1 Introduction

1.1 Nuclear β decay and TRINAT

Nuclear beta decay correlation experiments helped establish the nature of the weak interaction, a theory with spin-1 bosons coupling only to left-handed ν's. Such measurements can still assist particle physics by determining 1st-generation lepton-quark couplings of possible new particles. To do so, they must test Standard Model (SM) predictions at 0.1% or better, thus exploring physics at scales set by $M_W/\sqrt{0.001}$ or about 2 TeV (assuming standard electroweak coupling strength) [3]. Such accuracy would constrain or measure new 4-fermion effective field theory interactions competitive with phenomenological constraints from LHC p+p → e + ν + X and pion decay [4]. It could also have sensitivity to contributions from certain versions of minimal SUSY [5]. More generally, it would help determine or constrain couplings to 1st-generation quarks to assist with properties of particles found in direct searches.

Many beta decay measurements, including some of ours proposed, probe new physics by its "Fierz interference" with SM terms proportional to m_β/E_β, a ratio typically suppressed at higher energy. We show explicit examples of this below for our β and recoil spin asymmetries.

Progress in β-decay: An extra radiative correction has moved the value of V_{ud} about 3 σ from unitarity [1, 2]. Neutron β decay experiments have made advances recently. The β spin asymmetry has been measured by PERKEO III to much better accuracy [7], and both it and the β-ν correlation by aCORN are consistent with the standard model [8]. The β-ν correlation arXiv result of aSPECT [9] has considerably better accuracy than aCORN and disagrees in the value of g_A/g_V with PERKEO III by 2.8σ. PERKEO III has also achieved a much better Fierz interference term measurement [10] b= 0.017(20)stat(3)sys from the energy dependence of the β asymmetry. Trap-based lifetime experiments are now reaching some degree of consensus at high accuracy with apparently controllable systematics [11], while upgrades at 2 levels seek to confirm the discrepancy in beam-based experiments [12] which could indicate some new decay physics of the neutron. New approaches seeking to also isolate the rate of the proton decay branch are coming online [13].

The ^{8}Li and ^{8}B β decay ion trap measurements at Argonne National Lab, after producing constraints on Lorentz tensor interactions [16] similar to the Oak Ridge ^{6}He measurement, have now reached considerably better accuracy [17]. New techniques in nuclear β decay to measure a Fierz interference term include implantation into detectors [14] and cyclotron resonance microwave emission [15].

We will describe our plans in polarized ^{37}K to improve our A_β measurement by a factor of 3. We are also completing our upgrades to allow measurement of $A_{\rm recoil}$. The average $A_{\rm recoil}$ is about a factor of three more sensitive to V_{ud} than A_β in ^{37}K (where there is an accidental cancellation of two Jackson-Treiman-Wyld terms), and the momentum depedence of $A_{\rm recoil}$ will simultaneously constrain non-standard-model interactions by a term similar to the Fierz interference (see below).

An explicit model: If particular aspects of supersymmetric models are allowed (like left-right sfermion mixing), SUSY can generate scalar or tensor couplings as large as 0.001 [5], so β decay can be a surprisingly interesting probe of such possibilities. Much of this parameter space is excluded by null LHC results, yet the space is large, so such couplings will likely remain possible: typically those constraints depend on the mass of two partners at once, and the 2007 SUSY analysis of Ref. [5] did not explicitly use Tevatron limits in any case [6]. A full reanalysis would be needed to update this calculation, hopefully motivated by competitive β decay experiments.

