Deuteron Polarimeter for Electric Dipole Moment Search

an exploration of concepts

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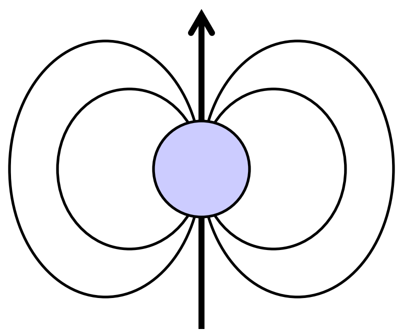
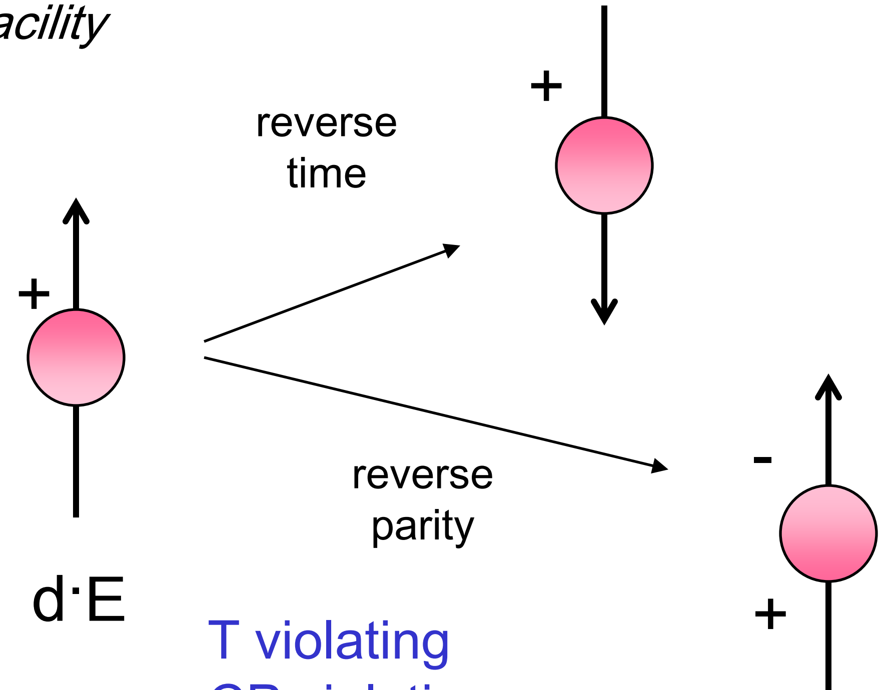
DIPOLES:





$\mu \cdot B$

$d \cdot E$

commonplace

T violating
CP violating

New sources of CP violation are needed to explain matter/anti-matter asymmetry of the universe.

SUSY predicts EDMs within 10-100 times below present limits.

A search to 10^{-29} e·cm will either find EDM or constrain theories.

Present limits: neutron $< 6.3 \times 10^{-26}$ e·cm
electron (Tl atom) $< 1.6 \times 10^{-27}$ e·cm
atom (^{199}Hg) $< 2.1 \times 10^{-28}$ e·cm
(screening reduces to 4×10^{-25} e·cm on neutron)

Usual method: place in E field, measure precession rate

Why build a storage ring?

- electric field at particle (**v** x **B**) 10-100 times stronger than lab fields
- can open search to **charged** particles (d, p, ^{3}He…)
  - deuteron especially sensitive to quark EDMs
- different systematic errors from trap searches

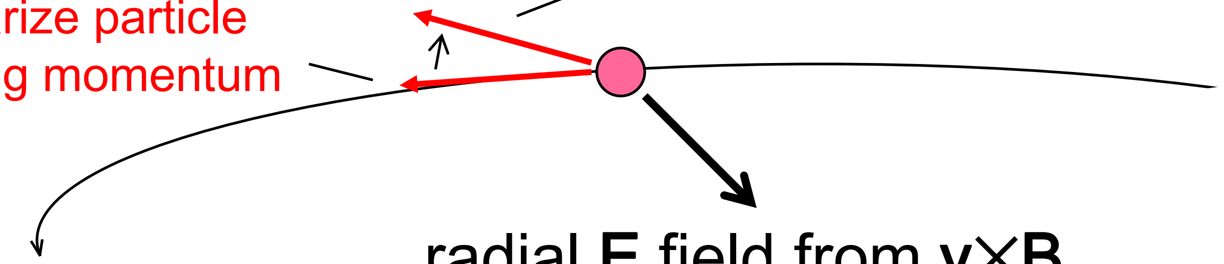
Issues:

- polarimeter must be efficient (>1%) and sensitive to $p_y > 10^{-6}$.
- design machine lattice for long spin coherence time
- control systematics ($\mathbf{B}_R$ most important)
  - toolkit: spin reversal, orbit reversal, independence of machine property (tune, location, momentum, …), time dependence (continuous measurement)

What is the signal?

