Polarimeter Planning

Ed Stephenson

November 7, 2006

E×B ring
p = 0.7 GeV/c
T = 126 MeV

2004 ← KVI LOI (+)

← COSY LOI (+)

← BNL proposal (–)

KVI run (80+110 MeV)
NaI detectors, broad range

2005

resonant ring
p < 1.5 GeV/c
T < 526 MeV

KVI run (110+133 MeV)
spectrometer, elastic only

Data not publishable:
BBS/NaI σ(θ) disagree
polarizations not separable

2006

Timeline

2006

Nuclear physics long-range plan

← BNL LOI (+)

KVI polarimeter meeting 12/5-7

NOW

letter to COSY, PAC 11/20-21
revive LOI

2007

visit COSY 1/9-13/7

← COSY proposal

FUTURE

running at COSY

BNL proposal

technical
design report
and review

2008

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revised for KVI workshop Dec. 5-6, 2006

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in progress

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Charge to polarimetry from the BNL PAC:

NOTE: It is not probable that we can reduce false asymmetries to below the level of our limiting EDM signal, nor can we run for long enough to reach the design statistical precision. Instead, we should:

demonstrate that false asymmetries are understood and controlled by matching models to experiment.

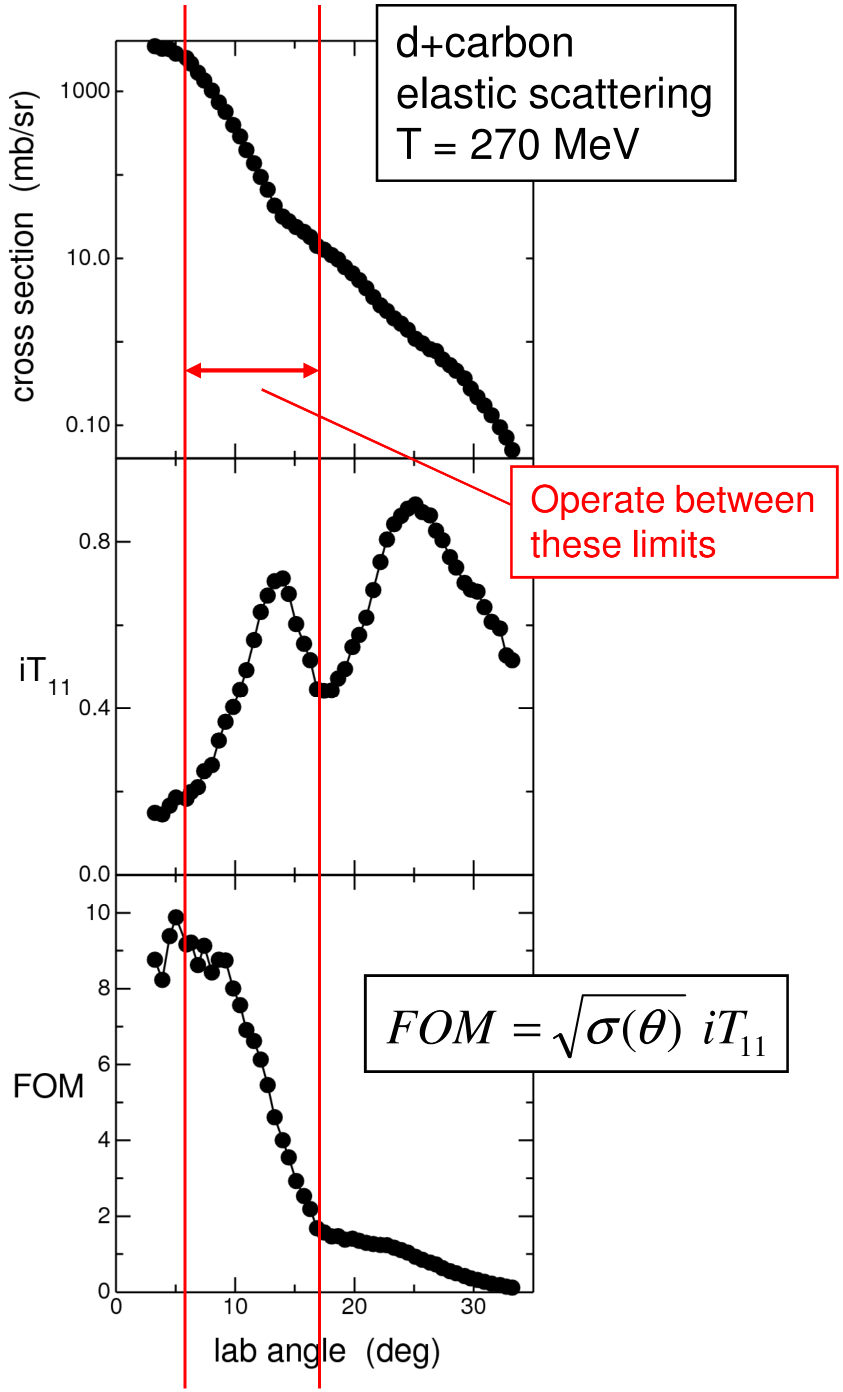
demonstrate that EDM-like signals can be extracted in the presence of other backgrounds.

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.



General Features of the Polarimeter

regardless of site

Vertical polarization (EDM) creates a left-right asymmetry in scattering from a target.

Best analyzer: carbon

Down-up asymmetry is sensitive to the horizontal polarization, which exhibits g-2 precession.

