CCALT:
Crystal calorimeter
At KLOE2

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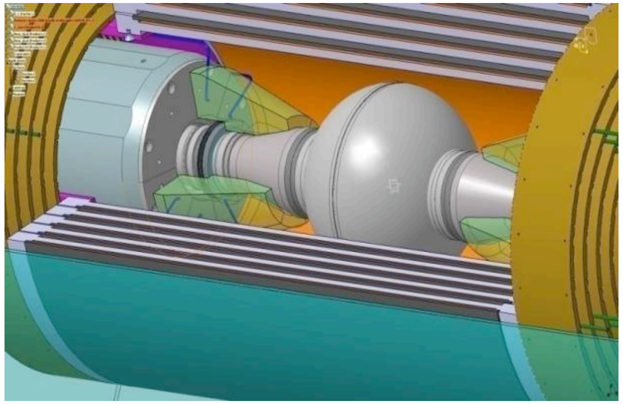
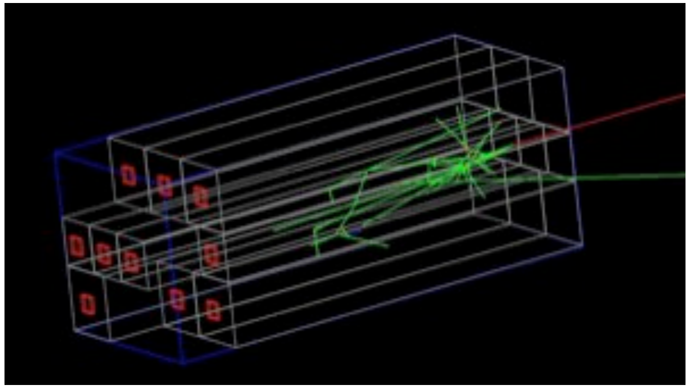
CALOR2010 - Beijing, May 10, 2010





Outlook

- KLOE 2 Upgrade: a crystal calorimeter with timing

- Physics motivations for a small angle calorimeter upgrade

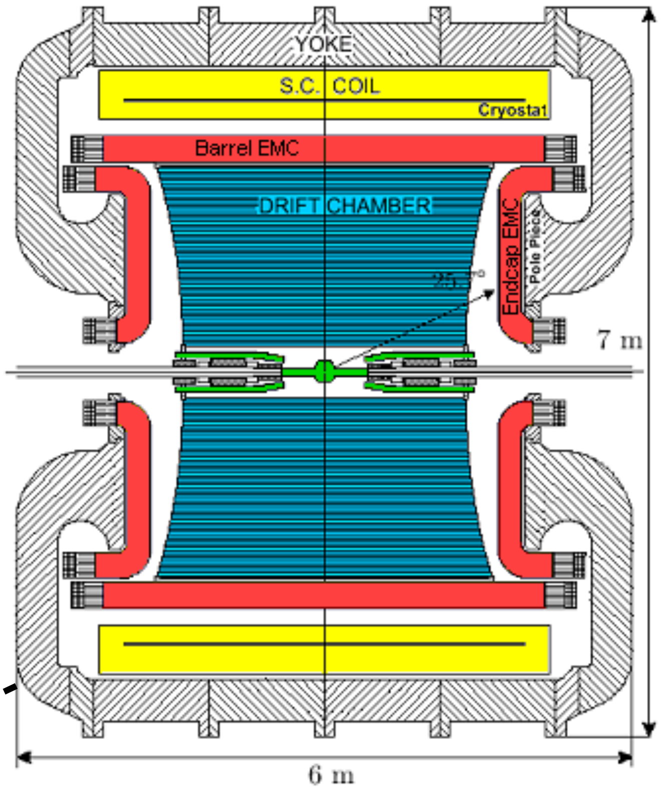
- The CCALT crystal calorimeter
    - requirements and first design
    - LYSO crystals + APD study
    - crystal matrix realization
    - test beams results
    - Monte Carlo studies
    - critical issues
- Plans

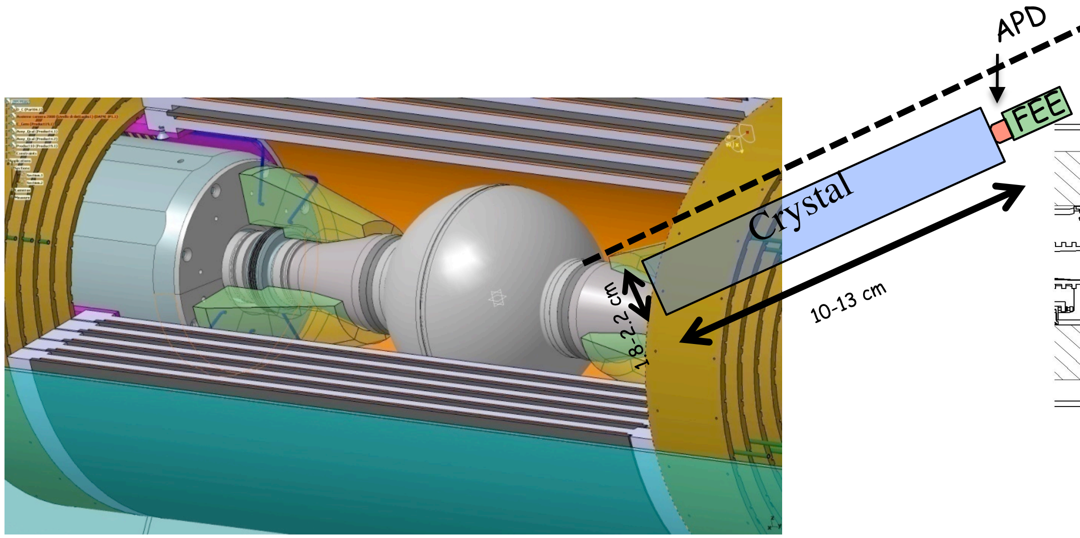
CCALT

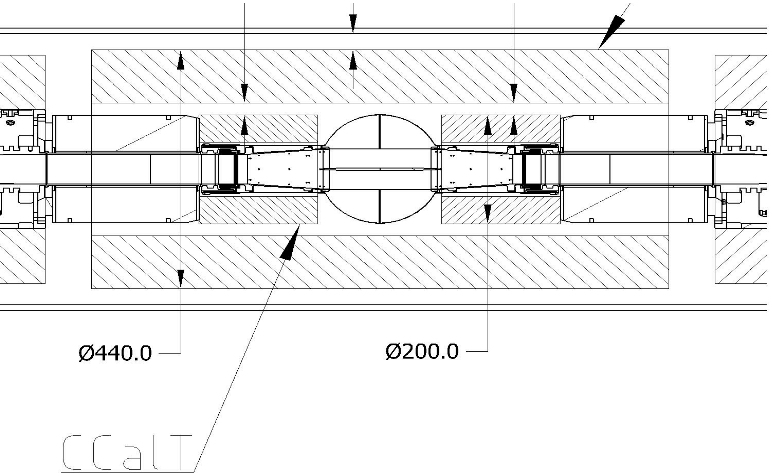
In the new machine layout of DAΦNE the position of the inner quadrupole, QD0, at 30 cm from IP, reduces to 18 d the minimum polar angle of the photons accepted by EMC

This opens the possibility to insert new calorimeters in this volume

We are desgning a crystals calorimeter with timing, CCALT, to improve acceptance for tagging photons coming from prompt η and K_S decays.







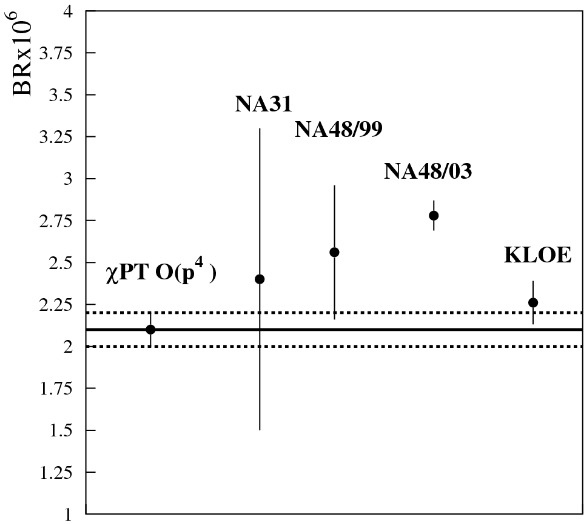
Physics improvement

There are some physics items that can benefit from these upgrades.

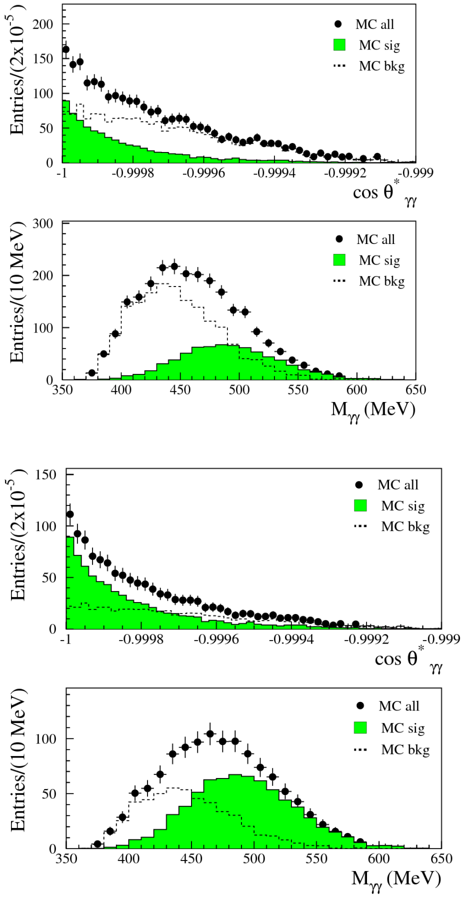
In particular, the last KLOE measurement on BR($K_S \to \gamma\gamma$) (JHEP 0805:051,2008).

3σ difference between KLOE and NA48.

KLOE confirms $O(p^4)$ prediction of ChPT.



Major bkg:$K_S \to 2\pi^0$ with 2 photons lost (beam pipe -QCAL inefficiency)



KLOE EMC covers down to 21 degrees.

With the CCALT extension down to 10 degrees.

