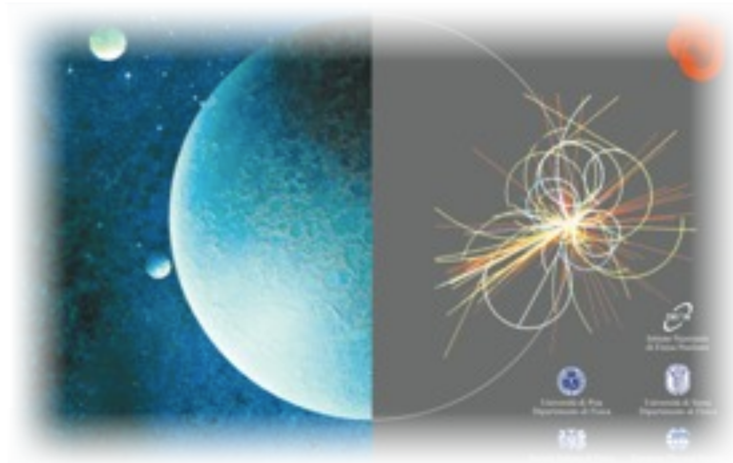

Timing resolution measurement of a 3'' Lanthanum Bromide detector

L. Galli, M. De Gerone, S. Dussoni, D. Nicolò, A.Papa, F. Tenchini, G. Signorelli

INFN Pisa, INFN Genova, PSI Villigen

12th Pisa Meeting on Advanced Detectors La Biodola, Isola d'Elba (Italy) May 20 - 26, 2012

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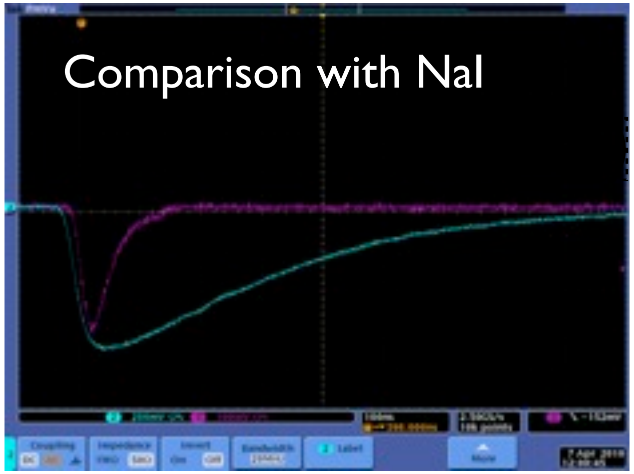
$LaBr_3$:Ce as a detector

$LaBr_3(Ce)$ recent dense, luminous and fast scintillator

Density (g/cm³)	**5.08**
LY (pho/MeV)	**63000**
Decay Time (ns)	**16**
λ emission (nm)	**380**
Refractive index	**1.9**



Unprecedented energy resolution: 3% FWHM @ 611 keV (1"x1" crystal)

Usage:
- nuclear spectroscopy
- nuclear imaging: TOF PET, SPET
- geophysics and astrophysics

HEP experiments in the high intensity frontier, in particular for cLFV searches:
- energy in the [50,100] MeV region
- excellent energy resolution is crucial for background rejection
- promising time resolution, to be investigated!

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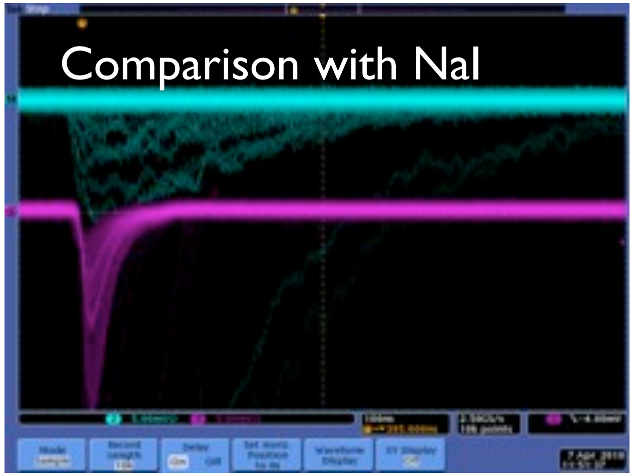

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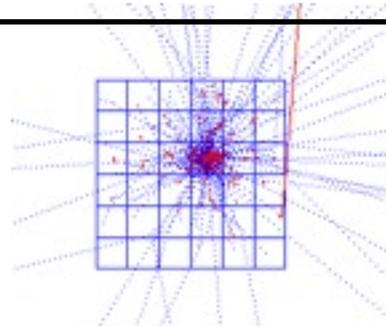
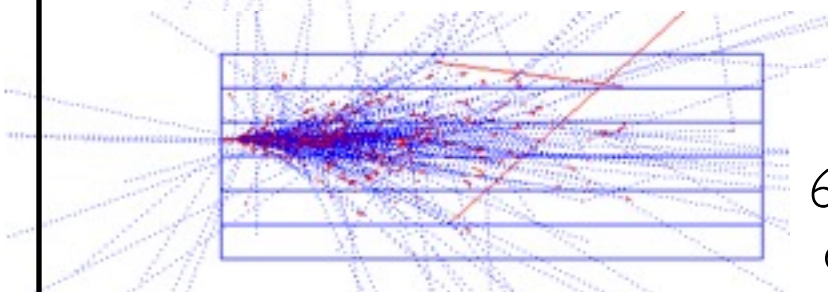
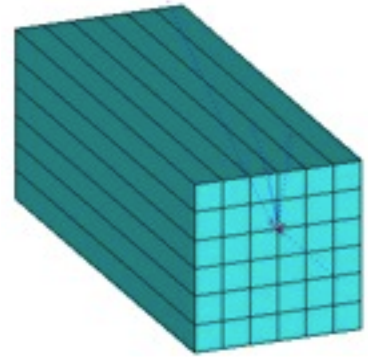
HEP segmented detector

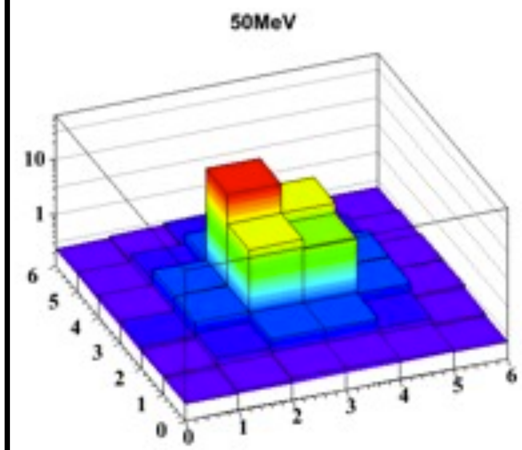


100 MeV gamma

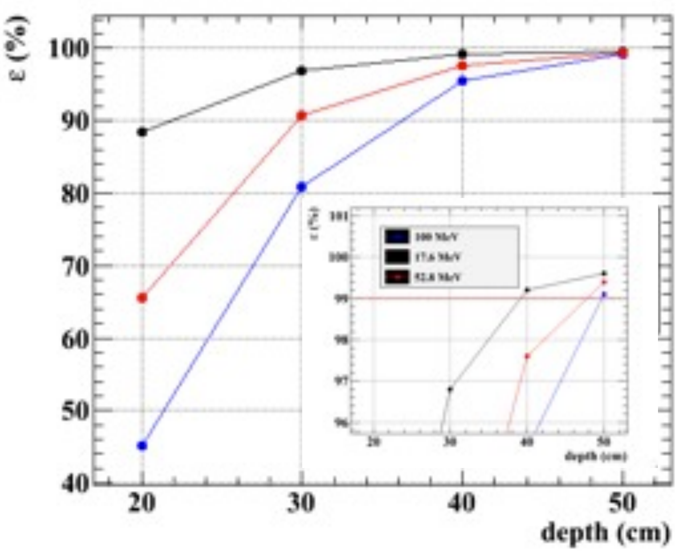




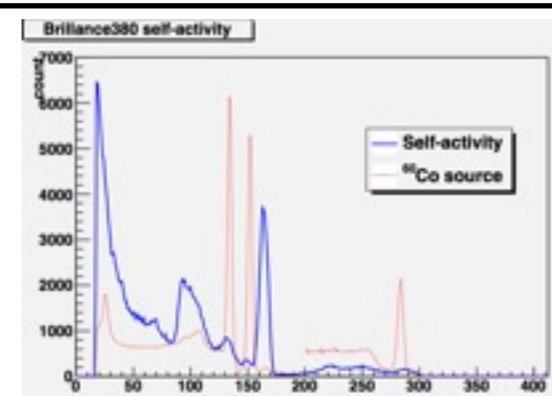
6x6 array of crystals, each 1”x1” x 50cm



