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EUROPEAN PHYSICAL SOCIETY HEP2015

JÜLICH FORSCHUNGSZENTRUM

EPS Conference on High Energy Physics, 22-29 July 2015, Vienna

Electric Dipole Moments – A Window for New Physics

July 2015 | Hans Ströher (Forschungszentrum Jülich)

New physics: empirical evidence (ν-oscillations, dark matter, baryon asymmetry) doesn´t a priori point to a specific mass scale

→ Direct searches („energy frontier")

→ Indirect searches („precision frontier")

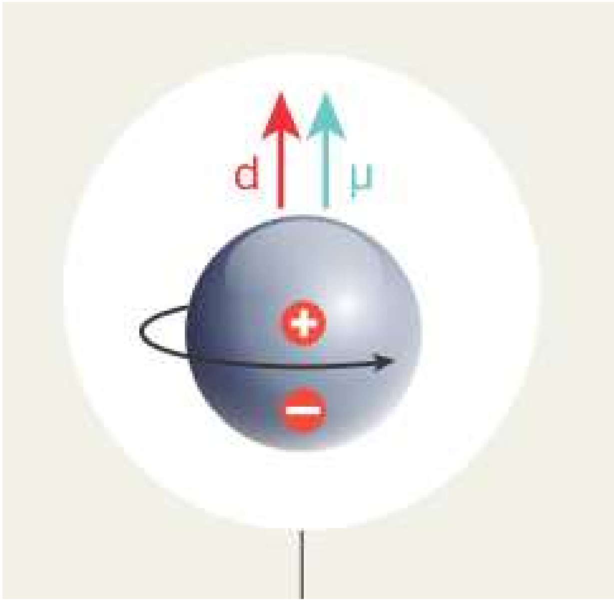
Precision observables that vanish (or are suppressed) by symmetry in the SM allow for new physics searches with indirect reach in both

- Energy scale
- Strength of coupling

<u>Example</u>: new **CP-odd sources → EDMs**

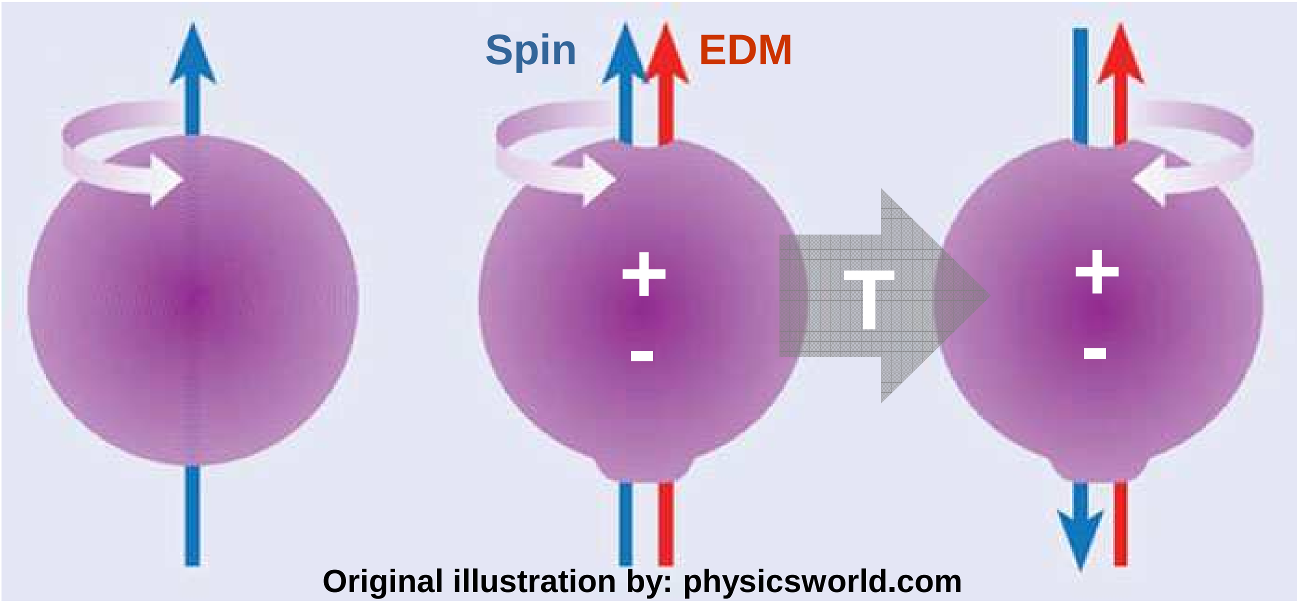
- Required for baryogenesis (Sakharov conditions)
- Strong CP problem (suppression of θ_{QCD})

