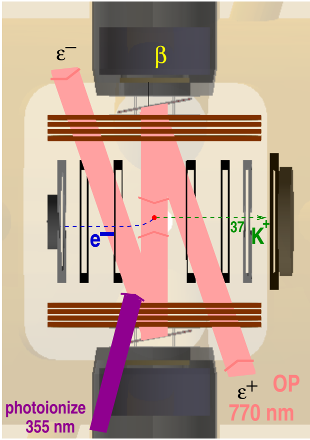
TRIUMF Precision measurement of the nuclear polarization of laser-cooled, optically pumped ^{37}K

- Motivation: spin-polarized β decay
- Direct Optical pumping

  Our polarization method also provides a continuous probe

  Complication: Coherent population trapping. Easy to kill.
- Measurement of ^{37}K polarization



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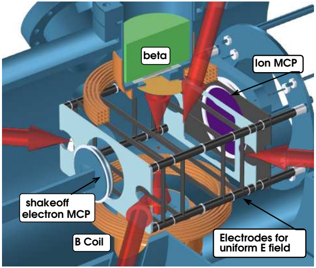
In support of our ^{37}K A_β result JH.00007 Ben Fenker et al.

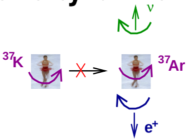
^{37}K spin-polarized experiments

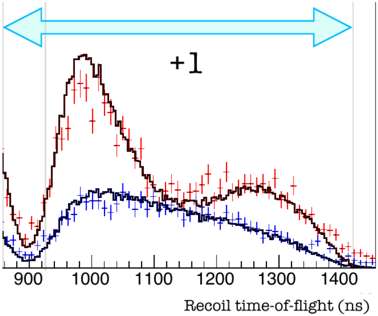
^{37}K A_β result JH.00007 Ben Fenker et al.



- 10,000 atoms trapped
- P measured in-situ on ^{37}K by atomic method
- ion + shakeoff e^- for A_{recoil}

Isobaric mirror decay has helicity-driven null

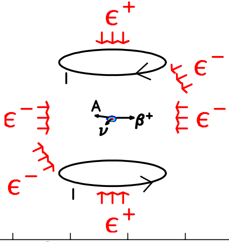




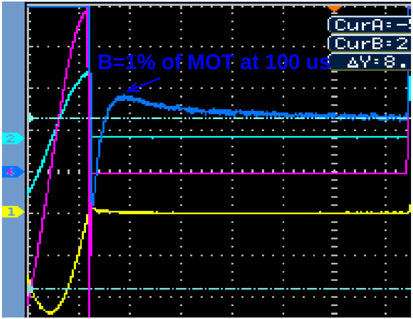
$$W(\theta) \approx 1 + a\cos(\theta_{\beta\nu})$$

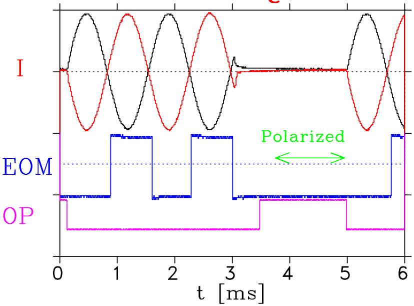
$$a = (A_\beta - B_\nu)P - a_{\beta\nu} + 2c/3 = 1 \text{ or } 0 \text{ indep. of } M_{GT}/M_F$$

AC MOT to turn off trap



MOT's 7 G/cm Bquad off to 1% of its value in 100 μs:





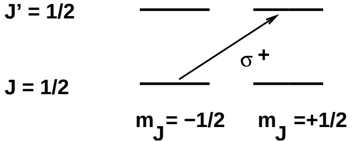
M. Anholm, M.Sc. thesis, UBC 2011

How to spin-polarize a nucleus with a laser: Part I

Polarize atom by Direct Optical Pumping

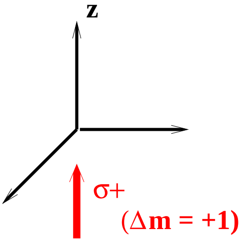
Biased random walk

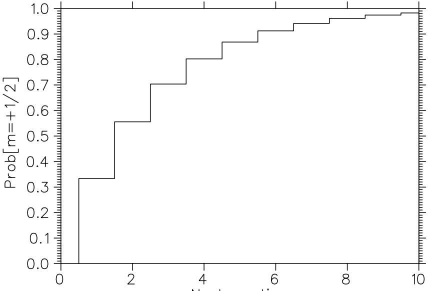
Simple example:



