R&D on large volume $LaBr_3$:Ce detectors

F. Camera
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Physics Cases

- **<u>Inelastic Scattering reactions</u>**
  - **The γ-decay of the Pigmy Dipole Resonance**
  - **The γ-decay GDR and GQR**

- **<u>Fusion Evaporation reactions</u>**
  - **GDR in hot nuclei**
  - **Isospin mixing in N=Z nuclei at finite temperature**
  - **Dinamic Dipole Emission**

↓

Measurements of high energy γ-rays (5-20 MeV)

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Large volume scintillators

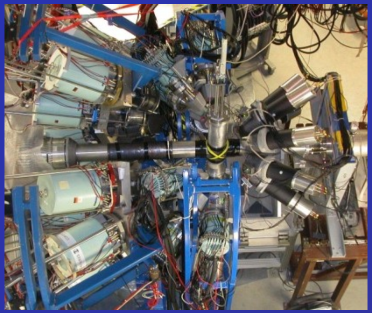
HECTOR$^+$ Array

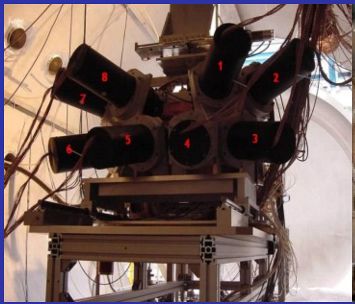
- High efficiency portable scintillator detector array

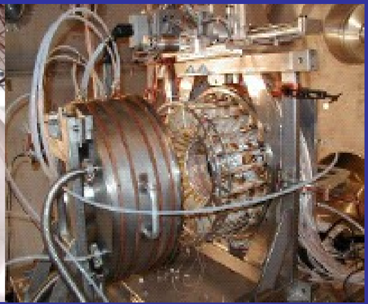
- 8 Large Volume BaF_2 Detectors (14 x 17 cm)
- 36 Small Volume BaF_2 Detectors

- <u>10 large Volume $LaBr_3$:Ce detectors (9 x 20 cm)</u>
  - 6 ready and 2 ordered and 2 ready to be ordered

- It was/will be coupled with
  - HPGe arrays   - RISING/PRESPEC (GSI) , AGATA (LNL,GSI) …
  - Scintillator array – DALI (RIKEN)
  - Fragment separators FRS (GSI), BigRIBS (RIKEN), ...
  - Charged particle detectors arrays GARFIELD and TRACE (LNL), Si (RIKEN)



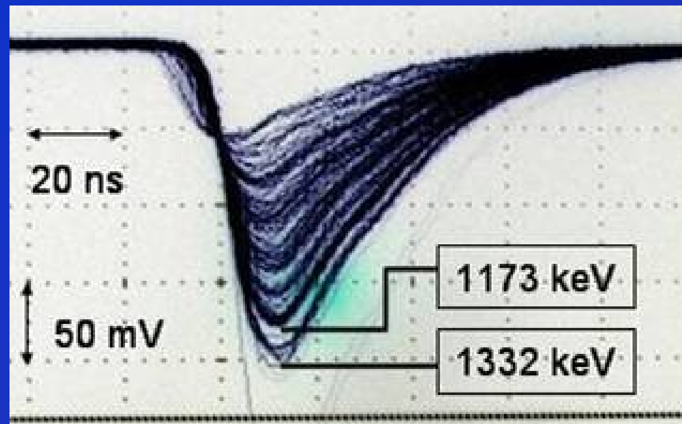


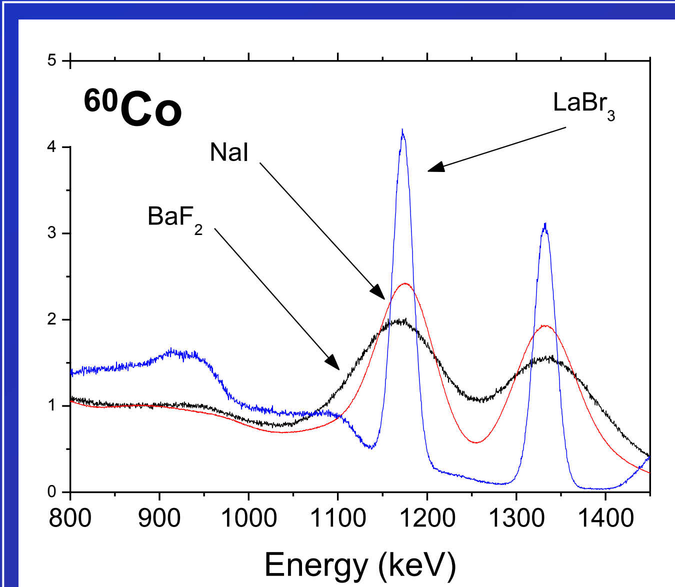


$LaBr_3$:Ce Scintillators

L.Y. ≈ 63 ph/keV
Decay Time ≈ 16 ns
λ ≈ 380 nm
N ≈ 1.9
ρ = 5.3 g/cm^3

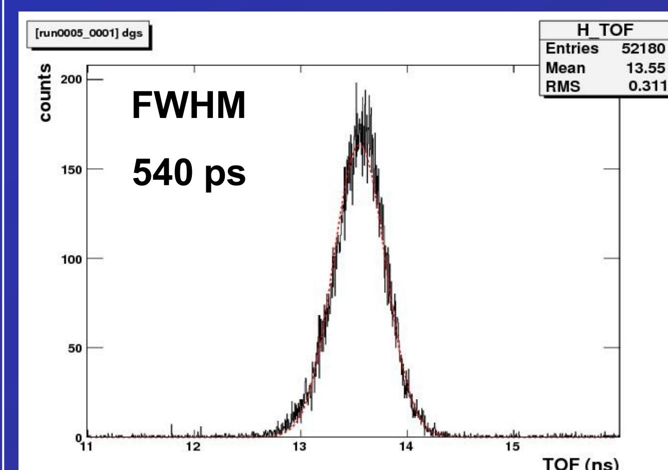
RL (661 keV) 1.9 cm





Large Interest in scientific community

- In 2007 more than 40 papers on $LaBr_3$ / $LaCl_3$ detectors published in IEEE and NIM



1 - 1"x1" $LaBr_3$:Ce
1 - 1"x1" $LaCl_3$:Ce
1 - 1.5 x 1.5 $LaBr_3$:Ce
1 - 3"x3" $LaBr_3$:Ce
6 – 3.5"x8" $LaBr_3$:Ce

R & D in Milano

- **Linearity, energy and time resolution tests** — S. Riboldi et al. CR IEEE 2010
  - Different PMT tested at different voltages
  - Voltage and temperature drifts
  - Voltage Divider Design
- **Response with high energy gamma rays** — F. Quarati et al. NIM A 629(2011)157
  - PuC source - 6.13 MeV γ-rays — N. Blasi et al. CR IEEE 2009
  - AmBe+Ni source - 8.98 MeV γ-rays — F. Camera et al. CR. IEEE 2007
  - p(20 MeV) + C $\Rightarrow$ 15.1 MeV
- **Internal radioactivity measurement** — R. Nicolini et al. NIM A 582(2007)55
  - Single and coincident measurements
- **PSA and particle Identification measurements** — F.Crespi et al. NIM A 602 (2009)520
  - Particle identifications tests on $LaBr_3$ and $LaCl_3$ — C. Boiano et al. CR IEEE 2010
- **Digital board development** — S.Brambilla et al. CR – IEEE – 2007; S. Riboldi et al. CR – IEEE – 2007; S. Brambilla et al. CR – IEEE 2008
  - Signals acquired with 100 MHz – 2 GHz ADCs
  - PSA algorithms tested for time, energy and PID
- **Gamma Imaging with Segmented PMT**
  - PSF experimental measurement — F. Birocchi et al CR IEEE 2009
  - test on 1”x1” and 3”x3” $LaBr_3$:Ce
- **GEANT simulations + Light tracking**
  - Simulation for 3”x3” LaBr3:Ce crystal — F. Birocchi et al C.R. IEEE 2010
- **Crystal uniform response**

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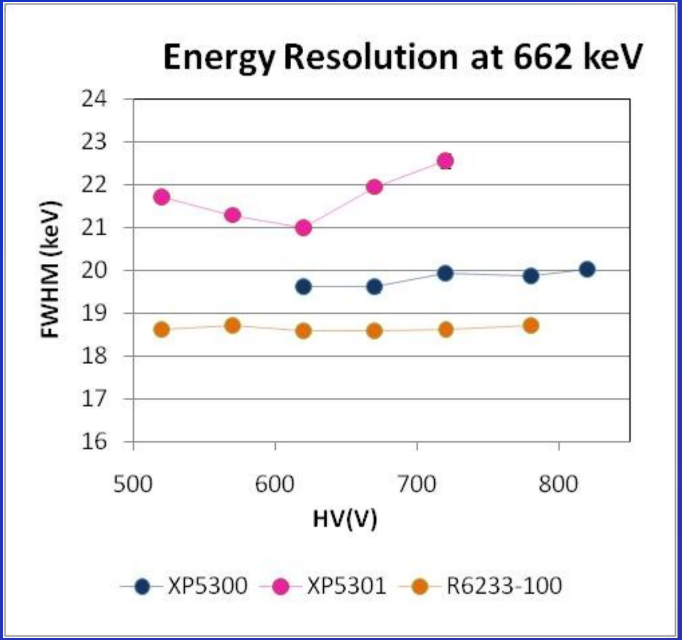
Energy resolution

LaBr3:Ce has an excellent energy resolution which must be preserved and optimizes

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	3.5"		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
Electron Tubes 9307B	6	3.5"				



