Storage Ring Electric Dipole Moment (EDM) Experiment

William Morse

BNL

Storage Ring EDM Collaboration

21 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
- University College, London/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 Groningen, KVI, Groningen/The Netherlands
- University of Massachusetts, Amherst, Massachusetts/USA
- Michigan State University, East Lansing, Michigan/USA
- Dipartimento di Fisica, Universita' "Tor Vergata" and Sezione INFN, Rome/Italy
- University of Patras, Patras/Greece
- Regis University, Denver, Colorado/USA
- CEA, Saclay, Paris/France
- University of Virginia, Virginia/USA

Spin Precession

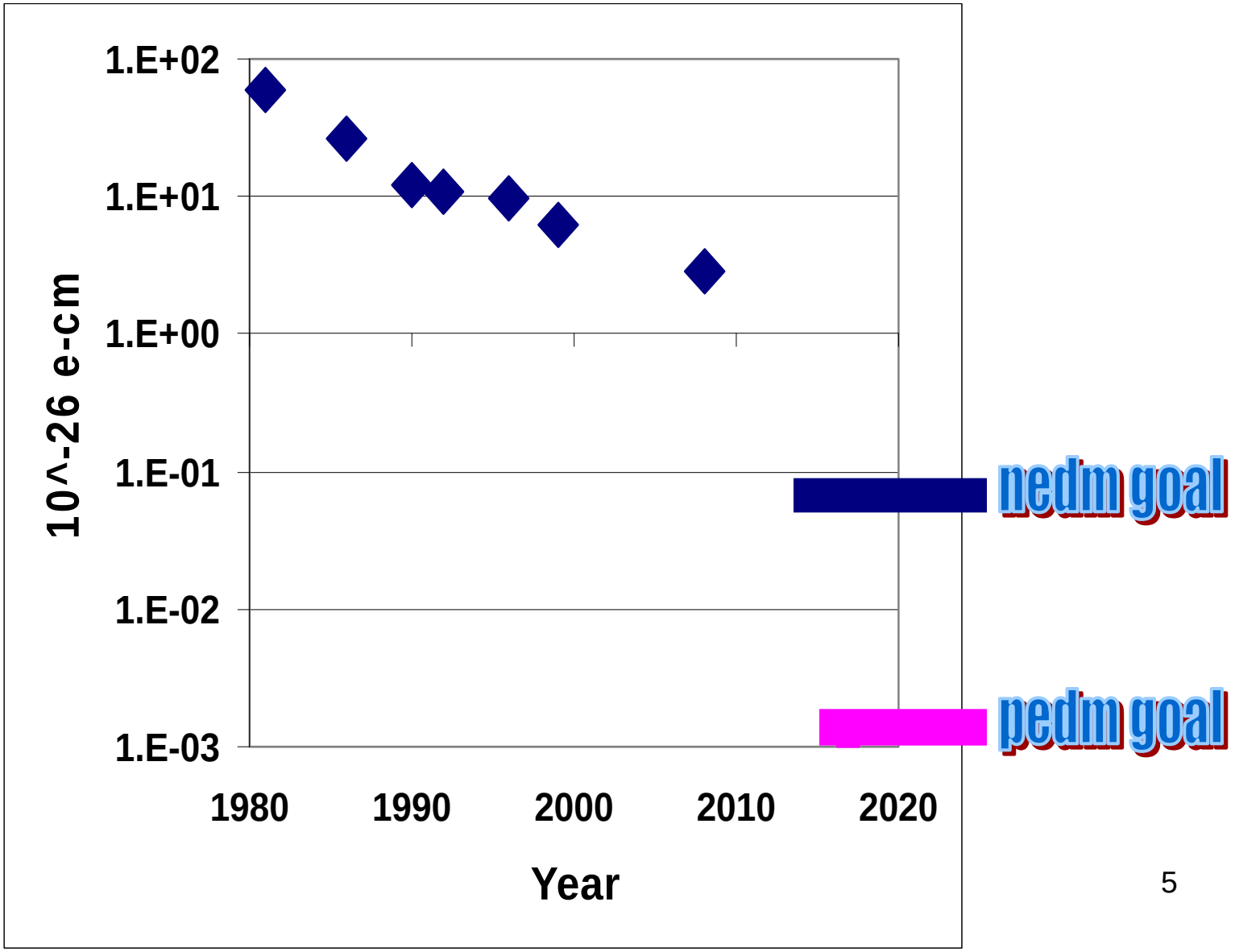
$$\frac{d\vec{S}}{dt^*} = \vec{\mu} \times \vec{B}^* + \vec{d} \times \vec{E}^*$$

permanent mdm and edm aligned along spin

EDM

- Permanent edm violates P and T symmetries.
- Field started by Norman Ramsey et al. in the 1950s.
- Sensitive searches have been done so far only on neutral systems: neutron, atoms, etc.

