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A Compton Spectrometer to monitor the ELI-NP beam energy

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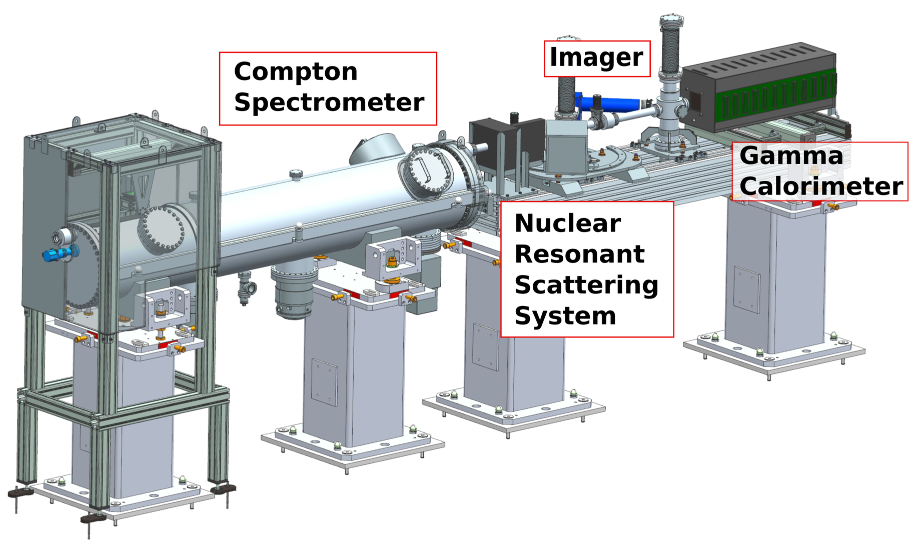
ELI-NP Project

The **ELI-NP facility** (Extreme Light Infrastructure - Nuclear Physics), currently under construction near Bucharest, is the pillar of the European project ELI dedicated to the generation of high intensity gamma beams for frontier research in nuclear physics [1]. The ELI-NP gamma beam will be obtained by collimating the radiation emerging from incoherent inverse Compton scattering of a laser light off a relativistic electron beam.

Gamma beam characteristic [2]:

Quantity	Specification
Minimum photon energy	200 keV
Maximum photon energy	19.5 MeV
Photon energy tunability	steplessly
Bandwith	$\leq 0.5\%$
Linear polarization	≥ 95 %
Photons per pulse	$\leq 2.6 \cdot 10^5$

Gamma Beam Characterization System [3]



- **Compton Spectrometer**
  High precision measurement and monitor of the photon energy spectrum by providing the peak energy and the energy bandwith.
- **Nuclear Resonant Scattering System [4]**
  Detects the resonant gamma decays of selected nuclear levels in order to provide an absolute energy calibration and allow the inter-calibration of detectors.
- **Beam Profile Imager [5]**
  Check beam alignment and spatial distribution.
- **Gamma Calorimeter [6, 7]**
  Provide the beam average energy and intensity.

References

[1] C.A. Ur et al., *The ELI-NP facility for nuclear physics*, Nucl. Instr. and Meth. in Phys. Res. B **355**, 198 (2015).

[2] Dimiter L. Balabanski, *Experiments with brilliant gamma beams at ELINP:A glimpse in the future*, J. Phys.: Conf. Ser. **966** 012018 (2018).

[3] O.Adriani et al., *Technical Design Report EuroGammas proposal for the ELI-NP Gamma beam System*, arXiv:1407.3669 [physics.acc-ph].

[4] M.G. Pellegriti et al., *The nuclear resonance scattering calibration technique for the EuroGammaS gamma characterisation system at ELI-NP-GBS*, J.inst. **12.03** (2017).

[5] P.Cardarelli et al., *A gamma beam profile imager for ELI-NP Gamma Beam System*, Nucl. Instr. and Meth. in Phys. Res. A, **893**, page 109-116, (2018).

