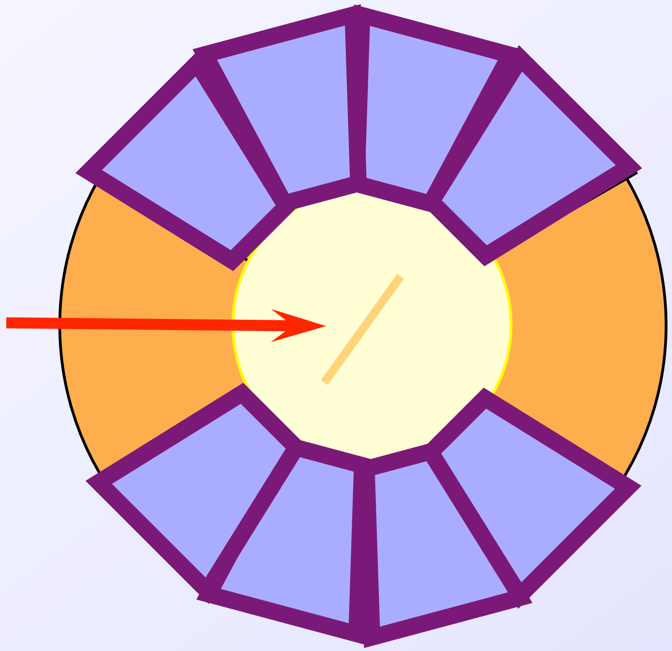
Detectors and photosensors



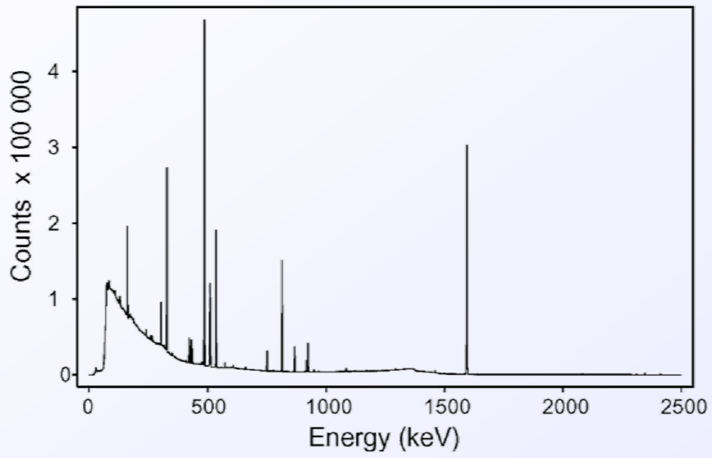
Luis M Fraile
Universidad Complutense, Madrid, Spain

Elements

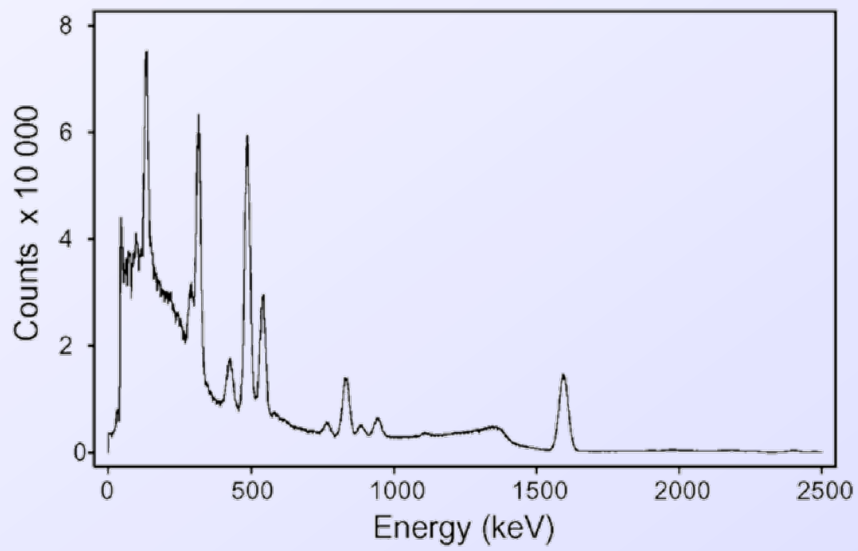
- ✓ **Detectors: $LaBr_3$:Ce**
  - Doping
  - SIZE and SHAPE
  - Shielding [Cu-Pb] - Simulations
  - Alternatives
  - Mechanical support (weight about 1.5 kg/detector mainly Pb+$LaBr_3$)
  - Simulation – integration
- ✓ **Photosensors**
  - PMs + voltage dividers
  - Alternatives
- ✓ **Front-end / timing electronics**
  - CFDs (ORTEC)
  - Digital options
- ✓ **DAQ**
- ✓ **Software**
  - Multidetector data – acquistion
  - Analysis

Advantages of $LaBr_3(Ce)$

Decay of 140La and 140Ba, Ge spectrum

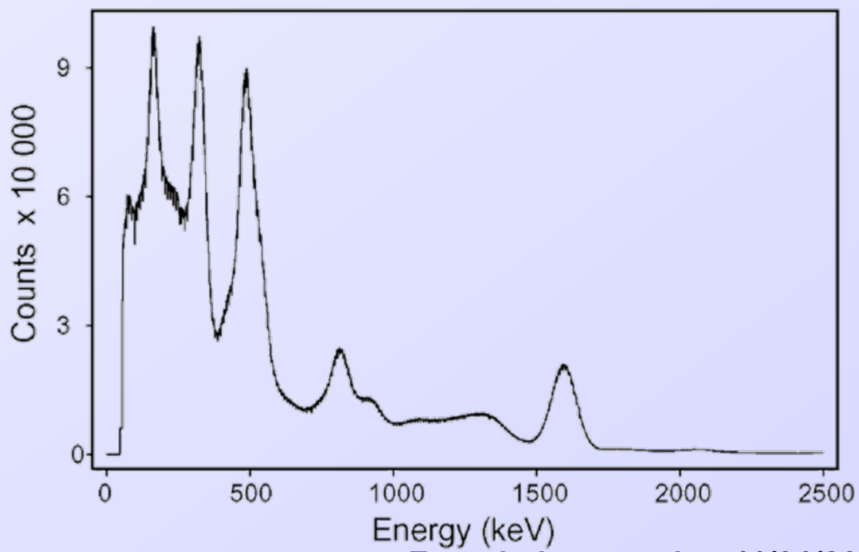


$LaBr_3(Ce)$ sp



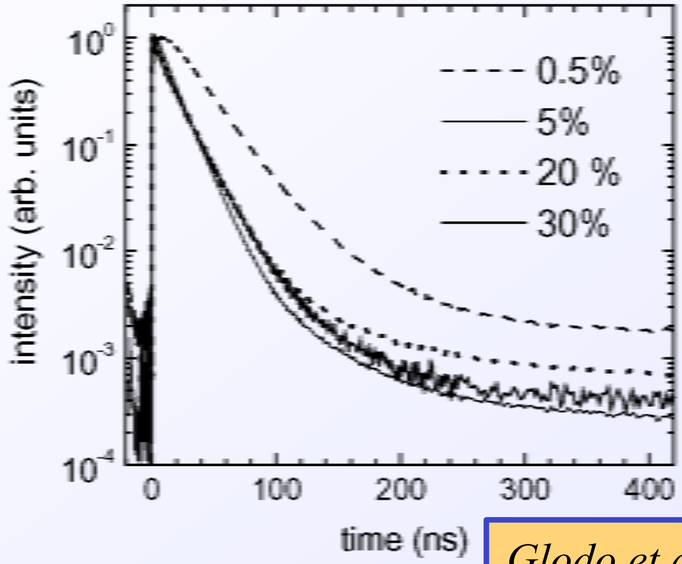
$LaBr_3(Ce)$ has much better energy resolution than BaF_2 (a factor of ~3) and currently very similar time resolutions.

