Measurement of Analog-Antianalog Isospin Mixing in ^{47}K Beta Decay

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2) University of British Columbia
3) University of Waterloo
4) Texas A&M University

Outline

- Testing time reversal symmetry (why and how)
- Isospin-Suppressed decay in ^{47}K
- Beta decay with trapped atoms in TRINAT
  (TRIUMF's Neutral Atom Trap)
- Results for the decay asymmetry and isospin mixing

Testing Time Reversal Symmetry

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

When t $\rightarrow$ -t :

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

i.e. any scalar triple product of momenta

Approach we utilize:

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

$$W_{e\nu} \propto 1 + A\, \boldsymbol{J}\cdot\boldsymbol{p}_e \times \boldsymbol{p}_\nu \qquad (1)$$

Aka "D"

and

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

(e.g. Calaprice et al. PRC 1977)

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

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

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Isospin-Suppressed Decay (anti-analog)

- Total isospin conserving decay ($\Delta T = 0$) 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 **Isospin Symmetry Breaking Time Reversal Violation** effects by a factor of ~100

  (because TRV is referenced to the small isospin symmetry breaking)
- RIB experiment performed at TRIUMF

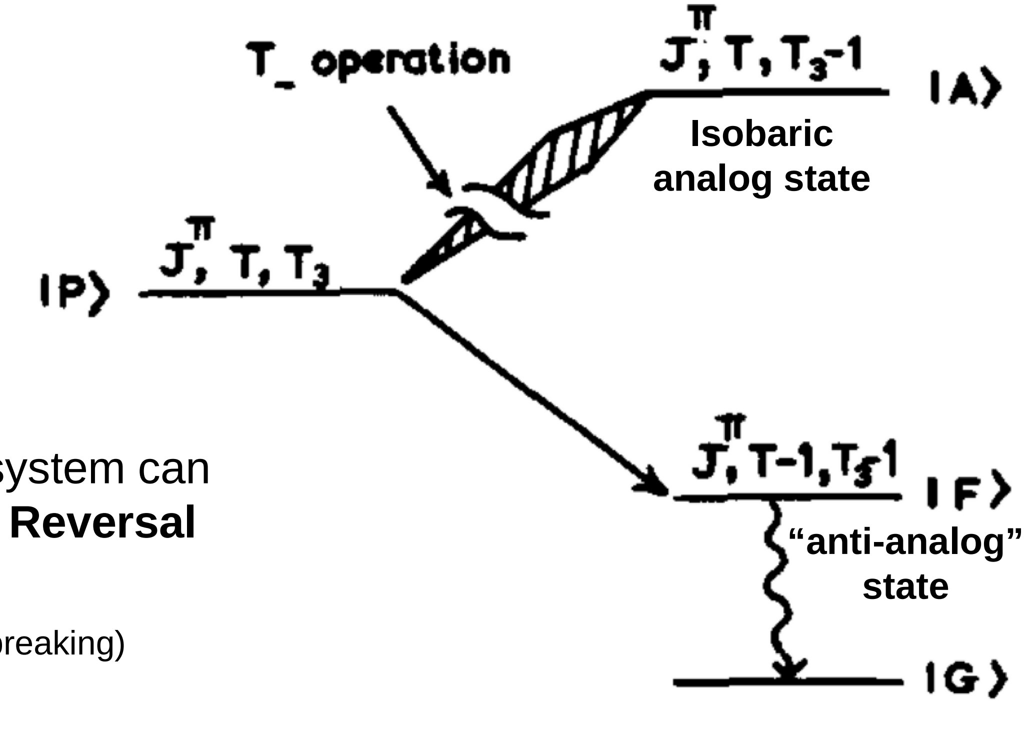


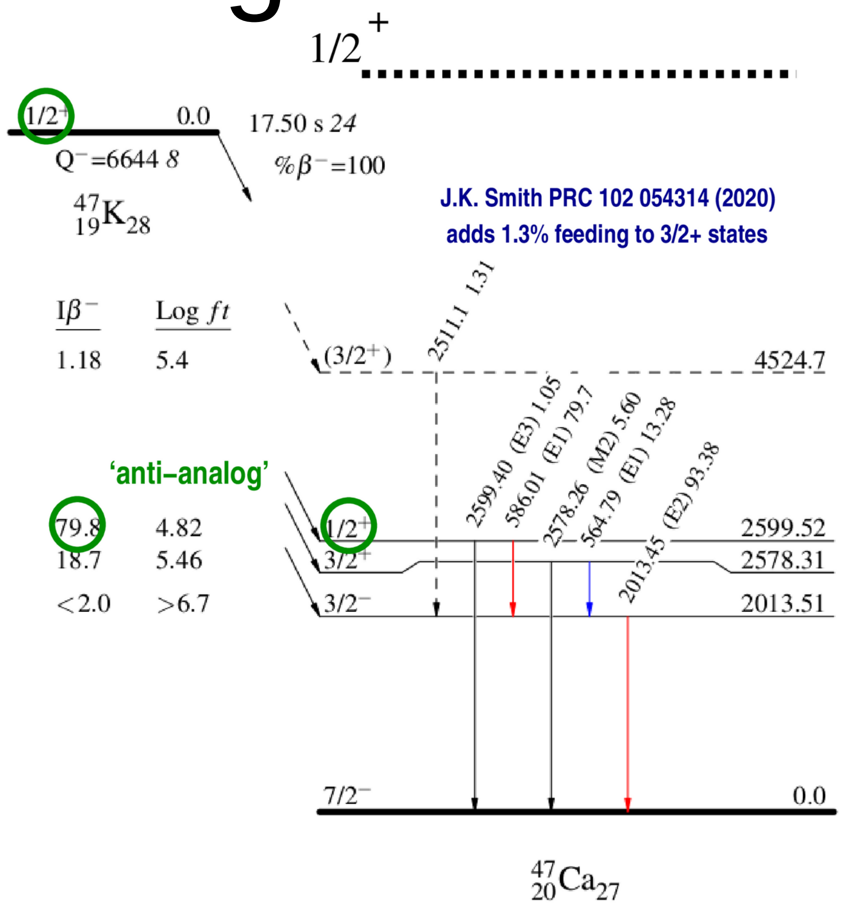
Fig. 1. Level diagram for isospin-hindered β-decay