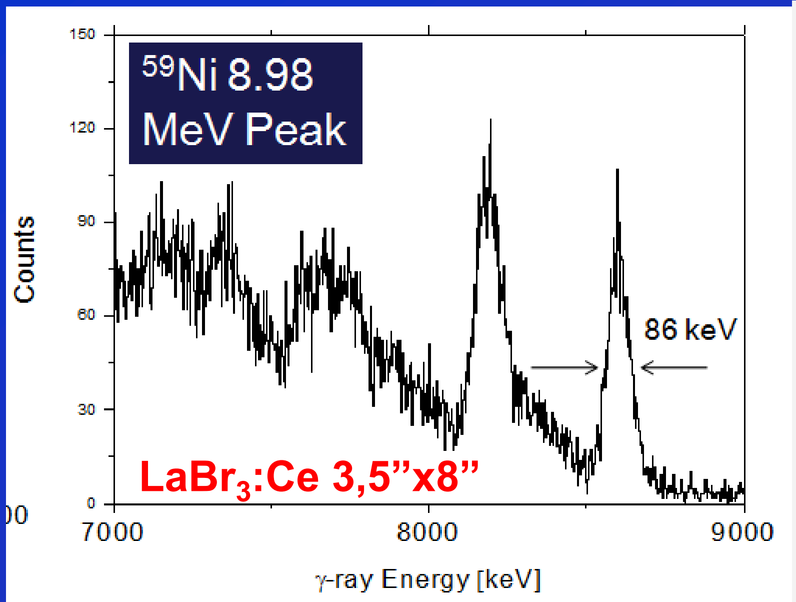
SBA photocathode works better than standard one even though better performances are expected from Q.E. arguments only

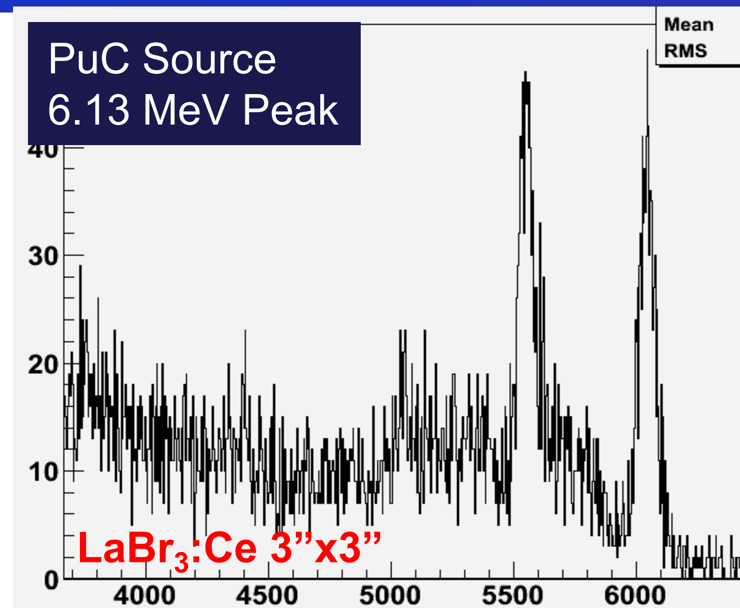
Normal 12 bit ADC (CAEN V878 series) is not optimal if a large dinamic range is required

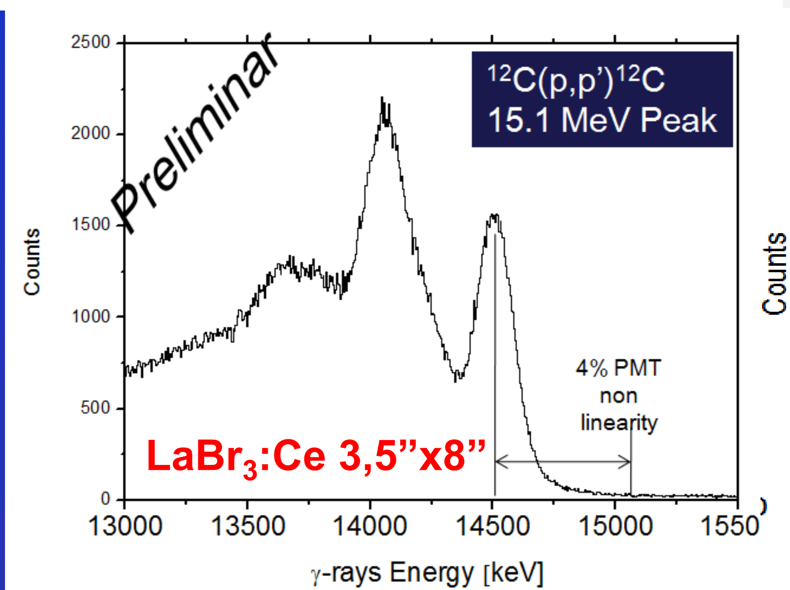
Two outputs from Voltage divider:

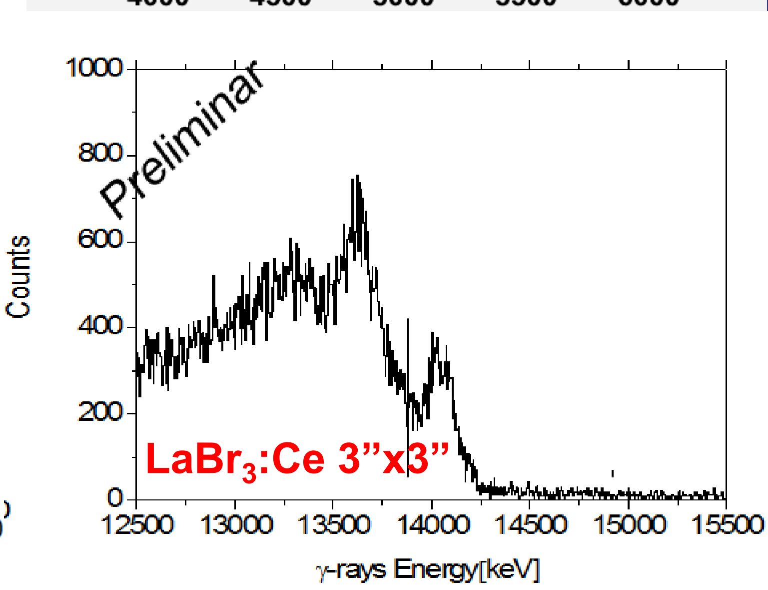
Dynode	1 - 20 MeV	Energy Range
Anode	1 – 6 MeV	Energy Range
Anode		Time

Measurements of mono-energetic high energy γ-rays
Excellent separation between F.E.P. and 1stE.P.

