ASSESSMENT OF SCINTILLATING DETECTORS FOR SPACE RADIATION PROTECTION

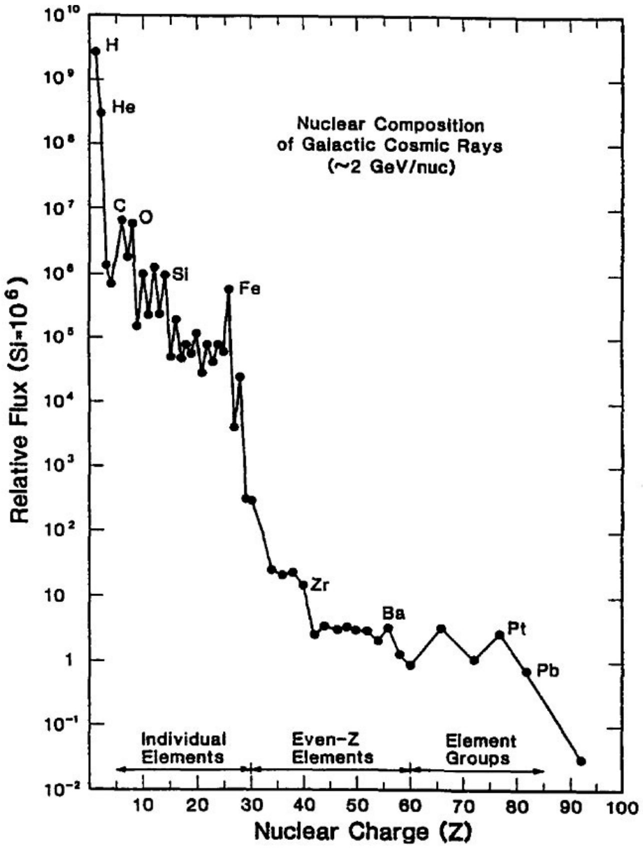
HUET Thomas (M2:PSA)

Supervisors:
Marie VANSTALLE & Alexandre SECHER

Space radiation protection

GCR (Galactic Cosmic Rays) = main hindrance for long-term exploratory missions in deep space

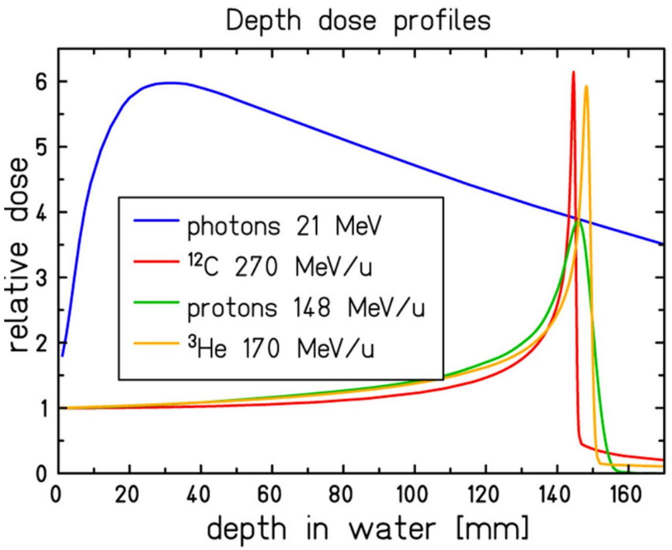
- Important Z range: from ^{1}H to ^{238}U
- Energies around 2GeV/n
- Lack of cross-sections data ⇒ Need of measurements on tissue-equivalent + shielding targets



[R.A. Mewaldt, 1988]

Danger for the astronaut’s health

- Ions inside matter: Bragg Peak
- 3-years mission to Mars: dose of approximately 1 Sv, increasing mortality due to radiation up to 10%



[Krämer et al., 2016]

	Absorbed dose (Gy)*	Effective dose (Sv)	Fatal risk, % (95% CI)	
			Men (age 40 years)	Women (age 40 years)
Lunar mission (180 days)	0·06	0·17	0·68% (0·20–2·4)	0·82% (0·24–3·0)
Mars orbit (600 days)	0·37	1·03	4·0% (1·0–13·5)	4·9% (1·4–16·2)
Mars exploration (1000 days)	0·42	1·07	4·2% (1·3–13·6)	5·1% (1·6–16·4)

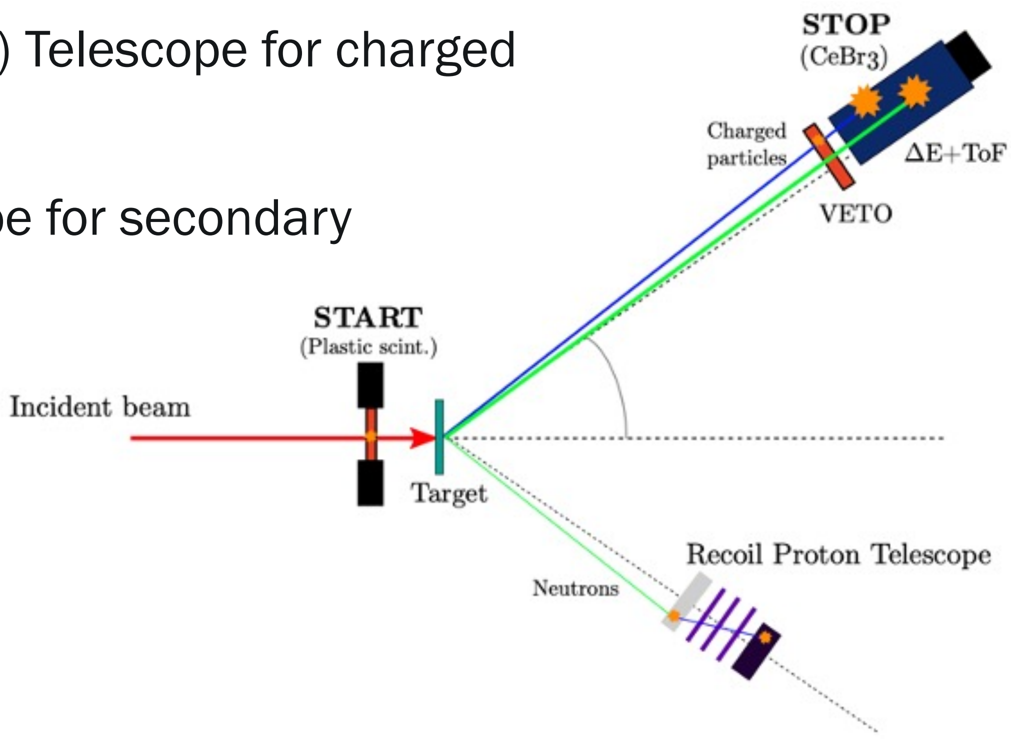
Calculations are at solar minimum, where GCR dose is highest behind a 5 g/cm^2 aluminium shield. *Mean for tissues known to be sensitive to radiation and at risk of cancer[2] including lung, colon, stomach, bladder, bone marrow, and breast and ovaries in women.[2,3] Competing causes of death are included in calculations because they decrease risk probabilities if high (ie, >5%).

Table: **Radiation risks for men and women on missions to the moon or Mars**

[Cucinotta, 2006]

CLINM experiment - DeSIs

- (Cross-sections of Light Ion and Neutron Measurements)
- Cross-sections measurements with incident beams of ^{4}He, ^{12}C, ^{16}O, ^{56}Fe from 400 MeV/u (GSI-SIS) to 4 GeV/u (FAIR)
- ΔE-ToF (Time-of-Flight) Telescope for charged particles
- Recoil Proton Telescope for secondary Neutrons (E<30MeV)

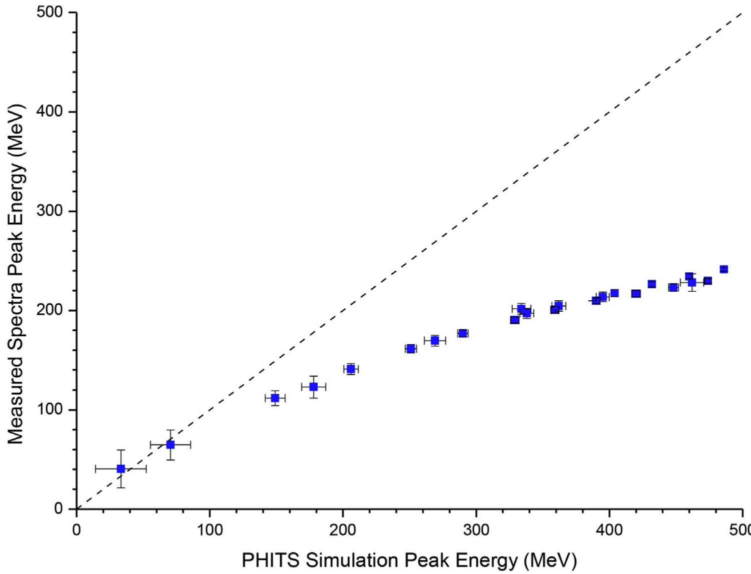


Internship goals

- Choose $CeBr_3$ detector because fast and good energy resolution
- Assessement of $CeBr_3$ detector:

- Gamma detector → caracteristics with charged particles ?
- High light yield → Saturation effect

  Which High Voltage Supply to use ?
- Energy resolution ?

