Calibration and Reconstruction Performances of the KLOE Electromagnetic Calorimeter

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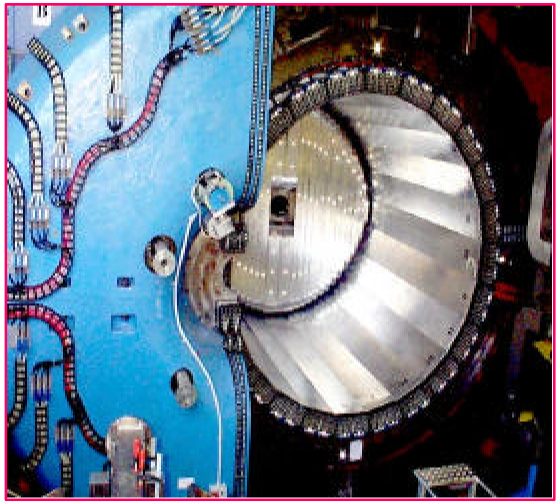
for the KLOE collaboration

IX Int.Conf.on Calorimetry in Particle Physics

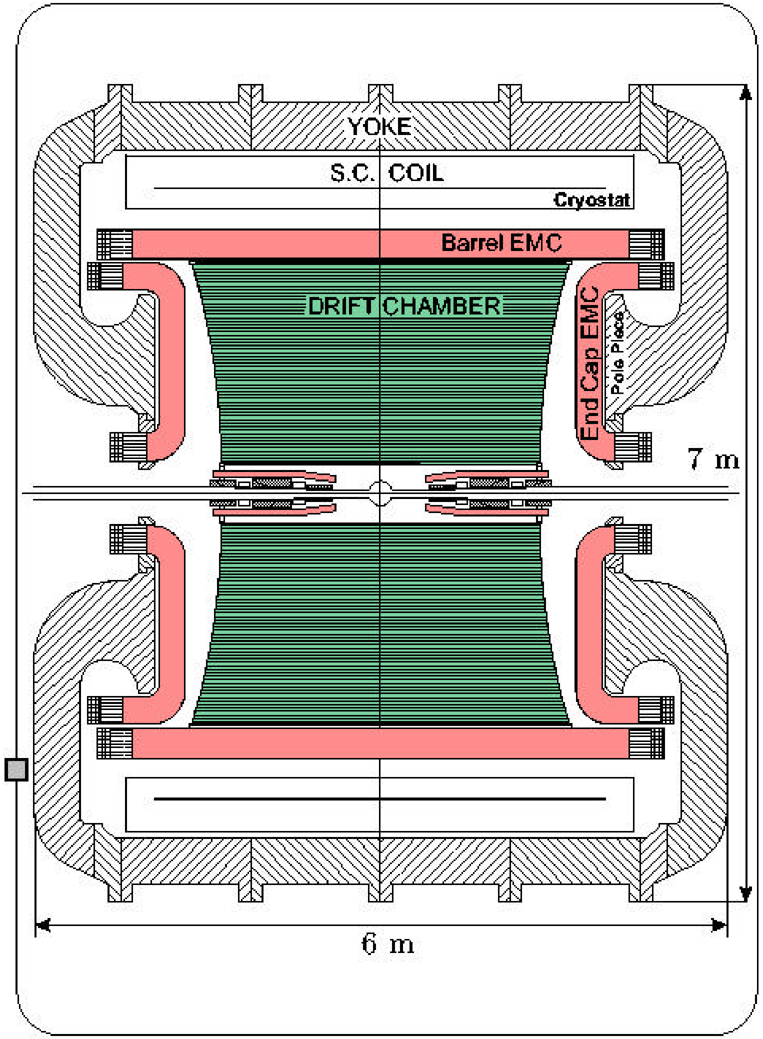
LAPP Annecy – 9-14 October 2000

Outline

- The KLOE experiment and the EMC design
- Reconstruction and calibration of energy
- Reconstruction and calibration of timing
- Performances on simple physics examples



THE KLOE Experiment @ DAΦNE



Be beam pipe (0.5 mm thick)

Instrumented permanent magnet quadrupoles (32 PMT's) QCAL

Drift chamber (4 m Ø × 3.3 m)
90% helium 10% isobutane
12582/52140 sense/total wires

Electromagnetic calorimeter
Lead/scintillating fibers

Superconducting coil
$B = 0.6$ T ($\int B\, dl = 2.2$ T·m)

DAΦNE: e^+e^- collider at ϕ peak; $\sqrt{s}$ = 1020 MeV

The **KLOE** goal is to measure Re(ε'/ε) to ~ $\boldsymbol{O}$ (10^{-4})

KLOE CALORIMETER REQUIREMENTS

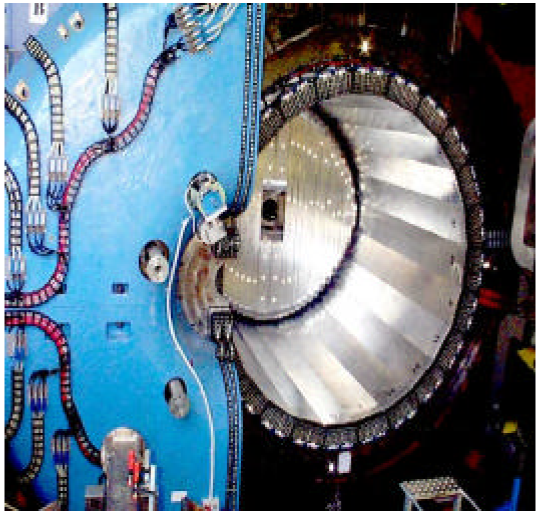
- **Reconstruct $K_S, K_L \to \pi^0\pi^0$ vertices with ~ 1cm resolution**
- **Discriminate $K_L \to \pi^0\pi^0$ from $K_L \to \pi^0\pi^0\pi^0$**
- **Fast for triggering and Bhabha background rejection**
- **Provide useful information for particle identification ($K_{\mu 3}$ rejection)**

