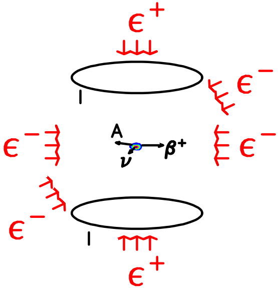
TRIUMF Neutral Atom Trap: decay topics

- **Tensor interaction constraints from singles recoil spin asymmetry**
- **Recoil momentum spectrum from I.C. of ^{86m}Rb**
- **Hyperfine spectroscopy of Rb $5s_{1/2} \rightarrow 5d_{5/2}$**
- **some foibles of electron timing with MCP's**
- **'AC MOT' for $^{37}\vec{K}$: see D. Melconian**



not covered: ^{38m}K β-ν correlation upgrade, except some prep

meta: at ISAC large amounts of many Rb isotopes are available from several common targets. We test equipment for K experiments while doing Rb experiments.

TRIUMF Neutral-Atom Trapping "TRINAT" for this decay work

UBC	TRIUMF	Tel Aviv	Undergrad
****R. Pitcairn**	J.A.Behr	D Ashery	B. Lee
****D. Roberge**	*A.Gorelov	****O. Aviv**	A. Gaudin
****T. Kong**	M.R. Pearson		B. Dej
	K.P. Jackson	U. Manitoba	T. Wiebe
	M. Dombsky	G. Gwinner	A. Chatwin-Davies
	P. Bricault	Texas A&M	A. Berman
	*C. Höhr	D. Melconian	
	*J. Holt	****S. Behling**	

****Grad Student** *Research Associate

Supported by Canadian NSERC, Canadian NRC through TRIUMF, WestGrid, Israel Science Foundation

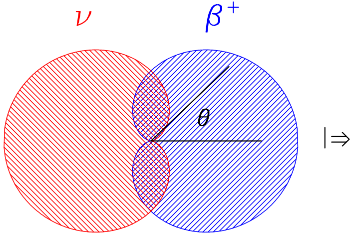
A new method for an old observable (Treiman '58)

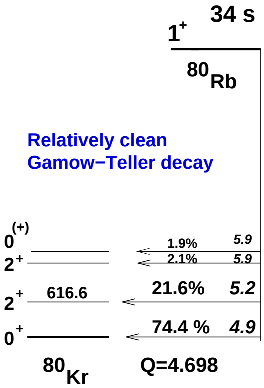
Final nuclei angular distribution wrt initial spin

$$W[\theta] = (1 + \tfrac{1}{3}cTx_2) - x_1(A_\beta + B_\nu)P\cos\theta - x_2 cT\cos^2\theta$$

$$x_1 \overset{Q>>m}{\longrightarrow} 5/8;\ P = \frac{\langle M\rangle}{I};\ T = \frac{I(I+1) - 3\langle M^2\rangle}{I(2I-1)}$$

- **For pure Gamow-Teller, A_{recoil} = 0 in SM**





$$A_\beta + B_\nu = \lambda_{J'J}(-2C_T C_T' + \langle \frac{m}{E_\beta}\rangle (C_T + C_T'))$$

Challenge: constrain ~ 0.01 recoil-order correction

β decay tensor interactions

4-Fermi contact interactions, Lee and Yang 1957

Generalization of Fermi's β decay theory: Lorenz scalar product of currents with matching Lorenz transformations

$$H_{\rm int} = \sum_{X=V,A,S,T} (\bar{\psi}_p O_X \psi_n)(C_X \bar{\psi}_e O_X \psi_\nu + C'_X \bar{\psi}_e O_X \gamma_5 \psi_\nu)$$

