

Nikhef



LOW-ENERGY PRECISION MEASUREMENTS

**ELECTRON-EDM**

Steven Hoekstra  
electron-EDM program leader  
Van Swinderen Institute for Particle Physics and Gravity  
University of Groningen



# NL-eEDM

## Measuring the electron-EDM with BaF molecules

### Scientific staff:

Anastasia Borschevsky  
Rick Bethlem  
Steven Hoekstra  
Klaus Jungmann  
Rob Timmermans  
Wim Ubachs  
Lorenz Willmann

### PhD students:

Parul Aggarwal  
Alexander Boeschoten  
Kevin Esajas  
Pi Haase  
Yongliang Hao  
Virginia Marshall  
Thomas Meijknecht  
Maarten Mooij  
Anno Touwen  
Artem Zapara

### Postdocs

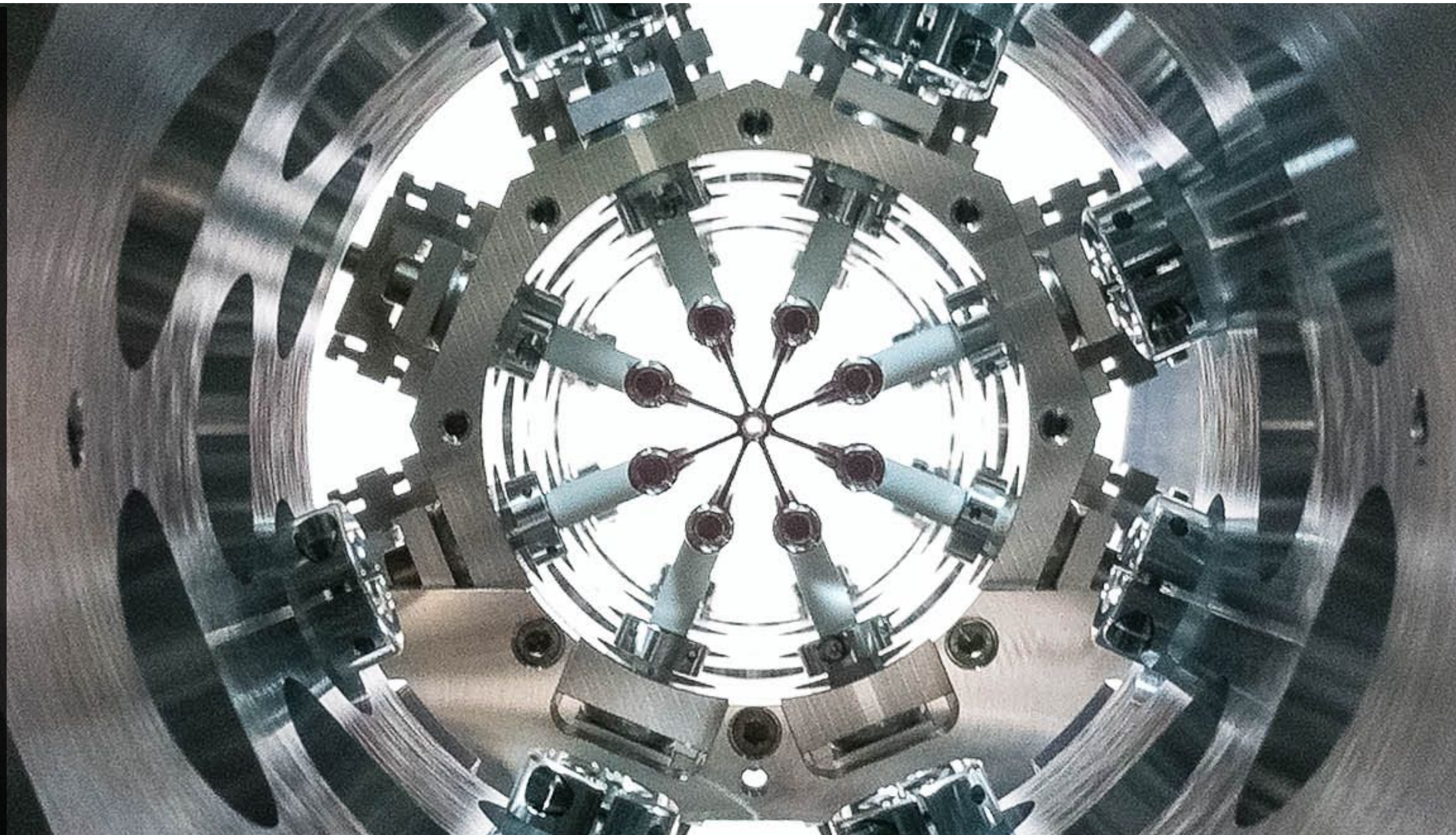
Malika Denis  
Yanning Yin

### Master students:

Hidde Makaske  
Sander Vermeulen  
Kees Steinebach  
Mark Buisman  
Rutger Hof  
Paul Hofland

### Bachelor students:

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Attie Hendriks  
Jente Joosten  
Richard Borchers  
Marit Fiechter



university of  
groningen

van swinderen institute for  
particle physics and gravity

Nikhef

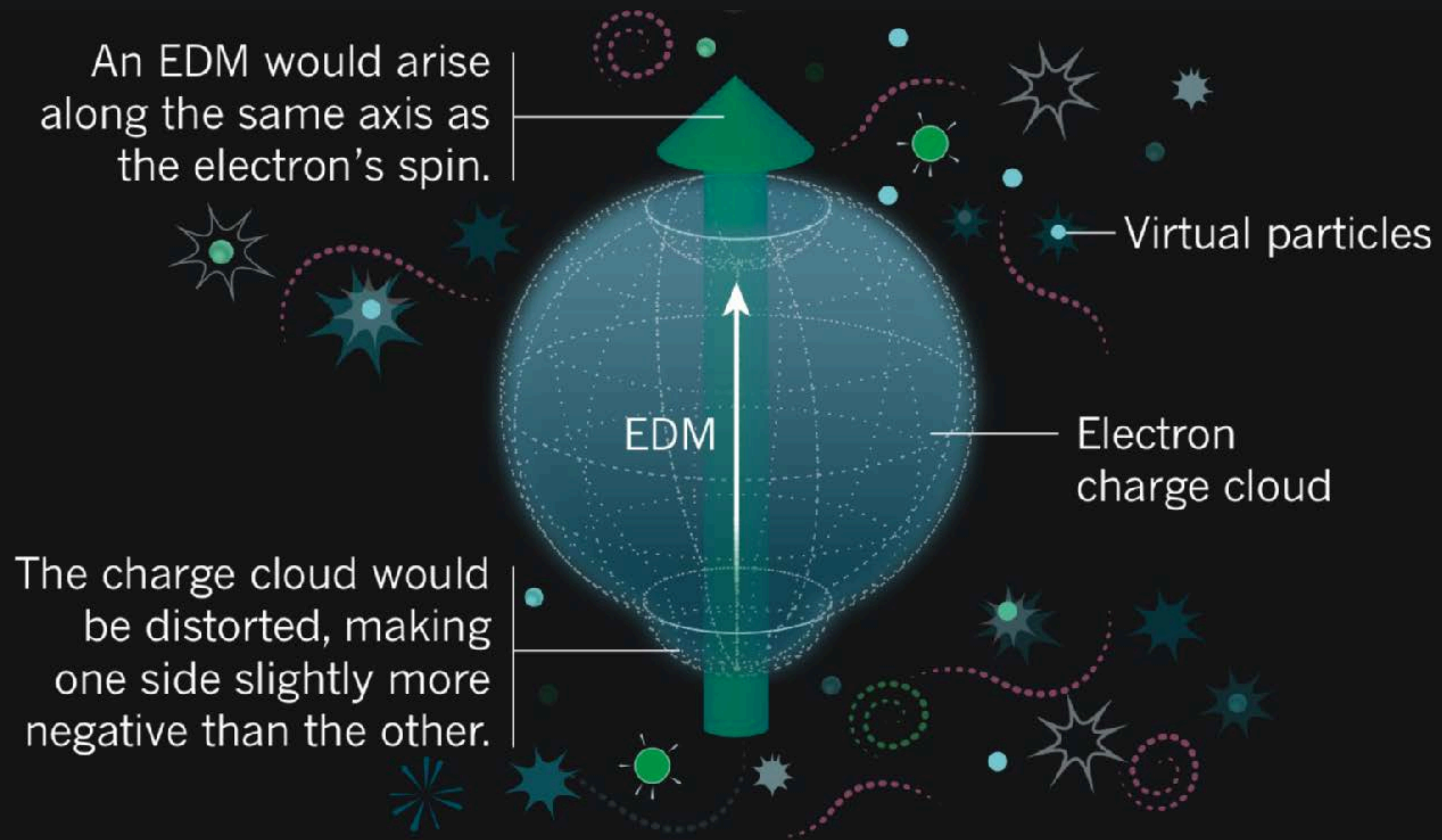
Dutch National Institute for (astro)Particle Physics



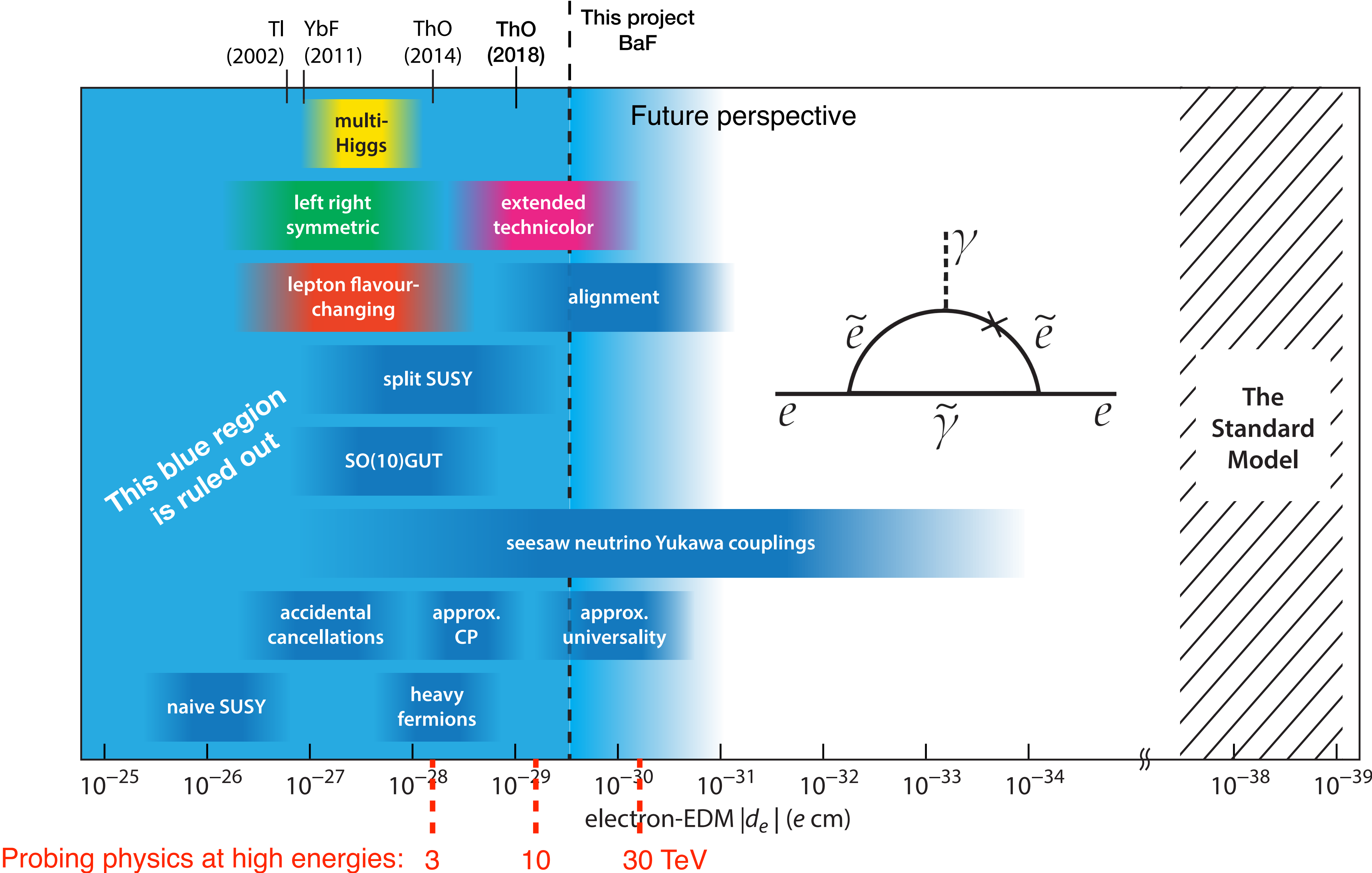


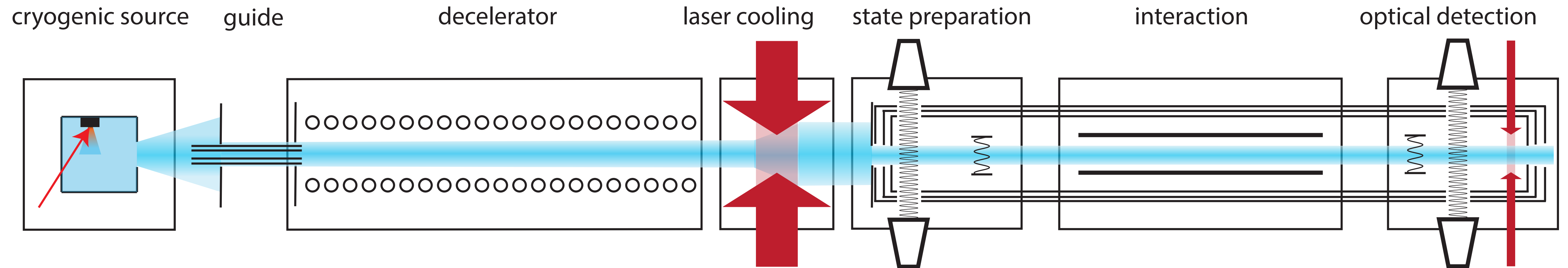
# Is the electron round?

