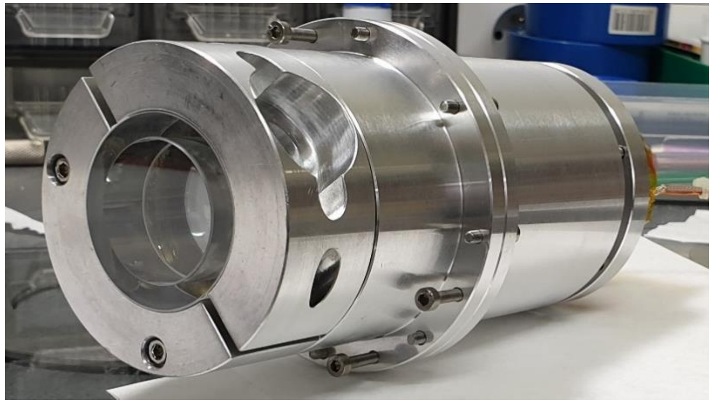
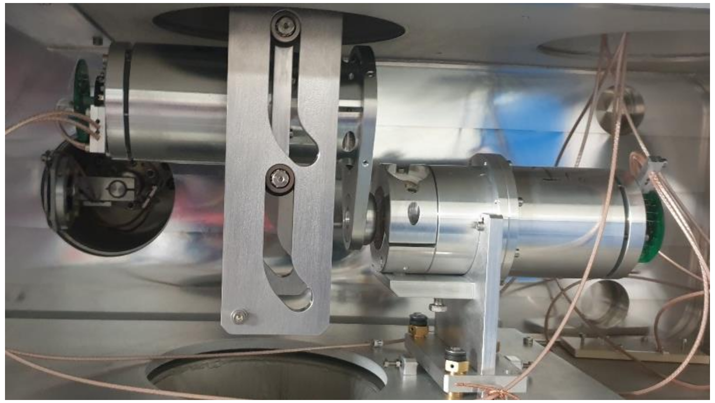
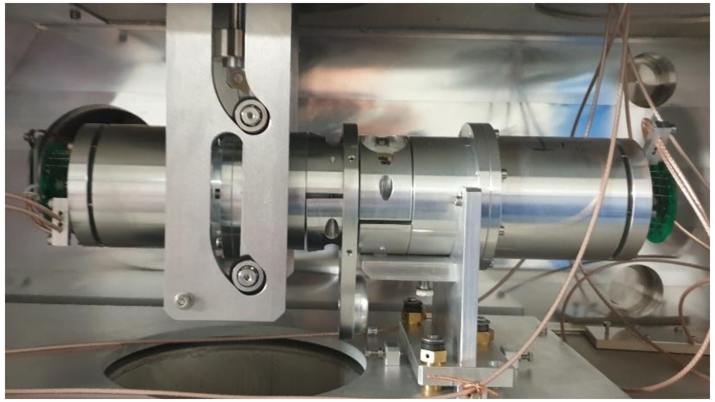






b-STILED: Search for Tensor Interactions in nucLear bEta Decay

Colloque GANIL 2023

Mohamad KANAFANI

October 11, 2023

Soustons, France

Outline

- Context and motivations
- b-STILED
- Data analysis
- Summary and outlook

Nuclear beta decay

Beta decay Hamiltonian: Respect Lorentz invariance

$$H_\beta = \frac{G_F}{\sqrt{2}} V_{ud} \Big[(\bar{\psi}_p \psi_n)(\bar{\psi}_e (C_S + C'_S \gamma_5) \psi_\nu)$$
$$+ (\bar{\psi}_p \gamma_\mu \psi_n)(\bar{\psi}_e \gamma^\mu (C_V + C'_V \gamma_5) \psi_\nu)$$
$$+ \frac{1}{2} (\bar{\psi}_p \sigma_{\lambda\mu} \psi_n)(\bar{\psi}_e \sigma^{\lambda\mu} (C_T + C'_T \gamma_5) \psi_\nu)$$
$$- (\bar{\psi}_p \gamma_\mu \gamma_5 \psi_n)(\bar{\psi}_e \gamma^\mu \gamma_5 (C_A + C'_A \gamma_5) \psi_\nu)$$
$$+ (\bar{\psi}_p \gamma_5 \psi_n)(\bar{\psi}_e \gamma_5 (C_P + C'_P \gamma_5) \psi_\nu) \Big]$$
$$+ h.c.$$

10 coupling constants!!

Standard Model:

- $C_V = C'_V = 1$
- $C_A = C'_A = -1.25$
- $C_S = C'_S = C_T = C'_T = 0$

Severijns N. (2004). Weak Interaction Studies by Precision Experiments in Nuclear Beta Decay. In J. Al-Khalili & E. Roeckl (Reds), The Euroschool Lectures on Physics with Exotic Beams, Vol. I (bll 339-381).

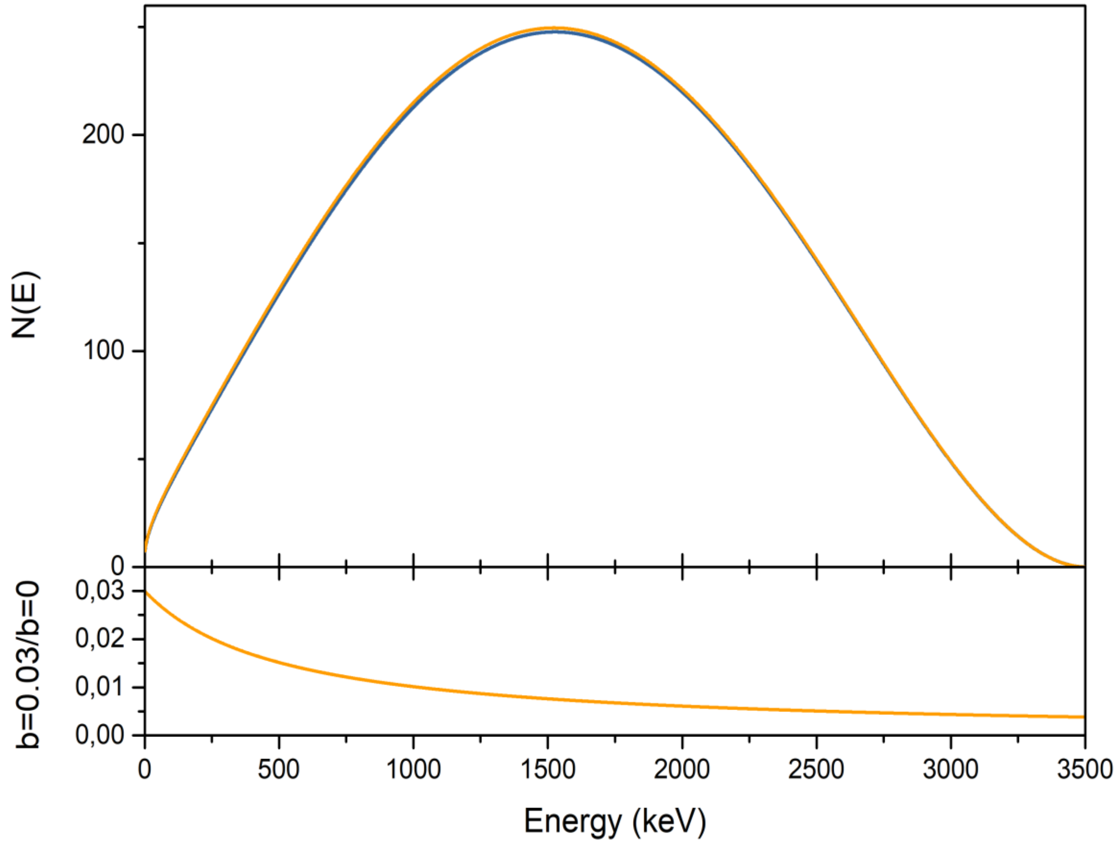
Fierz interference term

Pure Gamow-teller transition

$$b_{GT} \propto \gamma Re\left(\frac{C_T + C_T'}{C_A}\right)$$

Pure Fermi transition

$$b_F \propto \gamma Re\left(\frac{C_S + C_S'}{C_V}\right)$$



Standard Model: $b = 0$

Direct effect on the beta spectrum shape!

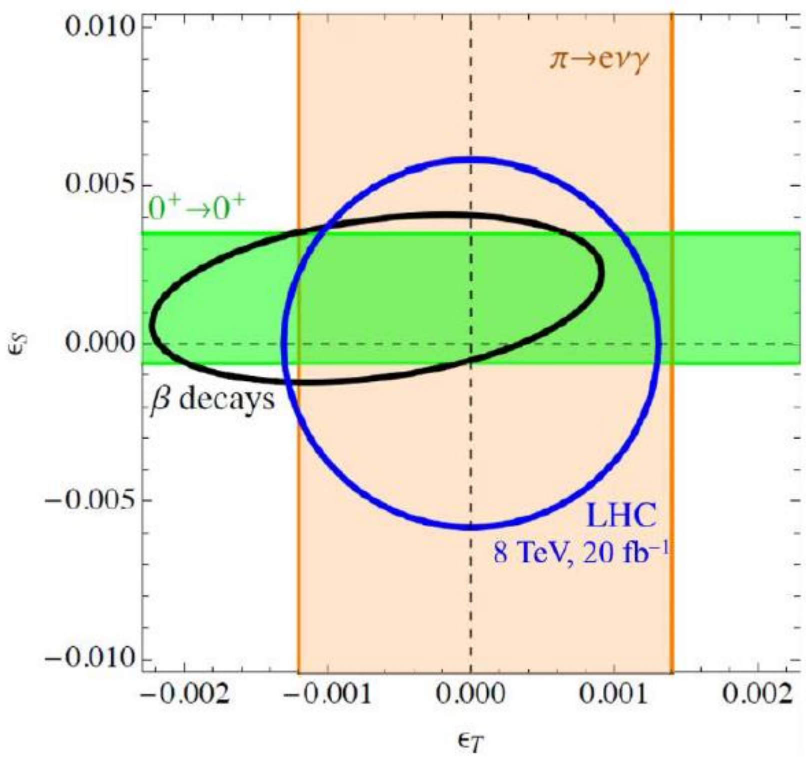
$$N(E) \propto \underbrace{(1+\eta)}_{\text{Corrections term}}\underbrace{pE(E-E_0)^2}_{\text{Phase space}}\left(1+\frac{m}{E}b\right)$$

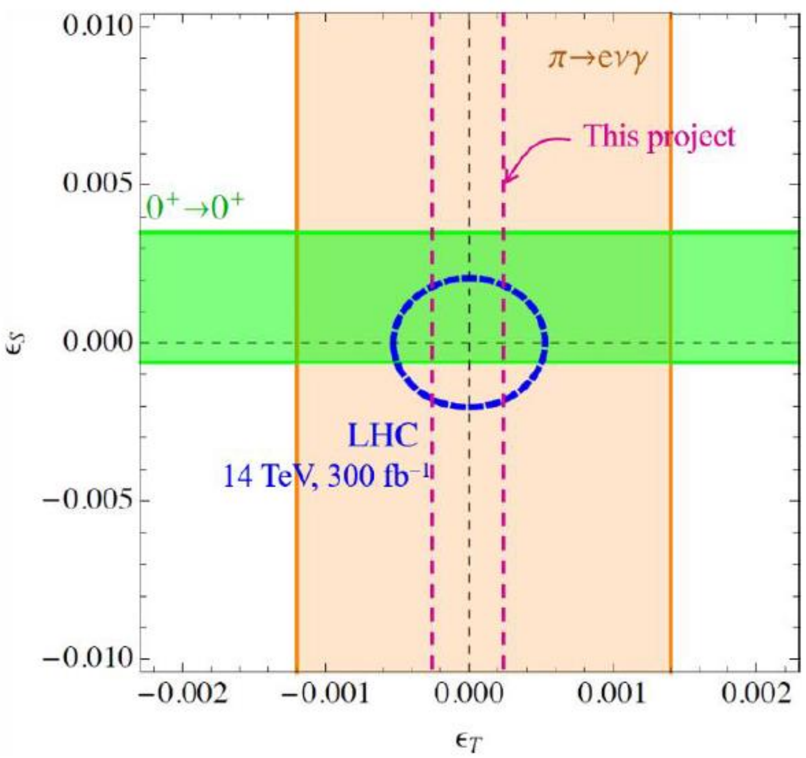
b-STILED : The goal

b-STILED : **b-S**earch for **T**ensor **I**nteractions in nuc**L**ear b**E**ta **D**ecay

b_{GT} for ^{6}He decay with $\Delta b_{GT} = 10^{-3}$

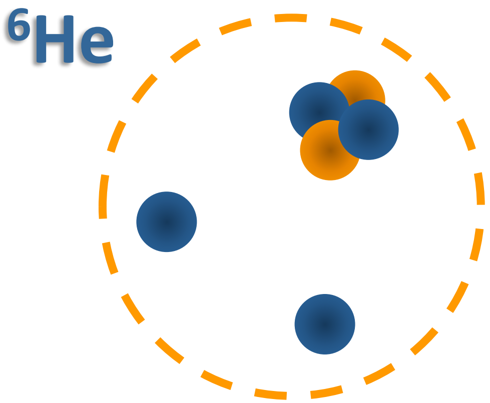
Fit the energy spectrum of ^{6}He decay to extract the Fierz term

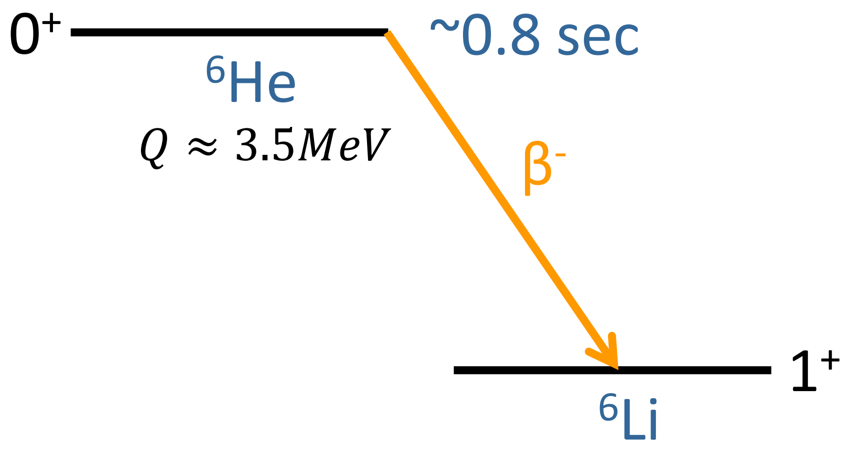


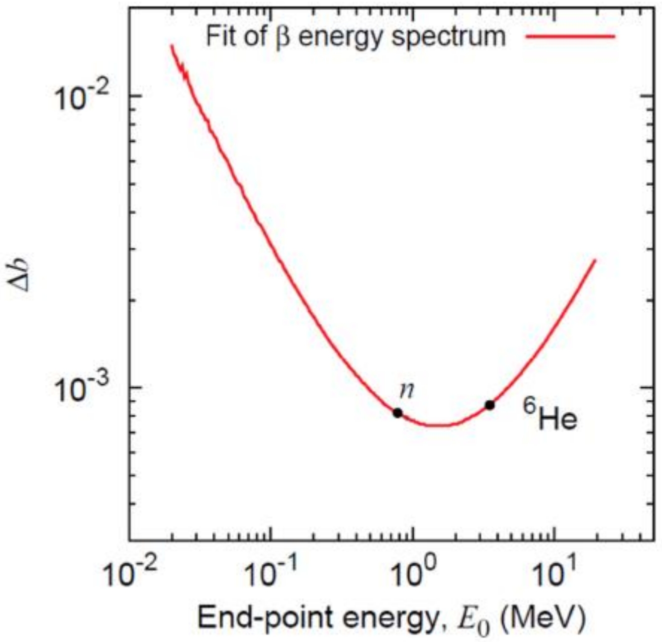


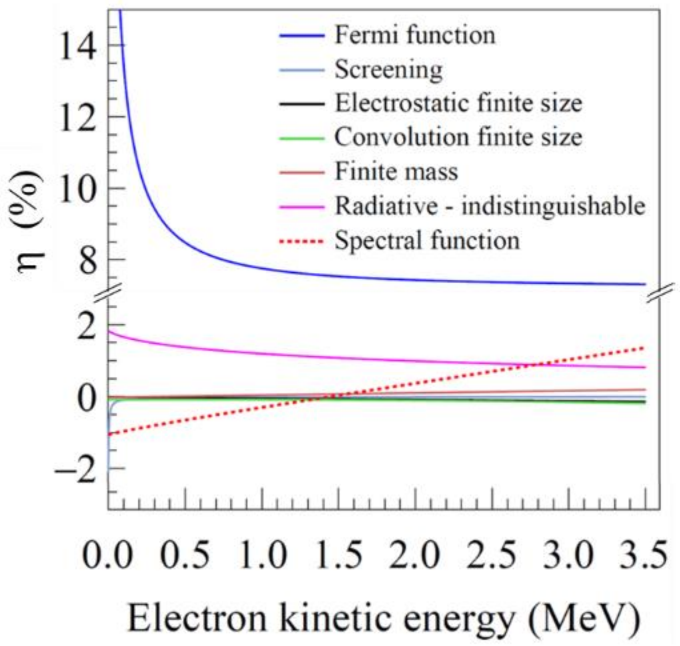
b-STILED : The perfect candidate

- Convenient half-life for implantation-decay cycles
- Pure GT transition and thus exclusively sensitive to tensor currents
- Convenient endpoint ~3.5MeV
- Theoretical corrections are known with high precision





