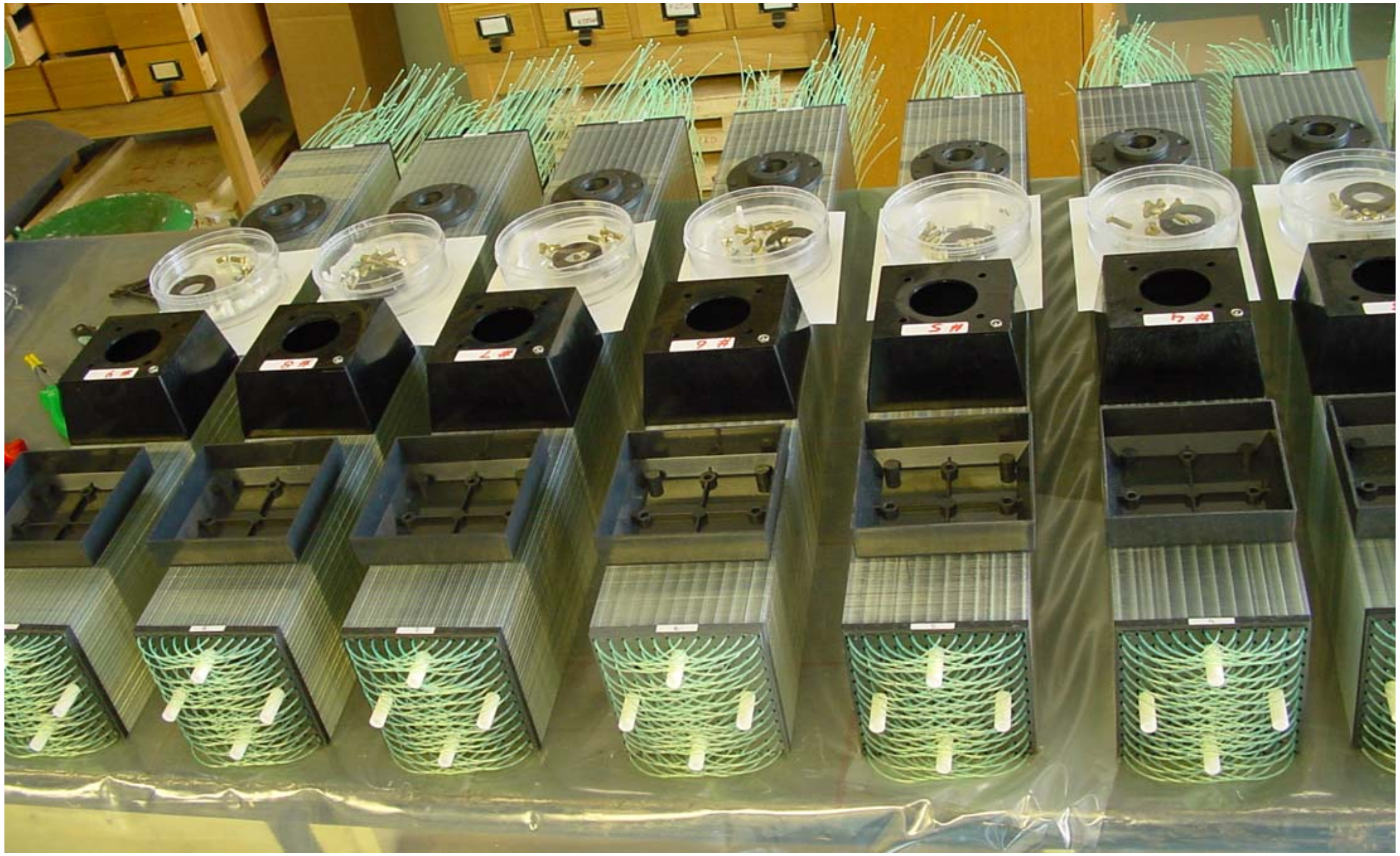


Shashlyk prototype parameters

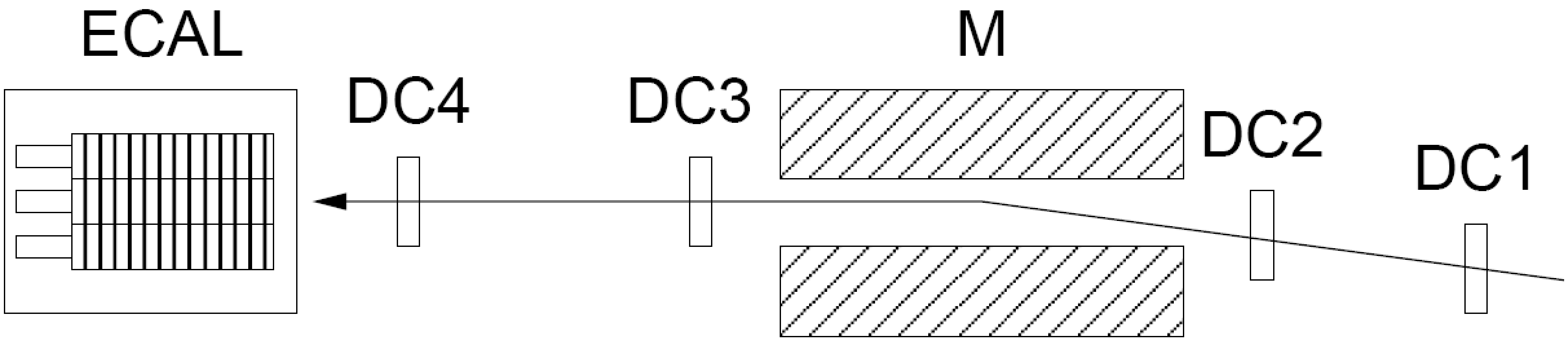
9 modules assembled in matrix 3x3

- Lead plate thickness: 0.275 mm
- Scintillator plate thickness: 1.5 mm
- Number of layers: 380
- Module size: 110 × 110 × 675 mm^3
- Effective Moliere radius: R_M=59 mm
- Effective radiation length: X_0=34 mm
- Total radiation length: $20X_0$
- Module weight: 18 kg
- Light collection: 144 (12×12) fibers BCF-91A (∅1.2 mm)
- Photodetectors : 10 dynodes PMT Hamamtsu R5800

Shashlyk modules produced at IHEP

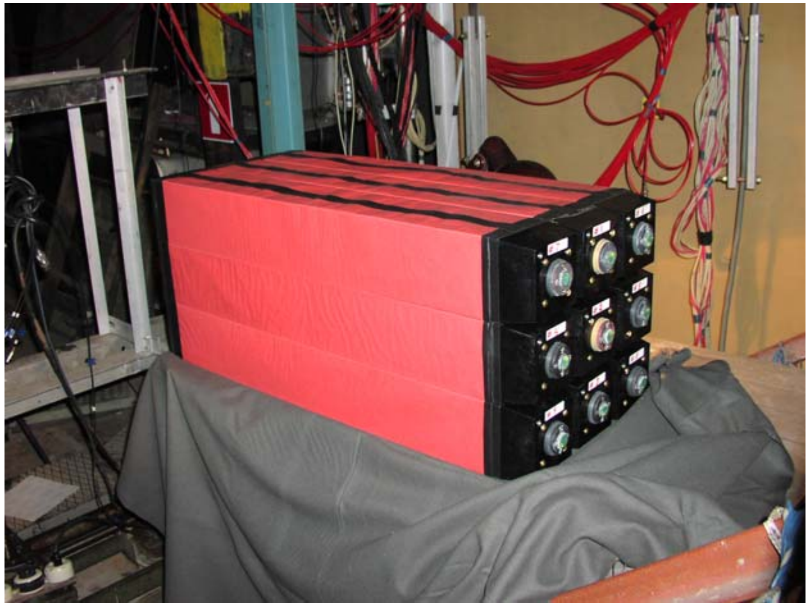


Test beam setup



- The secondary beam of negatively charged particles of momenta from 1 to 19 GeV/c contained electrons, muons, and hadrons, $\sigma_p/p > 3$ %
- DC1-DC4 - 4 sets of 2-coordinate drift chambers
- M – dipole magnet with bending angle 55 mrad
- Tagging system precision - $\sigma_p/p = 0.0013$
- Position coordinate was measured up to a precision of ~0.3 mm
- ECAL - Calorimeter prototype installed on a movable platform
- DAQ - VME and CAMAC with amplitude registration by 15-bit ADC modules LRS2285
- Time measurement from drift chambers by 10-bit TDC modules LRS3377