Golden channels:

- **Working as a veto for $K_S \to 2\pi^0$**
- **Increase acceptance for $K_S \to 3\pi^0$**

CCALT can reduce the background by a factor of 3

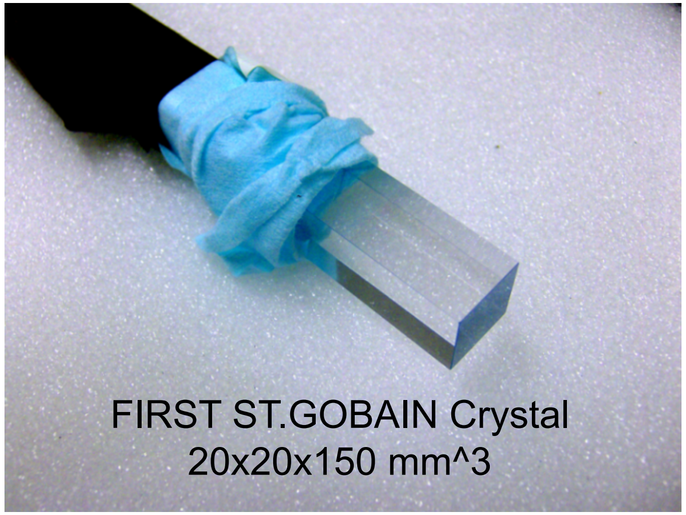
Requirements for the CCALT calorimeter

- Dense due to the small available space (15 cm long): small Xo and Moliere radius
- Extremey accurate on timing: 200-300 ps @ 20 MeV
  timing needed to reject accidental/machine Touschek bkg (100 kHz per channel)
  CCALT == Crystal Calorimeter with Timing
- Highly efficient for 20-300 MeV photons---> High Light Yield
- Small number of channels w photosensors working in 0.52 kGauss B field
- Energy resolution will be poor: no transversal coverage (3-4 cm radius)
- Reasonable position resolution (2-3 mm at 15 cm from IP) to improve energy resolution with kinematic fitting (K_s->$3\pi^0$ search)

LYSO crystals look as a perfect match for this work:

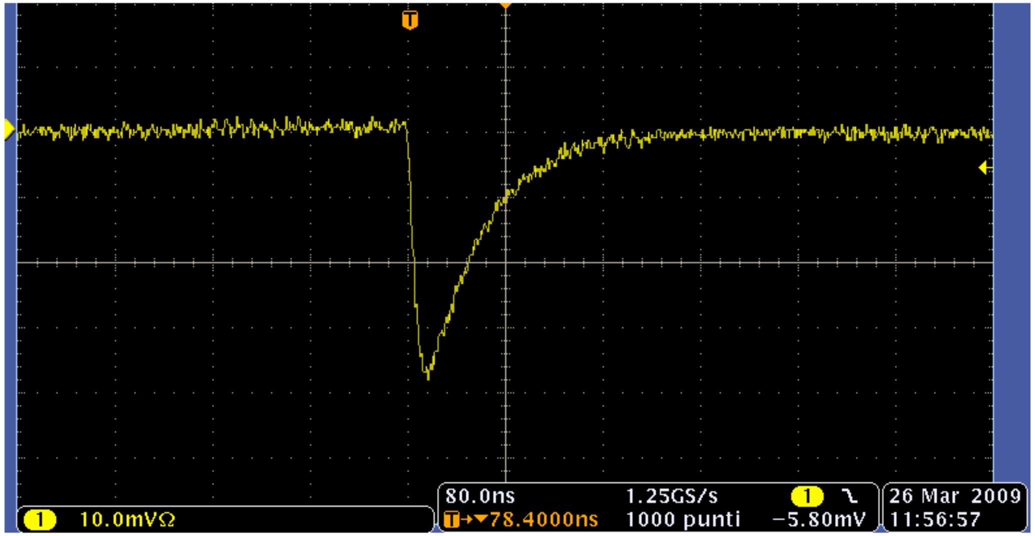
- high light yield: 27000 photons/MeV
- emission time of 40-42 ns
- X_0 = 1.1, Rm = 2 cm, refraction index = 1.8
- not hygroscopic
- good optical coupling with APD

First Test of crystal with CR (mar 2009)


FIRST ST.GOBAIN Crystal
20x20x150 mm^3

- Amplifier based on MAR8+
- APD 5x5 mm2
- X 25 amplification
- Bandwidth 1 GHz

- Large signals with CR (40 mV) with APD@410V
- HV from CAEN (CMS-like)
- Noise of few mV
- Readout by Lecroy ADC 400ns wide gate
- σ(ped) = 1.5 counts
- MIP(peak) = 50 Counts
- σ(MeV) = 0.6 MeV

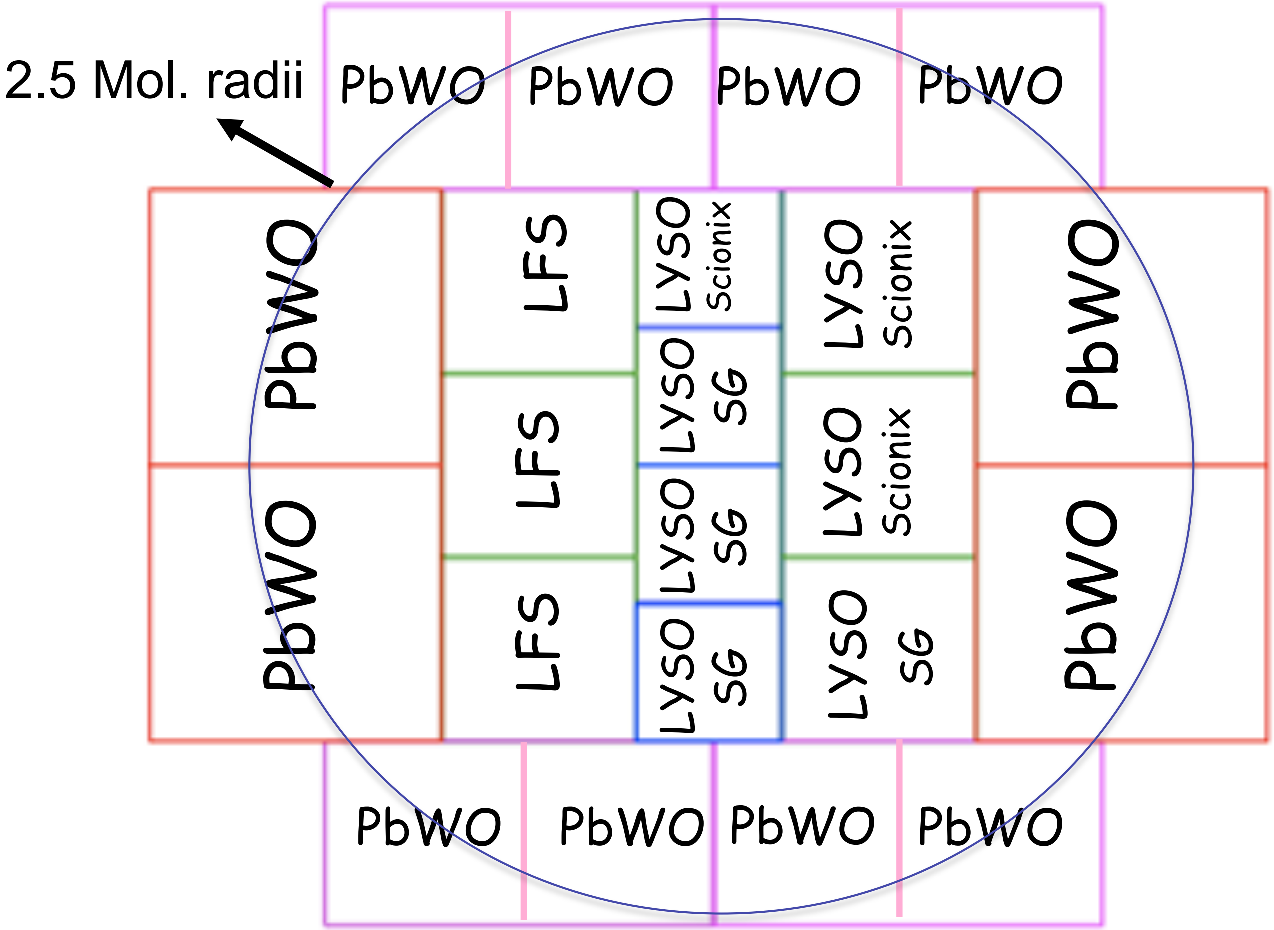


2009 - Crystal Matrix overview

Due to high LYSO cost, we assembled a cocktail of crystals:

- an inner core with 10 LYSO+APD

- an outer leakage-recovery section using PbWO+bialkali PM



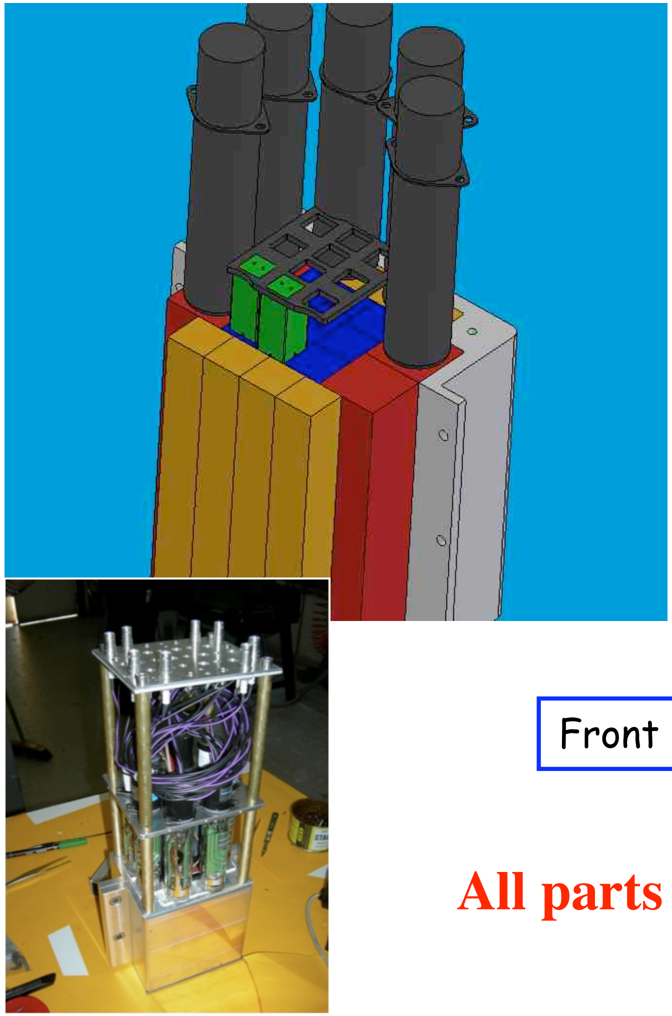
- PbWO from SICCAS
- LYSO/LFS from 3 companies:
  - Saint Gobain (SG)
  - Scionix Holland
  - Zecoteck (LFS)

