16 May 2014
HEP Seminar at Liverpool University
Yannis K. Semertzidis

Center for Axion and Precision Physics Research: CAPP/IBS at KAIST, Korea

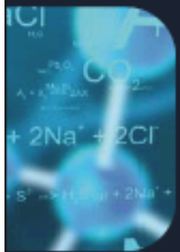
Se-Jung Oh (right), the president of the Institute for Basic Science (IBS) in Korea, and Yannis Semertzidis, after signing the first contract between IBS and a foreign-born IBS institute director. On 15 October, Semertzidis became the director of the Center for Axion and Precision Physics Research, which will be located at the Korea Advanced Institute of Science and Technology in Daejeon. The plan is to launch a competitive Axion Dark Matter Experiment in Korea, participate in state-of-the-art axion experiments around the world, play a leading role in the proposed proton electric-dipole-moment (EDM) experiment and take a significant role in storage-ring precision physics involving EDM and muon g-2 experiments. (Image credit: Ahram Kim IBS.)

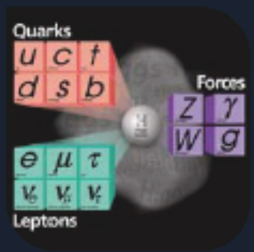
CERN Courier, Dec. 2013

- Completely new (green-field) Center dedicated to Axion Dark Matter Research and Storage Ring EDMs/ g-2. KAIST campus.

www.ibs.re.kr

Institute for Basic Science





Excellence

Autonomy

Openness

Creativity

Korea, New Initiative in Basic Sciences

- Economy is based on technology, exports.
- Need to invest in long-term basic science.
- Established the Institute for Basic Science, modeled after the Max Planck Institutes.

- Balanced approach: Basic science is critical to long-term viability of applied science.

- Foreigners are welcome, opening up the society/economy, Institutes.

Korea, KAIST in Daejeon

- Korea Advanced Institute of Science and Technology, >10,000 students
- Foreigners are very welcome
- All courses are taught in English

- KAIST President wish list: 10% foreign faculty, 10% women faculty, 10% foreign students

Bay
Sariwon
P'yonggang
Demarcation Line
Changyon
Ch'orwon
Haeju
Paengnyong-do
Sunwi-do
Ongjin
Kaesong
Munsan
Ch'unch'on
Kangnung
South Korea
Ullung-do
SEOUL
Inch'on
Kyonggi-man
Han-gang
Wonju
China
Suwon
Ch'onan
Kum-gang
Taejon
Naktong-gang
Andong
P'ohang
Yellow Sea
Kunsan
Chonju
Taegu
Ulsan
Masan
Kwangju
Pusan
35
Mokp'o
Yosu
Koje-do
Pu-Kwan Ferry
Strait
Japan
Chin-do
Tsushima
Korea
Cheju-haehyop
Kitakyushu
Fukuoka
Cheju
Cheju-do
Sasebo
125
130
0 50 100 Kilometers
0 50 100 Miles
Lambert Conformal Conic Projection SP 23N/45N
Boundary representation is not necessarily authoritative.

802191

Korean Alphabet (Hangul, 1443AD)

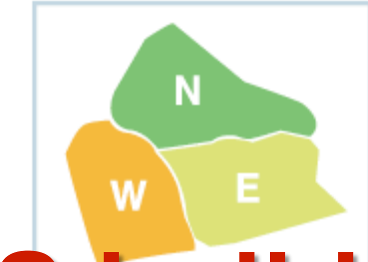
- 24 characters, consonants and vowels
- Easy to read, understand short sentences, orient yourself at public places
- Hard to understand complicated sentences
- Many people understand English

Center for Axion and Precision Physics Research: CAPP/IBS at KAIST, Korea

- Four groups
- 15 research fellows, ~20 graduate students
- 10 junior/senior staff members, Visitors
- Engineers, Technicians
- Promised: New IBS building at KAIST (critical)

CAPP's lab space at KAIST (CAPP is a "green-field" center)

한국과학기술원 건물안내도



New IBS building location at KAIST

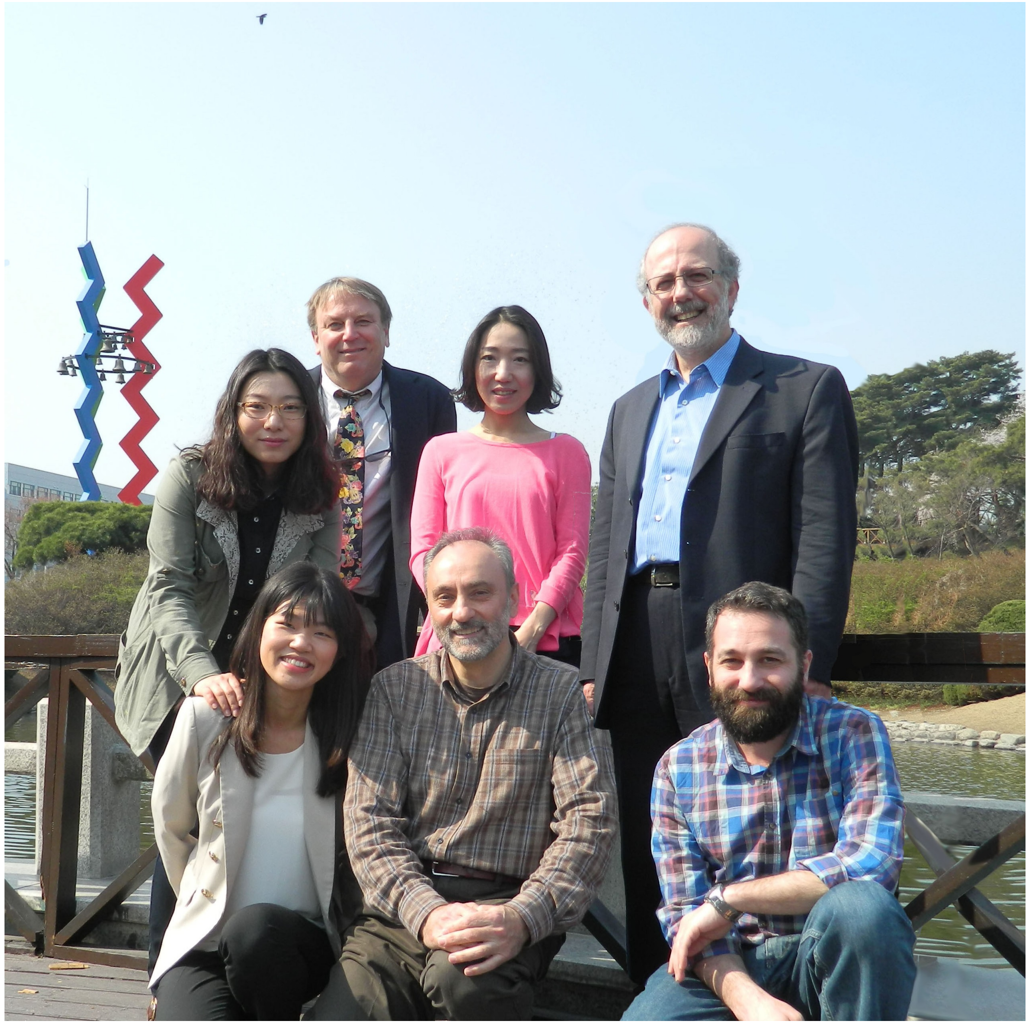
Physics building

New IBS building location at KAIST

A bird's eye view for the IBS building in KAIST campus.
The four connected buildings may enclose up to 10 IBS centers.
The red polygon shows a suggested area for IBS physics building which may change shape and size in the future.

Axion dark matter hunters

Recent (CAPP axion-dark matter group, 2014)



Hired two more Research Fellows and more are joining soon…

Strong visitor program:
Bring your ideas,
Teaching skills,
Your attitude!

CAPP-Physics

- Establish Experimental Particle Physics group. Physics involvement driven by the interest of CAPP individual scientists.
- Involved in important physics questions:
- Strong CP problem
- Cosmic Frontier (Dark Matter axions)
- Particle Physics (most sensitive proton EDM experiment, flavor conserving CP-violation)
- Muon g-2; muon to electron conversion (flavor physics)

Storage Ring Muon g-2: Rigorous Test of the Standard Model

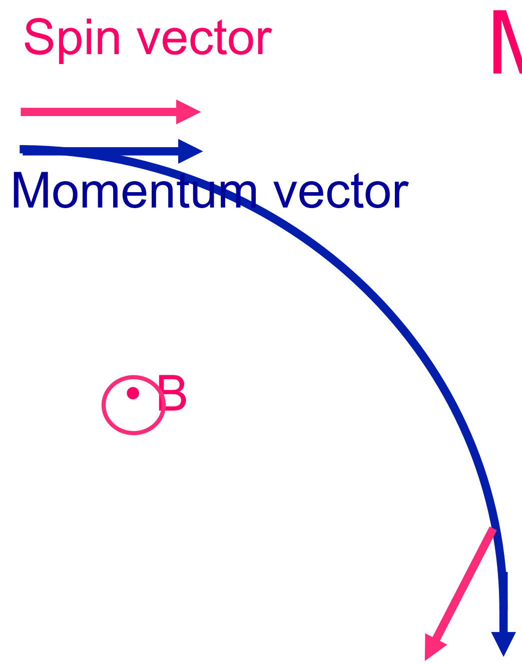
Spin Precession Rate at Rest

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

There is a large asymmetry in this equation: μ is relatively large, d is compatible with zero

The Principle of g-2

$$\text{At rest}: \frac{d\vec{s}}{dt} = \vec{\mu} \times \vec{B}$$



Moving: Non-relativistic case

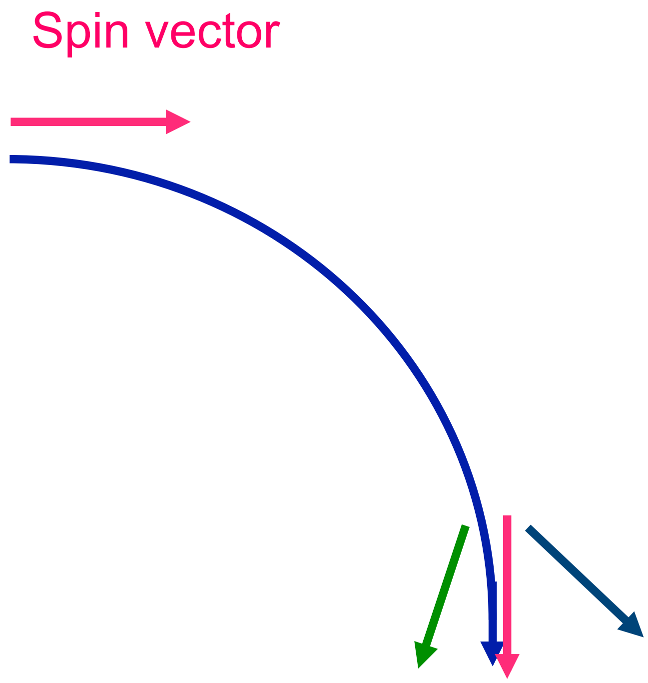
$$\omega_c = \frac{eB}{m}$$

$$\omega_s = \frac{g}{2}\frac{eB}{m}$$

$$\omega_a = \omega_s - \omega_c = \frac{g}{2}\frac{eB}{m} - \frac{eB}{m} = \left(\frac{g-2}{2}\right)\frac{eB}{m} \Rightarrow \boxed{\omega_a = a\frac{eB}{m}}$$

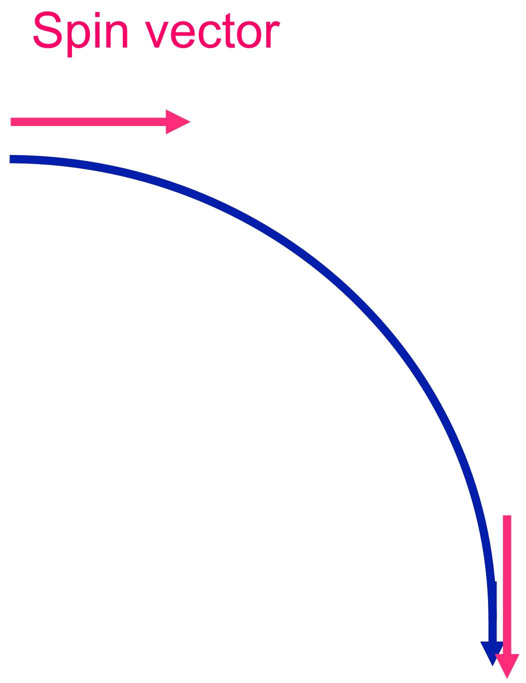
Effect of Radial Electric Field

E-field are used to focus the beam vertically



- Low energy particle
- …just right
- High energy particle

Effect of Radial Electric Field



- …just right, $\gamma \approx 29.3$

  for muons

  "magic"

  momentum

  (~3GeV/c)

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

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

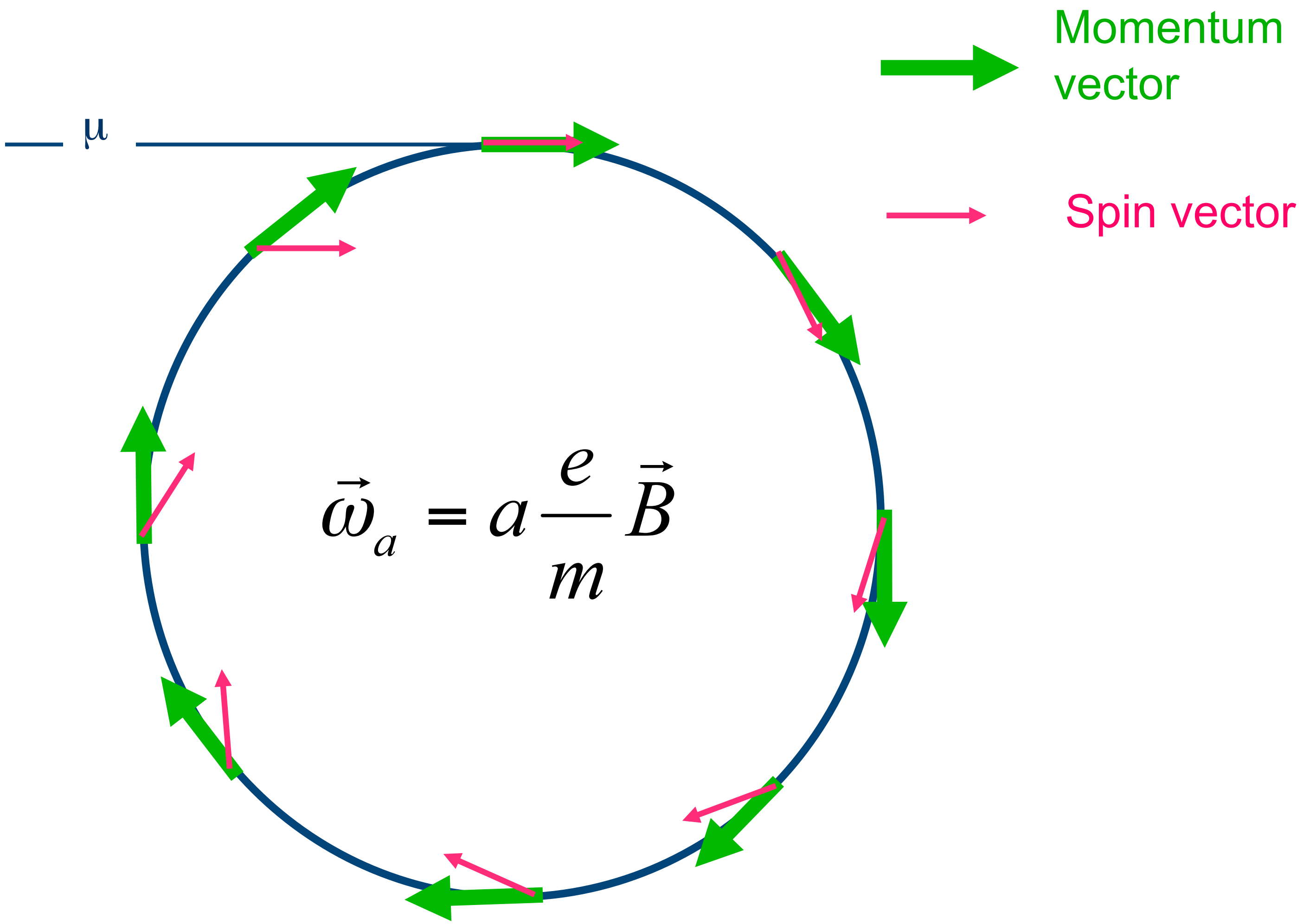
Muon g-2 focusing is electric: The spin precession due to E-field is zero at "magic" momentum (3.1GeV/c for muons, 0.7 GeV/c for protons,…)