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

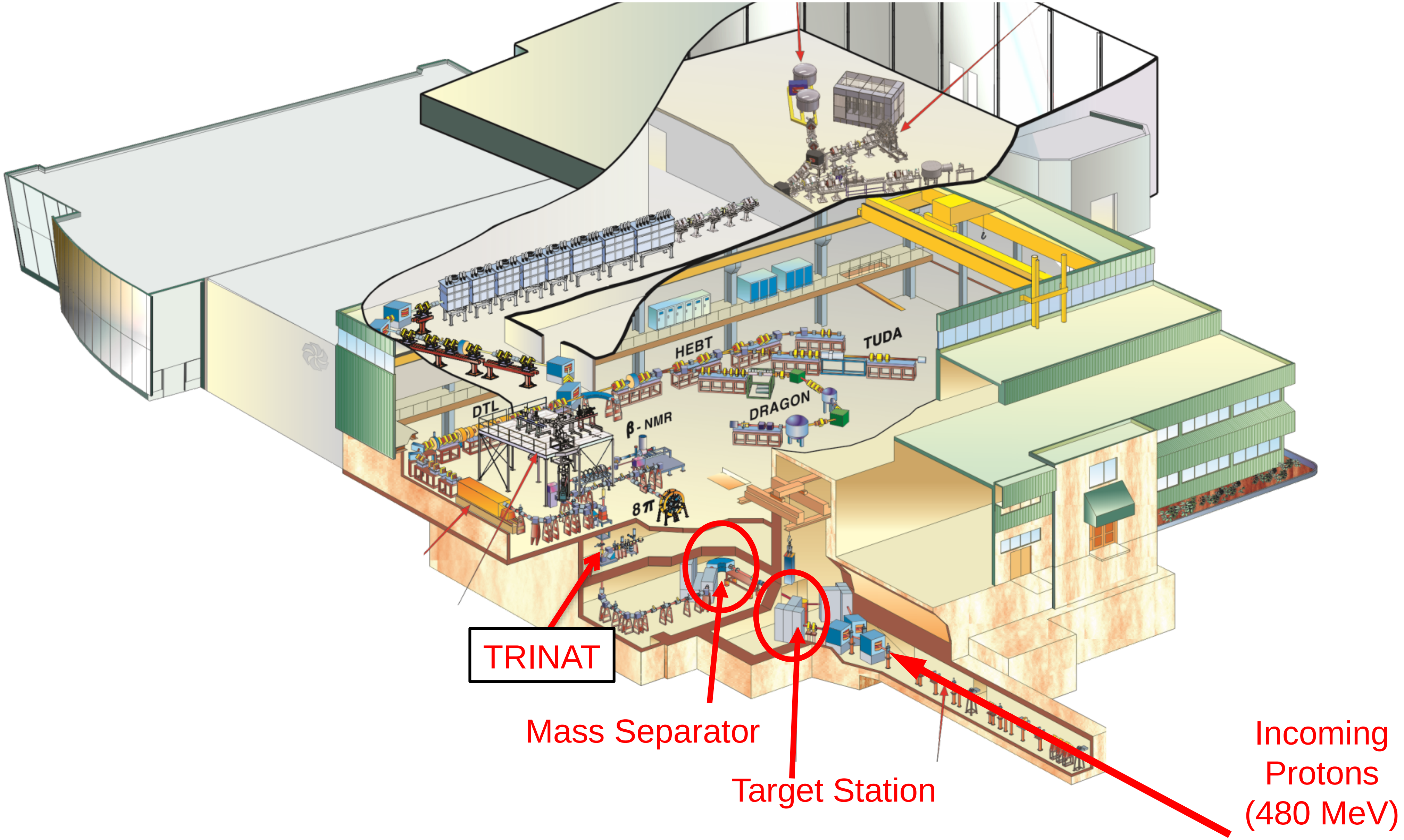
Isospin and Time Reversal Symmetry Breaking in ^{47}K

- Mixing of analog and “anti-analog” states is an intrinsically interesting test of isospin symmetry breaking
- Large branching ratio into anti-analog state
- N=28 to Z=20 decay simplifies structure
- ^{47}K Can be laser trapped and polarized
- We hope this can achieve sensitivity that will complement NOPTREX (A Neutron OPtics Time Reversal Experiment) and Calaprice et al. (1977 ^{56}Co β-γ) for **isospin symmetry breaking, Parity-symmetric, Time-asymmetric** effects
- Complementary to neutron EDM;

  (not constrained by bound set by Ng, Tulin Phys. Rev. D 85, 033001 (2012) providing D < 10^{-2})