nedm limits over last 30 years



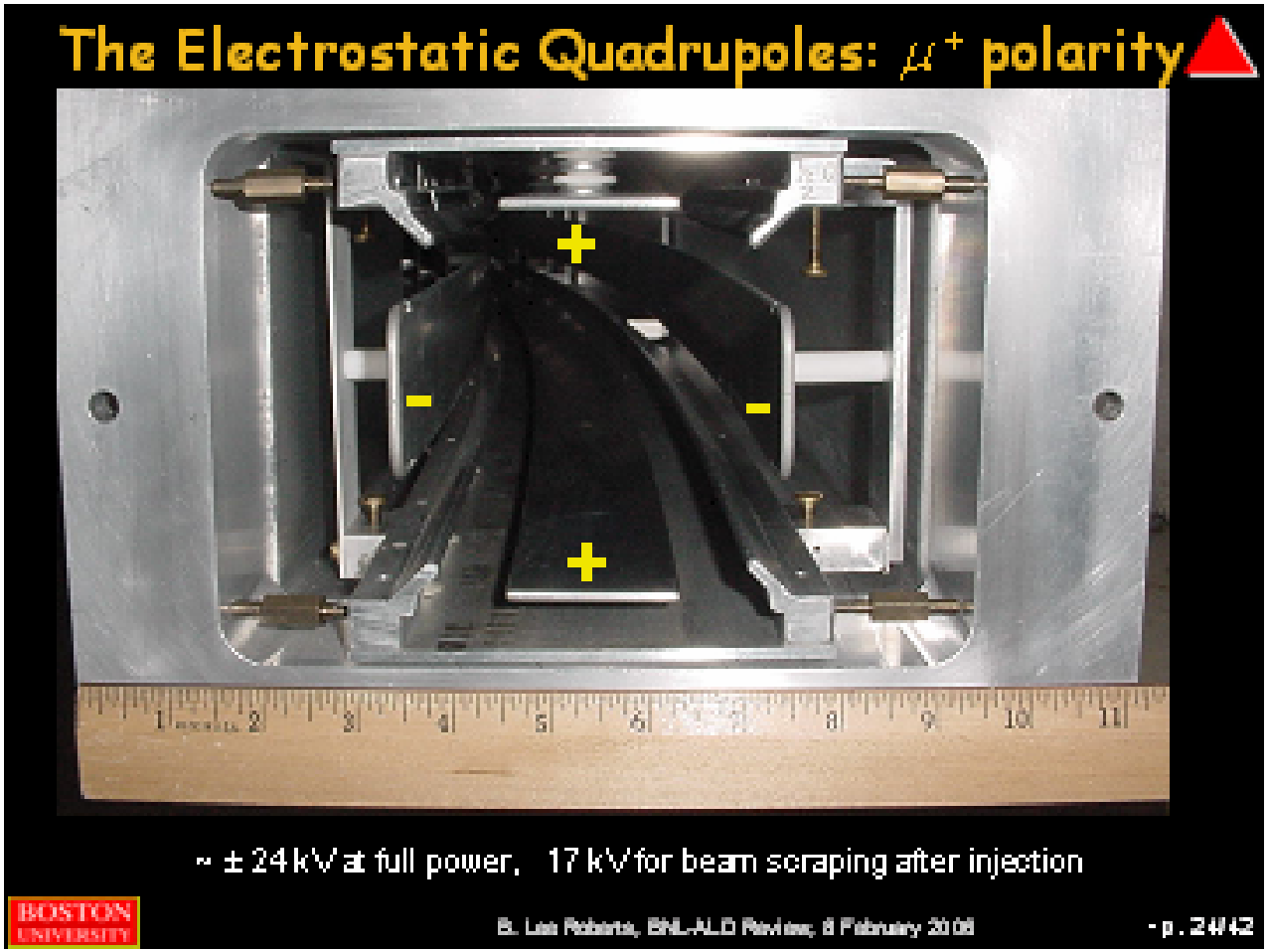
Idea Came From Our E821 Exp

- MDM $\vec{\mu} = \frac{ge\vec{S}}{2mc} \quad a = \frac{g-2}{2}$

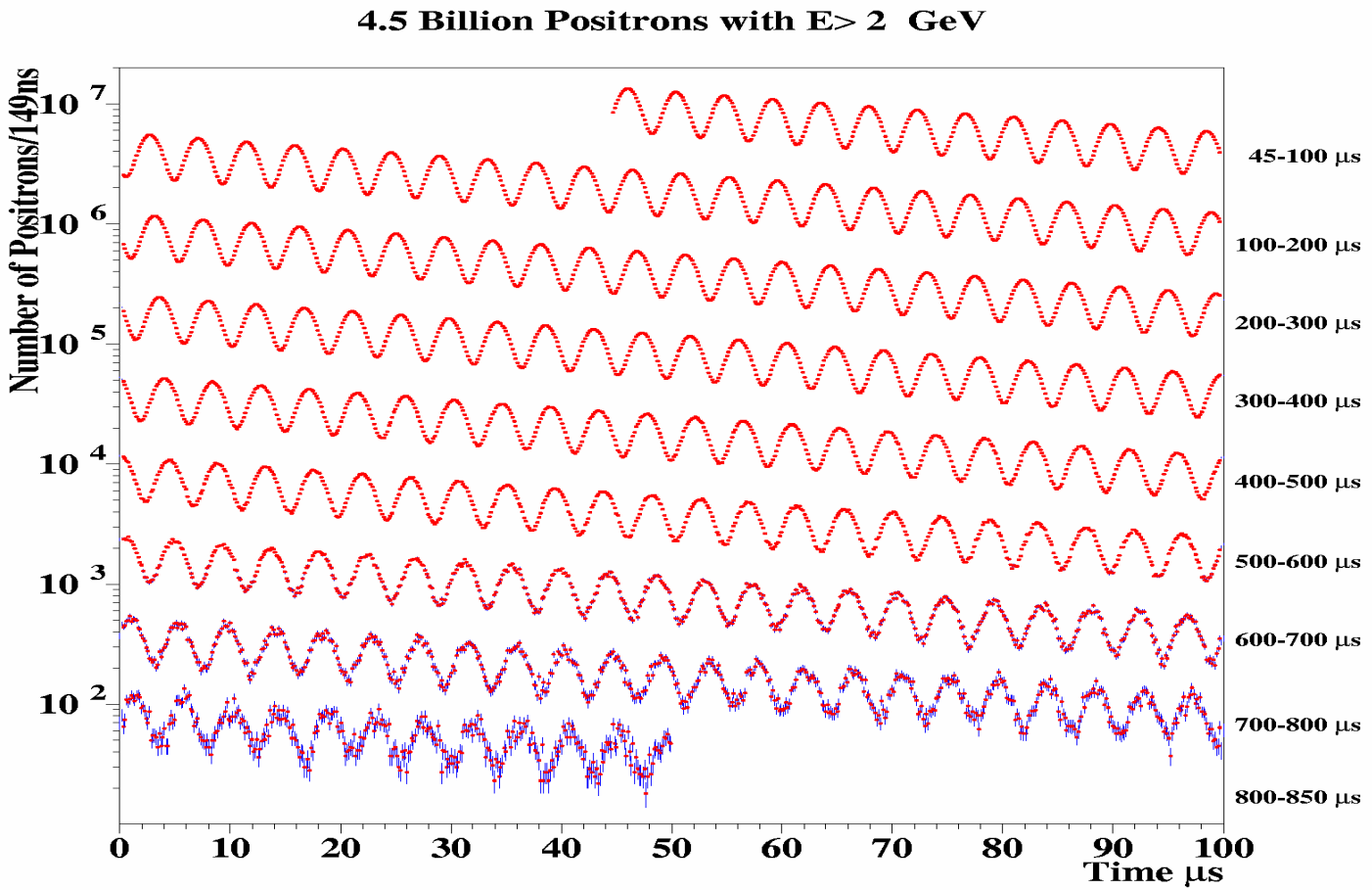
$$\frac{d\left(\hat{\beta} \bullet \vec{S}\right)}{dt} = \frac{e}{mc}\vec{S}_T \bullet \left[a\hat{\beta} \times \vec{B} + \left(\frac{g\beta}{2} - \frac{1}{\beta} \right) \vec{E} \right]$$

Muon g-2 E821 ran at magic p = 3.1GeV/c

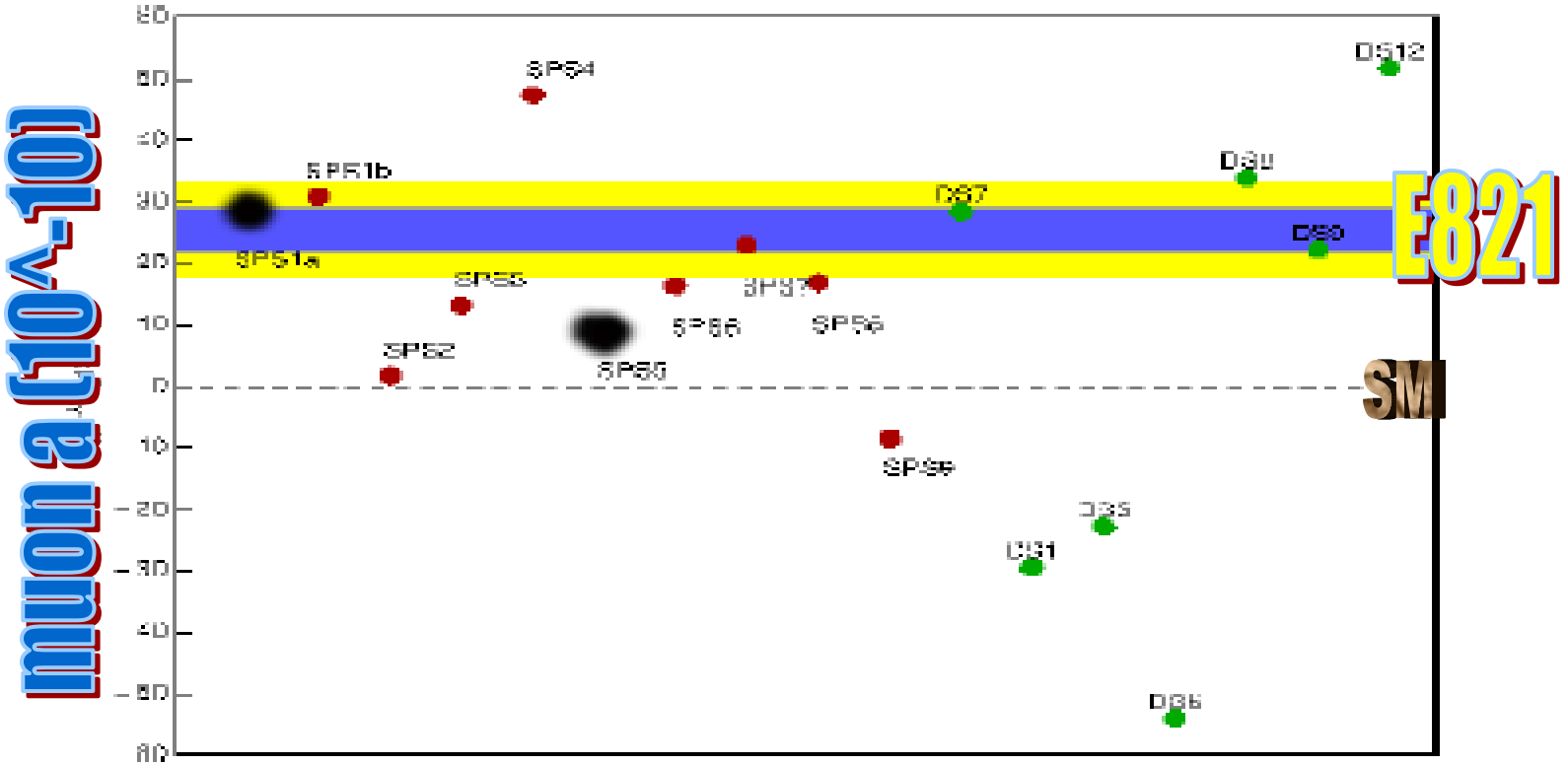
BNL E821 Electric Quadrupoles



E821 Spin Precession Data



Precision vs. Energy Frontier
SUSY Benchmarks



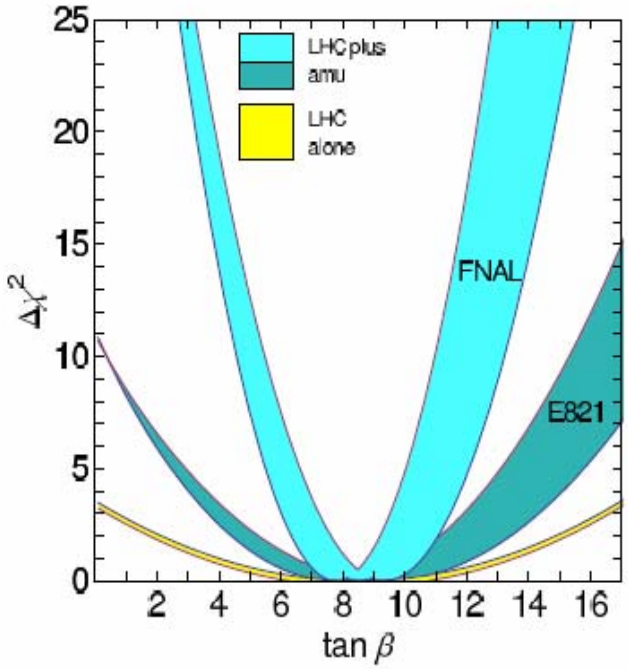
SPS benchmark points

LHC Inverse Problem ($300fb^{-1}$)

can't be distinguished at LHC
[Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]

Dominik Stockinger 3/18/11

EDM tells us about CP violation due to the New Physics!



