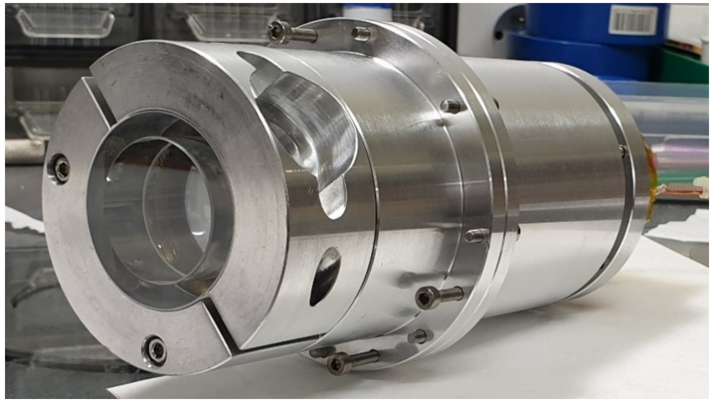

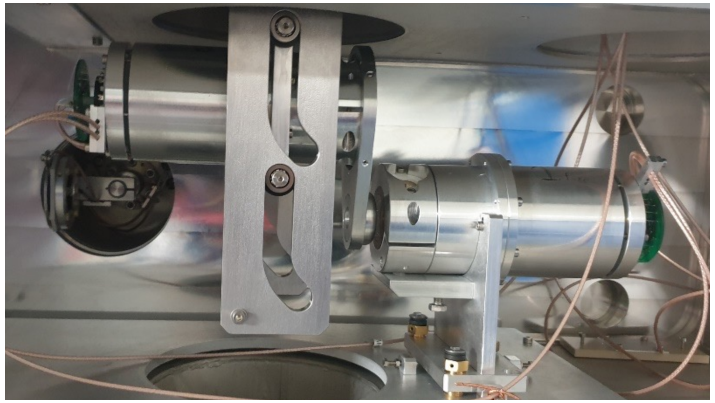

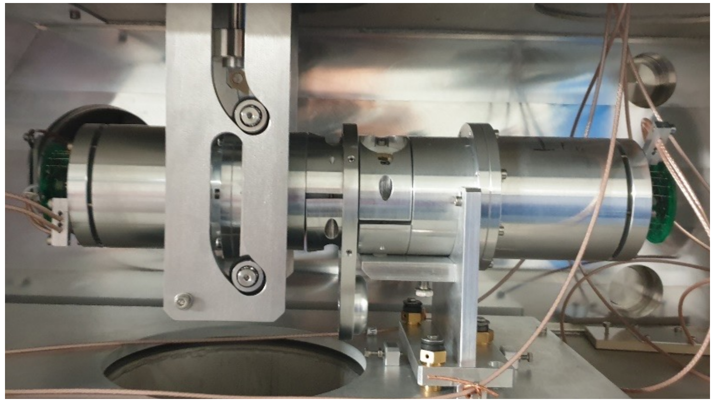

b-STILED: Search for Tensor Interactions in nucLear bEta Decay

PhyNuBe: Clustering and Symmetries in nuclear physics

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April 6, 2023

Aussois, France

lpc caen Laboratoire de physique corpusculaire
ANR PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR
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Outline

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

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:

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

Exotic currents!

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).

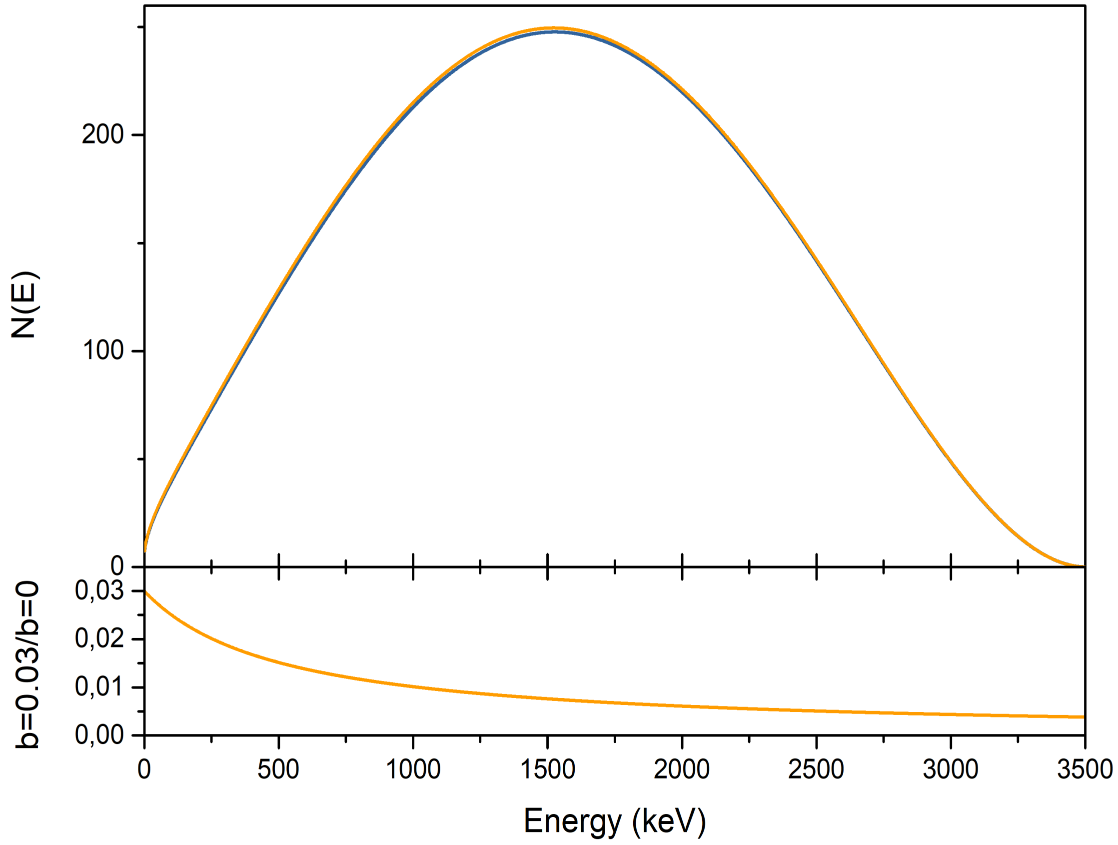
Fierz interference term

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!

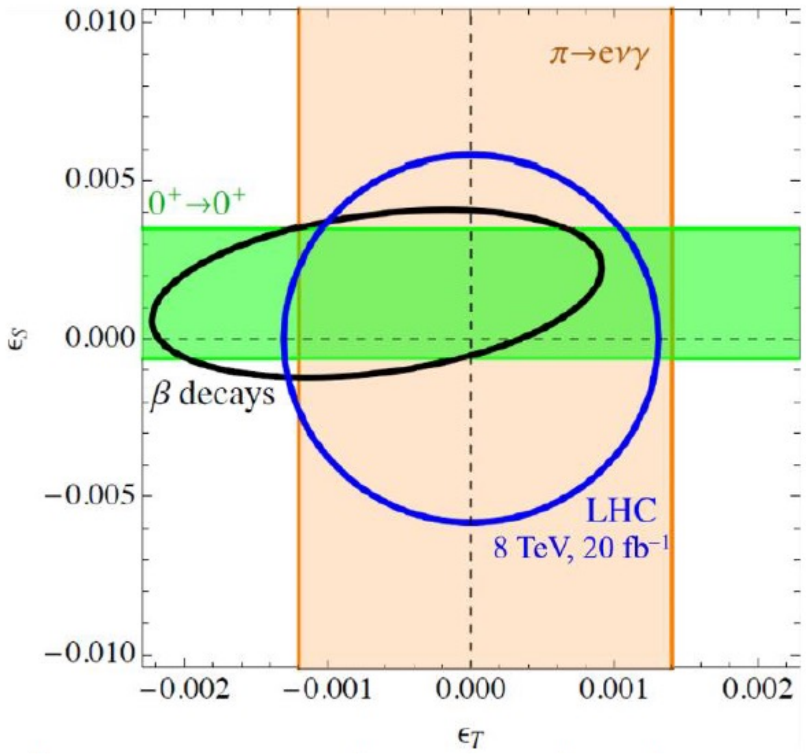
$$N(E) \propto \underbrace{(1+\eta)}_{\text{Corrections term}}\underbrace{pE(E-E_0)^2}_{\text{Phase space}}\left(1+\frac{m}{E}b\right)$$