The Electric Dipole Moment of the electron (eEDM)

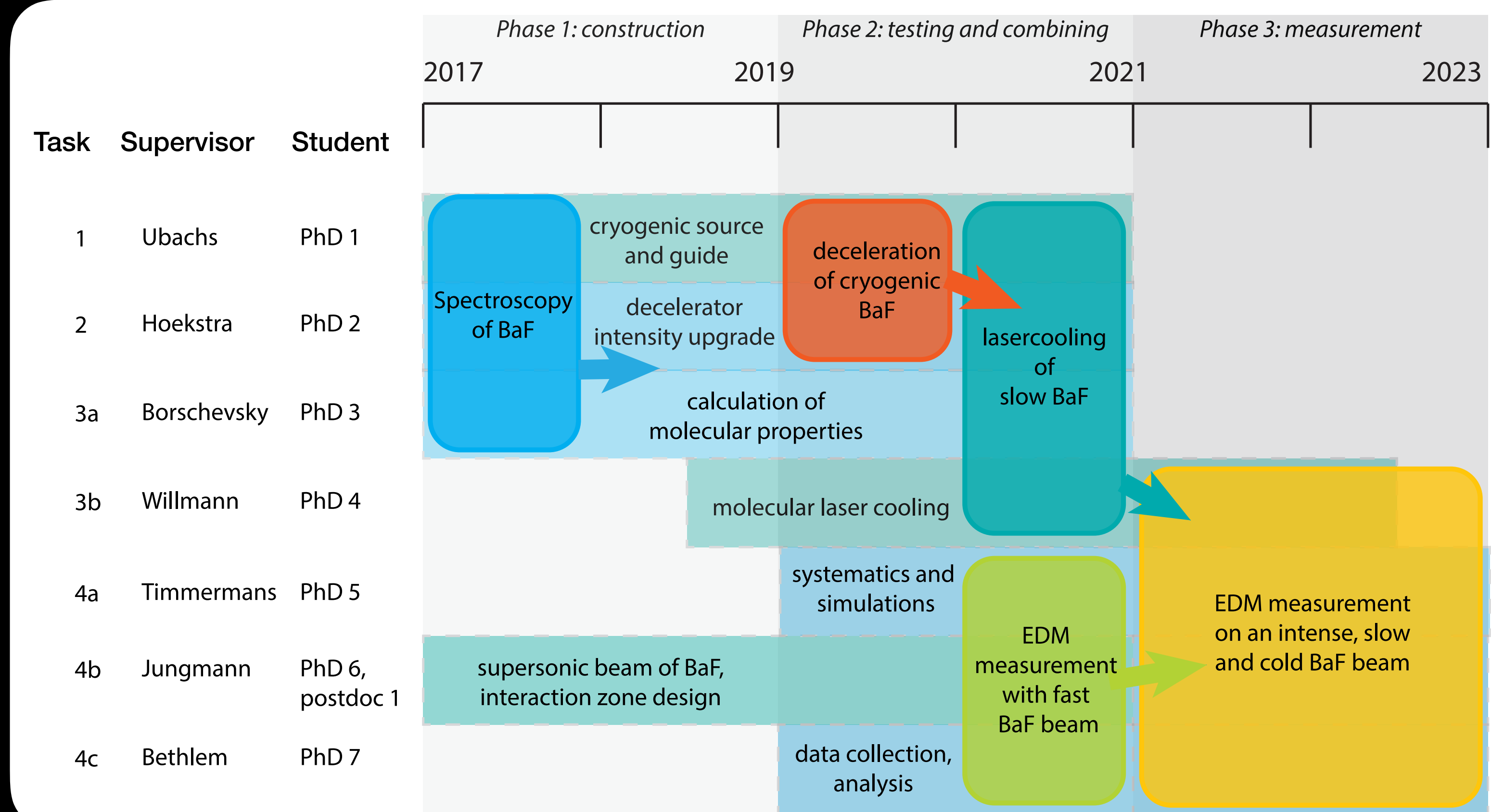


# Probing new physics with the eEDM





High eEDM sensitivity by using  
**intense** beam  
of **slow** molecules



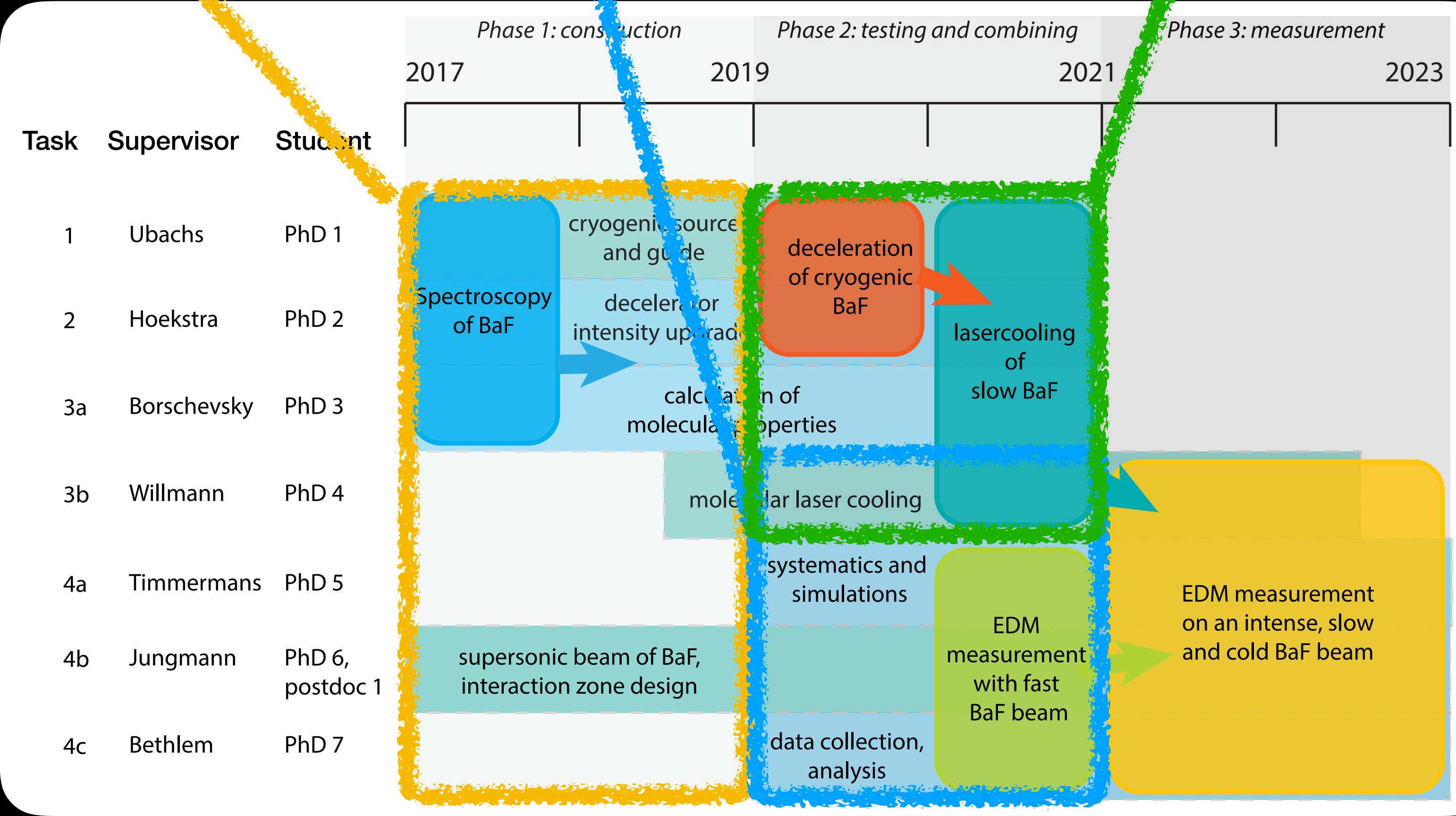


# Overview

Phase 1  
construction

Phase 2a  
fast beam eEDM

Phase 2b  
slow and intense beam





# Cryogenic sources (RUG and VU)

## RUG source

**Goal:** get quickly operational

**Status:**

- designed, built, operational
- SrF: velocity ~150-200 m/s
- Reached important milestone:
  - production of SrF from metal target

## VU source

**Goal:** best BaF source possible

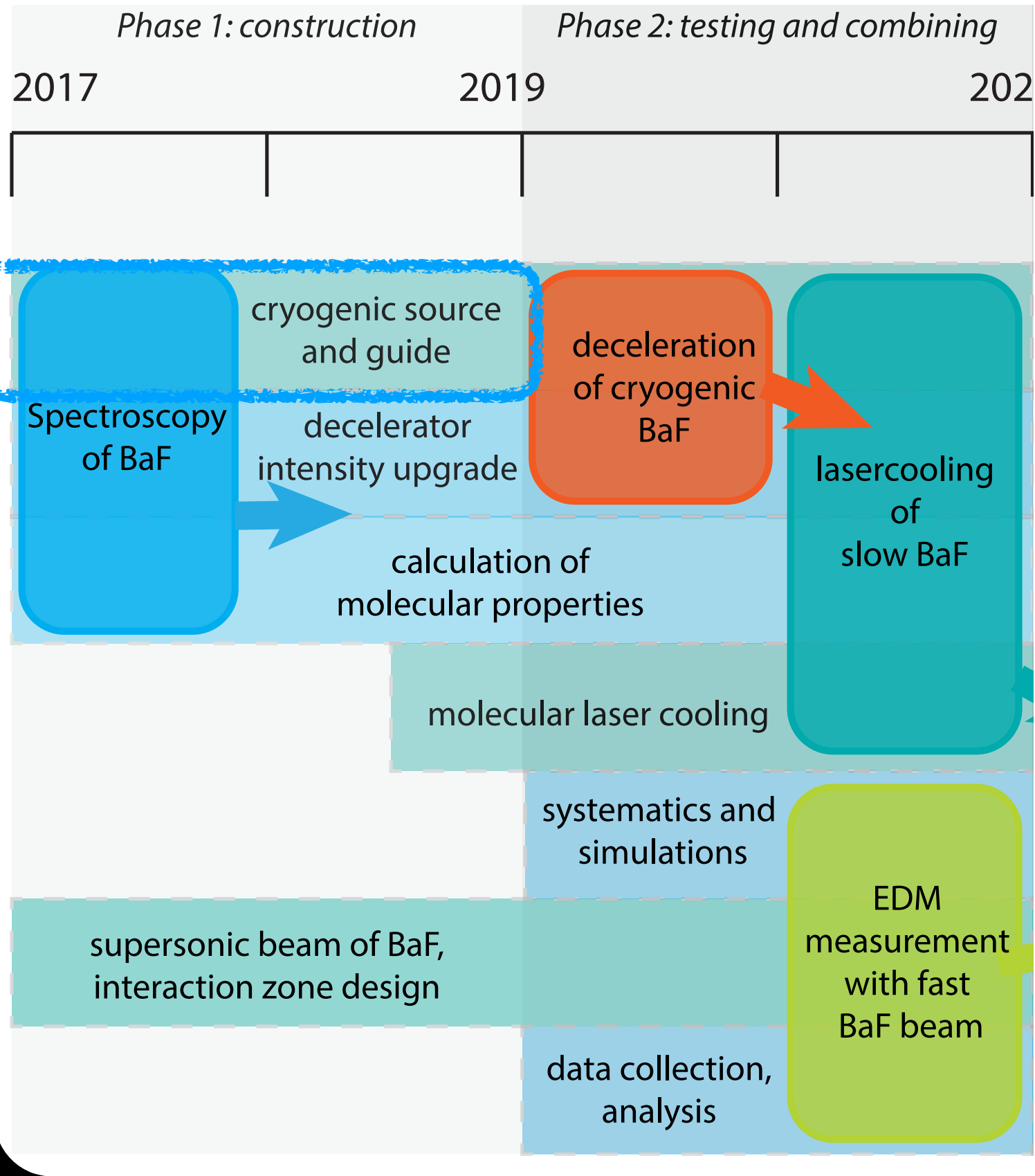
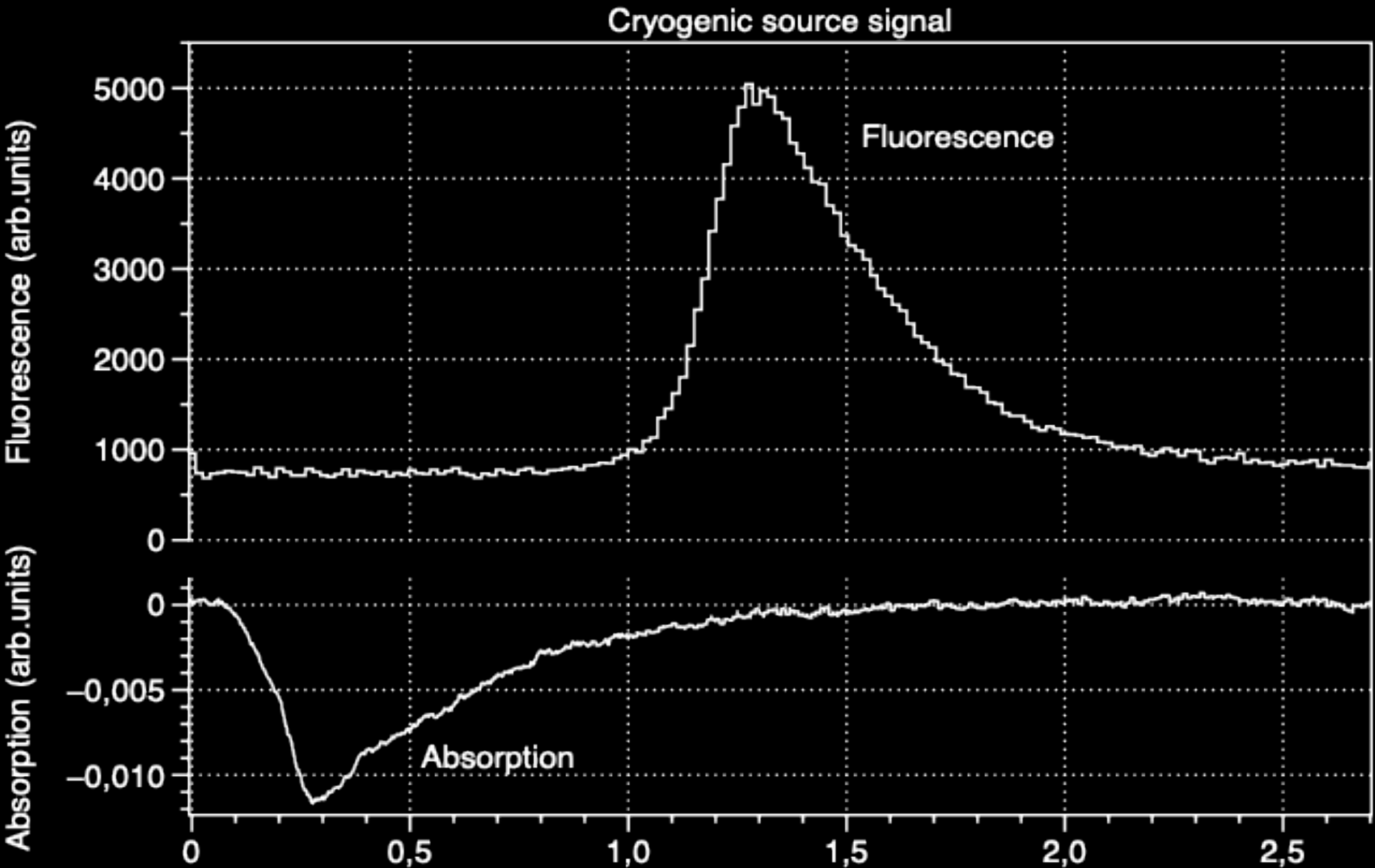
**Status:**

- Reached important milestone:
  - Two weeks ago first signal of BaF!

## Guide

**Goal:** increase #molecules into decelerator

**Status:** will be implemented in september



## People

Kevin Esajas	PhD
Maarten Mooij (VU)	PhD
Rutger Hof	Msc
Paul Hofland (VU)	Msc
Yanning Yin	Postdoc
Leo Huisman	Technican
Wim Ubachs	Staff
Steven Hoekstra	Staff
Rick Bethlem	Staff

