# $LaBr_3(Ce)$ detector and PMT tests at IPN Orsay

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**Abstract**

By the end of 2010, the PARIS collaboration should decide on the composition and configuration of the calorimeter that will be part of the SPIRAL2 instrumentation. In order to do so, intense studies are under way on scintillators like $LaBr_3(Ce)$ in stand alone mode or coupled with CsI(Na) or NaI(Tl) crystals in a phoswich configuration. We present here the energy and time resolution results obtained with standard sources for three single $LaBr_3(Ce)$ crystals of different sizes, for a $LaBr_3(Ce)$+NaI(Tl) phoswich and a $LaBr_3(Ce)$+CsI(Na) phoswich.

## 1 Introduction

The main goal of these measurements is to investigate the alteration of the energy resolution of a $LaBr_3(Ce)$ crystal when optically coupled with another type of crystal, as the light collection is made only at one end of the phoswich and the characteristics of the crystal coupled with $LaBr_3(Ce)$ can play an important role in the energy/time resolution. We have also measured the energy and time resolution of single $LaBr_3(Ce)$ of different sizes. Additionally, we wanted to measure also the influence of PMT − crystal coupling and of the choice of digitizer (ADC or QDC) on the obtained resolution.

## 2 Energy resolution measurements

The standard sources used for the tests were $^{22}$Na, $^{60}$Co and $^{137}$Cs. In the case of the phoswich crystals, we have placed the sources on the side, on one extremity for the $LaBr_3(Ce)$ energy resolution measurement and on the other extremity (next to the phoswich − PMT connection) for the CsI(Na)/NaI(Tl) crystals. For one set of measurements with the phoswich crystals, the Cs source was collimated and placed at different distances on the side of the scintillators, in order to check the homogeneity of the crystals coupled with $LaBr_3(Ce)$.

In the following, we describe the scintillators and the PMTs used for these measurements, together with the electronic set-up.

### 2.1 Scintillators and PMTs description

Details on the scintillators and the PMTs used for the present study are presented in Tables 1 and 2. In the following, we refer to the crystals by using the names given in Table 1. The B380_2 has the same size as the $LaBr_3$(Ce) in the two phoswich and so it will be used for comparison.

Table 1: Description of the crystals used for the tests.

| Crystal name | Dimensions |
|---|---|
| B380_1 | Φ1"x1" |
| B380_2 | 1"x1"x2" |
| B380_3 | 2"x2"x4" |
| PNaI | B380: 1"x1"x2" |
| | NaI(Tl): 1"x1"x6" |
| PCsI | B380: 1"x1"x2" |
| | CsI(Na): 1"x1"x6" |

We have used 4 different cylindrical PM tubes: Photonis XP5300B, considered as reference and characterized by a very good quantum efficiency (36%), Photonis XP2282, 2" PMT Hamamantsu R2083, and an 1" Hamamatsu R7899 (not covering the full surface when in contact with any of the crystals).

Table 2: List of the PM Tubes used for the energy resolution measurements.

| **PMT** | **Dimensions** | **Sensitivity in blue ($\mu$A/lmF)** | **Dynode output** |
|---|---|---|---|
| **XP5300B** | 3" | 14.6 | 5 |
| **XP2282** | 2" | ¡9.0 | 8 |
| **R2083** | 2" | 10.5 | 7 |
| **R7899-01** | 1" | 10.2 | anode reading |

After the analysis of different measurements, we have realized that the Photonis XP2282 tube used had a very bad sensitivity in blue (with respect to the Photonis data sheet) that influenced the energy resolutions obtained. This is very likely because the PMT is quite old and it served in many experiments.

## 2.2 The electronic setup

We used standard NIM and CAMAC electronics. For each PMT, the divider was designed with an anode and a dynode output. The dynode signal was connected to a Cremat (Charge) Preamplifier CR-113 [2], 1.5mV/pC, and then to an ORTEC Amplifier 572 and an ORTEC ADC 811 for energy measurements. We selected a shaping time of 0.5 $\mu$s for measurements of the $LaBr_3$(Ce) crystal resolutions and of 3 $\mu$s for the measurement of the energy resolution of NaI(Tl) and CsI(Na) crystals.

