The BGO alternative

Roma1 EMC Group

Intro

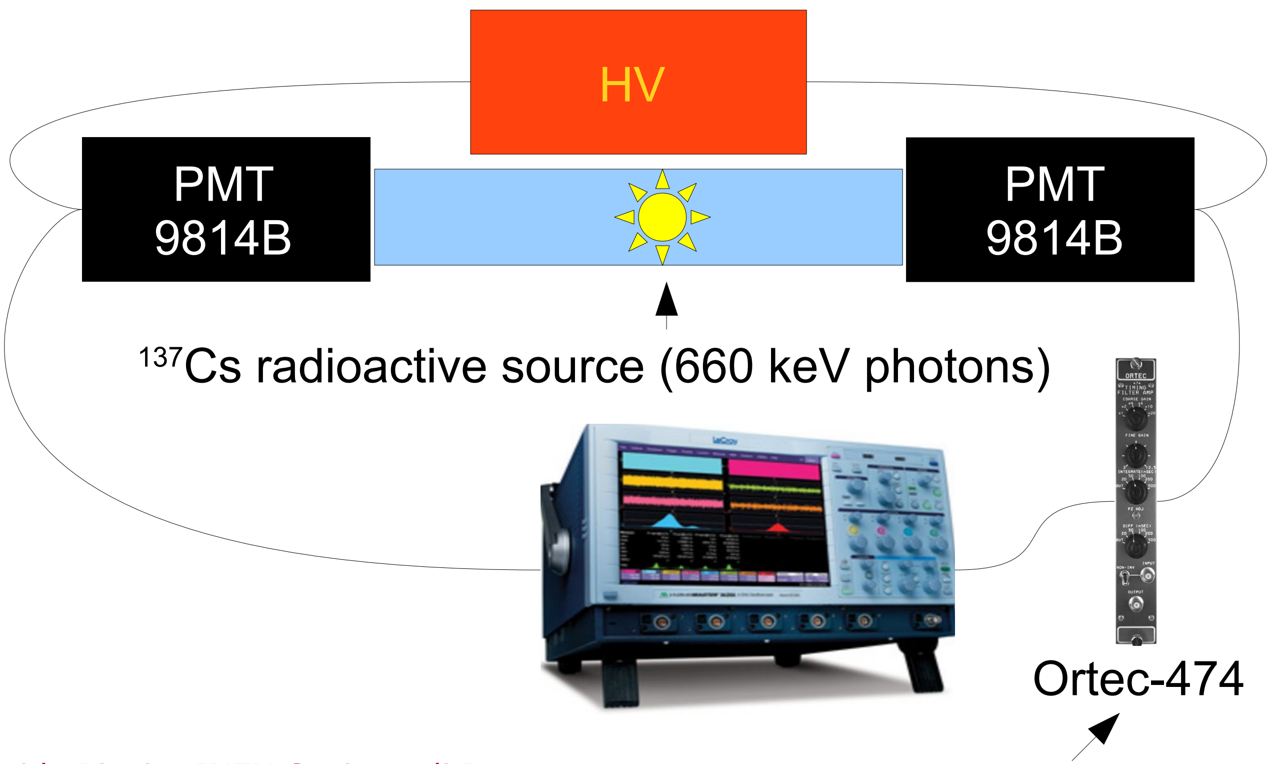
During last months we performed detailed studies of the performance of a single BGO crystal irradiated with a ^{137}Cs source;

The aims of this work were:

(1) the study of the energy resolution of the BGO in the low energy region;

(2) the evaluation of the impact of the front-end electronics integration time on the crystal performance;

All measurements performed on a L3-BGO crystal 2x2x18 cm^3,



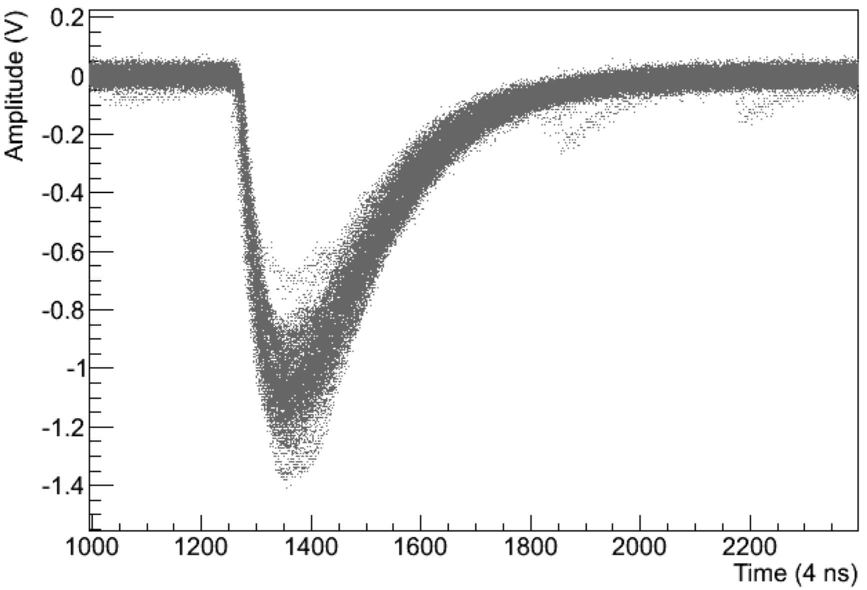
The energy resolution was studied as a function of the integration time of the readout for values of: 20ns, 100ns, 200ns and 500ns.

