Investigation of the properties of large volume $LaBr_3$:Ce scintillators with high energy gamma rays

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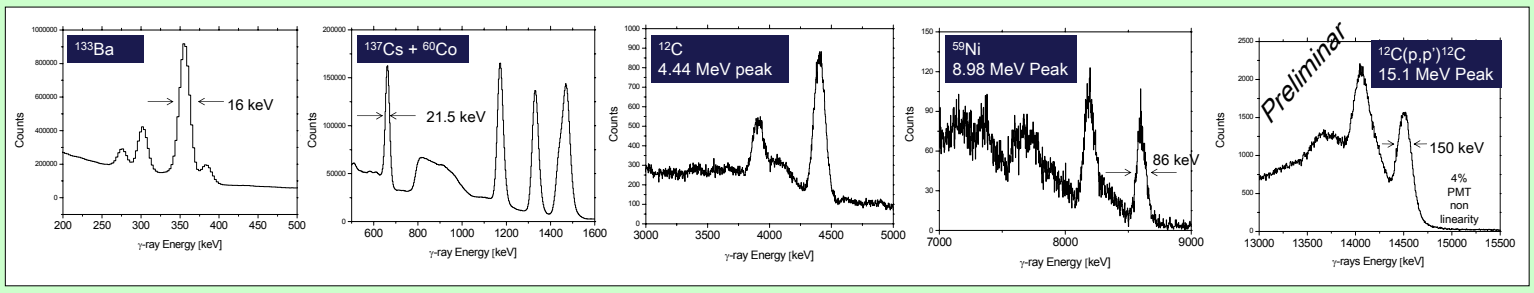
The properties of cylindrical 3'' x 3'' and 3.5" x 8" $LaBr_3$:Ce scintillators (see picture on the left) coupled to different Photonis and Hamamatsu Photomultiplier Tubes (PMTs) been investigated with γ-rays with energy up to 15 MeV. The PMTs used are R5300, XP5301, R6233, R6233-100, XP5700, XP3540 and R10233-100.
The tests have been done using the voltage dividers provided with the phototubes and, for the 3.5" x 8" $LaBr_3$:Ce detector, a specifically designed voltage divider coupled to a R10233-100 PMT. The new Voltage Divider provides both a pre-amplified signal for the energy measurement (from either anode or dynode) and direct anode signal for time measurement.
All the detector/PMT configurations have been tested in the energy range 100 keV - 15 MeV in terms of linearity, energy and time resolution for different values of the high voltage.

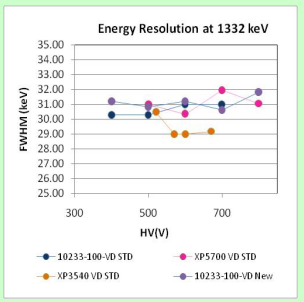
PMT Model	# Dynodes	Diameter	Cath. Lum. Sens.	Cath. Blue Sens.	Gain - Typical	HV - Typical
Photonis - XP5300	8	3 "		14.4 μa/lmF	2.4 10^5	1000
Photonis – XP5301 - Clarity	8	3"		17.3 μa/lmF	1.8 10^5	1000
Photonis – XP5700	8	3"		13 μa/lmF	2.4 10^5	1000
Photonis – XP3540	10	5"		11.9 μa/lmF	6.5 10^5	1200
Hamamatsu – R6233	8	3"	138 μa/lm		2.7 10^5	1000
Hamamatsu – R6233-100S	8	3"	167 μa/lm		2.4 10^5	1000
Hamamatsu – R10233-100	8	3.5 "	137 μa/lm		2.7 10^5	1000

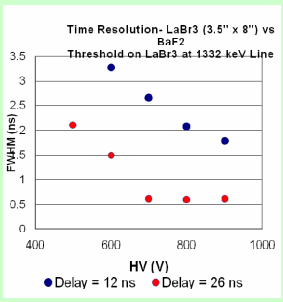
Table-1
The table shows the properties of the tested PMTs as listed in the general reference sheets and in the final test sheets which is provided with every delivered tube.
As Photonis gives the Cathode Blue Sensitivity while Hamamatsu the Cathode Luminous Sensitivity, the two figures are listed in different columns.

