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

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GDR-InF Workshop 2025
13th November 2025

Outline

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

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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

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

→ Measurement of *b* in a pure GT transition

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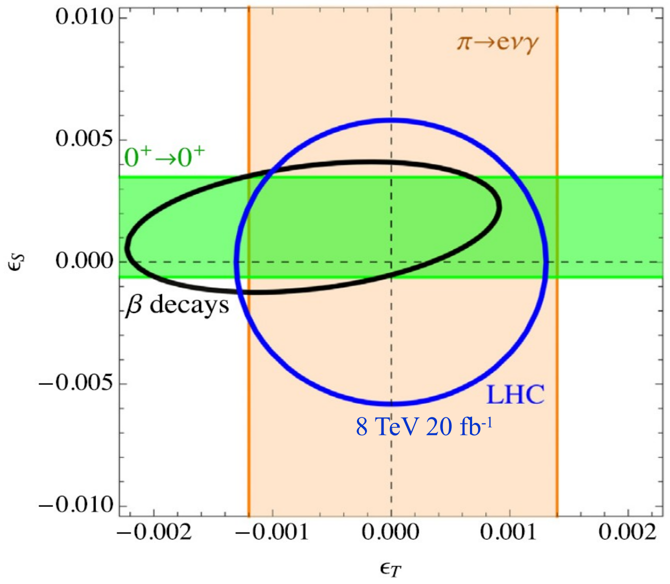
bSTILED goal

- 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 constaints)

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

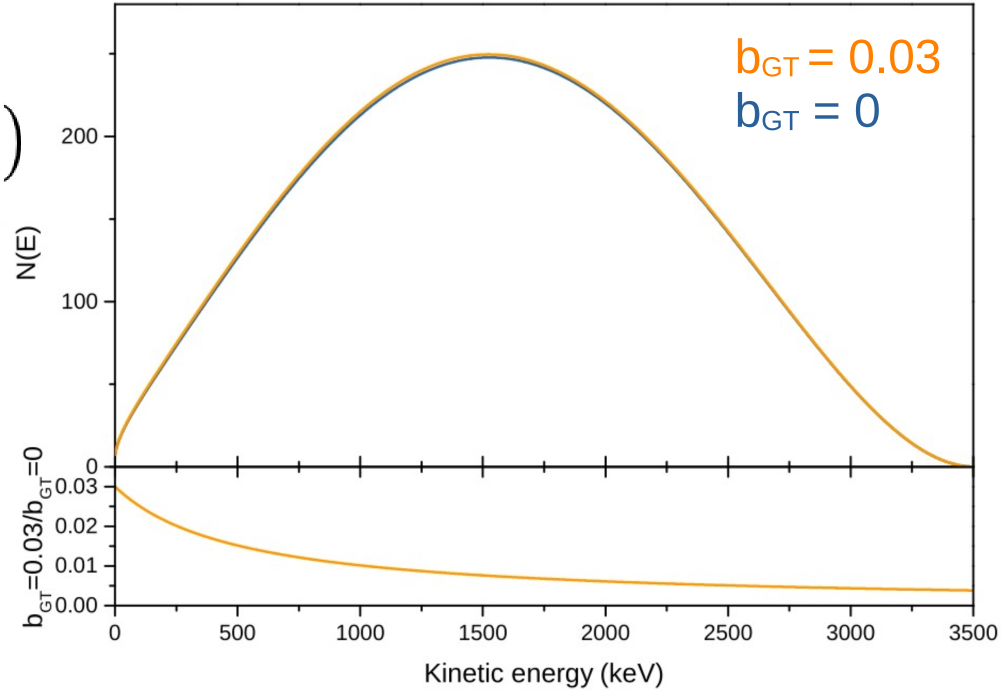
$$N(E) \propto F(Z,E)(1+\eta)pE(E-E_0)^2\left(1+\frac{m_e}{E}b_{GT}\right)$$

Fermi function

Theoretical corrections

Phase space

^{6}He β energy spectrum



Principle of the b-STILED project

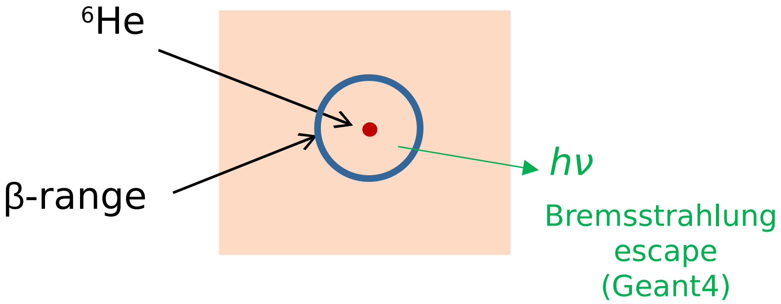
- Use ^{6}He : ideal candidate

  → 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)

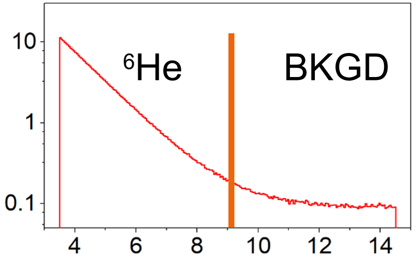
  → suppress E_{loss} from β backscattering (main systematic effect)



