The EDM program in Groningen

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

Van Swinderen Institute for Particle Physics and Gravity, RUG Groningen
and
LaserLaB Amsterdam, Department of Physics and Astronomy, VU Amsterdam

Main message of this talk:

1. Most exciting low-energy particle physics experiment
2. Ambitious and realistic plan
3. Team with perfect expertise for serious impact

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Is the electron round?

The Electric Dipole Moment of the electron (eEDM)

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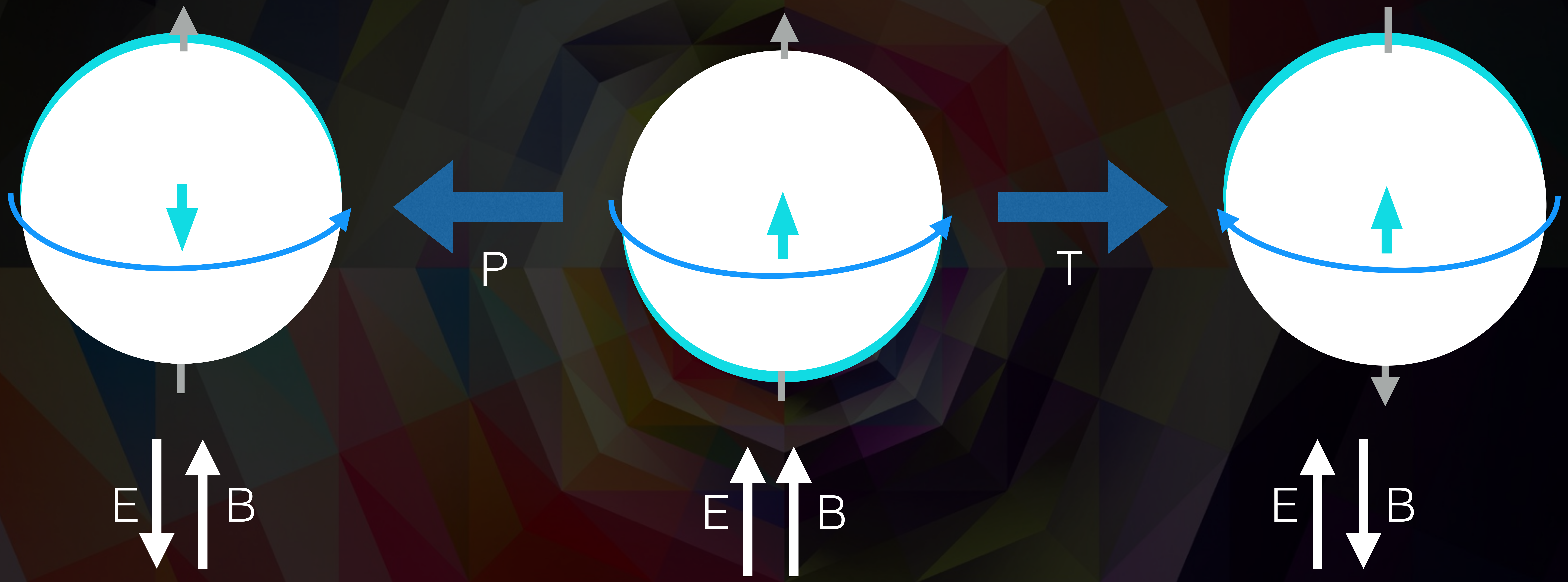
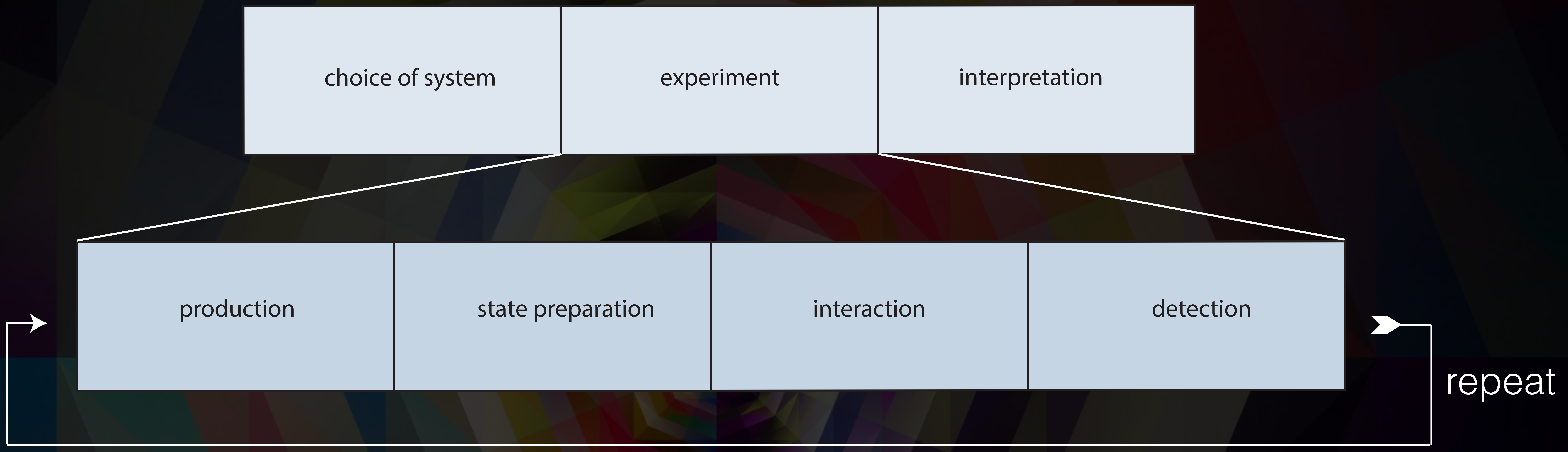


an eEDM would violate P and T Symmetry ->
violates CP symmetry by CPT theorem

How to measure an eEDM?



