Addendum to IS 449

Measurement of the isotope shift of ^{7,9,10,11}Be at COLLAPS

The BeTINa Collaboration

W. Nörtershäuser[1,2], K. Blaum[1,2], J. Ebele[4], Ch. Geppert[2], M. Kowalska[3], J. Krämer[1], R. Neugart[1], R. Sanchez[1], F. Schmidt-Kaler[4], D. Tiedemann[1], D. Yordanov[3], M. Zakova[1], C. Zimmermann[5]

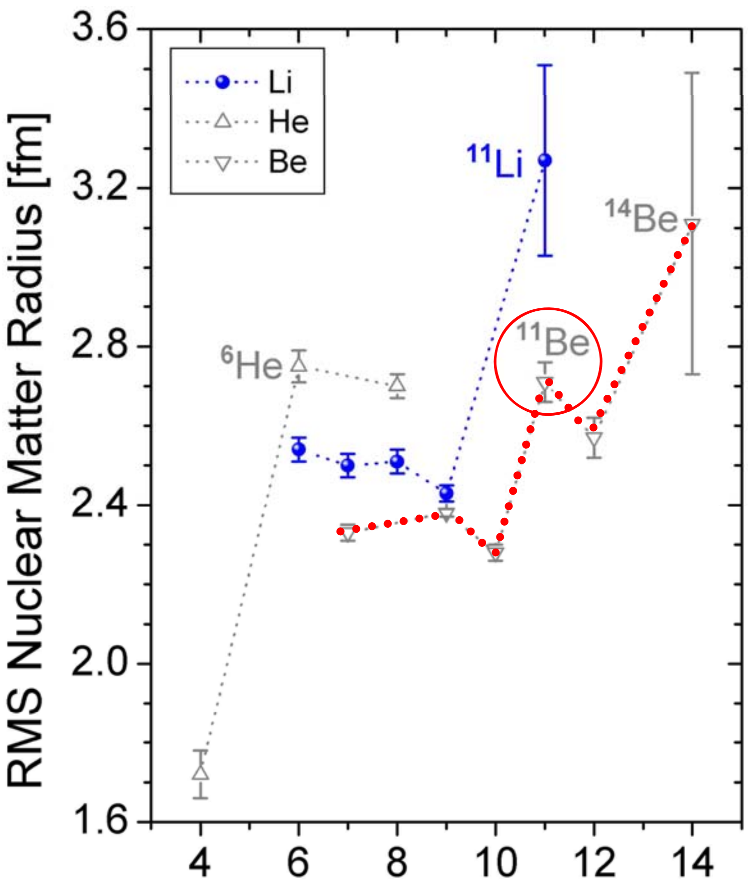
[1] Johannes Gutenberg-Universität Mainz, Germany
[2] GSI Darmstadt, Germany
[3] CERN, CH-1211 Genéve 23, Switzerland
[4] Universität Ulm, Germany
[5] Eberhard-Karls Universität Tübingen, Germany

Spokespersons: W. Nörtershäuser, C. Geppert
Local Contacts: D. Yordanov, M. Kowalska

Laser Spectroscopy of Highly Charged Ions and Exotic Radioactive Nuclei
(Helmholtz Young Investigators Group)

http://www.kernchemie.uni-mainz.de/laser

Radii of Halo Isotopes



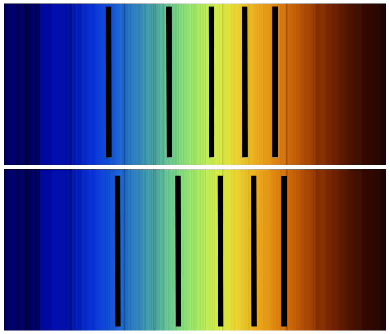
Charge radius measurements of light (Z<18) radioactive isotopes:

- 2003 : ^{6,7,8,9}Li at GSI G.Ewald et al., PRL 93, 113002 (2004)
- 2004: ^{6}He at Argonne, L.-B. Wang et al. PRL 93, 142501 (2004)
- 2004: ^{11}Li at TRIUMF, R. Sanchez et al., PRL 96, 033002 (2006
- 2007: ^{8}He at GANIL, P. Müller et al. PRL 99, 252501 (2007)

Isotope Shift

Isotop 1

Isotop 2



= Frequency difference in an electronic transition between two isotopes

$$\Delta\nu_{IS} = \Delta\nu_{MS} + \Delta\nu_{FS}$$

$$\frac{2\pi Z}{3} \Delta|\psi(0)|^2 \, \delta\langle r^2 \rangle$$ **Field Shift**

