Introduction to Polarimetry for a Storage Ring EDM Search

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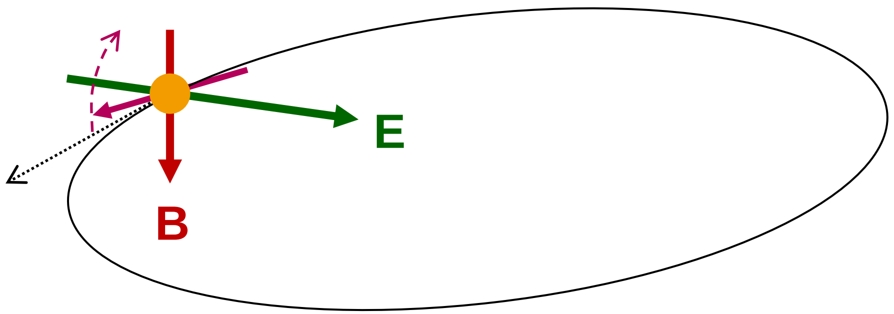
COSY Polarimeter Discussion
21 May 2015

Storage Ring EDM Search:



A storage ring EDM search requires the observation of a rotation of the longitudinal polarization into the vertical direction caused by a radial electric field from **E** or **v**×**B**.

Ring **E** and **B** field chosen to "freeze" precession in the ring plane.

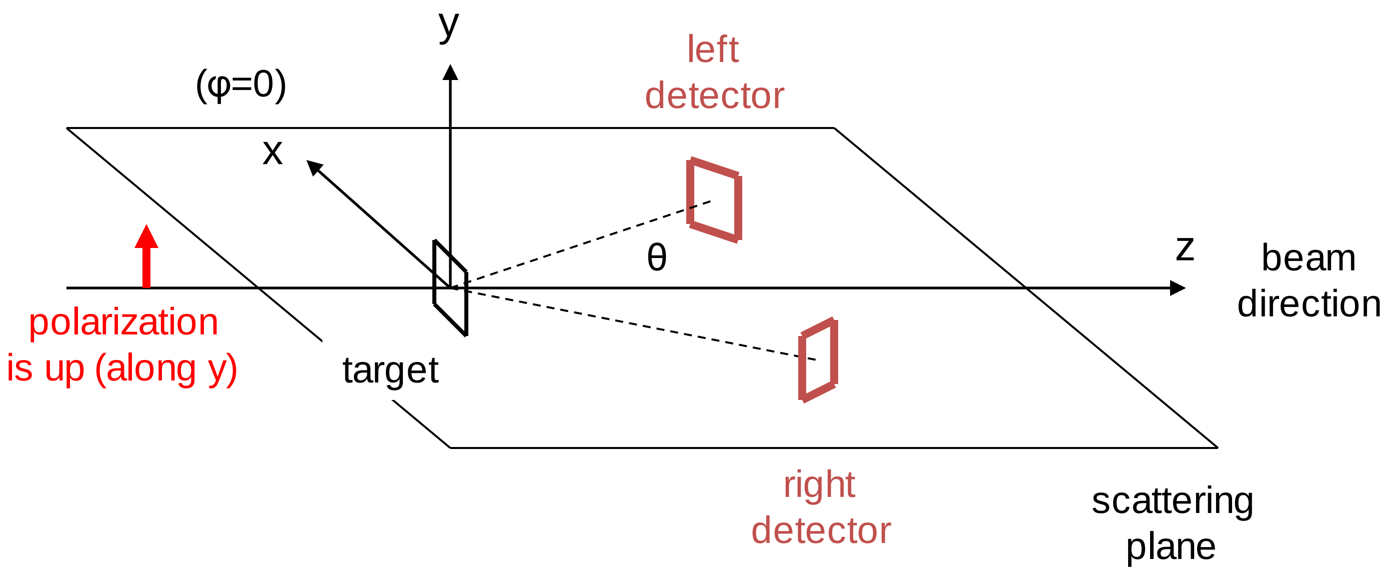
To allow the signal to build to a measurable level, the longitudinal polarization must remain for a long time (~ 1000 s).

Beams may be limited by ring features, collective effects.
Use nuclear scattering as a measurement of polarization.
Large set of polarimeter events needed for signal (10^{12} for μrad angle).
Continuous polarimeter operation (feedback to adjust spin direction).

It is important to use beam efficiently.

The usual solution (spectrometers, double scattering experiments) is to use very thick targets (several cm). The detectors record a broad group of events, not a specific channel. We need sensitivity, not accuracy.

A typical experimental layout contains:



A polarization of the beam (p) causes a difference in the rates for scattering to the left and right according to:

$$\sigma(\theta,\varphi) = \sigma_{unp}(\theta)\left(1 + pA(\theta)\cos\varphi\right)$$

unpolarized cross section (determined by nuclear effects in scattering) governs efficiency

analyzing power (determined by nuclear effects in scattering) governs spin sensitivity

Some systematic errors are handled by a combination of
detectors on the left (L) and right (R)
running with both directions of the polarization

$$\varepsilon = pA = \frac{r-1}{r+1} \qquad r^2 = \frac{L(+)\,\mathrm{R}(-)}{L(-)\,R(+)}$$

"cross ratio"

