Precision measurements in the β-decay of ^{6}He
Status of the b-STILED project

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Laboratoire de physique corpusculaire de Caen

Workshop ISOL-France VIII
17th March 2026

Outline

- Context and motivations
- The b-STILED project & LISE experiment
- Sources of systematic error
- Preliminary results

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Search for New Physics beyond Standard Model (SM)

- Search for ε_S, ε_T exotic contributions of weak interaction

  Dominant *Vector - Axial vector* (*V – A*) form established in SM

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Precision measurement of Ft, β-spectrum shape

→ Fierz interference term *b*

b → linear dependence on ε_S (Fermi) and ε_T (Gamow-Teller) → sensitive probe to NP

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- b-STILED (b : Search for Tensor Interaction in nucLear bEta Decay)

  → Measurement of *b* in a pure GT transition

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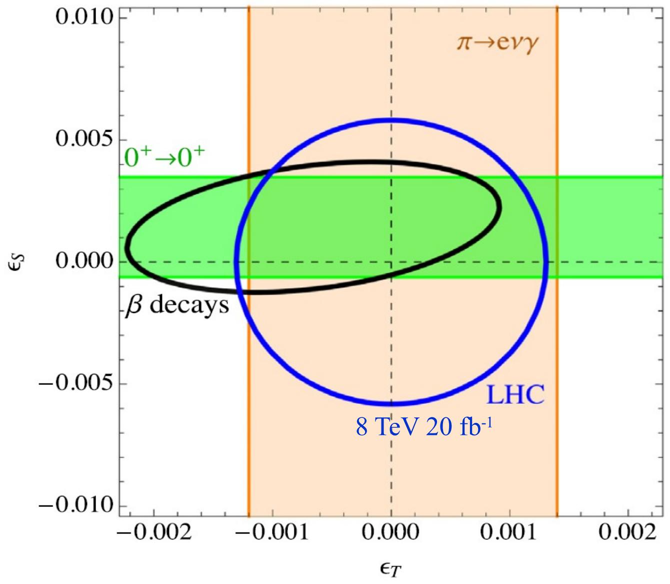
bSTILED goal

- bSTILED (b : Search for Tensor Interaction in nucLear bEta Decay)
  → Measurement of *b* in a pure GT transition

For pure GT, $b_{GT} = 6.2\ \varepsilon_T$ → measure b_{GT} to improve constraints on ε_T



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

Phase I : $\Delta b_{GT} = 4\times10^{-3}$
(Actual constraints from β decay)

Phase II : $\Delta b_{GT} = 1\times10^{-3}$
(competitive with projected LHC)

Principle of the b-STILED project

- Extract the Fierz term b_{GT} from the β-spectrum shape in the decay of ^{6}He

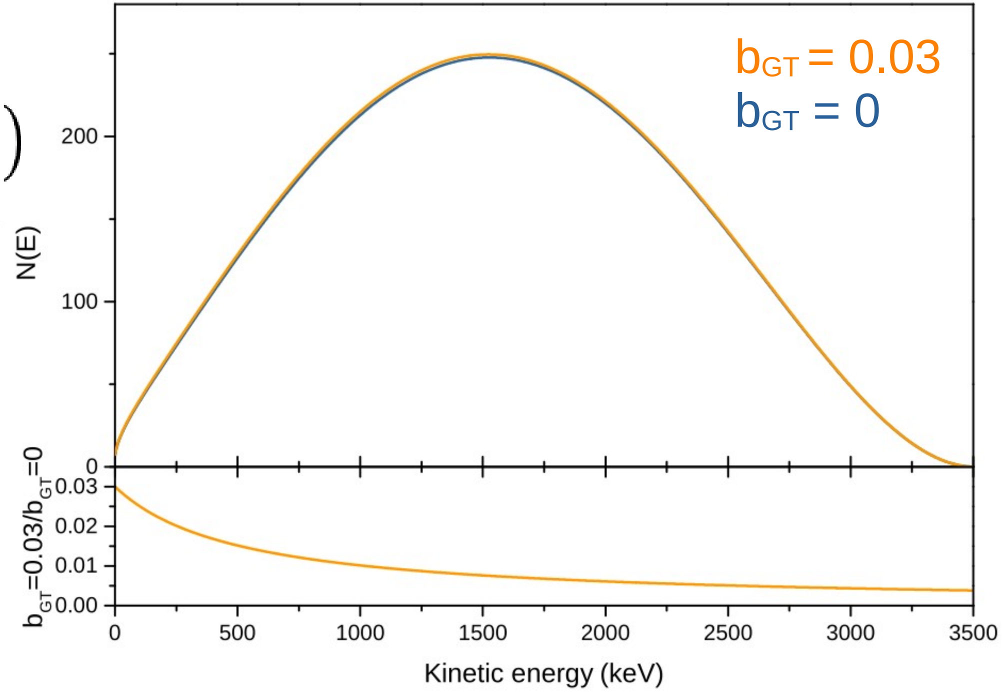
$$N(E) \propto F(Z,E)(1+\eta)pE(E-E_0)^2\left(1+\frac{m_e}{E}b_{GT}\right)$$

Fermi function

Theoretical corrections

Phase space

^{6}He β energy spectrum



Principle of the b-STILED project

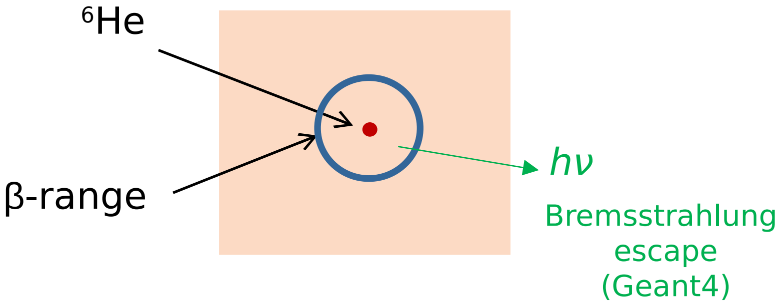
- Use ^{6}He : ideal candidate

  → pure GT transition, convenient $T_{1/2}$=0.8s, E_{bmax}=3.5MeV

  → high sensitivity theoretical corrections precisely known

- Implant ^{6}He in 4π detection setups (scintillators)