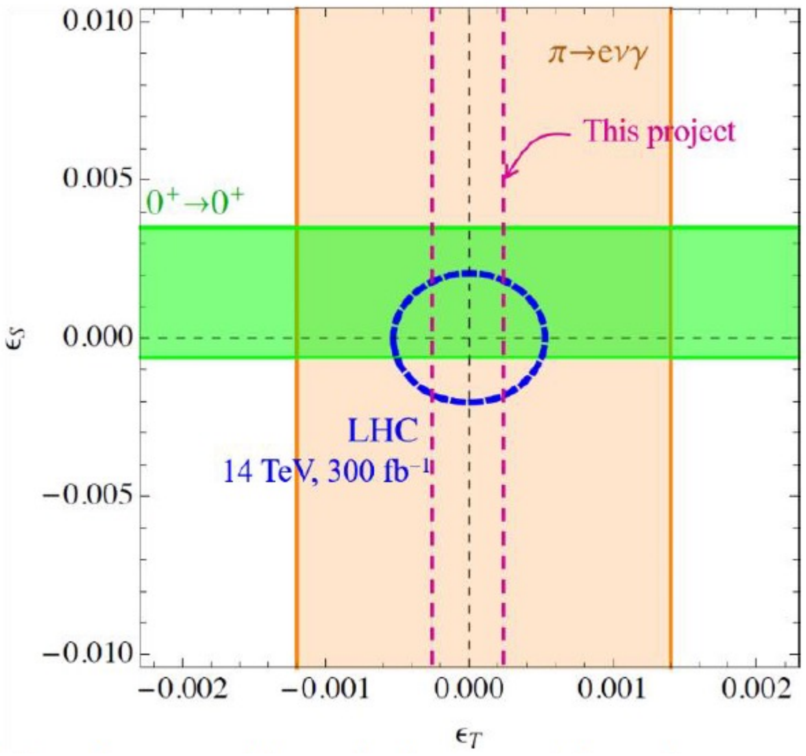
b-STILED : The goal

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

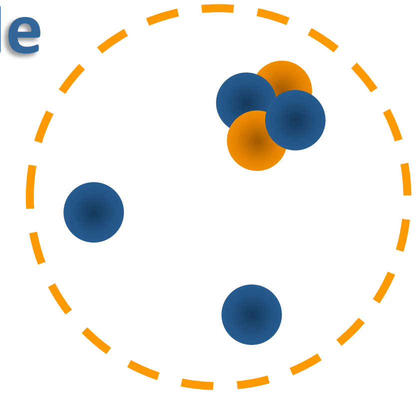


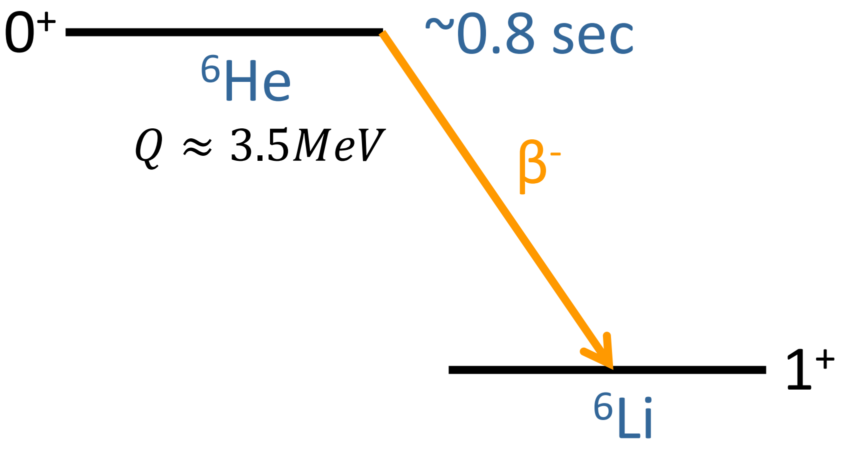


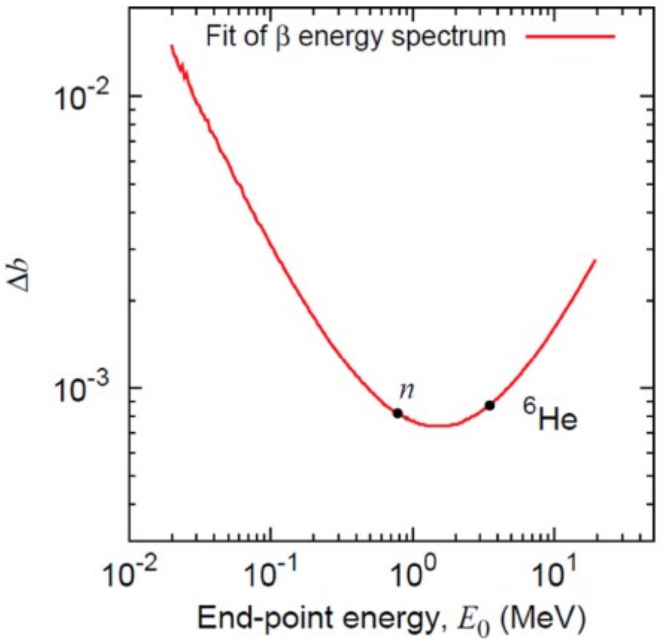
b-STILED : The perfect candidate

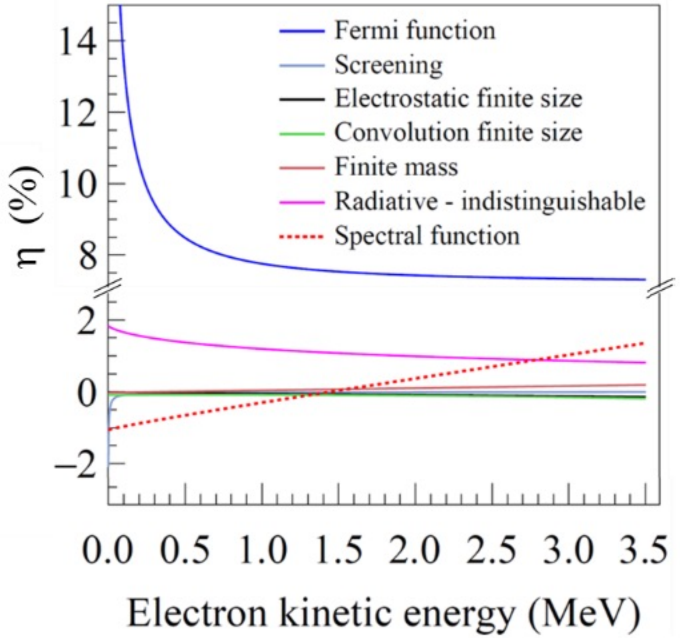
- Convenient half-life for implantation-decay cycles
- Pure GT transition and thus exclusively sensitive to tensor currents
- Convenient endpoint ~3.5MeV
- Can be produced with a high rate @GANIL
- Theoretical corrections are known with high precision

^{6}He

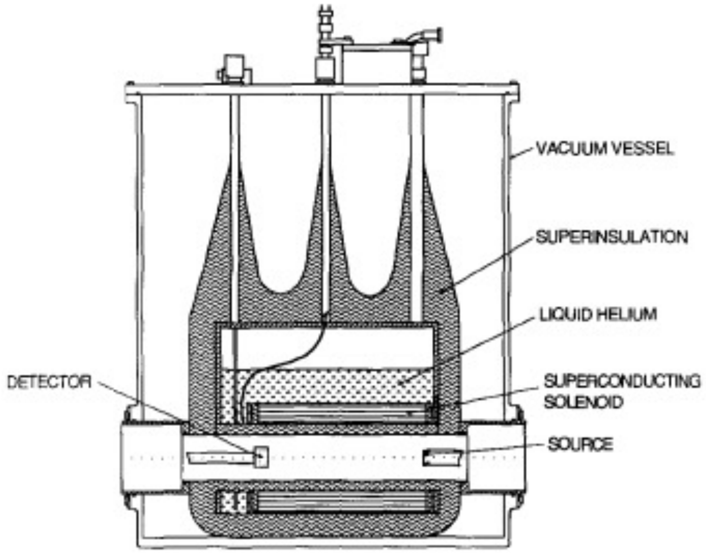


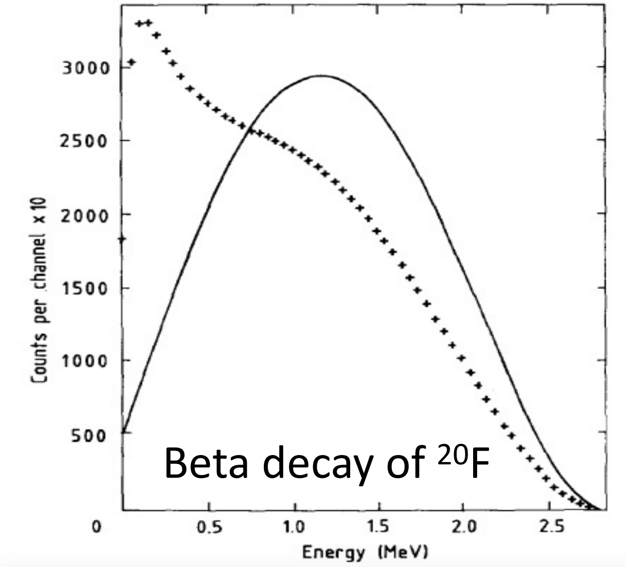






b-STILED : The two experiments

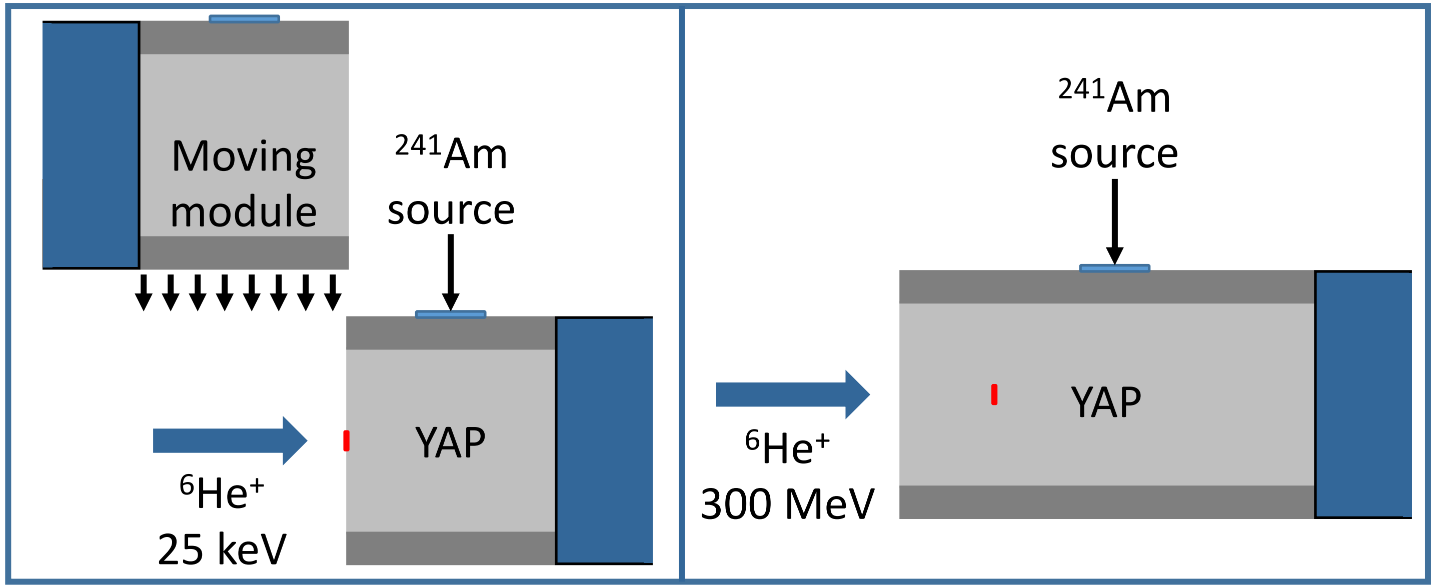




D.W. Hetherington et al., The shape factor of the ^{20}F beta spectrum. Nuclear Physics A, 494(1):1 – 35, 1989.