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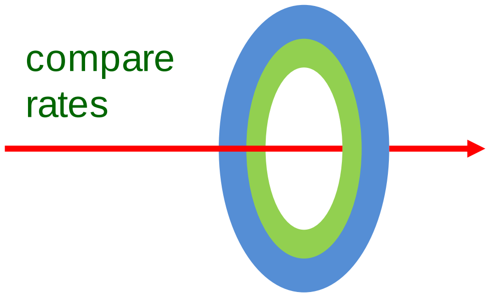
p(y) come from L vs. R (carried EDM signal)

p(x) comes from D vs. U (carries signal on deviation
of polarization direction in the plane – use it
to make corrections to the phase of in-plane angle

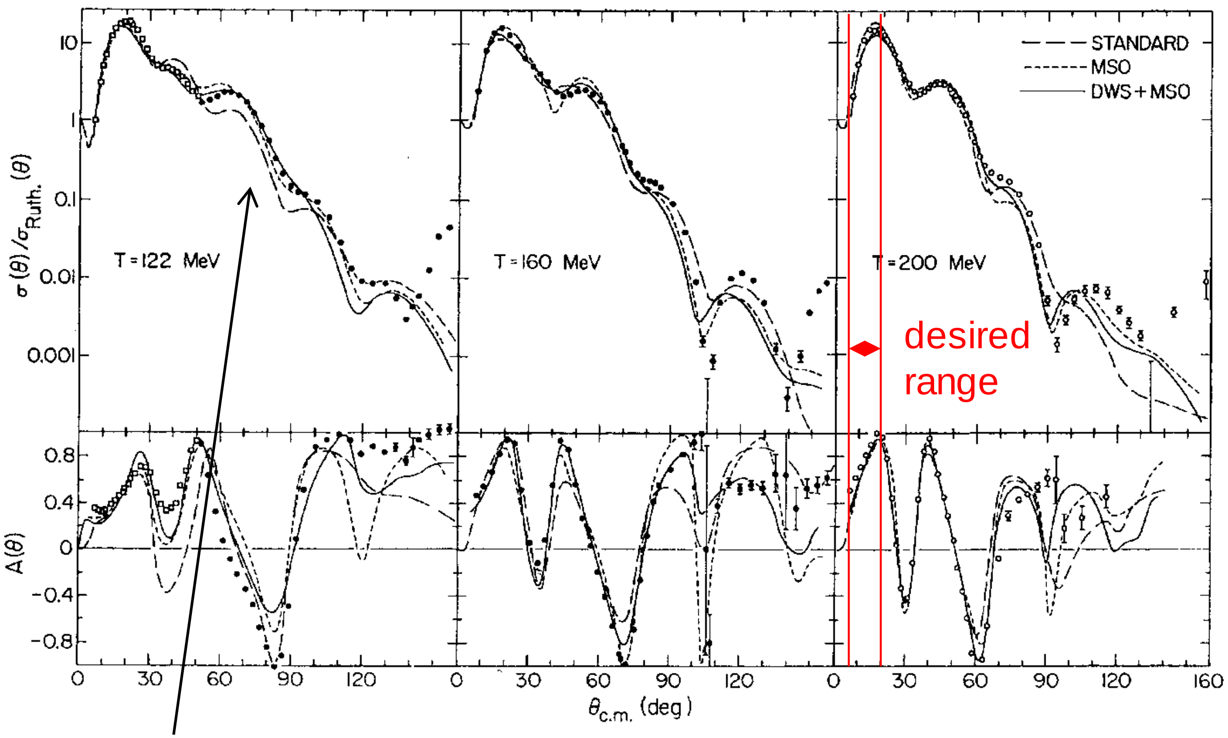
For deuterons, add t_{20} tensor polarization
and use it as a polarization monitor.

Systematic risk is L/R signal from tensor
combined with being off forward direction.



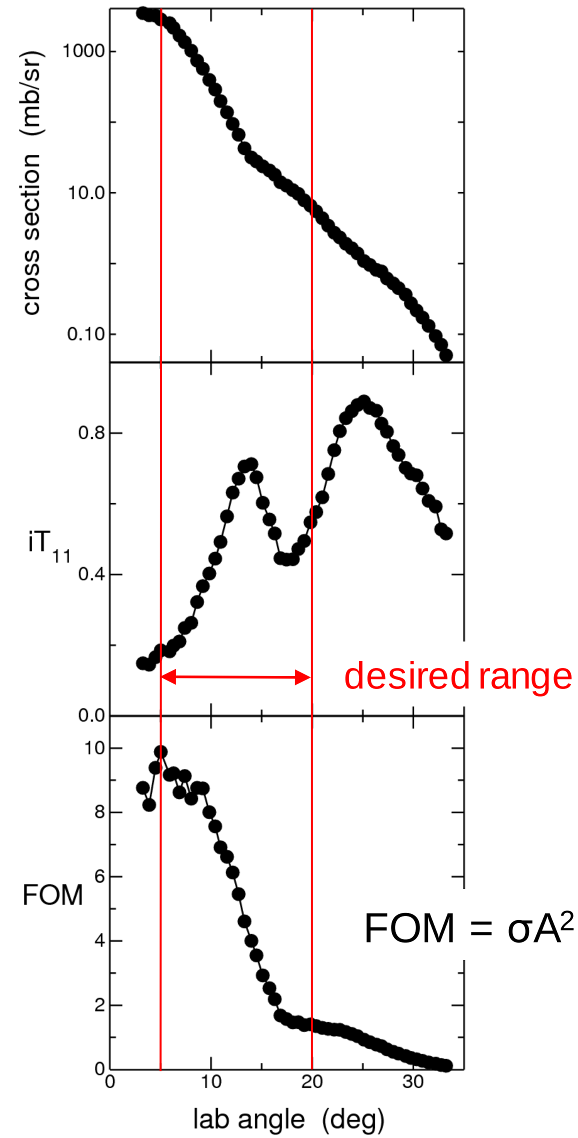
Elastic scattering provides the best polarization sensitivity.

p+C elastic



Note: cross section is divided by the Rutherford cross section

d+C elastic, 270 MeV



Y. Satou, PL B **549**, 307 (2002)

The Indiana data between 100 and 200 MeV

This polarimeter selected for elastic scattering.

