Spectroscopy of RaF Molecules for Fundamental Physics

Silviu-Marian Udrescu

PhD. Student, MIT

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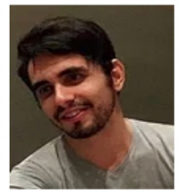
Thanks to…

Quantum chemistry:
R. Berger (U. Marburg, Germany),
T. Isaev (PNPI NRCKI, St. Petersburg)

***ISOLTRAP** (F. Wienholtz) , **RILIS** (S. Wilkins, K. Chrysalidis)*
Target group** (S. Rothe), **ISOLDE Technical group

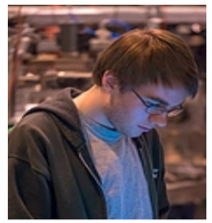
Graduate students

A. Brinson

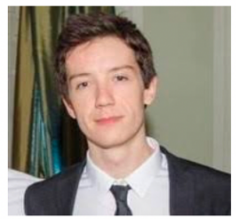


S. Udrescu

Postdocs



A. Vernon



S. Wilkins

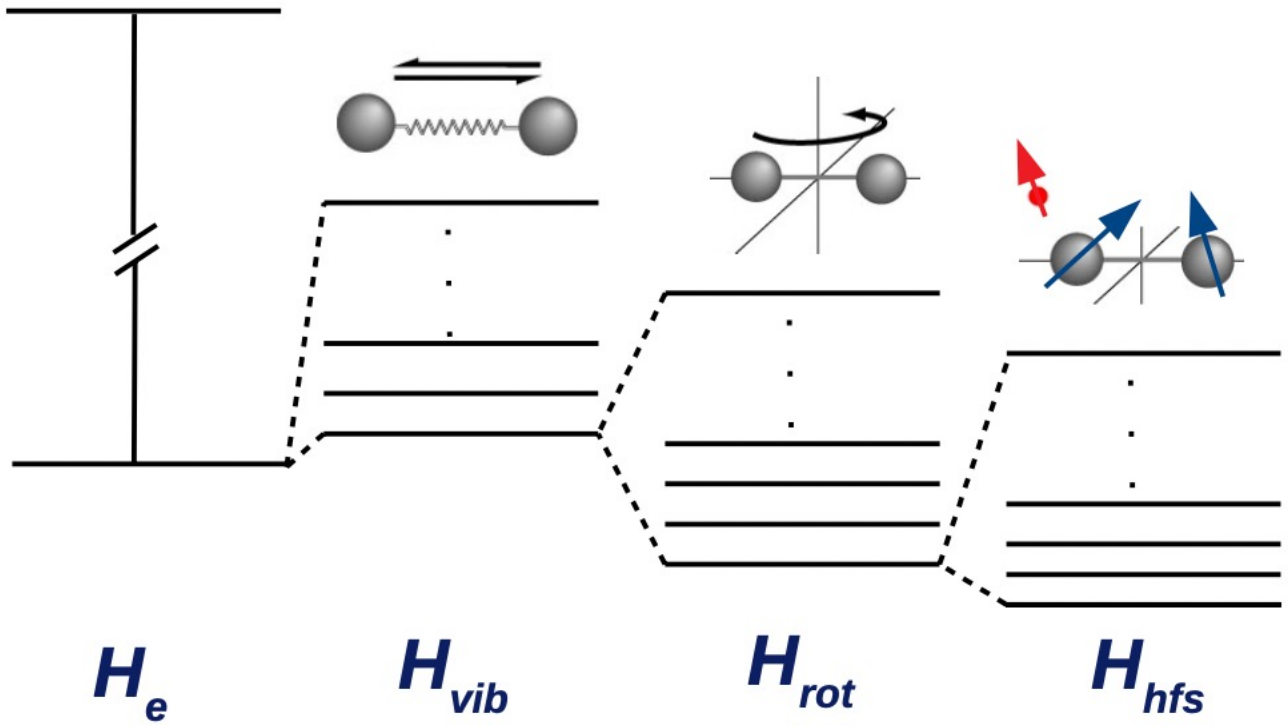
I. Belosevic

J. Karthein

Content

- Motivation
- Isotope shift in Radium Monofluoride
- High resolution spectroscopy of Radium Monofluoride
- Conclusions and Outlook

Why molecules?

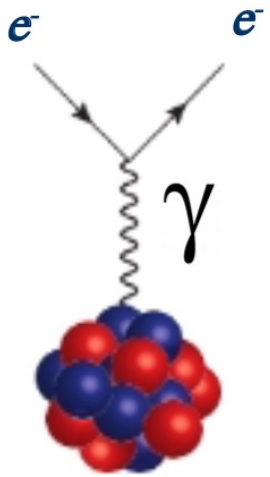


$$|s'\rangle = |s\rangle + \frac{\langle s| V_{PV} |p\rangle}{E_- - E_+} |p\rangle$$

$$H_{mol} = H_e + H_{vib} + H_{rot} + \ldots + H_{hfs} + H_{PV} + H_{PTV}$$

eV	~ 2	10^{-2}	10^{-5}	10^{-8}	$<10^{-12}$	$<10^{-15}$

Why short-lived radioactive molecules?



Low-energy SM tests

- **Nuclear matter**
- **Nuclear structure**
- **BSM searches**

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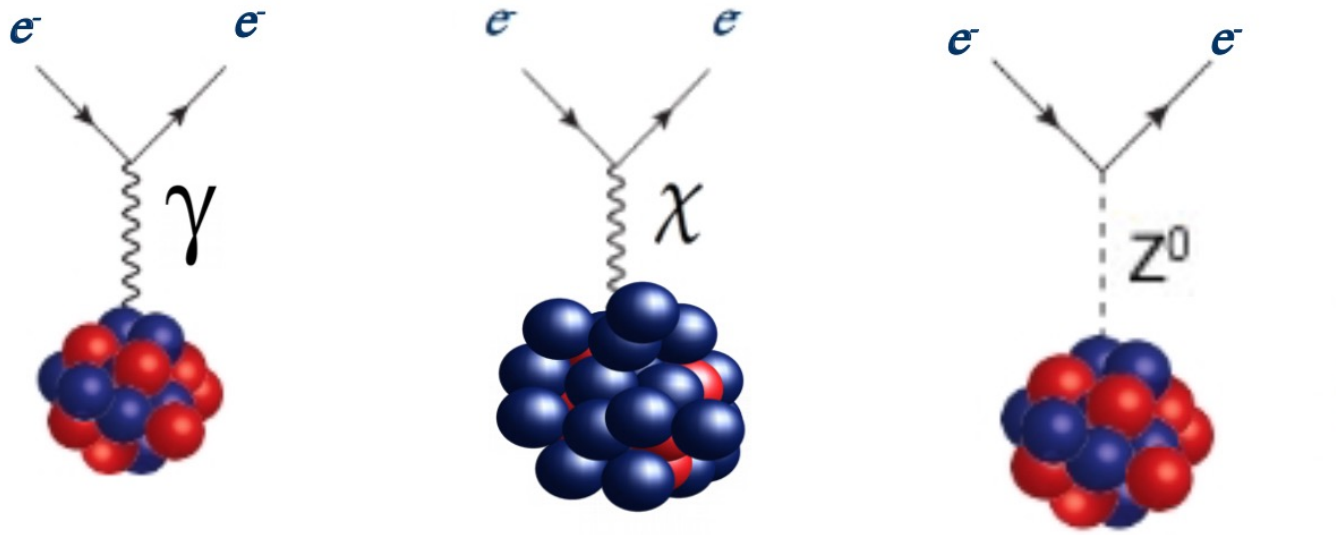

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New e-N interactions?

- Dark Matter properties?
- New forces?

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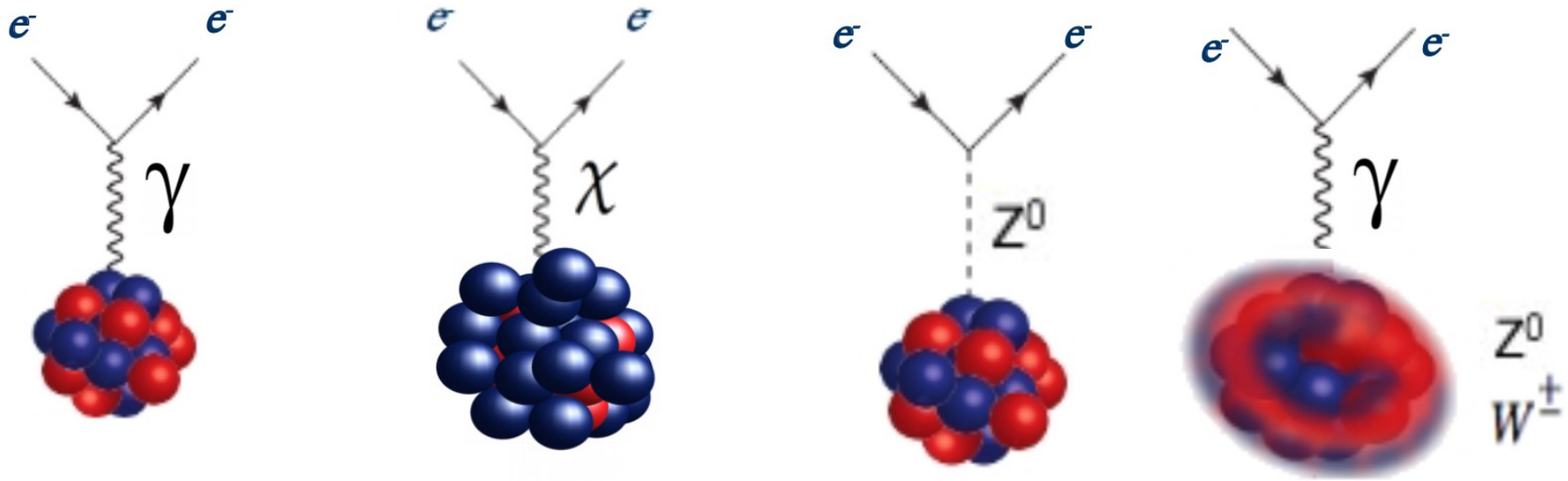

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P-violation

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- New forces?