[6] M.Lenzi et al., *A new-concept gamma calorimeter at ELI-NP*, J.inst.**12.02** (2017).

[7] R. Borgheresi et al., *Gamma beam characterization system for ELI-NP: The gamma absorption calorimeter*, 2016 IEEE NSS/MIC/RTSD, (2016).

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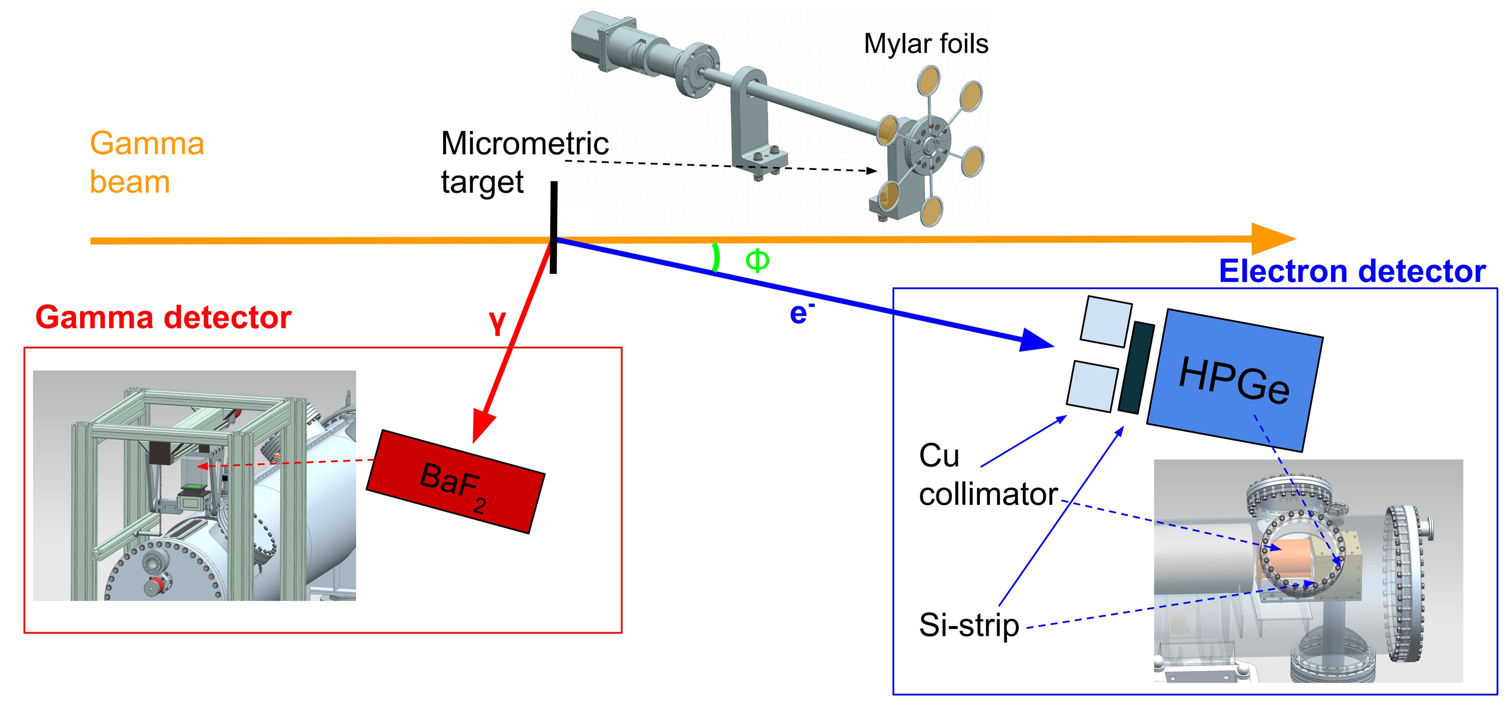
Compton Spectrometer

The aim of the Compton spectrometer is to reconstruct the ELI-NP γ **energy spectrum** with a non-destructive method. The basic idea is to measure *the energy* and *the scattering angle* of electrons recoiling at small angles from Compton interactions of the beam on a micrometric target (1-100 μm). The scattered gamma is also acquired for trigger purpose.