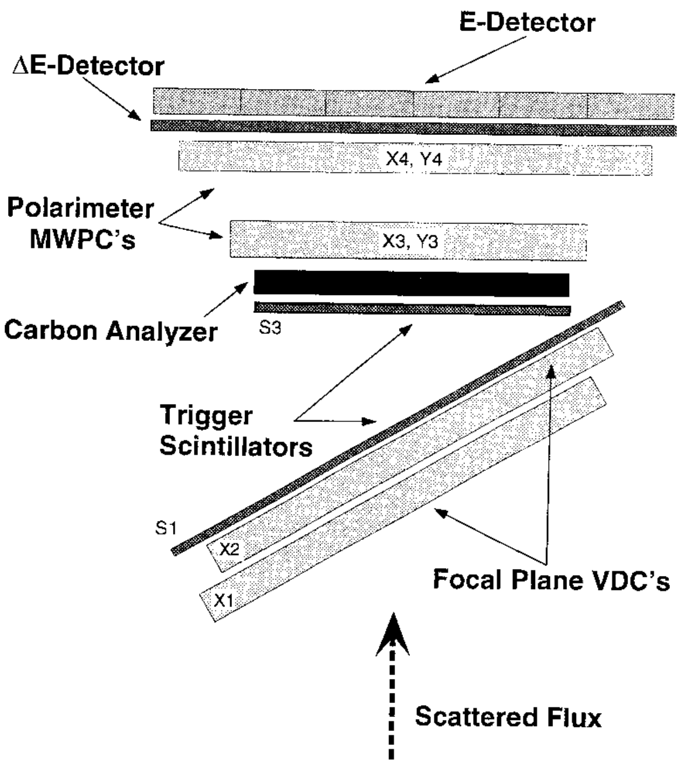
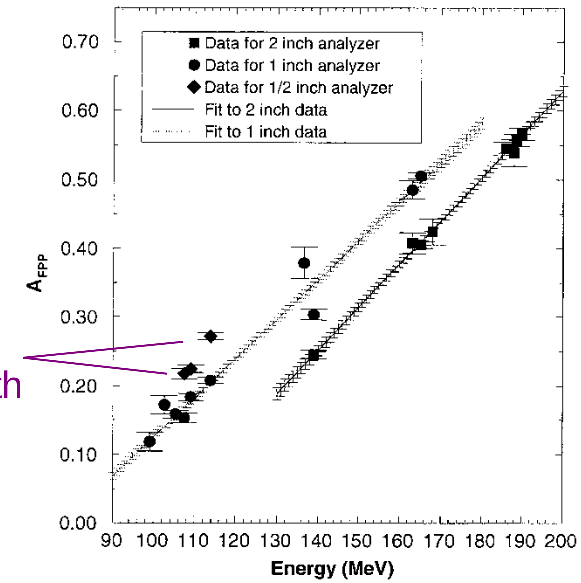
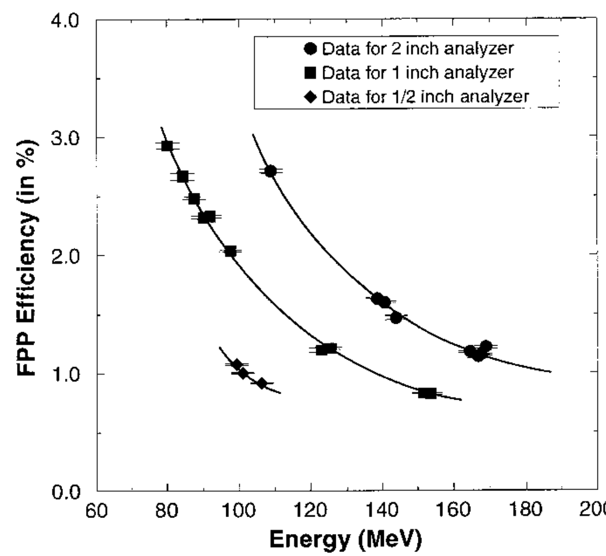


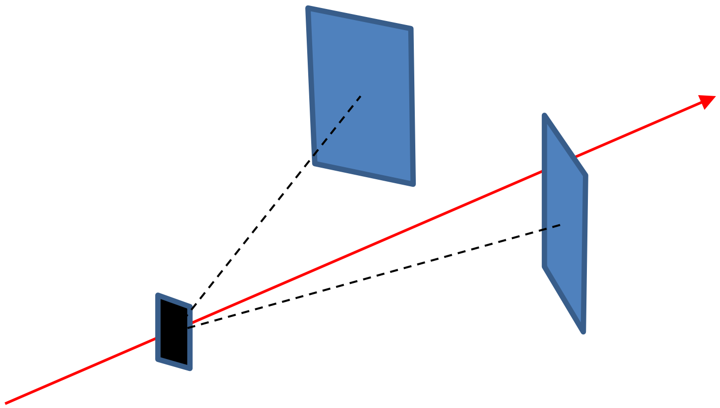
figure of merit is better with thinner target: σA^2





But thick target have not been used in storage ring measurements. This needed to be verified.

