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Laser polarization setup at ISOLDE, CERN: ^{35}Ar results and achievements

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Motivation

^{35}Ar is a **mirror** nucleus → measurement of β-asymmetry can be used to calculate V_{ud}

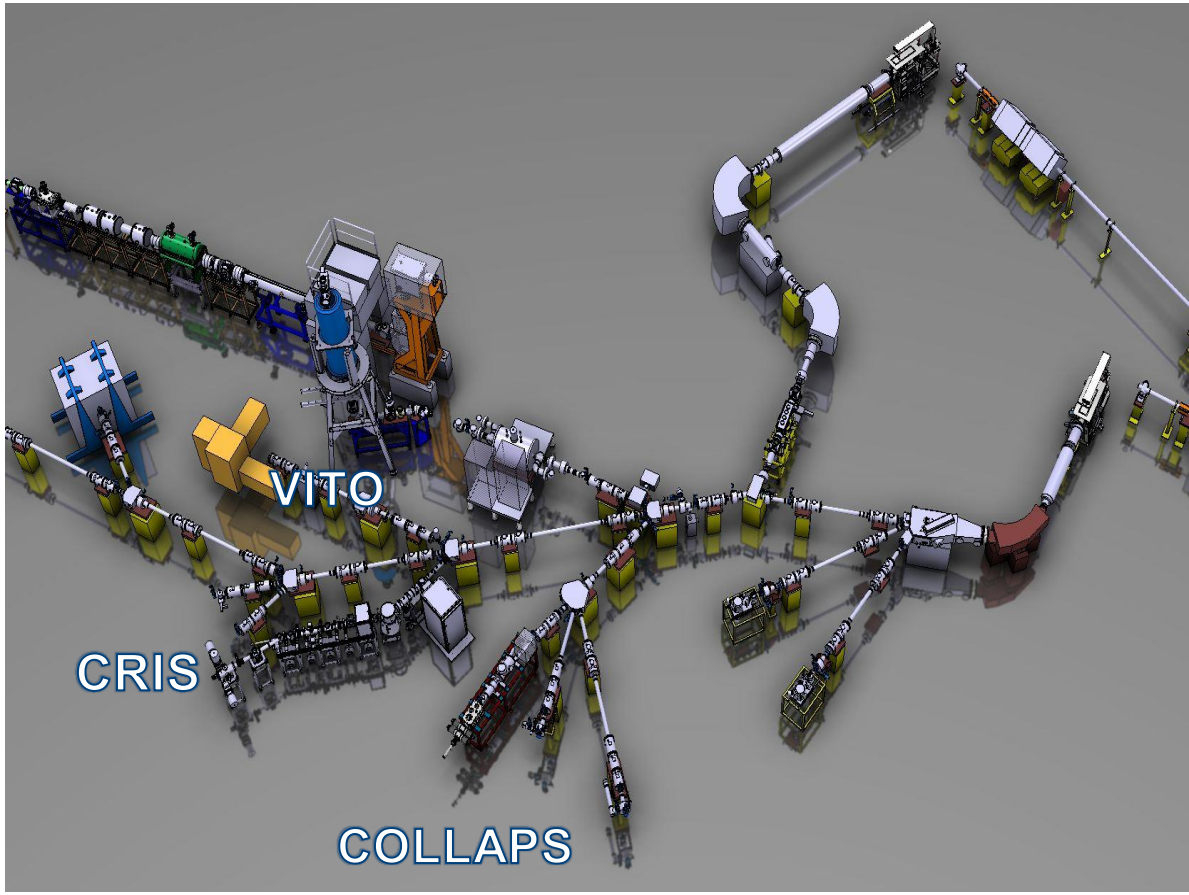
Determined from β-asymmetry

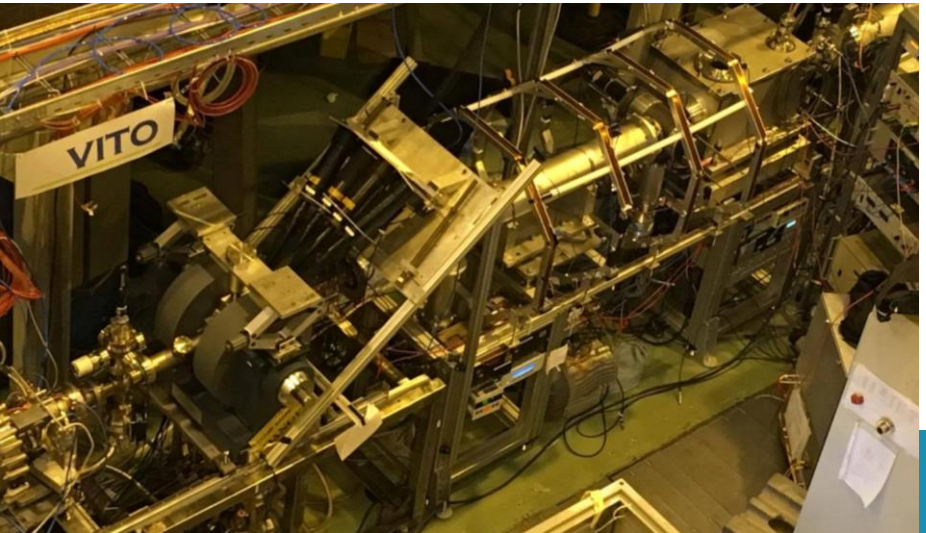
$$Ft_0 \equiv Ft^{mirror}\left(1+\frac{f_A}{f_V}\rho^2\right) = 2Ft^{0^+\rightarrow 0^+} = \frac{K}{G_F^2 V_{ud}^2 (1+\Delta_R^V)}$$

Current ΔV_{ud}: 2.2e-4 (all measurements combined)

With 0.5% relative precision on asymmetry: 4e-4 (single measurement!) → asymmetry of 20% needed for a reasonable measurement time

Location





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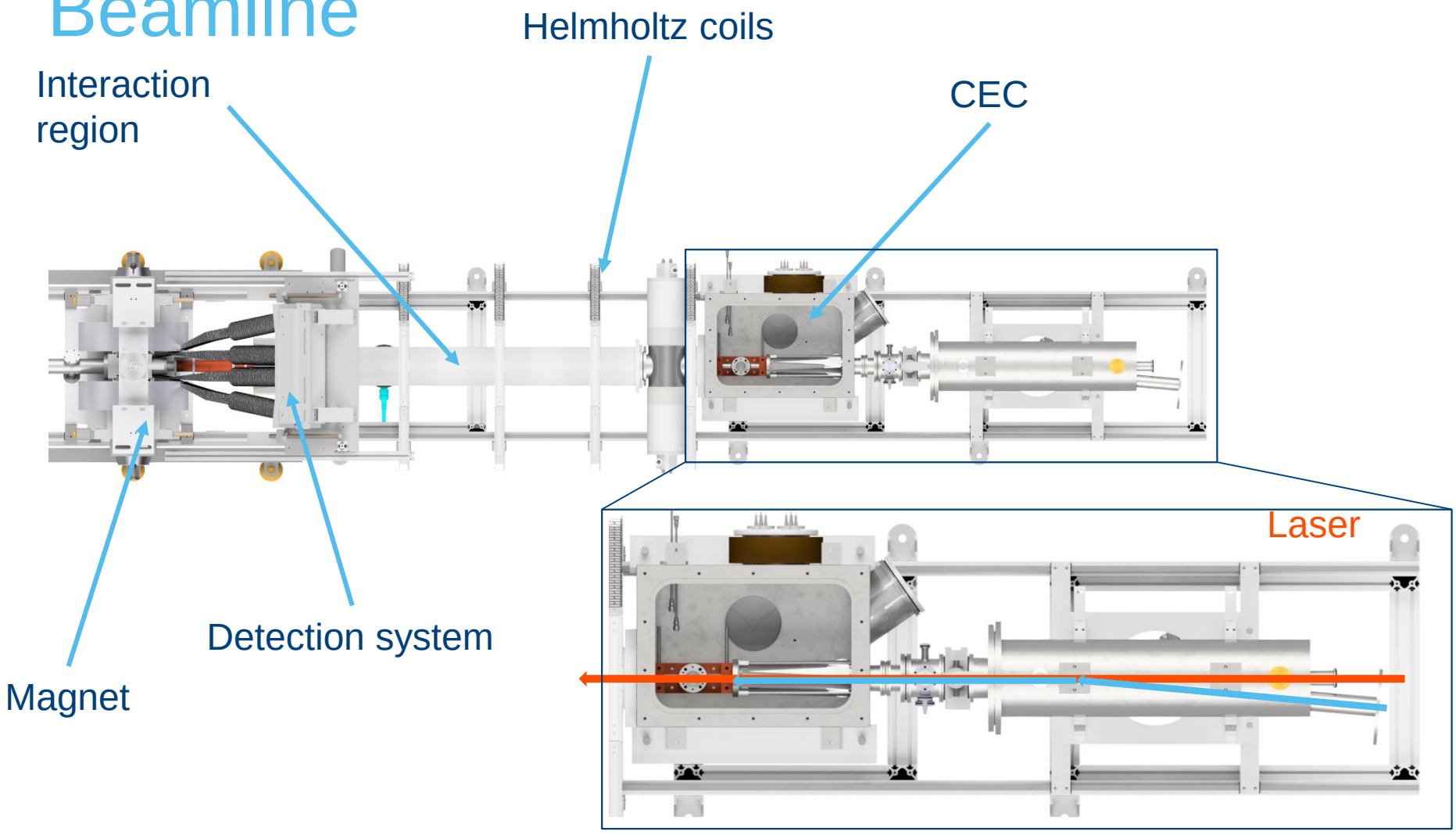
Beamline



