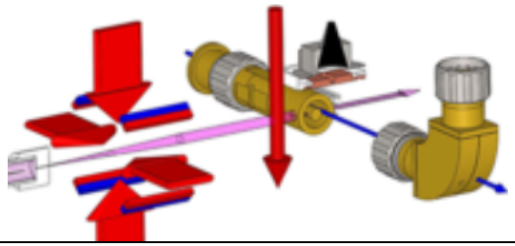
In the past year, we have also completed a measurement of the *n*=2 triplet P fine structure of atomic helium – which is part of a ppb program to test QED, look for possible beyond-the-standard-model physics, and determine the fine-structure constant

Editors' Suggestion

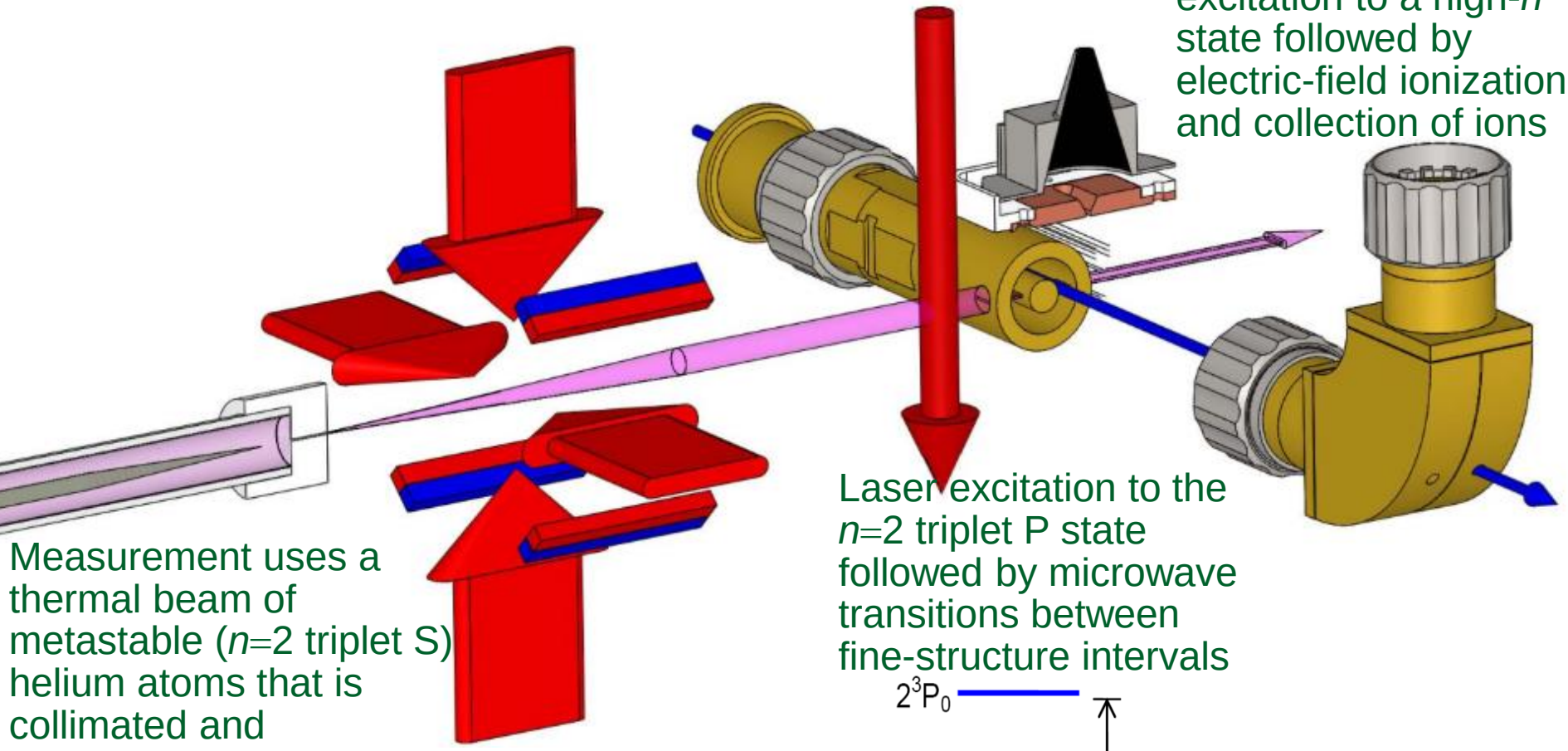
Ultrahigh-Precision Measurement of the $n = 2$ Triplet P Fine Structure of Atomic Helium Using Frequency-Offset Separated Oscillatory Fields