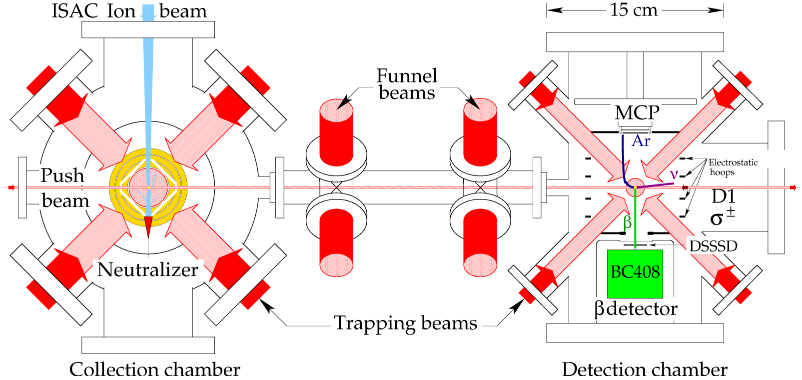
Standard Model W^+ exchange (coupling only to left-handed ν_L) $\longrightarrow$ C_V, C_A only, i.e 'V-A'

Severijns, Beck, Naviliat-Cuncic Rev Mod Phys 2006 global fit C_T/C_A=0.0086$\pm$0.0031 assuming SM chirality for C_T, C_S (and Serebrov 2005 n $t_{1/2}$)

Profumo Ramsey-Musolf Tulin PRD 2007: SUSY can produce $C_T \sim 0.001$ by left-right sfermion mixing

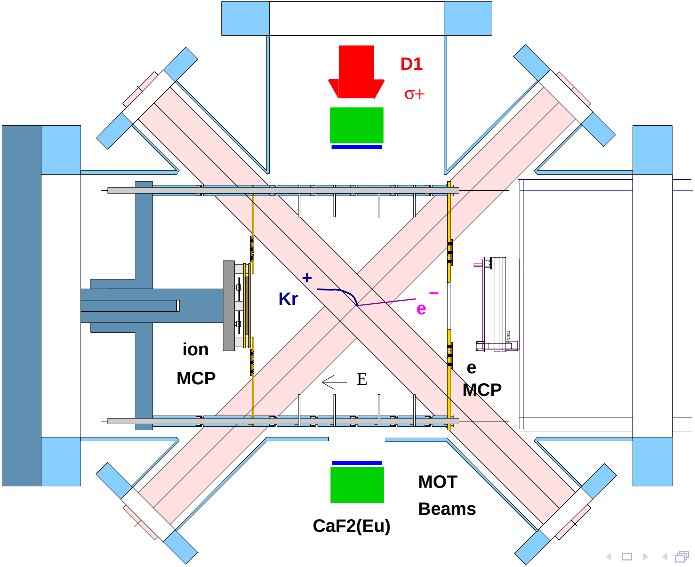
TRIUMF's Neutral Atom Trap

- Isotope/Isomer selective
- Evade 1000x untrapped atom background by $\rightarrow$ 2nd MOT
- 75% transfer (must avoid backgrounds!); 10^{-3} capture
- 0.7 mm cloud for β-Ar$^+$ $\rightarrow \nu$ momentum $\rightarrow$ β-ν correlation
- $>$97% polarized, known atomically



^{80}Kr daughter TOF, position; atomic e^- trigger

- like Vetter LBL PRC'08



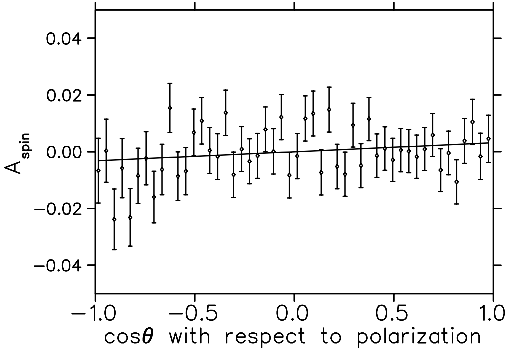
Measure:
θ_{recoil} **wrt** $\vec{I}$,
$|p_{recoil}|$

