Measurement of the Stark Shift of the $7s \rightarrow 8s$ Transition in Francium

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Atomic **P**arity **N**on**c**onservation in Francium

- Francium is an ideal candidate for APNC measurement.
- Understanding properties of the Stark shift will help in determining the APNC measurement.
- We performed single photon spectroscopy of the Stark induced $7s \rightarrow 8s$ transition in ^{211}Fr.
- We measured the differential scalar polarizability ($\Delta\alpha$).
- We also observed the β transition.

Theory: Stark Shift

- Energy levels of the atomic states are shifted by an amount $-\frac{1}{2}\alpha_{ns}E^2$ when in the presence of an electric field $\vec{E}$.
- α_{ns} is the scalar polarizability.
- We consider the Stark effect on the resonance transition, this is

$$-\frac{1}{2}\left(\alpha_{ns}-\alpha_{(n+1)s}\right)E^2=-\frac{1}{2}\Delta\alpha E^2$$

- $\Delta\alpha$ is the differential scalar polarizability between the ns and $(n+1)s$ states, and this is what we can measure.

Theory: Stark Induced Transition

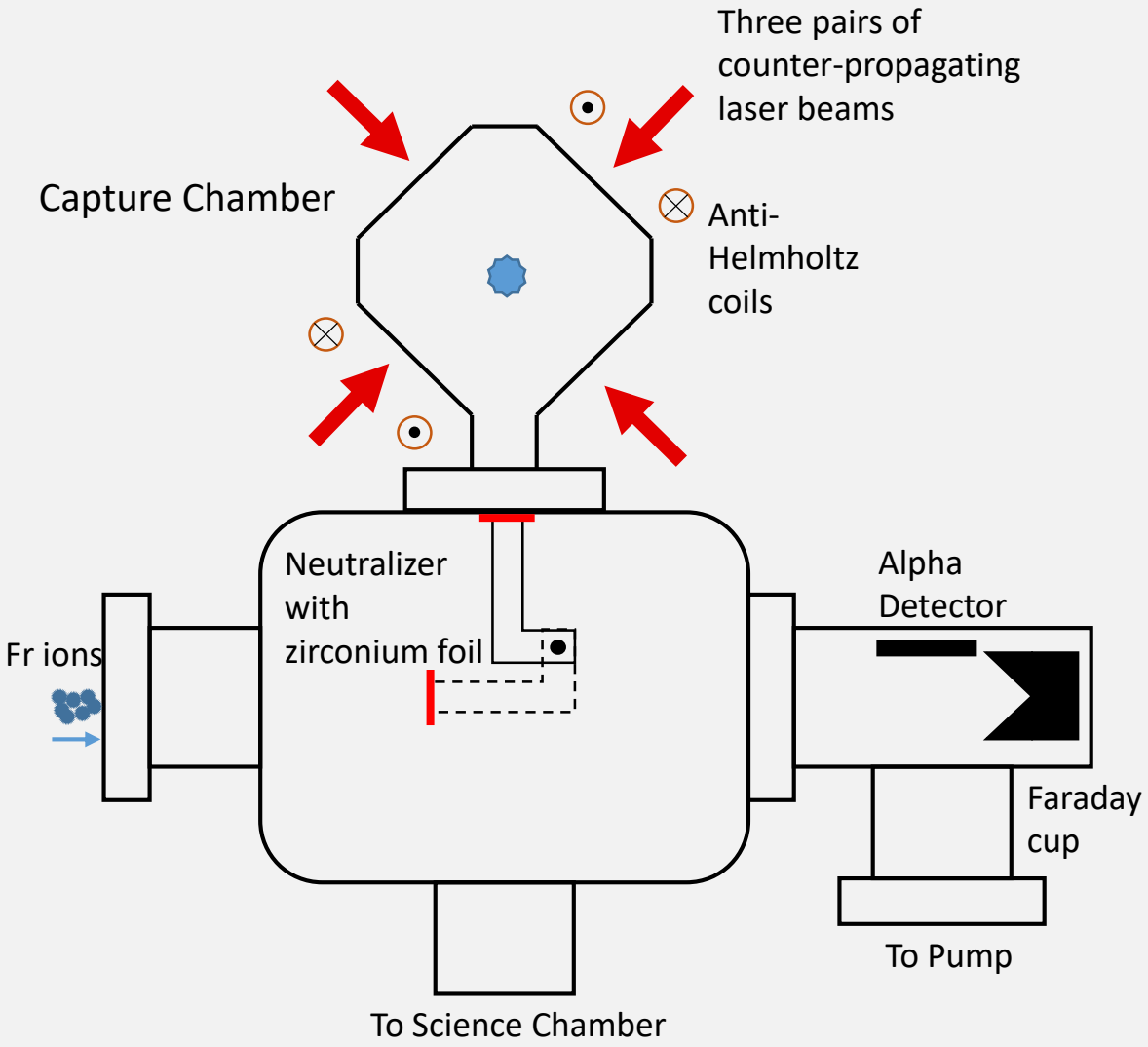
- The $7s \rightarrow 8s$ transition in francium is electric dipole forbidden.
- An electric field $\vec{E}$ will induce a small mixing of the $8s$ and $8p$ states.
- The Stark transition amplitude is expressed in terms of the total angular momentum F and F', as well as the magnetic quantum number M and M'

$$A(F, M \rightarrow F', M') = \alpha \vec{E} \cdot \vec{\epsilon} \delta_{FF'} \delta_{MM'} + i\beta \left(\vec{E} \times \vec{\epsilon}\right) \langle F'M' | \vec{\sigma} | FM \rangle$$

