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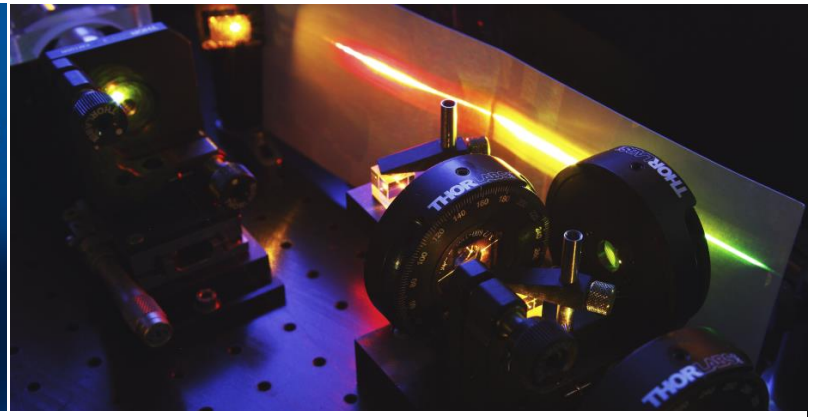
LASER SPECTROSCOPY OF HE-LIKE CARBON

First results of an all-optical charge radius



LASER SpHERe

KOALA

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A01: High-precision data on electromagnetic observables of light nuclei (A ≤ 12)

Inelastic e^- scattering

- Form factor of first excited state 0^+ of ^{4}He
- Longitudinal response function R_L of ^{4}He

  → both at S-DALINAC, IKP, TU Darmstadt
  → Following talks by Pavlos Koseoglou & Igor Jurosevic

Laser spectroscopy

- Nuclear charge radius of proton-halo candidate ^{8}B
  → Planned at ANL, Chicago
  → Talk by Laura Renth, Fr. 9:30
- Nuclear charge radii of ^{12}C, ^{10,11}B, (^{9}Be)
  → COALA at IKP, TU Darmstadt