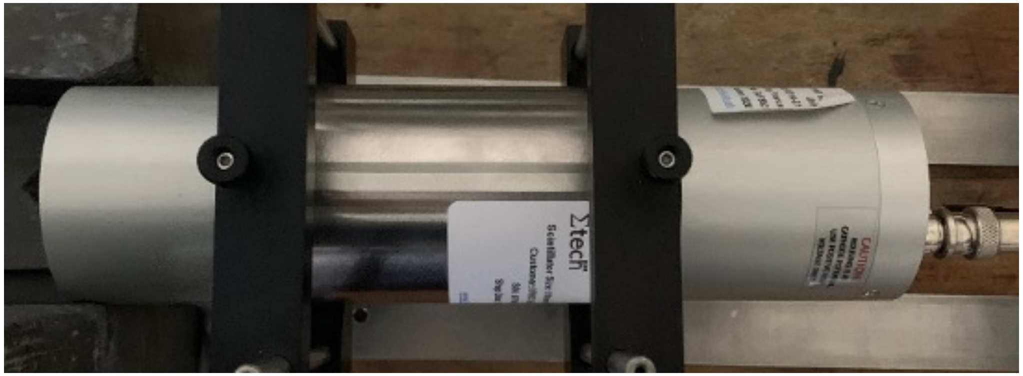


[Millert et al., 2018]

- Time resolution ?

(Determine the accuracy of the ToF measurements). We expect at least 200-300ps in coincidence

Cerium bromide detector



- Fast inorganics scintillator Provided by Advatech
- PhotoMultiplicator Hamamatsu (R6231-100)
  Manufacturer voltage supply of 1200V
- Theoretical values

Decay time	17ns
Time resolution	0.2ns
Energy resolution (FWHM)	3.6% at 662keV

Encapsulation:
- 0.4mm of Aluminum
- 1mm of Teflon

Phoswich detector

- Use as a benchmark detector, for time resolution (coincidence)
- Photomultiplicator PHOTONIS (XP3990)
  Manufacturer voltage supply of 1300V
- Theoretical values

NaI(Tl)	Decay time	230ns
	Time resolution	4.07ns
	Energy resolution (FWHM)	7% at 662keV
$LaBr_3$(Ce)	Decay time	16ns
	Time resolution	0.2ns
	Energy resolution (FWHM)	3% at 662keV

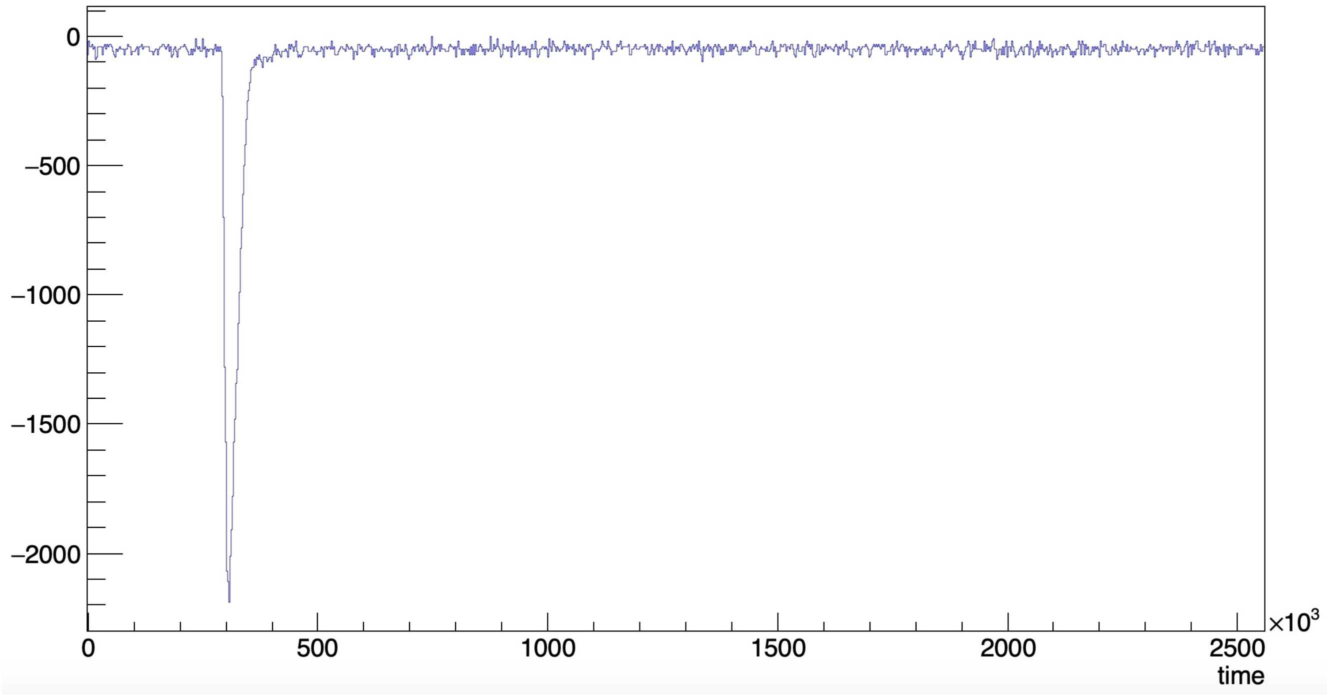
- Lanthanum bromide crystal (1''x1''x2'')
- Sodium iodide crystal (1''x1''x6'')

