Studies on BGO crystals

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Intro

During the month of August we performed a detailed study 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;

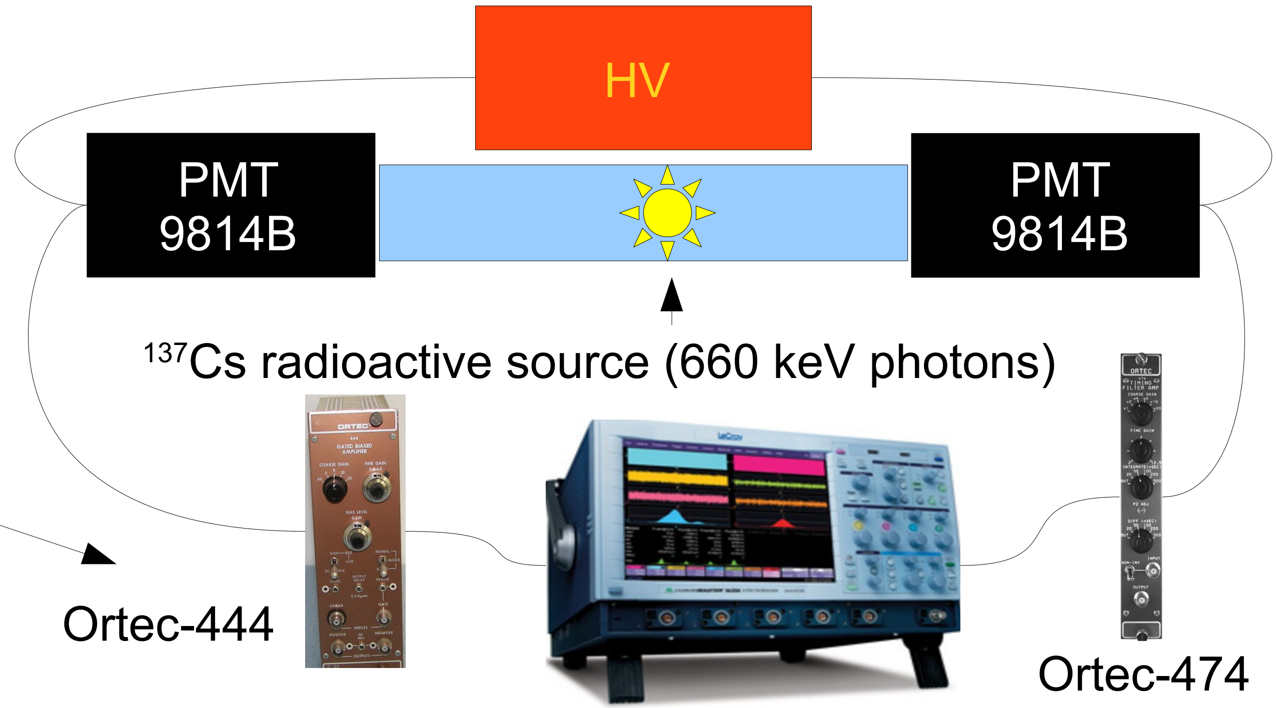
All measurements performed on a L3-BGO crystal 2x2x18 cm^3,

The crystal in test is different from the one studied in April (that broke), readout on both sides with PMT;

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.

