Improved Search for Tensor Interactions in Nuclear Beta Decay with the b-STILED experiment

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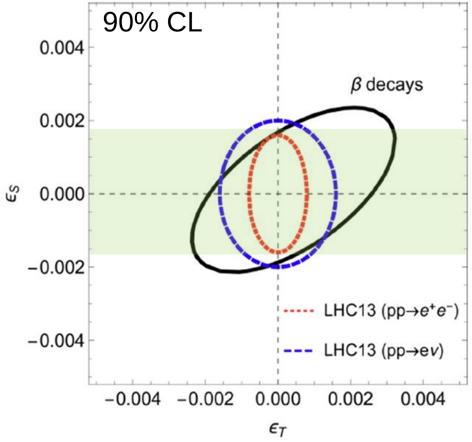
Search for BSM Physics in beta decay

- Precision measurements of Fierz interference term b in β-decay
  → sensitive to BSM Scalar (ϵ_S) and Tensor (ϵ_T) exotic couplings
  (talks by A. Garcia Wednesday and E. Liénard this morning)

  - Best constraints on ϵ_S
    Ft values in 0+→0+ transitions
    LHC *(pp → e⁺e⁻ + MET)*

  - Best constraints on ϵ_T
    dominated by
    LHC *(pp → e⁺e⁻ + MET)*

For left-handed neutrinos



A. Falkowski, M. Gonzáles-Alonso,
B. O. Naviliat-Cuncic, JHEP04 (2021)

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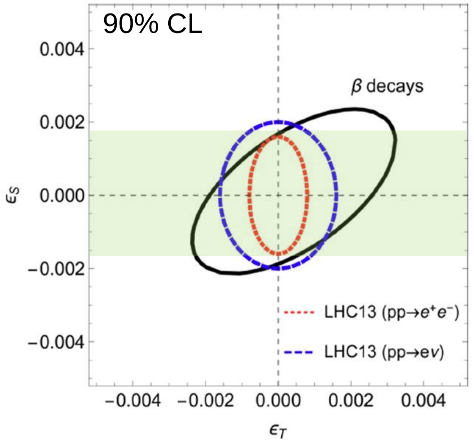

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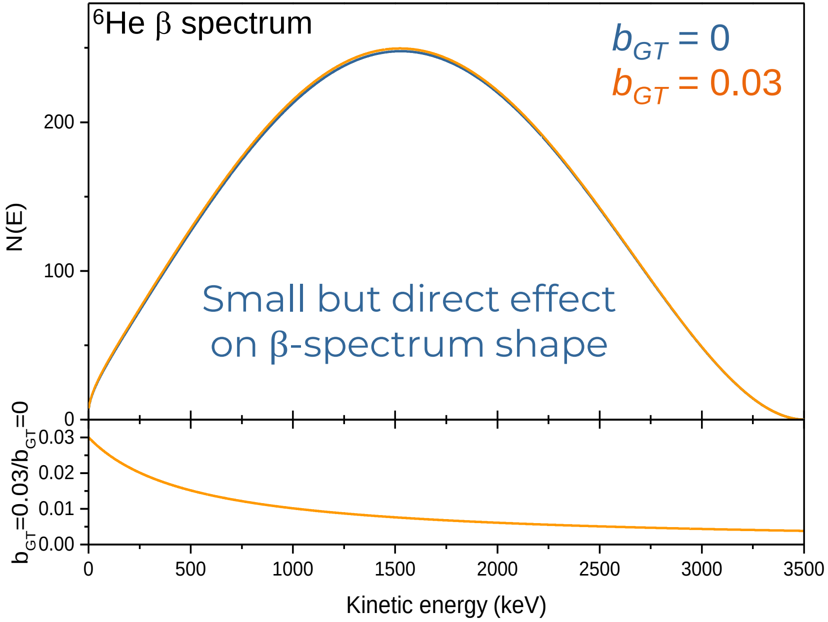
- b-STILED: b – Search for Tensor Interaction in nucLear bEta Decay
  - Measurement of the interference Fierz term b_{GT} in a pure GT transition (b_{GT} α ϵ_T)
  - Phase I (now): **Δb_{GT} = 4.10^{-3}** → present constraints from beta decay on ϵ_T
  - Phase II (future): Δb_{GT} = 1.10^{-3} → competitive with LHC