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

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


• The Muon Storage Ring:
B ≈ 1.45T, P_μ ≈ 3 GeV/c
HVON
•Previous muon g-2 Experiment at Brookhaven National Laboratory

Spin Precession in g-2 Ring (Top View)

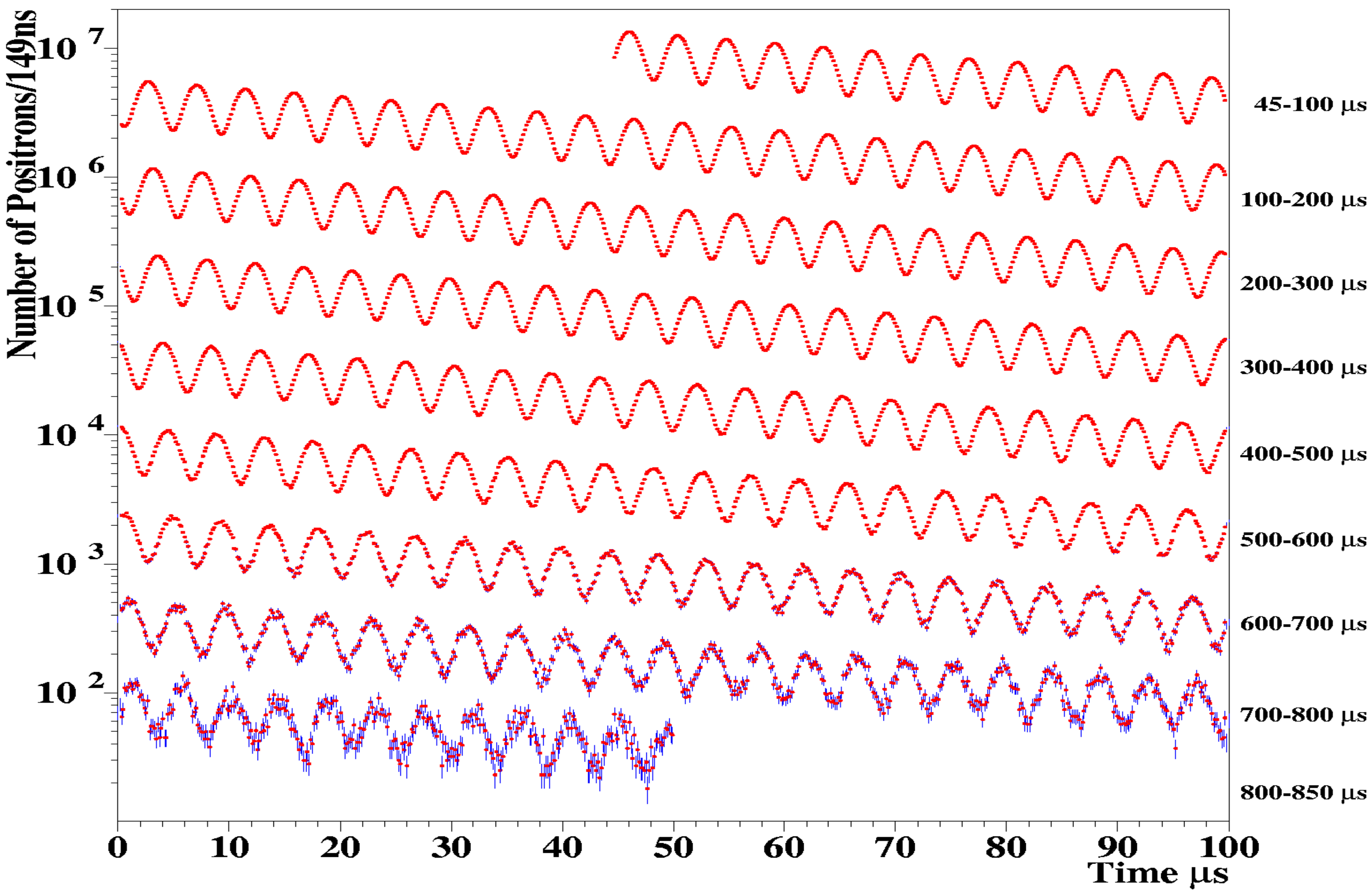


$$\vec{\omega}_a = a\frac{e}{m}\vec{B}$$

The electric focusing does not influence the g-2 precession rate

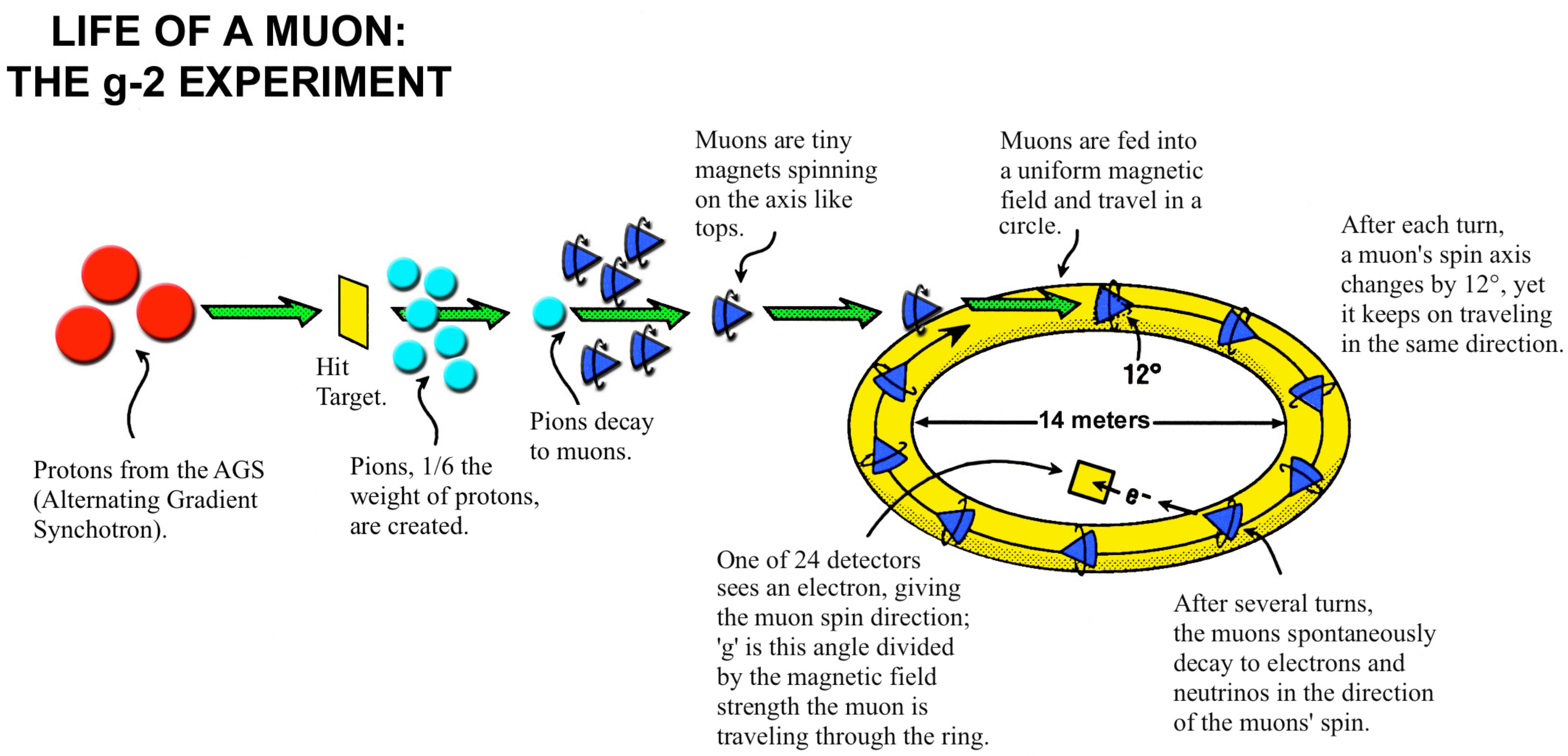
4 Billion e^+ with E>2GeV

$$dN/dt = N_0 e^{-\frac{t}{\tau}}\left[1 + A\cos\left(\omega_a t + \phi_a\right)\right]$$



Muon g-2 experiment: Best challenge to the Standard Model

- E821 at BNL: 1997-2004
- E969 at FNAL: first data in 2017



The muon g-2 coil moved to Fermilab for more intense beam

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D. Hertzog – Co-Spokesperson (hertzog@uw.edu)
B. L. Roberts – Co-Spokesperson (roberts@bu.edu)

Storage Ring Proton EDM: study of CP-violation beyond the Standard Model

Short History of EDM

- 1950's neutron EDM experiment started to search for parity violation (Ramsey and Purcell).
- After P-violation → EDMs require both P,T-Violation
- 1960's EDM searches in atomic systems
- 1970's Indirect Storage Ring EDM method from the CERN muon g-2 exp.
- 1980's Theory studies on systems (molecules) w/ large enhancement factors
- 1990's First exp. attempts w/ molecules. Dedicated Storage Ring EDM method developed
- 2000's Proposal for sensitive dEDM exp. developed.
- 2010's Proposal for sensitive pEDM exp. developed.
- 2013 Sensitive electron EDM result announced.

Storage Ring EDM Collaboration

>20 Institutions
>80 Collaborators

- Aristotle University of Thessaloniki, Thessaloniki/Greece
- Research Inst. for Nuclear Problems, Belarusian State University, Minsk/Belarus
- Brookhaven National Laboratory, Upton, NY/USA
- Budker Institute for Nuclear Physics, Novosibirsk/Russia
- Royal Holloway, University of London, Egham, Surrey, UK
- Cornell University, Ithaca, NY/USA
- Institut für Kernphysik and Jülich Centre for Hadron Physics Forschungszentrum Jülich, Jülich/Germany
- Institute of Nuclear Physics Demokritos, Athens/Greece
- University and INFN Ferrara, Ferrara/Italy
- Laboratori Nazionali di Frascati dell'INFN, Frascati/Italy
- Joint Institute for Nuclear Research, Dubna/Russia
- Indiana University, Indiana/USA
- Istanbul Technical University, Istanbul/Turkey
- University of Massachusetts, Amherst, Massachusetts/USA
- Michigan State University, East Lansing, Minnesota/USA
- Dipartimento do Fisica, Universita' "Tor Vergata" and Sezione INFN, Rome/Italy
- University of Patras, Patras/Greece
- CEA, Saclay, Paris/France
- KEK, High Energy Accel. Res. Organization, Tsukuba, Ibaraki 305-0801, Japan
- University of Virginia, Virginia/USA

http://www.bnl.gov/edm

Storage ring proton EDM proposal to DOE NP, Nov 2011

Why now?

- Exciting progress in electron EDM using molecules.
- Several neutron EDM experiments under development to improve their sensitivity level.
- Proton EDM could be decisive to clarify the picture.

Storage ring proton EDM method

- All-electric storage ring. Strong radial E-field to confine protons with "magic" momentum. The spin vector is aligned to momentum horizontally.

- High intensity, polarized proton beams are injected Clockwise and Counter-clockwise with positive and negative helicities. Great for systematics

- Great statistics: up to ~10^{11} particles with primary proton beams and small phase-space parameters.

PAC/Snowmass strong endorsement

- BNL PAC on EDM proposal (2008): “enthusiastic endorsement of the physics…need to demonstrate feasibility of systems”

- Snowmass writeup: “…Ultimately the interpretability of possible EDMs in terms of underlying sources of CP violation may prove sharpest in simple systems such as neutron and proton,…”

- FNAL PAC EDM EOI (2012): “The Physics case for such a measurement is compelling since models with new physics at the TeV scale (e.g., low energy SUSY) that have new sources of CP-violation can give contributions of this order…. The PAC recommends that Fermilab and Brookhaven management work together, and with potential international partners, to find a way for critical R&D for this promising experiment to proceed.”

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

Importance and Promise of Electric Dipole Moments

Frank Wilczek

January 22, 2014

The additional symmetry has another remarkable consequence. It predicts the existence of a new very light, very weakly interacting spin 0 particle, the *axion*. The possible existence of axions raises the stakes around these ideas, because it entails major cosmological consequences. Indeed, if axions exist at all, they must provide much of the astronomical "dark matter", and quite plausibly most of it.

Better bounds on θ, or especially an actual determination of its value, would allow us to sharpen these considerations considerably. Better measurements of fundamental electric dipole moments are the most promising path to such bounds, or measurement.

Electric Dipole Moments: P and T-violating when $\vec{d}$ // to spin

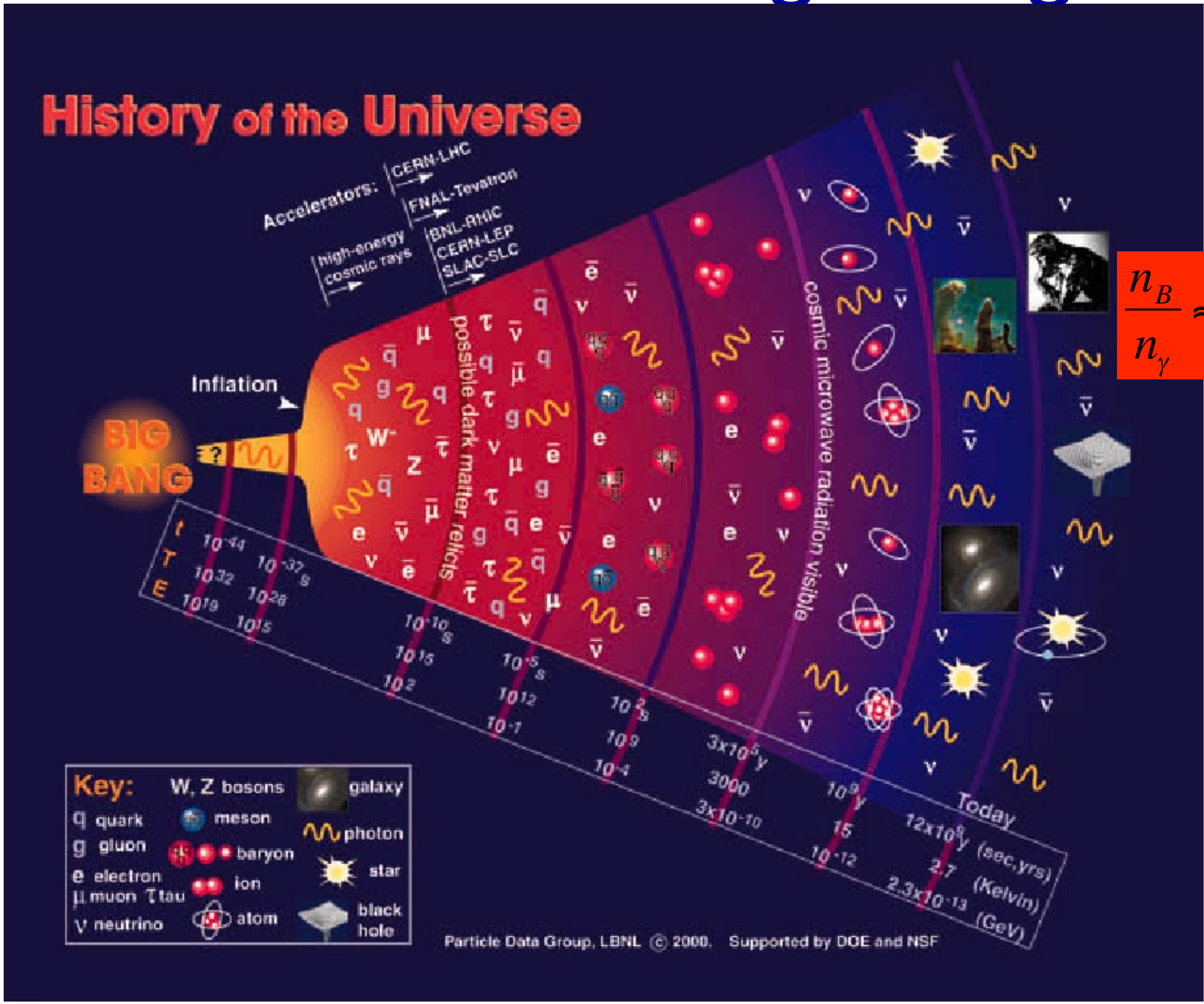
$$\vec{\mu} = g\left(\frac{q}{2m}\right)\vec{s},$$

$$\vec{d} = \eta\left(\frac{q}{2mc}\right)\vec{s}$$

$$\mathcal{H} = -\vec{\mu}\cdot\vec{B} - \vec{d}\cdot\vec{E}$$

	$\vec{E}$	$\vec{B}$	$\vec{\mu}$ or $\vec{d}$
P	$-$	$+$	$+$
C	$-$	$-$	$-$
T	$+$	$-$	$-$

