A=225 implantation for $^{221}$Fr for TRIUMF atom trap

- Introduction
- Physics motivation
- A=225 yield test at TRIUMF: lessons
- A=225 at ISOLDE
- Summary
A=225 implantation for $^{221}$Fr for TRIUMF atom trap

- FrTrap collaboration has 3 approved experiments for trapped Fr atoms
- Longest $t_{1/2}$ is $^{223}$Fr, $t_{1/2}=22$ min

We will develop the trap with Rb (lighter alkali) but ‘long-lived’ Fr would help

At TRIUMF: Dec 2010 after 500 MeV p beam off, tested what came out at A=225 for future implantation purposes. TRIUMF has no simultaneous implantation capability.

We could use this more regularly, and hopefully get more
FrPNC collaboration

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Supported by NSF and DOE USA, NSERC and NRC Canada, CONACYT Mexico.
Francium trap with present TRIUMF yields

$2 \mu \text{A} \ p$ on $30 \ \text{g/cm}^2 \ \ UC_x$ has sufficient yield for experiments given (many) weeks of beamtime

- $10^4$/s for collinear and other spectroscopy for $S1010$ hyperfine anomalies, neutron radii
- $10^7$/s for nuclear anapole: isoscalar/isovector weak nucleon-nucleon interaction in the nuclear medium $S1065$
- $10^8$/s for optical transition: parity violating electron-quark coupling and SM tests $S1218$
FrPNC collaboration:

Parity mixing
7s → 7(s+ε p)
Z-induced E1\text{PV}

Atomic PNC ∼ Z^2 N, in Fr 20x larger than in Cs

S1010 e⁻-quark weak coupling → optical PNC led by U. Manitoba Rb M1-Stark in progress

Weak N-N from nuclear anapole moment: U. Maryland, San Luis Potosi, William and Mary.
Sheng JPhysB 43 074004
Hyperfine anomaly

Spatial distribution of nuclear magnetism

\[ A_{s\frac{1}{2}}/A_{p\frac{1}{2}} \text{ (similar to } A_{s\frac{1}{2}}/g_{\text{nucleus}}) \]

- For \( A_{s\frac{1}{2}} \): bunched TITAN beams and collinear laser beamline
- Used for \(^{74}\text{Rb}\) charge radius from optical isotope shift
- \( A_{p\frac{1}{2}} \) needs laser-cooled atoms and doppler-free spectroscopy in a trap

Stony Brook, Grossman et al
PRL 83 (1999) 935
Dec 2010: implanted A=225 after p beam was off

1 day implantation $\rightarrow$ 2x10$^5$/s $t_{1/2}=5$m $^{221}$Fr

$^{221}$Fr
$t_{1/2}=5$m

$^{225}$Ac
$t_{1/2}=10$d

$^{225}$Ra
$t_{1/2}=15$d

2x10$^5$/s $t_{1/2}=5$m $^{221}$Fr

ISOLDE Summary reserve

J.A. Behr, TRIUMF
Implantation at SSP-GLM chamber

Is vacuum good enough to avoid surface contamination?
How to monitor $A=225$: $\alpha$ detectors in chamber... too much background?
Recoils from source

60 keV implantation $^{225}$Ra has range 76 A in W

$^{225}$Ac $\rightarrow \alpha + 100$ keV $^{221}$Fr

Lower-Z catchers produce less straggling (range 200 Ang, straggling 20 Ang). Will try at least two substrates (W and Si or ‘Glassy Carbon’). Optical polish might be helpful to avoid degradation of release from nonuniform surface.

P303 A=225 implantation for $^{221}$Fr
Safety issues from TAC-INTC-Feb2011:

Class C labs like ISOLDE hall can handle 100 LA. 1 LA for $^{225}$Ra is 1 KBq, for $^{225}$Ac is 800 Bq.

Proposal: test asked for at $10^7$/s, 1 d $\rightarrow$ 300 KBq. Reducing this by 3x ends up producing $8\times10^4$/s $^{221}$Fr at yttrium catcher and is good for testing the trap and some physics.

