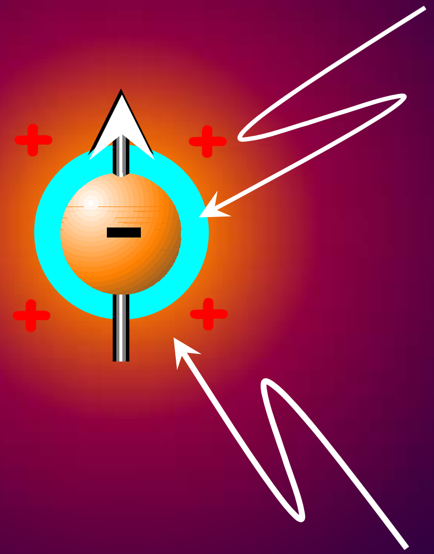
Is the electron round?
Search for the electron's EDM

E.A. Hinds

Centre for Cold Matter
Imperial College London

Toronto University, 7 March 2013

How a point electron gets structure



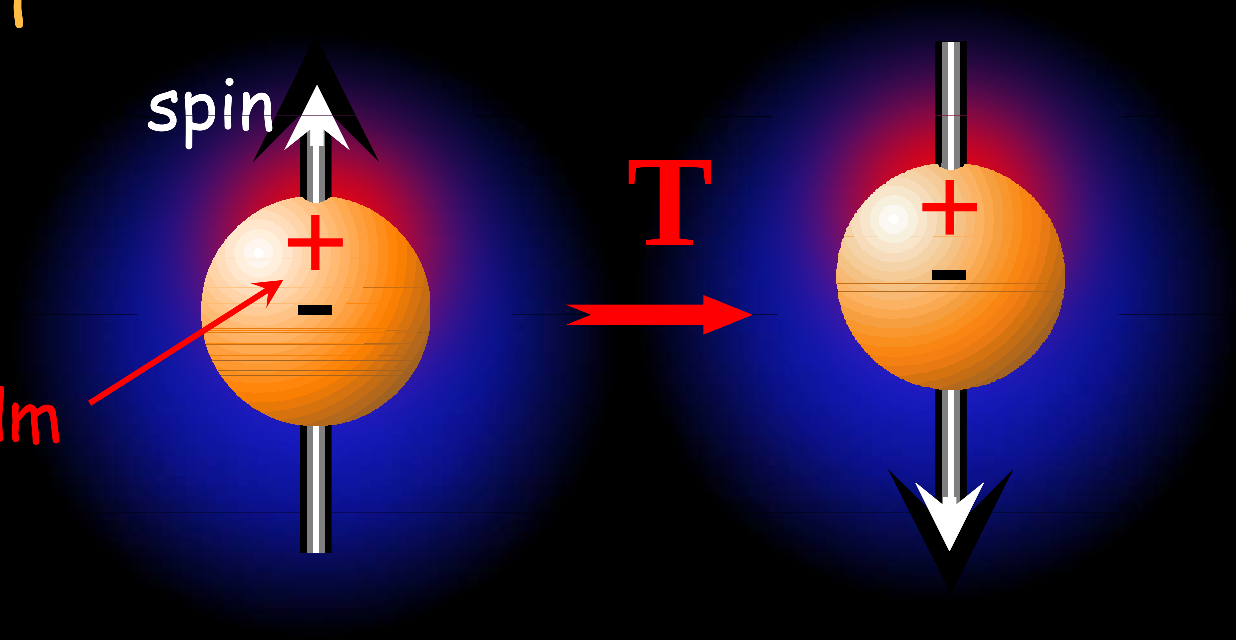
point electron

polarisable vacuum with increasingly
rich structure at shorter distances:

(anti)leptons, (anti)quarks, Higgs (standard model)
beyond that: new particles ………?

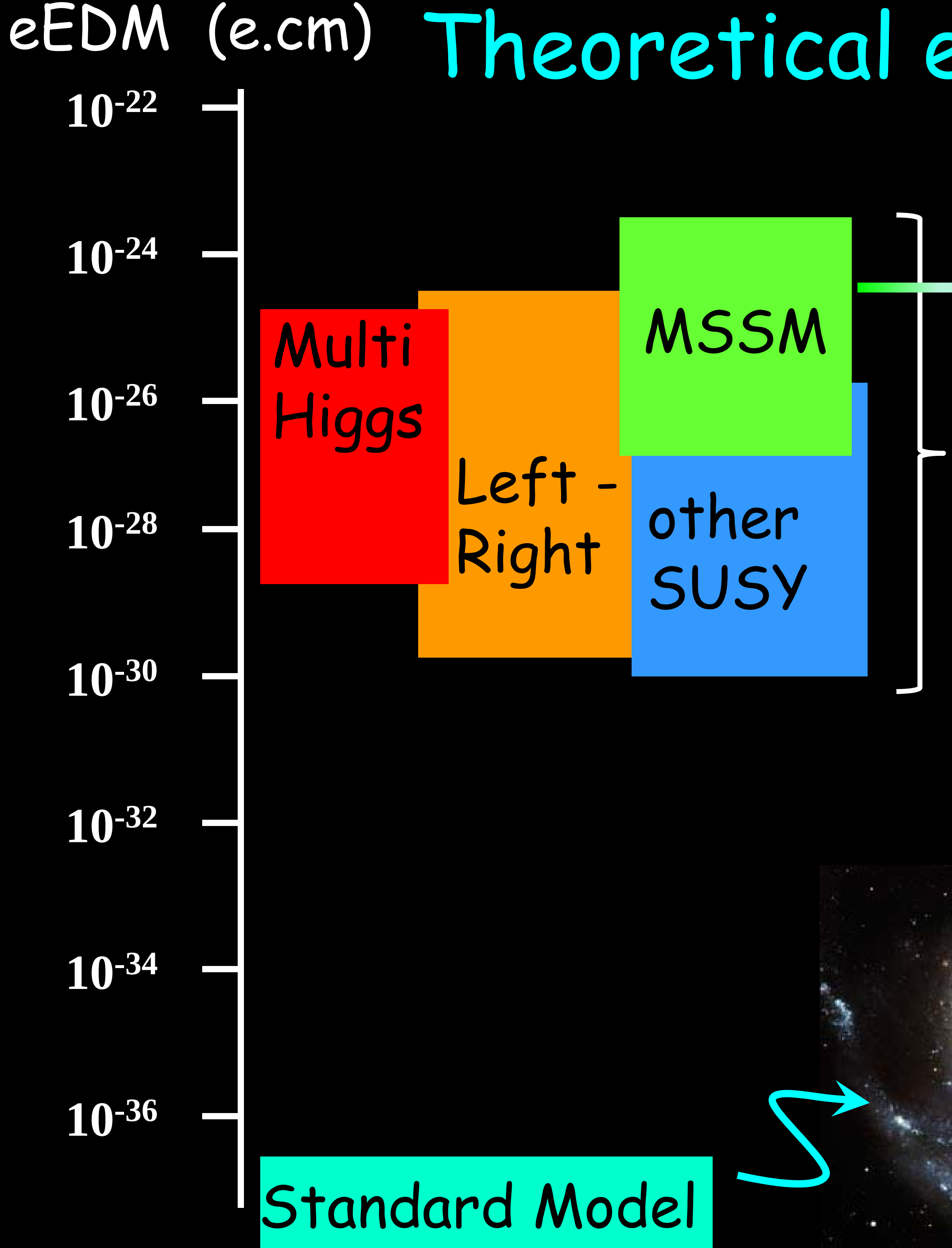
Electric dipole moment (EDM)