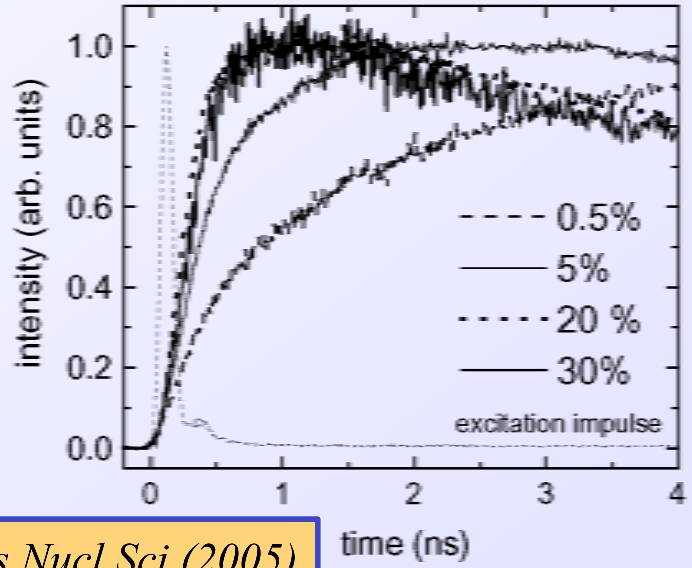
BaF_2 Sp



Much improved peak to Compton ratio, critical in Fast Timing

$LaBr_3(Ce)$: increased Ce doping





Glodo et al., IEEE Trans Nucl Sci (2005)

Fig. 2. Scintillation time profiles of $LaBr_3$:Ce samples doped with different Ce concentrations.

Fig. 3. Rising part of time profiles shown in Fig. 2. The numbers on the graph indicate nominal Ce concentration. On the far left an excitation

TABLE I

EFFECTS OF CE^{3+} CONCENTRATION ON LIGHT OUTPUT AND TIMING PROPERTIES OF $LABR_3$:CE. SEE DESCRIPTION IN TEXT.

Ce^{3+} Contr. %	Light Output %	Decay / Rise Times (intensity) ns/ns (%)	Effective Rise Time, ns	Timing Resolution		
				FWHM	$LaBr_3$:Ce	$\sqrt{(\tau / N)}$
					ps	
0.5	97	19/15 (56%), 15.2/2 (28%), 55 (16%)	9.4	390	361	83
5.0	100	15/0.38 (70%), 15/2.2 (27%), 55 (3%)	0.93	260	214	62
10.0	94	16.5/0.5 (89%), 4.5/0.5 (5%), 55 (6%)	0.5	182	106	67
20.0	92	17.5/0.16 (89%), 4.5/0.15 (5%), 55 (6%)	0.16	177	97	70
30.0	93	18/0.2 (91%), 2.5/0.2 (4%), 55 (6%)	0.20	165	73	70

Crystal size "ranging from 0.5 to 2.5 cm^3"

$LaBr_3$(Ce): increased Ce doping

✓ St Gobain not willing to test (again?) 10% doping [lastest discussion Dec 2010]

- results not reproduced with 10% crystal
- brittle
- homogeneity

✓ High doping patent held by Radiation Monitoring Devices, Inc. (Watertown, MA, USA) [including Glodo]

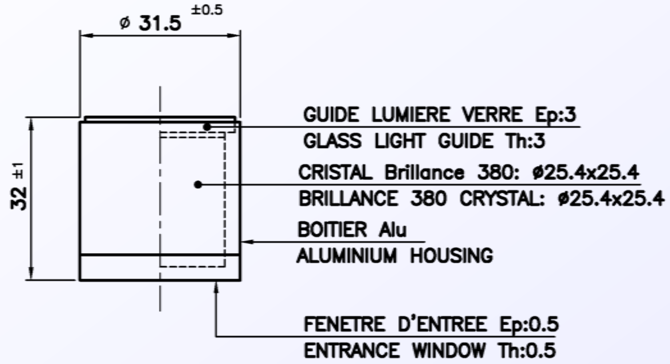
United States Patent 7,129,494
Shah, October 31, 2006

Very fast doped LaBr.sub.3 scintillators and time-of-flight PET

Abstract

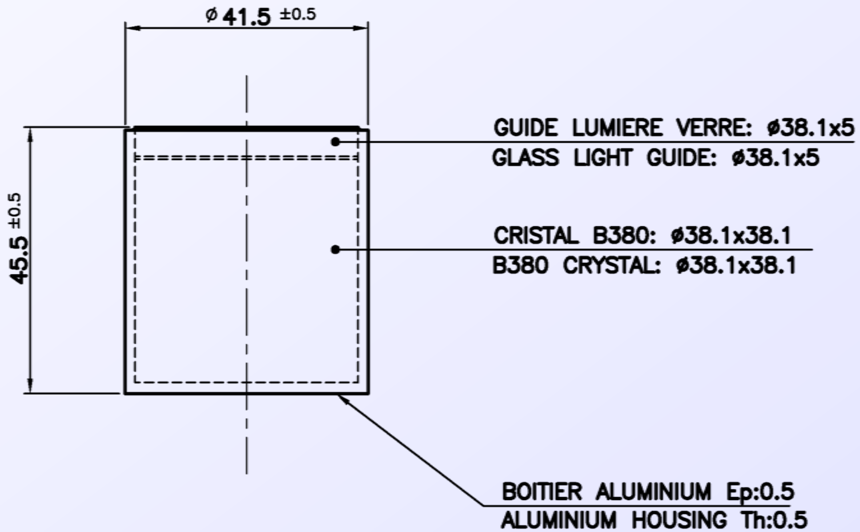
The present invention concerns very fast scintillator materials capable of resolving the position of an annihilation event within a portion of a human body cross-section. In one embodiment, the scintillator material comprises LaBr.sub.3 doped with cerium. Particular attention is drawn to LaBr.sub.3 doped with a quantity of Ce that is chosen for improving the timing properties, in particular the rise time and resultant timing resolution of the scintillator, and locational capabilities of the scintillator.

