STORAGE RING POLARIMETRY

Polarimeter Development

Requirements

1. Measure a change in the vertical polarization with a sensitivity of 10^{-6}.
   Provide a continuous record with time.
   Reduce systematic errors to below the sensitivity limit.

2. Track the magnitude of the polarization with time.

3. Provide transverse (X) asymmetry data continuously for control.
   Operate at high efficiency.

Polarimeter Development
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Development proposal made to COSY-Jülich in 2007.
Ring design was for 1 GeV/c deuteron beam (250 MeV)

Best scheme requires deuteron scattering from carbon.

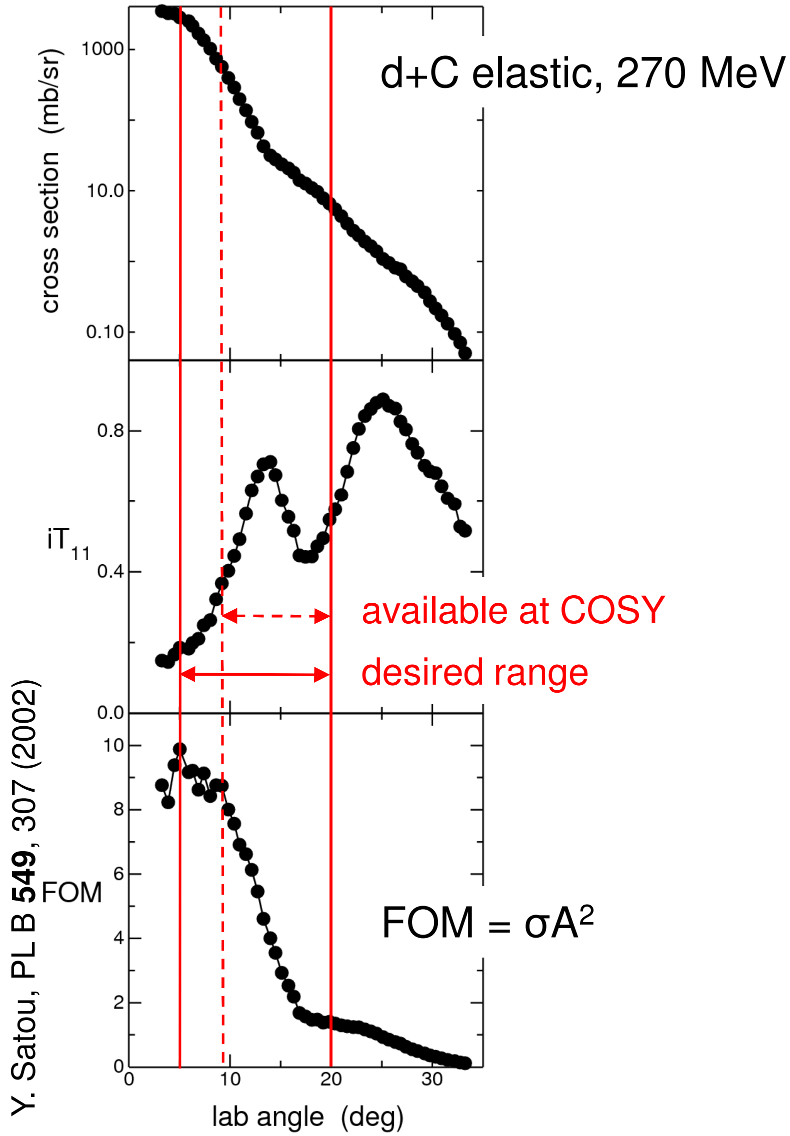
Conduct study using as much existing equipment as possible.

(Begin studies of production/preservation of horizontal polarization.)

Deuteron and proton polarimeters are similar.

