FRIB

Collinear Laser Spectroscopy on Neutron-Deficient Al Isotopes

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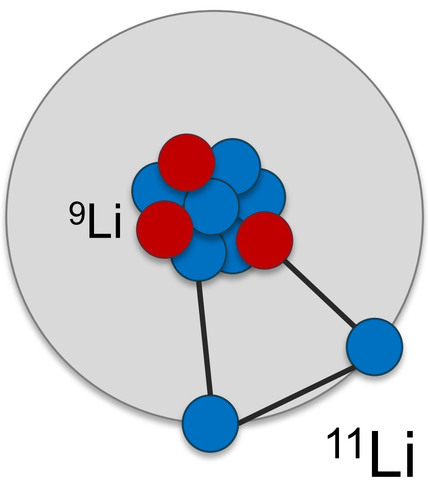
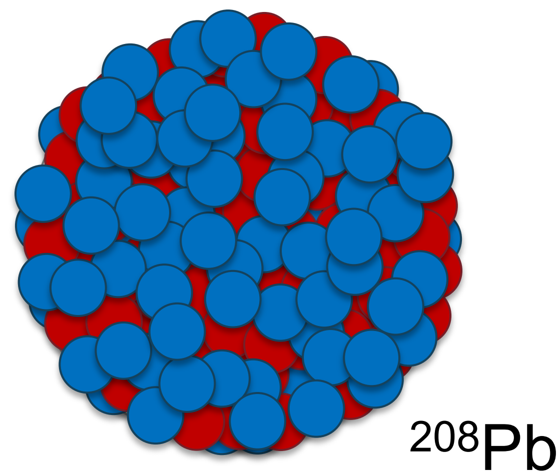
Halo Structure Near the Driplines

- Moving towards the driplines, unique structures occur, and understanding them is important to unveil driving nuclear forces.
  - Distribution beyond the compact core has been observed, including halo phenomena
- Compared to the neutron dripline the location of the proton dripline is more well known



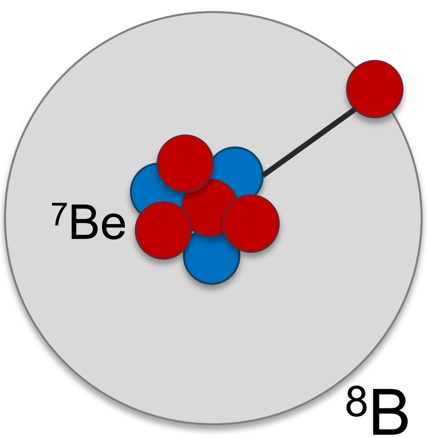


Cross Section: I. Tanihata, PRL 100, 192502 (2008)
Charge Radius: W. Nörtershäuser, Phys. Rev. C **84**, 024307 (2011)

Neutron Deficient Al Isotopes

- Proton halos are a rare phenomena due to the coulomb barrier and are hard to study due to the low production cross sections, being far from stability
- ^{22}Al and ^{23}Al lie near the proton dripline and their ground states have been thought to display proton-halo or skin phenomena

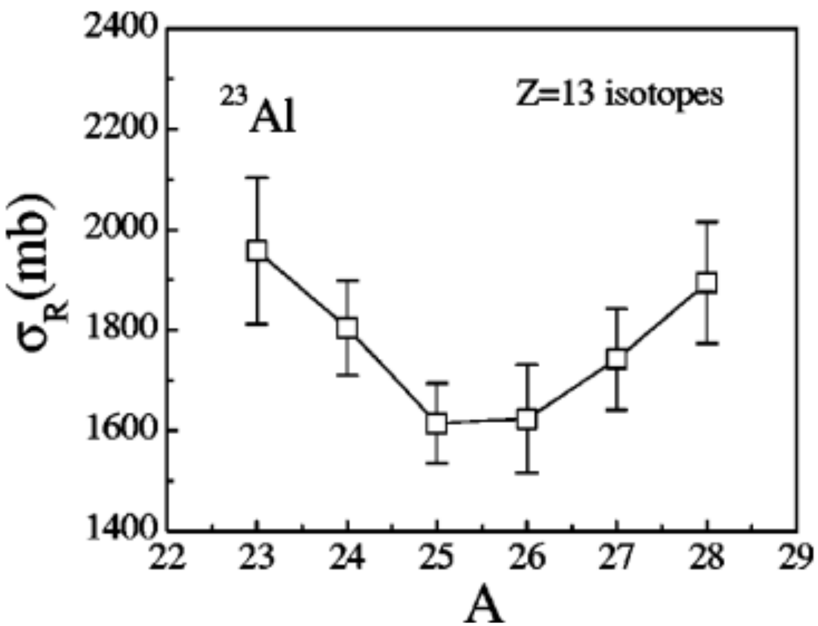
					22 Si	23 Si	24 Si	25 Si	26 Si	27 Si	28 Si	29 Si	30 Si
						22 Al	23 Al	24 Al	25 Al	26 Al	27 Al	28 Al	29 Al
				19 Mg	20 Mg	21 Mg	22 Mg	23 Mg	24 Mg	25 Mg	26 Mg	27 Mg	28 Mg
						20 Na	21 Na	22 Na	23 Na	24 Na	25 Na	26 Na	27 Na
				17 Ne	18 Ne	19 Ne	20 Ne	21 Ne	22 Ne	23 Ne	24 Ne	25 Ne	26 Ne
					17 F	18 F	19 F	20 F	21 F	22 F	23 F	24 F	25 F
		13 O	14 O	15 O	16 O	17 O	18 O	19 O	20 O	21 O	22 O	23 O	24 O
		12 N	13 N	14 N	15 N	16 N	17 N	18 N	19 N	20 N	21 N	22 N	23 N
9 C	10 C	11 C	12 C	13 C	14 C	15 C	16 C	17 C	18 C	19 C	20 C	21 C	22 C
8 B	9 B	10 B	11 B	12 B	13 B	14 B	15 B	16 B	17 B	18 B	19 B	20 B	21 B
7 Be	8 Be	9 Be	10 Be	11 Be	12 Be	13 Be	14 Be	15 Be	16 Be	17 Be	18 Be	19 Be	20 Be
6 Li	7 Li	8 Li	9 Li	10 Li	11 Li	12 Li	13 Li	14 Li	15 Li	16 Li	17 Li	18 Li	19 Li



Cross Section: I. Tanihata, et al. PRL 55, 24 (1985)
Quadrupole Moment: T. Minamisono, et al. PRL 69, 14 2058 (1992)