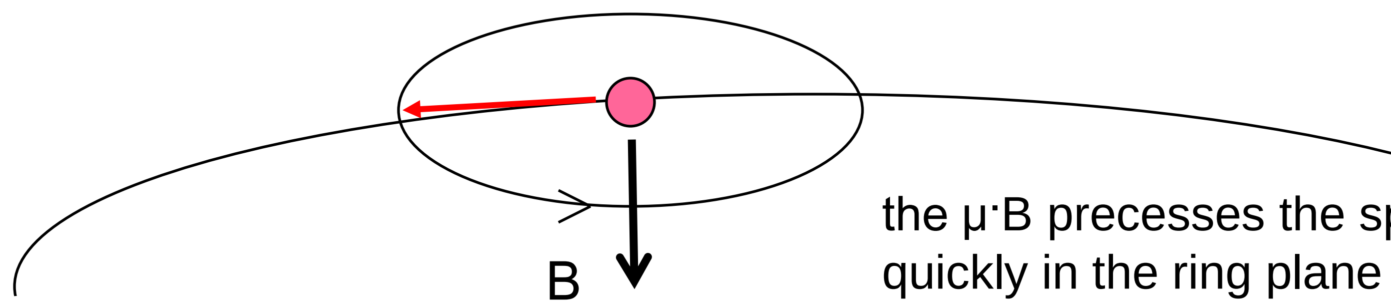
an EDM will cause spin to precess out of ring plane – vertical polarization rises with time

first polarize particle along momentum



radial **E** field from **v**×**B**

but there is a problem:



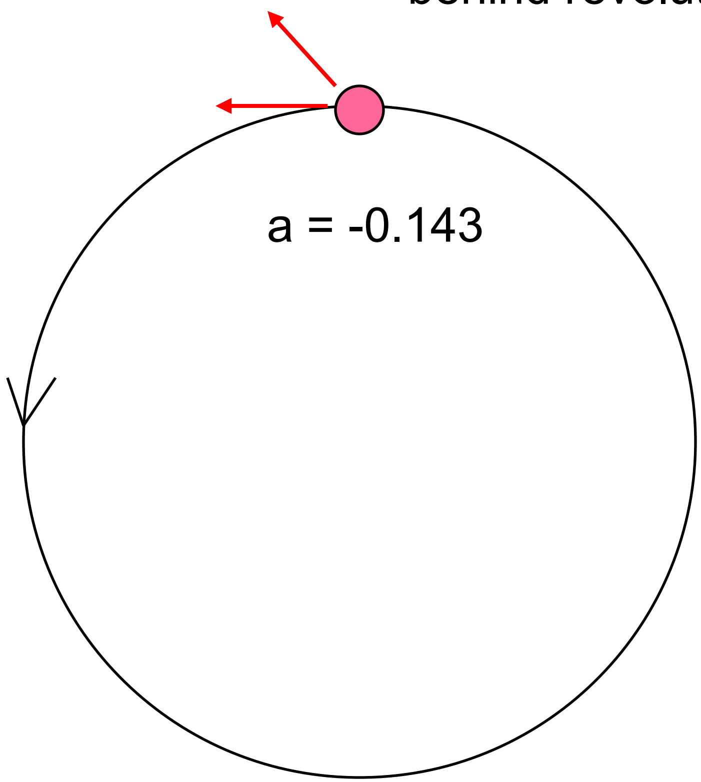
the μ·B precesses the spin quickly in the ring plane

(together the precession plane tilts, but this is hard to observe)

Method 1

good when anomalous moment is small (μ, d)

For the deuteron, $\omega_a < \omega_{cyc}$ and spin lags behind revolution around the ring.



Method 1

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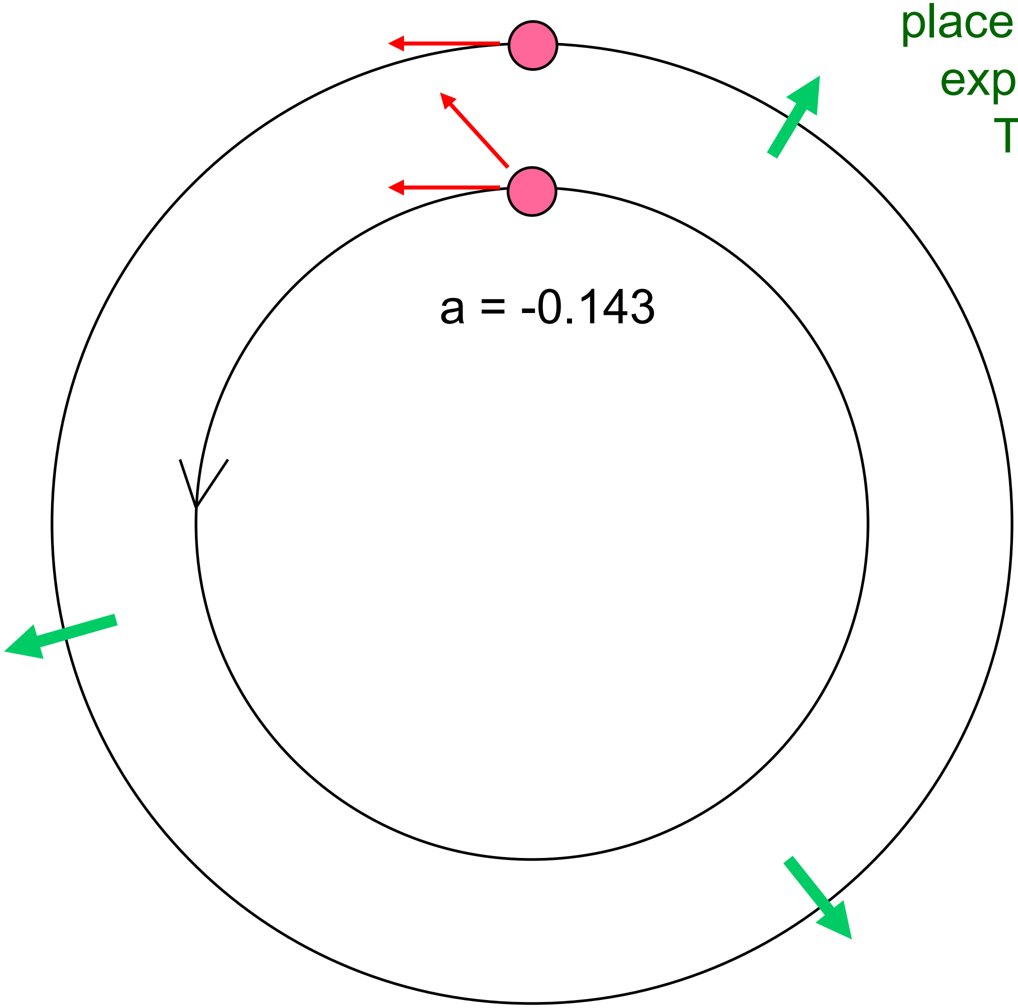