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

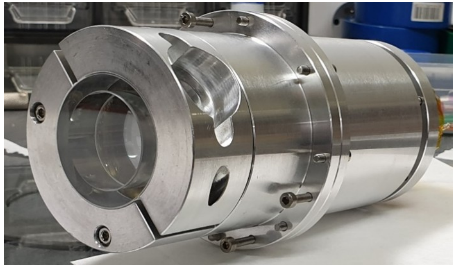
  → cst BKGD subtraction

  → $T_{1/2}$ measurement



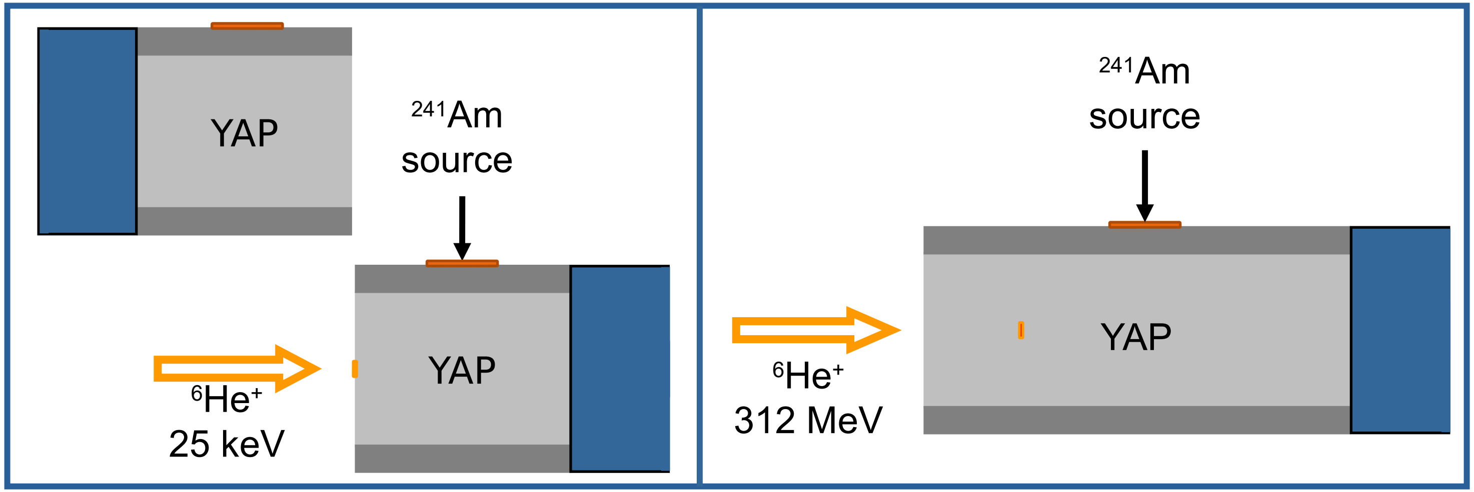
b-STILED: two experiments

- 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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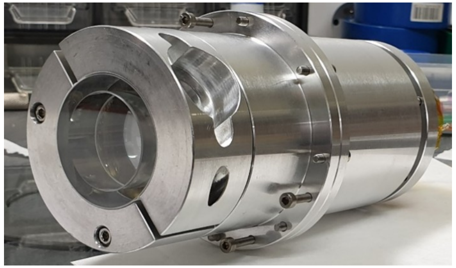

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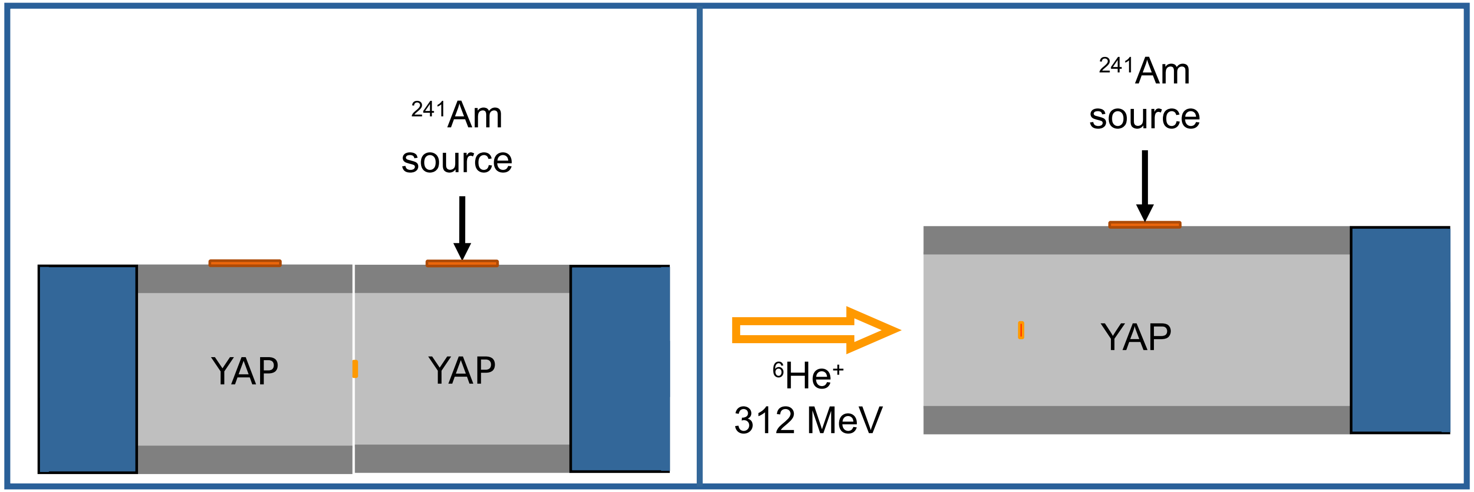

Light cross talk between PMTs

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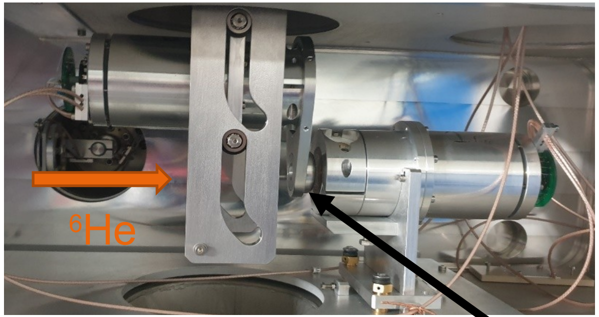
Low-energy experiment