Mass Effect, nuclear motion

finite size of the nucleus

$$MS \propto \frac{A - A'}{AA'} \xrightarrow{A \gg 1} \frac{1}{A^2}$$

$$FS \propto \frac{Z^2}{\sqrt[3]{A}}$$

He, Li, Be : 10 GHz ⟷ 0.001 GHz

Charge Radii Determination for Light Elements

$$\Delta\nu_{IS} = \Delta\nu_{MS} + \Delta\nu_{FS}$$

$$\Delta\nu_{FS} = \frac{2\pi Z}{3}\,\Delta|\psi(0)|^2\;\delta\langle r^2\rangle$$

EXPERIMENT → $\Delta\nu_{IS}$

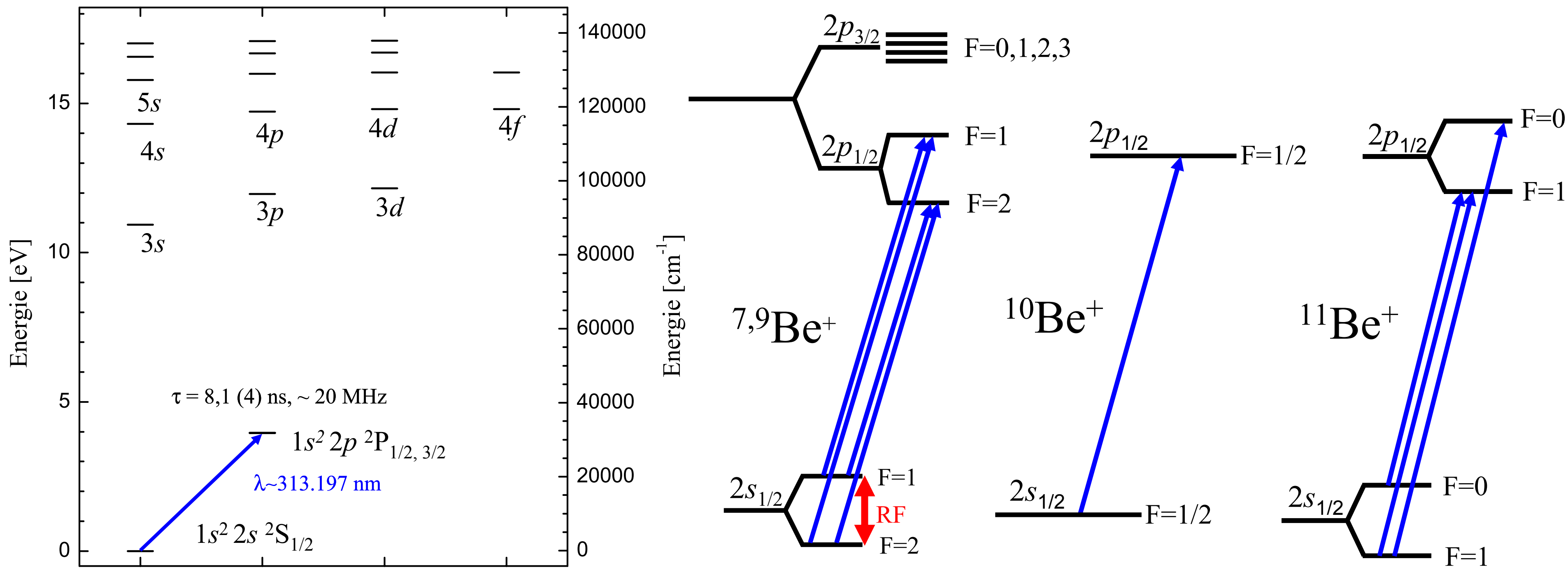
THEORY → $\Delta\nu_{MS}$, $\Delta|\psi(0)|^2$

Charge Radius :

$$\delta\langle r^2\rangle^{A,A'} = \frac{\Delta\nu^{A,A'}_{measured} - \Delta\nu^{A,A'}_{MS,\,Theory}}{C}$$