$\tan\beta = \frac{v_2}{v_1}$
central for understanding EWSB

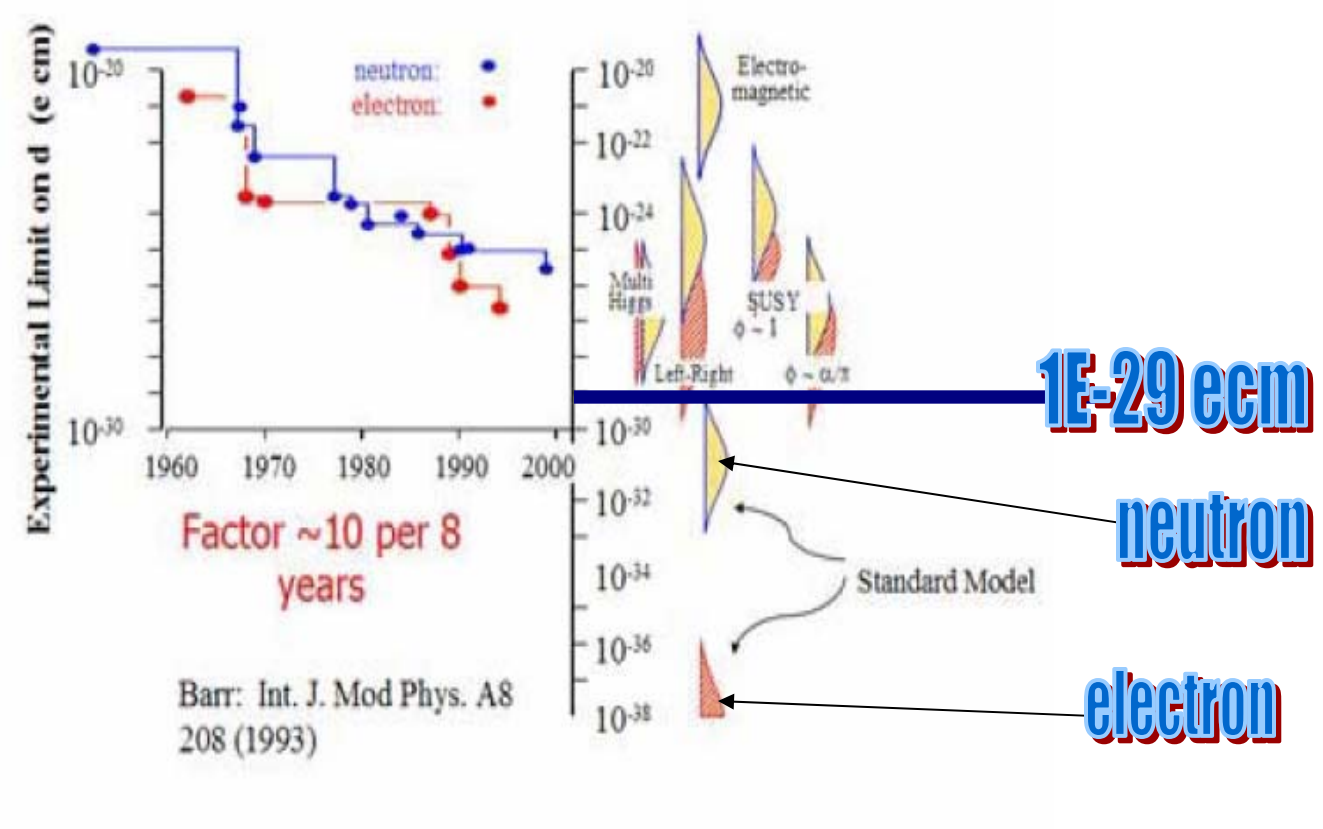
LHC: $(\tan\beta)^{\mathrm{LHC,masses}} = 10 \pm 4.5$ bad
[Sfitter: Lafaye, Plehn, Rauch, Zerwas '08, assume SPS1a]

a_μ improves $\tan\beta$ considerably

vision: test universality of $\tan\beta$, like for $\cos\theta_W = \frac{M_W}{M_Z}$ in the SM:

$$(t_\beta)^{a_\mu} = (t_\beta)^{\mathrm{LHC,masses}} = (t_\beta)^{H} = (t_\beta)^{b}?$$

EDM SM vs. New Physics



eedm deduced from atom, molecule exp + theory

Dedicated EDM Storage Ring Exp.

- BNL E821: $d_\mu < 1.8 \times 10^{-19}$ *ecm*.
- Yannis started thinking about a dedicated muon edm experiment in the mid-1990s.
- SM gives effectively nil Baryon Asymmetry of the Universe – so *new* T violating physics is needed!

Spin Precession in Storage Ring

MDM $$\frac{d\left(\hat{\beta}\bullet\vec{S}\right)}{dt}=\frac{e}{mc}\vec{S}_T\bullet\left[a\hat{\beta}\times\vec{B}+\left(\frac{g\beta}{2}-\frac{1}{\beta}\right)\vec{E}\right]\approx 0$$

EDM $$\frac{d\vec{S}}{dt}=\vec{d}\times\left(\vec{E}+\vec{\beta}\times\vec{B}\right)$$

edm precesses spin vertically

Freeze MDM Precession

- Radial Bending Electric Field = $\dfrac{aBc\beta\gamma^2}{1-a\beta^2\gamma^2}$

Part	a	τ (s)	$K.E.$ (GeV)	E_R (MV/m)	B_V (T)	$\varepsilon_{stat}/10^7 s$ (ecm)
muon	10^{-3}	$\approx 10^{-5}$	0.5	2	0.25	10^{-24}
D	-0.143	$\approx 10^{3}$	0.25	15	0.5	10^{-29}
P	1.793	$\approx 10^{3}$	0.23	15	0	10^{-29}

P Magic Energy is Perfect!

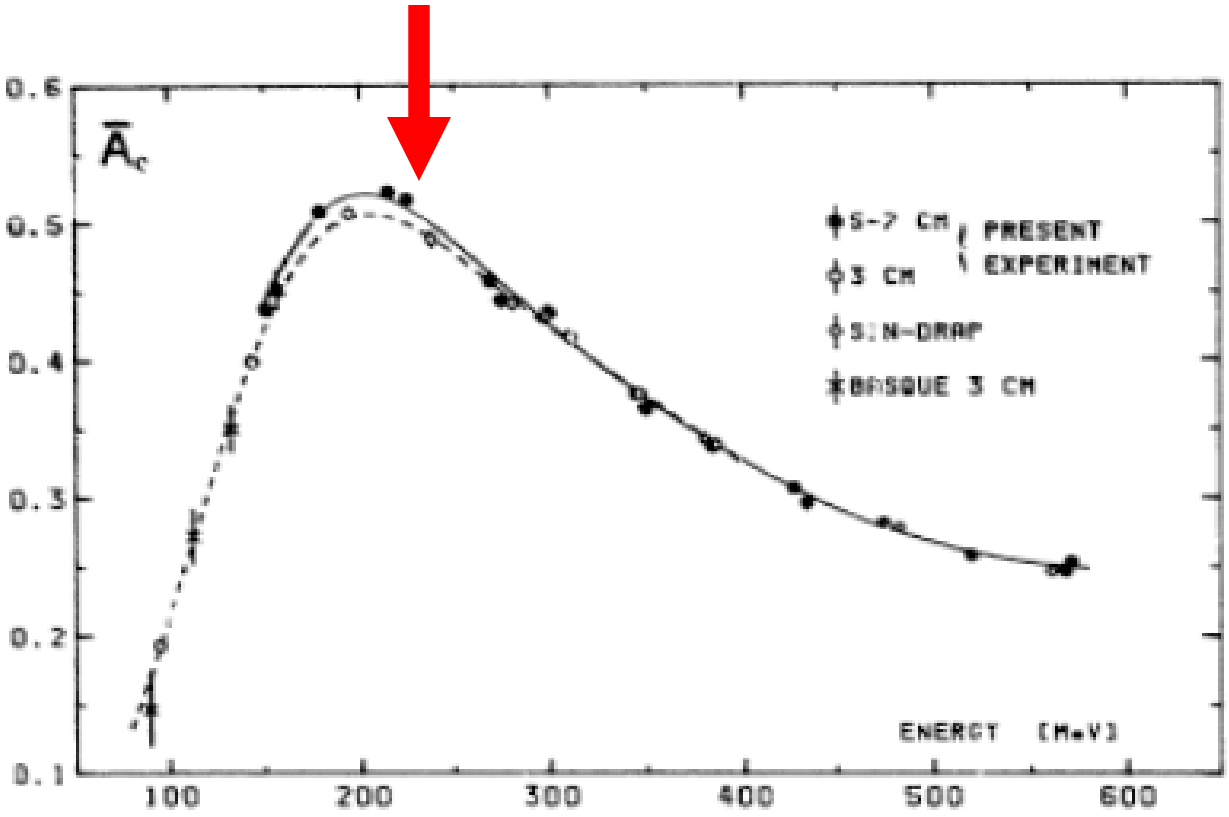


Fig. 4. Angle-averaged effective analyzing power. Curves show our fits. Points are the data included in the fits. Errors are statistical only

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

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.

