JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Rapid Light Manipulation Techniques for Collinear Laser Spectroscopy and their Application for Neutron-Deficient Francium

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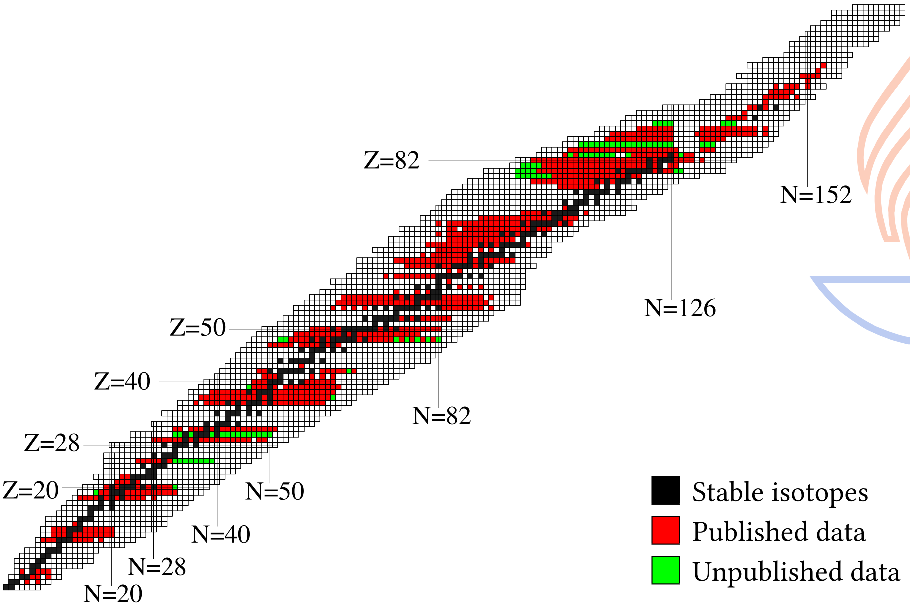
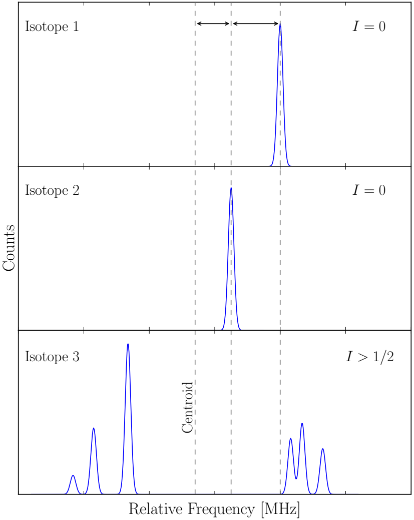
The Nuclear Laser Spectroscopic Landscape

Status as of July 20th, 2015

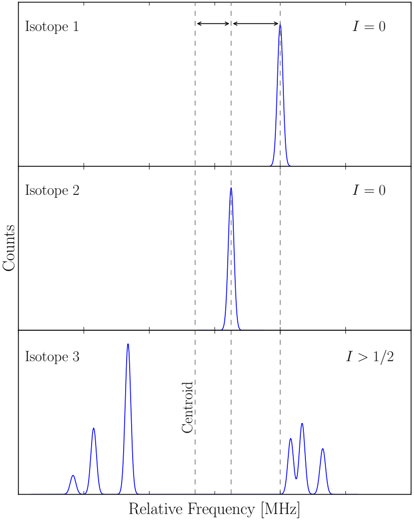




Isotope Shifts

→ Changes in RMS charge radii $\delta\langle r^2\rangle$

$$\delta\langle r^2\rangle^{A,A'} \approx \delta\langle r^2\rangle^{A,A'}_{\mathrm{sph}} + \langle r^2\rangle^{A'}_{\mathrm{sph}} \cdot \frac{5}{4\pi}\delta\langle\beta_2^2\rangle^{A,A'}$$



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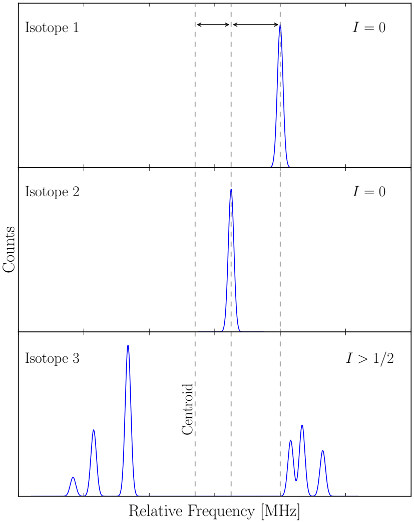
Hyperfine Structures

