PASPAG-SEE

PHOSWICH SCINTILLATOR ASSEMBLIES AND THEIR APPLICATIONS IN THE SIMULTANEOUS DETECTION OF PARTICLE AND GAMMA RADIATION – PASPAG
&
R&D ON NEW SECONDARY ELECTRON EMISSION MATERIALS – SEE

Contact: Olof.Tengblad@csic.es & P.Boutachkov@gsi.de

Keywords:
Scintillators, Phoswich, New-materials, Digital-electronics, DAQ, Gamma & Particle Detection, Secondary Electron Emission materials

Budget estimate: ***1.300.000 €***

The aim of: PASPAG – SEE

Using the R&D and KnowHow of the PARIS and CALIFA collaborations obtained within the INDESYS and GANAS projects the PASPAG-SEE aims for

- Simultaneous detection of Gamma and Particle Radiation by the use of new scintillator materials combined with the phoswich technique.
- Digital electronic and DAQ with improved throughput and more effective storage will be developed.
- R&D on new Secondary Electron Emission (SEE) materials will be performed in order to develop thin detectors for Low-Energy beam.
- The JRA aims for cost effective, reduced systems in size and complexity that can be used at several facilities.

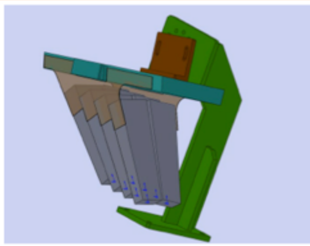
Paris – Califa @ IFJ

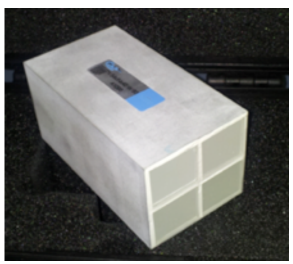
- Newly constructed cyclotron (IBA Proteus C-235).
- First experiment in hall!
- **Proton beam energies 70-230 MeV**, 0.7% resolution. < 1nA intensity.

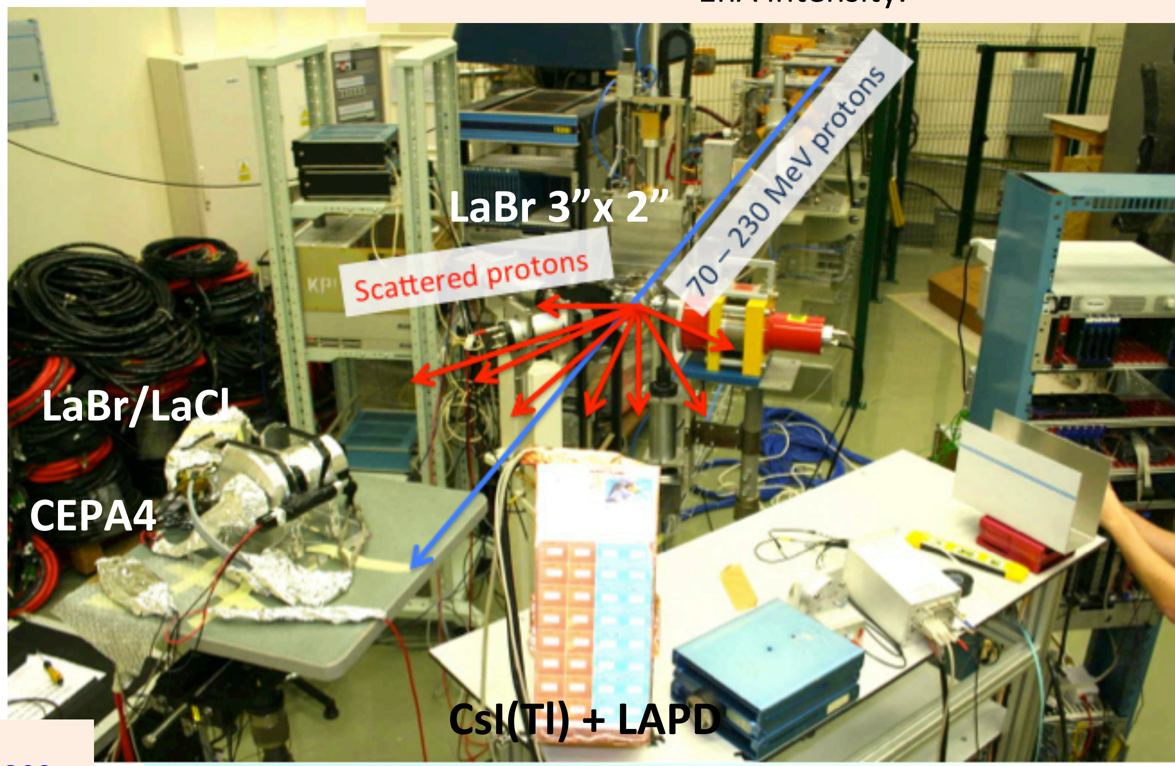
Different aspects tested on the same time

- Scintillator materials/sizes/segmentation
- Sensor: PM-tubes and LAPD
- Temp regulated PReAmp
- Electronics: Analogue, Digital,
- Pulse Shape Identification