Permanent **Electric Dipole Moments (EDM)** of non-degenerate fundamental systems (particles):



A vector (d), connecting the centroids of positive and negative charge distributions, in the direction of the spin vector (μ).

Permanent **Electric Dipole Moments (EDM)** of non-degenerate fundamental systems (particles):



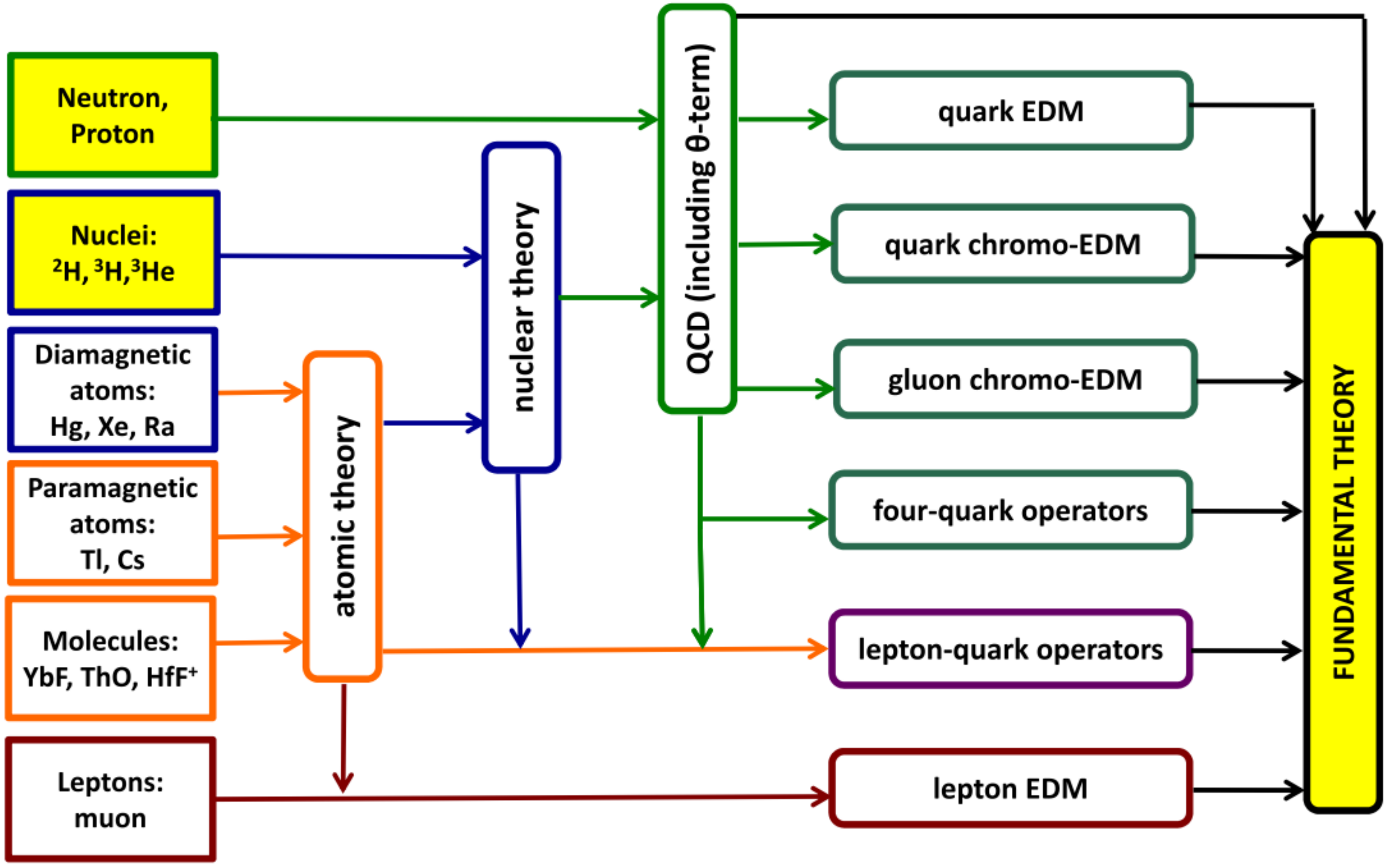
violate P- and T-, and (via CPT) also **CP-symmetry**

