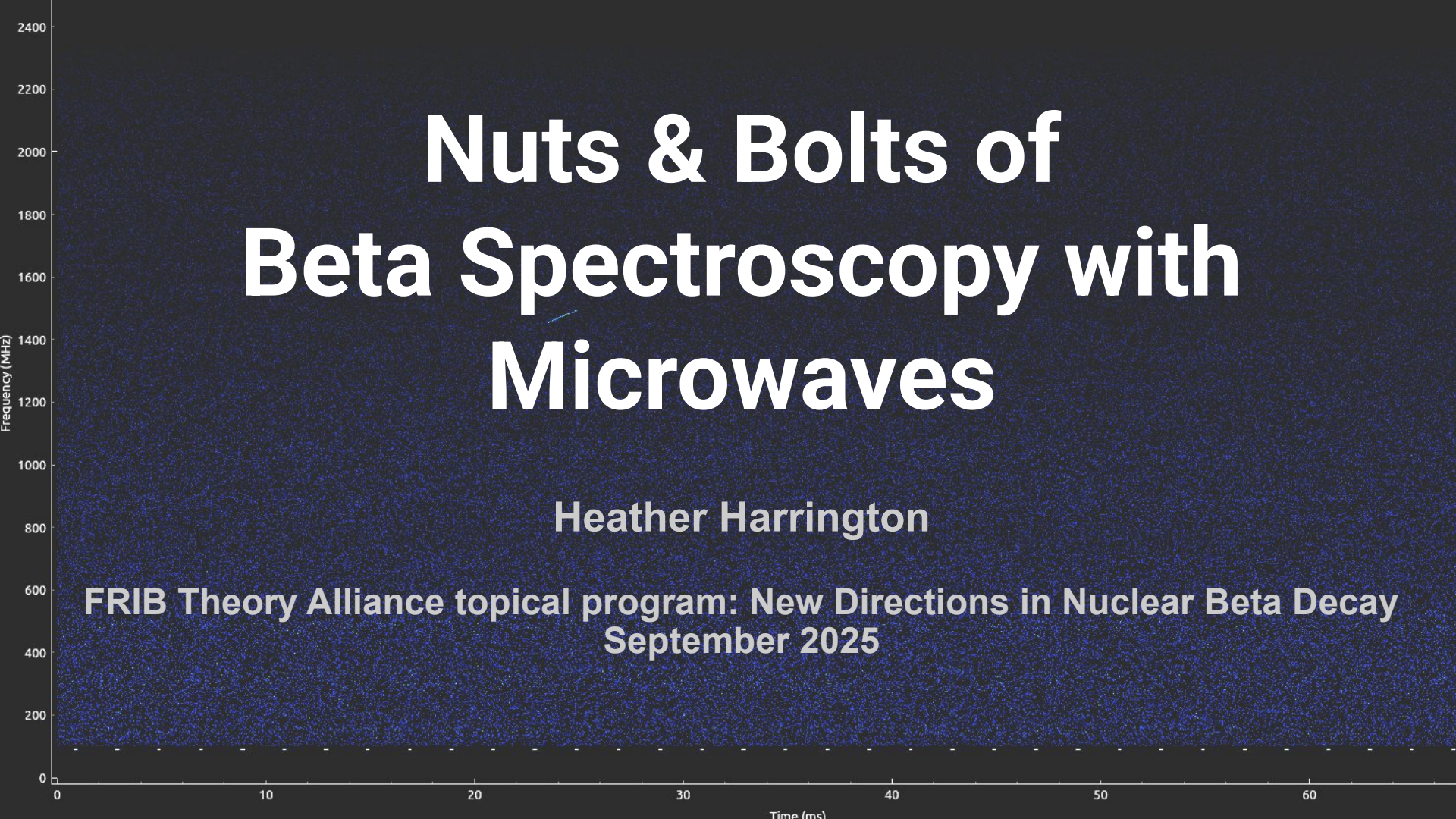


The background of the slide is a plot with 'Frequency (MHz)' on the y-axis (0 to 2400) and 'Time (ms)' on the x-axis (0 to 60). A blue line with significant noise is plotted, starting at approximately 1000 MHz at 0 ms and ending at approximately 100 MHz at 60 ms. The title text is overlaid on this plot.

Nuts & Bolts of Beta Spectroscopy with Microwaves

Heather Harrington

FRIB Theory Alliance topical program: New Directions in Nuclear Beta Decay
September 2025

Outline

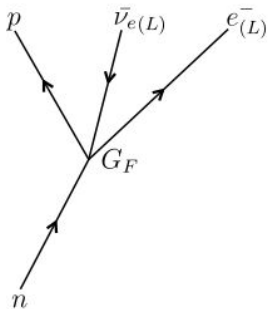
- Introduction to He6-CRES
 - Motivation (measure b_{Fierz} with $\Delta b \sim 10^{-3}$)
 - Cyclotron Radiation Emission Spectroscopy 101
 - He6-CRES
- Nuts & Bolts (Practical considerations and systematics)
 - Broadband strategy
 - SNRs and track slopes
 - Frequency and energy dependance
 - Scattering - vacuum and fast trap emptying
 - Efficiency drifts - temperature, fields
- Current status

Outline

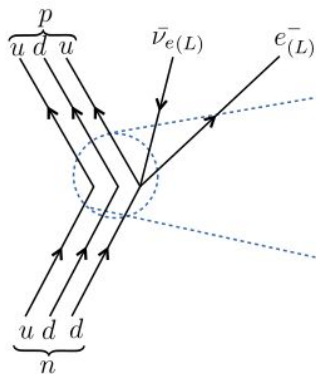
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Non V-A currents could result from BSM Physics

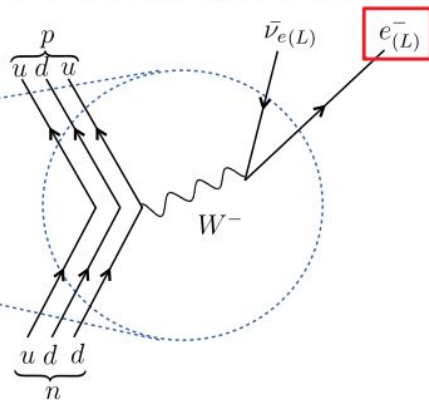
Fermi theory + V-A



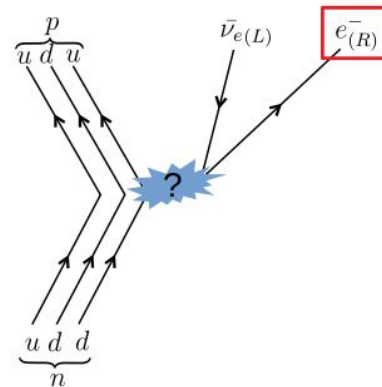
Quark model of nucleons



GSW-Electroweak theory (tree-level)



Chirality flipping



$$\mathcal{L}_{CC} = -\sqrt{2}G_F^0 V_{ud} \left[\bar{e}^L \gamma_\mu \nu_e^L \cdot \bar{u} \gamma^\mu (1 - \gamma^5) d \right] \quad \text{SM}$$

$$+ \epsilon_S \bar{e}^R \nu_e^L \cdot \bar{u} d \quad \text{Scalar}$$

$$+ \epsilon_T \bar{e}^R \sigma_{\mu\nu} \nu_e^L \cdot \bar{u} \sigma^{\mu\nu} (1 - \gamma^5) d \quad \text{Tensor}$$

Effects of new physics

$$\delta O \sim \frac{C_{new,i}}{C_{SM}} \left(\frac{2 M_W}{\Lambda} \right)^2$$

To reach $\Lambda \sim 10$ TeV need
 $\delta O \sim 10^{-4}$

He6-CRES Overview:

Jackson, Treiman and Wyld, Phys. Rev. 106 and Nucl. Phys. 4, 1957

Looking for kinematic effects of scalar or tensor currents in beta spectra

Long-term goal: Utilize ^{19}Ne (β^+), ^6He (β^-), and eventually ^{14}O (β^-) spectral ratios via CRES towards a precise (10^{-3}) measurement of b_{Fierz} .

- $b_{\text{Fierz}} \neq 0$ indicative of beyond the Standard Model (BSM) physics.

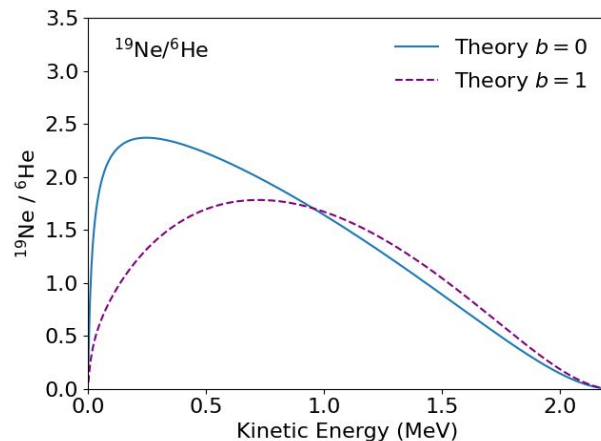
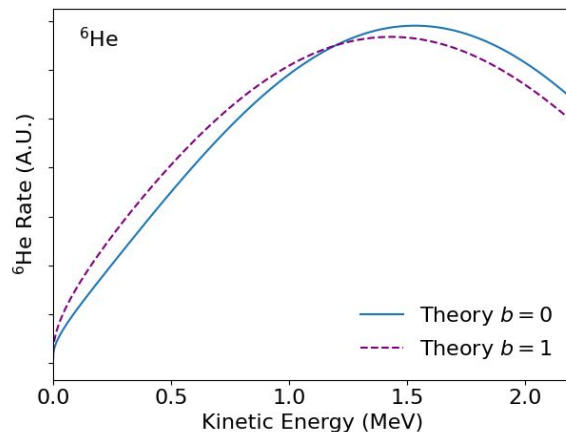
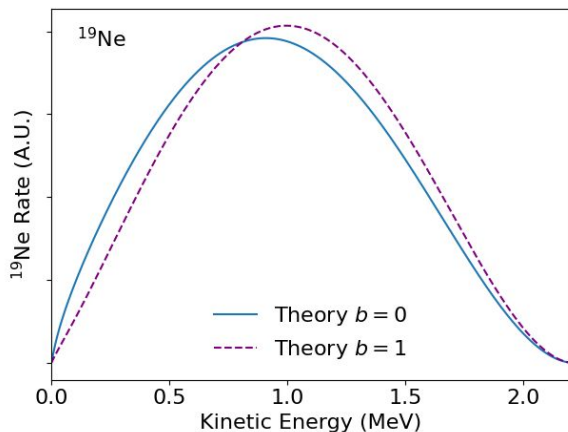
$$\frac{dN}{dE} \approx \frac{dN_{SM}}{dE} \left(1 + \underbrace{b_{\text{Fierz}} \frac{m}{E}}_{\text{BSM}} \right)$$

$\langle \sigma \tau \rangle$ and $\langle \tau \rangle$ are the Gamow-Teller and Fermi nuclear β -decay matrix elements, respectively

Non-standard effective couplings

$$\frac{\left[\frac{g_S}{g_V} \epsilon_S - 4 \left(\frac{\langle \sigma \tau \rangle}{\langle \tau \rangle} \right)^2 \frac{g_T}{g_V} \frac{g_A}{g_V} \epsilon_T \right]}{1 + \left(\frac{\langle \sigma \tau \rangle}{\langle \tau \rangle} \right)^2 \left(\frac{g_A}{g_V} \right)^2}$$

g_i : nucleon form factors



He6-CRES Overview:

Jackson, Treiman and Wyld, Phys. Rev. 106 and Nucl. Phys. 4, 1957

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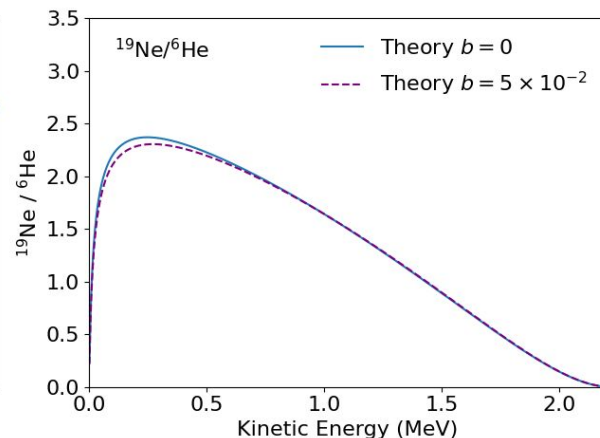
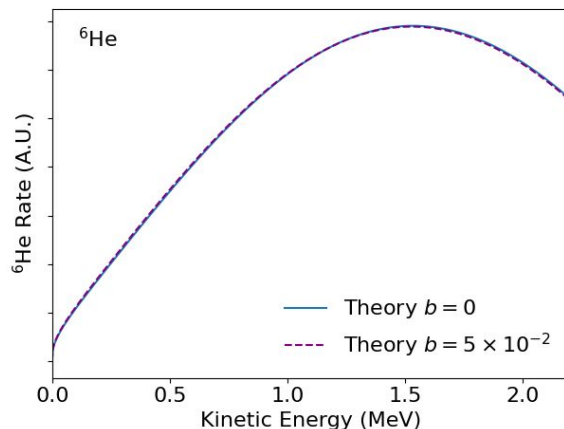
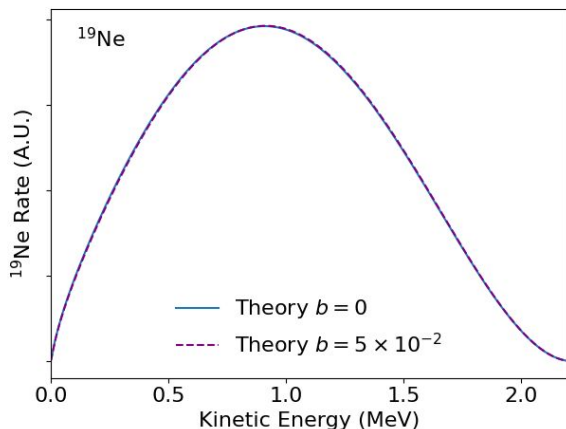
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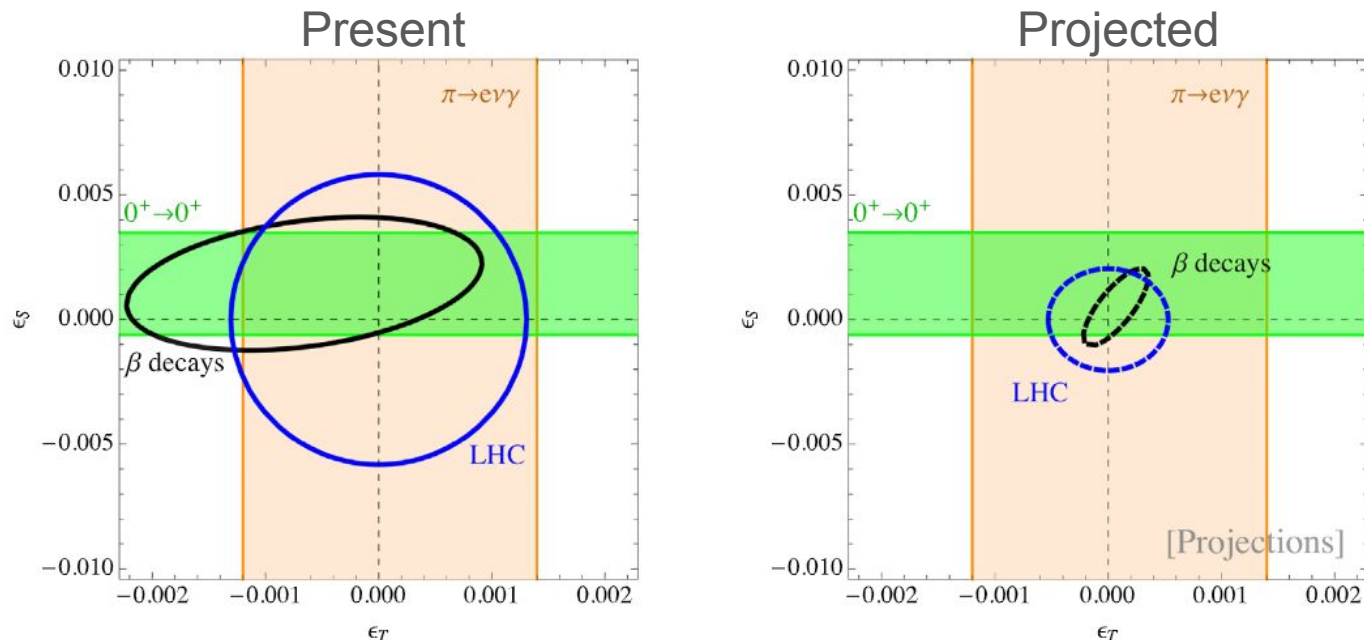
g_i : nucleon form factors



Complementary Low Energy and High Energy Probes

(can be compared with appropriate renormalization.)