Why is there so much matter after the Big Bang:



We see:

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

From the SM:

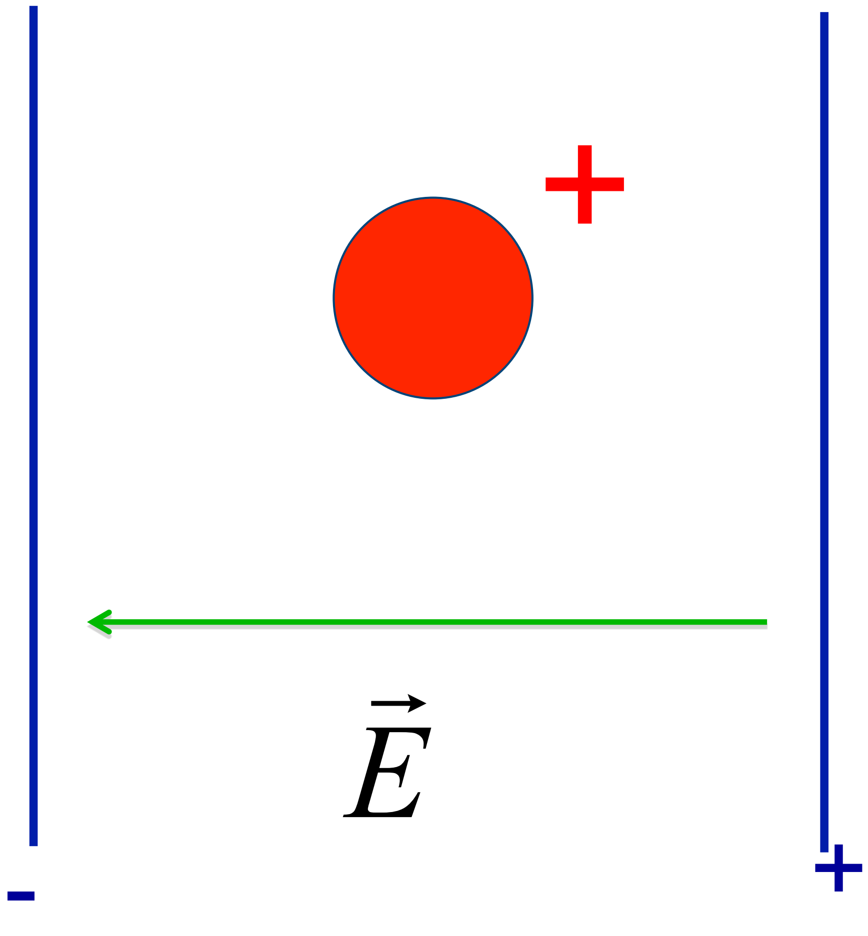
$$\frac{n_B}{n_\gamma} = \frac{n_{\bar{B}}}{n_\gamma} \approx 10^{-18}$$

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"

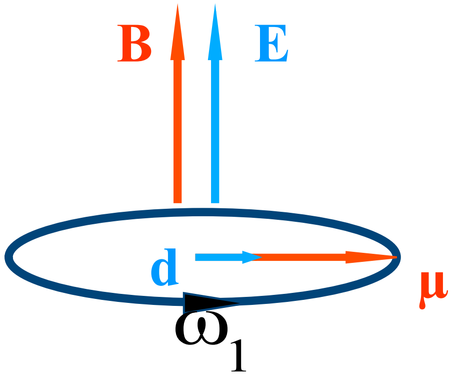
Phys. Rev. 78 (1950)

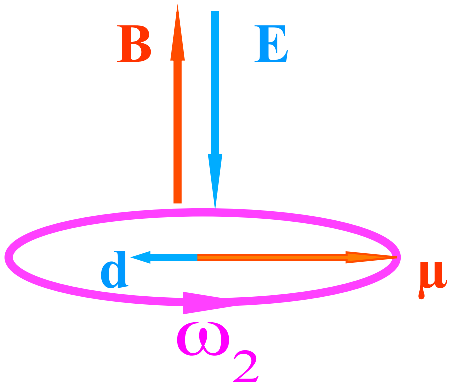
A charged particle between Electric Field plates would be lost right away…

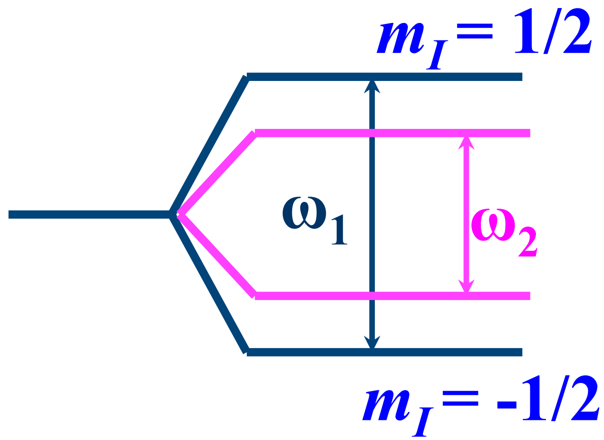


Measuring an EDM of Neutral Particles

$$H = -(d\,\mathbf{E} + \mu\,\mathbf{B}) \bullet \mathbf{I}/I$$







$$\omega_1 = \frac{2\mu B + 2dE}{\hbar} \qquad \omega_2 = \frac{2\mu B - 2dE}{\hbar}$$

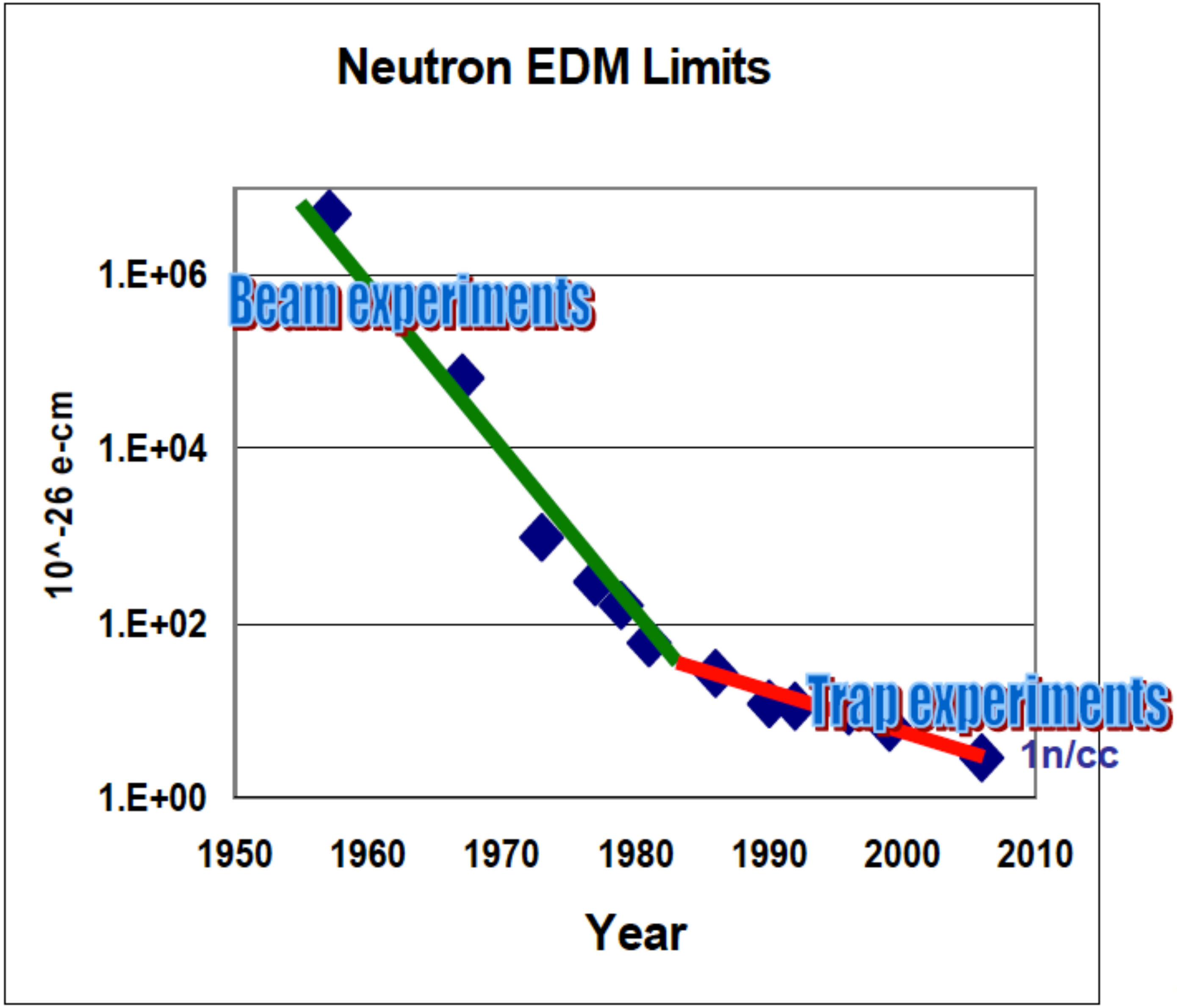
$$d = \frac{\hbar(\omega_1 - \omega_2)}{4E}$$

d = 10^{-25} e cm

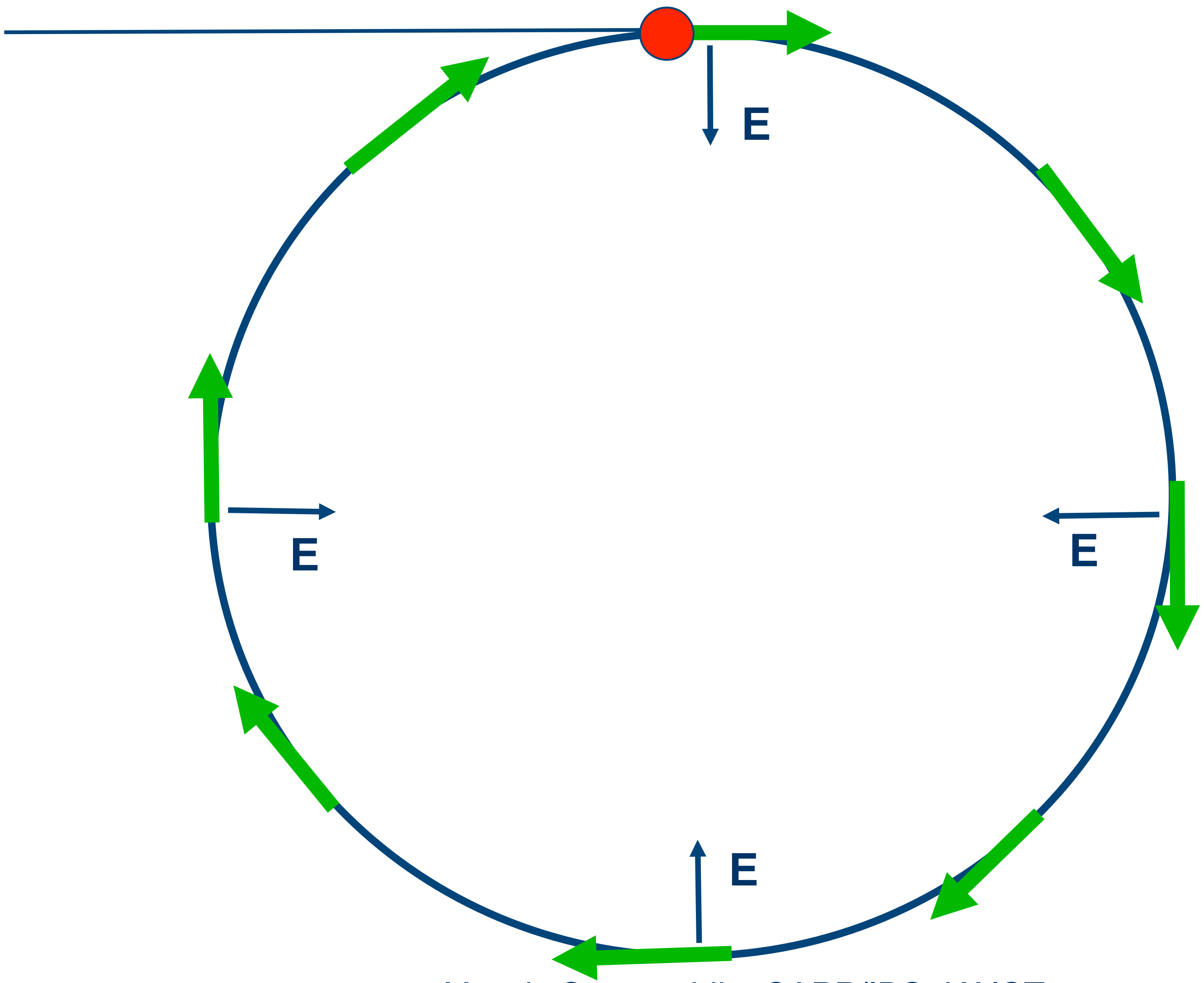
E = 100 kV/cm

$\Rightarrow$ **ω = 10^{-4} rad/s**

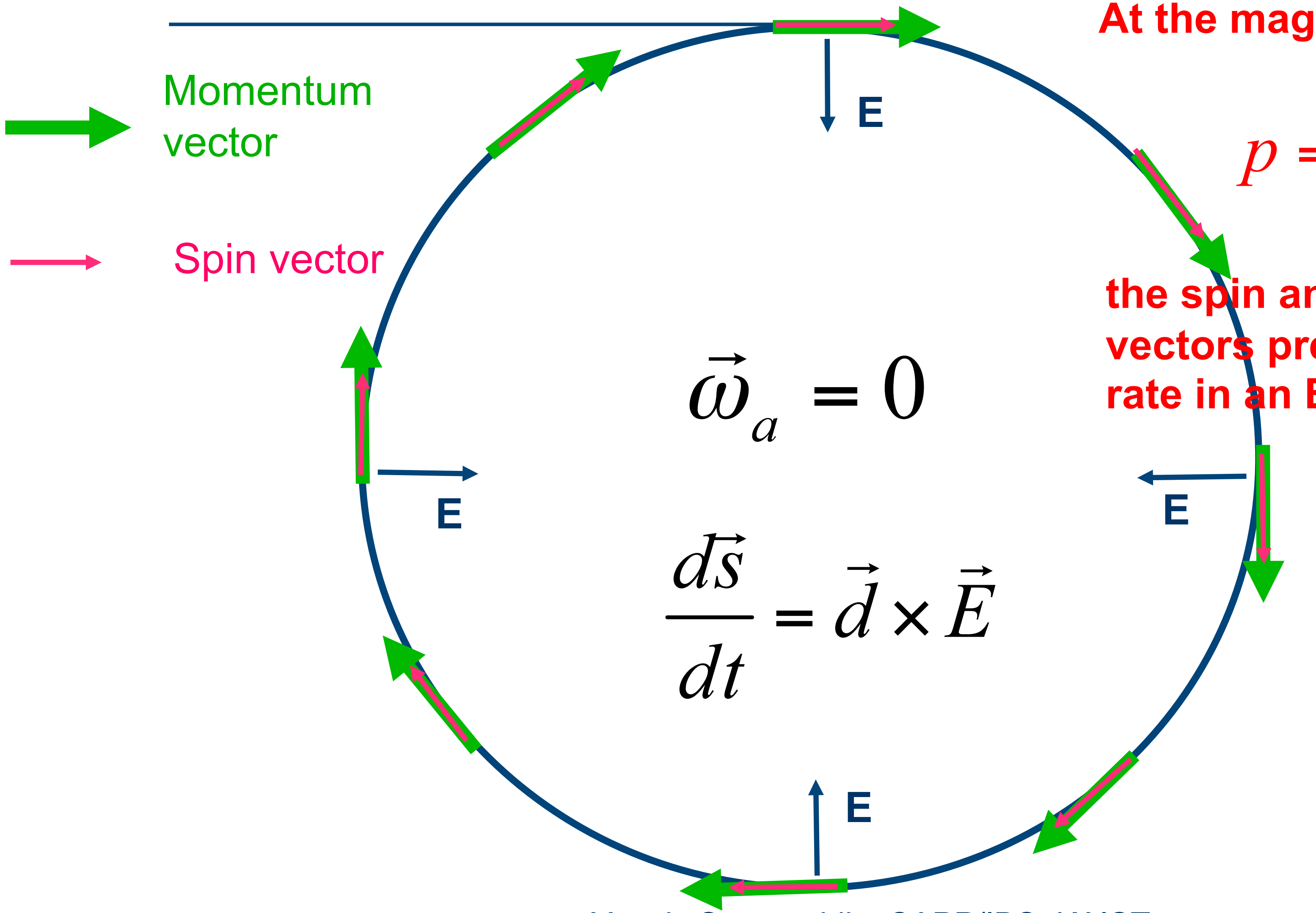
Proton storage ring EDM experiment is combination of beam + a trap



Stored beam: The radial E-field force is balanced by the centrifugal force.



