A new measurement of the electron edm

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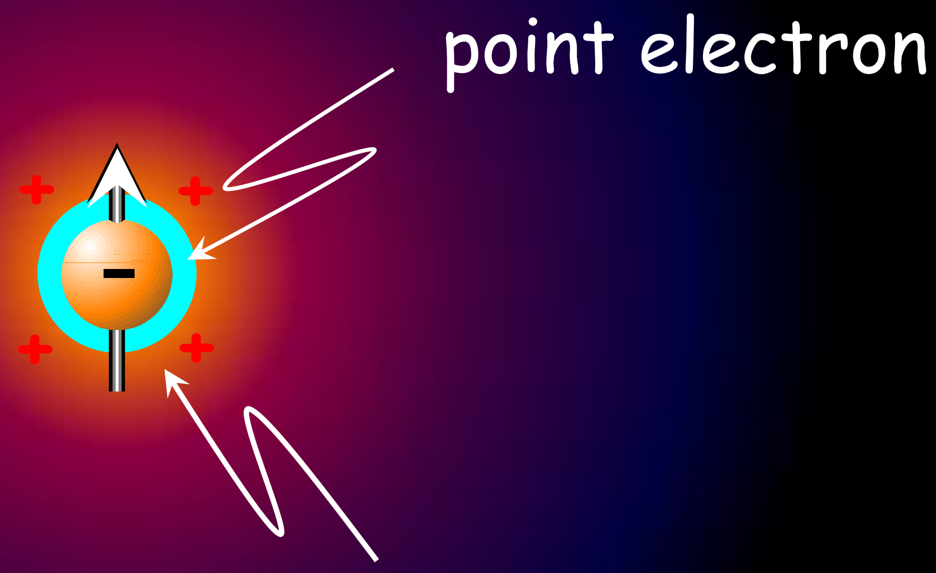
Birmingham, 26 October 2011

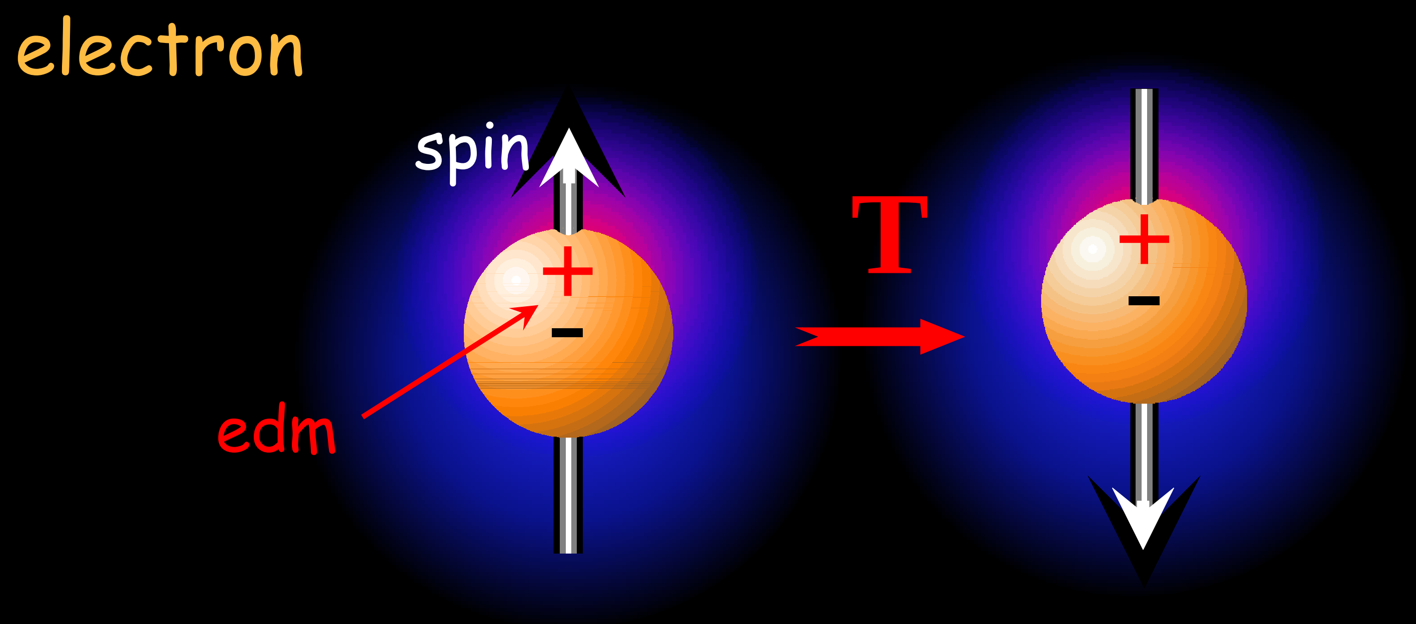
How a point electron gets structure



polarisable vacuum with increasingly rich structure at shorter distances:

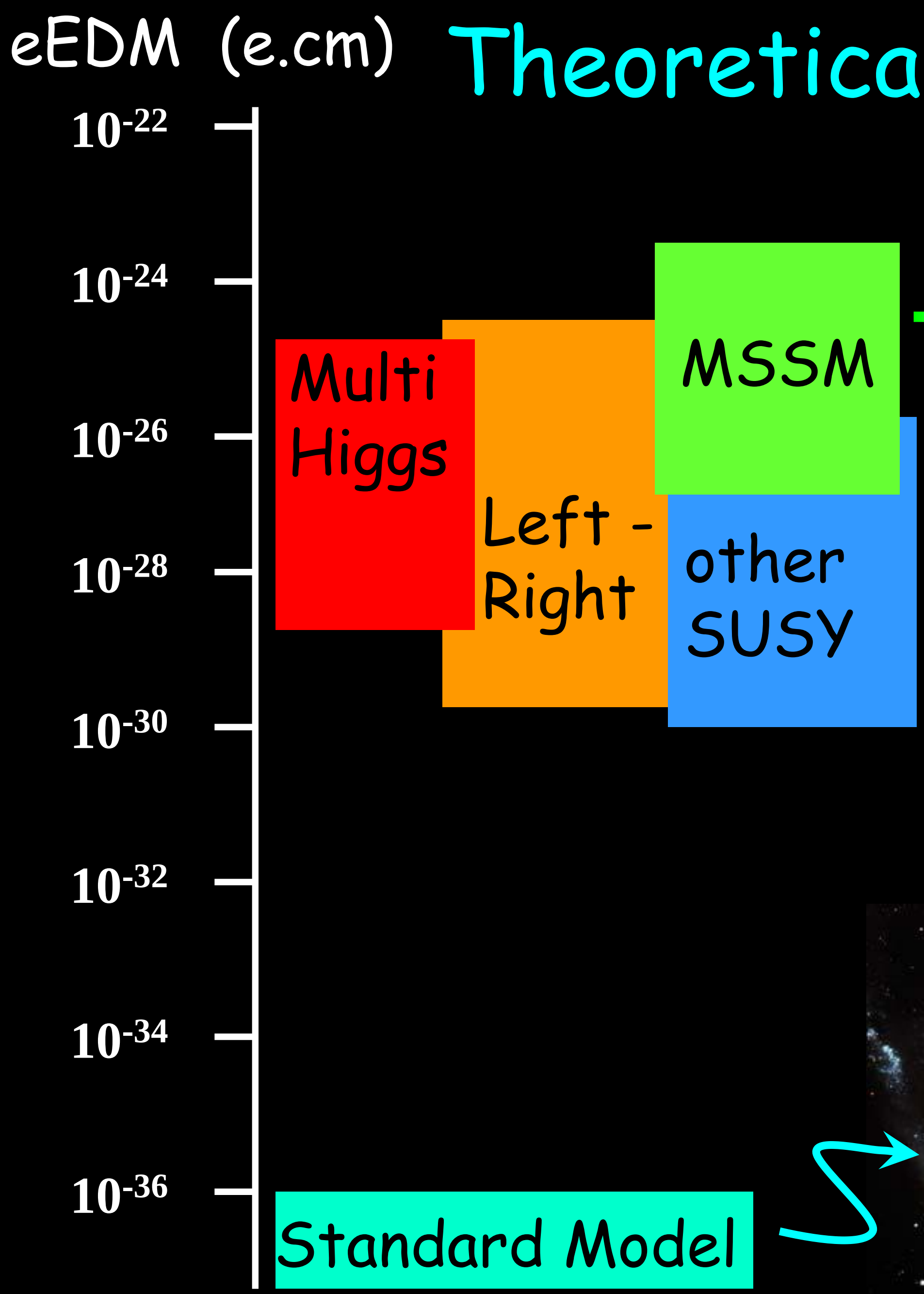
(anti)leptons, (anti)quarks, Higgs (standard model)
beyond that: supersymmetric particles ....?