1.2 Well-characterized ^{37}K decay

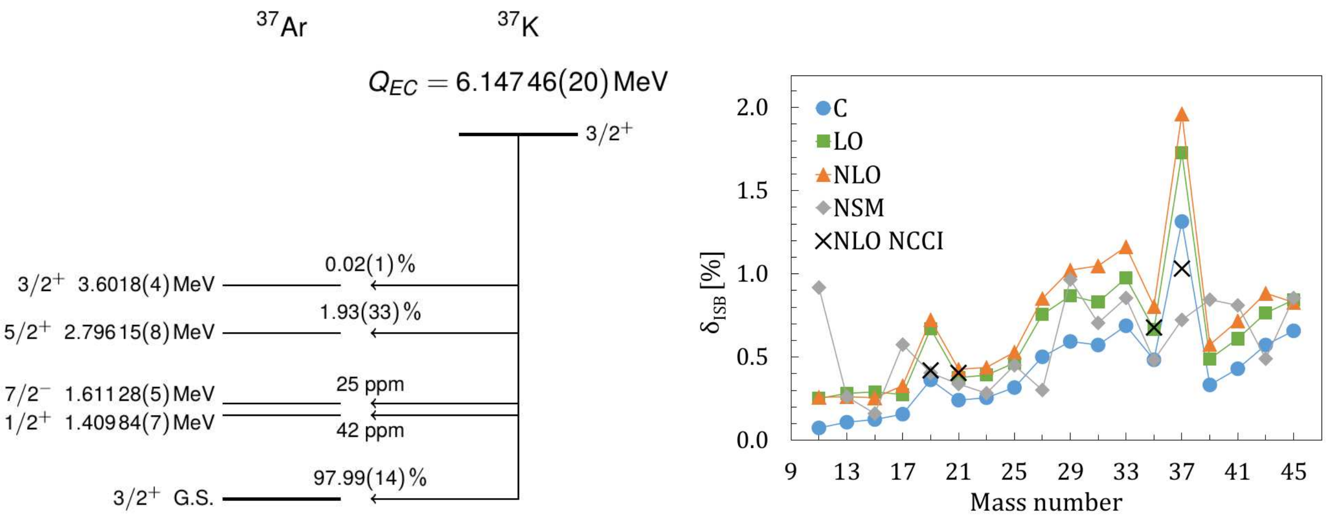

Figure 1: Left: β^+ decay scheme for ^{37}K; Right: A DFT that includes enough non-Coulomb non-standard model isospin breaking to explain the Nolen-Schiffer anomaly predicts a measureable change to isospin breaking for our case (see text).

I$^\pi$=3/2$^+$ ^{37}K primarily decays by a mixed Gamow-Teller/Fermi transition to its isobaric analog state ^{37}Ar. Such transitions are similar to neutron decay– the initial and final nuclear wavefunctions are almost identical (small corrections can be calculated from known electromagnetic moments). Correlations and physics similar to neutron decay can be studied, with the advantage that the lifetime can be measured much better, and the disadvantage that isospin breaking introduces complications.

The recent $t_{1/2}$ measurement by the Texas A&M part of the collaboration [19] lowers the uncertainty in SM predictions of correlations by factors of three. Analysis of the TAMU-measured branching ratio is now finished [20] and has reduced the ft uncertainty from 0.16% to 0.08%, contributing that percentage uncertainty to V_{ud}'s extraction. There is a 1.9% Gamow-Teller transition to an excited state [21] which we include in our simulations. Standard model corrections to the correlations to second order in $E_{\rm recoil}/Q$ are understood to better than 0.1% accuracy. Terms in the vector current (1st-order weak magnetism and a second-order term) are given by the electromagnetic moments, and the one second-order effect in the axial current that depends on nuclear structure is very small [18]. Radiative corrections similar to what has been done by Ferenc Glück [22] for our collaboration in $^{38{\rm m}}$K [23] are possible [24]: they do not alter A_β and would make ∼0.002 effects in β-recoil coincidences.

Isospin symmetry breaking in ^{37}K decay: Predictions from the ft measurement of the average value of A_β and the average value of $A_{\rm recoil}$ need independent knowledge of the Fermi matrix element, so rely on a calculation of isospin symmetry breaking. We are presently using the isospin breaking from a compilation of mirror decay calculations, a shell model with isospin-breaking terms tuned to the isobaric mass multiplet splittings by I. Towner with estimated 10% accuracy [29]. In our ^{37}K case the result for the change in M_F is δ_c= 0.0734(61)%.

We show goals for V_{ud} below, in particular from $A_{\rm recoil}$, that need the 5% accuracy claimed for the $0^+ \to 0^+$ ft values. It would be very helpful to have a modern approach to this calculation for mirrors as well. Theorists using the valence-space in-medium similarity renormalization group formalism [30] are calculating isobaric multiplet mass equations [31, 32]. They are working to apply their formalism to similar problems, and are considering applying this approach to ^{37}K β decay as one of several possible mirror decays [33].

One theory group using density functional theory had arrived at a calculation for ^{37}K [34] that agrees with Towner's, to accuracy undetermined by the method. A recent preprint from the same group now includes enough extra isospin breaking in the strong interaction to account for the Nolen-Schiffer anomaly, and after including deformation by Nilsson orbitals has a somewhat larger δ_C for our case (see Fig. 1 Right) [35]. We regard this as a provocative indication of what happens when one allows extra non-standard model isospin breaking in the strong interaction. Although there are more conventional explanations for the Nolen-Schiffer anomaly, in principle one could use all mirror decays to test such an interesting effect, yet we suspect the DFT-based calculations are not accurate enough. We believe angular correlations for isospin-breaking 2nd-class currents have been better formulated (see below).

2 Technical ^{37}K experimental progress

We have done our ^{92}Rb experiment S1810 at the design electric field of 1 kV/cm. There are still backgrounds from electrons going from the ion MCP to the electron MCP that are blocked with the MOT magnetic quadrupole field on. If these persist as we optically pump with quadrupole field off, we would implement a mesh in front of the ion MCP that would enable an electric field configuration to suppress these electrons. We estimate that will take about 6 months to implement, after which we could measure A_β and $A_{\rm recoil}$ simultaneously.

