JRJC 2024
27th November 2024

# Precision measurements in the β-decay of $^{6}He$
# Status of the bSTILED project

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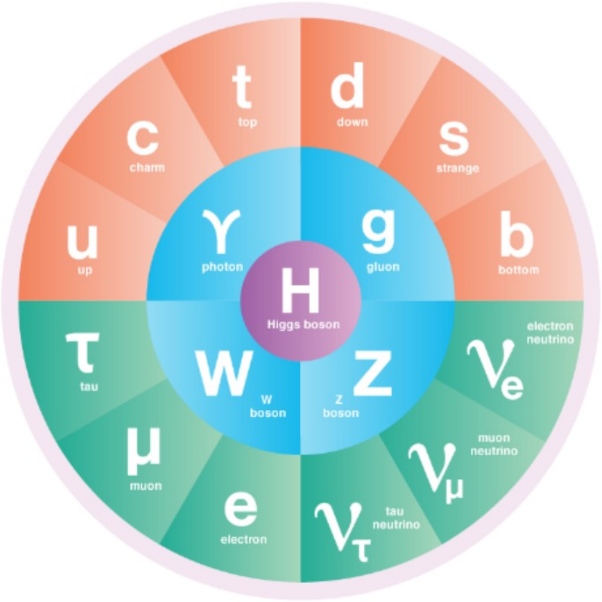
# Introduction : Context

## Standard Model of particle physics :

-Describe elementary particles and their interactions

-Strong model, consistent with constaints at TeV scale

-Describe three out of four fundamental forces



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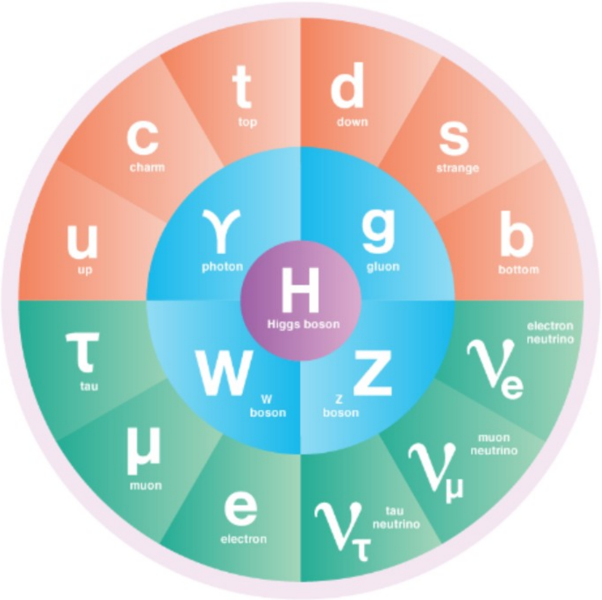


-Describe elementary particles and their interactions

-Strong model, consistent with constaints at TeV scale

-Describe three out of four fundamental forces

## Shortcomings of the Standard Model :

- Does not account for gravity
- No answer for the matter-antimatter asymmetry
- dark matter and dark energy
-...

⇒ Physics beyond the Standard Model

# Nuclear β-decay Hamiltonian

$$H_\beta = g_F \sum_i \left(\bar{\psi}_p O_i \psi_n\right)\left(\bar{\psi}_e O_i \left(C_i + C_i' \gamma_5\right)\psi_\nu\right) + h.c.$$

Fermi coupling constant ($g_F$) — Hadron current ($\bar{\psi}_p O_i \psi_n$) — Lepton current ($\bar{\psi}_e O_i (C_i + C_i' \gamma_5)\psi_\nu$)

$C_i$ : Even
$C_i'$ : Odd
→ 10 coupling constants → 5 forms of currents:

- Scalar ($C_S$, $C_S'$)
- Vector ($C_V$, $C_V'$)
- Tensor ($C_T$, $C_T'$)
- Axial-vector ($C_A$, $C_A'$)
- Pseudo-scalar ($C_P$, $C_P'$)

$C_i$ & $C_i'$ are determined experimentally

In the Standard Model :

- $C_V = C_V' = 1$
- $C_A = C_A' = -1.25$
- $C_S = C_S' = C_T = C_T' = 0$ → Current Constraints → Possibility for search of new physics

# bSTILED (b: Search of Tensor Interactions in nucLear bEta Decay)

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Goal of the project :

β decay precision measurements to search for Tensor contributions in pure GT transitions

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Fierz interference term : $b_{GT} \approx \gamma Re\left(\frac{C_T + C_T^{'}}{C_A}\right)$

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Goal of the project :

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In pure GT transitions :

Fierz interference term : $b_{GT} \approx \gamma Re\left(\frac{C_T + C_T^{'}}{C_A}\right)$

For these transitions, $b_{GT}$ only depends on $C_T/C_A$ value.

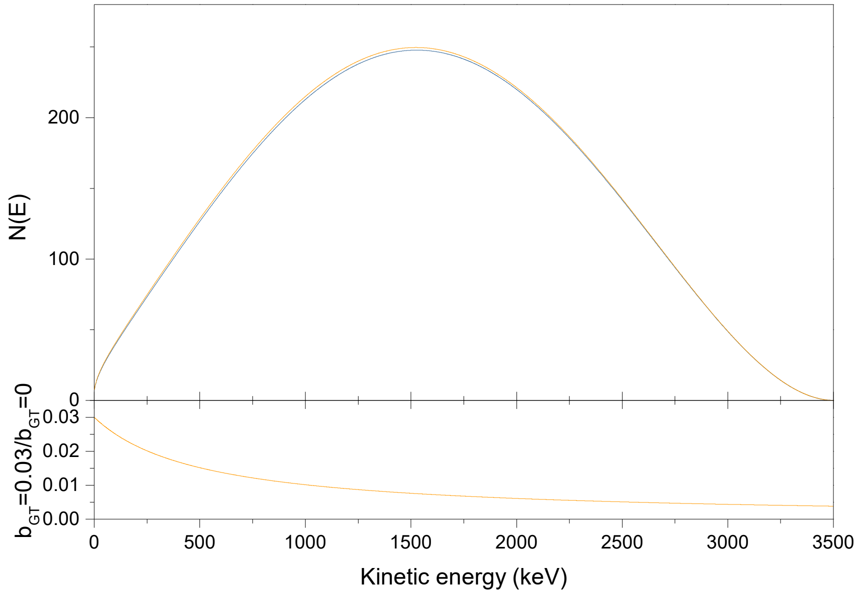
In Standard model : $b_{GT} = 0$ ($C_T = C'_T = 0$)

