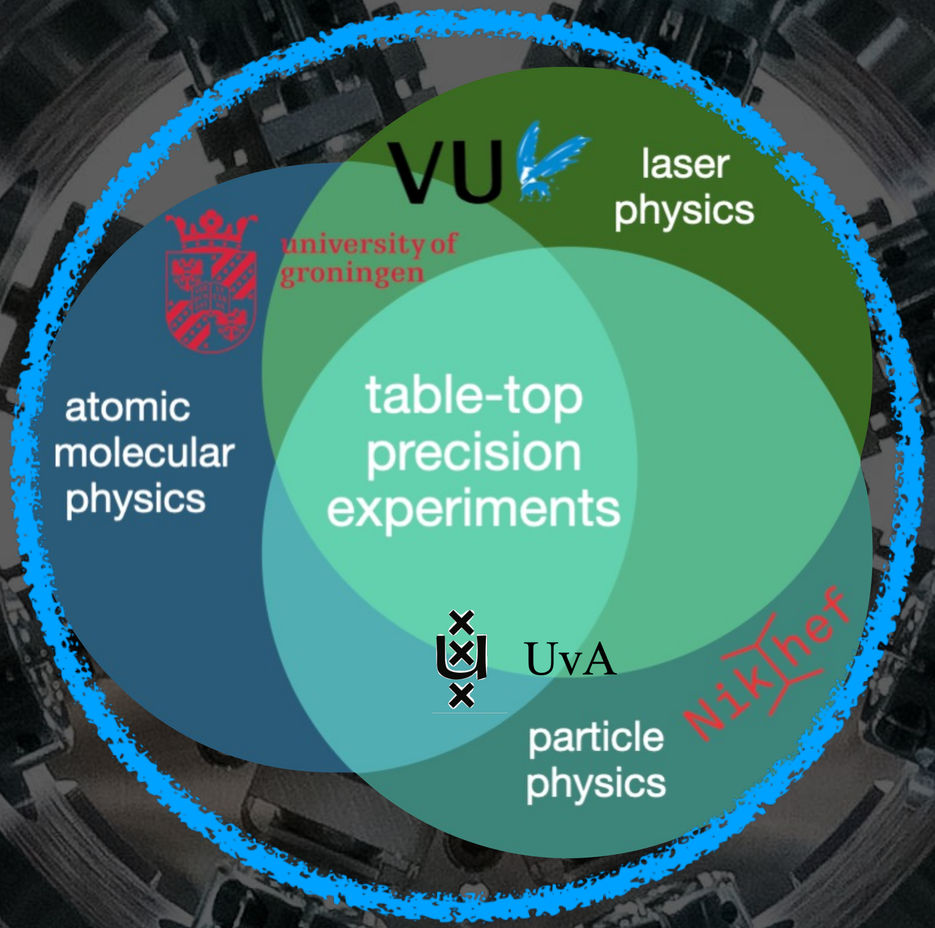
eEDM group

Nikhef Jamboree 2024

Introduction - Steven Hoekstra

eEDM group



Strong integration of theory and experiment

Nikhef Jamboree 2024

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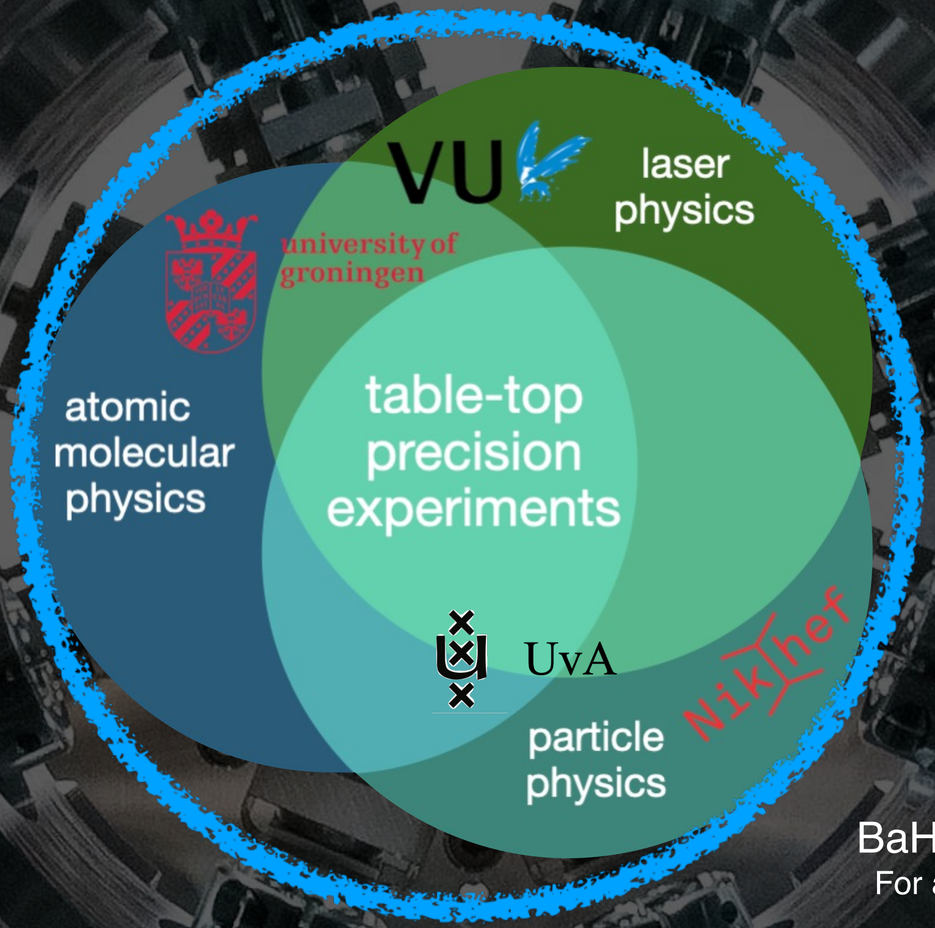


Strong integration of theory and experiment

NL-eEDM experiment
Probing the electron's electric dipole moment

BaH^+ ion trapping - Steve Jones
For a direct comparison of hydrogen and anti-hydrogen

Levitated nanospheres - Steven Hoekstra
Optomechanics for fundamental physics

Quantum Chemistry Theory - Anastasia Borschevsky
High-precision atomic and molecular calculations

Nikhef Jamboree 2024

Introduction - Steven Hoekstra

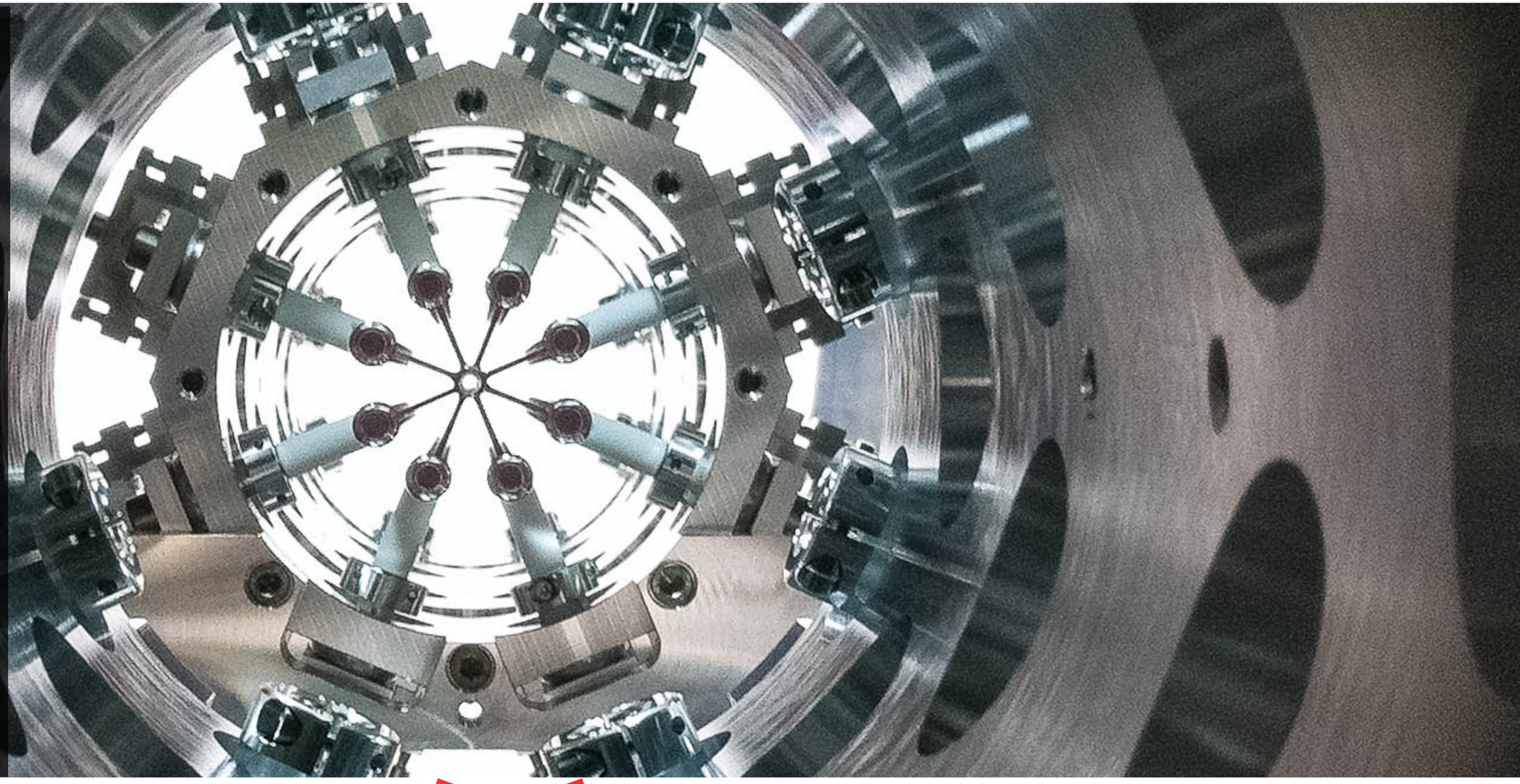
NL-eEDM: Dutch table-top precision experiment, probing new physics using decelerated molecules

Scientific staff:

Anastasia Borschevsky
Rick Bethlem
Steven Hoekstra
Rob Timmermans
Wim Ubachs
Jordy de Vries
Lorenz Willmann

PhD students and postdocs:

Akaash Srikanth
Agustin Aucar
Roman Bause
Alexander Boeschoten
Ties Fikkers
Joost van Hofslot
Jelmer Levenga
Virginia Marshall
Thomas Meijknecht
Maarten Mooij
Heleen Mulder
Eiffion Prinsen
Bart Schellenberg
Lucas van Sloten
Anno Touwen



university of groningen
van swinderen institute for particle physics and gravity

Nikhef
Dutch National Institute for (astro)Particle Physics

VU VRIJE UNIVERSITEIT AMSTERDAM

UvA

NL-eEDM: Dutch table-top precision experiment, probing new physics using slow molecules