- Place N electrons in parallel E and B fields
- Measure the precession frequency for time τ
- Reverse relative direction of the fields, measure again
- EDM signature: shift of precession frequency

Best measurements so far

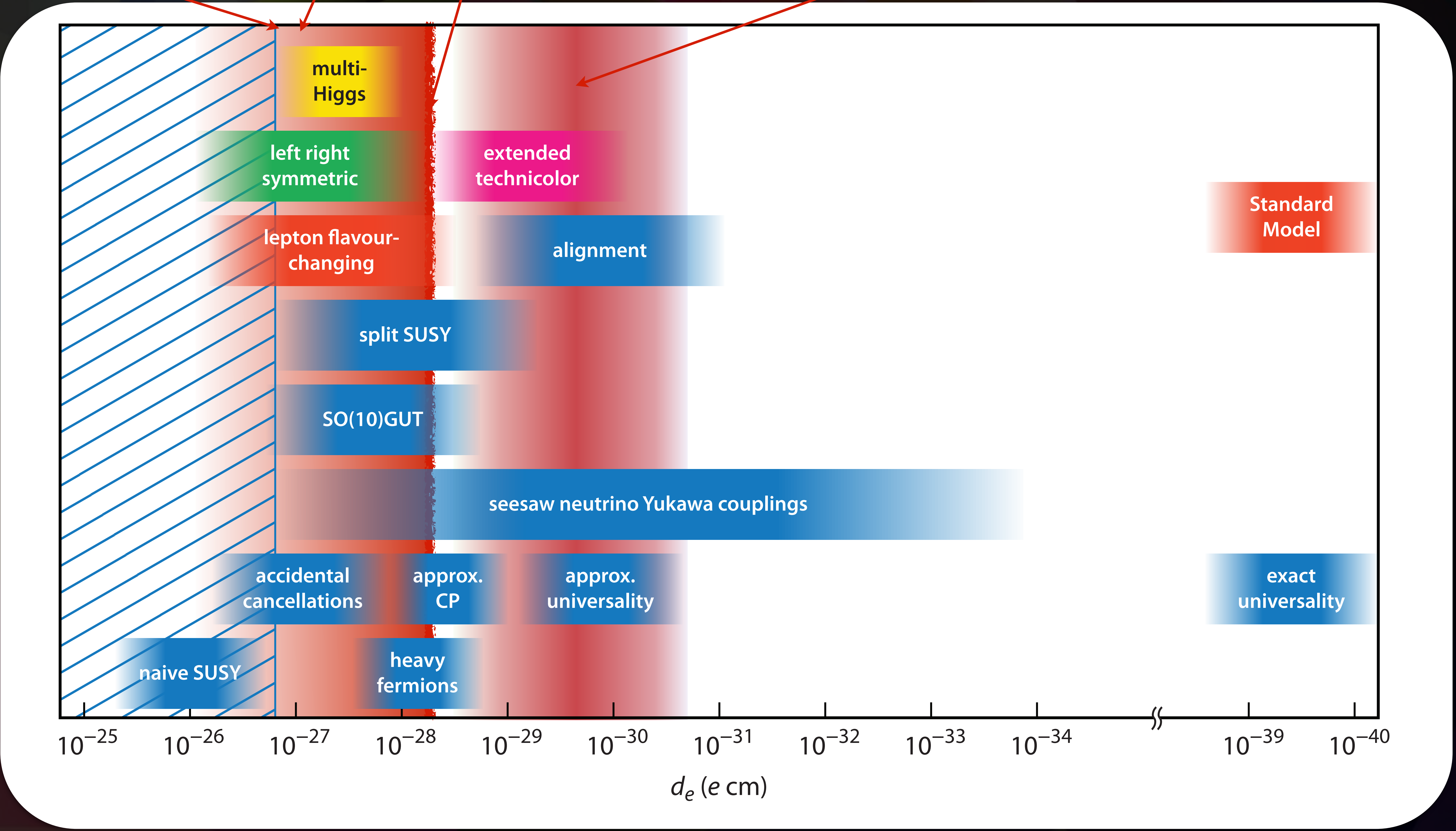
2011: YbF molecule result (Hinds et al, London)

2002: best experimental limit using thallium atoms

2014: ThO molecule result (DeMille, Gabrielse, Doyle, Yale/Harvard)

Statistical limit achievable in our proposal

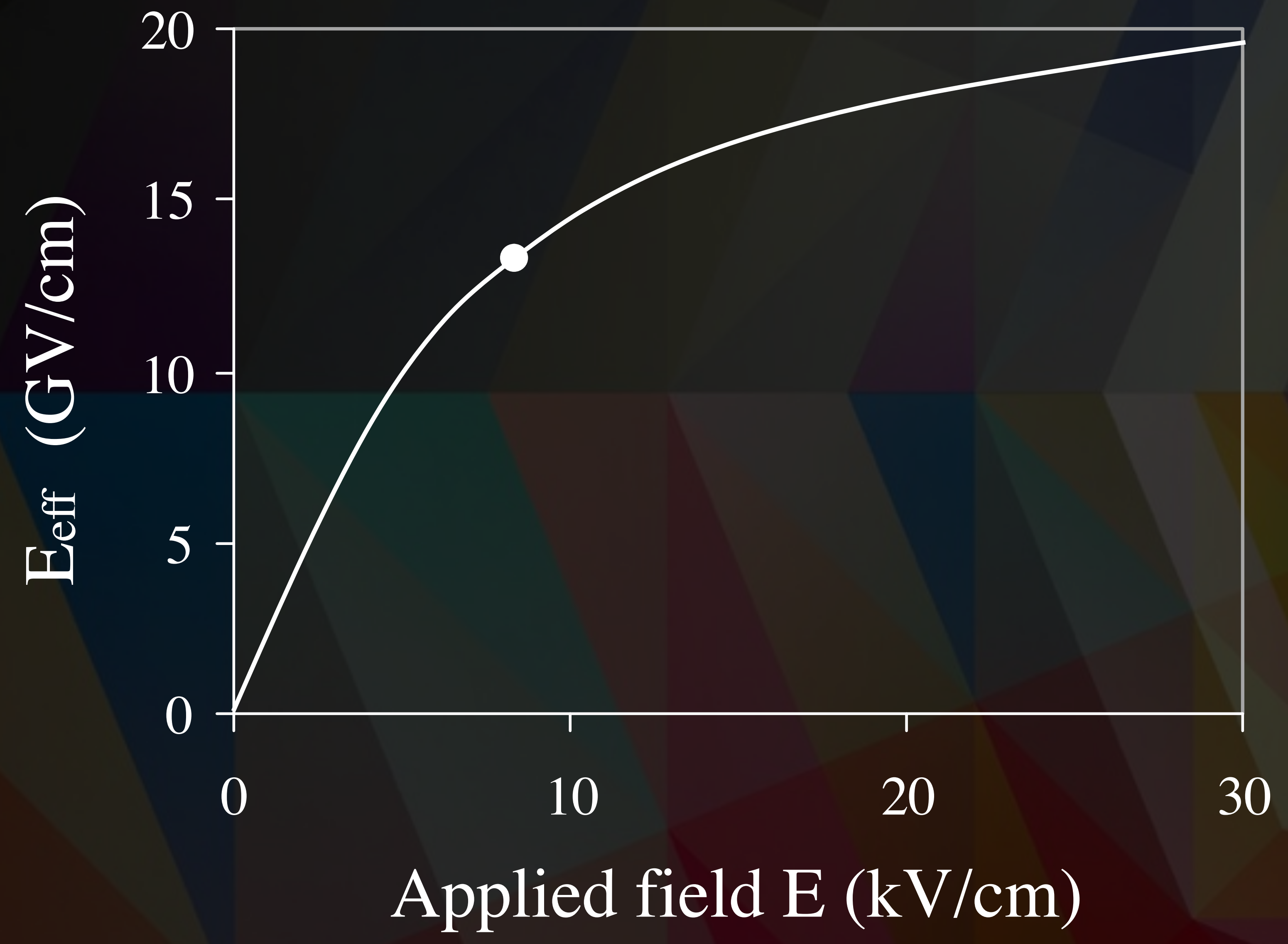
HfF+ / ThF+ results from Cornell team (Boulder) in between YbF and ThO results (unpublished)