Permanent **Electric Dipole Moments (EDM)** of non-degenerate fundamental systems (particles):

- Measurements of electric dipole moments are a unique, extraordinarily sensitive way to probe for a physical phenomenon of profound significance, violation of microscopic time-reversal invariance.
- They currently put the best limits on the θ parameter, and offer the most plausible means to determine that fundamental parameter.
- They also constrain many implementations of supersymmetry, a much-anticipated extension of the Standard Model, that supports quantitative unification of the basic forces of Nature.
- If supersymmetry is valid, it very plausibly leads to electric dipole moments not far beyond present-day limits, and within the scope of known experimental technique.

F. Wilczek, Jan. 2014

Multiple experimental input is required to disentangle the **fundamental source(s) of EDMs**:

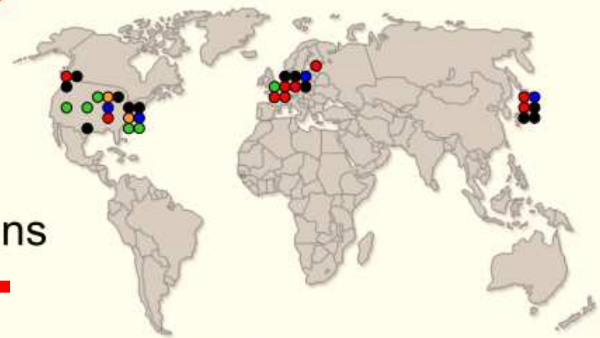


Jordy de Vries, 2012

Multiple experimental input is required to disentangle the **fundamental source(s) of EDMs**:

Rough estimate of numbers of researchers, in total ~500 (with some overlap)

- Neutrons (~200)
  - @ILL
  - @ILL,@PNPI
  - @PSI
  - @FRM-2
  - @RCNP,@TRIUMF
  - @SNS
  - @J-PARC
- Molecules (~50)
  - YbF@Imperial
  - PbO@Yale
  - ThO@Harvard
  - HfF+@JILA
  - WC@UMich
  - PbF@Oklahoma
- Atoms (~100)
  - Hg@UWash
  - Xe@Princeton
  - Xe@TokyoTech
  - Xe@TUM
  - Xe@Mainz
  - Cs@Penn
  - Cs@Texas
  - Fr@RCNP/CYRIC
  - Rn@TRIUMF
  - Ra@ANL
  - Ra@KVI
  - Yb@Kyoto



- Ions-Muons (~200)
  - ~~@BNL~~
  - @FZJ
  - @FNAL
  - @JPARC
- Solids (~10)
  - GGG@Indiana
  - ferroelectrics@Yale

P. Harris, K. Kirch, July 2012

Experimental status of EDMs: best limits for bare nucleon (n, p), lepton (e, μ), diamagnetic atom (^{199}Hg), paramagnetic atom (^{205}Tl) and molecules (YbF, ThO):

