PARIS — PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

PARIS detector – progress report

(15 September 2011)

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on behalf of the PARIS collaboration

LoI title: High-energy γ-rays as a probe of hot nuclei and reaction mechanisms

1. Introduction

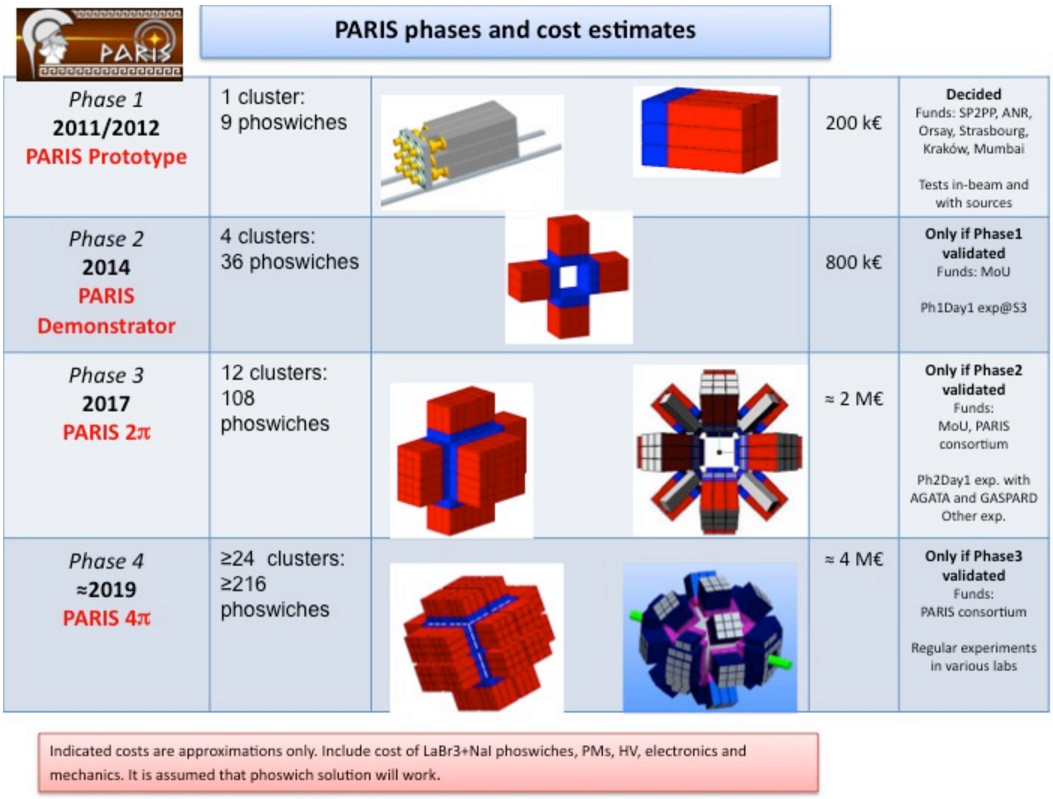

Fig. 1) Preliminary roadmap for the construction of PARIS array (the cost estimates are very tentative).

Following the recommendations of the SAC, the PARIS collaboration decided to concentrate on a detailed study of the cluster based structure of PARIS (which can be realized either in cube or semi-spherical geometry). The PARIS cluster will comprise nine phoswiches (2”x2”x2” LaBr3 optically

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coupled to 2”x2”x6” NaI and read out by a common PMT attached to the NaI). Providing that the phoswich concept proves to give satisfactory performance, a roadmap for construction of the PARIS array, as can be seen in Fig. 1, was agreed during the PARIS collaboration meeting in Strasbourg (January 2011). The general scenario assumes that the project will be phased, from Prototype, via Demonstrator, 2π array and finally PARIS 4π array. Each consecutive phase will be realized only if the preceding one was validated by test measurements. The indicated time-line is adjusted to the time-line of the SPIRAL2 project and proposed experiments. Of course, it will depend also (and mainly) on obtaining and sharing of capital investments and human resources between the collaborating parties of the PARIS project – this will be the subject of an MoU, which is presently under negotiation.