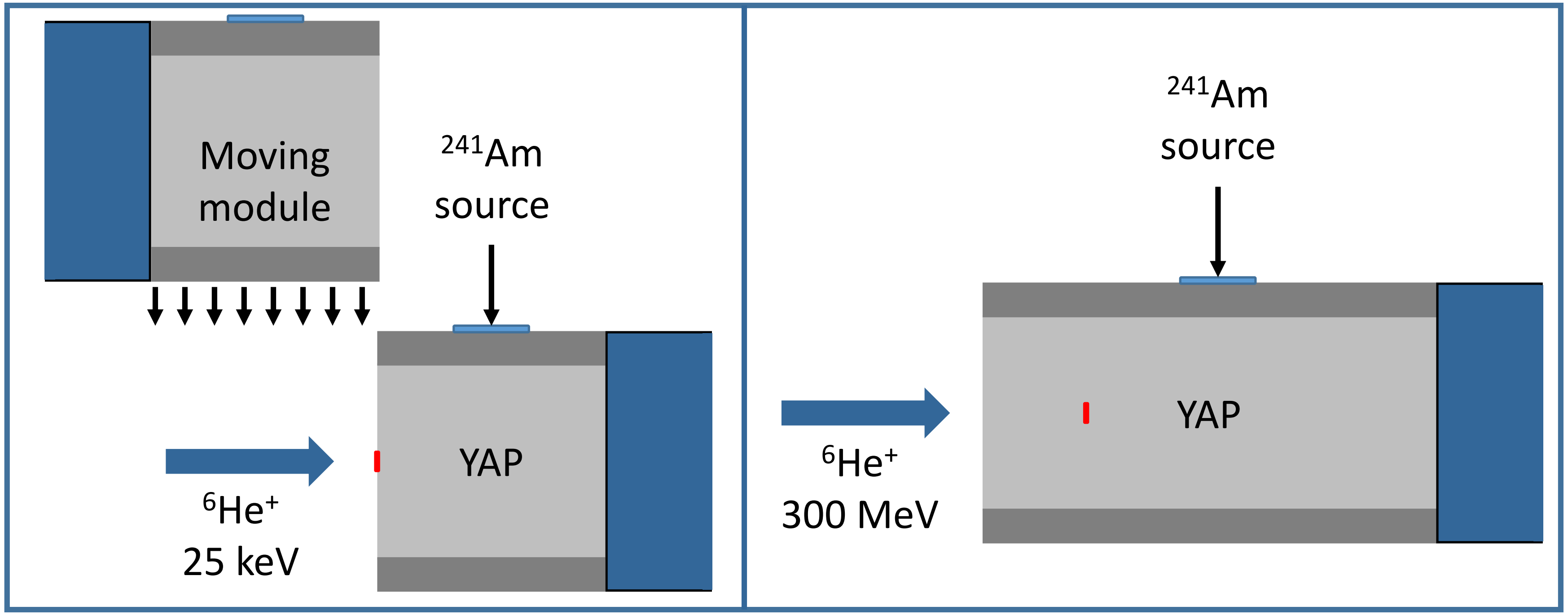




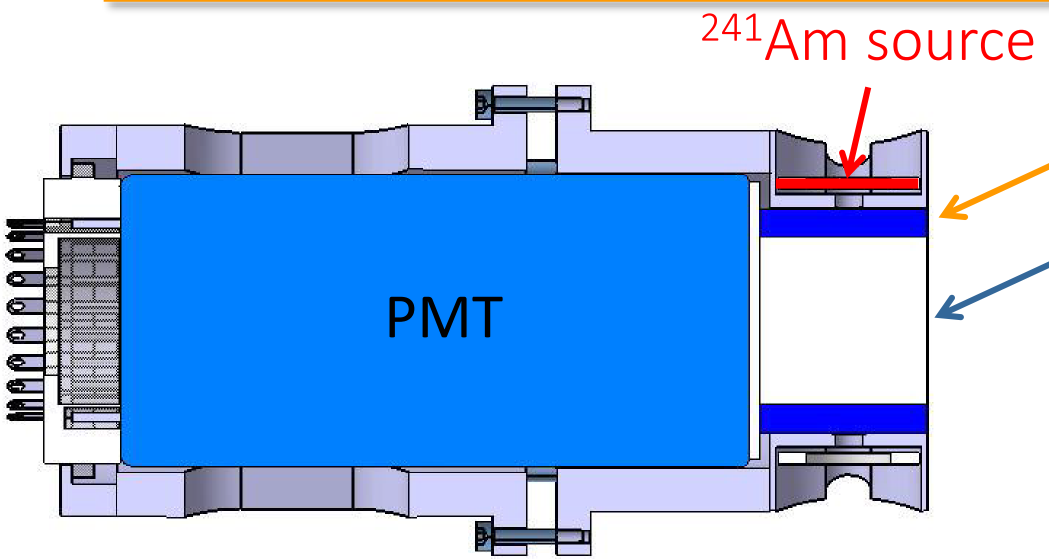
Phase I: 2 experiments with a goal of $\Delta b_{GT} = 4 \times 10^{-3}$:

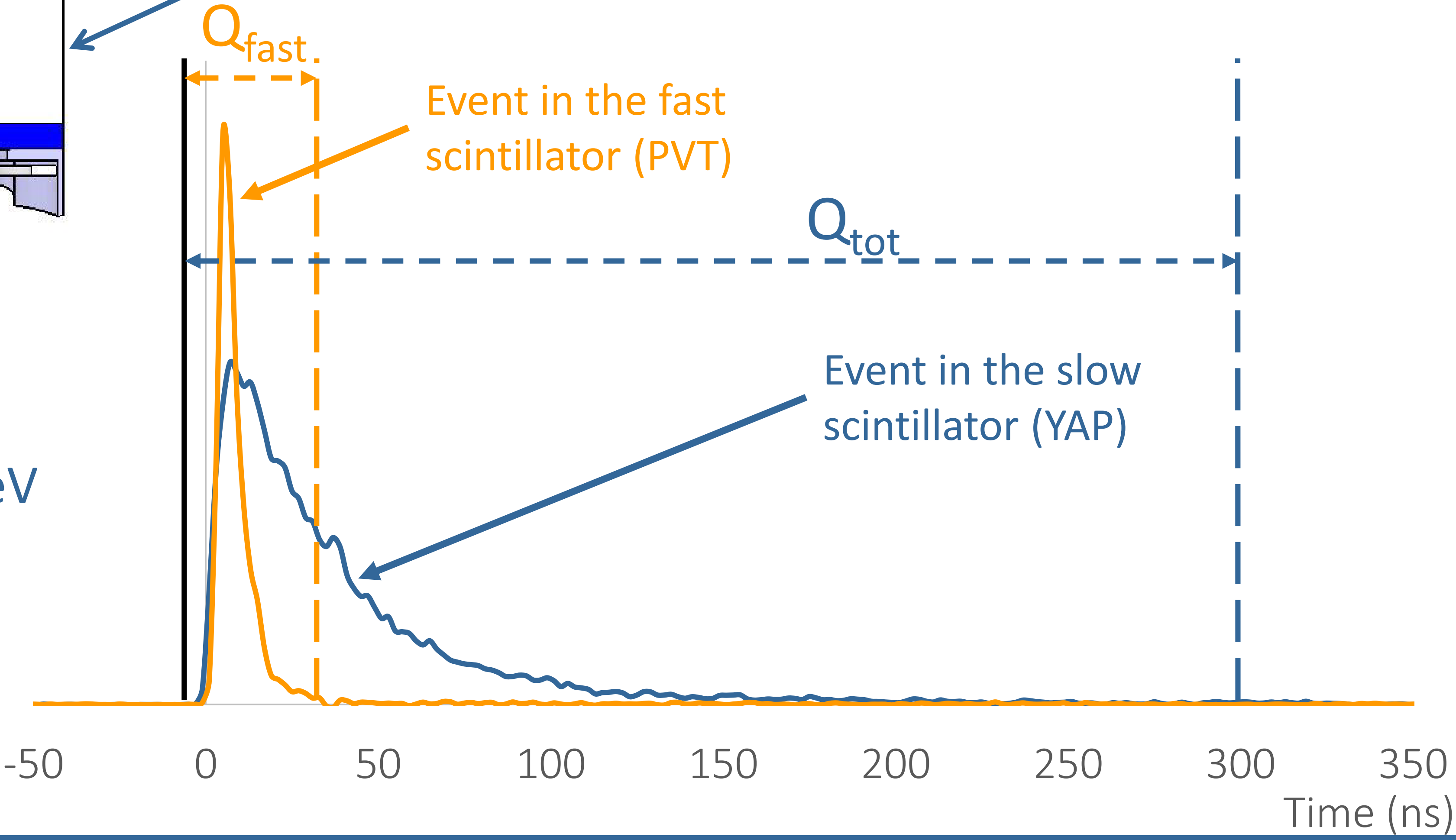
- Low energy experiment
- High energy experiment

4π detection geometry



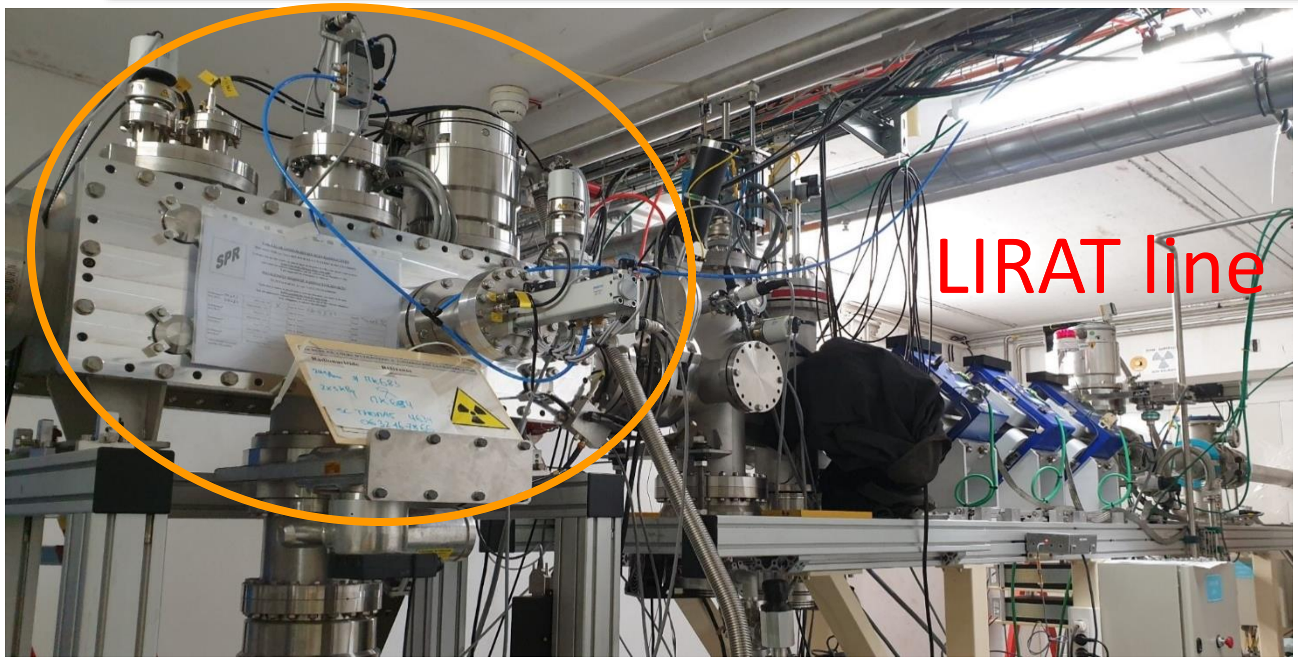
b-STILED : The phoswich detector

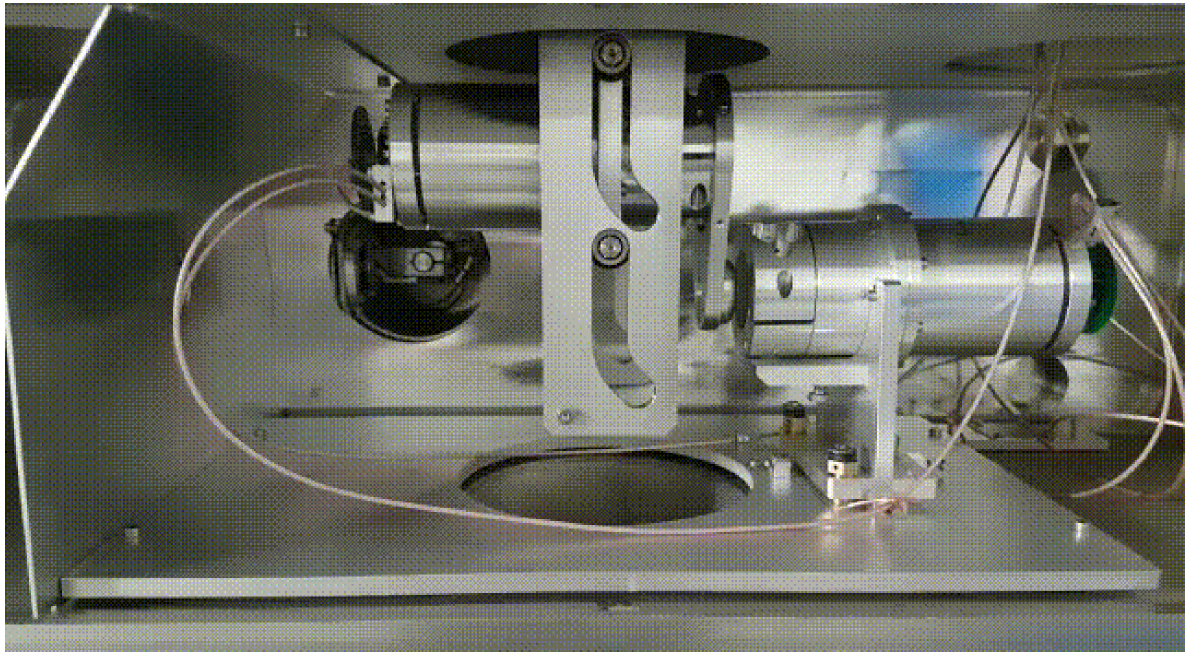




YAP properties:
- Linear energy response
- Good resolution ~5% @ 1 MeV
- Low Bremsstrahlung energy escape

Low energy experiment





May 2021 @GANIL

Typical cycle:
- 2.5 sec of implantation
- 12 sec of acquisition

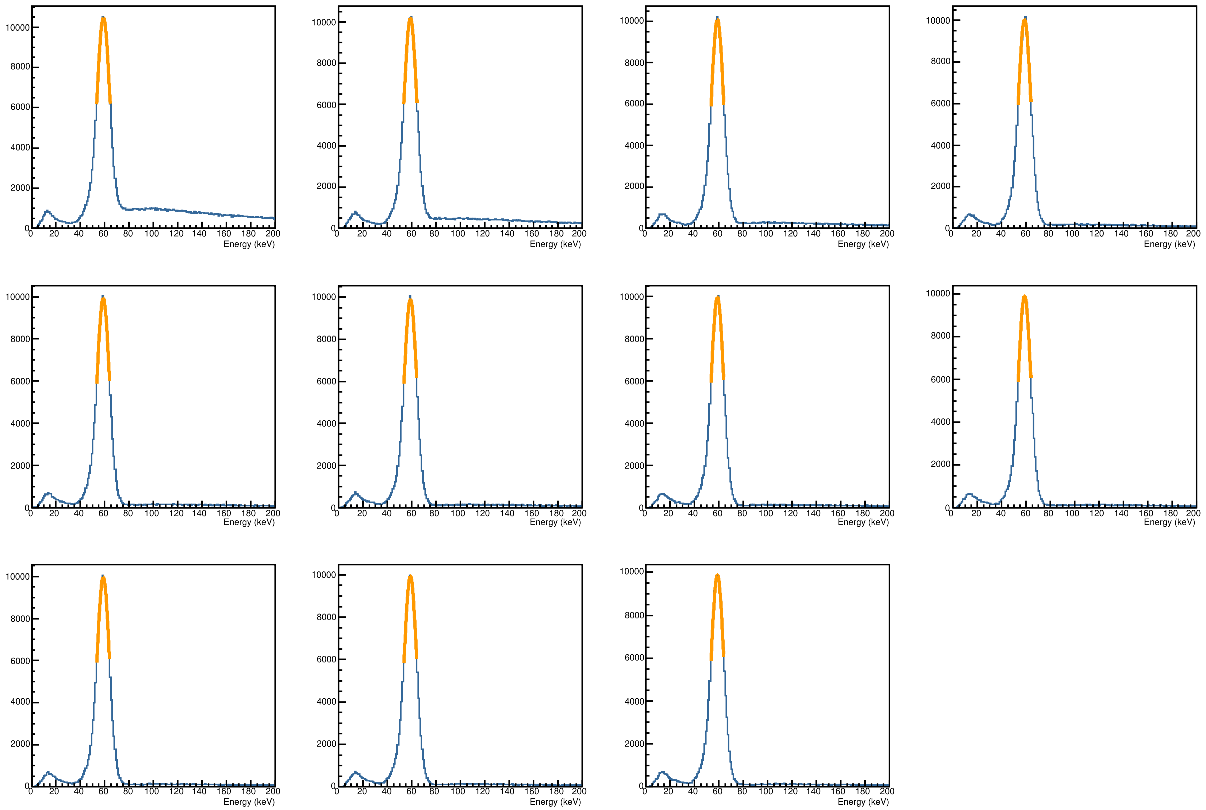
4 sets of measurements:
1) Different systematic conditions
2) BKG runs