Neutron Deficient Al Isotopes

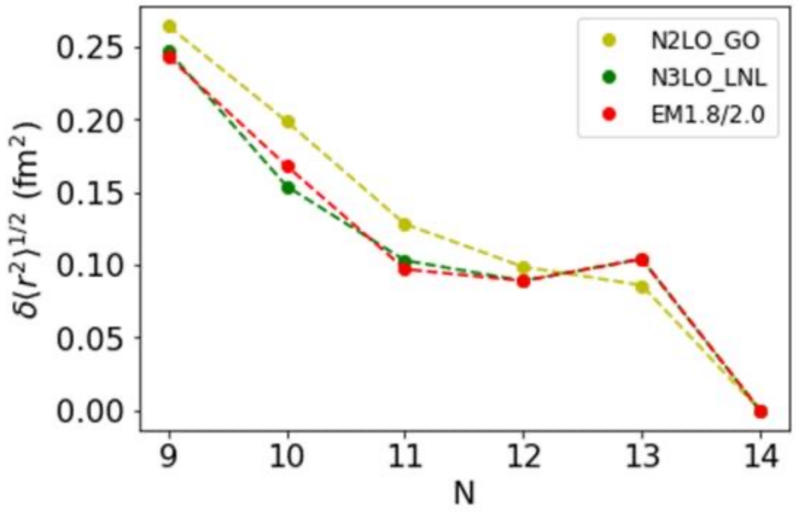
- Why ^{22}Al and ^{23}Al possibly have a proton-halo phenomena
  - Have a small proton separation energy, seen from systematic trends in the mass region; ~100 and 140.9 keV for ^{22}Al and ^{23}Al respectively[1]
  - Notable enhancement in its reaction cross section, although with a large uncertainty[2]
  - Loosely bound single proton attributed to isospin symmetry breaking interactions when compared to its mirror pair which does not display a halo structure[3]



(1) W. Huang, et al. Chinese Physics C 45, 030002 (2021).; (2) Cali, X. Z. et al. PRC 65(2), 246101-246105 (2002).; (3) J. Lee, et al., PRL 125, 192503 (2020).

Neutron Deficient Al Isotopes

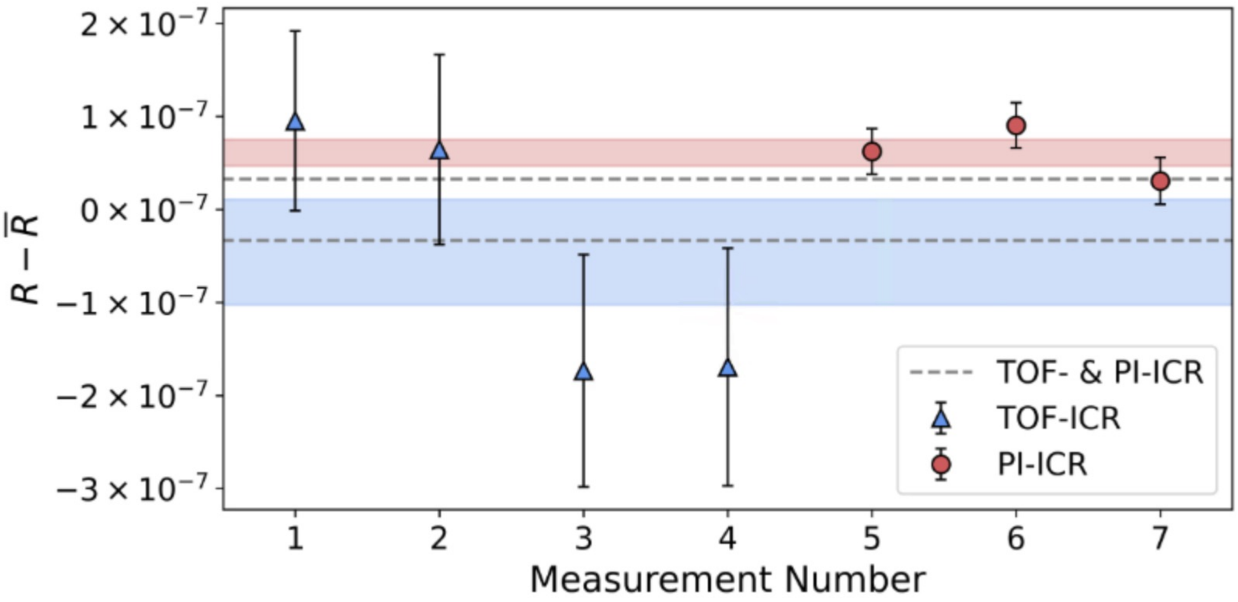
- Why ^{22}Al and ^{23}Al possibly have a proton-halo phenomena
  - Mean field calculations of its charge distribution support large quadrupole deformation[1]
  - An increasing radial extent predicts an increase of the mean square charge radius up to ^{22}Al[2]
  - The spin is known to be large, 4+ and 5/2+ for ^{22}Al and ^{23}Al respectively, and leads towards the final proton being in the d orbit in the ground state, which does not support existence of a halo structure



(1) R. Panda, et al. Physics of Atomic Nuclei 81, 417 (2018).; (2) "Valence-Space In-Medium-Similarity Renormalization Group Calculations" with different nuclear forces. (J. Holth et al.)

