TRIUMF - EEC SUBMISSION EEC meeting: 201507S *Original Proposal*	TRIUMF	**Exp. No.** S1603 - *In Preparation* **Date Submitted:** 2015-06-05 02:41:18

Title of Experiment:

Time reversal violation in radiative beta decay

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Beam Shift Requests:

15 shifts on: TRINAT (ILZ)
Comment:

5 test shifts with 80Rb.

10 production shifts with 38mK.

Basic Information:

Date submitted: 2015-06-05 02:41:18

Summary: One way to produce the amount of matter over antimatter seen requires additional sources of time-reversal violation (TRV). Null results in many types of TRV experiments provides motivation for this different type of experiment. We propose to measure a TRV 3-momentum asymmetry in the radiative beta decay of 38mK. Recently a detailed theoretical treatment was done at the U. Kentucky, showing that an MeV-scale

source of new physics involving a QCD-like sector weakly coupled to the standard model could generate large asymmetries in such an experiment. To do this, we need to detect the beta, recoil, and bremsstrahlung gamma, and our atom trap apparatus provides a good basis for this.

Experimental Facility

ISAC Facility:

ISAC-I Facility: TRINAT (ILZ)

Have all the Facility Coordinators and/or Collaboration spokespersons of the relevant experimental facilities been made aware of this proposal?: Yes

Secondary Beam

Isotope: 80Rb (test); 38mK

Energy: 20-30 keV

Intensity Requested: 4x10**8/s

Minimum Intensity: 2x10**8/s

Maximum Intensity: 10**9/s

OLIS: No

ISAC Target: Yes

Energy Units: keV

Energy spread-maximum:

Time spread-maximum:

Angular Divergence:

Spot Size:

Charge Constraints:

Beam Purity:

Special Characteristics:

Experiment Support

Beam Diagnostics Required:

TRINAT uses a Faraday Cup, a mini-PET camera for positron emission, and the number of trapped atoms.

Signals for Beam Tuning:

ILZ:FC10 and 10A, minimizing on local collimators.

DAQ Support:

Some ongoing TRIUMF DAQ support for TRINAT VME system is still needed

TRIUMF Support:

Continuing operating fund for TRINAT facility, about $5K/year.

Other Funding:

Present TRINAT grant is one year at $82,000, with $20,000 carryforward. We are applying for a 3-year project grant in October 2015.

Summary of possible hazards associated with the experimental apparatus, precautions to be taken, and other matters that should be brought to the notice of the Safety Officer.:

Laser and HV safety in TRINAT previously approved, unchanged. Isotopes are short-lived; local gamma-ray survey and flagging procedures have been established for these isotopes.

Summary Sakharov's criteria to produce the baryon asymmetry would require new sources of CP or CPT violation. Sensitive null results in time-reversal violating experiments in many sectors provide a motivation for experiments in systems with fewer preexisting constraints. TRV correlations of 3 independent momenta of 4-body final states have been searched for in a dedicated radiative K meson decay experiment and in LHCb and BABAR B meson decays.

We propose to measure a time-reversal violating asymmetry correlation of positron, neutrino, and gamma-ray in the radiative beta decay of 38mK. We have developed a GEANT 4 simulation with proof of principle that the background from positron decay can be handled, and a statistics-limited asymmetry of 0.01 can be reached per week of counting. A theoretical evaluation of this observable by Gardner and He has found that as much as 100% asymmetry is still allowed in our case, that final state contributions mimicking TRV are known and about 0.001, that the more familiar Lee-Yang 4-fermion Lagrangian terms do not contribute, and that low-energy (MeV scale) phenomenology can produce TRV in such decays but still be hidden from previous experiments.

1 Scientific value of the experiment: Time Reversal Violation in radiative β decay

1.1 Short overview of time-reversal violation

Additional sources of either time-reversal violation (TRV) or CPT violation are needed for Sakharov's mechanisms to explain the baryon asymmetry, the excess of matter over antimatter seen in the universe [1]. B meson decays thus far are consistent with one complex phase in the CKM matrix, the known source of CP violation, which falls many orders of magnitude short of what is needed. The equivalent phase in the neutrino mass matrix may be measureable in ambitious neutrino oscillation experiments. Continuing null results for the neutron EDM are close to ruling out certain explicit SUSY models as sources of the baryon asymmetry [2], and other EDM experiments have increased their sensitivity while still consistent with zero.

