Cold YbF search for the electron EDM status and plans

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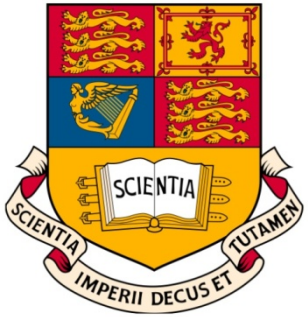


KITP, 12 March 2013

Theoretical estimates of eEDM

eEDM (e.cm)

10^{-22}

10^{-24}

10^{-26}

10^{-28}

10^{-30}

10^{-32}

10^{-34}

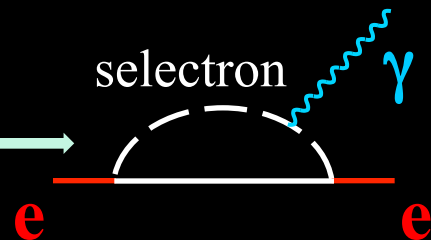
10^{-36}

Multi Higgs

Left - Right

MSSM

other SUSY



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

The interesting region of sensitivity

Standard Model

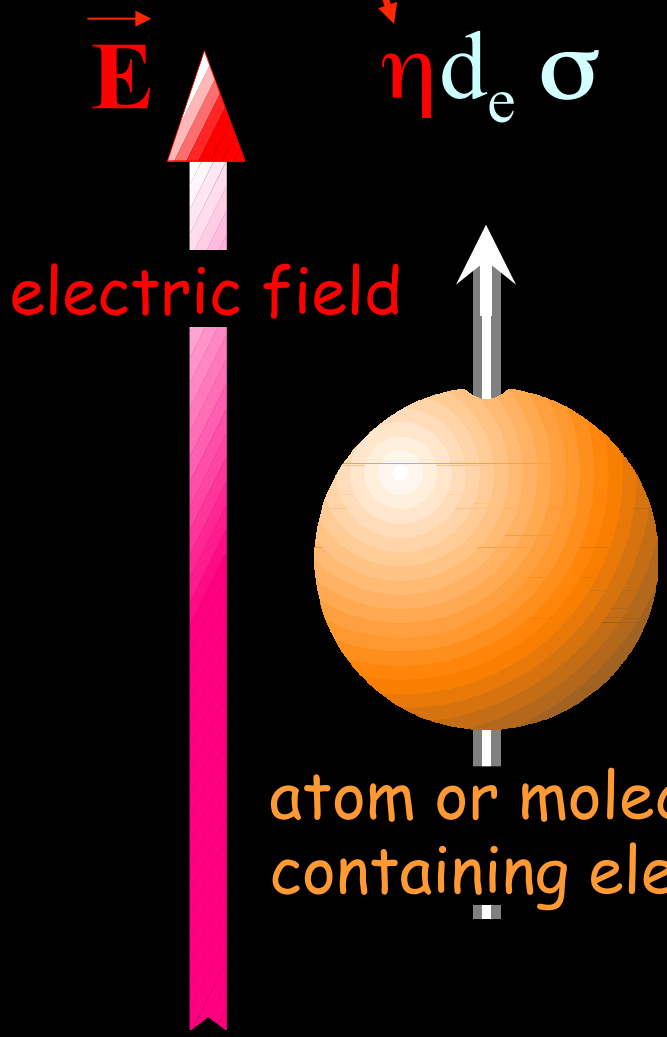
Insufficient ~~CP~~ to make universe of matter

A sensitive method

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

amplification (Sandars)

$\eta d_e \sigma$



Interaction energy

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

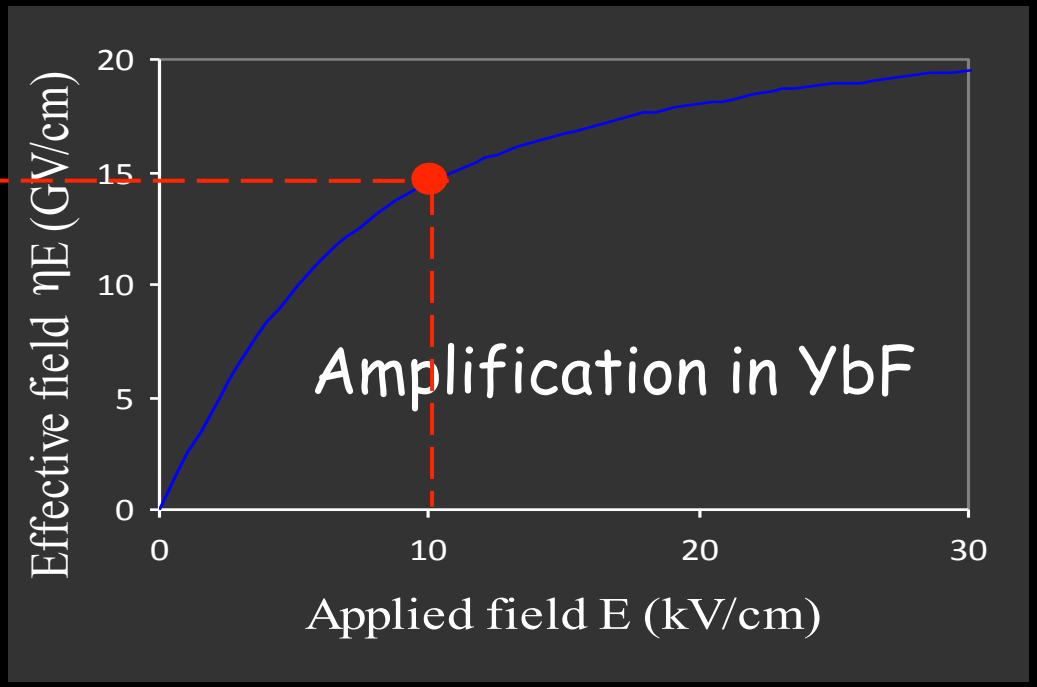
$F P$

Polarization factor

Structure-dependent relativistic factor ~ Z^3 (Flambaum)

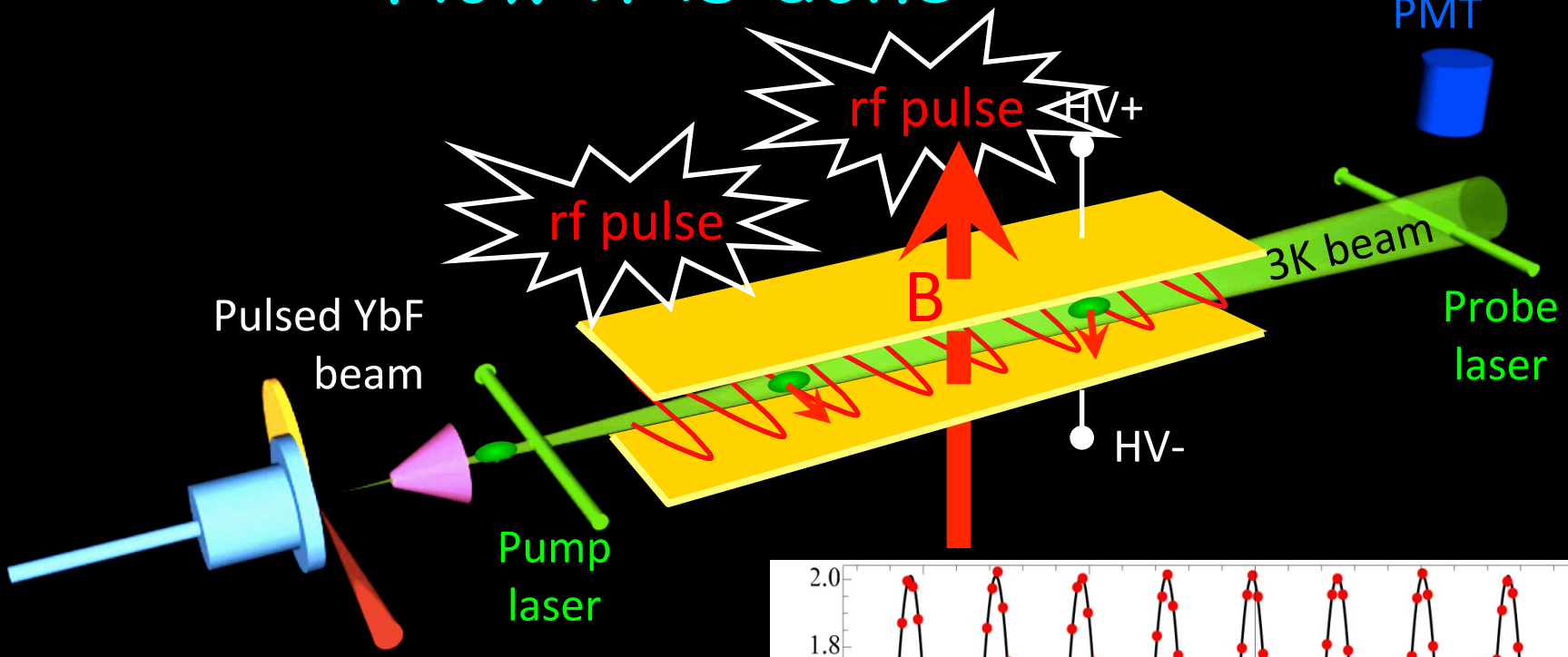
Our experiment uses a polar molecule – YbF