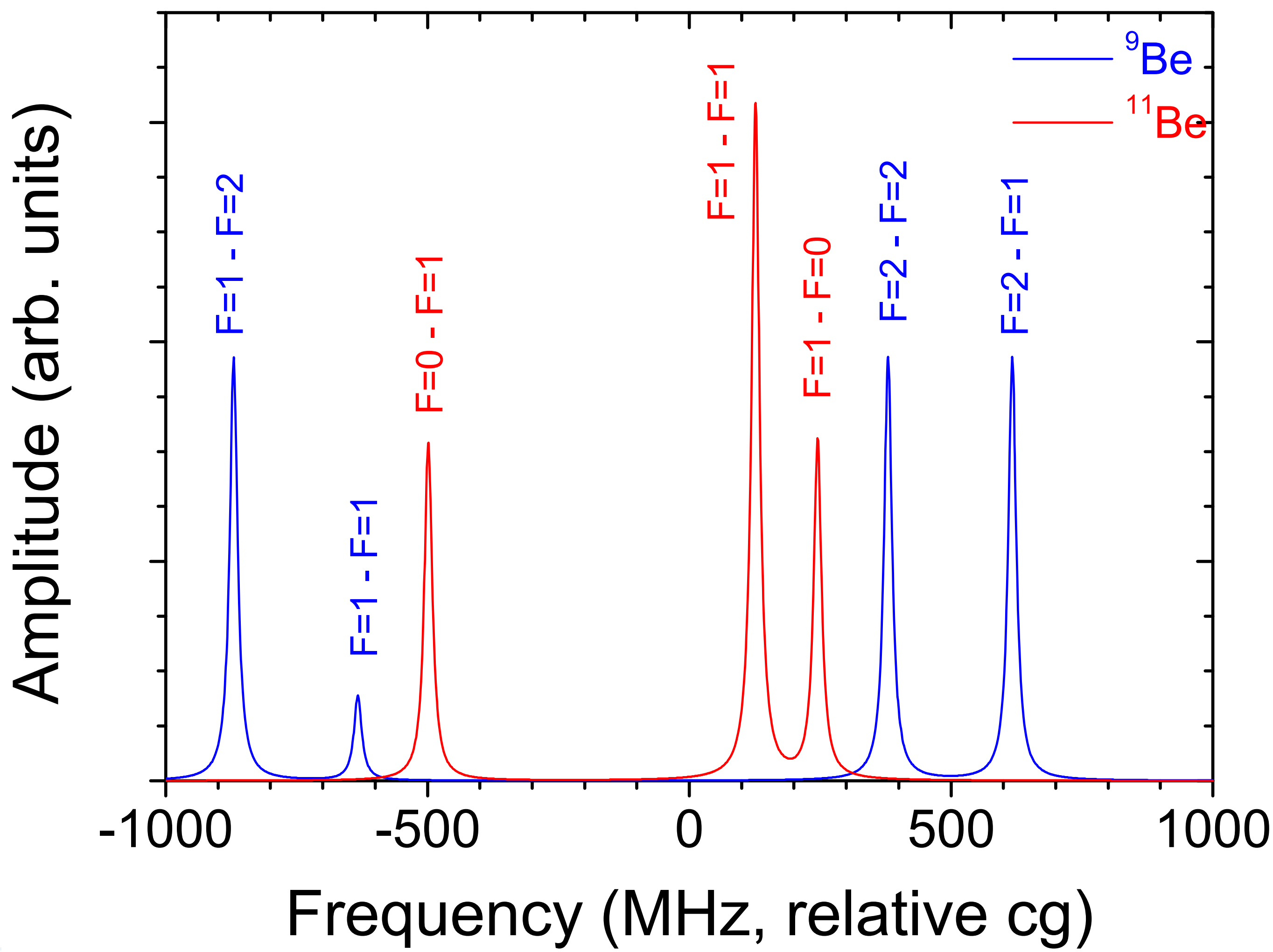
Isotope	$\delta\nu^{A,7}_{MS}$ [Puch06]	$\delta\nu^{A,7}_{MS}$ [Drake06]
^{6}Li	- 11 452.822 (2) (0)	-11 452.83 (2)
^{8}Li	8 634.990 (1) (1)	8 634.98 (2)
^{9}Li	15 331.797 (3)(13)	15332.03 (3)
^{11}Li	25 101.473 (9)(21)	25101.42 (3)

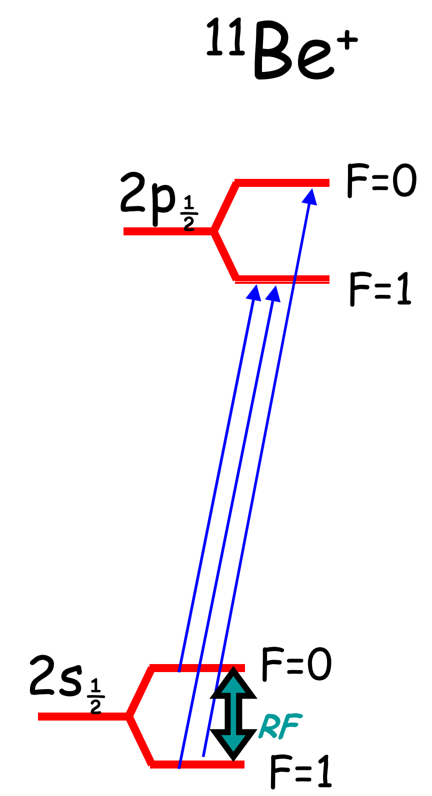
Level Scheme and Be^+ Transitions



Simulated Spectra

$\Gamma_{nat} \approx 20$ MHz





Why COLLAPS ?