In all the bending magnets, place an outward E field to expand the size of the orbit. This lengthens the time for the particle to complete a revolution while keeping the B field the same.

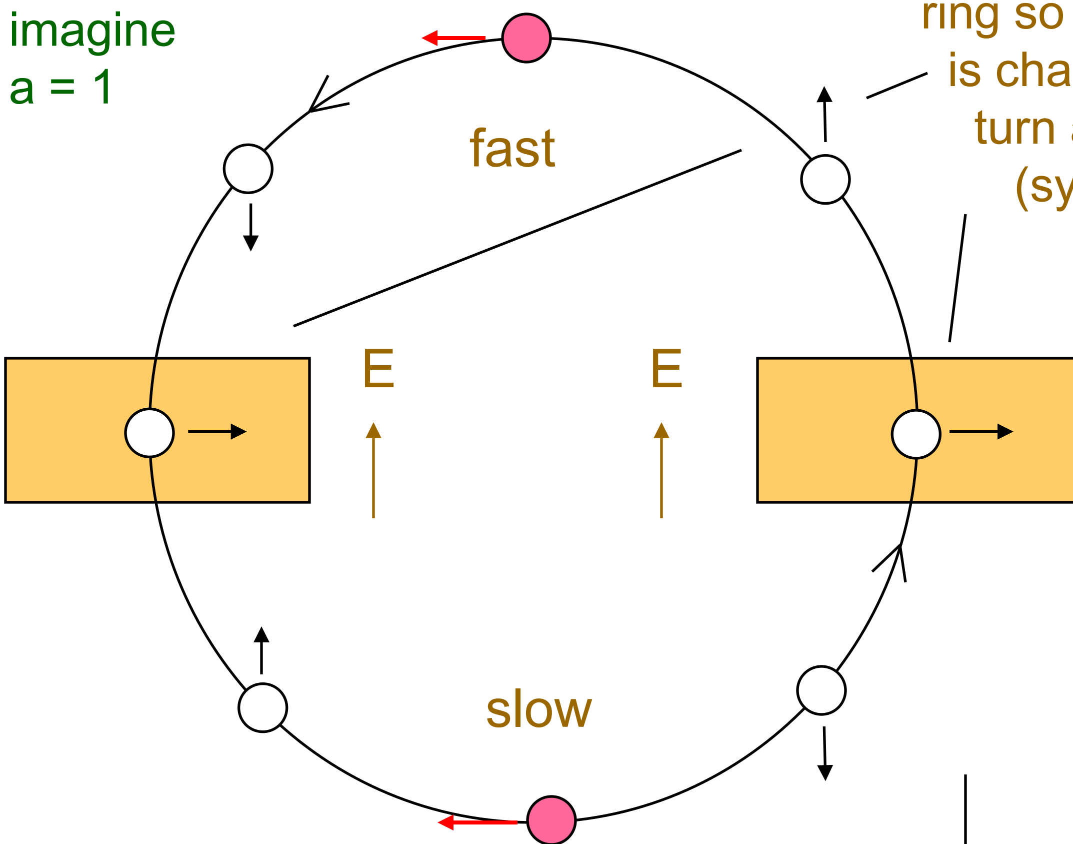
The right ratio of B and E makes $\omega_a = \omega_{cyc}$.

p = 0.7 GeV/c (126 MeV)
E = 3.5 MV/m
B = 0.21 T
radius = 13.3 m

Method 2

good for a broad class of charged particles

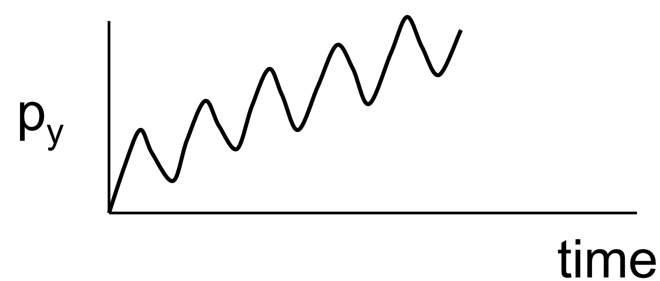
imagine
a = 1



Put 2 RF cavities in the ring so that the velocity is changed twice on each turn around the ring (synchrotron oscillation).