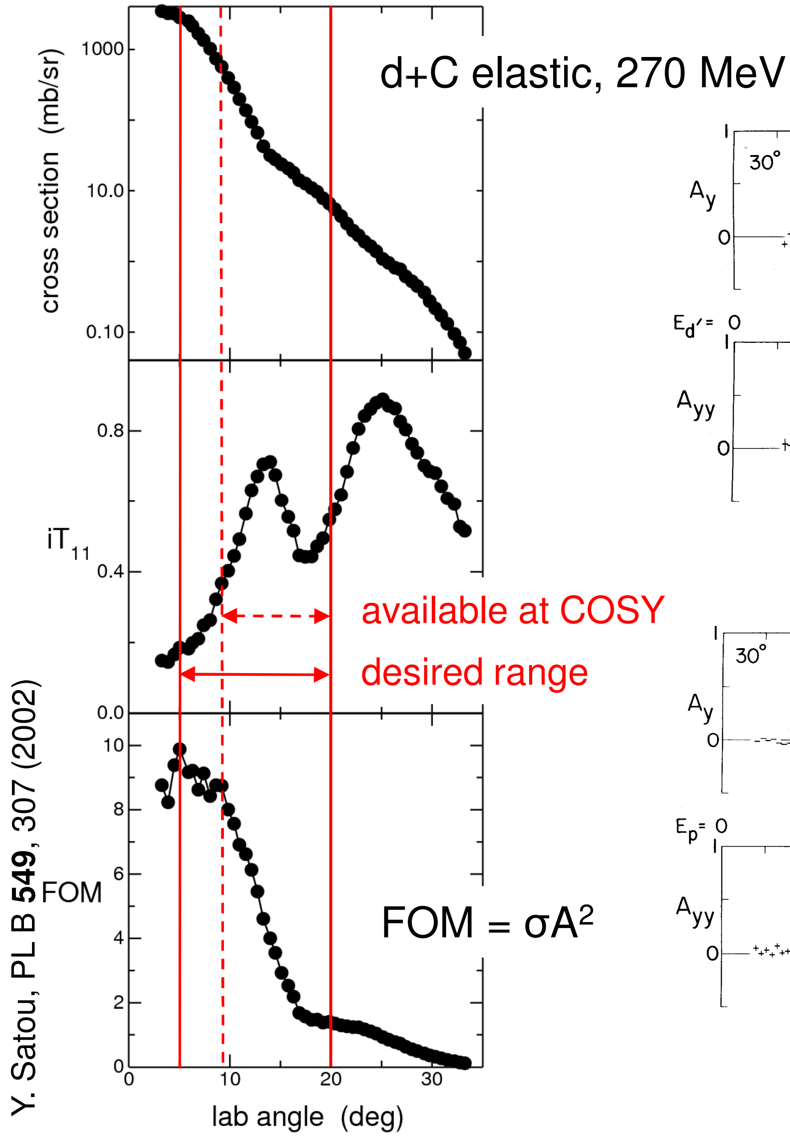
Polarimeter Development

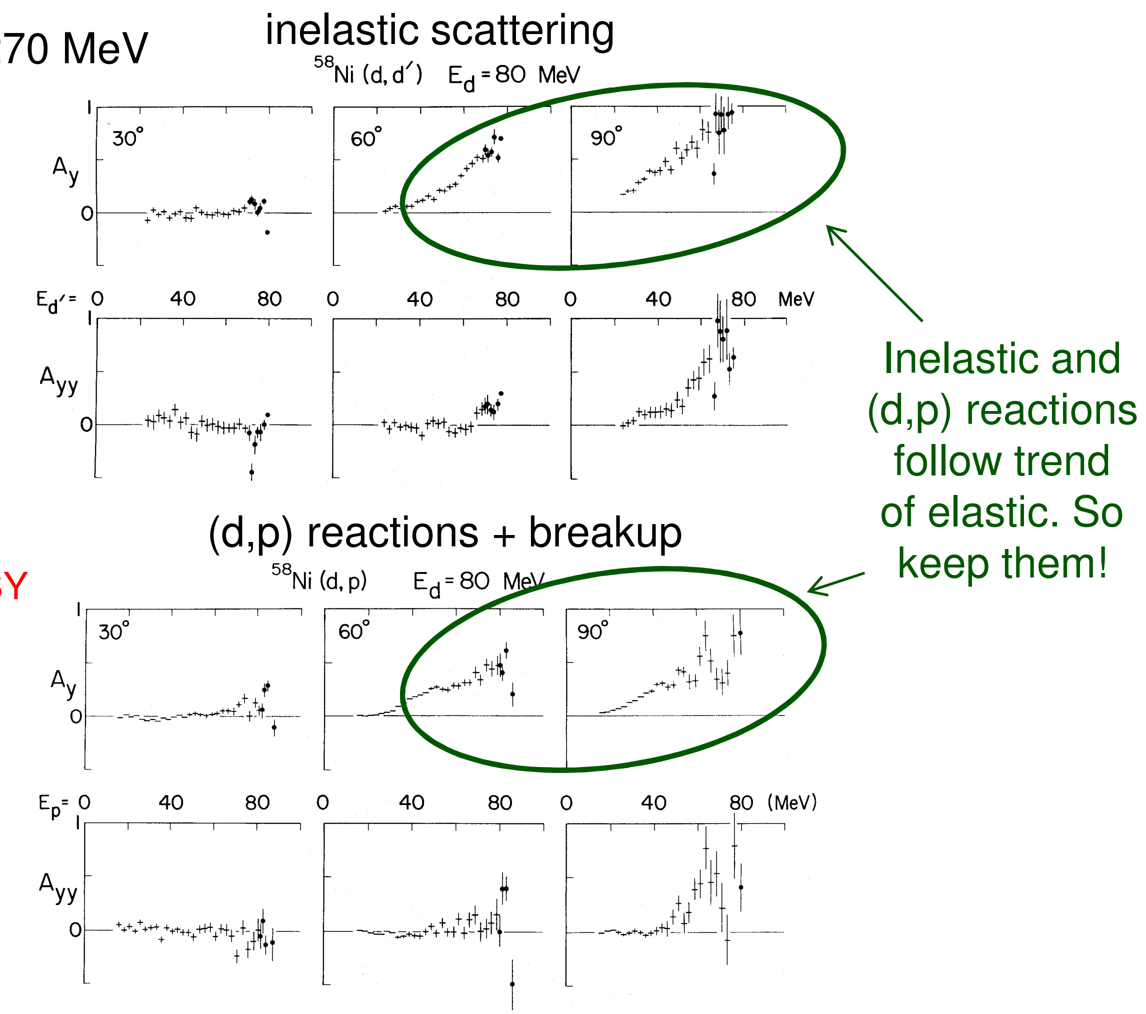
Analyzing Reaction Characteristics



Polarimeter Development

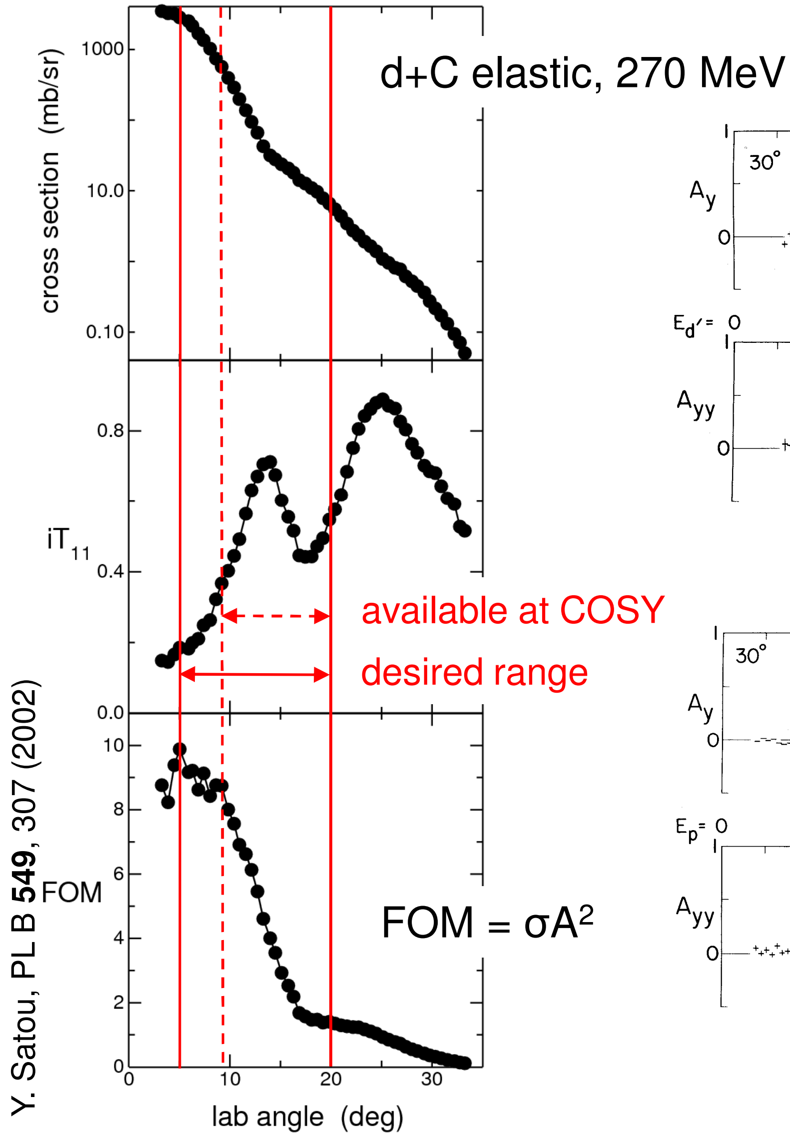
Analyzing Reaction Characteristics

