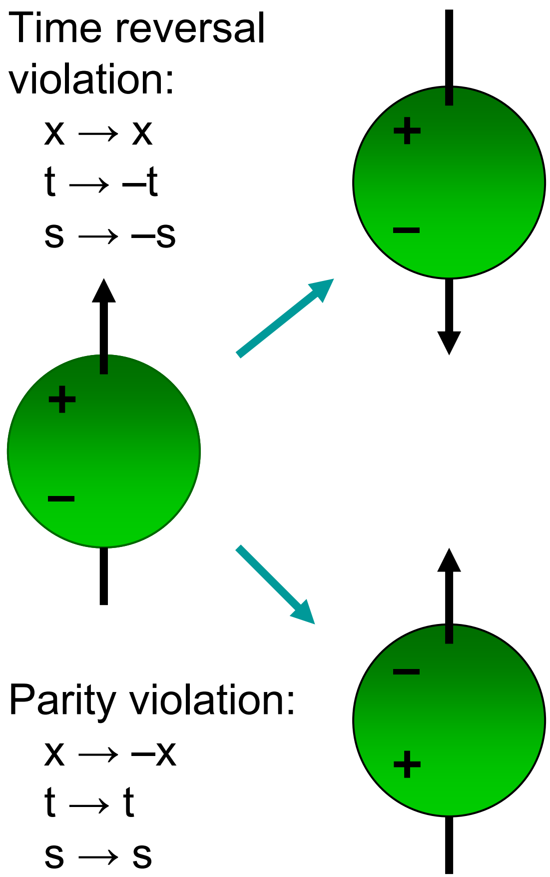
dEDM

deuteron electric dipole moment

First of a new class: EDM searches on charged particles using the $\mathbf{E=\gamma v\times B}$ field of a storage ring



Baryon asymmetry of the universe requires new sources of CP-violation. One indicator would be the observation of an intrinsic EDM.

Best theoretical candidate is SUSY. Next 10^3 crucial test: find it or die.

<u>Other EDM limits:</u>

neutron $< 2.9 \times 10^{-26}$ e·cm, PRL **97**, 131801 ('06)
electron $< 1.6 \times 10^{-26}$ e·cm on Tl, PRL **88**, 071805 ('02)
atom $< 2.1 \times 10^{-28}$ e·cm on ^{199}Hg, PRL **86**, 2505 ('01)
(but really $< 4 \times 10^{-25}$ e·cm on neutron)

(Statistical) goal for deuteron: 10^{-29} e·cm

Why start with the deuteron?

Technically:

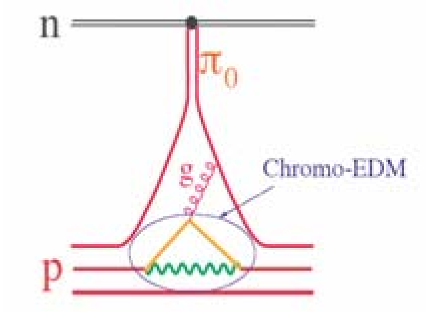
Polarized ion sources make intense beams, polarization >90%.
Forward angle deuteron scattering very sensitive to polarization.

Physically:

The deuteron has a special sensitivity to chromo-EDMs.

Compared to the neutron:

$$d_n = 0.83e\left(d_d^c + d_u^c\right) + 0.27e\left(d_d^c - d_u^c\right)$$
$$d_d = -0.2e\left(d_d^c + d_u^c\right) + 6e\left(d_d^c - d_u^c\right)$$



Information independent of neutron,
complementary within systematic study.
Deuteron structure is well determined.

At 10^{-29} e·cm: Sensitivity to equivalent mass: 10^3 TeV
Sensitivity to CP-violating phase: 10^{-5}
(beyond reach of LHC)

Status of Letter of Intent
presented to fall 2006 PAC

Please find below the recommendation of the NPP PAC from September.