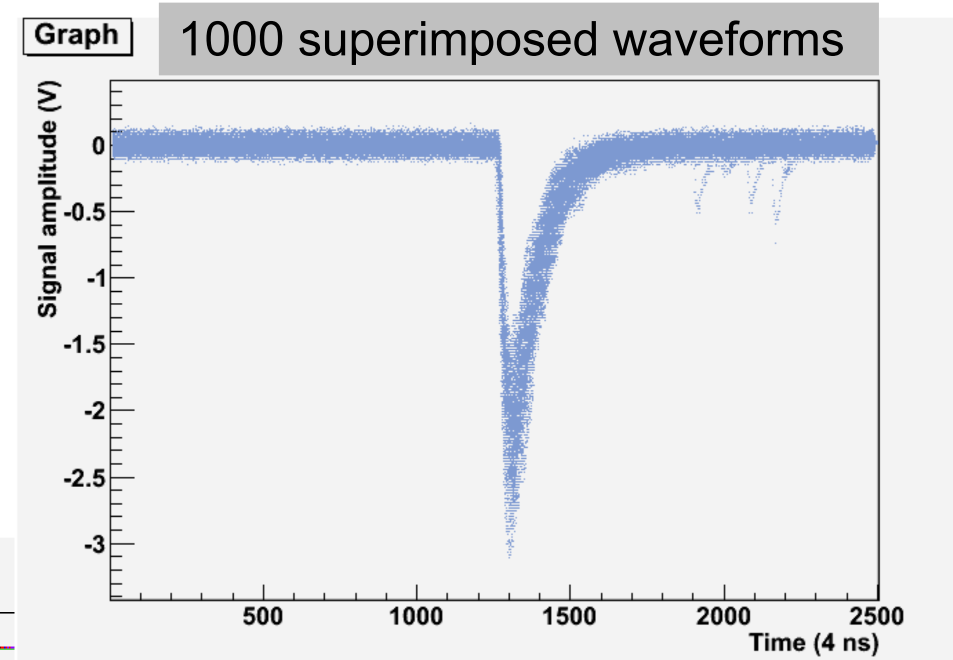
Measurements were taken with two different HV settings (High and Low) and two different amplification factors (2 and 10) on the Ortec-474;

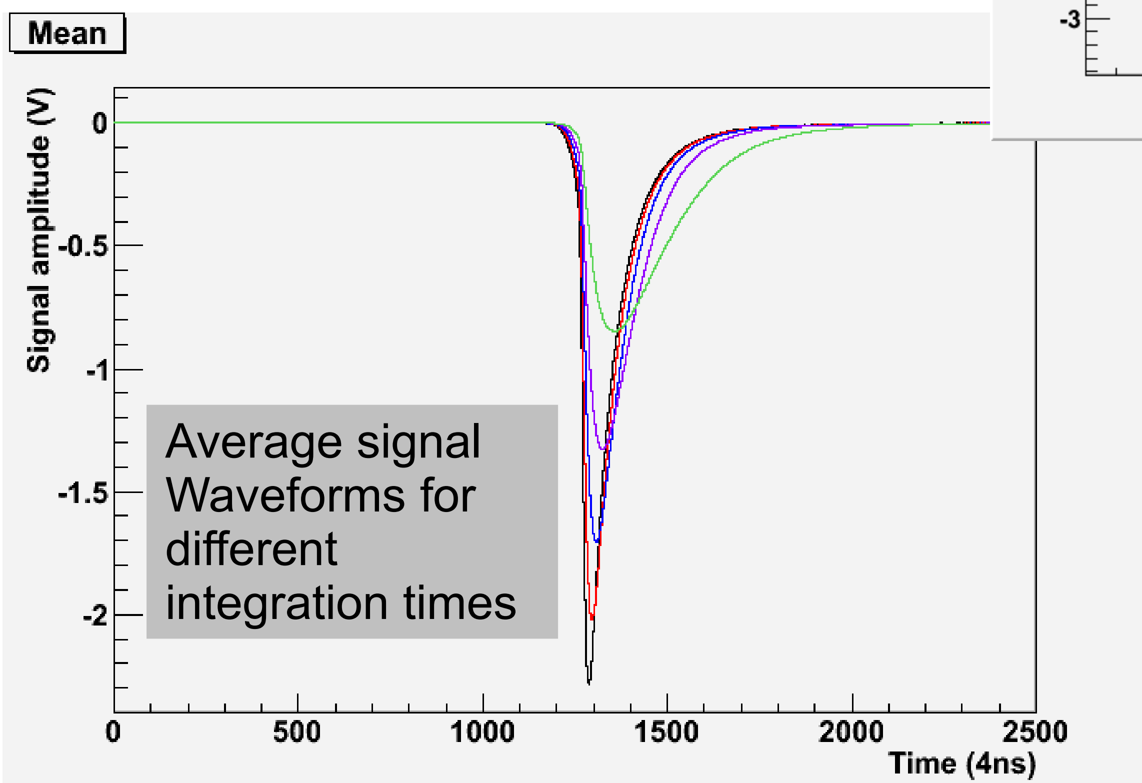
In all these configurations we acquired data with and without the radioactive source, and with random trigger (to allow a proper pedestal evaluation) for integration times of 20ns, 100ns, 200ns and 500ns.