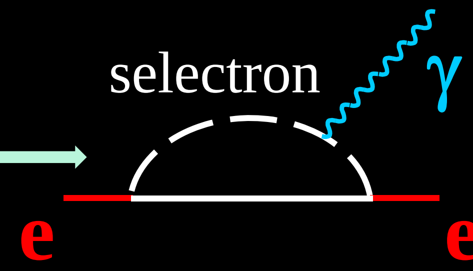
electron



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

Theoretical estimates of eEDM





$$\frac{\alpha}{\pi}\frac{m_e}{m_s^2}\sin\phi$$

The interesting region of sensitivity

Insufficient ~~CP~~ to make universe of matter

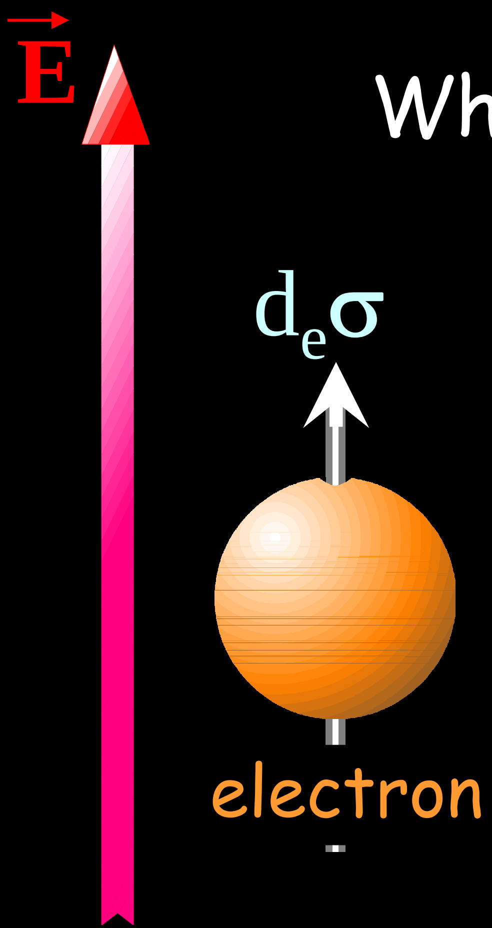
The magnetic moment problem

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

$= 1 \times 10^{-19}$ e.a_0

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

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



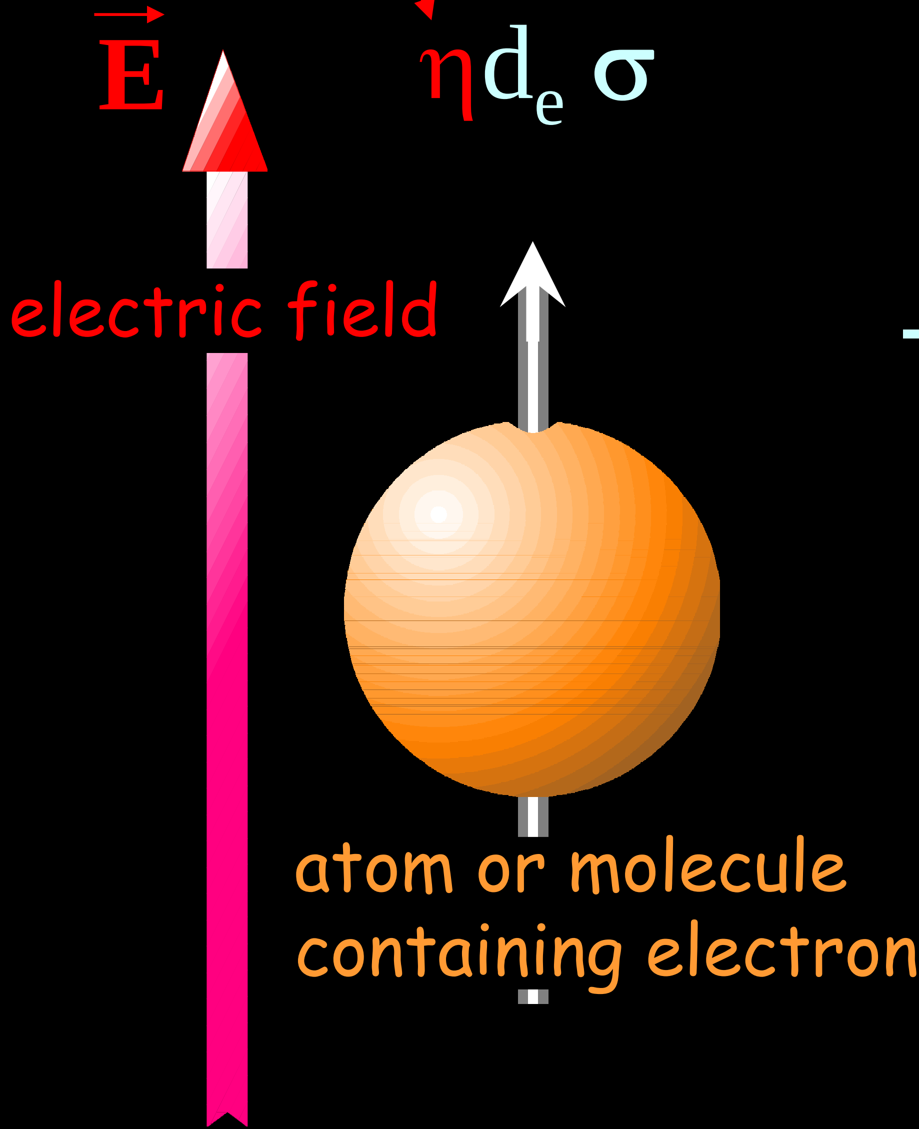
This is very small

A clever solution

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

amplification (Sandars)

$\eta d_e \sigma$



Interaction energy

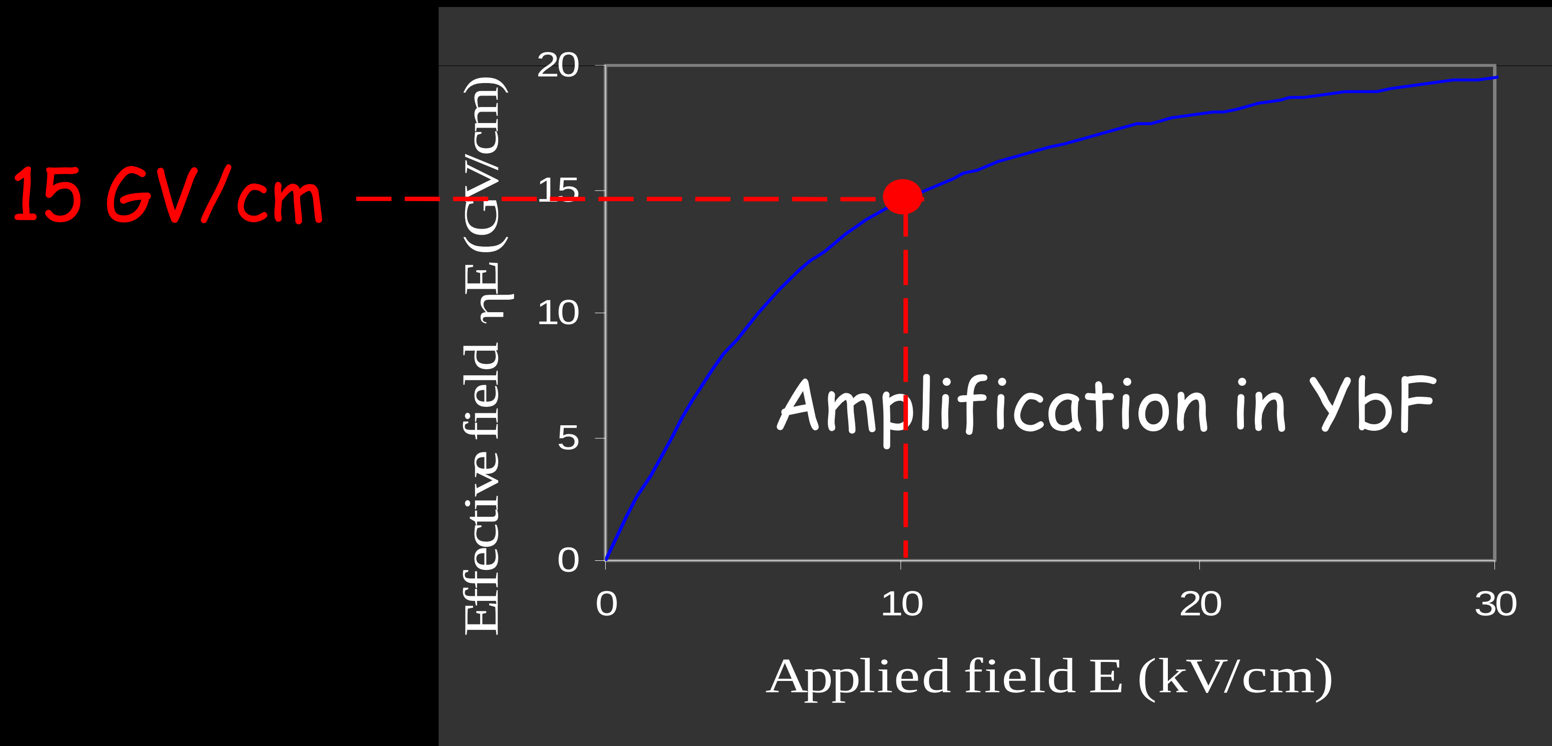
$$-d_e \, \eta \vec{E} \cdot \vec{\sigma}$$

