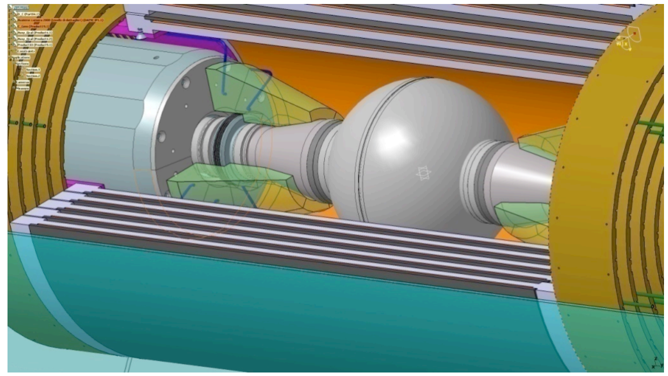
Test of a LYSO+APD matrix prototype for the KLOE-2 upgrade



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Frontier Detectors for Frontier Physics 2009

La Biodola (Elba's island)

26/5/2009

Talk Overview

KLOE-2 upgrade: a Crystal Calorimeter with Timing

- Physics Motivations
- Basic layout of the upgrade
- Test of single crystals+amplifiers
- Assembly of the Crystal Matrix

- Test with e-beam from 100 to 500 MeV
  - energy resolution and response
  - light yield
  - timing resolution
  - position resolution

- Conclusions and prospects

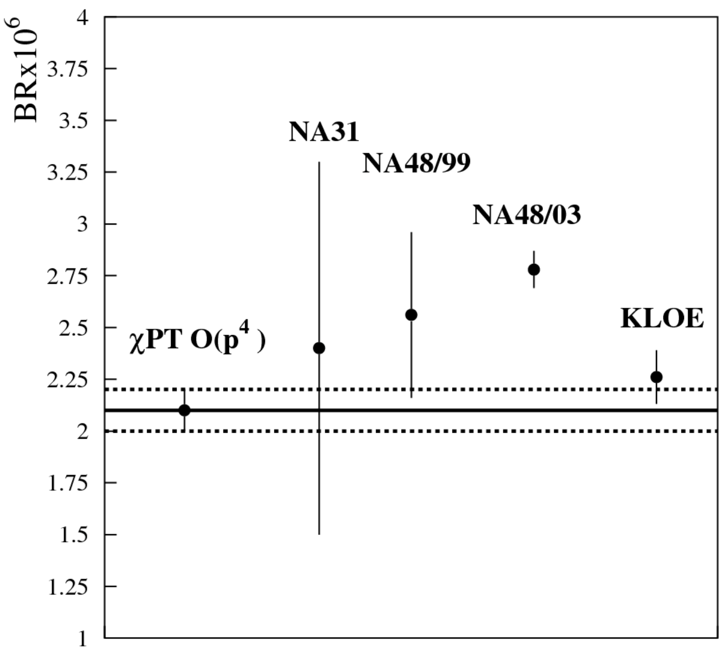
Physics Motivations

- EMC of KLOE covers up to $\theta \geq$ 21-22 °
- Needs extention at low angles (8°)

both as veto detector or as acceptance extension for rare decay channels

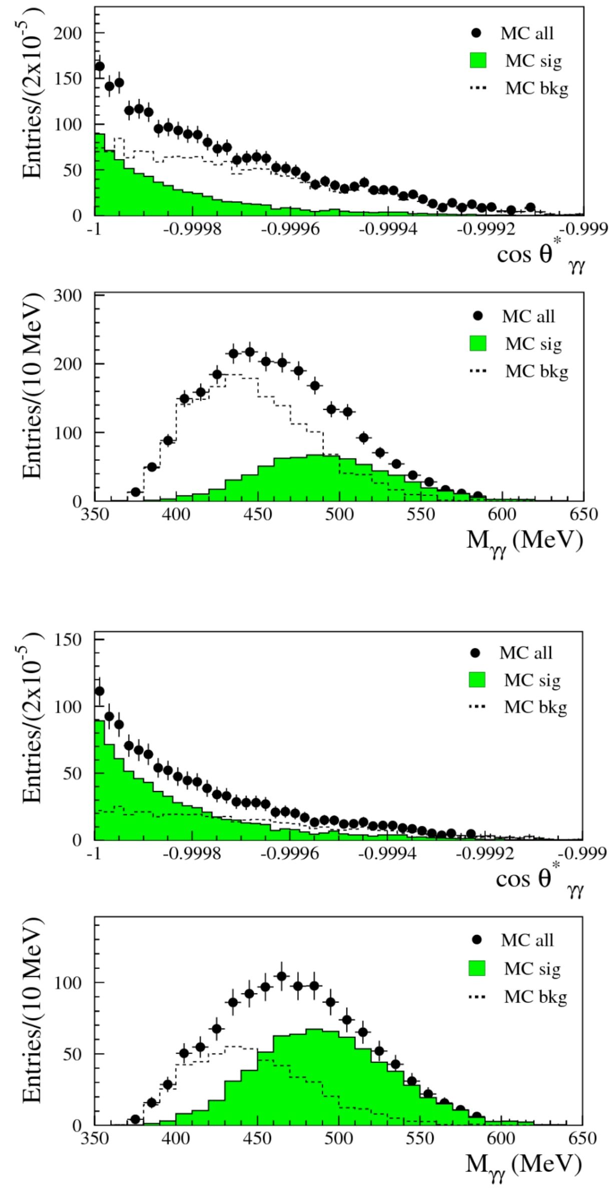
golden channels:

- (1) working as a veto $K_S \rightarrow \gamma\gamma$
- (2) acceptance ext: $K_S \rightarrow 3\pi^0$



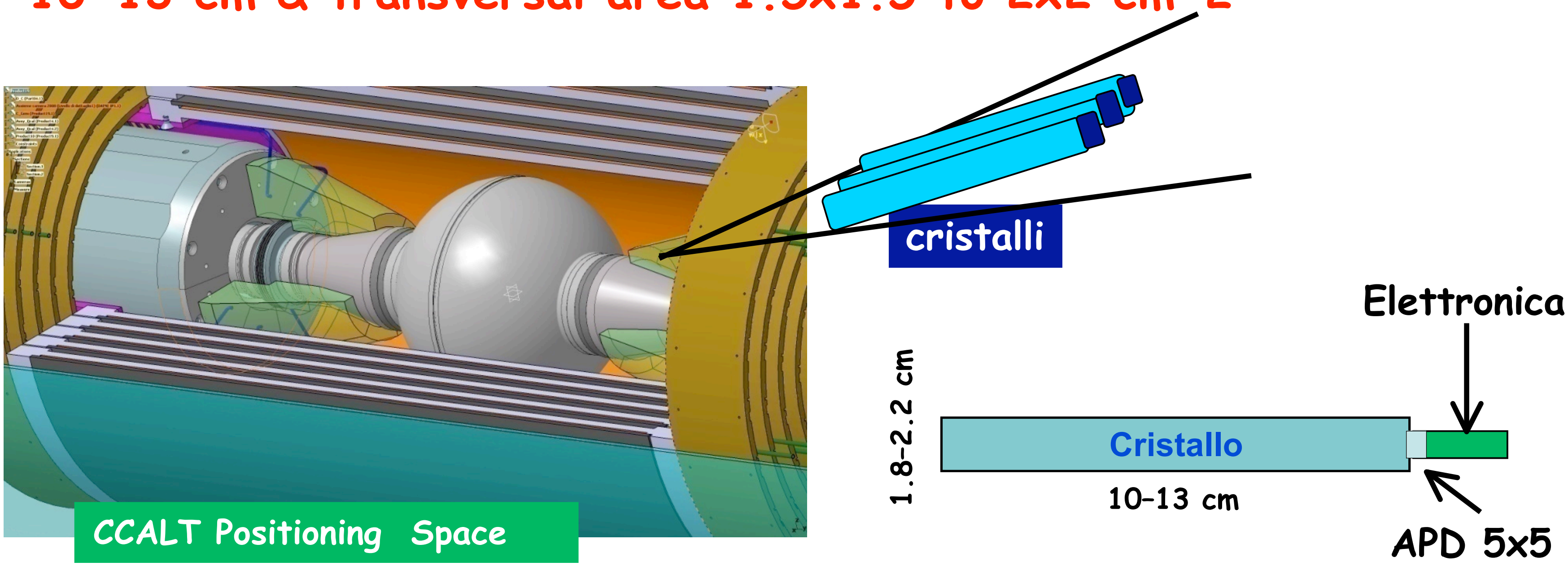
W/O UPGRADE

WITH UPGRADE



First design of the CCALT

- New machine layout of DAFNE --> the first quadrupoles @ 30cm from IP
- Spherical Beam pipe shape close to IP needed for Ks F.V.
- Only 20 cm of space in length available with the idea of keeping the detector also inside the constraint of quadrupole coverage in acceptance (18 degrees) to not interfere with main EMC reconstruction (and IT).
- **Solution: two small barrels of 24 crystals/each with length from 10-13 cm & transversal area 1.5x1.5 to 2x2 cm^2**



Requirements for a CCALT calorimeter

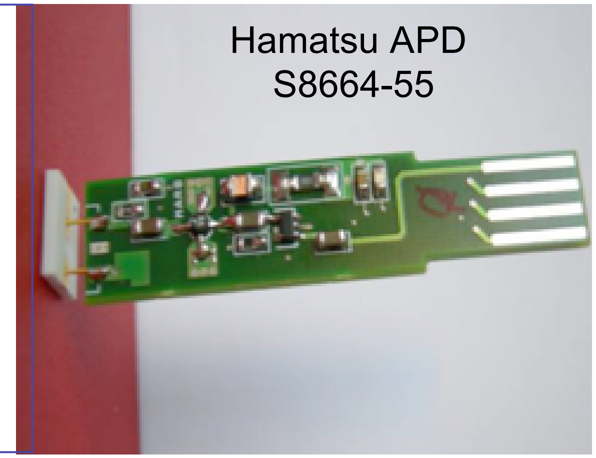
- Dense, small Xo, Rm
- Extremely Fast 300-500 ps @ 20 MeV
  (timing needed to reject accidental/machine bkg)
  A CCALT == Crystal Calorimeter with Timing
- Highly efficient ---> High Light Yield
- Small number of channels w photo-sensors working in B-Field (0.52 kGauss)
- Energy resolution will be poor: no transversal coverage.
- Reasonable position resolution (2-3 mm at 15 cm from IP) to improve energy resolution with kinematic fitting (Ks->3p0 search)

LYSO crystals look as a perfect match for this work:

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

Test of single crystals with CR

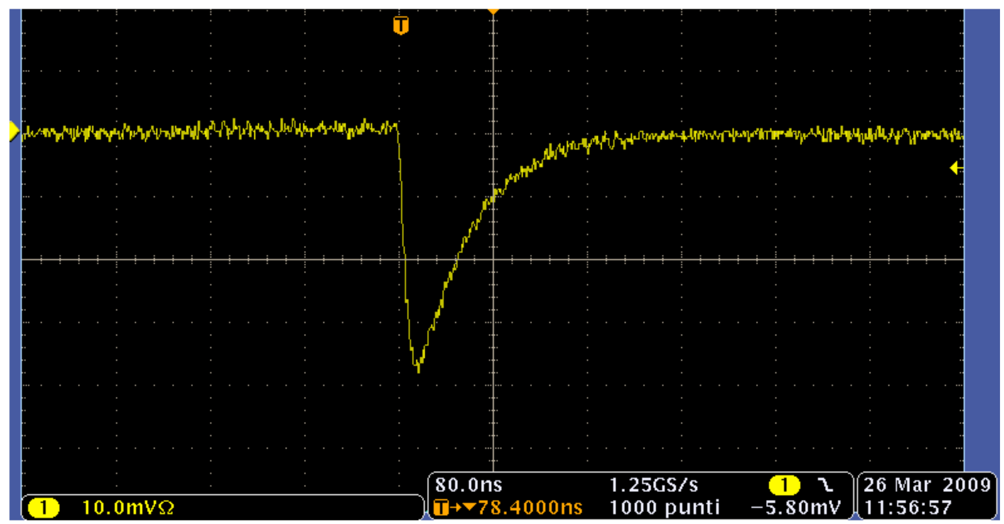
- Amplifier based on MAR8+
- X 25 amplification
- Bandwidth 1 GHz
- Prototypes not yet matched to KLOE EMC electronic chain



- Large signals with CR (40 mV) with APD@410V
- HV from CAEN (CMS-like)
- Noise few mV

Readout by Lecroy ADC 400ns wide gate

- σ(ped) = 1.5 counts
- MIP(peak) = 50 Counts
- σ(MeV) = 0.6 MeV



Crystal Matrix Composition

KLOE-2

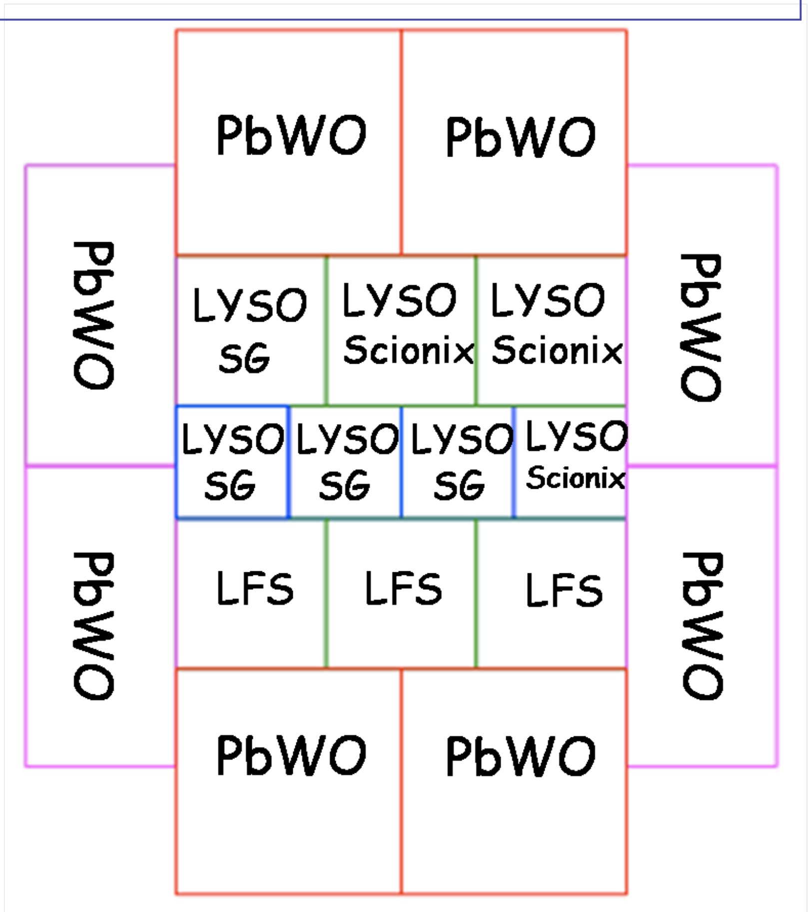
Due to the high LYSO cost we have realized a matrix with:

- an inner core done either by 10 LYSO+APD(CCALT) or 10 PbWO/LSO +SIPM (LET) crystals
- an outer leakage recovery section done by PbWO+PM

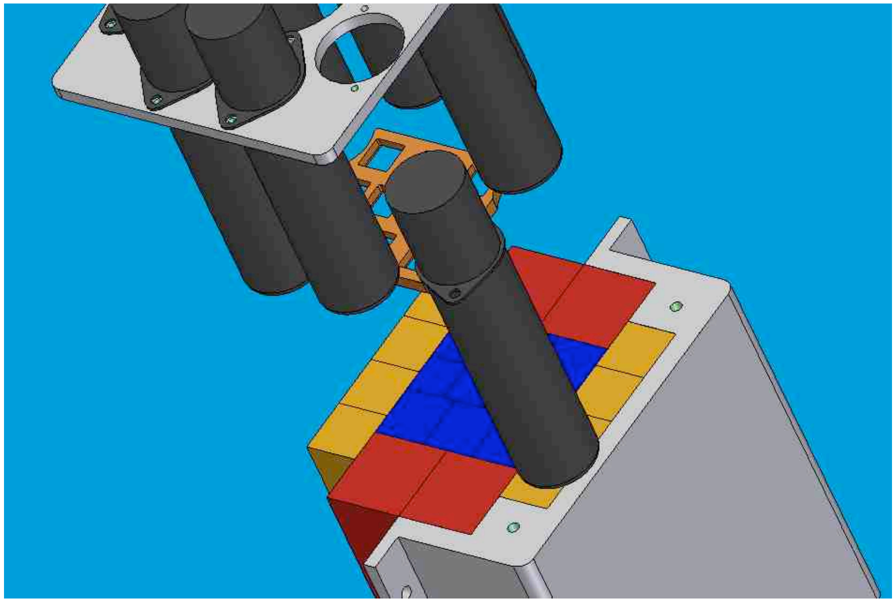
PbWO from SICCAS

LYSO/LFS from 3 producers:
-S.Gobain
- Scionix
- Zecotek (LFS)

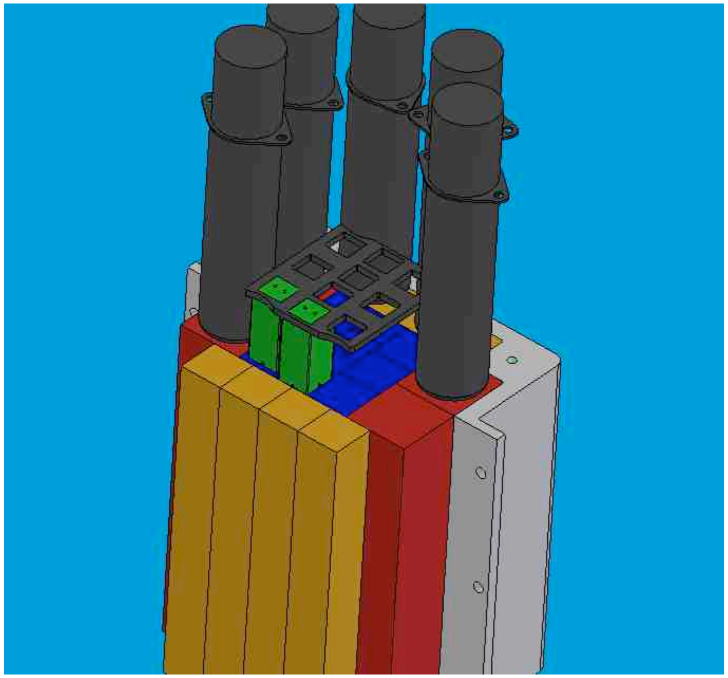
•3 Lyso-SG +1 scionix
3x(15x15x150)+15x15x130 mm3
•1 Lyso-SG +2 Lyso-Scionix
20x20x150 + 2x(20x20x130) mm3
• 3 LFS 20x20x130 mm3



Crystal Matrix overview



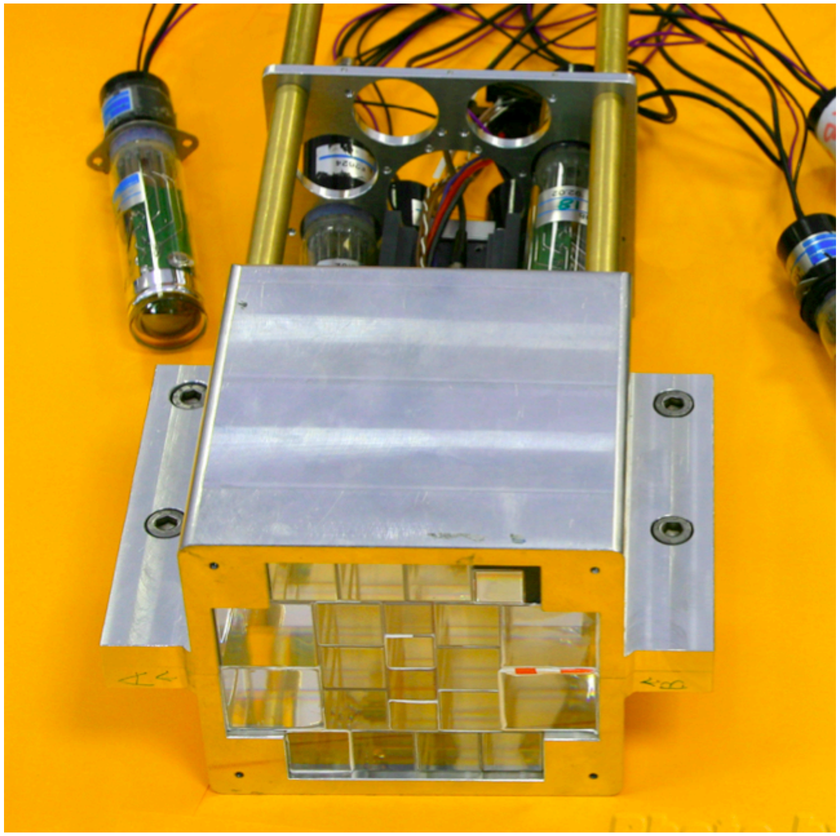
- External aluminum holder
  for the crystals
- Crystals wrapped in 100 μm of Tyvek apart from front and end faces. Front face kept free to insert LED for testing.
- PMs from outer matrix taken into position by external holder

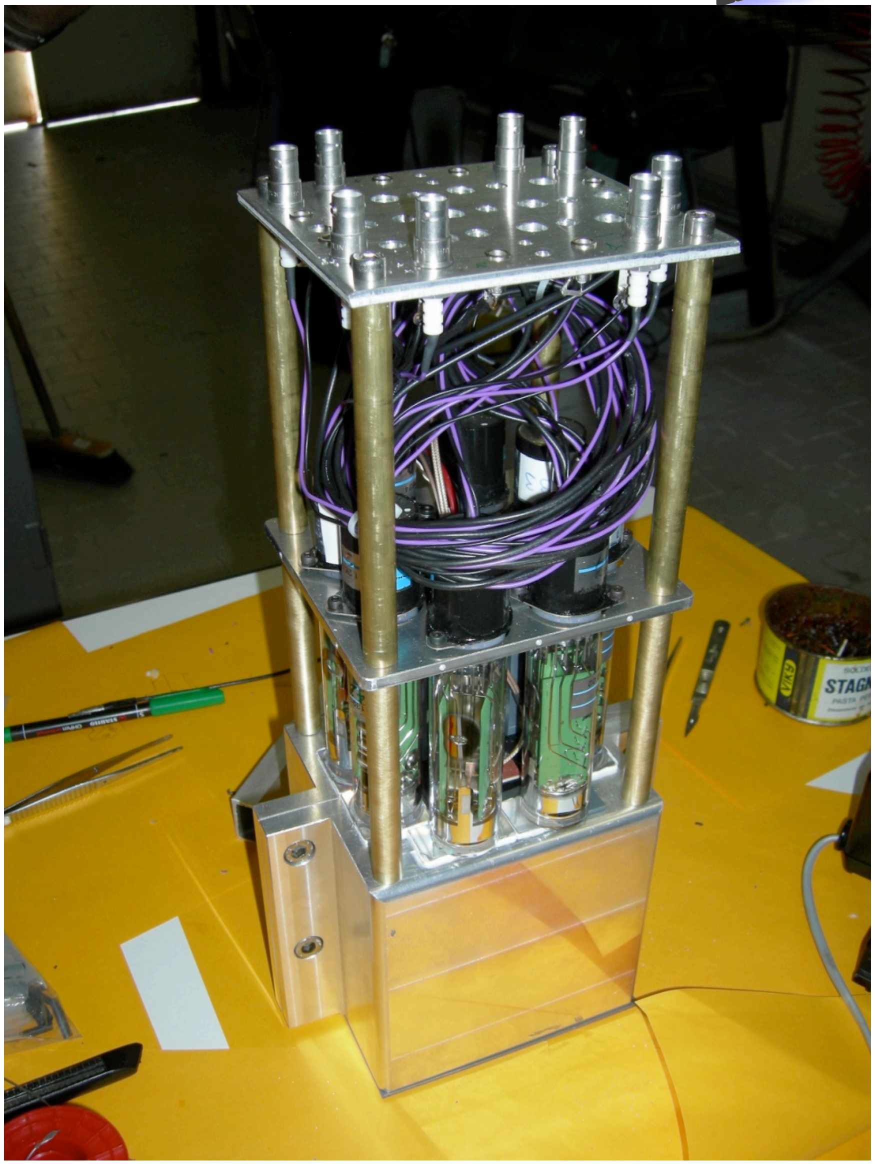


- Each APD inserted in a PVC mask and soldered to his amplifier.
- APD+amplifier inserted in a small box sustained by a PVC matrix
- Optical contact by means of Bicron optical grease

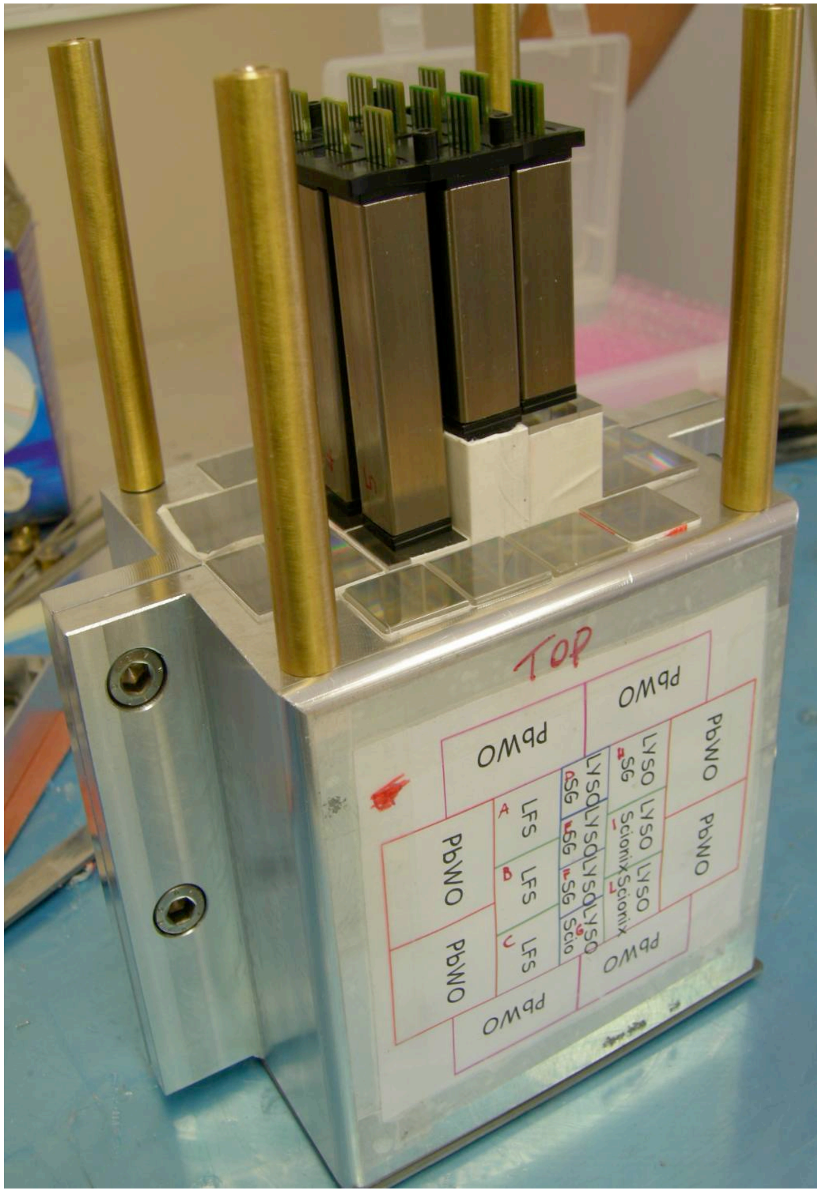
From CAD to realization (in pictures)

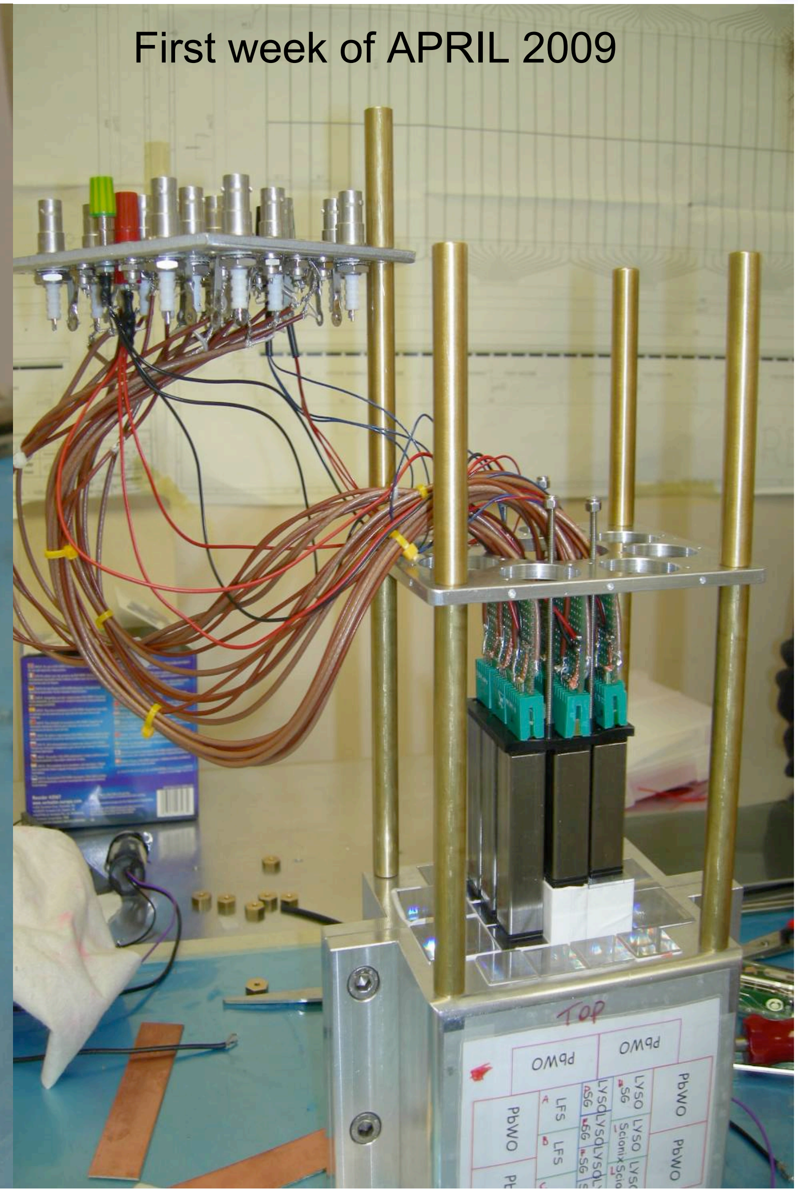
-First Assembly of overall matrix (march 2009), waiting for arrival of APD-amplifier boards
- test of Outer Matrix