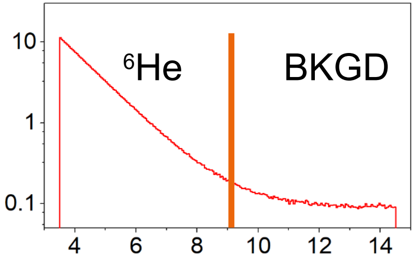
  → suppress E_{loss} from β backscattering (main systematic effect)



- Use implantation-decay cycles (3 s – 12 s)

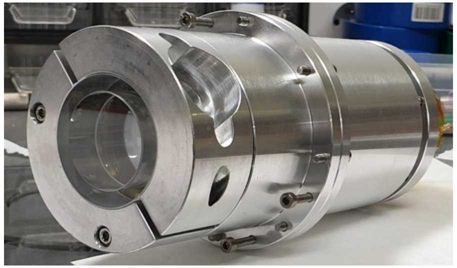
  → cst BKGD subtraction

  → $T_{1/2}$ measurement



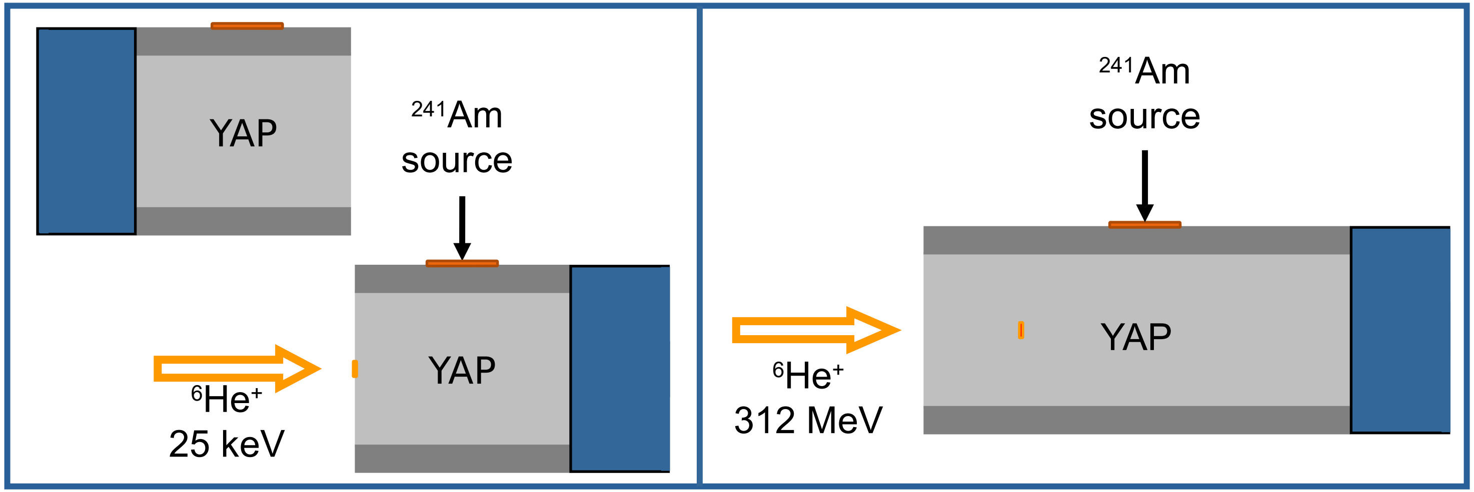
b-STILED: two experiments

- Use simple setups
- Test two techniques (different systematic effects)



Low-energy implantation at LIRAT/GANIL

High-energy implantation at LISE/GANIL



Light cross talk between PMTs

Contaminants due to nuclear reactions

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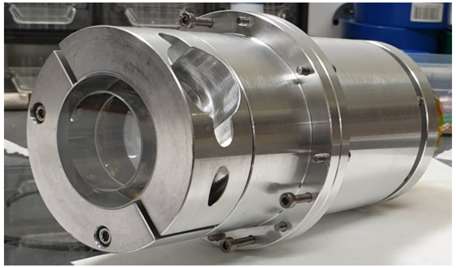

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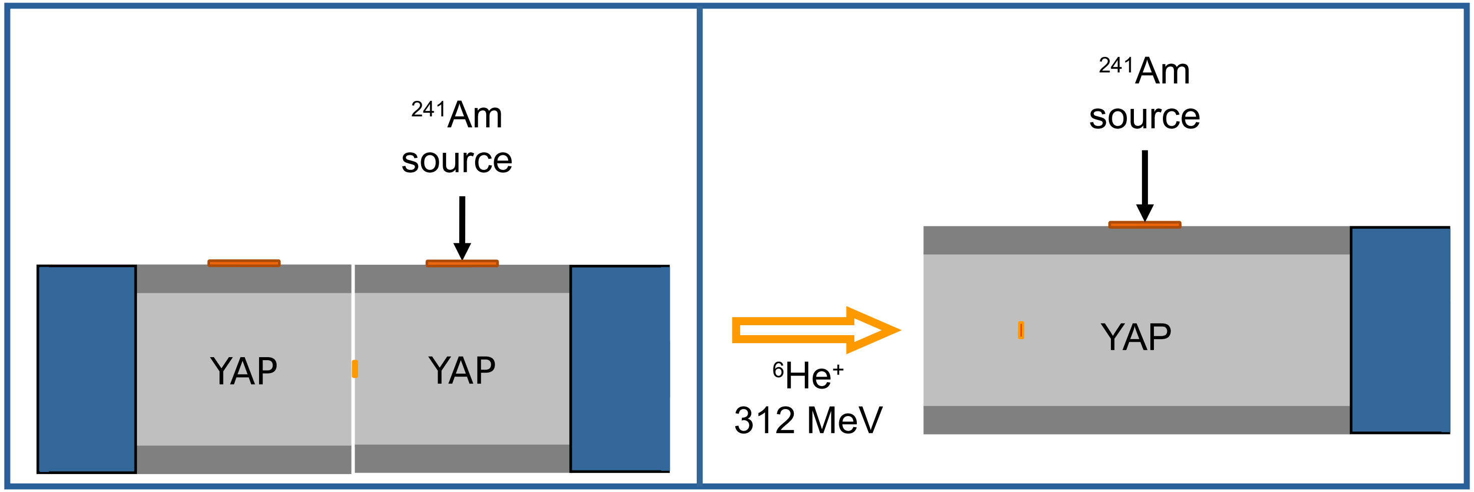