Principle of the measurement

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

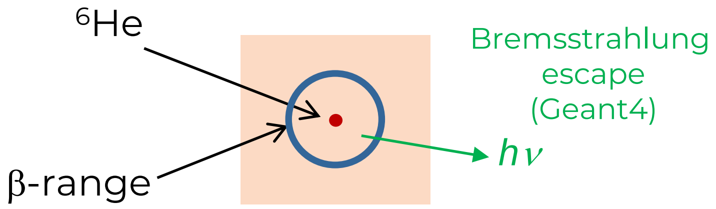
$$N(E) \propto \underbrace{F(Z,E)}_{\text{Fermi function}}\underbrace{(1+\eta)}_{\text{Theoretical corrections}}\underbrace{pE(E-E_0)^2}_{\text{Phase space}}\left(1+\frac{m_e}{E}b_{GT}\right)$$



- Choice of ^{6}He:
  - Pure GT transition
  - Precise theoretical corrections
  - $E_{\beta max}$=3.5MeV → high sensitivity
  - Convenient T1/2 of 0.8s
  - Copiously produced at GANIL

Phase I program at GANIL

- Use simple setups based on YAP scintillators (fast and linear response)
- Achieve a 4π detection geometry
  → suppress E_{loss} from β backscattering
  (main systematic effect)



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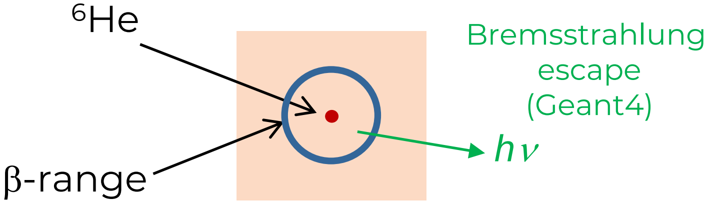
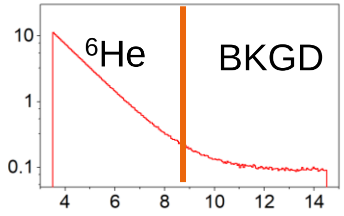
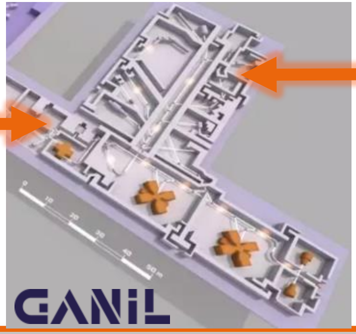


- Use implantation-decay cycles (3 s – 12 s)
  → cst BKGD subtraction
  → $T_{1/2}$ measurement for free



- Test two techniques (different systematic effects)

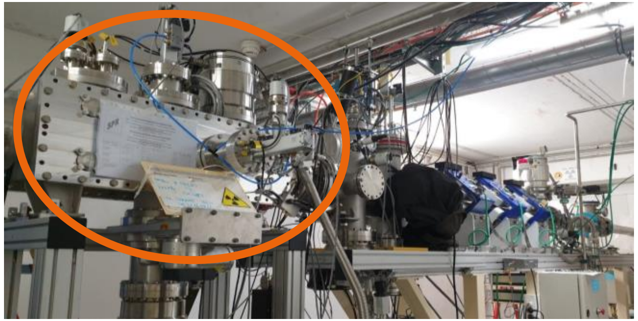
Low-energy implantation on **LIRAT**/GANIL **25 keV** ^{6}He



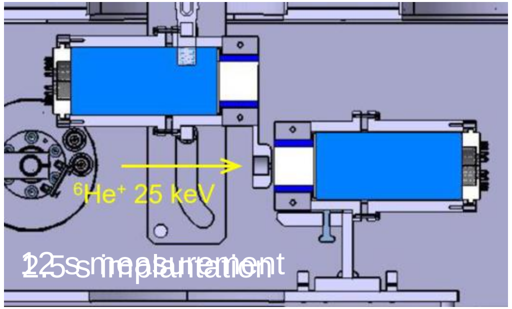
High-energy implantation on **LISE**/GANIL **312 MeV** ^{6}He

