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

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20th January 2026

Outline

- Context and motivations
- The b-STILED project
- “Low-energy” experiment
- “High-energy” experiment
- By-products

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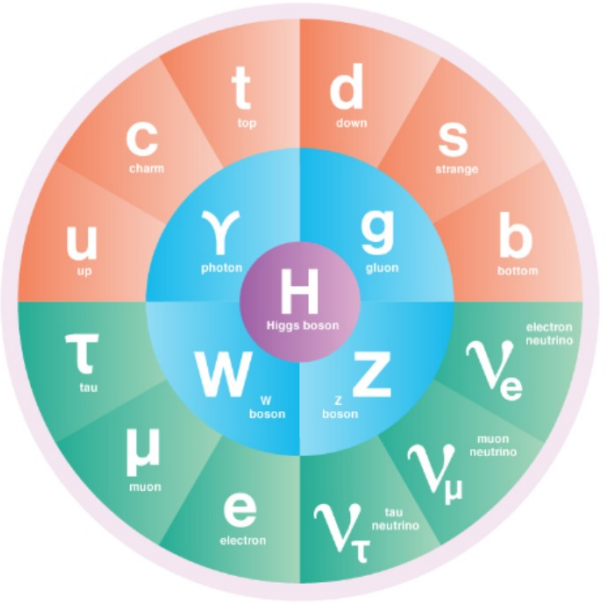
Context

- Standard Model of particle physics :

-Describe elementary particles and their interactions (3 of 4 fundamental forces)

-Consistent with constraints at TeV scale



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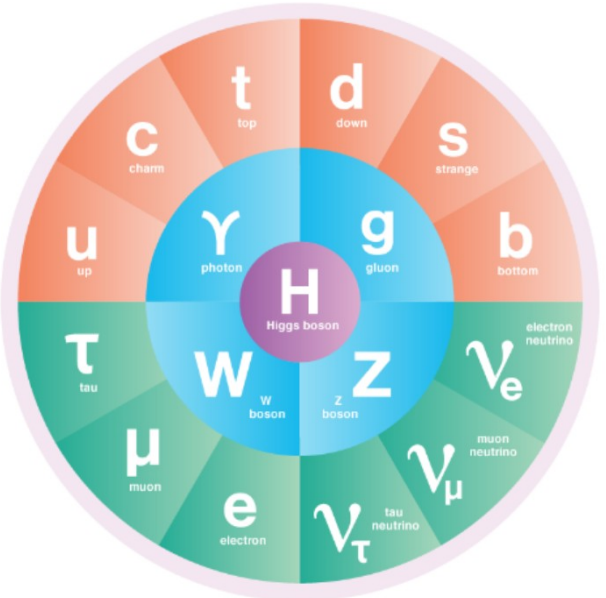

- Shortcomings of the Standard Model :

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

New Physics beyond the Standard Model

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

  no fundamental reason to exclude *Scalar* (*S*) and *Tensor* (*T*) contributions

  ➡ interesting search **window for New Physics**

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- Measurement at low energy, using β-decay

  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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  → Measurement of *b* in a pure GT transition

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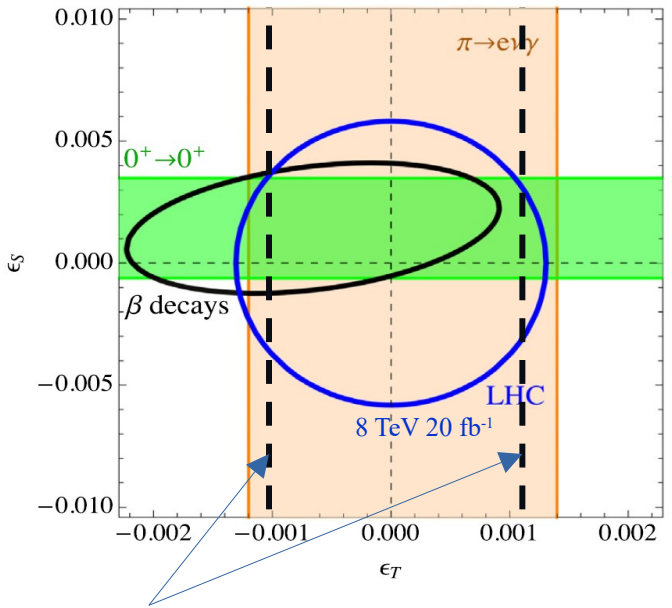
bSTILED goal

- 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 constaints from β decay)