shashlyk prototype pictures

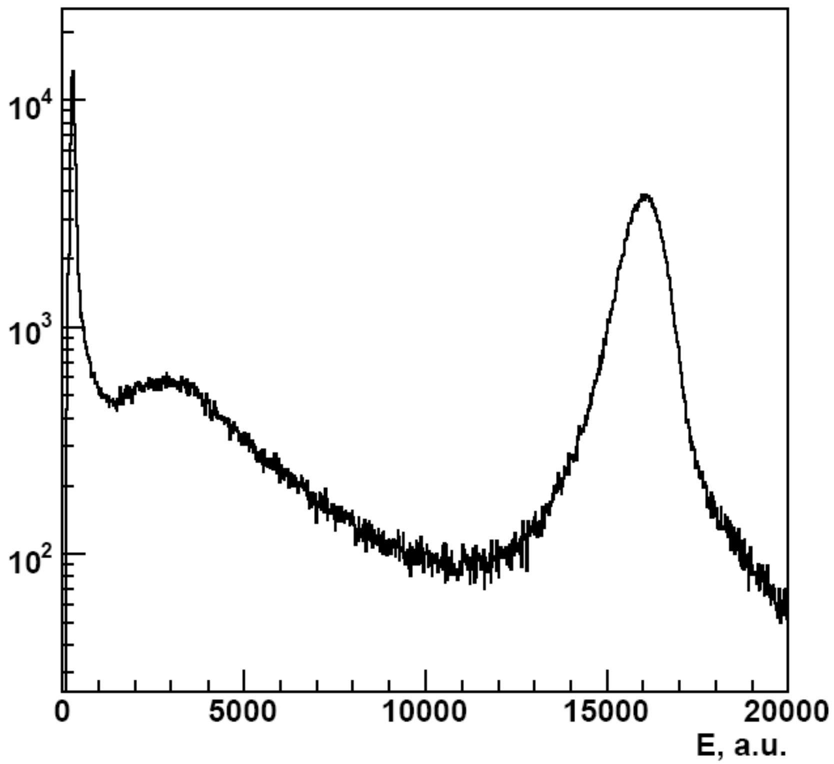


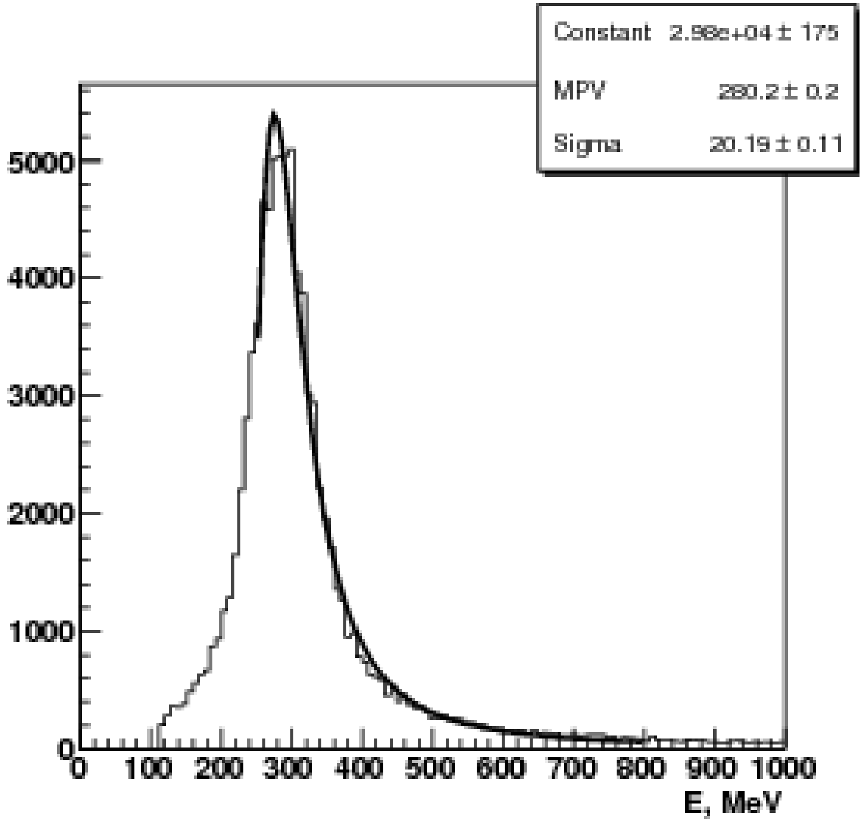
3x3 matrix of shashlyk modules and PMT attached to the modules

Monte Carlo simulations

- The relevant simulation tools were developed
- GEANT3 as a Monte Carlo engine with detailed description of materials and module geometry
- The detailed light propagation was applied taking into account optical properties of materials, reflections at plate borders, light capture by fibers taking into account the cladding and the Cherenkov light production and propagation inside the fibers
- Simulation parameters:
  - attenuation length in the scintillator: 70 cm
  - attenuation length in the fiber: 400 cm
  - scintillator refraction index: 1.59
  - inner reflection efficiency at large scintillator faces: 0.97
  - reflection of diffusion type at side scintillator faces: 0.97
  - reemission probability in fiber: 0.1
  - mean deposited energy for 1 optical photon in scintillator: 100 eV
- Cherenkov photons are generated by GEANT
  - Thresholds for e/γ: 10 KeV