LoI: Search for a Deuteron Electric Dipole Moment Using a Charged Particle Storage Ring

This letter proposes a search for a deuteron electric dipole moment using a stored beam. The goal is a statistical precision of about 10^{-29} e·cm; an appropriate level for an experiment we expect would take a number of years to develop. In this experiment, a longitudinally polarized beam develops a vertical spin component due to the torque of the motional electric field in the ring bending magnets acting on the electric dipole moment. The PAC is enthusiastic about this ingenious new approach to electric dipole moment searches. Because it is a new technique, however, there will be a daunting new set of false edm effects and associated systematic errors to consider. We believe it is very important to identify the most important of these difficulties and address them with a combination of simulation and measurement. We strongly encourage the collaboration to investigate the options for measurements in existing rings with polarized deuteron beams. Development of a program of simulations and tests should include, but not be limited to, complete characterization (intensity, size, energy, polarization) of the tails of the beam and their effects on the measurement, investigations of resonant extraction, considerations of correlations between energy and position in the 'extraction' region, and characterization of the effects of common lattice imperfections. Indeed, short of implementing the resonant enhancement of vertical polarization described in the proposal, measurements of zero left-right asymmetries at the requisite level must be demonstrated. A clear plan for near-term milestones including consideration of these issues (over perhaps a two-year period) should accompany any request to the laboratory for continued support.

Clearly there is enthusiasm for your continuing development of this experiment and I look forward to a plan as suggested in the last sentence of the recommendation.

The PAC is in favor of the physics goals.

The PAC favors an R&D program of ring simulations and polarimeter tests.

(supported again in spring 2007)

BNL plans to provide LDRD:
$ 230 K in FY 2007-08
applied for $ 700 K in FY 2008-10

Also from the Netherlands:
600 K€ already granted

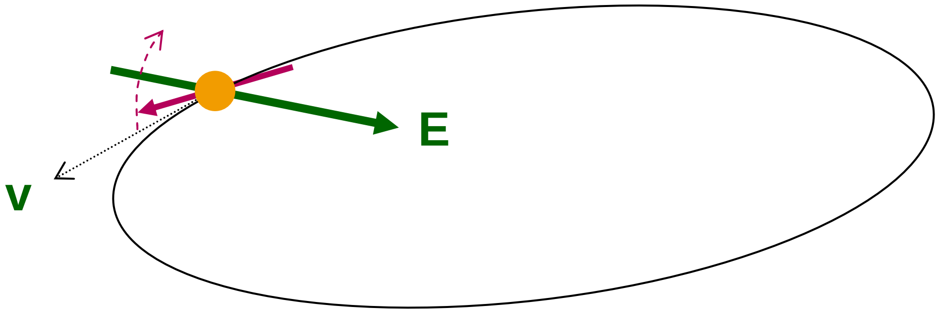
Goal: demonstrate feasibility of technique

(Included in nuclear physics long-range plan)

What is the method?

EDM Signal: observe precession of spin in large electric field.

Technique: create large E field from γ**v×B** on polarized beam circulating in a ring.



Experiment: watch for spin that starts out along **v** to acquire a vertical component.

What is the method?

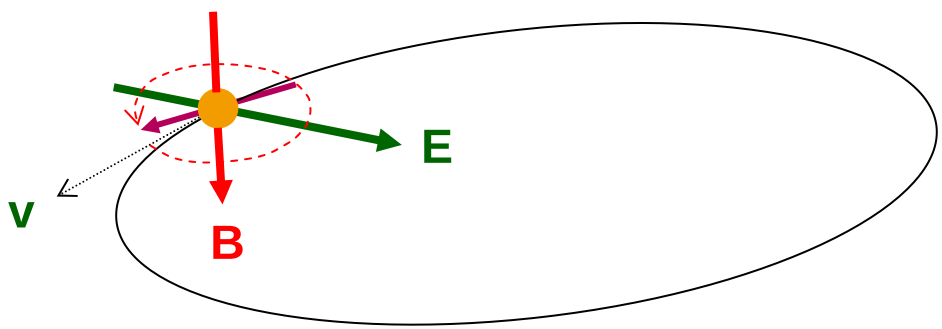
EDM Signal: observe precession of spin in large electric field.