2. Reports from the PARIS Working Groups

a) Detector WG (coord.: O. Dorvaux)

The strategy decided during the PARIS collaboration meeting in January 2011 in Strasbourg, since the PARIS specifications were fulfilled using small phoswich detectors (1"x1x2" LaBr3:Ce and 1"x1"x6" NaI(Tl)), was to go first for a PARIS prototype being a cluster composed of 9 large phoswich detectors (2"x2"x2" LaBr3:Ce + 2"x2"x6" NaI(Tl), called later in this report PWNaI. It was planned that at the beginning of 2012 we will have 9 such phoswiches coupled with different PM tubes (one possible choice is Hamamatsu R7723-100) and associated with different electronics and DAQ systems.
Accordingly, the actions have been to order from Saint-Gobain: 1 PWNaI by the IPN Orsay (already delivered and tested); 1 PWNaI by the IPHC Strasbourg (delivered and tested); 3 PWNaIs by IFJ PAN Krakow, using in part SP2PP funds (2 delivered and tested, 1 has been damaged during the shipment and sent back to Saint-Gobain). In addition 4 PM tubes were ordered by the University of York, using the SP2PP funds, from the Advatech company - model ET9815B for a comparison with the R7723-100 Hamamatsu PM tube. The ET9851B PM tubes have been tested in IFJ PAN Krakow and in IPHC Strasbourg.
Full test reports are available at the PARIS web page; here are only the main results. This chapter reports only the tests of the 4 large PWNaI from the point of view of energy and timing resolutions and on the tests of the ET9851B PMT.
The linearity of the purchased phoswiches, coupled to different PMTs and voltage dividers, were found to be very good at least in the energy range covered by gamma-sources (see examples in Fig. 2).

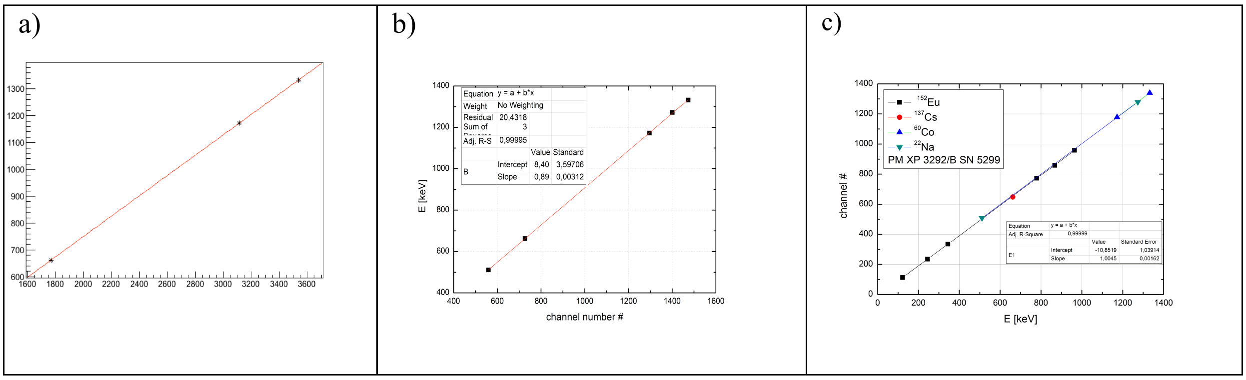

Fig. 2) Measured linearity: a) for IPNO PWNaI coupled to Hamamatsu R7723-100 PMT, b) for the A0_209 Krakow PWNaI coupled to XP3292B PMT; and for comparison c) for cubic 2”x2”x2 single LaBr3 crystal coupled to XP3292B PMT.

The spectra taken from phoswiches, when irradiating them with gamma-sources, could be decomposed on LaBr3 part and NaI either by simply shielding one of the part of the PWNaI and irradiating it from the side, of by more sophisticated digital signal processing, as is shown in Fig. 3. Those spectra provided information on the energy resolution of the LaBr3 as seen by PMT via 6” long NaI. The results are presented in the Table 1.