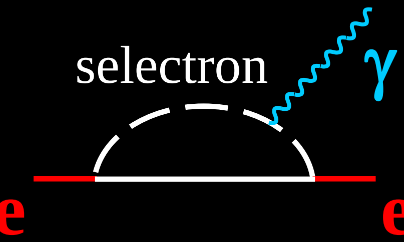
Electric dipole moment (EDM)



If the electron has an EDM,
nature has chosen *one* of these,
breaking T symmetry . . . ~~CP~~

Theoretical estimates of eEDM





The interesting region of sensitivity

Insufficient ~~CP~~
to make universe
of matter

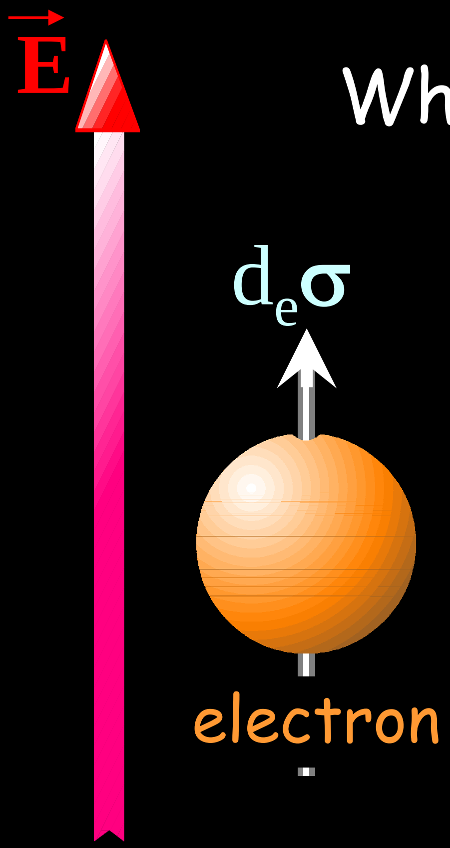
The magnetic moment problem

Suppose $d_e = 5 \times 10^{-28}$ e.cm (the region to explore)

$= 3 \times 10^{-19}$ Debye

In a field of 10kV/cm $\quad d_e \vec{\sigma} \cdot \vec{E} \simeq 1$ nHz

When does $\mu_B \cdot B$ equal this ? $\quad B \simeq 1$ fG

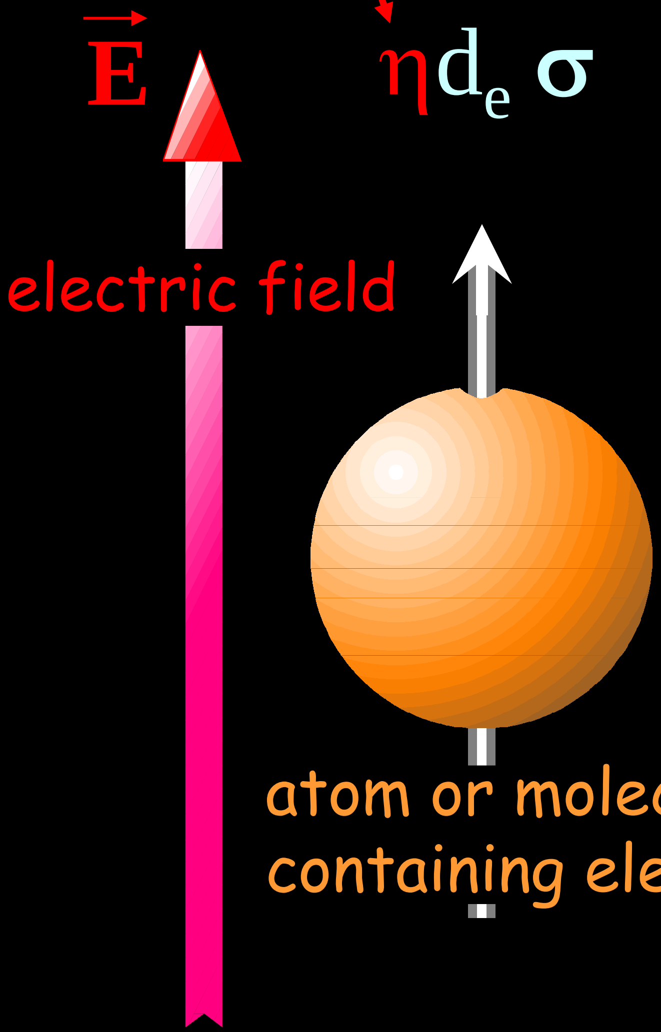


This is very small

A clever solution

For more details, see E. A. H. Physica Scripta T70, 34 (1997)

amplification (Sandars 1964)



