Amherst Center for Fundamental Interactions
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

Beta decay as a probe of new physics

Fierz interference term in nuclear decays

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NSCL
NSF
MICHIGAN STATE UNIVERSITY

Thanks to:
N. Birge, L. Broussard, N. Fomin, A. García, X. Fléchard, E Liénard, N. Severijns

General Context

Mainly two ways to search for the presence of the Fierz term in beta decay observables:

- "Indirect" searches (*Ft*-values, correlation coefficients), integrated or differential:

$$\tilde{X} = \frac{X}{1 + b\langle m_e/E_e \rangle}$$

- "Direct" searches (spectrum shape):

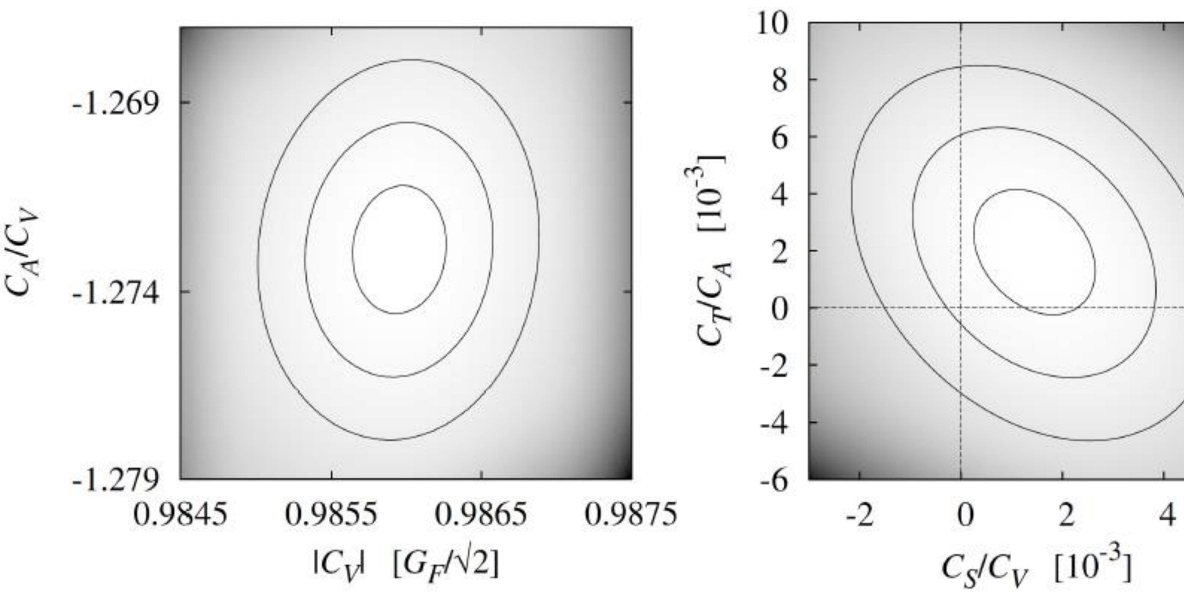
$$\left(1 + b\,\frac{m}{W}\right)$$

Current status of S and T constraints

- "Minimal fit" (LH-ν)

M. Gonzalez-Alonso, O.N.C., N. Severijns,
Prog. Part. Nucl. Phys. in print (2018)
arXiv:1803.08732

- From <u>contributions of the Fierz</u> term to $Ft(0^+ \to 0^+)$, τ_n and A_n



- Other neutron and nuclear data have very small impact.
- Constraint on Tensor is ~2 weaker than on Scalar.

Benchmark uncertainties

- How good we need to measure?…

M. Gonzalez-Alonso, O.N.C, N. Severijns, Prog. Part. Nucl. Phys. in print (2018) arXiv:1803.08732

Coefficient	Absolute uncertainty	Relative uncertainty	SM value
b_n	3.2×10^{-3}		0
a_n	4.7×10^{-4}	4.4×10^{-3}	$-0.10648(19)$
$\tilde{a}_n$	6.4×10^{-4}	6.1×10^{-3}	$-0.10648(19)$
A_n	5.9×10^{-4}	5.0×10^{-3}	$-0.11935(24)$
$\tilde{A}_n$	7.8×10^{-4}	6.5×10^{-3}	$-0.11935(24)$
$\tilde{B}_n$	1.2×10^{-4}	1.2×10^{-4}	$0.98713(5)$
b_F	2.3×10^{-3}		0
b_{GT}	3.9×10^{-3}		0
a_F	6.4×10^{-6}	6.4×10^{-6}	1
$\tilde{a}_F$	4.7×10^{-4}	4.7×10^{-4}	1
a_{GT}	4.0×10^{-6}	1.2×10^{-5}	$-1/3$
$\tilde{a}_{GT}$	3.7×10^{-4}	1.1×10^{-3}	$-1/3$

- …to impact couplings in β decay.
- (complementarity/competition with HE not considered here)

Sensitivity of recent indirect searches

- "Dedicated" (KU-Leuven): low temperature nuclear orientation

F. Wauters et al., Phys. Rev. C **80** (2009) 062501(R): $\tilde{A}$ in ^{114}In, $\Delta b_{GT} \sim 7\%$ (1σ)

F. Wauters et al., Phys. Rev. C **82** (2010) 055502: $\tilde{A}$ in ^{60}Co, $\Delta b_{GT} \sim 3.5\%$ (1σ)

G. Soti et al., Phys. Rev. C **90** (2014) 035502: $\tilde{A}$ in ^{67}Cu, $\Delta b_{GT} \sim 5.1\%$ (1σ)

…no impact on constraints

- "Opportunistic" (TRIUMF): polarized atoms in MOT

M. Anholm et al., DNP Meeting 2018, Hawaii: $\tilde{A}$ in ^{37}K, $\Delta b_{\text{mix}} \sim 4\%$ (1σ)

Current direct searches and plans

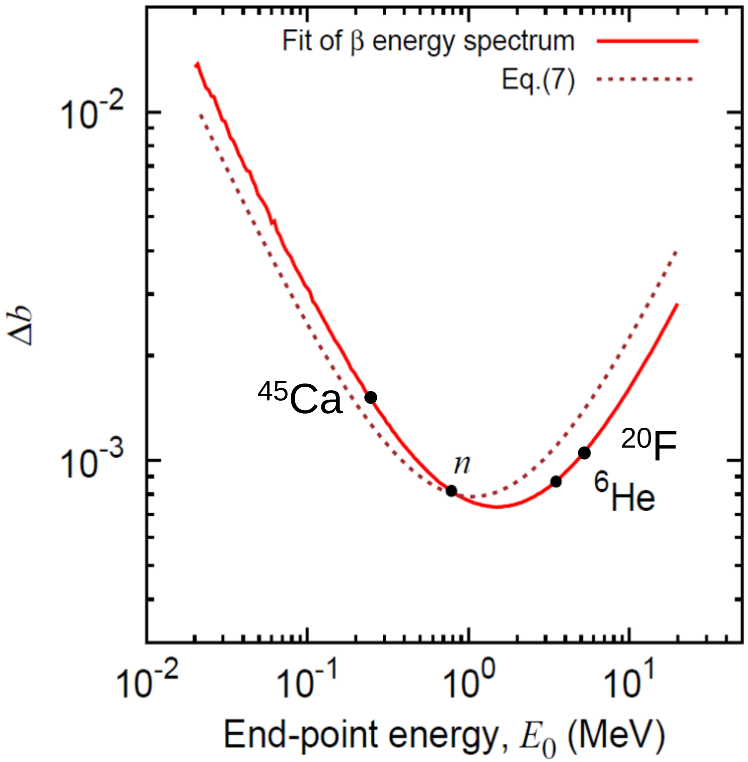
…explicitly considering the determination of b_{GT}