K. Kato, T. D. G. Skinner, and E. A. Hessels

Phys. Rev. Lett. **121**, 143002 (2018) – Published 4 October 2018

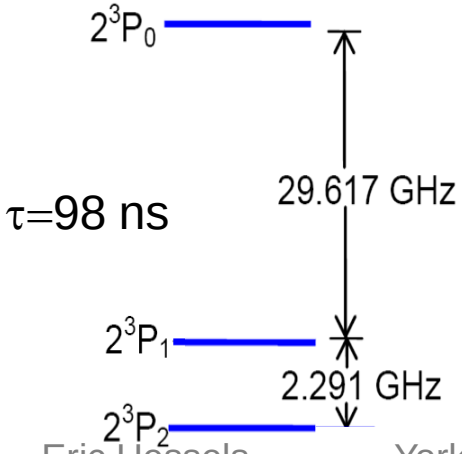


Near-unity detection efficiency by laser excitation to a high-*n* state followed by electric-field ionization and collection of ions



Measurement uses a thermal beam of metastable (*n*=2 triplet S) helium atoms that is collimated and concentrated using laser cooling techniques – produces an intense beam

Laser excitation to the *n*=2 triplet P state followed by microwave transitions between fine-structure intervals

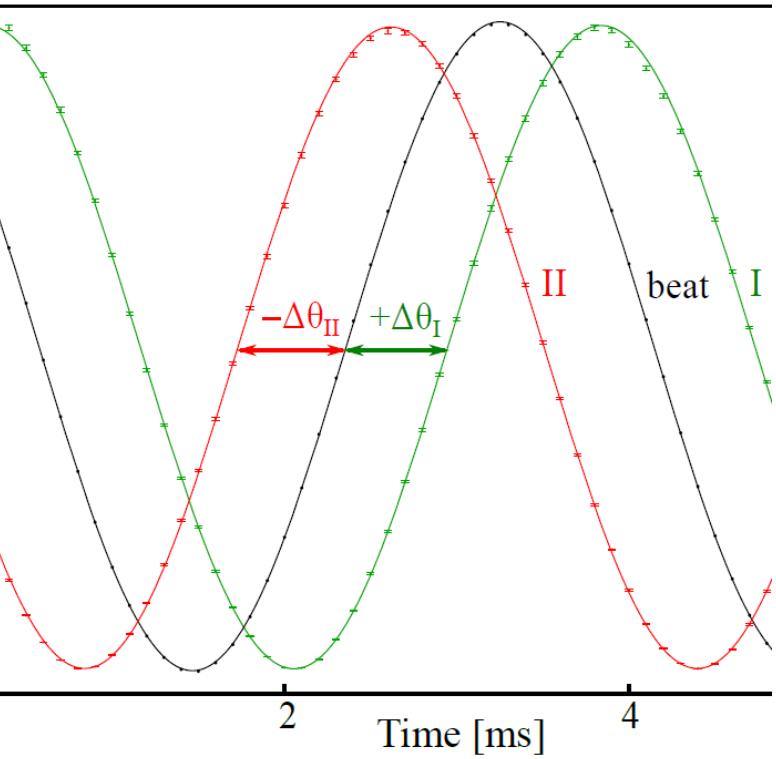


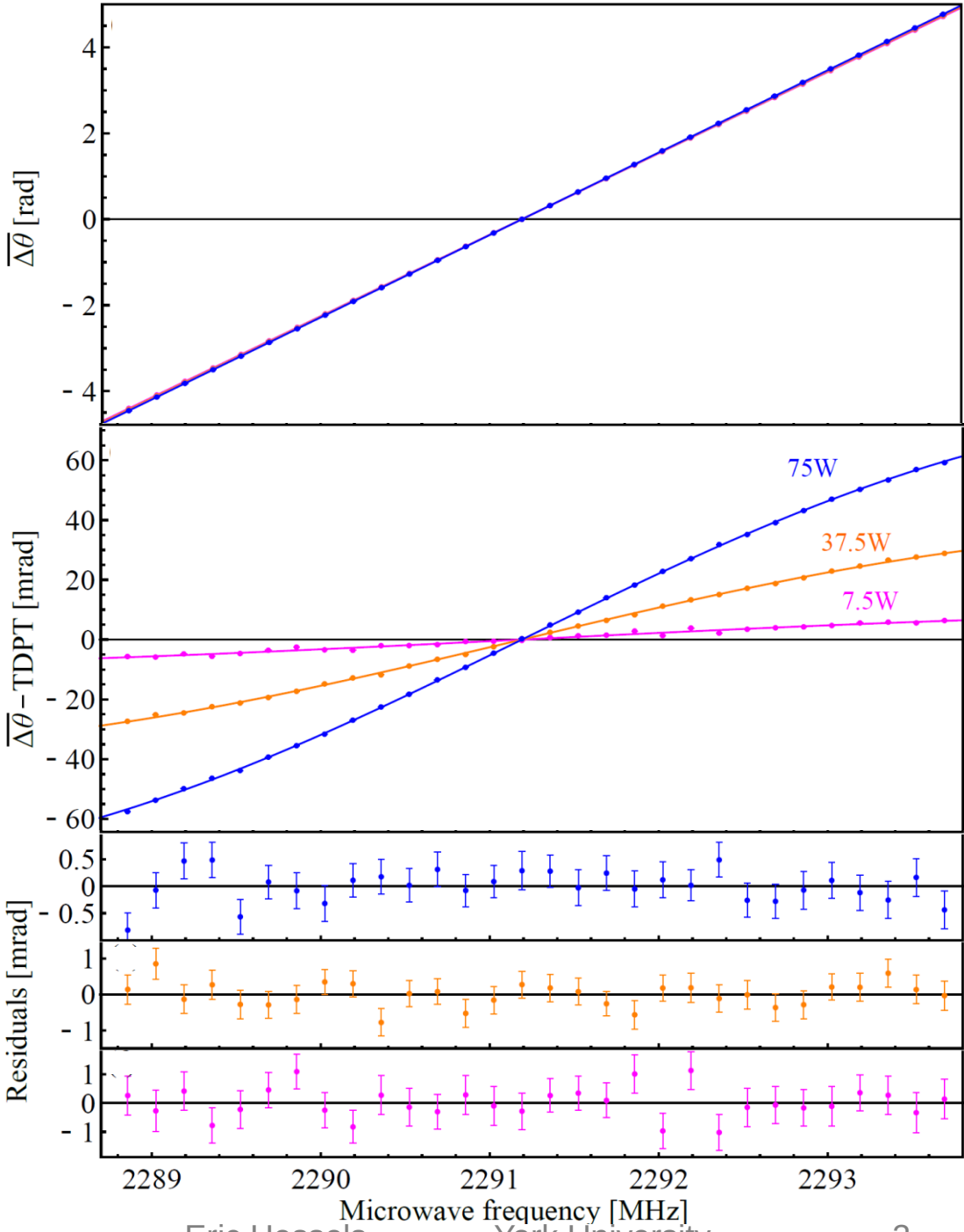
We use the FOSOF method

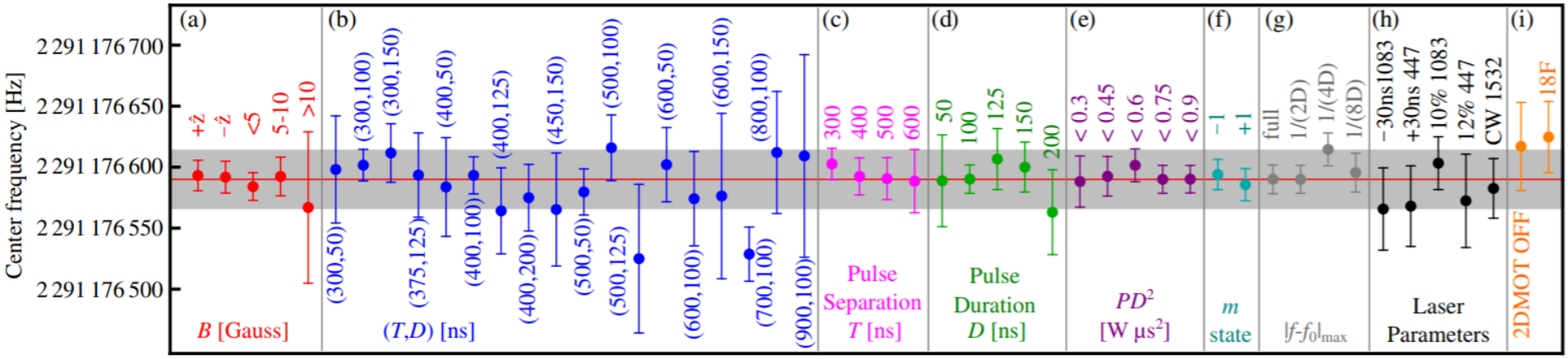
Exceptionally good signal to noise

Allows for experiments which span 10 lifetimes (e^{-10} signal size)