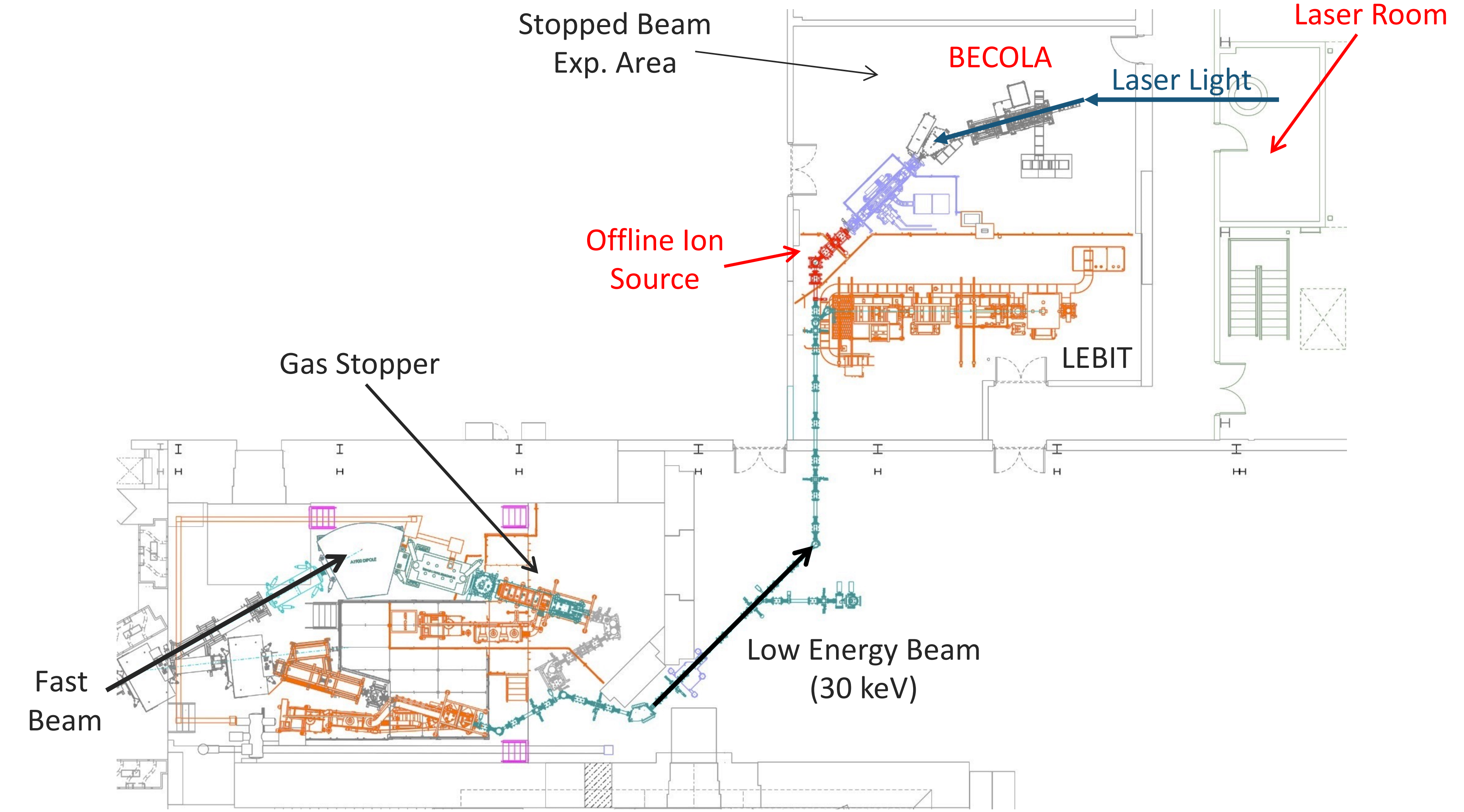
Neutron Deficient Al Isotopes

- Why ^{22}Al and ^{23}Al possibly have a proton-halo phenomena
  - First precision mass measurement of ^{22}Al performed by LEBIT observed a small proton separation energy of 99.2(1.0) keV which agrees with predictions made with the *sd*-shell USD Hamiltonians[1]
  - Investigating the result with the particle-plus-rotor model which includes coupling to continuum states does not lead to significant deformation or a fully developed halo structure[1]

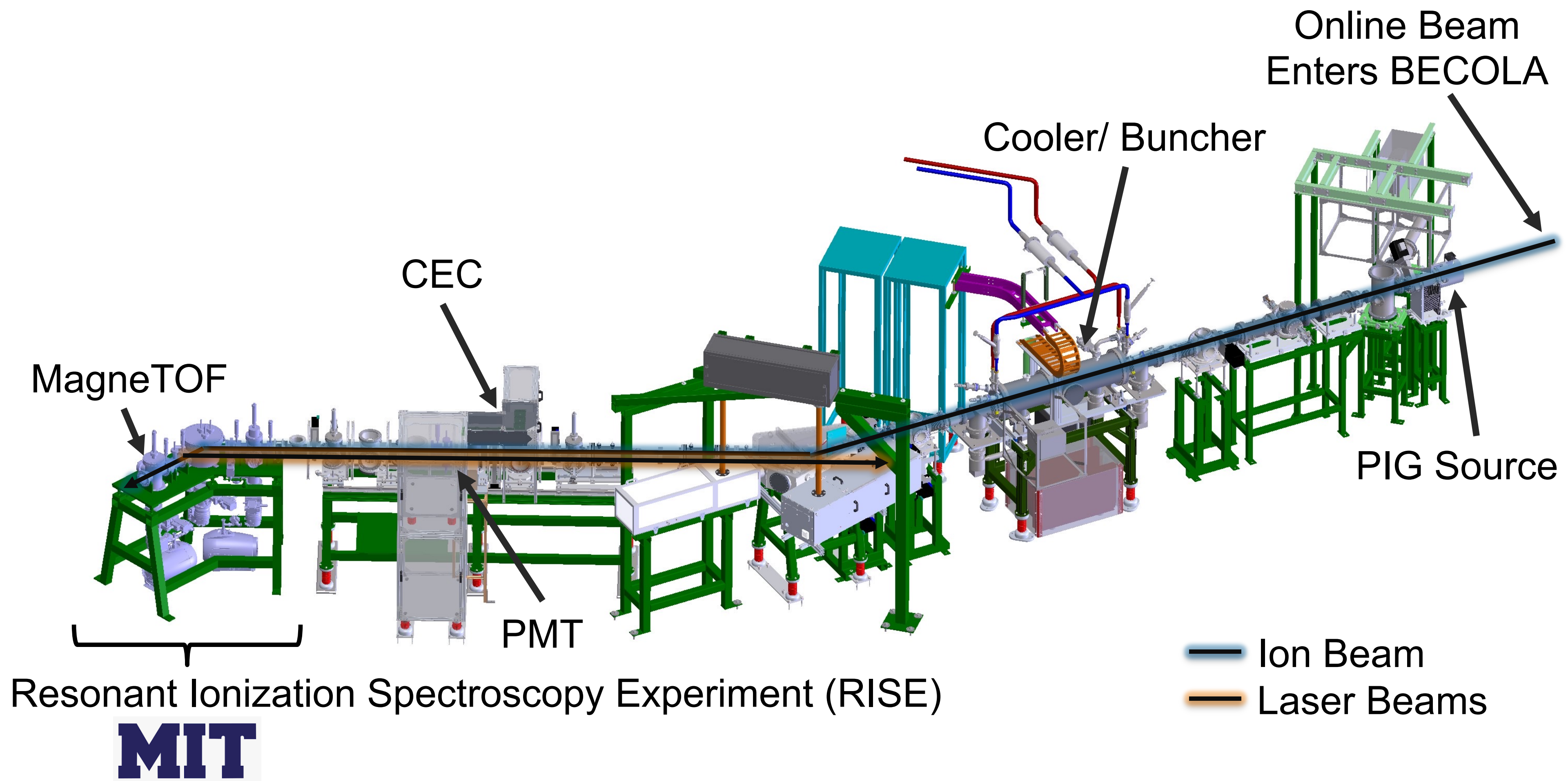


(1) Campbell, S. E., et al. Physical Review Letters 132.15: 152501(2024).

