

Title: Is the electron round?

Date: Mar 08, 2013 01:00 PM

URL: <http://pirsa.org/13030100>

Abstract: We have made a new measurement of the electron's electric dipole moment (EDM) using a beam of YbF molecules. By measuring atto-eV energy shifts in a molecule, this experiment probes new physics at the tera-eV energy scale. According to the standard model, this EDM is $d_e = 10^{-38}$ e.cm“ some eleven orders of magnitude below the current experimental limit. However, most extensions to the standard model predict much larger values, potentially accessible to measurement . Hence, the search for the electron EDM is a search for physics beyond the standard model. I will describe our experimental method, our current results and their implications for particle physics. I will also outline the prospects for further major improvement in sensitivity.

Is the electron round?

E.A. Hinds

Centre for Cold Matter
Imperial College London

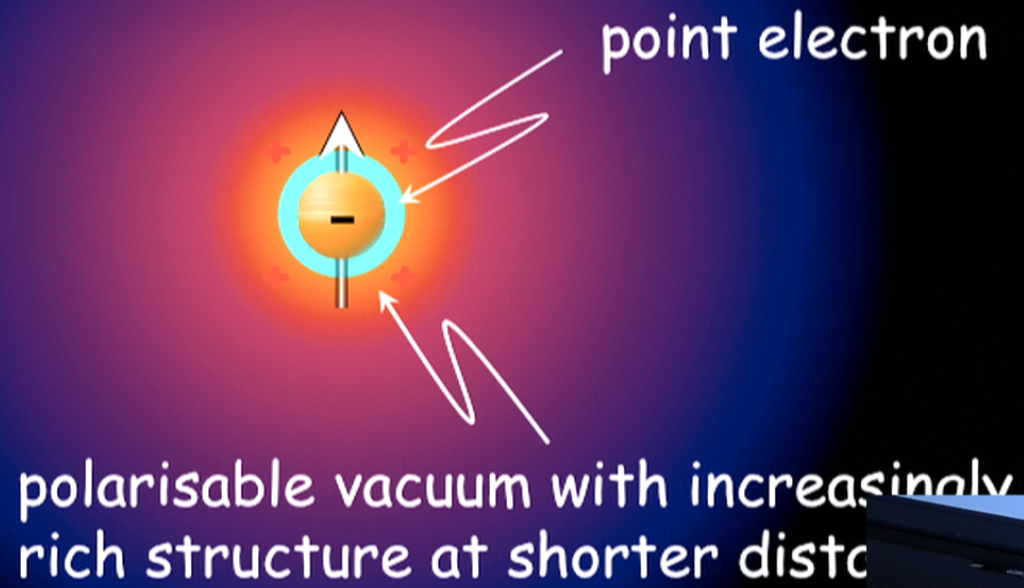


Perimeter Institute, 7 March 2013

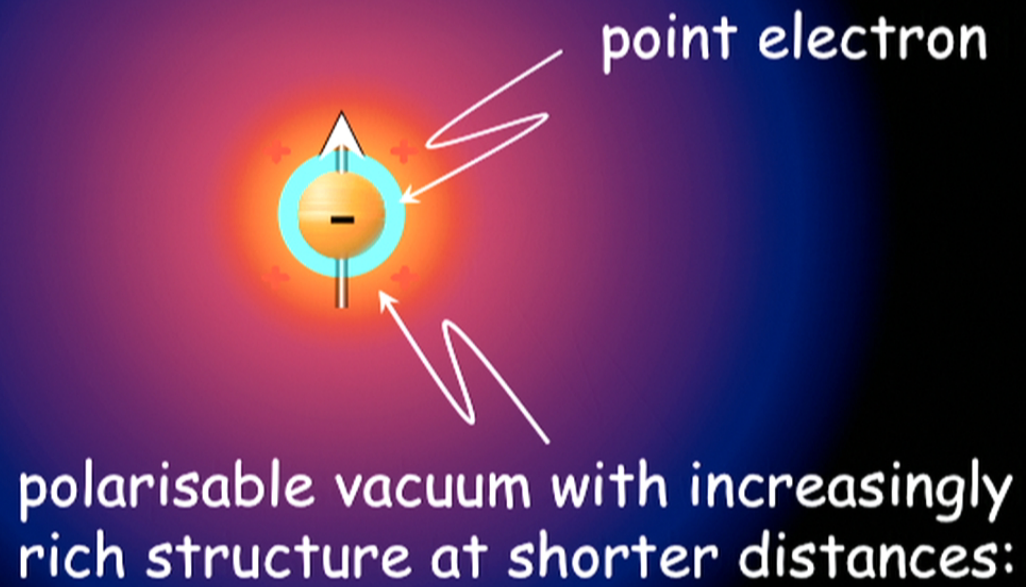
How a point electron gets structure



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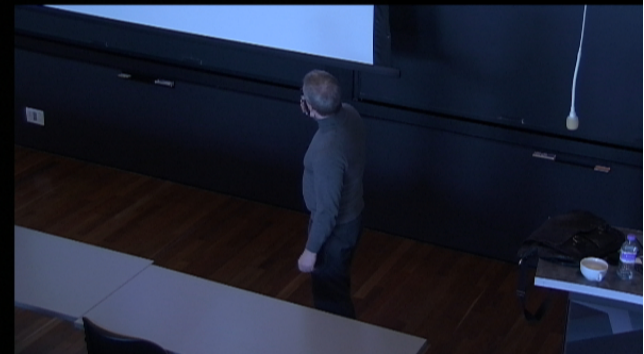
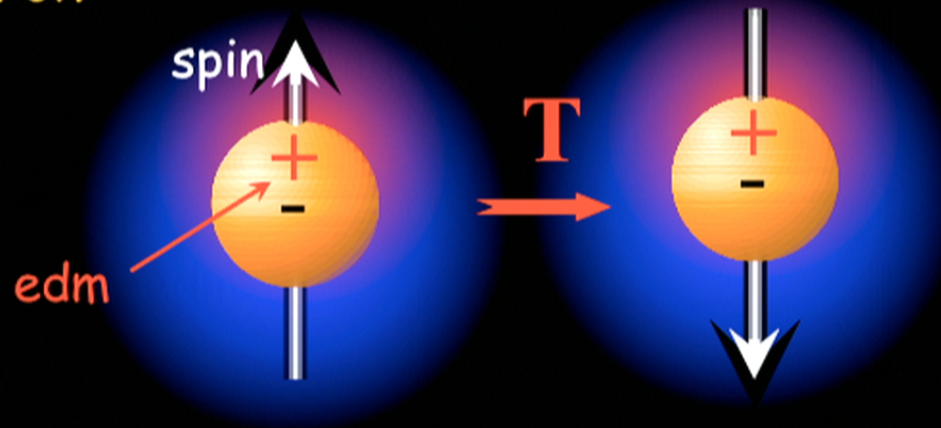
point electron

polarisable vacuum with increasingly
rich structure at shorter distances:

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

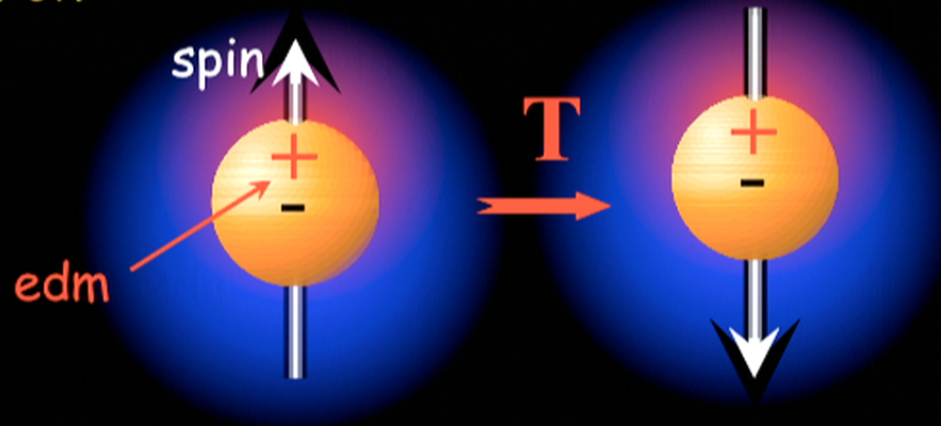
Electric dipole moment (EDM)

electron



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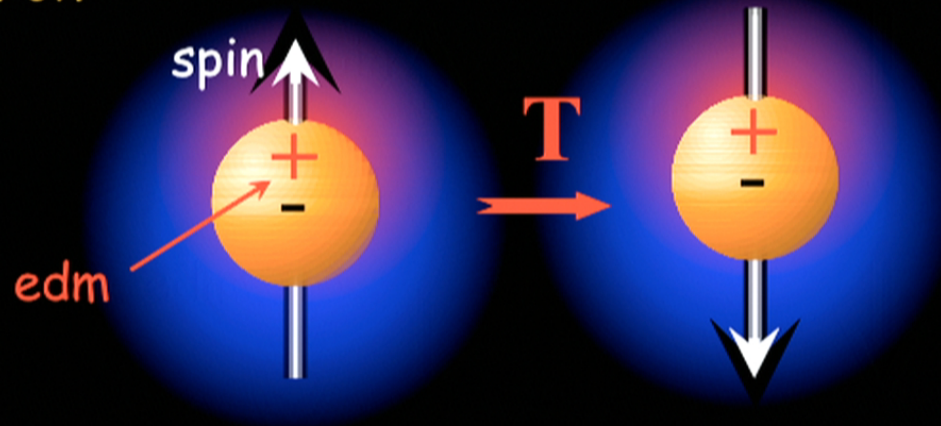
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If the electron has an EDM,
nature has chosen *one* of these,
breaking T symmetry

Electric dipole moment (EDM)

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eEDM (e.cm) Theoretical estimates of eEDM

10^{-22}

10^{-24}

10^{-26}

10^{-28}

10^{-30}

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Standard Model

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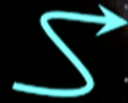
10^{-30}

10^{-32}

10^{-34}

10^{-36}

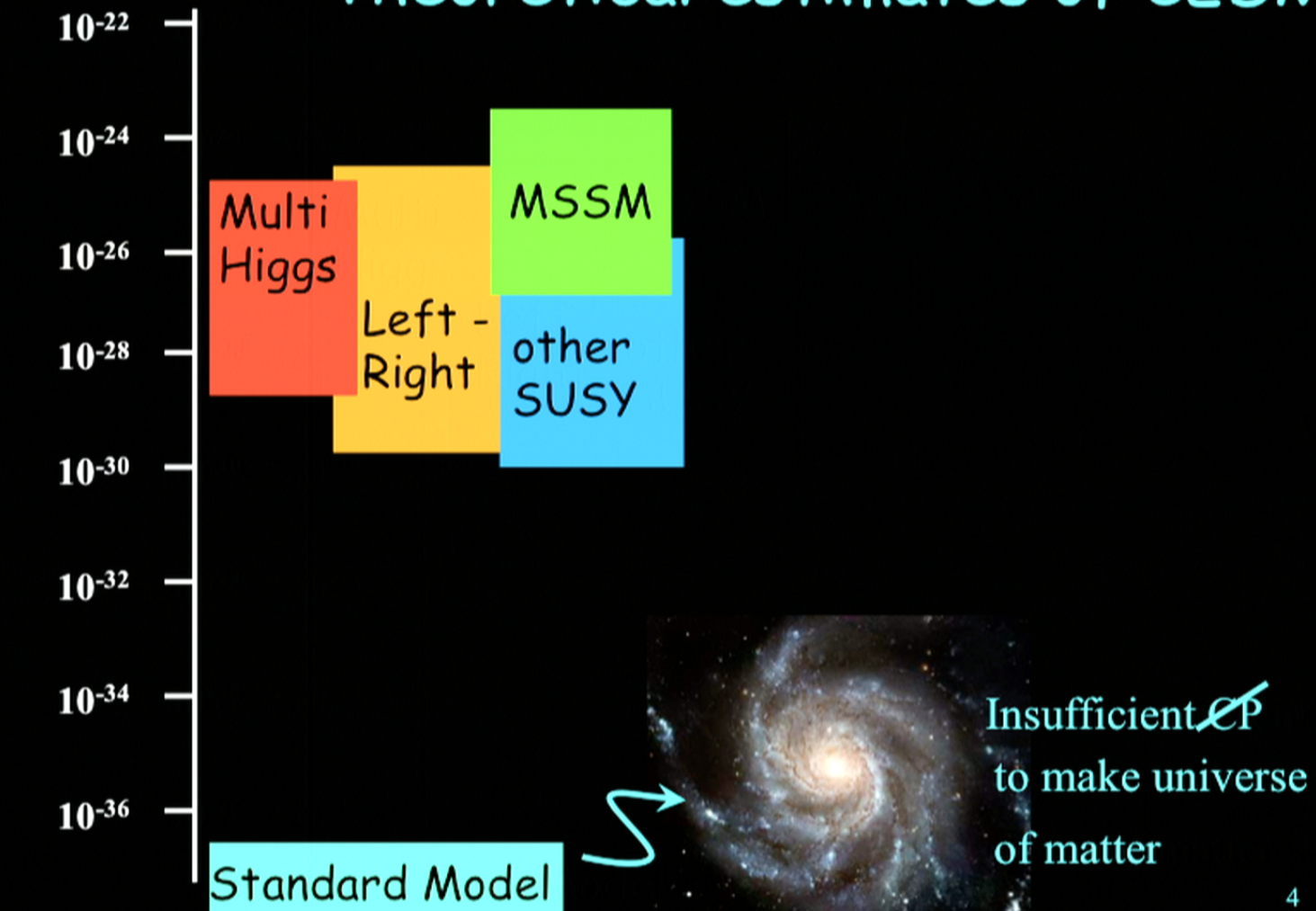
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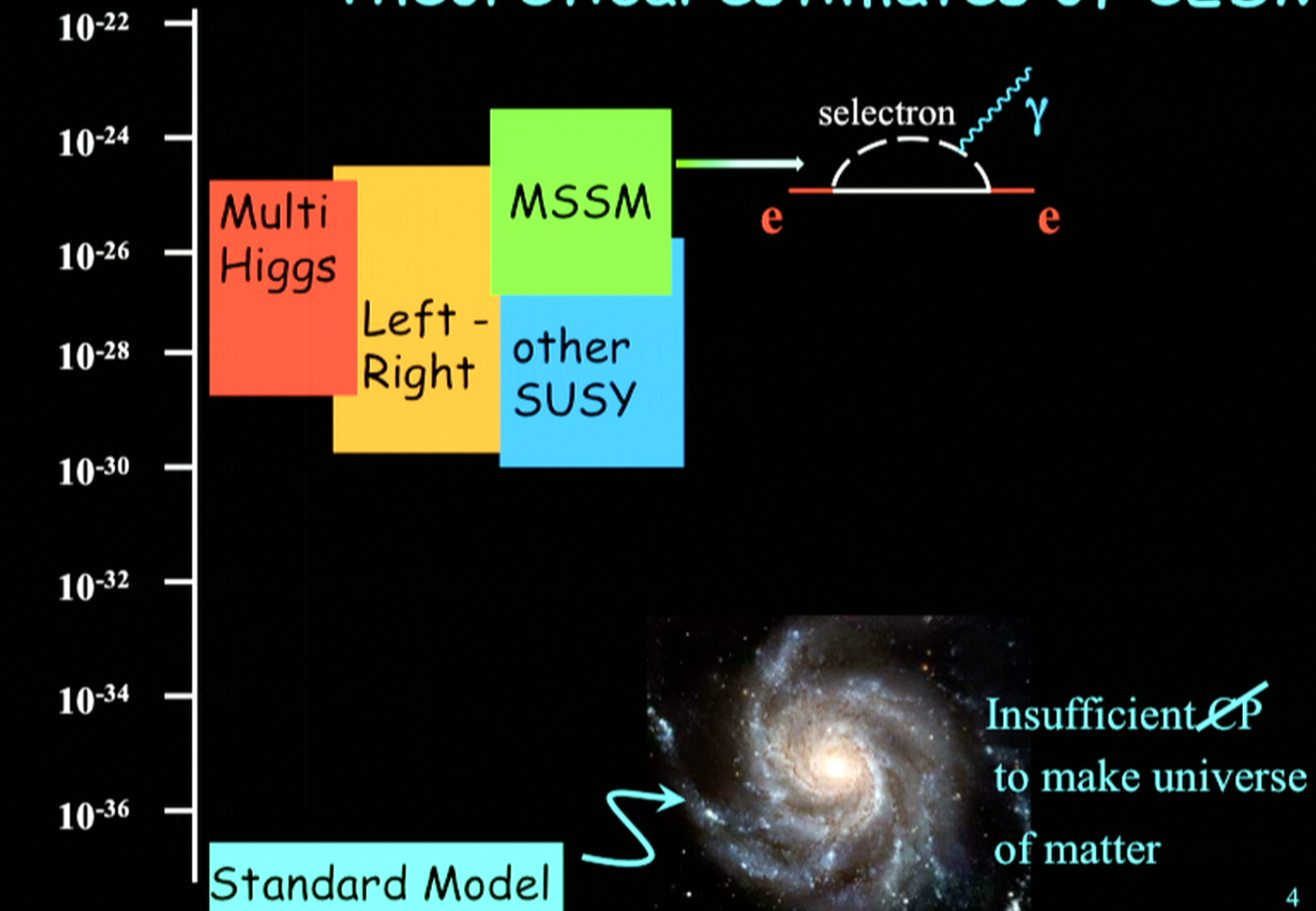
Insufficient ~~CP~~
to make universe
of matter