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

Principle of the b-STILED project

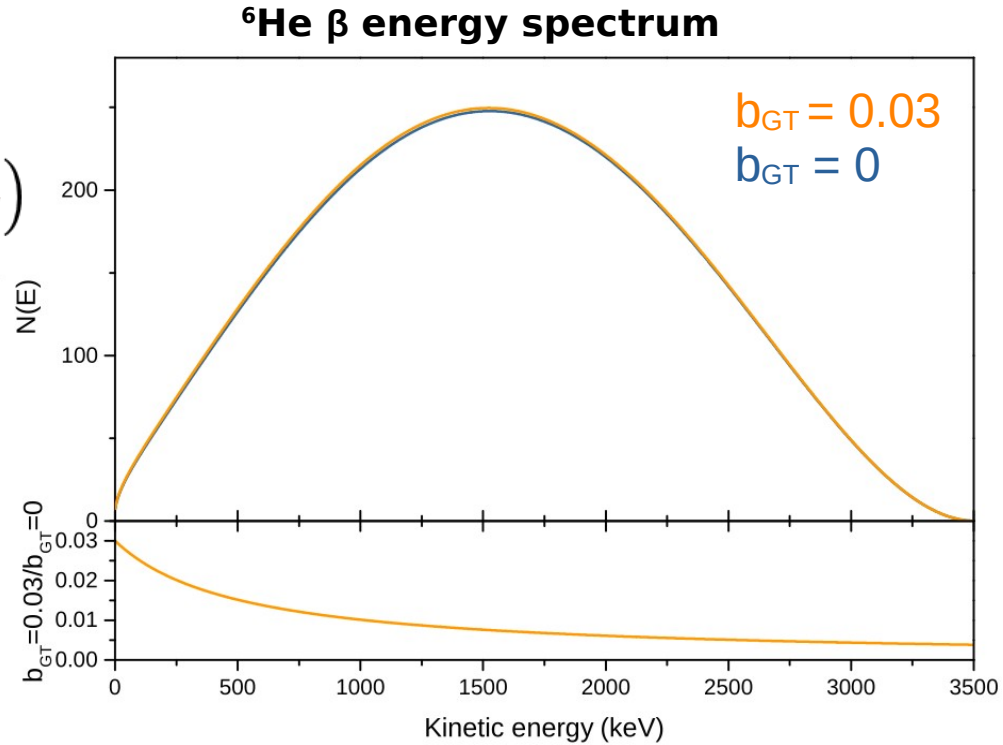
- Extract the Fierz term b_{GT} from the β-spectrum shape in the decay of ^{6}He

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

Fermi function

Theoretical corrections

Phase space



Principle of the b-STILED project

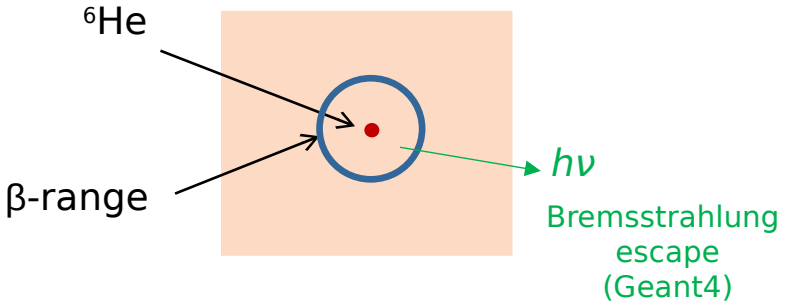
- Use ^{6}He : ideal candidate

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

  → high sensitivity and theoretical corrections precisely known

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

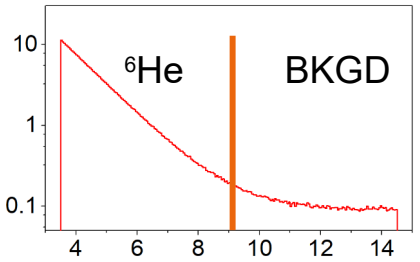
  → suppress E_{loss} from β backscattering
  (main systematic effect)