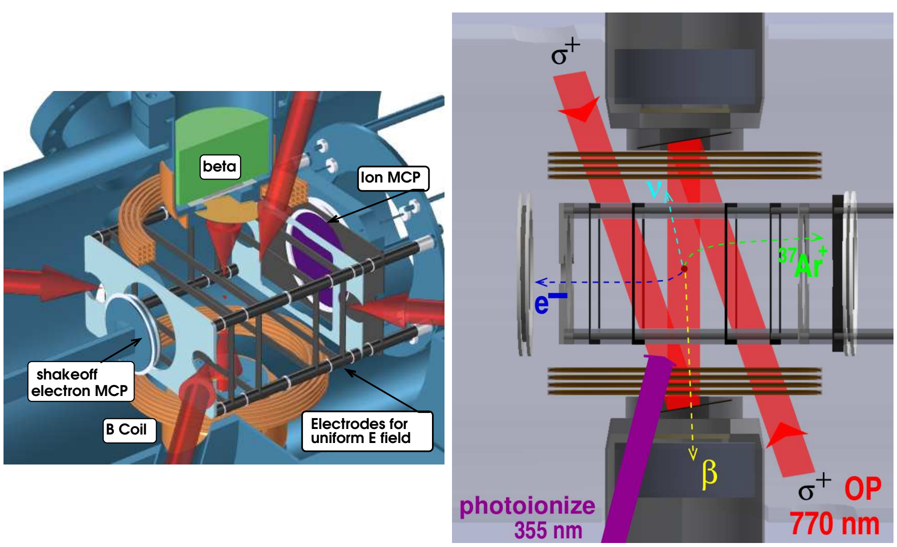

Figure 2: The present TRINAT detection MOT. The optical pumping and MOT vertical beams share a path, reflecting off a thin mirror in front of the β detector to provide better dΩ for βs. The near-uniform electric field collects ion and shakeoff e$^-$ to MCPs. The decay pattern shown on the right is helicity-forbidden if the ν goes straight up, independent of Gamow-Teller/Fermi ratio: See Section 3.5.

Confined in a 1 mm-sized cloud, the nuclei undergo beta decay, producing three products: a positron, a neutrino, and a recoiling daughter nucleus. The daughter nucleus has kinetic energy ∼ hundreds of eV and would stop in a nm of material, but it freely escapes the trap. By detecting it in coincidence with the positron, we can measure the momentum and angular distribution of the neutrino.

We detect β's in a double-sided silicon strip detector (DSSD) ΔE– plastic scintillator E telescope (Fig. 2). Coincidences are made with either atomic shakeoff e^- to remove backgrounds from untrapped atoms, or with recoiling ions for β-ν correlations with and without spin polarization. Technical features include an AC MOT [36, 37] that allows the magnetic field and eddy currents to be switched off to 1% of its value in 100 μs, so the atoms can be polarized by optical pumping with circularly polarized light. We have changed our 0.25 mm thick SiC-backed in-vacuum mirrors to 70 nm Au on 4 μm Kapton [38] to minimize scattering and lower the β energy threshold.

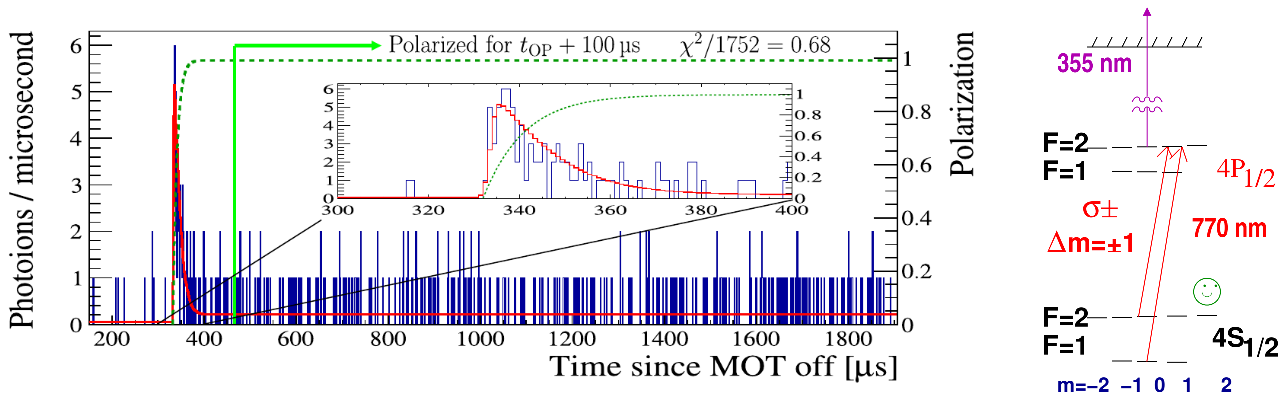

Figure 3: Optical Bloch equation fit to ∼1/6 of the ^{37}K photoionization data for one spin state, showing degree of polarization by optical pumping. Atoms absorb angular momentum by circularly polarized light until they are fully polarized. A photoionization laser has enough energy per photon to ionize only excited atoms, and the excited state population falls as the atoms become fully polarized. Laser power, detuning, and circular polarization are known. Larmor precession about an average ⊥ B field is fit. The uncertainty budget is in Table 1. [39].

2.0.1 Polarization progress:

We show in Fig. 3 the atomic probe of the polarization of the ^{37}K atoms and nuclei [39].

We have learned to spin-polarize nuclei by optical pumping of atoms, achieving vector polarization of 99.13±0.09% for ^{37}K. We make these measurements with atomic methods independent of the nuclear decays, probing the ^{37}K atoms in the detection apparatus while their beta decays are measured. We published the method in Ref. [39]. We separately published our development of elastomer-sealed viewports for UHV that introduce negligible stress-induced birefringence [40].

We consider the accurate polarization knowledge a major breakthrough: it allows us to propose here more ambitious polarized ^{37}K experiments with improvements of the present apparatus.