Proton-carbon at higher energies

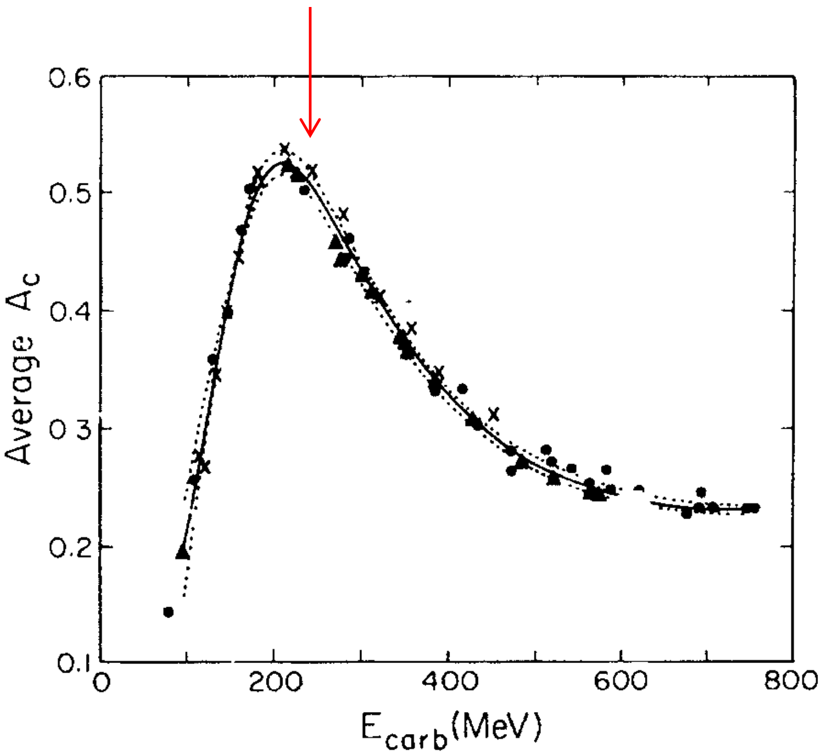


"Thin" detectors may be fine. Lower and upper cuts on the ΔE signal are helpful.

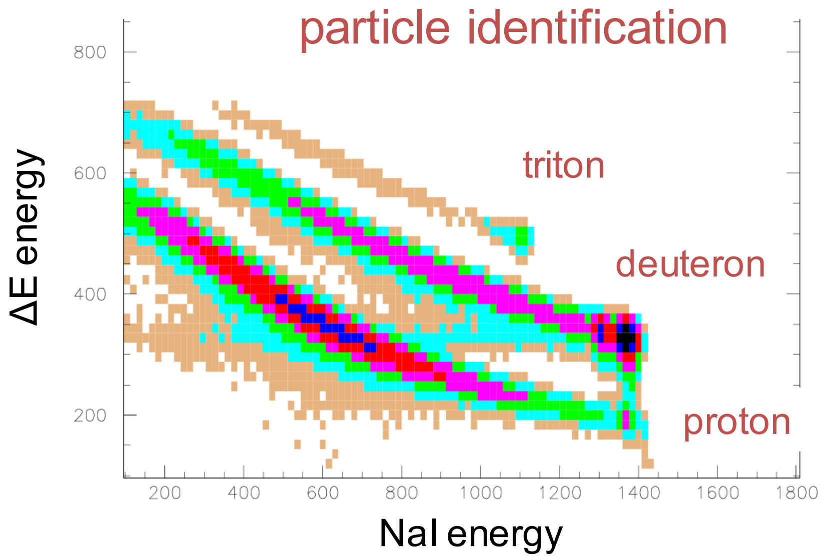
Energy of "magic" proton experiment.

At higher energies (Los Alamos, TRIUMF, Jefferson Lab…) the detectors were passing scintillators (no calorimetry).