The *current* experimental eEDM limit constrains SUSY particles up to 3 TeV

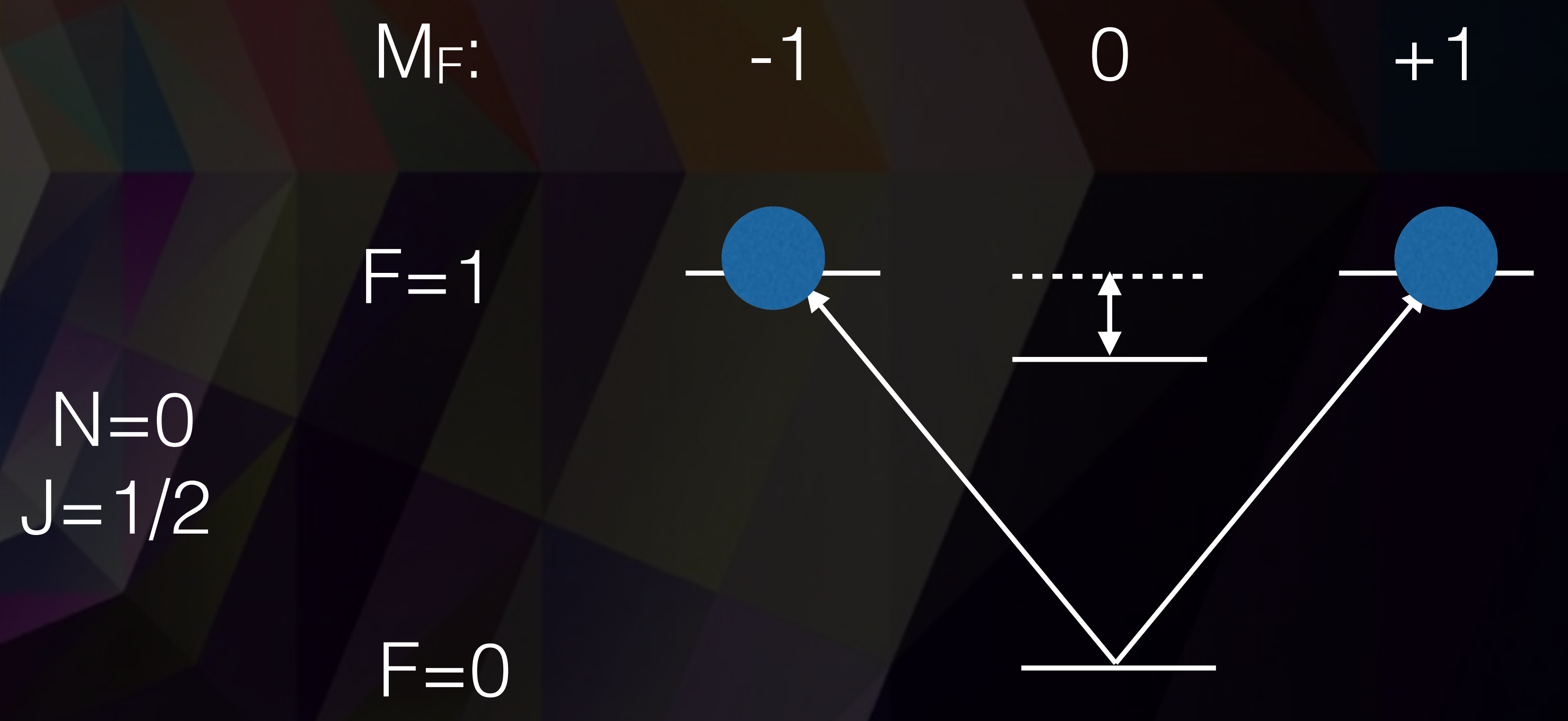
Particle physics with molecules?

Huge (~10^6) enhancement effects!



The valence electron is exposed to the *internal field* of the polarised molecule

Reduced sensitivity (~ 10^{-10}) to magnetic fields perpendicular to E



no fake-EDM from motion in magnetic field

Improve on ongoing experiments?