Expected Performances

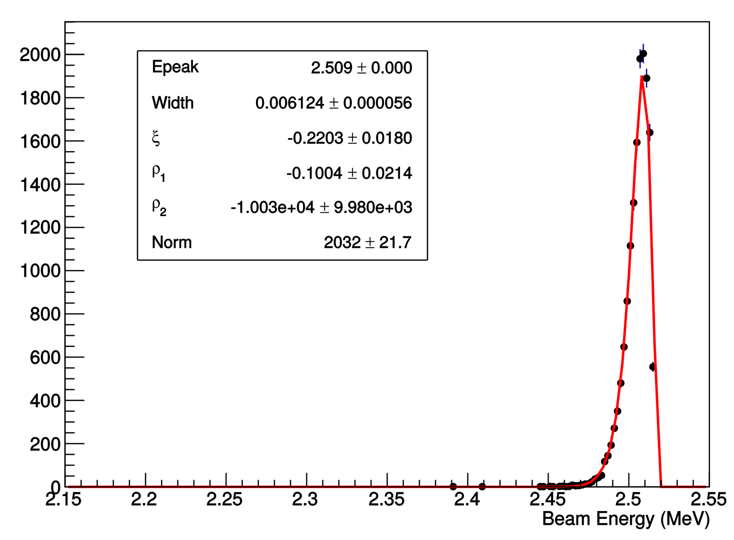
- **Beam peak energy uncertainties**

E_γ [MeV]	2.5	5	18.5
$\frac{\sigma_{stat}(E_\gamma)}{E_\gamma}$ [%]	0.04	0.02	0.02
$\frac{\sigma_{syst}(E_\gamma)}{E_\gamma}$ [%]	0.11	0.06	0.02

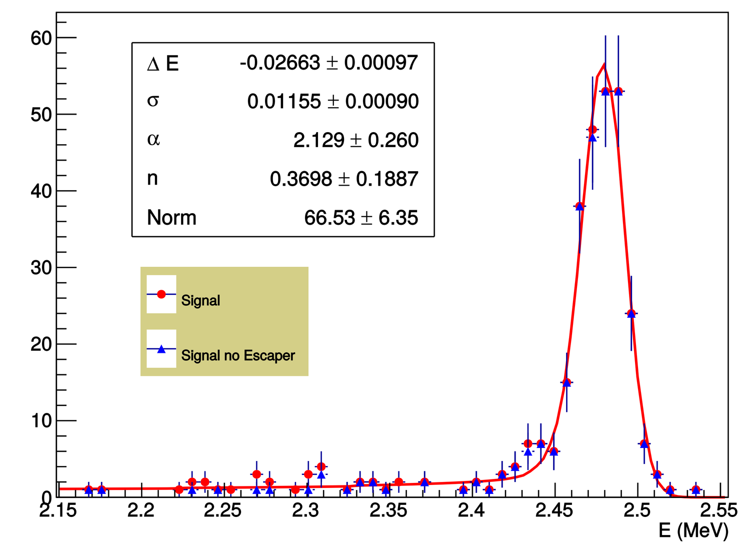
- **Beam bandwith uncertainties**

E_γ [MeV]	2.5	5	18.5
Simulated BW [keV]	6	13	34
Experimental σ [keV]	12	8	26
σ_{stat} (BW) [keV]	1.9	0.8	2.5
σ_{syst} (BW) [keV]	2.3	1.2	2.0