15 GV/cm

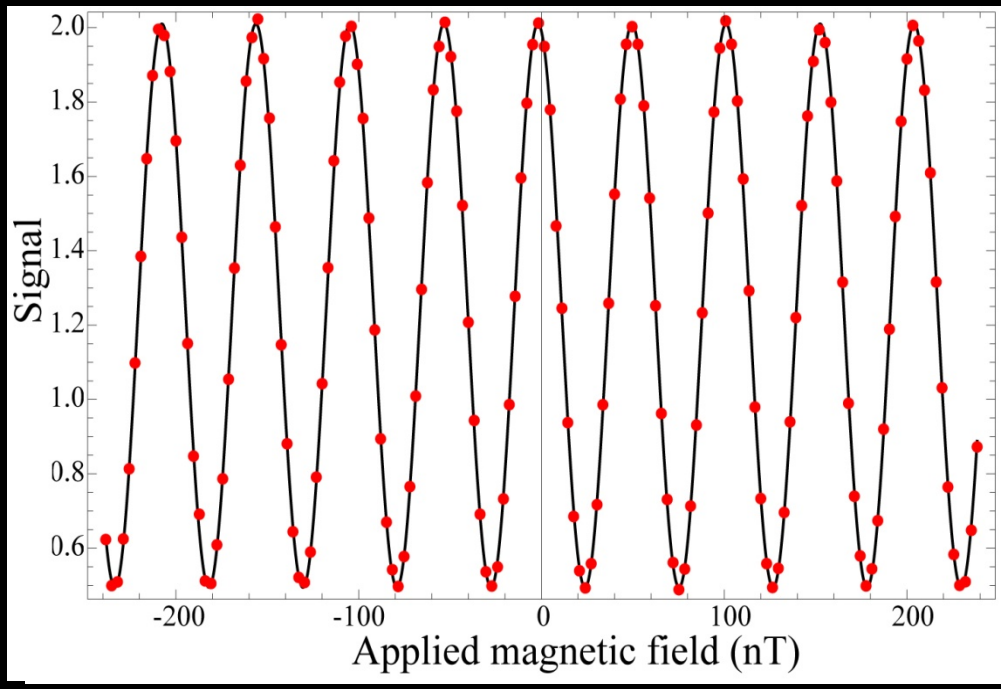


- EDM interaction energy is a million times larger (mHz)
- needs "only" nG stray B field control

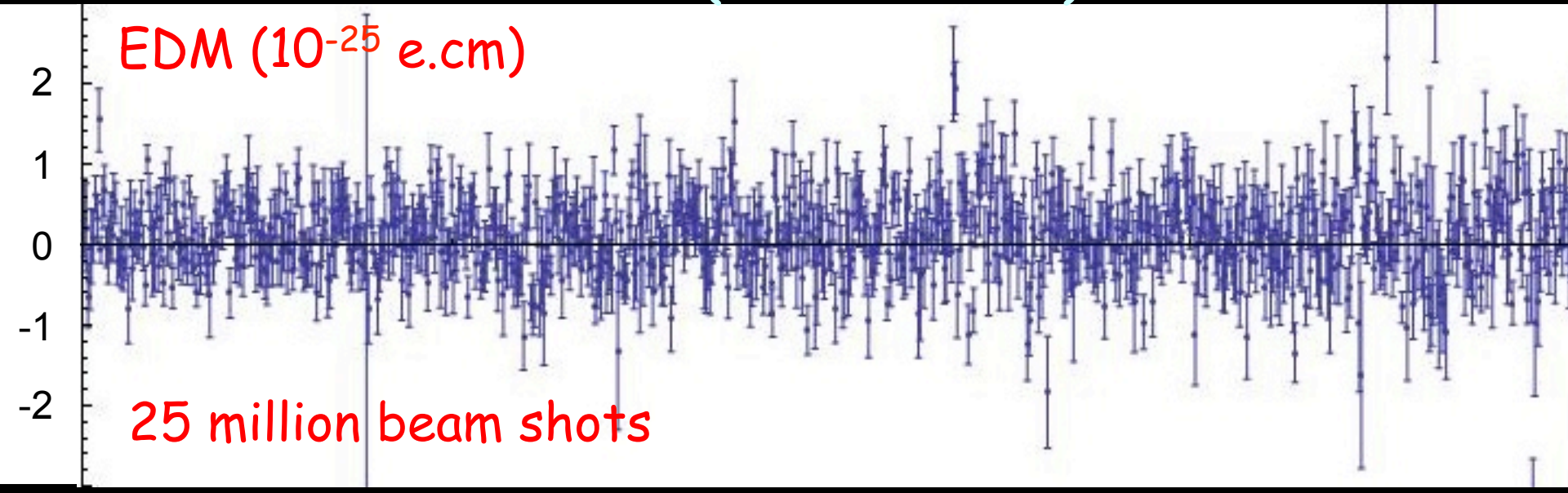
How it is done

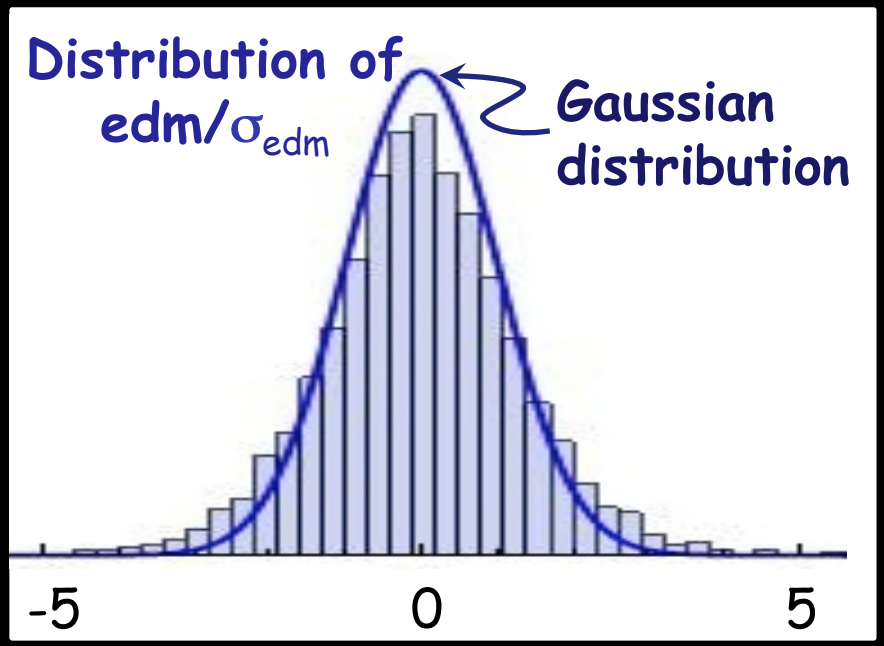


These "interferometer fringes" measure the spin rotation angle ϕ



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





bootstrap method determines probability distribution

Current status

- Previous result - Tl atoms — Regan *et al.* (PRL 2002)

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

90% confidence Liu/Kelley (PRL 1992)
89% confidence Dzuba/Flambaum (PRL 2009)
79% confidence Nataraj *et al.* (PRL 2011)