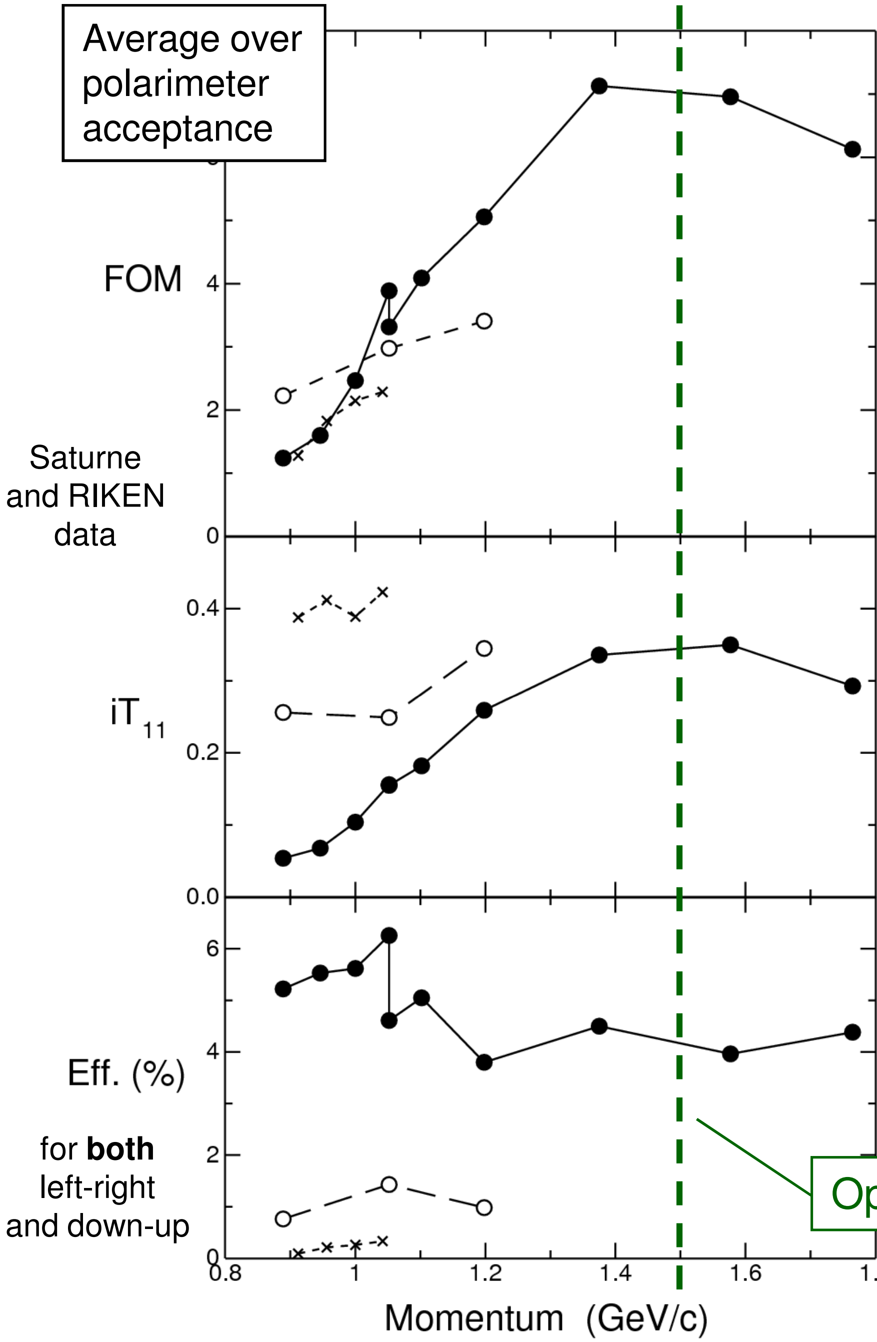
Sensitivity to tensor polarization is weak.

EDM signal is a rising vertical polarization component:

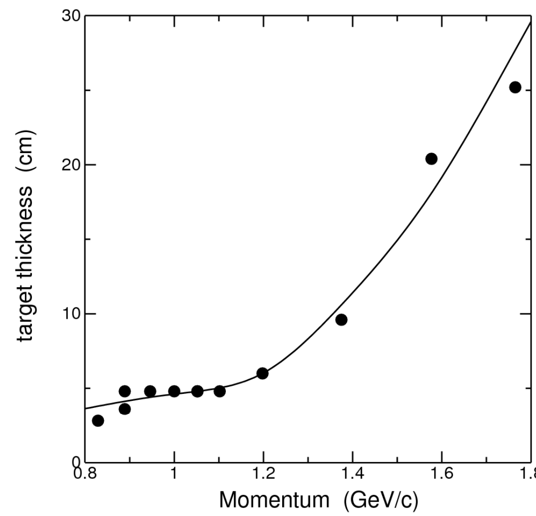
$$p_y = \sqrt{3}\ \langle iT_{11} \rangle\ p_0\ \omega_{EDM}\ \tau \left[1 - \exp\left(-\frac{t}{\tau}\right)\right]$$

At p = 1.5 GeV/c, $\langle iT_{11} \rangle$ = 0.36.

polarization coherence time

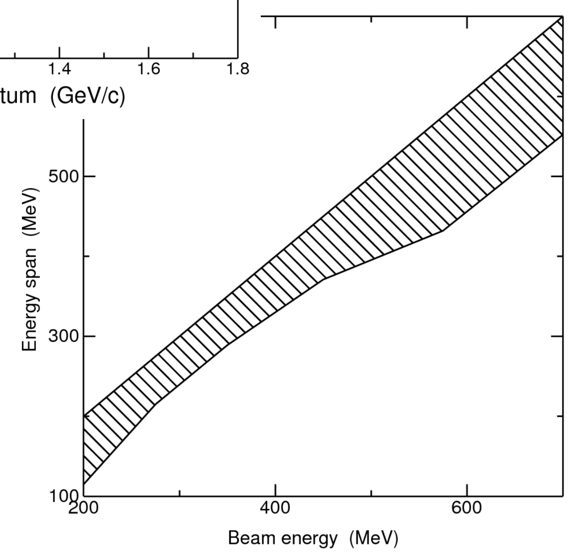


The choice of ring momentum depends on best polarimeter Figure of Merit and ring considerations (collective effects).



Target thickness chosen on the basis of maintaining FOM as feature shift with energy.

Actual span of energies inside target.



Operate here

NOTE: Guidance is needed on which momenta are likely in order to focus polarimeter development.

Goals for Polarimeter Studies

Before we have decided on extraction scheme (internal/external):

1 Measure d+carbon σ and iT_{11} in polarimeter range.

With polarimeter location/type decided:

2a For in-ring polarimeter, study beam-target interaction.

2 Predict (MC) and measure sensitivities to systematic errors.

3 Demonstrate ability to extract EDM signal shape.

4 Demonstrate ability to track g-2 precession for feedback signal.

Discussions have started with COSY-Jülich to run there.