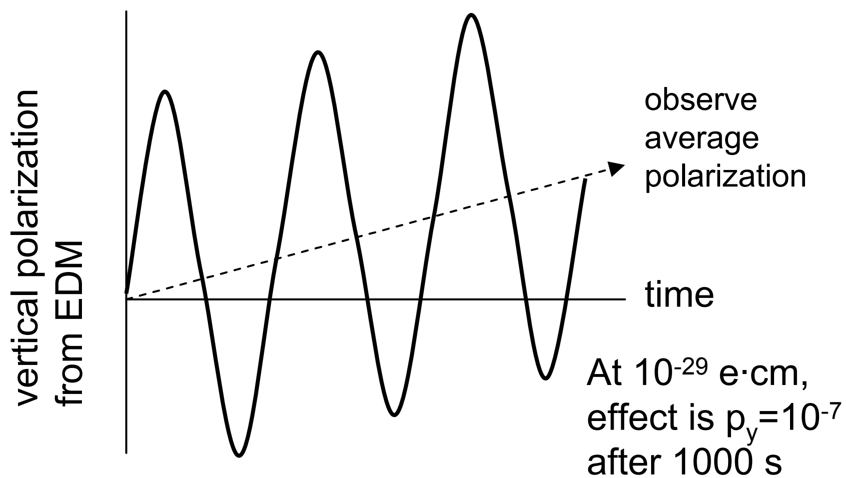
Technique: create large E field from $\gamma \mathbf{v} \times \mathbf{B}$ on polarized beam circulating in a ring.

Main technical challenge: rapid spin precession due to magnetic moment cancels EDM every rotation.

Solution: create synchrotron-spin resonance to accumulate EDM signal.

with velocity oscillation synchronized to polarization:





Experiment: watch for spin that starts out along **v** to acquire a vertical component.

But precession in magnetic field is much faster!

Requirements:

- prepare/preserve horizontal polarization
- monitor in-plane phase and frequency
- monitor growth of vertical polarization

Characteristics of the EDM ring

an example:

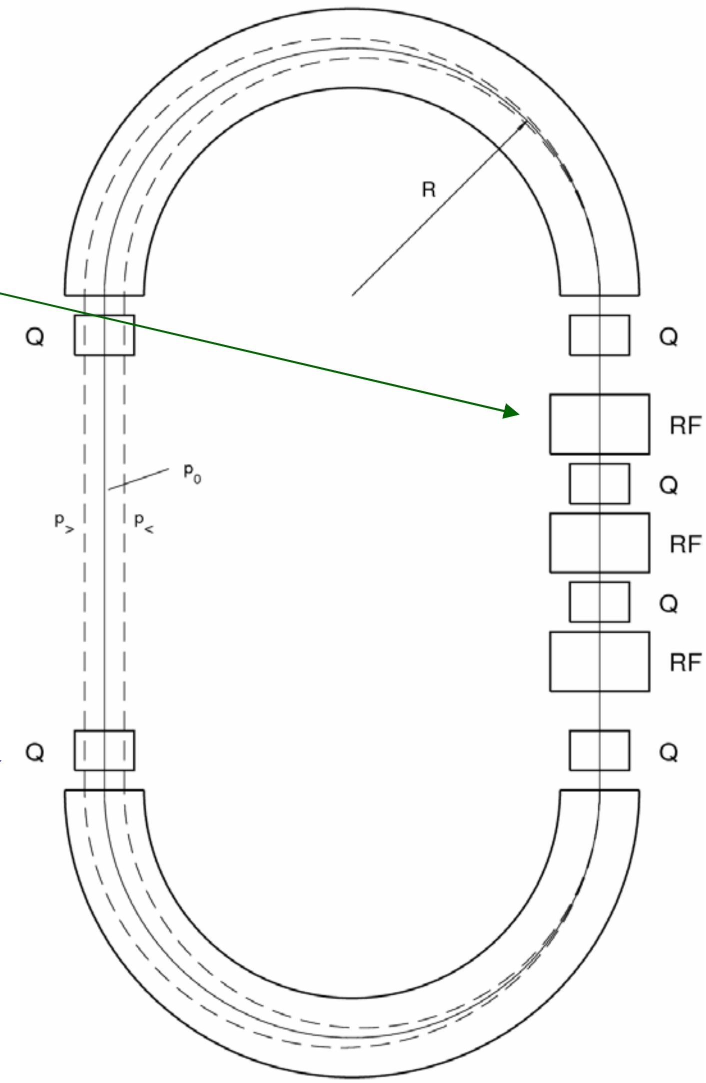
Superconducting RF cavities (D=0)
  keep beam bunched (preserve p)
  force synchrotron oscillations

Chromaticity: $$\alpha_p = \frac{p}{L}\frac{\partial L}{\partial p} = 1$$ suppresses harmonics

Polarization cancellations:
  flip polarization at source
  opposite synchrotron phase on different beam bunches

Electro-magnetic quads to reduce sensitivity to betatron oscillations.

