The KLOE Electromagnetic Calorimeter Calibration, monitor, and performance

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on behalf of the KLOE Collaboration

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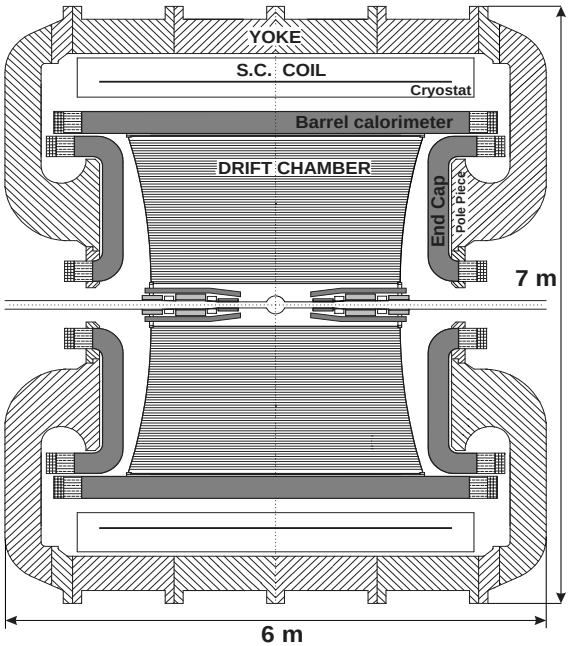
DAΦNE and KLOE

DAΦNE is a double-ring $e^+ e^-$ collider at $\sqrt{s} = 1020\, MeV$

Present luminosity $L \quad \sim 6 \cdot 10^{31} cm^{-2} s^{-1}$

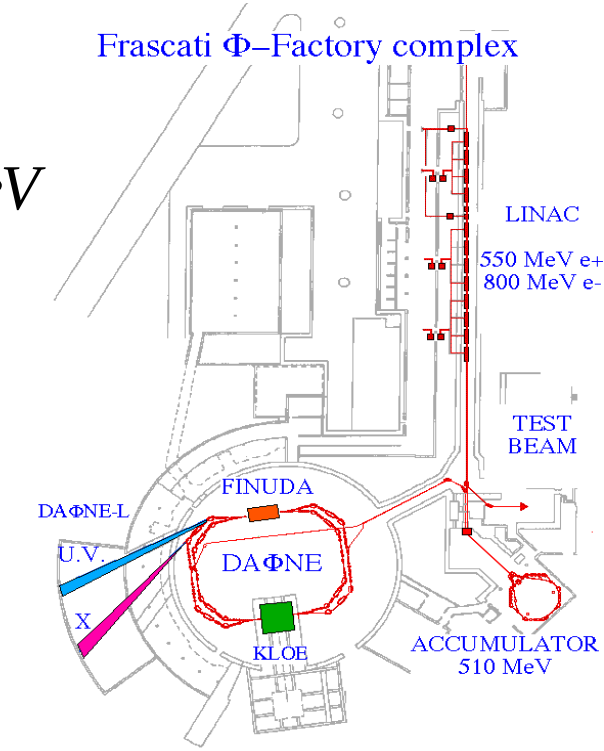
KLOE detector is designed for the study of CP violation in the decays of neutral kaons

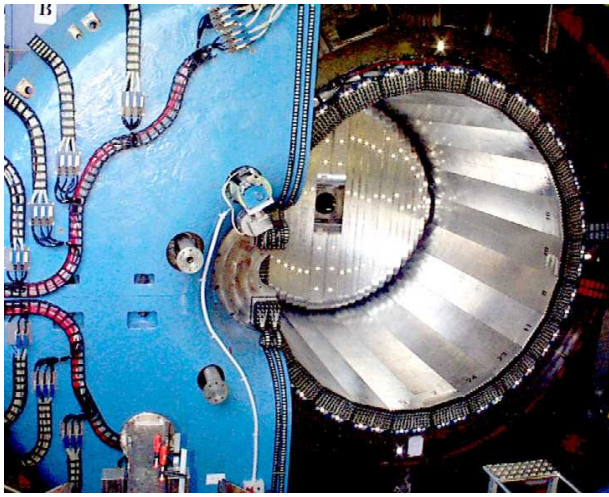


The detector is composed of a cylindrical drift chamber surrounded by the electromagnetic calorimeter, both embedded in a magnetic field of 0.52 Tesla

$$20 < E_\gamma < 510\, MeV$$

$$50 < P_{charged} < 510\, MeV/c$$





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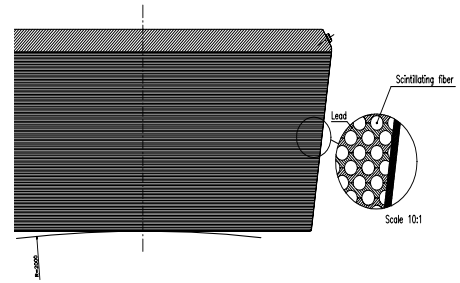
The KLOE Electromagnetic Calorimeter

$\rho \sim 5\,\mathrm{g/cm^3}$

Sampling lead-scintillating fibers calorimeter
Fiber:Lead:Glue=50:40:10

$X_0 \sim 1.6\,cm$



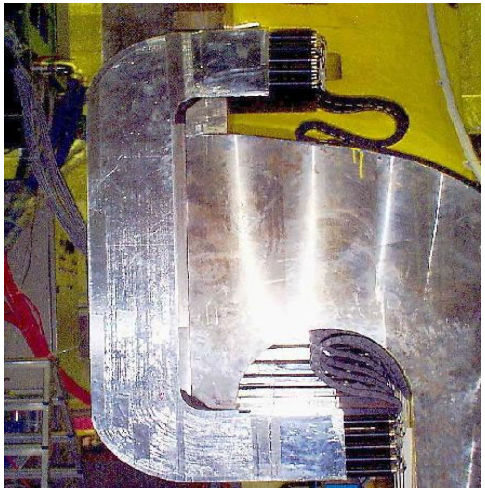
Sampling fraction for electrons $\sim 12\,\%$

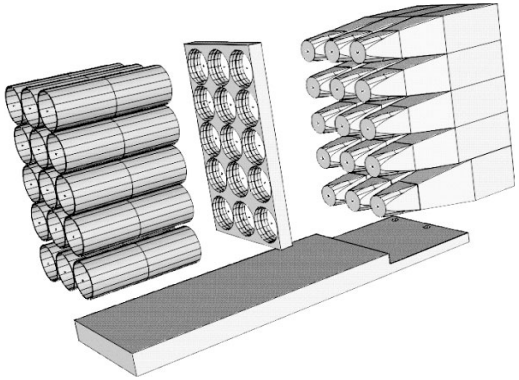
Light is collected at calorimeter ends by light guides coupled to PM's with granularity of $(4.4 \times 4.4)\,cm^2$

