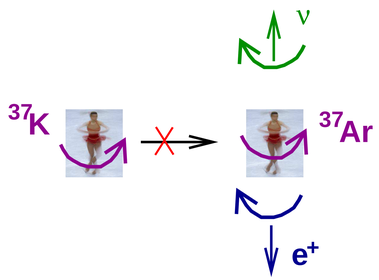
Optical pumping for β-decay

J.A. Behr, S. Smale, A. Vantyghem, I. Craiciu, A. Gorelov, C. Farfan, TRIUMF; M. Anholm, UBC; S. Behling, D. Melconian, B. Fenker, Texas A&M; D. Friesen, G. Gwinner, U. Manitoba

Support: NSERC, NRC through TRIUMF, U.S. D.O.E., State of Texas

Optical pumping of ^{41}K for β decay

- Nuclear β decay experiments to test the standard model
- Goal: laser-cooled, polarized ^{37}K atoms with vector polarization of $>$ 99.9%, with knowledge of the polarization from atomic observables at 0.1% accuracy.
- Diagnostics: time dependence of excited state population after optical pumping light turns on, using single-photon fluorescence counting and nonresonant photoionization
- Achieved: Nuclear polarization 0.995$\pm$0.04
- **Sensitive to ν helicity: normal left-handed ν does not allow these directions:**

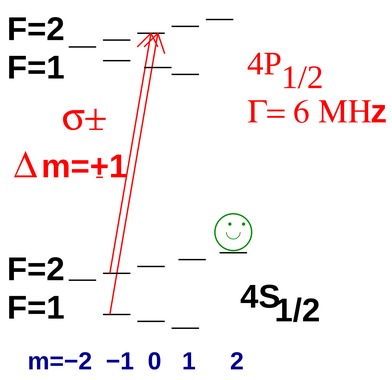


Optical Pumping

- optically pump ^{37}K atoms for 2 ms after AC MOT off
- $\sigma^{\pm}$ $4S_{1/2} \rightarrow 4P_{1/2}$ transition
- diode laser with RF injected, excites F=1 and F=2 from g.s.
- test with ^{41}K, almost same hyperfine splitting as ^{37}K

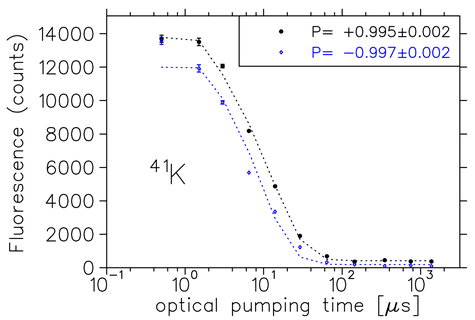
$\vec{F} = \vec{J} + \vec{I}$

$H_{hyperfine} = - \vec{\mu_N} \cdot \vec{B_e} = A \vec{I} \cdot \vec{J}$

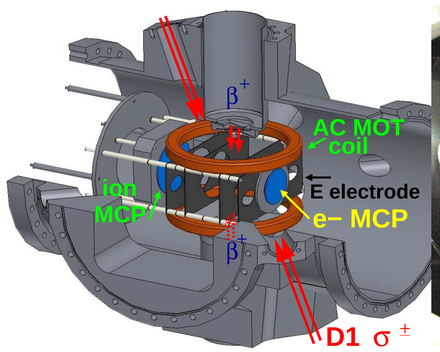


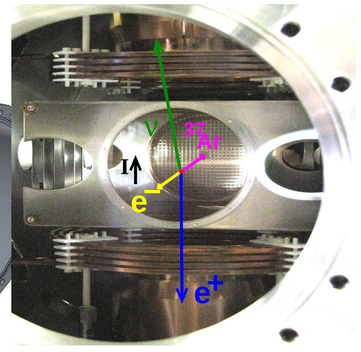
Fluorescence Diagnostic

- single-photon counting
- burst of fluorescence as atoms are optically pumped
- Modelled with rate equations including stray B field and imperfect S_3



β decay geometry and optical pumping



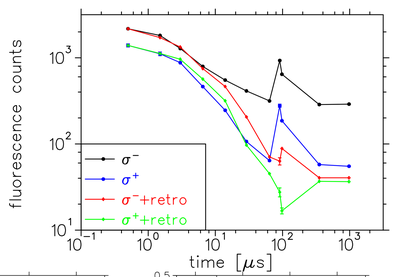


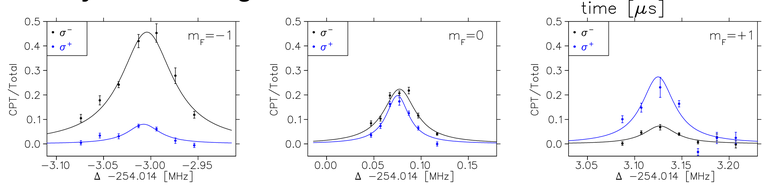
- AC MOT turns off Bquad fast ($<$ 1% after 0.1 ms)
- Trap and optical pumping share Z axis: Larger β^+ dΩ
- atomic e^- coincidences: measure A_{recoil}, remove backgrounds
- β^+ passes through 0.25mm SiC mirror substrates

- Combine 769.9nm D1 and 766.49 D2 with angle-tuned 780 nm laser-line filter
- Flip spin state with liquid crystal variable retarder
- Relieve stress from conflat viewports with fully annealed copper gasket (Stokes S_3=0.998 so far)

Coherent Population Trapping is bad for us

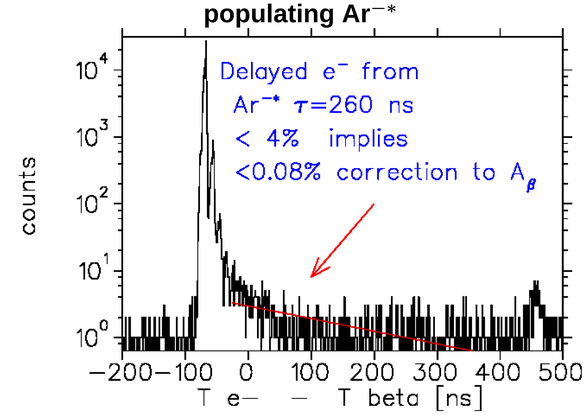
- Atoms trapped in the coherent dark state would have poor nuclear polarization
- Signature: at t= 80 μs, detune RF sidebands by 1 MHz
- Eliminate CPT by counter-propagating beams and by RF detuning





Atomic physics in β decay: Ar^-

Ar^- has a metastable state $3s^2\ 3p^5\ 4p$, τ=260 ns
Unusual configuration: if populated in β^+ decay, Ar^- can move before releasing the electron. Since Ar^- itself has an asymmetry in direction, this can generate a false β asymmetry
By fixing τ to the known value, we place an upper limit on populating Ar^{-*}



Energy of shakeoff electrons from β^+ decay: Use AC MOT Bquad as an electron spectrometer

- With uniform $|\vec{E}|$=350V/cm Bquad of the MOT can deflect electrons from the electron MCP
- More 15 eV electrons than sudden approximation calculations (Levinger PR 90 11 1953). Though these are optimal energies to break single-DNA strands, they do not break double strands and should not contribute much biological damage