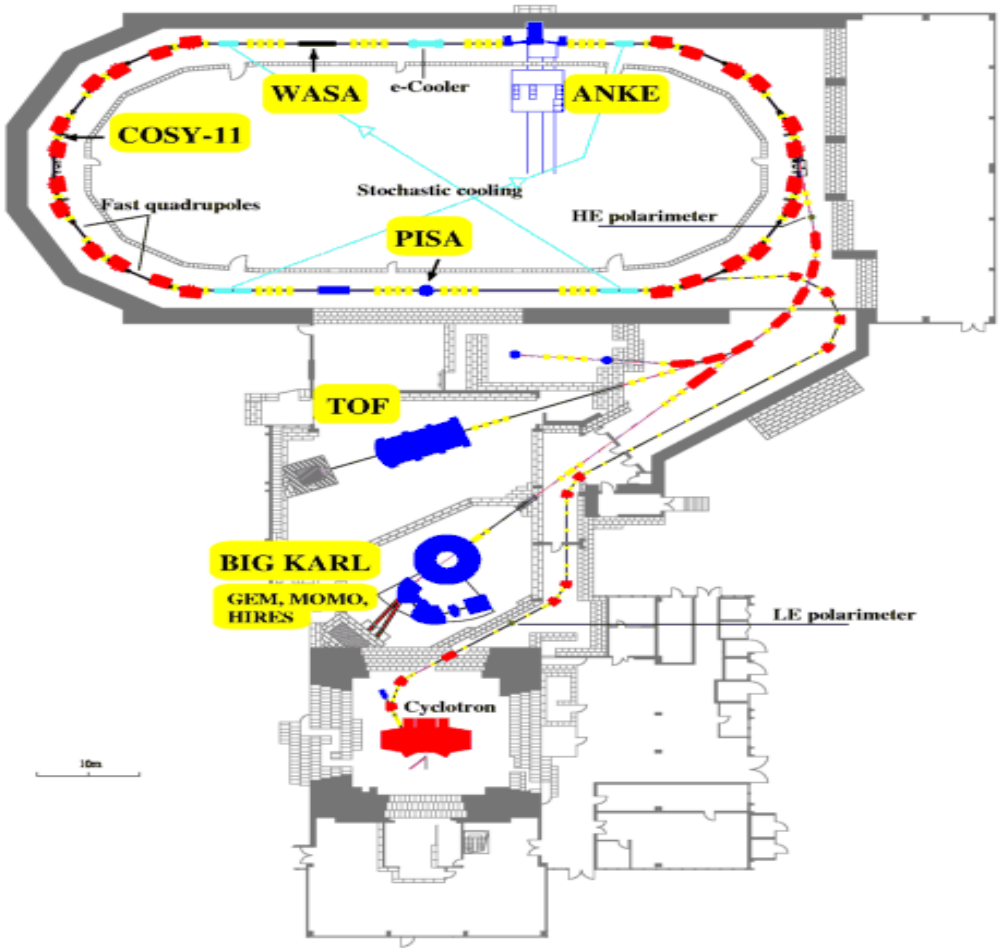
PEDM R&D Teamleaders

- E/B – W.M.
- BPM – David Kawall, U. Mass.
- Polarimetry – Ed Stephenson, I.U.
- COSY Simulation – Alfredo Luccio, BNL
- PEDM Lattice – Richard Talman, CU
- HSCT COSY Tests – Ed Stephenson, I.U.
- First HSCT Run January 2011 …..

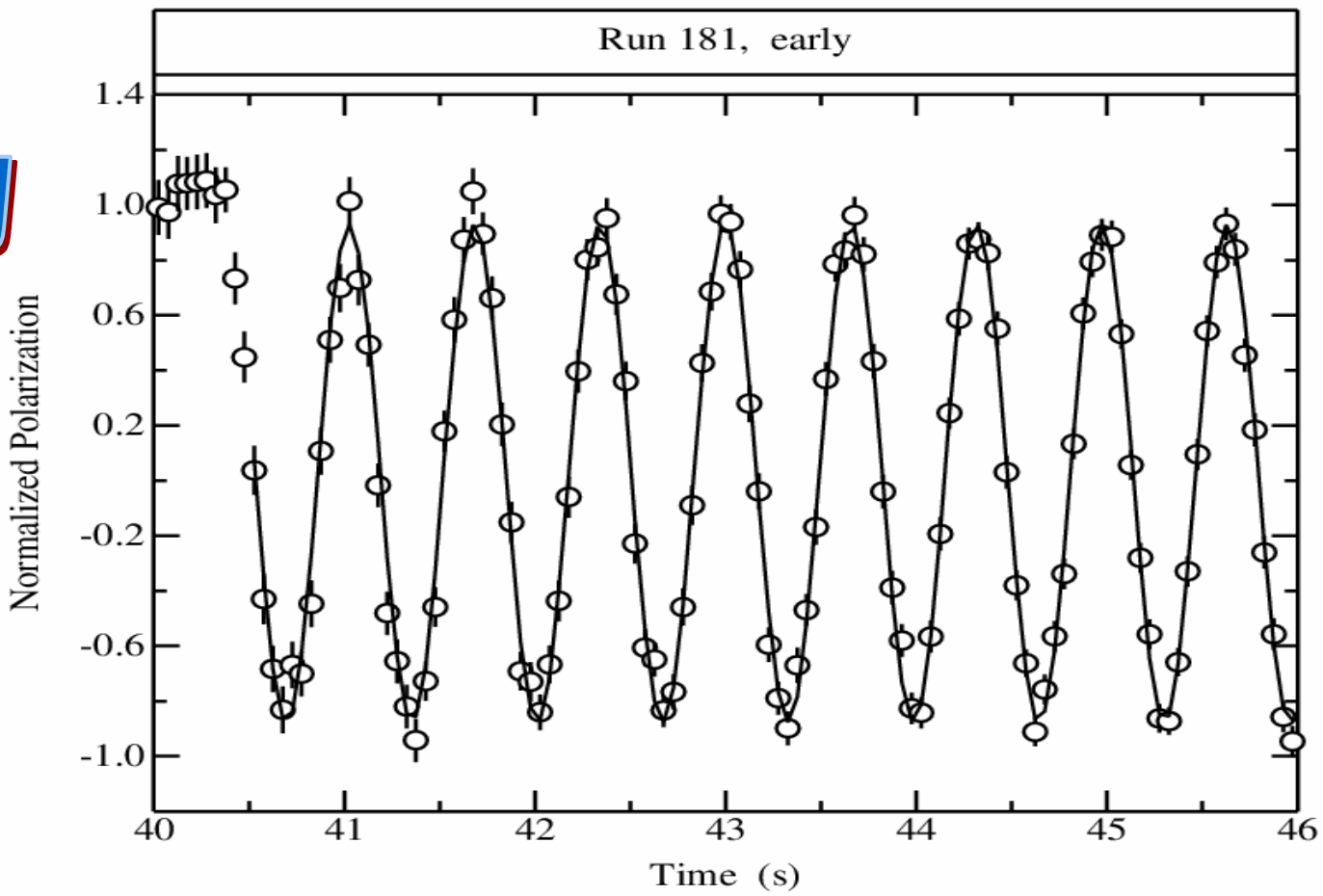
Spin Coherence Time with Horizontally Polarized Beams

- Goal: $\approx 10^3 s$
- HSCT $\propto a(dp/p)^{-2} + b\theta_x^{-2} + c\theta_y^{-2} + \ldots.$
- Add sextupole field $\propto x^2 - y^2$
- R&D plan to show this works at COSY, Julich, Germany with three runs.
- E.S. gave a CAD seminar last Friday on results of the first run.

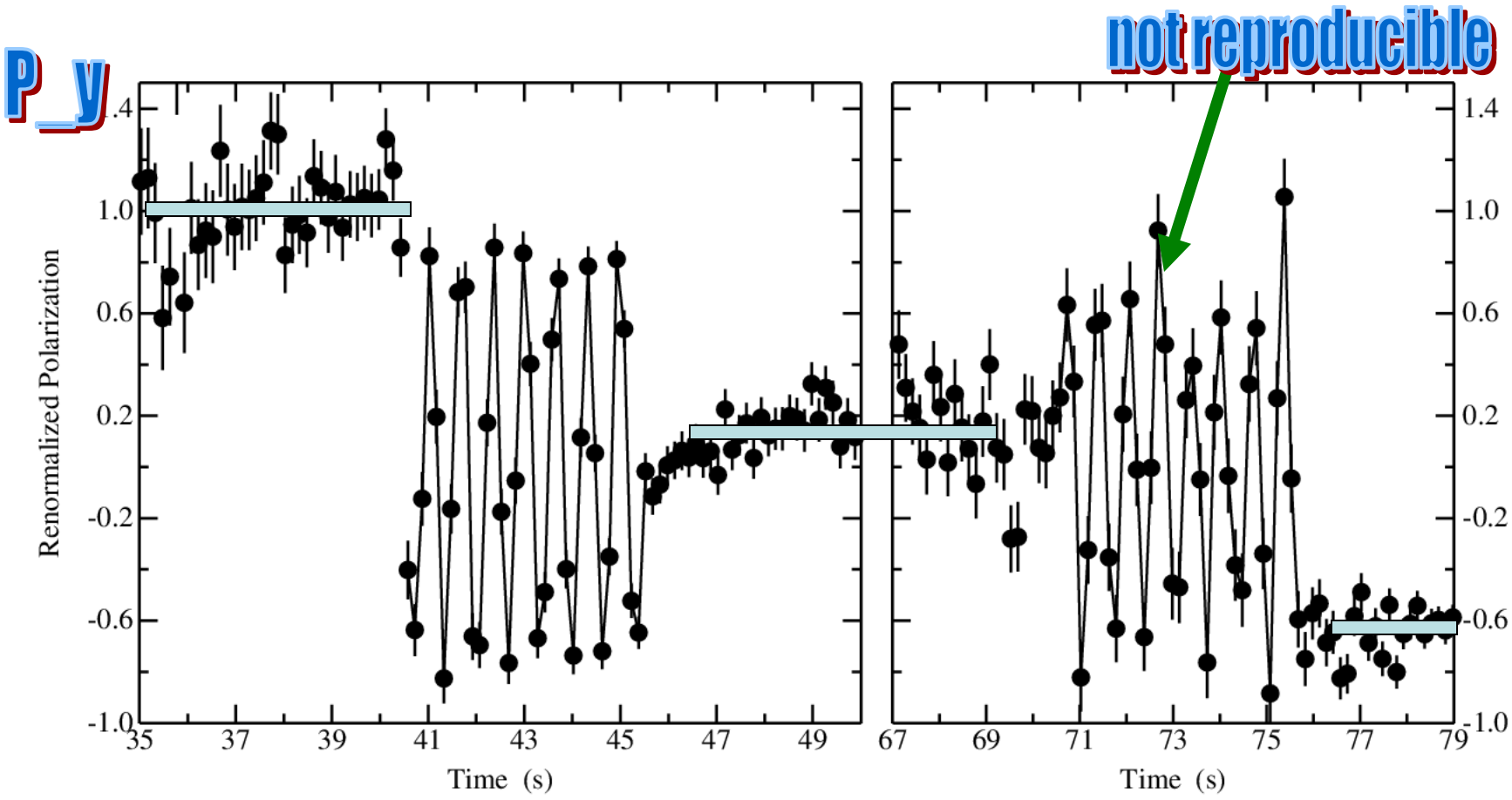
Cooler-Synchotron, Julich, Germany SREDM Collaborating Institution