- α transition: $\Delta F = 0, \Delta M = 0, \quad \vec{\epsilon} \parallel \vec{E}$
- β transition: $\Delta F = \pm 1, \Delta M = 0, \pm 1, \quad \vec{\epsilon} \perp \vec{E}$
- $\frac{\alpha}{\beta} \approx 5.05$ [1]

[1] M. S. Safronova, W. R. Johnson, and A. Derevianko, *Phys. Rev. A*, **60**, pp. 4476–4487, 1999.

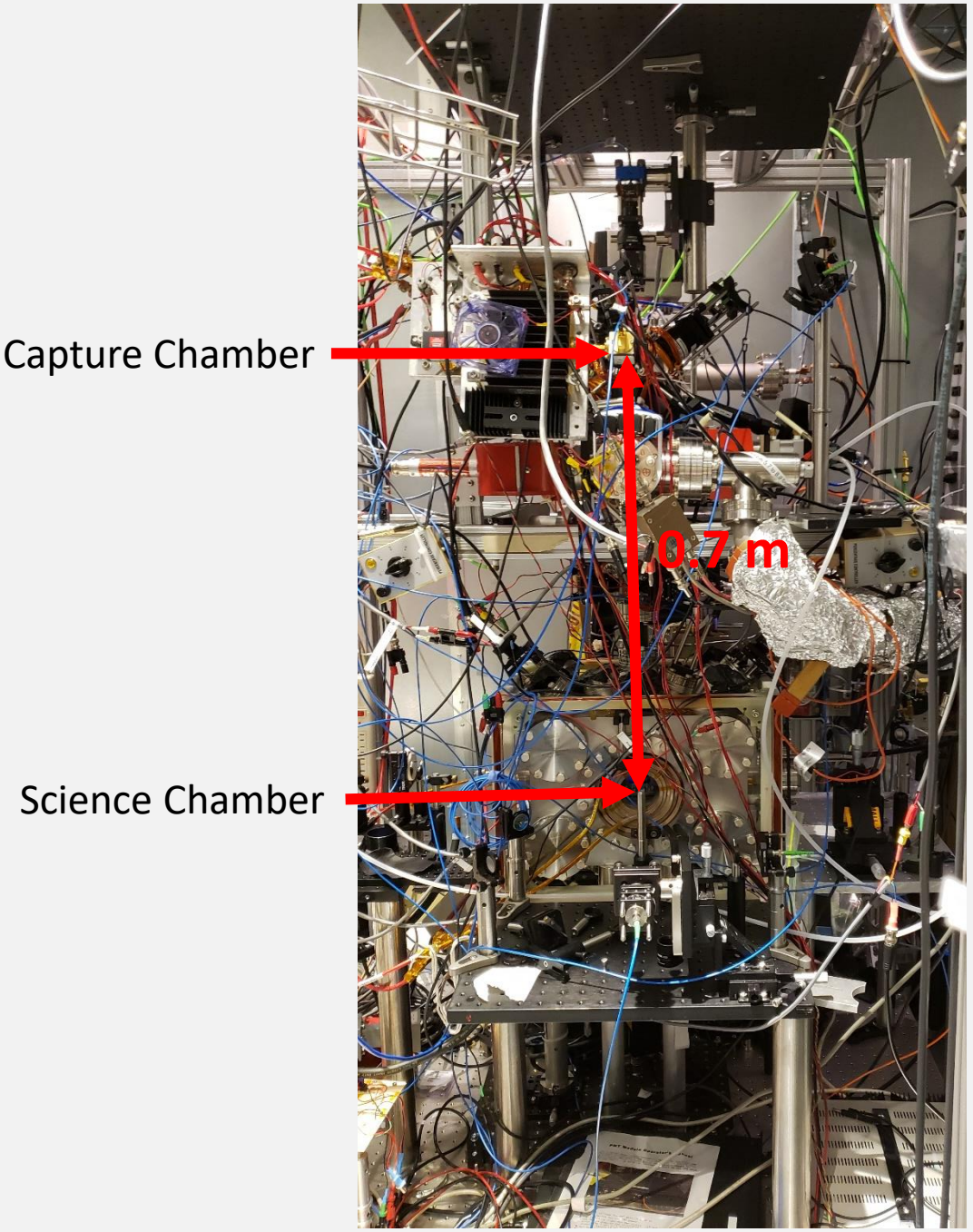
Experimental Setup



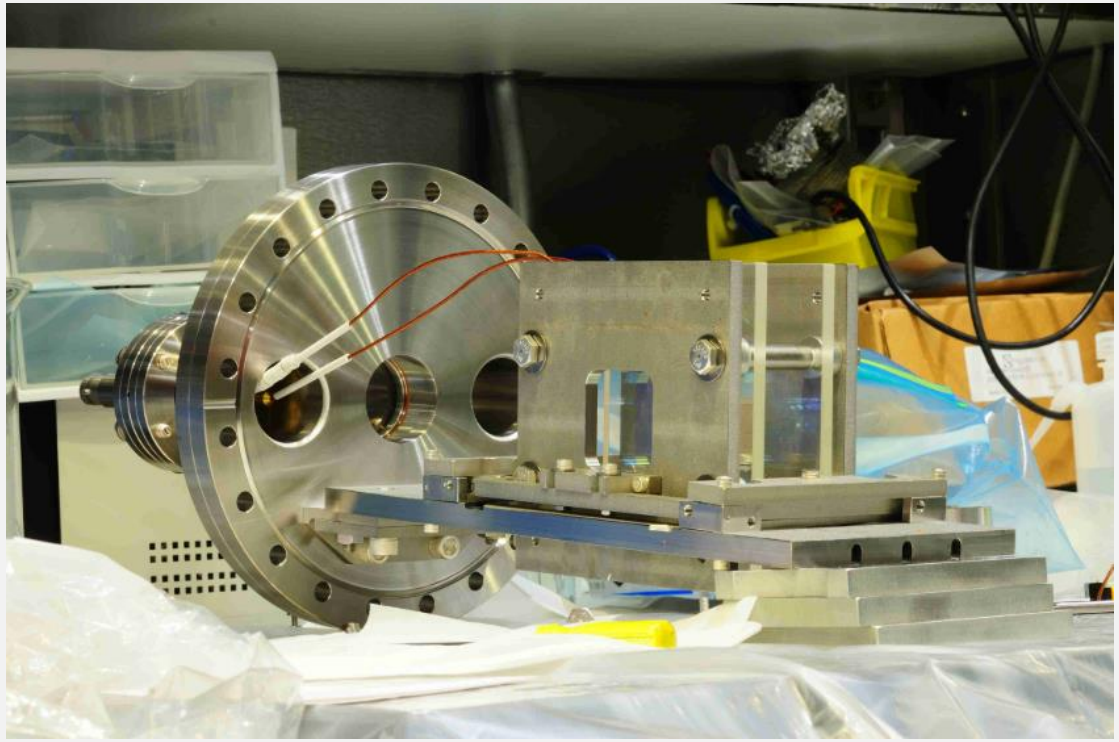
- Francium ions are produced by the Isotope Separator and Accelerator (ISAC) facility located at TRIUMF.
- Francium ions deposited on a Neutralizer
- Heat the zirconium foil, releasing neutral francium atoms
- Collected in a coated glass cell (capture chamber) using a magneto-optical trap (MOT)

Trap Transfer

- Atoms are then pushed 0.7 m down into a second chamber (Science Chamber).
- Trap atoms using another MOT
- Both MOTs share the same Ti:Sapphire lasers
- Frequency locked to a stabilized HeNe laser.
- We operate the MOTs on the D2 ($7s \rightarrow 7p_{3/2}$) line of francium