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

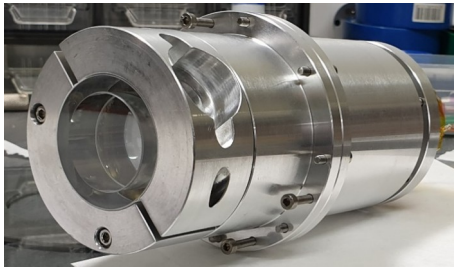
  → cst BKGD subtraction

  → $T_{1/2}$ measurement



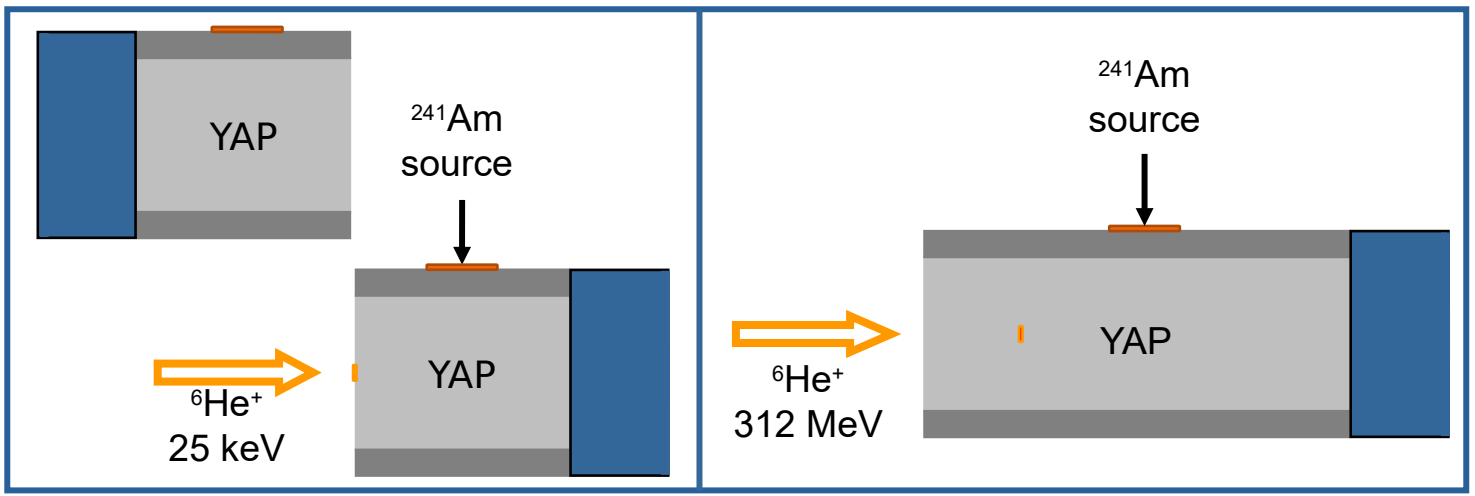
b-STILED: two experiments

- 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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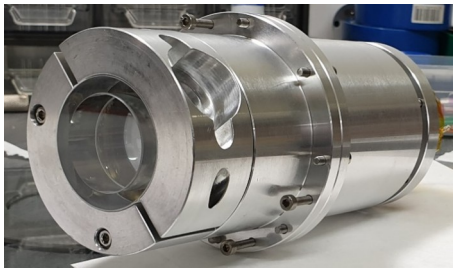

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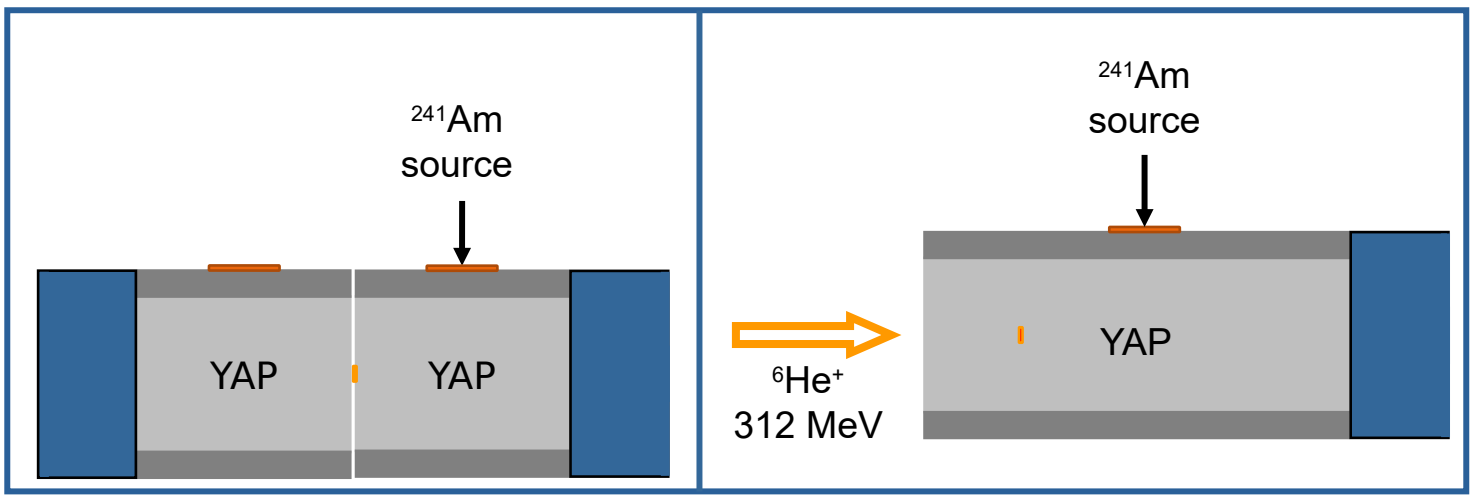

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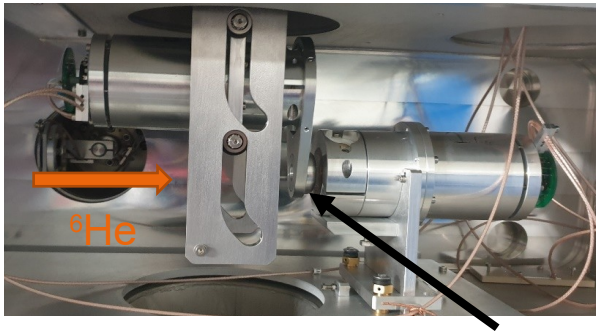
Low-energy experiment

- LIRAT-GANIL line, 25 keV $^{6}He^{+}$
  - Unexpected background : Bremsstrahlung from ^{6}He implanted on collimator
    → Complexified the analysis
  - 5 Sets of measurement



Φ 5mm collimator

Extracted statistical uncertainty after analysis of one set $\Delta b_{GT(stat)} \sim 3.9\ 10^{-3}$

Discrepancies between Sets ($\Delta b_{GT} \sim 2.10^{-2} > 3\ \Delta b_{GT(stat)}$)

→ strong systematic effect not fully understood (variation in Brem. background)

- May be difficult to reach phase I uncertainty goal
- 3 byproducts : -^{6}He halflife measurement

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

-Electron backscattering measurement

accepted in PRC

-Bremsstrahlung escape measurement

to be submitted...