We will need collaborators and equipment to do this:

- carbon target
- if external, need polarimeter detector system

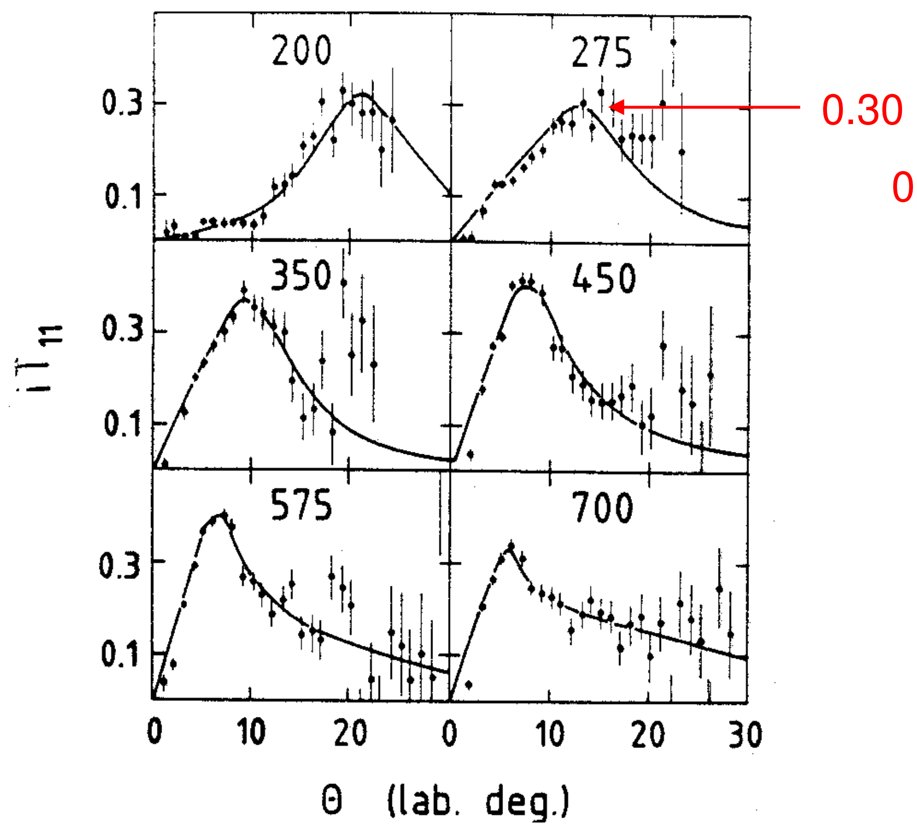
1

Why do we need more data?

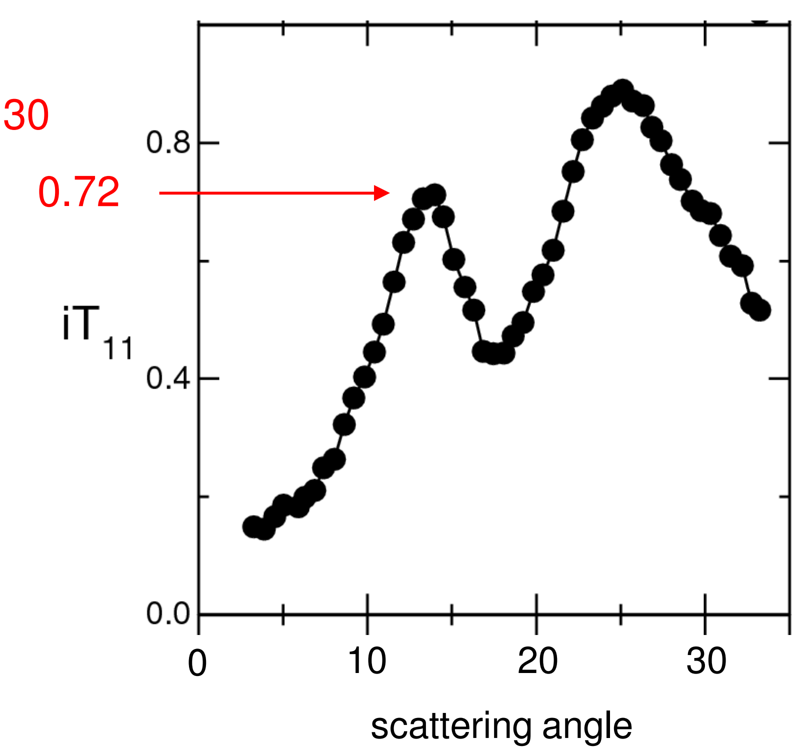
Basis for Monte Carlo calculations (separates inelastic/breakup).

Measurements at Saturne included non-elastic events.

An example at 275 MeV



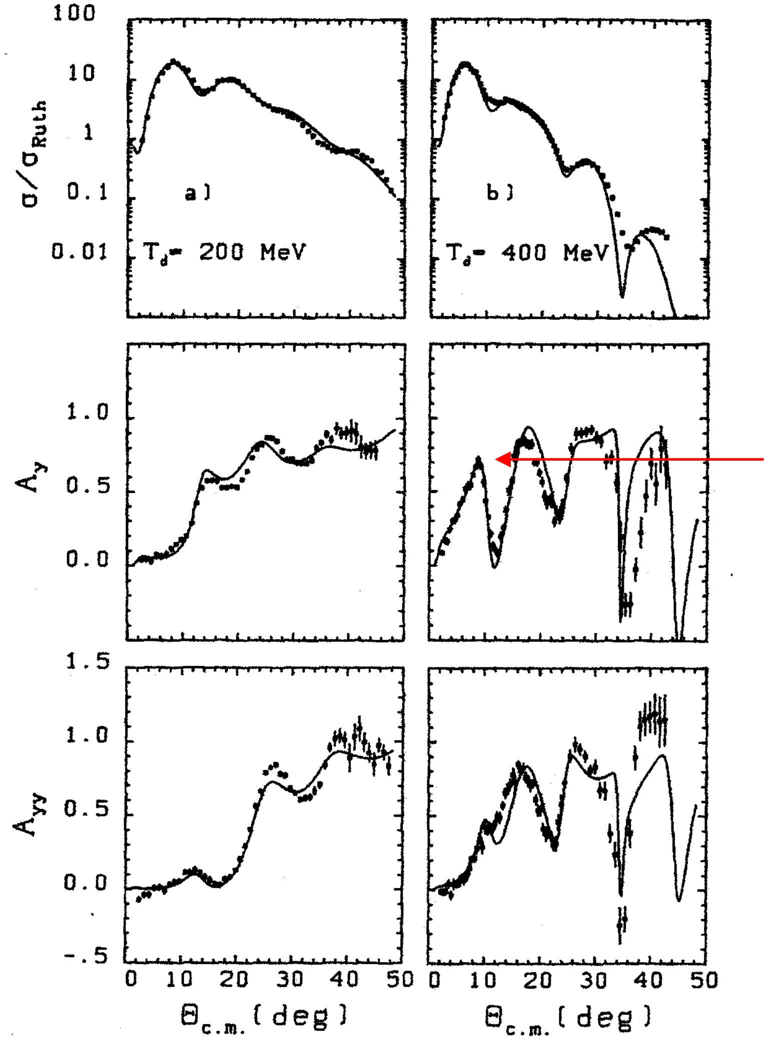
Bonin *et al.*, NIM **A288**, 389 ('90)

