

Storage Ring EDM Experiments

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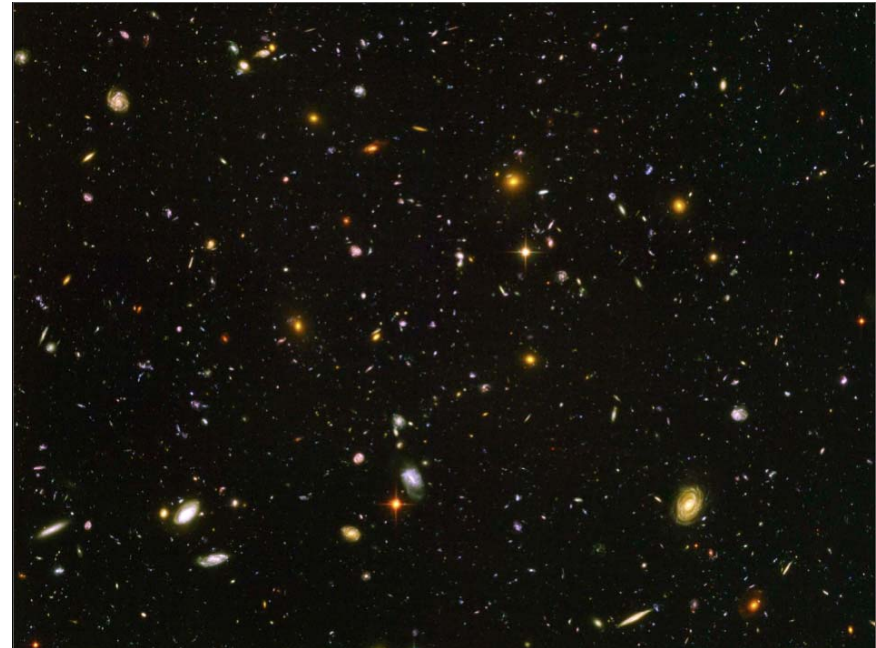
Brookhaven National Laboratory

- The storage ring method can do:
- Proton EDM at 10^{-29} e·cm (simpler) &
- Deuteron EDM at 10^{-29} e·cm

Storage Ring

Electric Dipole Moments

- The most sensitive experiments on beyond the SM CP-violation
- If an EDM is found it can help resolve the baryon-antibaryon asymmetry mystery of our universe (BAU)



Physics reach of pEDM

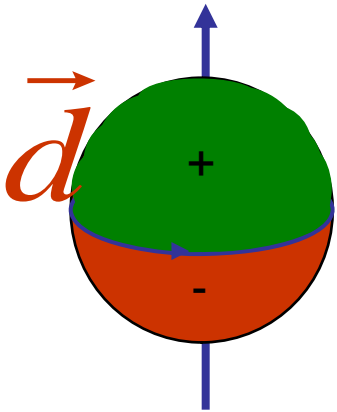
- Currently: $\bar{\theta} \leq 10^{-10}$, Sensitivity with pEDM: $\bar{\theta} < 0.3 \times 10^{-13}$
- Sensitivity to new contact interaction: **3000 TeV**
- Sensitivity to SUSY-type new Physics:

$$pEDM \approx 10^{-24} \text{ e} \cdot \text{cm} \times \sin \delta \times \left(\frac{1 \text{ TeV}}{M_{\text{SUSY}}} \right)^2$$

The proton EDM at $10^{-29} \text{ e} \cdot \text{cm}$ has a reach of **>300 TeV** or, if new physics exists at the LHC scale, **$\delta < 10^{-5} \text{ rad}$** CP-violating phase; an unprecedented sensitivity level.