MCP and electrostatic rings

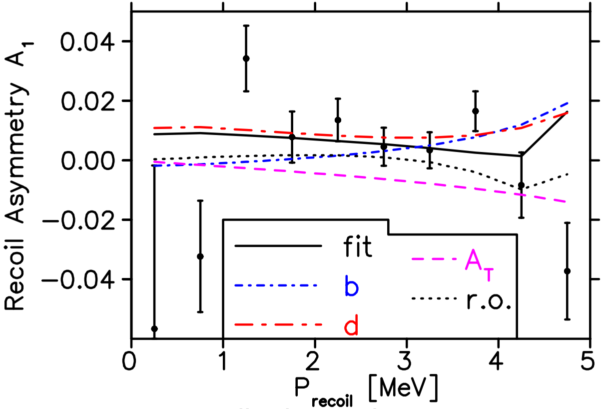
^{80}Rb Singles Recoil Asymmetry: data and fits

$$A_{\mathrm{spin}}[p_{\mathrm{recoil}}] = \frac{W[\theta, P] - W[\theta, -P]}{W[\theta, P] + W[\theta, -P]} = \frac{P A_1[P_r] \cos\theta}{1 + cTF_2[P_r]\cos^2\theta}$$

To extract the experimental asymmetry $A_1[p_{\mathrm{recoil}}]$, Fit for 0.5 MeV recoil momentum bins: E.g.: all Kr^{+2} data:



Distinguishing new tensors from S.M. corrections



$A_1[p_{\rm recoil}]$ differs for new tensor C_T, C_T' vs. SM higher-order

b weak magnetism

d QCD-induced tensor

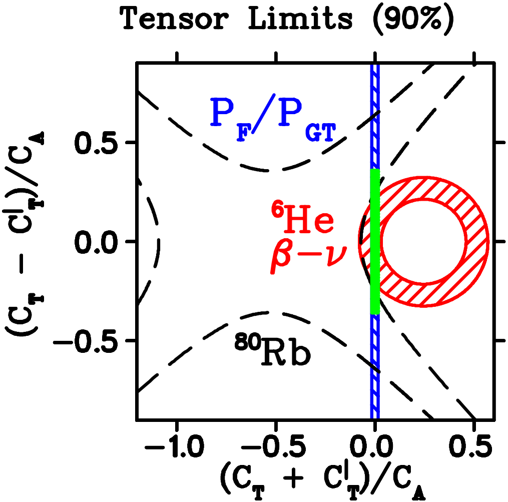
- Effects of ***d*** can be separated this way

Non-SM contribution to the asymmetry:

$\boldsymbol{A_T = 0.015 \pm 0.029 \pm 0.019}$

(Syst from b/AM_{GT}=4.7±4.7, nucleon value)

$^{80}\vec{\text{Rb}}$ decay: Tensor constraints



- Dash:
  C_T, C'_T, b, d all float
  limits not competitive
- Green bar:
  set b/AM_{GT}=4.7±4.7,
  assume $C_T + C'_T$=0
  (Carnoy ^{14}O/^{10}C 1991)
  $\rightarrow$
  $A_T = 0.015 \pm 0.029$ (stat)
  $\pm\, 0.019$ (syst) $\Rightarrow$

$|(C_T - C'_T)/C_A| < \mathbf{0.36}$
R. Pitcairn et al. PRC Jan 2009

- Complementary constraints to tensor couplings to ν_R compared to ^{6}He β-ν correlation (Johnson ORNL PR 1963)

Improvements?

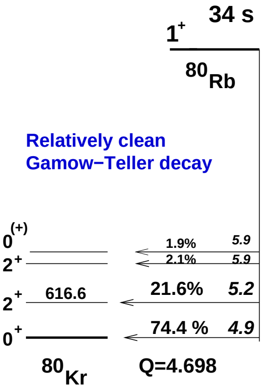
- constrain/measure $\boldsymbol{b}$ by $\boldsymbol{A}_\beta[p_\beta]$
- Use the higher-polarization methods demonstrated in ^{37}K
- ^{82}Rb for consistency
- γ coincidence to correct for $1^+ \rightarrow 2^+$
- Could do experiment to 0.001;

need nuclear structure theory guidance for

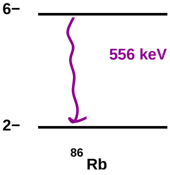
$$b/A = \boldsymbol{g_M M_{GT}} + \langle \boldsymbol{f} || \sum \boldsymbol{\tau_i^+ \vec{I}} || \boldsymbol{i} \rangle$$

$$d_I/A = \boldsymbol{g_A} \langle \boldsymbol{f} || \sum \boldsymbol{\tau_i^+ i \vec{\sigma}} \times \boldsymbol{\vec{I}} || \boldsymbol{i} \rangle$$