Energy deposit in single crystal O(10) MeV



100 MeV containment with depth = 50 cm

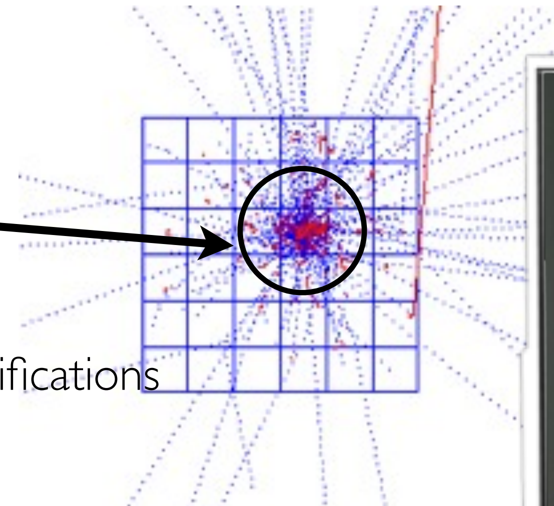


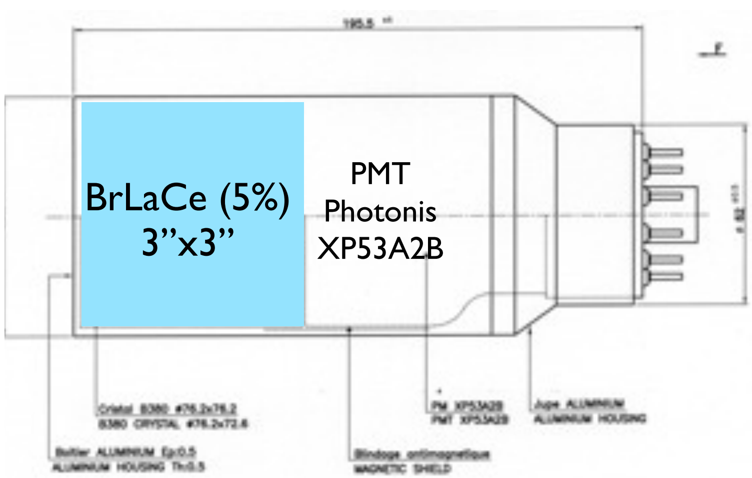
- ~1.5 MeV self-activity line
- Online equalization of all channels
- Online calibration and monitoring of energy scale

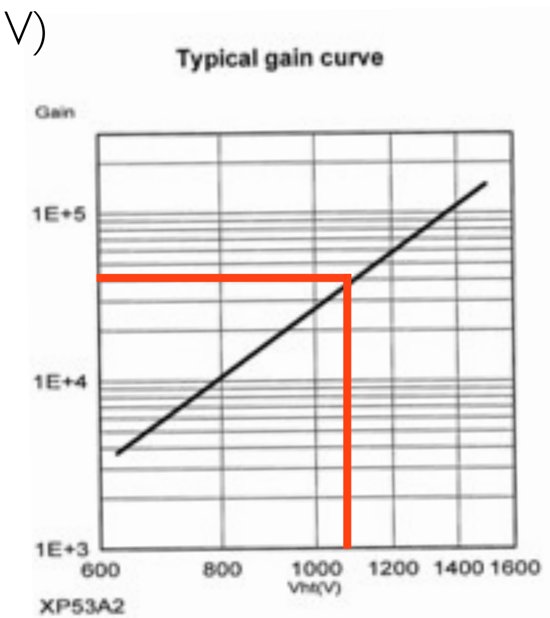
Brillance 380 detector

Customized detector from Saint Gobain

- largest crystal available: 3”x3”
  - good containment @ O(10 MeV)
- time measurement
  - fast PMT with low TTS according to our specifications
- energy/gain linearity (crystal sanity check)
  - monitored with last dynode output
  - PMT in “low gain mode” (HV = 1100 V)

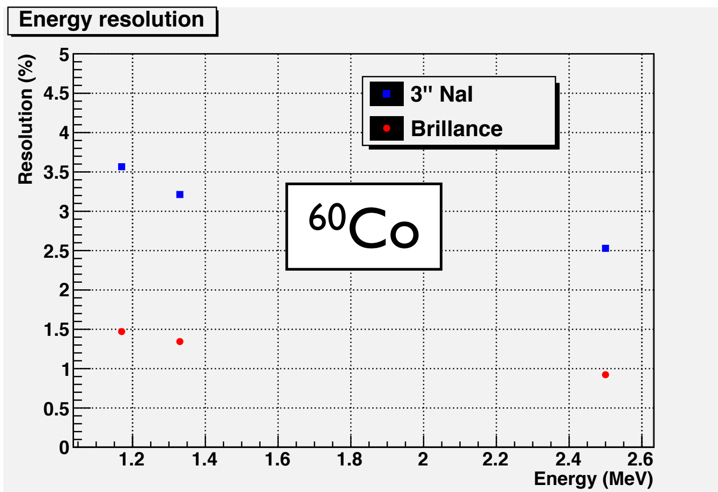


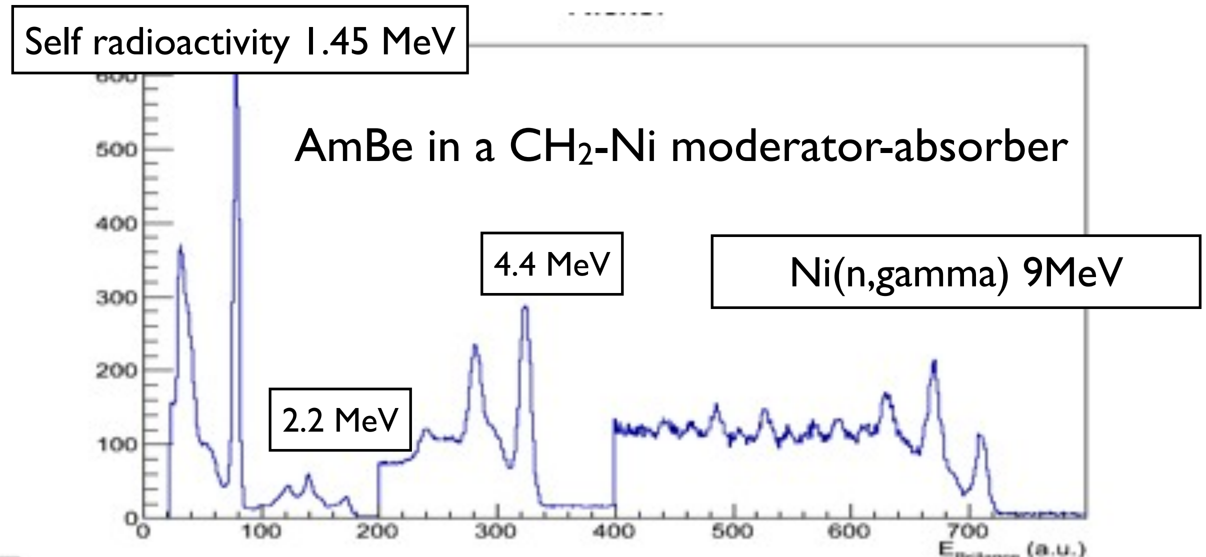


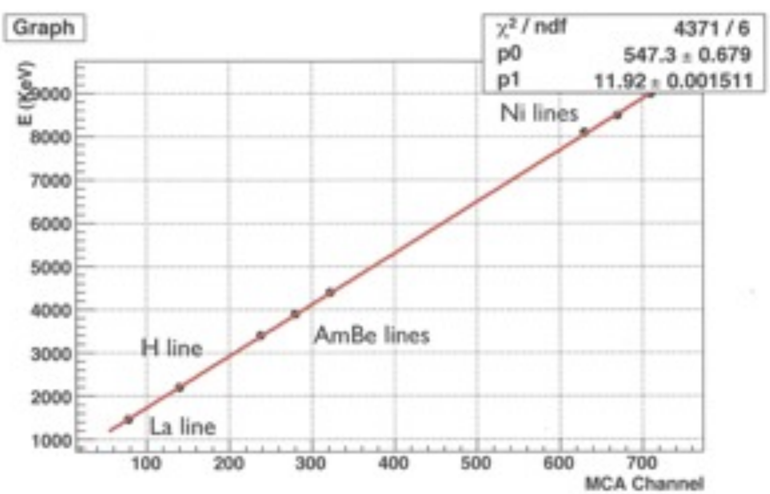


Confirm energy resolution

Our results consistent with previous measurements on 1''x1'' and 2''x2'' crystals even with a not optimized set-up