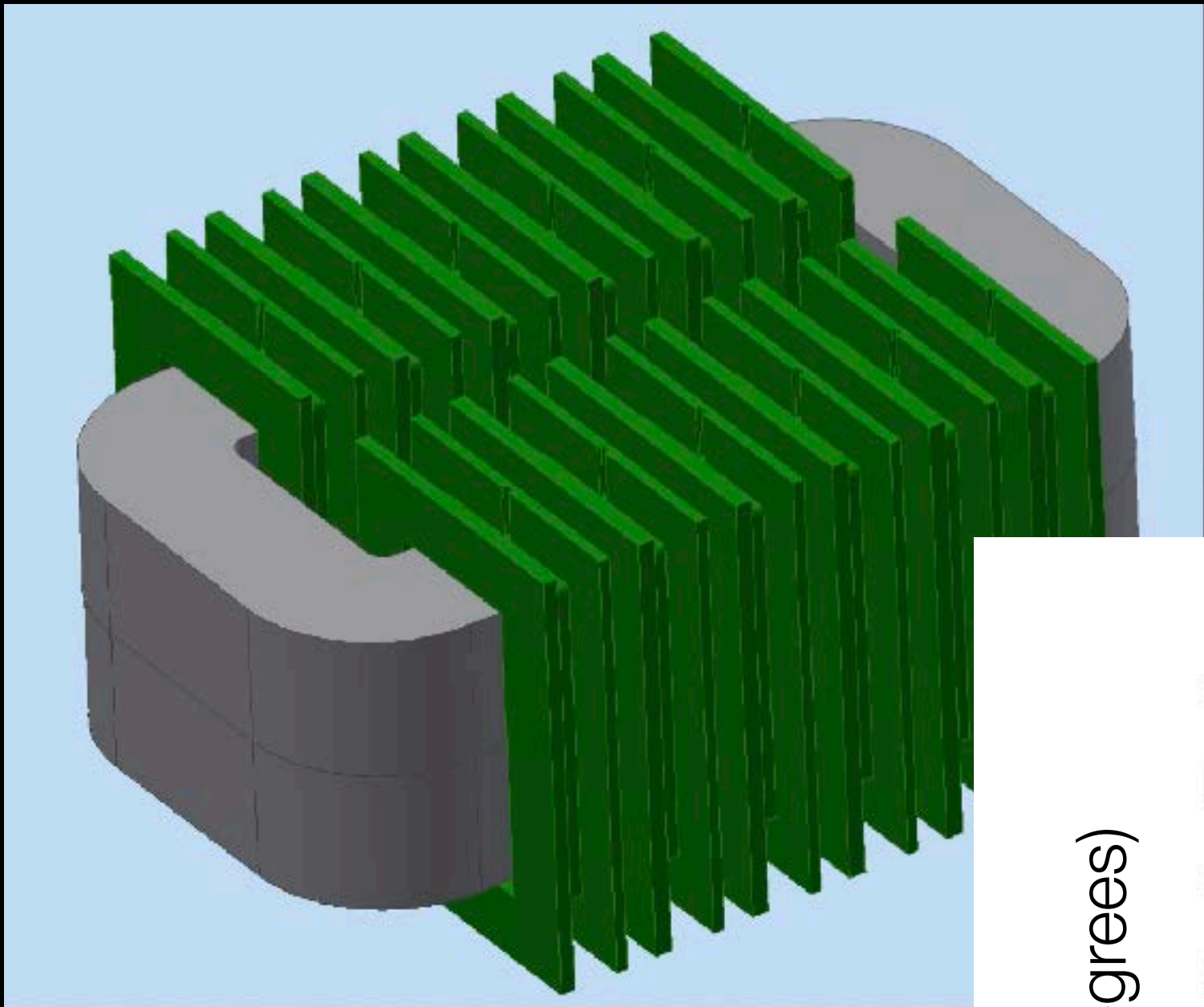


# Decelerator upgrade

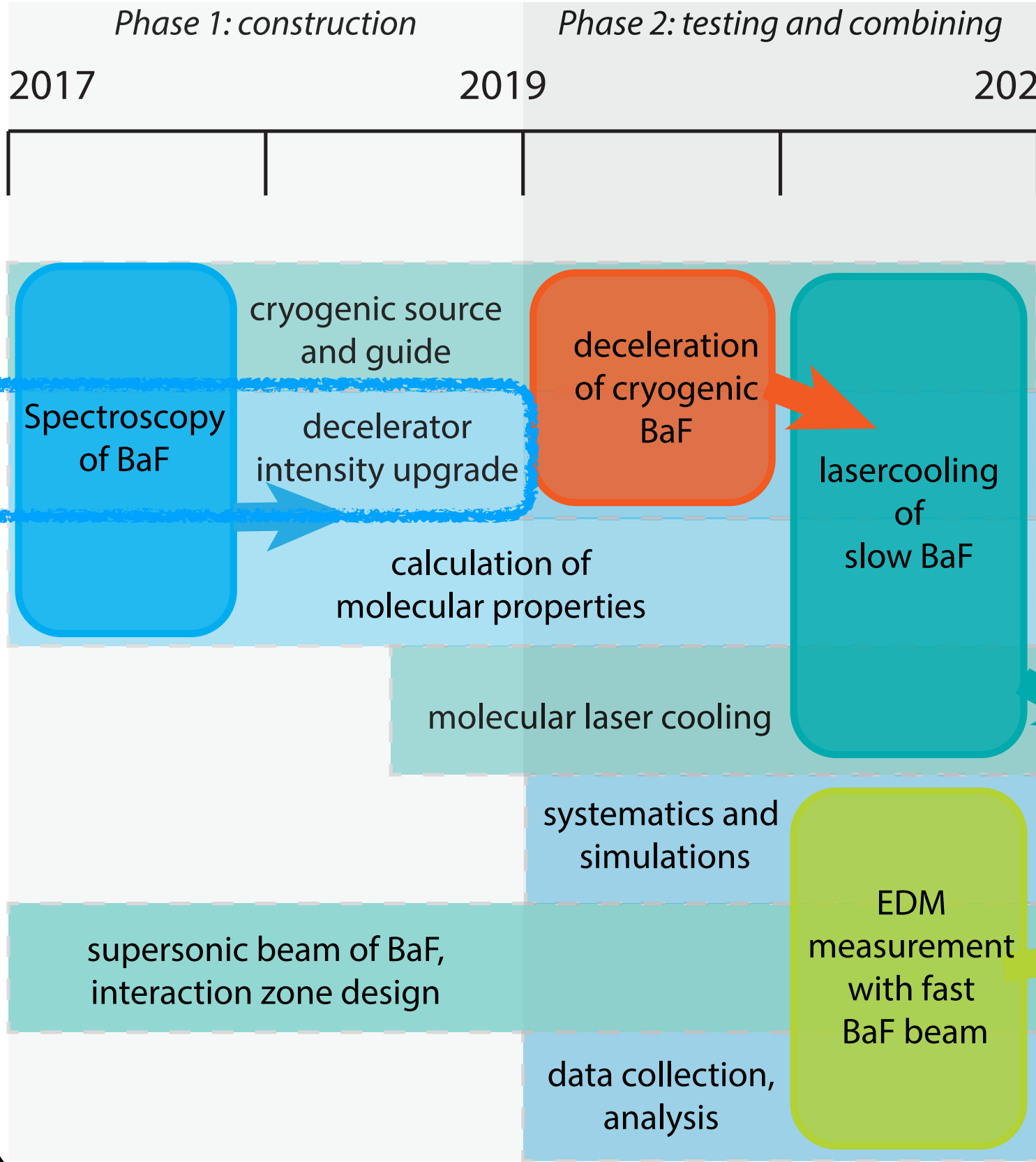
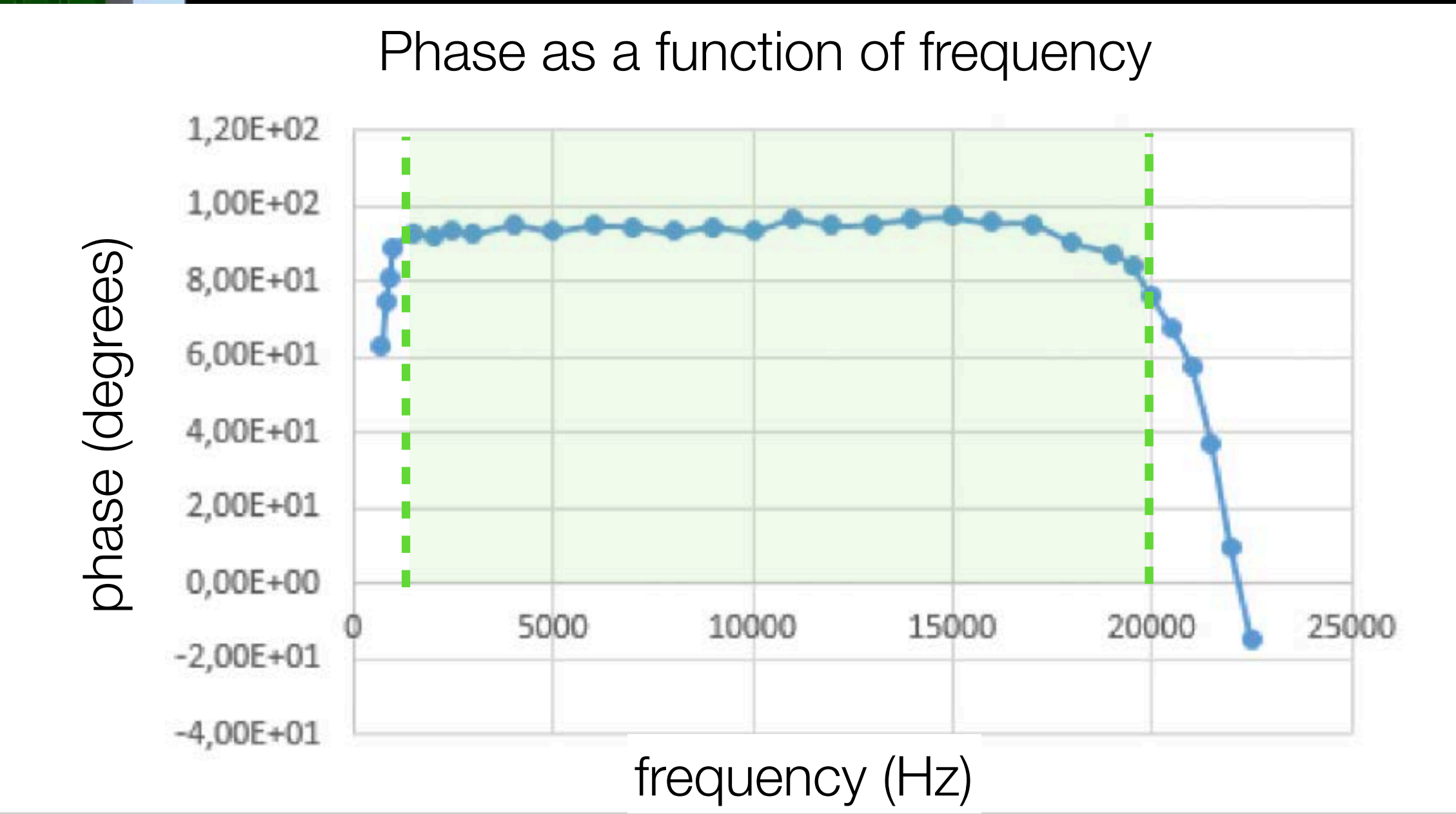
**High-voltage upgrade 5 -> 10 kV**