Stopped Beam Experimental Area



BECOLA Beamline



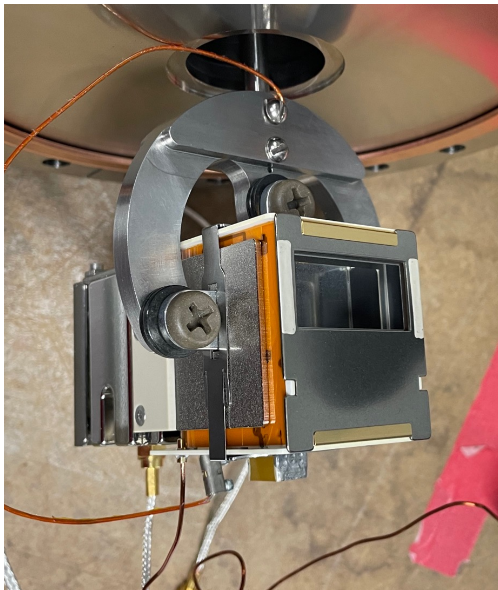
BECOLA - RISE

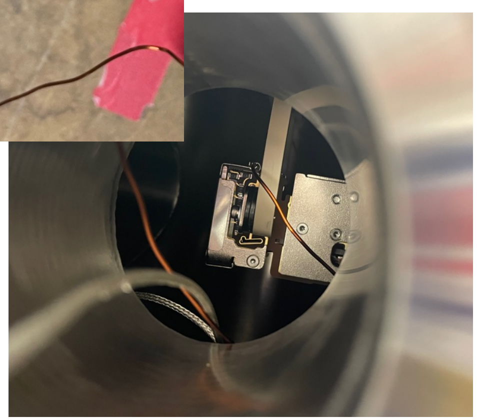
- The RISE install included an injection seeded cavity and upgrade to the BECOLA light transport system

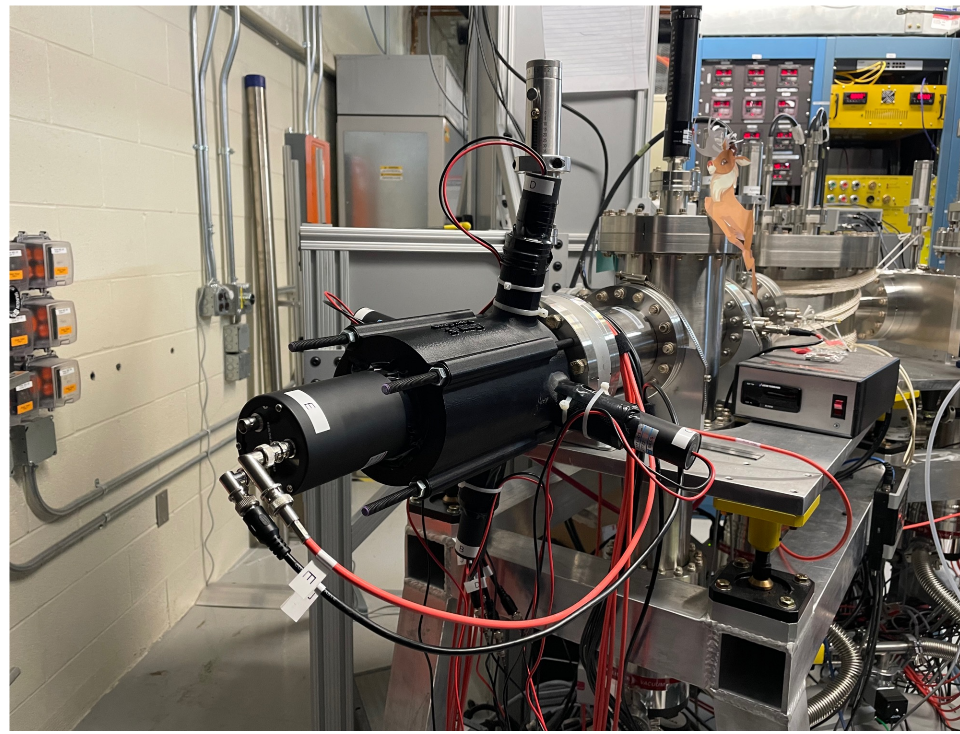
Injection Seeded Cavity photos removed for uploading slides to conference website.