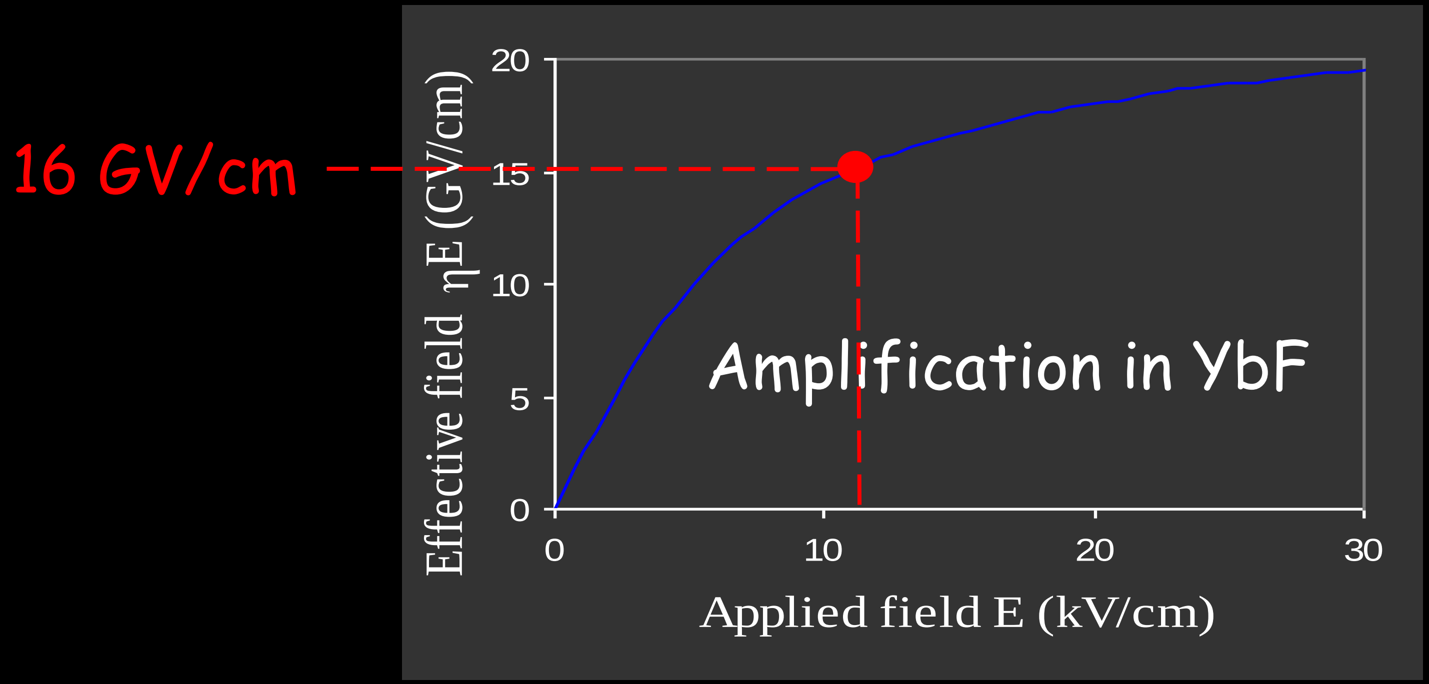
Interaction energy

$$-d_e\, \underbrace{\eta \vec{E}}_{F\,P} \cdot \vec{\sigma}$$

P: Polarization factor

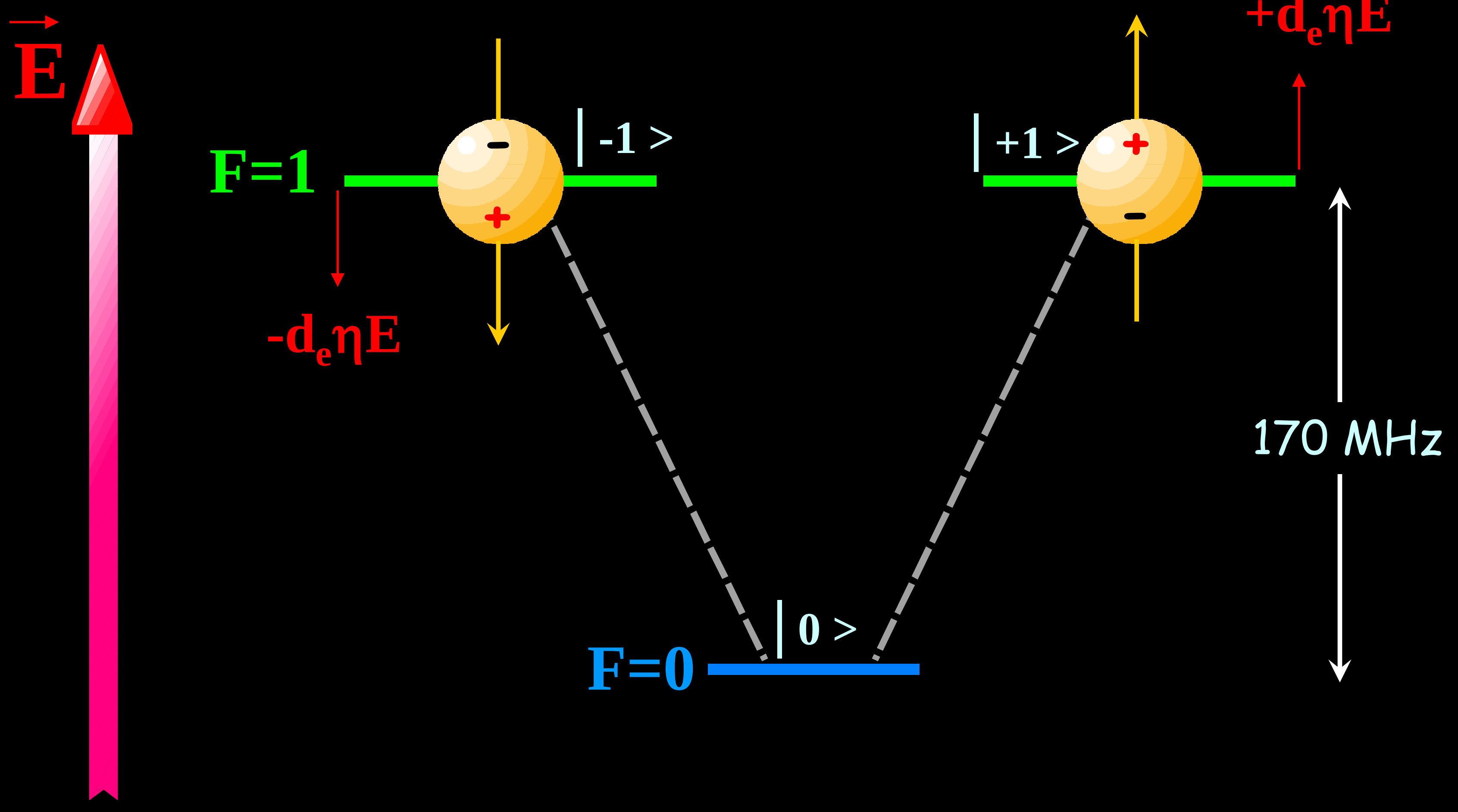
F: Structure-dependent relativistic factor $\propto Z^3$

Our experiment uses a molecule – YbF



- EDM interaction energy is a million times larger (mHz)
- needs nG stray B field control

