eEDM

Steven Hoekstra

Scientific staff:
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Rick Bethlem
Steven Hoekstra
Klaus Jungmann
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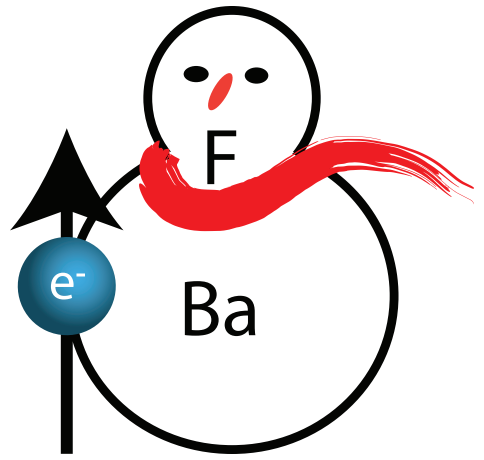

university of groningen
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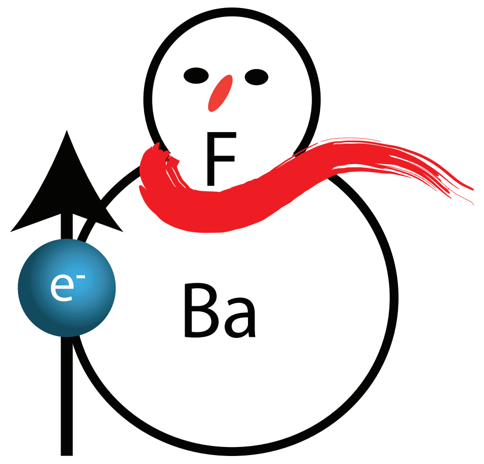
All started in 2017!



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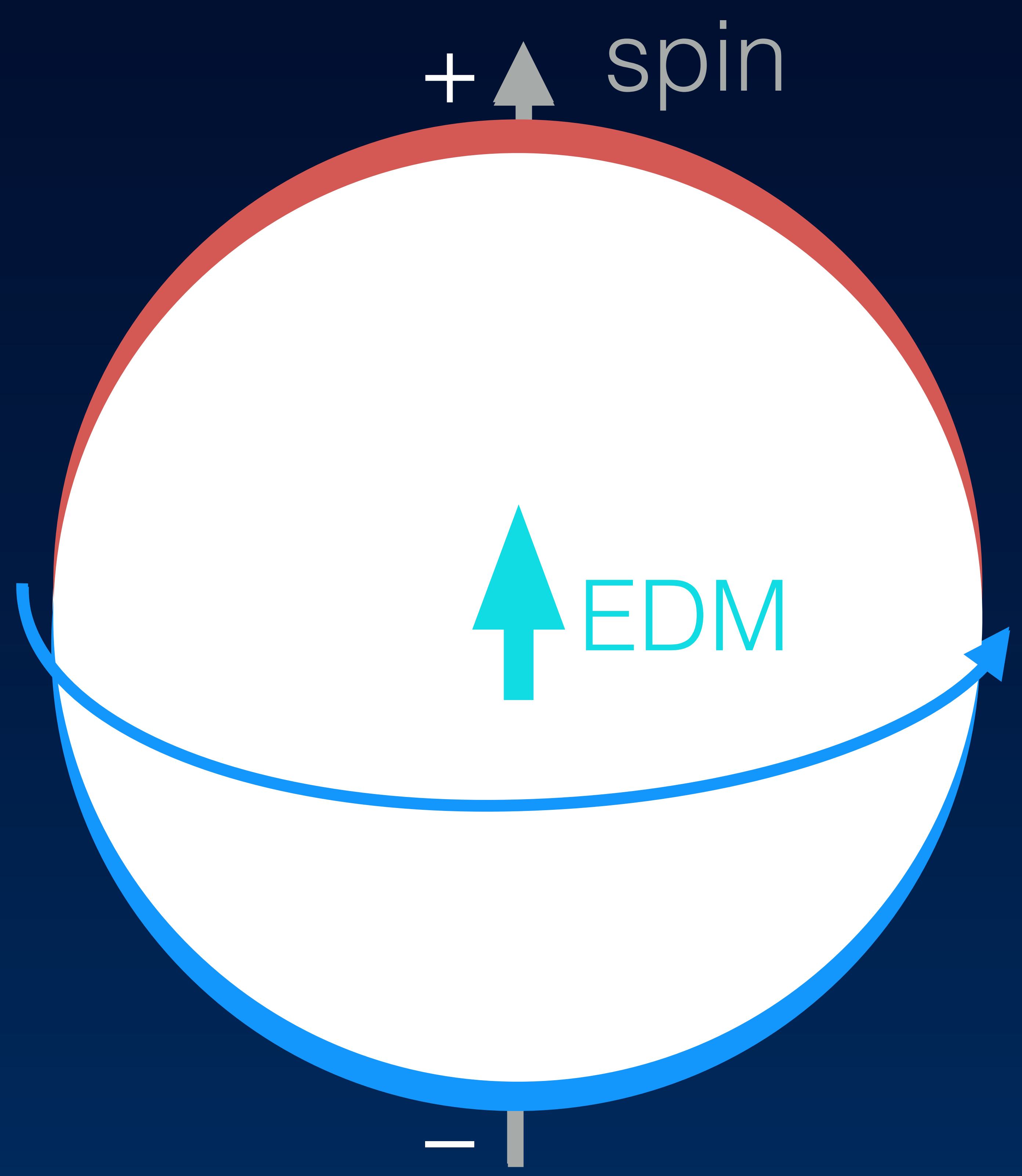
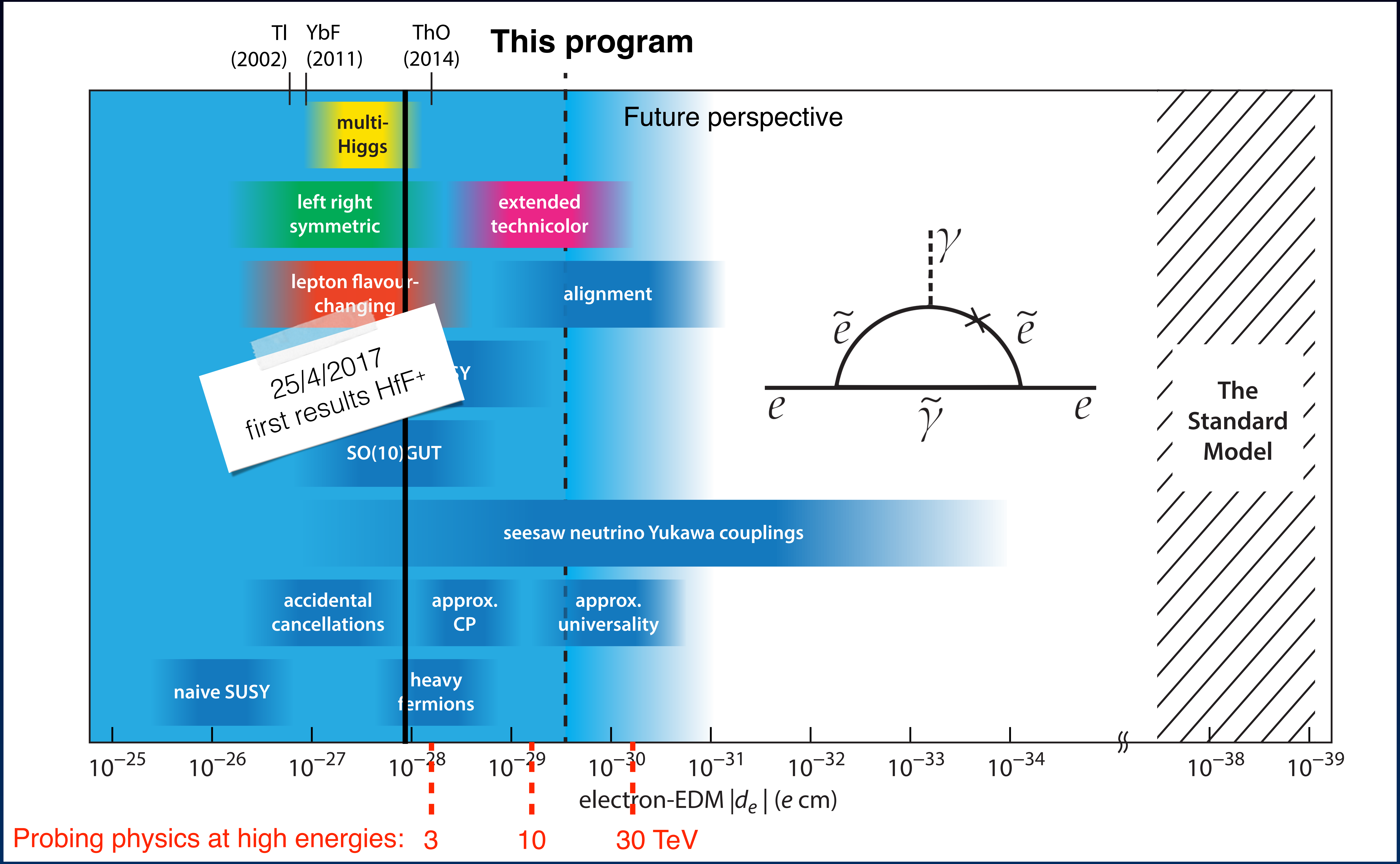
Is the electron round?

The Electric Dipole Moment of the electron (eEDM)

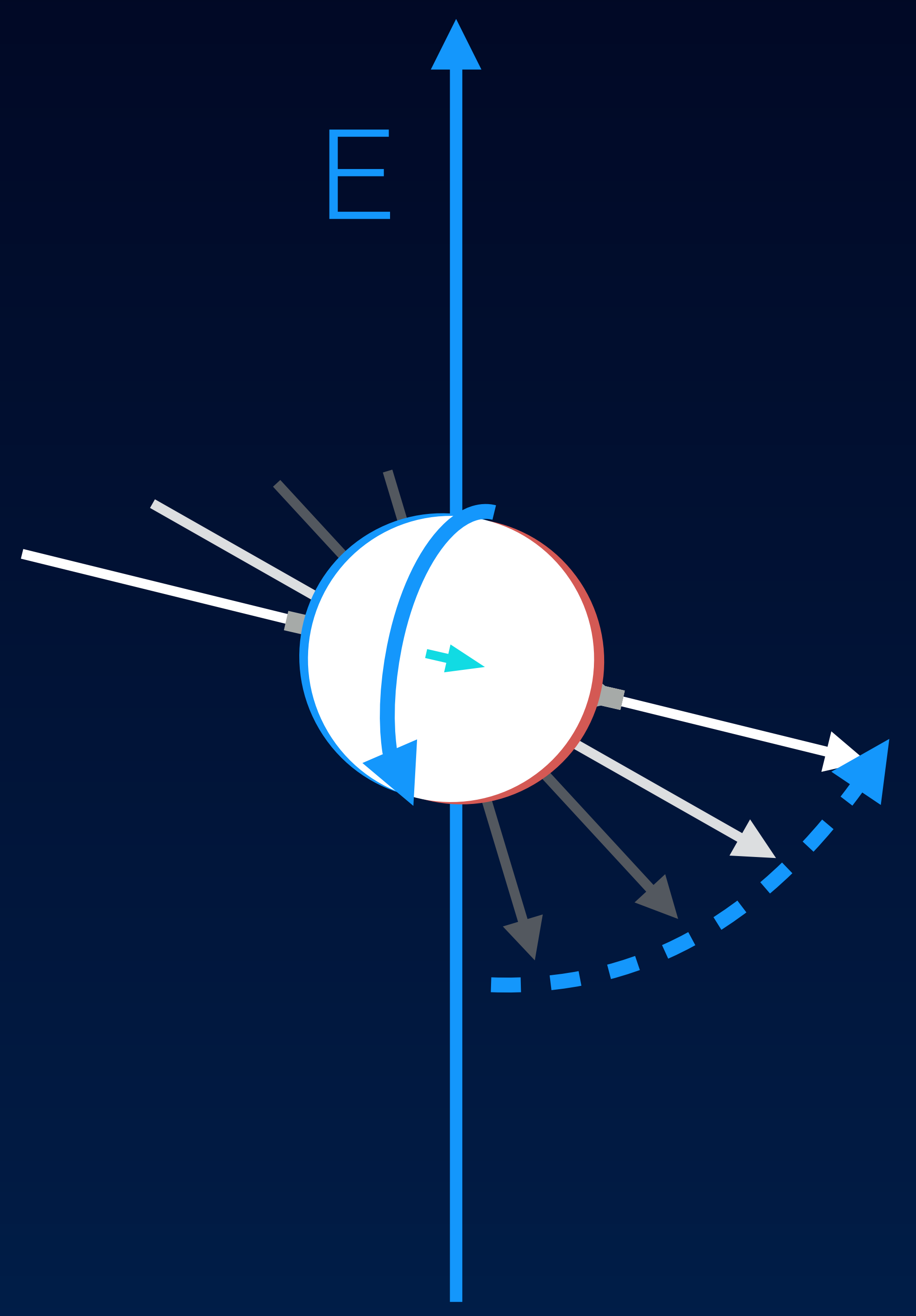
eEDM violates P, T and CP symmetry (provided CPT holds)

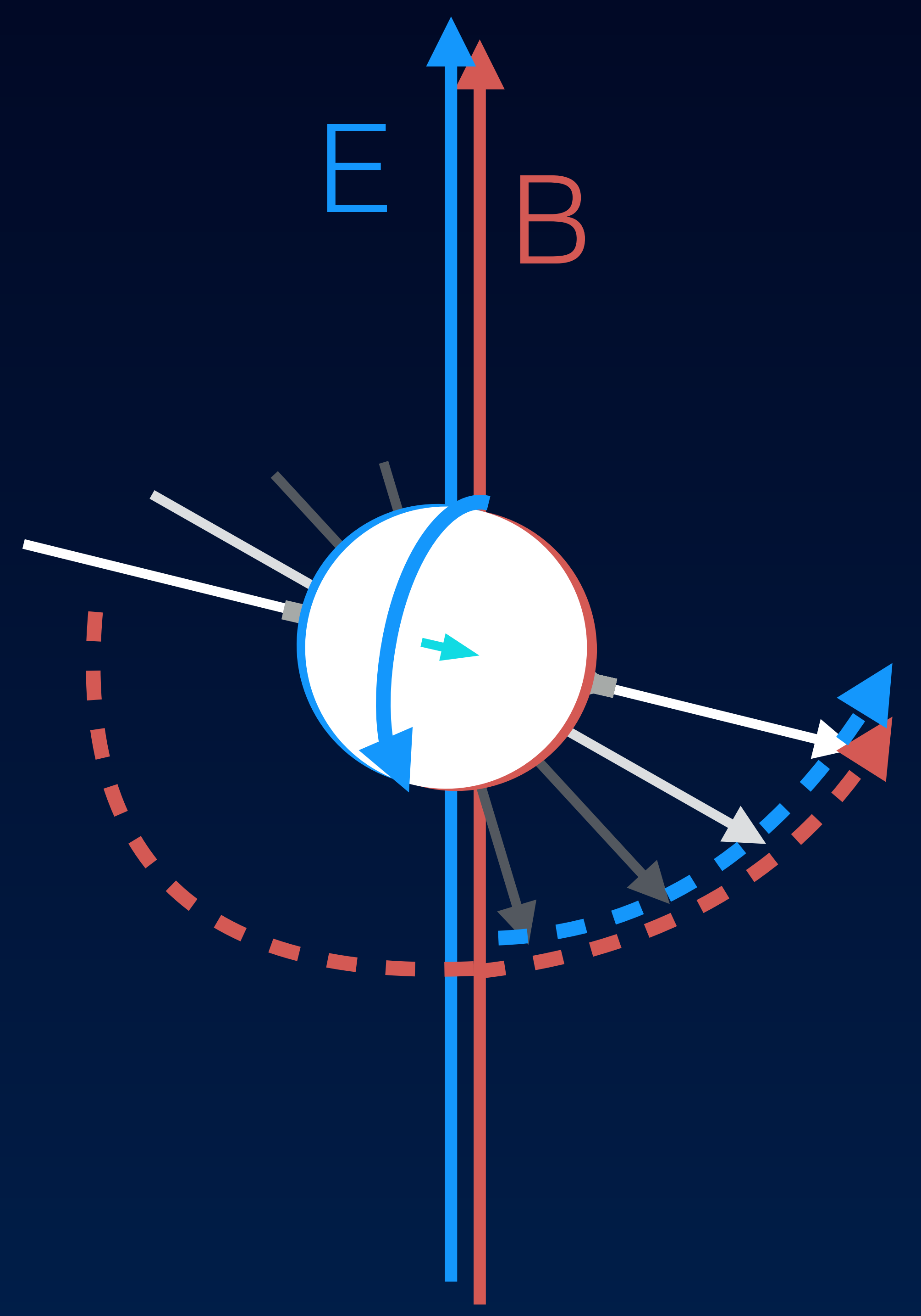




Next-generation experiment with **cold molecules**

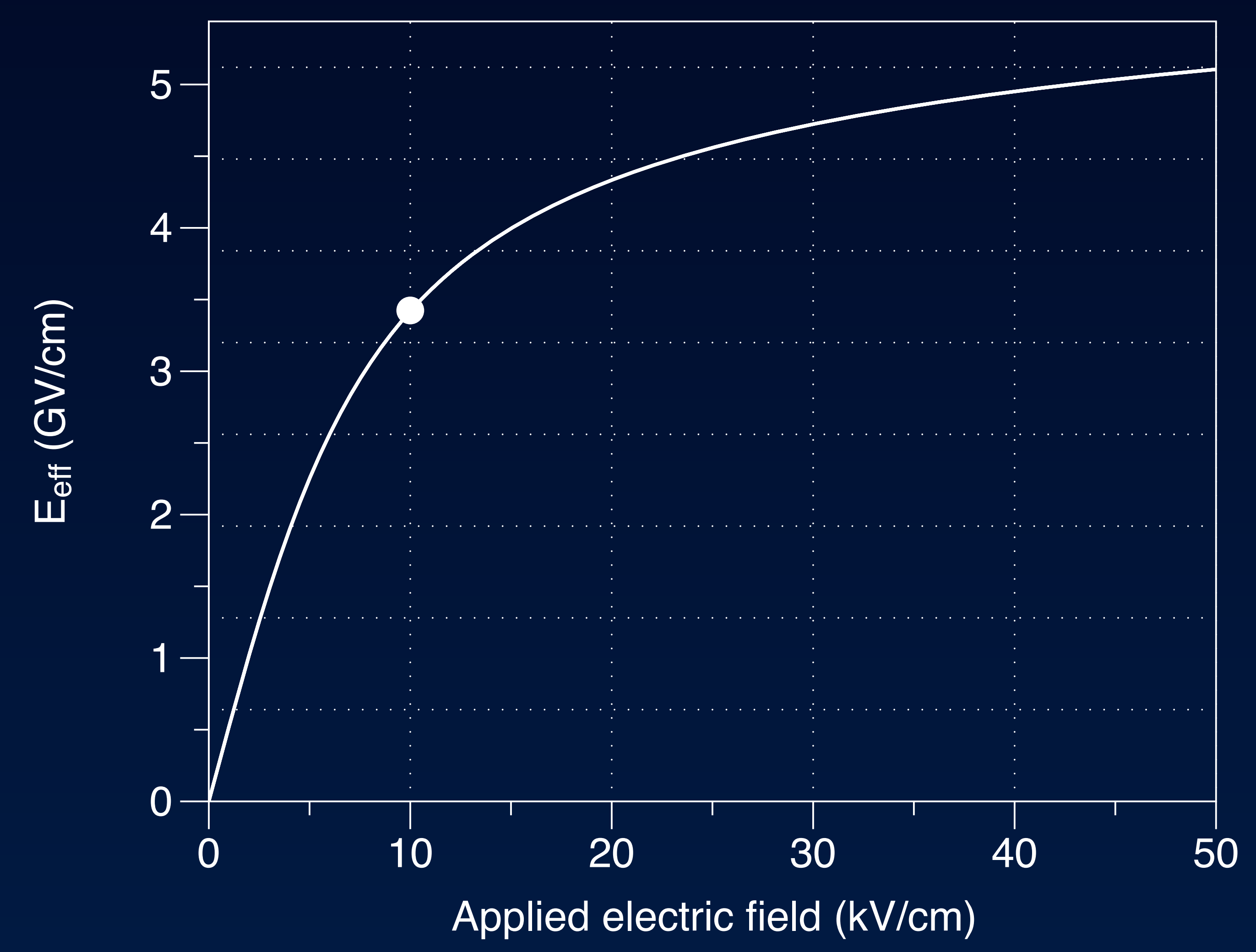
How to measure a dipole moment?





polar molecule

Effective electric field



precession!