4

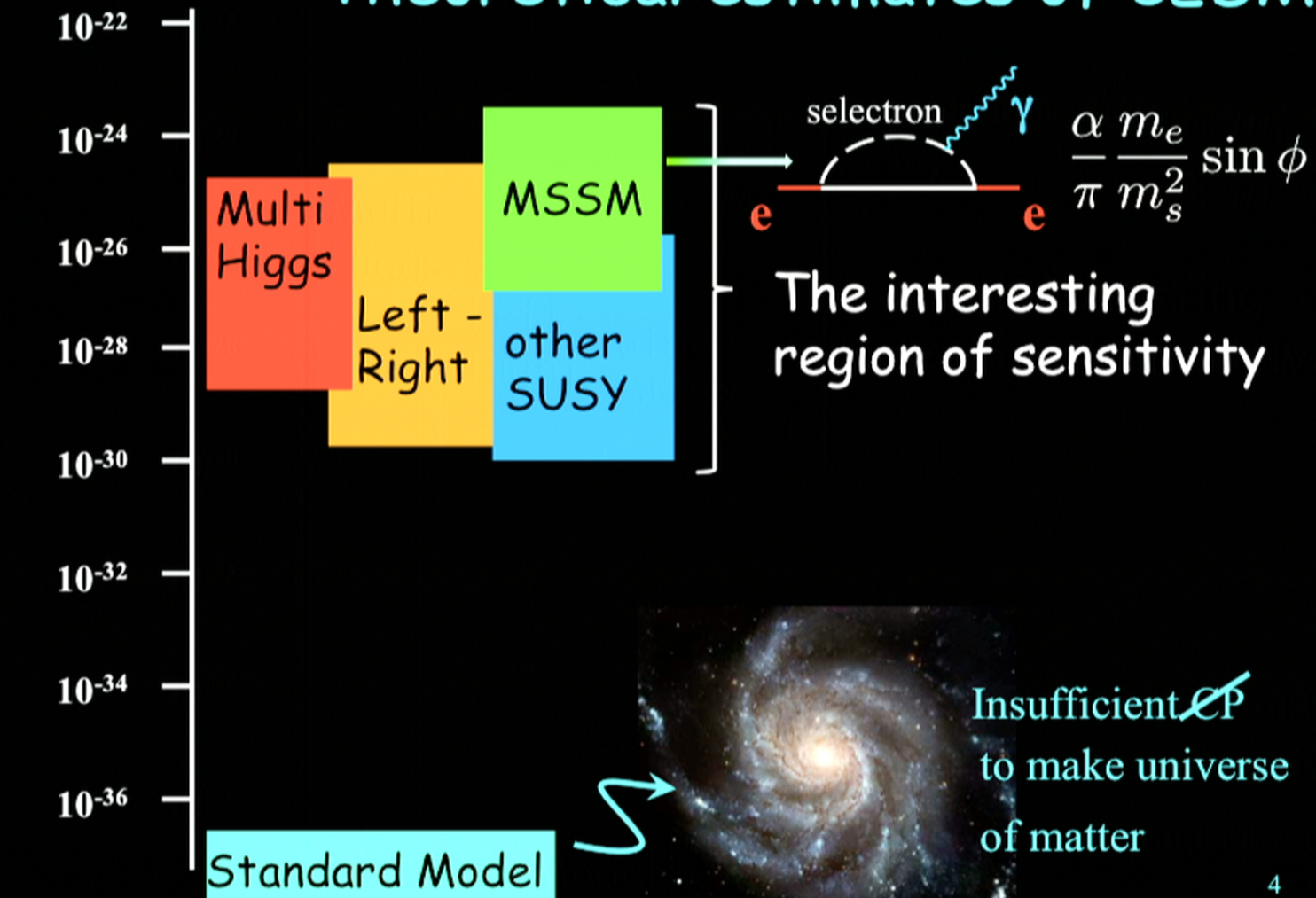
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The magnetic moment problem

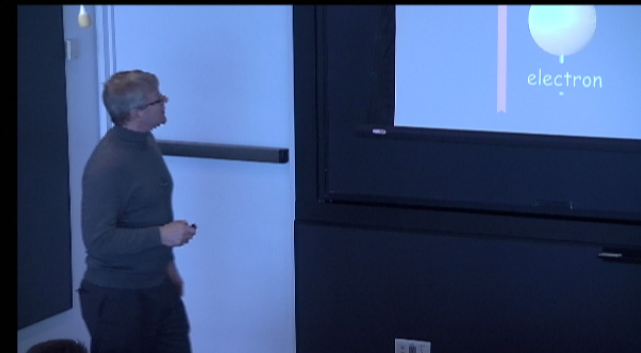
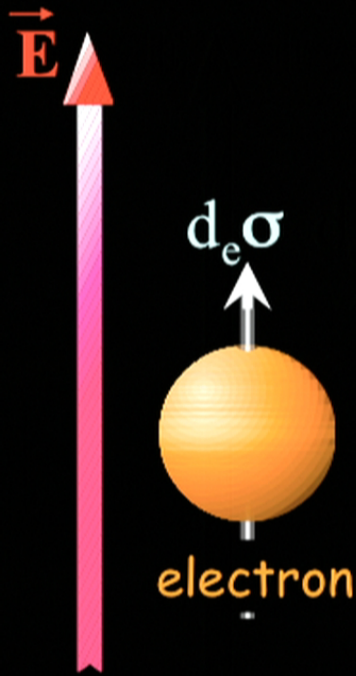
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The magnetic moment problem

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 $= 1 \times 10^{-19} \text{ e.a}_0$

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

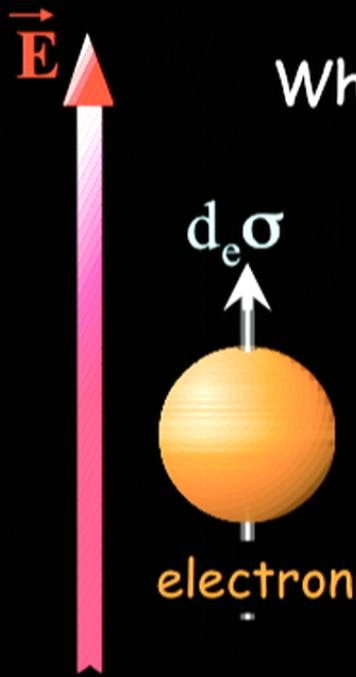


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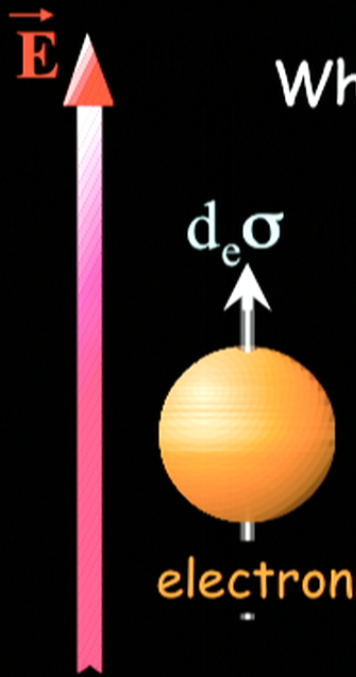


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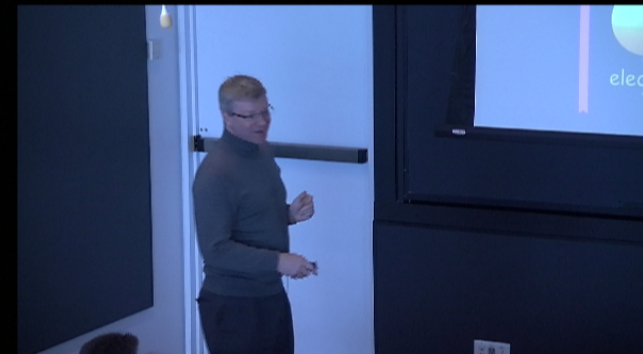
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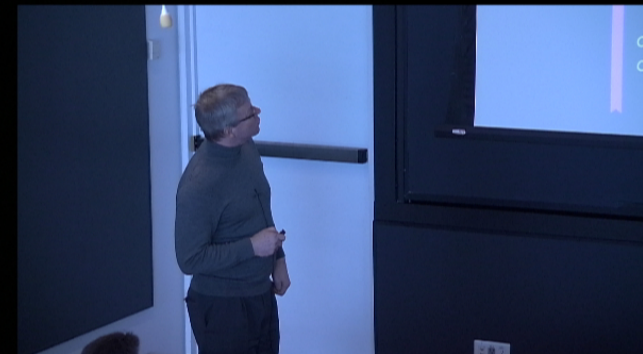
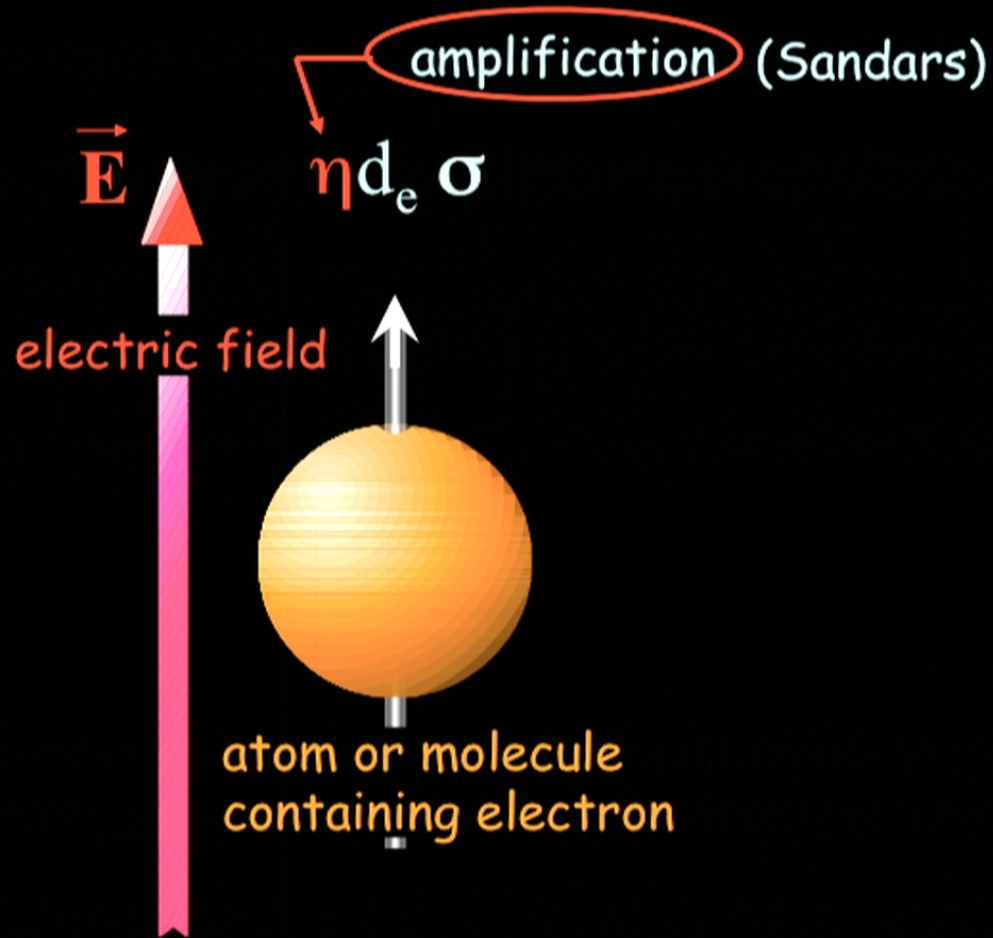


This is very small



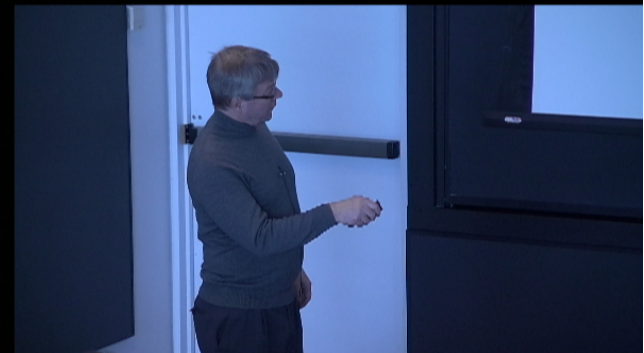
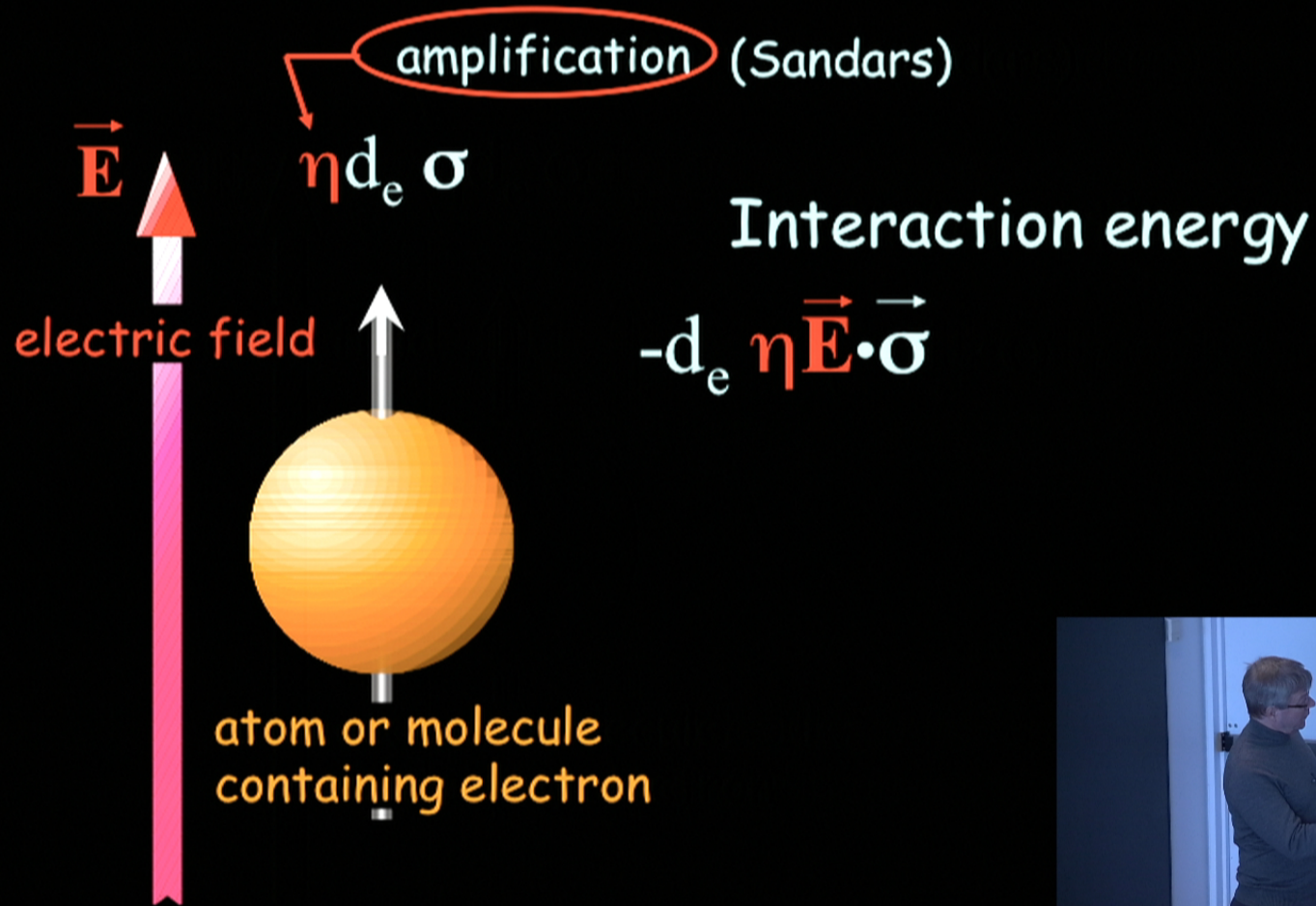
A clever solution