Isotope	Method	Lab/Institution
^{6}He	thin foil; 4π detector	GANIL/LPC-Caen
???	MWDC+scintillators	Krakow, Leuven
^{45}Ca	source in UCNA spectr.	UT, ORNL, NCSU, KUL++
^{6}He	CRES	UW, ANL++
^{6}He, ^{20}F	Calorimetry	NSCL/MSU, Wittenberg

Selection of candidates

Kinematic sensitivity

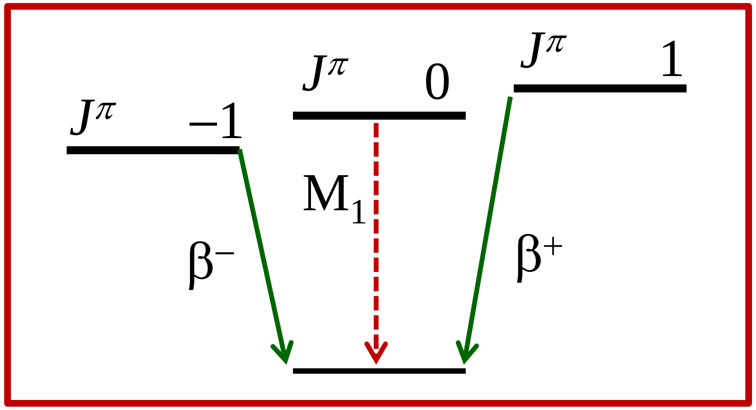
Uncertainty for 10^8 events
(assuming fit from 5% to 95% of end-point)



M. Gonzalez-Alonso and O. N.-C
PRC **94** (2016) 035503

Hadronic corrections

In an isospin triplet, the weak magnetism form factor can be determined from CVC



Candidates

^{6}He ^{20}F

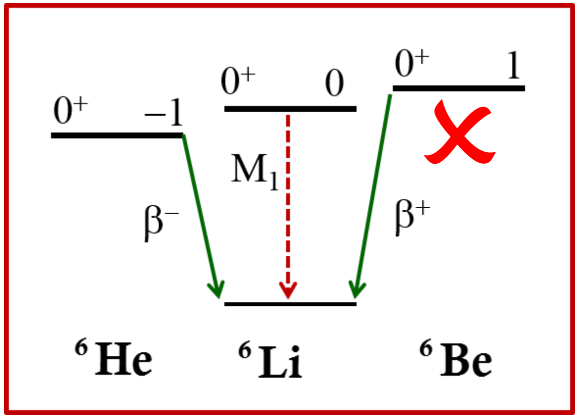
Sensitivity to form factors in ^{6}He

- Sensitivity to induced tensor: $$\frac{\Delta b_{GT}}{\Delta d} = 1.8\times10^{-5}$$
- Sensitivity to weak magnetism: $$\frac{\Delta b_{GT}}{\Delta b_{WM}} = 4.2\times10^{-4}$$

$$b_{WM} = \sqrt{\frac{6\Gamma_{M1}M^2}{\alpha E_\gamma^3}} = 68.22(79) \quad \Rightarrow \quad \Delta b_{GT} = 3.4\times10^{-4}$$

(Due to uncertainty on WM, $\Delta b_{WM} = 0.79$)

- In A=6 it is not possible to determine d experimentally from comparison with mirror decay.
- Calculation: d=2.4, F. Calaprice, PRC **12** (1975) 2016



Sensitivity to form factors in ^{6}He

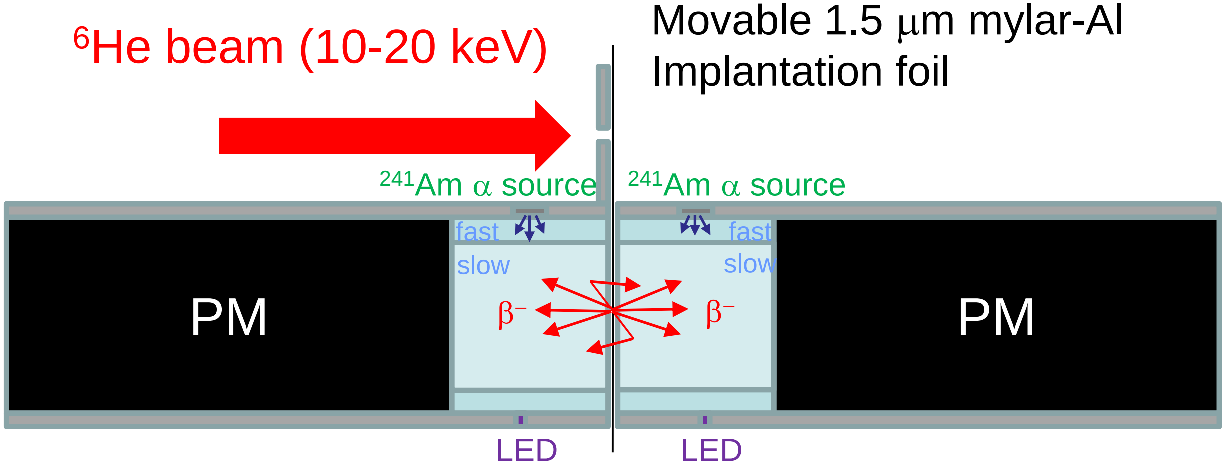
- In the decays of A=8, 12, and 20 triplets, it is observed (Barry's talk) that $d \approx b_{WM}$.

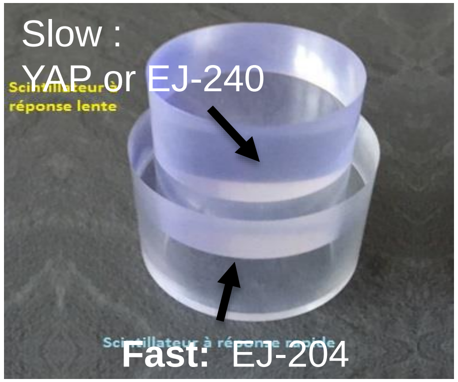
- There is no obvious explanations why d is suppressed in ^{6}He.

- If the error on d would be $\Delta d = 68.22 - 2.4$ then we get $\Delta b_{GT} =$ 1.3×10^{-3} !!!

