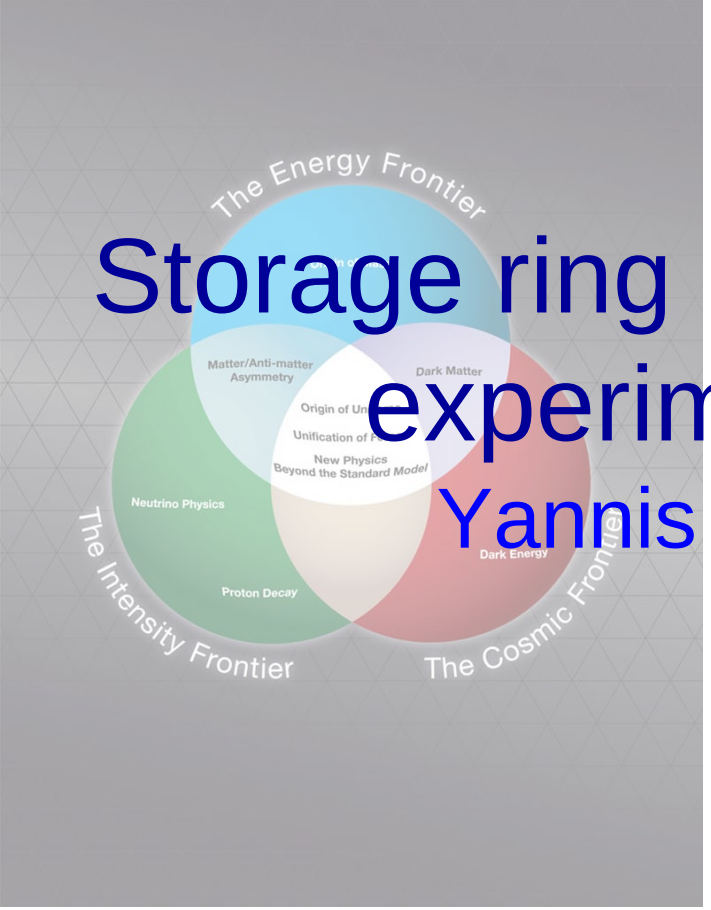
8th Patras Workshop on Axions, WIMPs, and WISPs
Chicago, 18-22 July 2012



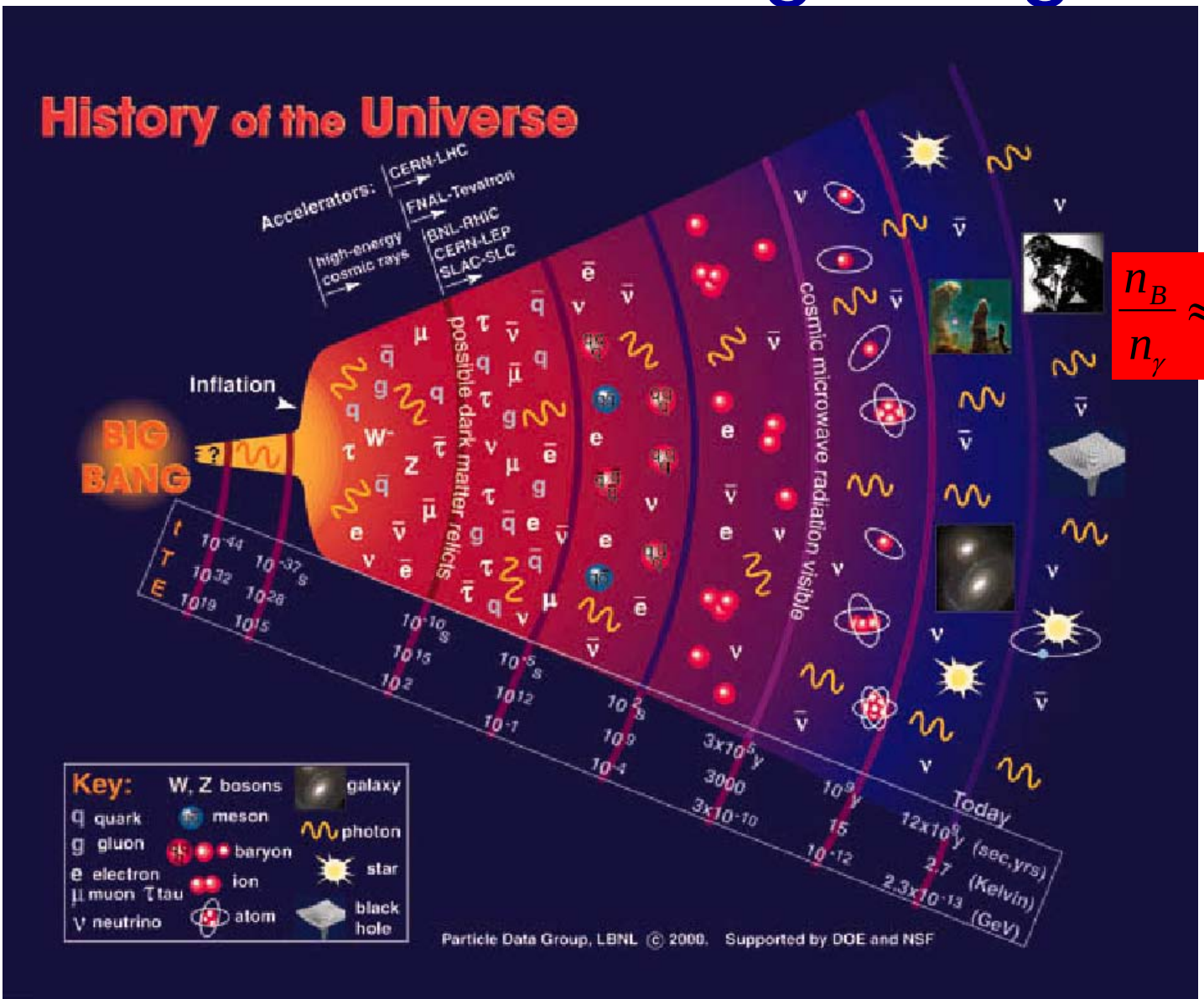
Storage ring Electric Dipole Moment experiment for the proton