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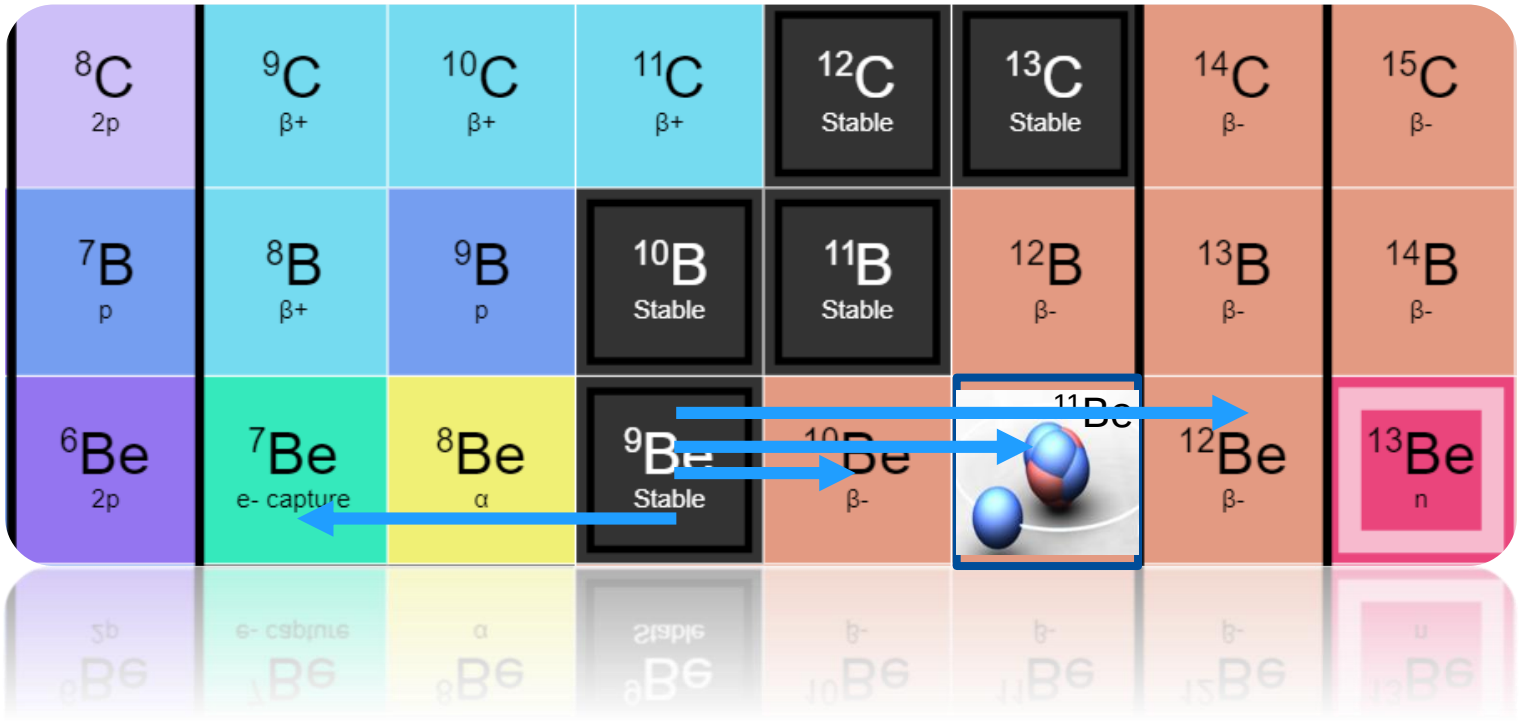
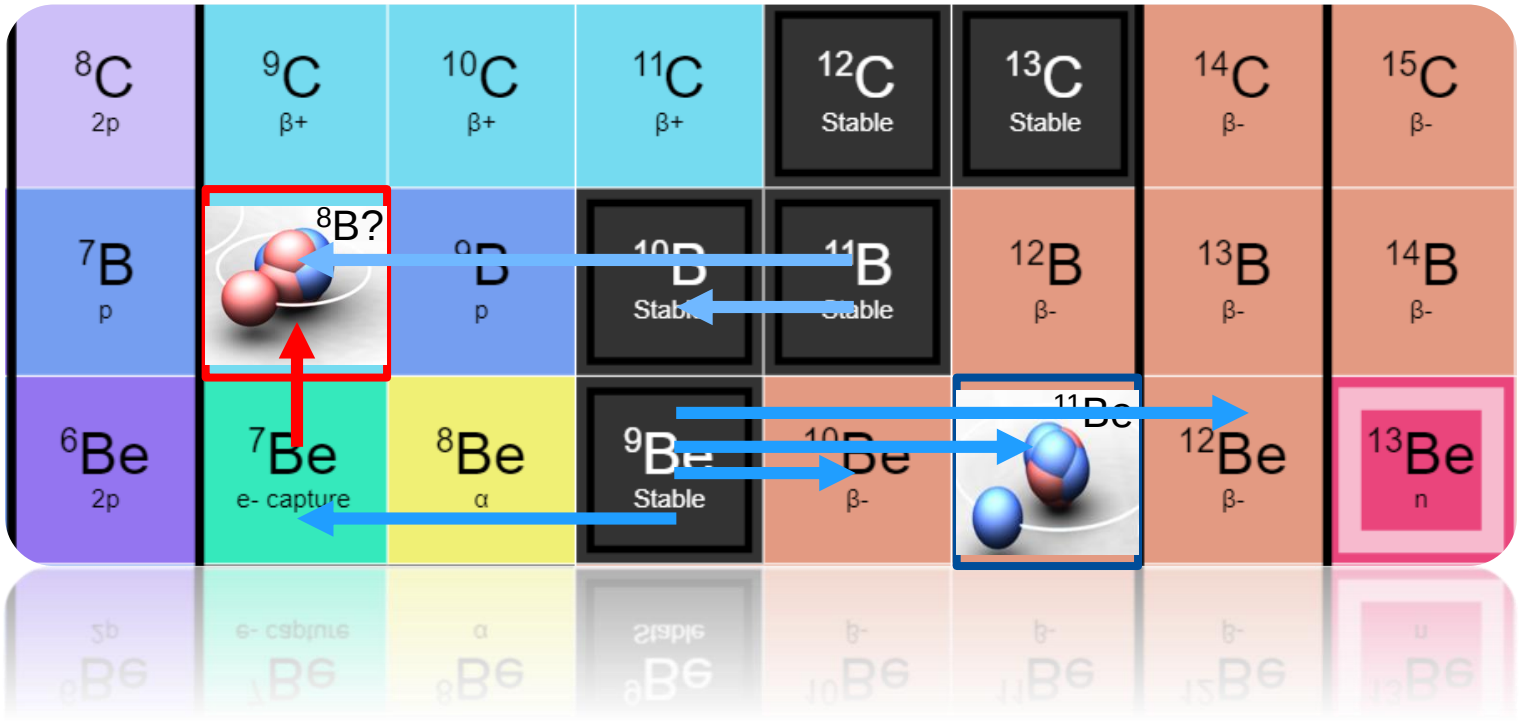