However, also magnetic dipole moment (and charge!)

Solution:
use electron embedded in a polar molecule!

We have selected BaF

Increasing the eEDM sensitivity

Measure energy shift that correlates with electric field direction reversal

statistical error: $$\sigma_d = \frac{\hbar}{e}\frac{1}{2\mathcal{E}_{\rm eff}\tau\sqrt{N}}$$

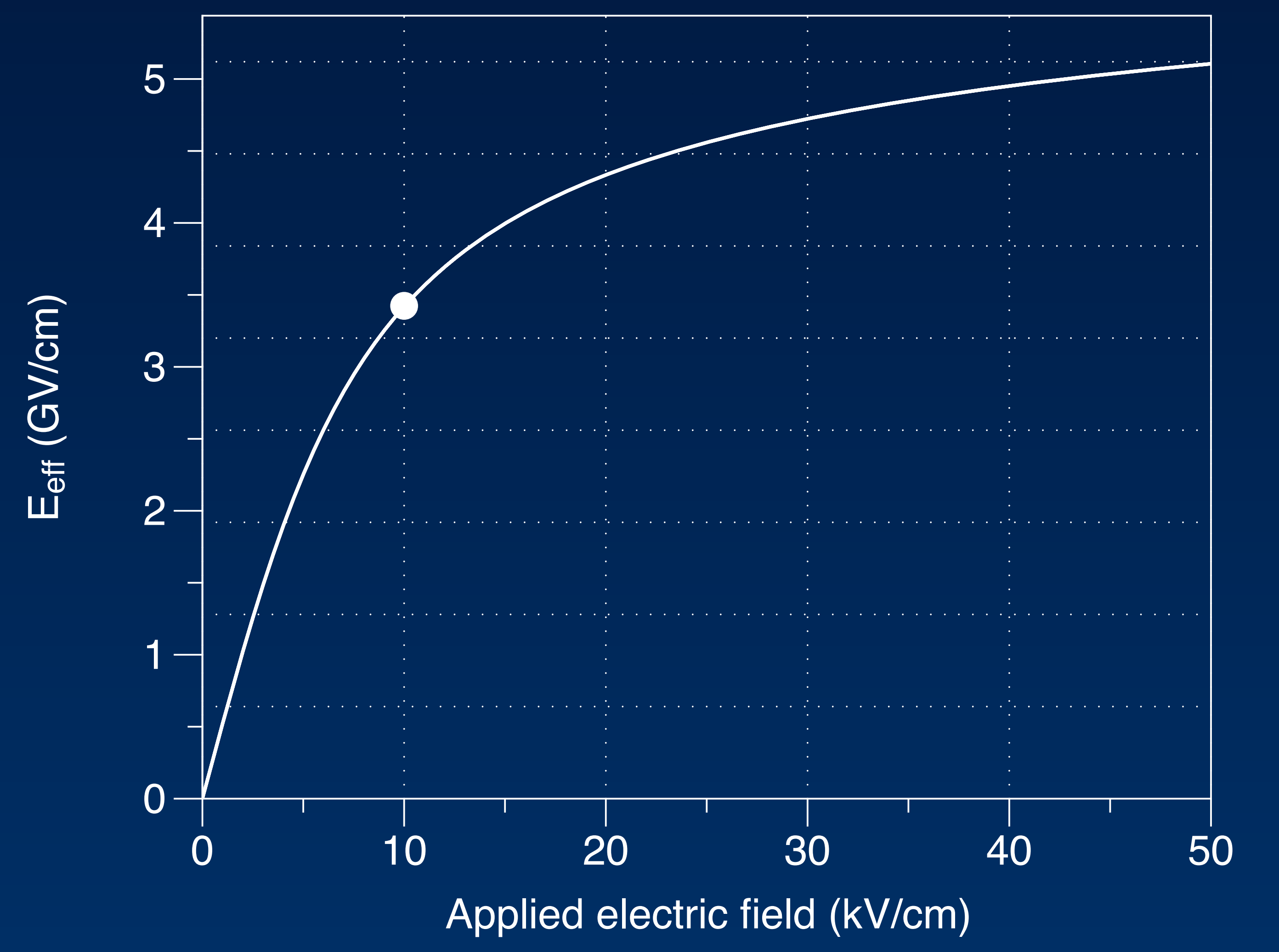
Cold Molecules

Number of detected molecules

Coherent interaction time

Effective electric field

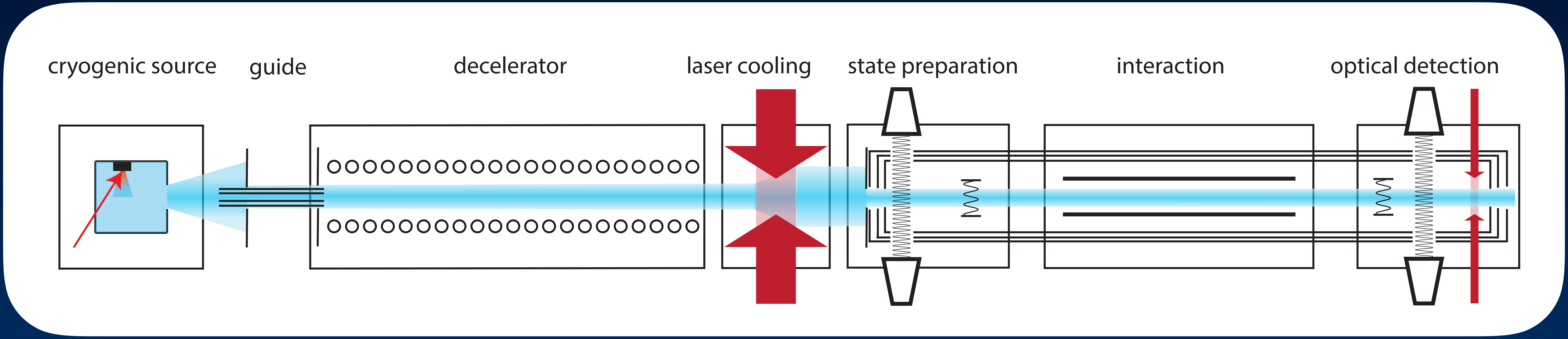
polar molecule

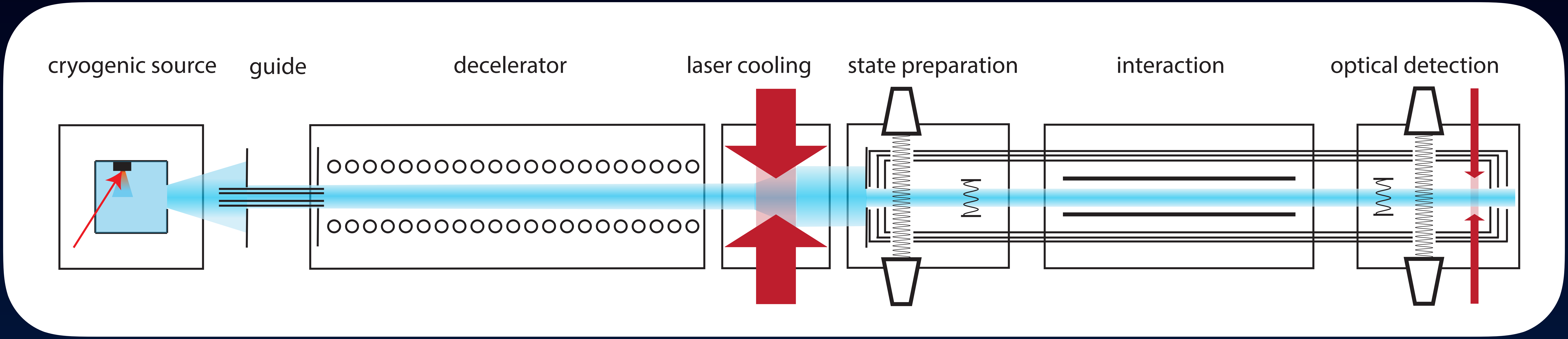


Combining three recent experimental breakthroughs:

1) Cryogenic source
2) Stark deceleration
3) Molecular laser cooling

Using BaF molecules, we can create a very **intense, slow and cold** beam





Highlights of 2017:

The team is growing
First results from theory
Experiment under construction

June 2017: eEDM kick-off Meeting

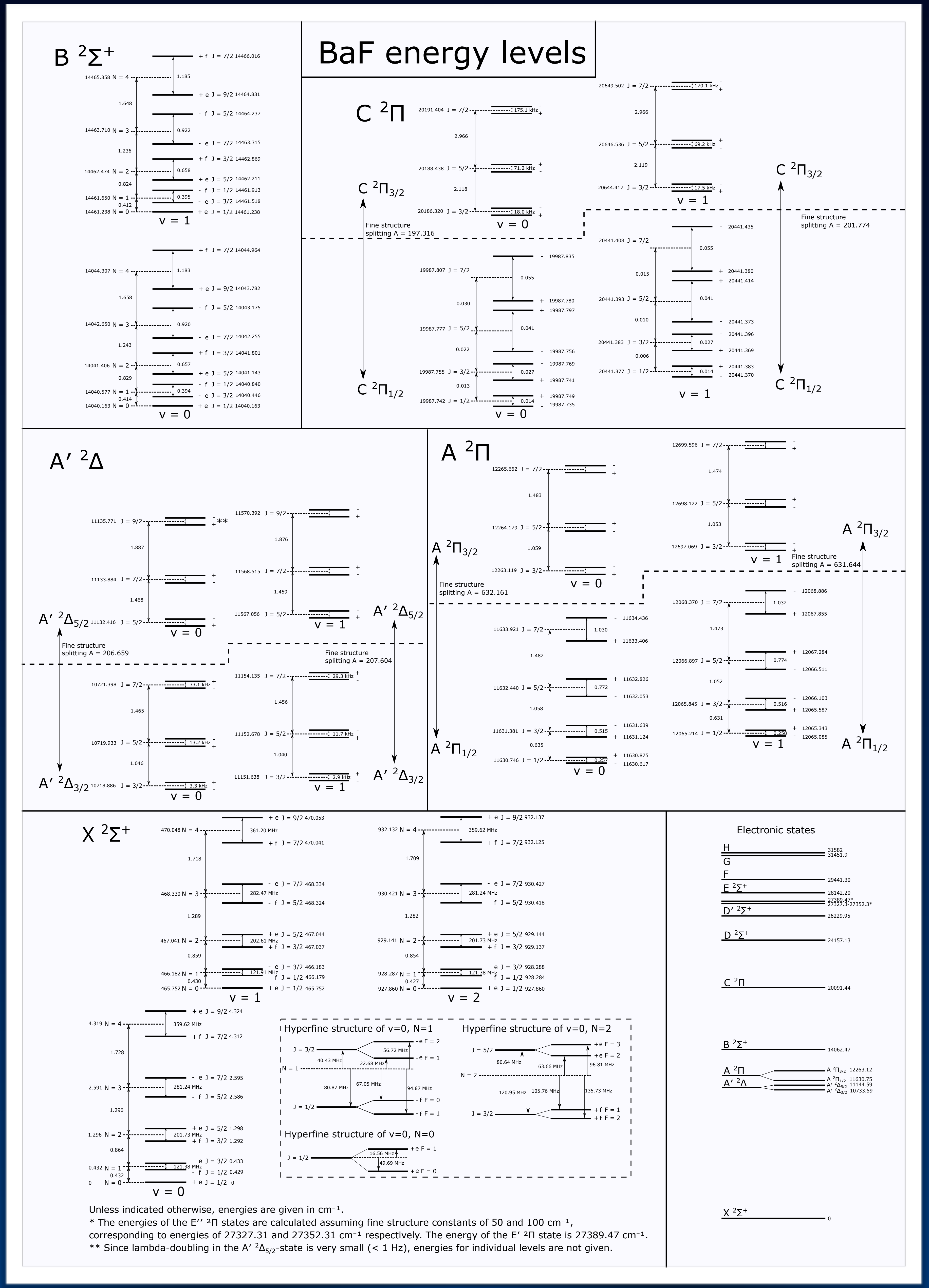
12-17 June 2107, eEDM program kickoff meeting and international summerschool, Ameland
“Low-energy precision measurements of physics beyond the standard model”