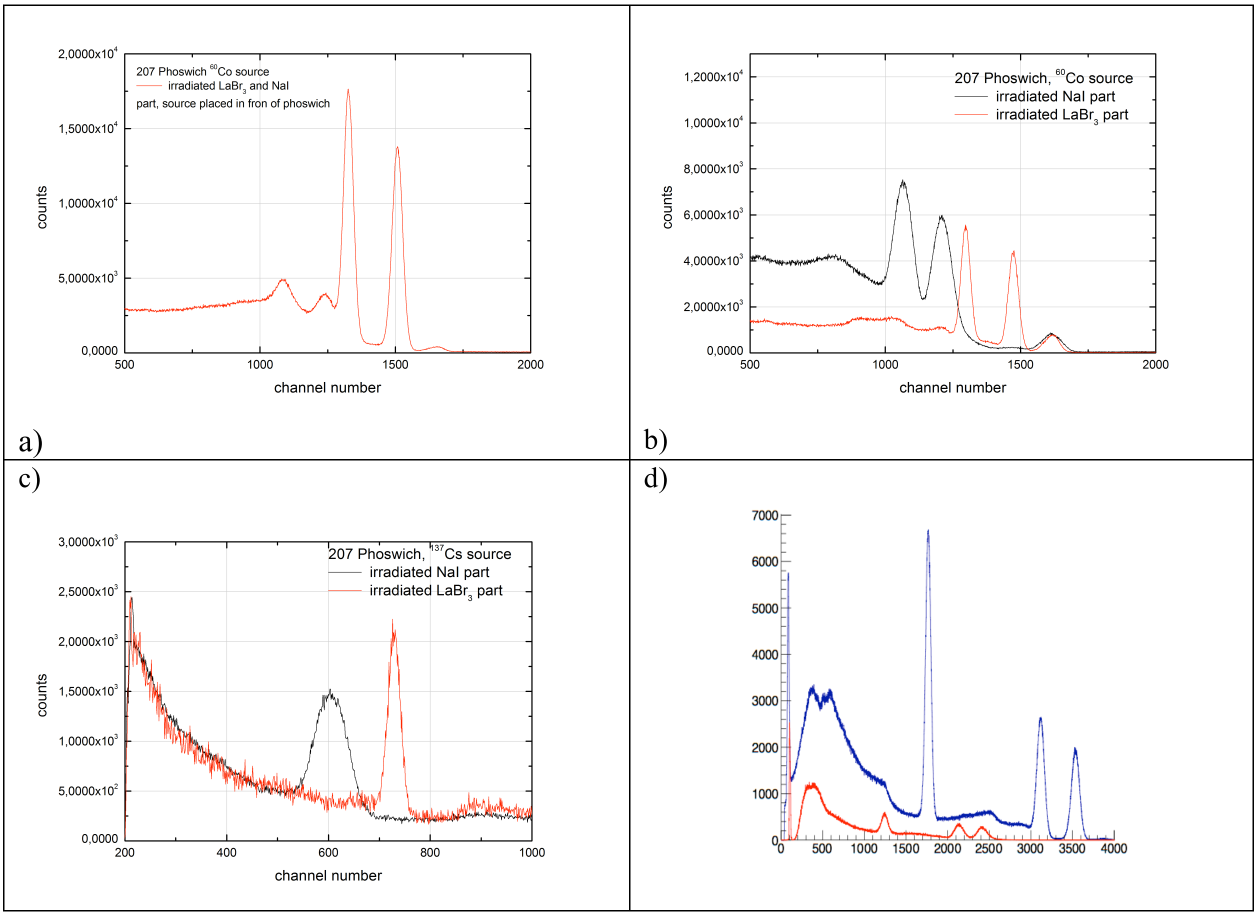

Fig. 3) a. Measured spectrum when phoswich (in this case IFJ PAN PWNaI) is irradiated with Co-source; b. Spectra corresponding to LaBr3 part and NaI part separated "mechanically" by irradiating side of the phoswich and shielding with lead brick either NaI part or LaBr3 part; c. same, bur for the Cs-source; d. NaI and LaBr3 spectra from the IPNO PWNaI irradiated simultaneously by both Co- and Cs sources, separated by digital pulse processing.

An example of timing resolution plot, obtained with standard analog electronics for IPNO PWNaI is shown in Fig. 4.