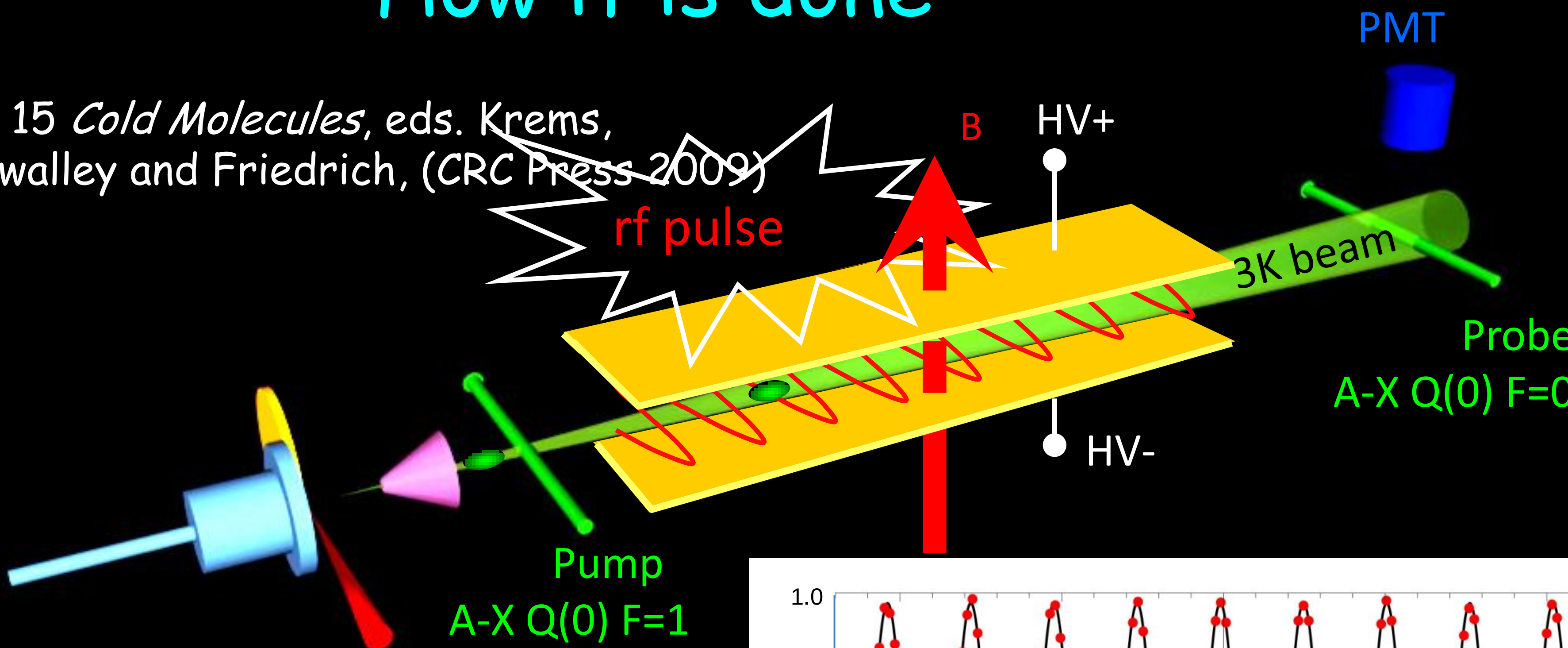
The lowest two levels of YbF $X^2\Sigma^+ (N = 0, v = 0)$

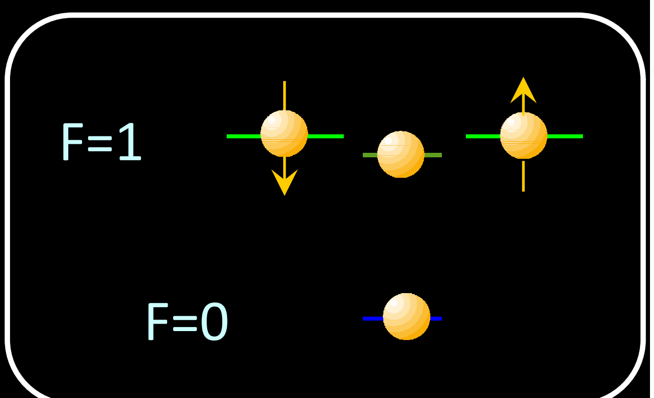


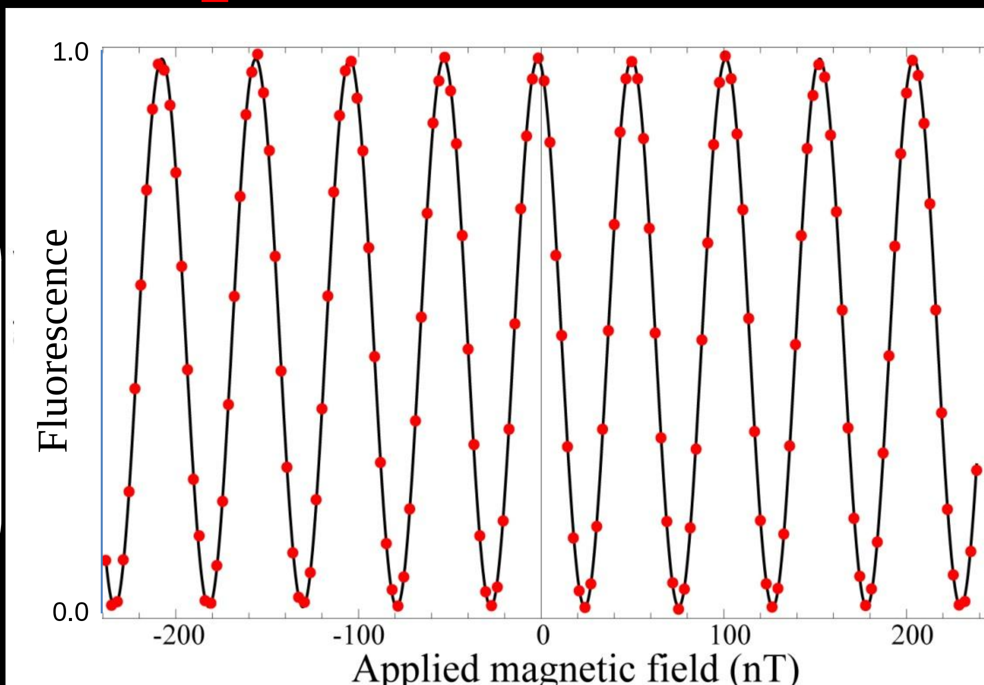
Goal: measure the splitting $2d_e\eta E$ to ~1mHz

How it is done

Ch 15 *Cold Molecules*, eds. Krems, Stwalley and Friedrich, (CRC Press 2009)