$\omega_{sync} = \omega_a$

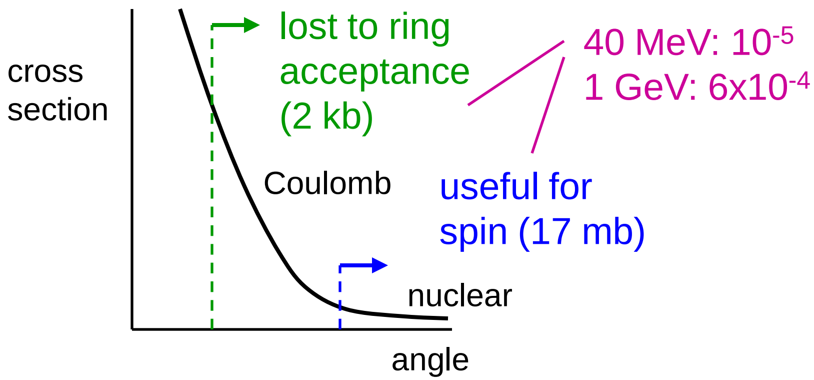
Vertical polarization accumulates in opposite way on opposite sides of the ring. But speed change means it does not cancel.



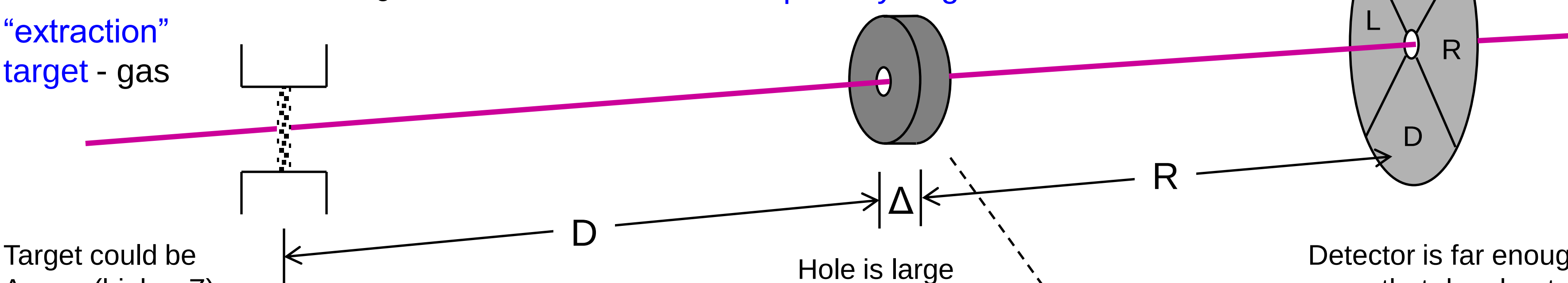
for protons, operate at $\omega_{sync} = \omega_a - 2$

EDM polarimeter

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



(POMME efficiency several percent)



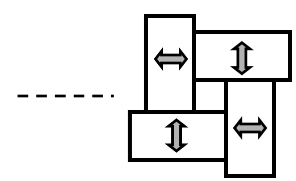
Target could be Ar gas (higher Z).

Target "extracts" by Coulomb scattering deuterons onto thick main target. There's not enough good events here to warrant detectors.

Events must imbed far enough from hole to not multiple scatter out of primary target, thus Δ << D. Δ, which is a large fraction of the deuteron range, sets scale for polarimeter.

Hole is large compared to beam. Every-thing that goes through hole stays in the ring. (It may take several orbits to stop scattered particle.)

Primary target may need to be iris to allow adjustment of position and inner radius. It may also need to be removed during injection.