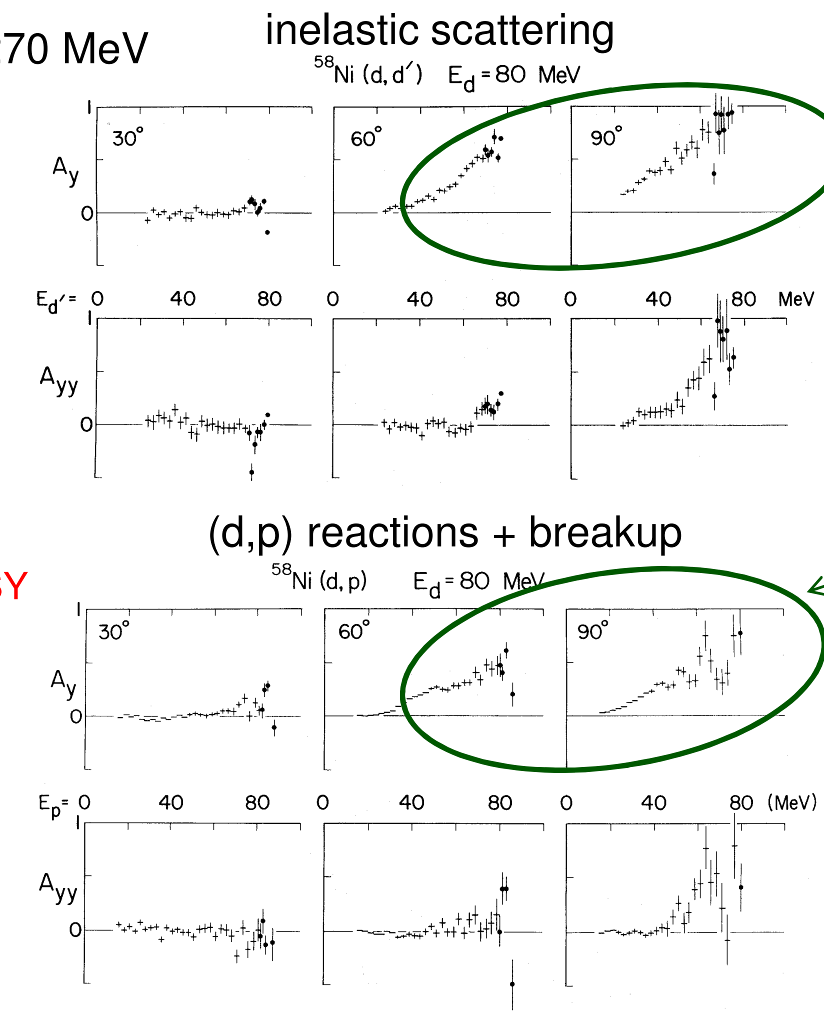




Polarimeter Development

Analyzing Reaction Characteristics





Inelastic and (d,p) reactions follow trend of elastic. So keep them!

(Tensor can be large and useful.)

DAQ does not keep just single channel.
Include low Q-value reactions.