1.2 Previous TRV experiments in nuclear β decay

Immediately after the discovery of nearly maximal parity violation in the weak interaction, papers appeared suggesting T-odd nuclear beta decay correlations to search for TRV, most involving the spin of one particle and the two independent lepton momenta [3]. (Since the recoil momentum is given by the other two, correlations between the three momenta are trivial and do not constrain TRV.) It is clear from these papers that the original hope was that the amount of TRV could be as large as parity violation, as there were few experimental constraints. Two of these distributions have been pursued in earnest, and experimental sensitivity to D and R have become better than 10^{-3} and consistent with zero. These experiments establish direct limits on imaginary parts of the 4-fermion Lagrangian scalar, tensor, and axial vector-vector interference terms, which describe a broad classes of physics, but not all possibilities. Most sources of TRV physics are indirectly constrained by null EDM experiments to produce $D < 10^{-5}$, if the possibility of cancellation between different physics sources making the EDMs is ignored. Leptoquark exchange has been constrained to contribute less than 10^{-4} to D [4], not by EDMs, but by experiments with no time-reversal violation such as atomic parity violation.

These sensitive null results in experiments involving spin provides motivation to look at other possibilities.

1.3 TRV in correlations of 3 independent decay momenta: examples from particle physics

We propose one of a different class of experiments involving correlations of 3 momenta in 4-body final states, not involving any spin.

TRV correlations have been pursued in radiative K decay in a dedicated experiment at INR in Moscow, where a TRV asymmetry consistent with zero of -0.015 $\pm$ 0.021 was observed [5], and several rounds of theoretical calculations of final state corrections were done [6].

Recent analyses of 4-body D meson decays at LHCb are reaching statistics-limited TRV asymmetry uncertainties as small as 0.003 [7], with similar sensitivity achieved from reanalysis of BABAR date [7], though none of these involve the photon. A general formalism and consideration of such experiments is in Ref. [8].

2 TRV in radiative β decay

A new source of time-reversal symmetry violation (TRV) has been proposed [9]. It could produce TRV asymmetries in radiative beta decay that are still allowed to be as large at 100% in some cases. We try to highlight the detailed results of Ref. [9] here.

2.1 A new physics term that generates photons with the weak decay

The standard model of particle physics contains a higher-order term, generated by QCD, that directly couples photons and the weak interaction together to nucleons [10]. This produces a contribution to the Lagrangian for neutron β decay that looks like the usual semileptonic vector current with an electromagnetism tensor $F_{\nu\rho}$ tacked on [9]:

$$L = -\frac{4c_5}{M^2}\frac{eG_F V_{ud}}{\sqrt{2}}\epsilon^{\sigma\mu\nu\rho}\bar{p}\gamma_\sigma n\bar{\psi}_{eL}\gamma_\mu\psi_{\nu,L}F_{\nu\rho} \tag{1}$$

If the coefficient c_5 is allowed to be complex, which would need physics beyond the standard model, then interference between such a term and the standard model's V-A term produces a contribution to the decay rate:

$$Im(c_5 g_V)\frac{E_\beta}{p_\beta k_\gamma}(\vec{p_\beta}\times\vec{k_\gamma})\cdot\vec{p_\nu} = -Im(c_5 g_V)\frac{E_\beta}{p_\beta k_\gamma}(\vec{p_\beta}\times\vec{k_\gamma})\cdot p_{\vec{\rm recoil}} \tag{2}$$

where we substitute neutrino momentum for sum of β and recoil momenta $\vec{p_\nu}$ = -$\vec{p_\beta} - p_{\vec{\rm recoil}}$, and note that the triple scalar product of like vectors vanishes.

By classically reversing either time or $\vec{r}$, this product of three momenta can be seen to be time-reversal and parity violating.

Since this term is directly producing the photon, we note that it is not suppressed by the fine structure constant α. The experiment must measure the the relatively rare radiative decay branch, but gains direct sensitivity to this class of new physics.