^{6}He at GANIL

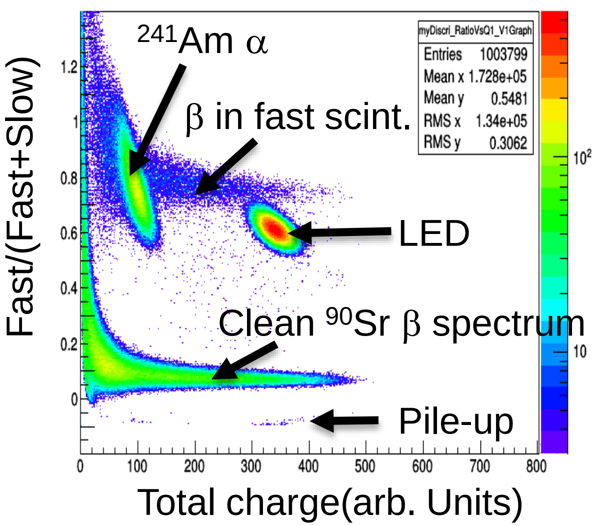
Courtesy: X. Flechard





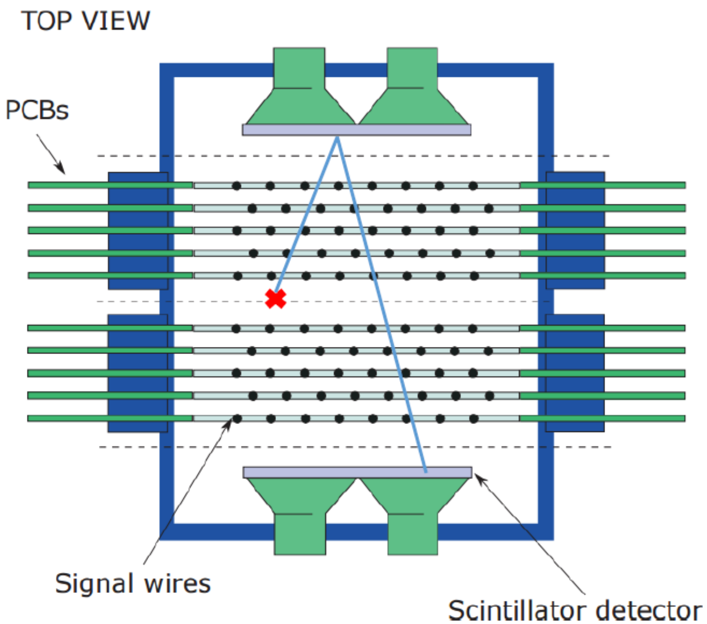
Calibration with ATRON electron accelerator

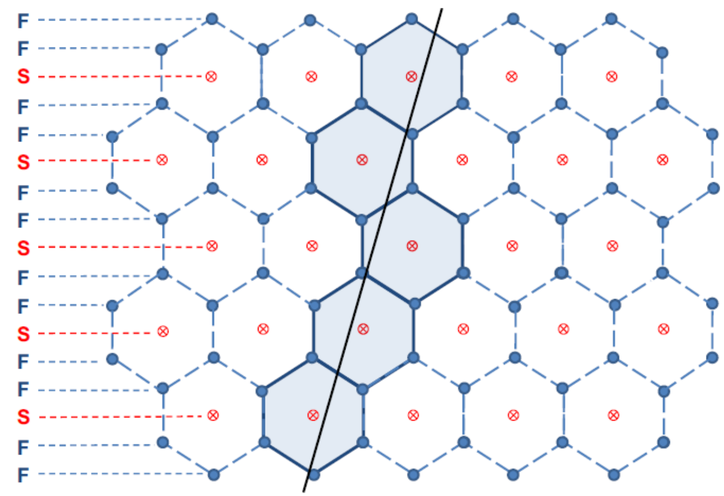
Tests with ^{90}Sr β source
EJ-240 & EJ-204 scintillators



miniBETA (Leuven, Krakow)

Courtesy: N. Severijns
(M. Perkowski, Mazurian Lakes Conf. 2017)

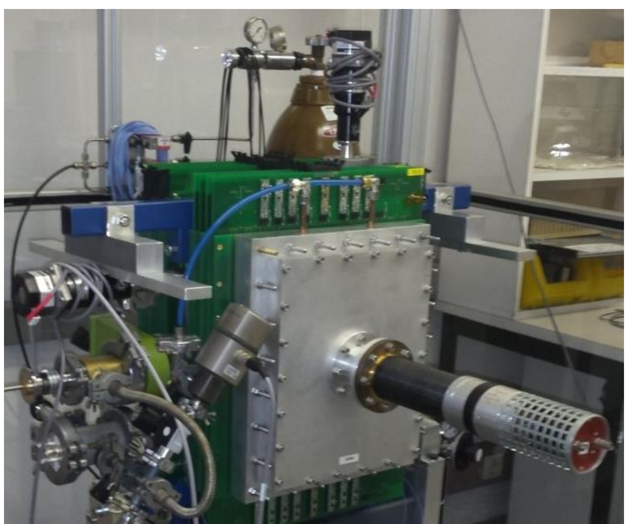




- Beta source inside detector
- Trigger with plastic scintillators
- Track with MWDC

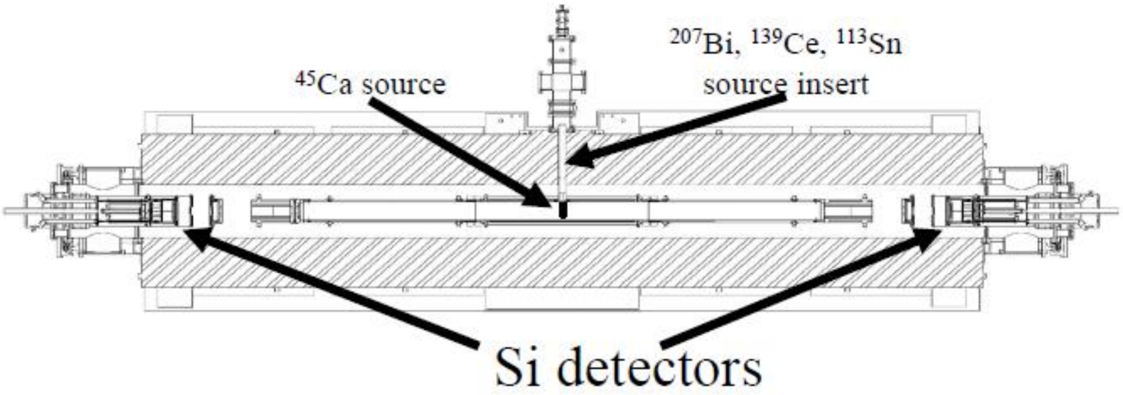
- Tested with cosmics:
- average efficiency ~90%
- position resolution ~0.5mm

- (not clear what source will be used)

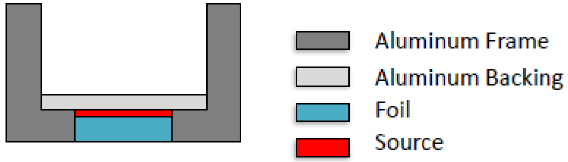


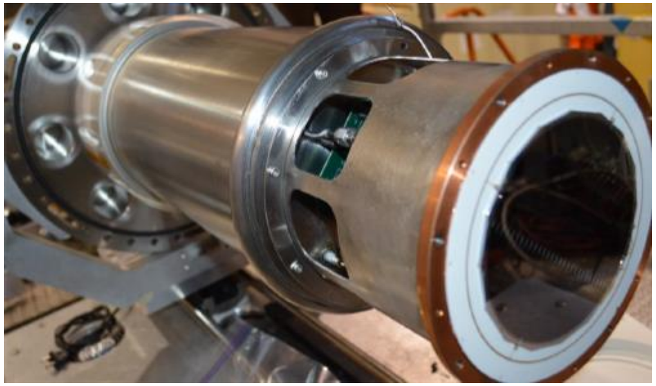
^{45}Ca at LANL

Courtesy: N. Birge, N. Fomin



Source geometry





- Recorded waveforms for each pixel
- 10^8 events collected

- Single crystal Si
- 100 nm dead layer
- 1.5 mm thick

- MC simulations under way
- Analysis in progress including corrections for cross-talk, backscattering, etc.