- Standard collinear measurements are limited by the uncertainty of the acceleration voltage

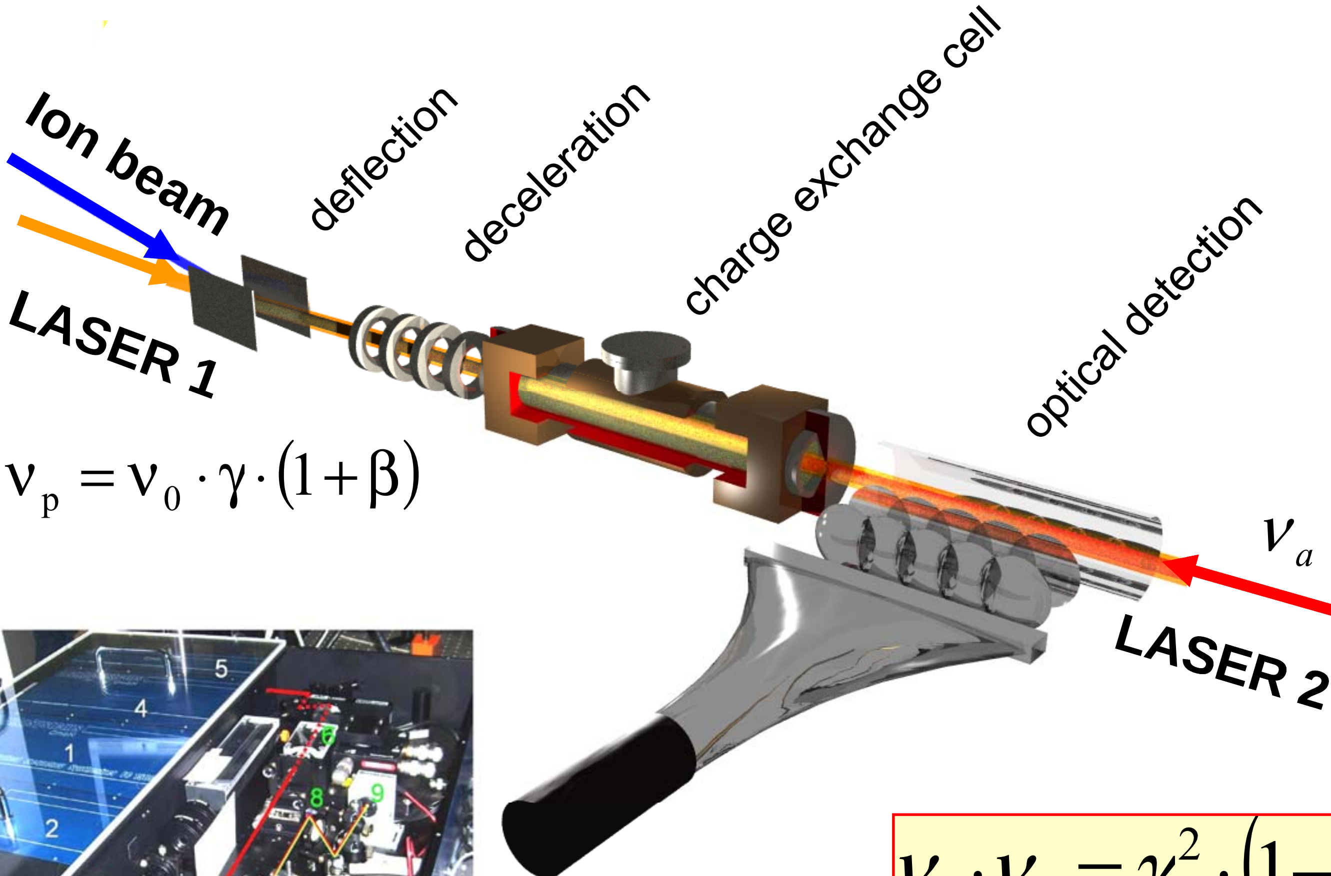
  Use “simultaneous” collinear-anticollinear measurement and absolute frequency determination with a frequency comb

- Field shift is too small in light isotopes

  FS constant in Be^+ 2*s*-2*p* is considerably larger than in lithium 2*s*-2*p* or 2*s*-3*s* since the electron is stronger bound

⇒ Charge radii can be measured to a good accuracy with COLLAPS if we apply "new" techniques !