The anode signal was connected to a Voltage Preamplifier with two outputs: one going to a ORTEC TFA 454 to start the gates for the coding in ADC/QDC and the other into a Lecroy QDC 2249A for charge integration. We have used the QDC for to purposes. The first is the comparison of the energy resolutions, obtained by using peak sensing and charge integration method; the second is the rejection of events where gamma-interactions are detected either in both $LaBr_3$(Ce) and NaI(Tl)/CsI(Na) crystals or in NaI(Tl)/CsI(Na) alone. Two gates where used for the signal integration: a short gate G1 (100 ns) dedicated to the $LaBr_3$(Ce) and a longer gate G2 (200 ns), delayed by 120 ns with respect to G1, to measure a possible contribution of the NaI(Tl)/CsI(Na) to the phoswich signal.

### 2.3 On energy resolution and homogeneity of the CsI(Na) and NaI(Tl) crystals

The energy resolution of the NaI(Tl)/CsI(Na) crystal associated with the $LaBr_3$(Ce) in the phoswich configuration is also a critical parameter to be considered. When putting the $^{137}$Cs source collimated on the side next to the connection with the PM tube, the energy resolution was 6.39 % for the NaI(Tl) crystal and 8.35 % for the CsI(Na) crystal. If we don't use the collimation, the measured energy resolution become 6.54 % for NaI(Tl) and 10.97 % for CsI(Na). The difference between the results with and without collimation in the case of CsI(Na) comes from the inhomogeneity of the CsI(Na) crystal that was measured to be of 25.4 % (the shift of the photopeak when moving longitudinally from an extremity to the other of the crystal). For the NaI(Tl) crystal, the inhomogeneity was measured to be 8.2 %.

### 2.4 Results

The raw data were analyzed with the ROOT package. The results are summarized in the table 3. We give in this table only the energy resolution with the ADC, as the results from ADC and QDC are compatible.

Table 3: $LaBr_3$(Ce) energy resolution $-\ \eta$(E), at 662 keV (%).

| | **XP5300B** | **XP2282** | **R2083** | **R7899** |
|---|---|---|---|---|
| **B380_1** | 3.09 | 3.95 | 3.38 | 3.38 |
| **B380_2** | 3.15 | 4.07 | 3.49 | 3.76 |
| **B380_3** | 3.04 | 4.98 | 4.03 | 6.9* |
| **PNaI** | 3.79 | 5.10 | 4.21 | 5.45 |
| **PCsI** | 4.51 | 6.19 | 4.91 | 7.19 |

**Not relevant: surface of the PMT is less than 1/4 of the crystal surface*

As one can see, the best results are obtained with the XP5300B PMT. This is not surprising because this PMT is one of the best existing on the market and suitable for these measurements. But these results should be taken only as reference and one should not expect to obtain these energy resolutions for the PARIS calorimeter.

Both XP2282 and R2083 are 2" diameter PM tubes but for the following discussions we'll only use the results obtained with R2083 for reasons specified earlier concerning XP2282. We compared the energy resolutions obtained using

R2083 with the reference ones (XP5300B) for all the crystals (excluding the case of B380_3 that is not fully covered by R2083). From table 4, second column, one can conclude that the measurements with one PMT can safely be compared with each other and that they reflect the crystal resolution.

If we compare now the results obtained with R7899 PMT with the reference ones (third column in table 4), it appears that there is a geometrical effect (the R7899 PMT does not cover the entire contact surface with the crystal) coupled with the presence of intermediate crystal (in the case of the phoswichs) that decreases the energy resolution between a single crystal and a phoswich. We see also a smaller ratio for the case of PCsI, compared with PNaI. The first value in this column is NR (not relevant) because the PMT has the same size as the crystal.

If we choose now to compare the energy resolutions of B380_2, PNaI and PCsI when measured with R7899 (this geometrical configuration is somehow similar to what PARIS might look like), we can see from the fourth column of table 4 the decrease in energy resolution when passing from single crystal to phoswich of 45 % for PNaI and of 91 % for PCsI.

Table 4: Comparison of different results listed in table 3.

| | ${\eta_{ref}}^*/\eta_{R2083}$ | $\eta_{ref}/\eta_{R7899}$ | $\eta_{B380\_2}/\eta_i$ *(with R7899)* |
|---|---|---|---|
| **B380_1** | 91.4 % | NR | – |
| **B380_2** | 90.3 % | 83.8 % | 1.0 |
| **B380_3** | NR** | NR | – |
| **PNaI** | 90.0 % | 69.5 % | 0.69 |
| **PCsI** | 91.8 % | 62.7 % | 0.52 |

* $\eta_{ref}$ *is the energy resolution obtained with XP5300B*
** *Not Relevant*

# 3 Time resolution measurements

For the time resolution measurements, we have used a different test bench. Its composition, the analysis procedure and the results will be presented here.