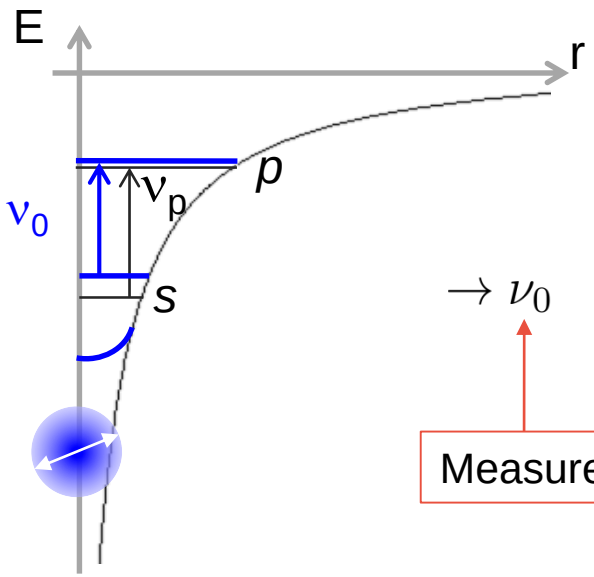
$$\delta\nu_{\mathrm{IS}} - \delta\nu_{\mathrm{MS}}^{\mathrm{Theory}} \propto \delta\langle r_{\mathrm{c}}^2 \rangle$$

$$R_{\mathrm{c}}(A) = R_{\mathrm{c}}(A_{\mathrm{ref}}) + \delta\langle r_{\mathrm{c}}^2 \rangle^{A_{\mathrm{ref}},A}$$

Reference Radius required



To gain information about the proton halo of ^{8}B, we need reliable and accurate reference radii for ^{9}Be and ^{10,11}B on equal footing