This term is proportional to g_V and involves a vector current, so the pure Fermi decay of $^{38\mathrm{m}}$K and the mixed Fermi/Gamow-Teller decay of ^{37}K are suitable. Ref. [9] calculated ^{35}Ar, so we adopt those results for planning purposes. A figure of merit is the experimental uncertainty, which for small theoretical asymmetry $\mathcal{A}$ is given by $\mathcal{A}\sqrt{\mathcal{BR}}$, where BR is the branching ratio governing the counting statistics. The theoretical asymmetry is roughly scaling with the square of the lepton momentum, which has maximum value 5 MeV instead of 1 MeV, and in Table I of Ref. [9] is 20-50 times greater for ^{35}Ar compared to the neutron. There is a similar scaling for the BR of order atomic number Z. The result is an uncertainty achievable for a similar number of beta decays about 200 times better for ^{35}Ar compared to the neutron, with similar answer for ^{37}K or $^{38\mathrm{m}}$K.

The $Im(c_5)$ term produces a TRV asymmetry that depends on the photon energy, an additional test of the theory.

2.2 Standard Model contributions mimicking TRV

It is well-known that reversing momenta of decay particles is not exactly equivalent to time reversal. The outgoing particles interact electromagnetically, and that part is not reversed.

False asymmetries from these 'final state' interactions have been calculated vary from 0.8 to 1.6x10^{-3} from 10 to 100 keV for ^{35}Ar [9]. The result scales by $(1-(\frac{M_{GT}}{M_F})^2/3)/(1+(\frac{M_{GT}}{M_F})^2)$, so is 1.1 times larger in $^{38\mathrm{m}}$K and 0.7 times the size in ^{37}K.

That scaling supresses the ^{19}Ne final state interactions by a factor of 20 [9], making it a good possible future candidate for an atom or ion trap experiment if methods can be found to take advantage of such sensitivity.

2.3 Constraints on TRV in radiative β decay from other sources

2.3.1 Constraints from 4-fermion Interactions

Gardner and He calculated the contributions to radiative beta decay to physics from 4-fermion interactions. Characterized by their Lorentz transformation properties, these tensor, scalar, and axial-vector/vector interference [3] have all been shown to be small enough in D and R experiments that they would make less than 10^{-6} contributions to the radiative β decay experiment considered here [9].

2.3.2 Constraints from EDM null results

We overstated the situation concerning EDM constraints in our LOI, going beyond careful statements in Ref. [9]. The situation is now clearer in the literature. The result remains that EDM constraints are not important to the source of new physics proposed, but we owe the committee some details here.

We were logically incorrect to say that null EDM experiments can't constrain a spinless observable. It is partly a question of the order to which one must calculate. E.g., even the TRV in the standard model, which does produce TRV in spinless observables, generates EDMs at high enough order (three loops for electron EDM). In contrast, there is a well-known TRV term in the fundamental QCD Lagrangian that depends on spin and directly produces EDMs, and therefore is known to have a coefficient Θ_{QCD} less than 10^{-9} or 10^{-10}. Another example is CP odd correlations in the 3-photon decay of orthopositronium: EDM null results constrain some general sources of new physics so their contributions are small, but explicit models, such as exact cancellations from scalar and pseudoscalar exchange particles, can evade such constraints [11].

A preprint by Dekens and Voss [12] has clarified the situation. They consider three effective field theory operators at TeV scale that generate both a TRV radiative nuclear beta decay asymmetry and, with higher-order corrections, EDMs. One of these EFT operators is even of similar form to Eq. 1, though it does couple to quarks directly and is not emergent from QCD. That is not a trivial concern, because they can apply perturbation theory to quarks that can't be done with nucleons at low energy [John Ng, private communication]. They quantify the resulting constraints on the coefficients of their EFT operators that result from EDM null searches, and state that this constitutes a demonstrative example that EDM null results can provide constraints on new physics that could contribute to radiative beta decay.

However, even if the coefficients are of order unity, these EFT operators produce radiative beta decay TRV asymmetries of 10^{-10}, which is clearly unmeasurable. Dekens and Voss use EDM null results to reduce the possible TRV asymmetry to 10^{-12}, which is impressive overkill. The structure of their EFT term scales explictly by (lepton momentum)^2/(mass scale)^2, which naturally kills TeV-scale contributions by 10^{-10}.