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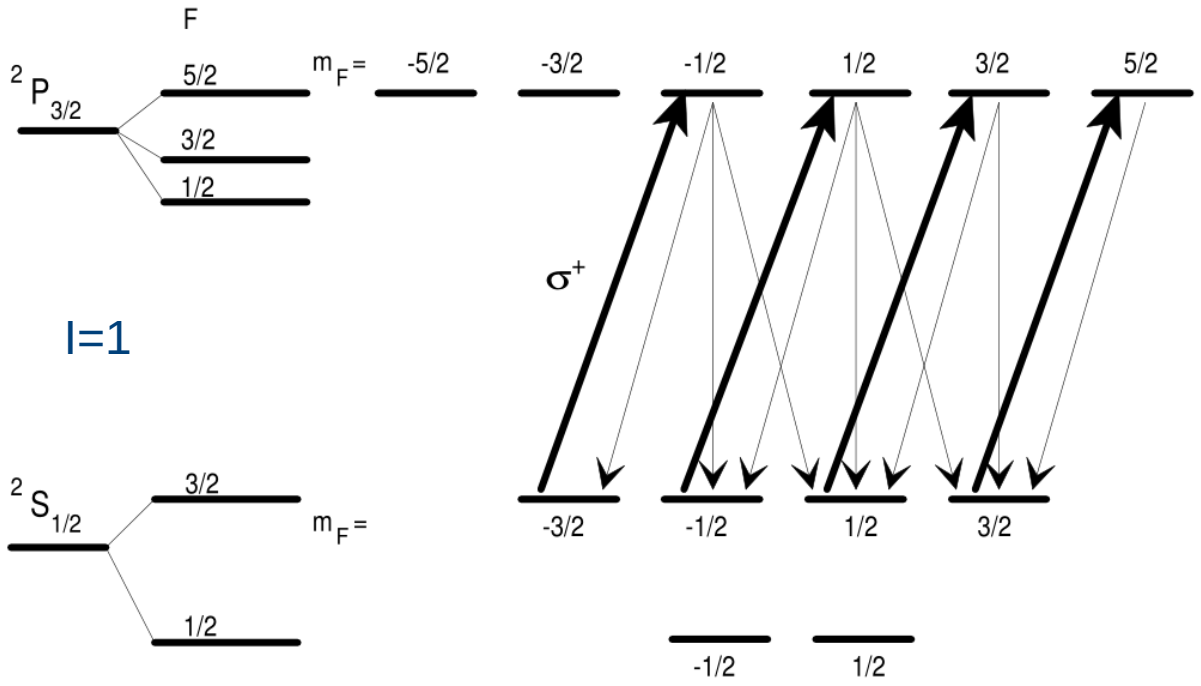
Laser Polarization: mechanism

Optical pumping with σ± polarized laser light in a 2m long interaction region (~μs interaction time) :

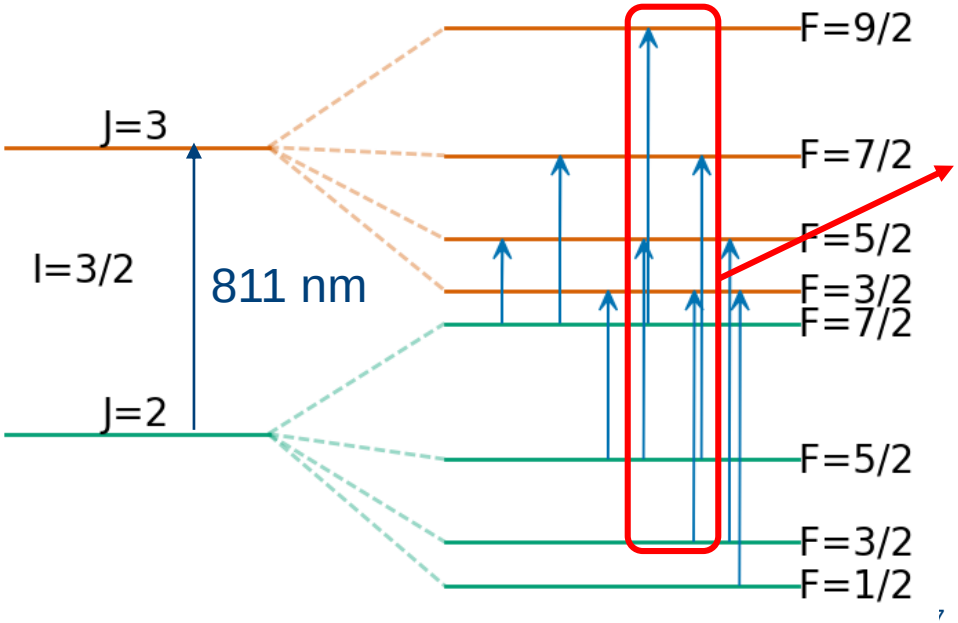


σ±: induces $\Delta m_F = \pm 1$ transitions, σ^+ was used for ^{35}Ar

Figure: Keim M, 1996, Messung der Kernquadrupolmomente neutronenreicher Natriumisotope, PhD Thesis

Multi-frequency pumping

- Goal: enhance the polarization for ^{35}Ar
- Closed cycle found at 811nm in Ar atom. But high spins result in many HFS levels → reduces the amount of polarization per level
- Solution: multi-frequency pumping

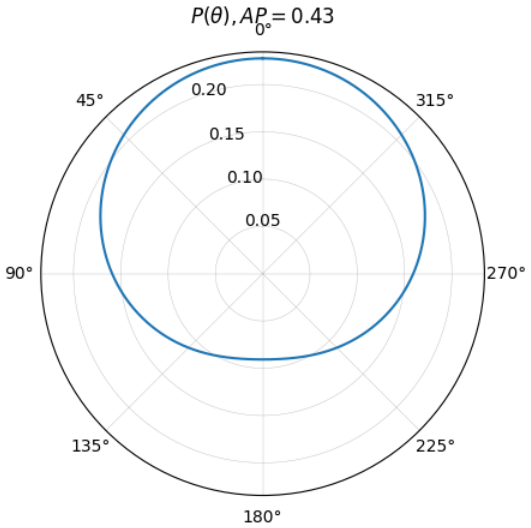


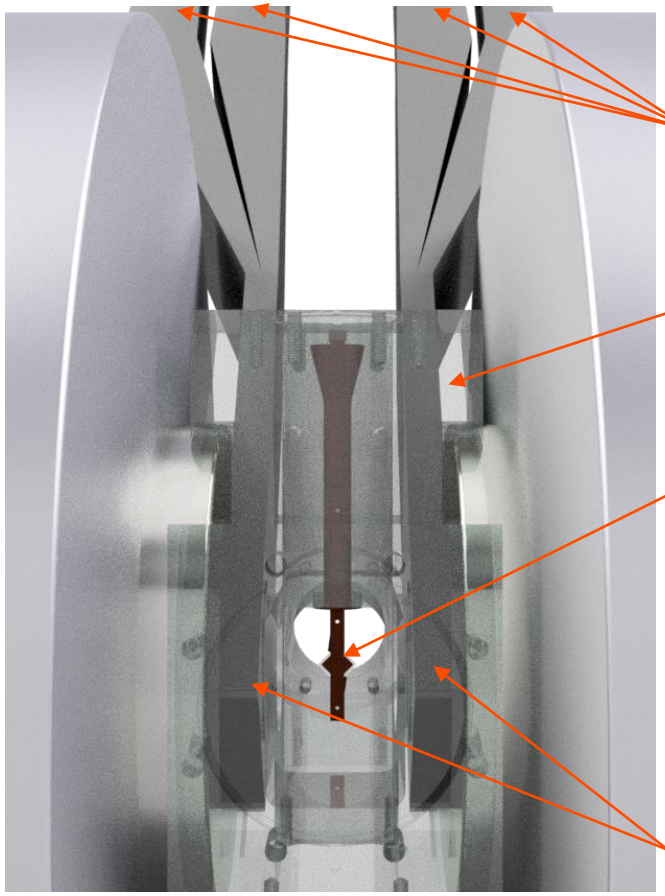
7/2 state: 60% of the population
Add population from 5/2 and 3/2: ≈100%

Measure laser-induced nuclear polarization: via the asymmetry in β-decay

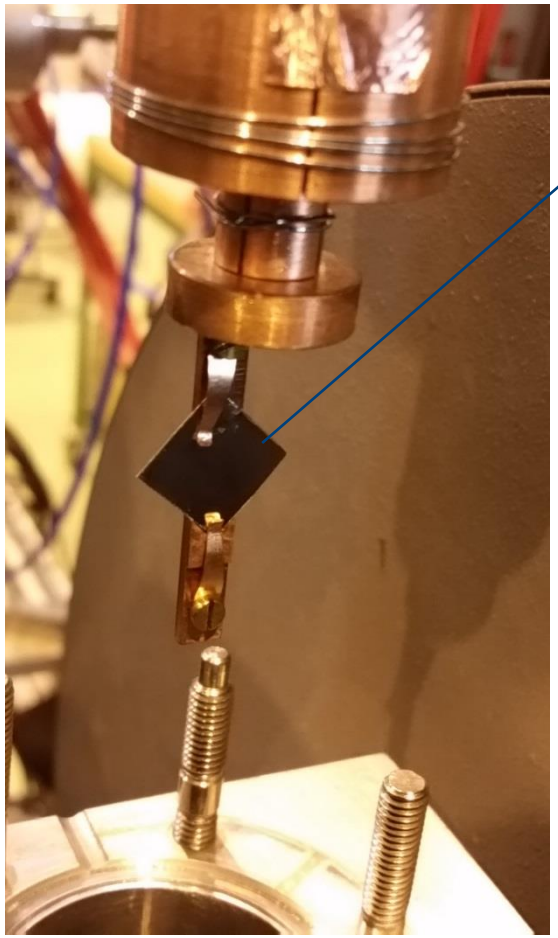
$$P(\theta) \sim 1 + AP\cos\theta$$

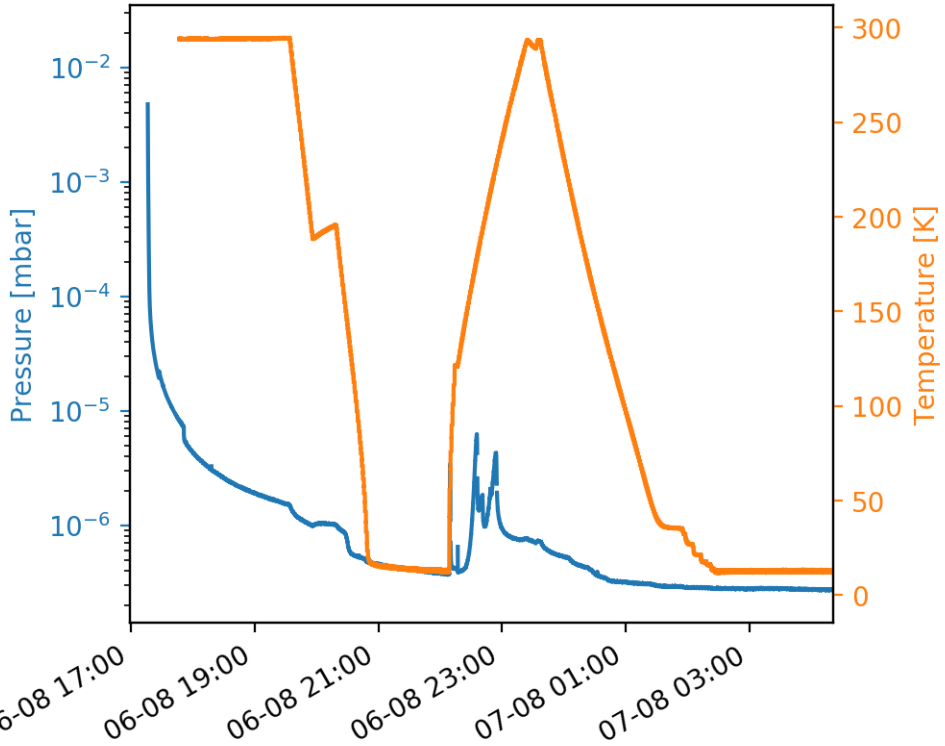
$$A_{exp} = \frac{N(0°) - N(180°)}{N(0°) + N(180°)} = AP$$