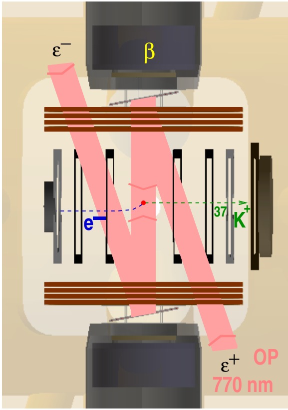
P(m=1/2) = 1 - $(2/3)^N$ after N steps

Need 12 photons absorbed to get to 99% of maximum.

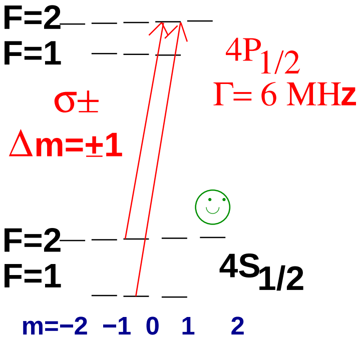




TRIUMF Direct Optical Pumping, *I*=3/2



- Biased random walk
- $\sigma^{\pm}$ light $4S_{1/2} \rightarrow 4P_{1/2}$ transition



- optimize with ^{41}K, almost same hyperfine splitting as ^{37}K

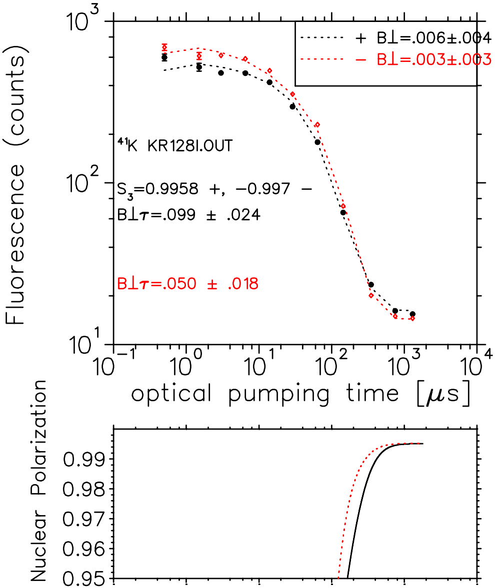
$\vec{F} = \vec{J}_{\text{atom}} + \vec{I}_{\text{nucleus}}$ $\quad H_{\text{hyperfine}} = -\,\vec{\mu_N} \cdot \vec{B_e} = A\,\vec{I} \cdot \vec{J}$

Spin flips: $\sigma^{+} \rightarrow \sigma^{-}$;

small frequency shift (-2 MHz) to compensate Zeeman shift

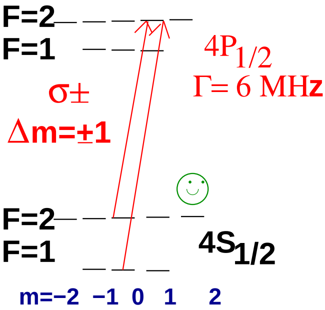
TRIUMF Fluorescence Diagnostic ^{41}K

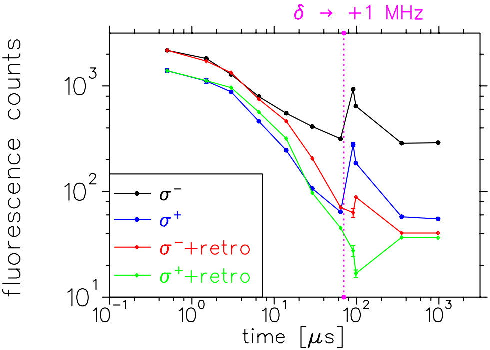
- **single-photon counting**
- **burst of fluorescence as atoms are optically pumped**
- **Modelled with rate equations including stray $B_\perp$ field and imperfect S_3**
- **Used to optimize parameters for use in ^{37}K**

