Report from SAND Calibration WG

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for the SAND Calibration WG

Meeting annuale della
Collaborazione DUNE Italia
October 29, 2024

Dipartimento di Fisica
Sapienza Università di Roma
INFN Istituto Nazionale di Fisica Nucleare

SAND Calibration WG

- Calibration: from detector signals to physical variables
  - ECAL: energy, time and positions of the particles
  - GRAIN: tracks, time, energy, ...
  - Tracker : r-t relations, track momentum, dE/dx for PID, ...
  - Timing alignment among the subdetectors
- Define a strategy for each subdetector:
  - Sources: cosmics, particles from beam, …
  - Choose suitable processes (given the expected fluxes of particles in the detector, e.g. for the ECAL: cosmic μ's as MIPs, MIPs from the beam, electrons and photons ....)
- Set a calibration procedure (Which level of precision ? How much time expected ?)
- Reference people: ECAL - P.Gauzzi, GRAIN: A.Surdo, Tracker: ……
- WG meetings generally every three weeks, on Thursday at 3 p.m. CET
- WG mailing list: dune-nd-sand-calibration@fnal.gov

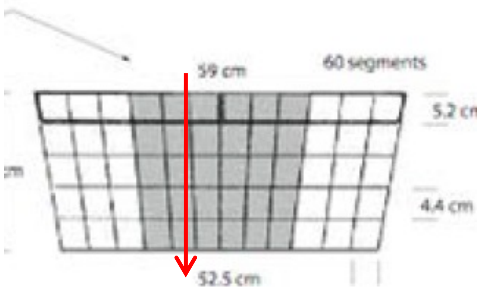
Studies on ECAL Calibration

R.D'Amico – P.Gauzzi

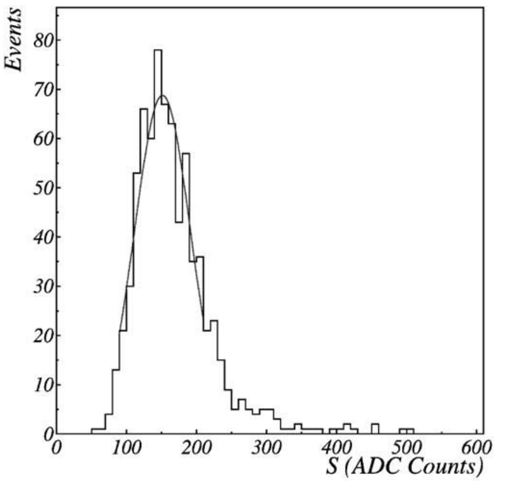
ECAL calibration in KLOE

- Calibration constants C_i determined with cosmic rays, Data-taking without circulating beams: muons = MIPs

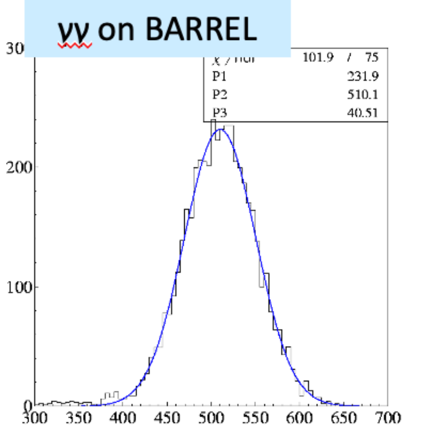
- 2.5 kHz of cosmics ⇒ "golden" MIPs, ~ 100 Hz



1 day data-taking ⇒ ~ 10^3 evts/cell
C_i = peak of the MIP distribution
⇒ ~ 1 – 2 % accuracy
Repeated every few months



- Average energy scale 38 MeV / MIP crossing a cell at the center (measured at test beams)
- Absolute energy scale set with Bhabha scattering events ($e^+e^-\rightarrow e^+e^-$) and $e^+e^-\rightarrow \gamma\gamma$: showers of 510 MeV
- Repeated every run (every 1 or 2 hours)
- 4 — 5 × 10^4 Bhabha evts in the Barrel
  $O(10^5)$ in the Endcaps
  $10^3 – 10^4$ γγ events in one run

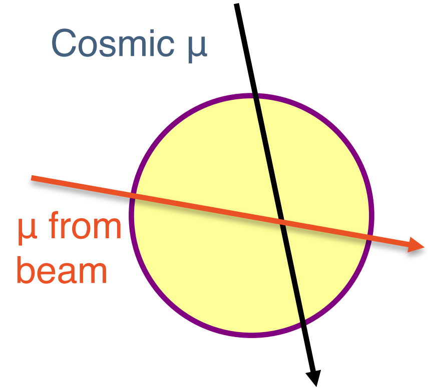


ECAL calibration in SAND

MIPs from cosmic rays: muon flux at surface ~ 0.02 μ/(s cm^2)

⇒ ~ 10^4 μ/s on ECAL (⇒ 100 Hz of "golden mips" in KLOE)

- Underground reduction of a factor of about 100 ⇒ ~ 100 μ/s on ECAL (no selection)
- Rough estimate by rescaling the KLOE numbers ⇒ 1 day (24 hrs): ~ 10 evts/cell
- Relaxing the "golden mip" selection: in few days ~ 10^3 evts/cell



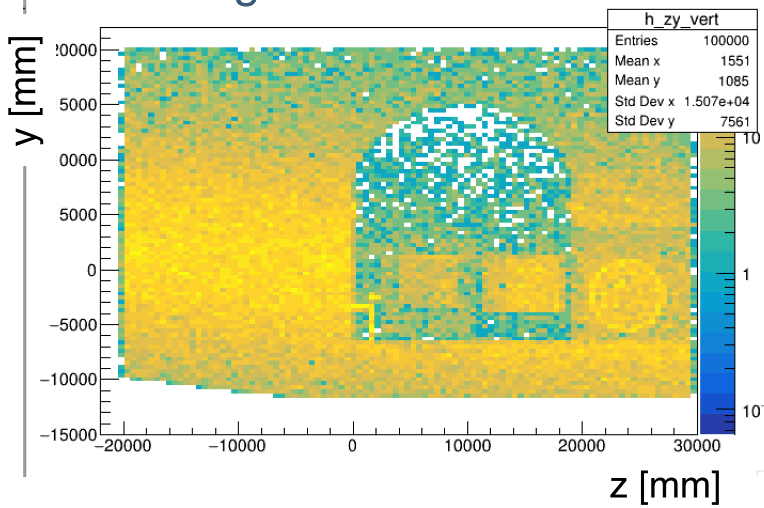
MIPs from beam (rock, magnet and Fe yoke,