$LaBr_3$(Ce) detectors



2.54 x 2.54 cm (10%) Ce doping since 2005

Time resolution 123(5) ps FWHM at 1.3 MeV

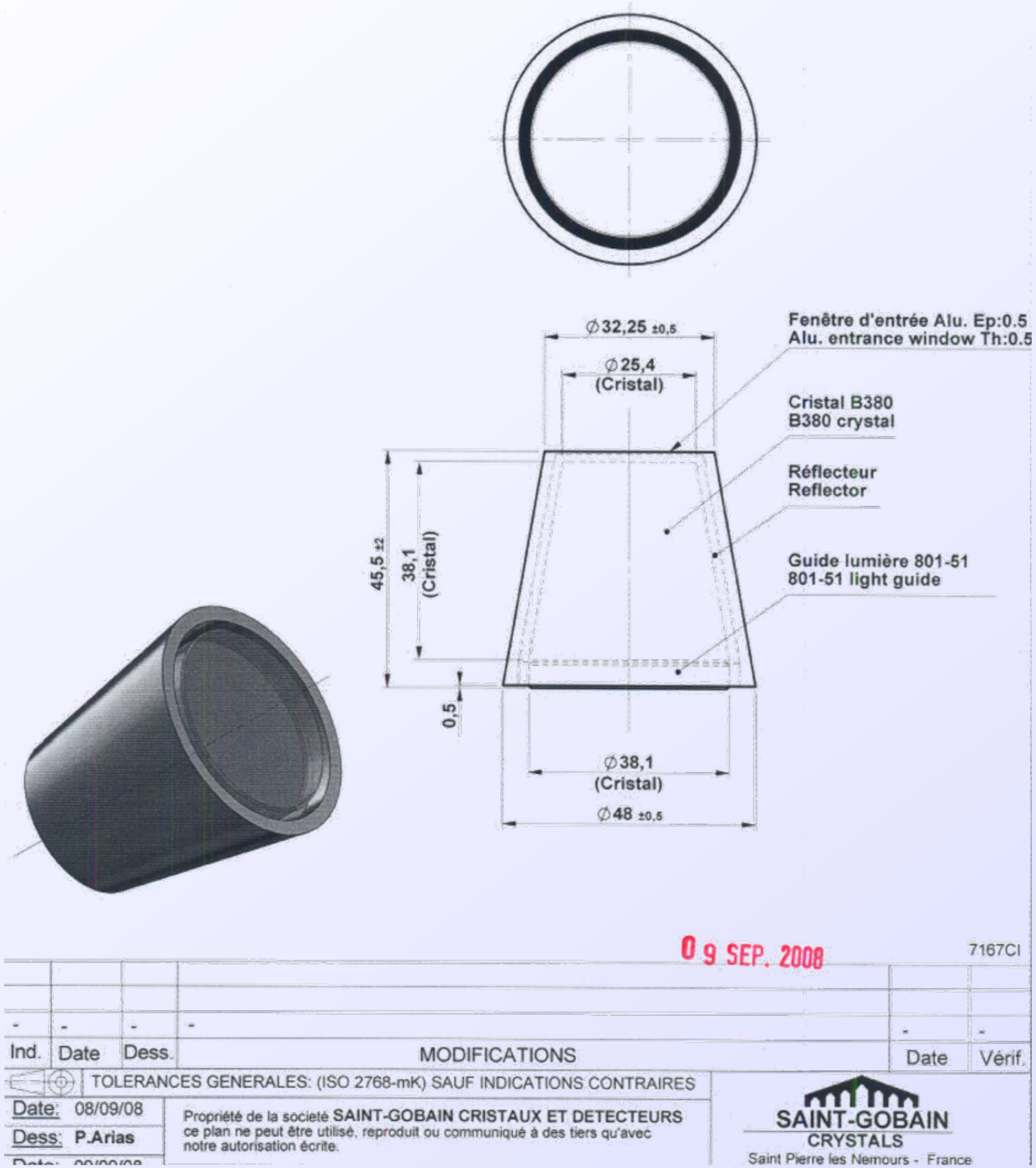


Larger crystals have a relatively better time resolution

38.1 x 3.81 cm 5% Ce doping since 2007

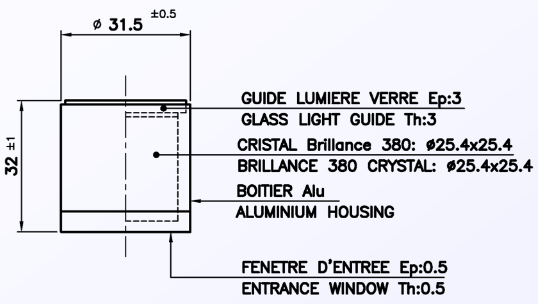
Time resolution 150(10) ps FWHM at 1.3 MeV

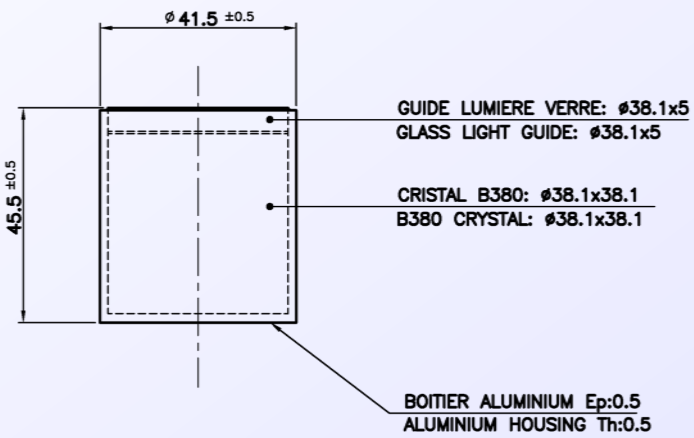
$LaBr_3(Ce)$ detectors

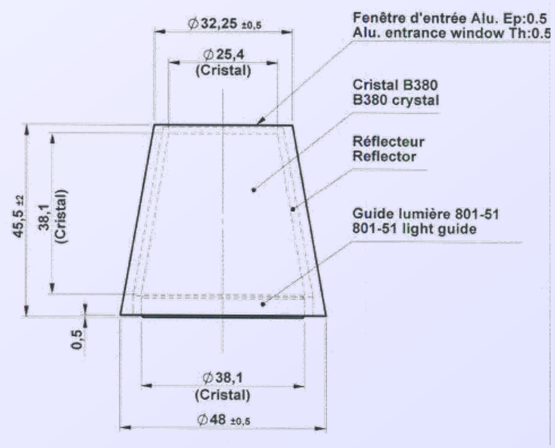


- ✓ Array arrangement
- ✓ The truncated cone geometry may offer better time resolution
  - 30% better for BaF_2
- ✓ High cost! (about 60% higher than for a cylinder) [under discussion]
- ✓ Three crystals in the collaboration (UCM, NIPNE x 2)

$LaBr_3$(Ce) detectors







25.4 x 25.4 mm (10%) Ce doping since 2005

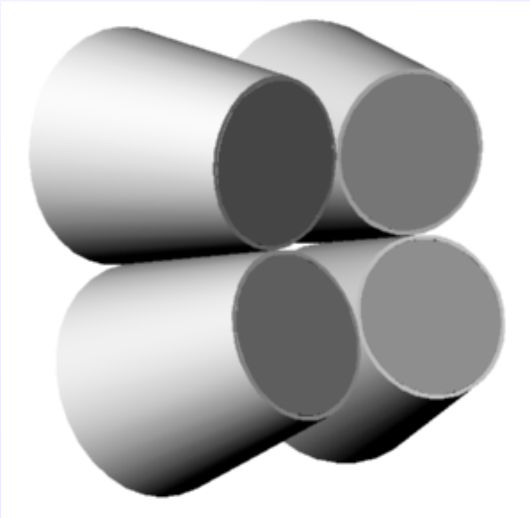
123(5) ps FWHM (@1.3 MeV)

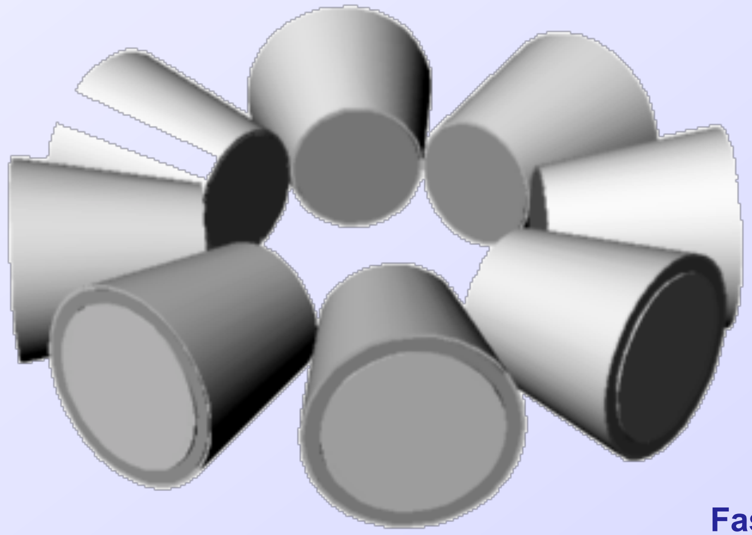
38.1 x 38.1 mm 5% Ce doping since 2007

150(10) ps FWHM

38.1/25.4 x 38.1 mm 5% Ce doping (2009)

