PARIS Prototype
SPIRAL2 PP : Detectors WG Report

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The objectives

The main goal was to determine what would be the optimized detector unit, which will fulfill the characteristics given by the PARIS physics case (12 SPIRAL2 LoI) for a gamma-ray calorimeter of a new generation. This detector can be used as a sum-energy detector (i.e. a calorimeter), a multiplicity filter of high resolution, as efficient for high-energy photons as low energy gamma rays. It needs to be:

- as efficient as possible in a wide energy range (from 50 keV to 40 MeV)
- with the best possible energy resolution for low energy gamma rays (~4% @ 662 keV)
- with a sub-nanosecond time resolution to discriminate gamma-rays against neutrons
- with a high granularity
- able to accept a high counting rate (50 kHz)

The prototype

After a complete investigation of different crystals coupled to different photodetectors such as APDs, the choice of the PARIS collaboration ended on a detector composed by cluster of nine units each in a cubic geometry. Each unit is made as a phoswich with a first shell of a new generation scintillator, the Lanthanum Bromide doped with a Cerium concentration of 5%, trade-named by Saint-Gobain factory $LaBr_3$(Ce), and a second shell composed of the standard crystal, the Sodium Iodide NaI(Tl). The innovative phoswich concept gives the great advantage to fulfill the PARIS specifications Physics case and is, in addition, more economic. A single unit is showed at the figure 1.

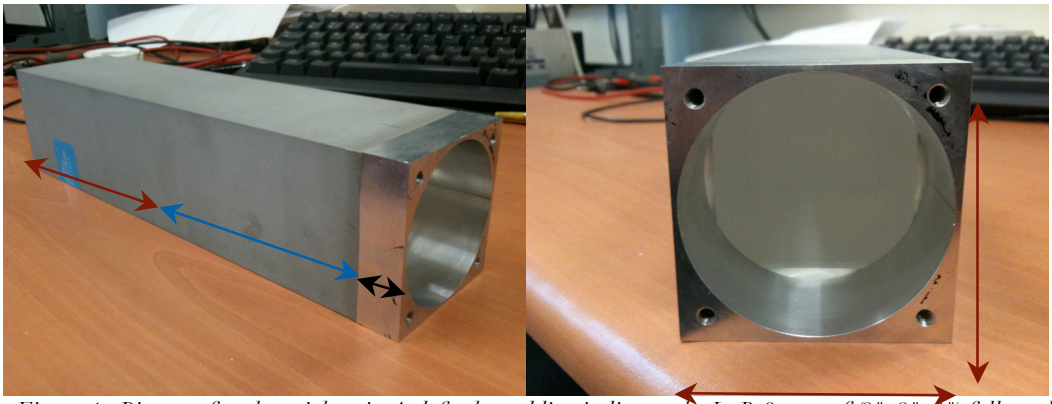

Figure 1 : Picture of a phoswich unit. At left, the red line indicates the LaBr3 part of (2"x2"x2") followed by the NaI part (2"x2"x6") symbolized in blue. The black line indicates a mechanical piece for the photo-tube stabilization. At the right side, this a view of the glass window at the back side of the unit.

The table below presents the status of the PARIS collaboration in terms of phoswich units : 2 units have been ordered by the IPHC Strasbourg and IPN Orsay, 3 by the Krakow group, 2 and 2 respectively by the TIFR and BARC laboratories in Mumbai. A full cluster of 9 units have been ordered by the collaboration in the frame of the PROVA project of the French ANR funding agency.

The given characteristics by St-Gobain factory for all delivered unit are listed in Appendix A. The energy resolution at 662 keV spreads from 4.1% to 4.8%.

Five units can be already tested in a cross-configuration. This will allow a first test for the add-back method and the results would be directly comparable with simulations.