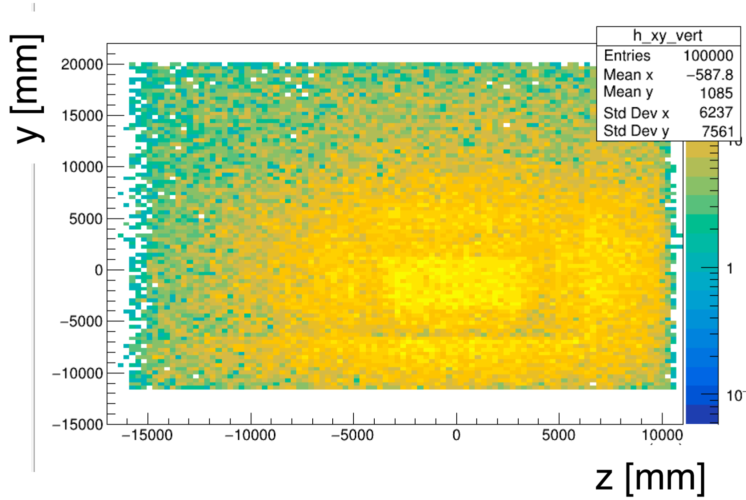
upstream ECAL modules)

- We need also muons from beam for the modules
  around the median plane and for the endcaps
- Started MC study of the rate of muons from beam events reaching the ECAL

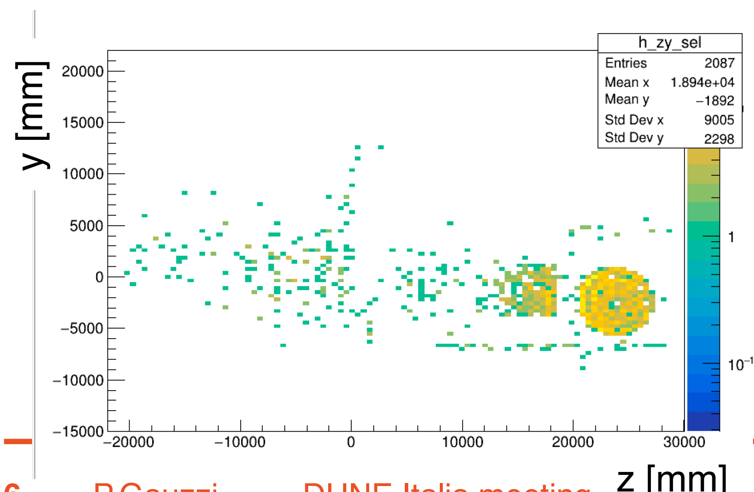
MIPs from beam

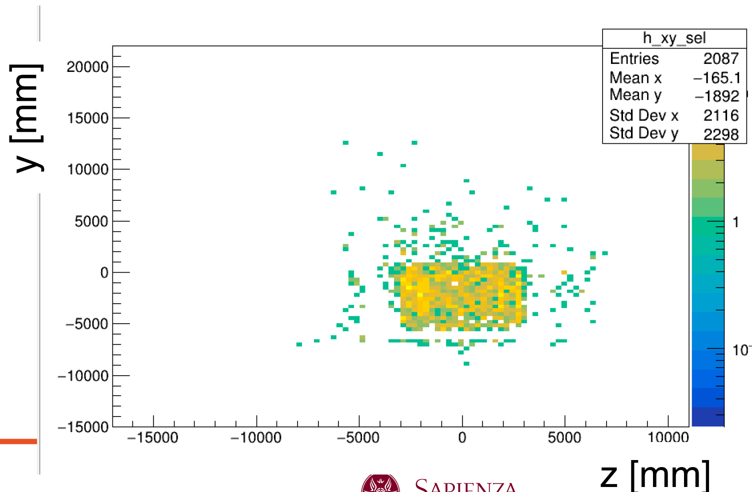
- Generation of 100000 ν_μ events with vertices in the hall and in the rock surrounding the hall



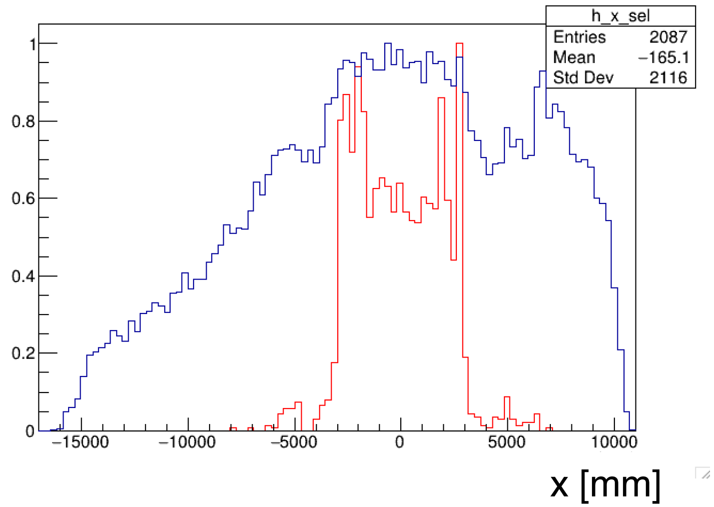


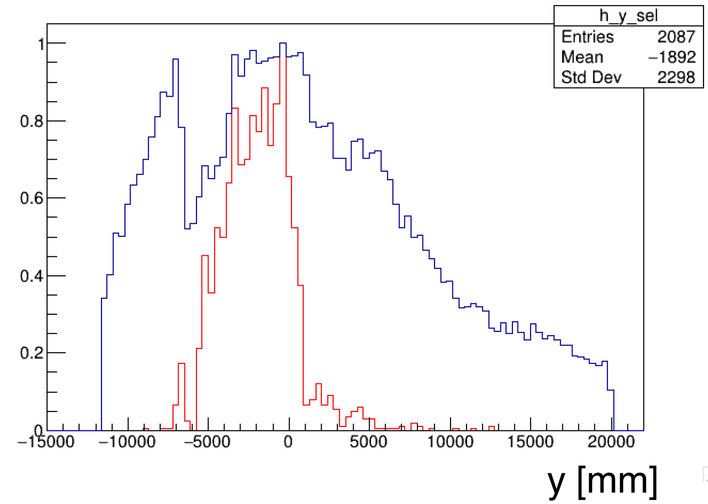
- Selecting events with at least a muon in the ECAL ⇒ ~ 2000 evts.