Yannis K. Semertzidis, BNL

- ✓Goal: 10^{-29} e□cm; Probe New Physics ~10^{3} TeV
- ✓Can probe fine-tuned SUSY (>>1TeV)

- ✓Systematics best in an all-electric ring and counter-rotating (CR) beams.

Why is there so much matter after the Big Bang;



We observe:

$$\frac{n_B}{n_\gamma} \approx (6.08 \pm 0.14) \times 10^{-10}$$

From the SM:

$$\frac{n_B}{n_\gamma} = \frac{n_{\overline{B}}}{n_\gamma} \approx 10^{-18}$$

The night sky as observed:

The great mystery in our Universe: matter dominance over anti-matter.

EDMs could point to a strong CP-violation source capable of creating the observed asymmetry.

The night sky according to the standard Model (SM)

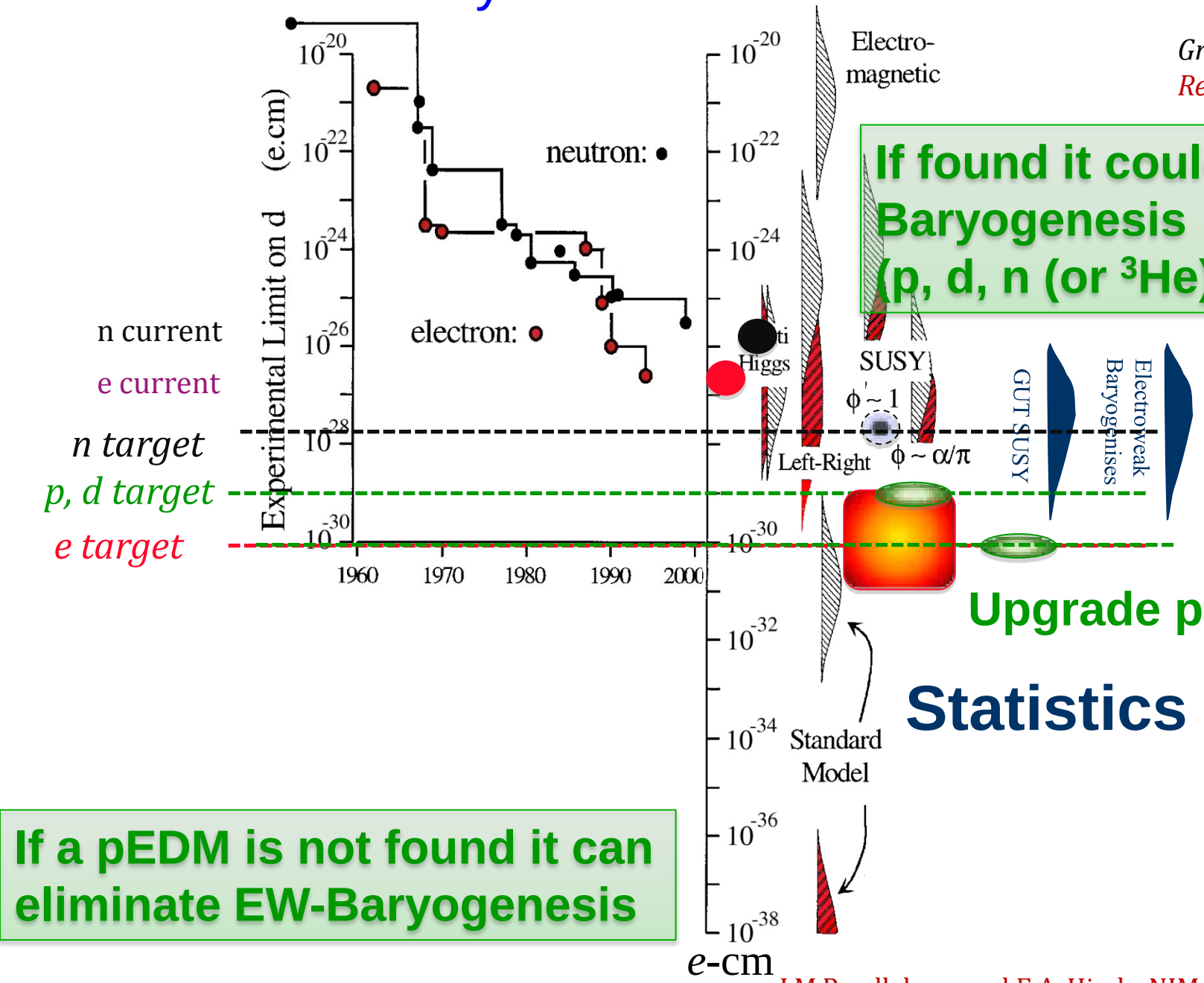
Very little matter survives annihilation with the anti-matter

Purcell and Ramsey:

"The question of the possible existence of an electric dipole moment of a nucleus or of an elementary particle…becomes a purely experimental matter"

Phys. Rev. 78 (1950)

Sensitivity to Rule on Several New Models



Gray: Neutron
Red: Electron

If found it could explain Baryogenesis (p, d, n (or ^{3}He))