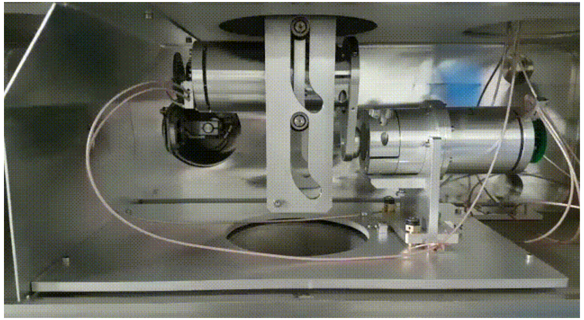
Low-energy setup

LIRAT-GANIL line, 25 keV $^{6}He^{+}$



Detection setup





M. Kanafani, PhD Thesis, UniCaen (2023)

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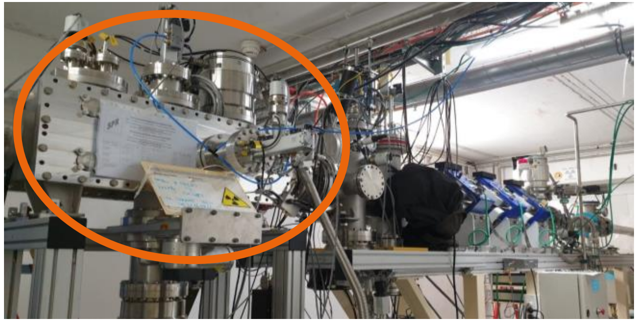

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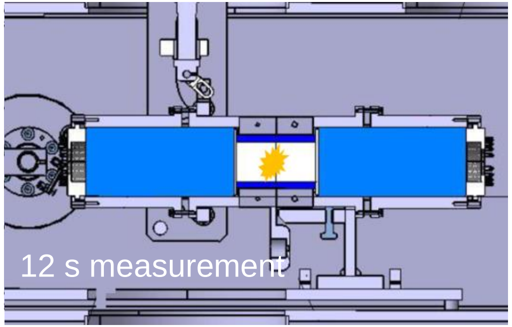
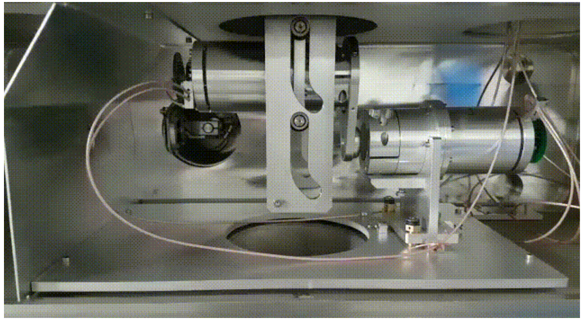




- 5 sets of measurements (for systematics):

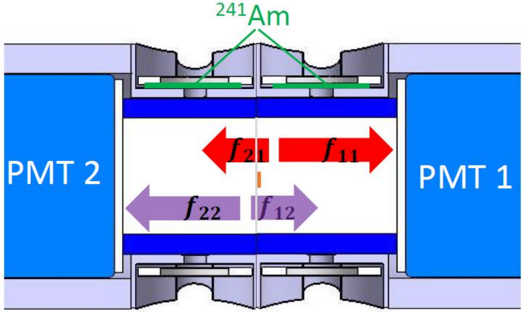
  3 sets (1,2,3) with different cycle duration, intensity, PMT voltages
  2 sets (4,5) for beam-on background (collimator obturated)

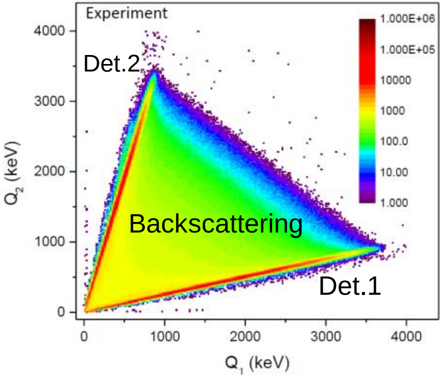
  Total stat: $4.5\times10^{7} \rightarrow \Delta b_{GT(stat)} \sim 2.8\ 10^{-3}$