First results from theory: understanding our molecule

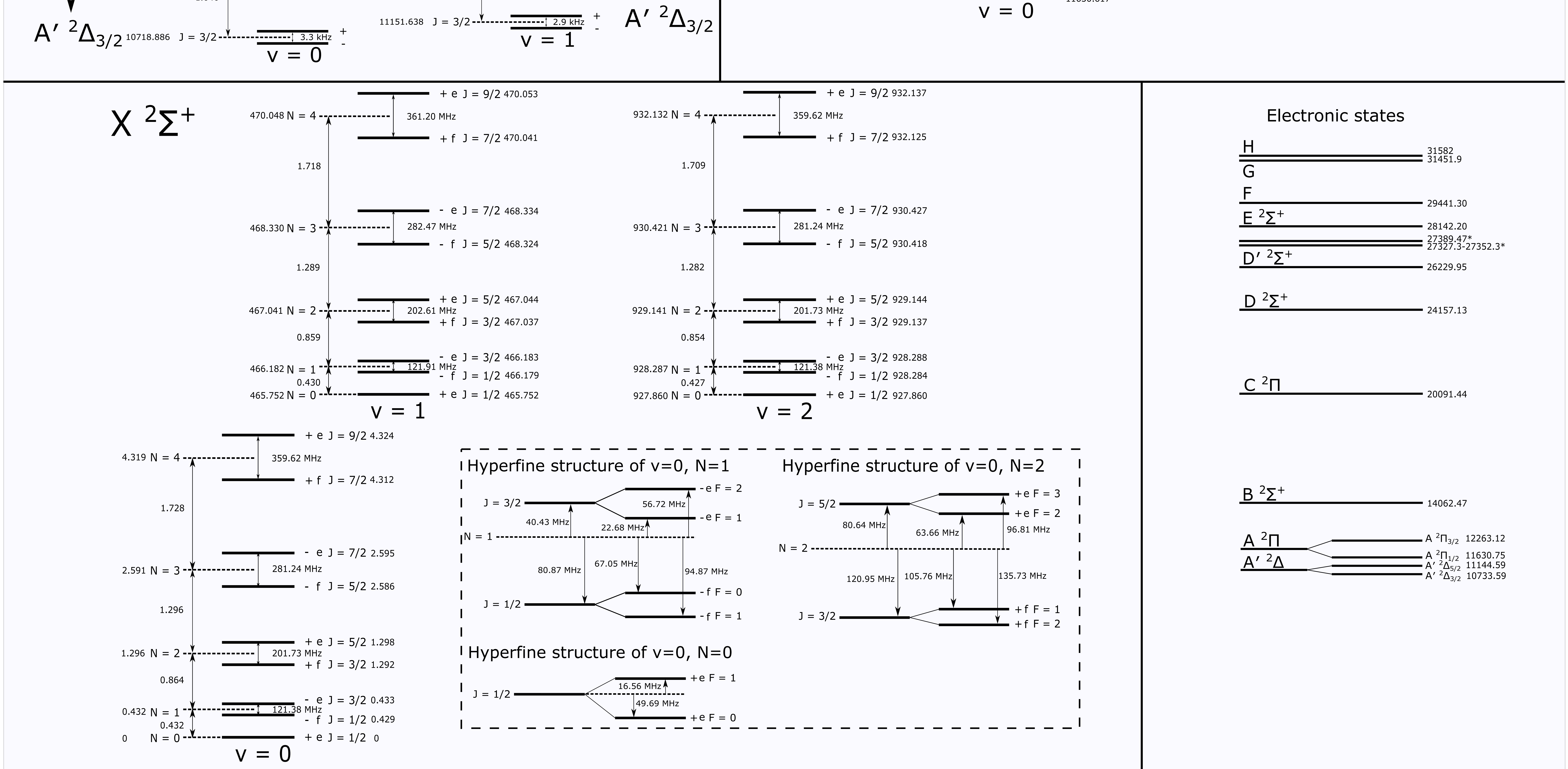
polar
molecule

Barium: 56 electrons
Fluorine: 9 electrons
Mass: 156 amu

BaF: 1 valence electron
Nuclear spin 1/2



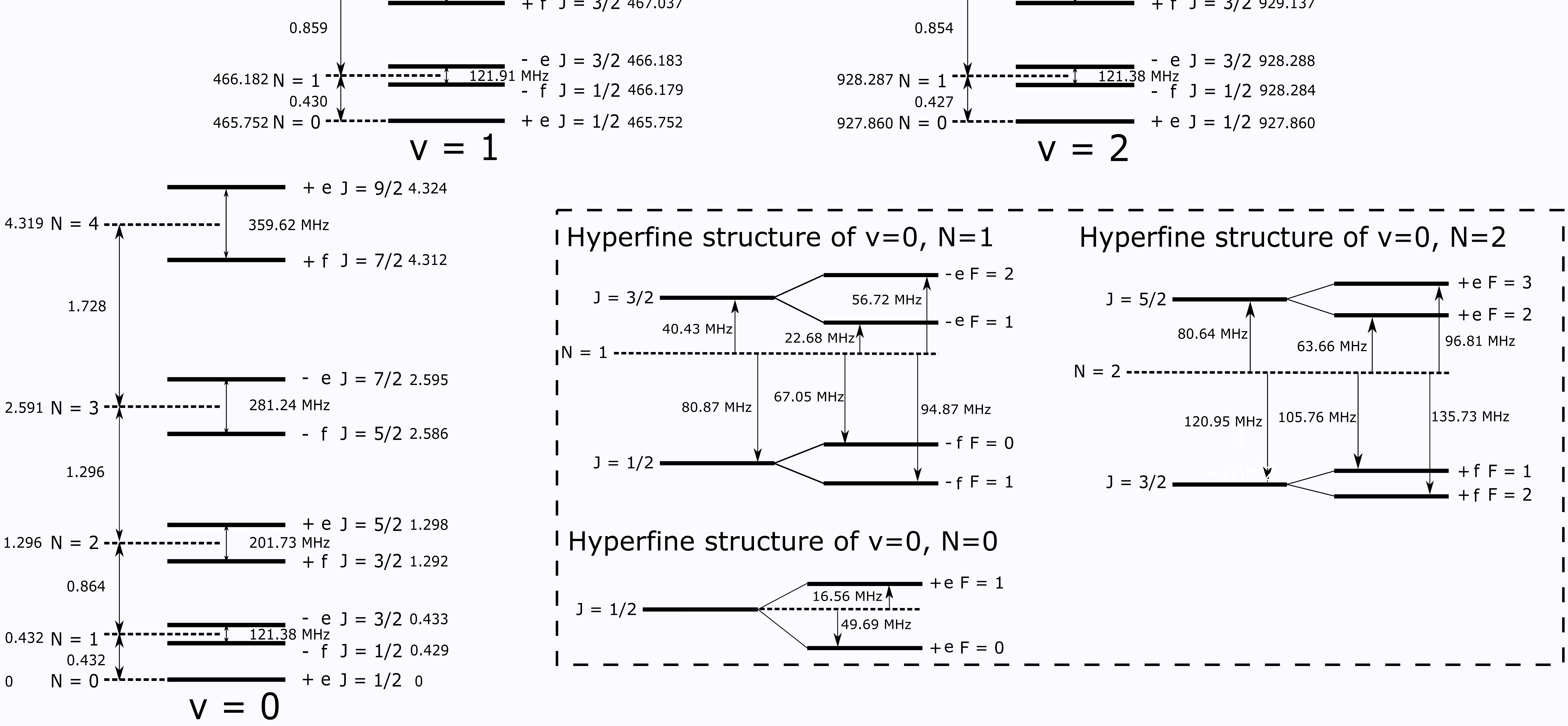
Poster summarising energy levels
based on best known spectrosopic constants
compiled by Jeroen Maat



Unless indicated otherwise, energies are given in cm^{-1}.

* The energies of the E′′ $^2\Pi$ states are calculated assuming fine structure constants of 50 and 100 cm^{-1}, corresponding to energies of 27327.31 and 27352.31 cm^{-1} respectively. The energy of the E′ $^2\Pi$ state is 27389.47 cm^{-1}.

** Since lambda-doubling in the A′ $^2\Delta_{5/2}$-state is very small (< 1 Hz), energies for individual levels are not given.



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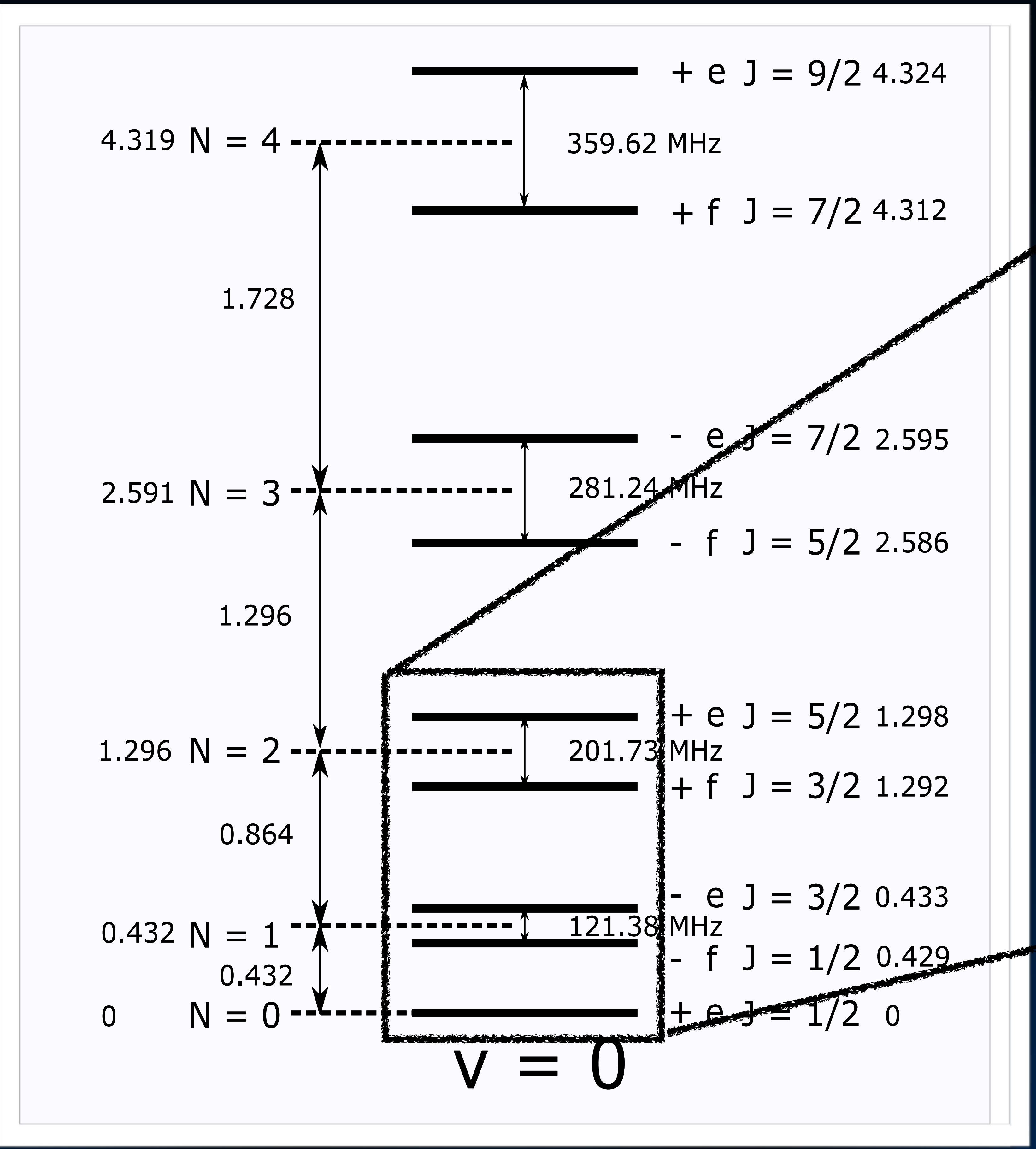
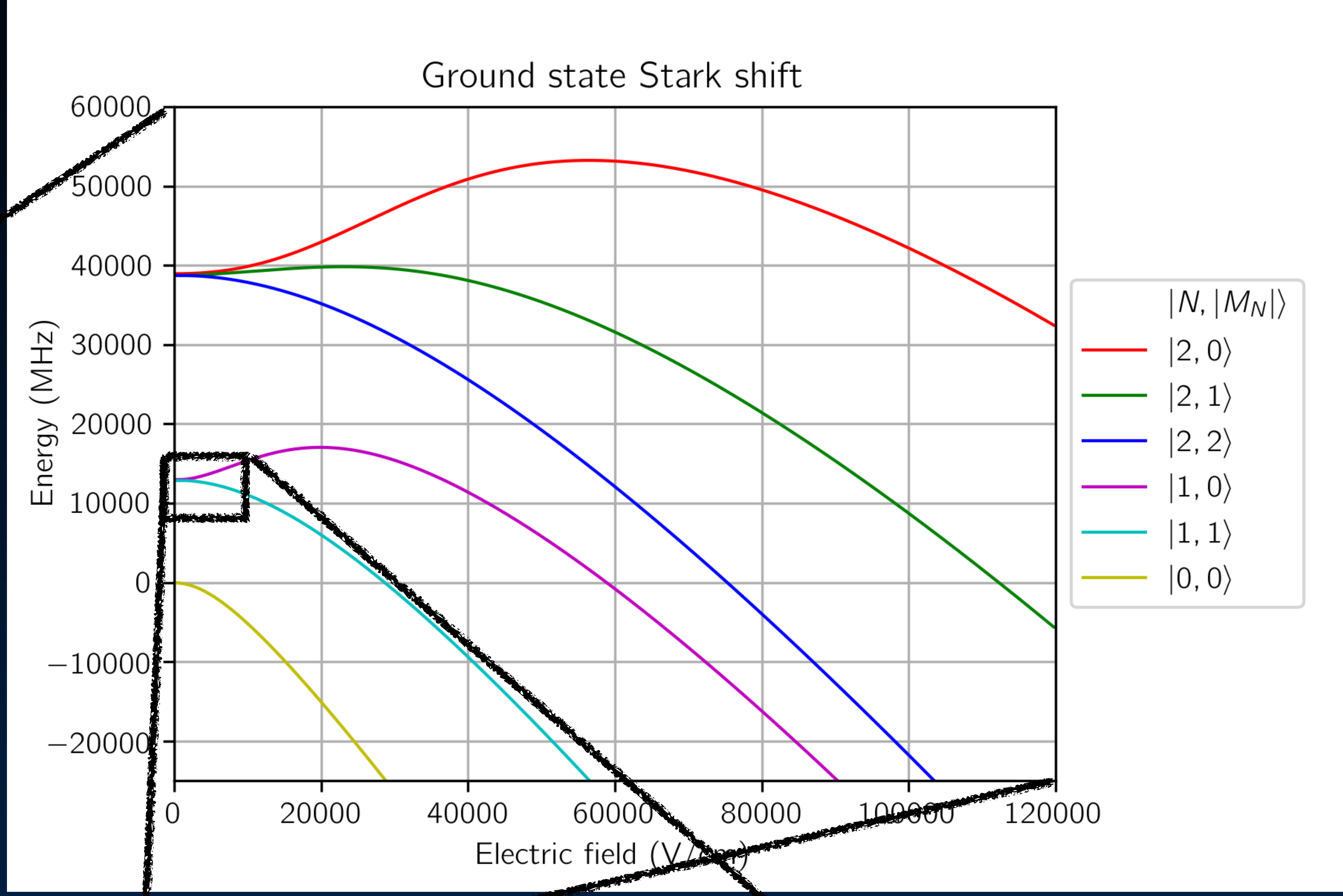
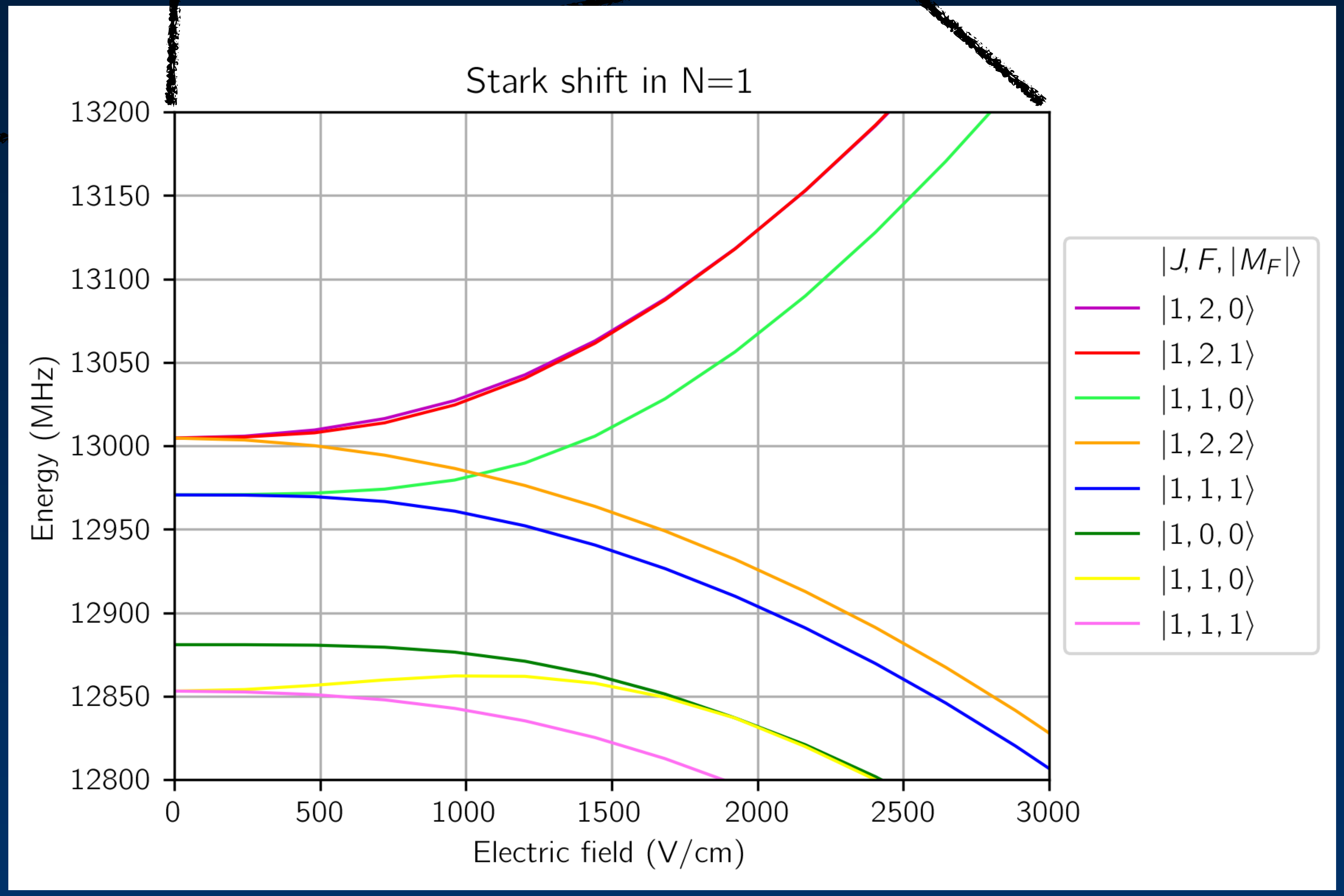
First results from theory: sensitivity to external fields