Huge distortion due to electrons backscattering

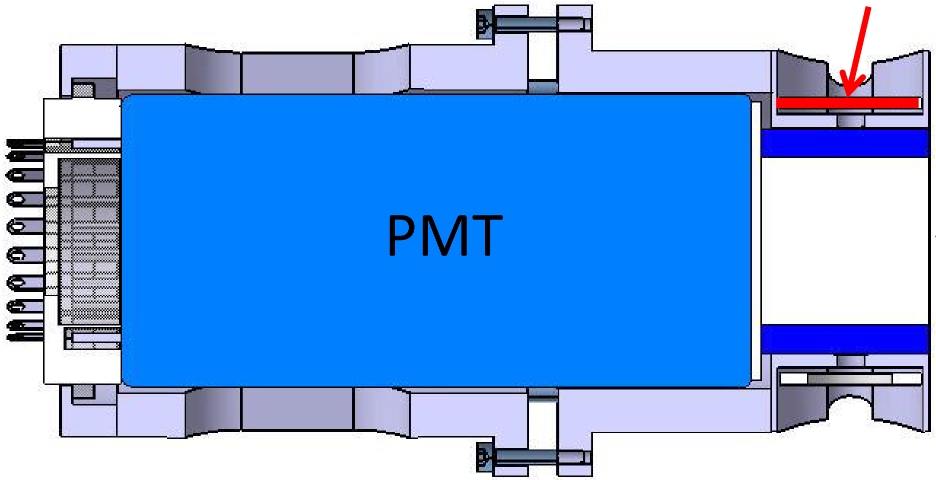
4π detection geometry



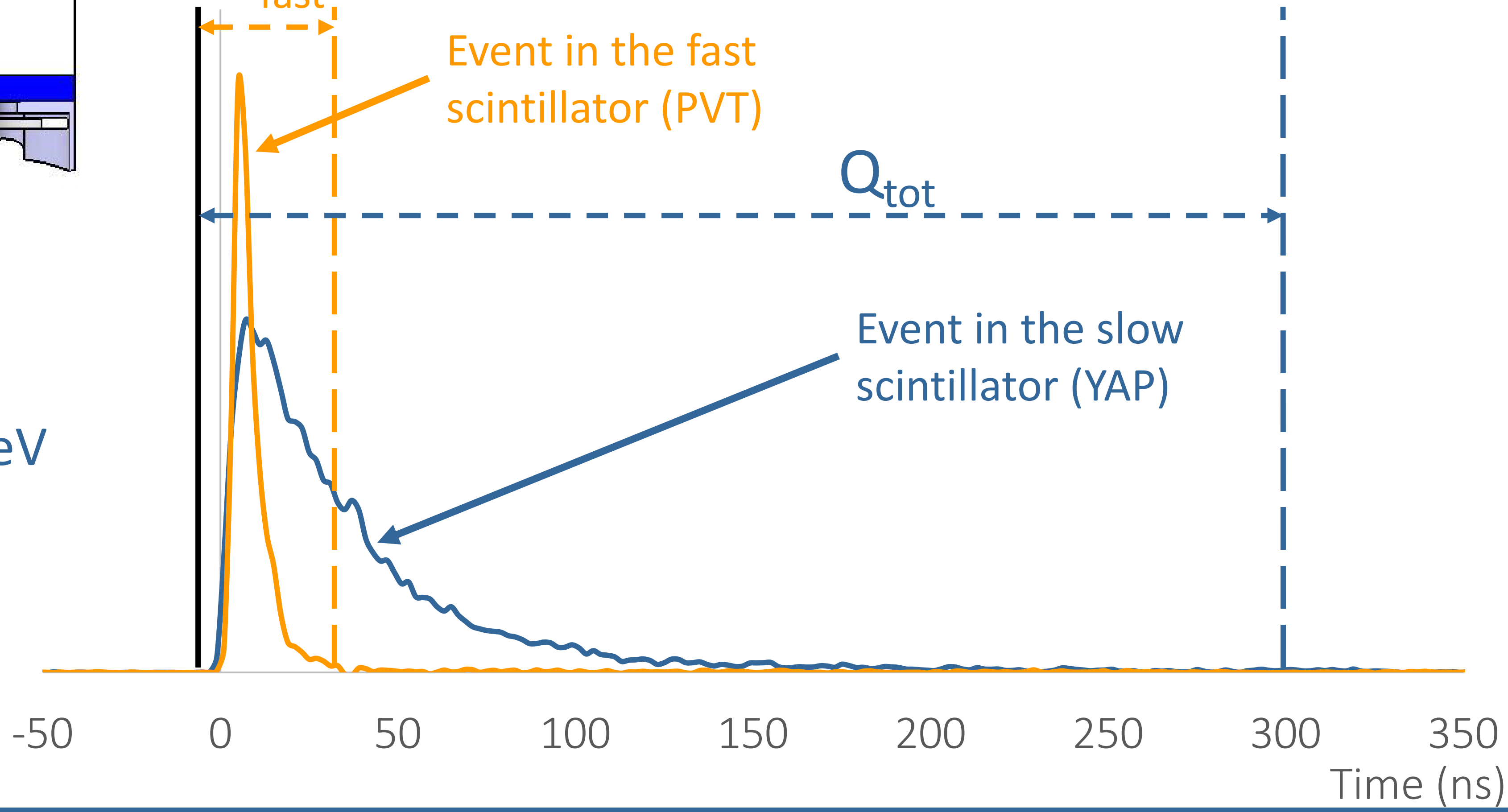
Phase I: 2 experiments with a goal of $\Delta b_{GT} = 4\times10^{-3}$:

- Low energy experiment
- High energy experiment

b-STILED : The phoswich detector

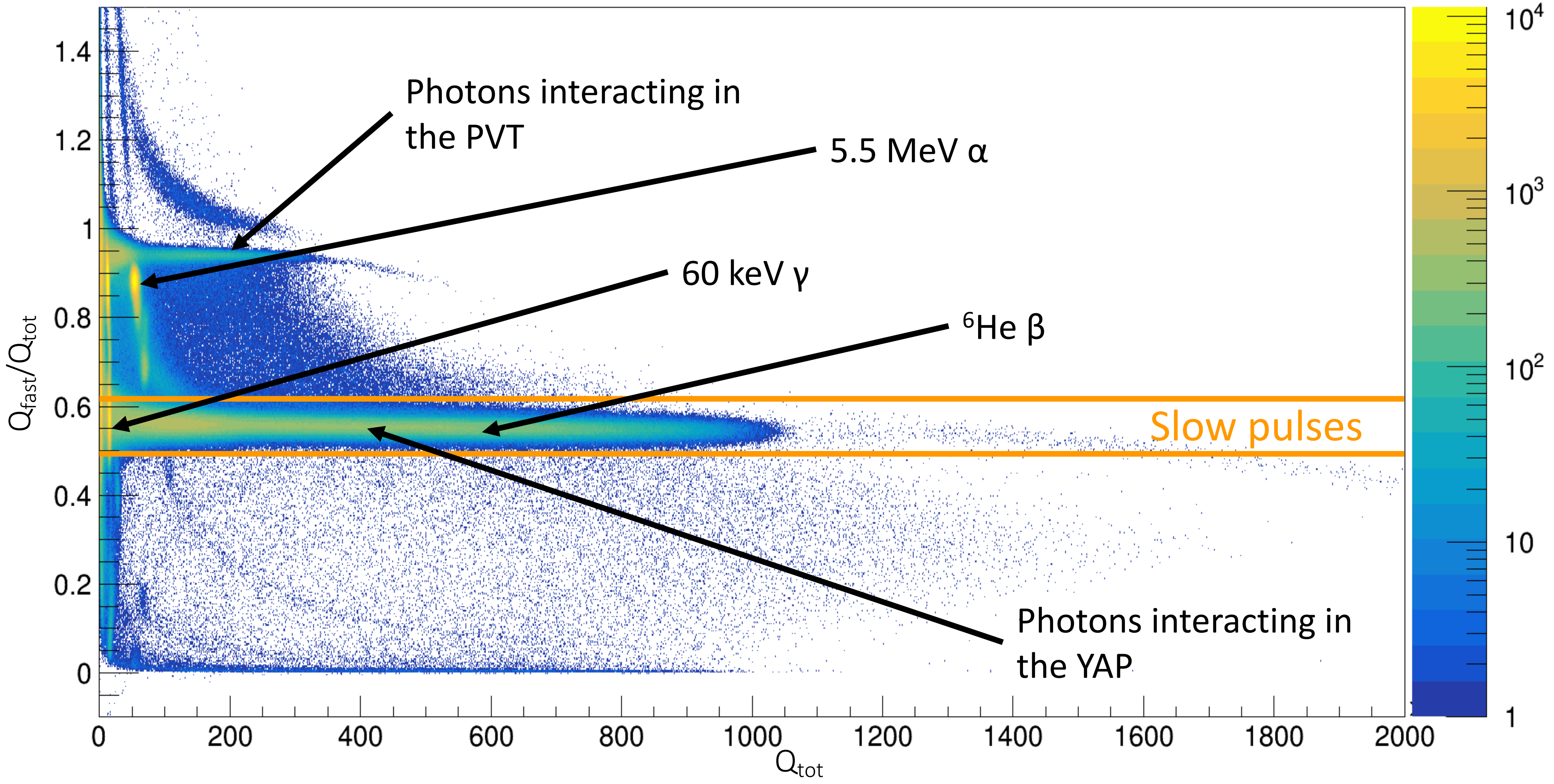


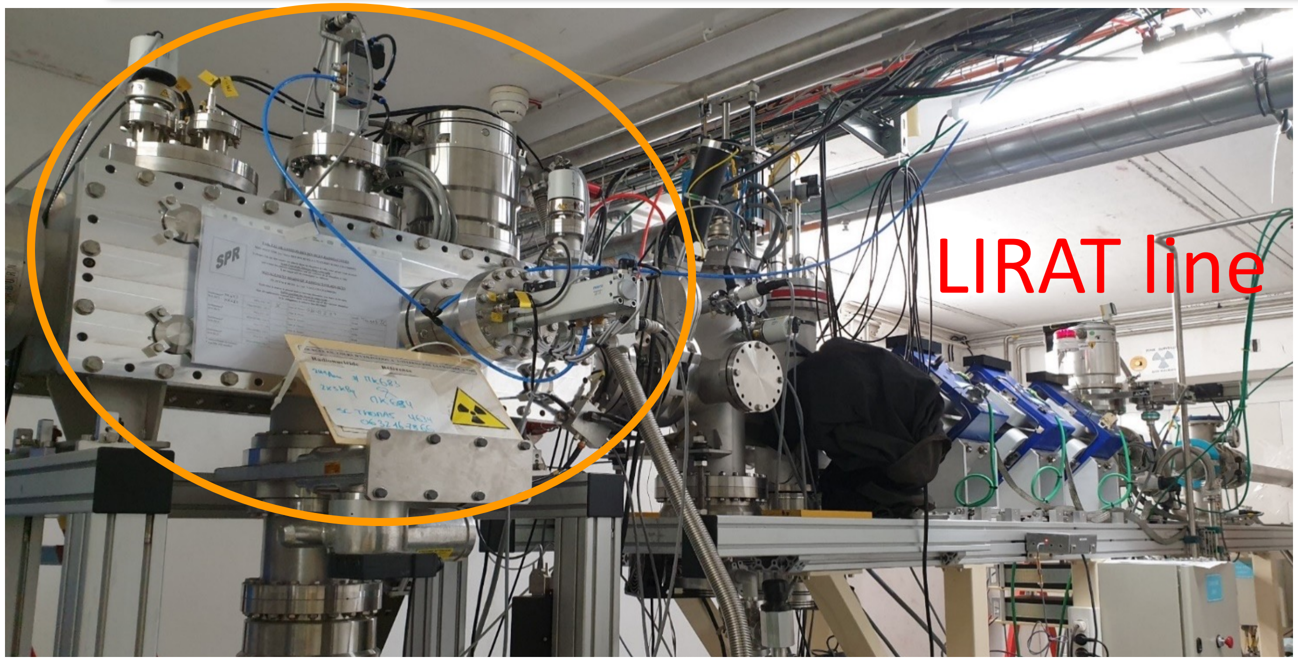
YAP properties:
- Linear energy response
- Good resolution ~5% @ 1 MeV
- Low Bremsstrahlung energy escape