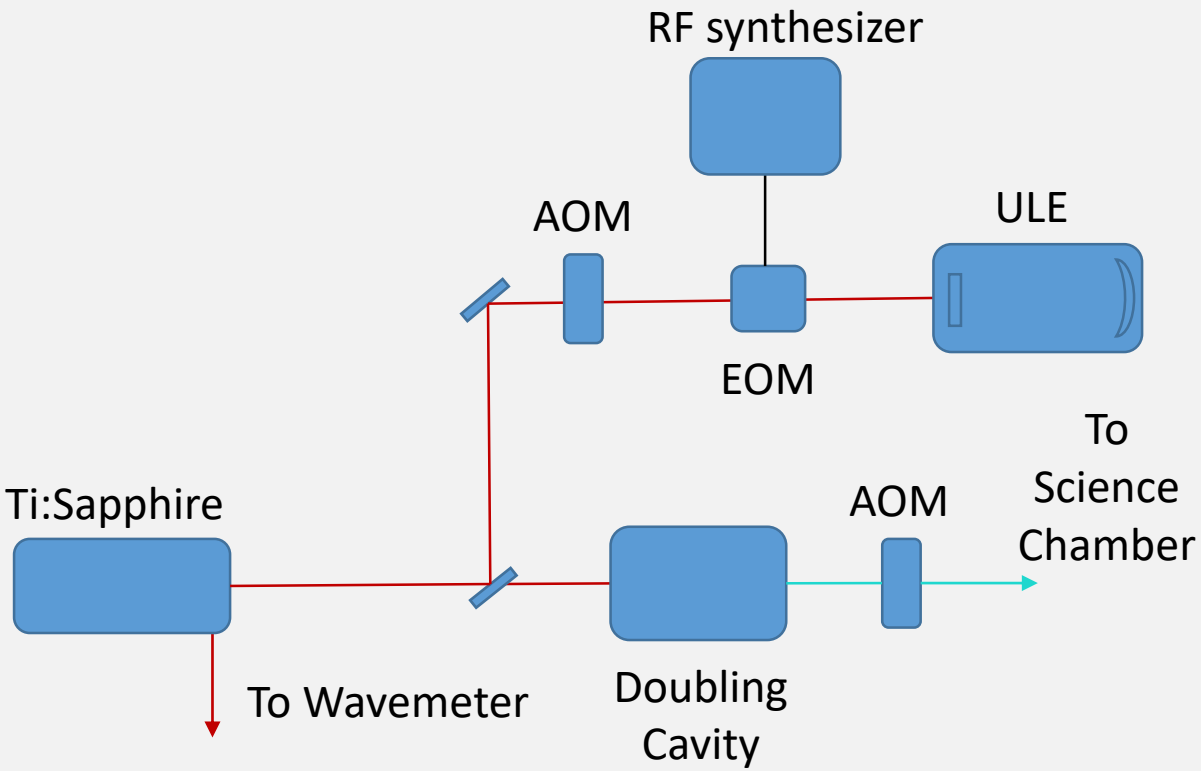
Electric Field Plates

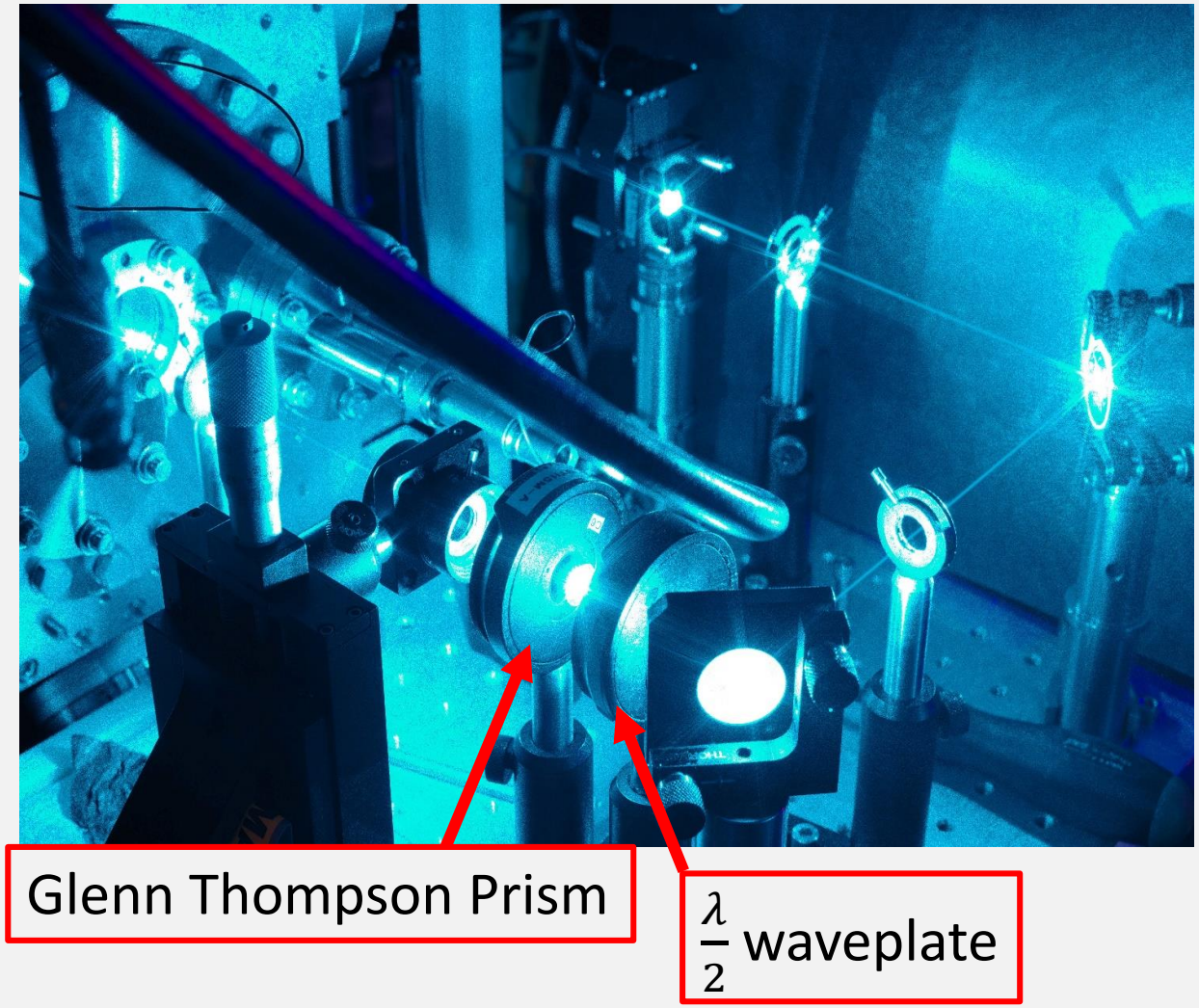


- The atoms are held between two indium tin oxide (ITO) coated field plates
- The spacing between the plates is $d = (2.858 \pm 0.003)$ cm
- One plate is held at ground while the other plate is connected to a calibrated high voltage power supply
- These plates are transparent to the light used to operate the MOT.