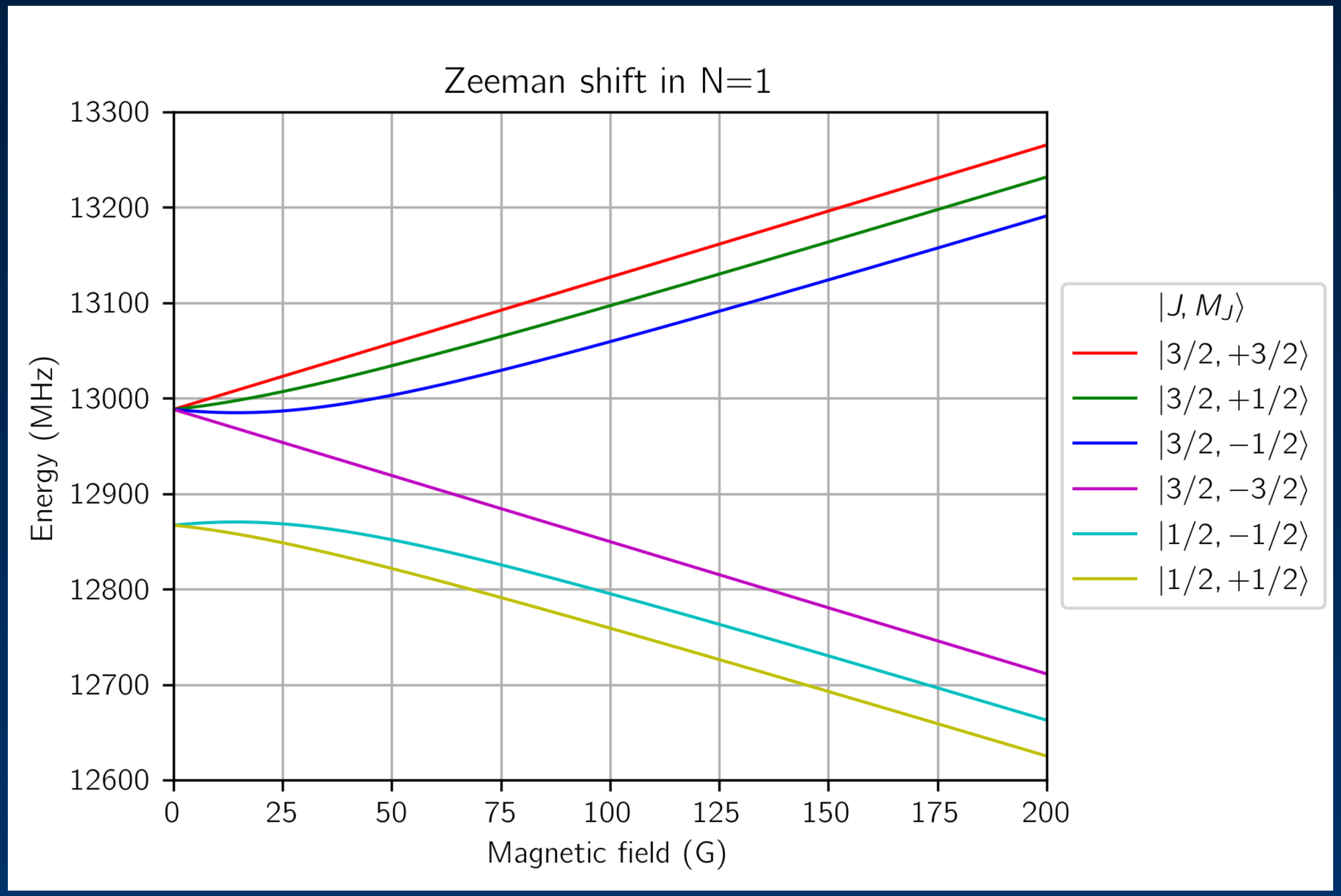
Master student: Jeroen Maat





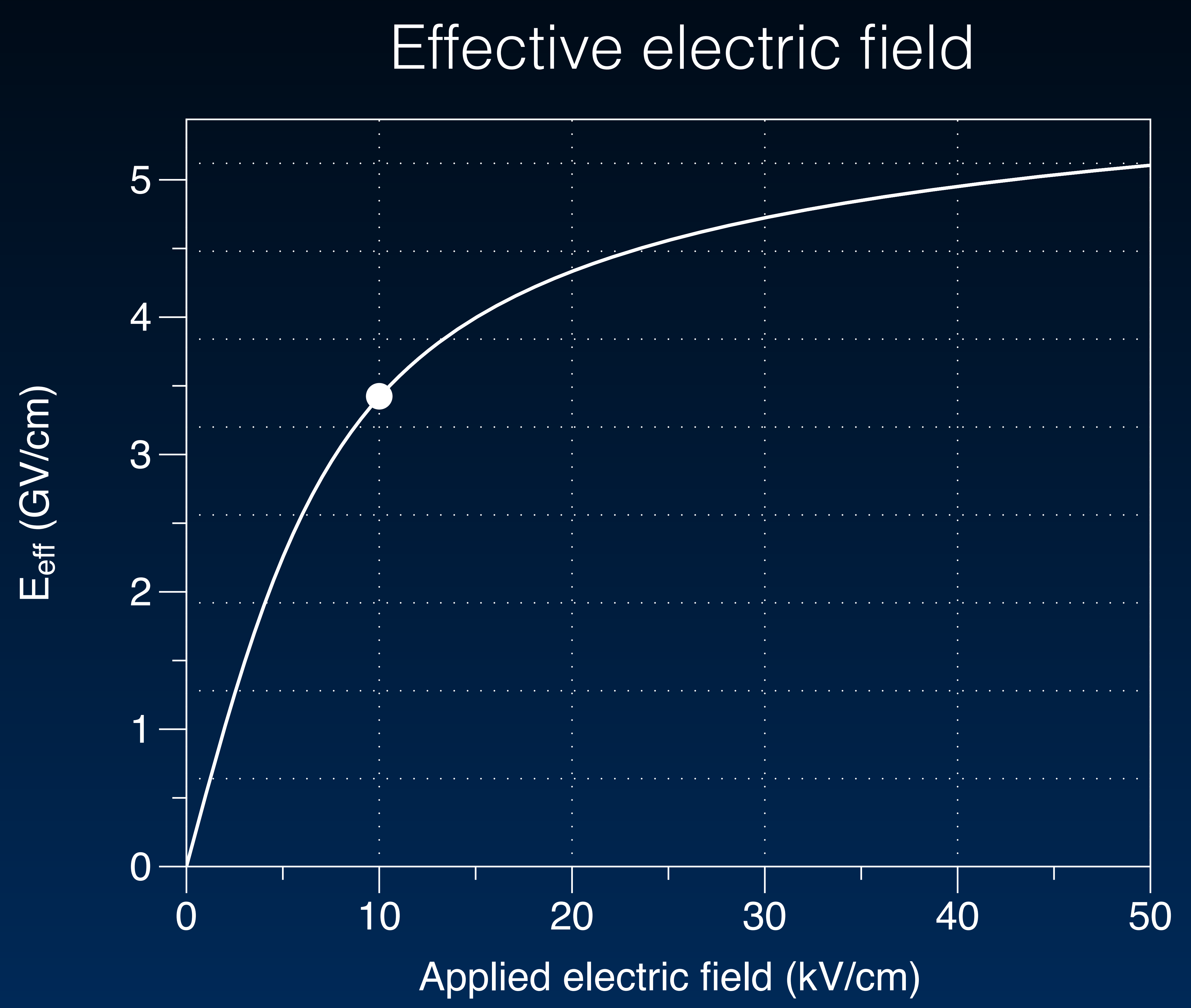
Important input for design of the interaction zone and Stark decelerator





First results from theory: the effective electric field

PhD student: Pi Haase



Aim:

Perform the most accurate calculation of the effective electric field, a crucial parameter for the eEDM measurement

Current status:

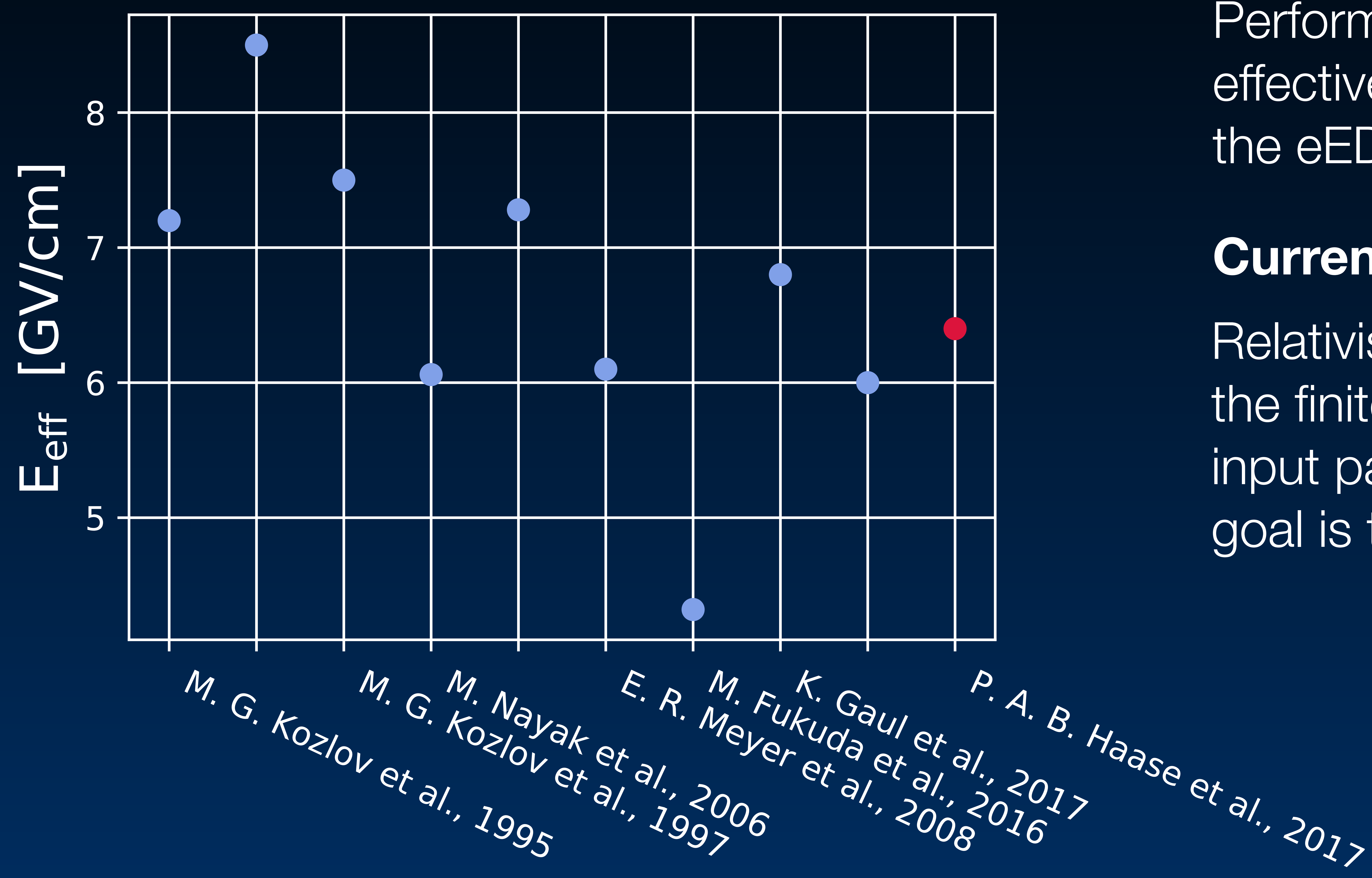
Relativistic coupled cluster in combination with the finite field method. Dependence on various input parameters is currently being tested. The goal is to reach a theoretical accuracy of ~ 1%.

Plans for 2018:

- Identify underlying mechanisms leading to high E_eff
- Can we disentangle sources of eEDMs?

First results from theory: the effective electric field

PhD student: Pi Haase



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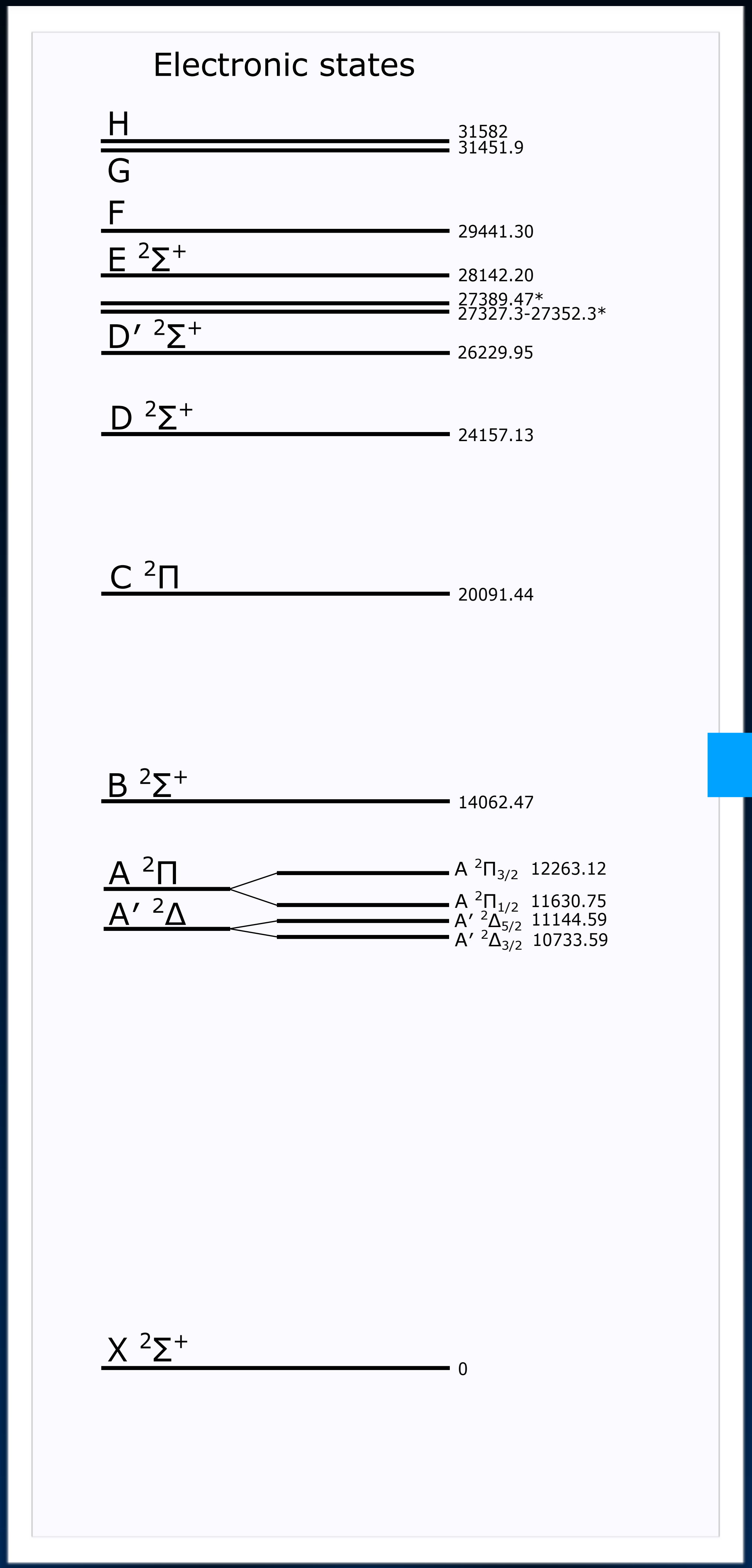
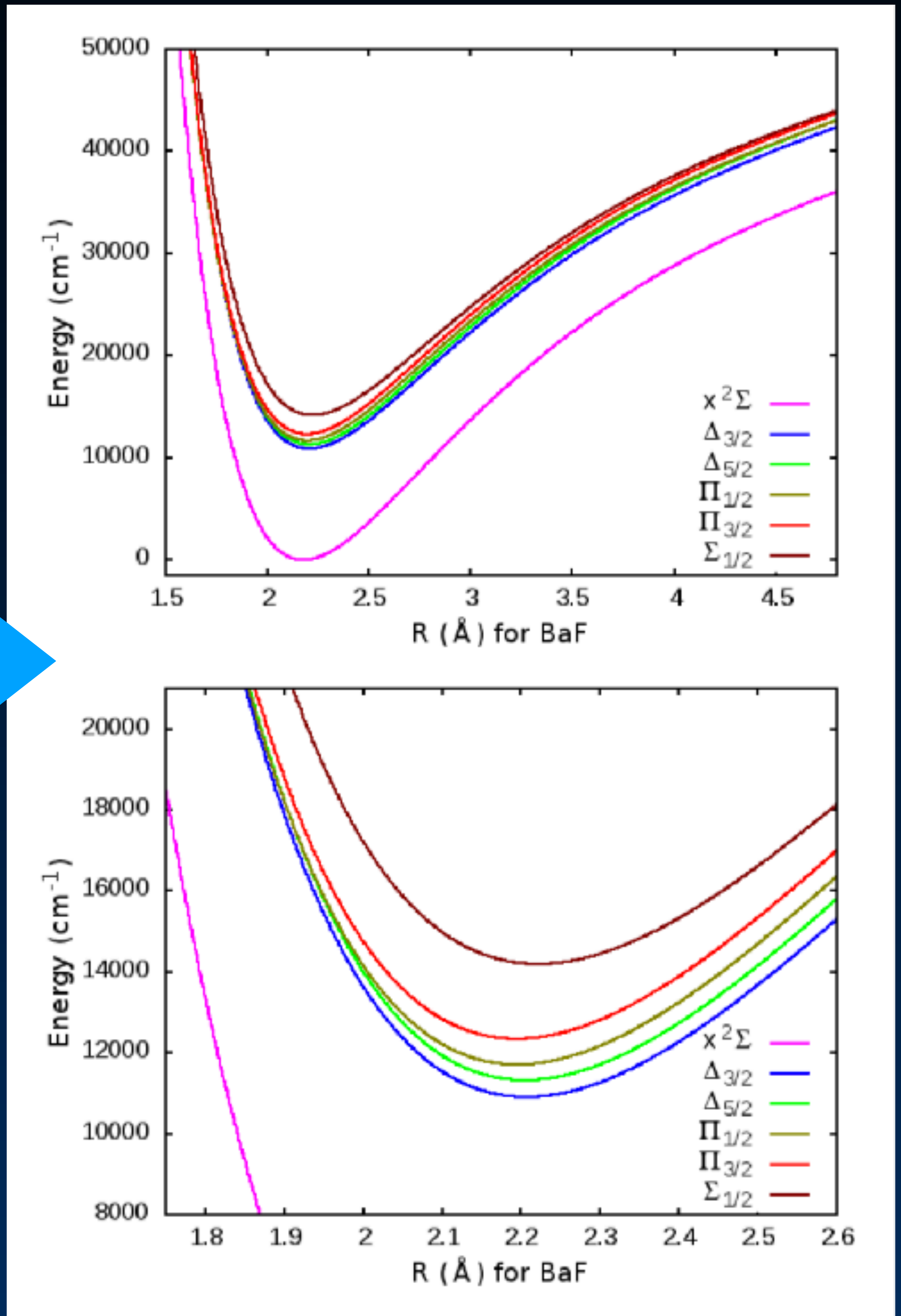
First results from theory: transition probabilities and linestrengths

PhD student: Yongliang Hao





Potential energy curves

Calculation of spectroscopic constants - compare to experiments

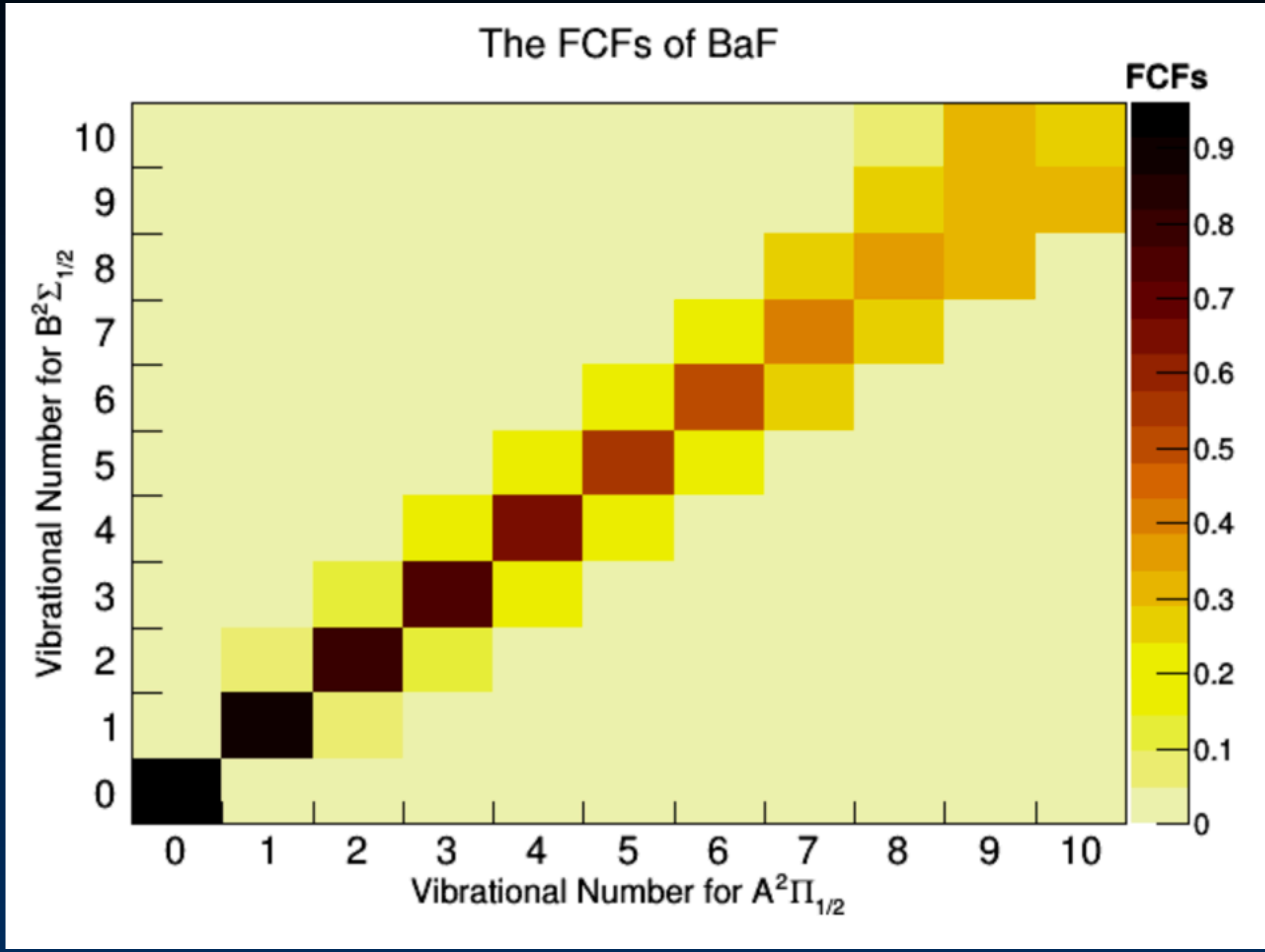
Determination of Franck-Condon factors and transition dipole moments