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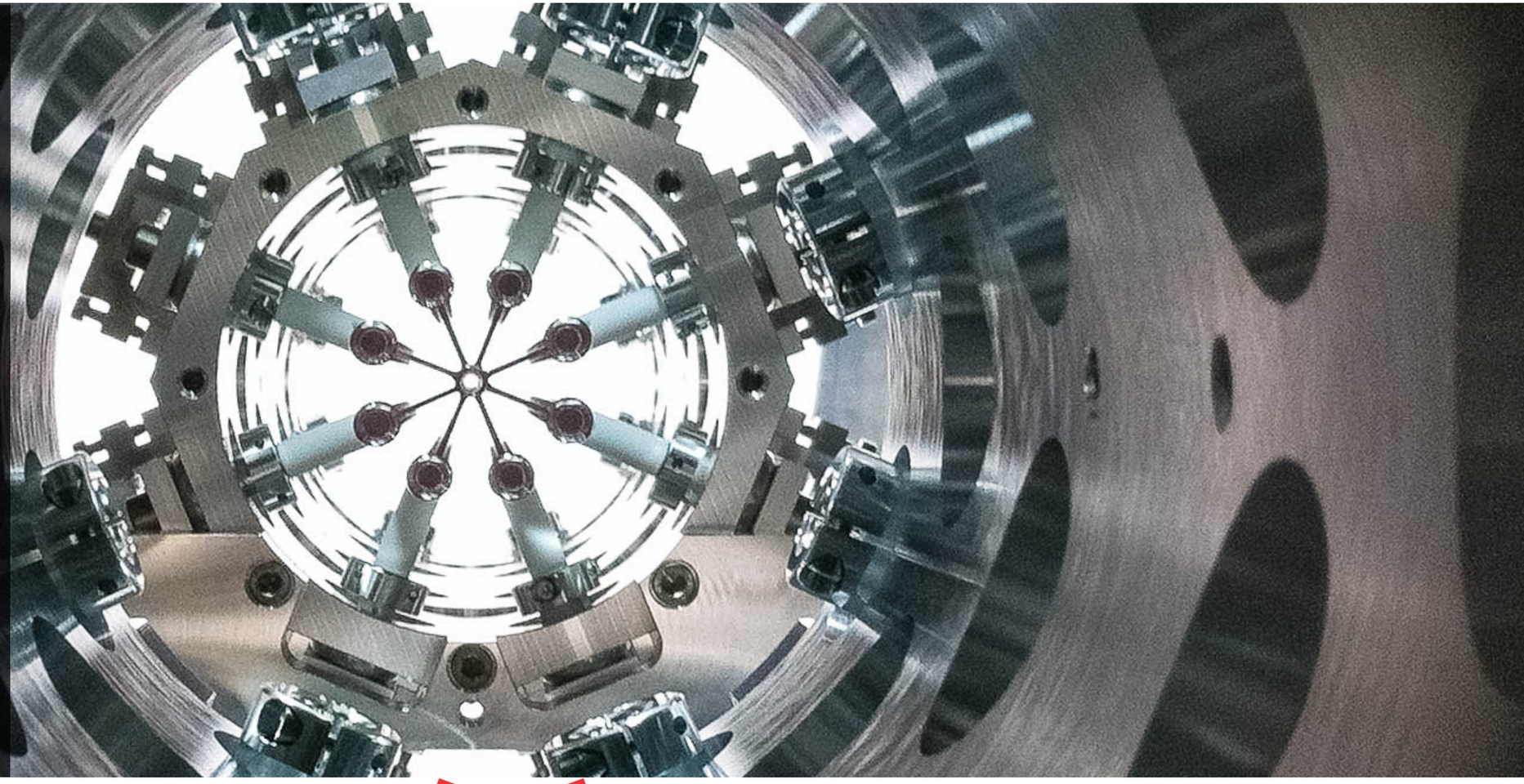
Jelmer Levenga (3/24)
Virginia Marshall (4/24)
Thomas Meijknecht (11/23)
Maarten Mooij
Heleen Mulder (10/23)
Eiffion Prinsen (7/23)
Bart Schellenberg (7/23)
Lucas van Sloten
Anno Touwen

Recently started
Recently left
Presenting today



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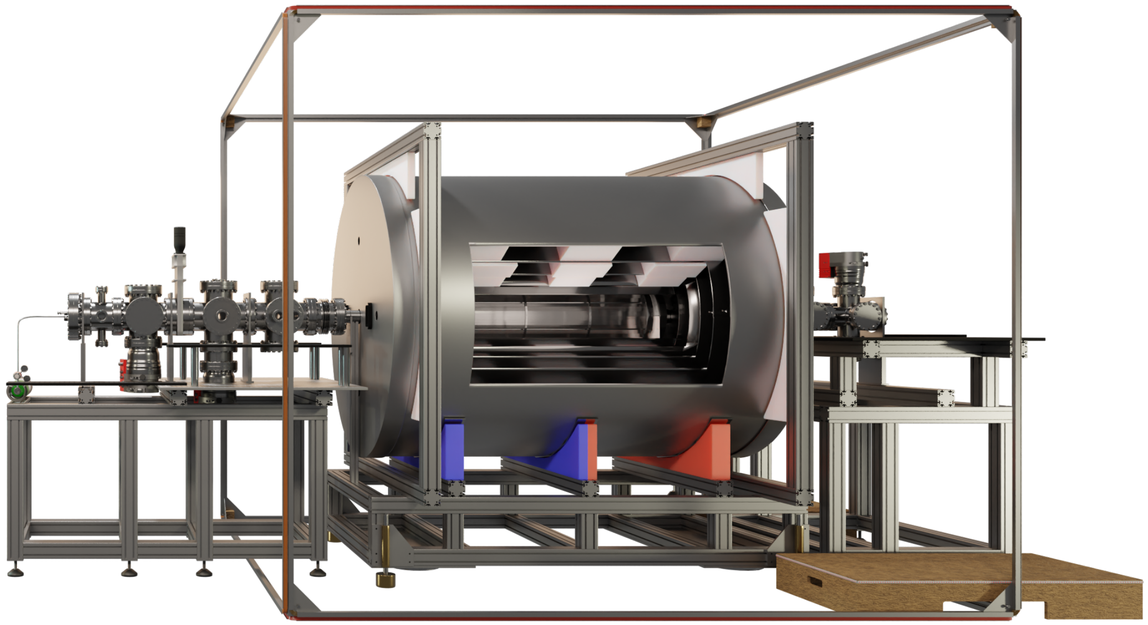
Phase 1: Fast beam

Supersonic beam (600 m/s)

Controlled field environment

Explore molecular structure

Spin interferometer measurement

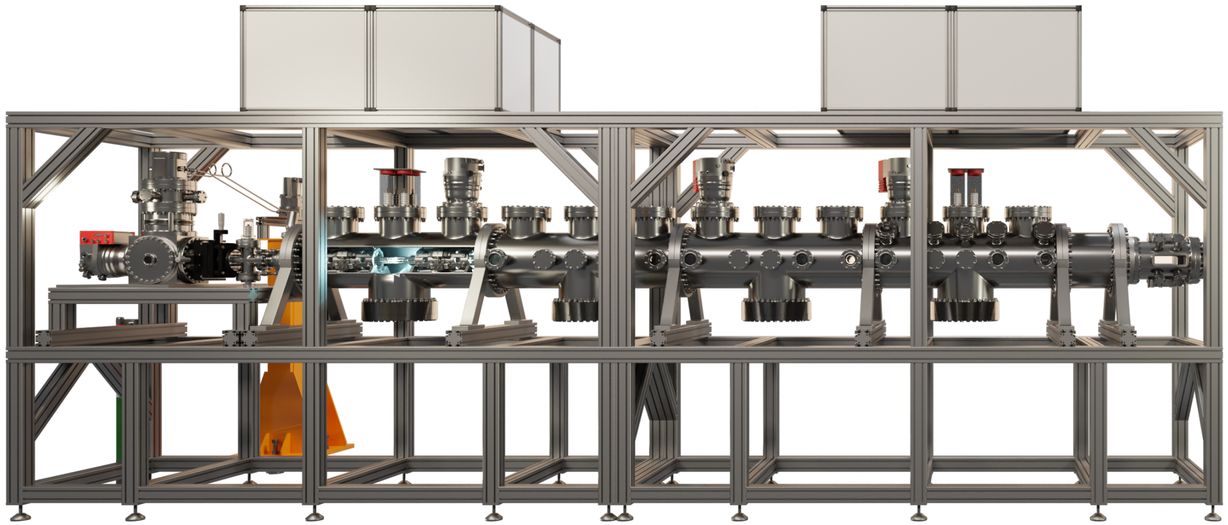


Understand systematics

-- Operational experiment, data taken, analysis ongoing --

march-april 2024:

Moved our experiment to a new building!



Phase 2: Slow beam

Cryogenic beam (200 m/s)