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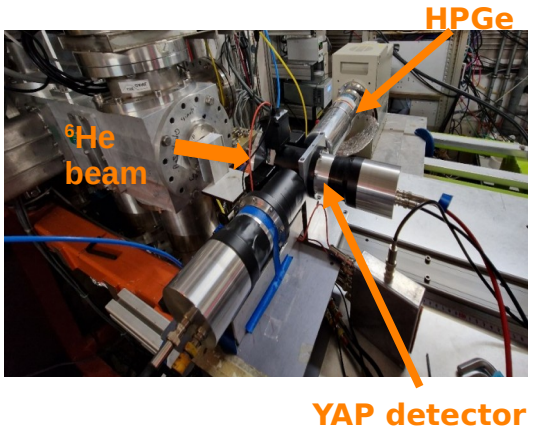
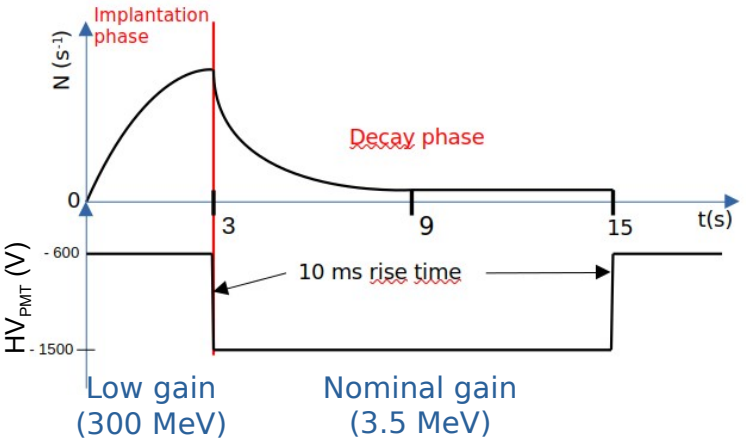
High-energy experiment

- Experiment at LISE - GANIL

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





- Simpler main detector (one YAP)
- Beam induced contaminants (HPGe)

- 4 sets of measurements

  2 crystal sizes, 2 distances, 2 beam intensities

  1.1x10^{8} good events → expected stat. uncertainty $\Delta b_{GT(stat)} = 1.2\text{x}10^{-3}$

High-energy experiment analysis : Contamination

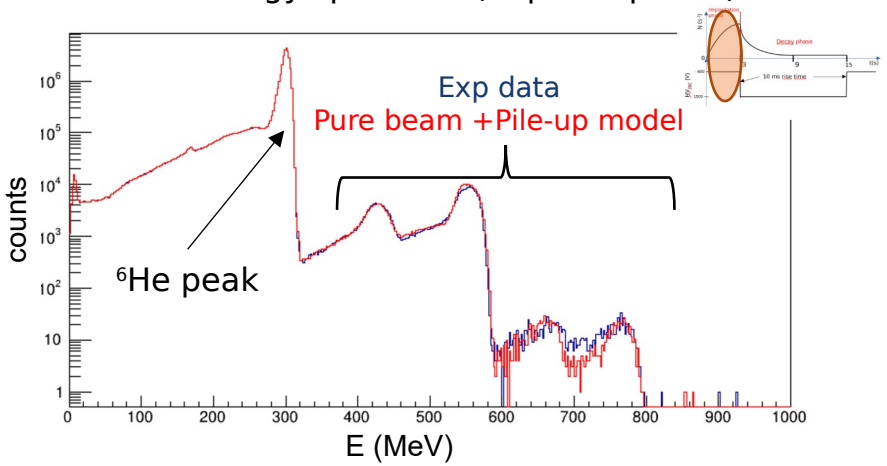
Beam inpurities :

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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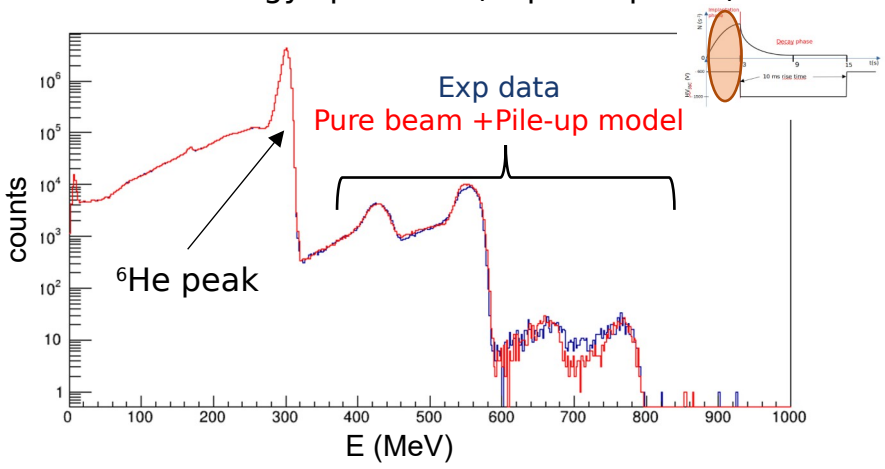


No visible contaminant (at the 10^{-5} level)

Beam induced contaminants :

Listing nuclear reactions in the detector

Listing and selection of most impacting potential contaminants

$50\ ms < T_{1/2} < 1\ mn$

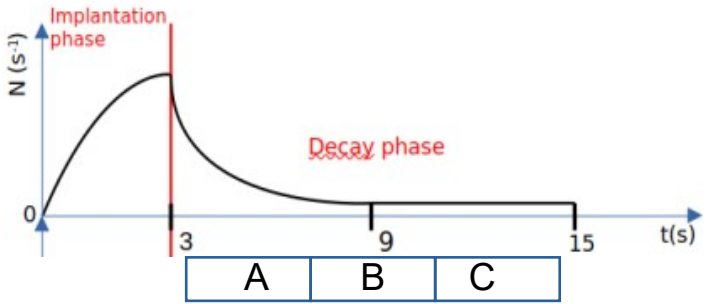
Identification : -β decay shape (YAP detection)
-ɣ ray emission (HPGe detection)