BECOLA - RISE

- Two new detectors – MagneToF and Beta Detector

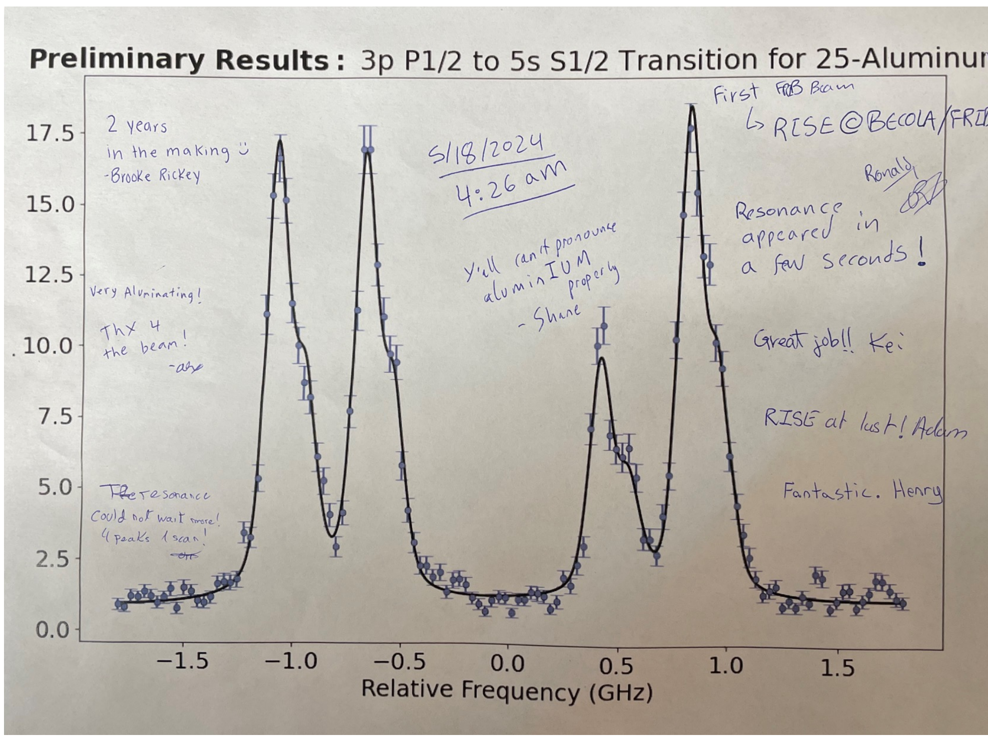


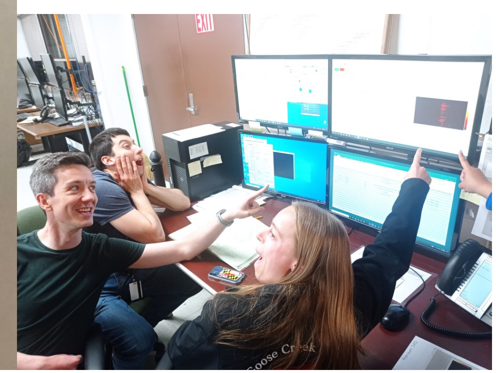




BECOLA - RISE

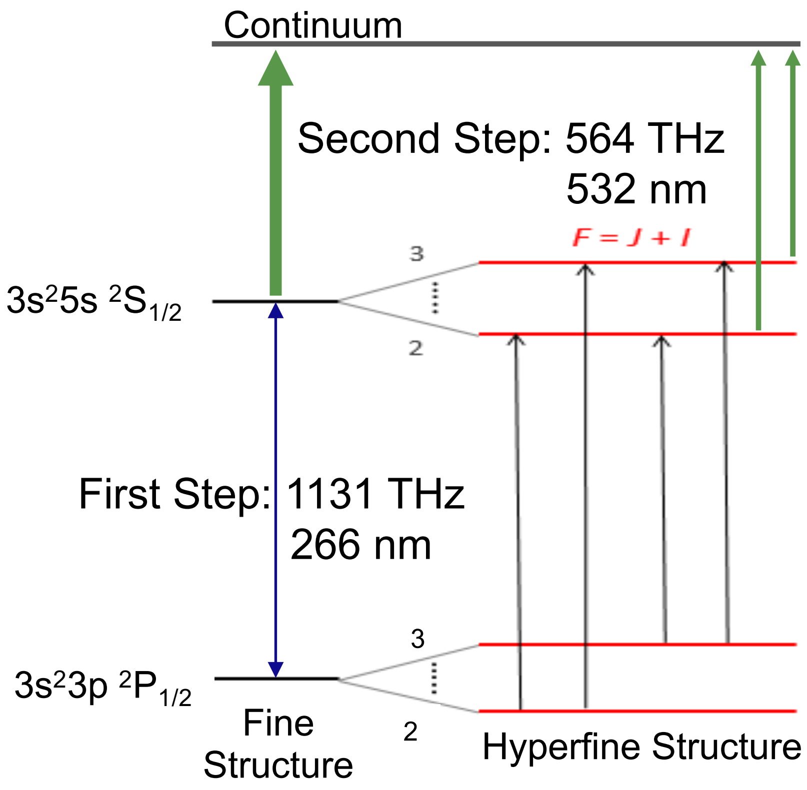
- In 2022 the RISE Beamline was added to the BECOLA beamline and was successfully commissioned with stable ^{27}Al
  - Throughout 2022-2023 7 transitions, involving 6 different states, were measured
- The RISE beamline received its first online FRIB beam on the 18th of May 2024





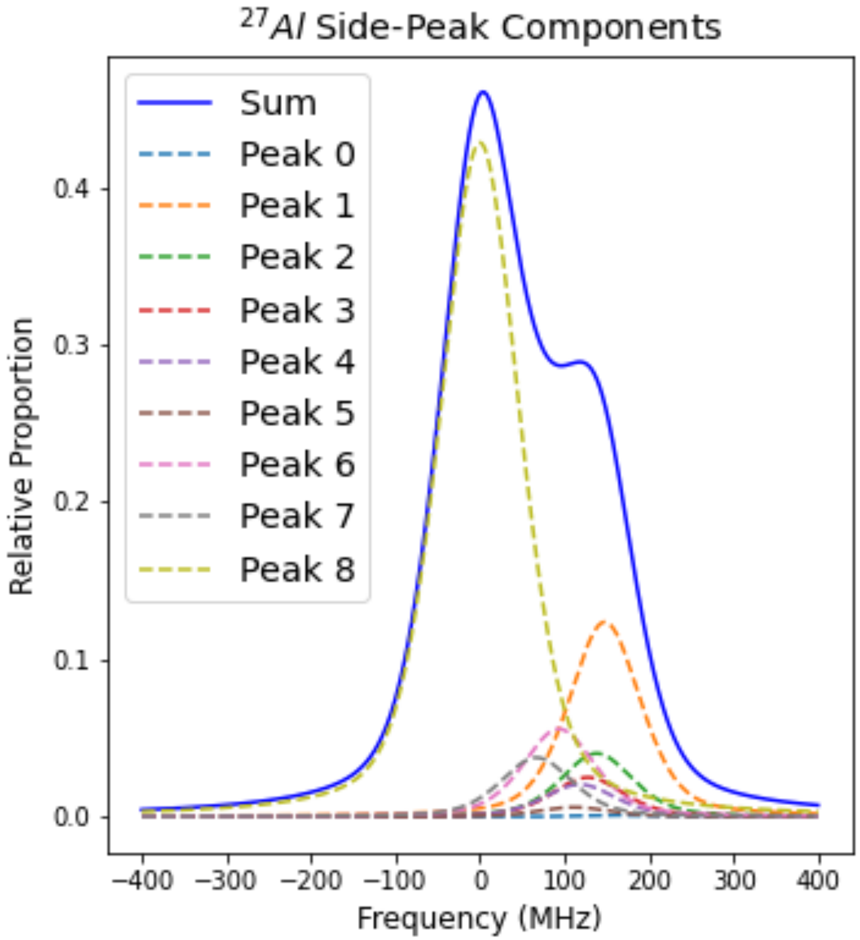
BECOLA – RISE Experiment

- At the BEam COoling LAser spectroscopy (BECOLA) facility at the Facility for Rare Isotope Beams (FRIB) we measured the change in mean-square nuclear charge radii for $^{22-25}Al$
  - Charge radius is a direct measurement of the proton distribution