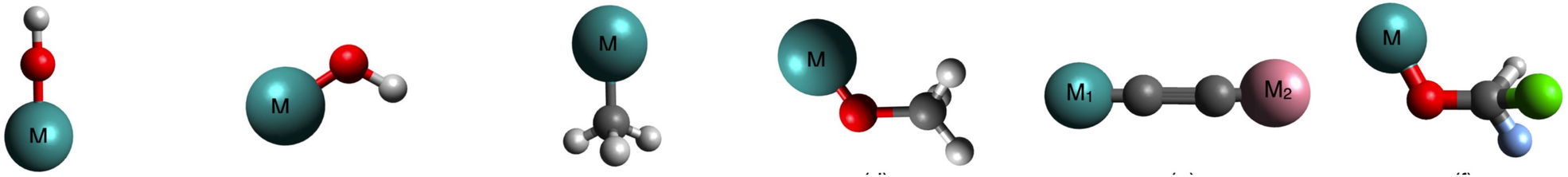
Transverse laser cooling

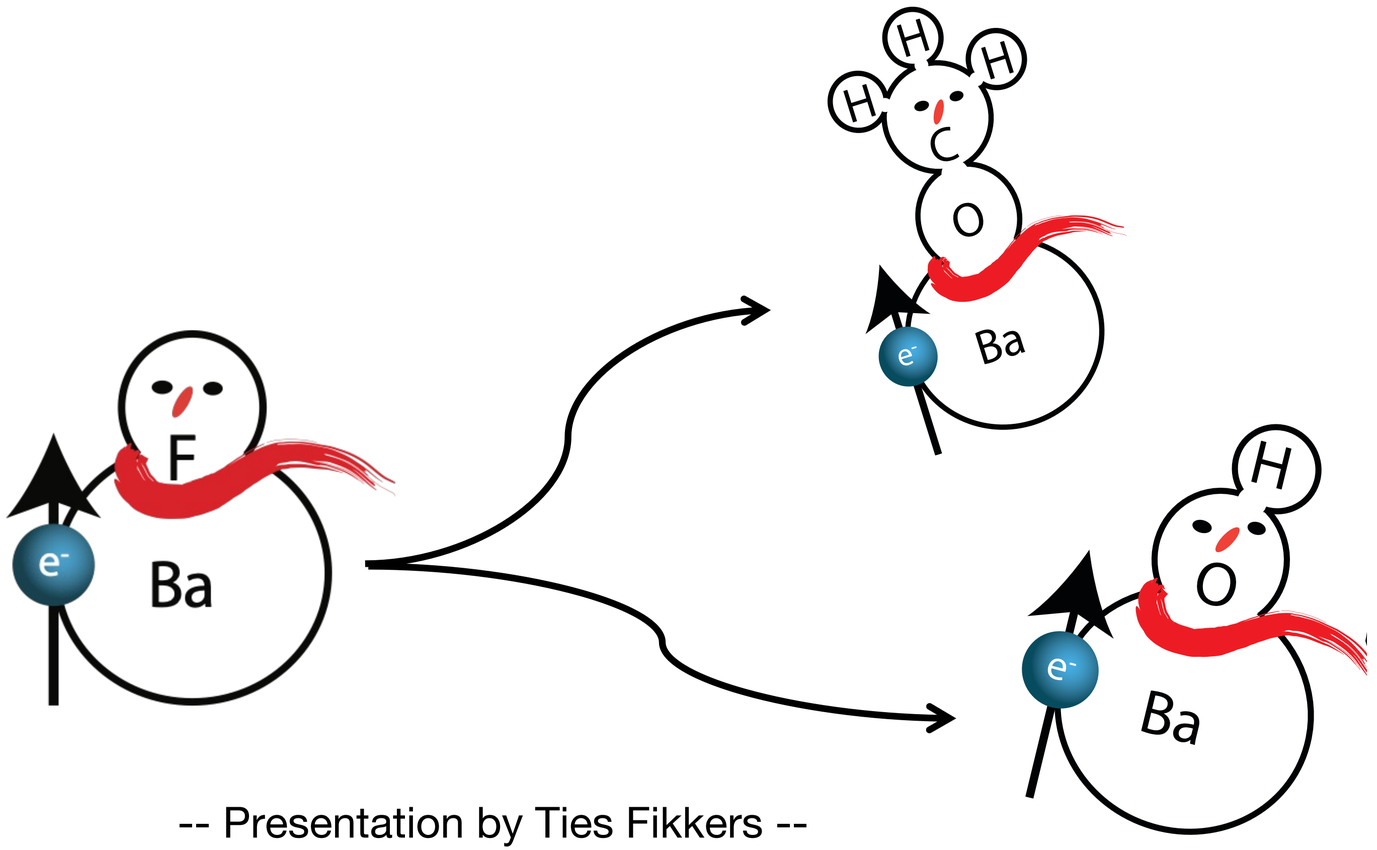
Stark deceleration

Increase statistics

-- Presentation by Joost van Hofslot --

‘Modding’ the molecules



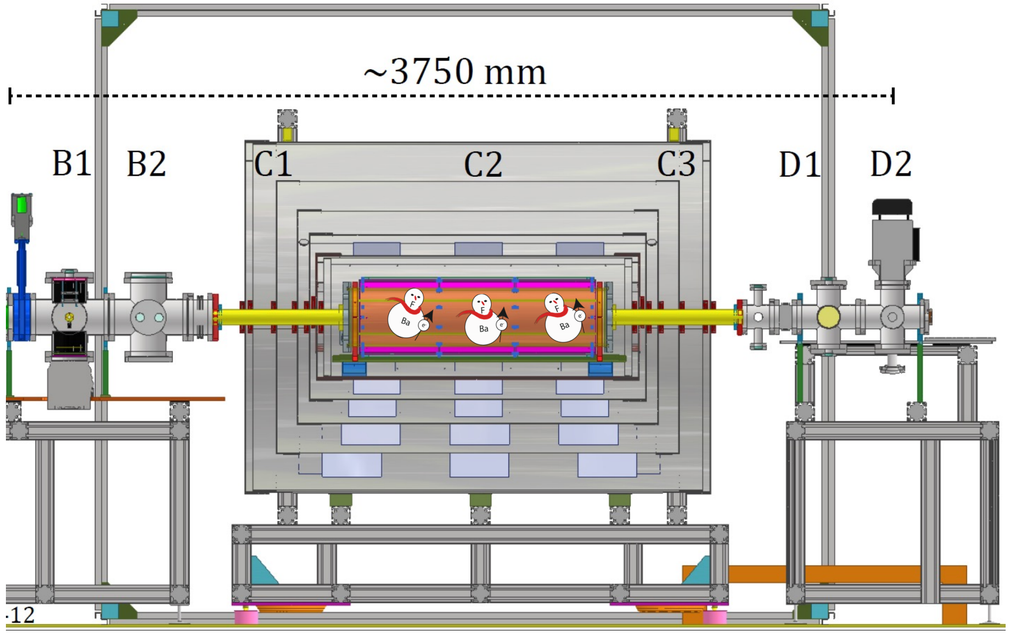


-- Presentation by Ties Fikkers --

An intense beam of BaF using laser cooling

Joost van Hofslot, NL-*e*EDM project

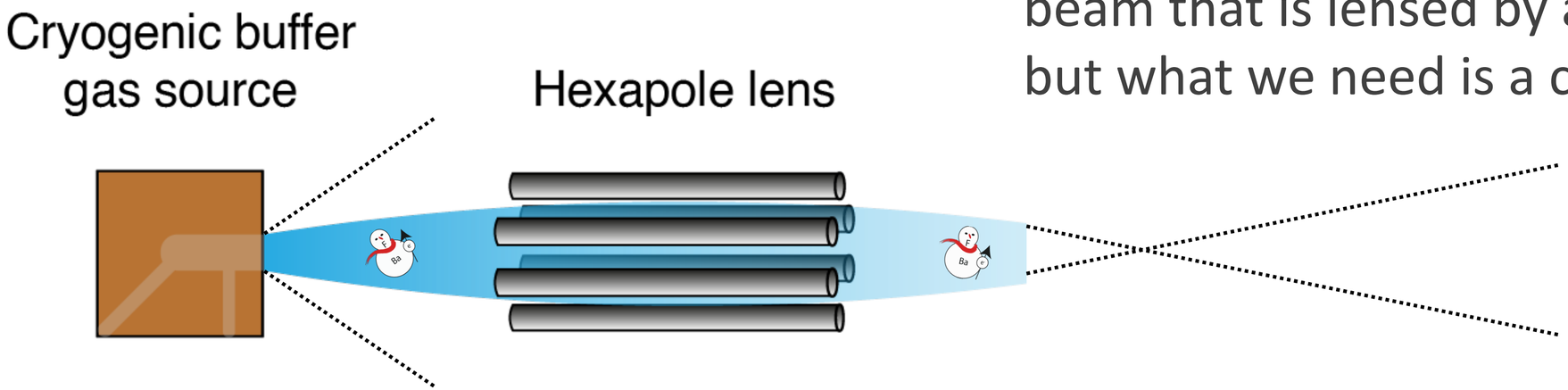
NL-*e*EDM



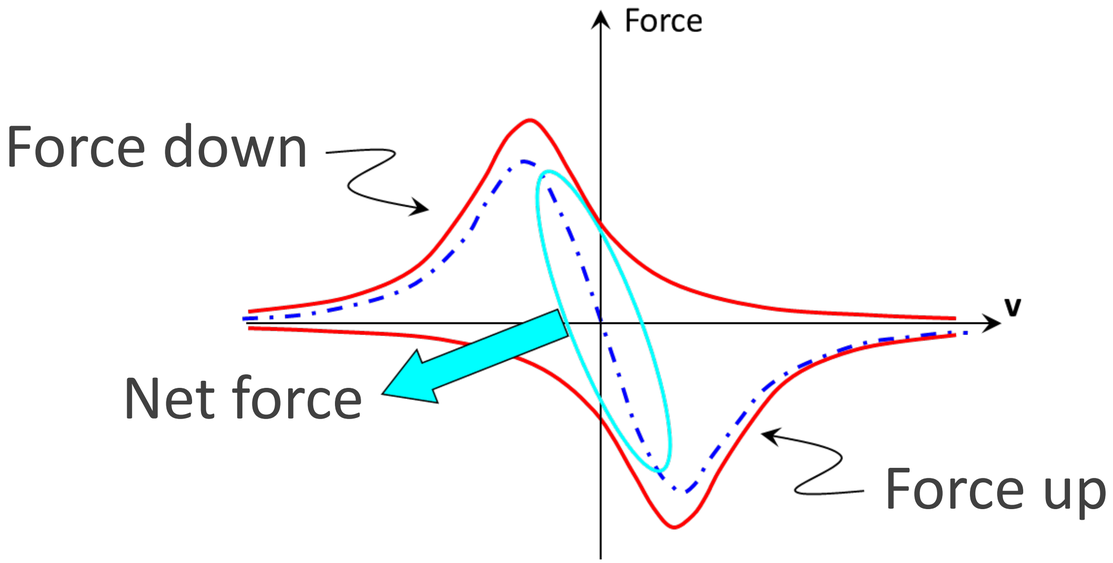
<u>Phase 1:</u> BaF beam of ~600 m/s, ~4m of free flight

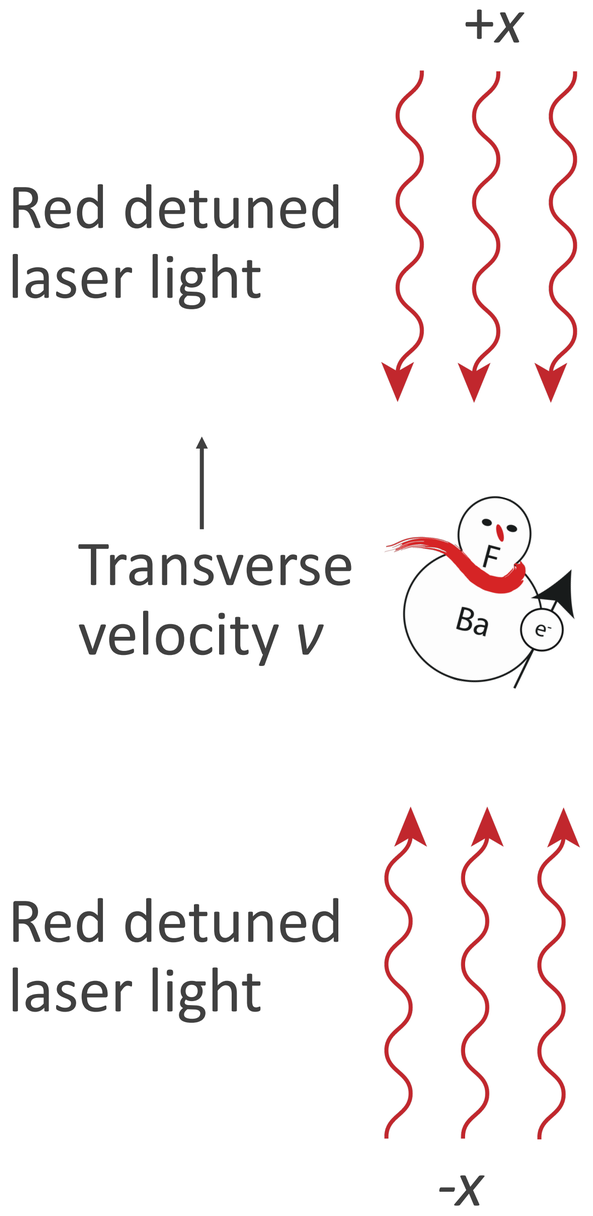
<u>Phase 2</u>: more and slower BaF molecules

We have developed a ~180 m/s cryogenic buffer gas beam that is lensed by an electrostatic hexapole, but what we need is a collimated beam.



Beam collimation using Doppler laser cooling





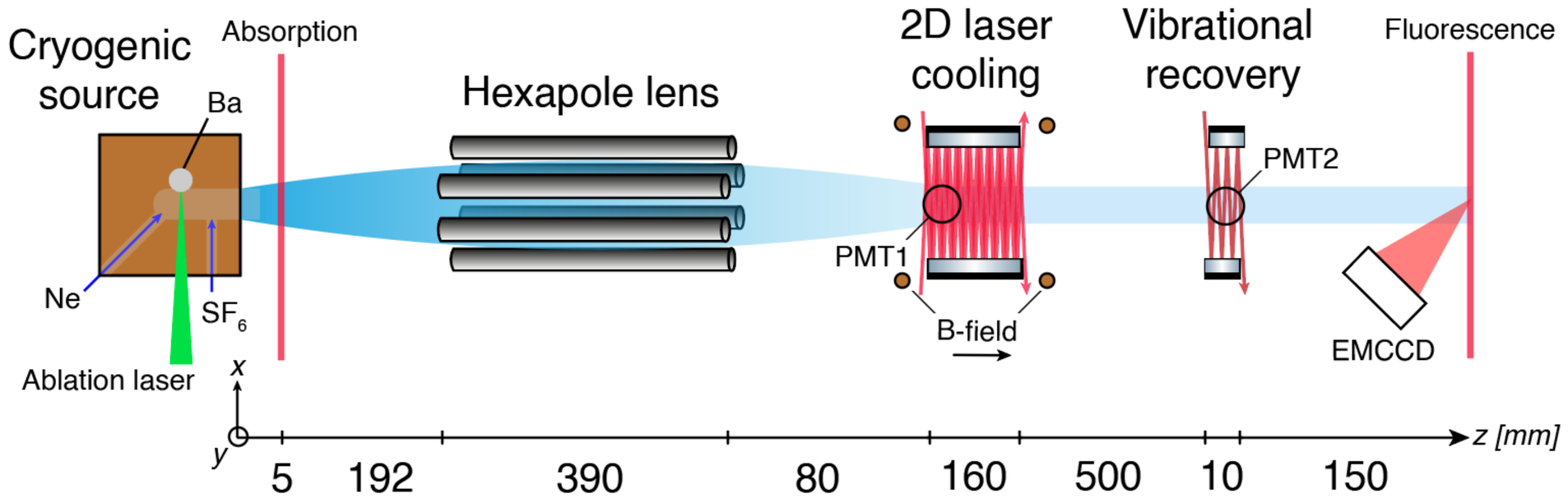
Consequence: force opposing molecule's velocity.