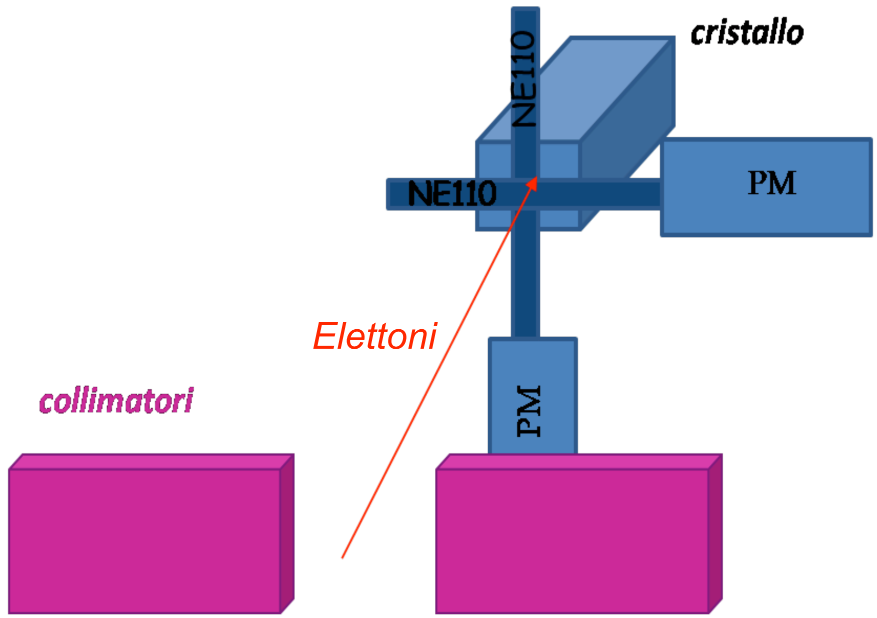


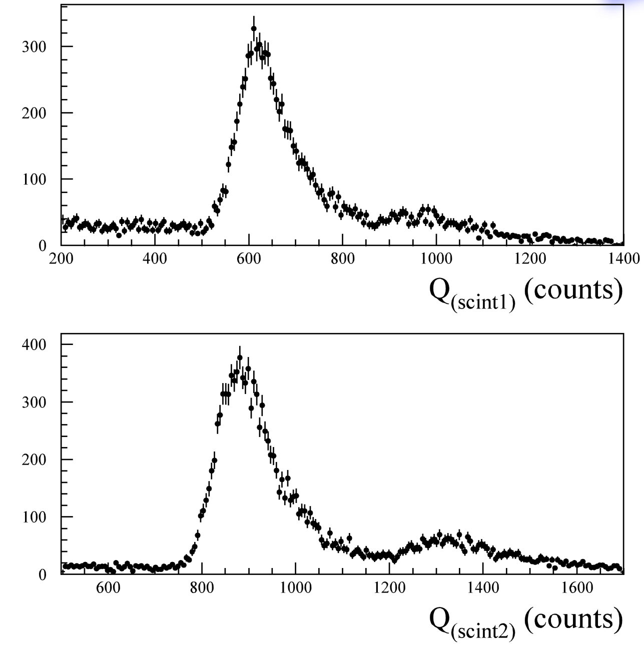
From CAD to realization (inner matrix)





Test Beam @ BTF (4-18 april 2009)



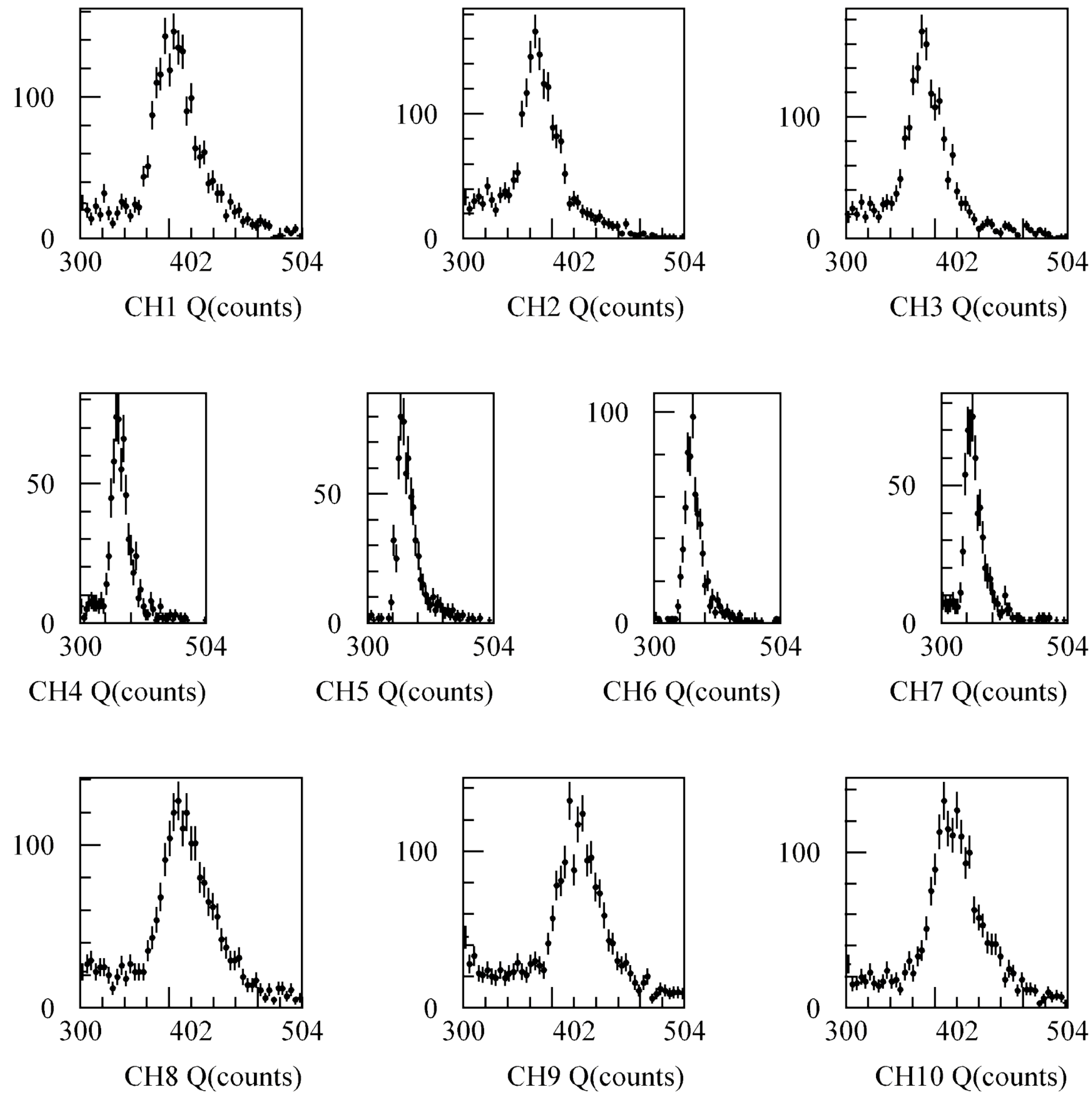


- BTF @ LNF provides electrons to experimental area with selectable multeplicity at few tens of Hz (i.e. the Linac repetition rate)
- To select clean electrons we required OFFLINE the firing of two external finger scintillators (1x0.5x5) cm^3 which defined also the beam spot on the calorimeter.
- Due to optical cross-talk between inner and outer matrix we lost a lot of days to understand data! In the second week we turned off the outer matrix and got two days of good "e" data with KLOE daq.

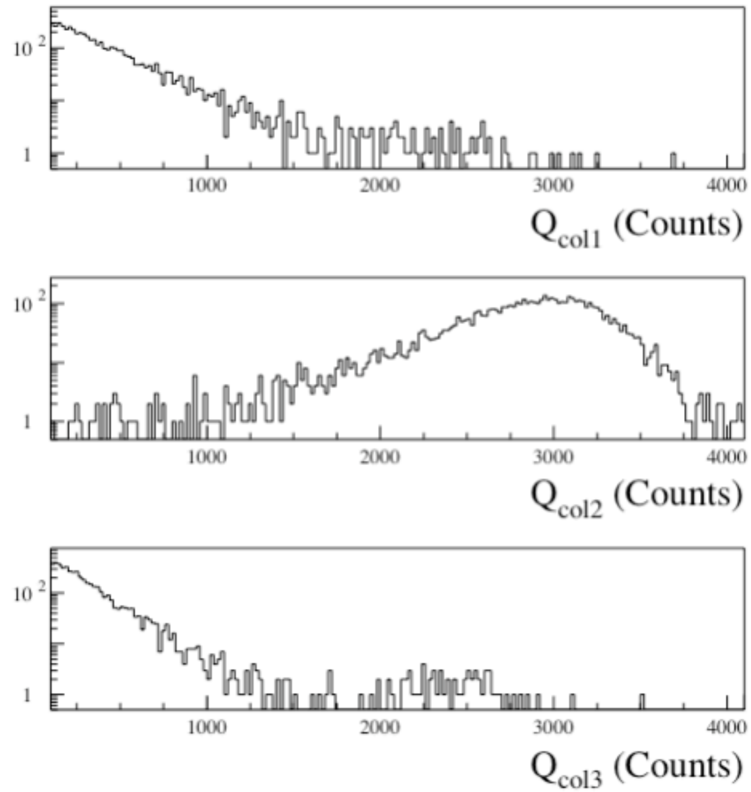
Inner Matrix MIP calibration @ BTF

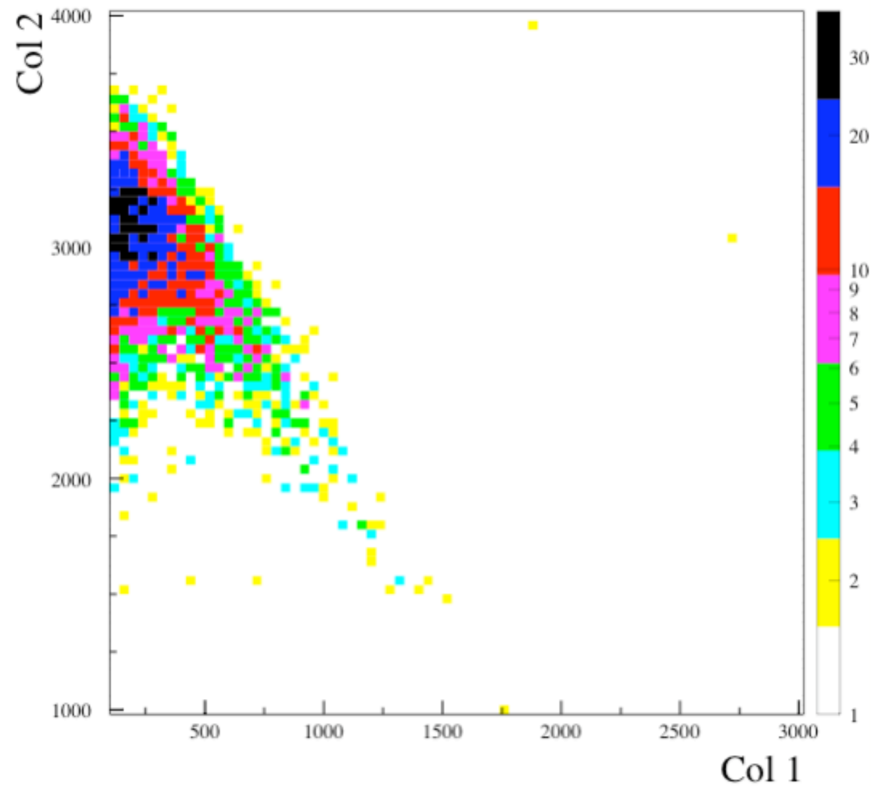
- ❑ Night runs with CR taken with a coincidence between two external NE110-scint counters
- ❑ Clean MIP selection
- ❑ Pedestal noise 4-5 counts with KLOE ADC chain (110 fc/count)
- ❑ MIP peak ~ 100 counts for 15x15 mm^2 crystal

  Peak precision < 1%



Response grouped by columns



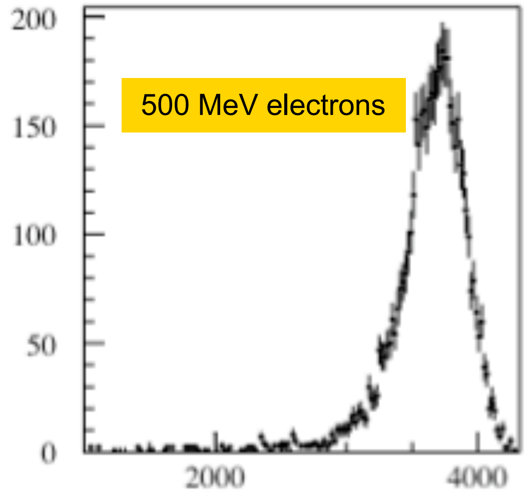


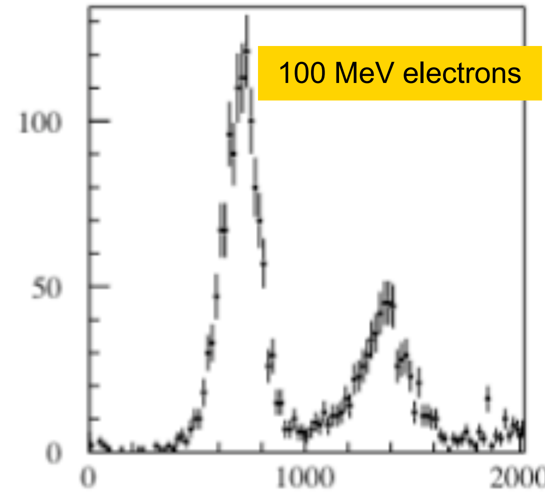
- Qcol = $\sum$(Qi/Mi) <M>, where <M> = 120 counts