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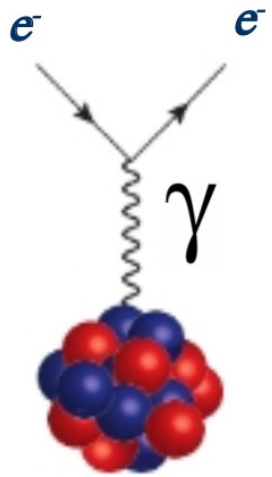

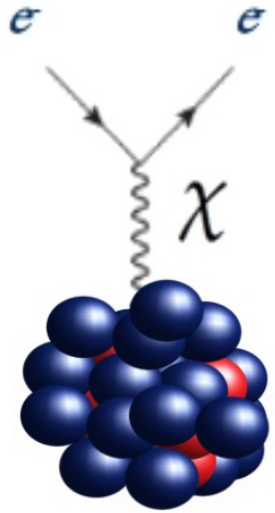

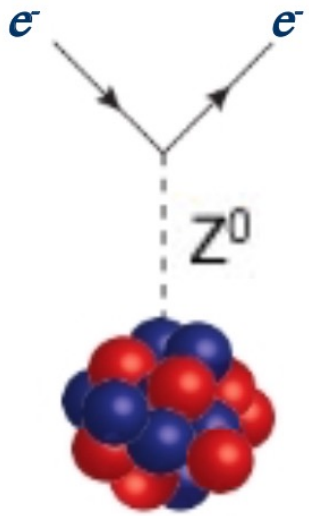

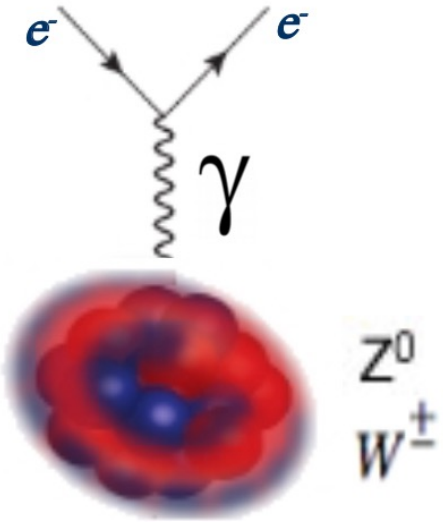

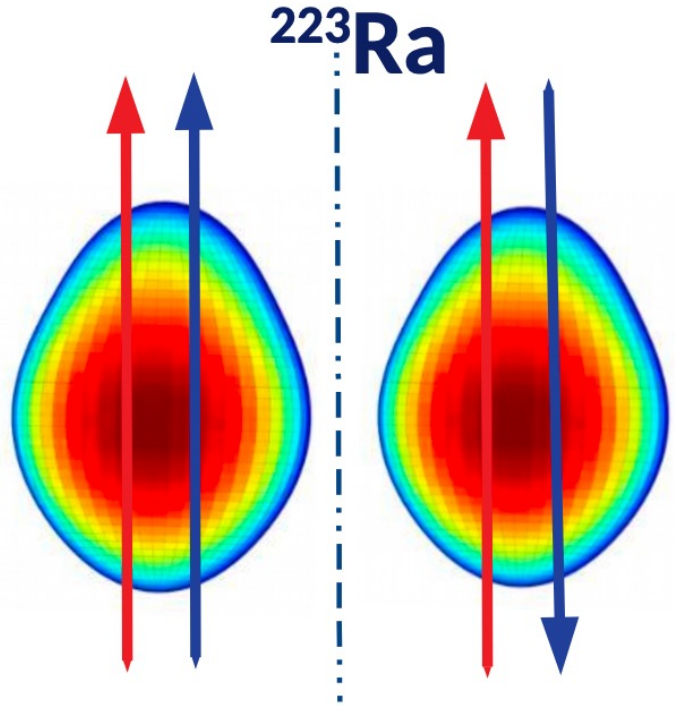

Low-energy SM tests

- Nuclear matter
- Nuclear structure
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New e-N interactions?

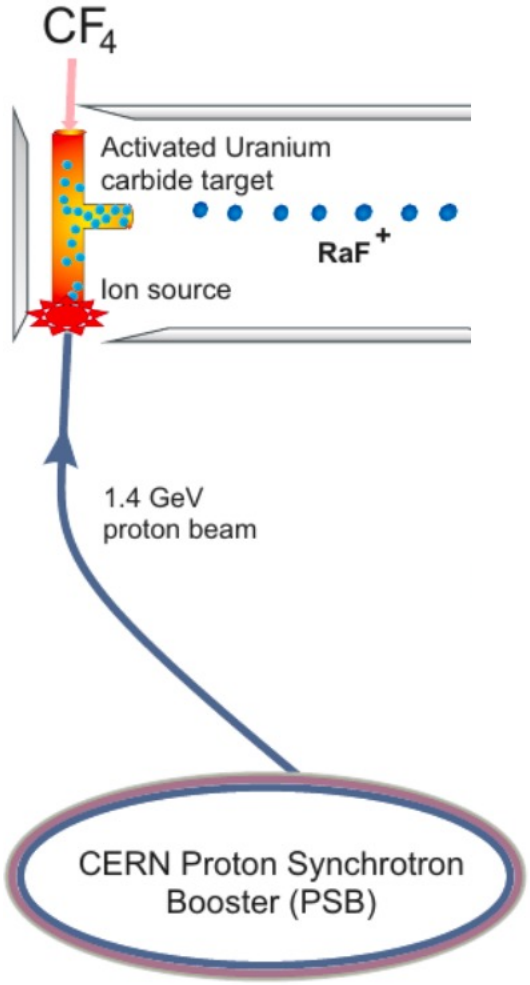
- Dark Matter properties?
- New forces?

P-violation

T-violation

- Baryogenesis

Experimental Setup



Garcia Ruiz, Berger et al. CERN-INTC-2018-017 (2018)

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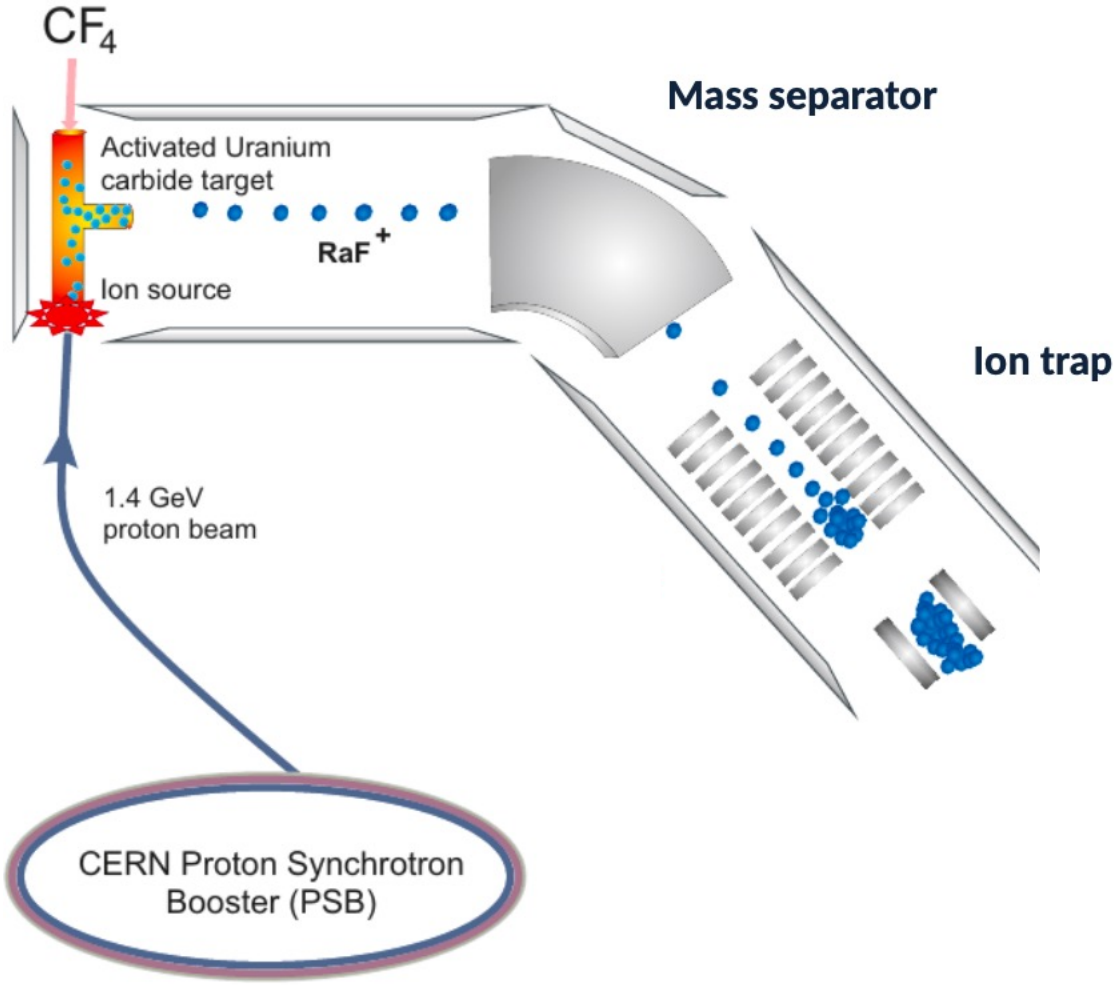

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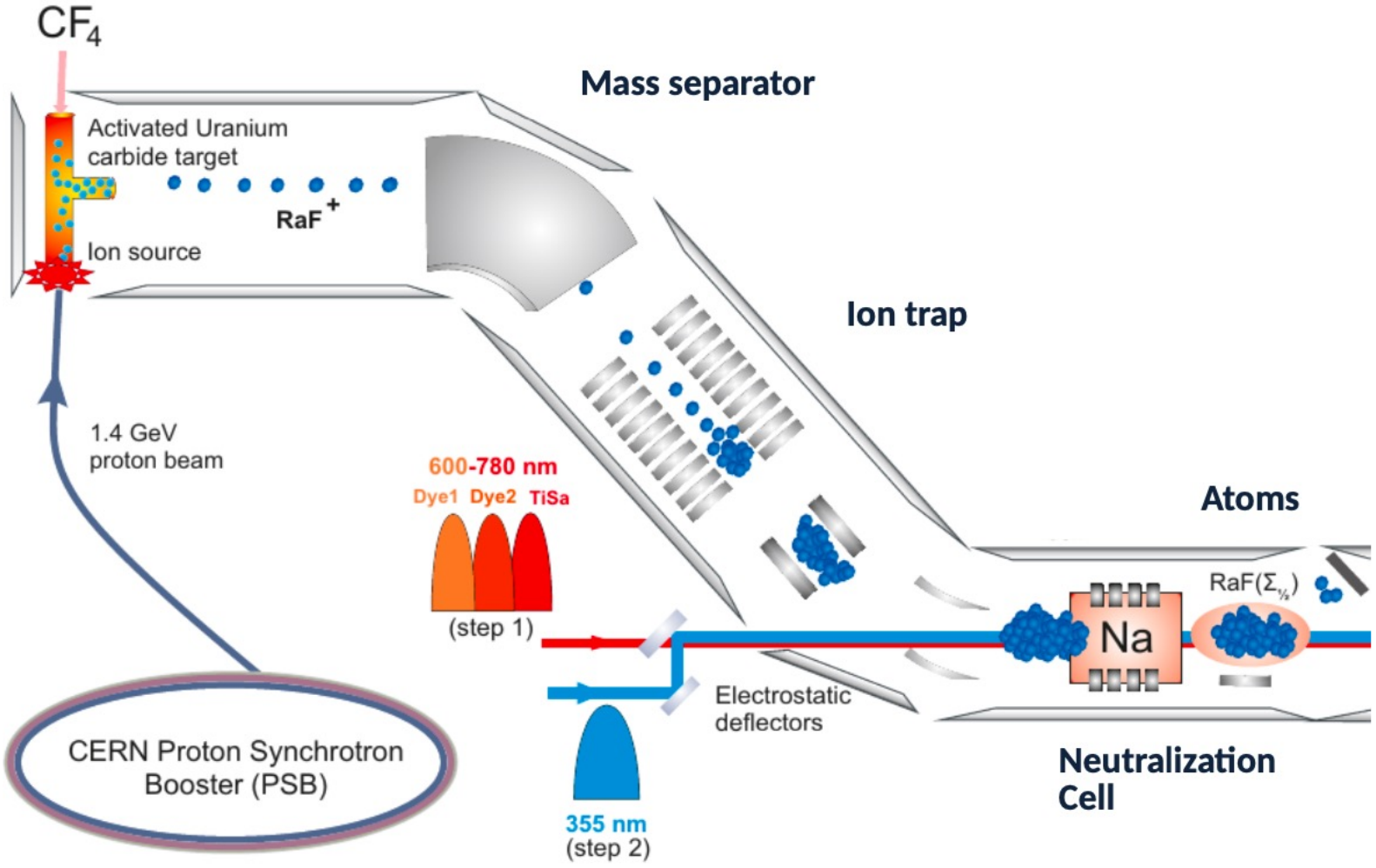