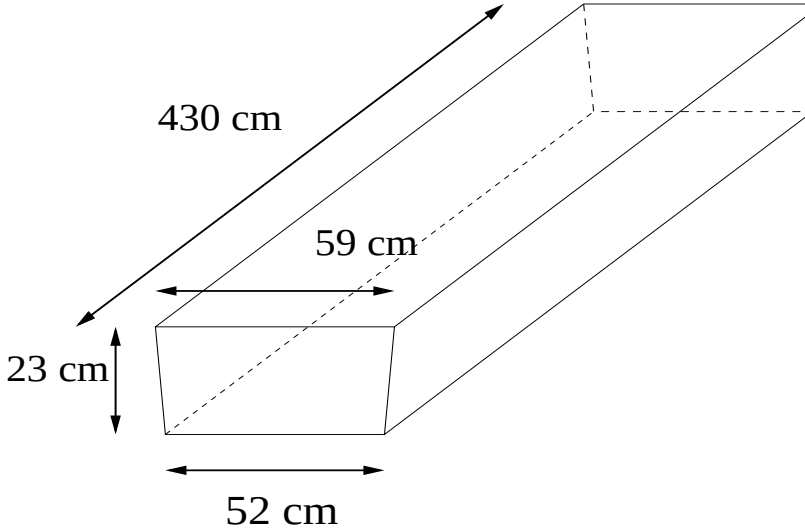
Barrel: 24 modules of trapezoidal cross section $(23 \times 59 \times 430)\,cm^3$

EndCap: 64 C-shaped modules

$(23 \times (8.8, 13.2, 26.8) \times (80 \rightarrow 400))\,cm^3$







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Energy reconstruction

S_i = signal in ADC counts

The energy signal, E, on each side of a cell is given by:

$S_{0,i}$ = zero-offset of the amplitude scal

$$E_i^{a,B}(MeV) = \frac{(S_i^{A,B} - S_{0,i}^{A,B})}{S_{M,i}} \times k_E$$

$S_{M,i}$ = response for a mip crossing the calorimeter center

k_E = energy scale in MeV

The cell energy, E, is taken as the mean of the determination at both ends:

$$E_i(MeV) = (E_i^A A_i^A + E_i^B A_i^B)/2$$

A_i = correction factor due to the attenuation along the fiber length

$$\left(A(s)/A(0)\right)^{-1} = a \cdot e^{-s/\lambda_1} + (1-a) \cdot e^{-s/\lambda_2}$$

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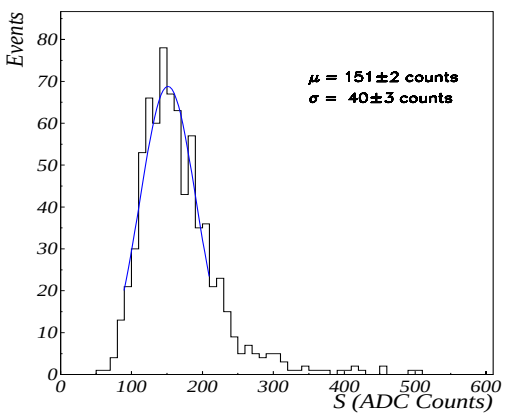
Calibration with mip

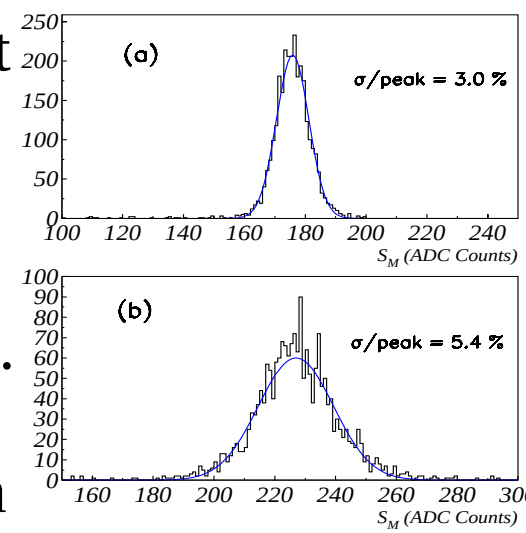
$$\frac{(S_i^{A,B} - S_{0,i}^{A,B})}{S_{M,i}}$$

Pedestals are acquired triggering on cosmic withou circulating beam (low occupacy runs). Most of the offset rms are below 4 ADC counts ~ 1 MeV. Lon term drifts are below 1-2 counts per month. Channe read-out is suppressed if $|S - S_0| < 3\sigma s_0$.



50-100 Hz of mip crossing only one column and almost orthogonal to the calorimeter surface are selected. Attenuation lenghts are obtained for each cell by fitting th distribution of pulse height vs longitudinal coordinate of the fibers.

Mip response is measured selecting cosmic rays crossing at the center (± 30 cm) of the calorimeter modules and fitting the peak of the distribution. Statistical uncertainty is 1-2%. Equalization must be kept at 5% level in order to avoid deterioration on resolution for analog-sum signal of trigger. Channel gains drift a few % per month. Energy measurement accuracy is obtained using correct calibration constants during reconstruction.



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Energy scale calibration using e.m. showers

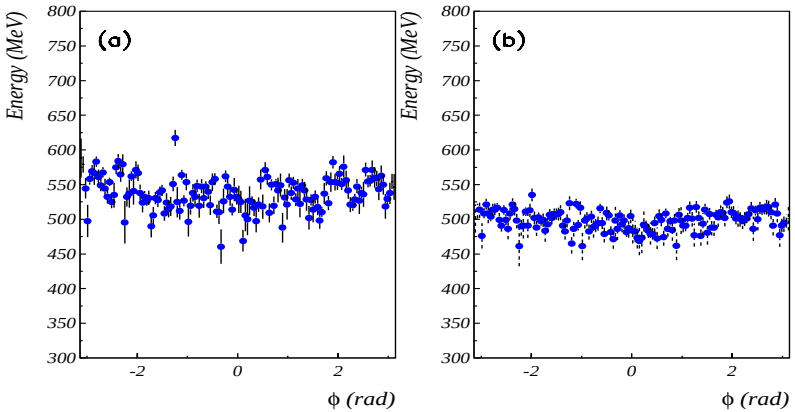
Bhabha and $\gamma\gamma$ events are selected on-line using only calorimeter information. An integrated luminosity of $\sim 100\, nb^{-1}$ yelds 150K of Bhabha and 10K of $\gamma\gamma$ Scale correction is applied at the column level since MIP method allows a precise cross-calibration between planes.

Bhabha: allows cross calibration of columns. An iterative procedure sets the mean value of the measured energy of each column around the expected one.

