Proposed Searches for Electric Dipole Moments of the Muon, Deuteron, and Proton in Storage Rings

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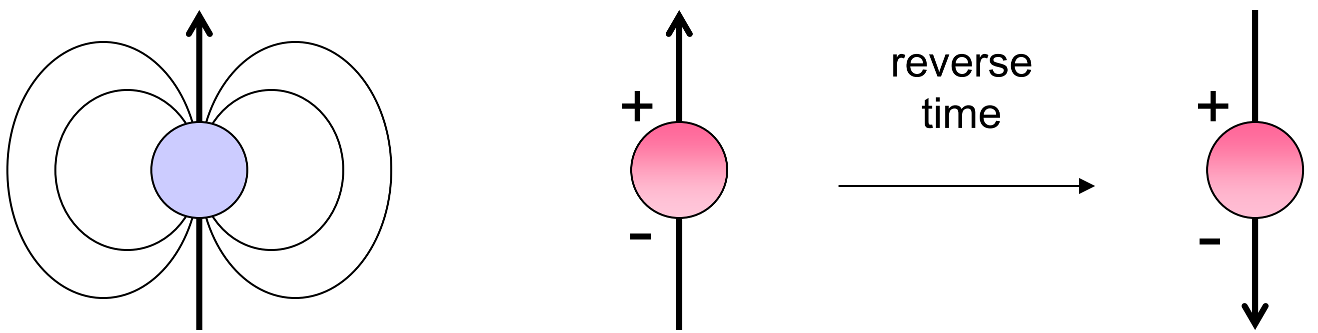
DIPOLES:



$\mu \cdot B$

commonplace

$d \cdot E$

T violating
CP violating

New sources of CP violation are needed to explain matter/ anti-matter asymmetry of the universe.

SUSY predicts EDMs within 10-100 times below present limits.

Present limits: neutron $< 6.3 \times 10^{-26}$ e·cm

electron (Tl atom) $< 1.6 \times 10^{-27}$ e·cm

atom (^{199}Hg) $< 2.1 \times 10^{-28}$ e·cm

screening reduces to 4×10^{-25} e·cm on neutron

Usual method: place in E field, measure precession rate

Why build a storage ring?

electric field at particle (**v** x **B**) 10-100 time stronger than lab fields

can open search to **charged** particles

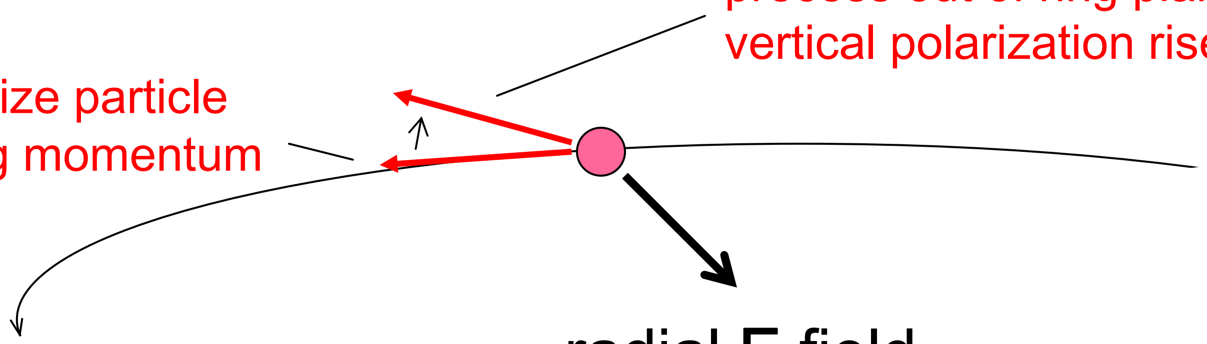
different systematic errors from trap/box searches

Issues:

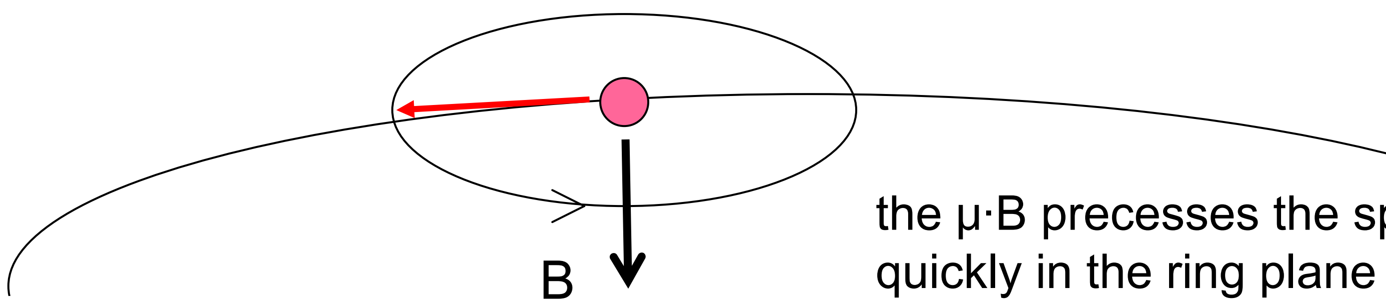
experiment still hard

costly compared to trap searches

What is the signal?



but there is a problem:

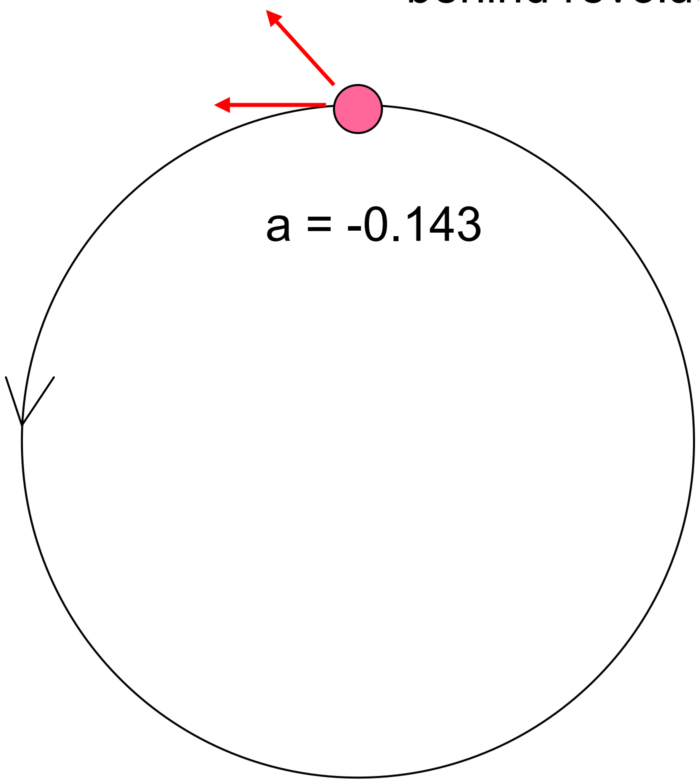


(together the precession plane tilts, but this is hard to observe)