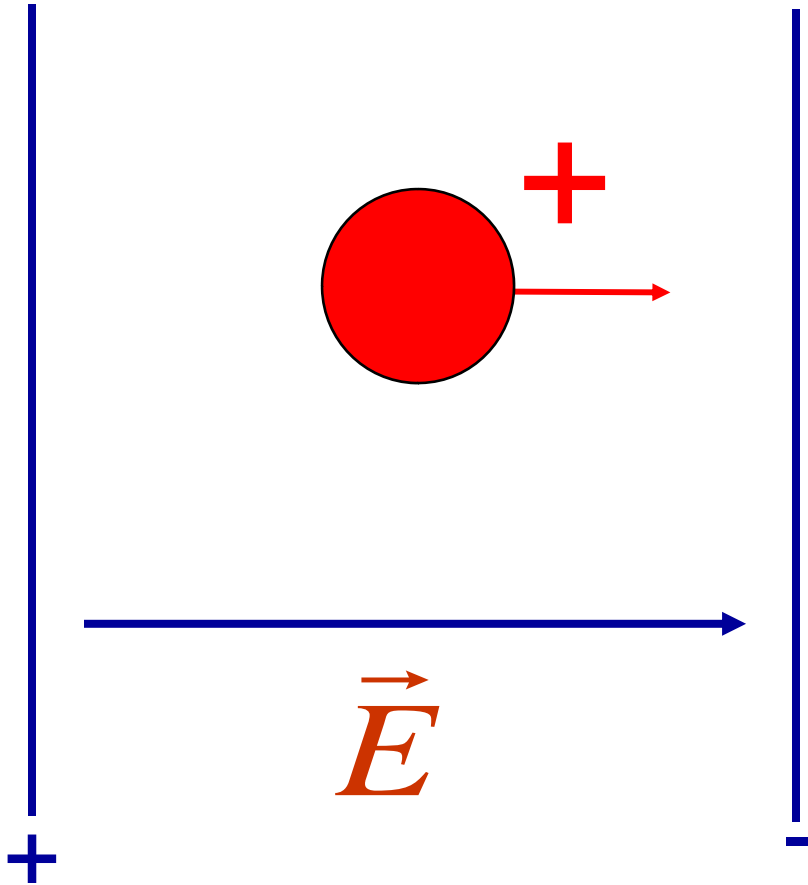
Electric Dipole Moments precess in an Electric field