Dekens and Voss have clarified for experimentalists that any measureable new physics contributing to radiative nuclear β decay through such terms is not going to have TeV scale. The experiments we plan are not complementary to high energy experiments.

Gardner and He in Ref [9] considered much lower-energy scales:

2.4 Physics and explicit model considered by Gardner and He

The physics example given by Gardner and He represents a class of physics that can generate large TRV asymmetries in radiative β decay while still evading other experimental constraints. The explicit physics model they consider has low energy scale $M \sim$ MeV. It involves a new sector of particles that strongly interact among themselves, but the c_5 coupling to our standard model can be small. The key component is ρ-like mesons with masses $\sim$ MeV so that they have maximal contributions at the energy scale probed by β decay. Such models may sound a little contrived, but they have remarkably few constraints, and could produce dark matter candidates as well [9]. In this way, charged current experiments through radiative decay can be used to explore some aspects of neutral current physics that are otherwise difficult to measure.

Consequences of the direct contributions of such physics can be considered, but since they involve QCD-like interactions, calculations involving them are not perturbative. So there is no clear path to calculating higher-order constraints from other physics. High-energy colliders can in principle look for such particles in missing momentum experiments, but will lose such particle in jet backgrounds.

2.4.1 The main constraint is from radiative neutron decay

The main constraint on the $Im(c_5)$ term is the agreement of radiative neutron β decay branch with the standard model at 10% accuracy [13]. The branching ratio has contributions proportional to $|c_5|^2$, less sensitive than the TRV asymmetry, which is linear in c_5 because it is from an interference term. The resulting constraint allows the TRV asymmetry to be as large as 10% in neutron β decay [9]. At the higher lepton momentum of the cases we have in mind, the constraint grows weaker, and the asymmetries in Table I of Ref. [9] can still be as large as unity in principle.

3 Description of the experiment and equipment:

Using the TRIUMF neutral atom trap (TRINAT), we can detect the recoiling nuclei with only a few 100 eV of kinetic energy from the beta decay of laser-cooled and trapped radioactive atoms. Measuring coincidences with βs then lets us measure the ν momentum event-by-event.

The present TRINAT detection vacuum chamber is shown in Fig. 1. We would modify this geometry. Common features include β^+ telescopes, the electric field, and the ion MCP to detect nuclear recoils (and the electron MCP, which detects shakeoff electrons efficiently and adds extra rejection of backgrounds). The flanges for the β^+ telescope would be kept this size. The β^+ telescope itself will be smaller diameter so it can be surrounded by shielding or high-Z scintillator for a 511 keV γ coincidence (as in Fig. 3).