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

→ strong systematic effect not yet understood

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

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

-Precise backscattering measurement

PRC accepted , 10.48550/arXiv.2505.18406

-Bremsstrahlung escape measurement

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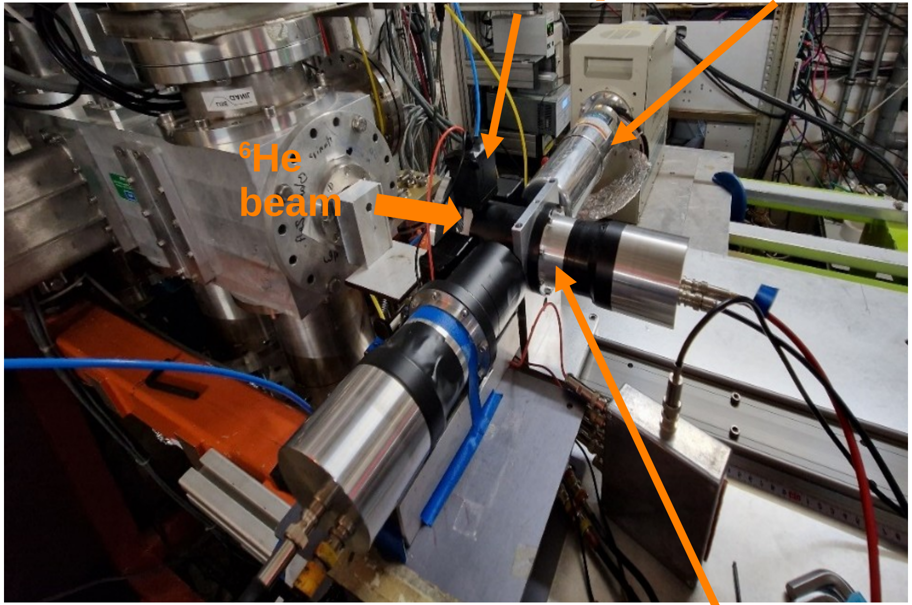
High-energy experiment

- Experiment at LISE - GANIL

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



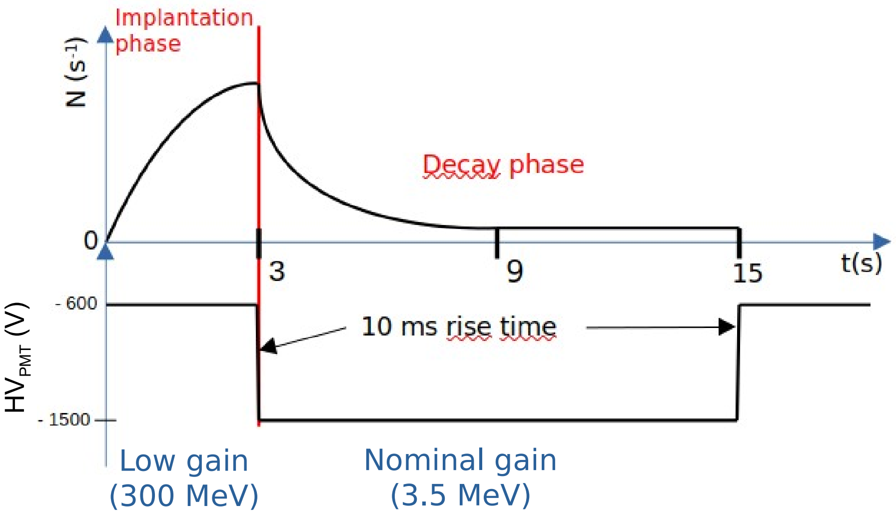
- Simpler main detector (one YAP)
- Control implantation profile (4 thin PVT hodoscope)
- LISE beam purity (measure implantation energy)
- Beam induced contaminants (HPGe)

High-energy experiment

- Measurement cycle

Beam switched on/off

PMT voltage low/high
→ implantation energy



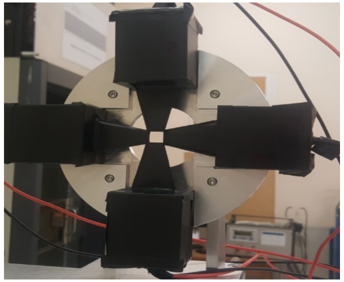
- 4 sets of measurements

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

(almost ok for phase II)

High-energy experiment analysis : Beam characteristics

Beam profile
(rates from hodoscope)

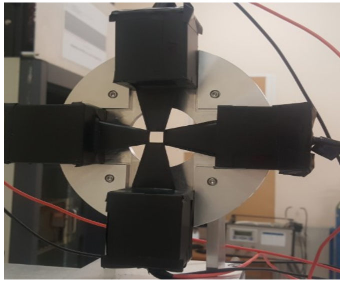


~ 0.4% implantation beyond 6mm from center

High-energy experiment analysis : Beam characteristics

Beam profile

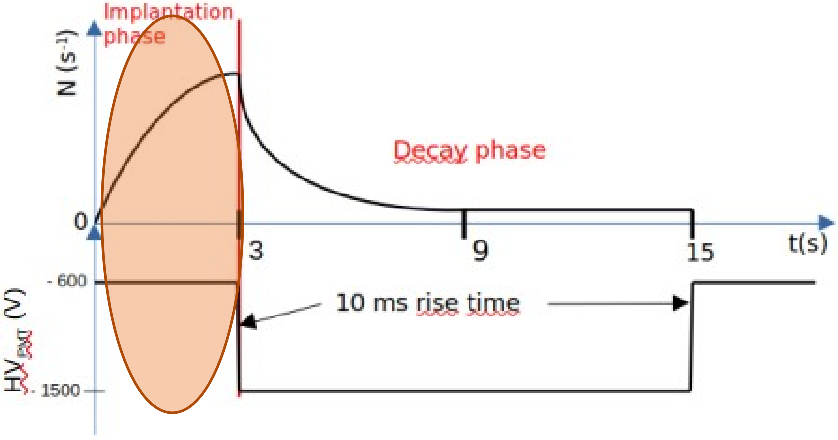
(rates from hodoscope)