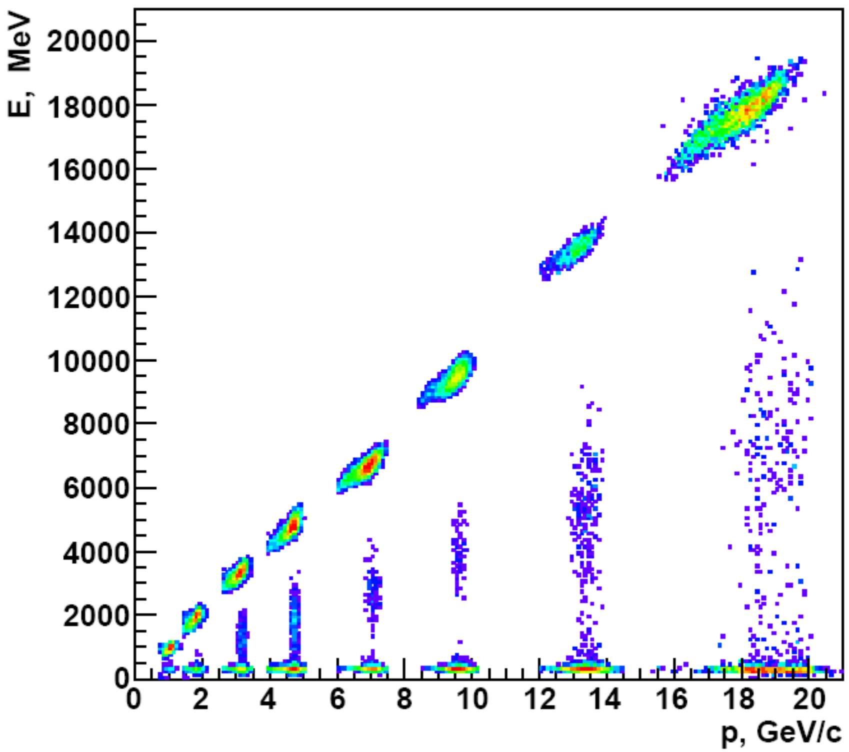
Calibration

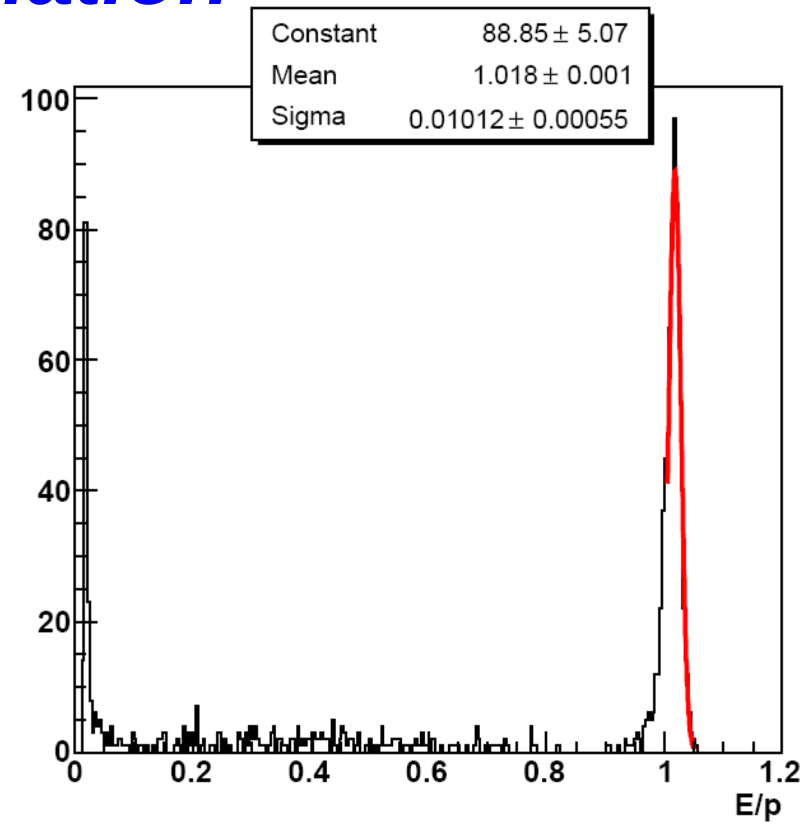




- Modules were calibrated by a 19-GeV beam using the x,y-moving table
- Best relative calibration coefficients - by equalizing MIP signals
- Absolute calibration - by setting the total E_{dep} in 3×3 matrix to 19 GeV
- Selection for MIP calibration – only one module has E_{dep} > 100 MeV
- MIP peak fitted by the Landau, MPV → served for relative calibration