Time resolution 140-145 ps FWHM at 1.3 MeV - Tested ISOLDE





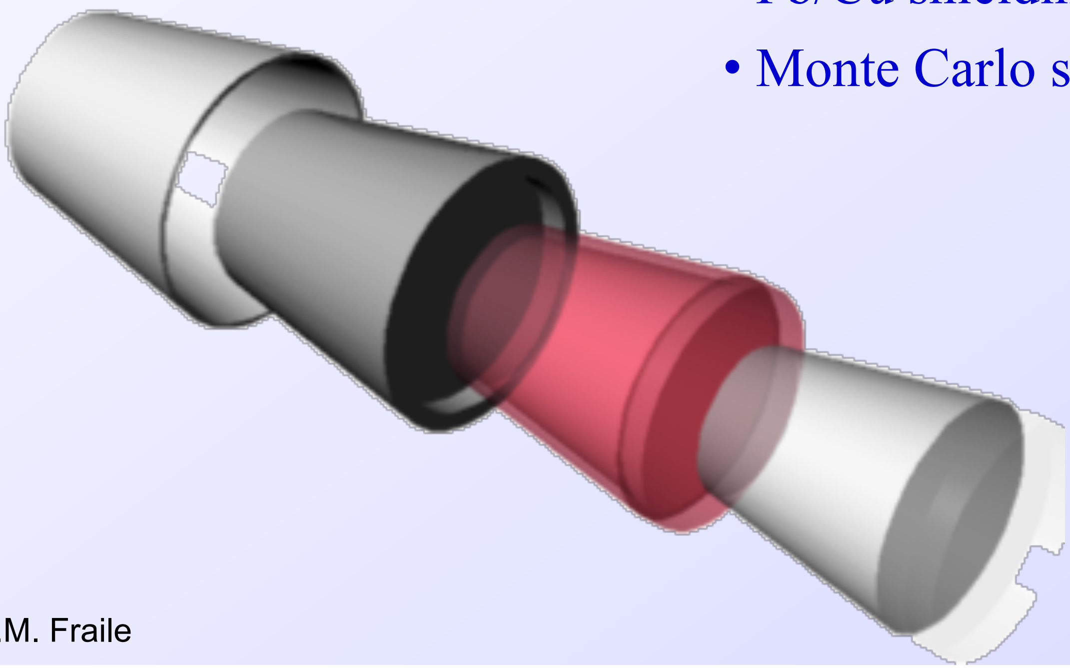
Shielding

✓ Al casing

- 48 mm Ø vs 38.1 mm crystal Ø
- Much reduced in later versions
- Cross-talk

✓ Pb shielding

- used now in exps
- Pb/Cu shielding
- Monte Carlo simulations



UCM
Grupo de Fisica Nuclear

Photomultipliers

XP20D0
8 stage

XP2020 URQ
12 stage

✓ XP2020 URQ: best timing response (28ns transit time at 2500-3000 V) but too high gain…

✓ XP20D0: 8 dynodes, needs to be operated at 1100 V for good timing (40 ns transit time)… but gain is too high and we have 15-20% nonlinearity (space-charge)

✓ XP20E0 6-dynode tube: 2 units purchased by UCM, using now Voltage divider 184K type (for D0). Not optimized for linearity

XP20E0
6 stage

Hamamatsu R9779

R9779
8-stage

✓ Accelerator ring at front-end

✓ Worse timing uniformity than Photonis XP20D0

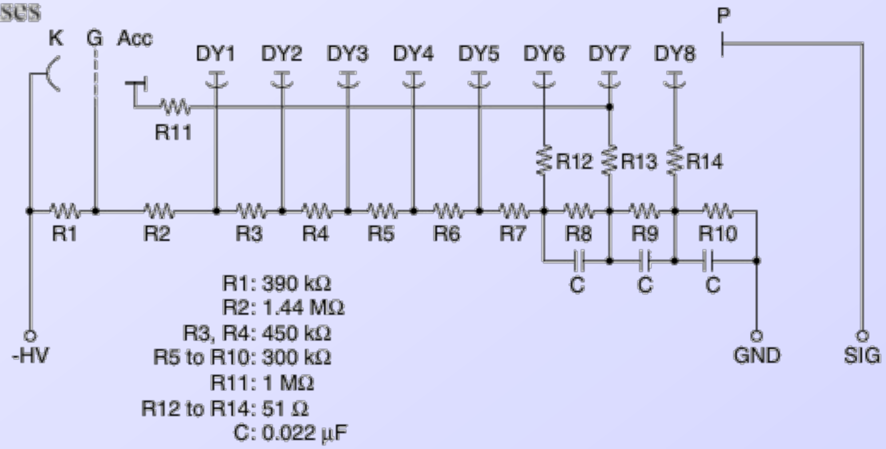
✓ Timing tested [vs EJ-200 10 mm disk coupled to XP2020Q, worse than these fast tubes]

F. Bauer et al., IEEE Trans Nucl Sci 54 (2007) 422

COINCIDENCE TIMING RESOLUTION

Tube	XP2020Q no. 42067 *(Reference PMT)*	Timing resolution
XP2020Q no. 42067	-	
XP2020Q no. 42107	317 ps	*224 ps*
R9779 no. 23	295 ps	192 ps
R9779 no. 24	307 ps	210 ps
XP20D0 no. 2103	288 ps	181 ps
XP20D0 no. 2111	272 ps	154 ps

Scintillator material is plastic, in all cases



✓ Electron tubes [UK]

- G Sperrin
- Production moved to US

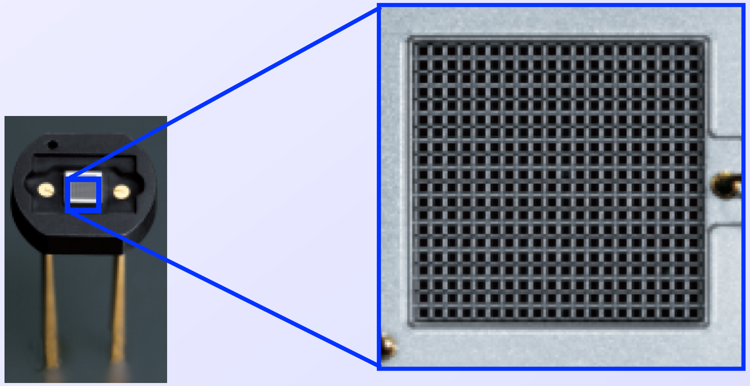
Hamamatsu **R5380** low gain, high current PMT's

Photosensors: SiPMs?

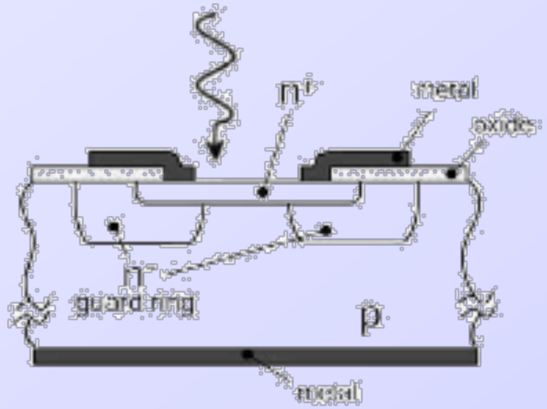
✓ SiPM (G-APD, MPPC, …)

- ARRAY of single Geiger mode Avalanche Photo-Diodes, operated above breakdown voltage (Gain ~1E6)
- Typically 100-1000 pixels / mm^2
- Pixel size ~20-30μm
- C_{pixel} ~ 50fmF
- Quenching resistor R_{pixel} ~ 1-10 MΩ
- All pixels connected in parallel only one signal line

  Output = Sum of individual pixel signals



- Bias voltage ~ 2 V above breakdown
- Features: high gain, low operation voltage, fast timing, compact size, “low cost”, compatible with magnetic fields