Consider CW and CCW operation



Issues: Oscillating $\mathbf{B}_r$ (from skew quad)
Polarization coherence time
Collective effects (space charge, etc.)

… do simulations !

Storage Ring Development Plan

Specify (set of) ring lattices for study.

Determine non-linear fields need to preserve horizontal polarization.

Include multiple errors, check for interactions.

Add EM fields from collective effects (space charge, images).

Vary β-functions around ring, find systematic signals.

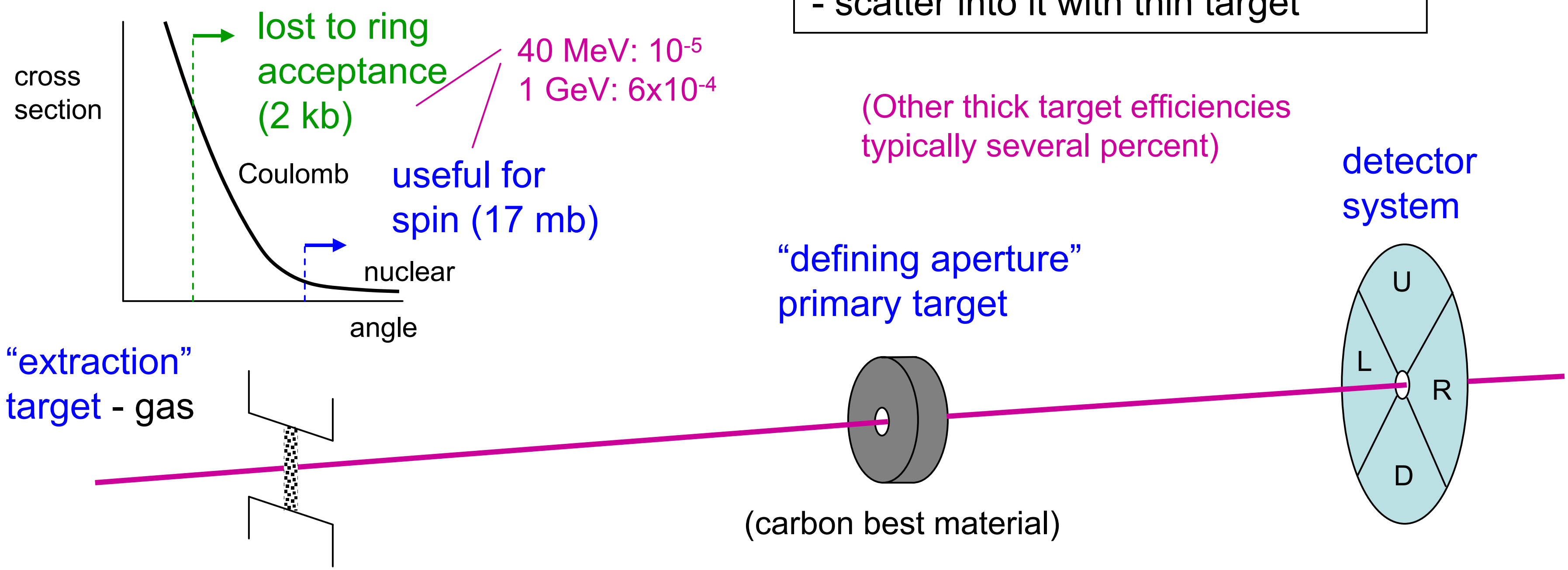
Study non-linear solution to cancel ω_a oscillations.

Examine tolerances on ring construction.
Test concepts for error reduction or cancellation.
Specify polarimeter requirements.