Beam energy distribution



Reconstructed beam energy



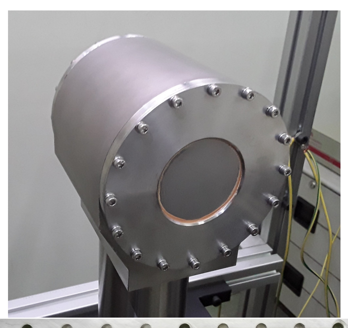
Electron Detector

$$E_{beam} = \frac{m_e \cdot T_e}{\cos(\phi)\sqrt{T_e \cdot (T_e + 2m_e)} - T_e}$$

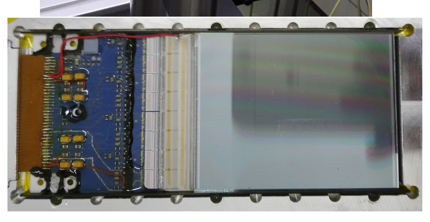
The energy of the Compton scattered electron (T_e) is precisely measured with an high purity germanium detector (HPGe) and the scattering angle (ϕ) is determined by a double sided silicon strip detector.

Detector design

→ The HPGe crystal is built in a planar custom configuration by CANBERRA:
- 80 mm, diameter
- 20 mm, thickness
- electrically cooled
- $\leq 1\mu$m, electrical contacts
- 100 μm, cryostat Be-window thickness

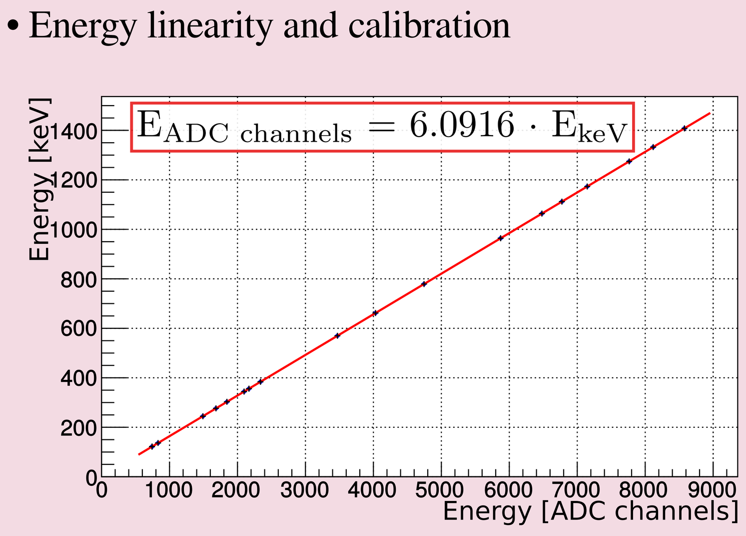


→ Double sided silicon strip detector produced by Hamamatsu:
- 5.33×7 cm^2
- 300 μm thickness
- 1024 strips for each view

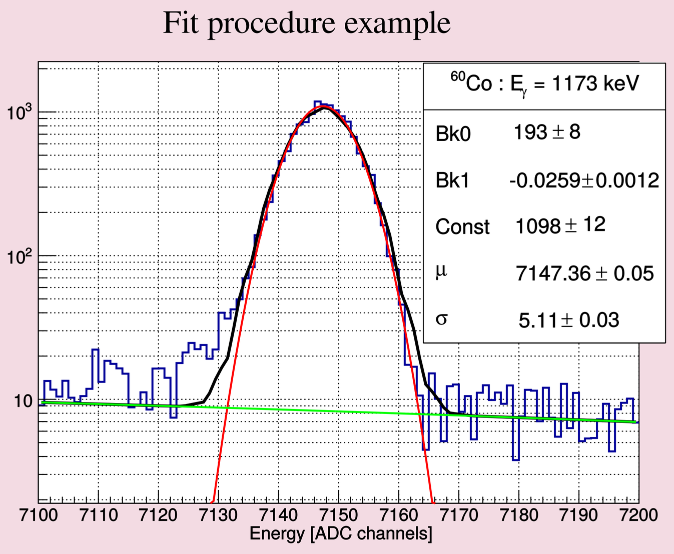


HPGe detector tests:

- Energy linearity and calibration

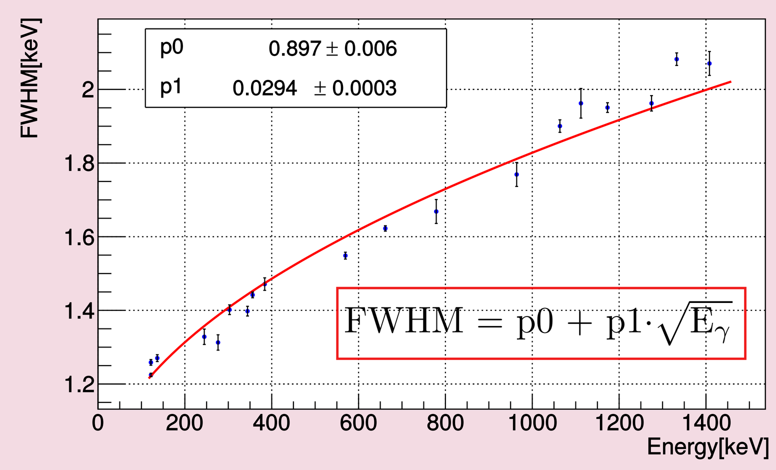


Fit procedure example



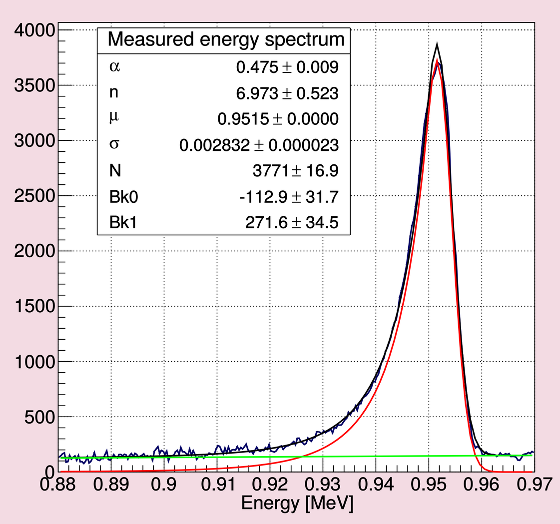
- Verified excellent energy resolution performances

Energy resolution at 1332 keV:
$R_E = \frac{FWHM}{E} = 1.57 \pm 0.02$ ‰



- Test with electron source

Verified the agreement between measurement and simulation of the detector response to electrons of definite energy emitted by ^{207}Bi source.



Simulation

μ [MeV]	σ [MeV]
0.95150 +- 0.00004	0.00310 +- 0.00002
1.0237 +- 0.0001	0.00430 +- 0.00010
1.0367 +- 0.0001	0.00333 +- 0.00006