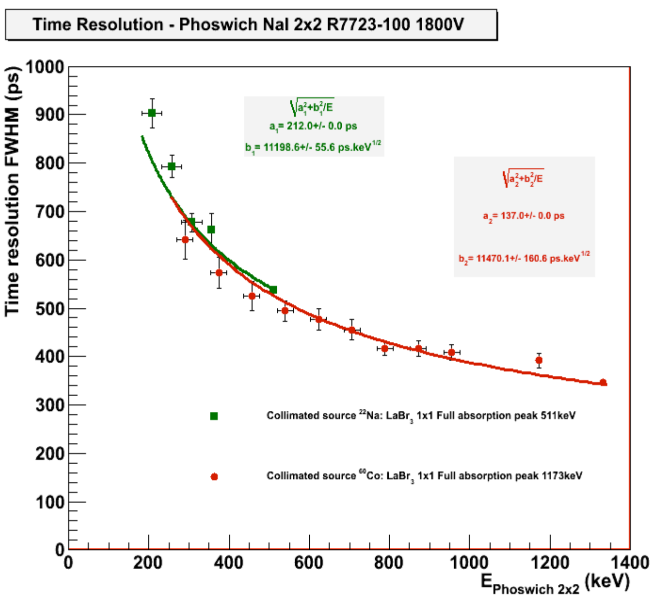

Fig. 4) Time resolution in ps for the PWNaI IPN Orsay detector

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Phoswich/ PMT	Energy resolution (%)					Energy Gated Timing Resolution (ps)		Linearity
	@662keV			@1332keV		@511keV	@1.1-1.4MeV	^{137}Cs, ^{60}Co
	St. Gobain	$LaBr_3$	NaI	$LaBr_3$	NaI			
IFJ PAN A0_207/ XP3292B	4.1	4.0	~11 side	2.9 side	6.0 side	710	530	Very good
IFJ PAN A0_209/ XP3292B	4.3	4.1	8.9 side	3.0 side	5.6 side	770	580	Very good
IPNO/ R7723-100	4.5	4.3	6.5-7 side	3.3		500	400	Very good
IPHC/ R7723-100	4.8	4.7	7.5-8	3.4	5.3			Very good
Single cubic 2"x2" Labr3/ XP3292B	*3.6*	*3.6*	*X*	*2.8*	*X*	*520*	*370*	*Very good*

Table 1. Main results for tested phoswiches in comparison with single cubic LaBr3 2"x2"x2".

All the performed so far tests of the LaBr3_NaI phoswiches concluded that:

• We clearly see a wide discrepancy in the quality of the crystals manufactured by Saint Gobain: from 4.1% to 4.8% energy resolution for the LaBr3 component @ 662 keV. It seems to be some certain "chronological effect" in the manufacture of the crystal, i.e. the latest the better, but this point has to be clarified with Saint Gobain. If so, the future parts of PARIS might indeed consists with phoswiches possessing relatively good 4% to 4.2% @ 662 keV energy resolution, thus fulfilling most of the Physics cases;

• We measure slightly better resolution for the LaBr3 component @ 662 keV than the St-Gobain specifications. The energy measurement with digital electronics is satisfactory and the timing measurement has been performed up to now only with analog electronics;

• The timing resolution fulfills the specifications and remains sub-nanosecond up to ~150 keV;

• The comparison tests between ET9851B PMT and R7723-100 PMT reveal that:

a) the ET9851B PMT has better timing resolution than the XP3292 PMT,

b) the ET9851B PMT has almost the same energy resolution as the R7723-100 PMT

However

a) The linearity of ET9851B PMT is not as good as expected compared to the R7723-100 PMT;

b) The gain of ET9851 PMT is ~10 times bigger than for the R7723-100 PMT which will limit the energy dynamic range;

c) The price of one ET9851 PMT is twice the price of one R7723-100 PMT;

d) Unless a real development will start for the ET9851 PMT, the R7723-100 PMT remains better when coupled with a PW NaI detector.

b) *Mechanics WG (coord.: S. Courtin)*

The recent work on the mechanics for the PARIS has been performed mainly in IPN Orsay. Efforts have been focused on the mounting of the detectors, i.e. coupling crystals (2''x2''x2'' LaBr3 + 2''x2''x6'' NaI) and PM tubes in single blocs that can be arranged later in cluster (PARIS Prototype) for a cubic or spherical geometry. The connecting piece has been machined (see Fig. 5a,), the prototype frame has been design and a mounting procedure has been established (Fig. 5b). The mounting procedure has been validated and will be used to mount further crystals (Fig 5c and 5d).