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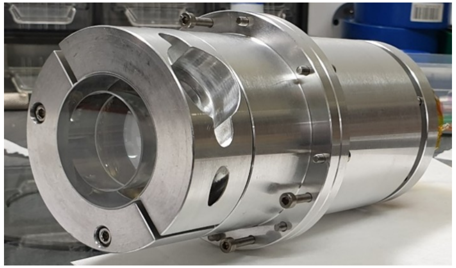
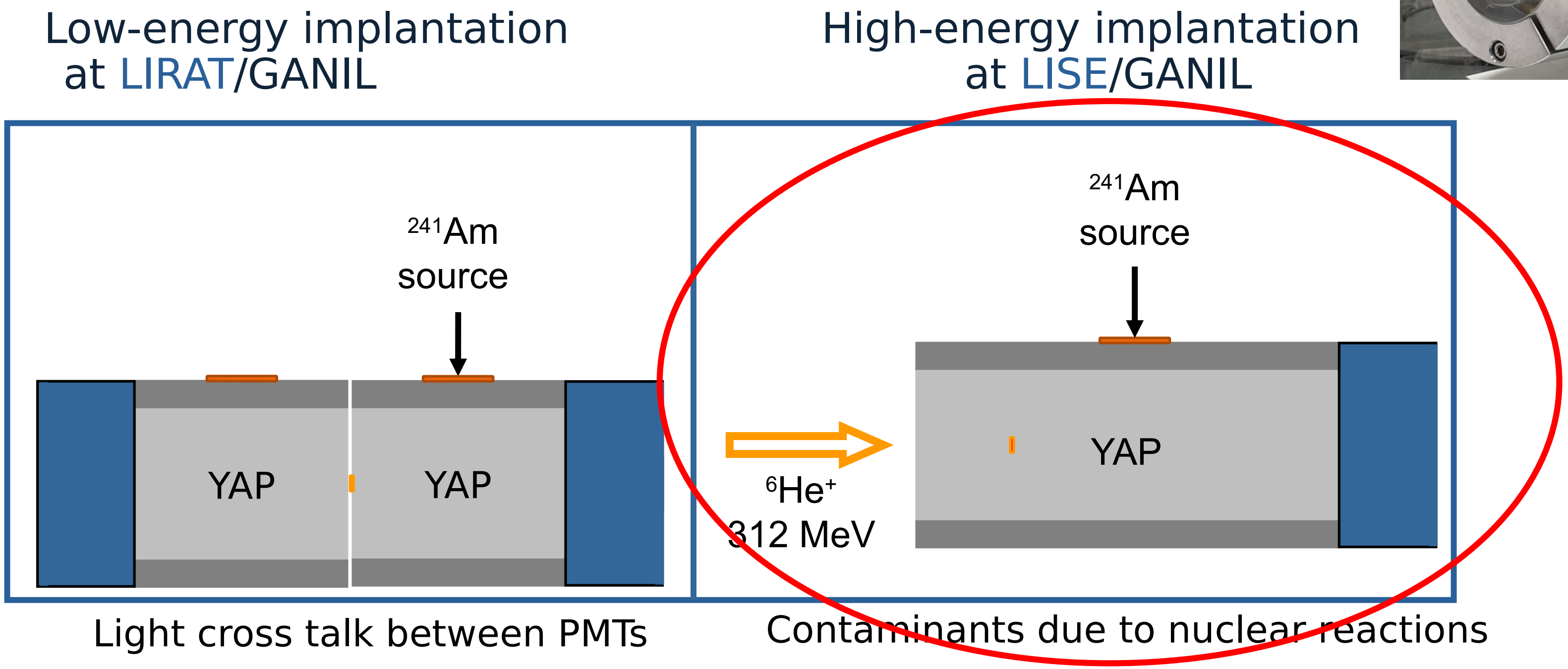
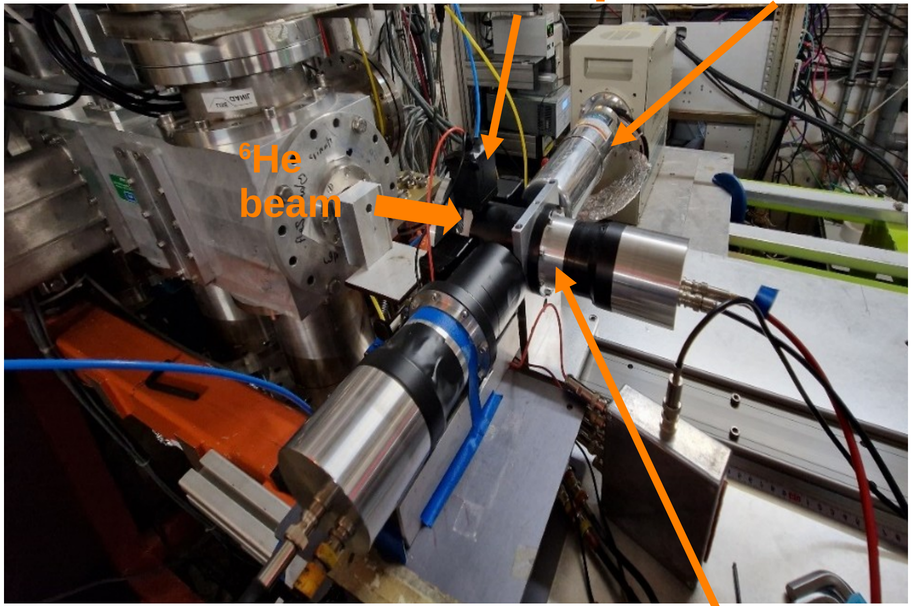