Timetable: 2007-08

EDM polarimeter

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



Increased efficiency comes from greater target thickness.

If hole in target is ring defining aperture, then all particlea are lost there regardless of what perturbed their course.

<u>Asymmetries</u>

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

carries EDM signal
small
increases slowly with time

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

carries in-plane precession signal
large
oscillates rapidly, slowly decreases

Operating characteristics for d+C polarimeter

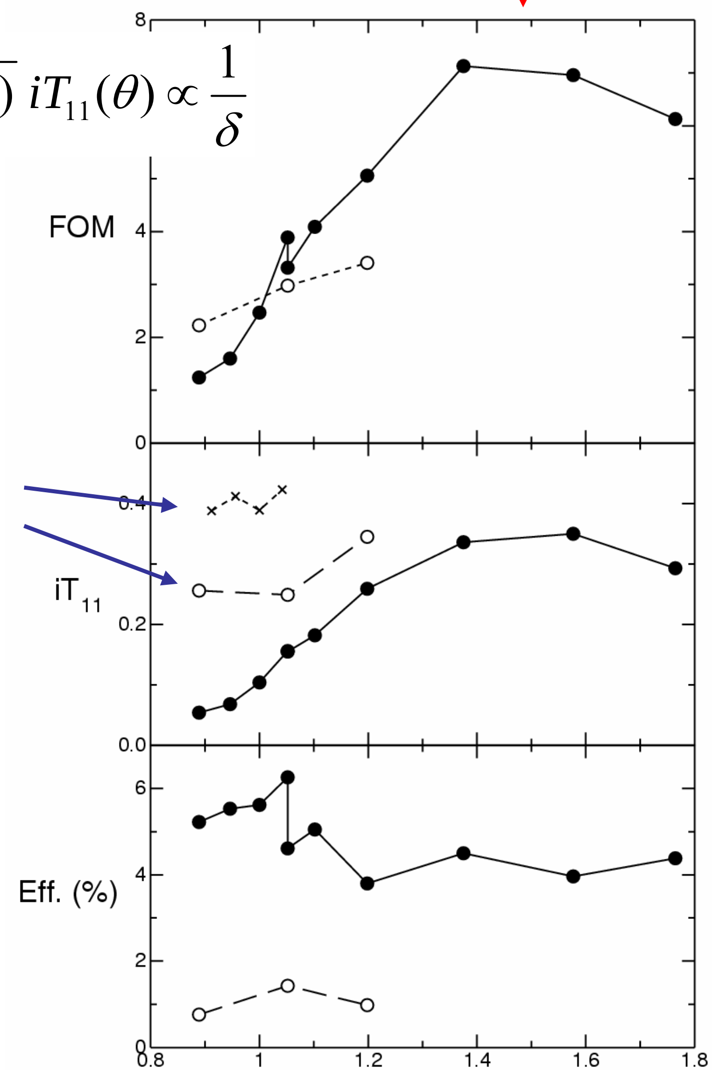
best operation

$$FOM = \sqrt{\sigma(\theta)}\; iT_{11}(\theta) \propto \frac{1}{\delta}$$

figure of merit

(optimizations for better iT_{11})

fraction of deuterons that hit the target and scatter into a range useful for spin measurement

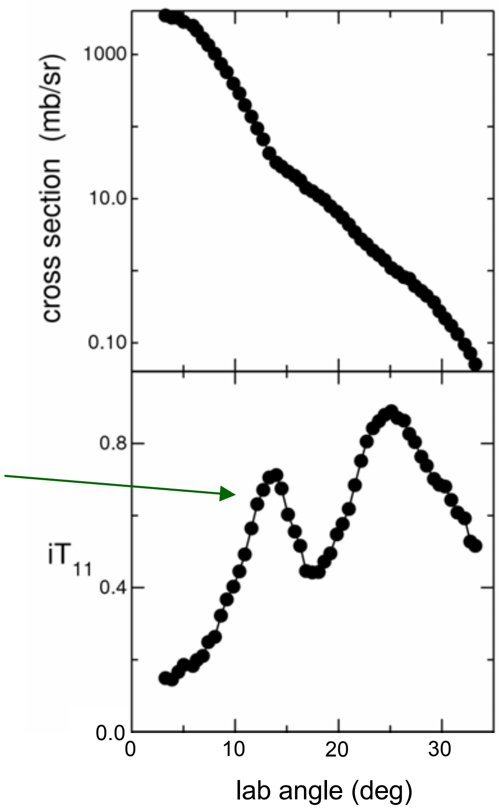


split between:

left-right

down-up

Sample data
d + C, 270 MeV



Use peak for spin measure-ment

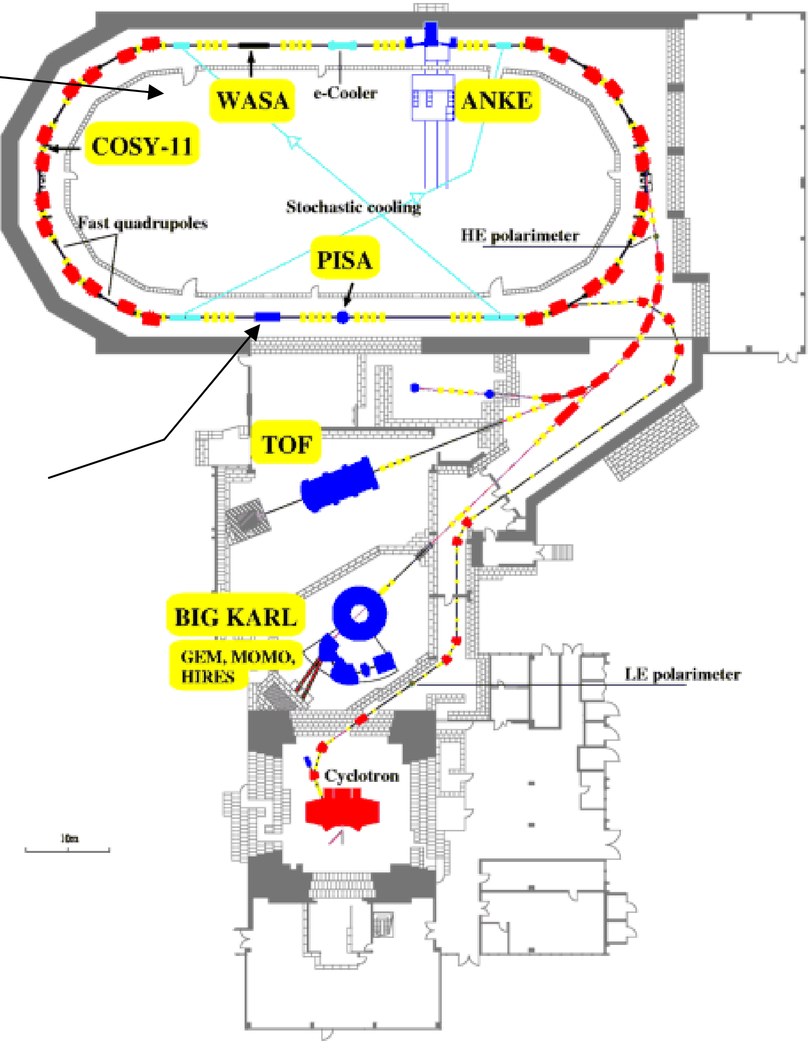
Effect goes as:

$$\sigma = \sigma_U \left(1 + it_{11} iT_{11} \cos\phi\right)$$

Polarimeter development at COSY (Jülich)

broad range data from WASA

polarimeter test data from EDDA



Developments needed

- annular carbon targets (EDDA)
- needle carbon (CH_2) (WASA)

Results from COSY PAC

May, 2007

The long term goal behind the polarimeter development described in this proposal is a test of the Standard Model of particle physics by means of a precision measurement of the electric dipole moment of the deuteron. The method proposed is novel and involves measuring the build-up of vertical polarization in a storage ring. The signal would allow unprecedented accuracies for the deuteron electric dipole moment, namely at the level of 10^{-29} e·cm. The PAC is intrigued by this possibility and expresses its strong support toward this very rewarding goal.