Encapsulation (hypothesis):
- 1.5mm of Aluminum

Acquisition system

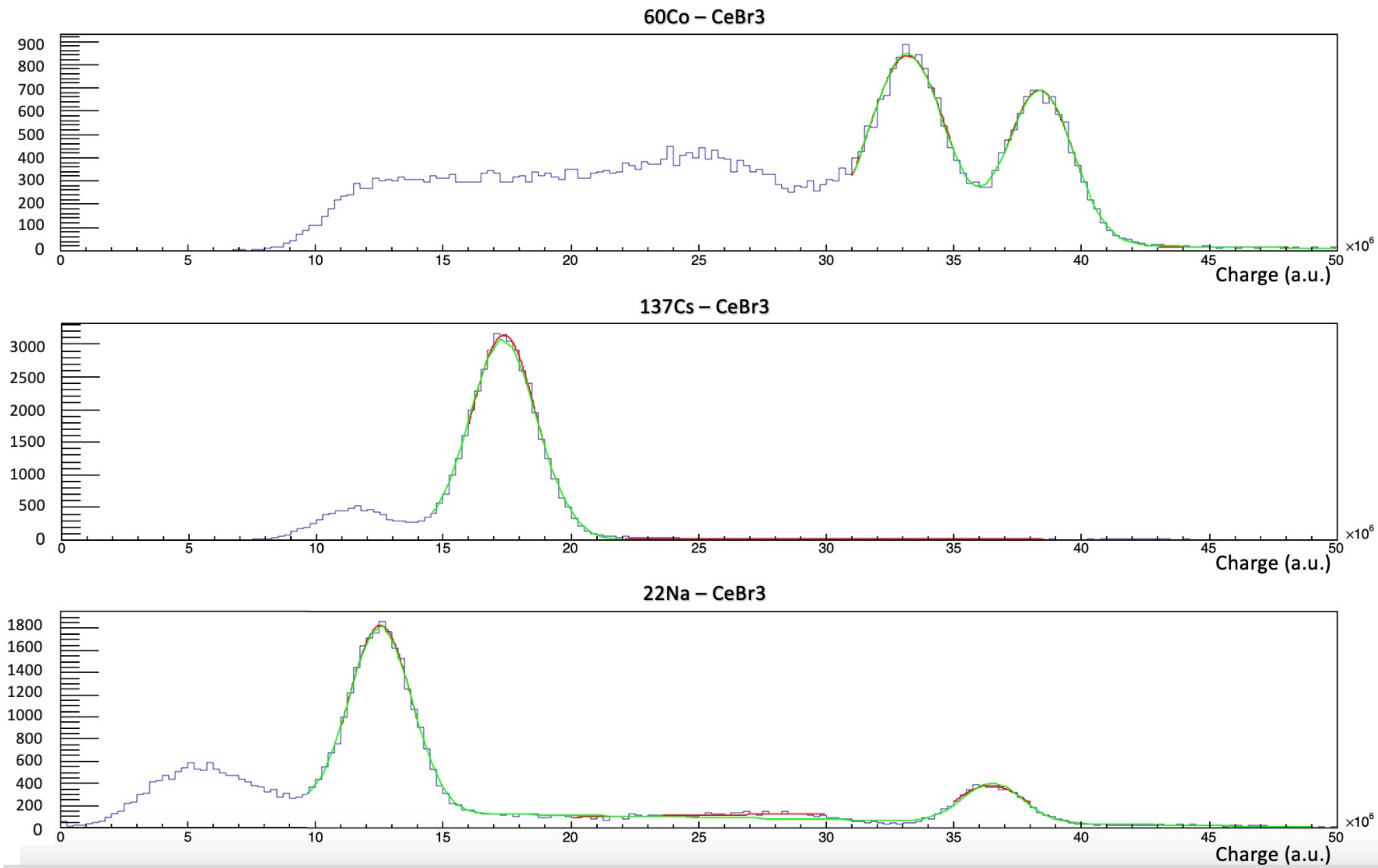
- WaveCatcher L.A.L. (8-channel)
- PXI National Instrument (PXIe-1071)

→ Support the software which is used to control the wavecatcher



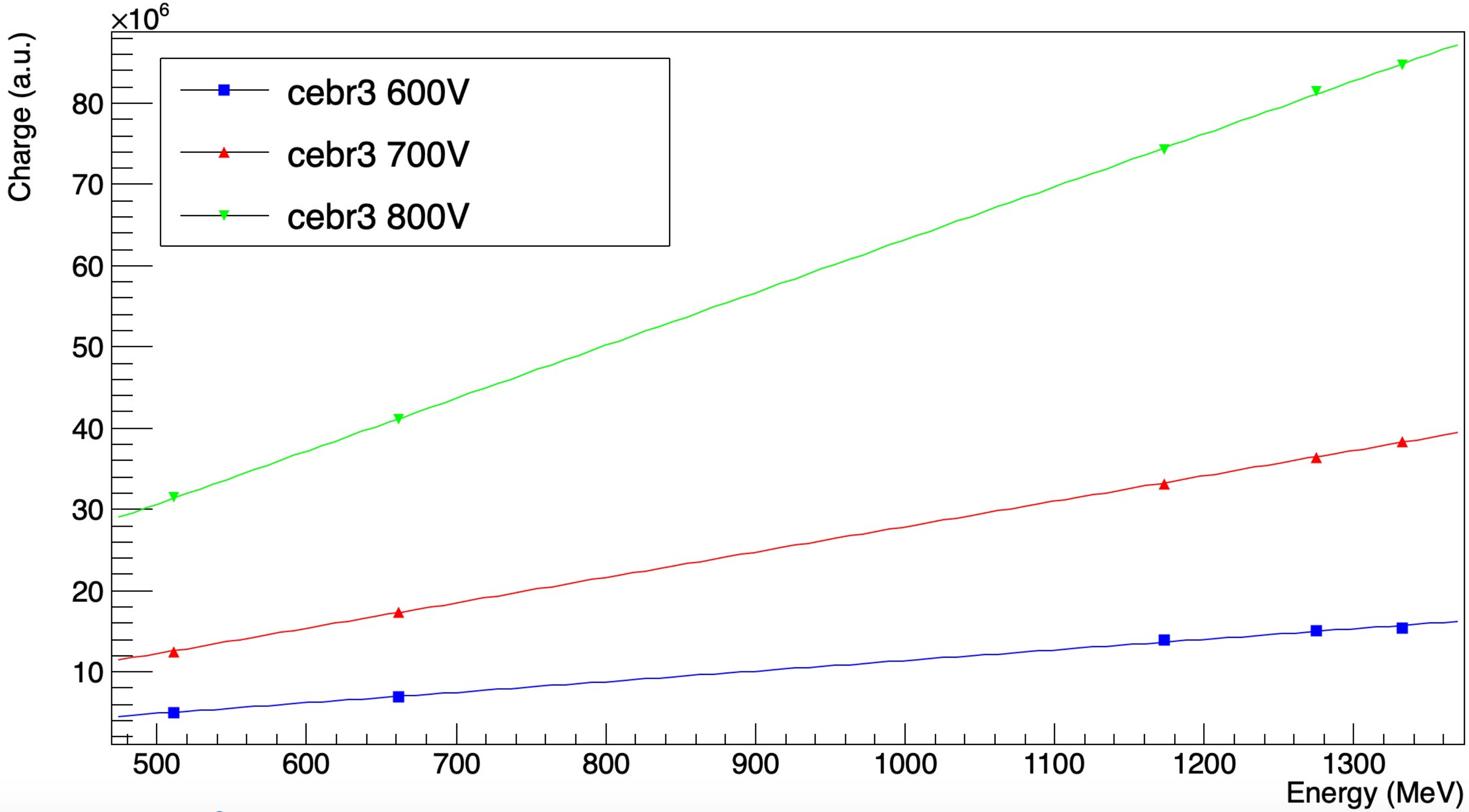
Energy resolution

3 gamma sources:
60Co (1173keV & 1333keV), 137Cs (662keV) and 22Na (511keV & 1274keV)