$\gamma\gamma$ events do not suffer any energy loss and are therefore used to set the energ scale imposing 510 MeV to the peak of the distribution of energy released by each photon.

$$k_E \sim 40\, MeV / MIP$$

$$\sim 1\, p.e.\, per\, MeV$$



Bhabha in barrel a) before b) after calibratio

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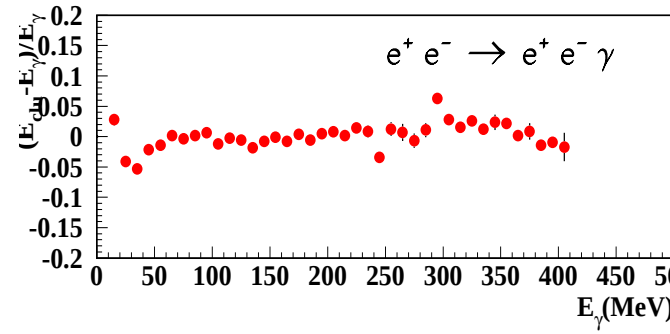
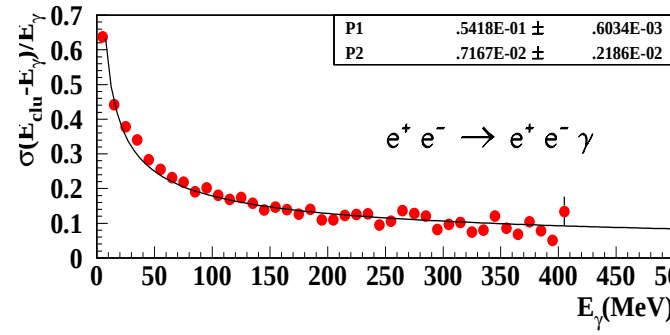
Energy resolution and energy response

Energy resolution and linearity are obtained using photon from radiative Bhabha events $e^+e^- \rightarrow e^+e^-\gamma$ determining photon direction and energy from tracks information.



Linearity is better than $\sim$ 1% for $E_\gamma > 50$ MeV
deviations from linearity are at the 4-5% level below 50 MeV



Resolution is dominated by sampling fluctuations.

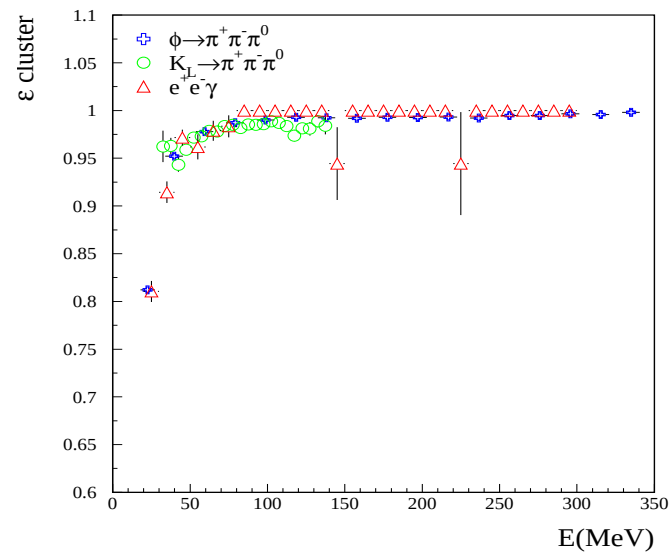
$$\sigma(E)/E = 5.4\%/\sqrt{E(GeV)}$$

Photon detection efficiency is measured using events:

$$e^+e^- \rightarrow e^+e^-\gamma$$

$$\phi \rightarrow \pi^+\pi^-\pi^0$$

$$K_L \rightarrow \pi^+\pi^-\pi^0$$



Efficiency > 99% is reached for $E_\gamma > 80$ MeV

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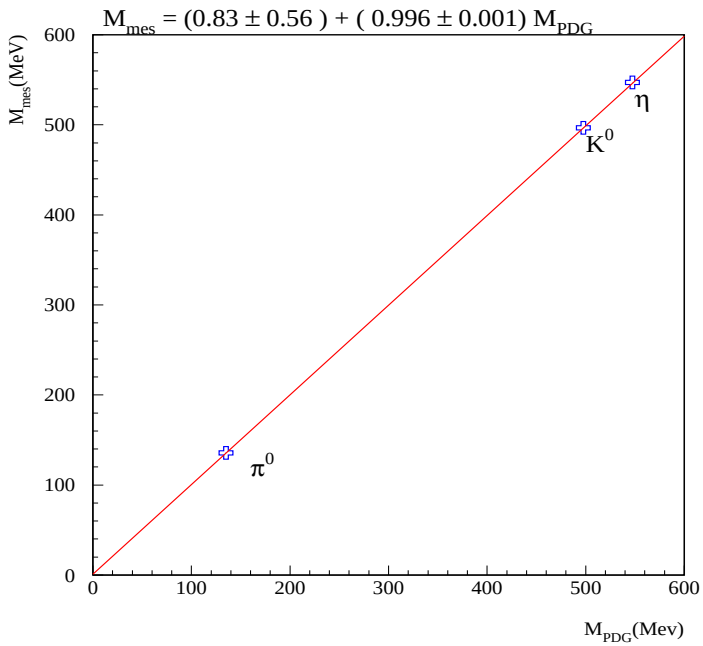
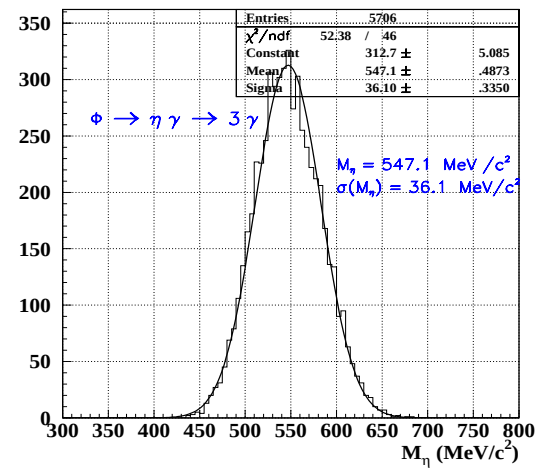
Masses

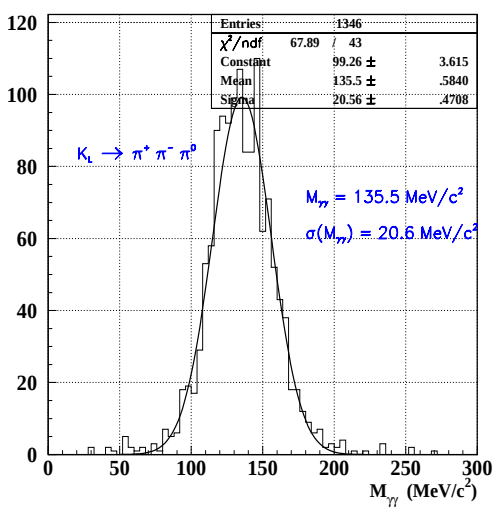


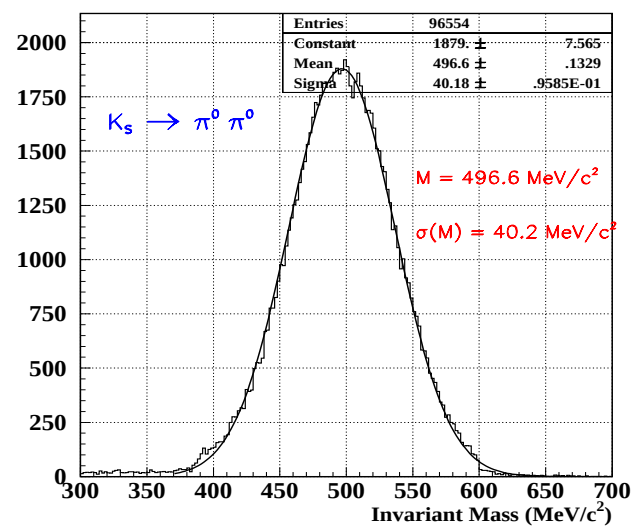
M_η from $\phi \rightarrow \eta\ \gamma \rightarrow 3\ \gamma$