The EDM vector \vec{d} is along the particle spin direction

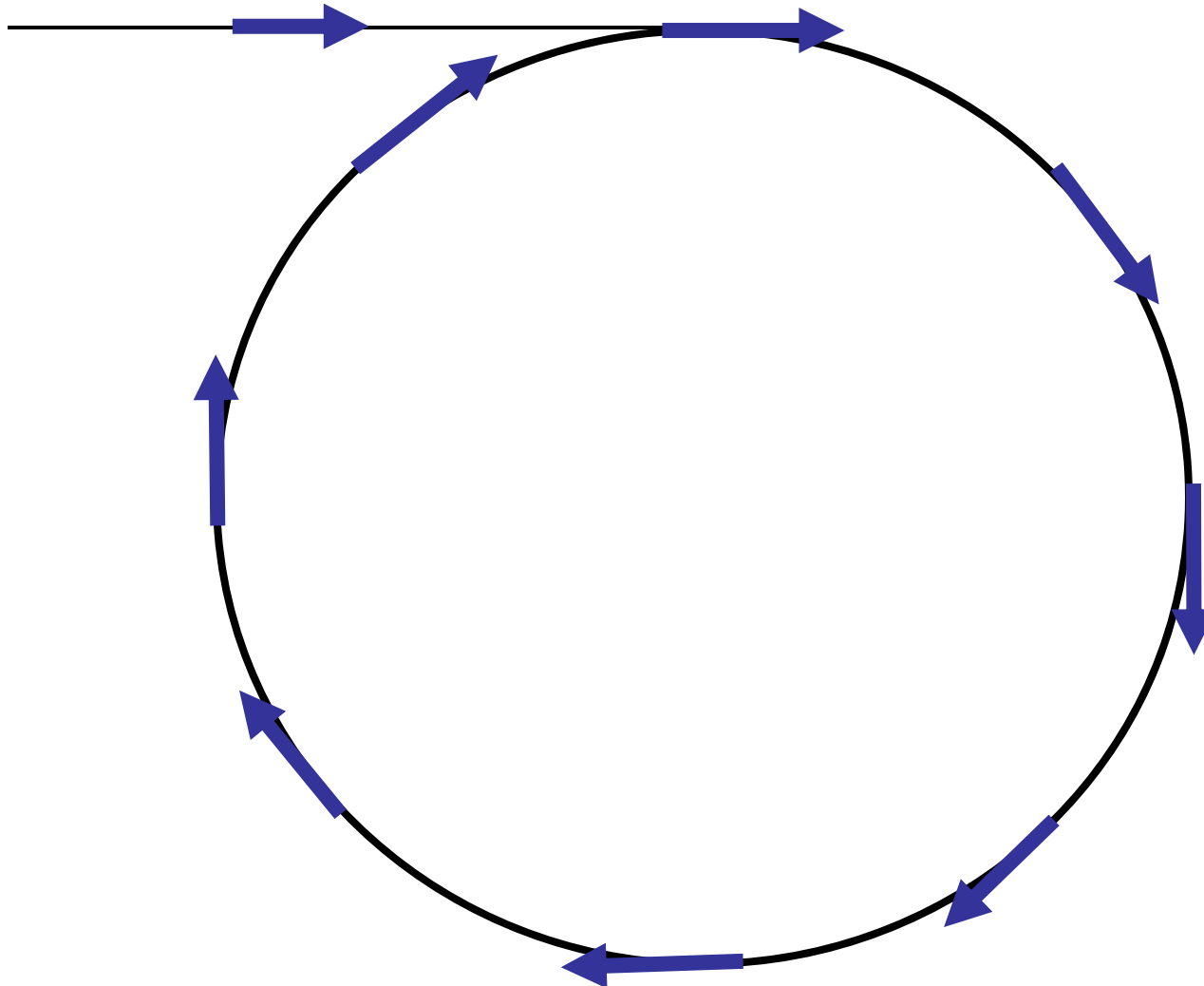


$$\frac{d\vec{s}}{dt} = \vec{d} \times \vec{E}$$

A charged particle between electric field plates would be lost right away...