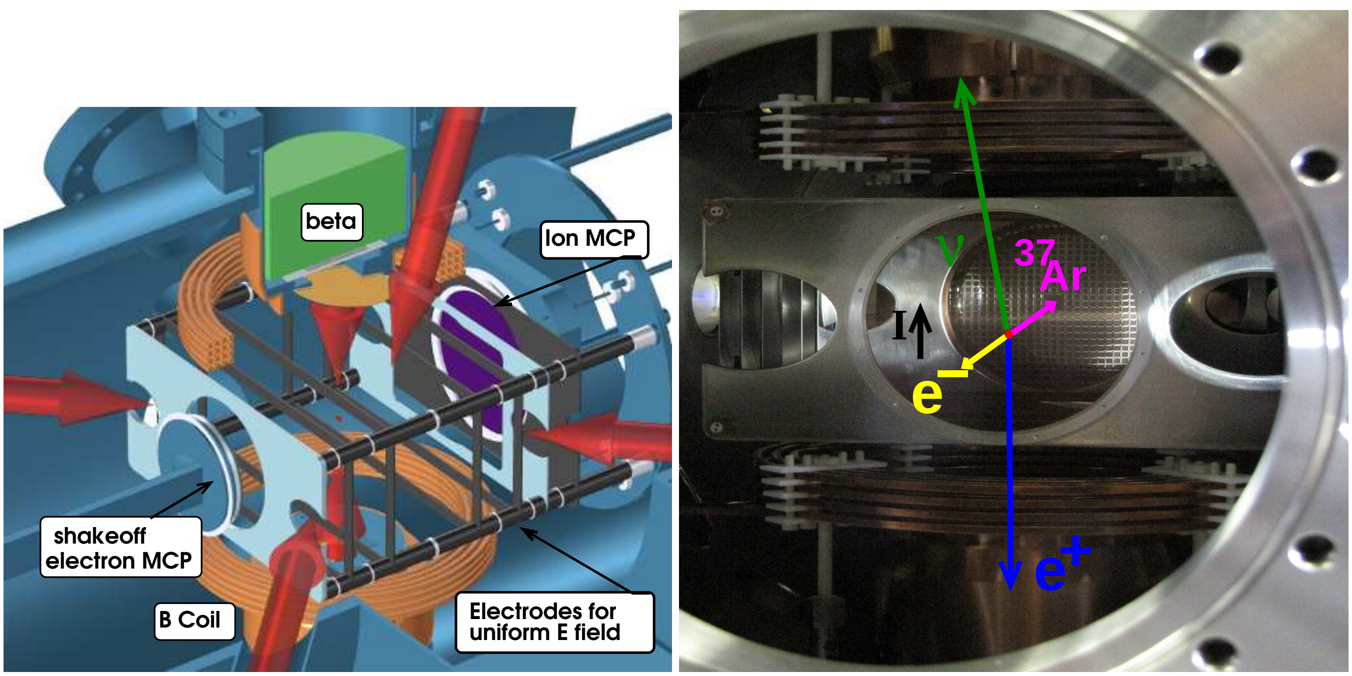

Figure 1: The present TRINAT detection MOT. The optical pumping and MOT vertical beams share a path, reflecting off a thin mirror in front of the β detector to provide better dΩ for βs. The β detector has a twin opposite it for asymmetry experiments (not shown). The near-uniform electric field collects ion and shakeoff e^- to MCPs. Scale is set by the ion detector 80 mm diameter.

γ **detectors** Detectors must be added to see the radiative γ-rays, which have branching ratio 7% above 10 keV and 5% above 50 keV [9]. Ports at $\pm$ 35 degrees to either side of the β^+ telescopes can be used for the γ-ray detectors by using re-entrant flanges with beryllium windows. So we explore below such a geometry with a GEANT4 simulation. The present GEANT4 simulation suggest the magnetic field coils are not producing significant backgrounds, but they can be placed outside the vacuum if necessary.

3.1 Simulation of time reversal by momentum flips

Time reversal in the correlation of Eq. 2 can be simulated by flipping all 3 momenta (γ, β, and recoil), then adding smooth rotations to choose various combinations of detectors.

One such asymmetry would keep γ and β in the same detectors, but take the difference in number of recoils moving initially away from and towards the TRINAT ion MCP. We detect such ions and compare them routinely in our β-ν correlation experiments [19], so are confident we could detect these with systematic error less than 0.002.

Another asymmetry would keep β and recoil momenta the same, but take the difference between count rates of the two γ detectors show in the figure.

To test the symmetry of the γ-ray detectors, we would study coincidences between pairs of β-γ, nuclear recoil-γ, or shakeoff e^--γ, which are not TRV. For concreteness, we consider primarily this γ asymmetry in the simulation below.

3.2 Bremsstrahlung γ-ray detection

We describe a conceptual design for an active coincidence of full-energy annihilation γs near the β^+ telescope.

One key concept is that the bremsstrahlung is correlated with the β direction (Fig. 2). This helps to increase efficiency: at 35^o they have half the maximum ($\sim$10^o) flux yet with finite triple scalar product (sin(35^o)=0.57). Thus a γ-ray detector at 35 degrees is a good compromise between detecting bremsstralung efficiently while maintaining a finite correlation.

Another key concept is that we will require the β^+ to reach the β^+ ΔE-E telescope. It is true that one cannot completely avoid a β^+ scattering on material before reaching the β^+ telescope. The challenge is to prevent bremsstrahlung from such scattering from reaching the γ detector. Our atom trap is a natural geometry for this, because there is not much material near the trapped atoms. It helps that not very much shielding is needed for $E_\gamma < 150$ keV.

