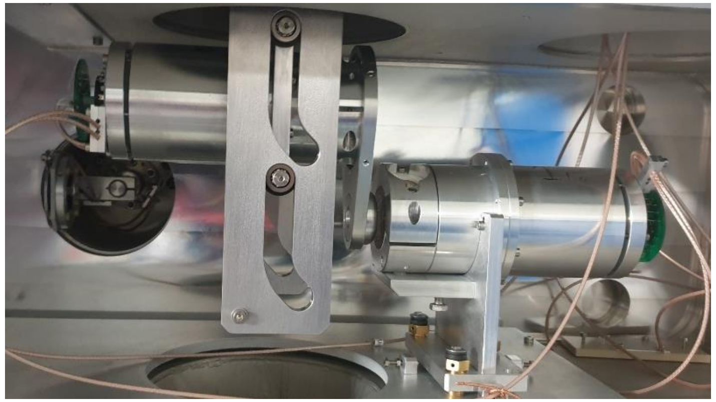
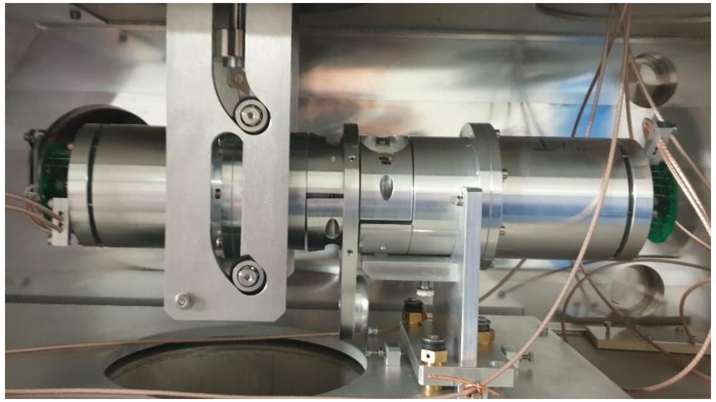
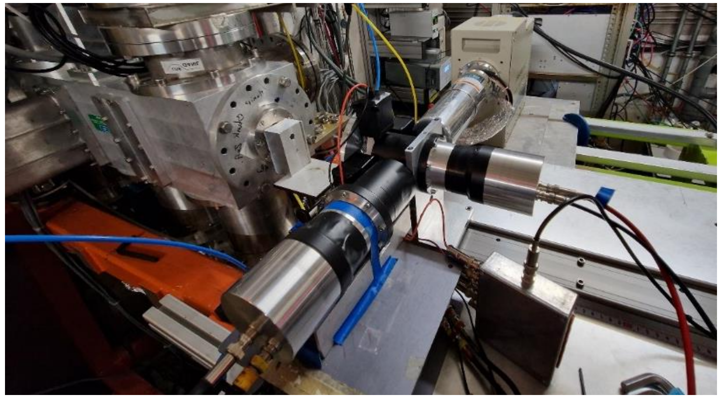






bSTILED

b:Search for Tensor Interactions in nucLear bEta Decay

IN2P3 Scientific Council

June 24-25 2024

Strasbourg, France

Outline

- Context and motivations
- Description of the project
- Genesis, Resources and Time Line
- Summary and outlook

Scientific Context : search for BSM Physics in beta decay

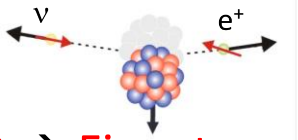
- Search for ϵ_S, ϵ_T exotic contributions of weak interaction

  Dominant *Vector - Axial vector* (*V – A*) form established in SM but no fundamental reason to exclude *Scalar* (*S*) and *Tensor* (*T*) contributions → search window for BSM physics

- Search at low energy, in β-decay

  Precision measurements of Ft-values, β-spectrum shape, correlations between leptons momenta, spin, and nuclear spin

S & *T* → opposite lepton helicity
(talk by M. Versteegen)



S & *T* → Fierz term $b \neq 0$
(linear dependence, impact β-spectrum)

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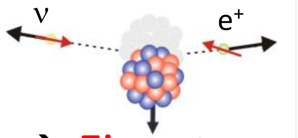


S & *T* → Fierz term $b \neq 0$
(linear dependence, impact β-spectrum)

- **Search at High energy colliders (LHC)**

  Channels $pp \rightarrow e + MET + X$ interpreted with the effective field theories (EFTs)

  V. Cirigliano, M.J. Ramsey-Musolf, Prog. Part. Nucl. Phys. 71 (2013)

- **EFTs input:**

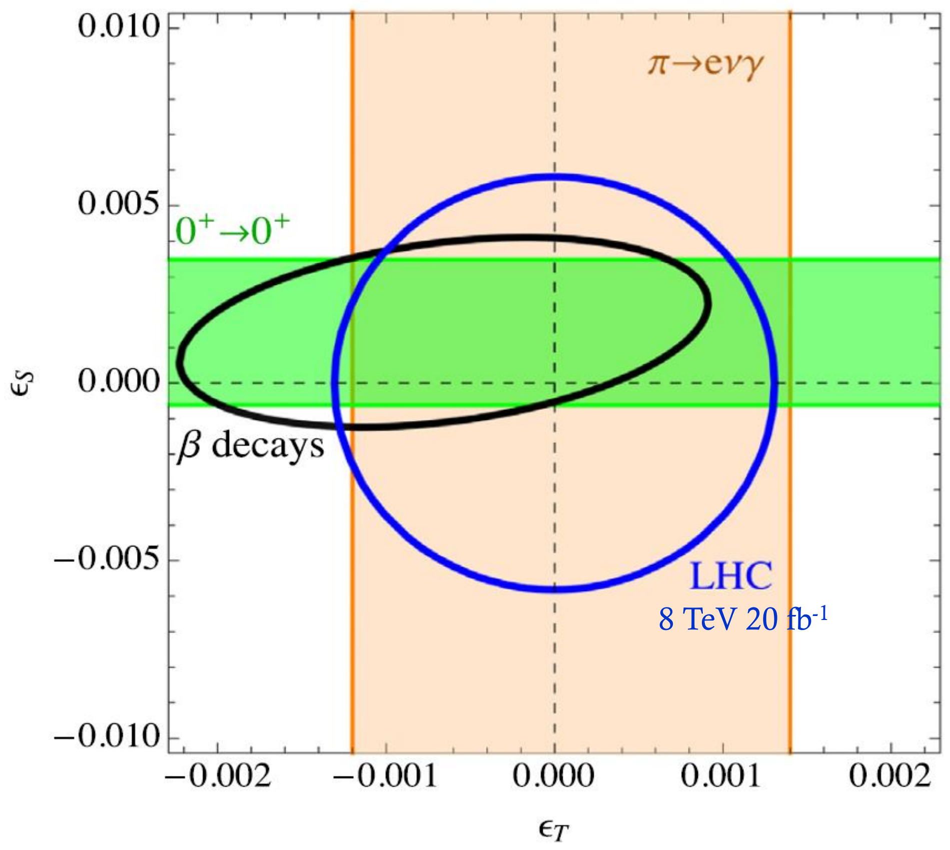
  Provides the energy scale probed for the BSM Physics $\epsilon_i \sim 10^{-3} \rightarrow \Lambda_{BSM} \sim 5\,TeV$

  Compare constraints obtained at high and at low energy

  M. Gonzalez-Alonso, et al. Prog. Part. Nucl. Phys. 104 (2019)
  A. Falkowski, et al., J. High Energ. Phys. 2021 (2021)

Scientific context: constraints on new physics (*S* and *T* couplings)