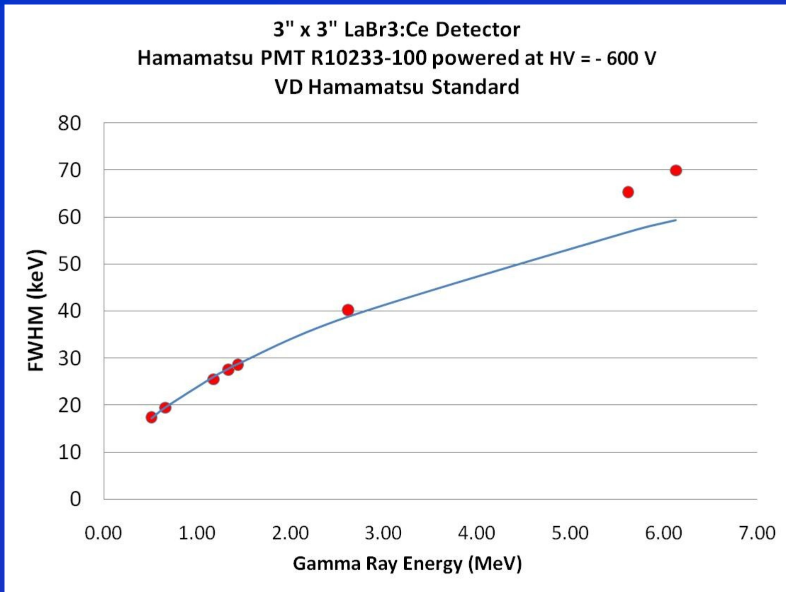


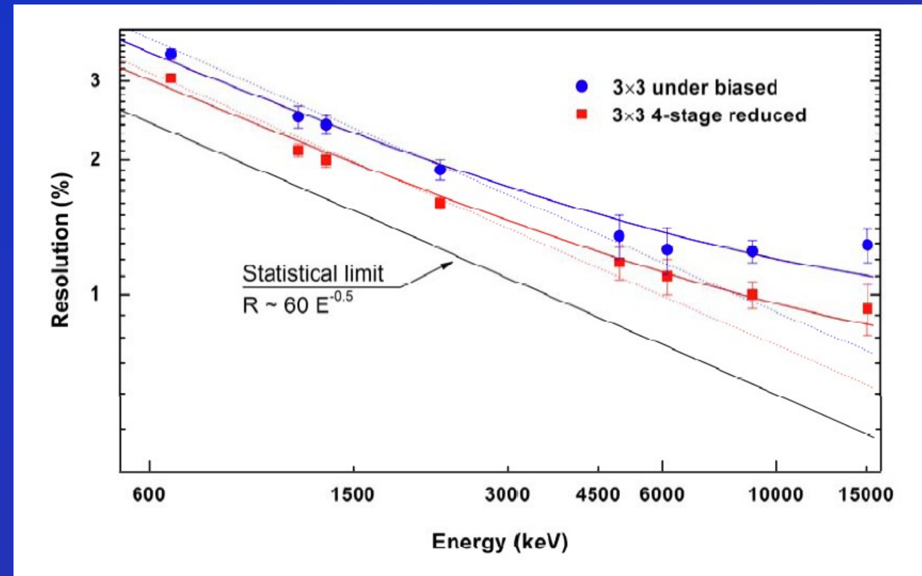




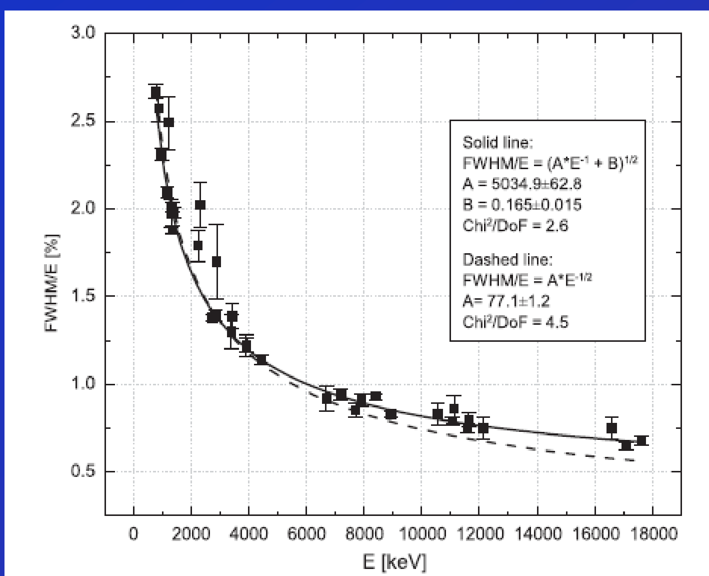


Energy resolution vs γ-rays energy





F. Quarati et al. NIM A 629(2011)157

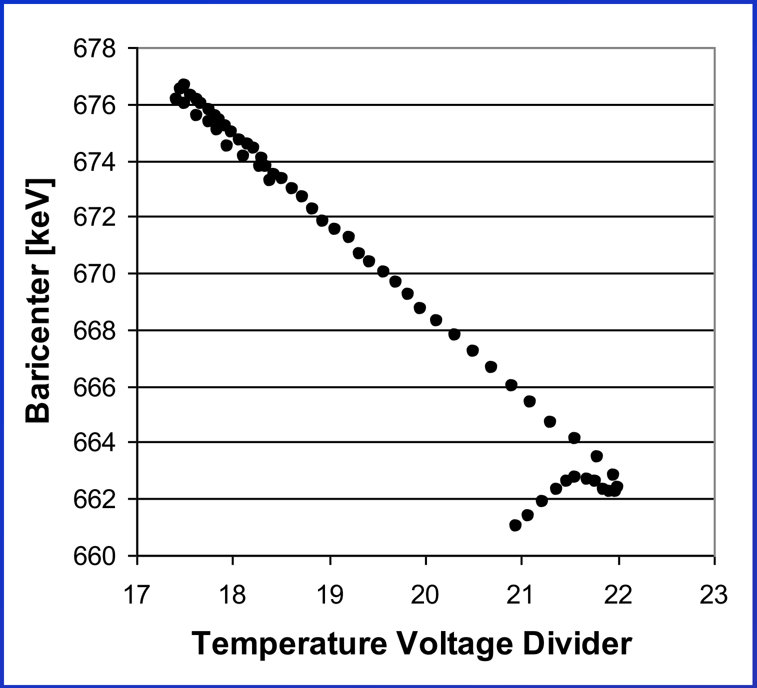


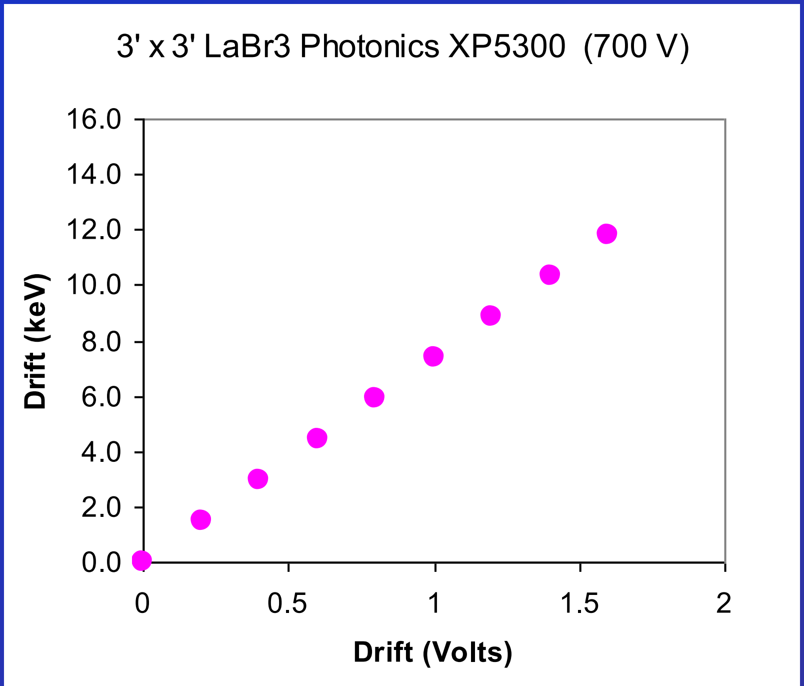
M. Ciemala et al NIM A608(2009)76–79

$LaBr_3$:Ce energy resolution seems not to follow the expected $(1/E)^{1/2}$ behaviour

- **Problem in $LaBr_3$:Ce ?**
- **PMT non idealities ?**
  - **PMT gain Drift**
    - **Temperature**
    - **Voltage drift**
    - **Count rate**

Gain Drift of the PMT with Temperature and Voltage





Because of the excellent energy resolution of $LaBr_3$:Ce scintillator the PMT non idealities might affect detector performances

$\Delta T = 1°$ $\Rightarrow$ $\Delta E \sim 2$ keV (@ 661 keV)
$\Delta V = 0.25$ V $\Rightarrow$ $\Delta E \sim 2$ keV (@ 661 keV)

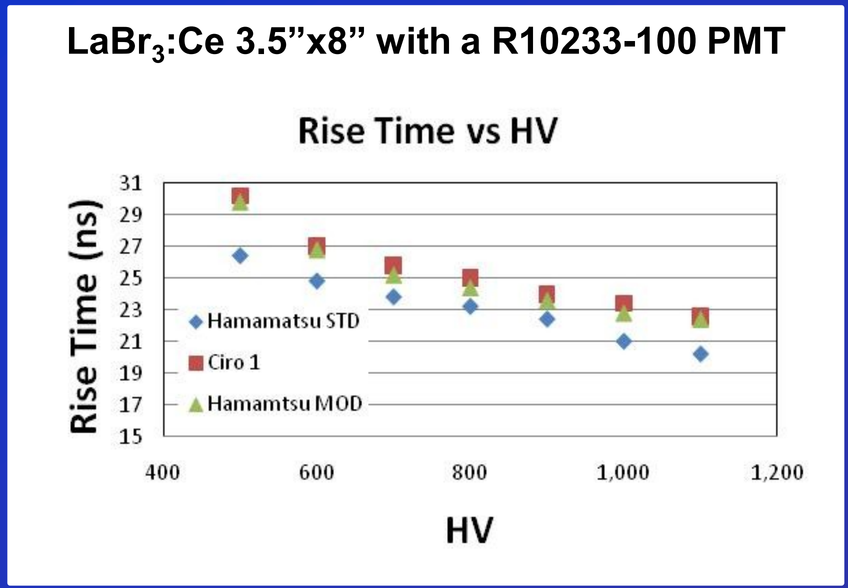
Gain Monitor

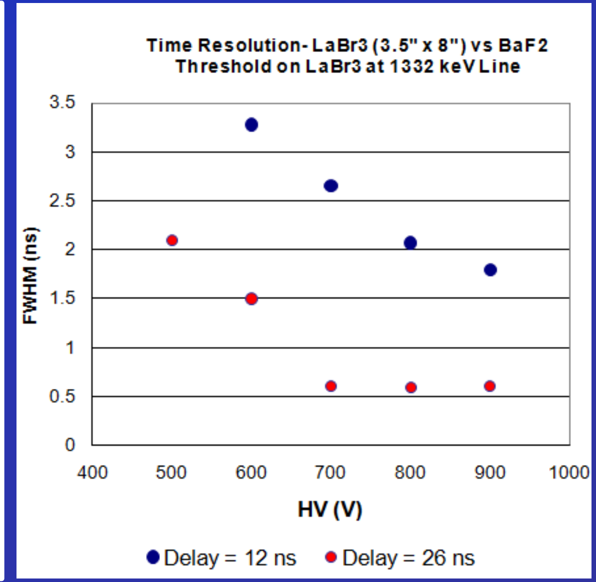
- LED
- internal radiation
- YAP light pulser

Time Resolution

The $LaBr_3$:Ce detectors have an excellent subnanosecond time resolution which must be preserved and optimized

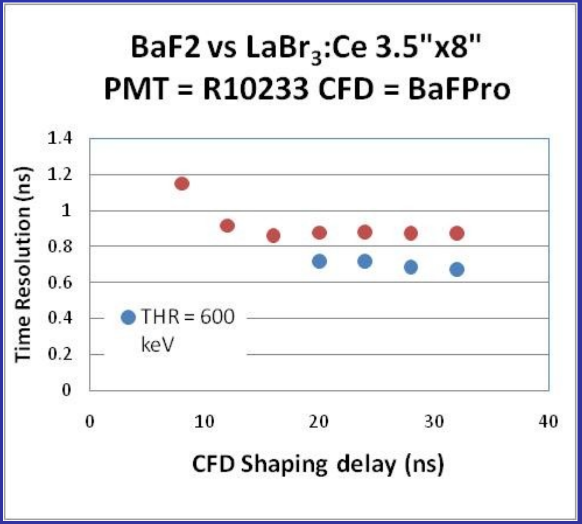
PMT	∅	RT(ns)
XP6060	2”	3
R6233	3”	6
R10233	3.5”	10
XP5700	3.5”	6
XP3540	5”	9.5