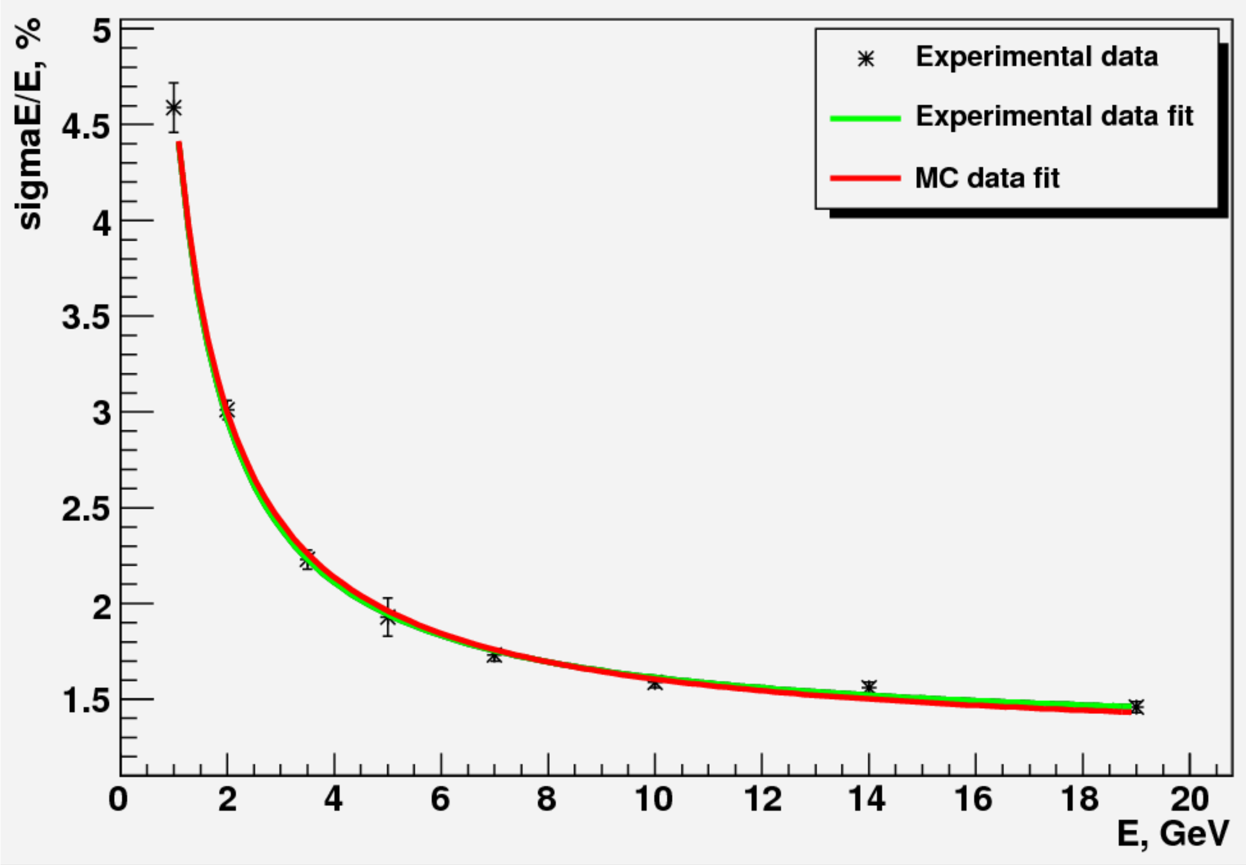
E vs P correlation





- Fixed ECAL, beam hitted central cell, exposed at 1, 2, 3.5, 5, 7,10, 14, 19 GeV
- Magnetic field in the magnet M was adjusted to provide the same bending angle
- p (measured by spectrometer) and E (by ECAL) are linearly correlated
- To obtain a true energy resolution, the measured E should be corrected by p
- Energy resolution - from the Gaussian fit of the right peak around E/p = 1

Energy resolution



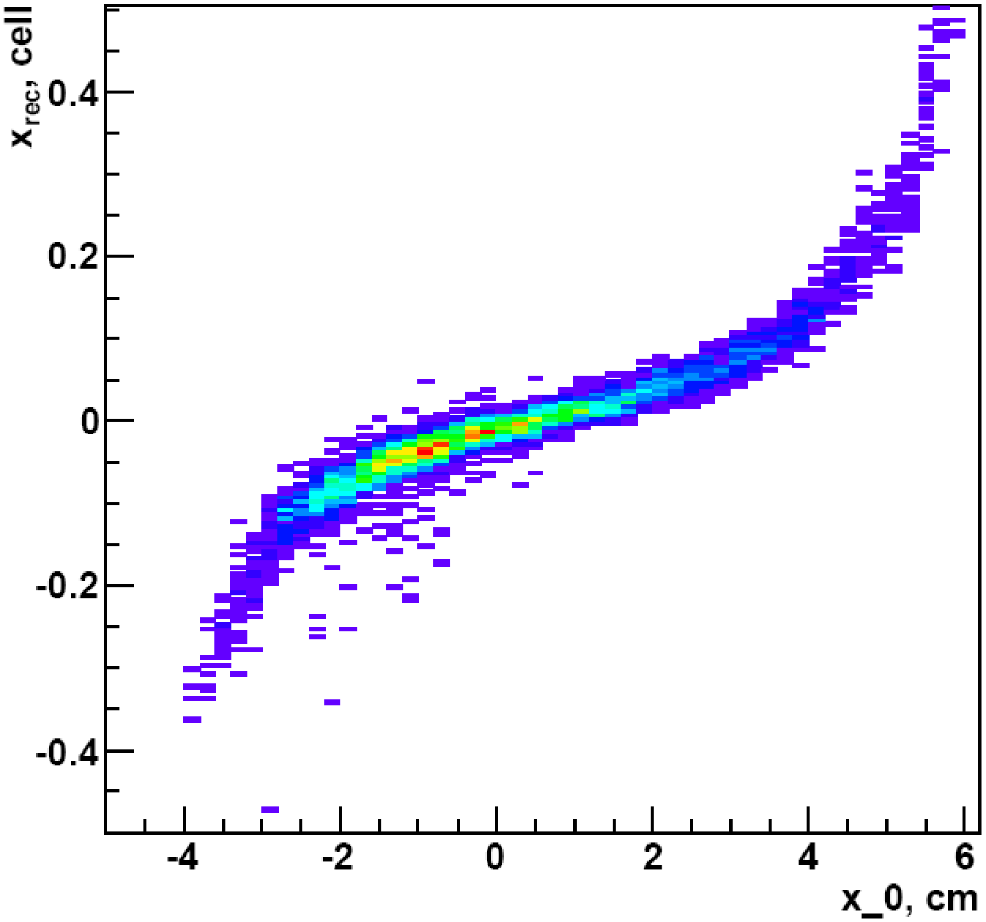
- Fit by the function:

$$\frac{\sigma_E}{E} = \frac{a}{E} \oplus \frac{b}{\sqrt{E}} \oplus c$$

- Experimental data:
  - a = 3.5 ± 0.3
  - b = 2.8 ± 0.2
  - c = 1.30 ± 0.04
- MC:
  - a = 3.3 ± 0.1
  - b = 3.1 ± 0.1
  - c = 1.23 ± 0.02