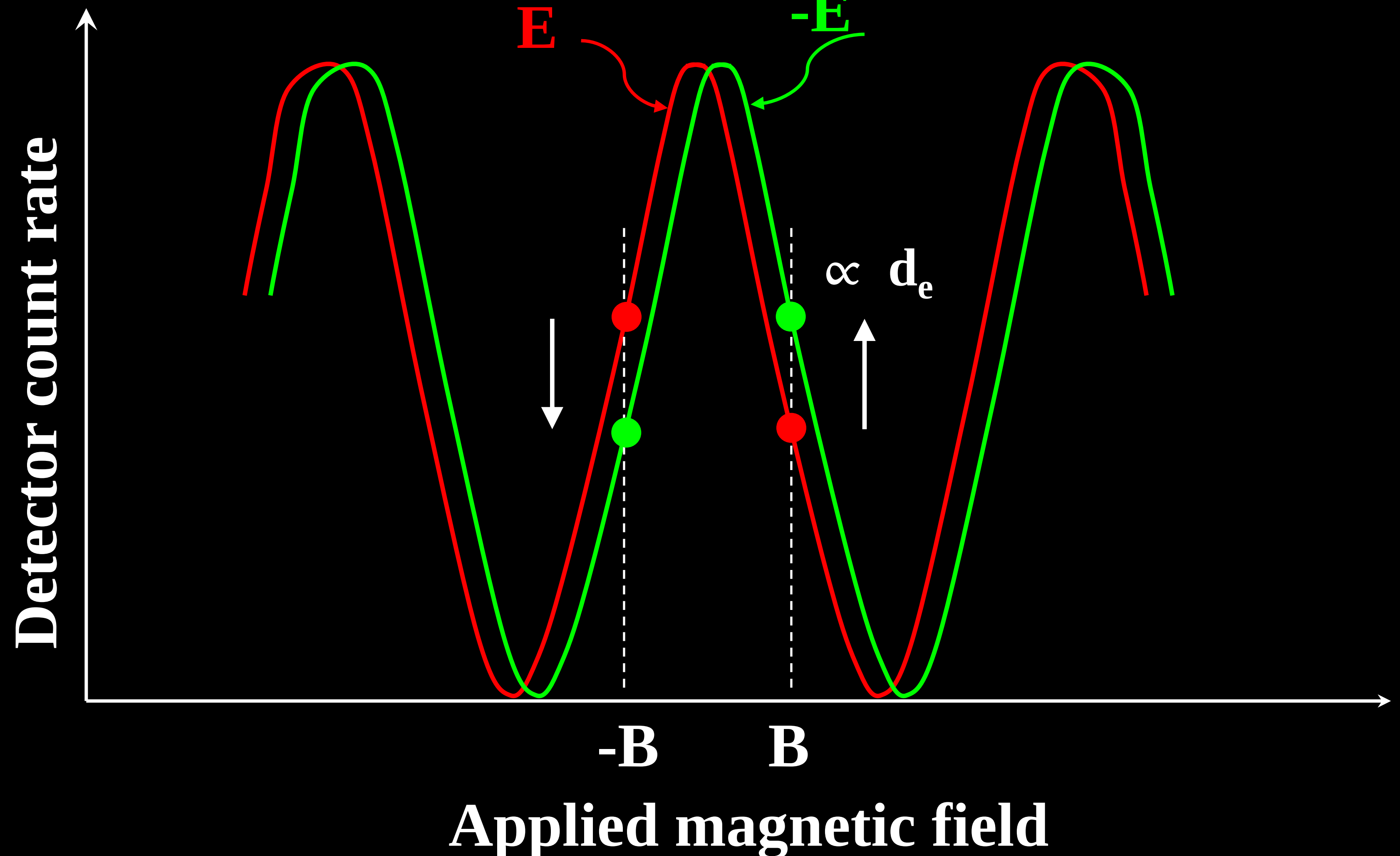




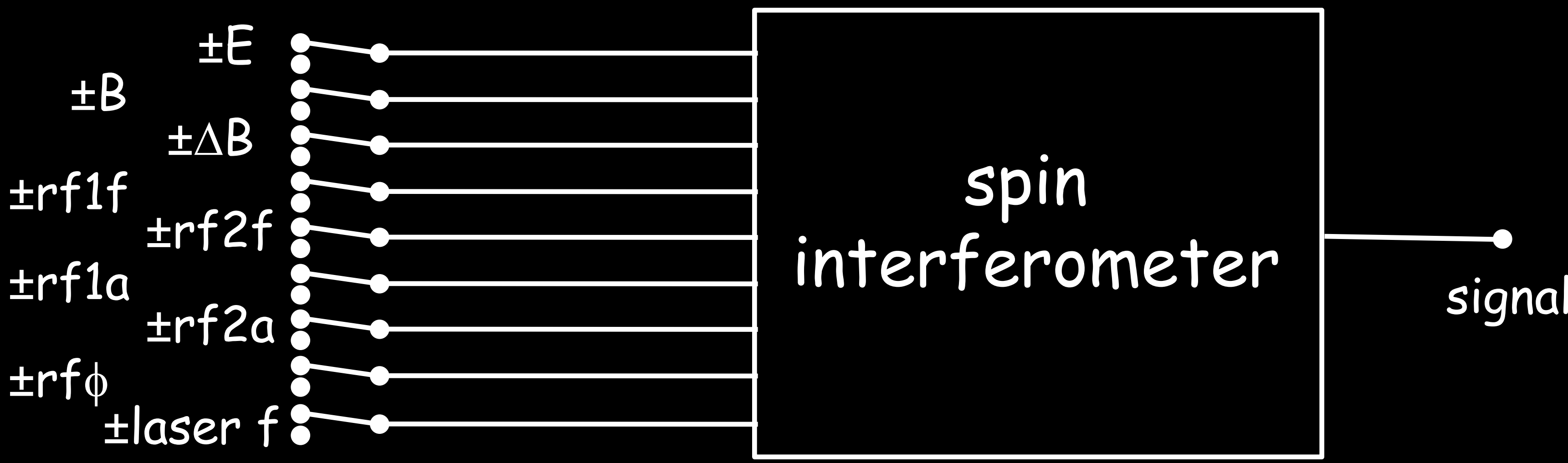


Measuring the edm

Interferometer phase $\phi = 2(\mu B \pm d_e \eta E)\tau/\hbar$



Modulate everything



9 switches:

512 possible correlations

- Generalisation of phase-sensitive detection
- Switch periodically on short timescale

  but randomly on long timescale.
- Measure all 512 correlations.

** Don't look at the mean edm **

- We don't know what result to expect.
- Still, to avoid inadvertent bias we hide the mean edm.
- A random blind offset is added that only the computer knows.
- More important than you might think.
  - e.g. Jeng, Am. J. Phys. **74** (7), 2006.

Measuring the other 511 correlations

	correlation	mean	σ	mean/σ
✓ fringe slope calibration	{DB}	{-19.8038,	0.251037}	78.888
✓ beam intensity	{SIG}	{150.576,	1.9145}	78.6502
✓ ϕ-switch changes rf amplitude	{EI, RF2A}	{0.0781105,	0.00478208}	16.334
✓ E drift	{RF1F, RF2F}	{0.0709938,	0.00481574}	14.742
✓ E asymmetry	{E, RF2F}	{0.0282234,	0.00457979}	6.16259
✓ E asymmetry	{E, RF1F}	{0.0239194,	0.00437301}	5.46978
✓ inexact π pulse	{DB, RF1A}	{-0.0212292,	0.00407424}	5.21058

- Nearly all are zero (as they should be) !