“In contrast to the (axial-)vector charges, the (pseudo-)scalar and tensor charges are renormalization-scale and -scheme dependent QCD quantities.” Values quoted in the $\overline{\text{MS}}$ scheme at $\mu = 2 \text{ GeV}$ scale



M. Gonzalez-Alonso, O. Naviliat-Cuncic, and N. Severijns, *Progress in Particle and Nuclear Physics* 104, 165 (2019).

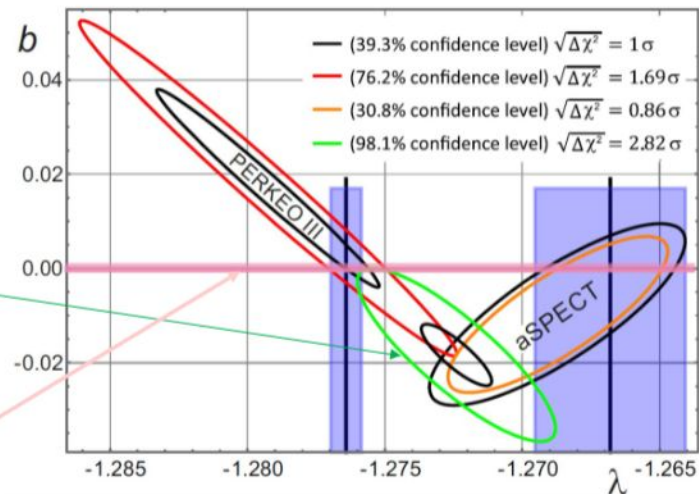
Some other motivation?

Tighter limits on b would simplify pinpointing the source of discrepancies in neutron beta decay and clarify issues with g_A

Two experiments can be reconciled *if* they assume a non-zero Fierz-interference:
 $b = -0.0181$ (65).

(..." Including other measurements like UCNA , aCORN , and PERKEO II would not add substantial information.")

$$\Delta b = 10^{-3}$$



from Phys. Rev. Lett. **132**, 102501 (2024)

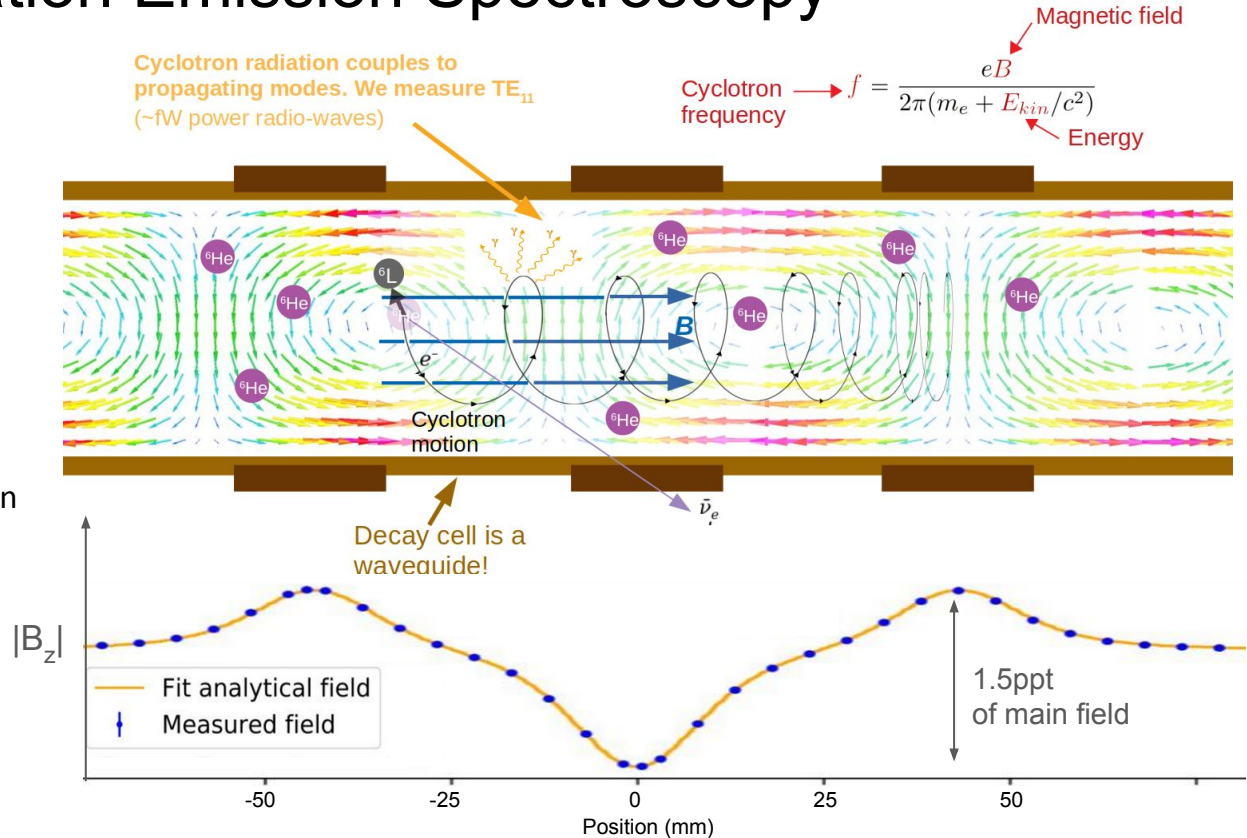
Garcia – DOE panel visit – Jan 2025

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Cyclotron Radiation Emission Spectroscopy

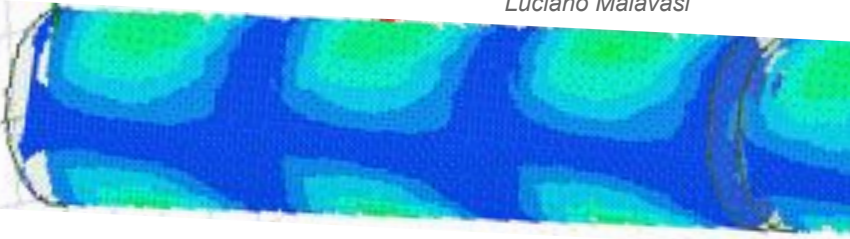
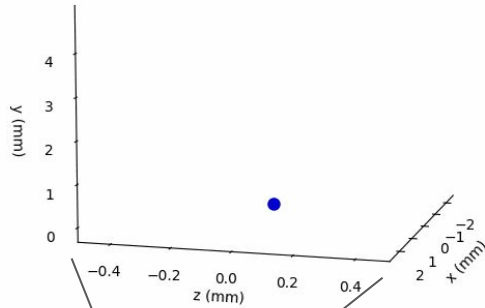
- Gaseous radioactive source β -decays in a strong background B-field.
- Betas moving in a magnetic field emit cyclotron radiation with a frequency inversely proportional to their energy.
- Magnetic bottle trap keeps beta confined for hundreds of ms.
- ~10 fW signals propagate down waveguide, are amplified, and digitized.



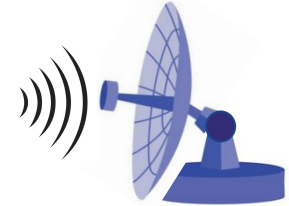
Cyclotron Motion and Radiation

$\beta - , \theta_{pitch} = 89.9^\circ, B=2T, \text{Trap current} = 1A$

$t = 0 \text{ ps}$



Kassiopea trajectory simulated by RJ Taylor

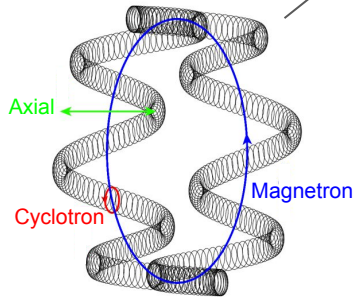


For He6-CRES:

$f_{Cyc} \approx 20 \text{ GHz}$

$f_{Axial} \approx 100 \text{ MHz}$

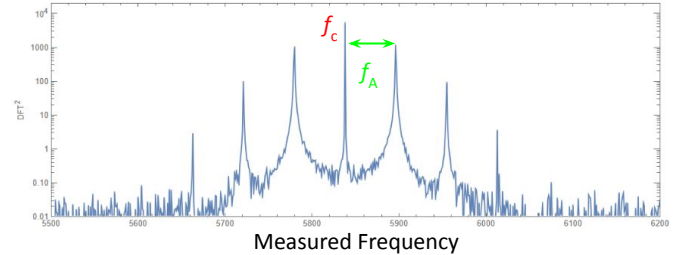
$f_{Mag} \approx 200 \text{ kHz}$



Decomposition of Motion

Length of each time sample: 3.4 μs
 = 68000 cyclotron periods
 = 340 axial periods
 = 0.7 magnetron periods

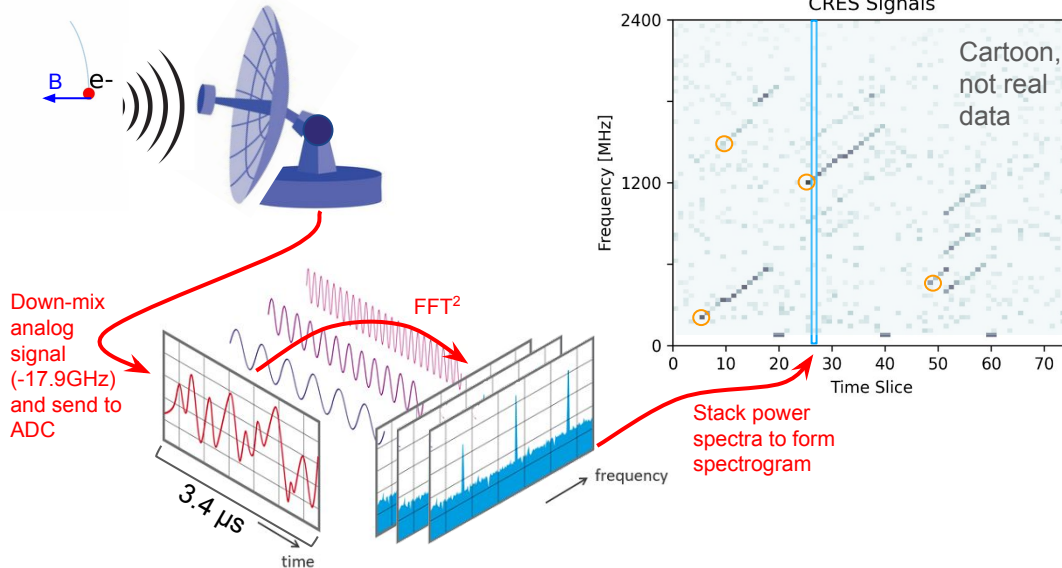
Sidebands simulated by Drew Byron



Doppler effect + 340 axial periods in a single time sample $\rightarrow$ sidebands

Cyclotron Radiation Emission Spectroscopy

- FPGA performs live FFT. Sequential FFTs build a frequency vs time spectrogram. Betas appear as tracks.
- From initial frequency and B-field can get the energy.



Cyclotron frequency $\rightarrow f = \frac{eB}{2\pi(m_e + E_{kin}/c^2)}$

Magnetic field

Energy

Advantages:

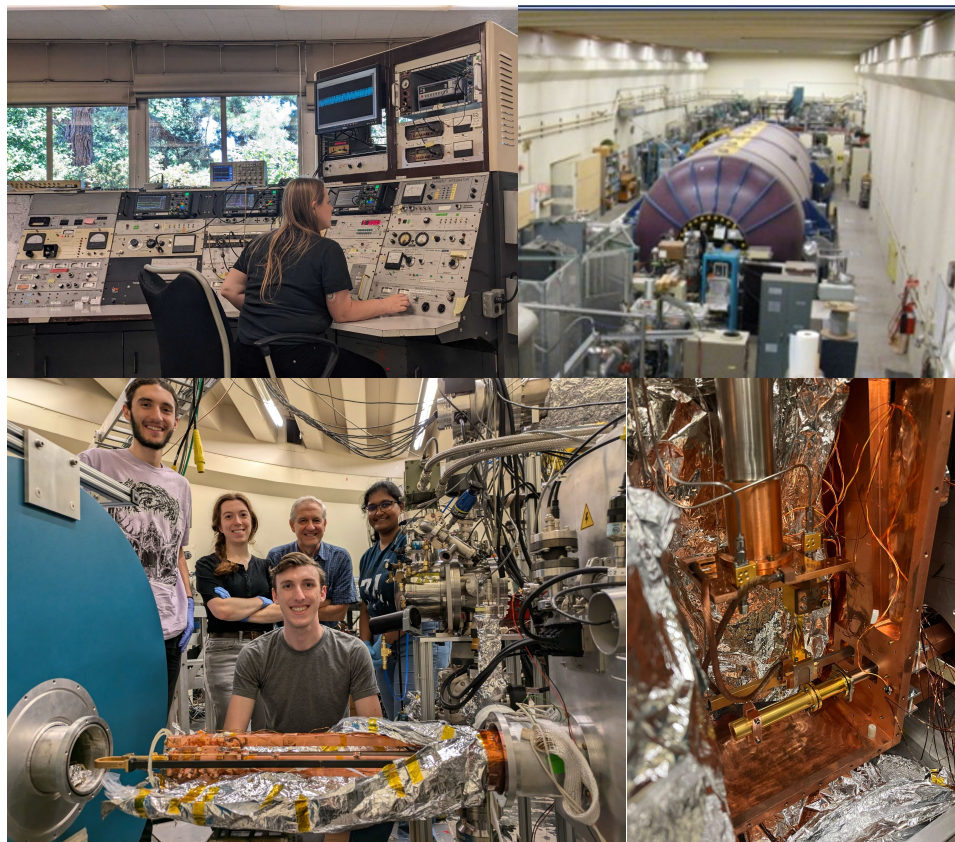
- Measures β energy at creation, before complicated energy-loss mechanisms.
- No backscattering
- Excellent energy resolution from frequency measurement
- Source gas is transparent to cyclotron radiation
- No background exterior to the gas