M_K from $K_S \rightarrow \pi^0\ \pi^0 \rightarrow 4\ \gamma$

M_{π^0} from $K_L \rightarrow \pi^+\ \pi^-\ \pi^0$





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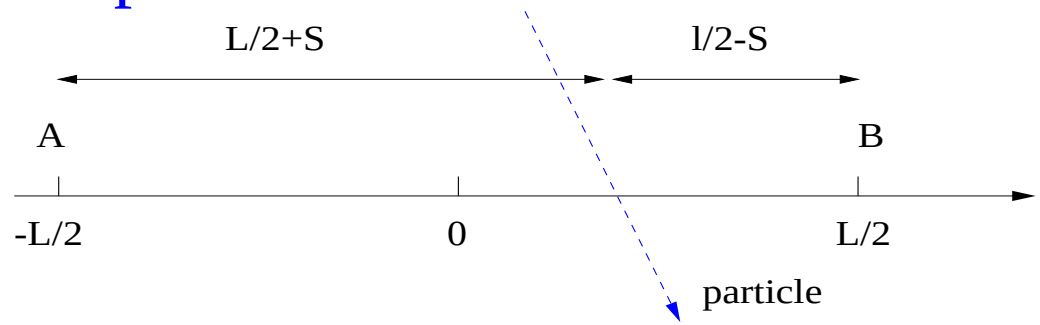
Reconstruction of time and position

$$t(ns) = \frac{t^A + t^B}{2} - \frac{t_0^A + t_0^B}{2} - \frac{L}{2v_f}$$

$$s(cm) = \frac{v_f}{2}(t^A - t^B - t_0^A + t_0^B)$$



$$t^A = t_0^A + \frac{L}{2v_f} + \frac{s}{v_f} + t$$

$$t^B = t_0^B + \frac{L}{2v_f} - \frac{s}{v_f} + t$$

$t^{A,B} = c^{A,B} \times T^{A,B}$ $\quad c^{A,B} =$ TDC calibration constants (~53 ps /count)

$v_f =$ Light velocity in the fibers (~17 cm /ns)

L = cell length (measured prior to installation)

$t_0^{A,B} =$ Time offset (pulse signal allow the measurement of time offsets due to cable length and TDC delay only up to ~ 1.5 ns)

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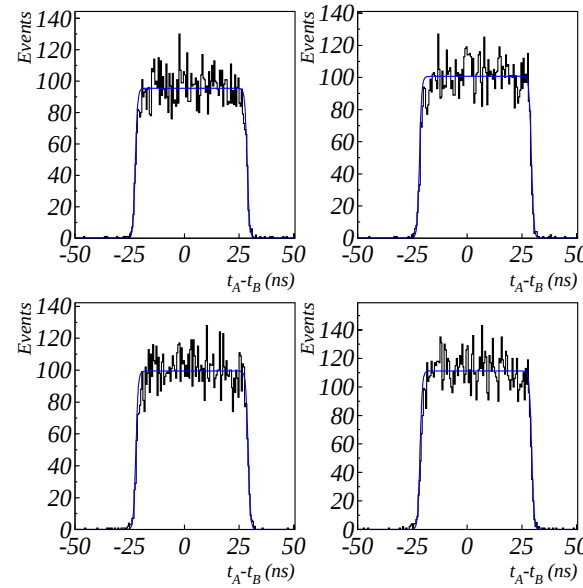
Timing calibration with cosmic rays

The values of v_f and time offsets are obtained with cosmic rays data.
For each cell $\Delta t_0^{A,B}$ and v_f are measured from $t^A - t^B$ distributions:

$$\Delta t^{A,B} = t^A - t^B = t_0^A - t_0^B + \frac{2S}{v_f} \quad \begin{cases} \text{Center} & \Delta t_0^{A,B} \\ \text{Width} & \dfrac{2L}{v_f} \end{cases}$$

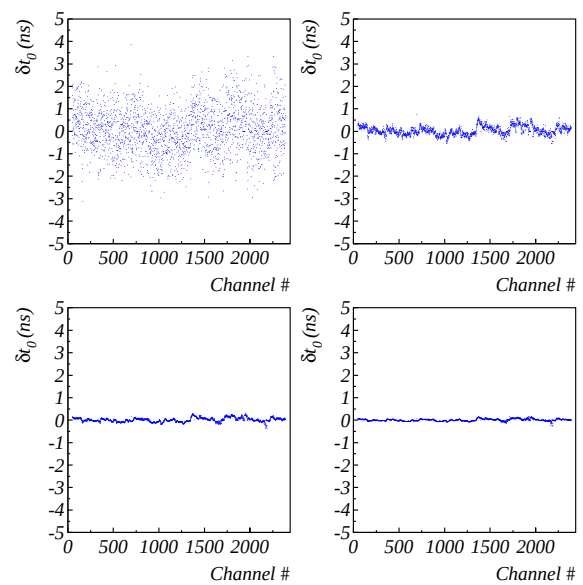


Results can be checked using DC information on the entry position S, measuring the slope $2/v_f$ and intercept $\Delta t_0^{A,B}$ of the straight line $\Delta t^{A,B}$ vs S.

Time equalization between cells is obtained by selecting straight tracks (P > 7 GeV):

$$\Delta t = \Delta R / c$$

An iterative procedure minimizes time residuals varying time offsets $t_0^A + t_0^B$ of each cell.