Spectroscopy Laser

- Frequency doubled Ti:Sapphire at 506 nm.
- The 1012 nm laser is split between the doubling stage and locking cavity
- EOM creates first order sideband, which is locked to a Fabry-Perot cavity using Pound-Drever-Hall (PDH) technique
- Scan sideband with EOM → Laser frequency scan over atomic resonance

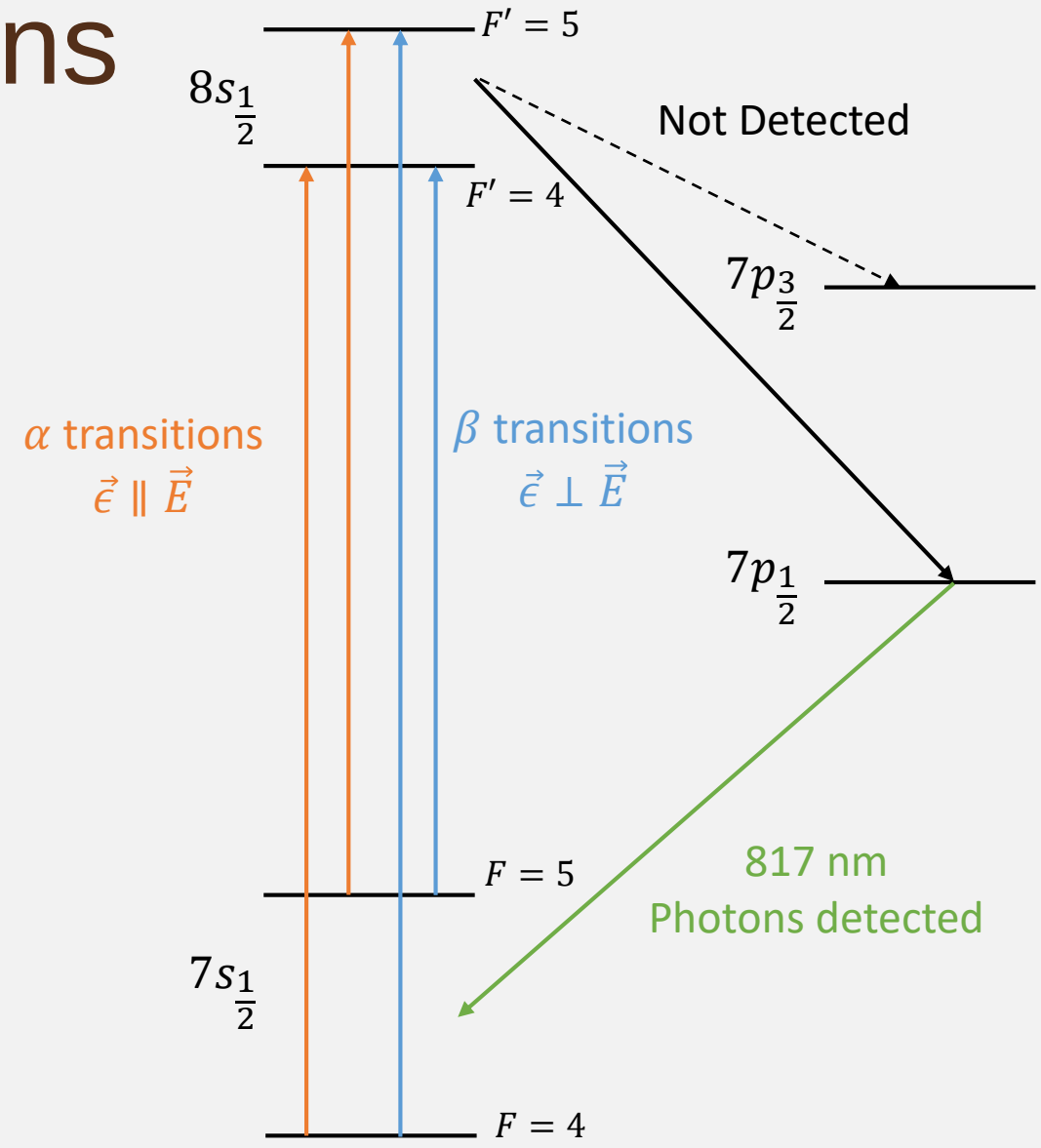




- Light is sent to the science chamber via a high power optical fiber cable.
- $\lambda/2$ waveplate + Glenn Thompson prism used to rotate polarization axis of the light at the chamber.
- We send ~ 100 mW of power to the atoms.