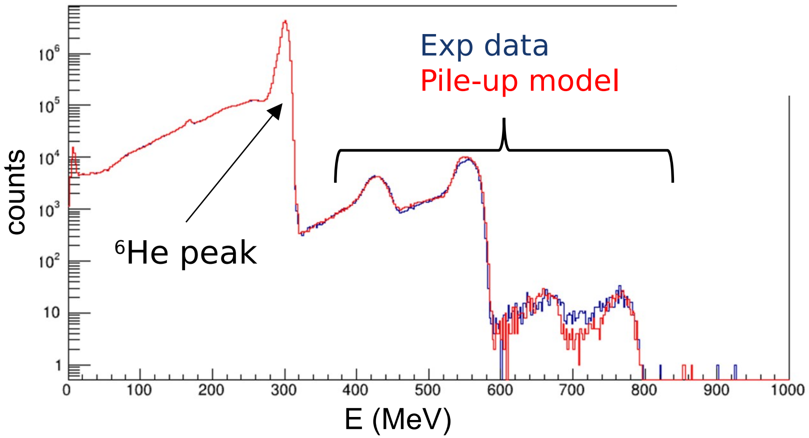
~ 0.4% implantation beyond 6mm from center

Potential contaminants (LISE++): ^{8}Li & ^{9}Be

Should appear at higher energy



YAP energy spectrum (Implant. phase)



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

High-energy experiment analysis : Beam induced contaminants

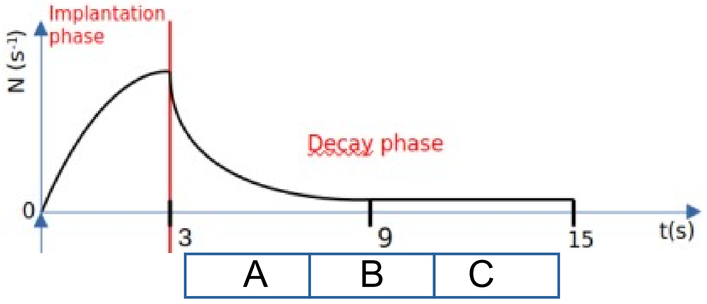
- List potential contaminants (fragmentation and fusion-evaporation)
- Selection of most impacting cases: 50 ms < $T_{1/2}$ < 1 mn
- Identification using:
  - YAP Energy spectrum
  - HPGe in implantation phase → look for excited states of contaminants (+ ^{6}He, Al, O, Y)
  - HPGe in decay phase → look for excited states of daughter nuclei

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}

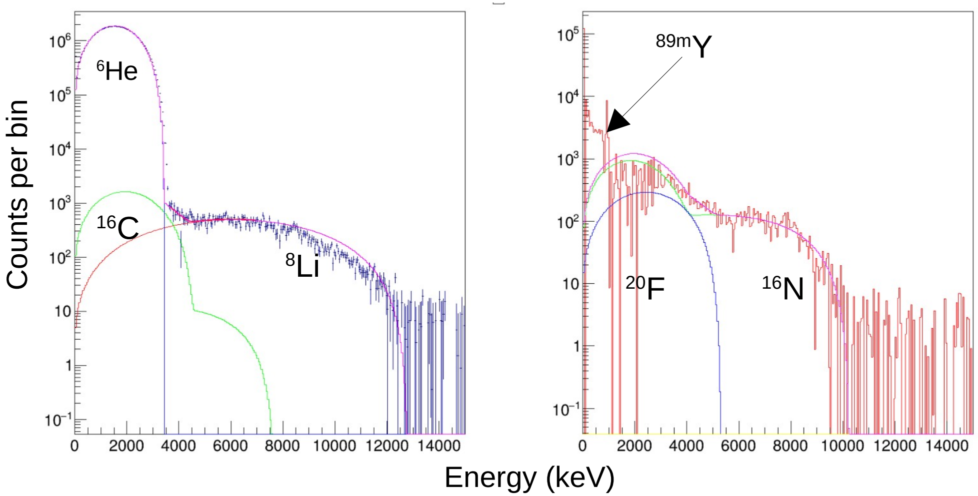


3 windows in cycle

Build linear combinations suppressing a specific half life and cst bkgd

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)



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)

Summary and conclusions

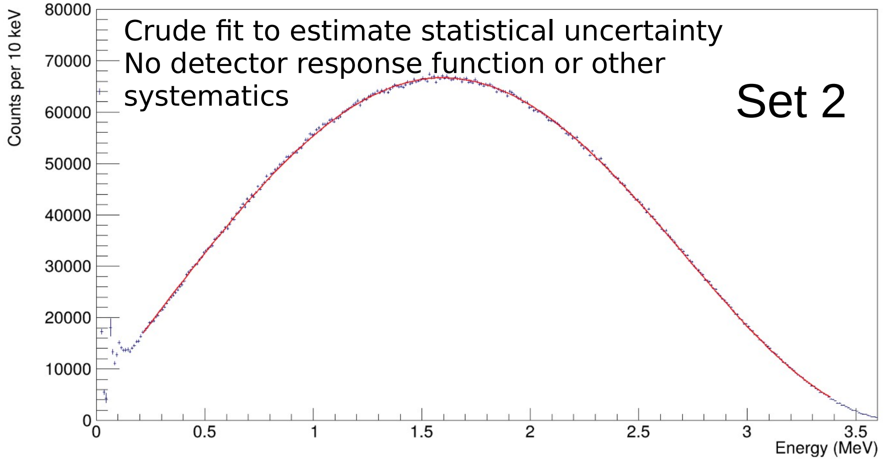
- Sufficient statistics for phase I and almost for phase II
- Excellent beam purity
- Beam induced contaminants does not seem to be a problem

(need to finalize the analysis)

- Next step : → Create fit templates

  → Study systematics

  (pileup, detector response...)