Courtesy: A. Garcia

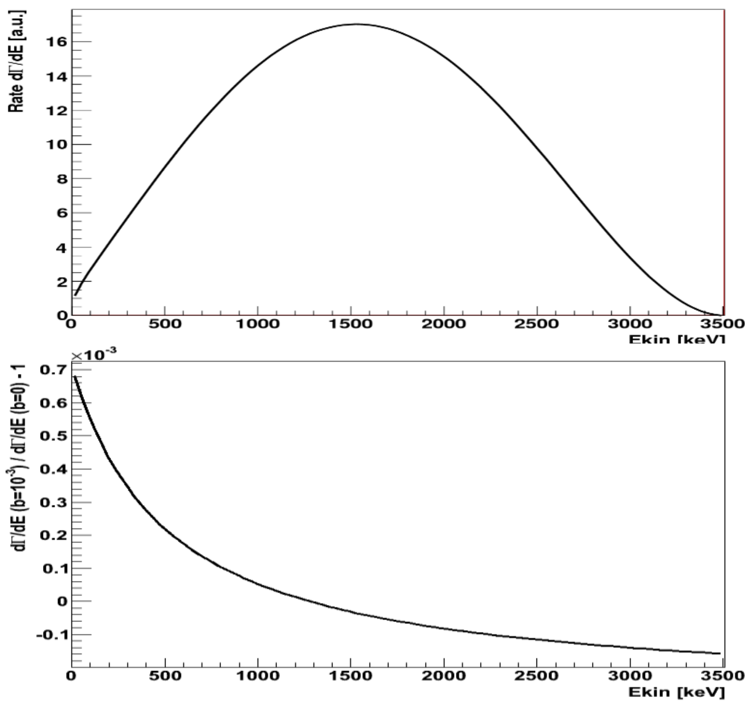
^{6}He little-b measurement at UW

W. Byron[1], M. Fertl[1], A. Garcia[1], G. Garvey[1], B. Graner[1], M. Guigue[2], A. Leredde[3], P. Mueller[3], N. Oblath[2], R.G.H. Robertson[1], G. Rybka[1], G. Savard[3], D. Stancil[4], H.E. Swanson[1], B.A. Vandeevender[2], F. Wietfeldt[5], A. Young[4]

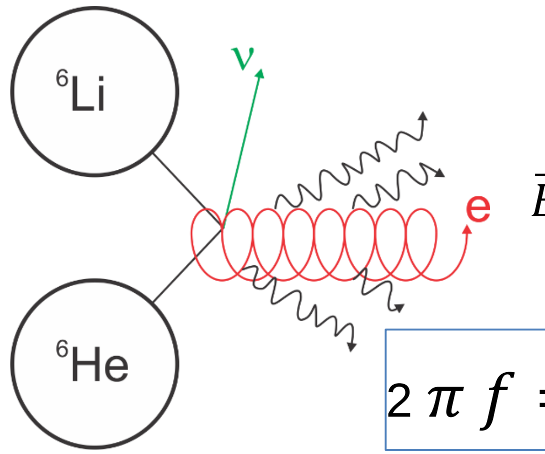
[1]*University of Washington*, [2]*Pacific Northwest National Laboratory*, [3]*Argonne National Lab*, [4]*North Carolina State University*, [5]*Tulane*

Goal: measure "little *b*" to 10^{-3} or better in ^{6}He

Stats not a problem.

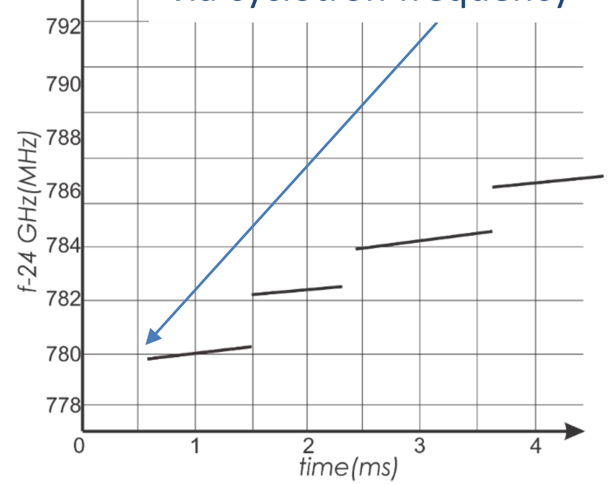


Use cyclotron radiation spectroscopy.
Similar to Project 8 setup for tritium decay.
PRL **114**, 162501 (2015)



$$2\pi f = \frac{q\,B\,c^2}{E}$$

Determine e's energy at birth via cyclotron frequency



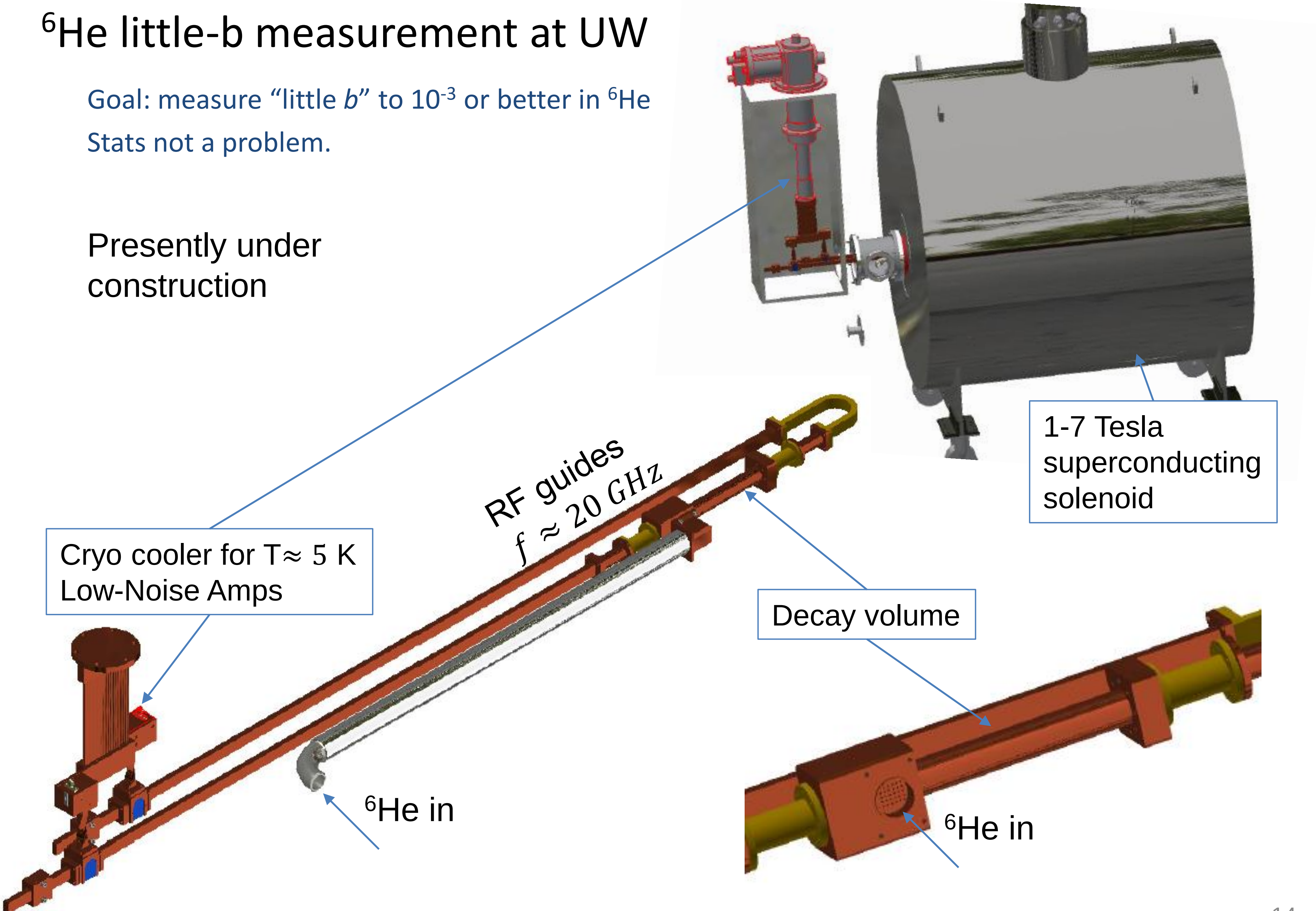
Courtesy: A. Garcia

^{6}He little-b measurement at UW

Goal: measure "little *b*" to 10^{-3} or better in ^{6}He

Stats not a problem.