- Complementarity of searches at High and Low energy



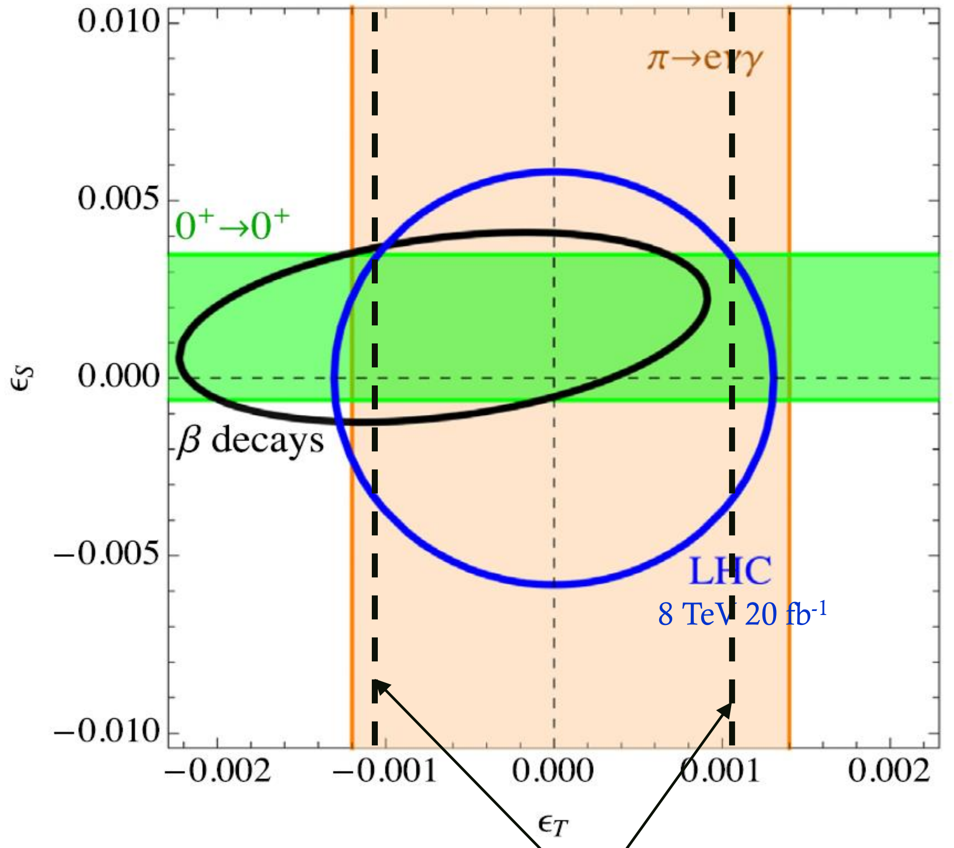
M. Gonzalez-Alonso, et al. Prog. Part. Nucl. Phys. 104 (2019) 165

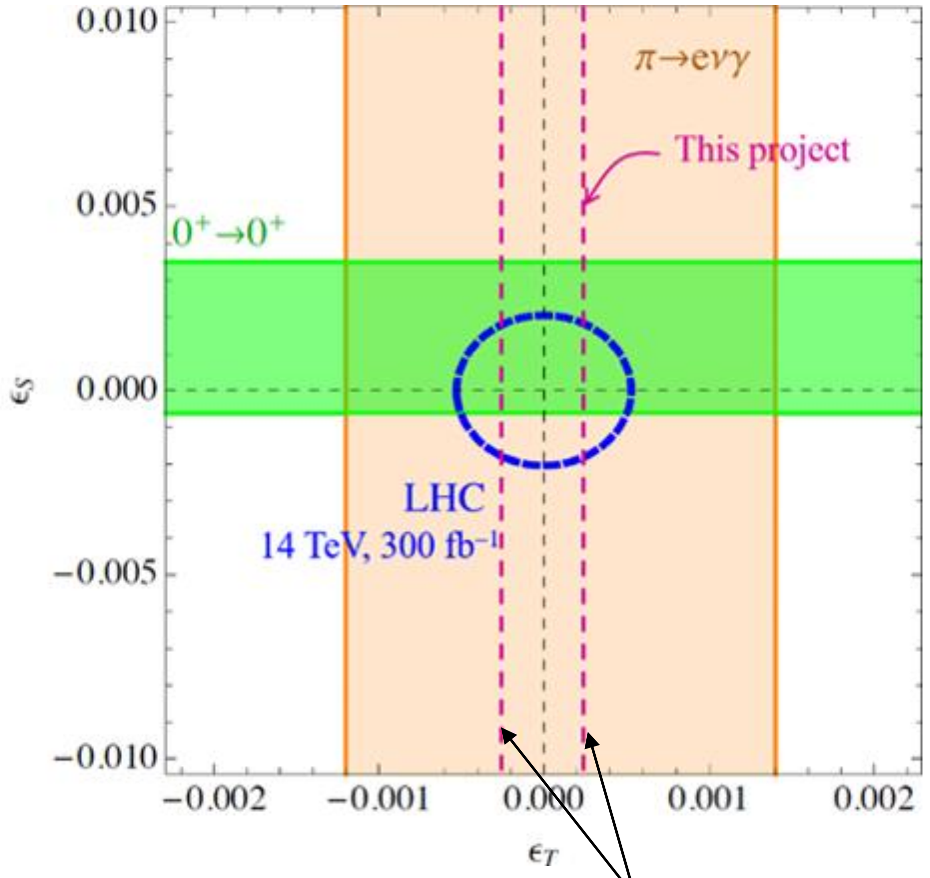
90% CL constraints
assuming left-handed neutrinos (higher sensitivity for β-decay)

Pion decay
$\mathcal{F}t$-values from $0^+ \to 0^+$ transitions $\to b_F$
All neutron and nuclear beta decay (correlations and $\mathcal{F}t$-values)
LHC pp → e + MET + X

Scientific context: goal of bSTILED

- Complementarity of searches at High and Low energy





- Phase I: $\epsilon_T < 6.3 \times 10^{-4}$ (1σ)
(most sensitive constraints from β decay)

- Phase II: $\epsilon_T < 1.6 \times 10^{-4}$ (1σ)
(competitive with projected LHC)

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Principle of the bSTILED project

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

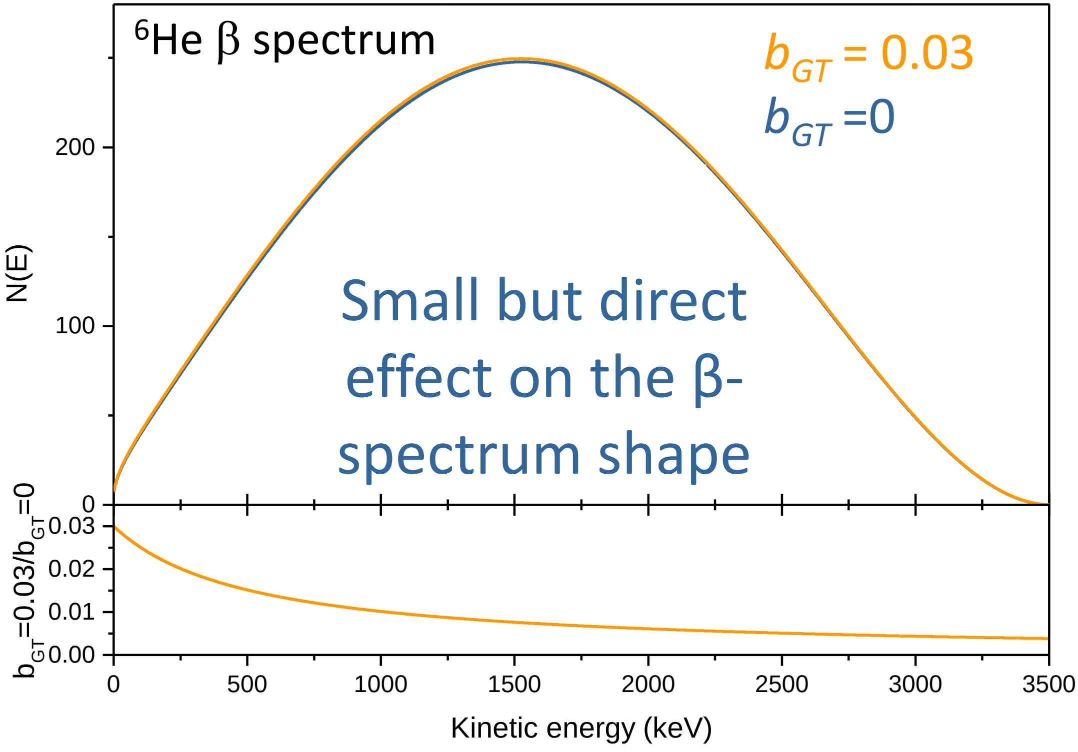
For pure Gamow-Teller transitions: $b_{GT} = 6.2\epsilon_T$