The only systematic error correction

- rf detuning from resonance

  makes a (small) interferometer phase shift

  We measure this by the {rf1f.B} and {rf2f.B} correlations

  they are both ~ 100 nrad/Hz

- Electric field "reversal"

  changes magnitude of E (slightly) causing a Stark shift

  We measure this by the {rf1f.E} and {rf2f.E} correlations

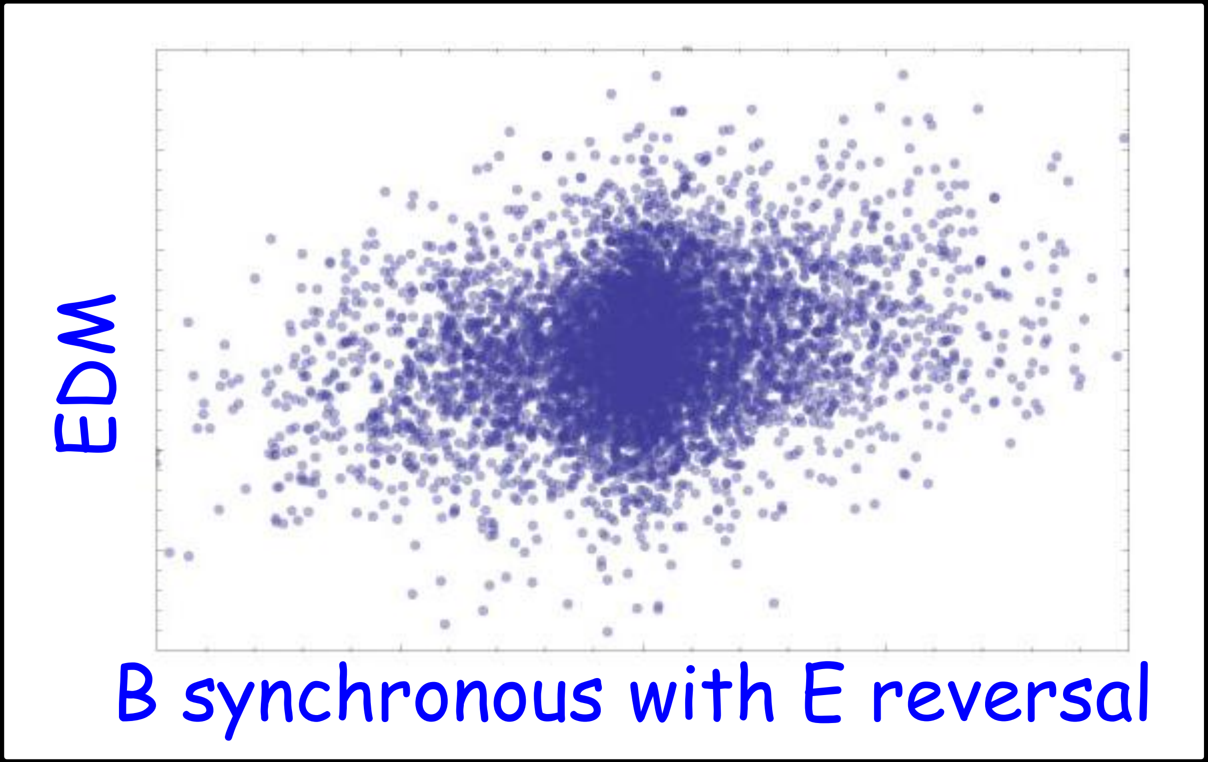
- Together $\Longrightarrow$ false EDM

  We measure and correct: $(+5.5 \pm 1.1) \times 10^{-28}$ e.cm.

- Magnetic field noise

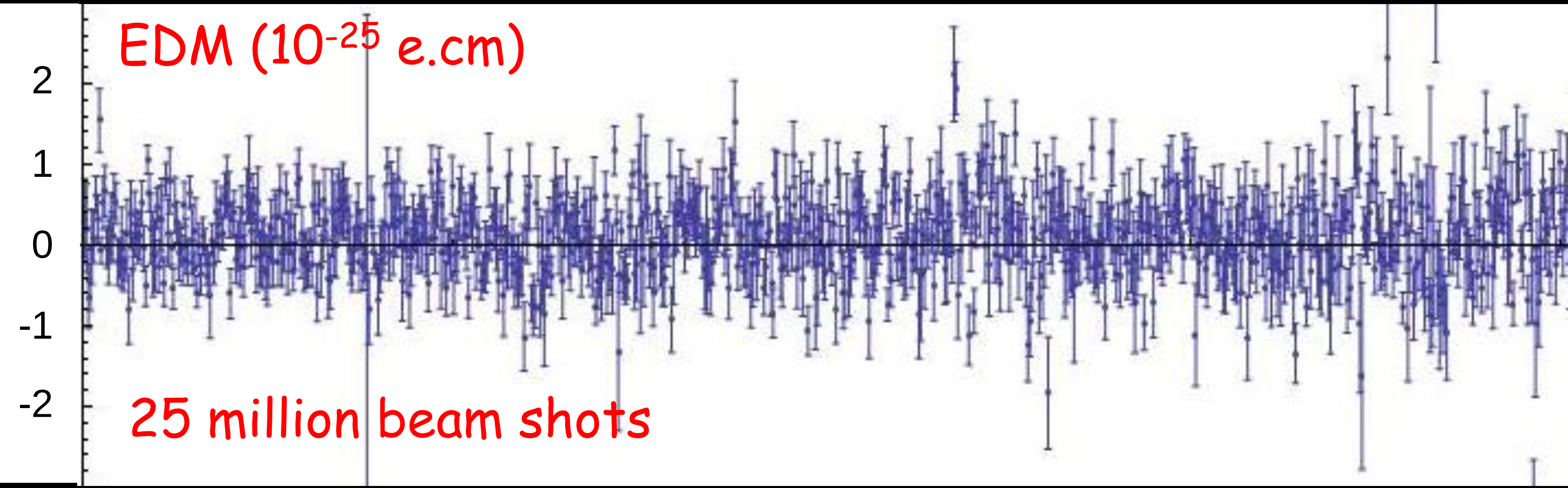
B fluctuations have some component synchronous with E reversal:

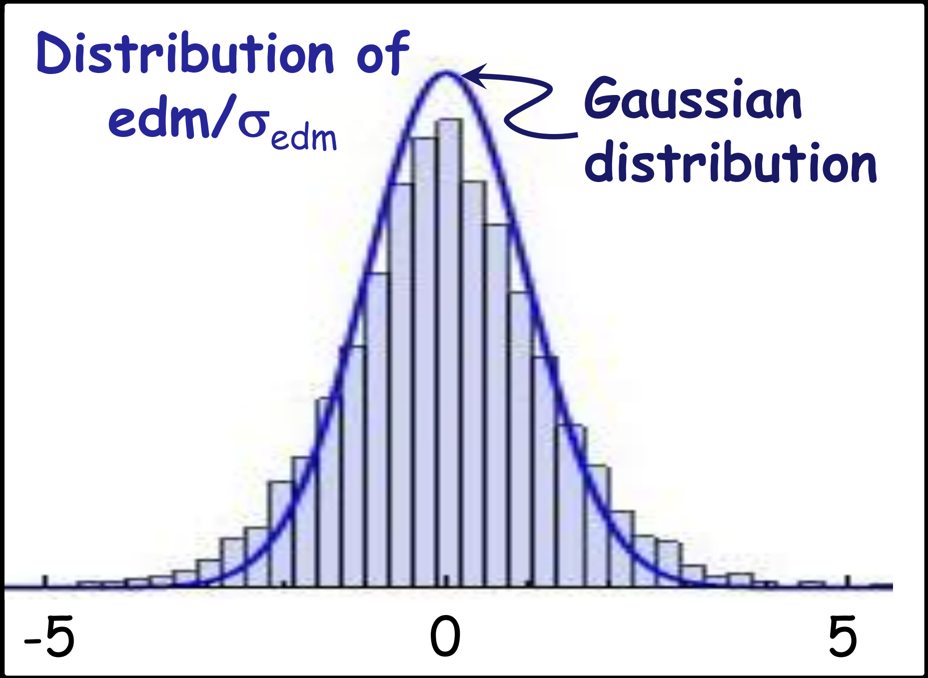
$\Longrightarrow$ EDM noise



We measure and correct: $(-0.3 \pm 1.7) \times 10^{-28}$ e.cm.

6194 measurements (~6 min each) at 10 kV/cm.





bootstrap method determines distribution

68% confidence level

?? ± 5.7 $\times 10^{-28}$ e.cm

includes blind offset

Current status

- Previous result - Tl atoms

Regan *et al.* (PRL 2002)
Nataraj *et al.* (PRL 2011)
Dzuba/Flambaum (PRL 2009)

$d_e < 2.0 \times 10^{-27}$ e.cm with 90% confidence

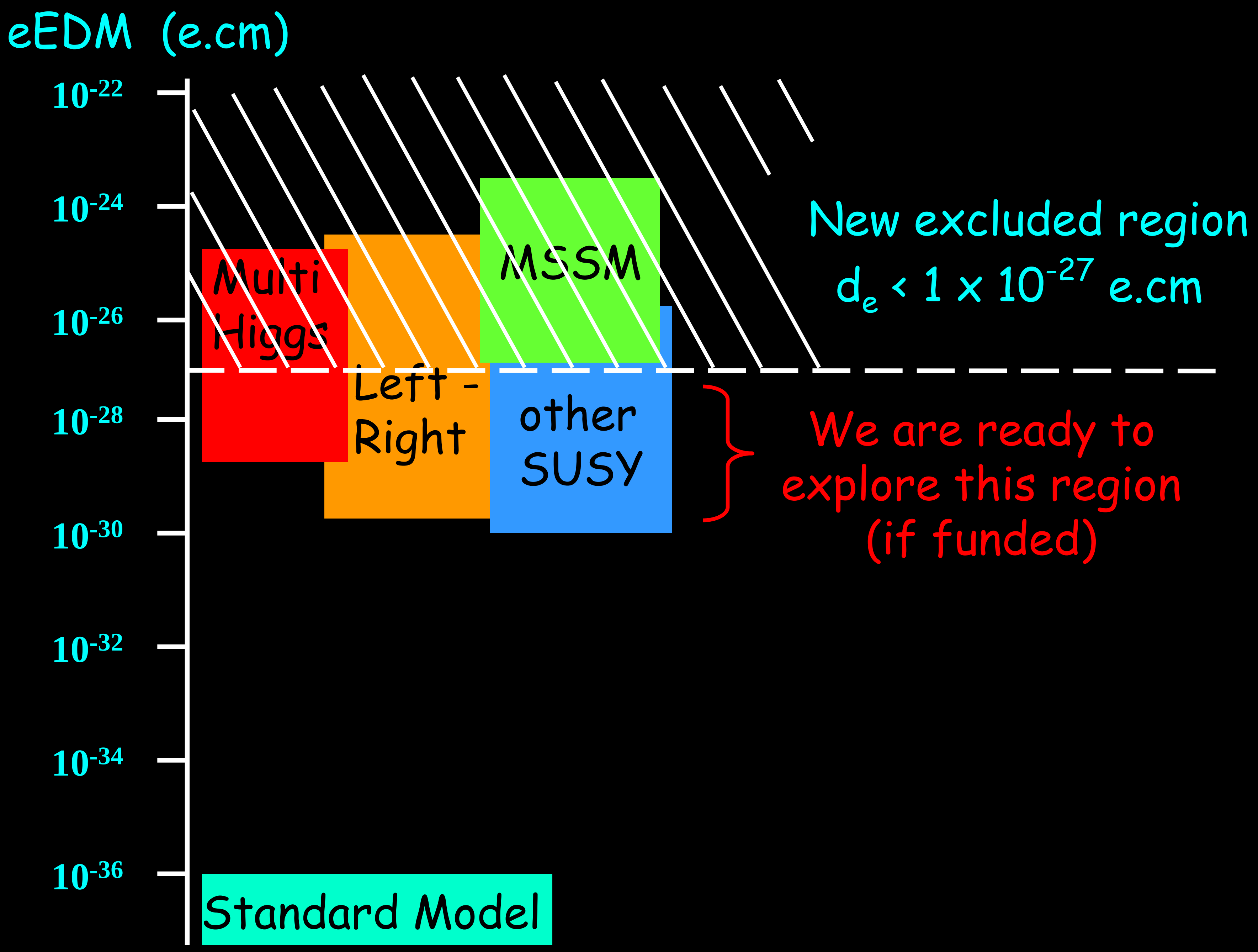
- New result – YbF – Hudson *et al.* (Nature 2011)