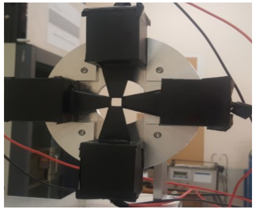
High-energy experiment

- Experiment at LISE - GANIL

→ implant 312 MeV ^{6}He nuclei 10 mm deep in the YAP (max β-range 4mm)



- Simple main detector (one YAP)
- Control implantation profile (4 thin PVT hodoscope)
- LISE beam purity (measure implantation energy)
- Beam induced contaminants (HPGe)

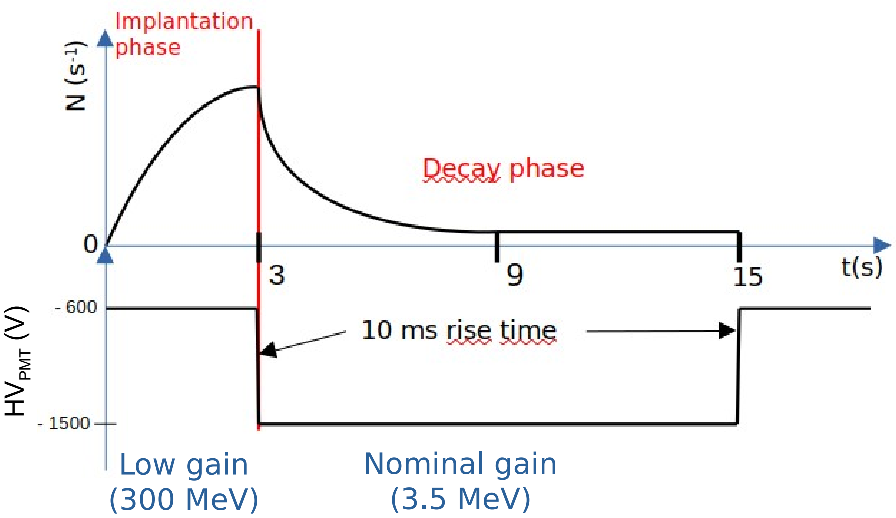


High-energy experiment

- Measurement cycle

Beam switched on/off

PMT voltage low/high
→ implantation energy



- 4 sets of measurements

2 crystal sizes, 2 distances, 2 beam intensities

$1.1x10^8$ good events → expected stat. uncertainty $\Delta b_{GT(stat)} = 1.2x10^{-3}$

(almost ok for phase II)

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Contamination : Unwanted nuclei present in the measurement

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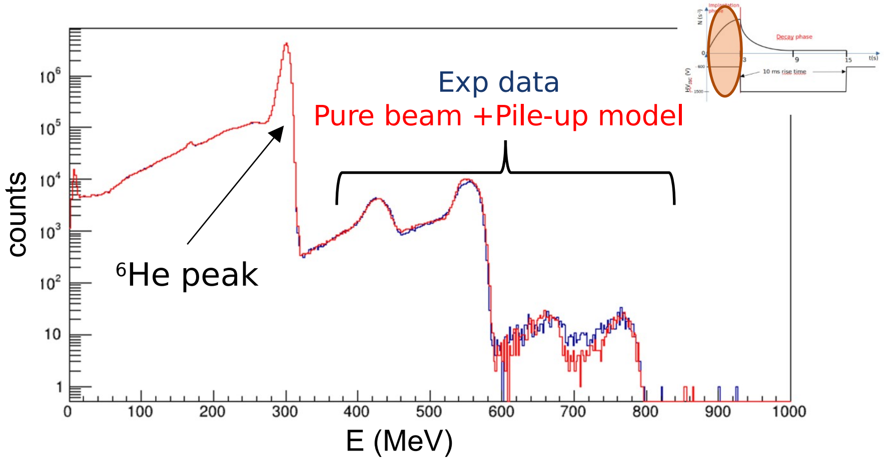
Beam inpurities :

Potential contaminants (LISE++)

- ^{8}Li & ^{9}Be

Should appear at higher energy than ^{6}He

YAP energy spectrum (Implant. phase)



No visible contaminant (at the 10^{-5} level)

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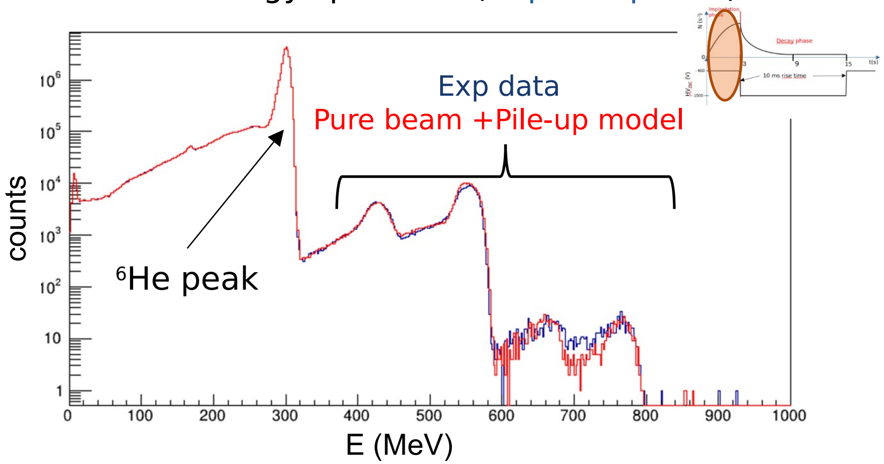

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Beam induced contaminants :

Nuclear reactions in the detector

Listing and selection of most impacting potential contaminants
$50\ ms < T_{1/2} < 1\ mn$