$CeBr_3$ – High voltage supply : 700V

Energy resolution CeBr3

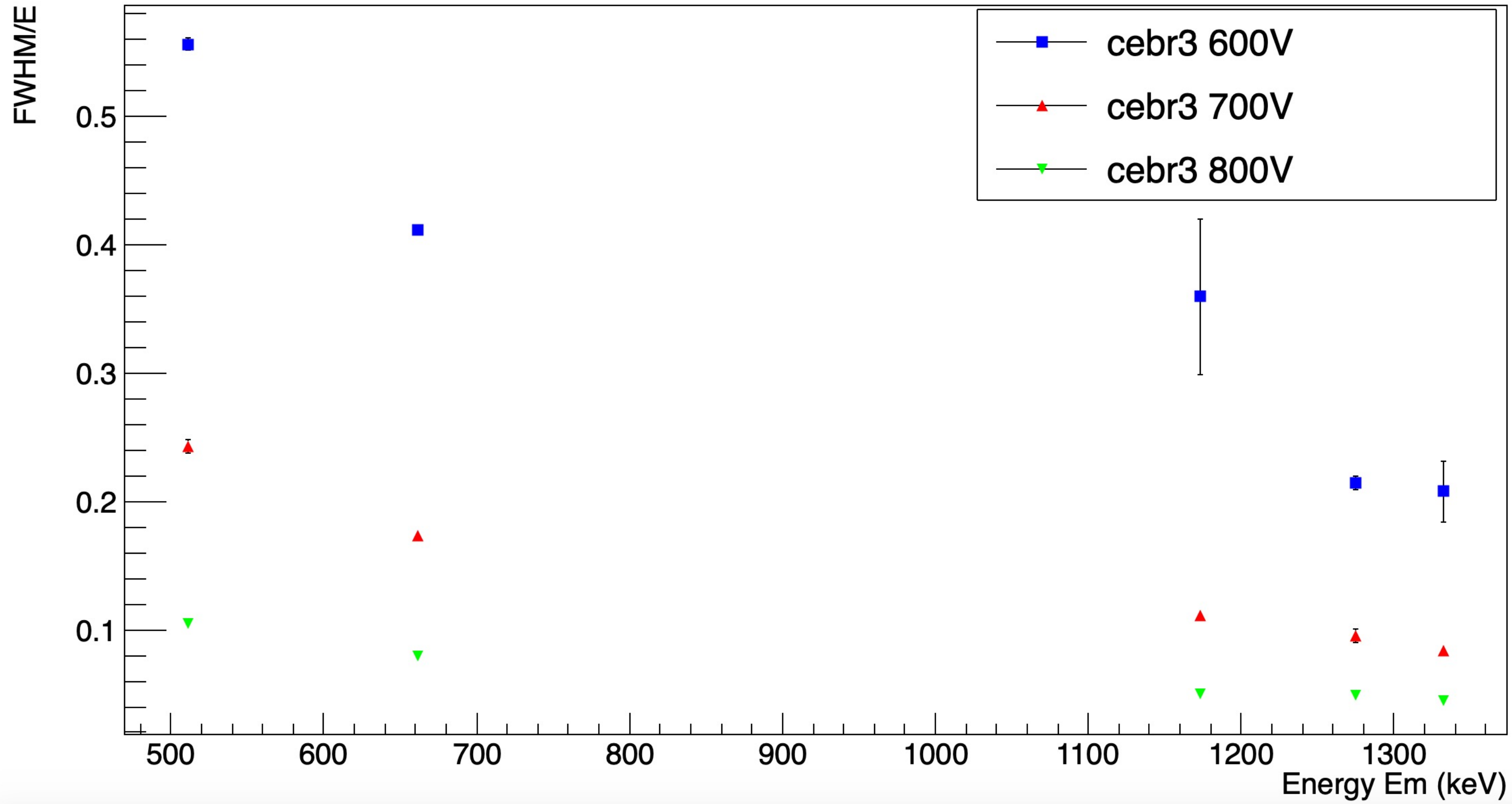


600V: χ^2/NDf = 13.28

700V: χ^2/NDf = 5.61

800V: χ^2/NDf = 9.75

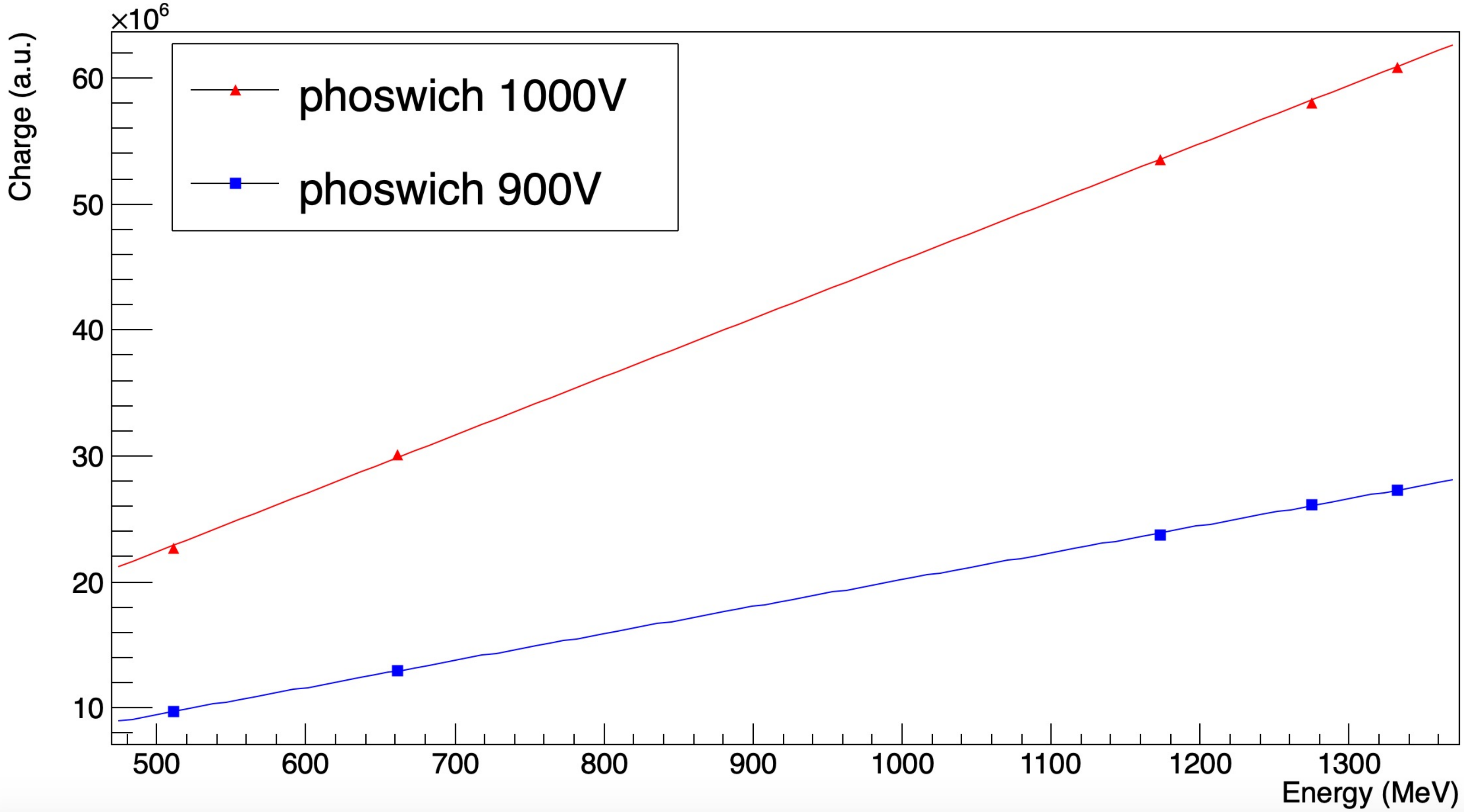
Energy resolution CeBr3



Better energy resolution for higher voltages (expected behaviour)