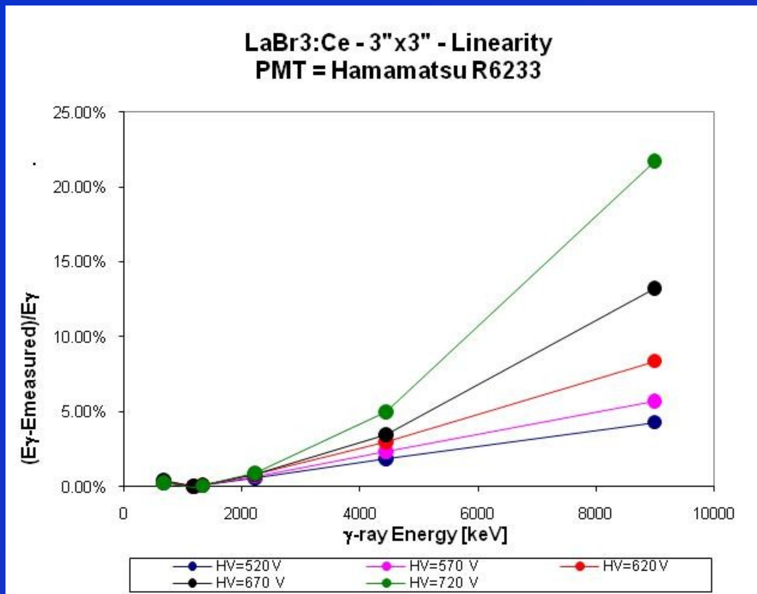


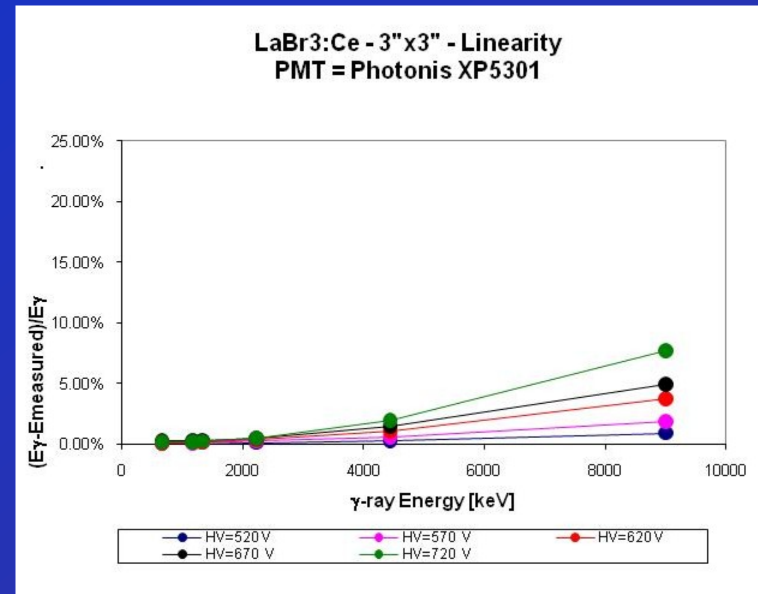
Also a large volume $LaBr_3$:Ce detector has a sub-nanosecond time resolution provided that the PMT is powered at a sufficiently high voltage.

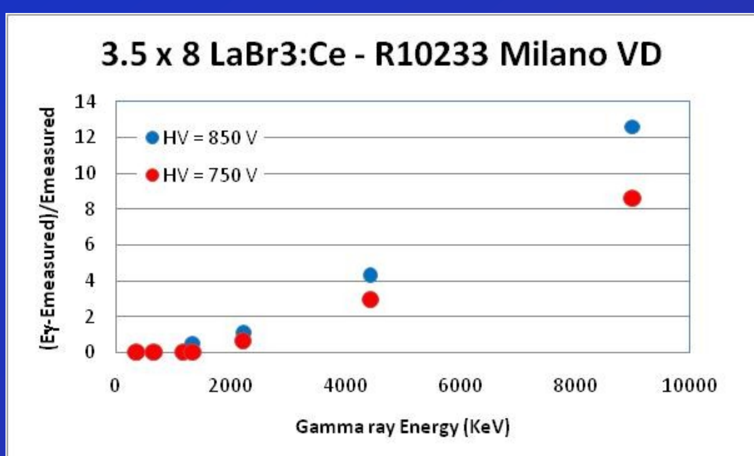
We have noticed very different results using different CFD modules



$LaBr_3$:Ce and PMT Linearity





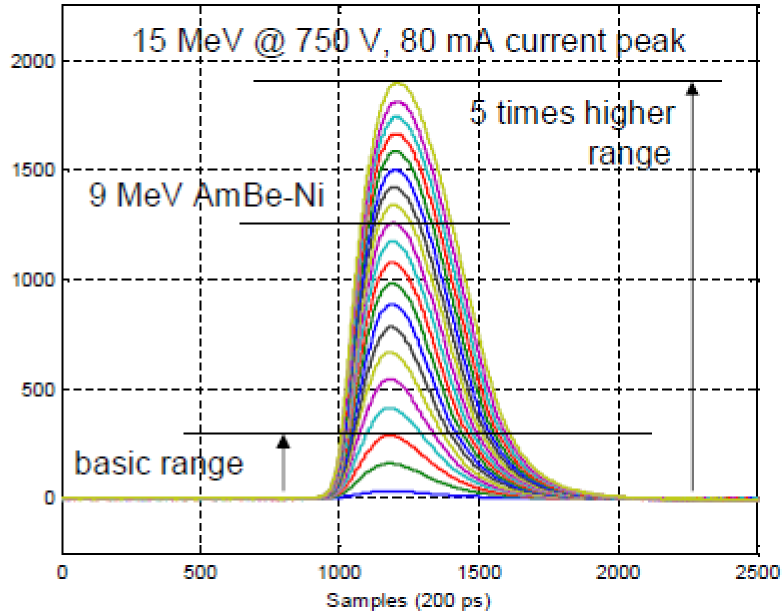


The extremely high photon yield of $LaBr_3$:Ce induce in a PMT a too large current making the anod signal saturate.

As γ-ray sources with energy higher than 9 MeV do not esist a non linear calibration curve is not reliable for high energy γ-rays

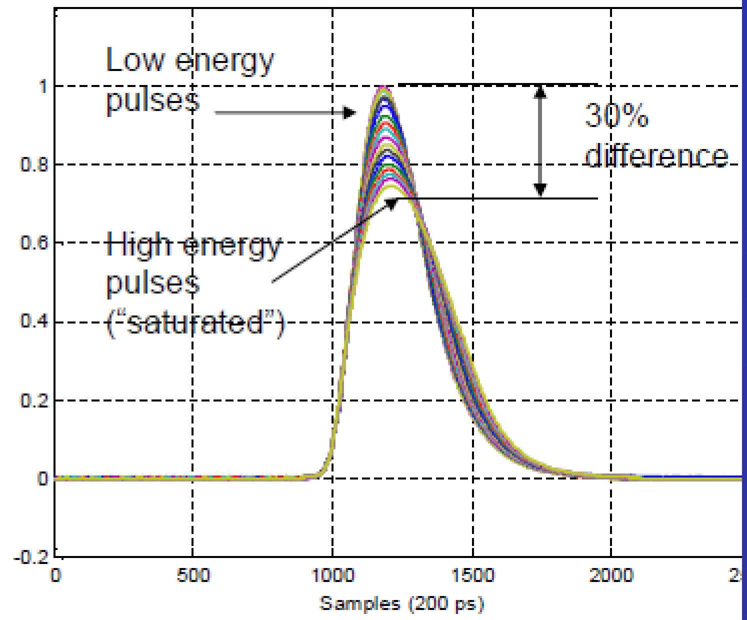
- **use a 6-4 dynode PMT**
- **take energy signal from a dinode**
- **Eliminate/correct non linearity using PSA**

$LaBr_3$:Ce and PMT Linearity
Pulse lineshape



Reference signals obtained by averaging pulses of similar energy (150 classes, from 100 keV up to 15 MeV) (only 1 class over 8 is represented)

Although apparently similar they are indeed different



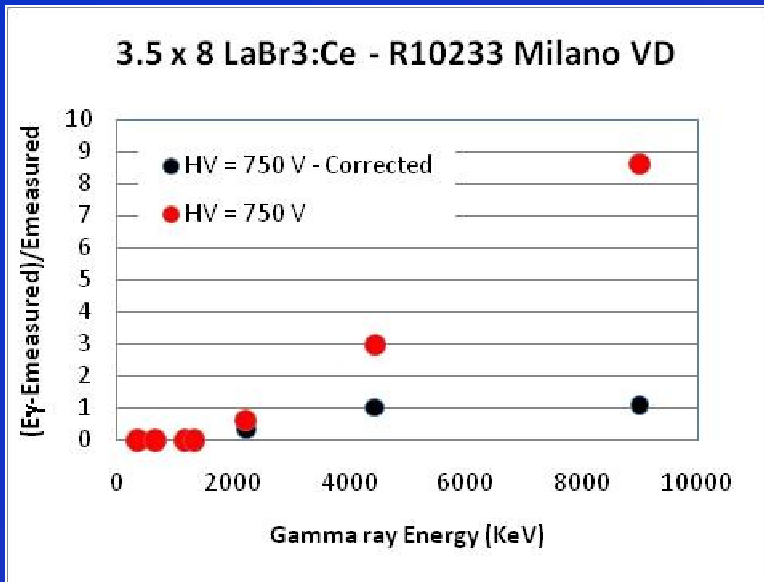
Reference signals normalized to unitary area

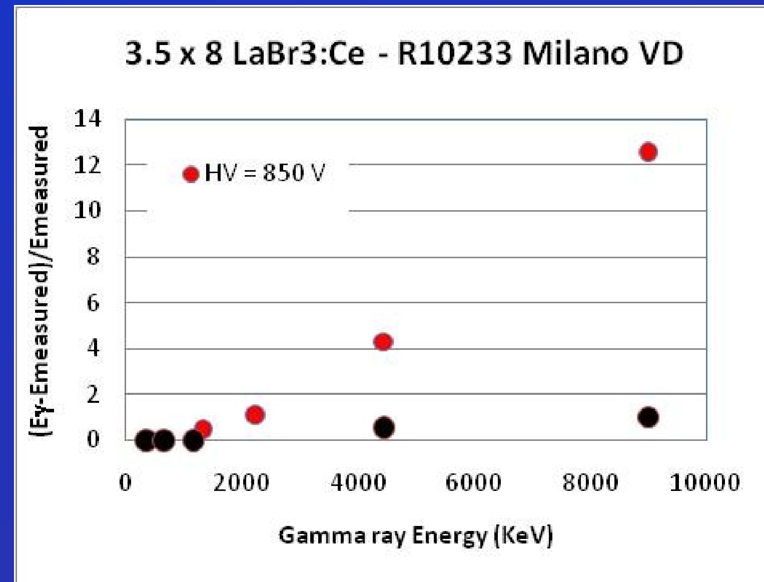
Signal is "saturated" in that the "top" part of high energy signals is lower than it should be for an ideal PMT