Our trap environment has modest magnetic fields with 10 G/cm gradients. Standard NaI(Tl) could work well as an X-ray detector, but would require development of magnetic field insensitive readout, e.g. large-area SiPMs. We assume 3 mm thick CsI(Tl) (or CsI(Na)) in the GEANT4 simulation, because it is not as hydroscopic, and TRIUMF has experience machining it.

CdZnTe has been demonstrated to have reasonable energy resolution (5 keV FWHM at 122 keV [14]). It is available in 25x25x5mm pixellated detectors, and the position information would be helpful to test the angular distribution and explore backgrounds, though admittedly our simulations suggest that statistics will not be adequate for a meaningful angular distribution. A room temperature semiconductor is very attractive in our trap geometry, where there is not pmuch room

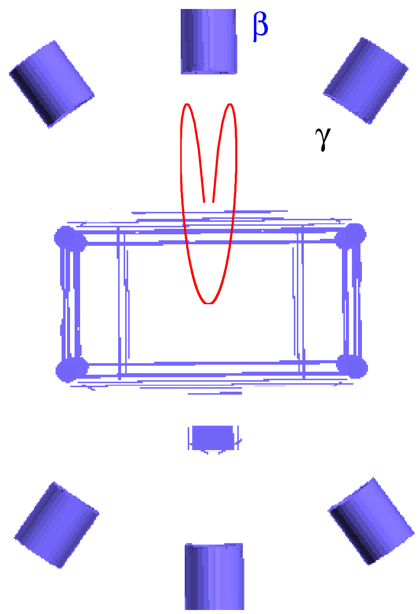

Fig. 2. The red curve is a polar plot of the angular distribution of the inner bremsstrahlung photons [18], shown superposed in a side view on the present TRINAT geometry looking along the electric field axis, and adding γ-ray detection aligned with existing viewport axes.

for cryostats. We are keeping this option in mind as we develop an NSERC funding proposal this fall.

3.2.1 Active coincidence for 511 keV pair

Need for β^+ emitters The vector current in Eq. 2 requires β^+ emitters. This produces a possible bremsstrahlung background from 511 keV annihilation γs.

^{38m}K is a pure Fermi decay, so it is sensitive to the physics, and it has about 4 times greater yields from TiC targets than ^{37}K. This is our best choice from trappable isotopes.

The mixed Fermi/Gamow-Teller decay of ^{37}K would also work well, and the 3 mm thickness of CsI is deliberately chosen to only have few percent interaction efficiency for the 2.7 MeV γs from a non-g.s. 2% branch, while still having near-unity efficiency at 100 keV.

We can find no suitable cases for β^- decay. To have a significant vector current, the decay must proceed to the isobaric analog state, but such decays are energetically forbidden in self-conjugate decays with higher Z than the neutron and tritium. There are isospin-forbidden Fermi decays caused by isospin mixing of low-lying states with the high-lying analog, but all cases we find have significant γ-ray production and rather small Fermi matrix elements. There can be vector currents contributing to forbidden decay. The recently famously clean ^{92}Rb $0^- \to 0^+$ β^- decay apparently goes by first-forbidden Gamow-Teller [15] which does not involve the vector current.

The short-lived potassium isotopes are only available from TiC targets. We also propose for tests ^{80}Rb, a reasonably clean Gamow-Teller decay with a 20% branch making a 616 keV γ-ray. This is readily available from several production targets, and would also provide a valuable null test for the physics considered.

GEANT4 simulation results We show in Fig. 3 the results of the active coincidence. The lower left figure shows the bremsstrahlung is overwhelmed by βs in the raw CsI spectrum, which is not surprising. The lower center figure requires a β^+ in the telescope with kinetic energy greater than 600 keV. Forcing the β^+ to reach the telescope eliminates a lot of background, with signal/background ratio near unity at 130 keV. This might provide a viable experiment at 10-30 keV, but the predicted asymmetry [9] is three times larger at higher energies.

The lower right figure requires two 511 annihilation γs in the BGO quadrant detector; if we know they are fully absorbed there, we know they don't contribute to backgrounds. This concept is working well in the simulation. We consider this a proof of principle that this method can work and allow an accurate experiment for β^+ emitters.