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



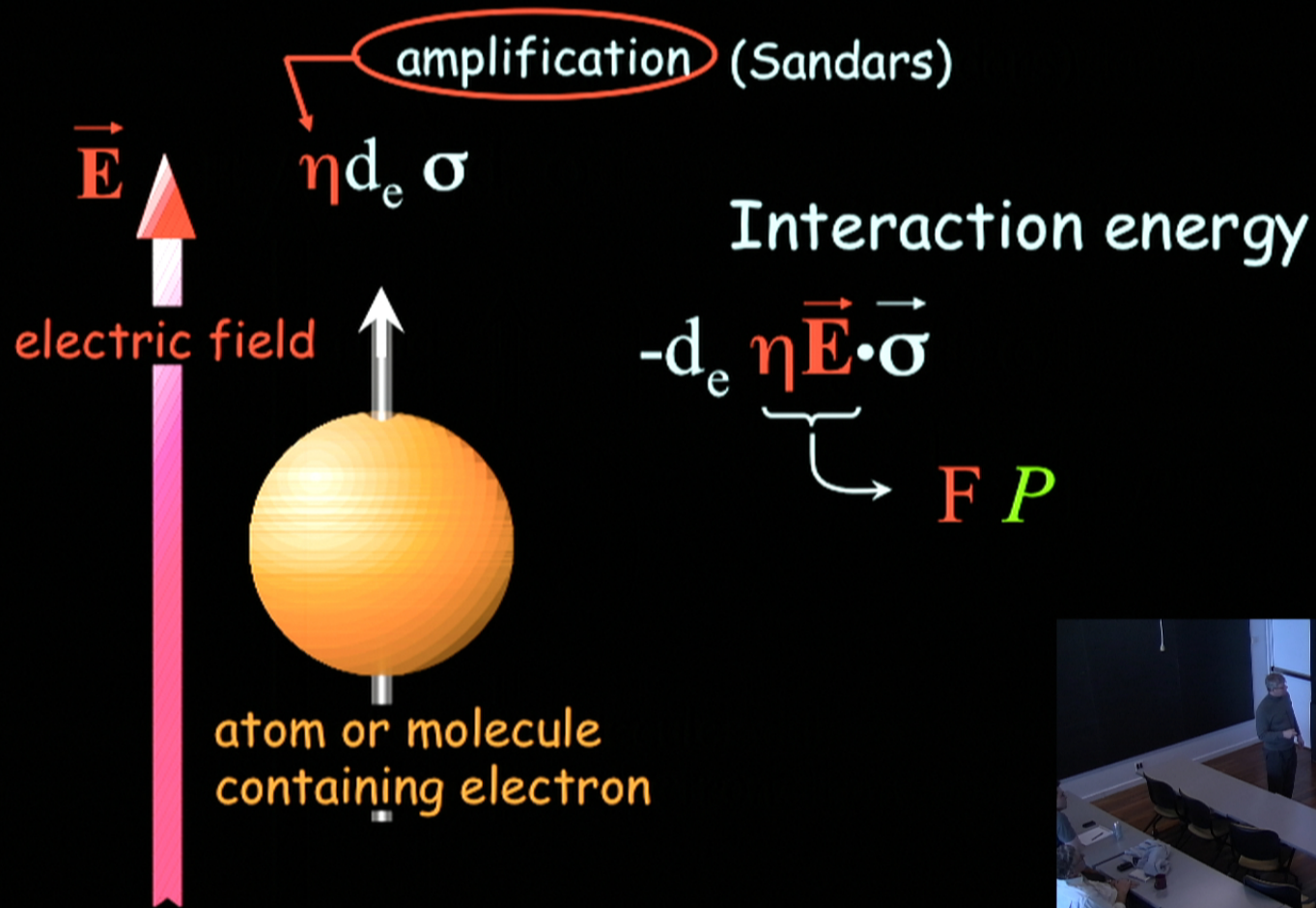
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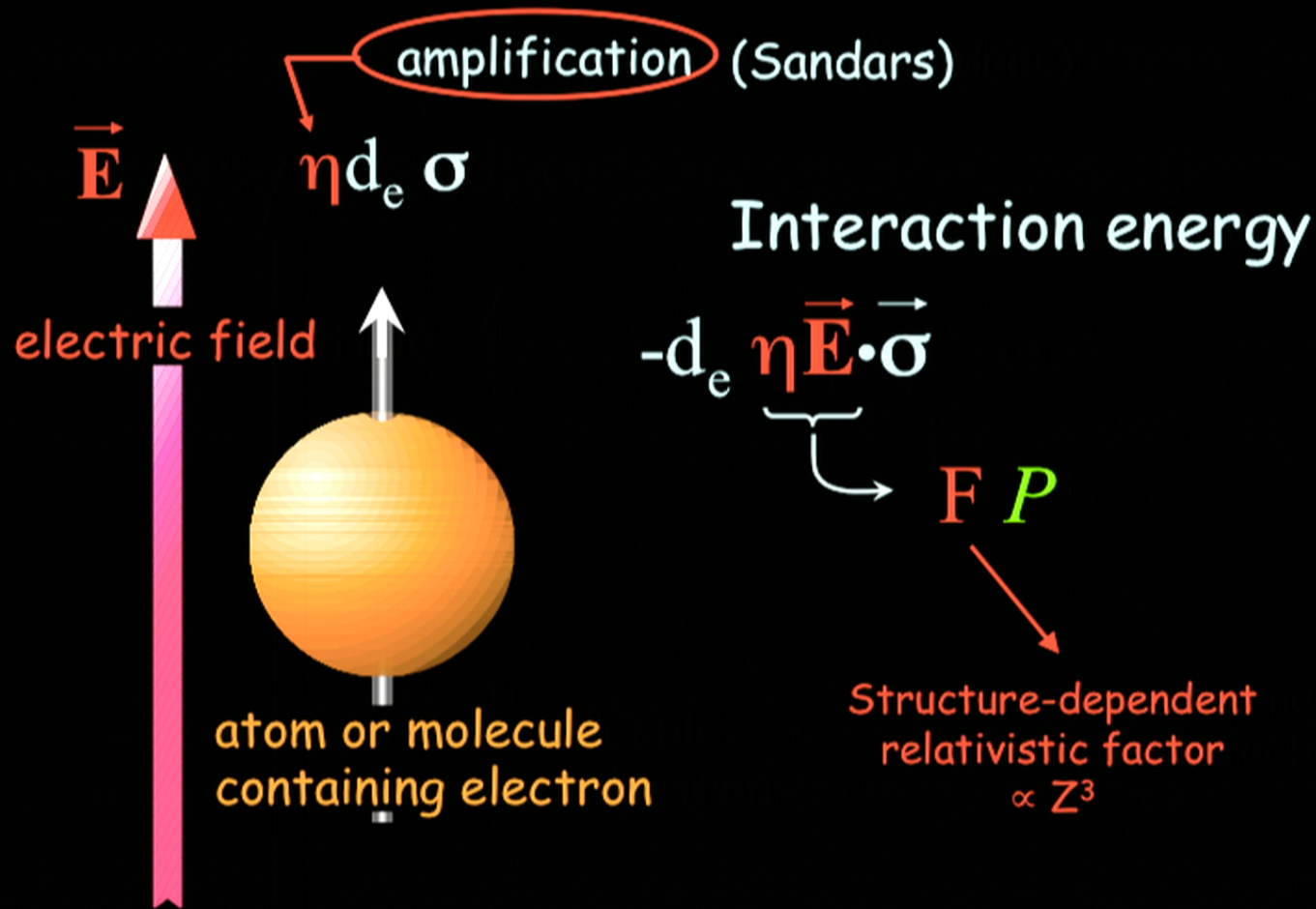
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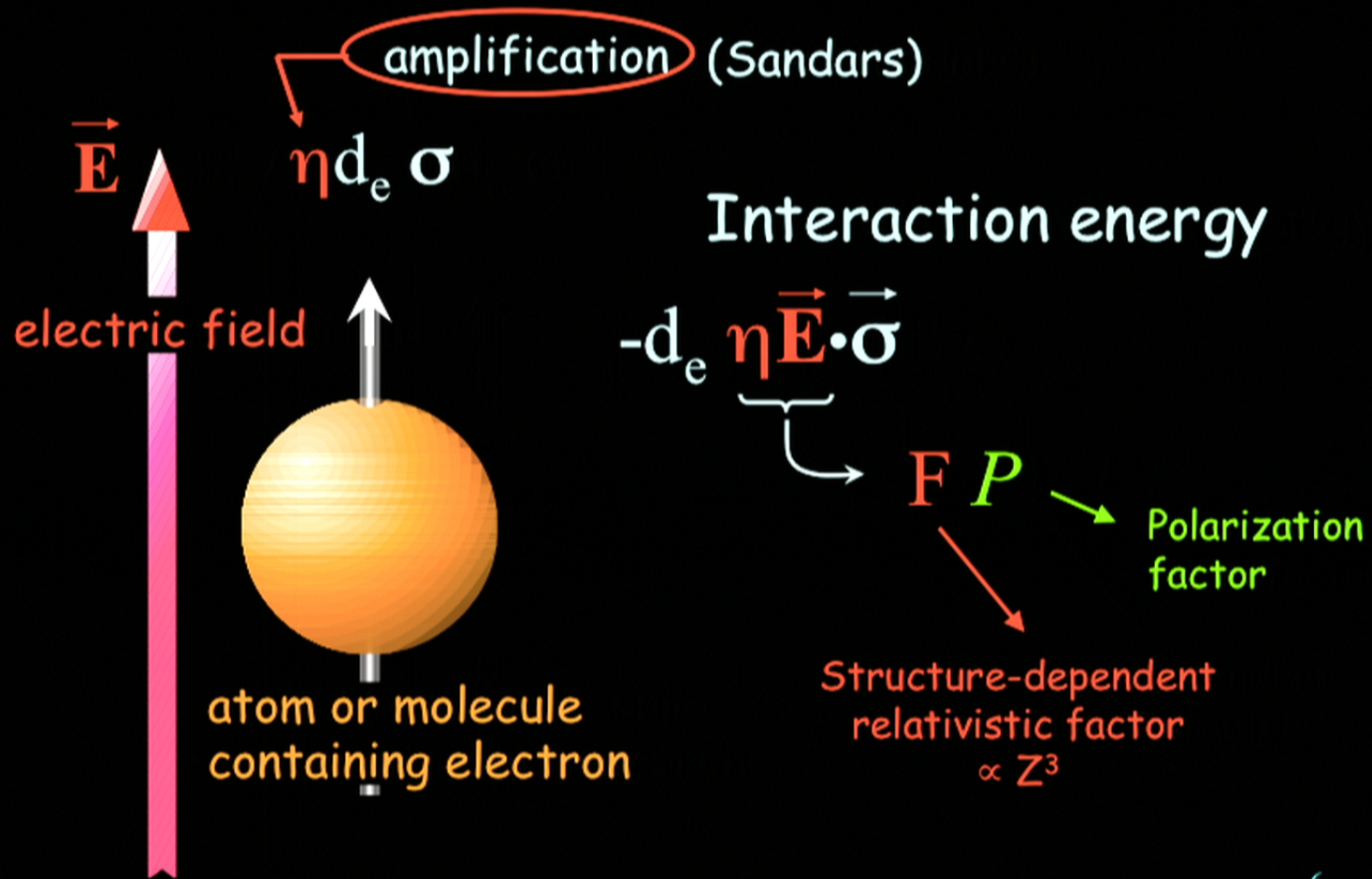
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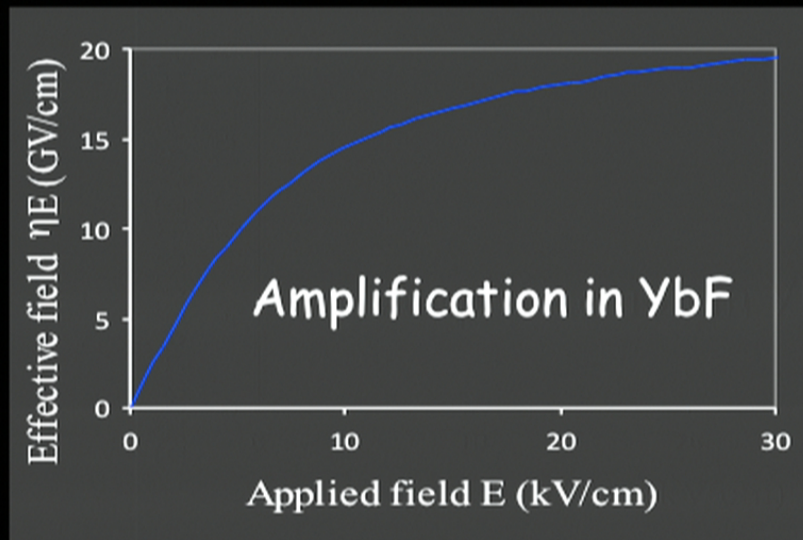


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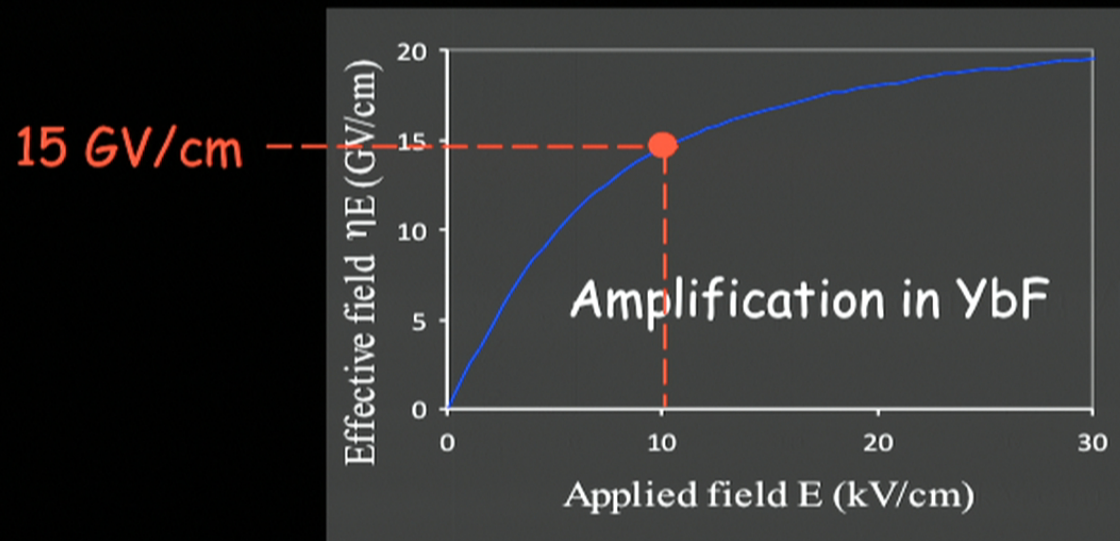
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Our experiment uses a polar molecule - YbF

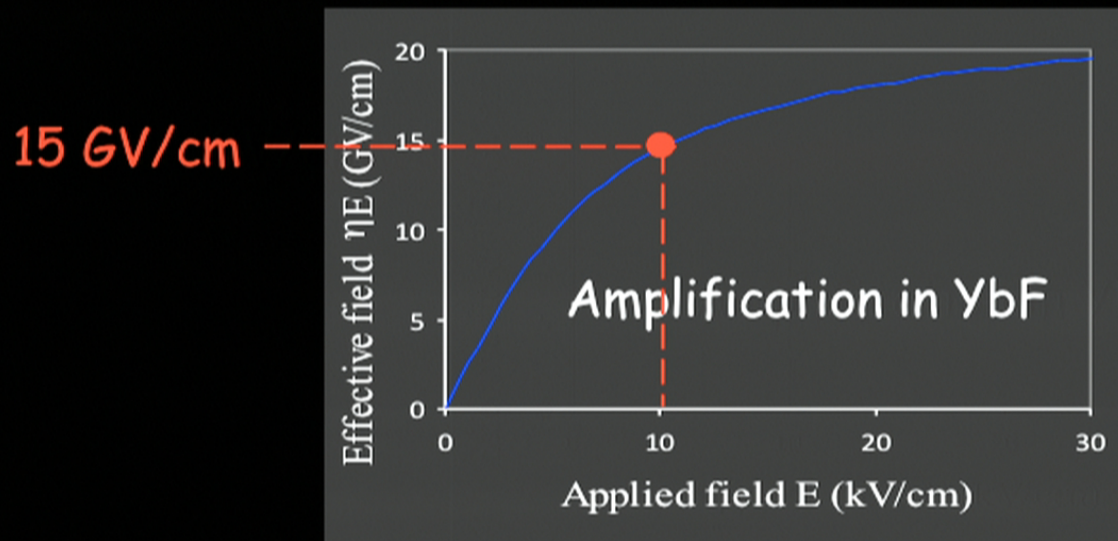


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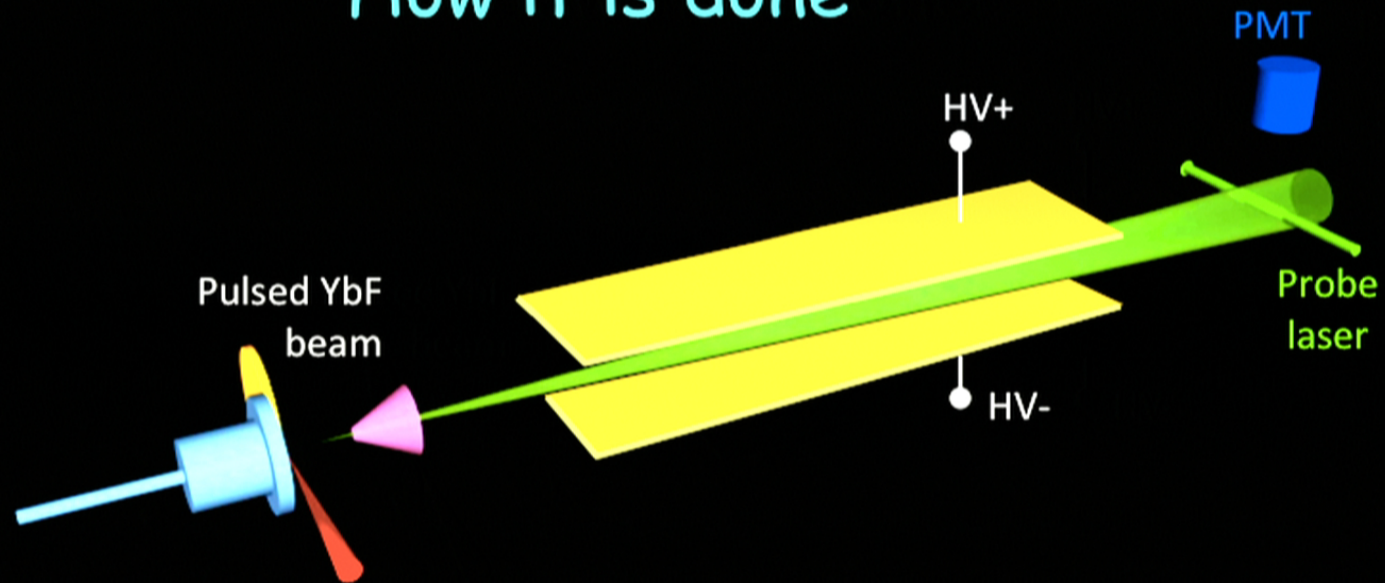
➤ EDM interaction energy is a million times larger (mHz)