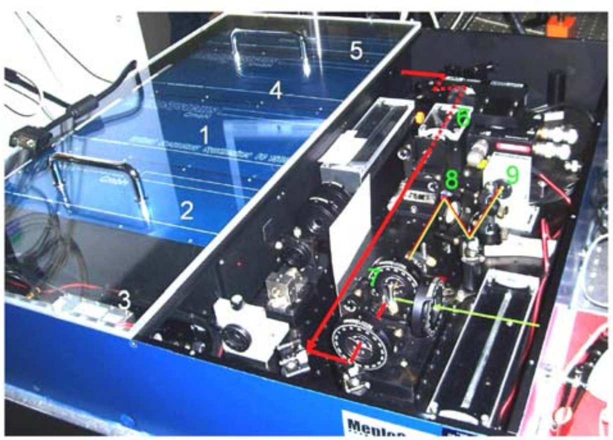
Approach



$$\nu_p = \nu_0 \cdot \gamma \cdot (1+\beta)$$

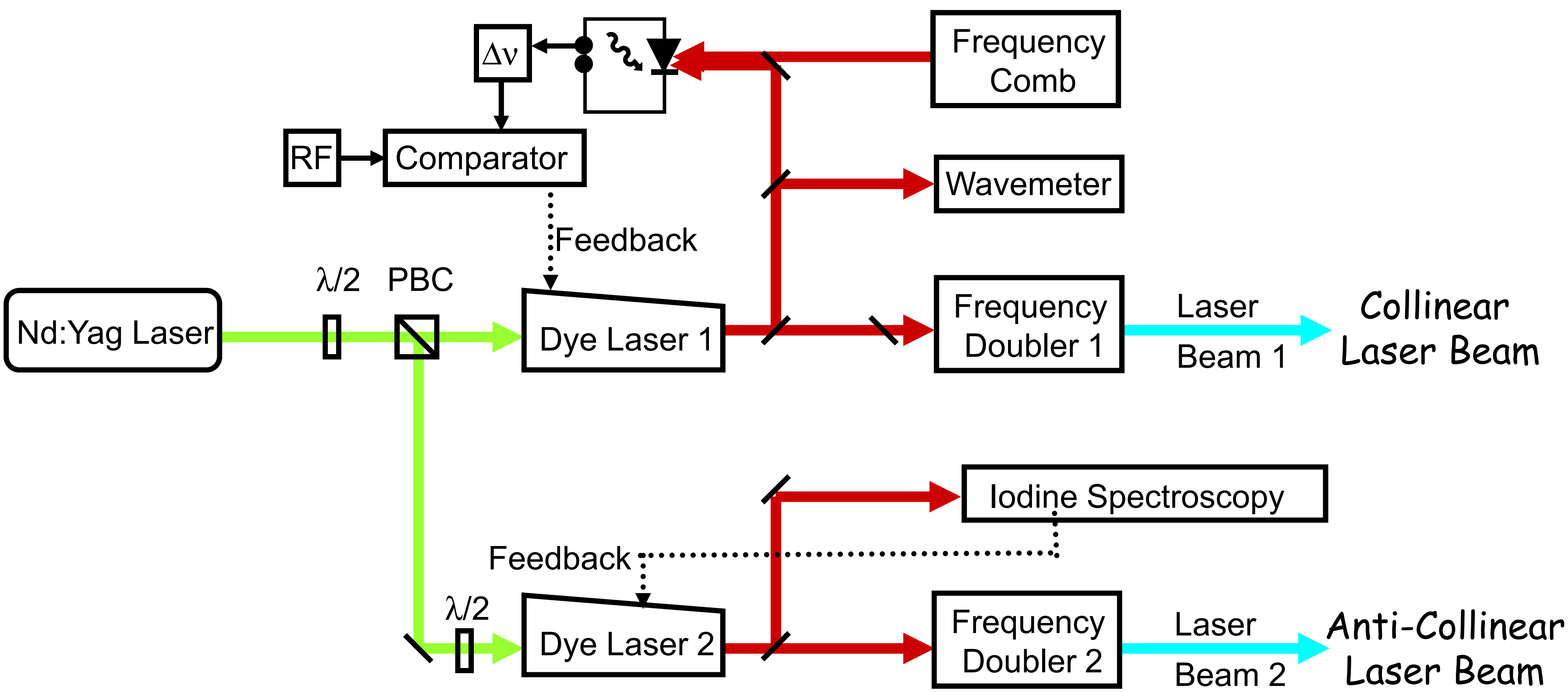
$$\nu_a = \nu_0 \cdot \gamma \cdot (1-\beta)$$