$F \, P$

Polarization factor

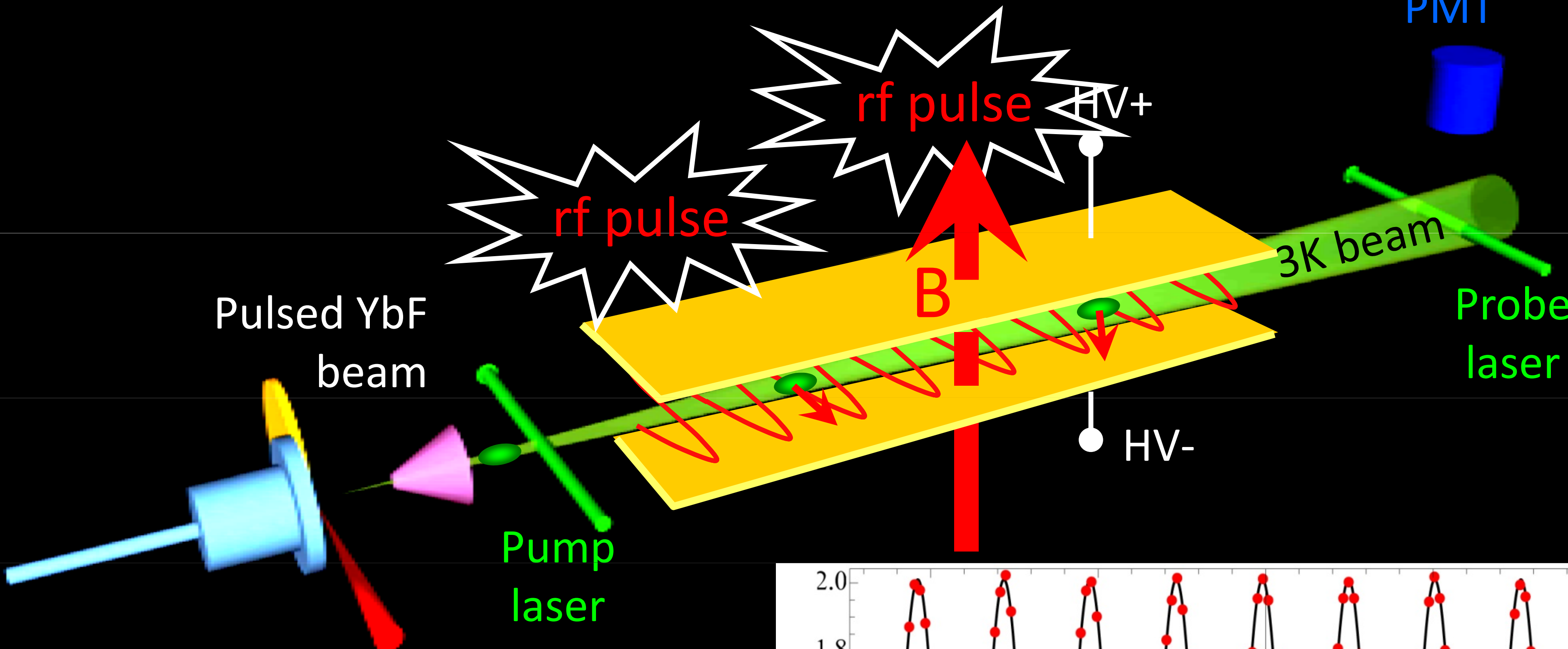
Structure-dependent relativistic factor $\propto Z^3$

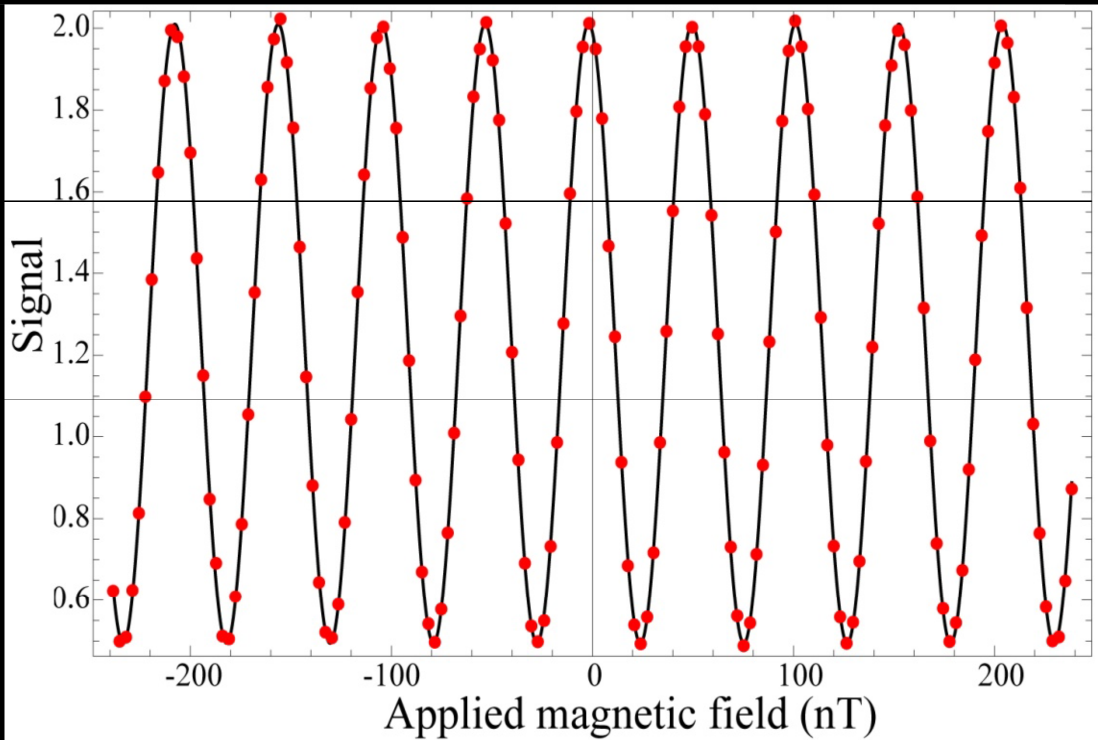
Our experiment uses a polar molecule - YbF