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He6-CRES Overview

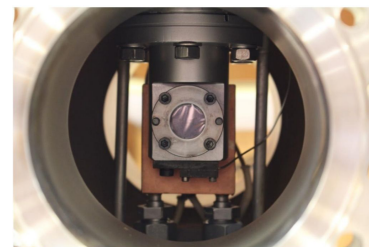
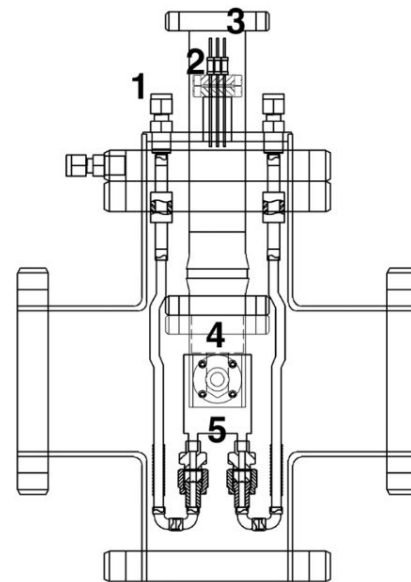
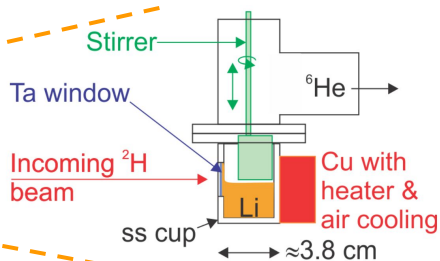
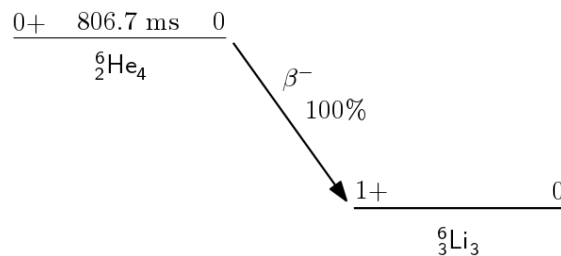
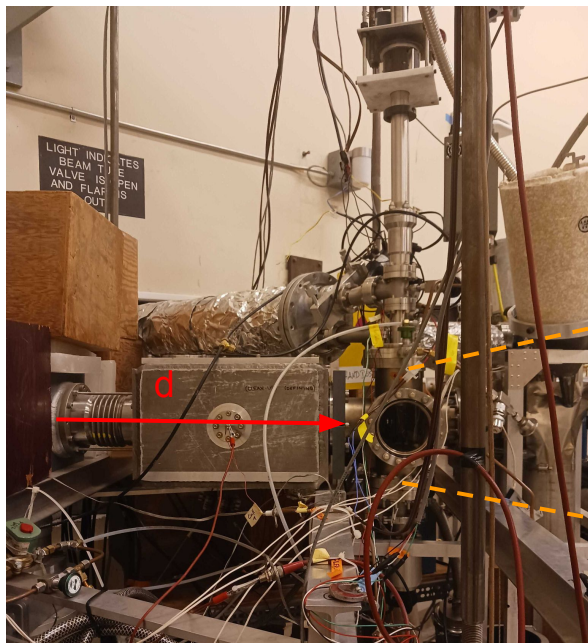
- A small experiment at CENPA at the University of Washington
- Use CRES to perform broadband beta spectrum measurements.
- Get Fierz Interference term, b_{Fierz} with $\Delta b \sim 10^{-3}$
- Complementary nuclei for BSM scalar and tensor couplings or cancelation of energy-dependant systematics. (${}^6\text{He}$, ${}^{19}\text{Ne}$, [${}^{14}\text{O}$ maybe later])



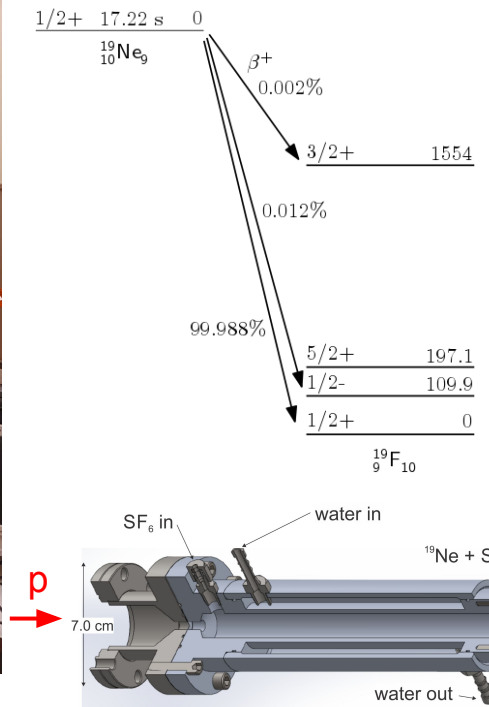
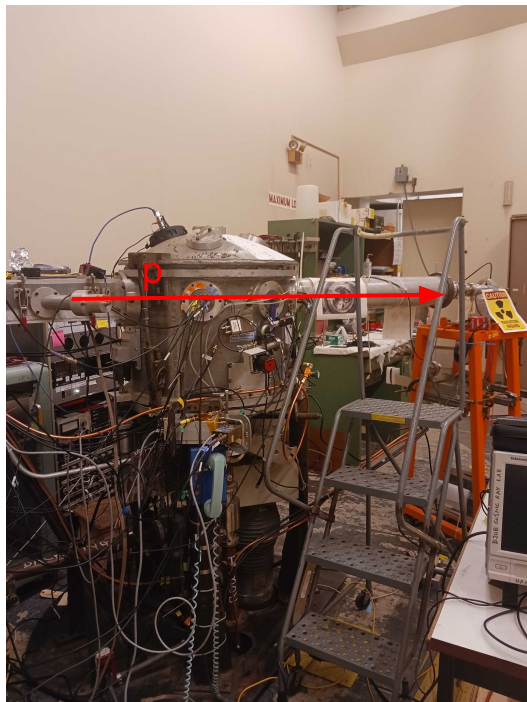
${}^6\text{He}$ source: ${}^7\text{Li}(\text{d}, {}^3\text{He}){}^6\text{He}$

${}^7\text{Li}(\text{d}, {}^3\text{He}){}^6\text{He}$ bombarding a molten lithium target with a **17.8-MeV deuteron beam** from the FN-tandem accelerator at the University of Washington.

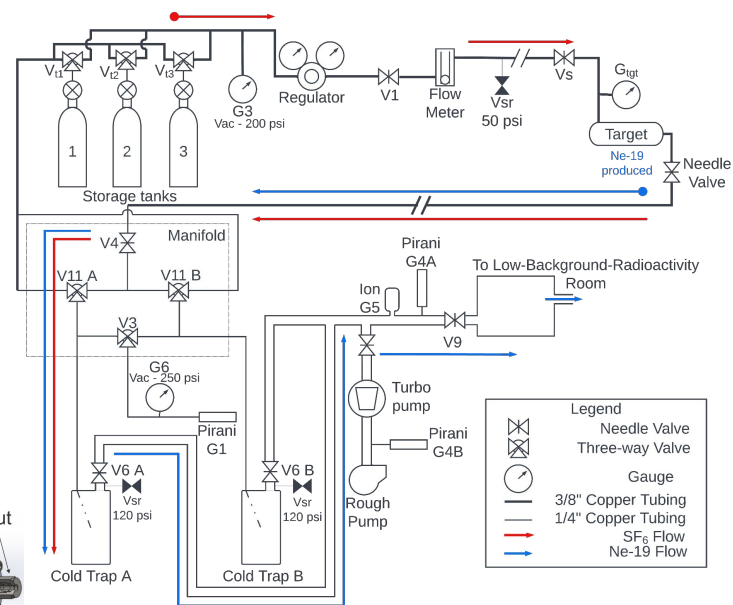
A. Knecht, et. al., Methods in Physics Research Section A, 660, 43 (2011).



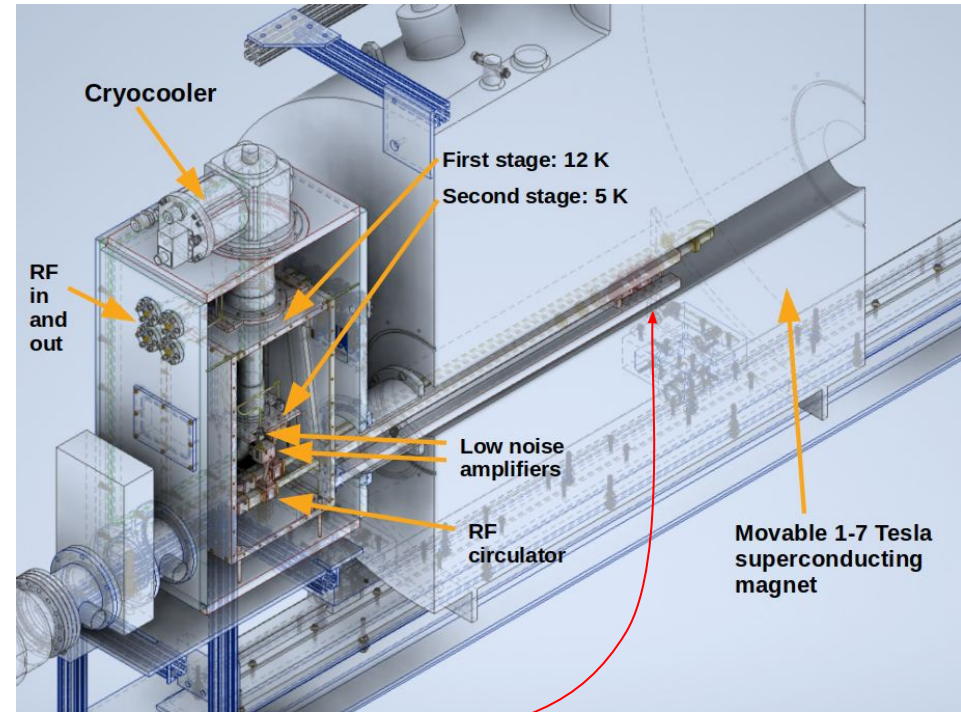
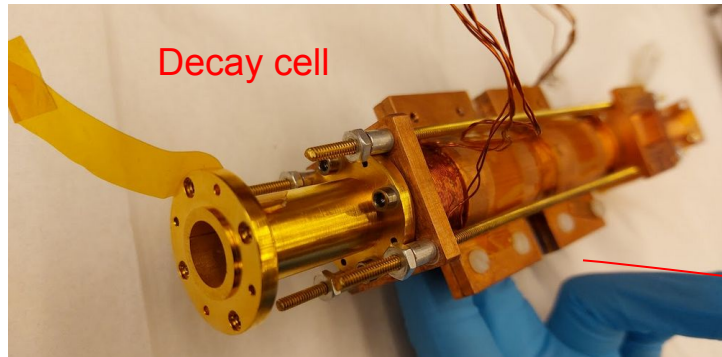
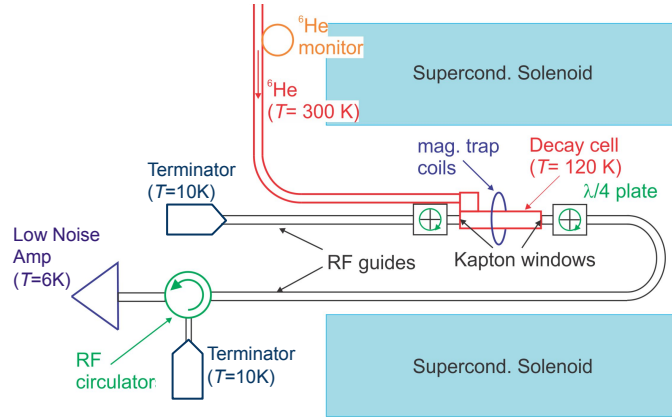
^{19}Ne source: $^{19}\text{F}(\text{p},\text{n})^{19}\text{Ne}$



$^{19}\text{F}(\text{p},\text{n})^{19}\text{Ne}$ on an SF_6 gaseous target with a **10-MeV proton beam**, similar to the Berkeley-Princeton source: *D. Dobson, The beta-decay asymmetry and nuclear magnetic moment of Neon-19, Ph.D. thesis, University of California, Berkeley (1963)*



He6-CRES Apparatus



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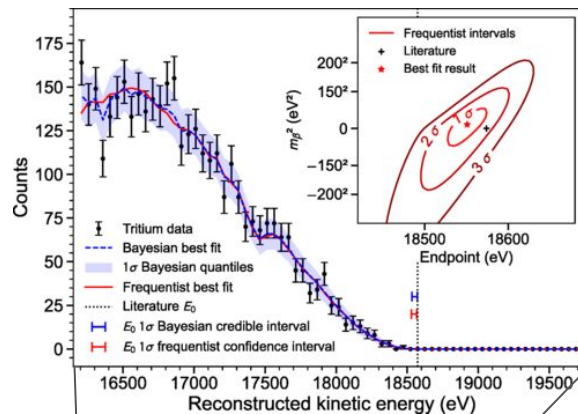
Broadband Strategy

1) Increase frequency bandwidth

- Increase sampling frequency. (Limited by time closure on your FPGA)
- Increase parallelization. Add more DAQ channels (parallel ambient receivers tuned to different frequency ranges w/ high and low pass filters + FPGAs to digitize/FFT/threshold those ranges+receivers)

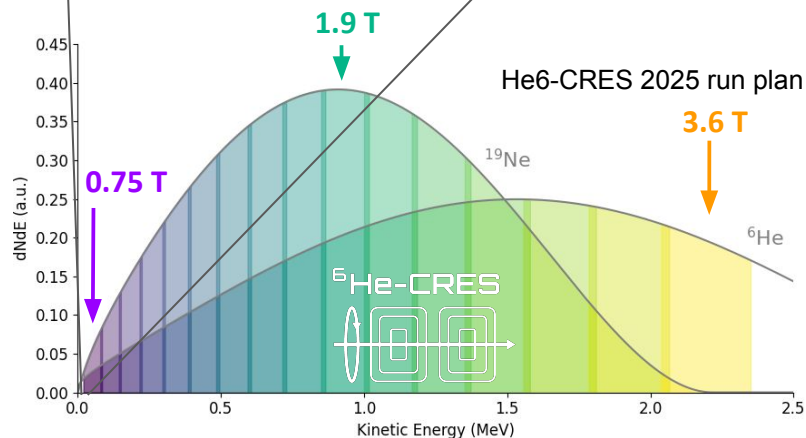
2) Take data at multiple magnetic fields

- Sequential field measurements
- Parallel field measurements. Multiple magnets/RF OR custom magnet with different fields and RF with multiple traps.



Project8 (tritium endpoint
CRES measurement)
Freq BW: **200 MHz**
Energy range: **4 keV**

*Project 8 Collaboration, Phys.
Rev. Lett. 131, (2023)*



Broadband Strategy

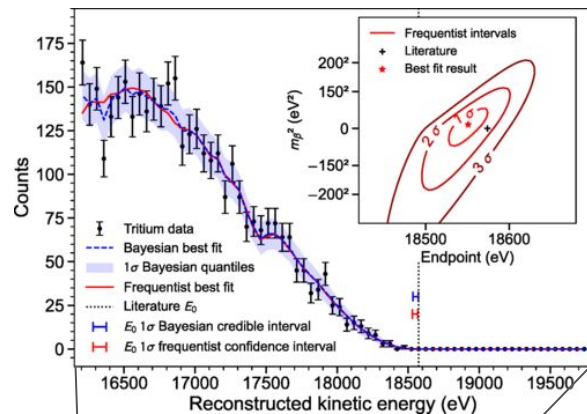
1) Increase frequency bandwidth

DAQ complexity

Upper limit where your SNR will drop

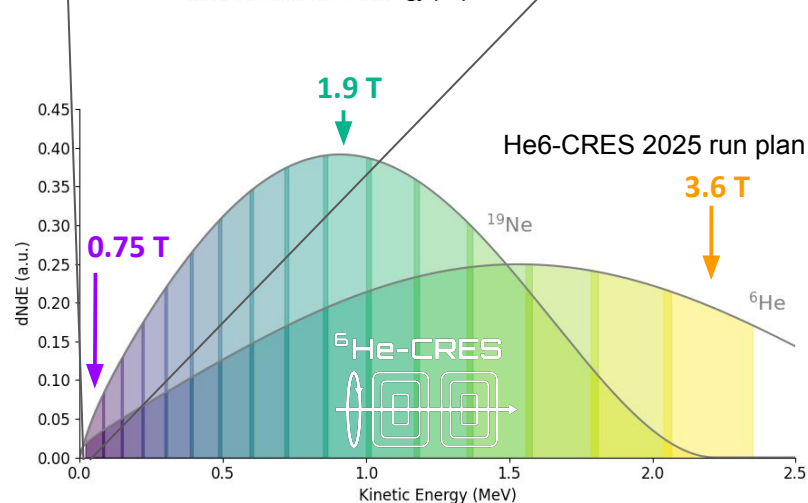
2) Take data at multiple magnetic fields

- Sequential field measurements (Systematic uncertainties from drifts! Need to normalize spectrum segments with an activity monitor that must be stable and well calibrated.)
- Parallel field measurements. Multiple magnets/RF OR custom magnet with different fields and RF with multiple traps. (Expensive)
(Need to calibrate for different efficiencies of each detector -> Systematic uncertainties)



Project8 (tritium endpoint CRES measurement)
Freq BW: **200 MHz**
Energy range: **4 keV**