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_{γ} = 0.909 keV)

High-energy experiment analysis : beam induced contaminants

- Extract contaminant contribution and impact on b_{GT}



3 windows in cycle

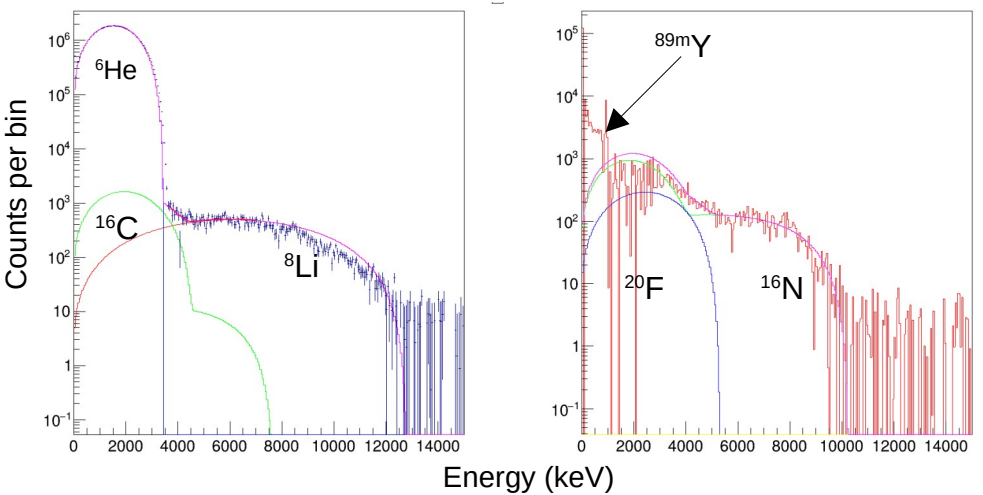
Build linear combinations suppressing a specific half life and cst bkgd

Expected fraction of decay (preliminary):

- ^{8}Li→ ~ 7 10^{-4}
- ^{16}C→ ~1.2 10^{-3}
- ^{16}N→ ~2.2 10^{-3}
- ^{20}F→ ~4 10^{-4}
- ^{89m}Y→ ~1.5 10^{-3}

Suppressing $T_{1/2}$ = 7.13 s (No ^{16}N, ^{20}F)

Suppressing $T_{1/2}$ = 0.8 s (No ^{16}C,^{8}Li,^{6}He)



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

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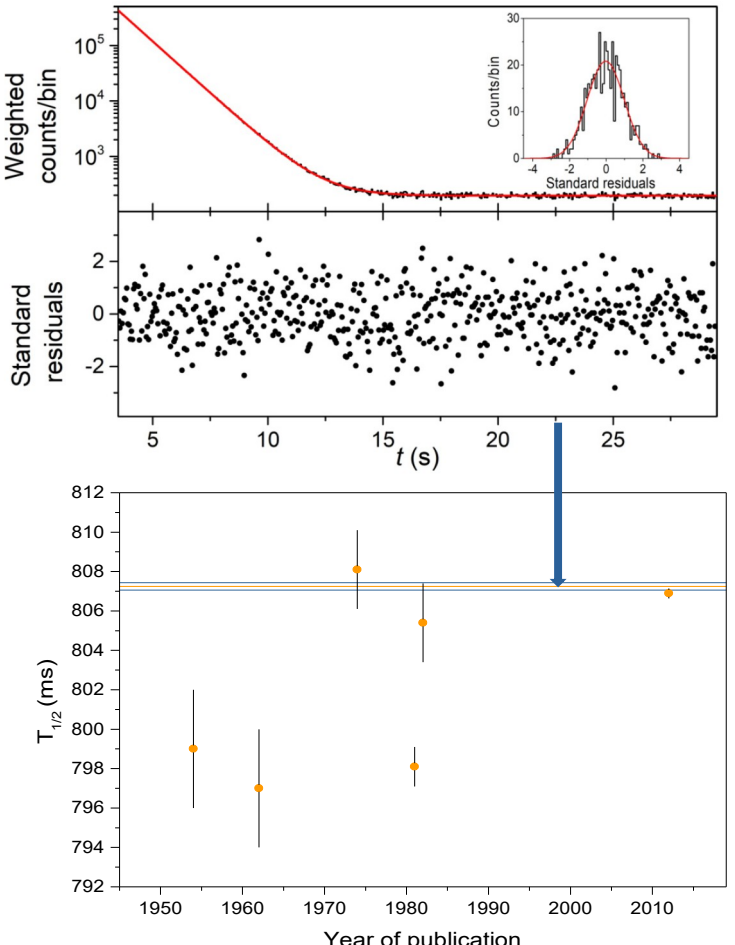
BP 1: Half life measurement of ^{6}He

- LIRAT experiment is an ideal setup:
  - Use adapted cycles
  - High rates, high purity beam
  - Gain and baseline corrections
  - Data Time stamp for offline analysis