- 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

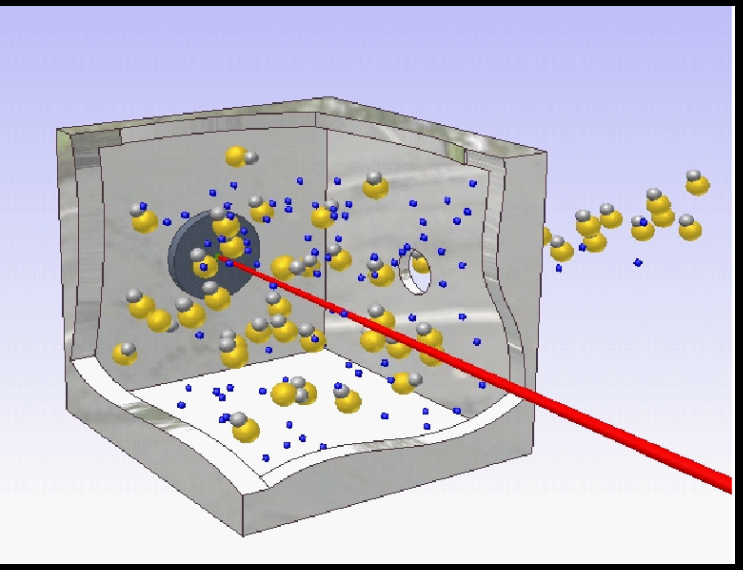
systematic - limited by statistical noise

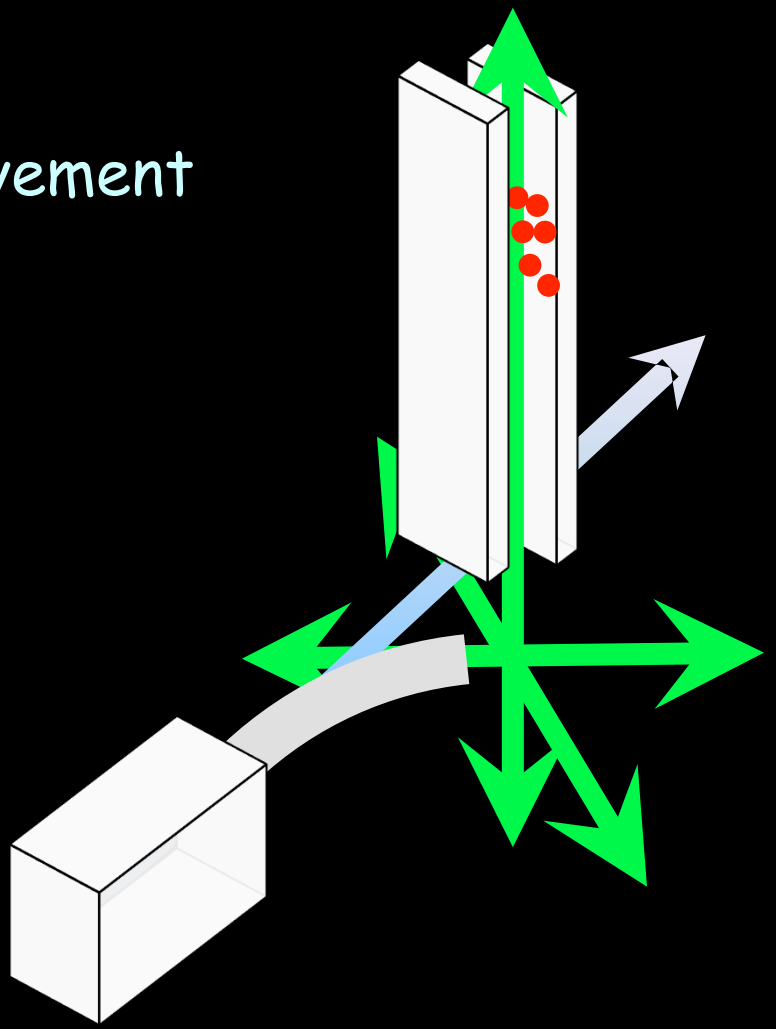
$d_e < 1 \times 10^{-27}$ e.cm with 90% confidence

How we are improving this

Phase 1 Small upgrades: 3 x improvement
– in progress

Phase 2 Cryogenic source of YbF
– almost ready

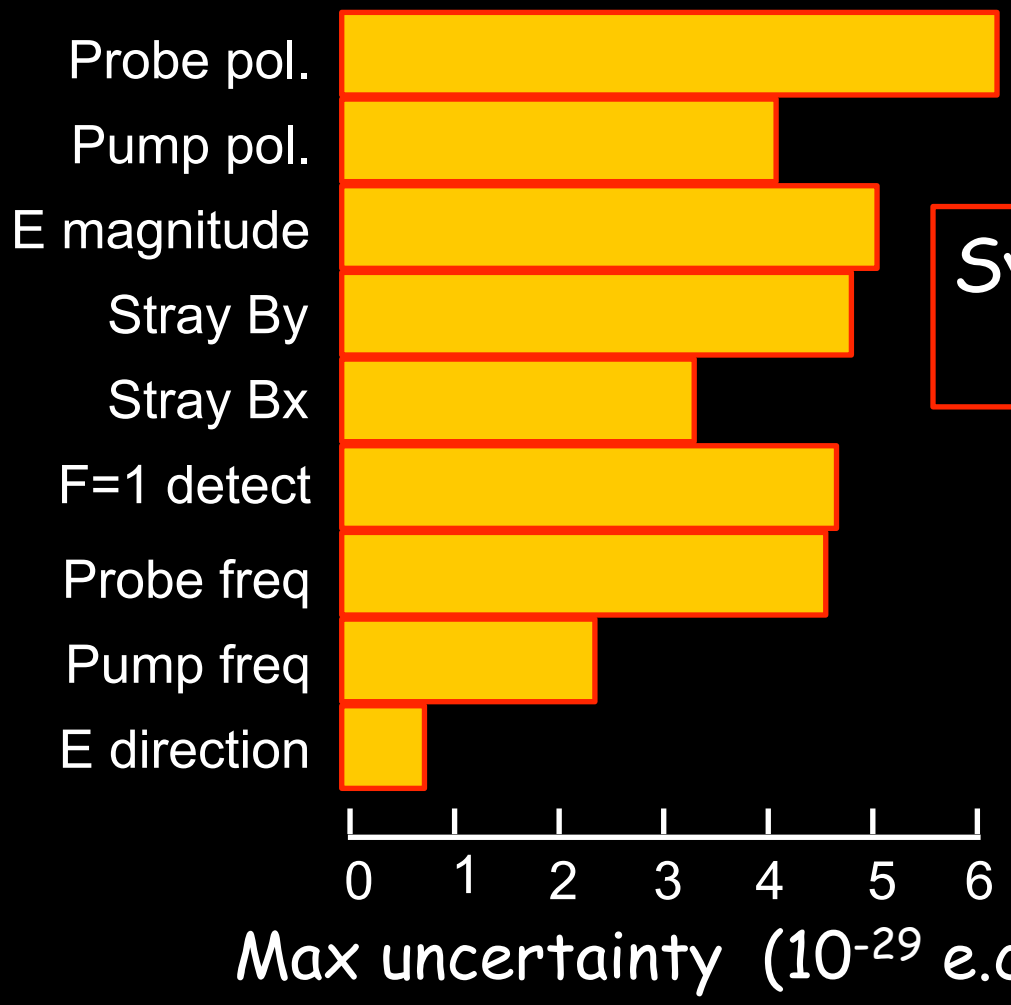




Phase 3 Laser-cooled molecular fountain
– being developed

Phase 1:

Defects emphasised



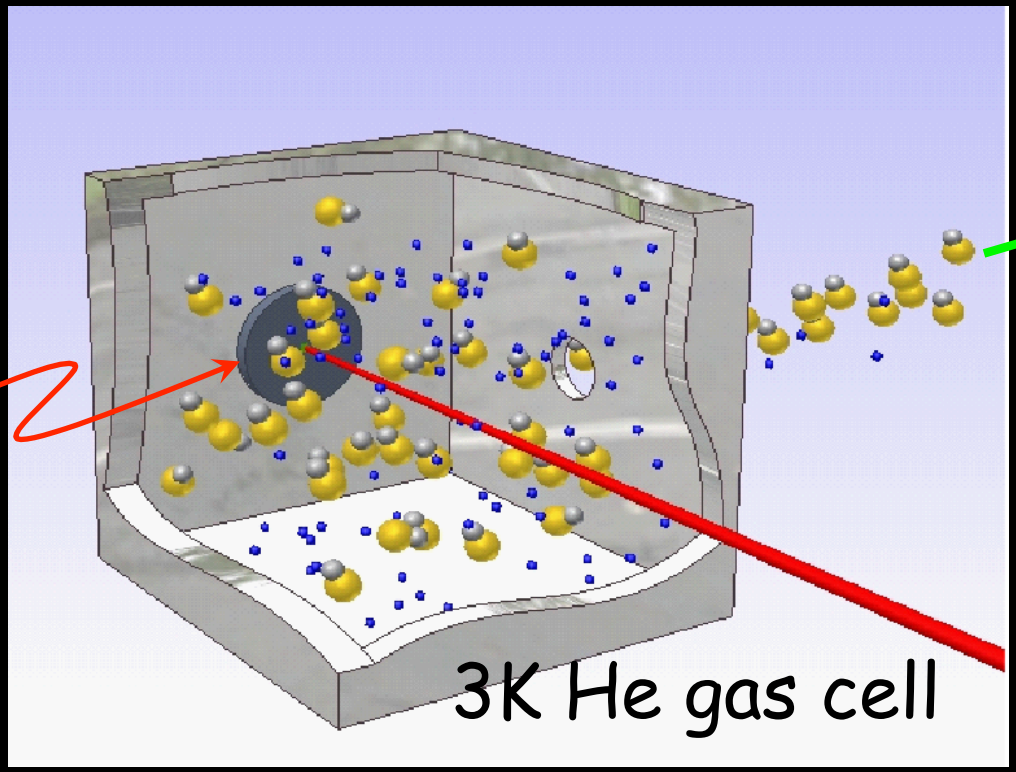
- Longer interferometer
- Lower background