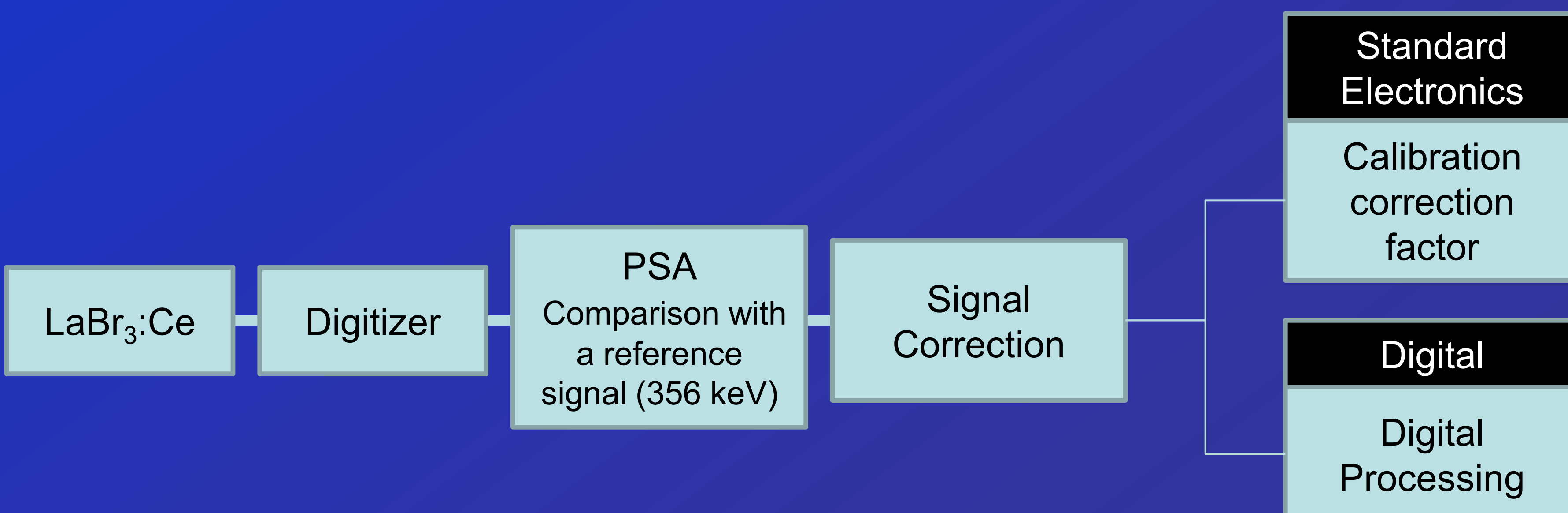
Signal "saturation" is a good marker?

S. Riboldi IEEE 2010

$LaBr_3$:Ce and PMT Linearity
PSA algorithm

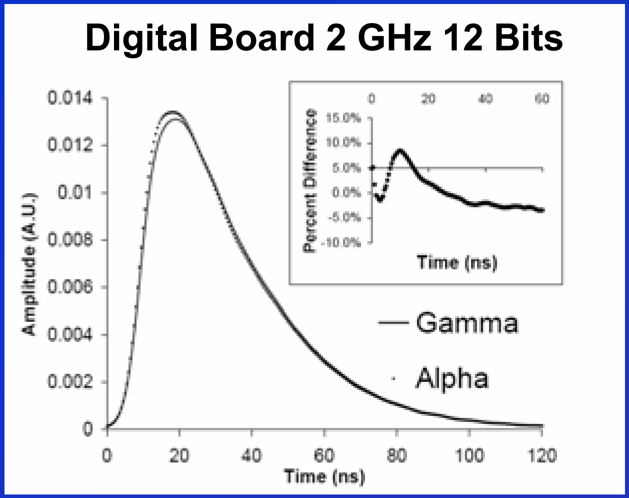






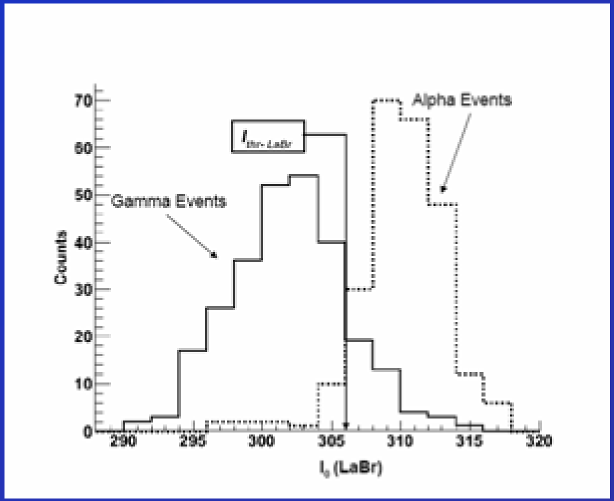
PSA in $LaBr_3$:Ce and $LaCl_3$:Ce

F.Crespi et al. NIM A 602 (2009)520

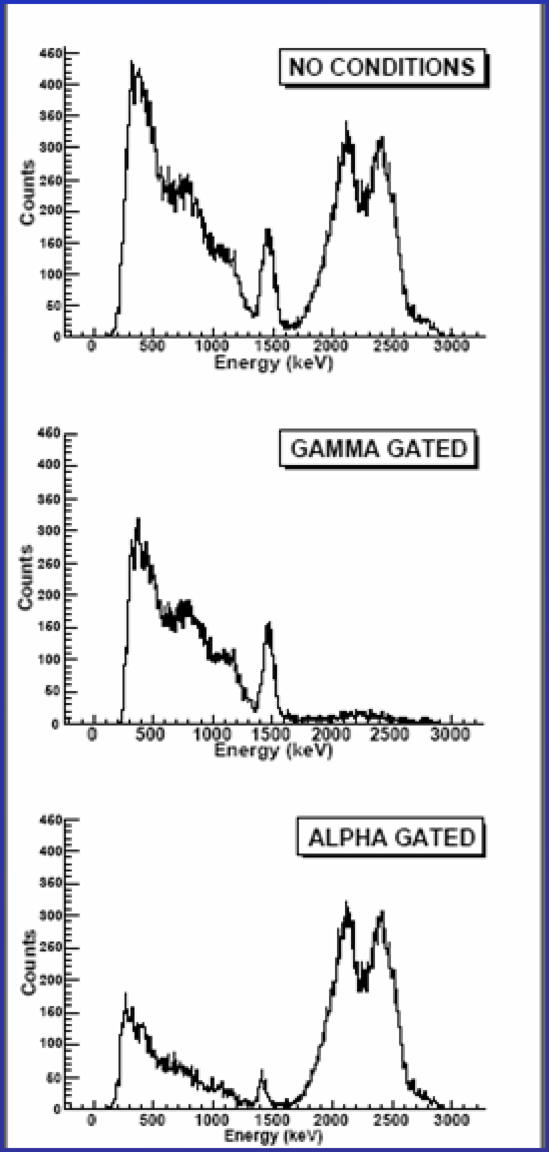


PSA

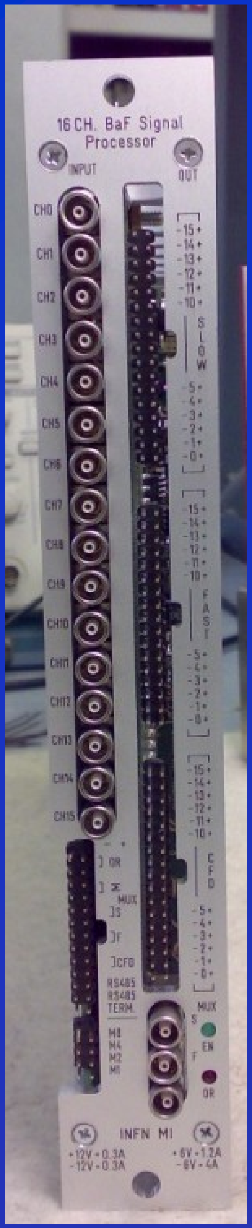
Algorithm



90% of particles identified

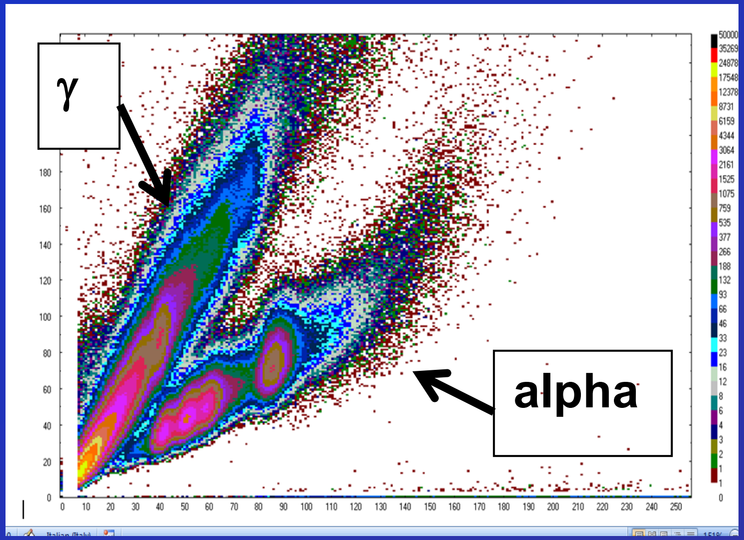


PSA in $LaBr_3$:Ce and $LaCl_3$:Ce



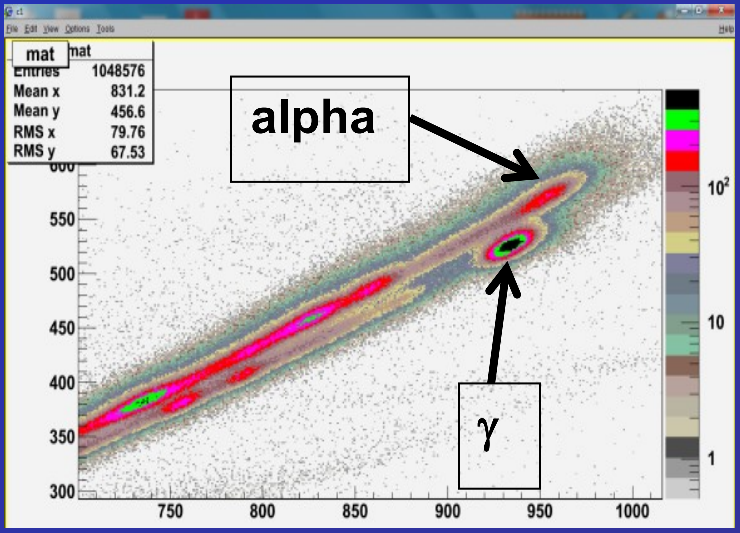
BaFPro Nim module

16 channels of Shaping amplifier
16 channels of CFD
16 channels of peak stretcher for BaF_2 Fast component