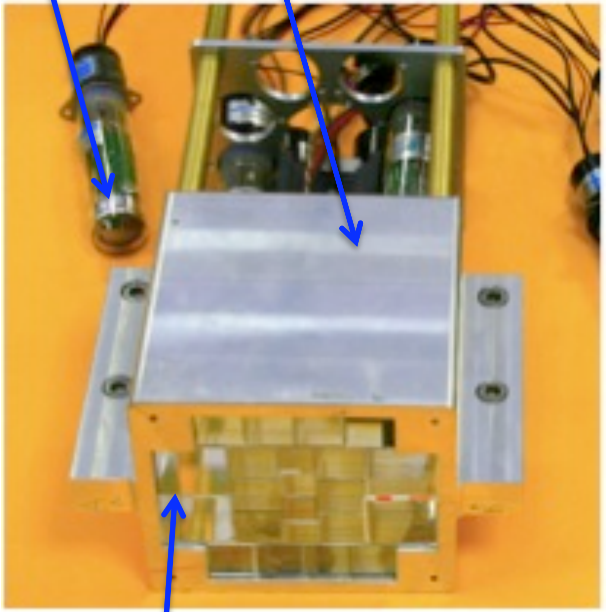
Crystal dimensions:

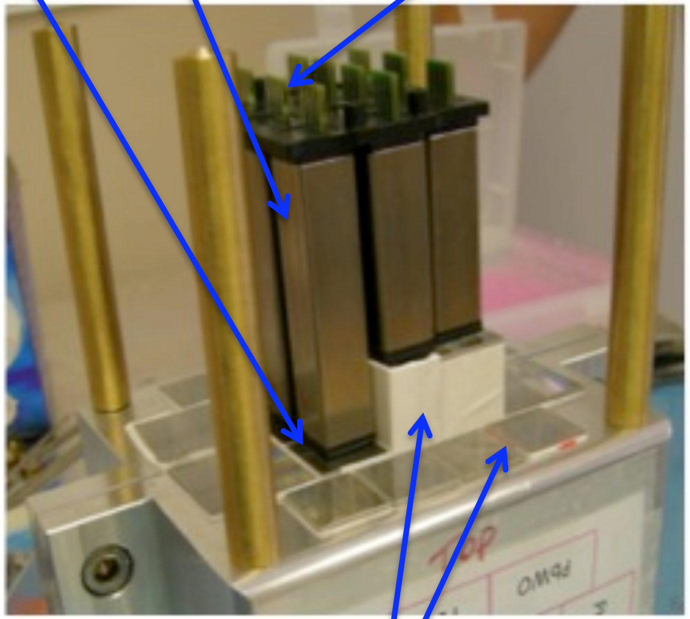
- 3 SG (15x15x150)mm^3
- 1 Scionix (15x15x130) mm^3
- 1 SG (20x20x150) mm^3
- 2 scionix (20x20x130) mm^3
- 3 LFS (20x20x130) mm^3

From CAD to realization

CAD drawing







Aluminum shell

APD+Pre box

Outer matrix PMs

APD mask

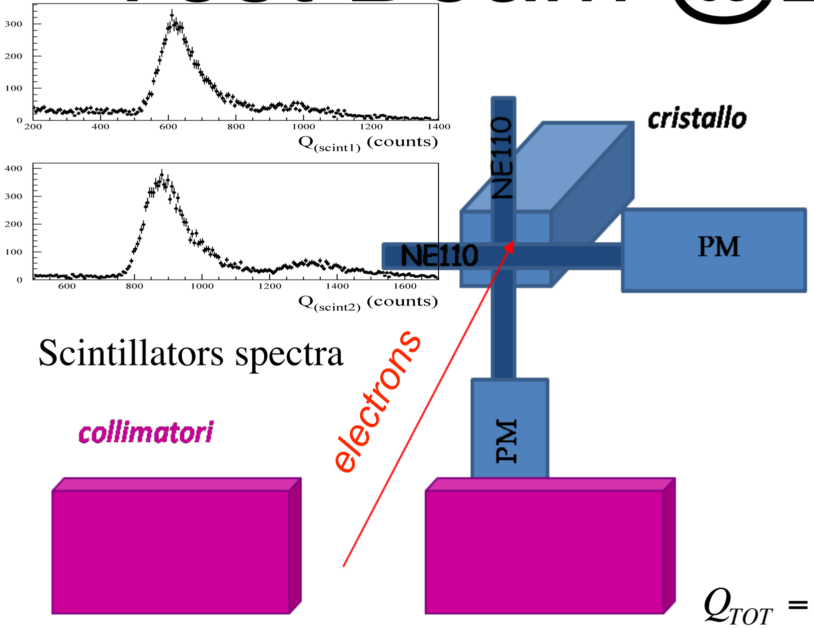
FEE cards

Front face free for LED pulsing

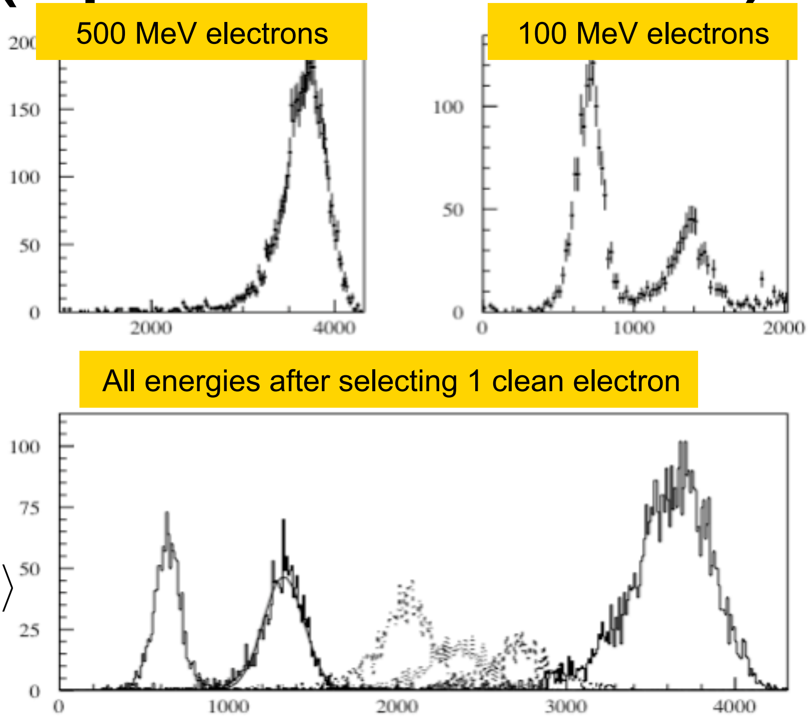
Different length crystals and boxes

All parts realized by LNF mechanical shop

Test Beam @BTF (april – oct 2009)



$$Q_{TOT} = \sum_i \left(\frac{Q_i - P_i}{M_i}\right)\langle M \rangle$$



- ❑ BTF @LNF provides 100-500 MeV electrons to experimental area with selectable multiplicity at few tens of Hz (i.e. the Linac repetition rate)
- ❑ To select clean electrons we required OFFLINE the firing of two external finger scintillators (1x0.5x5) cm^3 which defined also the beam spot on the calorimeter.
- ❑ We had a small optical leakage between the inner (LYSO) and outer (PbWO) matrix. 0.2% of the light was crossing the Tyvek and A(PM)/A(Apd) = 10^3

  This problem is now fixed wrapping with .2 mm layer pvc and ready for a new test beam!

Timing measurement at BTF

Each spill of 10 ns from LINAC consists of bunches separated 200-300 ps

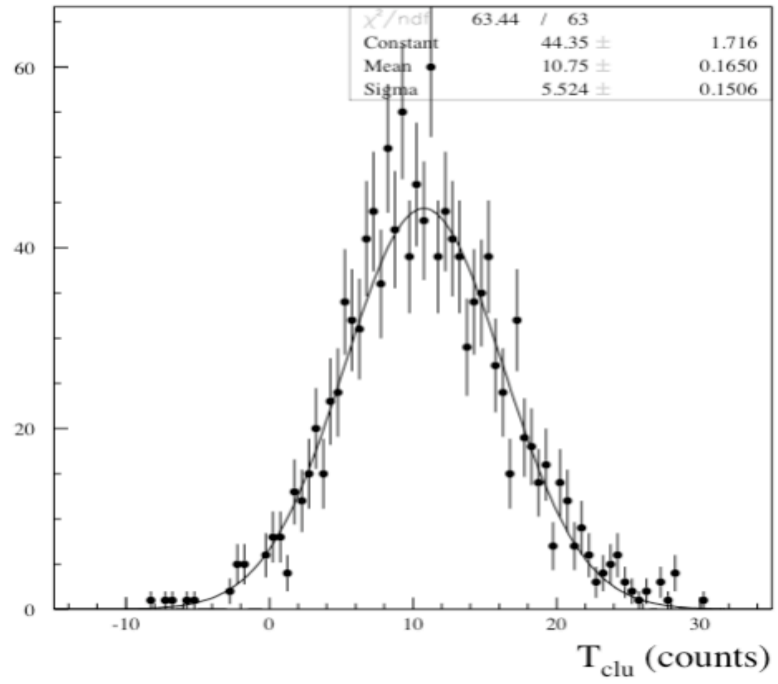
To eliminate the jitter of the start provided by the Linac Gate, we plot the difference of the calorimeter and finger scintillator times: $\Delta T = T_{clu} - T_{sc}$

Jiitter of the scintillator: $\sigma(T_{sc}(1) - T_{sc}(2))/\sqrt{2}$

KLOE TDC - 53 ps/Count

σ_{scint} = 245 ps @ 500 MeV
= 265 ps @ 100 MeV

100 MeV electrons



- ☐ $T_{clu} = \sum (T_i - T_{0i}) Q_i / Q_{tot}$
- ☐ Assuming all channels calibrated with 53 ps/Count!
- ☐ $\sigma(T_{clu})$ = 250 (49) ps at 500 MeV, 291 (120) ps at 100 MeV without (with) correction for trigger jitter