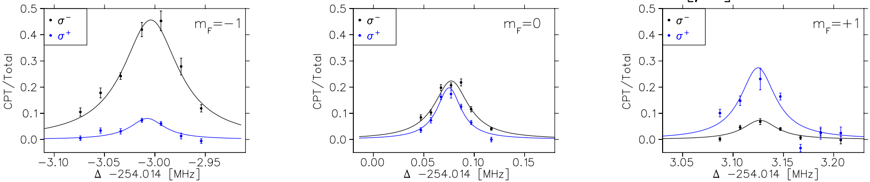


Coherent Population Trapping is bad

But easy to remove by counter-propagating beams and by RF detuning

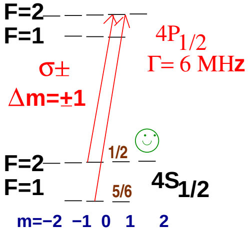






$\Rightarrow$ **B_z = 2.339(10) G**

Quantifying Polarization from excited state population



Tail ∼ few % of peak ⇒ We need tail/peak to ∼ 10% accuracy to extract *P* to ∼ 0.1%

We can't quite extract *P* by inspection:

$\Delta F = 0$ for Larmor precession

Same centroid *P* from 2 approaches:

Rate eqs for classical populations

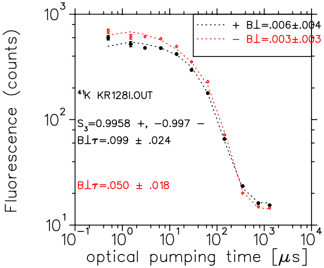
$$\frac{dN_i}{dt} = -R_{ji}N_i + R_{ij}N_j + \lambda N_j$$

Optical Bloch Eqs include $B_\perp$ rigorously

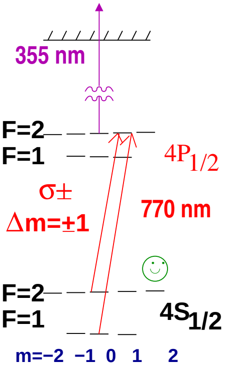
$$\frac{d\rho}{dt} = \frac{1}{i\hbar}[H, \rho] + \lambda$$

We measure S_3 and float $B_\perp$

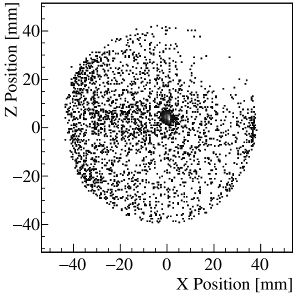
(S_3=-0.9958(8), -0.9984(13), +0.9893(14), +0.9994(5))

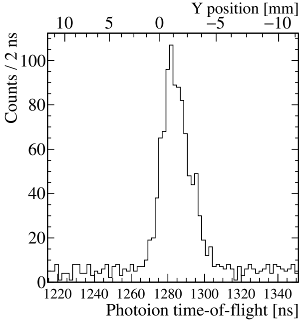


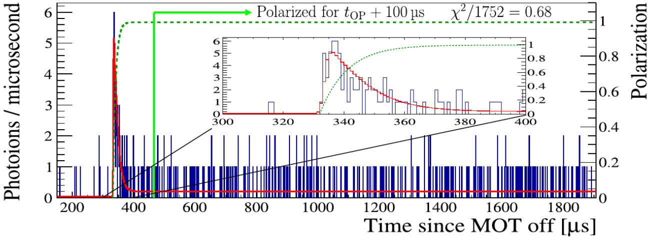
Optical pumping and probing ^{37}K



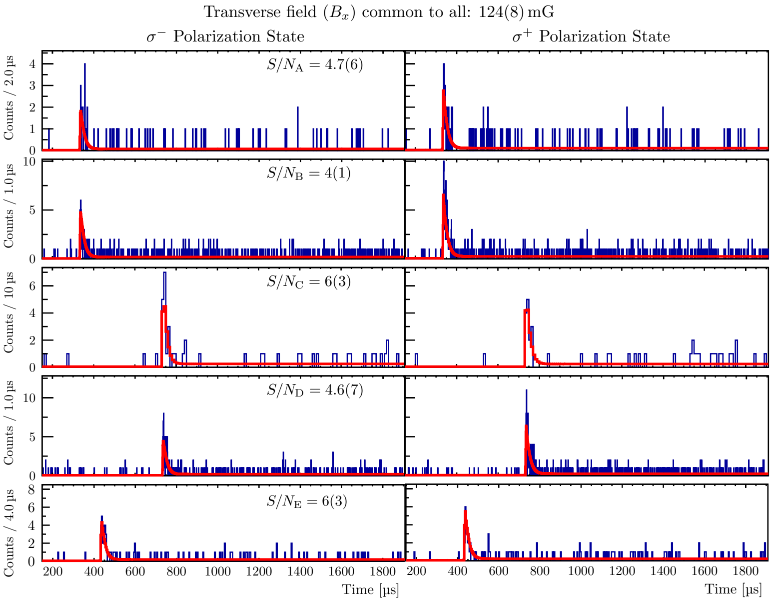
- **Photoionize ∼ 1%**
- **Does not change polarization**



