Experimental Measurement of Isospin Symmetry Breaking in 47K Beta Decay*

Abstract:

While both Charge-Parity (CP) symmetry, and more recently Time (T) symmetry have been shown to be violated in the weak interaction, it remains an open question whether new sources of CP violation could explain the matter-antimatter asymmetry in the universe.

TRIUMF's Neutral Atom Trap (TRINAT) is equipped to study the angular distribution of all decay products from spin-polarized beta emitting isotopes produced by the Isotope Separator and Accelerator (ISAC) facility. We discuss the latest result from a scheduled experiment in which we plan to simultaneously trap ~40000 laser-polarized 47K (t1/2 = 17.5 ± 0.24 s) atoms.

Decay from 47K (I=1/2) into the isobaric analog state is energetically forbidden, but instead 80% of the decays proceed via an isospin changing branch to a single I=1/2 state. The recoil asymmetry is made nonzero by the product of the Gamow-Teller and isospin-suppressed Fermi matrix elements, and we plan to measure this effect at TRINAT in order to test analog-antianalog isospin mixing. A future measurement of D Î · vβ × vν would have enhanced sensitivity to isospin-breaking, parity even, T-odd interactions, since constraints from the neutron EDM on D [Ng, Tulin PRD 2012] are relaxed for isospin-breaking interactions.

1)Testing Time Reversal Symmetry

- Symmetry of flipping the sign of time
- Violated in weak interaction, but thus far doesn't account for matter/antimatter asymmetry in the universe
- Enhanced in Isospin-Hindered Decay...

When t $\rightarrow$ -t :

$\vec{r} \rightarrow \vec{r}$ $\quad$ $\vec{p} \sim \frac{d\vec{r}}{dt} \rightarrow -\vec{p}$

i.e. any scaler triple product of momenta

(i) An "oriented nucleus-electron-neutrino" correlation, $W_{e\nu}$, of the form

$$W_{e\nu} \propto 1 + A\, J \cdot p_e \times p_\nu \qquad (1)$$

and

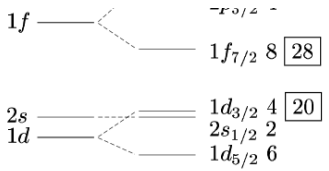
(ii) An "oriented nucleus-electron-γ" correlation, $W_{e\gamma}$, of the form

$$W_{e\gamma} \propto 1 + B\, J \cdot p_e \times k \left[\sum_{n=1,3} c_n (J \cdot k)^n + \ldots \right] \qquad (2)$$

A. Barroso and R.J.Blin-Stoyle (1973)

2) Isospin-Suppressed Decay (anti-analog)

- ΔT = 0 decay not energetically possible
- Pure Gamow-Teller without mixing
- Coulomb potential mixing of |A› and |F› contributes Fermi component, which impacts angular correlations
- Barroso and Blin-Stoyle suggest this simple system can enhance **Time Reversal Violation** effects by a factor of ~100