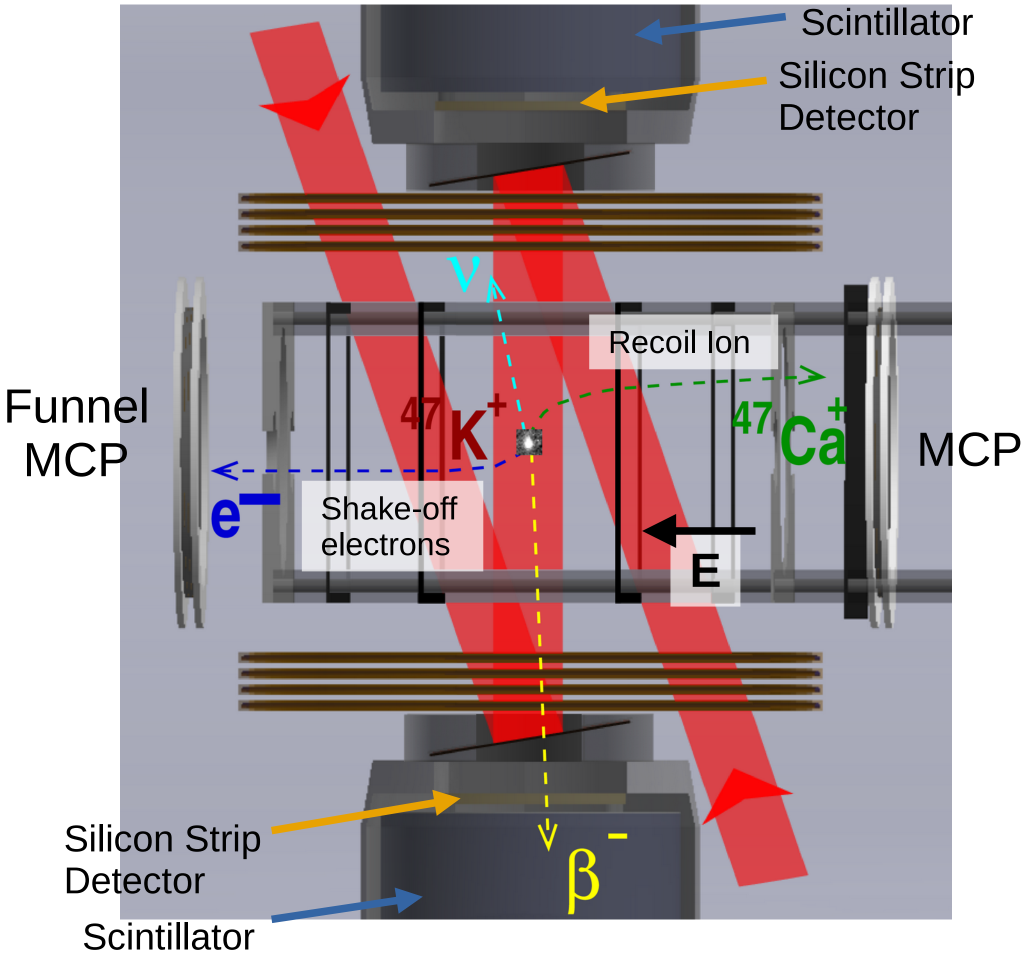


The Isotope Separator and Accelerator (ISAC) at TRIUMF



β Decays in TRINAT

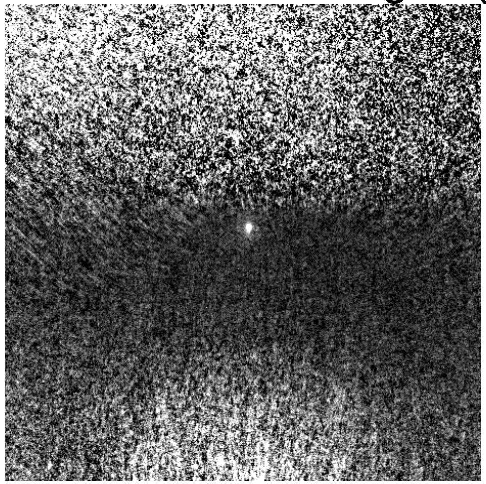
- Beta, decay product, and “shake-off” electron(s) are detected
- Energy and timing used to make cuts
- Atoms polarized either up or down



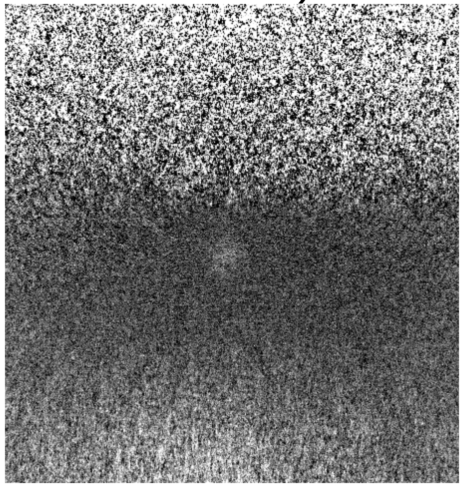
Trapping and Pumping

- Magneto-optical trap: de-tuned lasers and quadrupole B-field make a damped harmonic oscillator
- Optical pumping defines the initial polarization ("stretched" state)
- Trapping laser momentarily interrupted for decay measurement
- We alternate polarizations during measurement
- 1000 atoms in trap; 1 day measurement