Single Photon Avalanche Diodes (SPAD): S.Cova et al., Appl. Opt. 35 (1996) 1956

SiPMs

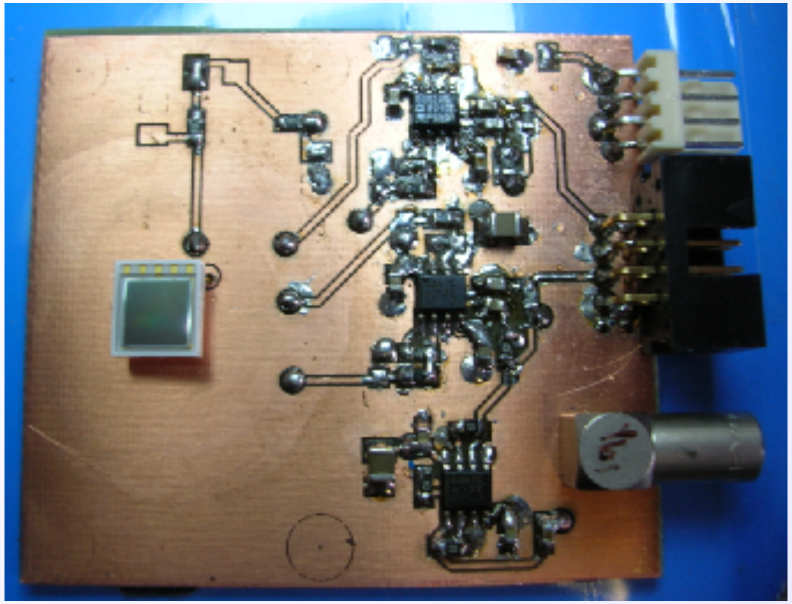
- ✓ Hamamatsu
- ✓ SenSL
- ✓ [New] Philips

$$N_{pixels} = N_{available} \cdot \left[1 - e^{\frac{N_{photo-electrons}}{N_{available}}} \right]$$

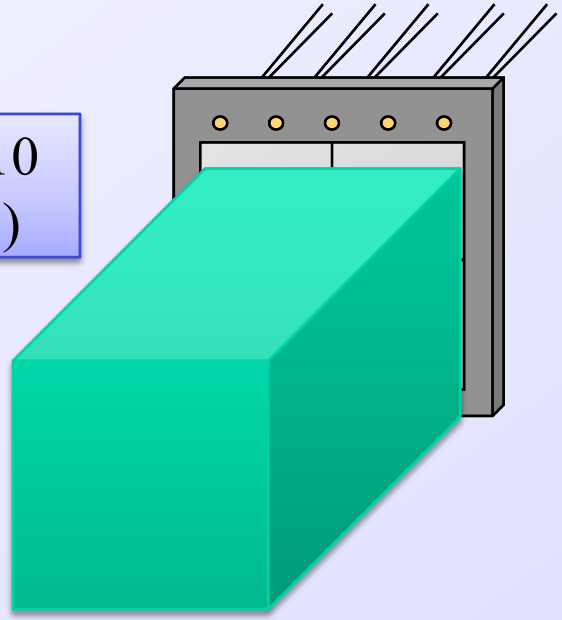
Linear if ~50% of pixels fired

Intrinsic QE ~80%
Fill factor

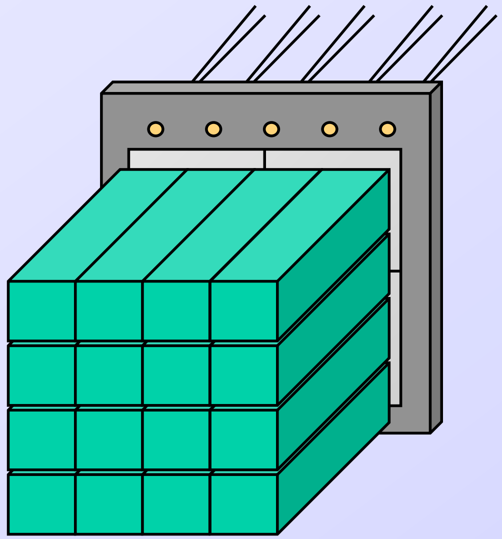
Test of Hamamatsu 2x2 SiPM array



LYSO crystal (10 × 10 × 20 mm^3)

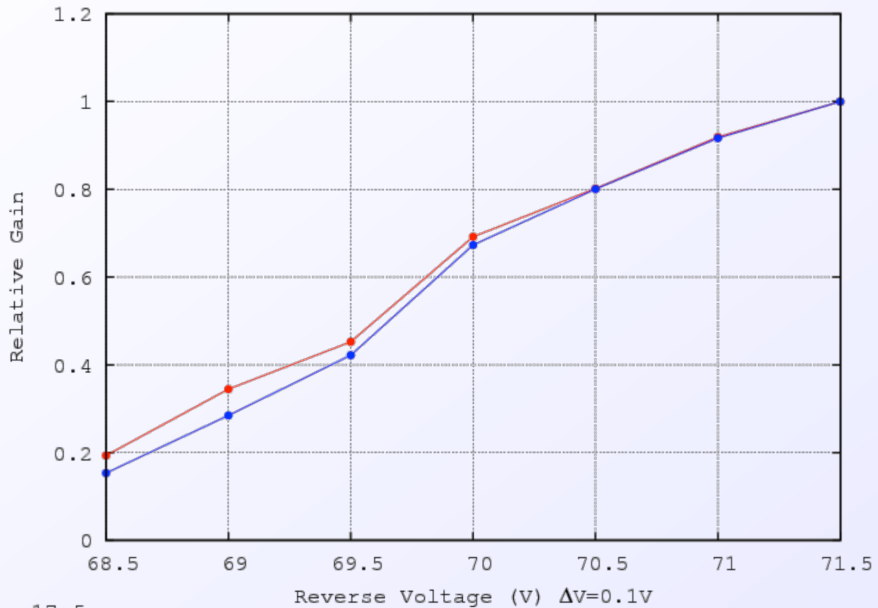


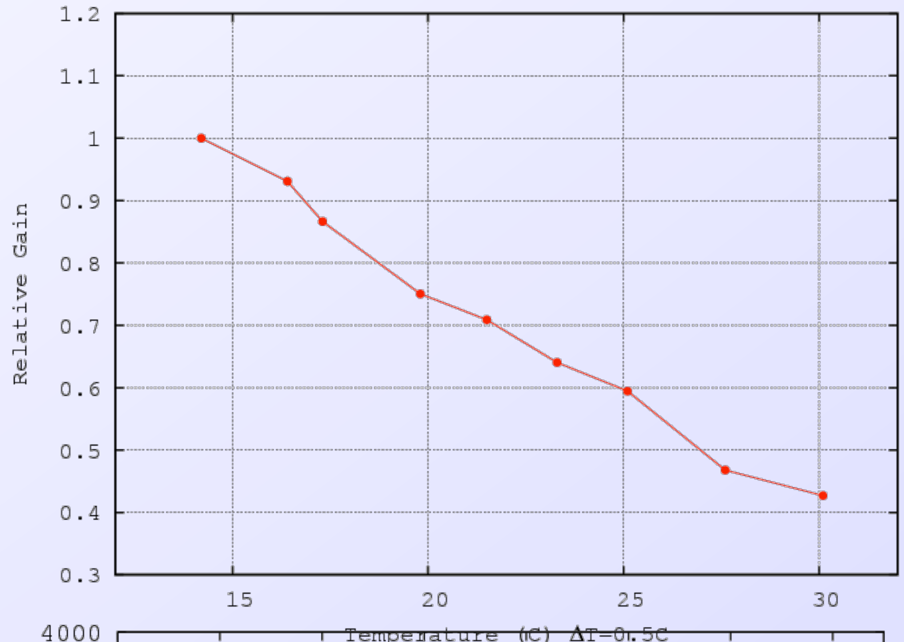
4 × 4 LYSO matrix (1.5 × 1.5 × 12 mm^3)