Spectra taken with a PC-based Multi Channel Analyzer

σ_E more than a factor 2 better than NaI

Linearity better than 1% up to 9 MeV

Time measurement method

The characterization of the Brillance time resolution was the aim of our measurement campaign

RECIPE: compare photon time between at least two coincident particles, with different devices

Implementation:

1) Physical sources

- production of two coincident photons from either ^{60}Co source:

  E_γ 1.17 & 1.33 MeV

  or nuclear reaction $^{11}B(p,\gamma)^{12}C$:

  E_γ 4.4 & 11.7 MeV

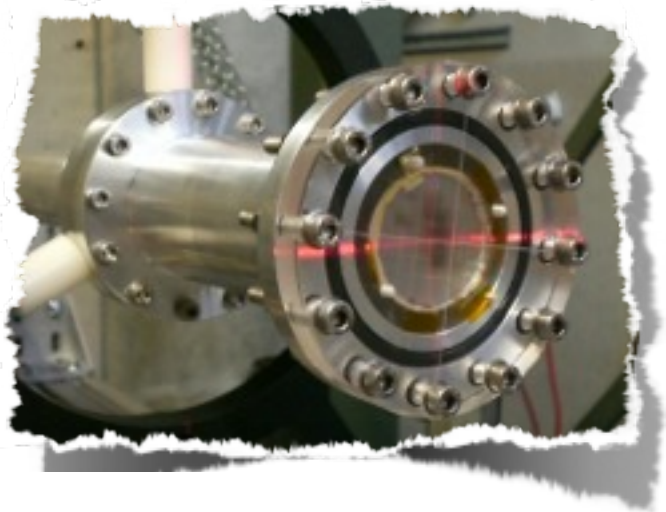
- This gives us the possibility to explore different energy range, in the region of interest

2) Instrumentation

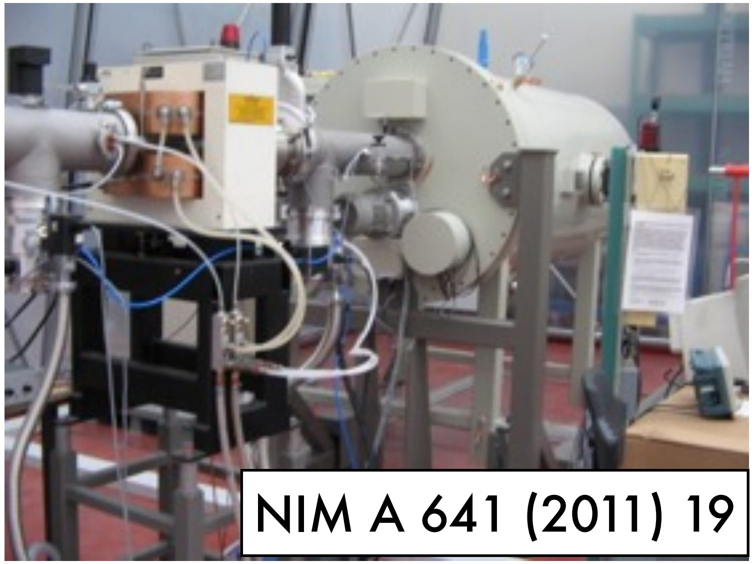
- Ideal case: 2 identical Brillance crystals
  - Real case: a set of different reference counters
- Together with a suitable DAQ architecture optimized for reliable and high quality data-taking

1) Gamma production

- Coincident E_γ = 4.4, 11.7 MeV from $^{11}B(p,\gamma)^{12}C$
  - Cockcroft-Walton accelerator @ Paul Scherrer Institut (Villigen) p-beam on $Li_2B_4O_7$ target
  - Working point E_p = 700 keV, I_p = 1 μA
- Coincidence rate ~20 Hz
- < 1 cm^2 beam spot



CW target used also as support for ^{60}Co source



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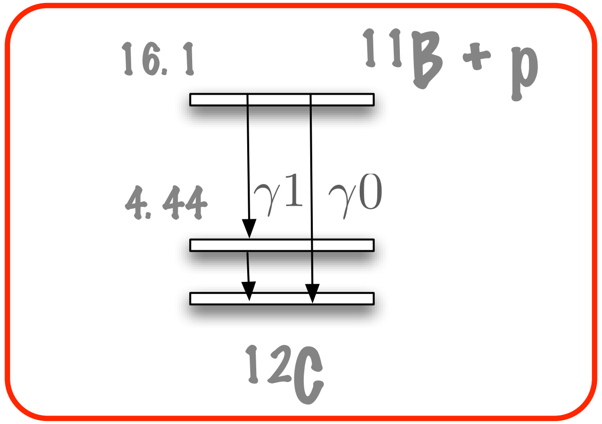
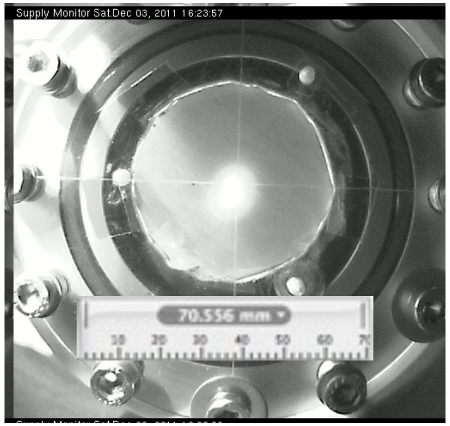


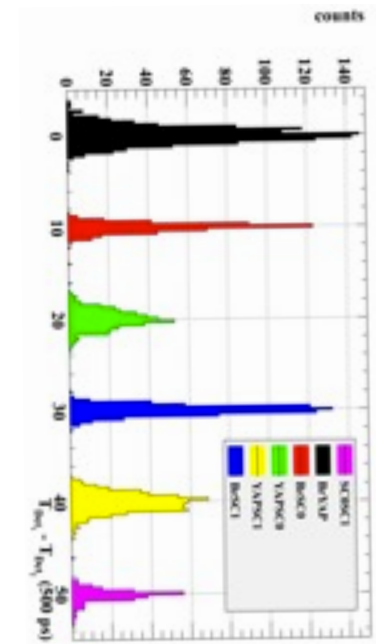


$\sigma_{beamspot} \approx 15\ ps(5mm)$

2) Resolution extraction

With 4 detectors and 2 monochromatic photons a system of 6 equations constraint the 4 unknown quantities

$$\left\{\begin{array}{lcllll}
\sigma^2_{ab} & = & \sigma^2_a & + \sigma^2_b & & \\
\sigma^2_{ac} & = & \sigma^2_a & & + \sigma^2_c & \\
\sigma^2_{ad} & = & \sigma^2_a & & & + \sigma^2_d \\
\sigma^2_{bc} & = & & \sigma^2_b & + \sigma^2_c & \\
\sigma^2_{bd} & = & & \sigma^2_b & & + \sigma^2_d \\
\sigma^2_{cd} & = & & & \sigma^2_c & + \sigma^2_d
\end{array}\right.$$

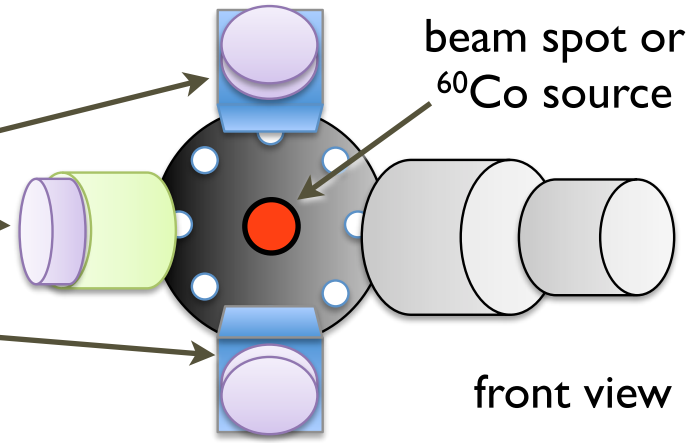


In the real case the equations take into account the different photon energies and the systematics such as electronics and beam spot contribution

