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Measuring the Electron EDM Using Ytterbium Fluoride (YbF) Molecules

mesur moment deupol trydanol yr electron

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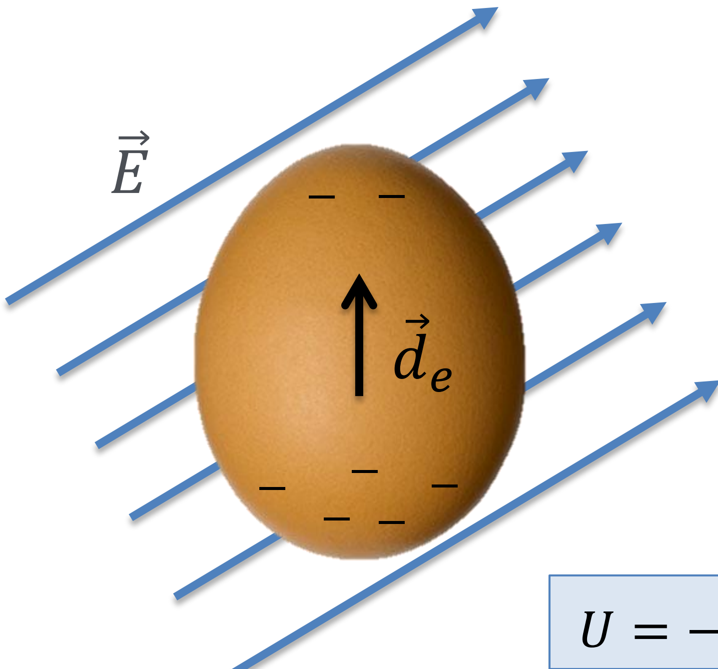
Science & Technology Facilities Council

EPSRC

THE ROYAL SOCIETY

The electron electric dipole moment (EDM)

- Displacement of centre of charge from centre of mass



$$U = -\vec{d}_e \cdot \vec{E}$$

$$\vec{d}_e \parallel \vec{\sigma}$$

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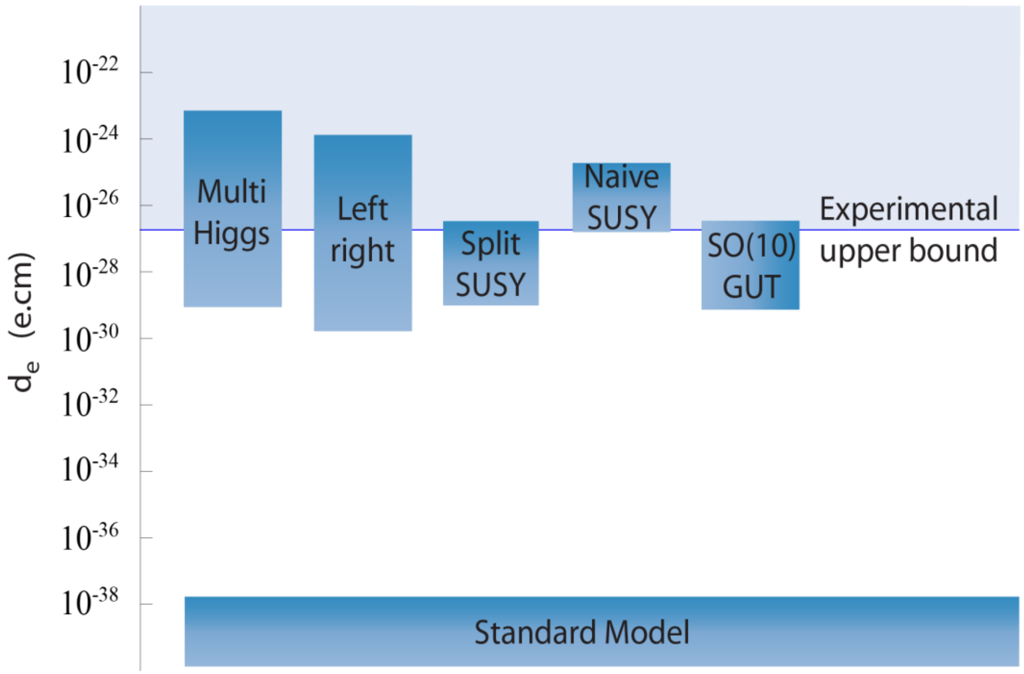
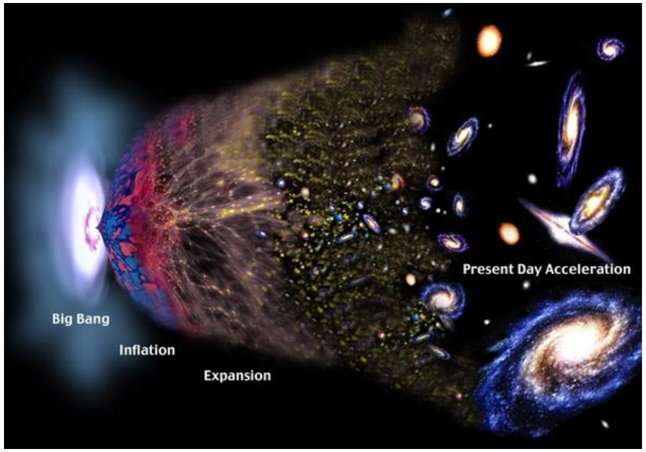
Electron EDM estimates