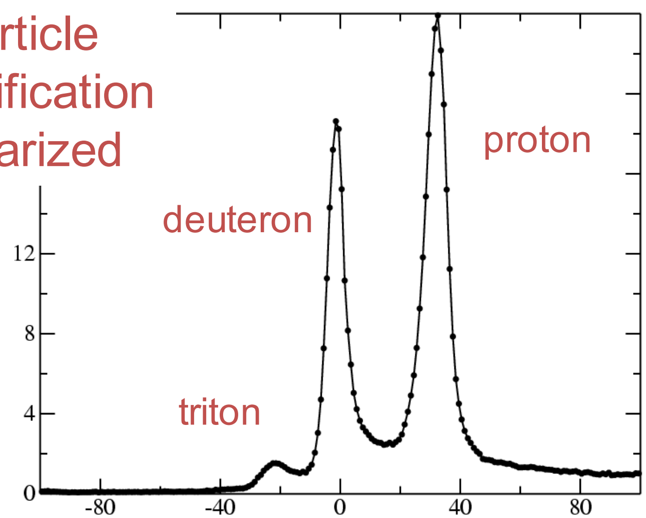
Similar results →



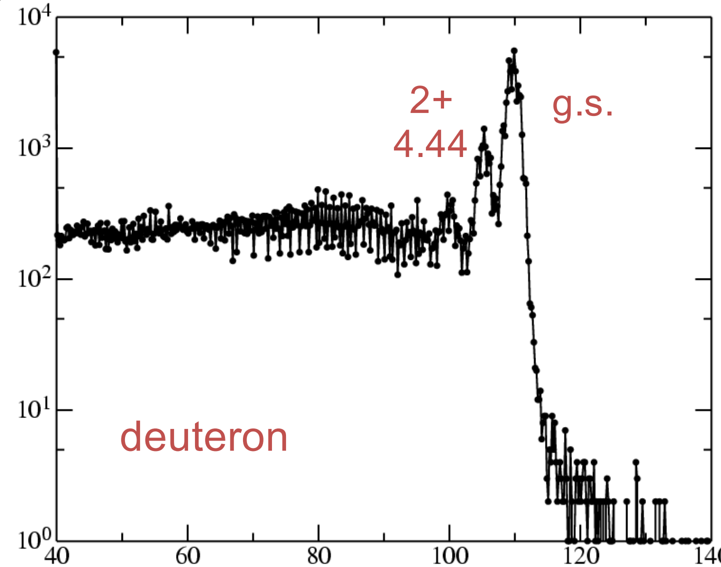
Deuteron spectra (110 MeV, 27°)

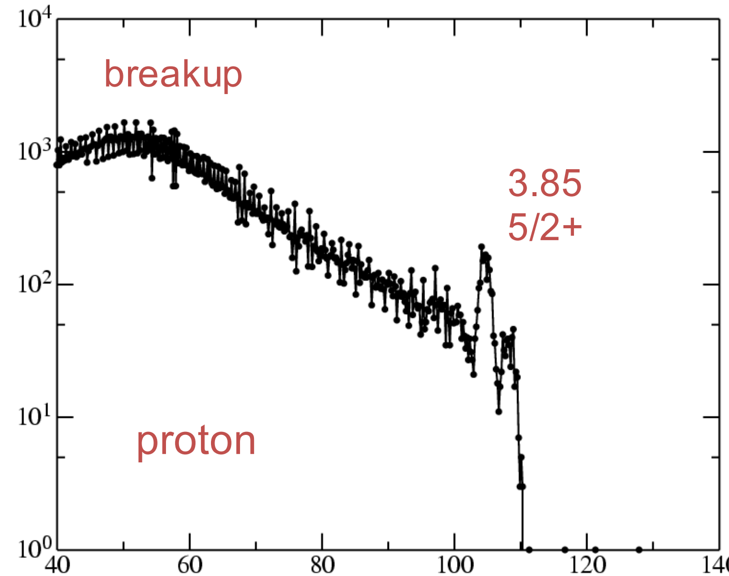


particle identification linearized



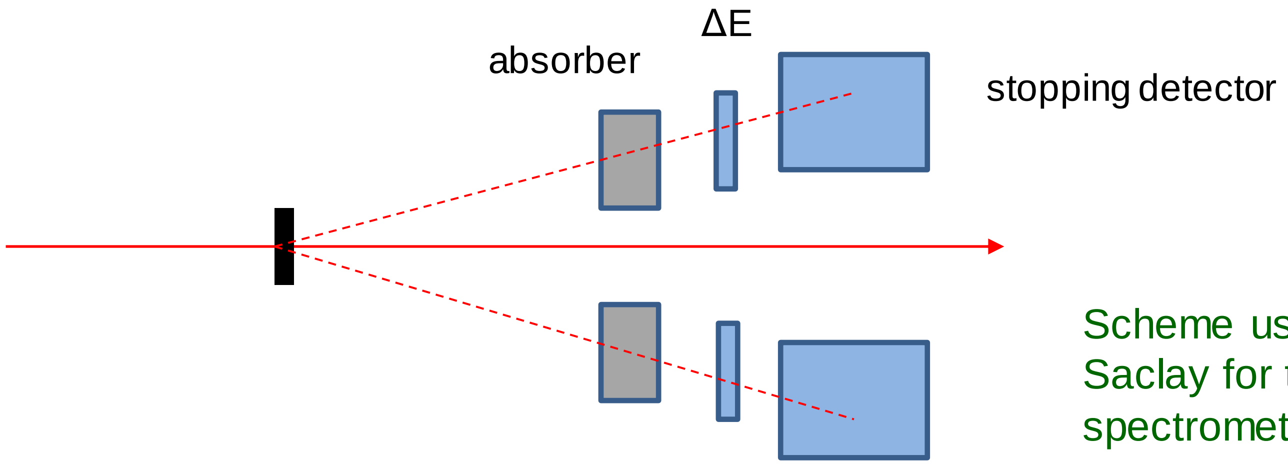
selected particle spectra





energy of particle emitted from target (MeV)