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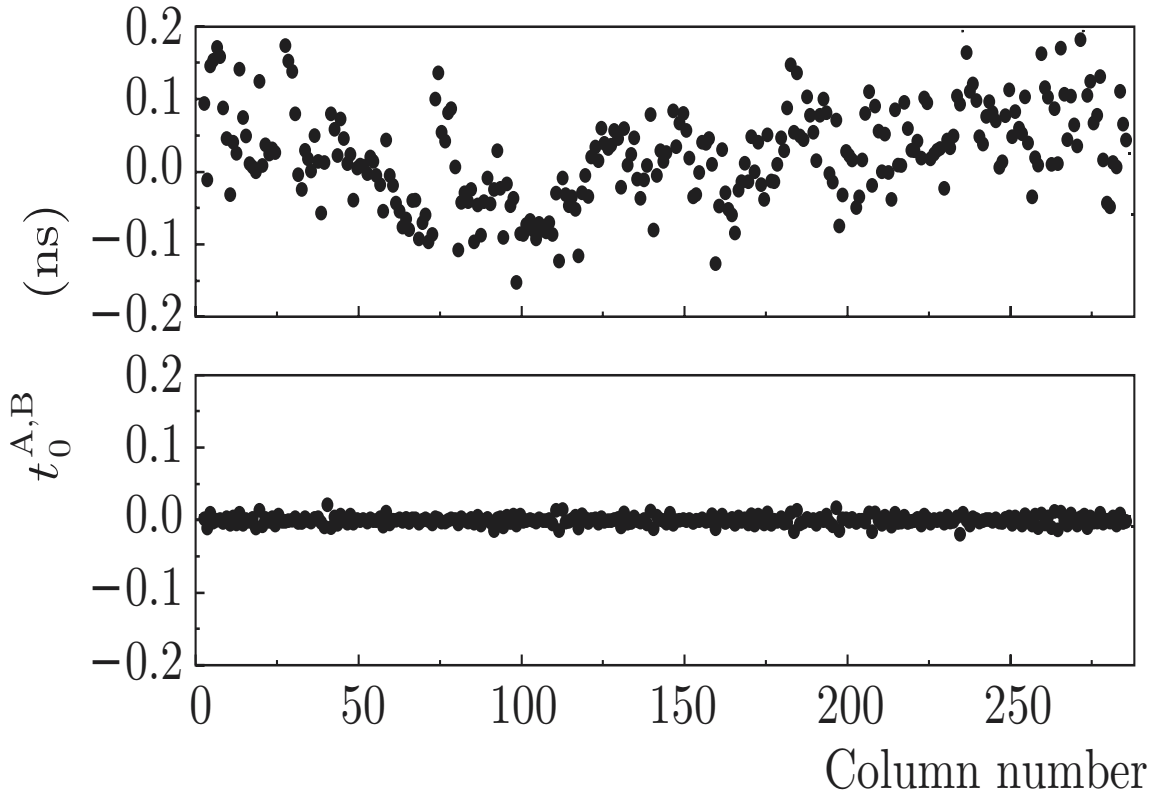
Equalization with gamma gamma

$\gamma\gamma$ events are used to find the fine corrections to the time offsets obtained with cosmic rays. The two photons are expected to enter the calorimeter at a time R/c. The correction is applied at the column level, since cross-calibration among planes is guaranteed by cosmic rays alignment. Residuals (T-R/c) are minimized by an iterative procedure.

The accuracy of the method is ~ 20 ps for 100 nb^{-1} of collected data.



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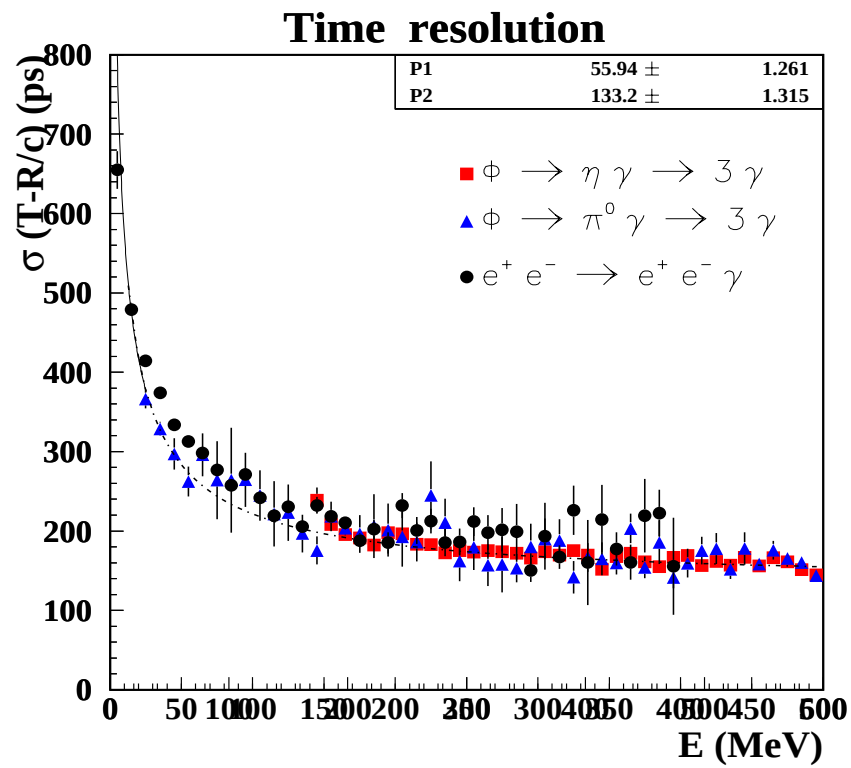
Time resolution

Time resolution is measured using T-R/c distribution of prompt photons. Three different data samples are used:

$$\phi \rightarrow \pi^0 \gamma \, , \pi^0 \rightarrow \gamma \, \gamma$$

$$\phi \rightarrow \eta \, \gamma \, , \eta \rightarrow \gamma \, \gamma$$

$$e^+ e^- \rightarrow e^+ e^- \gamma$$



The constant term is mostly due to the finite luminous point length (σ (IP) ~ 1.5 cm) affecting both T and R/c term.