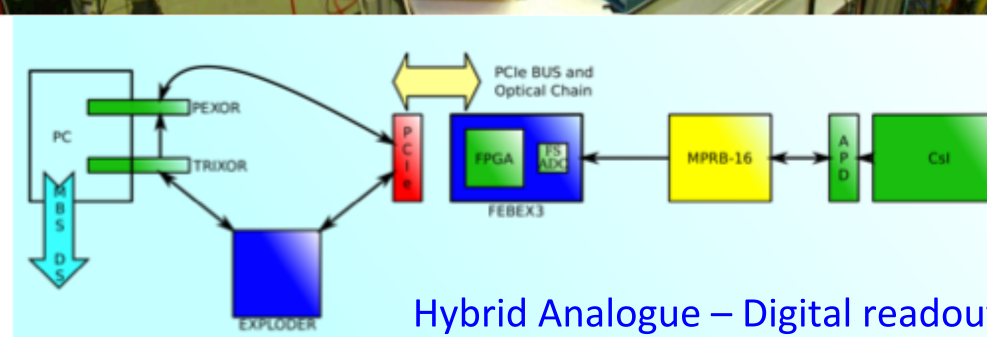
CALIFA petalo
64 CsI(Tl) +
LAPD





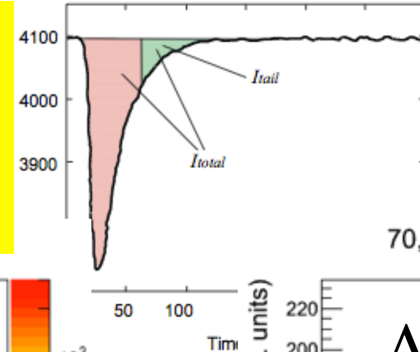


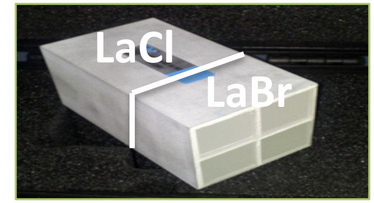
- **CEPA4** $LaBr_3$-$LaCl_3$ phoswich 4 detectors close packed in an Al (1mm) case
- Each detector is 40 + 60 mm long. The entrance window: 27 x 27 mm^2
- Readout: 4 Hamamatsu PM Tubes
- A DSSD detector (16x16) at the entrance face
- A VME CAEN Flash ADC (V1742) to digitize the signals