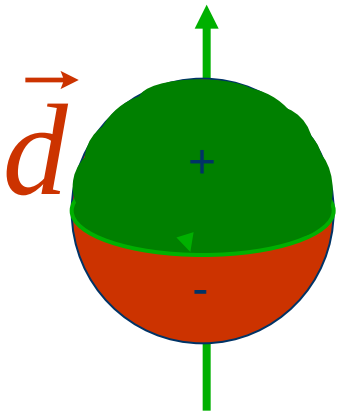
Upgrade possibility

Statistics limited

If a pEDM is not found it can eliminate EW-Baryogenesis

J.M.Pendlebury and E.A. Hinds, NIMA 440 (2000) 471

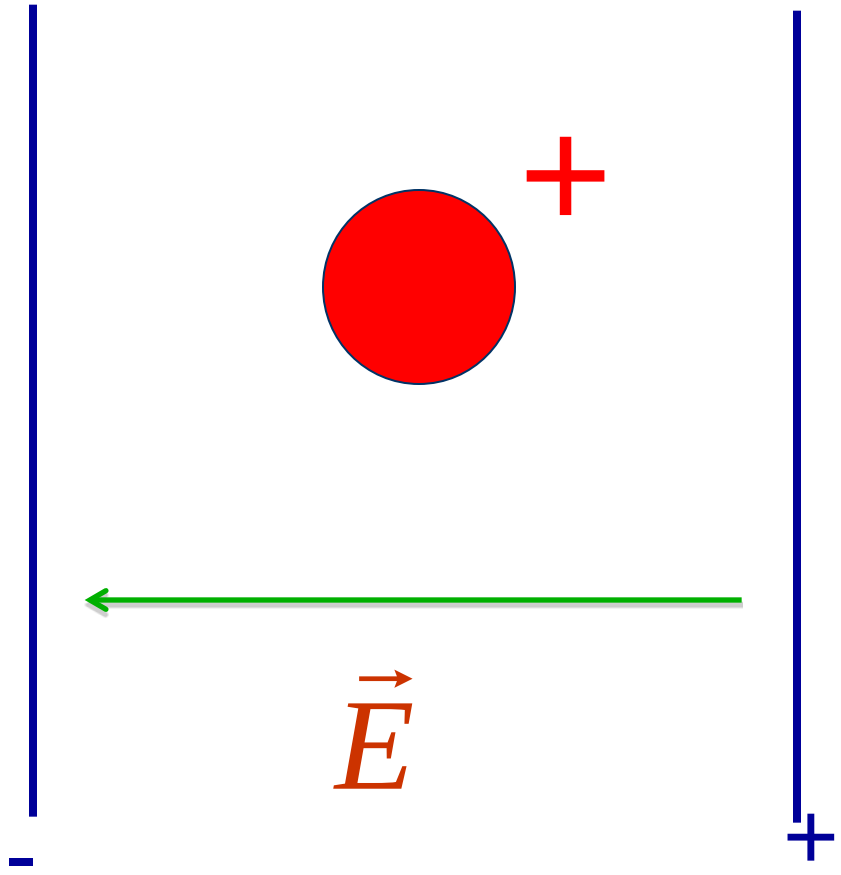
The Electric Dipole Moment precesses in an Electric field



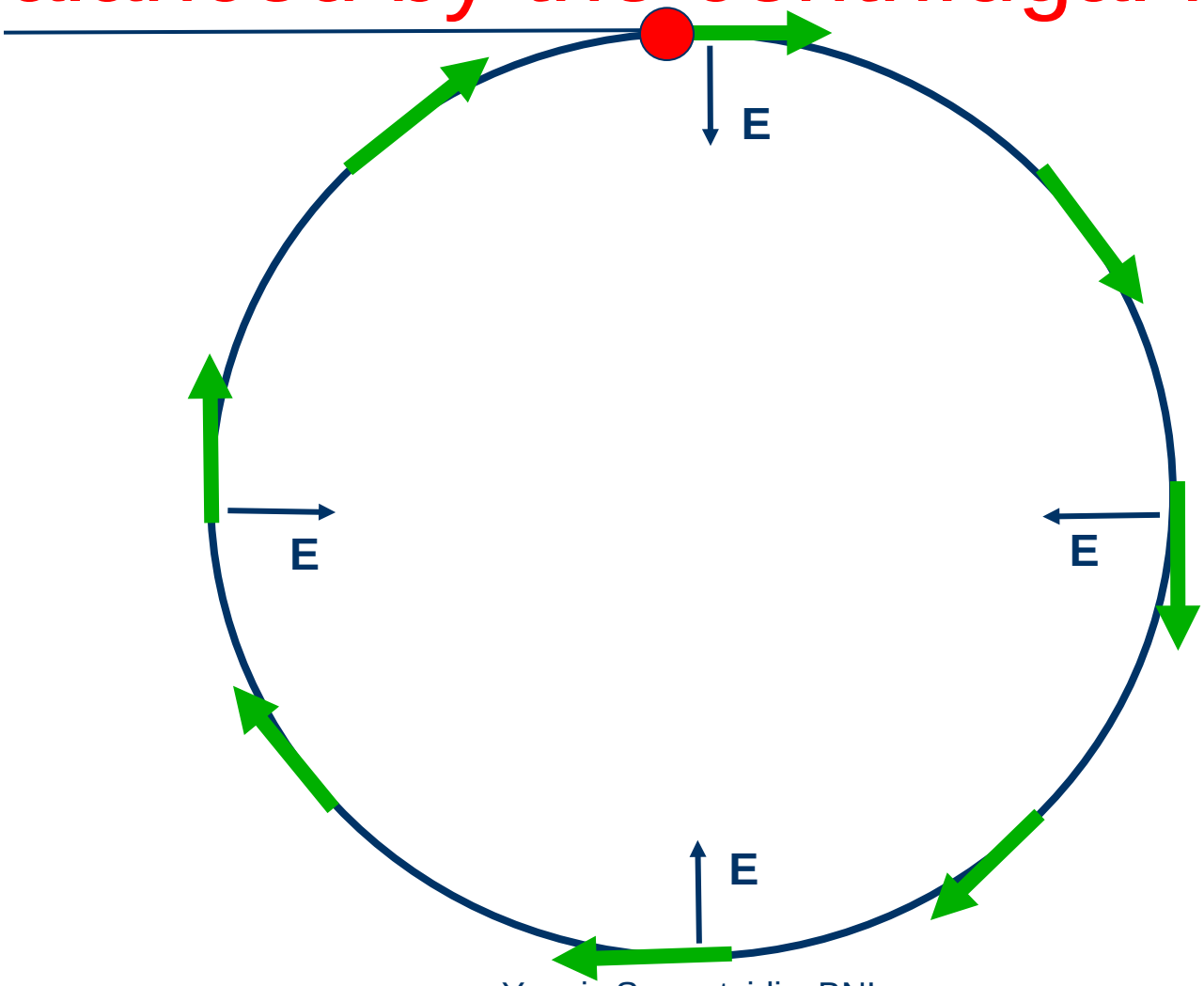
The EDM vector *d* is along the particle spin direction