Fast vs Slow in a 2”x3” BaF_2 detector

C. Boiano et al TNS-53(2006)444



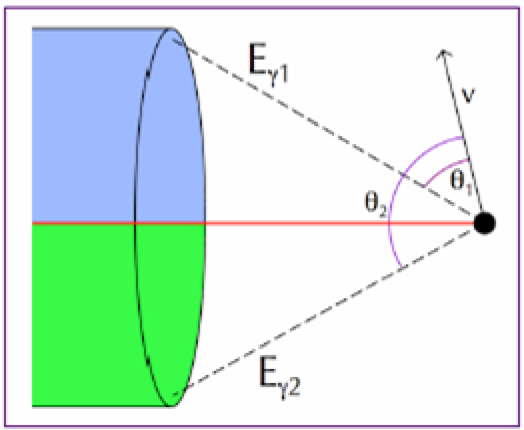
Fast vs Slow in a 3”x3” $LaBr_3$:Ce detector

C. Boiano et al IEEE 2010

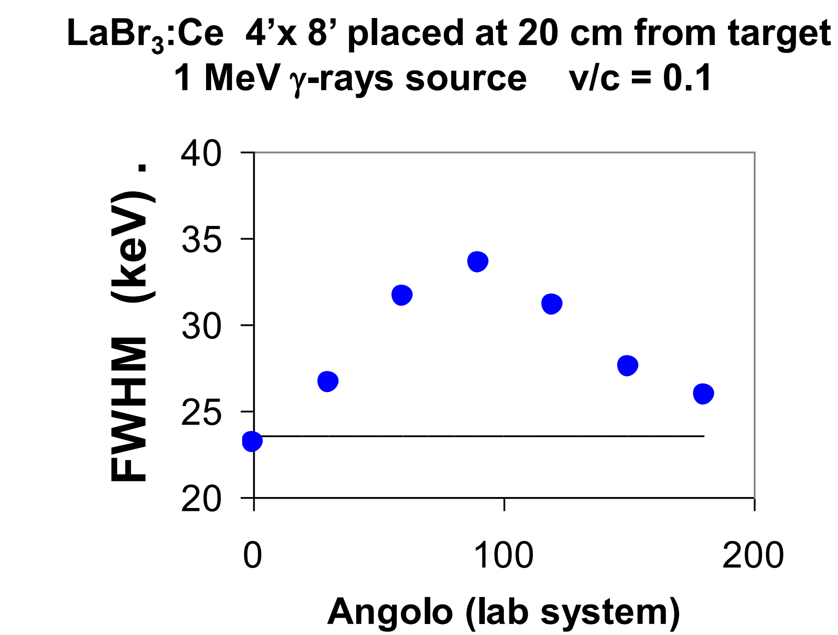
Doppler Broadening Correction

- **Large Crystals give large efficiency for high energy γ-rays (16% at 10 MeV) but they substand a large solid angle and this will affect energy resolution**

$$E_\gamma = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\vartheta_\gamma} E_{\gamma 0}$$



The γ-rays, even though monocromatic in the CM, enter with an energy spread due to the emission angle

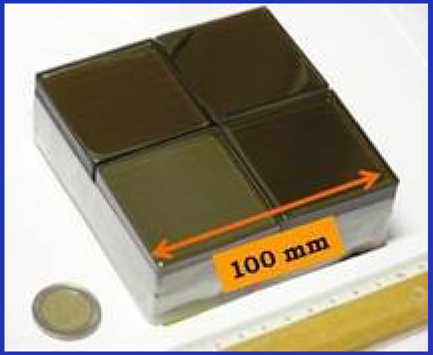


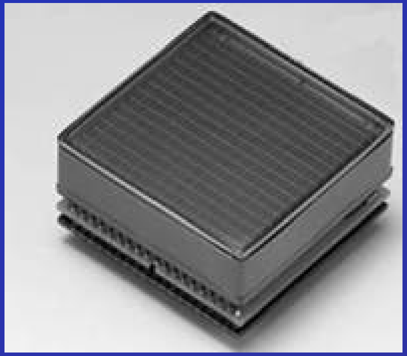
1 MeV γ-rays source v/c = 0.5

FWHM (60°) = 160 keV

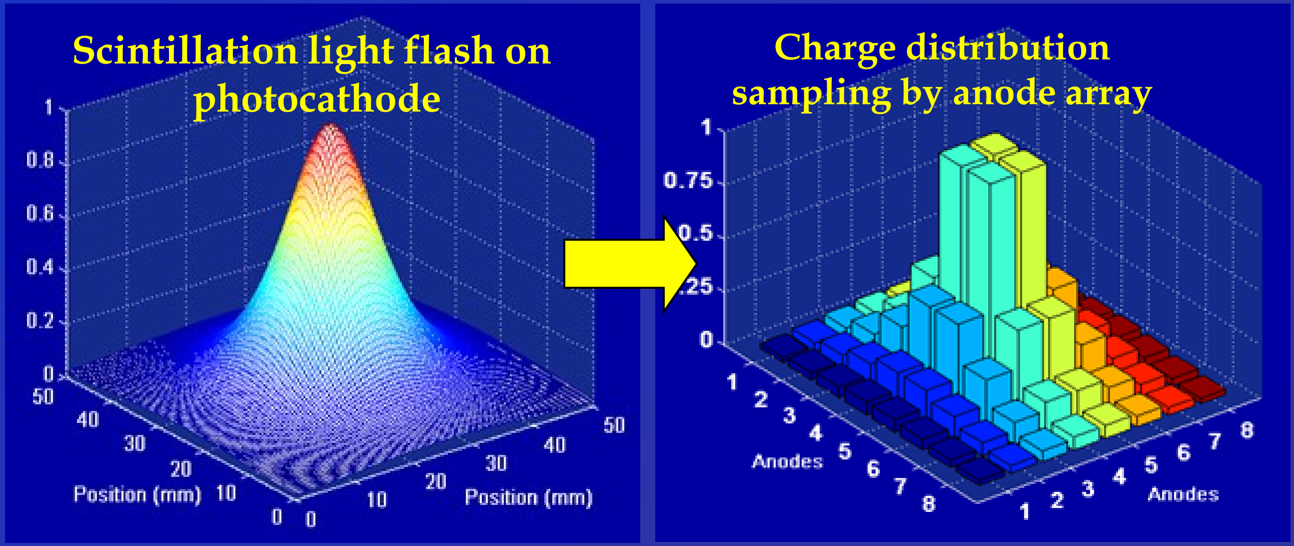
Doppler Broadening Correction – Imaging –

- Segmented Photosensor





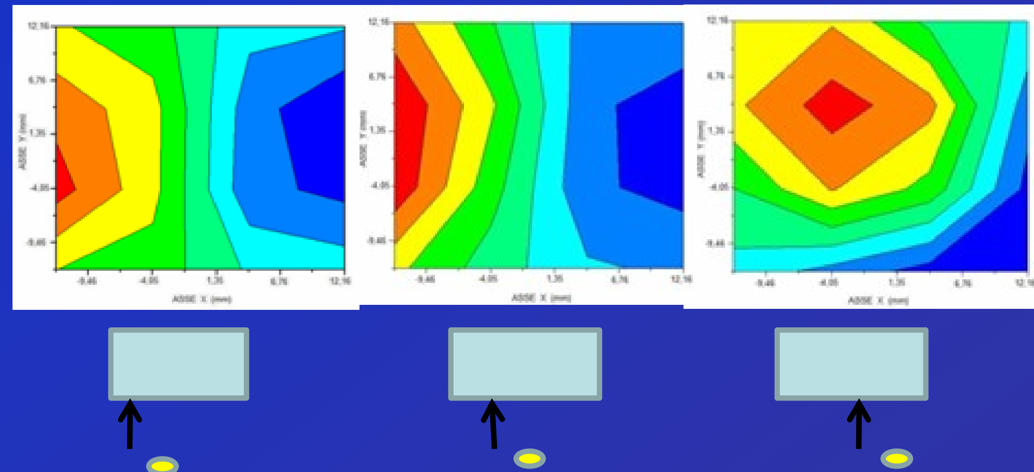
- Medical Imaging Techniques



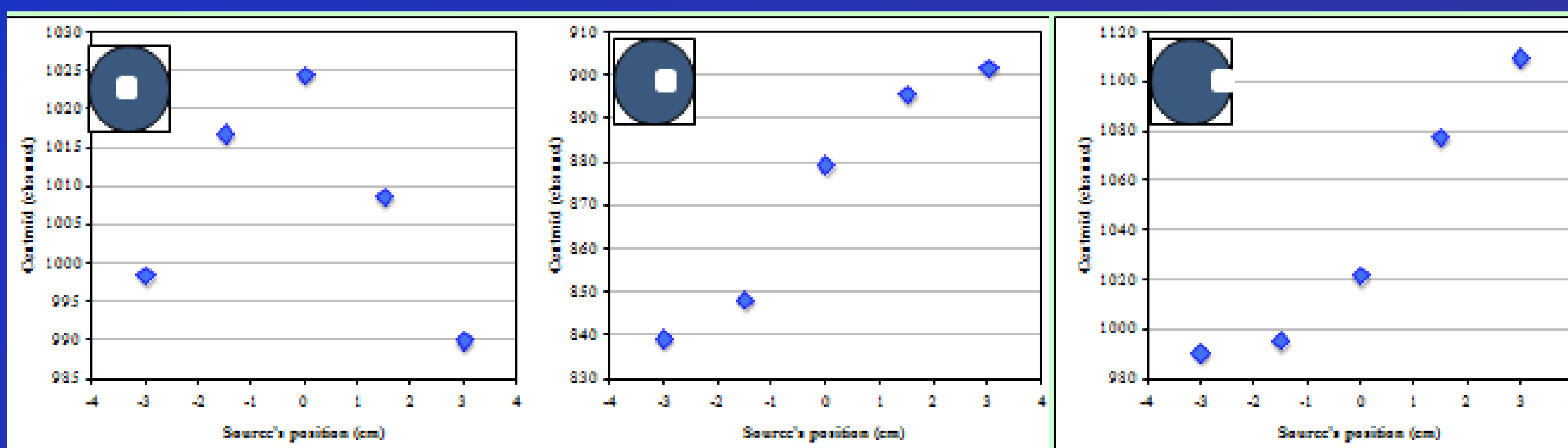
- Charge PSF
- Image PSF
  - Spatial Resolution
  - Spatial Linearity