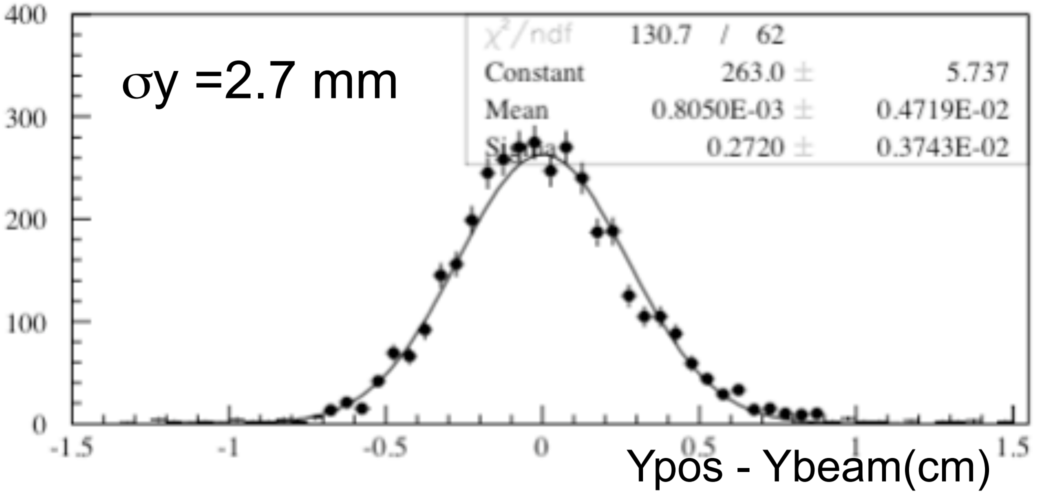
Position resolution @ 500 MeV

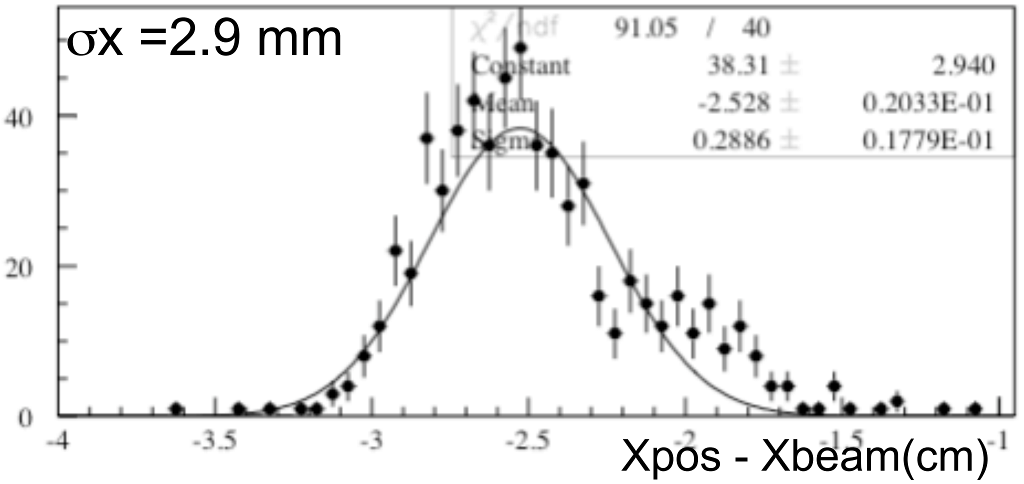
- Position reconstruction in prototype by means of energy weighted mean of the fired crystals

$$Xpos = \sum(XiQi)/Qtot$$
$$Ypos = \sum(YiQi)/Qtot$$

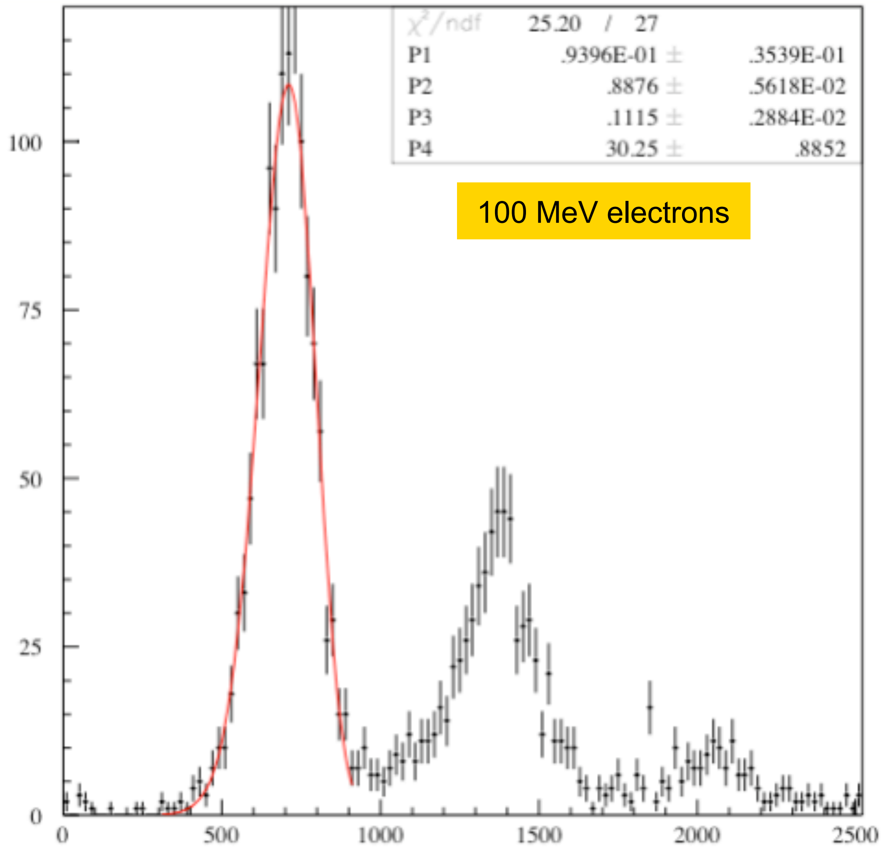
- we acquire also the beam position coordinates with a scintillating fibers hodoscope (3mm pitch)

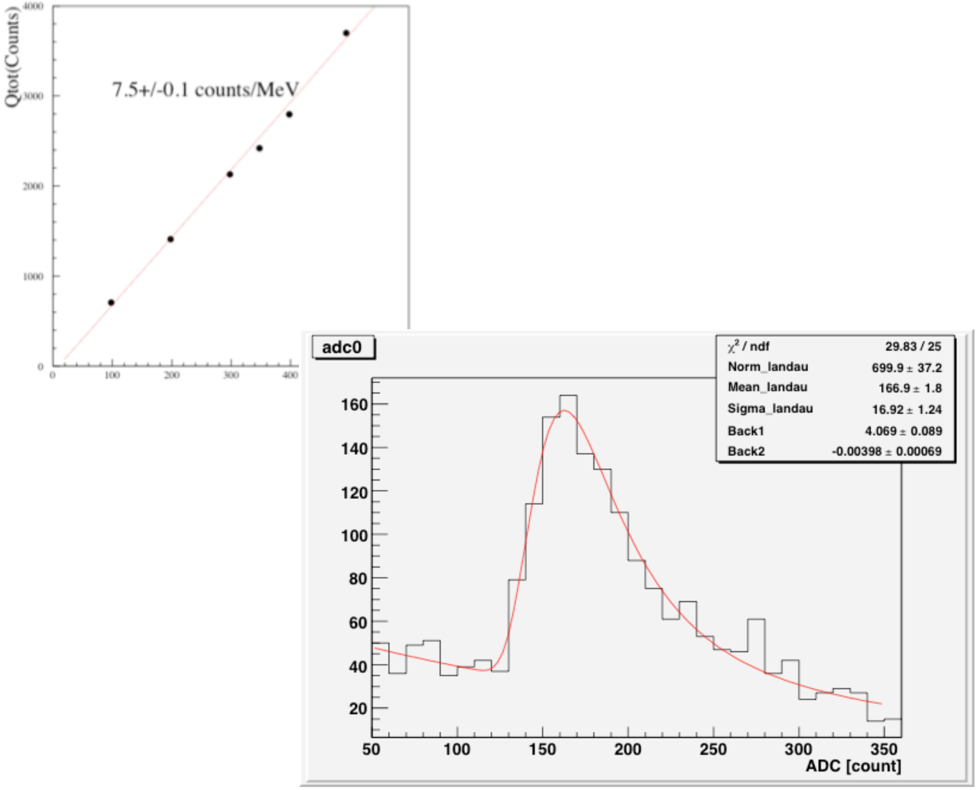
Resolution of ~2.8 mm compared to ~ 4.3 mm due to the pitch





TB09: Fit to the ADC spectra





$$\frac{df}{dE} = \frac{\eta}{\sqrt{2\pi}\cdot\sigma_E\cdot s_0}\cdot e^{-\frac{1}{2}\left\{\left[\frac{\ln\left[1-\frac{\eta}{\sigma_E}\cdot\left(E-E_{peak}\right)\right]}{s_0}\right]^2+s_0^2\right\}}$$

η= asym, σ= FWHM/2.35

<M> = 100 Counts; 1 MIP = 16 MeV

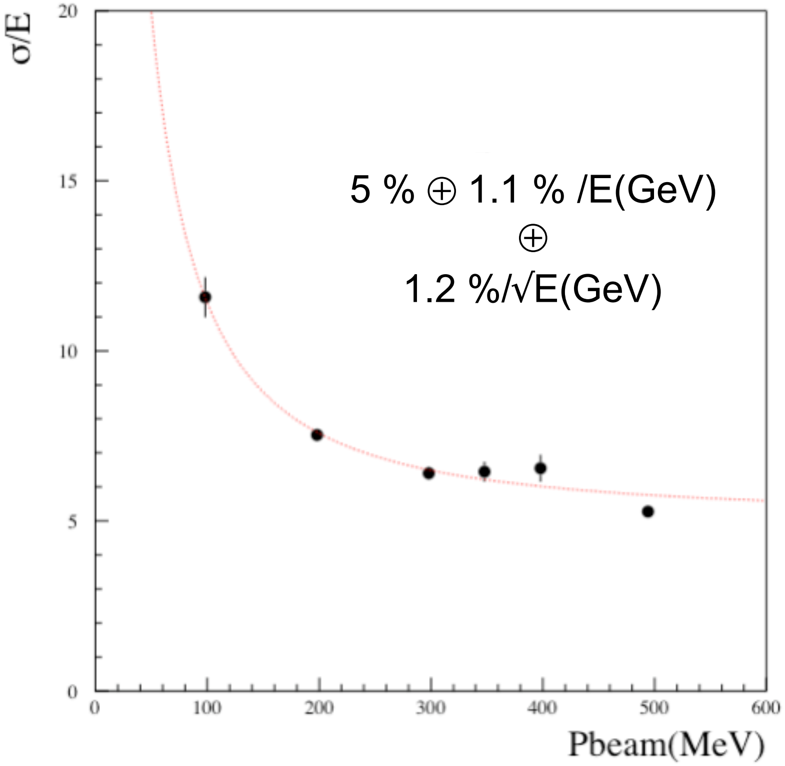
Gain vs HV from 300 to 500 (@ 410),

Gamp=25, adc count =.25 pC

Q(1e) = 1e •G_{apd} •G_{amp} = $1.6 \cdot 10^{-19} \cdot 3 \cdot 10^{2} \cdot 25$ =1.2 fC

1 MeV = 800 fC ---> 1 MeV = 400-700 pe

TB09: Energy resolution dependence



- Constant term dominated by leakage. Fixed by MC (4.0 – 5%).
- Noise term between 1.1 %/E(GeV).
- Stocastic term between 1.2%/√(E/GeV).