David A. Aguilar
Harvard-Smithsonian Center for Astrophysics

not enough CP violation

$$|d_e^{thallium}| < 1.6 \times 10^{-27} e.cm$$

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How small is that?

- Assume:
  - $d_e \approx 10^{-27} e.cm = 2 \times 10^{-19} e.a_0 = 5 \times 10^{-19} D$
  - $E \approx 1 GV/cm$

EDM interaction:

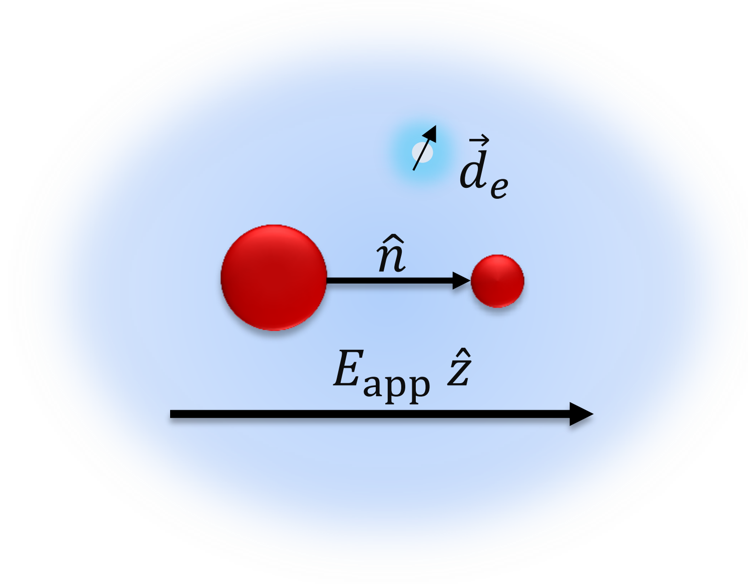
$$-\vec{d}_e \cdot \vec{E} \approx 0.25\ mHz$$

- $\equiv -\mu_B \cdot B$ for $\approx 17 fT$ magnetic field
- $\approx 10^{-10} cm^{-1}$
- $\approx 10^{-18} eV$

How atoms and molecules can help

- Amplify the electron EDM interaction!

$$-\vec{d}_e \cdot \vec{E}$$ → *complicated special relativity* → $$-\vec{d}_e \cdot \vec{E}_{\text{eff}}$$