Detection of the Photons

- Collect photons at 817 nm into a PMT.
- Synchronized PMT data collection and frequency scan
- MOT lasers are cycled on and off with an 8 ms period (62.5% duty cycle)
- Spectroscopy laser is turned on for 3 ms, and take data for 2.5 ms of the 3 ms

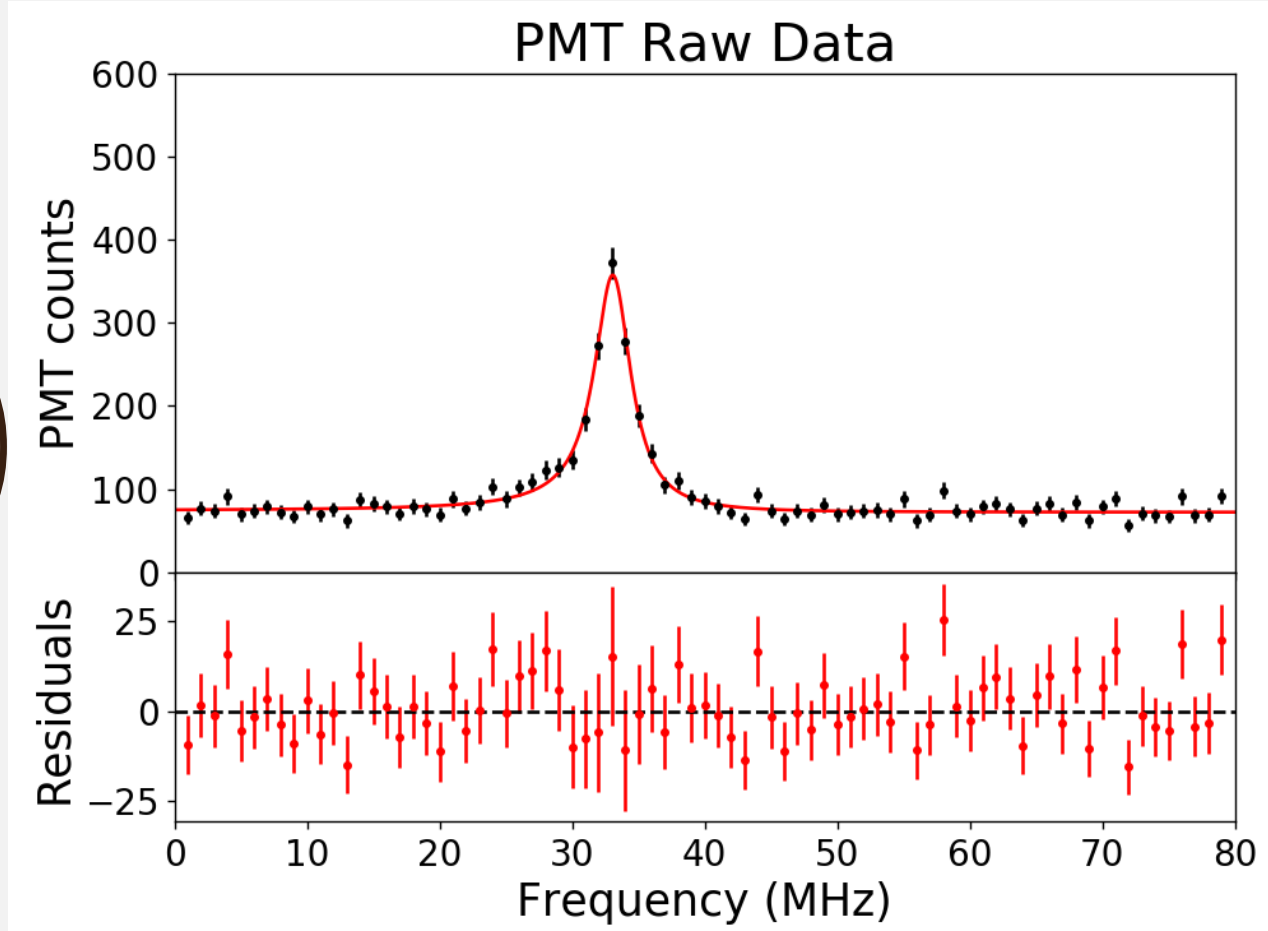


Stark Shift Results (Preliminary)

- Use α transition ($F = 5 \rightarrow F' = 5$) to perform the measurements
- Fit the raw data to an exponentially decaying Lorentzian

$$f(x) = h\left(a + e^{-x/\tau}\right)\left(\frac{\gamma^2}{4(x - x_0)^2 + \gamma^2}\right)$$

- Minimize χ^2_{red} using MINUIT, and extract the peak position.
- Figure shows a sample scan at 6.1 kV/cm