The best you can do: shot-noise limit on statistical error

$$\sigma_d = \frac{\hbar}{e} \frac{1}{2\mathcal{E}_{\text{eff}}\tau\sqrt{N}}$$

Number of detected molecules

Coherent measurement time

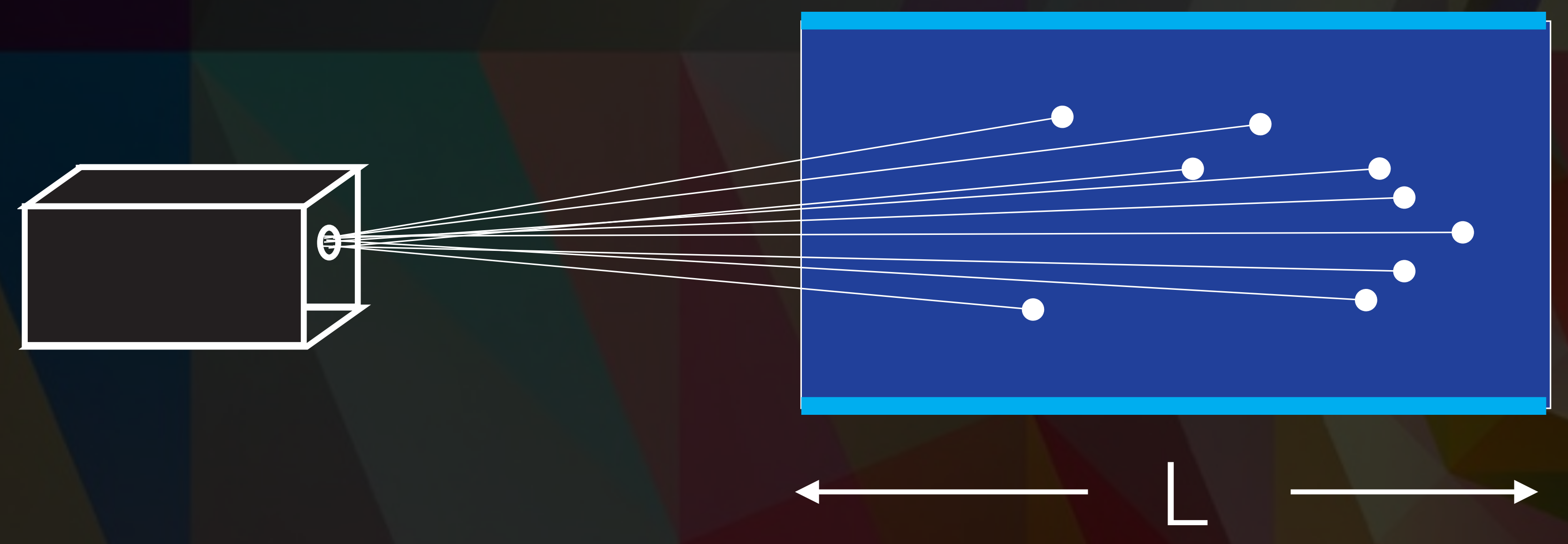
Effective electric field

We aim for a next-generation eEDM experiment using *cold* molecules

Recent progress in cooling methods allows for new generations of precision measurements

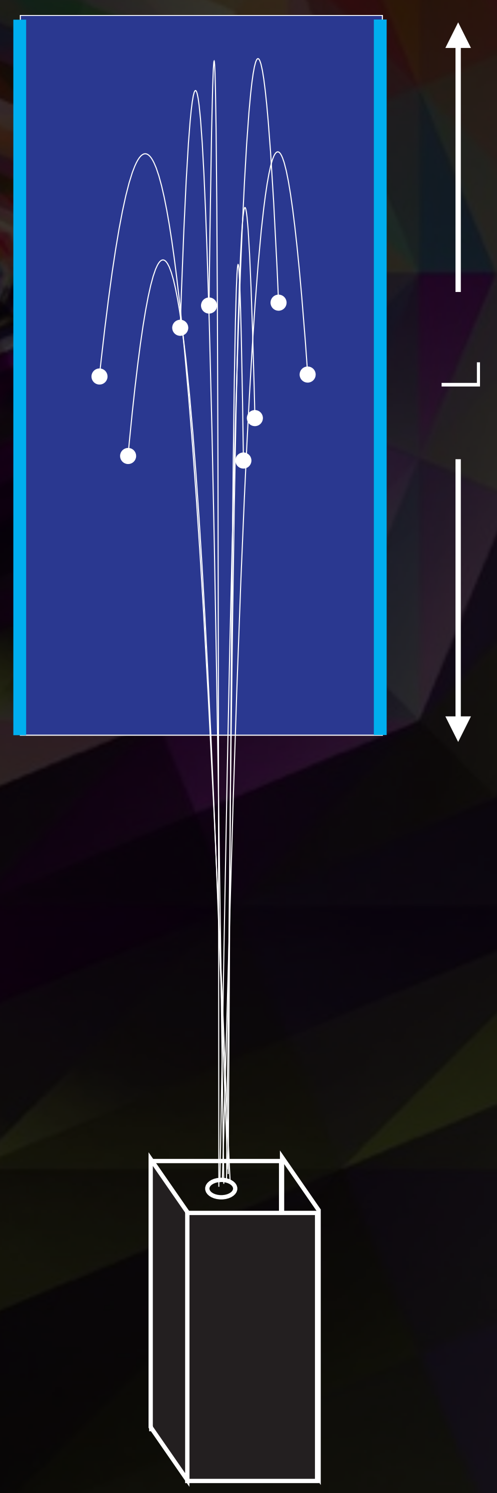
Experiments so far have been done in beams:

t ~ 1 ms
L ~ 0.5 m



fountain?

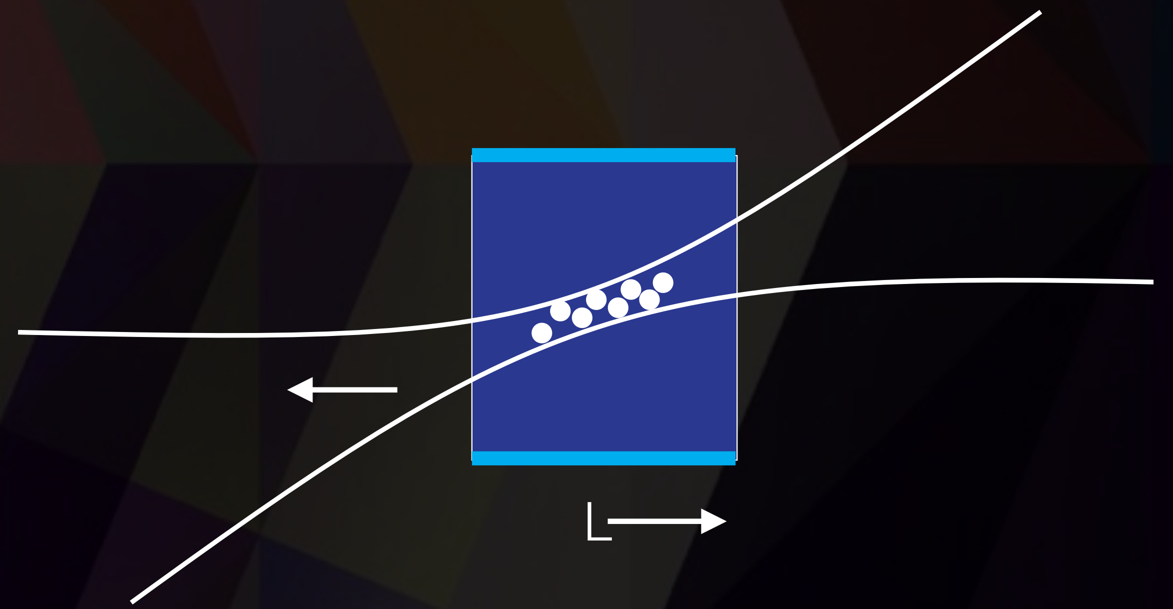
t ~ 100 ms
L ~ 0.5 m



slow vertical beam

trap?