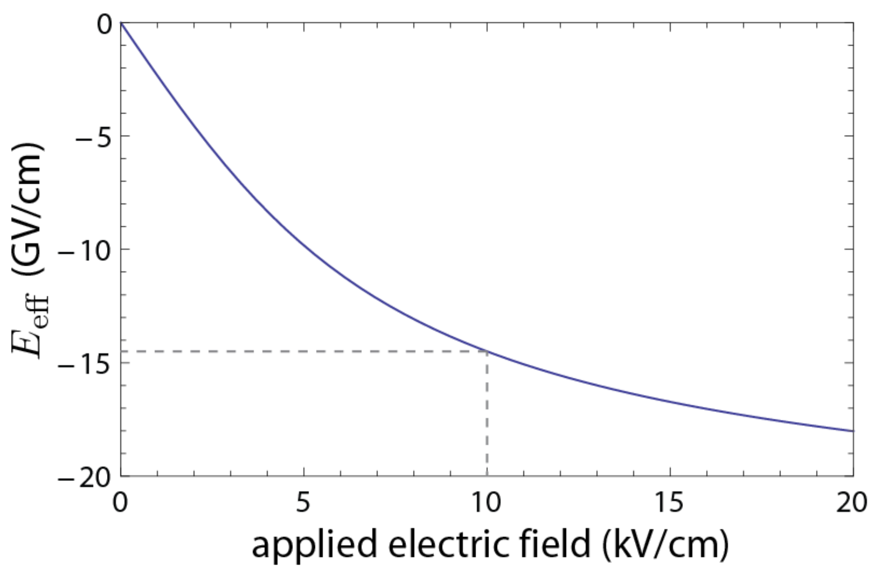
$$\vec{E}_{\text{eff}} = E_{\text{eff}}{}^{\text{max}}\ \eta\left(E_{\text{app}}\right)\ \hat{z}$$