Current uncertainties : $\Delta b_{GT} = 3.9 \times 10^{-3}$

# Fierz interference term for pure Gamow-Teller transitions

$$N(E) \propto F(Z,E)(1+\eta)\, pE(E-E_0)^2\left(1+\frac{m_e}{E}b_{GT}\right)$$

Fermi function — Theoretical corrections — Phase space

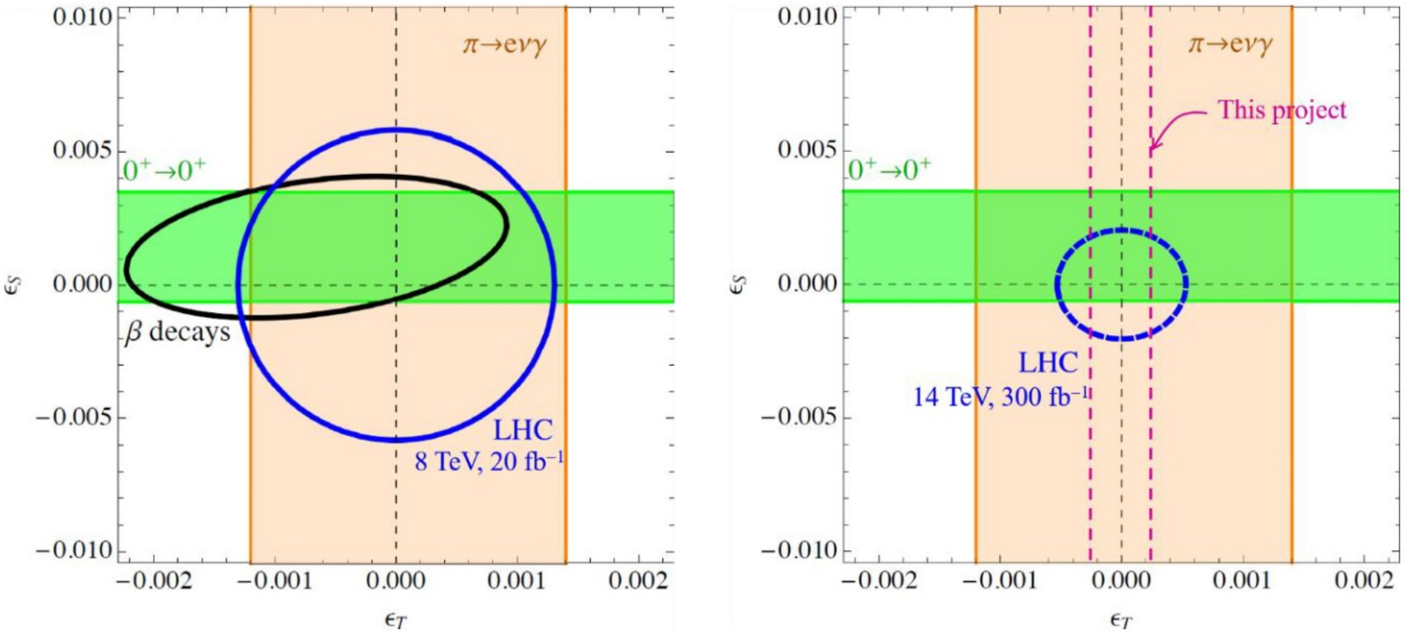



Direct effect on the β-spectrum shape

Very precise measurement of the beta spectrum to extract the Fierz term

$b_{GT} \neq 0$ } New physics

# Precision goal

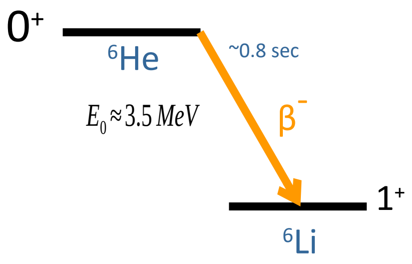


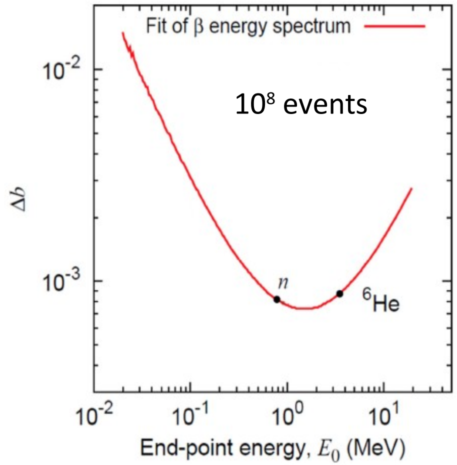

M. González-Alonso, O. Naviliat-Cuncic, N. Severijns, Prog. Part. Nucl. Phys. 104 (2019) 165.

- Phase I: $\Delta b_{GT} = 4 \times 10^{-3}$ → Current limits from β decay experiments
- Phase II: $\Delta b_{GT} = 1 \times 10^{-3}$ → Better than LHC @ 14 TeV

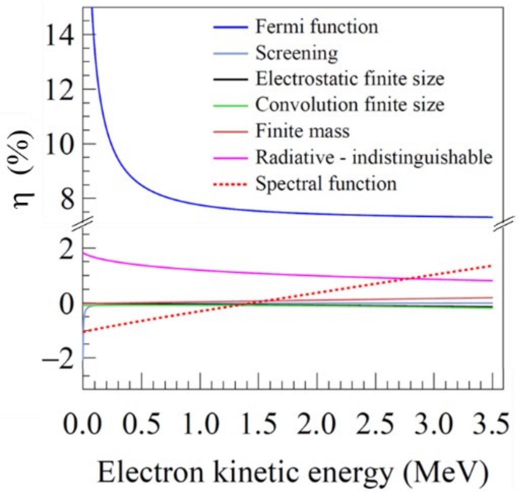
# The perfect candidate: $^6$He

- Pure GT transition and thus exclusively sensitive to tensor currents
- Endpoint energy (3.505 MeV) providing high sensitivity
- Theoretical corrections known with high precision
- Convenient half-life for implantation-decay cycles
- High intensity beam available at GANIL for both energy

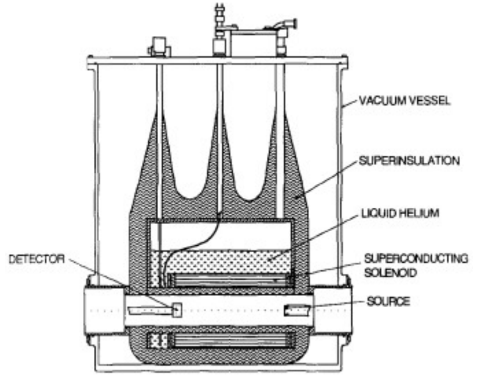


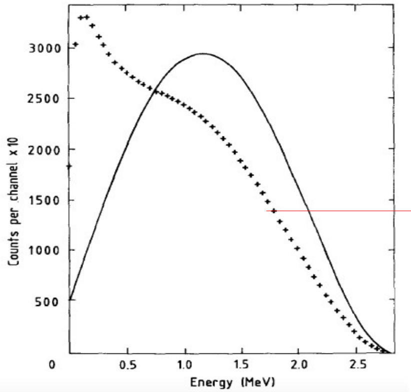




M. Gozales-Alonso, O. Naviliat-Cuncic
Phys. Rev. C 94 (2016) 035503



# Backscattering problem: the main systematic effect




D.W. Hetherington et al, Nuclear Physics A, 1989.