Disappointing results on ene resolution (12 % @ 100 MeV)

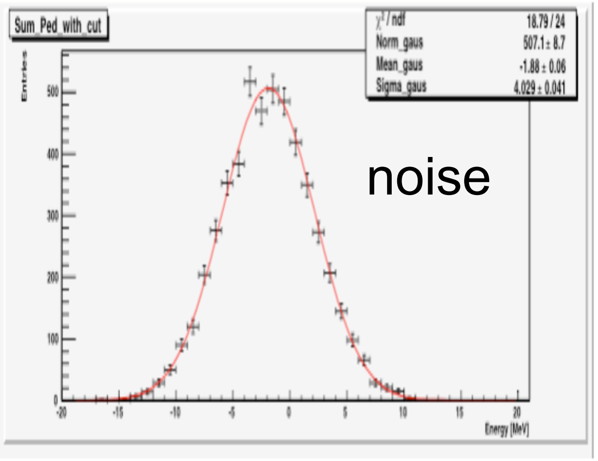
(1) Constant term dominated by leakage. (MC 4-5%)

(2) k/E term between ~ 1.1%/E(GeV).

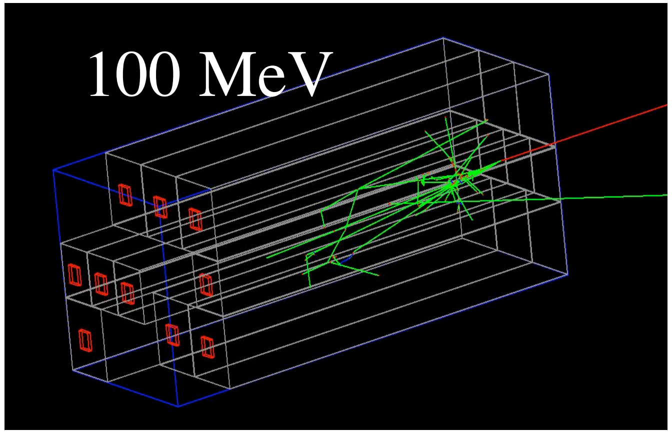
Electronic Noise Charge/chann ENC = 1 MeV.

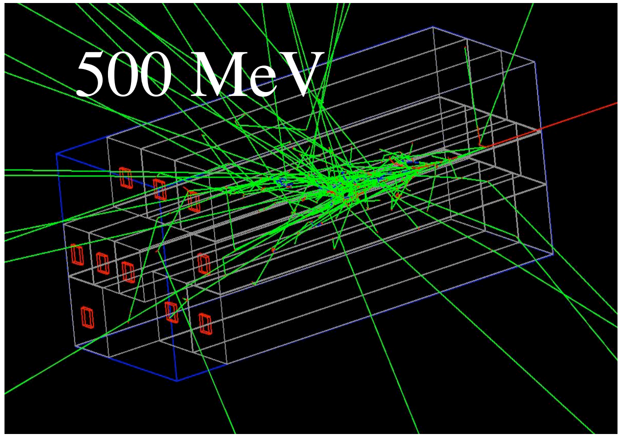
ENC(inner matrix)=4.2-4.8 MeV -> 0.48%/E(GeV)

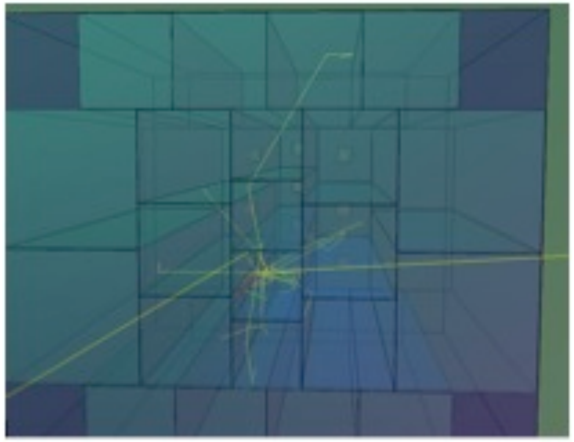
(3) Stochastic term between 1-1.2% vs expected from p.e. stat. < 0.2%



MC simulation of matrix: leakage term

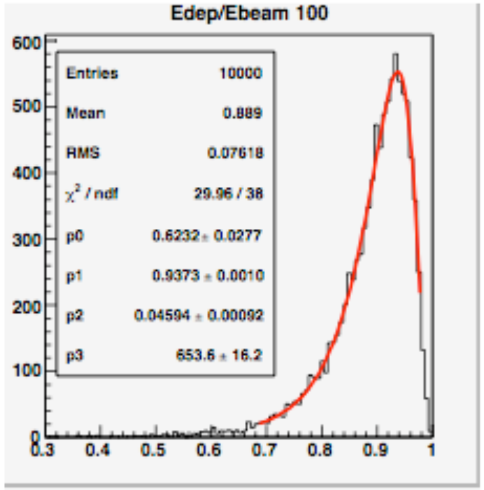






Considering only the inner core of 1.5 Moliere radii

- Detailed Geant-4 simulation
- All dimensions respected (crystals, wrapping, APD's)
- Beam spot dimensions ($5x5\ mm^2$, $10x10\ mm^2$)
- Optical transportation of photons + time emission spectra



E_{beam} (MeV)	Epeak	σ	σ/E
100	0,9373	0,04594	4,9%
200	0,9206	0,04212	4,6%
300	0,9112	0,03856	4,2%
400	0,9065	0,03728	4,1%
495	0,9019	0,03502	3,9%

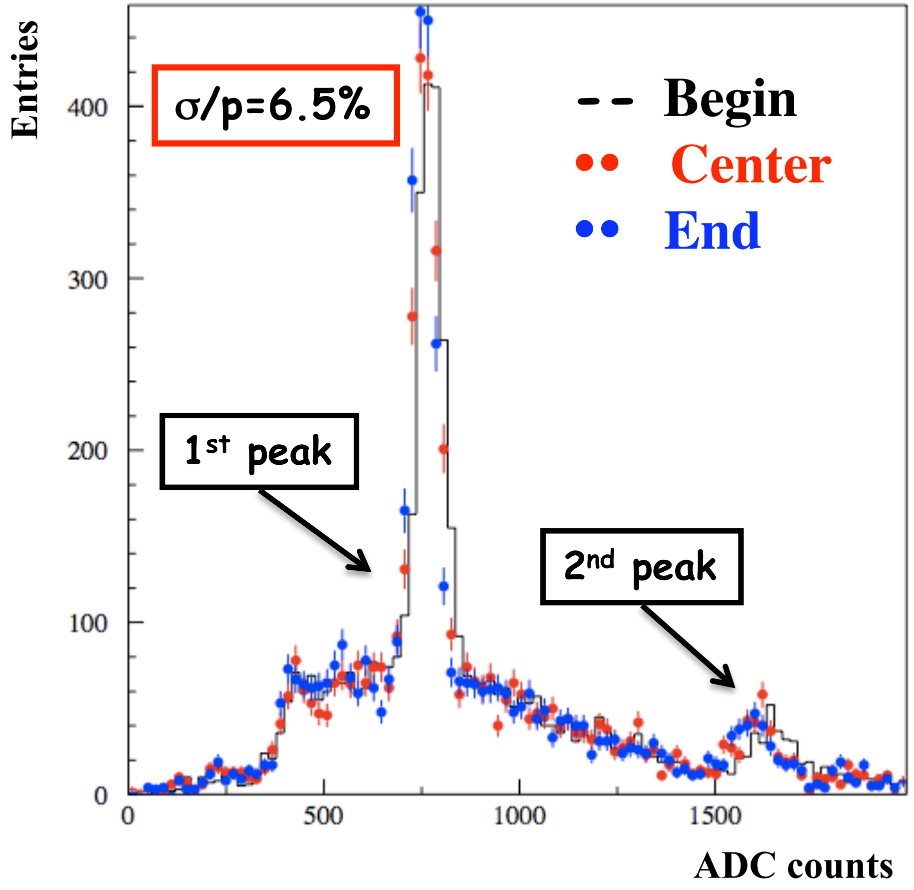
Geant can also be used to check whether any possible shower development Fluctuation convoluted with the Light Response Uniformity of crystals can play a role

LYSO longitudinal response

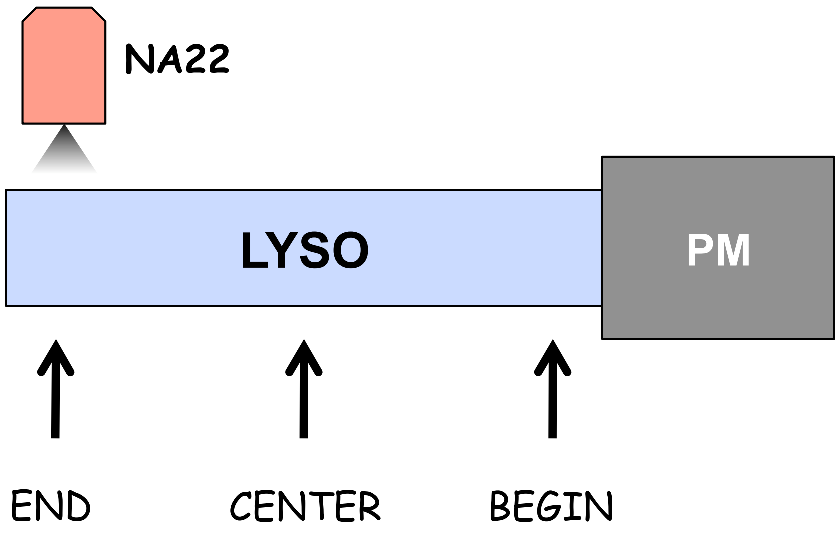
Longitudinal response of crystals tested by using a Na^{22} source and standard bialkali PM.

Cross check of different crystal faces.

