

Towards parity non conservation measurements in francium

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June 14th, SSP 2018



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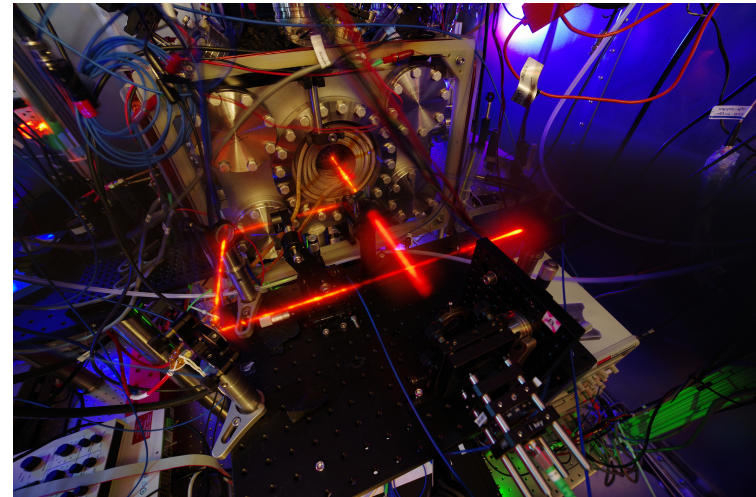
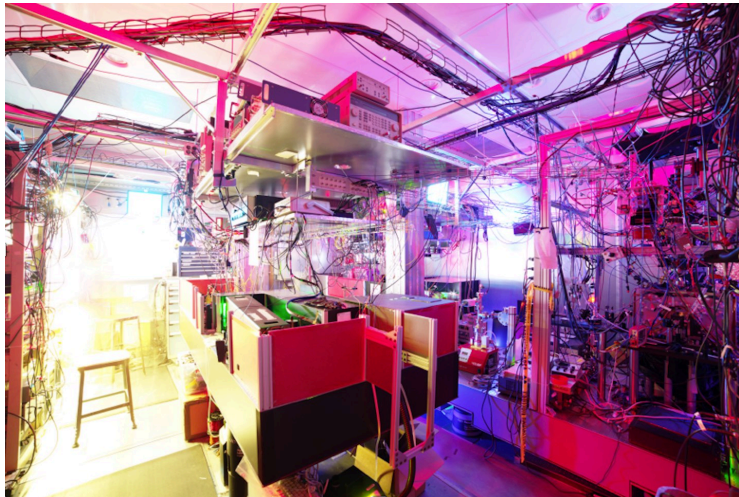


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APNC

- Study parity violation effects in neutral francium.
- Atomic physics experiment, studying electronic transitions.

- Test SM at low energies.
- Search for extra bosons.
- Weak interaction in nucleus.

Nuclear spin **independent**:

Coherent over all nucleons.

Nuclear spin **dependent** :

Interactions with valance nucleons. Main contribution from anapole moment of heavy nuclei.

The experiment

- Francium $Z=87$ (Heaviest alkali).
- APNC effect 18 times larger than Cs.
- Atomic structure theory same level as Cs. Good experiment and good theory
 \Rightarrow good test
- We use techniques of laser cooling and trapping for neutral atom to prepare the sample of atoms.

Tl, Pb, Bi, Yb, Dy,
Ra⁺, Ba⁺

Two approaches:

- Optical
- Microwave

V. Dzuba, V. Flambaum, O. Suhkov Phys. Rev A, 51 (1995) 3454
M. Safronova, W. Johnson Phys. Rev. A 62 022112(2000)
C. S wood et al. Science 275 (1997) 1759

The experiment

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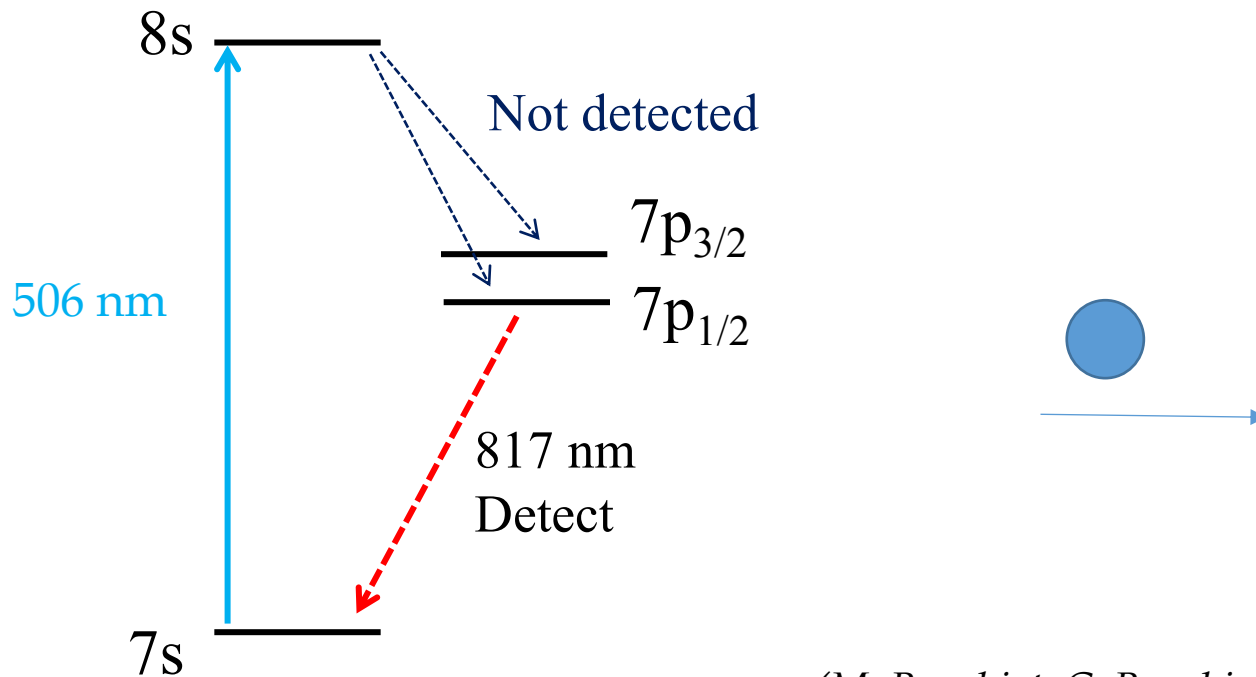
Two approaches:

- Optical
- Microwave

Spectroscopy of 7s-8s

The experiment

- Electric dipole forbidden.
- Small transition rate due to PNC effects ($\approx 10^{-20}$ of allowed).
- Use Stark Interference technique.

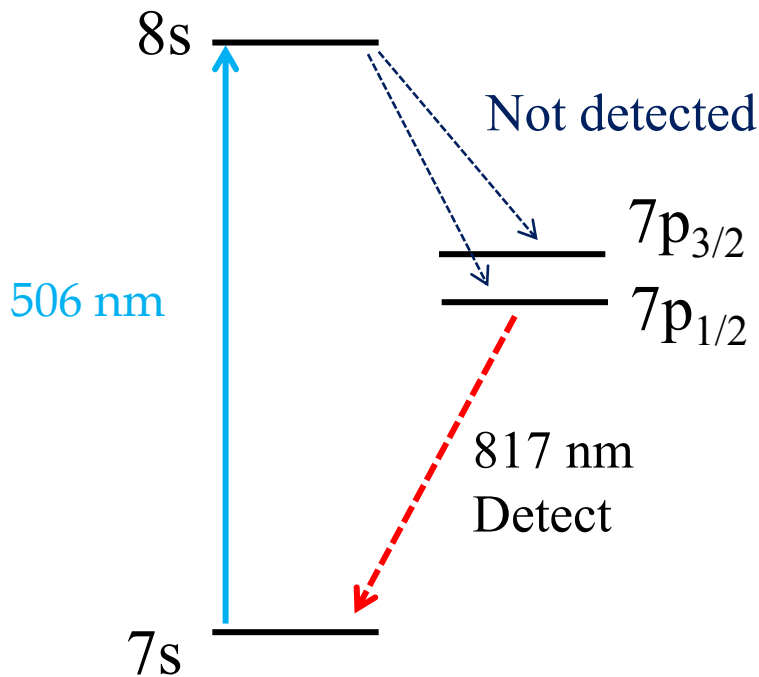


(M. Bouchiat, C. Bouchiat *J. Phys. (Paris)* 36 (1975), 493)

The experiment

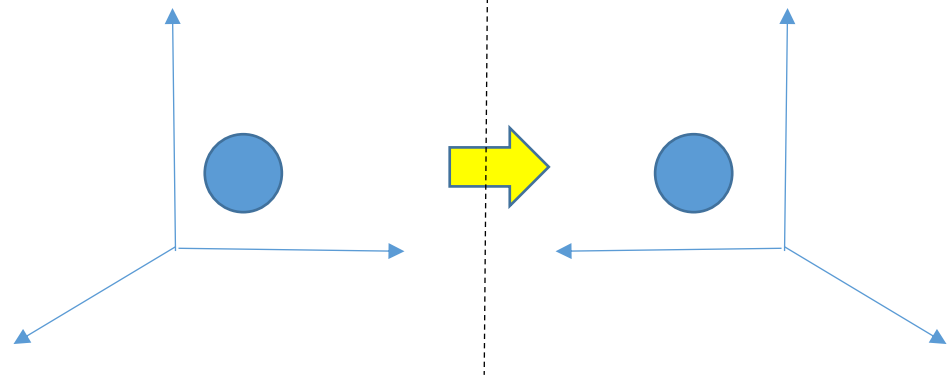
- Electric dipole forbidden.
- Small transition rate due to PNC effects ($\approx 10^{-20}$ of allowed).
- Use Stark Interference technique.

$$R \propto |A_{\text{stark}} + A_{\text{PNC}}|^2 \\ \approx (A_{\text{stark}})^2 \pm 2\text{Re}(A_{\text{stark}}A_{\text{PNC}}^*)$$