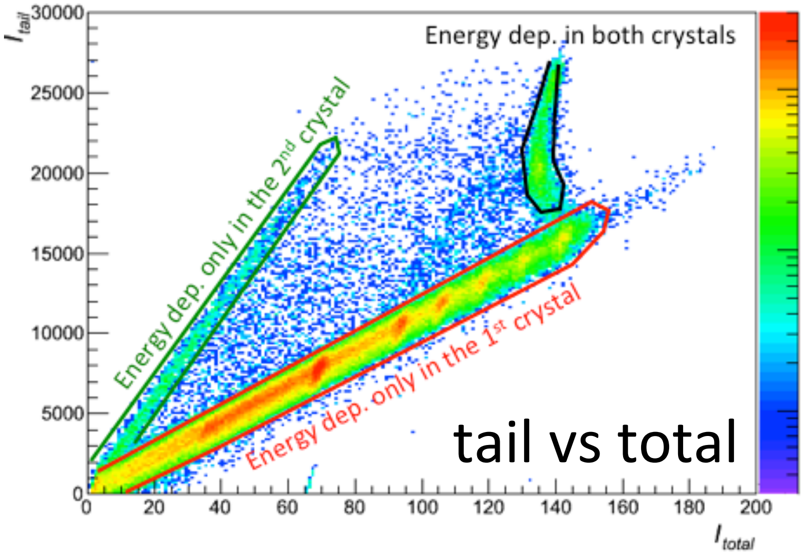
Pulse Shape Analysis

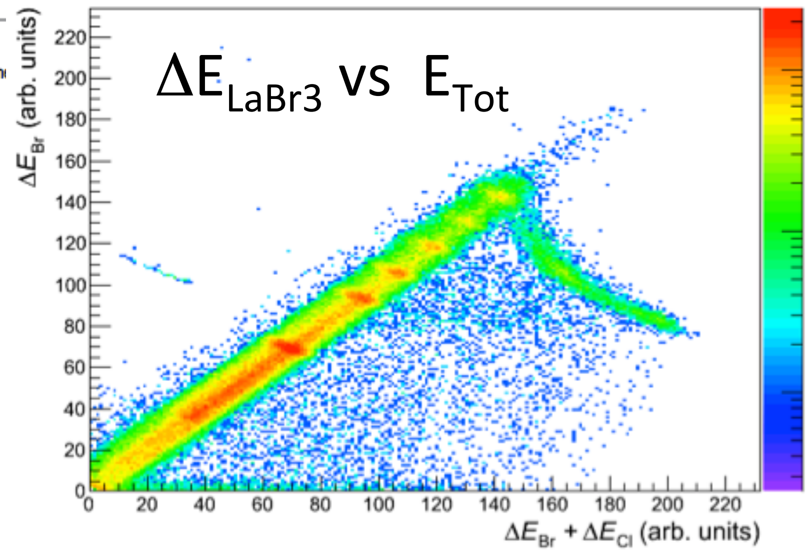
LaBr/LaCl Phoswich



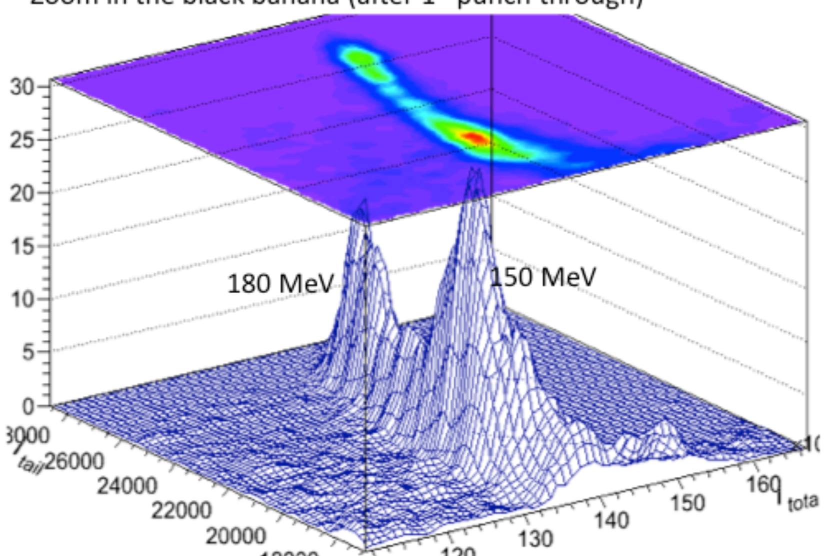


70, 90, 100, 110, 120, 130, 150, and 180 MeV

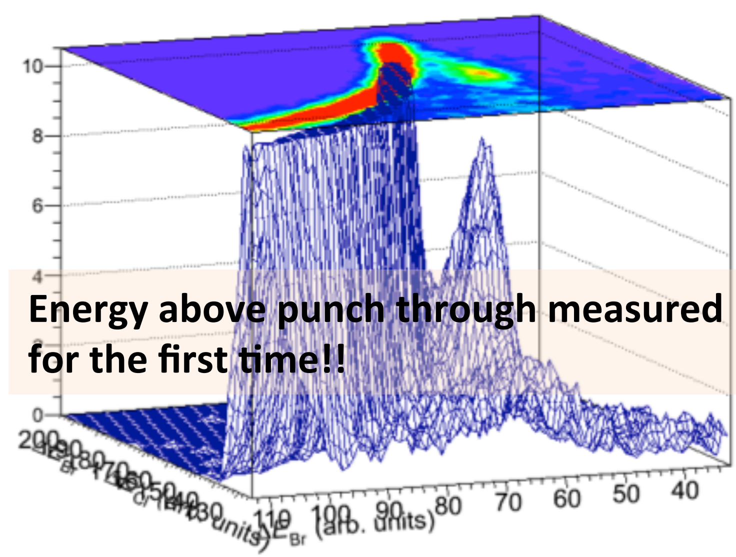




Zoom in the black banana (after 1st punch through)



220 MeV



WP1a New Scintillator Materials

In the last 10-15 years a large number of new high light-yield scintillator crystals have been discovered: Lanthanum Halides $LaBr_3$:Ce and $LaCl_3$:Ce, were already the target of an intense R&D activity within the JRA ENSAR-INDESYS project and the NuPNet GANAS project. → PARIS, CALIFA

- **Large number of brand new scintillator materials:**
  - **Recently available** — **$CeBr_3$, SrI_2, CLICK**
  - **near future** — **GYGAG, CLLB, and CLLC.**

UNIQUE FEATURES, WHICH SHOULD BE ACCURATELY TESTED FOR THE DEVELOPMENT OF THE FUTURE GAMMA RAY DETECTORS.

- **$CeBr_3$,** energy resolution slightly worse than that of $LaBr_3$:Ce but exhibit no internal radiation,
- **SrI_2** crystals have better energy resolution than $LaBr_3$ (2.7% at ^{137}Cs) they are brighter and more proportional even though they are slow and they suffer from strong self absorption, the
- **CLICK** crystal have an energy resolution of 4% at 661 keV but have high cross section for neutrons and PSA techniques can easily identify gamma, slow and fast neutron events and measure the neutron kinetic energy.
- **GYGAG** detector, which is a **CERAMIC MATERIAL** and there are new organic plastic scintillators are expected to have an energy resolution comparable to that of LaBr3:Ce.

ALL THESE BRAND NEW SCINTILLATOR MATERIALS NEED AN INTENSE R&D ACTIVITY TO BE FULLY UNDERSTOOD AND CHARACTERIZED.

→ **SCINTILLATION LIGHT RANGING [YELLOW – BLUE]**

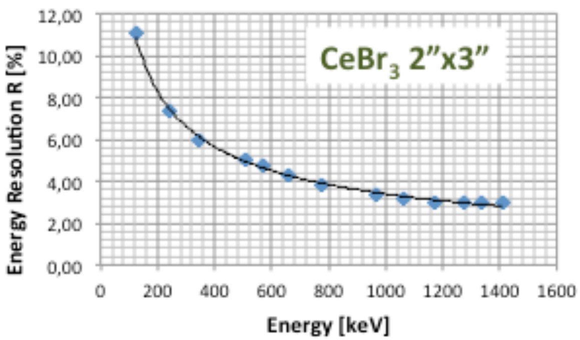
→ **NEED NEW HIGH PERFORMING PHOTO-SENSOR (SDD, SIPM, SBA-UBA-PMT..)**

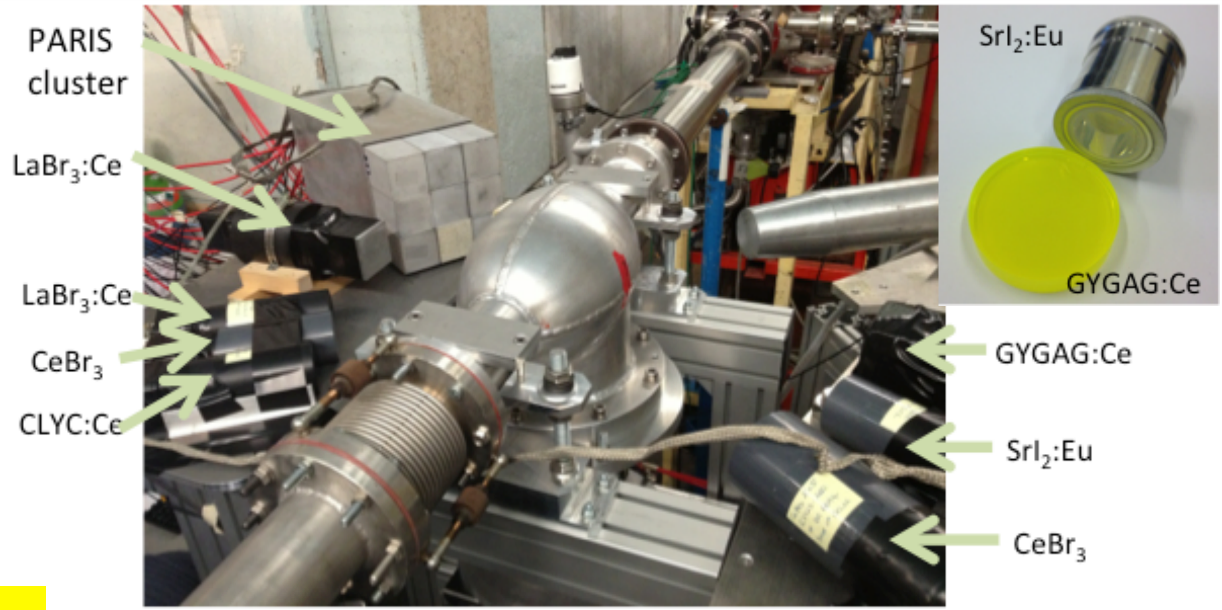
→ **NEW OPTIMIZED ELECTRONIC MUST BE DEVELOPED.**

These high light-yield materials could also provide good position sensitivity within continuous crystals that could be used to tackle the Doppler Broadening effect in basic research and be useful in several application as for example in the fields of homeland security, medical-imaging or radiotherapy dosimetry