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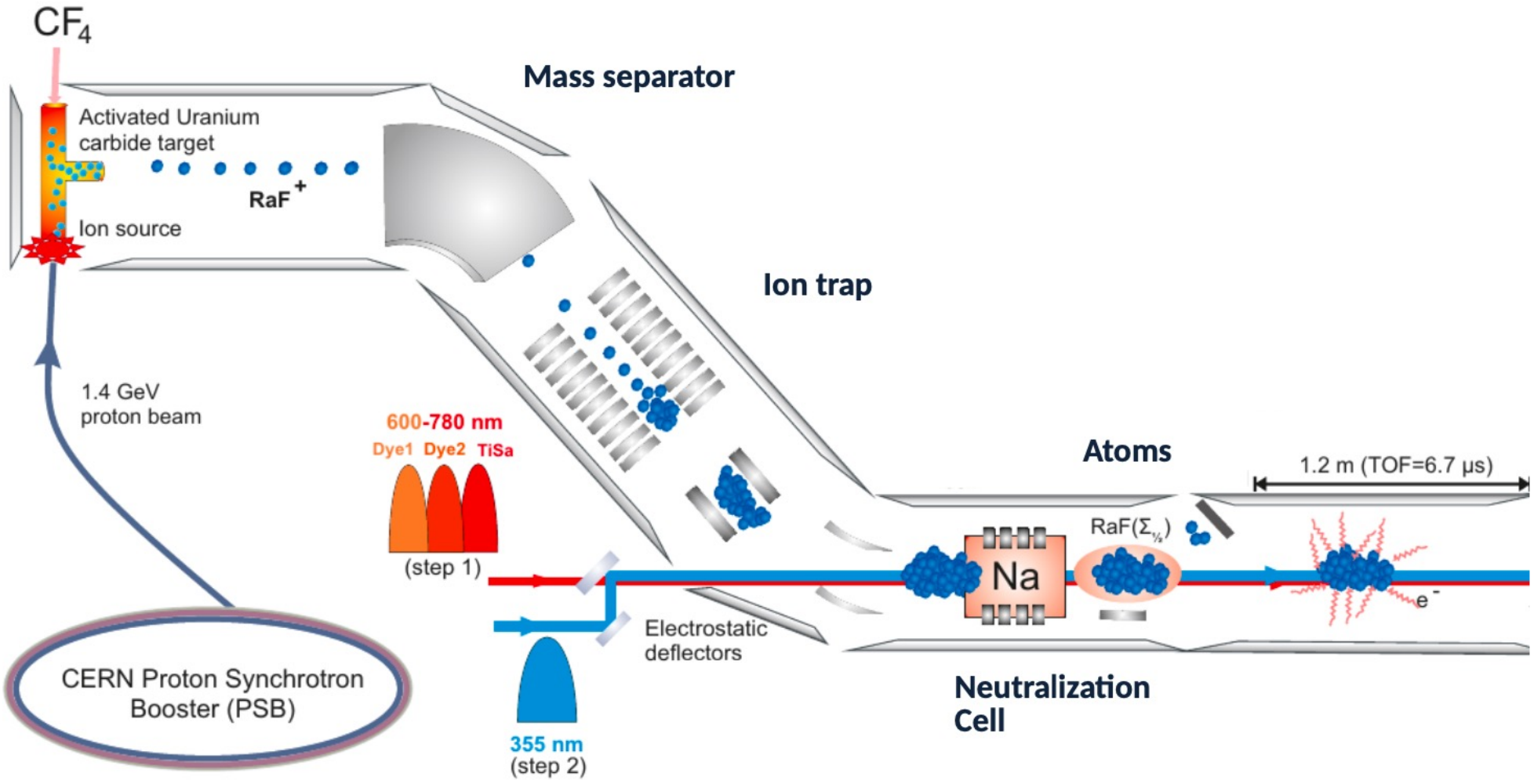

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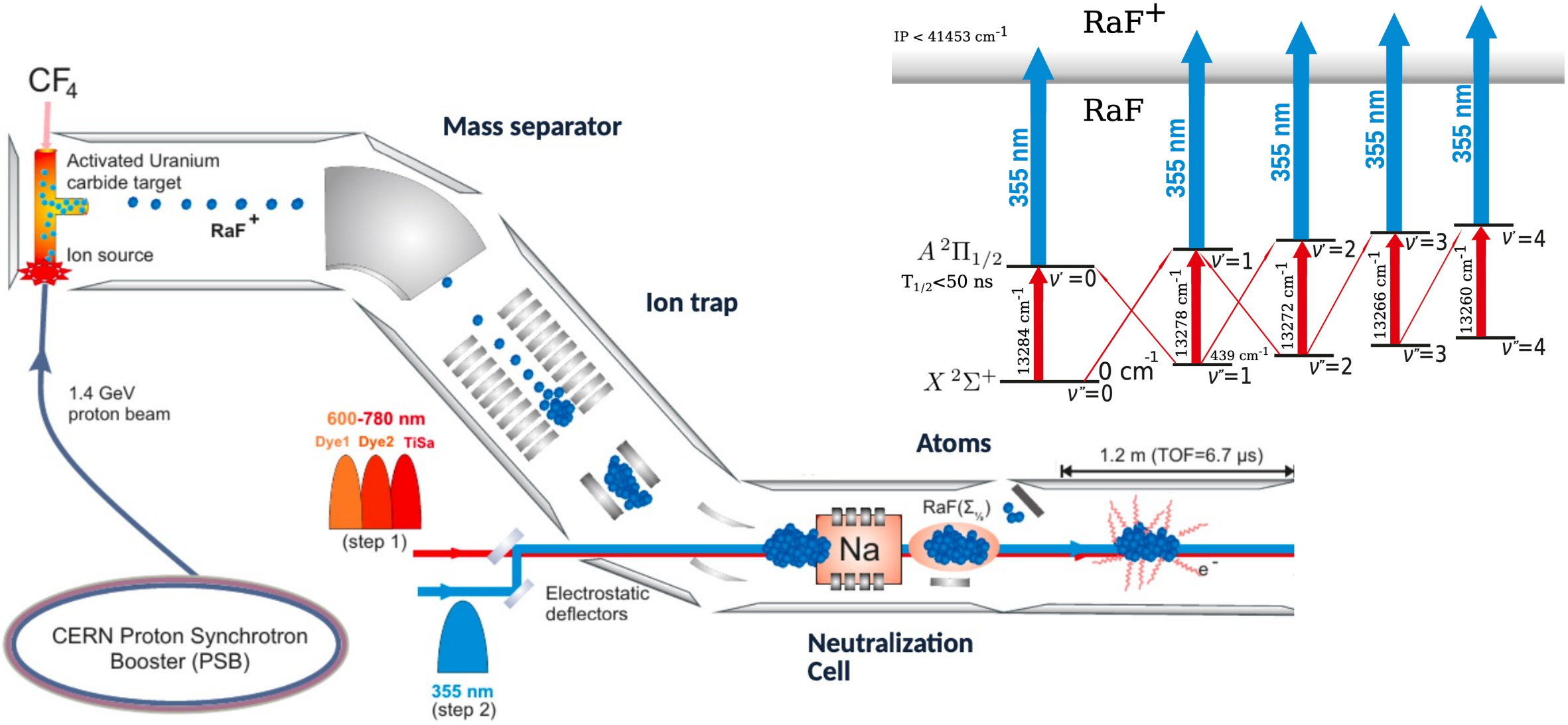

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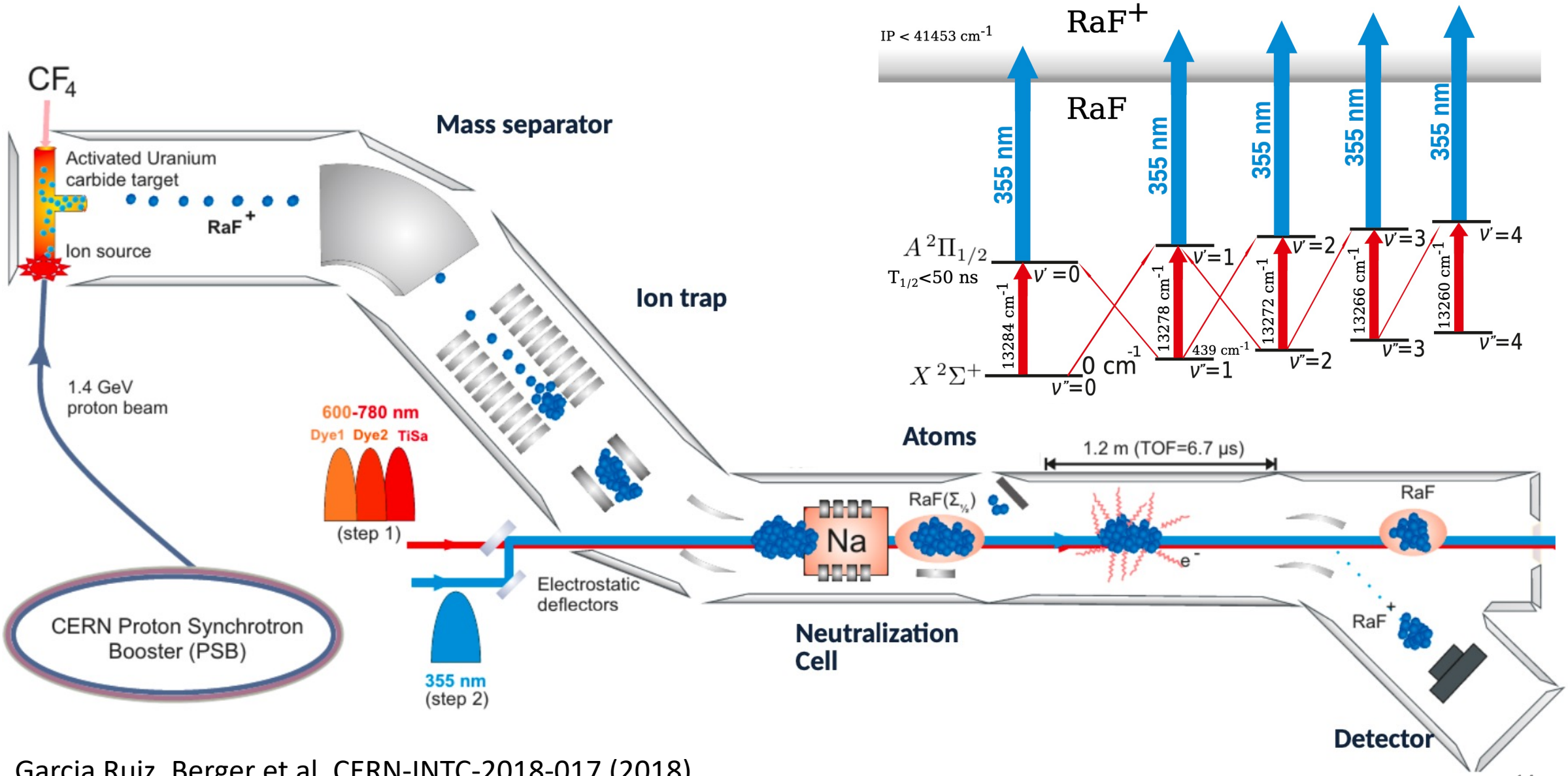