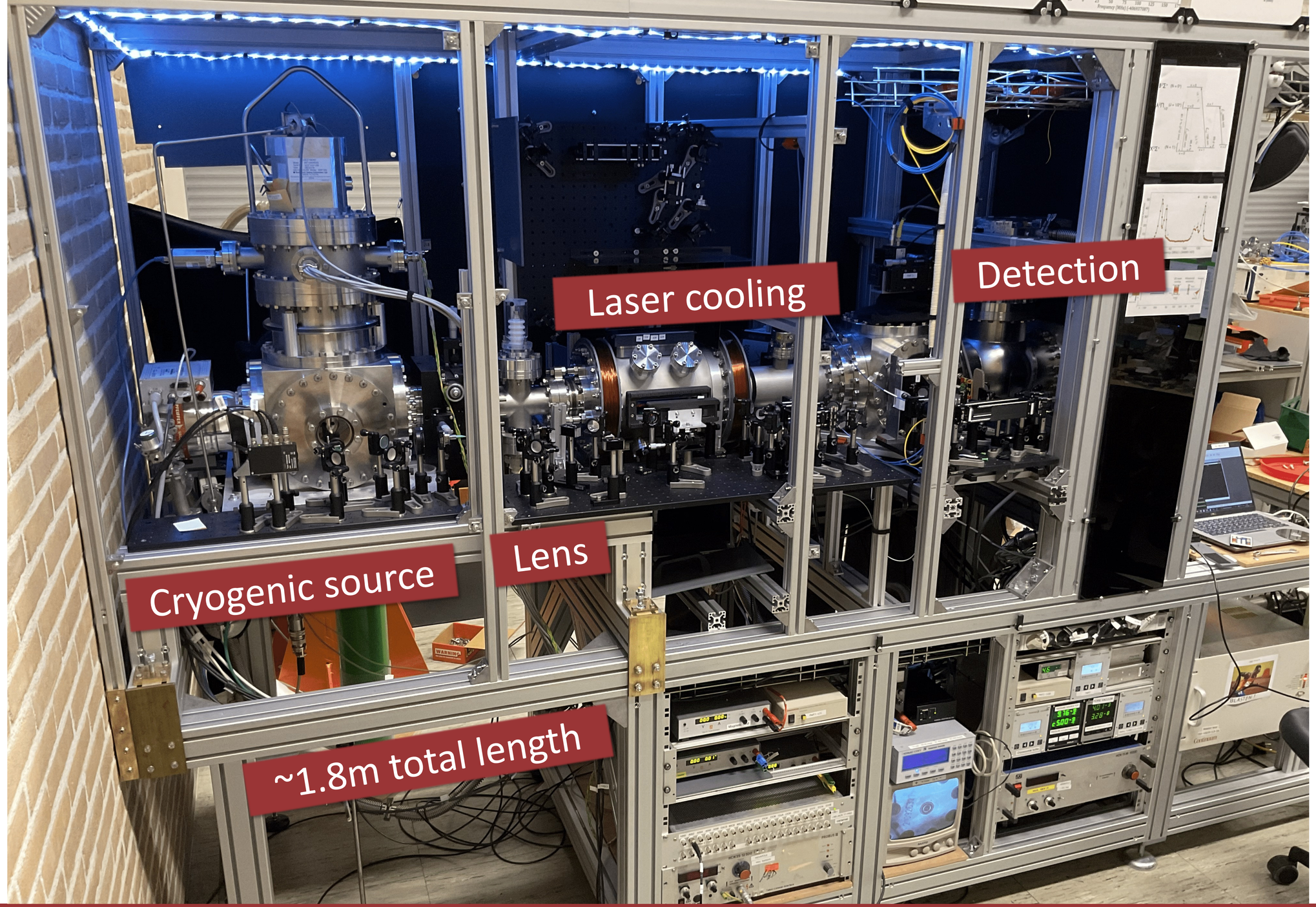
Laser cooling works extremely well for atoms.

Lets apply it to our BaF molecule!

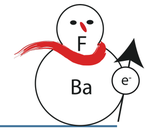
Experiment: apply laser cooling to the molecular beam around the focus of the lens

Effective laser cooling requires scattering ~2000 photons to cool to just above the Doppler limit of ~0.1 m/s.

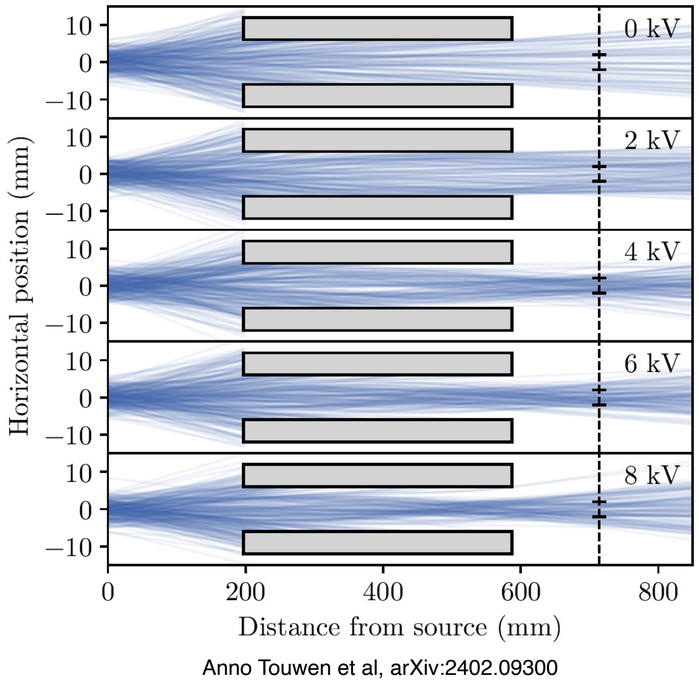



Laser cooling
Detection
Cryogenic source
Lens
~1.8m total length

The hexapole generates a strong electric field to manipulate the molecular beam

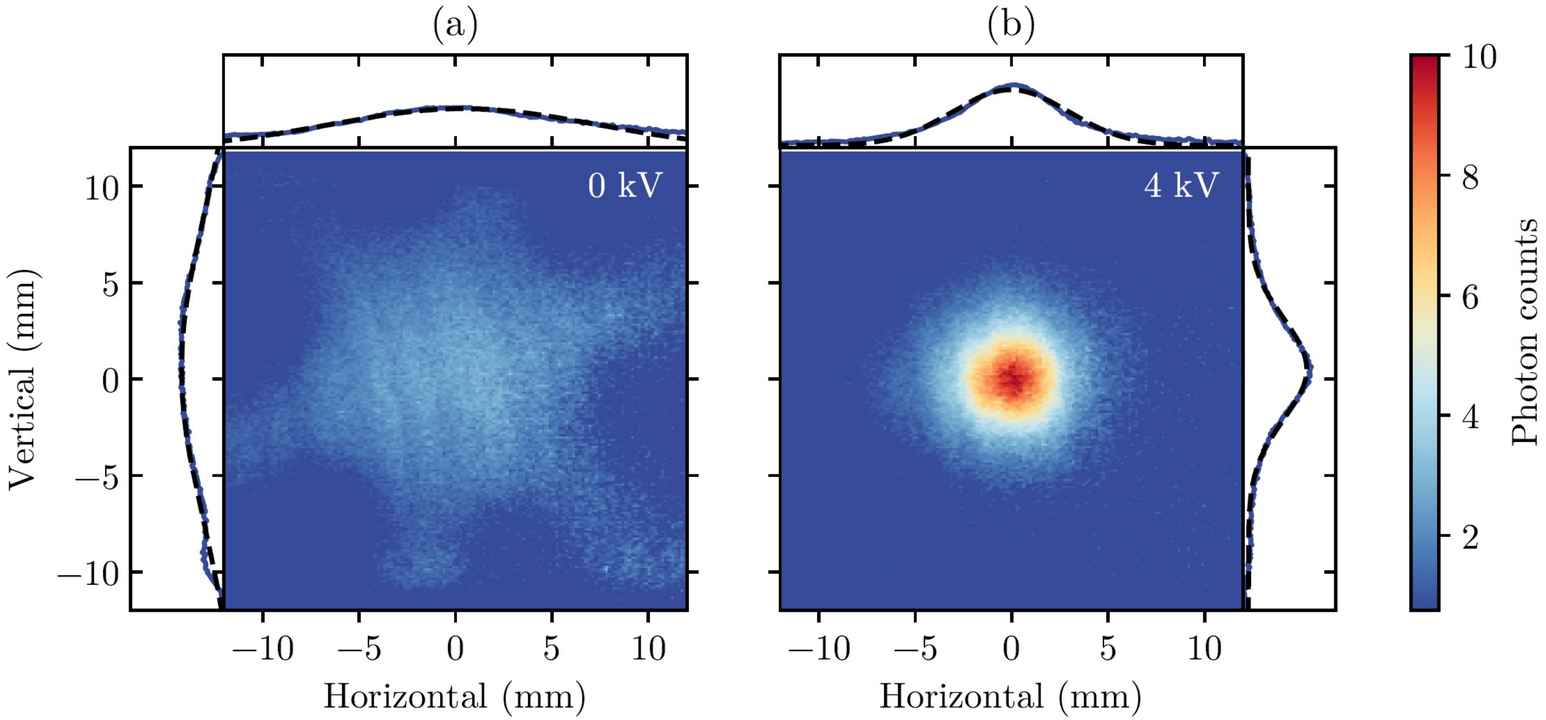


Simulation



Anno Touwen et al, arXiv:2402.09300

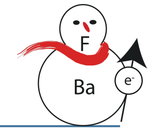
Measurement



Anno Touwen et al, arXiv:2402.09300

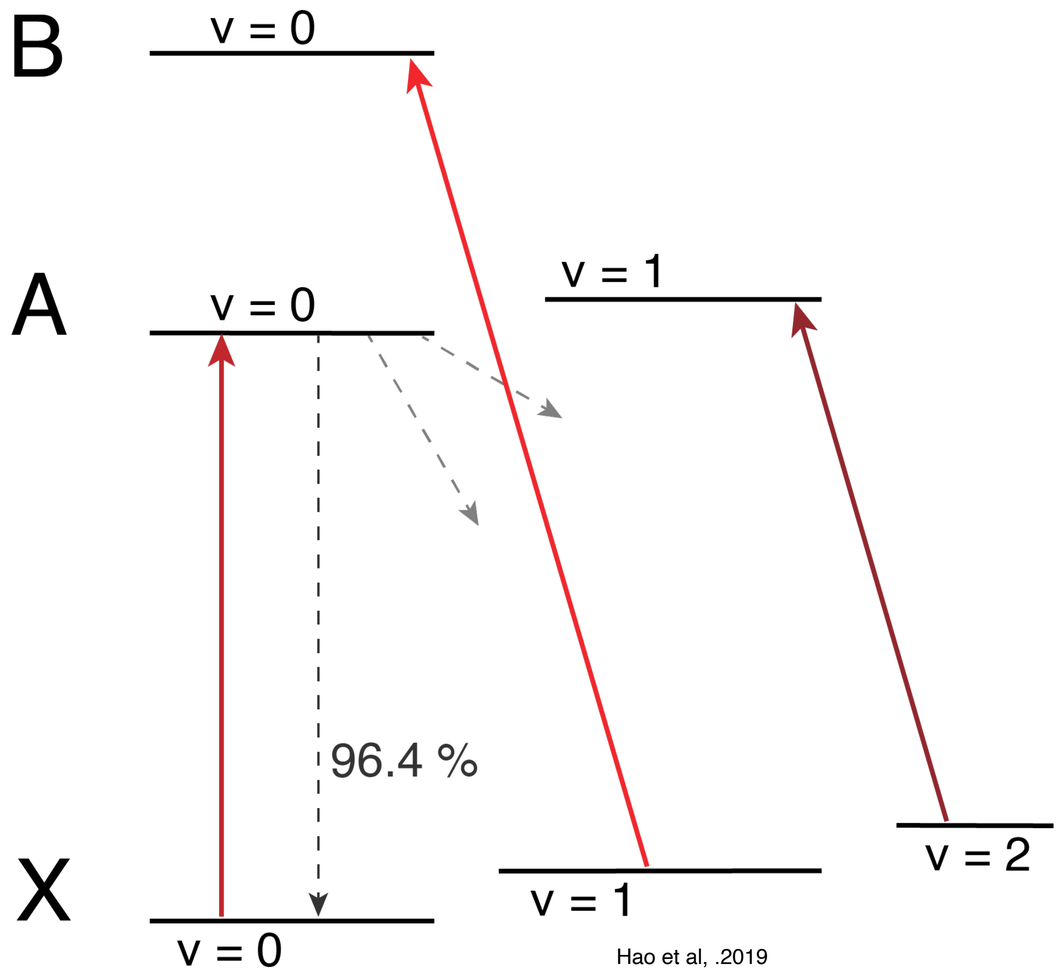
We can focus molecules with +-5 m/s into a relatively small area, and then…