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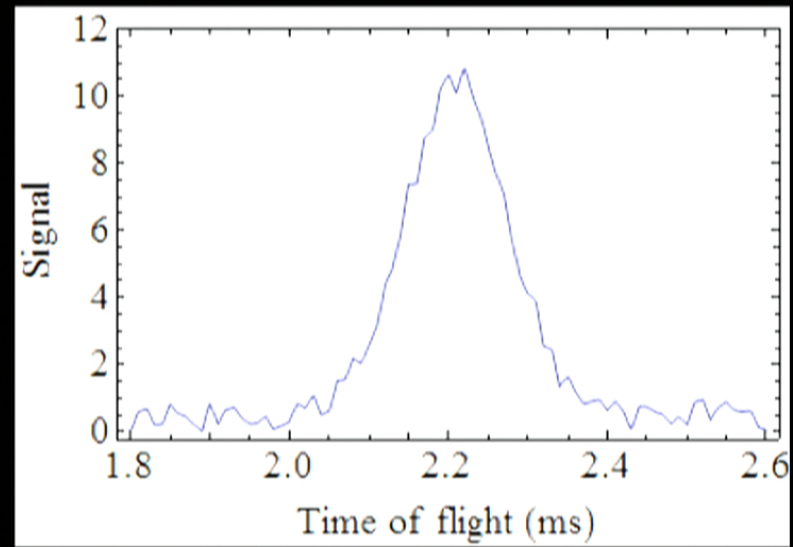
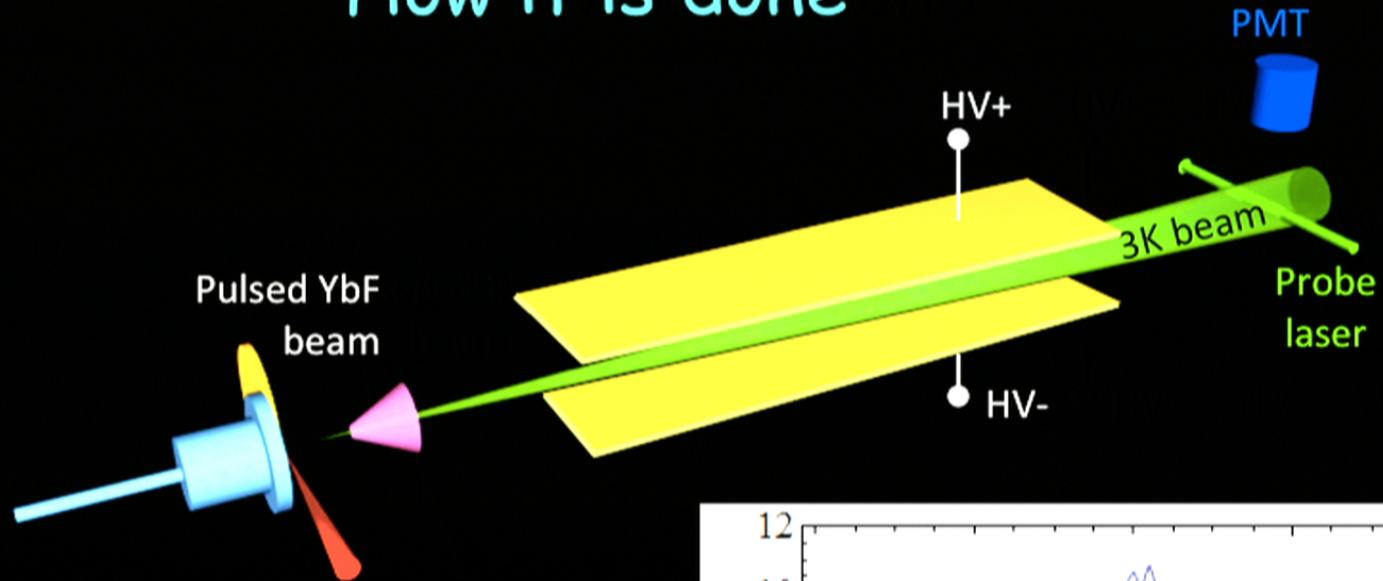


- EDM interaction energy is a million times larger (mHz)
- needs "only" nG stray B field control

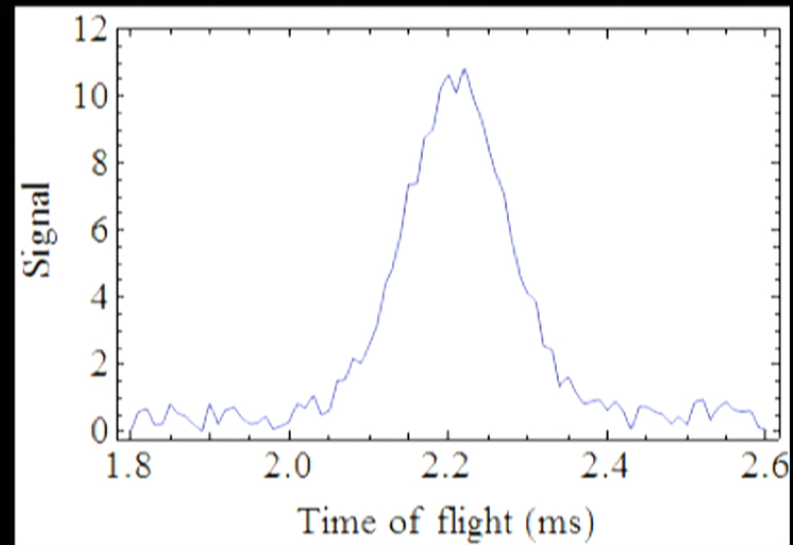
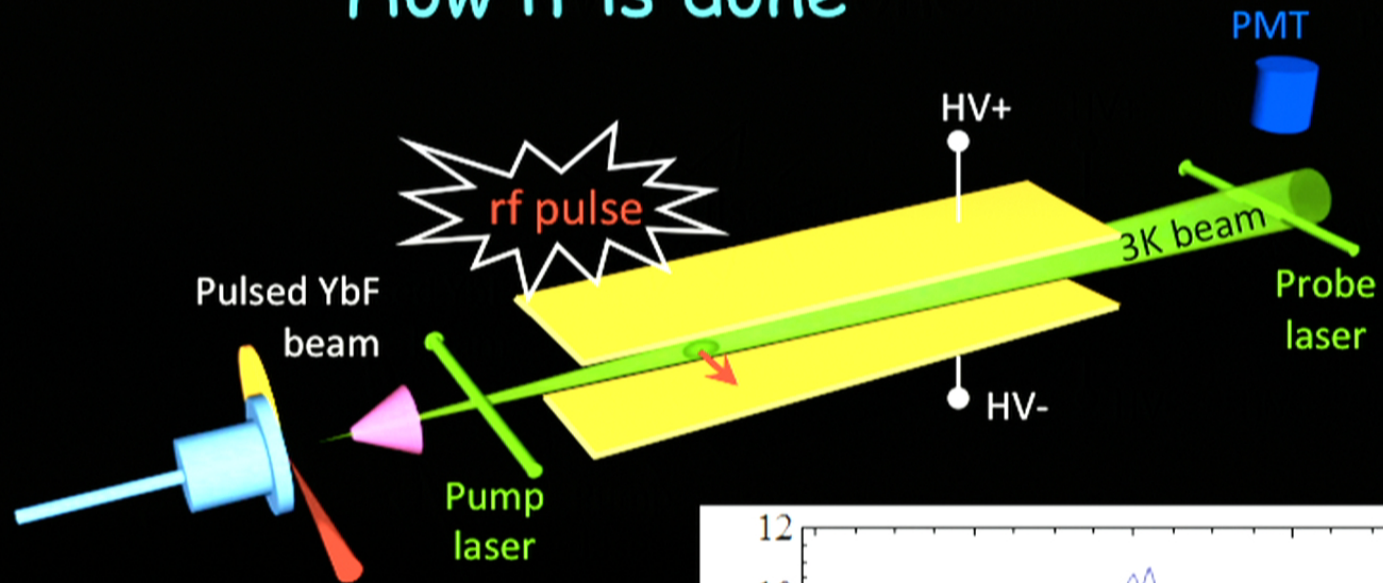
How it is done



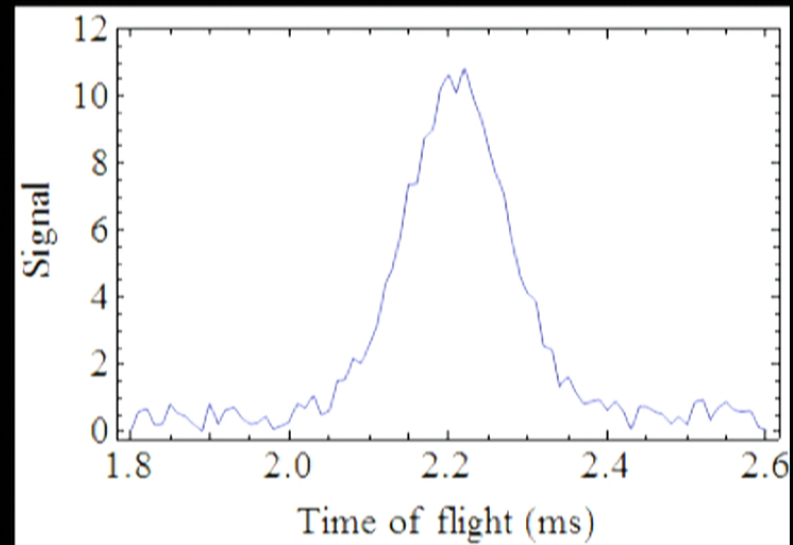
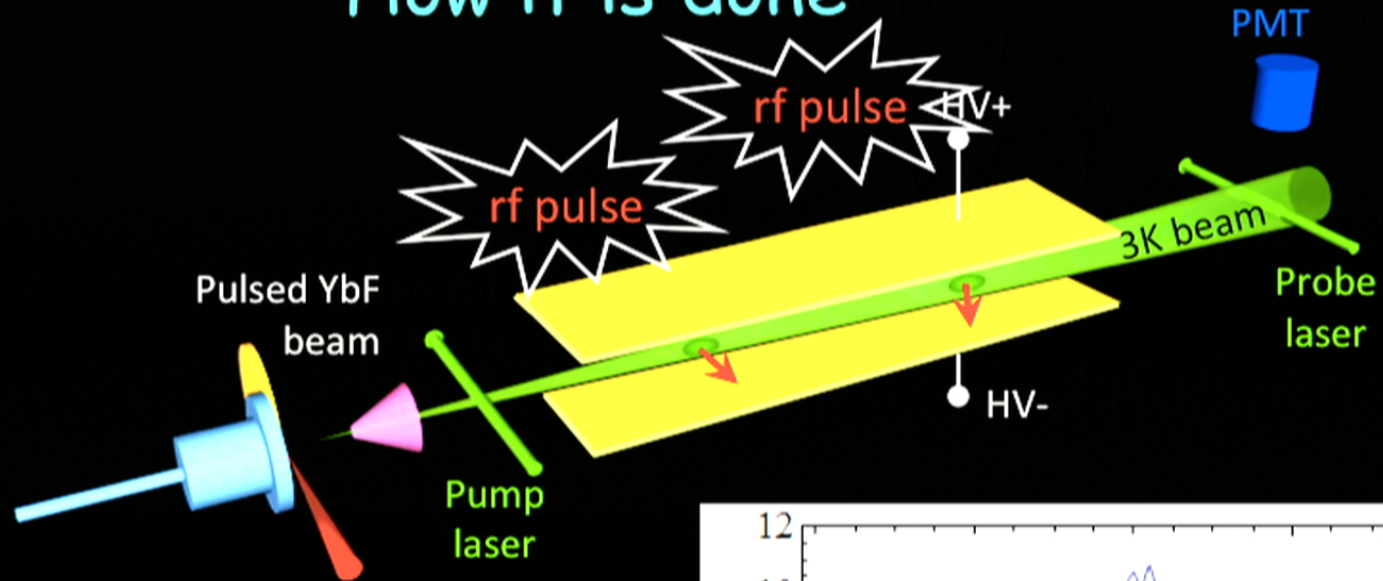
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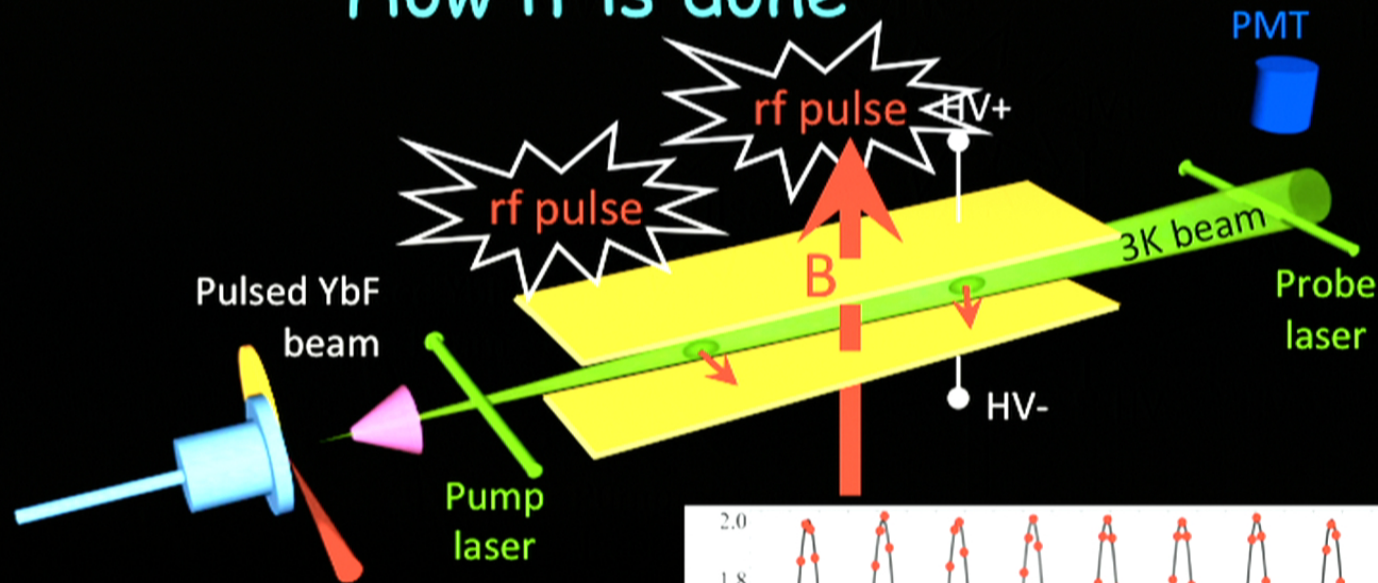
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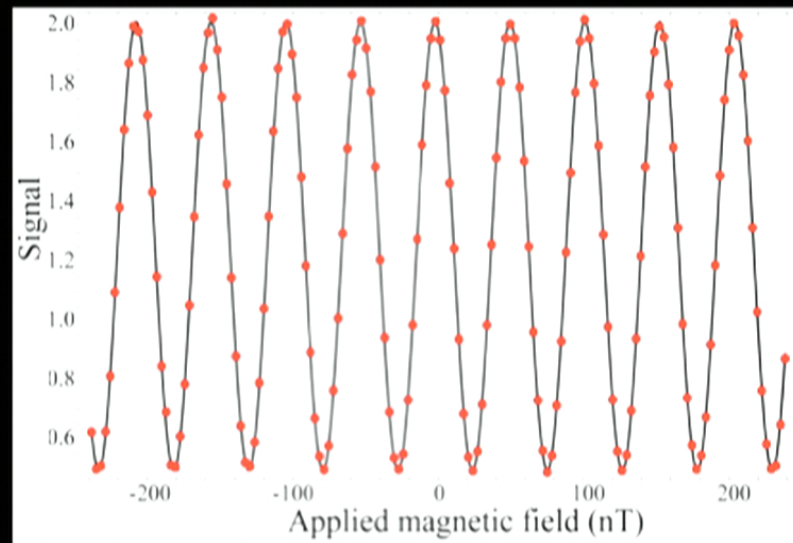
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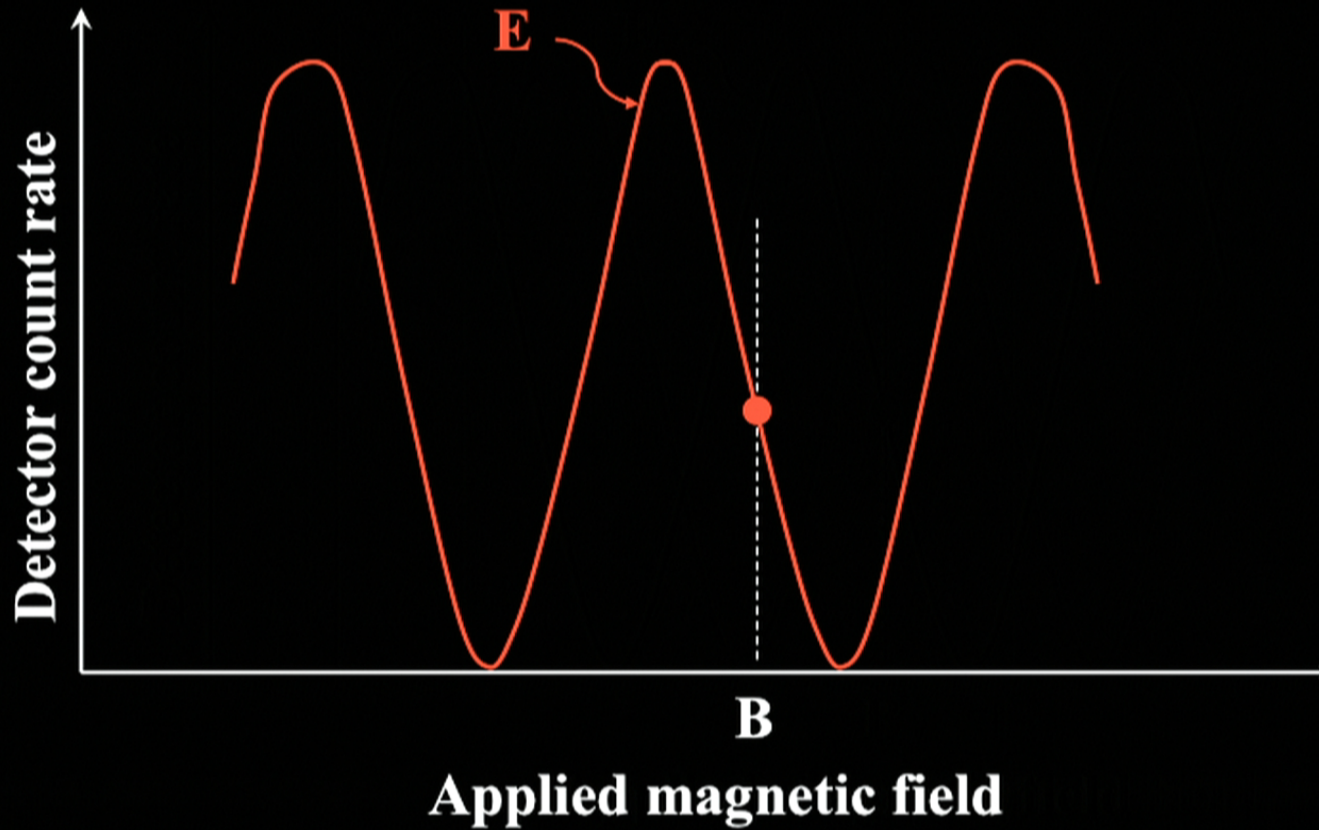