Essential input for efficient laser cooling and molecule detection schemes

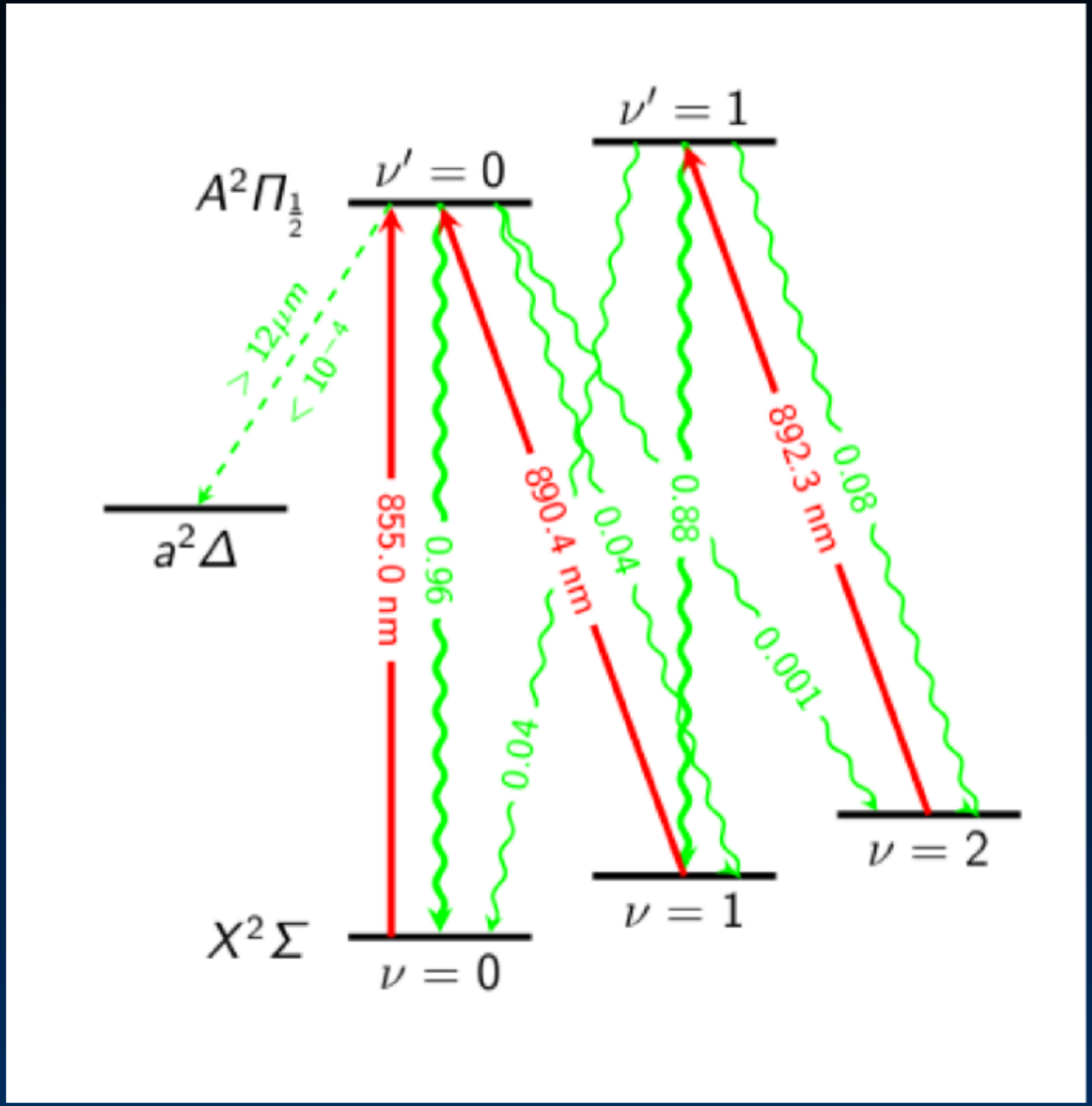
These accurate calculations incorporate electron correlation and relativistic effects.

First results from theory: transition probabilities and linestrengths

PhD student: Yongliang Hao

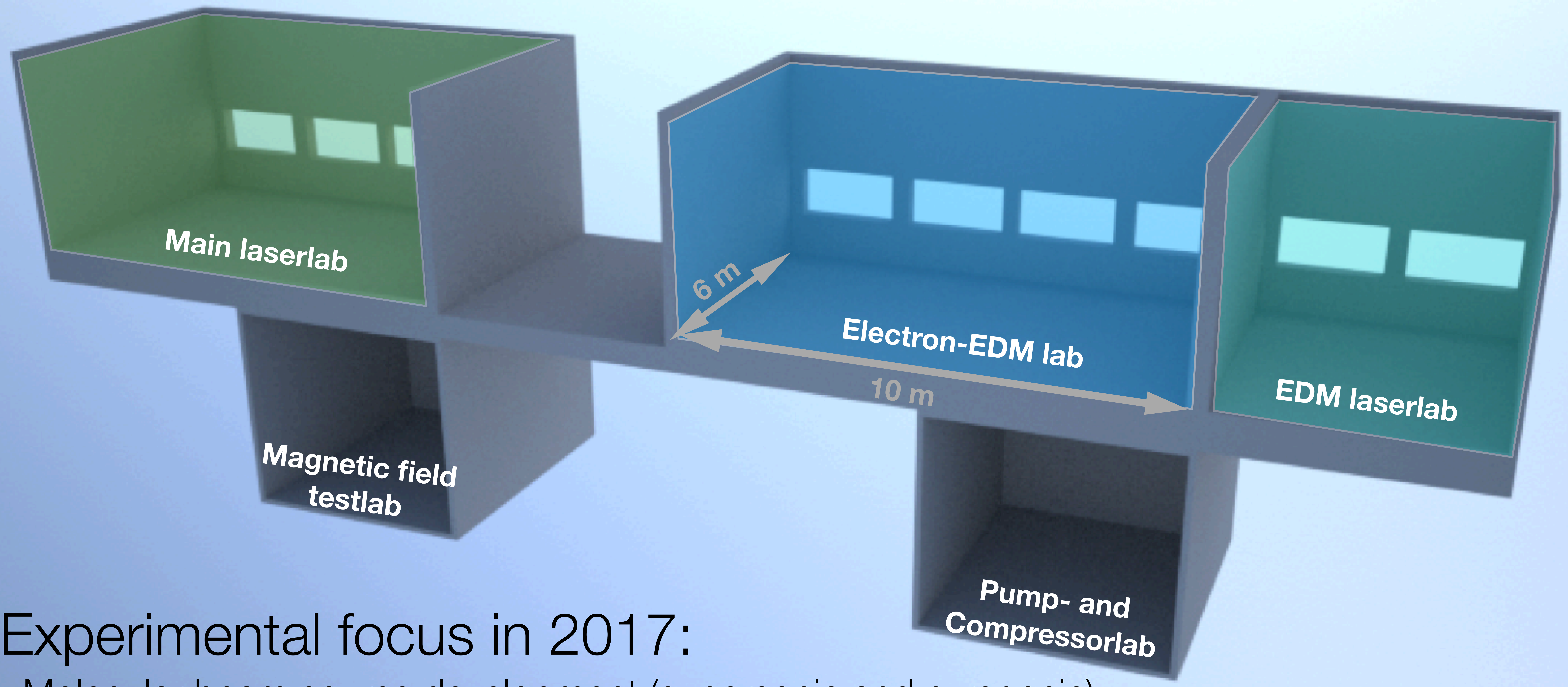


Calculated Franck-Condon factors



Proposed laser cooling scheme

Experiment construction: Labs @ VSI



Experimental focus in 2017:

- Molecular beam source development (supersonic and cyrogenic)
- Decelerator high voltage upgrade
- Interaction zone design

Experiment construction: Supersonic source

PhD student: Parul Agarwal

Aim:

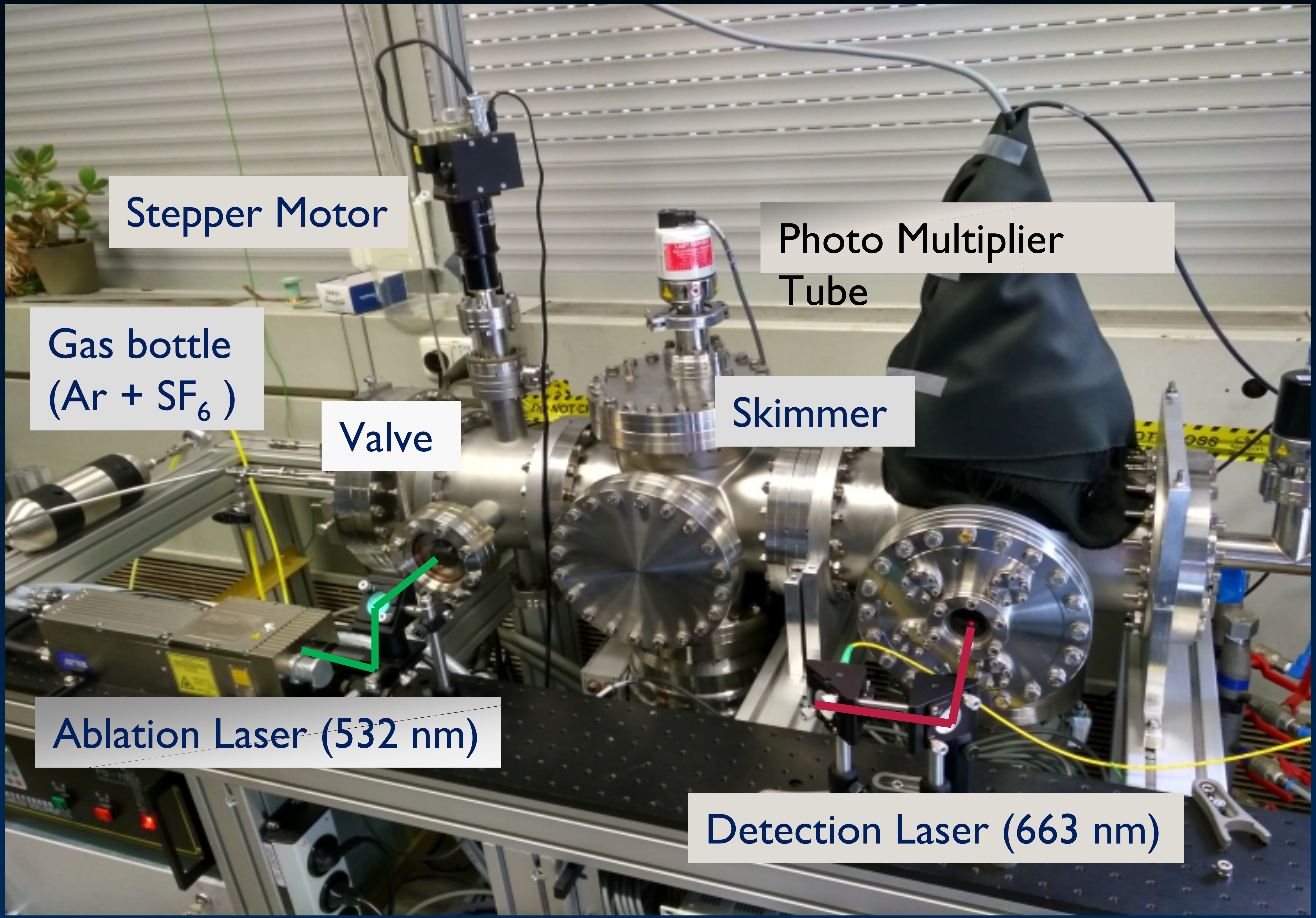
Identify the best way to produce an intense beam of BaF molecules

Current status:

Testing new supersonic valve and target rotation mechanism with SrF

Plans for 2018:

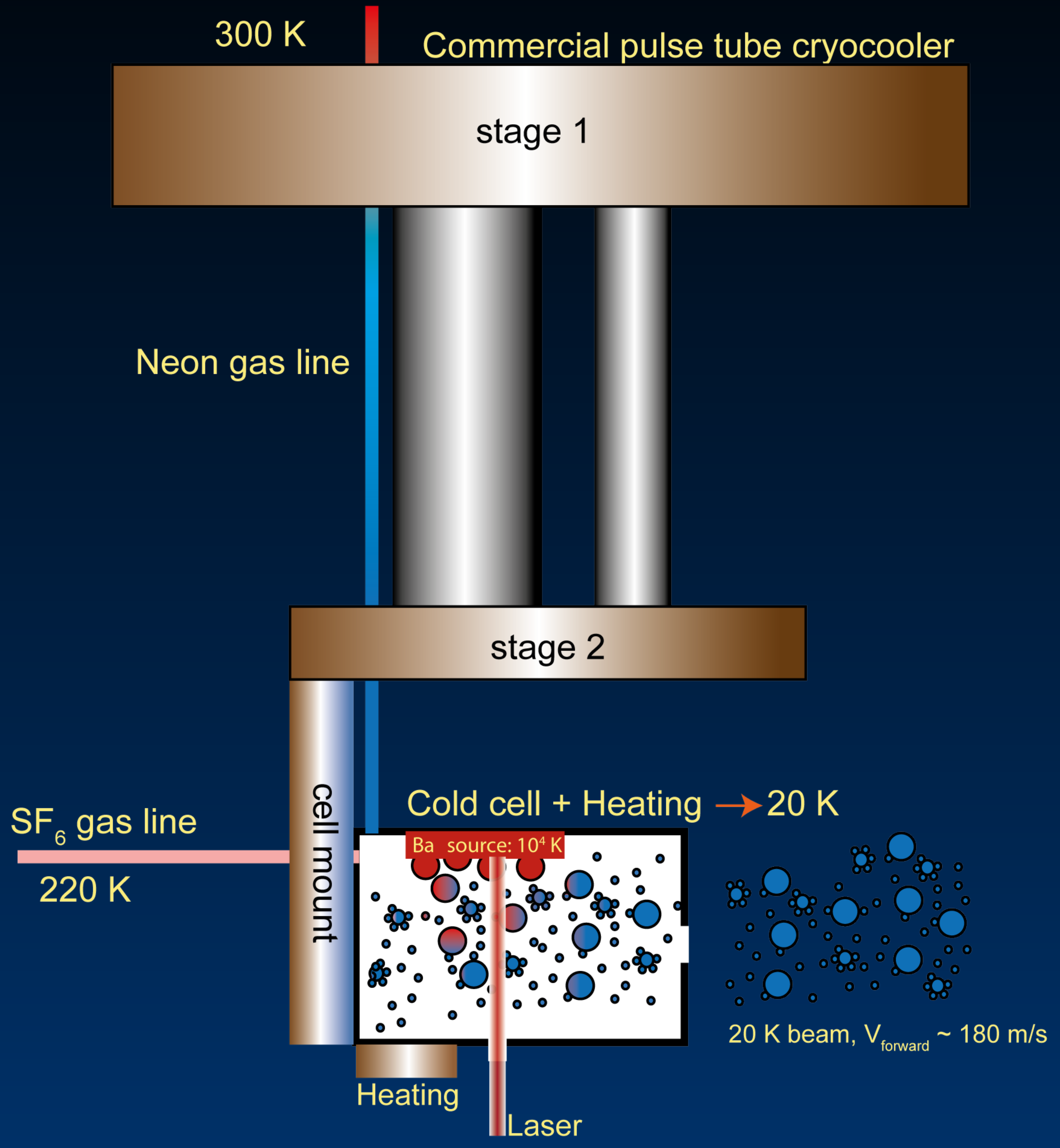
Use this supersonic beam to do first spectroscopy on BaF molecules