Complexity of laser cooling BaF

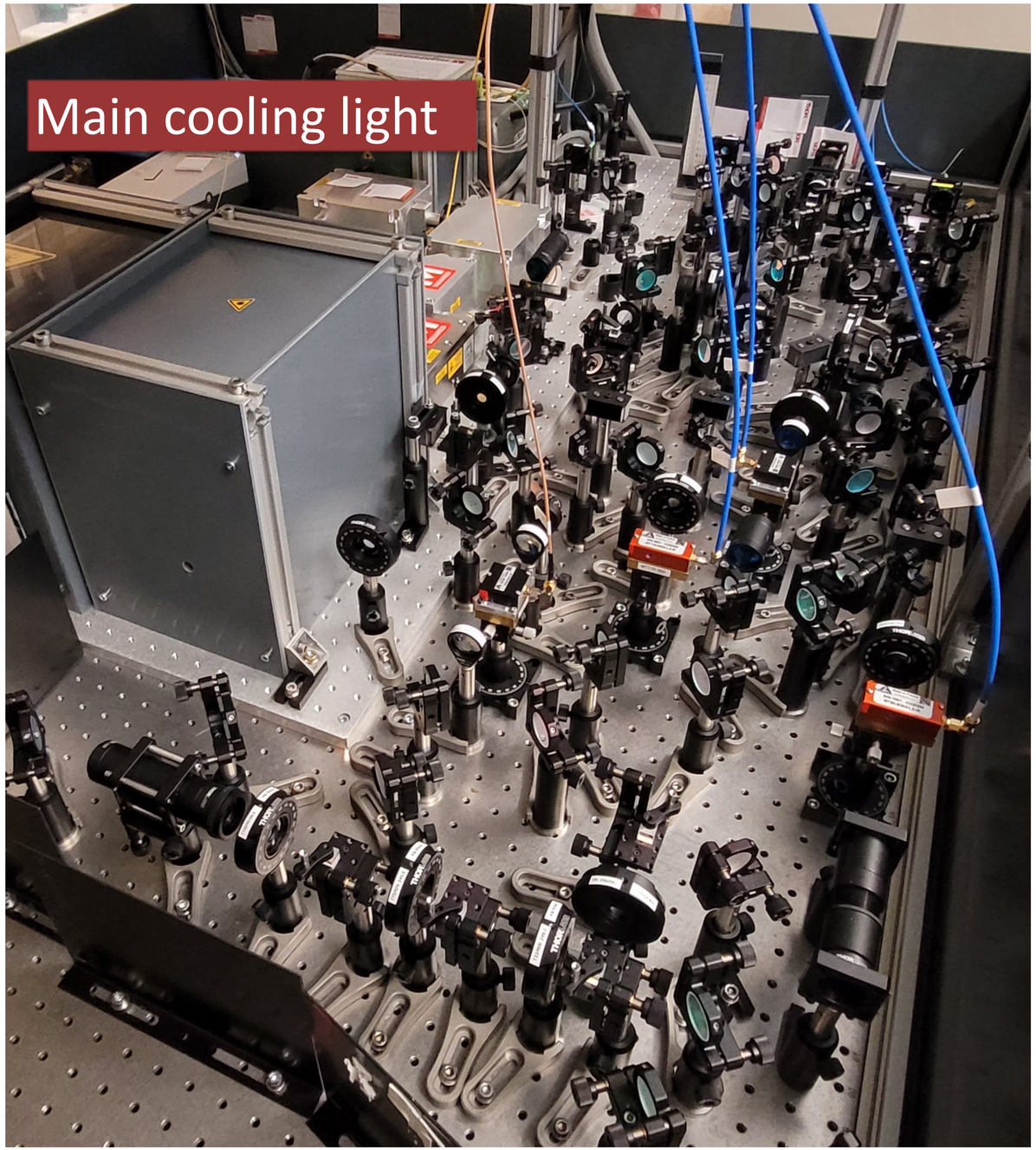


Rich energy structure in molecules introduces loss channels which complicates establishing a closed cycle