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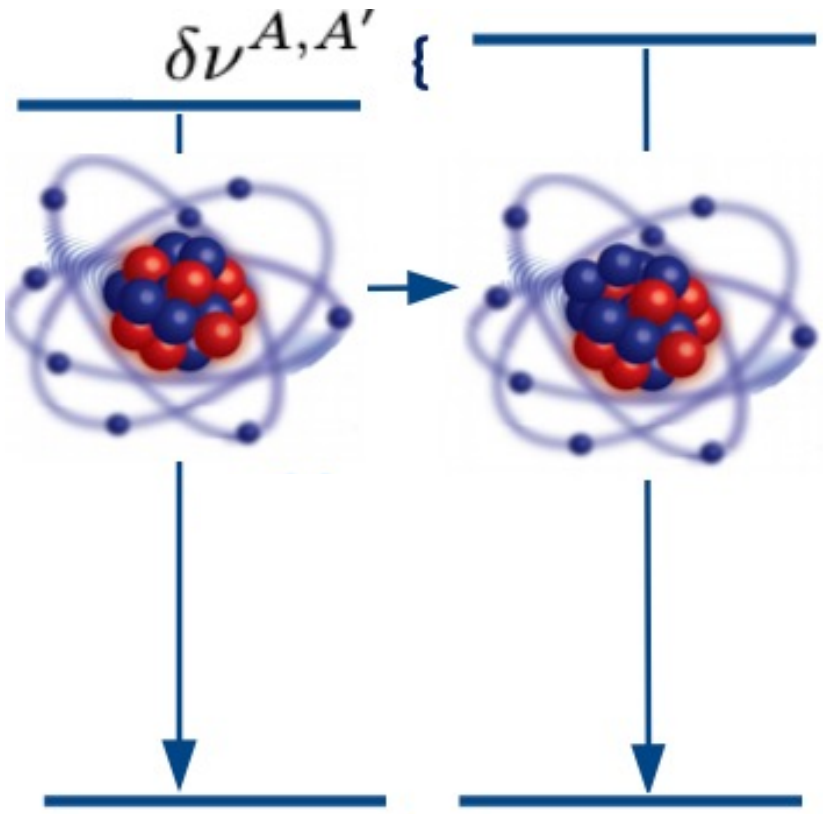
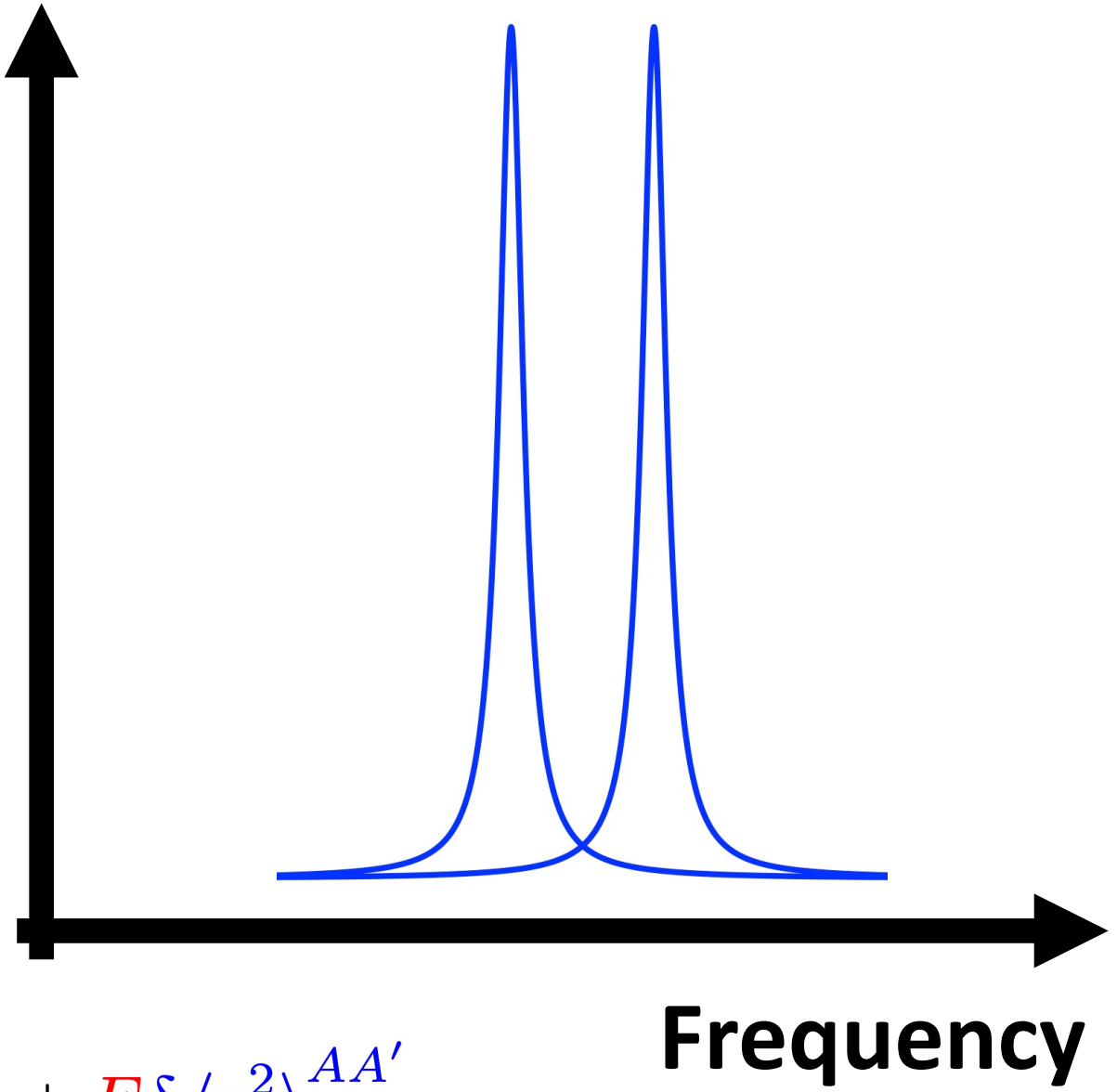
Isotope Shift

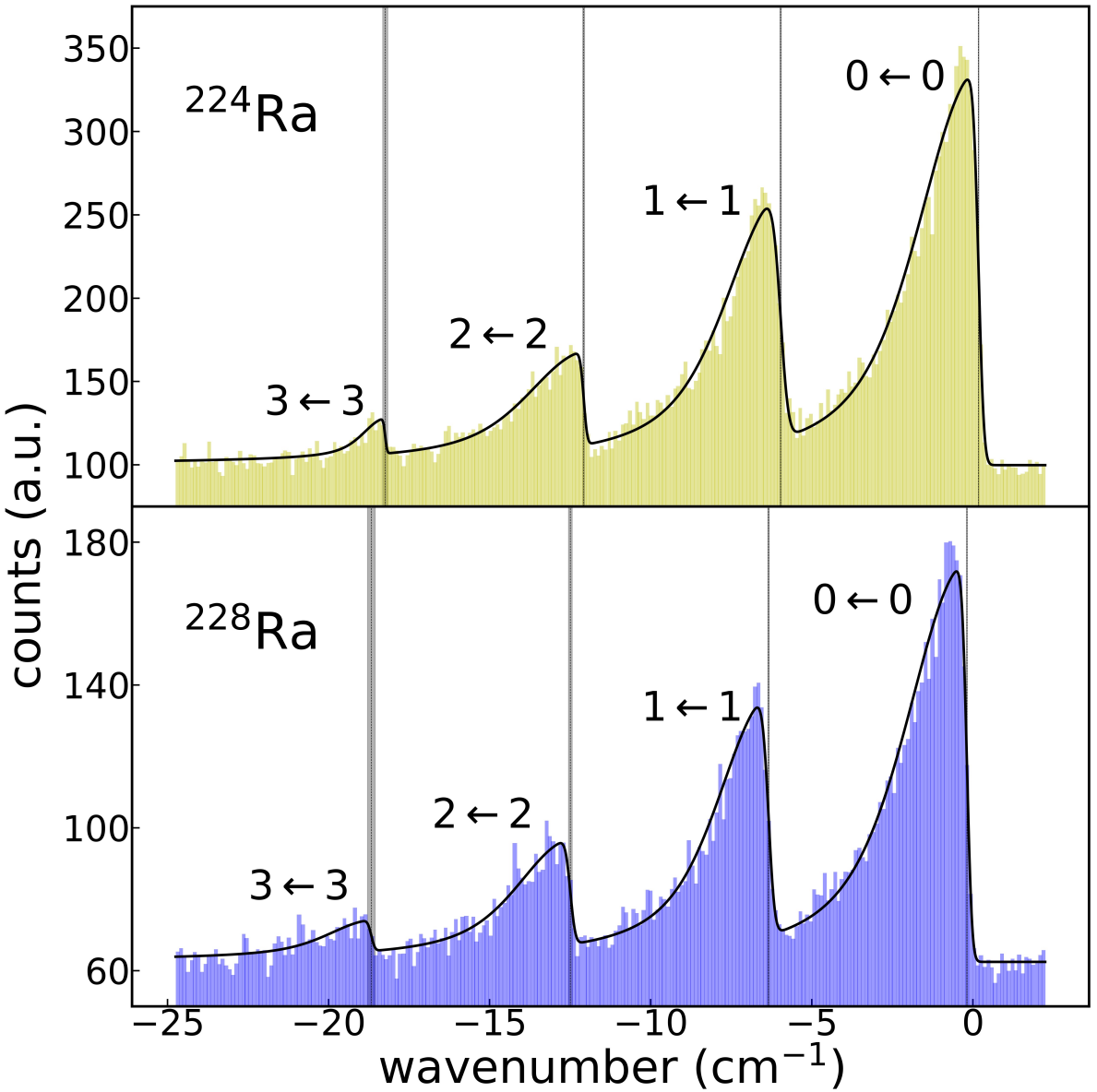


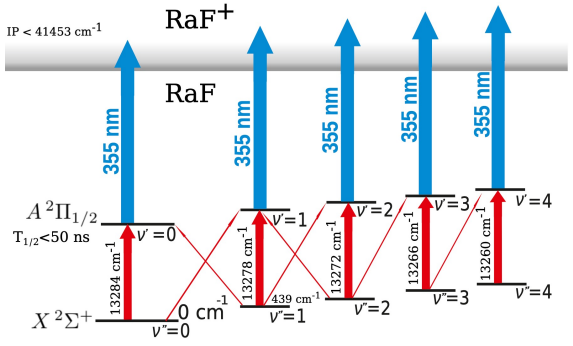
$\Rightarrow$



$$\delta\nu_{IS}^{AA'} = K\left(\frac{M_A - M'_A}{M_A M'_A}\right) + F\delta\left\langle r_c^2\right\rangle^{AA'}$$