$LaBr_3$:Ce 3.5" x 8" ≈ 1300 cm^3



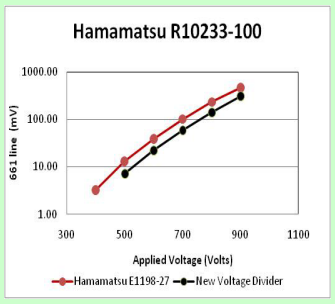
The plots in the top panel show the energy spectra as it was measured using a large volume 3.5" x 8" $LaBr_3$:Ce scintillator detector coupled with a R10233-100 Hamamtsu phototube. The first four panels show the energy spectra measured with sources: ^{133}Ba, ^{137}Cs, ^{60}C and Am-Be-Ni. The spectrum in the rightmost panel was measured in the reaction $^{12}C(p,p')^{12}C$ which produces a 15.1 MeV γ-ray from the direct decay of a 1^- state in $^{12}C^*$ to the ground state. The measurement was done at the INFN SUD Laboratory (Catania). The calibration of all the spectra has been done using only the ^{137}Cs and ^{60}Co lines. The spectra with sources has been acquired using a specially developed Voltage Divider powered at 800 V. The 15.1 MeV γ-rays spectrum was measured using the standard E1198-27 VD and a voltage of 500 V.

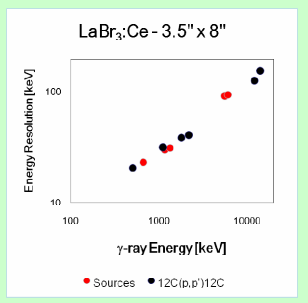


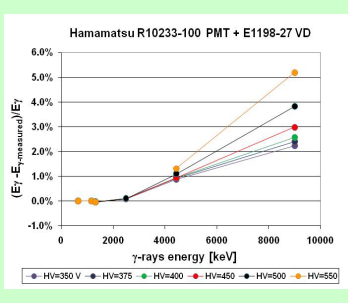


In the top plots the energy and time resolution measured using a 3.5"x8" LaBr3:Ce detector. The resolution values have been measured for different phototubes and for different voltages. The 5" PMT gives the best energy performances. Time resolution is strongly affected by the applied voltage.

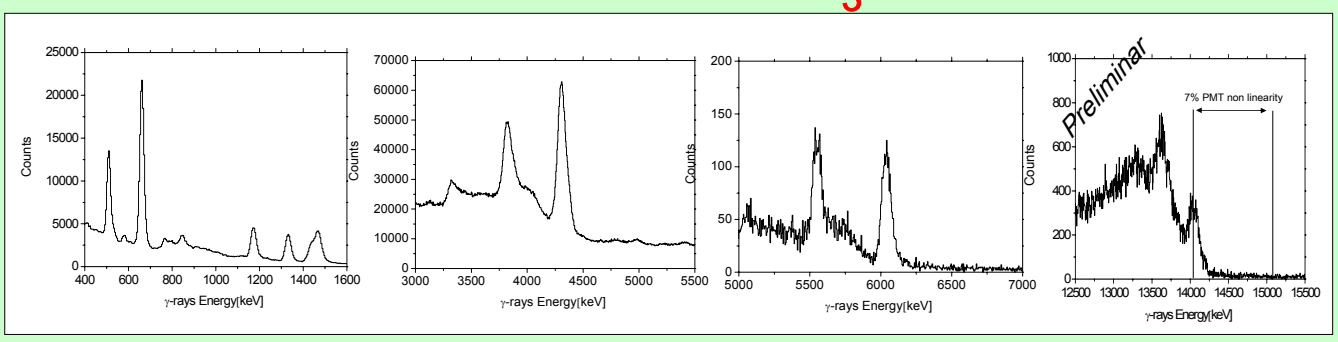
The plot on the leftmost panel displays the amplitude (in millivolt) of the 661.6 MeV line measured at the anode of R10233-100 PMT for different value of the applied voltage. The two lines refer to a new developed voltage divider (black line) and to the Hamamatsu E1198-27 (red line). The plot in the central panel shows the trend of the energy resolution (FWHM) measured between 300 keV and 15.1 MeV using R10233-100 PMT with E1198-27 VD (blue points) and the new developed VD (red points). The FWHM of the 15.1 MeV line is a little larger than expected but the data are still preliminary and the correction due to detector counting rate and PMT temperature have to be inserted. The plot on the right displays the measured linearity from 661.7 keV up to 9.89 MeV measured for the R10233 + E1198-27 Voltage Divider for different values of the applied voltages. As expected PMT linearity degrades as the voltage increases, a detailed study of linearity with the new developed VD is in progress.