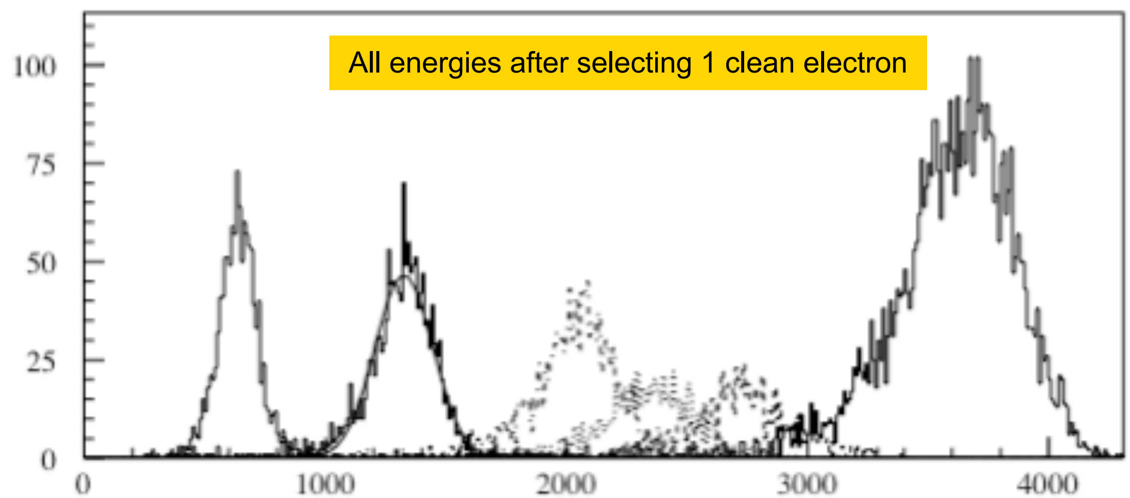
Energy spectra

- $Q_{tot} = \sum(Q_i/M_i)\langle M\rangle$, where $\langle M\rangle$ = 120 counts, M_i is the peak for MIP on channel I.
- To equalize each channel to the same deposited energy we corrected the larger crystals with the areas' ratio:

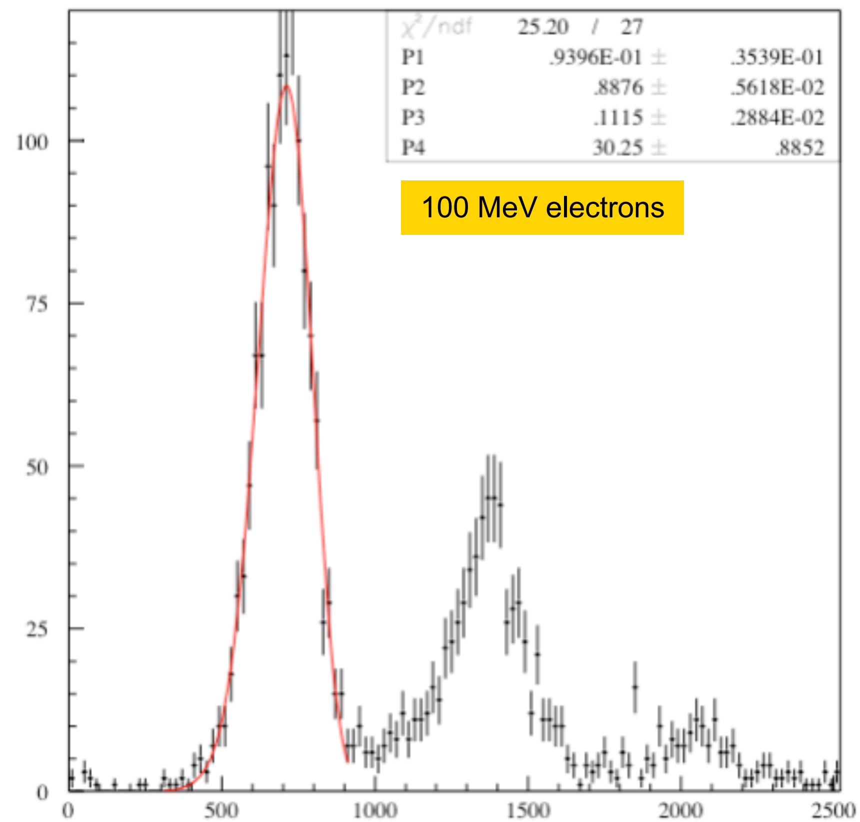
$$M_i(corr) = M_i \times A_s/A_l$$

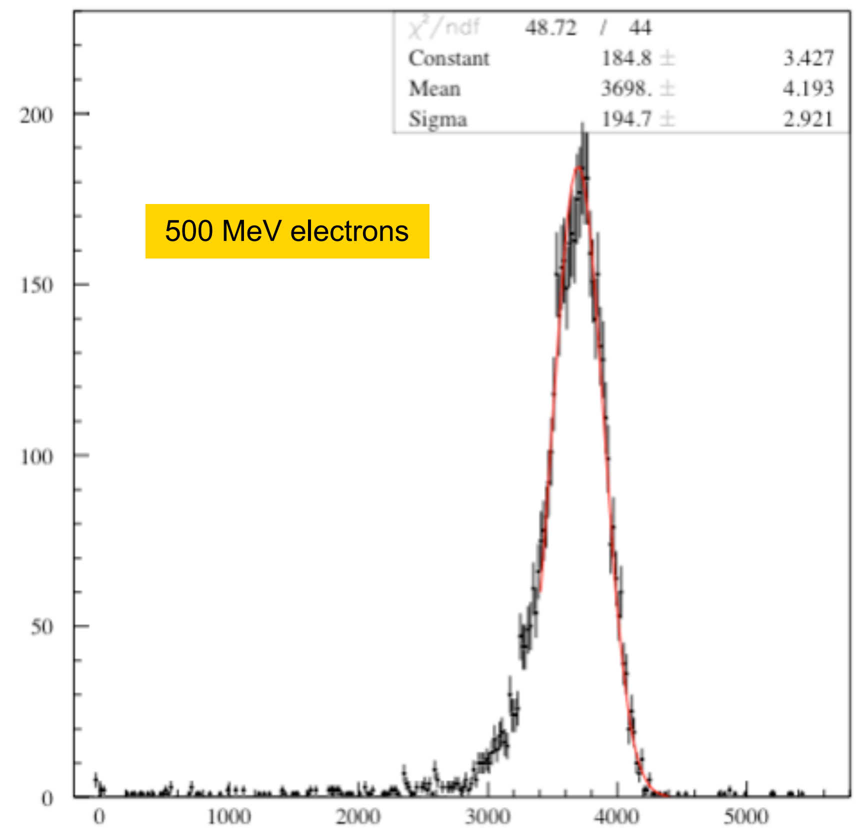






Fit to the spectra



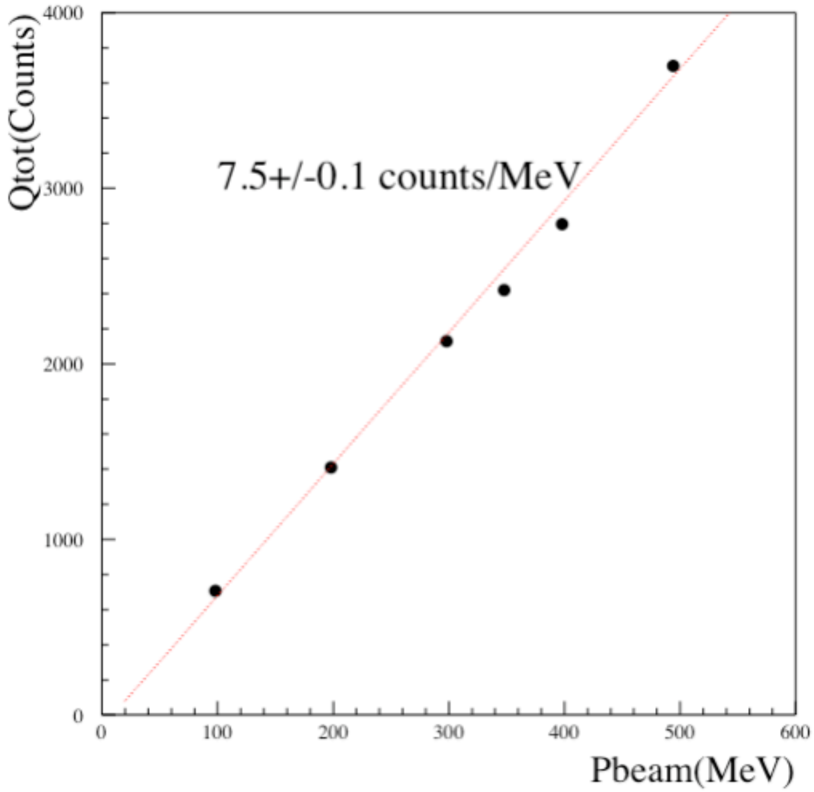


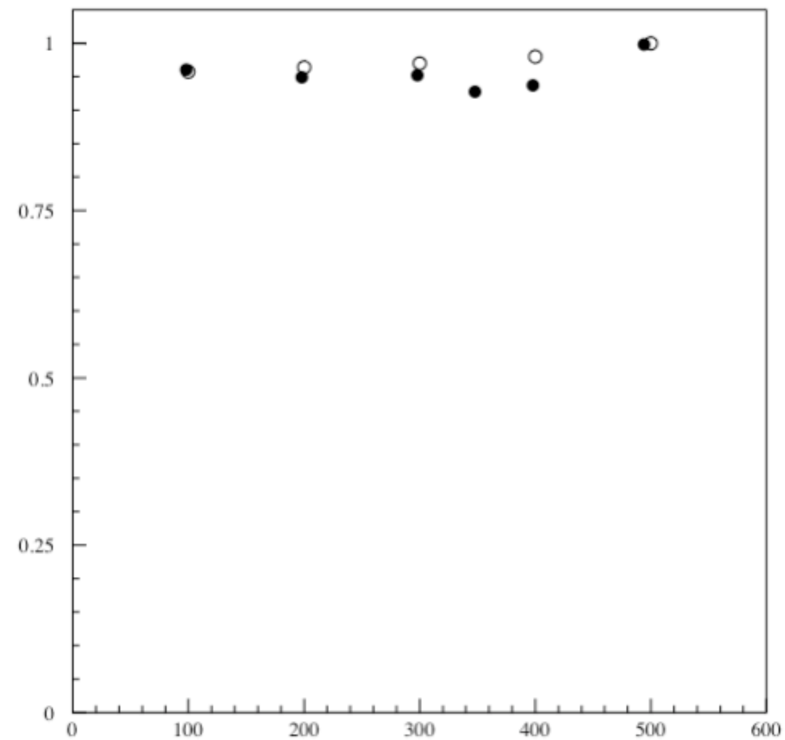
Example of a gaussian fit
in a region close to the peak.

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

η= asym, σ= FWHM/2.35

Linearity and light yield





<M> = 120 Counts --> 1 MIP = 120/7.5 MeV = 16 MeV

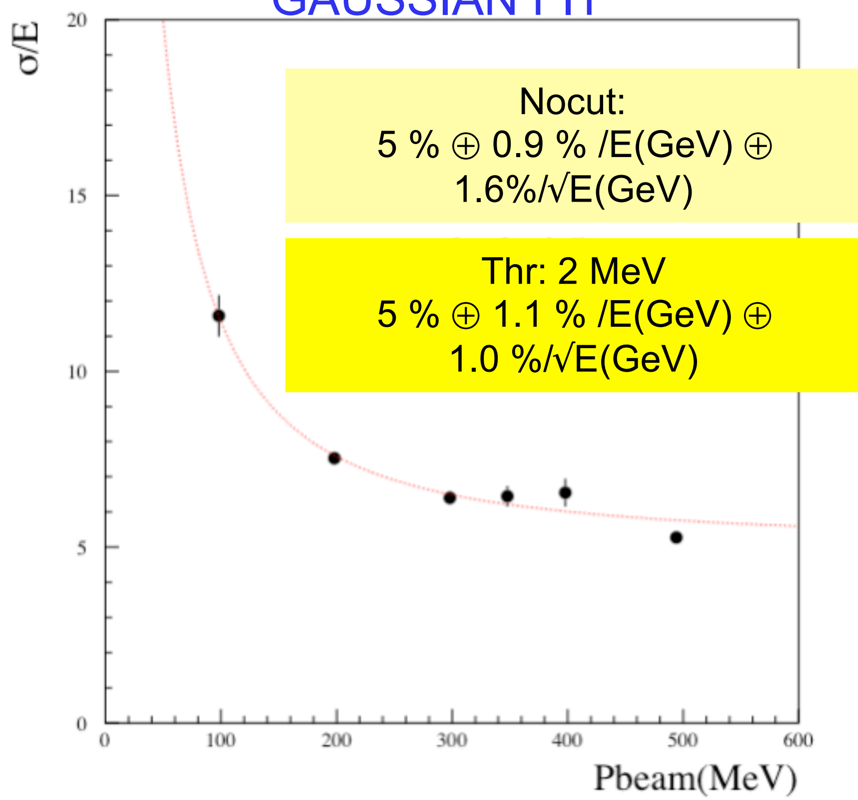
Gain vs HV from 300 to 500 (@ 410)