These "interferometer fringes" measure the spin rotation angle ϕ



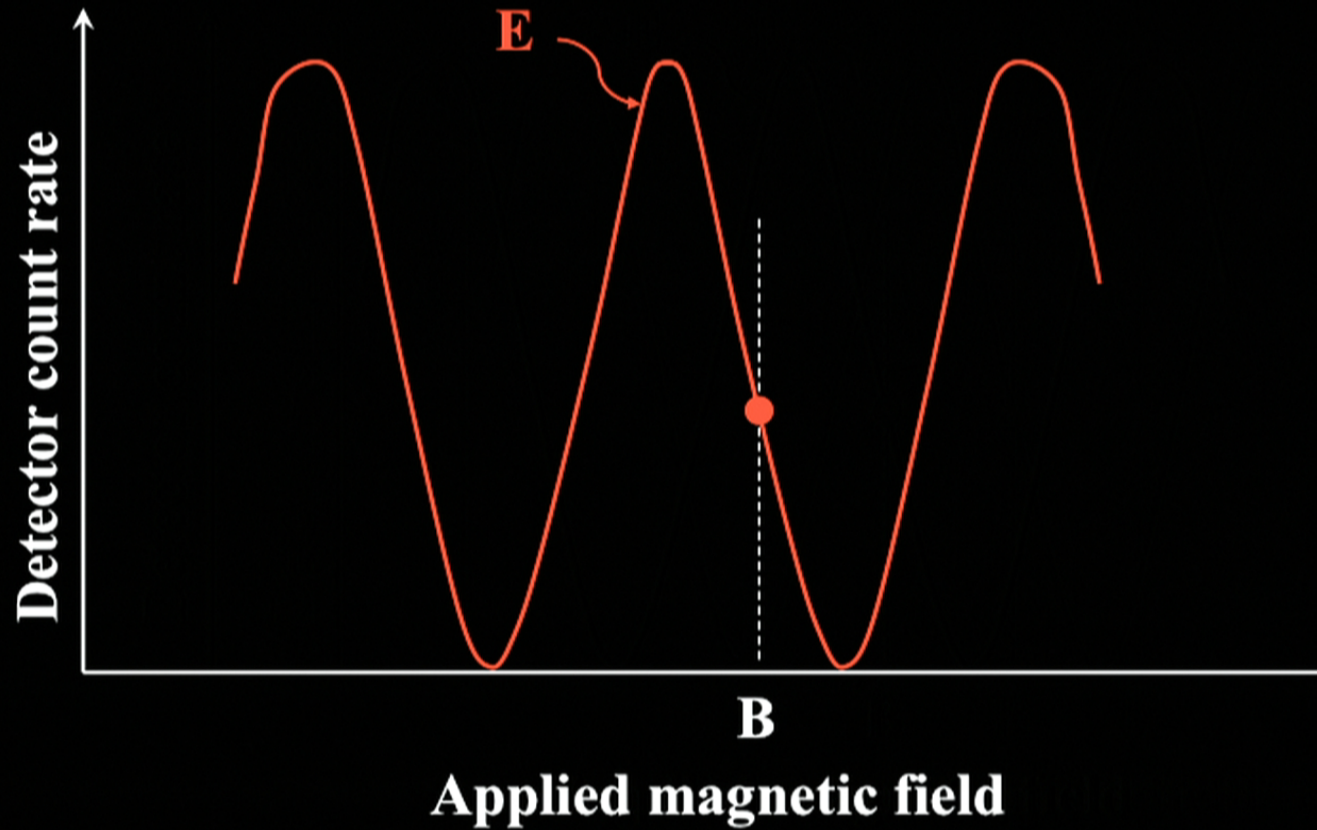
Measuring the edm

$$\text{Interferometer phase } \phi = 2(\mu\mathbf{B} + \mathbf{d}_e\eta\mathbf{E})\tau/\hbar$$



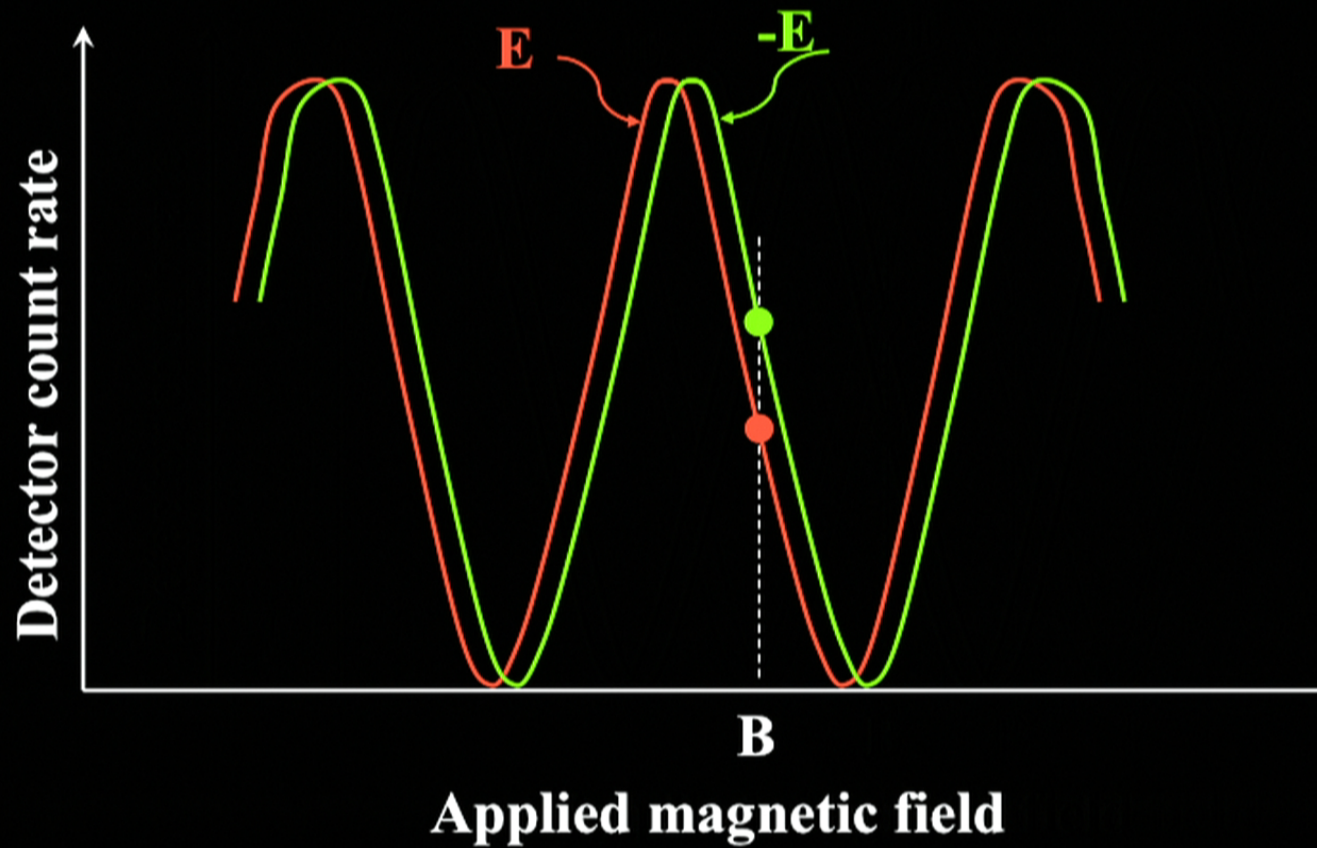
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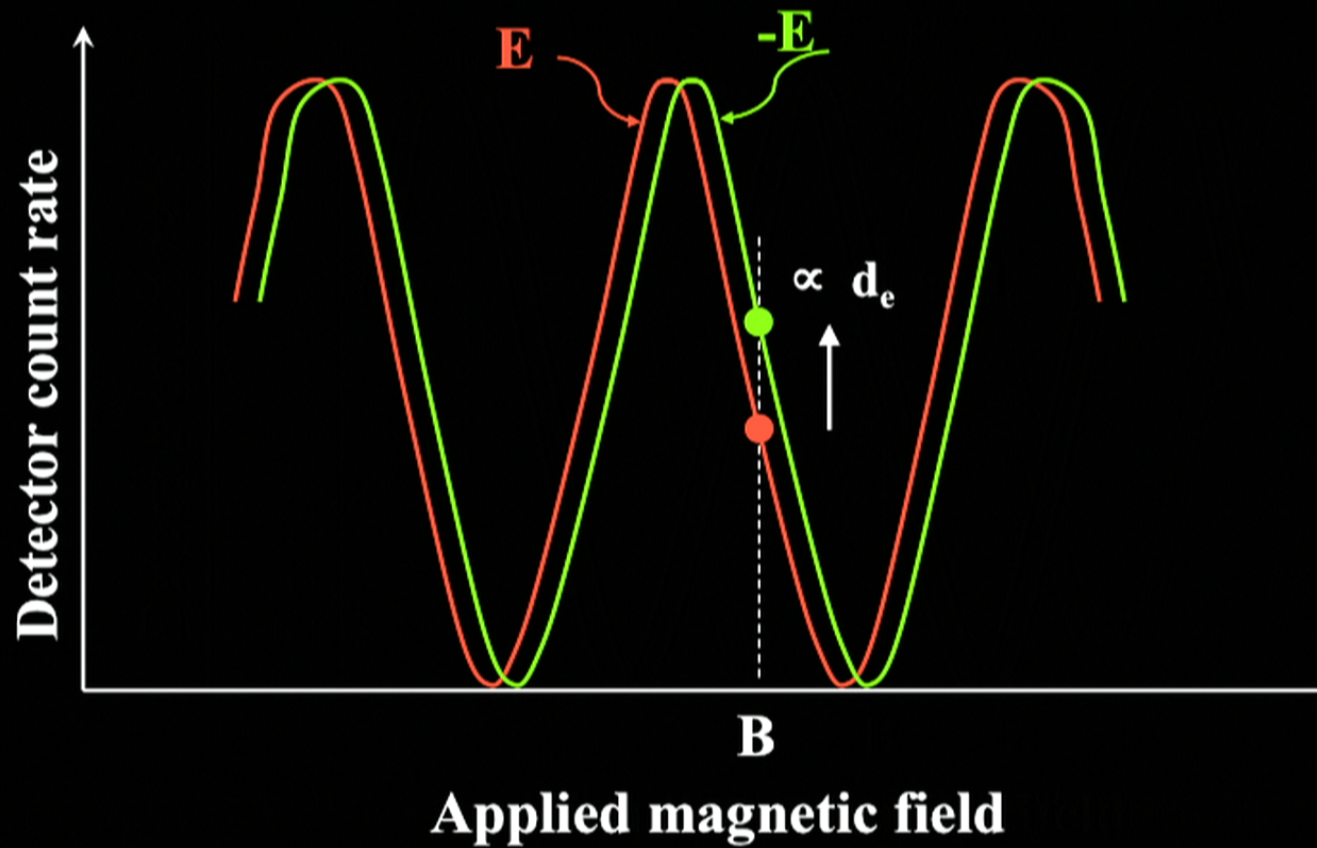
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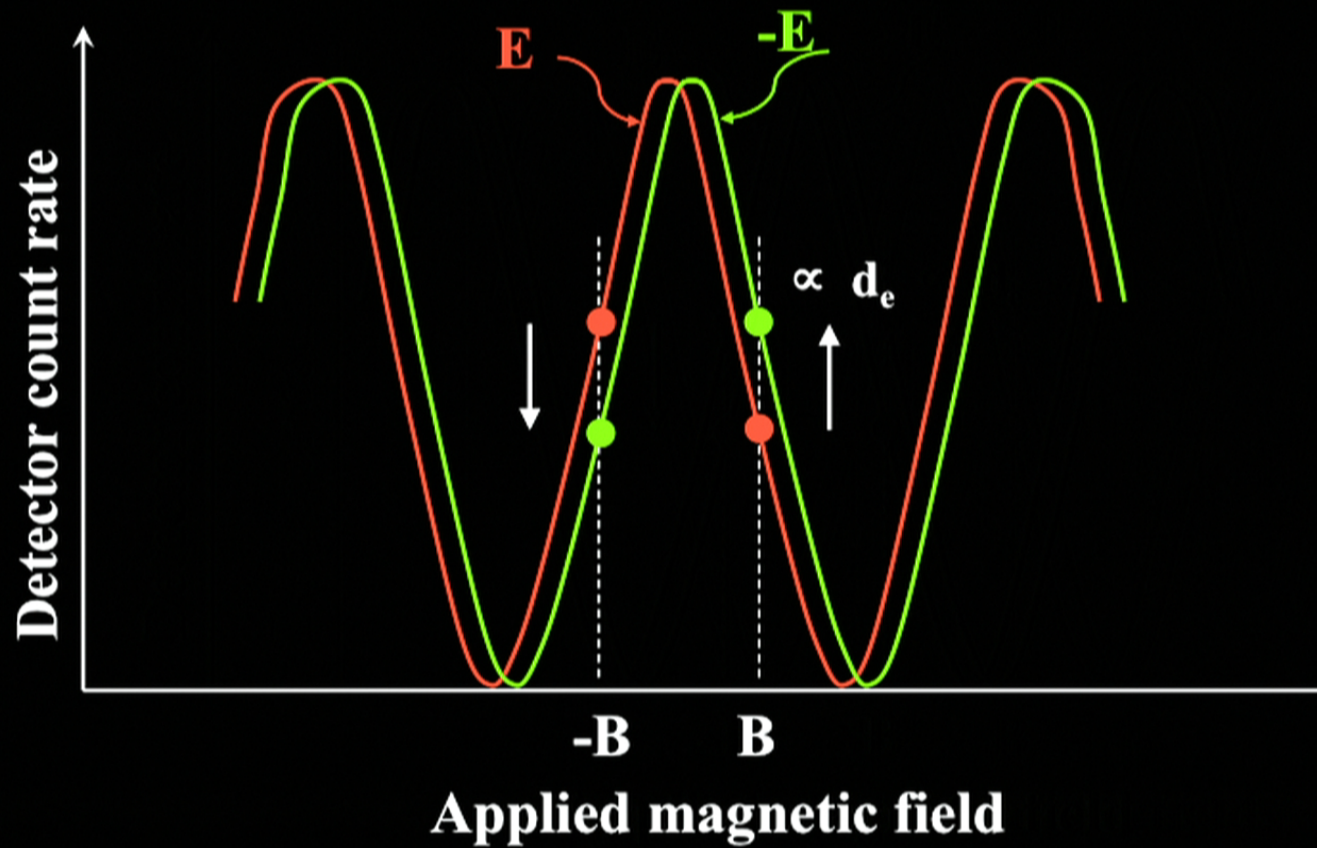
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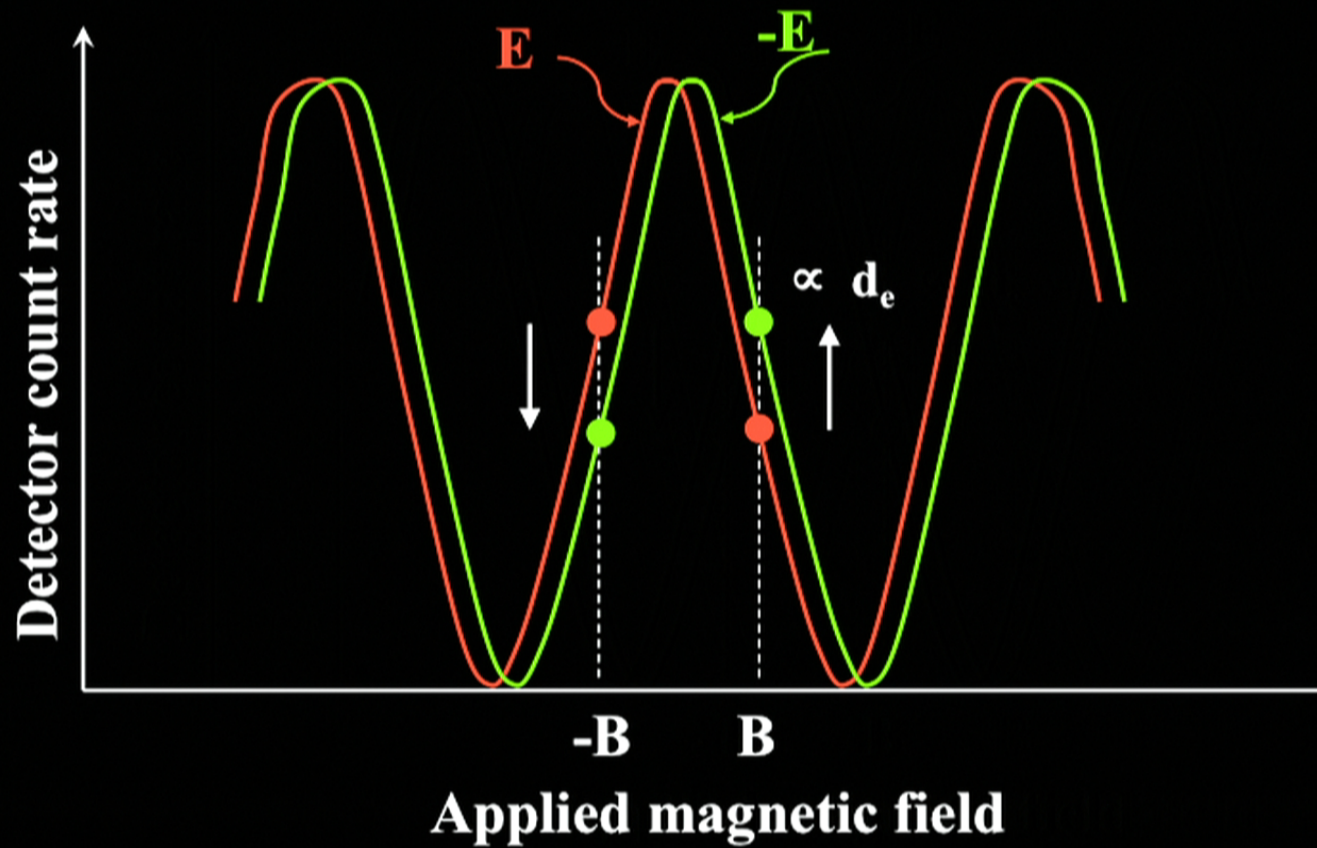
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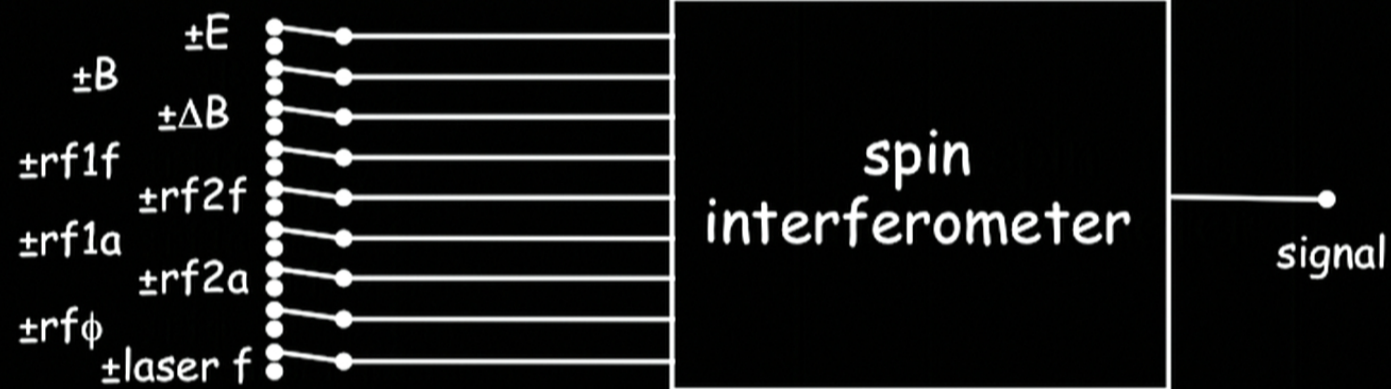
Measuring the edm