Extracted statistical uncertainty of one set $\Delta b_{GT(stat)} \sim 2.2\ 10^{-3}$

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

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

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 LNHB Henri Becquerel

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

O. Naviliat-Cuncic

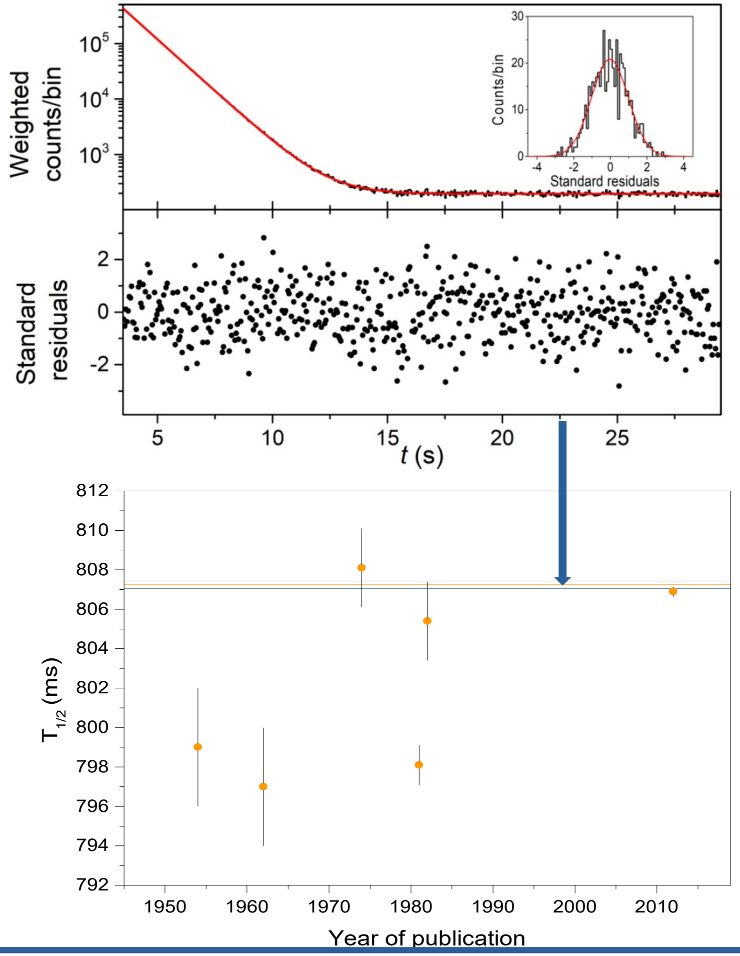
KU LEUVEN

S. Vanlangendonck

Backup slides

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 (not simple scalers)



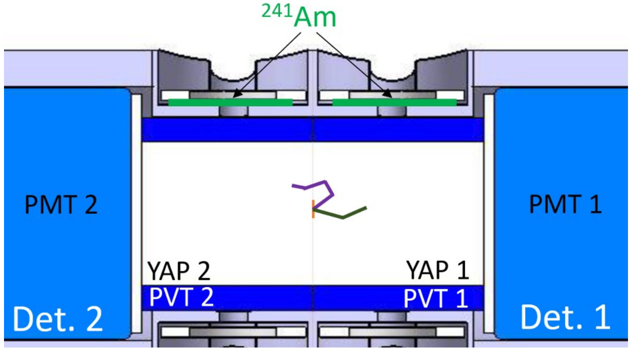
Most precise half life measurement for ^{6}He

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

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

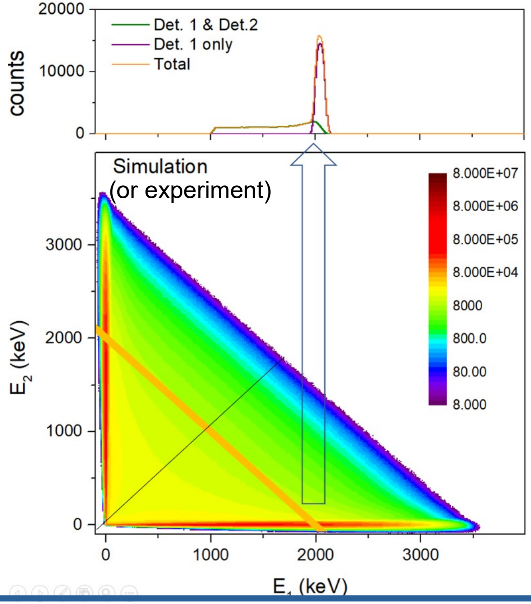
BP 2: Precise measurement of electron backscattering

- 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



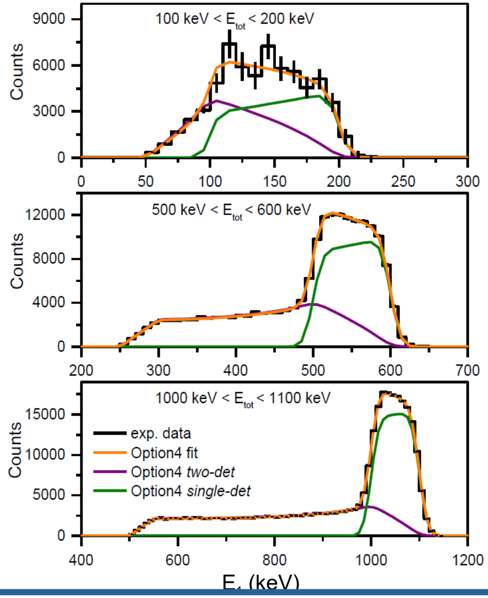
- ^{6}He decay electrons of LIRAT experiment
  → Backscattering probability up to 3.5 MeV