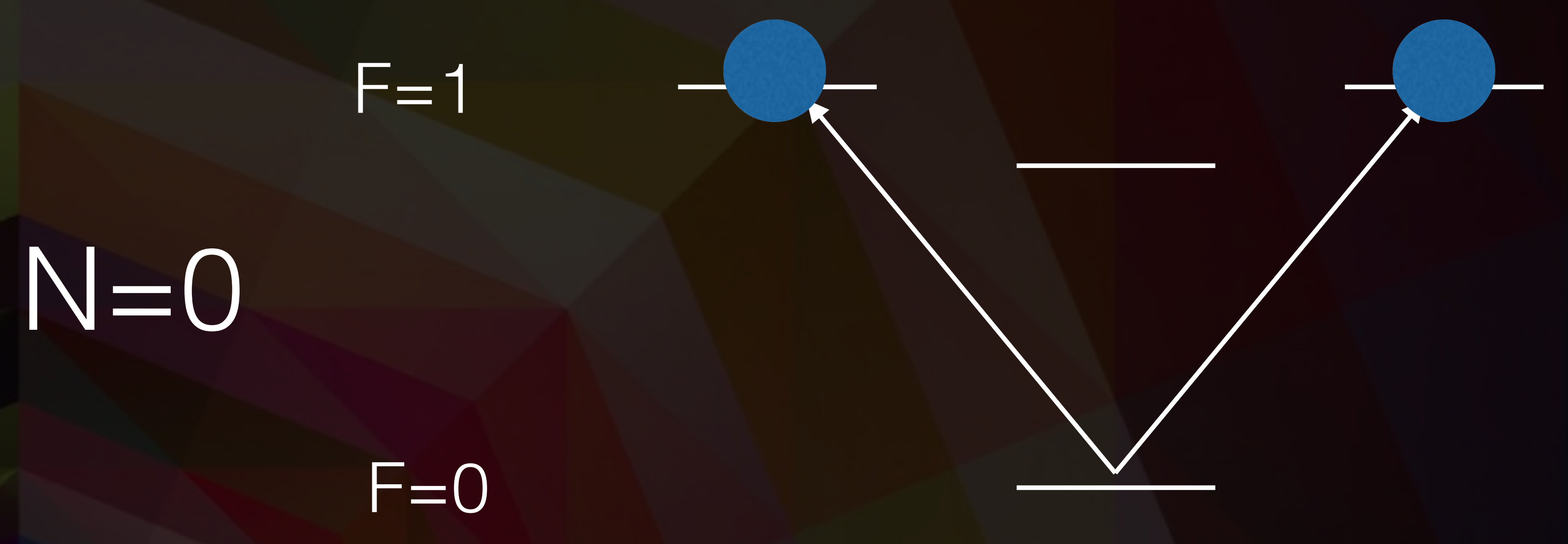
t ~ 1-10 s
L ~ 0.5 mm



molecules trapped in laser focus

Our approach

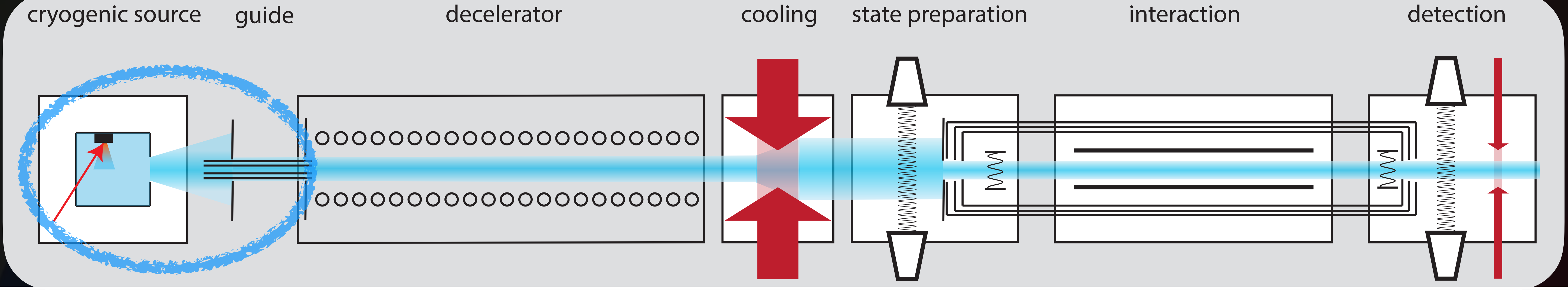
choice of the system:
rotational ground state of BaF
(barium-monofluoride)