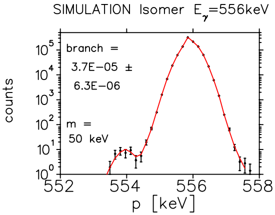
In Fermi decays or Fermi/Gamow-Teller mirror decays, recoil-order corrections are given by electromagnetic moments: ^{38m}K and ^{37}K



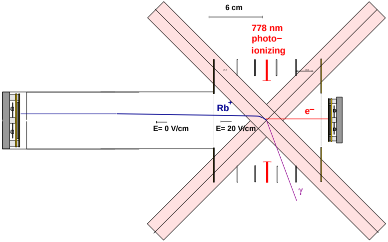
Exotic particles in isomer decay



1.0 m



$$p = \sqrt{E_\gamma^2 - m_x^2}$$

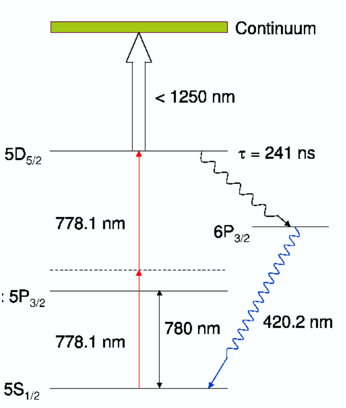


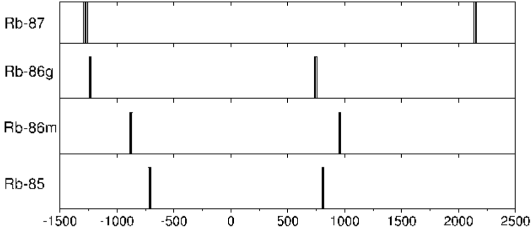
- Search for anything massive emitted from nuclear transition
- Independent of interaction in detector or lifetime
- If see a signal, could measure spin from polarized angular distribution

Models exist, but often need 10^{-6} sensitivity

Photoionization scheme

^{86m}Rb $\longrightarrow$ ^{86g}Rb neutral atom, 1.9 eV energy. Must photoionize:



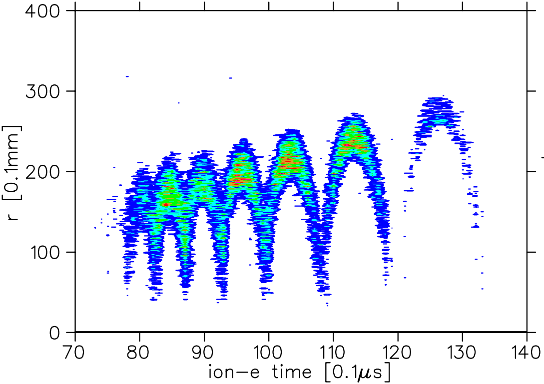


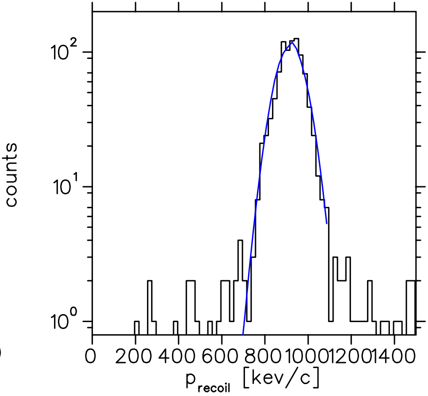
Frequency structure for 5S to $5D_{5/2}$ transitions in Rb isotopes (MHz)

A Doppler-free 2-photon transition resolves the daughter ^{86g}Rb from the trapped ^{86m}Rb AND excites atoms independent of velocity. Then 1064nm light from a fiber laser photoionizes the atoms

- Technique works, efficiency is not enough
- We see off-resonant ionization of ^{86m}Rb at about 1/sec

2% I.C. of trapped ^{86m}Rb: p=920 keV calibration





Good signal/background

Intrinsic momentum resolution $<$4%.