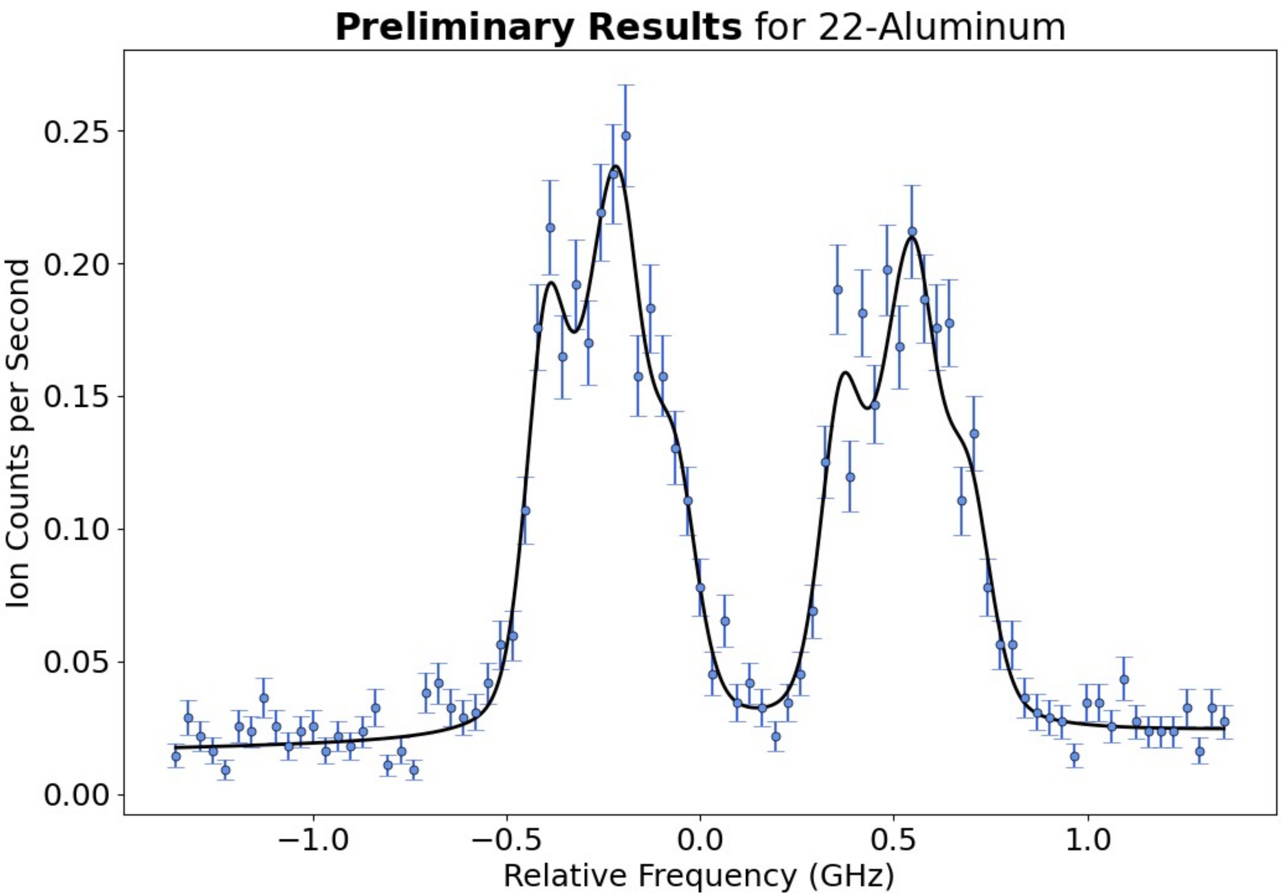
Aluminum Line-shape

- The charge-exchange reaction and in-flight spontaneous decay were simulated by Adam Dockery to find contributing energy components and relative amplitudes
- No free variables were introduced for side-peak amplitude or separation distance
- To maintain the line-shape and avoid inelastic collisions in the charge-exchange cell a low neutralization efficiency was used for the experiment



Preliminary Results

- $^{22-25}$Al were successfully measured at BECOLA-RISE



Preliminary Results

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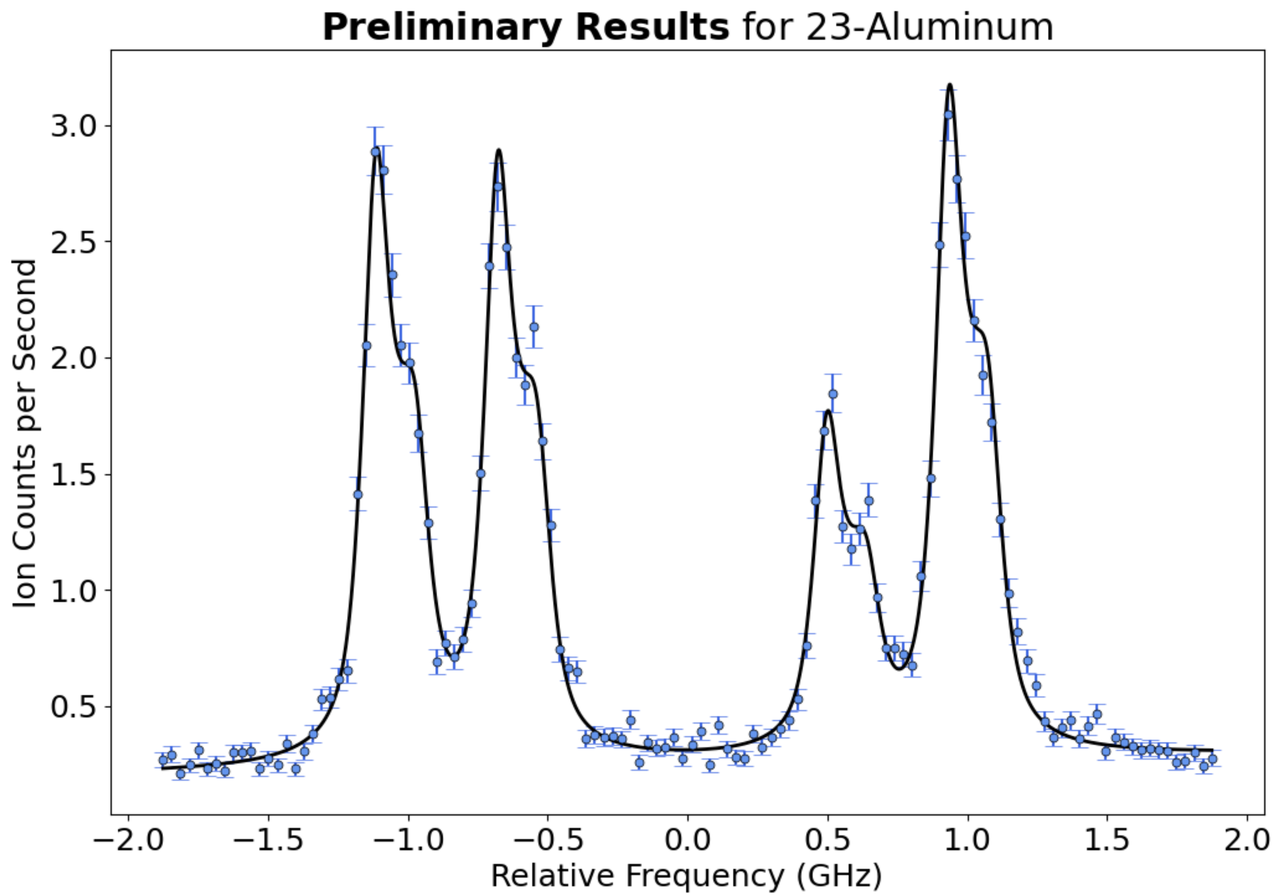