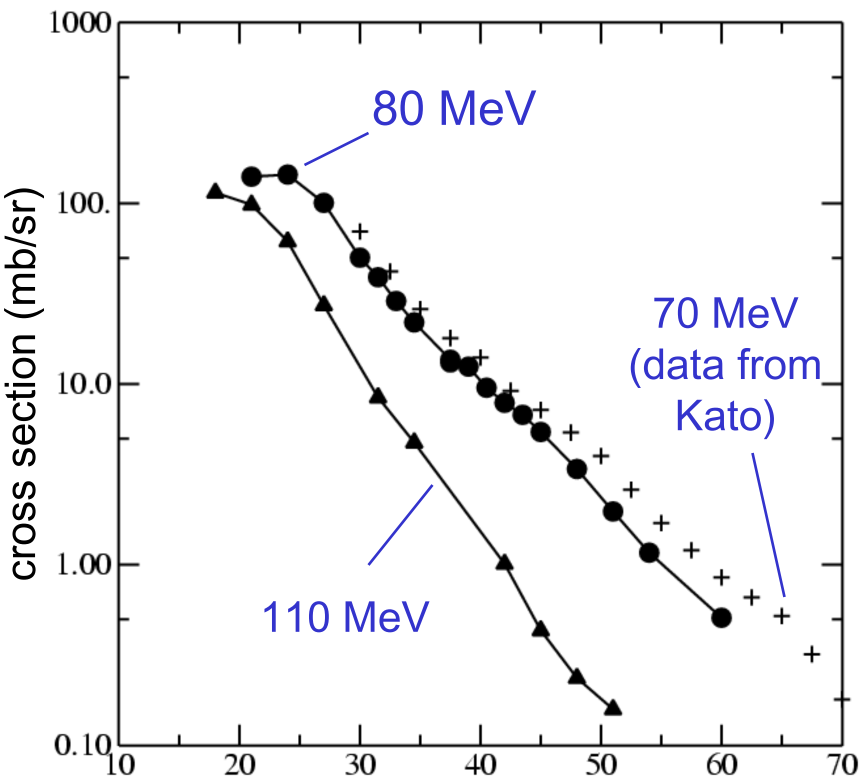


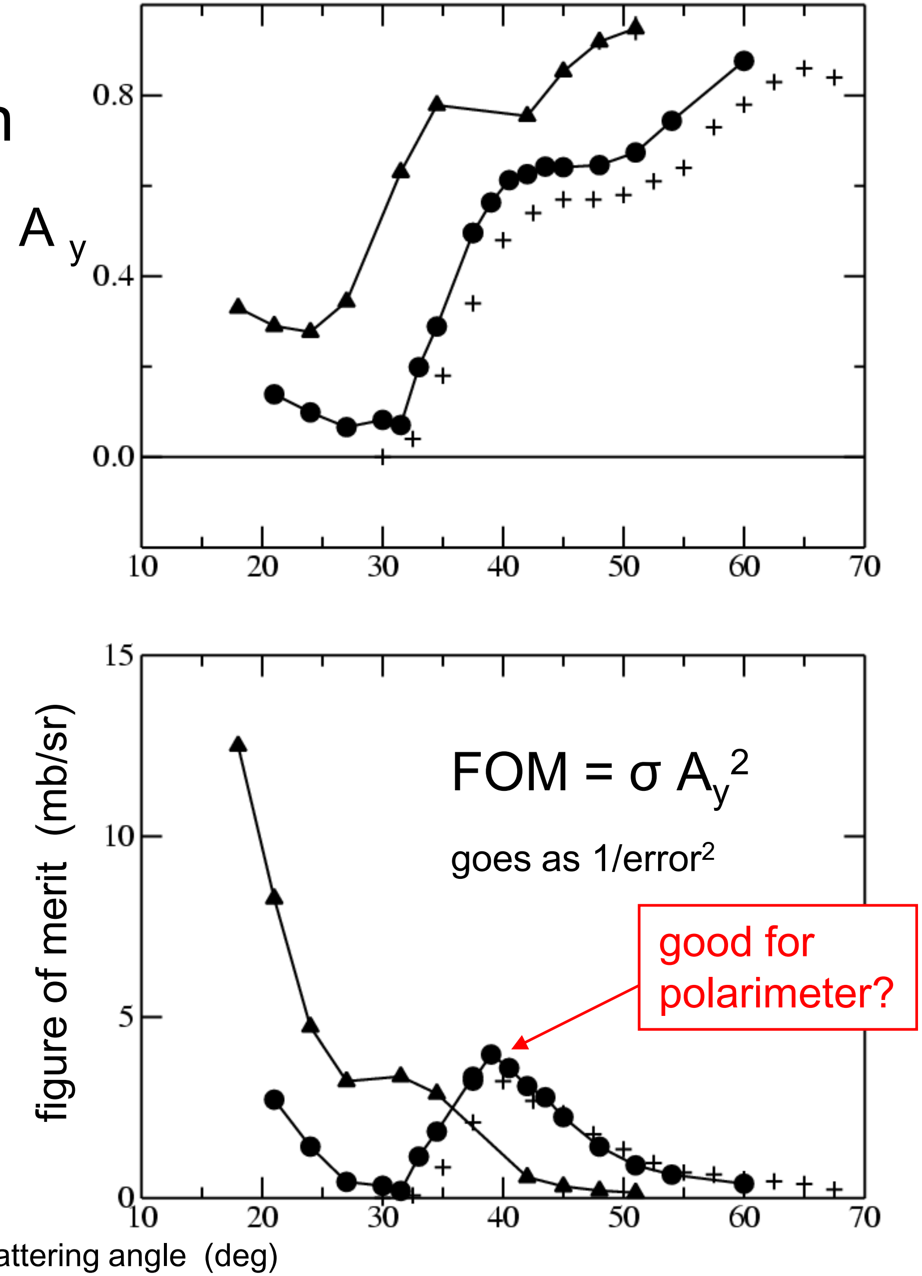
Detector is far enough away that doughnut illumination is not an acceptance issue: Δ < R.

Deuteron elastic scattering angular distributions on carbon

(data from the literature
and KVI studies with
plastic/NaI ΔE-E detectors)

(October, 2004)





New data from BBS at KVI - deuteron elastic scattering

(July, 2005)