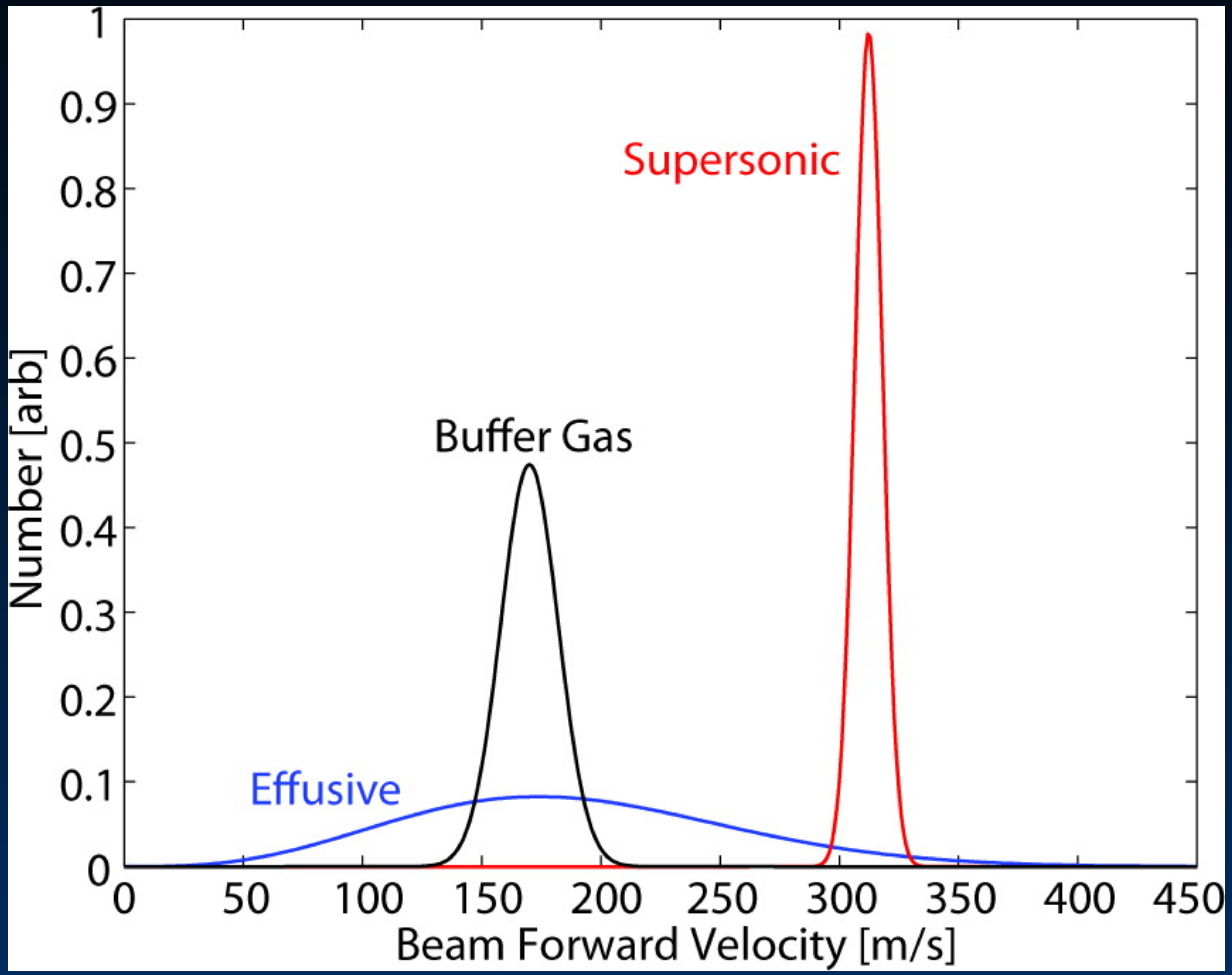


Experimental setup to test and optimize BaF beam production

Experiment construction: Cryogenic source

PhD student: Kevin Esajas, Maarten Mooij





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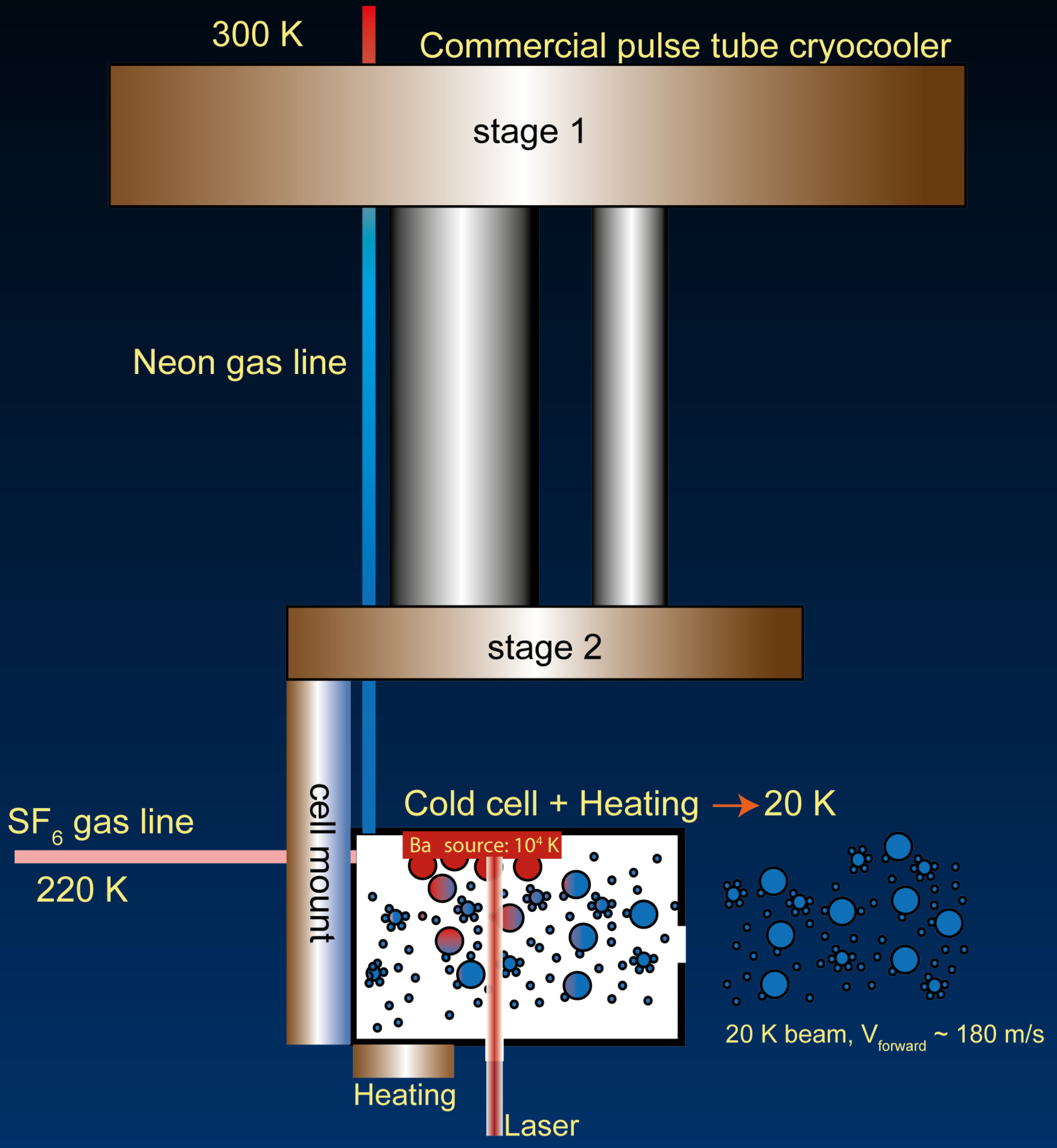

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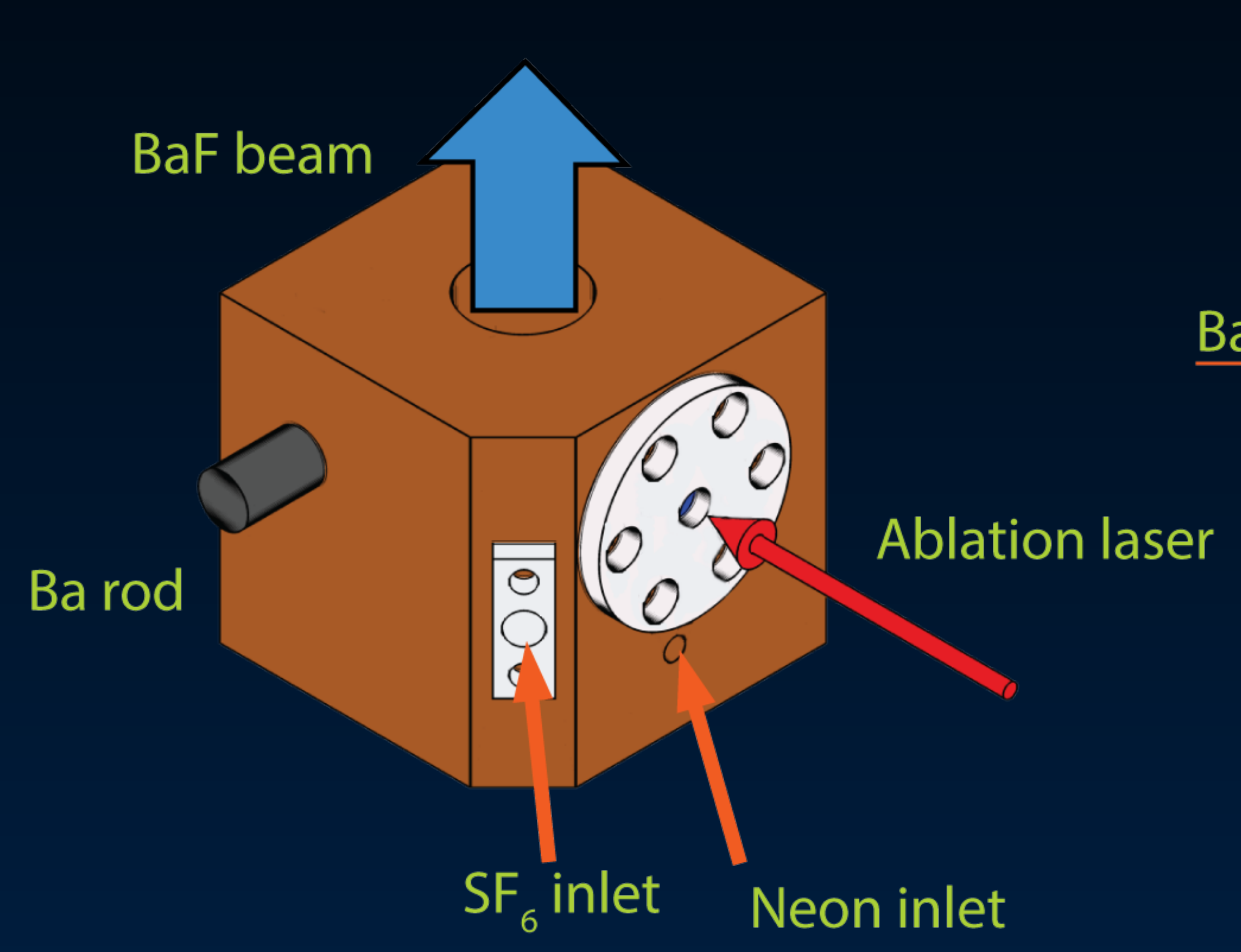
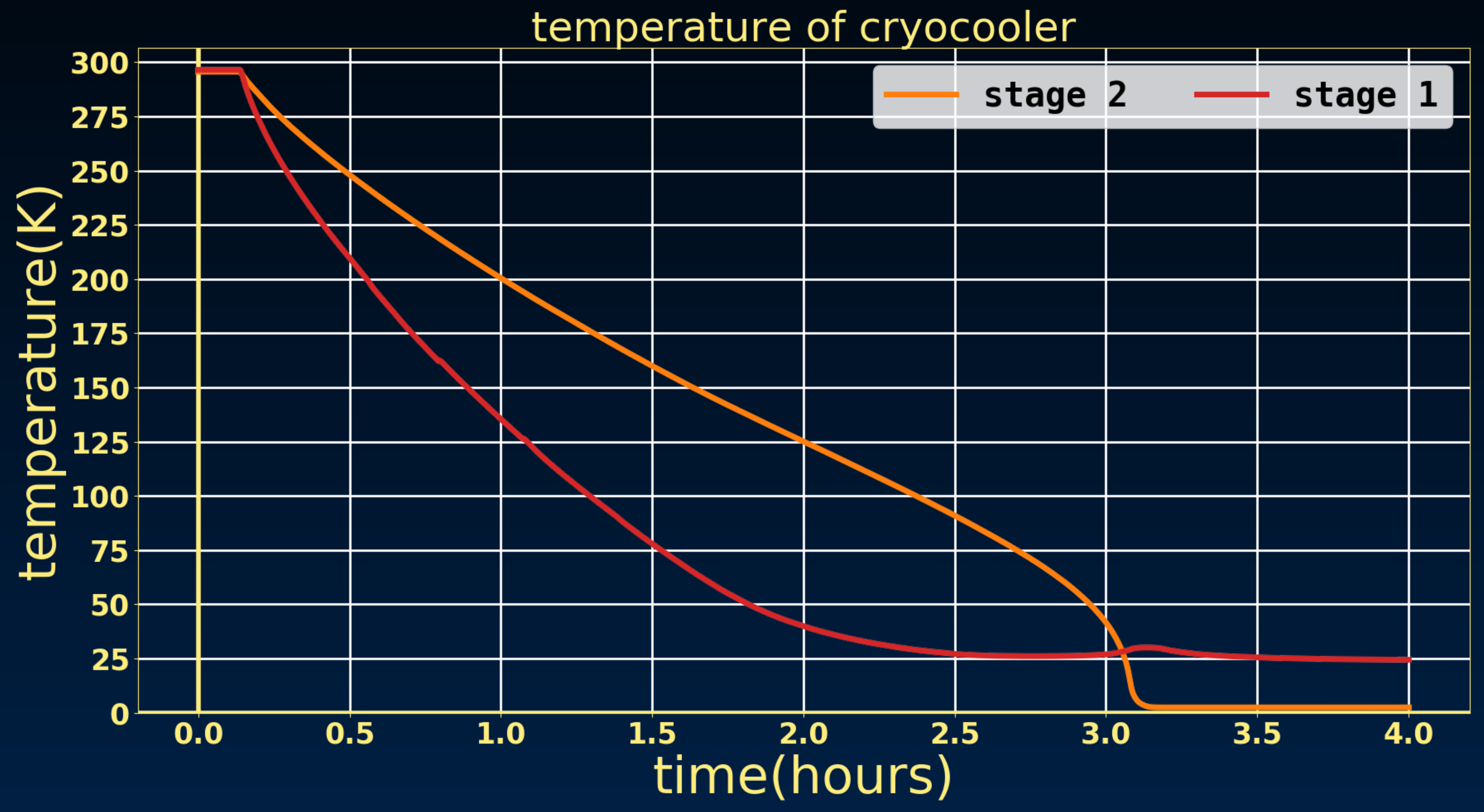


Cold cell, design in collaboration with Imperial College London



Characterising the source heat loads with cooldown tests

Aim:

Build the most intense BaF molecular beam source possible

Current status:

Source @ VSI almost complete, setting up 2nd source @ VUA

Plans for 2018:

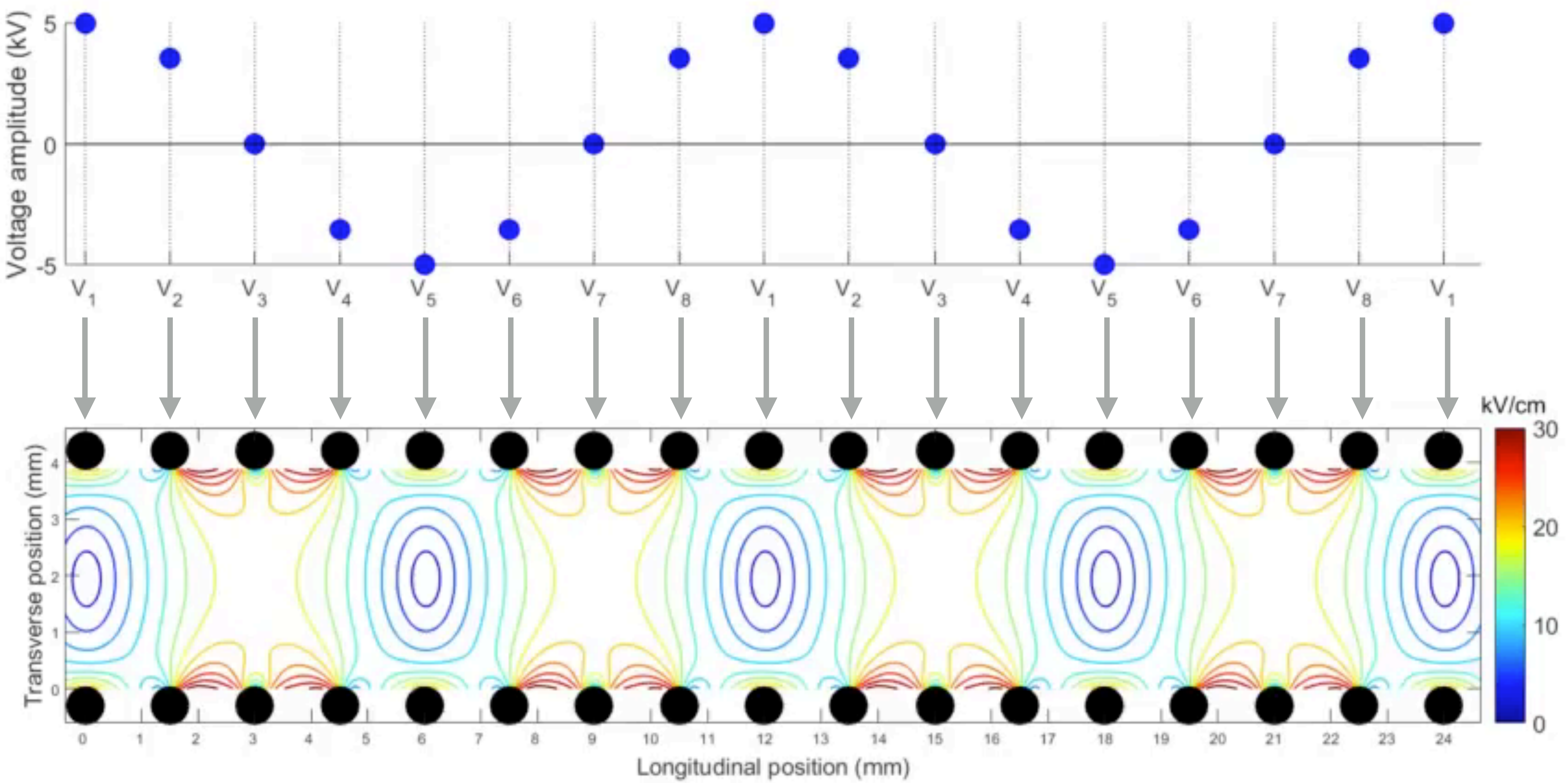
Combine cryogenic source with decelerator @ VSI, optimise BaF @ VUA