Isotope Shift of RaF - Results





Isotope Shifts of Radium Monofluoride Molecules, S. M. Udrescu *et al.* Phys. Rev. Lett. **127**, 033001, 2021

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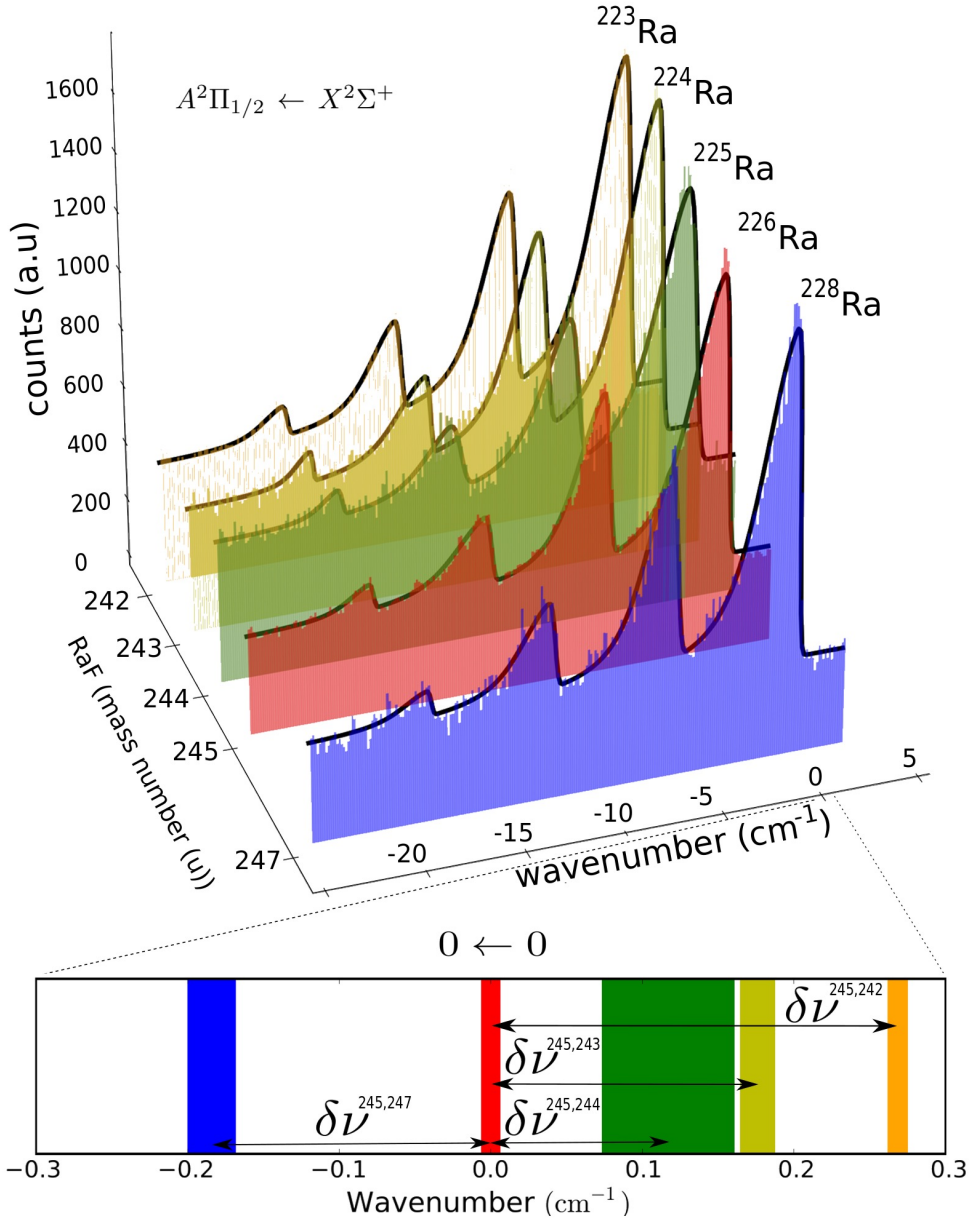

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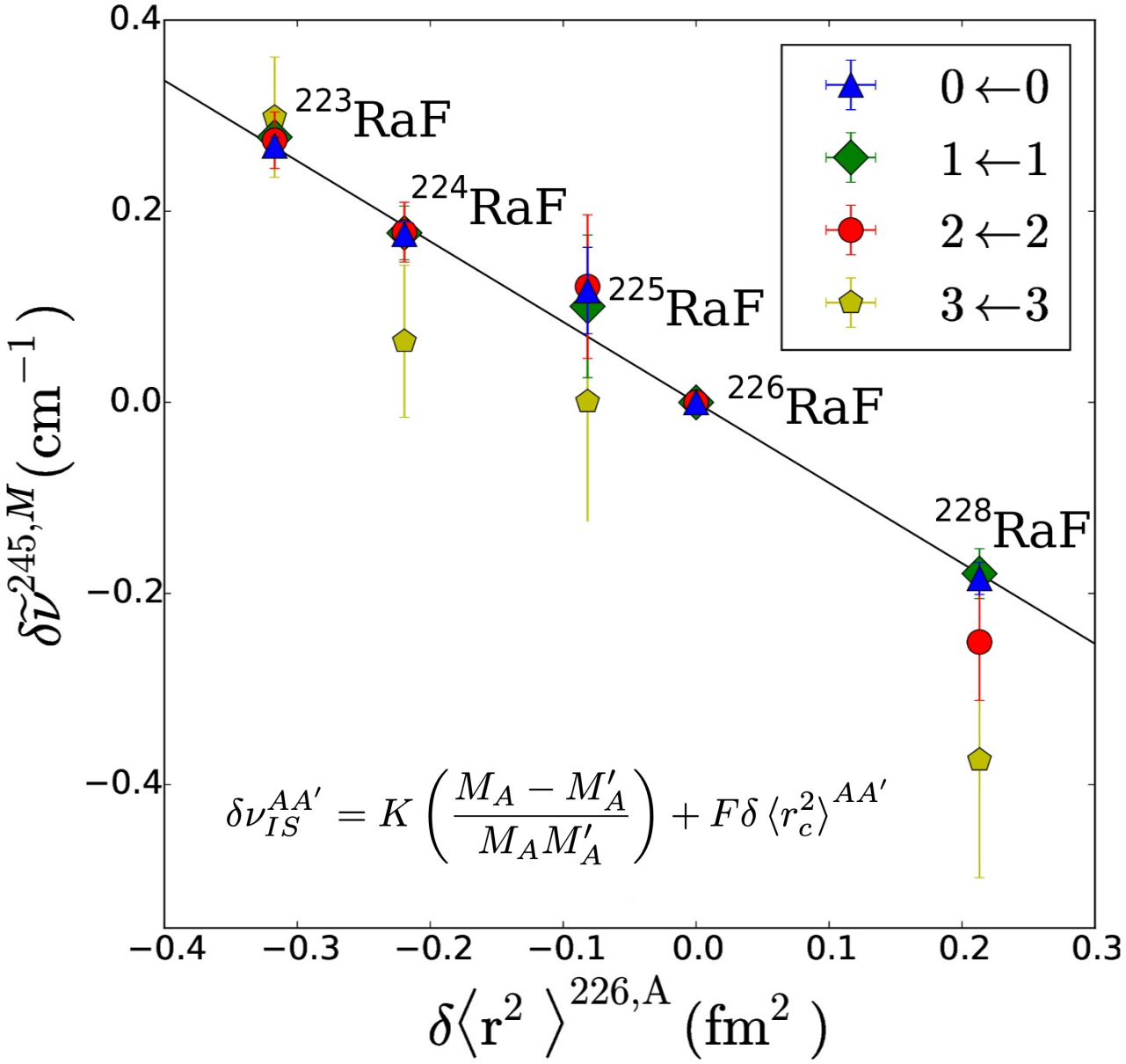

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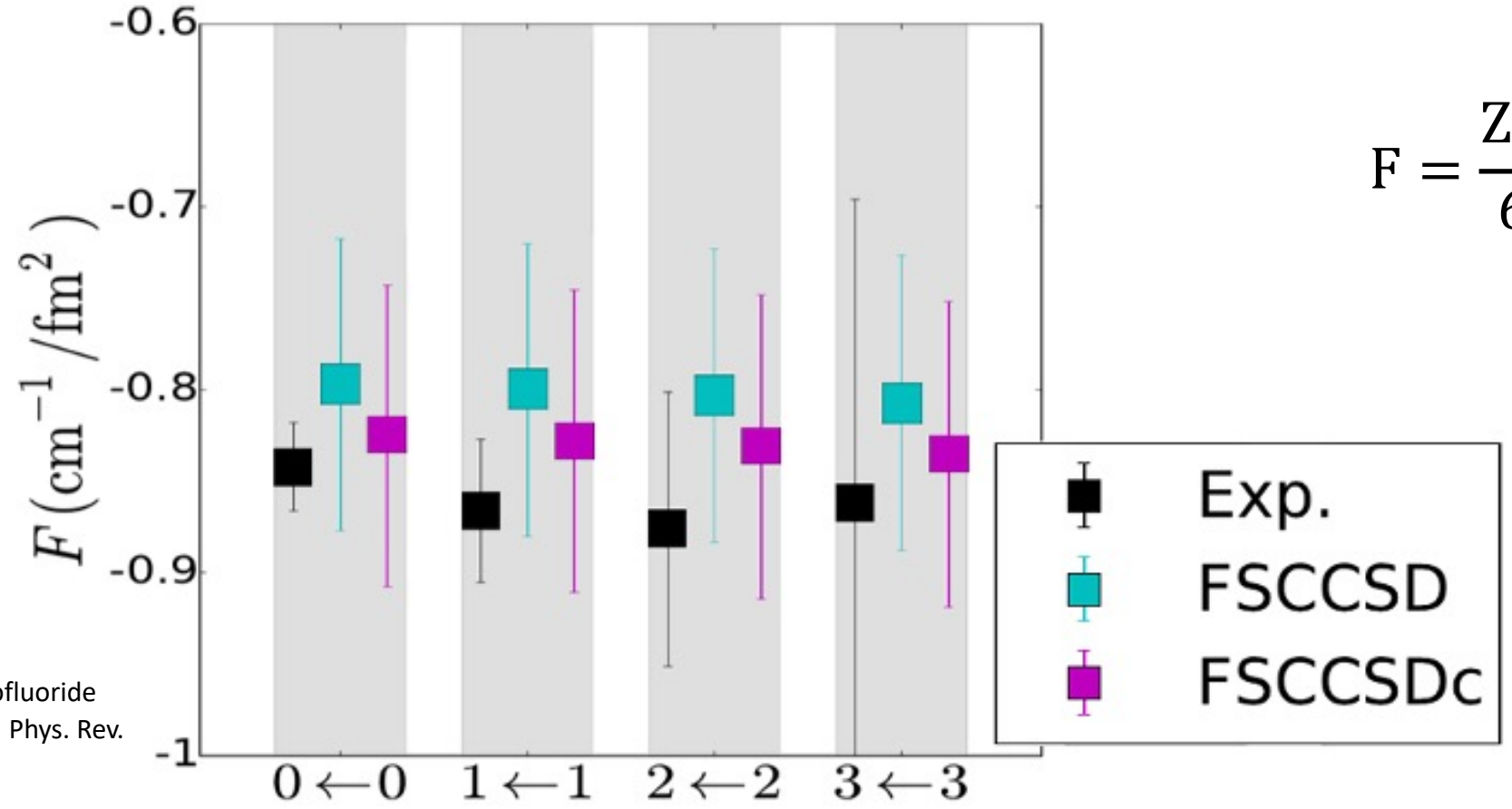
Isotope Shift of RaF - Results