Using an improved commercial twisted nematic liquid crystal device, we have improved our optical pumping laser polarization to near S_3= 0.999 in both states. We're now implementing an atomic probe of the initial polarization state before optical pumping. A higher-power 355 nm photoionizing laser should reduce all statistics-limited measurements (like cloud size) by $\sqrt{3}$ the next time we run. A newly installed higher-power optical pumping laser diode should double the optical pumping intensity, fighting Larmor precession to reduce depolarizing effects by about a factor of two.

Source	ΔP [$\times 10^{-4}$] σ^-	σ^+	ΔT [$\times 10^{-4}$] σ^-	σ^+	ΔP [$\times 10^{-4}$] σ^- PROJECTED
SYSTEMATICS					
Initial T	3	3	10	8	2
Global fit v. ave	2	2	7	6	1
$S_3^{\rm out}$ Uncertainty	1	2	11	5	0
Cloud temp	2	0.5	3	2	1
Binning	1	1	4	3	0
B_z Uncertainty	0.5	3	2	7	0.5
Initial P	0.1	0.1	0.4	0.4	0.1
Require $\mathcal{I}_+ = \mathcal{I}_-$	0.1	0.1	0.1	0.2	0
Total Systematic	5	5	17	14	2.5
STATISTICS	7	6	21	17	4
Total					
P= +0.9913 -0.9912	9	8			
T= -0.9770 -0.9761			27	22	
PROJECTED Total					
P= +0.996 -0.996				ΔP =	5x10^{-4}

Table 1: Uncertainty budget for ^{37}K vector polarization and tensor alignment from our atomic probe [39], and projected improvements assumed same for σ^- and σ^+ (see text)

3 Polarized experiments in ^{37}K decay

3.1 2018 result: the beta asymmetry of ^{37}K

We have measured the asymmetry of the β emission with respect to the nuclear spin of ^{37}K to be A_β= -0.5707(13)$_{\rm stat}$(13)$_{\rm syst}$(5)$_{\rm pol}$, in agreement with the theory prediction of -0.5706(7). The theory includes recoil-order corrections of -0.0009 known well from the electromagnetic moments of the parent and progeny nuclei. This is published in Phys Rev Letters [26].

3.1.1 Phenomenology independent of E_β

First we interpret the average A_β without considering its energy dependence.

V_{ud} Our result for A_β after recoil-order corrections, together the measured Ft value and calculated isospin mixing correction, can be interpreted as a measurement of V_{ud}=0.9741±0.0027. The result is plotted with other measurements in Fig. 4a [27], still using the 1975 Princeton ^{19}Ne A_β result. (A draft preprint exists for an improved ^{19}Ne result [28].) Our present ^{37}K result is providing a valuable consistency check for the isospin T=1/2 nuclei.

Right-handed currents: In Fig. 4, we show complementarity of our measurement with other beta decay measurements of the two parameters in left-right symmetric models. Our result implies a mass for a W_R coupling to wrong-handed ν_R greater than 310 GeV at 90% confidence, similar to the results from ^{12}N β^+ polarization [52]. The combination implies a mass for W_R greater than 420 GeV at 90%. Much of the parameter space in left-right symmetric models has been excluded in direct W searches that the LHC has extended to 3.6 TeV [43, 44] and in precision measurements of polarized μ decay [45]. In non-manifest left-right models, contributions from β decay correlations scale like the right-handed coupling $(\frac{g_R}{M_R})^4$, and the average from nuclear β decay implies coupling $g_R \leq 8$ at 4 TeV— the physics remains perturbative for $g_R \leq 4\pi$ so this is a meaningful statement.

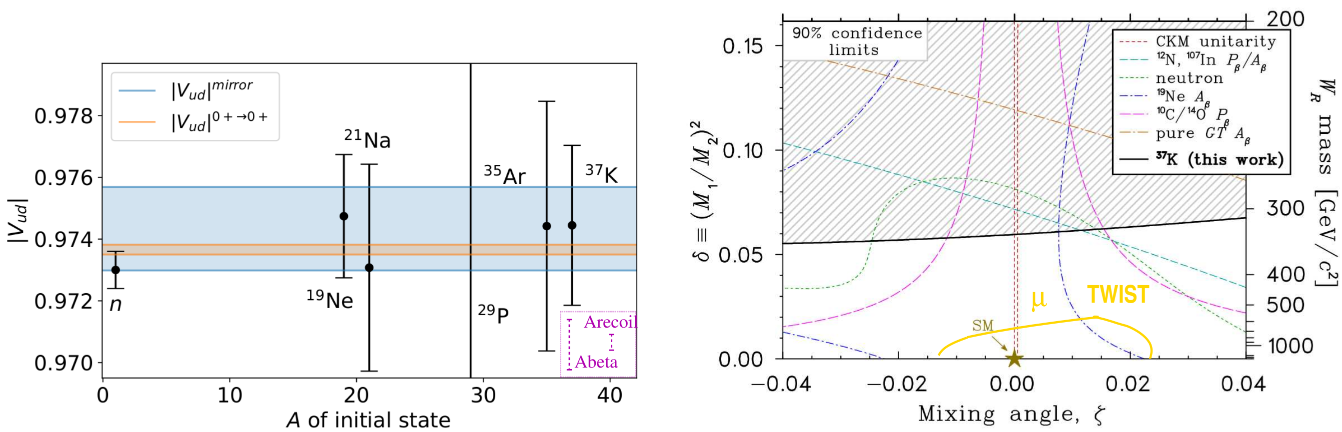

Figure 4: Physics from average A_β: a) ^{37}K A_β and other beta decay contraints on V_{ud} from isospin T=1/2 decays, from [27] Hayen and Severjins after G-T radiative corrections. We also show projected uncertainty for: 1/3 the uncertainty in A_β; ultimate uncertainty in $A_{\rm recoil}$ with 5% δ_C uncertainty. b) Right-handed V+A currents from nuclear and neutron β decay, in manifest left-right model.