$$\nu_a \cdot \nu_p = \gamma^2 \cdot (1-\beta^2)\nu_0^2 = \nu_0^2$$

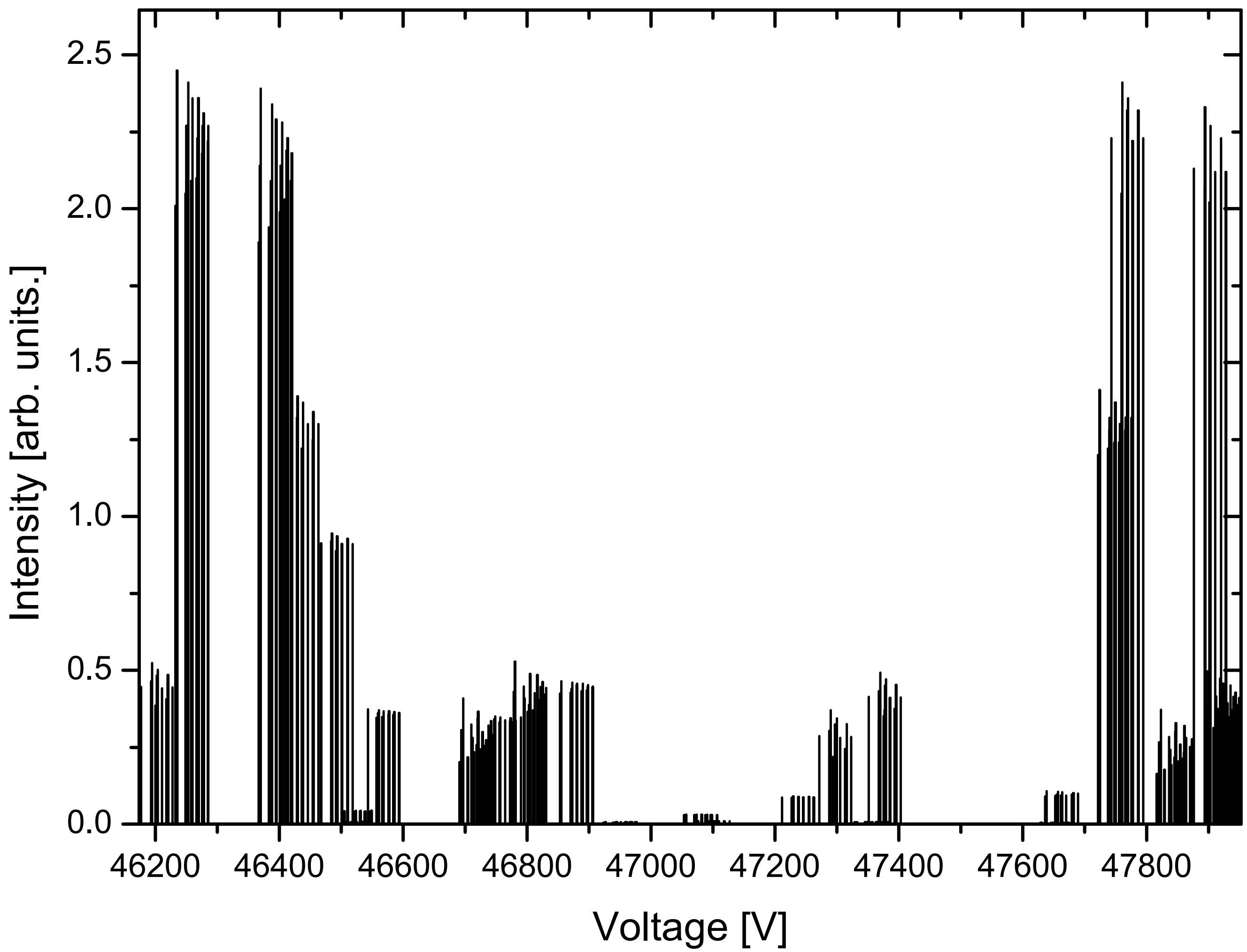


Frequency Comb