$$\sigma_t(E) = \frac{56\,ps}{\sqrt{E\,(GeV)}} \oplus 133\,ps$$

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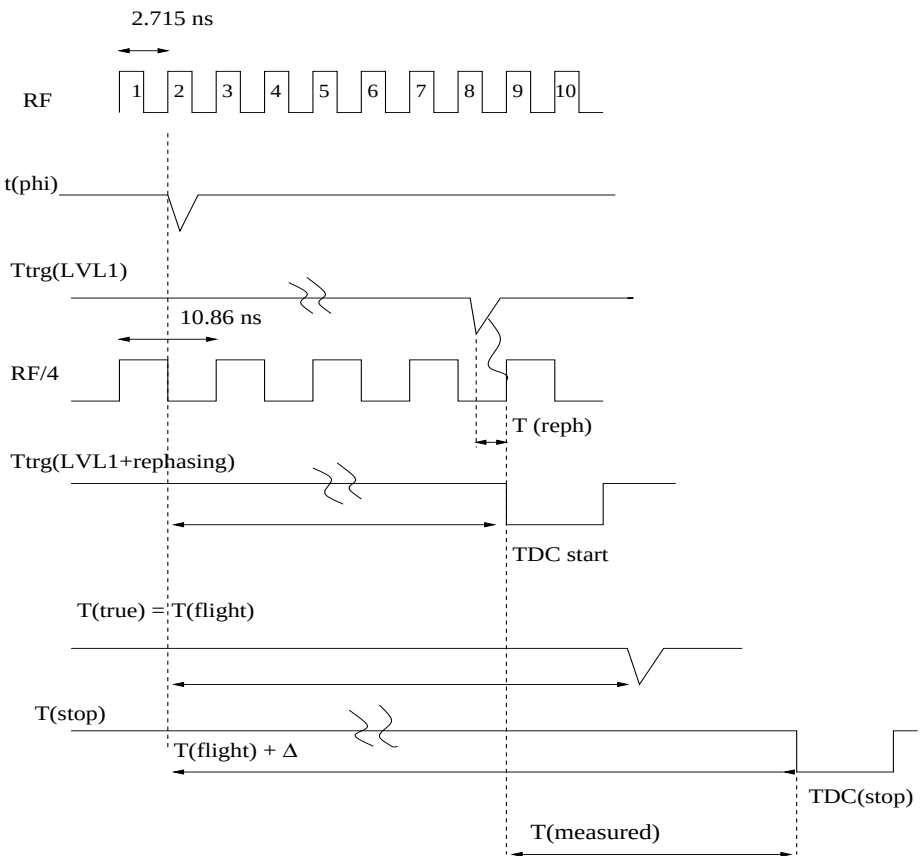
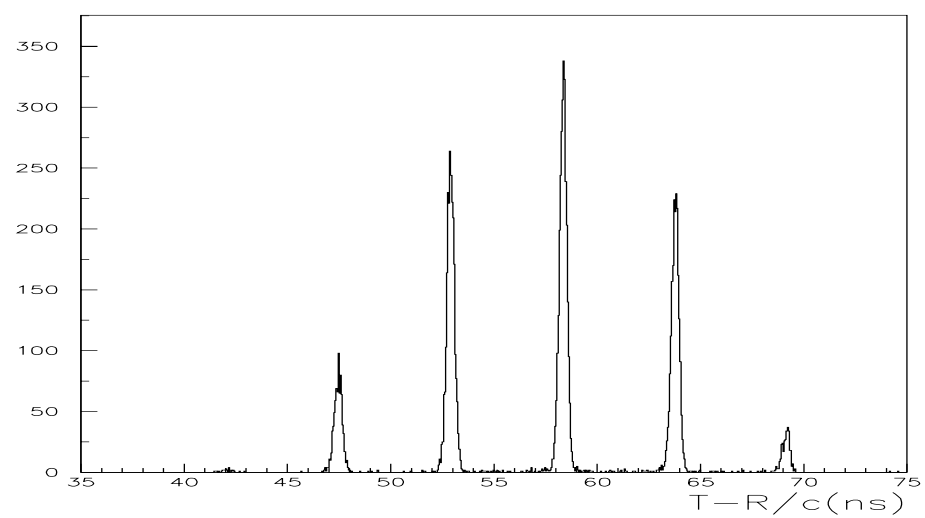
Absolute time scale calibration (I)



The DAΦNE radio frequency has a period T_{RF} =2.715ns.
Start to TDC is given by the L1 trigger afte
syncronization with the RF/4 signal.

$$t_{measured} = t_{true} + \Delta - N \times 2.715$$

The distribution of T-R/c for $\gamma\gamma$ events shows well separated peaks due to the spread of trigger time formation. The distance between peaks gives an estimate of T_{RF} .
The ratio $T_{RF}^{Peak} / 2.715$ gives the TDC scale correction.



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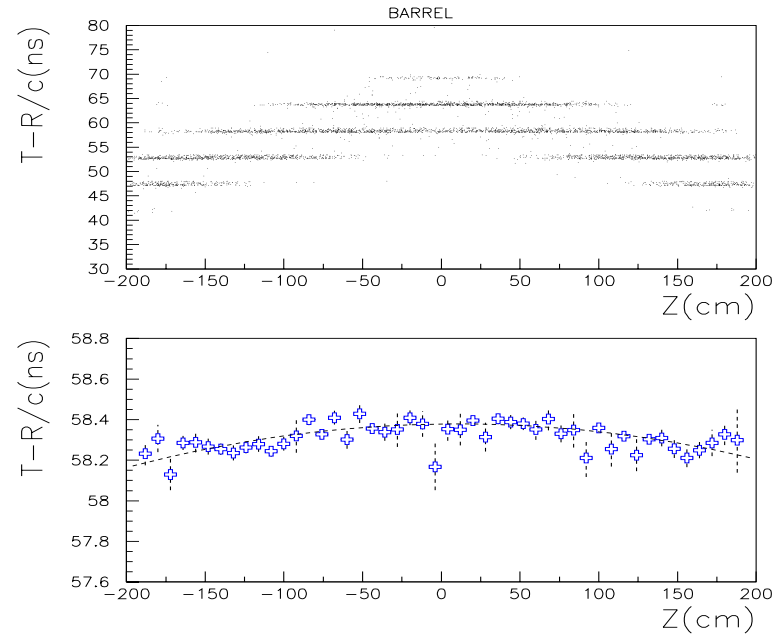
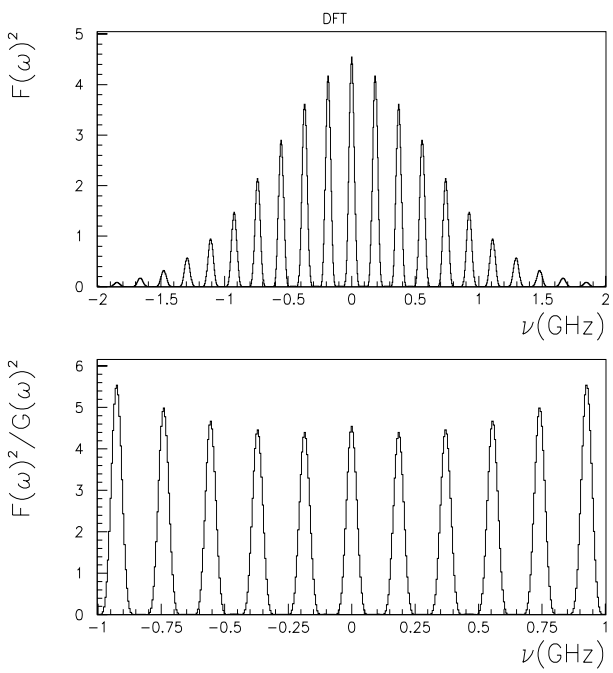
Absolute time scale calibration (II)

The time needed to form a trigger signal depends on the photon impact position on the calorimeter modules.

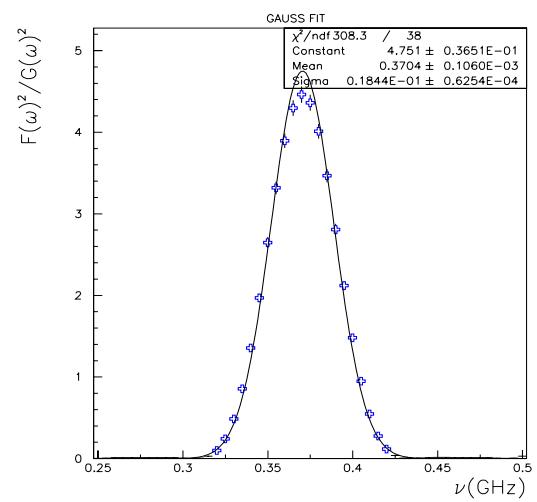


A parabolic dependence of T-R/c on impact position along the fibers affects time-scale calibration of ~ 1%. A correction is applied at the cluster level.