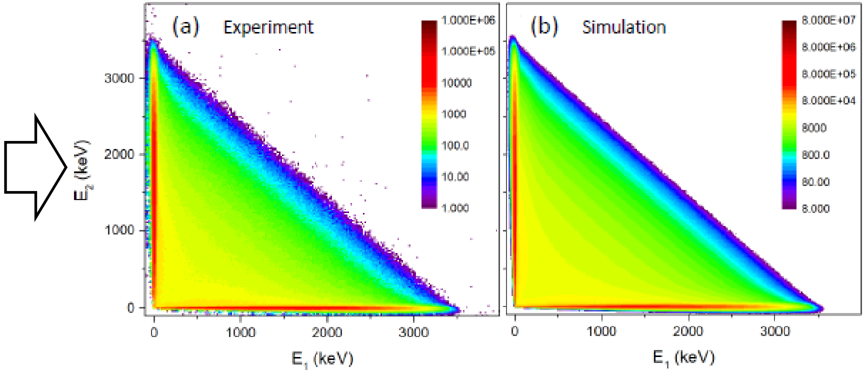
M. Kanafani, PhD Thesis, UniCaen (2023)

Low-energy experiment analysis

Light cross-talk between detectors → Simultaneous calibration and cross-talk correction→ E_1 , E_2







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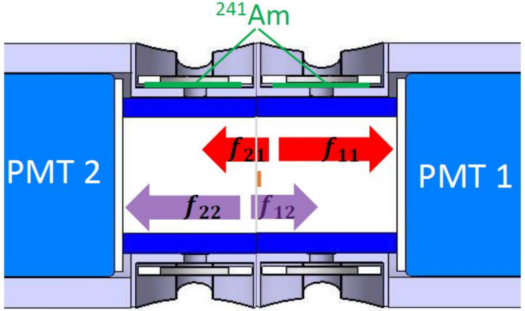
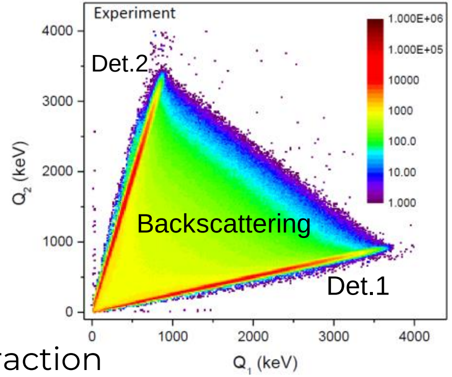
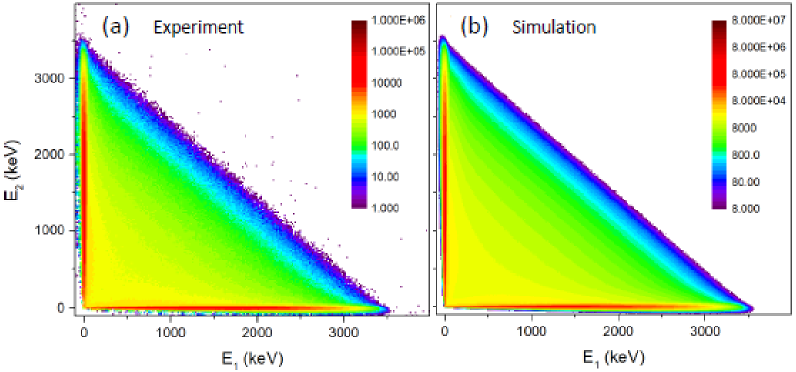
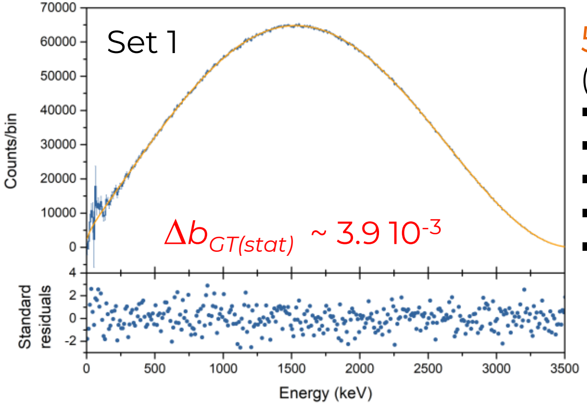