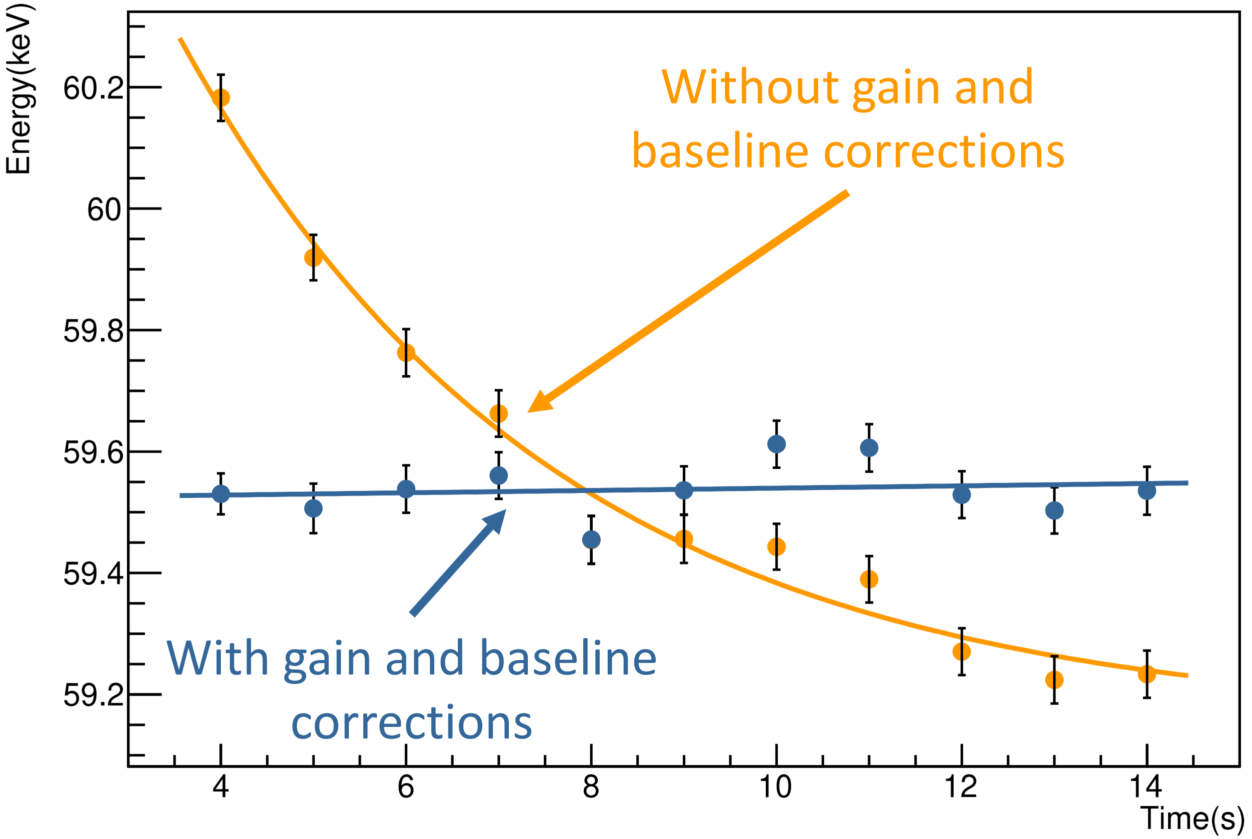
DAQ:
- Time stamp
- Deposited energy

Energy calibration (60 keV gammas)

First energy calibration with the 60 keV peak

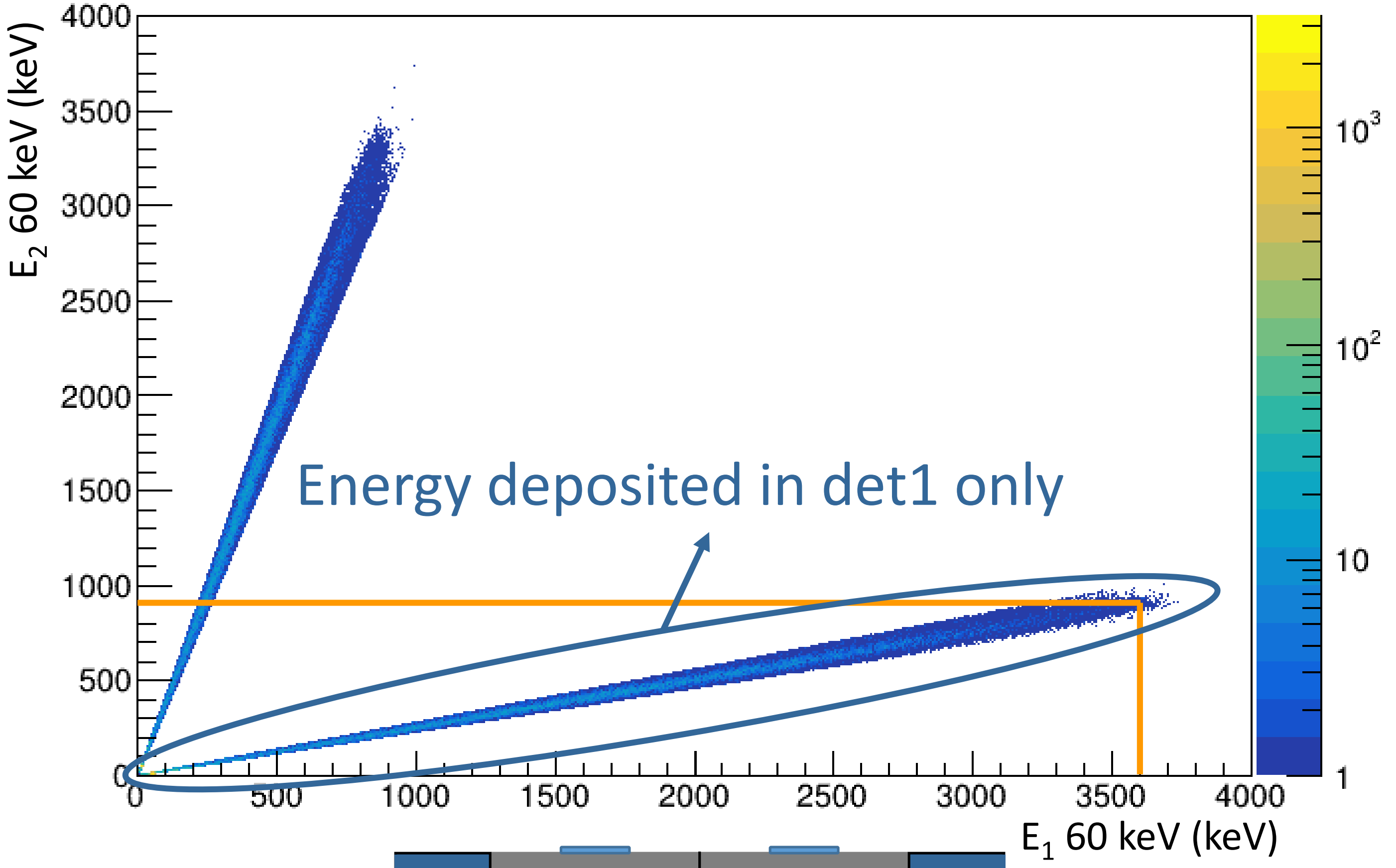
- Correct relative gain and baseline fluctuations during the cycles for each detector
- Match the 60 keV peak position in det1 and det2

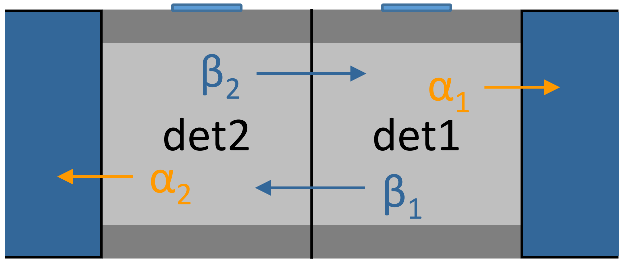


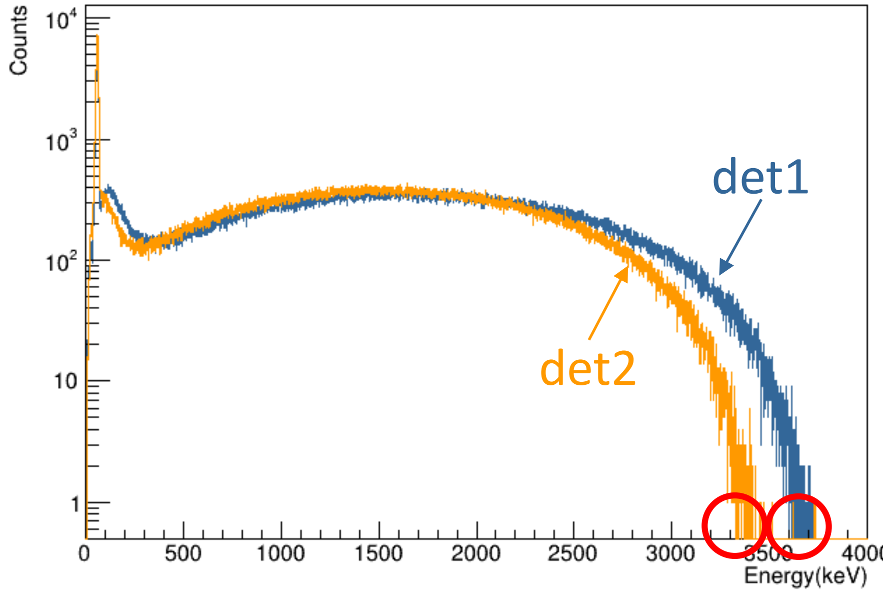


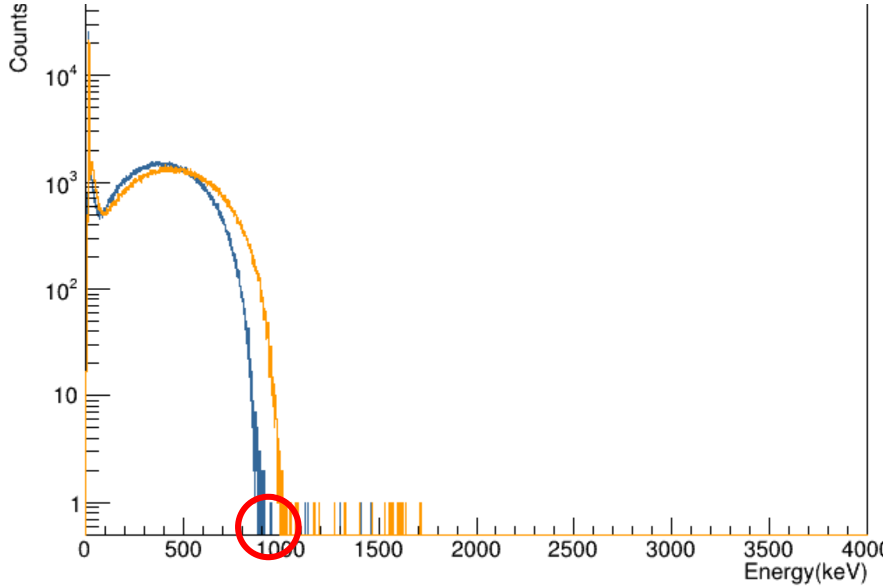
Light cross-talk

After calibration with 60 keV peak







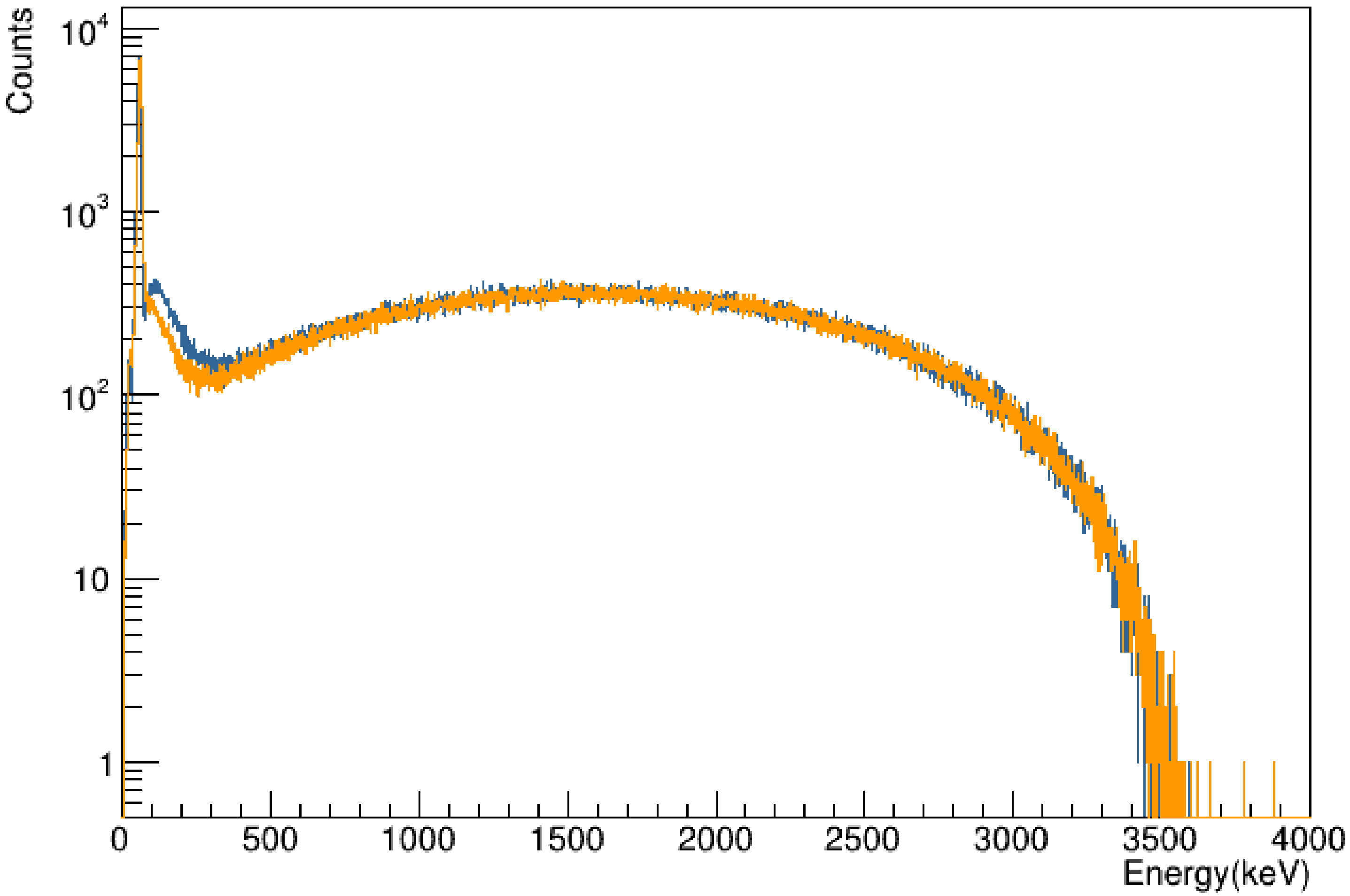


Refine calibration (^6He endpoint)

Second calibration accounting for endpoint mismatch

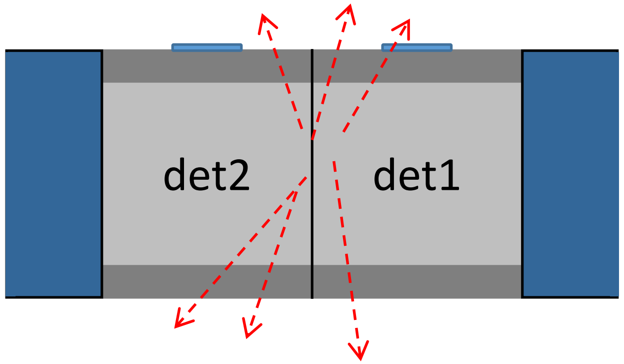
$$E_1 = \frac{\alpha_1 E_{1(60keV)} - \beta_2 \alpha_2 E_{2(60keV)}}{1 - \beta_1 \beta_2}$$

$$E_2 = \frac{\alpha_2 E_{2(60keV)} - \beta_1 \alpha_1 E_{1(60keV)}}{1 - \beta_1 \beta_2}$$



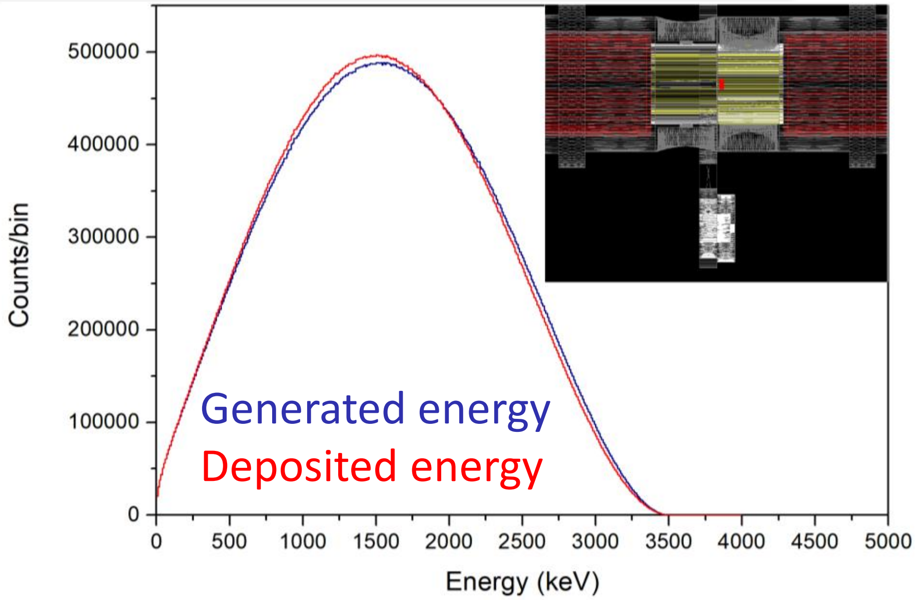
Bremsstrahlung escape

$$N(E) = PS(E) \cdot FF(E) \left[\alpha_0 + \alpha_1 \cdot \frac{1}{E} + \alpha_2 \cdot E + \alpha_3 \cdot E^2 \right]$$