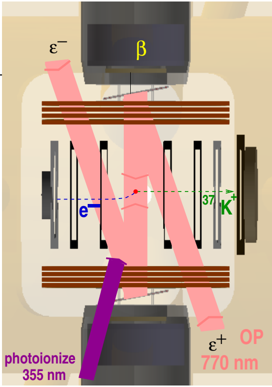




Polarization fit to all ^{37}K data



TRIUMF Uncertainty Budget for ^{37}K polarization



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

$P(\sigma^+) = +0.9913(8)$ $T(\sigma^+) = -0.9770(22)$

$P(\sigma^-) = -0.9912(9)$ $T(\sigma^-) = -0.9761(27)$

→ B. Fenker JH.00007 ^{37}K A_β

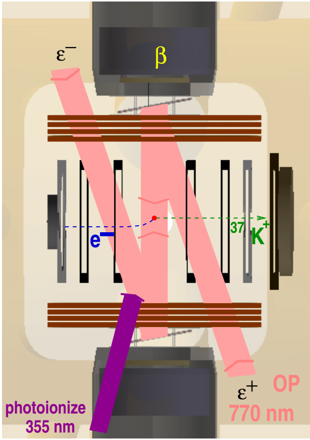
Precision measurement of the nuclear polarization of laser-cooled, optically pumped ^{37}K

- Direct Optical pumping provides a continuous probe
- Measurement of ^{37}K vector polarization and tensor 'alignment'

$$P(\sigma^+) = +0.9913(8) \quad T(\sigma^+) = -0.9770(22)$$
$$P(\sigma^-) = -0.9912(9) \quad T(\sigma^-) = -0.9761(27)$$

1-P = 0.87%, known to ≈ 10% of its value

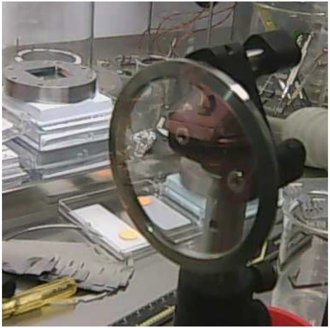
J.A. Behr, I. Craiciu, A. Gorelov, S. Smale, C.L. Warner, L. Lawrence, B. Fenker, R.S. Behling, M. Mehlman, D. Melconian, G. Gwinner, M. Anholm, J. McNeil, D. Ashery, I. Cohen



TEXAS A&M UNIVERSITY
UNIVERSITY OF MANITOBA
THE UNIVERSITY OF BRITISH COLUMBIA
אוניברסיטת תל-אביב TEL AVIV UNIVERSITY

In support of our ^{37}K A_β result JH.00007 Ben Fenker et al.

Improvements in progress

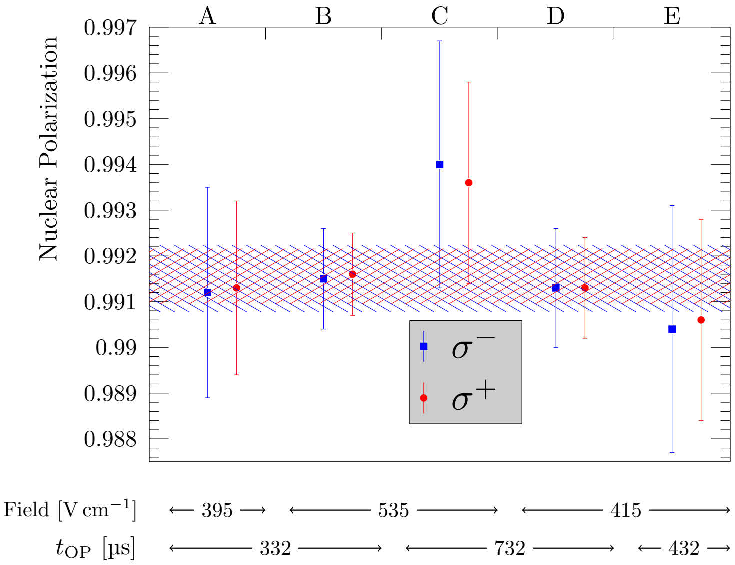


Lower E_β threshold (0.5 MeV) by changing mirrors from 0.25 mm SiC to 0.012 mm mylar 'pellicles'