**Goal:** 10x more molecules

**Status:** transformer prototype tested, bandwidth in spec: 1.5 kHz to 20 kHz



Measurement of transformer bandwidth



## People

Parul Aggarwal

PhD

Artem Zapara

PhD

Hidde Makaske

Msc

Leo Huisman

Technician

Rick Bethlem

Staff

Steven Hoekstra

Staff

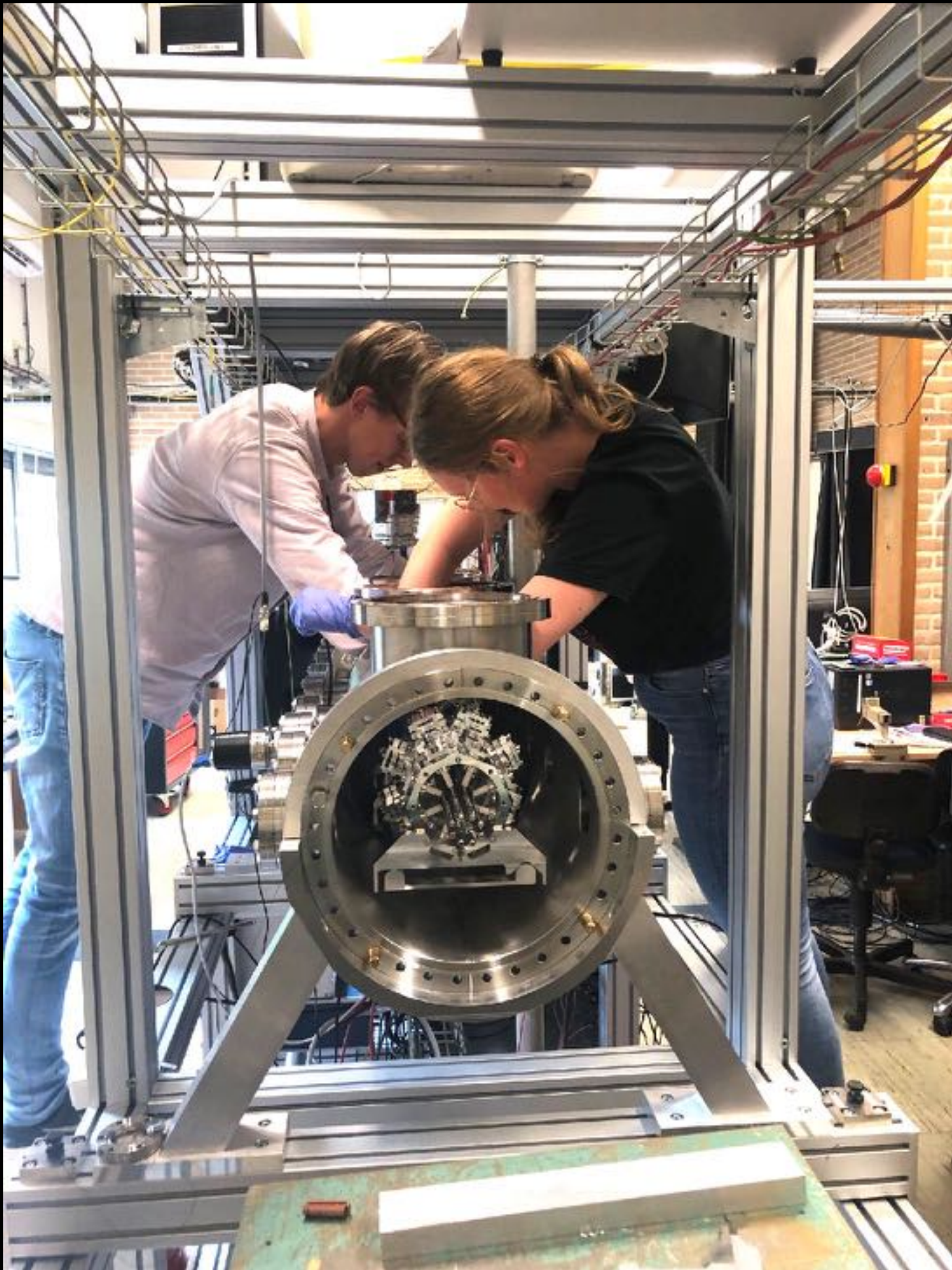


# Decelerator upgrade

## High-voltage upgrade 5 -> 10 kV

**Goal:** 10x more molecules

**Status:** transformer prototype tested, bandwidth in spec: 1.5 kHz to 20 kHz

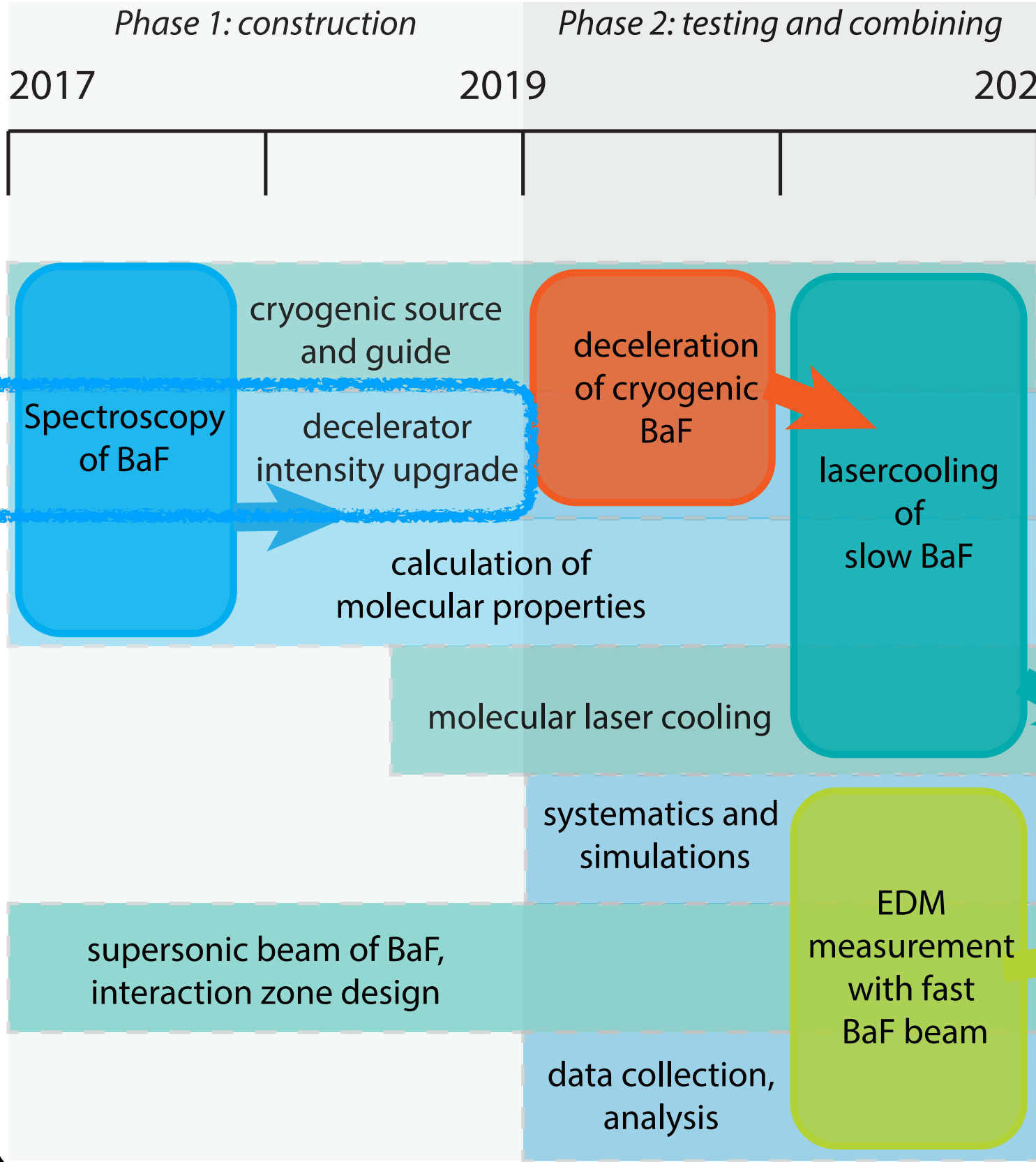
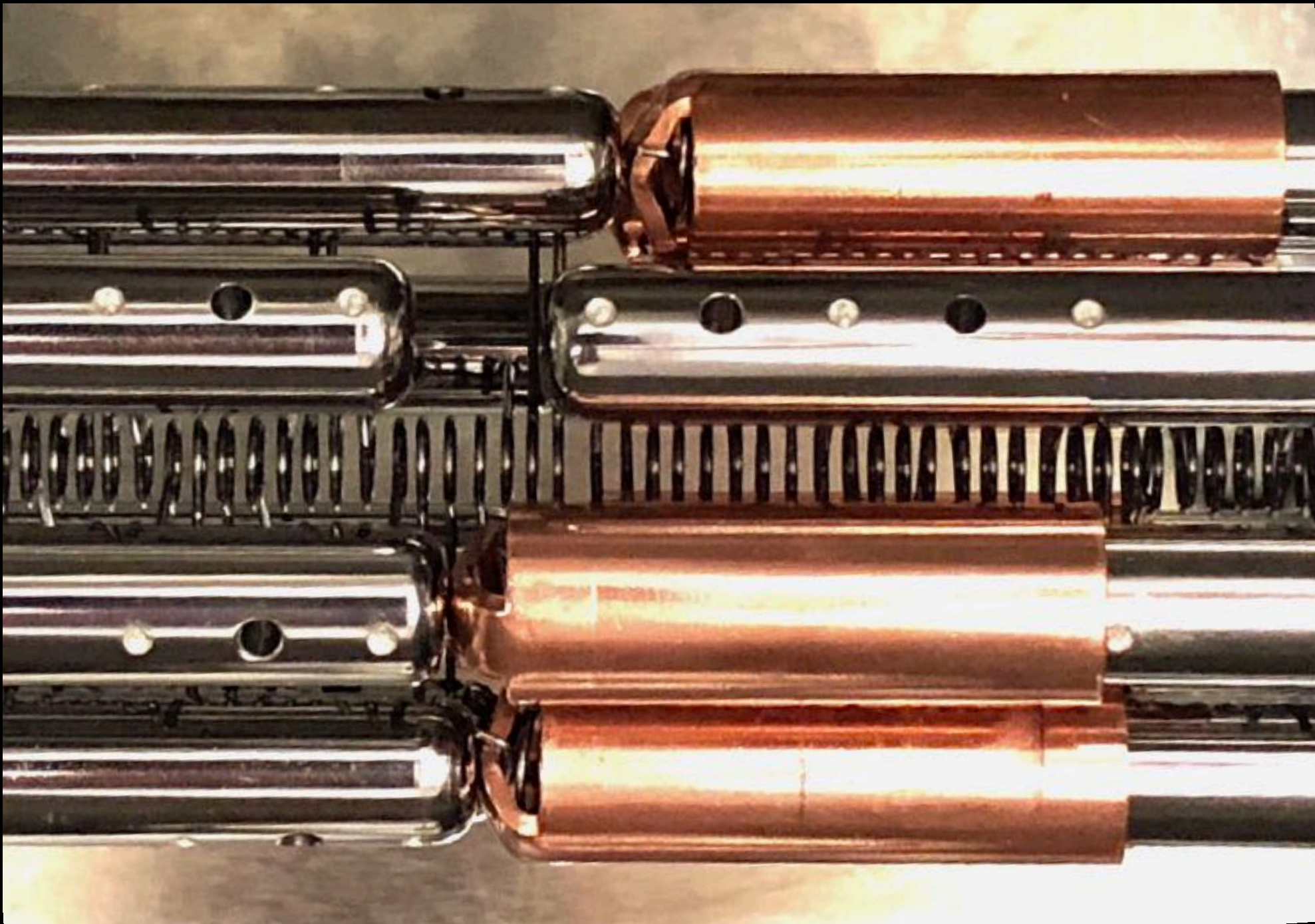


## Re-alignment of the decelerator

**Goal:** fix kink, improve module alignment

**Status:**

- changed direction of decelerator
- improved alignment
- improved connections
- Reached important milestone:
  - HV conditioning complete



## People

Parul Aggarwal	PhD
Artem Zapara	PhD
Hidde Makaske	Msc
Leo Huisman	Technician
Rick Bethlem	Staff
Steven Hoekstra	Staff

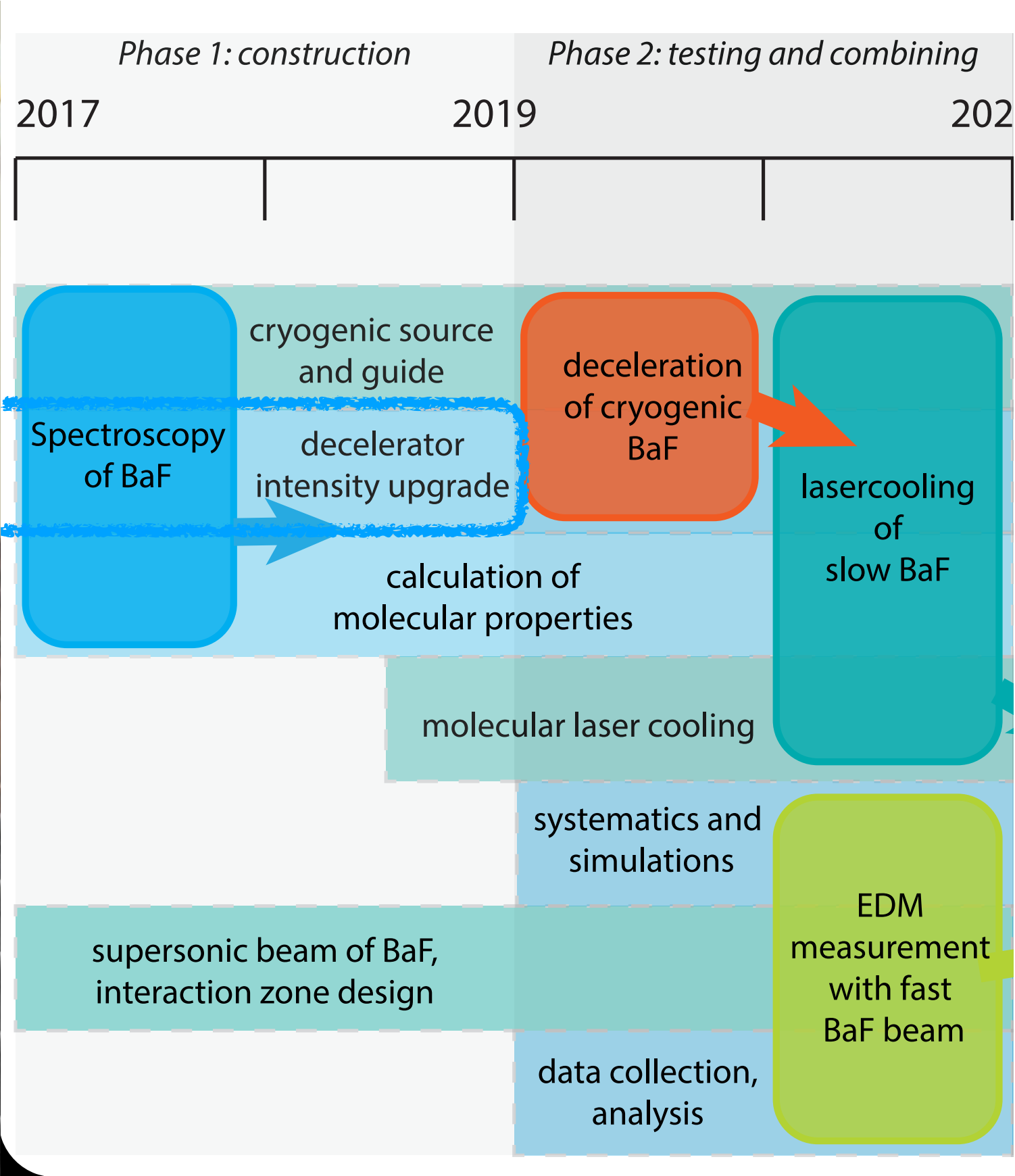


# Decelerator u

**High-voltage upgrade 5 -> 10**  
**Goal:** 10x more molecules  
**Status:** transformer prototype t  
bandwidth in spec: 1.5 kHz to 2



PhD Thesis defence 24-5-2019



## People

Parul Aggarwal	PhD
Artem Zapara	PhD
Hidde Makaske	Msc
Leo Huisman	Technician
Rick Bethlem	Staff
Steven Hoekstra	Staff