One possible approach: use absorbers

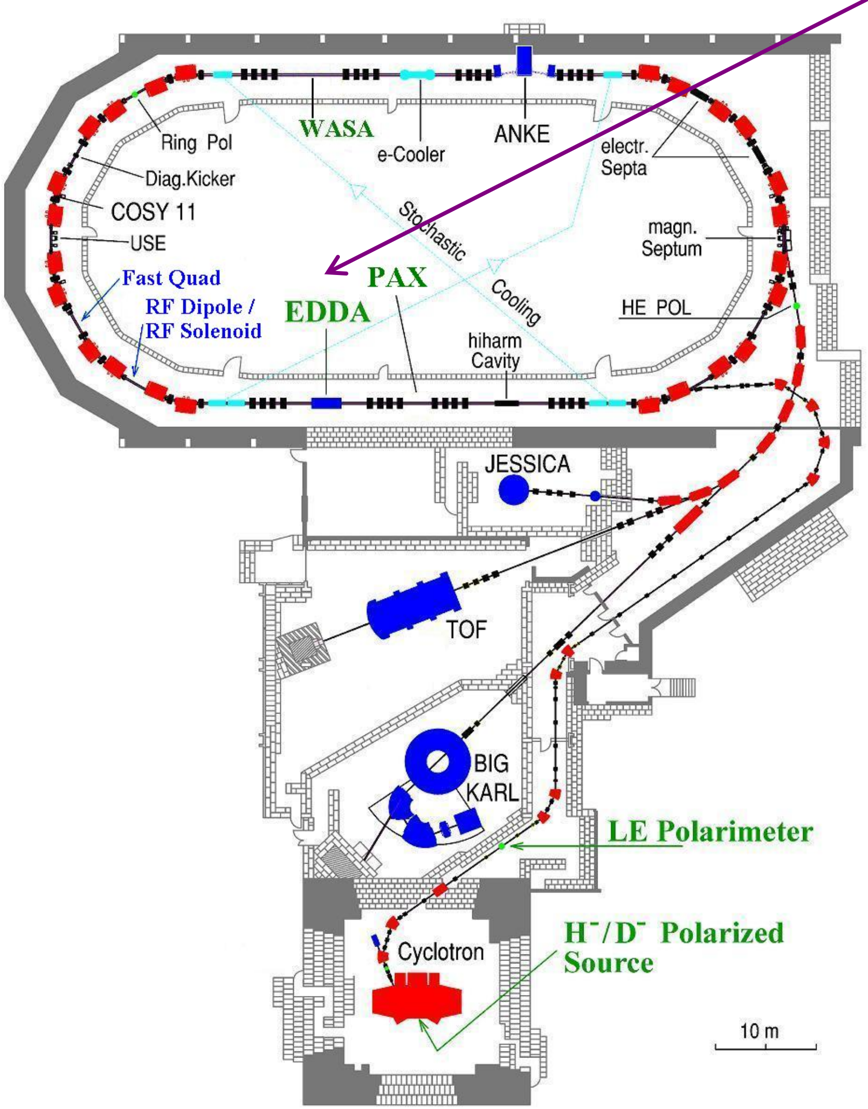


Scheme used by Saclay for their spectrometer.

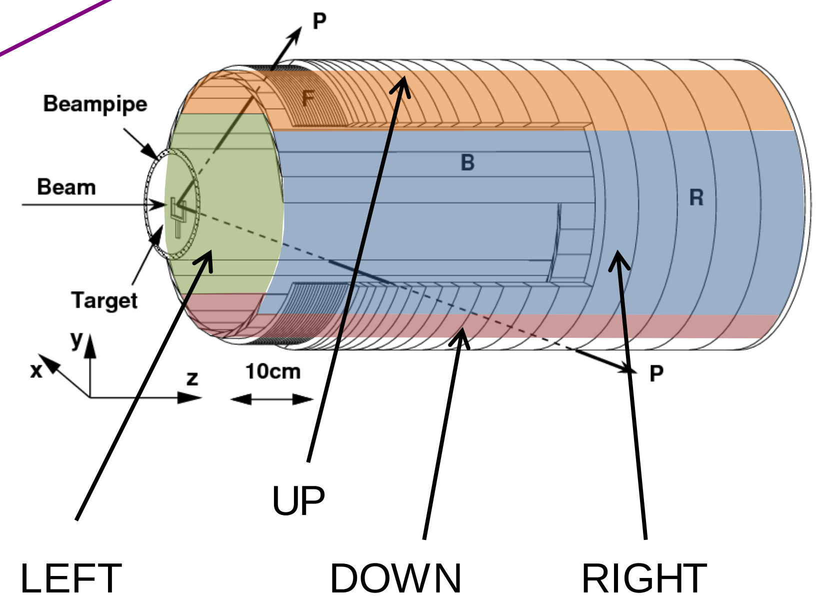
(+) Raw fux is reduced by the absorbers.
(−) Multiple scattering degrades quality of tracking.

COSY storage ring

polarized deuterons, 0.97 GeV/c



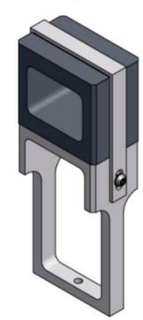
EDDA detector



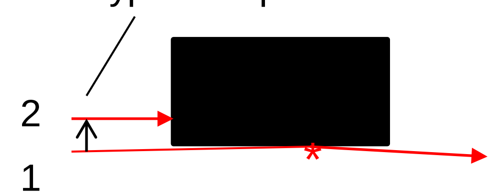
Azimuthal angles yield two asymmetries:

$$\varepsilon_{EDM} = \frac{L-R}{L+R} \qquad \varepsilon_{g-2} = \frac{D-U}{D+U}$$

15 mm C
target



typical depth ~ 0.2 mm



double-hit extraction?:
deflect at (1), then oscillate to (2)

How to manage systematic errors:

(measuring left-right asymmetry)

Usual tricks: Locate detectors on both sides of the beam (L and R).
Repeat experiment with up and down polarization.
Cancel effects in formula for asymmetry (cross-ratio).

From experiments with large induced errors and a model of those errors:

$$pA = \varepsilon = \frac{r-1}{r+1} \qquad r^2 = \frac{L(+)R(-)}{L(-)R(+)}$$

But this fails at second order in the errors.