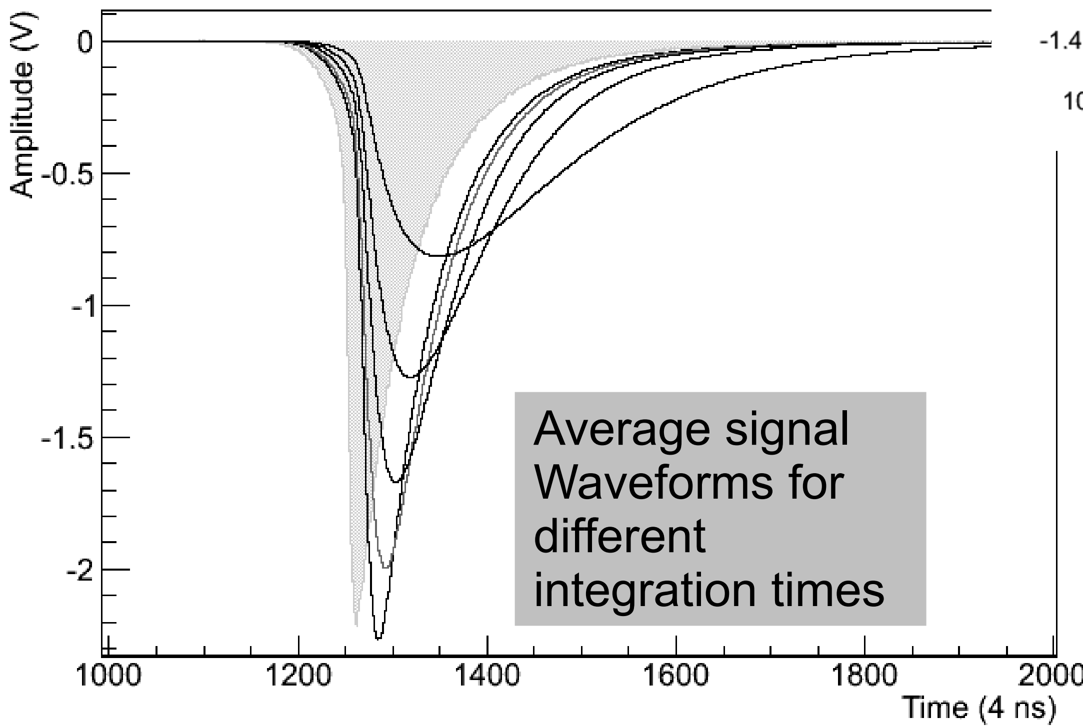
Signal waveforms

In an off-line analysis, event by event, all waveforms were studied;

For every integration time we acquired 15k events;

1000 superimposed waveforms

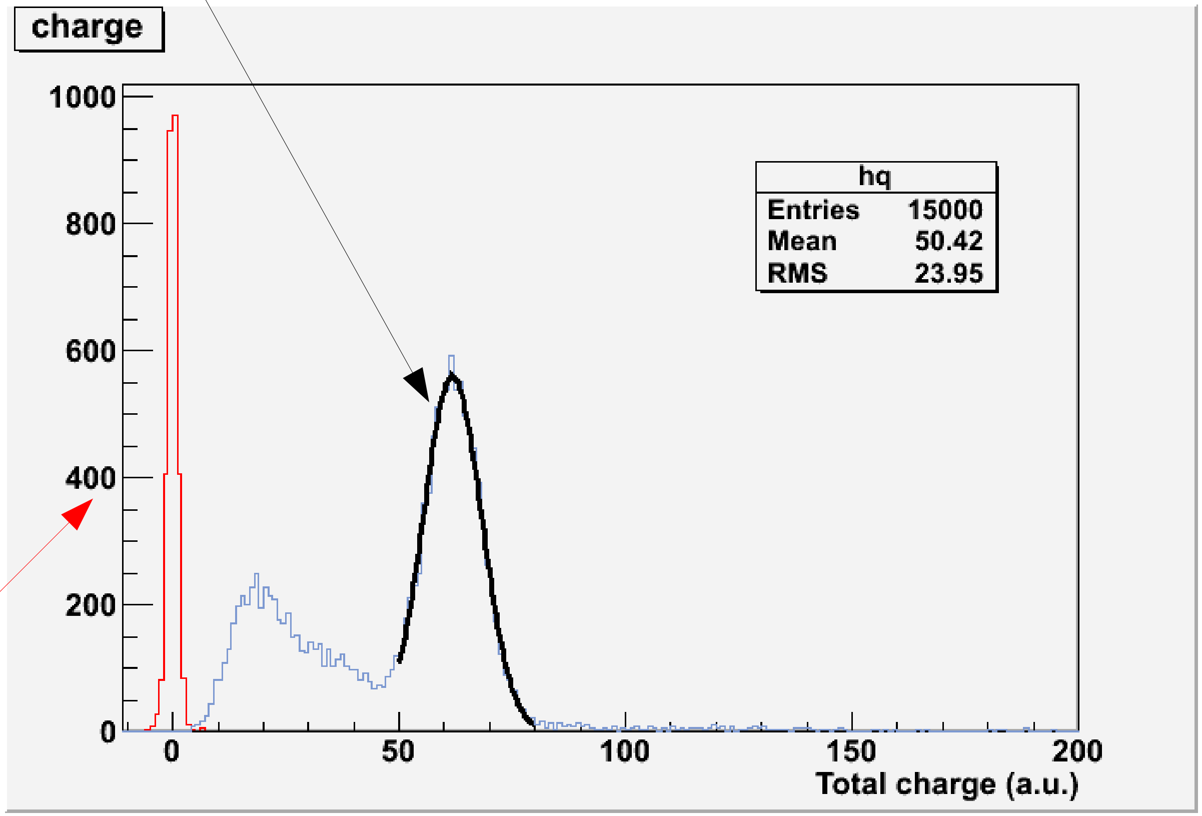




Average signal Waveforms for different integration times

Charge Spectra

For each integration time we evaluated the spectra of the total charge and we fitted it with a Gaussian;



Red: charge spectra with the random triggers (i.e. the pedestal due to electronics noise). Its width is 10% of the signal peak width. Thus is contribution in quadrature is negligible.