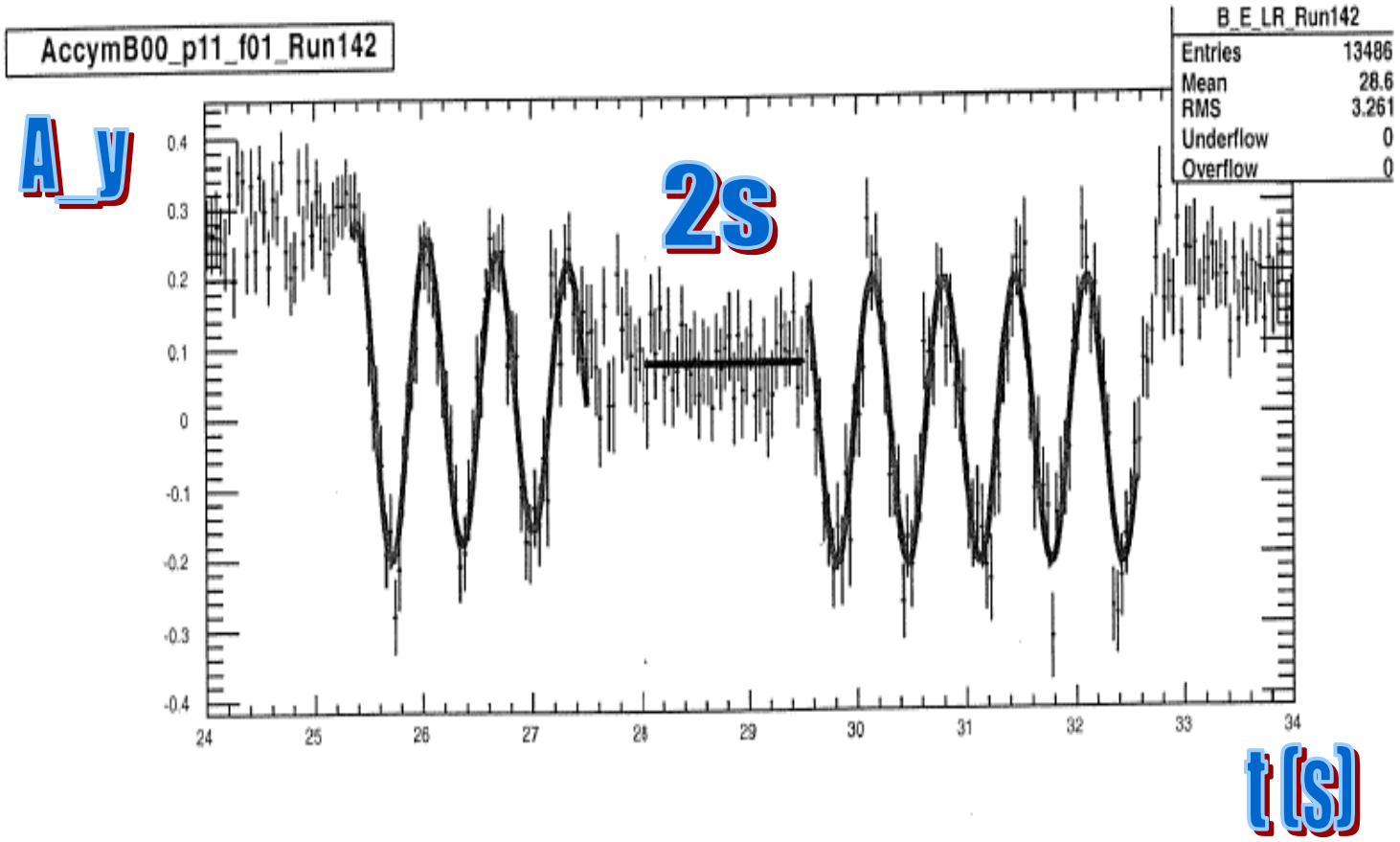
Turn on RF Solenoid at Resonance Frequency 871,434 Hz



Horizontal Plane



For <10s (10M cycles) the plot is always reproducible.



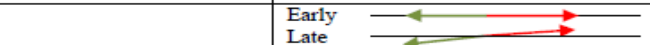
COSY PAC

- Ed presented first HSCT run result to COSY PAC last March.
- Desmond Barber, COSY PAC HSCT chairman: “This is very good work!”
- Second run for next winter approved.
- Improve the DAQ so that we can measure HSCT directly.
- Start playing with the sextupoles, etc.

Systematics Checks

- “EDM = Extremely Difficult Measurement”
- from 2010 BNL Colloquium on nedm expts by Martin Cooper.
- CW/ CCW (like time reversal) – every fill.
- S●P = ±1/2 (parity) – every fill.
- Fill 1000s and 200s long (edm effect reduced by factor of 5) – every other fill.
- Transverse spin (zero edm effect) 10% of measurement time.

Systematic Errors

Effect	Comment	Remediation	Comment
EDM signal.	Early to late change in vertical polarization		Early  Late The EDM signal is the difference between the EDM effects in the counter rotating (CR) beams.
Radial B-field, dipole.	The only first order systematic error	CW/CCW beam storage. Vertical tune modulation. Observe induced radial magnetic field at the tune modulation frequency.	Beam position monitors (BPM) magnetometers (based on existing technology) are used to pickup the signal. Other frequency signals are also on for calibration purposes.
Radial B-field, sextupole.	We will spot-check around the ring using a magnetometer but we will also check for it using stored protons.	Store beam for 200s instead of 1000s for regular runs every other run.	Once we know its level we can cancel it. It's expected to be changing very slowly.
Geometrical phases, a.k.a. Berry's phase, etc., a major systematic error in neutron EDM experiments.	In the "magic" momentum proton EDM experiment this effect is expected to be negligible, but we will be checking it.	Run with the proton spin transversely polarized instead of the longitudinal for regular runs. The systematic error is enhanced by two to three orders of magnitude.	We expect to use 10% of the runs to check for it and for checking malfunctions creating longitudinal magnetic fields. Alternatively we could include a couple of bunches in the regular runs having transverse spin direction.
Vertical E-fields balanced by the force of gravity.	The EDM-like signal is due to v×**E** radial B-field in the proton's rest frame. This is a small effect but at 10^{-29} e·cm we are just sensitive to it.	Early  Late The EDM-like signal has opposite sign for the CR beams due to v×**E** nature of the effect.	Since we'll take the difference between the signals of the CR beams, the effect will cancel. The cancellation needs to be good at the 10% level, whereas we'll know it much better.
Vertical E-field due to possible vertical misalignment of the RF cavity	It's only a problem if the particles lose energy, e.g. due to longitudinal impedance around the ring. Otherwise the average vertical E-field seen by a particle is zero (otherwise it would accelerate).	We place a lingitudinal impedance limit of 10KΩ for the ring. We will be enhancing the impedance when aligning the RF-cavity.	Energy loss is a time reversal violating effect and therefore can create a systematic error. Using the FNAL electro-static separator study we believe we can minimize the longitudinal beam impedance well below the 10KΩ limit.
Vertically offset quadrupole could cause vertical beam oscillation at the tune modulation frequency.	The closed orbits of the CR beams are the same in an all-electric ring. The CR beams have opposite magnetic fields but a very small effect could still be present.	We will be using button BPMs developed by the NSLS II group to sense the vertical beam oscillation from the CR beams and minimize it using beam-based alignment.	The button BPMs are sensitive to the beam E-fields and those from the CR beams will add, while their magnetic fields will subtract.
Polarimeter systematic errors	Those are mainly related to the beam drifting on the target from early to late times. Due to non-linearities they can induce systematic errors.	Storing positive and negative helicity bunches in the same direction plus using a combination of observables to enhance the systematic errors due to non-linearities.	The polarimeter systematic error work at COSY and KVI has finished and the long polarimeter paper has been sent out for publication. The expected systematic error in our experiment is $\ll$ 1ppm.