Experiment construction: Molecule deceleration

PhD student: Artem Zapara

Experiment construction: Molecule deceleration

PhD student: Artem Zapara



Experiment construction: Molecule deceleration

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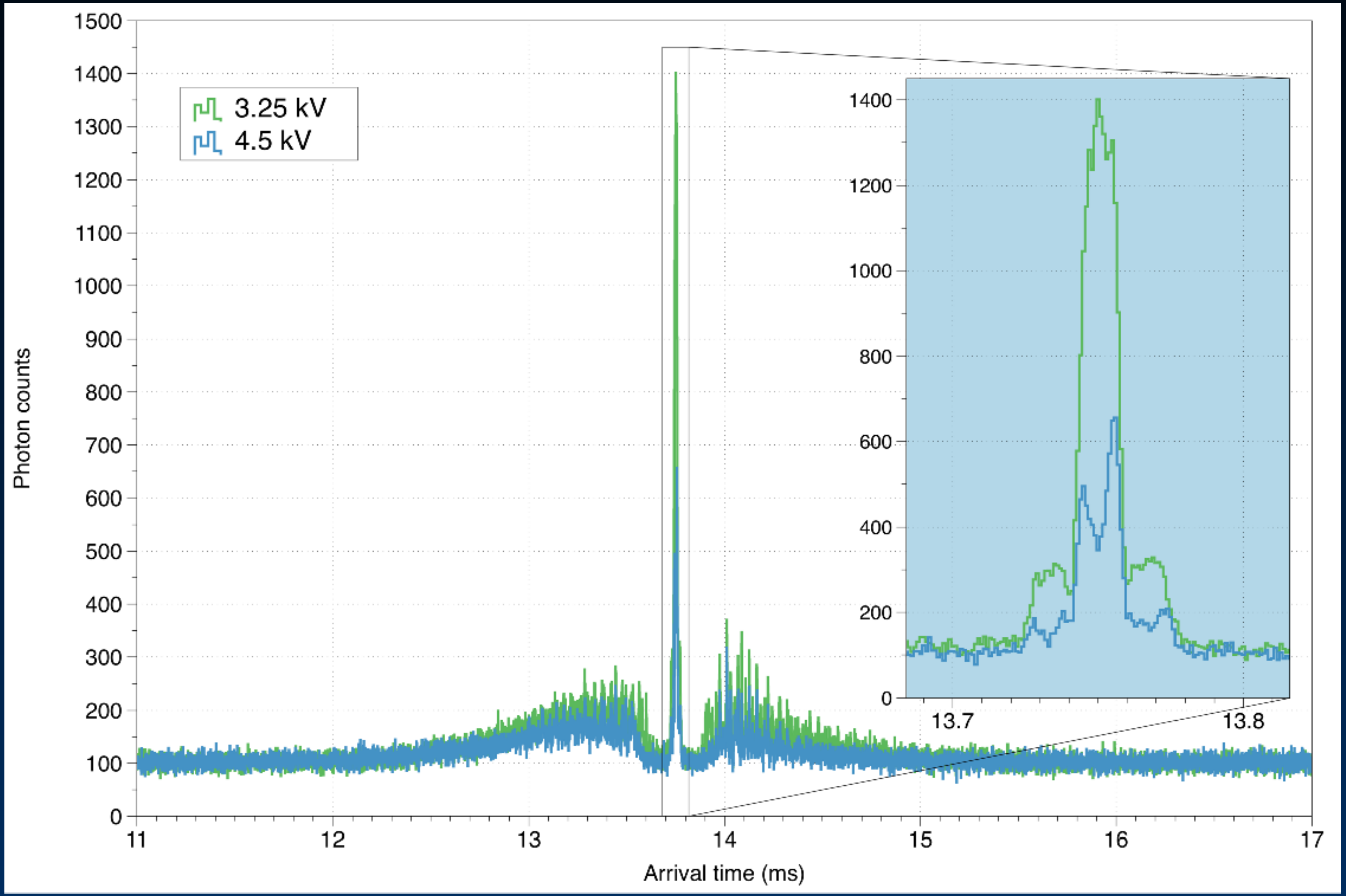

Measured time-of-flight profiles

Aim:

Demonstrate efficient deceleration of heavy diatomic molecules

Current status:

Identified loss mechanism, related to shape of high-voltage waveform.
Solution: cool the beam source.

Plans for 2018:

Trap SrF molecules, then move to BaF.
Upgrade of high-voltage electronics

Experiment construction: Molecule deceleration

PhD student: Artem Zapara

Prototype transformer dec 2017

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Demonstrate efficient deceleration of heavy diatomic molecules

Current status:

Identified loss mechanism, related to shape of high-voltage waveform.
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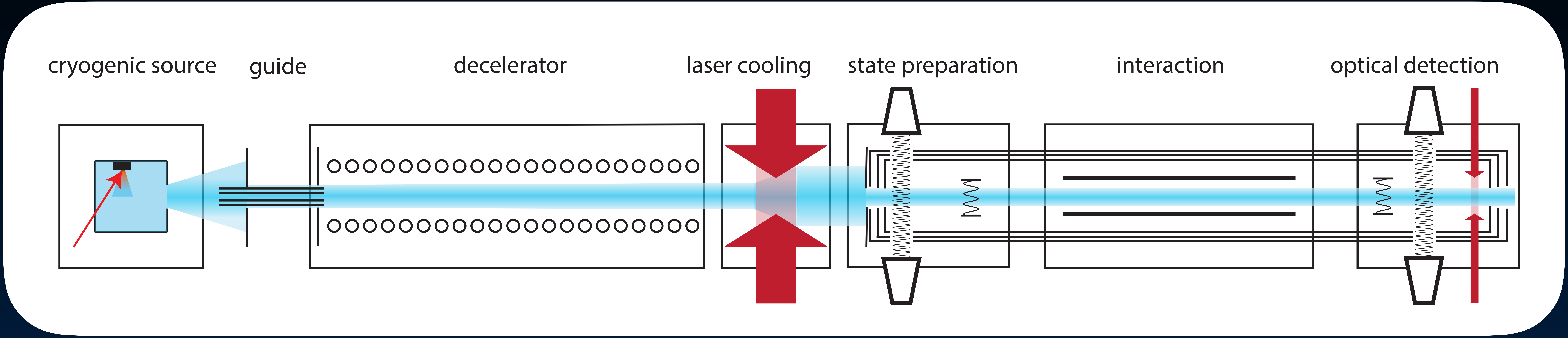
Upgrade of high-voltage electronics

Experiment construction: Interaction zone

PhD student: Thomas Meijknecht



Aim:

Design and construct an interaction zone that controls the magnetic field at the 50 pT level, while applying a strong electric field.

Current status:

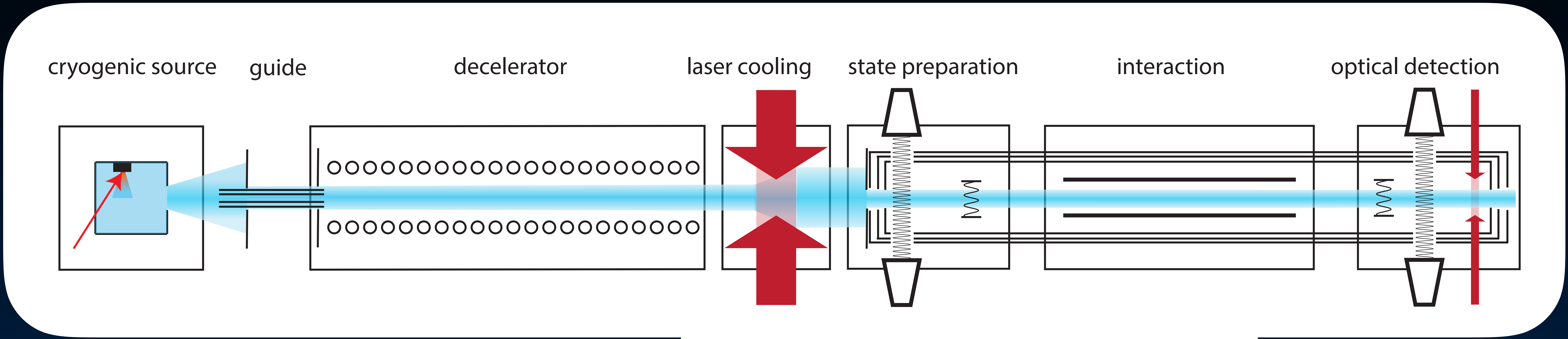
Performing COMSOL simulations on electric and magnetic fields, testing active and passive magnetic field shielding

Plans for 2018:

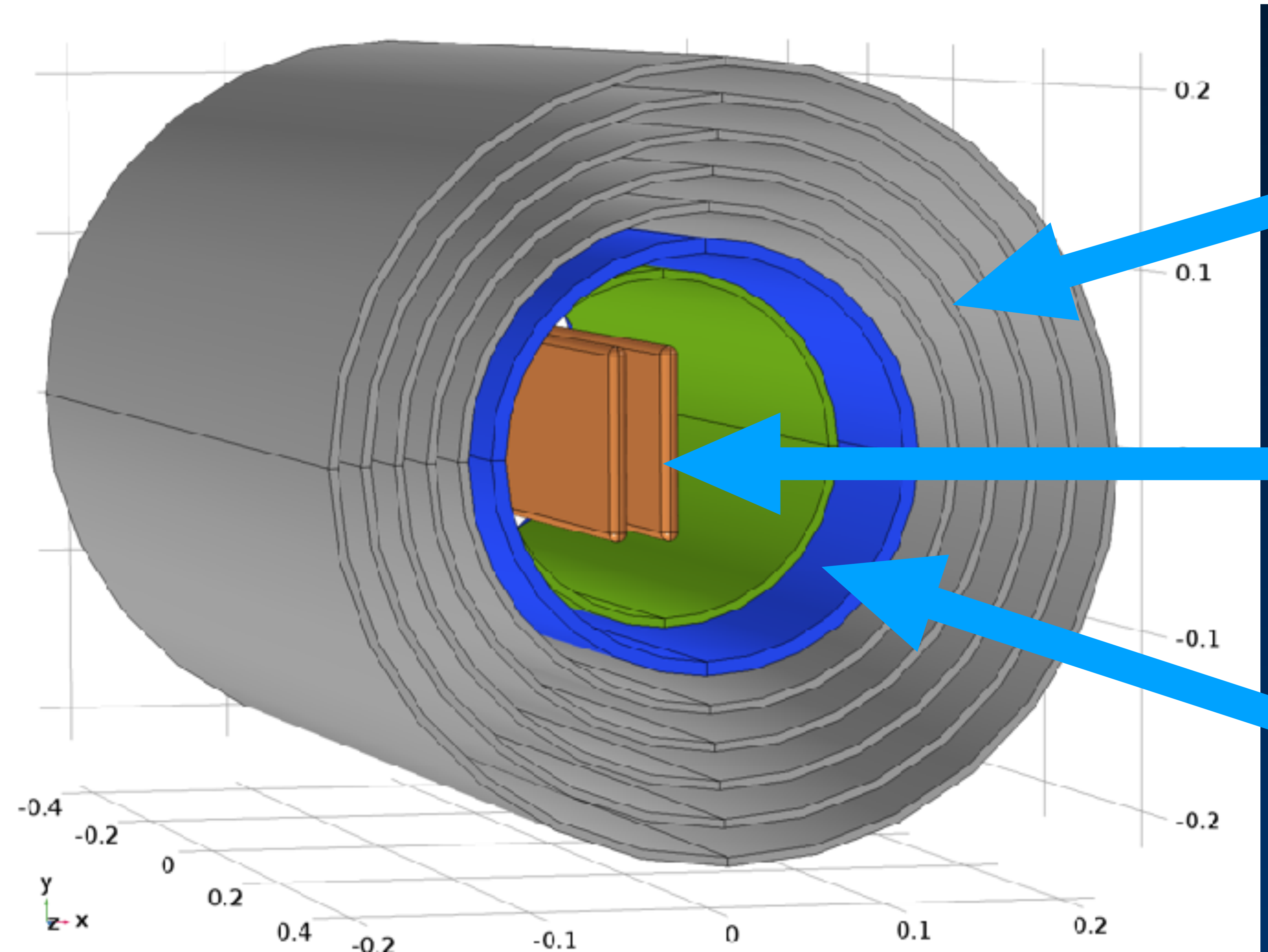
Complete design, use BaF molecular beam for first tests