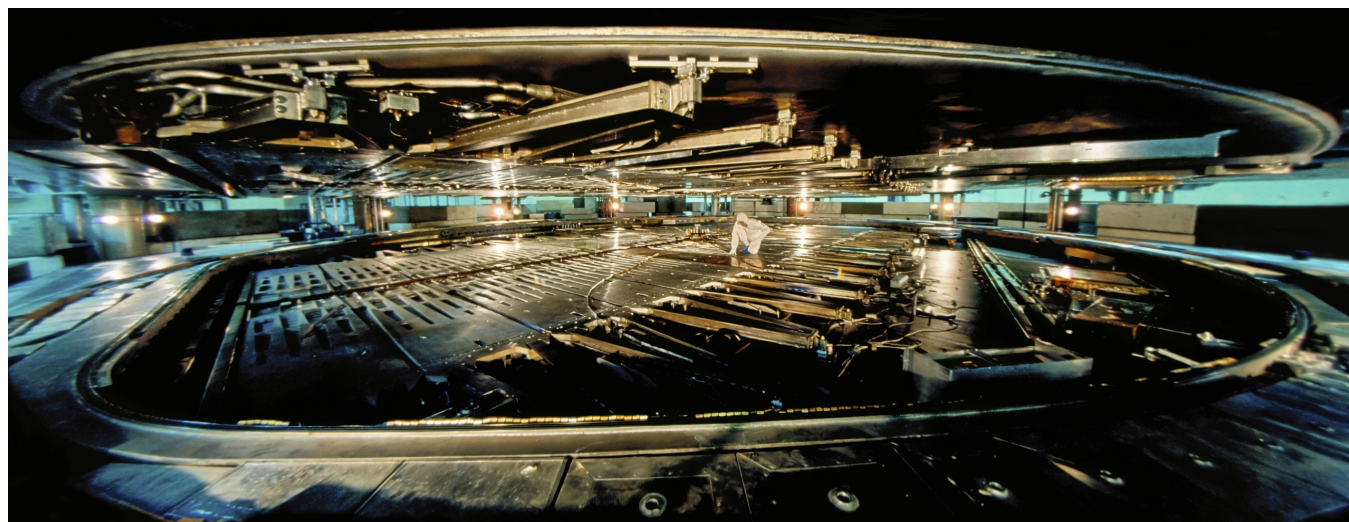
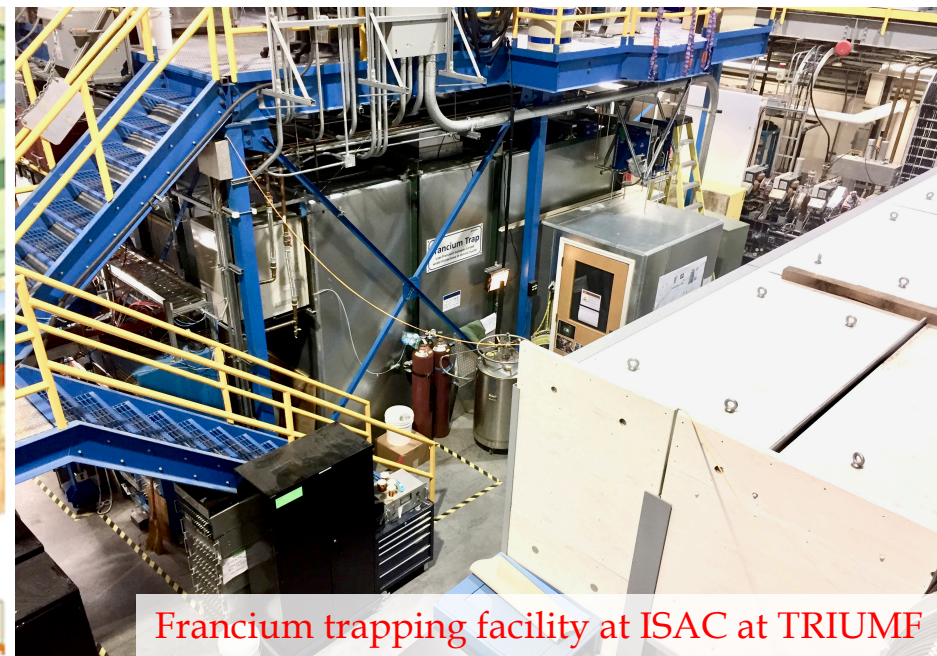
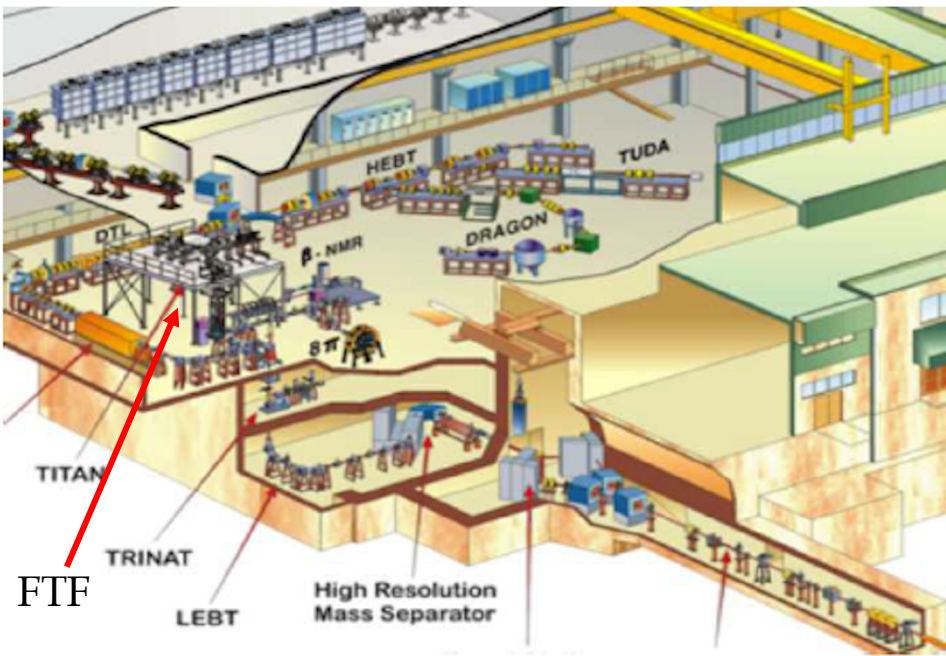
Recipe:

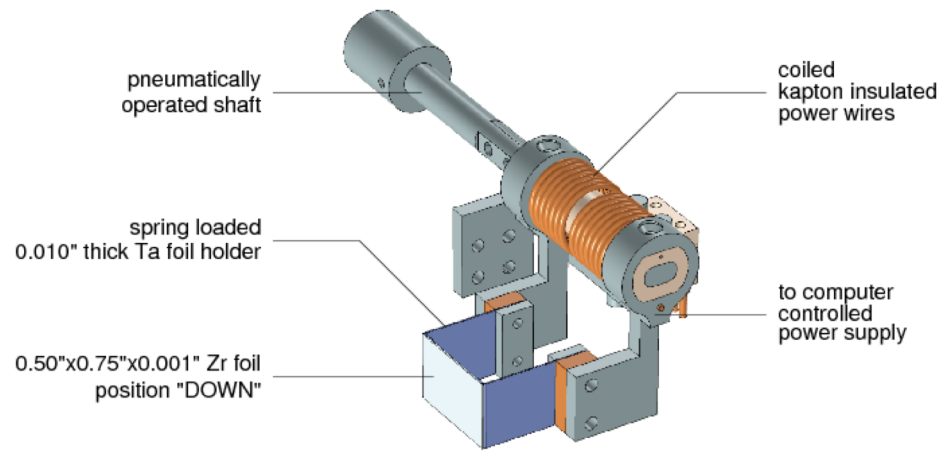
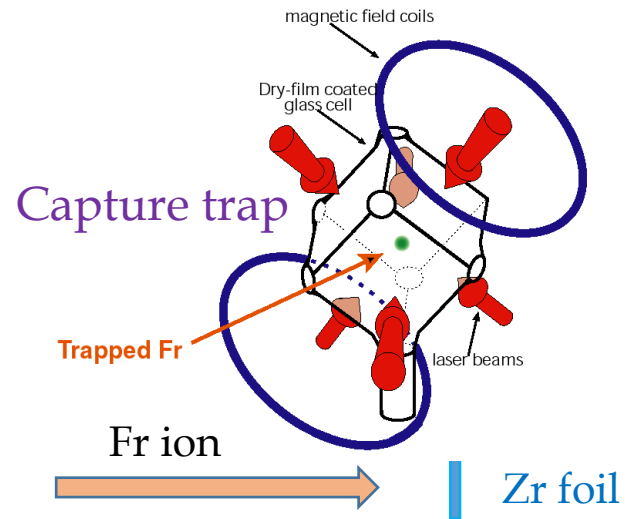
- Define coordinate.
 - E field
 - B field
 - Laser direction
 - Put atom
 - Measure rate.
- Reverse coordinate.
 - Measure rate.



Modulation on a constant background

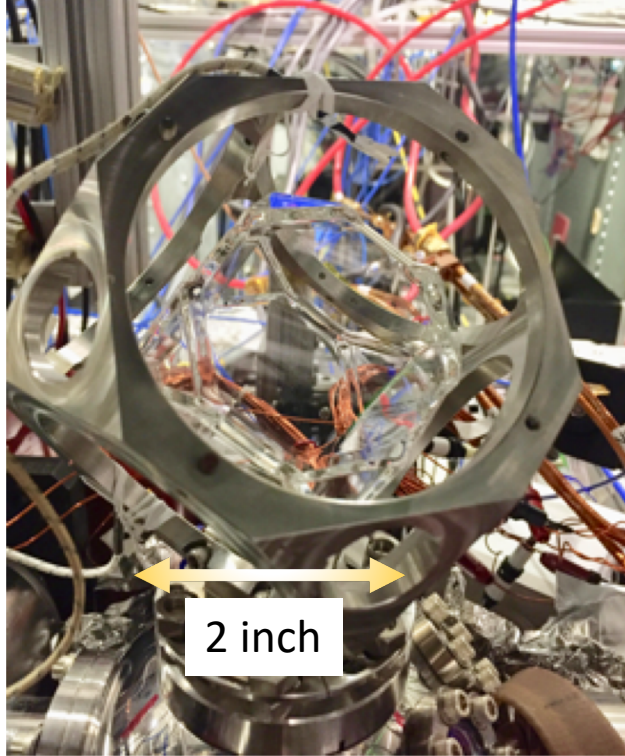
Fr has no stable isotope → experiment at TRIUMF
500 MeV proton beam, UC_x target, up-to 2×10^9 /s.



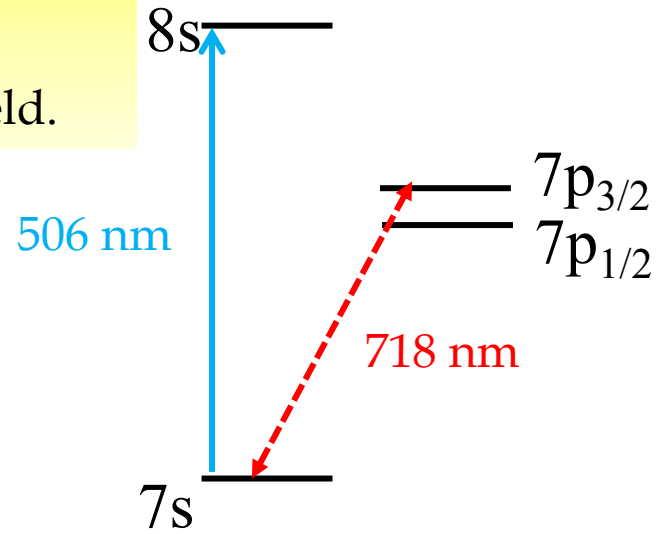


Neutralizer:

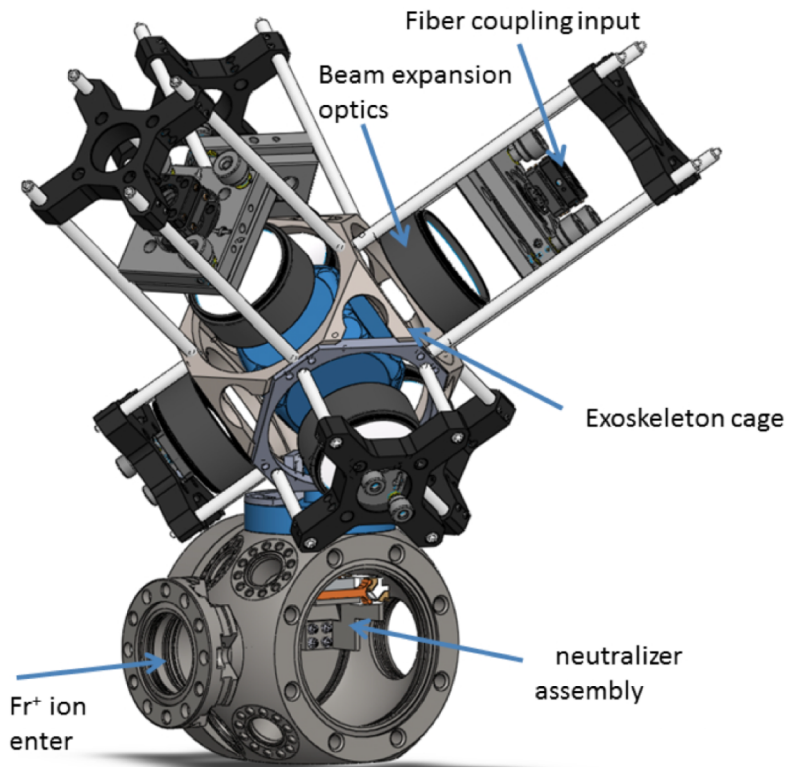
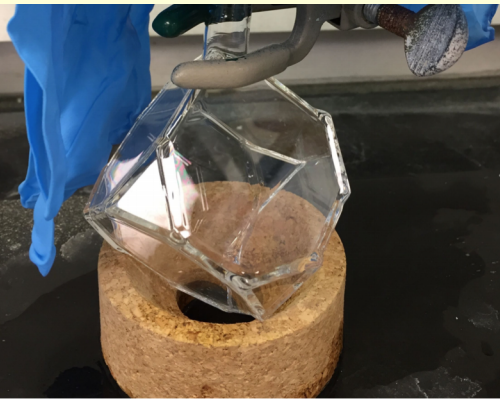
- ✓ Zr, work function 4.0 eV, mechanically strong, ionization potential of Fr 4.1eV.
- ✓ Up-to 30% release, 800°C, 500,000 cycles.