Signal waveforms

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

For every integration time we acquired 15k events;





Analysis

For each event two main parameters were evaluated:

- The Total Charge.

Since the oscilloscope is DC coupled to the PMT, all the charge produced reaches the oscilloscope. Thus, even if the waveform shape changes accordingly with the integration time, the area under the curve (proportional to the total charge) should be constant. Its fluctuations being related to the intrinsic energy of the system;

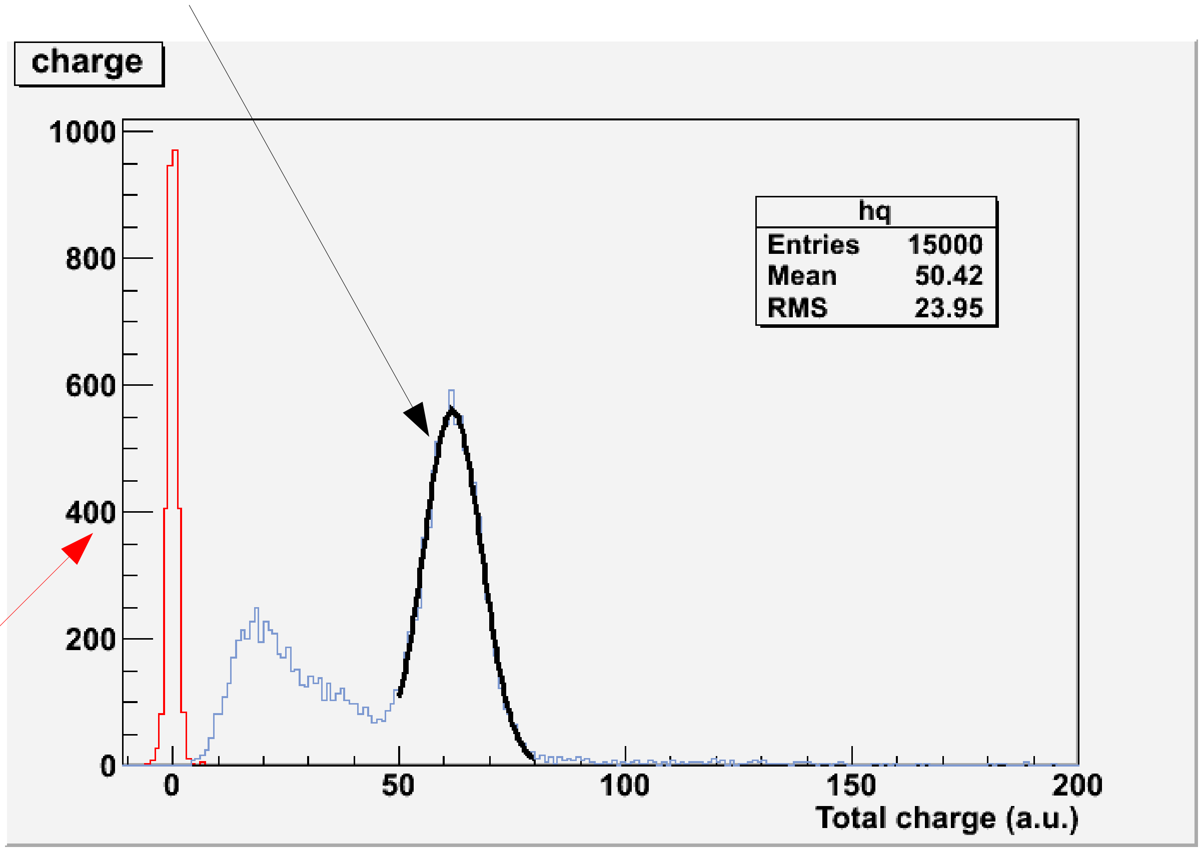
- The Signal Maximum Amplitude.