Material characterization

New Scintillator materials have been tested with **gamma rays up to 22 MeV** during the in-beam testing of cluster for the PARIS detector demonstrator, at the end of May 2013 @ IPNO tandem





Fast rise time (for gamma)
- **Few ns (using quartz window PMT)**

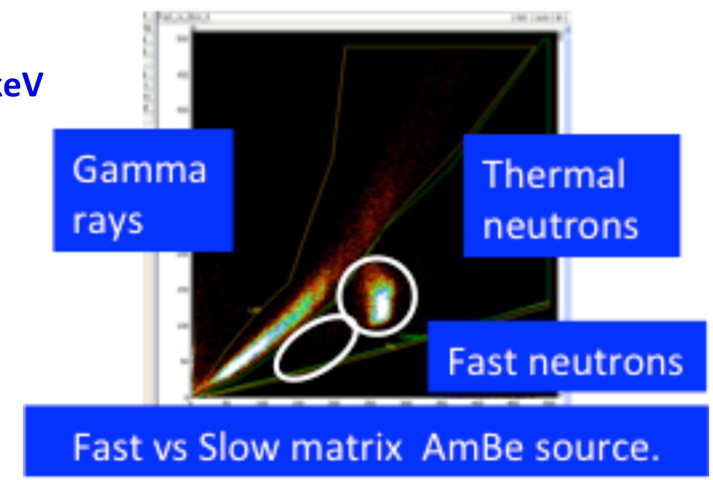
Good energy resolution
- **FWHM < 5% at 661 keV**

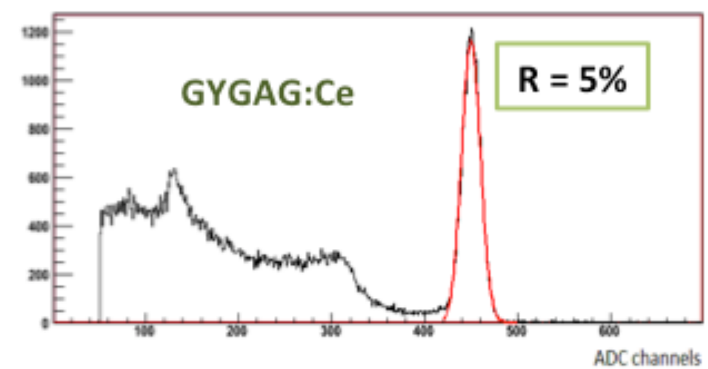
High sensitivity on thermal neutrons
- **^{6}Li enrichment is possible**

High sensitivity on fast neutrons

$^{35}Cl + n \Rightarrow {}^{35}S + p$ cross sections ≈ 200 mb

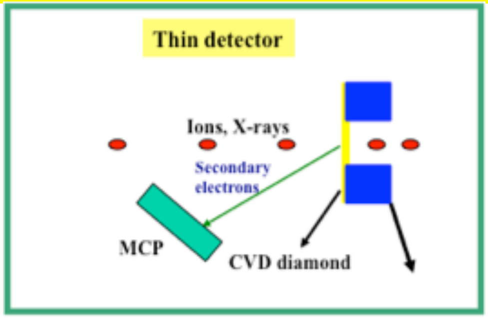
CLYC:Ce

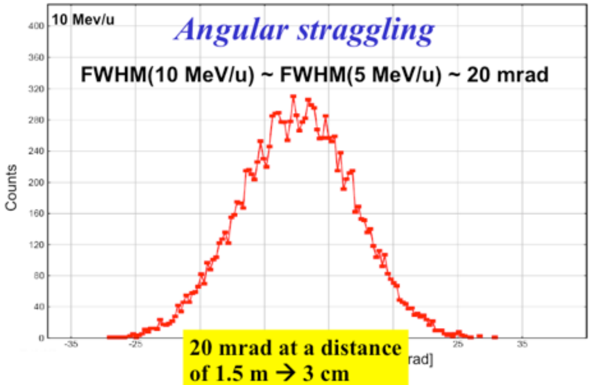




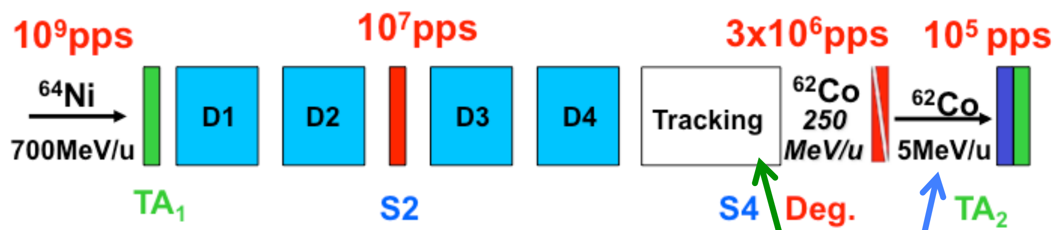
Real alternatives to $LaBr_3$:Ce for nuclear physics applications