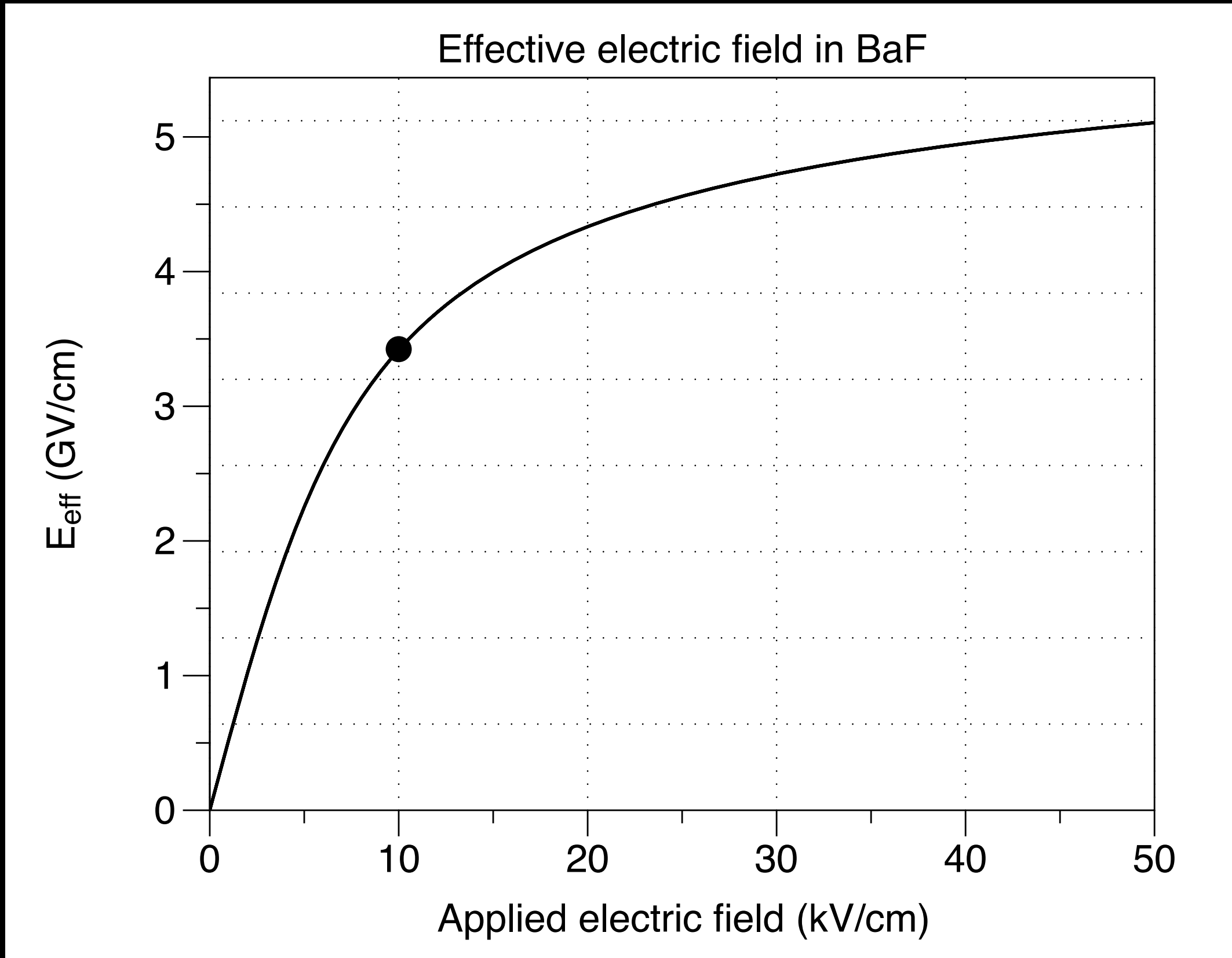
# Calculation of molecular properties

## Method development for highest accuracy

### Effective electric field in BaF

**Goal:** interpretation of measurement

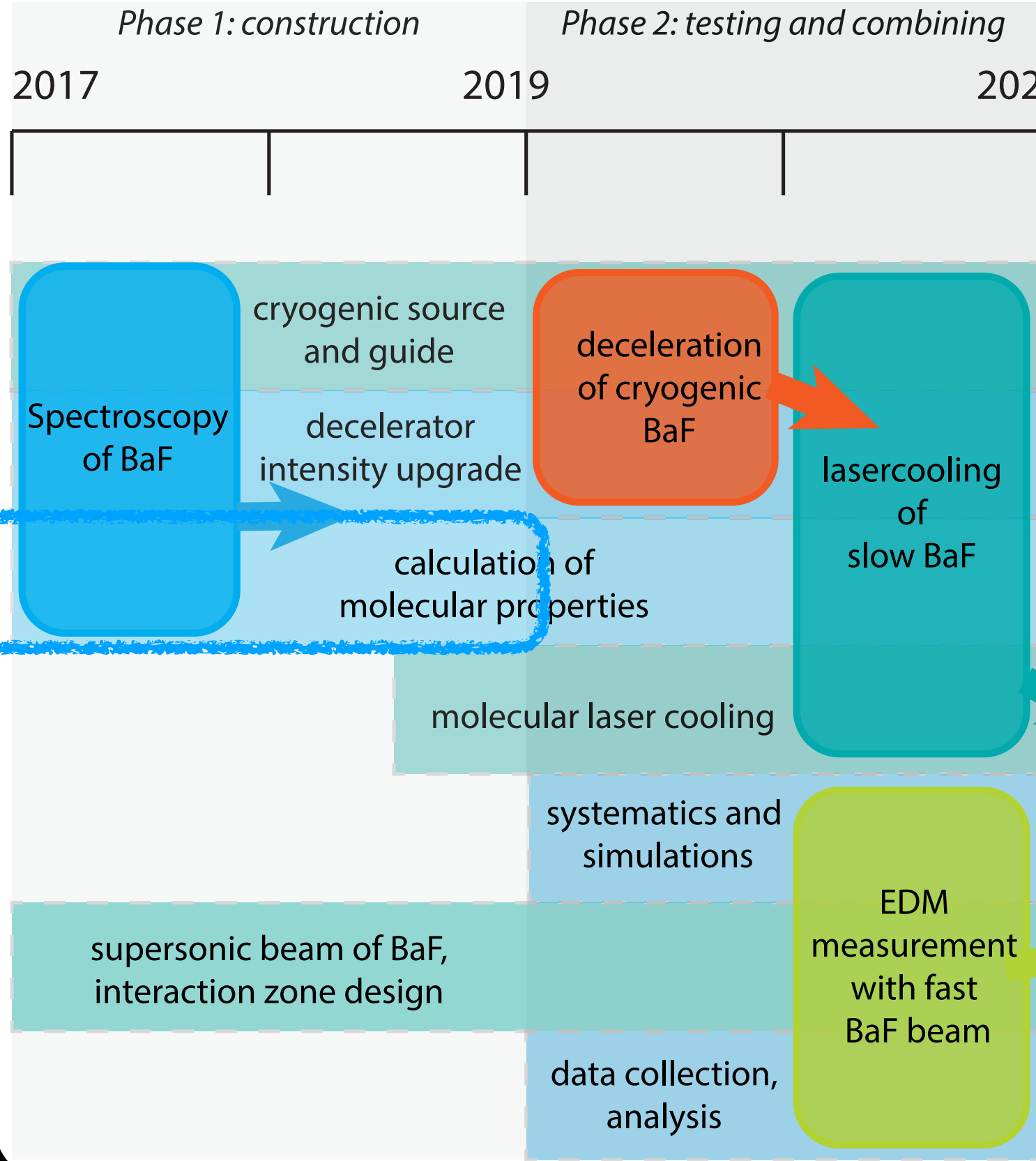
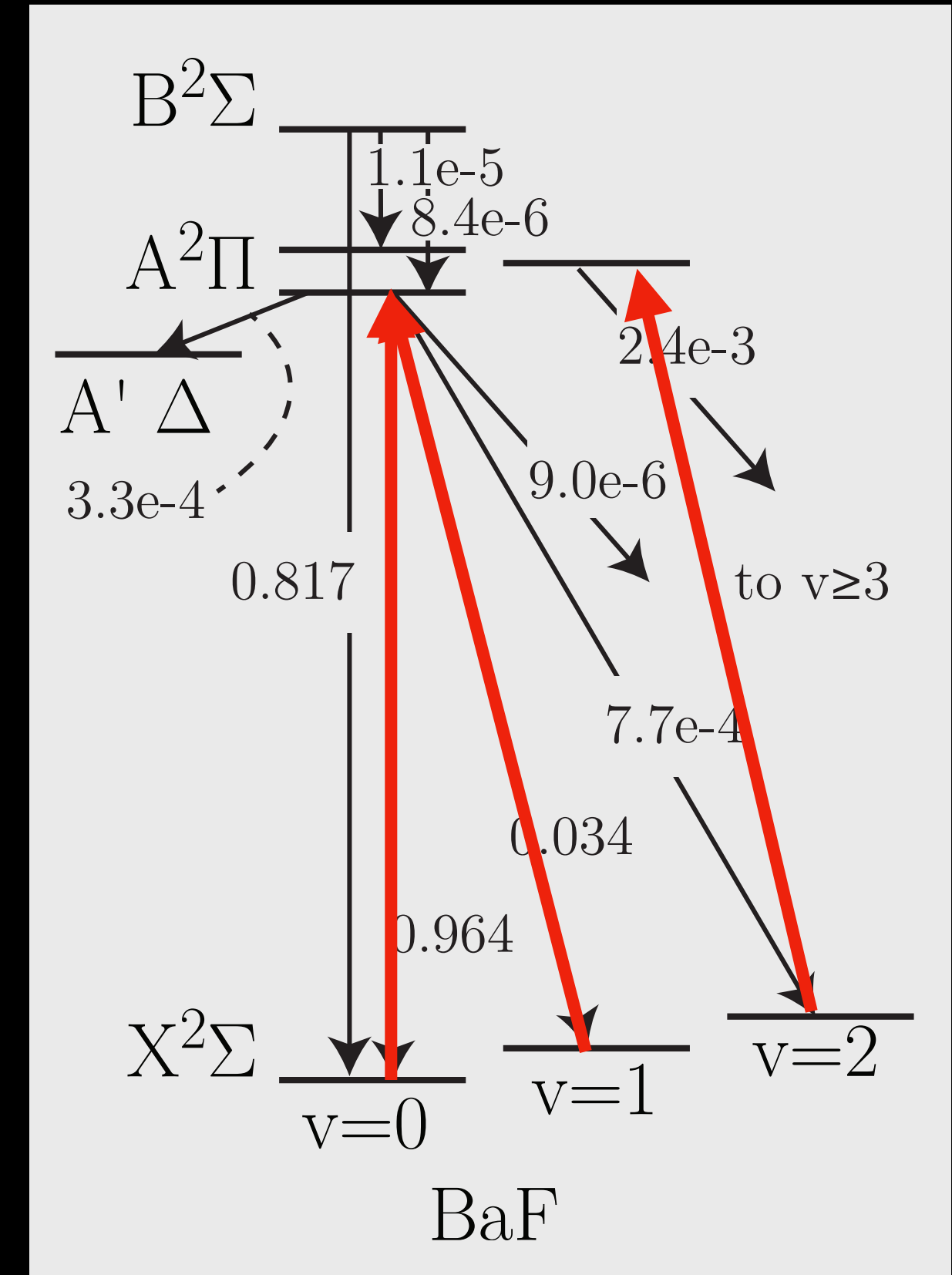
**Status:** most accurate value determined. Results in 2 papers, with analysis of systematic effects in calculation.



### BaF molecular structure

**Goal:** laser cooling, state transfer

**Status:** identified best cooling scheme, paper published in Journal of Chemical Physics



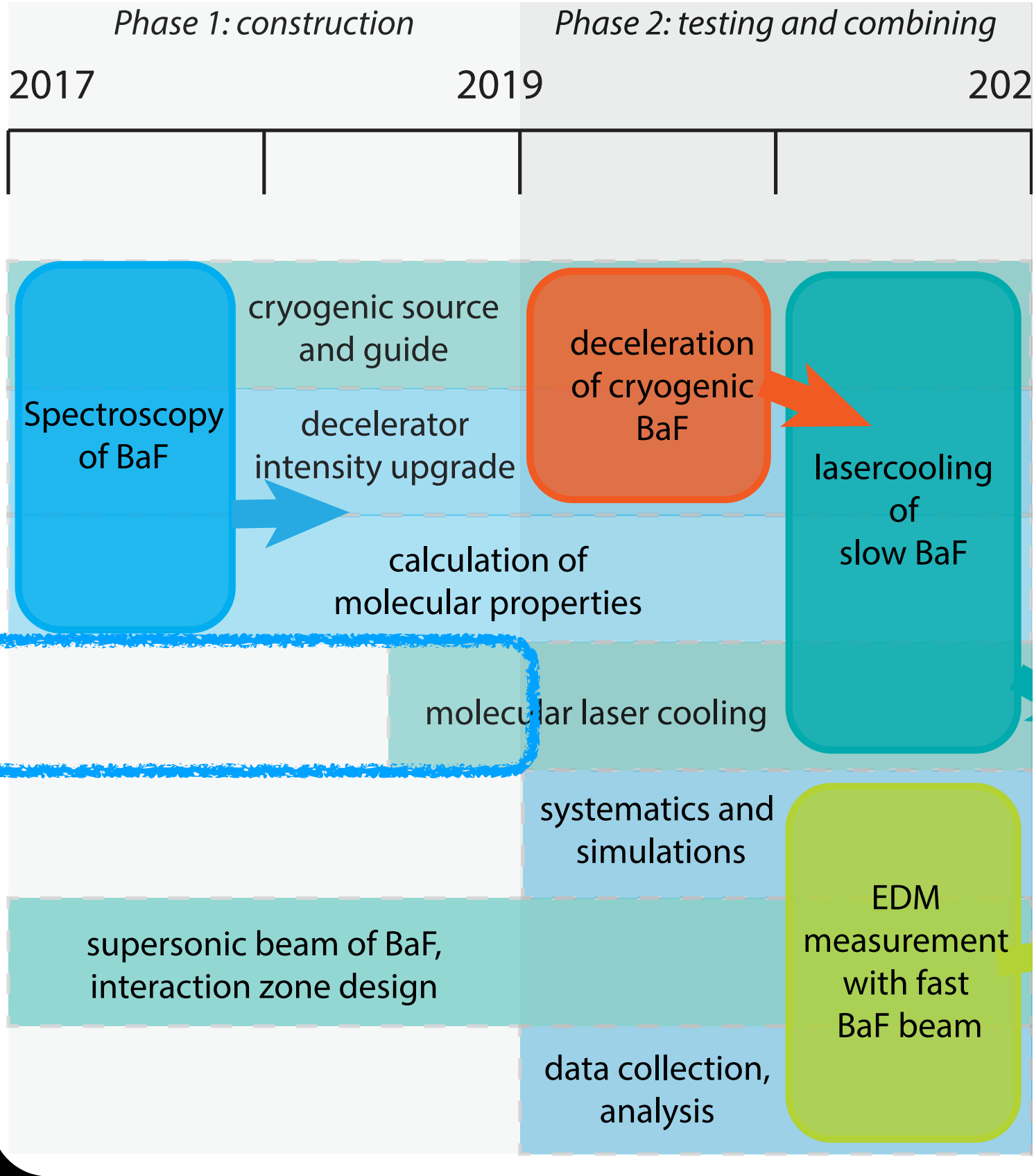
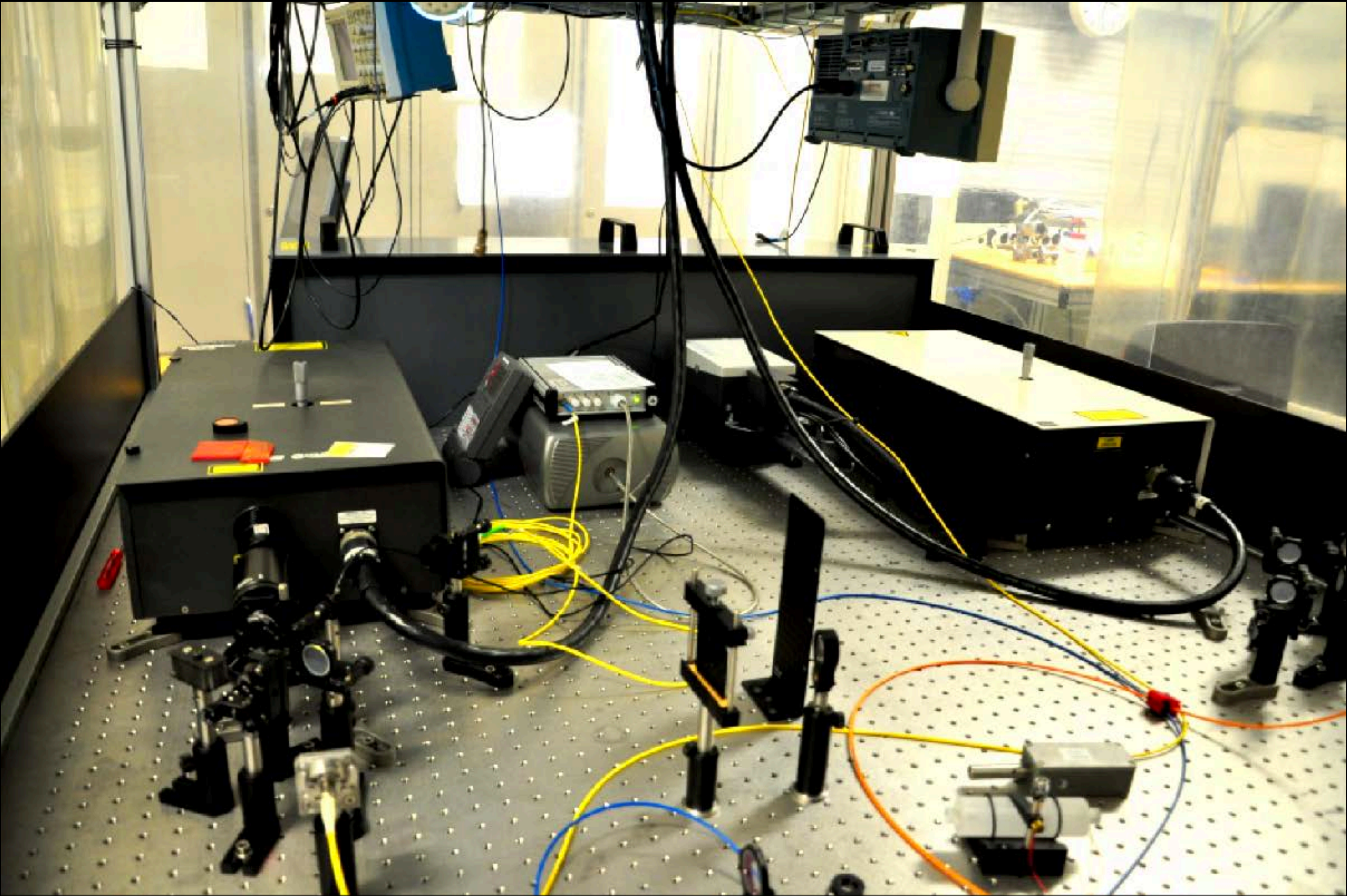
### People

Pi Haase	PhD
Yongliang Hao	PhD
Diewertje Douglas	Msc
Malika Denis	Postdoc
Anastasia Borschevsky	Staff



# Laser systems

**Goal:** flexible laser system: state preparation, cooling and molecule detection  
**Status:** laser system operational