110 MeV

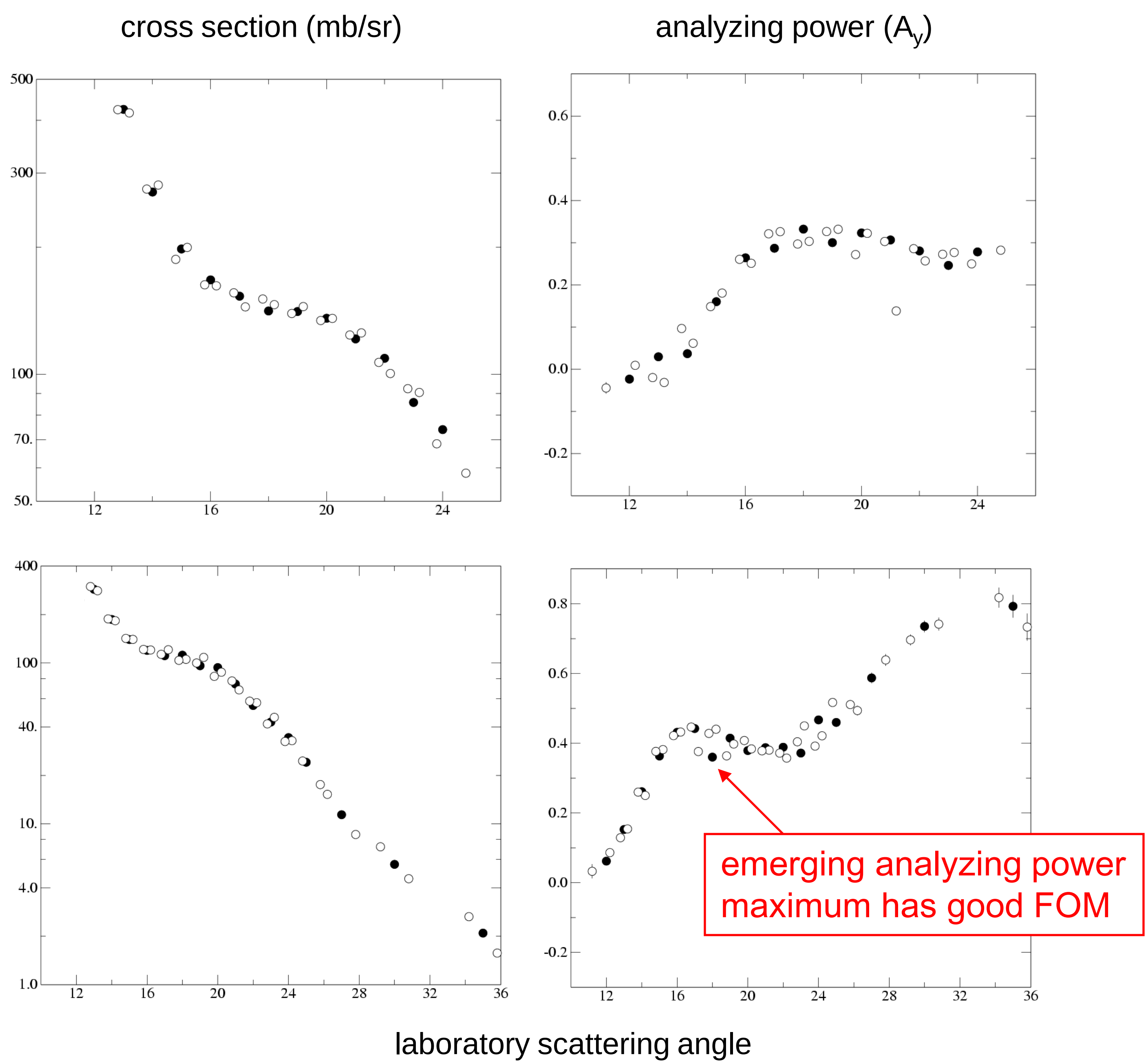
angle acceptance imposed in software after reconstruction from focal plane data

● central angle

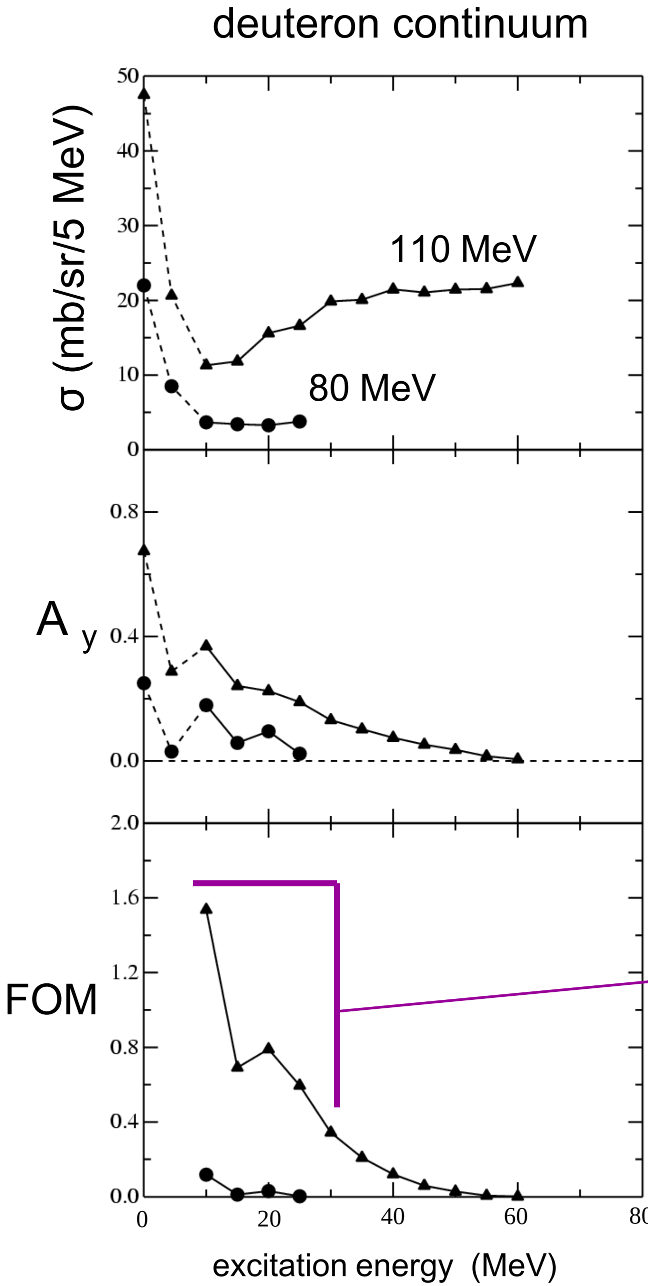
○ angle displaced by 1° from the central angle