Most precise half life measurement for ^{6}He

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

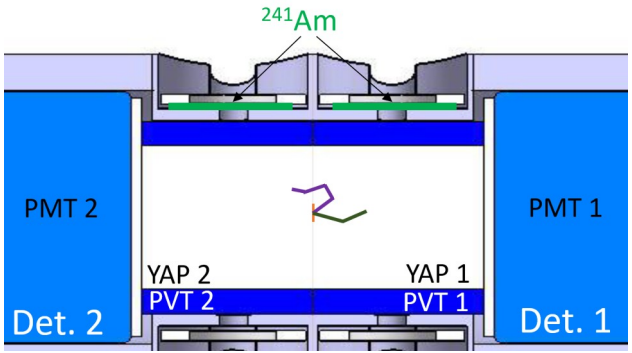
M. Kanafani et al, Phys.Rev. C 106 (2022) 045502



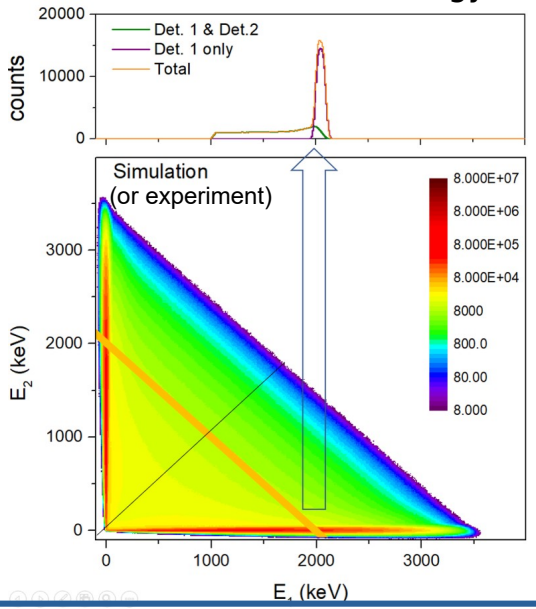
BP 2: Precise measurement of electron backscattering

- Lack of experimental data in the 100 keV- few MeV range
  → Poor benchmarking of Geant4
  → Conservative systematic error on BS (10%-20%) in data analysis

- ^{6}He decay electrons of LIRAT experiment
  → Backscattering probability up to 3.5 MeV