structure dependent factor $\sim Z^3$

polarisation factor $\langle \hat{n} \cdot \hat{z} \rangle$

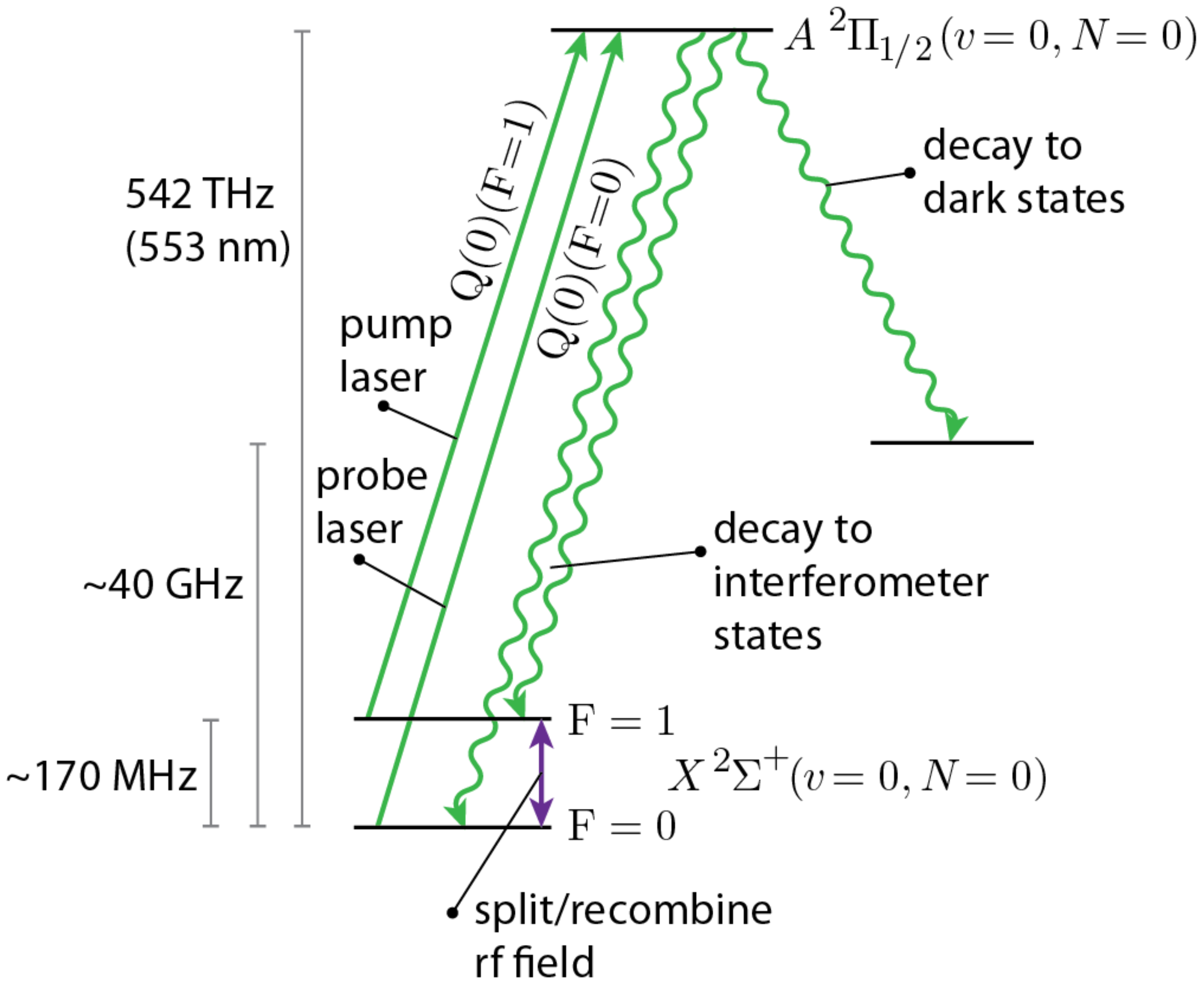
YbF electric field enhancement

- $\vec{E}_{\mathrm{eff}} = 14.5\ \mathrm{GV/cm}$ for $\vec{E}_{\mathrm{app}} = 10\ \mathrm{kV/cm}$
- Enhancement of 10^6!



- Needs ‘only’ nano-Gauss level of B-field control

YbF energy levels



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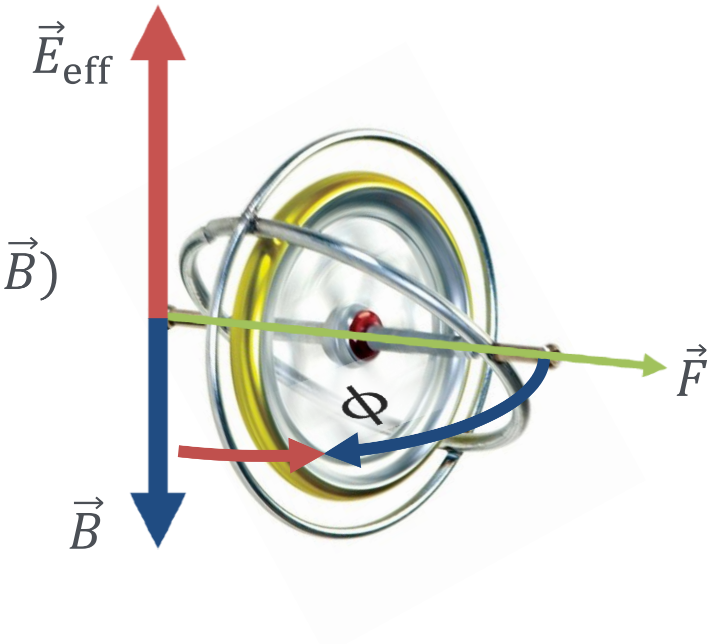
EDM measurement