→ 2.5×sensitivity

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

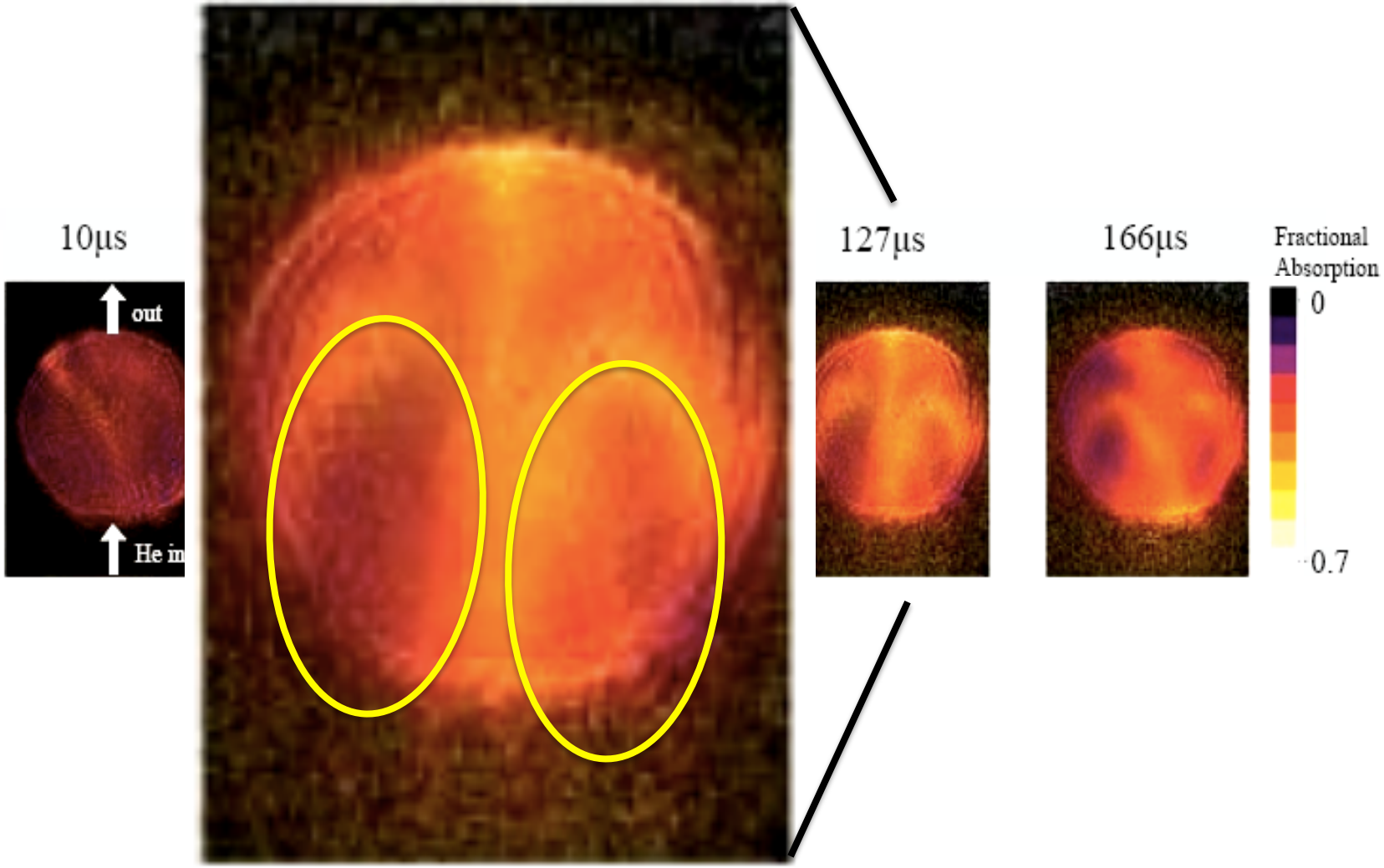
Now making a
2×10^{-28} e.cm
EDM measurement

Phase 2 - cryogenic buffer gas source of YbF



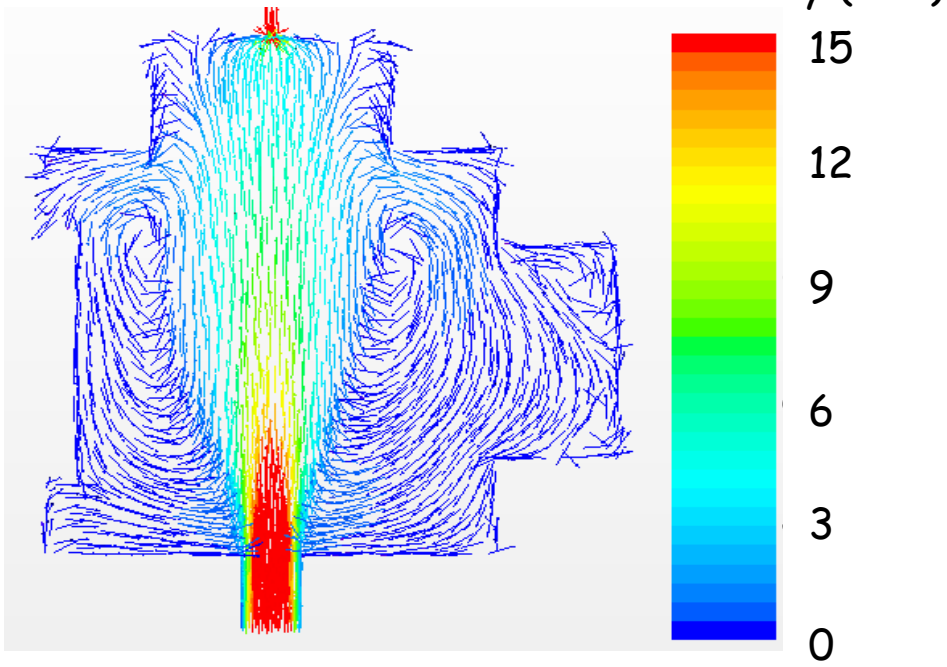
YbF distribution in the cell (absorption images)