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

How it is done

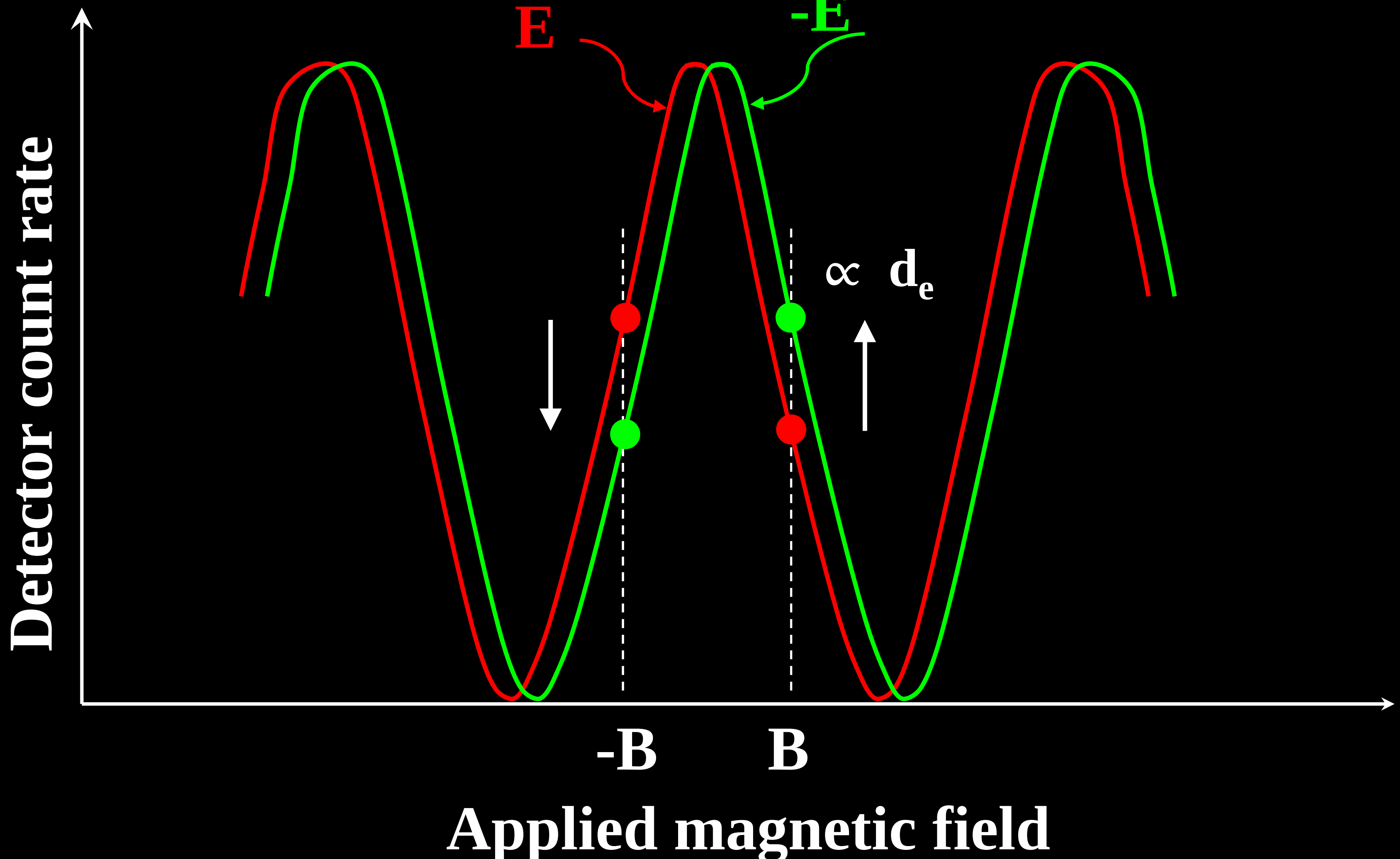




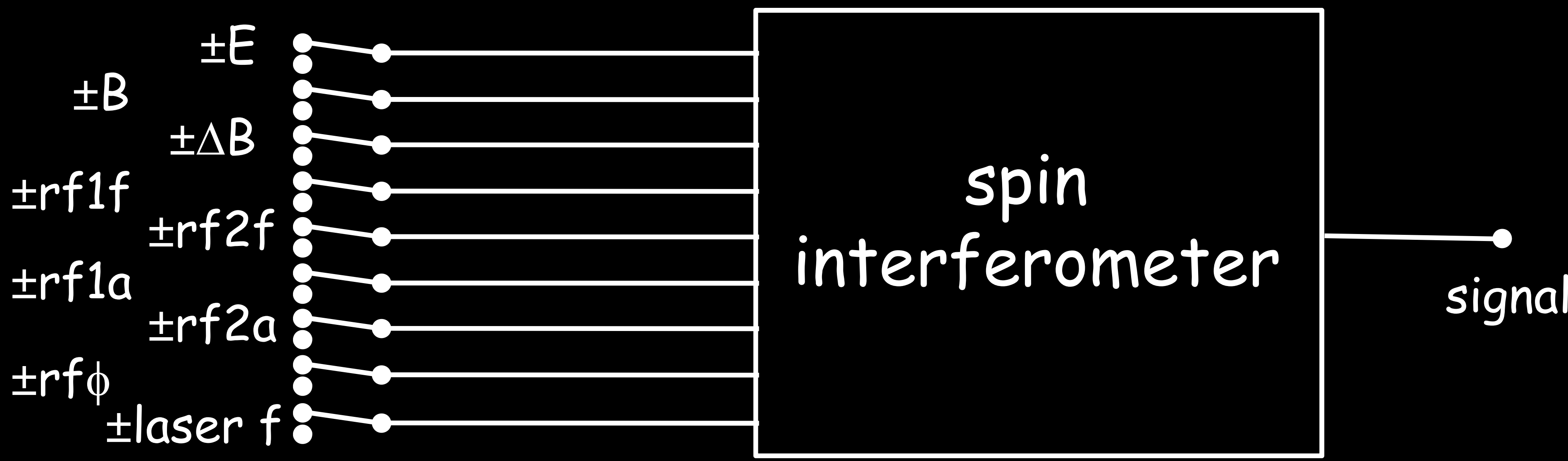
These "interferometer fringes" measure the spin rotation angle ϕ

Measuring the edm

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



Modulate everything



9 switches:

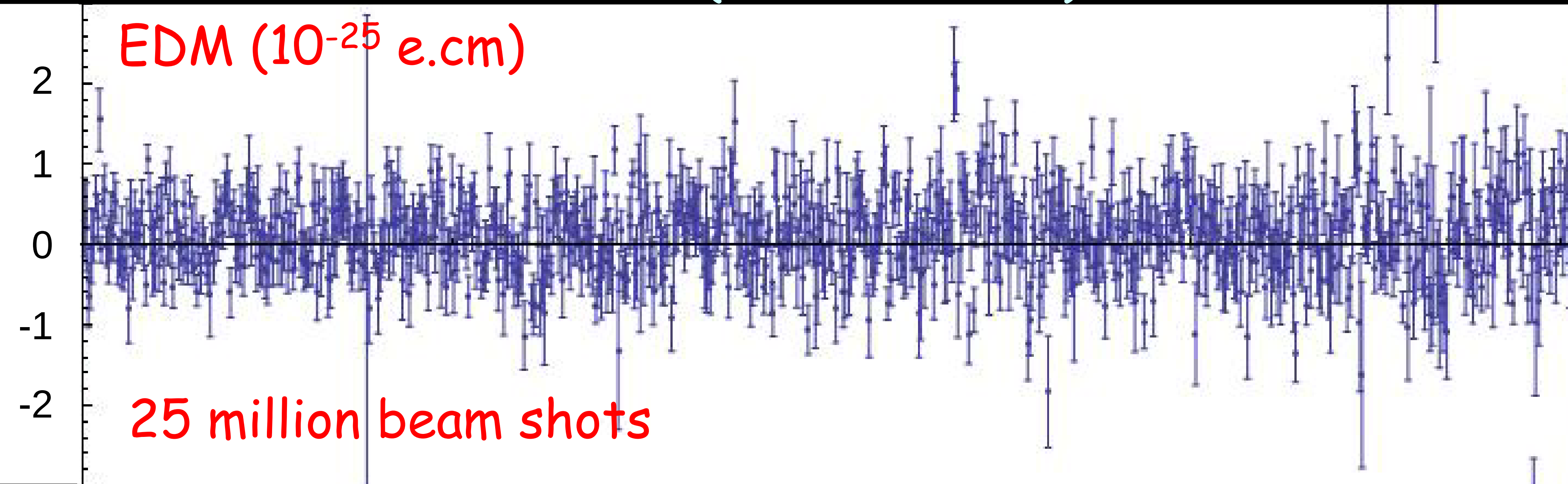
512 possible correlations

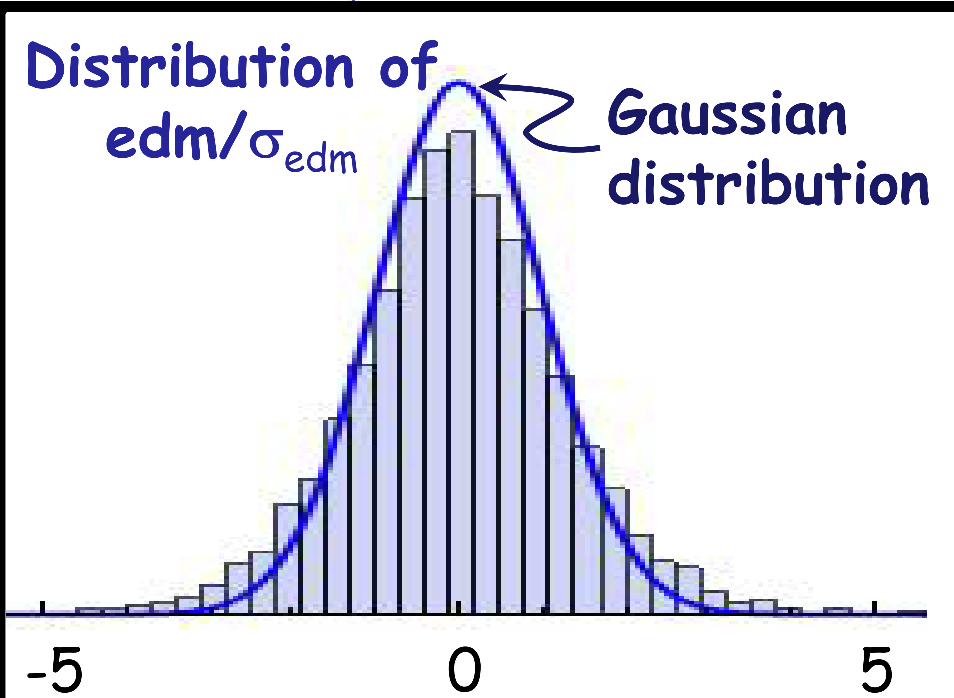
- Generalisation of phase-sensitive detection
- Measure all 512 correlations.
- E·B correlation gives EDM signal