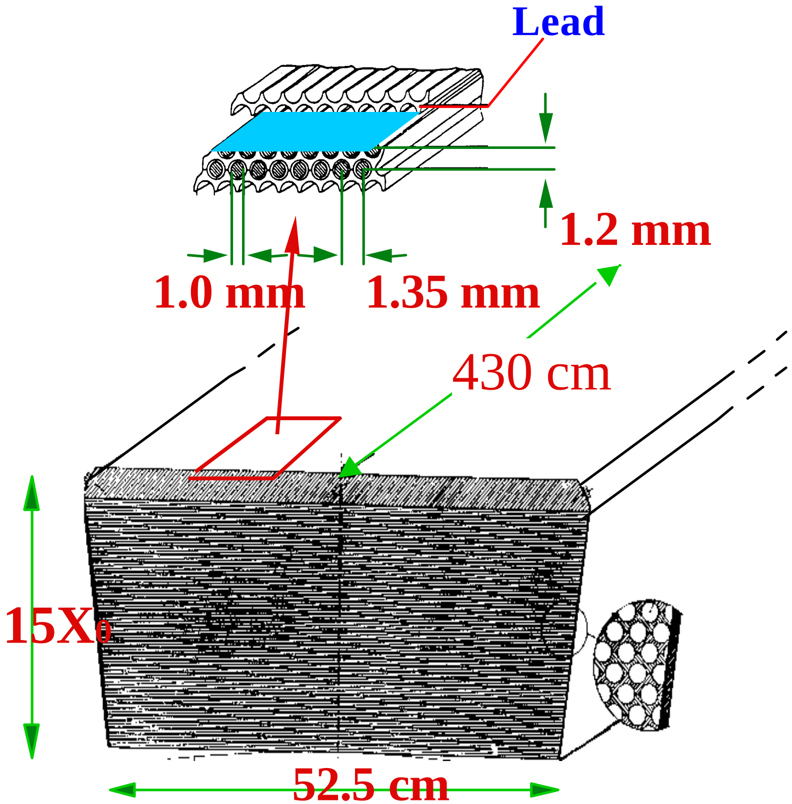
- **$\sigma(E)/E \sim 5\% / \sqrt{E(\text{GeV})}$**
- **High efficiency $20 < E_\gamma < 300$ MeV**
- **$\sigma(t) \sim 70$ ps $/ \sqrt{E\,(\text{GeV})}$**
- **$\sigma_{x,y,z} \sim 1$ cm for photon conversion point**
- **Hermeticity**

THE CALORIMETER STRUCTURE

Fine sampling lead/scintillating fibers calorimeter

- **Volume Ratio Fiber:Lead 50:50**
- **Energy sampling fraction 13 %**
- **X_0 = 1.6 cm r=5.3 g/cm^3**





- 24 barrel modules: 4.3m length
60 cells (5 layers) – 4.4×4.4 cm^2 granul.
- 2 × 32 endcap modules 10/15/30 cells
- 4880 read-out channels

Fiber choice: Kuraray SCSF-81 and Pol.Hi.Tech 0046

PM choice: Mesh Hamamatsu R5946 1.5”

ENERGY CALIBRATION with COSMICS

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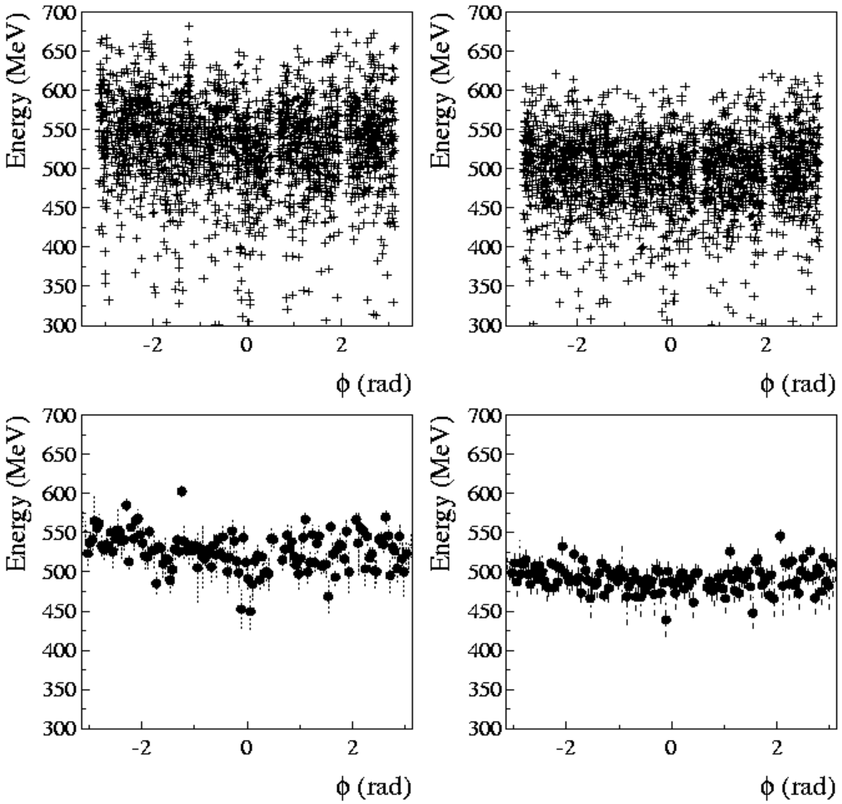
- **Online filter selects 100 Hz of golden mips in the whole detector**
- **Peak of the ADC spectrum = response at calorimeter center (MIP) (~1 day data taking ® 1000 events/cell ® 1 ¸ 2 % stat. accuracy)**
- **The attenuation curve is measured for each channel and used in the reconstruction procedure** $(w(z) = A\ e^{-z/l1} + (1-A)\ e^{-z/l2})$