Serial Number	M001 IPNO	M002 IPHC	A0-207 IFJ PAN	A0-302 IFJ PAN	A0-209 IFJ PAN	A1504 TIFR	A1505 TIFR	BARC	BARC	1 cluster PROVA

Serial Number	M001 IPNO	M002 IPHC	A0-207 IFJ PAN	A0-302 IFJ PAN	A0-209 IFJ PAN	A1504 TIFR	A1505 TIFR	BARC	BARC	1 cluster PROVA
Ordered	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Delivered	yes	yes	yes	yes	yes	yes	yes	very soon	very soon	may-june
Tested	yes	yes	yes	yes	yes	no	no			

Choice of the PM tube

A wide variety of different PM tubes have been tested. The full test is reported in Appendix B.

The PARIS collaboration fixes his choice on the R7723-100 PM tube from Hamamatsu. It has the advantage to have a really high photocathode efficiency of 35%, a very nice transit time of 1.2 ns and a rather low gain of 10^4. The characteristics of this phototube is given in Appendix C.

A full study of the linearity in high voltage and in energy has been checked as it is shown in figure 2.

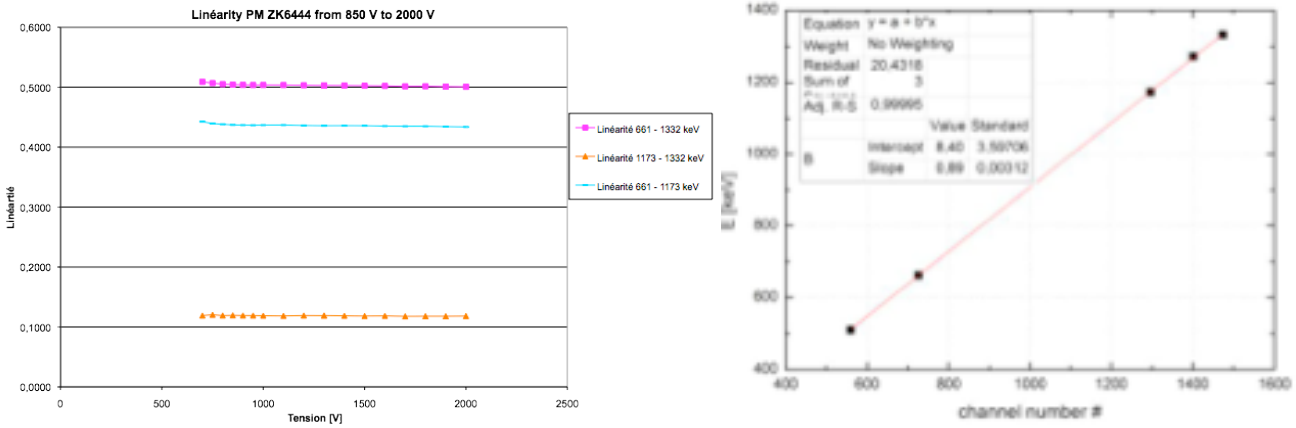

Figure 2 : Left) Linearity obtained with a XP3292B PM tube from 511 keV to 1.4 MeV. Right) Linearity test for the R7723-100 PM tube from 850 V to 2000 V.

To obtain such results a tapered configuration of a dedicated voltage divider has been proposed by Hamamatsu and then realized at the IPHC Strasbourg. The configuration ratio is :

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	P
Standard ratio	4	1	2	1	1	1	1	2	1	
Tapered ratio	6	1	2	1	1.2	1.5	2	4.5	2	

A R&D has been launched also on transistor based voltage dividers to improve the energy resolution.

A new PCB has been developed in order to fit in a "cluster" configuration (see figure 3). The anode and the 6th, 7th and 8th dynode outputs are possible.

To ensure the best possible optical coupling, a mechanical design has been developed as shown in figure 3. The mechanical design for the cluster configuration is developed by the IPN Orsay as shown at figure 3 (see I. Matea's talk : http://paris.ifj.edu.pl/Bormio2012/agenda_PARIS.htm).