$$N(E) \propto \underbrace{F(Z,E)}_{\text{Fermi function}}\underbrace{(1+\eta)}_{\text{Theoretical corrections}}\underbrace{pE(E-E_0)^2}_{\text{Phase space}}\left(1+\frac{m_e}{E}b_{GT}\right)$$

Fermi function

Theoretical corrections

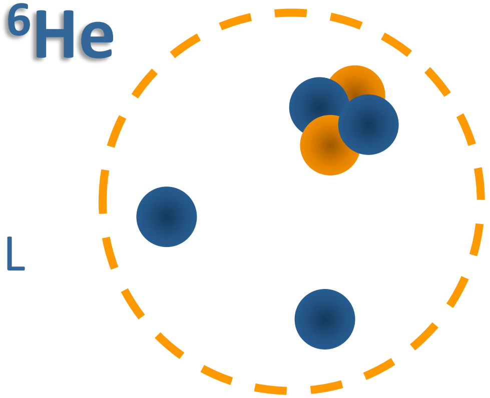
Phase space

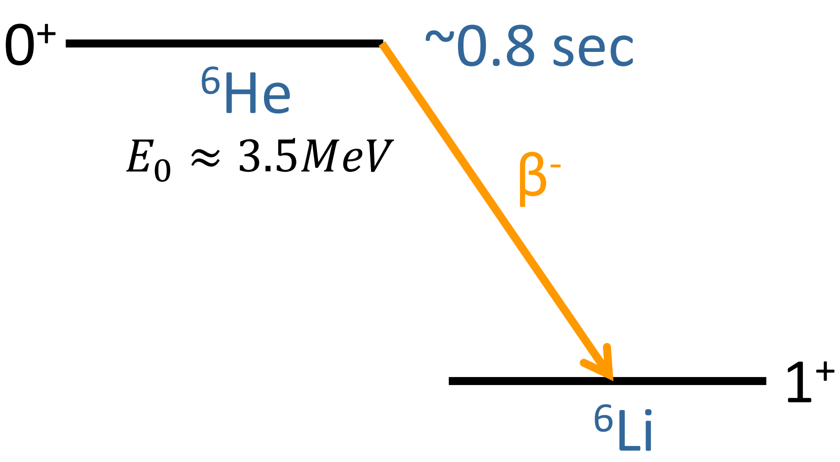


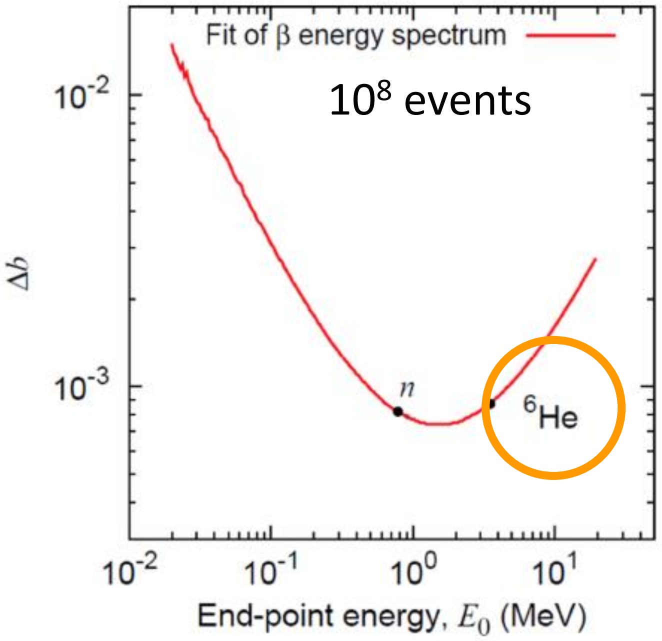
- Precision goal:
  Phase I: $\Delta b_{GT} = 4 \times 10^{-3}$
  Phase II: $\Delta b_{GT} = 1 \times 10^{-3}$

The choice of ^{6}He

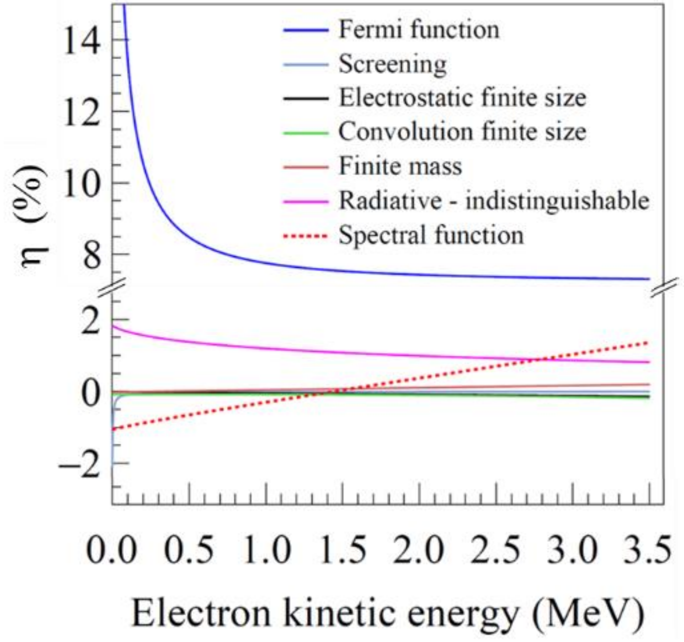
- Pure GT transition (GS to GS) only sensitive to tensor currents
- Endpoint energy providing high sensitivity to b_{GT}
- Theoretical corrections known with high precision
- Convenient half-life for implantation-decay cycles, copiously produced at GANIL







M. González-Alonso et al, PRC, 2016.

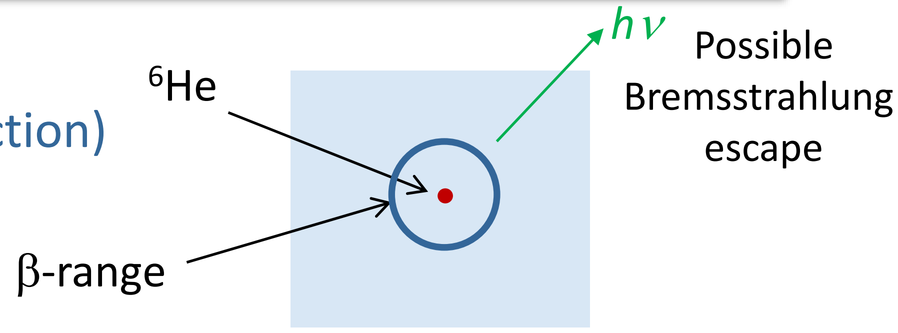


$\Delta b_{GT} < 10^{-3}$

Phase I: bSTILED experiments at GANIL

- Use 4π detection setups to suppress backscattering
  Use implantation-decay cycles 3 s – 12 s (cst BKGD subtraction)