Torque:

$$\frac{d\vec{F}}{dt} = (\vec{d}_e \times \vec{E}_{\mathbf{eff}}) + (\vec{\mu} \times \vec{B})$$



$$\phi = \frac{(\mu B \mp d_e E_{eff})T}{\hbar}$$

$\Delta\phi < 7\ \mu rad$

or

$\Delta U < 2\ mHz$

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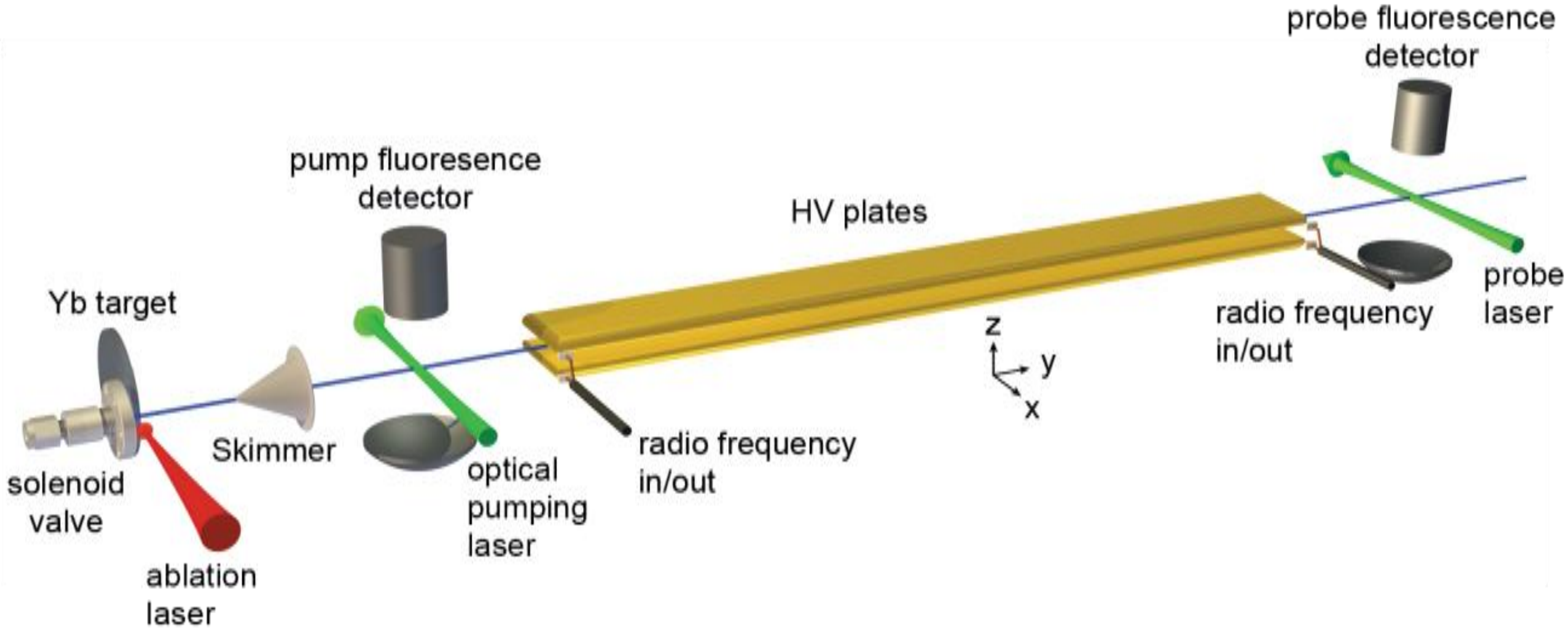
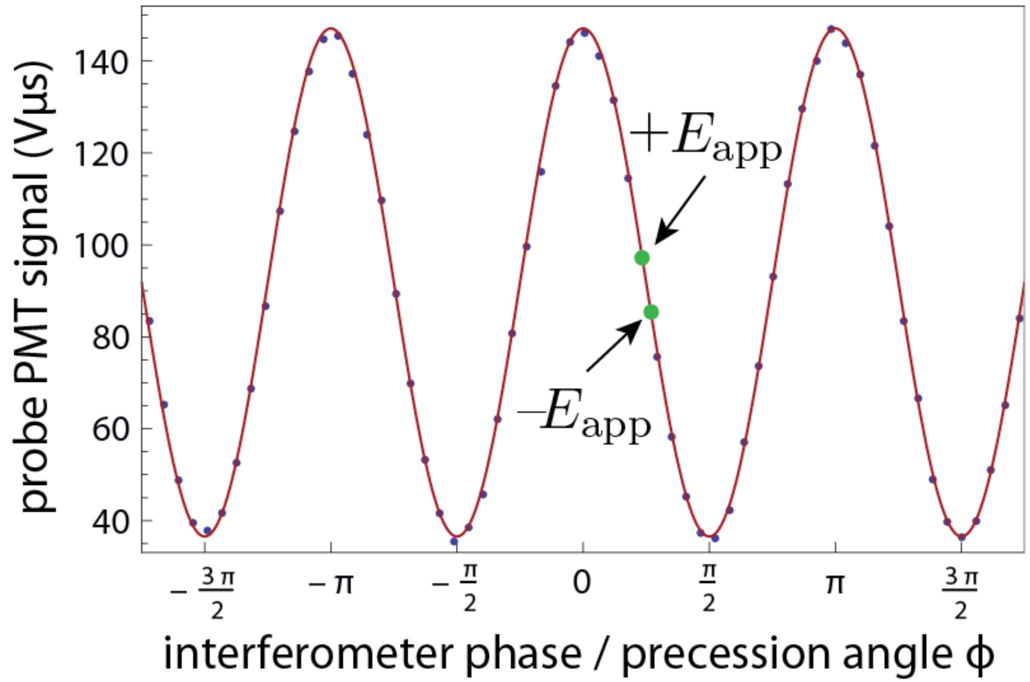
Measuring the electron EDM