Experimental Setup

Need 3 reference detectors:

- 1 YAP crystal 2"x2" (cylindrical)
- 2 BC404 cubes 4x4x4 cm



all detectors were read out by very fast Hamamatsu PMT R5924 (2" fine mesh, TTS ~450 ps)

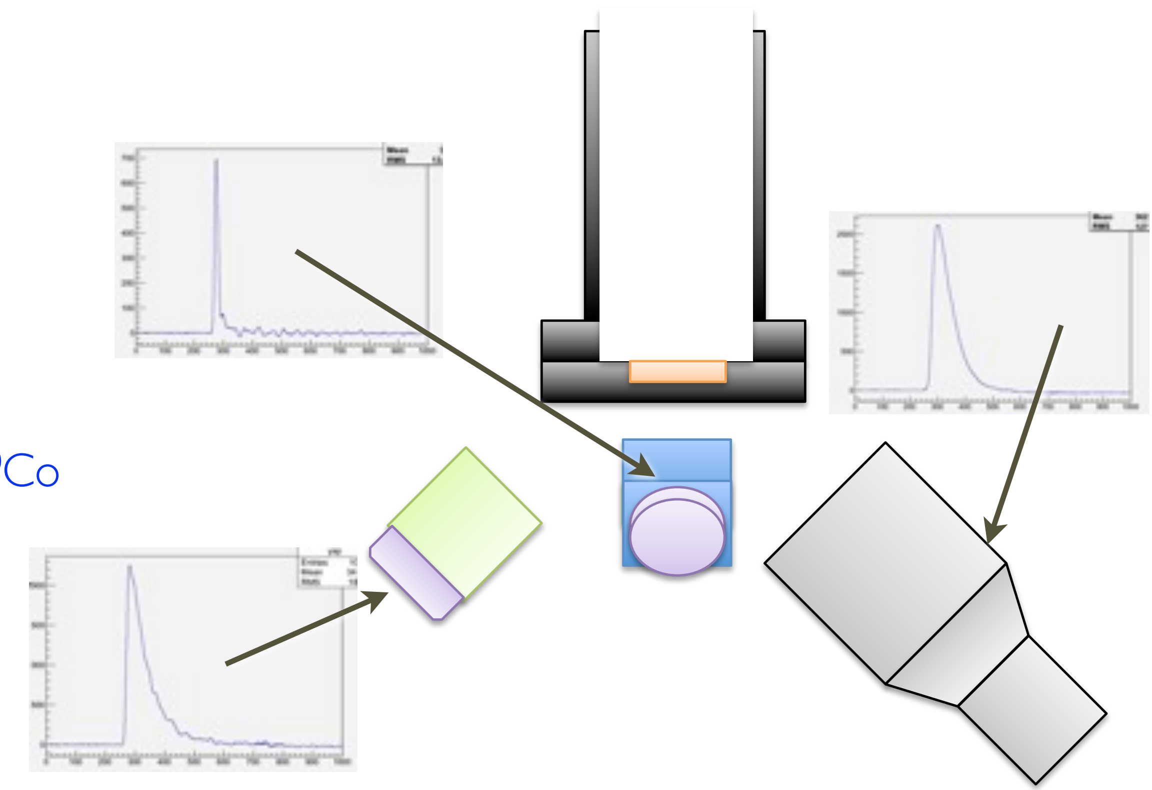
Symmetrical geometry

Maximizes coincidence rate

All detectors subtend ~same solid angle

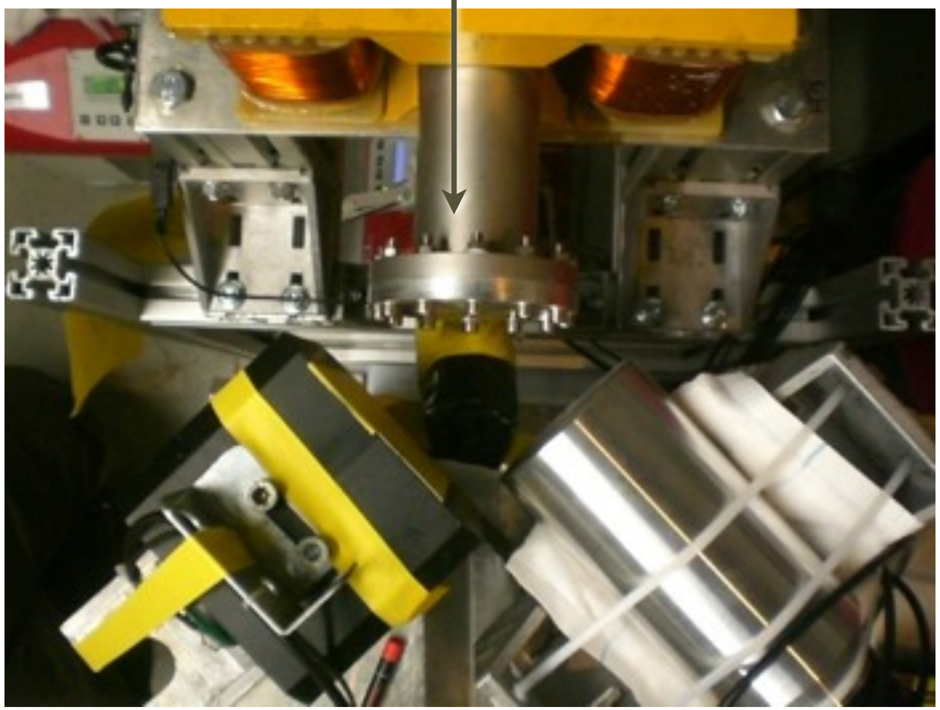
Allows fast calibration & cross-check with ^{60}Co