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



$$\vec{\omega}_a = 0$$

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

At the magic momentum

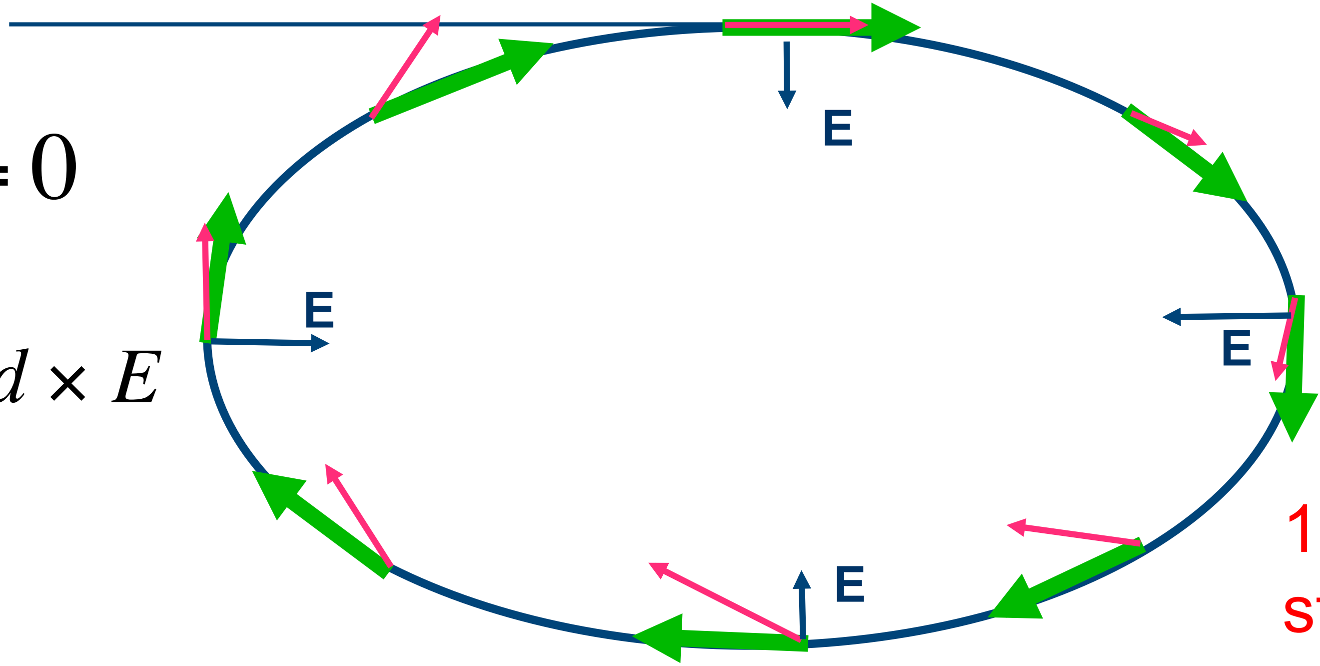
$$p = \frac{m}{\sqrt{a}}$$

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

The spin precession relative to the momentum in the plane is kept near zero. A vert. spin precession vs. time is an indication of an EDM (*d*) signal.

$$\omega_a = 0$$

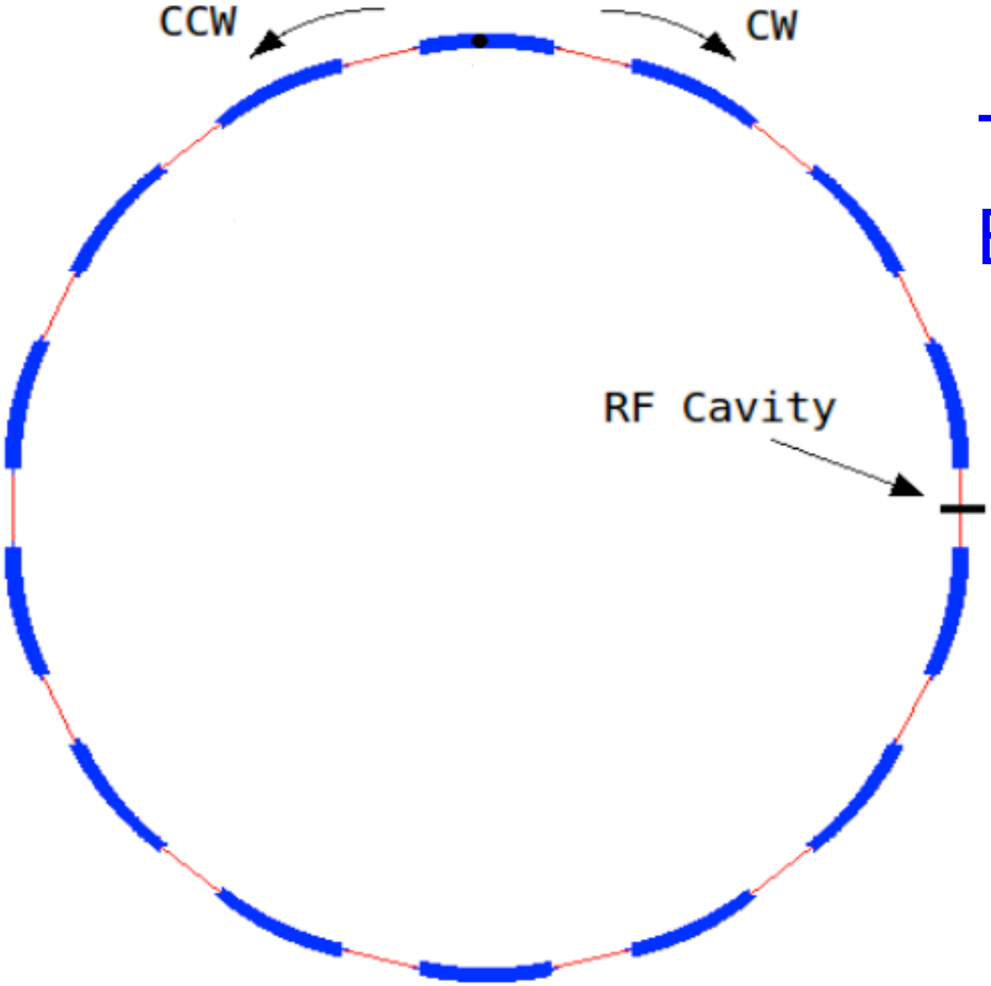
$$\frac{ds}{dt} = d \times E$$



10^3 second storage time

Several publications from ~5 years worth of tests including COSY/Germany plus 3 PhD theses showing feasibility of the method.

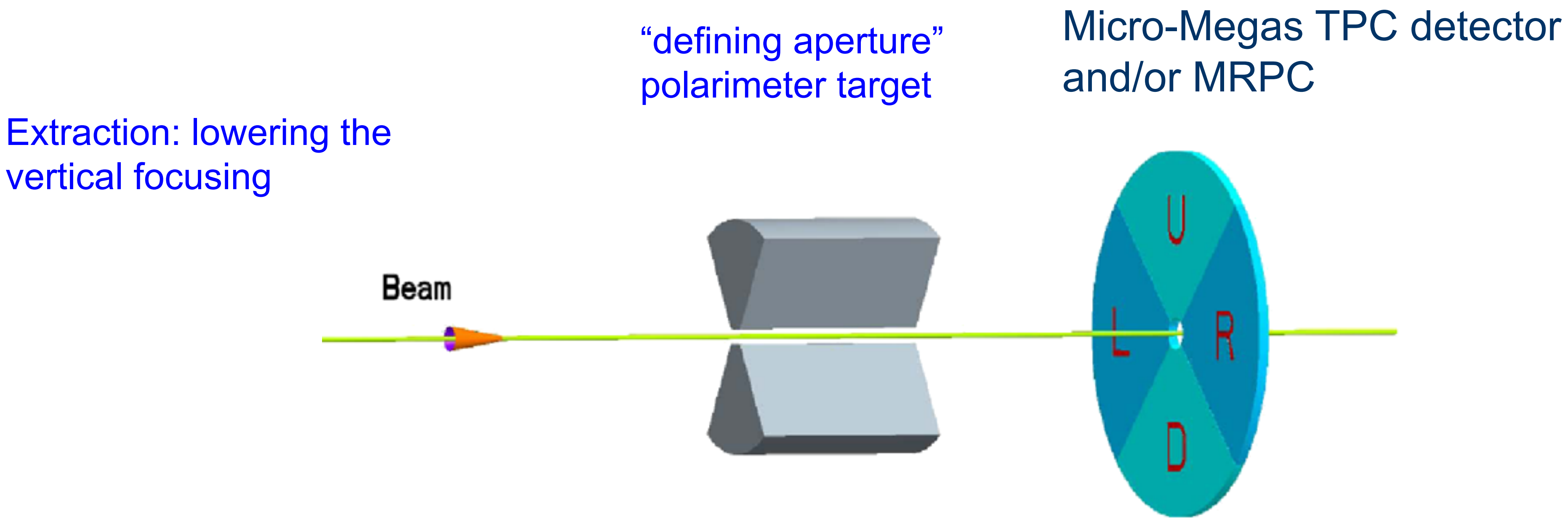
The proton EDM ring



Total circumference: 300 m
Bending radius: 40 m

Weak vertical focusing
Stronger horizontal focusing

pEDM polarimeter principle (placed in a straight section in the ring): probing the proton spin components as a function of storage time



$$\varepsilon_H = \frac{L-R}{L+R}$$

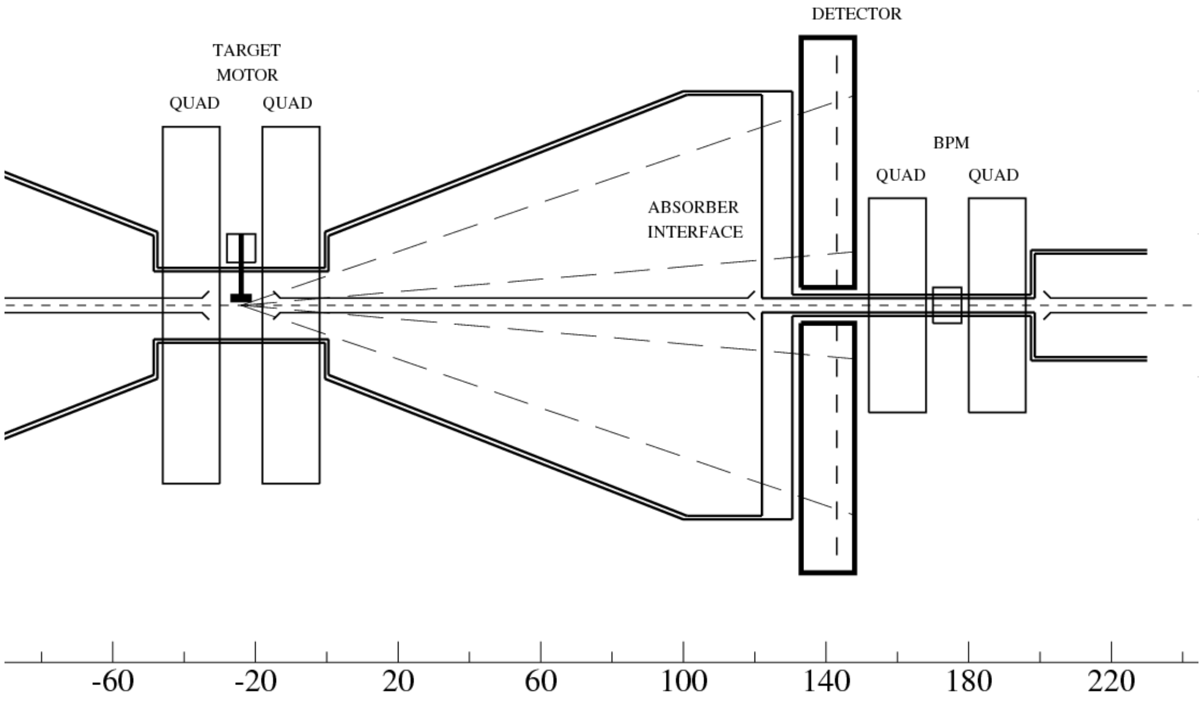
carries EDM signal
increases slowly with time

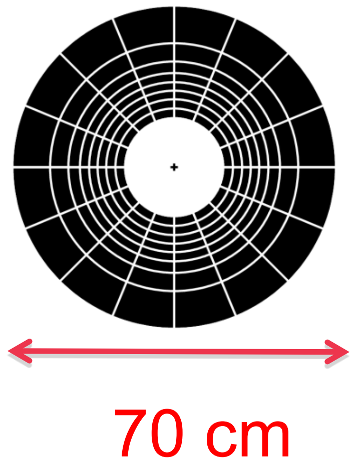
$$\varepsilon_V = \frac{D-U}{D+U}$$

carries in-plane (g-2)
precession signal

Polarimeter design, rates:

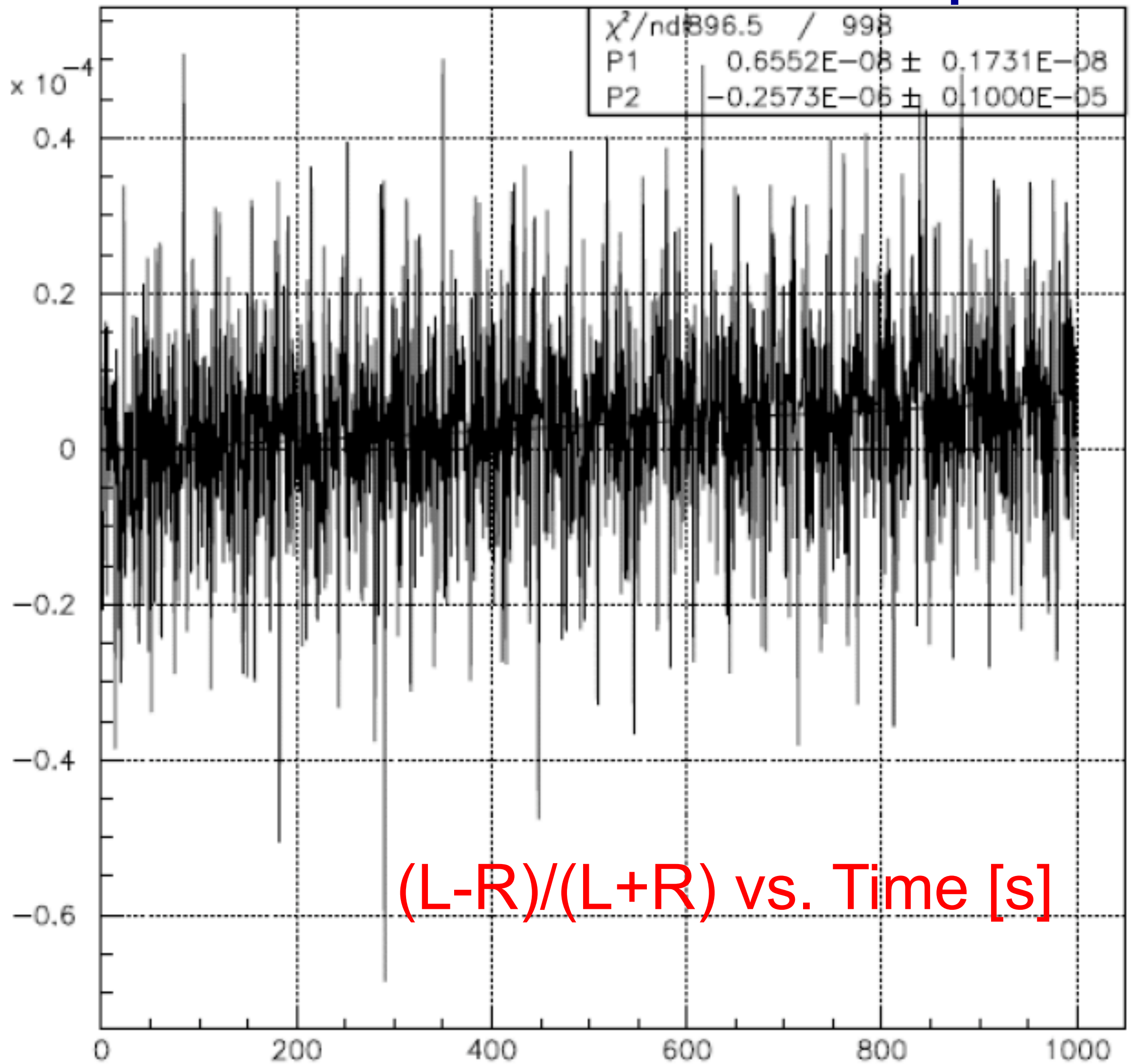
- Beam rates ~10^2 Hz/cm^2 on average but much higher at small radius. Design: ~1KHz/pad.