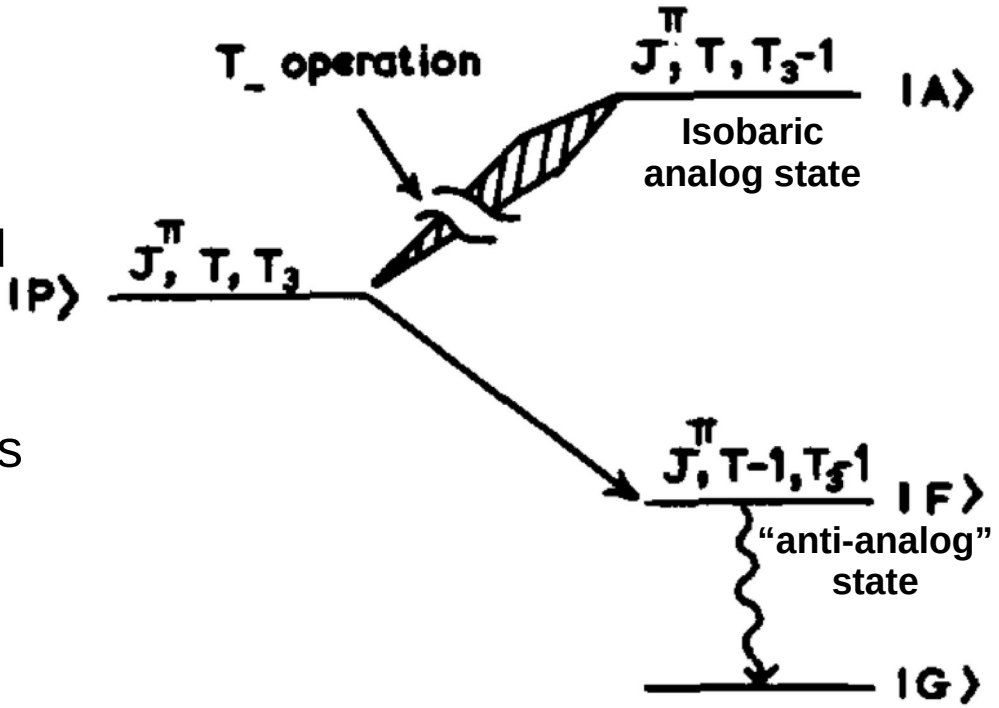
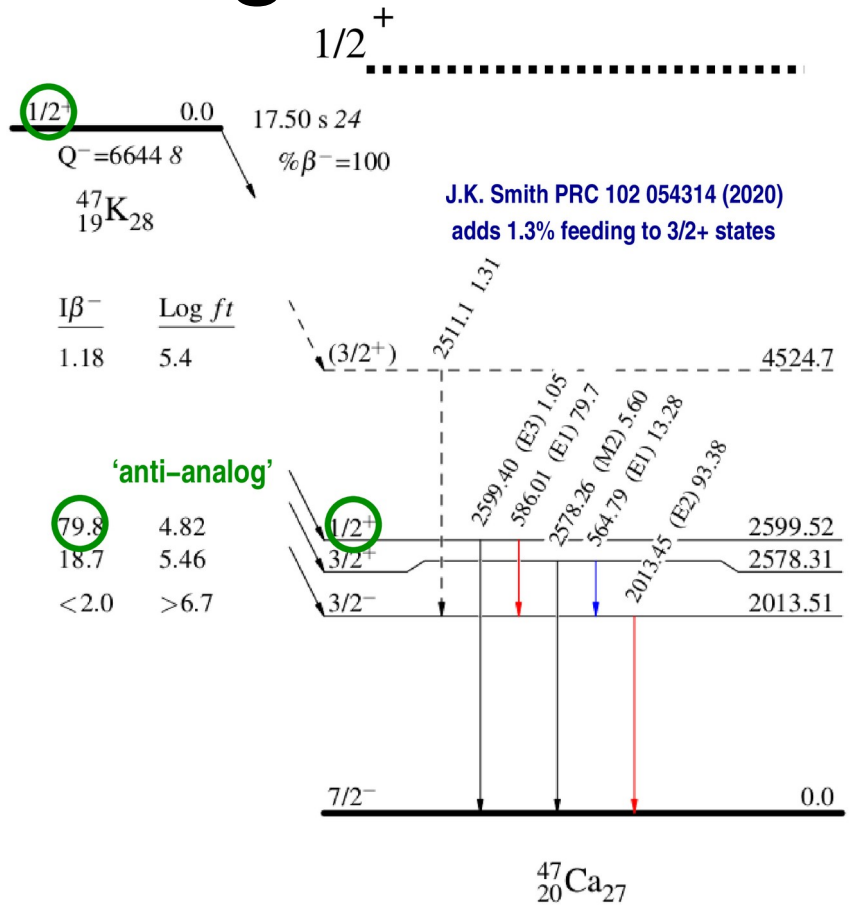


Fig. 1. Level diagram for isospin-hindered β-decay

A. Barroso and R.J.Blin-Stoyle (1973)

3) Isospin and Time Reversal Symmetry Breaking in ^{47}K

- Isospin mixing of analog and “anti-analog” is an intrinsically interesting test for nuclear theory
- Large branching ratio into anti-analog state
- N=28 to Z=20 decay simplifies structure
- ^{47}K Can be laser trapped and polarized
- Besides NOPTREX (A Neutron OPtics Time Reversal EXperiment), we know of no other experiment sensitive to Parity-symmetric, Time-asymmetric interactions