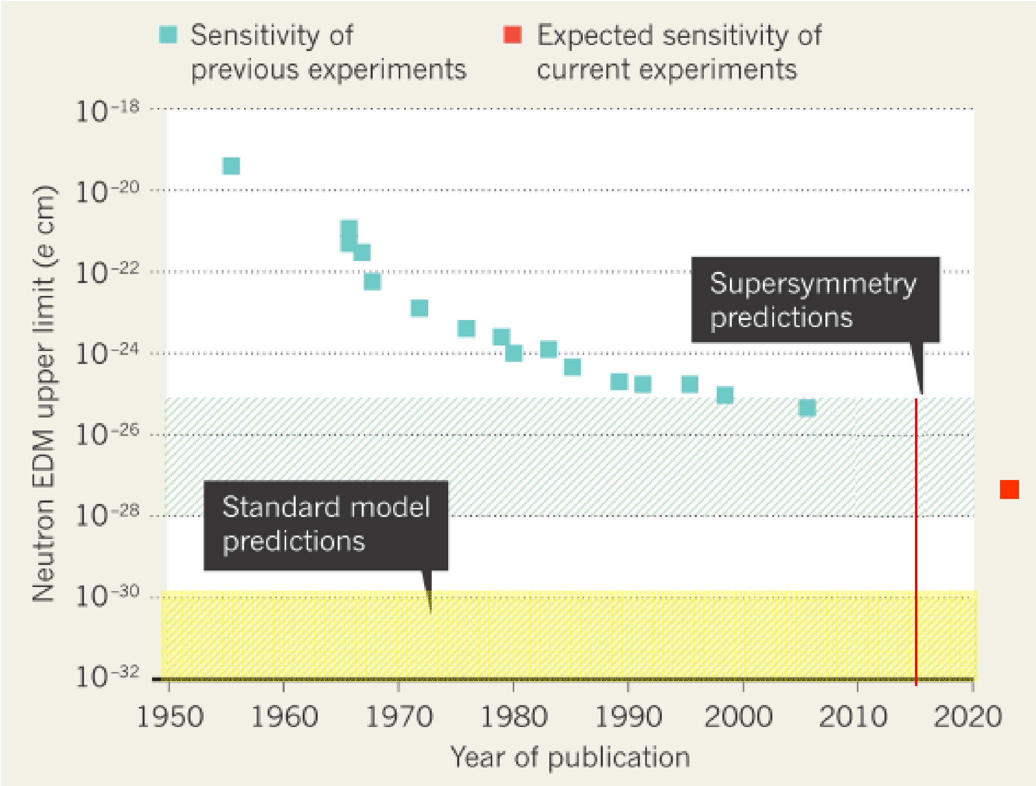
System	upper limit [ecm]	Comment
n	2.9×10^{-26} 90% C.L.	direct limit
μ	1.9×10^{-19} 95% C.L.	direct limit
^{199}Hg	3.1×10^{-29} 95% C.L.	best direct EDM limit of any experiment; best indirect limit for proton $d_p < 8 \times 10^{-25}$ecm
^{205}Tl	9×10^{-25} 90% C.L.	used to set a limit for the electron $d_e < 1.6 \times 10^{-27}$ecm
YbF	1.1×10^{-22} 90% C.L.	used to set a limit for the electron $d_e < 1.05 \times 10^{-27}$ecm

Ongoing/future projects

ThO **$|d_e| < 8.7 \times 10^{-29}$ *ecm* 90% C.L.** **factor 10 in next 10 yrs**

P. Harris, K. Kirch, July 2012

nEDMs: past, ongoing and future experiments:



Adapted from: Nature, Vol 482 (2012)

→ UCN: reactors (ILL, FRM II), accelerators (PSI, …)