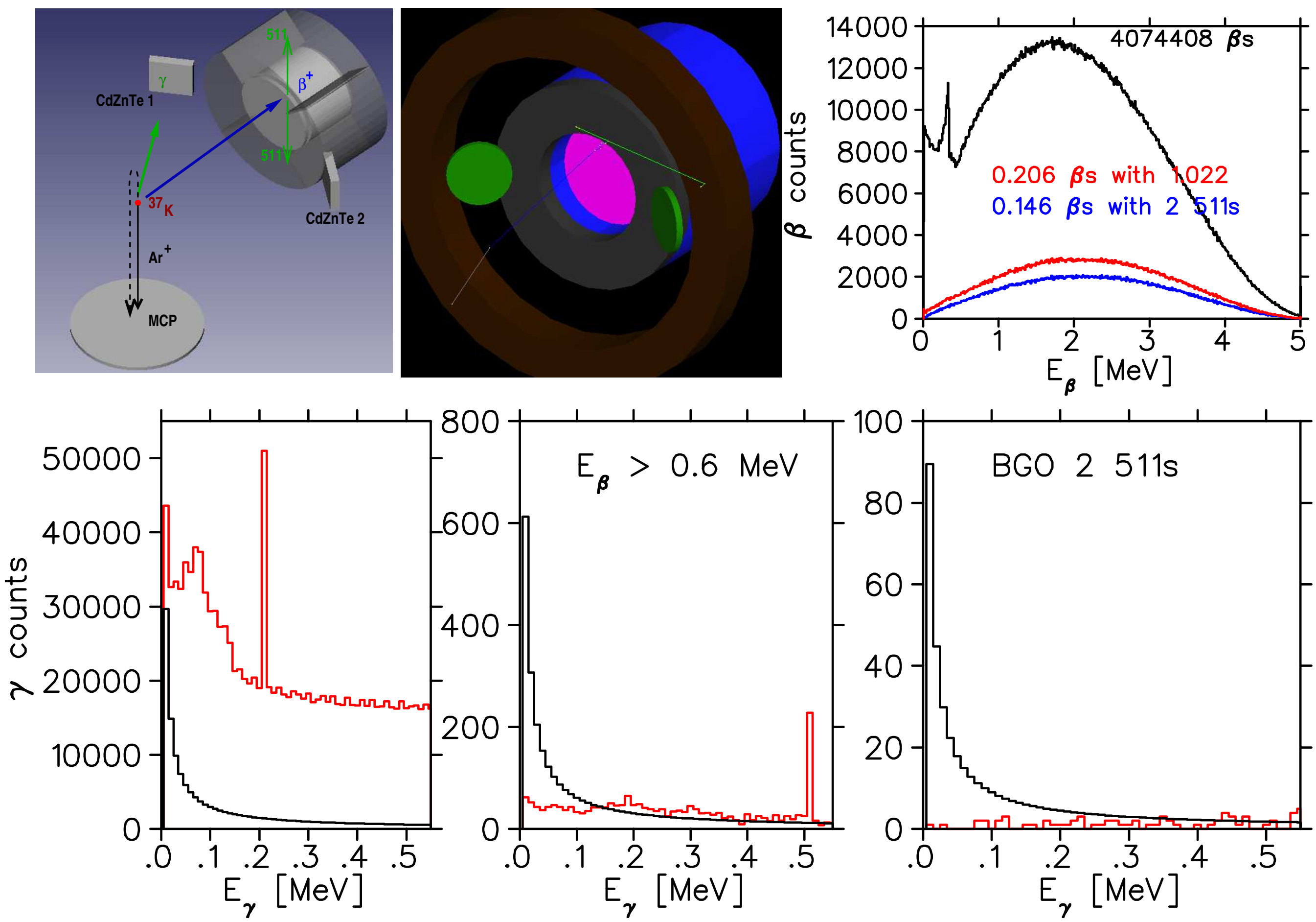

Fig. 3. Geant4 simulation of the conceptual geometry (top left) for about 1 12-hour shift of counting. Top center: Plastic scintillator for β^+s (violet), surrounded by active 511 detection by BGO in 4 quadrants (blue), with bremsstrahlung γ-ray detectors from 3mm thick CsI(Tl) (green). The gray is a tungsten collimator, and the orange is one of the two copper field coils. The event shown is a β^+ stopping and annihilating in the scintillator, with the 511s detected in the BGO (this is not clear in the solid view). Top right plot: The β^+ detector response to ^{38m}K is as expected; efficiency is lost when requiring 511 in the BGO. Bottom figures show the energy in the CsI bremsstrahlung detectors, with bremmstrahlung signal in black, and background in red. Bottom left has no cuts; center requires a 600 keV β^+ and is helpful; right requires two 511 keV γs in the BGO.