A strong distortion of the spectrum is induced by the backscattering of electrons

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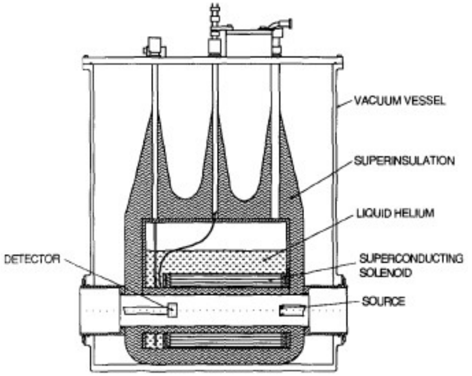


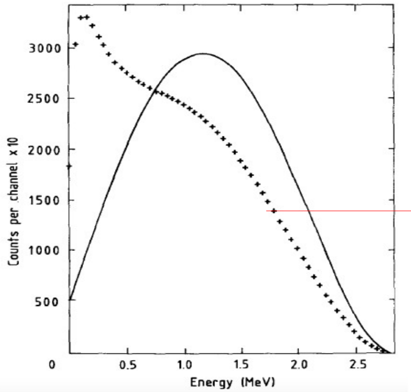


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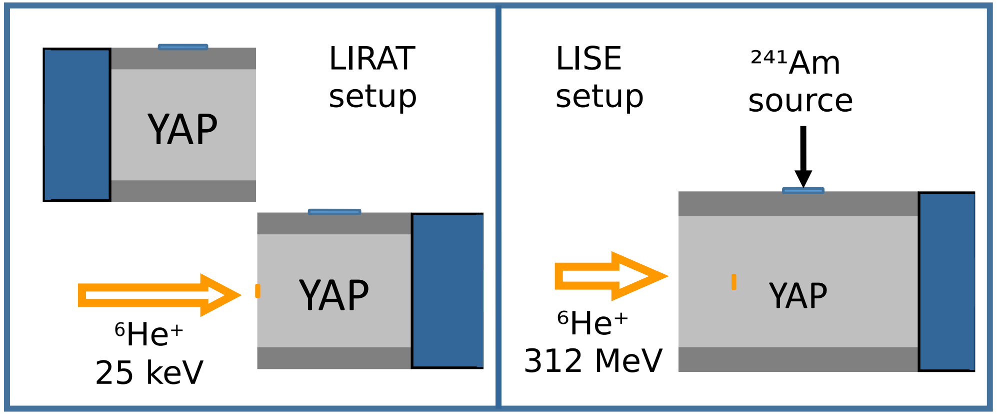
A strong distortion of the spectrum is induced by the backscattering of electrons

Solution : 4π detection geometry

- Low energy experiment (LIRAT, 2021)
- High energy experiment (LISE, 2023)



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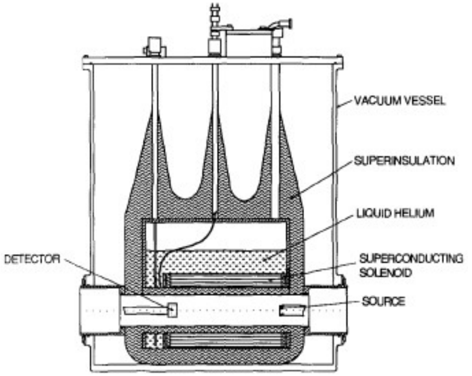


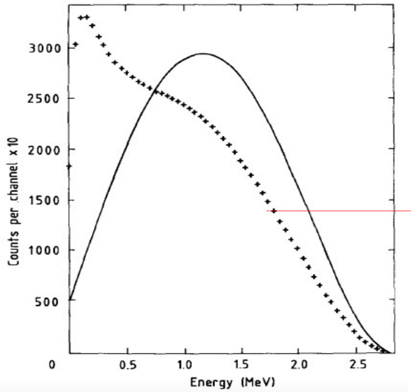


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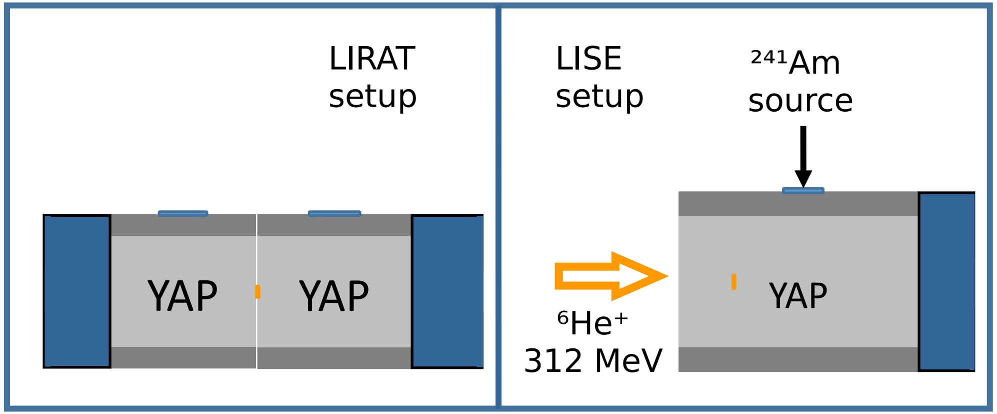

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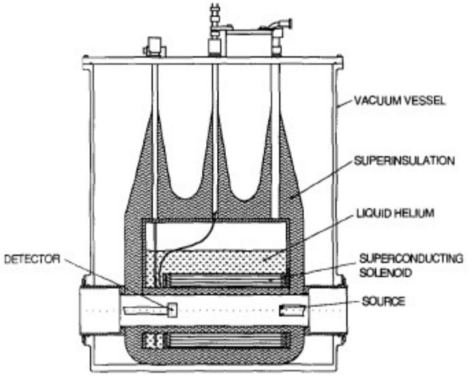