WP1b Secondary Electron Emission Nanomaterials and Radiation Detectors





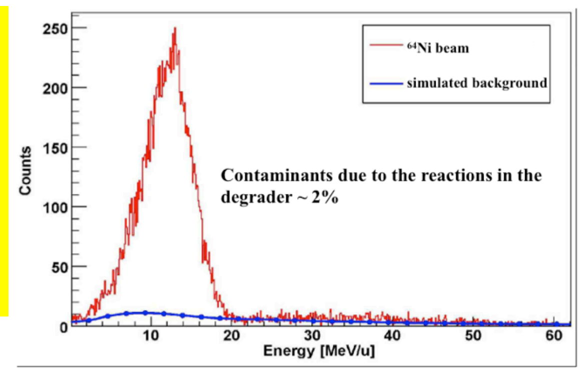
Slowed down beams projects @ FRS



- Track the trajectory before and after slowing down
- ID energy particles before the secondary target

Present Status

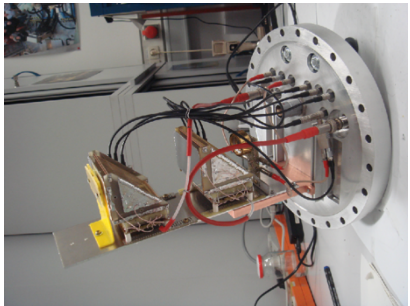
Energy spread after slowing down to 10 MeV/u is 8 MeV/u.
On the limit, need R&D



Estimated upper limit for the Doppler shift due to energy+angular straggling

E=10 MeV/u L=1.5 m

- Scintillator, 100 micron — $dE_\gamma / E_\gamma = 0.02$
- Diamond, 40 micron, no energy loss information — $dE_\gamma / E_\gamma = 0.05$
- **Secondary Electron Detectors, 150 ps time resolution** — $dE_\gamma / E_\gamma = 0.0075$
- Si, 40 micron, 100ps time resolution, energy loss added back — $dE_\gamma / E_\gamma = 0.007$



WP2 – Signal Processing

During the development of new Phoswich detectors the most promising results had been achieved using scintillator combinations with the High Resolution Material LaBr suggested for a series of new instruments like PARIS, CALIFA and SHOGUN.

- **Fully digital data acquisition systems** → provide the best separation of Phoswich signals and best energy resolution especially for charged particles passing through the material layers.

- Due to the fast emission of LaBr the only way to reduce the amount of data is a **digital pre-processing of the data already in the frontend**. Commercial systems on the market do neither provide the needed firmware nor sufficient access to the Hardware resources to allow for a fast and effective development.

- **Algorithms** now developed in the Framework of the GANAS & PARIS Projects have to be adapted to **higher clock frequencies and to run in real time**.

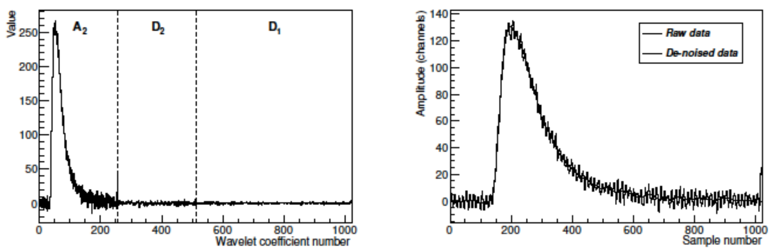
- **New algorithms** → developed first on the CPU based platforms → **transformed to run on FPGA**

- **Data reduction** → down to the essential numbers the user needs for calibrations, and data analysis. Essentially the ideal digitizers should behave like a MCA with additional features like trigger handling data monitoring and data checking (**time and location stamp**).

→ This would allow for a variable scaling in such system useful in small lab applications as well as in large-scale detector arrays

Digitized Pulse handling

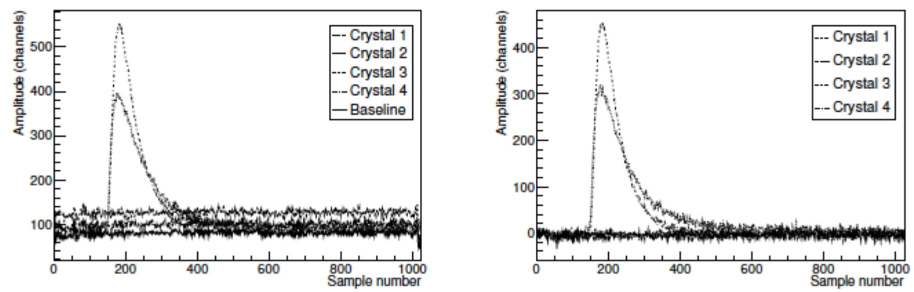
Wavelets for noise reduction



(a) Two level discrete wavelet transform coefficients.

(b) Noise reduction using wavelets.

Base line subtraction using neighbouring channels

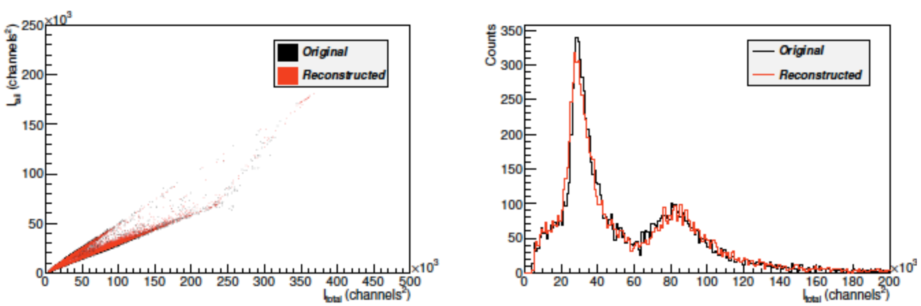


(a) Raw data and baseline.

(b) After baseline subtraction.