- Test two techniques (different systematic effects)
  - Low energy implantation → LIRAT/GANIL
  - High energy implantation → LISE/GANIL



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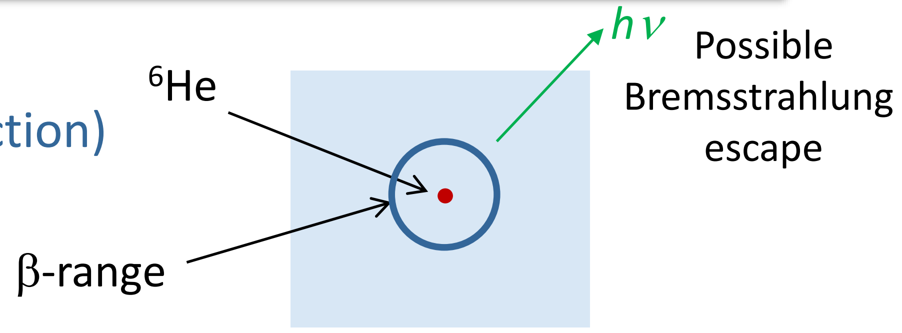
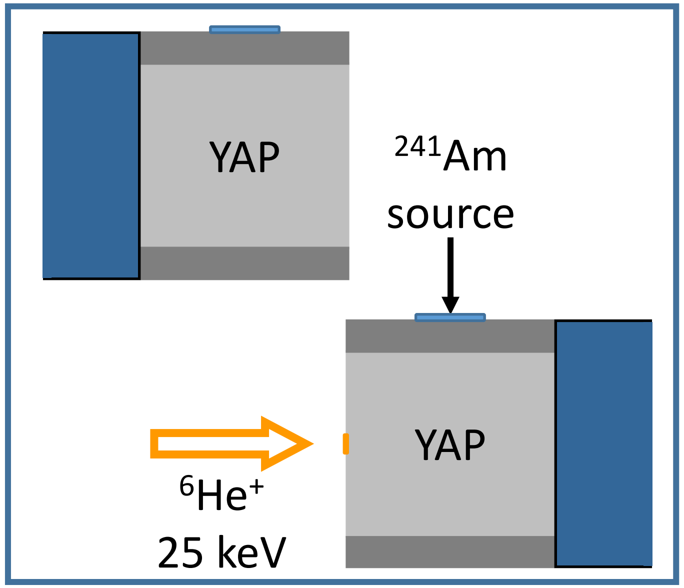
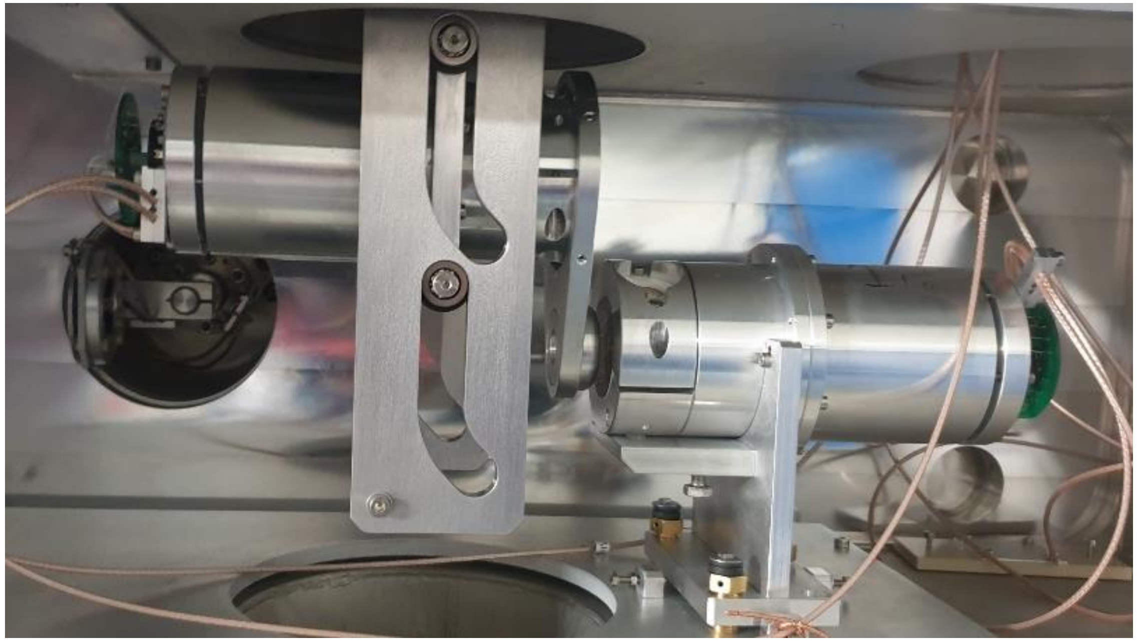


LIRAT experiment



2 detectors under vacuum,
light cross talk between PMTs



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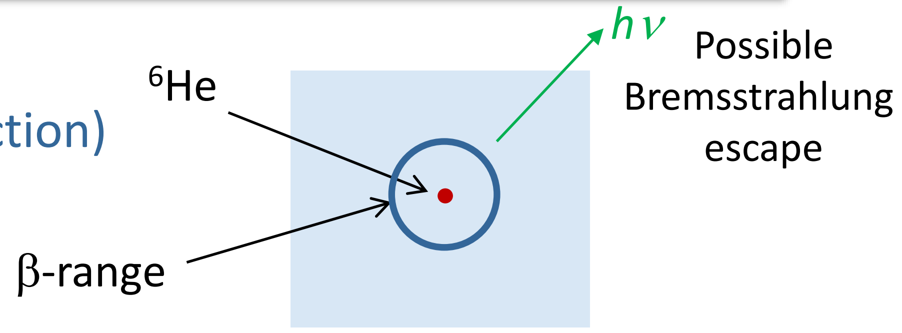

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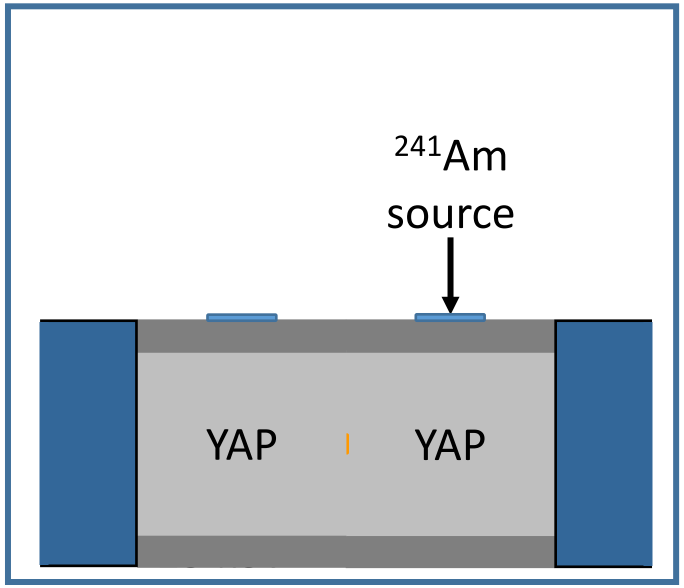
LIRAT experiment