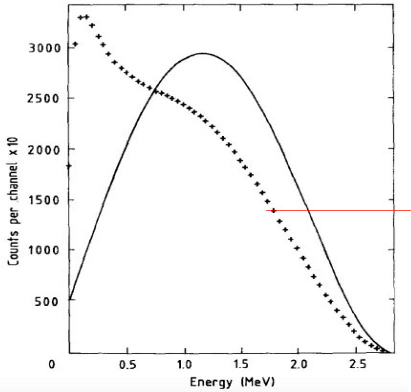


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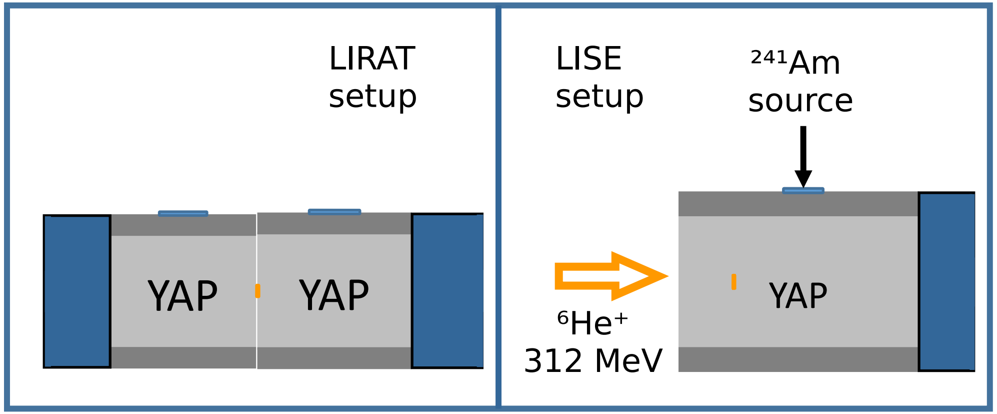
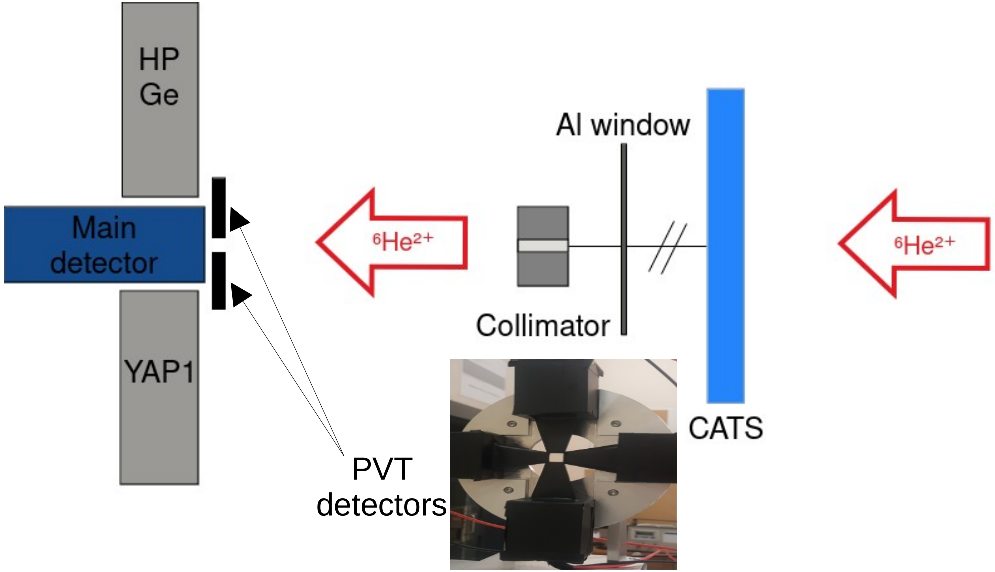
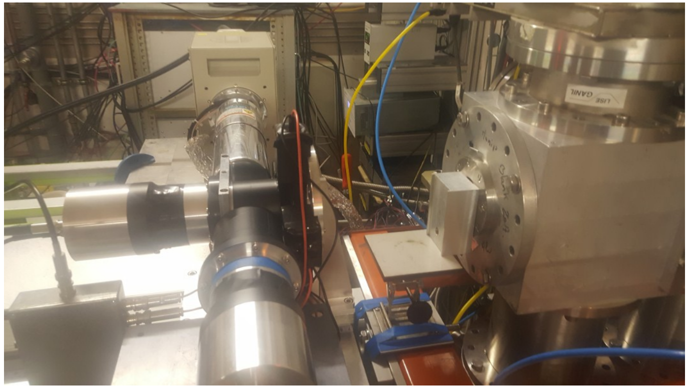


# b-STILED @ LISE experiment (April-May 2023)



## 2 different YAP crystal geometries :

-Ø 3cm by 3cm long (YAP3)
-Ø 4cm by 5cm long (YAP2)

## 4 Sets of measurements :

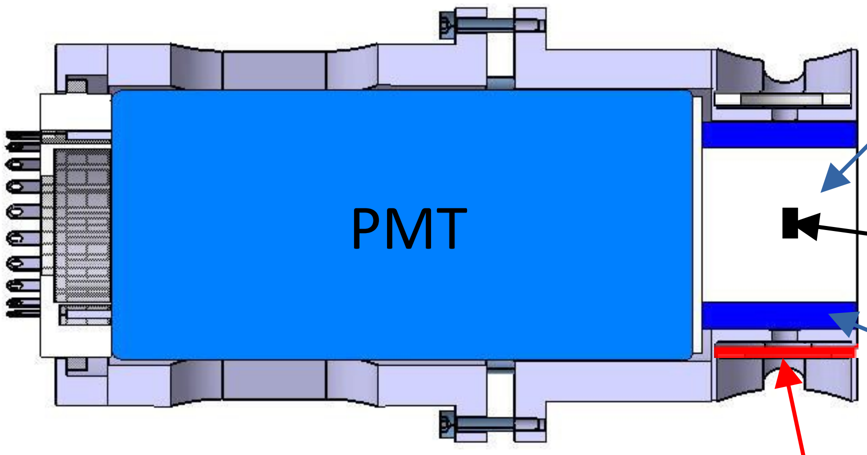
- 1 nominal for both geometries
- 1 with different systematic for both geometries

## Statistical goal :

-1.8 x $10^7$ $^6$He decay events
($\Delta b_{GT\ stat} = 2.8 \times 10^{-3}$ )

# Phoswich detector

2 scintillators read out by one PMT




Main scintillator :

YAP:Ce crystal scintillator with τ = 25 ns

- Linear energy response
- Good resolution ~5-6 % @ 1 MeV
- Low Bremsstrahlung energy escape

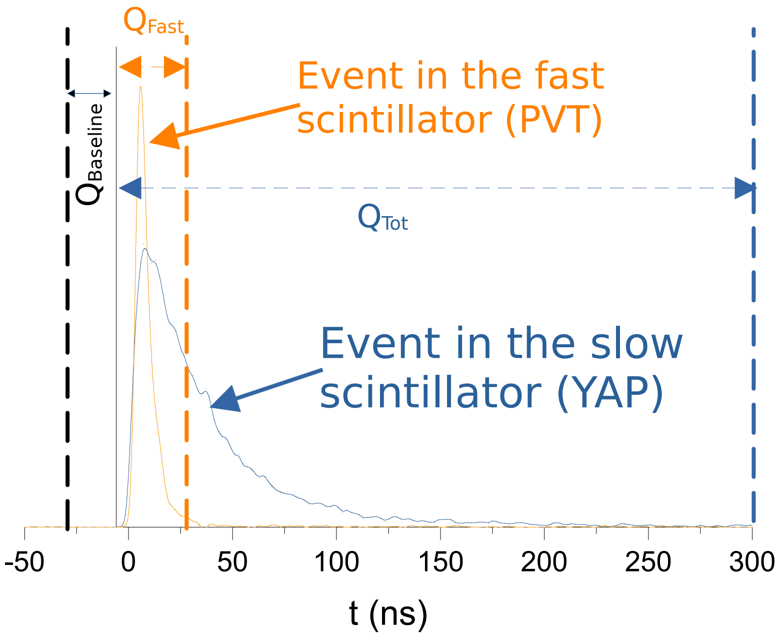
$^{6}$He implantation (~1 cm deep)
( > range of $e^-$ in YAP)