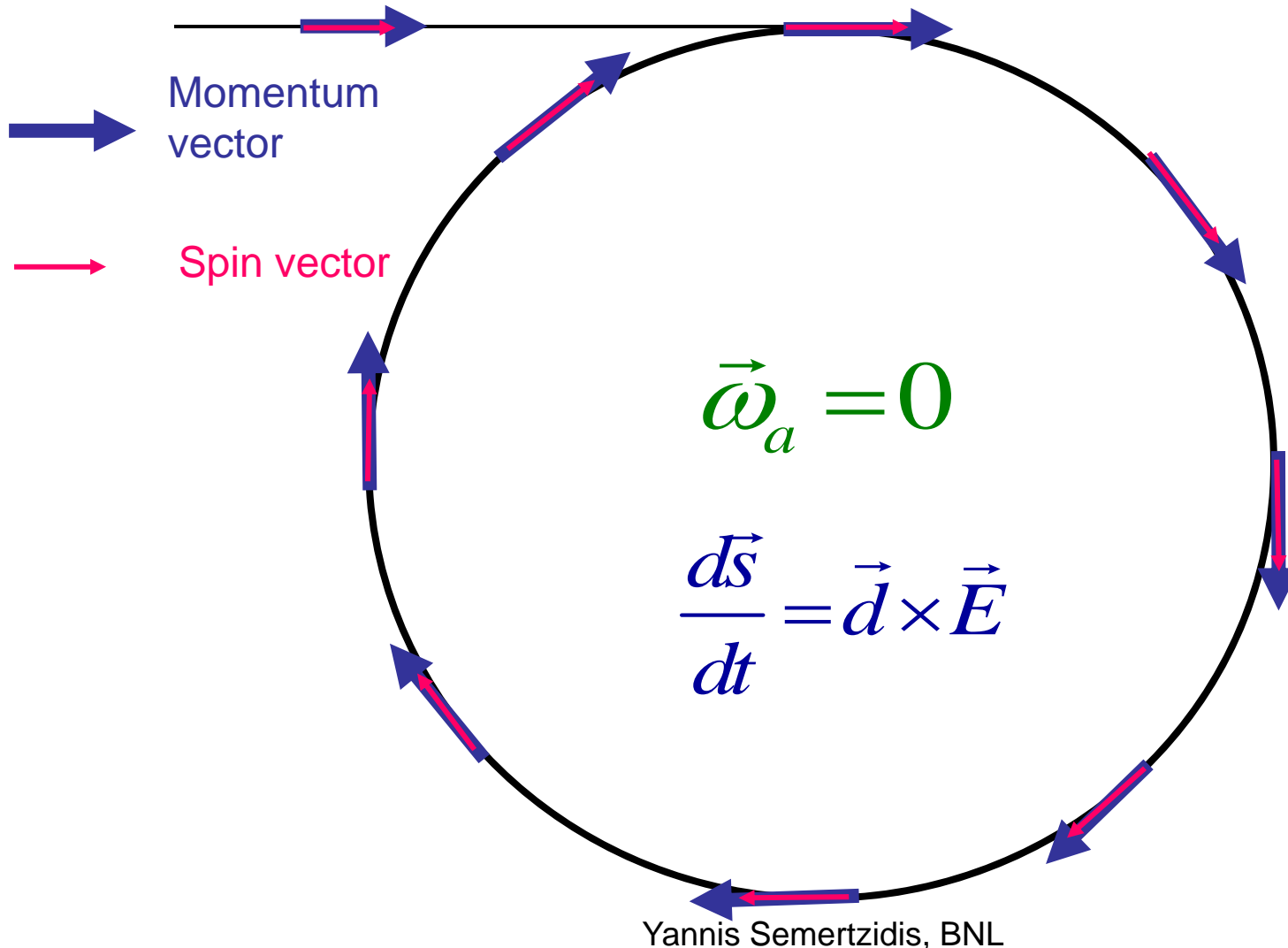


...but can be kept in a storage ring for a long time (bend by radial E-field)



Yannis Semertzidis, BNL

The sensitivity to EDM is optimum when the **spin vector** is kept aligned to the momentum vector