In the real experiment, the signal provided by the charge pre-ampli (CSP) will be sent to a shaper sensitive to its maximum amplitude and not to the total charge. Thus, the amplitude fluctuations downstream of the Ortec-474 will translate in the real energy resolution on the experiment. To study the fluctuations of the signal amplitude a simple mathematical model of the integrating circuit was developed and fitted to the waveforms event by event.

$$V_{out}(t) = R_{in} Q \frac{\left(e^{-t/\tau} - e^{-t/RC}\right)}{\tau - RC}$$

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 relative resolutions obtained for different integration times in different conditions are reported in the plot;

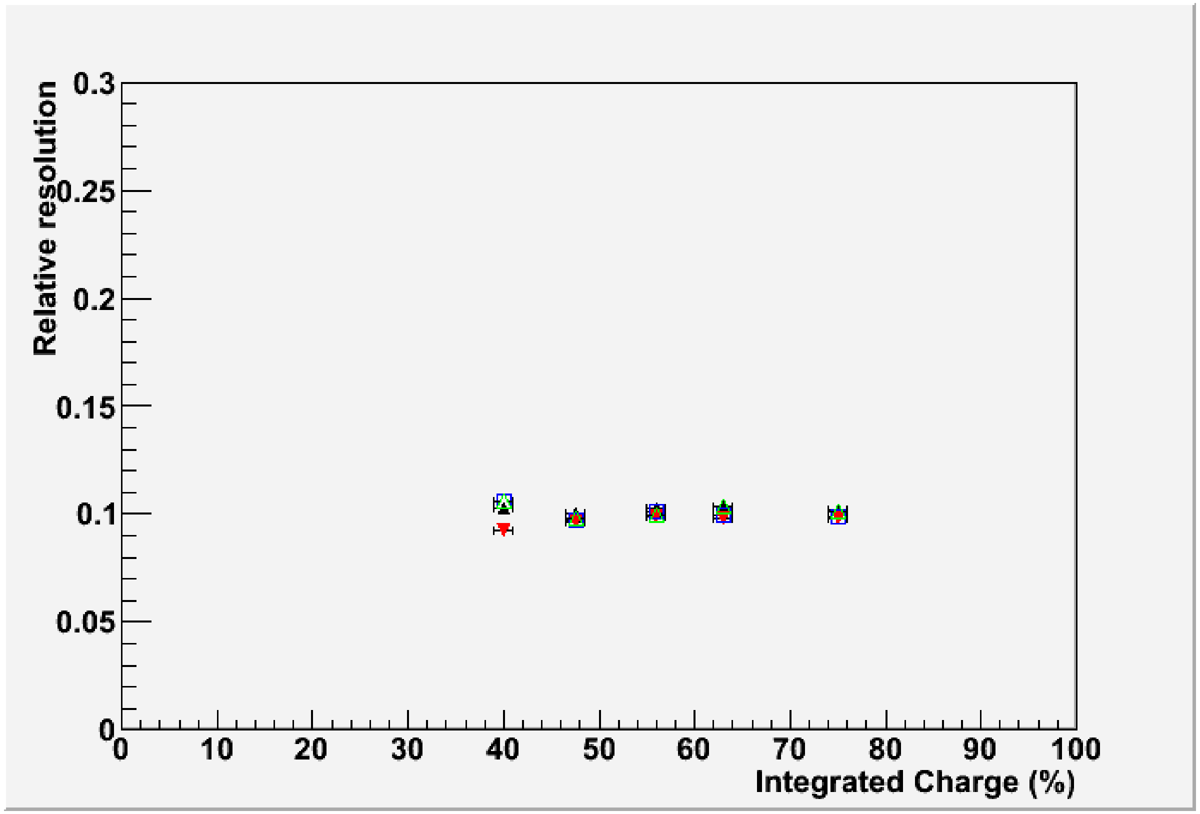
Black: High HV + Gain 10

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



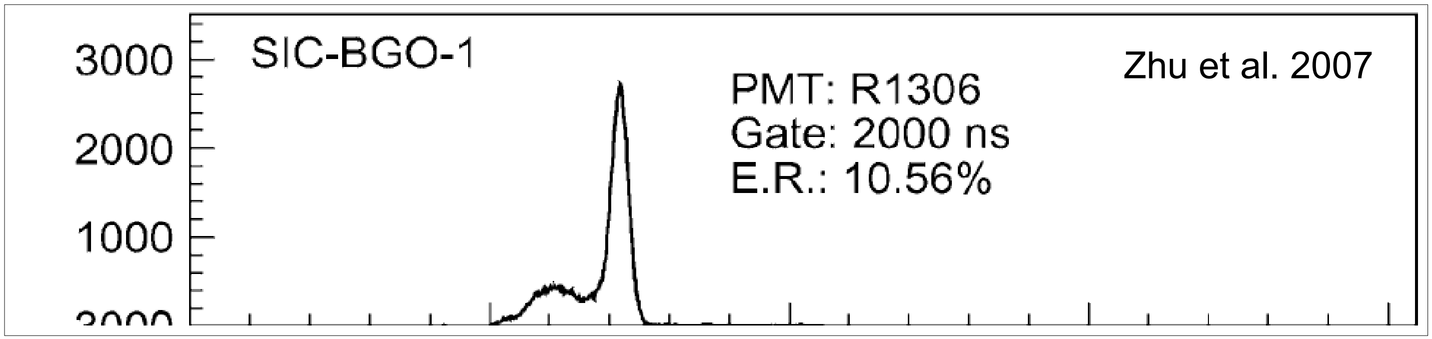
Resolutions is quite stable between different conditions and different integration times. Average results are: 10.2 ± 0.1, 9.7 ± 0.1, 10.1 ± 0.1 and 10.2 ± 0.1;

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 could increase the number of p.e. up to a factor 3 upgrading the energy resolution.