Polarimeter Development

Polarimeter Properties

Broad acceptance for high efficiency:

Angle range = 5° to ~20°
Excitation range < ~40 MeV
No particle identification
Stable properties rely on stable gains, thresholds, etc.
Build and calibrate (including systematic errors properties)

Implications for polarimeter design:

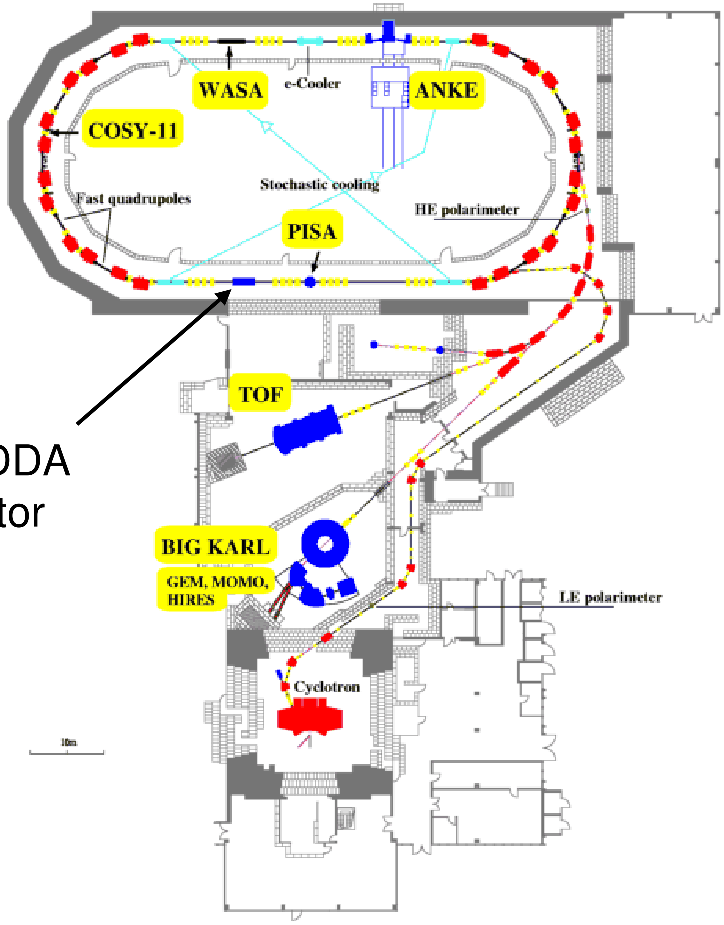
Low analyzing power particles can be removed with an absorber
Count everything above threshold
DAQ can be simple (scaler) and fast for high statistics, low dead time
Detector must be insensitive to rate changes
Thick targets are required (several cm) for high efficiency (~1%)

Design features that go beyond current polarimeters:

Extraction from a storage ring onto a thick internal target
Reduction of systematic error effects to 10^{-6}

Polarimeter Development
COSY tests

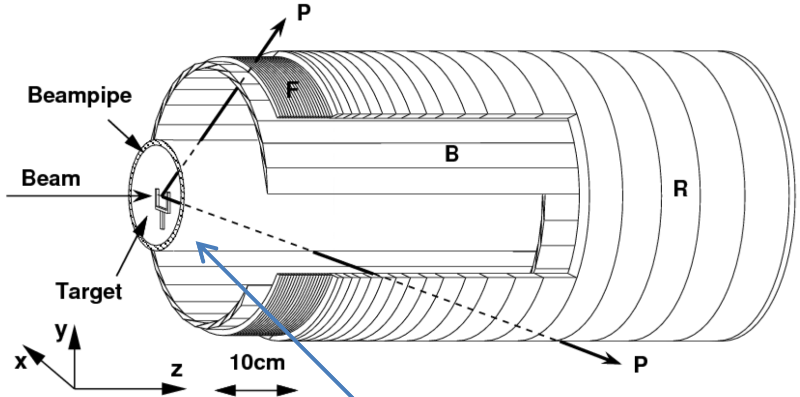
COSY ring:



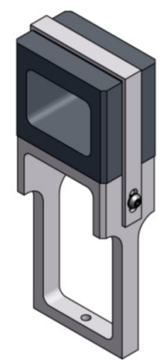
Use EDDA detector

EDDA detector:

Rings and bars to determine angles.



Tube target, extracts along inside edge.



Polarimeter Development
COSY tests

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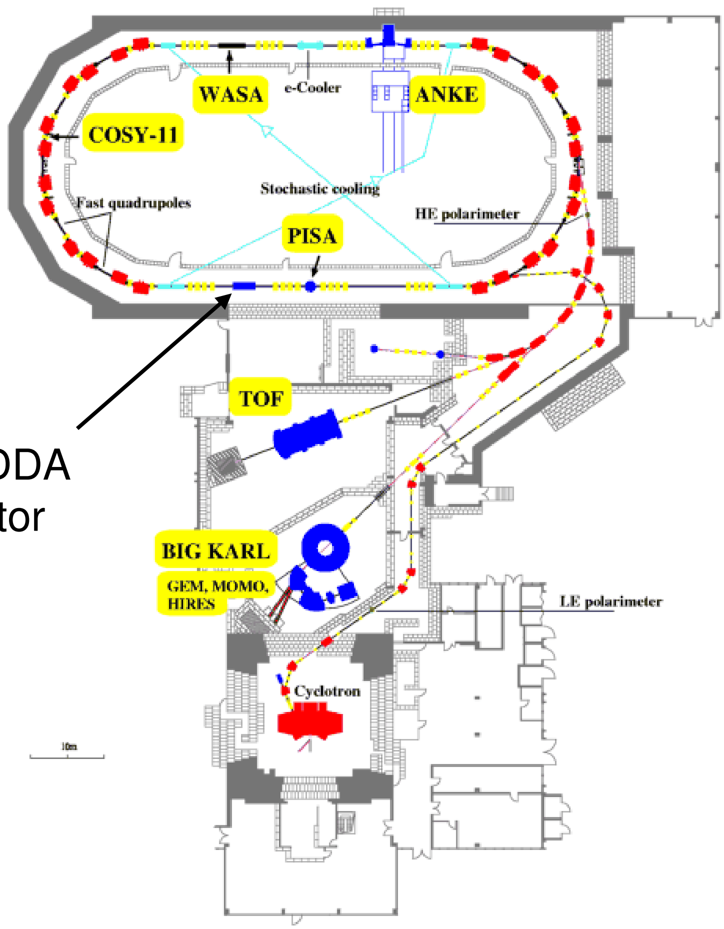