Freezing the horizontal spin precession in the presence of E-fields

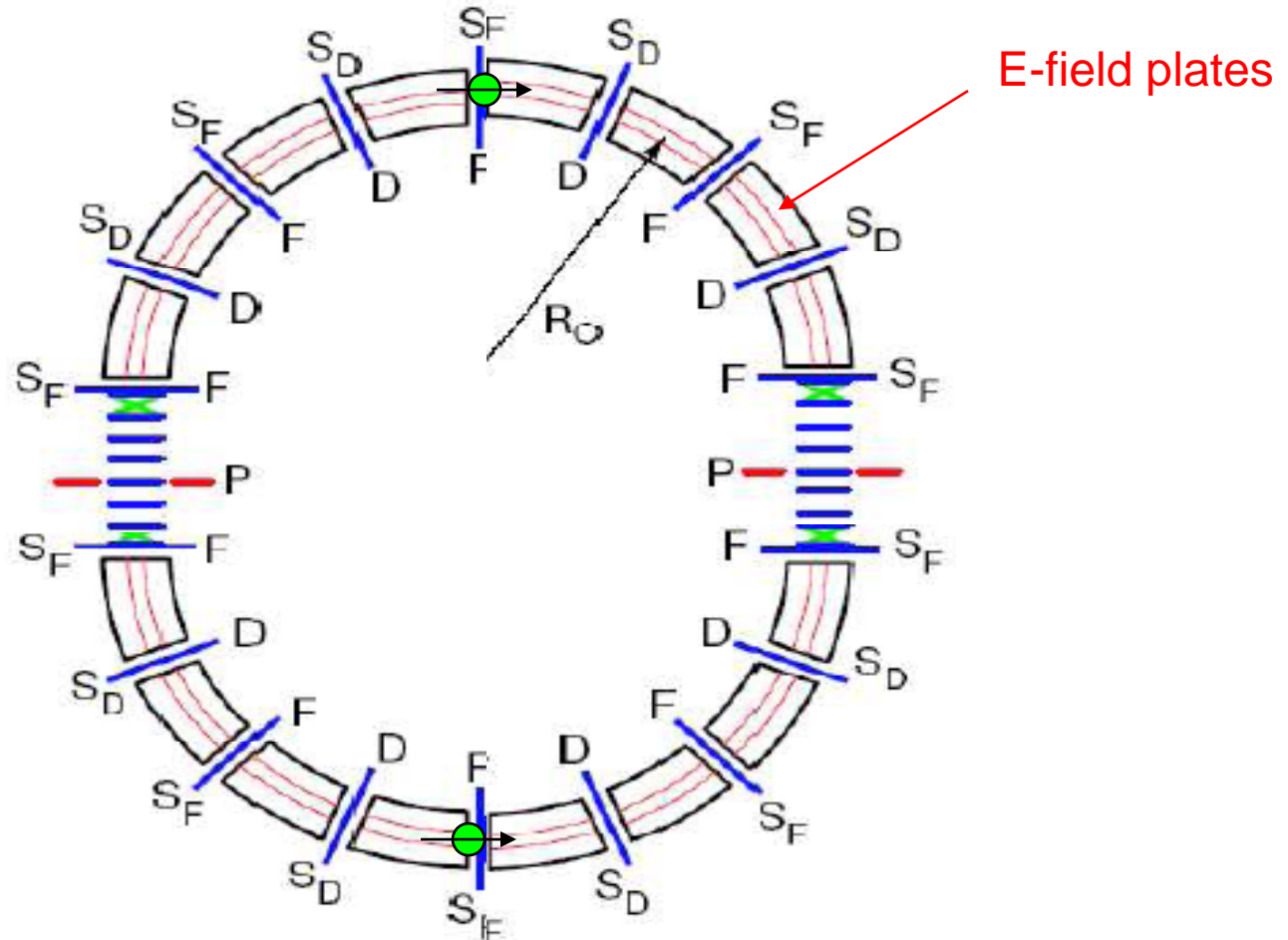
$$\vec{\omega}_a = -\frac{e}{m} \left[a - \left(\frac{m}{p} \right)^2 \right] \vec{\beta} \times \vec{E}$$

- The spin precession is zero at “magic” momentum (0.7 GeV/c for protons, 3.1 GeV/c for muons,...)

$$p = \frac{m}{\sqrt{a}}, \text{ with } a = \frac{g-2}{2}$$


Proton EDM lattice

Two bunches with opposite polarization



- Radial E-field (no dipole B-field). $R_0 \sim 25\text{m}$
- Magnetic quadrupoles (FODO)
- Magnetic sextupoles (S_F, S_D for Spin Coherence Time)
- P: Polarimeter

Experimental needs

Two Proton bunches	0.7 GeV/c	$\geq 80-90\%$ polariz.; 	$\sim 10^{10}$ /bunch
Beam emittance: 95%, unorm.	Horizontal: 3mm-mrad	Vertical: 10mm-mrad	$(dp/p)_{rms} \sim 2.5 \times 10^{-4}$
<100m base length/each	Rep. rate: 10^3 s	Beam energy: ~ 1 J, 3mA	Average beam power: ~ 1 mW

- Polarized proton beams are needed. Otherwise CERN can provide the above beam parameters at the LEIR facility

Current status

- We have proposed the SR EDM to the BNL PAC in March 2008, which enthusiastically endorsed its physics reach.
- We are scheduled to have a conceptual technical review in the fall of 2009.