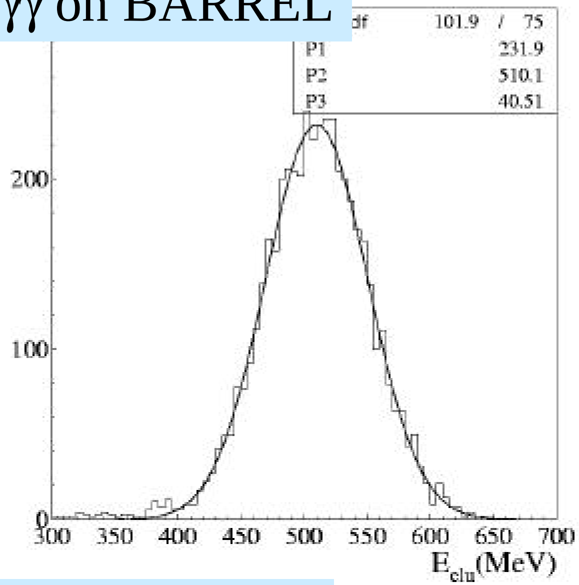
ENERGY CALIBRATION with E.M. SHOWERS

- Bhabha events for cell cross-calibration
- **e^+e^- ®gg** to set the absolute energy scale
- Automatic procedure: every **100 nb^{-1}**

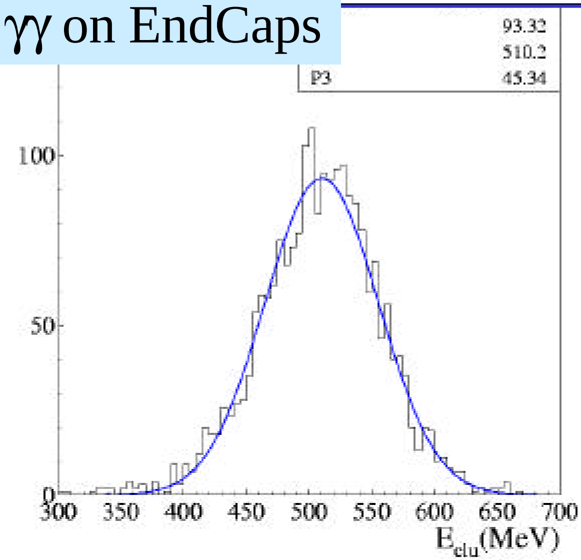
Before ……………… After Calibration



γγ on BARREL



γγ on EndCaps



LINEARITY IN ENERGY RESPONSE AND ENERGY RESOLUTION

- **Average energy scale:**

  → **38 MeV/MIP**

- **Using the number of p.e./MIP measured at cosmic test:**

light yield ~1 p.e./MeV per side

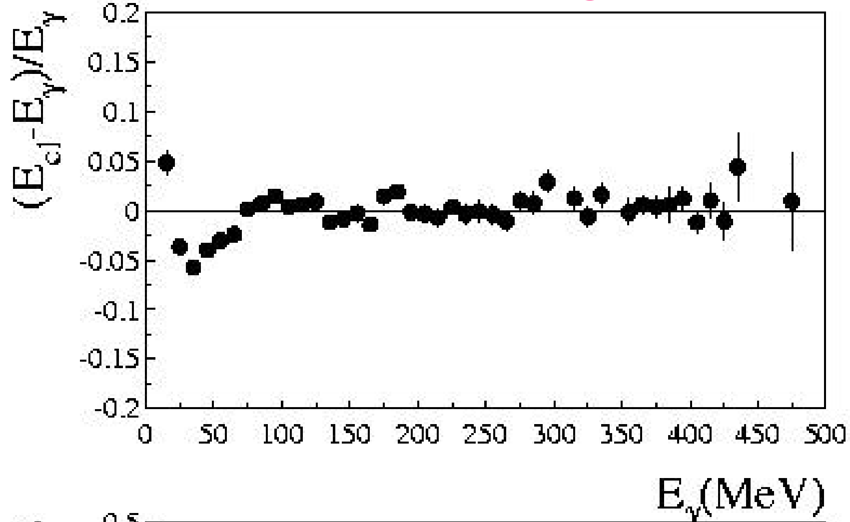
@ calorimeter center

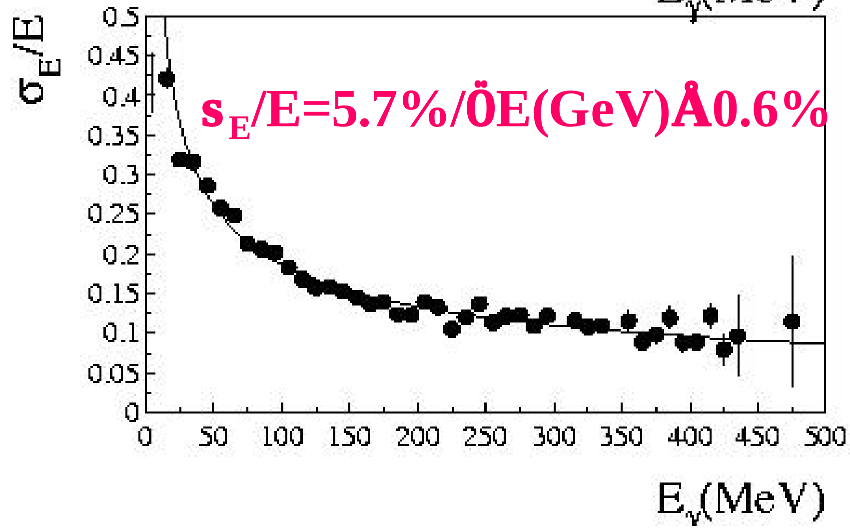
- **A factor of 2 more light near the PMs**