** 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.
- An offset is added that only the computer knows.
- More important than you might think.
  - e.g. Jeng, Am. J. Phys. **74** (7), 2006.

2011 Data:
6194 measurements (~6 min each) at 10 kV/cm.





bootstrap method determines probability distribution

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	[illegible]	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

- The rest are zero (as they should be) !
- Only now remove blind from EDM

Current status

- Previous result - Tl atoms

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

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

- 2011 result – YbF

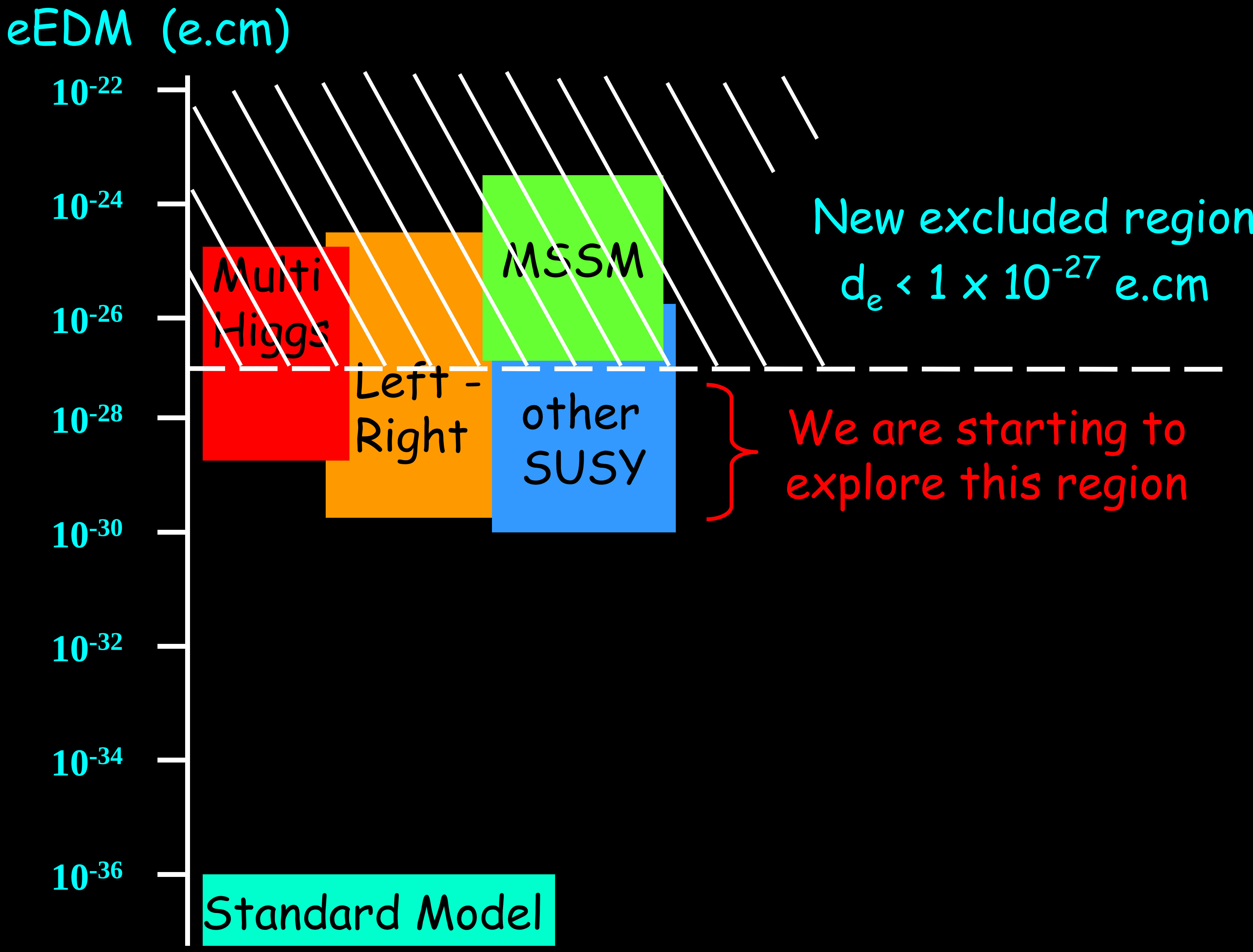
Kara *et al.* NJP 14, 103051 (2012)
Hudson *et al.* (Nature 2011)

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

68% statistical

systematic - limited by statistical noise

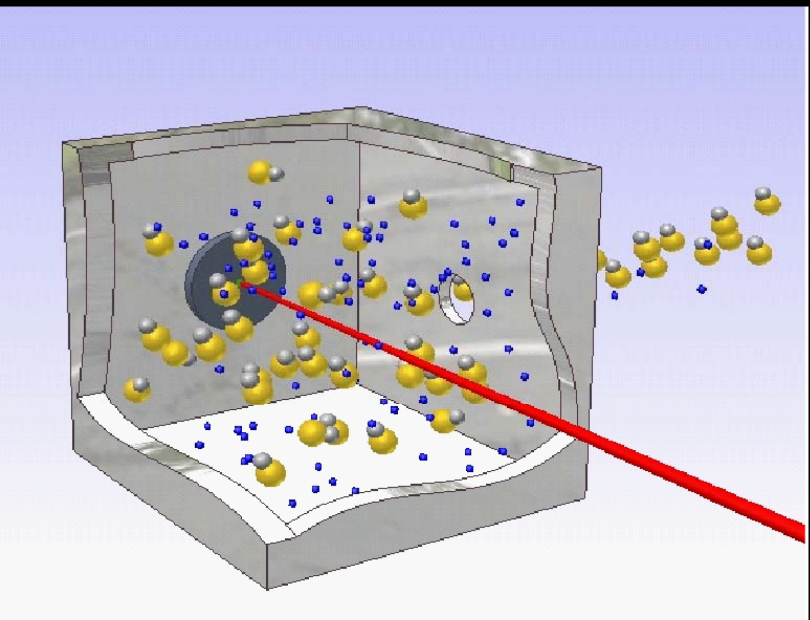
$d_e < 1 \times 10^{-27}$ e.cm with 90% confidence