$$\rightarrow \nu_0 = \nu_{\mathrm{point}} + F \times \langle r_c^2 \rangle$$

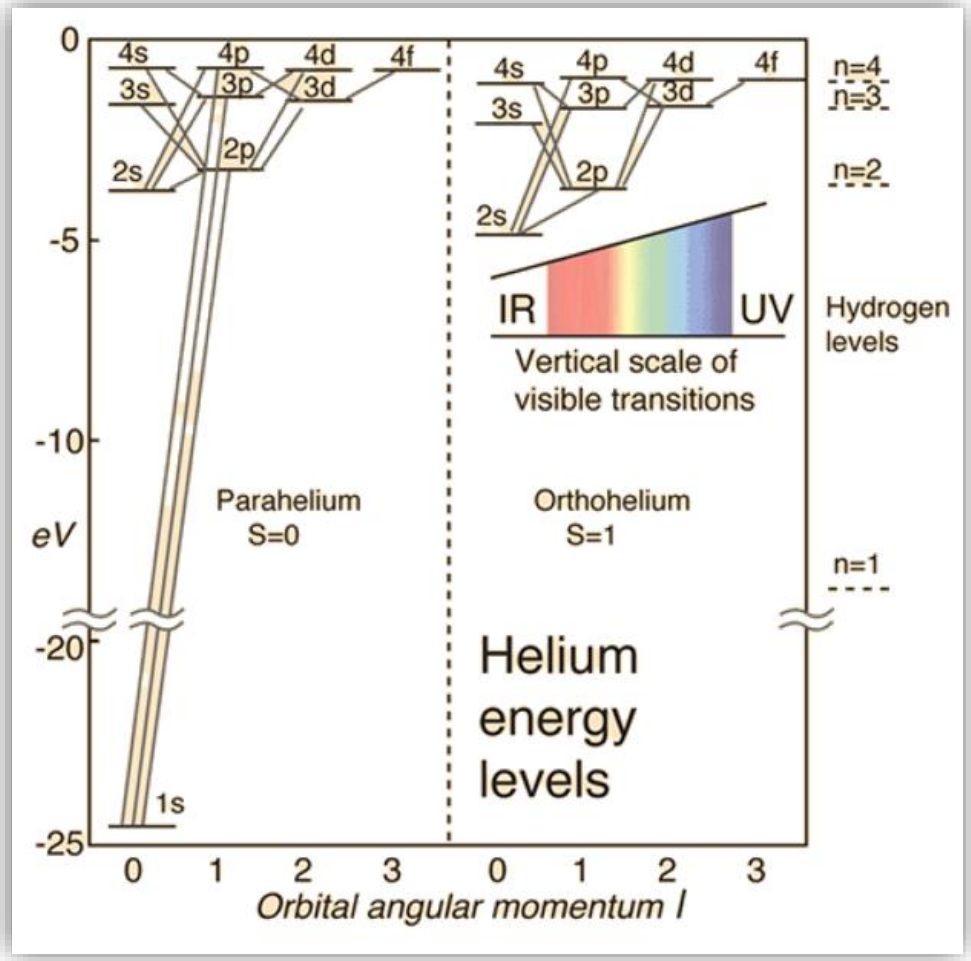
Measure | Calculate | Obtain

$$\delta\nu_{\mathrm{FS}} = \underbrace{-\frac{Ze^2}{6\varepsilon_0}\Delta\,|\Psi_e(0)|^2_{i\rightarrow f}}_{\text{Electronic Factor}} \times \langle r_c^2 \rangle$$

(→ Wavefunction)

$$= F_{i\rightarrow f}\,\langle r_c^2 \rangle$$

- Measure transition frequency ν_0
- Compare with high-precision atomic-structure calculations for a point-like nucleus ν_p
- **So far** applied only for H-like systems → H, μH and μHe
- **He-like systems** are now in reach
  Yerokhin, Patkóš & Pachucki, PRA 98, 032503 (2018)
  Patkóš, Yerokhin & Pachucki,, PRA 103, 042809 (2021)
  Yerokhin, Patkóš & Pachucki, PRA 106, 022815 (2022)



http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/helium.html

Ion species	Lifetime $^3S_1$	$^3S_1 \rightarrow {}^3P_0$ wavelength
He	2.2 h	1082 nm
Li^+	50 s	548 nm
Be^{2+}	1.8 s	372 nm
B^{3+}	150 ms	282 nm
C^{4+}	21 ms	227 nm
N^{5+}	3.9 ms	190 nm
...	...	...

Good reasons for $^{12}C^{4+}$

- Nuclear charge radius very well-known
  → Test for theory
- Transition wavelength directly available @ COALA
- No hyperfine structure

BUT: Experimental technique with fast measurement cyles needed → **Collinear laser spectroscopy!**

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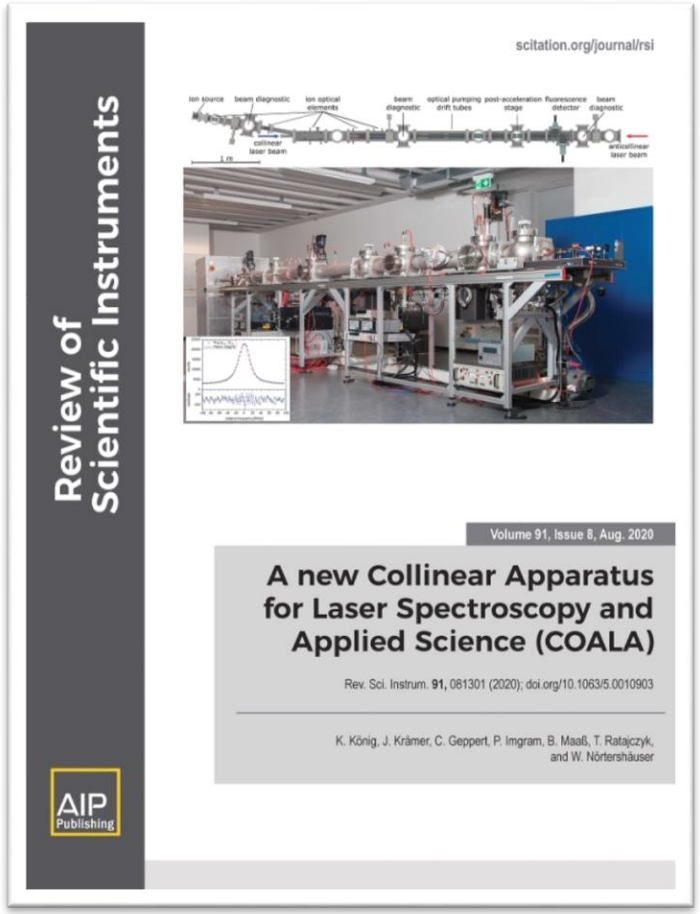