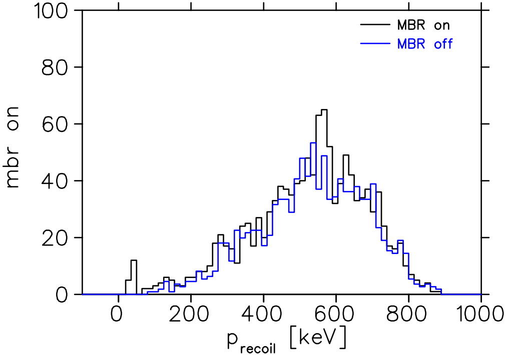
Test of sensitivity to MeV-mass ν in ^{81}Rb EC decay

γ-ray events, laser on/off, 8 hrs

Less than 1 event/min

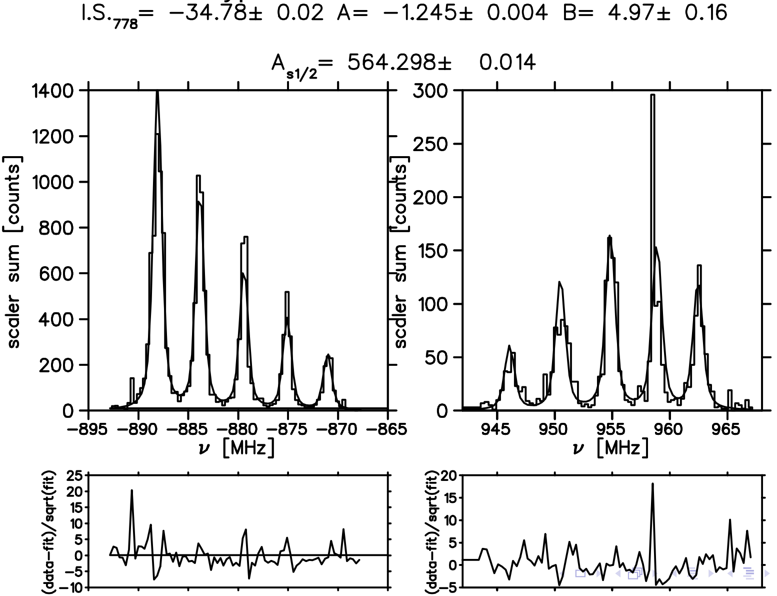
Background is probably most accidentals
Do γ's ever produce 'shakeoff' e^-'s?

Lower-velocity case ^{81m}Rb would give more time to photoionize and minimize transit time broadening, sensitivity to 10 keV $<$ m $<$ 80 keV



PRELIMINARY High-statistics method on trapped atoms

Could measure hyperfine anomalies in the Rb chain



hyperfine anomalies, magnetic octupoles

A. Pérez Galván et al. / Physics Letters B 655 (2007) 114–118

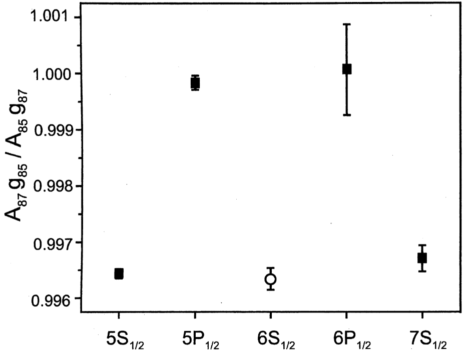
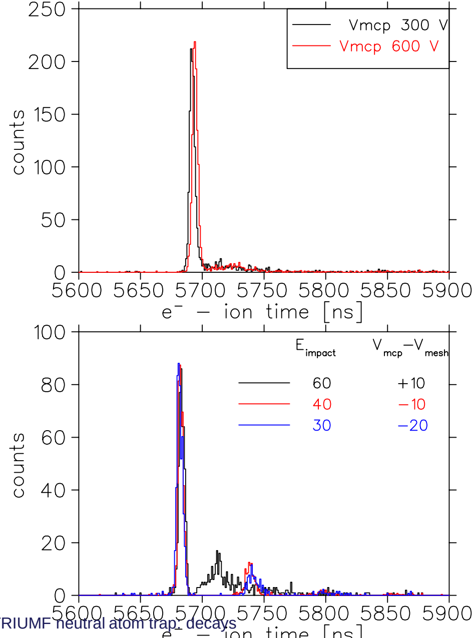
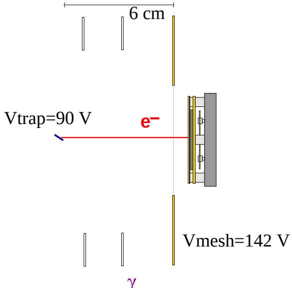