Method 1

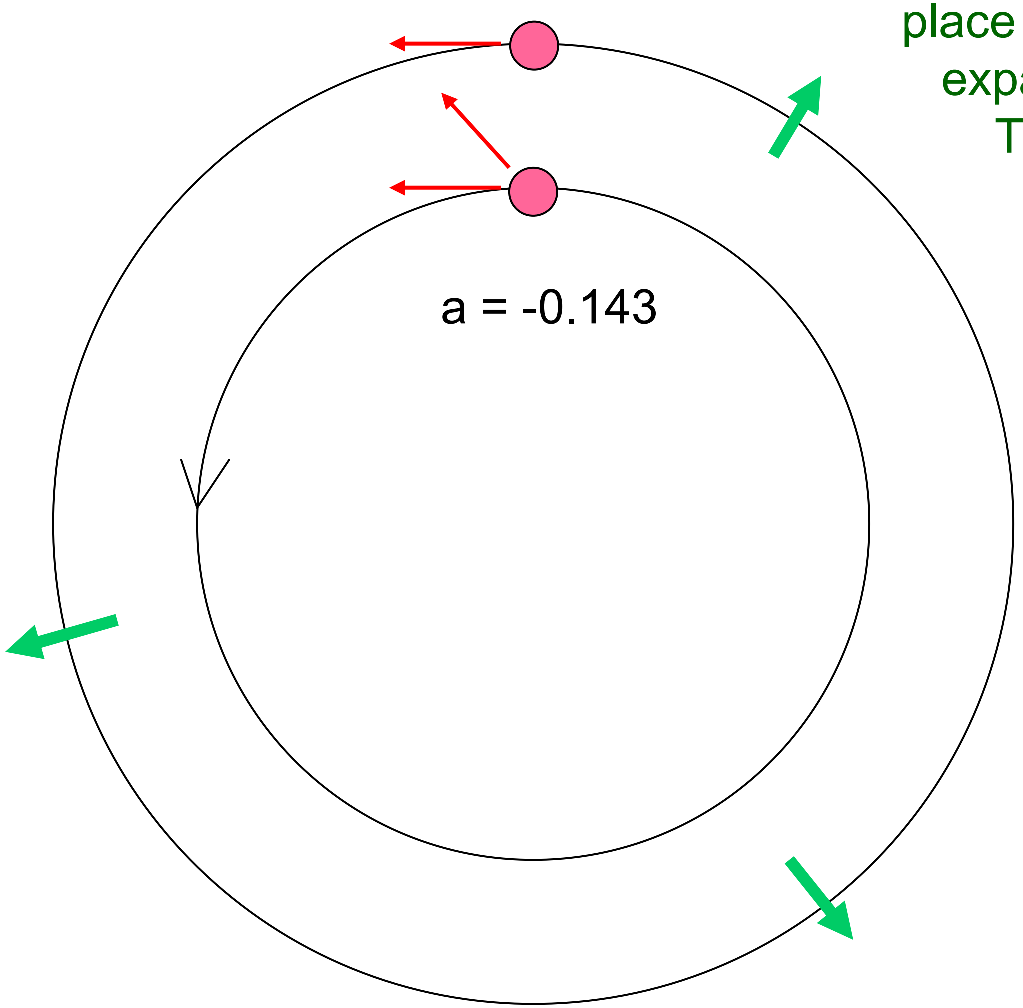
good when anomalous moment is small (μ, d)

For the deuteron, $\omega_a < \omega_{cyc}$ and spin lags behind revolution around the ring.



Method 1

good when anomalous moment is small (μ, d)



In all the bending magnets, place an outward E field to expand the size of the orbit. This lengthens the time for the particle to complete a revolution while keeping the B field the same.