$$\delta\nu_{IS}^{AA'} = K\left(\frac{M_A - M'_A}{M_A M'_A}\right) + F\delta\left\langle r_c^2\right\rangle^{AA'}$$

$$\mathrm{F} = -0.839(33)\,\frac{\mathrm{cm}^{-1}}{\mathrm{fm}^2}$$

$$\mathrm{F} = \frac{\mathrm{Z_A e^2}}{6\epsilon_0}\,\rho_e$$



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Future Isotope Shift Measurements

- New opportunities for nuclear studies of heavy elements (e.g. ThO, PaO)

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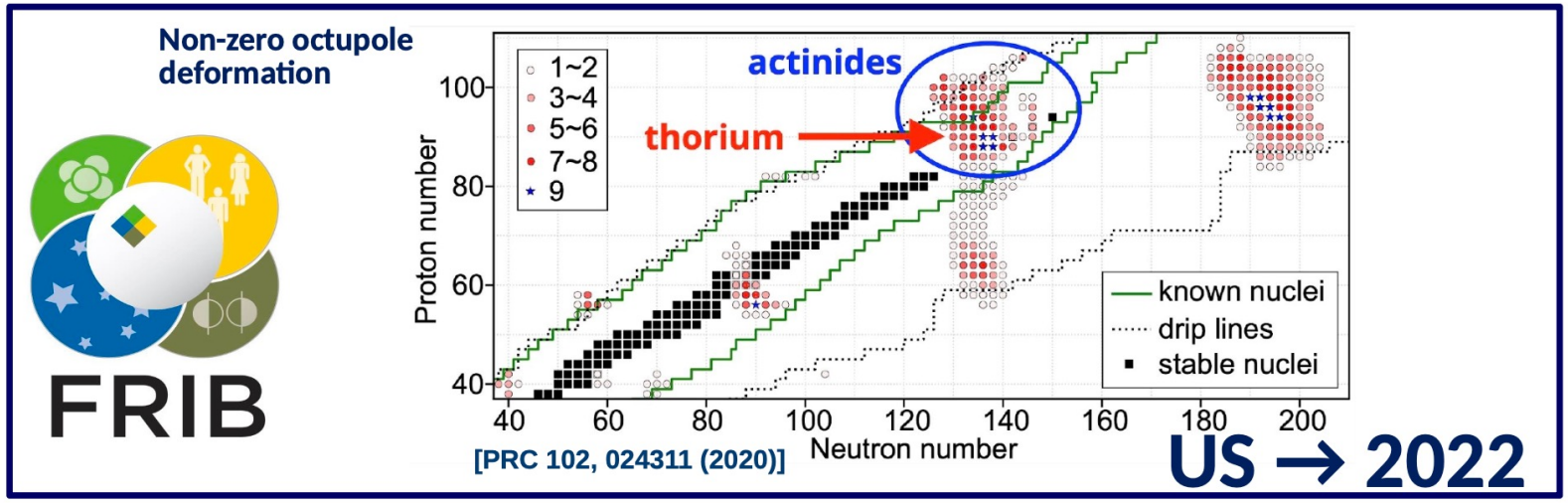
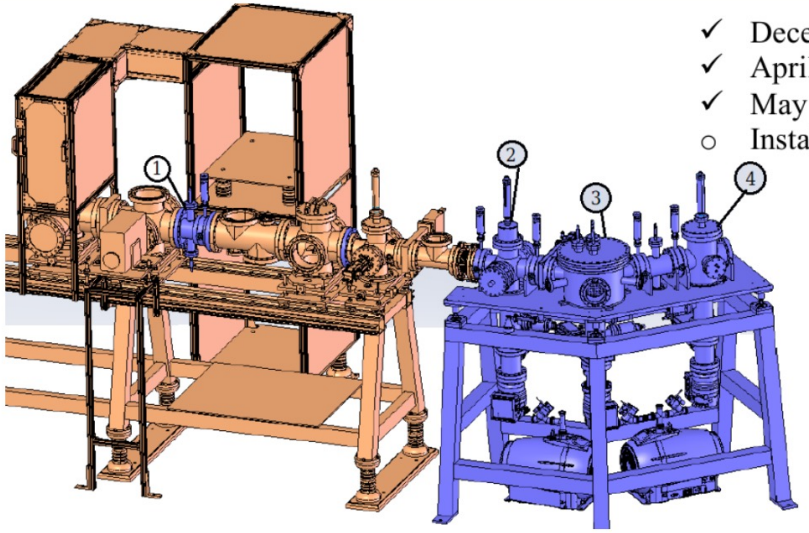
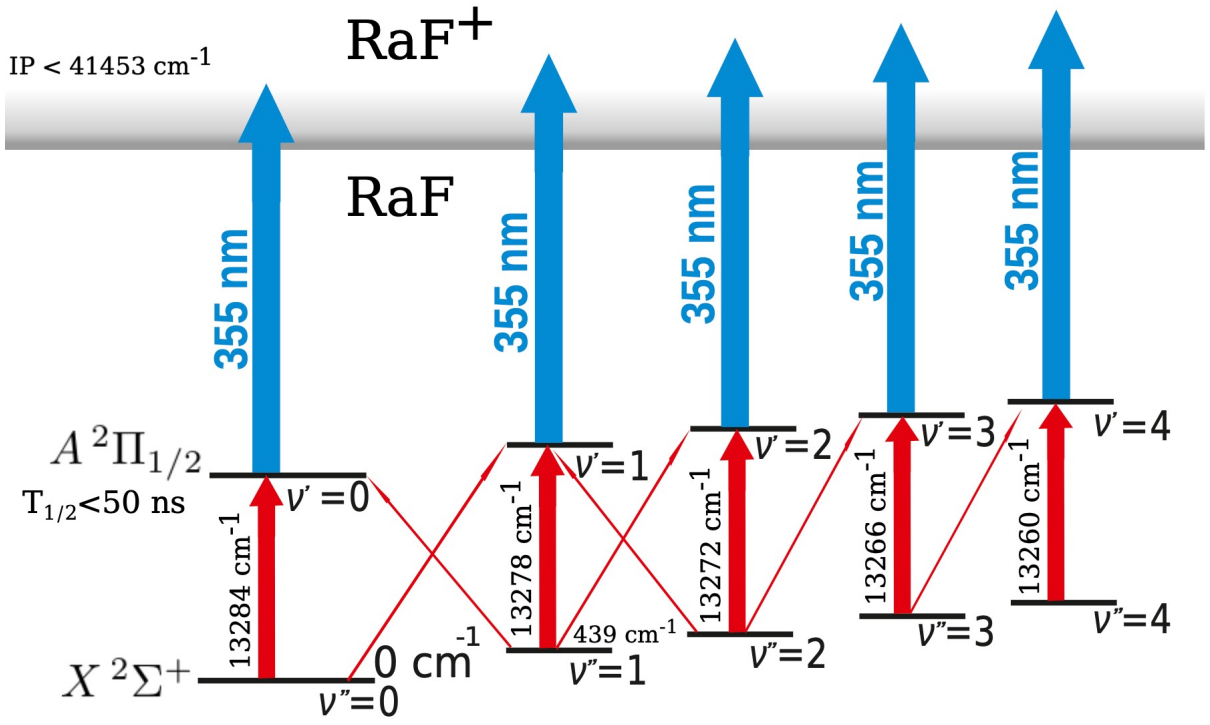




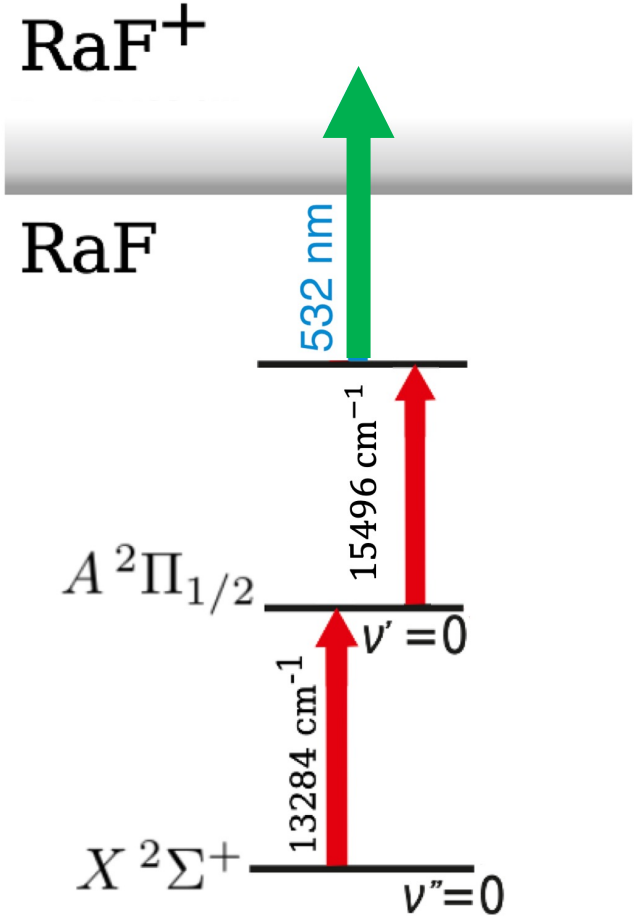
- ✓ December 2020: CRIS project started Dec 2020.
- ✓ April 2021: Beamline design completed.
- ✓ May 2021: Experimental parts are being purchased.
- ○ Installation at FRIB expected in March 2022.