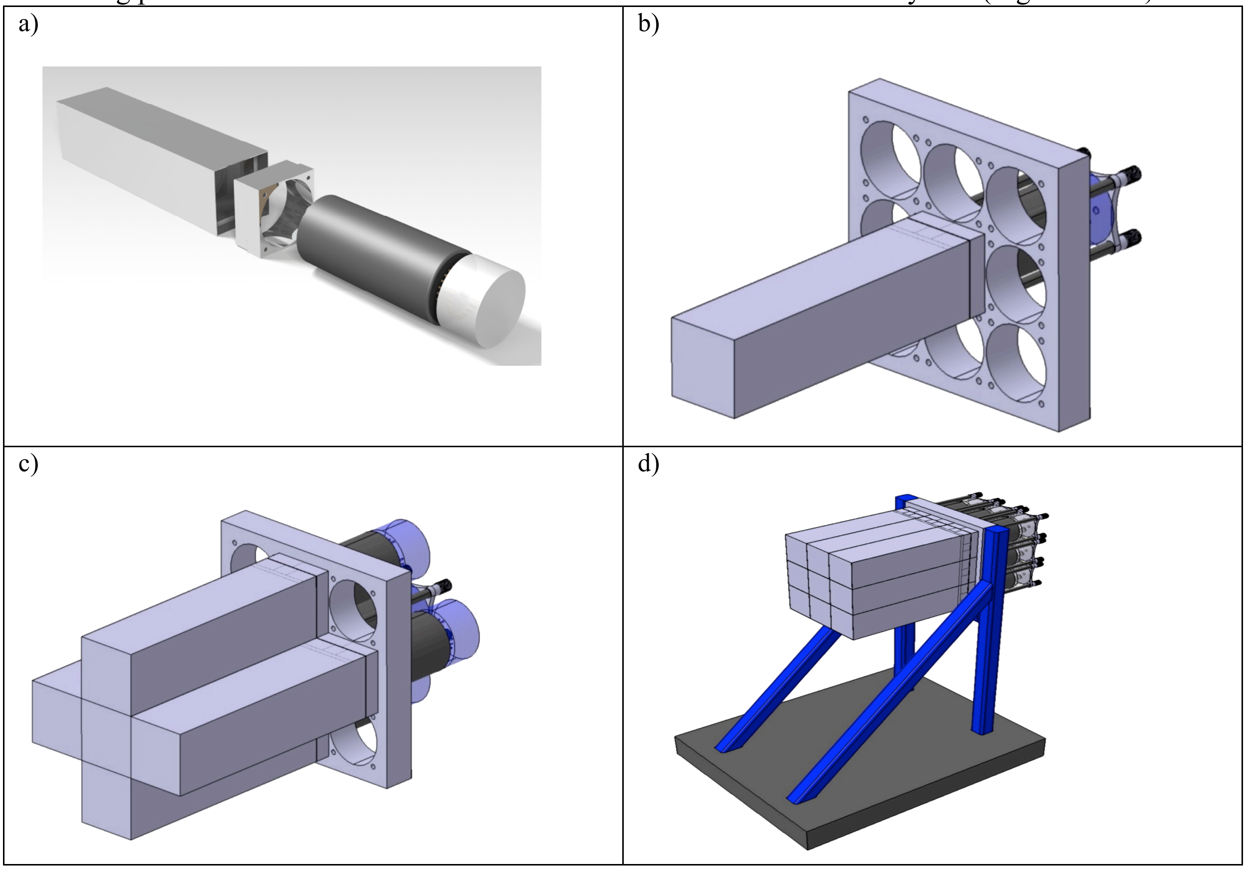

Fig. 5) Visualization of the stages for mounting the PARIS prototype: a) single block phoswich (LaBr3+NaI in aluminium can + connecting piece + PM); b) one block mounted in the frame (present status); c) 5 detectors (1 from Orsay, 1 from Strasbourg and 3 from Krakow) forming a cross-shape prototype - autumn 2011; d) full PARIS prototype (with 4 additional phoswiches from BARC and TIFR Mumbai) – beginning 2012.

c) Simulation WG (coord.: O. Stezowski)

For the last year, the work has been focused on one hand on developing more complex simulations, using realistic Physics generators, and on the other hand on studying advanced reconstruction algorithms.
In order to fulfil all the Physics cases, PARIS is made of clusters (3x3) that can be arranged in different configurations in quasi-cubic or in quasi-spherical shapes. Basic simulations of such shapes have been performed to characterize the arrays.
Reconstruction algorithms have been studying involving different kind of add-back procedures to determine the best-expected performances of the different configurations (see fig 1a,b). The clusters built by the algorithms are characterised by a quality factor giving fine controls to improve the performances (see fig 1c).