Resolution on total charge

- The charge produced always reach the scope and so the resolution obtained shouldn't depend on the RC value;
- The relative resolutions obtained for different integration times in different conditions are reported in the plot;

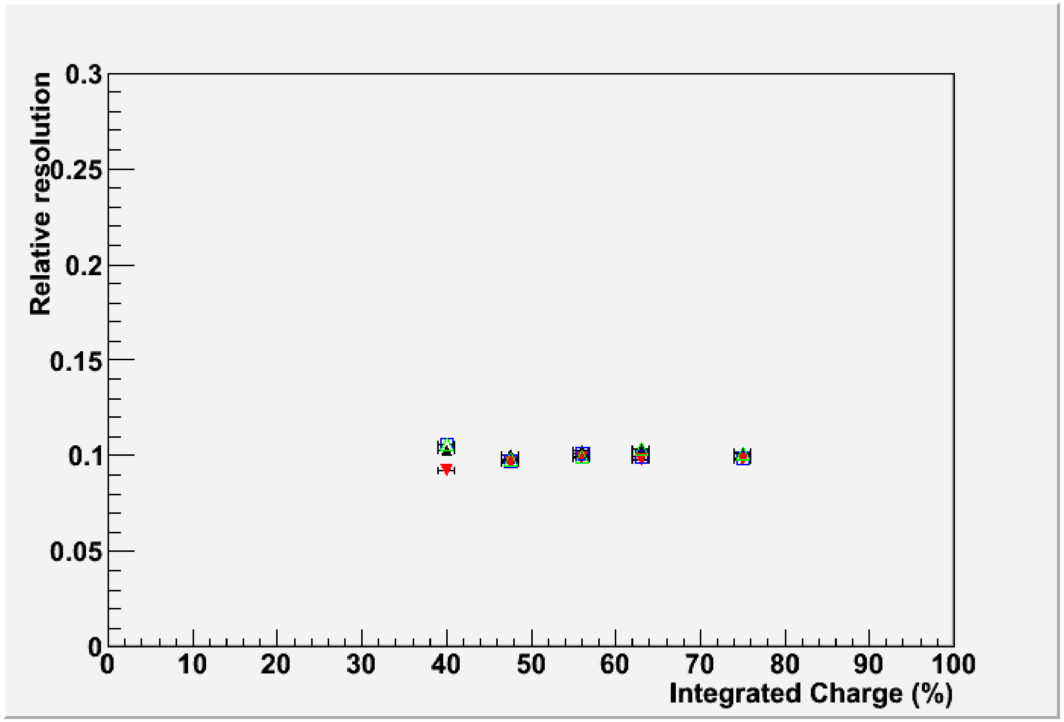
Black: High HV + Gain 10

Red: High HV + Gain 10

(two datasets were taken in different days to check the stability of the results)

Blue: High HV + Gain 2

Green: Low HV + Gain 10



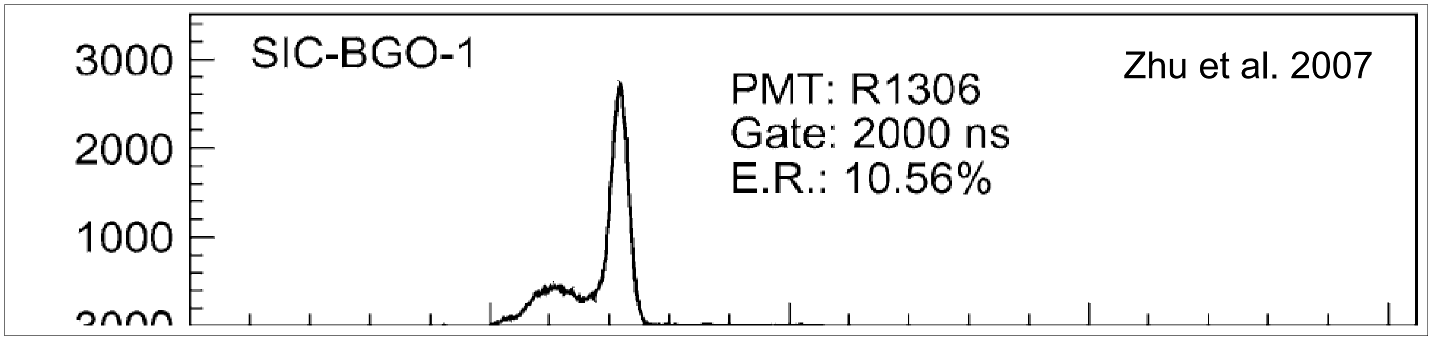
Resolutions is quite stable between different conditions and different integration times. Average results are: 10.2 ± 0.1, 9.7 ± 0.1, 10.1 ± 0.1 and 10.2 ± 0.1;

Grand-average: 10.0%;

Resolution on total charge

An energy resolution of 10% is thus found in all our measurements.

In agreement with the one published by R. Y. Zhu obtained with a similar setup (^{137}Cs source on BGO readout with a PMT);



From this result we can evaluate a number of at least 100 p.e./0.662 MeV (i.e. 150 p.e./MeV);

This will result in 7500 p.e. at 50 MeV and thus in a statistical contribution to the energy resolution of 1.1%;

The use of an APD readout can increase the number of p.e of a factor 3 upgrading the energy resolution.