Possible pEDM Timeline at BNL

07 08 09 10 11 12 13 14 15 16 17

- ✓ Spring 2008, Proposal to the BNL PAC
- 2008-2012 R&D phase; ring design
- Fall 2009 Conceptual Technical Review
- Fall 2011, Finish systematic error studies:
 - a) spin/beam dynamics related systematic errors.
 - b) Polarimeter systematic errors studies with polarized beams
 - c) Finalize E-field strength to use (goal $\sim 15\text{MV/m}$)
 - d) Establish Spin Coherence Time (goal $\sim 10^3\text{s}$)
- Start of 2013, finish pEDM detailed ring design
- FY 2014, start ring construction
- FY 2017, pEDM engineering run starts
- FY 2018, pEDM physics run starts

What's next

We need <2 years (technically driven schedule) from now to finish the R&D items:

1. E-field strength, alignment and stability
2. Spin coherence time of 10^3 seconds
3. Polarimeter development runs at COSY/Germany

Doing the experiment at CERN?

- CERN would have to get into the polarized proton physics (using the LEIR facility - no interference with LHC operations)
- Significantly contribute with labor and engineering to design and construct the EDM ring. Estimated cost (rough) \$20M + 50% contingency.
- We would ask NSF/DOE to contribute to the experiment components.

Plan

- The current plan at BNL: We can expect to finish the EDM ring construction in 2017
- It is possible to do this in half the time here (technically driven schedule) if CERN adopts it as high priority. A strong interest from CERN could send a strong signal to the Storage Ring EDM Collaboration

Summary: storage ring EDM method

- It can do the pEDM at 10^{-29} e-cm and dEDM at similar level (the current best goal on nEDM is $\sim 2 \times 10^{-28}$ e-cm).
- Sensitive even to the “...variant of split SUSY in which scalars are heavy...of 100TeV or more...” see Ed. Witten’s talk
- It’s a high sensitivity, high risk with high discovery potential experiment. CERN, with its LEIR facility, could take up the challenge

Extra slides

Physics strength comparison

System	Current limit [e·cm]	Future goal	Neutron equivalent
Neutron	$<1.6 \times 10^{-26}$	$\sim 10^{-28}$	10^{-28}
^{199}Hg atom	$<3 \times 10^{-29}$		10^{-25} - 10^{-26}
^{129}Xe atom	$<6 \times 10^{-27}$	$\sim 10^{-30}$ - 10^{-33}	10^{-26} - 10^{-29}
Deuteron nucleus		$\sim 10^{-29}$	3×10^{-29} - 5×10^{-31}
Proton nucleus	$<7 \times 10^{-25}$	$\sim 10^{-29}$	4×10^{-29} - 2.5×10^{-30}

Proton Statistical Error (230MeV):

$$\sigma_{d_p} \approx \frac{3\hbar}{E_R A P \sqrt{N_c f T_{Tot} \tau_p}}$$

- τ_p : 10^3 s Polarization Lifetime (Coherence Time)
- A : 0.75 The left/right asymmetry observed by the polarimeter
- P : 0.9 The beam polarization
- N_c : 2×10^{10} p/cycle The total number of stored particles per cycle
- T_{Tot} : 10^7 s Total running time per year
- f : 0.01 Useful event rate fraction (efficiency)
- E_R : 15 MV/m Radial electric field strength

$$\sigma_{d_p} \approx 10^{-29} \text{ e} \cdot \text{cm/year}$$

Main issues

- E-field strength: 150kV/cm, 2cm plate distance
- E-field alignment: 10^{-6} rad; Average: 10^{-9} rad
- Polarimeter systematic errors to 1ppm (early to late times-not absolute!). The EDM signal is 5ppm early to late change in $(L-R)/(L+R)$ counts.
- Spin Coherence Time (SCT): $\sim 10^3$ s

2. Combined E&B-fields:

$$\vec{\omega}_a = -\frac{e}{m} \left[a\vec{B} + \left(a - \left(\frac{m}{p} \right)^2 \right) \vec{\beta} \times \vec{E} \right]$$

- Using a combination of dipole B-fields and radial E-fields to freeze the spin. The required E-field is

$E \approx aBc\beta\gamma^2$, i.e. the smaller the a the better!

Deuteron: Momentum 1 GeV/c, B=0.5 T, E=120KV/cm

Deuteron, sensitivity: 10^{-29} ecm

Neutron EDM Timeline