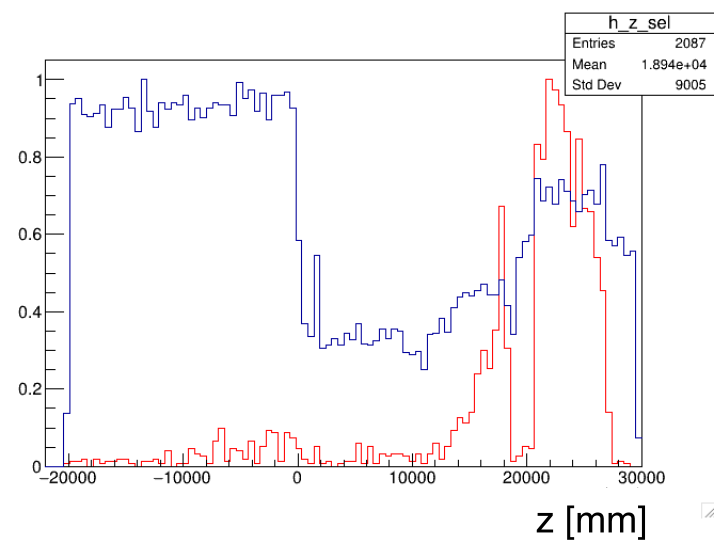
MIPs from beam





— All events

— Events with at least one muon in the ECAL

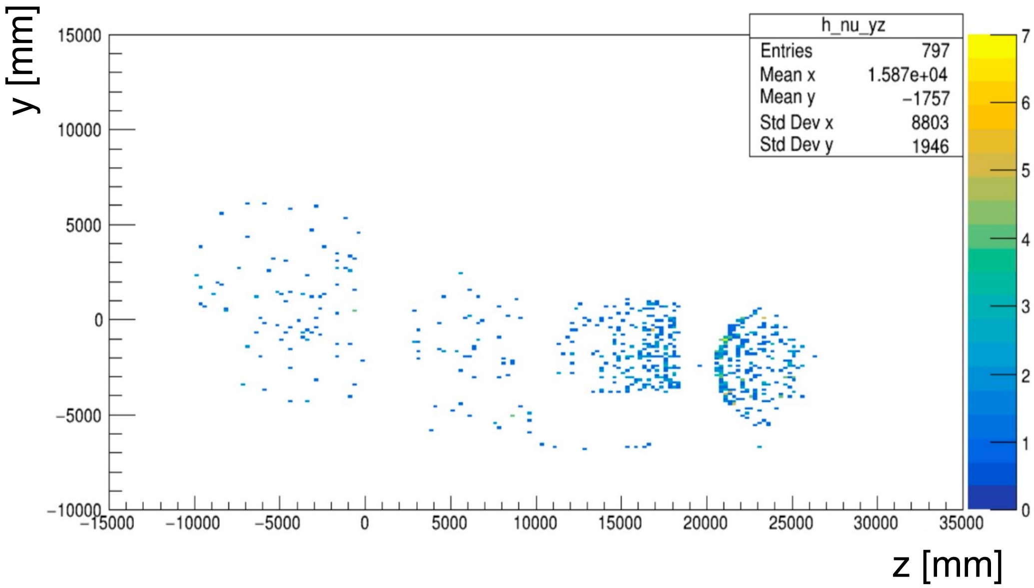


- We can restrict the generation window to DUNE_ND_HALL (X and Y in ~ -6.0 – 6.0 m) and to cut at Z > -10 m

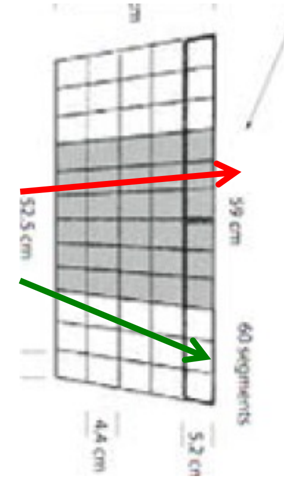
MIPs from beam

- Test: generation of 25000 ν_μ in that window ⇒ 797 events with at least 1 cluster from μ
- This sample corresponds to ~ 30 spills

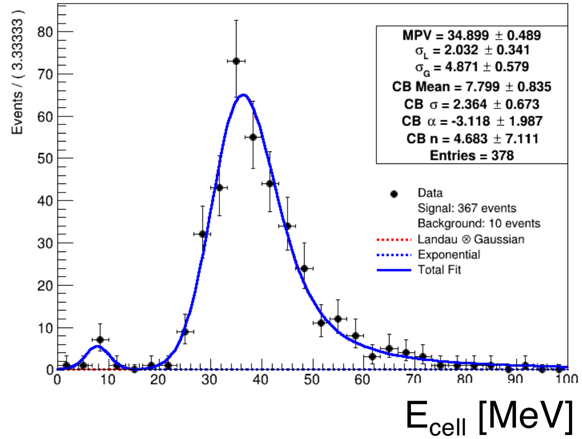
Vertices	
Rock	104
Fe Yoke	224
ECAL upstream modules	86
TMS	278
Cryostat/Solenoid	28
Others	57