Fig. 3. Ratio of hyperfine constants normalized by the nuclear g factors showing hyperfine anomaly differences in ^{85}Rb and ^{87}Rb based on five different electronic states. The value for the $6S_{1/2}$ (circle) comes from the present measurement. See the text for the other references (squares).

Nez OC 1993 D5/2 is 0.9955±0.0005 → C magnetic octupole term? Tanner found C=0.56(7) kH in Cs P3/2 PRL 2003.
Need few KHz accuracy. We see 100Khz absolute shifts now, though A in 85,87Rb consistent at 20 KHz.
Statistical errors demonstrated.
Turn off B field, linearly polarized light, more stable MOT and/or larger 778 nm beam, don't dither scanning AOM, linearly polarized light in cell.

e^- MCP timing defects





- e^- not hitting the channels backscatter or produce a secondary that can launch and return with enough energy to trigger MCP
- for $V_{trap} < V_{MCP} < V_{mesh}$ time structures as some scattered e^-s escape into the mesh region and then return

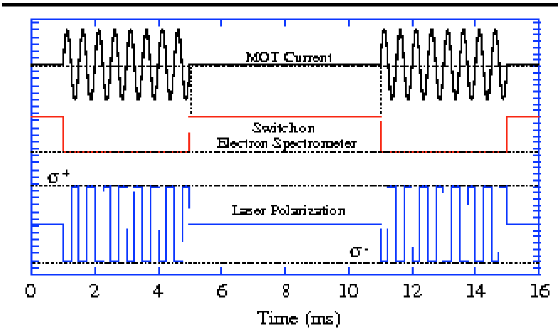
Implications

- Exotic particle searches: simulates ‘tachyons’ so ‘OK’ BUT zero-momentum photoions now produce finite-momentum tails– we can reject events from MCP center.
- β-ν ^{38m}K : To measure the recoil momentum spectrum, must understand this timing for the E_e spectrum produced in the β decay. Big challenge. Will probably concentrate on the β-recoil technique.
- $A_{\rm recoil}$ is OK

AC MOT

We have 97±1% polarization of ^{37}K, but can only chop MOT's B field on and off on 2 msec timescales. Improve:

Harvey and Murray Manchester PRL 101 173201 2008



We want to use for polarized experiments: can switch B fields much faster, so atoms will not expand as much during the optical pumping process.

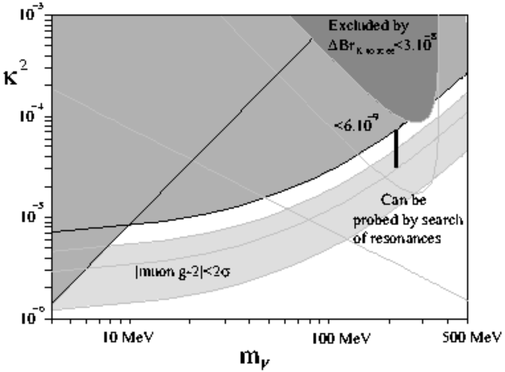
May also help with expelling dimers (Vetter PRC 77 35502 has identified this as a possibly serious background in β-ν correlations with atom traps.)

spare slides
spares

Approved as a 'Signature-based general search'

- 0^- particles favored in Magnetic transitions
- 0^+ favored in Electric transitions (like E4 of ^{86m}Rb)

Pospelov hep-ph 0811.1030 explanation for PAMELA β^+ excess (but no $\bar{p}$ excess): SUSY dark matter heavy particle decays via new U(1)' symmetry to massive boson, which then decays. Constraints on its coupling as a function of its mass:



- Constraints and searches welcome in any mass range.