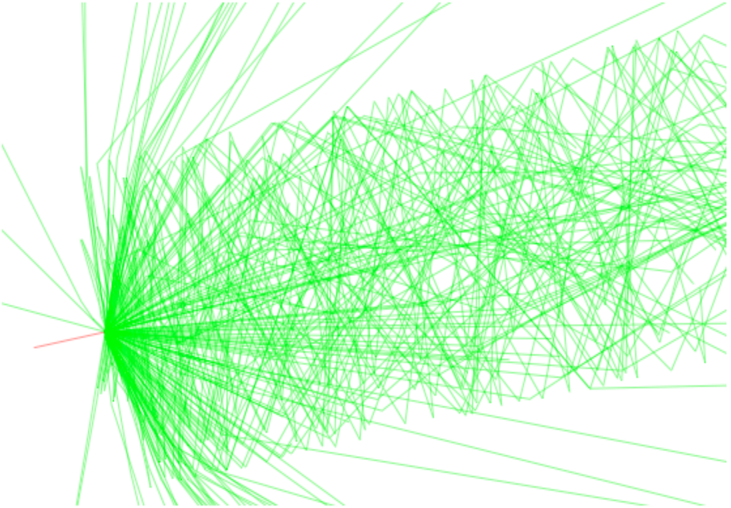
Maximum variation below 5% (LY: 240 pe - 1st peak → 470 pe/MeV)

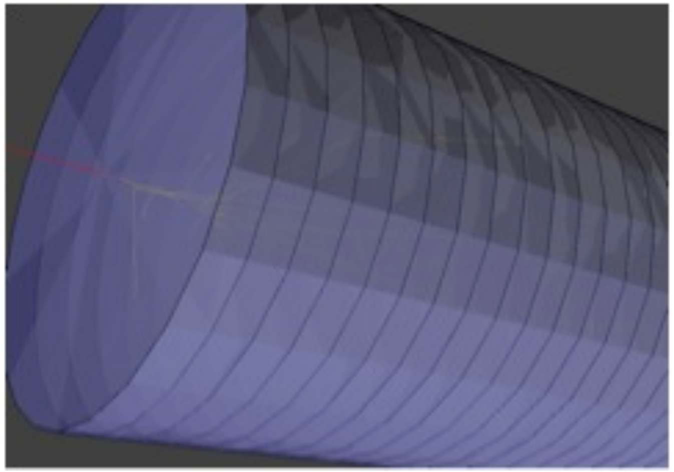


Na^{22} 1st peak	**0.511 MeV**
Na^{22} 2nd peak	**1.275 MeV**



Convolution of LRU and shower shape





Due to the large CPU time needed to simulate the whole matrix we have simplified the Geometry to understand the effect of LRU convolution and used two techniques:

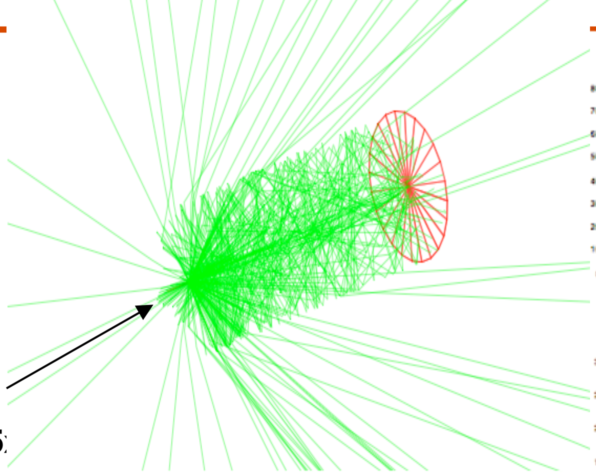
LYSO Cylinder of R=10 cm (5 Rm) L=50 cm

1) Full simulation of optical transportation with a LRU dependence on GEANT code
2) Collecting the hits in z-slices of 0.5 cm weighted by LRU dependence on (z)

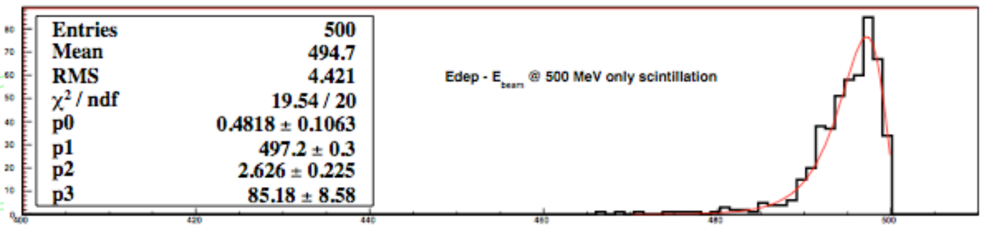
- Wrapping of mylar (100 μm)
- LO=1000 photons/MeV
  w.r.t. 27000/MeV in real life (CPU limit)
- λ_a=100 cm

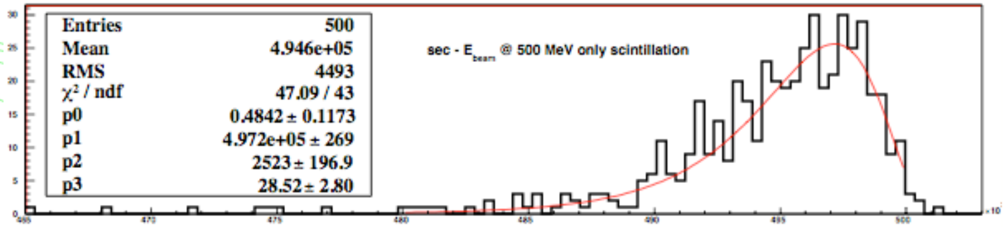
- EffiCollection == Tunable

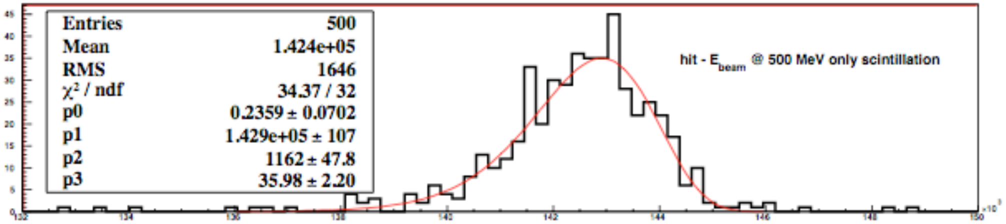
Resolution of 5 RM CILINDER @ 500 MeV



e$^-$ @ 500MeV 0,5
trigger area



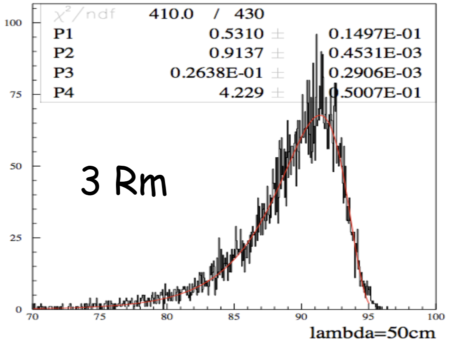




We monitor the statistical fluctuations at every stage of the shower evolution:

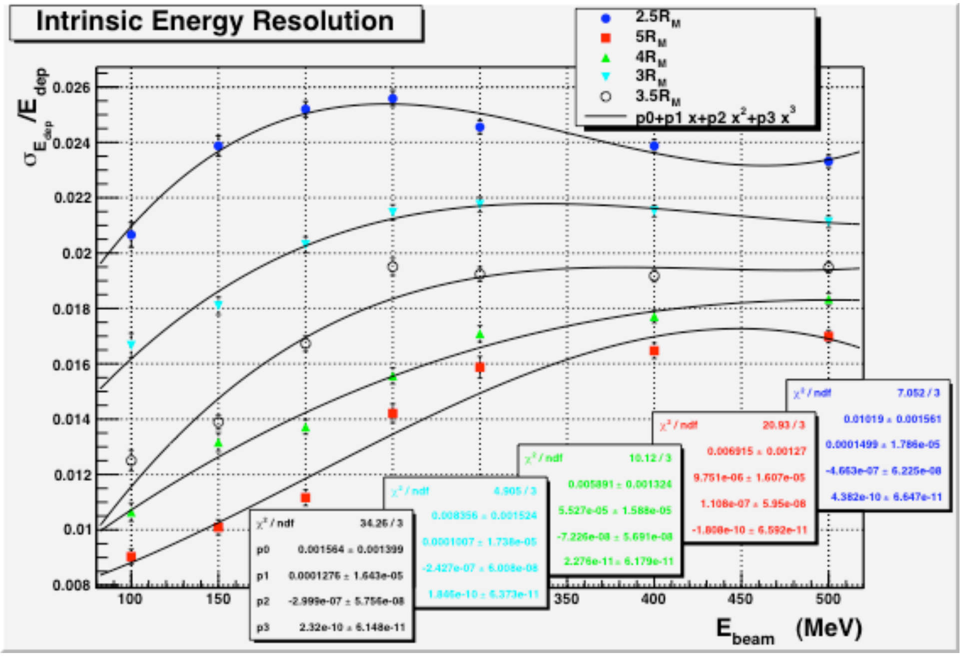
- •Energy deposited(leakage)
- •Number of secondaries e+e-
- •photoelectrons

Sigma E/Edep	0.5%
SigmaNsec/Nsec	0.5%
SigmaNhit/Nhit	0.8% vs 0.2 (p.e.)



Similar results obtained with the simplified simulation , with delta=5%, max effect < 2%

MC summary of signal fluctuations



✓ Leakage contribution small

(0.8 to 0.2 % with Rm=5, l=15, l=50 cm)
~1-1.2% @ Rm=3.5 with L=15.

✓ LY is not the limiting factor.

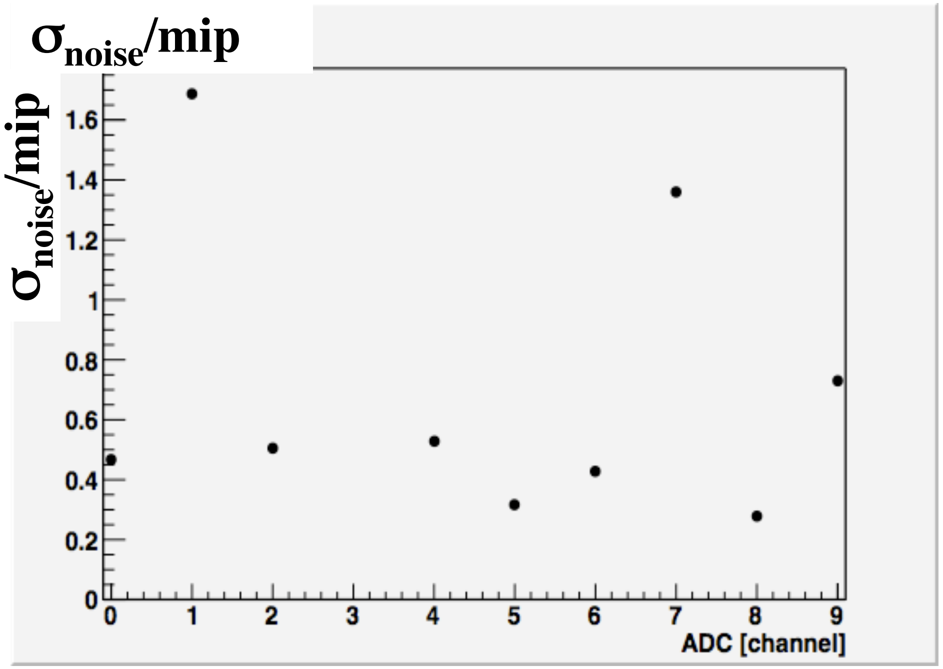
Even with a smaller than expected LY we observe other source of intrinsic signal fluctuations