Interference fringes



$$S = \cos^2\phi$$

$$\phi = \frac{(\mu B \mp d_e E_{eff})T}{\hbar}$$

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Lots of other parameter modulations

- E-field direction ← *demonstrated in last slide*
- B-field direction
- B-field magnitude
- rf pulse frequency (independently)
- rf pulse amplitude (independently)
- rf pulse phase difference
- laser frequency

see Hudson et al. *Stochastic multi-channel lock-in detection* arXiv:1307.4280

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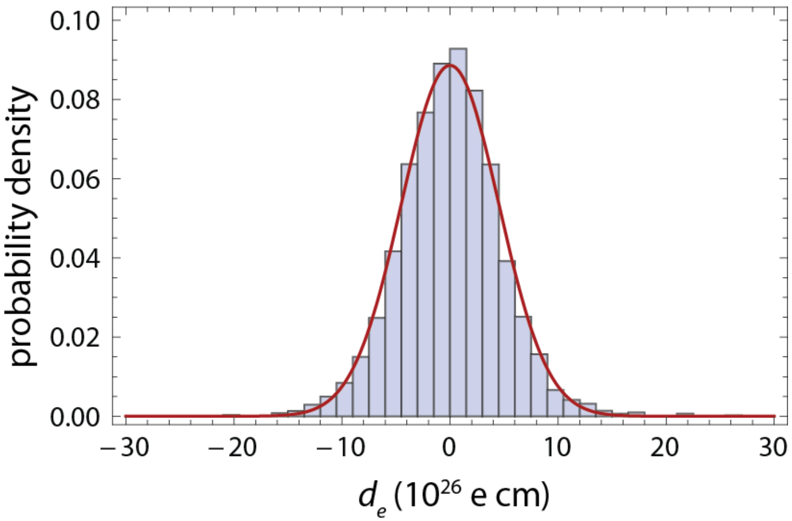
Result

- 2011 dataset: 6194 measurements (6min/measurement)



$$d_e = \left(-2.4 \pm 5.7_{stat} \pm 1.7_{syst}\right) \times 10^{-28} \mathrm{e.cm}$$

$d_e < 1 \times 10^{-27} \mathrm{e.cm}$ with 90% confidence

J J Hudson et al. *Nature* **473** 493-496 (2011)
D M Kara etal. *New. J. Phys.* **14** 103051 (2012)