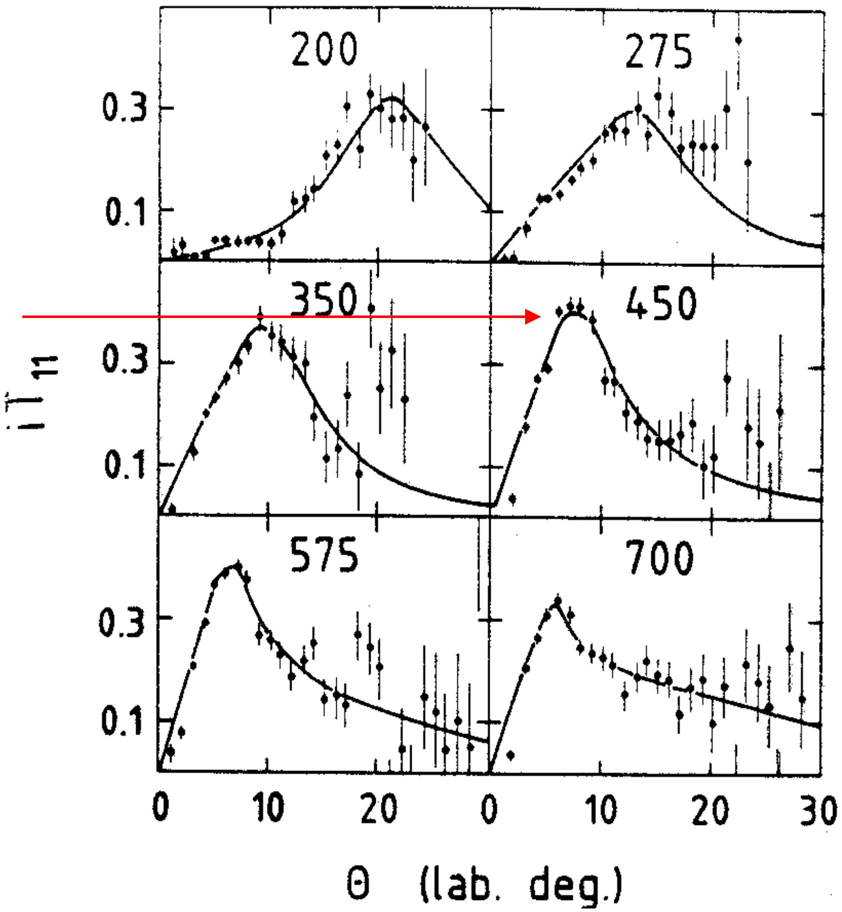


Y. Satou, private communication

At 400 MeV:

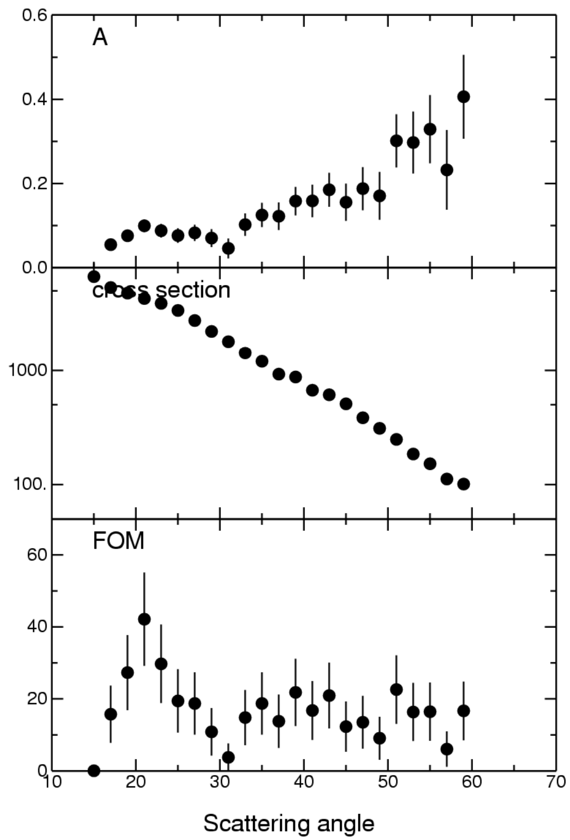
d+oxygen elastic scattering





Polarimeter modeling

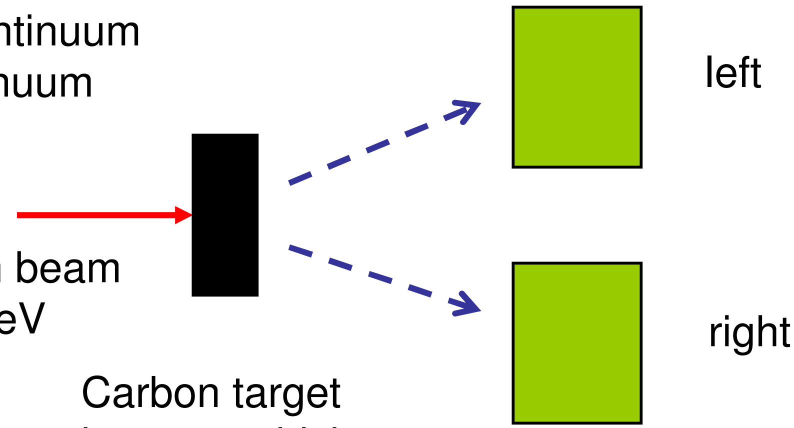
Preliminary
Result: (5 MeV threshold)
200,000 events