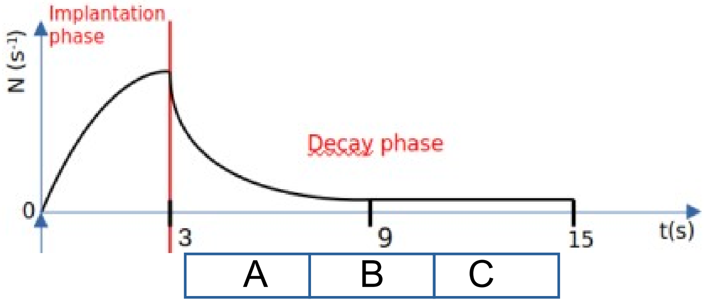
Identification : -β decay shape (YAP detection)
-ɣ ray emission (HPGe detection)

Contaminants unambiguously identified so far (preleminary):

- ^{8}Li ($T_{1/2}$ = 840 ms, $E_{\beta max}$ = 12.97 MeV)
- ^{16}C ($T_{1/2}$ = 747 ms, $E_{\beta max}$ = 4.66 MeV)
- ^{16}N ($T_{1/2}$ = 7.13 s, $E_{\beta max}$ = 10.42 MeV)
- ^{20}F ($T_{1/2}$ = 11.163 s, $E_{\beta max}$ = 7.02 MeV)
- ^{89m}Y ($T_{1/2}$ 15.663 s, $E_{ɣ}$ = 0.909 keV)

Sources of systematic error

- Extract contaminant contribution and impact on b_{GT}



3 windows in cycle

Build linear combinations suppressing a specific half life and cst bkgd

Expected fraction of decay (preliminary):

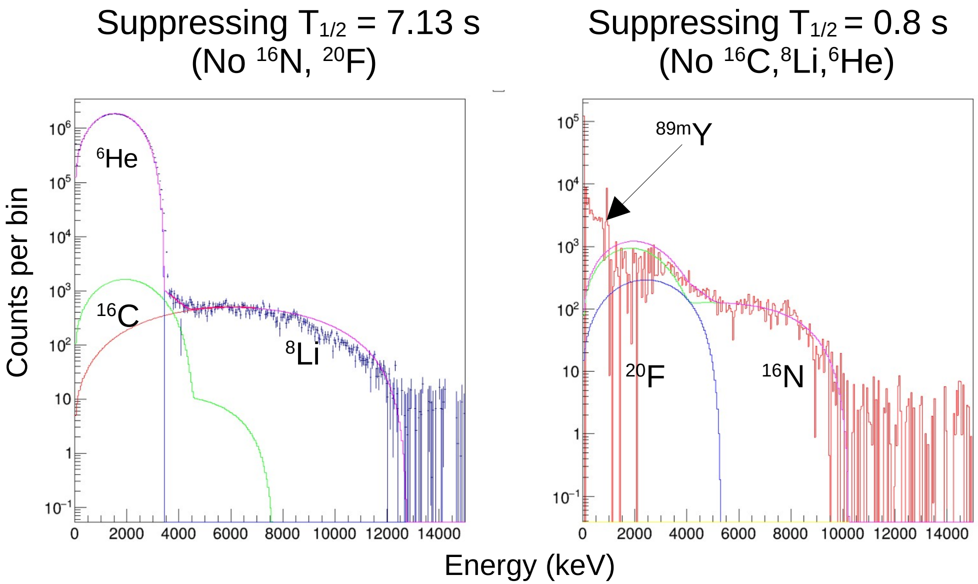
$^{8}Li \rightarrow \sim 7\ 10^{-4}$

$^{16}C \rightarrow \sim 1.2\ 10^{-3}$

$^{16}N \rightarrow \sim 2.2\ 10^{-3}$

$^{20}F \rightarrow \sim 4\ 10^{-4}$

$^{89m}Y \rightarrow \sim 1.5\ 10^{-3}$



$\Delta b_{GT(syst)} \sim 10^{-3}$ (assuming 20% error on contaminant fraction)

Possibility to suppress long halflives

Sources of systematic error

Bremsstrahlung Escape (BE)

- **Loss of energy** from Bremstrahlung photons

  ↳ **Simulation** needed to estimate the effect

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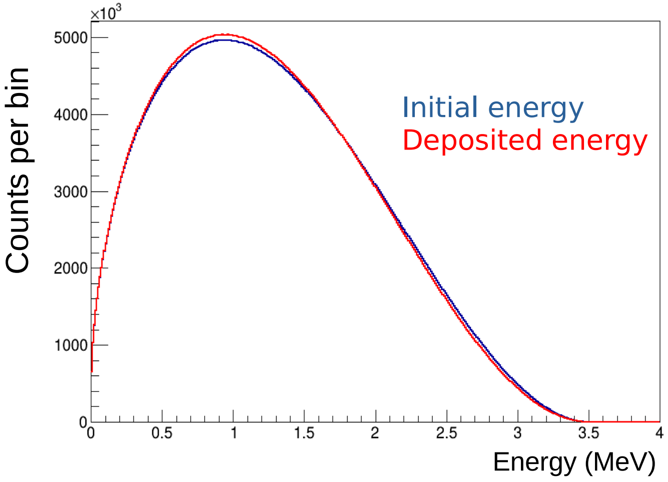
Beta energy spectrum expressed as: $$N(E)=F(Z,E)pE(E-E_0)^2 \cdot \sum_{i=-1}^{1} E^i$$



E_{dep} - E_{Init}

Energy spectrum at i = -1 order

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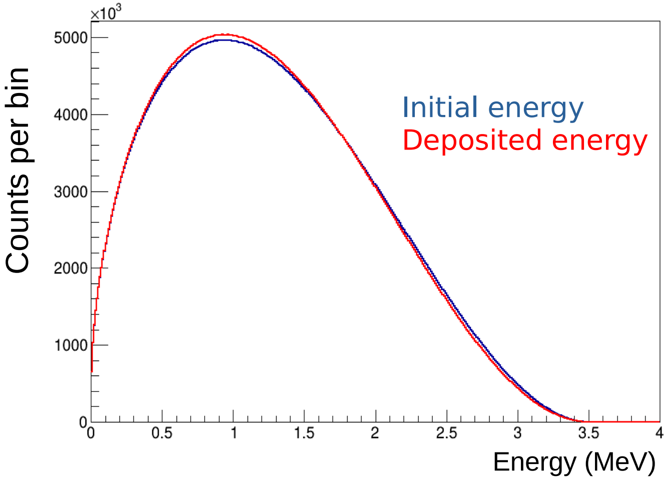

