Precision measurements in the beta decay of ^{6}He

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Abstract

Precision measurements in nuclear beta decay have proven their capability to search for new physics beyond the standard model (SM), by looking for deviations of certain sensitive observables away from their SM predictions. The study of the full beta energy spectrum offers a great mean to search for new physics. The long-term goal of this work is to perform the most precise measurement of the beta-energy spectrum in ^{6}He decay in order to extract the Fierz interference term ***b***. This term depends linearly on the coupling constants, allowing us to search for or to constrain the presence of exotic tensor interactions in the nuclear beta decay. For this purpose, we are performing two experiments at the Grand Accélérateur National d'Ions Lourds (GANIL) with slow (25 keV) and fast (300 MeV) beams of ^{6}He. The two measurements give the possibility to study carefully systematic effects accompanying each of them. The experiment with the low energy beam was already performed in 2021. The setup of this experiment allows not only the Fierz term extraction, but also a high precision measurement of the ^{6}He half-life. The spectrum shape analysis is still in progress; however, the half-life analysis is completed resulting by the world's most precise value.

Fierz interference term "b"

Pure Gamow-teller transition ($\Delta J = 0, \pm 1$)

$$b_{GT} \propto \gamma Re\left(\frac{C_T + C_T'}{C_A}\right)$$

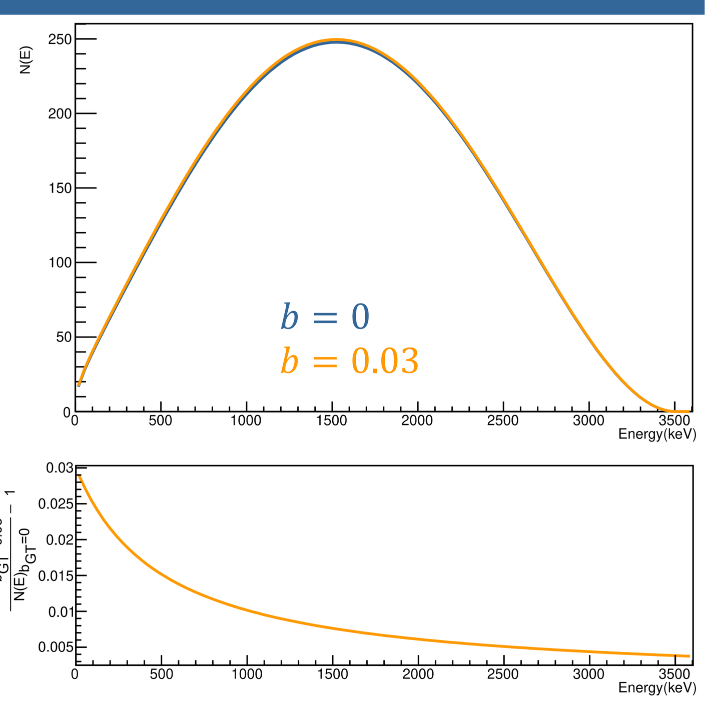
Standard Model predictions:

- $C_A \approx -1.25$
- $C_T = C_T' = 0$

$\Rightarrow$ $\boxed{b_{GT} = 0}$

$$N(E) \propto \underbrace{(1+\eta)}_{\text{Corrections term}} \underbrace{pE(E-E_0)^2}_{\text{Phase space}} \left(1 + \frac{m}{E} b_{GT}\right)$$