Energy escape

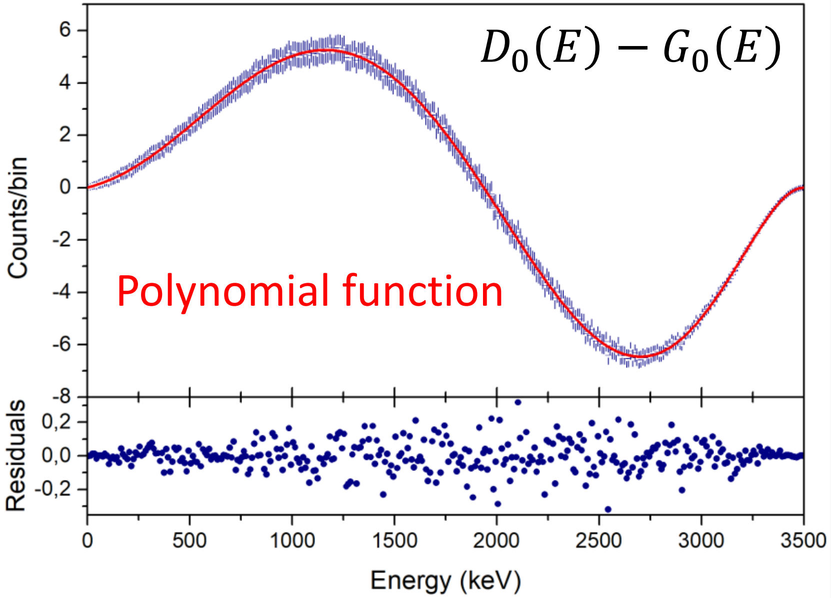
$$N(E_{dep}) = ?$$



$$G_i(E) = PS(E) \cdot FF(E) \cdot E^i \xrightarrow{\text{GEANT4}} D_i(E)$$

$$i = -1, 0,1,2$$

$$f_i(E) = norm \times \left(D_i(E) - G_i(E)\right)$$



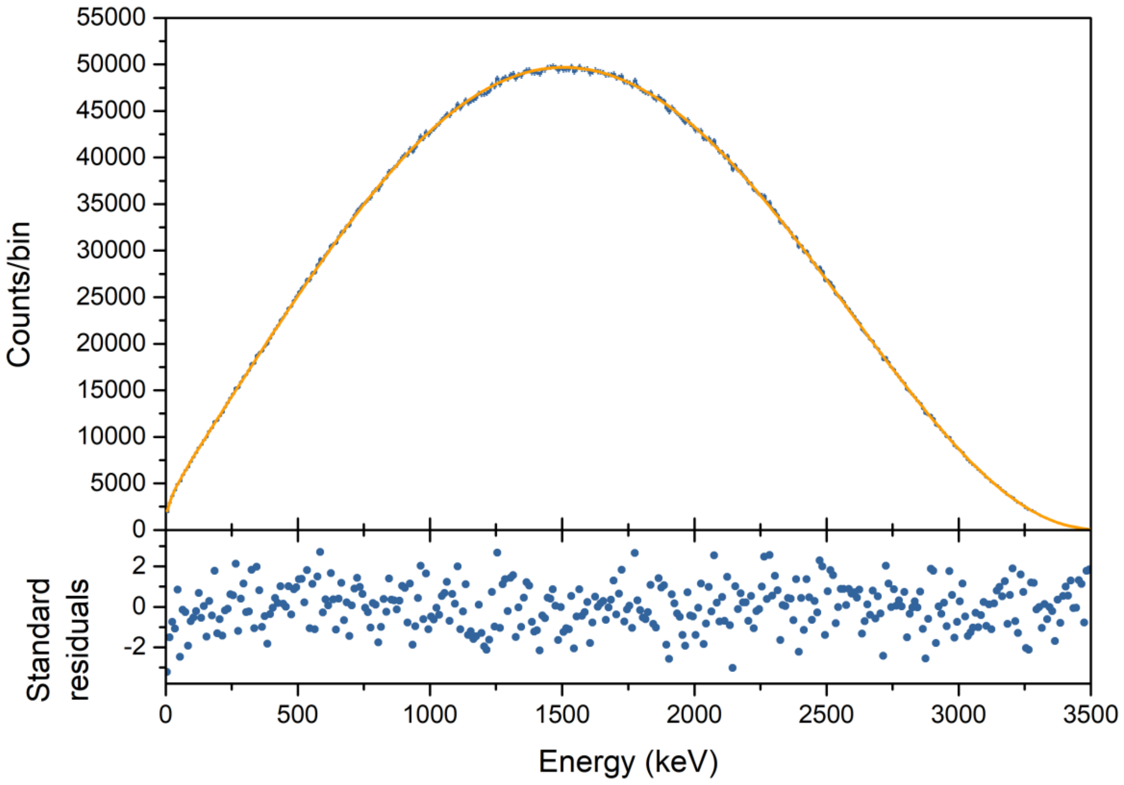
Analytical function that describes the bremsstrahlung escape

Testing the fitting method

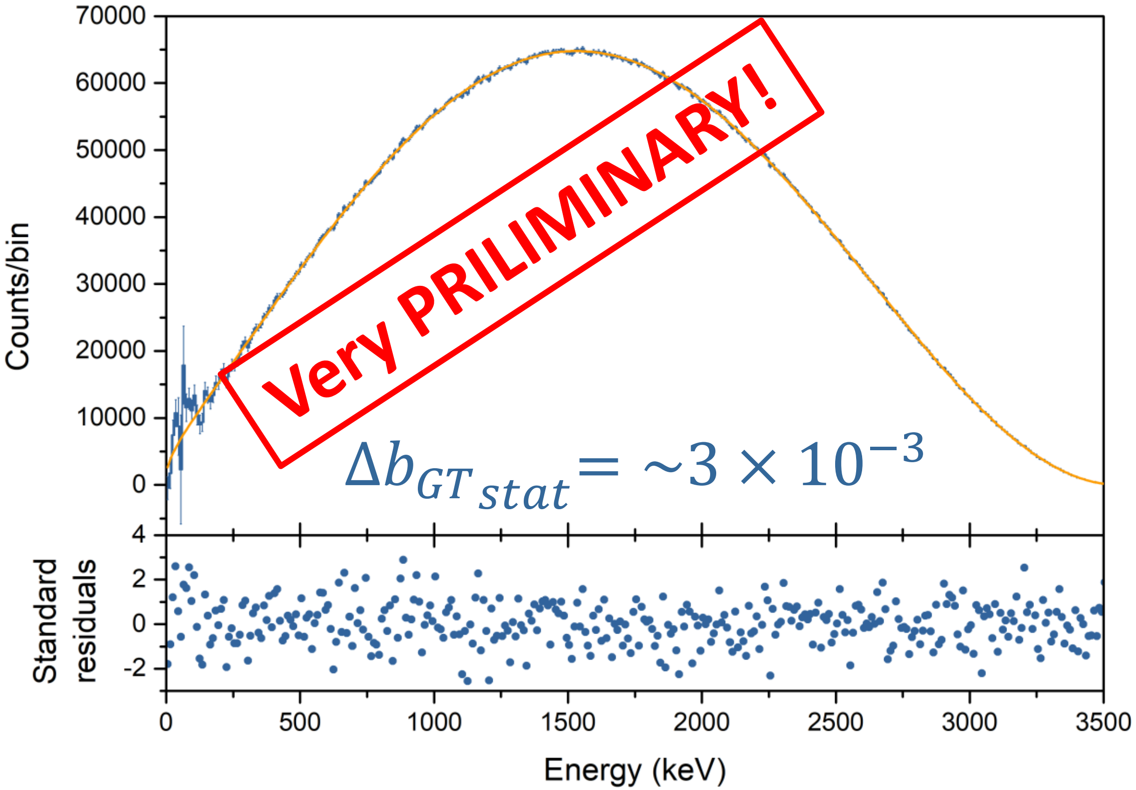
$$F(E) = norm \times \sum_{i=-1}^{2} \alpha_i \left[PS(E) \cdot FF(E) \cdot E^i + f_i(E) \right]$$

$$fitFct(E) = F(E) * gaus(E)$$

Spectrum generated with G4



Experimental spectrum



$\Delta b_{GT\,stat} = \sim 3 \times 10^{-3}$

Summary and outlook

Summary:

- The energy calibration with the gain and baseline corrections, and the matching of the endpoints is done.
- The sources of background are well identified and can be subtracted with the BKG runs.
- The fit function for the energy spectrum was tested with simulated data and can be used to fit the experimental data.

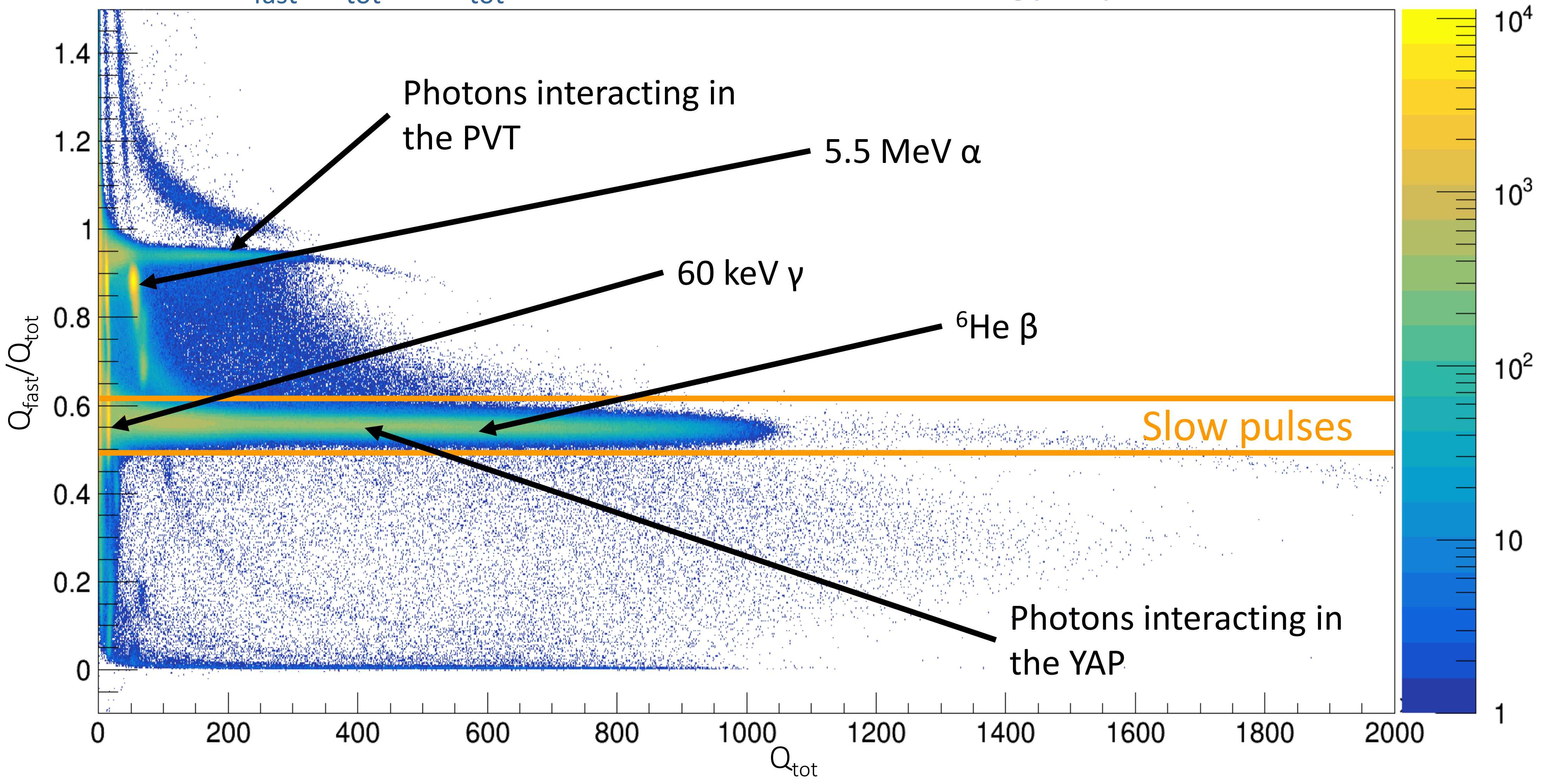
Outlook:

- Background subtraction
- Pileup estimate
- Energy calibration of the background runs
- YAP linearity
- Radiative corrections
- Bremsstrahlung energy escape

Thank you for your attention!

Pulses discrimination

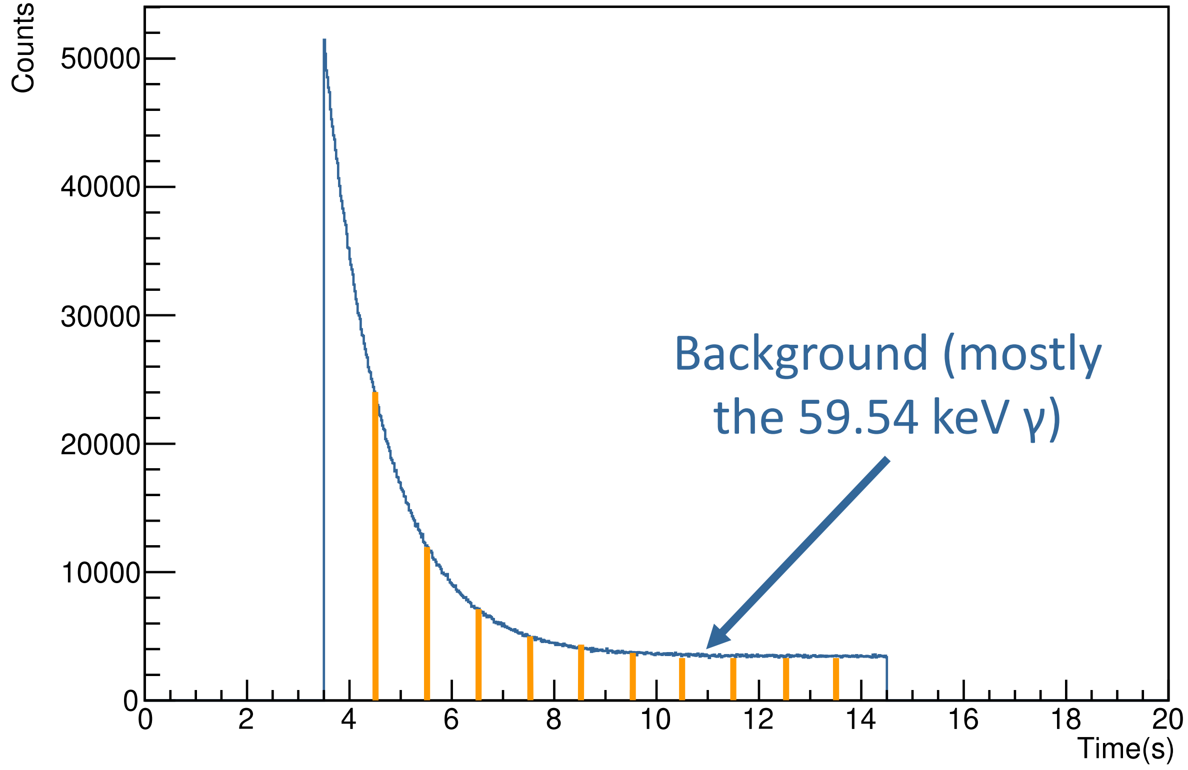
Q_{fast}/Q_{tot} vs Q_{tot} for one run of the low energy experiment



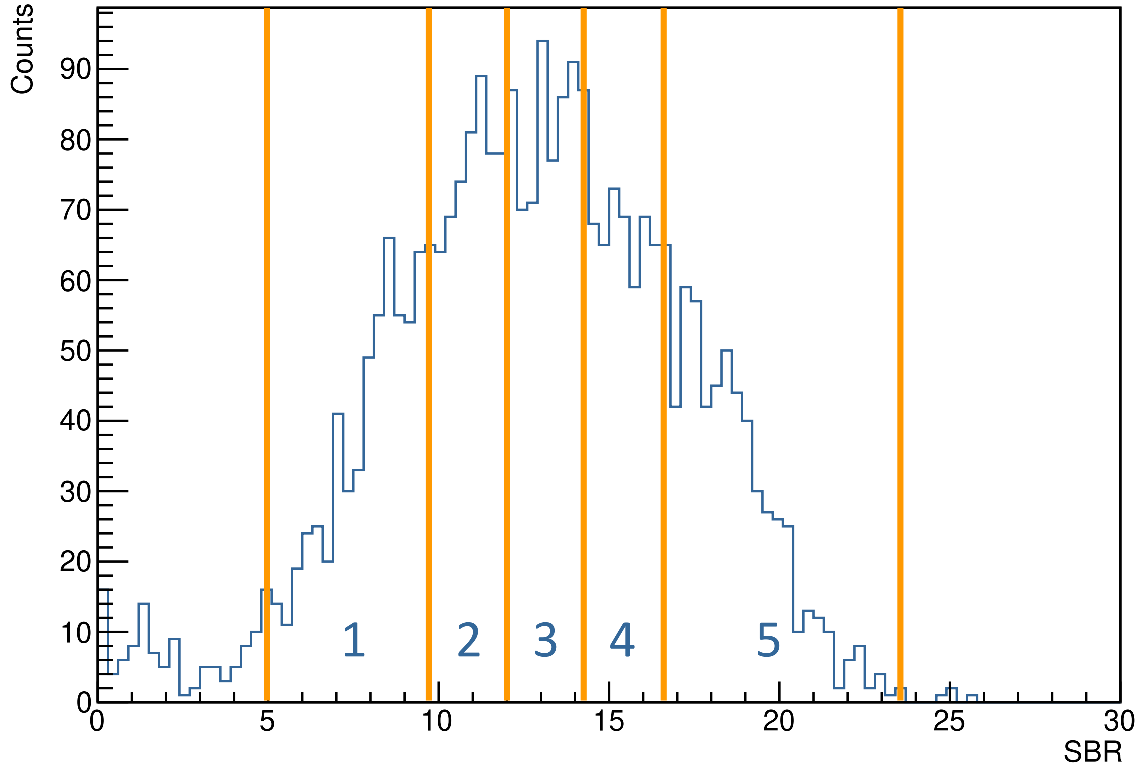
First energy calibration

A very accurate energy calibration is required to control any baseline or gain variation.