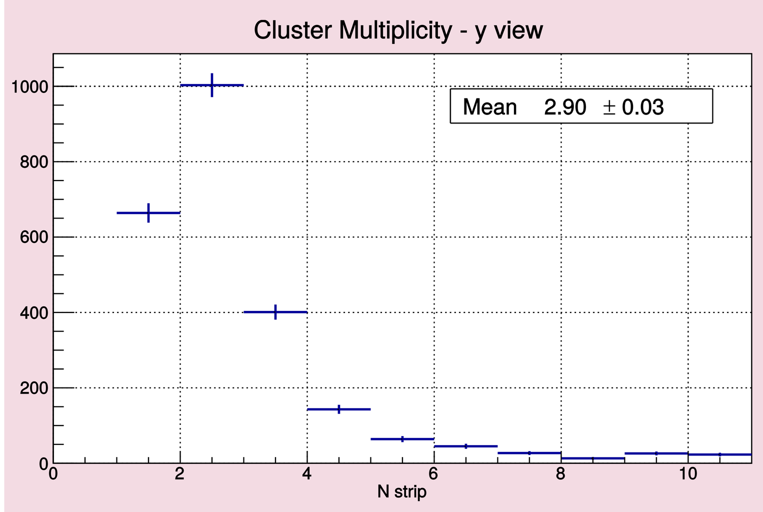
Measurement

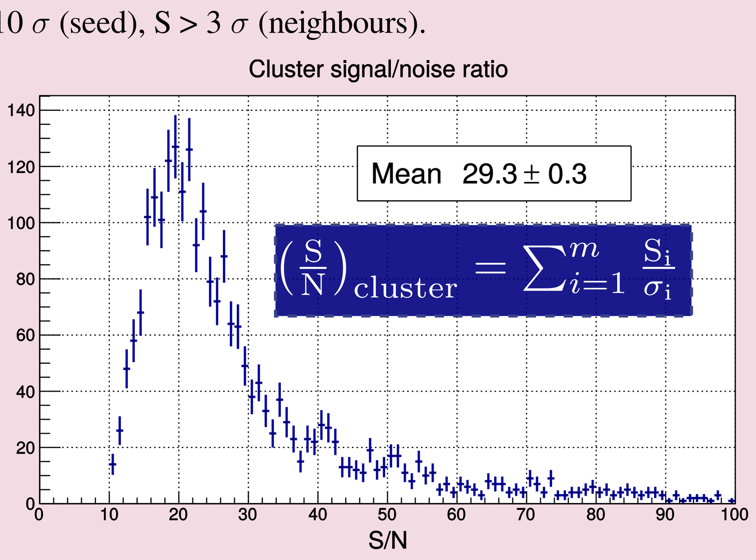
μ [MeV]	σ [MeV]
0.95152 +- 0.00003	0.00283 +- 0.00002
1.0241 +- 0.0001	0.00362 +- 0.00006
1.0367 +- 0.0001	0.00314 +- 0.00007

Si-strip preliminary tests:

- Test with cosmic rays

Cluster inclusion cuts used for the reconstruction: S > 10 σ (seed), S > 3 σ (neighbours).

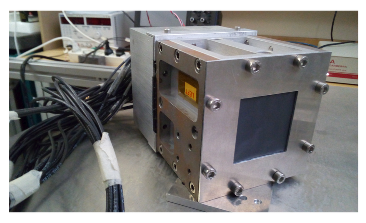




Gamma Detector

The scattered photon is detected in coincidence with the electron to provide a trigger for the data acquisition of the spectrometer. This coincidence is very effective in suppressing the background acquisition from pair production, Compton photons and beam particle.