After beam-on + CST BKGD subtraction



5 free parameters fit:

(G4 simulation fit templates)

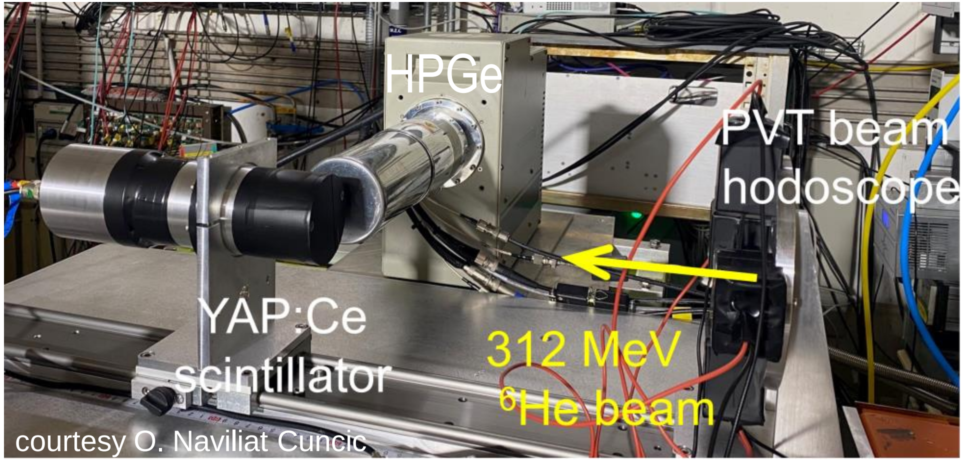
- b_{GT}
- Normalization
- Calibration slope
- Detector resolution
- On-line BKGD normalization

Discrepancies between Sets 1,2,3!!!
(Δb_{GT} ~2.10^{-2} > 3 $\Delta b_{GT(stat)}$)

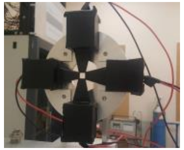
→ Strong systematic effect to be understood!
→ Suspect unstable on-line BKDG (difficult to deal with)
→ Focus on High-energy experiment

High-energy experimental setup

- Experiment at LISE - GANIL (inspired by former experiments at MSU, ^{20}F & ^{6}He)
  → 312 MeV ^{6}He nuclei implanted 9.5 mm deep into the YAP (max β-range 4mm)



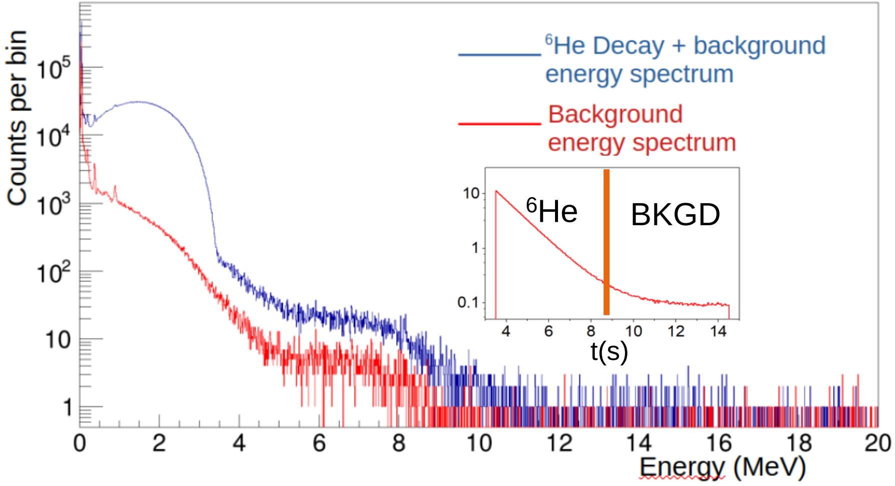
- Single YAP as main detector
  (PMT Voltage lowered during implantation → implantation energy)
- Thin PVT hodoscope
  (control implantation profile)
- HPGe
  (Beam induced contaminants)