**People**

Virginia Marshall  
Oliver Böll  
Lorenz Willmann

PhD  
Technician  
Staff

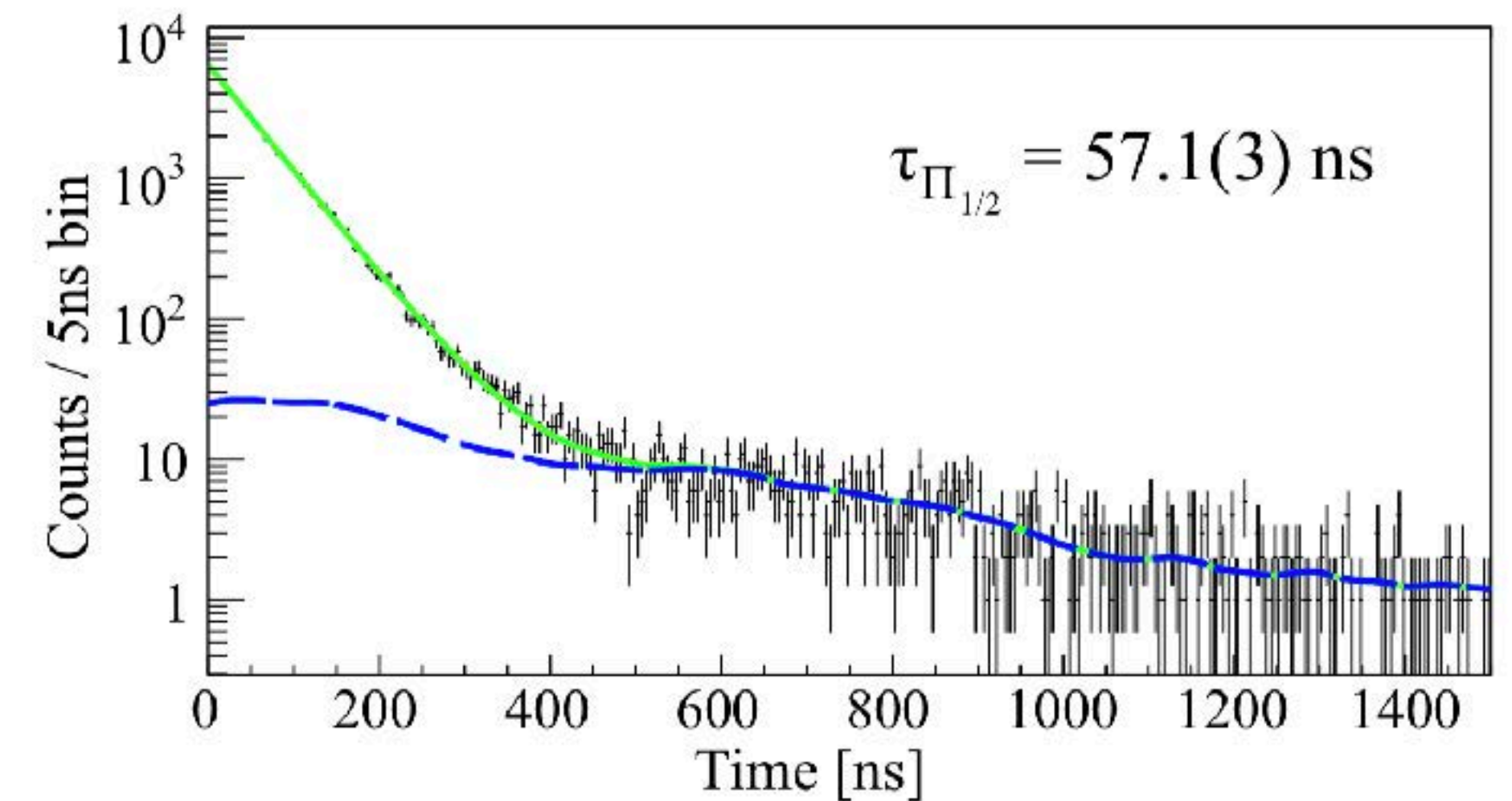
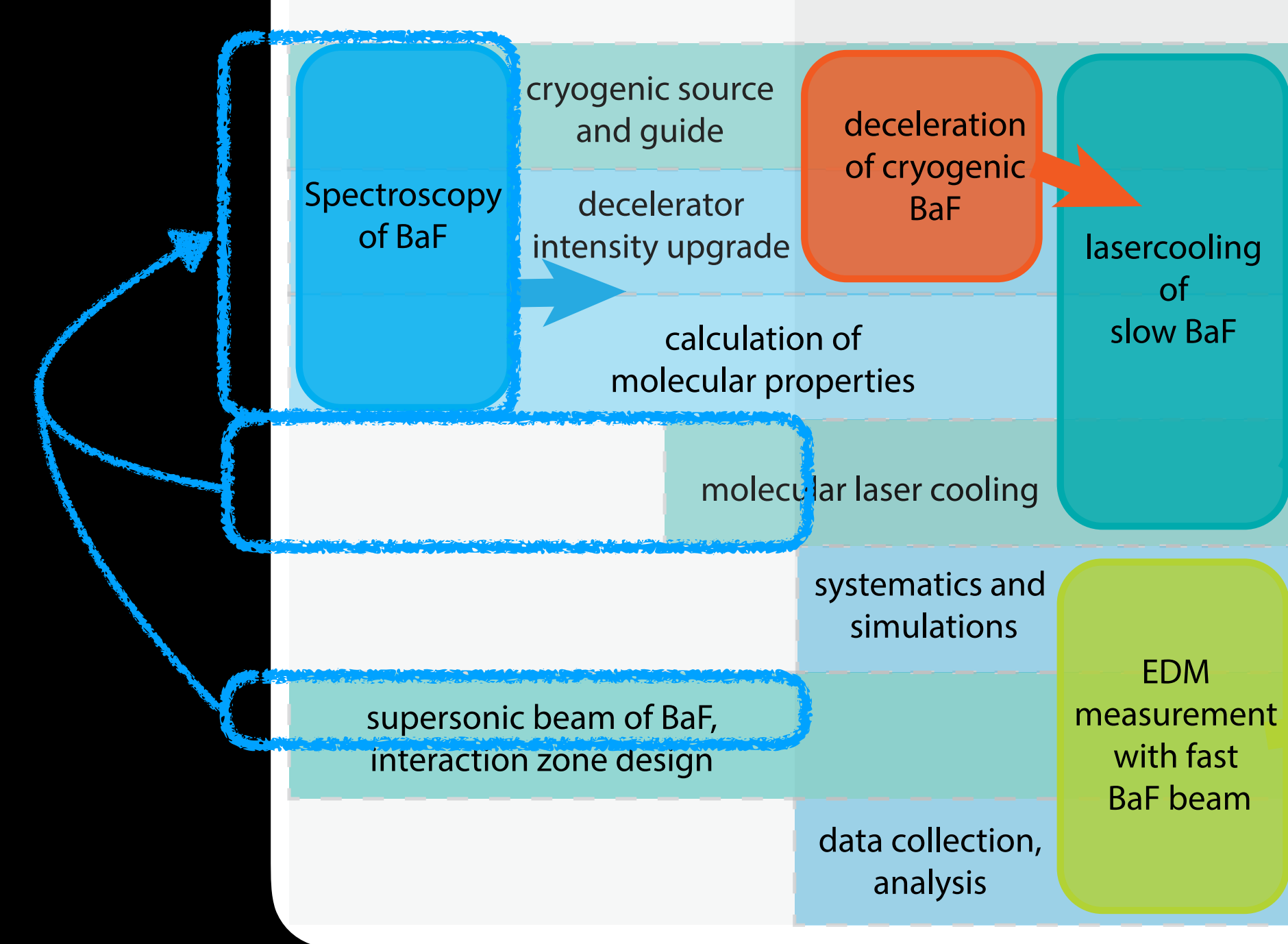
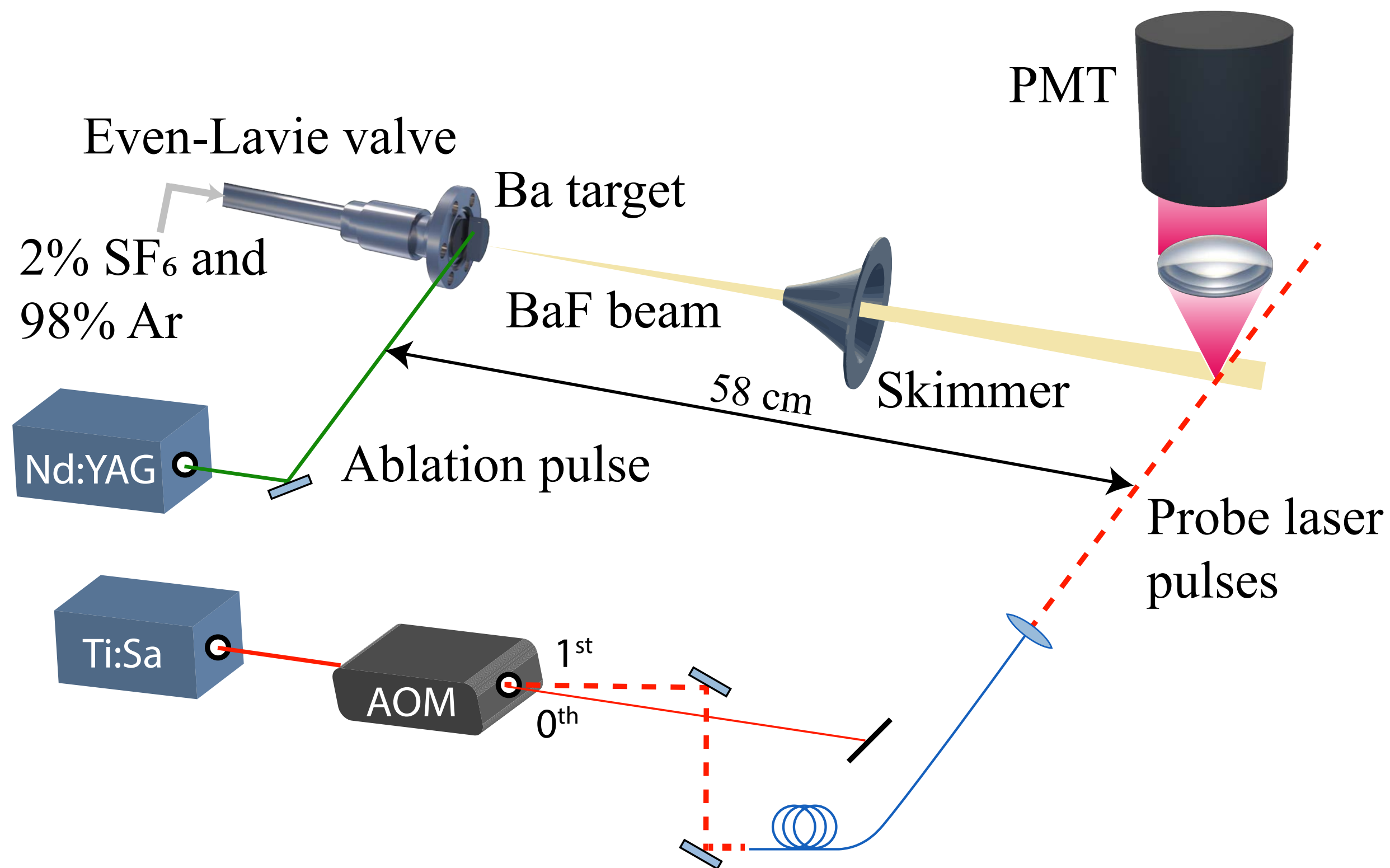


# Supersonic beam

**Goal:** create a BaF beam for spectroscopy and fast-beam eEDM

**Status:** supersonic beam operational

- very cold beam  $\sim 1$  K
- combined with IR excitation and fluorescence detection zone
  - spectroscopy of BaF: lifetime measurement of electronic excited state in BaF
  - paper submitted.



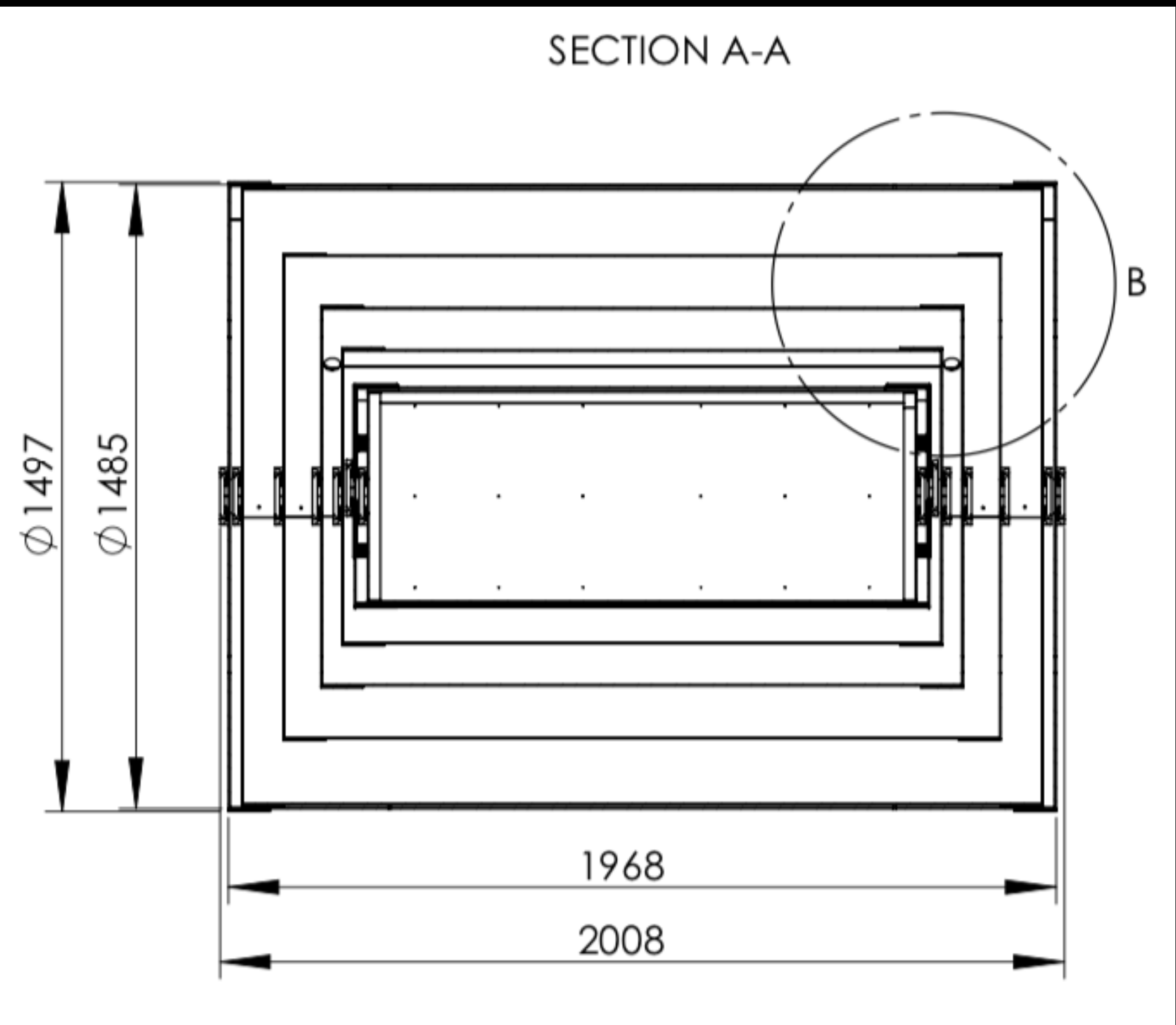


# Interaction zone

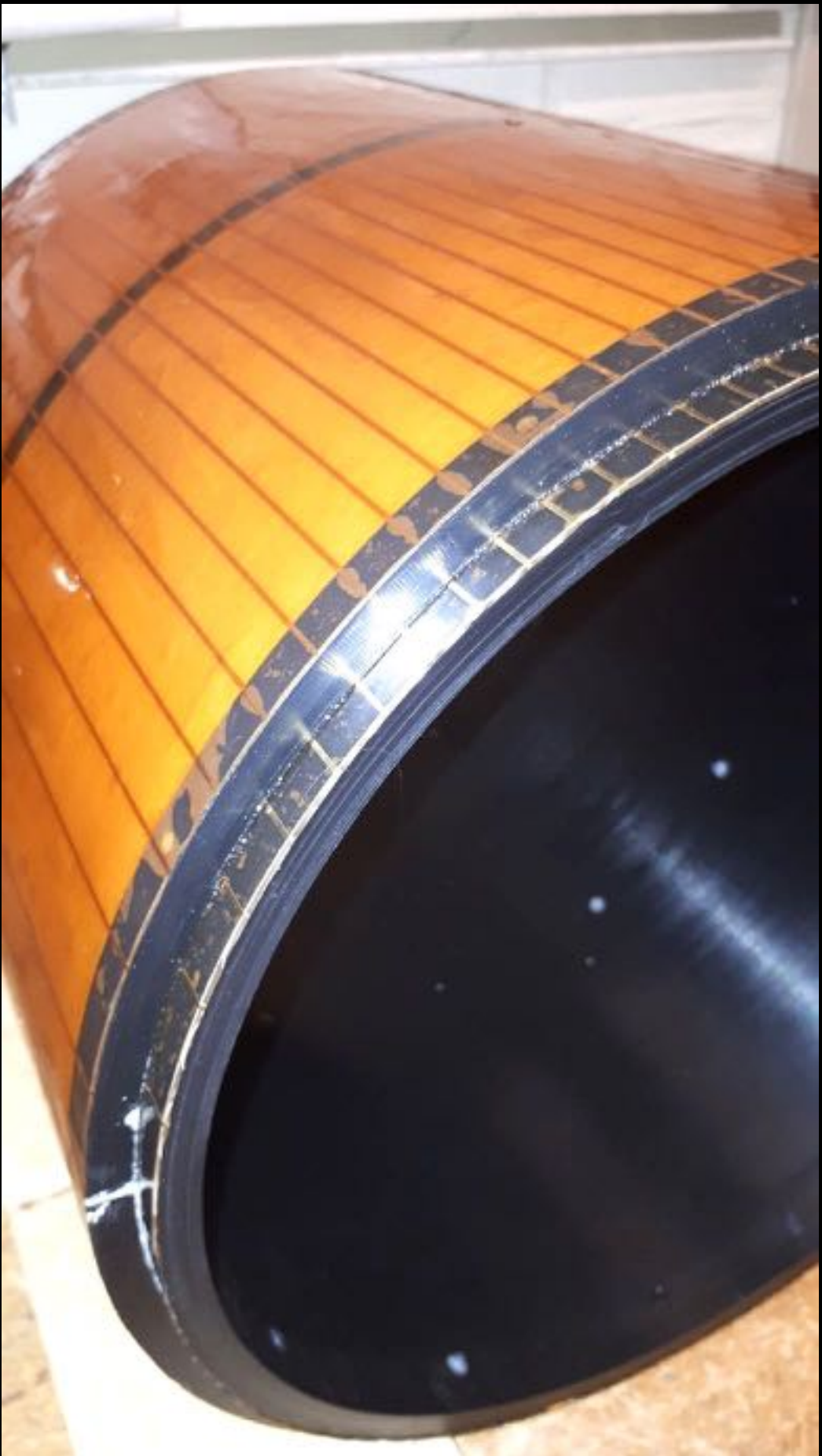
**Goal:** create controlled electric (strong) and magnetic (weak) field region