Zhu et al. 2007

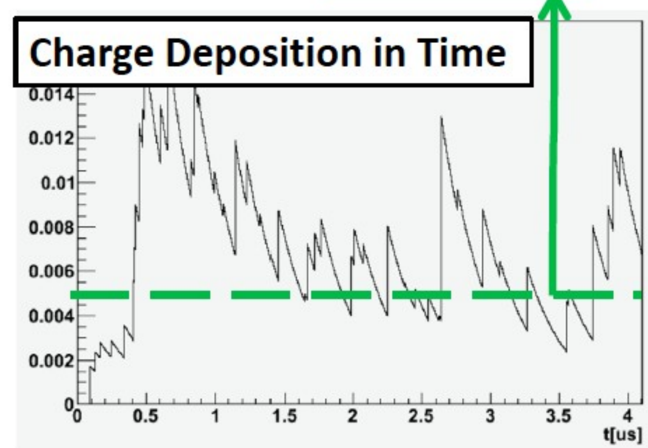
TABLE III
RESULT OF LIGHT RESPONSE UNIFORMITY WITH APD READOUT

Sample	A end coupled to APDs		B end coupled to APDs	
ID	LO_{mid} (p.e./MeV)	δ (%)	LO_{mid} (p.e./MeV)	δ (%)
SIC-BGO	420	0 ± 2	430	1 ± 2
CTI-LSO	1,580	3 ± 2	1,610	-7 ± 2
CPI-LYSO	1,310	3 ± 2	1,320	-10 ± 2
SG-LYSO	1,610	5 ± 2	1,680	-4 ± 2

Pile-up

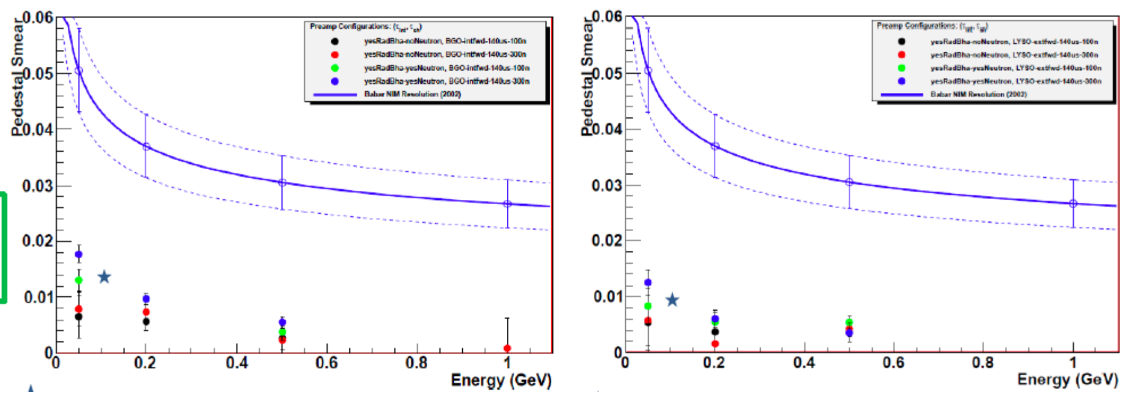
- The time decay constant of the BGO signals is about 300 ns;
- This will demand for a long integration time in the FE electronics;
- The large integration time may give rise to large fluctuations on the signal baseline due to high amount of soft particles expected

$$\sigma_E = \sigma_{p.e.} \oplus \sigma_{elec} \oplus \sigma_{intrinsic} \boxed{\oplus\, \sigma_{pedes}}$$



- Simulation carried out by Daniel & Co demonstrated that we can happily survive with an integration time up to 300 ns, but 100 ns can be safer;

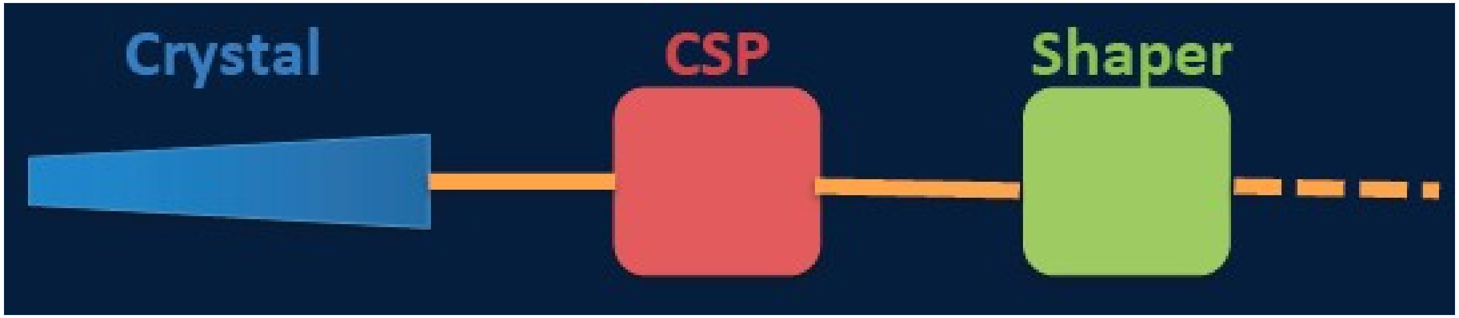
Same conclusion for the BGO pulses.



- What is the effect of such an integration time on the energy resolution?