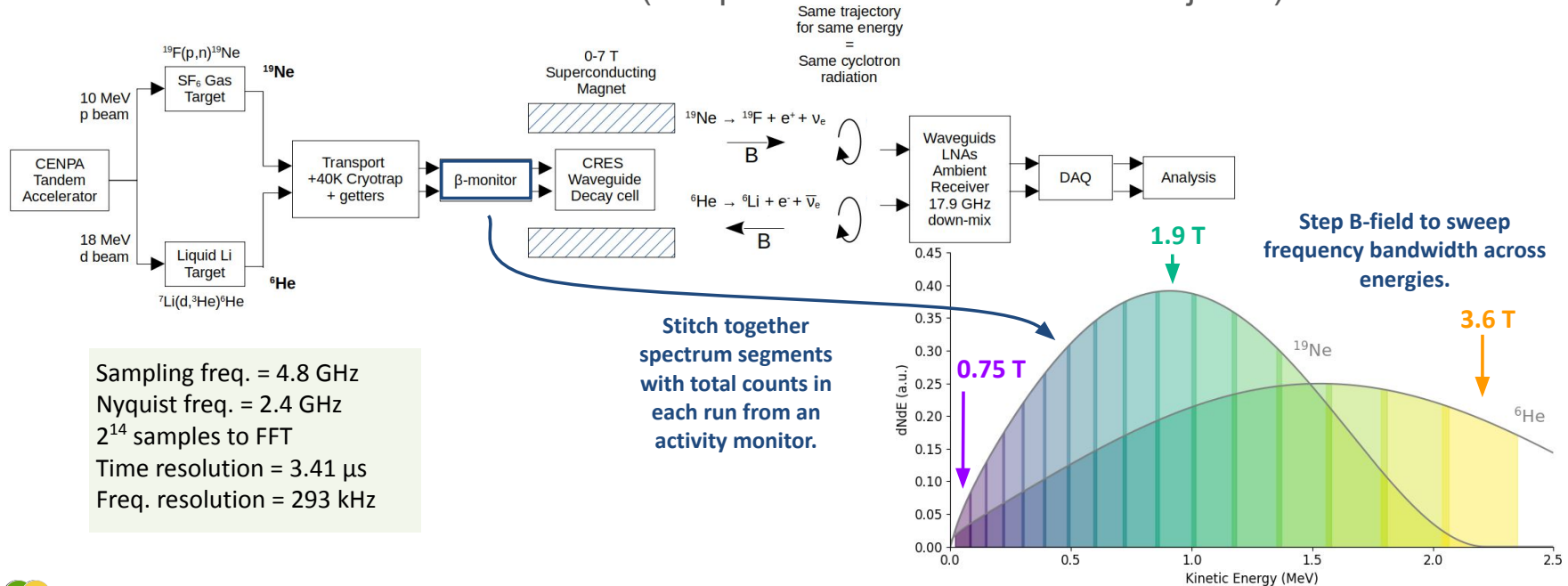
Project 8 Collaboration, Phys. Rev. Lett. 131, (2023)



He6-CRES Current Broadband Strategy

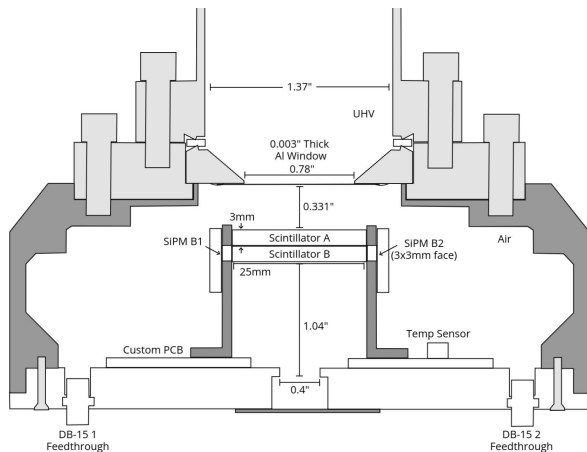
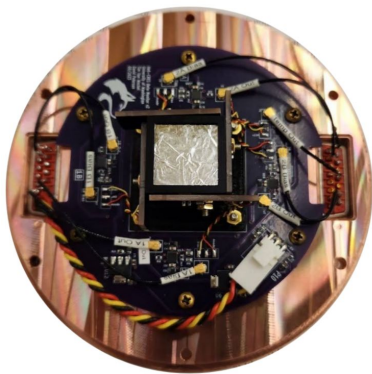
Single DAQ channel: $\Delta f = 2.3$ GHz (compare to 200 MHz for Phase II Project 8)

Sequential field measurements: 16 fields gives contiguous spectrum measurement from 0.02 to 2.35 MeV. $\rightarrow \Delta E = 2.33$ MeV (compare to 4 kHz for Phase II Project 8)

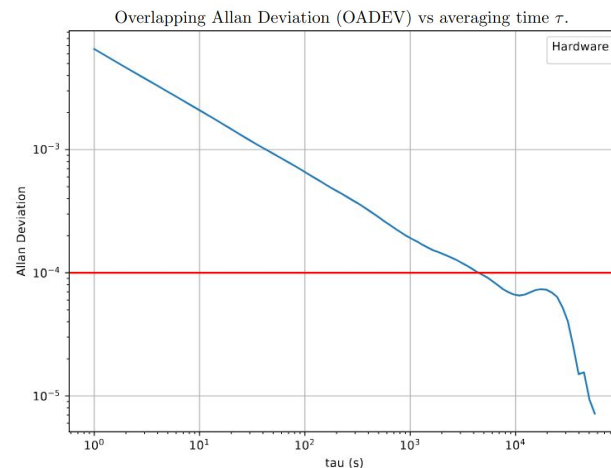
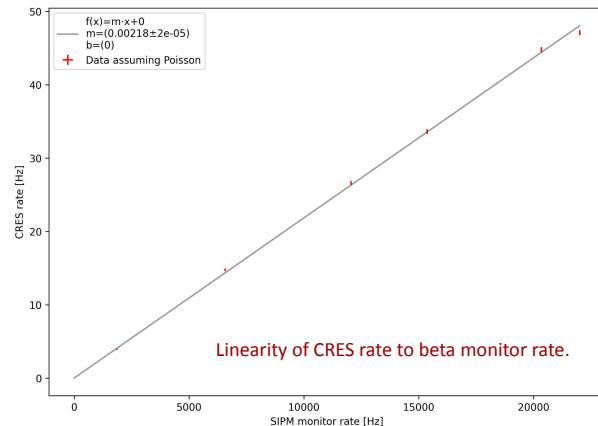


Beta Monitor

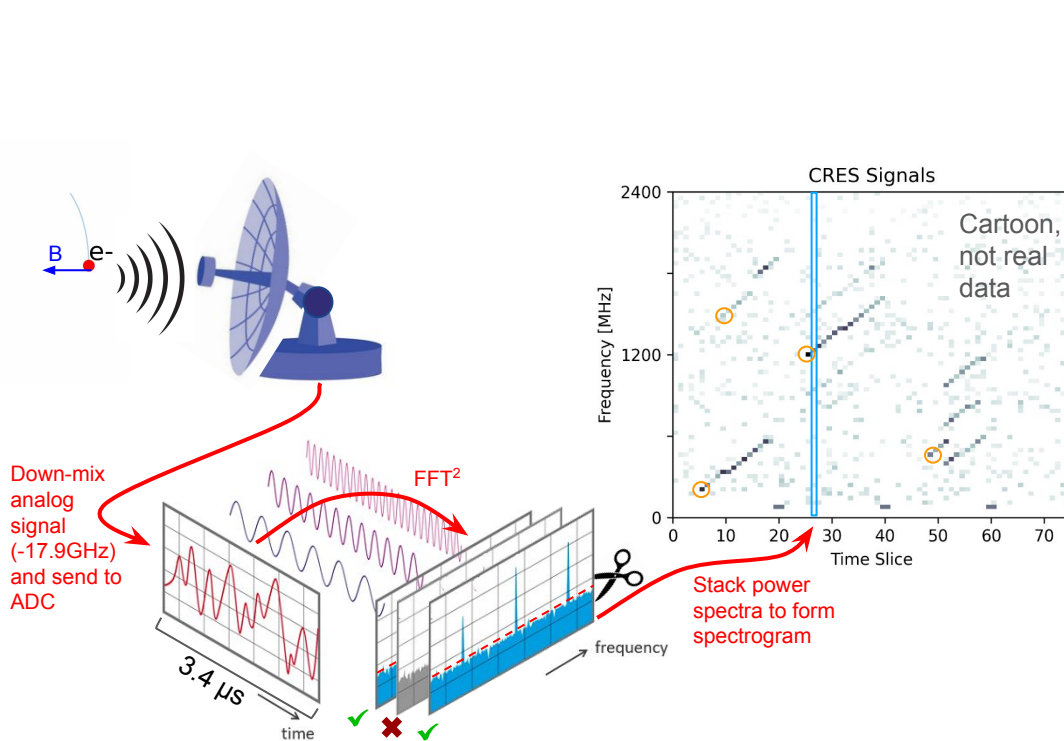
- Monitors activity of source over a run to stitch together spectrum segments.
- Employs two plastic scintillators in coincidence to remove backgrounds and two SiPMs on each scintillator.
- Each SiPM has a designated power supply with temperature compensation.
- Rigorously characterized.



Component	Part Number	Operating Voltage
Scintillator	Eljen Technologies EJ-212	Not Applicable
Silicon Photomultipliers (SiPMs)	Hamamatsu S14160-3050HS	41.39 V*, 41.55 V*, 41.68 V*, 41.79 V*
Power Supplies	Hamamatsu C11204-01	5V
Microcontrollers	Arduino Nano	5V
Ethernet Shield	W5500	5V



A Note About Data Rate



Cyclotron frequency $\rightarrow f = \frac{eB}{2\pi(m_e + E_{kin}/c^2)}$

Magnetic field

Energy

2.3 GHz bandwidth, 293 kHz frequency resolution, writing every time slice = 2.4 GB/s !

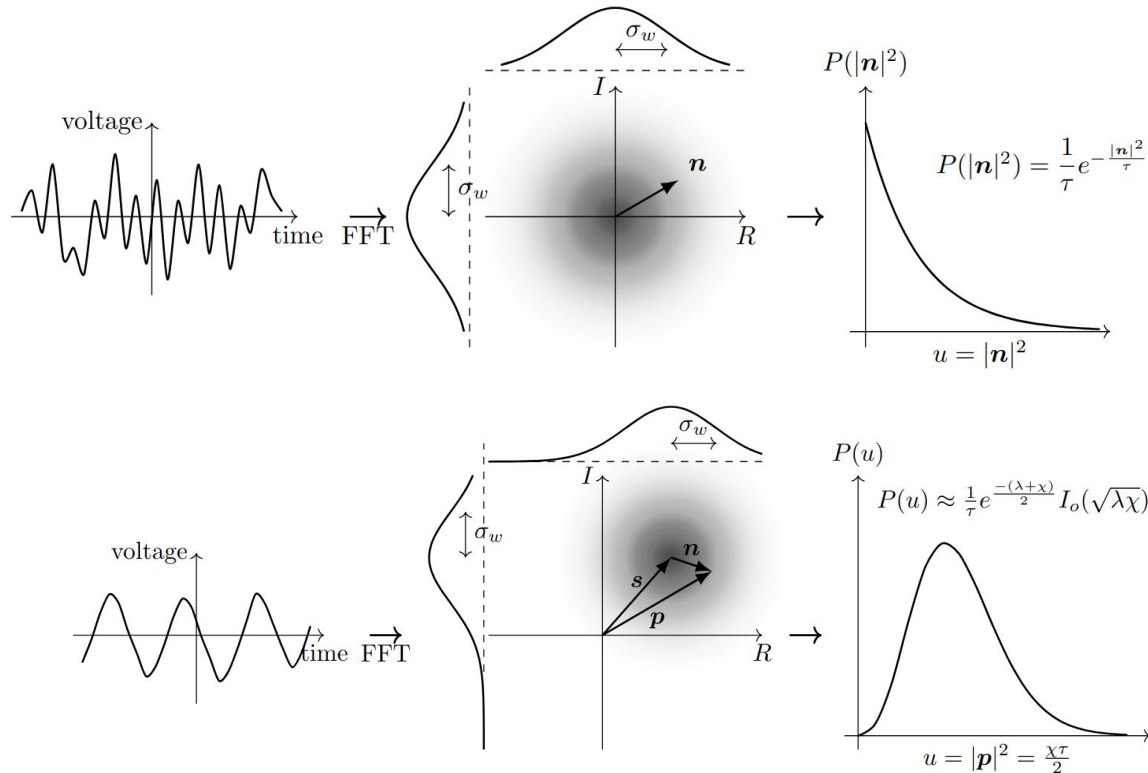
Most is noise.

With zero-suppression, only 12MB/s

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Signal and Noise



Thermal noise power is exponentially distributed:

$$P(u) = \frac{1}{\tau} e^{-u/\tau}$$

With mean:

$$\tau = 4k_B \Delta f$$

Signal power pdf is a non-central chi-squared distribution characterized by the non-centrality parameter:

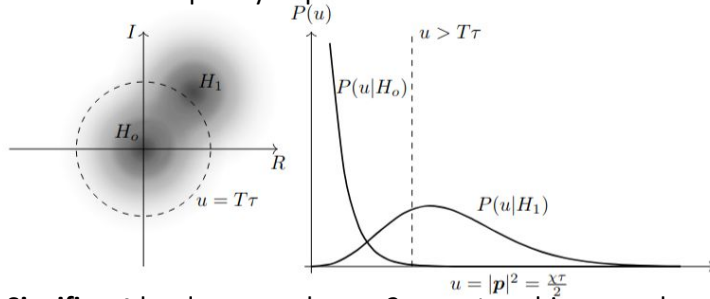
$$\lambda = \left(\frac{s_r}{\sigma_w} \right)^2 + \left(\frac{s_i}{\sigma_w} \right)^2 = \frac{|\mathbf{s}|^2}{\sigma_w^2} = \frac{2|\mathbf{s}|^2}{\tau}$$

Measured power:

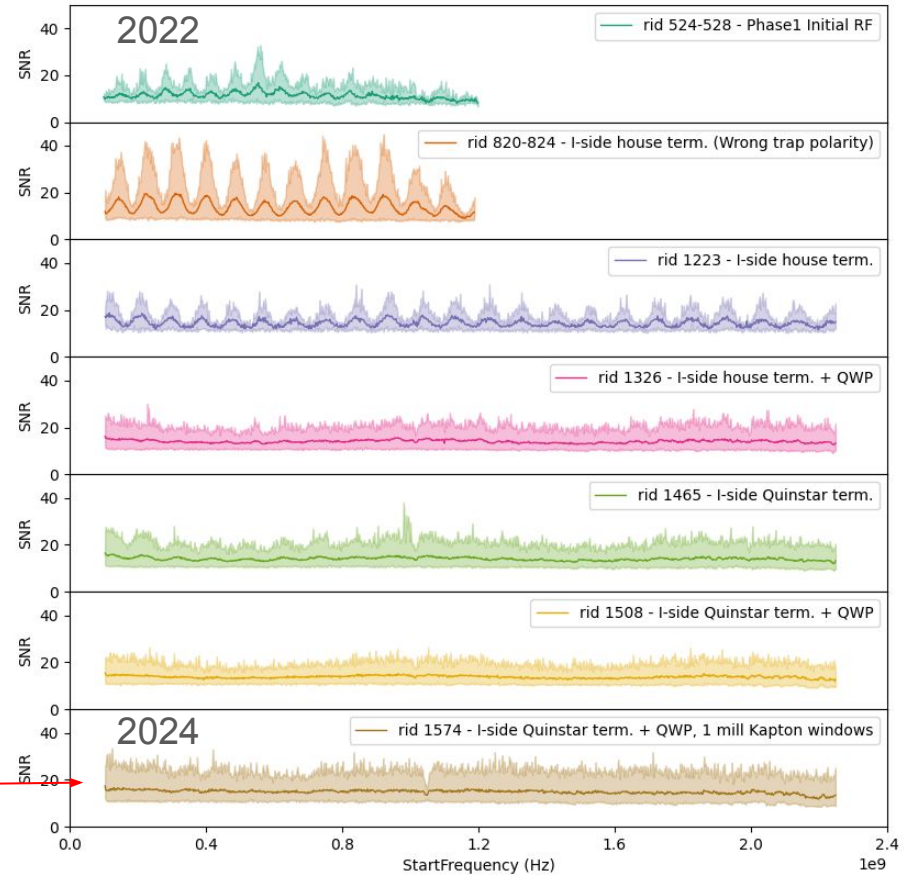
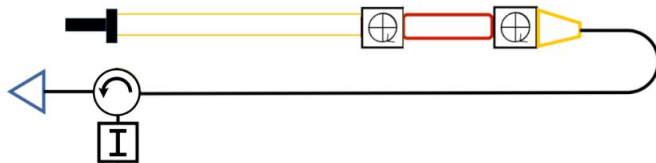
$$u = |\mathbf{p}|^2 = p_r^2 + p_i^2 = |\mathbf{s} + \mathbf{n}|^2$$