Only First Order Systematic Error

- $dS/dt^* = d \times E^* + \mu \times B^*$
- Need to know $\langle B_R \rangle$ as seen by the beams accurately.
- Same accuracy as the neutron edm experiments at the same accuracy.
- With only electric fields, the CW/CCW closed orbits are identical, by time reversal invariance.
- Checked with simulations.

$\langle B_R \rangle$

- However, $\langle B_R \rangle$ will split the CW/CCW vertical closed orbits: $F = e(E + v \times B)$.
- Need relative BPM accuracy $\approx$10 nm/$\sqrt{}$Hz.
- We use the beams to tell us $\langle B_R \rangle$ as seen by the beams – much better than the neutron edm case!
- Neutron edm systematic error: B field - neutron position mapping to get average.

New idea: Modulate Vertical Tune

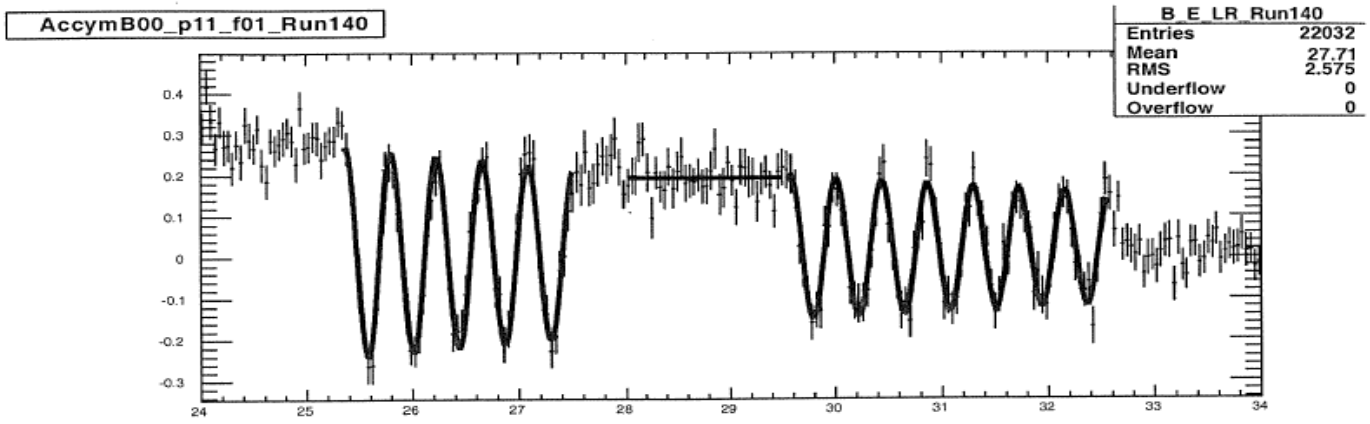
- Average CW/CCW closed orbit difference.
- Yannis' idea – modulate Q_y.
- $Q_y \approx 0.10 + 0.01 \times \cos(\omega t)$. We choose ω!
- Brilliant, but simple, idea.

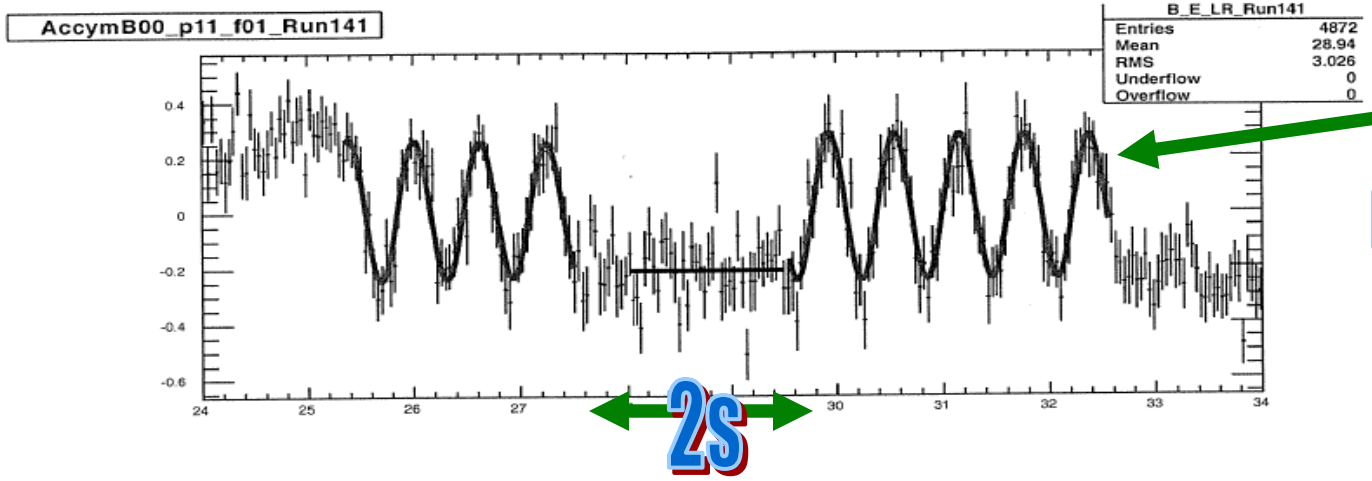
$$< dy_{CW/CCW} >= \frac{2R_0 \beta < B_R >}{E_0 Q_y^2}$$

Storage Ring EDM

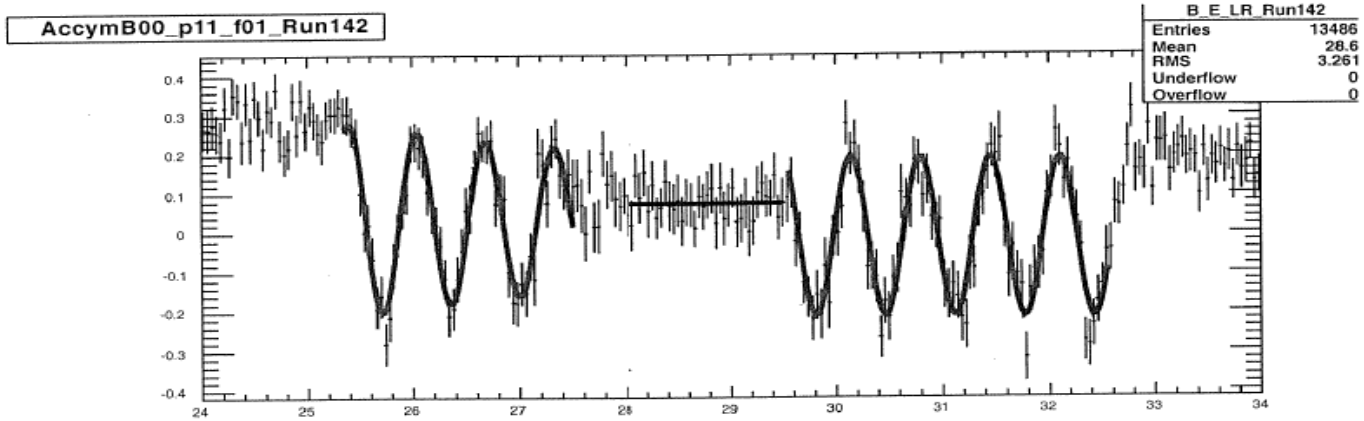
- June 2008, BNL PAC:
- MUST DO PHYSICS!
- Dec. 2009, passed Technical Review 1.
- Mar. 2011, passed Technical Review 2.
- Submitting PEDM CD0 Proposal to DoE next month.