Take all angles upward of 18º.

efficiency = 2.5 %
average A = 0.099
figure of merit
= 2.11 x 10^{-4}

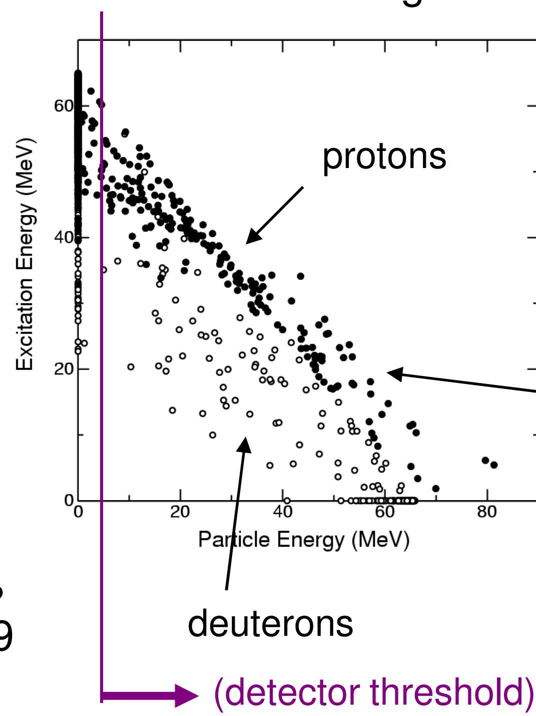
deuteron elastic
deuteron continuum
proton continuum



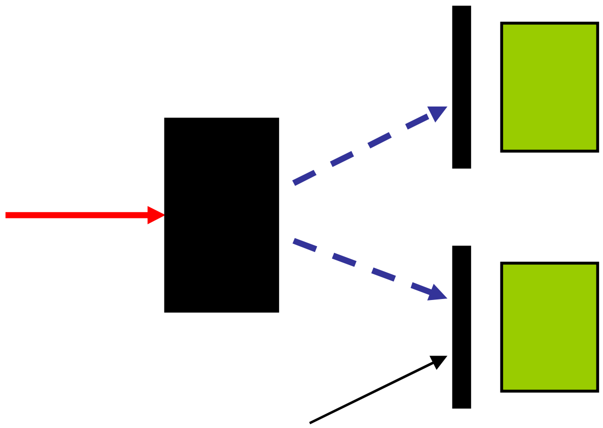
Deuteron beam at 126 MeV

Carbon target is 2.3 cm thick at a density of 2.22 gm/cm^2.

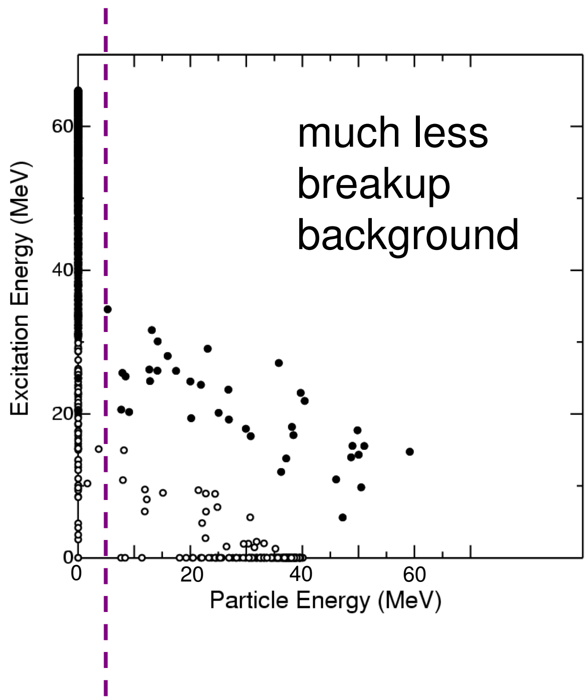
These detectors cover half of azimuth. The rest is used for in-plane component.

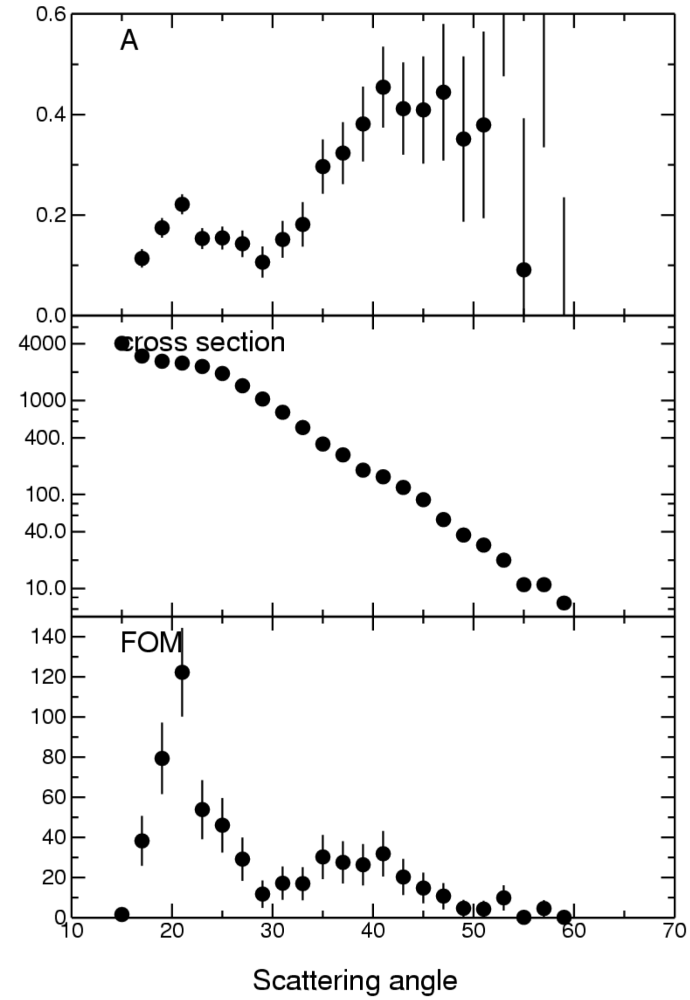


The problem with the low analyzing power is that too many breakup protons fall into the acceptance.