Implantation setup



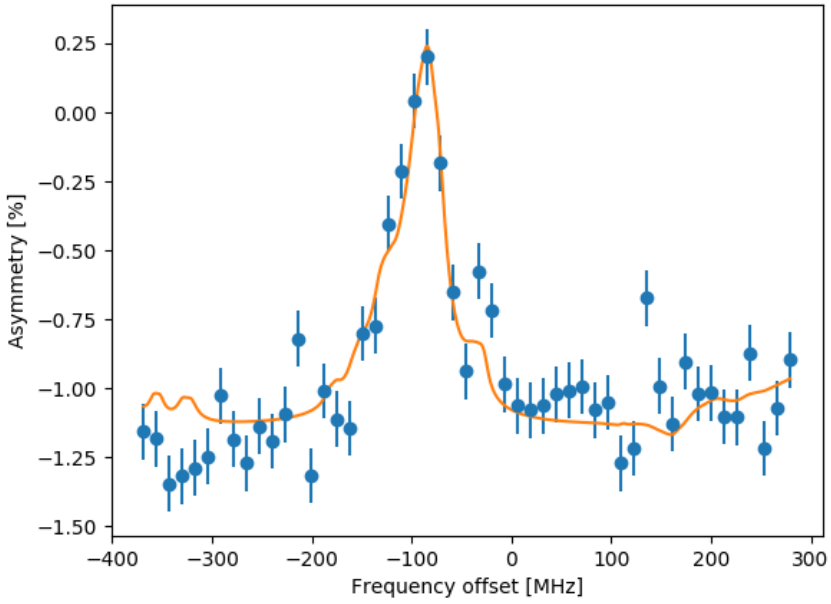


- Closed cycle He cold head: cools down to 10 K (~1.5 hours)
- Several hosts tested: Si, KBr, **KCl**, **NaCl**, Pt

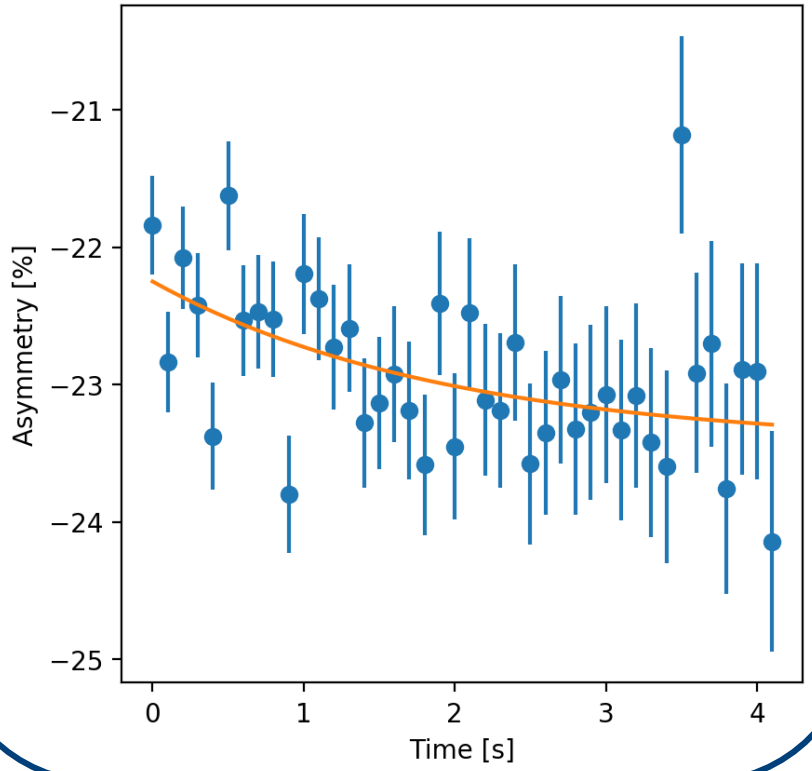
Typical data

Contains information about the environment of the implanted Ar

Hyperfine scan



Relaxation curve



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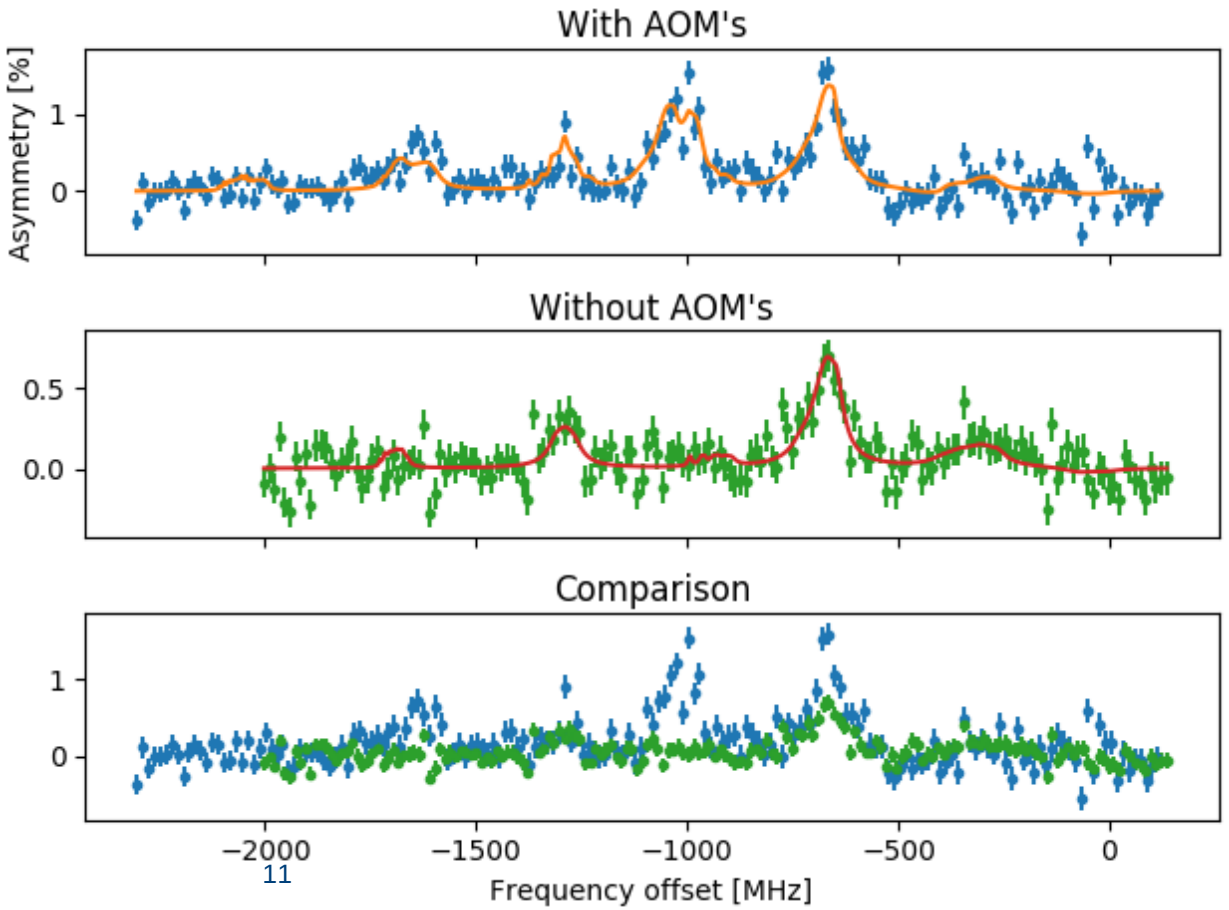
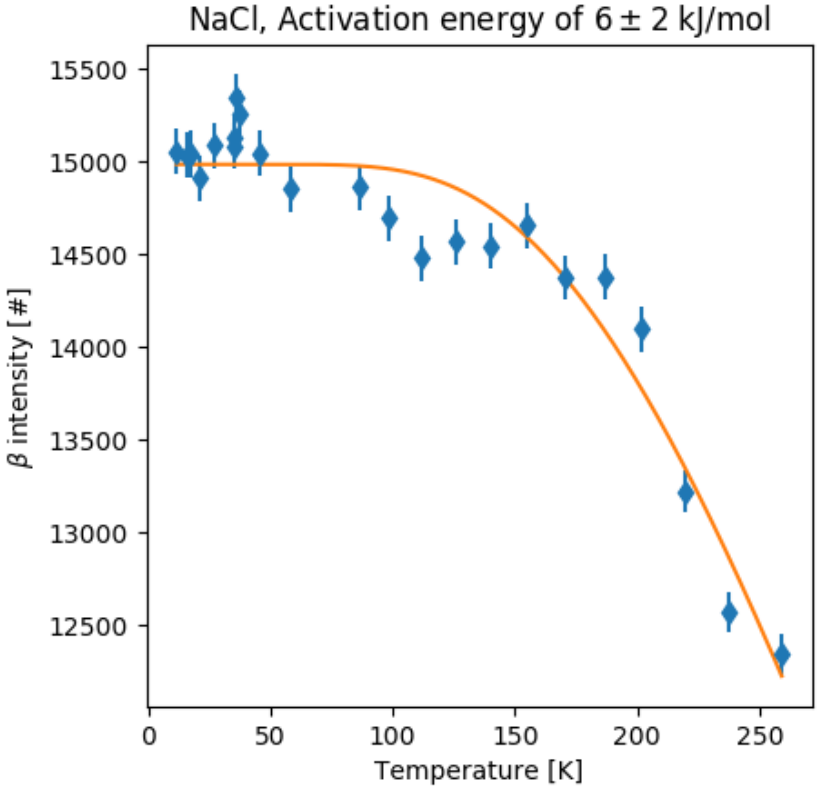
Polarization succes