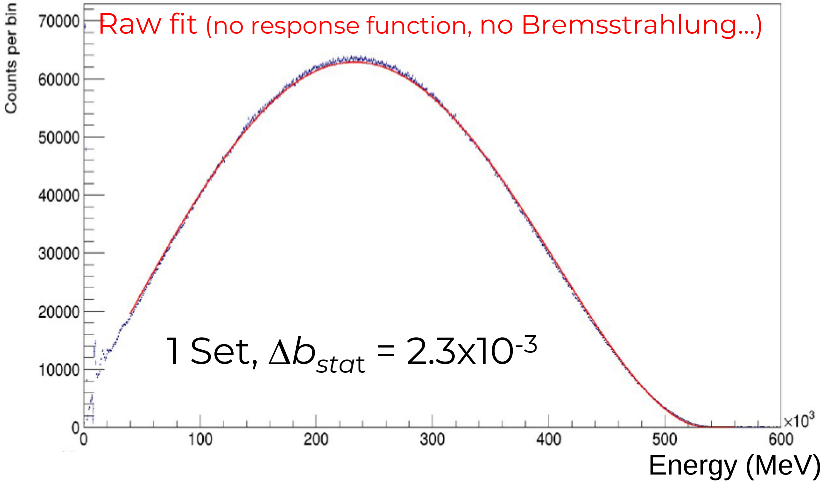
- 4 sets of measurements (2 crystal sizes, 2 distances, 2 beam intensities)
  - Excellent beam purity ($<10^{-5}$)
  - Very good beam alignment ~ 0.4% implantation beyond 6mm from center
  - 1.1×10^{8} good events → expected stat. uncertainty **$\Delta b_{GT(stat)} = 1.2 \times 10^{-3}$!!!**

Undergoing analysis

Raw calibrated spectra



Cst background subtracted spectrum



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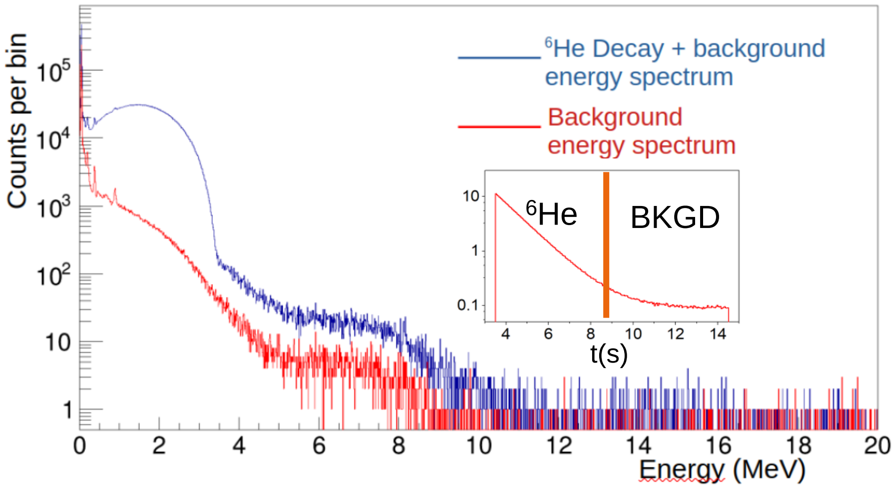