YbF is by trapped in vortices inside cell

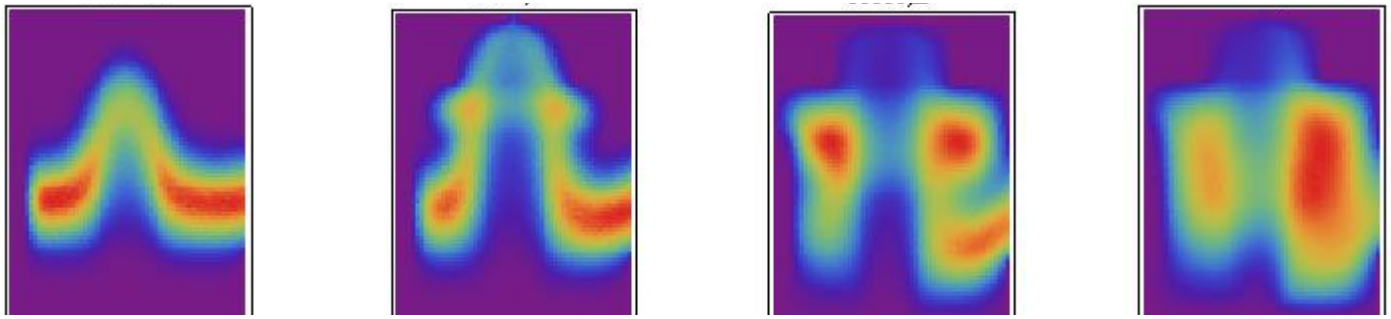


Simulating flow in buffer gas cell

He flow calculated using STAR-CCM+



YbF density calculated using Star-ccm+



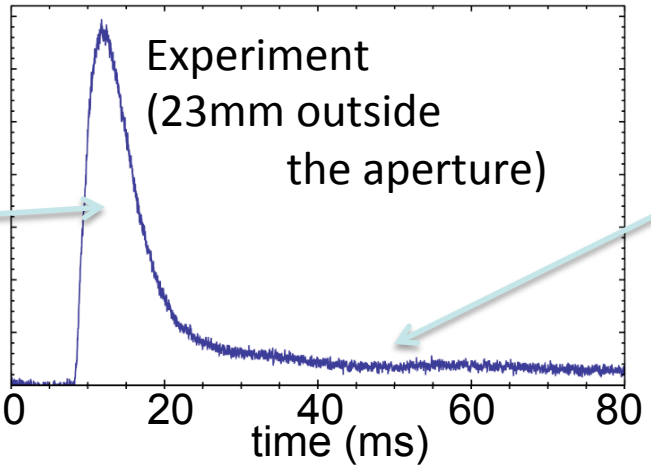
Better cell design required, but this is what we have

YbF beam velocity: 50 - 200 m/s

intensity: 1-2 x 10^{10} /sr/pulse

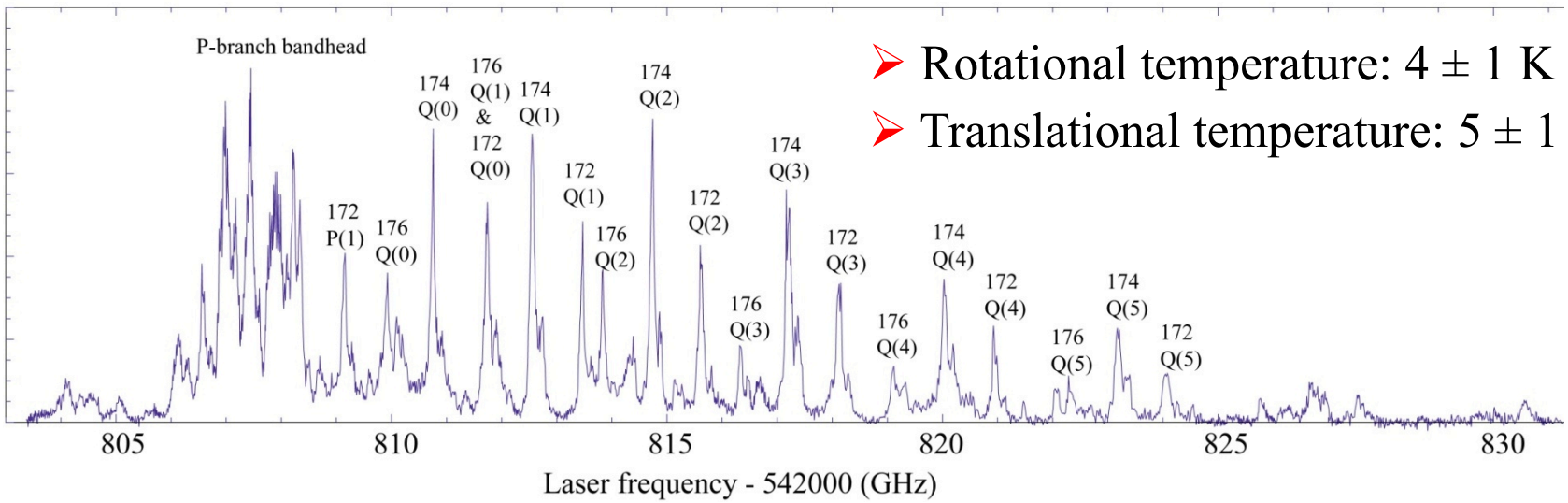
Time profile of YbF beam

10 ms pulse



long tail from vortex trapping

Cryogenic beam spectrum



- Rotational temperature: 4 ± 1 K
- Translational temperature: 5 ± 1 K

10 × more molecules/pulse

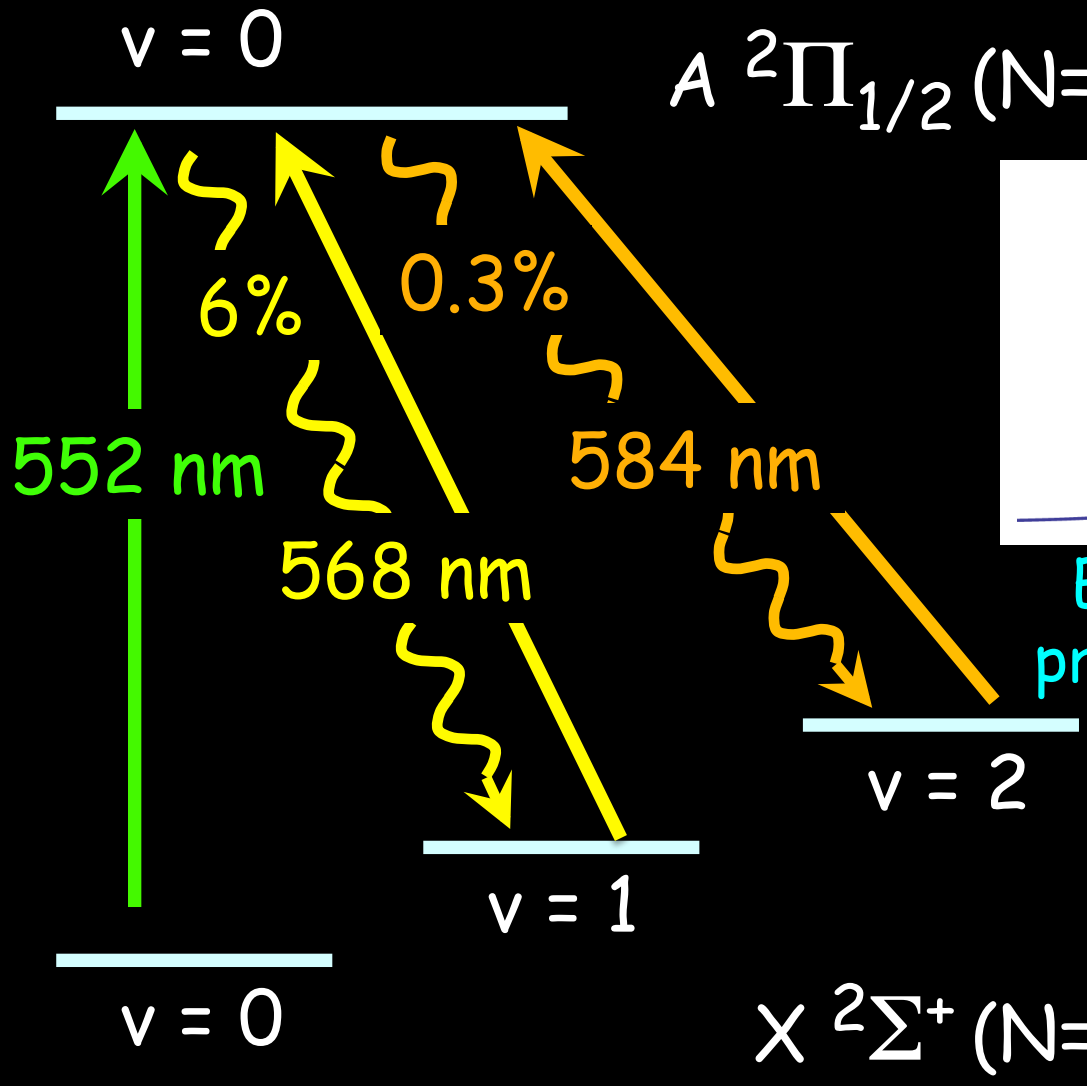
4 × longer interaction time (slower beam)