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

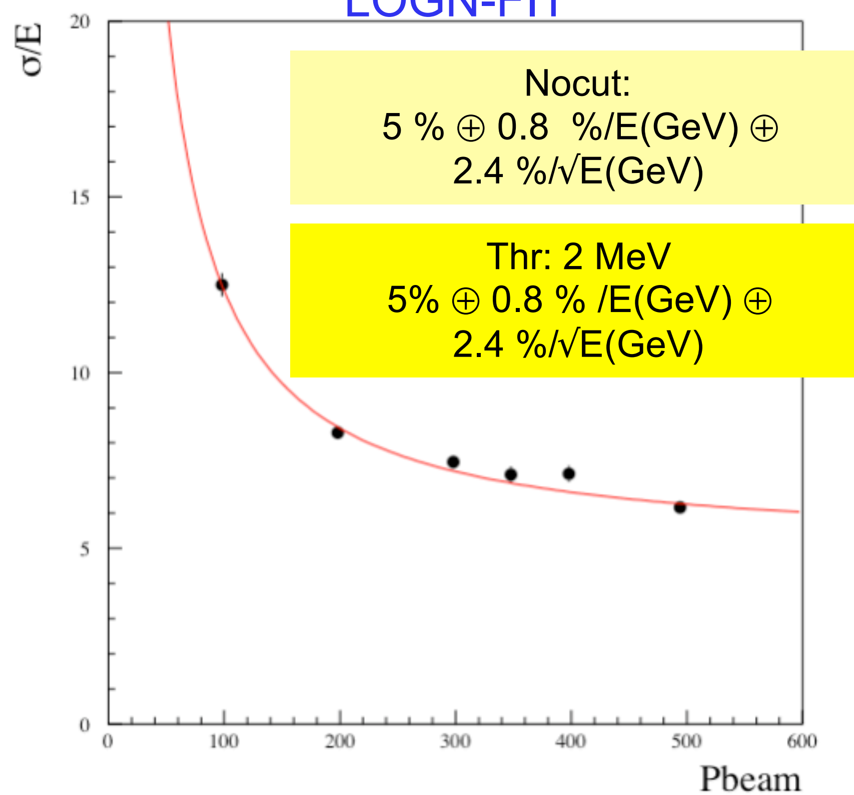
1 MeV = 820 fC ---> 1 MeV = 400-700 pe

Energy resolution dependence

GAUSSIAN FIT



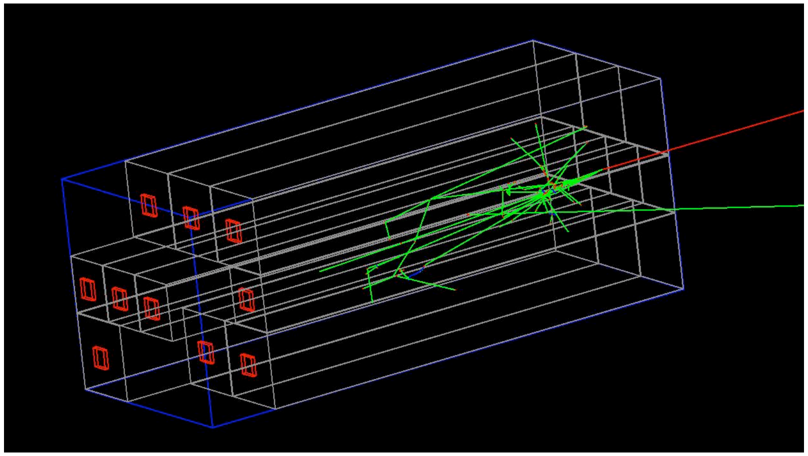
LOGN-FIT



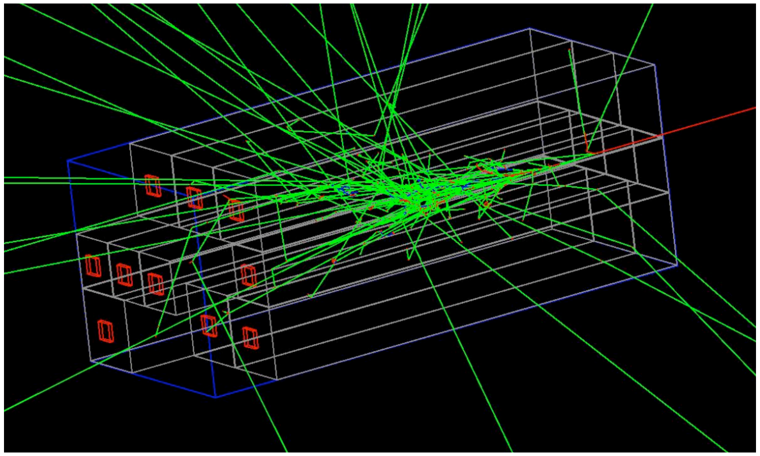
- Constant term dominated by leakage .. Fixed by MC
- Noise term between 0.8-1.1 %/E(GeV)
- Stocastic term between 1--2.4%/√(E/GeV)
  few data taking points .. Instable fit.

MC simulation

100 MeV

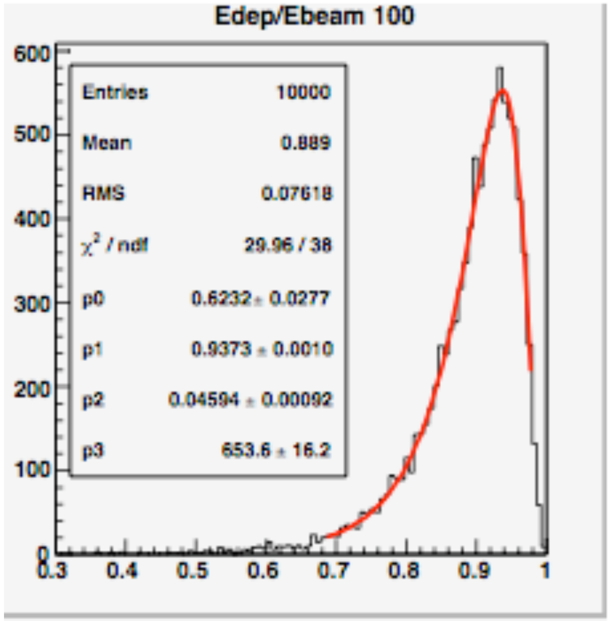


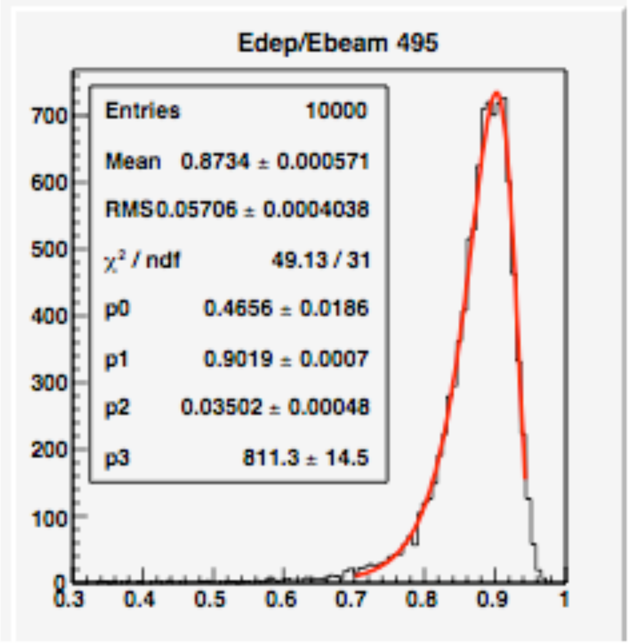
500 MeV



- Detailed MC simulation in progress with Geant-4
- All dimensions respected (crystals, wrapping, APD's)
- Beam spot simulated with different dimensions
  (5x5 mm^2, 10x10mm^2)
- Simulation of time emission spectra OK
- Optical transportation of photons underway (... study as a function of photons-yield needed .. CPU time)

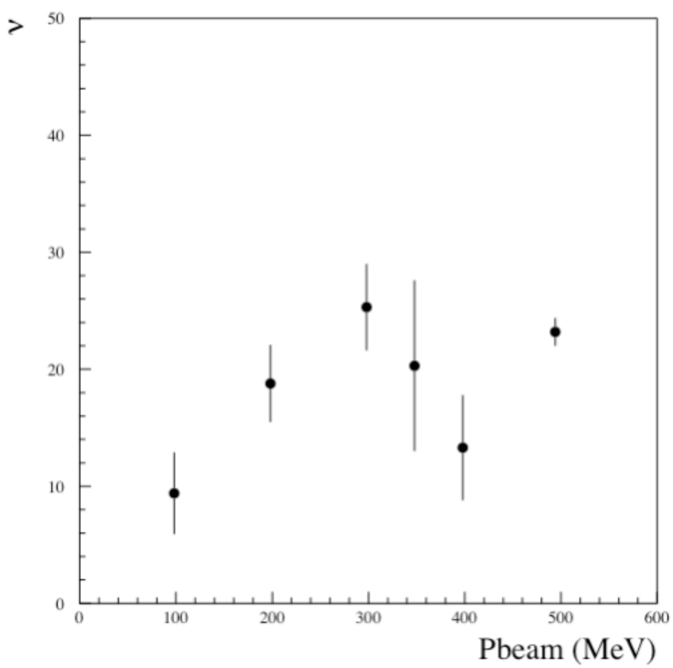
Leakage term and MC simulation

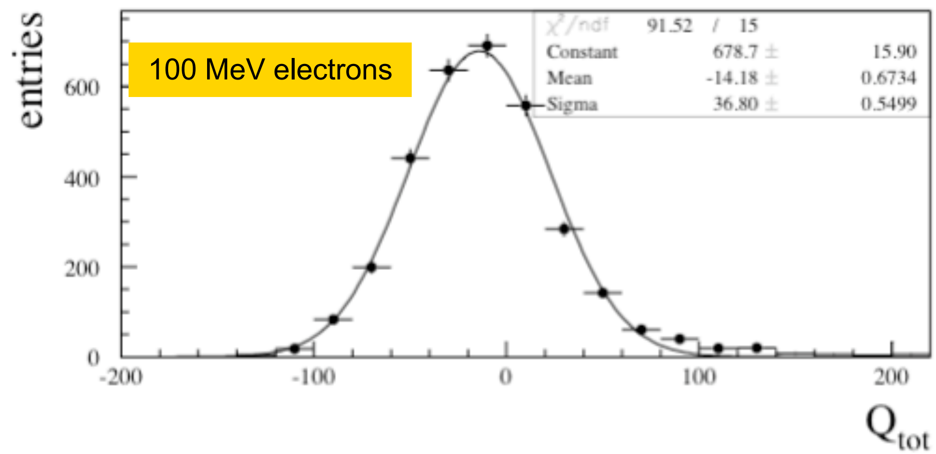


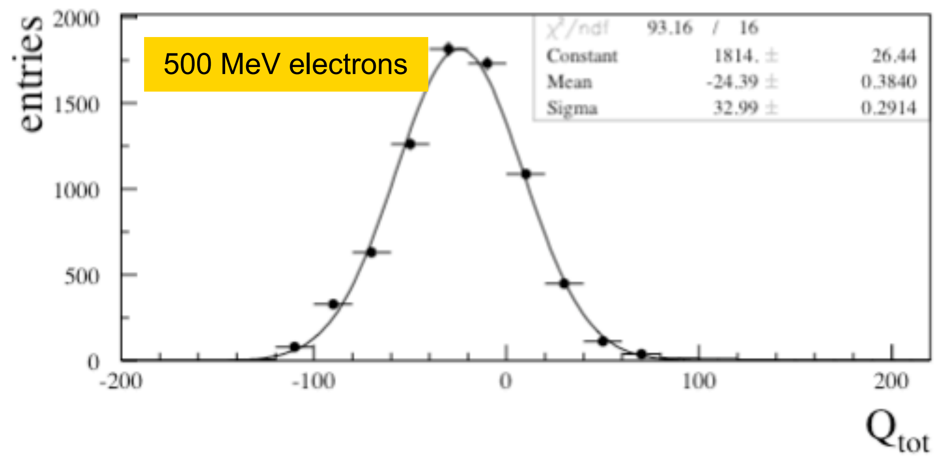


E_{beam} (MeV)	Epeak	σ	σ/E
100	0,9373	0,04594	4,9%
200	0,9206	0,04212	4,6%
300	0,9112	0,03856	4,2%
400	0,9065	0,03728	4,1%
495	0,9019	0,03502	3,9%

Consideration on noise term





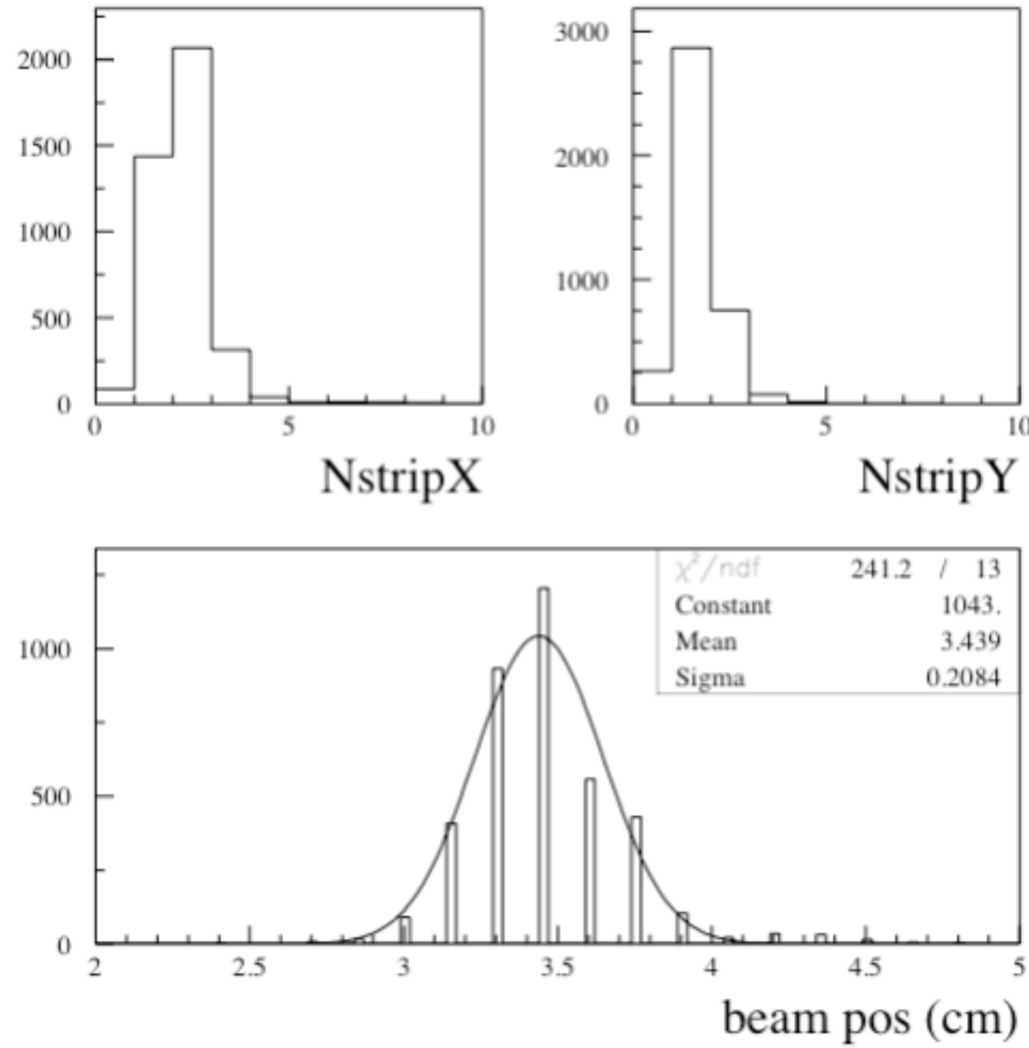


Decrease of asymmetry parameter in Logn fit vs Pbeam indicate more gaussian shape due to noise..