- **Energy resolution dominated by sampling fluctuations**

- **No cuts have been made on “holes” or specific detector regions**

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



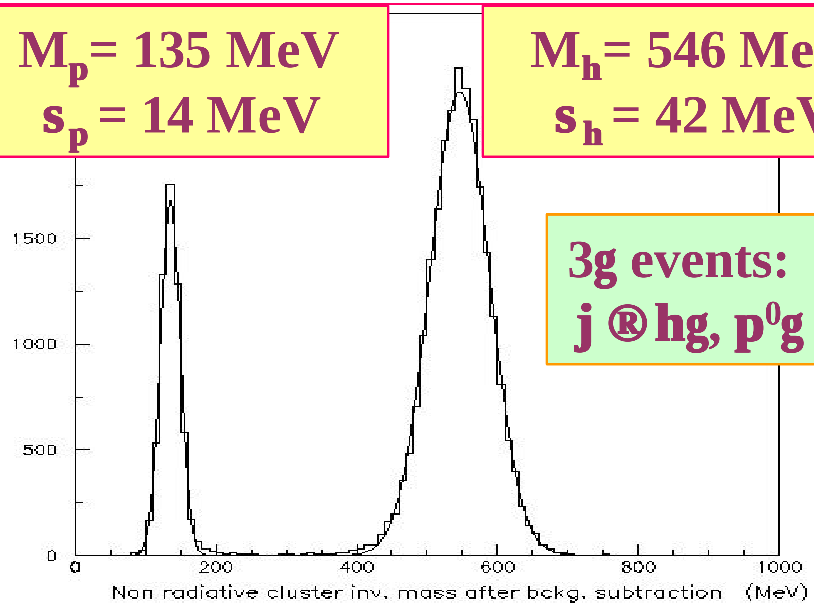


EXAMPLES OF MASS RECONSTRUCTION

M_p= 135 MeV
s_p = 14 MeV

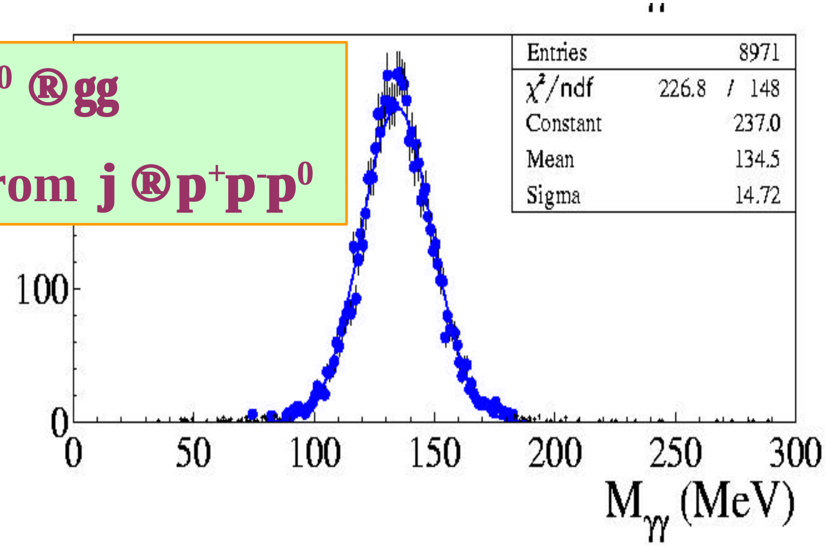
M_h= 546 MeV
s_h = 42 MeV

3g events:
j ®hg, p^0g



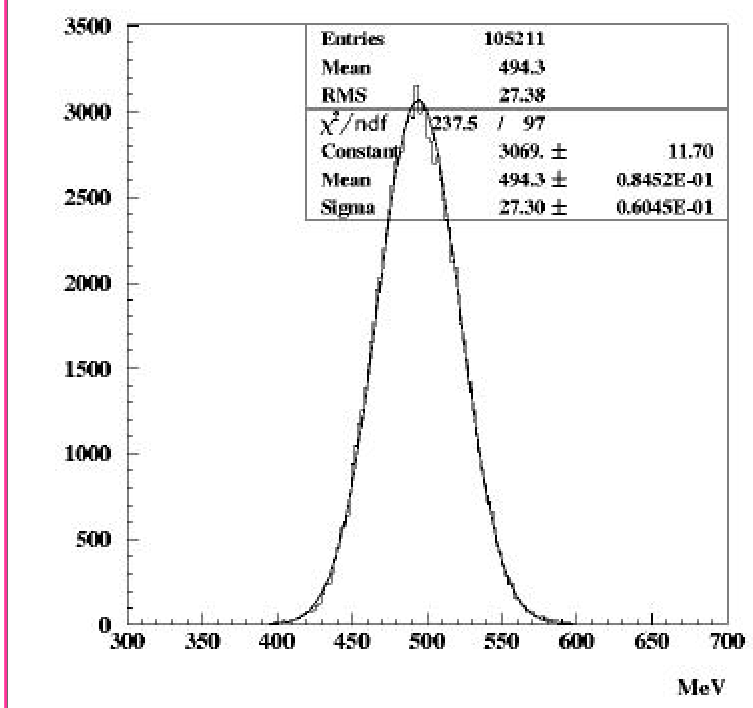
p^0 ®gg

from j ®$p^+p^-p^0$



K_S ® p^0 p^0

M_K= 494 MeV
s_K = 27 MeV



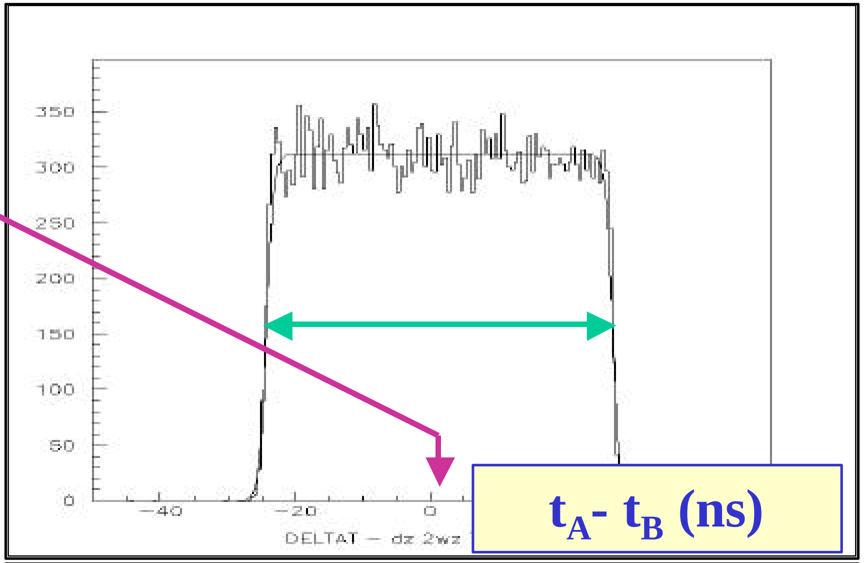
Mass reconstruction within 1%with PDG. Resolutions are in good agreement with MC expectation.