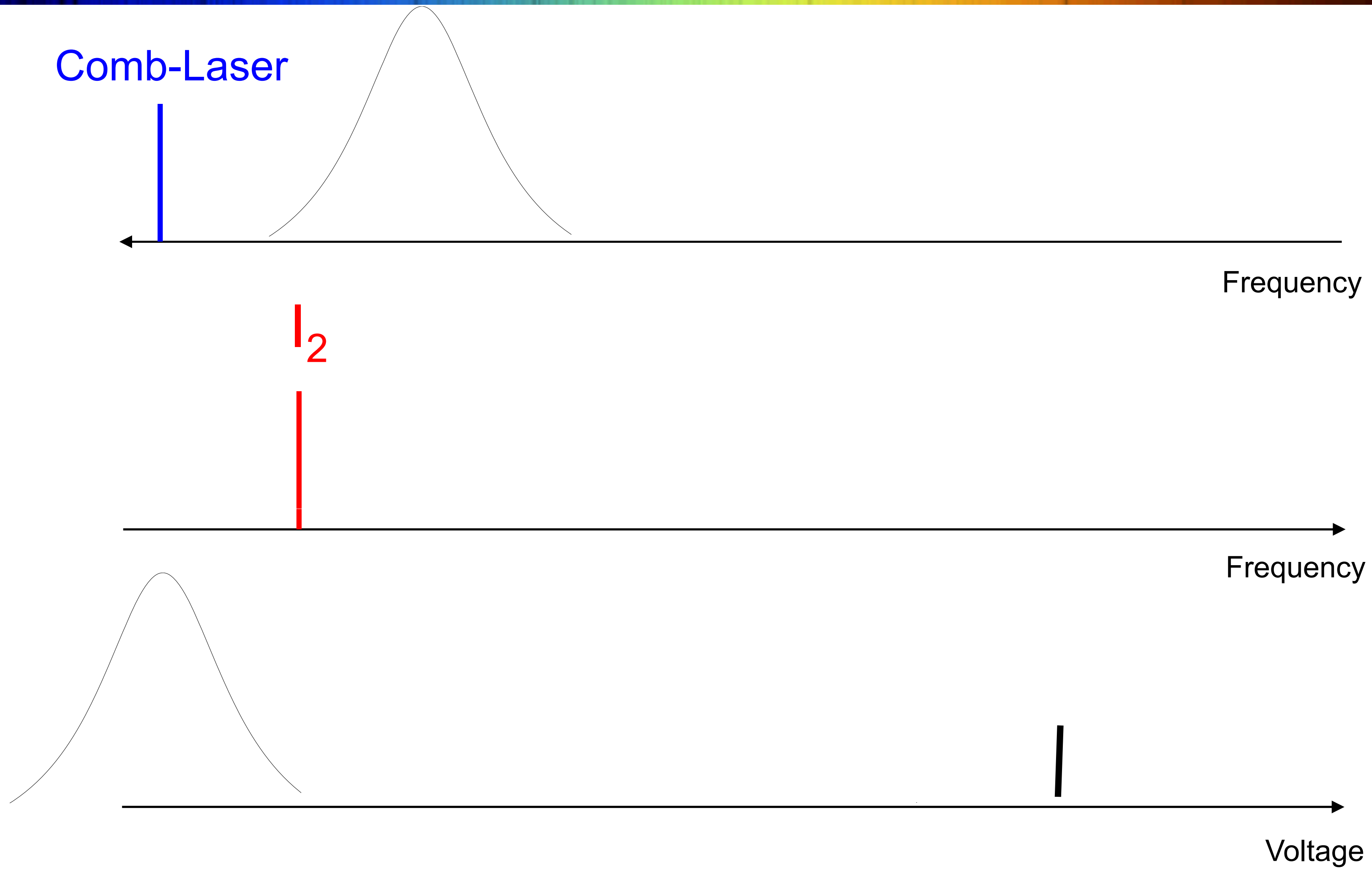
Laser System for Beryllium Spectroscopy



Iodine Lines for the $^{9}Be^{+}$ $2s_{1/2} \rightarrow 2p_{1/2}$ transition (cg)