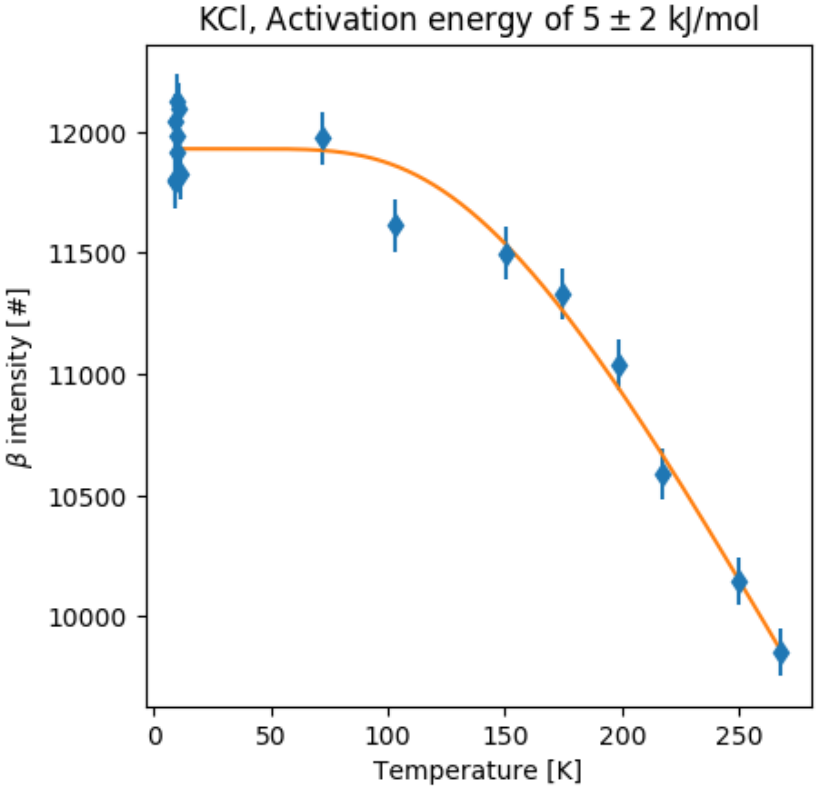
- Transition was fully saturated with all beams
- Signal gain of factor 1.7 by pumping 3 hyperfine transitions
- Signal itself: 1.5-2%



β-intensity

- Arrhenius-like behavior of implanted radioactivity → Activation energy in order of magnitude for diffusion in similar crystals [1]





$Arrhenius \sim \exp(-{}^{Q}/_{RT})$

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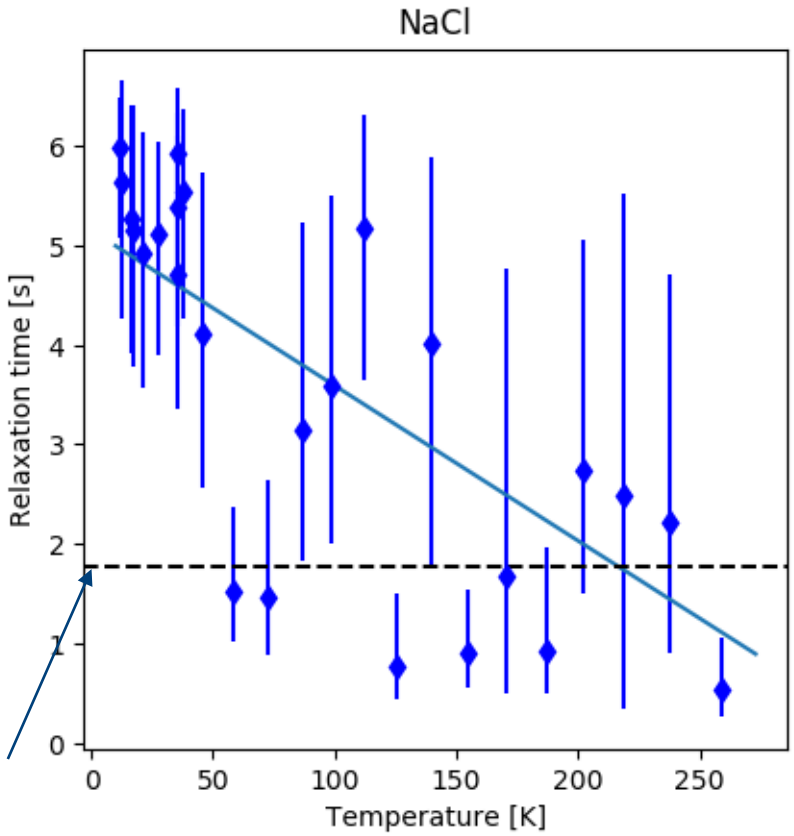
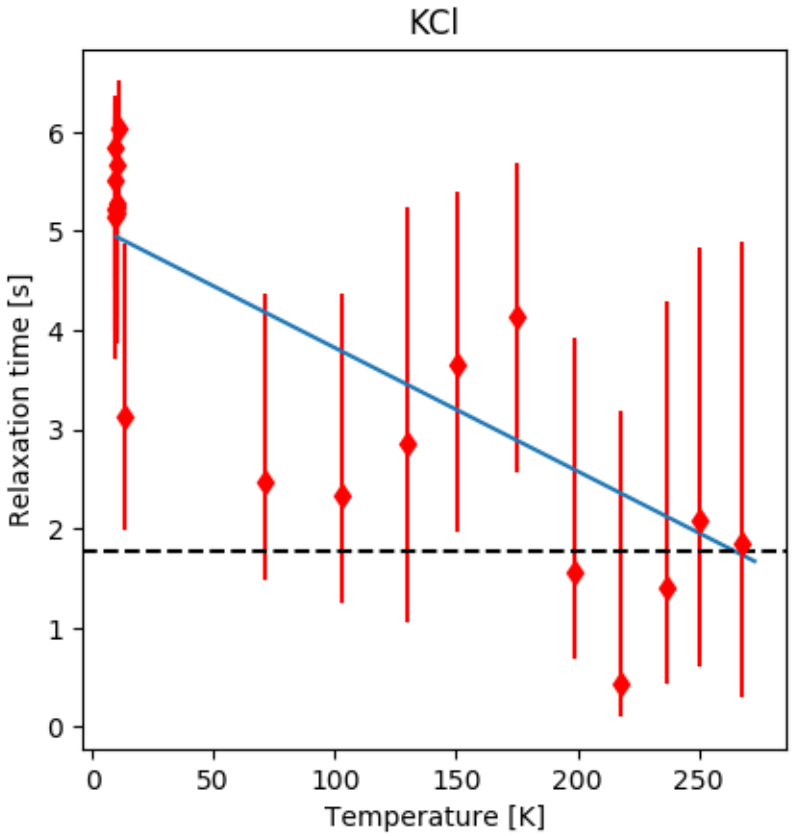
[1] Burton, J. J. and Jura, G. (1967). Self Diffusion in Solid Argon: The Activation Energy. *Journal of Physics and Chemistry of Solids*, *28*(1), 705–710.

Relaxation time trend





Halflife

Upward trend/phase transition visible: possible freezing of Ar used to vent the beamline

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Conclusion

Achieved

- Maximal signal of 2% was seen in KCl at 10 K in one spectrum, average of 1.5% at 10 K
- Polarization optimization with multi-frequency pumping worked as expected from simulations

Outlook

- Observed asymmetry is ~5 times less than expected, factor 10 less than needed → project on hold until we find an explanation

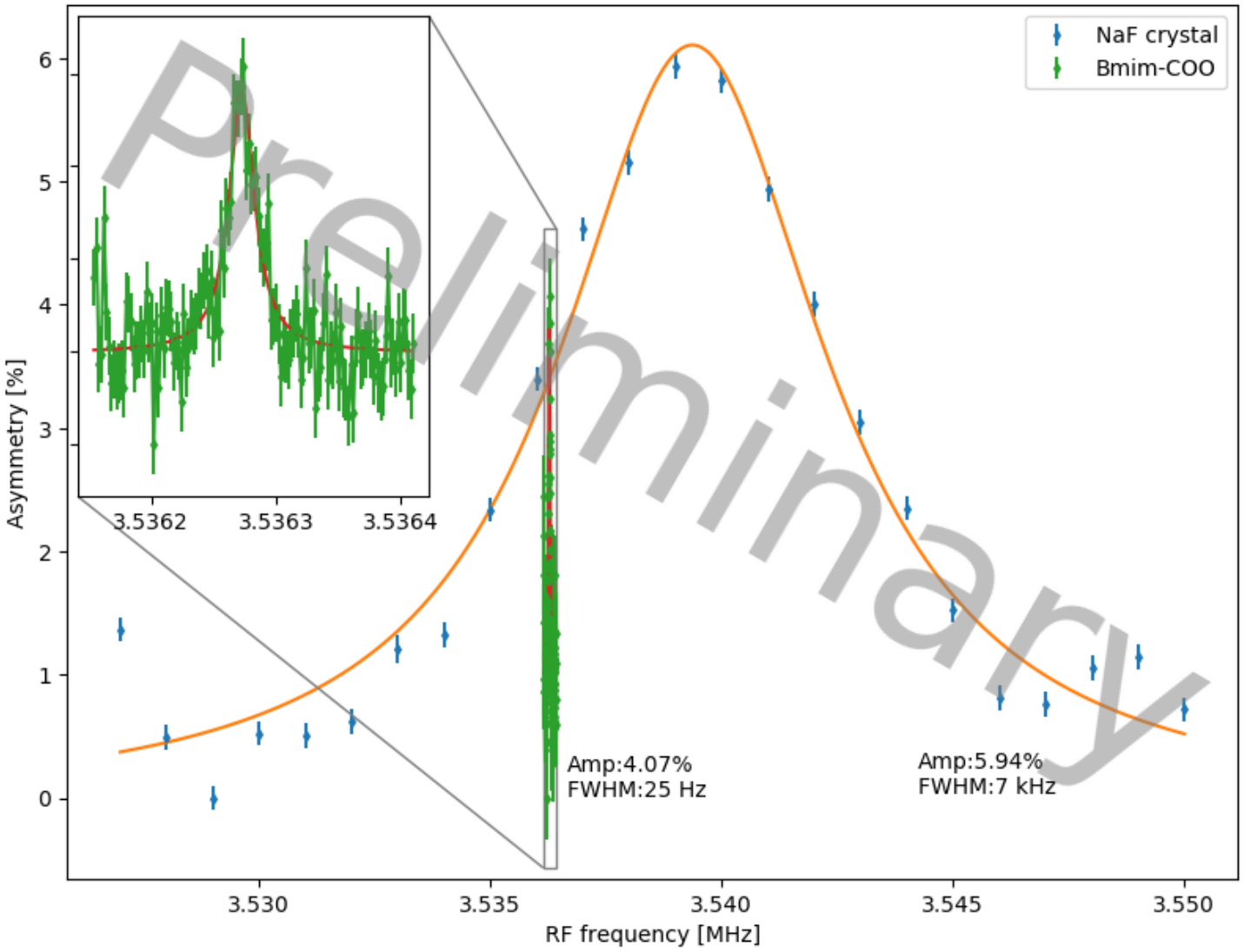
Thank you

Thank you to the CRIS, COLLAPS and ISOLTRAP groups for lending equipment!