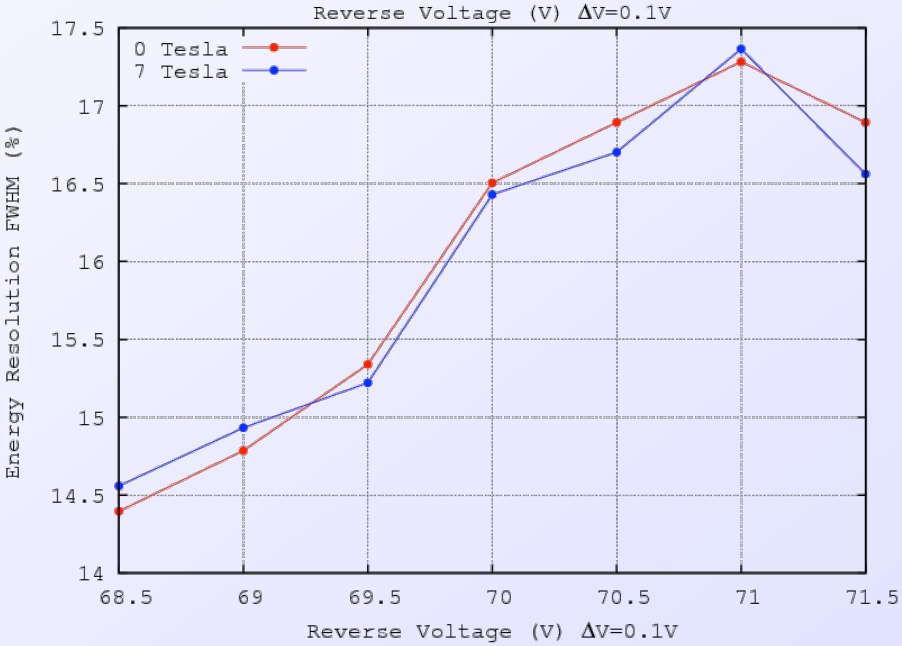


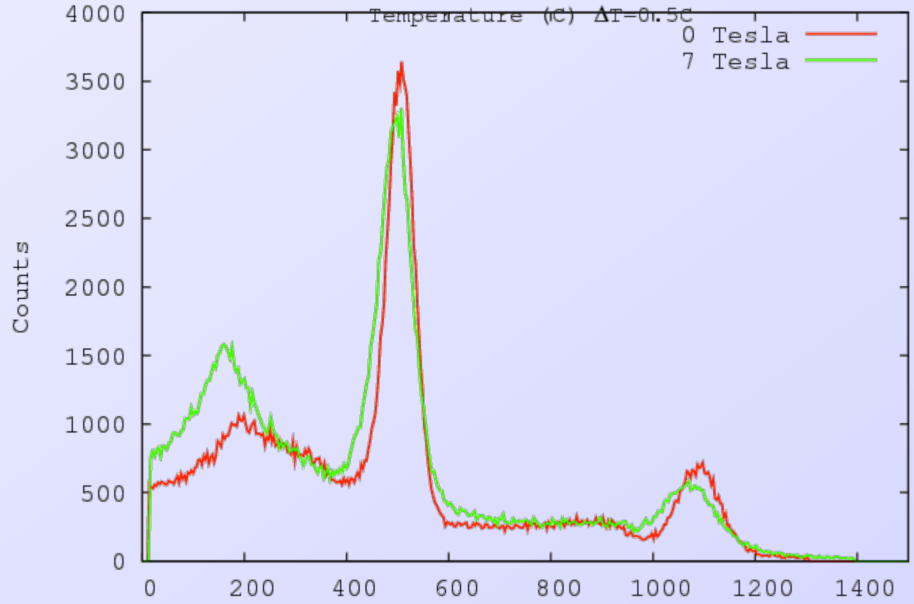
Bruker BioSpec 70/20 USR – 7 Tesla
LIM – Hospital Gregorio Marañón