Using the data itself, devise parameters:

$$\phi = \frac{s-1}{s+1} \quad s^2 = \frac{L(+)L(-)}{R(+)R(-)},$$

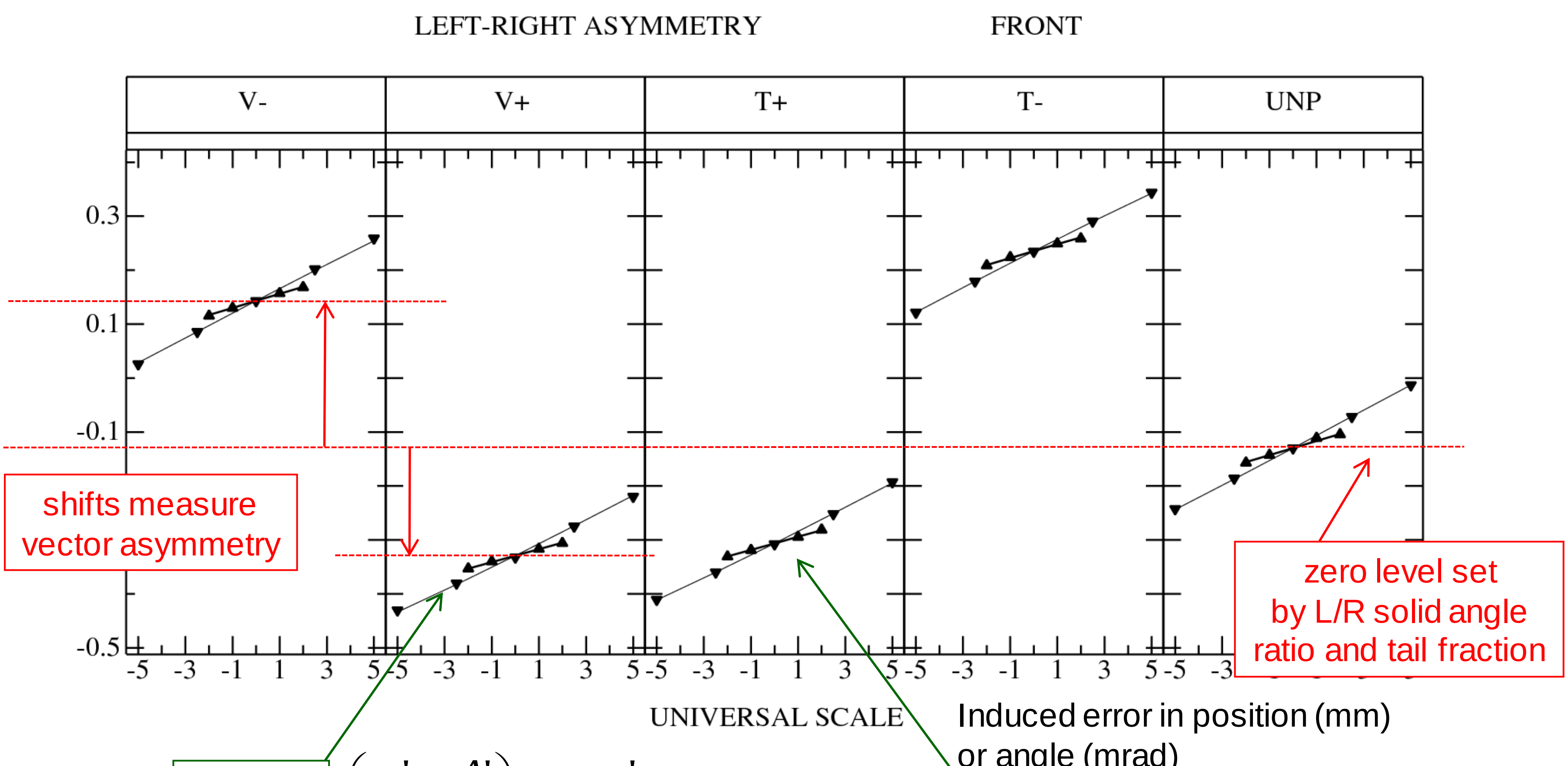
and rate $W = L + R$

Calibrate polarimeter derivatives and correct (real time):

$$\varepsilon_{CR,corr} = \frac{r-1}{r+1} - \left(\frac{\partial \varepsilon_{CR}}{\partial \phi}(\phi)\right)_{MODEL} \Delta\phi - \left(\frac{\partial \varepsilon_{CR}}{\partial W}(W)\right)_{MODEL} \Delta W$$

Changes to beam position/angle produced effects that calibrate the polarimeter for errors.