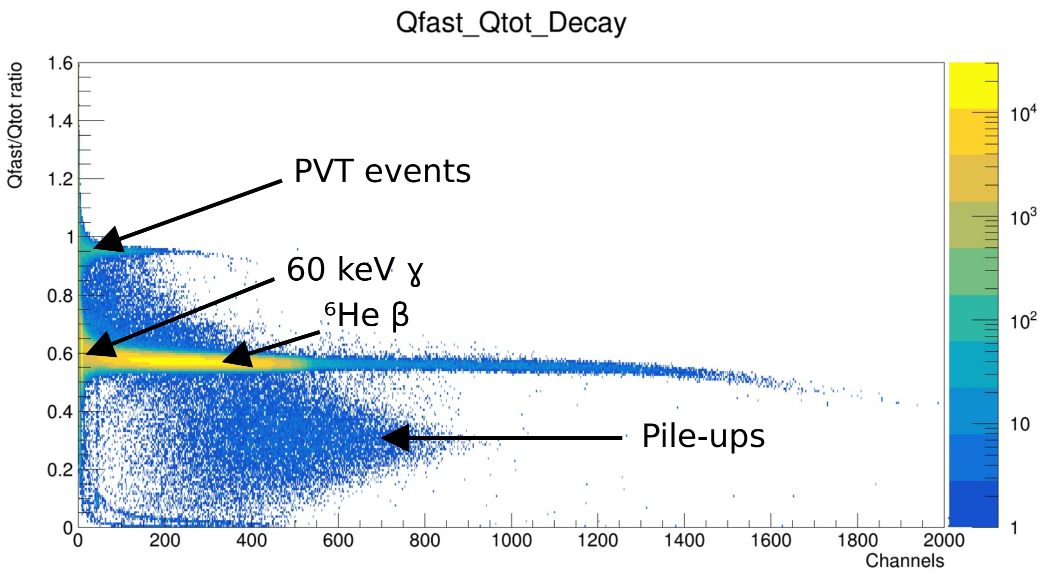
Veto and PMT gain fluctuations :

PVT: Plastic scintillator with τ = 1,8 ns

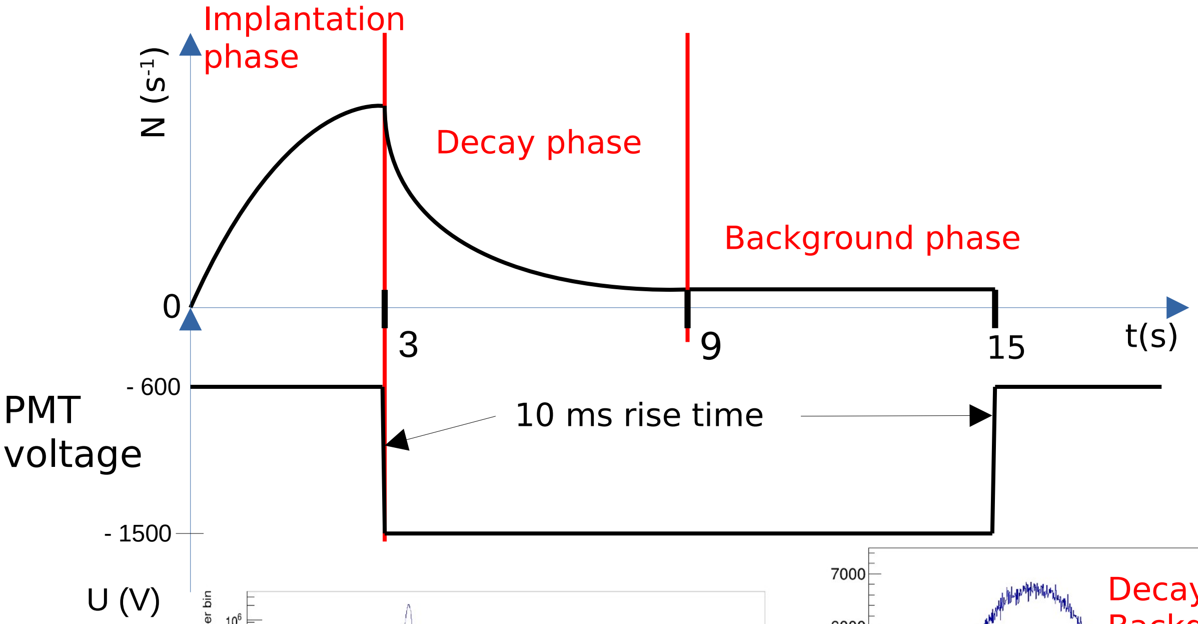
For monitoring of gain variations :
$^{241}$Am source

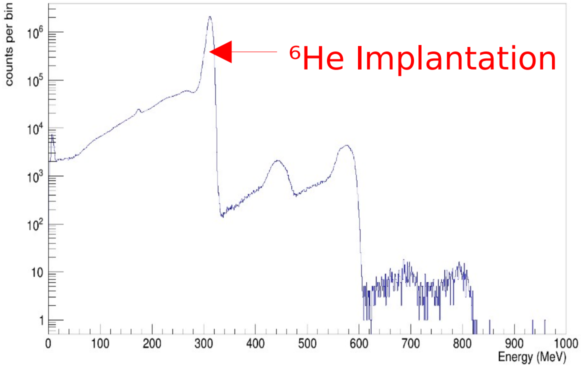
# Event selection by pulse shape discrimination