3.1.2 Phenomenology for E_β dependence of A_β

The dependence of A_β on E_β (Fig. 5a) is in good agreement with the SM. It is straightforward for us to include in this fit a Fierz term, and we show a statistical uncertainty of 0.04. An analysis of systematic uncertainties is in progress by our U. Manitoba Ph.D. student, and preliminary results indicate a similar systematic uncertainty. Here are our contraints on non-SM physics that would change $A_\beta[E_\beta]$, along with other experiments.

Our ^{37}K case is sensitive to combinations of scalar (S) and tensor (T) terms, which, unlike the SM, make ν and β^+ with same chirality. The S and T interactions that couple to existing ν_L can interfere with the SM, producing the 'Fierz' term linear in the couplings and $\propto m_\beta/E_\beta$. In contrast, S and T interactions coupling to wrong-handed ν_R are quadratic in the small couplings. Specializing to terms coupling to normal-chirality ν_L, we show an exclusion plot of S vs. T interactions in Fig. 5b. (Uncertainties on Vud increase by 3 times when C_S is allowed to float and change $0^+ \to 0^+$ Ft values with $\langle \frac{m_\beta}{E_\beta} \rangle$, motivating independent measurements of C_S.) Assuming C_S and C'_S are constrained to be small from other experiments, we show tensor interactions coupling to ν_L and to ν_R in Fig. 5c. We tie the best two previous direct constraints on $C_T - C'_T$.

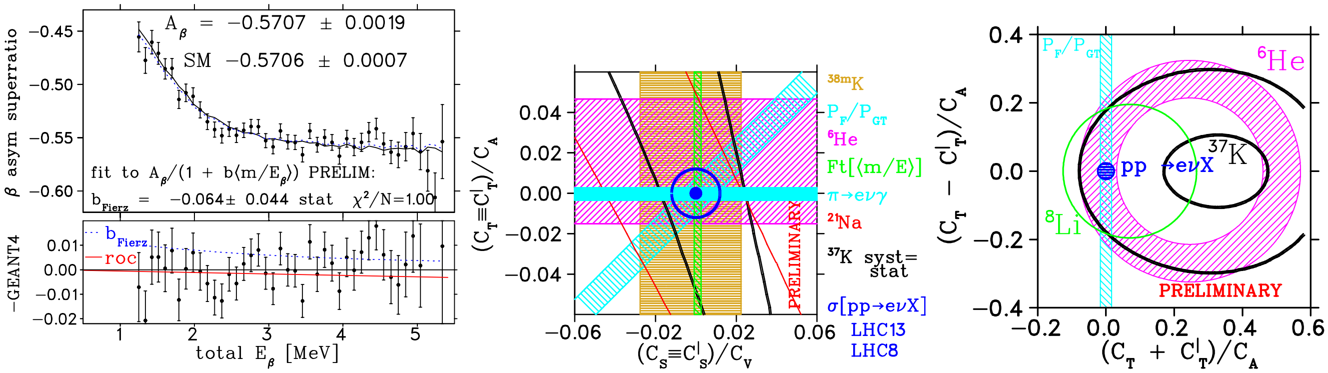

Figure 5: (a) A_β of ^{37}K as a function of energy, fit with (preliminary) and without Fierz term; (b) 90% CL exclusion on S and T couplings to ν_L from ^{37}K A_β (assuming systematic=statistical uncertainty), other nuclear decays [23, 54, 22, 55, 41], $\pi \to e\nu\gamma$ [53], LHC $\sigma[pp \to e\nu X]$ [4, 42]; (c) Exclusion (for $C_S = C'_S = 0$) on T couplings to ν_L (horizontal axis) and ν_R (vertical) [54, 22, 16, 4]. Quark→nucleon form factors are assumed unity [57, 3, 58, 59].

Also shown is the LHC's less direct constraint on the tails of high-mass resonances from the measured cross-section for pp→ $e\nu X$ [4, 42]. This sets the scale of our goal– to be complementary to particle physics, we must reach 3-5 times better in our observables.

Second-class currents when combining quarks into nucleons would violate isospin symmetry, and though there are interesting tests in hadronic τ decays from B physics [46], nuclear β decay has the most sensitivity to many types [47]. We can fit $A_\beta[E_\beta]$ for a 2nd-class tensor term, which grows linearly with E_β, producing $d_{\rm II}$ = (-2.2±2.5) $b_{\rm wm}$. Weak magnetism $b_{\rm wm}$ is quite small in ^{37}K, and this value for $d_{\rm II}$ is about 3-4 times larger than known constraints from other systems [48]. So we are not yet at a level where we can help the community constrain these, but our planned improvements would let us do that.