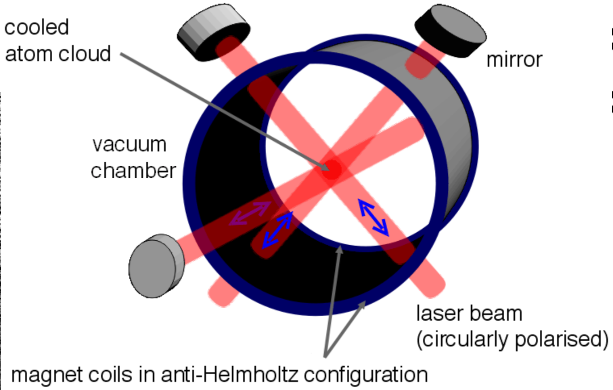
Summed ^{47}K images (Summer 2023):



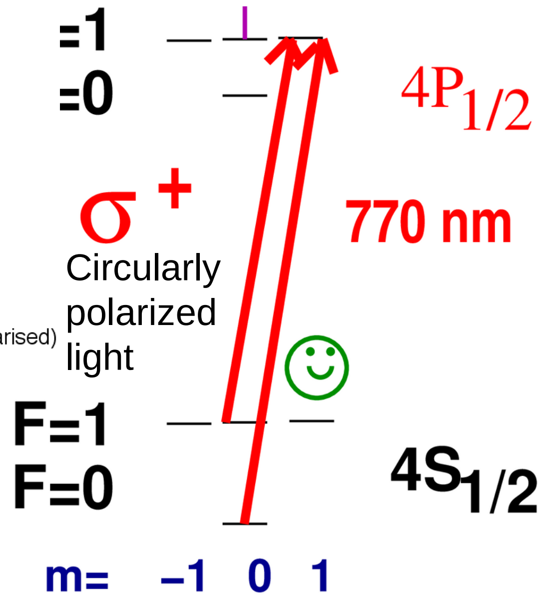
Trapping



Chopping laser and B field



Courtesy of Wikipedia



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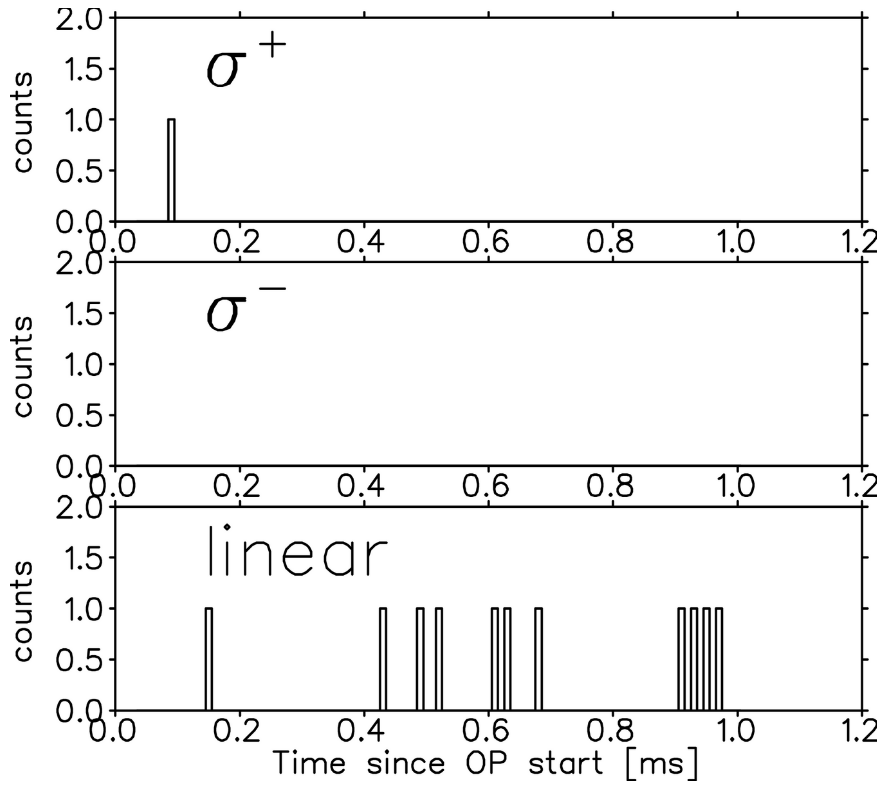
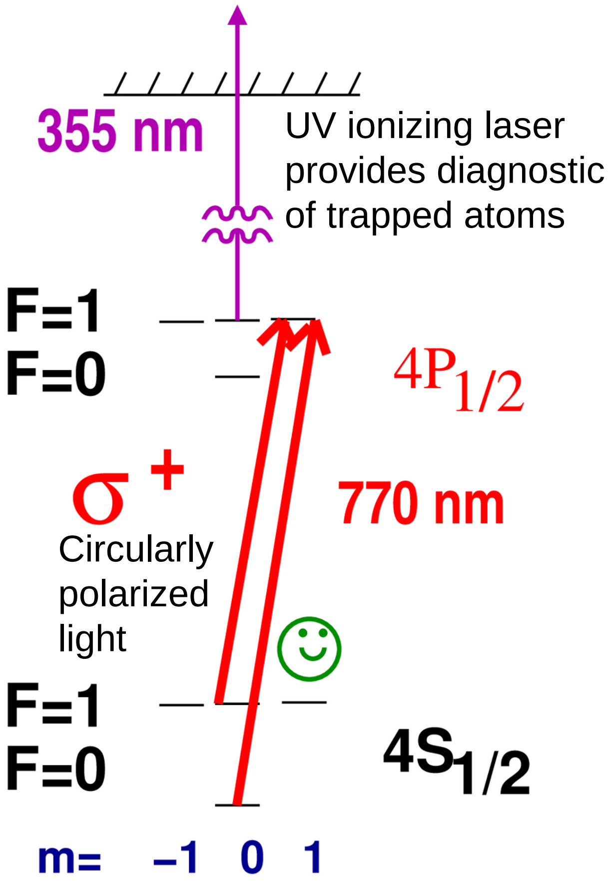
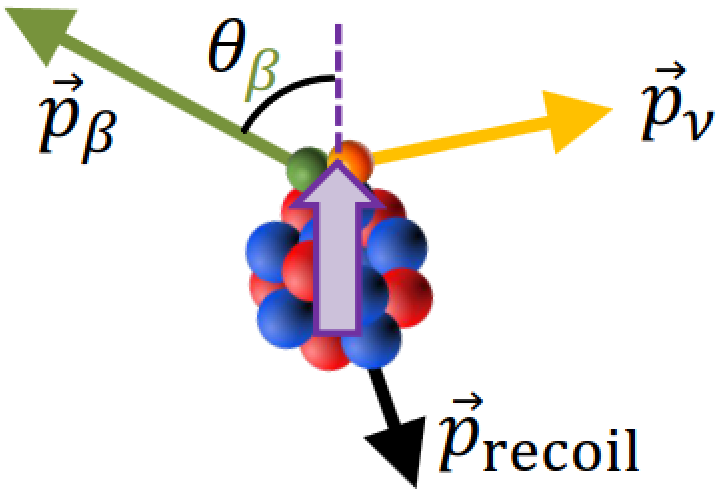