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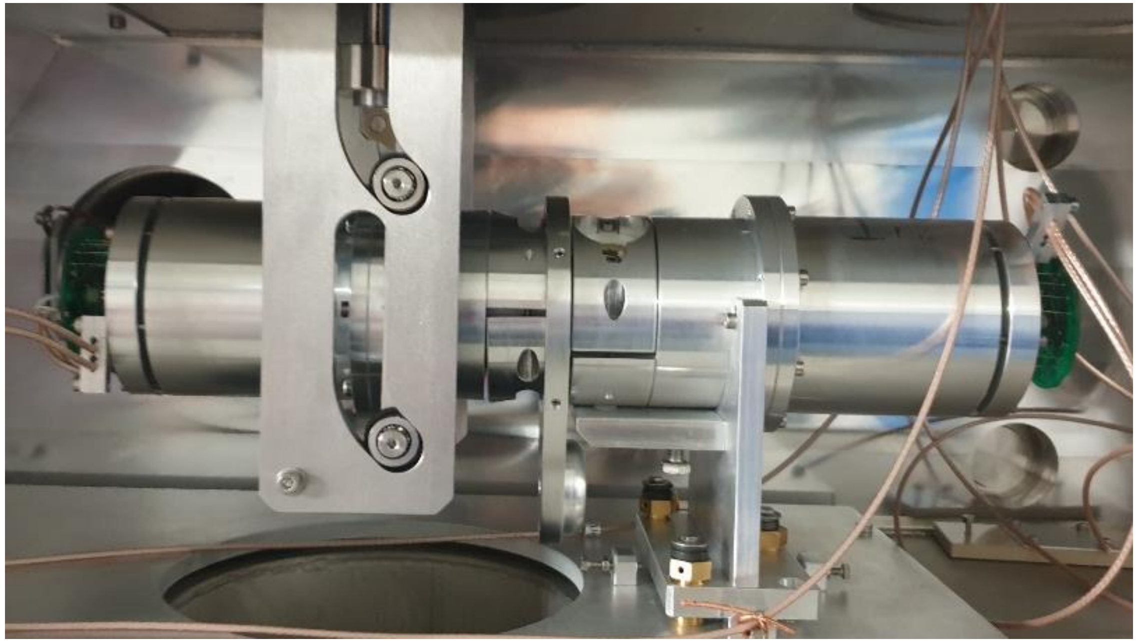
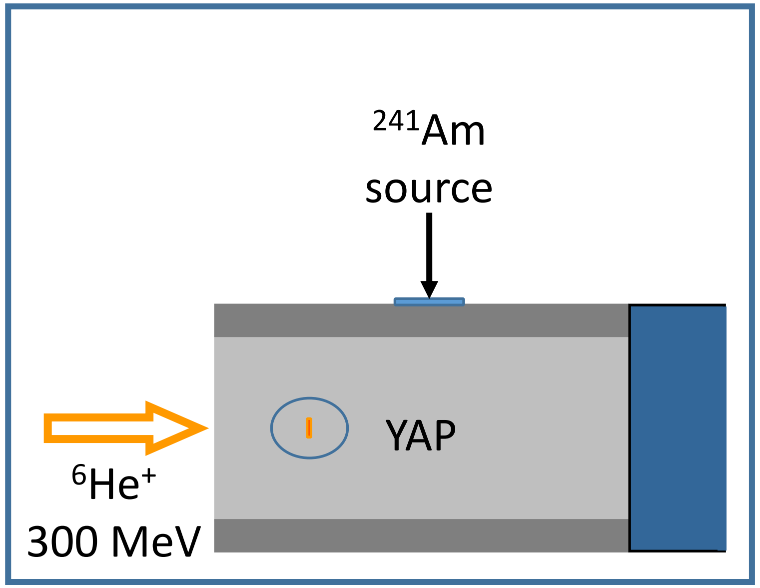


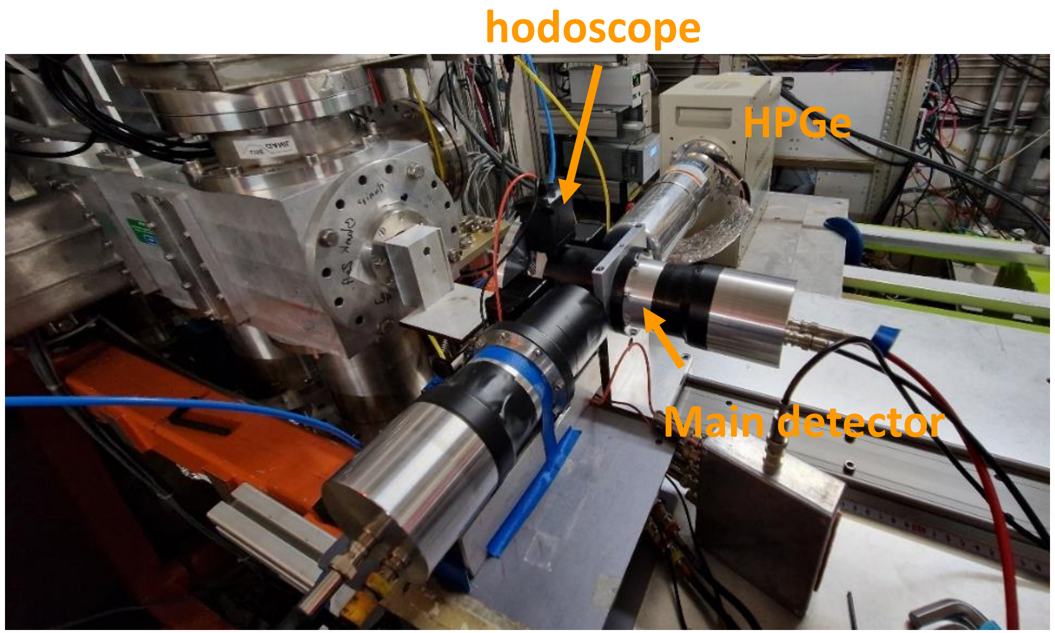
Phase I: bSTILED experiments at GANIL

- LISE experiment: implant ^{6}He nuclei 10 mm deep in the YAP detector (max β-range 4mm)

LISE experiment



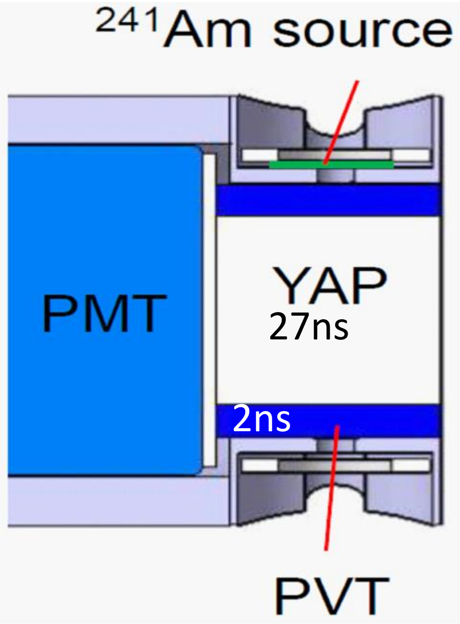
Background due to nuclear reactions during implantation phase