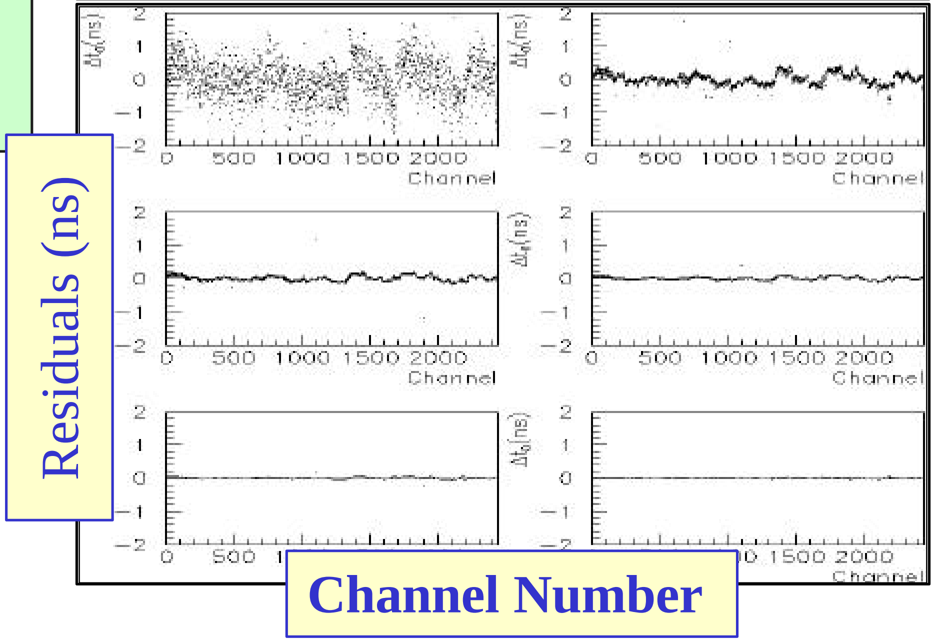
TIMING CALIBRATION WITH COSMIC RAYS

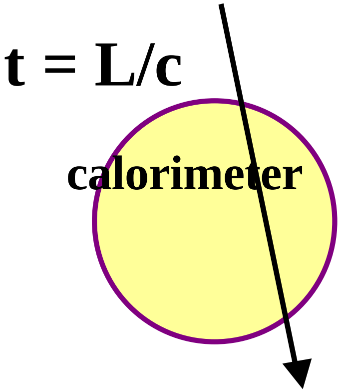
v_{eff} **from the width**

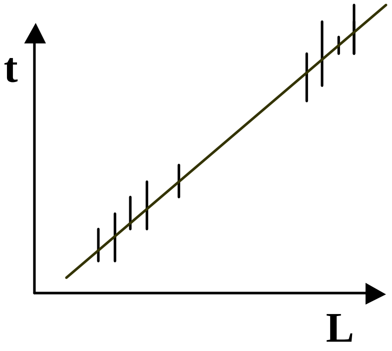
$\Delta t^0 = t^0_A - t^0_B$ **is the center**

- Select straight cosmics (high |**p**|)
- 5+5 time measurements of known track length L
- Fit t-L relation; $t^0 = t^0_A + t^0_B$ time offsets obtained trough iterative minimization of fit residuals









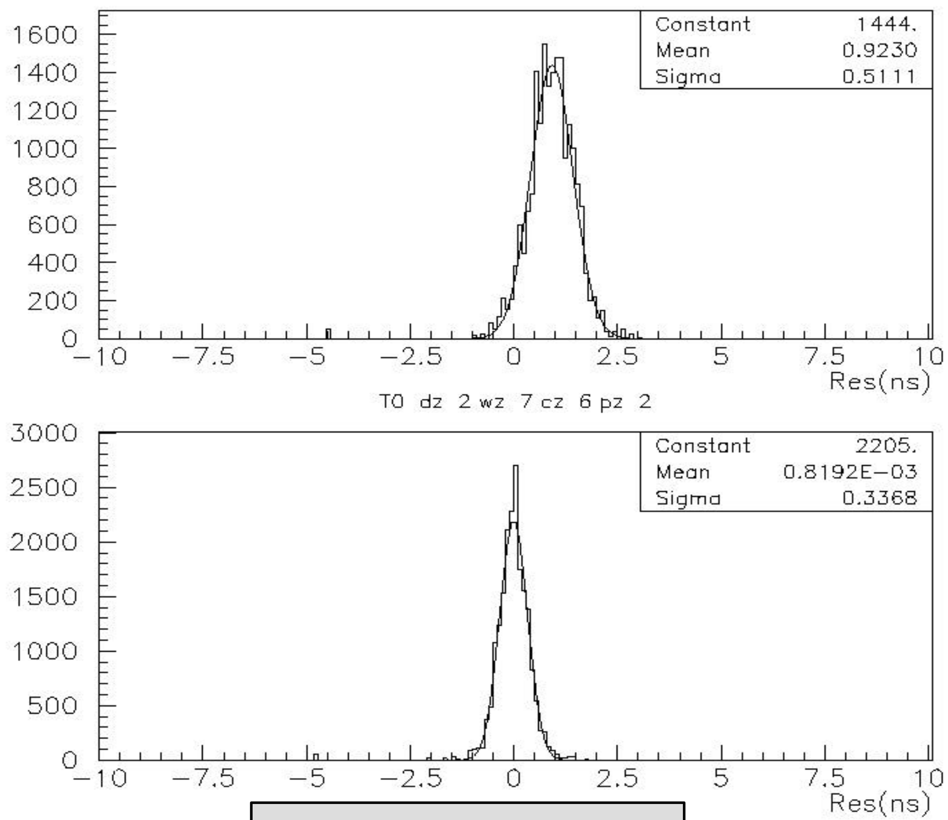
TIMING CALIBRATION WITH COSMIC RAYS … continue

• In 1 hour of data taking we collect enough statistics to calibrate t^0's and v_{eff} with the following accuracy:

• 30 ¸ 40 ps for each t^0

• 0.3 % on v_{eff} (average value 16.7 cm/ns)

Before iterations...