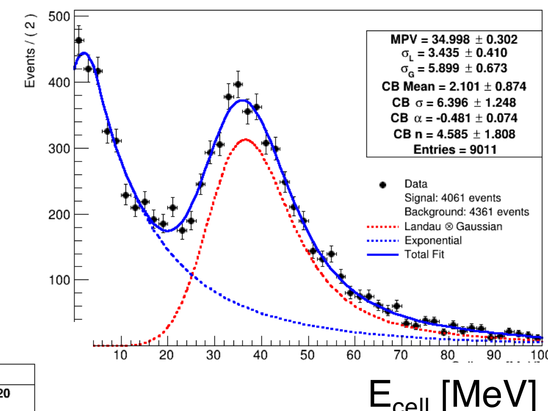
MIPs from beam



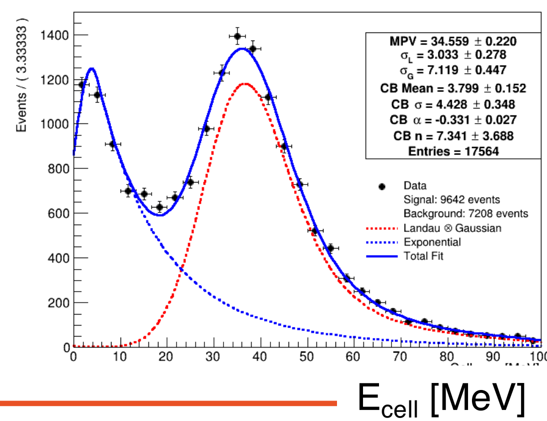
- Golden mips: all the cluster cells in the same column
- Low statistics
- Clean distribution
- Good peak fit



- Less stringent selection: at least 3 cells in the same column
- Peak still clear

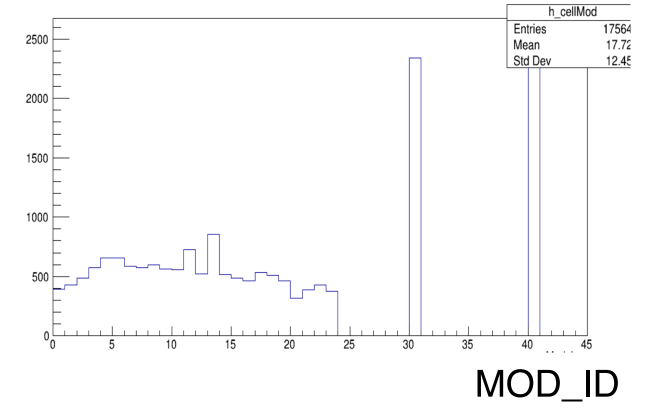


- No conditions on muon clusters

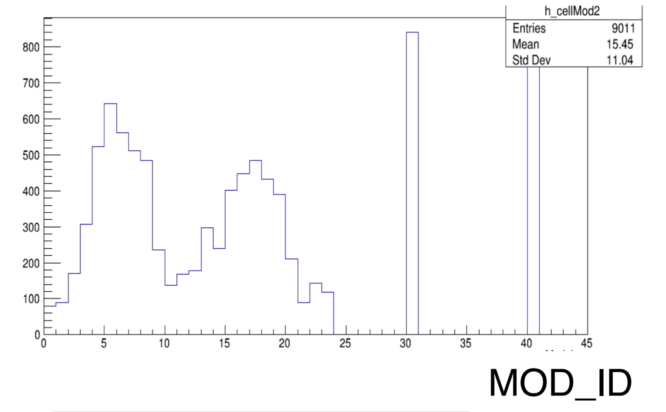


MIPs from beam

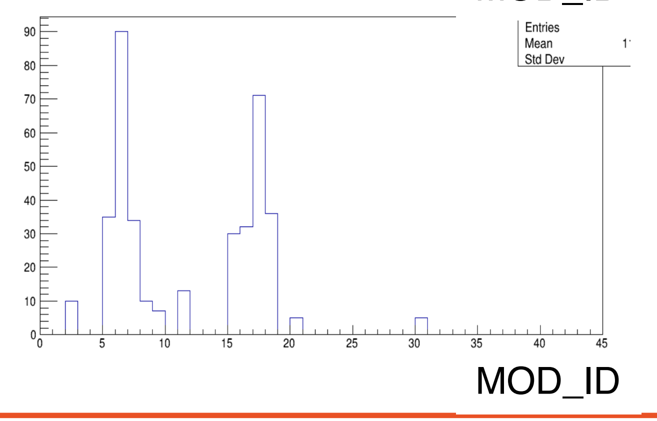
- Occupancy:
  - No conditions on muon clusters



  - At least 3 cells in one column



  - Golden mips

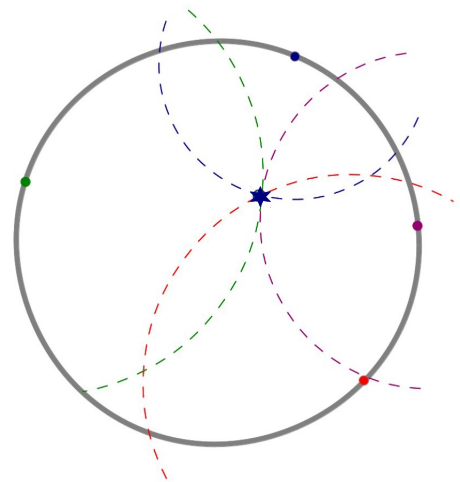


Energy scale calibration in SAND

- γ's from π^0 decays, invariant mass reconstruction (need a vertex from the tracker)
- γ + electrons: ~ 30% of photons from π^0 convert in the tracker