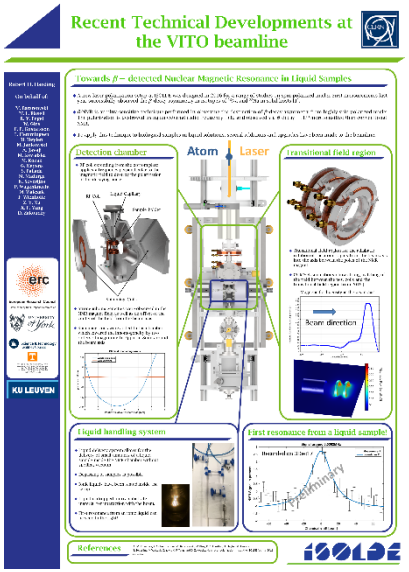
M. Baranowski[1], C. Beattie[2], M. L. Bissell[3], R. D. Harding[4,5], H. Heylen[6], M. Jankowski[7], A. Javaji[7], A. Kanellakopoulos[8], M. Kowalska[5], G. Neyens[5,8], S. Pallada[5,9,10], N. Severijns[8], P. Wagenknecht[7], M. Walczak[11], F. Wienholtz[5], Z. Y. Xu[8], X. F. Yang[8], D. Zakoucky[12]

[1] Adam Mickiewicz University, Poland
[2] Georgetown University
[3] University of Manchester, UK
[4] University of York, UK
[5] CERN, Switzerland
[6] Max-Planck-Institut für Kernphysik, Germany
[7] University of Oldenburg
[8] KU Leuven, Belgium
[9] University of Copenhagen, Denmark
[10] Democritus University of Thrace, Greece
[11] Poznan University of Technology, Poland
[12] Nuclear Physics Institute, Czech Republic

Fresh results



See poster by Rob Harding (#22)



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Questions?

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Backup slides

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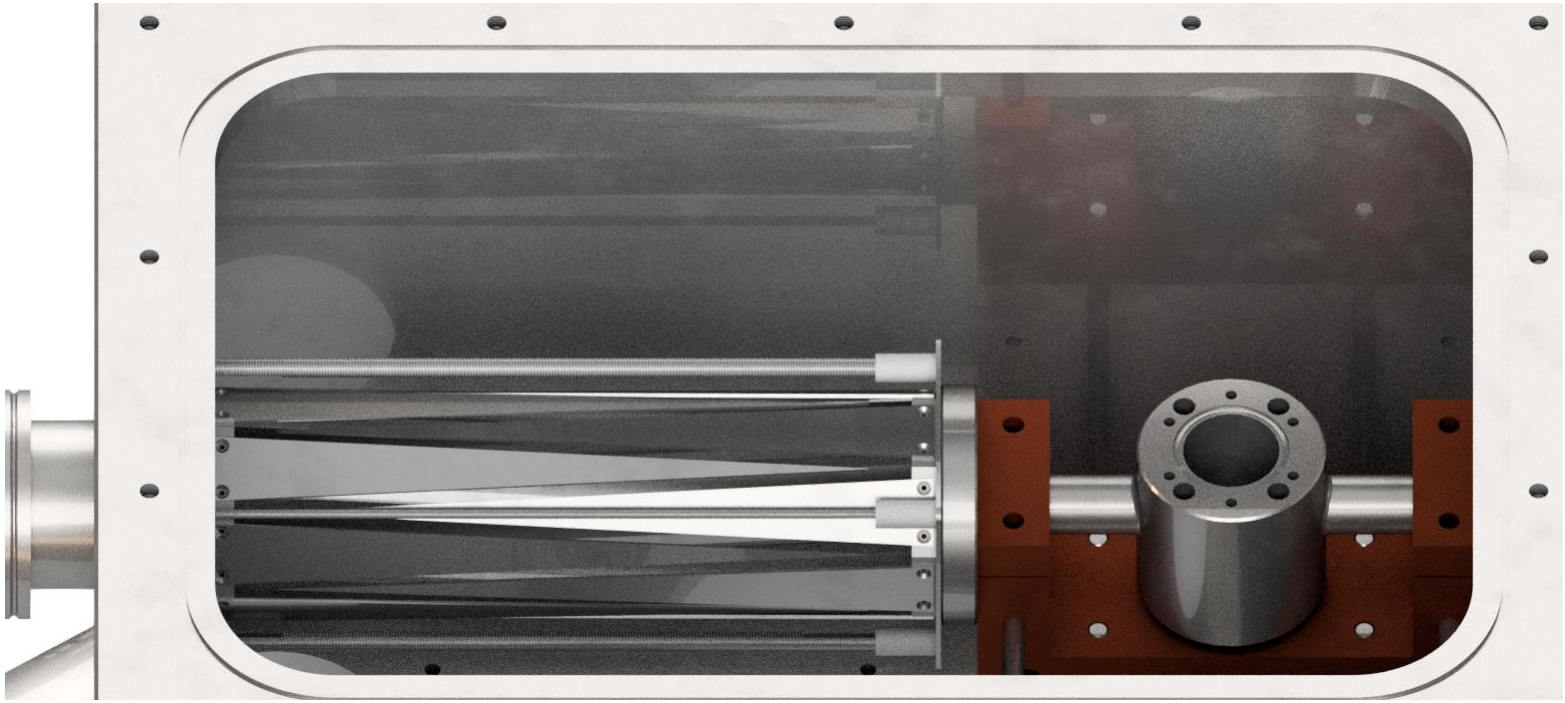
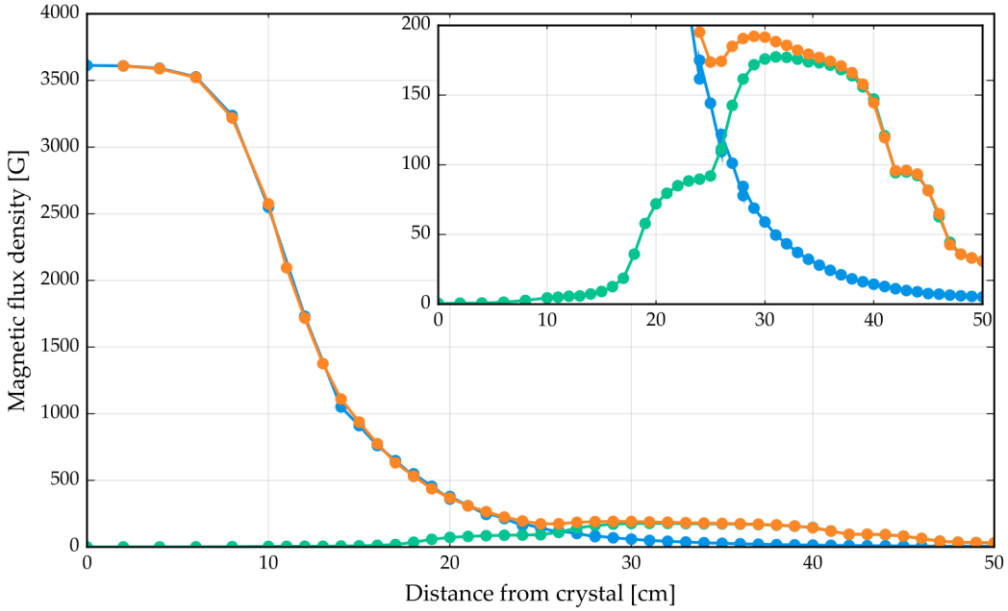
Doppler shifting the frequency

$$f_{beam} = f_{laser}\sqrt{\frac{1-\beta}{1+\beta}}, \beta = v/c$$



Magnetic field

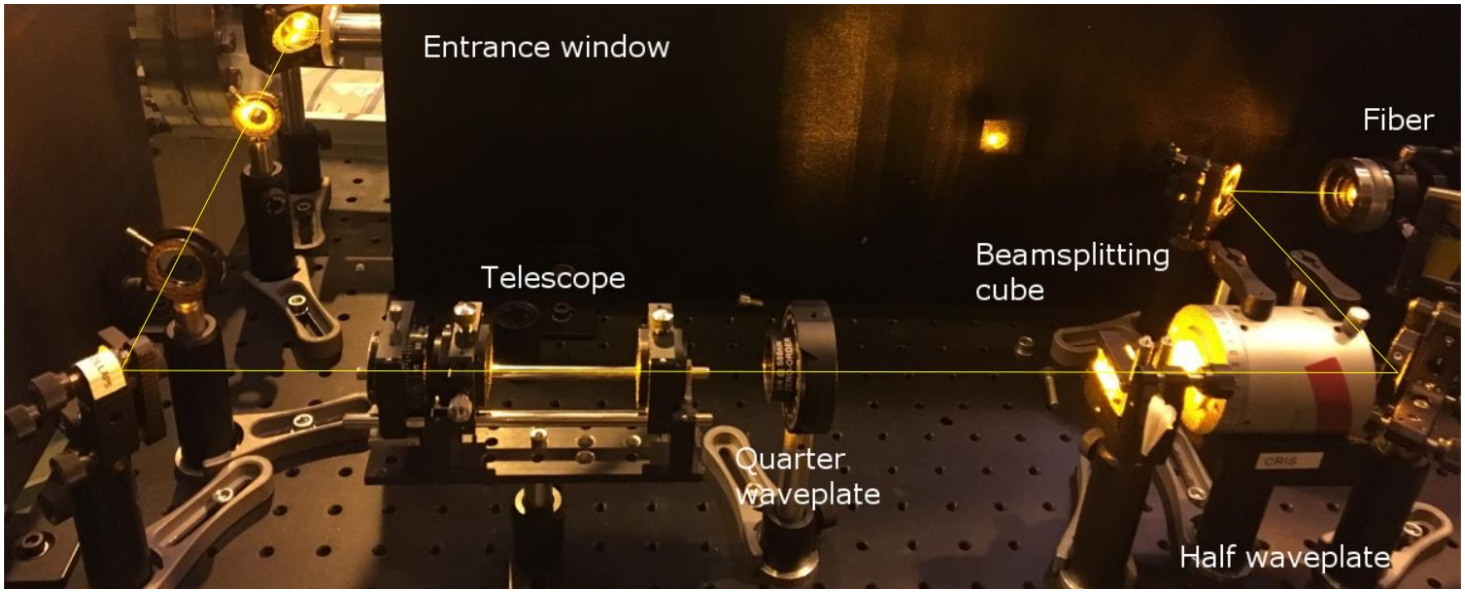
- Polarization is created along the beamaxis, magnet has field perpendicular → configure field to rotate polarization