3.2 Improvements in A_β

One key is producing better polarization P of ^{37}K. For the average correlation measurements we measure PA_β or $PA_{\rm recoil}$, so we need to reduce the uncertainty on P. We considered these improvements in Section 2.0.1 above.

The backscatter correction, the first line of the uncertainty Table 2 below, can be reduced by making the collimator/mirror holders out of a lower-Z material than stainless steel (see Fig. 6). We are considering CeSiC (carbon fiber reinforced silicon carbide ceramic) or glassy carbon. Scaling by Z (∼ correct for normal incidence diffusive saturated backscatter [49]), our goal is to decrease backscatter by a factor of ∼ 2. The pellicle mirrors were in place for S1810, so we also have high-statistics data down to lower β energy than in Fig. 6 to benchmark GEANT4 more accurately.

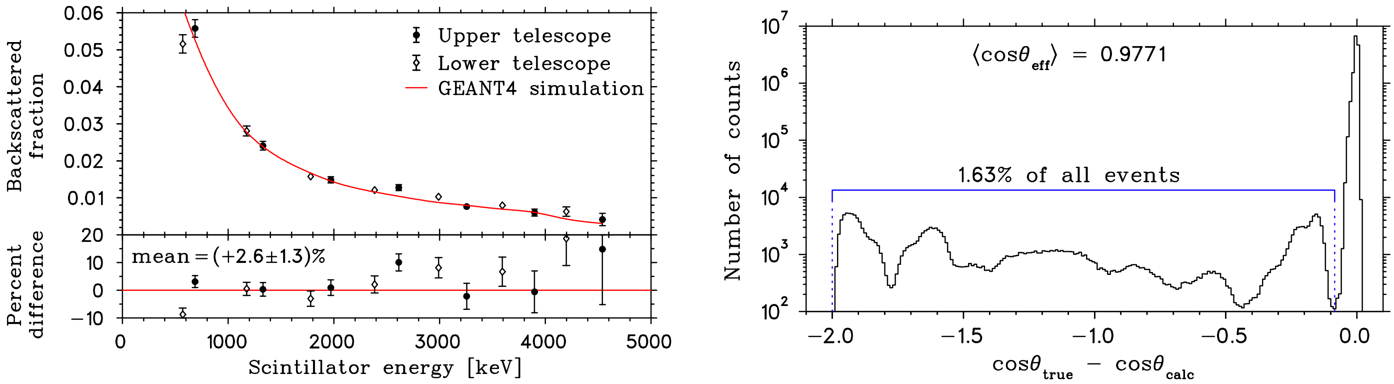

Figure 6: β scattering from our PRL [26]. Left: Double hits in our DSSD reject backscatter from the plastic scintillator– we modelled this with GEANT4 to better than 5%. Right: Simulated events with incorrectly 'measured' cosine, used for the correction, its uncertainty, and to plan materials. Referring to Fig.2, main contributors are the opposite collimator, B field coils, and the nearby collimator.

3.2.1 Suppression of background from atoms on other surfaces

We make a background correction of $(1.3 \pm 0.7) \times 10^{-3}$ by subtracting the shakeoff e^- time-of-flight peak at 10 ns with respect to the β^+ trigger (Fig. 7). This background mostly comes from decays of untrapped atoms.

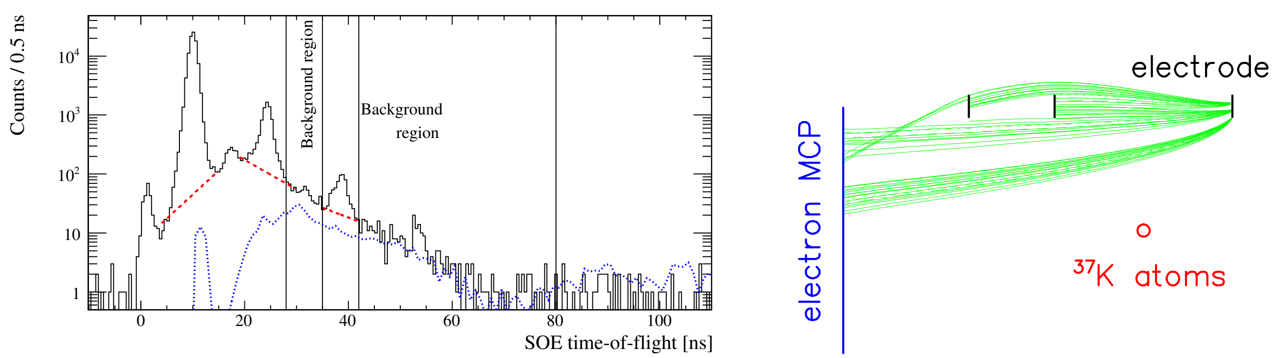

Figure 7: Left: Shakeoff e^- time-of-flight spectrum w.r.t. the β^+ trigger.The peaks at 24, 39, and 54 ns we have measured with photoelectrons: they are from e^- that did not fire the e^- MCP, but produced secondaries that leave the MCP and then are recollected by the electric field. The dotted line simulates events from untrapped ^{37}K. The simulated background peak at 12 ns is from the electrode to the right of the cloud in Fig. 2. Right: Trajectories of e^- from this electrode with field E=150 V/cm, some of which terminate at other electrodes.