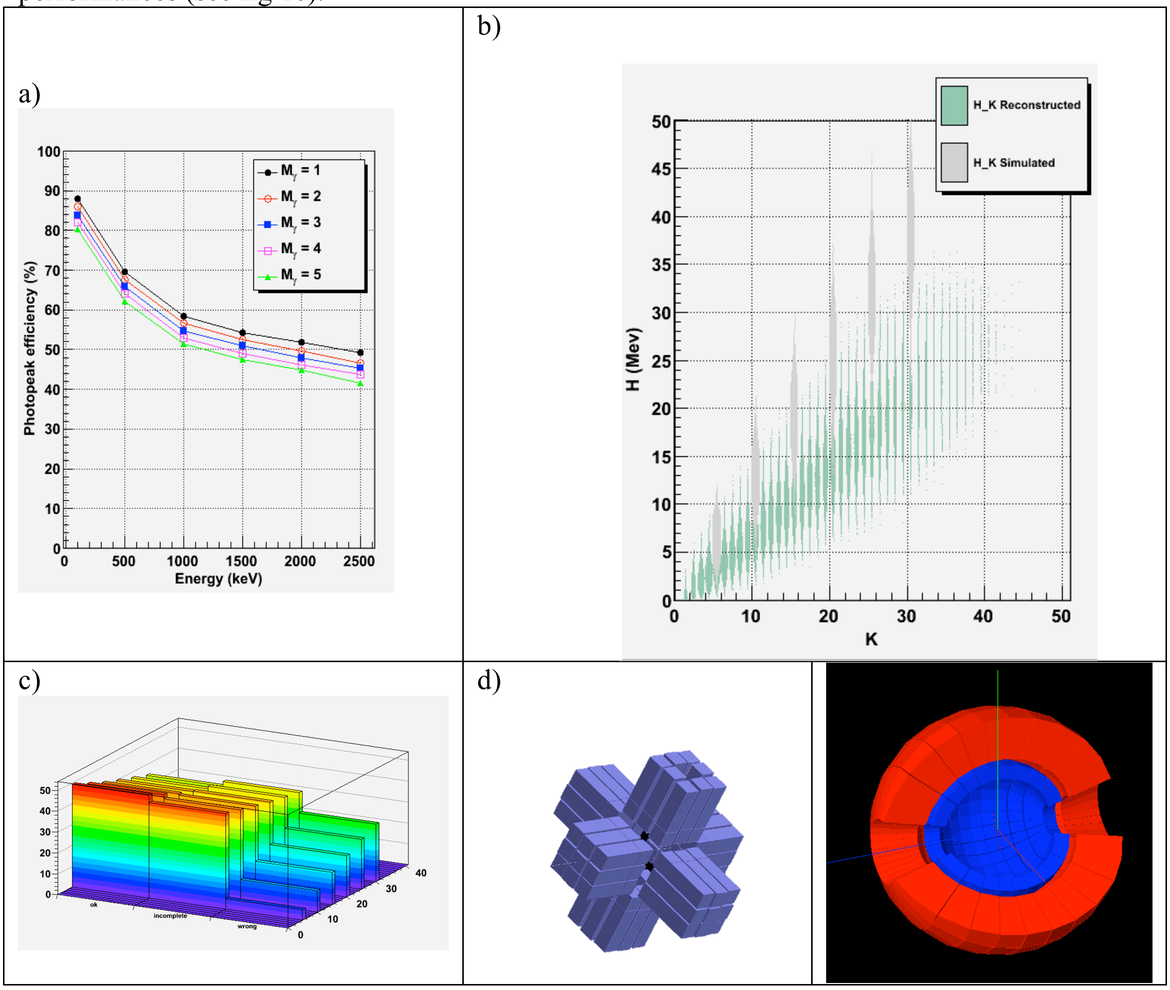

Fig. 6) [a]. Photopeak efficiency as function of energy at different multiplicities for an addback based on the closest neighbours involving the two layers. [b] Sum energy (H) as function of multiplicity (K) for simulated and reconstructed events. [c] Cluster quality as function of multiplicity. Ok means the cluster collects all the energy of an incoming g-ray, incomplete means part of its energy is missing. Wrong in case more than two g-rays are included in the cluster. [d] Geometries used for the different studies.

An interface to the MC CASCADE code has been completed in order to generate gamma and particle emissions in fusion-evaporation reactions. Fig. 7 shows the results of using such generator for the reaction 380 MeV ^{48}Ti impinging ^{40}Ca target in the case of full PARIS cube made of 200 phoswiches.