Det.1 vs Det.2 energy



Slices

E_1 energy profiles

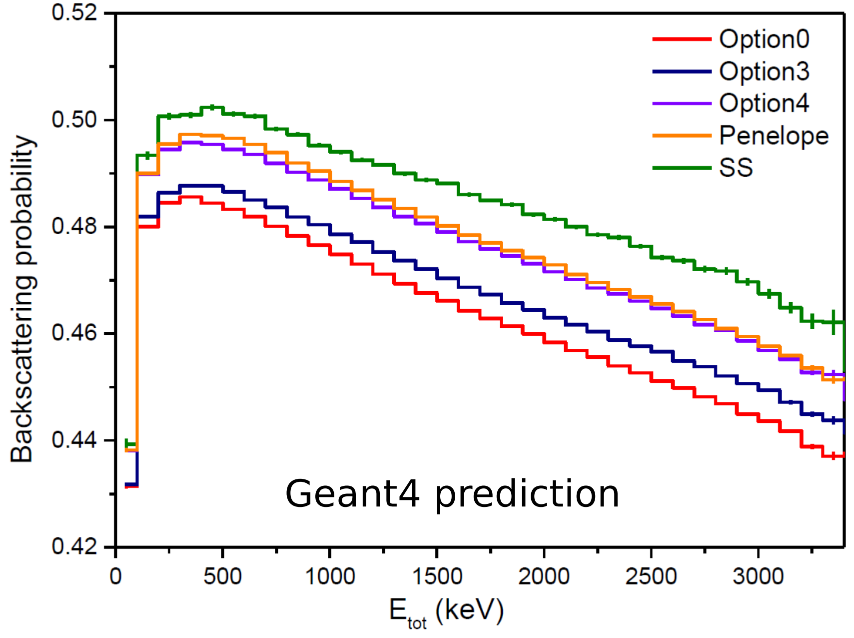


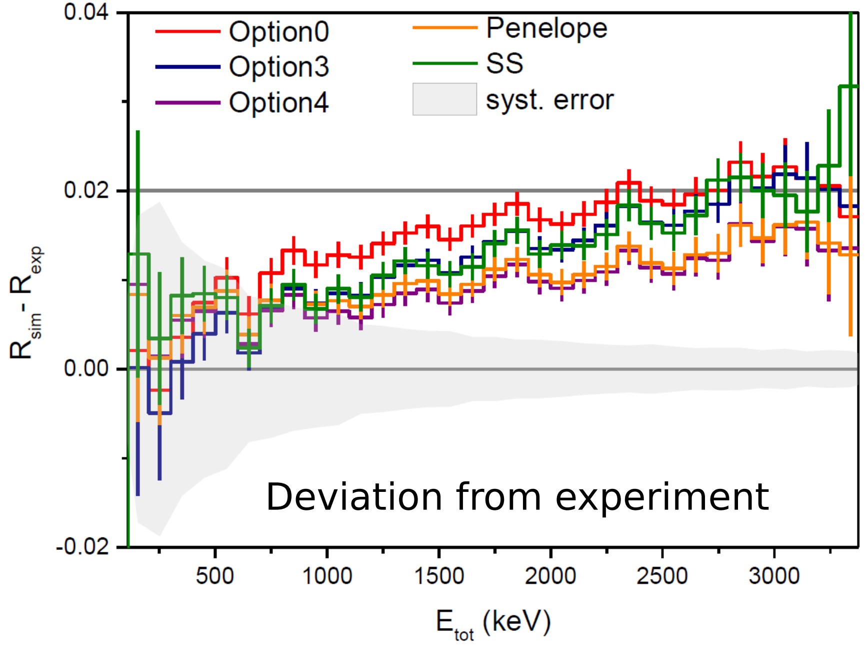
Fit exp w sim

Experimental vs Geant4
Backscattering probability

BP 2: Precise measurement of electron backscattering

Comparison with Geant4, several EM low energy options





Relative deviations below 4% (Option4 & Penelope)!

Article in preparation…

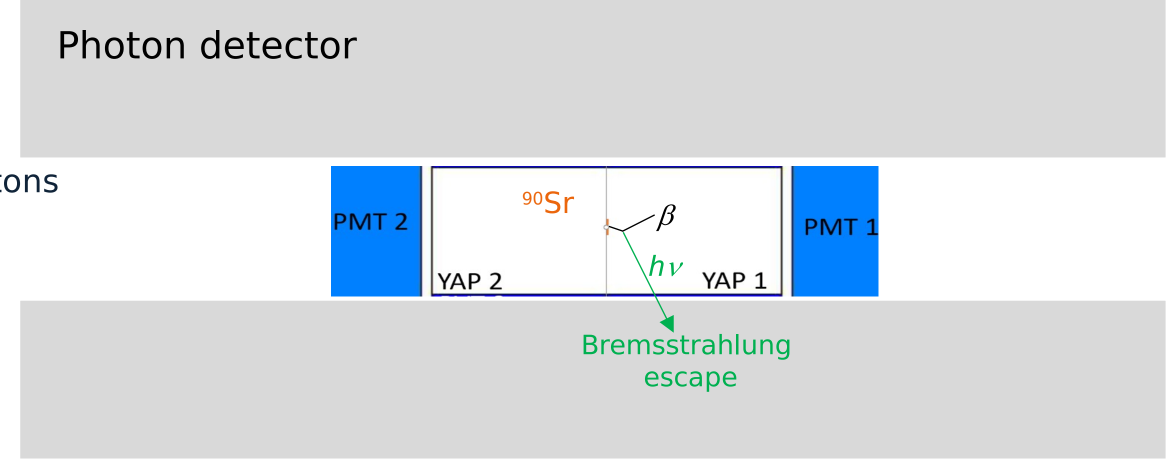
BP 3: Measurement of Bremsstrahlung escape