- Blue: perpendicular, green: along, orange: total

Light characteristics

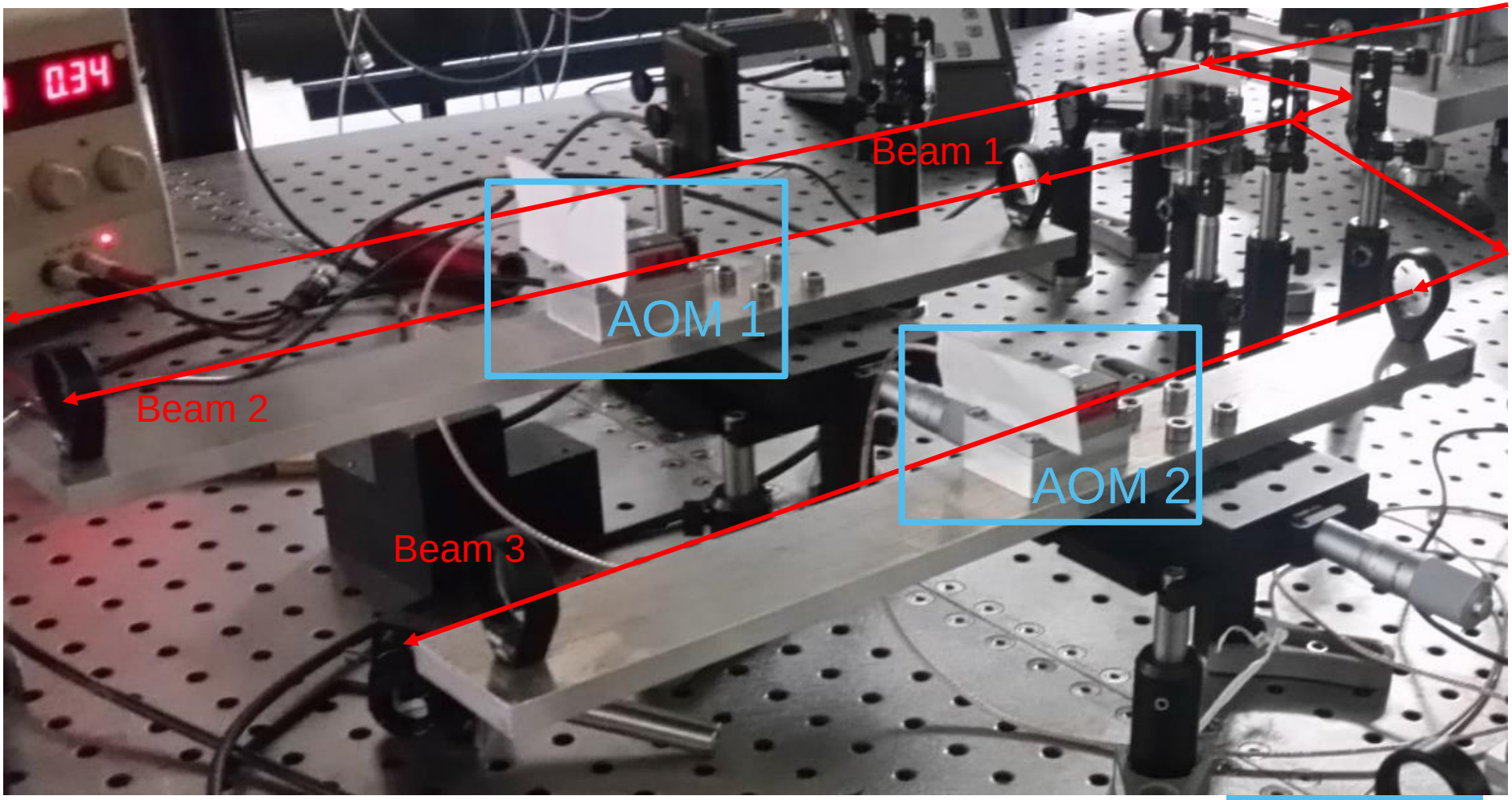
- λ/4 after λ/2 waveplate creates σ±



- High power is crucial for inducing many optical pumping cycles!

AOM Setup

Factory efficiency: 85%
Measured efficiency: ~80%



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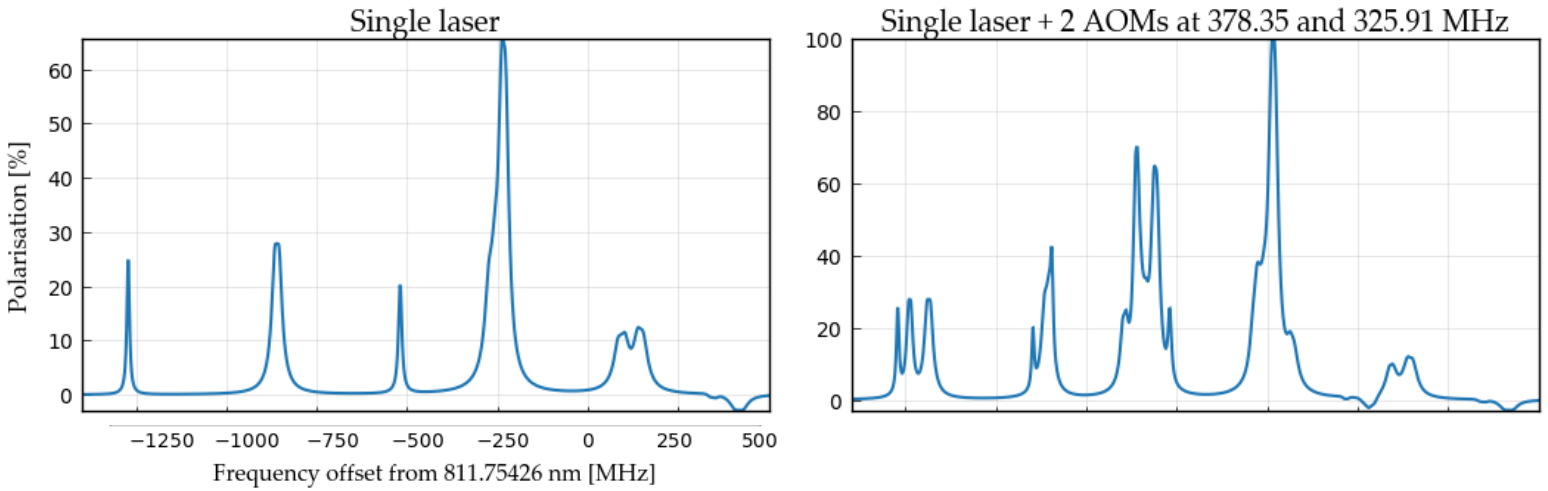
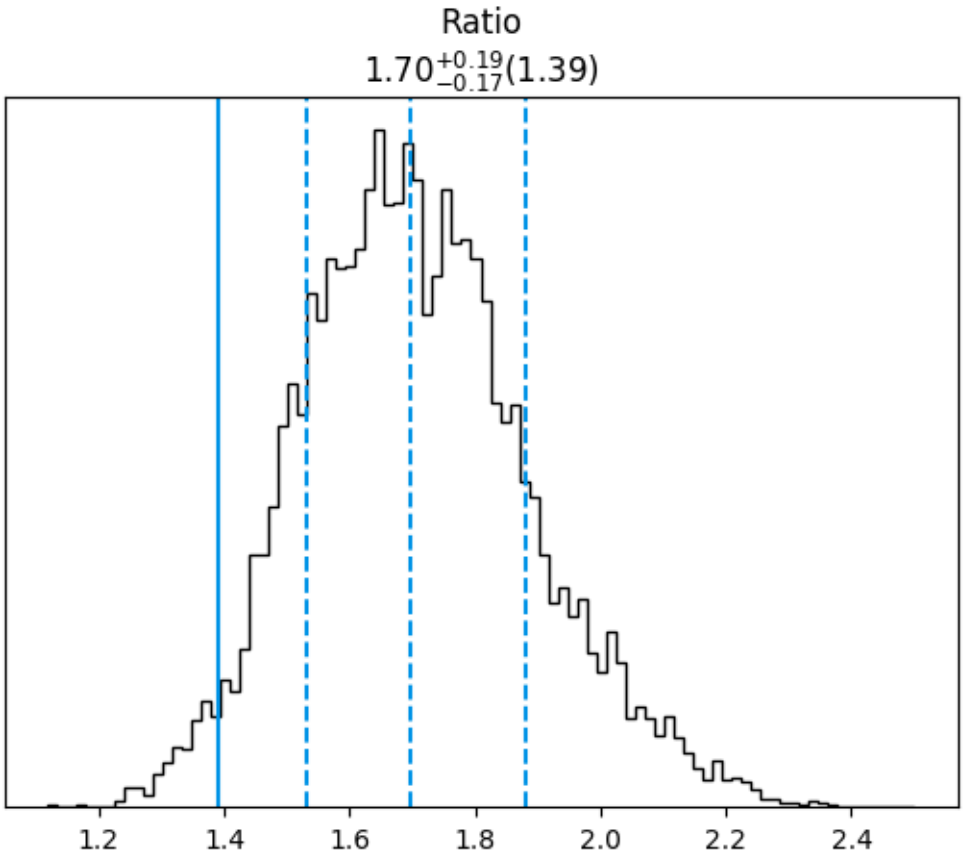
Simulation results