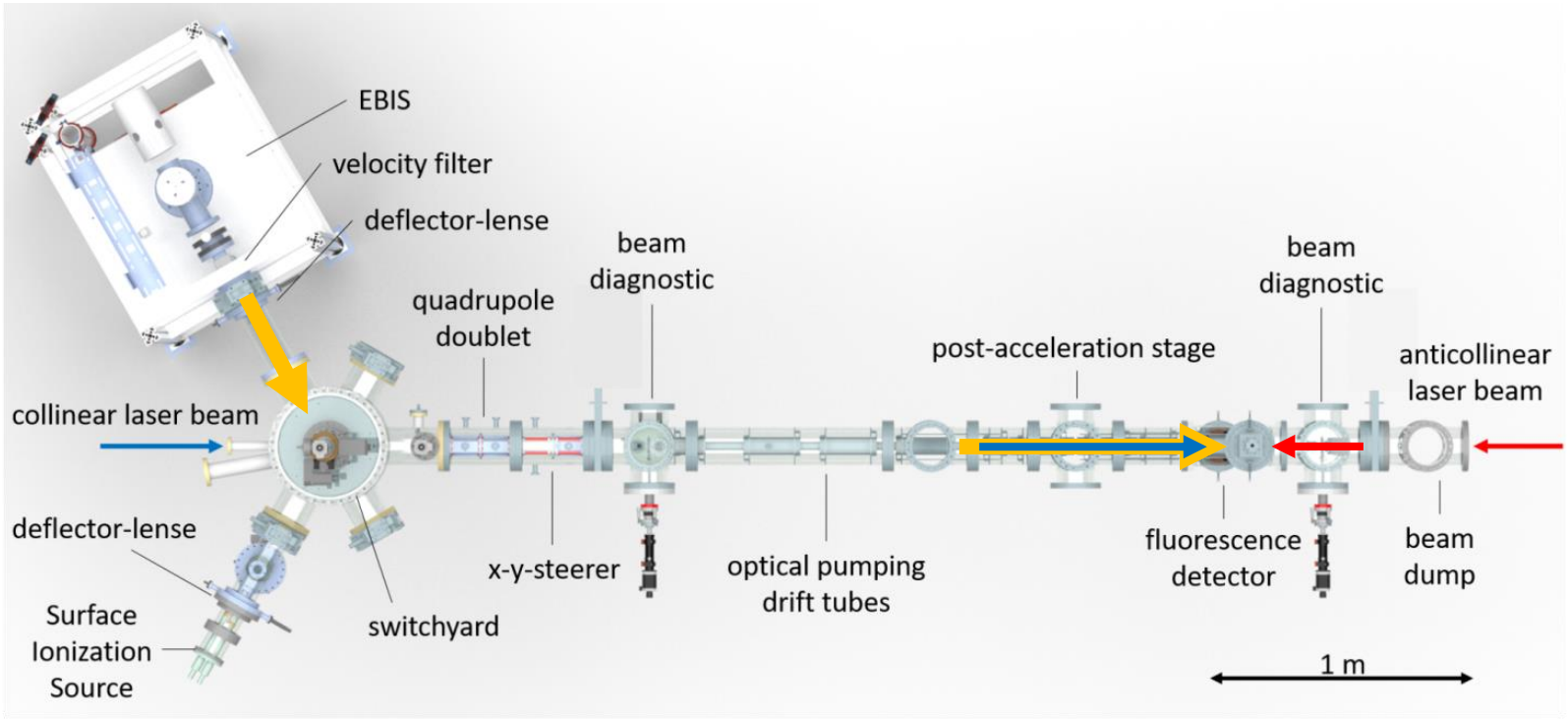

$$\left.\begin{aligned} \nu_c &= \nu_0\gamma(1+\beta) \\ \nu_a &= \nu_0\gamma(1-\beta) \end{aligned}\right\} \quad \nu_c \cdot \nu_a = \nu_0^2\gamma^2 \cdot (1+\beta)(1-\beta) = \nu_0^2$$