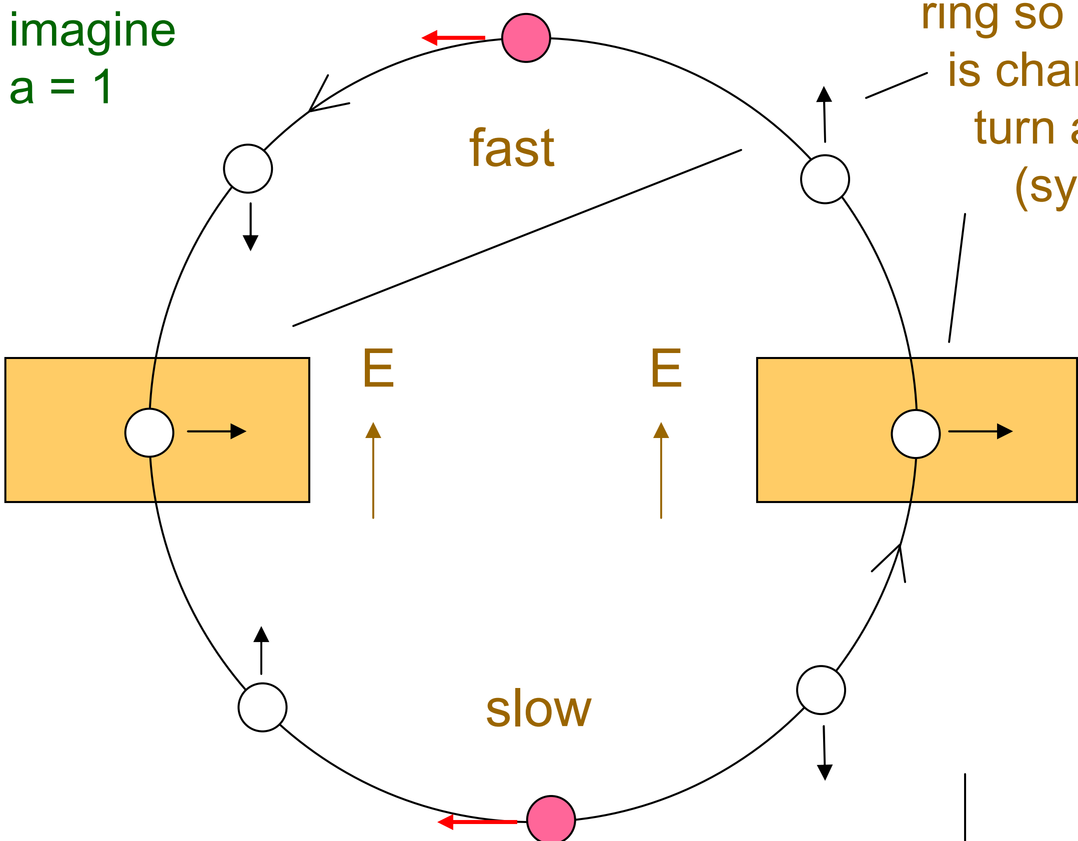
The right ratio of B and E makes $\omega_a = \omega_{cyc}$.

p = 0.7 GeV/c (126 MeV)
E = 3.5 MV/m
B = 0.21 T
radius = 13.3 m

Method 2

good for a broad class of charged particles

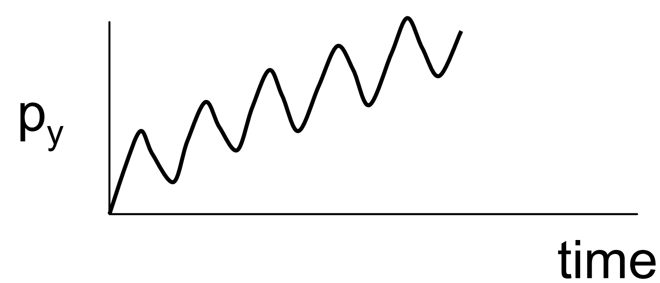
imagine
a = 1



Put 2 RF cavities in the ring so that the velocity is changed twice on each turn around the ring (synchrotron oscillation).

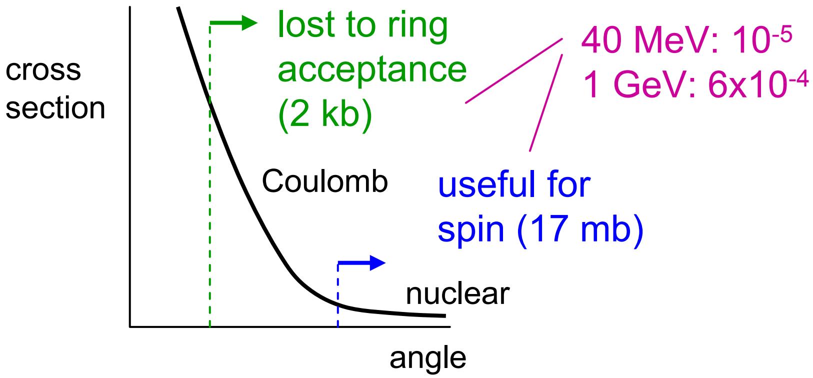
$\omega_{sync} = \omega_a$

Vertical polarization accumulates in opposite ways on opposite sides of the ring. But speed change means it does not cancel.