1) Wavelets for noise reduction
2) Base line subtraction using neighbouring channels
3) Correlation pattern recognition → Decomposition of traces LaBr3 / LaCl3 part
4) Data reduction

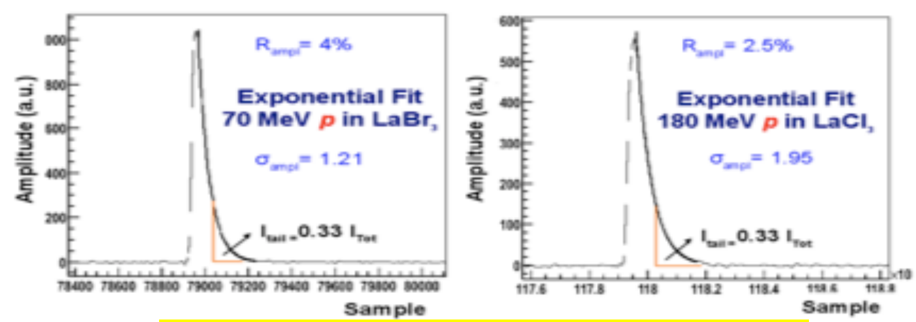
Correlation pattern recognition



(a) I_{tail} versus I_{total}

(b) I_{total}

Data reduction



→ Input to Geant 4 simulation

RPID – A new digital particle identification algorithm for CsI(Tl) scintillators

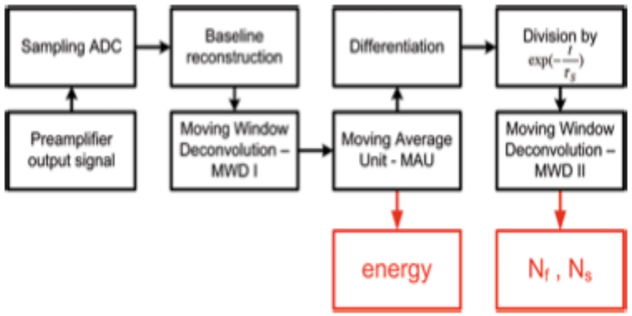


Fig. 1. schematic description of the RPID: the energy is determined after the first deconvolution, the RPID evaluation after the second. Further explanations are given in the text.

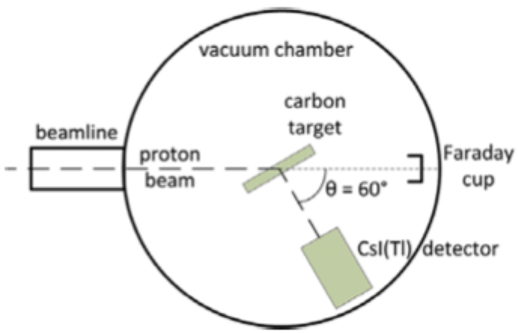
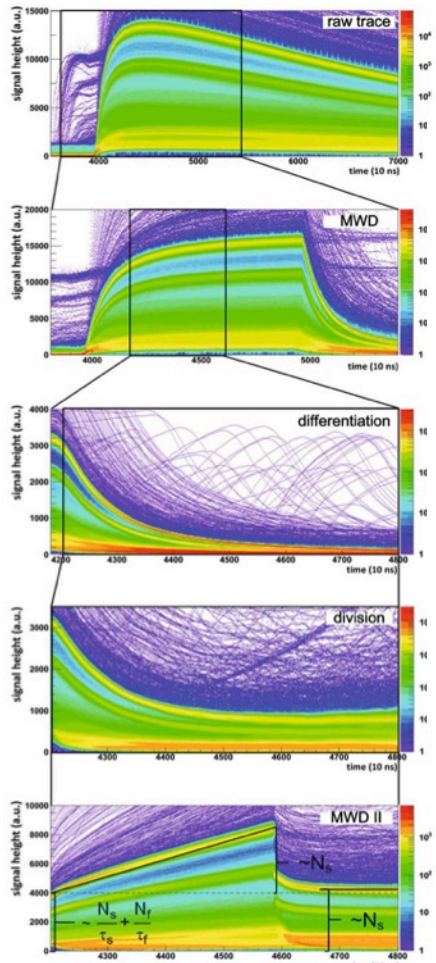


Fig. 4. Schematic drawing of the detector setup at the MLL.



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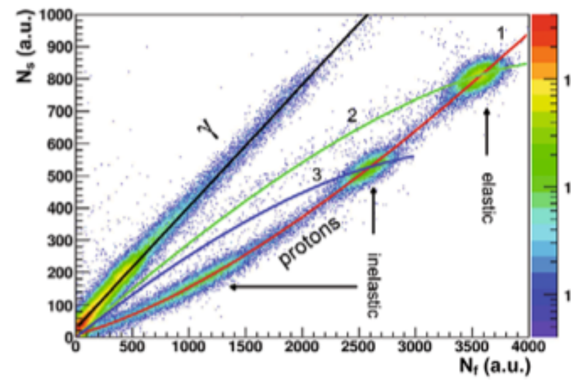
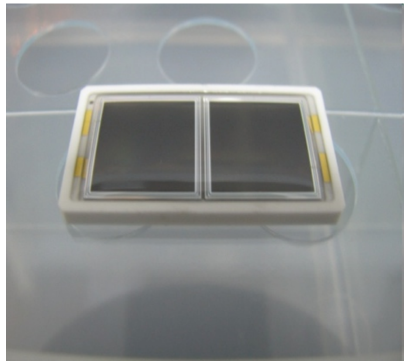


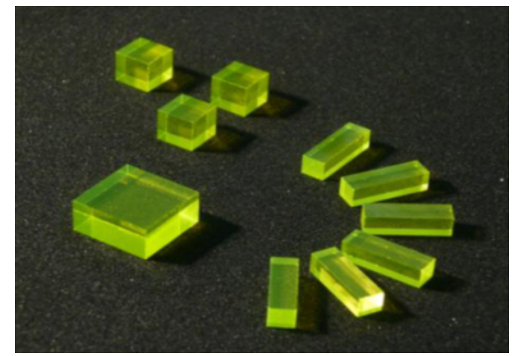
Fig. 5. First result of the *Reconstructive Particle Identification Algorithm (RPID)*. Photons and protons are well separated also for low energies. The red line (1) is fitted to the proton line and based on this fit, the green (2) and blue (3) lines are calculated as a function of scattered protons of two different energies that have not been stopped completely in one crystal.