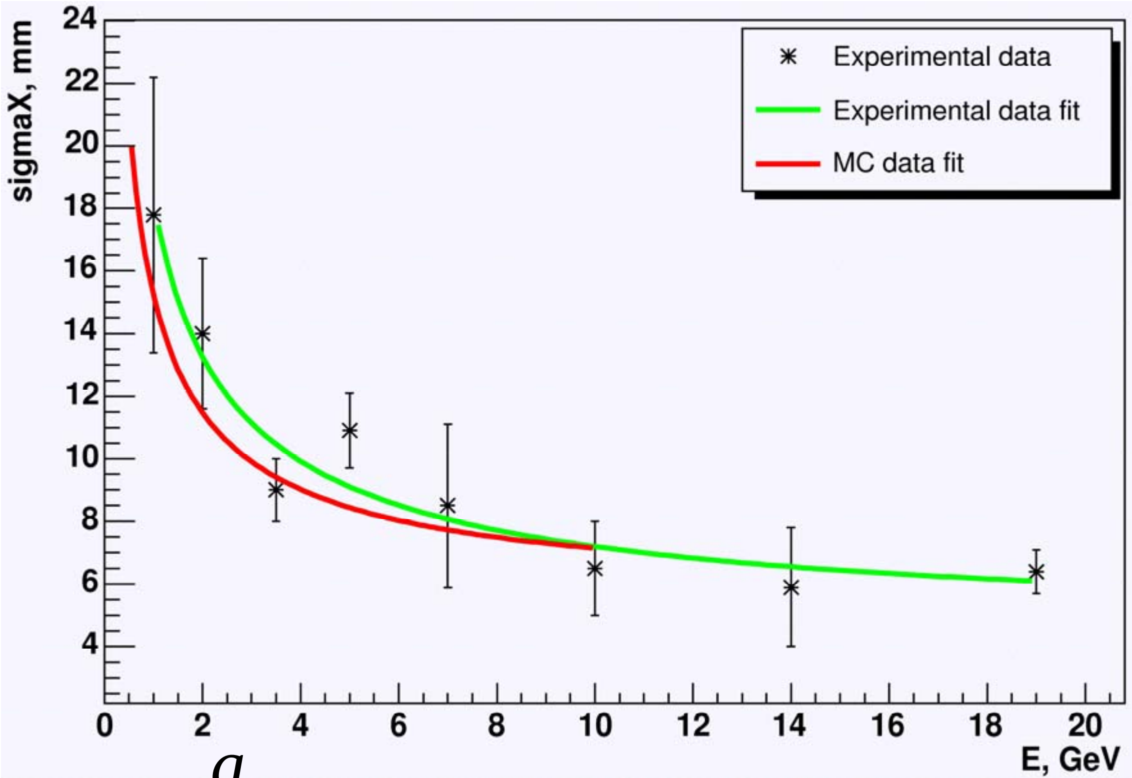
- Good agreement with MC
- Good agreement with previous studies at lower energies (2.9%/ √E at 50-1000 MeV: G.S.Atoian et al., NIM A 584 (2008) 291)

S-Curve



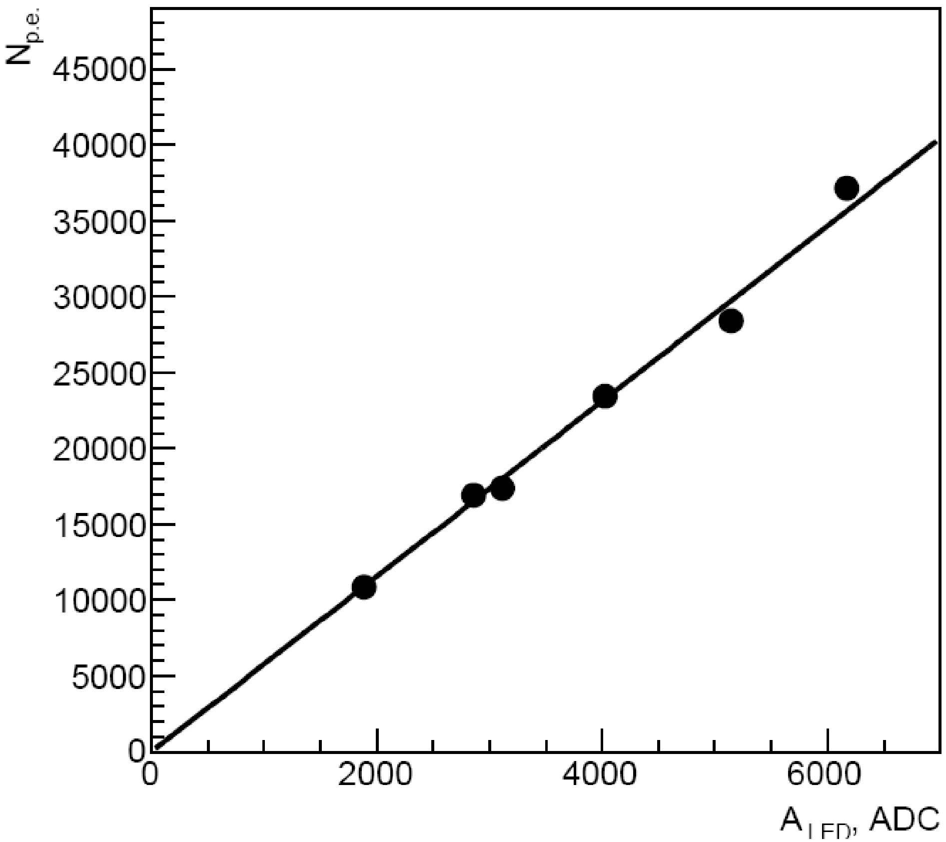
- A position resolution has been measured by comparison of exact impact coordinate of the beam particle, measured by the last drift chamber DC4, and the center-of-gravity of the electromagnetic shower developed in the calorimeter prototype