...After iterations

<u>for a MIP in a cell</u> <u>(~38MeV)</u> : s(t) ~ 340 ps

corresponding to: s(t) ~ 64 ps / õE(GeV)

FINE TUNING OF TIMING CALIBRATION with gg

Each **100 nb^{-1}** the **t^{0}'s** in all columns are recalibrated using **e^+e^- ® gg** to improve their determination

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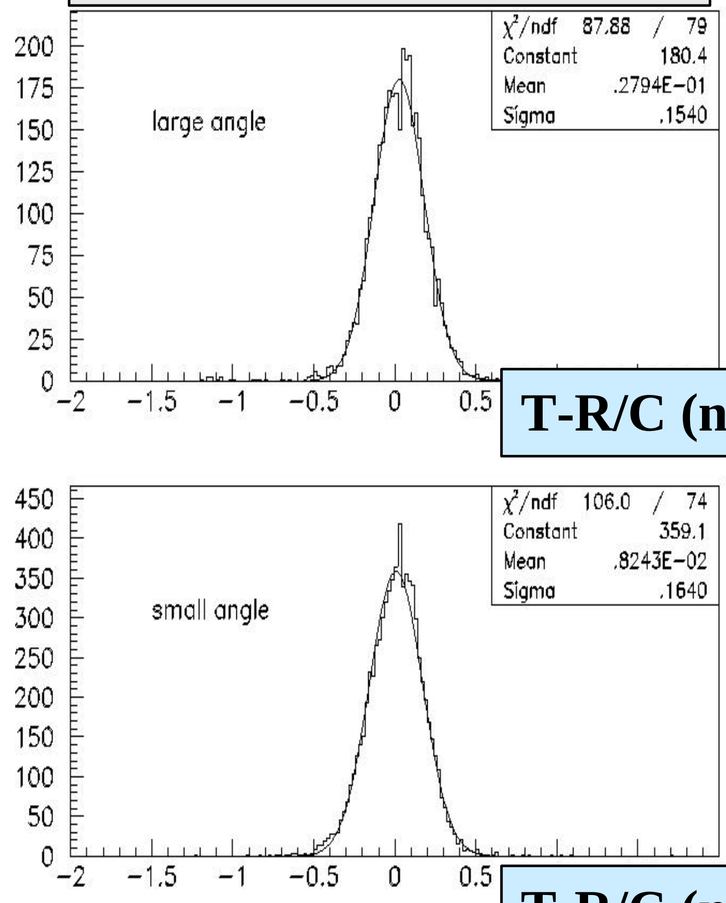
T-R/C (ns)

Channel Number

Time spectra with

e^+e^- ® gg



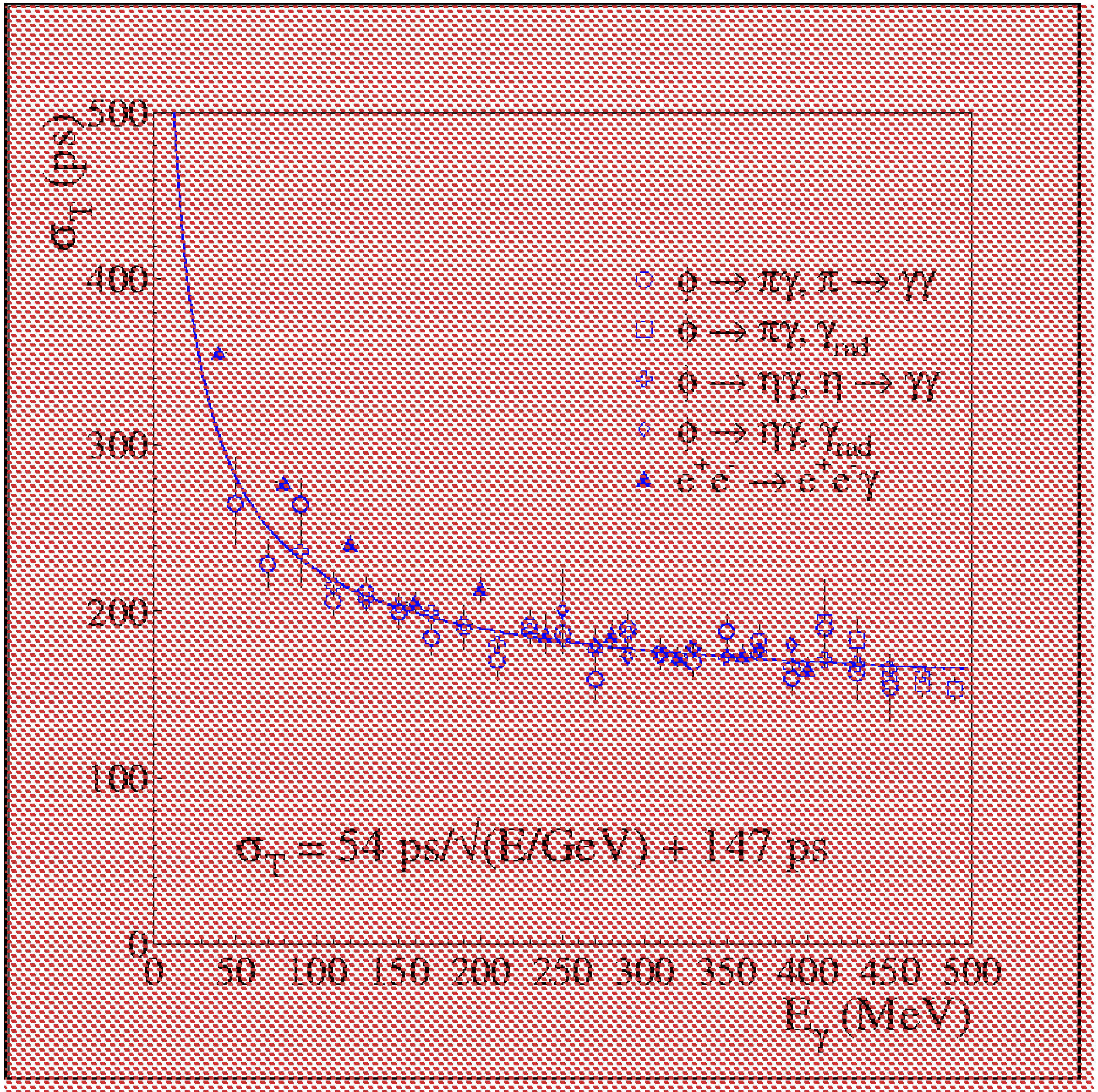
T-R/C (ns)