Often need 10^{-6} sensitivity

hyperfine anomaly in ^{86m}Rb, ^{86g}Rb

- We can deduce the $5D_{5/2}$ specific mass shift, of atomic structure interest (testing many-body calculations, also for α[redshift]). Also sharpen long-standing issues with Rb charge radius chain from $5S_{1/2} \rightarrow 5P_{3/2}$
- Precision on $A_{D5/2} < 4$ KHz $\longrightarrow$ sensitivity to a 'hyperfine anomaly' $A_{D5/2}/A_{S1/2}$ different by 1% with 3σ accuracy, depending on systematic errors (under evaluation).

Sensitive to the spatial distribution of the unpaired nucleons

$^{85}_{37}\text{Rb}^{48}$ $5/2^-$ $\pi 1f^{-1}_{5/2}$ $^{87}_{37}\text{Rb}^{50}$ $3/2^-$ $\pi 2p^{-1}_{3/2}$, full $\nu 1g_{9/2}$

NNDC/NDS says predominant configurations:

^{86g}Rb 2^- $\pi 1f^{-1}_{5/2}$ $\nu 1g^{-1}_{9/2}$ "^{85}Rb+n"

^{86m}Rb 6^- $\pi 2p^{-1}_{3/2}$ $\nu 1g^{-1}_{9/2}$ "^{87}Rb-n"

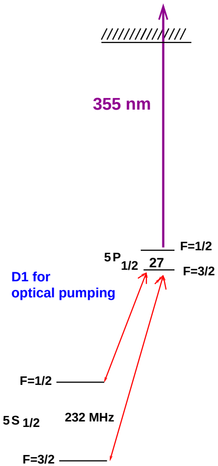
Which will have larger valence nucleon radius?

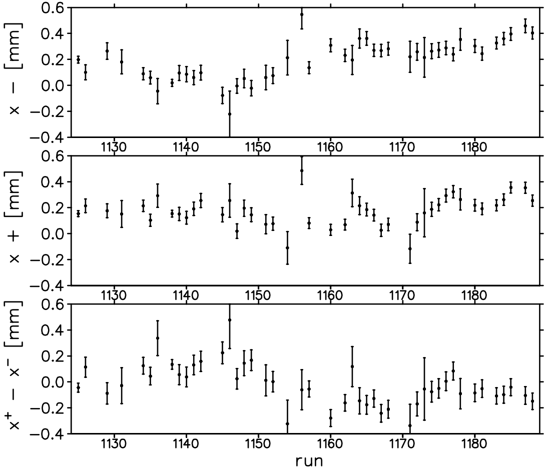
^{88,89}Rb are possible, along with $^{76-84}$Rb and $^{90-97}$Rb

Photoionization Diagnostic → cloud position

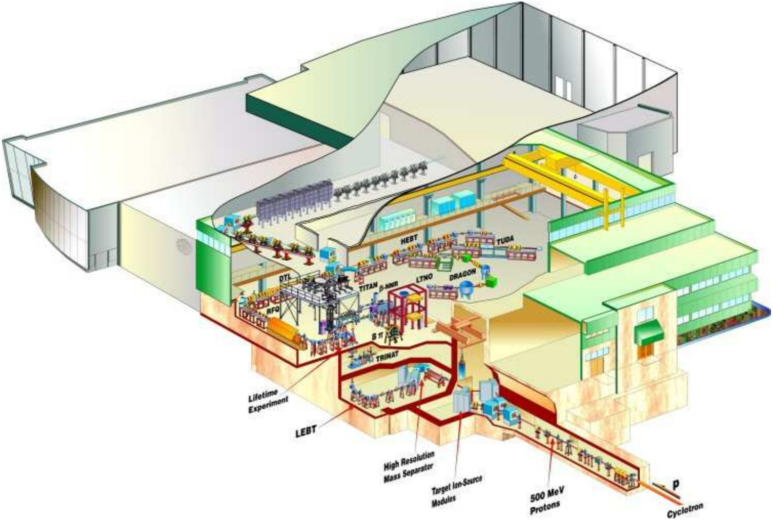
MOT on/off 30 μs; Optical pumping off/on to polarize