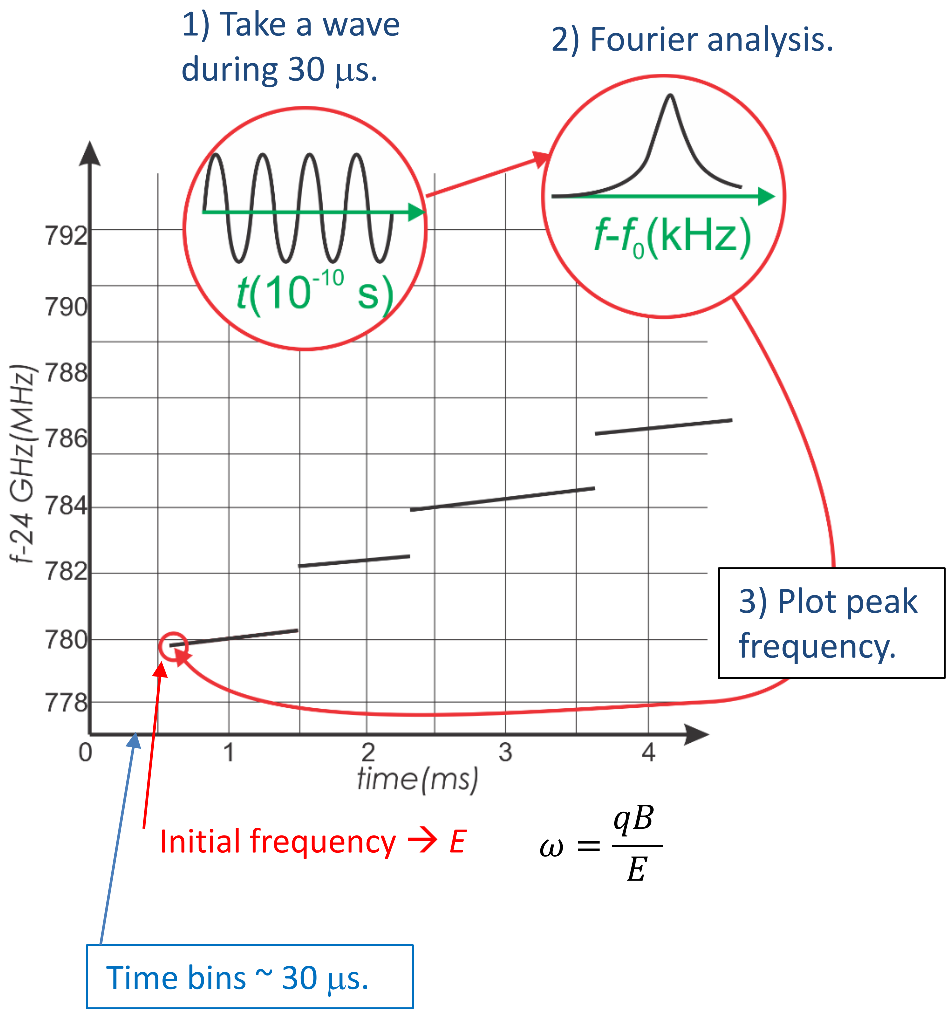
Presently under construction



Courtesy: A. Garcia

Why do we like the Project-8 technique for ^{6}He?

- Measures beta energy at creation, before complicated energy-loss mechanisms.
- High resolution allows debugging of systematic uncertainties.
- Room photon or e scattering does not yield background.
- 6He in gaseous form works well with the technique.
- 6He ion-trap (shown by others to work) allows sensitivity higher than any other proposed.
- Counts needed not a big demand on running time.



Courtesy: A. Garcia

We have put together a collaboration, written and submitted a proposal.
Now kick-started by DOE and UW funds.

Phase I: proof of principle
2 GHz bandwidth.
Show detection of cycl. radiation from 6He.
Study power distribution.

Phase II: first measurement ($b < 10^{-3}$)
6 GHz bandwidth.
6He and 19Ne measurements.

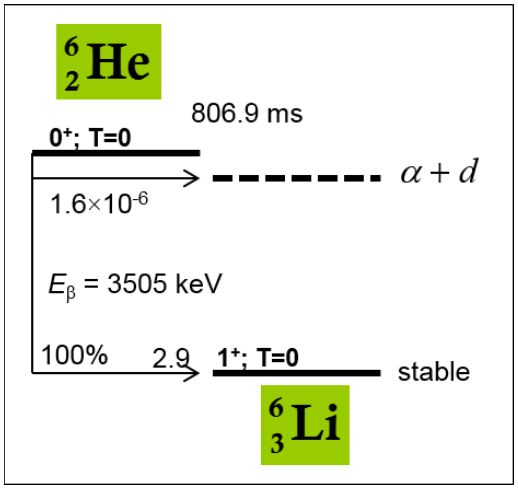
Mission until Aug. 2020 (Phases I and II)

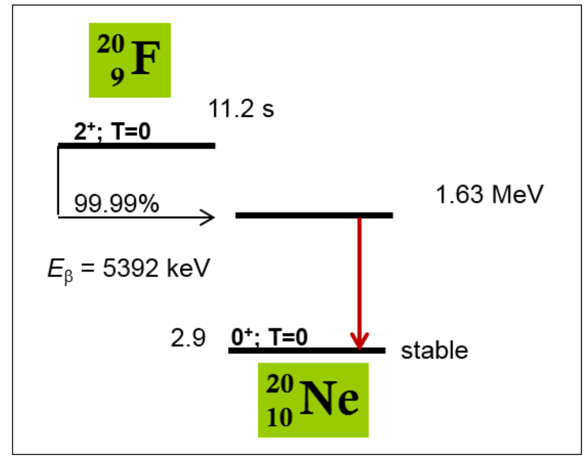
Phase III: ultimate measurement ($b < 10^{-4}$)
ion-trap for no limitation from geometric effect.

Calorimetric technique at NSCL

MSU: M. Hughes, X. Huyan
U.Witt: E. George, P. Voytas

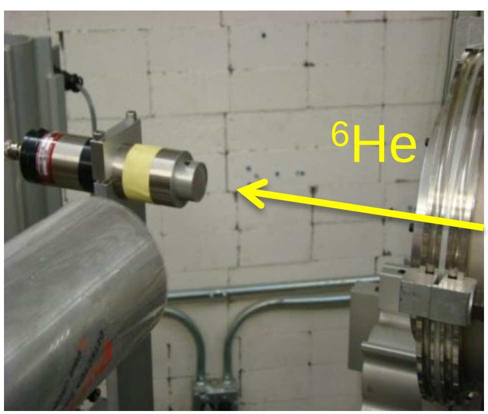
- Eliminates effect of electron backscattering from detectors
- Chopped beam: implantation/decay



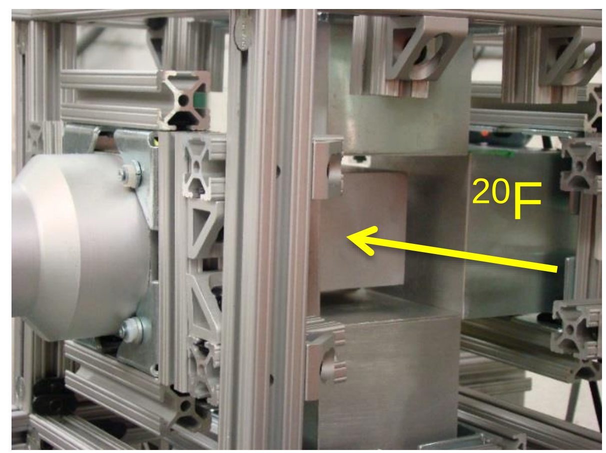


From workshop at ACFI

CsI(Na)
NaI(Tl)