Spatial resolution (center)



- Fit by: $\sigma_x = \frac{a}{\sqrt{E}} \oplus b$ [mm], E in GeV
- Experiment: a = 17.6 ± 0.9, b = 4.6 ± 0.9
- MC: a = 14.2 ± 0.6, b = 5.5 ± 0.9
- Resolution near the module edge is 3 times better

Light output



- Light output was measured with the highly stable LED light
- A set of runs with 6 different LED amplitudes
- $N_{p.e}$~$(A/\sigma_A)^2$, where
  - A - LED amplitude
  - σ_A - dispersion
- Slope - the number of p.e. per one ADC count
- Dividing by the calibration coefficient → $N_{p.e.}$ detected by the PMT, when E_{dep} = 1 MeV per module
- $N_{p.e.}$ = 5.3 ± 0.2 per 1 MeV

Detection inefficiency

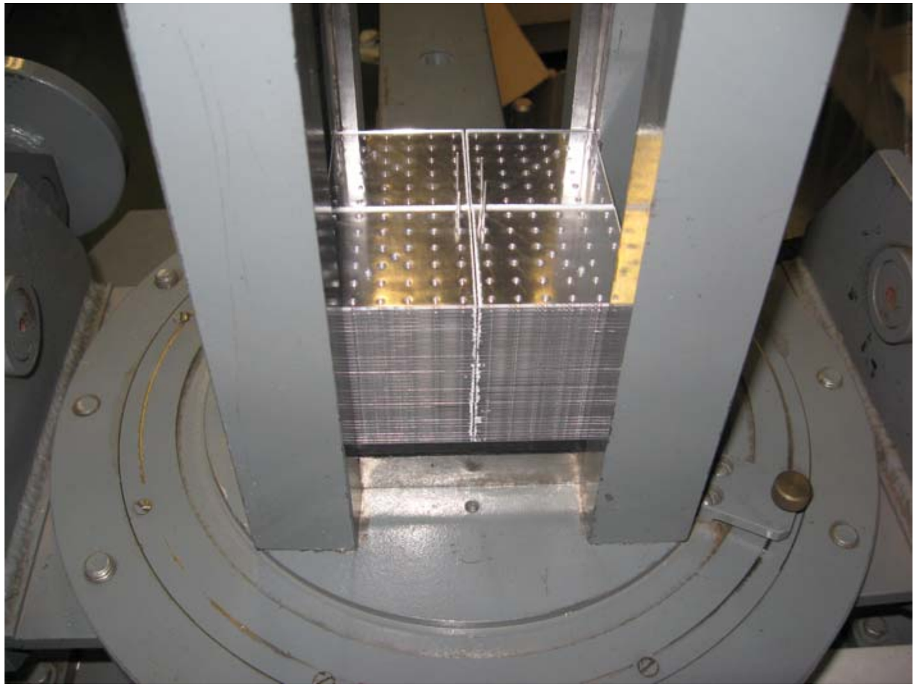
- Due to various mechanical inhomogeneities (holes for WLS fibers, steel strings, boundaries between modules) one can expect to observe the dependence of E_{dep} on the hit coordinates
- In PANDA environment minimal angle of incident particles in FS EMC is 1.7^0
- MC studies showed that lateral non-uniformity has turned out to be negligible even for this minimal incident angle
- $<E_{dep}>$ was measured as a function of (x, y) for two energy intervals, E < 0.5 GeV (MIP) and 16 < E < 22 GeV (electromagnetic shower)
- Within the available statistics, no lateral non-uniformity of the energy response is observed

Plans for the near term future

- Improve spatial resolution by using more complicated reconstruction methods – “shower pattern” method etc
- Confirm the absence of lateral non-uniformity or find the criteria/conditions when non-uniformity is observable
- We plan to have shashlyk test beam run in 2008 with prototype of 8x8 cells
- Test beam studies will include prototype energy and position resolution as well as test of π^0 reconstruction capabilities in the energy range up to 15 GeV
- MC studies of energy and position resolution for small cell (55x55 mm^2 and 70x70 mm^2)
- Neutrals reconstruction MC studies for different cell sizes
- Development of the enhanced methods of reconstruction
- Manufacturing of the prototype with 55x55 mm^2 cell sizes is started at IHEP