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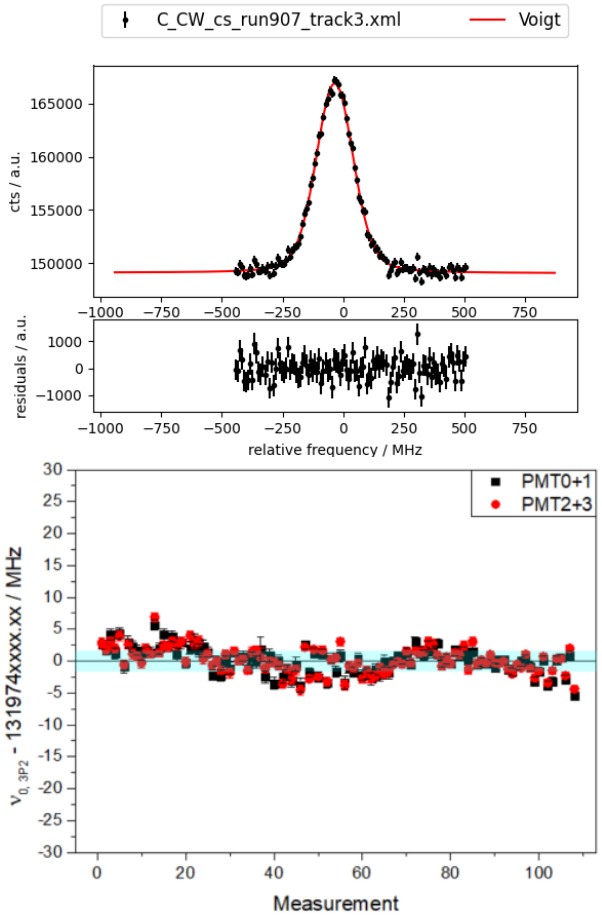
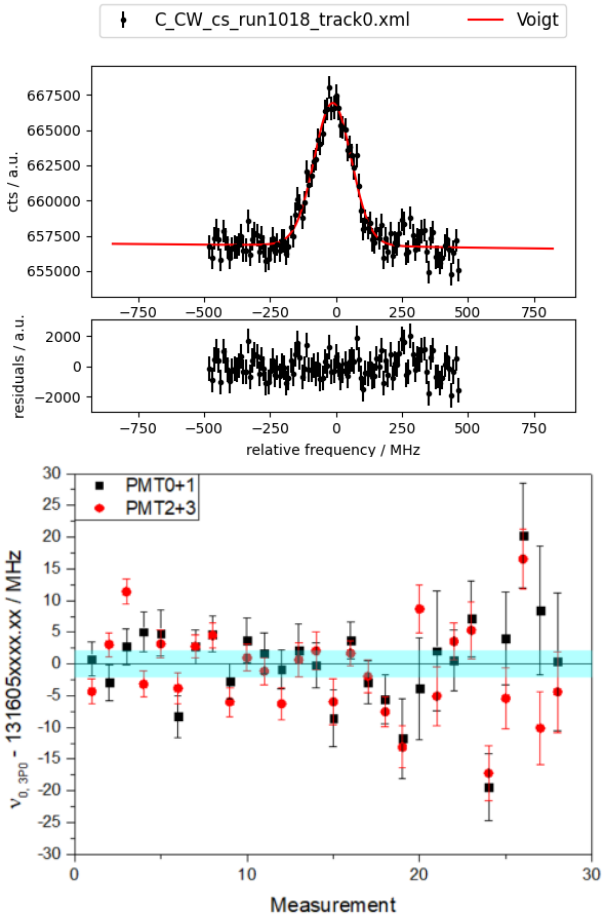
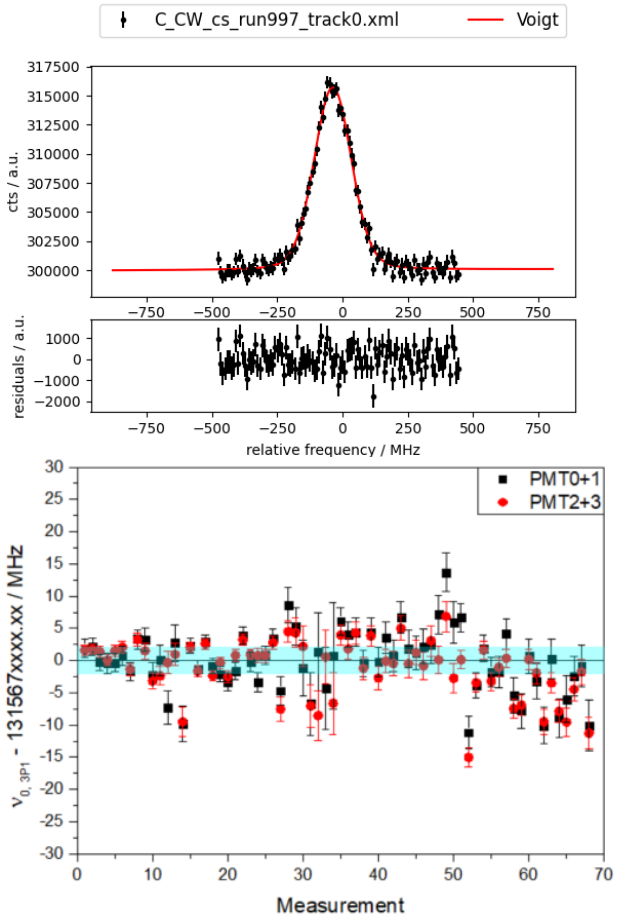
$^3P_2$