The EDM signal: early to late change

- Comparing the (left-right)/(left+right) counts vs. time we monitor the vertical component of spin



M.C. data

Figure 2. (L-R)/(L+R) vs. time [s] is shown here as well as the fit results to two

Large polarimeter analyzing at P_{magic}!

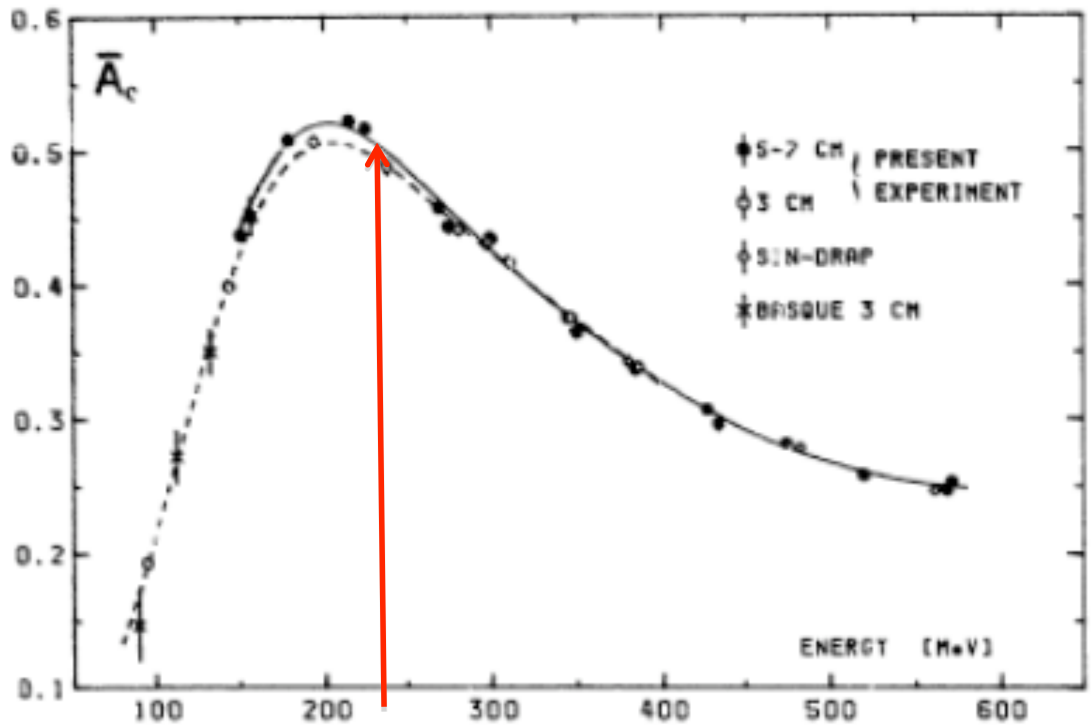


Fig. 4. Angle-averaged effective analyzing power. Curves show our fits. Points are the data included in the fits. Errors are statistical only

Fig.4. The angle averaged effective analyzing power as a function of the proton kinetic energy. The magic momentum of 0.7GeV/c corresponds to 232MeV.

The proton EDM ring evaluation
Val Lebedev (Fermilab)

Beam intensity 10^{11} protons limited by IBS

	Soft focusing	Strong focusing
Circumference, m	263	300
Qx/Qy	1.229/0.456	2.32/0.31
Particle per bunch	$1.5 \cdot 10^{8}$	$7 \cdot 10^{8}$
Coulomb tune shifts, $\Delta Q_x/\Delta Q_y$	0.0046/0.0066	0.0146/0.0265
Rms emittances, x/y, norm, μm	0.56/1.52	0.31/2.16
Rms momentum spread	$1.1 \cdot 10^{-4}$	$2.9 \cdot 10^{-4}$
IBS growth times, x/y/s, s	300/(-1400)/250	7500
RF voltage, kV	13	10.3
Synchrotron tune	0.02	0.006

Proton Statistical Error (230MeV):

$$\sigma_d = \frac{2\hbar}{E_R P A \sqrt{N_c f \tau_p T_{tot}}}$$

τ_p : 10^3s Polarization Lifetime (Spin Coherence Time)
A : 0.6 Left/right asymmetry observed by the polarimeter
P : 0.8 Beam polarization
N_c : 10^{11}p/cycle Total number of stored particles per cycle
T_{Tot}: 10^7s Total running time per year
f : 0.5% Useful event rate fraction (efficiency for EDM)
E_R : 10.5 MV/m Radial electric field strength (83% azim. cov.)

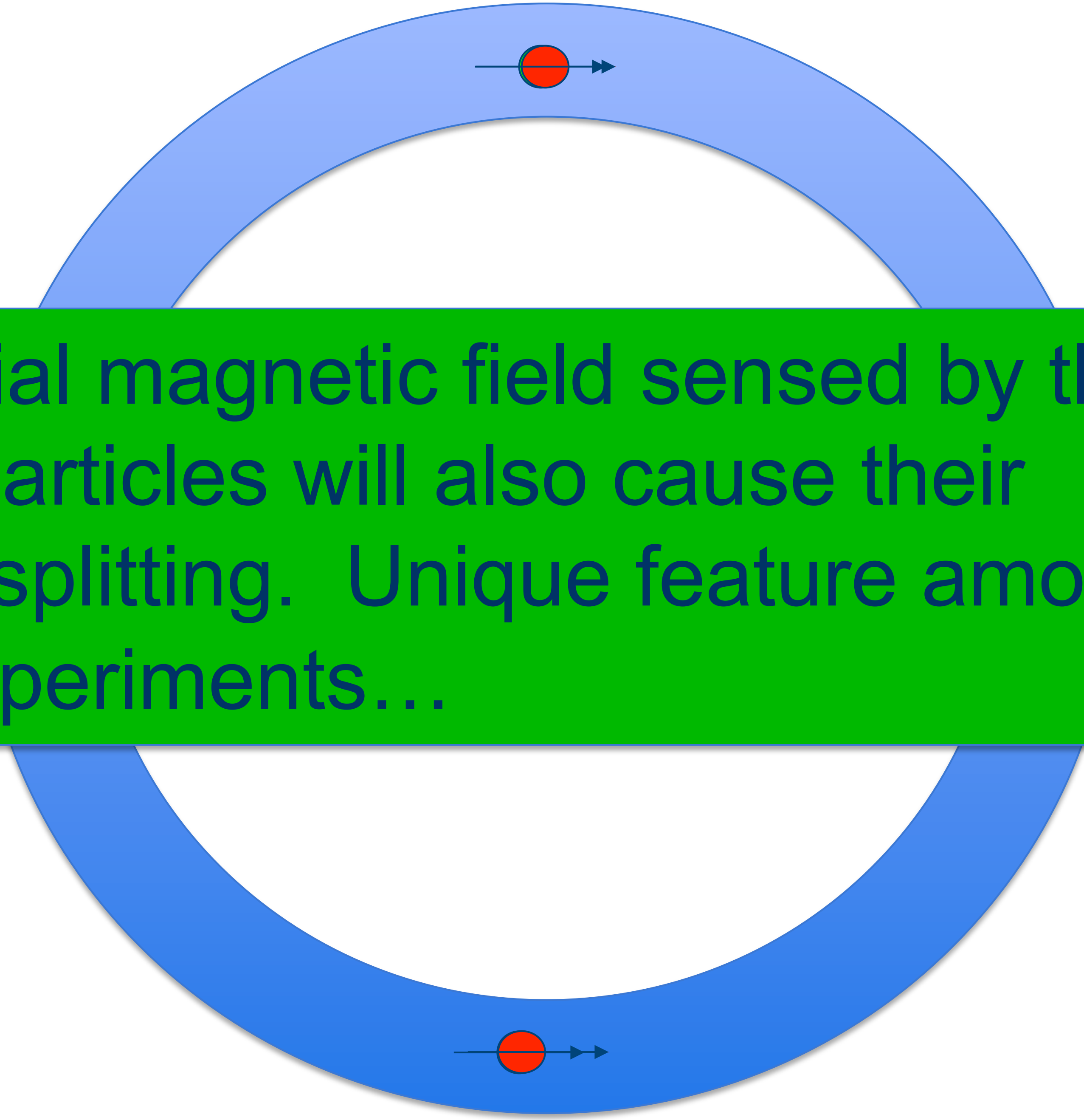
$\sigma_d = 10^{-29}$ e-cm / year

Main Systematic error for neutron and proton EDM experiments (similar sensitivity)

- Neutron: magnetic fields. Use SQUIDs or co-magnetometers.

- Proton: Radial magnetic fields. Use counter-rotating beams and modulate vertical tune. Use SQUIDs to sense field at modulation frequency.

Clock-wise (CW) & Counter-Clock-wise Storage



Any radial magnetic field sensed by the stored particles will also cause their vertical splitting. Unique feature among EDM experiments…

Distortion of the closed orbit due to a radial B-field

$$y(\vartheta)=\sum_{N=0}^{\infty}\frac{\beta R_0 B_{rN}}{E_0\left(Q_y^2-N^2\right)}\cos\left(N\vartheta+\varphi_N\right)$$

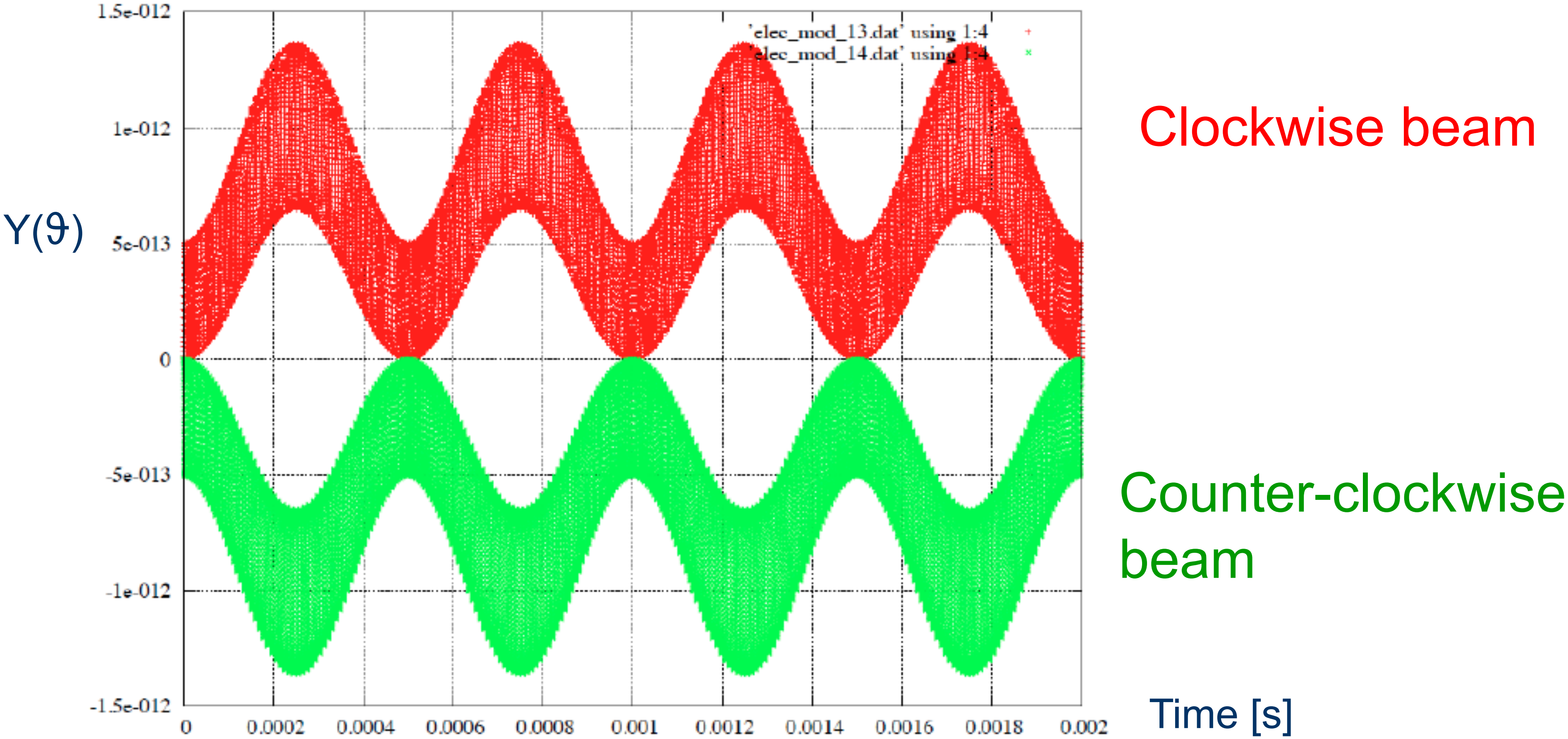
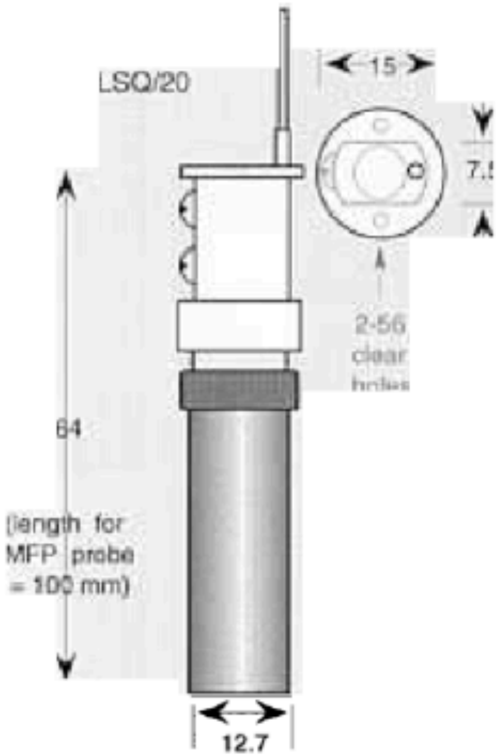
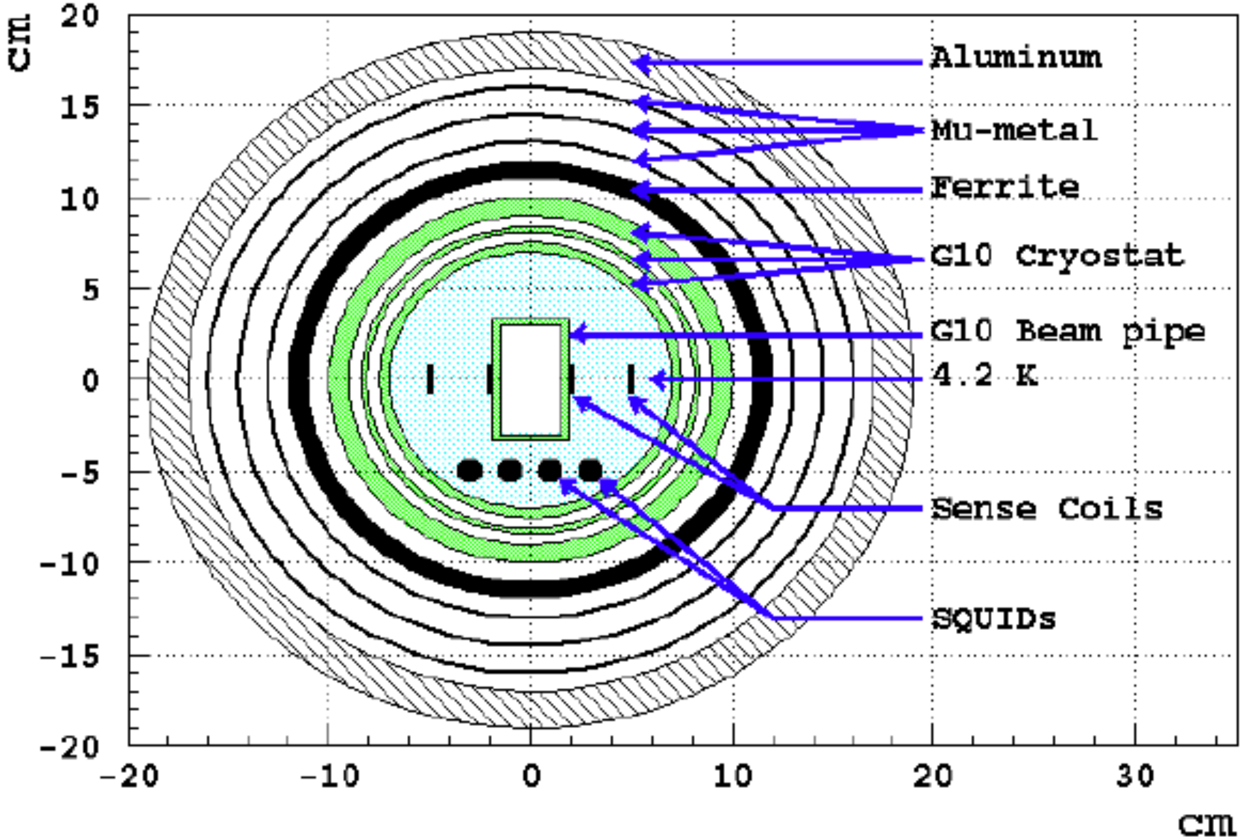