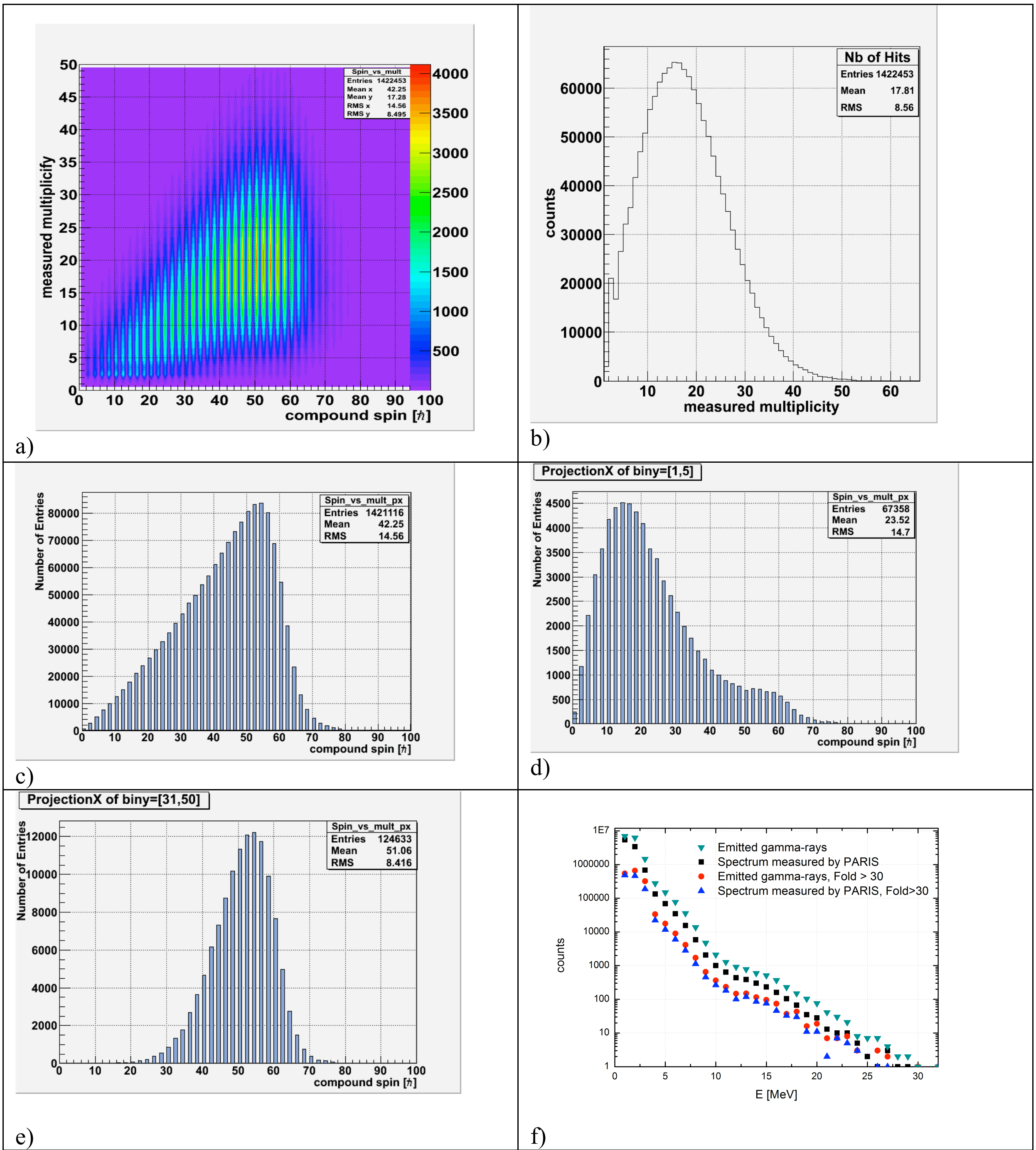

Fig.7) Simulation of the $^{48}Ti+^{40}Ca$ reaction at 380 MeV leading to ^{88}Mo compound nucleus: a) Measured multiplicity (fold) vs. spin; b) measured multiplicity (fold) of the low energy transitions along yrast line; c) a spin distribution of ^{88}Mo d) selection of the spins distribution, when gating on folds<6 (note that apart from low spins, also the high spins are selected – this is connected to the alpha-particle emission); e) selection of the spin distribution when gating on folds>30; e) emitted and measured spectra from the GDR gamma-decay – total and when selecting high-spins (folds>30).

With the first PARIS cluster available (prototype), the work will be focused now on comparing measurements and simulations to check, understand and optimise what could be the real performances of PARIS for gammas and neutrons. Fig. 8 shows such simulations for a cluster made of 9 phoswiches. When one is using the partial add-back procedure (i.e. requiring always a signal from LaBr3 to be present, for example to have better timing), the simulated energy resolution is quite close to that for single LaBr3 detectors, thus fulfilling requirements of most of the PARIS physics cases. But of course this is related to the decreased overall efficiency. The best efficiency can be achieved for such a physics cases, where the very good energy (and time) resolution is not very much important.