Reflections and Interference

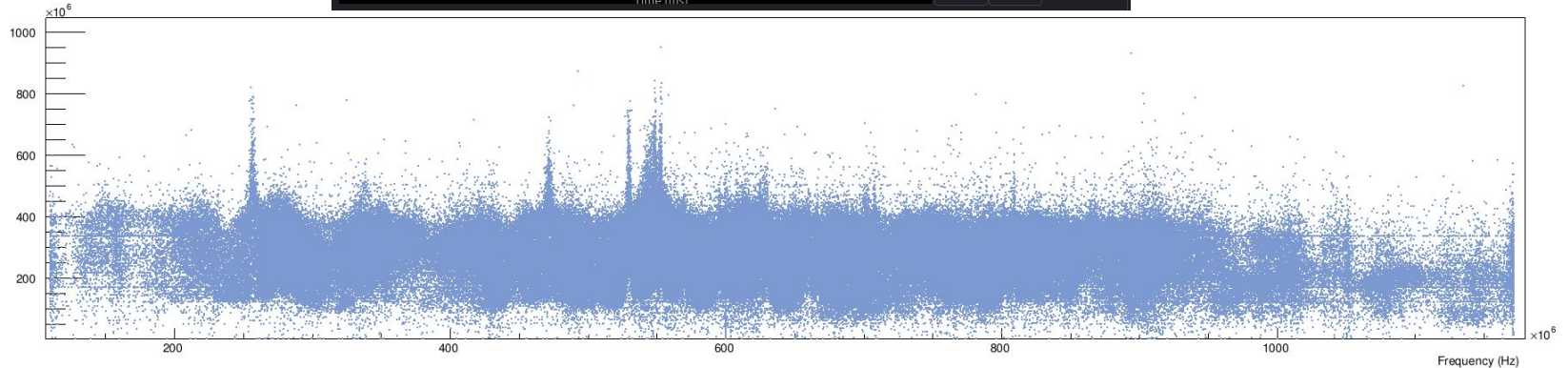
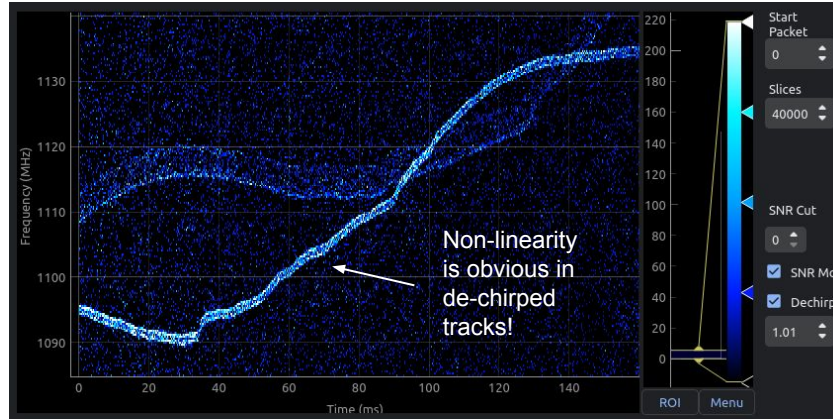
- Any reflections in the waveguides create frequency-dependent interference!
(Fabry-Pérot interferometer)
- This causes frequency-dependence of the SNR!



- Significant** hardware work over 2 years to achieve nearly constant SNR as a function of frequency.
- Put quarter-wave plate front of terminator to reduce SNR oscillations. Left-going radiation from beta attenuated from repeated reflections off terminator and does NOT interfere with light going to the LNA.



Slope Resonances



Slope Variation

We now understand that the $\mathbf{E}_{nm} \cdot \mathbf{J}$ coupling has higher harmonics that need to be considered.

Kleppner anticipated such behavior:
PRL **47**, 233 (1981)

At cutoff, the guides behave like cavities, which show up as resonances in the waterfall plot slopes.

N Buzinsky et al 2024 New J. Phys. 26 083021

Inhibited Spontaneous Emission Daniel Kleppner

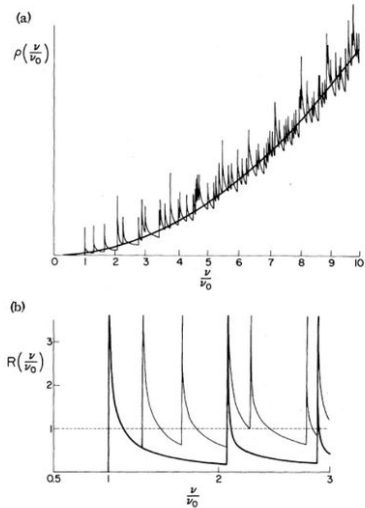
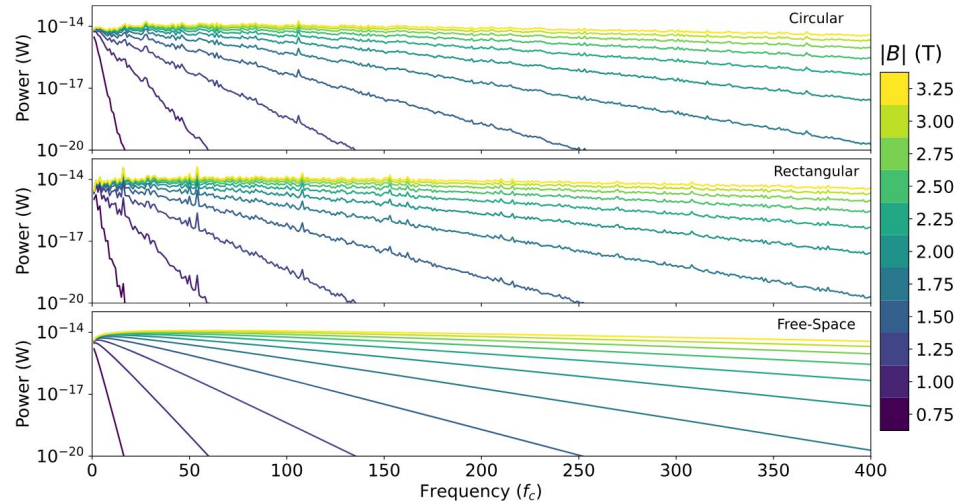


FIG. 1. (a) Mode density in a perfectly conducting cylindrical waveguide. Frequency is in units of the lowest cutoff frequency of the waveguide, $\nu_0 = 0.29c/a$, where a is the radius. For clarity, the singularities have been truncated. The smooth curve represents the mode density in free space. (b) Ratio of waveguide mode density to free-space mode density. The heavy

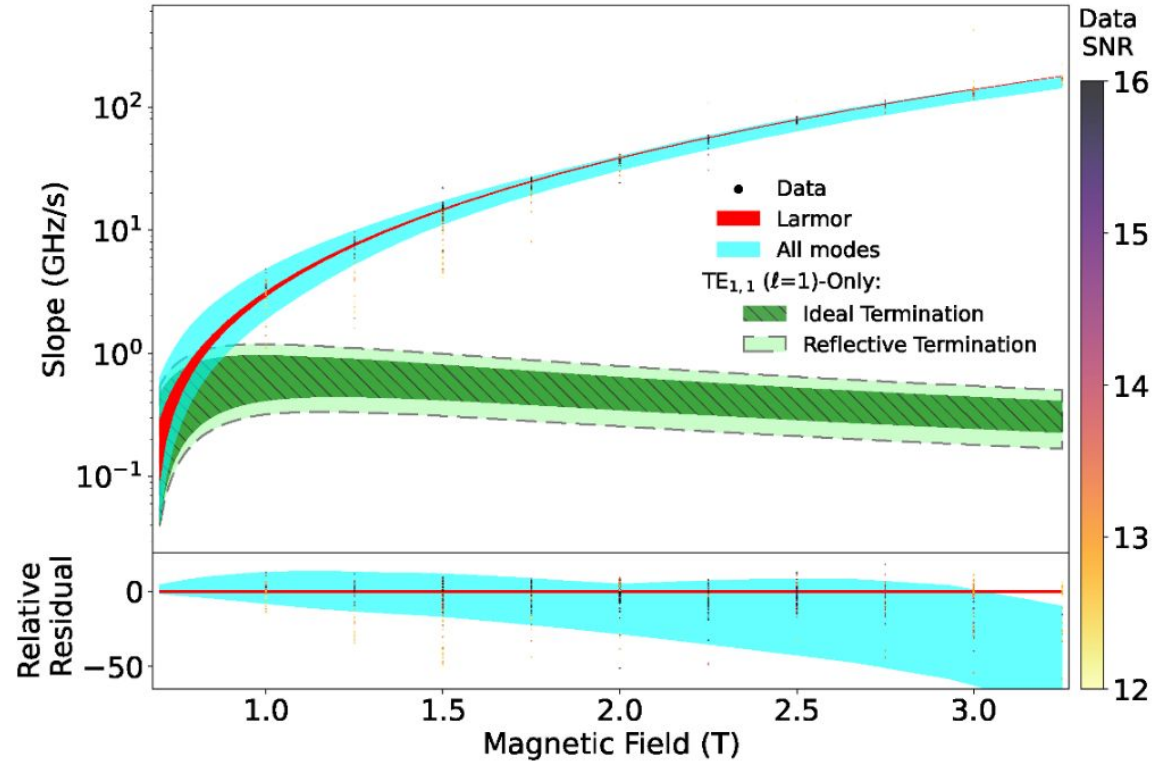


Power spectrum over the first 400 harmonic frequencies f_c , as a function of magnetic field, for the circular waveguide (top), rectangular waveguide (center), and free-space (bottom), given $f_c = 18$ GHz.

Slope Variation

Observed correspondence between the total radiated power emitted by individual $e^\pm$ s in a circular waveguide (slope) and the free-space expectation given by the Larmor formula.

$$P_{\text{Larmor}} = \frac{q^2 \omega_c^2 \gamma^4 v^2}{6\pi \epsilon_0 c^3}$$



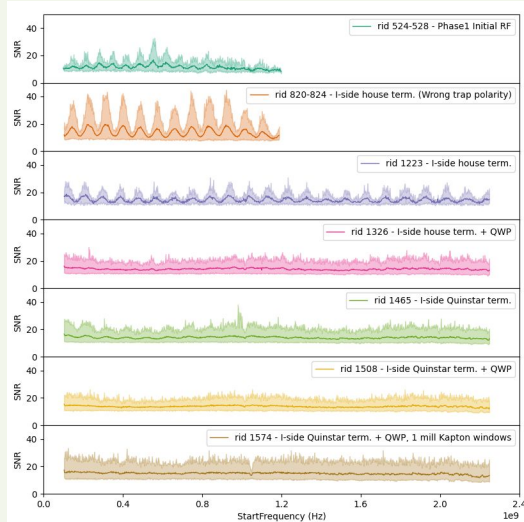
N Buzinsky et al 2024 New J. Phys. 26 083021

Outline

- Introduction to He6-CRES
 - Motivation (measure b_{Fierz} with $\Delta b \sim 10^{-3}$)
 - Cyclotron Radiation Emission Spectroscopy 101
 - He6-CRES
- **Nuts & Bolts (Practical considerations and systematics)**
 - Broadband strategy
 - SNRs and track slopes
 - **Frequency and energy dependance**
 - Scattering - vacuum and fast trap emptying
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- Current status

Frequency and Energy Dependence

Frequency



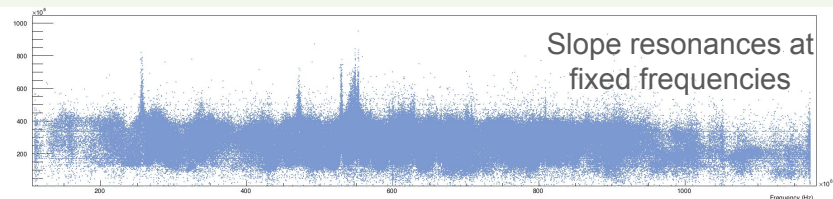
Frequency-dependant SNR

Frequency-dependant signal interference

Frequency-dependant noise interference

Reflections

Slope resonances at fixed frequencies

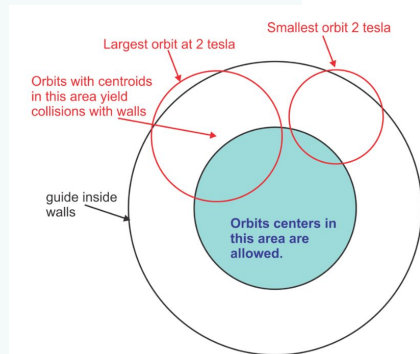
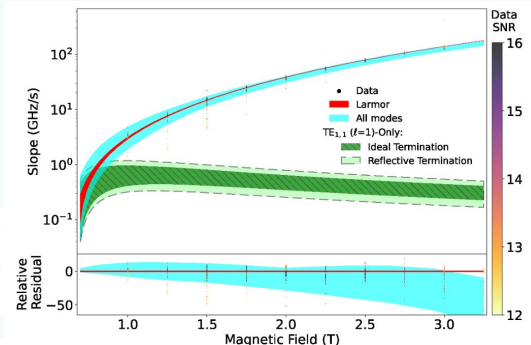


Energy

Energy dependence of slope

Energy dependence of Power in TE11

$$P_{\text{Larmor}} = \frac{q^2 \omega_c^2 \gamma^4 v^2}{6\pi \epsilon_0 c^3}$$



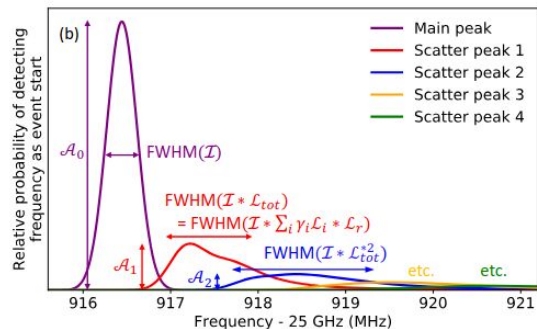
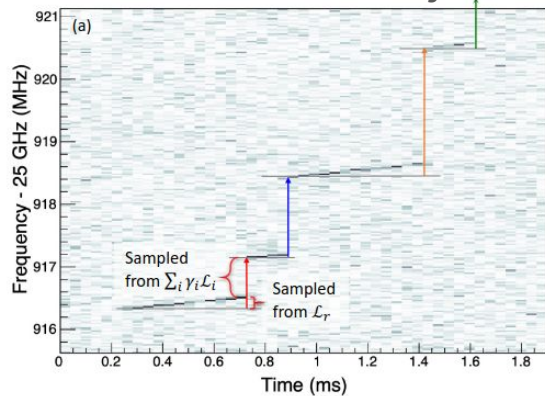
Wall effect:
Fiducial volume depends on energy