Peak Amplitude

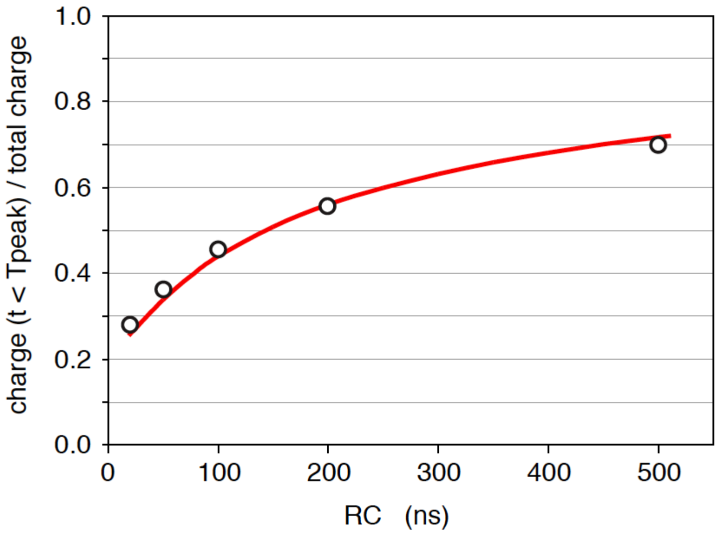
In the real readout electronics there will be a shaper downstream of the CSP and it will be sensitive only to maximum amplitude A of the signal provided by the CSP;



Since the Shaper part is linear, the statistical contribution to the energy resolution will be given by the fluctuations of A;

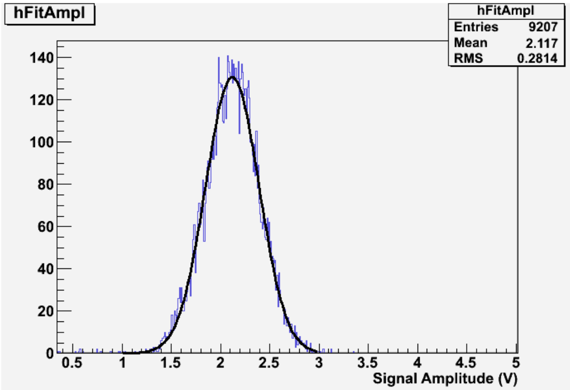
Our simple hypothesis is that A will fluctuate as the square root of the number of p.e. integrated by the CSP. So it will depend on the integration time RC.

We calculated the fraction *f* of integrated charge before the peak and we developed (G. Penso) a toy MC to check the exp. results.



RC	20 ns	50 ns	100 ns	200 ns	500 ns
f(peak)	28.1%	36.1%	45.4%	55.6%	69.9%

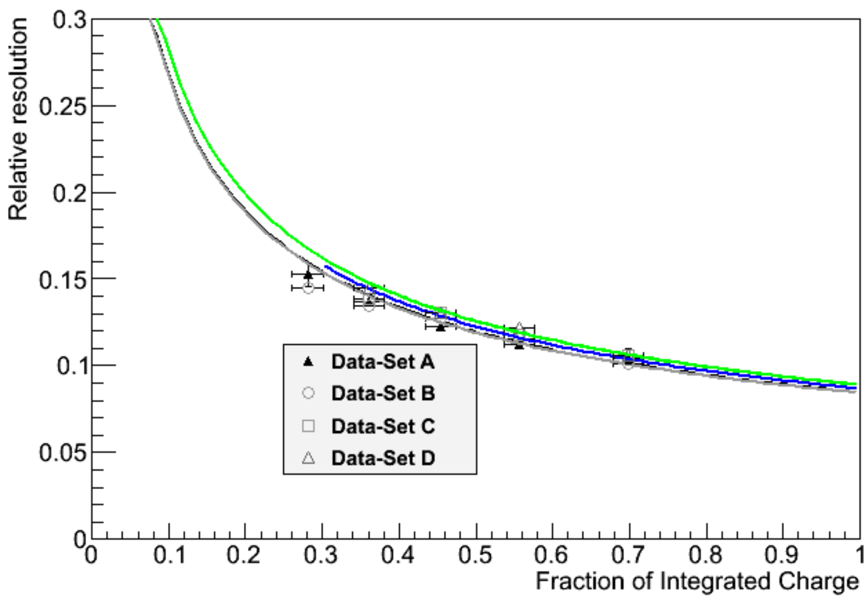
Relative resolution vs integrated charge



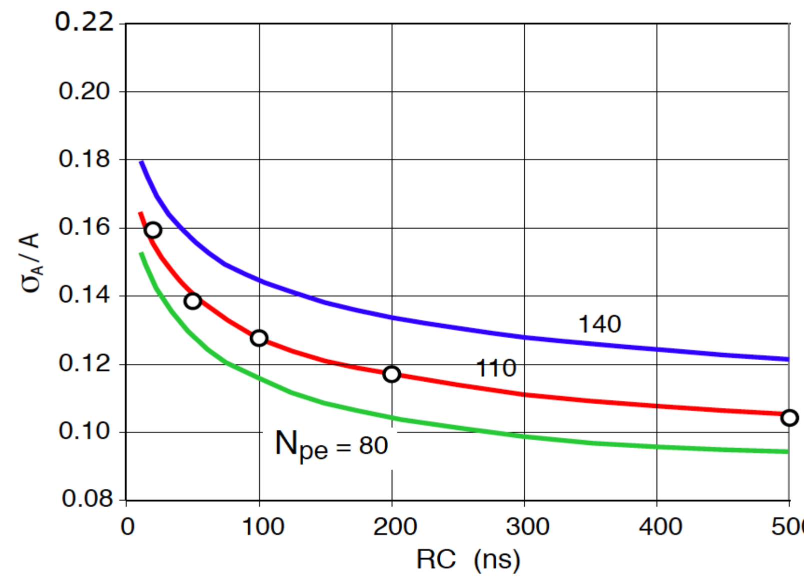
For each RC value between 20 ns and 500 ns we fitted the signal amplitude spectrum with a gaussian curve;

Than we plotted σ_A/A as a function of *f* and the behavior was fitted;

Since the pedestals are negligible, no other terms are summed $\rightarrow$ $\frac{\sigma_A}{A} = \frac{\sigma_0}{\sqrt{f}}$



Results from the fits to the different data-sets gives a σ_0 between 8.5% and 9.0%.