Two identical counters to check systematics

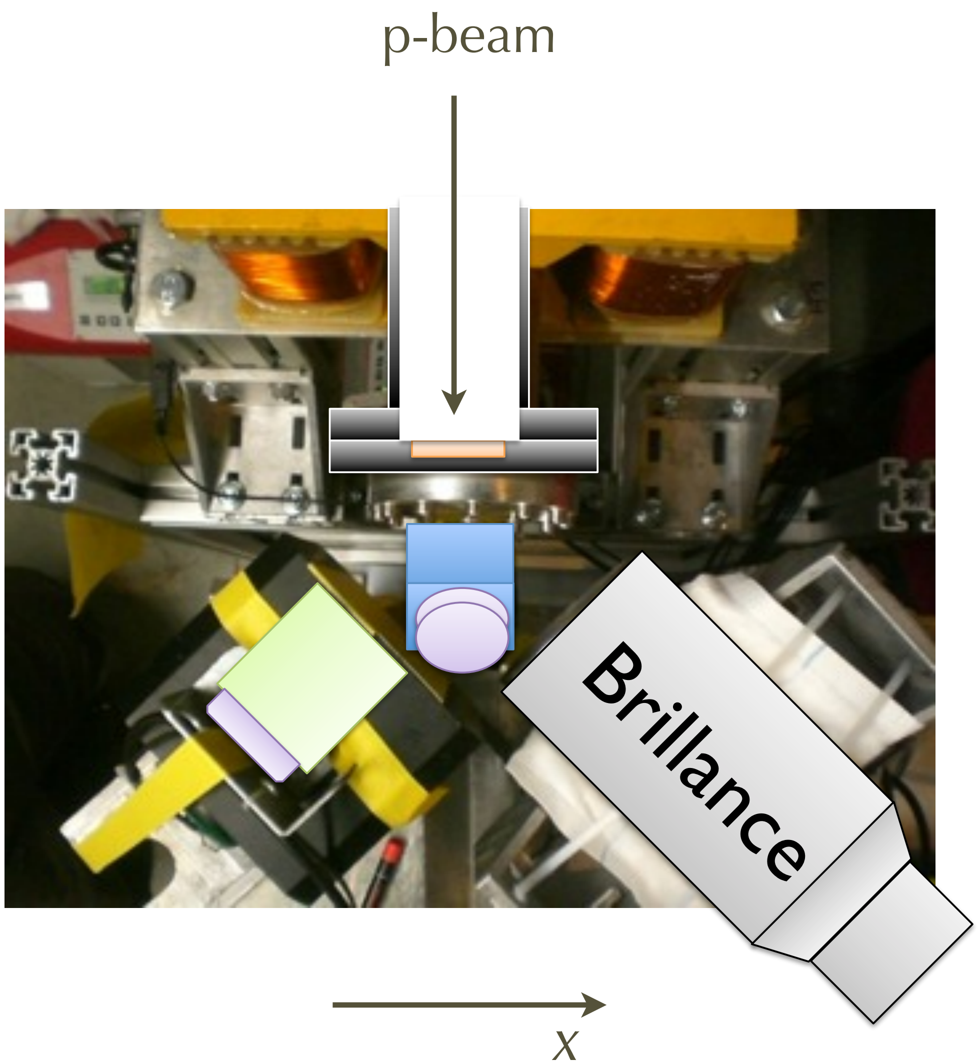


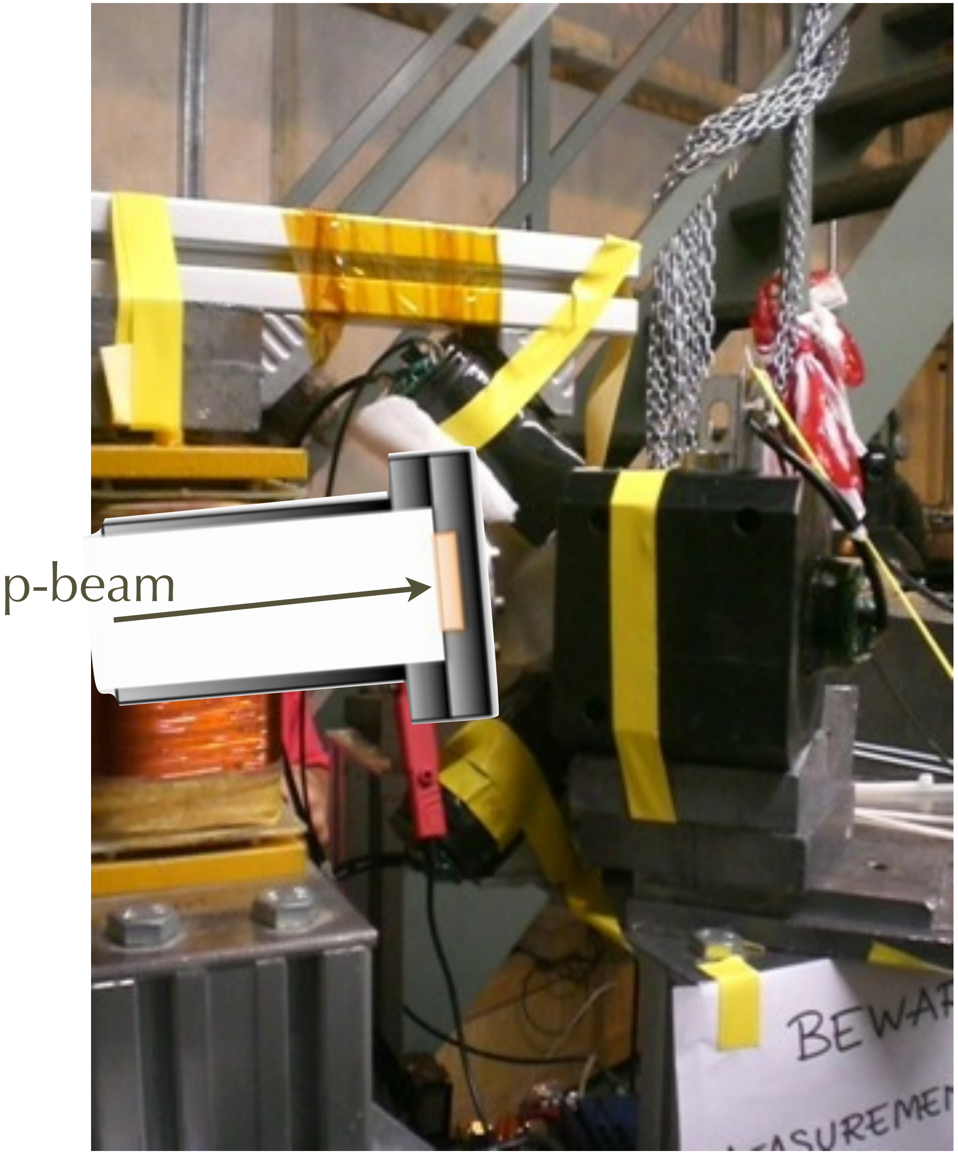
Experimental set-up: pictures

p-beam



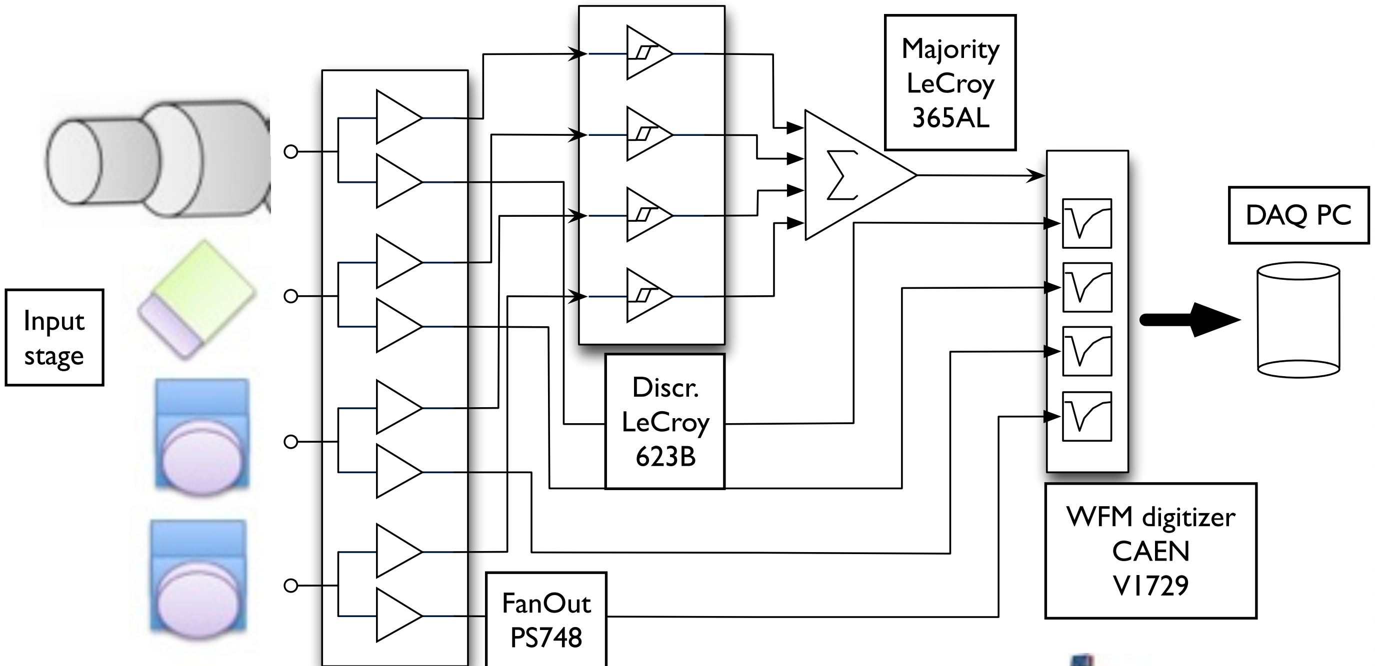
Experimental set-up: pictures

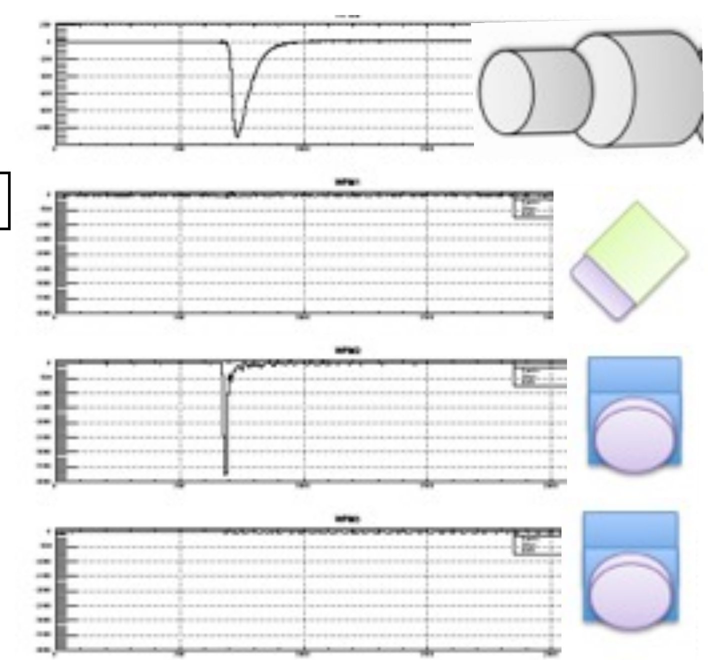




Electronics

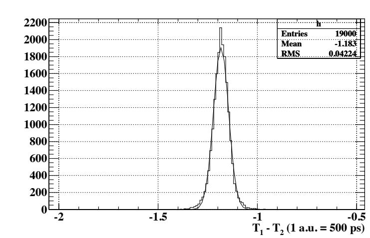
Maximum care of the electronics chain: waveform digitizer to preserve the maximum information from the detectors, QDC CAEN V465 and TDC CAEN V488 for redundancy