In order to achieve the necessary sensitivity, new methods have to be developed for the polarization measurement as well as for a detailed understanding of the spin dynamics of the ring. So far, it is estimated that a total 8 weeks of beam-time will be required. The spin studies will need to be based on quantitative modeling of the spin motion in the ring as well as on spin manipulations like the ones that are performed by the SPIN@COSY project. It appears highly advisable to coordinate the programs among the two groups.

As a first step the development of a highly efficient polarimeter making use of the EDDA target station and the EDDA scintillator is proposed. A thick annular carbon target is to be designed and placed at the EDDA position. While the PAC accepts and supports this development effort by granting one week of beam-time it appears unlikely that the measurement can be performed in the next period. In particular, the collaboration first has to become familiar with the EDDA and COSY setups so that it will be able to make efficient use of the limited beam-time. The PAC therefore encourages members of the collaboration to participate in scheduled runs at COSY. The PAC appreciates the effort to involve more people in the project and asks the collaboration to prepare detailed plans of the next steps including quantitative milestones and manpower resources for its next meeting. In the meantime, the collaboration can be assured of the continuing support of the PAC.

Support for the physics goals.

Beam time granted (but not scheduled) for first goal: high efficiency polarimeter with annular carbon target.

Remaining goals:

- make horizontal polarization
- measure in-plane precession
- check sensitivity to synchrotron oscillations
- measure cross section and analyzing power for deuteron-induced reactions

Running to be scheduled in early 2008 through 2010

Systematic Error Studies (an example)

KVI, Groningen, the Netherlands

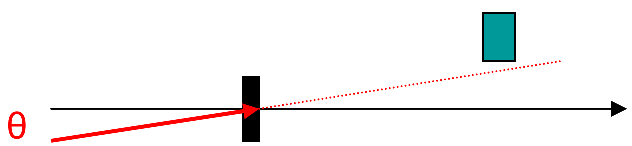
The Toolbox:

- spin reversal (at source, in different bunches)
  - combined with cross-ratio calculations
- correct time dependence
  - depolarization confirmed from in-plane values

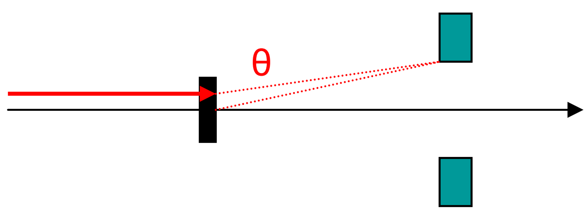
Challenge:
Predict these terms from Monte Carlo, then check in lab. This demonstrates methodology.

An illustration:

angle error



position error



both represented by θ

Fix problem with spin-flip and cross ratio:

$$p_y = \frac{1}{\sqrt{3}\langle iT_{11}\rangle}\frac{r-1}{r+1} \qquad r^2 = \frac{L_+R_-}{L_-R_+}$$

Systematic effects come at higher order and constrain allowed size of θ.

$$\frac{\Delta\varepsilon}{\varepsilon} = \varepsilon^2 u^2 + 2\varepsilon\frac{1}{iT_{11}}\frac{\partial iT_{11}}{\partial\theta}u\theta + \frac{1}{iT_{11}}\frac{\partial^2 iT_{11}}{\partial\theta^2}\theta^2$$

asymmetry ~ 0.01 (residual p_y)

$u = p_+ + p_-$

~0.1

~ –0.07

requires θ < 0.02° difference + to –

Summary of dEDM project status

Resonant method appears feasible, statistical limit ~10^{-29} e·cm

BNL PAC supports physics goals, R&D to determine feasibility

- Spin tracking to test ring lattice designs
- Polarimeter proof-of-principle tests

Future:

Technical review

Full proposal

Storage Ring EDM Collaboration

Presented to the BNL PAC, September 2006.

Additional for COSY:

- NFM Brantjes, KVI
- R Gebel, COSY
- K Jungman, KVI
- A Lehrach, COSY
- B Lorentz, COSY
- R Messi, U. Rome
- D Prasuhn, COSY
- M da Silva, KVI
- L Willmann, KVI
- HW Wilshut, KVI

Letter of Intent:

Development of a Resonance Method to Search for a Deuteron Electric Dipole Moment using a Charged Particle Storage Ring

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