Discrete Fourier Transform is calculated and corrected for Gaussian smearing. The period T_{RF} is obtained

fitting the peak @ $\omega = \frac{2\pi}{T_{RF}}$



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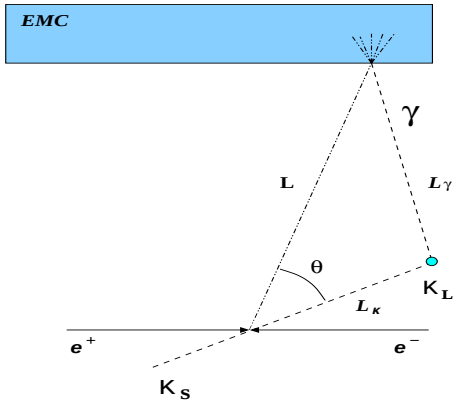
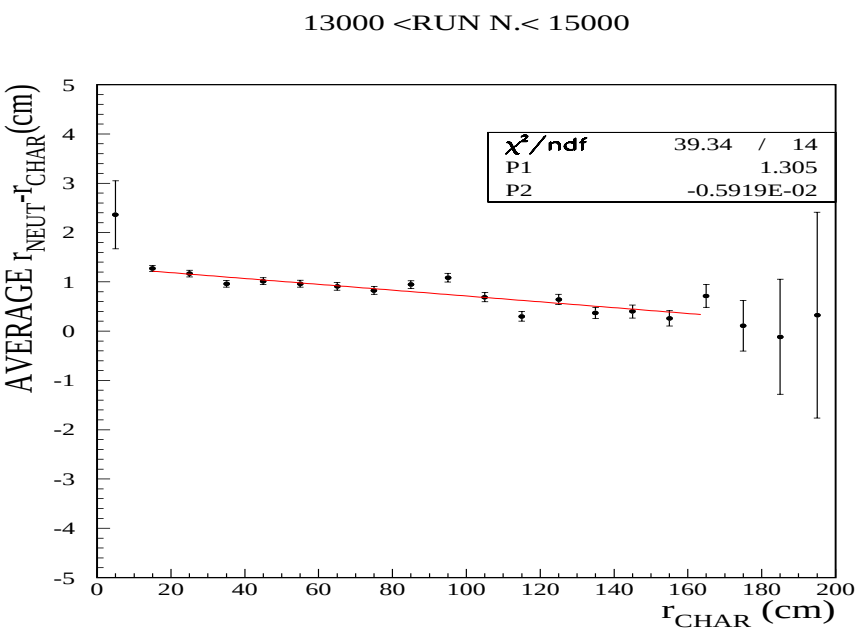
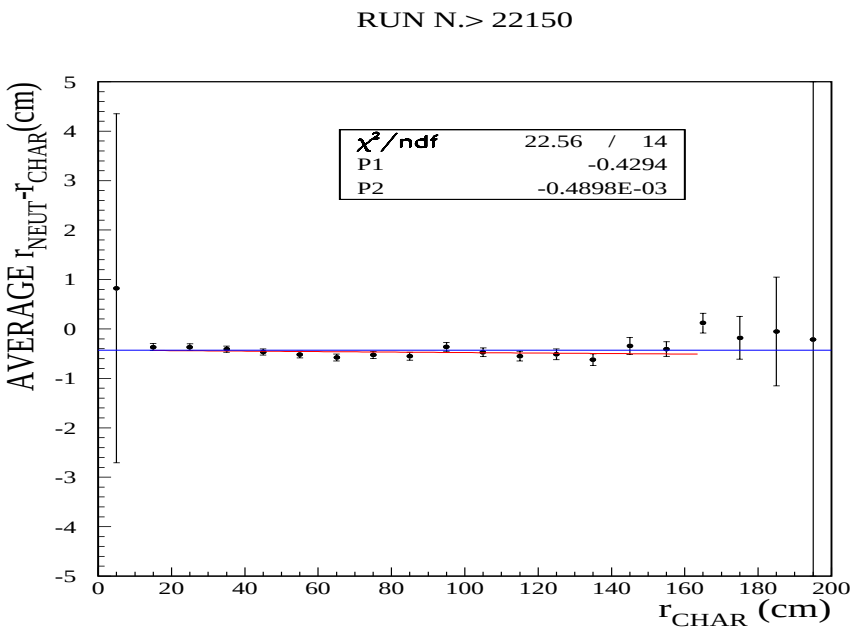
Absolute time scale calibration (III)

The time scale calibration is checked in $K_L \rightarrow \pi^+ \pi^- \pi^0$ decays, comparing verte position obtained with DC tracks and with photons.



Wrong calibration leads to a linear dependence on the K_L path length of the difference between neutral and charged vertex position





0.5% error in time scale

After calibration

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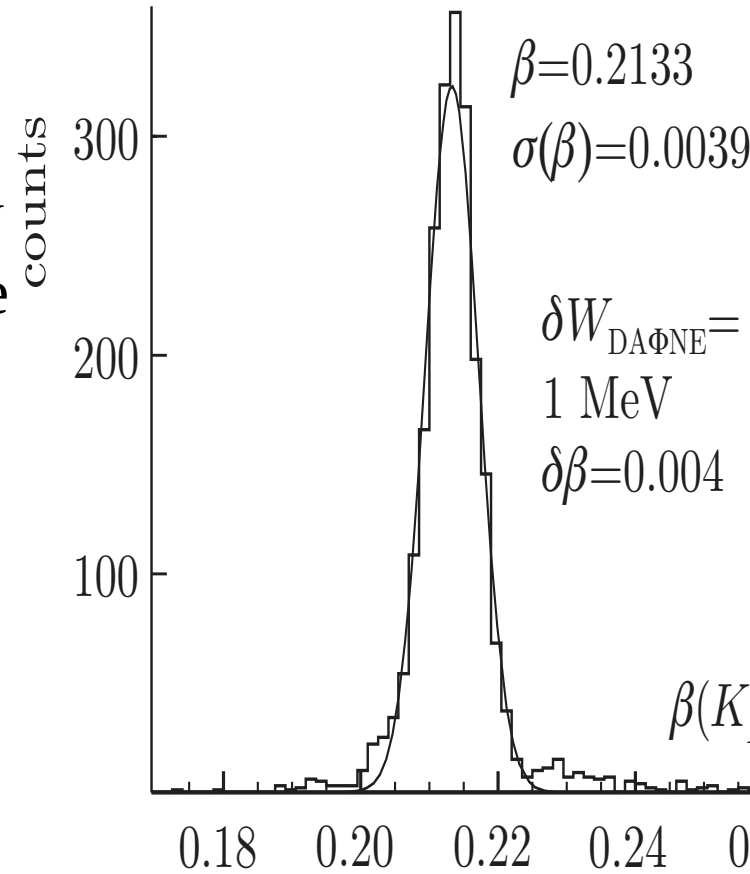
K- crash tag with KLOE calorimeter

K_L interacting in the calorimeter (K-crash) allows the tagging of a pure K_S sample. A unique signature of K-crash events is provided by the low value of the velocity β (~ 0.2) measured from the interaction time. The width of the distribution is dominated by the intrinsic spread of the machine energy (W).

$$\delta\ \beta = 0.004$$

$$\frac{\delta\ W}{W} = \gamma^2 \cdot \beta \cdot \delta\ \beta \simeq 10^{-3} \Rightarrow \delta\ W \simeq 1\,MeV$$



The measurement of β can be used to monitor the variations in the mass energ of DAΦNE.