## 3.1 Scintillators and PMTs description

At the present time, we have results on time resolution only for the B380_1 and B380_3 crystals. We intend to extend the measurements to PNaI crystal. For these measurements, each crystal was connected to only one PMT: B380_1 with a Photonis XP20D0 PMT and B380_3 with a Photonis XP2282 PMT (different from the one used for the energy resolution measurements but from same generation).

### 3.2 The electronic setup

Each PMT divider had a dynode and an anode output. The dynodes were used for the energy information whilst the anodes were connected to a Constant Fraction Discriminator (Enertec 7174). From the discriminator, the logic signals of each crystal chain were taken to the start/stop inputs of an ORTEC TAC 567 module, for the time resolution measurement. The energy (from the dynodes) and the time signals were coded by an ORTEC ADC 811. The ADC gate was started by the coincidence between the two crystal chains provided by a Lecroy Coincidence Unit 625.

### 3.3 Analysis procedure

In order to obtain the intrinsic resolution of each crystal, we have measured coincidences between the two crystals using $^{22}$Na and $^{60}$Co collimated sources (to avoid backscattering events). By selecting one energy in one crystal and different energies in the second crystal, we could obtain the time resolution curve as a function of the energy for the second crystal. A quadratic function of the inverse of the energy was adjusted to the experimental data following the expression:

$$f(E) = \sqrt{a^2 + b^2/E} \tag{1}$$

assuming that the resolution goes as the square root of the energy. The coefficient $b$ is also given in the table 5. Using this parameter, the intrinsic time resolution can be deduce for a given energy. The $a$ coefficient is related to the time resolution of the partner detector at the selected energy.

### 3.4 Results

The intrinsic time resolution results are listed in table 5.

Table 5: $LaBr_3$(Ce) intrinsic time resolution (ps)

| | **@511 keV** (ps) | **@1173 keV** (ps) | **@1332 keV** (ps) | **b coef** (ps $\sqrt{keV}$) |
|---|---|---|---|---|
| **B380_1** | 208(9) | 137(6) | 129(5) | 4700(200) |
| **B380_3** | 499(35) | 329(23) | 309(22) | 11269(800) |

The result for B380_3 has to be further investigated, as the PMT used (XP2282) might not have (due to its age) a good quantum sensitivity and thus can give a worst time resolution than expected.

## 4 Conclusions

We have measured the energy resolution of 3 $LaBr_3$(Ce) crystals of different sizes and of 2 phoswich crystals that belong to the PARIS collaboration. These measurements were performed with different PMTs in order to determine the energy resolution decrease when the light is not entirely collected from the crystal. We have also measured the energy resolution of each crystal composing the two phoswichs. The time resolution for selected couples of crystal and PMT were also investigated.

By comparing the energy resolution results for B380_2, PNaI and PCsI, we see a decrease in the energy resolution when going from single crystal to phoswich crystal and that the NaI(Tl) phoswich has a better energy resolution that the CsI(Na) phoswich. The difference in energy resolution between PNaI and PCsI was also investigated and turned out to be due to the inhomogeneity of the long crystal attached behind $LaBr_3$(Ce). These inhomogeneities can go up to 24 % and, consequently, degrade $LaBr_3$(Ce) and NaI(Tl)/CsI(Na) crystal resolutions.

The time resolutions obtained for the B380_1 crystal are compatible with the ones published in literature [1]. We also intend to measure the time resolution using the Hammamatsu R2083 PMT.

We would like also to measure the time resolution of the PNaI phoswich with the same test bench and to see how much the time resolution is degraded when going from cylindrical PMTs to square PMTs.

Also, we plan to make energy resolution measurements with a Lecroy Oscilloscope 715 Zi for the 5 crystals that were tested. This is important to trigger the decision on the best electronic to be used with PARIS detector.

## References

[1] Moszynski et al. *Nuclear Instruments and Methodes A567*, page 31, 2006.

[2] www.cremat.com.