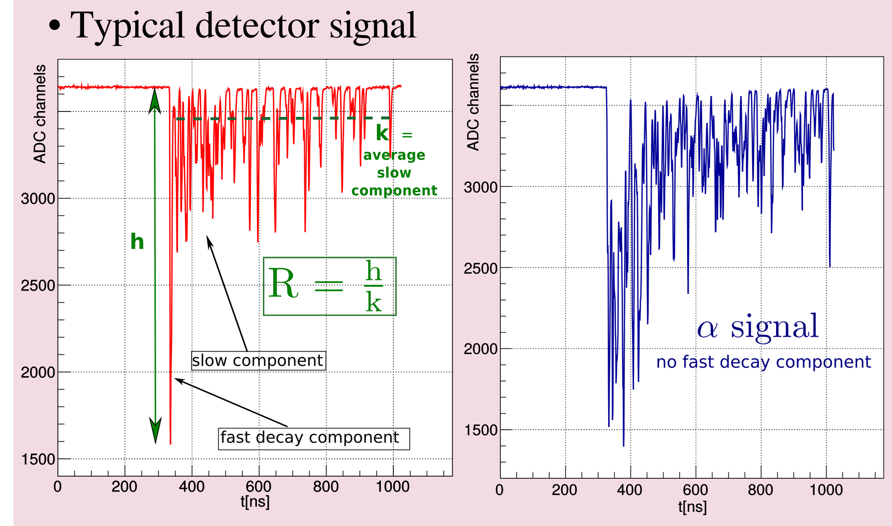
Detector design



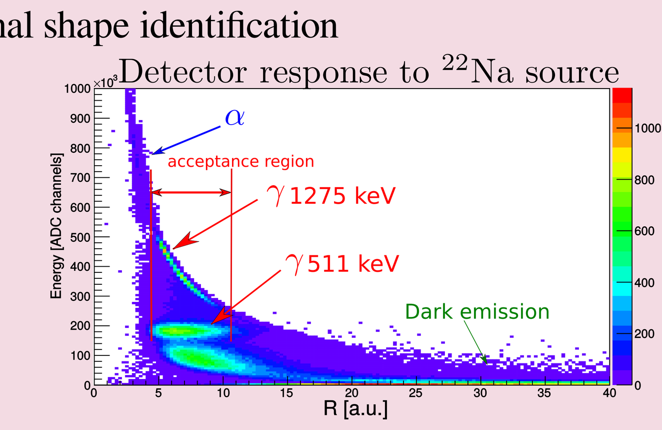
→ Small calorimeter of 4x4 Barium Floride (BaF_2) crystals ($1.2 \times 1.2 \times 5$ cm^3) read out by H12700A HAMAMATSU multianode PMT.

BaF_2 detector tests:

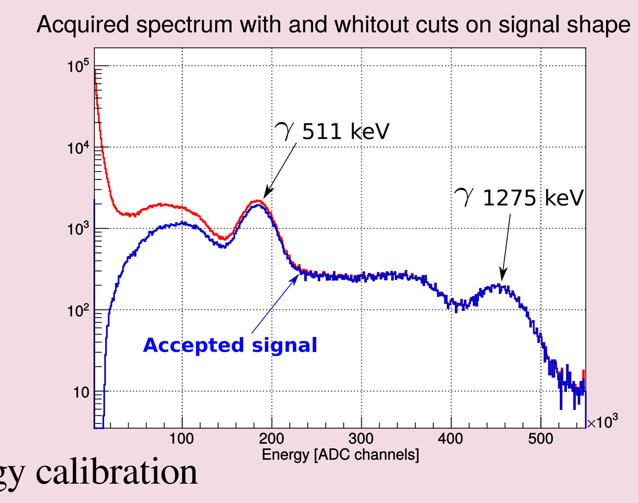
- Typical detector signal



- Signal shape identification

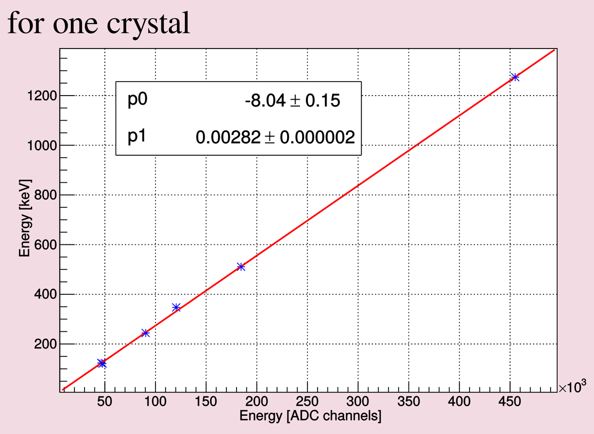


Acquired spectrum with and whitout cuts on signal shape



- Energy calibration

Example for one crystal



- Detector self-calibration

The intrinsic radioactivity of BaF_2, originated from natural ^{226}Ra impurities, can be used to self-calibrate the detector.