Group 5



slopes given by

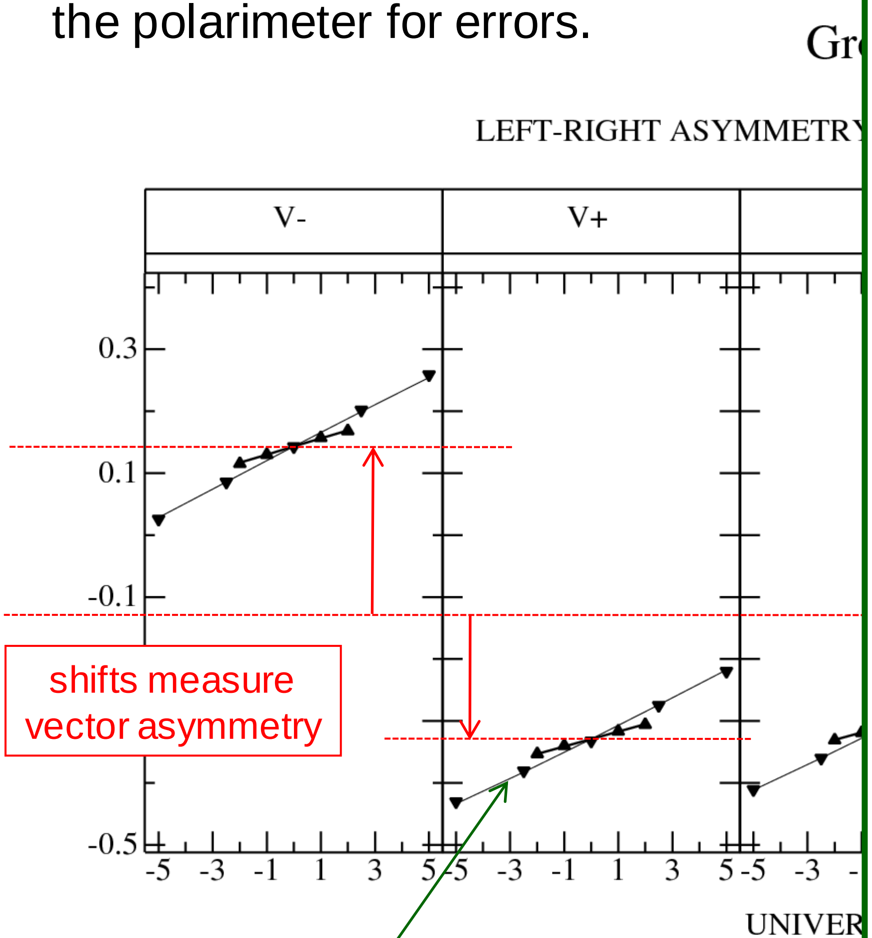
$$\left(\frac{\sigma'}{\sigma}+\frac{A'}{A}\right)\varepsilon^2-\frac{\sigma'}{\sigma}$$

slope difference measures "effective" distance to detector

$$\frac{\sigma'}{\sigma}=-0.02562(9) \quad \frac{A'}{A}=0.0055(3) \quad \frac{1}{rad}$$

X/θ = 52.4(8) cm

Changes to beam position/angle produced effects that calibrate the polarimeter for errors.



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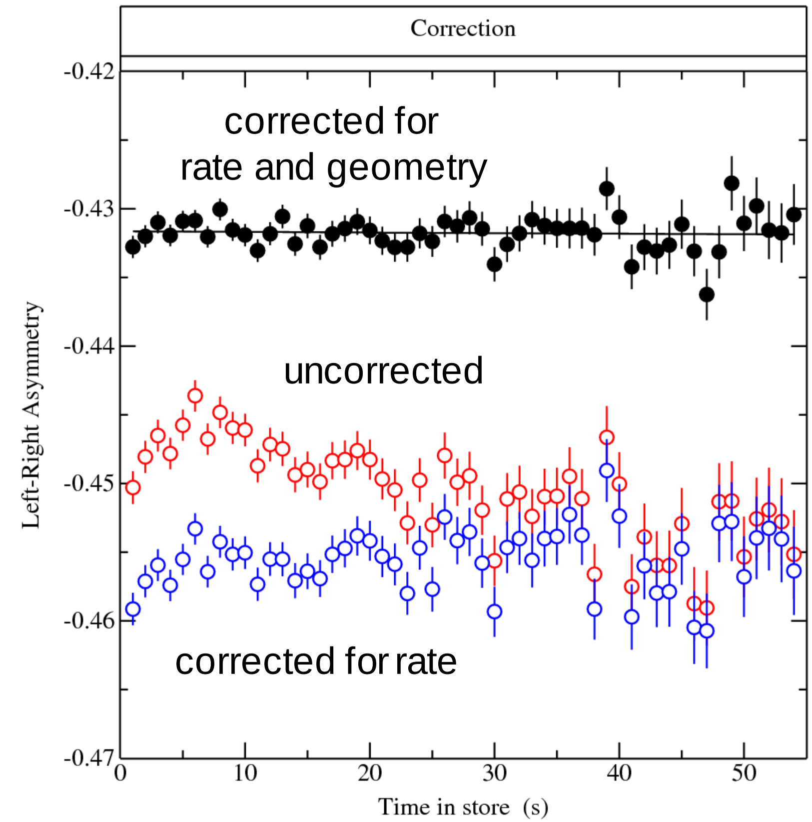
$$\frac{\sigma'}{\sigma}=-0.02562(9) \qquad \frac{A'}{A}=0.0055(3)\ \frac{1}{rad}$$

Application to data with errors shows correction in real time.



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Further systematic effects (to be more fully considered):

Beam size effects (not large).

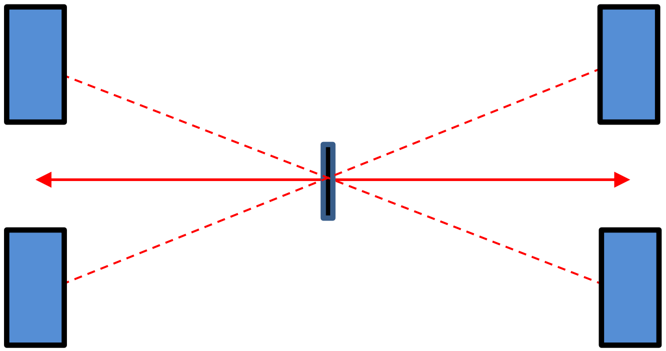
More complex phase space patterns.

Beam polarization profiles (direction, spin tune)

May need precise traceback.

Useful information about various systems:

- Energy resolution
- Time resolution*
- Position tracking
- Angle tracking
- Rate capability
- Percent coverage
- Particle Identification
- Main backgrounds
- Size
- Bi-directionality
- Cost



*pulse separation ~ 30 ns