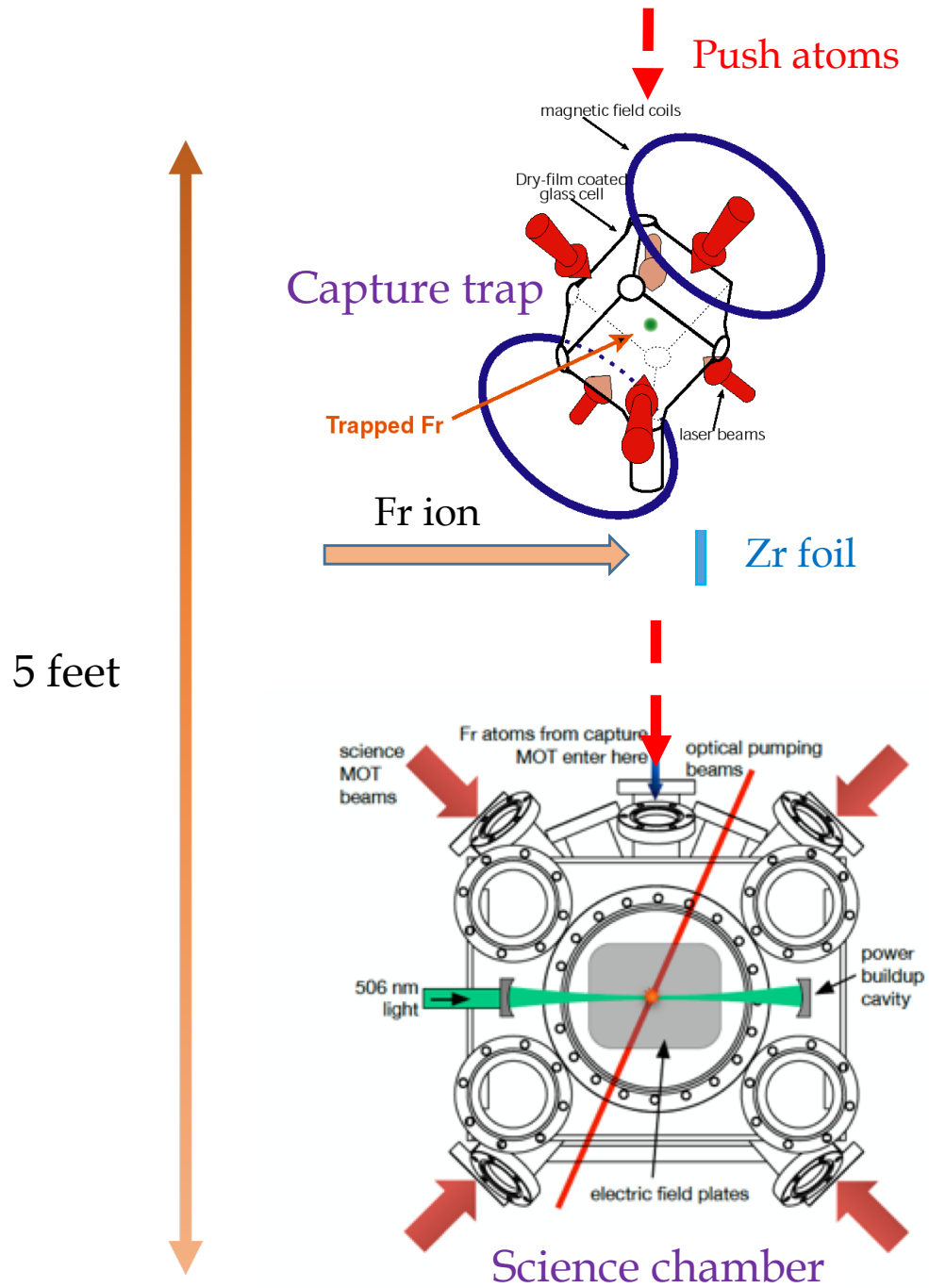


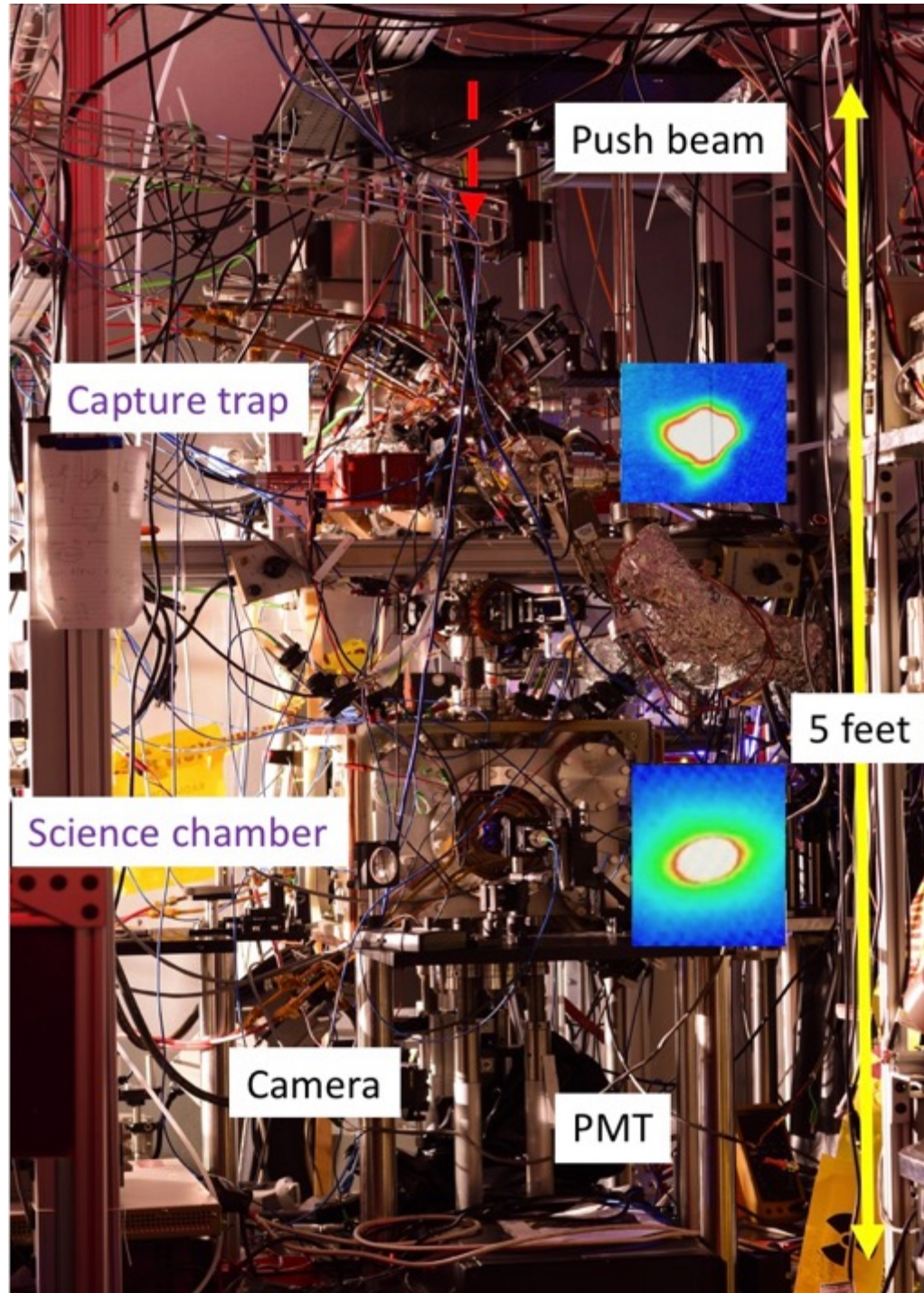
Trap:
 ✓ Two lasers.
 ✓ Quadrupole B field.



✓ New coating procedure.
 ✓ December 2017, short lived Rb.
 ✓ Works well.



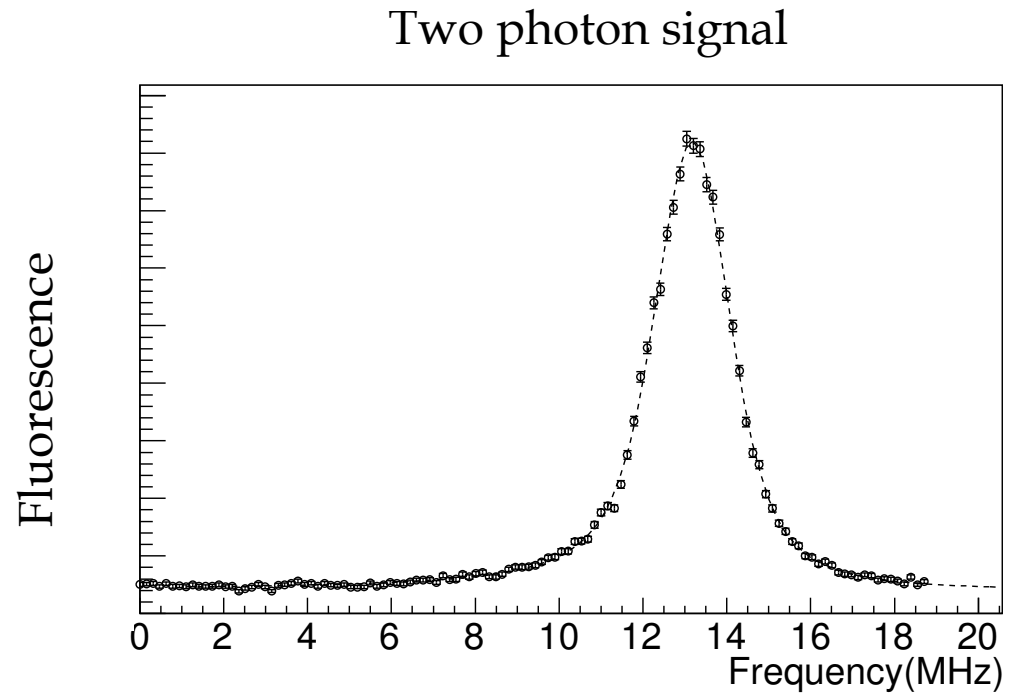
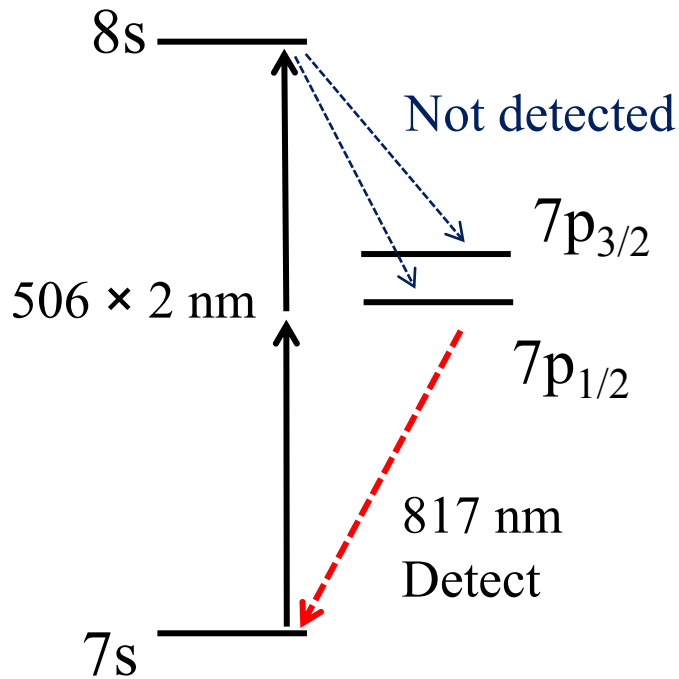