→ Future goal: sensitivity limit: **(few times) 10^{-28} *e* cm**

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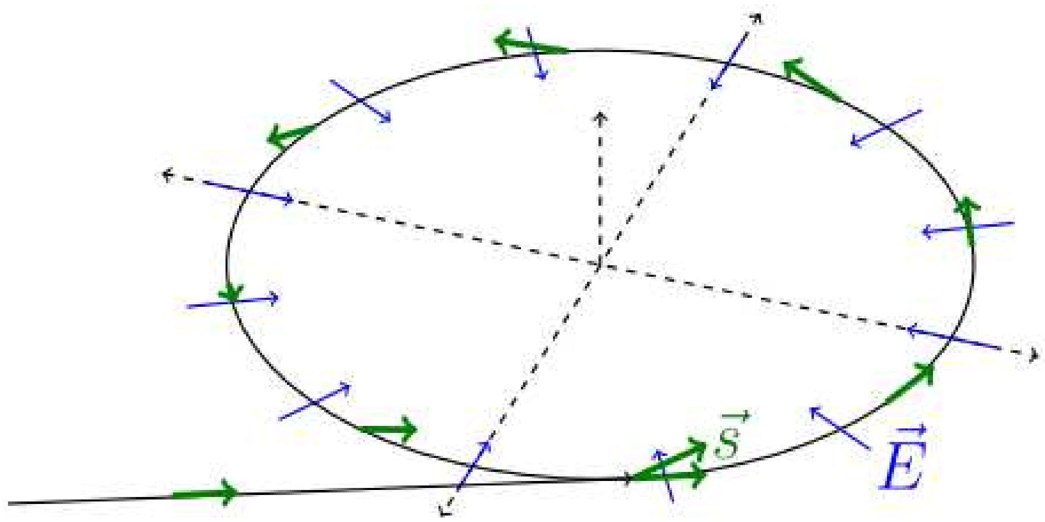
ThO		$\|d_e\| < 8.7 \times 10^{-29}$ *ecm* 90% C.L.	factor 10 in next 10 yrs

P. Harris, K. Kirch, July 2012

Charged particle (p, d) EDMs: principle of experiment:

- Inject polarized particles into a storage ring
- Apply radial electric field E



- Non-zero EDM → spin rotation out of the plane

Charged particle (p, d) EDMs: principal challenges

- Spin motion also due to MDM

$$\frac{\mathrm{d}\vec{s}}{\mathrm{d}t} = \vec{s} \times \left(\vec{\Omega}_{\mathrm{MDM}} + \vec{\Omega}_{\mathrm{EDM}}\right)$$

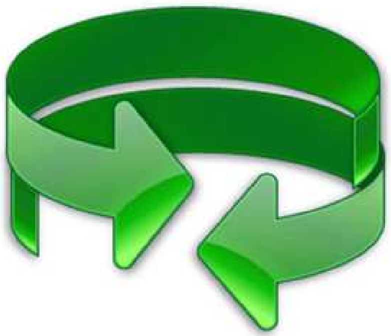
$$\vec{\Omega}_{\mathrm{MDM}} = \frac{q}{m} G \vec{B}$$

- B = 0 „all-electric ring“
- „Magic momentum“ – spin in momentum direction
  Spin motion equation („Thomas BMT“) shows:
  → ds/dt is due to EDM (only for **protons**, G > 0))

- For **deuterons** (and ^{3}He) [with G < 0]
  → combined E-B benders required → magic mom.

Charged particle (p, d) EDMs: technological challenges

- EDMs are very small (…)
  → systematics, fake EDM effects
- Current solution:
  → dedicated precision storage ring with **two beams** (CW, CCW)



→ goal: **sensitivity of 10^{-29} *e cm***
(stepwise approach: R&D, precursor, **srEDM-ring**)