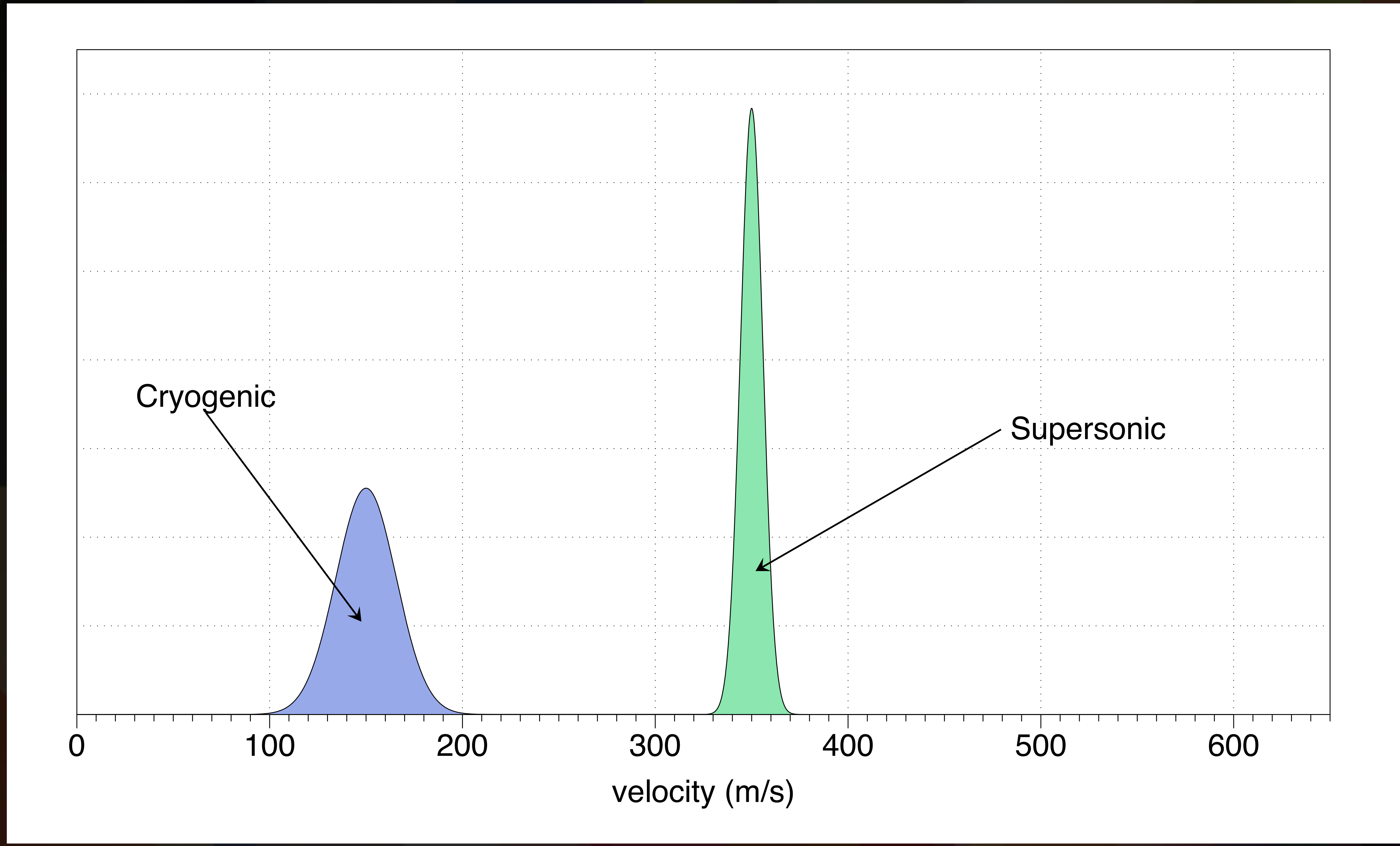


key ingredient:
intense, *slow* and *cold* beam

Best possible combination of
interaction time and N

I. *Intense:* cryogenic source

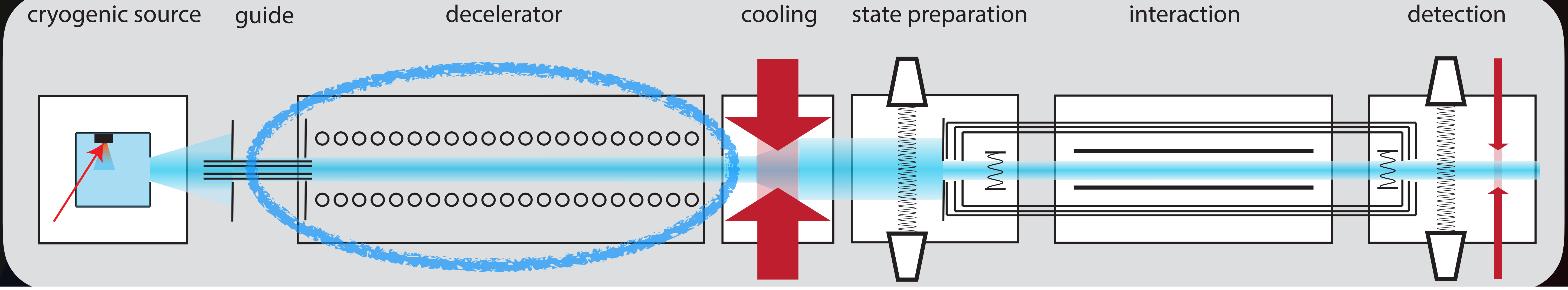




ThO cryogenic source

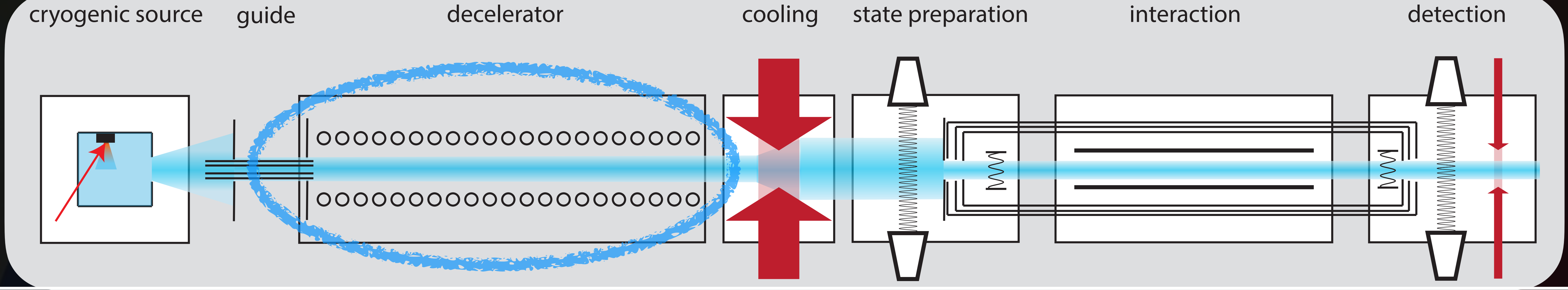
- Use electrostatic guide to bring molecules to decelerator
- N: ~ 10^{10} molecules/shot through the guide, based on BaF, YbF, CaH and ThO results
- Long pulse is not an issue in a beam experiment
- 10 Hz operation demonstrated on BaF cryogenic source with moving pill.
- Novel but proven technology