$LaBr_3$:Ce crystal: Point Spread Function Image

1”x1” $LaBr_3$;Ce +
H8500C-100 Mod 8 PMT

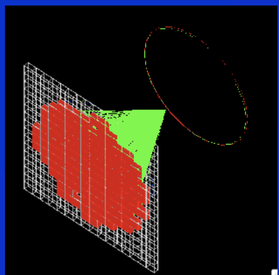


3”x3”
$LaBr_3$:Ce +
Shielded
PMT

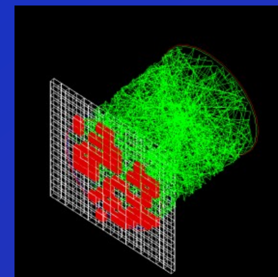


The Point Spread Function image for different collimated γ-ray beam-positions shows that position sensitivity is achievable in 1”x1” and in $LaBr_3$:Ce 3” x 3” crystals

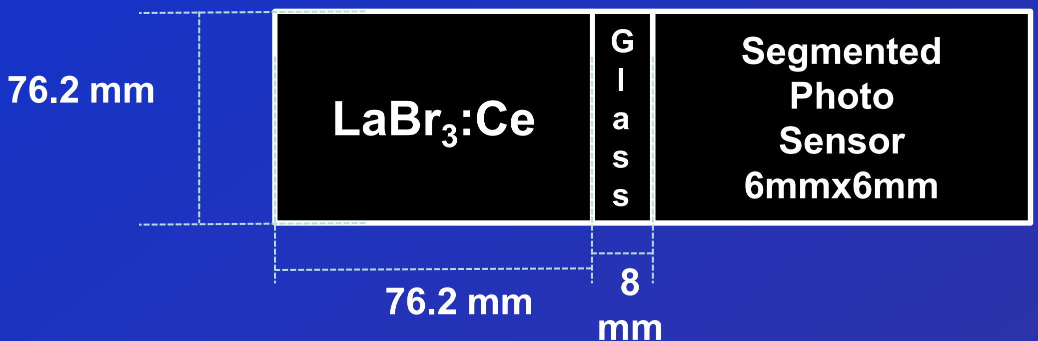
3" x 3" Simulated $LaBr_3$:Ce

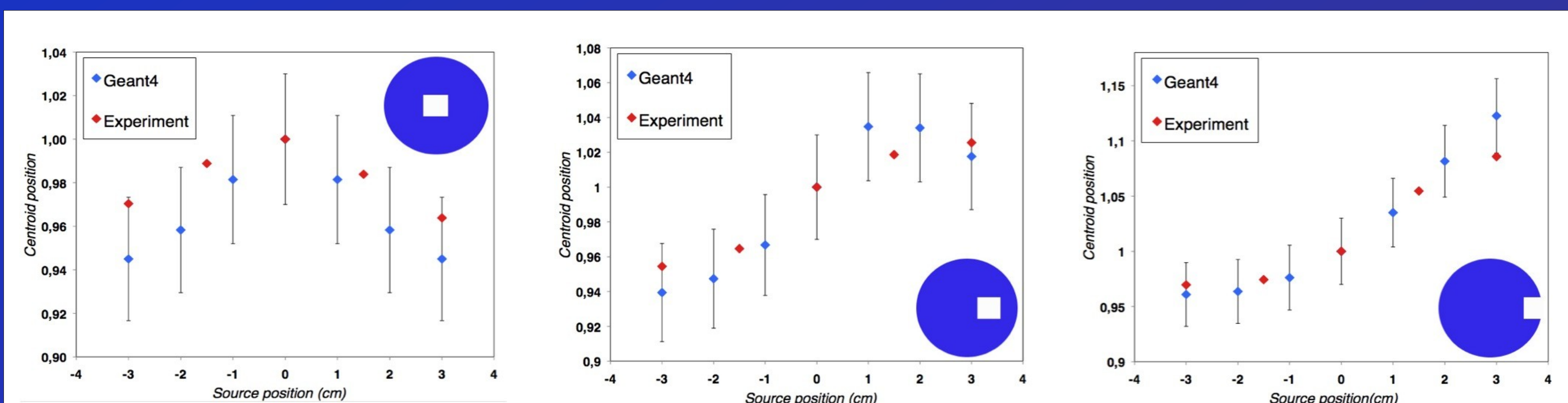


3"x3" $LaBr_3$:Ce crystal with dark fully absorbing surphaces coupled with an ideal segmented photosensor.

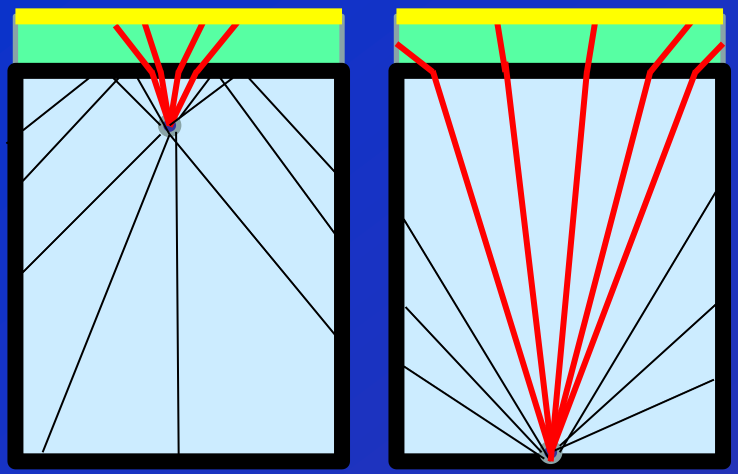


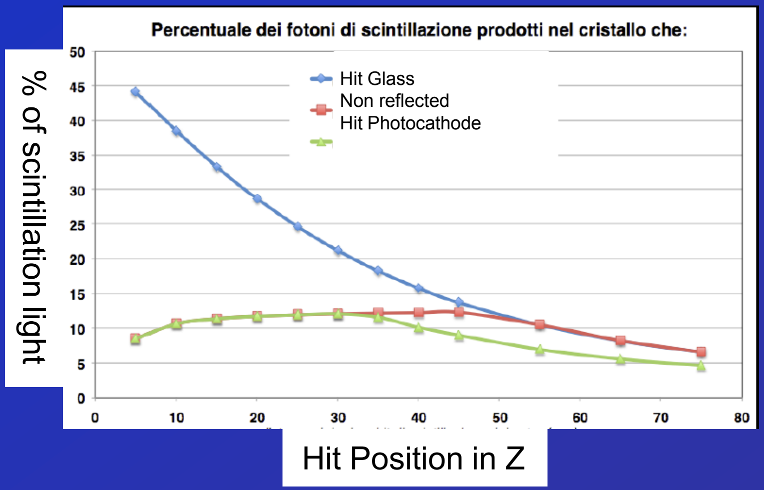
3"x3" $LaBr_3$:Ce crystal with diffusing surphaces coupled with an ideal segmented photosensor.