Add Fe absorber of 6 mm thickness.





		was
efficiency	= 1.0 %	2.5 %
average A	= 0.18	0.099
figure of merit	= 3.4×10^{-4}	2.1×10^{-4}

Polarimeter possibilities at COSY

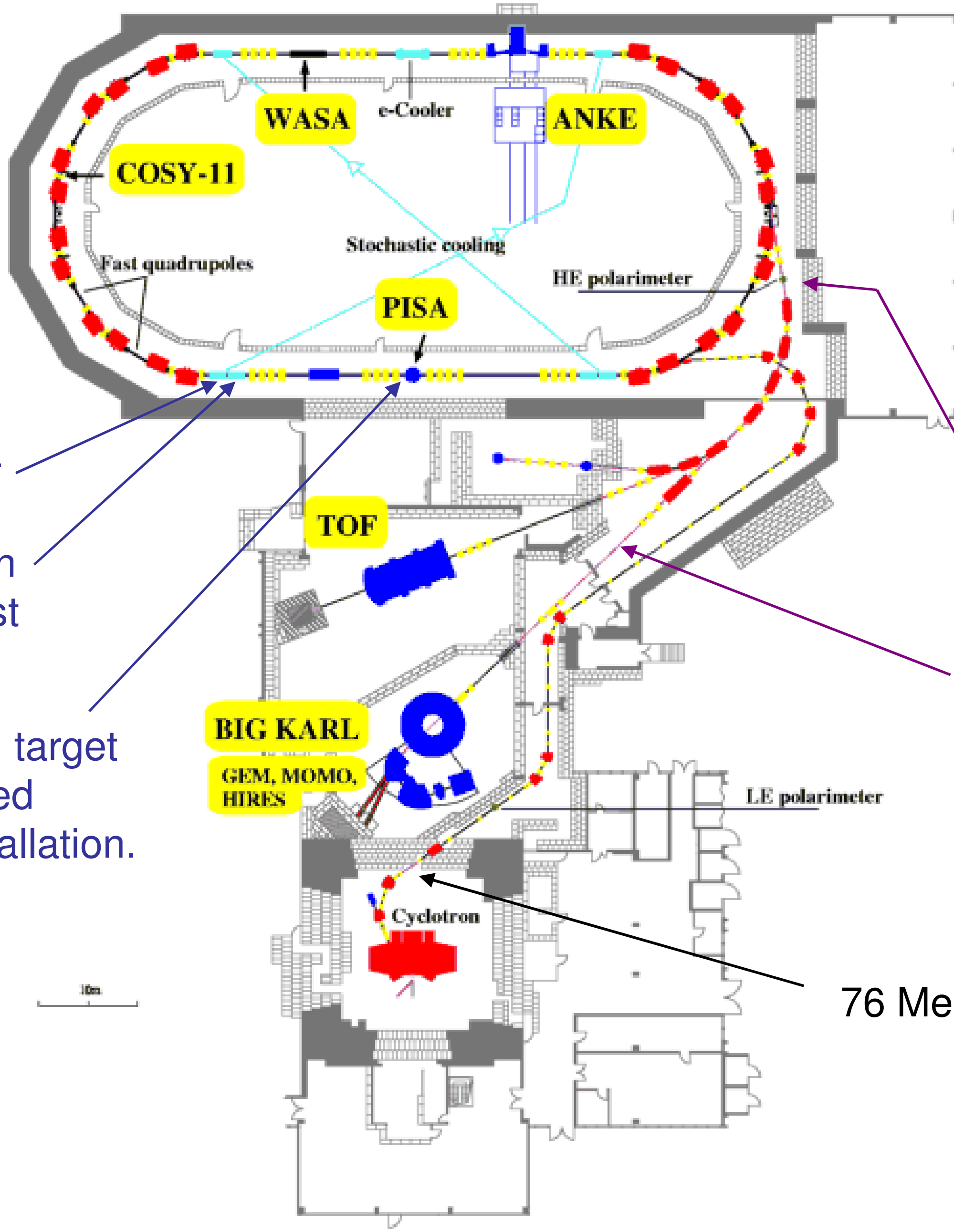
<u>Internal option</u>:

Use EDDA detector

Annular carbon target goes just upstream.

Gas jet extraction target uses new polarized atomic target installation.

NOTE: We would abandon plans in original COSY LOI to install prototype.



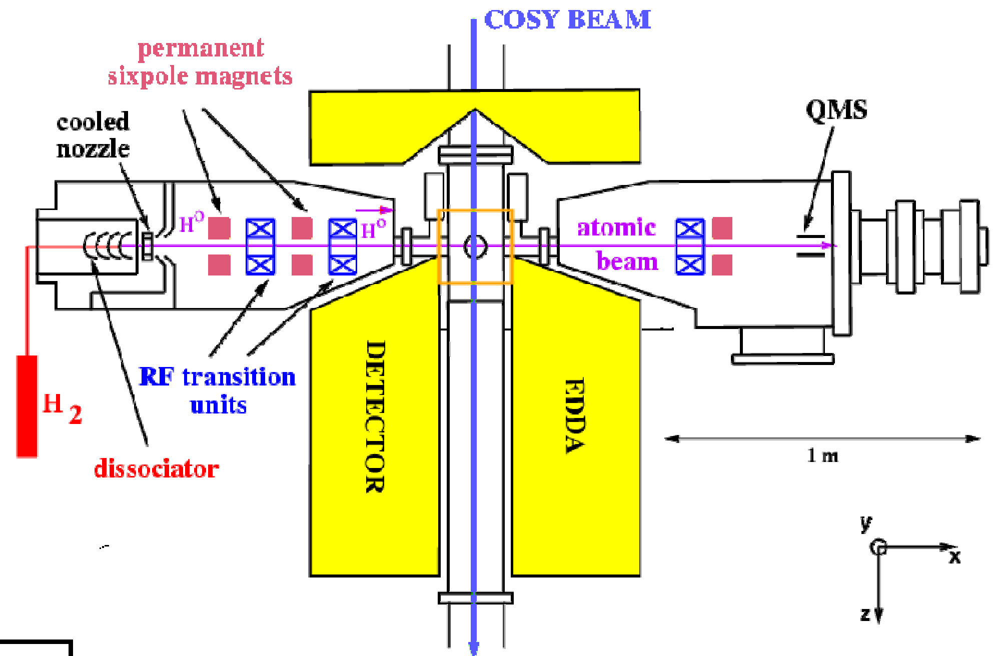
<u>External option</u>:

Mount solid target and new scintillator array at appropriate location in the extracted beam line.