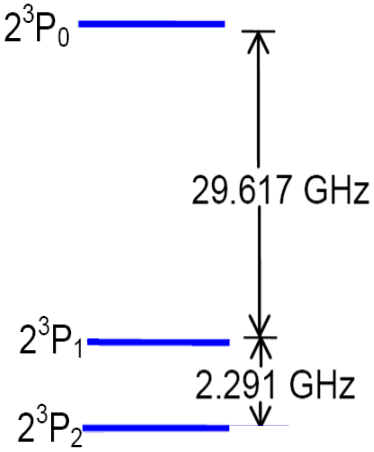
Each point below is 20 ms of data with e^{-4} signal size







$$[E(2^3\mathrm{P}_1) - E(2^3\mathrm{P}_2)]/h = 2\,291\,176\,590(25)\ \mathrm{Hz}$$



To take full advantage of this precision measurement we need:
(1) a measurement of the other fine structure interval
(which we can do with the same technique)
(2) the next order of QED theory ($\alpha^8 m_e c^2$)

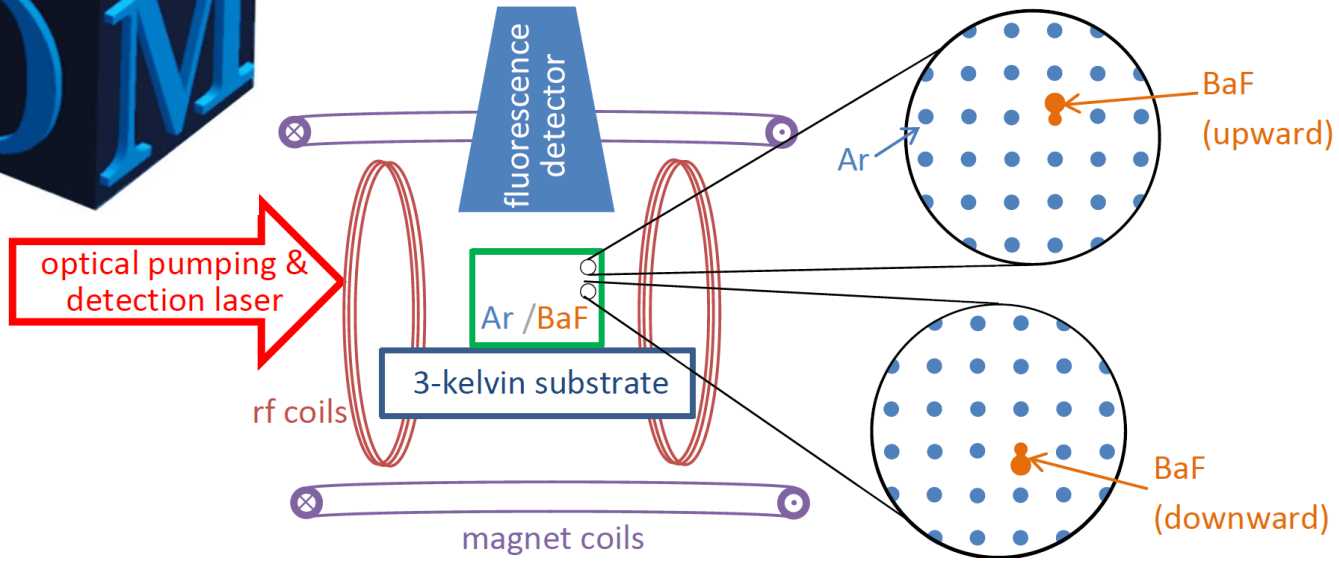
Will lead to ppb test of QED, 100x more accurate tests of exotic spin-dependent electron-electron interactions, 0.5 ppb determination of α

Determination of α, when compared to g_e-2 and atom interferometry, will test QED and beyond-the-standard-model physics for g_e-2

This year we have started a new major initiative: EDM^3 (electron Electric Dipole Moment measurement using Molecules in a solid argon Matrix)

Editors' Suggestion

A. C. Vutha, M. Horbatsch, and E. A. Hessels
Phys. Rev. A **98**, 032513 (2018) – Published 28 September 2018



shows promise to improve limit by 2 to 4 orders of magnitude (or more)

Motivation (why measure an electron edm?)