- CAEN V1729 waveform digitizer
  - *4 channels, 12 bit, 2 Gsamples, 300MHz BW*
- DAQ
  - *root-based front-end: online monitor and well defined data structure*
  - *~50 Hz maximum rate*

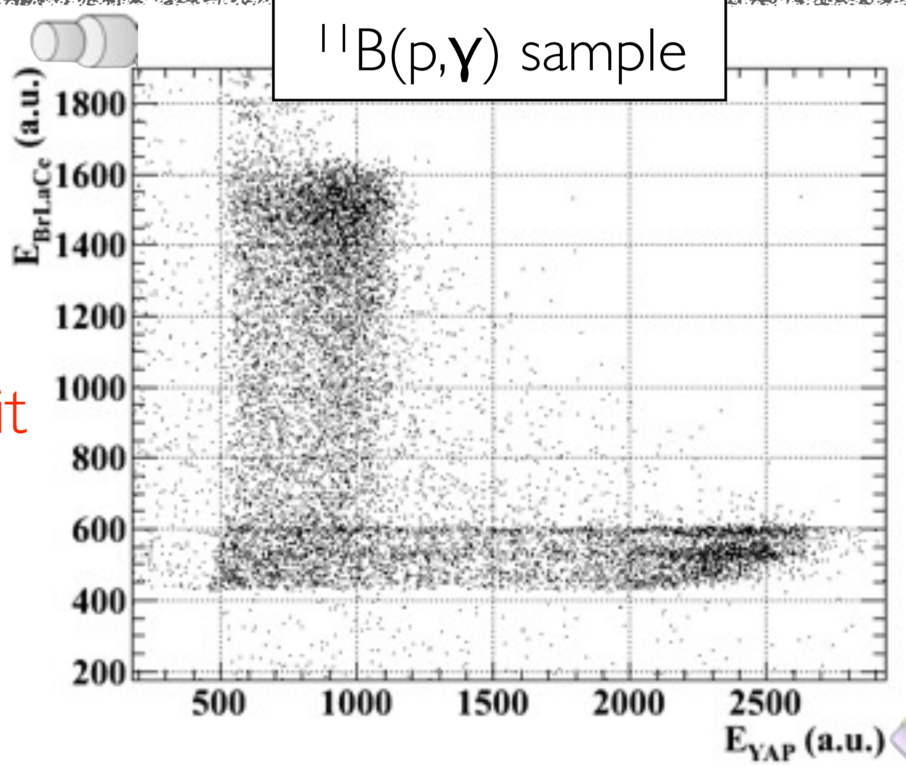
Trigger majority
any combination of two over the four detectors over threshold



$$\sigma_{ele} \approx 20ps$$

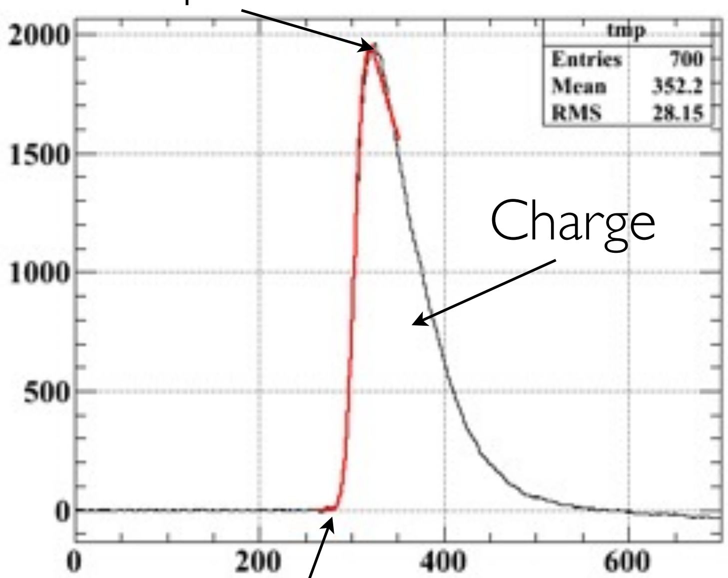
Data analysis

Select coincidences of detector pairs
- energy deposit on the detectors
- QDC and the waveform charge



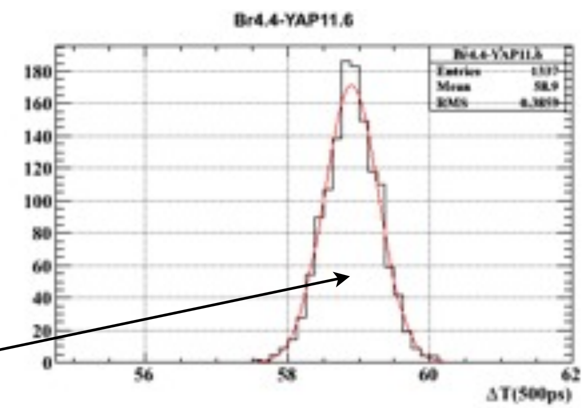
Time for each detector from waveform fit
- $f(t) = A * ERF(t - t_0, \sigma) * e^{-t/\tau} + C$

Amplitude



T_0

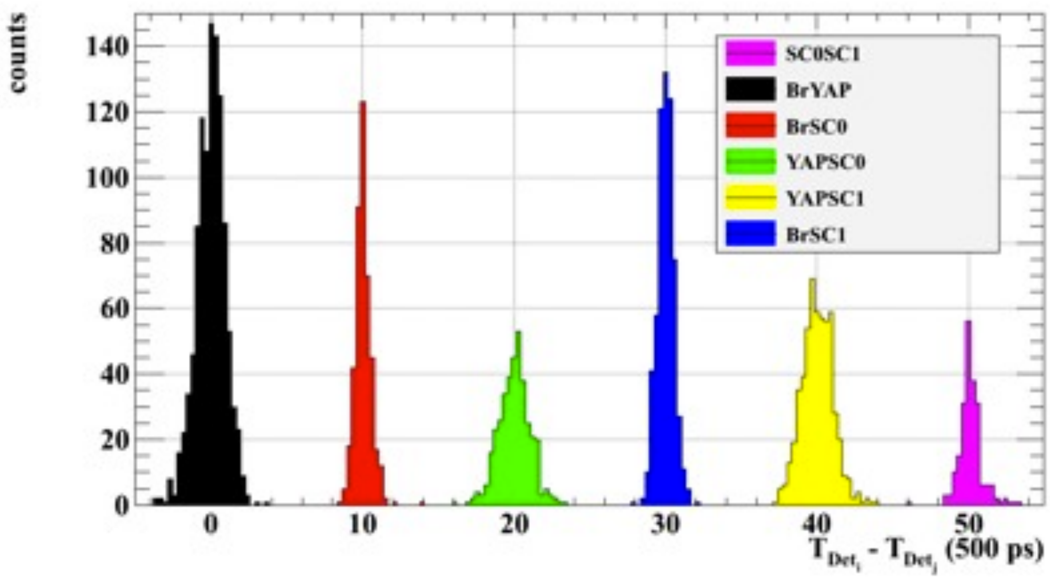
- Correct residual time-amplitude correlations
- Gaussian fit of detector pair distributions
  - Compute detector offsets
  - Initialize global fit

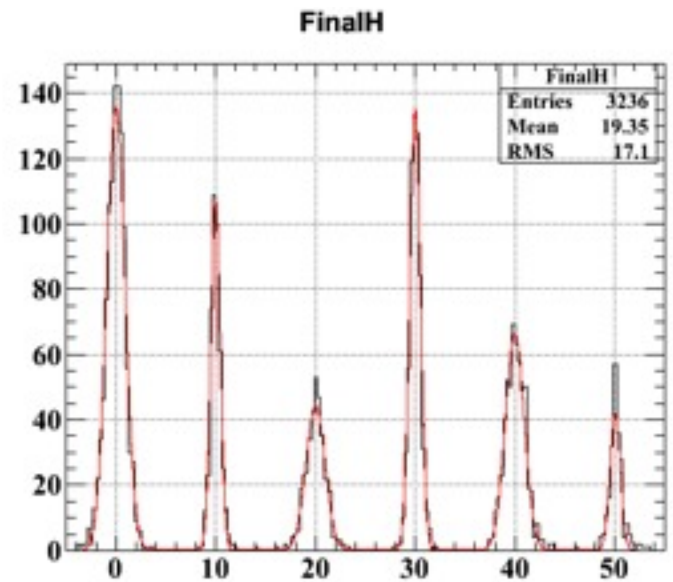


Resolution extraction

The number of ΔT combinations is larger than the number of variables

- simultaneous fit of all combinations to extract all the time resolutions.
- Systematic contributions taken into account in the fit.