1) Q_{tot} w.o. e beam shows σ(total noise) from 4.3 to 4.9 MeV.
2) Single channels with beam σ (ped) = 1.1-1.2 MeV --> 3.6-3.8 MeV
3) Noise twice larger than what measured in electronic lab
--> coupling with KLOE EMC chain? Still under study

Position resolution measurement

- Special runs @ 500 MeV taken reading out also the BPM of BTF .. based on X-Y hodoscope of scintillating fibers (3 mm -pitch)
- Plots shown correspond to events with only 1 "electron" selected offline



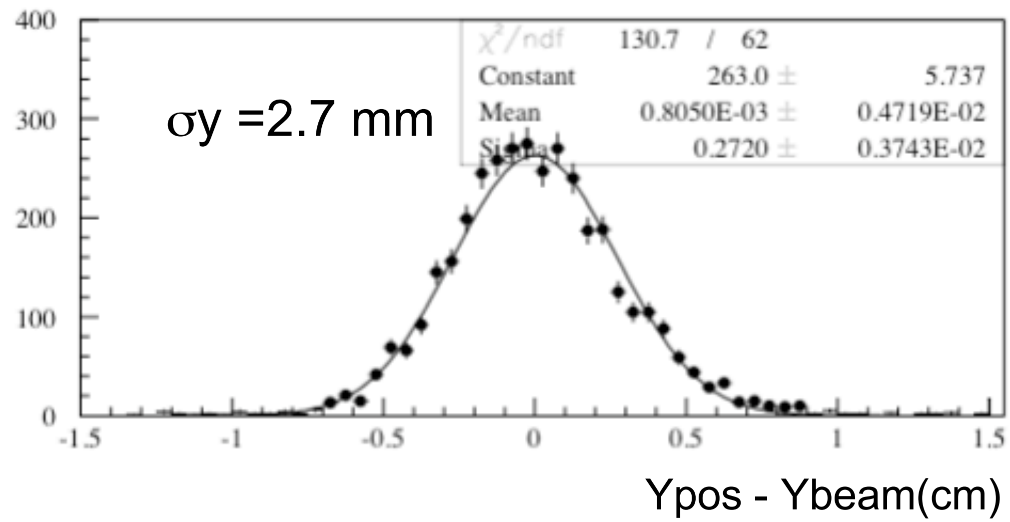
Position resolution @ 500 MeV

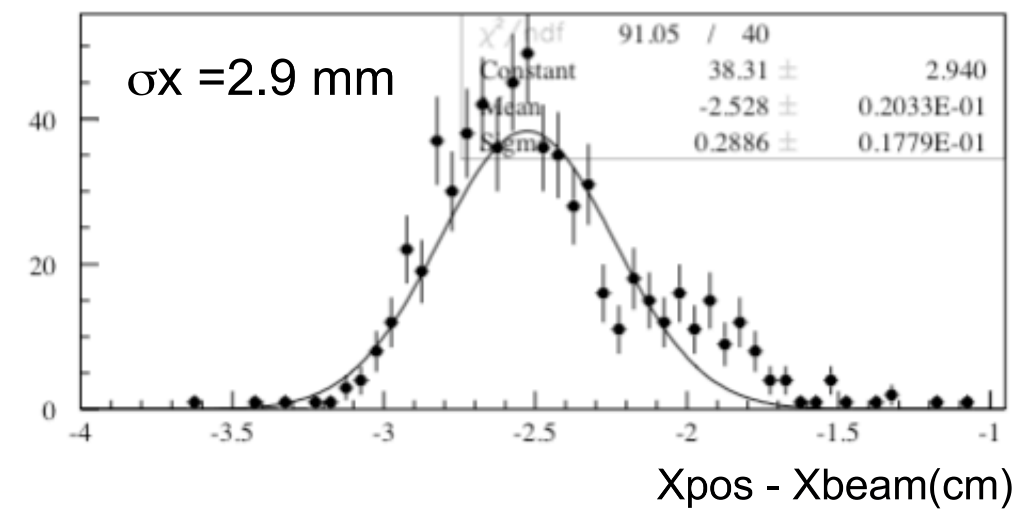
KLOE-2

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

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

Resolution 2.8 mm vs > 4.3 mm due to the pitch in agreement with expectations





Timing measurement at BTF

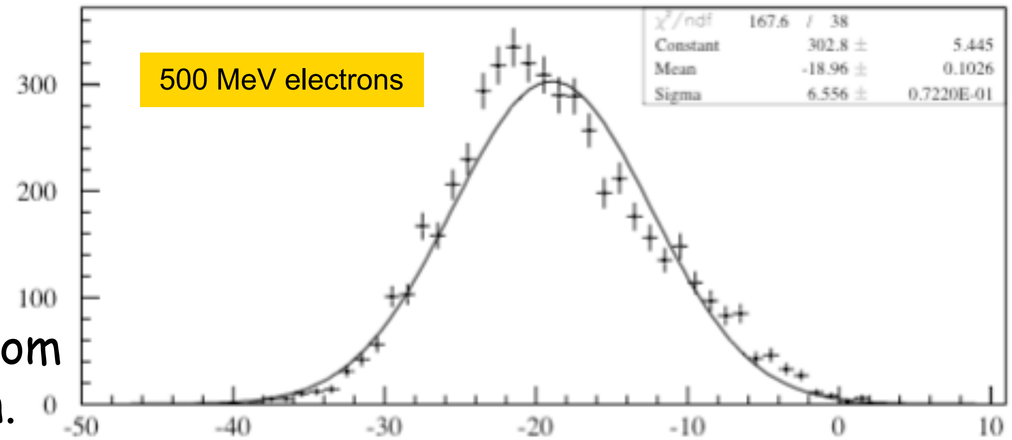
Each spill arriving from LINAC consists of many bunches separated of 200-300 ps for a total of 10 ns.

When using as TDC start the Gate from Linac we get a 10 ns wide distribution. To eliminate this we offline correct For the arrival time provided by the Two finger scintillators limiting the Beam spot.

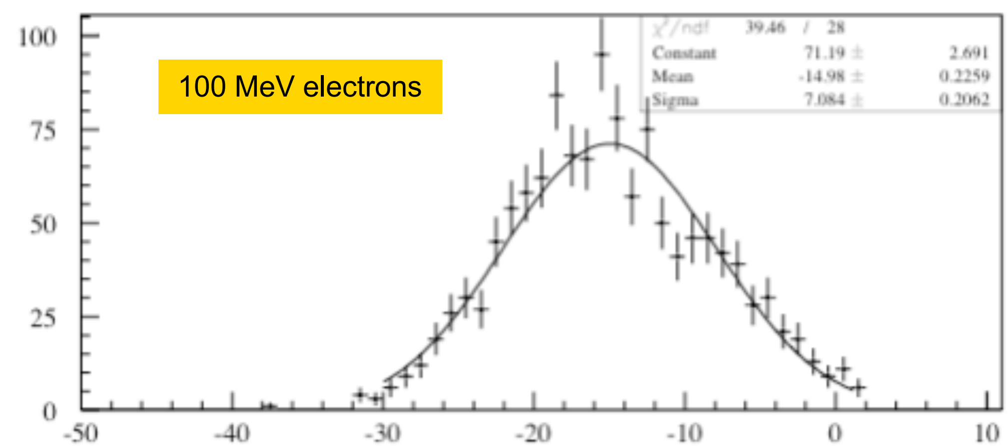
Jitter of the start: $\sigma(\Delta T)/\sqrt{2}$

KLOE TDC -- 53 ps/Count

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



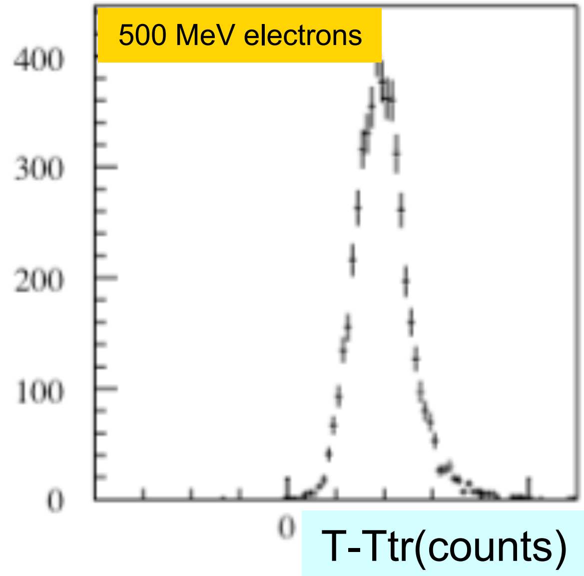
ΔTtr (counts)

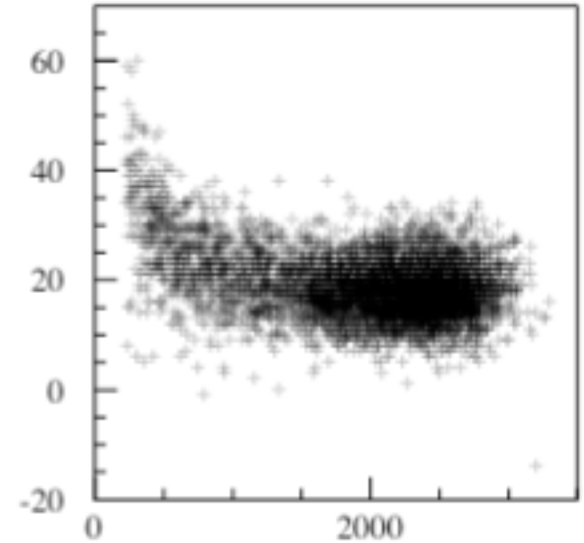


ΔTtr (counts)