46 MeV/nucleon

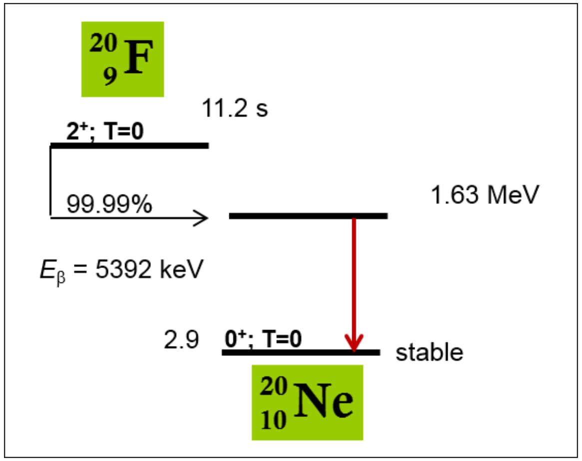


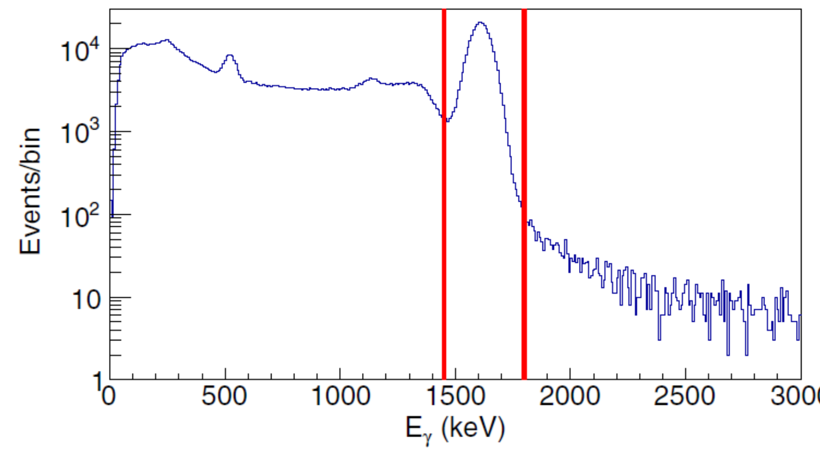
CsI(Na)
PVT

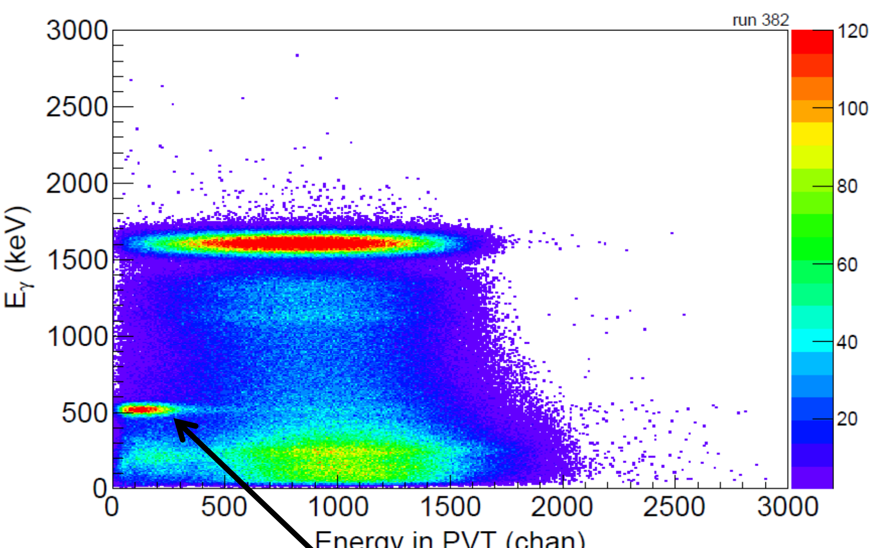
132 MeV/nucleon

Data from ^{20}F

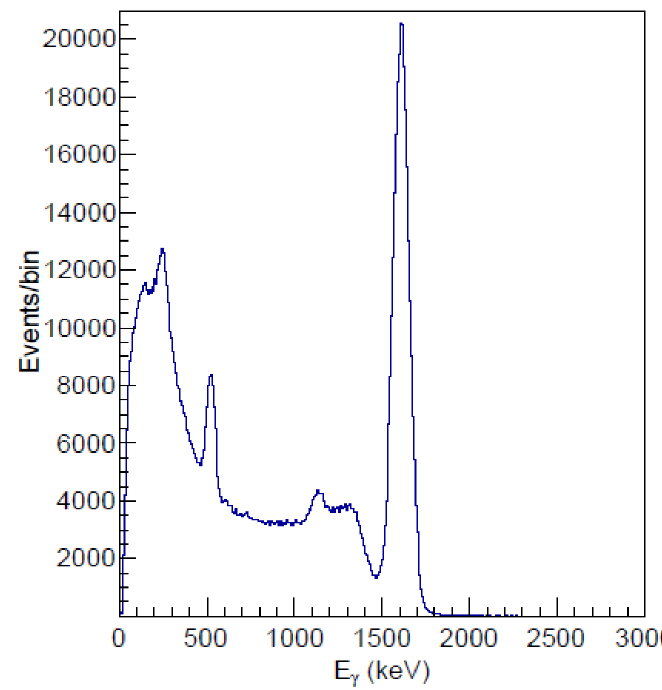
M. Hughes et al. PRC **97** (2018) 054328