- Classical rate equations adopted for multiple laser frequencies



- Expectation of ~2 times larger signal and addition of extra peaks
- Frequency shifts of 378 and 325 MHz needed: Acousto-Optic Modulators (AA Opto-Electronic MT325, MT378 with associated RF amplifier)
- Technical difficulty: overlap needs to happen with **beam splitters** instead of **polarizing beam splitters** due to need for the same σ polarization

Simulation results



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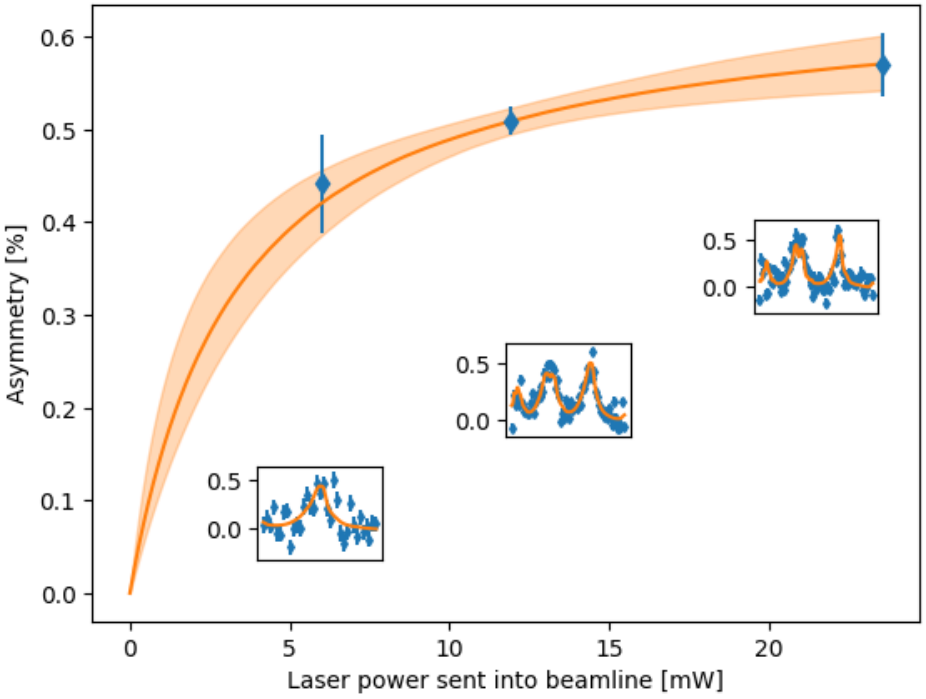
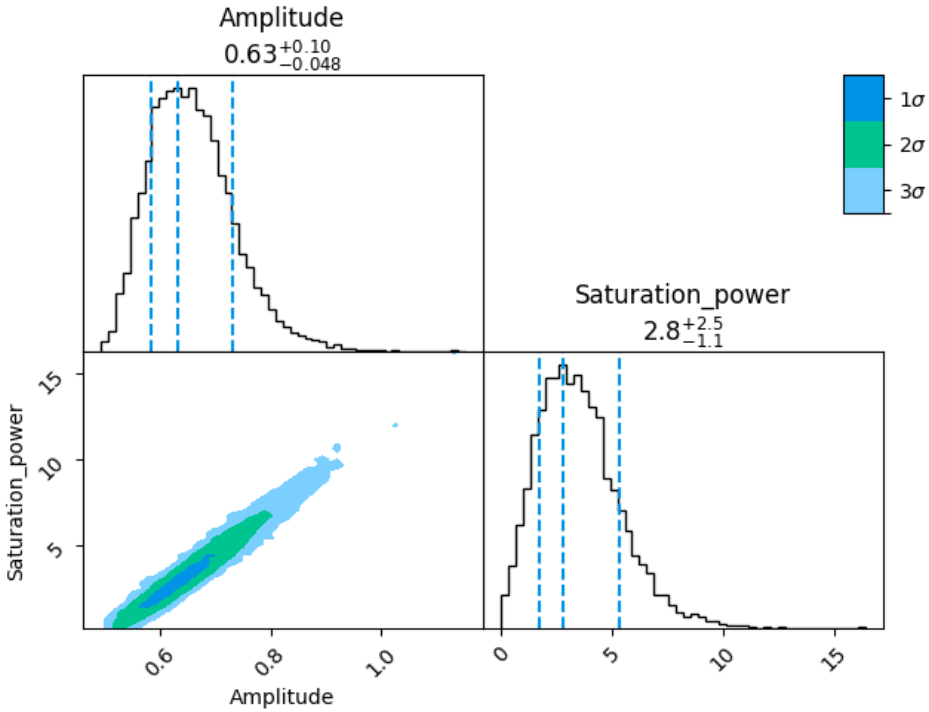
Saturation curve

$$Asym = Amp \frac{{}^{P}/_{P_0}}{1 + {}^{P}/_{P_0}}$$





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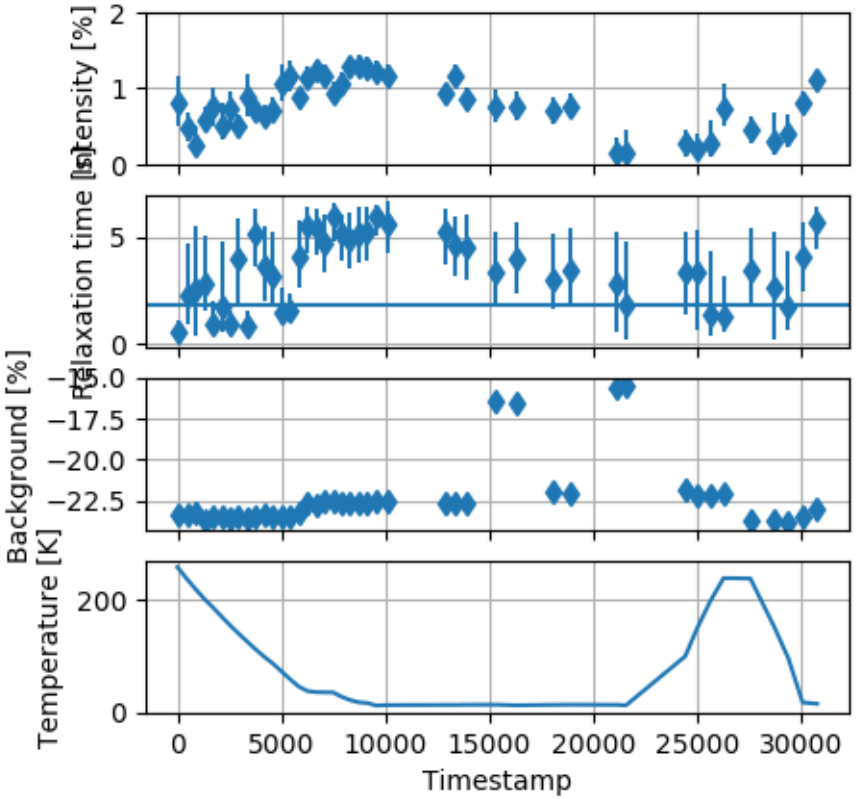
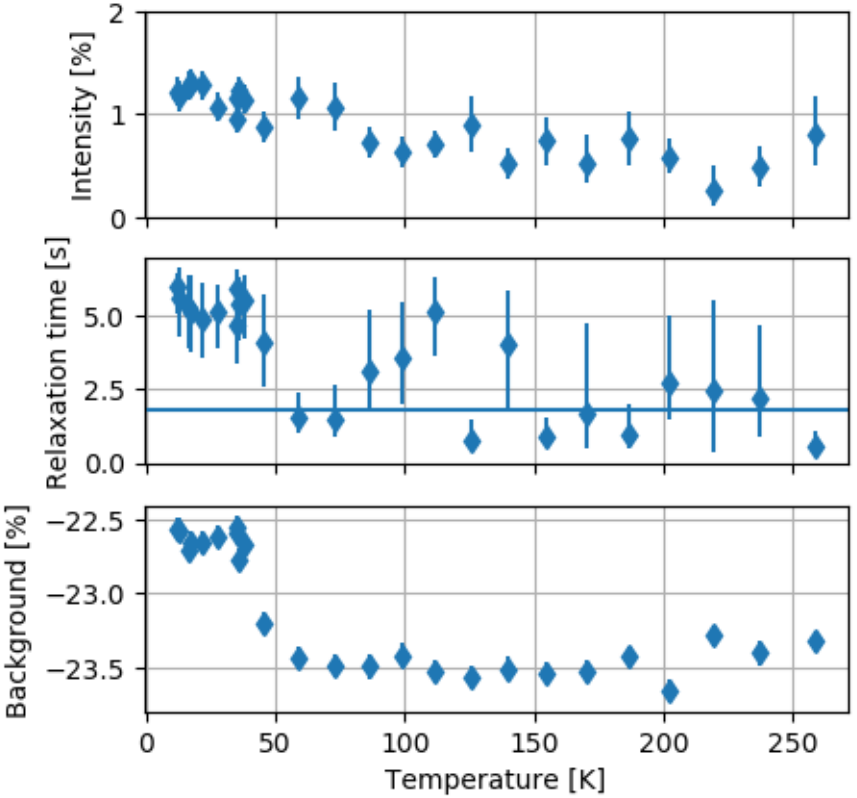
Asymmetry Results