Input: DVI - 800x600p@60.25Hz
Output: SDI - 1920x1080i@60Hz

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



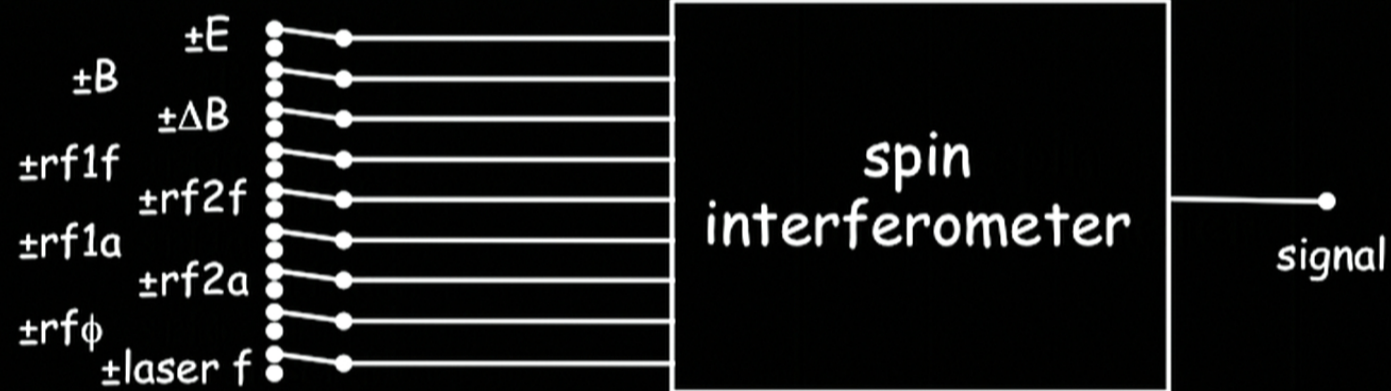
Modulate everything



9 switches:

512 possible correlations

Modulate everything

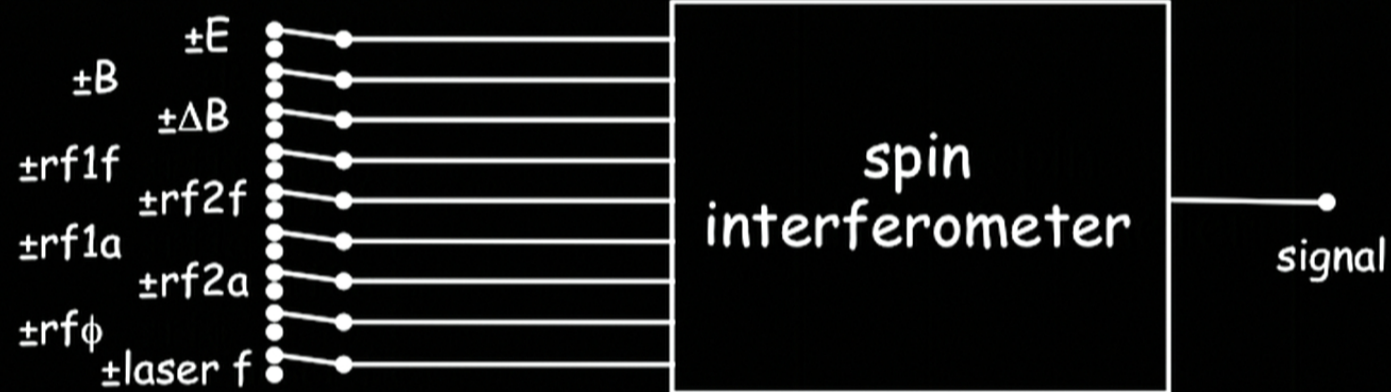


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• Generalisation of phase-sensitive detection

Modulate everything



9 switches:

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- Generalisation of phase-sensitive detection
- Measure all 512 correlations.

Modulate everything



9 switches:

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- Generalisation of phase-sensitive detection
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- 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.



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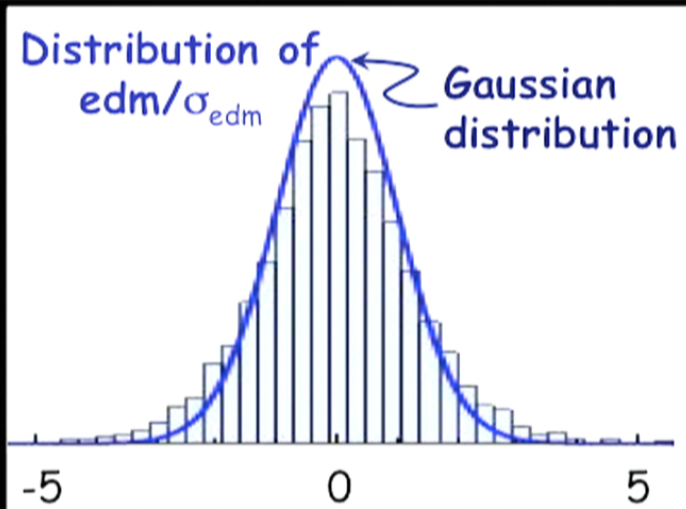
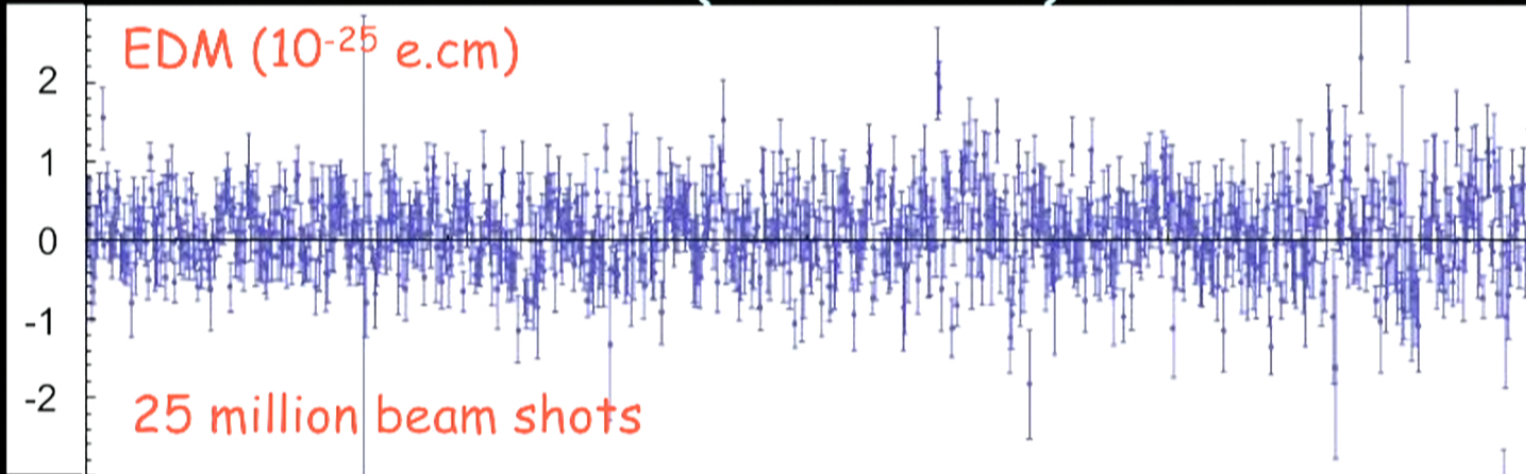
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- We don't know what result to expect.
- Still, to avoid inadvertent bias we hide the mean edm.
- An offset is added that only the computer knows.
- More important than you might think.
 - e.g. Jeng, Am. J. Phys. 74 (7), 2006.

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



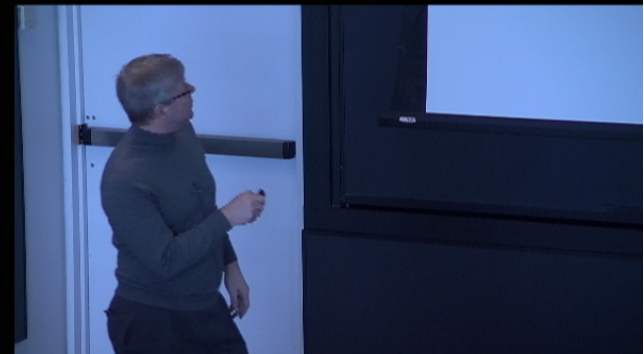
bootstrap method
determines
probability distribution

Measuring the other 511 correlations

correlation	mean	σ	mean/ σ
{DB}	{-19.8038, 0.251037}		78.888
{SIG}	{150.576, 1.9145}		78.6502
{PI, RF2A}	{0.0781105, 0.00478208}		16.334
{RF1F, RF2F}	{0.0709938, 0.00481574}		14.742
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{DB, RF1A}	{-0.0212292, 0.00407424}		5.21058

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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)