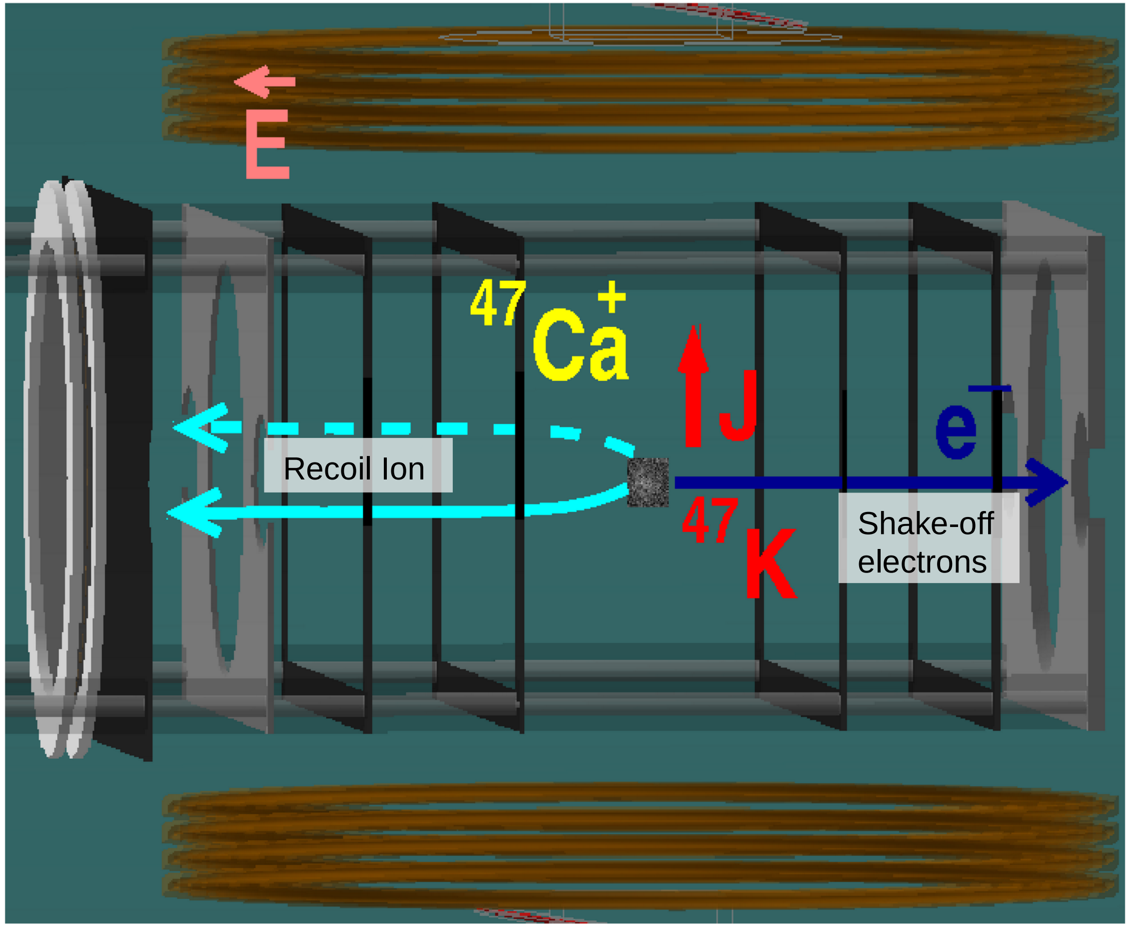
~92 ± 6% polarized



$^{47}Ca^{+}$ Recoil Asymmetry Result

- Charge State >1+ in coincidence with shakeoff electrons





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