76 MeV deuterons

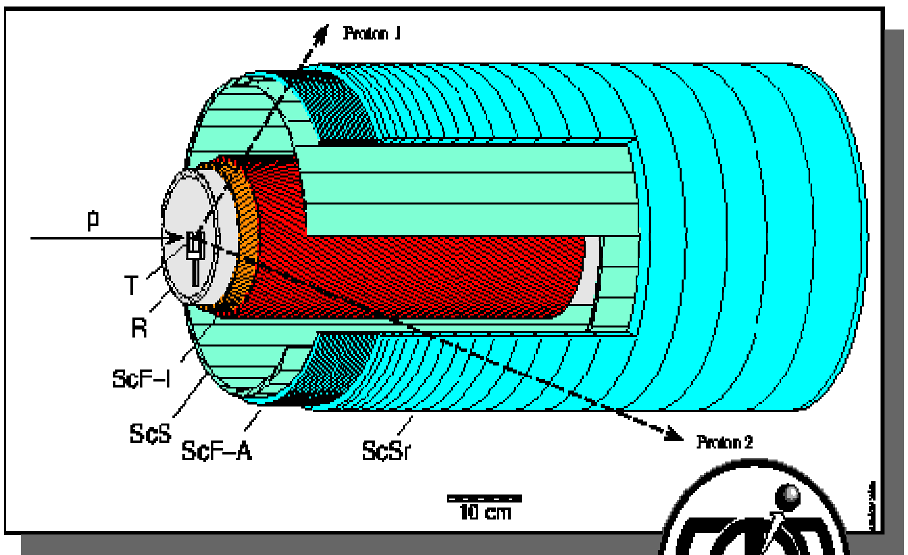
EDDA detector

Schematic of polarized target

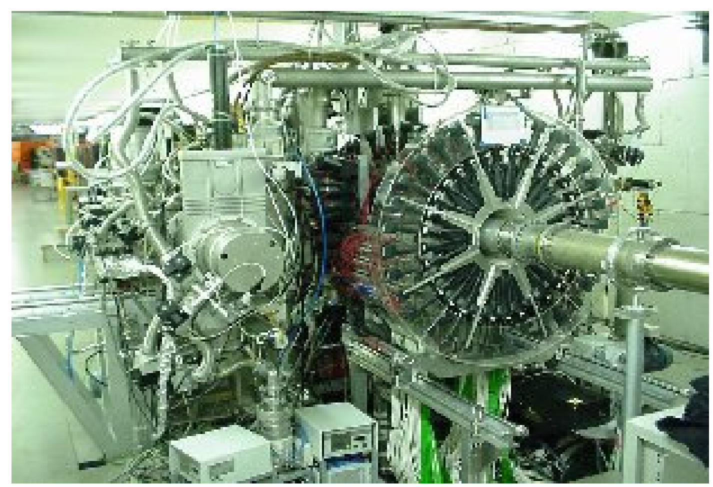


Tracking for p+p and d+p scattering

Cut–Away View of the EDDA Detector



The picture shows the active parts of the EDDA detector with PP–fiber–target (T), beampipe (R), inner layer consisting of four scintillating fiber helicas (ScF–I), and the outer layer made of scintillator bars (ScS), scintillator semi rings (ScSr) and scintillating fibers (ScF–A).



View of downstream readout

2

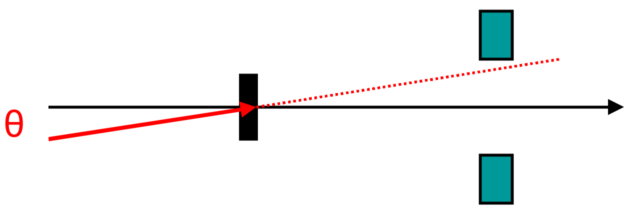
Dealing with systematic errors

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

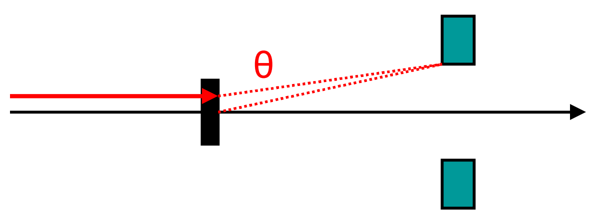
Challenge:
Predict these terms from Monte Carlo, then check in lab.
This demonstrates methodology.

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.

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

- $\frac{\Delta\varepsilon}{\varepsilon}$: asymmetry ~ 0.01 (residual p_y)
- $u = p_+ + p_-$
- $\frac{1}{iT_{11}}\frac{\partial iT_{11}}{\partial\theta}$: ~0.1
- $\frac{1}{iT_{11}}\frac{\partial^2 iT_{11}}{\partial\theta^2}$: ~ –0.07
- requires θ < 0.02° difference + to –

We must be particularly careful about anything that changes with polarization!

What is likely to be a problem?

- Velocity dependence
- Any position change ($D \neq 0$) or angle change (angular dispersion $\neq 0$).
- For internal polarimeter, angle changes that rock across target hole edge.
- Dependence on rates or circulating current.
  - (Signal gets buried in other exponential effects.)

Need rounded hole edges?