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

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

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



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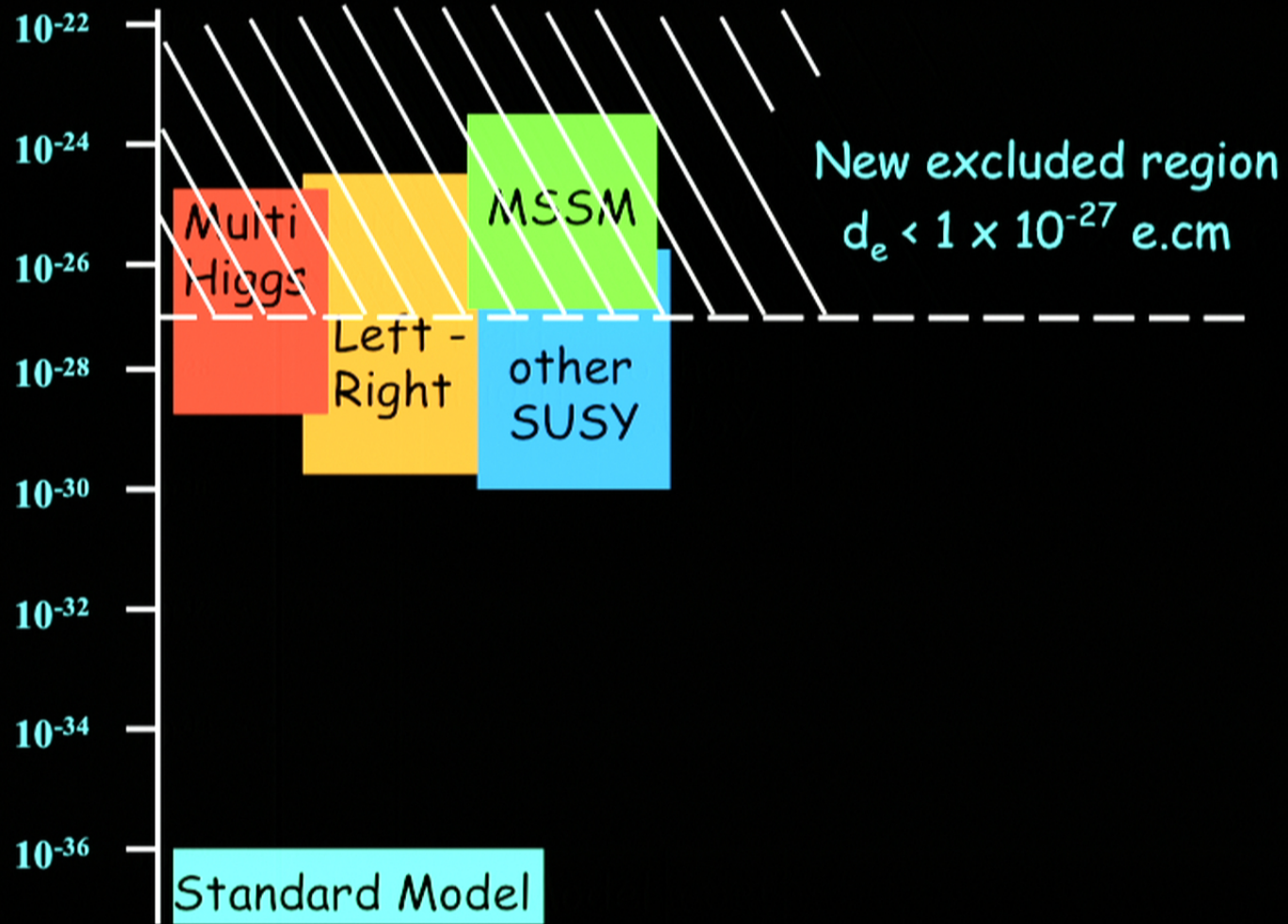
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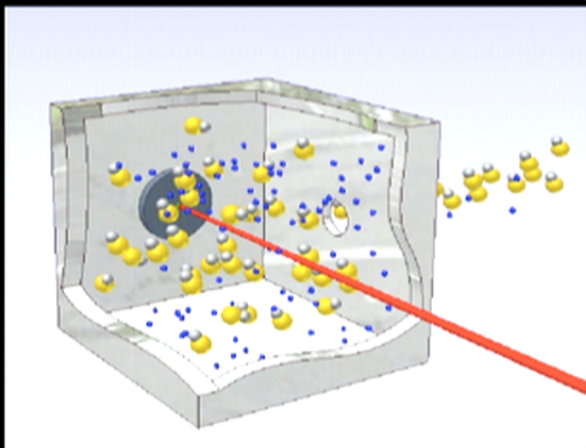
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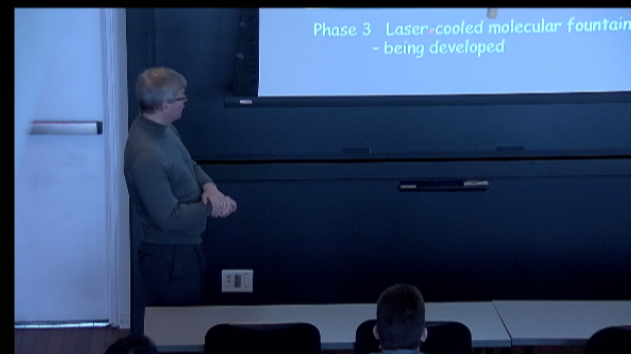
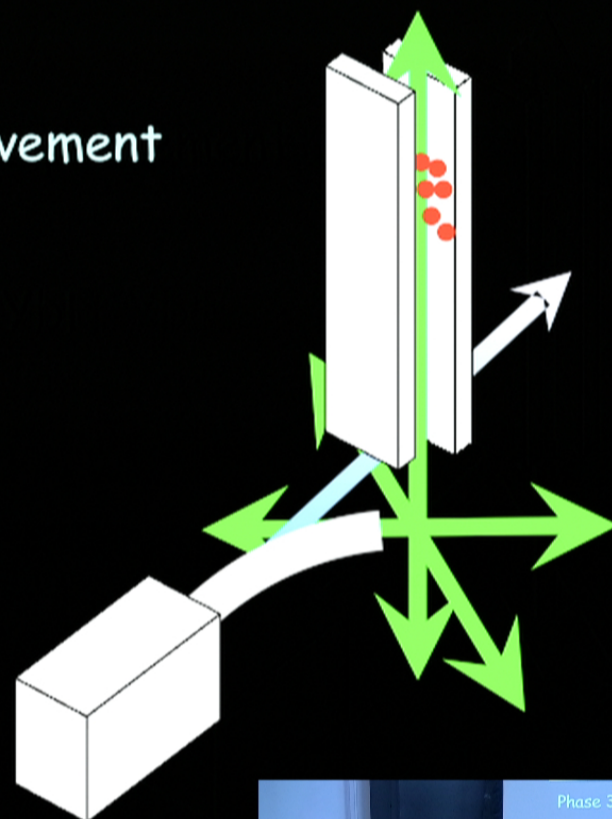
How we will improve

Phase 1 Small upgrades: 3 x improvement
- in progress

Phase 2 Cryogenic source of YbF
- almost ready

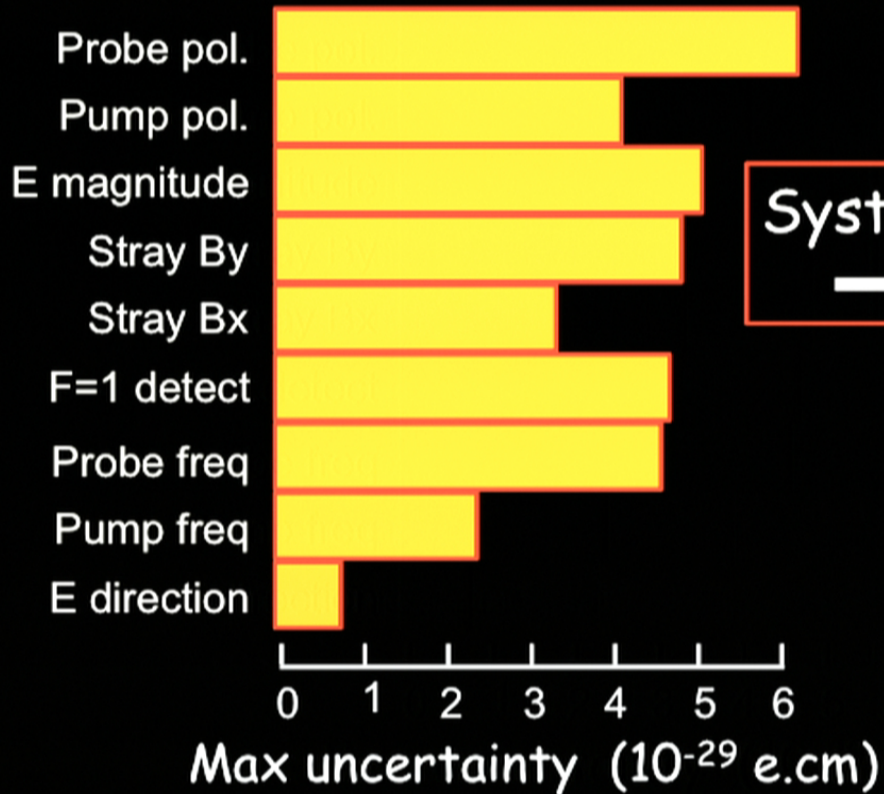


Phase 3 Laser-cooled molecular fountain
- being developed



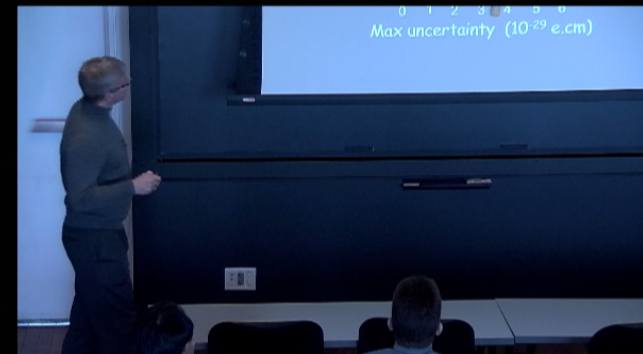
Phase 1:

Defects emphasised



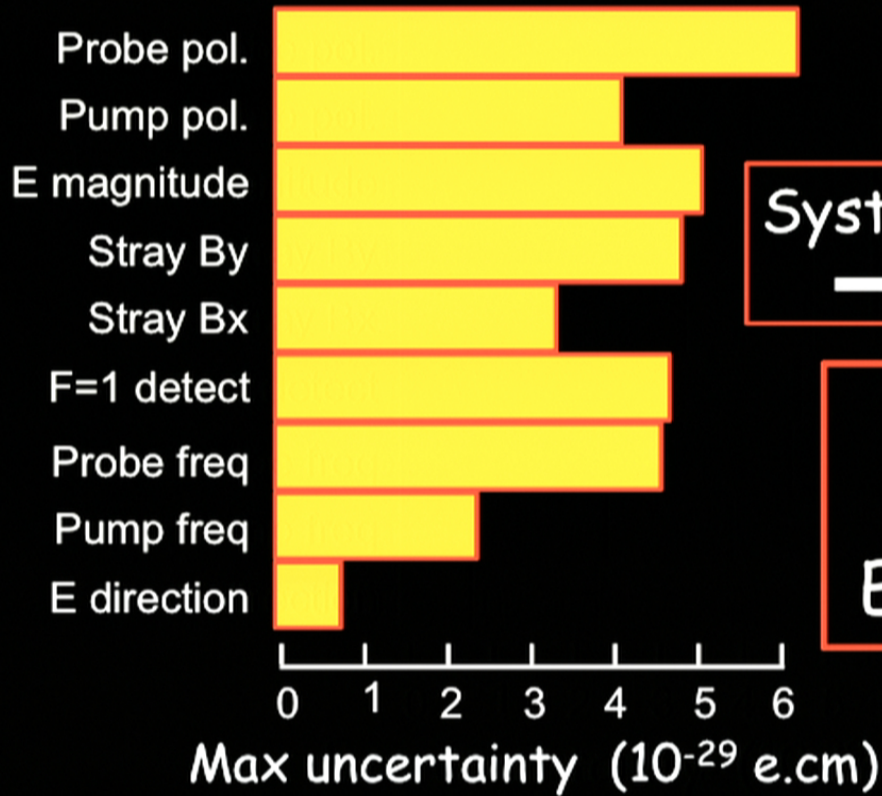
- Longer interferometer
- Lower background
→ 2.5x sensitivity

Systematics emphasised
→ total < 10⁻²⁸ e.cm



Phase 1:

Defects emphasised



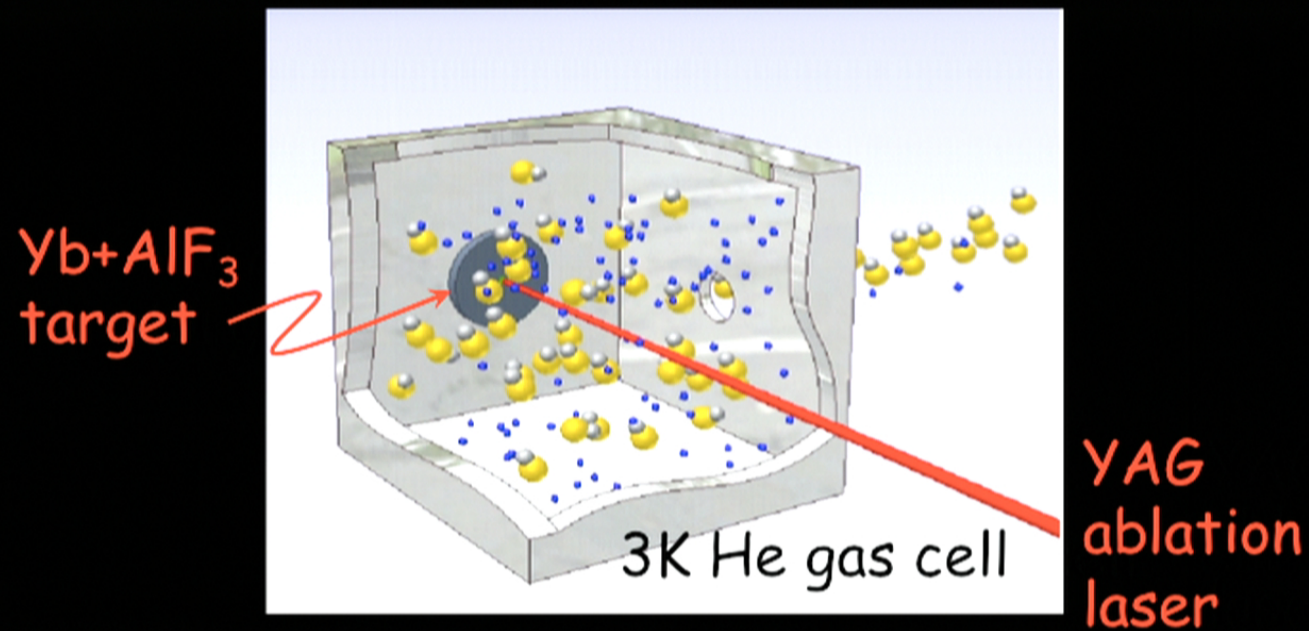
- Longer interferometer
- Lower background
→ **2.5x sensitivity**

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

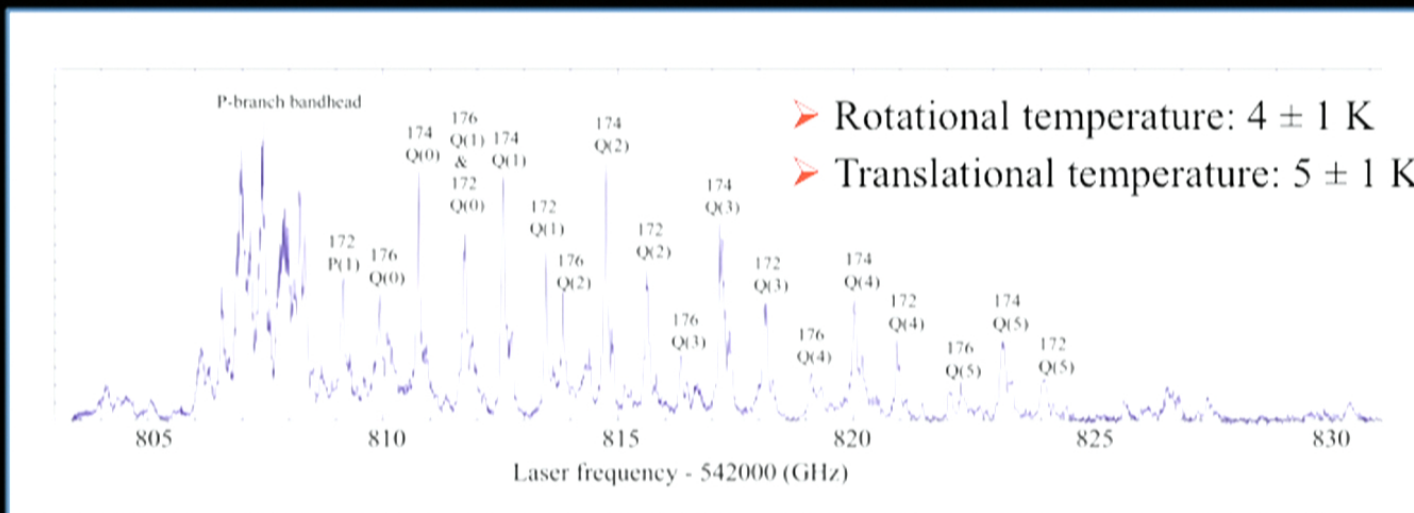
Now making a
 2×10^{-28} e.cm
EDM measurement