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Scattering

Project8

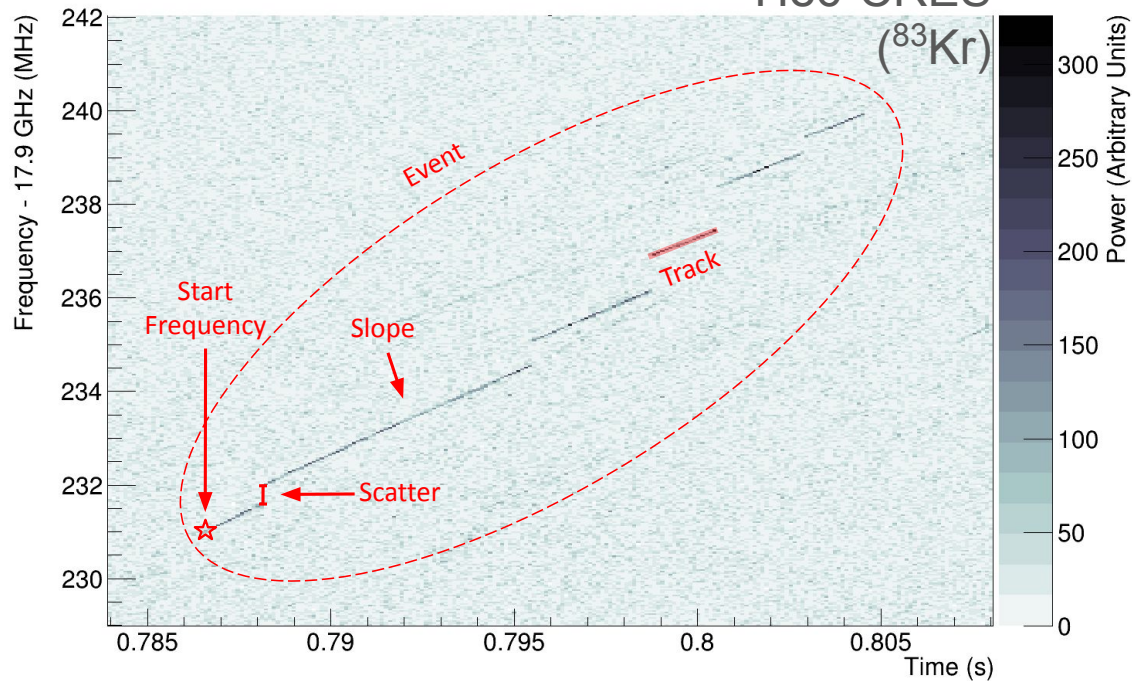


Phys. Rev. C 109, 035503

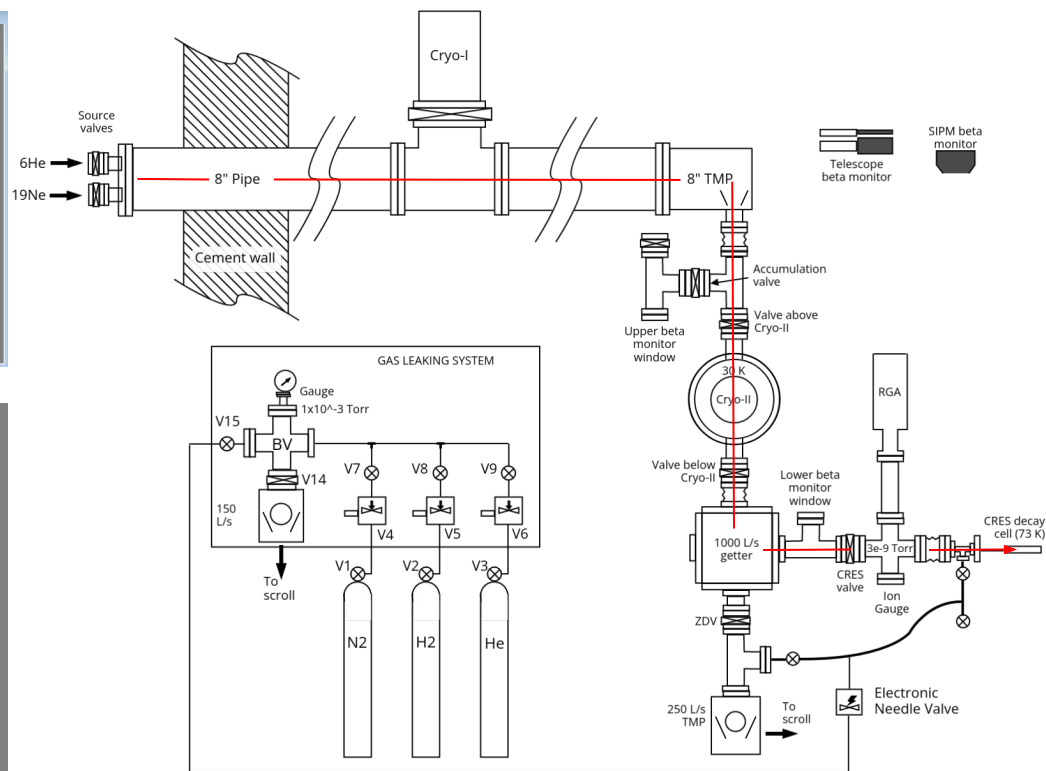
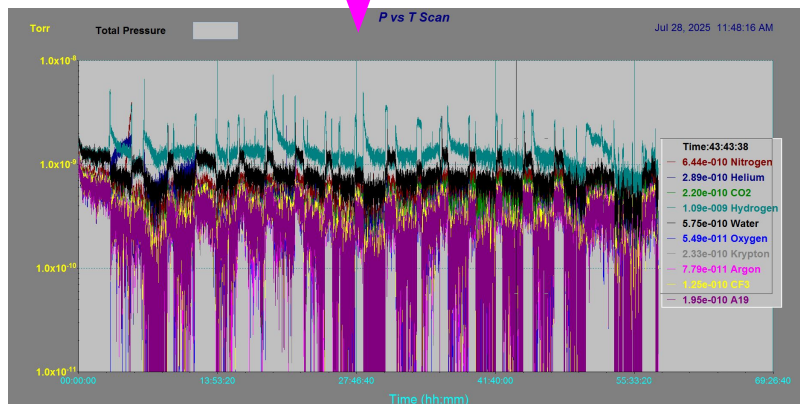
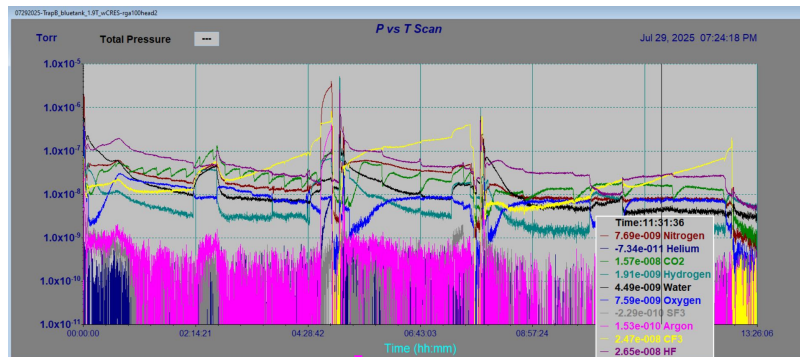
Spectrogram

He6-CRES

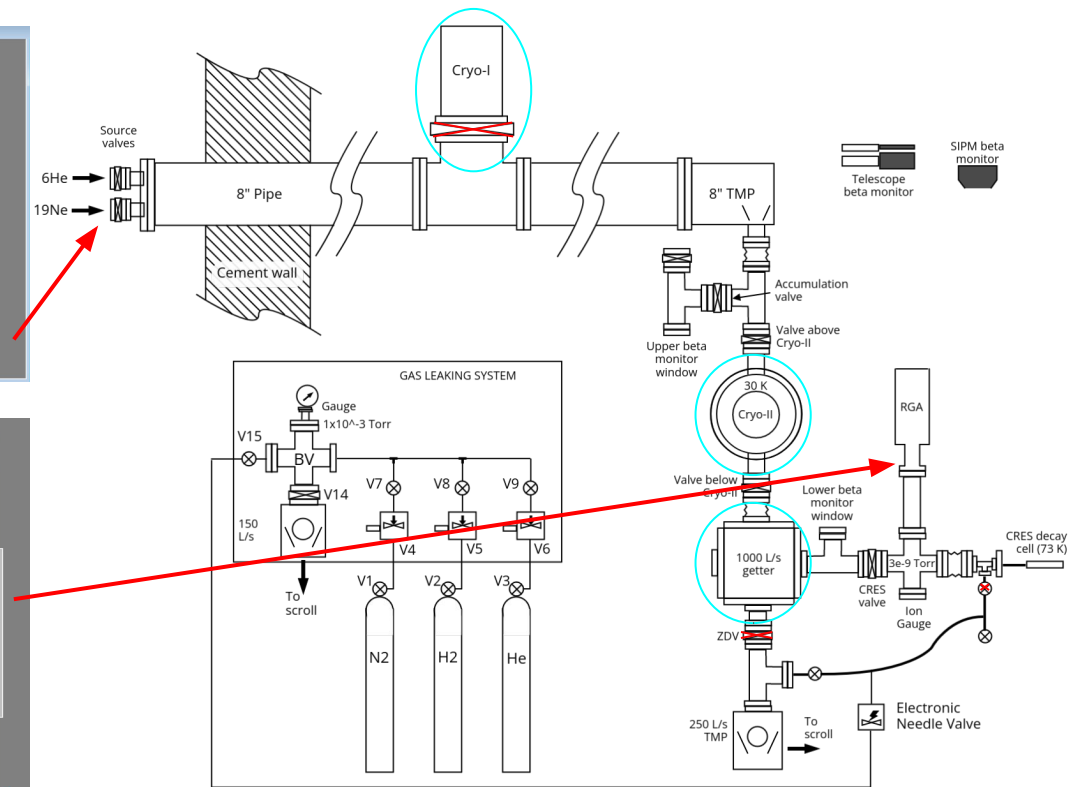
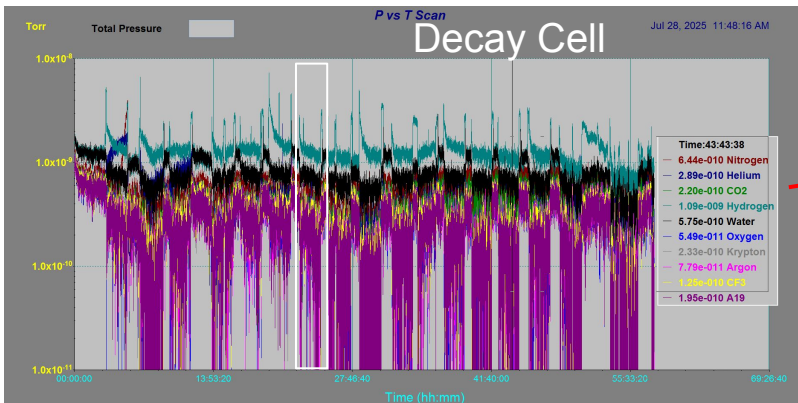
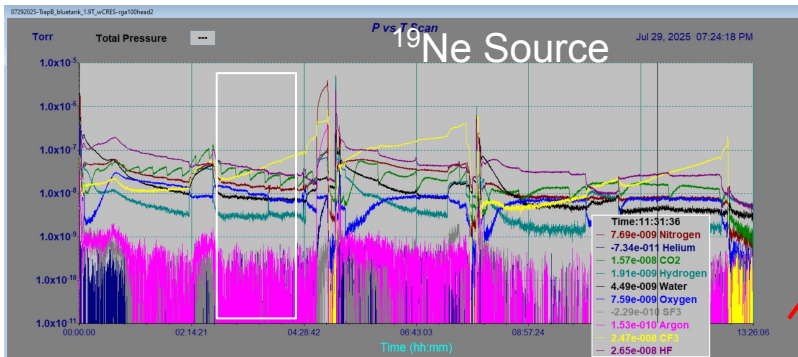
(^{83}Kr)



Scattering: Vacuum Is Very Important!

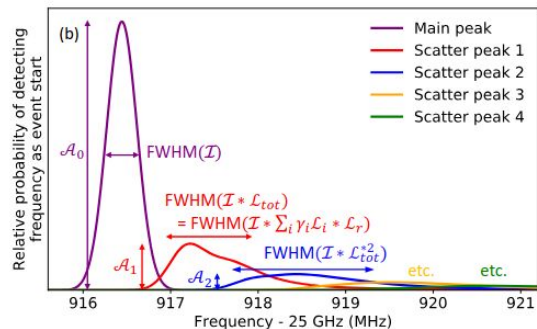
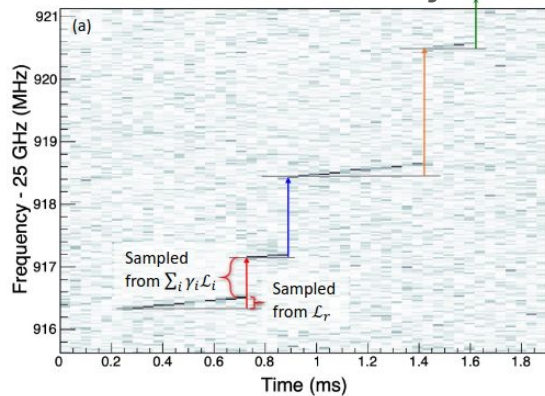


Scattering: Vacuum Is Very Important!



Scattering

Project8

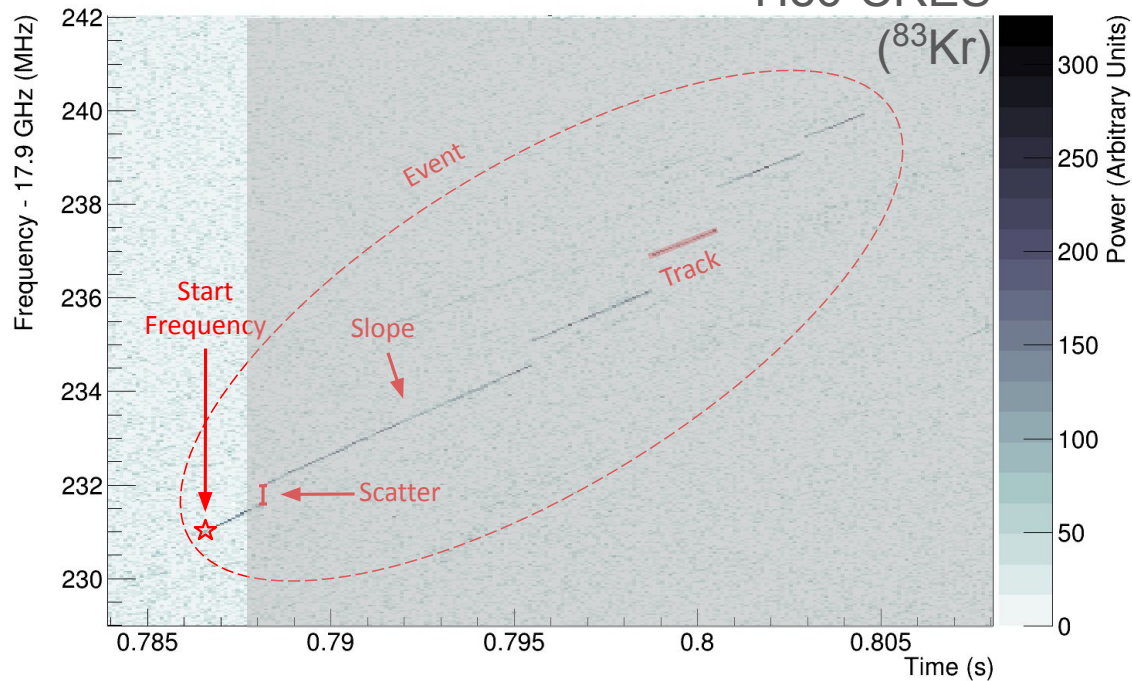


Phys. Rev. C 109, 035503

Spectrogram

He6-CRES

(^{83}Kr)