Figure 11.3: Simulation results for counter-rotating particles. The vertical beam

Schematic of a SQUID BPM system





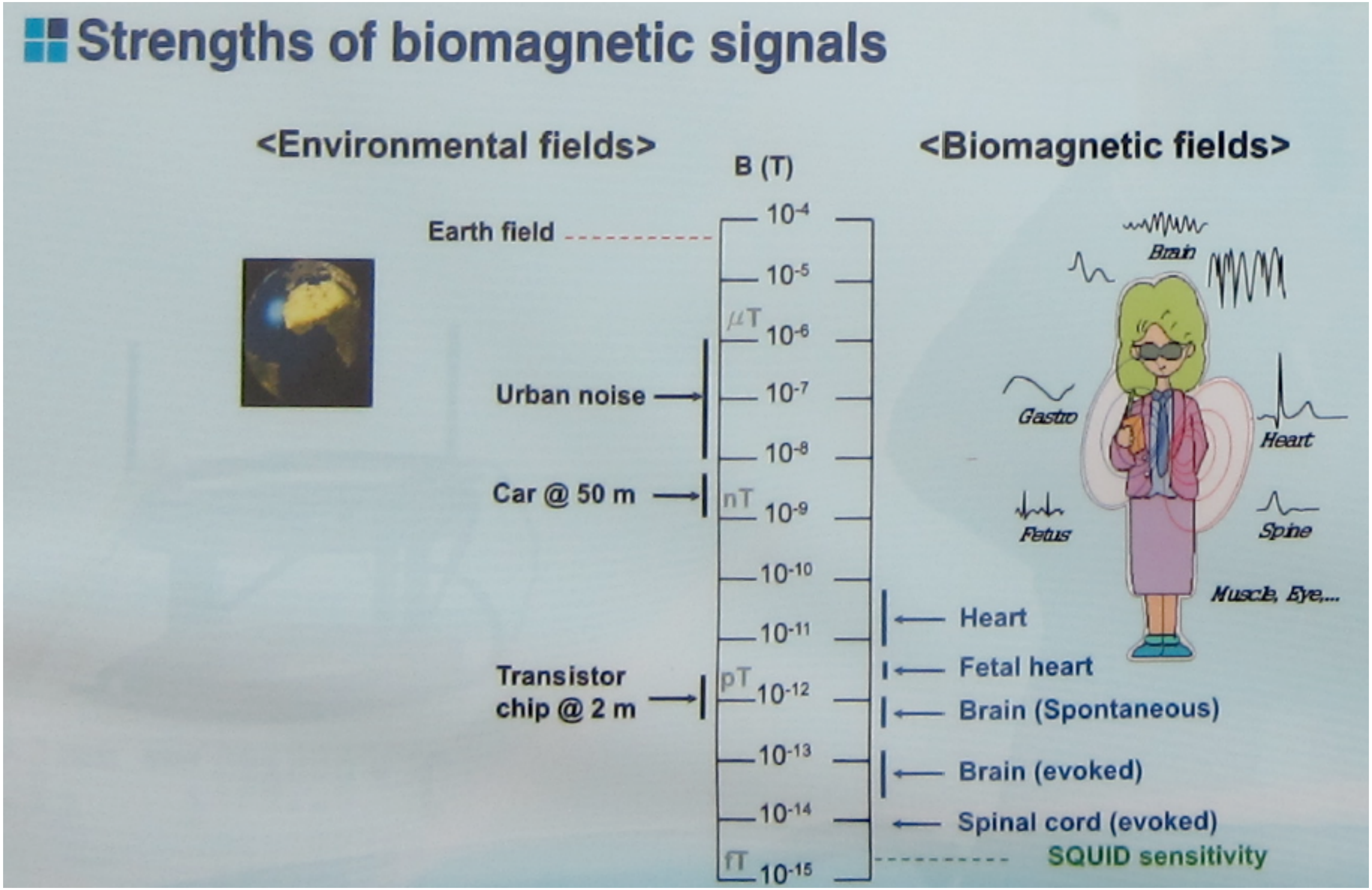
- Tristan Technology LSQ/20 SQUID
- 64 mm long, 12.7 mm diameter
- ≤ 1 fT$/\sqrt{\mathrm{Hz}}$

- Beam's eye view schematic of a SQUID BPM system
- Sense coils, leads, SQUIDs at 4.2K; leads and SQUIDs in SC shields
- Ferrite and μ-metal at room temp$\Rightarrow$ superconducting shield?
- More magnetic shielding outside Al. Super-insulation too noisy!
- Ceramic instead G10? Low susceptibility, better for UHV, more robust?

B-field shielding

- The counter-rotating beams sense the average radial B-field. It splits the two beams creating a radial B-field at ~10KHz. This field is to be sensed by the SQUID-based BPMs.

- The B-field needs to be less than 200 nG (20pT) everywhere. The issue here is residual B-fields originating from the mu-metal walls. It is found to be within specs.


Strengths of biomagnetic signals
<Environmental fields>
<Biomagnetic fields>
B (T)
10-4
10-5
μT 10-6
10-7
10-8
nT 10-9
10-10
10-11
pT 10-12
10-13
10-14
fT 10-15
Earth field
Urban noise
Car @ 50 m
Transistor chip @ 2 m
Heart
Fetal heart
Brain (Spontaneous)
Brain (evoked)
Spinal cord (evoked)
SQUID sensitivity
Brain
Gastro
Heart
Fetus
Spine
Muscle, Eye,...

SQUID gradiometers at KRISS

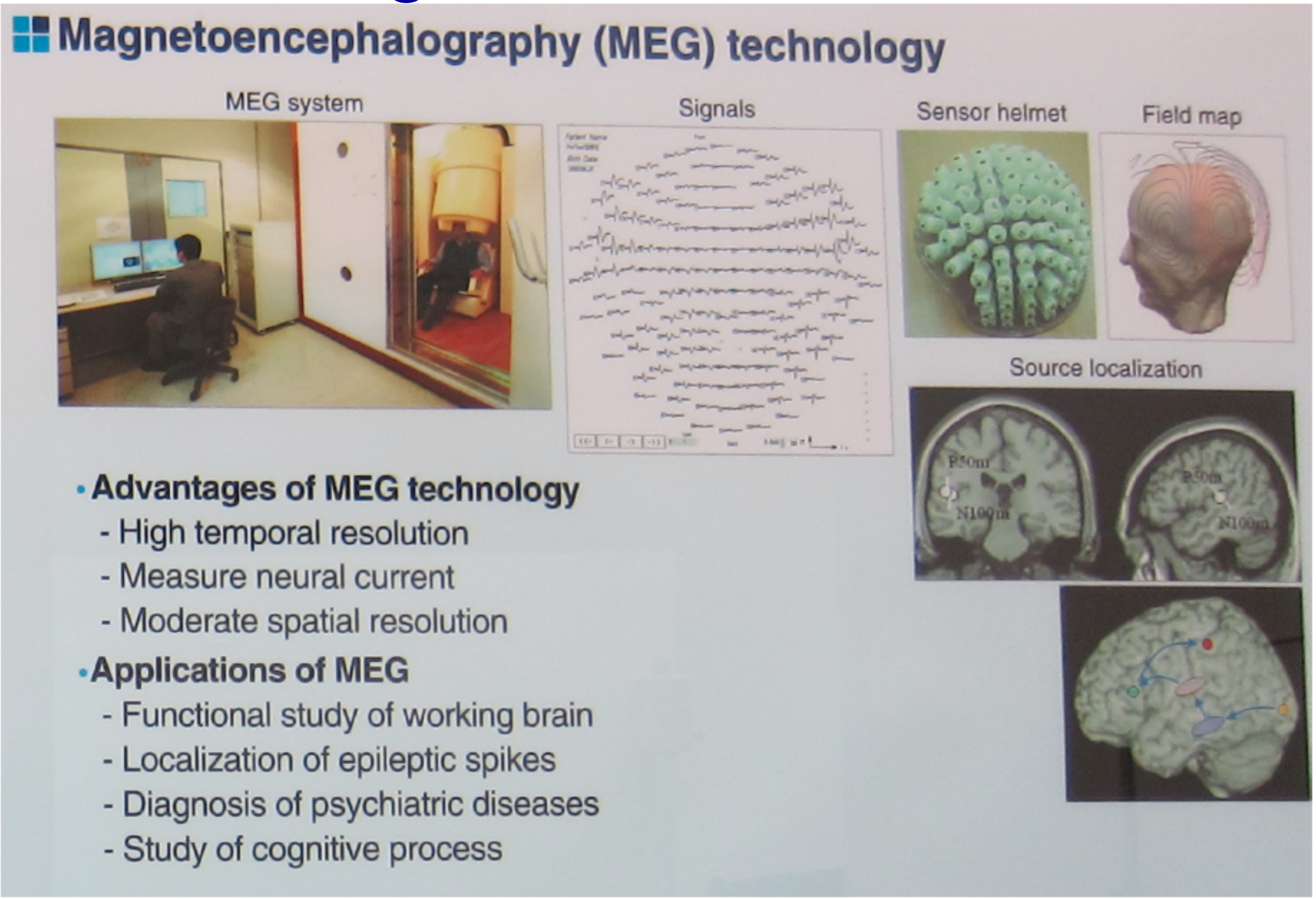
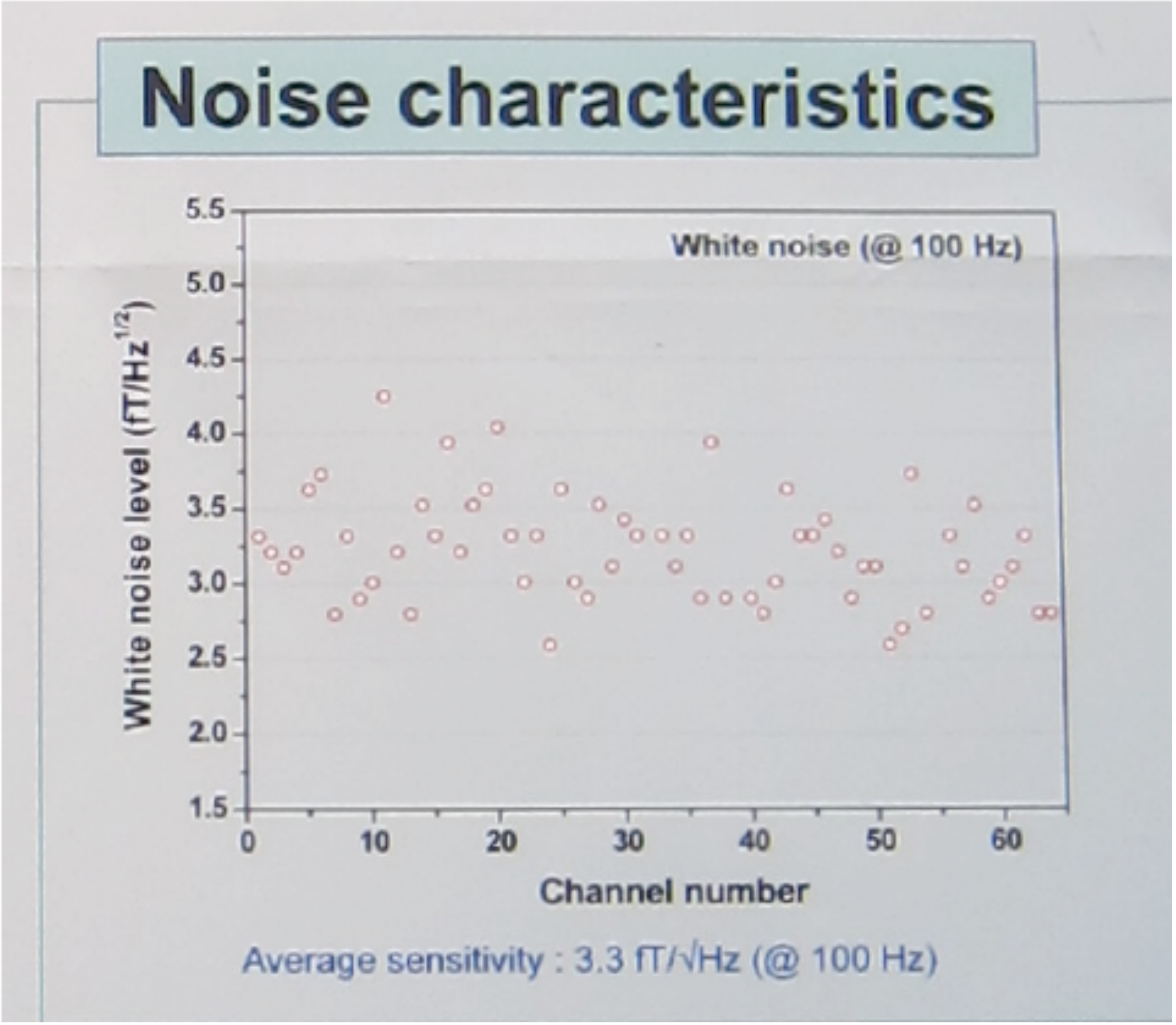


Figure 2. The Magneto encephalography (MEG) technology developed at KRISS. The specially made room reduces the magnetic field noise by about three orders of magnitude at 10 Hz.