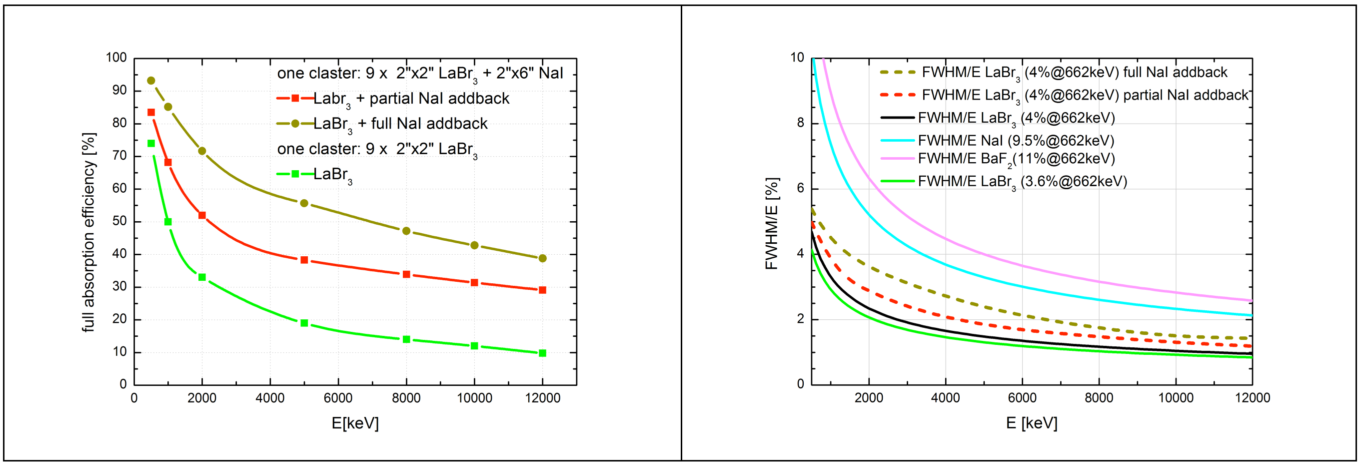

Fig.8) Left: Simulated relative (i.e. when gamma rays were shining only on the central detector of the cluster) photo-peak efficiency for one cluster made of 9 phoswiches after a full add-back procedure and a partial add-back without including events having deposit only in NaI. For comparison the efficiency for a case of a cluster made only with 9 LaBr3 2"x2" crystals. Right: Simulated energy resolution for a cluster made of 9 LaBr3 crystals (with 3.6% and 4.0% resolution at 661 keV), cluster made of 9 NaI crystals and the resolution resulting from the addback (full and partial). For comparison - energy resolution of large BaF2 crystals from the HECTOR array.

Very soon, more and more realistic physics generators are going to be produced to cover the different PARIS Physics cases and thus to prepare the first campaign. This includes the impact of radioactive background due to exotic beams in case of SPIRAL2 experiments. As well, the PARIS simulation package will be extended to allow coupling with other arrays (GASPARD, AGATA, NEDA and SHOGUN).

d) *Electronics WG (coord.: P. Bednarczyk)*

During 2011 the signals from single LaBr3 and phoswich (LaBr3_NaI) were readout using analogue and digital electronics. Such measurements were performed mainly at IPHC Strasbourg, but recently also in IPN Orsay and IFJ PAN Krakow.

It turned out that convoluted pulses from a phoswich detector irradiated with a source can be fully resolved by using two independent analogue QDCs gated with a short ~150ns and a long ~1μs gates. In the same time the phoswich pulses were sampled with CAEN V1751 digitizer working at 1 and 2 Gsample/s frequencies; TNT2 and DT5 digital cards developed by the IPHC electronics group were also applied. The offline pulse shape analysis showed that the standard Jordanov's trapezoid filter provides a gamma energy determination with an acceptable resolution.

A new data acquisition system in IFJ PAN enables simultaneous analogue and digital processing of phoswich signals. This DAQ is based on a VME data bus and runs under especially developed Kmax software that is a common project with Univ. of Milan. Standard CAEN QDCs serve for energy determination, whereas the STRUCK SIS3320 digitizer is used for the pulses sampling at 250 MHz up to 1 GHz frequency. The system will be used to optimize the pulse processing algorithms for PARIS phoswich detectors.

The GANIL and IFJ PAN engineers have advanced the common development of a general-purpose digital card for GANIL based experiments – NUMEXO2. Such a card is being considered to be used with EXOGAM2, NEDA and PARIS detectors. The NUMEXO2 card is a hybrid unit that will contain an experiment-dedicated digitizer, Global Trigger and Synchronisation interface (GTS) and a PPC for slow control and data readout. In particular, an implementation of the GTS interface in the NUMEXO2 VIRTEX 5 FPGA is currently tested.

5. Conclusions

In conclusion, it has been shown that the phoswich is a viable solution for the elements of the eventual PARIS calorimeter, in terms of it meeting the requirements for energy and timing resolution. The next step is to explore the performance of a cluster of nine phoswich detectors and this phase has already begun with five detectors delivered and a further four on order. In-beam testing of this cluster will proceed in the coming year. The next phase will be a demonstrator of four clusters each of nine phoswich detectors. At our meeting in September 2011, we have established the framework for the next stage through discussion of the form of an MoU, which we hope to have received sufficient signatures by the end of 2011.