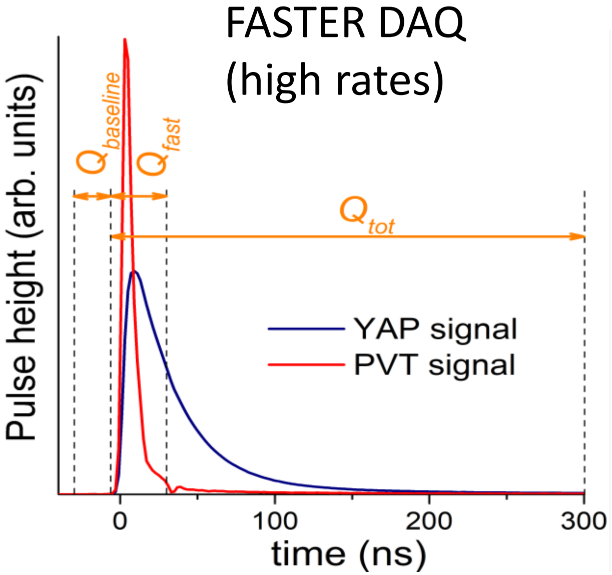


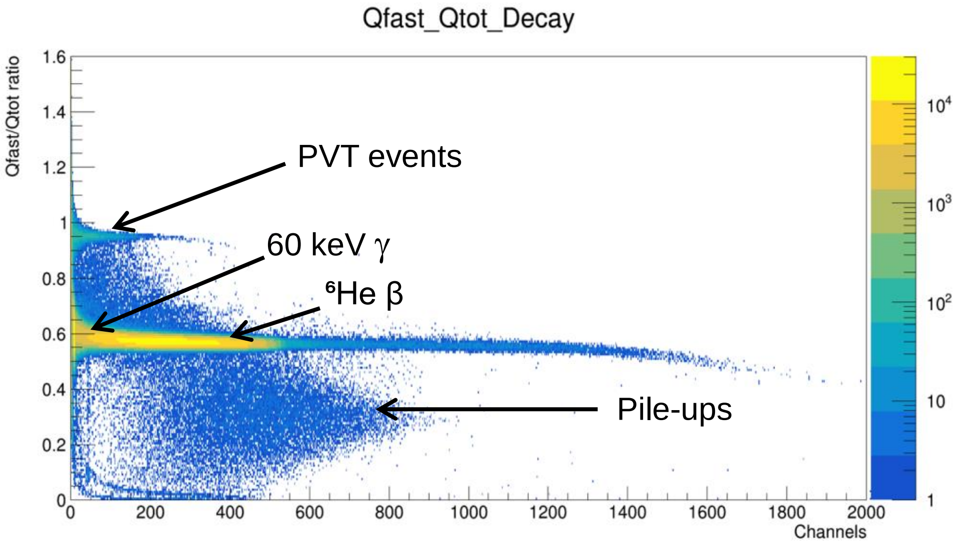
- Phase II: push the most promising technique to gain a factor 4 (if possible)

Choice of the detectors

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







3 integration windows → baseline monitoring, pulse shape analysis and pile-up

Outline

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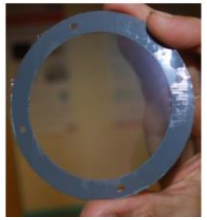
Genesis and resources

- Collaborative effort between three French institutions (2020):

  - Detector design & characterization, DAQ, data analysis and systematic effects
    (X. Fléchard, E. Liénard, G. Quémener, O. Naviliat-Cuncic & technical staff)

  - Production of ^{6}He beams at low- and high-energy with sufficient intensity and purity
    (J-Ch. Thomas & technical staff)

  - Production of calibration sources for the detectors calibration
    (X. Mougeot & S. Leblond)



500 nm thick sources

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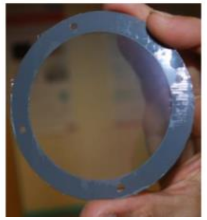


500 nm thick sources

- Project submitted to ANR and GANIL PAC in 2020
    - Both experiments accepted by the GANIL PAC with high priority
    - Approved for funding by ANR (290k€ for 4 years, extended to 2026)
    - PhD of M. Kanafani (2020-2023) funded by Region Normandie
    - PhD of R. Garreau (2023-2026) funded by IN2P3

Anticipate no request for funding until 2026

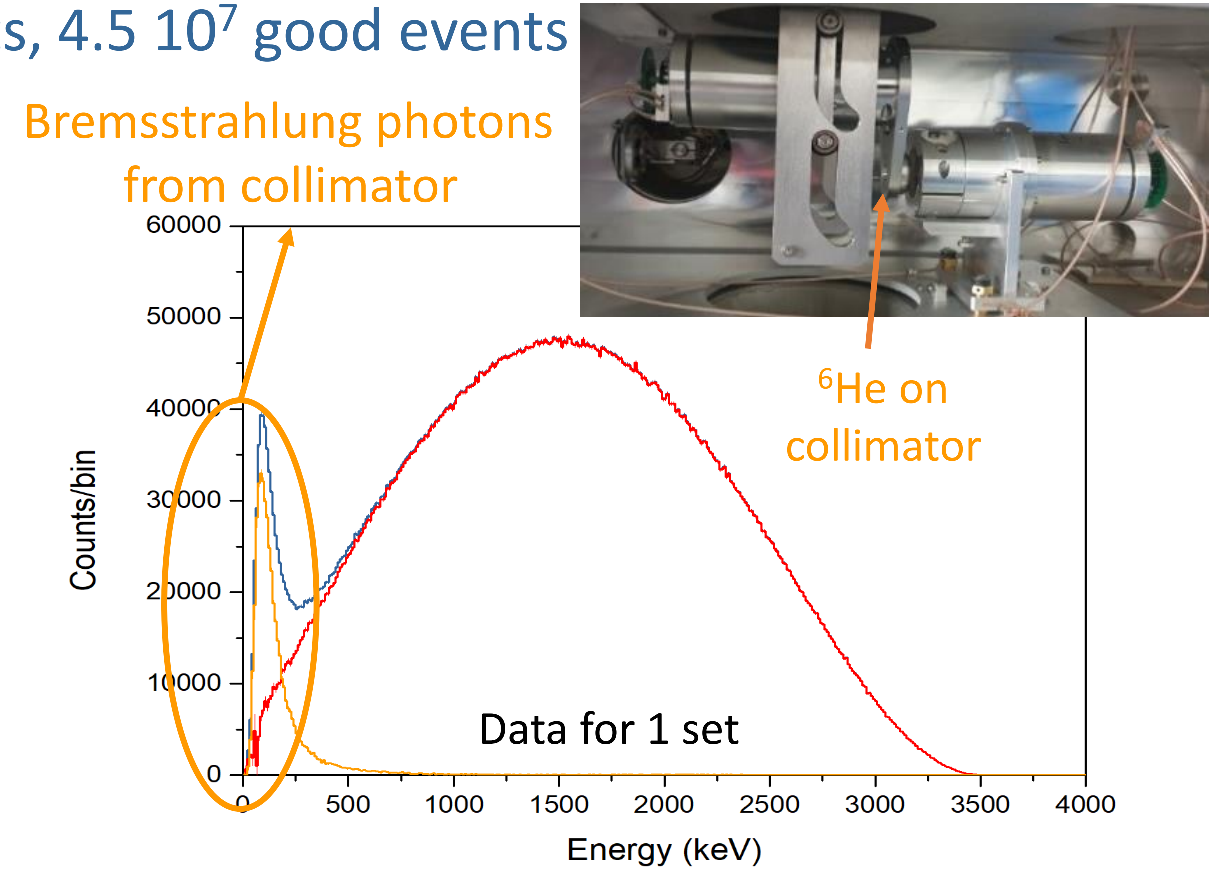
Phase I - step 1: low energy experiment at LIRAT/GANIL

- May 2021: ~ 2 days, 3 sets of measurements, 4.5 10^7 good events

  2 cycle lengths, 2 PMT voltages, 2 beam intensities

  \+ online background runs (~ 500 cycles)

  with thin Aluminum cap on last collimator (BKGD run)