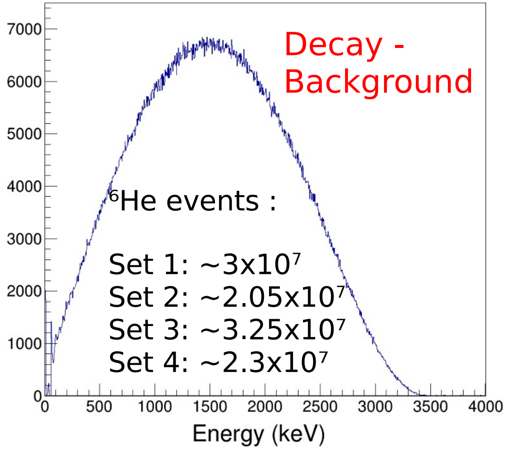


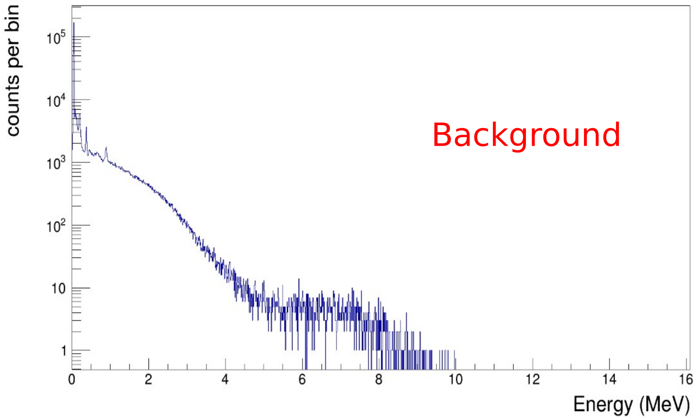



# Measurement cycle



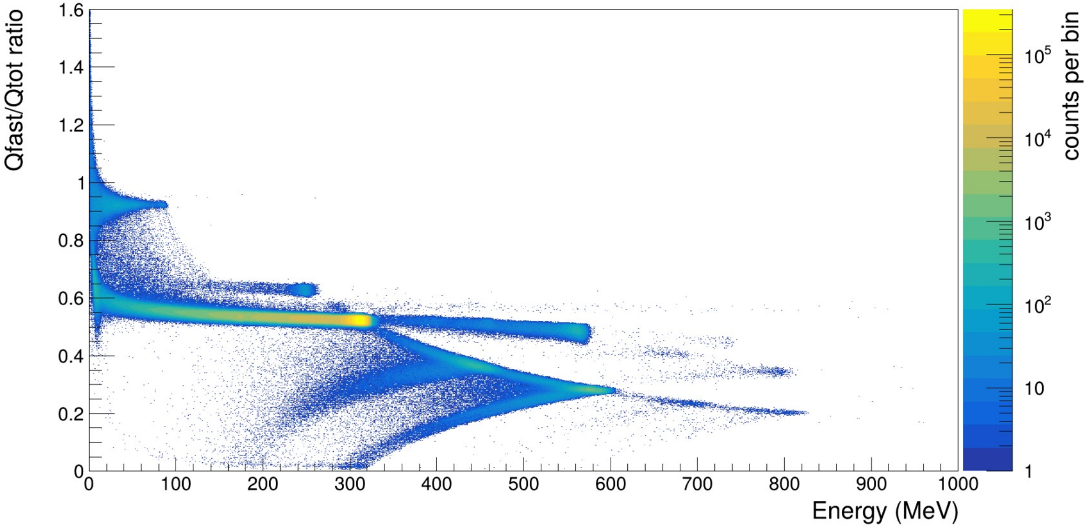



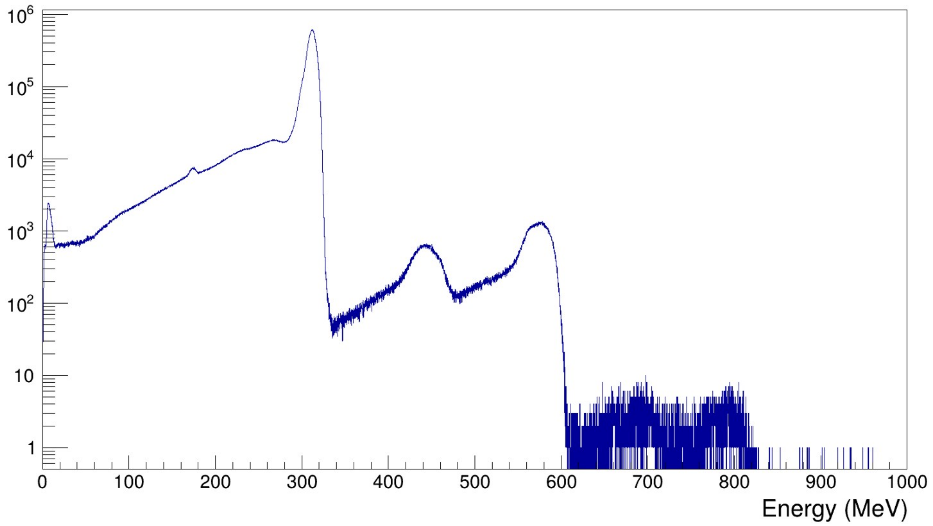



# Beam analysis status

## Beam implantation selection



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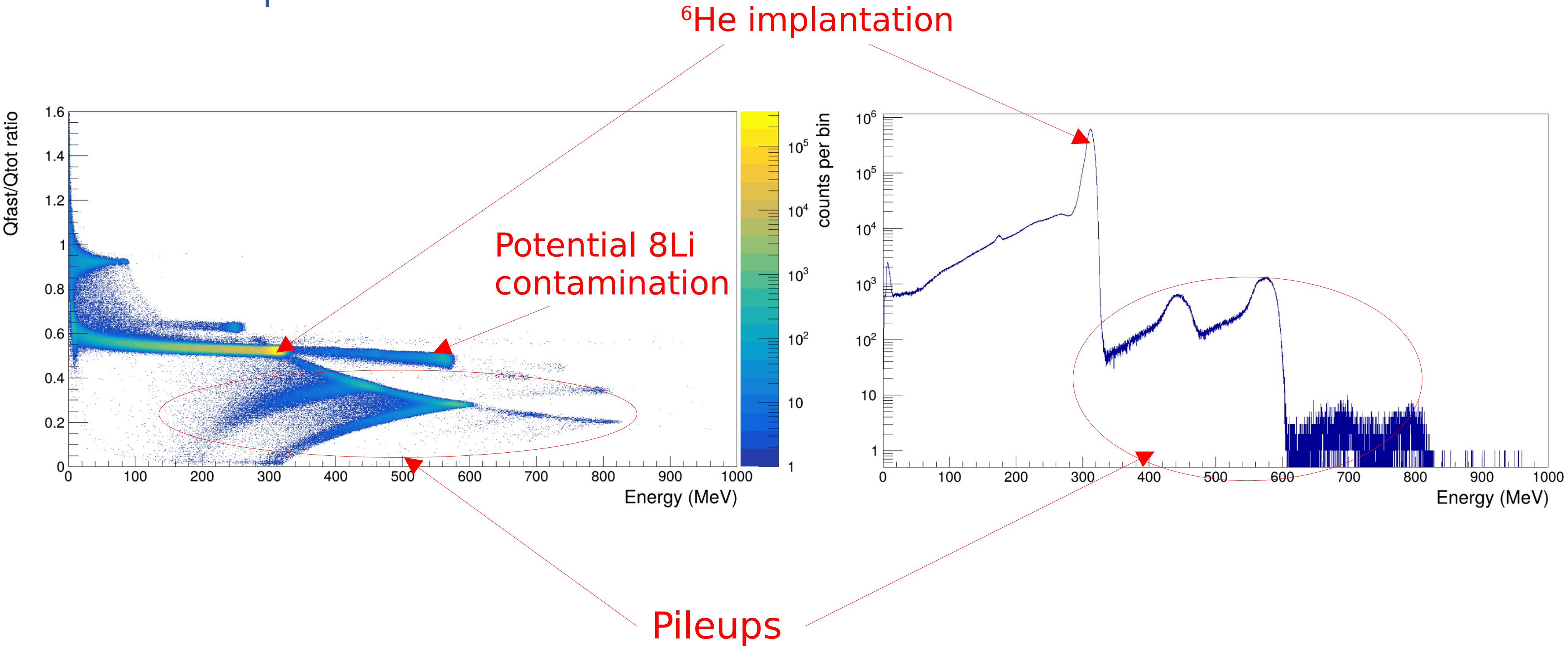