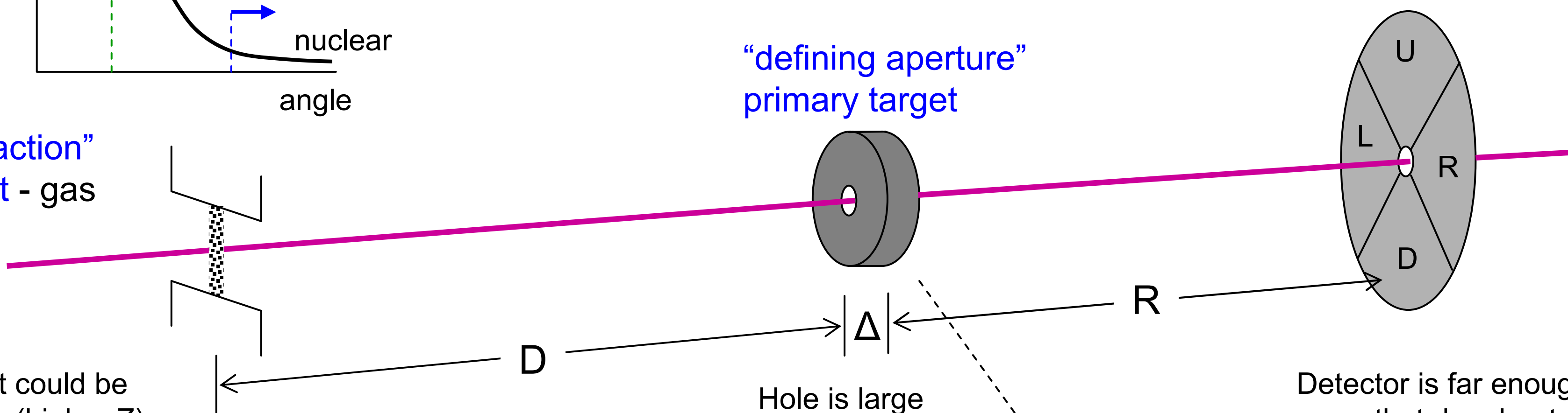
for protons, operate at $\omega_{sync} = \omega_a - 2$

EDM polarimeter



IDEA:
- make thick target defining aperture
- scatter into it with thin target

(POMME efficiency several percent)



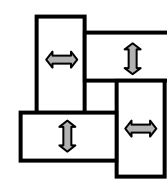
Target could be Ar gas (higher Z).

Target "extracts" by Coulomb scattering deuterons onto thick main target. There's not enough good events here to warrant detectors.

Events must imbed far enough from hole to not multiple scatter out of primary target, thus Δ << D. Δ, which is a large fraction of the deuteron range, sets scale for polarimeter.

Hole is large compared to beam. Every-thing that goes through hole stays in the ring. (It may take several orbits to stop scattered particle.)

Primary target may need to be iris to allow adjustment of position and inner radius. It may also need to be removed during injection.



Detector is far enough away that doughnut illumination is not an acceptance issue: Δ < R.

Challenges:

systematic contribution from $\mathbf{B}_r$ at particle

closed orbit cancels B_r on average (lab frame)

Method 1: Tilted E field produces B_r from v x E.
Cancel by repeating experiment CCW vs. CW.
(limits sensitivity to 10^{-27} e·cm for deuteron)

Method 2: Can come from RF cavity (out of phase and off axis), sample with different vertical tunes

polarization coherence time

longitudinal orientation is unstable equilibrium, so reduce perturbations with field corrections

Method 2 phase space coherence time

reduce perturbations

Prospects:

designs look feasible for p, d, and possibly ^{3}He
excellent sensitivity to EDMs on quarks or in NN interaction

sensitivity limits are (roughly):
10^{-27} e·cm in Method 1
~ 10^{-29} e·cm in Method 2 (running time about 4 months
with spin coherence time ~ 20 s)

all systematic errors checked so far are manageable

Plans:

continue ring designs, systematic error investigations

do polarimeter R&D (deuteron at KVI, Groningen)

gather material for a proposal