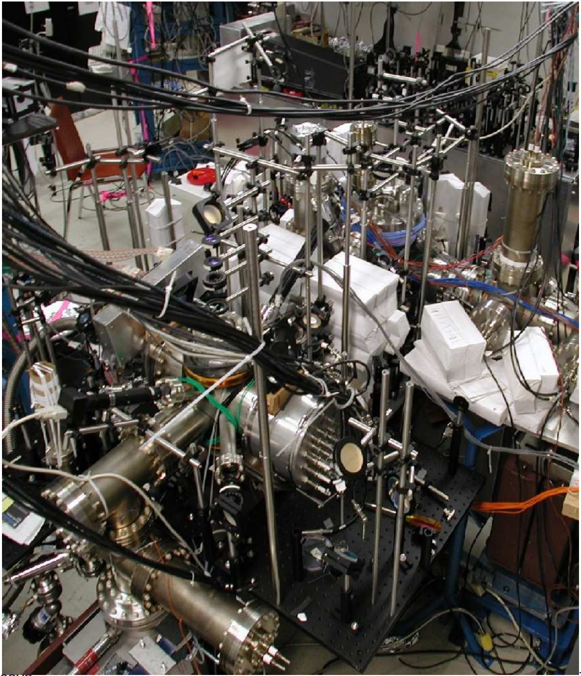
Cloud shifts $<$ 0.03 mm with spin flip $\Rightarrow$ A correction $<$ 0.0012 σ_A $<$0.00005





TRIUMF-ISAC

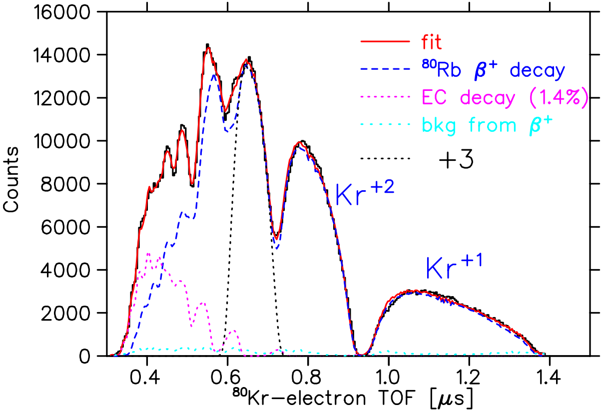

HEBT
TUDA
DTL
TITAN
β-NMR
LTNO
DRAGON
RFQ
8 π
TRINAT
Lifetime Experiment
LEBT
High Resolution Mass Separator
Target Ion-Source Modules
500 MeV Protons
p
Cyclotron

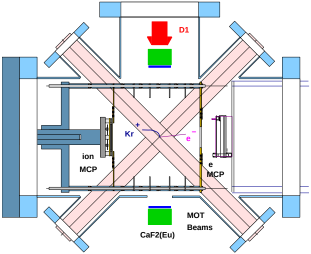


TRINAT lab

TOF of ^{80}Kr daughter with atomic e^- trigger

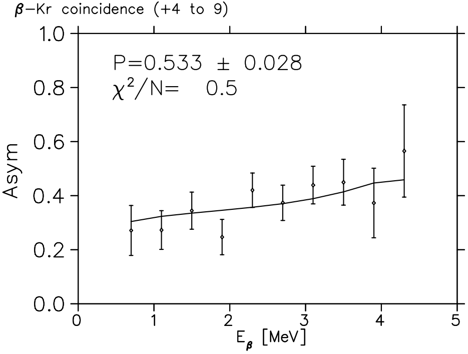
- High-statistics technique
  - efficiency $\sim$ 50%





^{80}Rb Polarization diagnostics

β asymmetry



Result: P=0.55±0.05

EC recoils, separated by TOF and high-momentum cut