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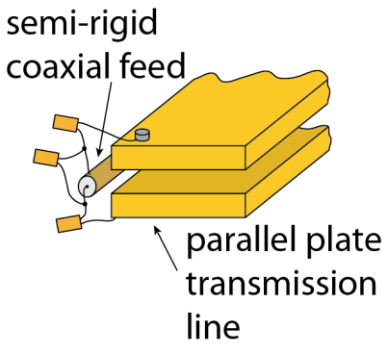
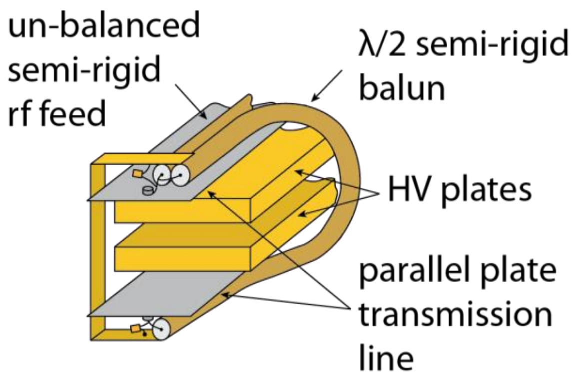
Upgrades since 2011

- 3rd layer of magnetic shielding
  - Less magnetic field noise
- Longer inner magnetic shield
  - Reduce end effects
- Separate rf transmission line from HV plates
  - Reduce end effects, higher applied E-field, less leakage



old scheme



new scheme

- Shorten rf pulses
  - Reduce systematics associated with rf detuning

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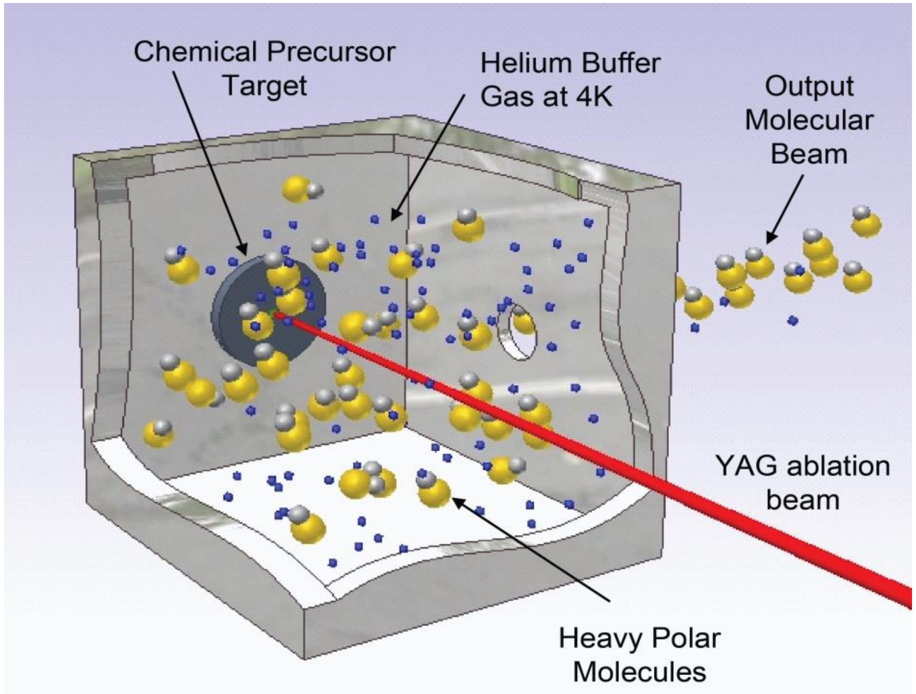
Future upgrades