Low energies

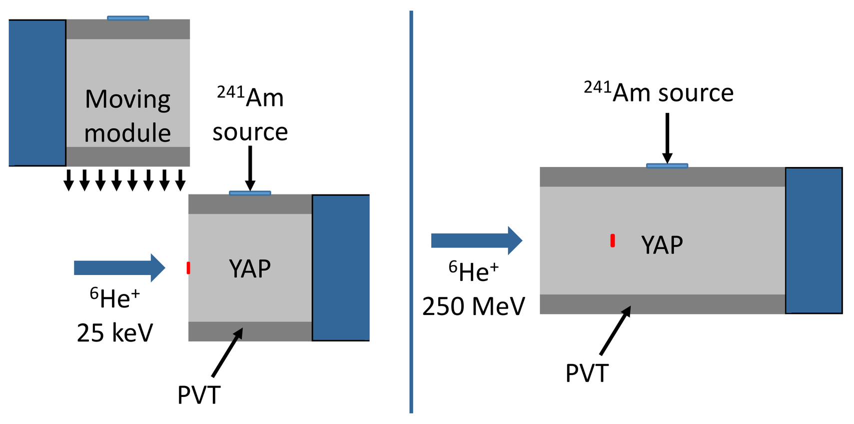


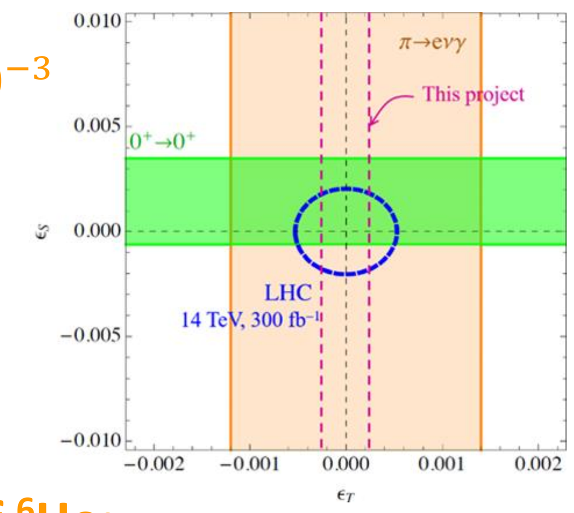
b-STILED project

GOAL $\Rightarrow$ b_{GT} for ^{6}He decay with $\Delta b_{GT} = 10^{-3}$

2 experiments (4π detection geometry):

Low energy experiment | High energy experiment





Choice of ^{6}He:

- Relatively large endpoint ~3.5MeV
- Pure GT transition (tensor currents)
- Can be produced with a high rate @GANIL
- Corrections are known with high precision

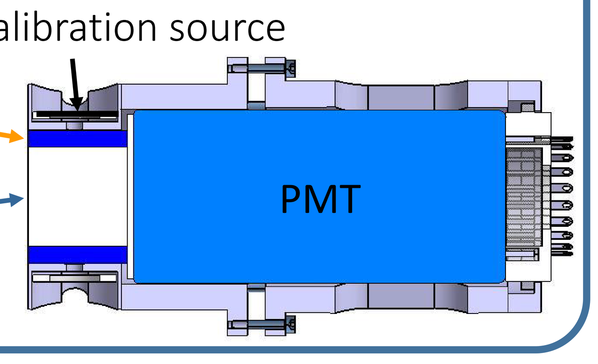
Experimental setup (Low energy experiment)

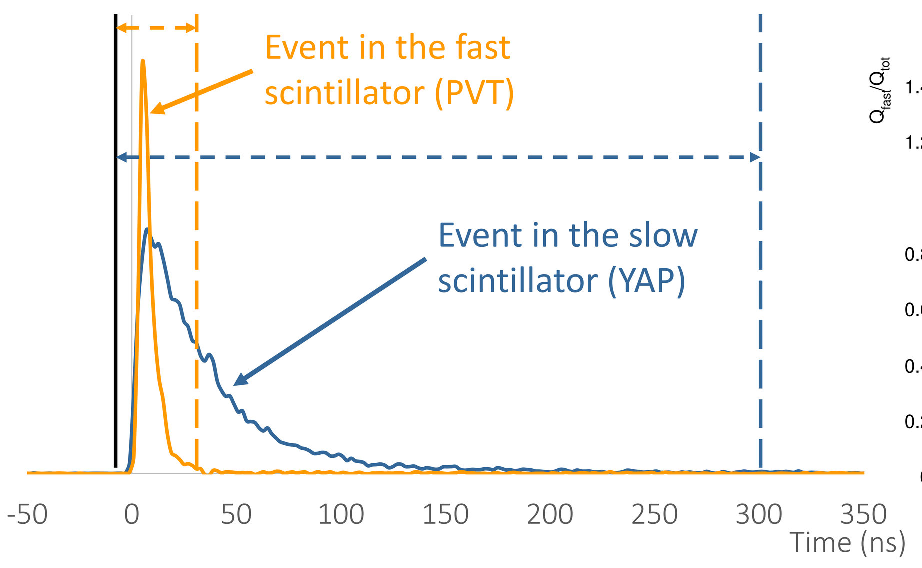
LIRAT beam line | Beam collection | Decay measurement