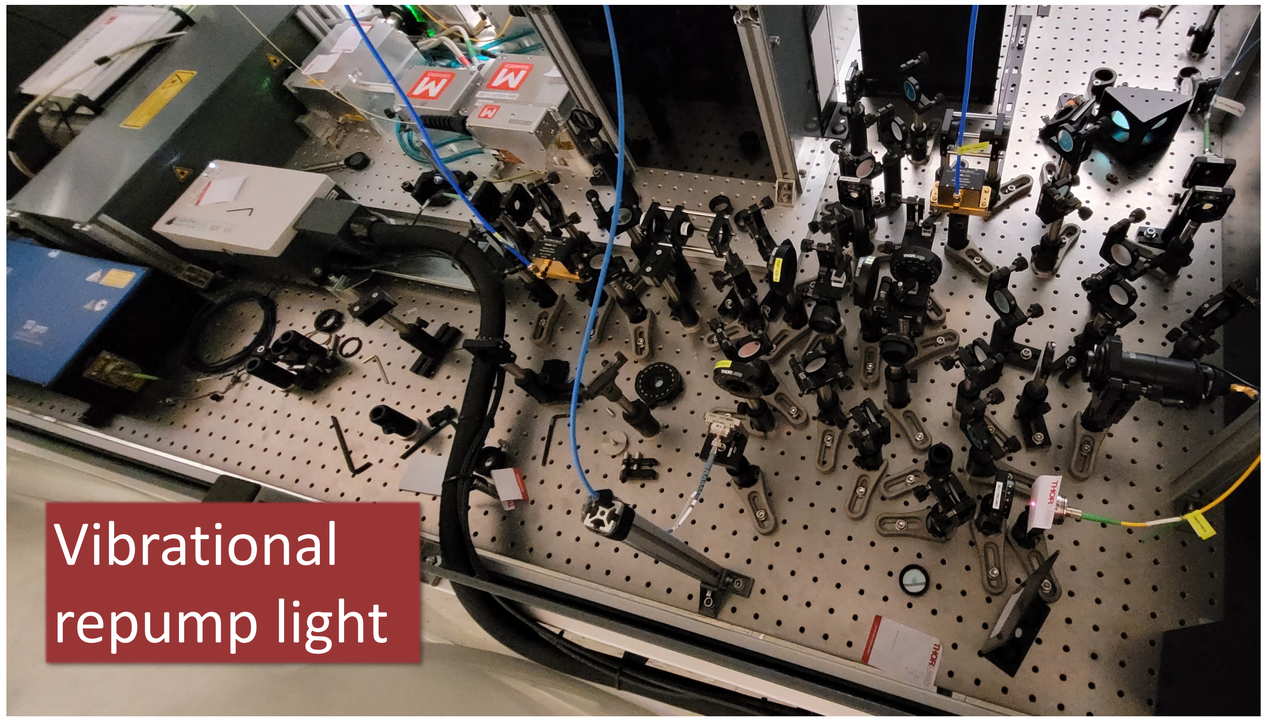
For example: vibrational branching



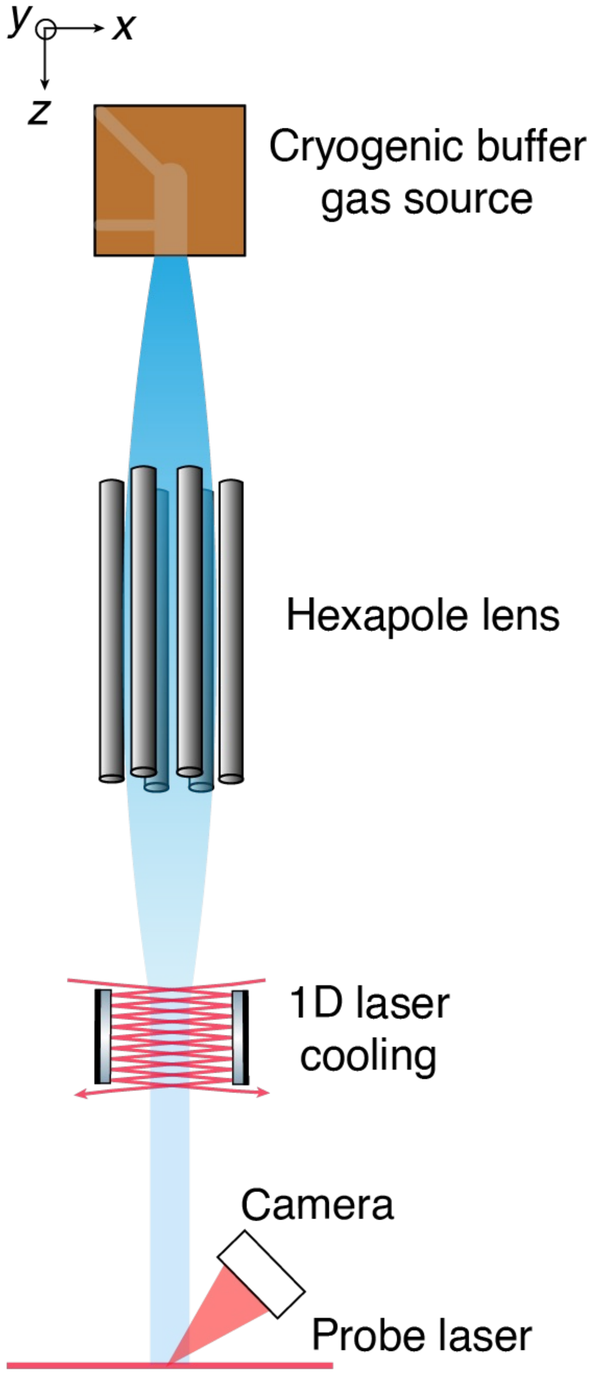
Hao et al, .2019



Generating all the necessary laser light requires quite some optics

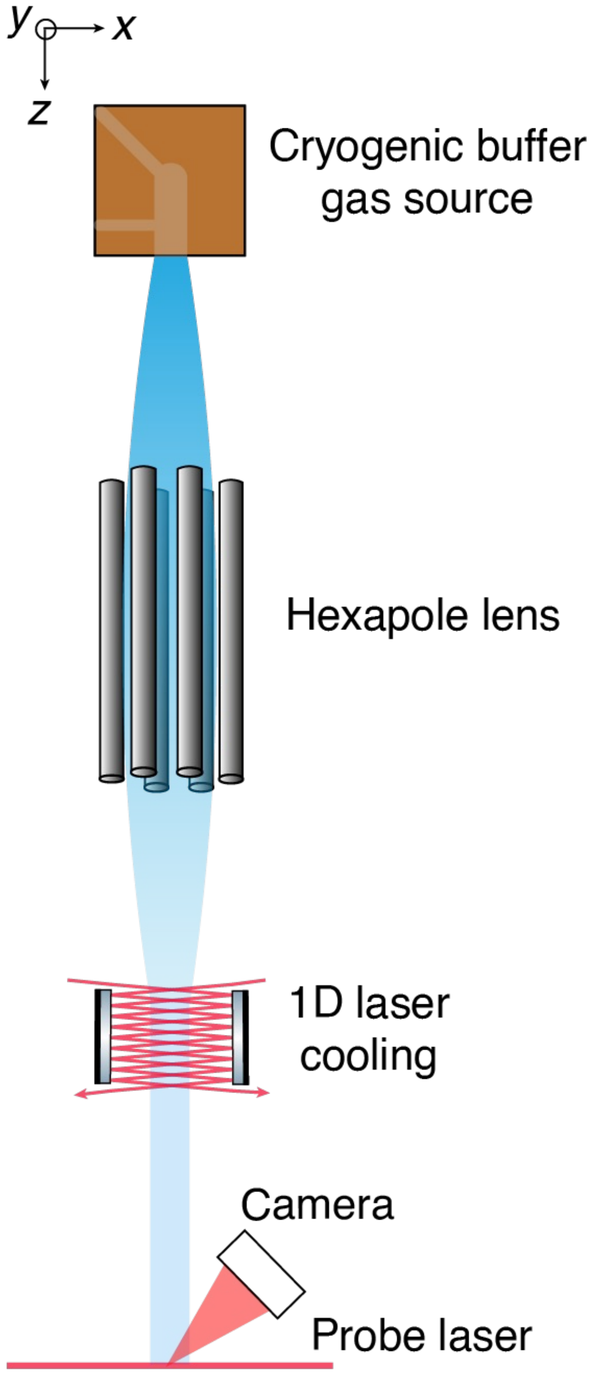


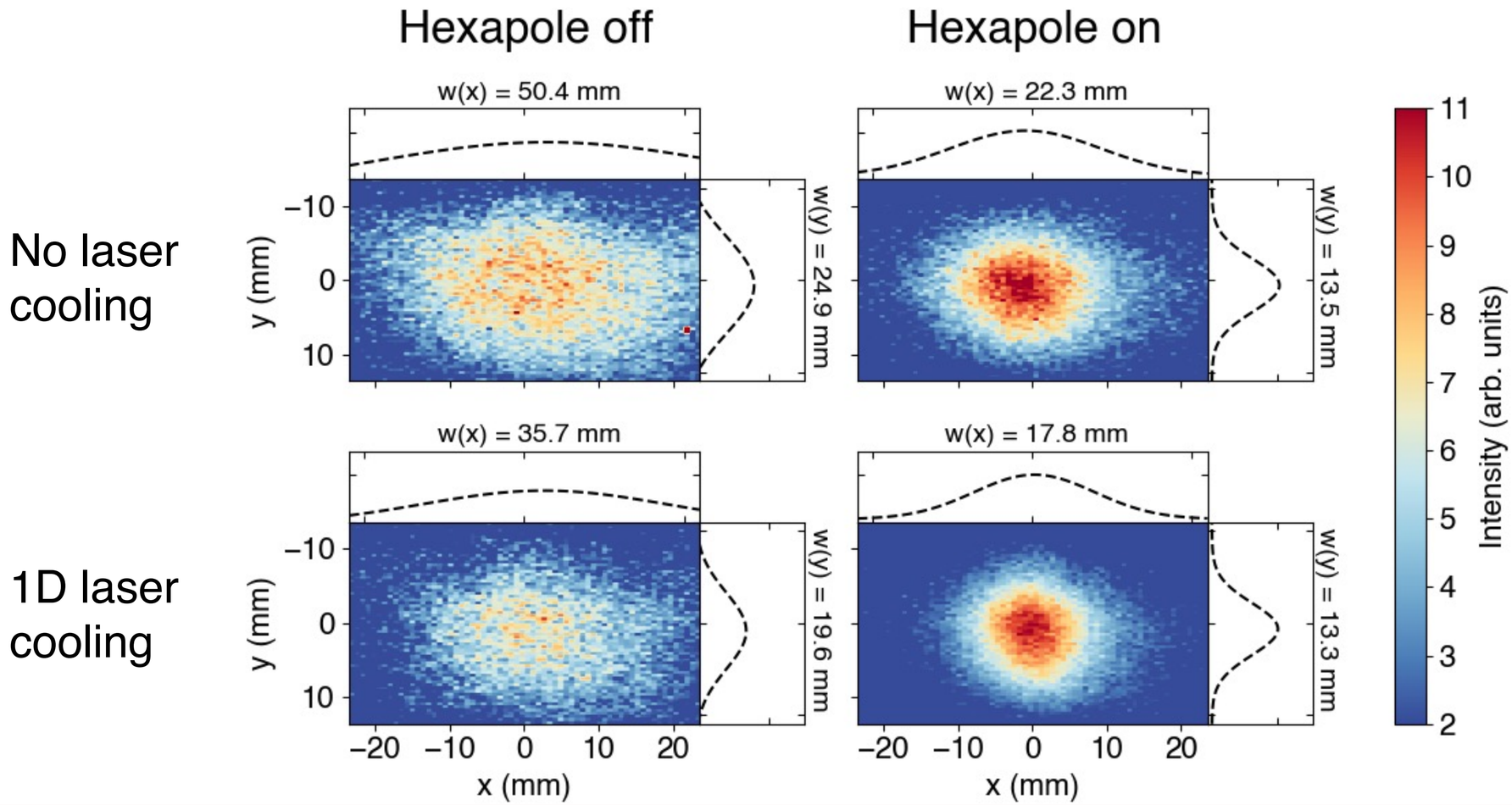
Recent results



Recent results

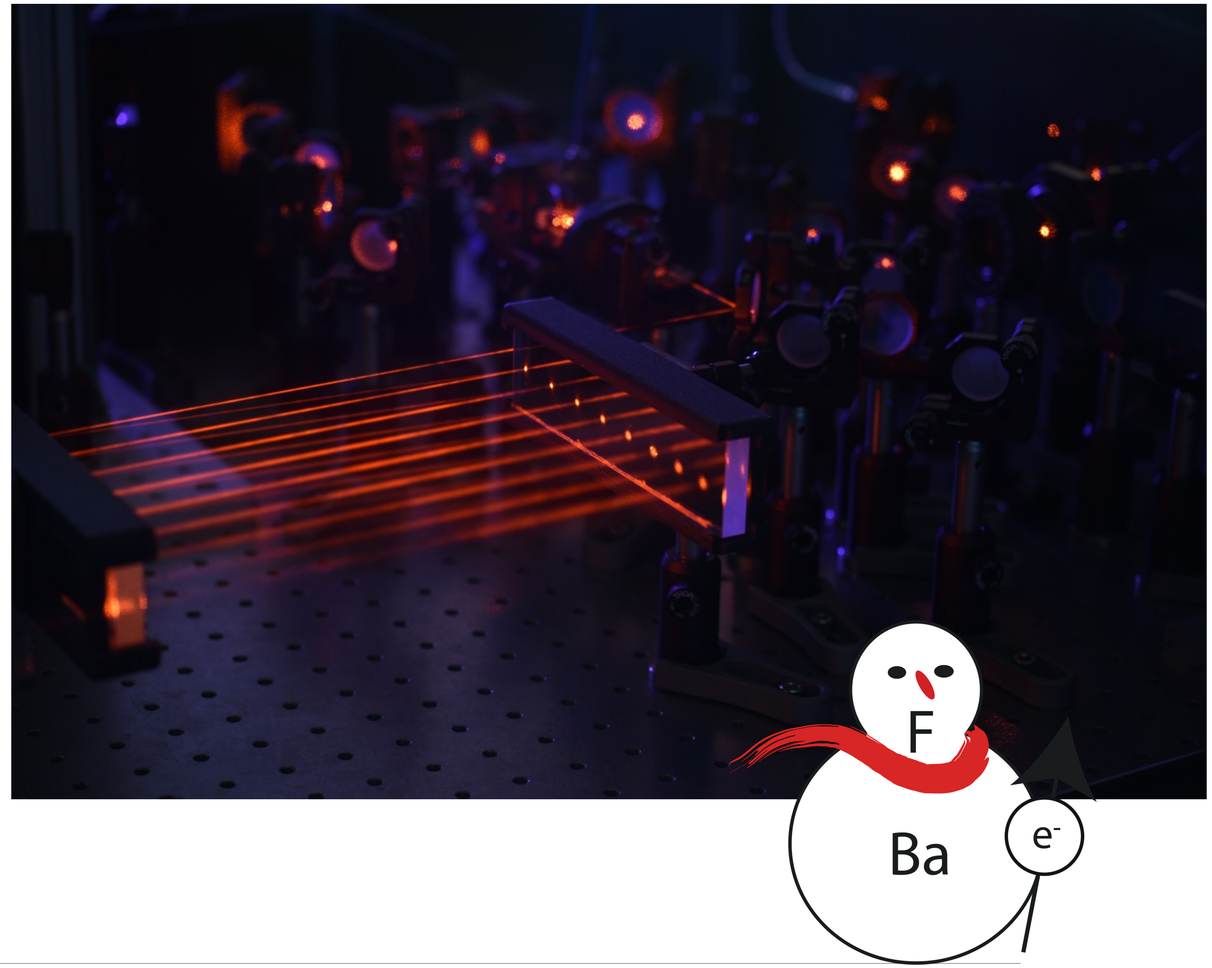
Fluorescence images show improved collimation when both lensing and laser cooling





Summary

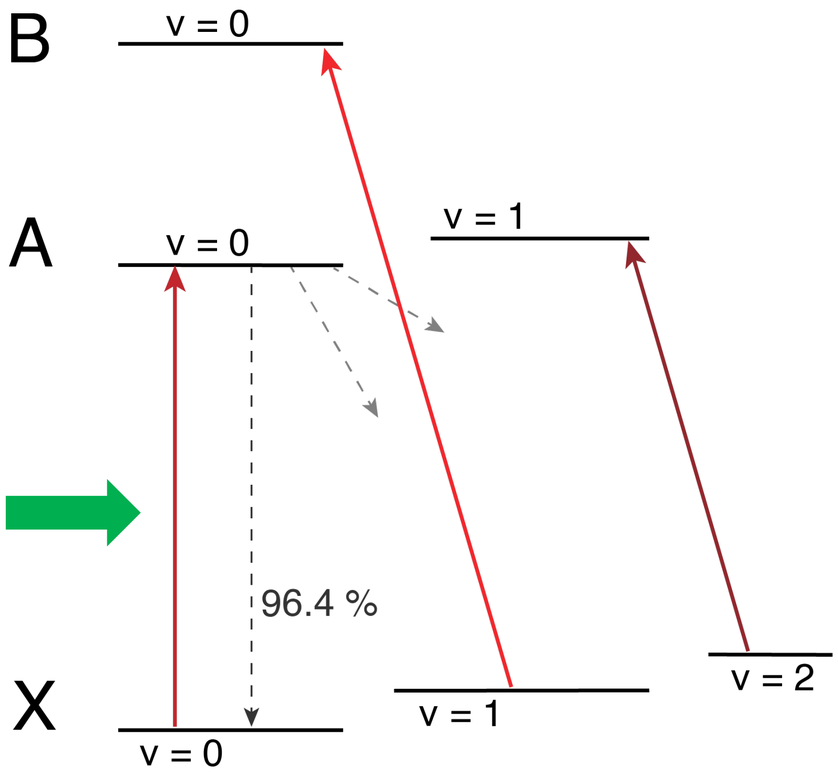
A focused and laser cooled cryogenic beam of BaF is the next phase of the *e*EDM experiment

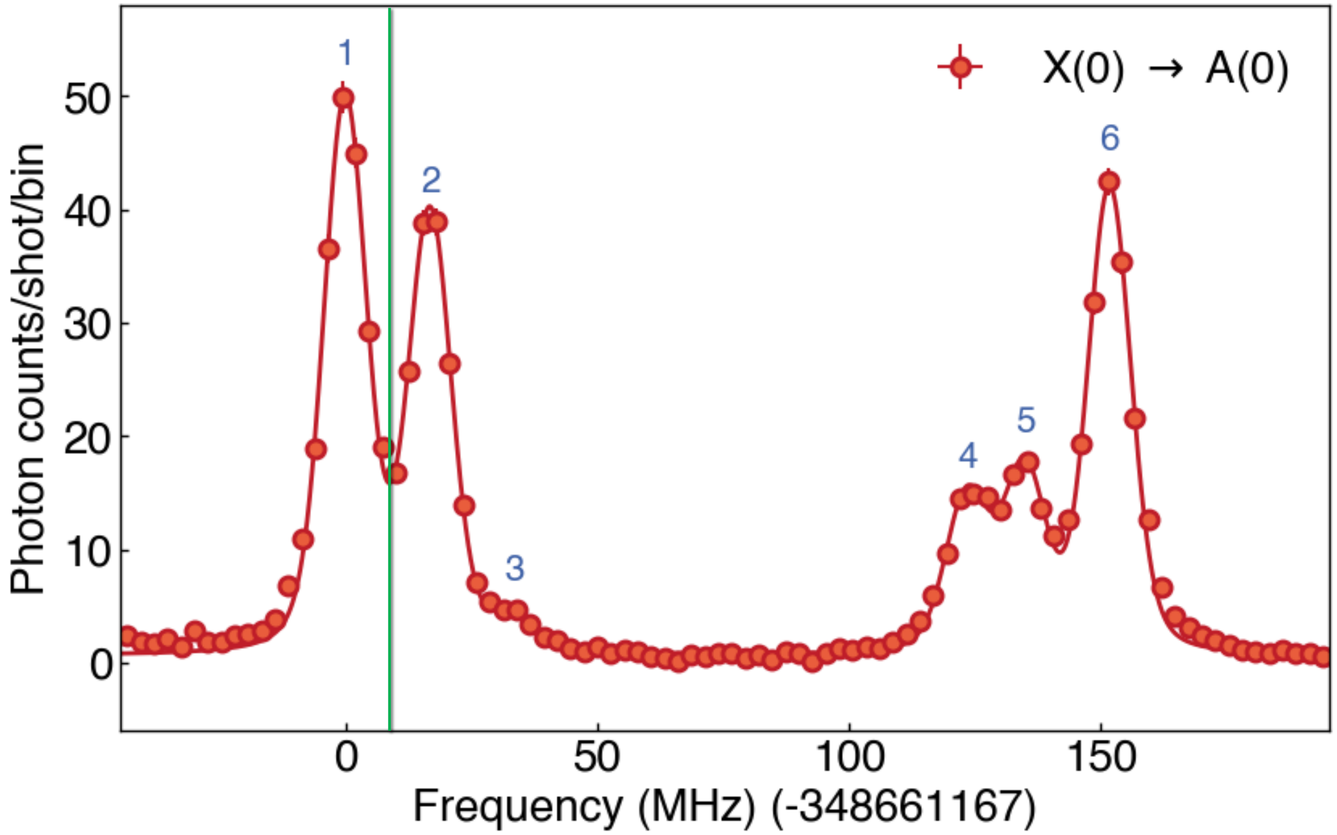


Next: polyatomic molecules with Ties

Backup: competing Doppler cooling and heating

Example: spectroscopy of laser cooling transition shows that a single laser can be red detuned (=cooling) from transition 2, but blue detuned (=heating) from transition 1!