4) Decays in TRINAT

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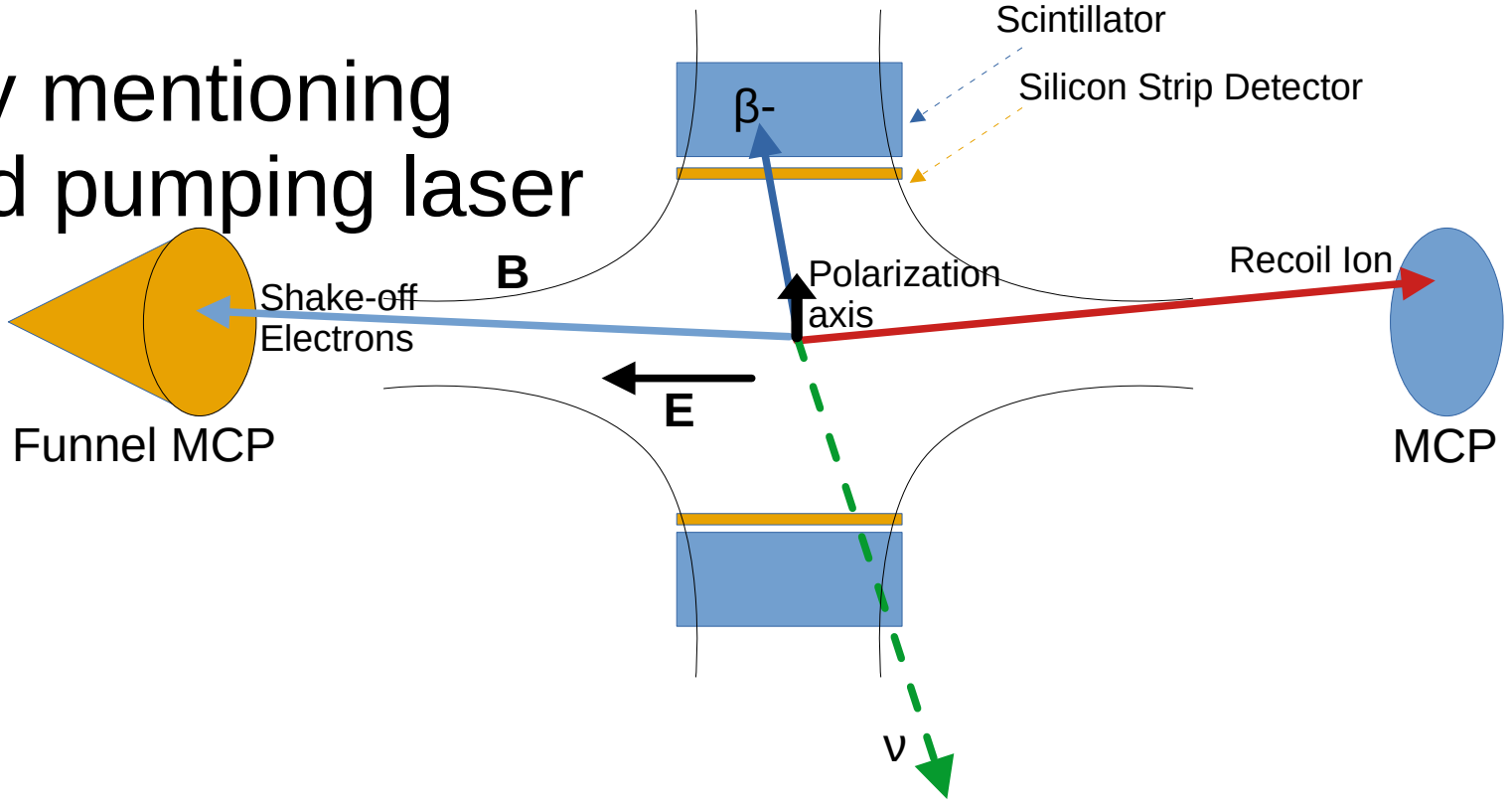
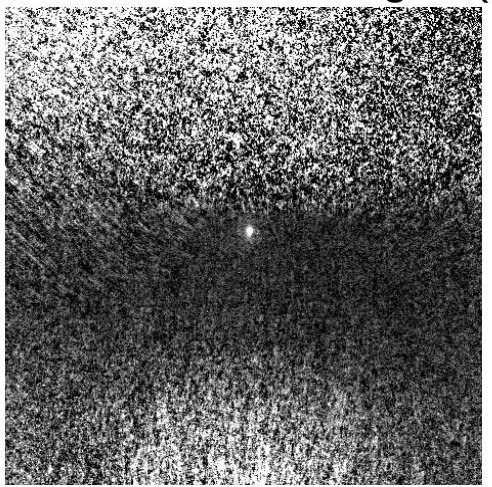
- Finish by mentioning MOT and pumping laser



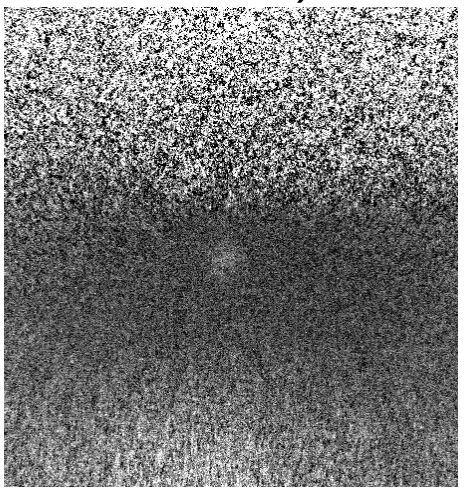
5) Trapping and Pumping

- Optical Molasses with minimum potential at centre (Anti Helmholtz? Power?)
- Optical pumping defines the initial polarization (“stretched” state)
- Trapping laser momentarily interrupted for decay measurement
- We alternate polarizations during measurement
- Repumping?