The results of the toy MC are compatible with the experimental data and seem to indicate a light yield of 110 p.e.

Conclusion on the energy resolution

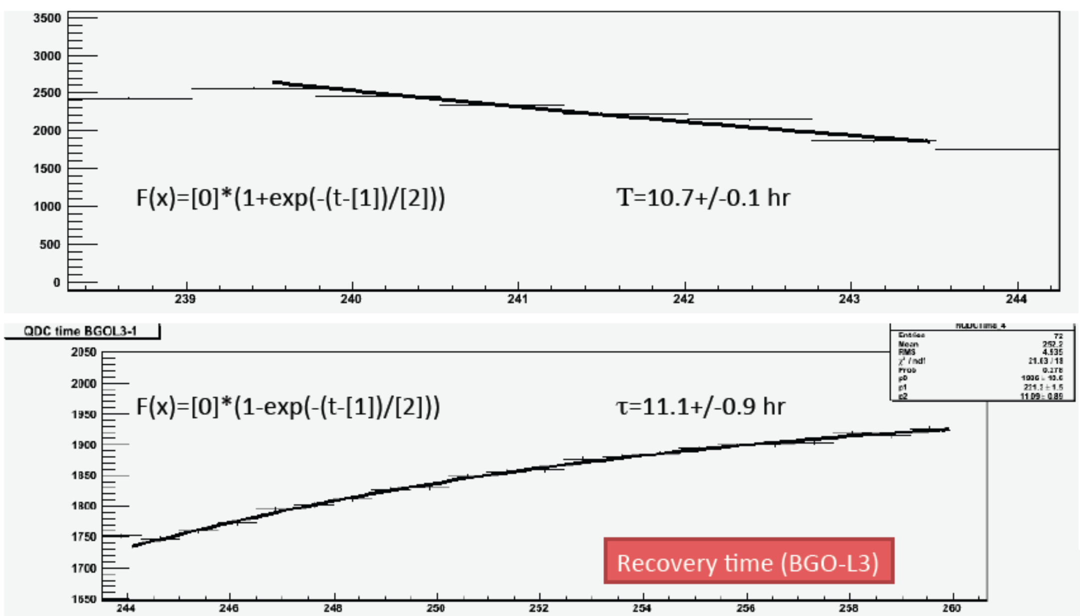
- Lab measurements showed that BGO light yield is high enough to provide a very good energy resolution already around 50 MeV;
- The energy resolution scales as the square root of the charge integrated in the pre-amplifier;
- With a 100 ns long integration time in the FEE, we are going to integrate half of the total charge;
- With a 100 ns long integration time in the FEE, we measured a resolution of 12.5% on the ^{137}Cs photons
- We can thus expect a statistical term of 1.5% to the energy resolution at 50 MeV;
- In these conditions, the results of Daniel's simulation indicate that the effect of the soft photons pile-up to the signals are completely under control;
- From this point of view, BGO seems able to provide the required energy resolution for the SuperB EMC

Aging and Radiation Hardness

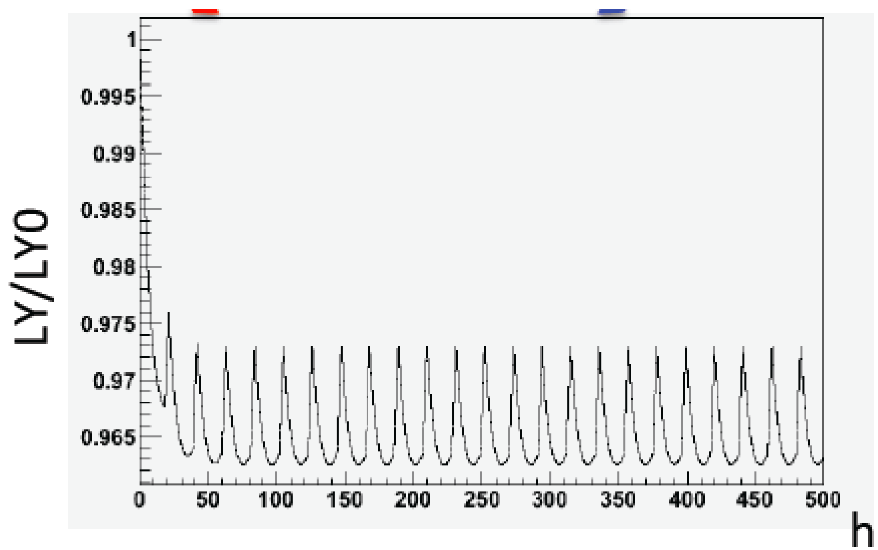
- Last week, we tested a couple a BGO crystals: one from L3 and one brand new;
- Results are very preliminary, but with a dose rate of about 10 rad/h (10 (?) times the background expected in SuperB), we measured a decay time for the BGO light output of about 10/h;

BGO-L3 crystal (#1)