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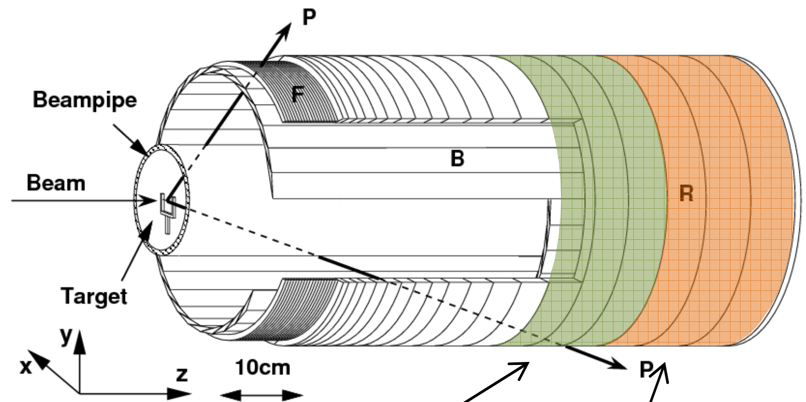

REAR: This is a check of methods

FRONT: This is where EDDA looks like an EDM polarimeter.

Run at 0.97 GeV/c.

Polarimeter Development
COSY tests

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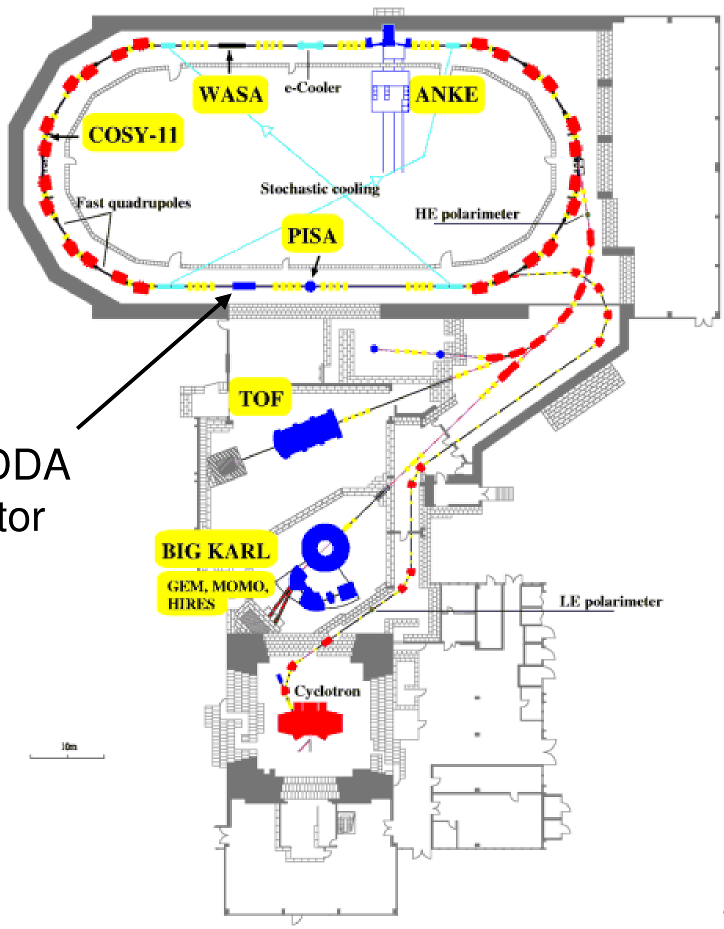