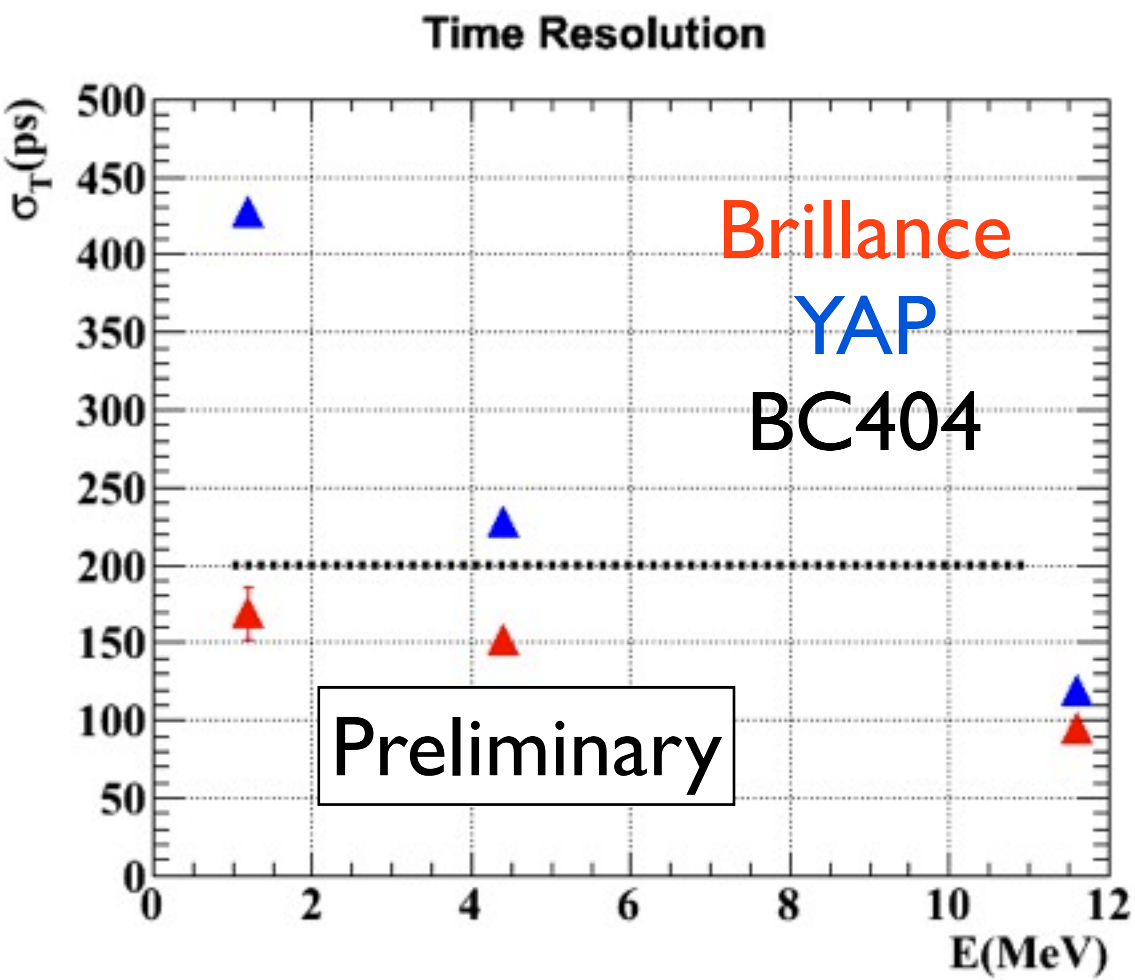




$$f(\sigma_{ij}) = \sum_{i,j} C_{i,j} Gaus(x - \mu_{i,j}, \sigma_{i,j}) \qquad \sigma_{i,j} = \sqrt{\sigma_i^2 + \sigma_j^2 + \sigma_{ele}^2 + \sigma_{beamspot}^2}$$

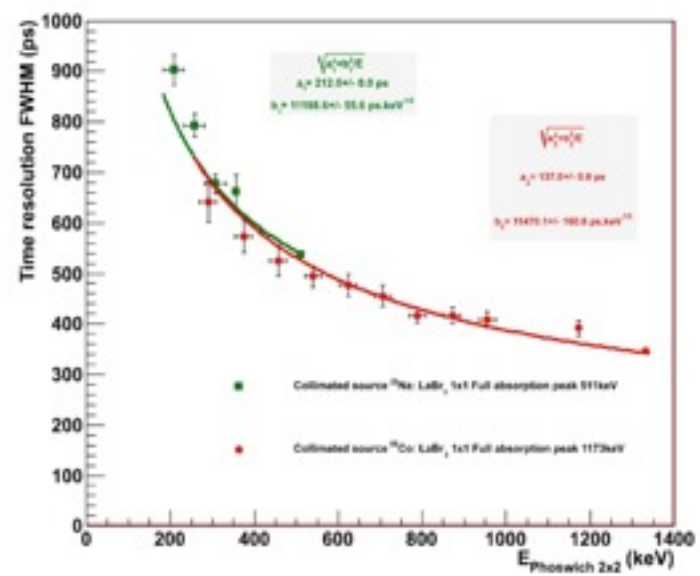
Results

The time resolution ~85 ps @ 11.7 MeV, promising for time reconstruction in a large volume calorimeter.



Sanity check

result consistent with PARIS experiment at the ^{60}Co energy



http://paris.ifj.edu.pl/

Conclusions

Are $LaBr_3(Ce)$ segmented detectors ready for HEP experiments?

- (Energy resolution/linearity)
- Easy inter-calibration - energy scale
- Excellent single crystal timing resolution @12 MeV

Work ongoing

- New measurements in preparation:
  - Energy resolution and linearity with 17.6 MeV from $^{11}Li(p,\gamma)^{12}Be$ with CW
  - Time resolution with 55 MeV photons from π^0 decays from π^- p CEX @ PSI

Preliminary studies encourage further investigations

Backup

LaBrCe characteristics

Scintillator	Density (g/cm^3)	LY (pho/keV)	Decay Time (ns)	Wavelength of max emission (nm)	Refractive Index @max	Energy Resolution (% fwhm @ 662 keV)	F.O.M. $\sqrt{(\tau/LY)}$
BC 404	1.03	12	1.8	408	1.58	-	0.39
BrLaCe 380 (5% Ce)	**5.08**	**63**	**16**	**380**	**1.9**	**2.9%**	**0.5**
YAP	5.35	22	26	347	1.95	4.38%	1.09
LYSO	7.1	27	41	425	1.82	~8%	1.23
NaI(Tl)	3.67	38	250	415	1.85	7.0%	2.6
BGO	7.13	9	300	480	2.15	9.05%	5.8