Time constant (rough) measurements



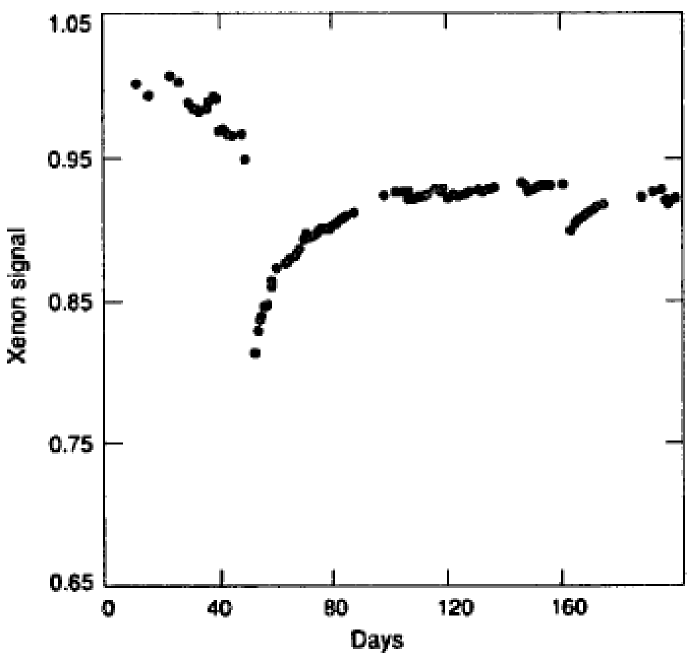
- This means that, during the DAQ phase, the response will fluctuate



- Aging induced fluctuations are expected to be of the order of 1%;

Aging effects

- We can neglect them or we can think of correcting all the data off-line, by using some candle as for example Bhabha events;
- L3 did it always for the temperature induced fluctuations and also for sudden aging due to accidents in the machine. As the one below:



- Calo response after a serious beam loss

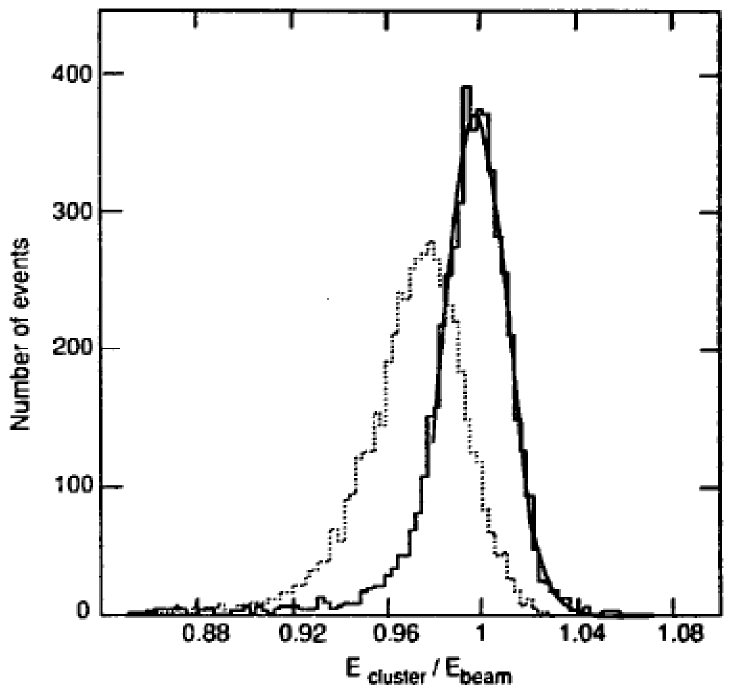


Fig. 15. Energy resolution of the BGO barrel. Dotted line: uncorrected data ($\sigma^{E} = 1.70\%$). Continuous line: corrected data ($\sigma^{E} = 1.25\%$).

Conclusion

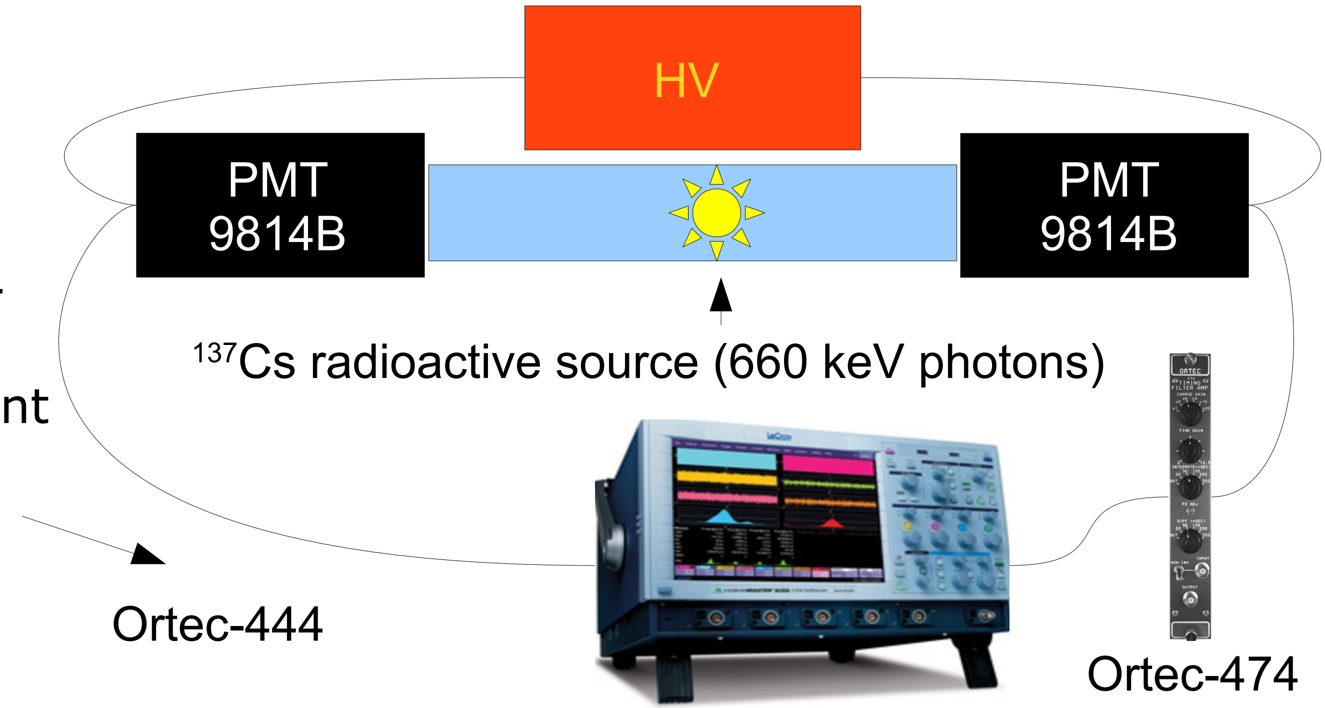
- According to our measurements and studies, BGO seems able to provide the energy resolution required for equipping the SuperB BGO
- So far, the main issue is represented by the effect of the aging;
- A large light drop was found, but we measured a slow time constant;
- We have to investigate further if the effect can be "neglected" (as shown from Riccardo) or we can imagine to follow the radiation effect with an off-line re-calibration of the calorimeter.
- The important fact is that L3 crystals behave as the brand new one, so we can think of reusing the L3 end-cap crystals;
- In this case and the total cost can be of the order of half a Million Euro.