WP3 - Hybrid Array: GAGG +CsI(Tl) + APD + Low interaction material housing



Test of new materials Ce:GAGG

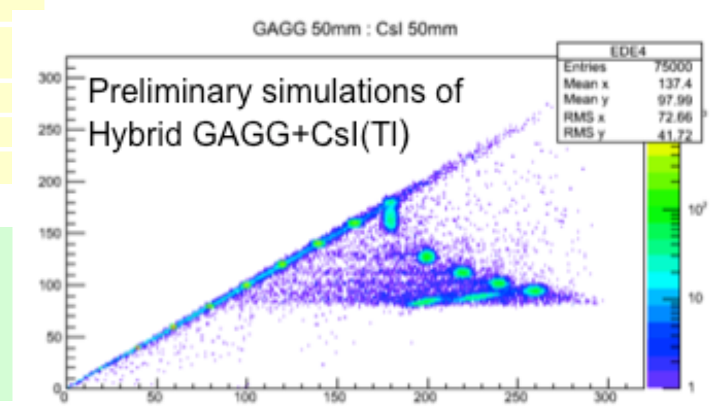
First samples ordered to Furukawa CO
Tests coupled with LAAPDs
Eventual extension to other photosensors



Physical and Scintillation Properties

Scintillators	$Ce:Gd_3Al_2Ga_3O_{12}$ (Ce:GAGG)	$Ce:Lu_{1.8}Y_{0.2}SiO_5$ (Ce:LYSO)	$Bi_4Ge_3O_{12}$ (BGO)	$Ce:LaBr_3$
Density (g/cm³)	**6.63**	7.1	7.13	5.08
Light yield (photon/MeV)	**60,000**	34,000	8,000	75,000
Decay time (ns)	**88 (91%) 258 (9%)**	40	300	30
Peak emission (nm)	**520**	420	480	375
Energy resolution (%@662keV)	**5.2** (5x5x5mm³ with APD)	10	12	2.6
Hygroscopicity	**No**	No	No	Yes
Cleavage	**No**	No	No	No
Melting point (℃)	**1,850**	2,150	1,050	783

- Construction of medium size arrays
- Test with high energy gamma (ELI) and proton (Krakov)
- Prototype evaluation



Idea: Mount as Phoswich detector with CsI(Tl) & coupled to LAAPD

WP4: Towards applications

With and without Magnetic field

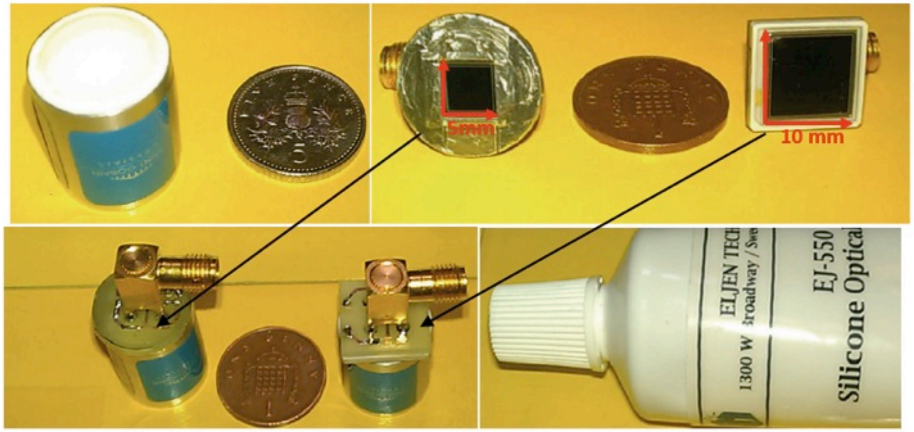


Fig1: LaBr$_3$(Ce) detector and the 5 x 5 mm and 10 x 10 mm APD sensors used for measurements.

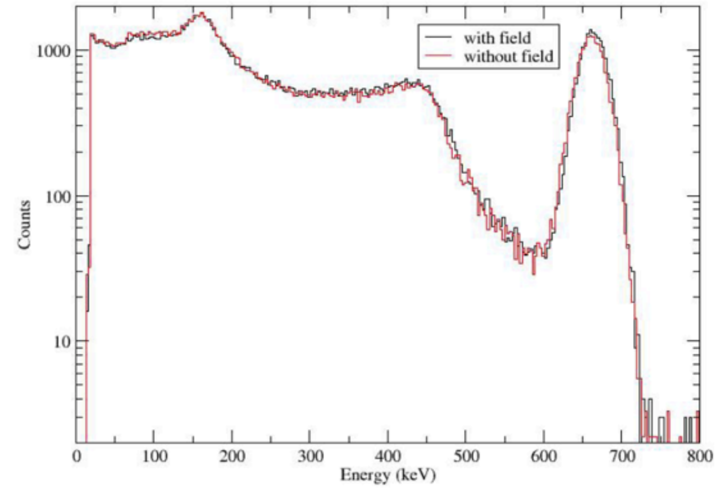
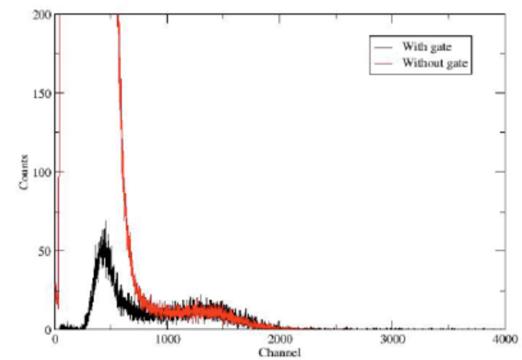


Figure 6: The 3-T MRI magnet at the York Neuroimaging Centre. The detectors are placed on the side of circular cage shown in the centre of the magnet. The cables from the detectors can be seen stretching along the bed.