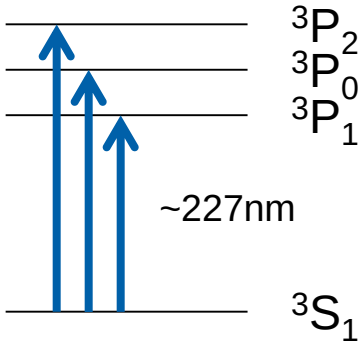


$^3P_0$



$^3P_1$





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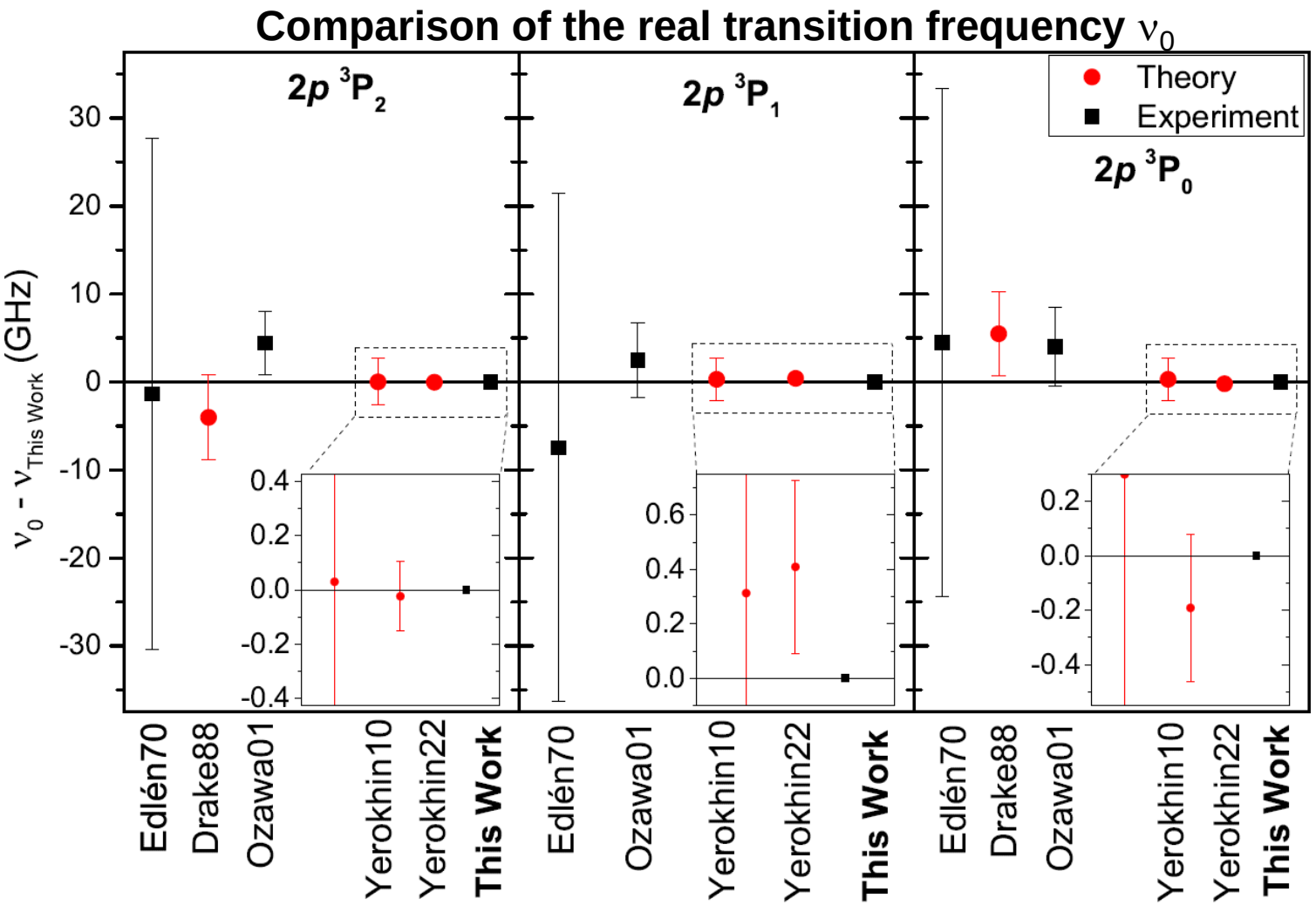
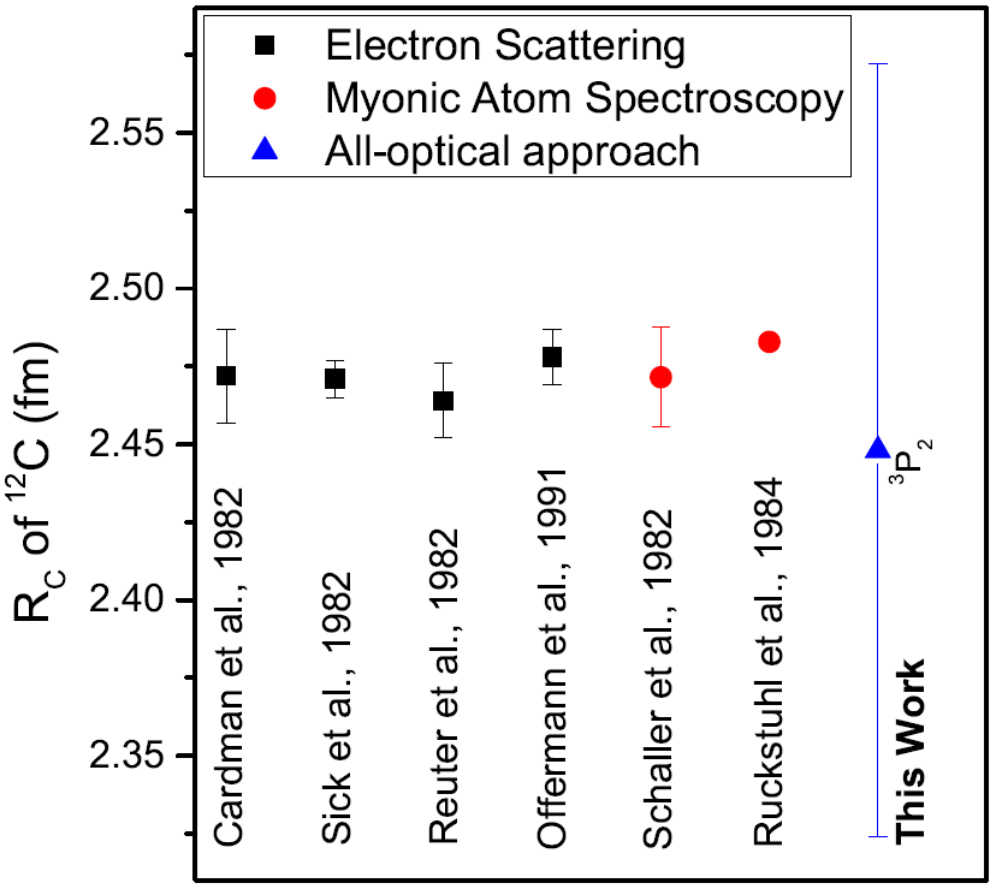


- Experimental value ν_0 improved by more than **3 orders of magnitude**!
- Theoretical value improved by **one order of magnitude**
- **Good agreement** between Exp. and Theory in ν_0
  → Small deviation in $^3P_1$ could hint to problem with FS-Mixing



Summary & Outlook

- **First important steps** towards all-optical charge radii of ^{12}C, ^{10,11}B (and ^{9}Be)
  → reached targeted experimental uncertainty
  → more work needed from atomic-structure theory for competitive all-optical R_C

- **First** high-precision laser spectroscopy in C isotope chain
  → starting point for regular isotope shift measurements to extract **$\delta\langle r^2\rangle$ between ^{12}C & ^{13}C**
  → Longterm: Radioactive isotopes

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THANK YOU FOR YOUR ATTENTION!

DFG Deutsche Forschungsgemeinschaft

SFB 1245

Federal Ministry of Education and Research

LASER SpHERe

ALA

HFHF Helmholtz Forschungsakademie Hessen für FAIR

HGS-HIRe for FAIR

Helmholtz Graduate School for Hadron and Ion Research