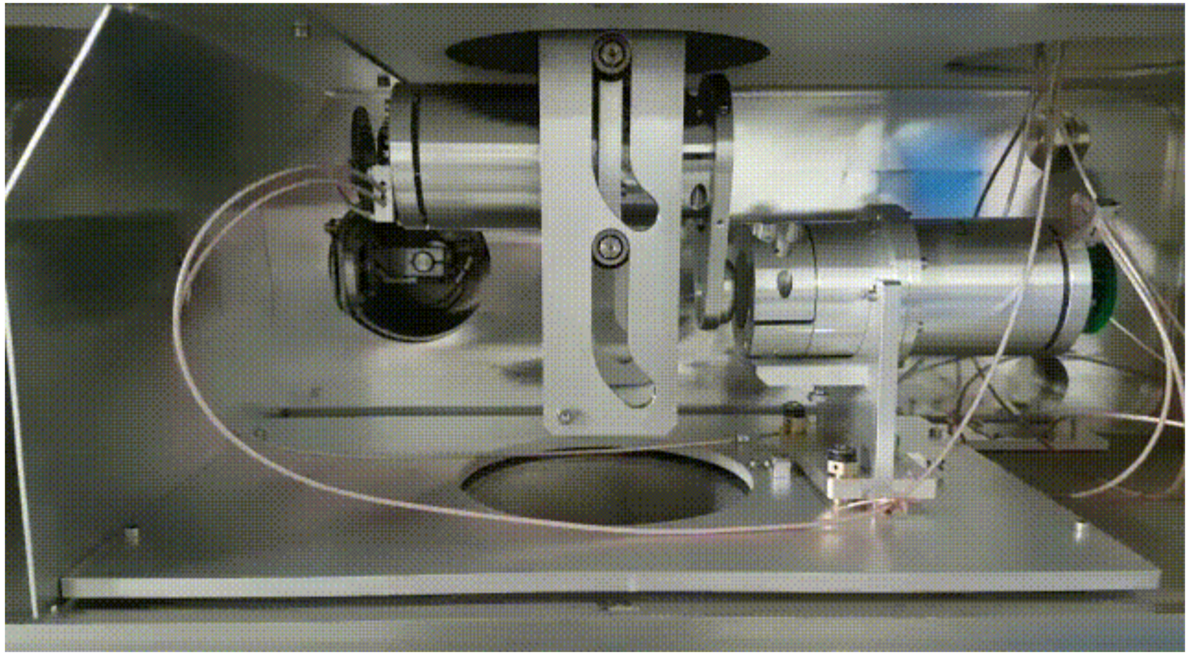


Pulses discrimination

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







May 2021 @GANIL

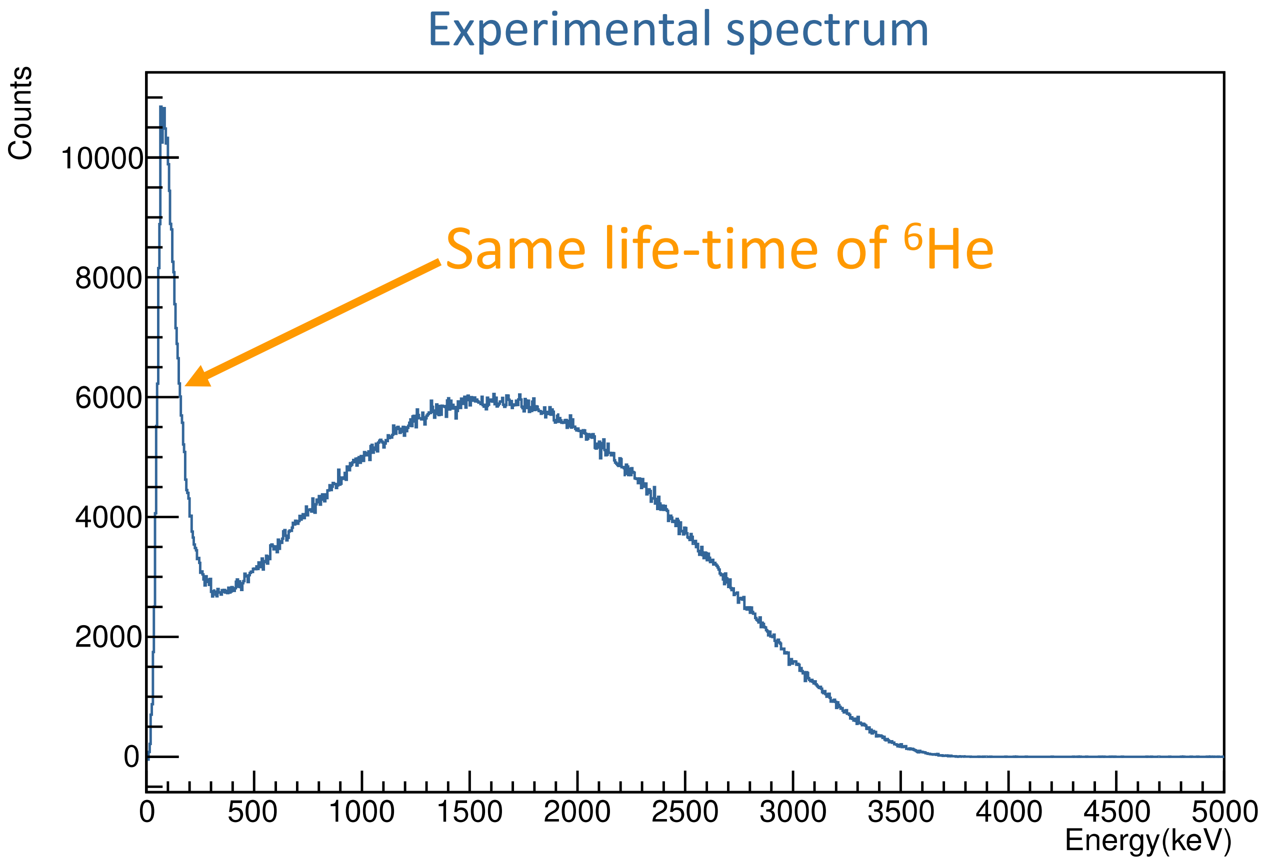
Typical cycle:
- 2.5 sec of implantation
- 12 sec of acquisition

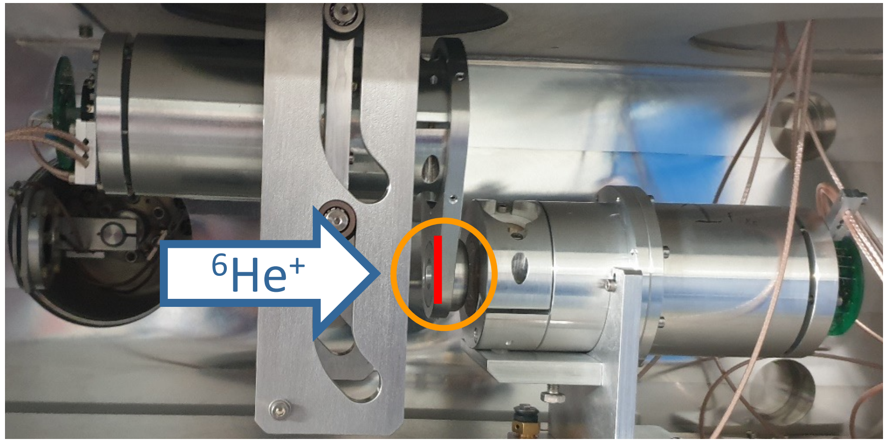
4 sets of measurements:
1) Different systematic conditions
2) BKG runs (runs with cap)