**Status:**

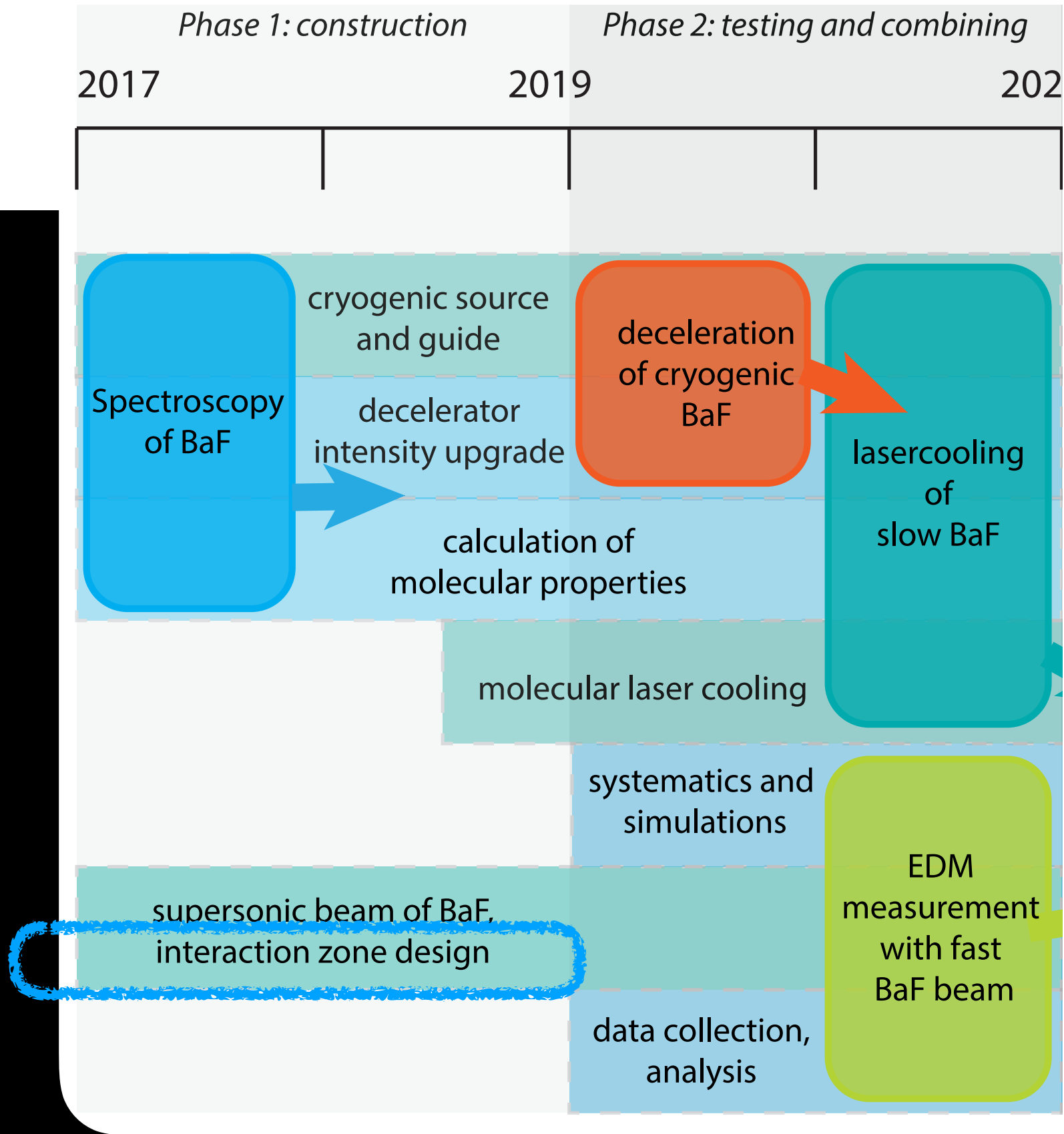
- design of magnetic shield, magnetic field coils and electric field plates finished
- delivery of shield, coils and plates expected. Prototype field coil manufactured @ nikhef.



Magnetic field shielding



Prototype field coil



## People

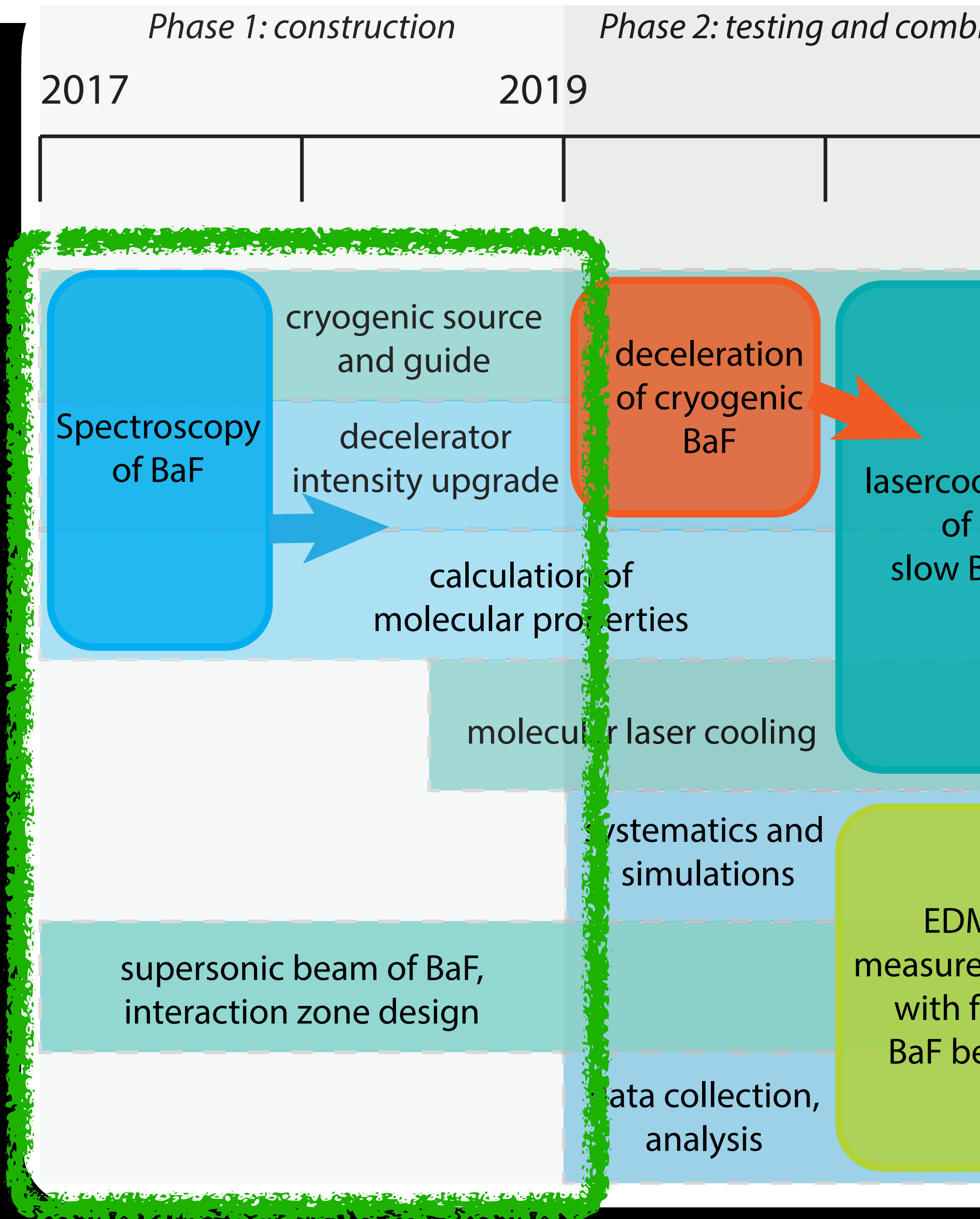
Thomas Meijknecht  
Leo Huisman  
Oliver Böll  
Lorenz Willmann  
Klaus Jungmann

PhD  
Technician  
Technician  
Staff  
Staff



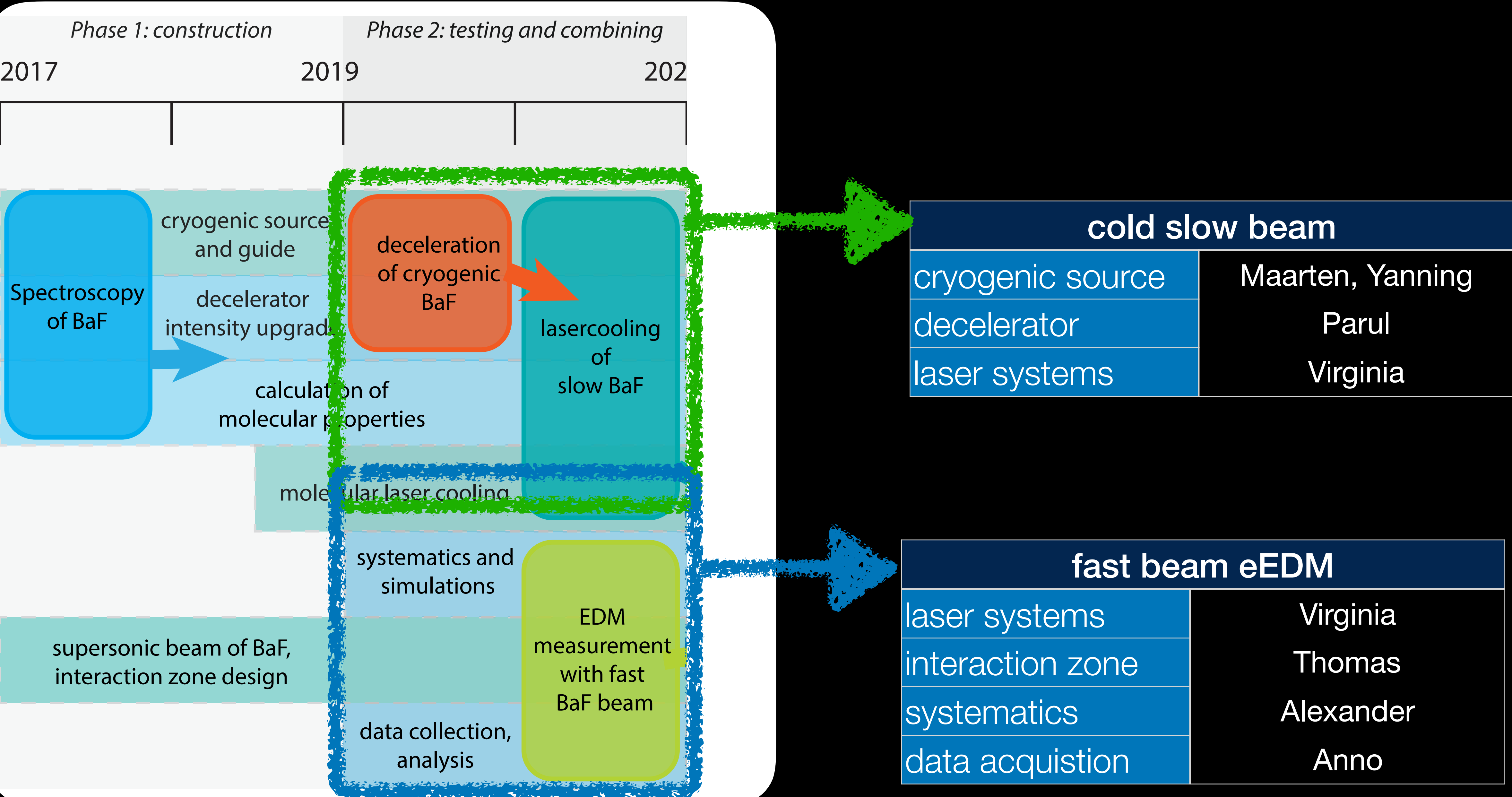
# Summary of status: phase 1 completed

	status	
cryogenic source	operational	✓
decelerator upgrade	ongoing	⚡
molecular properties	done	✓
laser systems	operational	⚡
supersonic beam	operational	✓
spectroscopy of BaF	done	✓
interaction zone design	done	✓

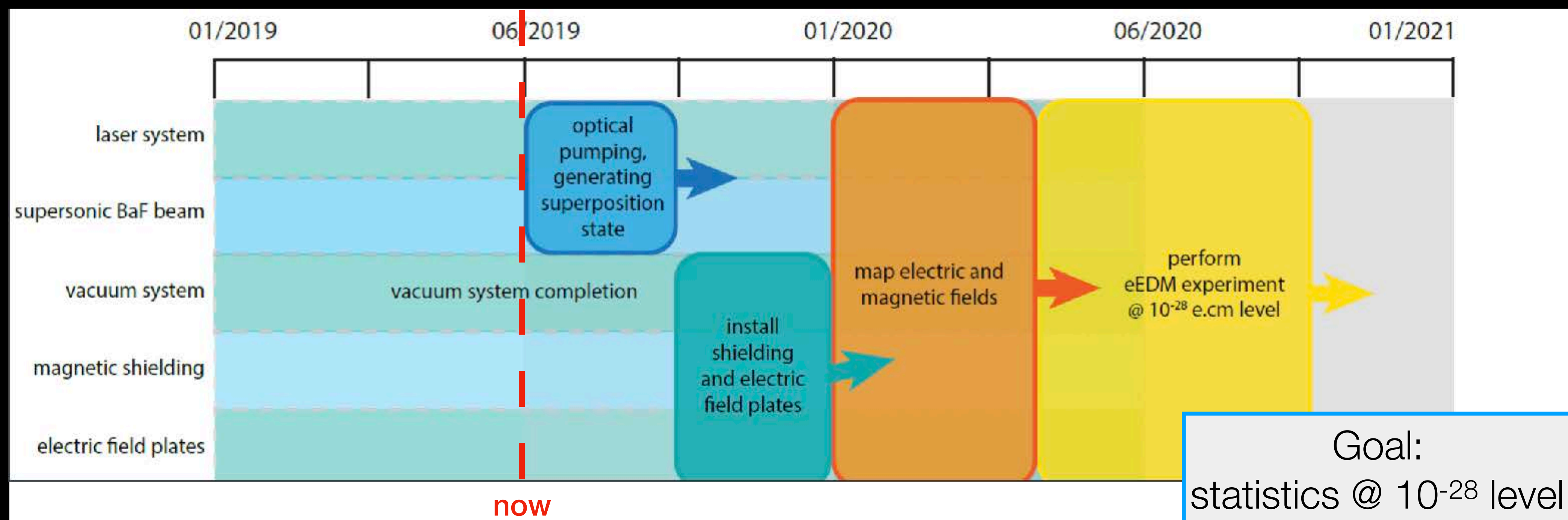
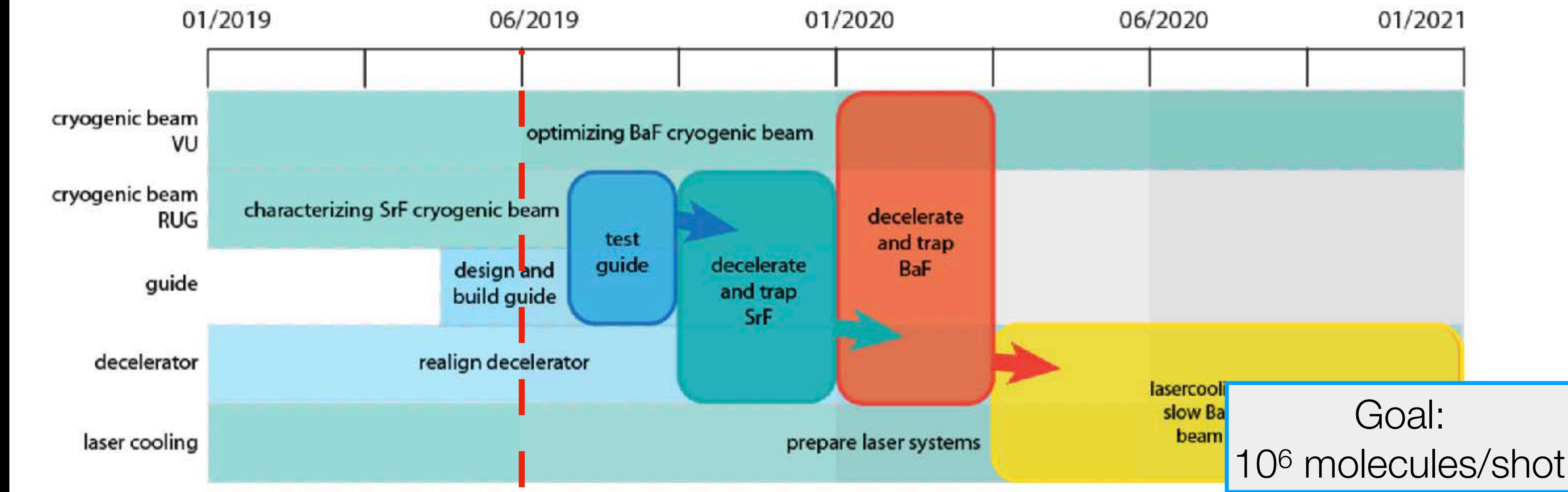