Test physics beyond the Standard Model (matter/antimatter asymmertry (CP violation)

If a new CP violating particle of energy Λ couples to the electron with a strength α_{eff}, the expected d_e is

$$\frac{d_e}{e} \sim \left(\frac{\alpha_{\text{eff}}}{4\pi}\right)^n \left(\frac{m_e c^2}{\Lambda^2}\right) \sin(\phi_{\text{CP}})(\hbar c)$$

Current limit on d_e already tests physics at 10-to-100-TeV level

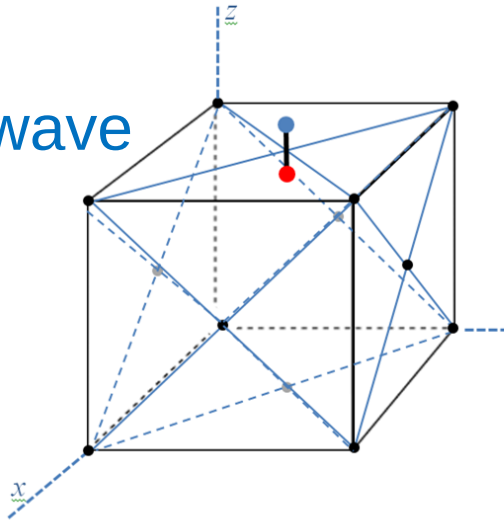
A 10^4 improvement would test physics at 100 times higher energies

Our proposal for measuring d_e : molecules in a matrix

Embed BaF molecules in solid Ar

Ar solid is transparent: allows for laser and microwave spectroscopy and observation of fluorescence

Matrix orients the molecules relative to Ar crystal



1 mm^3 Ar with ~1 ppb of BaF: 10^{10} BaF

Precess for T ~ 10 ms

Reuse molecules (repeat for a month) $N \sim 10^{15}$ to 10^{18}

Our statistical limit : $\delta d_e = \dfrac{\hbar}{2\, E_{\text{eff}} \sqrt{N\, T}} \sim 10^{-31}$ to $10^{-33}\ e\,\text{cm}$