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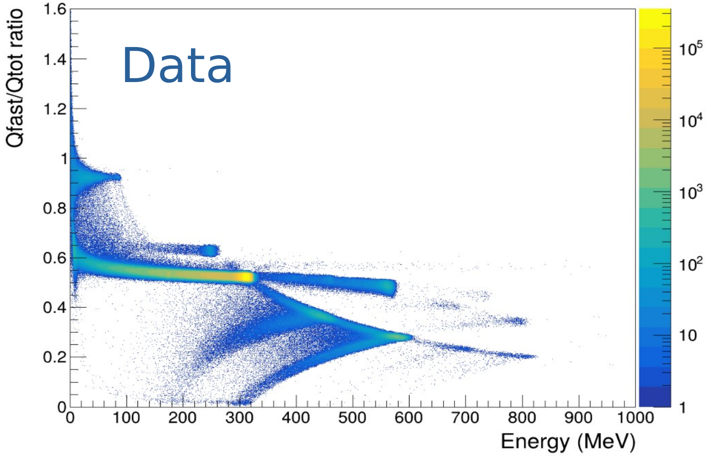
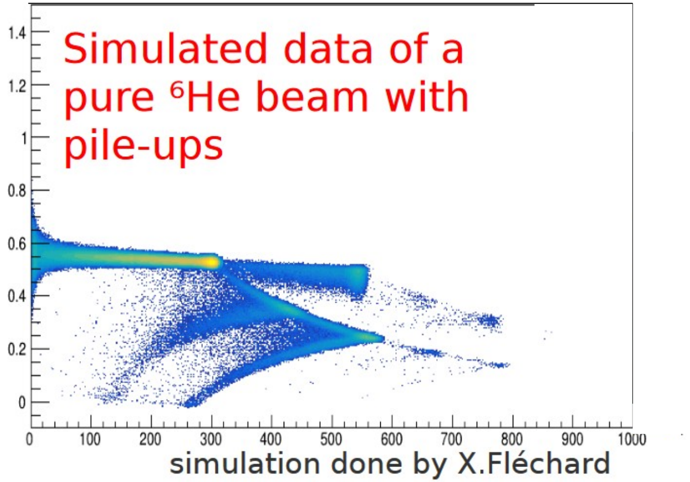
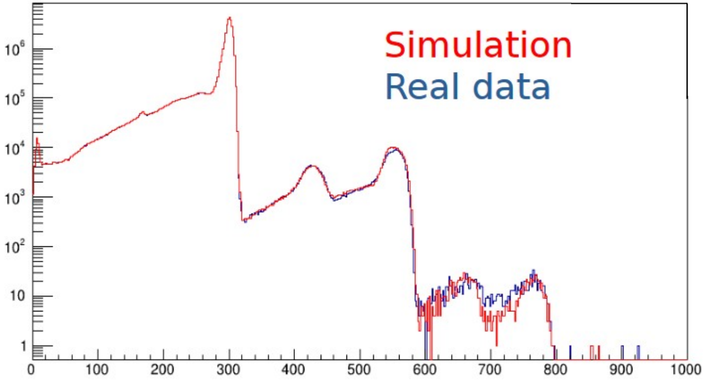