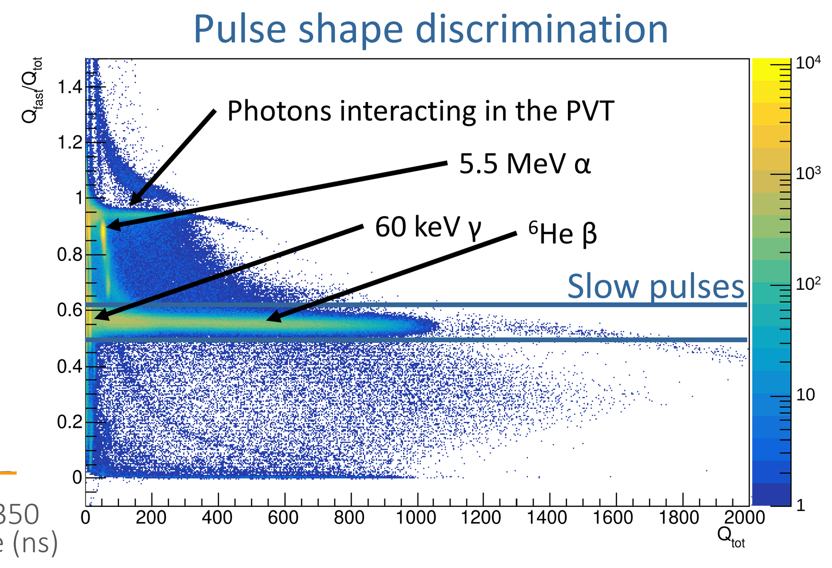
3 sets of measurements:
1) Cycles length
2) PMs polarization voltages
3) Beam intensity

DAQ:
- Time stamp
- Deposited energy

Phoswich detector:

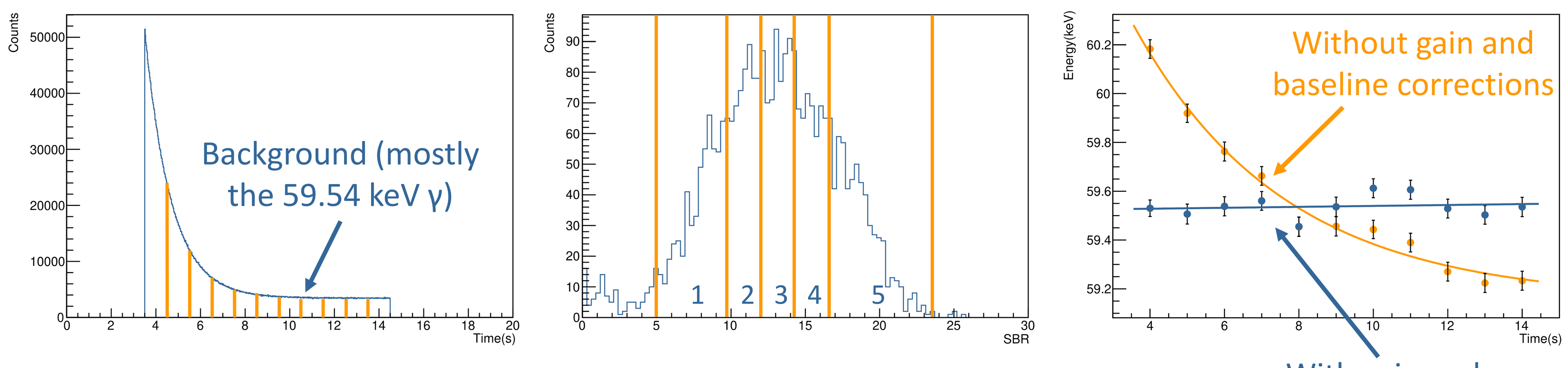




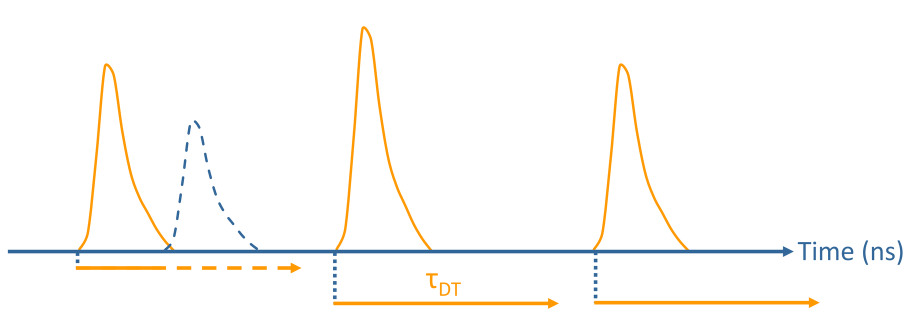


Half-life measurement

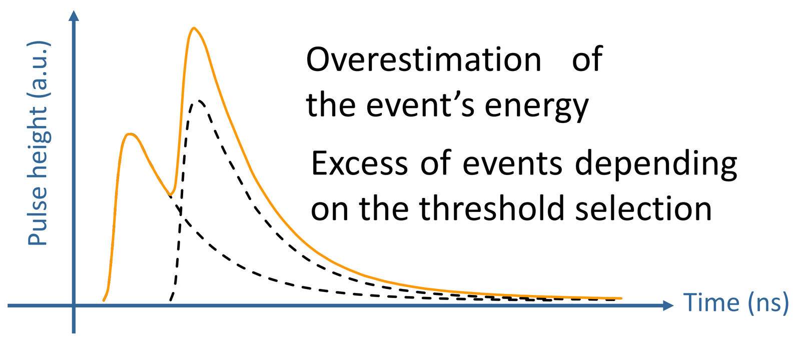
❖Gain and baseline corrections - ^{241}Am

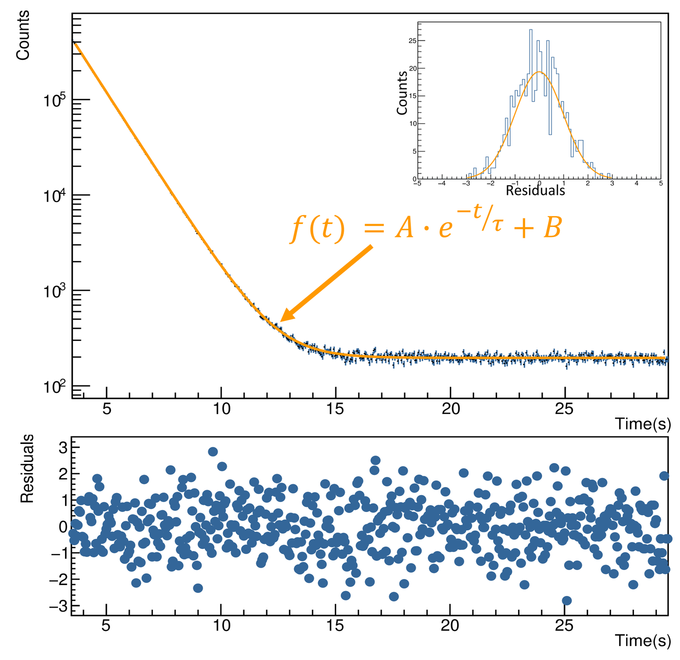


❖Non-extensible dead-time (neDT)



❖Pile-up





To compensate for these two effects, each event was given the following weight:

$$w(t) = \frac{1 + \tau_{DT} \cdot r_T(t)}{1 + \alpha_E(t)}$$

Probability to miss an event due to dead-time

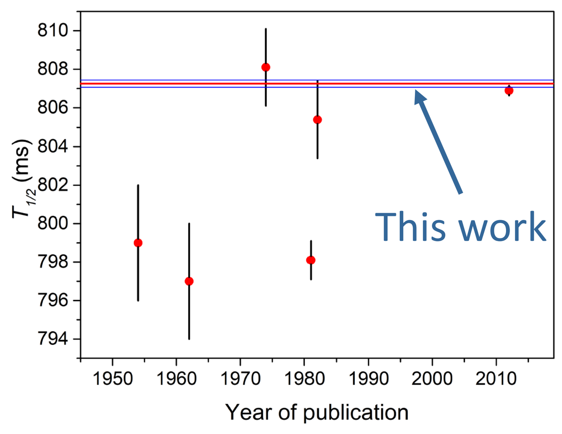
Ratio of the excess of detected events due to pile-up

Half-life result

Half-life results with the systematic corrections and errors for the 3 sets of measurements