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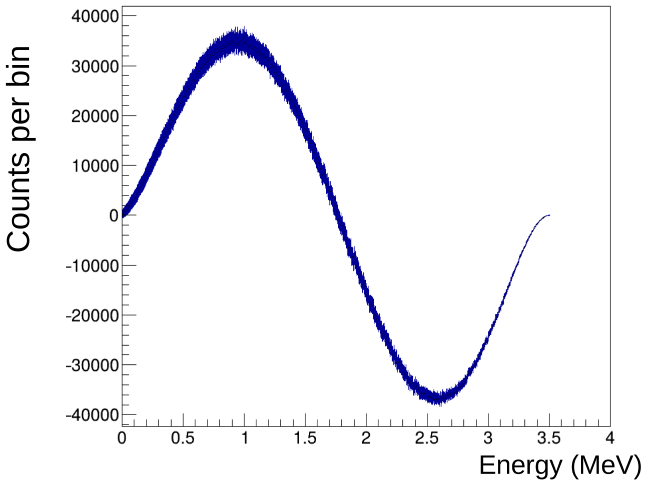

Effect of BE on the energy spectrum

Sources of systematic error

Pileup : Two events counted as one

↳ Two types of pileup : -Pileup between short halflives nuclei (^6He, ^8Li...)
-Pileup of an ^6He with constant background

Estimation model :

For a [T_1, T_2] time interval

Short halflife pileup → $$\frac{R_0^2 \times \Delta T \times \tau_{6He}}{2}\left(-\exp^{\frac{-2\times T_2}{\tau_{6He}}} + \exp^{\frac{-2\times T_1}{\tau_{6He}}}\right)$$

Pileup ^6He/Background → $$R_0 \times R_b \times \Delta T \times \tau_{6He}\left(-\exp^{\frac{-T_2}{\tau_{6He}}} + \exp^{\frac{-T_1}{\tau_{6He}}}\right)$$

R_0 : initial rate of each cycle

R_b : rate of constant background

ΔT : Maximum integration time

τ_{6He} : ^6He decay constant

Sources of systematic error

To simulate pileup spectra

Linear combination to suppress long halflives → « **pure** » **^{6}He spectrum**

Spectrum in the [11,14.4] s interval of the cycle time → **Background spectrum**

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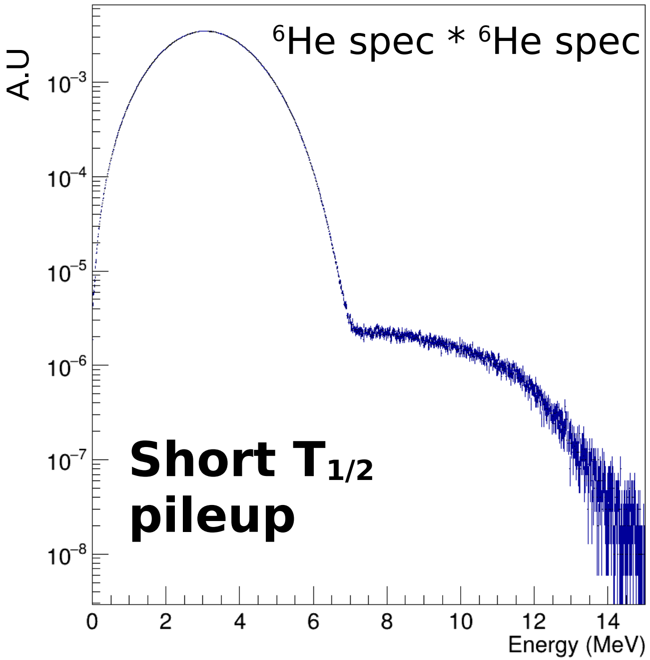

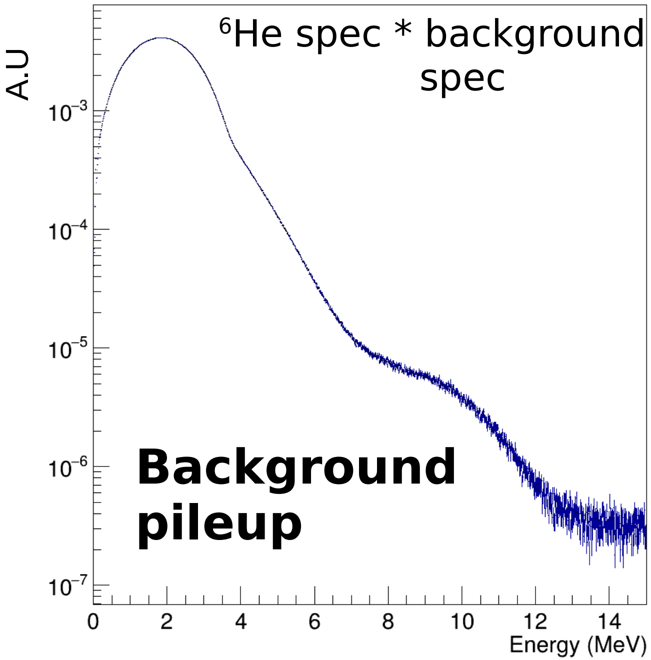

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Fit model

Beta decay spectrum description → $PS \times FF \times \sum_{-1}^{1} f\left(E^{i}\right)$

f(E^i) : μ * (E^i + BE_correction(E^i))

μ : theoretical parameters

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Model construction→ Beta decay description + corrections