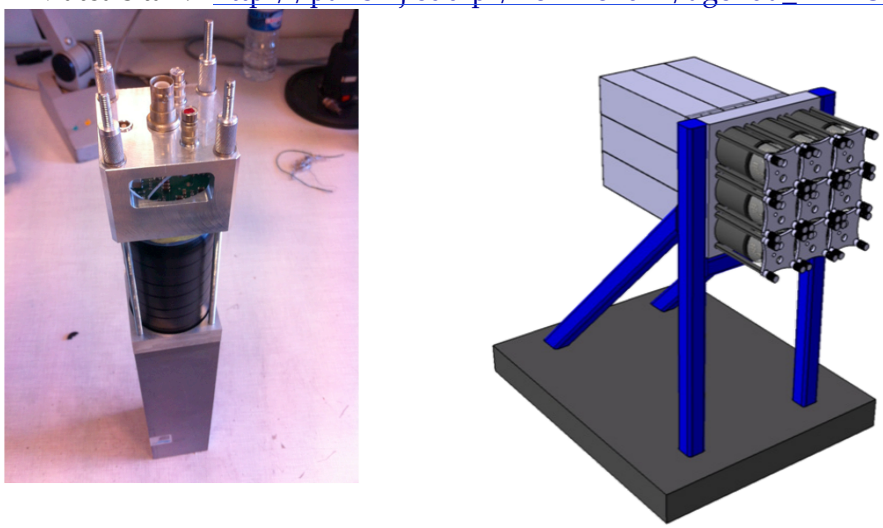

Figure 3 : Mechanical design for optical coupling between the R7723-100 PM tube (left side) and the cluster configuration (right side) developed at the IPN Orsay.

A meeting with Hamamatsu engineers has been held in March 2012. It turns out that the R7723-100 phototube is the best choice for the PARIS Physics case. An optimized value of the working gain has to be checked. The preliminary assumptions are the following:

- a light yield of 10000 photoelectrons/MeV (measured at IPN Orsay taking into account the photocathode efficiency) for the $LaBr_3$ part of the phoswich
- a good linearity in the energy range of 0,15 - 25 MeV
- a maximum counting rate at 50 kHz for a mean energy of 0,6 MeV
- a maximum peak current of 80 mA on the anode signal

The optimum gain value would be around 3.10^4. This has to be checked under beam irradiation especially the impact on the PARIS performances taking into account the add-back and a rather high-energy threshold in the NaI part.

Energy and Timing resolutions

A large set of measurements has been performed. We only show here the main items:

- we performed energy resolution measurement using analog and digital electronics : the results are comparable in terms of energy resolution. Using a 100 MHz sampling electronics coupled with a preamplifier (modified Cremat CR113) and a algorithm based on the Jordanov'one, we clearly distinguish the two components coming from the $LaBr_3$ and NaI parts as shown in figure 4. The energy resolution results are summarized in the table below. The PARIS measurements are slightly better than the Saint-Gobain specifications. It spreads from 4.0% to 4.7%. The measured resolutions for the A207 and A207 phoswiches have been ob-