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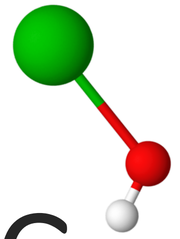


Advantages of Polyatomic molecules

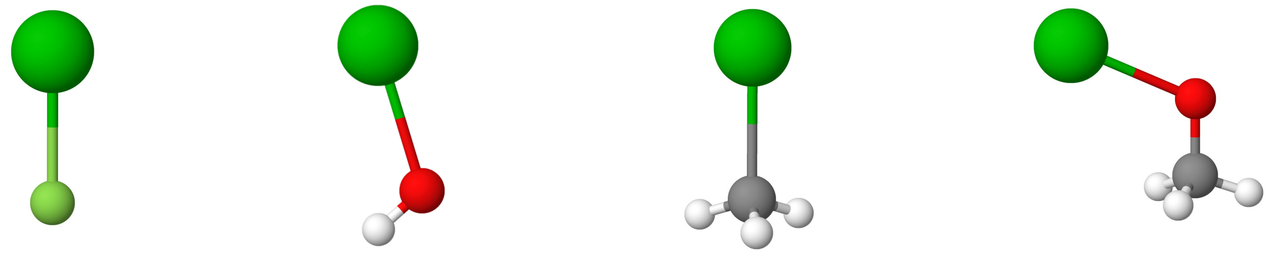
Ties Fikkers

eEDM sensitivity

eEDM sensitivity comparible to BaF

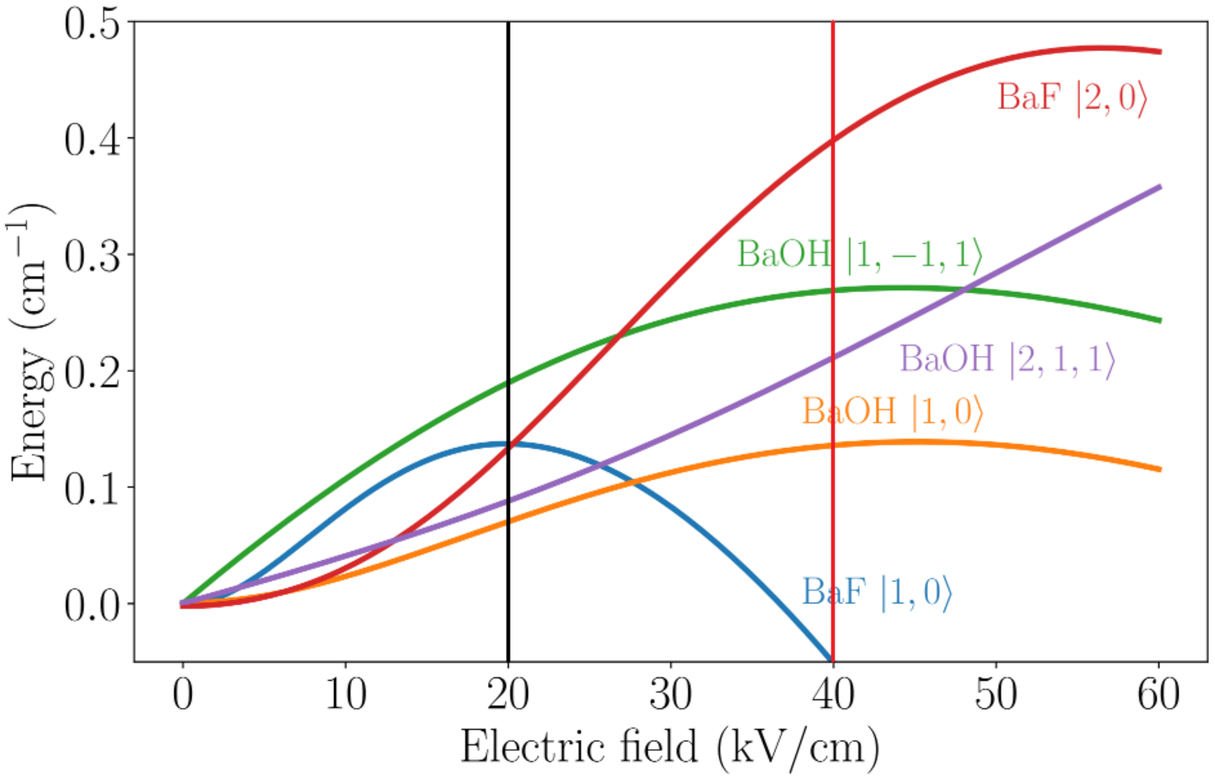
Molecule	W_d $[10^{24}\,\frac{h\mathrm{Hz}}{e\mathrm{cm}}]$	W_s $[h\mathrm{kHz}]$
$BaCH_3$	$\mathbf{3.22 \pm 0.11}$	$\mathbf{8.42 \pm 0.29}$
$BaOCH_3$	3.05 [73]	
BaOH	3.10 ± 0.15 [38]	
BaF	3.13 ± 0.12 [37]	8.29 ± 0.12 [37]

[1] Y. Chamorro, et al. 2022 https://doi.org/10.1103/PhysRevA.106.052811



Deceleration using electric fields

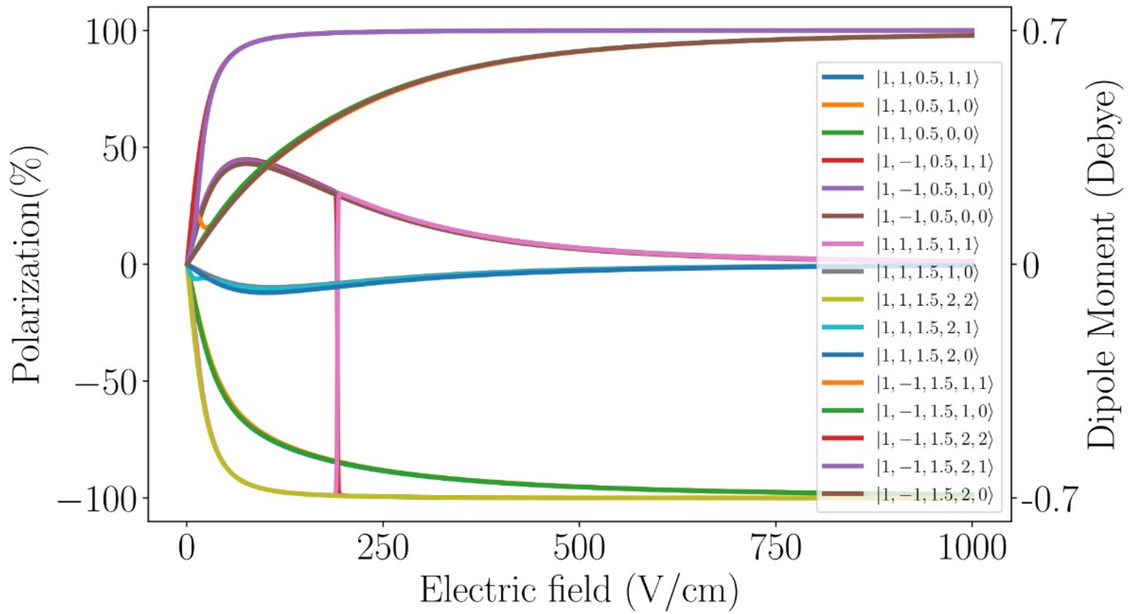
Stark shift BaOH and BaF N=1 and N=2



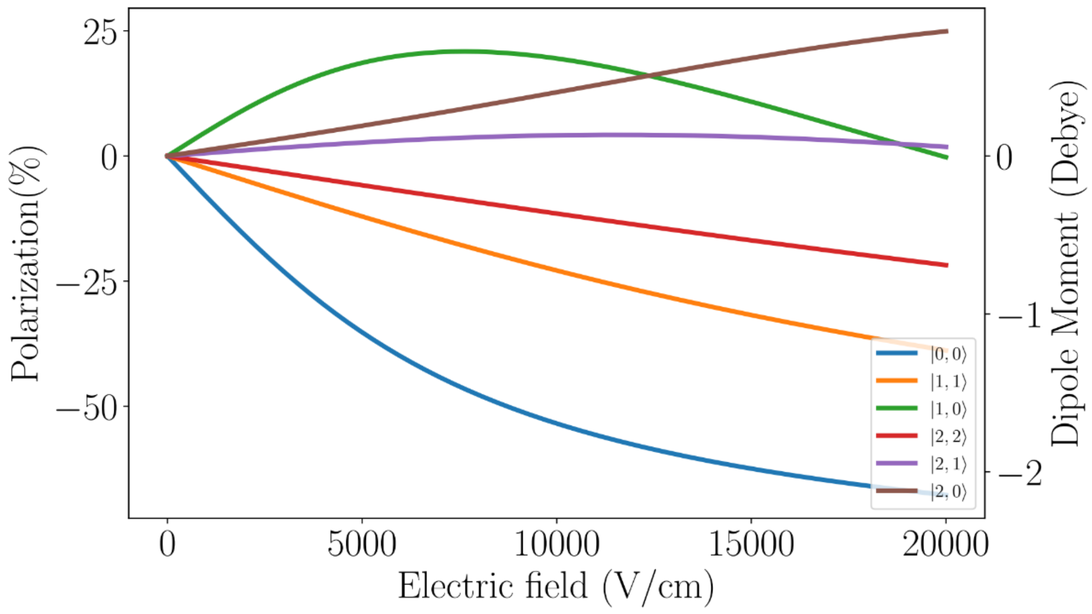
Stark shift comparible to BaF

Polarizability

BaOH

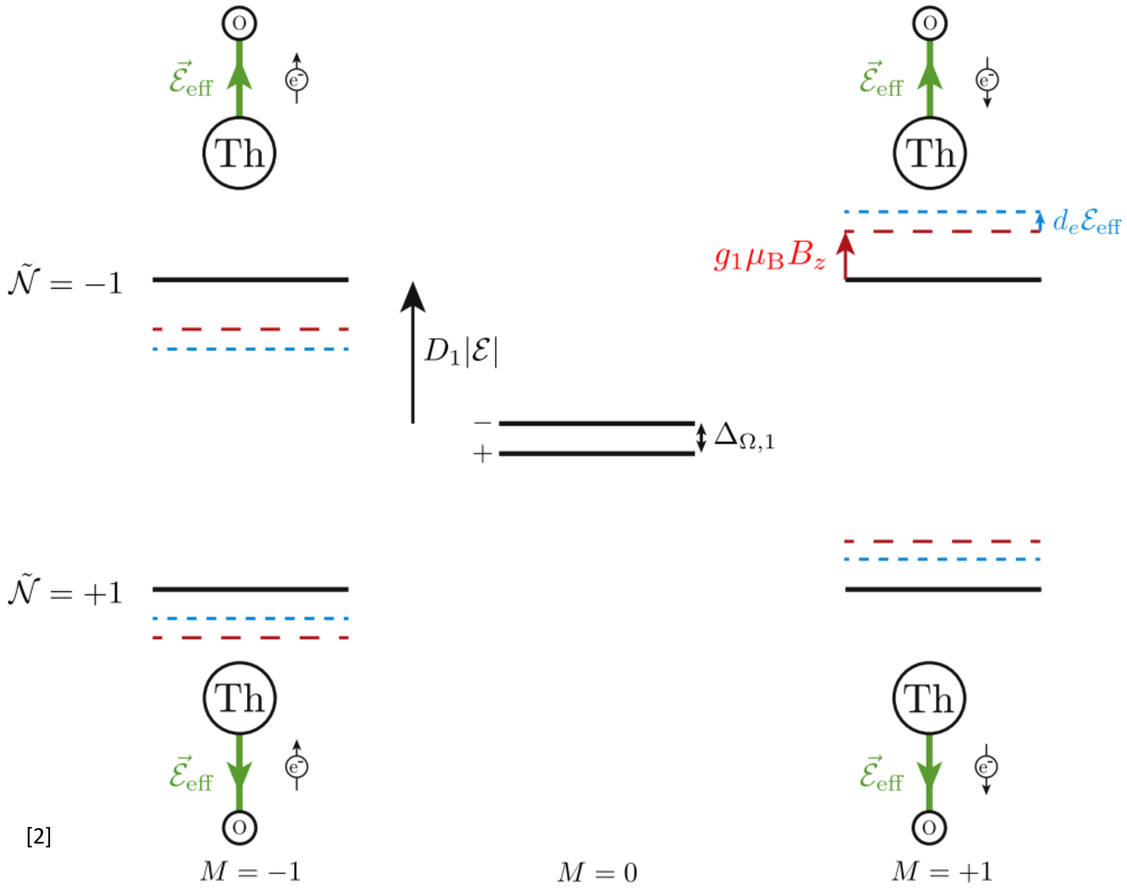


BaF



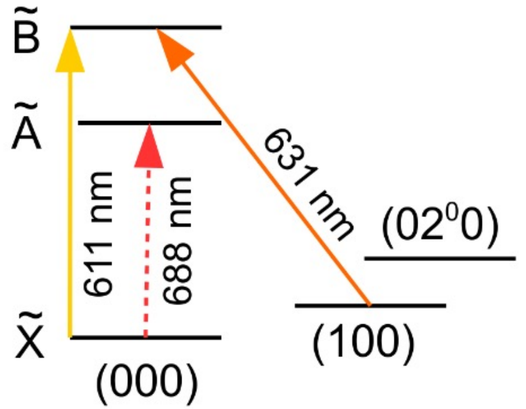
At low E-field strength BaOH is already fully polarized

Systematic error rejection and laser cooling



[2]