Tests with Rb

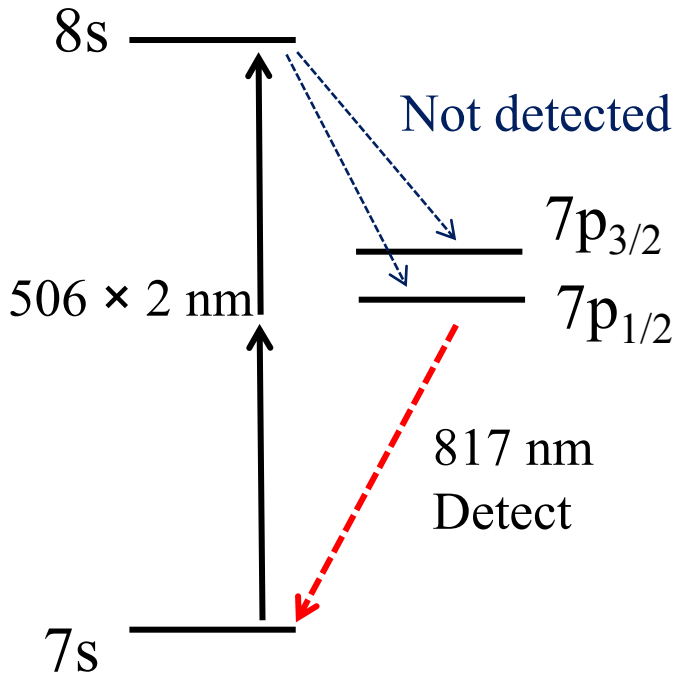
Most recent result

- Observed for the first time 7s-8s transition using two photon spectroscopy in ^{208}Fr , ^{209}Fr , ^{210}Fr , ^{211}Fr , ^{213}Fr . Radioactive lifetime ($T_{1/2}$) from **50 s to 192 s**.
- Isotope shifts.

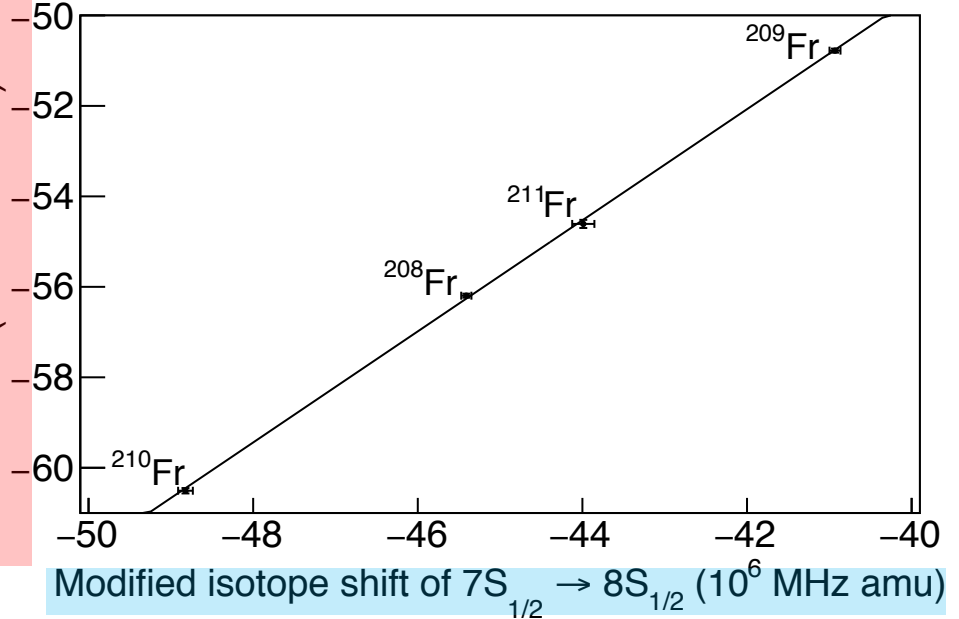


King plot

Most recent result



Modified isotope shift of
D1 line (10^6 MHz amu)



$$\left(\frac{M_A M_{A'}}{M_A - M_{A'}} \right) \delta\vartheta_{IS,D1} = (N_{D1} + S_{D1}) - (N_{SS} + S_{SS}) \frac{F_{D1}}{F_{SS}} + \frac{F_{D1}}{F_{SS}} \left(\frac{M_A M_{A'}}{M_A - M_{A'}} \right) \delta\vartheta_{IS,SS}$$

Slope $\propto (\Delta\Psi(0)^2)_{D1} / (\Delta\Psi(0)^2)_{SS}$

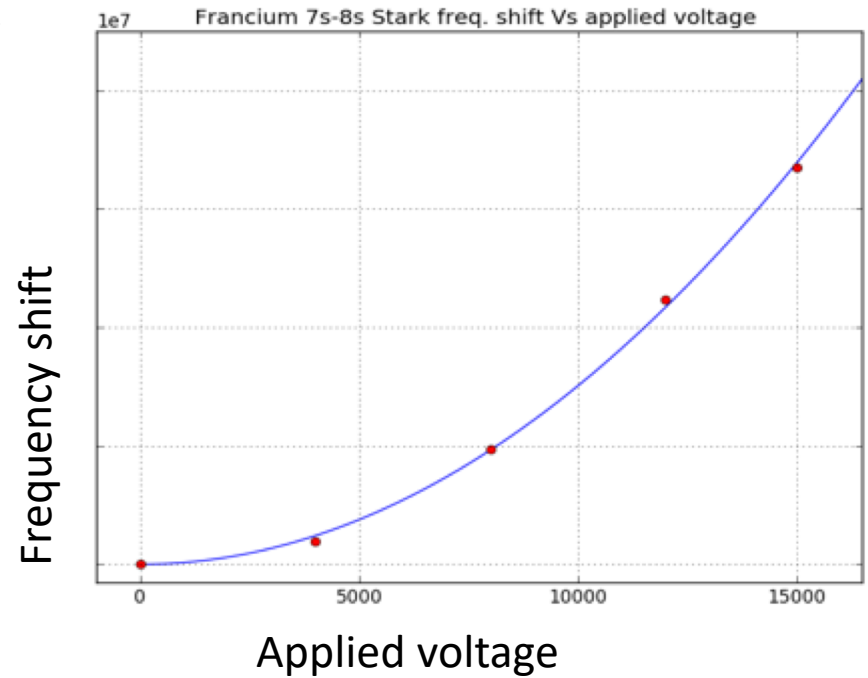
1.228 ± 0.019 (experiment)

1.234 ± 0.010 (*ab. initio* theory)

Phys. Rev. A 97, 042507 (2018) M. Kalita et al. with theory by V. Dzuba, V. Flambaum, M. Safronova

Most recent observation

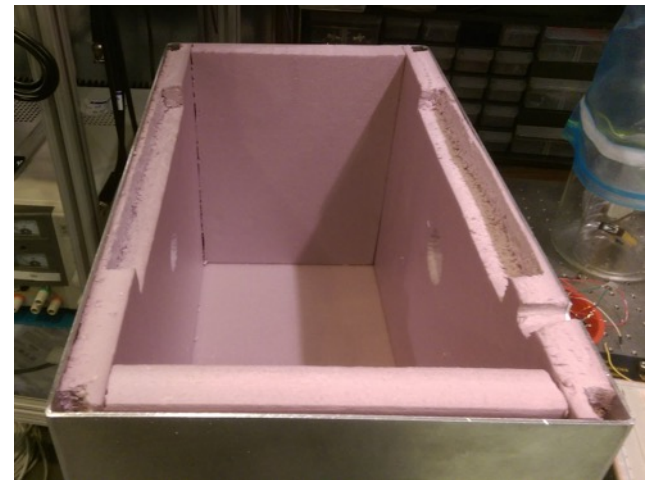
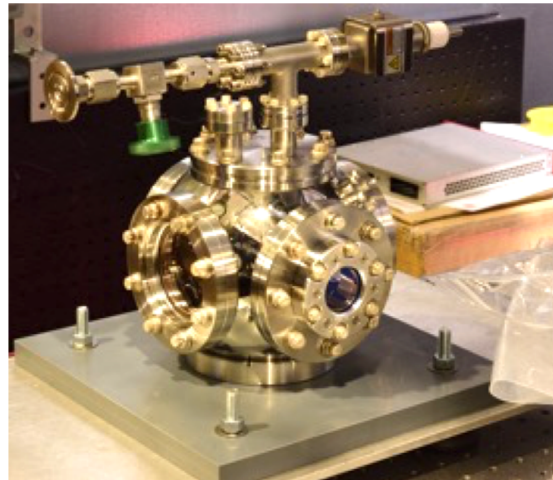
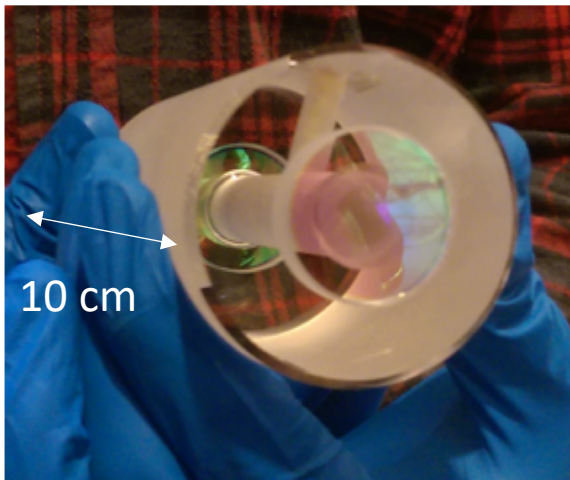
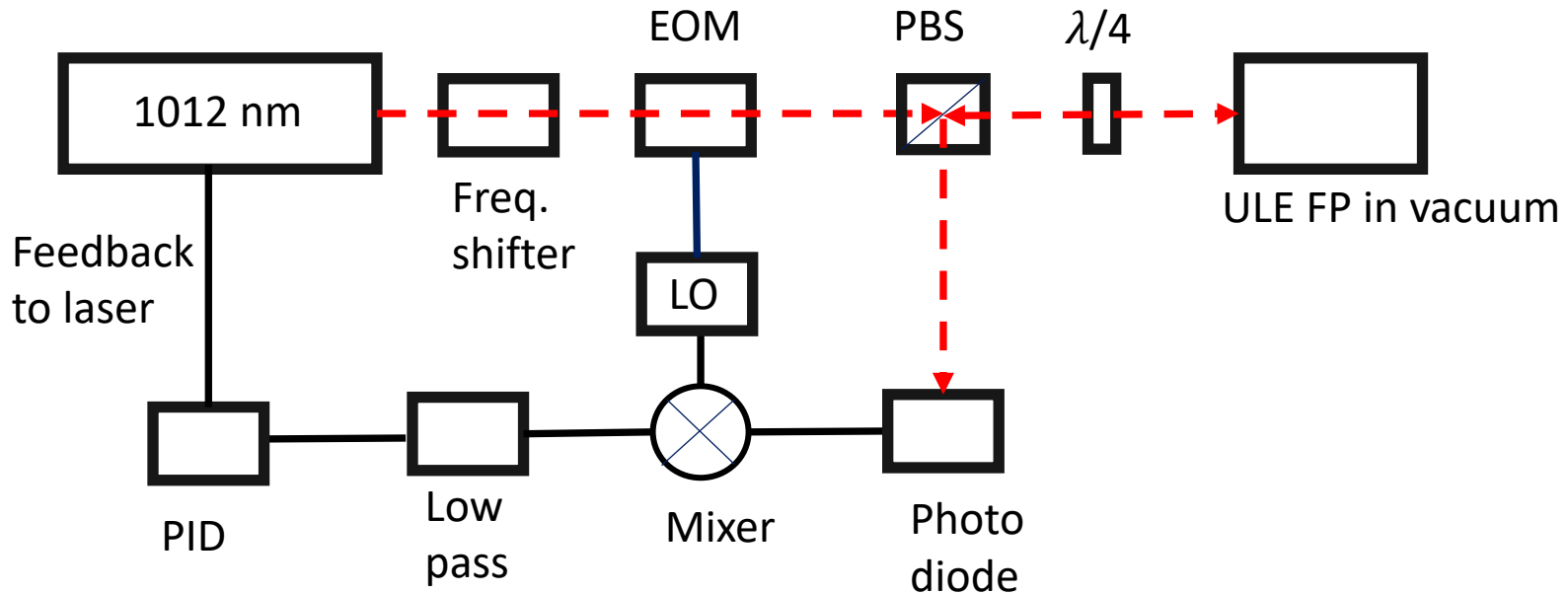
- DC Stark shift of the 7s-8s transition.
- Test steel electrodes with holes.