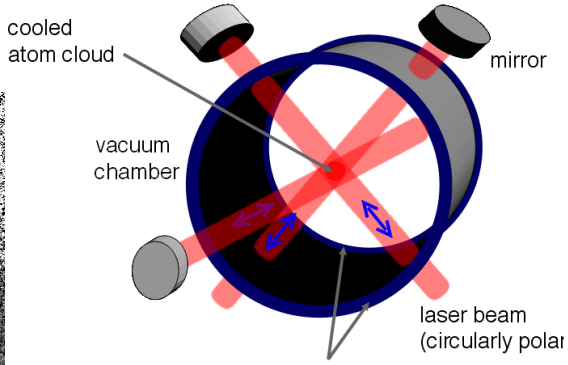
Summed ^{47}K images (Summer 2023):



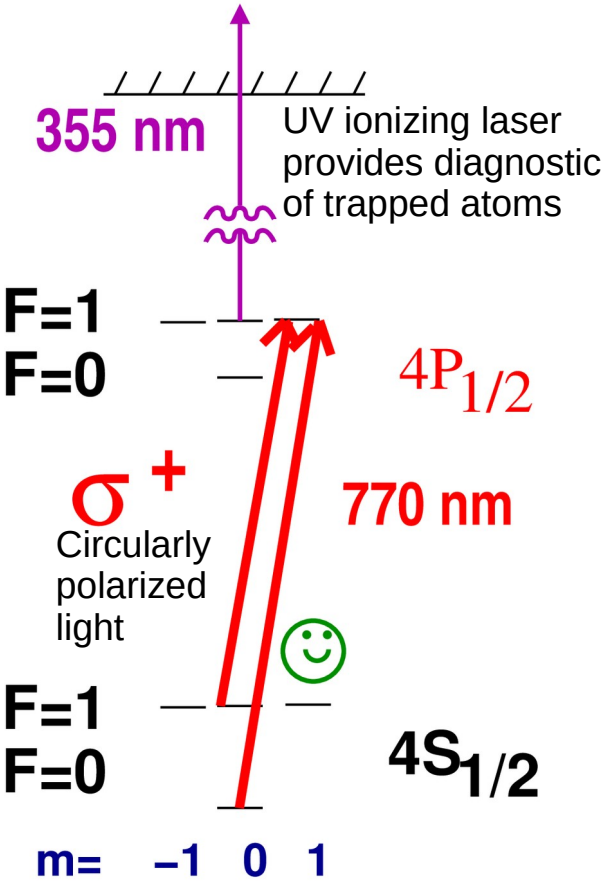
Trapping



Immediately After Laser Blocked



Courtesy of Wikipedia

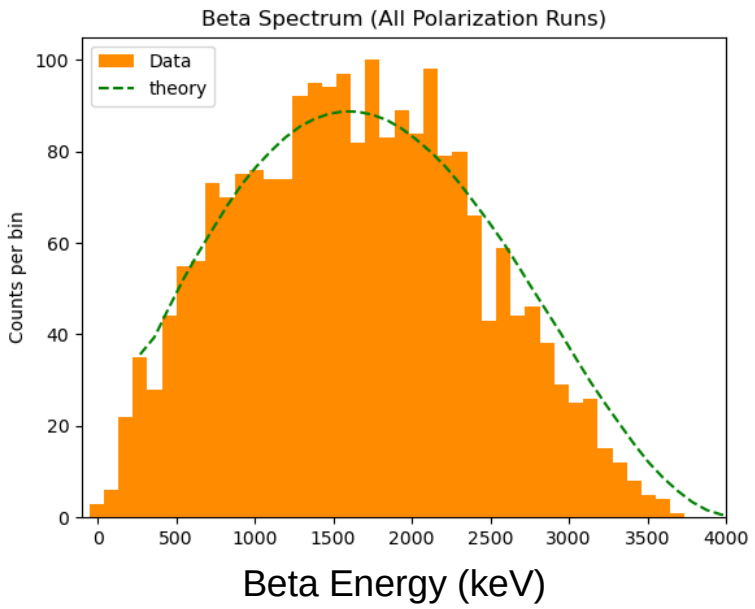


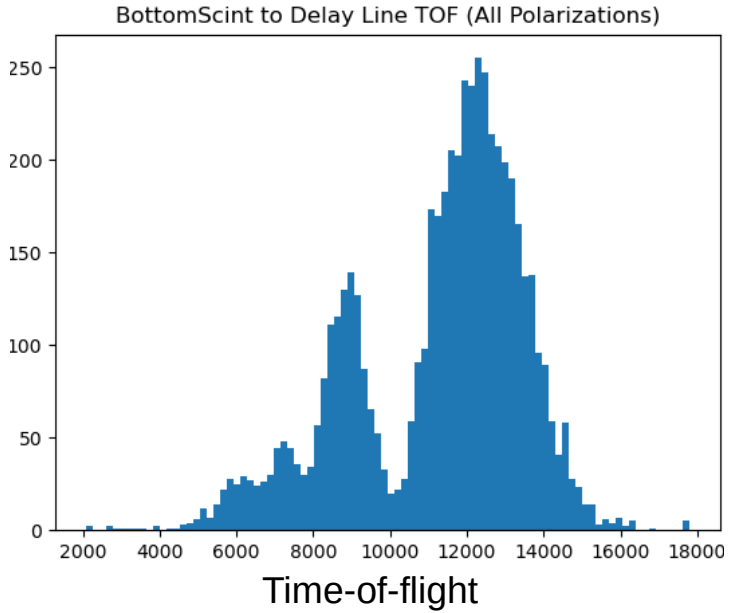
6)Check Beta Spectrum/Look for Asymmetry