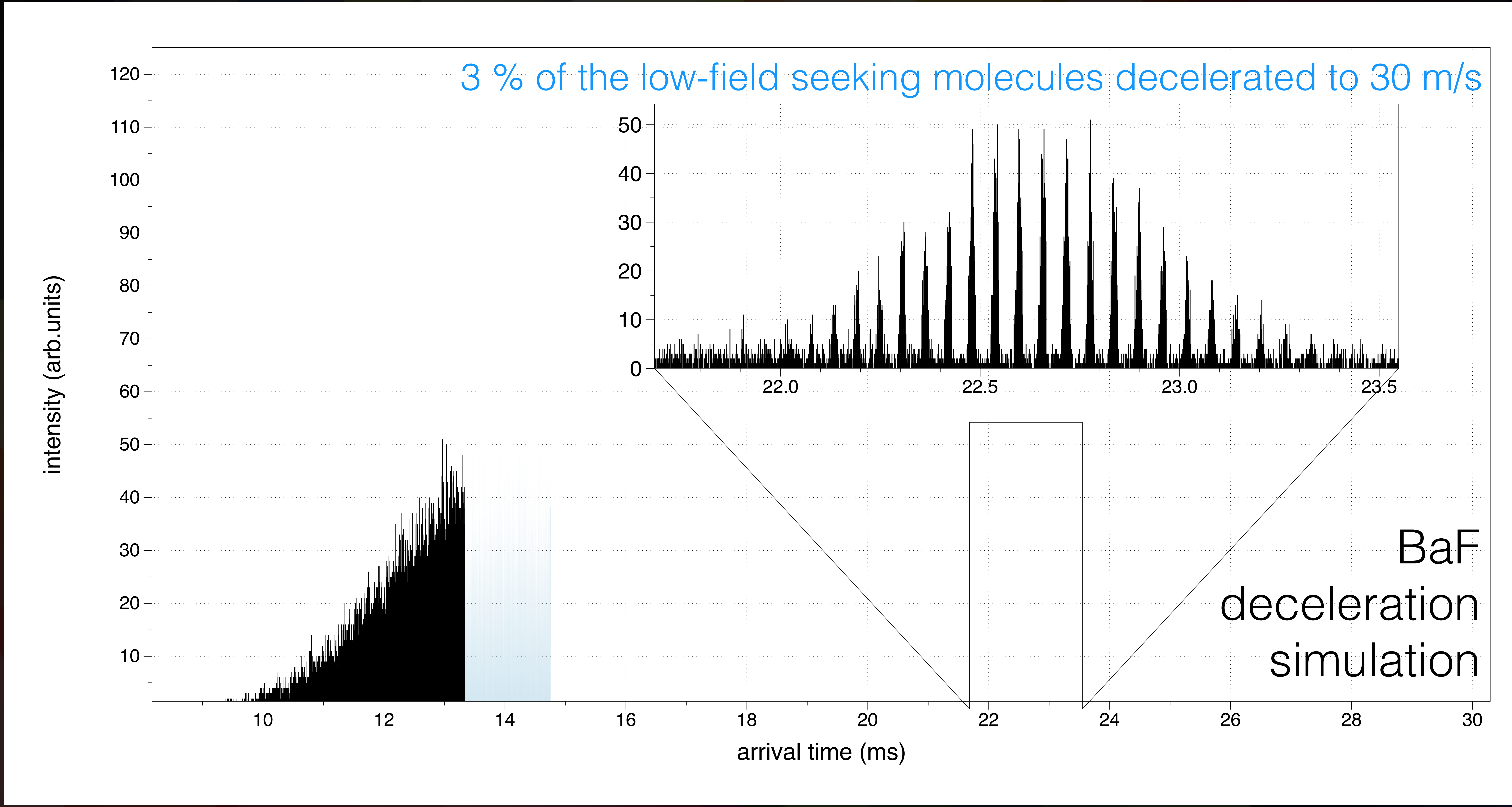
II. *slow:*
the decelerator



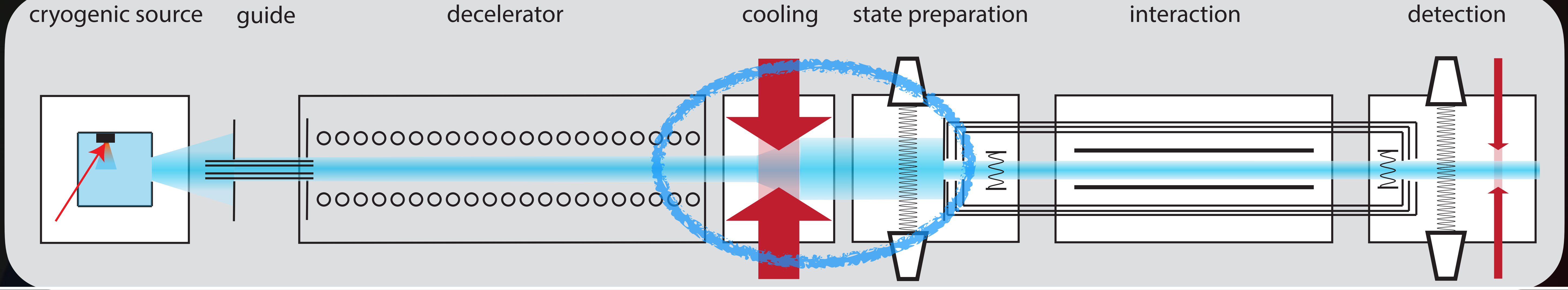
Existing machine @ VSI,
SrF deceleration demonstrated