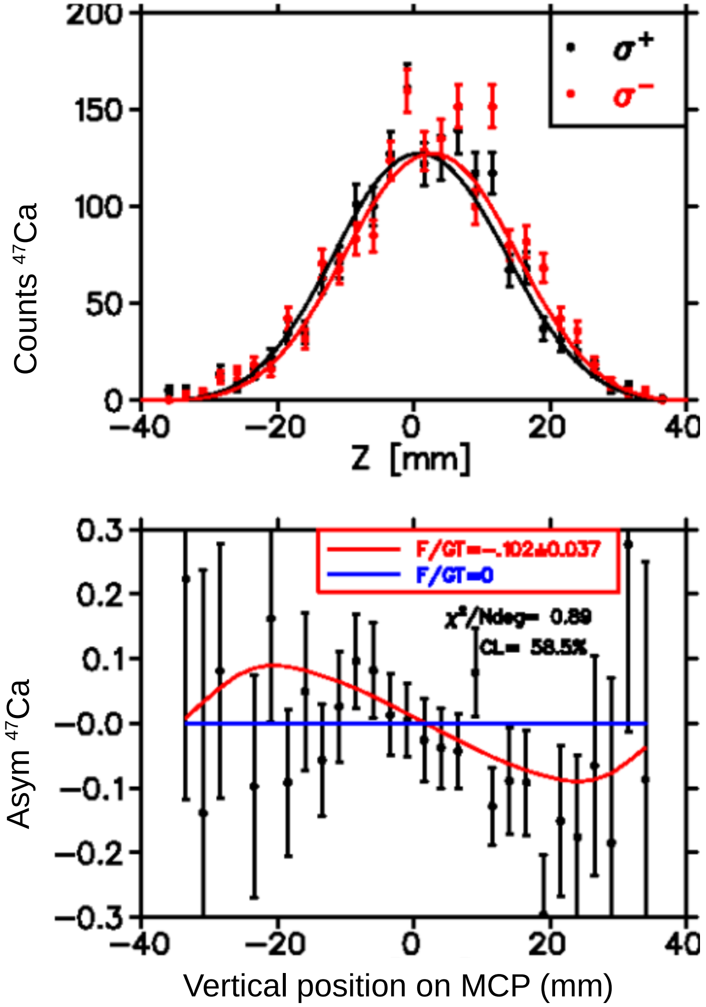


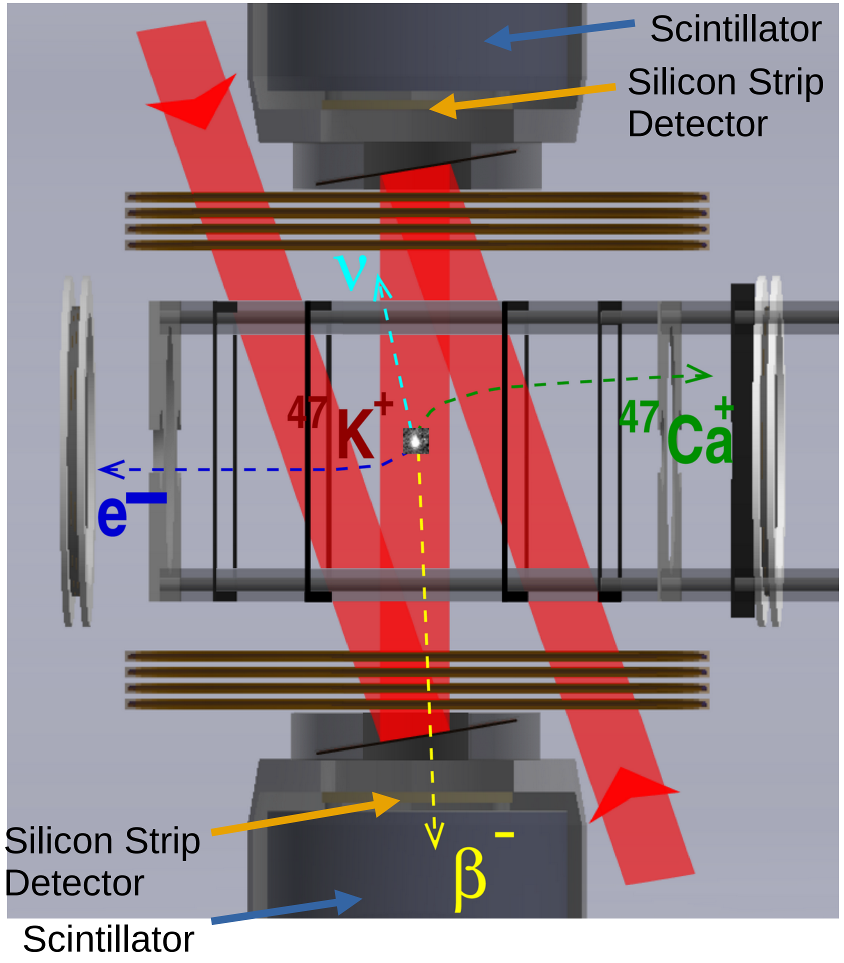
- Polarization dependence of recoils visible on MCP

$$A_{\mathrm{recoil}} = 2\sqrt{\frac{J}{J+1}} G_V M_F / G_A M_{\mathrm{GT}} \cdot f(p_r)$$