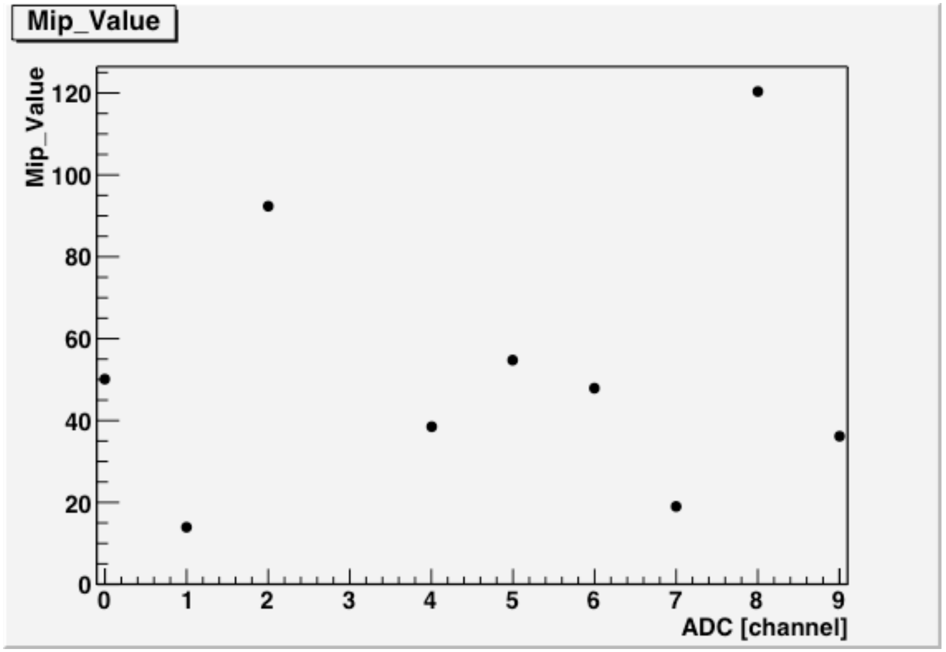
✓ Not negligible effect -> shower shape convoluted with longitudinal response.

We see effects at the level of 1.6 % @ 20 MeV, 0.8 % @ 500 MeV

Work is in progress to quantify the effect in a sistematic way with the simplified simulation

BTF_oct_09, noise studies

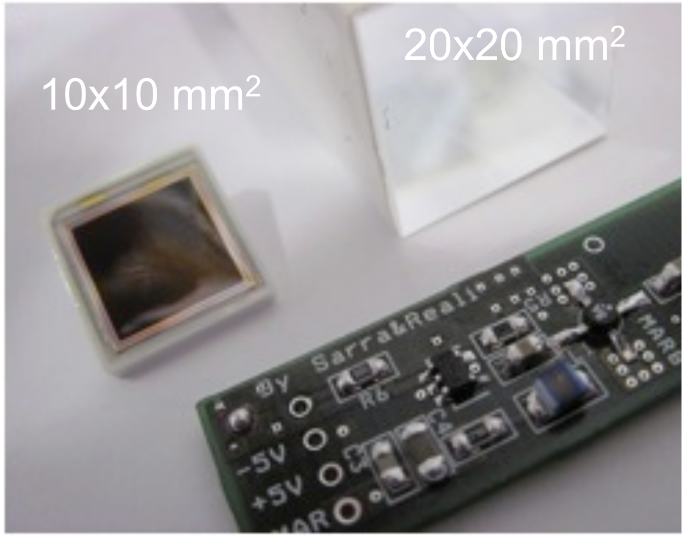




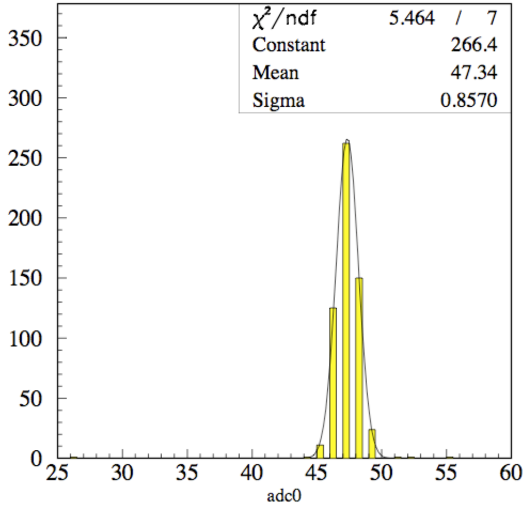
1) APD 5x5 mm2 used
2) Crystals of two transversal area
Small 15x15 mm2
Large 20x20 mm2
Rcoll = 1/9, 1/16

1) Minimization of noise for single channel tried increasing HV w/o reaching Geiger mode. The HV increase on larger crystals improves gain without introducing noise
2) High noise channels are the ones where the gain could not be raised enough to increase the mip value (photoelectron statistics):bad optical coupling
200-300 KeV small
500-600 KeV large

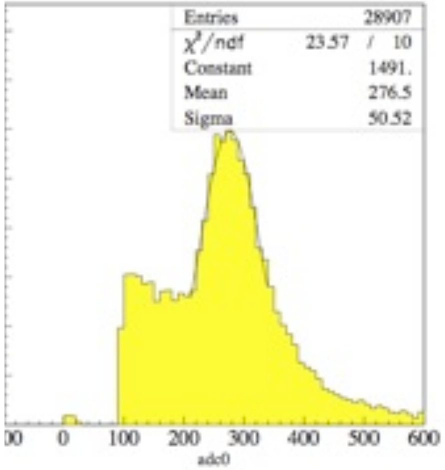
Determination of best working point



Single channel noise



Single channel MIP response



We find an optimized Vbias trade-off looking for

(1) a low signal spread due to gain variation and

(2) a reasonably low ENC

For a Saint Gobain crystal and an APD at 450 V

- **ENC = Sigma(ped)/Mip(Peak)* Mip(MEV) = 90 KeV,**
- **dG/G ≤ .7%**

TestBeam critical issues and plans

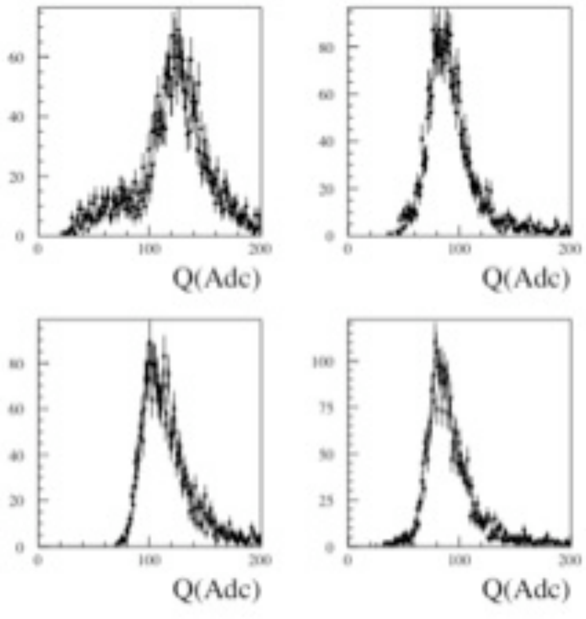
The energy resolution terms at BTF are not too clear:
- Leakage 5%, Noise 4%, Npe=0.3%, shower= 1% @ 100 MeV

Why do we get 12%? Additional contribution?

(1) We started questioning the beam energy spread
- experts replied: Δp/p 1 % (2 %) for e-/e+ @500 MeV
- no measurements below 300 MeV
- only existing measurement w AMS-02 silicon tracker indicated Δp/p ~ 15% @ 50 MeV

(2) We were   limited in precision by a
not working OUTER MATRIX
now operational

(3) Looking for a more precise test beam



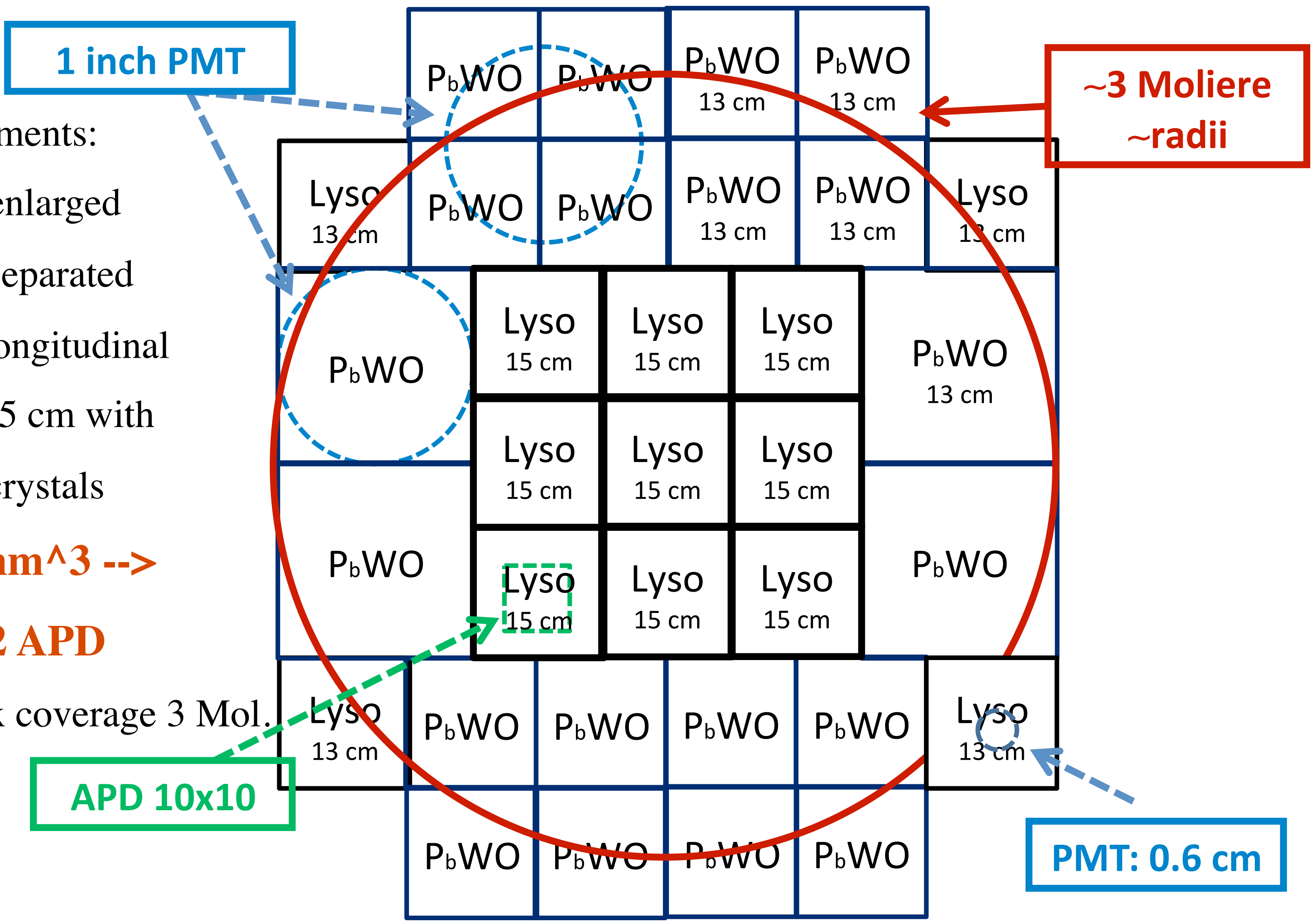
New TB with an improved matrix

A lot of improvements:

1) Outer matrix enlarged
and optically separated

2) Inner matrix longitudinal
dimension of 15 cm with
new SICCAS crystals
20x20x150 mm^3 -->
10x10 mm^2 APD

3) Overall matrix coverage 3 Mol.
radii.