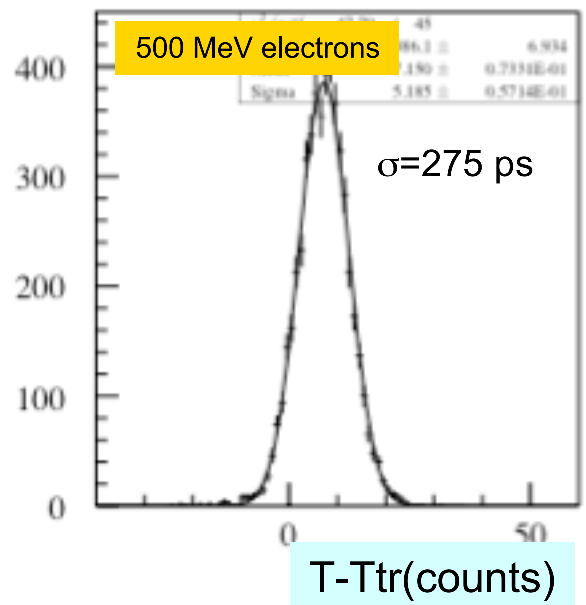
Calorimeter timing single cells

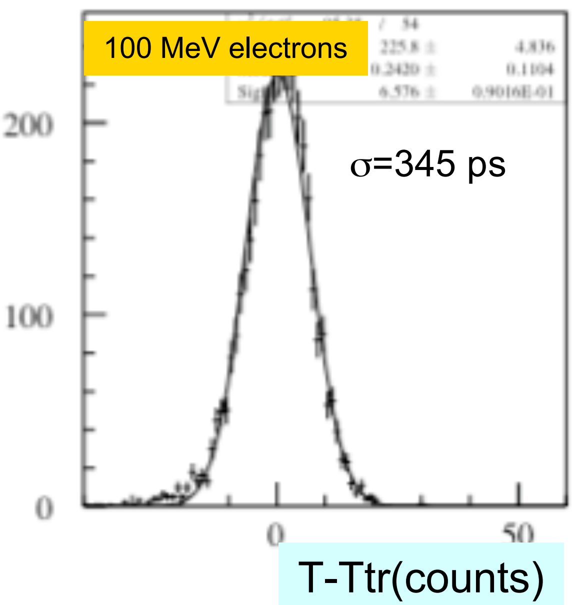
Central Cell
No Slewing corrected



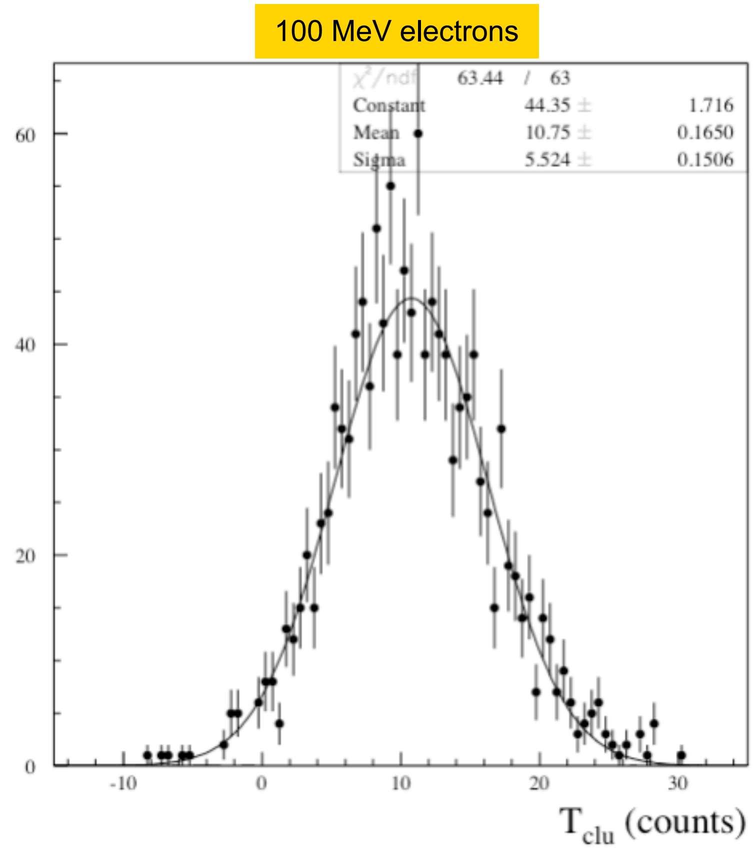


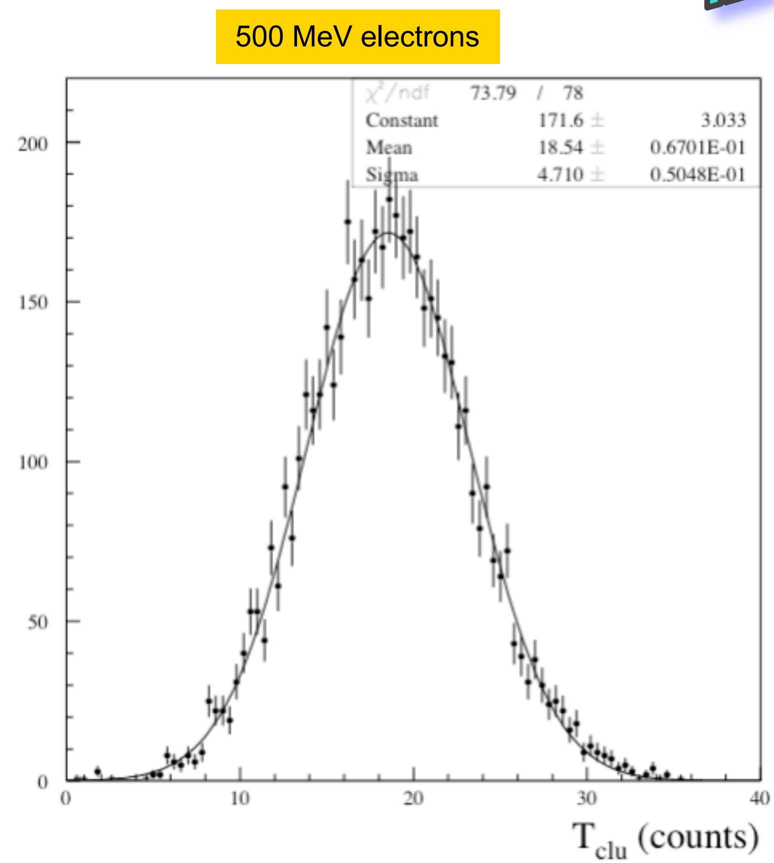
Central cell
Slewing corrected





Calorimeter timing clusters





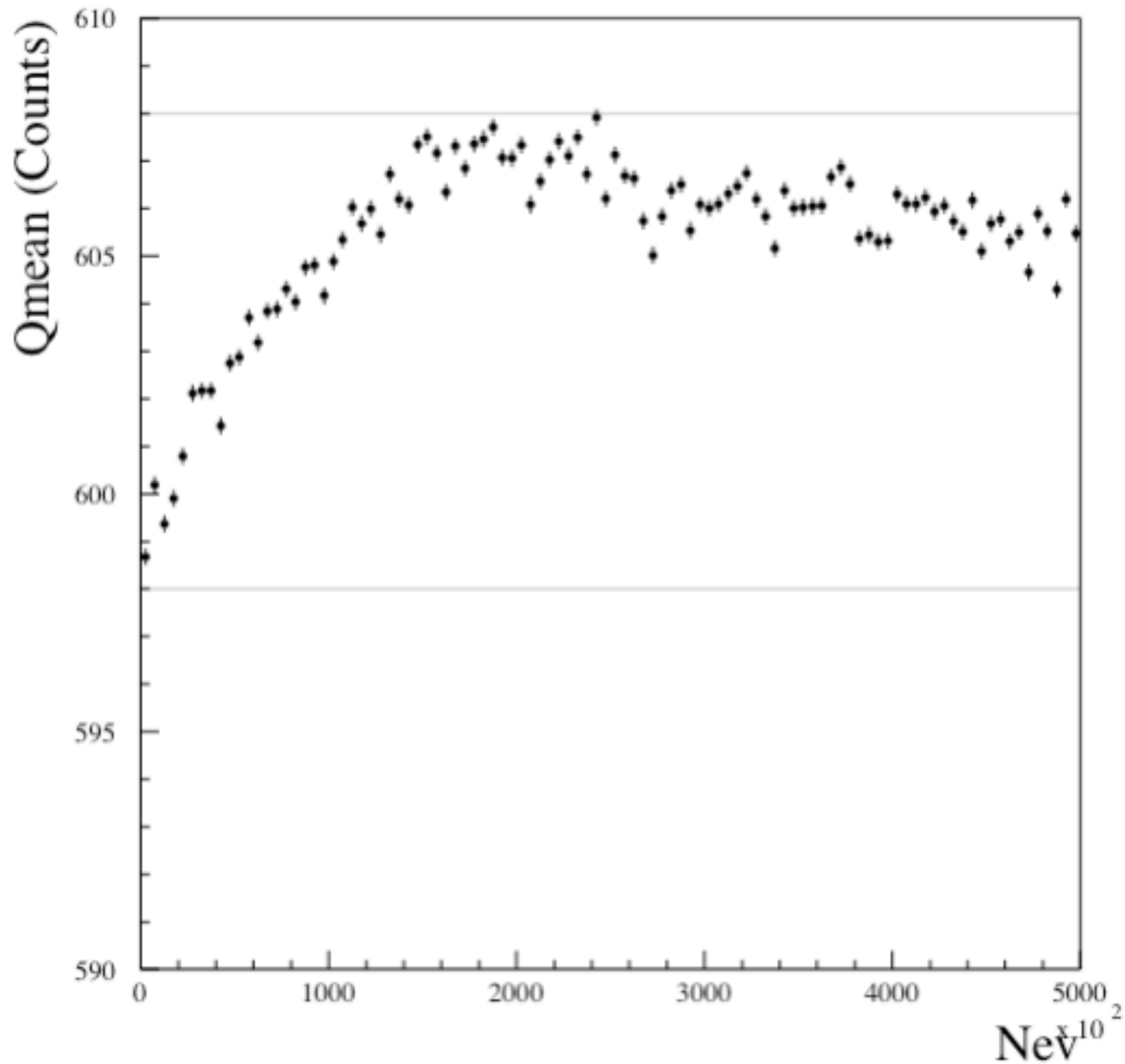
- $T_{clu} = \sum(T_i - T_{0i})Q_i/Q_{tot}$
- Assuming all channels calibrated with 53 ps/Count!
- $\sigma(T_{clu})$ = 250 (49) ps at 500 MeV, 291 (120) ps at 100 MeV without (with) correction for trigger jitter
- Consistency with cr/single crystal measurements in progress

Conclusions

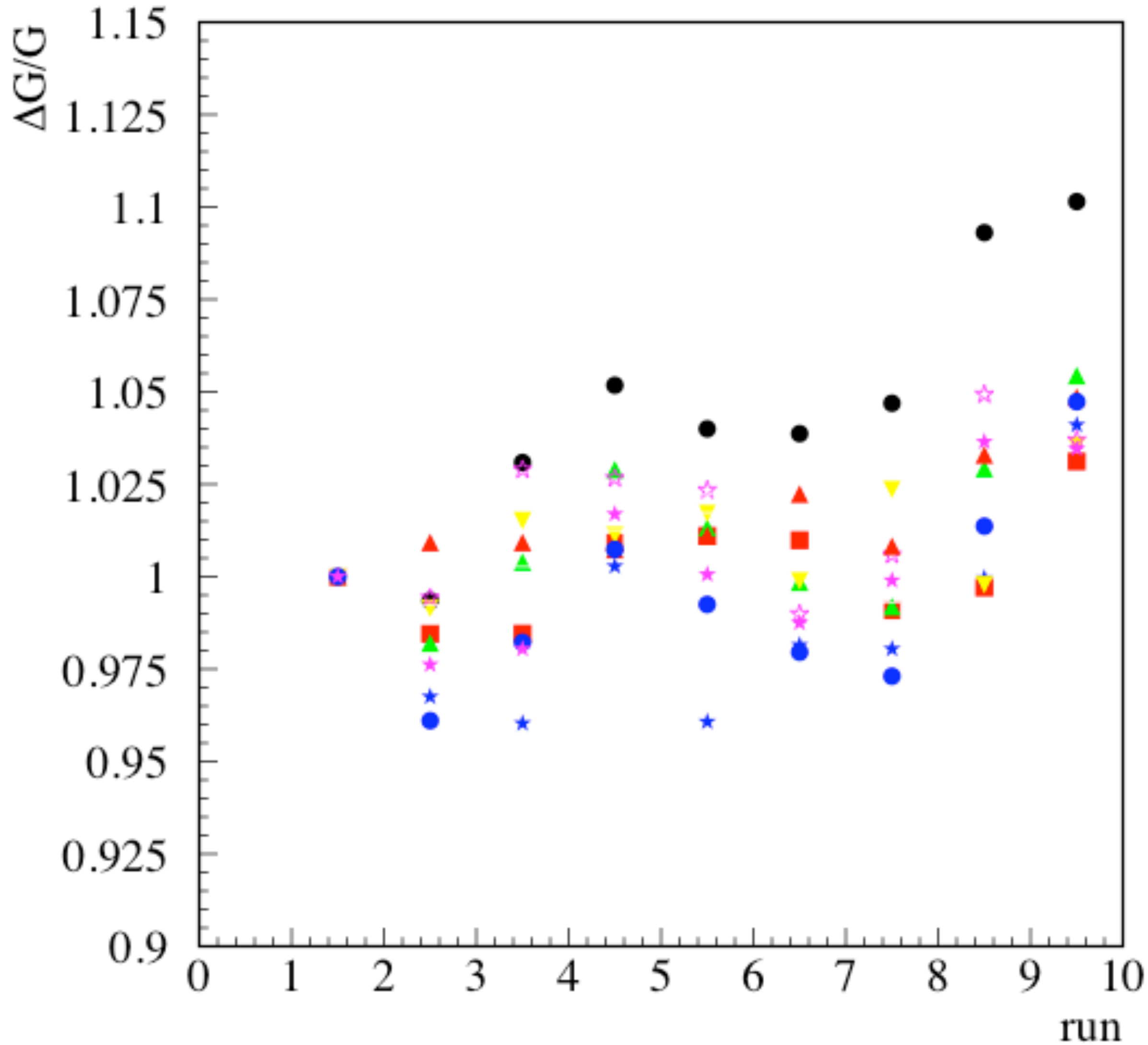
- We are designing a Crystal Calorimeter with timing for KLOE-2 upgrade (2011-2012)
- First prototype has been built and tested with CR and e-beam
- High Light Yield observed
- Energy resolution dominated by leakage at higher energy
  - k/E component too high w.r.t. lab measurement of noise
  - stocastic term between 1-2%/√(E/GeV)
- Position resolution 2.8 mm @ 500 MeV as expected
- Timing resolution 250-300 ps from 100 to 500 MeV without correcting for trigger jitter.
  - *Already satisfies detector requirement.*
- Next Plans (fall 2009)
  - identify /correct noise term
  - make a test with outer matrix functioning
  - longer data taking for single crystals certification
  - reduce time jitter of the trigger