NaCl





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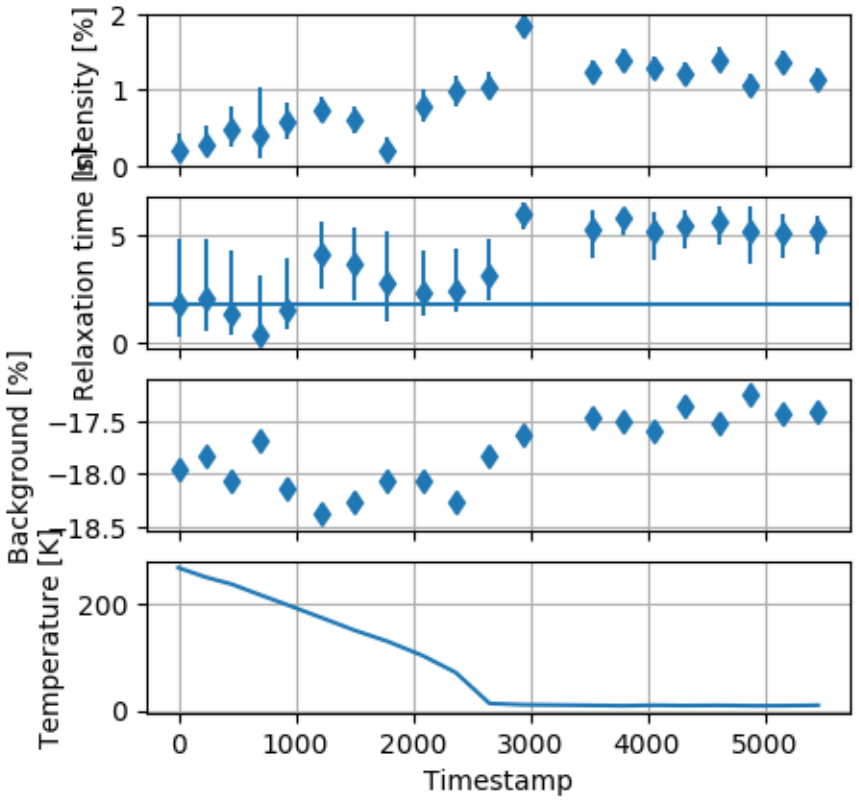
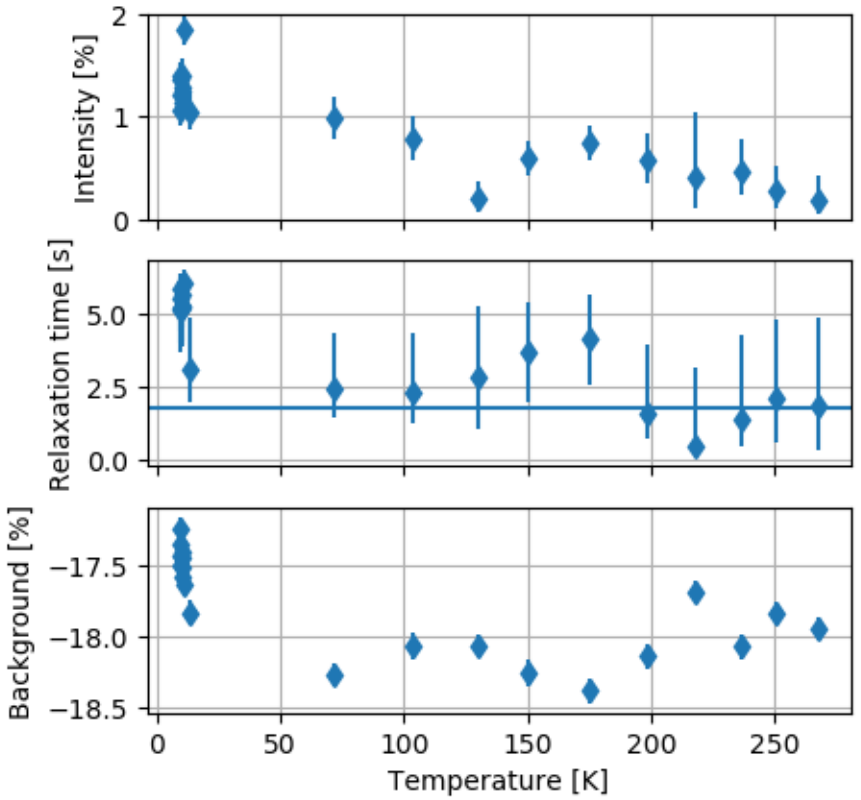
Asymmetry Results

KCl





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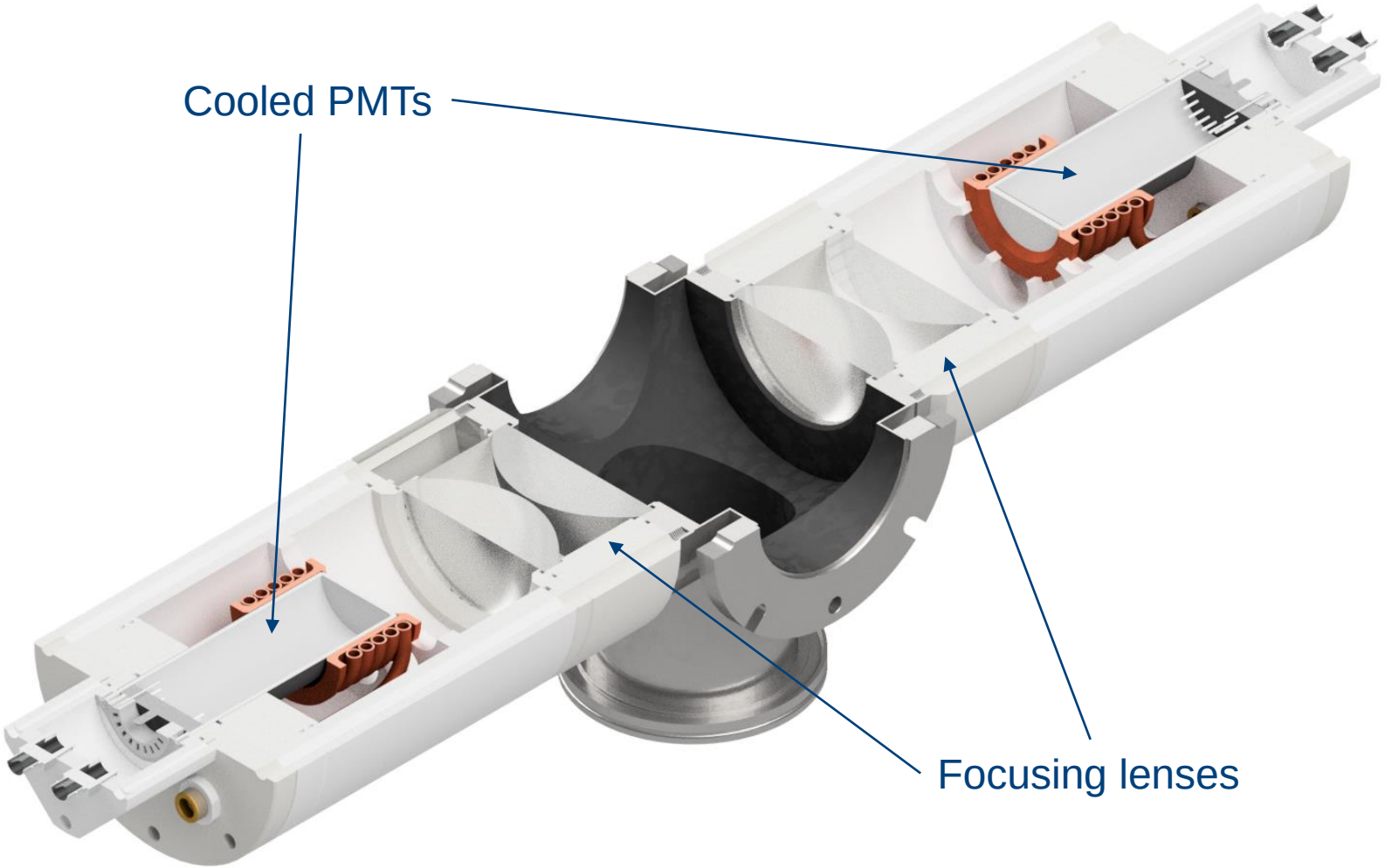
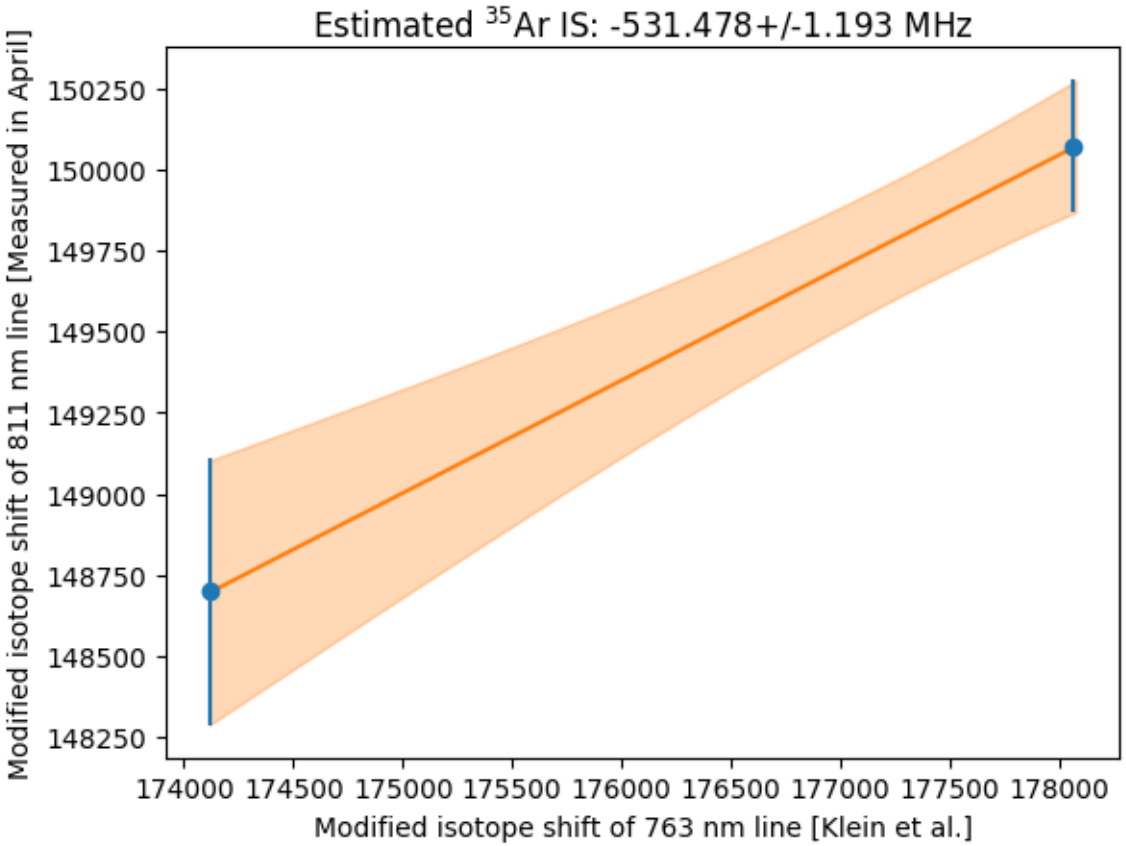
Optical detection



Estimated Isotope Shift



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