1 inch PMT

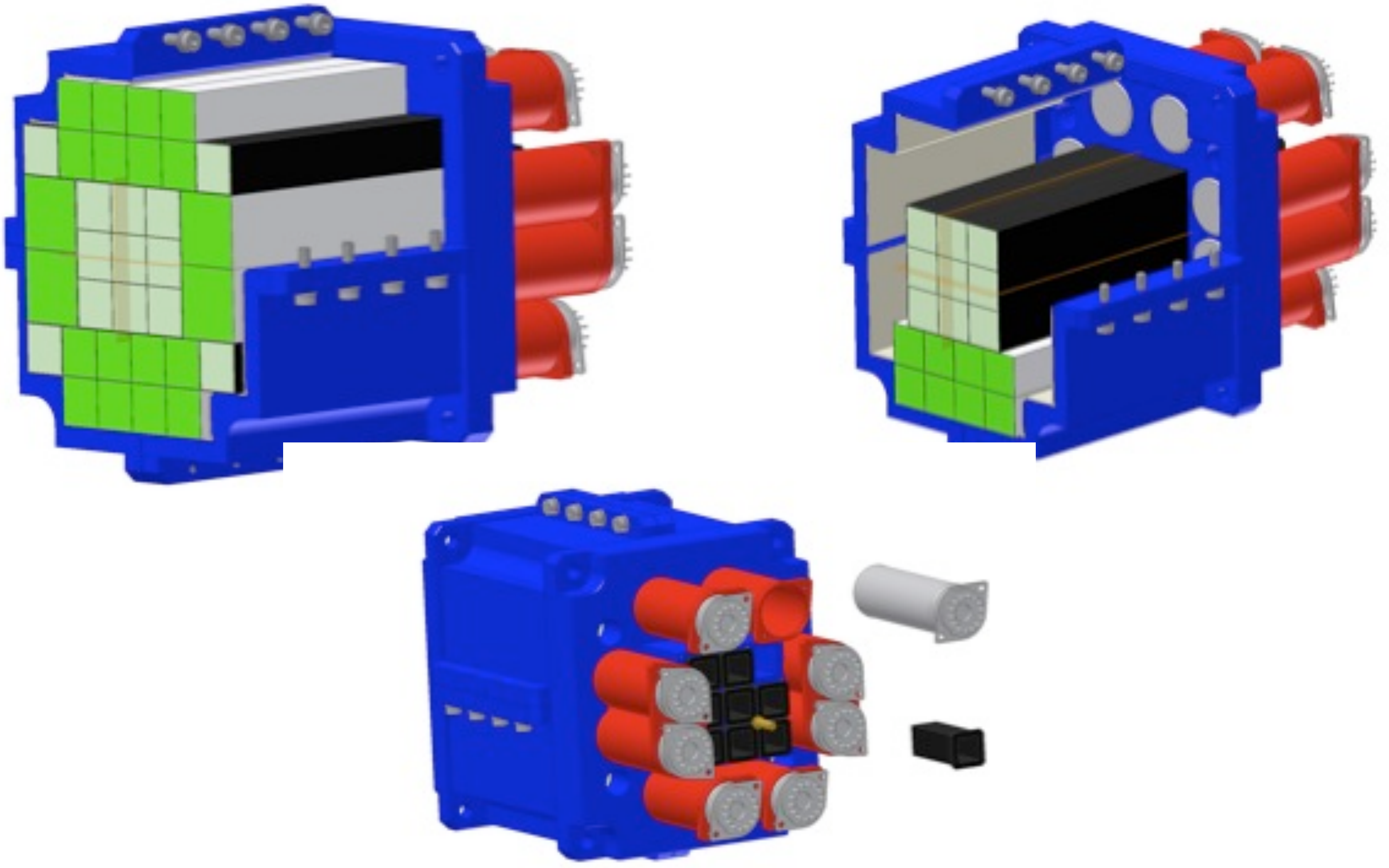
~3 Moliere ~radii

APD 10x10

PMT: 0.6 cm

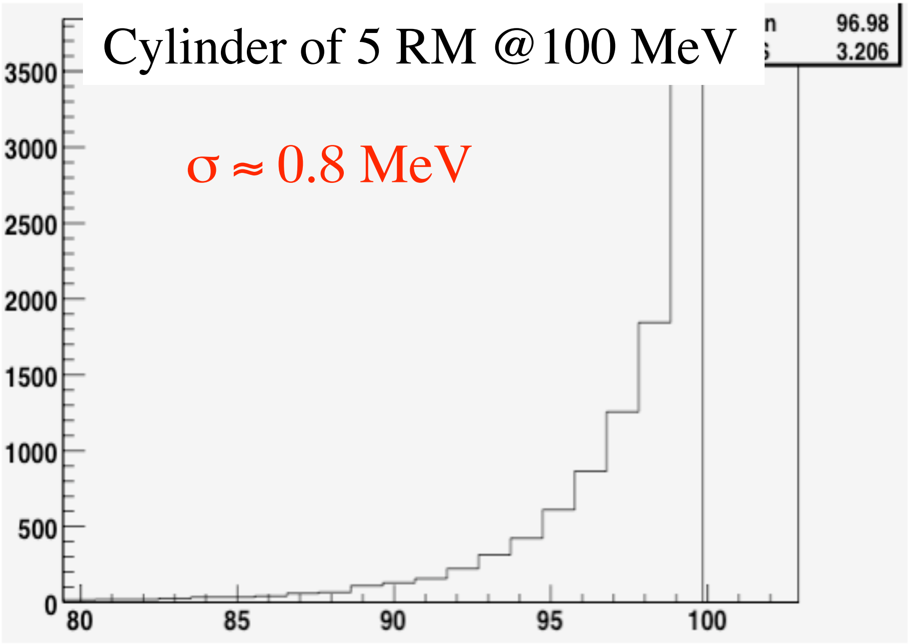
new LYSO crystals and 10x10 mm2 APD's ordered

New matrix layout

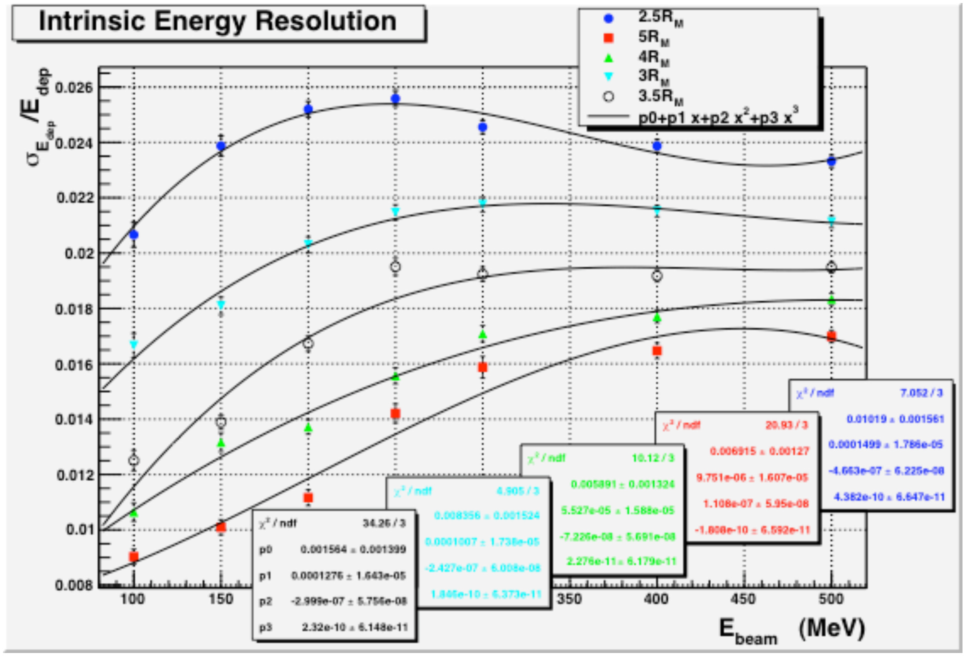


energy resolution expectations @100MeV with a 3 Moliere radii matrix

- Negligible photostatistic term
- Disuniformity of crystals: shower development fluctuations -> MC studies show small effects O(1%);
- Electronic noise -> is 4 MeV 4%@100 MeV for the inner matrix -> aim to Σ 90KeV/√N =.45 MeV <1%;
- Intrinsic resolution (Leakage,back-splashes)< 2%


Cylinder of 5 RM @100 MeV

σ ≈ 0.8 MeV



CCALT conclusions & plans

❑ First prototype has been built and tested with CR and e-beam
❑ High Light Yield observed
❑ Energy resolution not well understood
❑ Timing resolution 250-300 ps from 100 to 500 MeV. Can improve using larger area APD's ($\sqrt{2}$)

The prototype already satisfies the Kloe2 detector requirements.
We don't know yet if O(100-200 KHz) rates are an issue

PLANS for 2010:

- new test beam at MAINZ (tagged photons - 50 ps jitter $\Delta p/p<1\%$) to test energy resolution and high rates behaviour of the detector
- make electronics prototypes ---> final for KLOE2
- COMPLETE engineering for the insertion between IP and QD0