Test of Hamamatsu 2x2 SiPM array

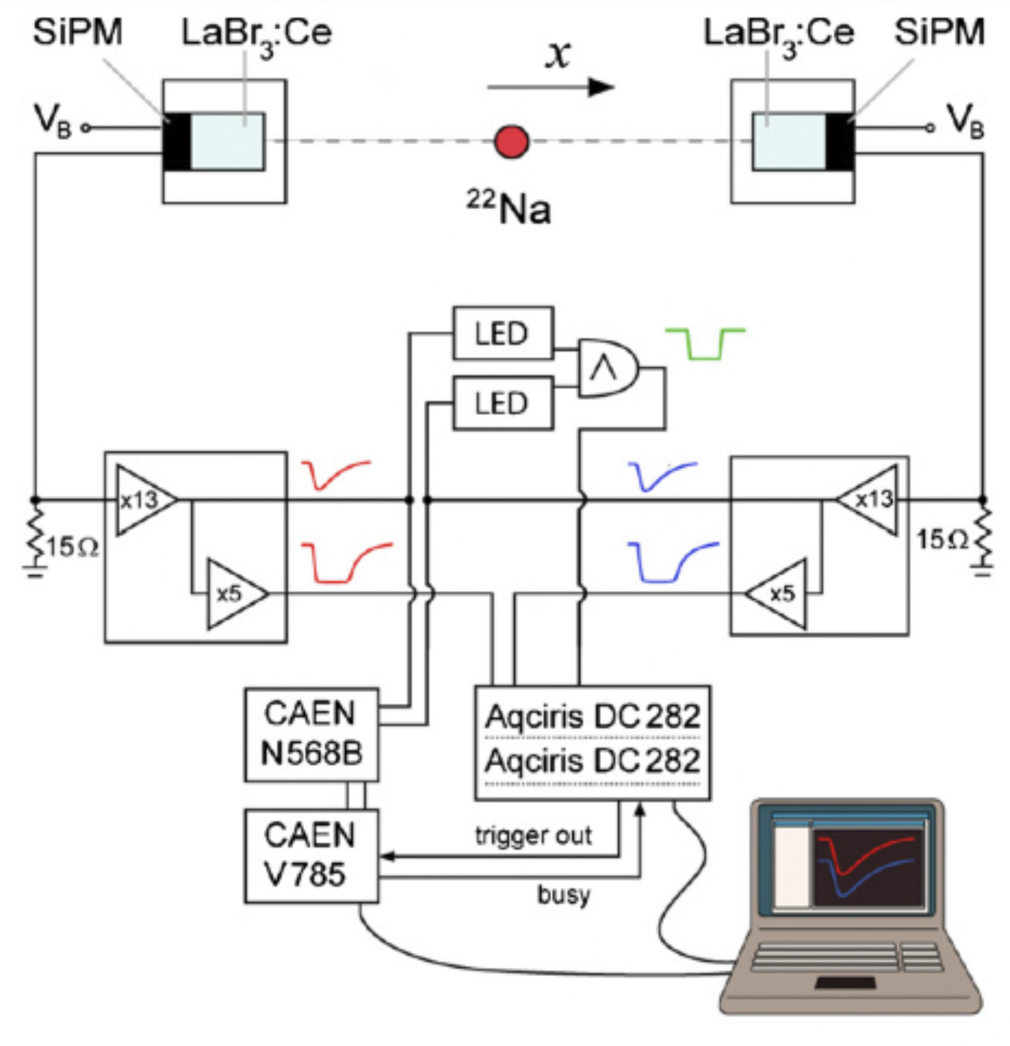


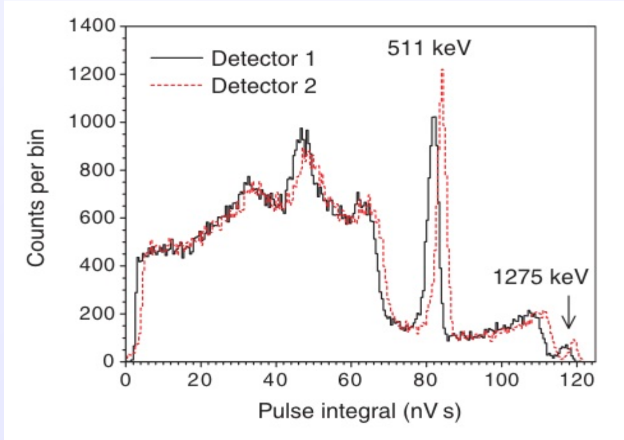


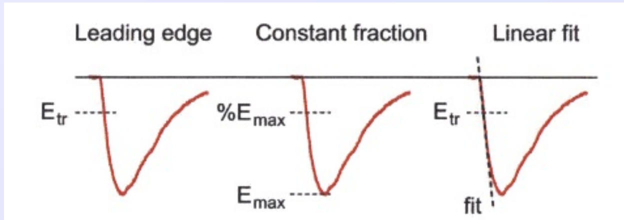


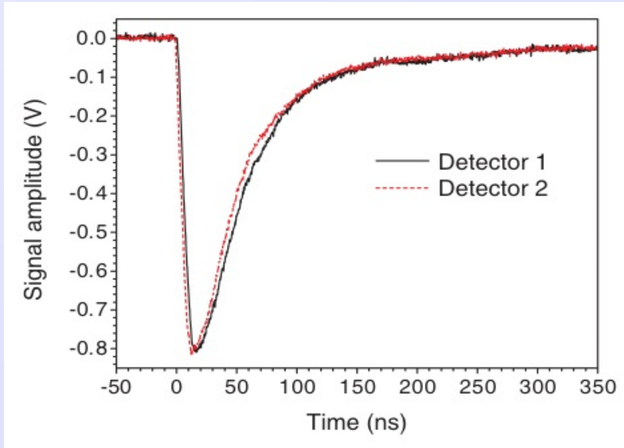


[Small] $LaBr_3$:Ce and SiPMs timing







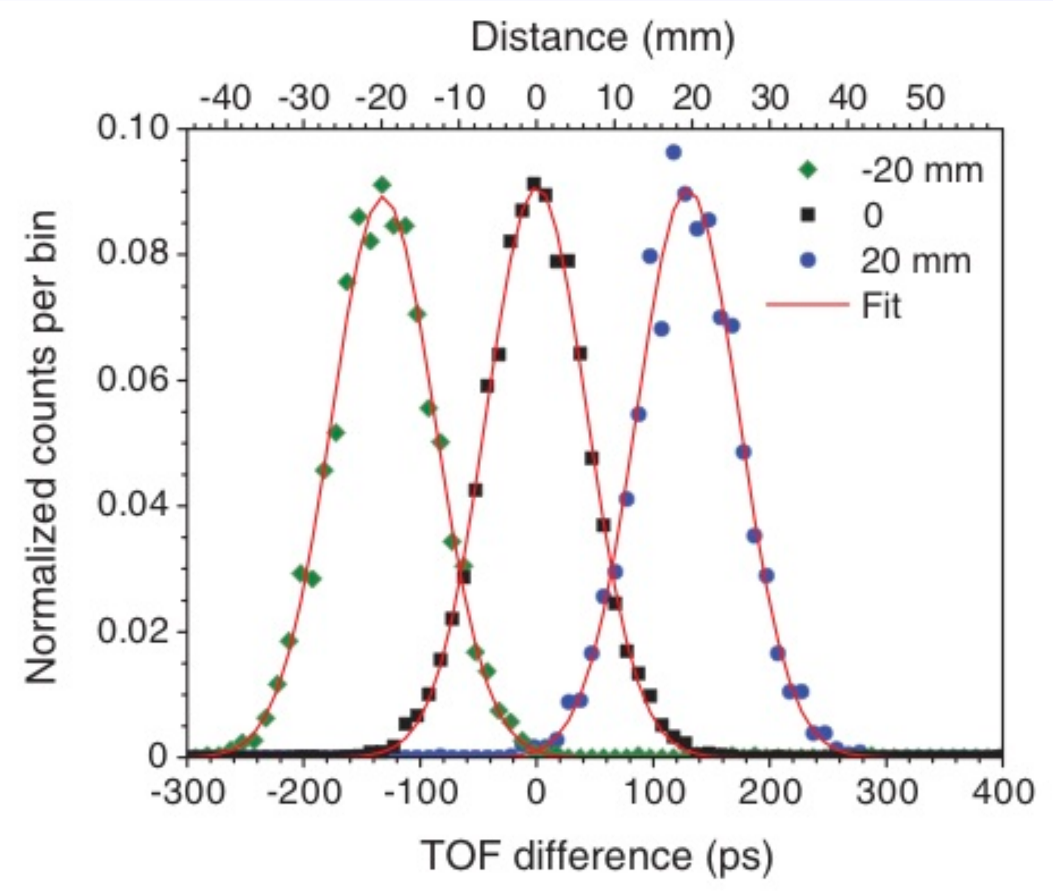


$LaBr_3$:Ce and SiPMs for time-of-flight PET

D.R. Schaart, Phys. Med. Biol. 55 (2010) N179–N189

[Small] LaBr$_3$:Ce and SiPMs timing

Two 3 mm × 3 mm × 5 mm LaBr$_3$:Ce crystals + two 3 mm SiPMs



SiPMs, using a ^{22}Na point source located at *$x_1 = -20$ mm ± 0.25 mm (green diamonds), $x_2 = 0$ mm ± 0.25 mm (black squares), and $x_3 = 20$ mm ± 0.25 mm (blue circles). The red curves indicate Gaussian fits to the data. The average coincidence resolving time (CRT) equals 101 ps ± 2 ps FWHM, corresponding to 15.1 mm ± 0.3 mm FWHM.*