The evolution of the count rate within a cycle



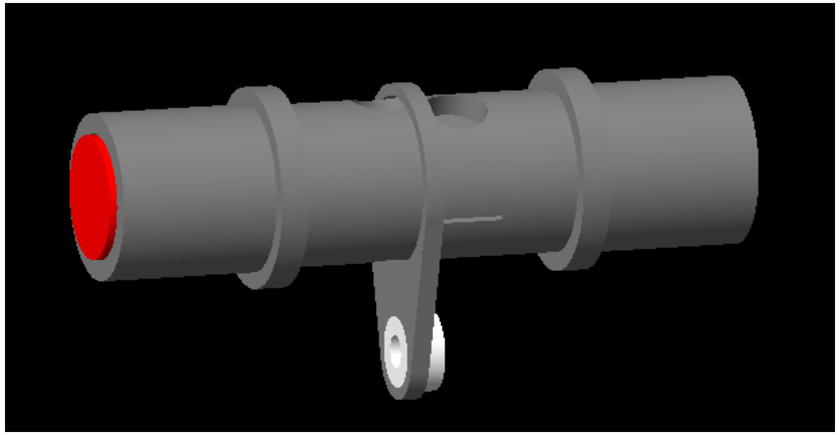
Distribution of the signal to BKG ratio for all the cycles of 1 set of measurements

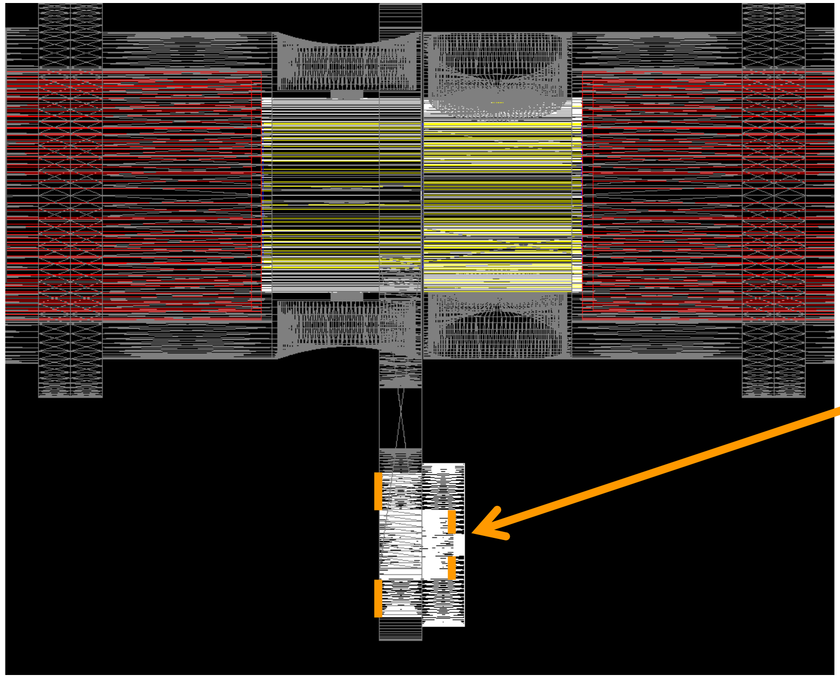


The gain and baseline variations depends on the count rate variations

Backgrounds investigation

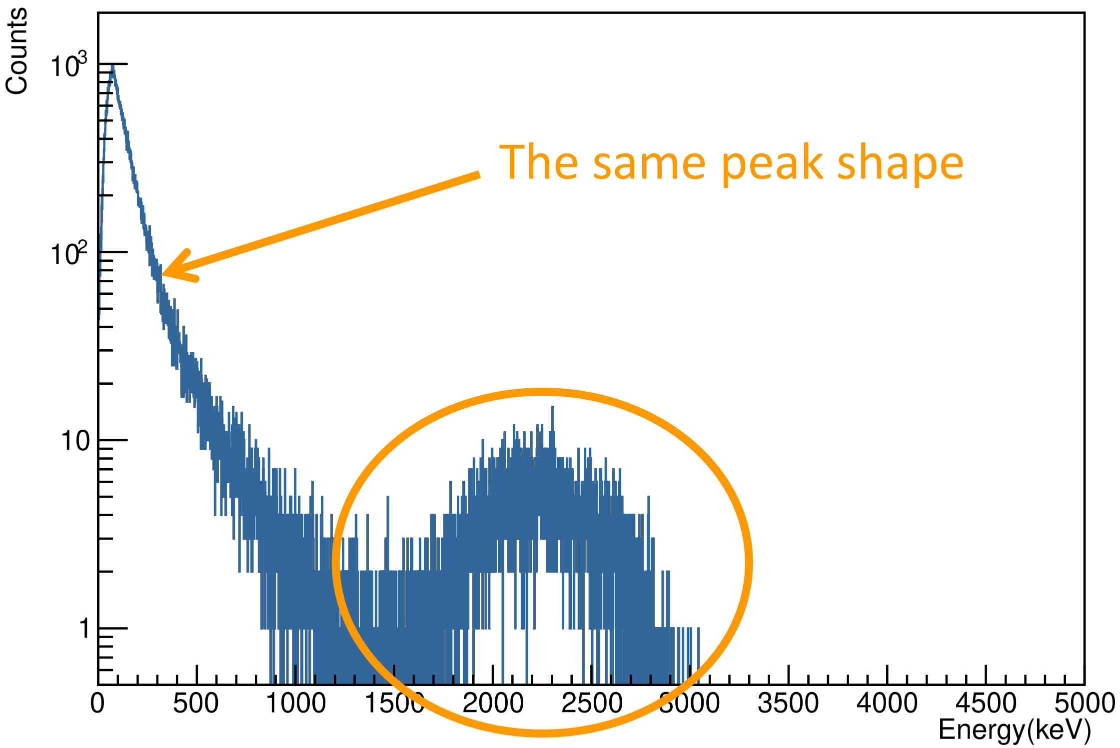
Detection system construction in Geant4





$^6He^+$ in the collimator

Deposited energy into YAP

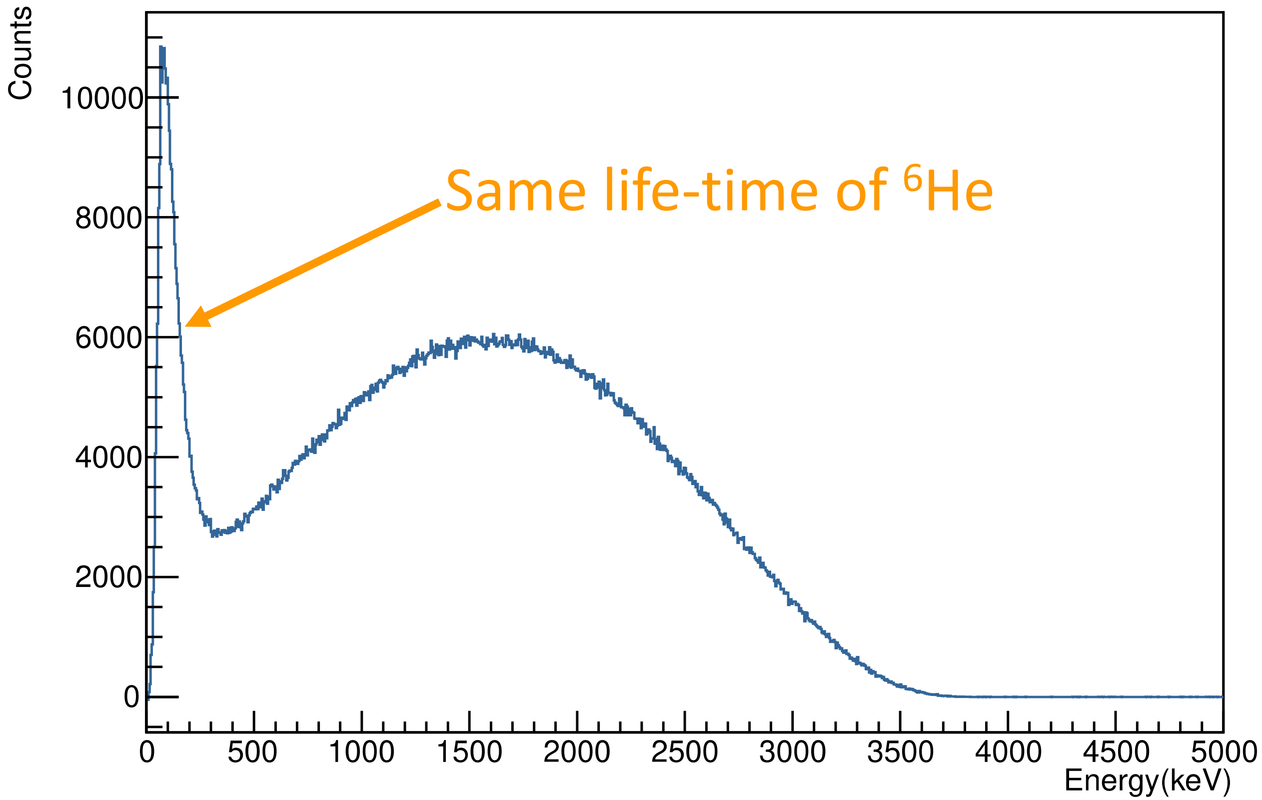


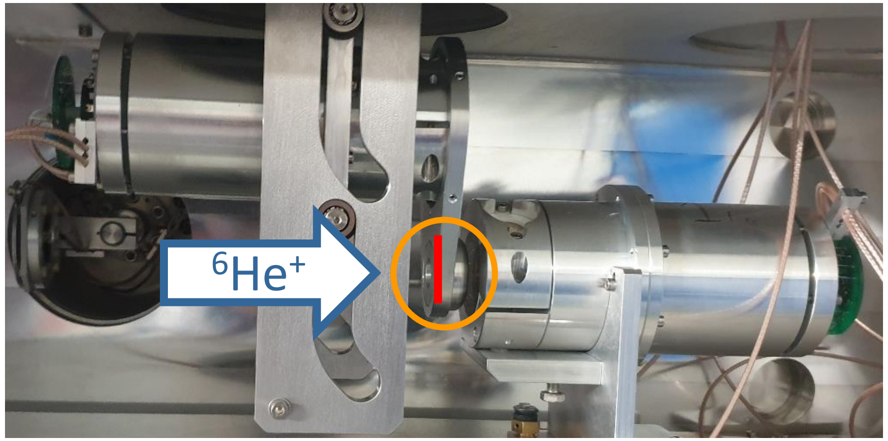
- ✓ Bremsstrahlung peak
- ✓ Electrons from ^6He decay on the collimator