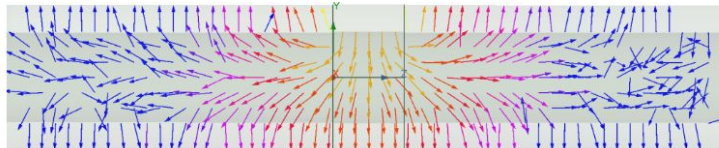
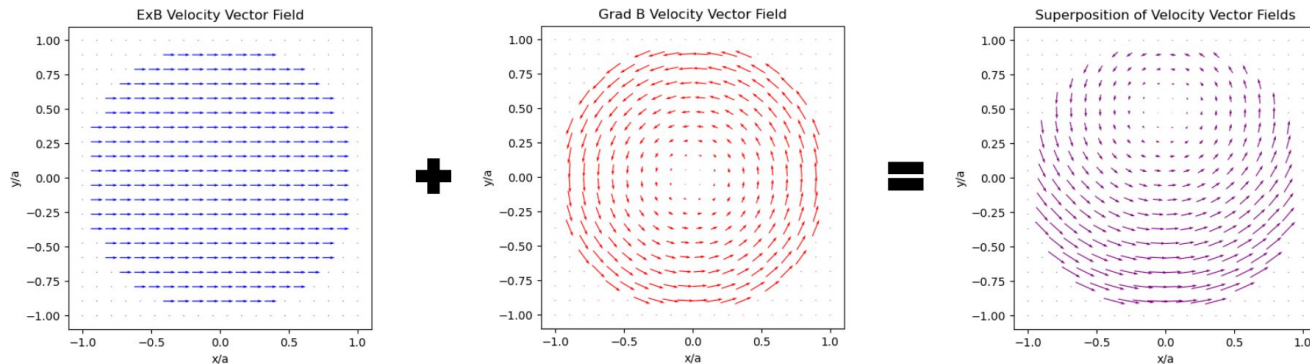
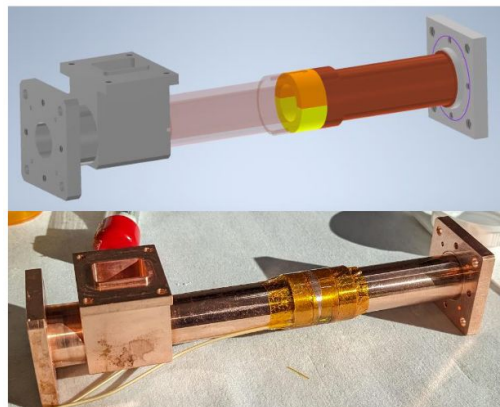


Fast Trap Emptying with Electrode Pulsing

Leave magnetic trap on constantly, pulse electrodes to quickly push all betas to the wall and empty the trap.

$$\text{Grad-B drift: } \mathbf{v}_{\nabla B} = \frac{K_{\perp} \mathbf{B} \times \nabla B}{qB^3}$$

$$\text{Combining with ExB drift : } \mathbf{v}_D \approx \left[\mathbf{E}_c - \frac{c^2}{\omega_c} \left(1 - \frac{1}{\gamma} \right) \nabla B_c \hat{\mathbf{B}}_c \right] \times \frac{\hat{\mathbf{B}}_c}{B_c}$$



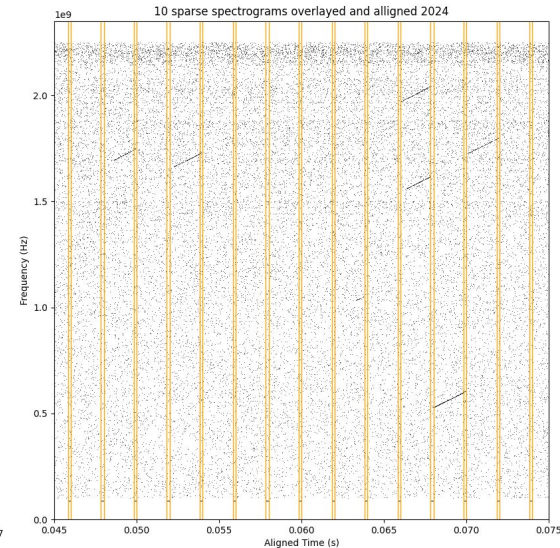
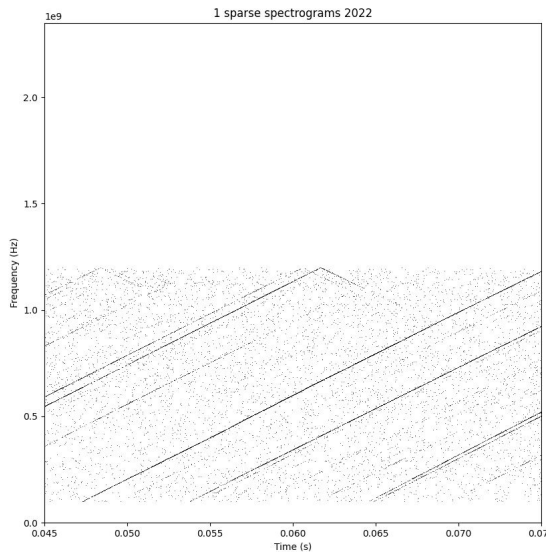
Hardware: RJ. Taylor
Simulations: Nick. B and RJ.

Fast Trap Emptying with Electrode Pulsing

Leave magnetic trap on constantly, pulse electrodes to quickly push all betas to the wall and empty the trap.

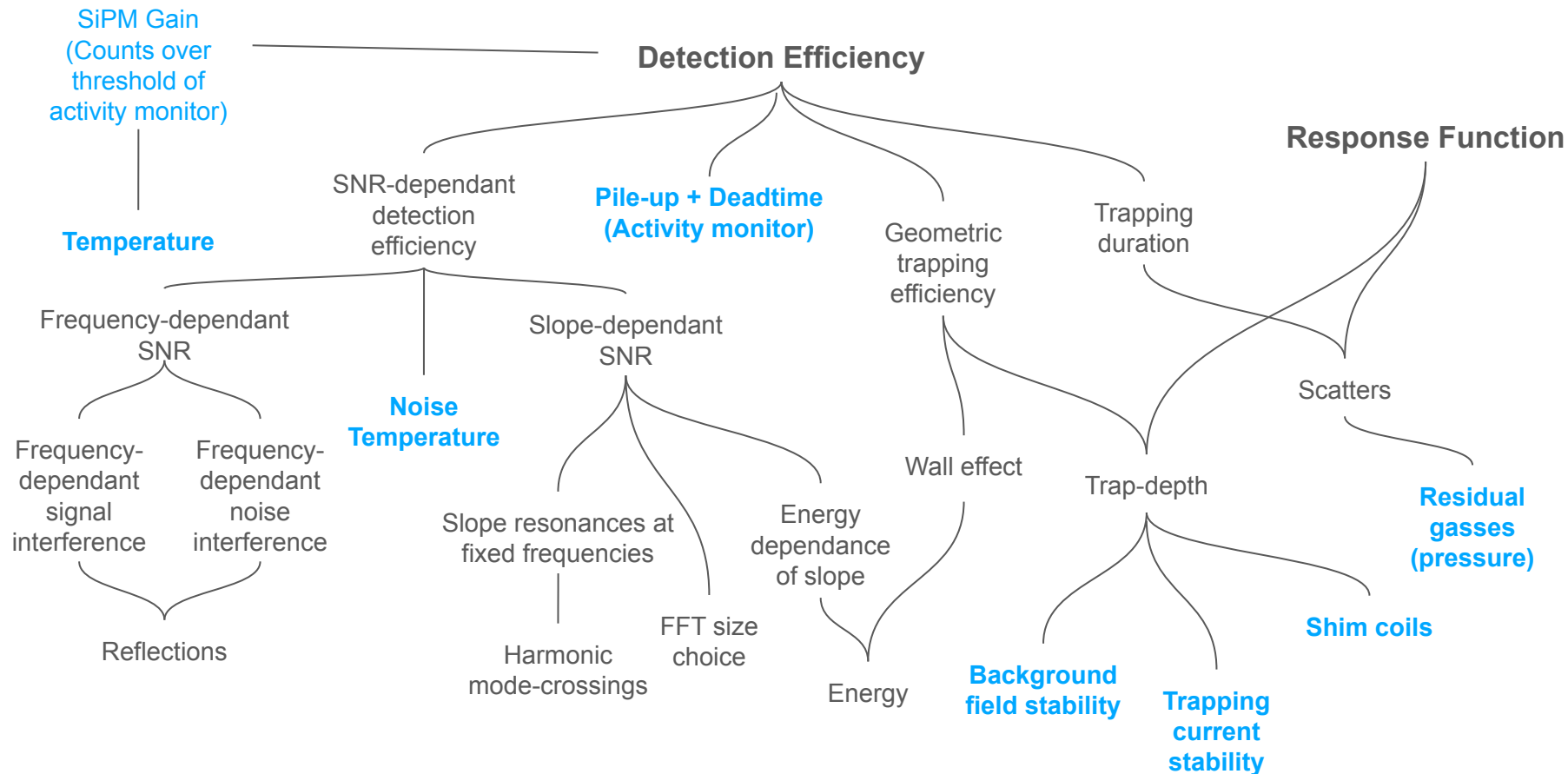
Design a decay cell that

- Creates a strong and reversible electric field
 - Mirrored electrodes (simulated in Ansys), in-house designed and built power switch.
 - Bimodal 600V pulse found to work well to clear >99%.
- Acts as a good waveguide
 - Tested with simulation (HFSS)/ physical measurement (VNA)
- Can easily replace original decay cell: same dimensions, cryogenic, UHV
- Fast emptying
 - Empties in <0.2 ms: 75x faster than turning off trap coils (limited by eddy currents)



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Efficiency drifts - temperature, fields

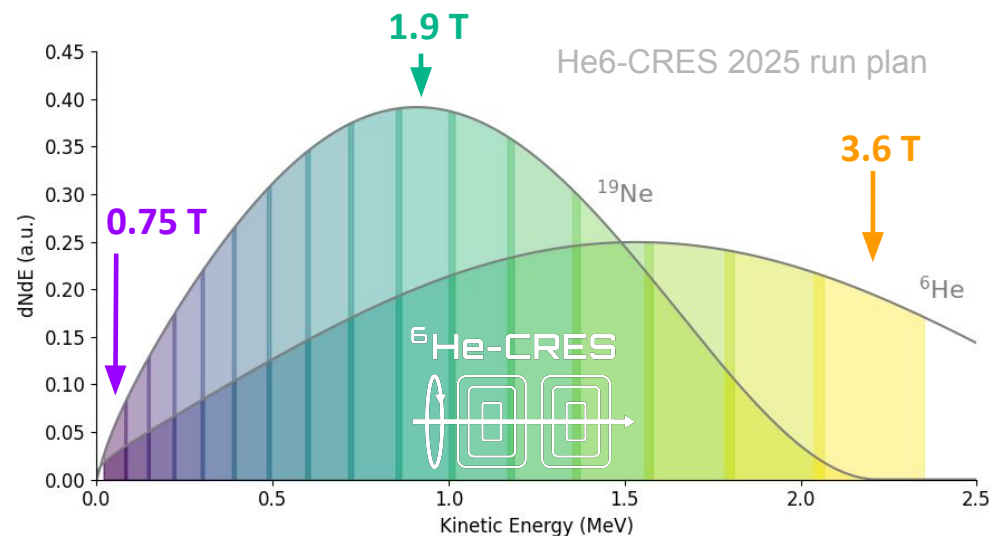
Table 1: Table of systematic uncertainties

Source	Relative efficiency drift	$\Delta b \times 10^3$
RF noise temperature	0.3% - 0.6%	4.0 - 8.0
Beta monitor instability	0.3%	4.0
Relative trap depth	0.0033%	0.044
Rate-dependent effects	0.002%	0.027

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Current Status: 10^{-2} campaign



Goals:

- First measurement of b_{fierz} with CRES
- Contiguous spectrum measurement from 0.02 to 2.35 MeV.
- Overlap of spectrum segments to demonstrate stitching/monitor normalization.
- Ratio beyond endpoint of Ne-19 to constrain contaminants.
- $O(10^{-2})$ sensitivity to b_{fierz}
- Energy resolution better than the full field (PRL), showing the frequency dependent sensitivity canceling in the ratio.
- Basic systemic budget.
- Will inform path to $1e-3$ measurement wrt statistics and systematics.

Plan:

16 Fields each isotope (0.75 T - 3.6)
~2hr of data at each field for each isotope.
112,000 s live data total each isotope (~31 hr > 1 day)
3.68e-3 projected statistical sensitivity to b_{fierz}

ExB pulsing with 4 ms cycle (0.18 ms bimodal 600 V pulse to empty)
2.2 GHz usable bandwidth (100 - 2300 MHz, might get up to 2350 in analysis) All data with standard 1.5 ppt trap defined from min to max with normal polarity

Current Status: Taking Data!

AUGUST 2025

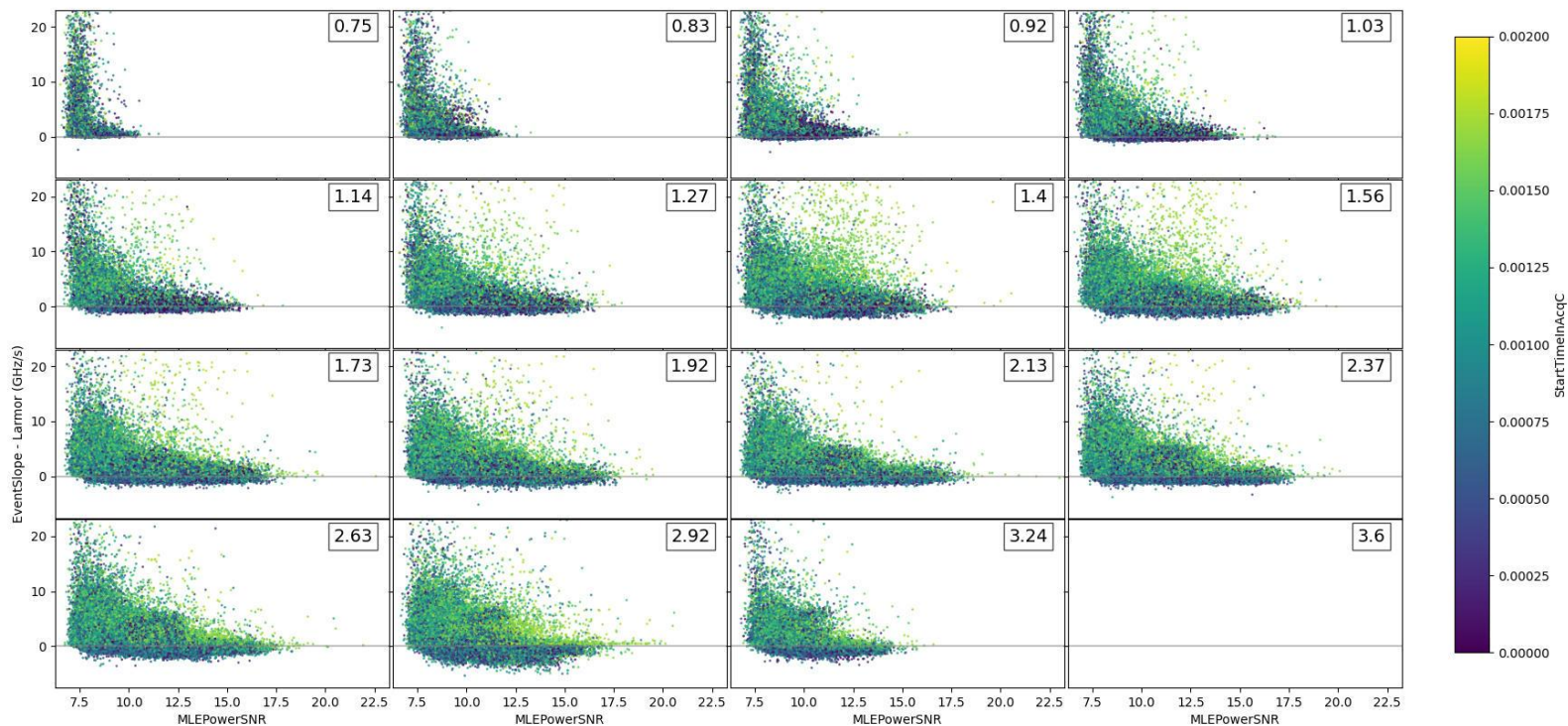
JULY 2025						
SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4 Independence Day	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28 ^{19}Ne Data	29	30	31 ✓		

SEPTEMBER 2025						
SUN	MON	TUE	WED	THU	FRI	SAT
	1 Labor Day	2	3	4	5	6
7	8	9	10 ★	11	12	13
14	15	16	17	18	19	20
21	22	23 ^6He Data?	24	25	26	27
28	29	30				

Download & Print Free Calendars From [Wiki Calendar](#)