Experiment construction: Interaction zone

PhD student: Thomas Meijknecht



Schematic overview of the interaction zone design



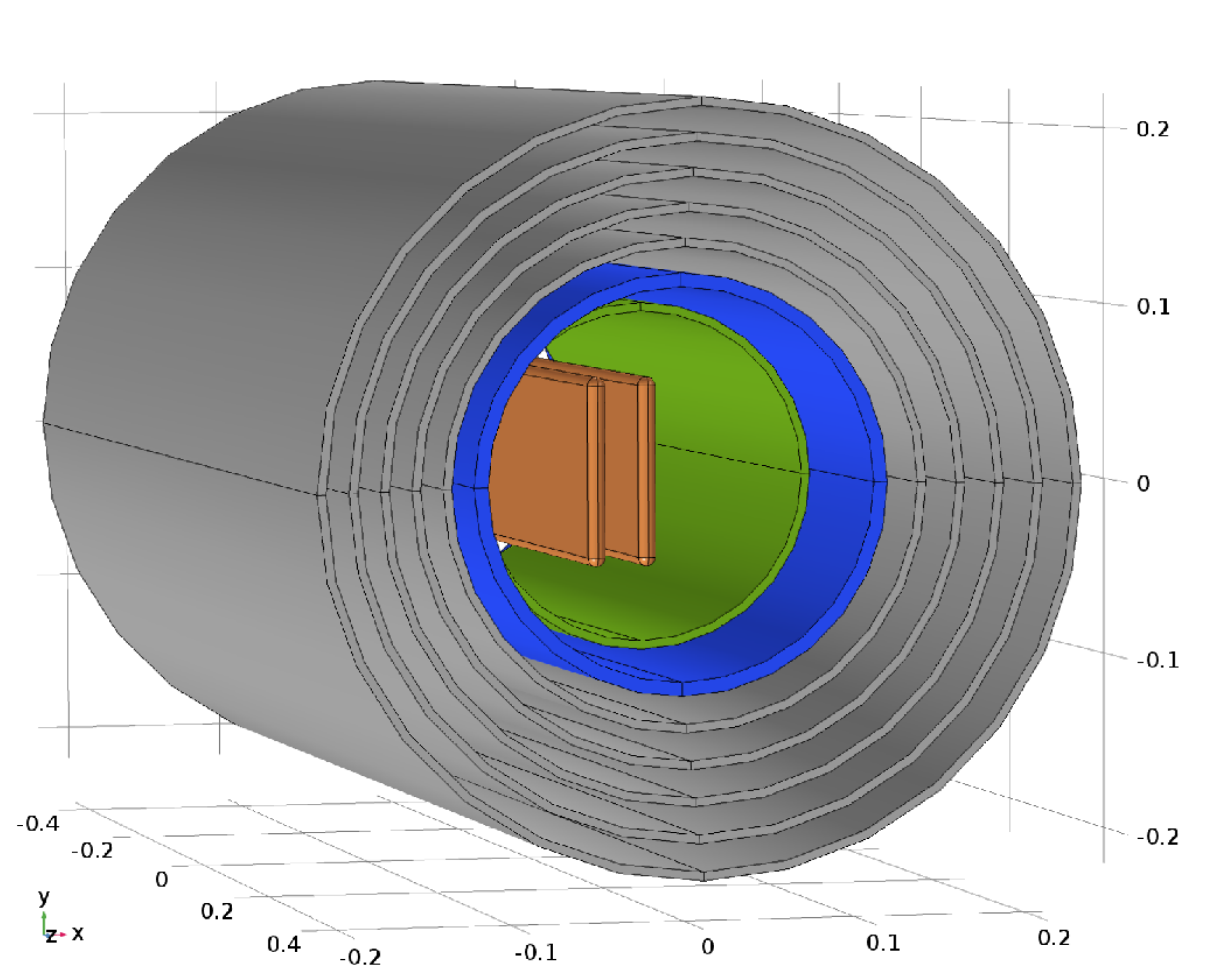
Mu-metal shielding detection region

Electric field plates

Magnetic field coil and vacuum chamber

Experiment construction: Interaction zone

PhD student: Thomas Meijknecht



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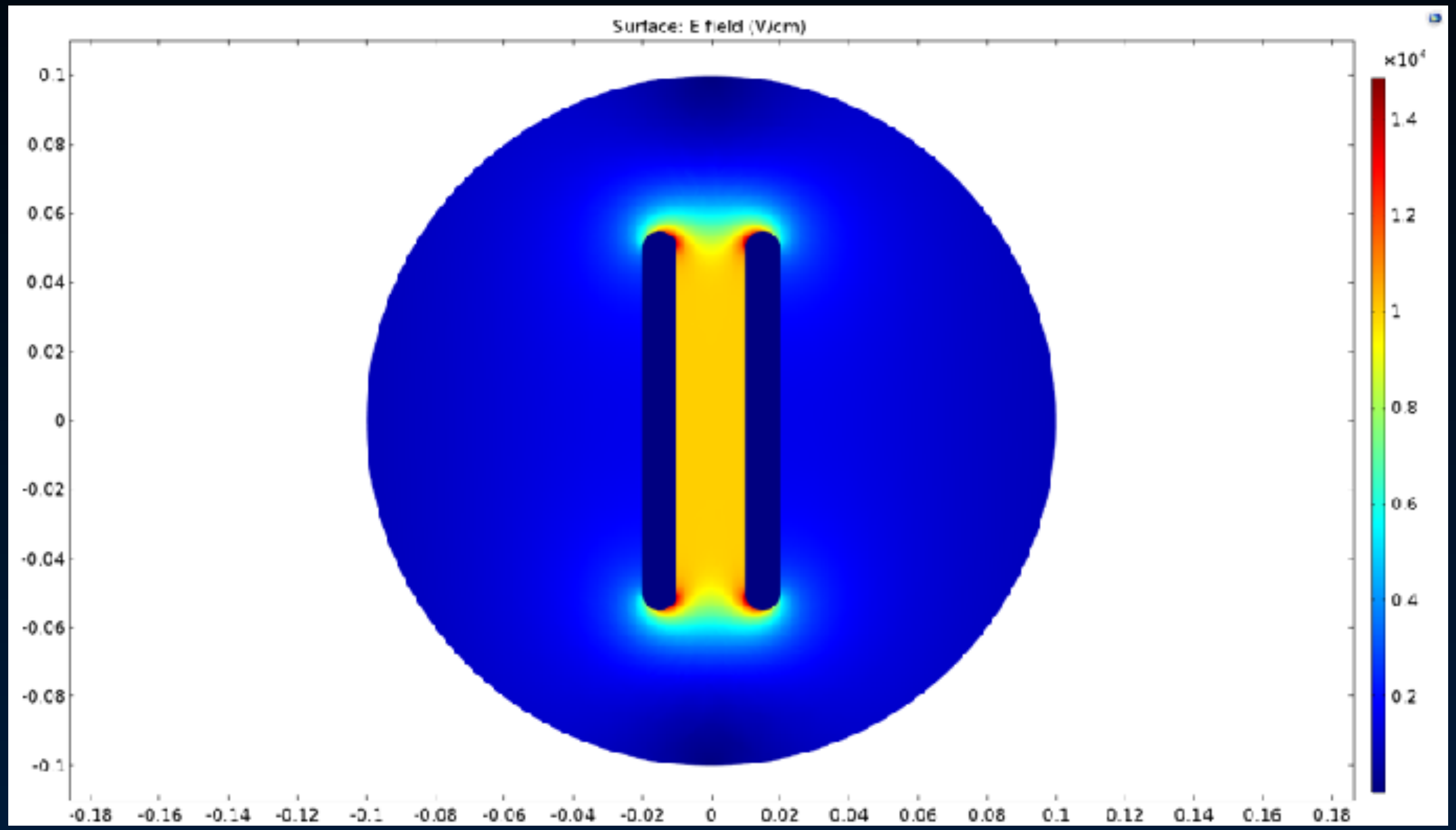
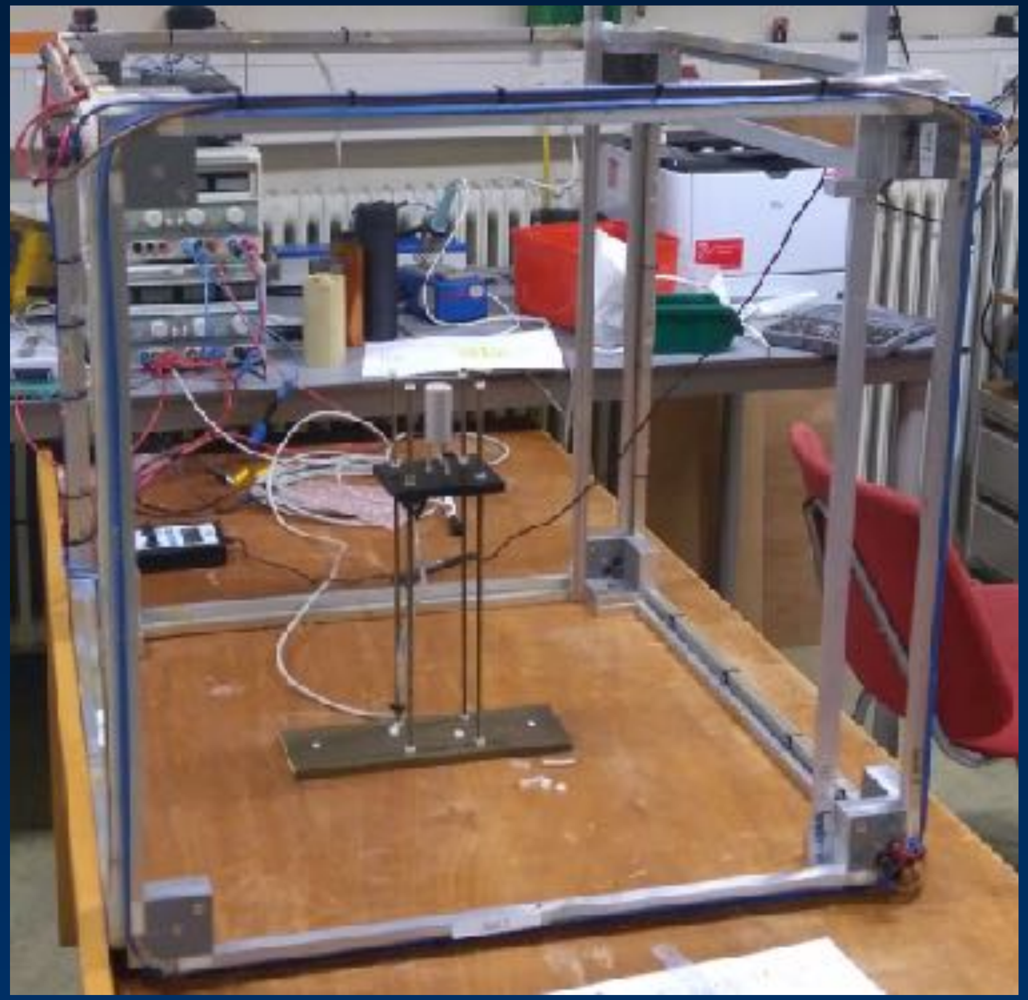


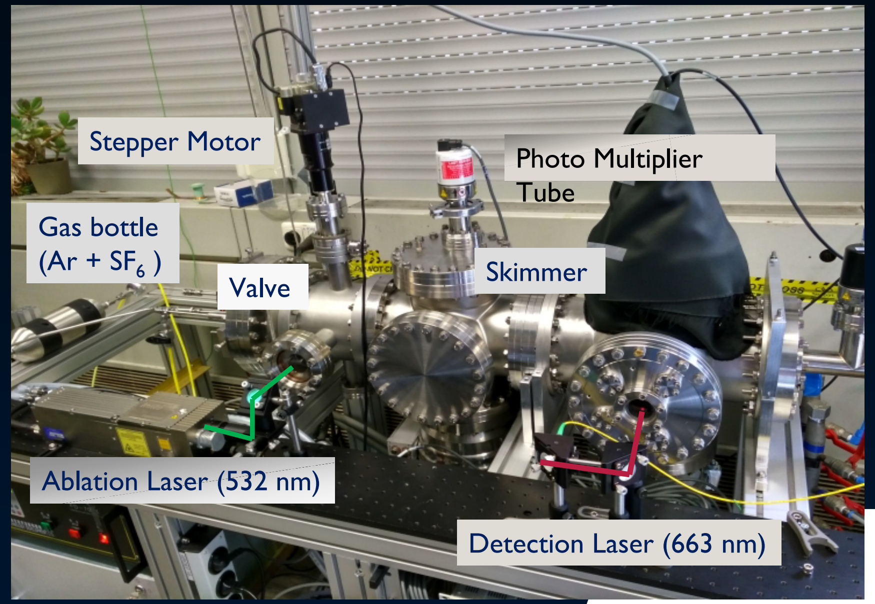
Electric field homogeneity calculations

Test setup for
active magnetic
field compensation

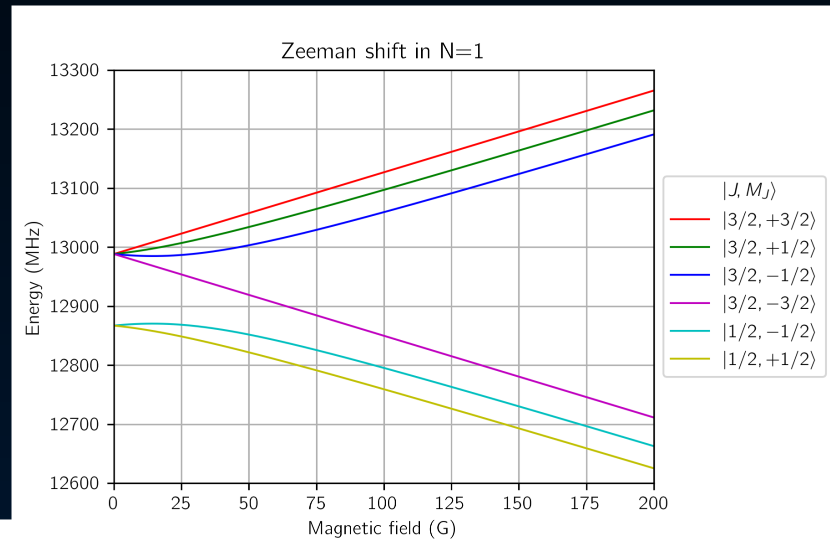


Conclusions

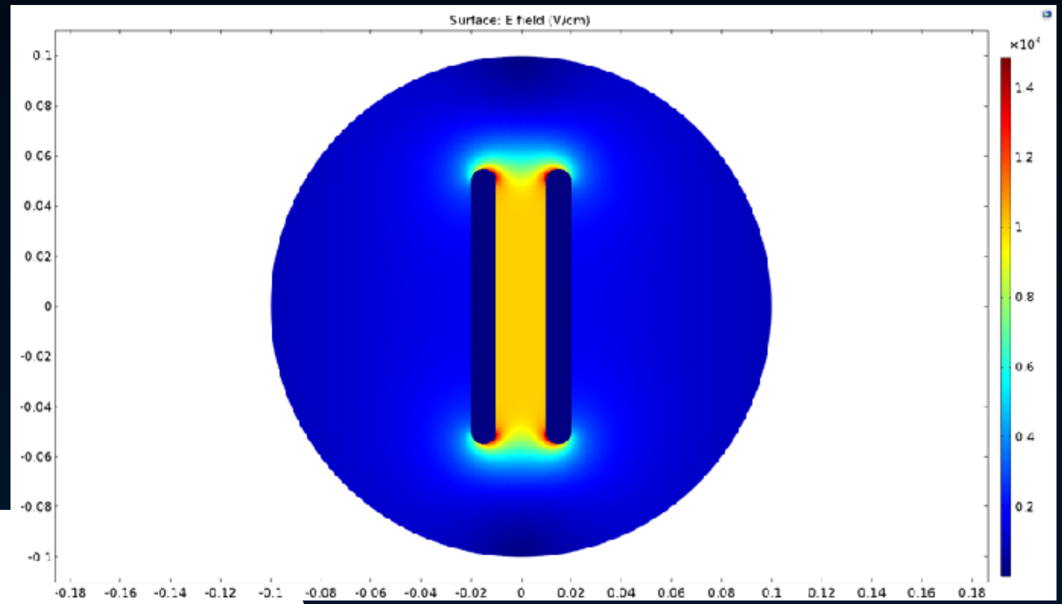
Good progress on all fronts: strongly integrated program of theory and experiment



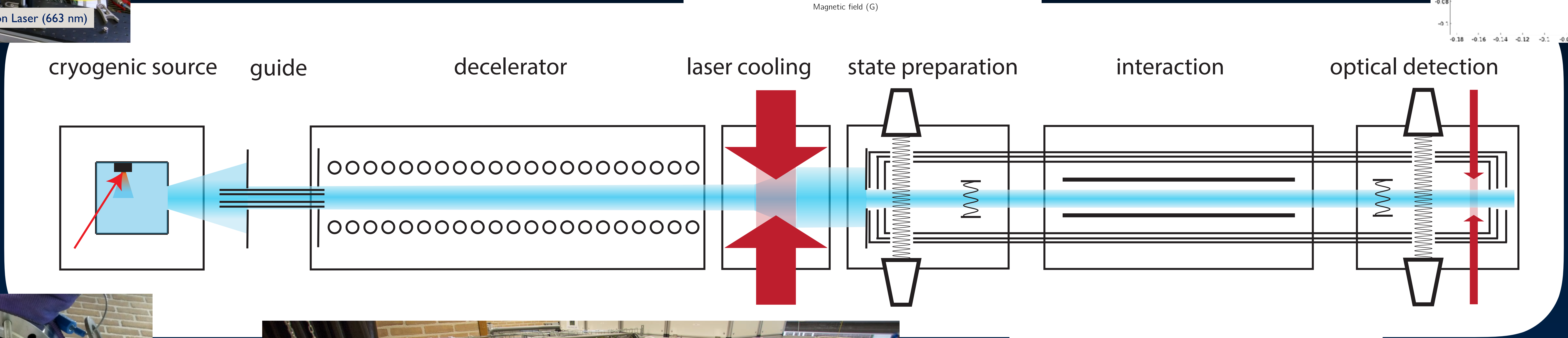
Supersonic source



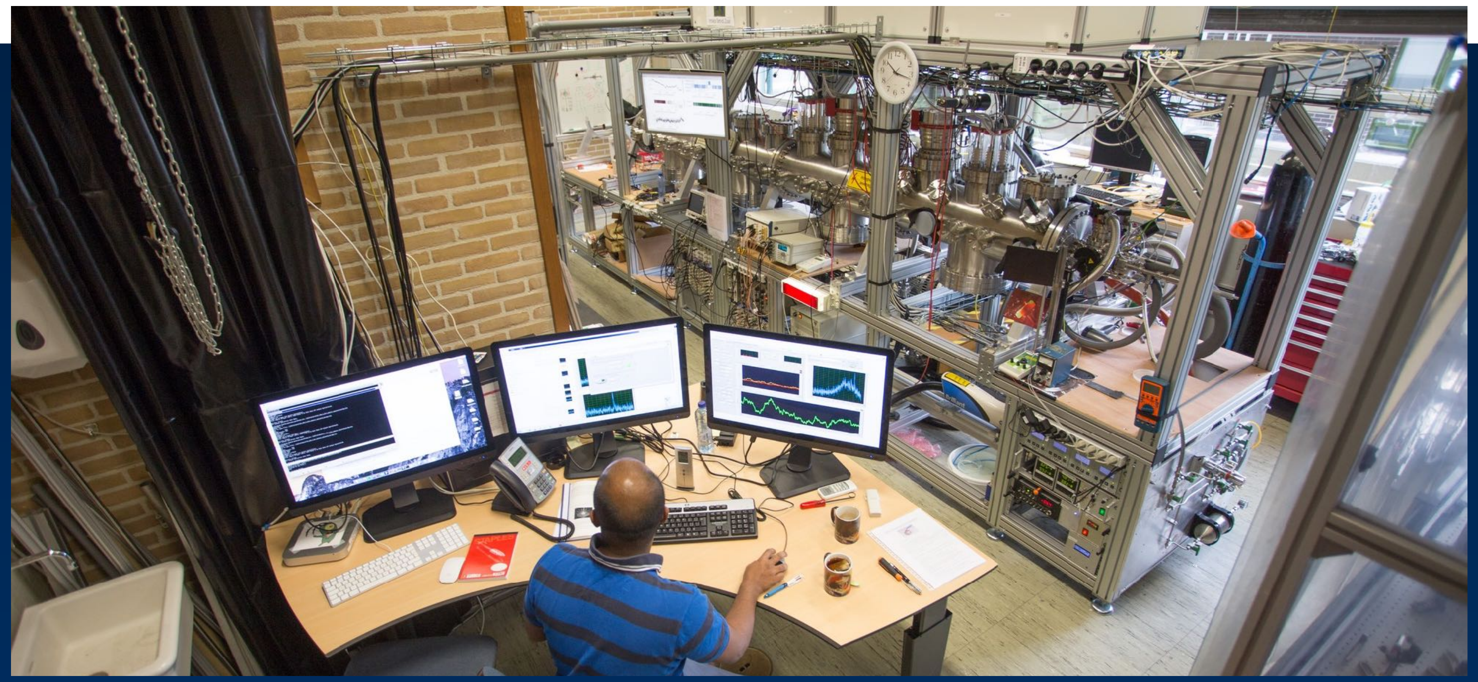
Magnetic field sensitivity



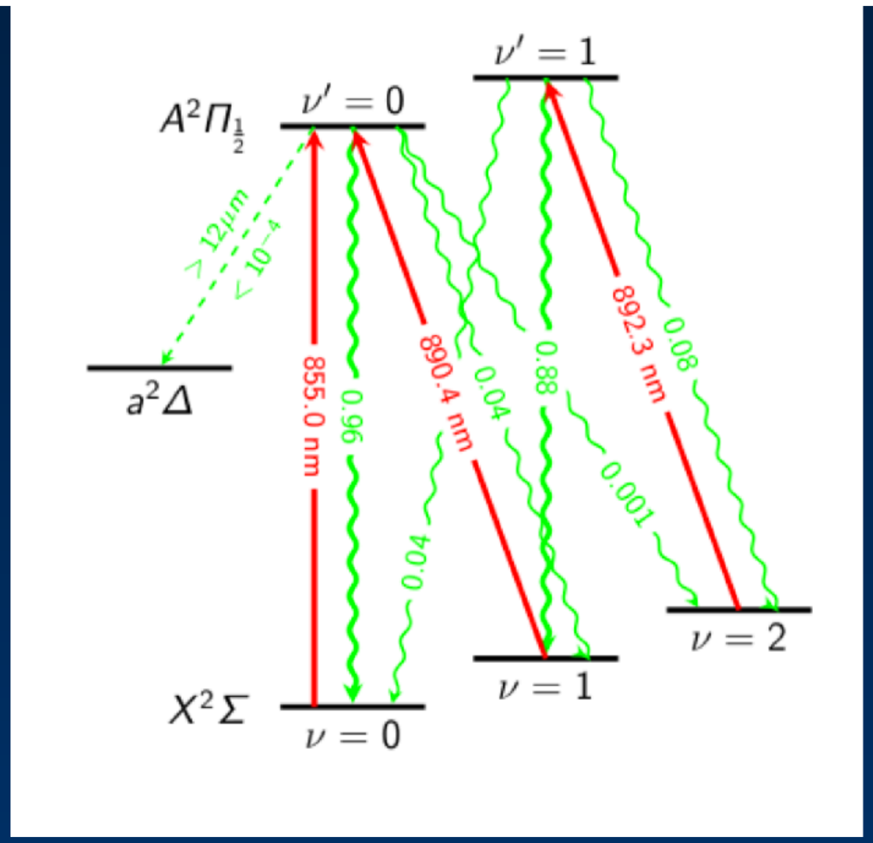
Interaction zone design



Cryogenic source



Molecule decelerator



Laser cooling and detection

Connections to other programs

On physics:

Providing new ingredients for a global (beyond) the Standard Model analysis, complementing LHC experiments

On experimental techniques:

Optics, interferometers, measuring small forces

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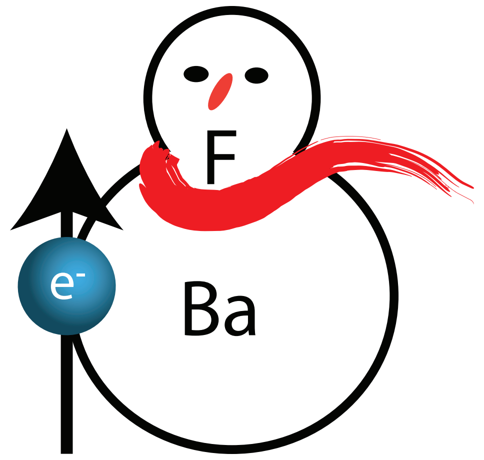

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