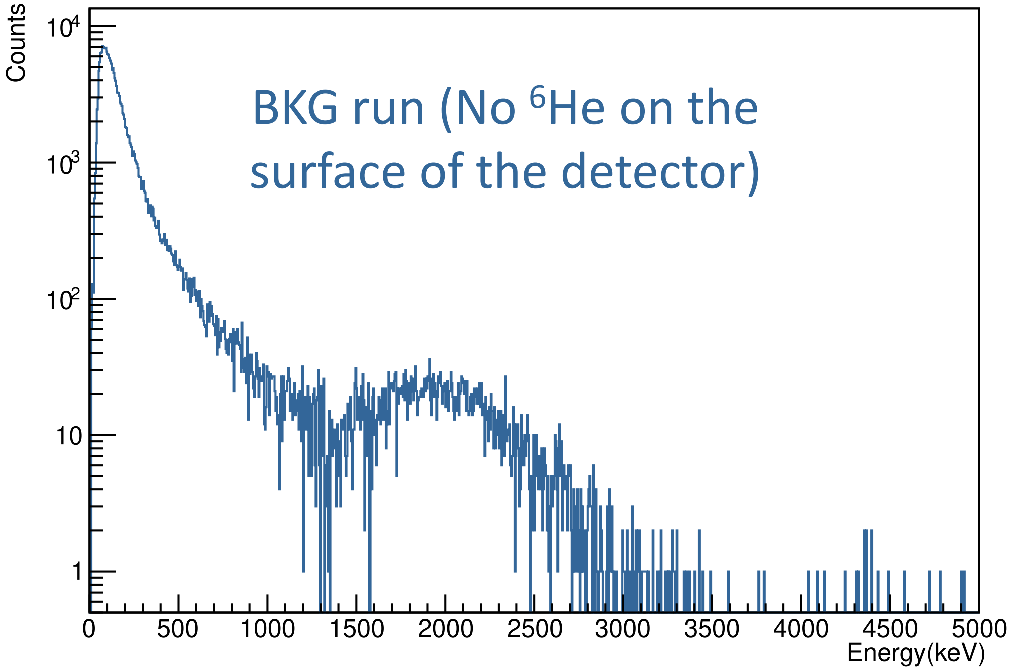
Backgrounds investigation

Following constant background subtraction

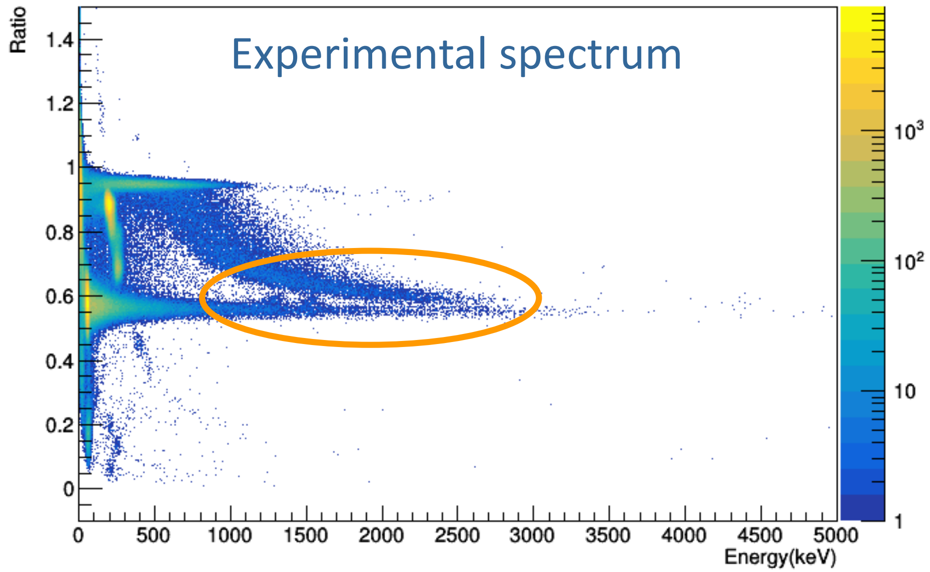
Experimental spectrum

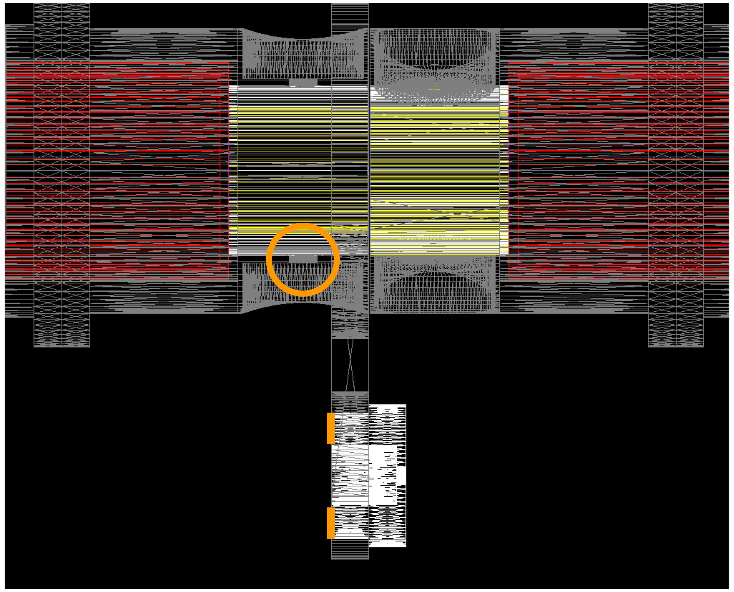


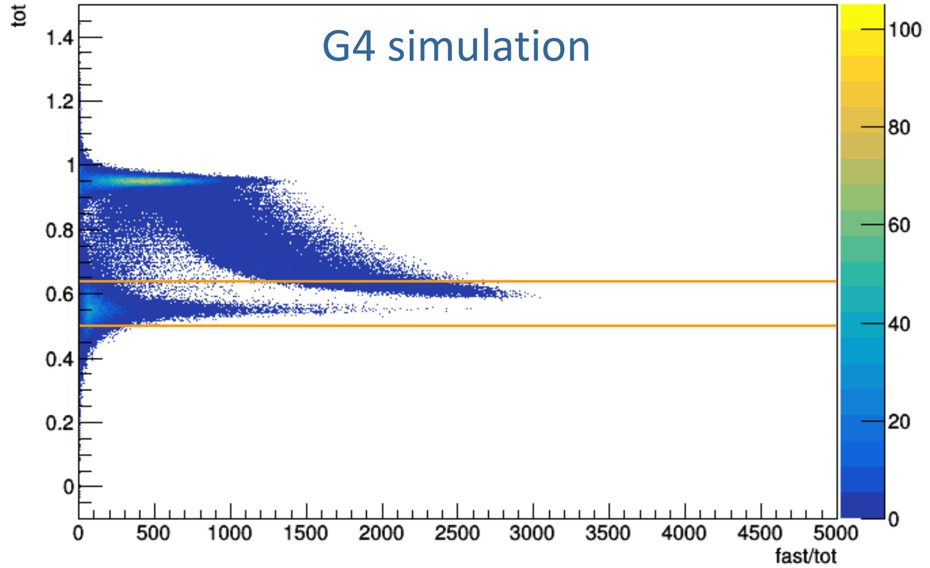


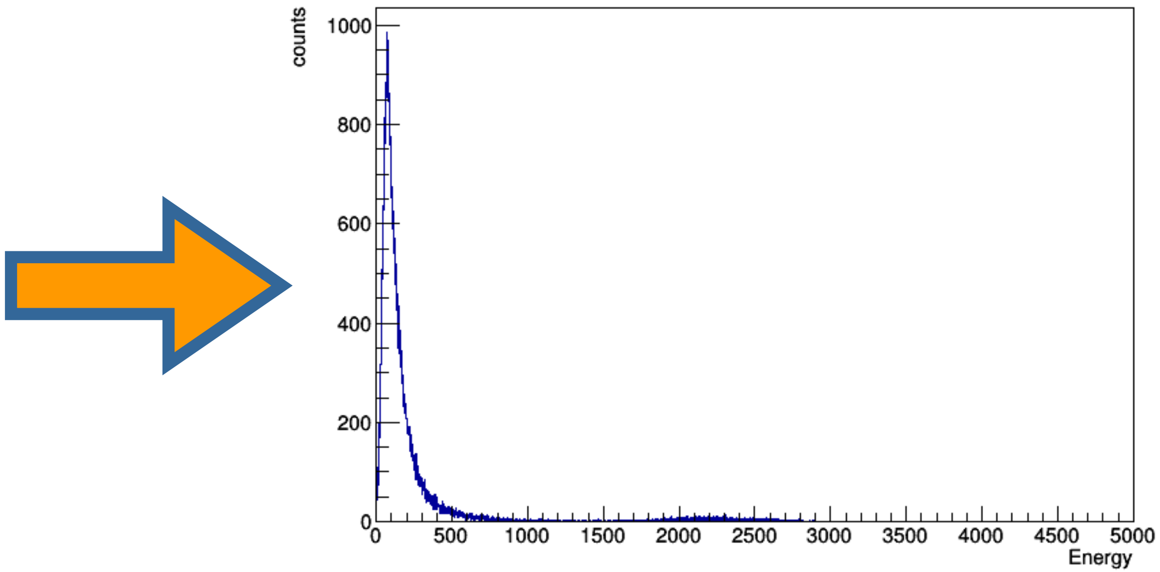


Geant4 simulations electrons

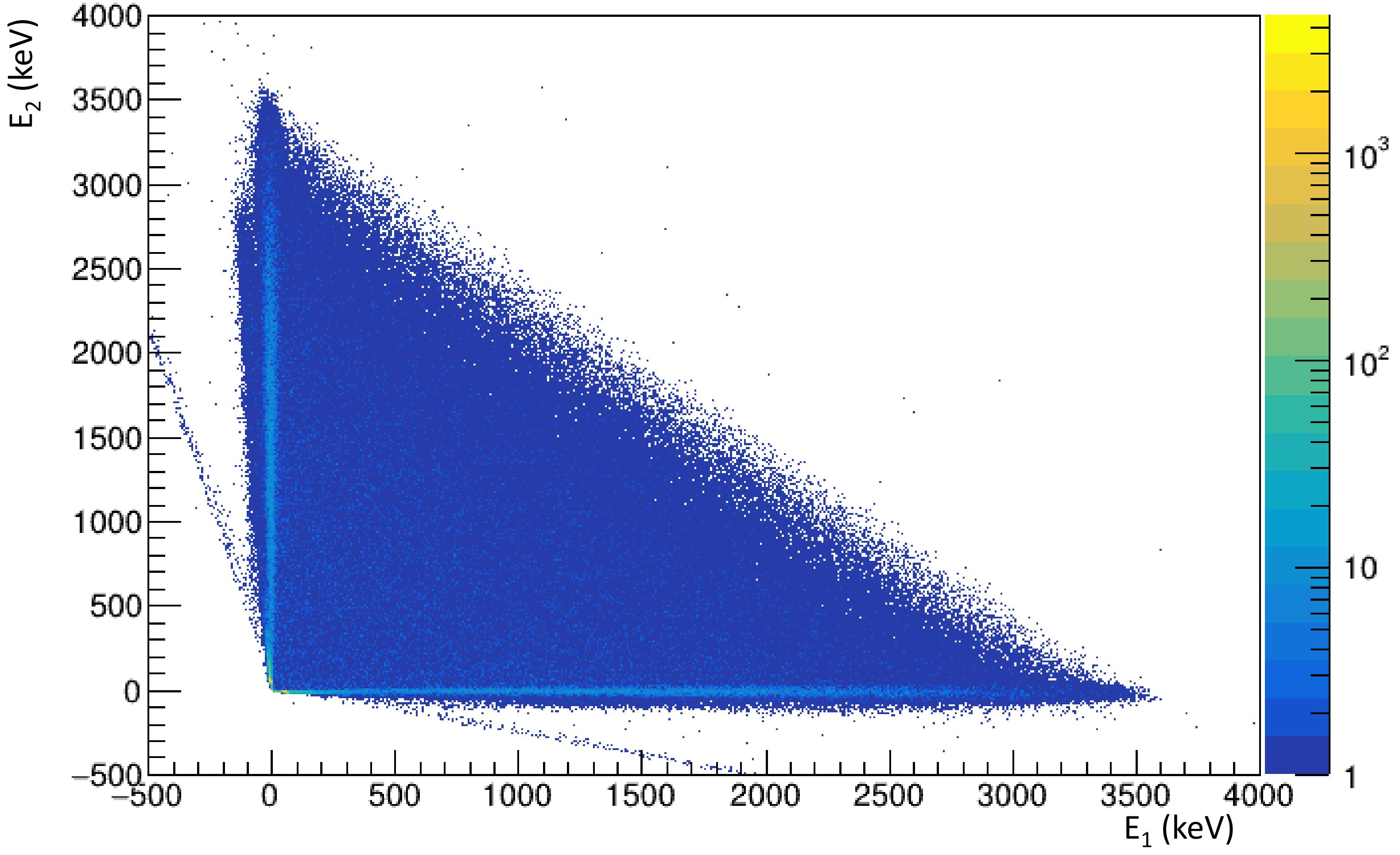




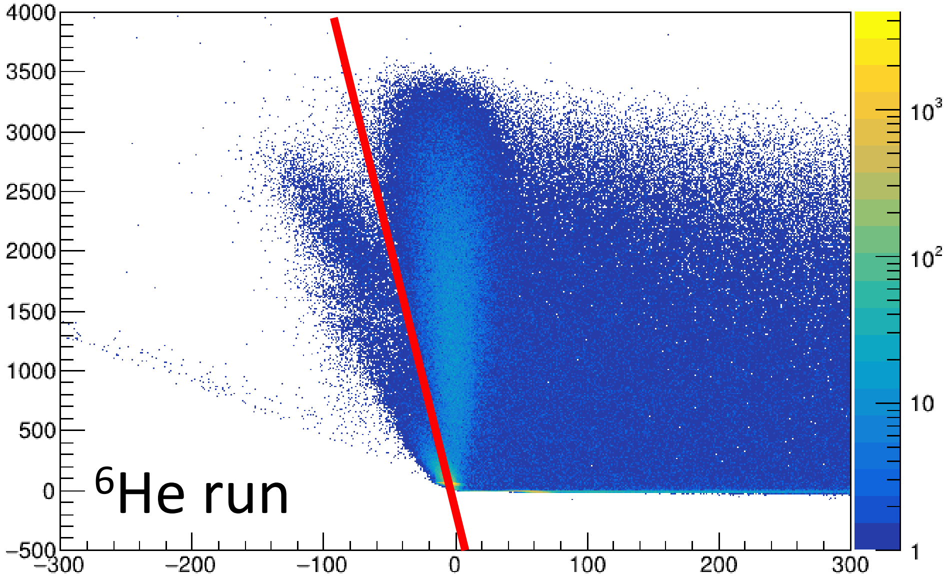


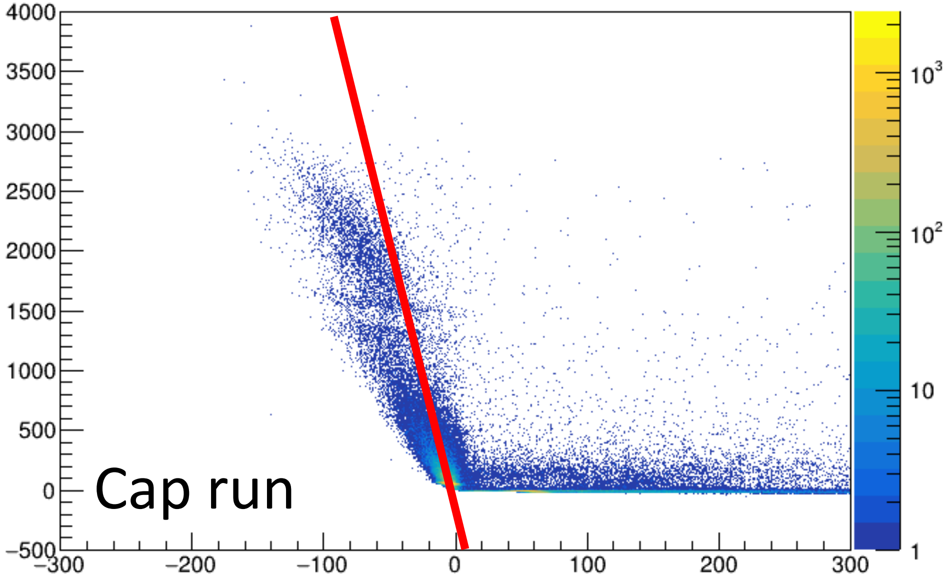


Deposited energy reconstruction

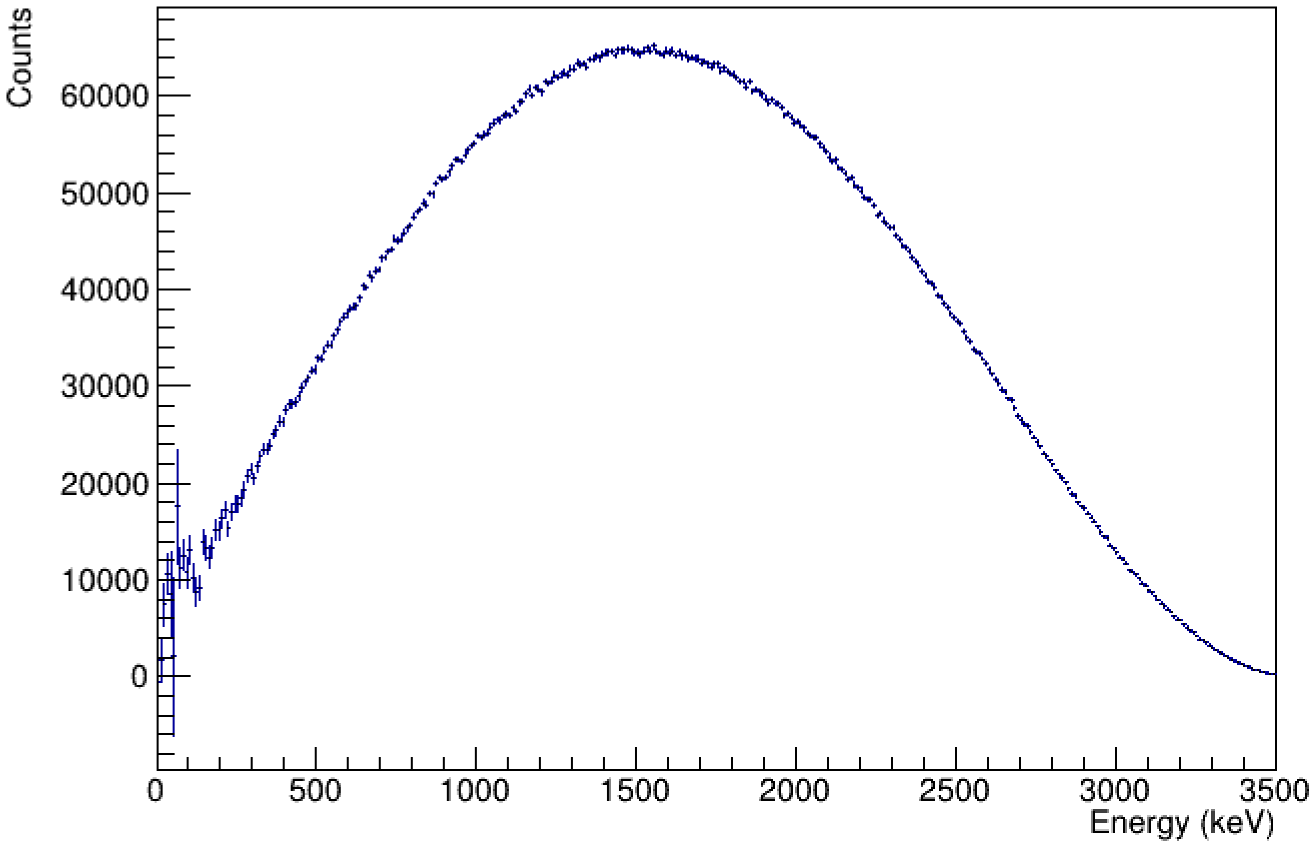


Data selection and background subtraction

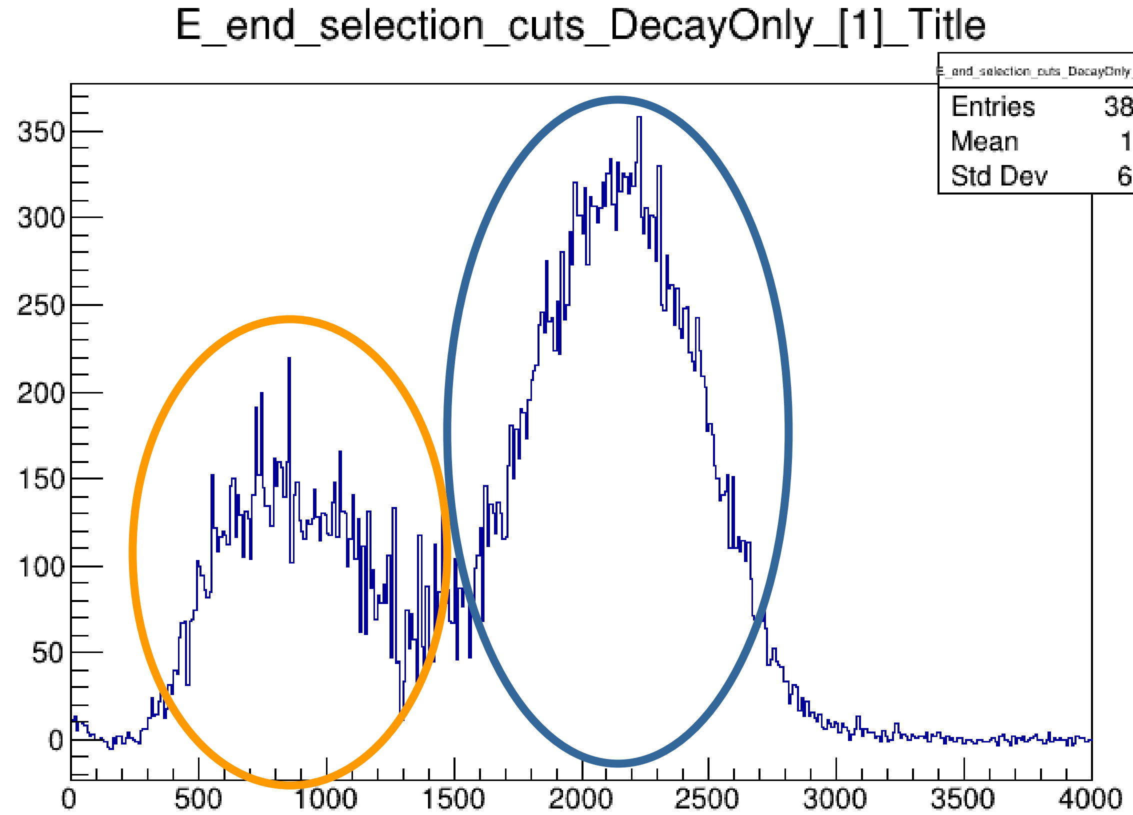




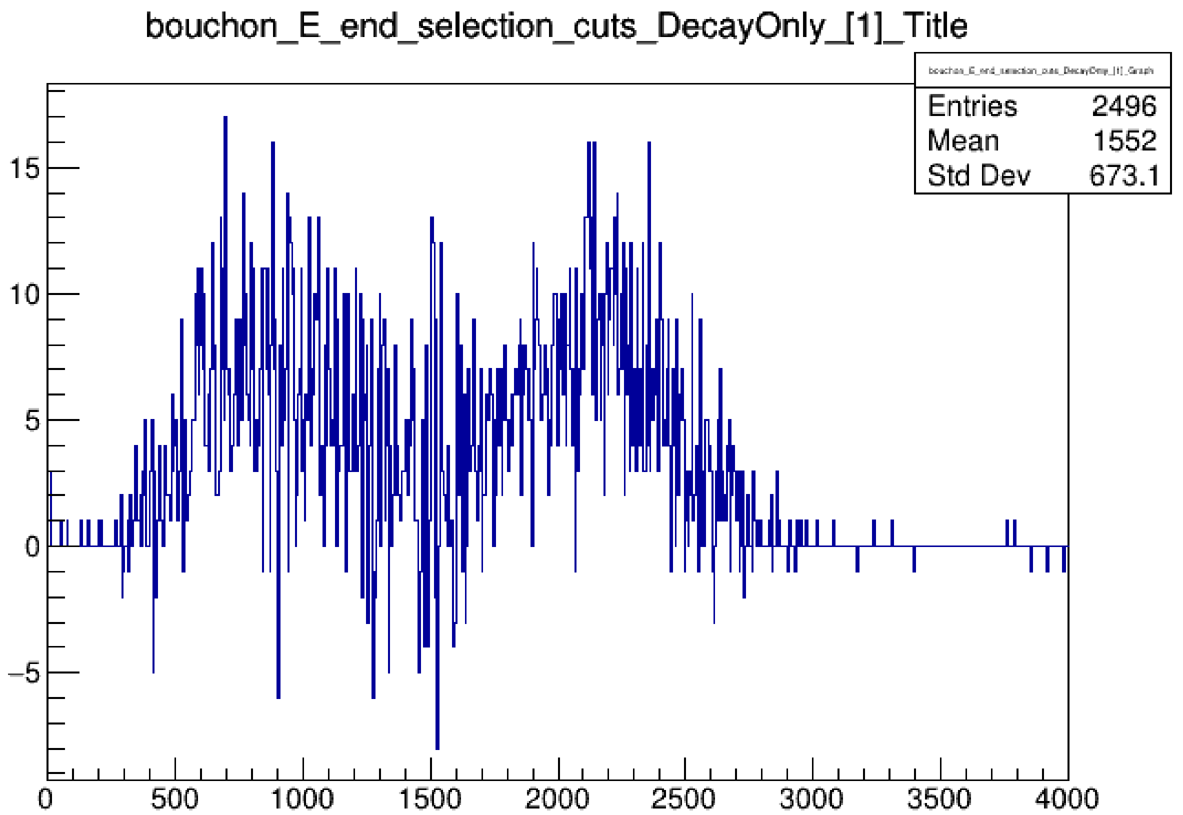
Experimental spectrum after Bremsstrahlung peak subtraction



Bremsstrahlung peak subtraction