3.2.2 Higher-order considerations

This is an interesting γ-ray spectroscopy experiment, and further optimization of the simulations is ongoing, hopefully to be explored by a student if the experiment is approved:

Accidental coincidences are not shown, but become a significant correction at the 400 Hz rates planned per detector, because of the large background suppression needed. This might require compromising to a faster scintillator than CsI(Tl) with less light output. CsI at this 3 mm thickness also has shows in GEANT4 about 10% escape of the subsequent K X-ray after photoabsorption, a possible plus for NIST's choice of BGO for a γ detector [13].

Much of that raw rate in the γ detectors is from direct β^+s. The old-school technique of adding 2.5 cm of Be in front of the γ detector to stop the β^+s passes about 1/2 of 30 keV γs, and is being checked for 'outer bremsstrahlung' production.

The useful Table I of Ref. [9] has the highest TRV asymmetries from photons above the 341 keV Compton edge for annihilation, which still has more than 1.5% branch, and this might motivate use of the higher energy resolution CdZnTe at commercial 5 mm thickness.

Use of more clever passive shielding might also allow a geometry that can be used without the 511 coincidence near the β^+ detector, and therefore allow our present higher solid-angle β^+ detectors compatible with our other correlation experiments.

3.2.3 Real Term: previous measurements

The radiative γ branch in ^{38m}K produces an 0.002 correction in our β-ν correlation measurement [19], and it would be helpful for our next generation experiment S1070 to test the calculation directly. There have been many efforts to measure 'inner bremsstrahlung, dating from at least 1945, and we do not review the entire field here. The radiative β decay of the neutron was a true tour de force in a clean theoretical system, but was able to achieve only $\sim$ 10% accuracy on the branching ratio $3.13 \pm 0.34 \times 10^{-3}$ [13] (though a thesis exists with smaller uncertainties from the next generation data). Bienlein and Pleasonton in the well-understood Gamow-Teller decay of ^{6}He [17] saw substantial deviations from theory below 0.3 MeV γ energy, blamed on not understanding the detector lineshape; the radiative branch is much smaller in ^{6}He than the 5-7% branch in ^{37}K and makes for a much more difficult measurement. Boehm and Wu have γ-ray spectra in agreement with theory from 25 to 100 keV photon energy using NaI for ^{147}Pm and ^{35}S [16]. We do not underestimate the difficulties here, but we believe accurate measurements can be done in optimized geometries.

4 Readiness

The trap is working for this purpose. We require development of γ-ray detection, the smaller-diameter β telescopes, and the 511 coincidence annular detector. We intend to apply for funding for these, to be available April 2016, with possible beamtime in 2017.

Yields: ISAC delivered in June 2014 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. Yields of ^{38m}K are a factor of four higher than ^{37}K from this material. The yields were due to improvements in TiC particle size and are expected to be reproducible by the target chemists. It is these higher yields that have encouraged us to make proposals such as these requiring coincidences.

5 Estimated Uncertainties and Beamtime required:

Our efficiency for collected recoil ions in our electric field is about 7%– roughly 15% of the recoils are ions in positron decay, and our MCP efficiency is 55%. For 40,000 atoms of trapped $^{38\mathrm{m}}$K and 1.5% solid angle for the shown β^+ detectors, we need one shift to collect 3% statistics and 10 shifts for 1% on a TRV asymmetry between γ-ray detector pairs.

We request 5 shifts of the relatively clean ^{80}Rb decay to develop the apparatus. This is available from many targets in large quantities, and 10 shifts of $^{38\mathrm{m}}$K time.

The change of the β telescope to include addition of γ detectors can be done relatively easily once developed, but all the schemes we have compromise something from the approved ^{37}K and $^{38\mathrm{m}}$K correlation experiments (E field uniformity and β solid angle), so we require dedicated beamtime.

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