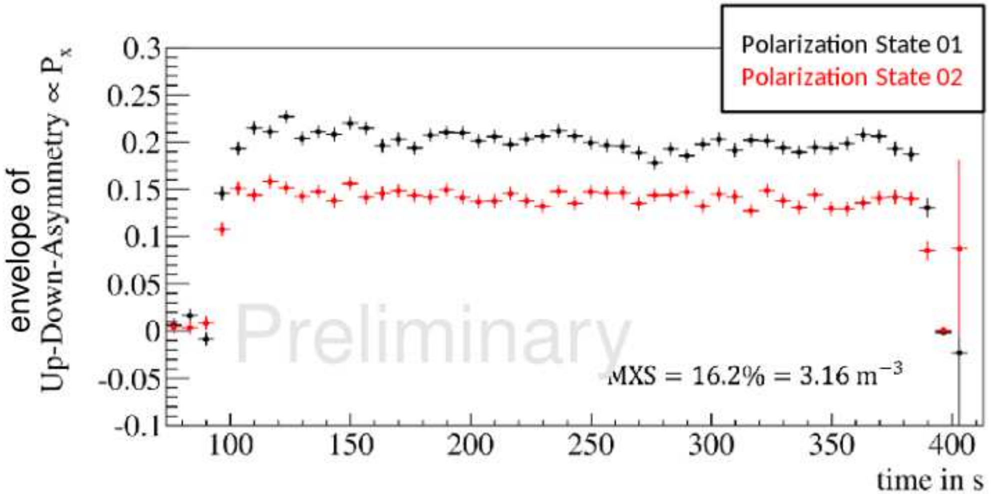
Charged particle (p, d) EDMs: key technologies

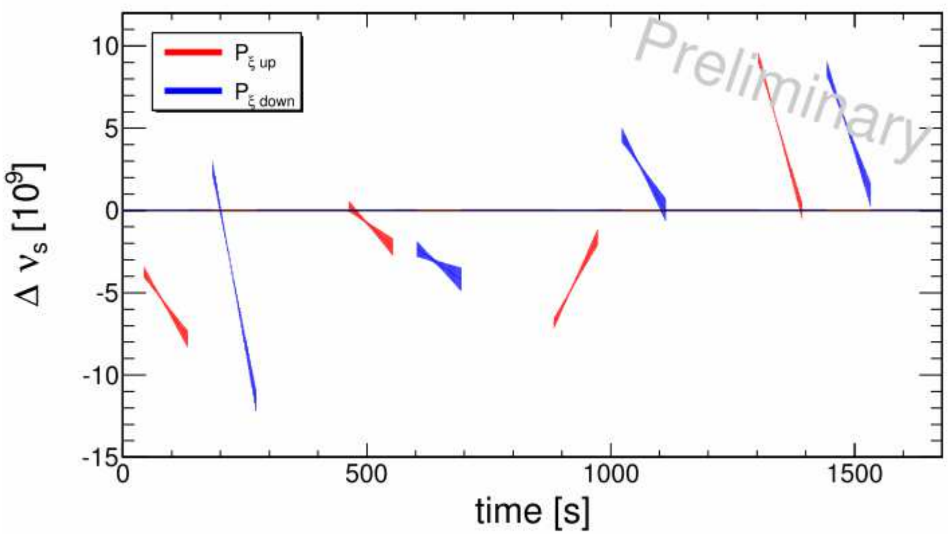
- Polarimetry – detect spin rotation of 1 *nrad/s*
- Spin coherence time – at least 1000 *s*
- E/B benders – high electric fields > 10 *MV/m*
- Beam position – relative measurement; feedback
- Shielding of external fields
- (…)

→ Talk by **Mei Bai** (today, 12:30 h, Accelerator session)
„*Accelerator physics challenges in EDM measurements*"

→ **Best place** to pursue srEDM:
COSY at Forschungszentrum Jülich (FZJ), Jülich

Side remark: recent results obtained at COSY





spin coherence time **SCT** of a few 1000 s

spin tune measurement:

$$\Delta\nu_s = 10^{-8} \rightarrow \Delta p/p \approx 10^{-7}$$

Charged particle (p, d) EDMs: Project at Jülich

Cooler Synchroton COSY

- Perfect R&D machine
- Precursor expt. in 2017/18
- Injector for dedicated ring

JEDI Collaboration

http://collaborations.fz-juelich.de/ikp/jedi/

~ 110 (11 countries)

Embedded in **JARA**|Fame

Welcome to join!


Thank you!