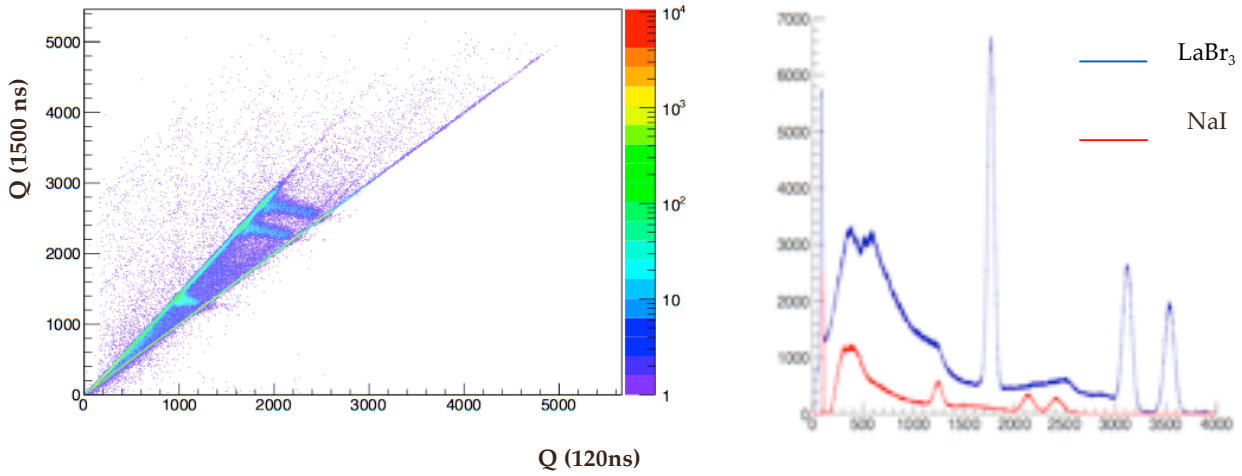

Figure 4 : Two components charge spectra (left side) and its projections after selecting each component (right side) using ¹³⁷Cs and ⁶⁰Co sources

- Some online tools have been developed in TUC acquisition system such as bi-dimensional spectra, improved resolution determination and calibration
- Energy's measurements have been also performed using a analog electronics, specially modified for the phoswich configuration by a Krakow-Milano groups (see M. Zieblinski and S. Brambila's talks : http://paris.ifj.edu.pl/Bormio2012/agenda_PARIS.htm). The figure 5 shows the discrimination between the $LaBr_3$ and the NaI components using the "Milano BaF2 board" and its projections using a of 6 MeV high energy gamma source.

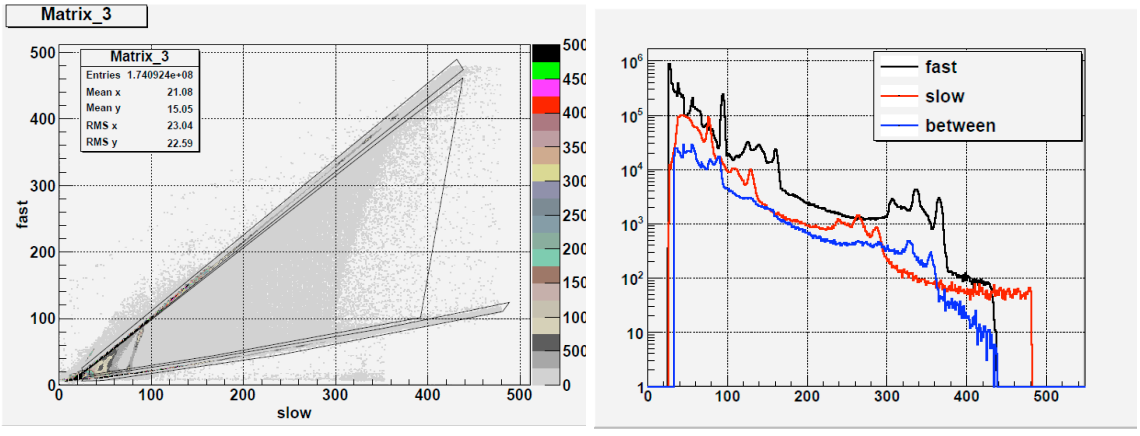

Figure 5 : Two components charge spectra (left side) and its projections after selecting each component (right side) using a 6 MeV gamma source.

- Timing resolution have been obtained using analog electronics by the IPNO group and is given as function of the photon energy at the figure 6. The FWHM intrinsic timing resolution for a phoswich unit is of 360 ps @ 1 MeV and has been obtained between a phoswich and a small $LaBr_3$ 1"x1"x2" crystal.