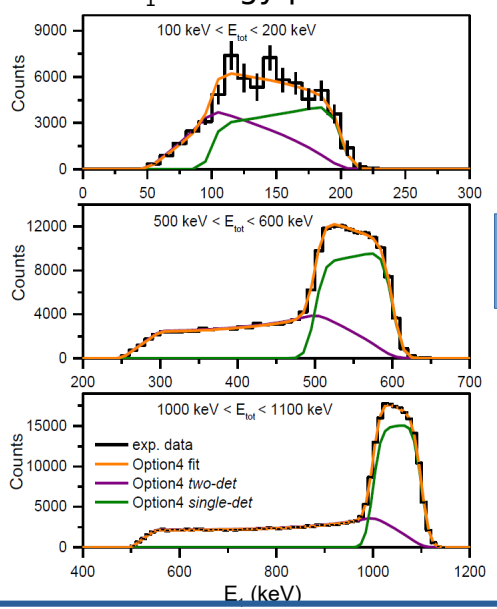


Det.1 vs Det.2 energy



Slices

E_1 energy profiles



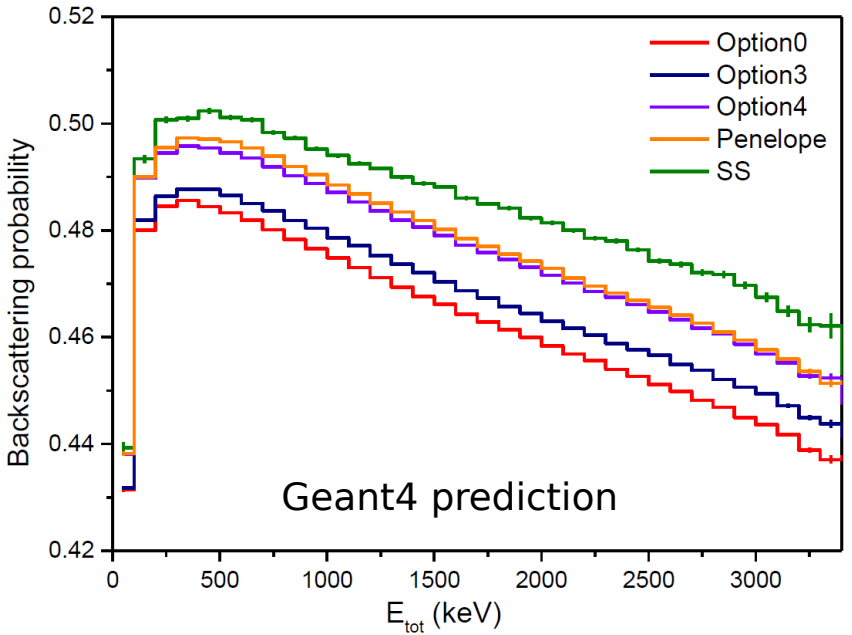
Fit exp w sim

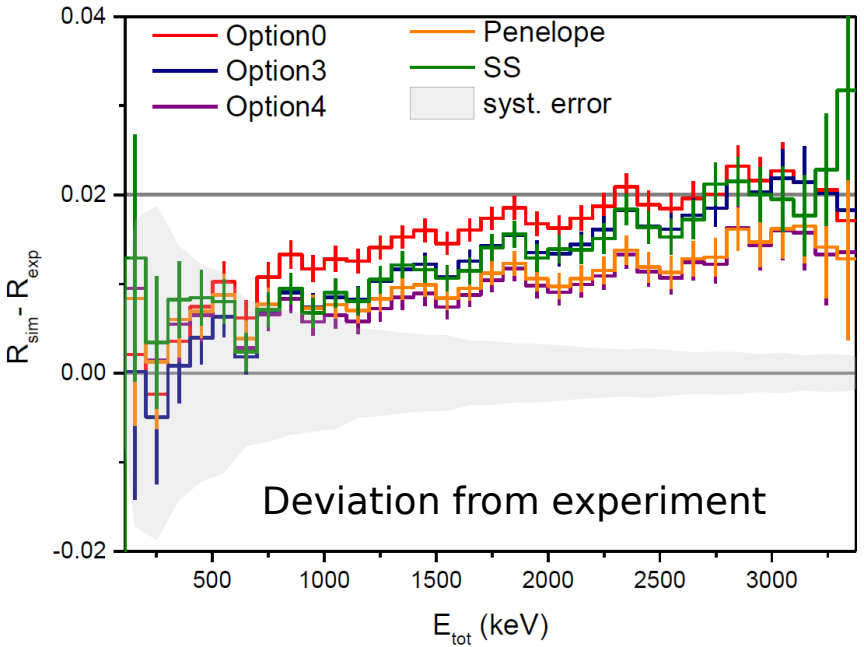
Experimental vs Geant4 Backscattering probability

Accepted in PRC !

BP 2: Precise measurement of electron backscattering

Comparison with Geant4, several EM low energy options





Relative deviations below 4% (Option4 & Penelope)!

BP 3: Measurement of Bremsstrahlung escape

- Basic idea:

  LIRAT-like geometry with ^{90}Sr beta source

  Inserted in High efficiency ɣ detector for escaping photons

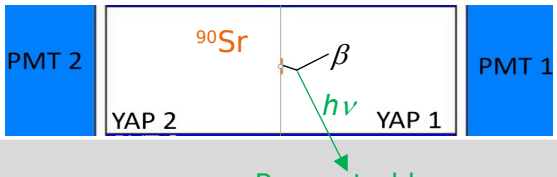
  Record single β events and coincidences with photons

Measurement at FRIB in April 2024

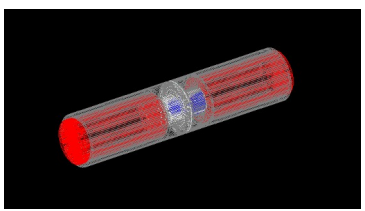
Collaboration with ORNL and IRL-NPA

Use of ORNL MTAS detector

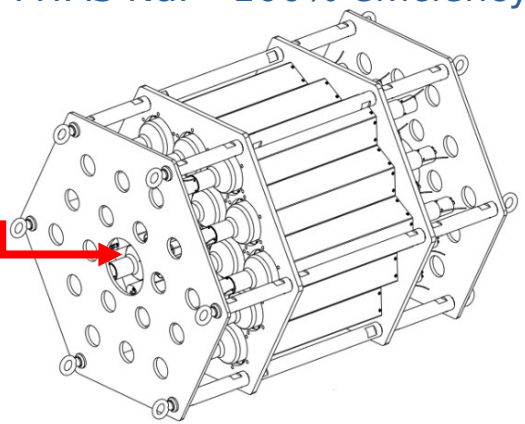
Photon detector



YAP + ^{90}Sr source



MTAS NaI ~100% efficiency



OAK RIDGE National Laboratory

B.C. Rasco
Th. Ruland
K.P. Rykaczewski

Summary and conclusions

- With LIRAT and LISE experiments, sufficient statistics for the goal of phase I (and almost for phase II)

- Analysis of the LIRAT data complexified by unanticipated source of background
  - Analysis on hold…
  - Provided 3 nice by-products !!!

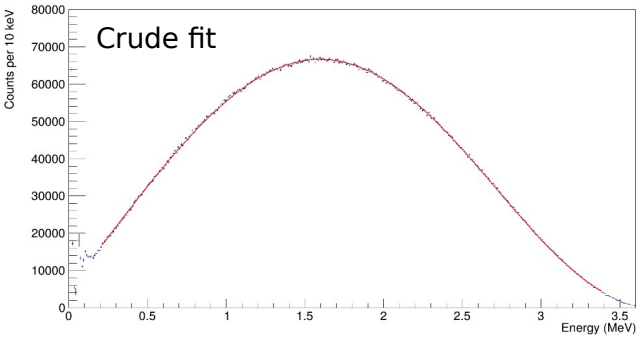
- For LISE data

  - Sufficient statistics for phase I and almost for phase II
  - Excellent beam purity
  - Beam induced contaminants does not seem to be a problem

(need to finalize the analysis)

  - Non-proportionality of YAP may be the limit with $\Delta b_{GT} \sim 10^{-2}$

    → requires efforts to reach goal of phase I...



Extracted statistical uncertainty for one set

$\Delta b_{GT(stat)} \sim 2.2\ 10^{-3}$

THANKS FOR YOUR ATTENTION !