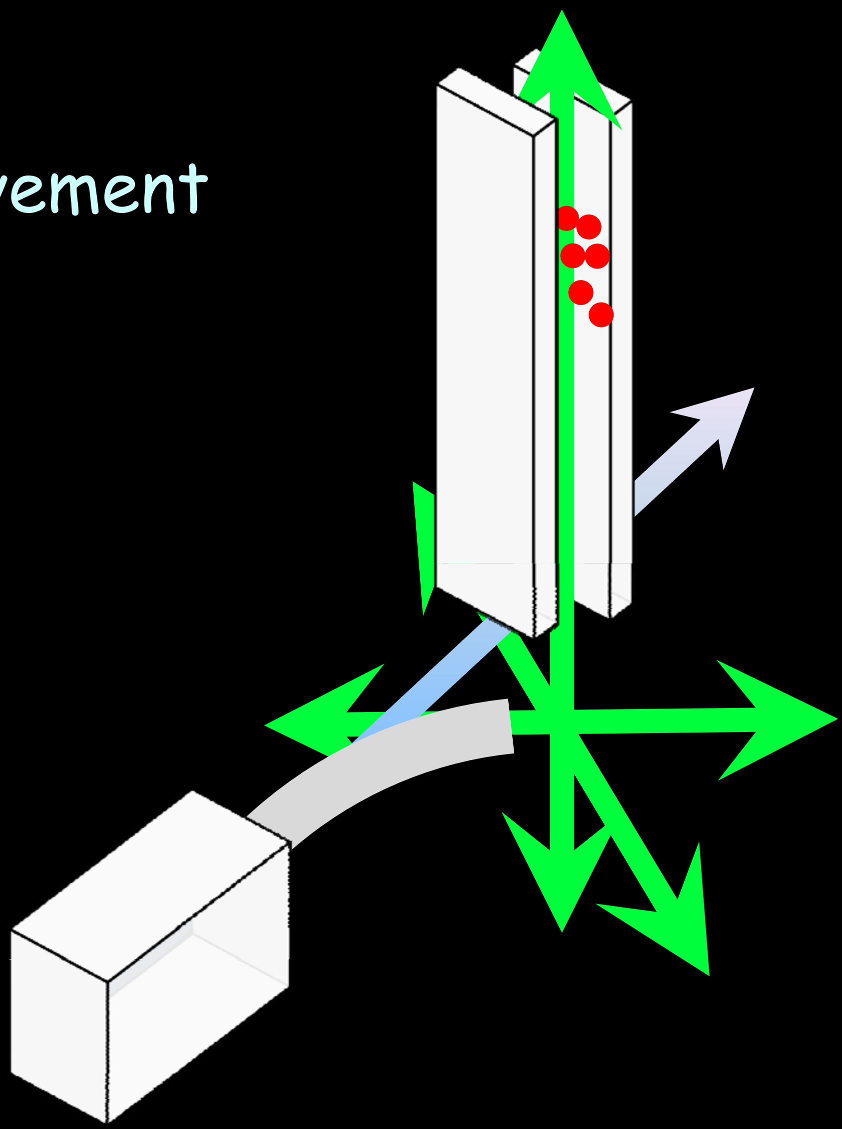

eEDM (e.cm)
10-22
10-24
10-26
10-28
10-30
10-32
10-34
10-36
Multi Higgs
Left - Right
MSSM
other SUSY
Standard Model
New excluded region
$d_e < 1 \times 10^{-27}$ e.cm
We are starting to explore this region

How we will improve

Phase 1 Small upgrades: 3 x improvement
– in progress

Phase 2 Cryogenic source of YbF
– almost ready

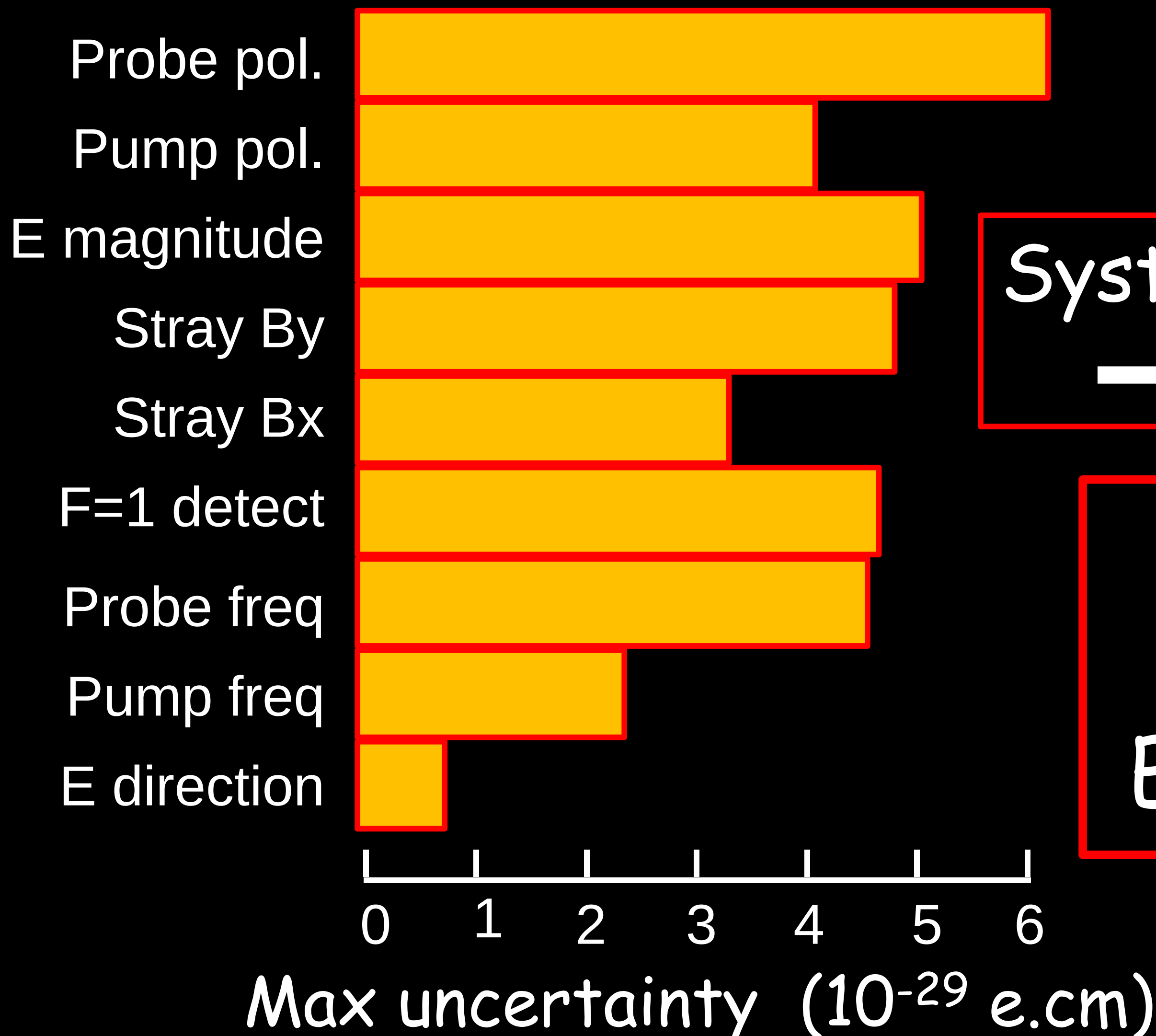




Phase 3 Laser-cooled molecular fountain
– being developed

Phase 1:

Defects emphasised



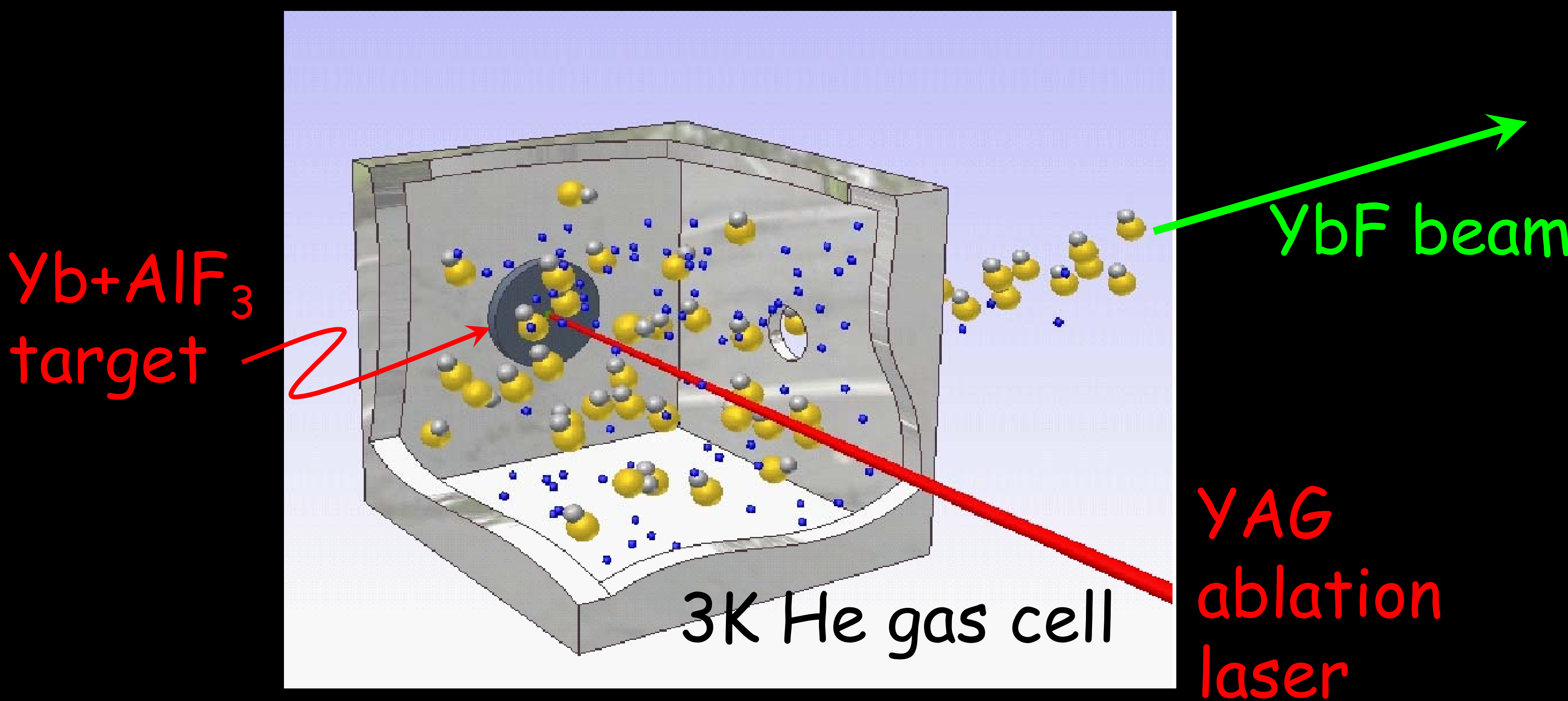
- Longer interferometer
- Lower background

→ 2.5×sensitivity

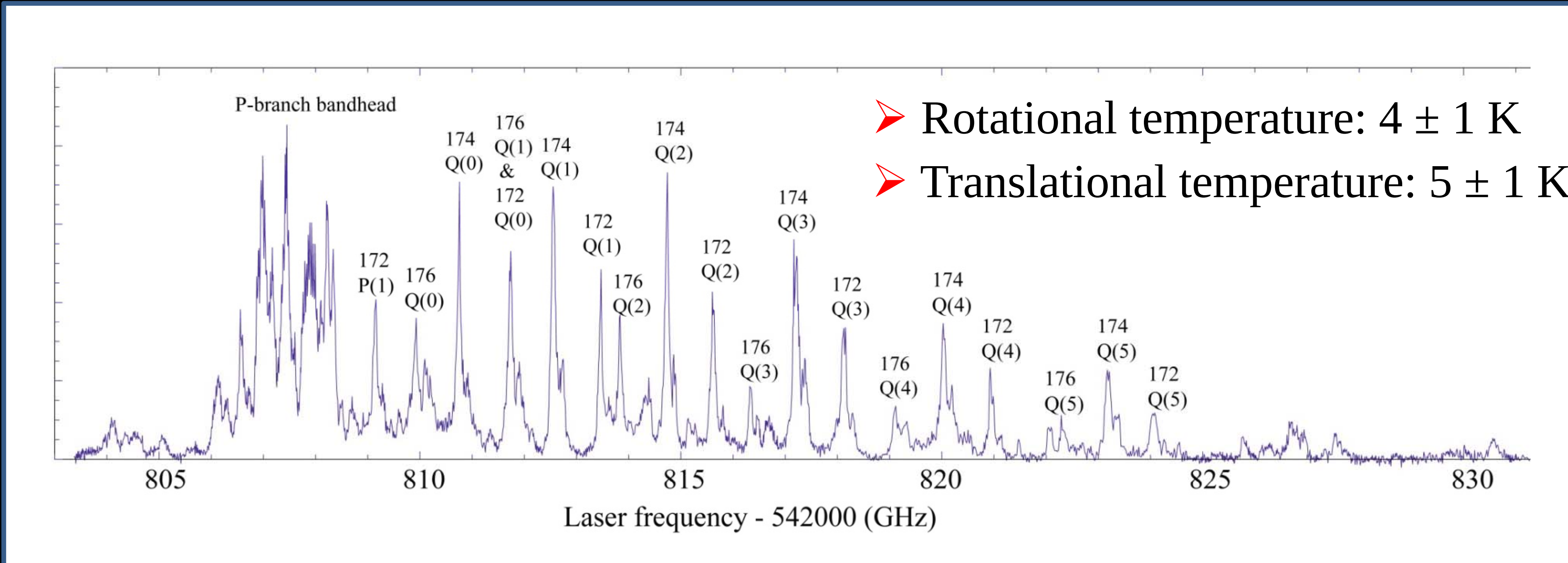
Systematics emphasised
→ total < 10^{-28} e.cm

Now making a
2×10^{-28} e.cm
EDM measurement

Phase 2 - cryogenic buffer gas source of YbF



Cryogenic beam spectrum



10 × more molecules/pulse

4 × longer interaction time (slower beam)

=> 10 × better EDM signal:noise ratio

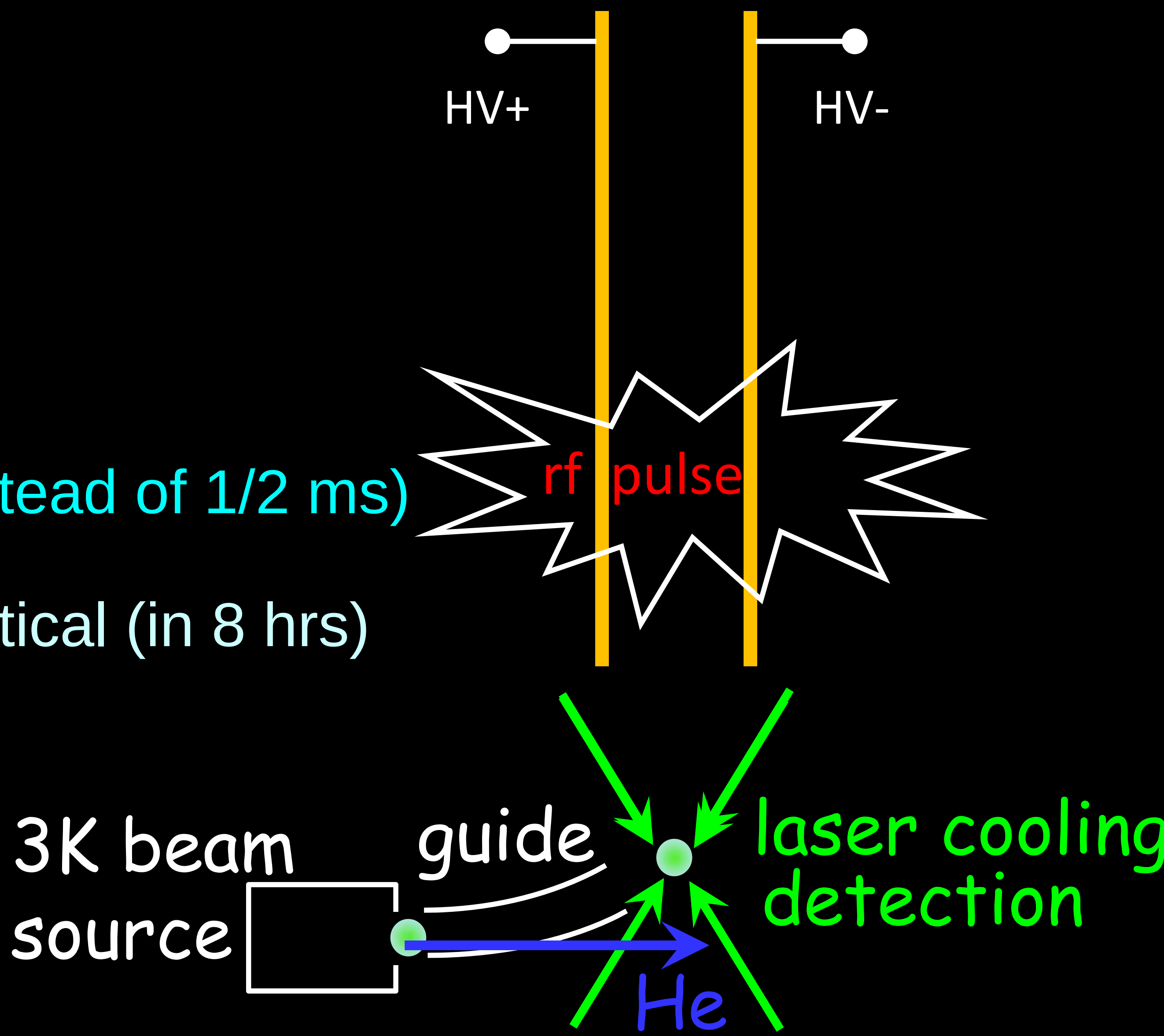
=> access to mid 10^{-29} e.cm range

Phase 3 – a molecular fountain

Laser cooling

1/2 sec flight time (instead of 1/2 ms)