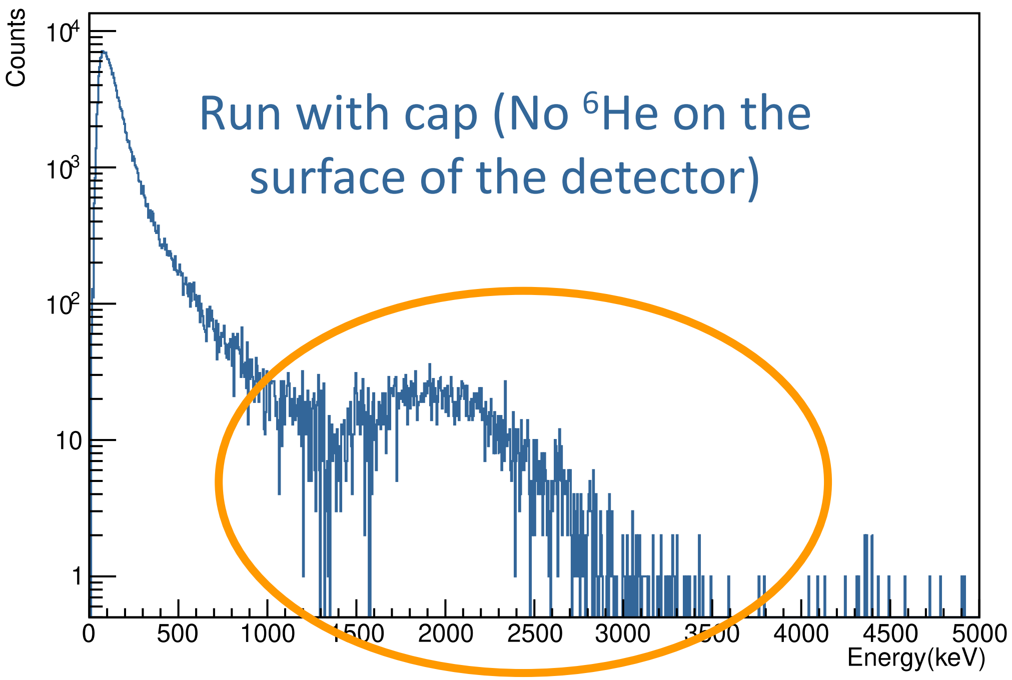
DAQ:
- Time stamp
- Deposited energy

Backgrounds investigation

Following constant background subtraction

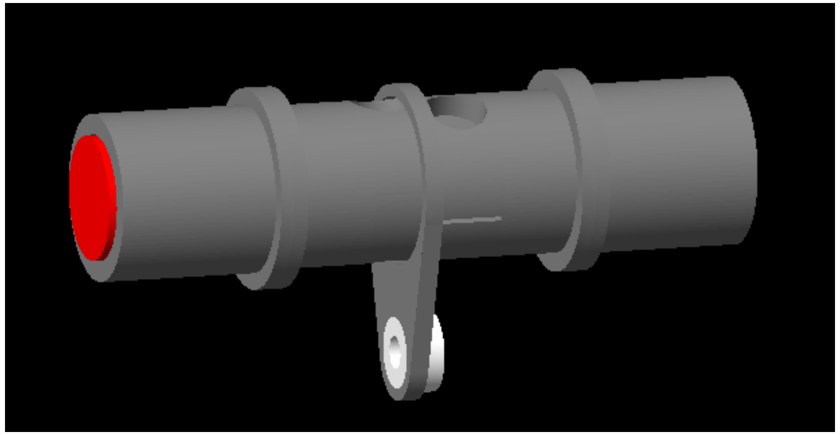


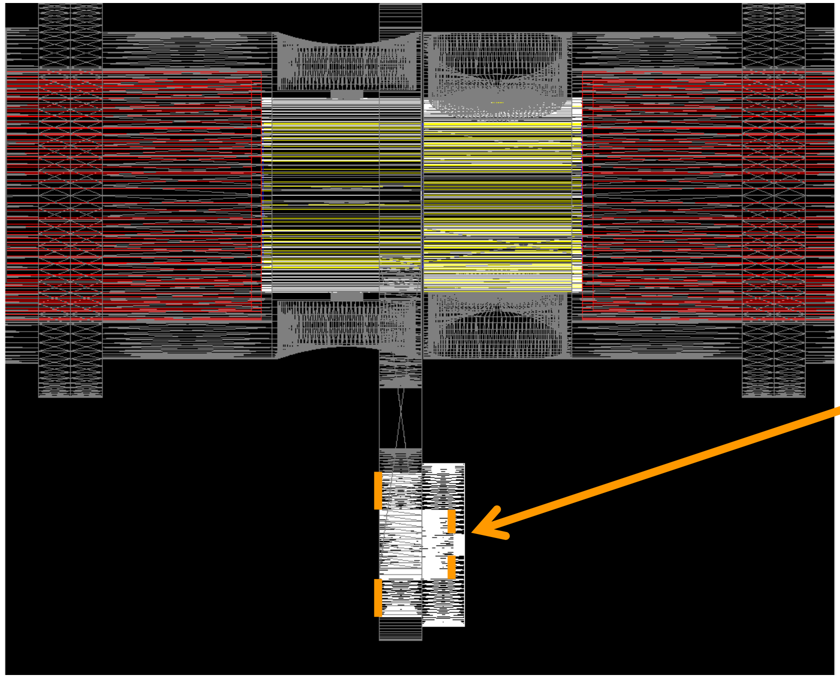




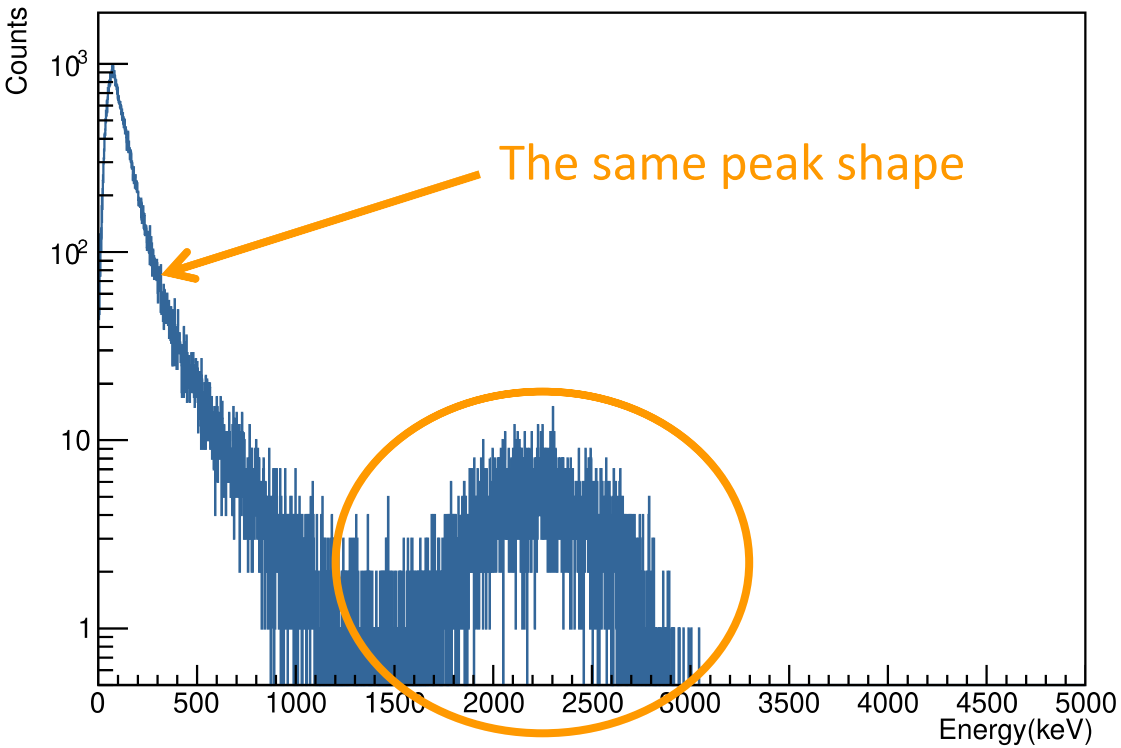
Backgrounds investigation

Detection system construction in Geant4





Deposited energy into YAP



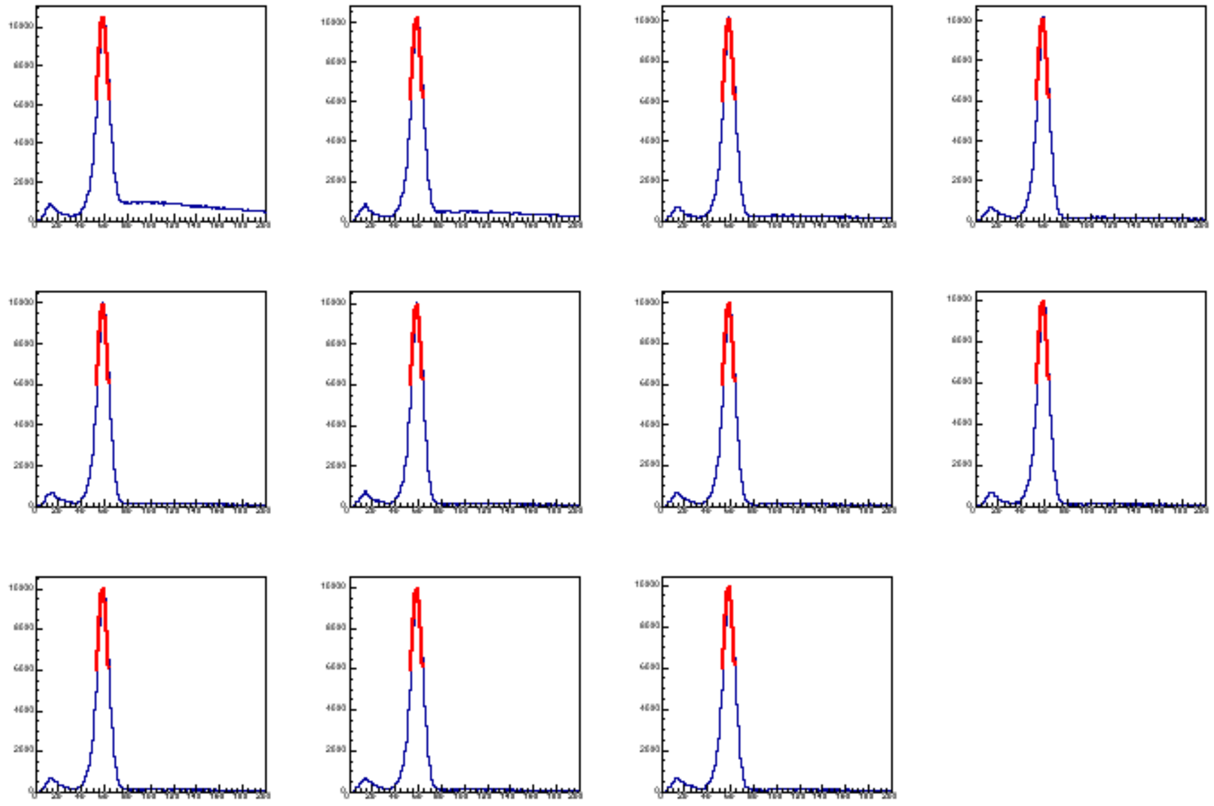
$^6He^+$ in the collimator

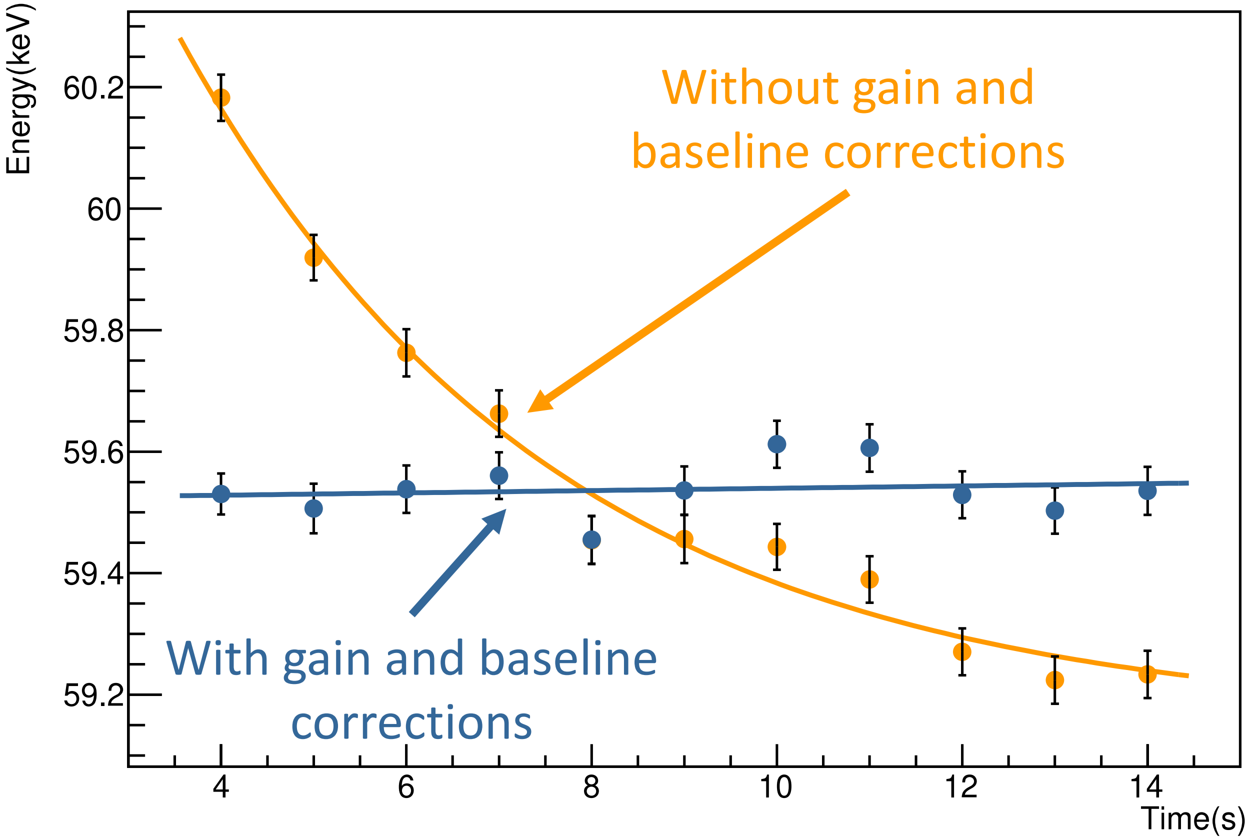
- ✓ Bremsstrahlung peak
- ✓ Electrons from ^6He decay on the collimator

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

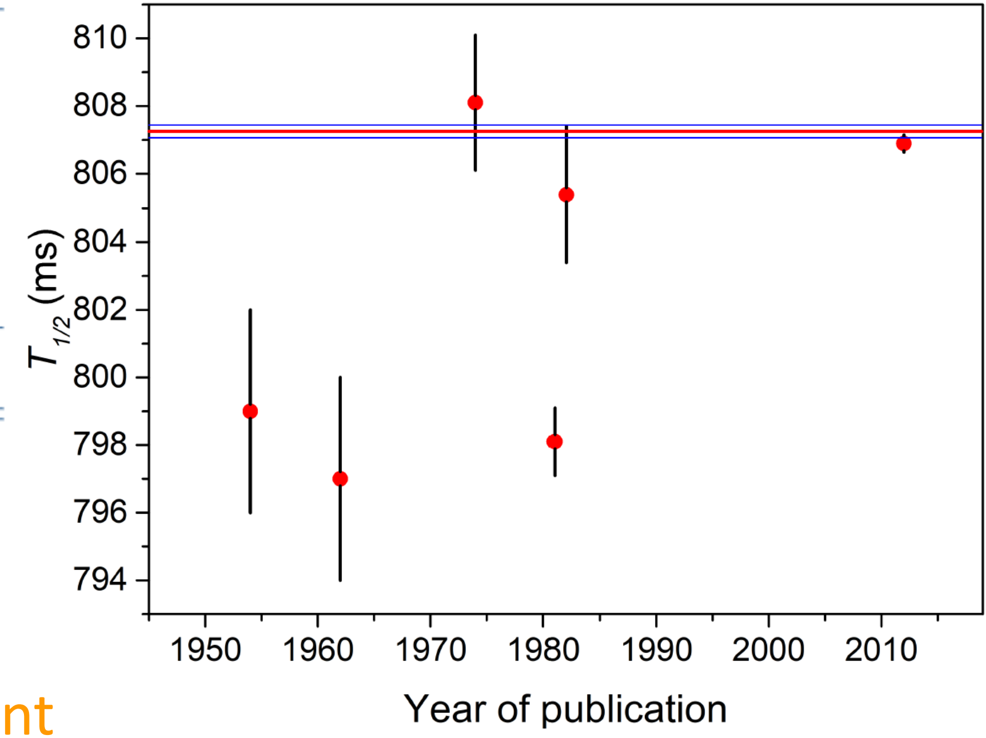




Half-life of ^{6}He

	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)