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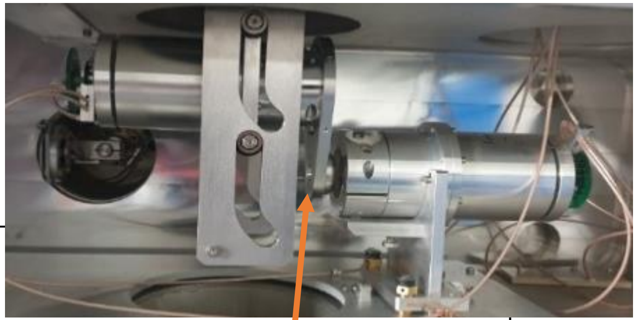
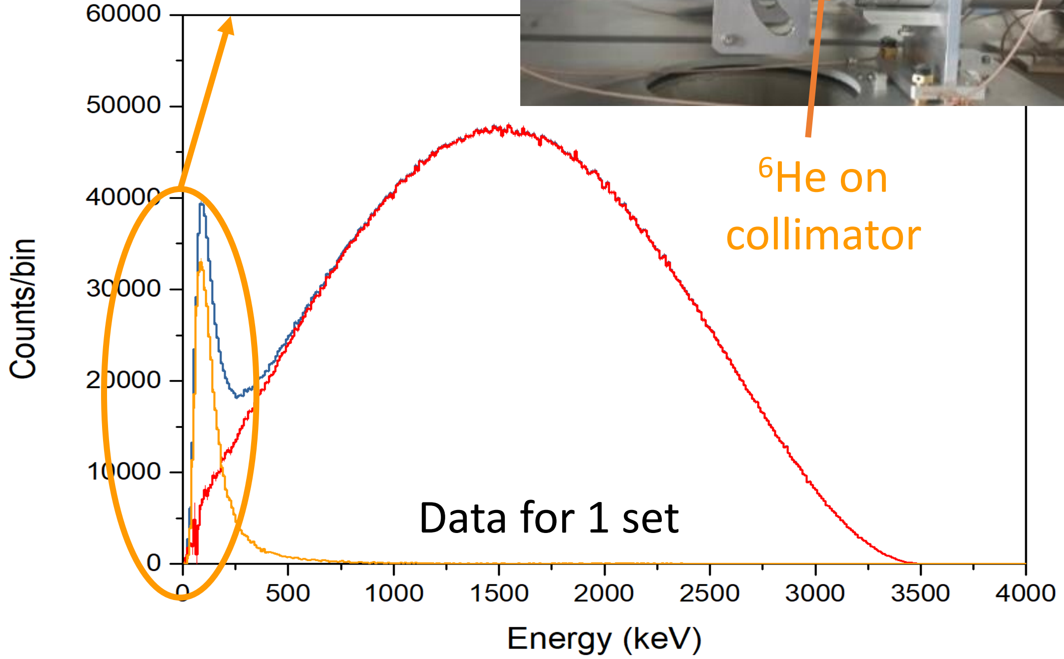
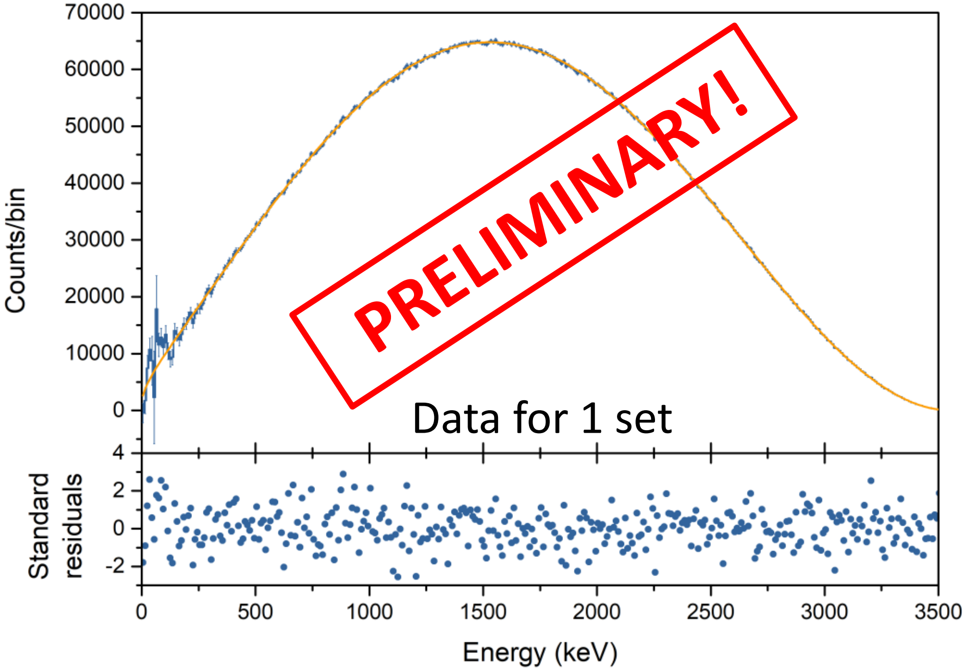




- Fit with 5 free parameters:

  b_{GT}, calibration slope, BKGD normalization, resolution



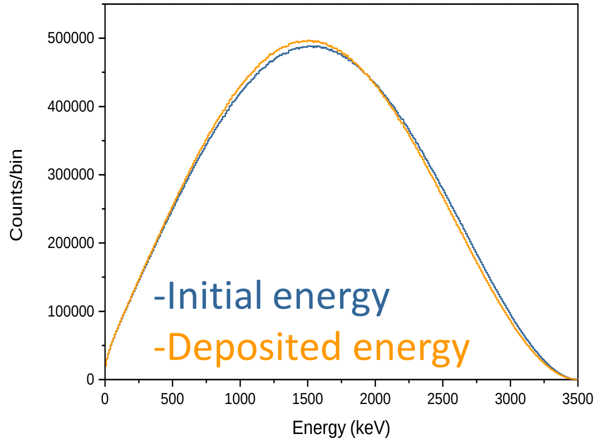
$\Delta b_{GT(stat)}$ ~ 3.9 10^{-3} (for 1 set)

Phase I - step 1: low energy experiment at LIRAT/GANIL

- Work on b_{GT} extraction and Systematic errors still ongoing…

	Systematic effect		Δb_{GT}
studied	Resolution function (adding a second coefficient)		$< 2 \times 10^{-3}$
	b_{WM}	Theoretical corrections	2.6×10^{-4}
	Radiative		3.7×10^{-4}
	Bremsstrahlung escape (5% error on G4)		2.5×10^{-3}
	Cerenkov (10% error on G4)		5×10^{-4}

G4 simulations



Need dedicated measurements

Phase I - step 1: low energy experiment at LIRAT/GANIL

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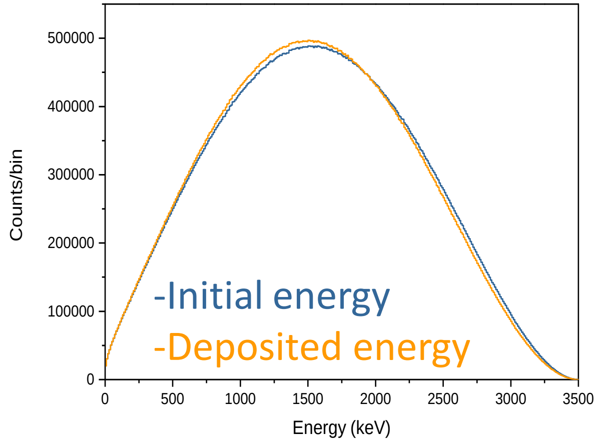
studied	Cerenkov (10% error on G4)		5×10^{-4}
ongoing	Pile-up (preliminary)		$< 1 \times 10^{-3}$
ongoing	Events selections (to be refined)		6×10^{-3}
ongoing	Calibration slope for BKGD run		2×10^{-3}
ongoing	Detector non proportionality (preliminary)		$\sim 10^{-2}$
	Total		?