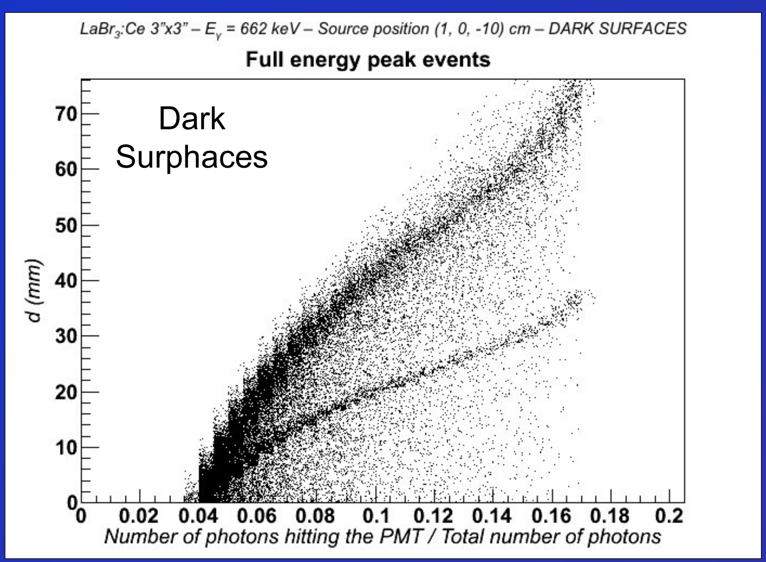


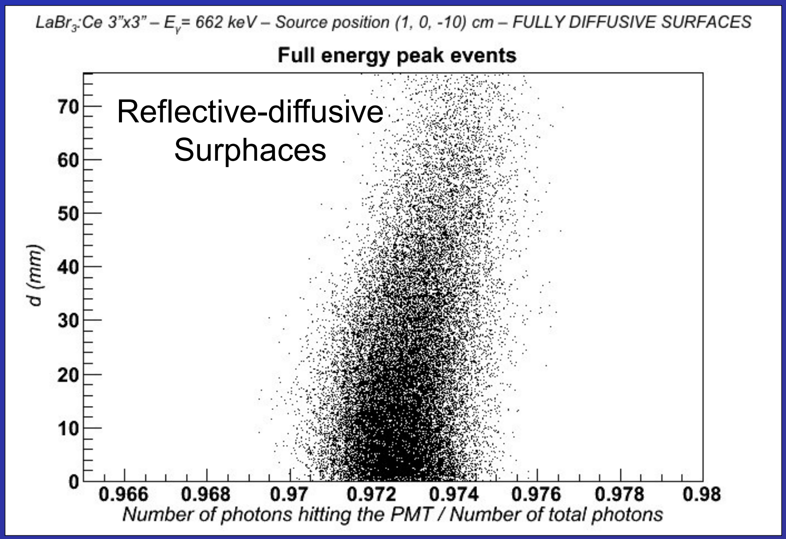


3” x 3” Simulated $LaBr_3$:Ce
PSF Charge

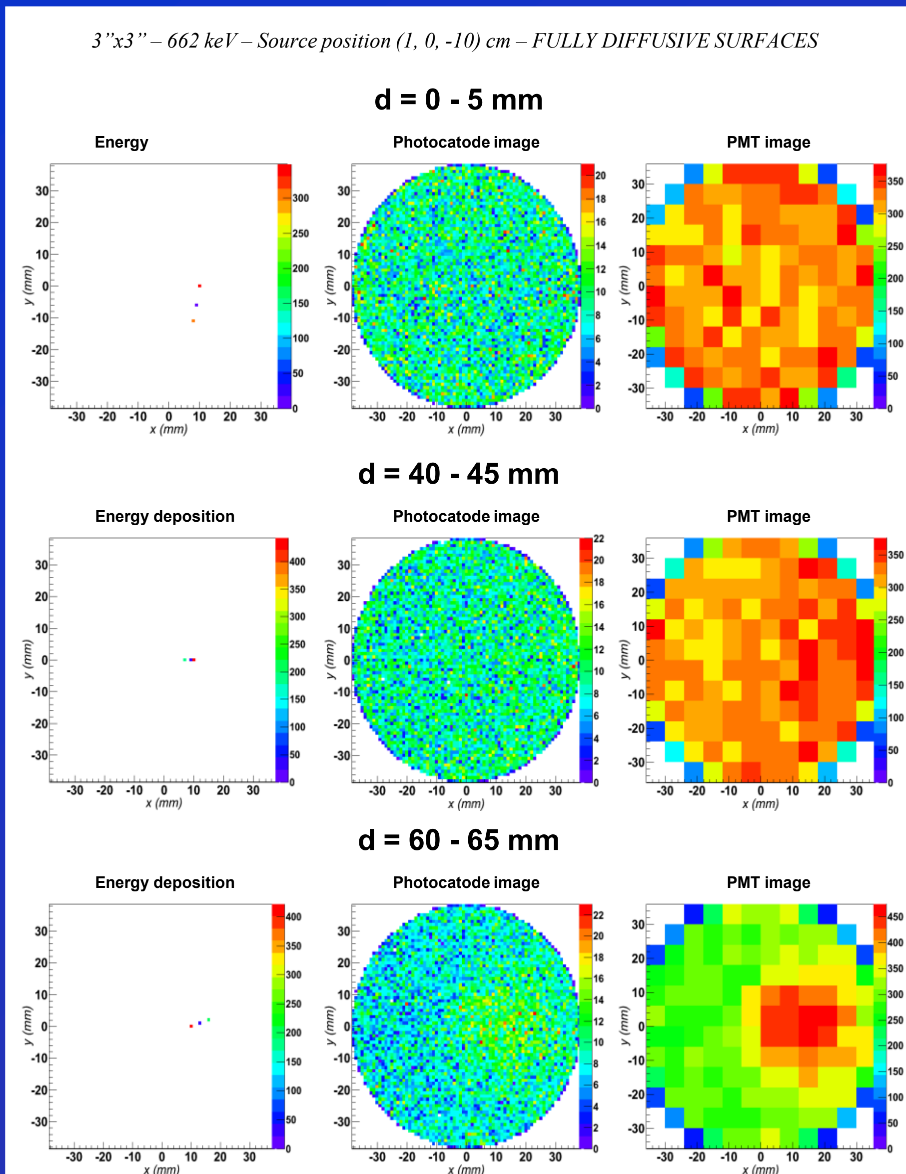


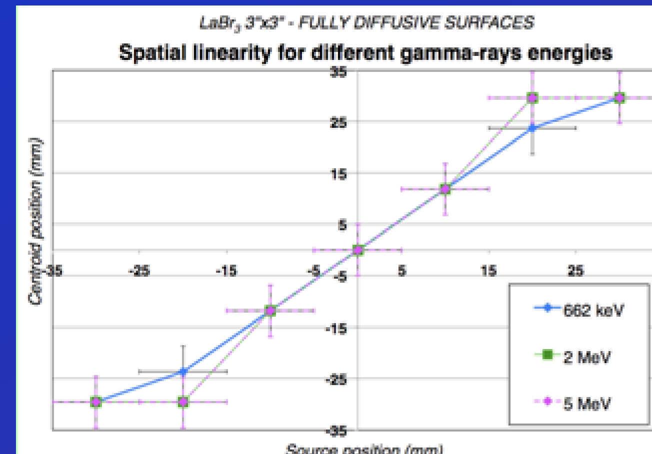


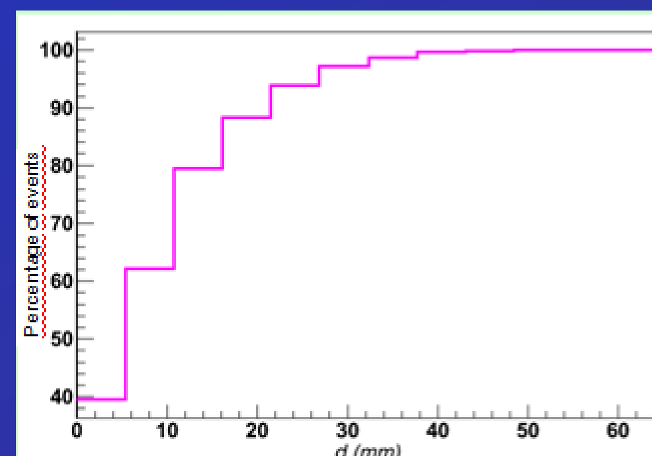




3” x 3” Simulated $LaBr_3$:Ce
PSF Charge







In the case of a NON collimated of 662 keV γ-rays, for each γ-ray which has deposited all its energy in the detector, on an event by event basis, we have extracted the X-Y position of the first interaction and we have compared it with the real one. In 80% of the cases it is possible to identify the first hit position within 1 cm

Conclusion

We have started an R&D project concerning large volume $LaBr_3$:Ce for gamma spectroscopy

The project points at the construction of a transportable array ($HECTOR^+$) which is composed of 10 large volume $LaBr_3$:Ce and 8 large volume BaF_2

- Linearity, energy and time resolution tests
- Response with high energy gamma rays
- Internal radioactivity measurement
- PSA and particle Identification measurements
- Digital board
- Gamma Imaging with Segmented PMT
- GEANT simulations + Light tracking
- Crystal uniform response

There are still several aspects which remain to be understood but $LaBr_3$:Ce gives a fantastic opportunity for all those experiments where efficiency, time and energy resolution are a key factor

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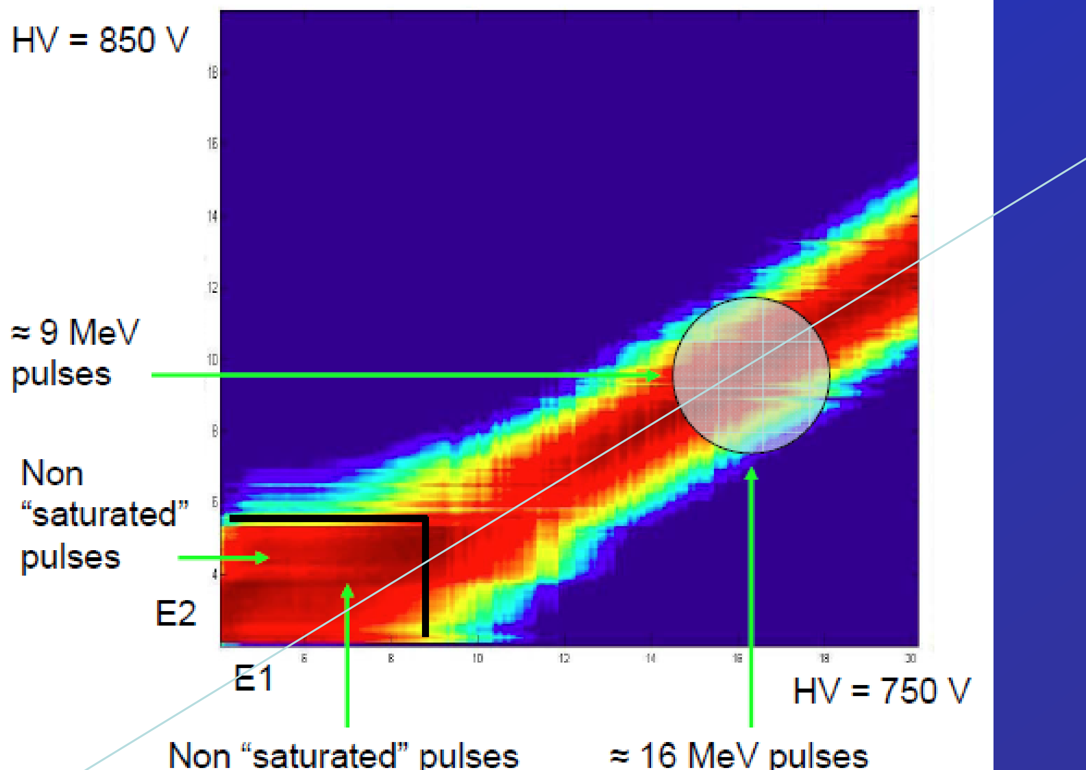
$LaBr_3$:Ce and PMT Linearity
Cross correlation of individual pulses

Signal saturation depends on both HV level and radiation energy

Investigation of PMT behavior and effectiveness of algorithms for non linearity correction for very high energy of pulses can also be estimated with lower energy pulses but higher HV level

8.99 MeV @ 850 V

≈ 16 MeV @ 750 V



E1 = SUM(PULSE1) (@750 V)

E2 = SUM(PULSE2) (@850 V)

M(E1,E2) = XCORR(PULSE1,PULSE2)

Pulse lineshapes depend mainly on the current they produce inside the PMT