$d_e = (-2.4 \pm 5.7 \pm 1.5) \times 10^{-28}$ e.cm

68% statistical

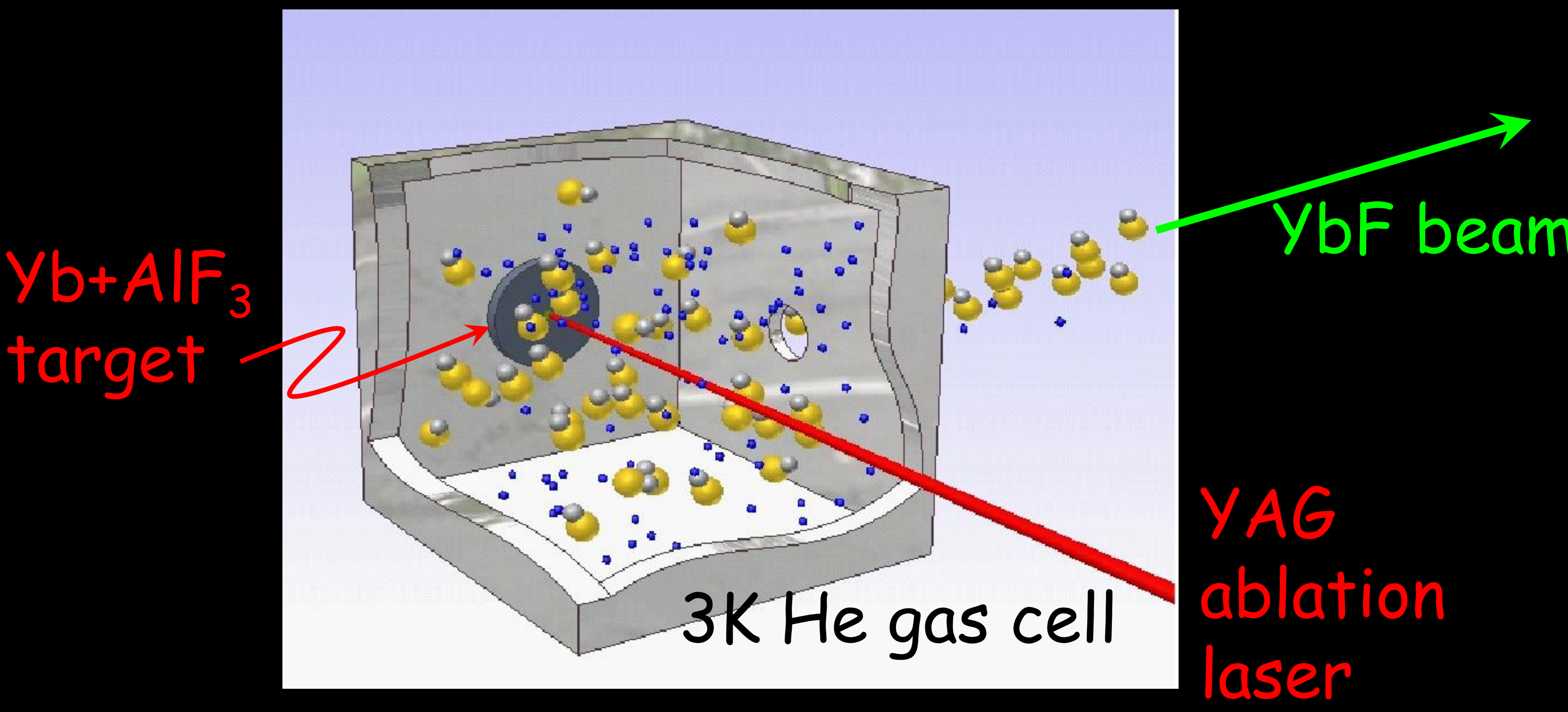
systematic - limited by statistical noise

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



eEDM (e.cm)
10^{-22}
10^{-24}
10^{-26}
10^{-28}
10^{-30}
10^{-32}
10^{-34}
10^{-36}
Multi Higgs
Left - Right
MSSM
other SUSY
Standard Model
New excluded region
$d_e < 1 \times 10^{-27}$ e.cm
We are ready to explore this region (if funded)

New cryogenic buffer gas source of YbF



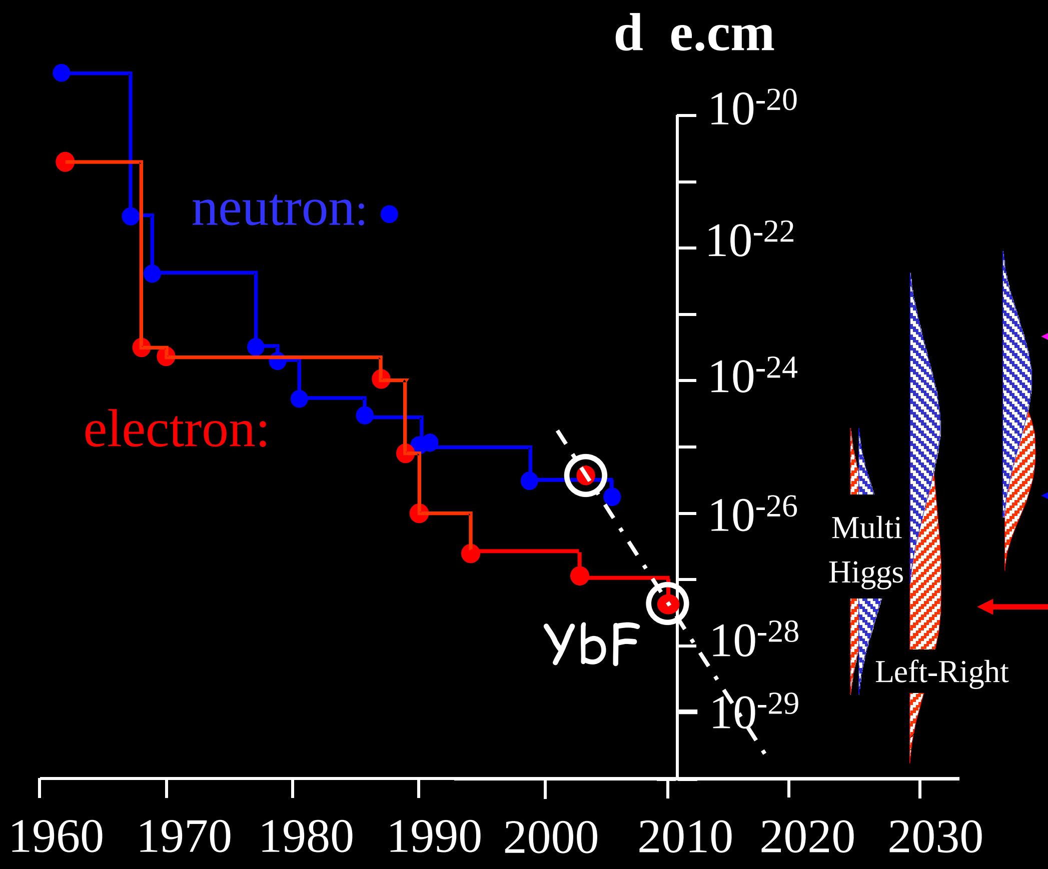
15 × more molecules/pulse

3 × longer interaction time (slower beam)

=> 10 × better signal:noise ratio

=> access to mid 10^{-29} e.cm range

Current status of EDMs



d(muon) ≤ 7×10^{-19}

d(proton) ≤ 5×10^{-24}

d(neutron) ≤ 3×10^{-26}

d(electron) ≤ 1×10^{-27}

Summary

e- EDM is a direct probe of physics beyond SM

specifically probes CP violation
(how come we're here?)

absence of EDM suggests no
min. supersymmetry

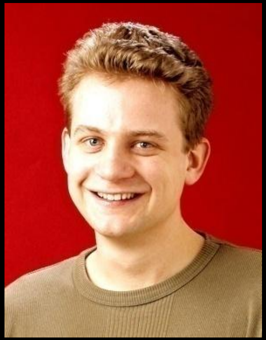
Atto-eV molecular spectroscopy tells us about TeV particle physics!

EDM Group Members

Jony Hudson

Ben Sauer

EAH



Mike Tarbutt

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