=> 6×10^{-31} e.cm statistical (in 8 hrs)



Tarbutt *et al.* arXiv:1302.2870

Some eEDM experiments in preparation

Acme collab. Harvard/Yale ThO : $^3\Delta_1$ metastable beam

Leanhardt group, Michigan WC : $^3\Delta_1$ ground state beam

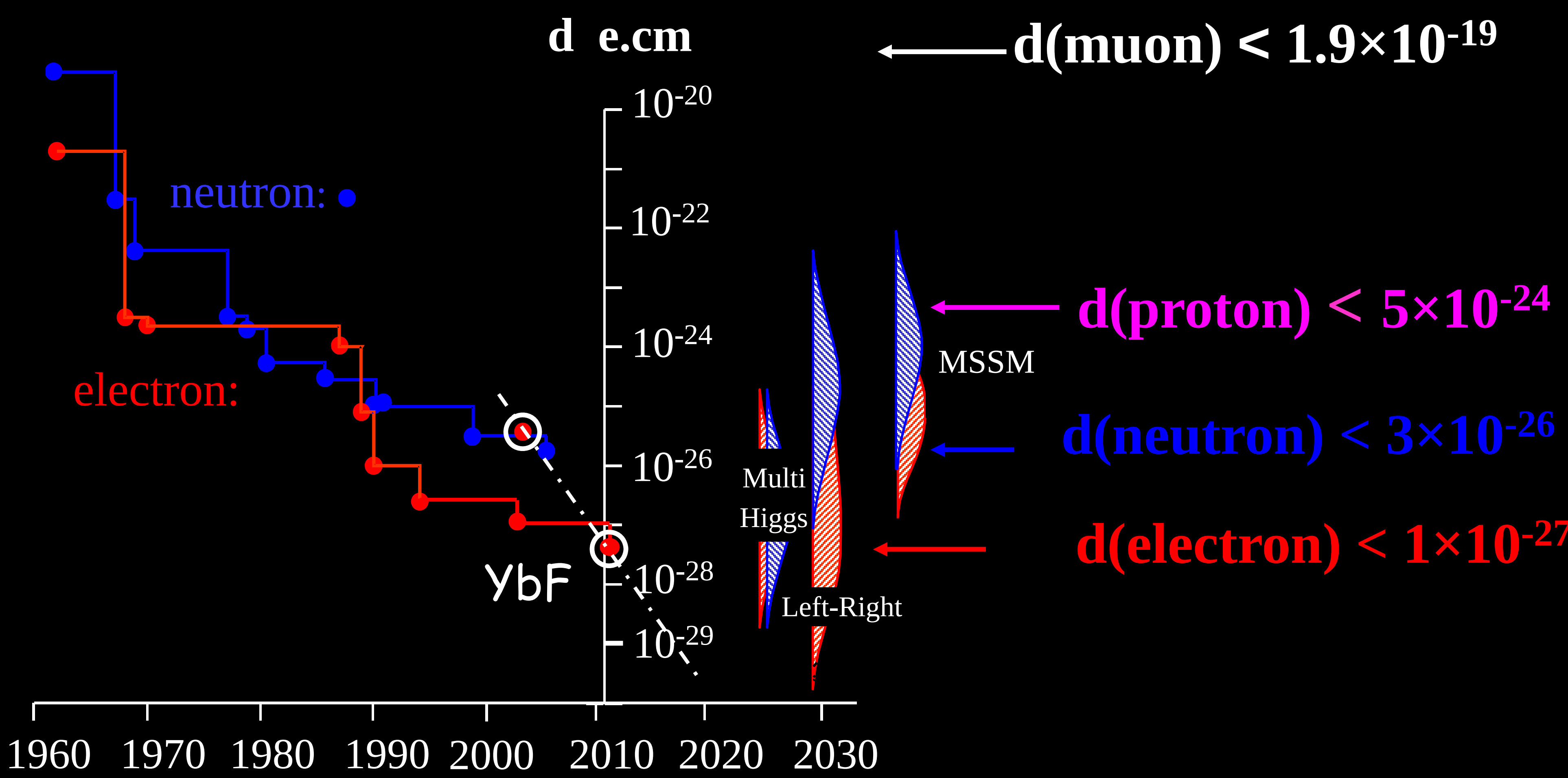
Cornel Group JILA HfF^+ : $^3\Delta_1$ ground state ion trap

Atom experiments in preparation

Cs in optical lattice: Weiss group, Penn State (next year?)
Heinzen group, Texas (2 years?)

Fr in a MOT: Tohoku/Osaka (starting 2014)

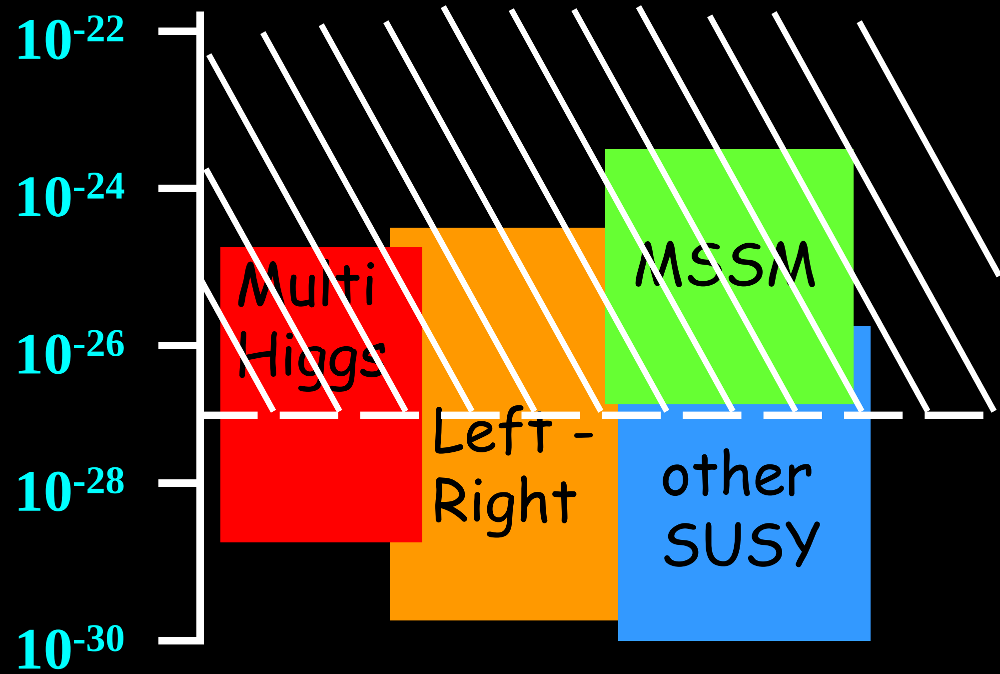
Current status of EDMs



Summary

e- EDM is a direct probe of physics beyond SM

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



we see a way to reach $<10^{-30}$

Atto-eV molecular spectroscopy tells us about TeV particle physics: the electron is too round for MSSM!

Thanks to my colleagues...

Jony Hudson

Mike Tarbutt

Ben Sauer

EDM measurement:

Joe Smallman
Jack Devlin
Dhiren Kara

Buffer gas cooling:

Sarah Skoff
Nick Bulleid
Rich Hendricks

Laser cooling:

Thom Wall
Aki Matsushima
Valentina Zhelyazkova
Anne Cournol

EPSRC Engineering and Physical Sciences Research Council

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