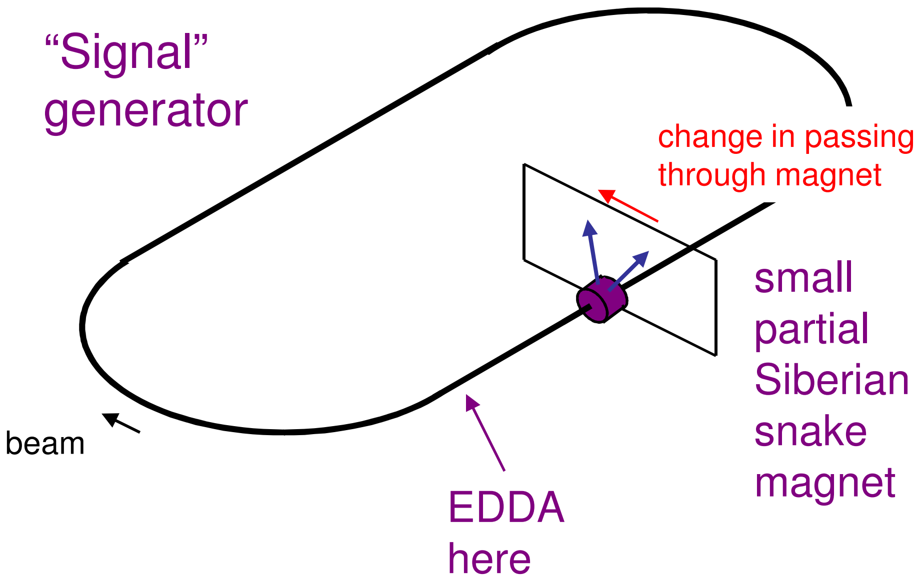
Other potential issues:

- Spot size, tails, or spot complexion
- Cross-talk from g-2 precession (falling asymmetry).
- Deuteron self-polarization effects
- Parity violation (spurious asymmetries, spin rotation)
- Effects from gravity, earth's rotation, tides, etc.

Cologne group has remeasured spontaneous T_{20} at 10-20 MeV, still reports 1-2% effect. Prediction (Stephenson and Johnson) is (now) $T_{20} = 9.6 \times 10^{-6}$ for effect of atomic electrons. Strong force T_{20} is probably less, needs estimate. Effects driven by static quadrupole moment.

Digging EDM signals out of noise

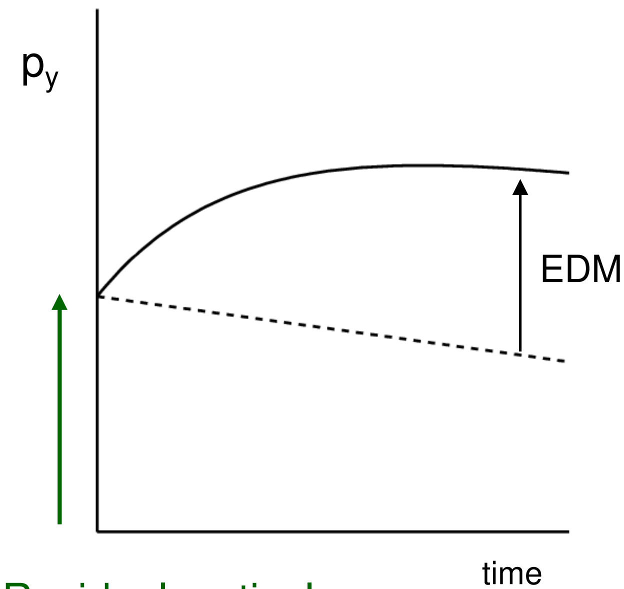
"Signal" generator



A partial Siberian snake can be used with a time-dependent current to make a "signal" by precessing the polarization away from the vertical direction.

Can such a signal be detected?

It may be difficult to distinguish EDM signal from backgrounds more complicated than linear, as exponential resembles other exponentials.



Residual vertical polarization at injection.

It helps that time constant is derived from g-2 depolarization.

4 Measure g-2 precession

Consider balance between rapid feedback to synchrotron forced oscillation phase (monitored with beam position readout) and statistics in polarimeter.

This more complete system test requires:

- bunched beam
- timing readout into scintillators (fast)
- g-2 analysis software (master clock, pulse counter)
- scheme for precessing vertical polarization into plane

Polarimeter group meeting:

KVI-Groningen
Tuesday - Thursday
December 5-7, 2006

Organizer: Gerco Onderwater

Purpose: Look at list of tasks, assign priorities and responsibilities.

Improving the data base for d + Carbon:

We need more data between 200 and 600 MeV, possibly including low-lying inelastic channels and deuteron breakup (outgoing protons detected).

What exists?

40-70 MeV from Kato (elastic)
KVI: 76, 113, and 133 MeV
broad range and elastic
270 MeV from Satou (elastic)
French polarimeter data

Could we use the ANKE detector chicane?
- detector angle range, selectivity
- targets? carbon fiber? gas?
  How do we get luminosity?
- what happens to breakup protons?
- calibration of EDDA as deuteron polarimeter for this beam?

soon

What can you learn from theory?
- optical model program
- breakup calculations
- 6 person-months

?

Could we use large volume detectors?
- what kind of detector, who has them?
- energy resolution
- dE particle identification
- location (fixed target on extraction beam line)
- target?

soon

?

What about RIKEN?
- will have 250-800 MeV pol. d
- spectrometer (<15°) end of 2008
- propose end of 2008, run 2009

NOTE: No word from COSY:
letter to PAC
time of visit
next proposal dates

…all this is aimed at

Monte Carlo design of polarimeter
- optimize performance
- predict systematic sensitivities

later

Meanwhile, there is the question of “extraction”.

Don’s list:
- get lattice (latest MAD output?)
- locate polarimeter elements
- calculate efficiency
(meanwhile
- emittance growth from jet
- depolarization effects)

soon

Baryshevsky calculation

underway

…in preparation

Other machine things:
- spin rotator: design, build, test
- can we force synchrotron oscillations at the right frequency, what RF equipment is needed

big, perhaps expensive effort

NOTE: It would help to know the energy.

Question: Do we need a phased COSY proposal?

In-ring polarimeter
- need detailed layout
- gas target using spin-filter assembly
- build a carbon annular target
- how to use EDDA detector

after we know what we want

Extraction line setup
- beam properties
- need detailed layout
- target construction
- detector construction (!)

Objectives of polarimeter studies:
- demonstrate pulse-to-pulse measurements
- with unpolarized beam, demonstrate no effect in presence of forces synchrotron oscillations
- demonstrate sensitivity to small effects (partial Snake)
- predict and measure systematic effects, demonstrate method
- study beam-target interactions