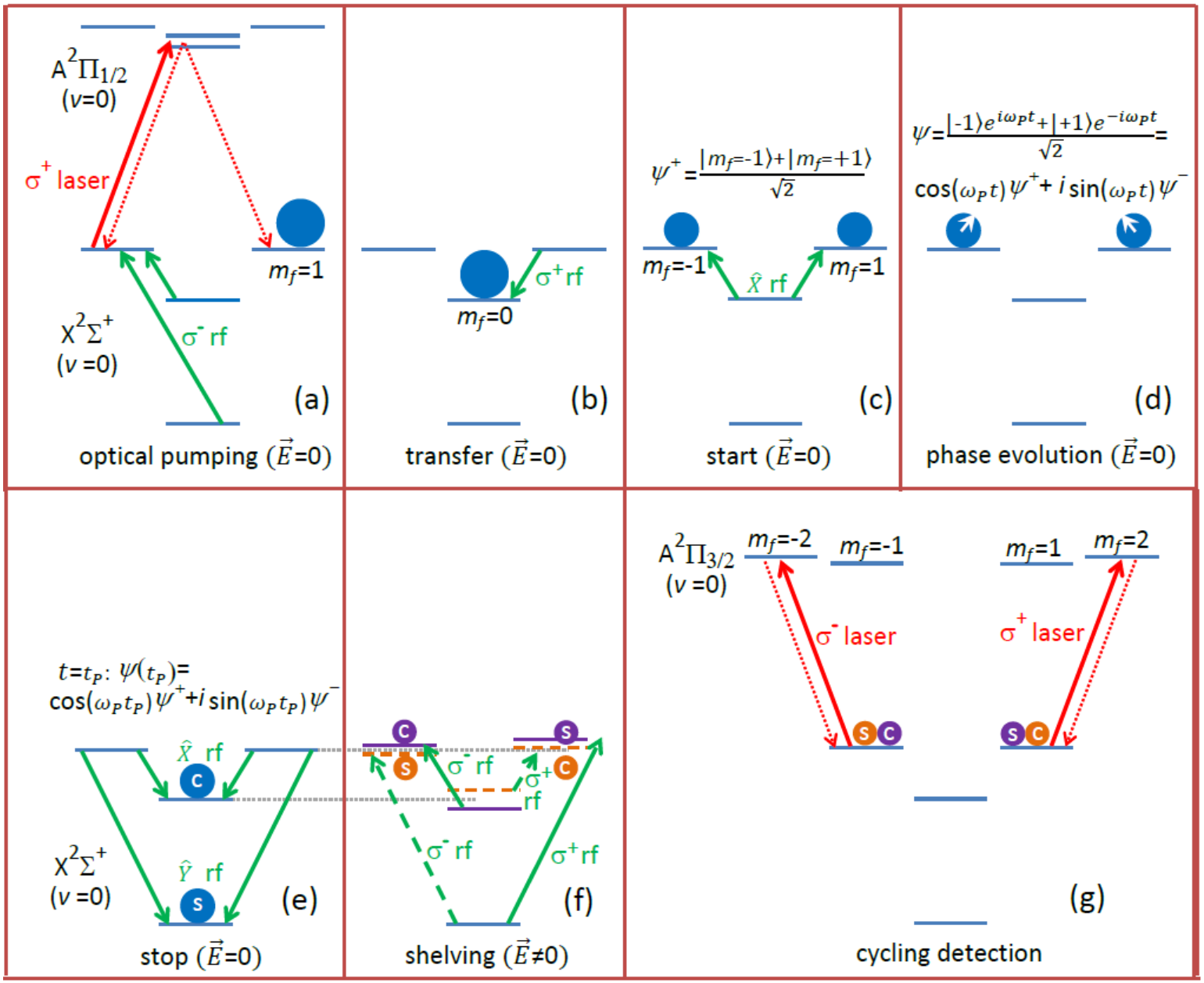
30 times smaller for 1 cm^3

15 times smaller for molecule with larger E_{eff}

5 times smaller for 2 years of data collection

Orders of magnitude lower than current limit!

Measurement scheme



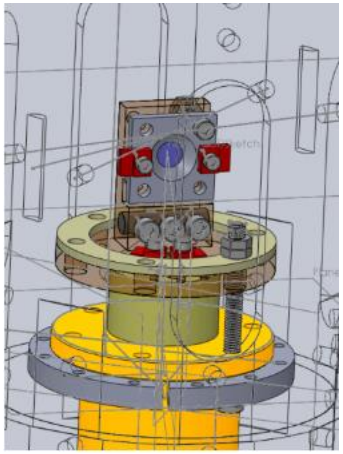
Our proposal for measuring d_e: Systematic effects

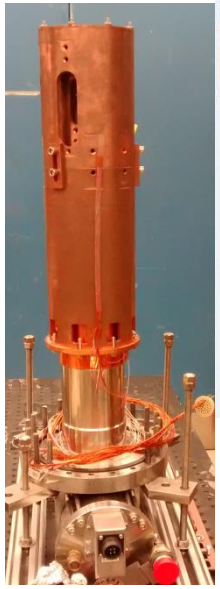
Why we think systematic effects can be controlled well:

1) Excellent statistical uncertainty allows for extensive studies
2) Small size of sample: excellent shielding/uniformity of fields
3) No applied electric field during precession
4) Simultaneous precession of interspersed +ẑ, -ẑ molecules
5) Cold (<4 K) – control of B, freeze out other physics
6) Stationary molecules – no motional fields, geometric phases
7) Control molecules –2nd embedded molecule with small E_{eff}
8) Repeat with: new Ar crystal (impurities, imperfections), other inert gas, other polar molecule (see an effect α E_{eff}), other substrate for Ar crystal
9) Many ways to reverse rel. direction of ***E***, ***B*** (incl. rf tuning)
10) Large dynamic range on parameters that can be varied (*B*, *T*, delay times between steps, etc.)

Progress to date (see: edmcubed.com)

- assembled a collaboration
- extensive modelling and calculations on BaF and solid Ar
- refurbished a laboratory
- vacuum system in place
- cryogenic system in place





Progress to date (see: edmcubed.com)

- assembled a collaboration
- extensive modelling and calculations on BaF and solid Ar
- refurbished a laboratory
- vacuum system in place
- cryogenic system in place
- transparent solid argon samples demonstrated
- laser systems in place for BaF spectroscopy
- isotopically pure BaF^{+} produced using electrospray source

(All in the past 9 months)