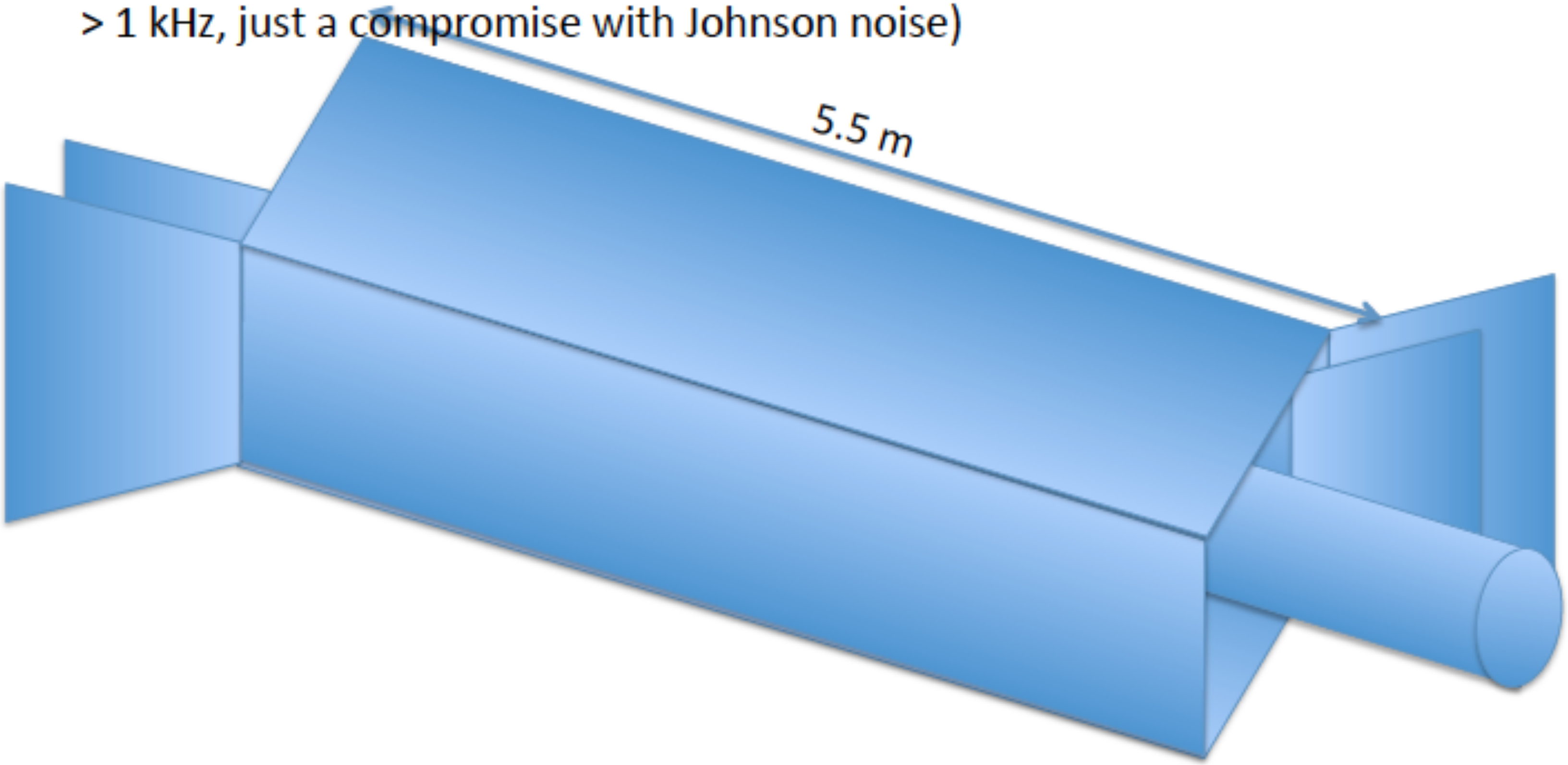
SQUID gradiometers at KRISS



Peter Fierlinger, Garching/Munich

A prototype shield

The continuation of this first project:
- One 'segment' of a shield of a storage ring
- Cuboid shield with exchangeable parts, ID ca. 1 m, OD ca. 1.5-1.6 m, 5-6 t weight
- Contains all features that may be critical for ring shield
- Versatile and a acutally too large compared to ring-segment
- Can be shrinked and significantly simplified to become final ring-segment.
- Fits aluminum shields to demonstrate > 10^7 SF (any large value easily possible at > 1 kHz, just a compromise with Johnson noise)



Feasibility of an all-electric ring

- Two technical reviews have been performed at BNL: Dec 2009, March 2011
- Fermilab thorough review. Val Lebedev considers the concept to be sound.
- First all-electric ring:
  - AGS-analog
  - Ring radius 4.7m
  - Proposed-built 1953-57
  - It worked!

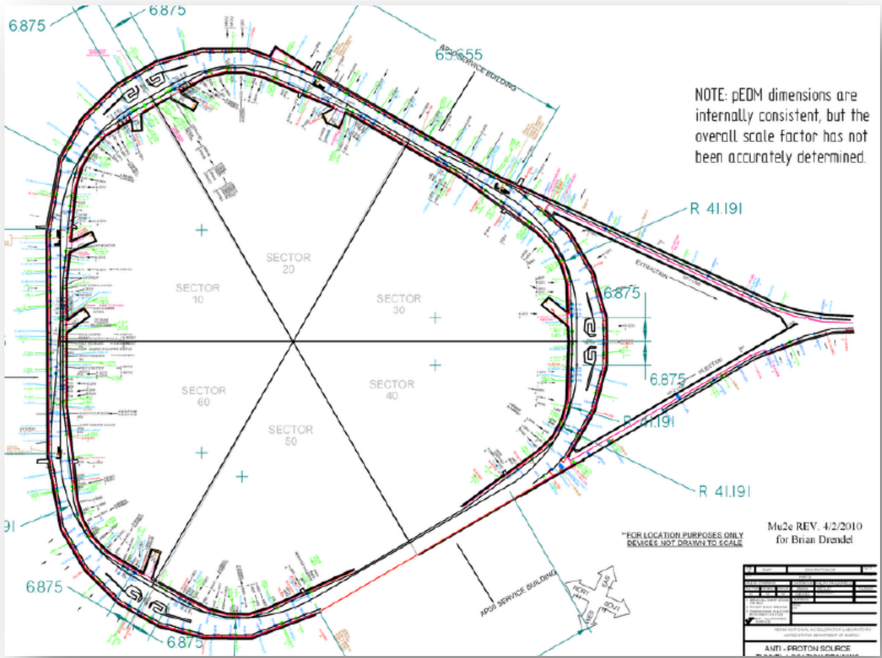
srEDM International Collaboration

- COSY:
  - Strong collaboration with Jülich/Germany continues
  - We've been doing Polarimeter Development, Spin Coherence Time benchmarking, Syst. Errors, Beam/Spin dynamics simulation, etc. for >5 years w/ stored pol. beams.
- JLAB: breakthrough work on large E-Fields
- KOREA:
  - We are forming the EDM group and getting started with system developments.
- ITALY (Ferrara, Frascati,…)
- TURKEY (ITU,…)
- GREECE (Demokritos, …)

Three PhDs already: KVI, Ferrara, ITU

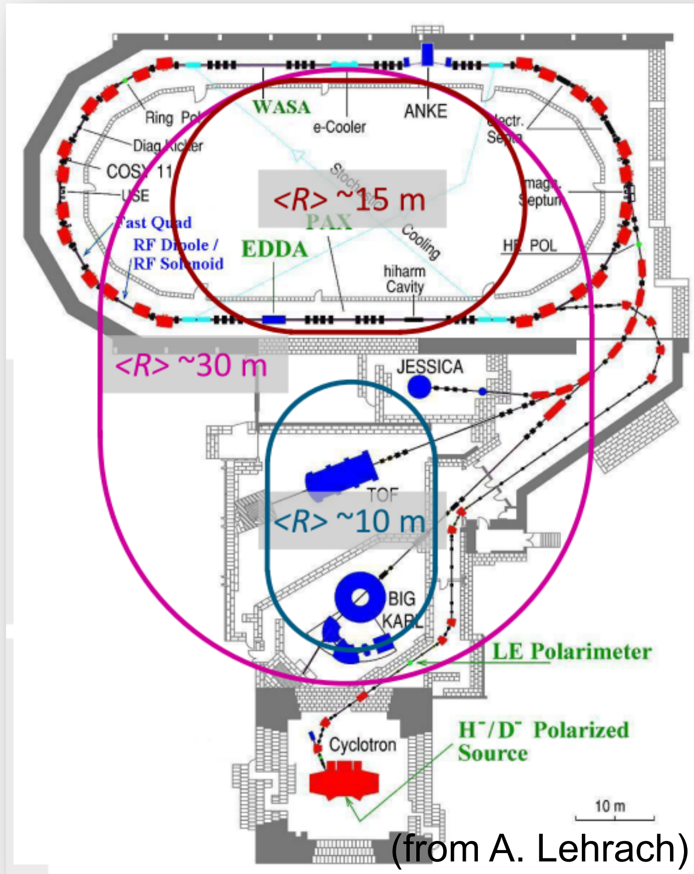
EDMs: Storage ring projects

pEDM in all electric ring at FNAL



CW and CCW propagating beams

Jülich, focus on deuterons, or a combined machine



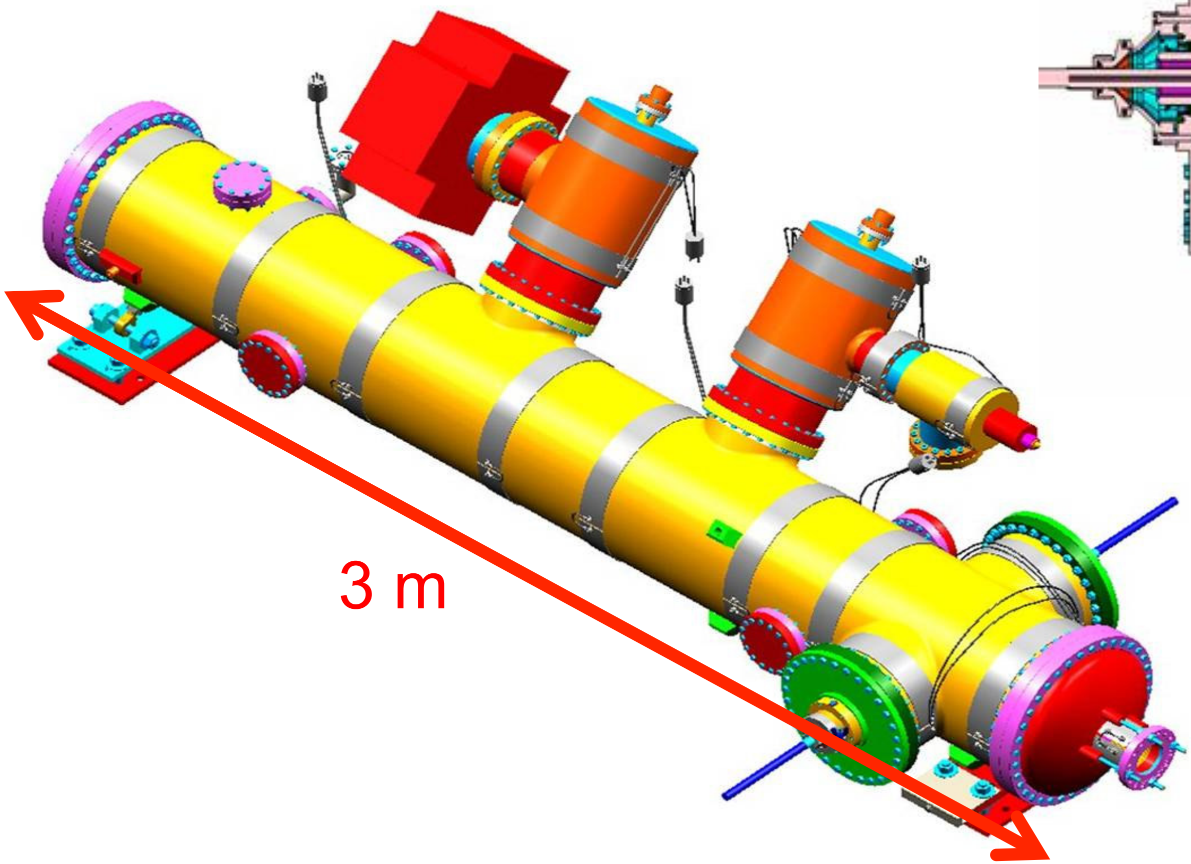
Our proton EDM plan

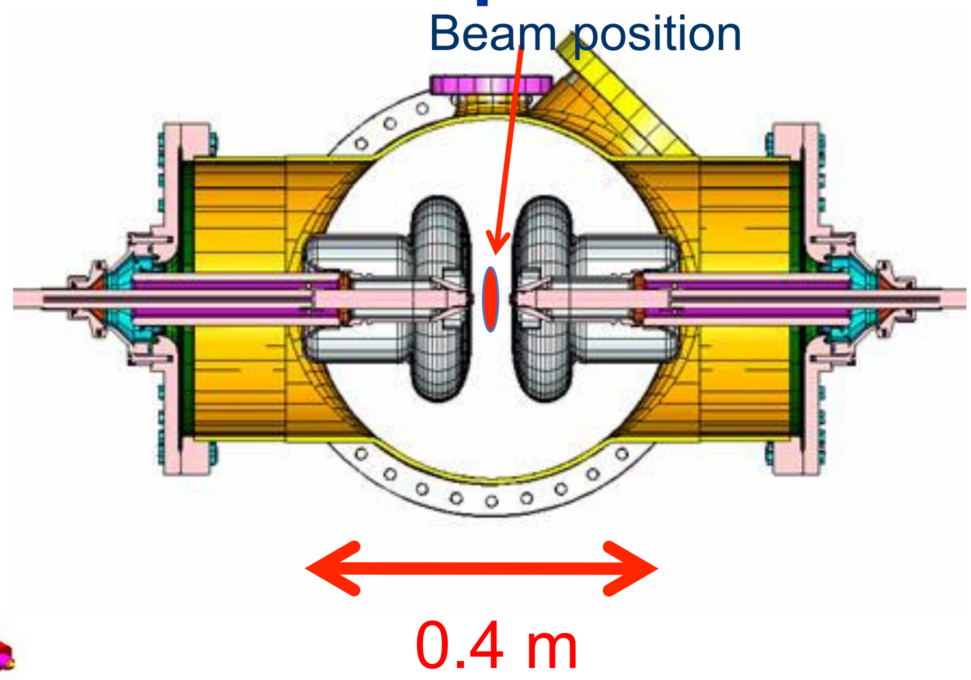
- Develop the following systems (funded by IBS/ Korea, COSY/Germany, applying for NSF support, and seek support from DOE-HEP/NP):
  - SQUID-based BPM prototype, includes B-field shielding (UMass, CAPP/Korea, BNL,…)
  - Polarimeter development (Ind. Univ., CAPP, COSY,…)
  - Electric field prototype (Old Dom. Un. (NSF), JLab,…)
  - Study of systematic errors (BNL, FNAL, Cornell,…)
  - Precision beam and spin dynamics simulation (BNL, CAPP, Cornell, COSY,…)
  - Lattice optimization, beam diagnostics (MSU (NSF),…)

Large Scale Electrodes, New: pEDM electrodes with HPWR

Parameter	Tevatron pbar-p Separators	BNL K-pi Separators	pEDM
Length	2.6m	4.5m	3m
Gap	5cm	10cm	3cm
Height	0.2m	0.4m	0.2m
Number	24	2	10^2
Max. HV	±180KV	±200KV	±150KV

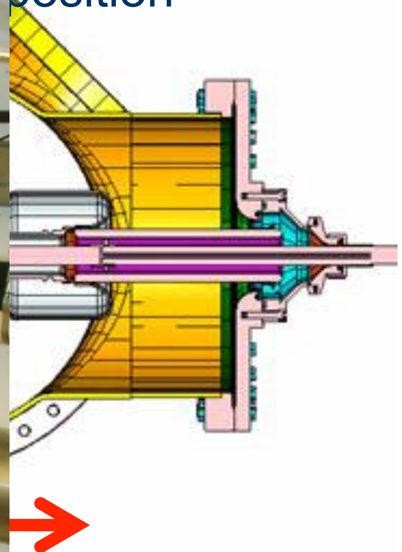
E-field plate module: Similar to the (26) FNAL Tevatron ES-separators