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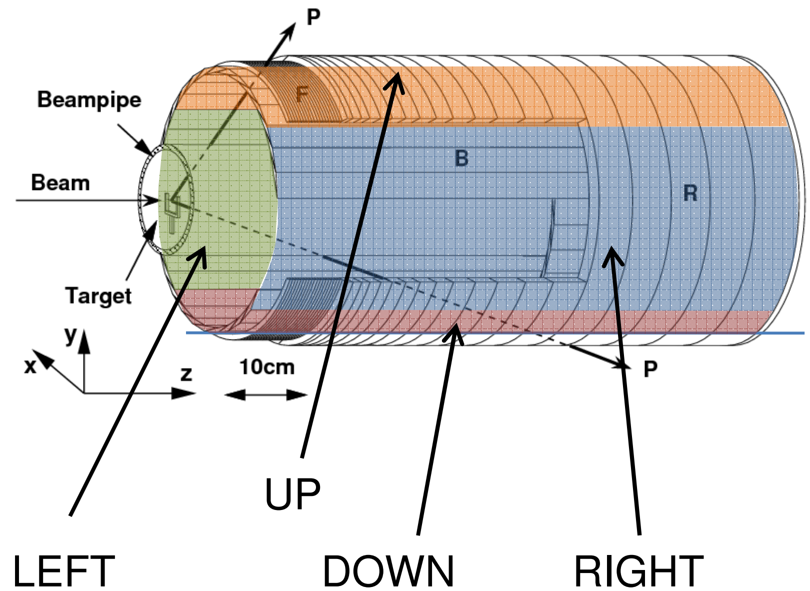
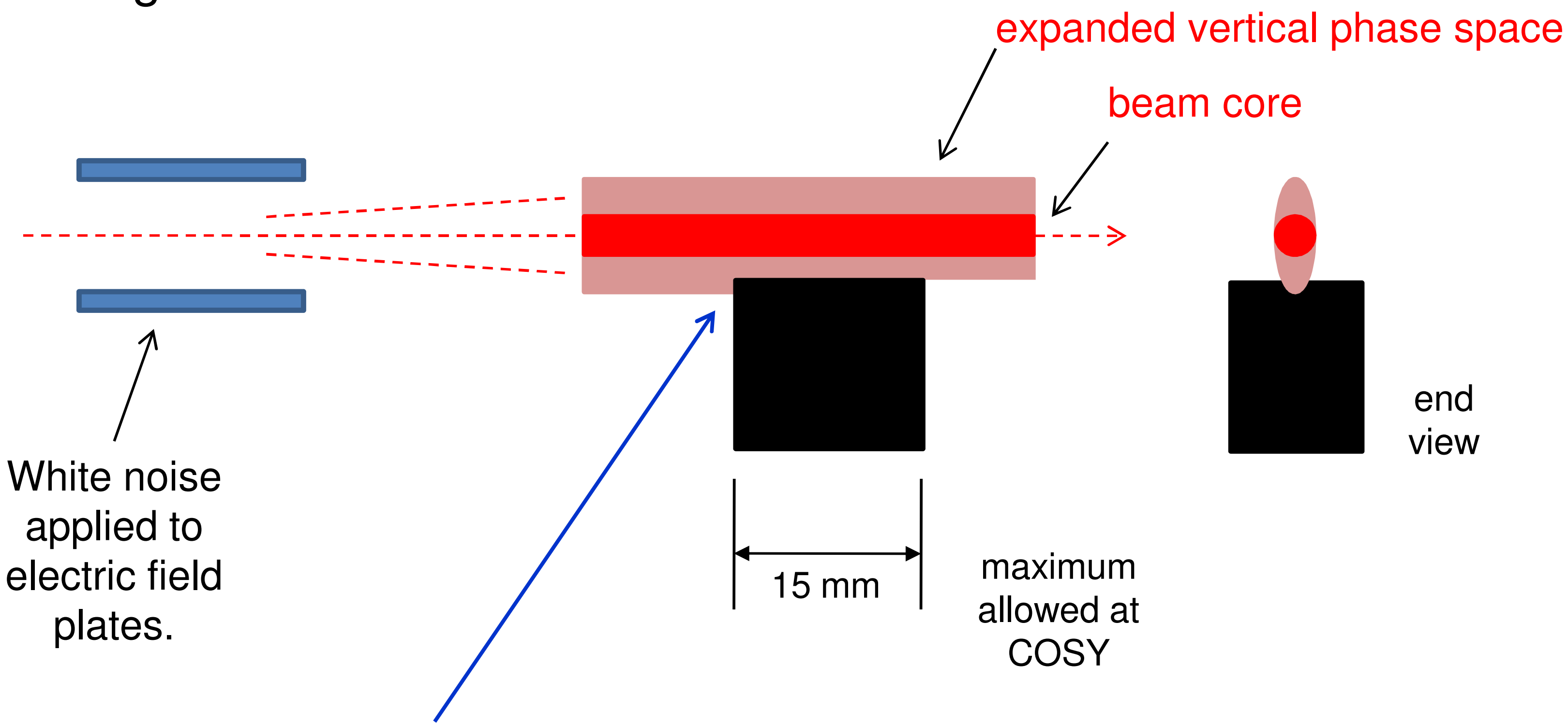


Azimuthal angles yield two asymmetries:

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

Polarimeter Development
Target Concept

Target solution found at COSY:



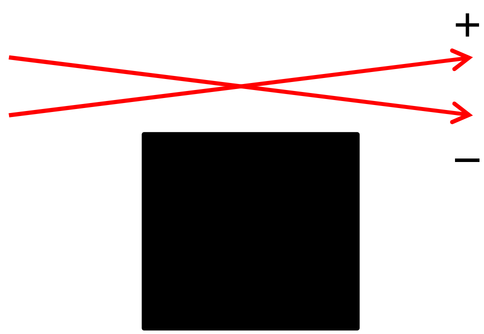
Do enough particles penetrate far enough into the front face to travel most of the way through the target?

This requires a comparison of the efficiency with model values.

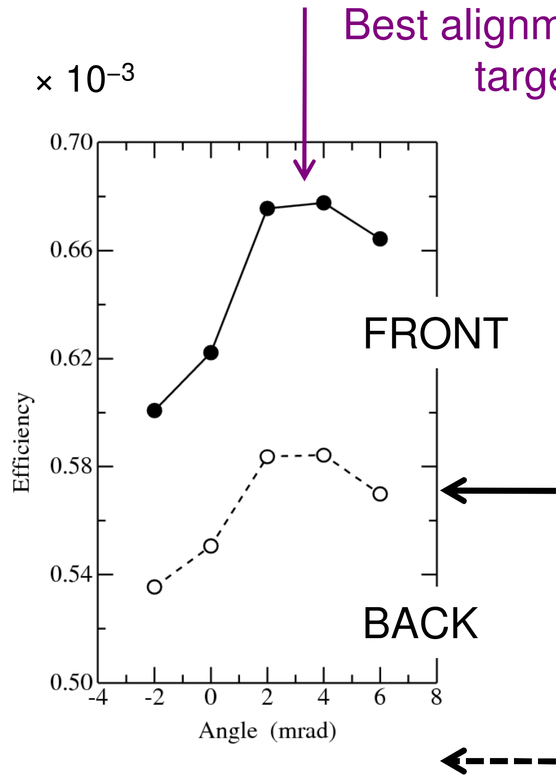
Polarimeter Development
Target Vertical Angle and Efficiency Test

Rocker test:

How sensitive to vertical angle?