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

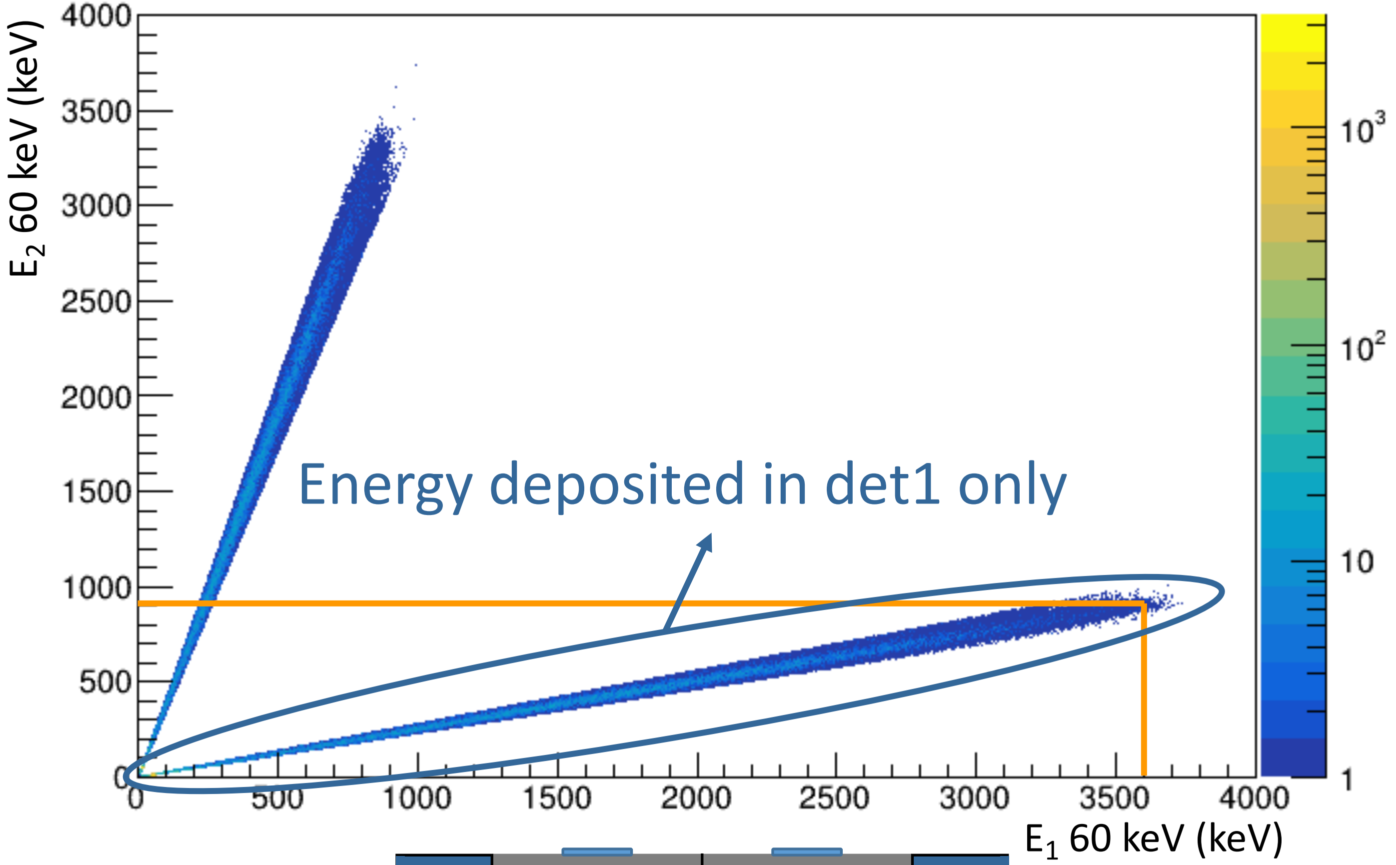


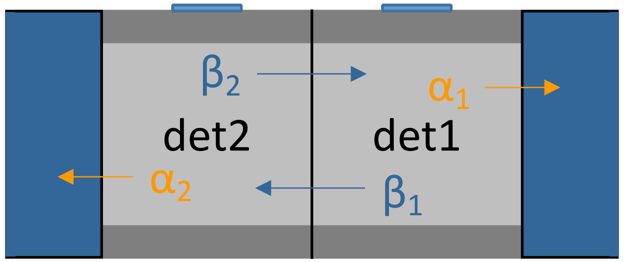
M. Kanafani et al., Phys. Rev. C 106, 045502 (2022).

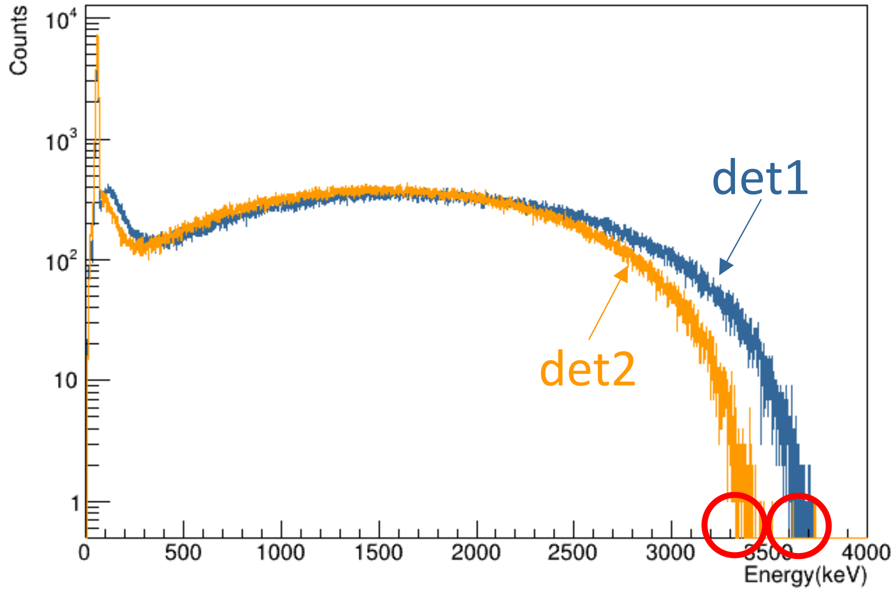
Our result is the most precise value, and is in agreement with the last and previously most accurate value. It resolves the discrepancy between the two sets of values

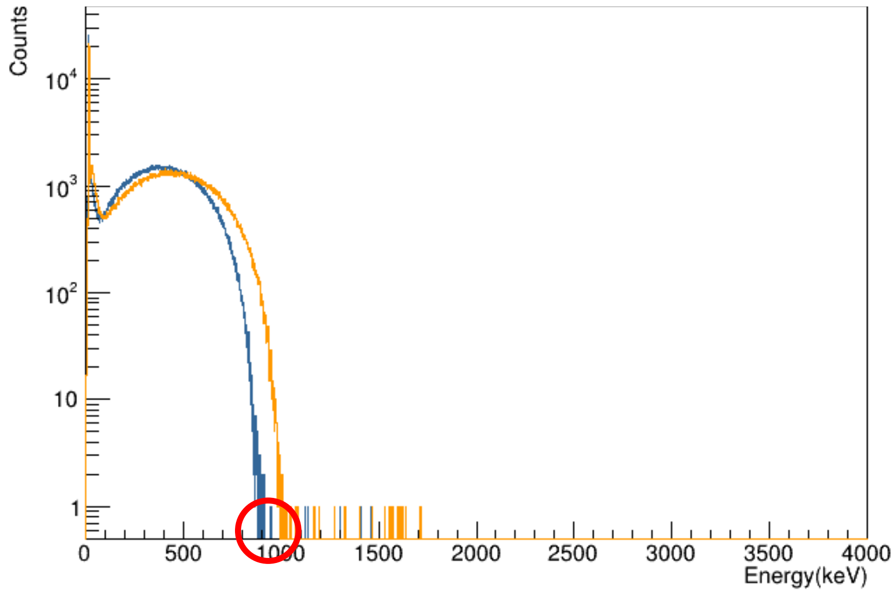
Light cross-talk

After calibration with 60 keV peak







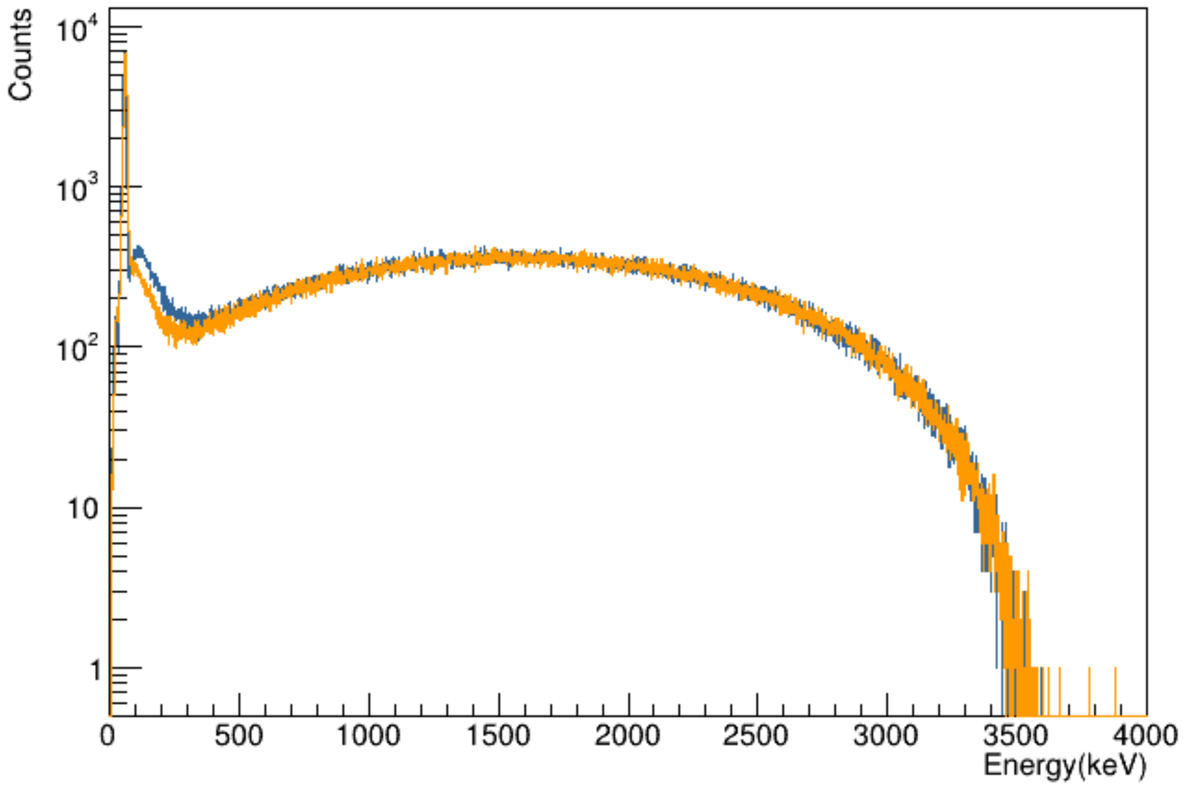


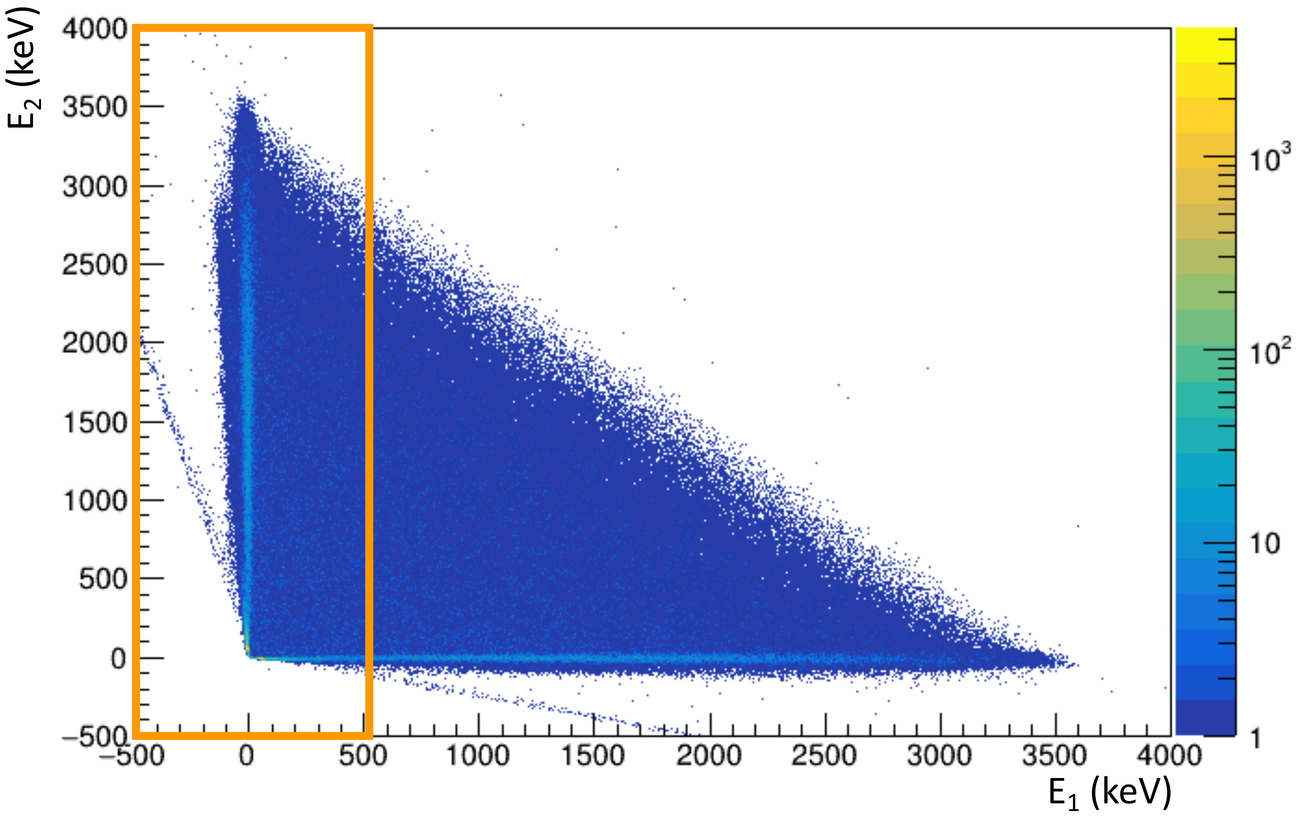
Refine calibration (^{6}He endpoint)