Conversion point uncertainty

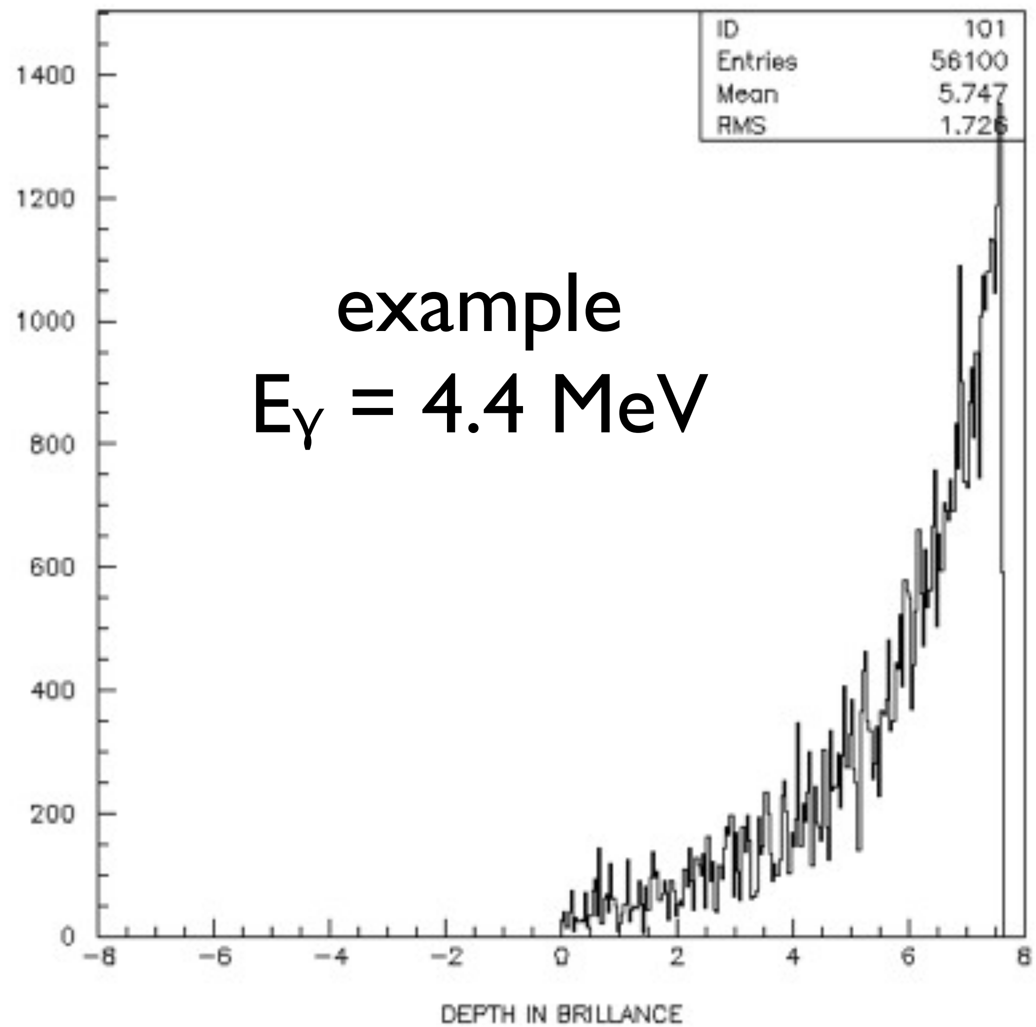
$$\sigma_t = \sigma_x / c$$

$$\sigma_{t_{1.25MeV}} = 51ps$$

$$\sigma_{t_{4.4MeV}} = 57ps$$

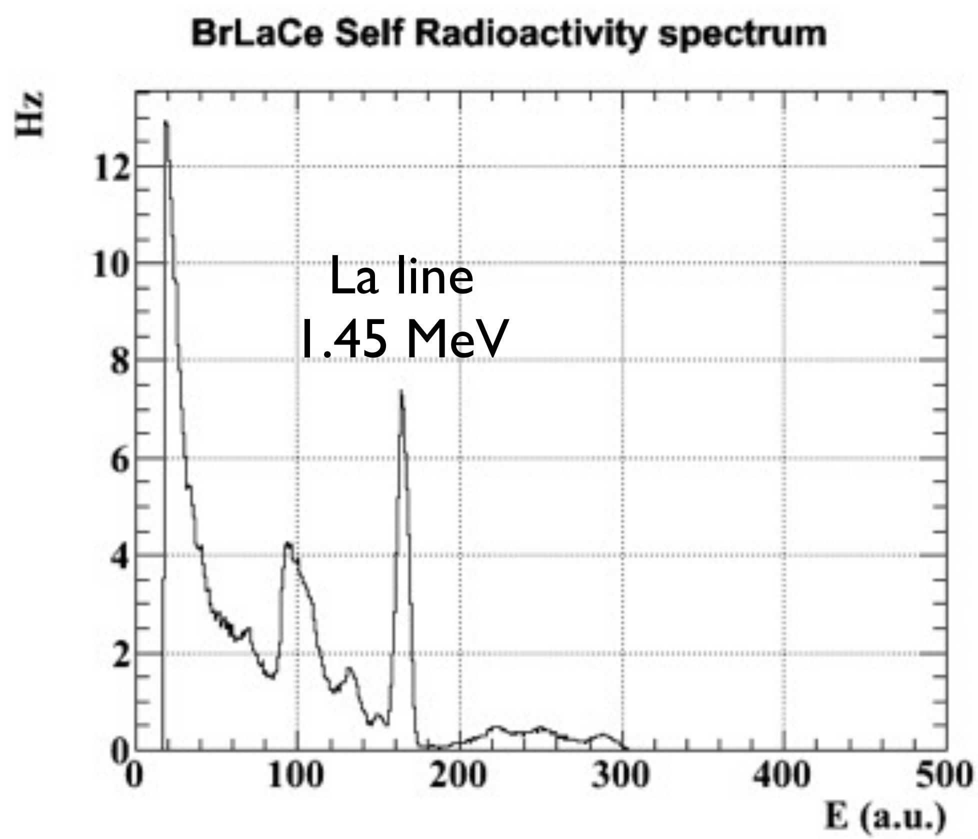
$$\sigma_{t_{11.7MeV}} = 54ps$$

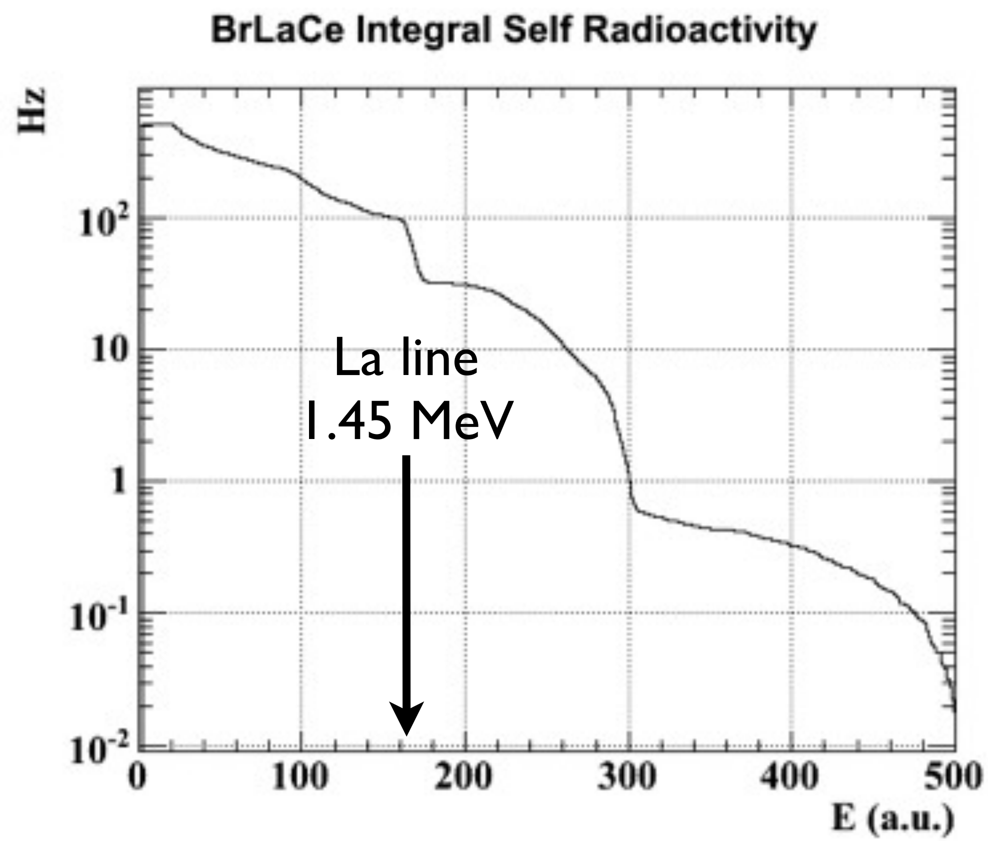
example
E$_\gamma$ = 4.4 MeV



BrLaCe self-activity

Activity ~ 1 Bq/cm³ [70 keV, 5 MeV]





$$La + e^- \rightarrow Ba + \nu_e + \gamma$$