Best alignment with target front edge.



Efficiency is the sum of events into the down and up segments of the detector divided by the particles lost from the beam.

Measurements are higher than Monte Carlo predictions based on model of EDDA detector and deuteron-carbon reactions, including elastic, inelastic and transfer.

Polarimeter Development

Target Vertical Angle and Efficiency Test

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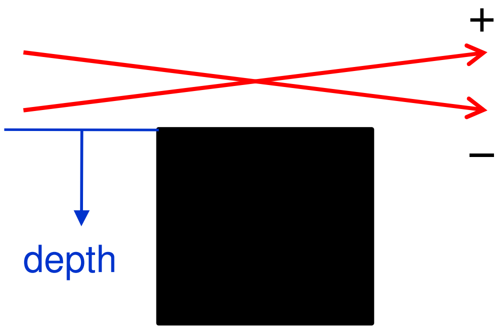

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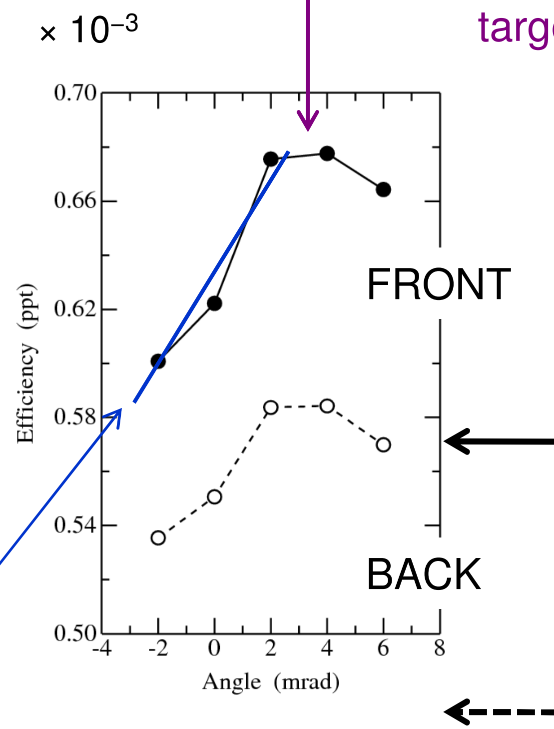

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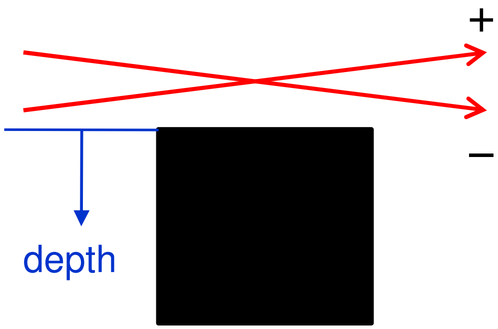
Slope corresponds to typical depth in target of 0.2 mm, larger than the multiple scattering width of σ = 0.013 mm after 15 mm of carbon.

Polarimeter Development

Target Vertical Angle and Efficiency Test

Rocker test:

How sensitive to vertical angle?



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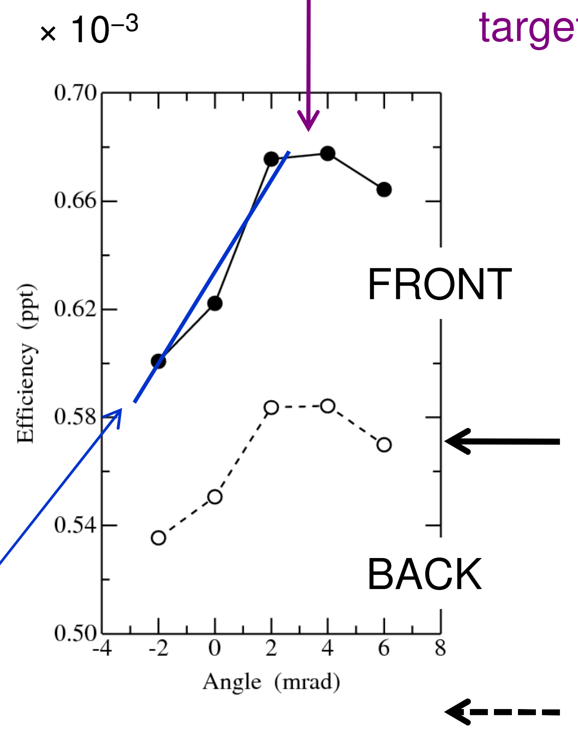

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Efficiencies are low (×10) because of thinner target and larger minimum angle.

Success.

Polarimeter Development
Systematic Error Effects

Goal: keep errors in change of asymmetry to less than 10^{-6}.