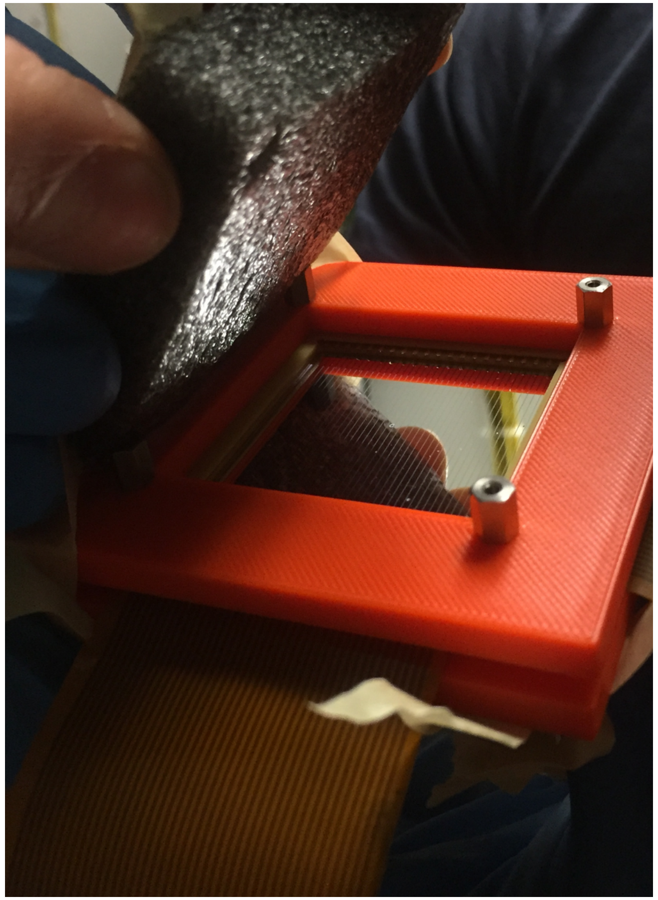
$$\frac{M_F}{M_{GT}} = 0.103 \pm 0.041$$

Beta Asymmetry Approach

- Comparison of number of top vs bottom scintillator events



Beta Energy/Electron Tagging for Beta Asymmetry

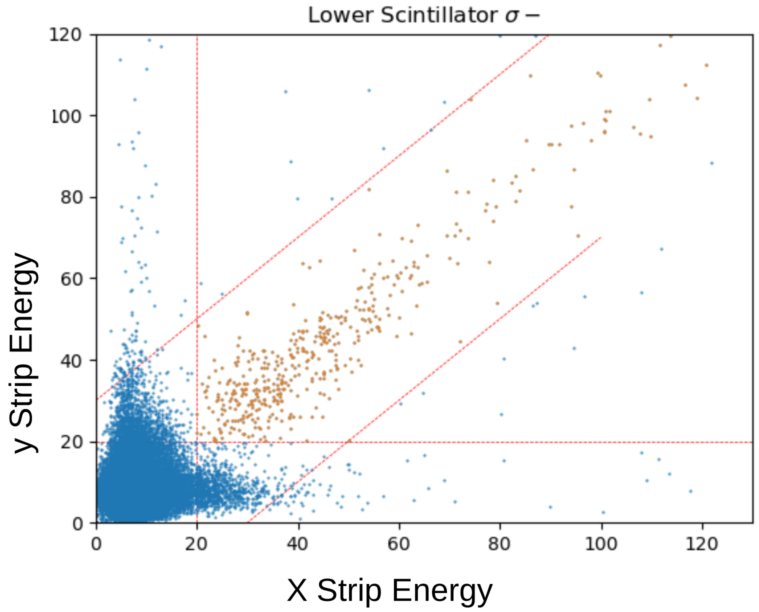


Double-Sided Silicon Strip Detector
~290 um, 30 V

- Tests revealed several failed DSSSD 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
- Further suppressed background events



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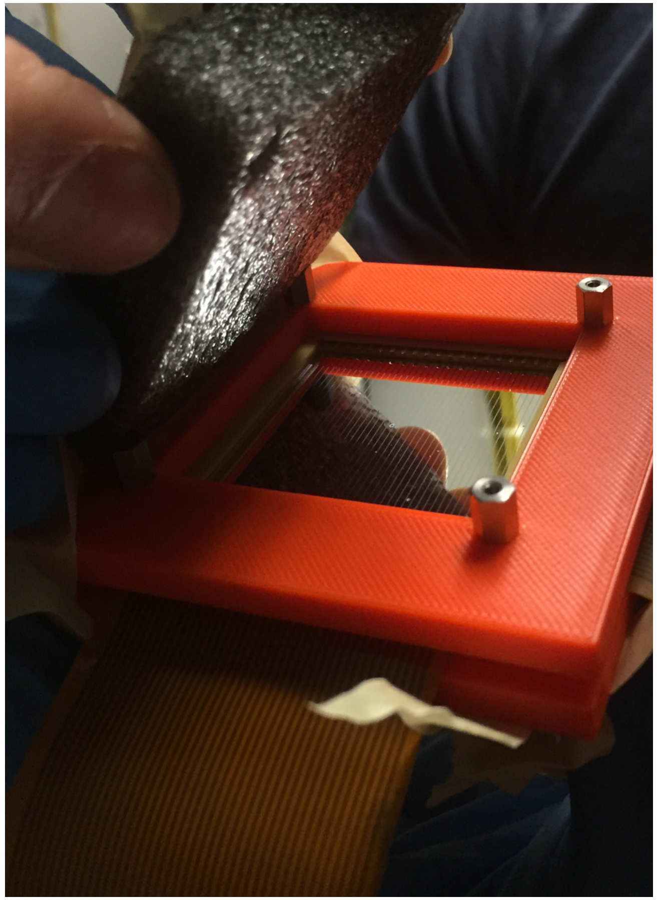