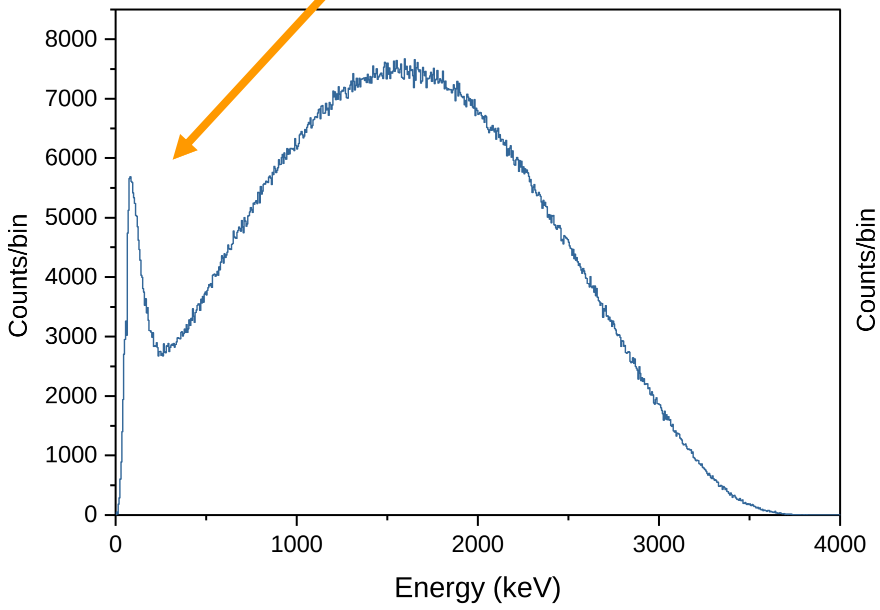
$^{6}He^{+}$ runs



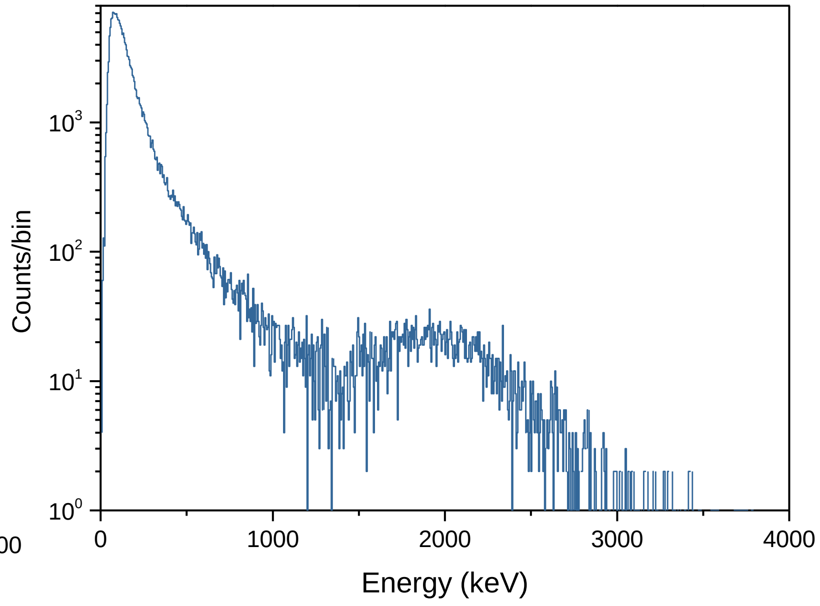
Cap runs

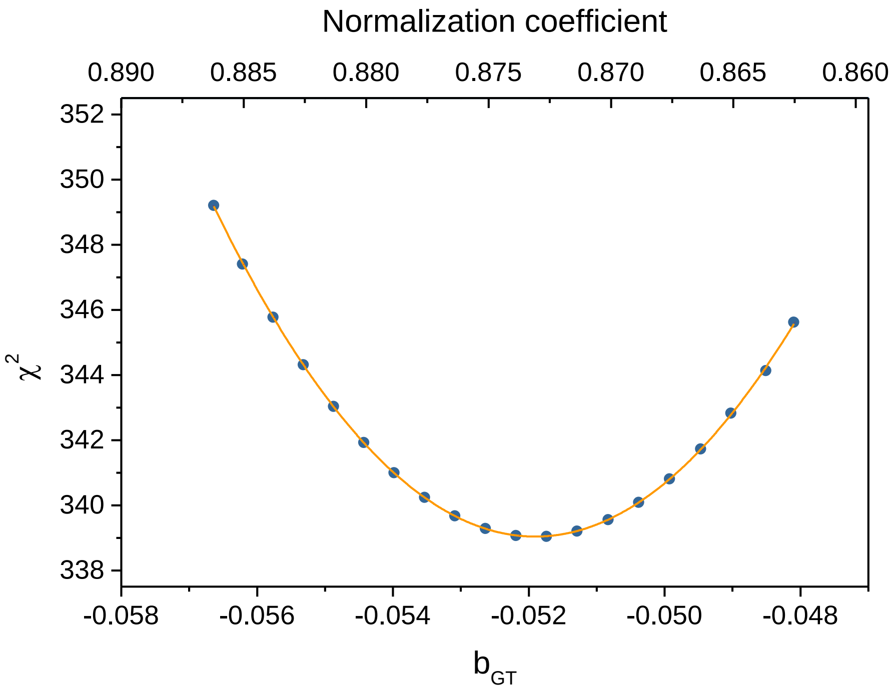
Bremsstrahlung peak subtraction

Same life-time of ^{6}He



Run with cap (No ^{6}He on the surface of the detector)

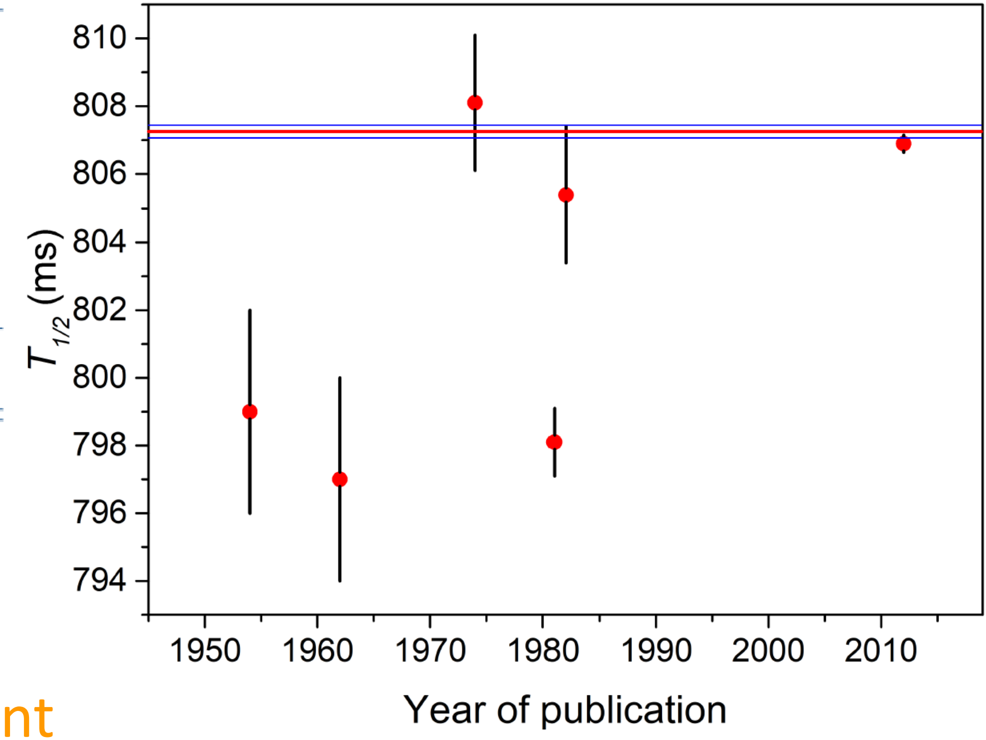




Half-life of ^6He

	Set (1)	Set (2)	Set (3)
$T_{1/2}$[ms]	807.42(25)	807.16(26)	807.10(35)
Gain	0.75(7)	0.77(10)	0.78(6)
Baseline	0.09(3)	0.04(2)	0.05(9)
Pile-up	0.10(1)	0.25(1)	0.11(1)
Binning	<0.01	<0.01	<0.01
total correction	0.94(7)	1.06(11)	0.94(11)

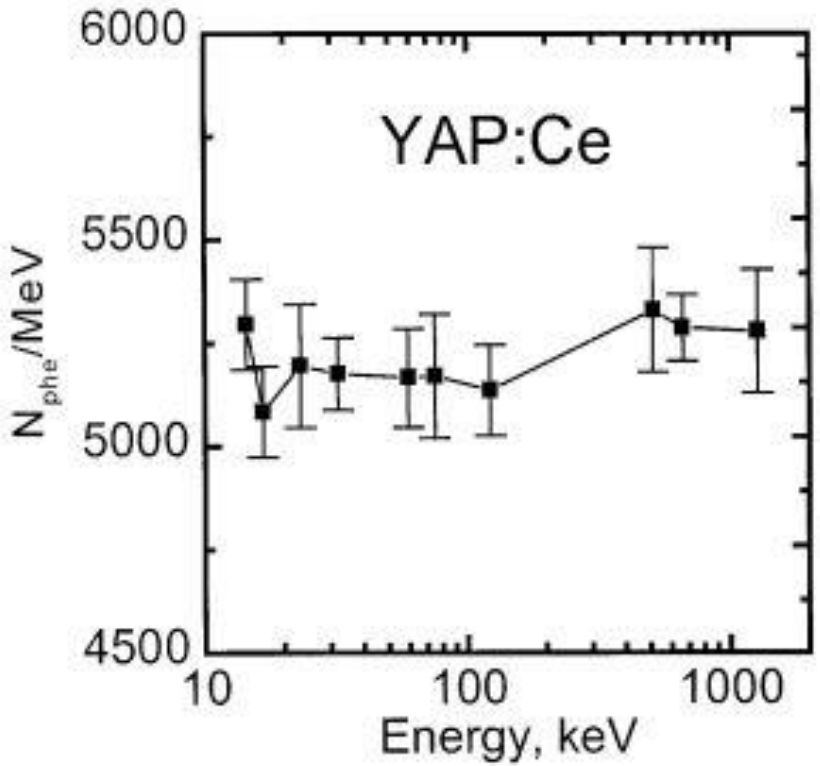
$$T_{1/2} = 807.25 \pm 0.16_{stat} \pm 0.11_{syst}\ ms$$



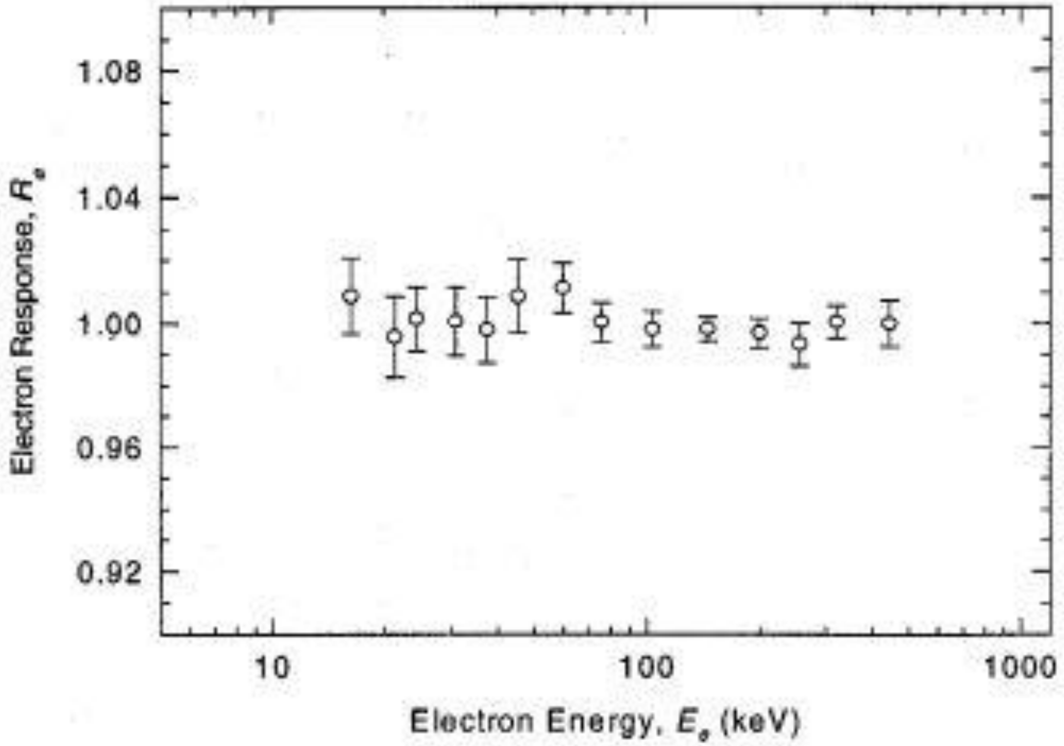
M. Kanafani et al., Phys. Rev. C 106, 045502 (2022).