FRIB

High Resolution spectroscopy of ^{226}RaF



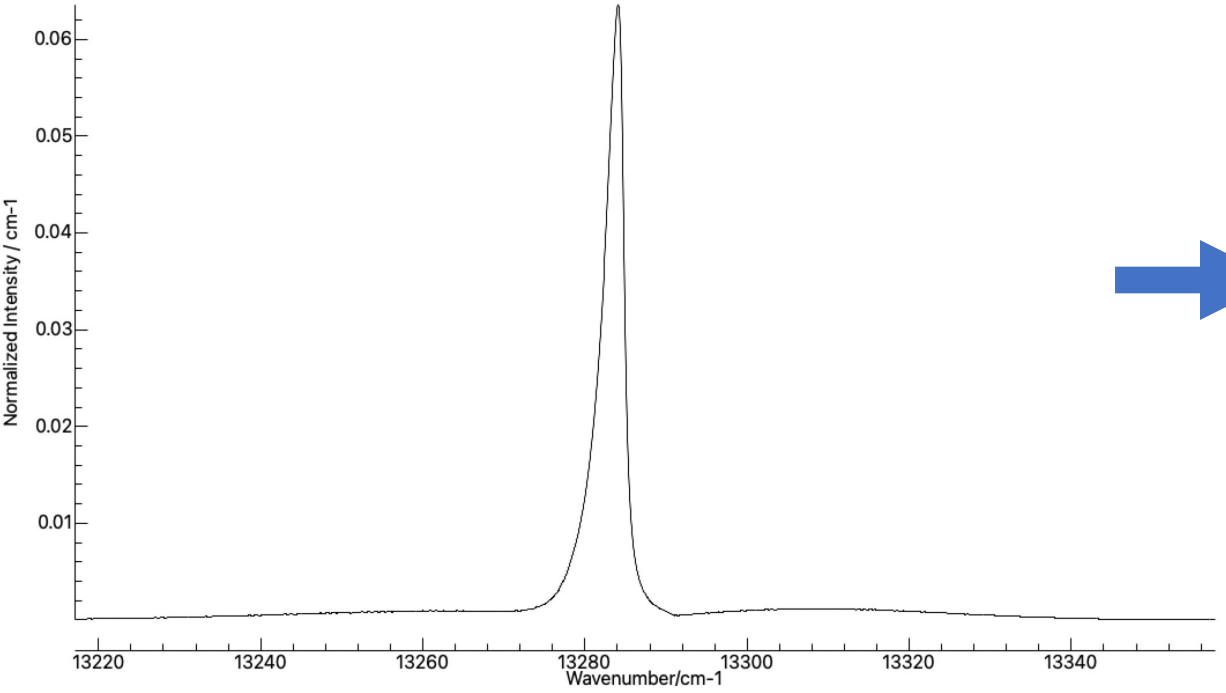
⇒

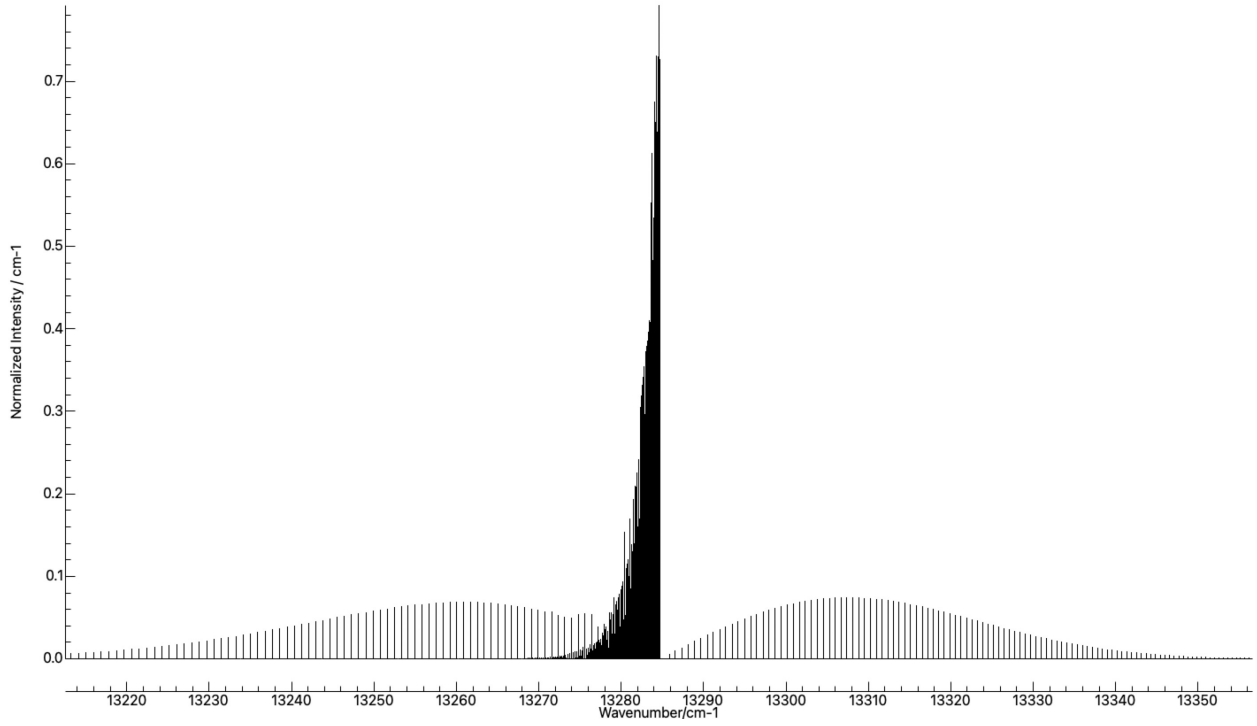


10 GHZ

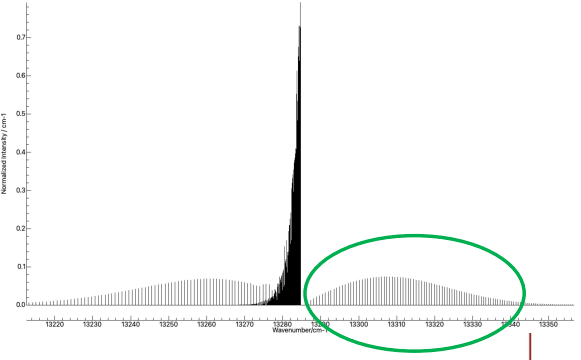
50 MHZ

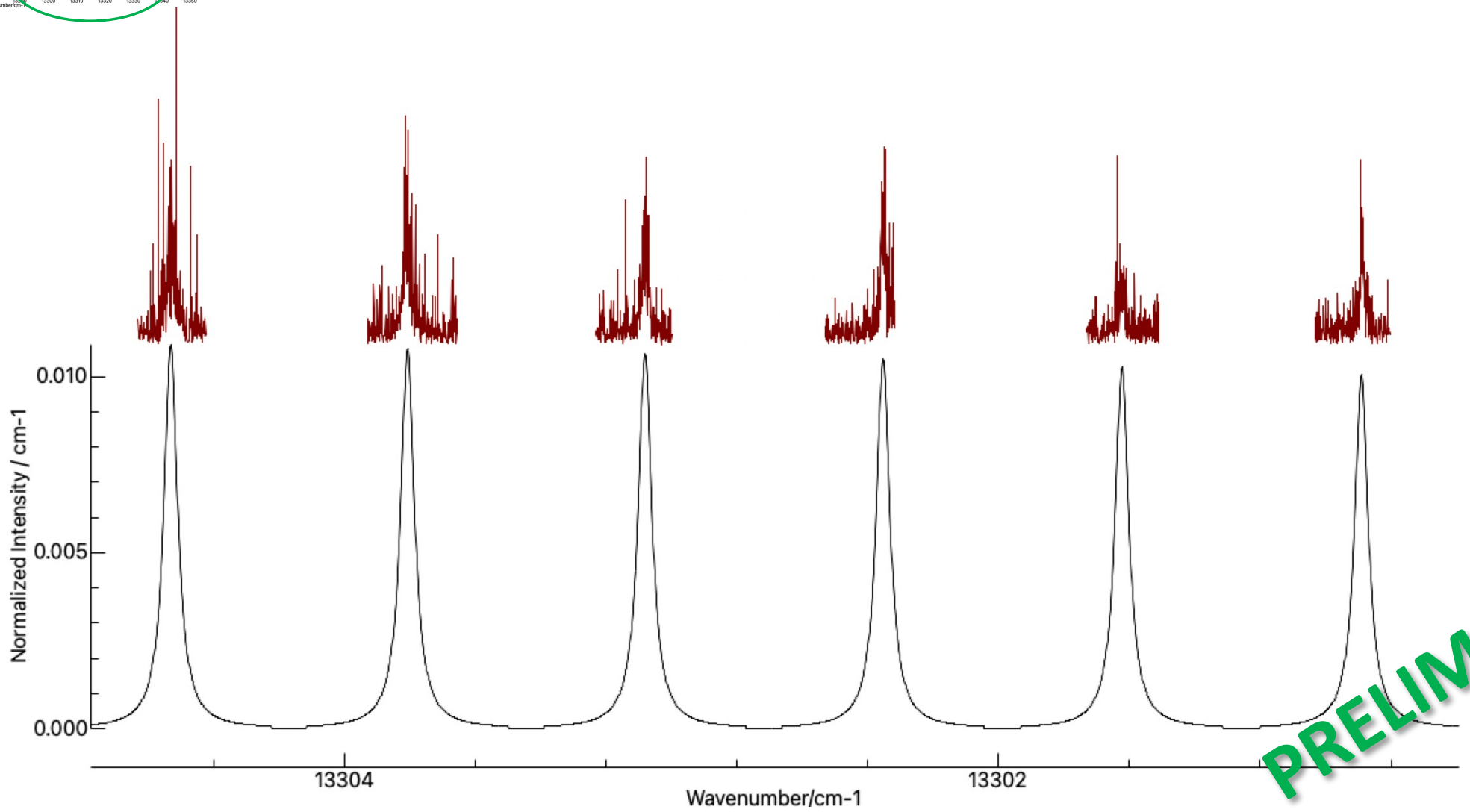
High Resolution spectroscopy of ^{226}RaF