Back up

Measurement Set-up

Events acquired with an oscilloscope;

The “trigger-side” this time was amplified with an Ortec-444 to get rid of its electronics noise and was sent to the oscilloscope trigger. This allowed to acquire a more “clean” data sample;



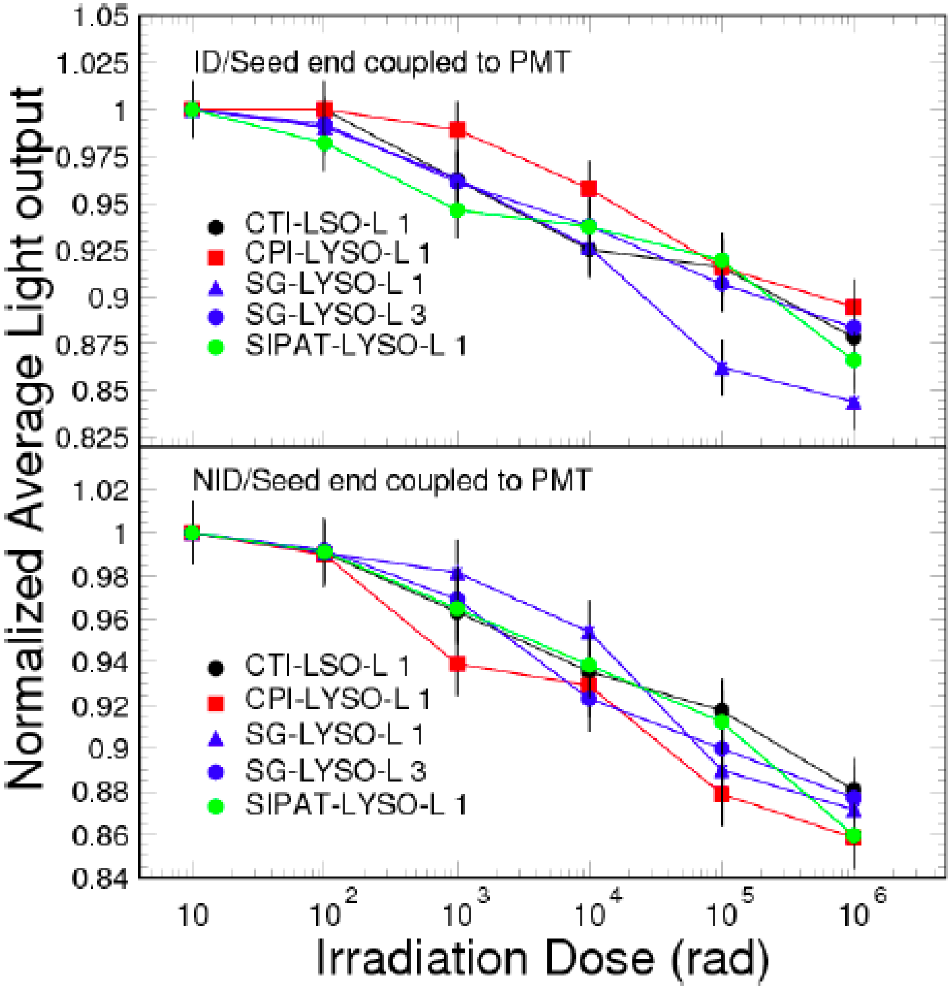
The “signal side” passes through an Ortec-474 pre-amplifier with variable integration time and 2 ms differentiation time (effect negligible) and is thus acquired by the oscilloscope.

Measurements were taken with two different HV settings (High and Low) and two different amplification factors (2 and 10) on the Ortec-474;

In all these configurations we acquired data with and without the radioactive source, and with random trigger (to allow a proper pedestal evaluation) for integration times of 20ns, 100ns, 200ns and 500ns.

LYSO Rad Hardness

10% - 15% loss by PMT



9% - 14% loss by APD