II. *slow:* the decelerator

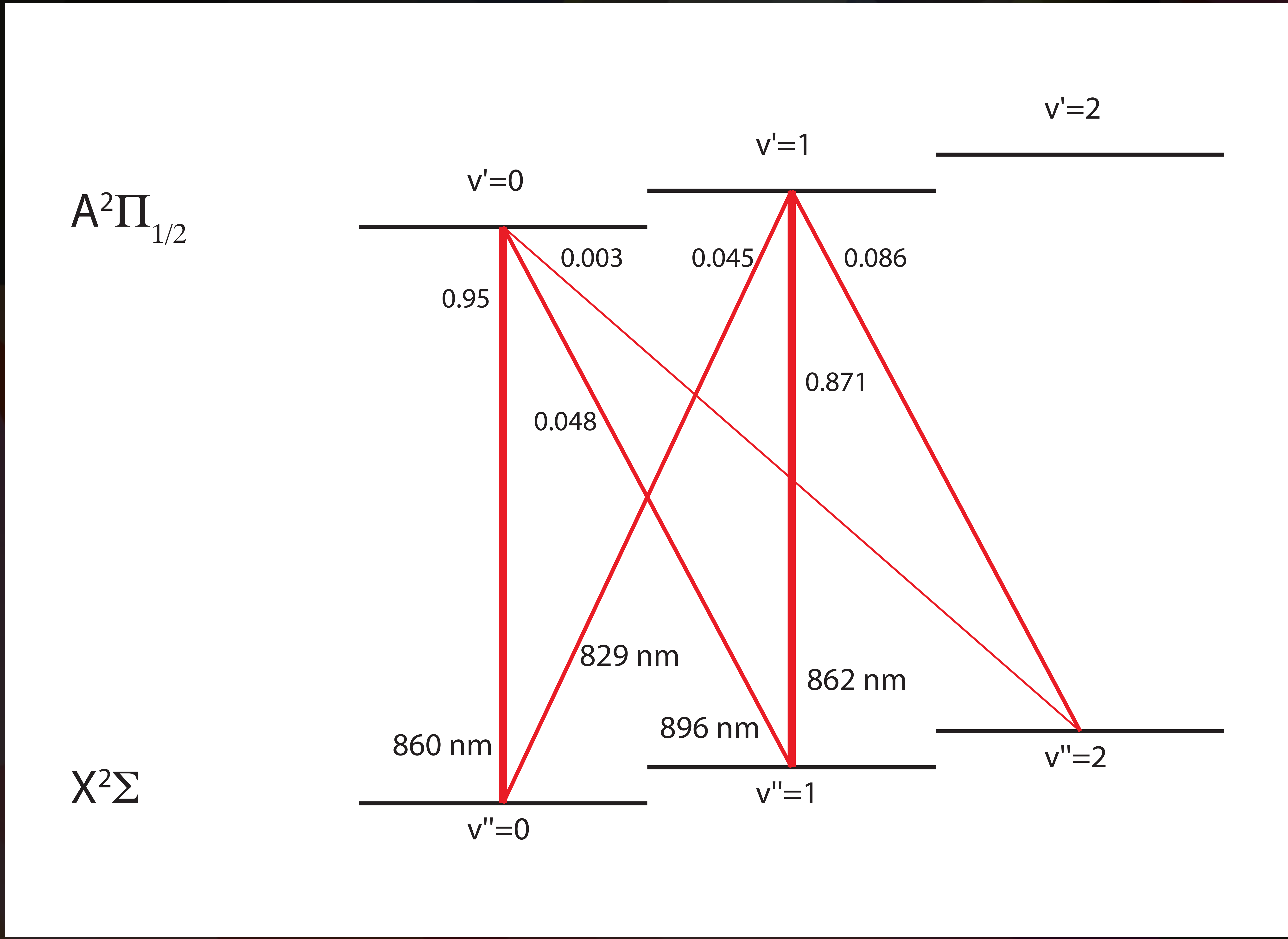




III. *cold*: laser cooling



Transverse laser cooling of BaF: essential to be able to profit from slow beam



Without cooling, density loss would compensate interaction time gain.

Comparable to CaF, SrF, SrF:

- Excited state lifetime ~ 50 ns
- Franck-Condon factors good
- Convenient diode laser wavelengths
- optical molasses laser cooling to 200 microKelvin in 3 - 5 ms

initial $v_\perp$ max. 5 m/s
final $v_\perp$ ~ 20 cm/s
→ beam expands

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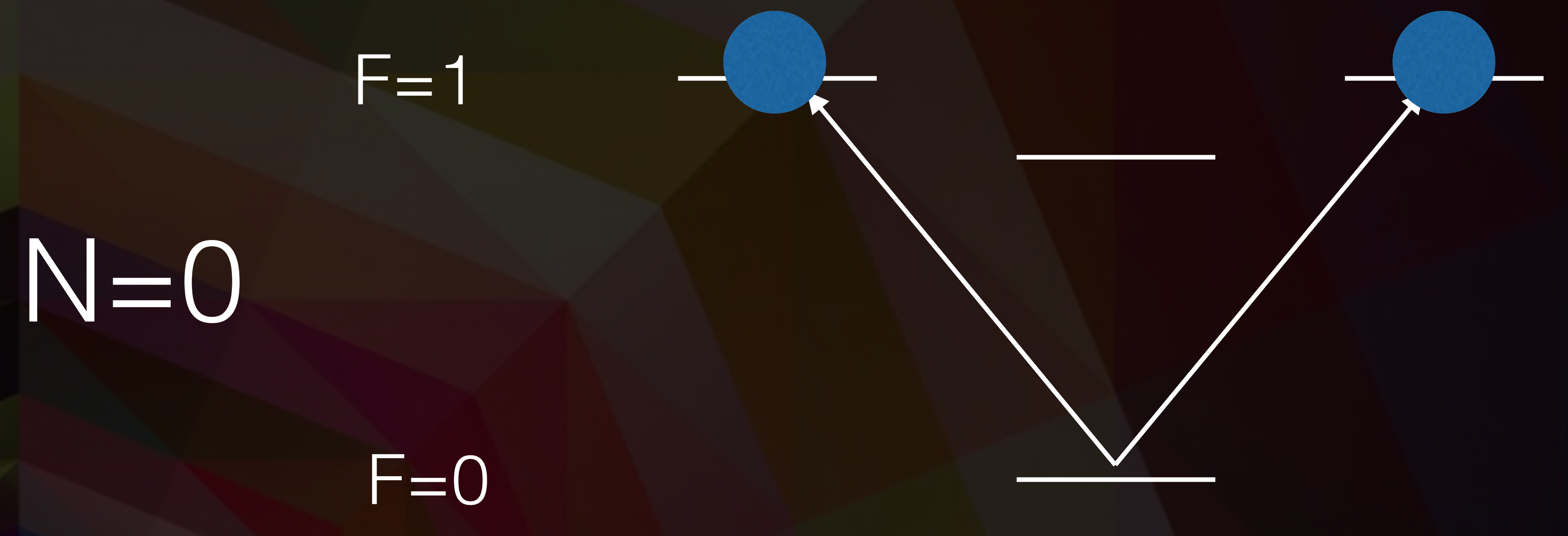

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The EDM team

Lorenz Willmann

VSI

Rick Bethlem

VU

Wim Ubachs

VU

Anastasia Borschevsky

VSI

Lasers, spectroscopy, laser cooling

Molecular beams, deceleration, molecular fountain

Molecular structure and spectroscopy

Matching Expertise

Molecular structure calculations, beyond the Standard Model

EDMs, particle physics theory

Stark deceleration, molecular beams, laser cooling

EDMs, precision measurements, magnetic field control

VSI

Rob Timmermans

VSI

Klaus Jungmann

VSI

Steven Hoekstra

EDM program within Nikhef

- This EDM program is the novel, focused contribution of the VSI
- It is complementary to the existing Nikhef portfolio
- We look forward to collaboration opportunities on both physics and technology!

end