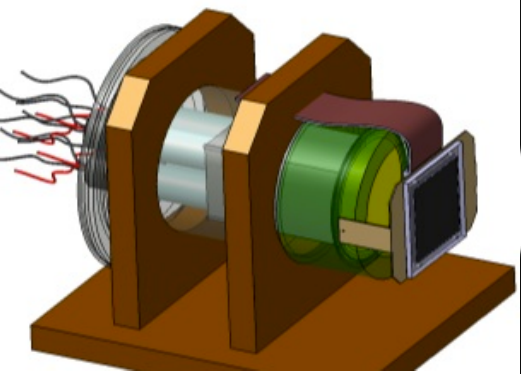


Noise reduction by Coincidence between 2 sensors

MEDICAL APPLICATIONS Planned test run in Sept. 2013

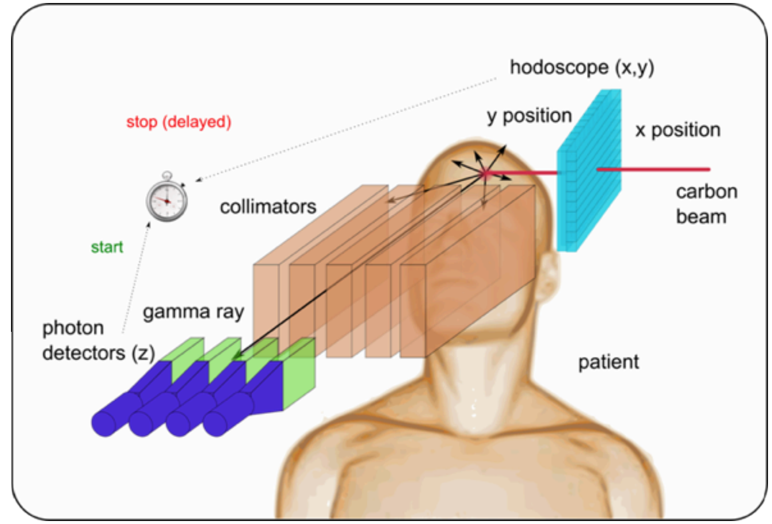
- Hadrontherapy: the detection of nuclear reaction products (e.g. protons and γ-rays) resulting from the interaction of a ^{12}C beam with the tissue provides relevant information that can be used for the verification of the delivered dose.

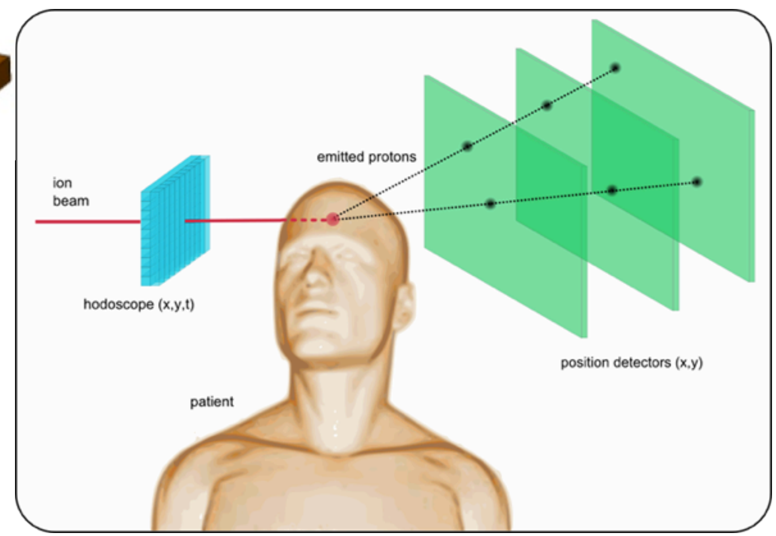
- CEPA4: good energy res
protons produced in the
for instance, ^{12}C ions at se



- DSSD in front of CEF
determination of the angi
protons.

- Applications in dosimetry using the spatial distribution and energy spectrum of protons and γ-rays. Verification of physical models used in MC simulations for hadrontherapy (GATE). To be used at HIT (Heidelberg) in the near future.





Figs. from Prof. Joseph Remillieux

Summary

WP1a – Phoswich

Material Characterization
- Treatment
- Test set-up
- Optical absorption/emission spectra

Sensor – combinations
- SiPM (time) combined APD (energy)
- CCDD position sensitivity
- Gain stabilization

System integration

WP1b – SEE

CVD – diamond & Nano materials
- Time resolution
- Position resolution

→ Energy loss detectors for low energy beams

WP2 – Signal Processing

Electronics
- Fast scintillators
- 10x more data → Deadtime free
- Combining different Light output
- Front end integration
- Table top

Process- handling
- Data reduction
- p, γ, n, separation
- Isotope identification

WP3 - Hybrid Array
- Merging of PW prototypes
- Different segmentations
- Tracking clustering
- Evaluation of PW
- Analysis of Array
- Parallel processing
- Test experiments ELI, Krakow, Warsaw

WP4 – Applications
- Reactor neutrons
- Neutrino spectrum from reactors
- Cosmic particle in space
- Home land security
- Biological imaging

PASPAG-SEE

Contact: Olof.Tengblad@csic.es & P.Boutachkov@gsi.de

Participants:

Germany	TU Munich	R. Gernhäuser
	TU Darmstadt	T. Kröll
	GSI	P.Boutachkov
	UC Cologne	J.Jolie
France	IPNO Orsay	I. Matea
	IPHC	M. Rousseau
Italia	INFN	F. Camera
Poland	IFJ PAN	Maria Kmiecik
	SLCJ	P. Napiorkowski
	Rzeszow University of Technology,	M. Cholewa
Romania	IFIN-HH/ELI-NP	D. Balabanski
Spain	USC	L. Cortina
	IEM-CSIC	O. Tengblad
Sweden	CTH	T. Nilsson
UK	U. York	D. Jenkins

The collaboration has the
Know-How, Ideas and Tools
to make this R&D successful

→ 15 partners from 8 EU countries

Keywords: Scintillators, Phoswich, New-materials, Digital-electronics, DAQ, Gamma & Particle Detection, Secondary Electron Emission materials

Budget estimation: *1.300.000 €*