→ Nuclear spin I

→ Magnetic dipole moment μ

→ Electric quadrupole moment Q_S

$$Q_0 \approx \frac{5Z\langle r^2\rangle_{\text{sph}}}{\sqrt{5\pi}}\langle\beta_2\rangle\left(1 + 0.36\langle\beta_2\rangle\right)$$



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$\delta\langle r^2\rangle \rightarrow \langle\beta_2^2\rangle$ dynamic deformation

$Q_0 \rightarrow \langle\beta_2\rangle$ static deformation

Spins:

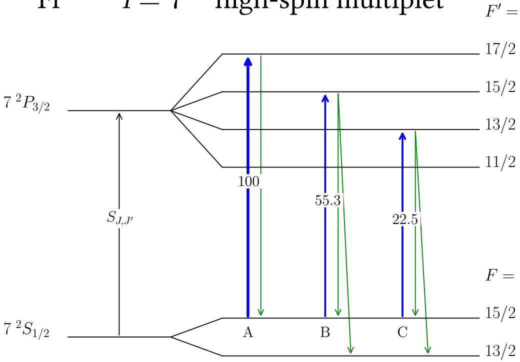
- I nuclear
- $\mathcal{J}$ electronic
- F total; $\vec{F} = \vec{I} + \vec{\mathcal{J}}$

Selection Rules:

$\Delta\mathcal{J} = 0, \pm 1; \mathcal{J} = 0 \not\leftrightarrow \mathcal{J}' = 0$

$\Delta F = 0, \pm 1; F = 0 \not\leftrightarrow F' = 0$

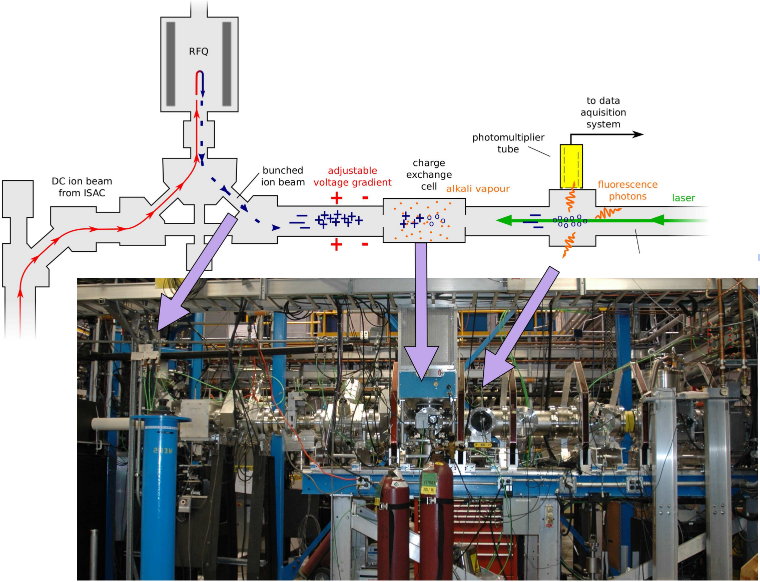
^{208}Fr $\quad I = 7 \quad$ high-spin multiplet



Relative intensities of individual HFS transitions:

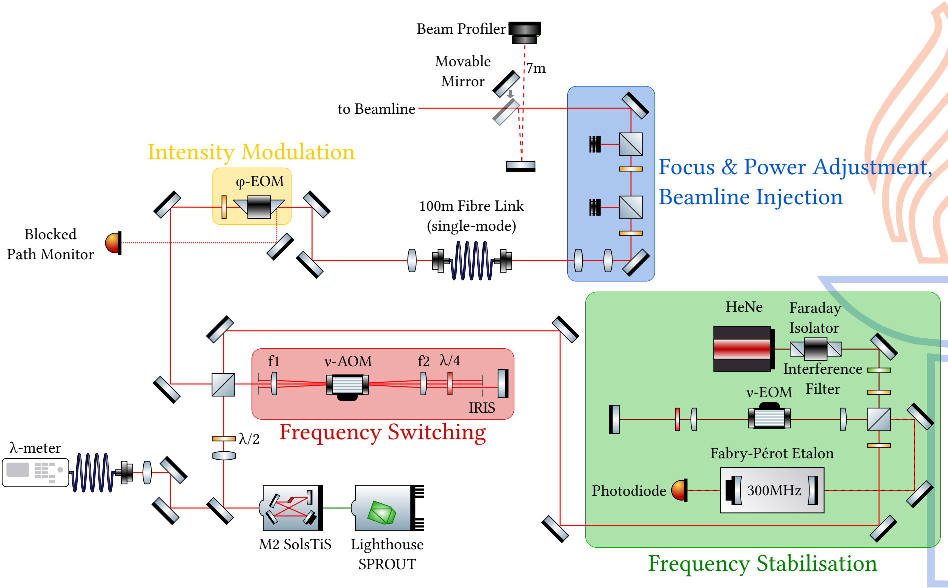
$$S_{F,F'} = (2F+1)(2F'+1)\begin{Bmatrix} F & F' & 1 \\ \mathcal{J}' & \mathcal{J} & I \end{Bmatrix}^2 S_{\mathcal{J},\mathcal{J}'},$$

The Laser Spectroscopy Beamline @ TRIUMF



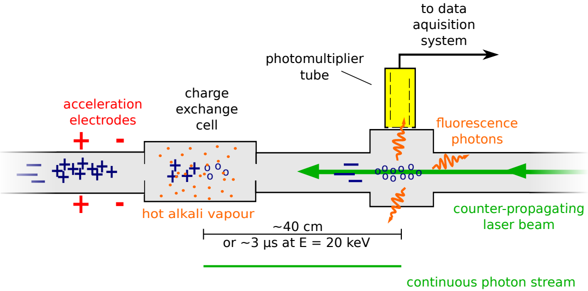
Collinear Laser System

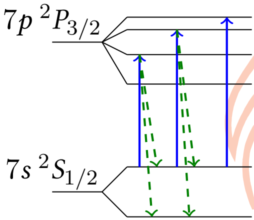
for Intensity Modulation and Fast Frequency Switching

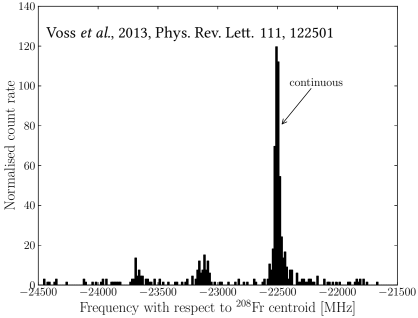


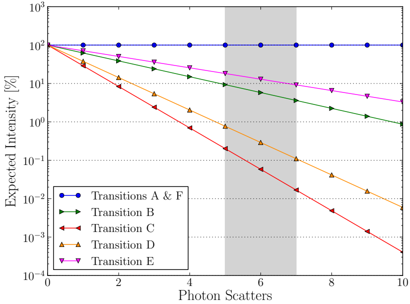
High-Frequency Intensity Modulation

Voss *et al.*, 2013, PRL 111, 122501









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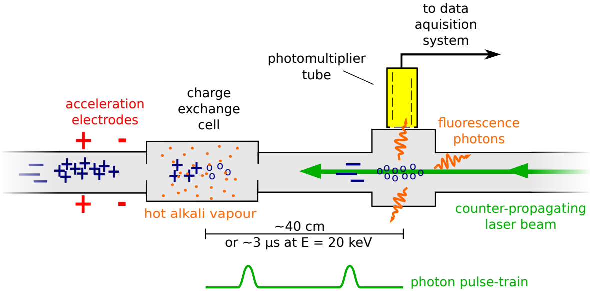
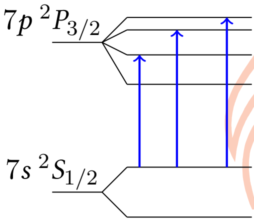
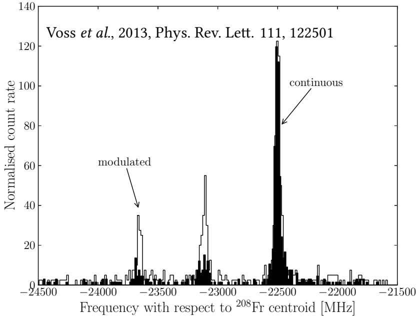
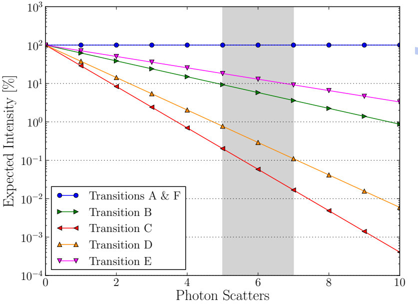
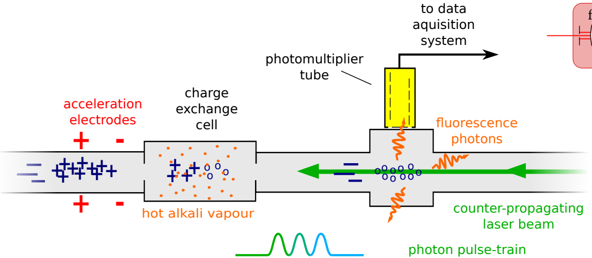