-Short halflives pileup
-^{6}He/Background pileup } **Analytical model**

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convoluted with **resolution** → Estimated using 59.54 keV ^{241}Am ɣ peak

Resolution model : $\sigma_E = \sqrt{(\alpha_{stat} \times \sqrt{E})^2 + \alpha_{elec}^2 \times \sqrt{\frac{306}{24}}}$

E: energy
α $_{stat}$: statistical uncertainty from scintillation
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Time ratio between charge integration windows

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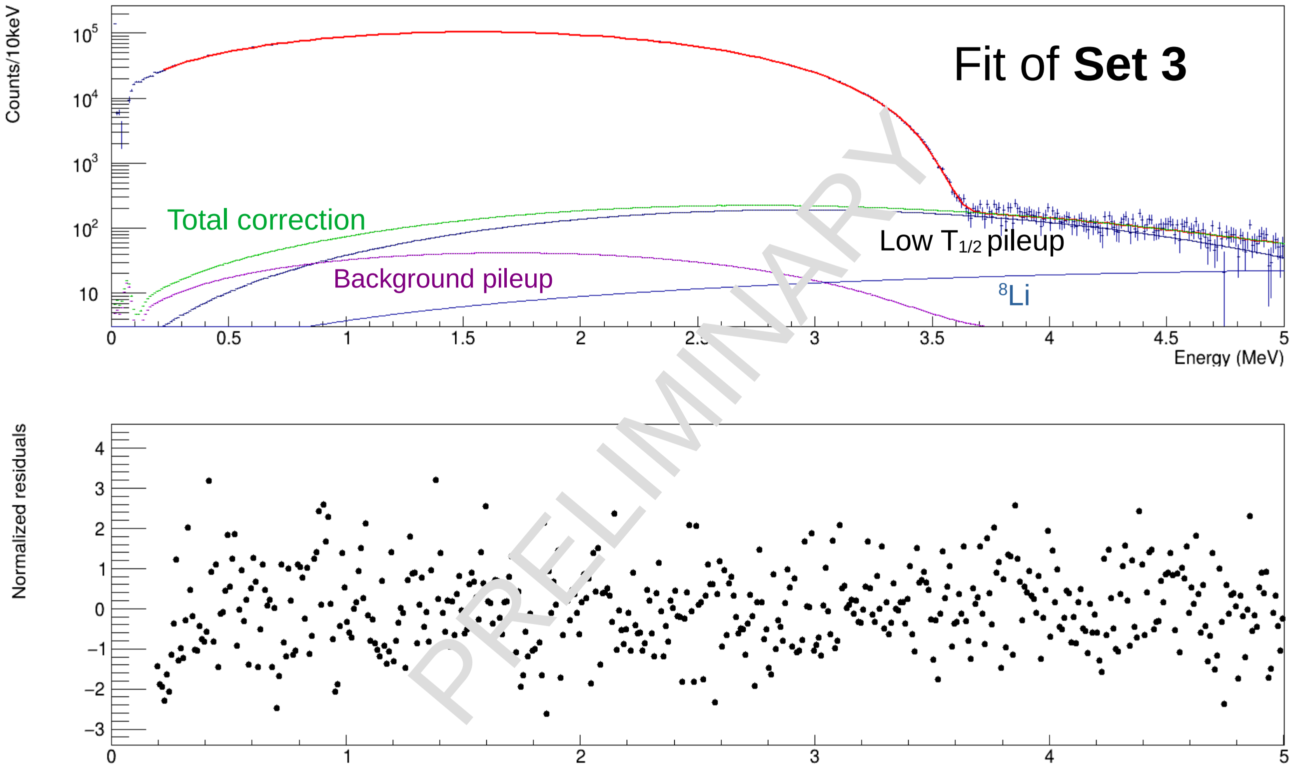
Fit free parameters : Norm , b$_{GT}$, slope

Preleminary results

Using **suppressed long halflives** data

	Set 1	Set 2	Set 3	Set 4
b_{GT}	$2.56e^{-3}$	$-3.8e^{-4}$	$2.192e^{-2}$	$2.899e^{-2}$
$u(b)_{STAT}$	$1.59e^{-3}$	$2.06e^{-3}$	$1.73e^{-3}$	$2.02e^{-3}$
Chi2/NDF	1.043	1.113	1.025	1.002
p-value	0.2467	0.042	0.337	0.478



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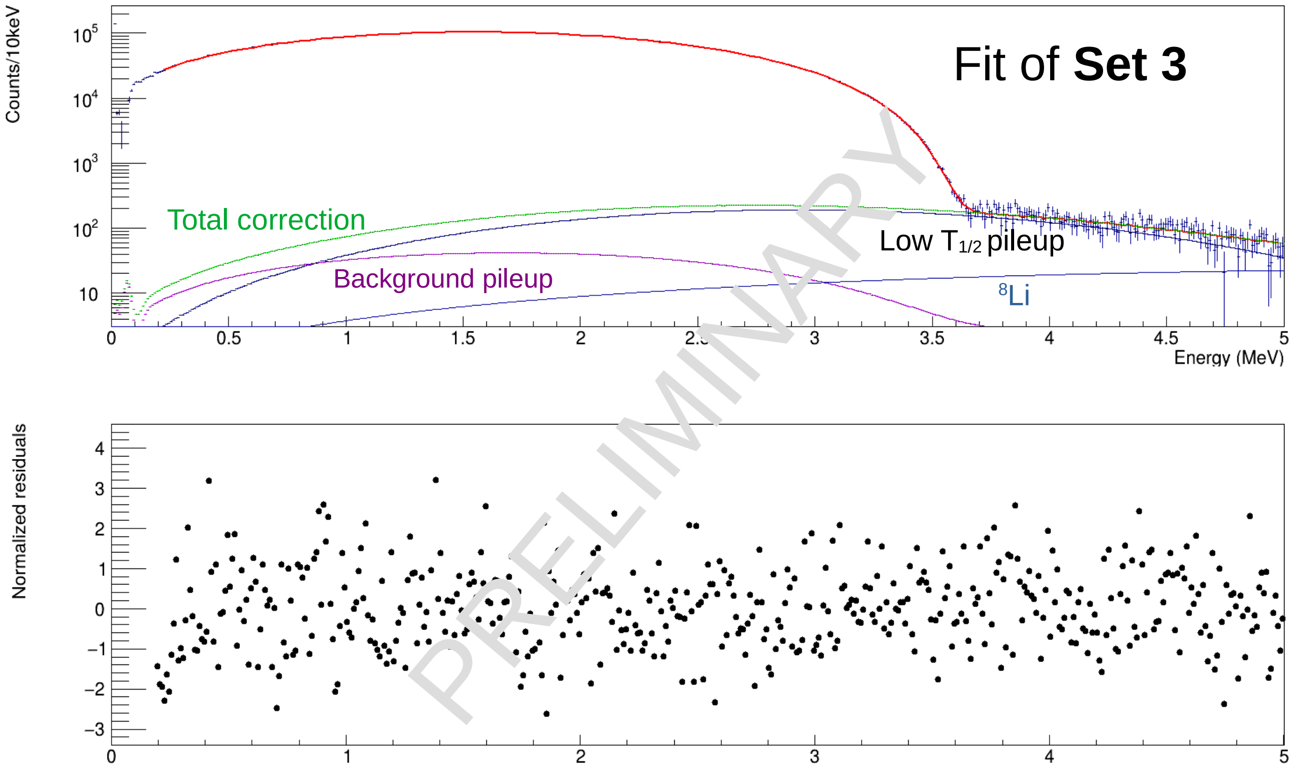