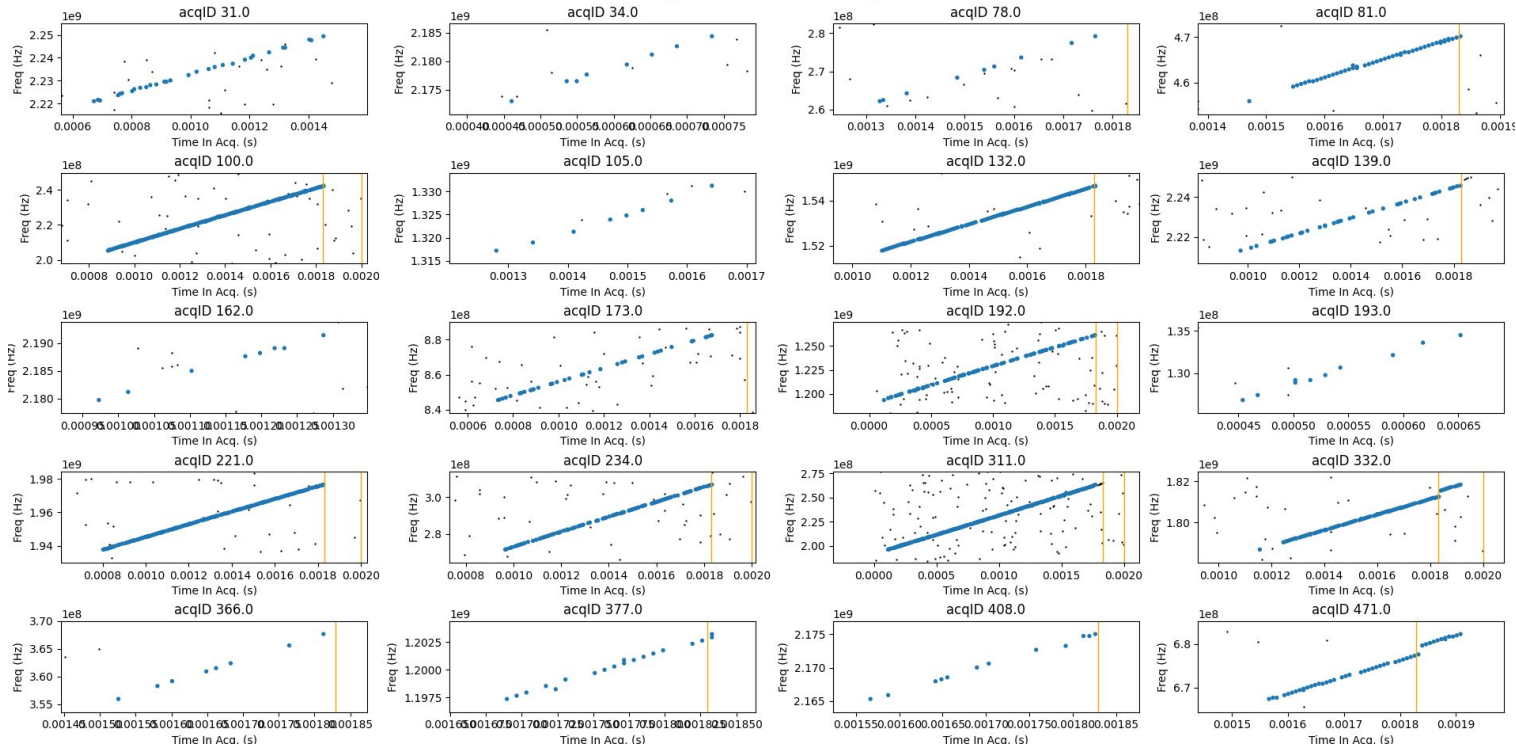
+ Systematic studies of
reproducibility, trap depth, and rate
linearity

Current Status: Taking Data!



Current Status: Taking Data!

Acquisitions with 1 Track(s)



Stay tuned...

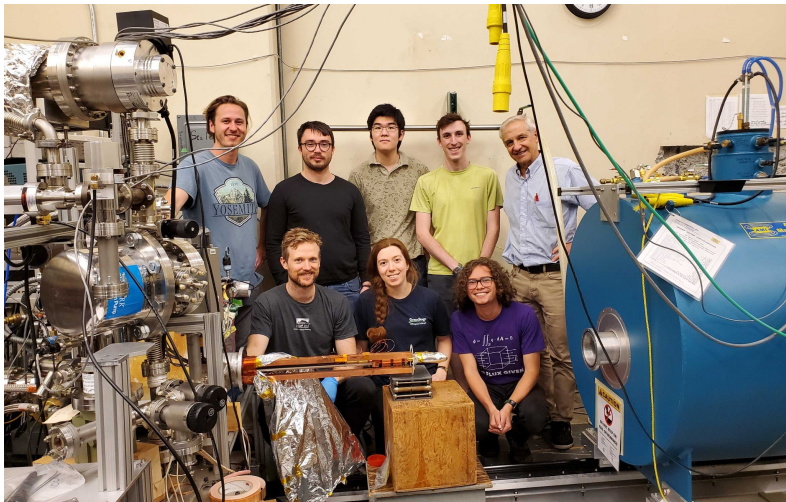
Big Takeaways for using CRES for beta spectroscopy

Challenges:

- **Need to minimize reflections and ensure good termination.**
 - RF reflections cause frequency-dependant SNR (and thus detection efficiency)
- **Will ALWAYS have residual frequency-dependence**
- **Will ALWAYS have energy-dependance**
 - Slope and wall effect.
- **Can only cancel out one of these at a time with a ratio of isotopes.**
 - Up to stability/reproducibility of the B field
- **Good vacuum + trap emptying are KEY**
- **Good magnetic trap depth control is KEY**
- **If you cannot measure your entire ROI of the spectrum at once, expect systematic uncertainties from drifts.**

Advantages:

- Measures β energy at creation, before complicated energy-loss mechanisms.
- No backscattering
- Excellent energy resolution from frequency measurement
- No background exterior to the gas (any charged particle from the walls or outside the decay cell is not observed)



He6-CRES Collaboration

W. A. Byron, N. Buzinsky, B. Dodson, A. Garcia, A. Goodman, A. Gorman, H. Harrington, L. Hayen[†], M.E. Higgins, N.C. Hoppis, P.T. Kolbeck, B. Maxwell, L. Malavasi, D. McClain[‡], D. Melconian[‡], P. Mueller^{**}, N. Oaxaca, N. S. Oblath[‡], G. Savard^{**}, D. Stancil[†], D. W. Storm, H. E. Swanson, R.J. Taylor[†], J. Tedeschi[‡], M.W. Thomas, B. A. VanDevender[‡], C. Wiseman, F. Wietfeldt^{††}, A. R. Young[†], X. Zhu.

[†]Department of Physics, North Carolina State University, Raleigh, NC.

[‡]Texas A&M, College Station, TX.

^{**}Argonne National Laboratory, Lemont, IL.

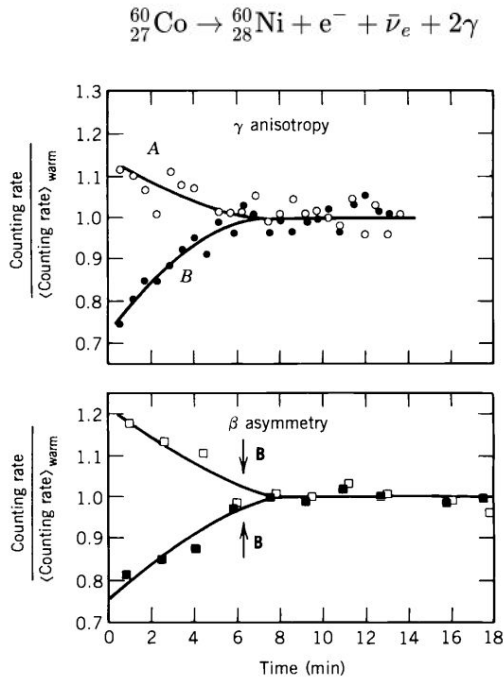
[‡]Pacific Northwest National Laboratory, WA.

^{††}Department of Physics, Tulane University, New Orleans, LA.

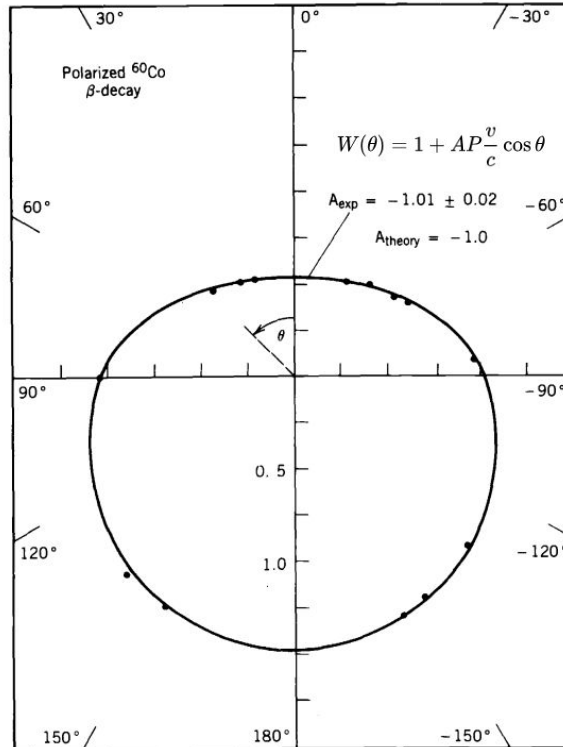


Backup Slides

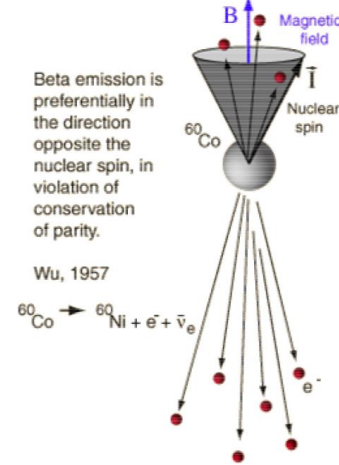
1957: Non-conservation of parity



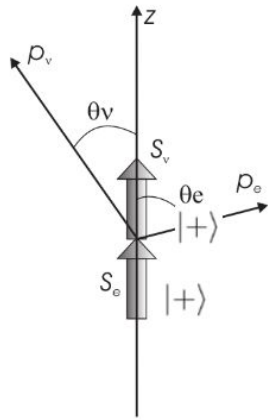
C. S. Wu et al., Phys. Rev. 105, 1413 (1957)



Improved results of C. S. Wu and co-workers on the parity violation in the ${}^{60}\text{Co}$ β decay. From L. M. Chirovsky et al., Phys. Lett. B 94, 127 (1980)



Standard Model – Left Handed Charged Weak Interaction



Helicity: Projection of spin onto momentum.

$$|+\rangle = \cos(\theta/2)|+\rangle - \sin(\theta/2)|-\rangle$$

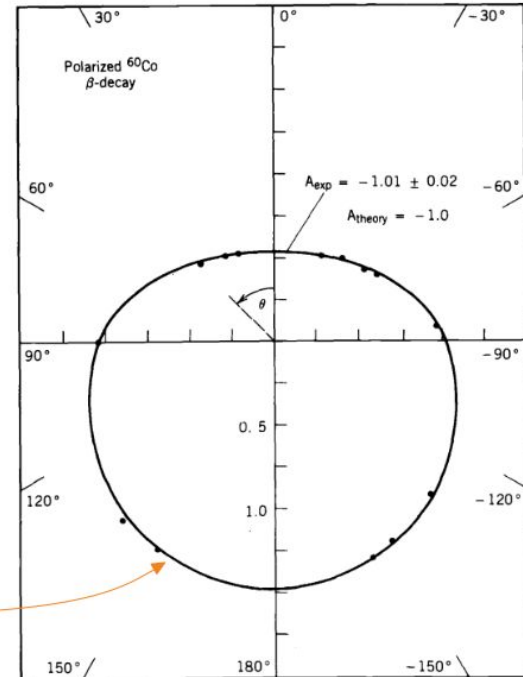
$$|-\rangle = \sin(\theta/2)|+\rangle + \cos(\theta/2)|-\rangle$$

Chirality:

$$\frac{dW}{d\Omega} = \frac{1}{2\pi} [\langle +|\theta-\rangle_L + \langle +|\theta+\rangle_L]$$

$$\frac{dW}{d\Omega} = \frac{1}{2\pi} \left[\sin^2(\theta/2) \frac{(1 + p_e/E_e)}{2} + \cos^2(\theta/2) \frac{(1 - p_e/E_e)}{2} \right]$$

$$= \frac{(1 - (p_e/E_e) \cos \theta)}{4\pi}$$



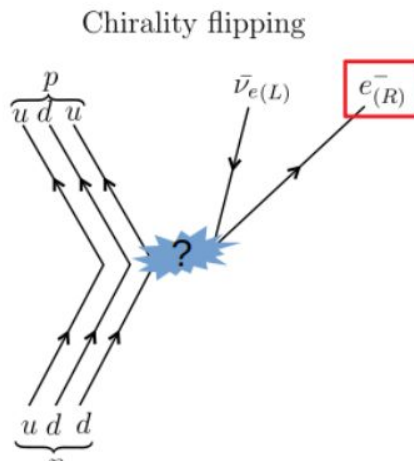
Beta Decay correlations (alphabet soup) and scale of new physics

Jackson, Treiman and Wyld (Phys. Rev. 106 and Nucl. Phys. 4, 1957)

$$\frac{d\Gamma}{d\Omega_e d\Omega_\nu dE_e} = \underbrace{\frac{G_F^2 |V_{ud}|^2}{(2\pi)^5} p_e E_e (E_o - E_e)^2 \xi}_{\text{basic decay rate}} \left[\underbrace{1 + a \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu}}_{\beta-\nu \text{ correlation}} + \underbrace{b \frac{m_e}{E_e}}_{\text{Fierz term}} + \frac{\langle \vec{J} \rangle}{J} \cdot \left(\underbrace{A \frac{\vec{p}_e}{E_e}}_{\beta \text{ asym}} + \underbrace{B \frac{\vec{p}_\nu}{E_e}}_{\nu \text{ asym}} + \underbrace{D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}}_{T\text{-violating}} \right) + \dots \right]$$

Lee-Yang effective couplings

$$\begin{aligned} C_i &= \frac{G_F}{\sqrt{2}} V_{ud} \bar{C}_i \\ \bar{C}_V &= g_V (1 + \epsilon_L + \epsilon_R) \\ \bar{C}_A &= -g_A (1 + \epsilon_L - \epsilon_R) \\ \bar{C}_S &= g_S \epsilon_S \\ \bar{C}_T &= 4g_T \epsilon_T, \end{aligned}$$



Non-standard effective couplings

$$b = \pm 2\gamma(Z) \frac{\left[\frac{g_S}{g_V} \epsilon_S - 4 \left(\frac{\langle \sigma \tau \rangle}{\langle \tau \rangle} \right)^2 \frac{g_T}{g_V} \frac{g_A}{g_V} \epsilon_T \right]}{1 + \left(\frac{\langle \sigma \tau \rangle}{\langle \tau \rangle} \right)^2 \left(\frac{g_A}{g_V} \right)^2}$$

$\langle \sigma \tau \rangle$ and $\langle \tau \rangle$ are the Gamow-Teller and Fermi nuclear β -decay matrix elements, respectively

He6-CRES Overview

Long-term goal: Utilize ^{19}Ne (β^+) and ^6He (β^-) spectral ratios via CRES towards a precise (10^{-3}) measurement of b_{Fierz} .

- $b_{\text{Fierz}} \neq 0$ indicative of beyond the Standard Model (BSM) physics.

$$\frac{dN}{dE} \approx \frac{dN_{SM}}{dE} \underbrace{\left(1 + b_{\text{Fierz}} \frac{m}{E}\right)}_{\text{BSM}}$$

- Would arise from non-standard chirality-flipping scalar and tensor currents via interference with standard vector or axial vector currents

$$\begin{aligned} \mathcal{L}_{CC} = \sqrt{2}G_F V_{ud}^{CKM} \{ & \bar{e}^L \gamma_\mu \nu_e^L \cdot \bar{u} \gamma^\mu (1 - \gamma^5) d \\ & + \epsilon_S \bar{e}^R \nu_e^L \cdot \bar{u} d \\ & + \epsilon_T \bar{e}^R \sigma_{\mu\nu} \nu_e^L \cdot \bar{u} \sigma^{\mu\nu} (1 - \gamma^5) d \} \end{aligned}$$

- At the 10^{-3} level:

$$\frac{b_{\text{Fierz}}(^{19}\text{Ne})}{-0.7204} \approx b_{\text{Fierz}}(^6\text{He}) = \frac{8\epsilon_T}{g_A}$$

DAQ