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

X. Mougeot
S. Leblond
G. Craveiro

T.E. Haugen
O. Naviliat-Cuncic

S. Vanlangendonck

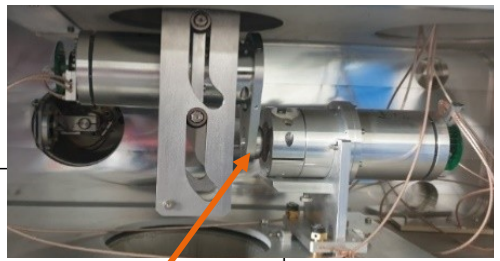
J.C. Thomas
V. Morel
F. Marie-Saillenfest

O. Naviliat-Cuncic

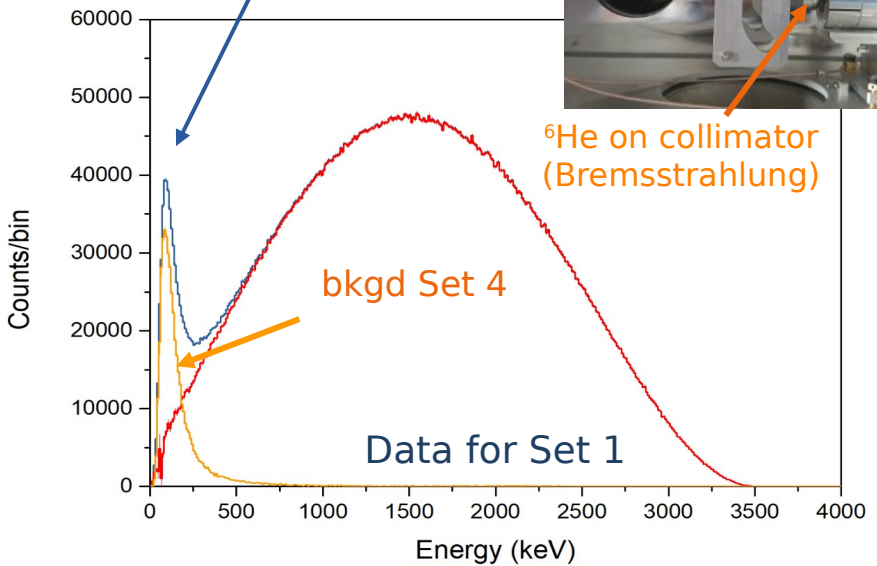
Backup slides

Low-energy experiment analysis

Unexpected peak at low energy

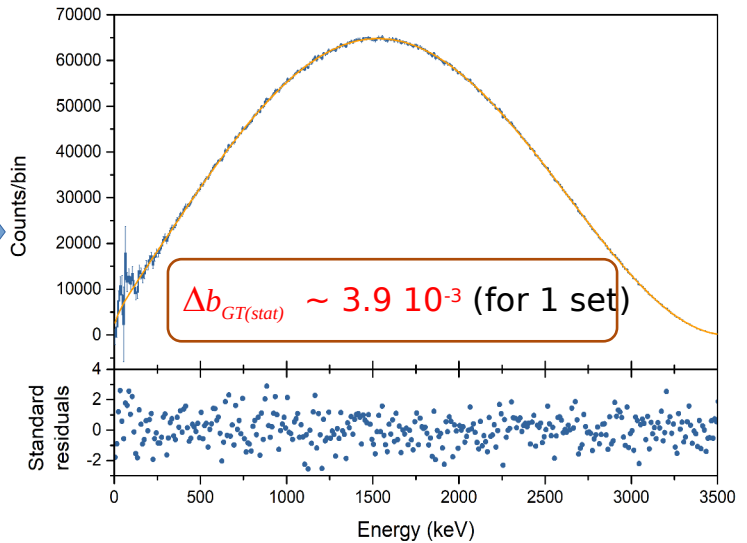


^{6}He on collimator
(Bremsstrahlung)



Set 4
substraction

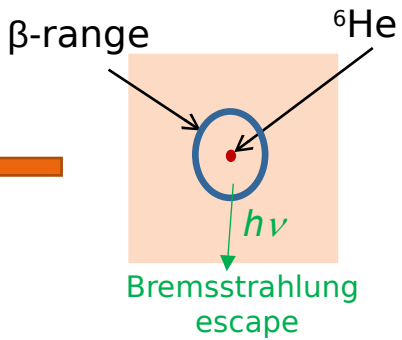
Fit with 5 free parameters:
b_{GT}, calibration slope,
Bkgd normalization, resolution
(use Geant4 simulation fit templates)



Low-energy experiment analysis

Sources systematic errors

	Systematic effect	Δb_{GT}
studied	b_{WM}	2.6×10^{-4}
	Radiative corrections	3.7×10^{-4}
	Bremsstrahlung escape (5 % error on G4)	2.5×10^{-3}
	Cerenkov (10%error on G4)	5×10^{-4}
	Detectors resolution	$< 2 \times 10^{-3}$
ongoing	Pile-up (preliminary)	$< 1 \times 10^{-3}$
	Calibration for BKGD run (preleminary)	$< 2 \times 10^{-3}$
	Detector non-proportionnality (litterature)	$\sim 10^{-2}$
	Total	?



Dedicated measurements

M. Kanafani, PhD Thesis, UniCaen (2023)