Far from the 3% announced by the manufacturer

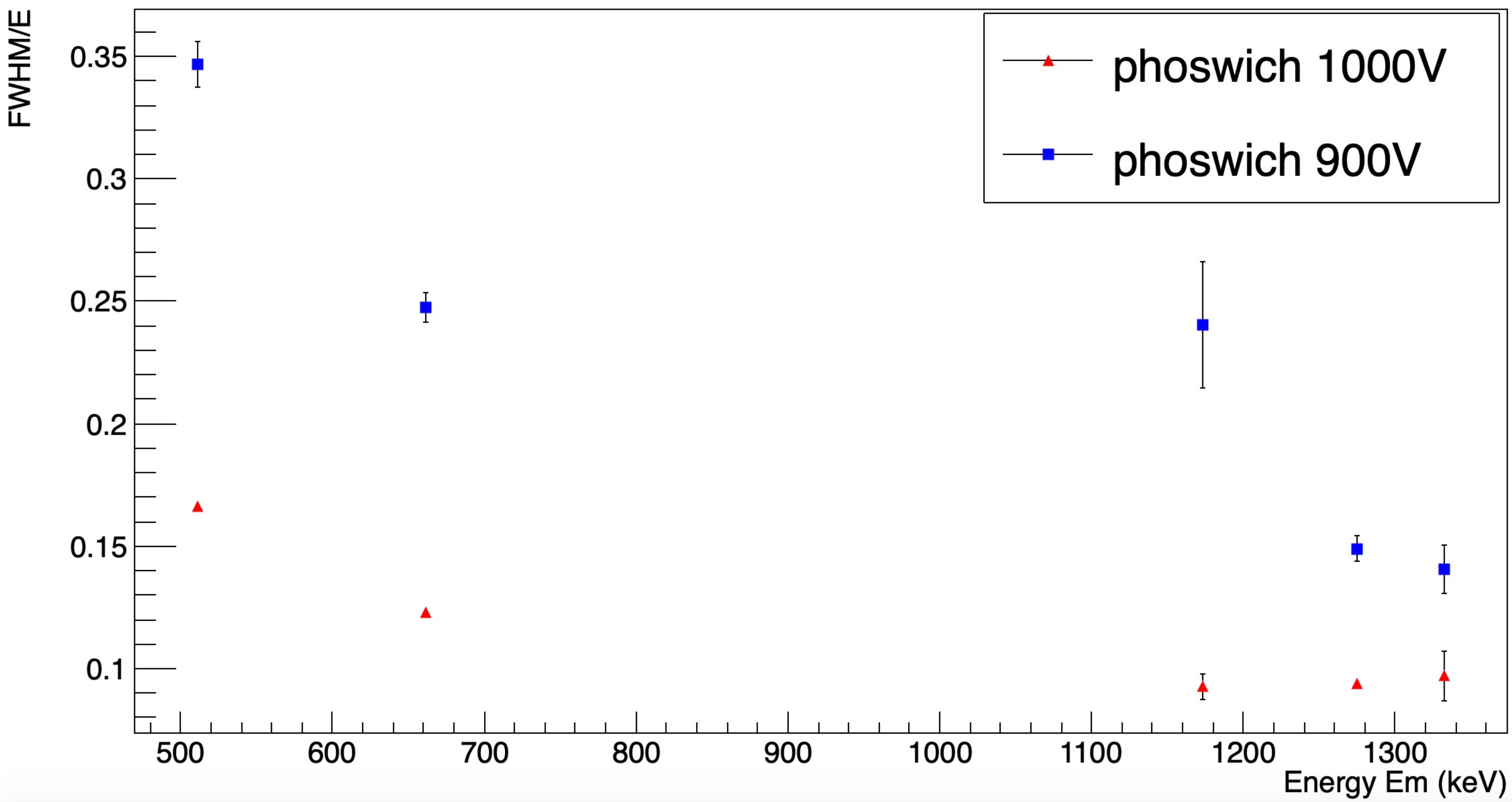
Energy resolution Phoswich



900V: χ^2/NDf = 1.28

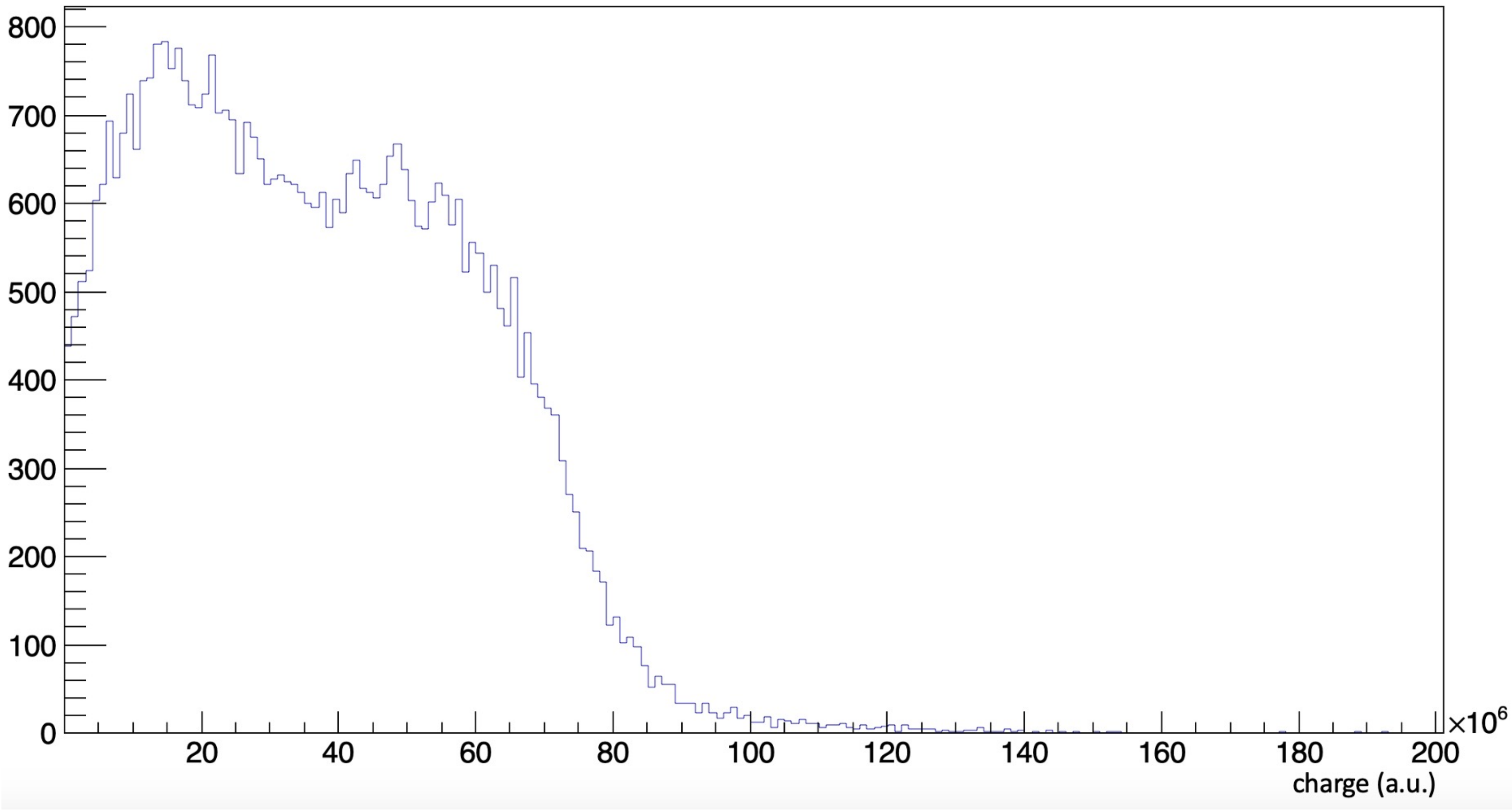
1000V: χ^2/NDf = 16.21

Energy resolution Phoswich



High FWHM/E especially for small energies (~25% for E_{γ}=662keV).
Resolution dominated by NaI → separate NaI and $LaBr_3$ with pulse shape analysis