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

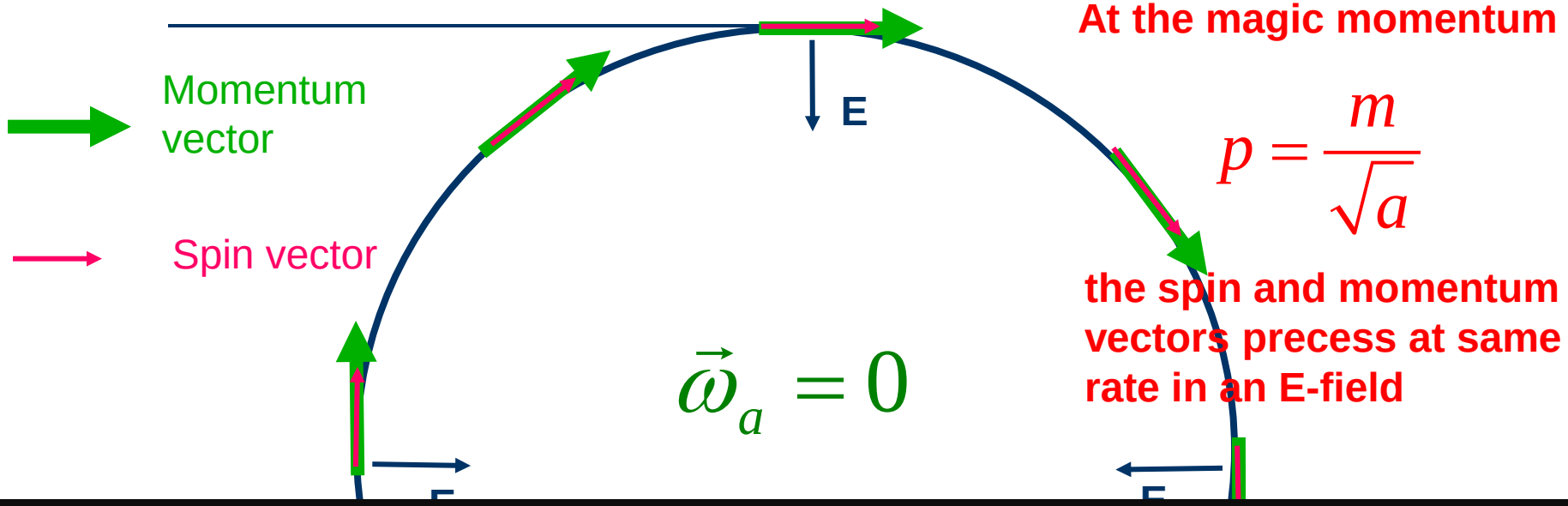
A charged particle between Electric Field plates would be lost right away…



…but can be kept in a storage ring for a long time. The radial E-field is balanced by the centrifugal force.