Second calibration accounting for endpoint mismatch

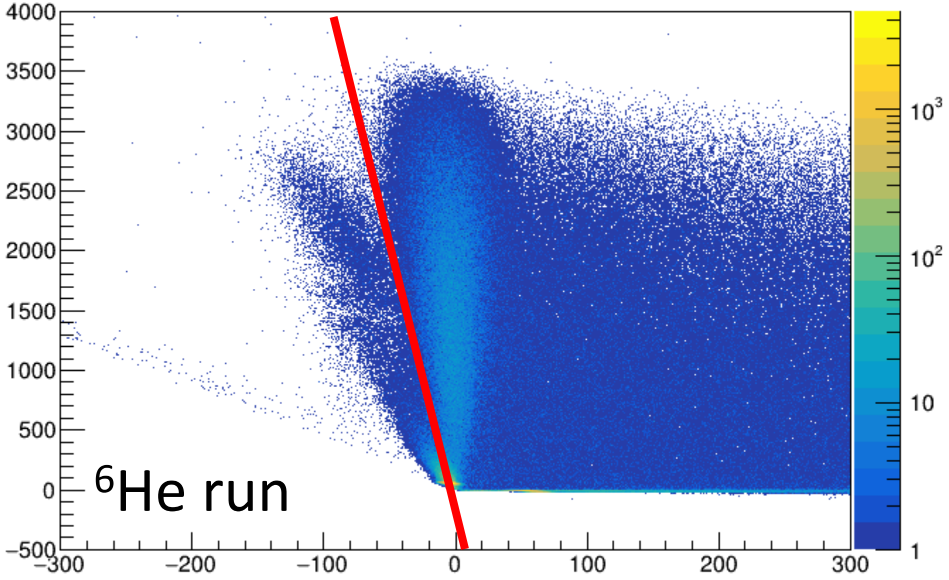
$$E_1 = \frac{\alpha_1 E_{1(60keV)} - \beta_2 \alpha_2 E_{2(60keV)}}{1 - \beta_1 \beta_2}$$

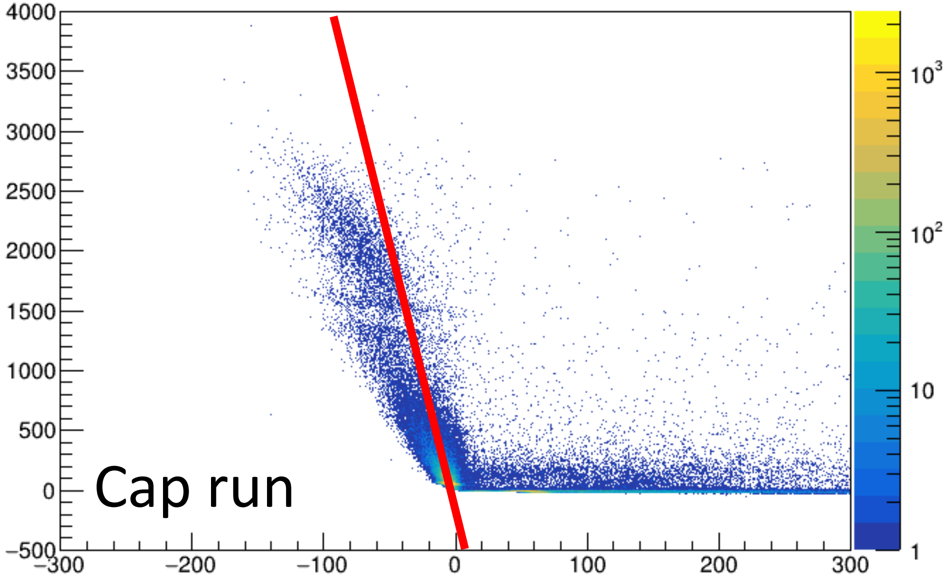
$$E_2 = \frac{\alpha_2 E_{2(60keV)} - \beta_1 \alpha_1 E_{1(60keV)}}{1 - \beta_1 \beta_2}$$