M. Kanafani, PhD Thesis, UniCaen (2023)

G4 simulations



Need dedicated measurements

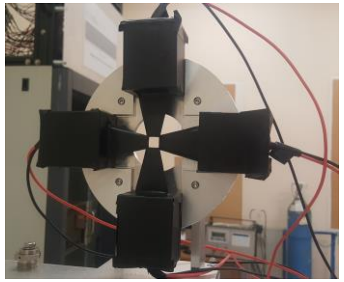
Most of the work to come

Phase I - step 2: high energy experiment at LISE/GANIL

- May 2023: ~ 3 days, 4 sets of measurements, 1.1 10^8 good events

  2 crystal sizes, 2 distances, 2 beam intensities

- Collected statistics → $\Delta b_{GT(stat)} = 1.2\ 10^{-3}$



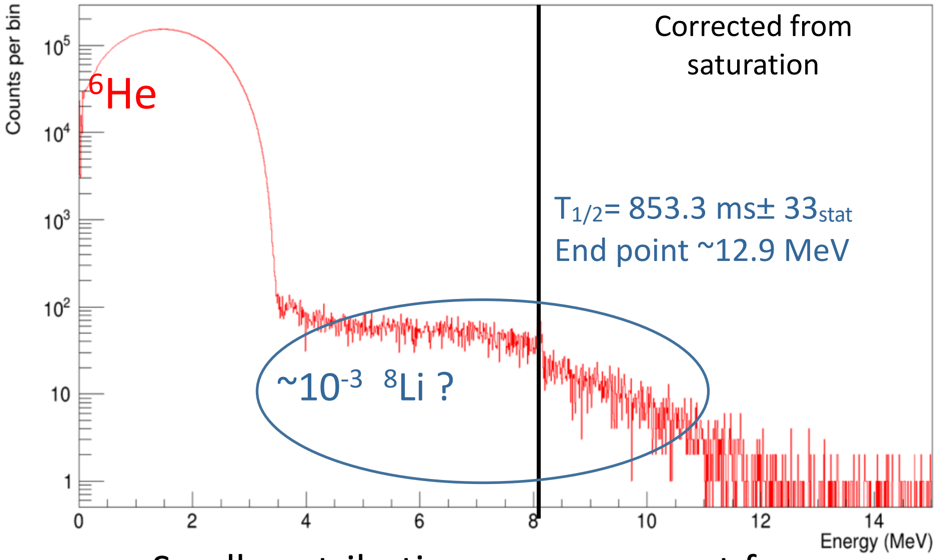
- Beam characteristics analysis:

  Hodoscope → ~ 99% implantation in the center of the YAP (r<6 mm)

  Implantation energy spectrum → no potential beam contaminants (<10^{-5})

- Induced BKGD study:

1 set after cst BKGD subtraction



Small contribution we can correct for

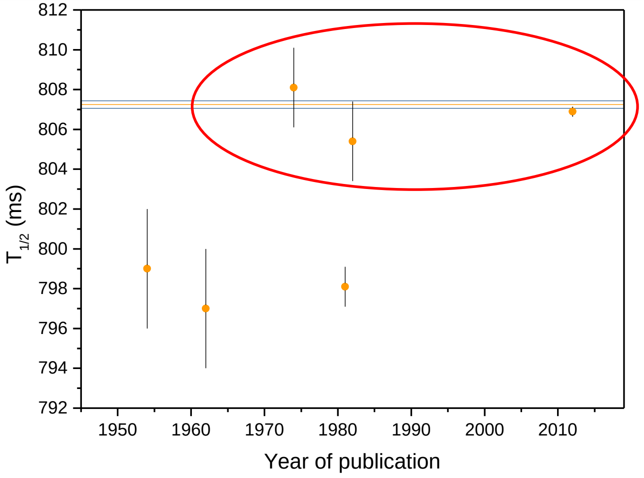
Work in progress...

Phase I : byproducts

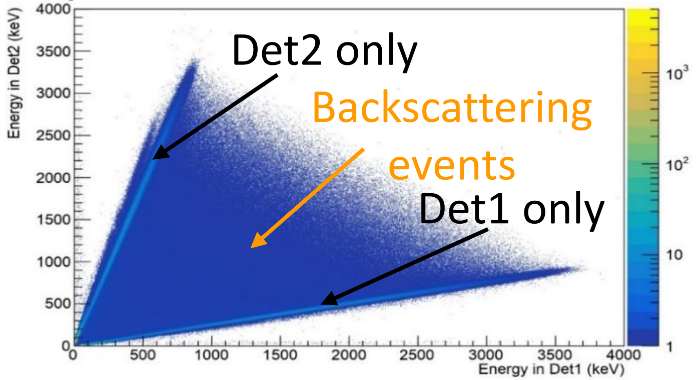
- Most precise half life measurement for ^{6}He

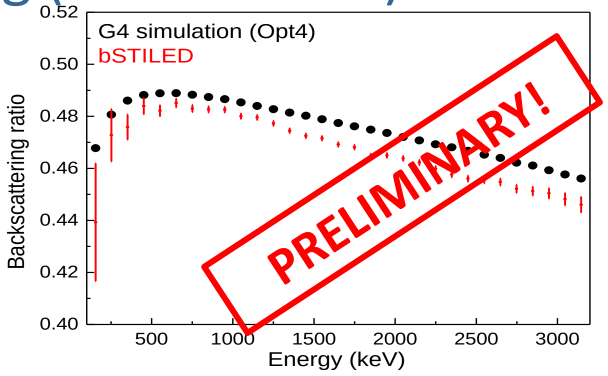
$$T_{1/2} = 807.25 \pm 0.16_{stat} \pm 0.11_{syst}\ ms$$

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



- Precise quantification of backscattering (0.2-3.2 MeV)

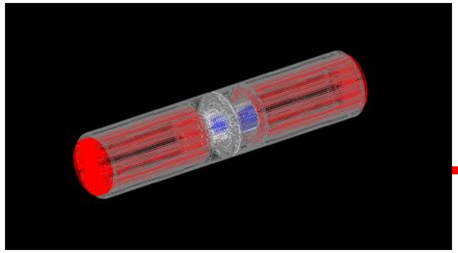




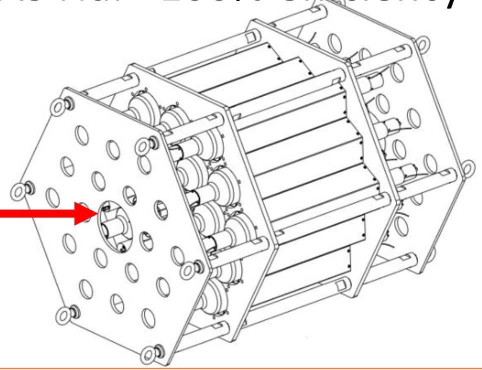
In queue for publication…

- Bremsstrahlung escape characterization: using MTAS detector @ FRIB (April 2024)

YAP + ^{90}Sr source



MTAS NaI ~100% efficiency



Work in progress…

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Summary & outlook

- No difficulty to reach requested statistics for the two techniques
  - $\Delta b_{GT(stat)} < 1.\,10^{-3}$ can be reached in 1 week (for the 2 experiments)
- No dramatic systematic effect (yet) that could prevent to reach the goal of phase I
  - Error due to potential YAP detector non proportionality ~ 1% → to be improved
- Several significant byproducts associated to phase I
- Too early to choose between low & high energy techniques
  - Need to progress on analysis of both experiments (PhD Romain Garreau, post-doc A. Kadyan in fall 2024)
  - Redo experiment at LIRAT with shielding and reduced implantation on collimator?
- Focus now on YAP detector characterization (non-proportionality)
  - Detector studies with sources from LNHB (β and CE) (PhD G. Craveiro & post-doc A. Kadyan)
  - Detector studies with γ sources combined with scintillation light propagation simulations (internship H. Azakaye, post-docs A. Kadyan & S. Vanlangendonck)
  - Measurements with electron beam ? (ATRON, Cherbourg 0.2 MeV – 3.8 MeV)

Collaboration

PhD & Postdoc technical support

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

X. Mougeot
S. Leblond
G. Craveiro

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

T.E. Haugen
O. Naviliat-Cuncic

O. Naviliat-Cuncic

S. Vanlangendonck