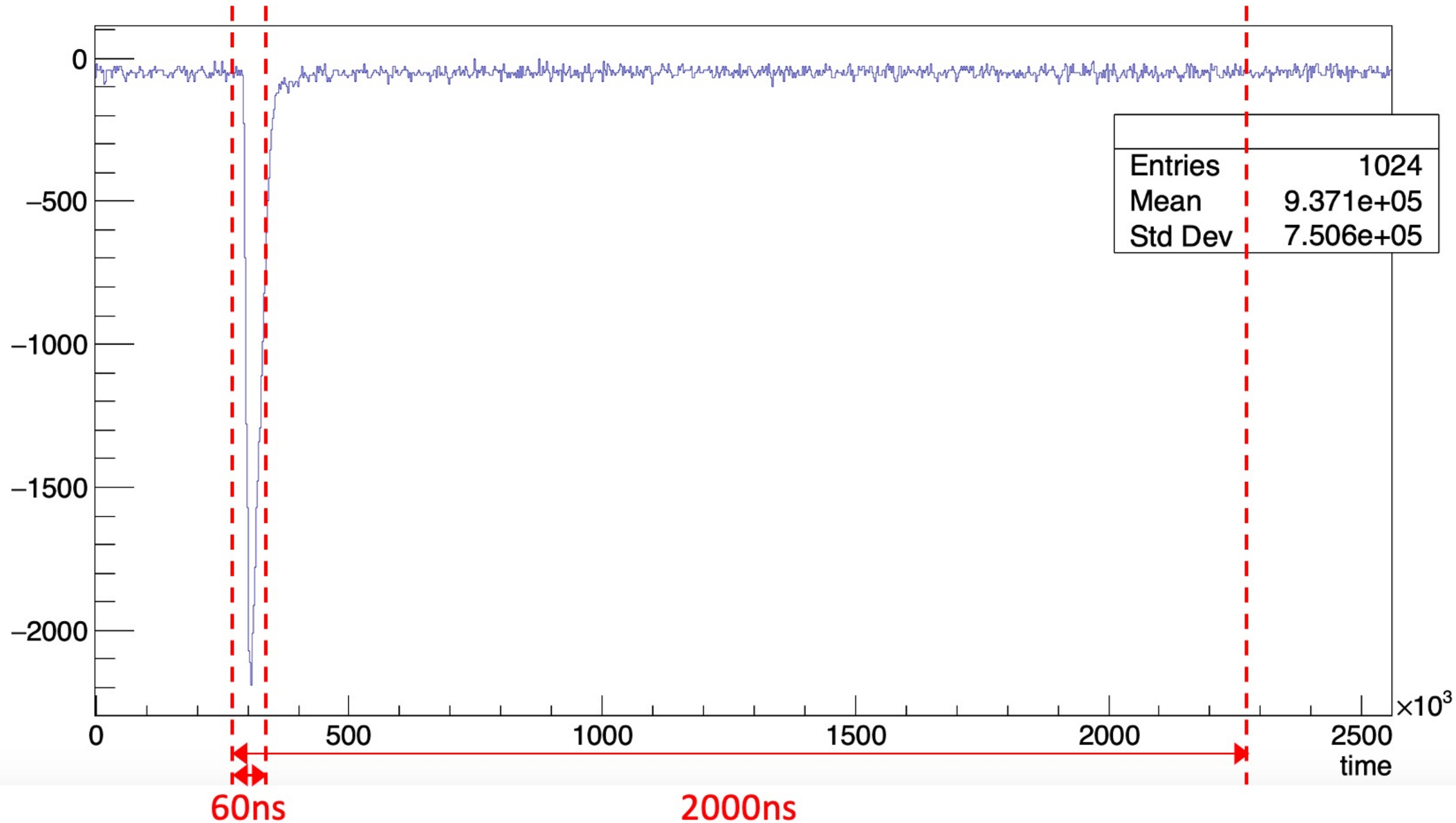
Pulse shape analysis



Charge histogram 1100V with ^{60}Co source

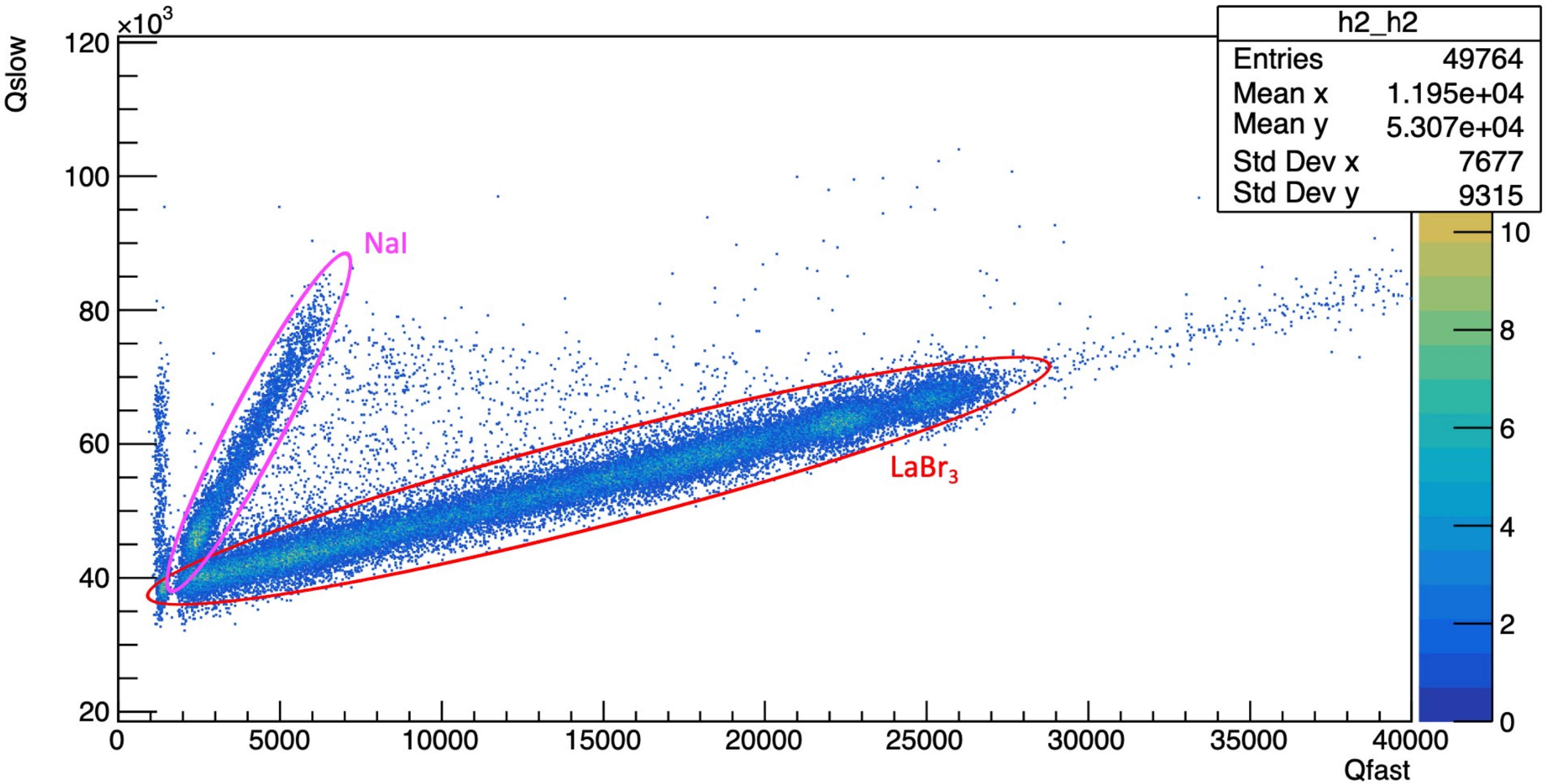
Identification of the two gamma rays?

Pulse shape analysis



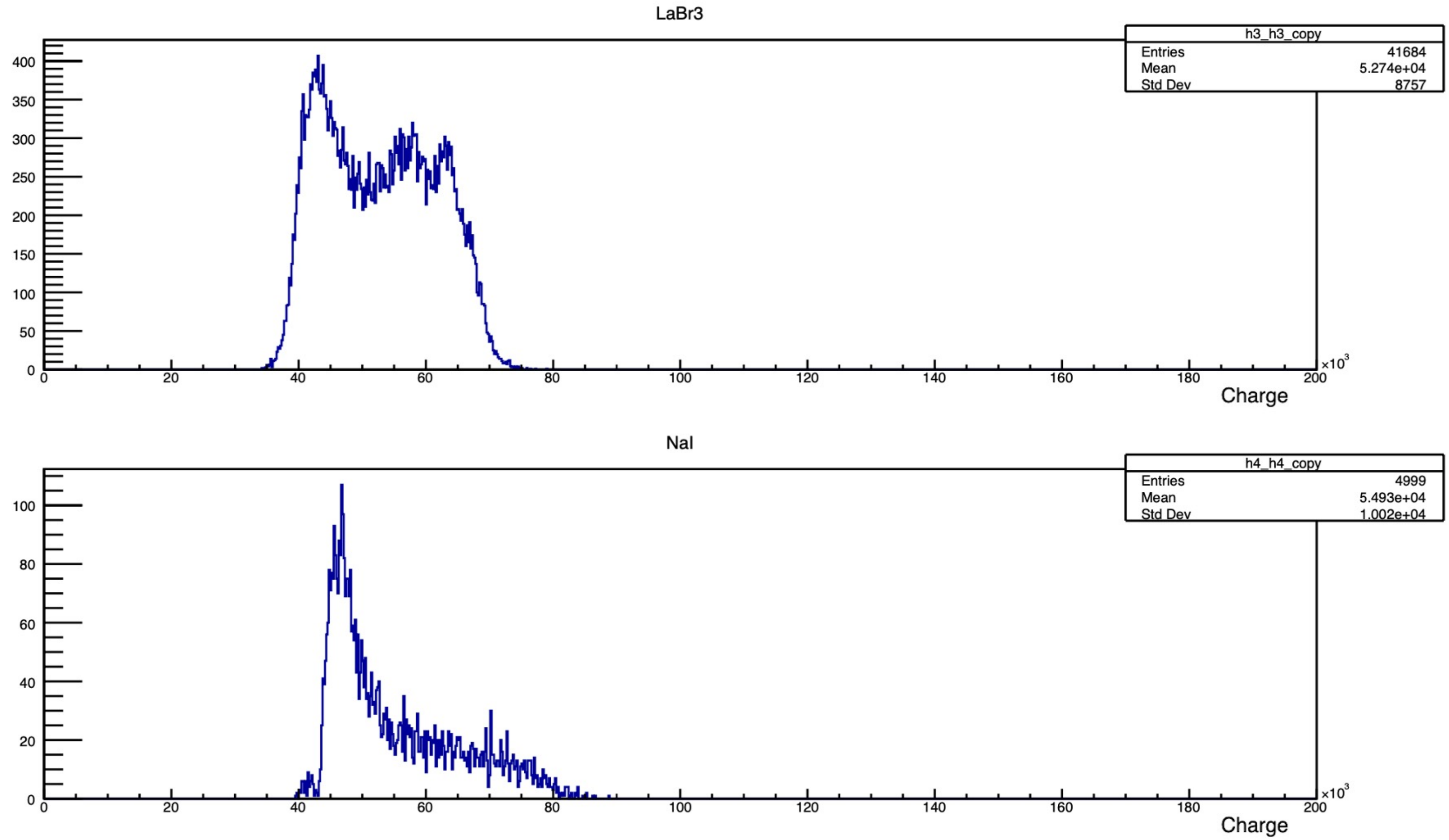
Integrate the signal on a long time period (Qslow – 2000ns) and on a short time period (Qfast – 60ns)