Laser cooling scheme for SrOH



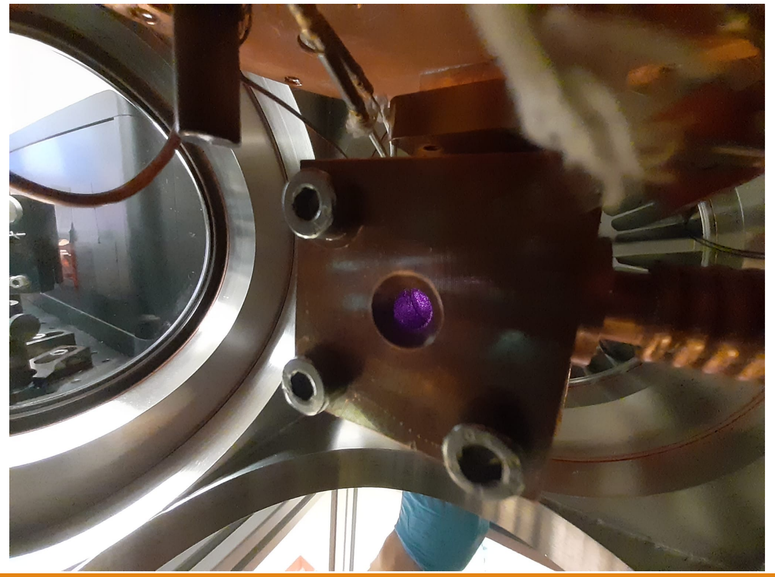
[3]

[2] J Baron et al 2017 New J. Phys. 19 073029

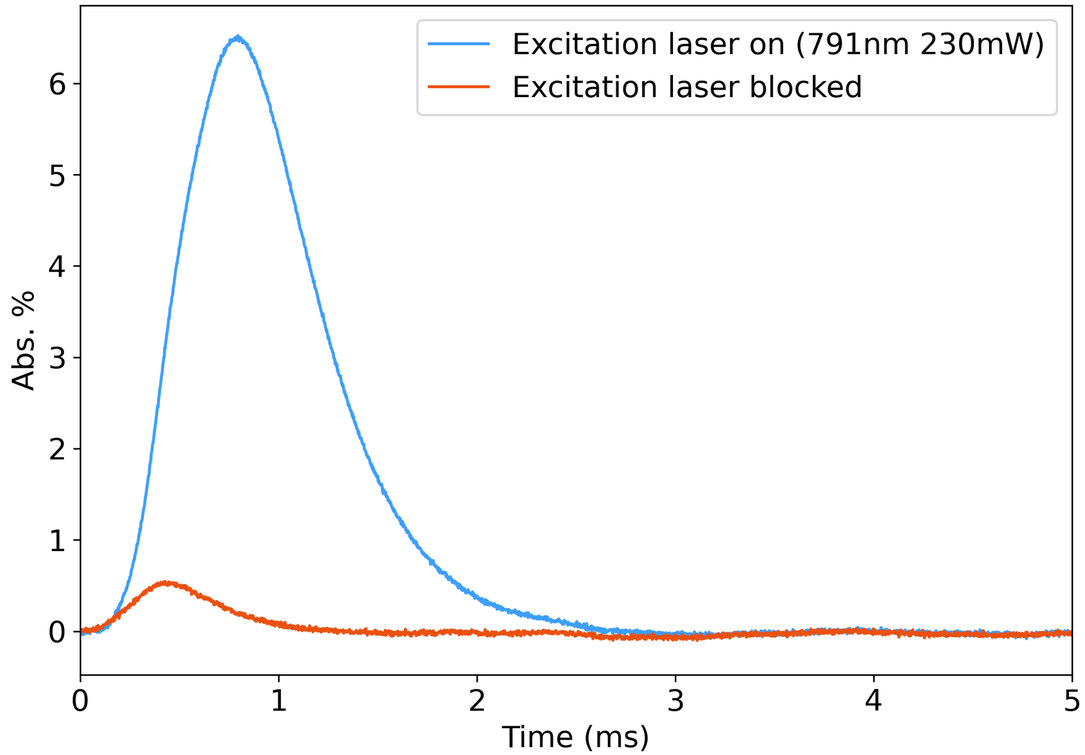
[3] I Kozyryev et al 2017 Phys. Rev. Lett. 118, 173201

Production and enhanced yield of BaOH

- Metal + water vapor, consistent but still low yield
- 1S to 3P excitation of Ba, much higher yield



Enhanced yield BaOH of the N=3, J=7/2



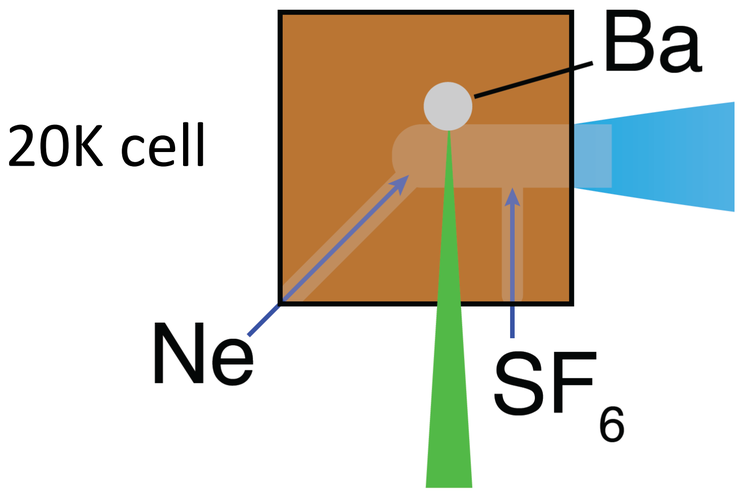
Conclusion

	BaOH	BaF
eEDM sensitivity	✓	✓
Stark shift	✓	✓
Polarization in low E-Field	✓	✗
Systematic error rejection	✓	✗
Laser cooling	✓	✓
Production of molecules	✓	✓

Production of molecules

How are the molecules produced?

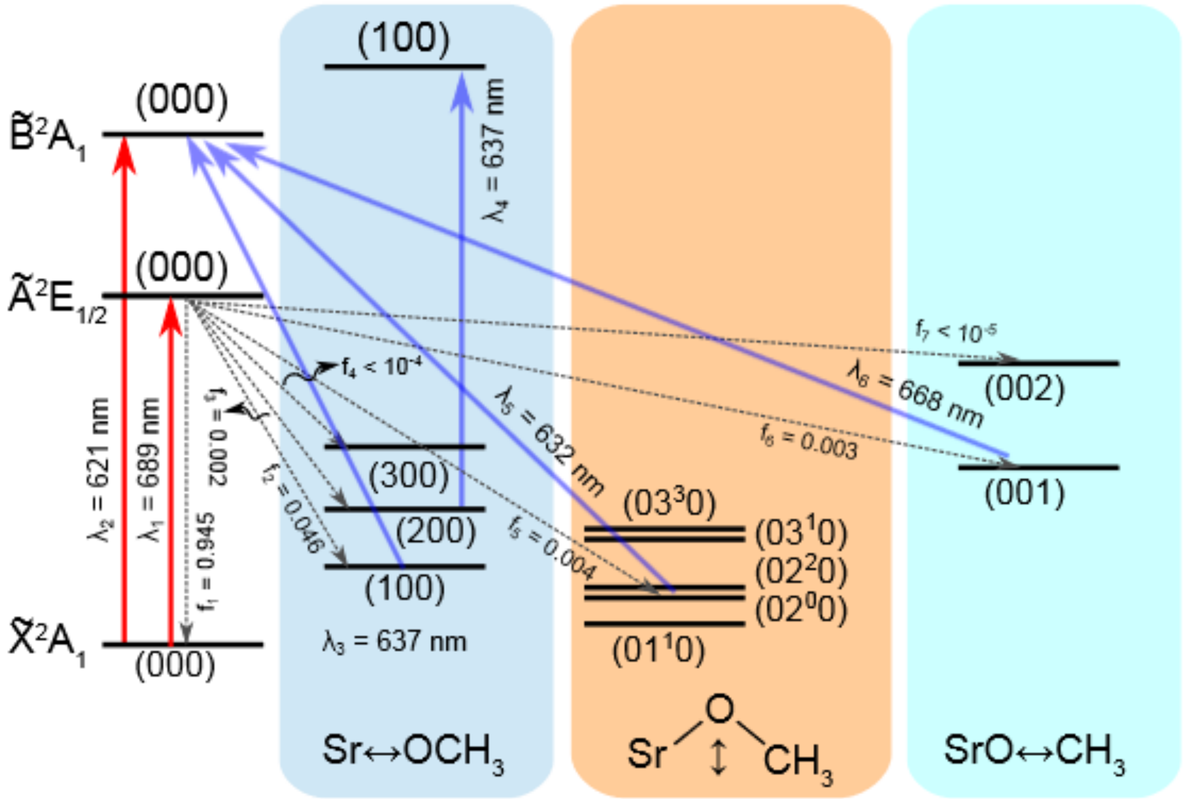
1. Ablation of metal or salt target
2. Introduce gas or vapor
3. Molecules thermalize with buffer gas
4. Molecules exit the cell



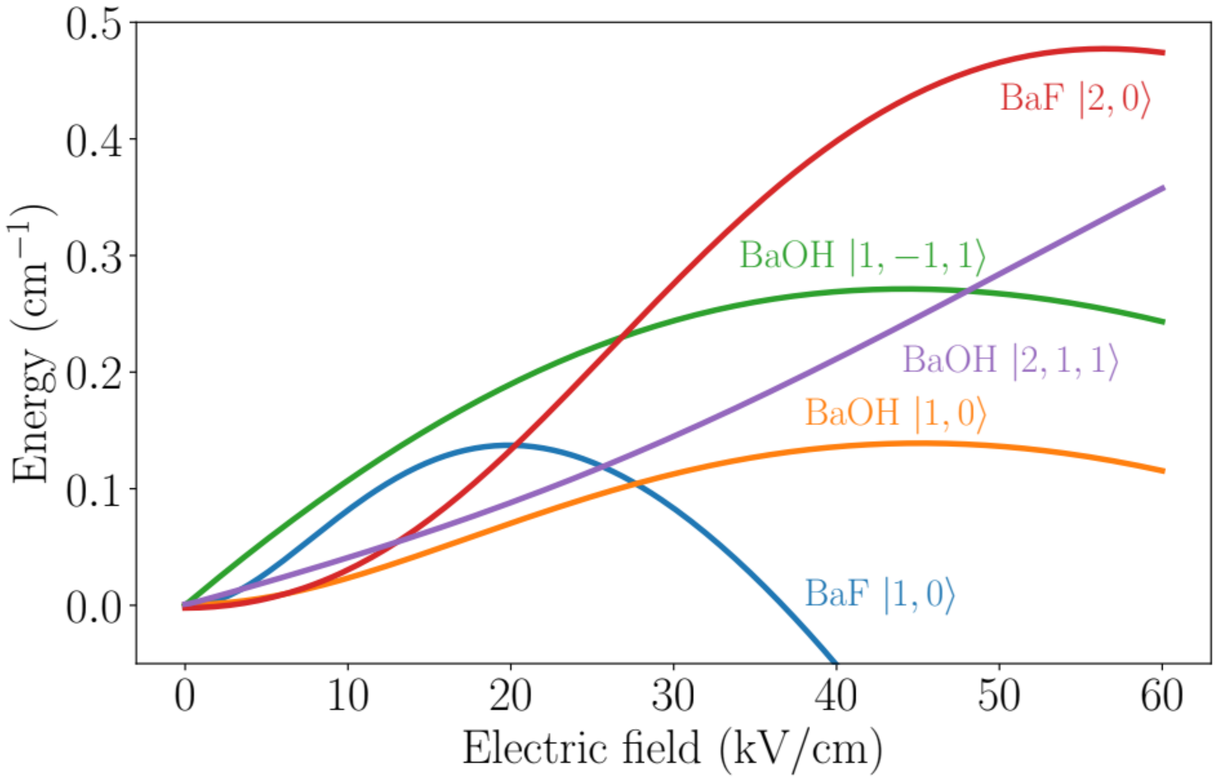
Laser cooling SrOCH3

$$^{2S+1}\Lambda_{\Omega}(v_1\, v_2^l\, v_3)$$

Laser cooling scheme for SrOCH3



Stark shift


0.5
0.4
0.3
0.2
0.1
0.0
Energy (cm^{-1})
0
10
20
30
40
50
60
Electric field (kV/cm)
BaF $|2,0\rangle$
BaOH $|1,-1,1\rangle$
BaOH $|2,1,1\rangle$
BaOH $|1,0\rangle$
BaF $|1,0\rangle$