133 MeV

Plan: continue measurements at higher energy, design polarimeter using Monte Carlo

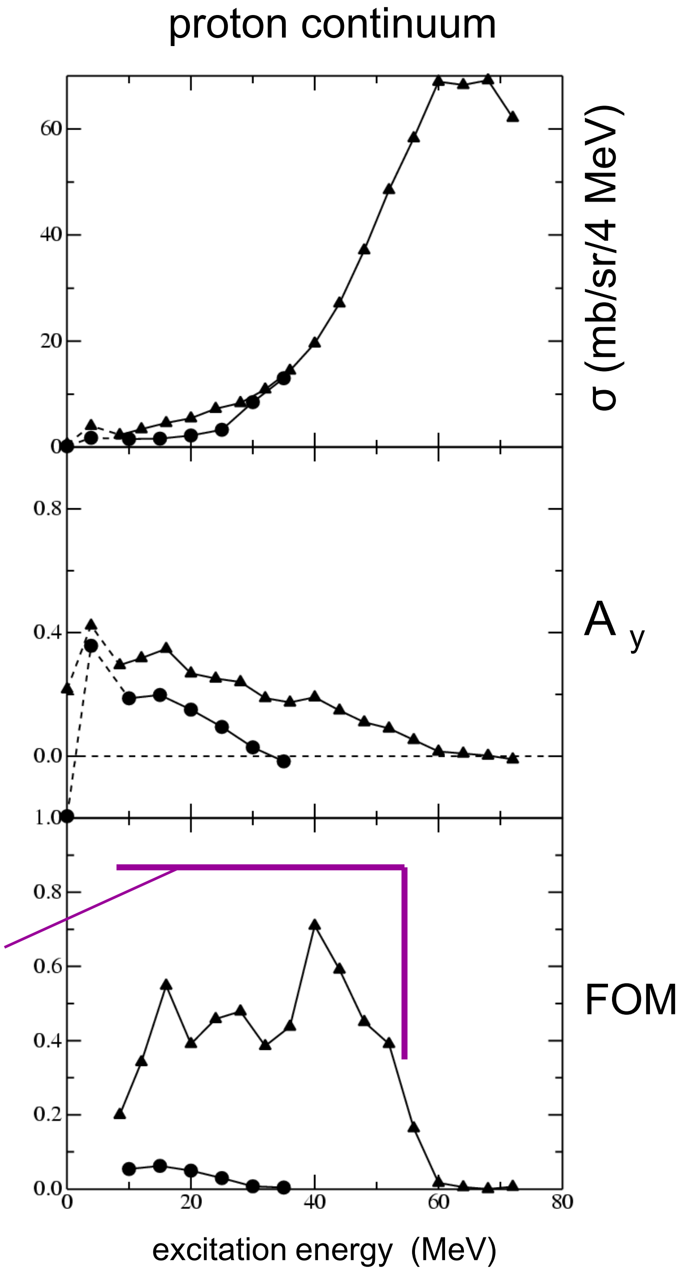


Deuterons and protons from the continuum
34.5°



The positive analyzing powers from the spin-orbit interaction extend into the continuum for both deuterons and protons (neutron transfer or breakup).

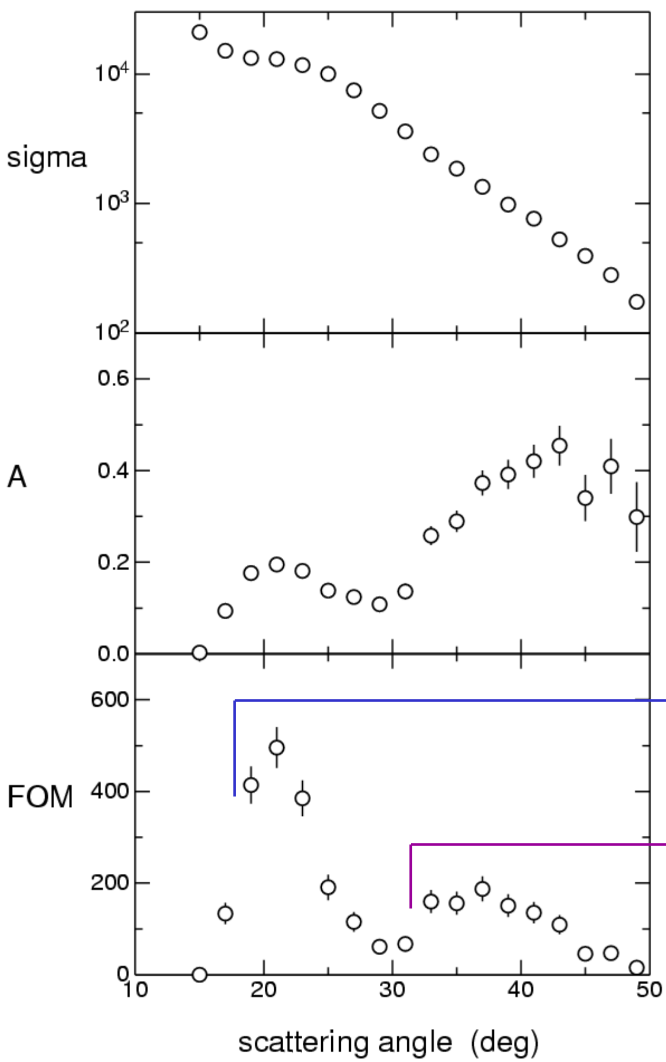
The design should include some of these regions.