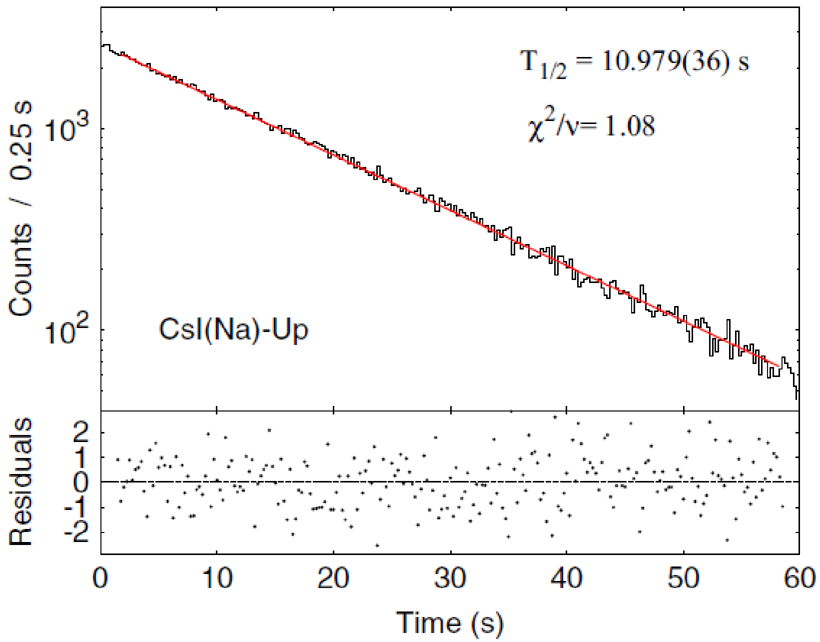




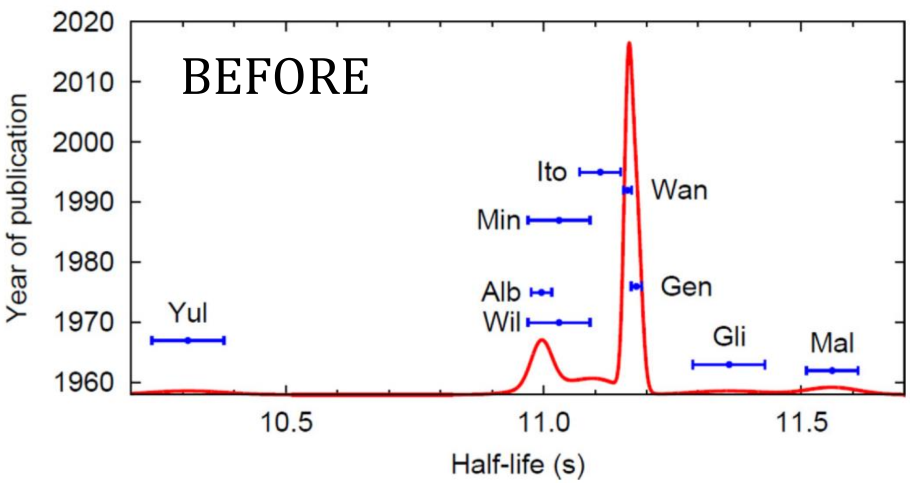
^{10}C, ^{11}C beam induced background



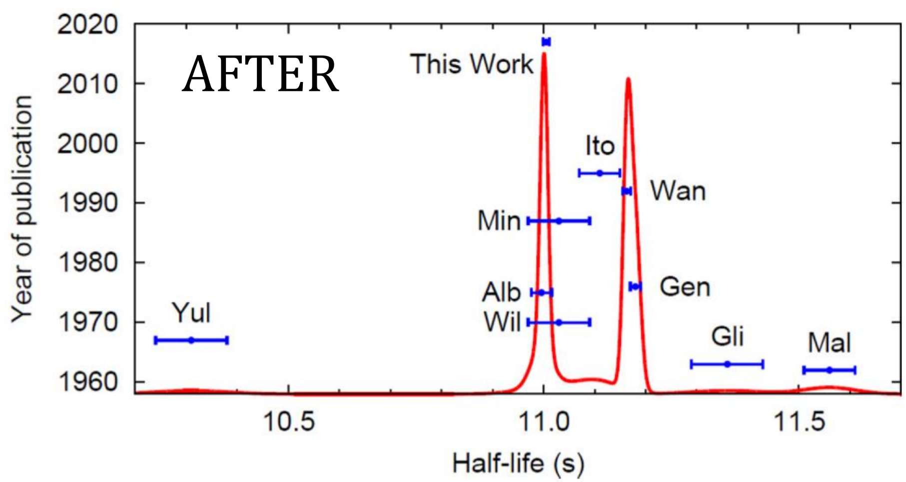
^{20}F half-life



M. Hughes et al. PRC **97** (2018) 054328

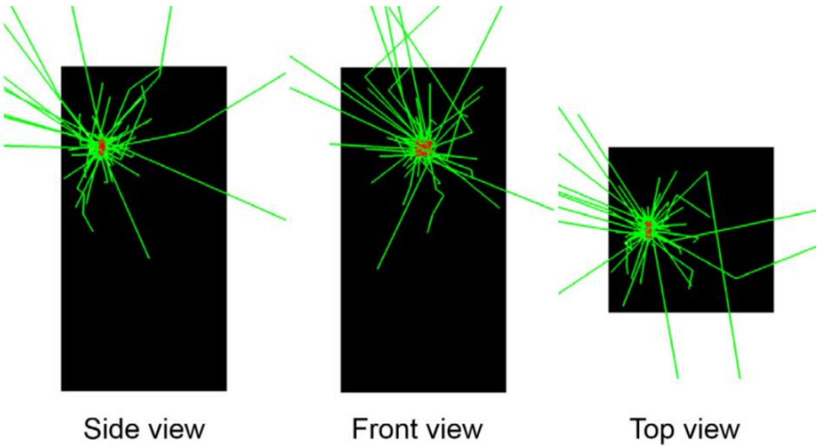


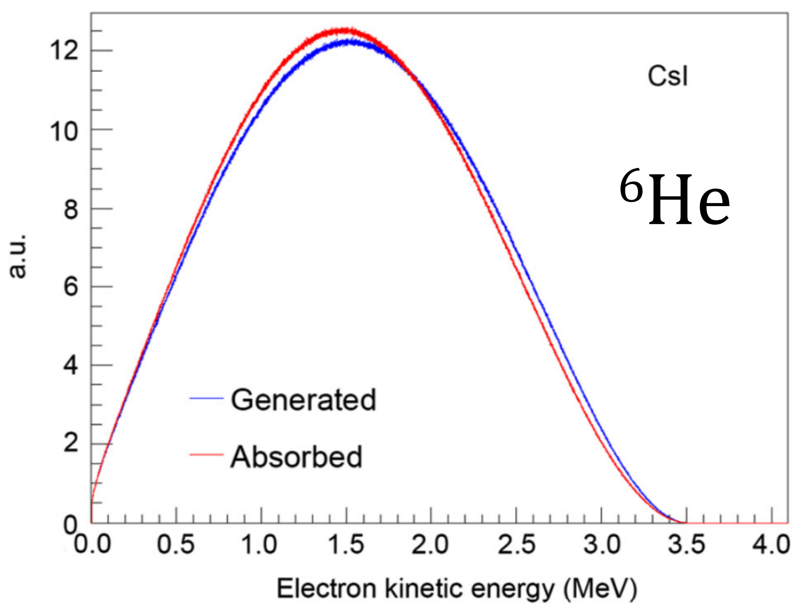
17 combined std. dev. discrepancy!



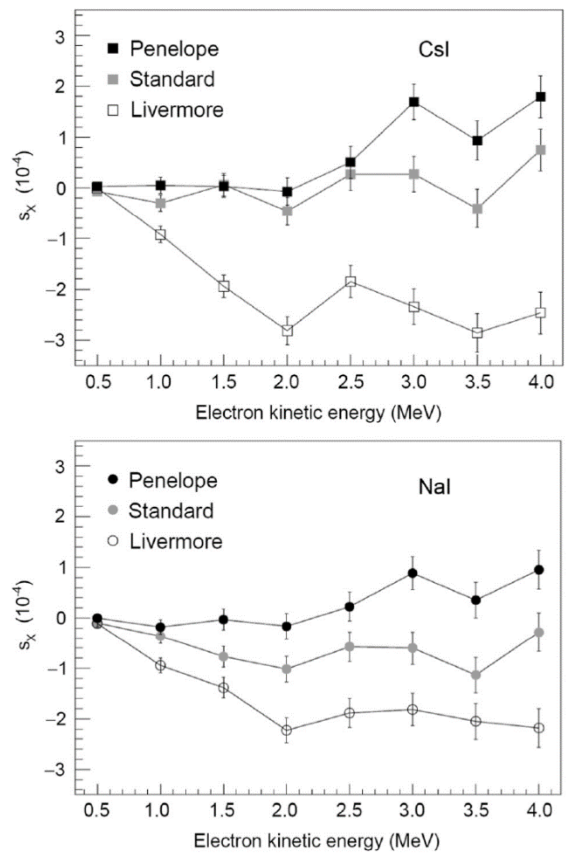
- Our result was confirmed by group from Notre Dame.
- Level of uncorrelated background is smaller than 8×10^{-6}