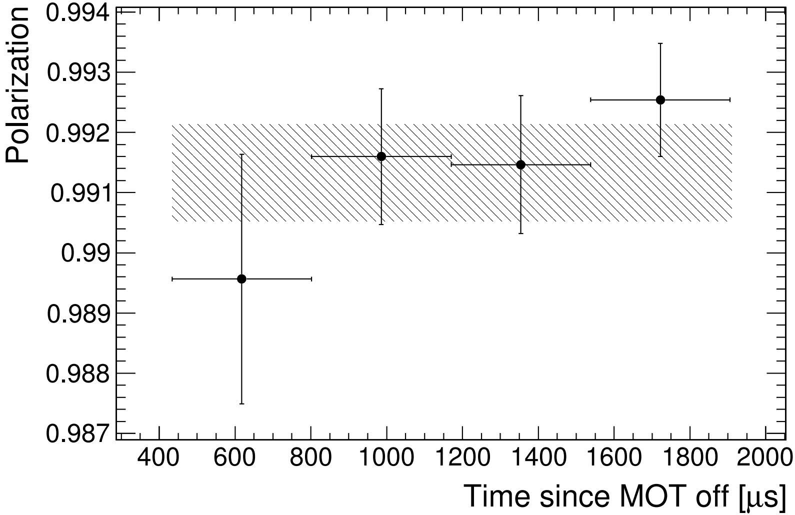
- trim stray B field gradients better
- improve S_3, flipping, (S_3=-0.9958(8), -0.9984(13), +0.9893(14), +0.9994(5)) and gradients.
- add flipping of B_z
- higher-power 355 nm photoionizing laser by 3x to improve statistics
-
- gentler RAC-MOT with lower-frequency half-sinusoid to dissipate 1/10 the power while maintaining confinement (L. Lawrence, McMaster, Poster EA.00150)

TRIUMF

Polarization by data set

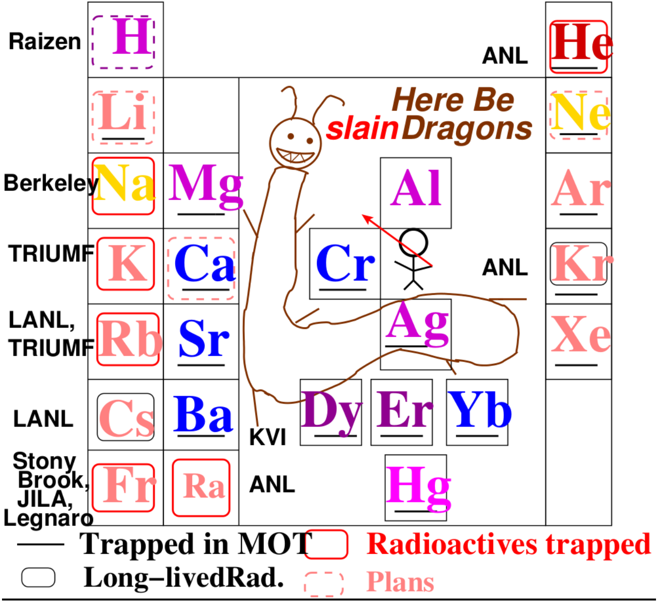


Polarization time dependence



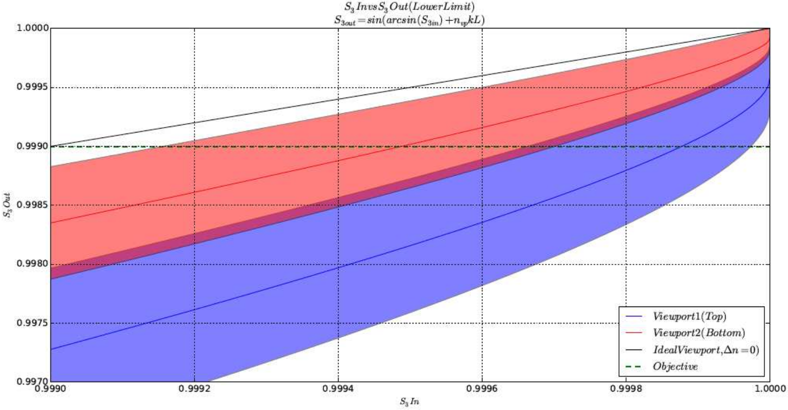
^{41}K data also suggest a 1 millisec B_{quad} component
materials: 316L, 316LN, Ti, glassy carbon electrodes

What elements can be laser cooled?