The trap mean lifetime is about 10 sec, limited by collisions with residual gas at the pressure of 3x10^{-10}Torr. If lost ^{37}K atoms decay while stuck on certain surfaces– e.g. the optical pumping mirrors, or the electrode to the right of the atom cloud here and in Fig. 2– the β^+ can reach the β^+ telescope and the shakeoff e^- can reach the electron MCP. The figures include a simple simulation of these trajectories, which are consistent with a large fraction of the TOF spectrum.

The main issue is the simulated peak at 12 ns, which comes from the electrode to the right of the cloud. This can't be timed out, but increasing the electric field to the design of E=1200 V/cm (to collect ions efficiently, see below) will guide these electrons to the edge of the e^- MCP, where they can be rejected by the position readout. The longer TOF shakeoff e^- are from atoms on the mirrors– since much of the TOF is in the region from mirror to electrode of much lower field, these will still be rejected by TOF. For test runs, we can also make the vacuum 50x worse to enhance this background and understand it.

We summarize these and other projected uncertainties for A_β in Table 2. Trap parameters are expected to be defined better statistically using the higher-power photoionization laser.

Source	ΔA_β [$\times 10^{-4}$]	Projected
Systematics		
Background	8	0
Correction 1.0014 1.0000		
β scattering†	7	3
Correction 1.0234 1.01		
Trap parameters		
Position (typ. $\leq \pm 20\mu$m)	4	2
Sail velocity (typ. $\leq \pm 30\mu$m/ms)	5	3
Temperature (typ. $\leq$ 0.2mK) & width	1	0.7
Thresholds		
BB1 Radius† $15^{+3.5}_{-5.5}$ mm	4	4
BB1 Energy agreement ($3\sigma \leftrightarrow 5\sigma$)	2	2
BB1 threshold (60$\leftrightarrow$40 keV)	1	1
Scintillator threshold (0.4 $\leftrightarrow$ 1.0 MeV)	0.3	0.3
Shakeoff electon t.o.f. region ($\pm 3.8 \leftrightarrow 4.6$ns)	3	1
Geometry definition		
SiC mirror thickness† ($\pm 6\mu$m)	1	0
Be window thickness† ($\pm 23\mu$m)	0.9	0.9
BB1 thickness† ($\pm 5\mu$m)	0.1	0.1
Scintillator or summed†	1	1
Scintillator calibration ($\pm$0.4ch/keV)	0.1	0.1
Total systematics	12	7
Statistics	13	6
Polarization	5	2
Total uncertainty	18	8

Table 2: Uncertainty budget for A_β. Items with † are related to β scattering.

Fierz term We discussed above our Au-covered kapton pellicle mirrors along the β detector axis, which lower our E_β threshold and improve sensitivity to the Fierz term. The largest preliminary systematic, the shakeoff e^- background, we expect to eliminate as above. The backscatter as a function of E_β is a work in progress. Our goal is to reach uncertainty 0.01, complementary to PERKEO III [10].

3.3 New observable A_{recoil}: sensitivity and discovery potential

Simultaneously, we would improve our recoil singles asymmetry experiments and β-recoil coincidence experiments. Recoil singles will provide much higher statistics, as 11% of the recoils are charged and are collected in our apparatus.

The observable A_{recoil} is proportional to the sum of the lepton spin asymmetries $A_\beta + B_\nu$. There are terms in B_ν proportional to m_β/E_β. The recoil momentum dependence of A_{recoil} then becomes a powerful tool to measure the Fierz term, and we show the sensitivity in the next subsection.

For A_{recoil} we simultaneously detect the few 100 eV recoiling nucleus and an atomic shakeoff electron, using microchannel-plate based detectors situated opposite from each other in the same uniform electric field. We did measure A_{recoil} in a similar geometry to Fig. 2 in ^{80}Rb decay [50], where $A_{\text{recoil}} \approx 0$ in SM. The figures in that paper demonstrate clean TOF spectra and detailed measurement of the recoil angular distributions as a function of recoil momentum. The interpretation in ^{80}Rb is limited by recoil-order corrections [25], which depend in this heavy-nucleus Gamow-Teller case on imprecise nuclear structure calculations.

For shakeoff e^- detection, we have replaced a large HEX75 with a 40 mm diameter MCP chevron detector and an existing compact wedge-and-strip position readout– this size is intercepting less e^- background, and we used it for the S1810 ^{92}Rb experiments.

We derived analytic expressions for the recoil singles angular distribution [50],

$$W[P_r,\theta]dP_r d(\cos\theta_r) = [f_1(P_r) + bf_6(P_r) - (a_{\beta\nu} + \frac{cT}{3})f_2(P_r) + cTf_3(P_r) + cTf_5(P_r)\cos^2(\theta_r)$$
$$-P\ A_{\text{recoil}}\ f_4(P_r)\ \cos(\theta_r) + P\ \delta B\ f_7(P_r)\ \cos(\theta_r)]\ \ dP_r d(\cos\theta_r),$$

where we define A_{recoil} as the SM prediction for the sum of β and ν asymmetries $A_\beta + B_\nu$ plus terms quadratic in small new couplings, and f_N's are rational functions of P_r. The coefficients b and δB depend linearly on non-SM quark-lepton couplings $C_s + C_s'$, $C_t + C_t'$ [51].