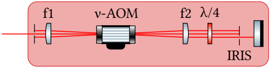




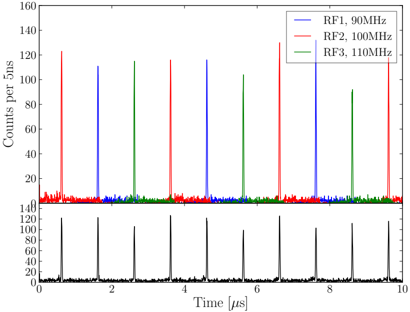




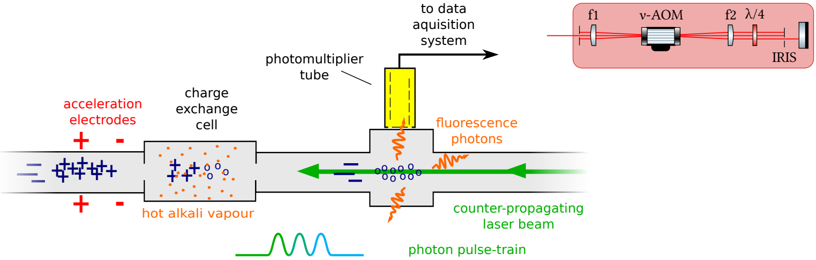
to data
aquisition
system
photomultiplier
tube
acceleration
electrodes
charge
exchange
cell
fluorescence
photons
hot alkali vapour
counter-propagating
laser beam
photon pulse-train



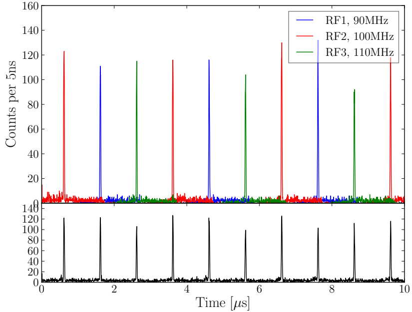
f1
ν-AOM
f2
λ/4
IRIS



RF1, 90MHz
RF2, 100MHz
RF3, 110MHz
Counts per 5ns
Time [μs]



f1
ν-AOM
f2
λ/4
IRIS
to data aquisition system
photomultiplier tube
acceleration electrodes
charge exchange cell
fluorescence photons
hot alkali vapour
counter-propagating laser beam
photon pulse-train



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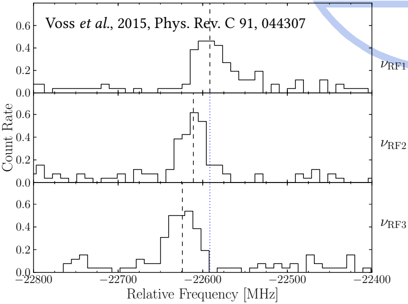
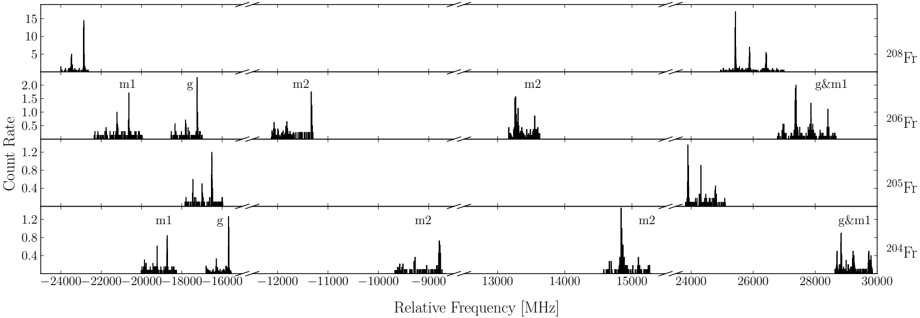