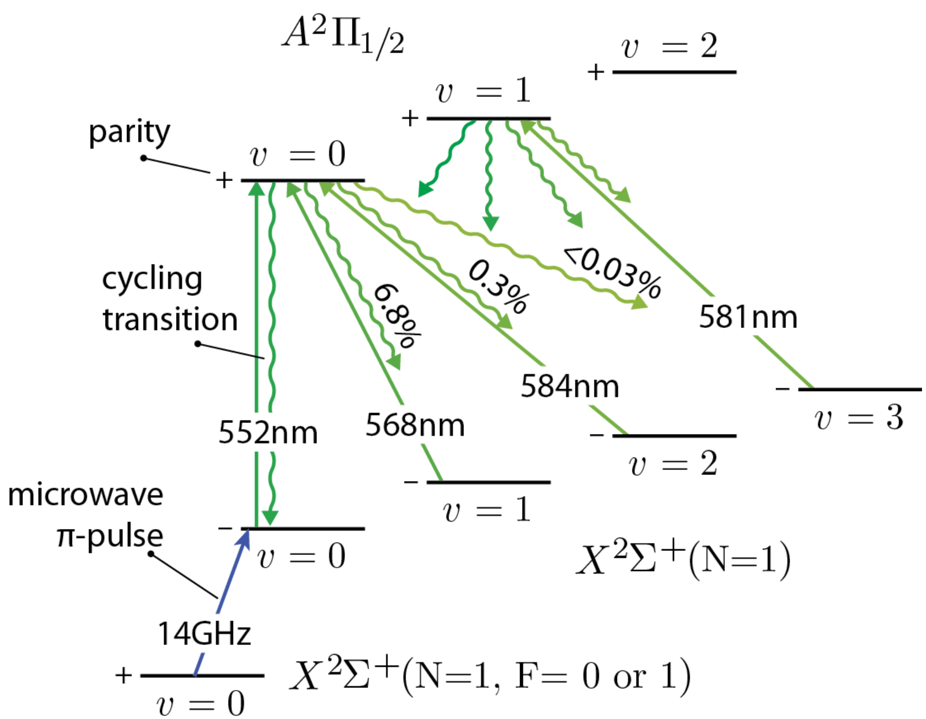
- Buffer gas source
  - » See James Bumby's poster



- *3 x longer interaction time*
- *10 x more molecules*

Future upgrades

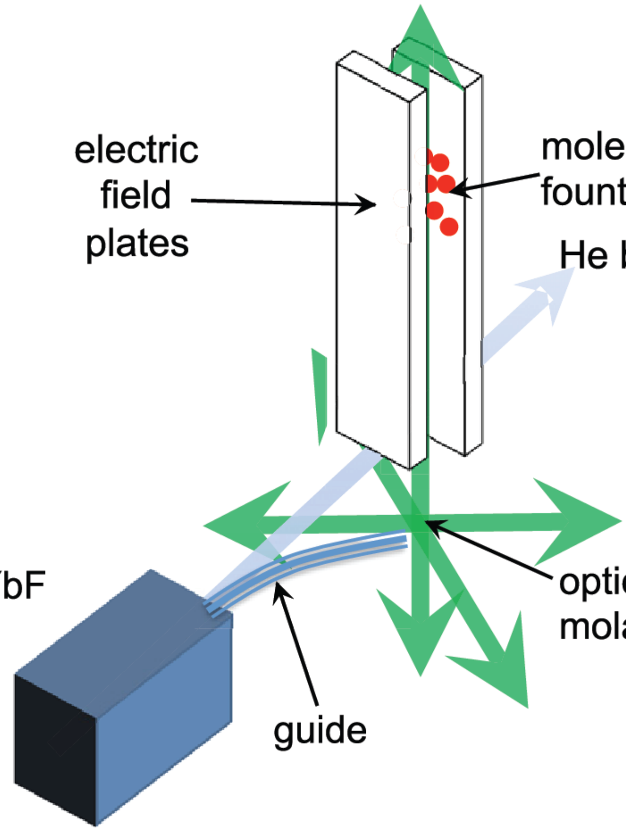
- Detect molecules using N=1
  - » Talk to Isabel Rabey



- *30 x more photons per shot*

YbF fountain

- 0.5s coherence time instead of 0.5ms
  - 6×10^{-31}e cm in 8hrs



Tarbutt *et al.* New J. Phys. **15** 053034 (2013)

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The YbF eEDM team

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EDM measurement

- Measure the EDM induced splitting