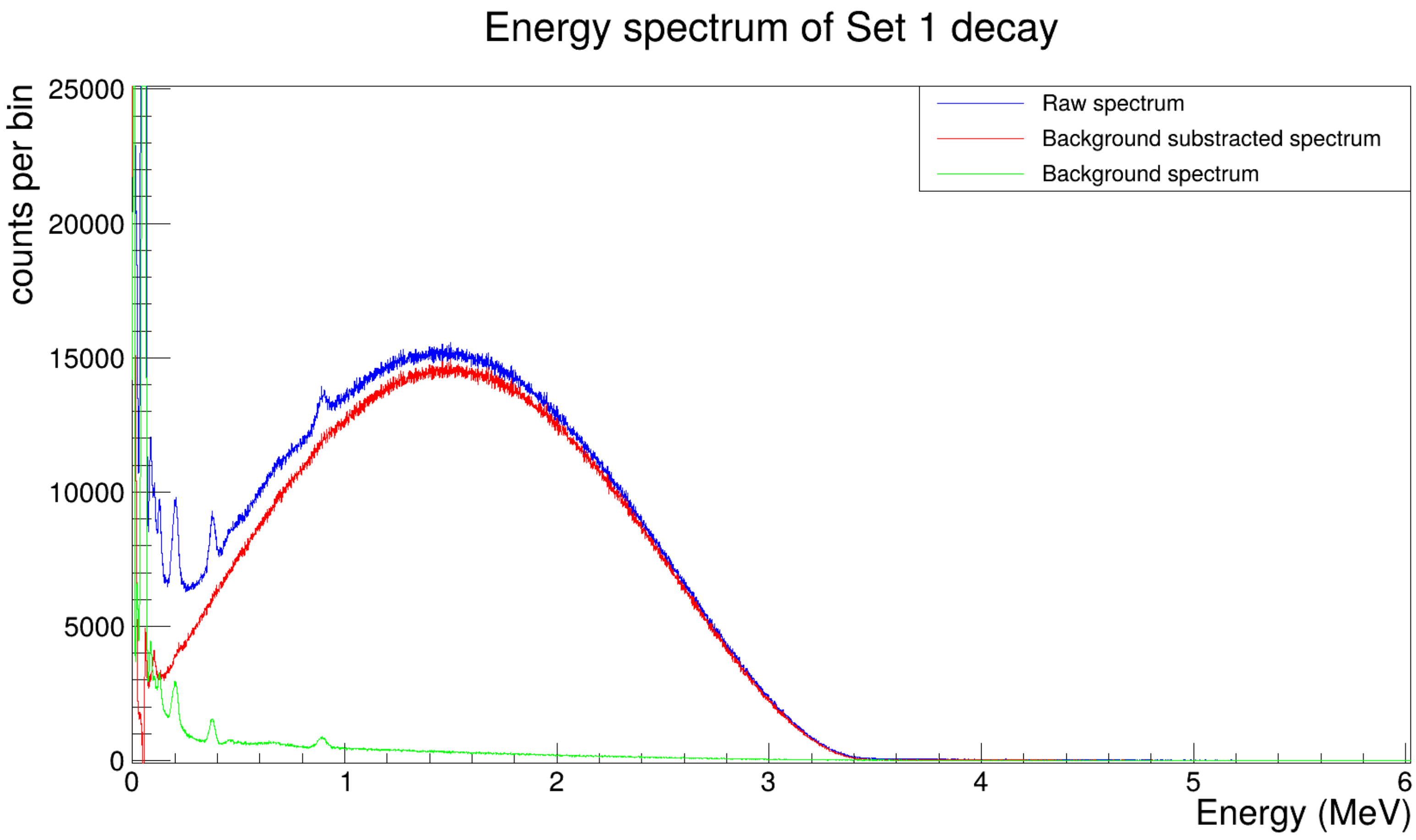




-Simulation is in agreement with the data at the $10^{-5}$ level

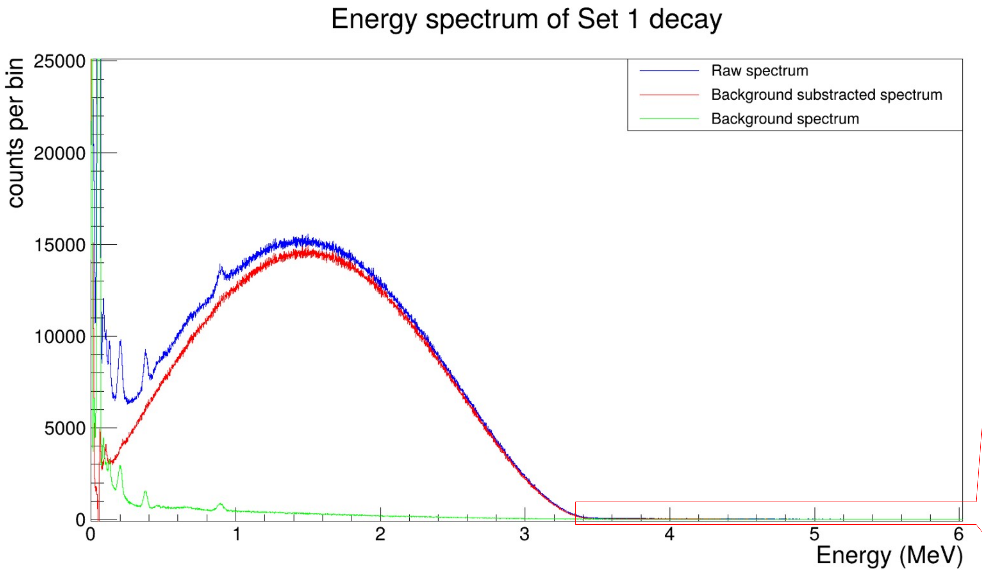
-Beam has no contamination

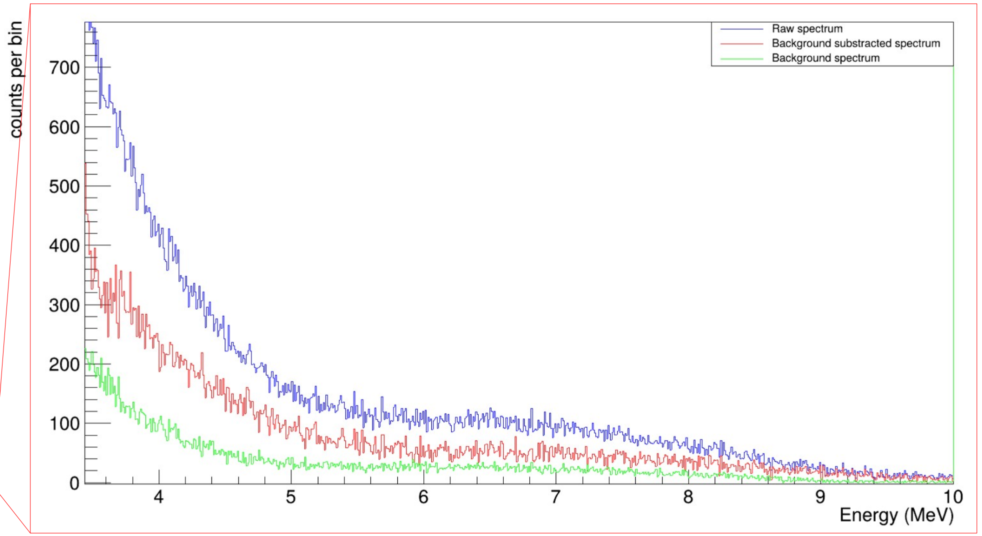
# Decay phase analysis status



# Decay phase analysis status

Study of presence of beam induced contamination :



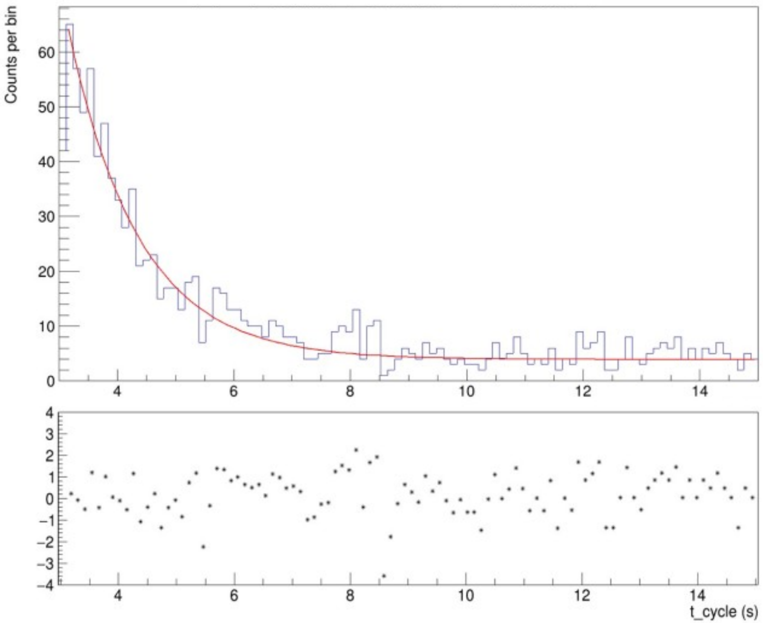




Presence of non-background events at E > 3,505 MeV

# Decay phase analysis status

Study of presence of beam induced contamination :

Using half-life measurement for high energy (>3.5 MeV) :




Results : 2 contributions with $T_{1/2}$ = 0,853(33)$_{stat}$ s and $T_{1/2}$ = 7,83(75)$_{stat}$ s

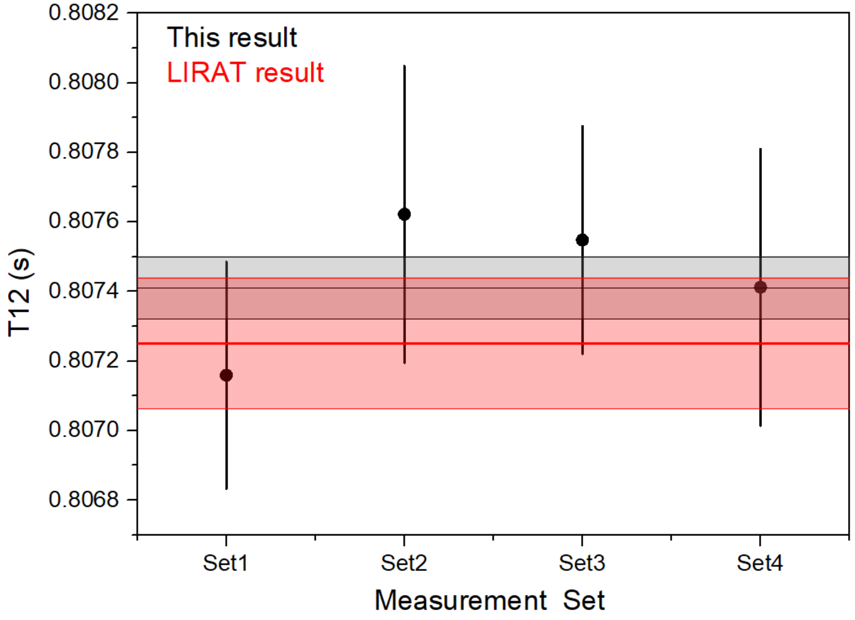
Corresponds to $^{8}Li$ ($T_{1/2}$ = 839.9 ms, $E_{\beta- \, max}$ = 12.974 MeV) and $^{16}N$ ($T_{1/2}$ = 7,13 s, $E_{\beta,max}$= 10,419 MeV) at the $10^{-3}$ level

Other possible contaminations at lower population
→ HpGe data analysis

# Decay phase analysis status

Measurement of $^{6}He$ half-life :

LIRAT result : 807.25(16)$_{stat}$(11)$_{syst}$ ms




-Use of an energy threshold $E_{thresh}$ = 100 keV

-$^{16}N$ decay included in the fit, contribution is a free parameter

-Result : 807.41(9)$_{stat}$ ms is compatible with most precise measurement of $^{6}He$ half-life

-Presence of $^{16}N$ at ~$1.5 \times 10^{-3}$ level.

# Conclusion and perspective

**Conclusion** :

-No contamination in the beam at the $10^{-5}$ level

-Beam induced contamination of $^{8}Li$ and $^{16}N$ at the $10^{-3}$ level

-Measured $^{6}He$ half-life compatible with most precise value (M.Kanafani & al.)

**Perspectives** :

- Refining contamination study by constraining contribution of potential other contamination

- Systematic study using Geant4 Simulation for corrections

- Measurement of bGT

# THANKS FOR YOUR ATTENTION !