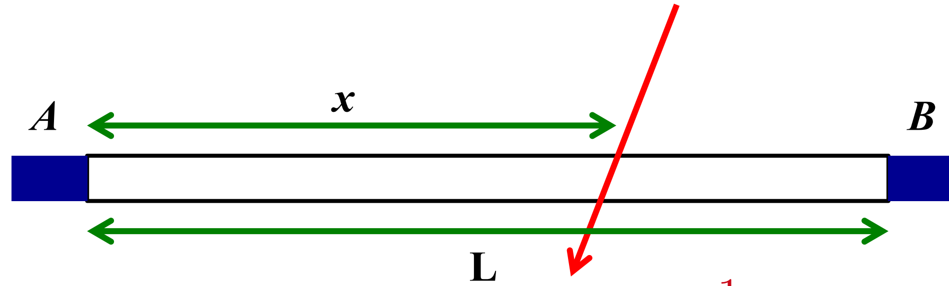
  $\Rightarrow$ ~ 50% of π^0 have at least one $\gamma \to e^+e^-$. (from DUNE-doc-13262 A Near Detector for DUNE)
- High energy electrons from ν_e interactions $\Rightarrow$ need the momentum measurement in the tracker

- Possibility to exploit $K^0 \to \pi^0\pi^0 \to 4\gamma$
- From a naive rescaling of $K^0 \to \pi^+\pi^- \Rightarrow O(10^5)$ evts in 5 years of FHC data-taking
- Reconstruct a vertex with the ECAL only, back-propagating each of the 4 photons, but the times of the ECAL cells must be very well aligned



Time calibration

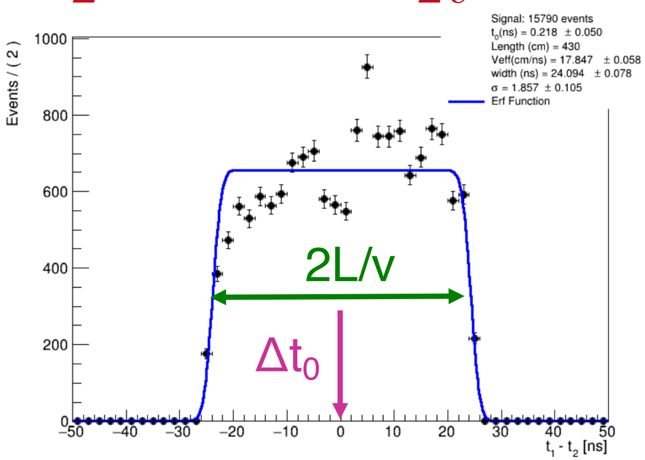
- MIPs: uniform illumination of the ECAL for calibration of time and coordinate along the fibers



$$t_0 = \frac{1}{2}(t_A^0 + t_B^0)$$

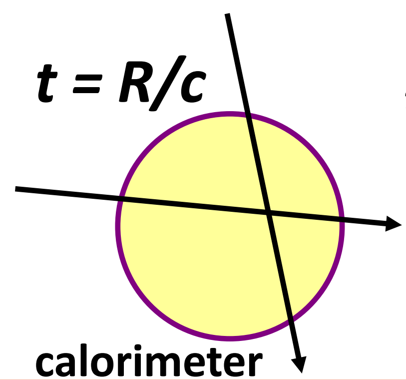
$$\Delta t_0 = \frac{1}{2}(t_A^0 - t_B^0)$$

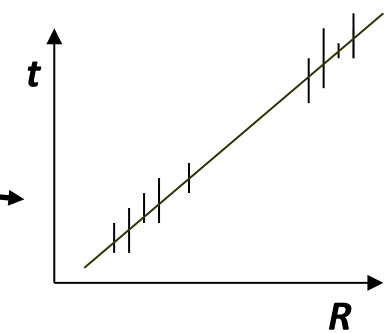
$$t = \frac{1}{2}(t_A + t_B) - \frac{L}{2v} - t_0 - t_G^0 \qquad x = \frac{1}{2}v(t_A - t_B) - \Delta t_0$$



Fit function: sum of two Error functions
Width ⇒ 2L/v , L =430 cm fixed,
v free parameter ≈ 17 cm/ns

- t_0's from fit of straight tracks (p > 6 GeV): cosmic muons and beam muons





Conclusions

- We need both cosmic and muon beams for the ECAL calibration
- Evaluating the rate of good muons from beam from MC
- Next steps:
  - Produce few x 10^6 events to increase the statistics
  - Define a strategy to calibrate the Endcaps and the modules with low statistics
  - Start the study of the energy scale calibration

- Strategy of time alignment with the other subdetectors has to be studied

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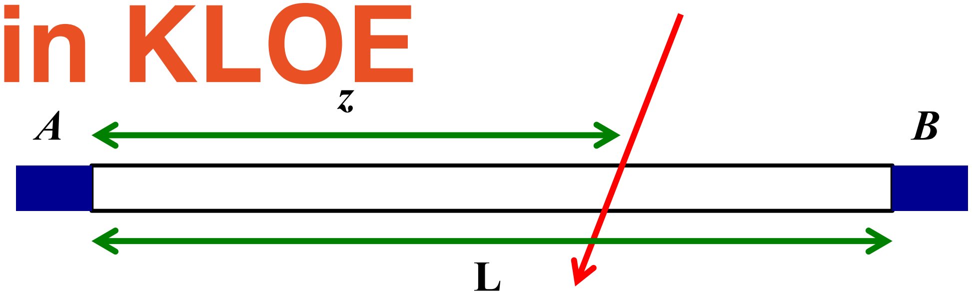
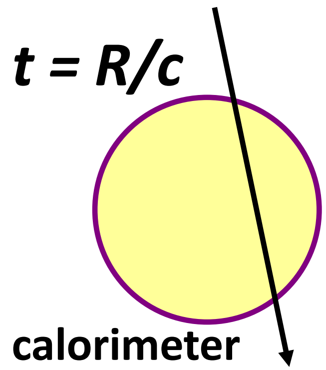
Time calibration in KLOE

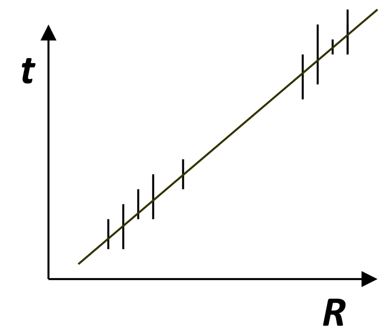
- MIPs: uniform illumination of the ECAL for time and z-coord. calibration