- 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

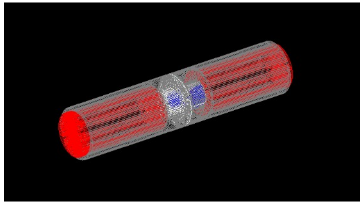


Measurement at FRIB in April 2024

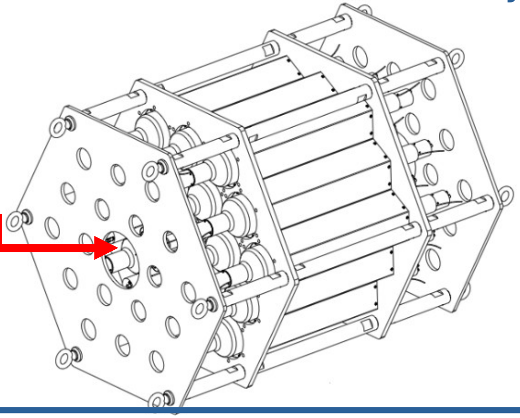
Collaboration with ORNL and IRL

Use of ORNL MTAS detector

YAP + ^{90}Sr source



MTAS NaI ~100% efficiency



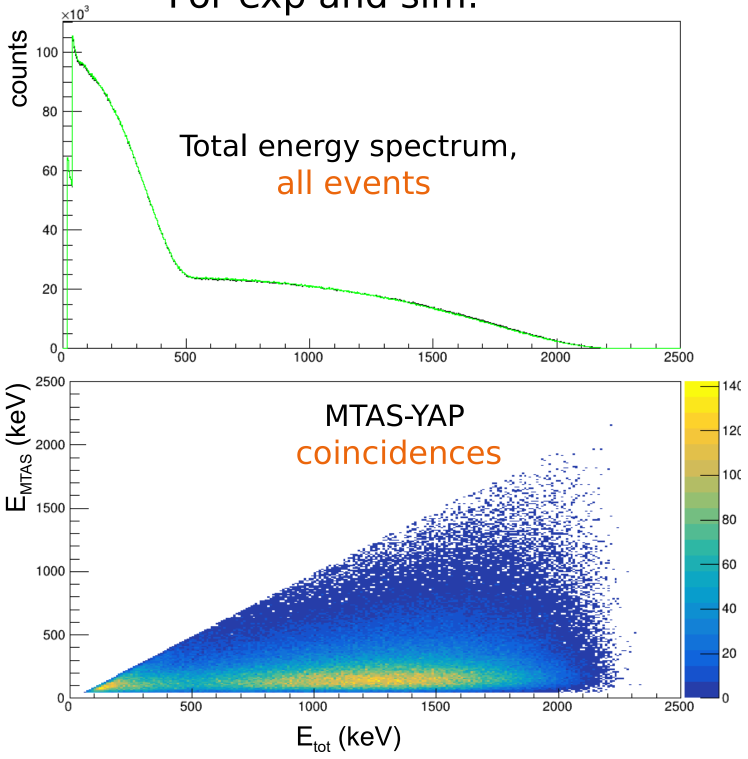
Oak Ridge National Laboratory

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

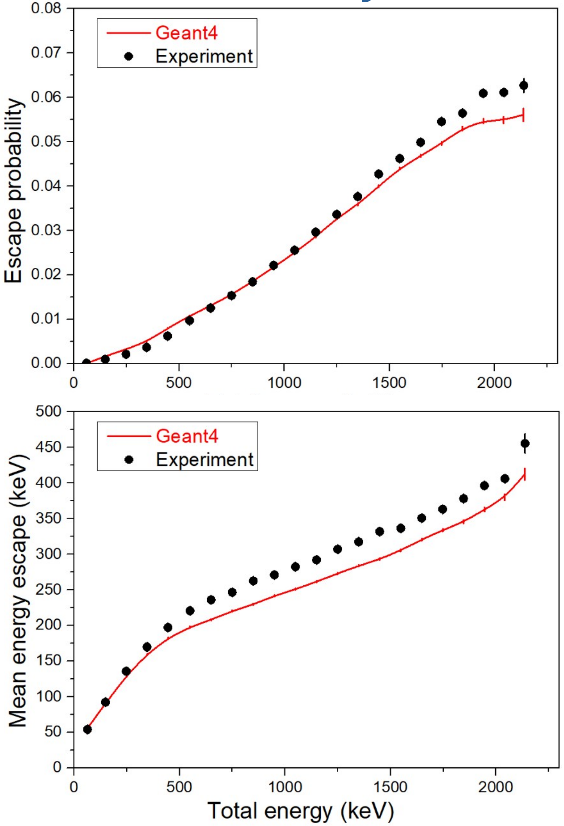
BP 3: Measurement of Bremsstrahlung escape

Comparison with Geant4 (EM option4):

For exp and sim:



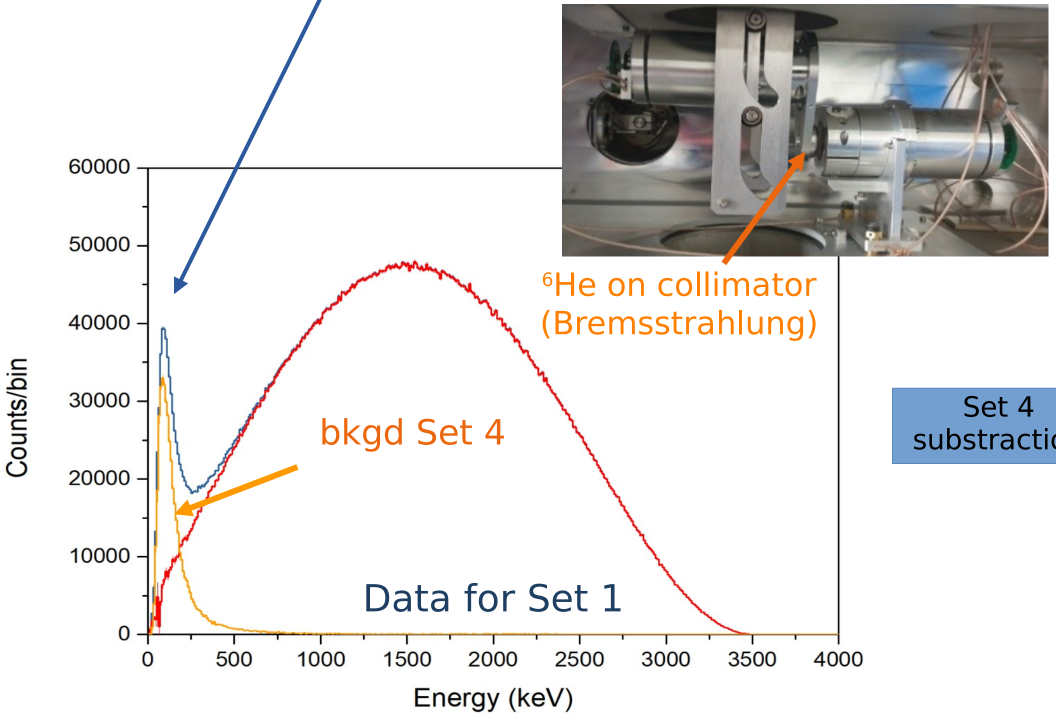
Preliminary!