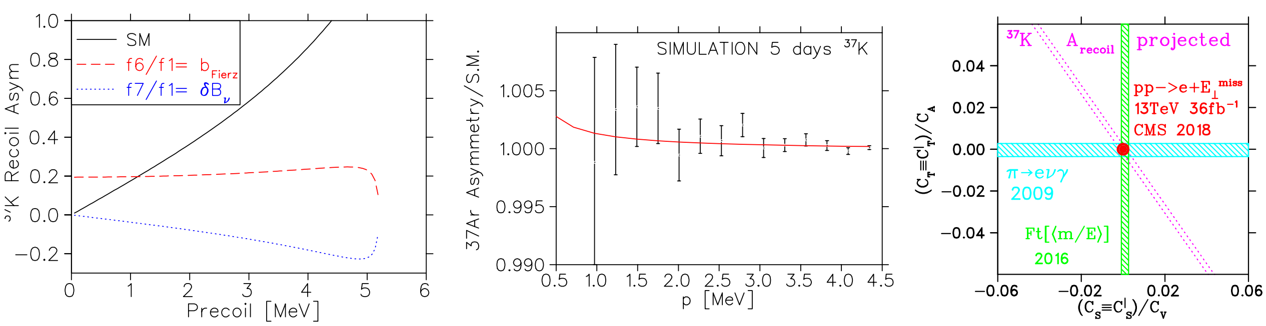

Figure 8: **a:** The recoil singles asymmetry as a function of recoil momentum from ^{37}K decay, showing the SM prediction ('asym'), and the functional dependence of the non-SM extensions from the Fierz interference term b ('f6') and changes in ν asymmetry δB ('f7'). **b:** Simulation of 5 days of the ^{37}K recoil singles asymmetry with 10,000 atoms trapped, showing the momentum dependence of the simulated data divided by the SM prediction. **c:** Resulting 90% exclusion plot, on same scale as Fig. 5b. We also show existing limits from $\pi \to e\nu\gamma$ [53] and from the energy dependence of $0^+ \to 0^+$ Ft values [55].

The terms contributing to the asymmetry are shown in Fig. 8. The SM and the non-SM extensions have different dependence on recoil momentum, so can be determined simultaneously.

The simulation shown for illustration in Fig. 8 has δB= 0.0018±0.0008, an uncertainty smaller than the world average in nuclear β decay and similar to that from $\pi \rightarrow e\nu\gamma$ [53], and at the level possibly produced by SUSY left-right sfermion mixing [5]. The resulting exclusion on C_S vs. C_T is shown in Fig. 5c.

That exclusion plot assumes we fix V_{ud} from other experiments, and have a 5% accurate calculation of isospin breaking. We could instead extract V_{ud} to the accuracy shown in Fig. 4 Left, while constraining tensor currents primarily from the momentum dependence of $A_{\rm recoil}$. That would determine $C_t + C_t'$ to 0.003 accuracy independent of isospin breaking, an uncertainty smaller than the most accurate single previous experiment in nuclear β decay [54].

3.4 Summary

We're encouraged by the small uncertainty on our determination of the ^{37}K nuclear polarization by atomic methods. We have shown our future plans: improvements on A_β in ^{37}K, along with our plans to measure the spin asymmetry of recoils $A_{\rm recoil}$, a high-statistics observable. From the average values of A_β and $A_{\rm recoil}$, we could determine V_{ud} to an accuracy competitive with each single $0^+ \rightarrow 0^+$ case (except the very best one, ^{26m}Ar), and simultaneously constrain non-SM quark-lepton interactions from the momentum dependence.

The higher-statistics observable $A_{\rm recoil}$ is projected to reach the sensitivity in Fig. 8, complementary to LHC 13 TeV sensitivity. (We note that after the present shutdown the LHC will test many things with similar beam properties, then shut down for more upgrades– so their sensitivity is unlikely to improve until perhaps 2025.)

We have a U. Manitoba Ph.D. student finishing analysis of the Fierz term. Our UBC student who has done the ^{92}Rb $\beta - \nu$ correlation experiment for an M.Sc. now wants to test the standard model with $A_{\rm recoil}$ for a Ph.D. project. We are recruiting one or two more graduate students through UBC and Texas A&M for this spin-polarized program. Our plan is to finish upgrades of the present geometry, then have beamtimes measuring A_β and $A_{\rm recoil}$.

ISAC Yields We note that for our June 2014 experiment, ISAC delivered more ^{37}K than before by factors of three, reaching reliable yields of 1x10^8/s which allowed us to trap 10,000 atoms and count 5/sec beta-recoil coincidences continuously for 10 days spread over 3 weeks. The yields were due to smaller titanium carbide particle size and are expected to be reproducible by the target chemists. These high yields are enabling our entire proposed program to proceed.

3.4.1 Shift request

(We have used a few shifts of S1188 for development of the apparatus: our remaining 10 shifts on S1188 are expiring now.)

We request a total of 20 shifts for simultaneous measurements of A_β and $A_{\rm recoil}$.

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