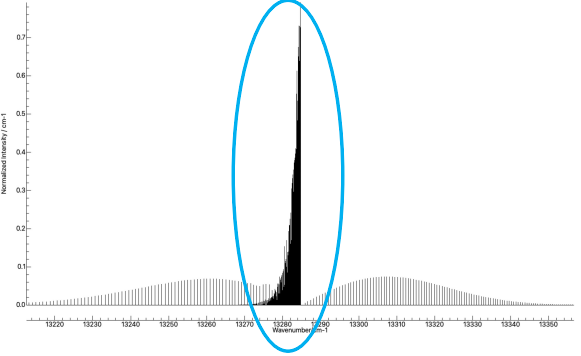
Results

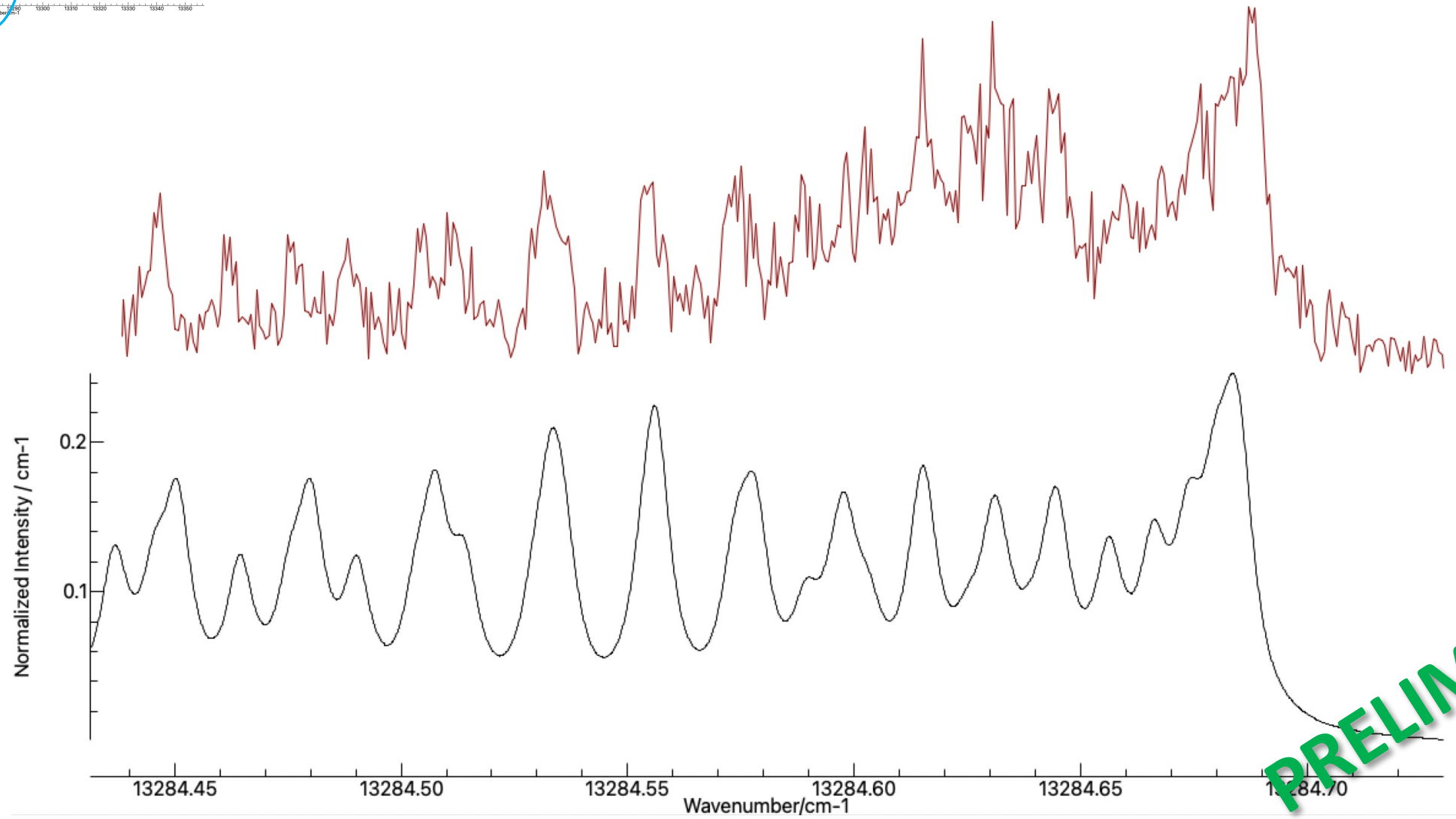




PRELIMINARY

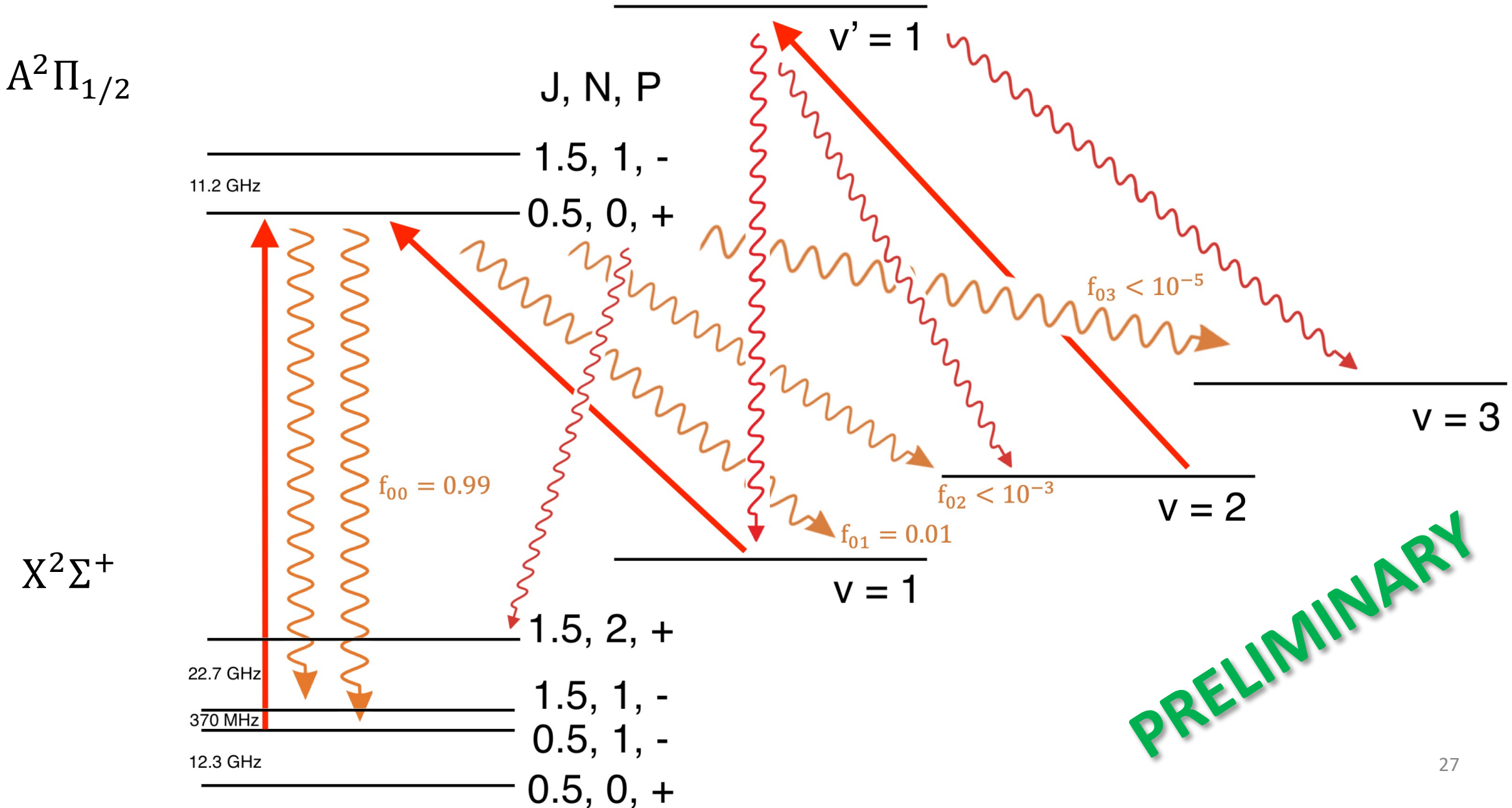
Results





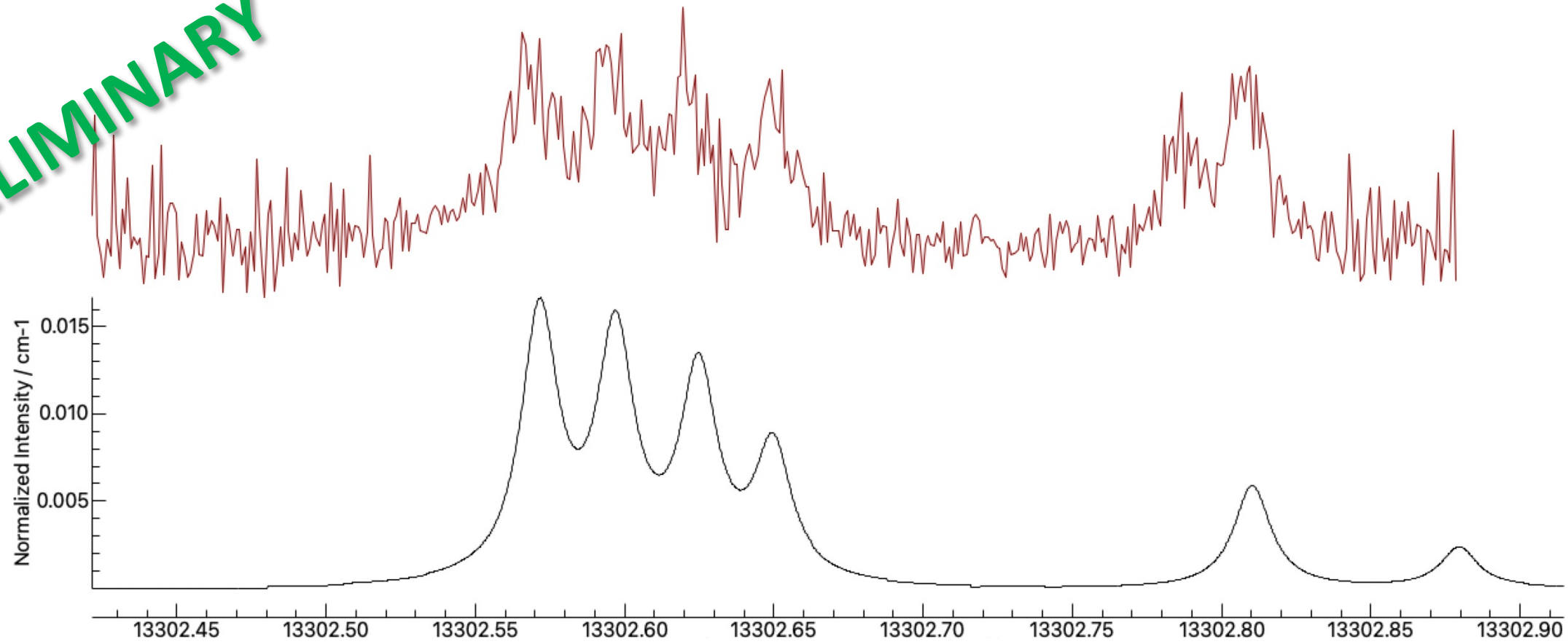
PRELIMINARY

Laser cooling scheme



High Resolution spectroscopy of ^{223}RaF (spin 3/2)

PRELIMINARY



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- Searches for P,T-odd effects (e.g. electron EDM, Nuclear Shiff moment, Nuclear magnetic quadrupole moment)
- Extend the techniques to other molecules beside RaF (e.g. ThO, PaO, RaO, RaH, AcF, RaOH, ThF^+)

Thank you!