T-R/C (ns)

TIME RESOLUTION

Comparing the difference of timing between **gg** events at small and large angle we estimate that of the 147 ps of constant term:

- 50 ps mis-calibration
- 55 ps bunch spread
- 120 ps machine time spread

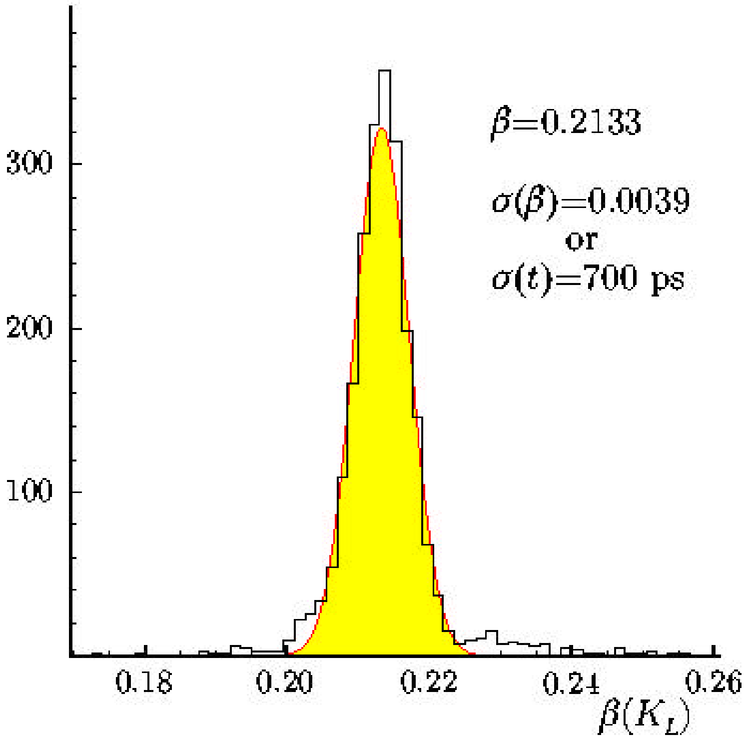


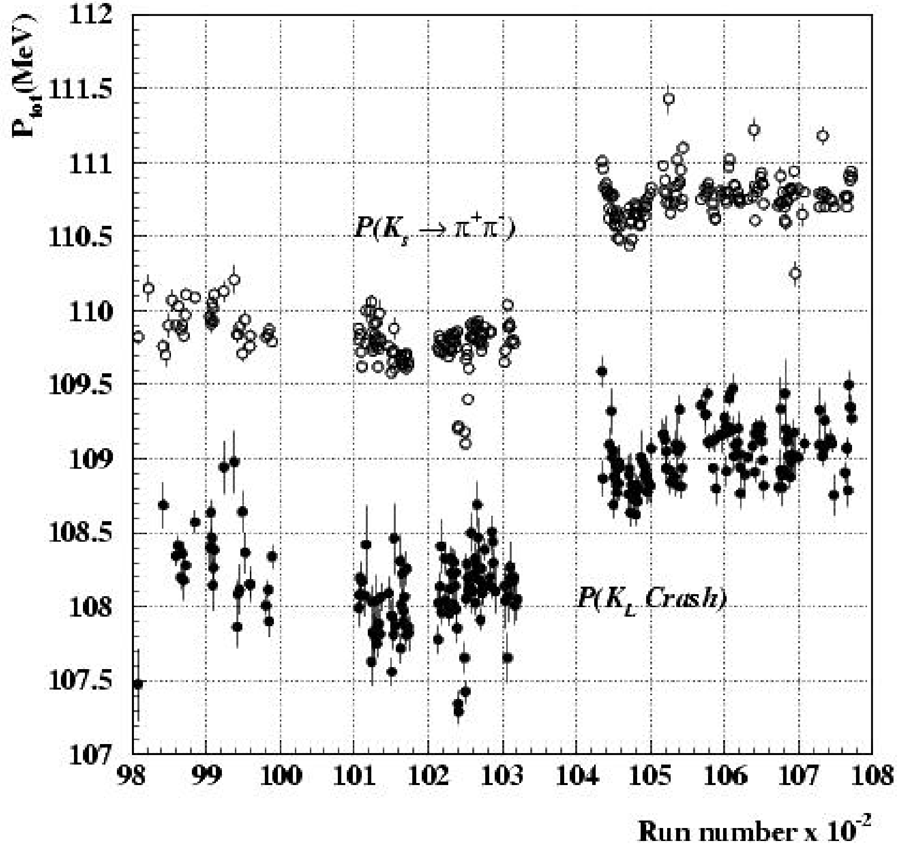
TIMING PERFOMANCES: identification of K_l interacting on EMC

Clean signature (late neutral cluster) is used for K_S tag

Reconstruction of b^* depends on the ϕ boost. Its width measures the machine energy spread