Phase 2 - cryogenic buffer gas source of YbF

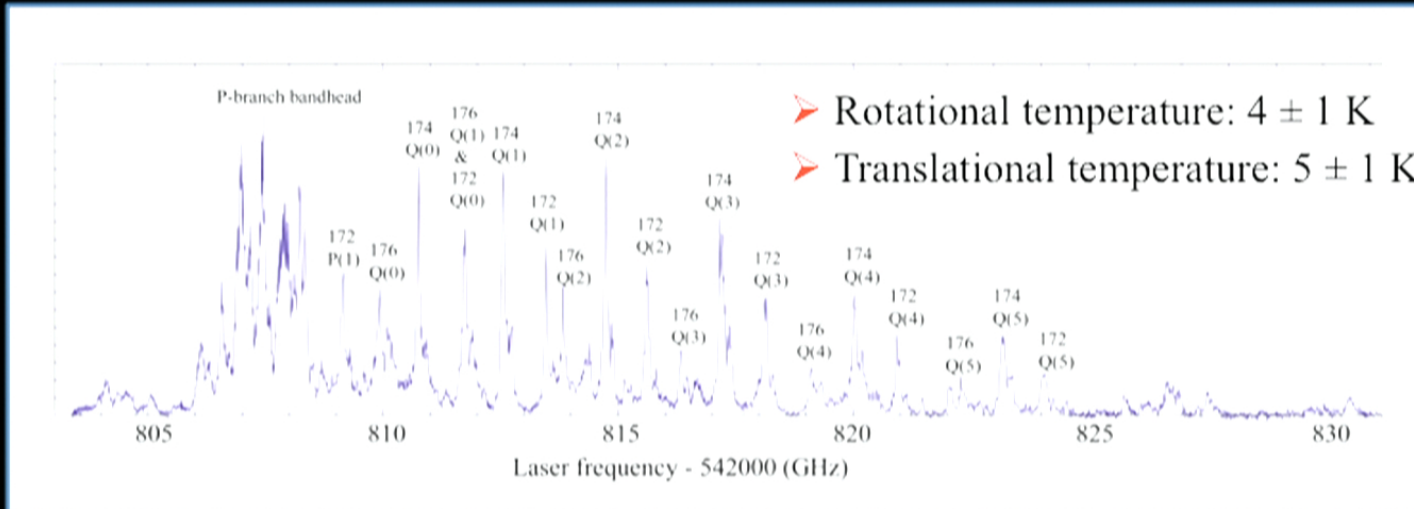


Cryogenic beam spectrum



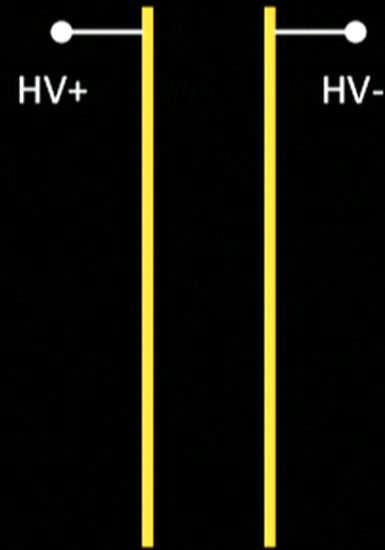
10 × more molecules/pulse

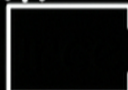
Cryogenic beam spectrum



10 × more molecules/pulse
4 × longer interaction time (slower beam)
⇒ 10 × better EDM signal:noise ratio

Phase 3 - a molecular fountain

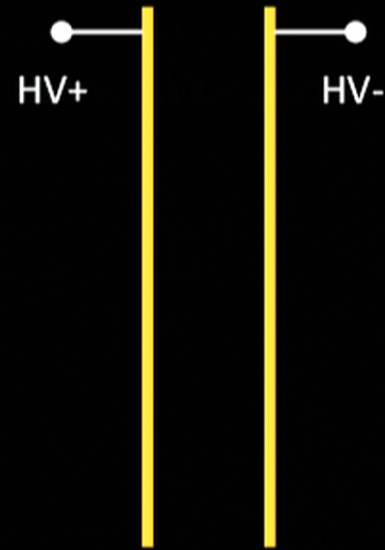


3K beam source  guide

Tarbutt *et al.* arXiv:1302.2870

20

Phase 3 - a molecular fountain

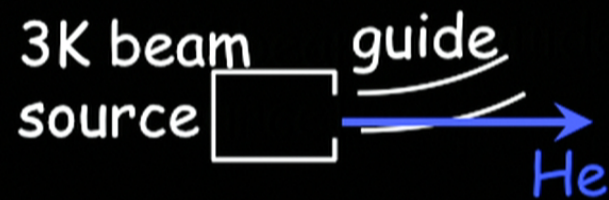
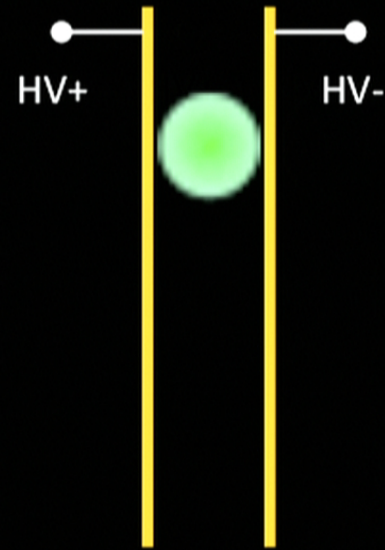


3K beam
source  guide

Tarbutt *et al.* arXiv:1302.2870

20

Phase 3 - a molecular fountain



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

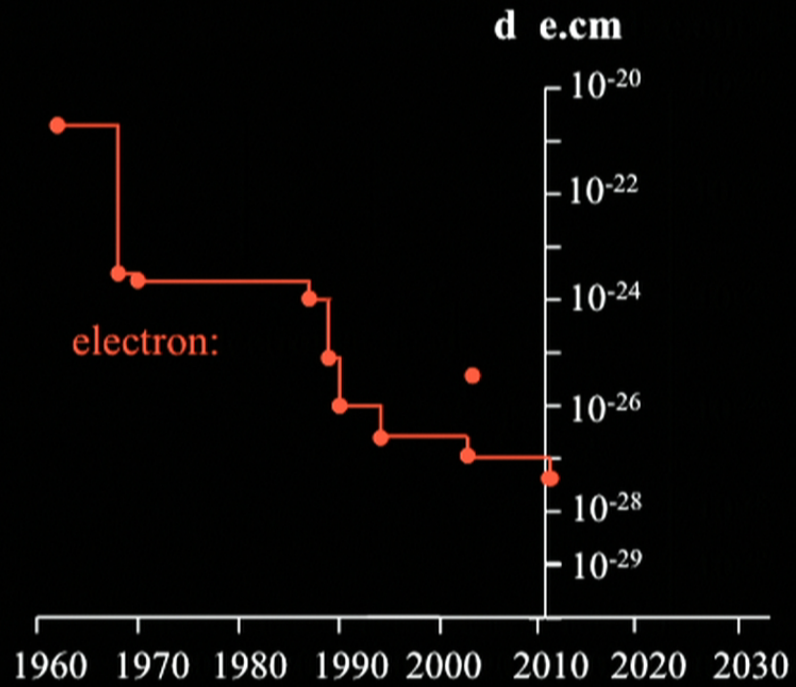
Cornel Group JILA HfF⁺ : $^3\Delta_1$ ground state ion trap

Atom experiments in preparation

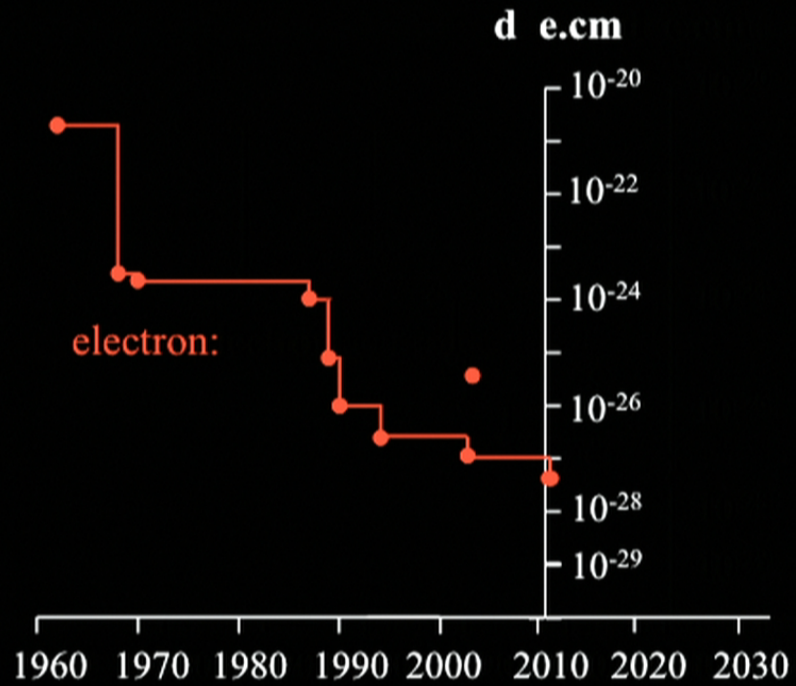
Cs in optical lattice: Weiss group, Penn State (next year?)

Heinzen group, Texas (2 years?)

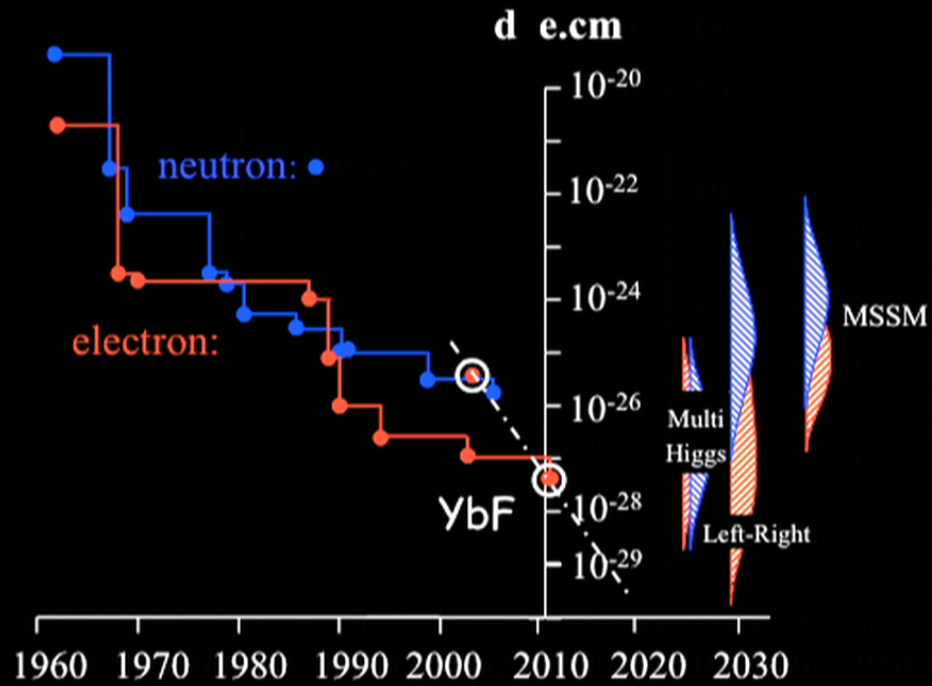
Current status of EDMs



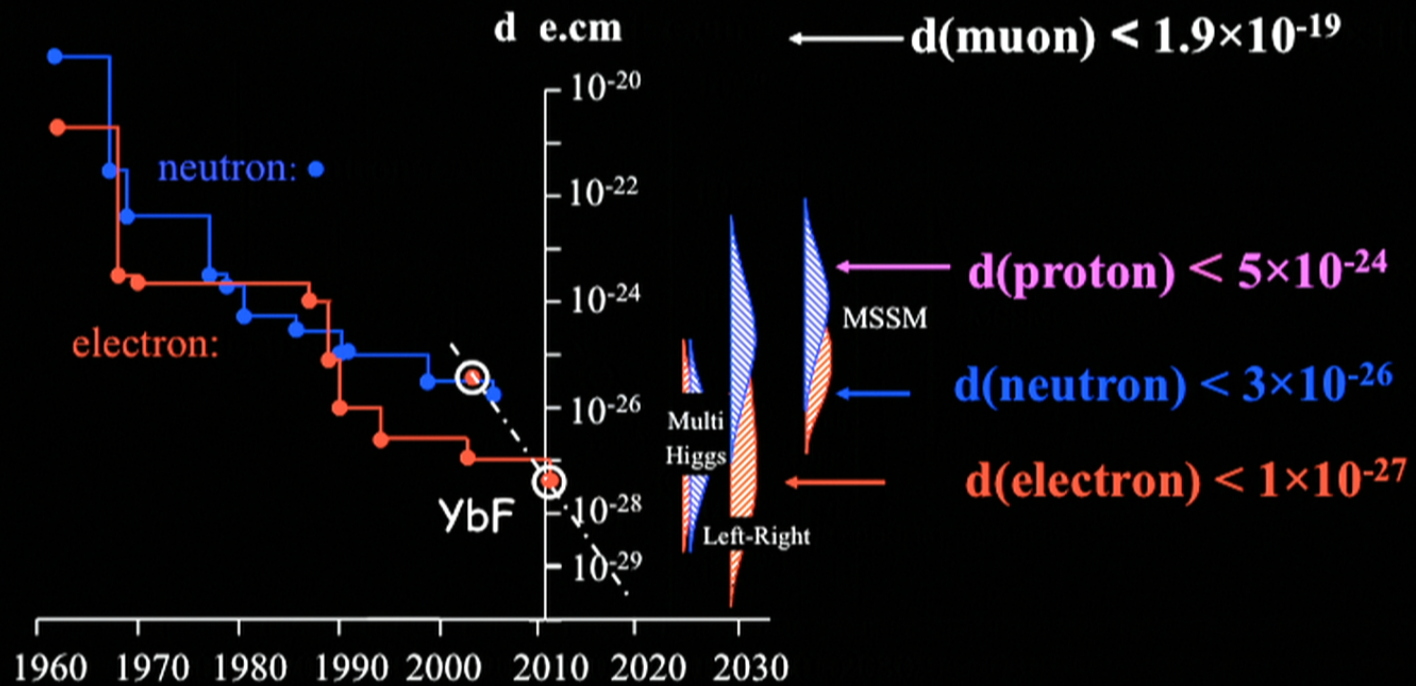
Current status of EDMs



Current status of EDMs



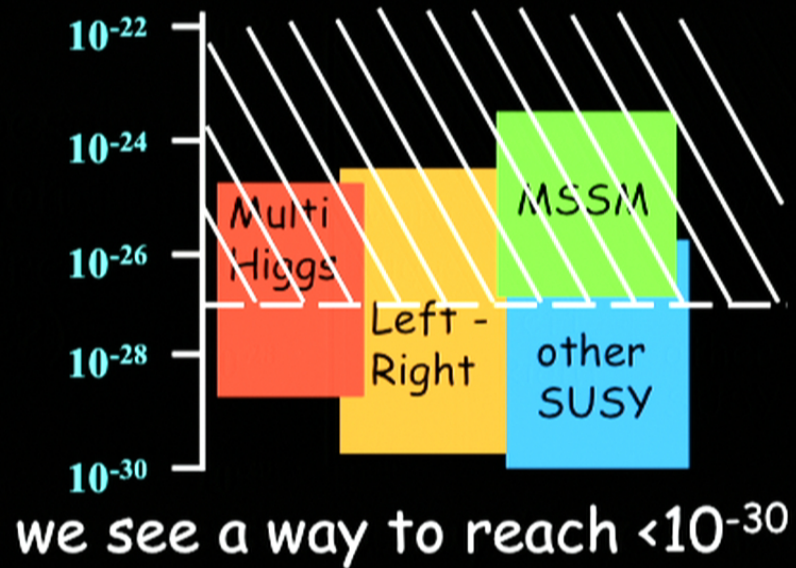
Current status of EDMs



Summary

e- EDM is a direct probe of physics beyond SM

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



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

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

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:

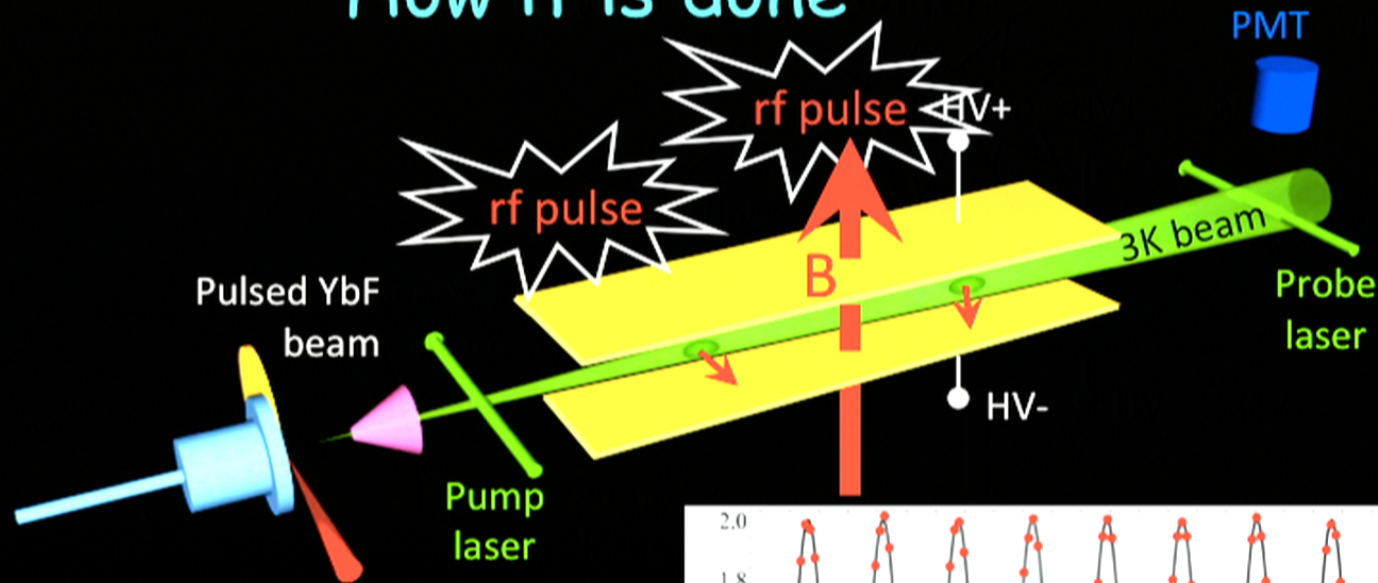
Thom Wall
Aki Matsushima
Valentina Zhelyazkova
Anne Cournol



Science & Technology
Facilities Council

Sc THE ROYAL
SOCIETY

How it is done



These "interferometer fringes" measure the spin rotation angle ϕ