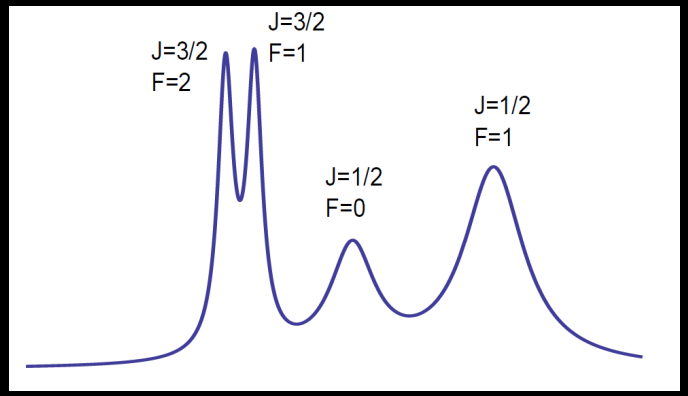
=> 10 × better EDM signal:noise ratio

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

Phase 3 - laser-cooled YbF fountain

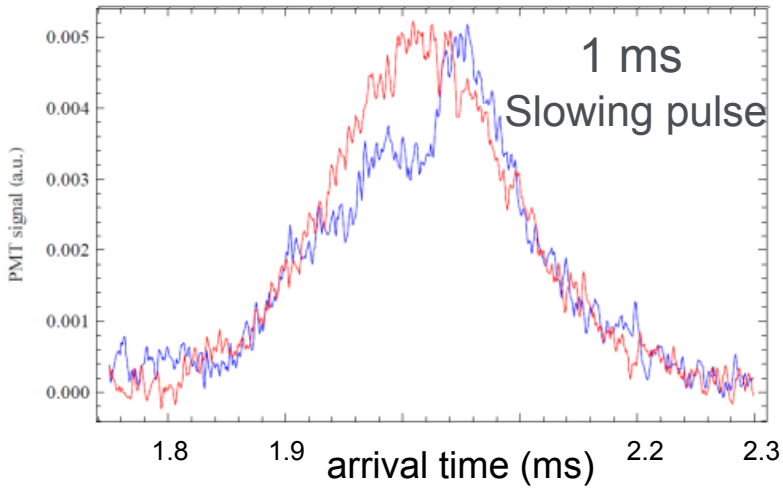
The YbF cooling scheme



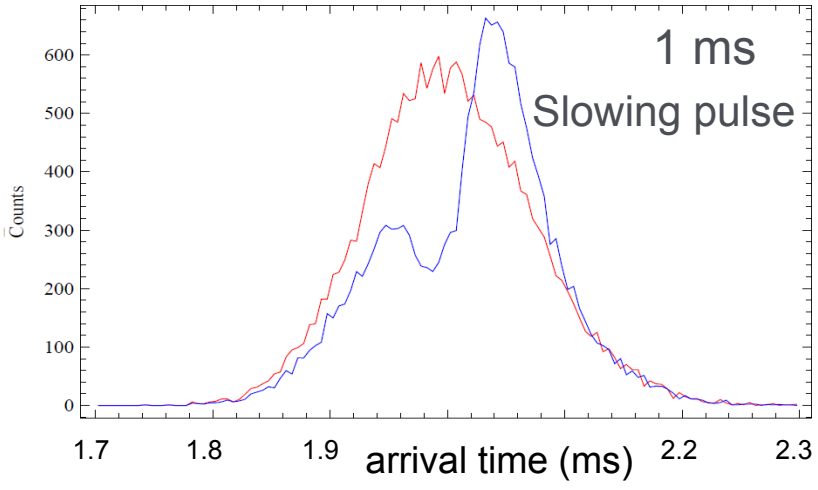


Each laser has to provide 4 hyperfine frequencies

Learning by slowing a 600m/s CaF beam

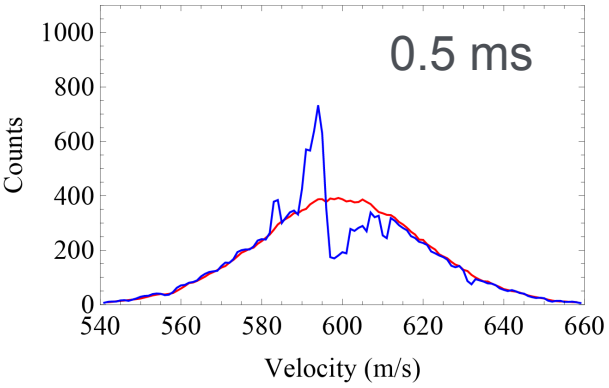


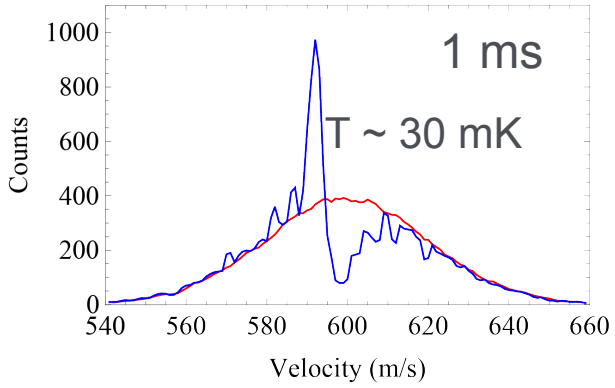
Data

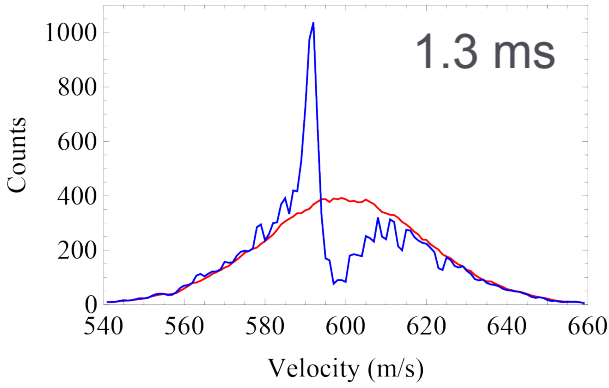


Simulation