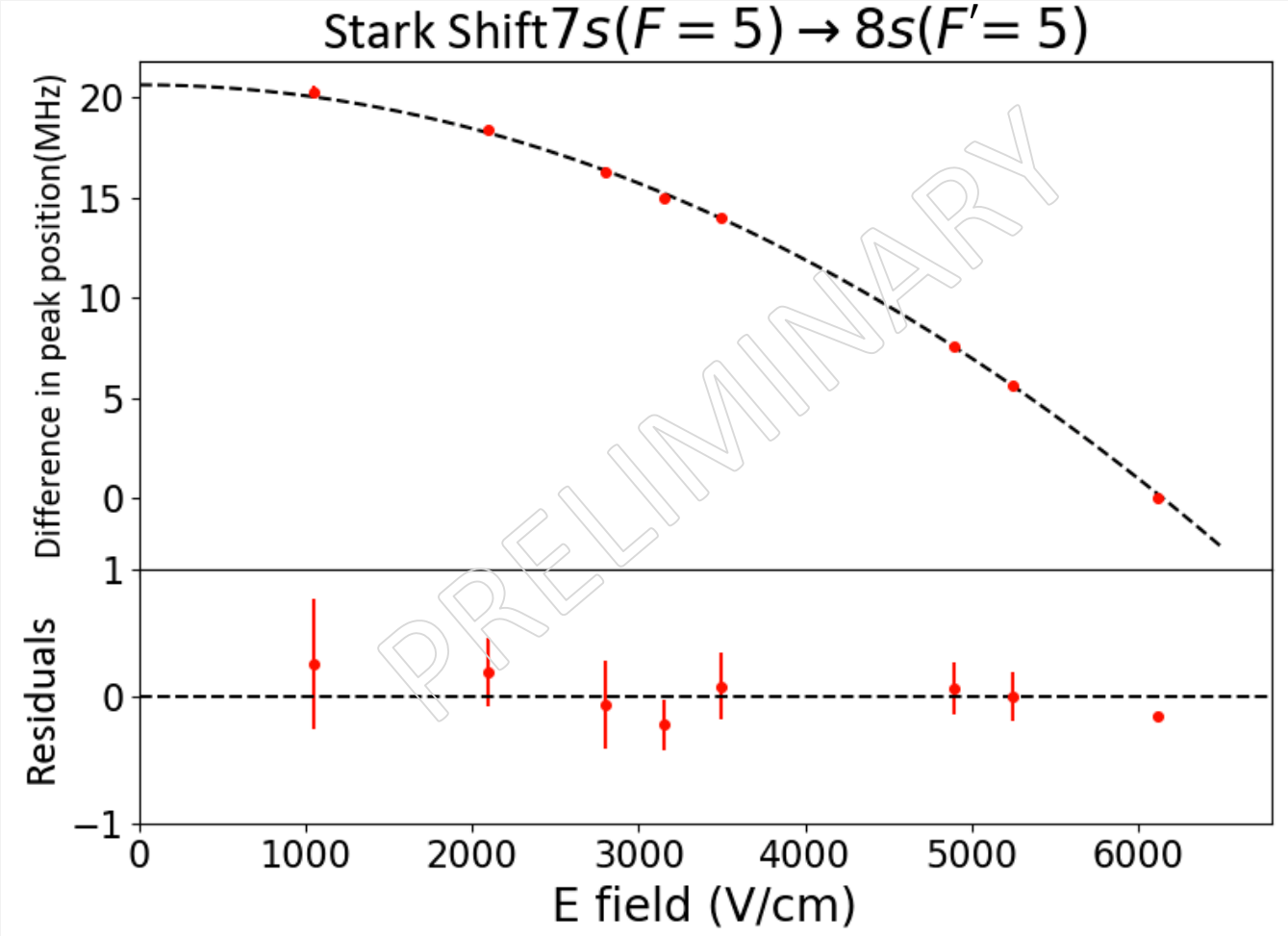


Stark Shift Results (Preliminary)

- Difference in peak position as a function of the electric field, using 6.1 kV/cm as a reference.

$$f(x) = a + bx^2$$

- Measured value: $\Delta\alpha_{meas.} = (-0.5465 \pm 0.0069_{stat.} \pm 0.0030_{sys.})$ Hz(V cm^{-1})$^{-2}$



- Measured value: $\Delta\alpha_{meas.} = (-0.5465 \pm 0.0069_{stat.} \pm 0.003_{sys.})$ Hz(V cm^{-1})$^{-2}$
- Theoretical value taken from table[1]:

$\Delta\alpha_{theo.} = (-0.5619 \pm 0.0032)$ Hz(V cm^{-1})$^{-2}$

$\Delta\alpha_{theo.} = -0.5494$ Hz(V cm^{-1})$^{-2}$

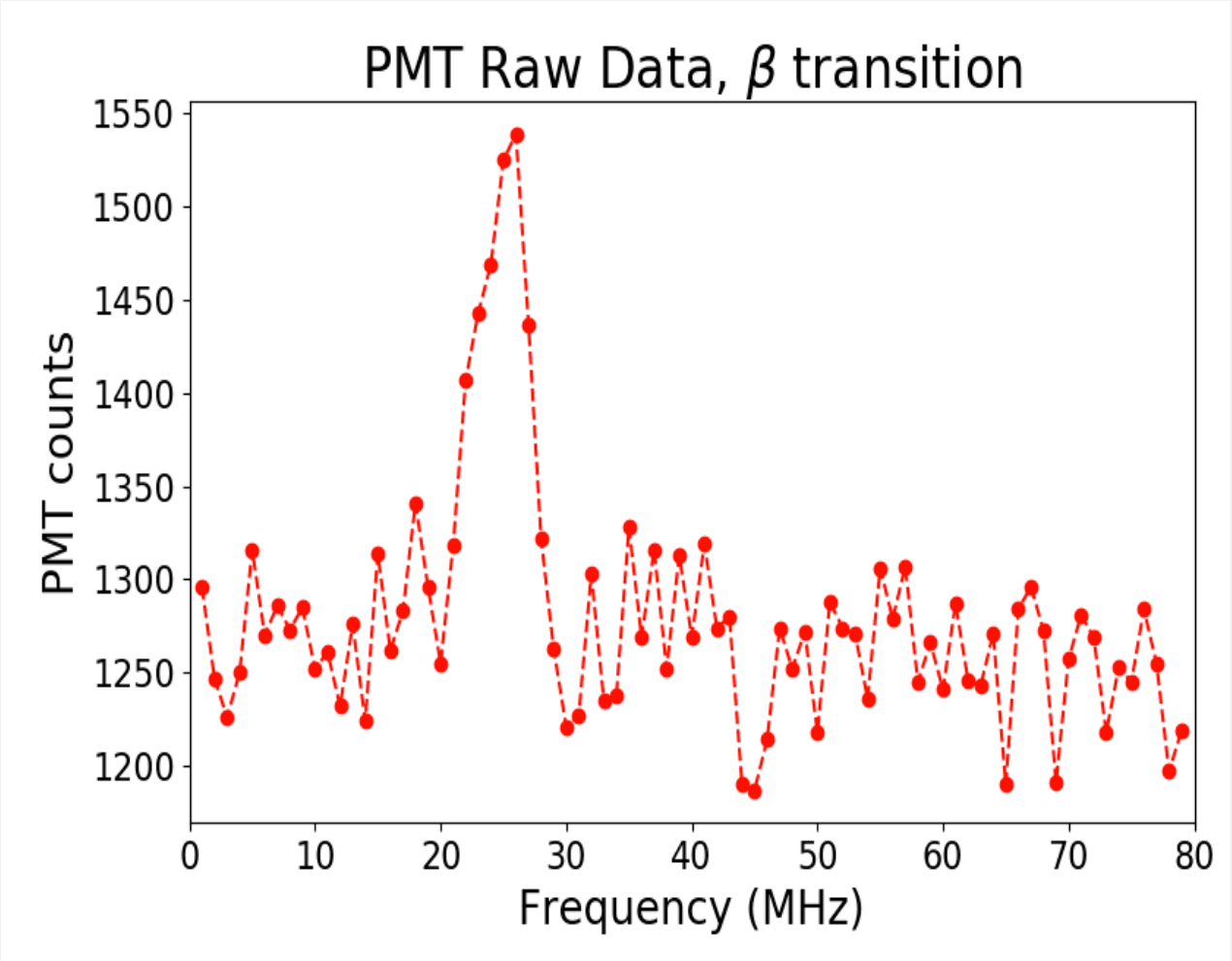
TABLE X. Contributions to the differences in static polarizabilities (a.u.) of $(N+1)s$ and the Ns ground states of alkali-metal atoms.

	Na	K	Rb	Cs	Fr
$\Delta\alpha^{main}$	2938.6	4673.7	4851.0	5868.4	4419.3
$\Delta\alpha^{tail}$	1.9	1.5	2.9	3.0	11.1
$\Delta\alpha_{vc}$	0.0	0.1	0.2	0.4	0.8
$\Delta\alpha^{SD}$	2940.5	4675.3	4854.1	5871.8	4431.2
Recomm.					4517(26) [a]
Expt.				5837(6) [b]	

[a]Value obtained using experimental energies and either experimental or scaled SD matrix elements.
[b]Reference [23].

[1] M. S. Safronova, W. R. Johnson, and A. Derevianko, *Phys. Rev. A,* **60**, pp. 4476–4487, 1999.

β Observation



- Milestones: observation of the β transition
- This observation is key for future APNC measurement.

Conclusion

- Neutralize ^{211}Fr, and trap between ITO coated field plates using MOTs
- Performed single photon spectroscopy on the Stark induced $7s \rightarrow 8s$ transition
- Measured $\Delta\alpha$ and observed β transition in ^{211}Fr

Thank You!