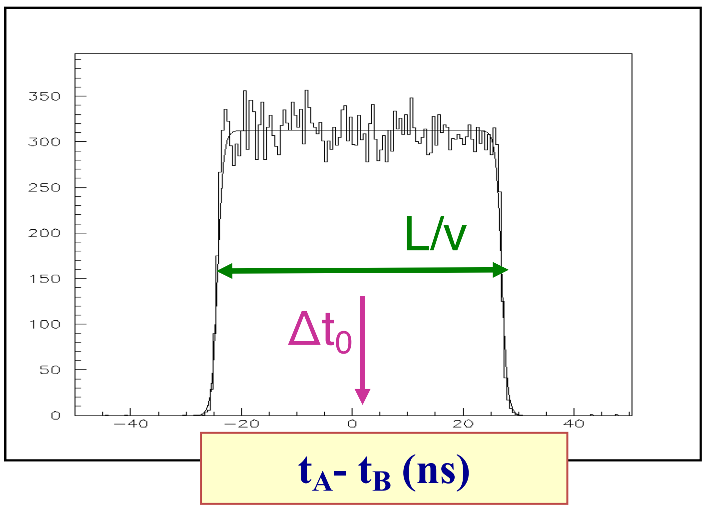
$$t = \frac{1}{2}(t_A + t_B) - \frac{L}{2v} - t_0 - t_G^0$$

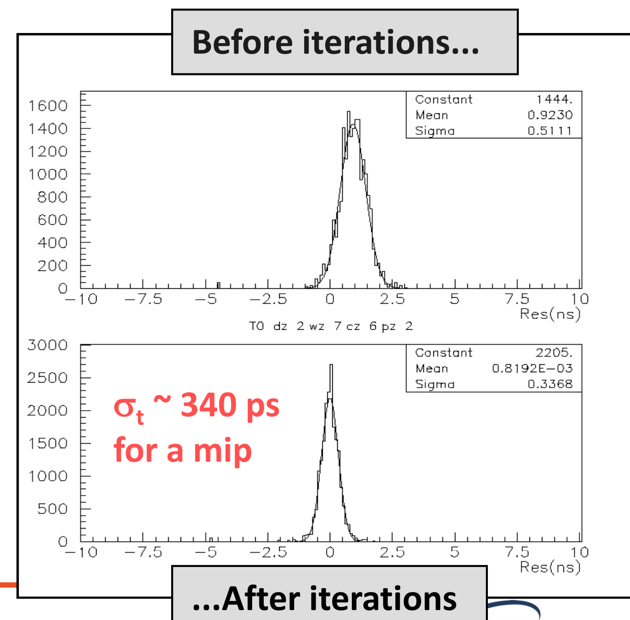
$$z = \frac{1}{2}v(t_A - t_B) - \Delta t_0$$





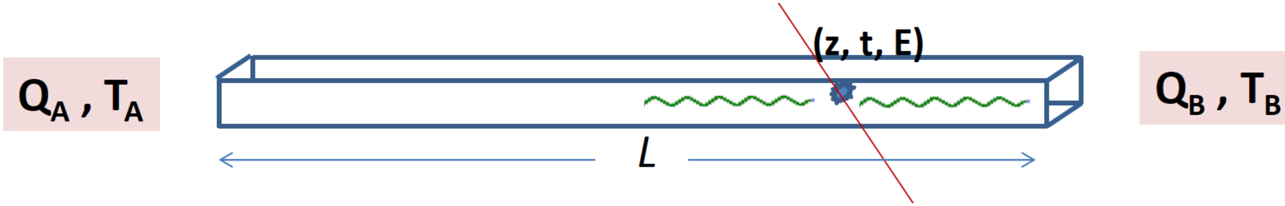






- Fine determination with Bhabha and γγ t_0's at ~ 20 ps

Time calibration in KLOE



$$E_i^{(A,B)}[\mathrm{MeV}] = \frac{(Q_i^{(A,B)} - P_i^{(A,B)})[\mathrm{ADC\ counts}]}{C_i[\mathrm{ADC\ counts/MIP}]} K \times f_{MIP2MeV}[\mathrm{MeV/MIP}]$$

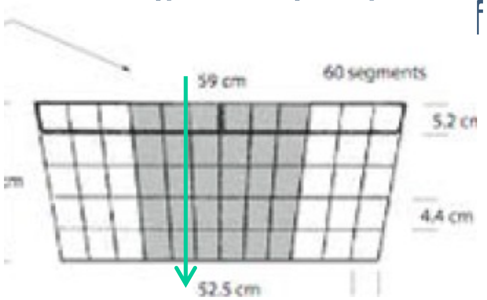
- C_i = peak of the MIP distribution
- **Corrections to the C_i with the Bhabha scattering events ($e^+e^- \rightarrow e^+e^-$): showers of 510 MeV**
- **Absolute energy scale K fixed at cluster level with the $e^+e^- \rightarrow \gamma\gamma$ events**

$$\Rightarrow \mathrm{Calib.\ Const.} = \frac{K}{C_i}$$

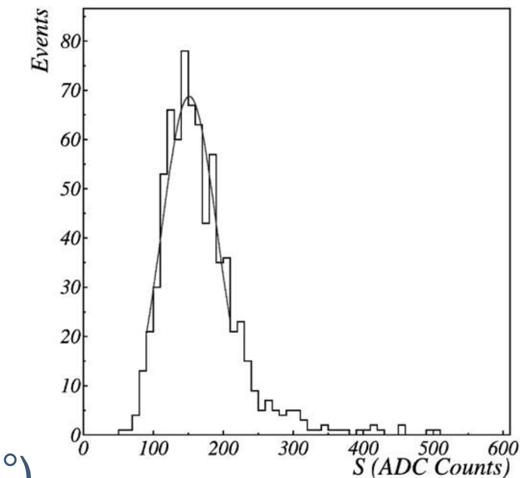
ECAL calibration in KLOE

- Calibration constants C_i determined with cosmic rays, Data-taking without circulating beams: muons = MIPs