- Additional material

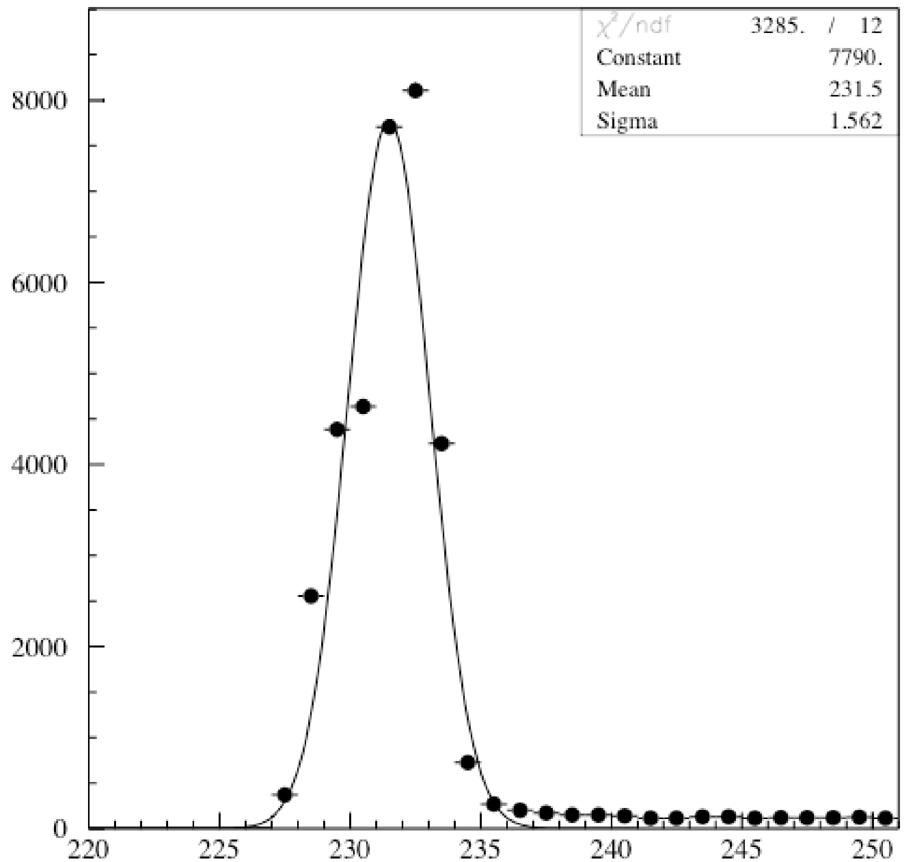
Response to LED vs time

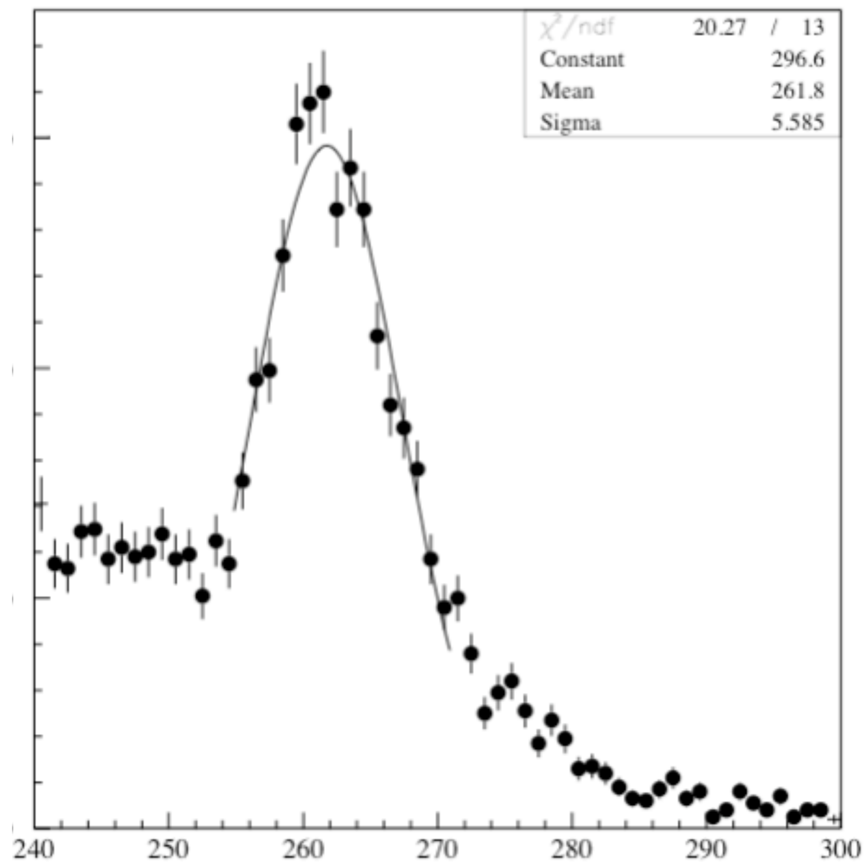


Response to MIP vs time

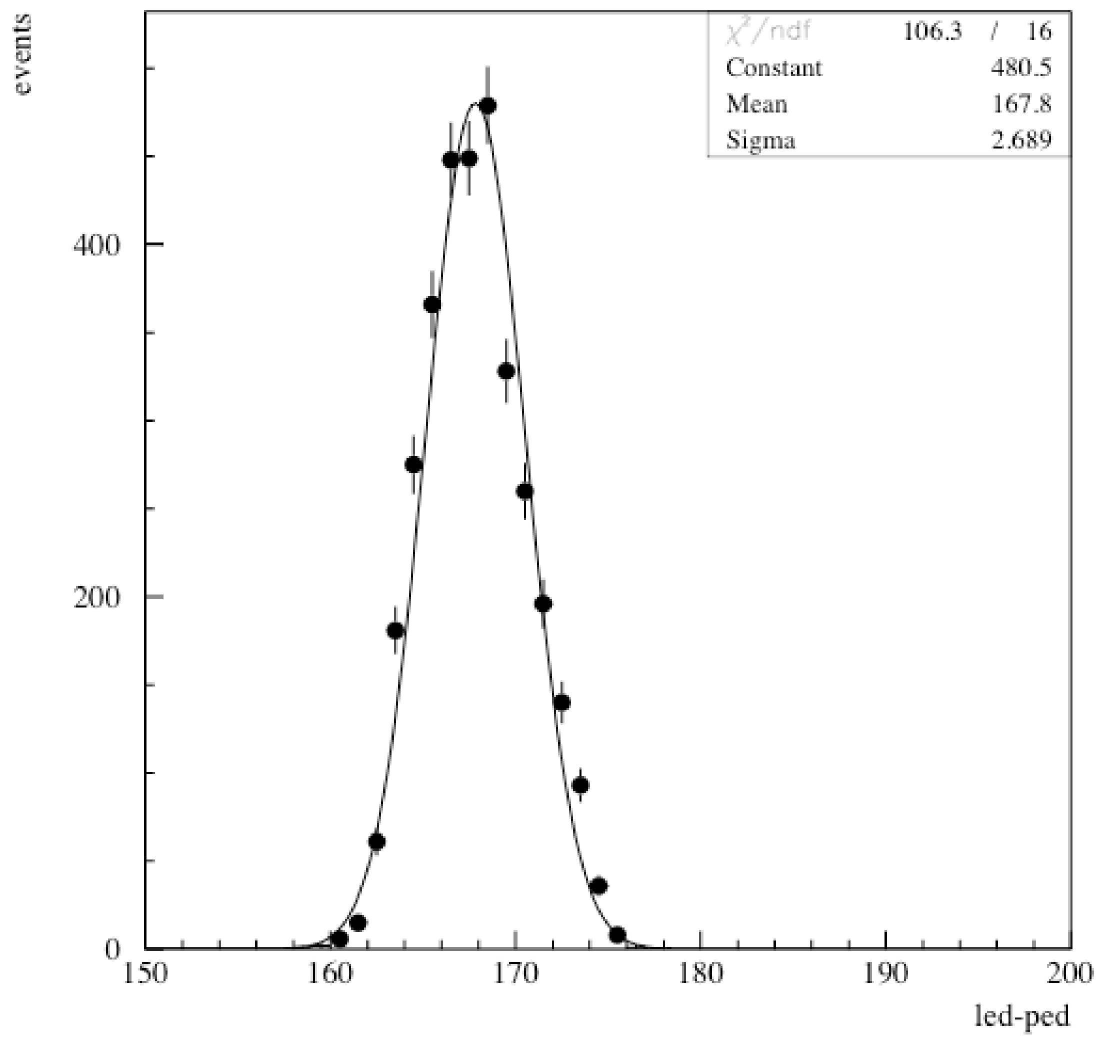


Example of MIP fitting @ test lab





Example of LED fitting @test lab



Need of timing @ KLOE-2

The main constraint comes from accidental background:

- simulation of new optics suggest a x 5 increase of Touschek background rate: from 5 MhZ in EMC to 15 MhZ with screens around inner quads

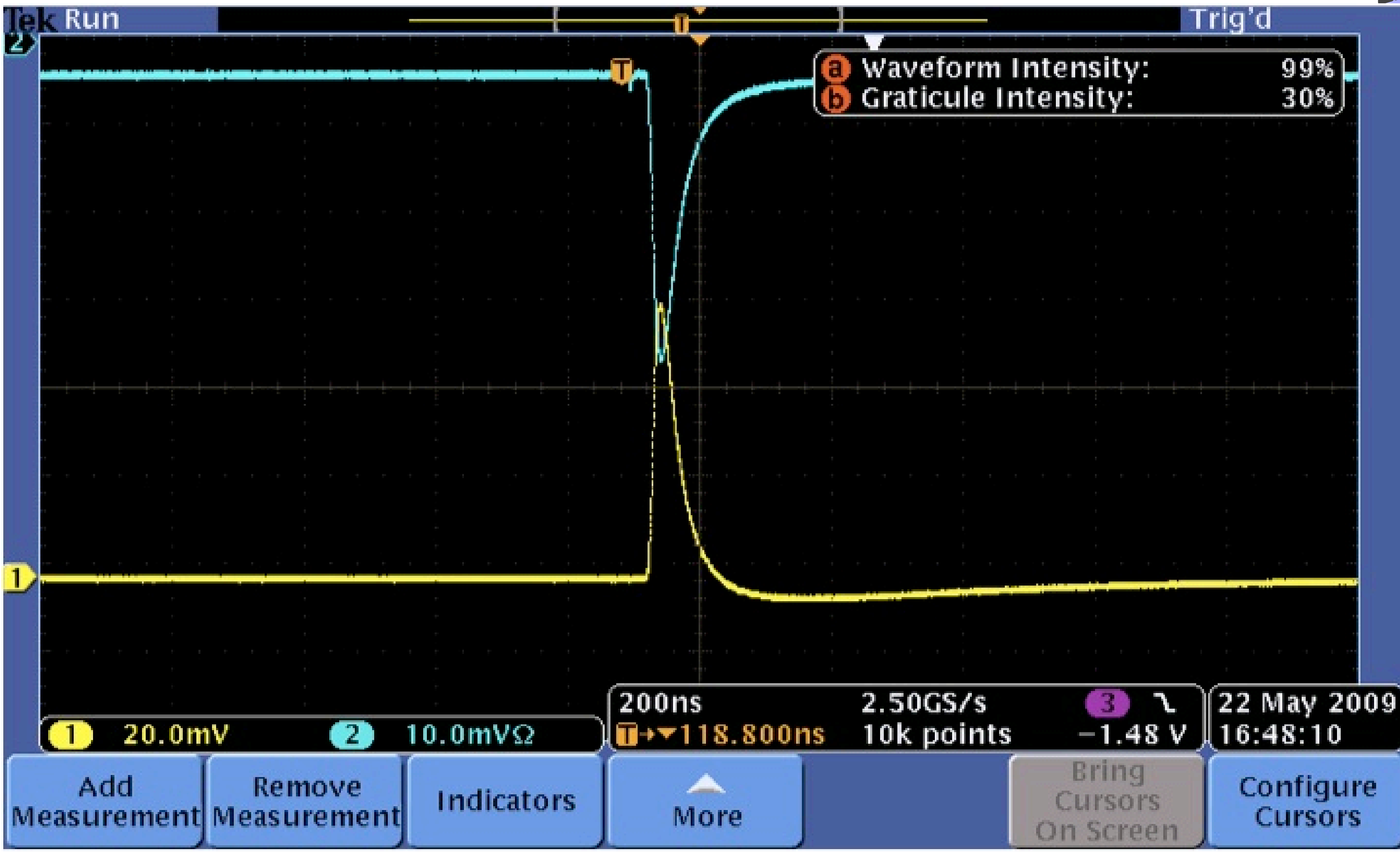
- to play conservative we want to be able to keep up a rate of 0.5 MhZ/channel.

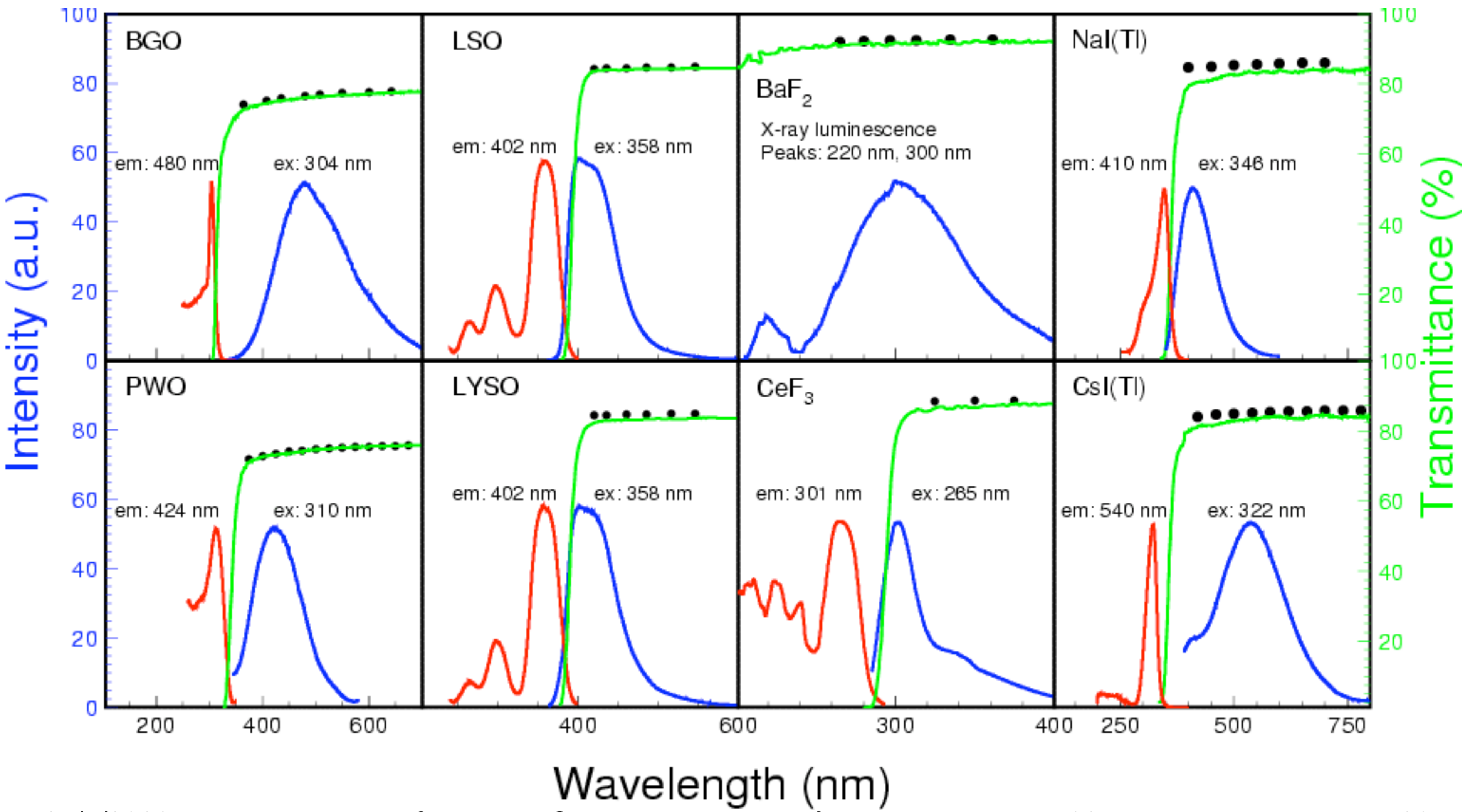
- A prompt time window of 2 ns -->

  makes Pacci = 1ns * 0.5 Mhz = 1% ---> negligible
- WE NEED A CALORIMETER with 300-500 ps time resolution @ 20 MeV

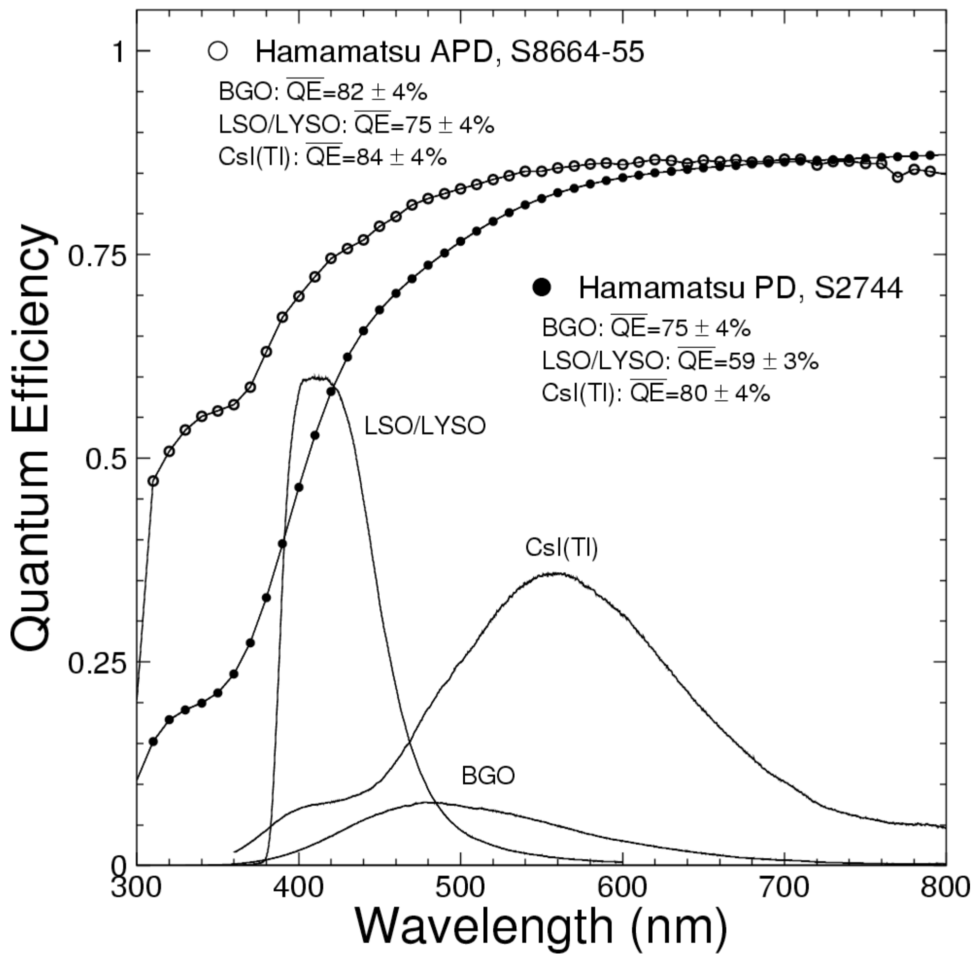
- CCALT

Example of LED signal





BGO
em: 480 nm
ex: 304 nm
LSO
em: 402 nm
ex: 358 nm
BaF$_2$
X-ray luminescence
Peaks: 220 nm, 300 nm
NaI(Tl)
em: 410 nm
ex: 346 nm
PWO
em: 424 nm
ex: 310 nm
LYSO
em: 402 nm
ex: 358 nm
CeF$_3$
em: 301 nm
ex: 265 nm
CsI(Tl)
em: 540 nm
ex: 322 nm
Intensity (a.u.)
Transmittance (%)
Wavelength (nm)


Hamamatsu APD, S8664-55
BGO: $\overline{QE}$=82 ± 4%
LSO/LYSO: $\overline{QE}$=75 ± 4%
CsI(Tl): $\overline{QE}$=84 ± 4%
Hamamatsu PD, S2744
BGO: $\overline{QE}$=75 ± 4%
LSO/LYSO: $\overline{QE}$=59 ± 3%
CsI(Tl): $\overline{QE}$=80 ± 4%
LSO/LYSO
CsI(Tl)
BGO
Quantum Efficiency
Wavelength (nm)
1
0.75
0.5
0.25
0
300
400
500
600
700
800

LYSO vs LFS

	LYSO	LFS
Density	7.1	7.2 – 7.3
Attenuation length (cm)	1.2	1.12
Decay constant (ns)	41	35 - 36
Max emission (nm)	420	435 - 438
Light yield (relative NaI)	75	80 - 85
Energy resolution	8	9 - 12
Hygroscopic	NO	NO
Refractive index	1.81	1.78