Deviations up to 10%

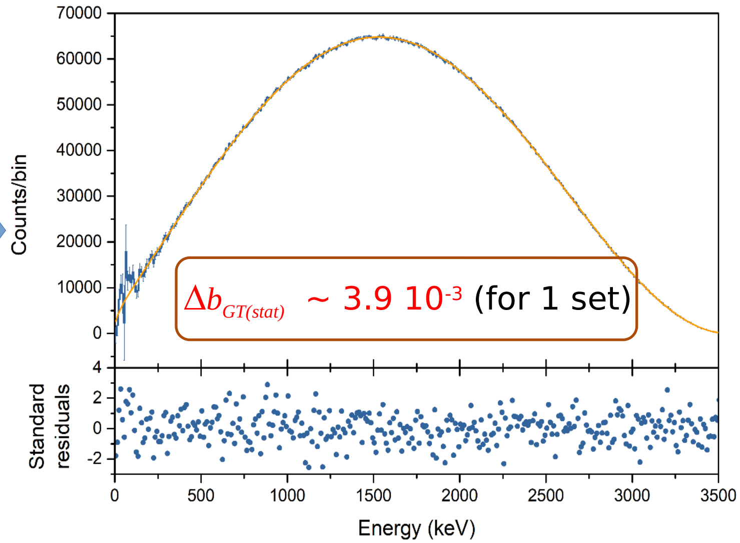
Low-energy experiment analysis

Unexpected peak at low energy



Set 4 substraction

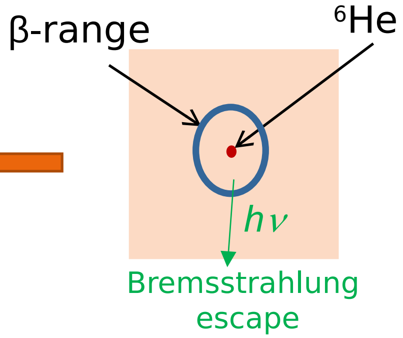
Fit with 5 free parameters:
b_{GT}, calibration slope,
Bkgd normalization, resolution
(use Geant4 simulation fit templates)



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	?

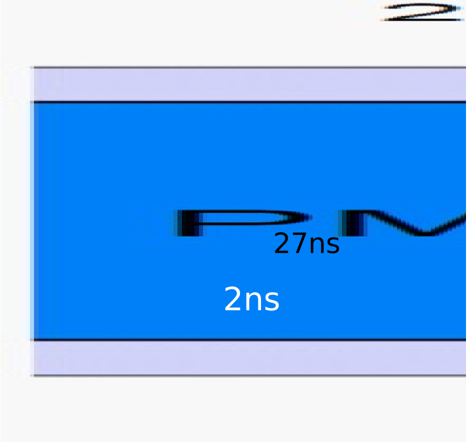


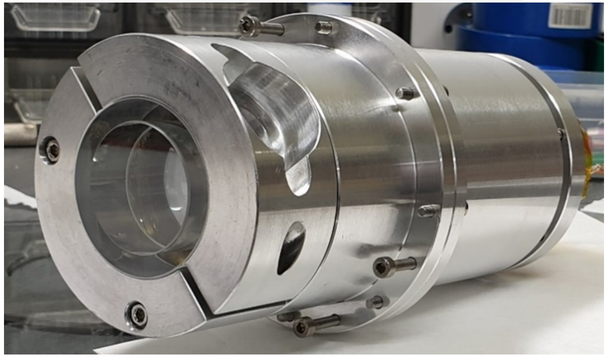
Dedicated measurements

M. Kanafani, PhD Thesis, UniCaen (2023)

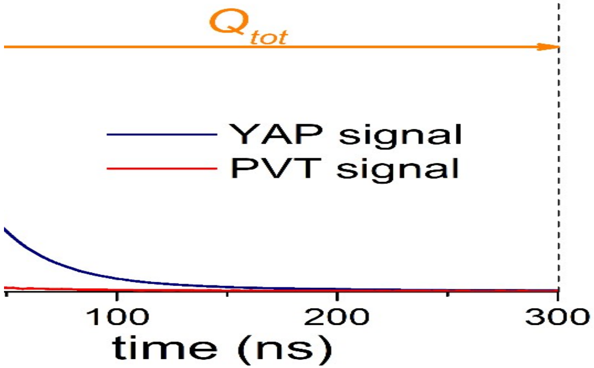
Choices for the experiment

- Use YAP:Ce as main scintillator → fast, linear, less Bremsstrahlung escape
  + plastic scintillator (veto) and ^{241}Am source (gain monitoring)





FASTER DAQ
(high rates, minimal dead time)



- 3 integration windows for signals
  - → baseline monitoring, pulse shape analysis and pile-up
- timestamp (2ns)
  - → event time within implantation/decay cycle