Extra

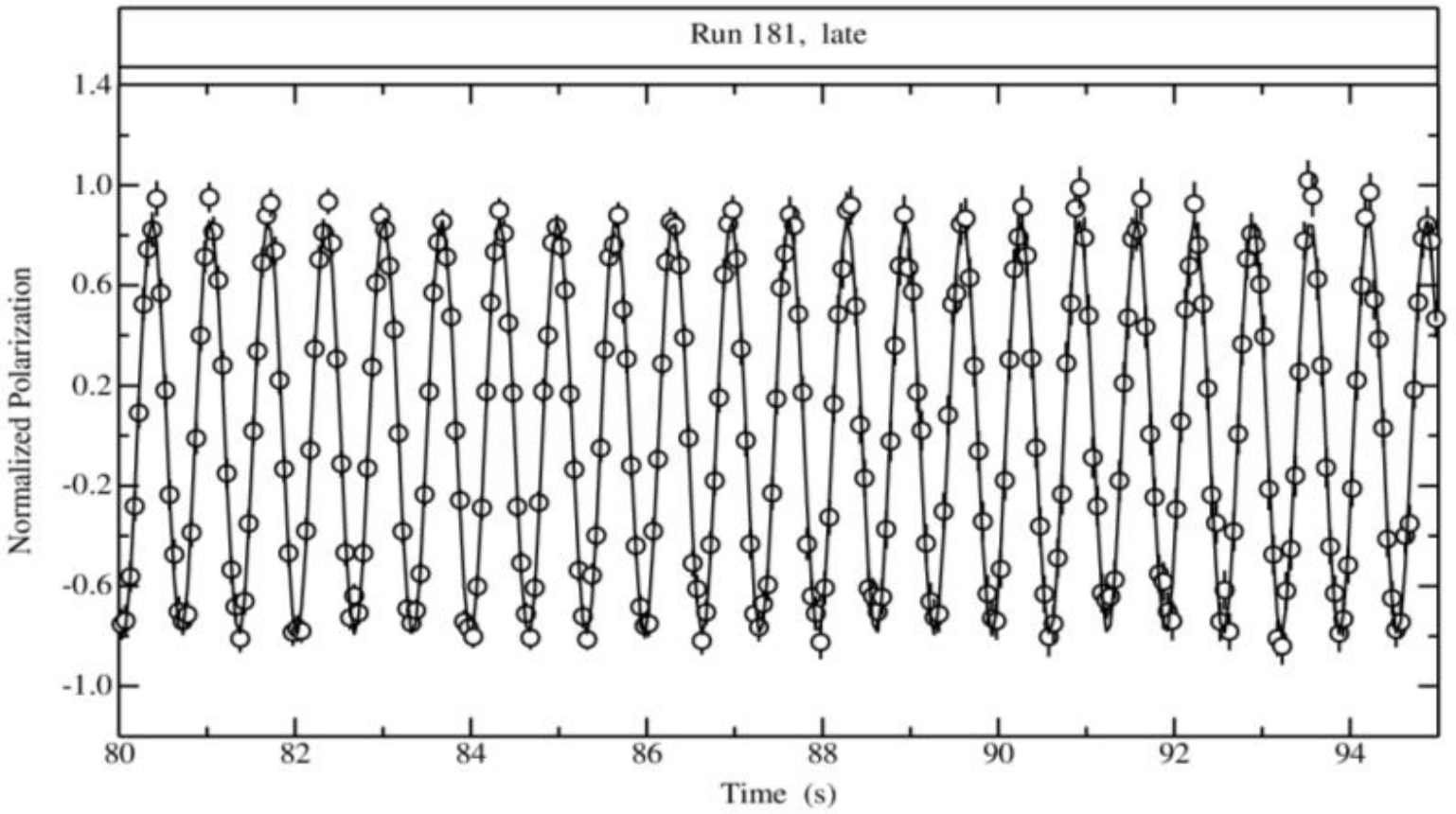




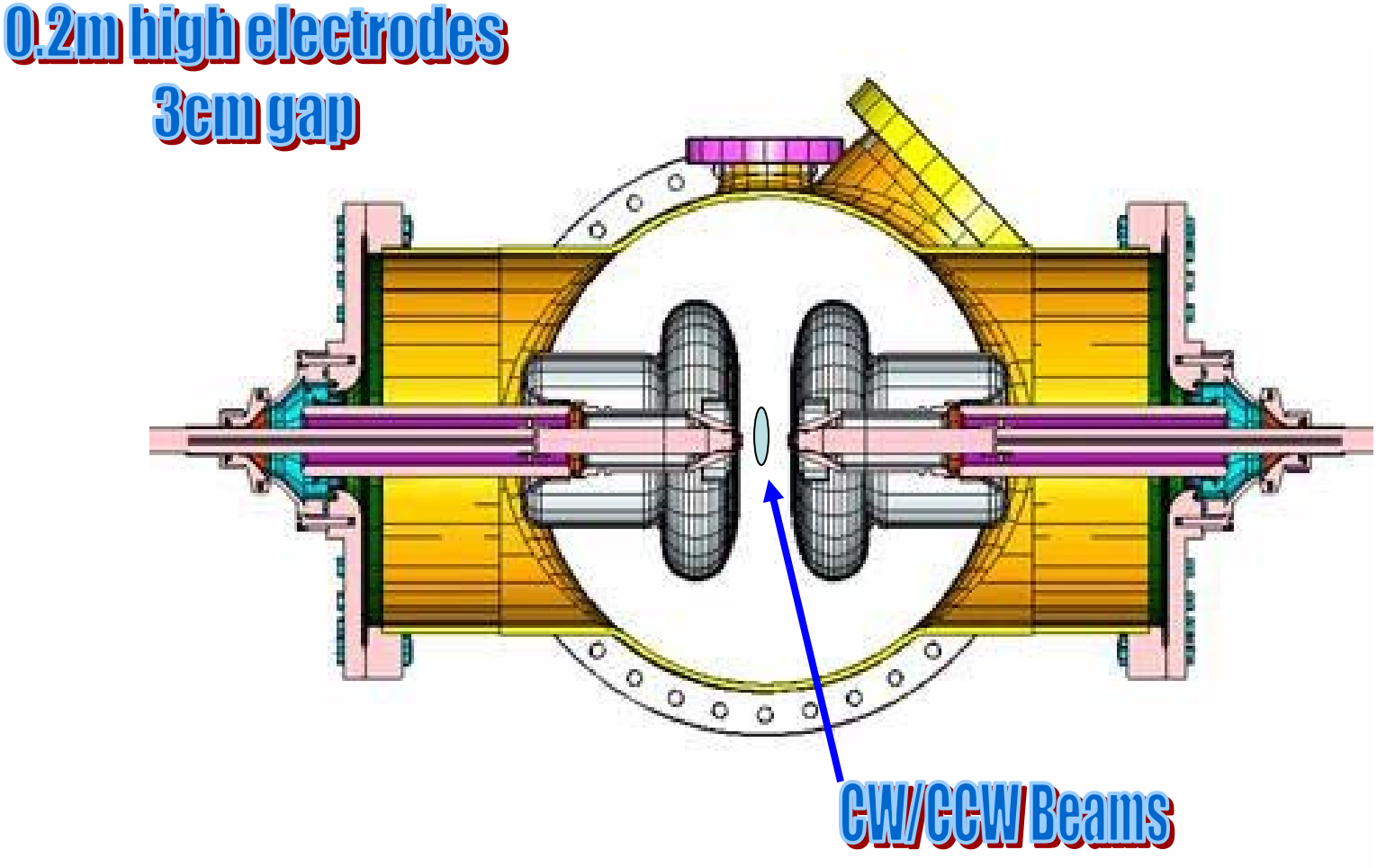
always reproducible



Last part of the one minute long fill!