Escape of Bremsstrahlung radiation





X. Huyan et al. NIMA **97** (2018) 054328



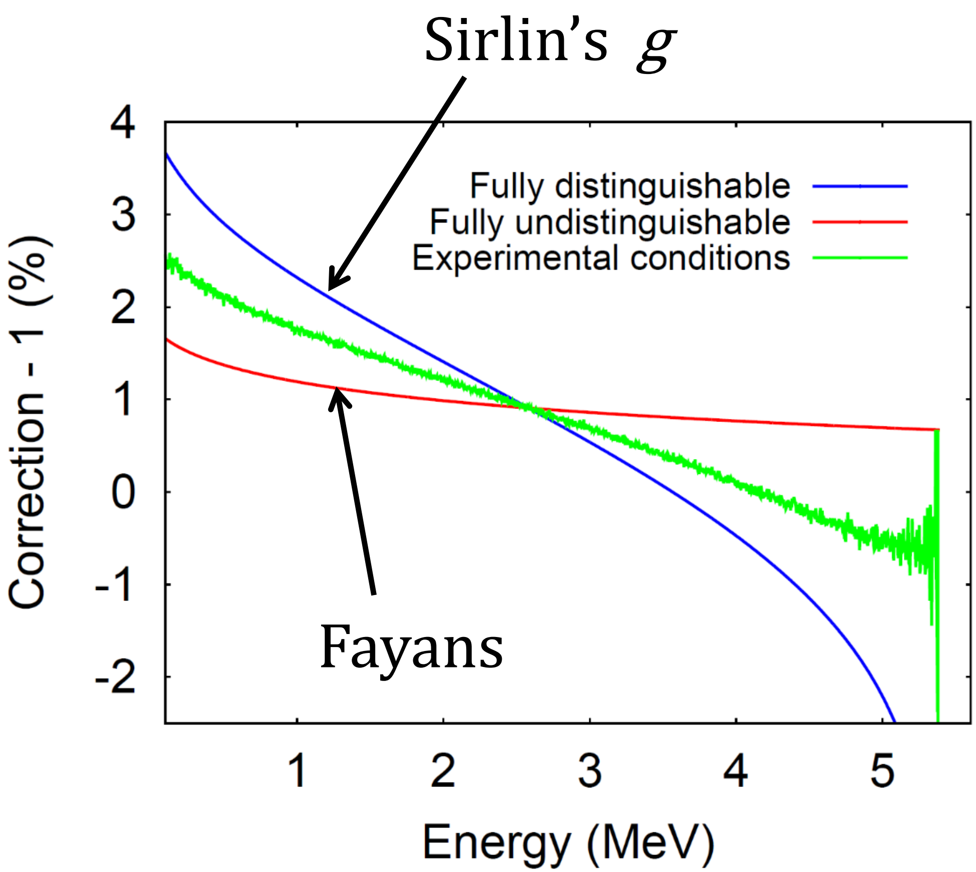
(relative to Option4)

For ^{6}He spectrum, the differences correspond to about 5% of the linear term due to WM.

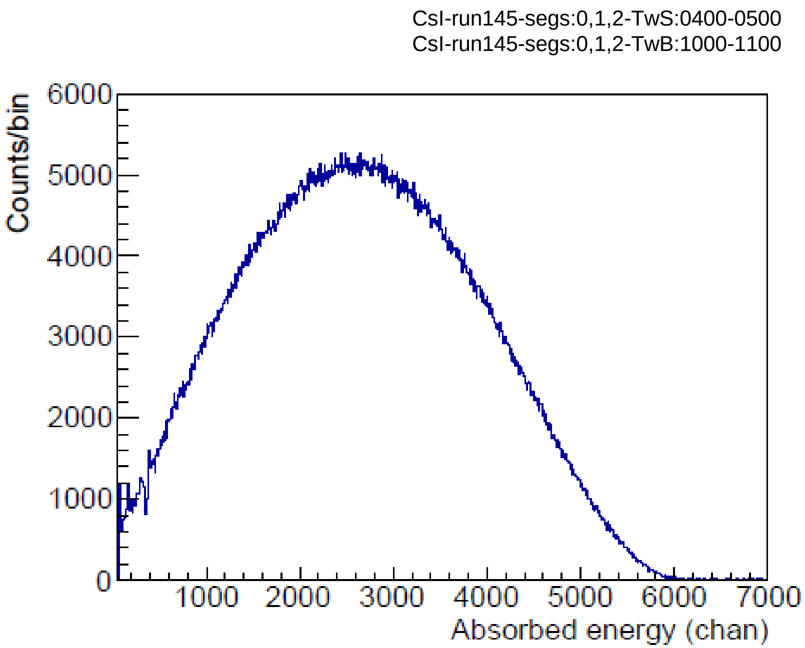
Radiative corrections

Theoretical corrections to phase space

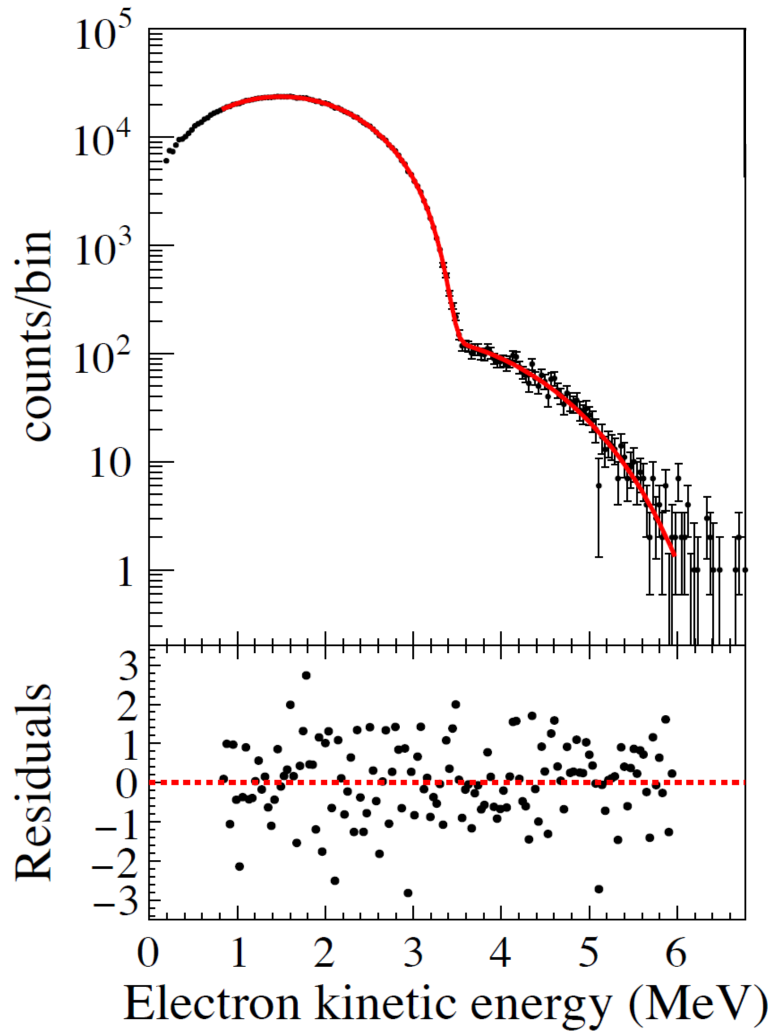
^{20}F decay



Example of fit in ^{6}He



X. Huyan



~100 independent spectra collected with CsI(Na) and NaI(Tl)

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Status and Outlook

- Current level of statistical sensitivity:

  - 3×10^{-3} for ^{20}F
  - 1.5×10^{-3} for ^{6}He (with CsI and NaI detectors)

- Uncorrelated background in ^{20}F is negligible but the effect of summing due to Bremsstrahlung and 1.6 MeV photon in implantation detector makes the analysis more complicated.

- New beam request for ^{6}He is in preparation.

Summary

- Several innovative experimental approaches are considered to reach new levels of sensitivity for the measurements of the Fierz term.

- "Which experimental approaches provide the most promising probes for new physics…"?