Shashlyk prototype production at IHEP

Shashlyk prototype production at IHEP

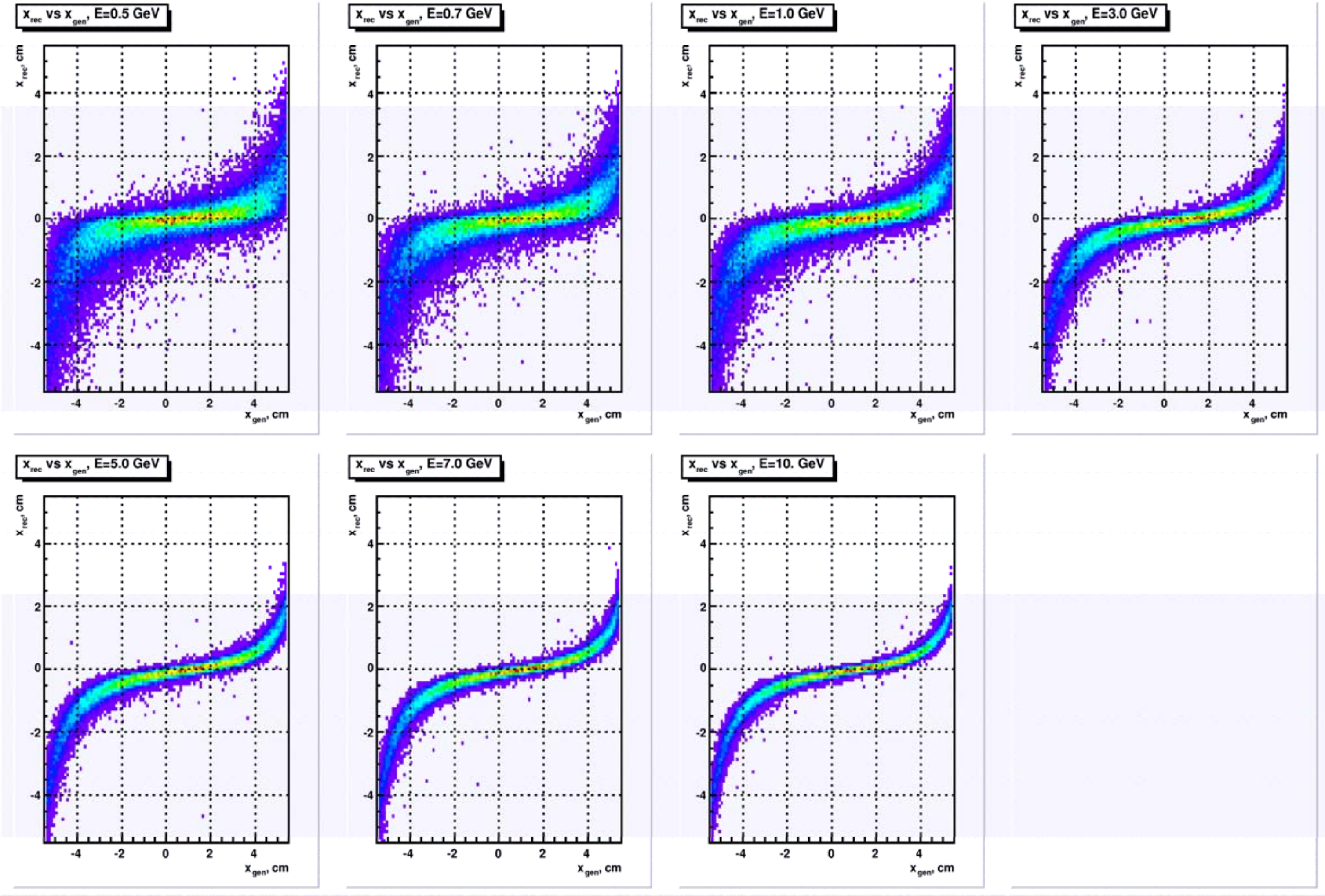


Conclusions

- The measurements of energy and position resolutions of the electromagnetic calorimeter prototype of fine-sampling type have been carried out at the IHEP test beam facility at the Protvino 70 GeV accelerator:
    - **Energy $\sigma_E/E = 2.8/\sqrt{E} \oplus 1.3 \oplus 3.5/E$ [%]**
    - **Position (at the cell center) $\sigma_x = 17.6/\sqrt{E} \oplus 4.6$ [mm]**
    - **Good agreement with MC results**
    - **Consistent with the previous results at lower energies**
- The measured $N_{p.e.}=5.3 \pm 0.2$ per 1 MeV deposited within module
- The non-uniformity of the energy response due to mechanical inhomogenities has turned out to be negligible. MC is in good agreement with experimental results
- Final conclusion on lateral sizes of the FS EMC cells as well as on Shashlyk longitudinal sampling structure could be done only after study of reconstruction efficiency of π^0-mesons at upcoming test beam with 55x55 mm cell size prototype

BACK-UP SLIDES

S-curve MC (0.5 – 10 GeV)



Big cell vs small cell

- 350 110x110 mm^2 cells vs 1400 55x55 mm^2 cells
- Angular resolution of big cell twice worse then in target EMC forward endcap (testbeam results)
- For efficient neutral pions reconstruction usually we need two showers with >1.5 cell distance
- Detailed MC studies to compare reconstruction efficiency with big and small cells