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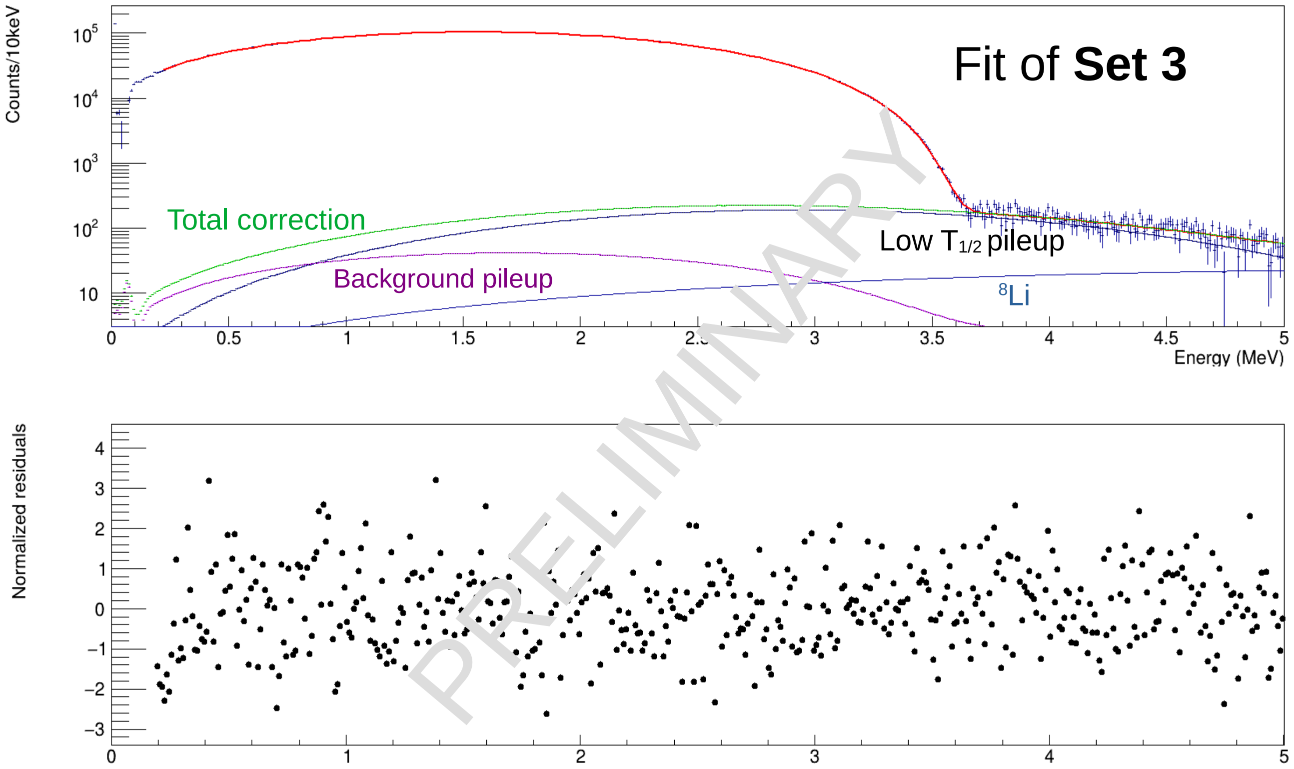
Corrections still **missing** :

- Quenching
- PMT non-linearity
- Effect of Cerenkov light
- Better weak magnetism model



Conclusion & perspectives

- Sufficient statistics for phase I and almost for phase II
- Excellent beam purity
- Beam induced contaminants are not a problem
- Fit model with the main systematics included
- Discrepancies between sets

Perspectives

- Systematic study : non-proportionnality, effect of the different corrections
- Estimation of the uncertainties

THANKS FOR YOUR ATTENTION !

LPC Caen

D. Etasse
X. Fléchard
R. Garreau
L. Hayen
M. Kanafani
F. Lebourgeois
E. Liénard
J. Lory
O. Naviliat-Cuncic
J. Perronnel
A. Rani
Ch. Vandamme

Laboratoire National Henri Becquerel (LNHB)

X. Mougeot
S. Leblond
G. Craveiro

GANIL

J.C. Thomas
V. Morel
F. Marie-Saillenfest

Michigan State University

T.E. Haugen
O. Naviliat-Cuncic

IRL NPA CNRS - MSU

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KU Leuven

S. Vanlangendonck

Backup slides