Pulse shape analysis



Distinguish two groups: one corresponding to the NaI crystal events and the other to the $LaBr_3$ crystal events

Pulse shape analysis

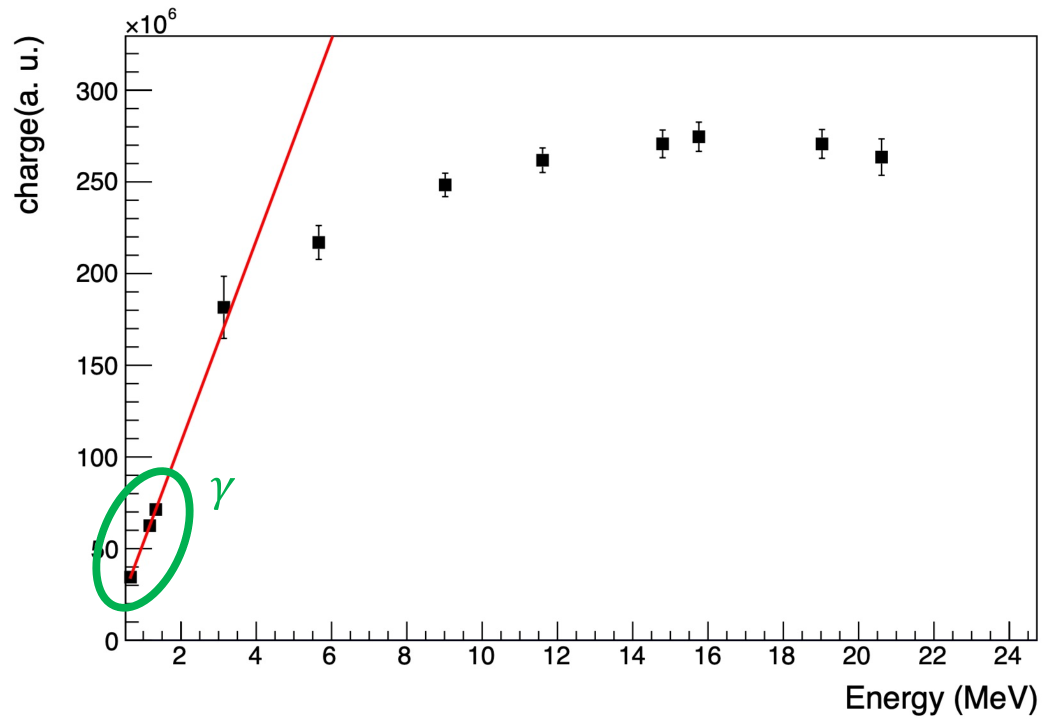


- Separation of the two signals is incomplete, the resolution of the NaI still dominates
- High voltage supply value may not be appropriate
- Rebound phenomenon was observed on the signal → Use of an attenuator

Saturation effect

- CYRCé: Cyclotron (IPHC) accelerate protons up to 25MeV
- For high voltage supply → saturation effect observed

20 positions
20 attenuation (Al foil)
20 proton energies
from 4.03MeV to 23.71MeV



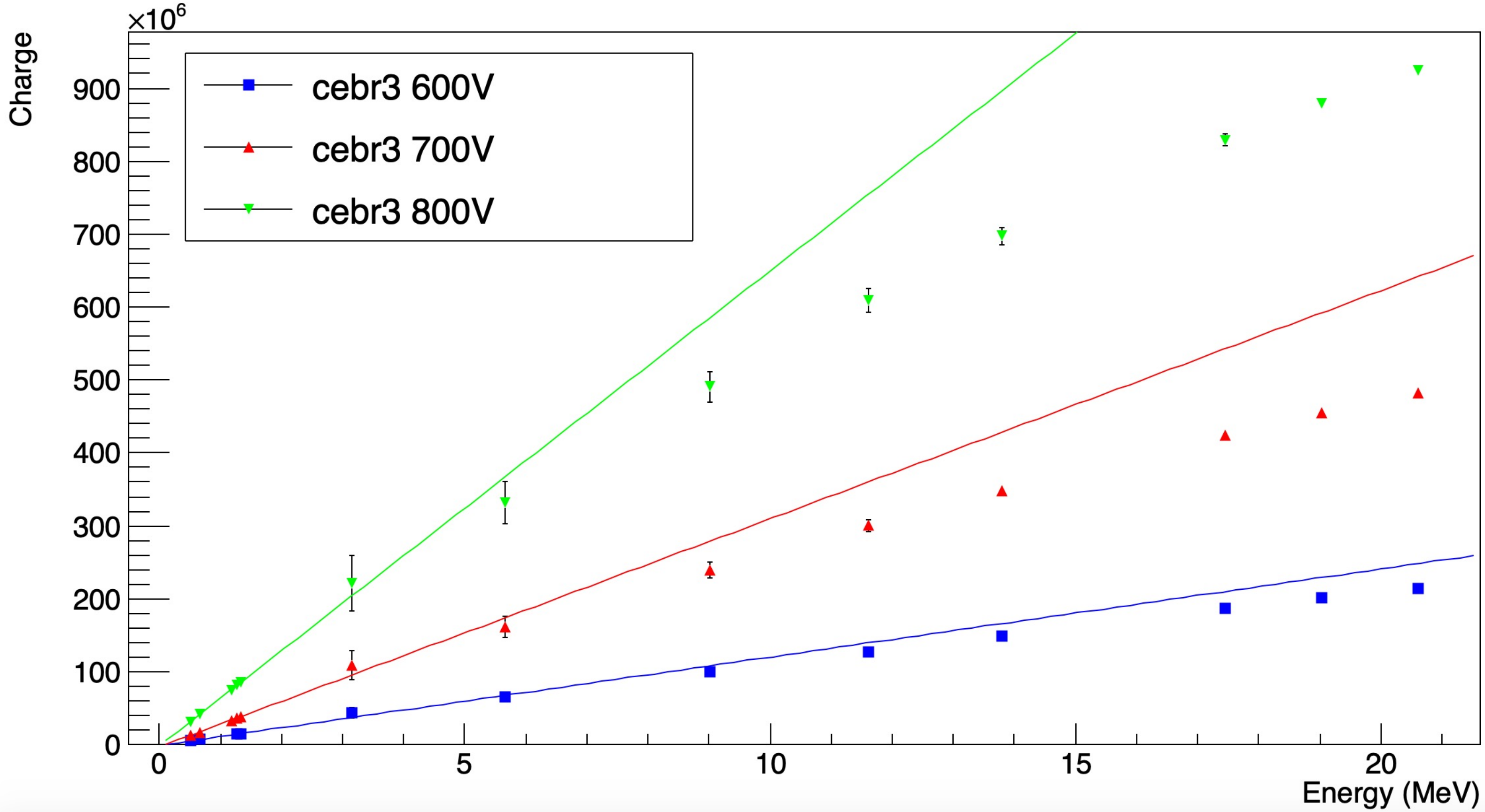
Saturation effect - CYRCé

Detector	High Voltage	γ sources and proton energy (MeV)
$CeBr_3$	600V, 700V & 800V	137Cs; 60Co; 22Na
		23.71; 22.30; 20.90; 17.83; 16.08; 14.17; 12.02; 10.80; 9.56
Phoswich	900V & 1000V	137Cs; 60Co; 22Na
		23.71; 22.30; 21.60; 20.90; 19.46; 18.65; 17.83

- Before entering the $CeBr_3$ detector, the protons are going through 48.85mm of air, 0.4mm of Aluminum and 1mm of Teflon.
- Before entering the Phoswich detector, the protons are going through 48.85mm of air and 1.5mm of Aluminum.