The proton EDM uses an ALL-ELECTRIC ring: spin is aligned with the momentum vector



At the magic momentum

$$p = \frac{m}{\sqrt{a}}$$

the spin and momentum vectors precess at same rate in an E-field

High Intensity: 10^{11} per pulse! (Proton beams come from primary sources)

- Muon g-2: Precision physics in a Storage Ring

- Statistics limited… to improve sensitivity by a factor of 4 at Fermilab

Breakthrough concept: Freezing the horizontal spin precession due to E-field

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

Muon g-2 focusing is electric: The spin precession due to E-field is zero at "magic" momentum (3.1GeV/c for muons, 0.7 GeV/c for protons,…)

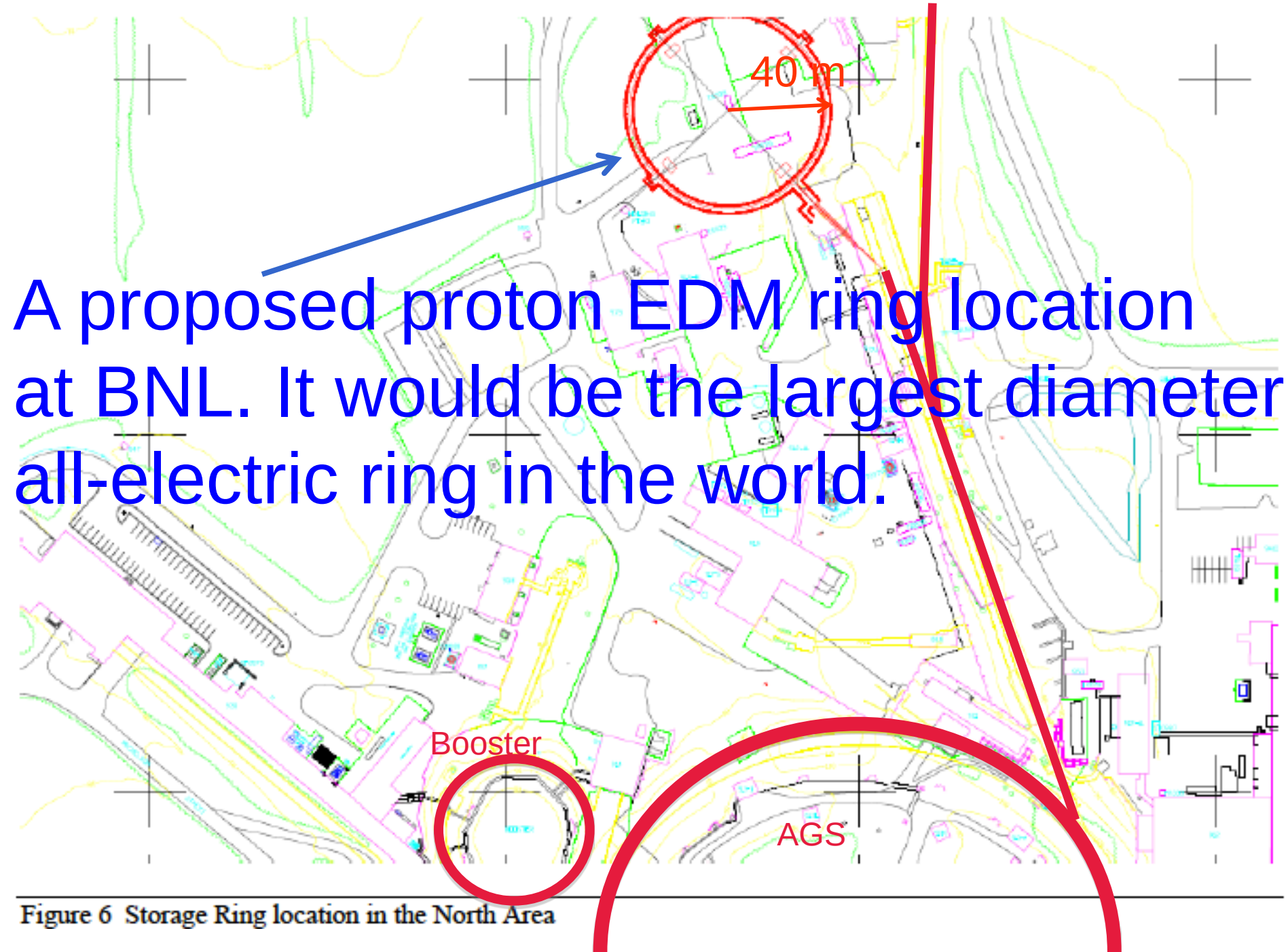
$$p = \frac{m}{\sqrt{a}}, \text{ with } a = \frac{g-2}{2}$$

The "magic" momentum concept was used in the muon g-2 experiments at CERN, BNL, and …next at FNAL.