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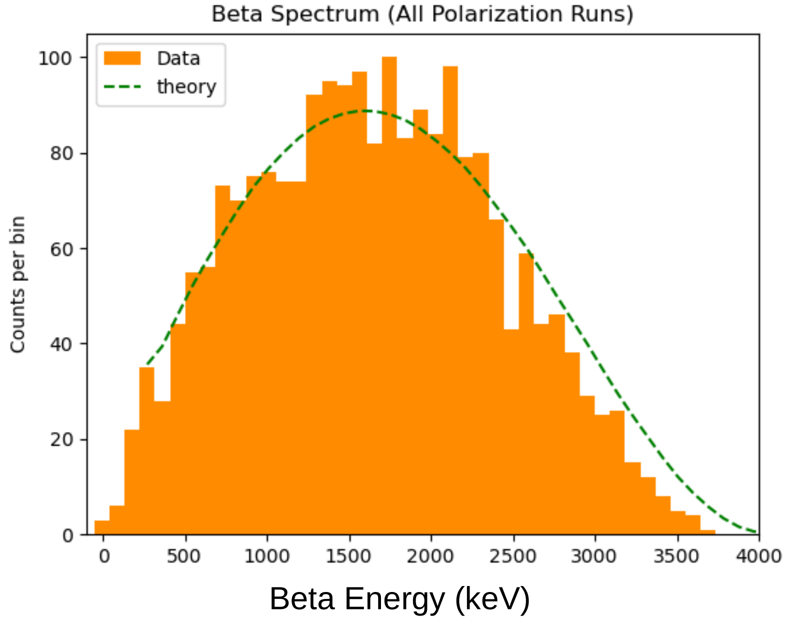
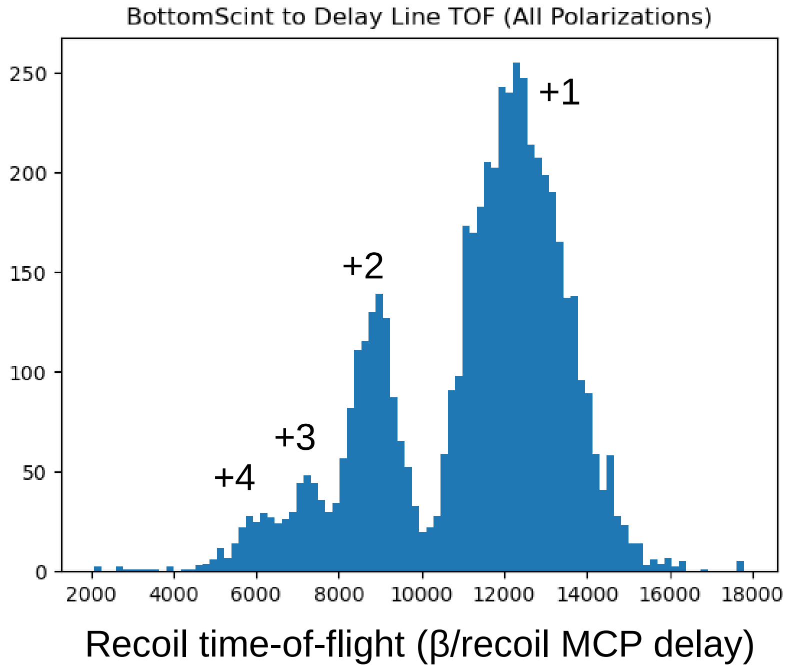


$$\frac{M_F}{M_{GT}} = 0.076 \pm 0.091$$

Additional Statistics from Electron-Recoil Coincidences Possible

- +1 recoils partly miss MCP
- Opportunity for greater statistics if not dependent on the shakeoff electrons
- Requires modelling missed ions or a higher E-field



Final Isospin Symmetry Breaking Result

Weighted Average of Recoil and Beta Asymmetries:

$$\frac{M_F}{M_{GT}} = 0.098 \pm 0.037$$

Gives

$$\langle \bar{A} | V_{Coulomb} | A \rangle = \boxed{101 \pm 37\, keV}$$

Compare to harmonic oscillator estimate[1]: $\langle \bar{A} | V_{Coulomb} | A \rangle = 0.35 \frac{\sqrt{n_1 n_2}}{2T} \frac{Z}{A^{2/3}} \mathrm{MeV}$ = 160 keV for ^{47}Ca

- Larger A/Ā mixing than ^{56}Co (3 keV)[2] and ^{71}As (28 keV)[3]
- Better agreement with simple model; ^{47}Ca has only one state with same J^{π}
- Purely statistics lacking, upgrades are underway that would enable 10x the ^{47}K data over 2 shifts
- Motivates theory calculations for the time reversal violating nuclear matrix elements, and future high-statistics TRV test at TRINAT

[1] N. Auerbach & B.M. Loc. Nuc. Phys. A, 1027 (2022): [2] Markey Bohm PRC 1982 [3]Severijns PRC 2005

Thank You!