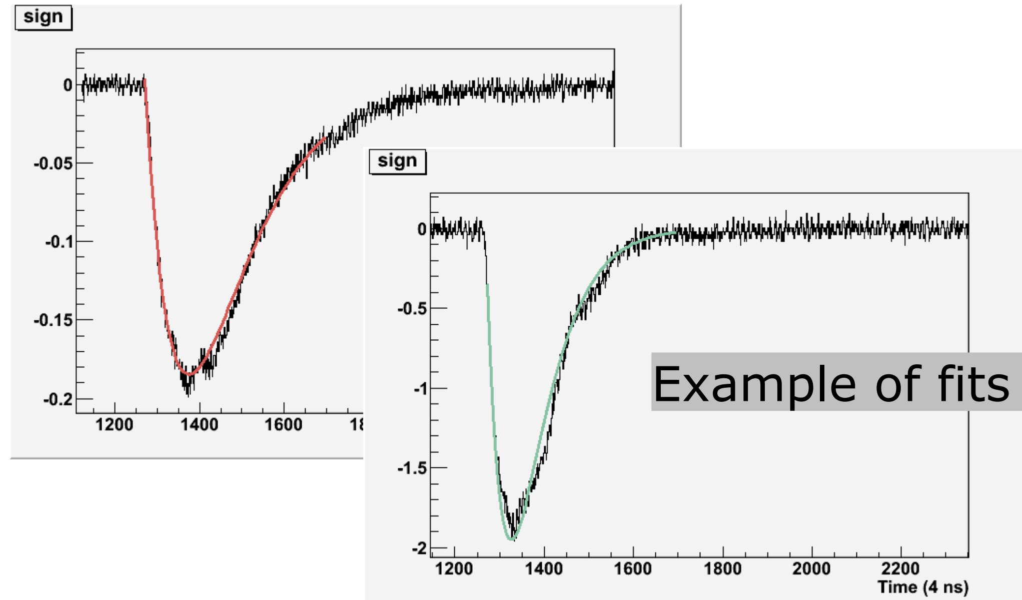
Zhu et al. 2007

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

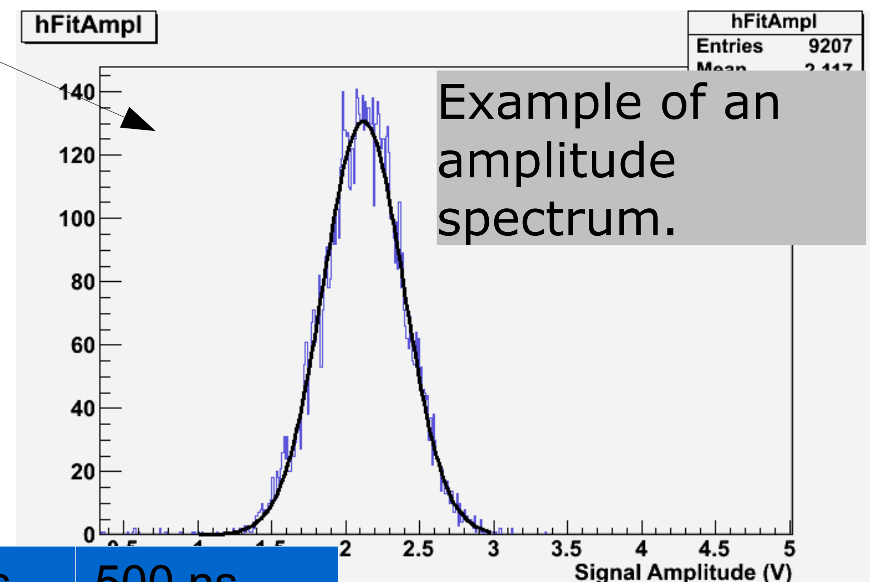
Peak Amplitude

To evaluate the signal amplitude, event by event, a fit is performed on the recorded waveforms;



Example of fits

For each set of measurements, the spectrum of the