The miracles that make the pEDM

1. Magic momentum (MM): **high intensity (10^{11})** charged beam in an all-electric storage ring
2. High analyzing power: A>50% at the MM
3. Weak vertical focusing in an all-electric ring: SCT allows for 10^3s beneficial storage; prospects for much longer SCT with mixing

4. The beam vertical position tells the average radial B-field; the main systematic error source



A proposed proton EDM ring location at BNL. It would be the largest diameter all-electric ring in the world.

Figure 6 Storage Ring location in the North Area

EDMs of hadronic systems are mainly sensitive to

- Theta-QCD (part of the SM)

- CP-violating sources beyond the SM

Alternative simple systems are needed to be able to differentiate the CP-violating source (e.g. neutron, proton, deuteron,…).

pEDM at 10^{-29} e•cm is > an order of magnitude more sens. than the best current nEDM plans

Measure all three: proton, deuteron and neutron EDMs to determine CPV source

Super-Symmetry (SUSY) model predictions:

$$d_n \simeq 1.4(d_d - 0.25 d_u) + 0.83e(d_u^c + d_d^c) - 0.27e(d_u^c - d_d^c)$$

Possible to establish axion mechanism? (Em. Mereghetti)

$$d_N^{I=1} \simeq 0.87(d_u - d_d) + 0.27e(d_u^c - d_d^c) \qquad d_N^{I=1} = (d_p - d_n)/2$$

$$d_N^{I=0} \simeq 0.5(d_u + d_d) + 0.83e(d_u^c + d_d^c) \qquad d_N^{I=0} = (d_p + d_n)/2$$

The current status

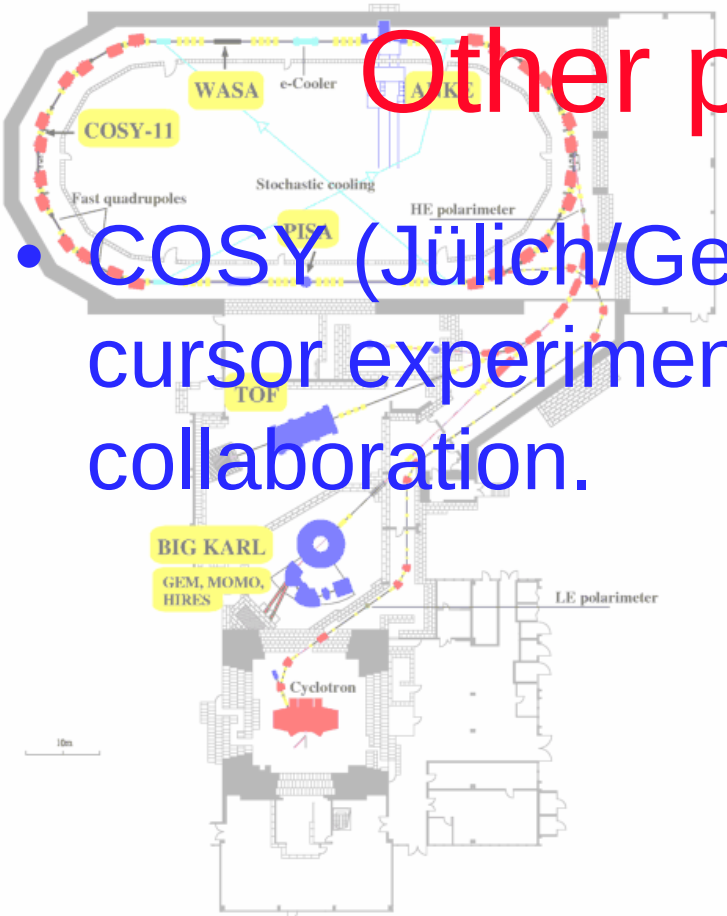
- Have developed R&D plans (need $1M/year for two years) for

  1) BPM magnetometers, 2) SCT tests at COSY, 3) E-field development, and 4) Polarimeter prototype