- Interim Setup not suitable for precision measurement.

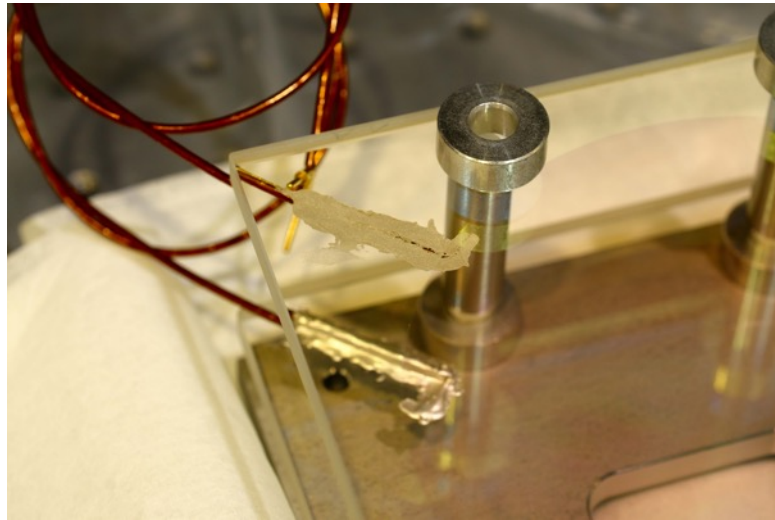
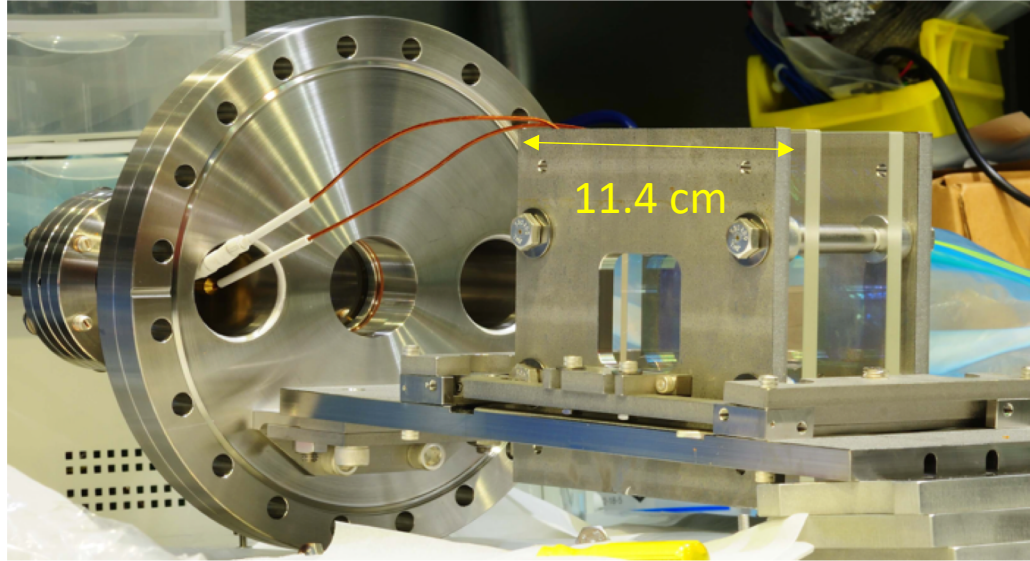
System upgrade

- Laser lock for 506 nm based on ULE Fabry Perot cavity and PDH method.
- ✓ Installed.



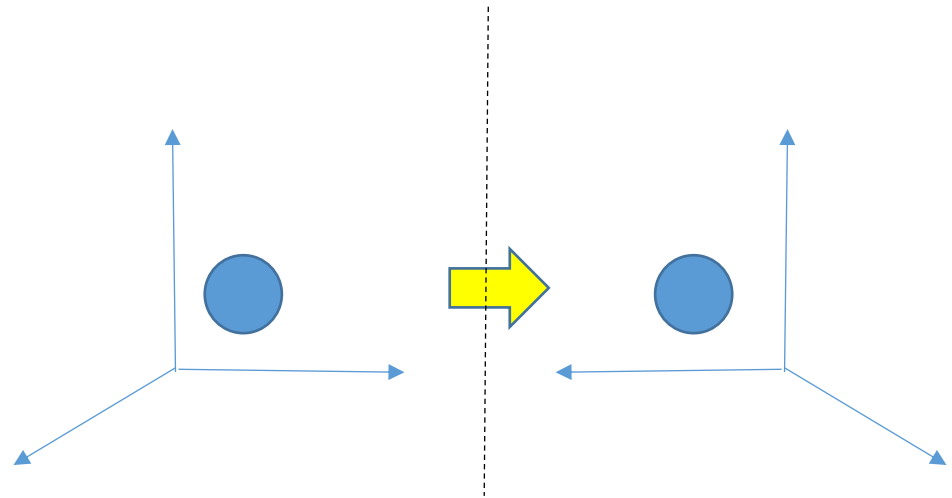
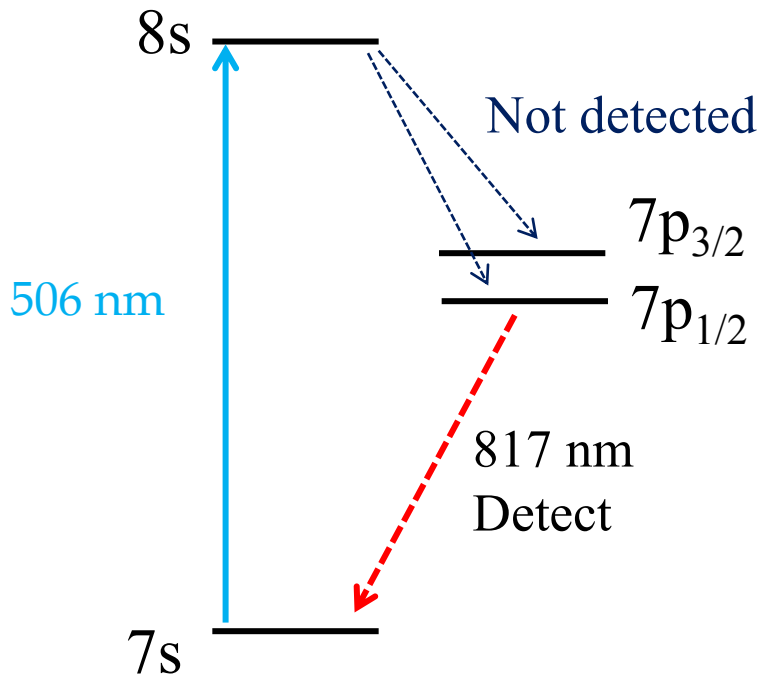
System upgrade

- Transparent Electric field plates with ITO coating.
- ✓ Installed.



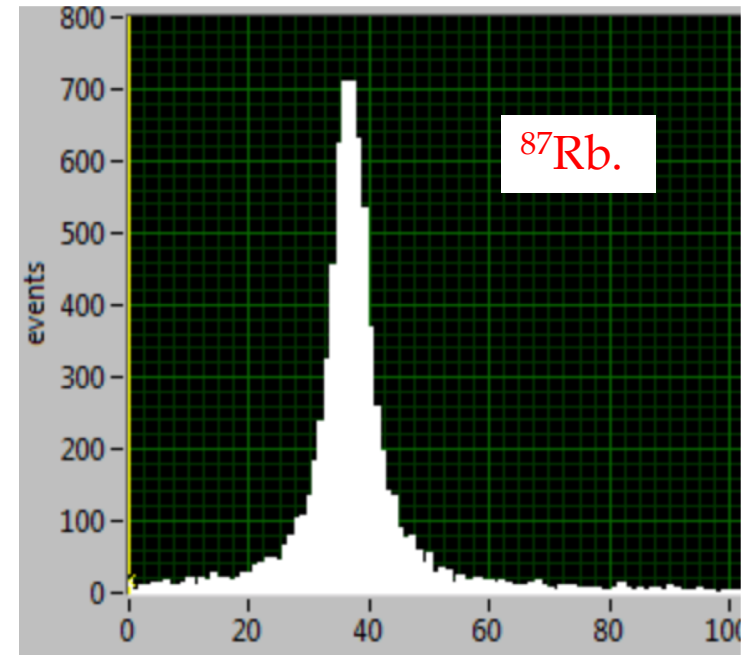
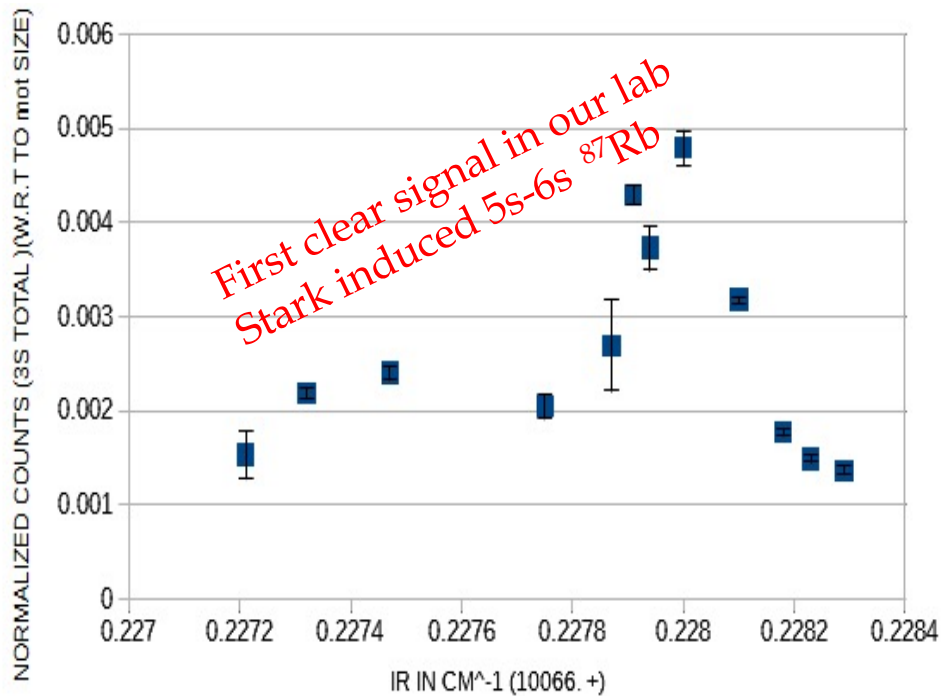
Towards observation of Stark induced 7s8s