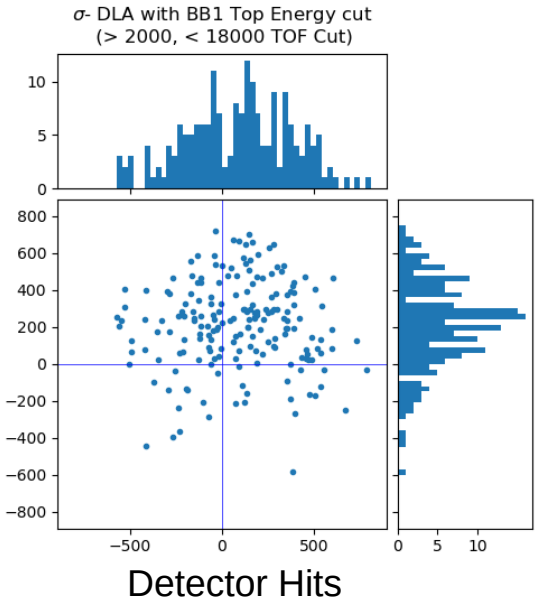
- Recoils are a sensible place to look

$$A_{\text{recoil}} = 2\sqrt{\frac{J}{J+1}}G_V M_F / G_A M_{\text{GT}},$$

Many +1 recoils left on the table

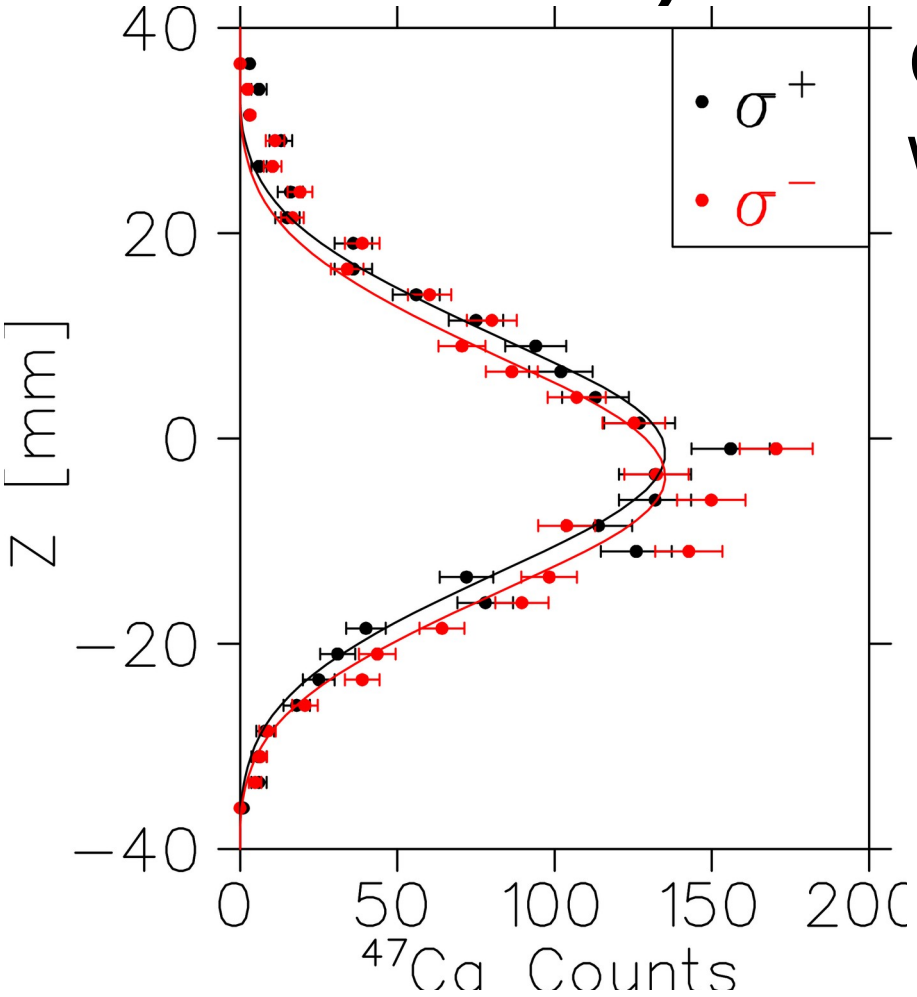


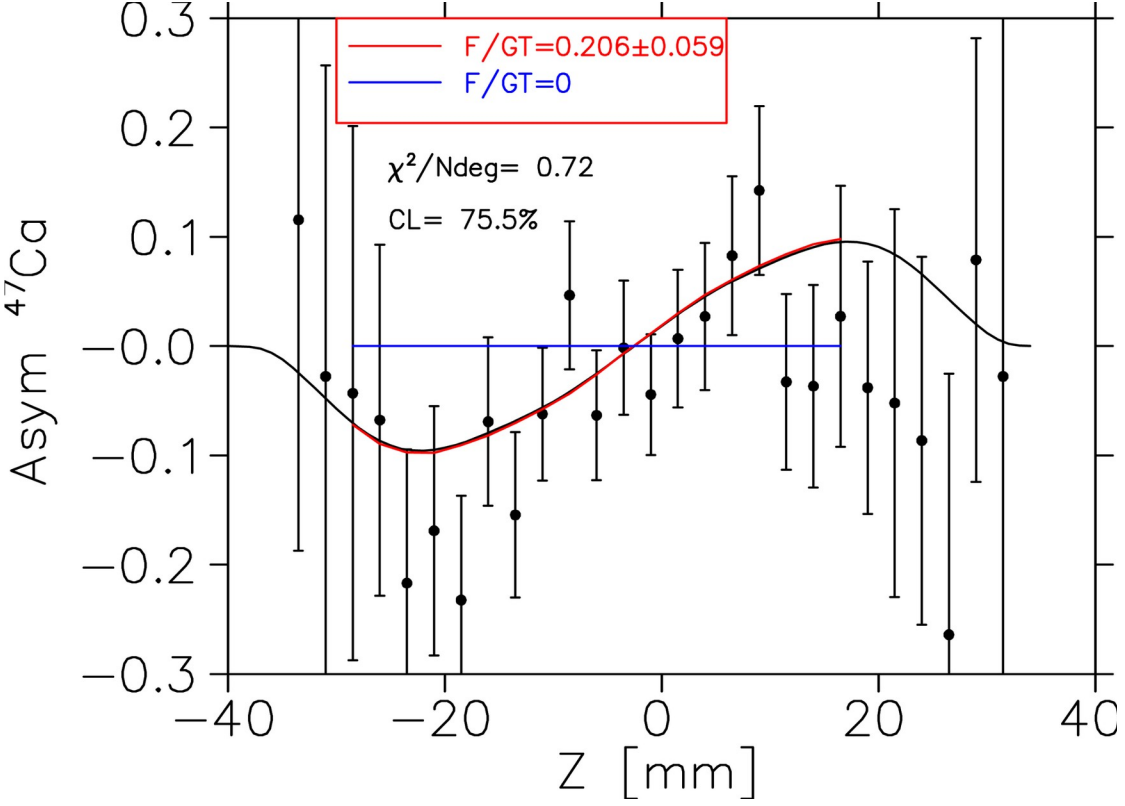




7) Ion Recoil Result

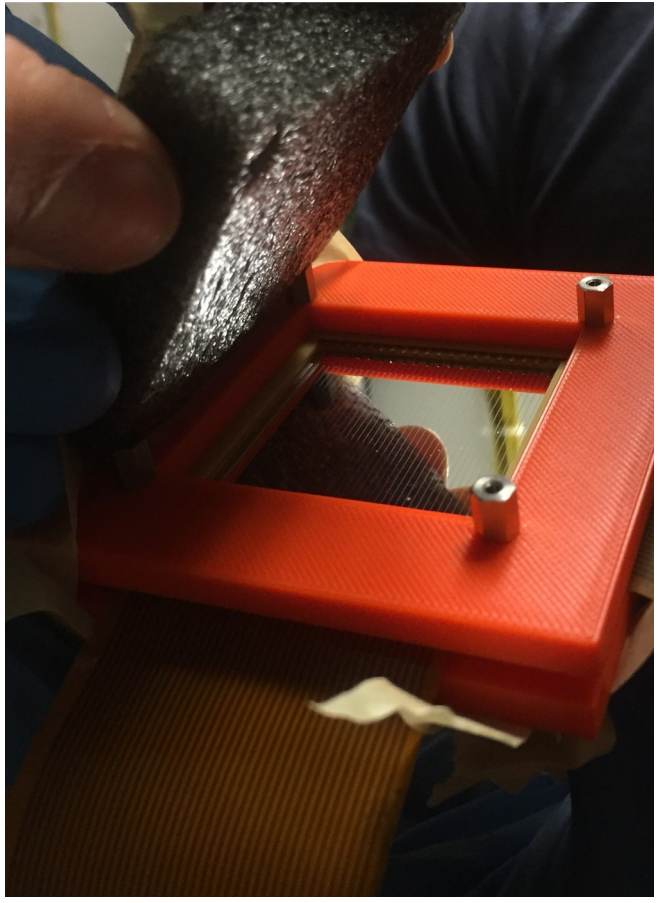
Charge State >1+ in coincidence with shakeoff electrons





8) Strip detector/energy cuts eMCP tagging result

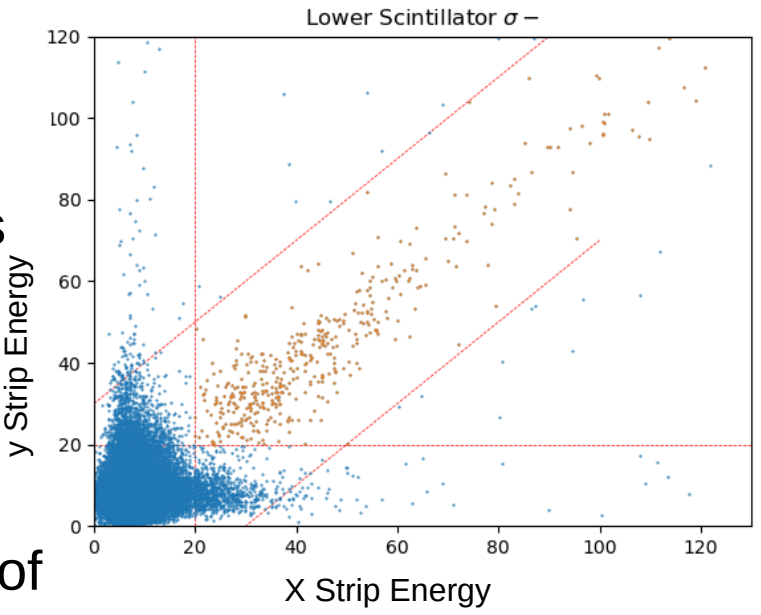
Double-Sided Silicon Strip Detector



- DSSSD tests revealed several failed strips
- Wires sensitive to vibration and air currents
- Refurbishment of silicon strip detector (ATLAS wire-bonding)

Thanks to Nicolas Massacret and Sebastian Manson

- Enabled energy tagging of betas
- Suppressed background events from scintillator-shakeoff electron coincidences



9)Preliminary Result for Isospin

and Time Reversal Violation Implications?

Electrons + Recoil MCP:

$$\frac{M_F}{M_{GT}} = 0.21 \pm 0.06 \pm systematics$$

Electrons and β/DSSSD:

$$\frac{M_F}{M_{GT}} = 0.06 \pm 0.10 \pm systematics$$

From:

$$A_\beta = -0.489 \pm 0.121 \pm systematics$$

- 1000 atoms trapped for 1 day
- Observed ^{47}Ca direction asymmetry WRT spin
- Fermi contribution calculated via two different observables
- Statistics lacking, but we expect to be able to get 10x ^{47}K the data over 2 shifts, pending improvements to the laser
- We would love to see theory calculations for the nuclear matrix element!