E-field plate module: Similar to the (26) FNAL Tevatron ES-separators

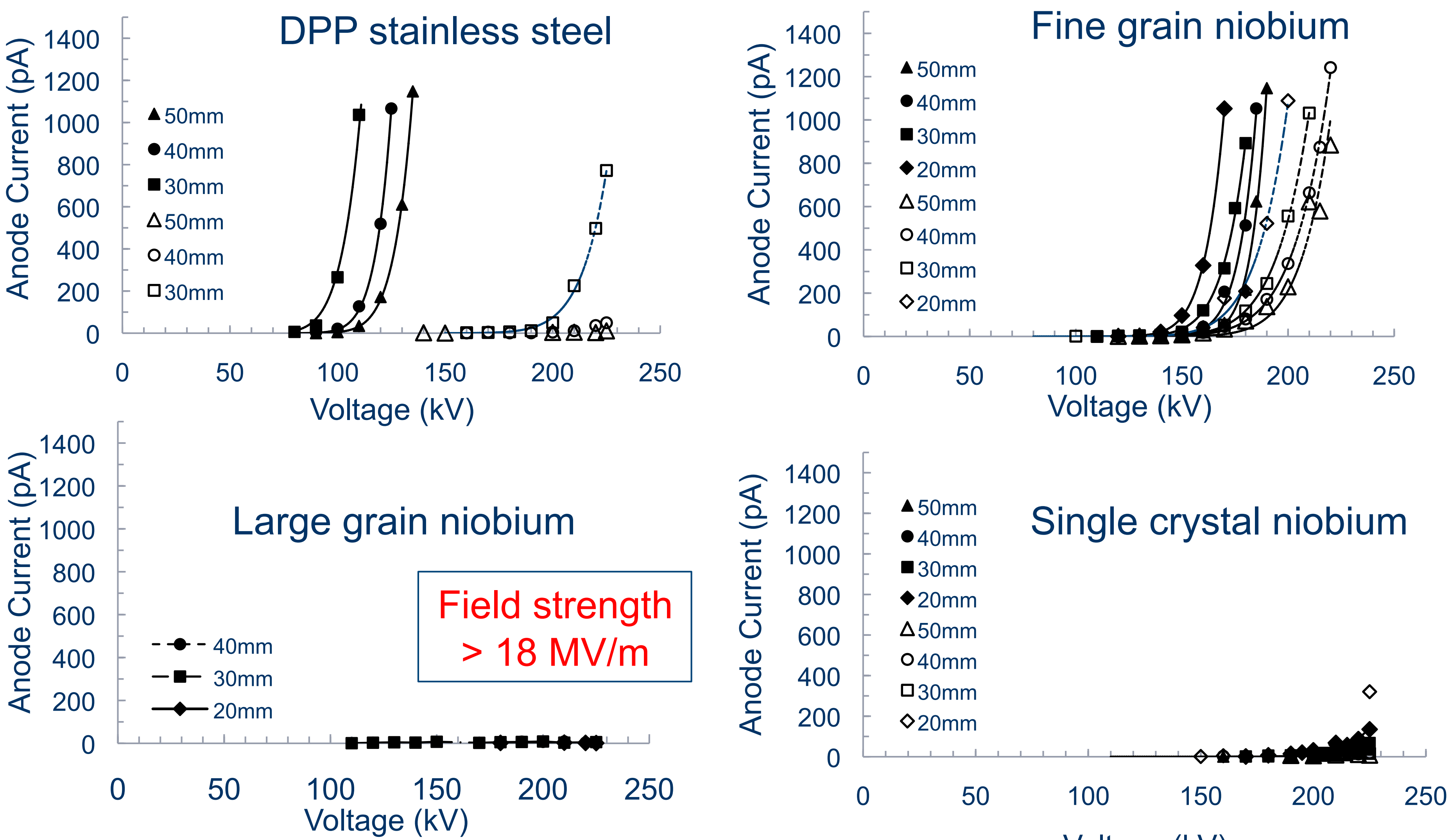
position



Field Emission from Niobium

Work of M. BastaniNejad
Phys. Rev. ST Accel. Beams, 15, 083502 (2012)

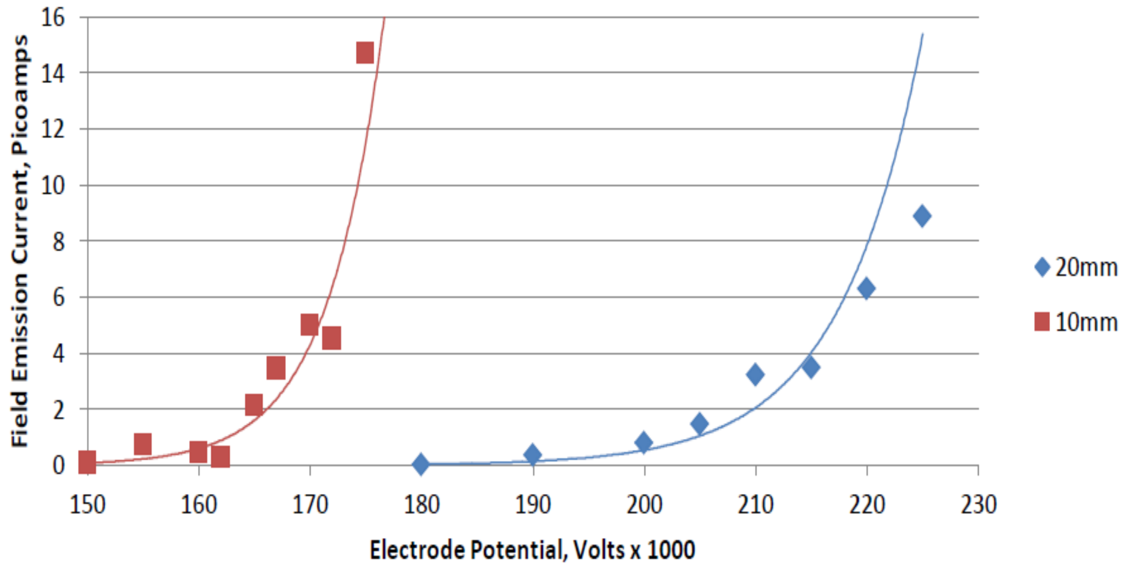
Buffer chemical polish: less time consuming than diamond paste polishing



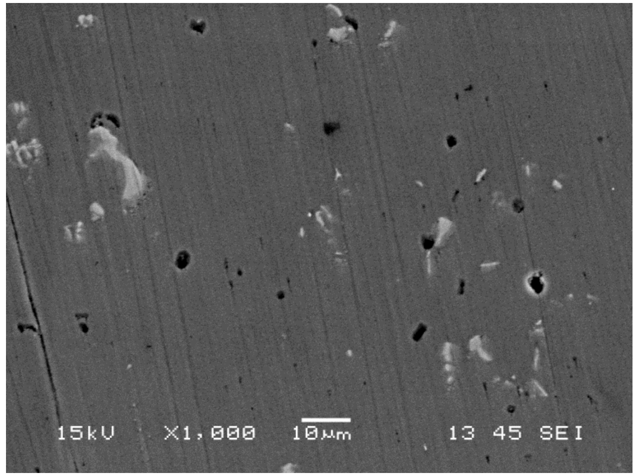
Conventional High Voltage processing: solid data points
After Krypton Processing: open data points

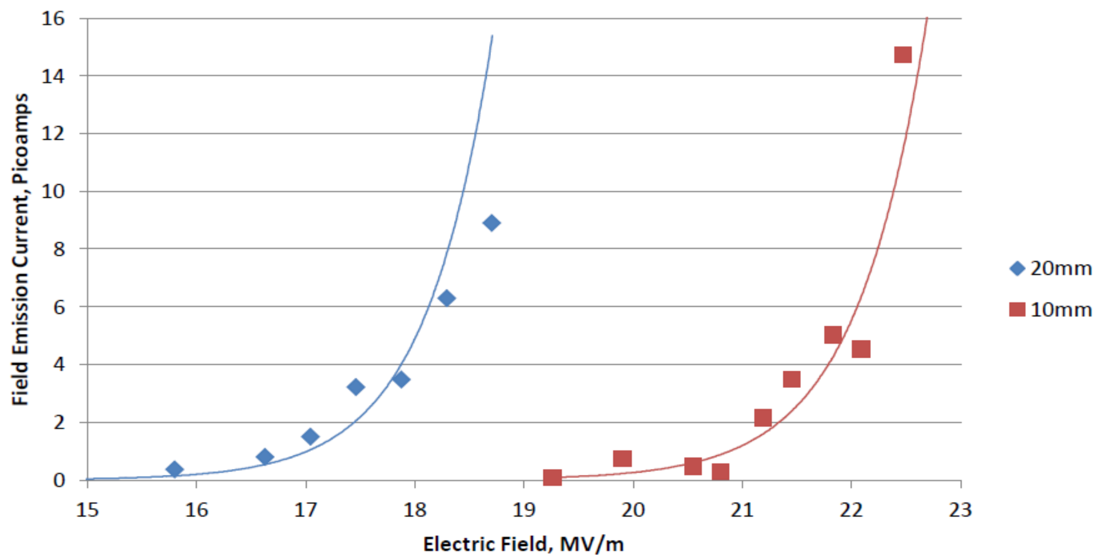
What about TiN-coated Aluminum?

No measureable field emission at 225 kV for gaps > 40 mm, happy at high gradient

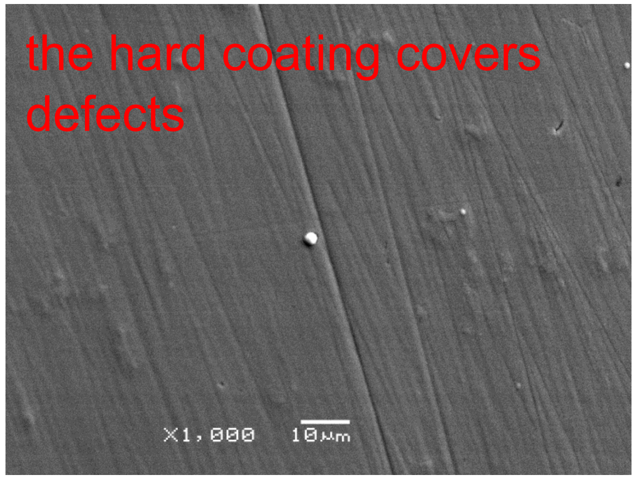


Bare Al



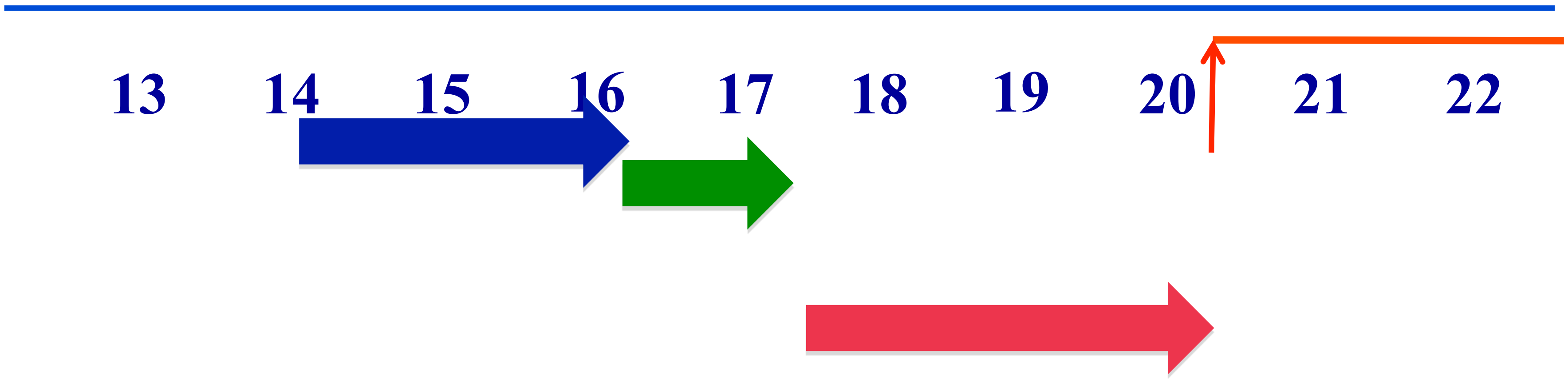


TiN-coated Al



Work of Md. A. Mamun and E. Forman

Technically driven pEDM timeline



- Two years system development
- One year final ring design
- Three years beam-line construction and installation

Physics strength comparison (Marciano)

System	Current limit [e·cm]	Future goal	Neutron equivalent
Neutron	$<1.6\times10^{-26}$	$\sim10^{-28}$	10^{-28}
^{199}Hg atom	$<3\times10^{-29}$	$<10^{-29}$	10^{-25}-10^{-26}
^{129}Xe atom	$<6\times10^{-27}$	$\sim10^{-29}$-10^{-31}	10^{-25}-10^{-27}
Deuteron nucleus		$\sim10^{-29}$	3×10^{-29}-5×10^{-31}
Proton nucleus	$<7\times10^{-25}$	$\sim10^{-29}$-10^{-30}	10^{-29}-10^{-30}

Physics reach of magic pEDM (Marciano)

- Currently: $\bar{\theta} \leq 10^{-10}$, Sensitivity with pEDM: $\bar{\theta} < 0.3\times10^{-13}$

- **Sensitivity to new contact interaction: 3000 TeV**

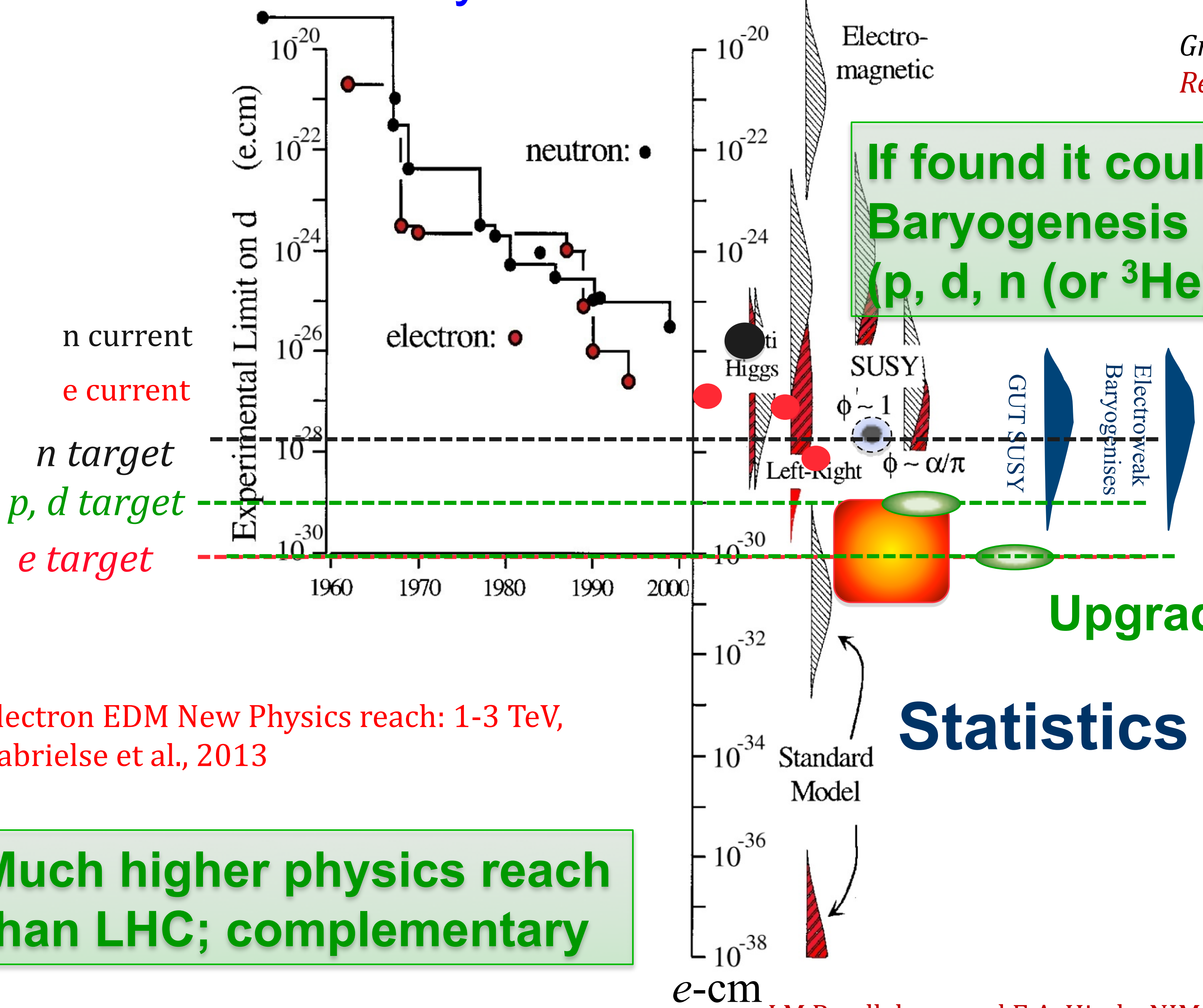
- **Sensitivity to SUSY-type new Physics:**

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

The proton EDM at 10^{-29}e·cm has a reach of >300TeV or, if new physics exists at the LHC scale, $\delta<10^{-7}$-10^{-6} rad CP-violating phase; an unprecedented sensitivity level.

The deuteron EDM sensitivity is similar.

Sensitivity to Rule on Several New Models



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

Upgrade?

Statistics limited

Electron EDM New Physics reach: 1-3 TeV, Gabrielse et al., 2013

Much higher physics reach than LHC; complementary

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

Summary

- The storage ring proton EDM has been developed. The breakthrough? Statistics!
- Best sensitivity hadronic EDM method.
- Expecting the HEPAP endorsement of the P5 report: May 22.
- Proton EDM: Probe EW-Baryogenesis, high-mass scale New Physics at $\sim 10^3$ TeV.