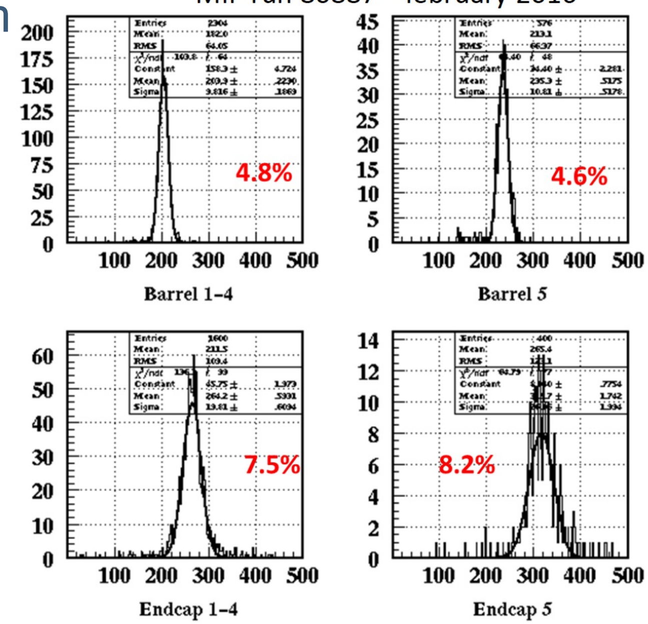
- 2.5 kHz of cosmics
  “golden” MIPs, ~ 100 Hz



μ crossing one column (almost orthogonal to the module, within 10°) at the module center (± 20 cm in the longitudinal coordinate)



MIP run 80887 – february 2016

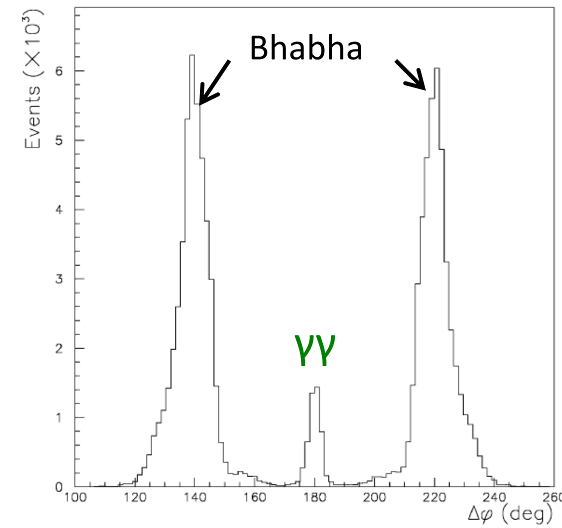


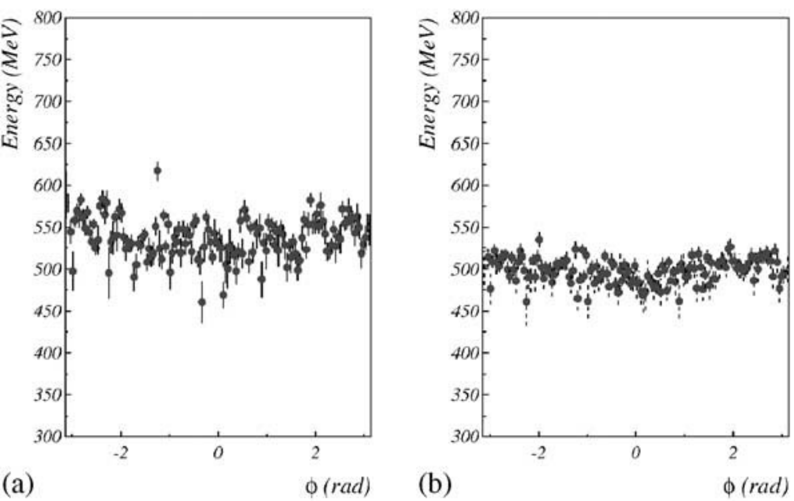
- 1 day data-taking ⇒ ~ 10^3 evts/cell
- C_i = peak of the MIP distribution ⇒ ~ 1 – 2 % accuracy

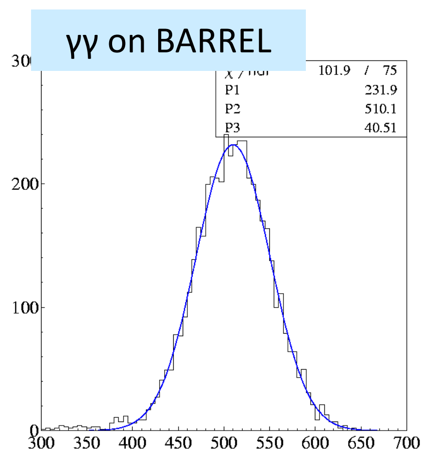
- Repeated every few months
- Used to equalize HVs to have uniform trigger thresholds

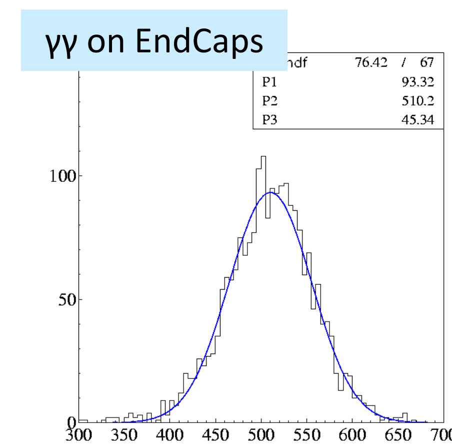
ECAL calibration in KLOE

- Average energy scale 38 MeV / MIP crossing a cell at the center (measured at test beams)
- Absolute energy scale set with Bhabha scattering events ($e^+e^-\rightarrow e^+e^-$) and $e^+e^-\rightarrow \gamma\gamma$: showers of 510 MeV
- Repeated every run (every 1 or 2 hours) (~ 100 nb^{-1} in KLOE, ~ 1 pb^{-1} in KLOE-2)
- 4 — 5 × 10^4 Bhabha evts in the Barrel
  $O(10^5)$ in the Endcaps
  $10^3 - 10^4$ γγ events in one run