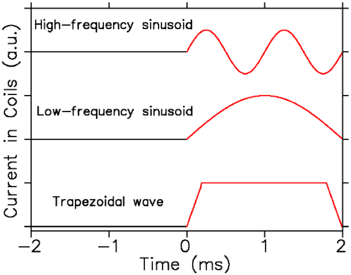


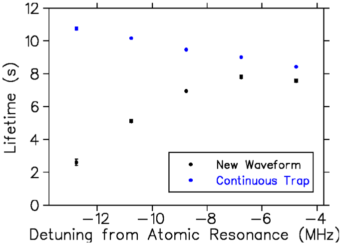
Viewport birefringence

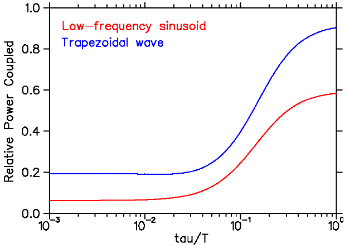
Characterizing viewport birefringence allows prediction of $\boldsymbol{S_3}$ in center given $\boldsymbol{S_3}$ in and out.

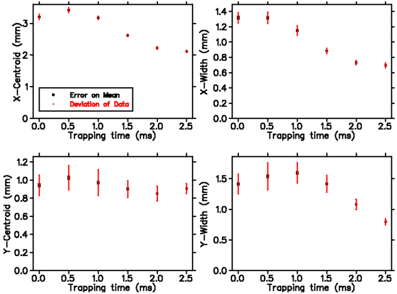


gentler RAC MOT





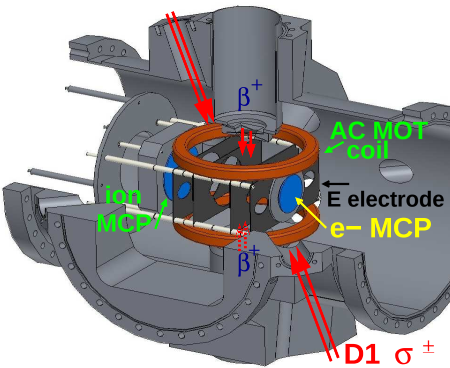


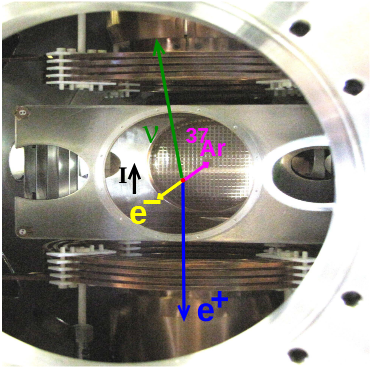


1/2-sinusoid dissipates less power and keeps confinement.

Liam Lawrence, McMaster U., poster CEU at DNP, Oct 14 downtown

β decay geometry and optical pumping



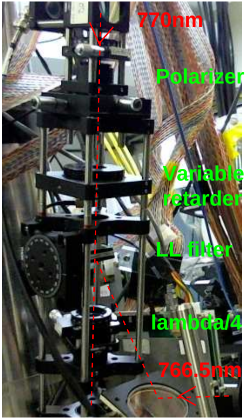


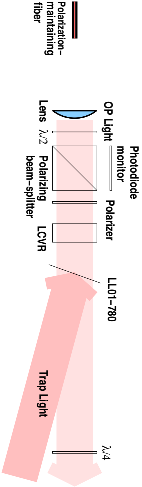
- AC MOT turns off Bquad fast ($< 1\%$ after 0.1 ms)
- Trap and optical pumping share Z axis: Larger β^+ dΩ

- atomic e^- coincidences: measure A_{recoil}, remove backgrounds
- β^+ passes through 0.25mm SiC mirror substrates

TRIUMF

Optics Techniques





- 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-induced birefringence with PCTFE (Neoflon) viewport seals (S_3=-0.9958(8), -0.9984(13), +0.9893(14), +0.9994(5))