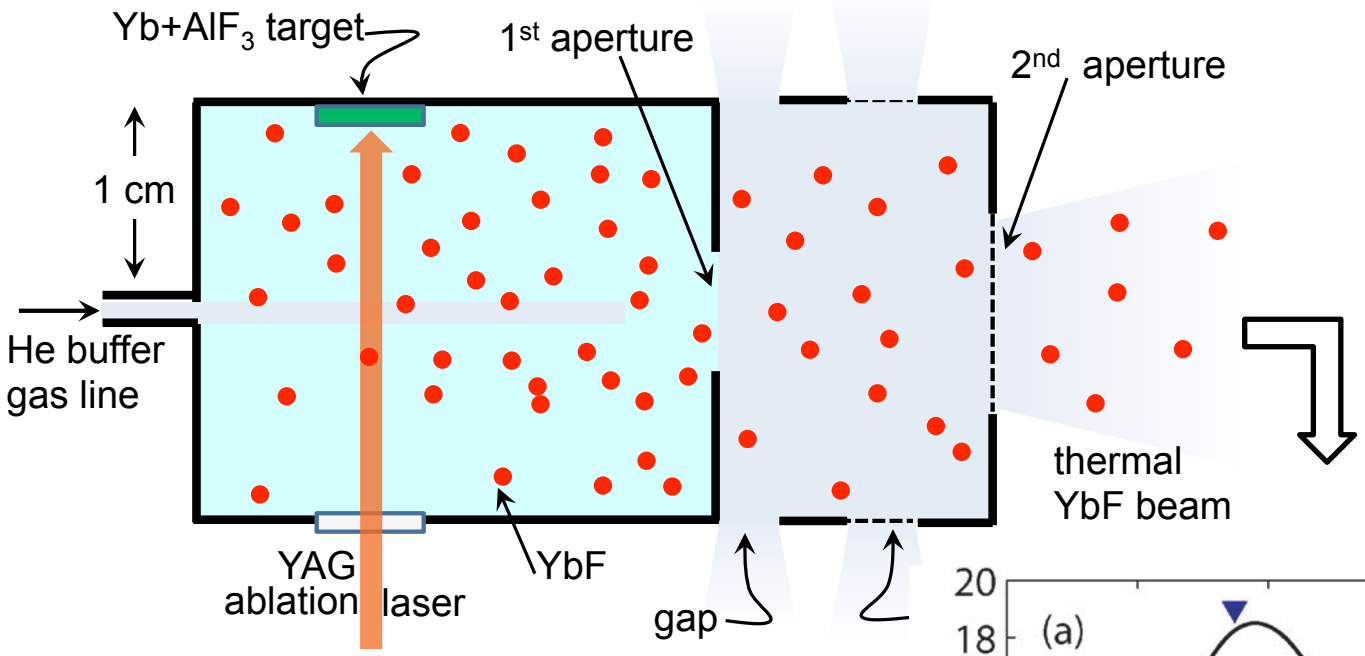
velocity from same simulation







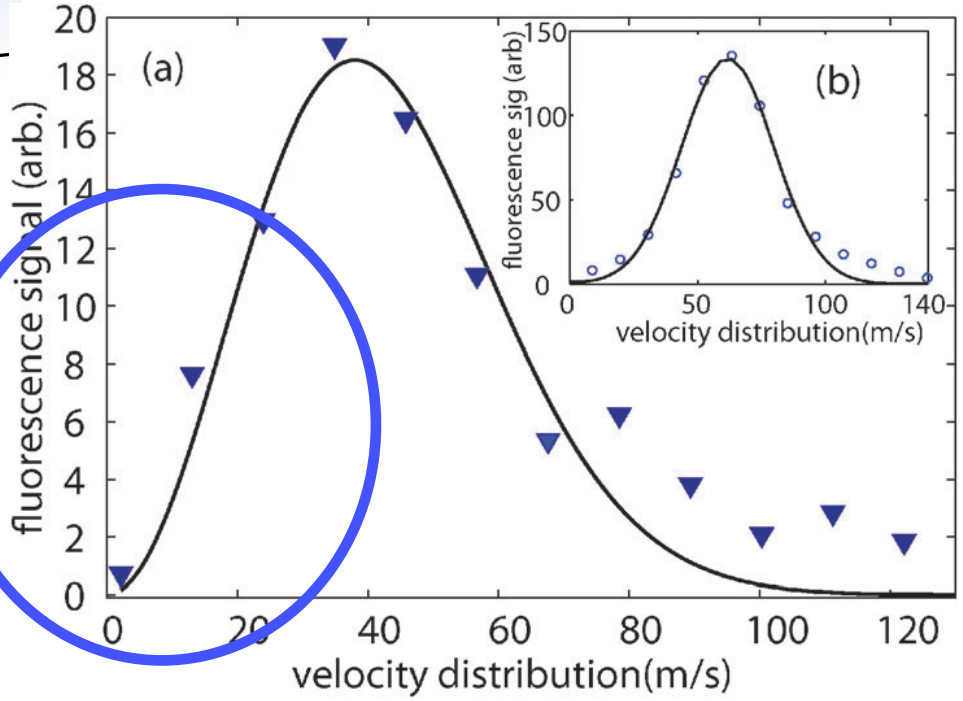
Thermal beam source to load YbF optical molasses



Doyle group

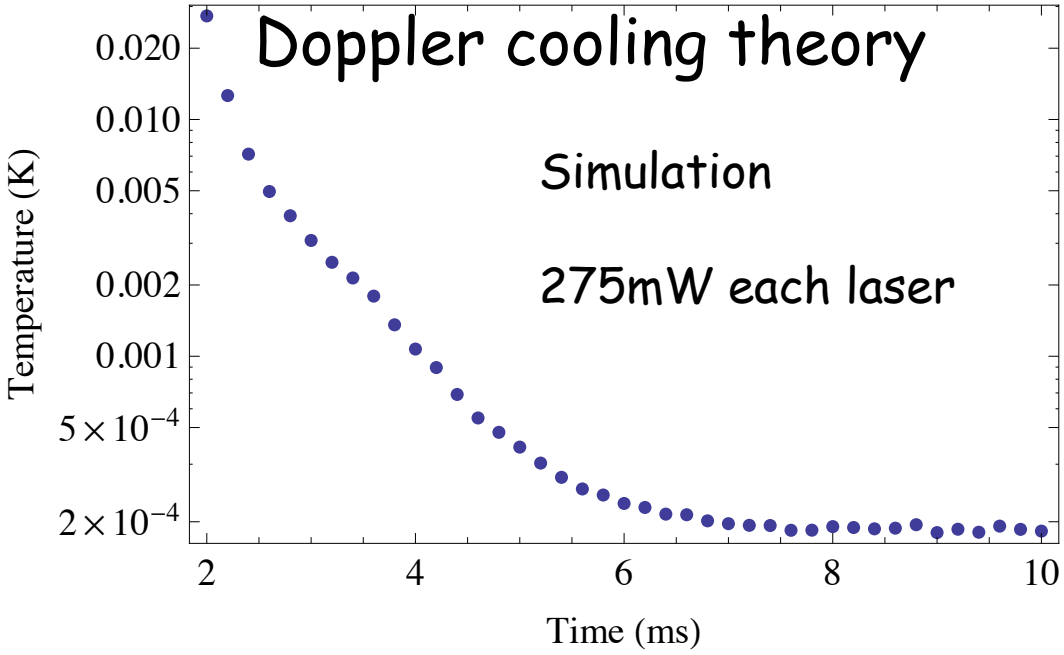
PCCP. **13**, 18986 (2011)

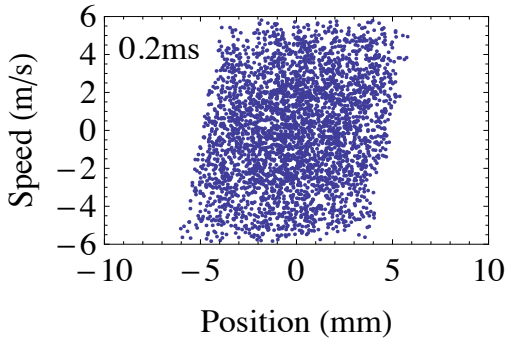
slow molecules will be caught in molasses

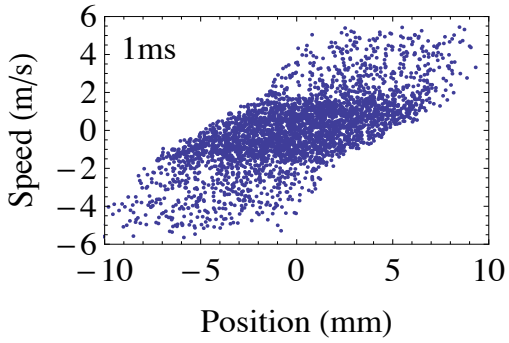


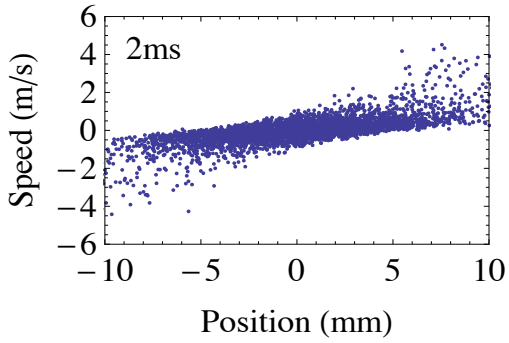
Application to YbF

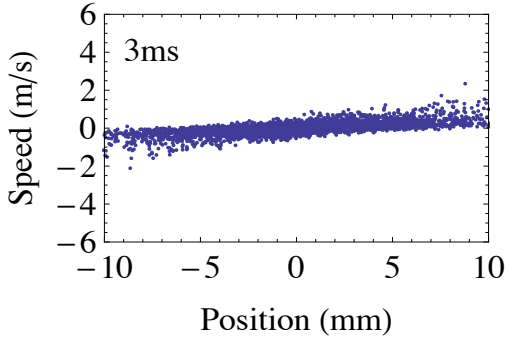
3D optical molasses can capture the slow molecules