amplitudes obtained from the fits are fitted with a gaussian;



Example of an amplitude spectrum.

For each setting we recorded the average and the sigma of the gaussian and we evaluated the relative resolution as their ratio;

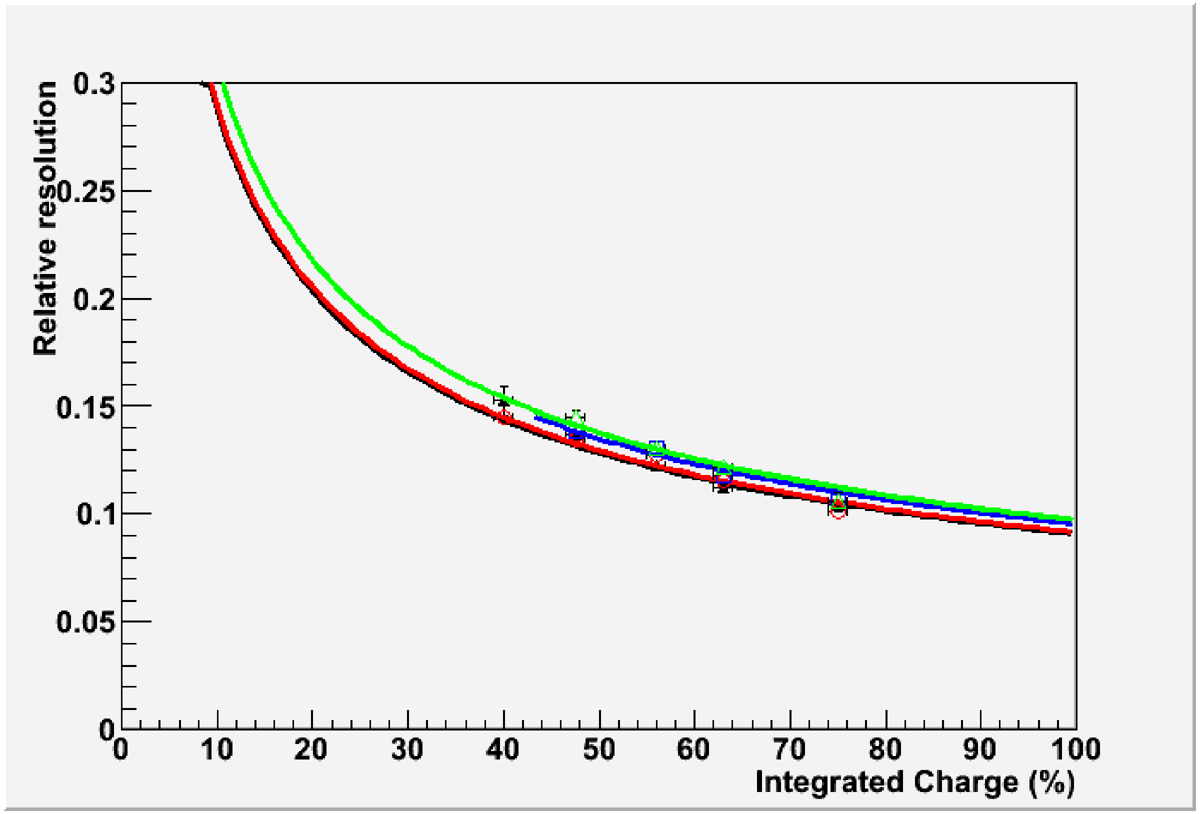
We calculated the fraction *f* of integrated charge before the peak:

RC	20 ns	50 ns	100 ns	200 ns	500 ns
f(peak)	40.0%	47.5%	56.0%	63.0%	75.0%

Relative resolution vs integrated charge

Our hypothesis is that the relative resolution obtained by looking at the peak amplitude is mainly due to the number of integrated p.e. and thus it improves with the square root of the fraction of the integrated charge *f* ;

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



Results from the fits are:

High HV + Gain 10
σ_0 = 90.8 ± 0.6;

High HV + Gain 10
σ_0 = 91.6 ± 0.5;

High HV + Gain 2
σ_0 = 95.4 ± 1.0;

Low HV + Gain 10
σ_0 = 97.3 ± 1.1;

In average for *f* → 100% the σ_A/A → 9.4% (average resolution in charge was 10.0%)

Resolution for 100 ns integration time

The energy resolutions for an integration time of 100 ns (56% integrated charge) are:

High HV + Gain 10 σ_A/A = 12.2%;
High HV + Gain 10 σ_A/A = 12.7%;
High HV + Gain 2 σ_A/A = 13.0%;
Low HV + Gain 10 σ_A/A = 13.0%;

for an average resolution of 12.7%, i.e 61 p.e./0.66 MeV $\rightarrow$ 93 p.e./MeV;

Such a light yield would give a statistical contribution to the energy resolution at 50 MeV lesser than 1.5%;

Also in this case the use of an APD based readout could improve the light yield;

Effects of photons from rad-Bhabha

With 100 ns integration time, the baseline fluctuations due to soft photons are expected to be lower than 2 MeV, comparable with the LYSO

model	T_{dec} (ns)	T_{int} (ns)	central barrel	forward barrel	external FWD	internal FWD
LYSO	50	50	N/A	N/A	0.4	2.6
BGO (short)	300	100	N/A	N/A	0.5	1.4
BGO (long)	300	300	N/A	N/A	2.5	5.8
CsI(Tl) (BaBar)	1300	700	2.4	7.3	N/A	N/A
CsI(Tl) (short)	1300	300	0.6	2.0	N/A	N/A

Table 1. Contribution to the resolution (in MeV) induced by machine background on clusters for several plausible crystal decay times (T_{dec}) and integration times (T_{int}). The model refer to which configuration the toy simulation is intended to approximate.

Conclusion and future steps

- Lab measurements showed that BGO light yield is high enough to provide a very good energy resolution already around 50 MeV;
- The energy resolution seems to scale as the square root of the charge integrated in the pre-amplifier, so that even for a 100 ns long integration time in the FEE a statistical term of 1.5% is expected at 50 MeV;
- In the above configuration, the baseline fluctuations due to soft photons are expected to be lower than 2 MeV, comparable with the LYSO;
- We intend to perform the same studies with APD+CSP on a BGO and a CsI crystal to confirm the behavior. Setup is ready, we hope to have first results by the end of September;
- A detailed aging test is foreseen on 2 "brand-new" and 2 "L3" BGO crystals at Casaccia in Autumn (why not perform in the same time a test on LYSO?);
- A 100 L3 crystal matrix is now in Rome and can be equipped for a test beam (likely BTF) in Spring time.
- I really want to thank Daniel for the huge job he did!