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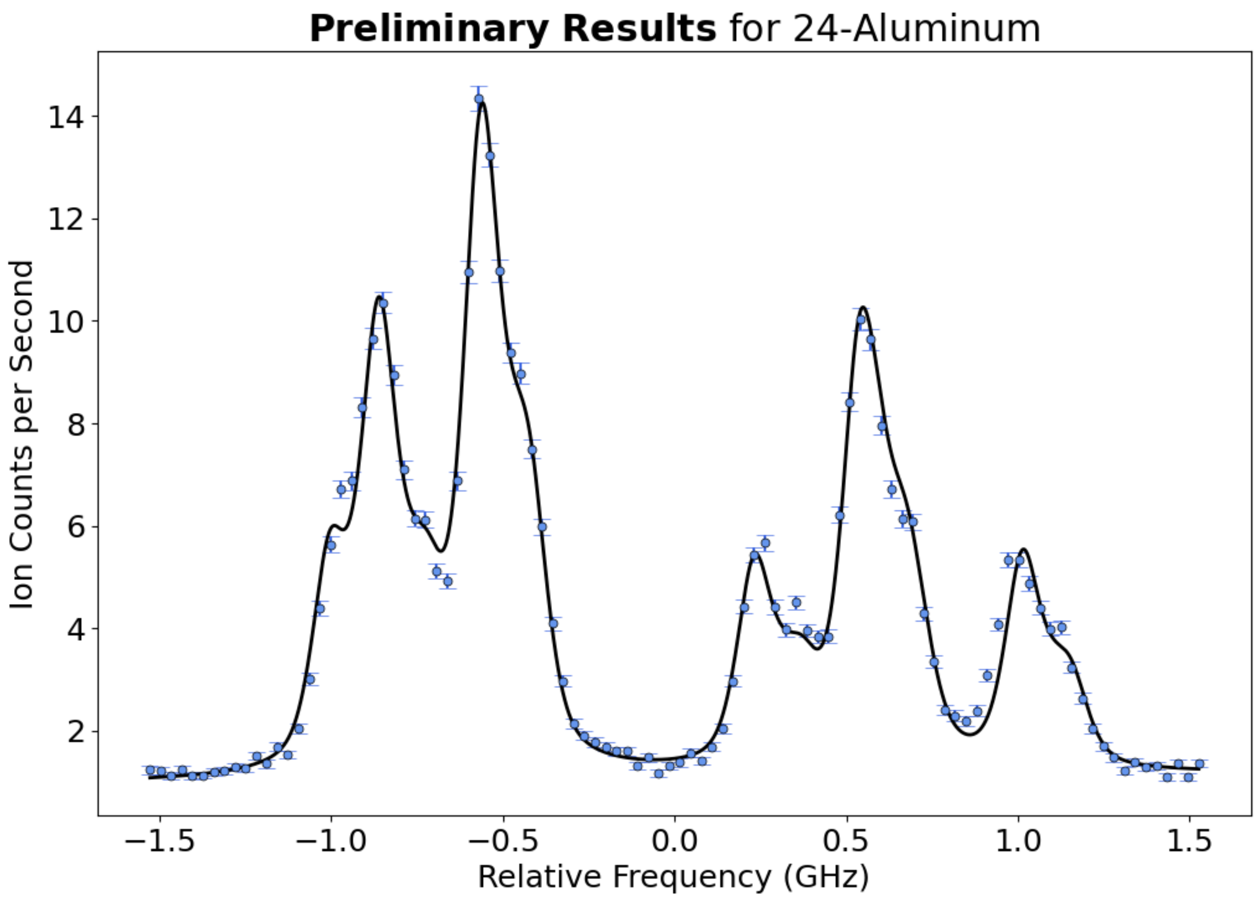

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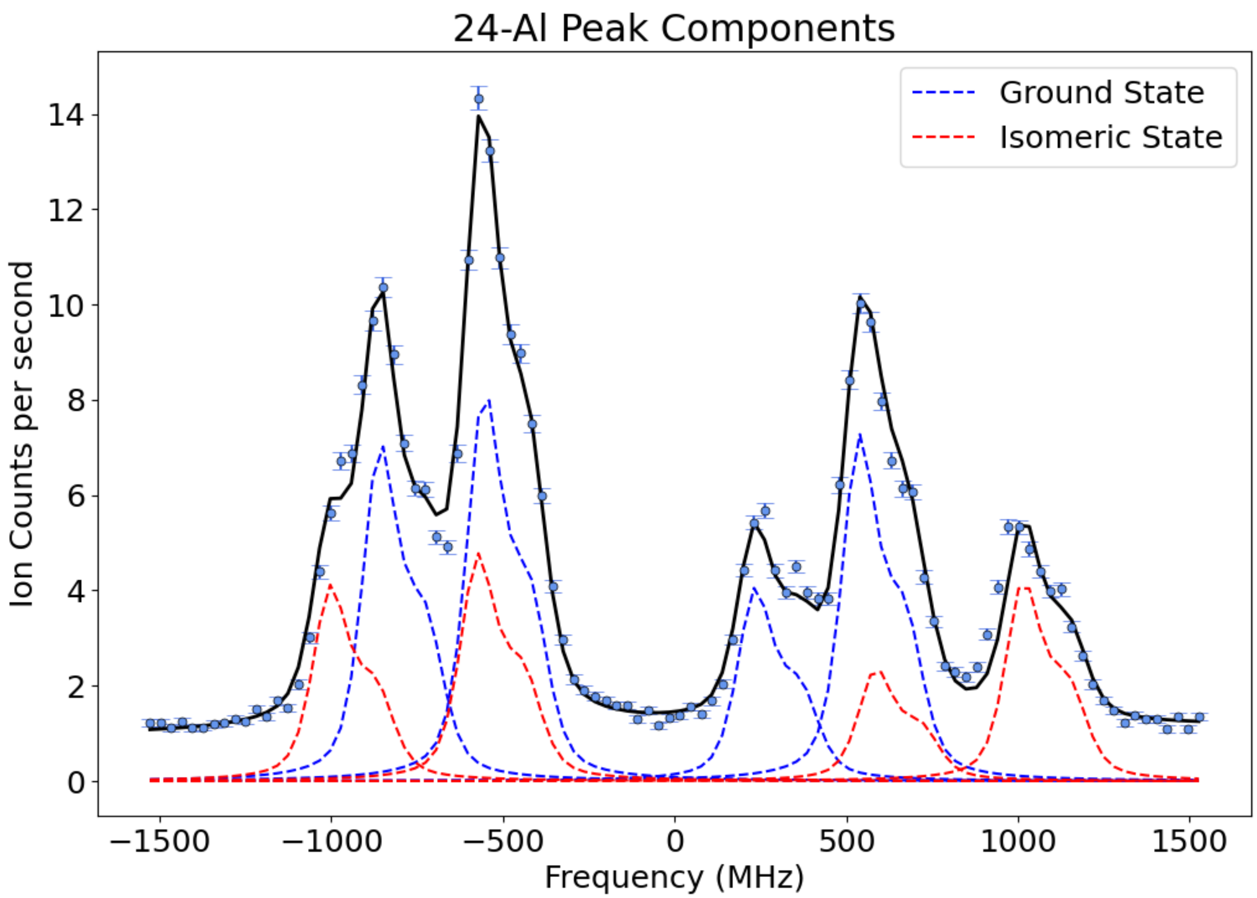