Our result is the most precise value, and is in agreement with the last and previously most accurate value. It resolves the discrepancy between the two sets of values

YAP linearity



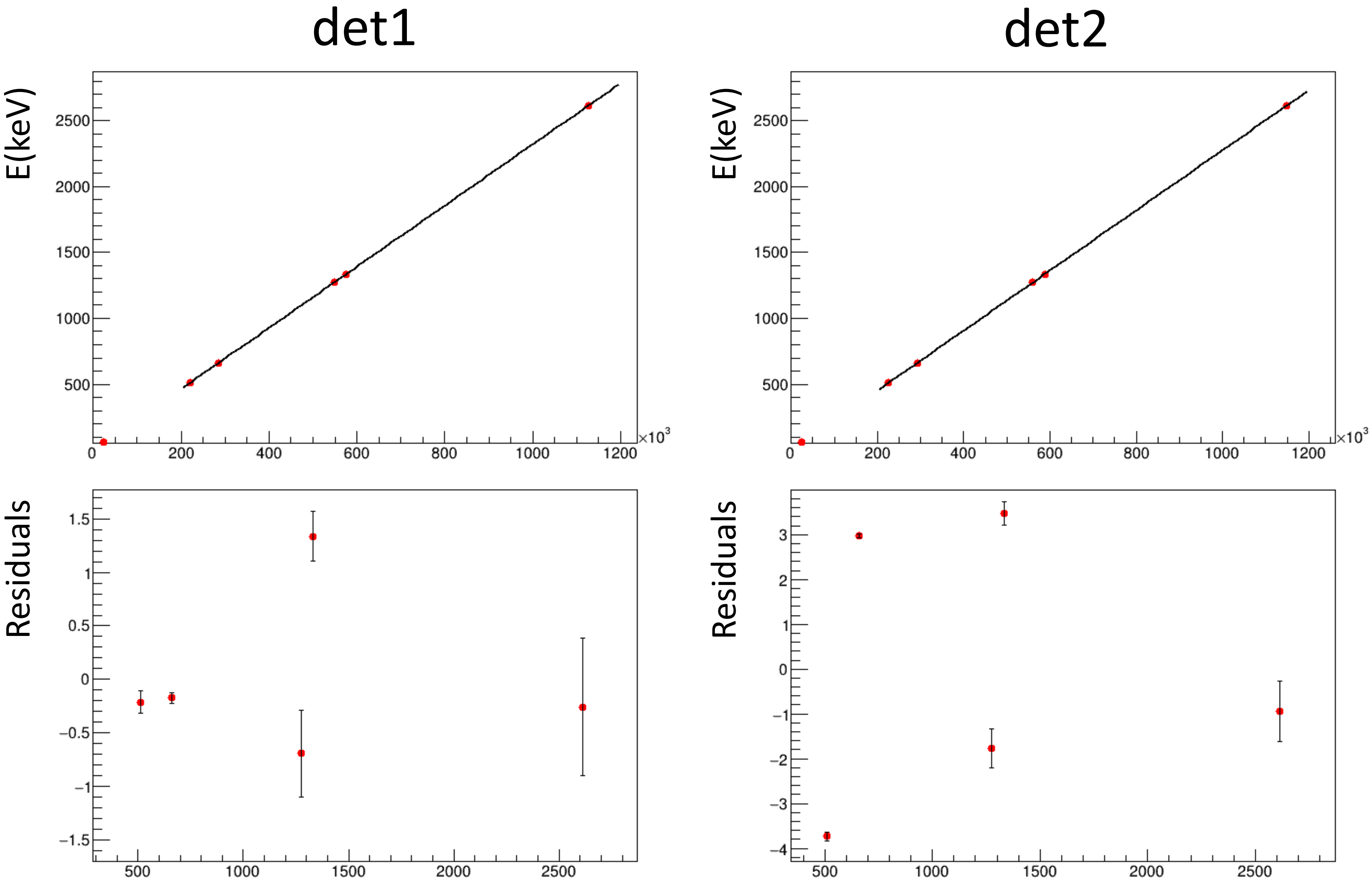
M. Kapusta et al. Nucl. Instr. and Meth. in Phys. Res. A 421 (1999) 610—613



W. Mengesha et al. "Light yield nonproportionality of CsI(Tl), CsI(Na), and YAP," in IEEE Transactions on Nuclear Science, vol. 45, no. 3, pp. 456-461, June 1998.

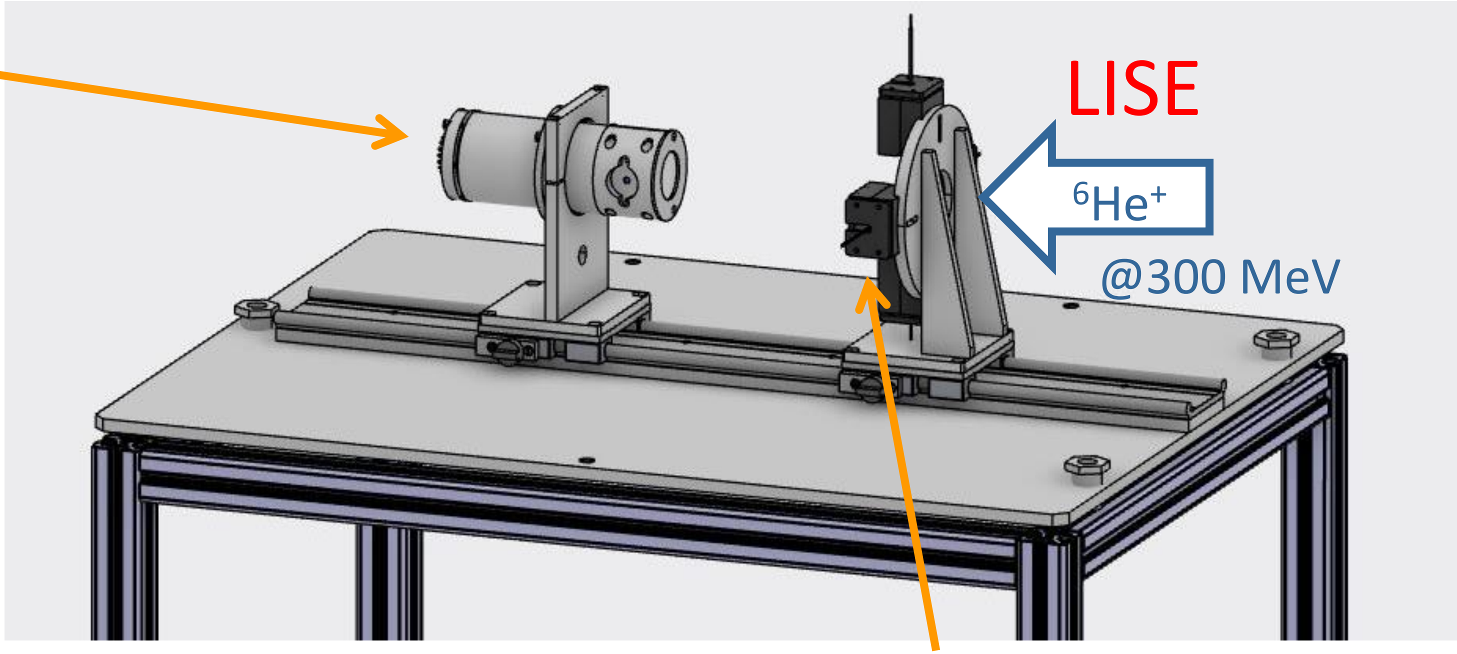
YAP linearity

Tests with
calibration sources

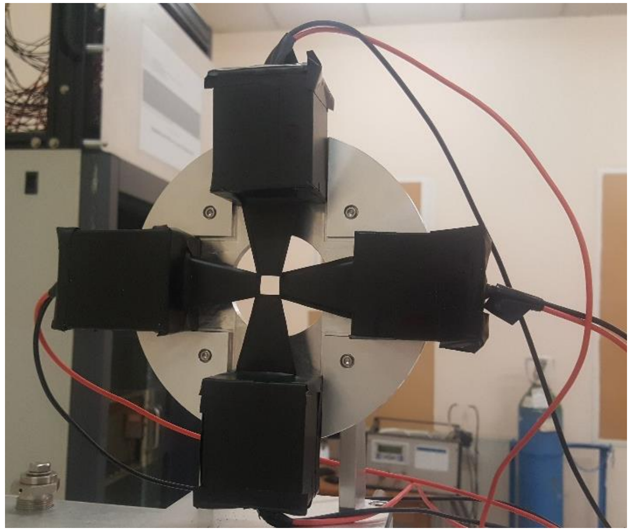


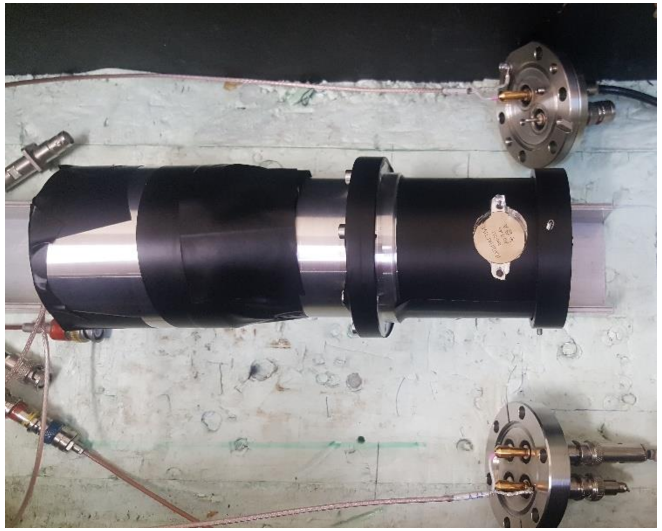
High energy experiment

Main detector (YAP)

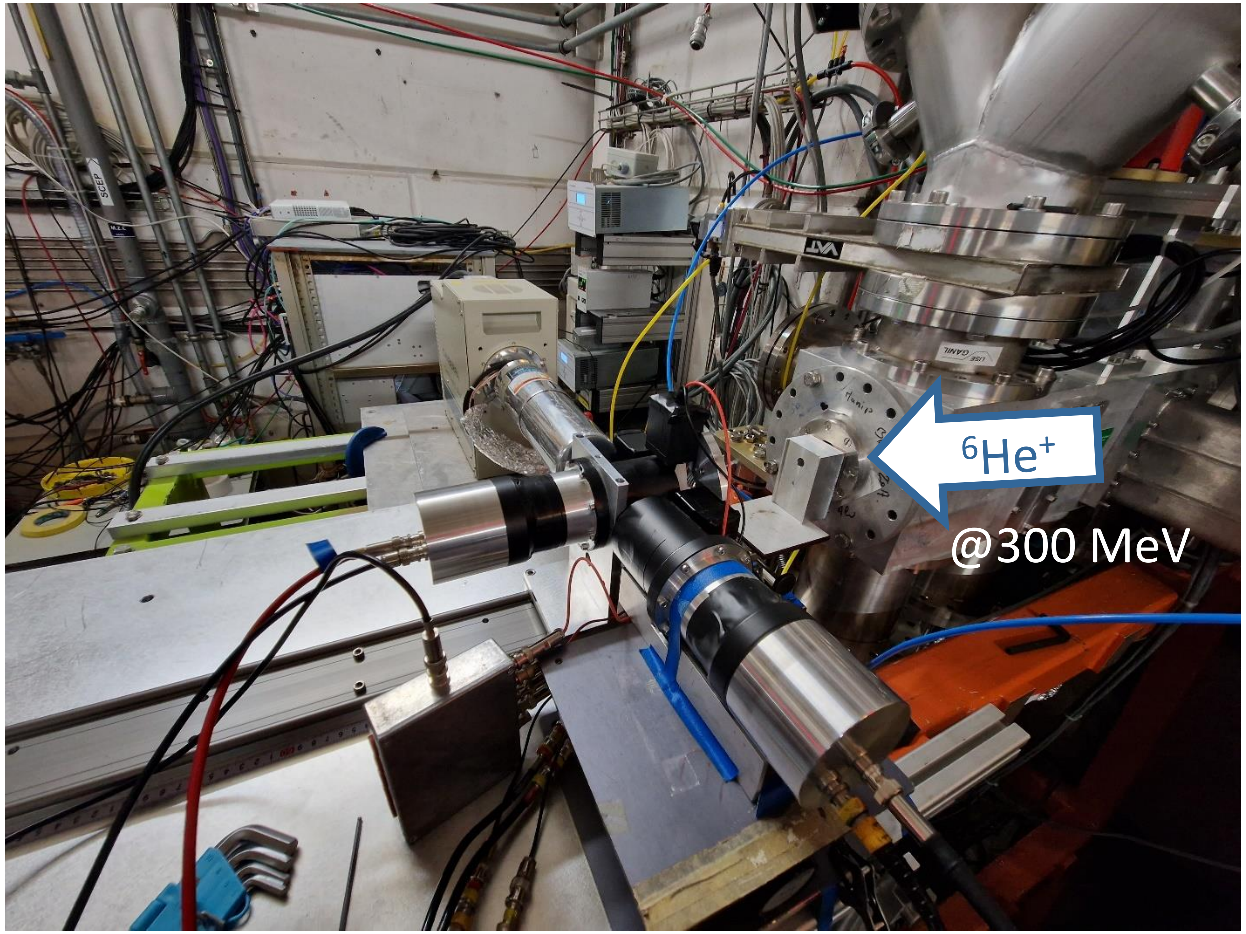


Plastic scintillators

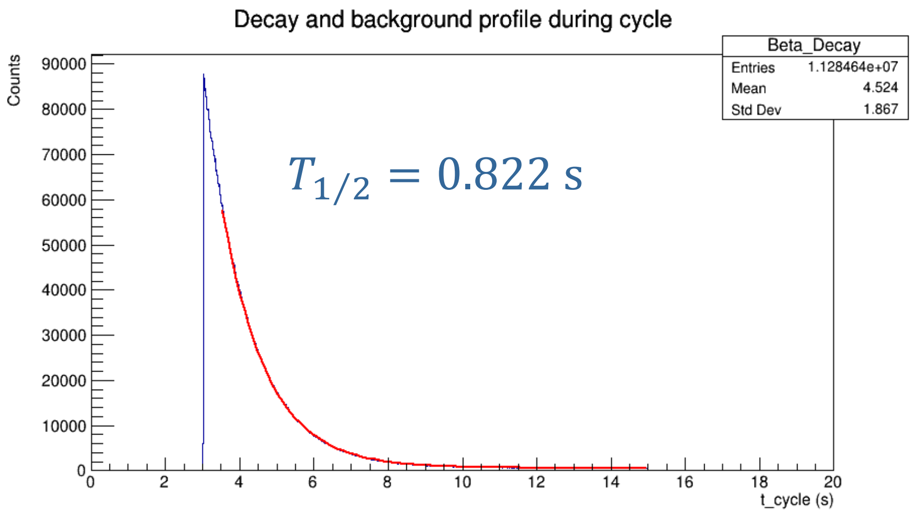


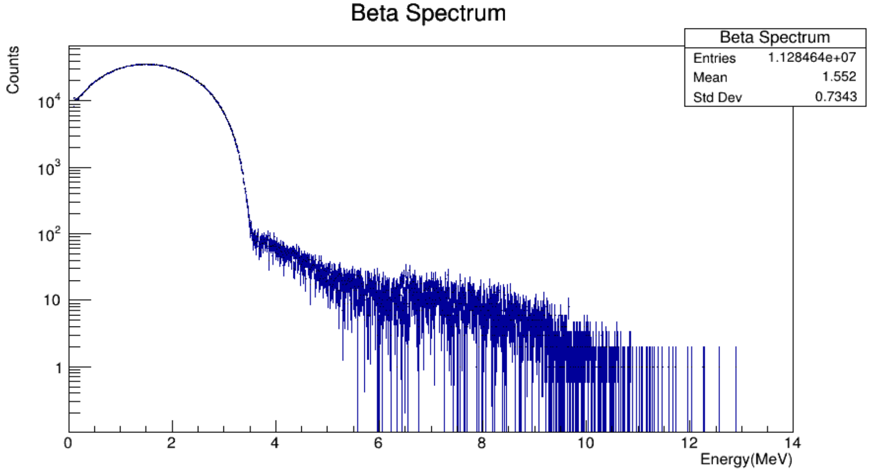


High energy experiment



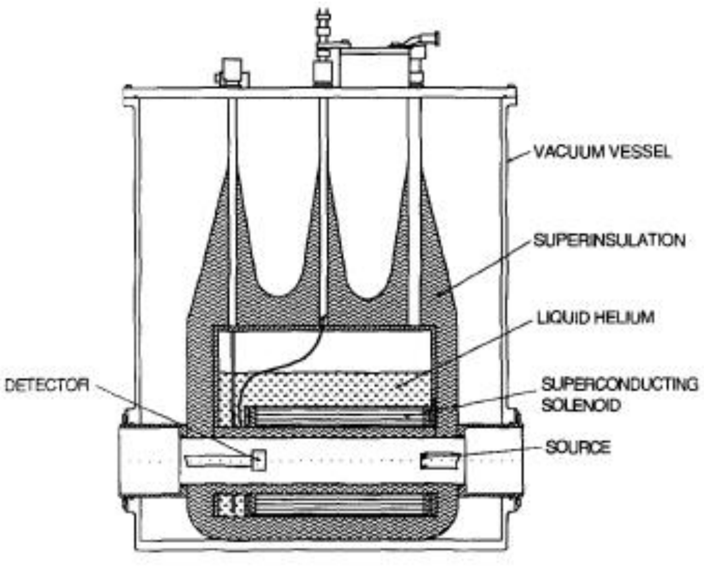
April 2023 @GANIL

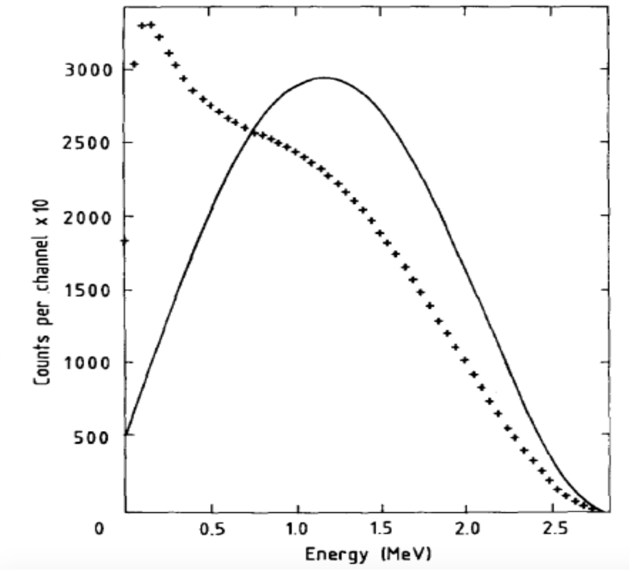




Romain Garreau is working on the analysis

Electrons backscattering





Huge distortion due to electrons backscattering

D.W. Hetherington et al., The shape factor of the ^{20}F beta spectrum. Nuclear Physics A, 494(1):1 – 35, 1989.