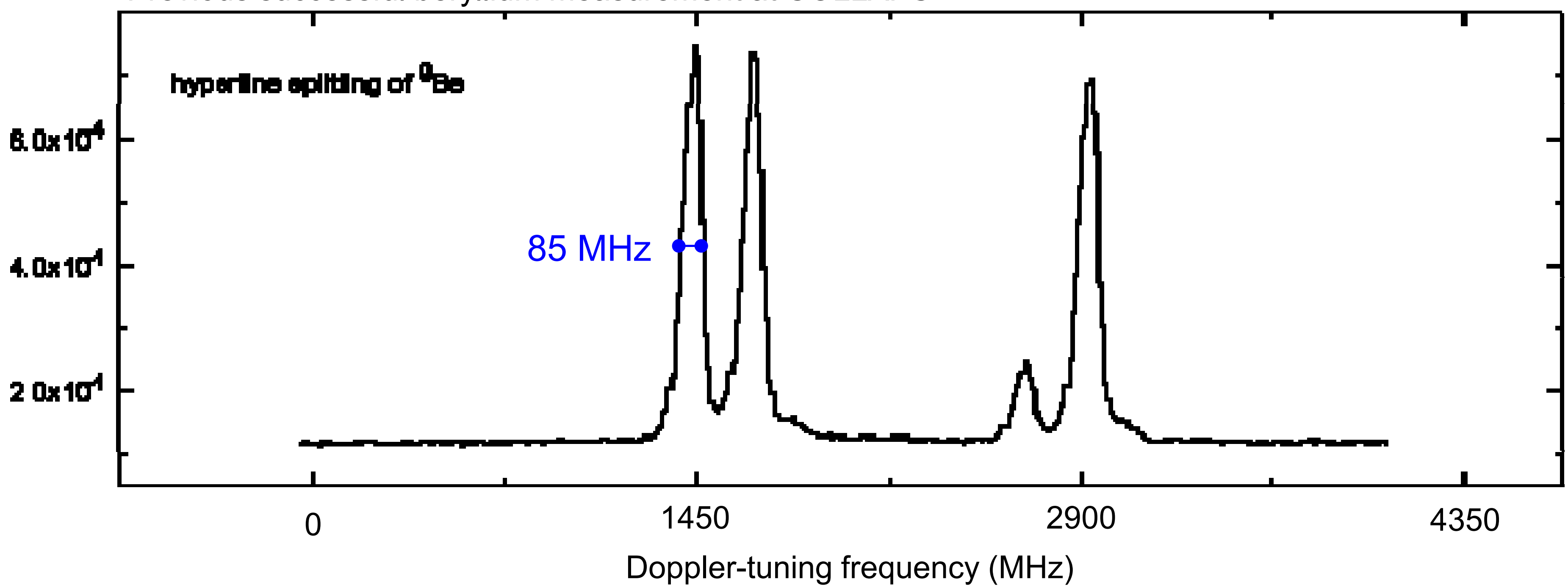


Measurement Procedure



Be Hyperfine Measurements at COLLAPS

Previous successful beryllium measurement at COLLAPS



+ Mass shift calculations by G.W.F. Drake and Z.-C. Yan / K. Pachucki:
→ Exakt position of Be Resonances within a few MHz

Reachable Accuracy

Absolute frequency determination

Line center accuracy	1 MHz
1 mrad Laser – Ion Beam Angle	0.005 MHz
1 mrad Missalignment of laser beams	0.75 MHz
Clock-related comb uncertainty	< 0.10 MHz
Total Uncertainty	**< 2 MHz**

IS determination (differential effects)

Line center accuracy	<1 MHz
1 mrad Laser – Ion Beam Angle	0.005 MHz
1 mrad Missalignment of laser beams	0.075 MHz
Total Uncertainty	**~ 1 MHz**

Beamtime Request and Schedule

- Test Beamtime in April / May (8 shifts)
- On-line Run in June / July (16 shifts)

Summary :
A nuclear charge radius determination of ^{7,9,10}Be and the 1-Neutron Halo Nucleus ^{11}Be with an accuracy of better than 5% R_c is feasible by frequency-comb based collinear laser spectroscopy at COLLAPS.

Tabelle 6.1.: Atomare Kenndaten der vier für BeTINa relevanten Berylliumisotope

	I	Masse $/10^{-6} \cdot u$	μ_I/μ_N	Lebensdauer
^{7}Be	$\frac{3}{2}$	7.016.929,83(11)[Aud03]	1,398(15)[Kap99]	53,3 d
^{9}Be	$\frac{3}{2}$	9.012.182,2(4)[Aud03]	1,7749(2)[Sto05]	stabil
^{10}Be	0	10.013.533,8(4)[Aud03]	0	$1{,}5 \cdot 10^{6}$ a
^{11}Be	$\frac{1}{2}$	11.021.658(7)[Aud03]	1,6814(13)[Kap99]	13,8 s

	$A(2S_{1/2})$ /MHz	$A(2P_{1/2})$ /MHz	$\sqrt{\langle r_l^2 \rangle}$/fm
^{7}Be	− 743,36(1,64)[Neu07]	−139,91(64)[Neu07]	
^{9}Be	− 625,008837048(10)[Win83]	−118,6(3,6)[Bol85]	2,519(12)[Jan72]
^{11}Be	−2676,3(2,0)	−508(20)	