Polarimeter Monte Carlo simulations

Simulation for 126 MeV

2.3 cm carbon at 2.22 g/cm^2
0.6 cm carbon absorber
5 MeV counter threshold



For a range of energies (120-500 MeV)

Consider:
- target geometry and shape
- range absorbers (reduce breakup!)
- scintillator readout (pulse/current)
- scintillator segmentation

Study:
- angle/position misalignments
- effects of central hole

Engineering runs:
- calibration
- polarimeter-ring interactions

eff. = 0.87%, ‹A› = 0.18
  likely to grow as energy goes up

eff. = 0.11%, ‹A› = 0.33
  large A, but small cross section
  reduces importance as energy rises

Statistics

p = 1.5 GeV/c

$$\sigma = \frac{4\hbar}{d\sqrt{\tau_p}\; vB\; \underline{it_{11}\, iT_{11}}\; \sqrt{N_c\, fT_{tot}}}$$

fractional error: 0.24

1.6 T (B)

~0.36 ($it_{11}\, iT_{11}$)

10e-29 e·cm (d)

spin coherence time 100 s (τ_p)

particles per fill 10e11 (N_c)

polarimeter efficiency 1% (f)

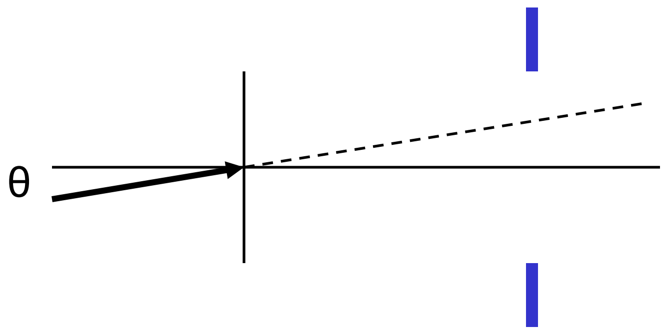
run time 10e7 s (T_{tot})

Orlov: expect rate of growth of 10^{-7}/s at d = 10^{-29} e·cm

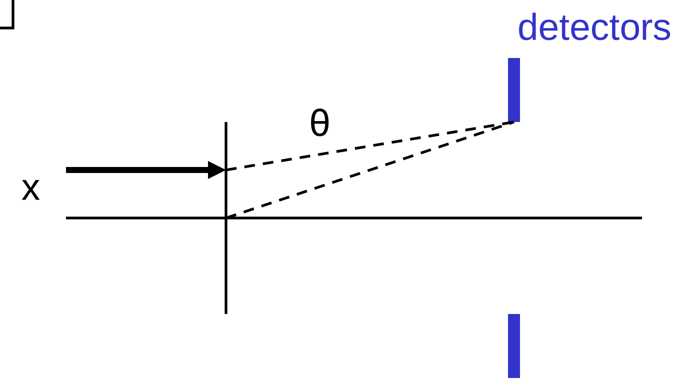
So asymmetry (pA) may be ~ $10^{-6} – 10^{-5}$

Polarimeter Systematic Errors

Displacement / angle errors



angle shift



position shift

Usual remedy:

- measure on both sides (L/R)
- flip initial spin
- use cross ratio formula

$$\varepsilon = pA = \frac{r-1}{r+1} \qquad r = \sqrt{\frac{C_{L+}C_{R-}}{C_{L-}C_{R+}}}$$

left/right efficiency differences cancel

+/− luminosity differences cancel

spin

detector

Errors that are second order in θ and $u = p_+ + p_-$.

$$\varepsilon_{meas} = \varepsilon + \frac{1}{1-\varepsilon^2}\left[\varepsilon^3 u^2 + 2\varepsilon^2 \frac{A'}{A} u\theta + \varepsilon\left(\frac{A''}{A}(1-\varepsilon^2) - \left(\frac{A'}{A}\right)^2 \varepsilon^2\right)\theta^2\right]$$

may appear near 10^{-28} e·cm, but wrong time dependence

Prospects:

designs look feasible for p, d, and possibly ^3He
excellent sensitivity to EDMs on quarks or in NN interaction

sensitivity limits are (roughly):

10^{-27} e·cm in Method 1 (limit is vertical **E** field control)

~ 10^{-29} e·cm in Method 2 (running time about 4 months with spin coherence time ~ 20 s)

all systematic errors checked so far are manageable

Plans:

continue ring designs, systematic error investigations

do polarimeter R&D (deuteron at KVI, Groningen)

gather material for a proposal