- Laser lock for 506 nm with ULE reference. ✓
- Transparent Electric field plates with ITO coating. ✓



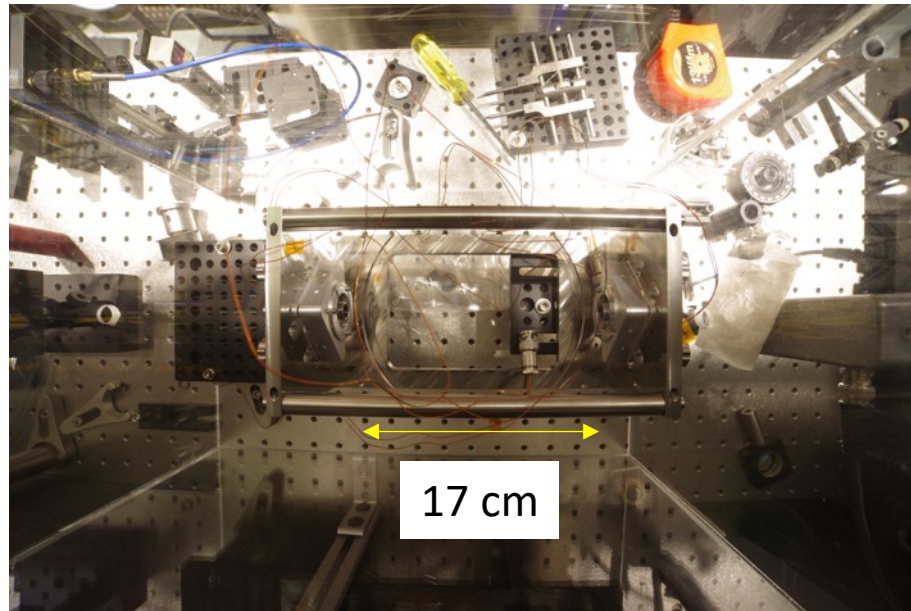
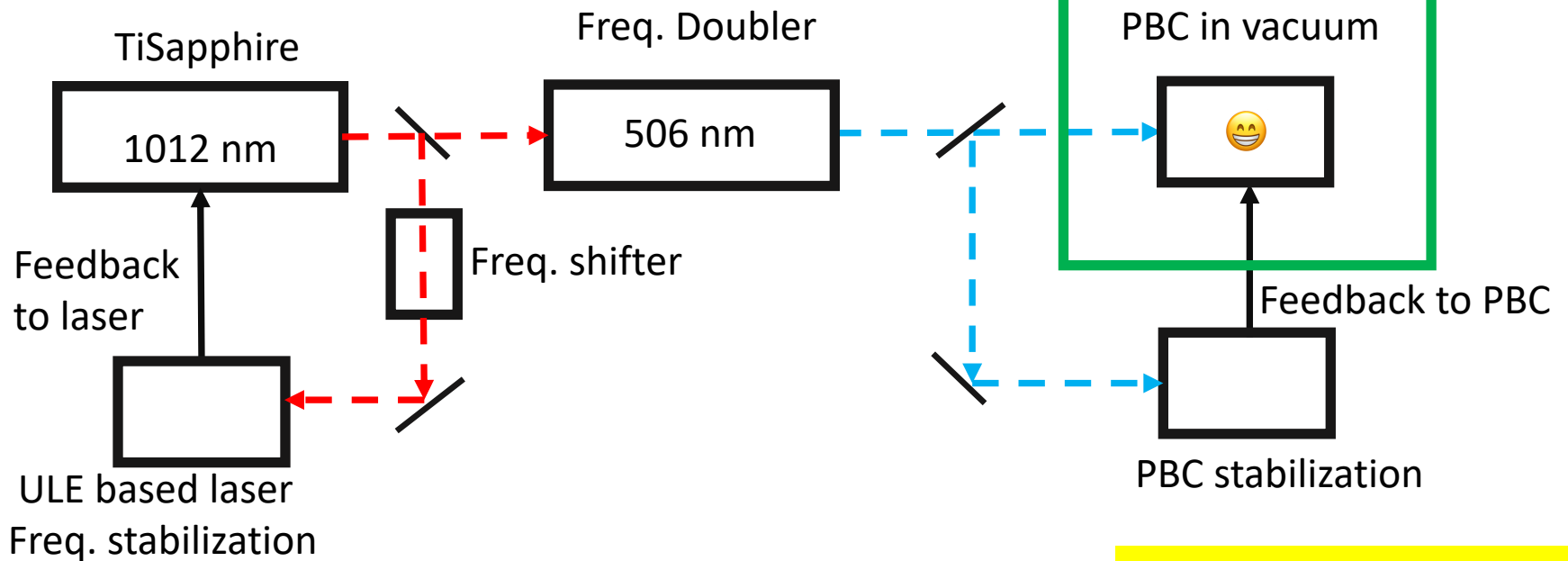
Current work: with Rb

- **Stark induced 5s-6s transition in ^{87}Rb .**



- Preparing for a precision DC Stark shift measurement in Rb.

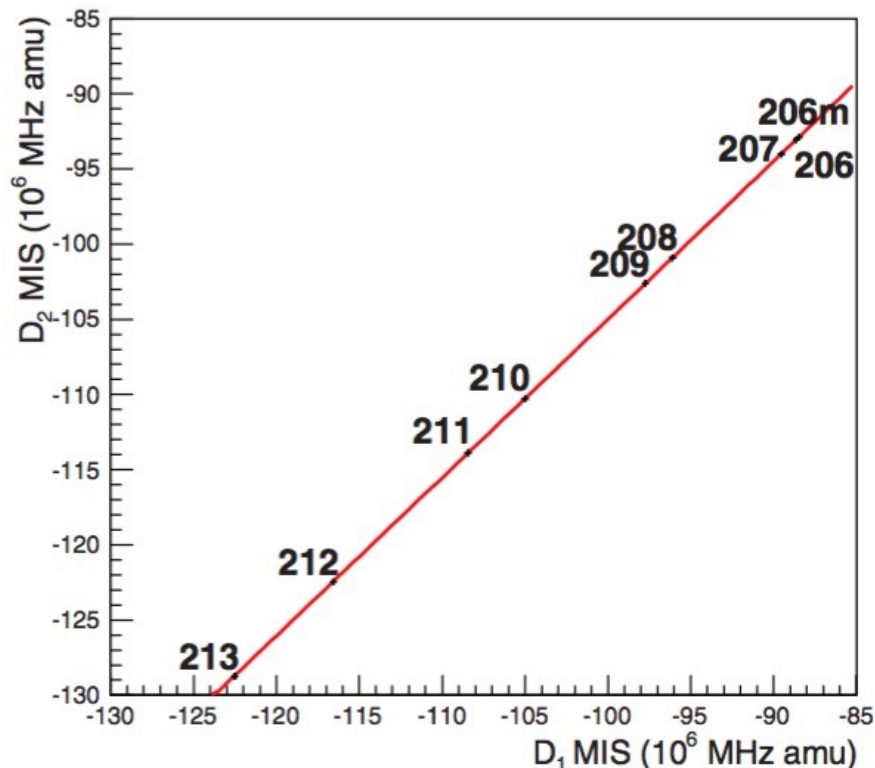
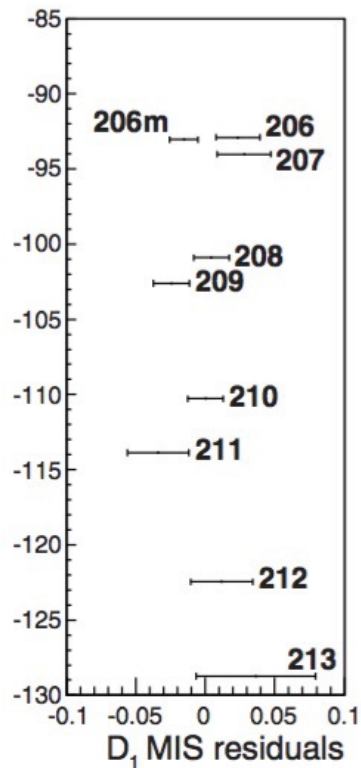
Current work : 506/493 nm light



- ✓ Lock primary light to ULE
- ✓ Get doubled light
- Lock PBC to doubled light

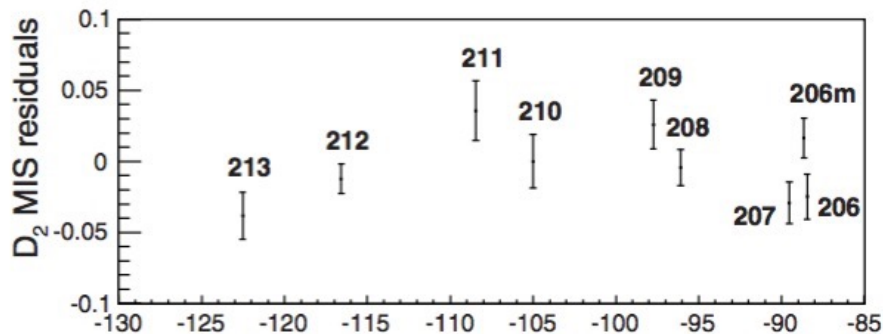
D1 isotope shifts in a string of light francium isotopes

Collister et al., Phys Rev A 90, 052502 (2014) and A 92, 019902(E) (2015)