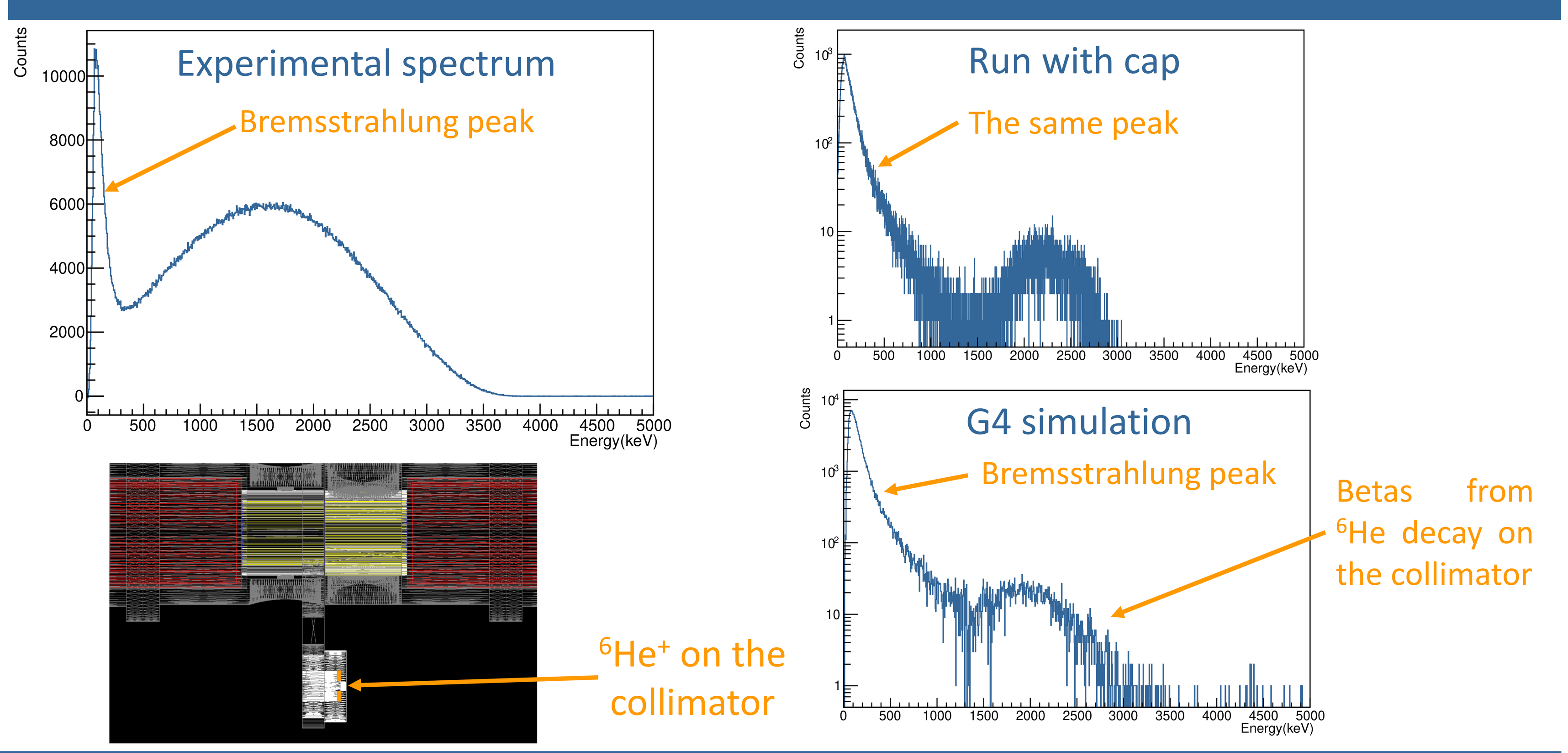
	Set (1)	Set (2)	Set (3)
$T_{1/2}$[ms]	807.42(25)	807.16(26)	807.10(35)
Gain	0.75(7)	0.77(10)	0.78(6)
Baseline	0.09(3)	0.04(2)	0.05(9)
Pile-up	0.10(1)	0.25(1)	0.11(1)
Binning	<0.01	<0.01	<0.01
Total correction	0.94(7)	1.06(11)	0.94(11)

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



M.Kanafani et al., arXiv:2207.06071 (2022)

Beta spectrum shape analysis



Summary and Outlook

Summary

- The gain and baseline corrections are crucial for measuring the half-life with a precision better than 10^{-3} sec.
- Our half-life result is in agreement with the latest two values and resolves the discrepancy between the two sets of measurements.
- The origin of the Bremsstrahlung peak within the beta spectrum is identified, and can be added to the fit function.

Outlook

- Carry on the beta spectrum shape analysis in order to extract the Fierz term.
- Parametrize the different effects affecting the beta spectrum's shape like the Bremsstrahlung peak at low energy and the Bremsstrahlung energy escape.
- Optimize the fit procedure which will be used to fit the experimental beta spectrum.

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