# Phase 2: fast beam eEDM and cold slow beam









# Proud of the team!





extra material



# Meeting and management structure

## Meetings:

- weekly paper discussion by students
- bi-weekly friday eEDM meetings with all involved
- separate staff meetings
- yearly meeting in september: look back, plan ahead
- 2017 & 2019: International summerschool 'Search for new physics with low-energy precision tests'

## Managing the program:

- decision on major investments: SH, LW, RB
- electronic logbook and document sharing





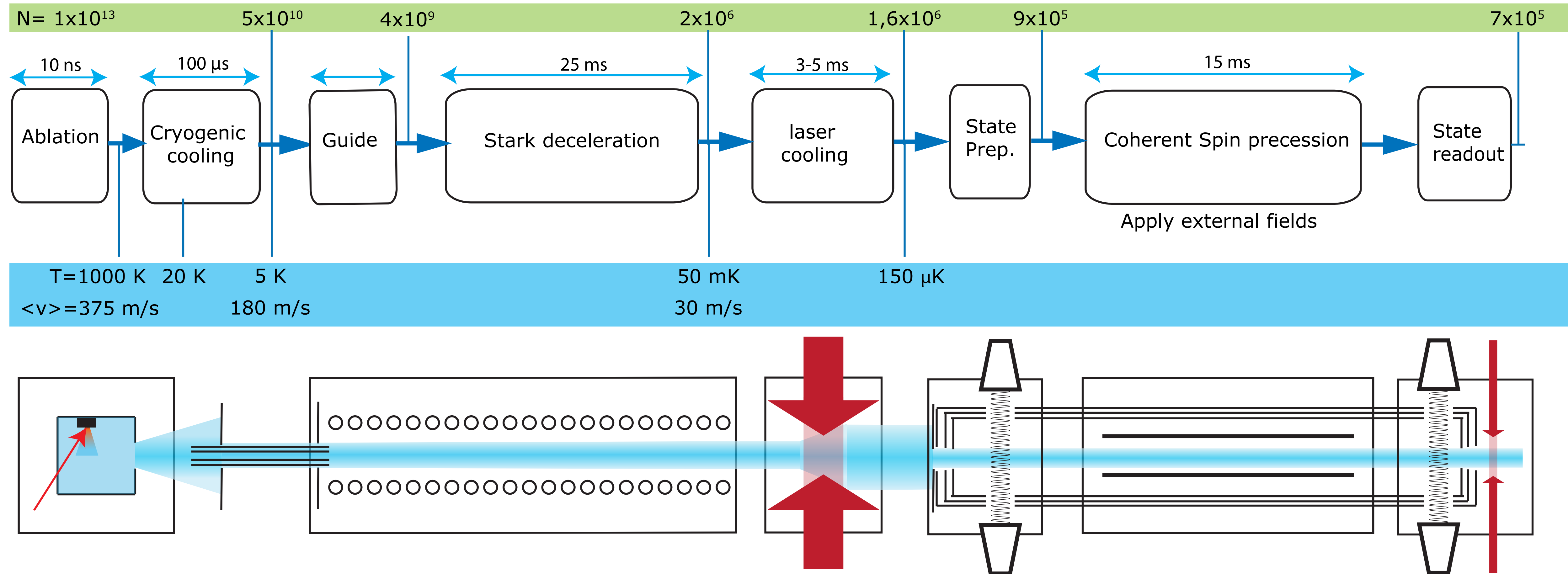
# Key numbers

**Table 1.** The estimate of the number of molecules that can be detected per repetition of the experiment. We aim to run the experiment at 10 Hz.

Item	Number	Units	Resulting # mol./shot
Source	$10^{13}$	Molecules/shot	
	0.005	Extraction efficiency from buffer gas cell	
	0.24	Fraction in $v = 0$ , $N = 2$	$5 \times 10^{10}$ from source; $4 \times 10^9$ in desired state,
	0.3	Fraction in low-field seeking states	$v_{\text{long}} = (180 \pm 50) \text{ m/s}$ , $v_{\text{trans}} = \pm 30 \text{ m/s}$ .
Decelerator	0.002	Fraction in velocity acceptance	
	0.3	Fraction in spatial acceptance	
	0.7	Efficiency of deceleration relative to guiding	$2 \times 10^6$ , $v_{\text{long}} = (30 \pm 6) \text{ m/s}$ , $v_{\text{trans}} = \pm 5 \text{ m/s}$ .
Laser cooling	0.8	Laser cooling efficiency	
	0.7	State transfer efficiency	$9 \times 10^5$ , $v_{\text{long}} = (30 \pm 6) \text{ m/s}$ , $v_{\text{trans}} = \pm 0.2 \text{ m/s}$ .
Interaction zone	0.8	Transmission and state transfer efficiency	
	1.0	Detection efficiency	$7 \times 10^5$



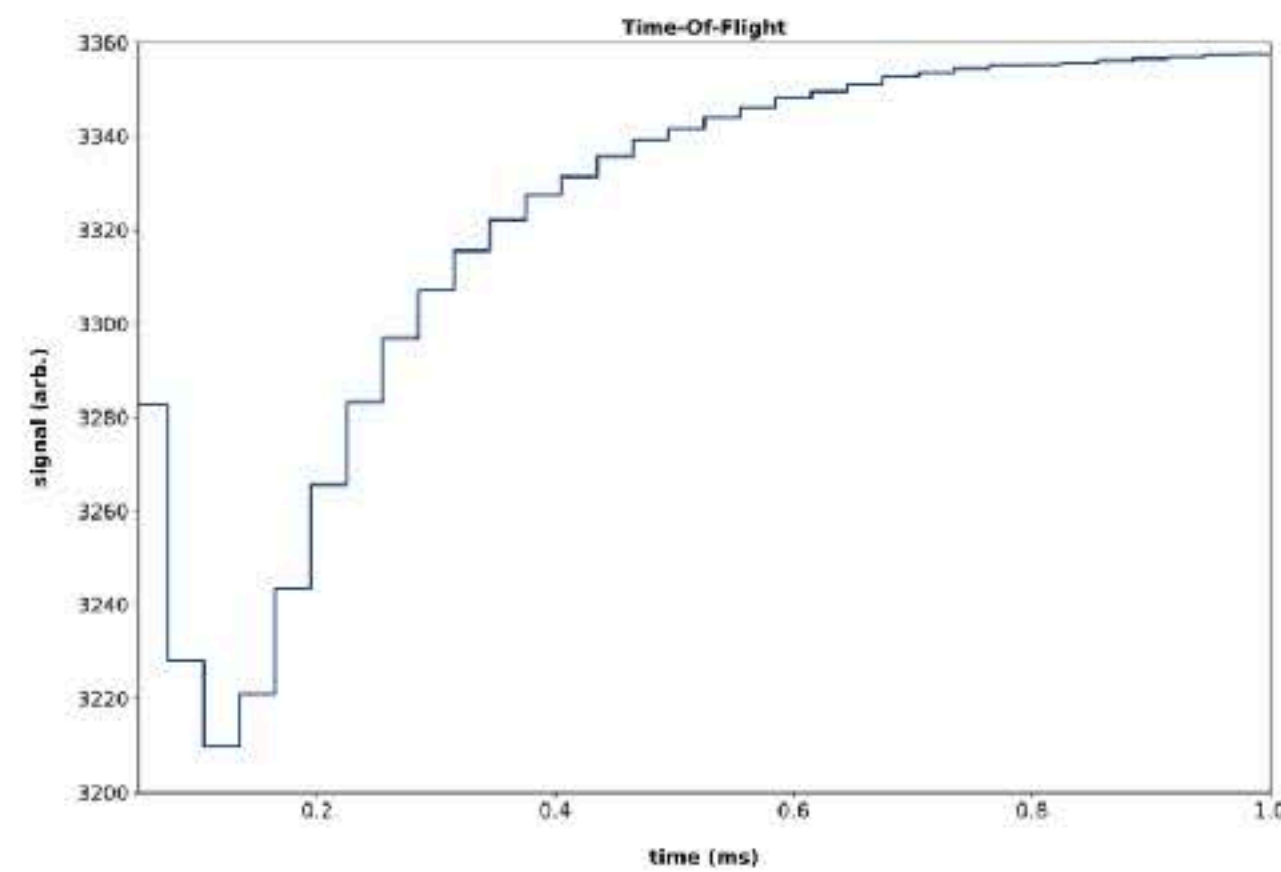
# Key numbers



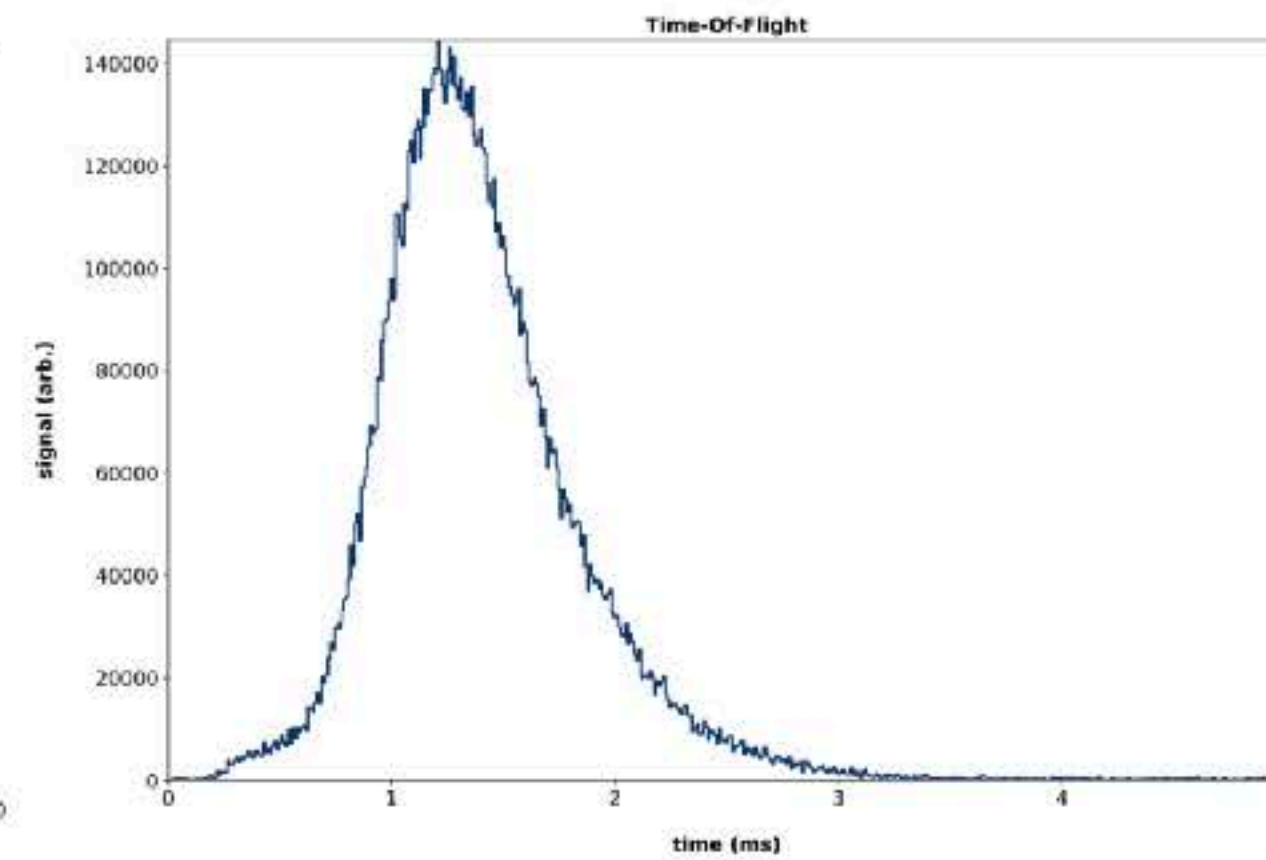


# Cryogenic source data June 2019

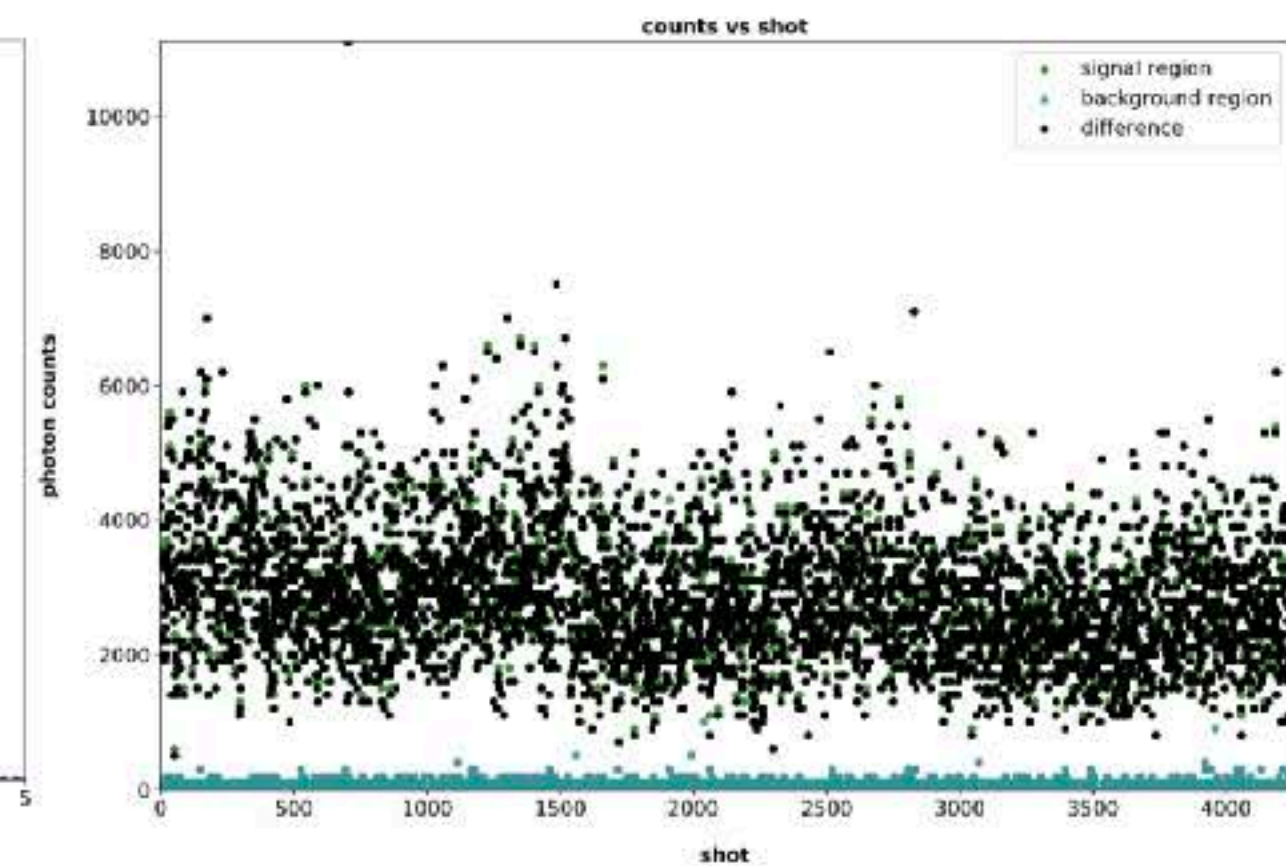
- After 5 mm:  
absorption detection



- After 30 cm:  
LIF detection



- Net counts per shot:  
~3000



- Cell temperature and Neon flow effects