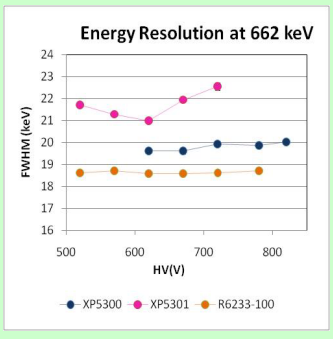


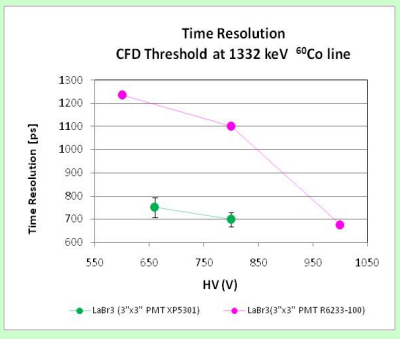


$LaBr_3$:Ce 3" x 3" - 350 cm^3



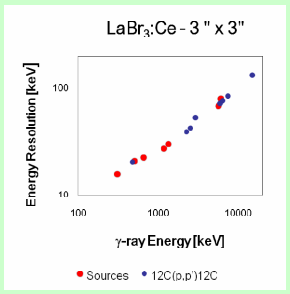
The upper plots show the energy spectra as was measured using a large volume 3" x 3" $LaBr_3$:Ce scintillator detector coupled with a XP5300 Photonis Phototube and a Voltage Divider VD202K/01 powered at 500 V. The first three panels of the plot show the energy spectra measured with sources: ^{137}Cs, ^{60}C and PuC. The spectrum in the right panel was measured in the reaction $^{12}C(p,p')^{12}C$ which produces a 15.1 MeV γ-ray from the direct decay of a 1^- state to the ground state. The measurement was done at the INFN SUD Laboratory (Catania). The calibration of all the spectra has been done using only the ^{137}Cs and ^{60}Co lines. The non linearity of the PMT is evident for high energy γ-rays.

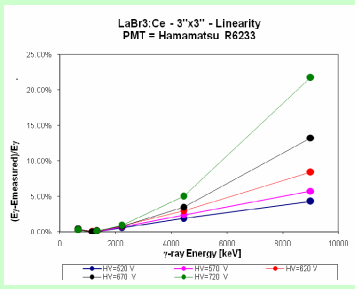


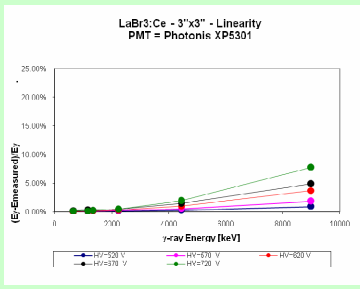


In the top plots the energy and time resolution measured using a 3"x3" LaBr3:Ce detector. The resolution values have been measured for different phototubes and for different high voltages. It is evident that the SBA photocathode of the R6233-100 gives a much better energy resolution and that the time resolution is affected by the high voltage which affects the risetime of the pulse.

The three plots on the right show i) the behavior of the energy resolution vs the energy of the incident γ-rays as was measured using a large volume 3" x 3" powered at 500 Volts. The $LaBr_3$:Ce scintillator detector was coupled with a XP5300 Photonis Phototube and a Voltage Divider VD202K/01. As expected in a log-log scale the data show a linear trend, ii) The PMT energy linearity plots. Two different PMTs, Photonis model XP5301 and Hamamatsu model 6233-100 have been used. As expected the linearity degrades increasing the high voltage of the PMT. The Hamamatsu PMT shows a much larger non linearity as compared to the Photonis one (the two plots have the same Y scale).







Conclusions:
The plots shown in this poster describe the response in terms of time, energy resolution and PMT linearity of large volume LaBr3:Ce crystals. Detector performances have been tested changing the PMT, Voltage Divider, the applied voltage and with gamma radiation ranging from 300 keV up to 15.1 MeV. The Hamamatsu PMTs with SBA photocathode in general provide better energy resolution but a much worser linearity. Time resolution, which is critical for gamma spectroscopy applications, depends on the applied voltage. Using standard passive voltage dividers, there is a tradeoff between time resolution and linearity. An especially developed Voltage Divider capable to extract a preamplified signal from the anode/dinode and a time signal from the anode is under tests. The results of the tests shows that these detectros can be successfully used in arrays for gamma spectroscopy.