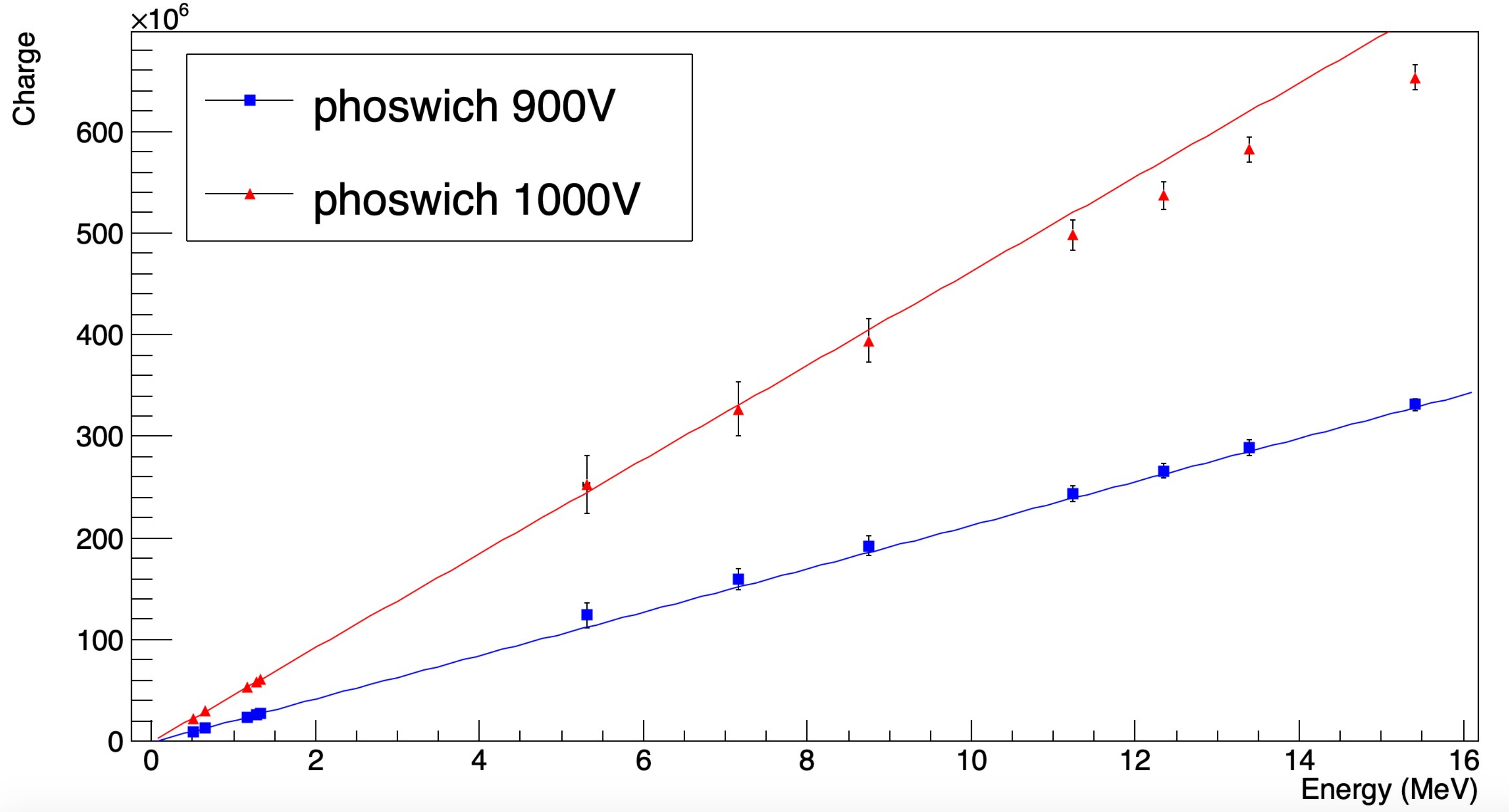
CeBr3	E_{exit} (MeV)	23.71	22.30	20.90	17.83	16.08	14.17	12.02	10.80
	E_f (MeV)	20.61	19.03	17.44	13.80	11.60	9.02	5.66	3.14
Phoswich	E_{exit} (MeV)	23.71	22.30	21.60	20.90	19.46	18.65	17.83	
	E_f (MeV)	15.42	13.39	12.34	11.24	8.75	7.17	5.31	

Saturation effect CeBr3



Important saturation effect for supply voltages of 800V and 700V.

Saturation effect Phoswich



Important saturation effect for supply voltages greater than 1000V

Outcomes and prospects

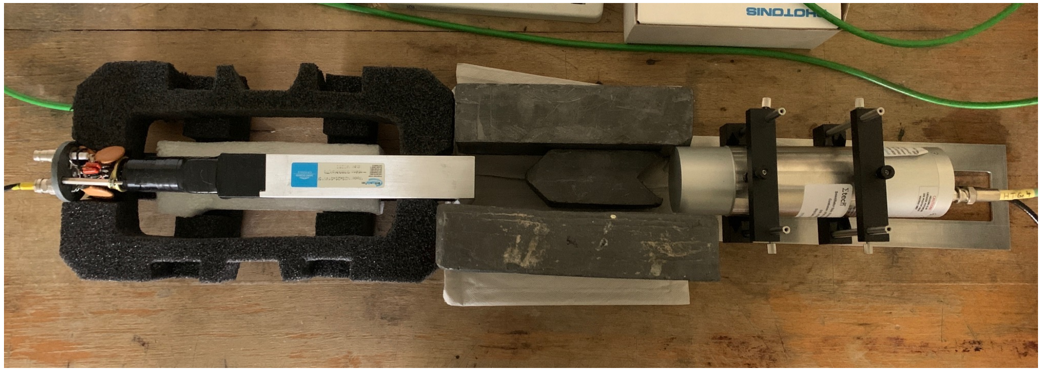
- High voltage supply chosen for Cerium bromide detector: 600V
- High voltage supply chosen for Phoswich detector: 900V

- Another experiment with 4MeV Van de Graaff accelerator (IPHC).

Targets: ^{27}Al (E_γ from 5 to 12 MeV), ^{50}Ti (E_γ from 5 to 7 MeV) and ^{58}Ni (E_γ from 5 to 10MeV).

- Calibration in Time for both detectors (Coïncidence)

Determine the accuracy of the ToF measurements



- Compare results with Monte Carlo simulation (e.g. Geant4)

Thanks for your attention.

Question ?

References

[R.A. Mewaldt, 1988] - R.A. Mewaldt, Elemental Composition and Energy Spectra of Galactic Cosmic Rays, in Interplanetary Particle Environment. *JPL Publication.* 1988

[Krämer et al., 2016] - Krämer, M. *et al.* Helium for radiotherapy? Physical and biological verifications of a novel treatment modality. *Med.Phys.* 1995-2004

[Cucinotta, 2006] - Cucinotta FA, Durante M. Cancer risk from exposure to galactic cosmic rays: implications for space exploration by human beings. *Lancet Oncol.* 2006

[Miller et al., 2018] - Miller et al., Investigation of the LaBr3 scintillator response to heavy ions. *Radiation Measurements*. 2018

Bragg Peak

At those energies, the energy loss per unit distance dE/dx is dominated by the inelastic collistions with the electrons of the target medium.

Bethe-Bloch formula :

$$\frac{dE}{dx} = \frac{4\pi e^4 Z_t Z_p^2}{m_e v^2}\left[\ln\frac{2m_e v^2}{< I >} - \ln(1-\beta^2) - \beta^2 - \frac{C}{Z_t} - \frac{\delta}{2}\right]$$

Where Zp and Zt correspond to the nuclear charge of the projectile and the target, m_e and e to the mass and the charge of the electron, < I > to mean ionization energy of the target medium, v to the speed of the projectile, β = v/c, C to the charge sreening constant and δ the correction factor of charge density.

Recoil proton telescope

The RPT is based on the detection of the recoil proton elastically scattered by a neutron in a thin hydrogenated target. The energy of the recoil proton E_p is related to the incident neutron energy E_n by the relationship:

$$E_n = \frac{E_p}{\cos\theta}$$

where θ is the angle between the incident neutron and the recoil proton directions.

Full Width at Half Maximum

$$\frac{FWHM}{E} = 2.35\,\frac{\sigma}{C}$$

σ is the standard deviation and C is the mean value for the charge.