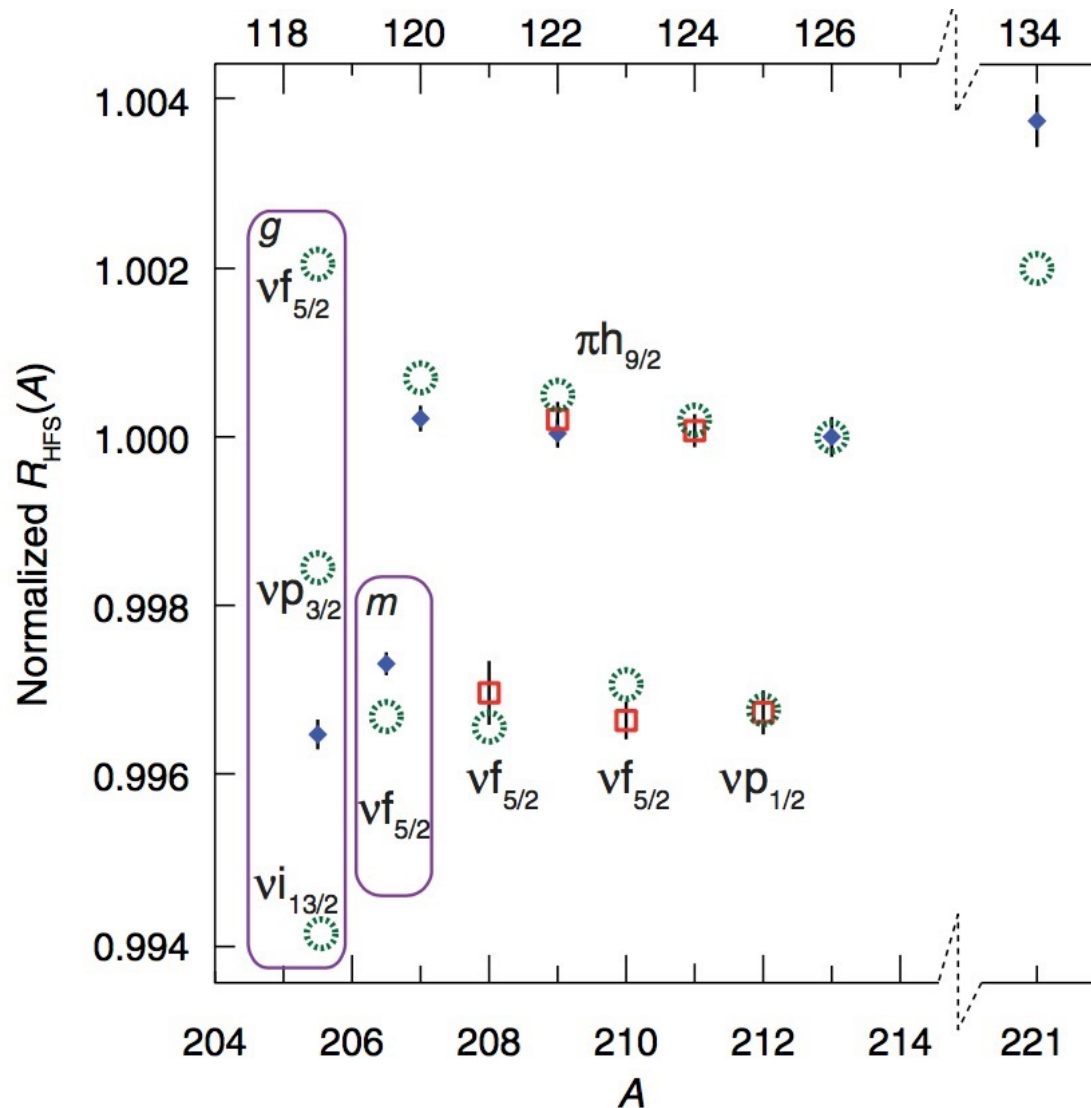
Benchmarks state-of-the-art atomic theory

Fit Results
$\chi^2 / \text{ndf} = 7.00094 / 7$
slope = 1.0521 ± 0.0008
int = 194 ± 78 GHz amu



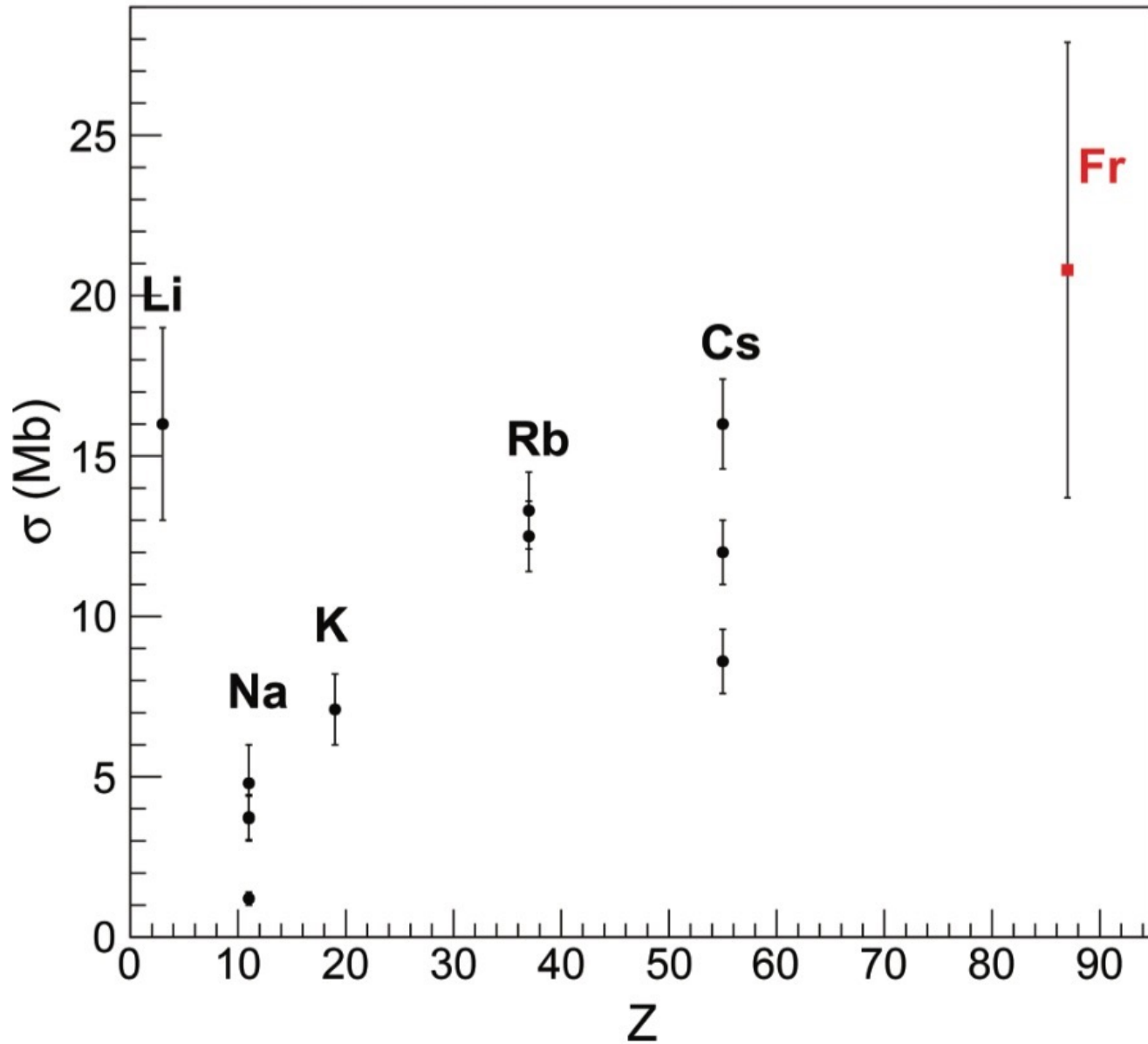
Hyperfine anomaly in light francium isotopes

Zhang et al., Phys Rev Lett 115, 042501 (2015)



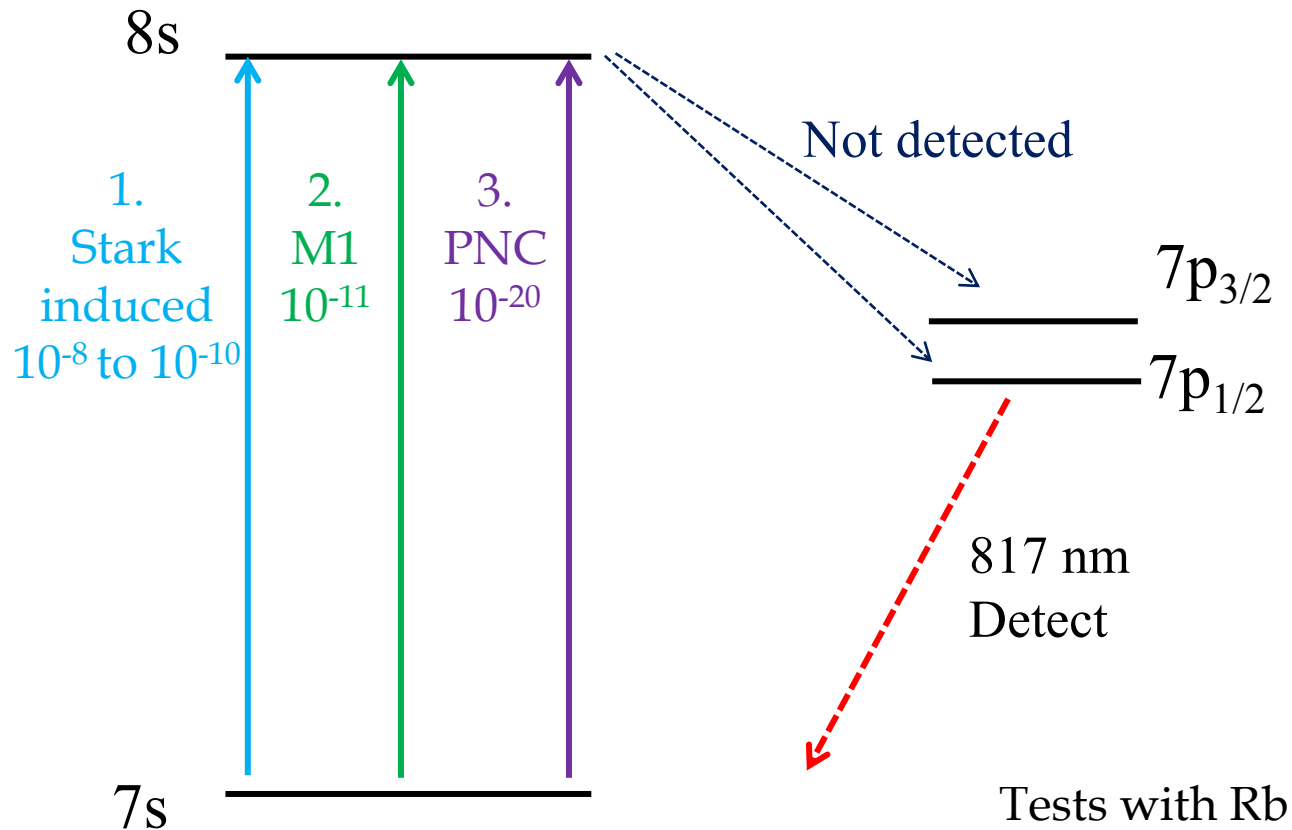
Reconfirms that in terms of nuclear structure, 208-213 are “good” nuclei for APNC/anapoles

Francium $7p_{3/2}$ photoionization – Collister et al. 2017, Can. J. Phys.