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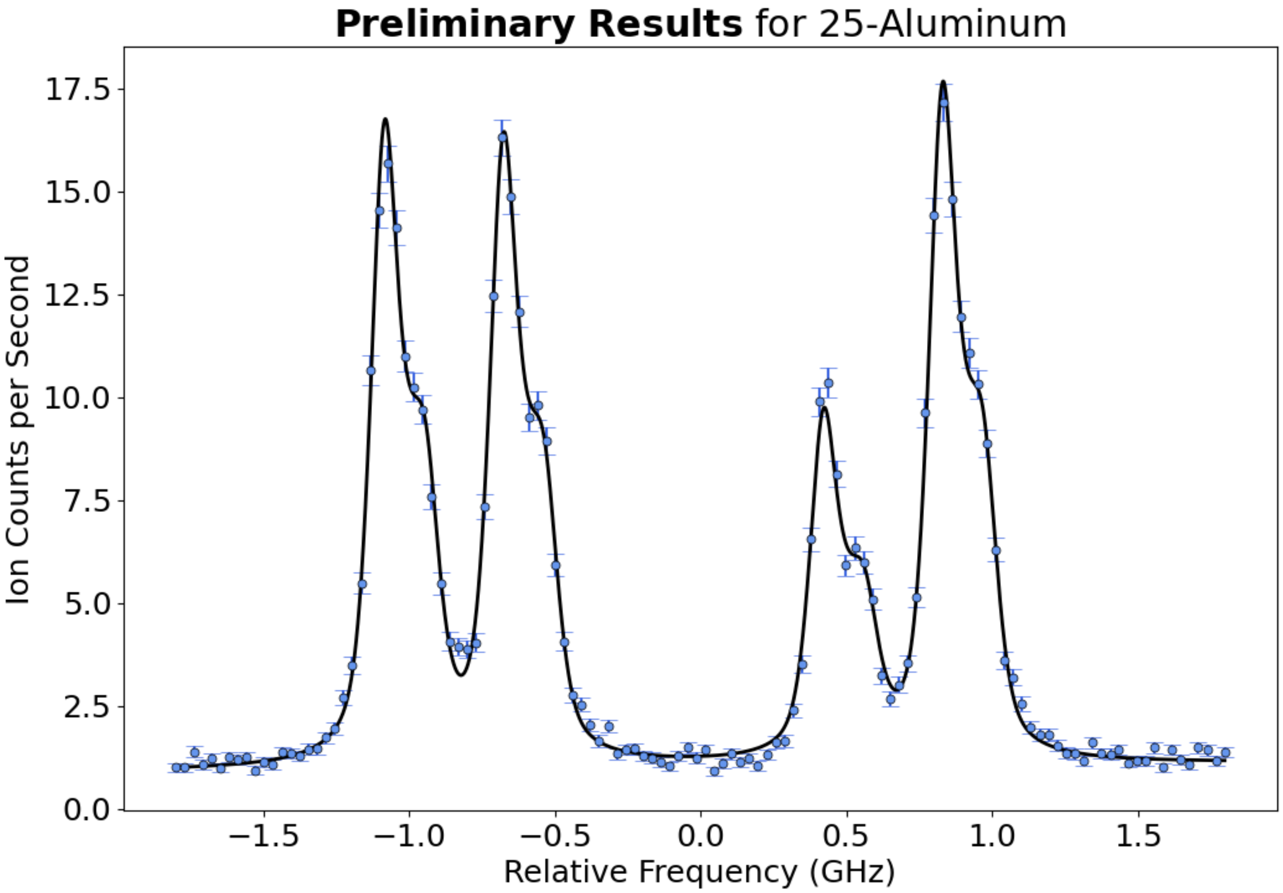

Principle to Deduce Charge Radius

- Isotope shift: frequency shift of an atomic transition between different isotopes
  - $\delta v^{A,A'} = \delta v^{A,A'}_{mass\ shift} + \mathrm{F(Z)}\delta\langle r^2\rangle^{A,A'}$
  - Theoretical calculations of atomic factors are available through Leonid Skripnikov (Saint Petersburg State University)[1]
    - » F = 70.11(12) $\frac{MHz}{fm^2}$
    - » K_{MS} = -0.7(2.1) GHz u

Results from the Aluminum experiment will be published in a future publication.

(1) Skripnikov, I., et al. arXiv:2404.13369v1 [physics.atom-ph] 20 Apr 2024.

Preliminary Results

- Preliminary charge radii trend

Results from the Aluminum experiment
will be published in a future publication.

Preliminary Results

- Preliminary results with published $^{28-32}$Al values

Results from the Aluminum experiment
will be published in a future publication.

Conclusions

- The RISE beamline was successfully added to the BECOLA beamline and commissioned with Aluminum
- Preliminary results for the differential mean square charge radii were obtained for $^{22-25}Al$
- A detailed analysis of the online Aluminum data is ongoing and a publication of the results will be written

Thank you

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  - Henry Sims

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    - Jonas Karthein
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*Currently at Duke University