- Can this ever go higher? Our proposal also requests $10^8$/s for a week, about 100x more to allow $^{221}$Fr anapole moment measurement.
- Shipment is more straightforward: 4 MBq is the limit for excepted quantity; could be shipped as exempted quantity. 4 GBq is the limit for Type A air shipment container, so we will not exceed that.

First test and further tests needs Type A air shipment container (TRIUMF can supply).
**Timetable:**

August 2011 Install trap with stable Rb
December 2011 on-line test with Fr at TRIUMF
January 2012 off-line test with A=225 produced at TRIUMF

Spring 2012: Implantation of $10^7$/sec for 8 h or $10^5$ Bcq
- W, Si, C samples, two of each
  - Test of safety and source quality, pick Si vs. W

Already this would let us develop trap experiments on Fr and measure hyperfine anomaly and atomic M1 of $^{221}$Fr

Summer 2012: Implantations of much more?:
- goal: $10^7$/sec $^{221}$Fr in the Yttrium foil for anapole moment, i.e. $5 \times 10^7$/sec $^{225}$Ra decays, i.e. $10^9$/sec A=225 yield for 1 day.
Summary of request

SSP collection chamber on GLM

- Our submitted proposal requested 50 $\mu$Curie implantations in W, Si, C for tests
- Divide by 3, for Class C ISOLDE Hall limit = 15 $\mu$Curie, $10^7$/s for 8 hours, 6 samples $\Rightarrow$ 48 hours

- 1000 $\mu$Curie implantations for anapole moment for $^{221}$Fr. Can a small chamber be mounted that could be valved off and shipped?
**A=225 implanted source → \(^{221}\)Fr**

No heating, no radiochemistry, 2 week half-life

**Implant \(^{225}\)Ra at TRIUMF or ISOLDE**

Place source 3mm from Yt catcher

\(\alpha\) decay of \(^{225}\)Ac ejects 100 keV \(^{221}\)Fr into 1 cm spot

Remove source

Move Yt to trap, heat, trap compatible with existing high-efficiency UHV trap loading
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

1.3330 Spherical Cube
Kimball MCF133-SC6 .7in thick

1.9700 Connect to vacuum pump
All-metal valve VAT 48124-CE24

1.8470 Port connect to receiver cube
Pneumatic Positioner Huntington L-2171-6-LL

3.5500 Maximum extended position
This length is right to the center of the receiver cube

Change the source from this port

Minimum extended position

Close Coupler
Kimball Physics MCF133-ClsCplr-A2

This length is right to the center of the receiver cube

Retracted position, rest length

This length is right to the center of the receiver cube

Pneumatic Positioner Huntington L-2171-6-LL

Connect to vacuum pump

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FrPNC: weak neutral current

Parity mixing
\[ s \rightarrow (s + \epsilon \ p) \Rightarrow Z^0\text{-induced} \ E1_{PV} \]

Atomic PNC $\sim Z^2 N$, in Fr $\approx 18x$ larger than in Cs

1st step: measure M1 by M1-Stark interference (led by U. Manitoba)
The atomic theory has been done to 1% accuracy and Cs-like accuracy of 0.3% should be possible.

Largest Wieman Stark-M1 interference syst scales to be 3x smaller
Projected $10^7$ trapped atoms $\rightarrow 0.1\%$ statistics/day
FrPNC: Weak N-N from nuclear anapole moment

U. Maryland, San Luis Potosi, William and Mary

Parity-violating E1 hyperfine transition

Statistically significant signal very quickly: must beat down systematics of the hyperfine M1

50 µm-sized cloud of Rb atoms 35 in:

a) cigar-shaped rotating-beam dipole trap;
b) add a 1D blue detuned standing wave to better confine the atoms.
RF-shielded, T controlled room, LEBT
FrPNC status and 5-year reach
TRIUMF demonstrated yield will let the whole envisioned PNC program go forward

- Maryland has DOE support for an anapole experiment and RF-shielded enclosure here. Trapping technology to hold atoms demonstrated, pursuing a Rb anapole. Orozco sabbatical at TRIUMF fall 2011.
- Manitoba has NSERC support for M1-Stark interference in Rb, 1st step toward Stark-PNC interference for electron-quark weak coupling

U. Maryland dual traps

P303 A=225 implantation for $^{221}$Fr