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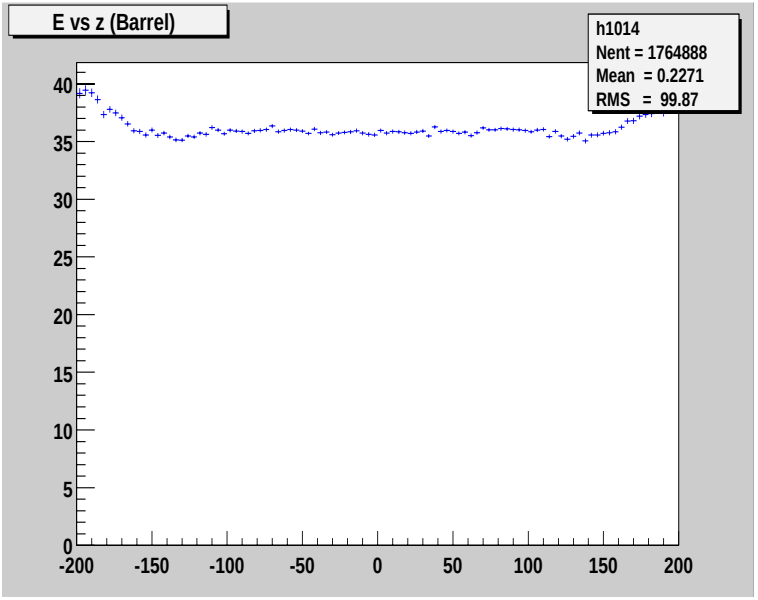
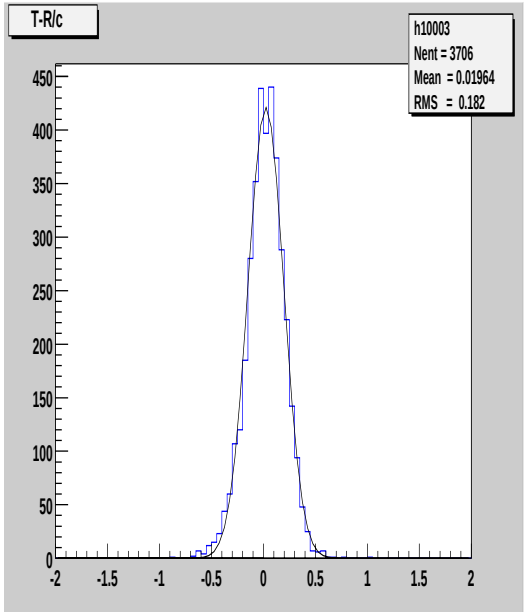
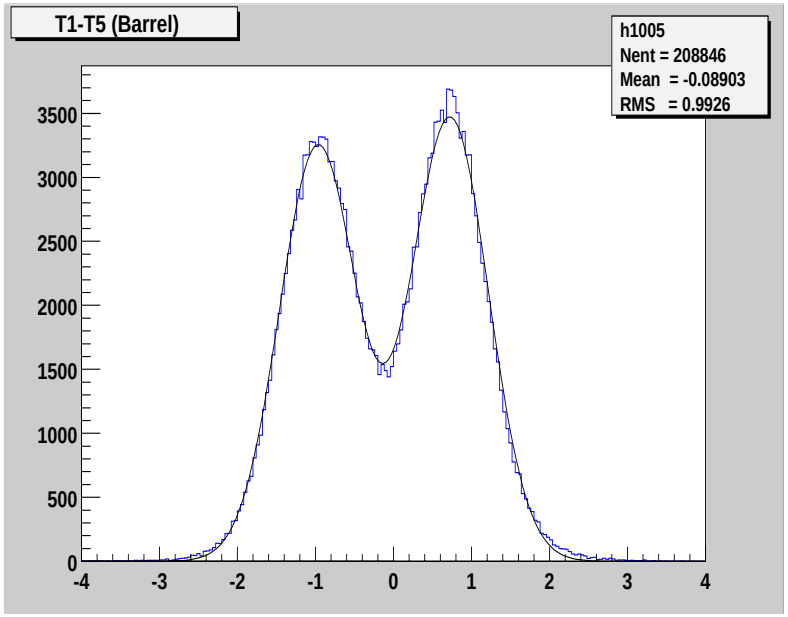
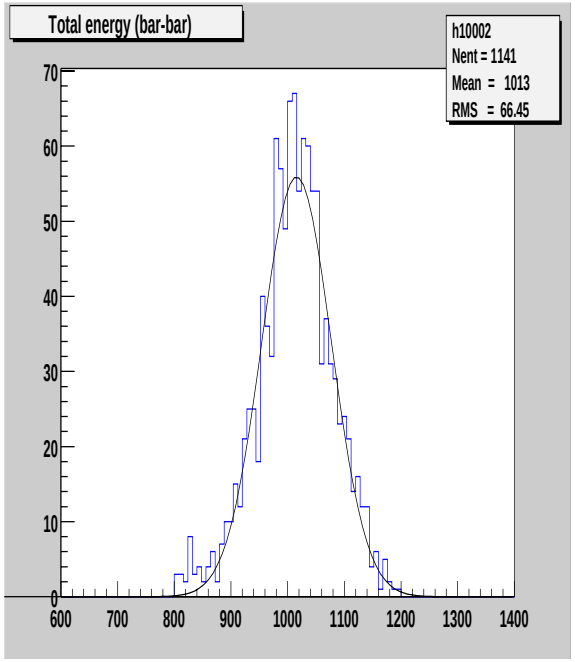
Online monitor using mips, Bhabha, and $\gamma\ \gamma$









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Conclusions

The performance of the KLOE calorimeter has been measured with high accuracy and found very close to the design specifications.

Energy resolution: $\sigma(E)/E = 5.4\%/\sqrt{E(GeV)}$

Linearity: ~ 1% for E_γ > 50 MeV

Photon efficiency: > 99% for E_γ > 80 MeV

Time resolution: $\sigma_t(E) \sim 56\,ps/\sqrt{E(GeV)}$

Time scale calibration: $\delta T/T \approx$ 1-2 ‰

Good time and energy stability

Good reliability

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