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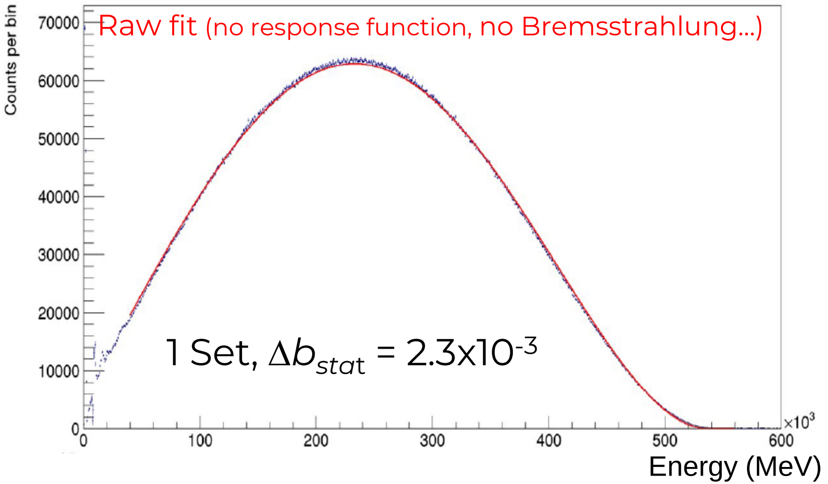


- Study of beam induced contaminants (created during implantation)
  - 909 keV gamma from ^{89m}Y (15.66s) at the 10^{-3} level
  - 5 beta emitters identified so far, with contributions at the 10^{-3} level

    ^{16}N (7.13s), ^{16}C(0.747s), ^{8}Li(0.840s), ^{20}F(11.07), ^{10}C(19.29s)

Expected impact on extraction of *b* is Δb_{syst} **< 1.0 10^{-3}**

R. Garreau, PhD Thesis, UniCaen

Perspectives for the high-energy experiment

- High statistics (almost enough for Phase II)
- Excellent beam purity
- Beam induced contaminants do not seem to be a problem
  (need to finalize this study)

- Next step: Geant4 simulations (fit templates)
- Study the other systematic effects
  (implantation region, Bremsstrahlung escape, detector response…)

Expected sensitivity: $\Delta b_{GT} \sim 10^{-2}$ (eq. to $\Delta\tilde{a}_{\beta\nu} \sim 10^{-3}$ for sensitivity to NP!)
limited by present knowledge of the detector non-proportionality
→ Better detector characterization
→ adapt technique with semiconductor detectors?

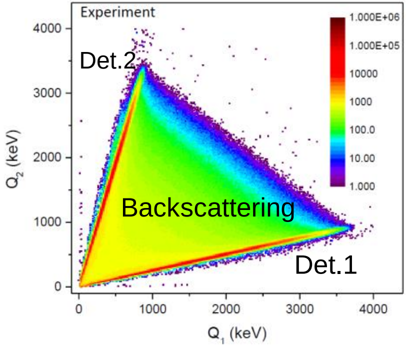
Some complementary results

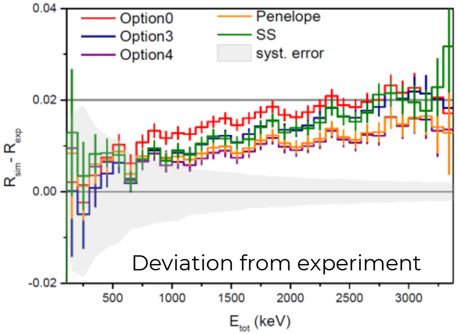
- Most precise half life measurement for ^{6}He

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

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

- Precise quantification of backscattering (0.2-3.2 MeV range)



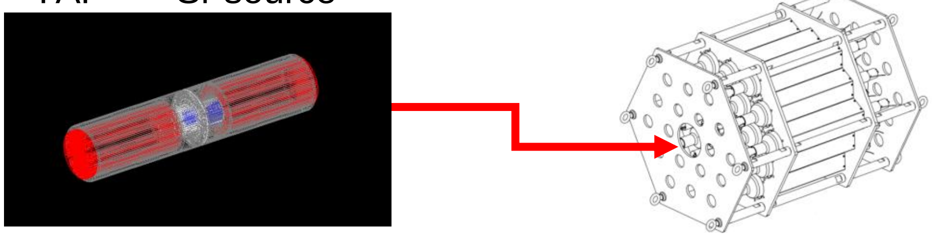


Submitted to PRC

- Bremsstrahlung escape characterization using MTAS detector @ FRIB

YAP + ^{90}Sr source

MTAS NaI ~100% efficiency



Analysis ongoing…

Thanks for your attention!

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