Improving optical pumping methods for nuclear β decay

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Optical pumping of ^{37}K for β decay asymmetry

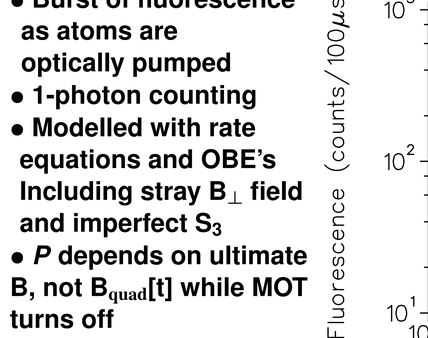
β angular distribution $W(\theta)d\theta = 1 + P\,A_\beta \cos(\theta)$

- We've polarized ^{37}K atoms with nuclear polarization $P = \frac{\langle m_I \rangle}{I} = 0.9913 \pm 0.0009$ and measured:

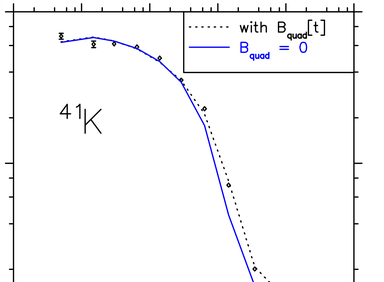
$A_\beta[\text{exp.}] = -0.5707(13)_{\text{syst}}(13)_{\text{stat}}(5)_{\text{pol}}$ Theory -0.5706(7)

Best fractional accuracy A_β in nuclei

B. Fenker *et al.* Phys Rev Lett **120** 062502 (2018)



Normal-handed ν forbids:



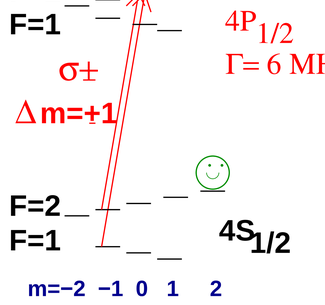
$P < 1$ mimics wrong-handed ν

Direct Optical Pumping

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

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

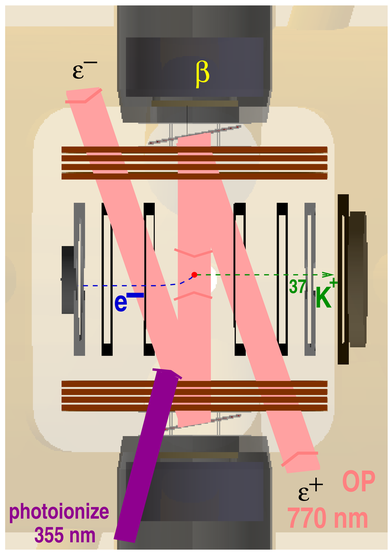
$H_{\text{hyperfine}} = -\vec{\mu}_N \cdot \vec{B}_e = A\,\vec{I} \cdot \vec{J}$

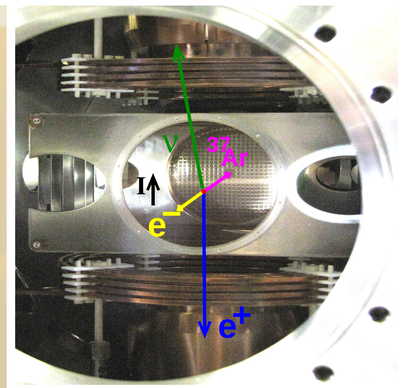


Fluorescence Diagnostic stable ^{41}K, 10^6 atoms

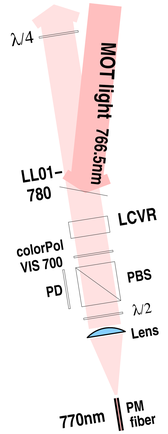
- Burst of fluorescence as atoms are optically pumped
- 1-photon counting
- Modelled with rate equations and OBE's Including stray $B_\perp$ field and imperfect S_3
- P depends on ultimate B, not B_{quad}[t] while MOT turns off
- Optimize parameters for ^{37}K polarization

β decay geometry and optical pumping





- Trap and optical pumping share Z axis: Larger β^+ dΩ



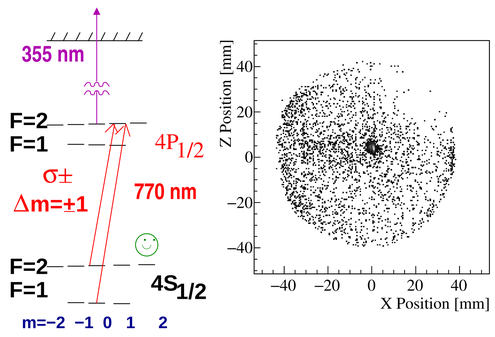
- Combine OP and MOT beams with angle-tuned 780 nm laser-line filter
- Flip spin state with liquid crystal variable retarder
- Relieve stress-induced birefringence with PCTFE (Neoflon) viewport seals C.Warner Rev Sci Instr 85 113106 (2014) S_3=-0.9958(8), -0.9984(13), +0.9893(14), +0.9994(5)

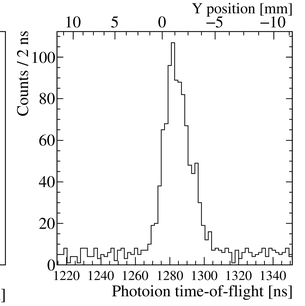
Improvements in progress

- Trim $B_\perp$ field gradients
- Twisted nematic liquid crystal: $S_3 \to \pm 0.9996$
- PMT $\to$ 100 μs CMOS $\Rightarrow$ dP/dz ?
- 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
- Lower E_β threshold (0.5 MeV) by changing mirror substrates 250μm SiC $\to$ 70 nm Au 4μm Kapton pellicles $\leftarrow$ [Stern Family of National Photocolor]

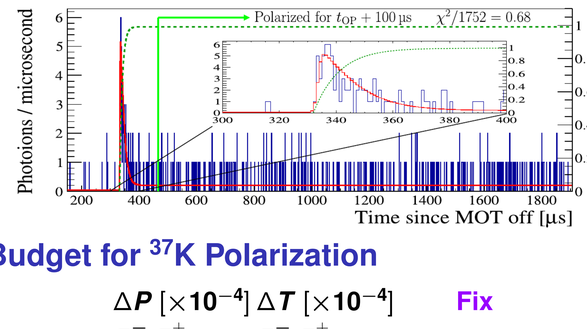
Polarization probe $t_{1/2}$=1 s ^{37}K, 10^4 atoms

B. Fenker *et al.* New Jour Phys 18 073028 (2016) 10% of data





- Photoionize $\sim$ 1%
- *in situ* probe of P of decaying nuclei



Uncertainty Budget for ^{37}K Polarization

Source	ΔP [$\times 10^{-4}$] σ^-	σ^+	ΔT [$\times 10^{-4}$] σ^-	σ^+	Fix
SYSTEMATICS					
Initial T	3	3	10	8	Prep state
Global fit v. ave	2	2	7	6	
S_3^{out} Uncertainty	1	2	11	5	Better flips
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	More 355nm

1-P = 0.87% $\pm$ 0.09% I.e. we know the 'tail' to $\sim$ 10%.

We hope to bring the polarization closer to 1, which will naturally increase the precision.

The accurate polarization probe of the atoms as they decay is enabling more accurate angular correlations of the β and ν w.r.t. the nuclear spin to test Standard Model predictions.