The End

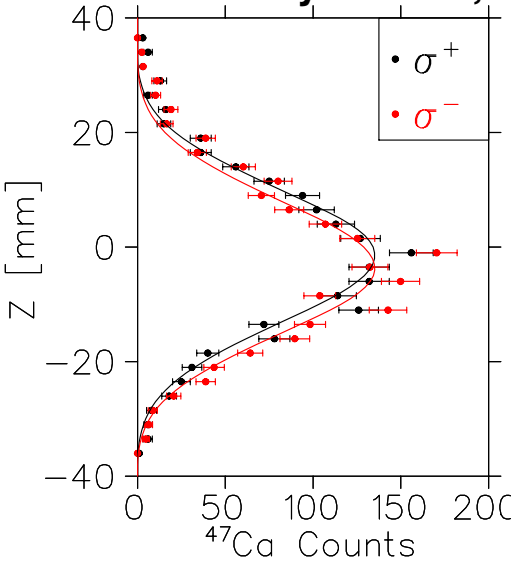
- Doesn’t small M_V imply greater sensitivity to TRV?

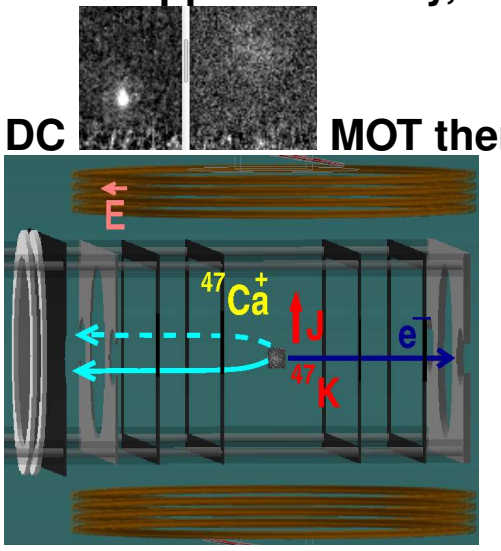
$$M_{\mathrm{V}} = \frac{\langle \mathrm{F}|V_{\mathrm{c}}|\mathrm{A}\rangle\langle \mathrm{A}|T_{-}|\mathrm{P}\rangle}{E_{\mathrm{F}} - E_{\mathrm{A}}} + \frac{\langle \mathrm{F}|V_{\mathrm{t.v.}}|\mathrm{A}\rangle\langle \mathrm{A}|T_{-}|\mathrm{P}\rangle}{E_{\mathrm{F}} - E_{\mathrm{A}}} \qquad (8)$$

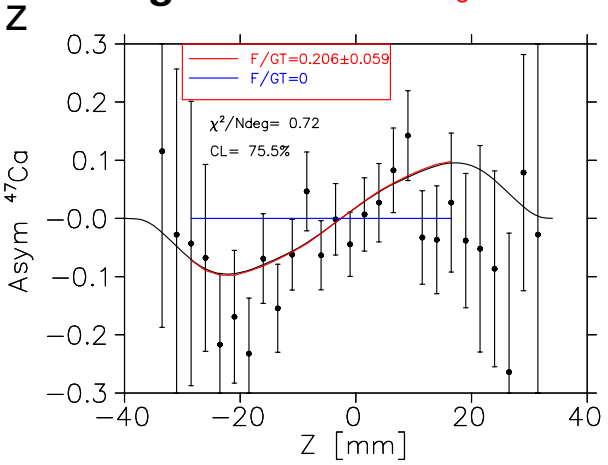
Proposal: “Assuming 50 keV Coulomb mixing”

Results

Preliminary results, 1000 atoms trapped for 1 day, isospin breaking ^{47}K without weak mag







We would like to see calculations for the nuclear matrix element

Nonzero ^{47}Ca direction asymmetry wrt spin

⇒ a nonzero Fermi contribution

M_F / M_{GT} = 0.21 ± 0.06 stat ± ? syst ⇒

$\langle \bar{A} | V_{\text{Coulomb}} | A \rangle$ = 160 ± 50 stat ± ? syst keV

With laser improved to collect more ^{47}K, we hope to take 10x the data Dec 20-21

β's+eMCP, A_β (corrected for dΩ and % strips)

σ^+: top 13*1.08/1.13 bot 23, Asym= -0.30±0.16

σ^-: top 41*1.08/1.13 bot 12 Asym= 0.53±0.12

(Ave Asym)/P=0.96±0.04/v=0.966 /$\langle \cos \rangle$ = 0.99

=

A_β = -0.489 ± 0.121 (stat) ± ? (syst)

Gamow-Teller calculation -0.416 ⇒

M_F / M_{GT} = +0.06 ± 0.10 stat ± ? syst