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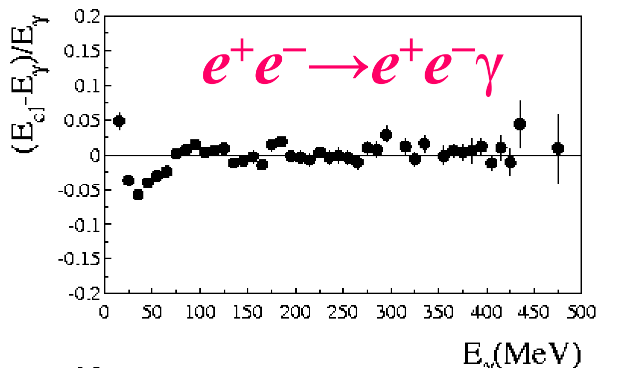
ECAL calibration in KLOE

- **Linearity of the response and energy resolution measured with radiative Bhabha scattering ($e^+e^- \to e^+e^-\gamma$) by detecting the charged tracks in the drift chamber**

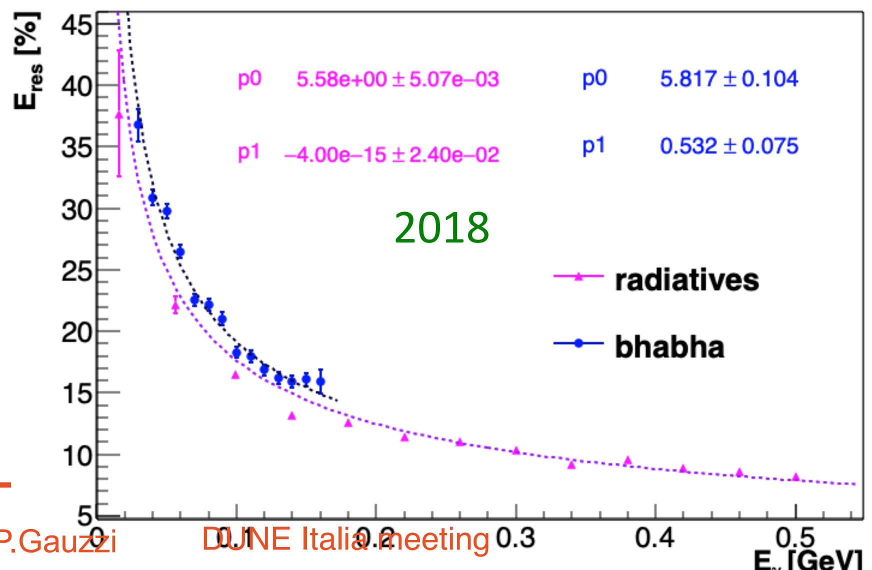
- **Linearity within 1% for E > 70 MeV** $\frac{E_{cl} - E_\gamma}{E_\gamma}$

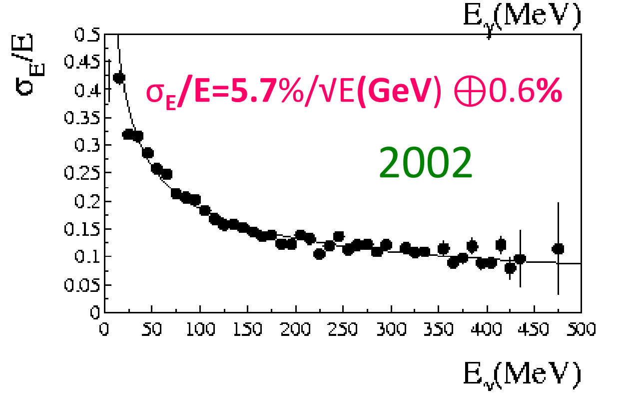
$$E_\gamma = \sqrt{s} - E_+ - E_-$$

E_+ and E_- from p_+ and p_- measured in the Drift chamber (much better resolution for charged tracks)



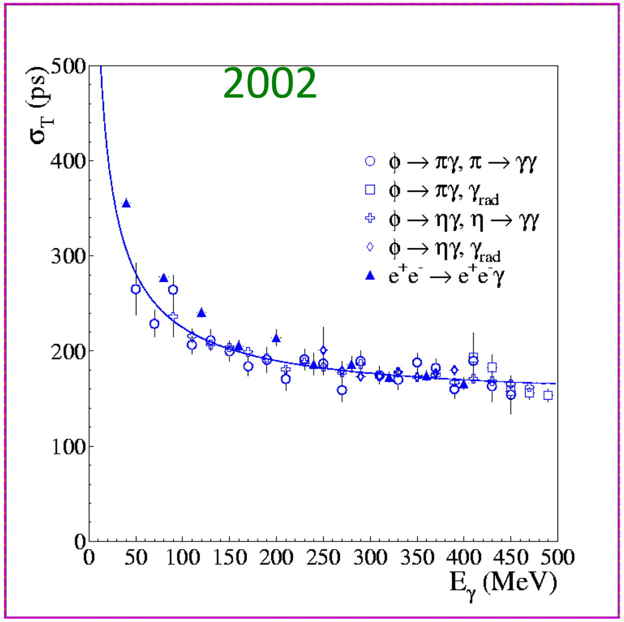
- **For $E = 100$ MeV $\Rightarrow \sigma_E = 18$ MeV**





- **Measured with different processes: $\phi\to\pi^0\gamma$ ($\pi^0\to\gamma\gamma$), $\phi\to\eta\gamma$ ($\eta\to\gamma\gamma$), $\phi\to\pi^+\pi^-\pi^0$, $e^+e^-\to e^+e^-\gamma$**

$$\sigma_t = \frac{57\ \mathrm{ps}}{\sqrt{E\ [\mathrm{GeV}]}} \oplus 140\ \mathrm{ps}$$



- **The constant term has two contribution: a term common to all the cells, due to the spread of the DAΦNE Interaction Point position, and a proper constant term, uncorrelated among cells, due to a residual miscalibration**

$$140\ \mathrm{ps} = 92\ \mathrm{ps} \oplus 105\ \mathrm{ps}$$