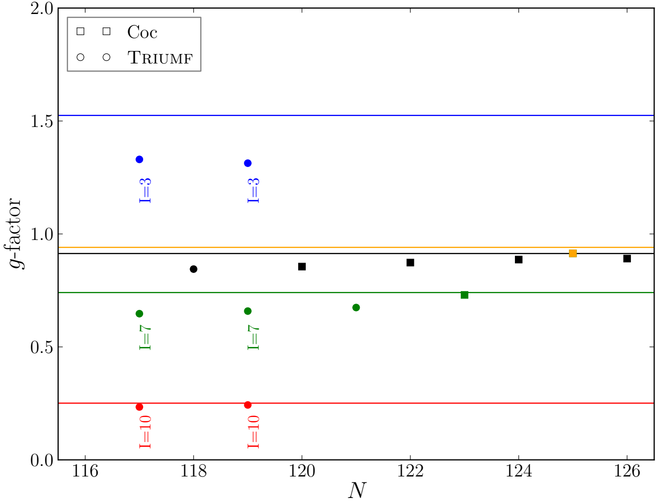
Voss et al., 2015, Phys. Rev. C 91, 044307
Count Rate
Relative Frequency [MHz]
ν_{RF1}
ν_{RF2}
ν_{RF3}



Voss *et al.*, 2015, Phys. Rev. C 91, 044307

⇒ First direct and unique spin determinations:

Mass	gs	m1	m2
206	3	7	10
205	9/2		
204	3	7	10



Voss *et al.*, 2013, Phys. Rev. Lett. 111, 122501 & 2015, Phys. Rev. C 91, 044307
Coc *et al.*,1985, Phys. Lett. B. 163, 66

g_{emp} corresponding to

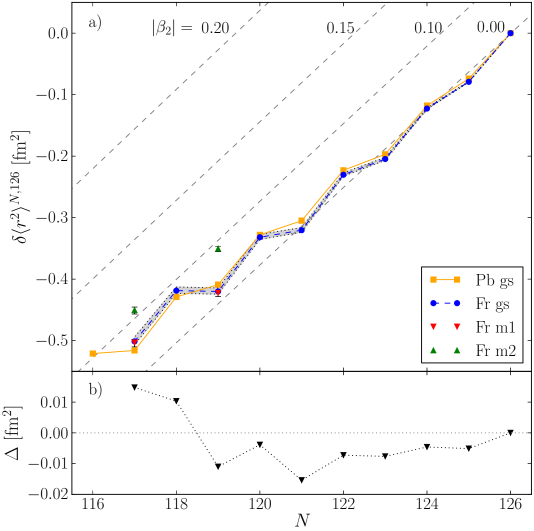
$[(\pi 1h_{9/2}) \otimes (\nu 3p_{3/2})]_3$

$[(\pi 1h_{9/2}) \otimes (\nu 3p_{1/2})]_5$

$[(\pi 1h_{9/2})]_{9/2}$

$[(\pi 1h_{9/2}) \otimes (\nu 2f_{5/2})]_7$

$[(\pi 1h_{9/2}) \otimes (\nu 1i_{13/2})]_{10}$



Voss *et al.*, 2013, Phys. Rev. Lett. 111, 122501 & 2015, Phys. Rev. C 91, 044307

Coc *et al.*,1985, Phys. Lett. B. 163, 66 (re-evaluated)

Summary

- developed fast-frequency intensity modulation for collinear laser spectroscopy
- successfully demonstrated suppression of hyperfine pumping on neutron-deficient Fr and neutron-rich Rb
- rapid frequency switching further enhances the technique
- coincidence methods allow the PMT signal to be disentangled for individual analysis
- techniques may be applied at all facilities pursuing collinear laser spectroscopy on atomic species
- first direct and model-independent nuclear spin determination for neutron-deficient Fr isotopes and isomers
- g-factors suggest strong mixing of shell-model states for ground states
- $\delta\langle r^2\rangle$ mark onset of deformation around $N = 119$ in Fr

Collaboration: (sorted by Number of Participants)

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