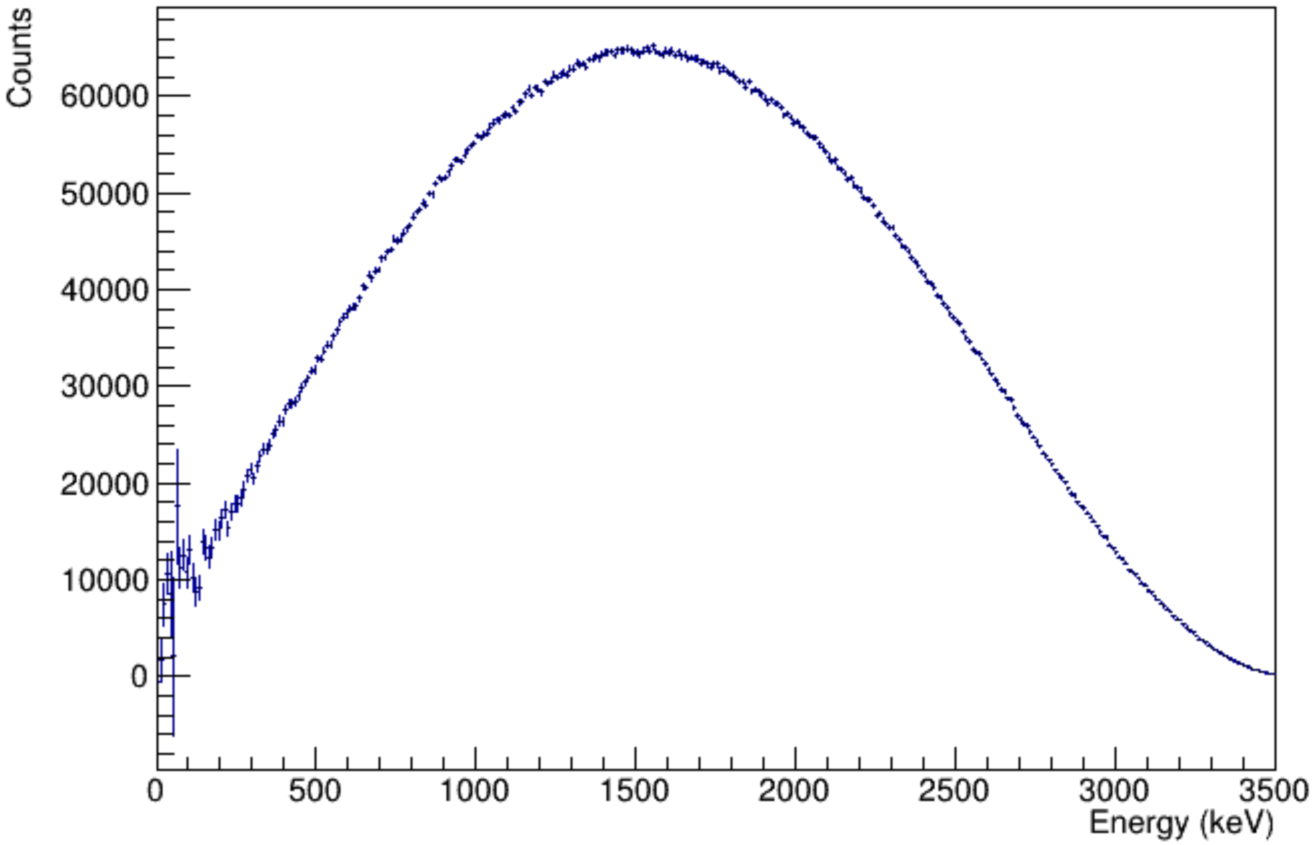


Data selection and background subtraction



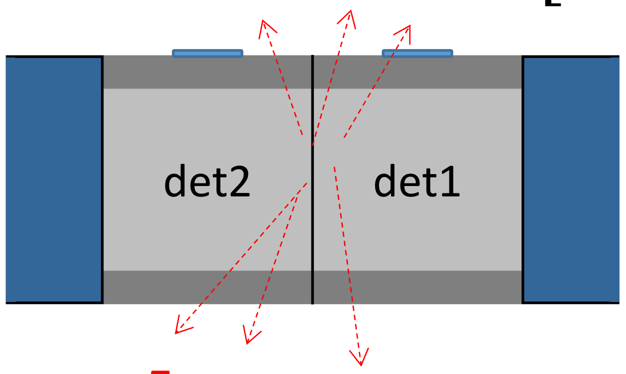


Experimental spectrum after Bremsstrahlung peak subtraction

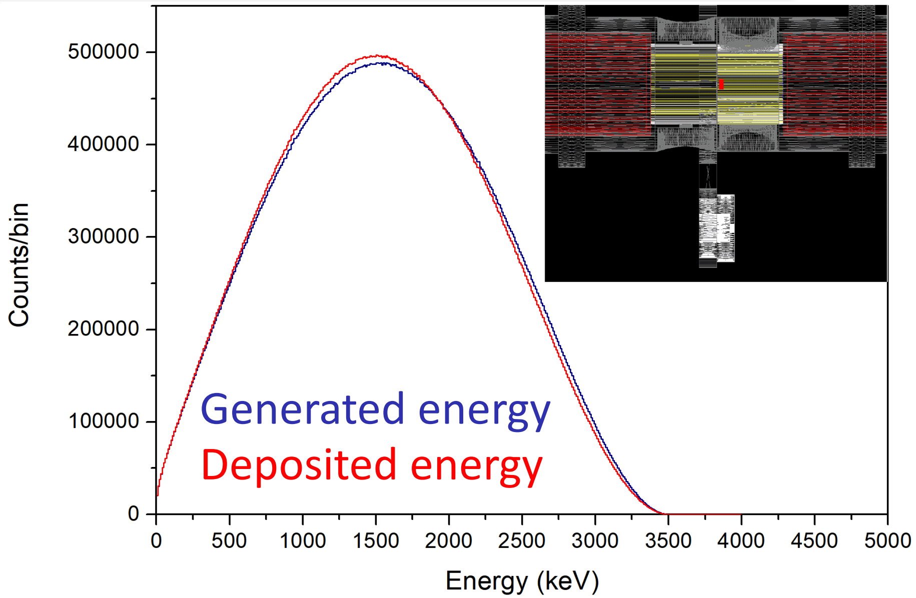


Bremsstrahlung escape

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



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

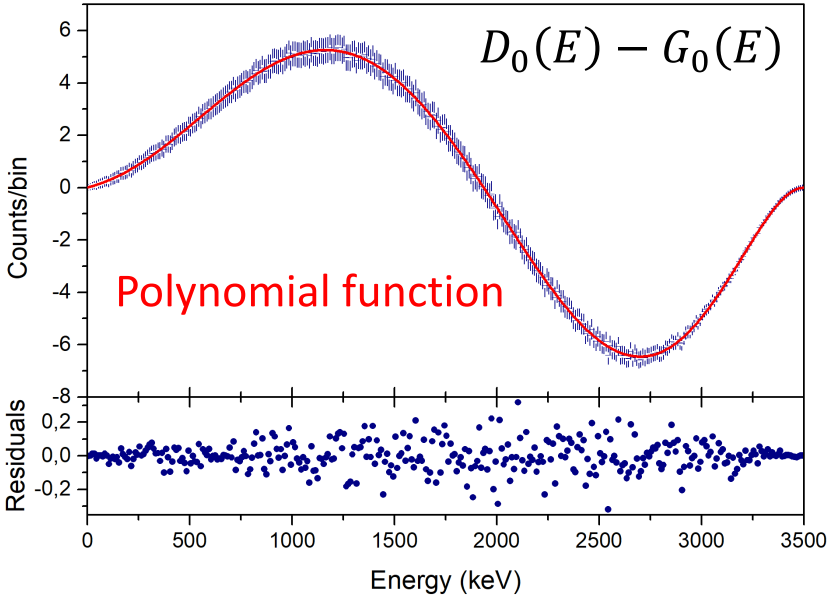


$$G_i(E) = PS(E) \cdot FF(E) \cdot E^i$$ **GEANT4** $$D_i(E)$$

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

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

Analytical function that describes the bremsstrahlung escape

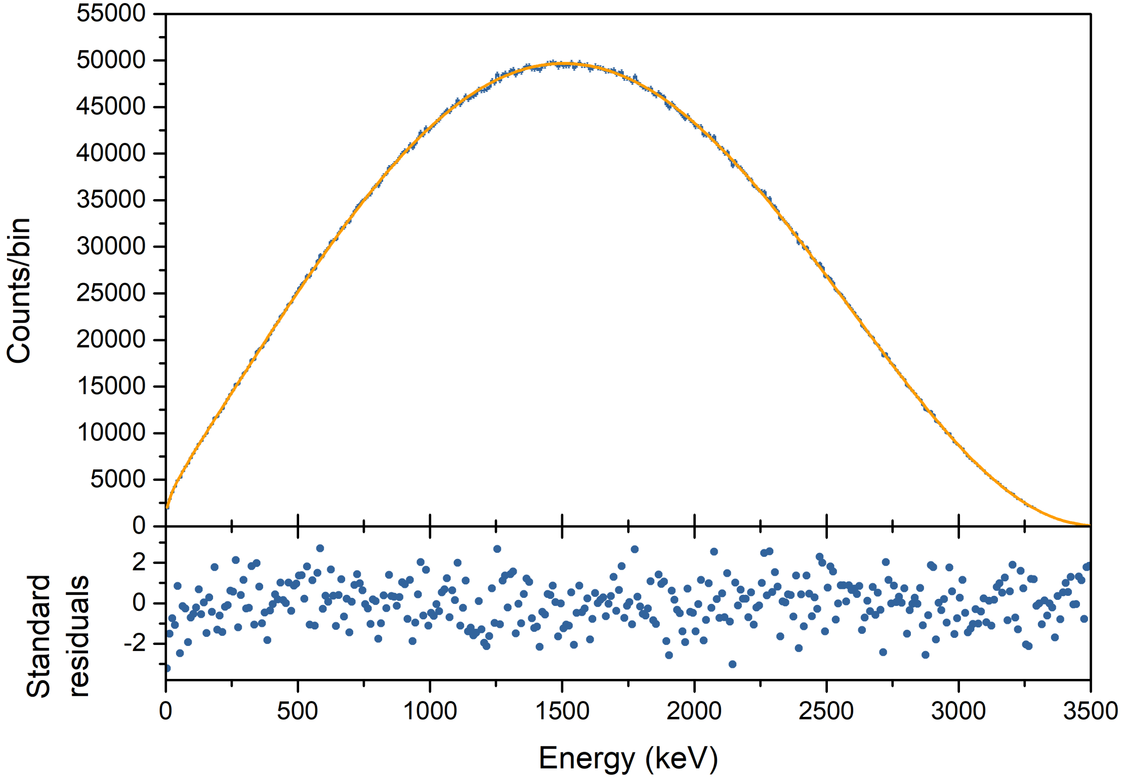


Testing the fitting method

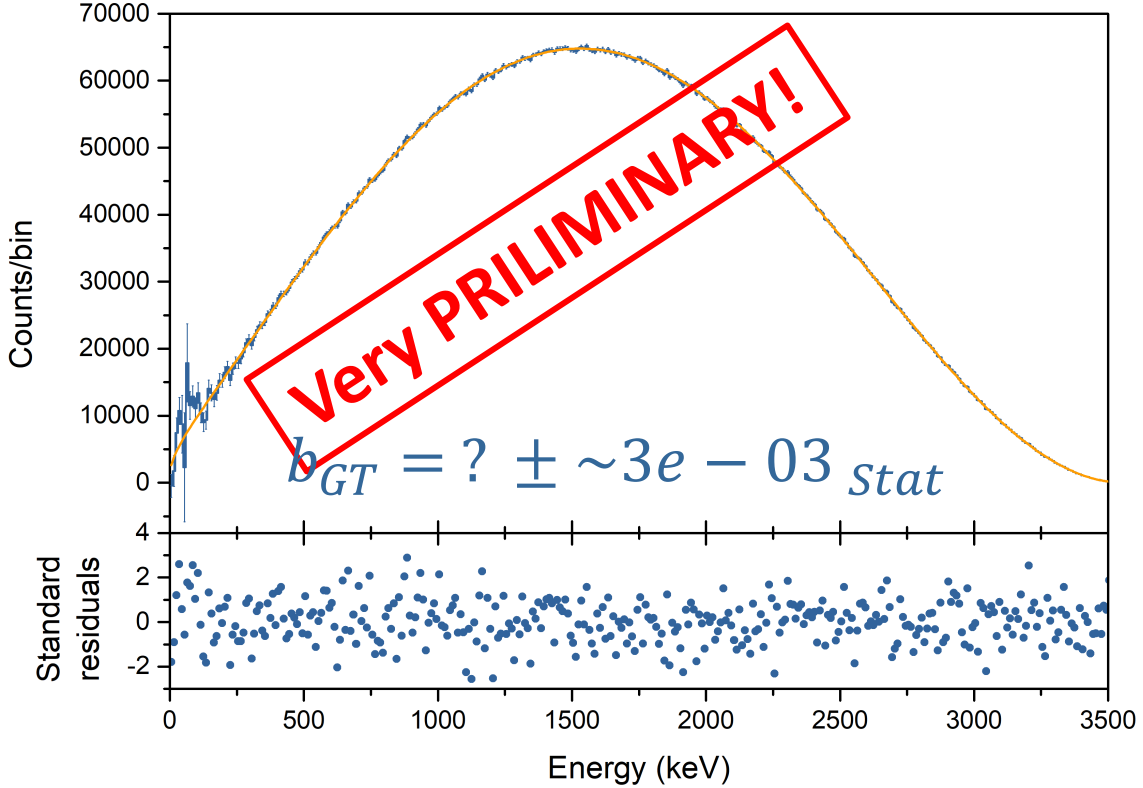
$$F(E) = norm \times \sum_{i=-1}^{2} \alpha_i \left[PS(E) \cdot FF(E) \cdot E^i + f_i(E) \right]$$

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

Spectrum generated with G4



Experimental spectrum



Summary and outlook

Summary:

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

Outlook:

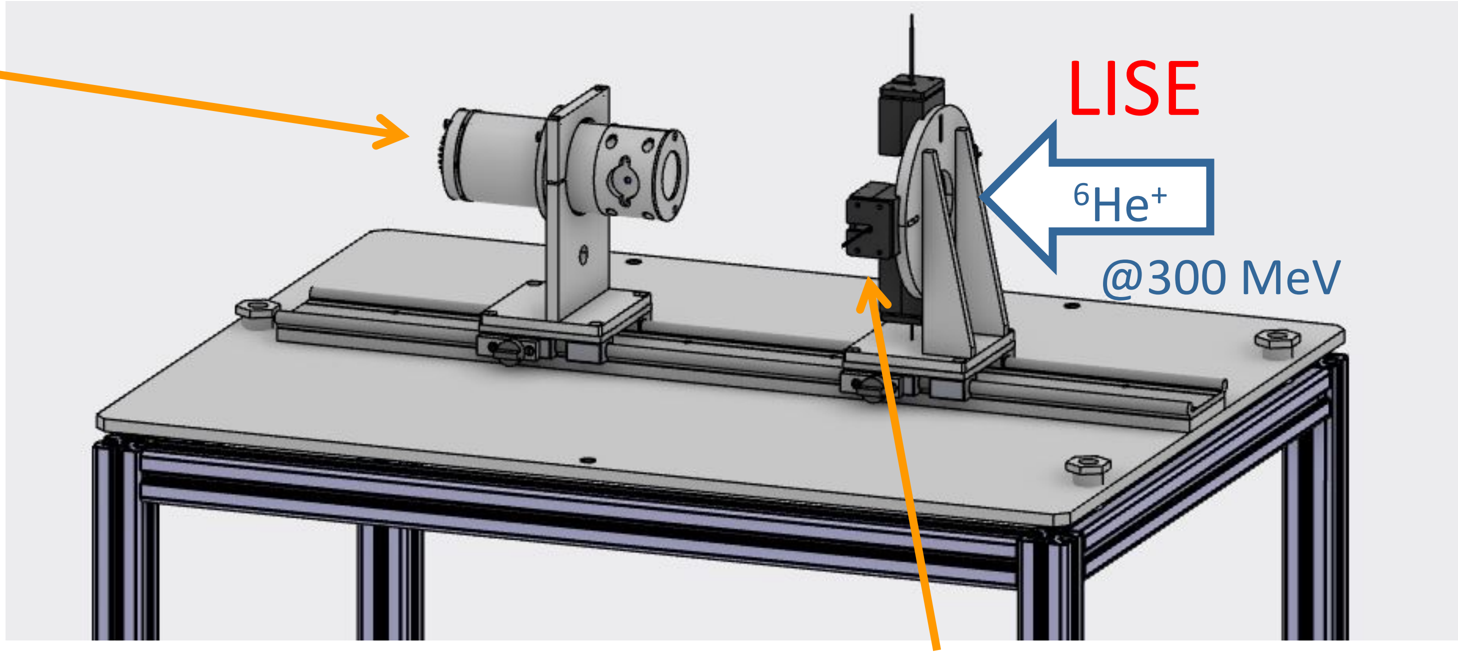
Carry on the experimental data fitting to extract the Fierz term and to study systematic effects:

- Calibration of cap runs
- Data selections
- Detectors response function (resolution, linearity)

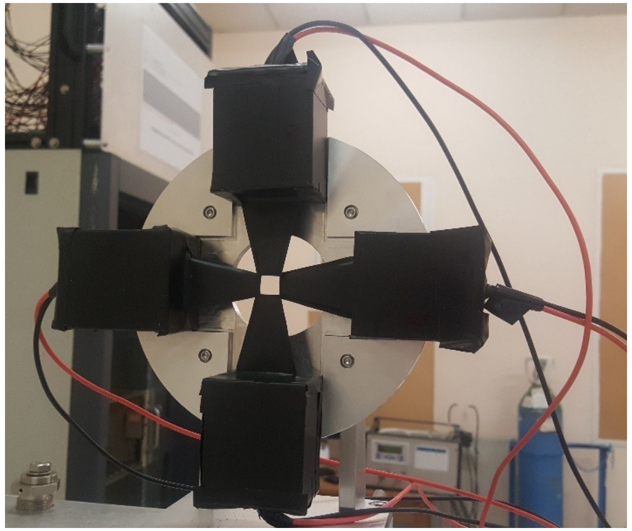
High energy experiment

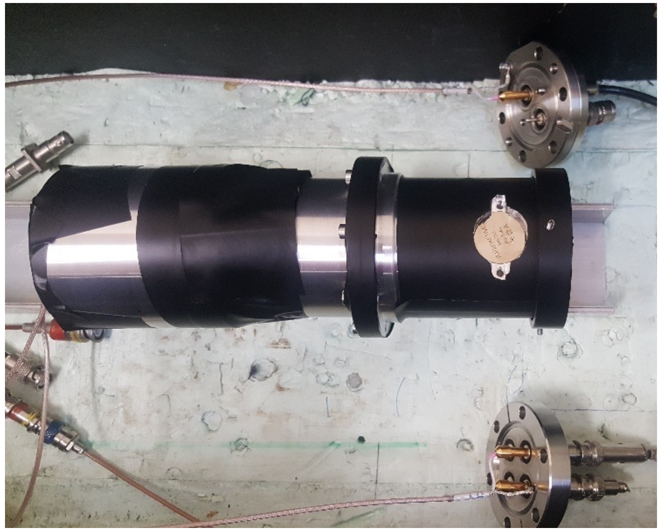
Main detector (YAP)

Scheduled @GANIL
April 2023



Plastic scintillators





- ✓ Detectors are mounted
- ✓ testing the detectors

Thank you for your attention!