Pedm E



Recent Progress from LC/ERL

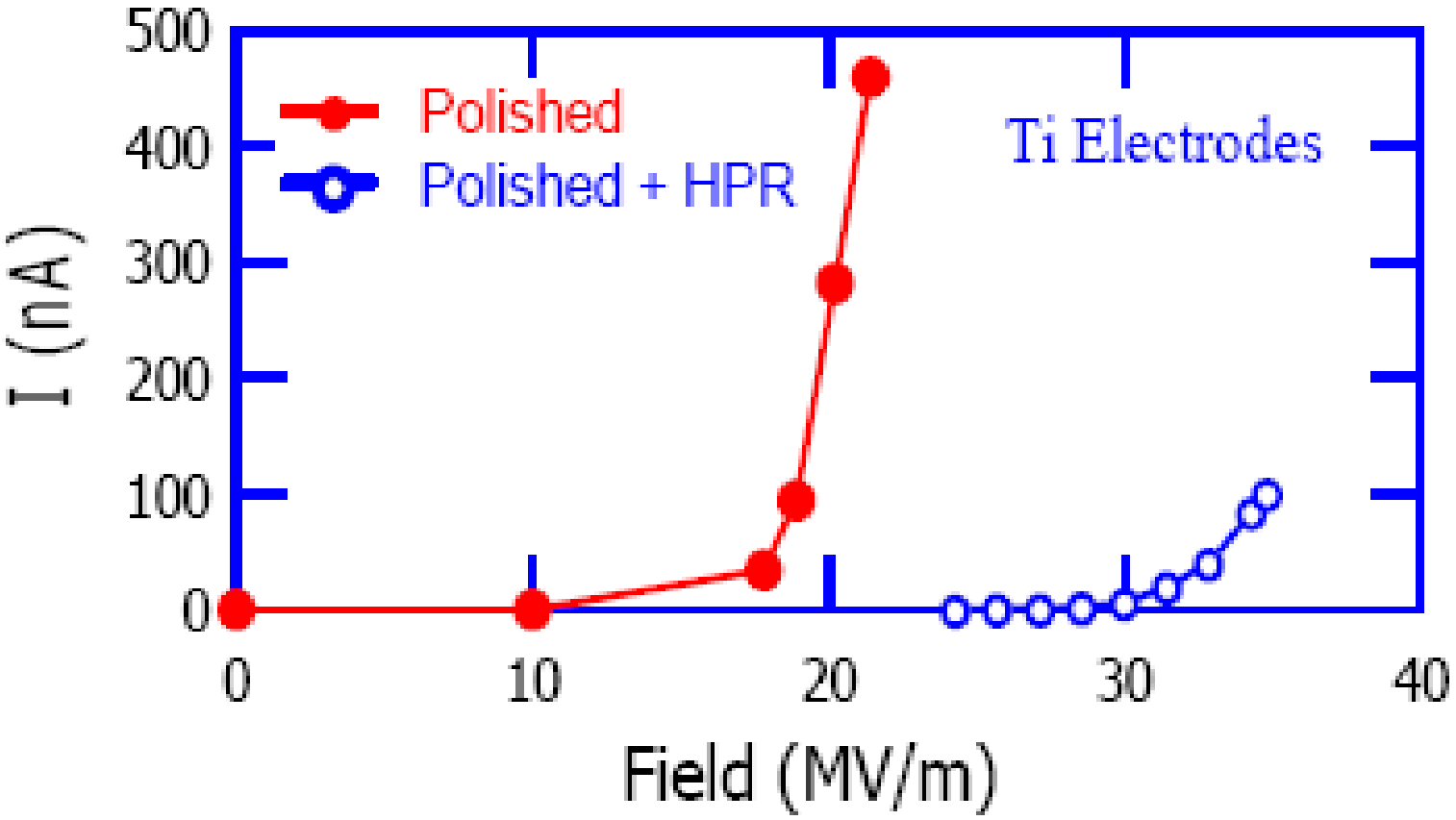
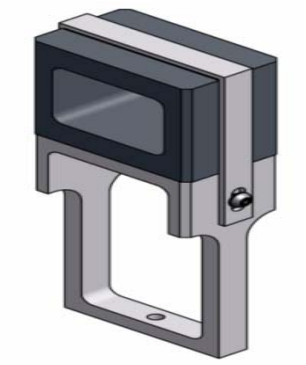
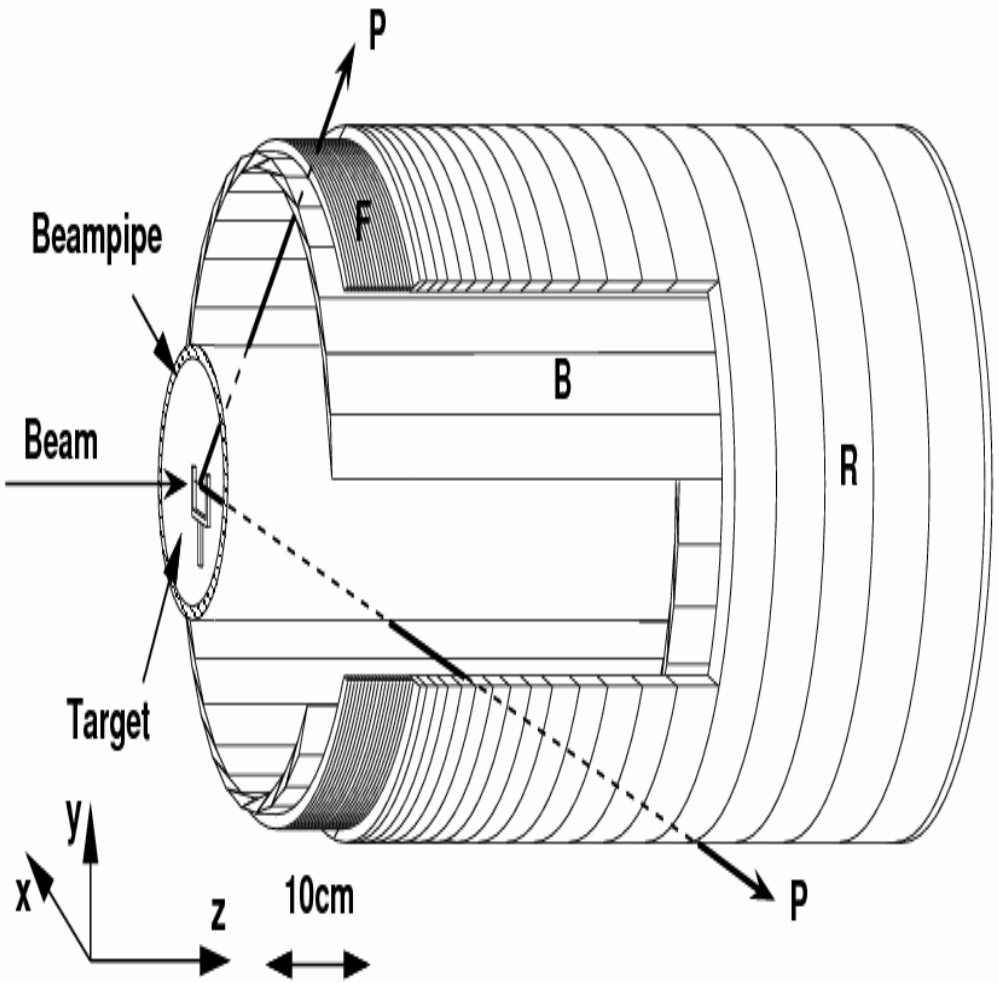


Fig. 4. Field emission current as a function of applied gradient for a 150-mm-diameter stainless steel electrodes: (squares) a typical untreated sample, (circles) first measurement of GCIB treated sample, (triangles) re-measurement of GCIB treated sample after high-voltage conditioning [14].

EDDA Detetcor





Studies of the Horizontal Spin Coherence Lifetime at COSY

P. Benati[1], D. Chiladze[2,3], J. Dietrich[3], M. Gaisser[3], R. Gebel[3], G. Guidoboni[1], V. Hejny[3], A. Kacharava[3], P. Kulessa,4 A. Lehrach[3], P. Lenisa[1], B. Lorentz[3], R. Maier[3], D. Mchedlishvili[2,3], W.M. Morse[5], A. Pesce[1], A. Polyanskiy[3,6], D. Prasuhn[3], F. Rathmann[3], Y.K. Semertzidis[5], E.J. Stephenson[7], H. Stockhorst[3], H. Ströher[3], R. Talman[8] Yu. Valdau[3,9], Ch. Wiedeman[3] and P. Wüstner[10]

1 University of Ferrara and INFN, Italy, 2 Tbilisi State University, 3 Forschungszentrum Jülich, Germany, 4 Jagiellonian University Krakow, Poland, 5 BNL, 6 Institute for Theoretical and Experimental Physics, Moscow, Russia, 7 Center for Exploration of Energy and Matter, Indiana University, Bloomington, IN, 8 Cornell University, Ithaca, NY USA, 9 Petersburg Nuclear Physics Institute, Gatchina, Russia, 10 ZEL, Forschungszentrum, Jülich, Germany

Deuteron E/B R_0 = 8.4m

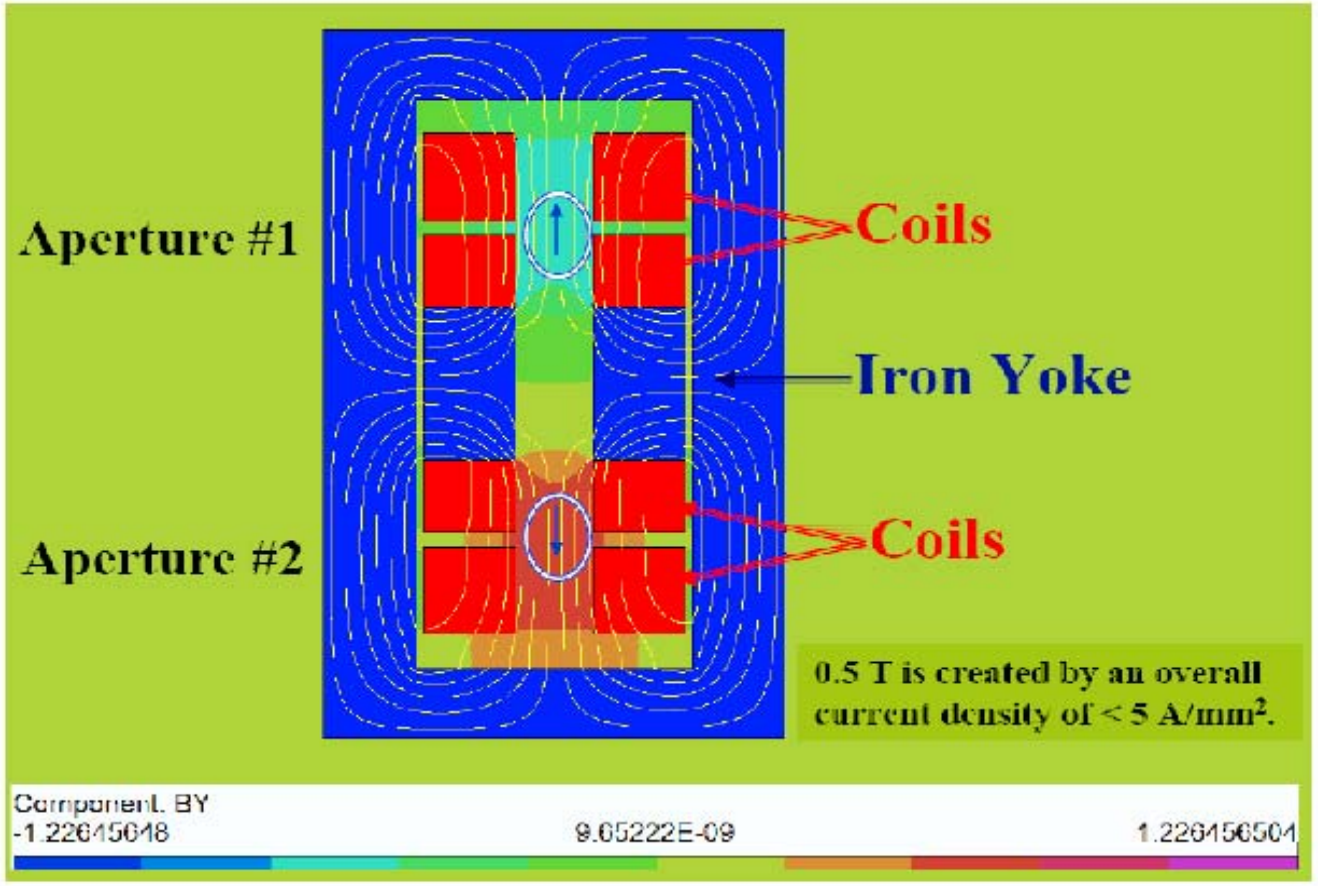


Figure 1: A schematic of the common coil magnet design (the horizontal and vertical scales are not the same). When the deuteron beam travels CW in aperture 1, the beam travels CCW in aperture 2.

B_r and distortion of the vertical closed orbit