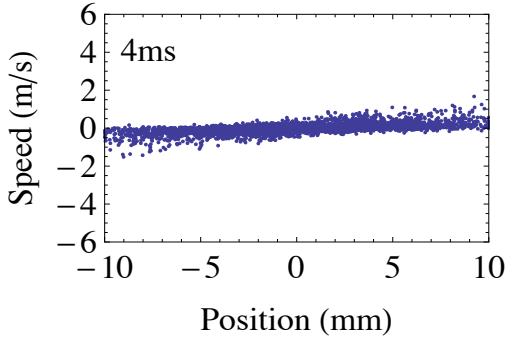


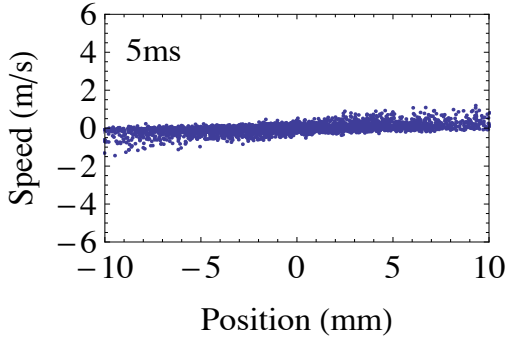










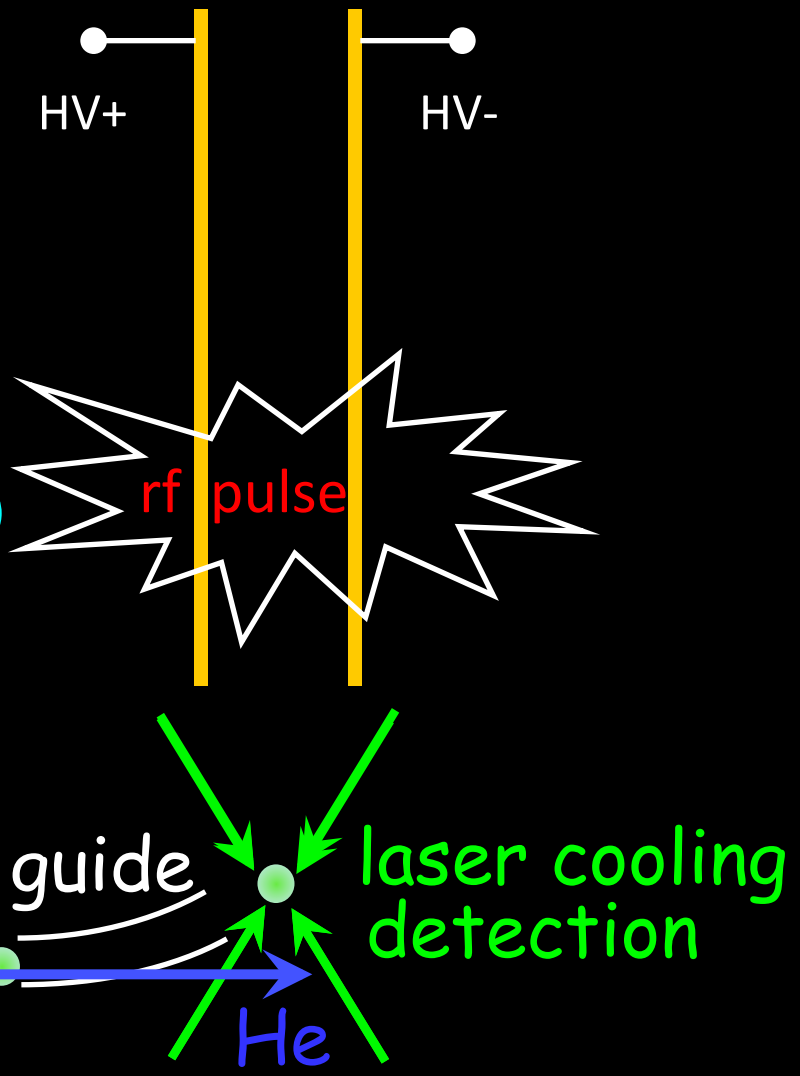


proposed YbF fountain for EDM

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

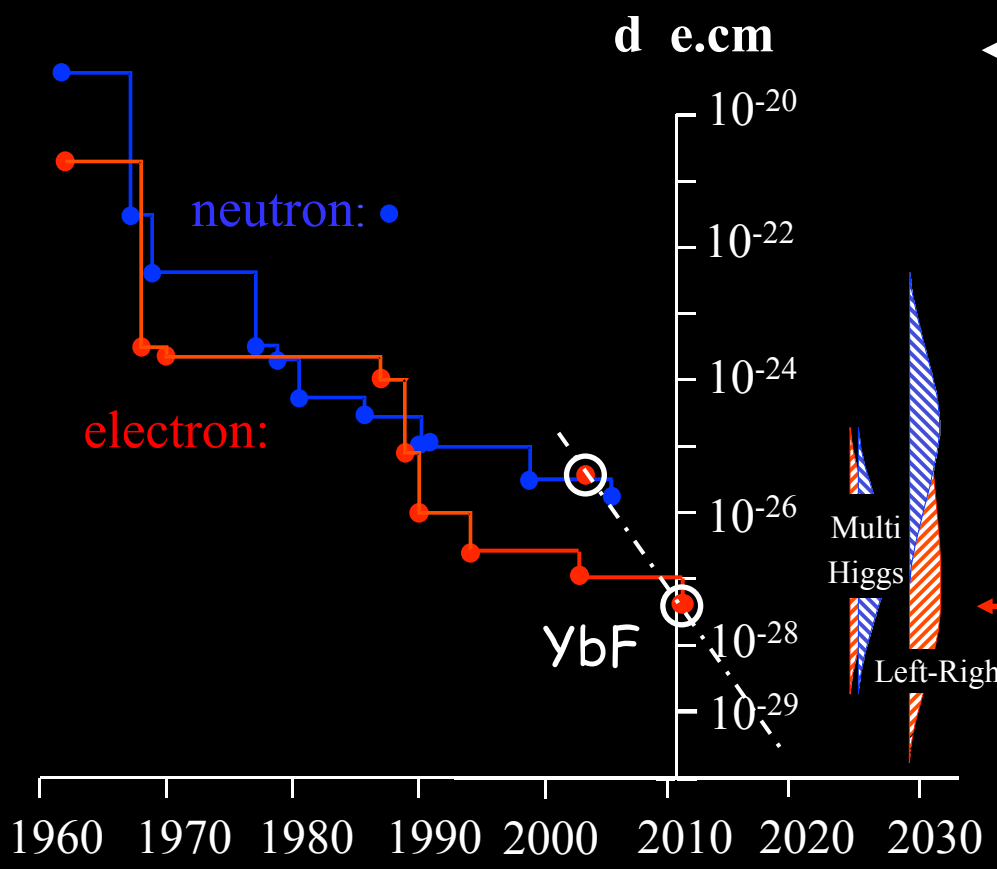
Cornel Group JILA — HfF^+ : $^3\Delta_1$ ground state ion trap

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



d(muon) < 1.9×10^{-19}

d(proton) < 5×10^{-24}

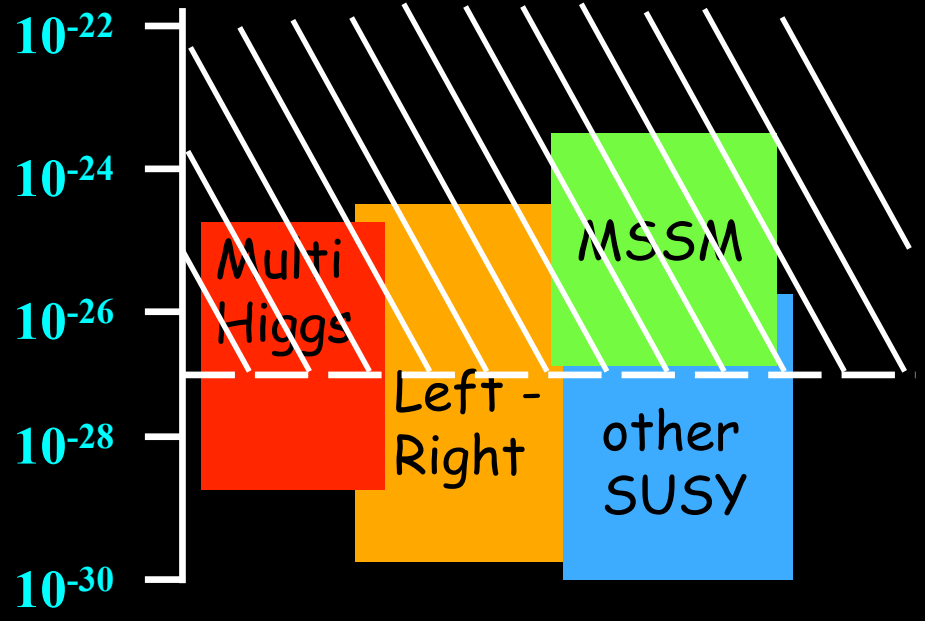
d(neutron) < 3×10^{-26}

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?)



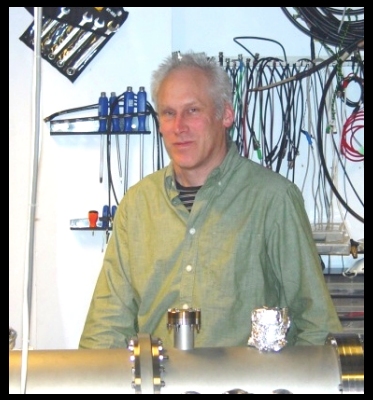
we see a way to reach $<10^{-30}$

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

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