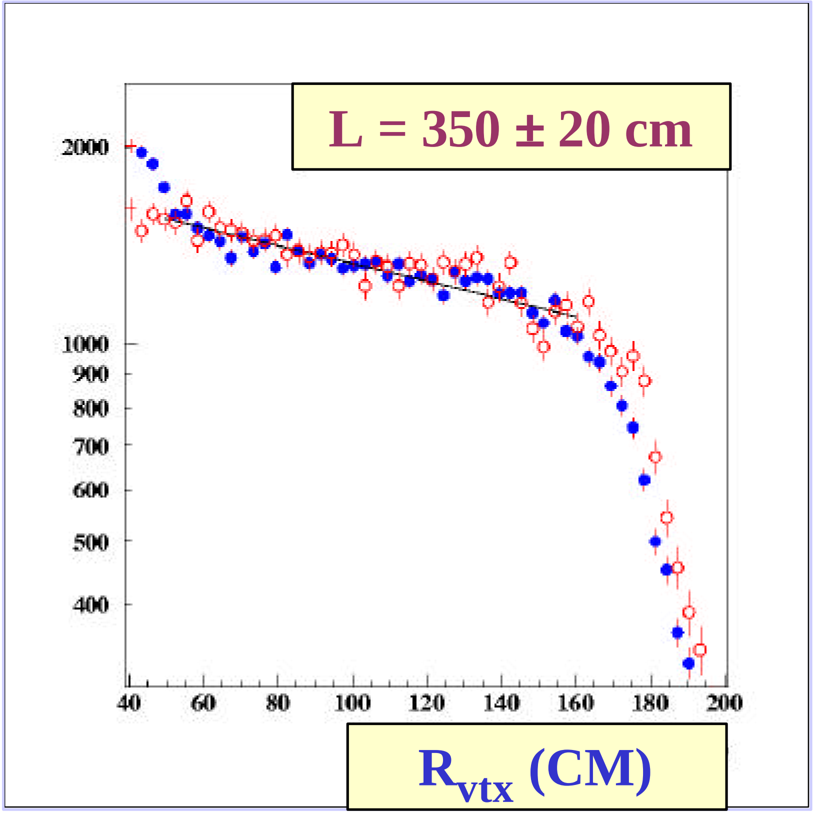
$dE_f \sim 1$ MeV $\Rightarrow db^* \sim 0.004$



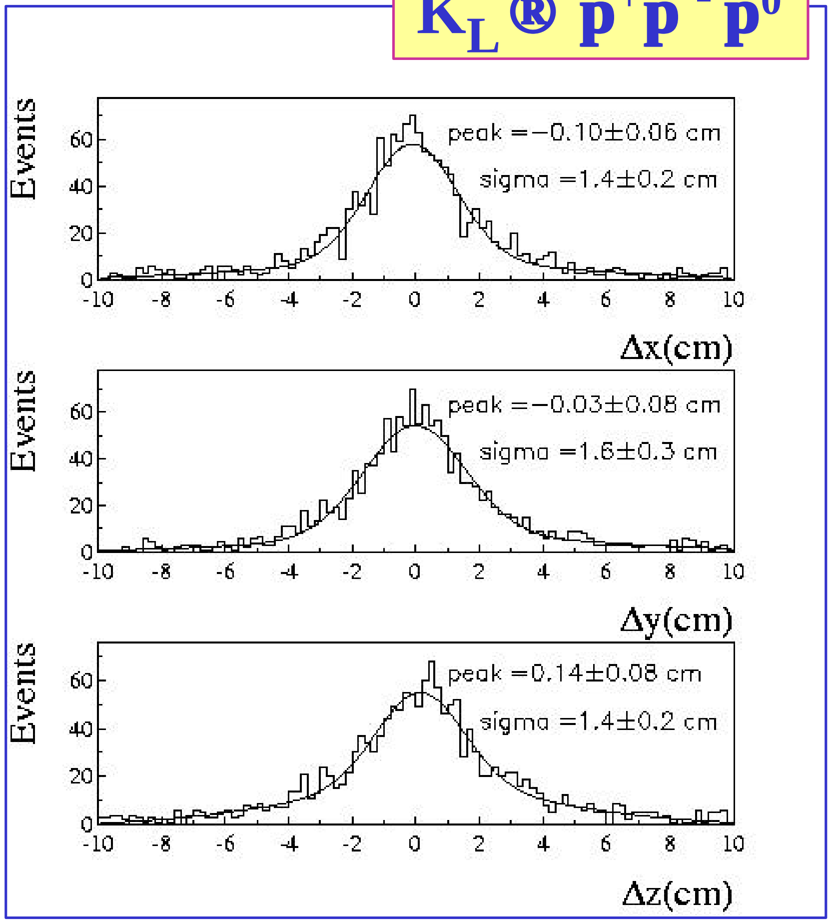


RECONSTRUCTION AND ALIGNEMENT OF NEUTRAL VERTEX

K_L ® $p^0 p^0 p^0$



K_L ® $p^+ p^- p^0$



For K_L ® $p^+ p^- p^0$, residuals not expected to differ from K_L ® $p^0 p^0$ but resolution is worse:

	$K_L \rightarrow p^+ p^- p^0$	$K_L \rightarrow p^0 p^0$	$K^\pm \rightarrow p^\pm p^0$
N_g	2	4	2
E_g	60—80 MeV	100—120 MeV	100—120 MeV

CONCLUSIONS AND OUTLOOK

• The KLOE Calorimeter has been kept in operation as a whole apparatus for more than 2.5 years in good operating conditions ® (the number of dead channels always below 0.1 % and overall good detector stability)

• The calibration procedures of energy and timing are working.

- Energy resolution of **5.7 % / Ö (E/GeV)** measured
- Timing resolution of **54 ps /Ö (E/GeV) Å 50 ps** achieved
- Good calibration stability observed in 6 months of operation.
- Reconstruction of masses and neutral vertices satisfactory

• Work is in progress to:

1) complete the setting of the time scale

2) correct the residual response non-linearity and the response along cracks regions

3) make fully automatic the calibration procedures