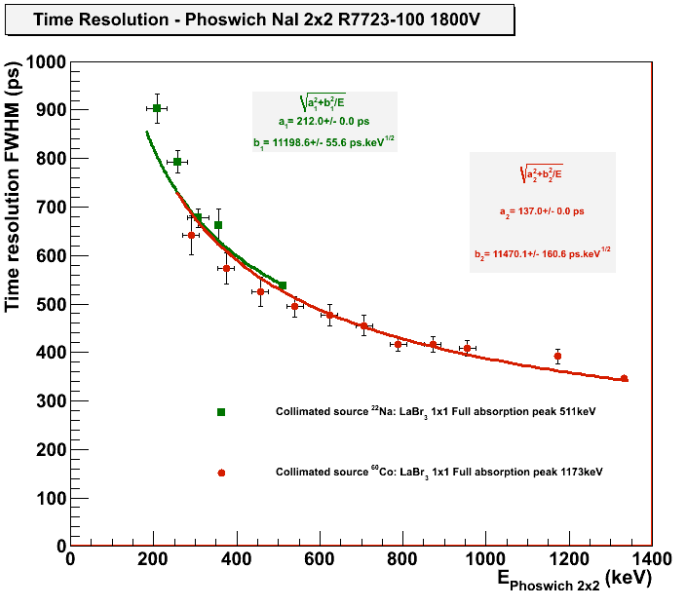

Figure 6 : Time resolution as function of gamma-rays energy. (Courtesy of Th. Zerguerras IPN Orsay).

- We also performed some preliminary results of timing measurement using a standard external CFD coupled with a digital TDC implemented in the FPGA. The sampling rate was 250 MHz and the treatment was based on the Bardelli et al. algorithm (see NIM A521 (2004) 480-492). We obtained a time resolution of 580 ps @ 1332 keV (see M. Rousseau's talk : http://paris.ifj.edu.pl/Bormio2012/agenda_PARIS.htm).
- A five channels preamplifier card has been developed equipped with CR11x CREMAT units, an attenuator from 0 to 7 db, and an offset correction at IPHC Strasbourg.

To summarize linearity, energy and time measurements, the table below shows the results obtained with the 5 tested phoswich units : 3 by the Krakow group, and 2 by the IPNO and IPHC groups. The two last ones will be tested by TIFR group very soon.

	Energy resolution (%) - PM R7723-100					Energy gated Timing Resolution (ps)	
	FWHM@662 keV			FWHM @1332 keV		FWHM @511 keV	FWHM @1.1-1.4 MeV
	LaBr3	NaI	St Gobain	LaBr3	NaI		
PWNaI A0_207	6.1 ET9815B		4.1	4.4 ET9815B		840	360
PWNaI A0_302	3.6		4.2	4.0		710	590

	Energy resolution (%) - PM R7723-100					Energy gated Timing Resolution (ps)	
PWNaI A0_209	6.8 ET9815B		4.3	4.6 ET9815B		700	400
PWNaI M001	4.3	6.5-7	4.5			389 @662	241 @1332
PWNaI M002	4.7	7.5-8	4.8	3.4	5.3		
PWNaI A1504			4.5				
PWNaI A1544			4.6				

Conclusions and perspectives

The final detector unit for the PARIS collaboration is fixed: it will be a phoswich configuration composed by a first layer of 2"x2"x2" $LaBr_3(Ce)$ crystal followed by a second layer of 2"x2"x6" NaI(Tl) crystal. Seven units have been delivered with five fully tested. Eleven other units have been ordered and should be delivered before end of year 2012.

Five phoswich crystals, constituting the PARIS SP2PP prototype, were fully tested in 3 laboratories: Strasbourg, Orsay and Krakow. The results, although are showing somewhat different characteristics for different crystals, are very positive. The PARIS SP2PP prototype gives satisfaction in terms of efficiency, time and energy resolutions and linearity to fulfill the specifications of the PARIS Physics cases.

Nine units will then be assembled in a 3x3 cluster configuration for the final prototype. This prototype will be tested under beam conditions with high-energy gamma rays, high intensity flux and neutron emission. A proposal for testing the prototype, given in appendix, has been already accepted by the IPN Orsay PAC. The test experiment should occur end of year 2012, probably with two clusters.

The collaboration for the PARIS Detector WG

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APPENDICES

- Saint-Gobain phoswich detector specifications

- PM tube comparison R7723-100 and ET9851B - Report from Krakow group - Sept 2011

- Tests Results for 2 large PW_NaI - Report from Krakow group - Sept 2011

- R7723-100 characteristics