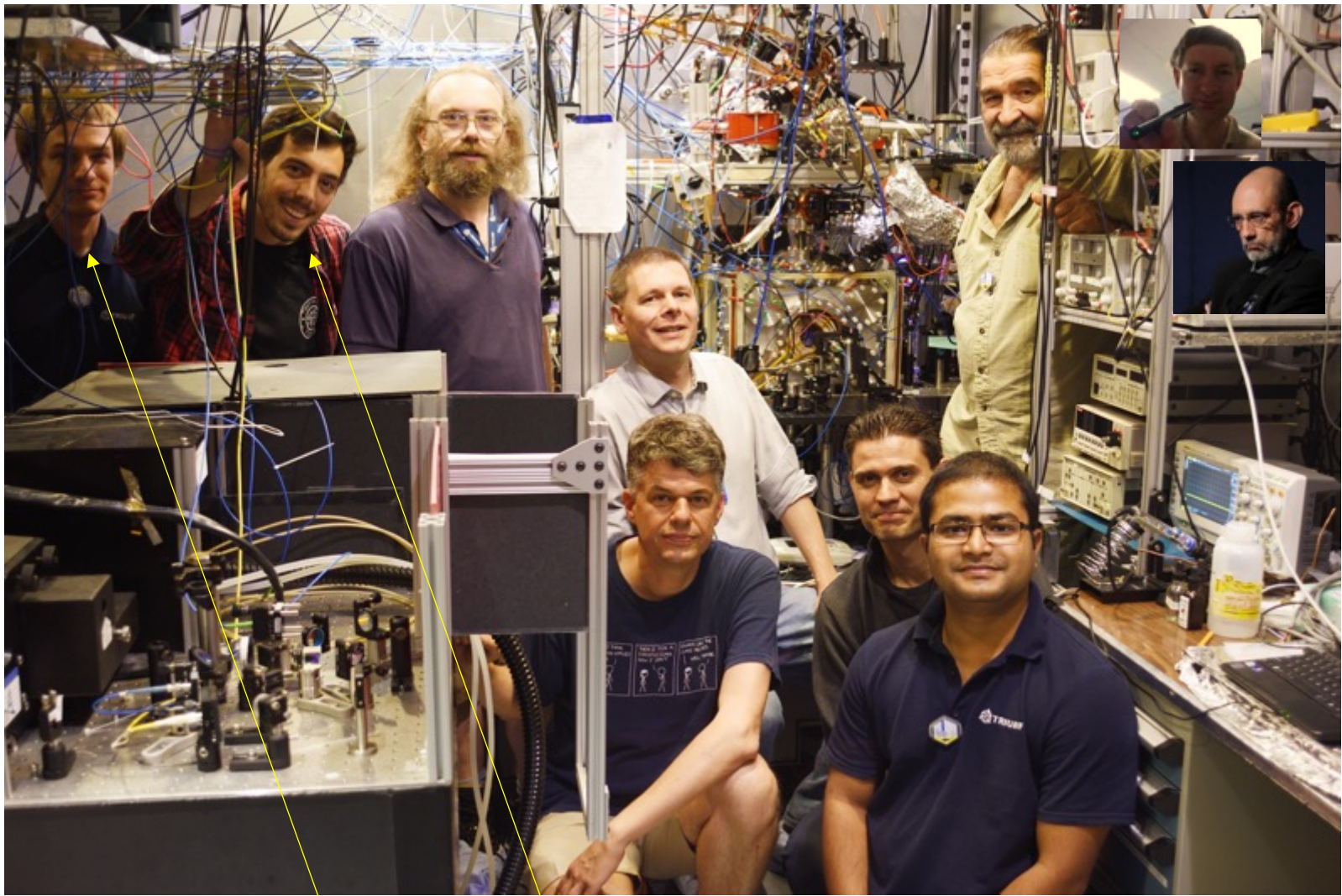
Things to do before attempting Stark interference:

- Observe Stark induced 7s-8s.
- Do a precision DC Stark shift measurement.
- Measure $M1/\beta$.

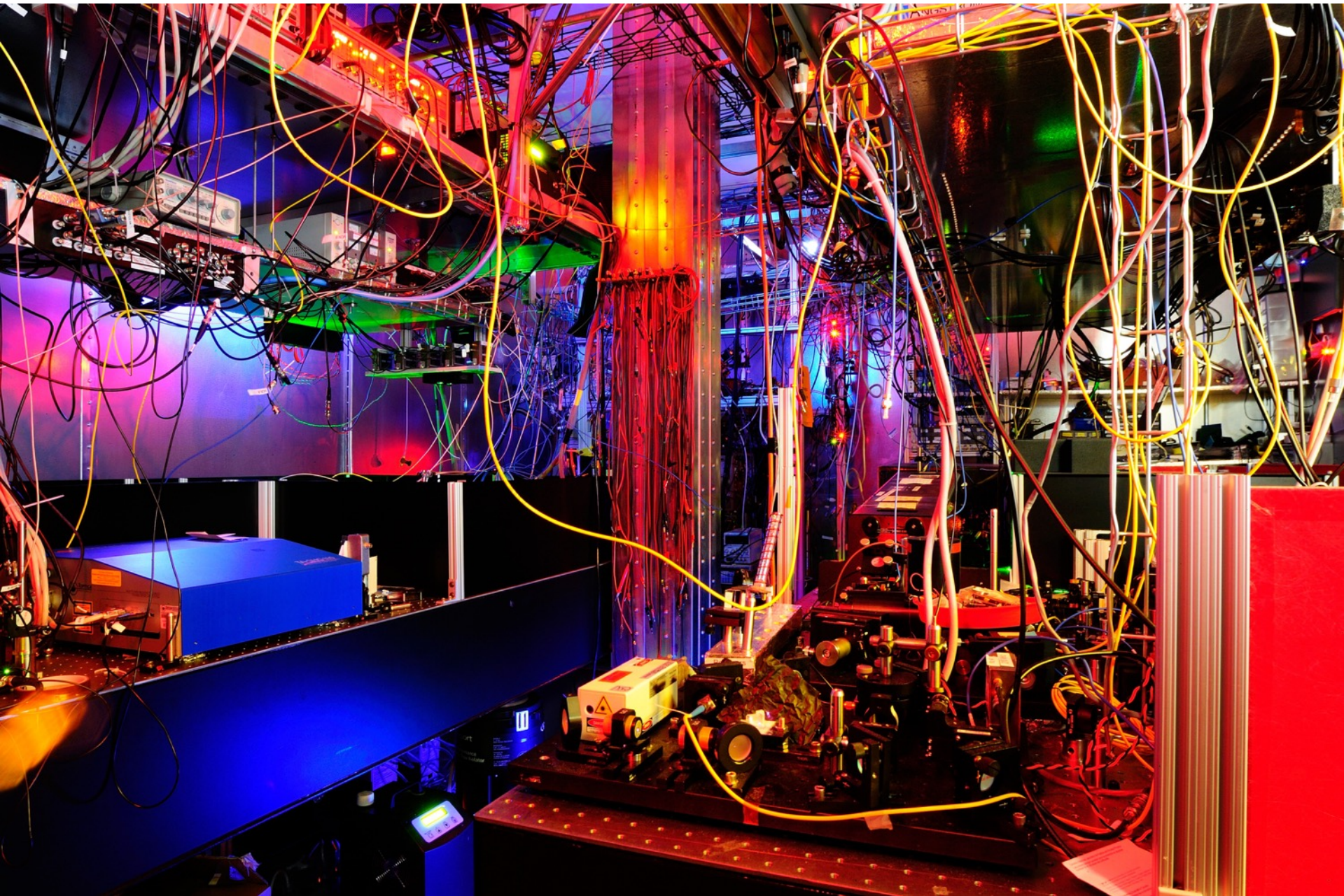


Conclusion:

- Several francium isotopes have been trapped at the Francium Trapping Facility at TRIUMF.
- **The 7s-8s transition has been observed in several isotopes using two photon spectroscopy.**
- Towards observation of single photon Stark induced 7s-8s transition we have installed transparent electric field plates and a stable laser at 506 nm.
- Developing a vacuum compatible power build up cavity at 506 nm.
- Developing B field control system.
- Aim to observe Stark induced transition in francium and measure DC Stark effect in September 2018 beam time.

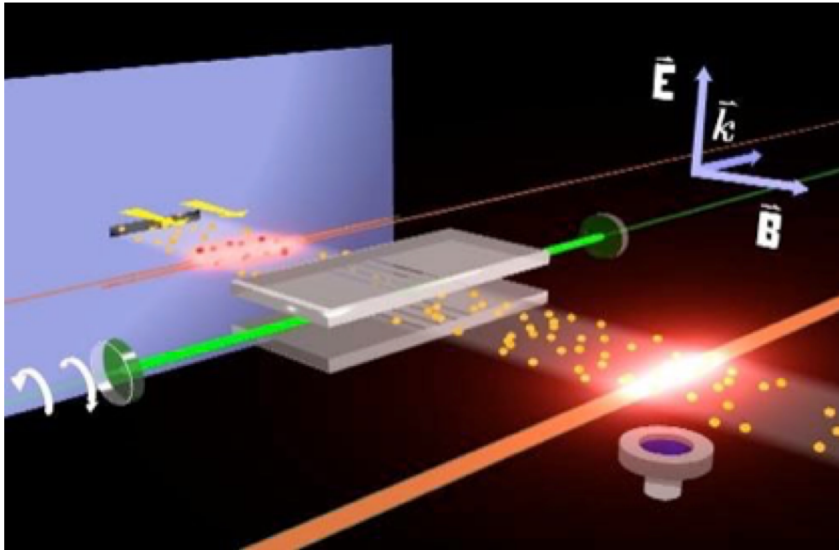


From left to right: **Michael Kossin**, **A.C. DeHart**, Matt Pearson, Seth Aubin, Gerald Gwinner, Eduardo Gomez, Mukut Kalita, Alexandre Gorelov, John Behr, Luis Orozco.
Not in the picture: **Andrew Senchuk**, **Tim Huckle** and our theory colleagues : Marianna Safronova, Vladimir Dzuba, Victor Flambaum.

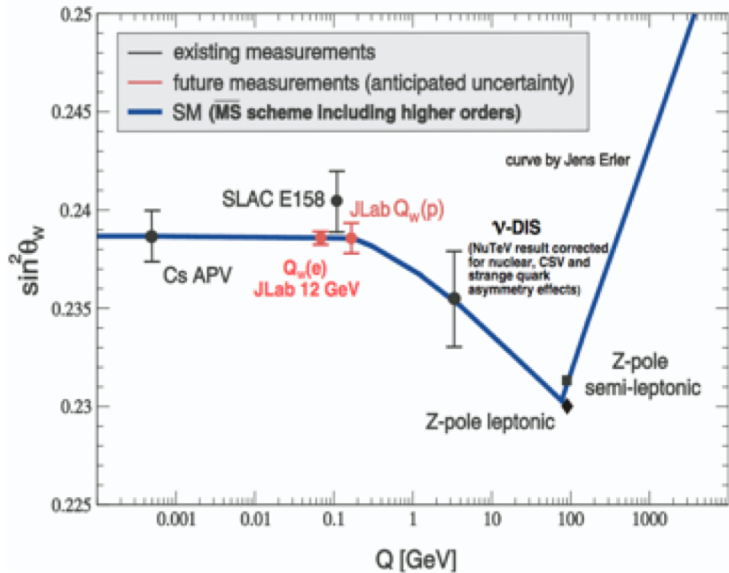


Thank You

The cesium experiment



Weak mixing angle: Running of $\sin^2\theta_w$



R.D. Carlini, AIP Conference Proceedings 1261.1 (2010)

III. RESULTS AND DISCUSSION

7s — The value of the spin-independent PNC amplitude for the 5s–6s transition in ^{87}Rb (without Breit, QED, and neutron skin corrections) is

$$|E_{\text{PNC}}| = 1.400 \times 10^{-12} ea_B(-Q_W/N). \quad (8)$$

This is in very good agreement with the value

$$|E_{\text{PNC}}| = 1.39(2) \times 10^{-12} ea_B(-Q_W/N)$$

presented in our early calculations [10].

Dye laser
540 nm

$op_{1/2}$

C. S. Wood et. al.

10.1126/science.275.5307.1759

6s —

	Isotope	Nuclear spin (<i>I</i>)	
Good experiment	208	7	d test
	209	9/2	
	210	6	
Tl, Pb, Bi, Yb	211	9/2	
	213	9/2	