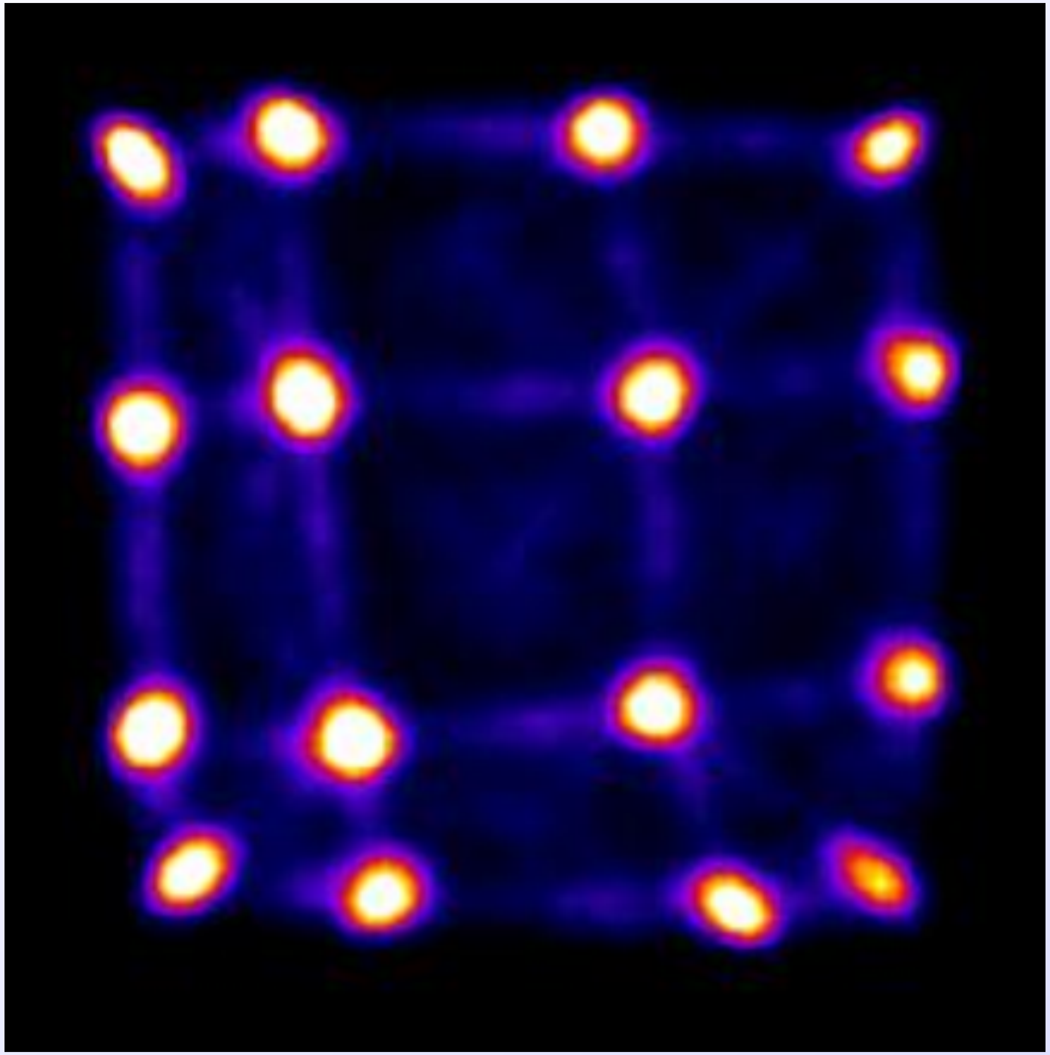
Discussion

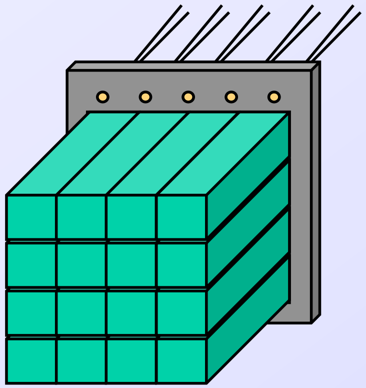
- ✓ Timing detectors
- ✓ Beta detectors
- ✓ Photosensors
- ✓ DAQ – Electronics
- ✓ Calibration, software, analysis
- ✓ DESPEC array

- ✓ PMs-VDs / explore options
- ✓ Simulations
- ✓ Money matrix / funding
- ✓ Proposals
- ✓ TDR
- ✓ Beta detector / AIDA

- ✓Planning

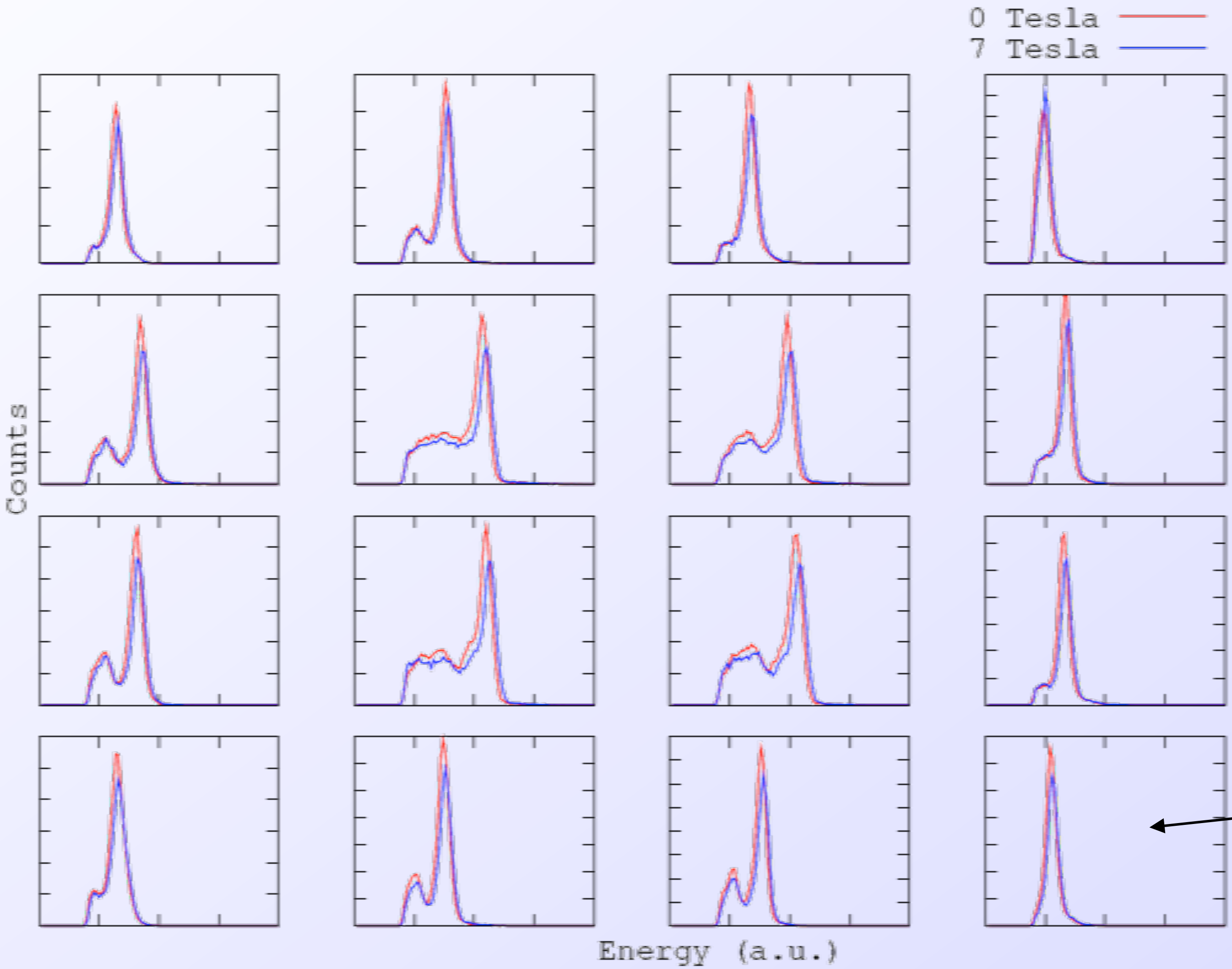
Flood Field Image



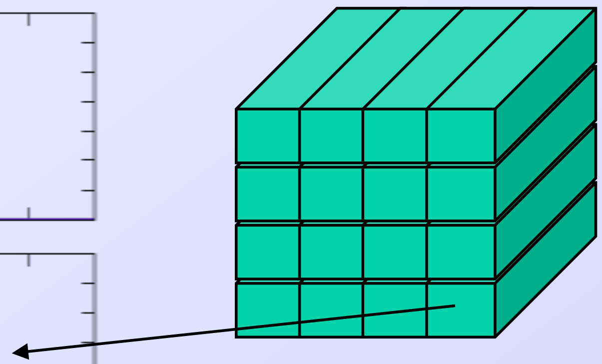


- ^{18}F
- 68.2 V - 20ºC
- $5 \cdot 10^5$ counts
- Software Anger logic

Crystal Energy Spectrum



- ^{18}F
- 68.2 V - 20ºC
- $3 \cdot 10^4$ counts/crystal



Energy Resolution @ 511keV

FWHM (%)	0 Tesla	7 Tesla
Center	11.2	11.9
Center Edge row	14.1	14.4
Corner	21.7	21.4