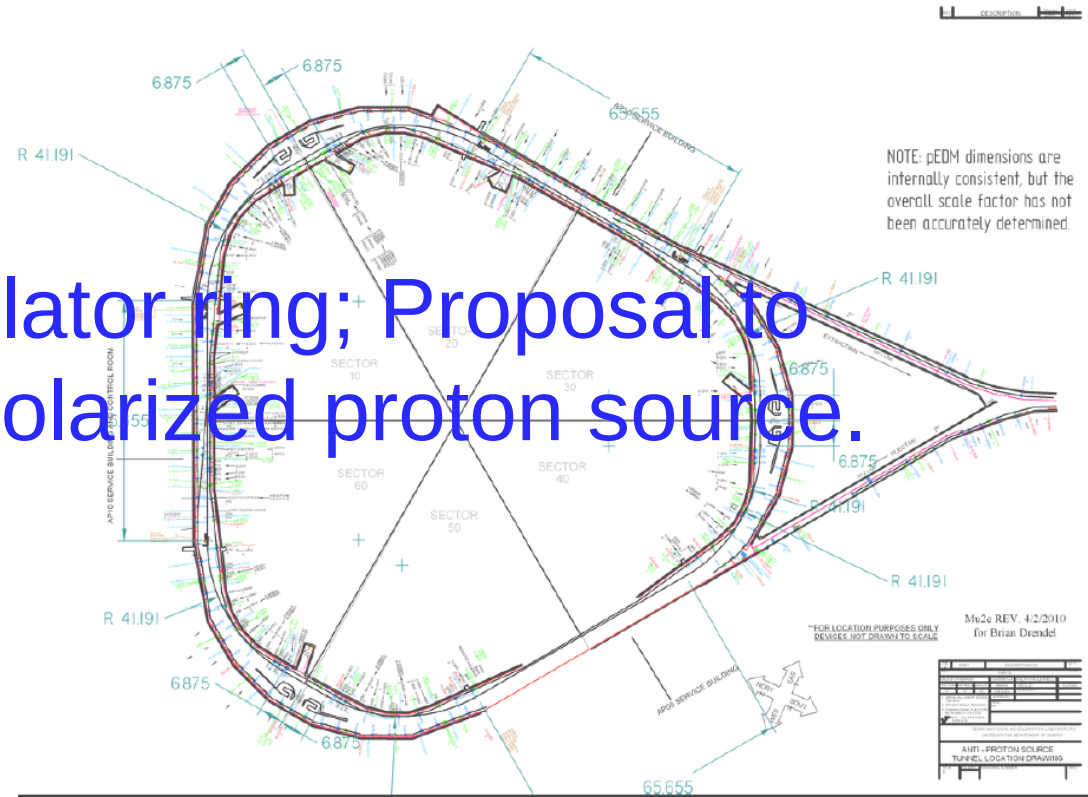
- We had two successful technical reviews: Dec 2009, and March 2011.
- Sent a proposal to DOE NP for a proton EDM experiment at BNL: November 2011

Other possible places?

- COSY (Jülich/Germany); proposal for a pre-cursor experiment; we have a common R&D collaboration.



- Fermilab, accumulator ring; Proposal to Fermilab? Need polarized proton source.



Common R&D with COSY

EDM at Storage Rings

JÜLICH FORSCHUNGSZENTRUM

International srEDM Network

Institutional (MoU) and Personal (Spokespersons …) Cooperation

srEDM Collaboration (BNL)		srEDM Collaboration (FZJ)
Common R & D		
RHIC Beam Position Monitors (…)	Spin Tracking	**EDM-at-COSY** Polarimetry Spin Coherence Time Cooling (…)
		Study Group
DOE-Proposal		Precursor; Ring Design
CD0, 1, …		HGF Application(s)

Slide by H. Stroeher, Director of IKP II

Axion dark matter sensitivity?

Oscillating EDM:

See talk by Peter Graham.

Peter W. Graham, Surjeet Rajendran

Phys. Rev. D84 (2011) 055013

In magnetic storage rings the spin precesses at $(1+G \times \gamma)f_{cycl}$. G=1.8 for the proton. Create a spin resonance at specific frequency related to axion mass.

Axion dark matter sensitivity?

In magnetic storage rings the spin precesses at $(1+G \times \gamma)f_{cycl}$. G=1.8 for the proton. Create a spin resonance at specific frequency related to axion mass.

The clocks run slower by a factor of γ, thus making accessible higher axion masses, e.g. RHIC polarized protons up to 250 GeV.

In electric rings and magic momentum: animation

Summary

- ✓ Proton EDM physics is a must do, > order of magnitude improvement over the neutron EDM
- ✓ E-field issues well understood
- ✓ Working EDM lattice with long SCT and large enough acceptance (~10^{-29} e•cm/year)
- ✓ Polarimeter work
- Planning BPM-prototype demonstration including tests at RHIC
- Old accumulator ring could house the proton EDM ring at Fermilab; BNL: new tunnel needed
- ✓ Sensitivity to dark-matter axions