Things can change: geometry
rate

Use standard tricks

$\uparrow + \downarrow$ L + R

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

(good to first order in the errors)

Correct effects arising at higher order

Try to use detector information: correction parameters

Geometry: $\varphi = \frac{s-1}{s+1} \qquad s^2 = \frac{L(+)L(-)}{R(+)R(-)}$

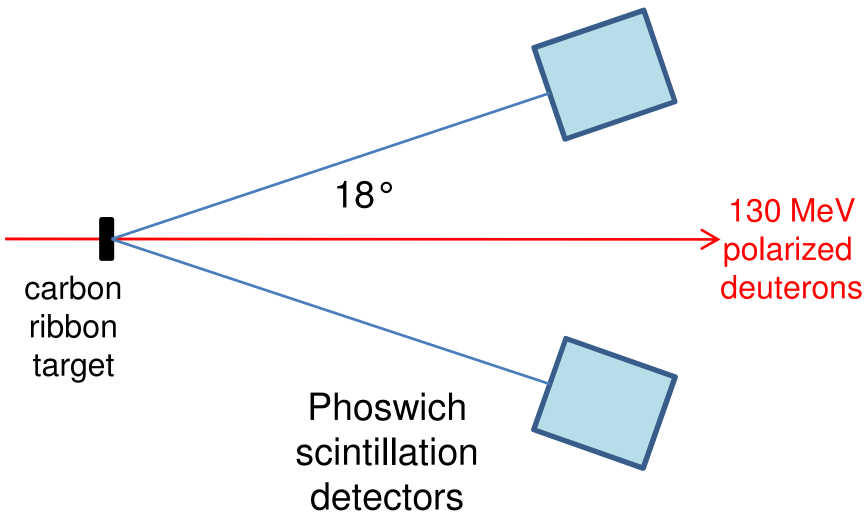
Rate: $L + R$ (instantaneous rate)

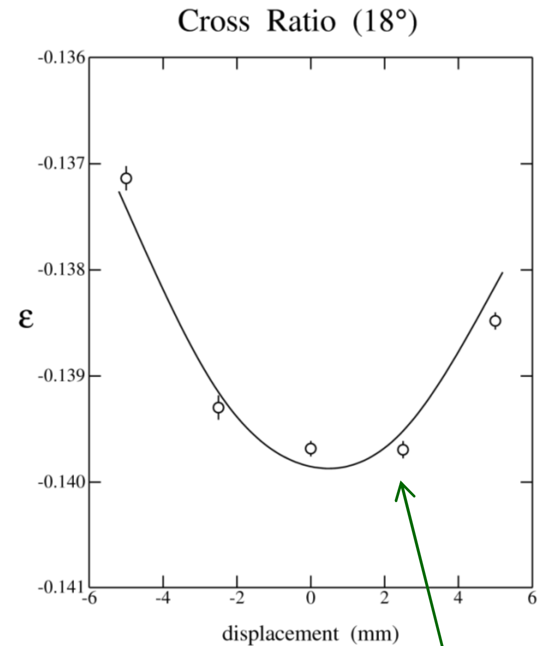
This requires a *calibration* of sensitivity to systematic errors.

Will this work?

Polarimeter Development

Tests made at the KVI (2007)





Calculation based on deuteron elastic scattering data at 130 MeV and measured beam polarizations.

The cross ratio fails at second order in the errors.

$$\varepsilon(\exp) = \varepsilon + \frac{1}{1-\varepsilon^2}\left\{\varepsilon^3 u^2 + 2\varepsilon^2\left(\frac{1}{A}\frac{\partial A}{\partial x}\right)ux + \varepsilon\left[\left(\frac{1}{A}\frac{\partial^2 A}{\partial x^2}\right)(1-\varepsilon^2) - \left(\frac{\partial A}{\partial x}\right)^2\varepsilon^2\right]x^2\right\}$$

"true" asymmetry

observed asymmetry

$$u = p(+) - p(-),\ p(-) < 0$$

Measure effects using errors >100 bigger than expected.

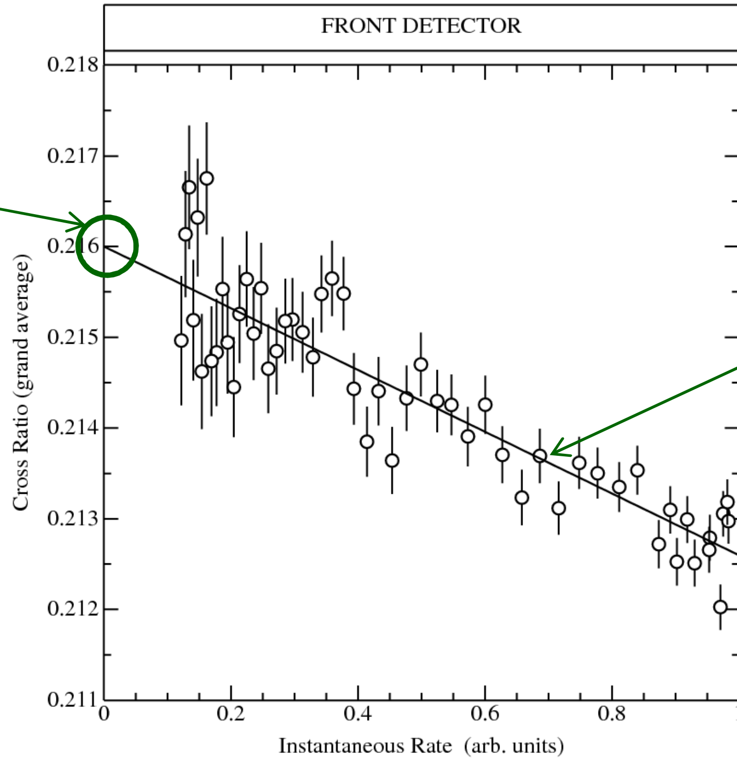
(Note: Asymmetry will also be larger.)

Polarimeter Development
COSY results

Scan:
position –2 to 2 mm
angle –5 to 5 mrad
Rate varies during store

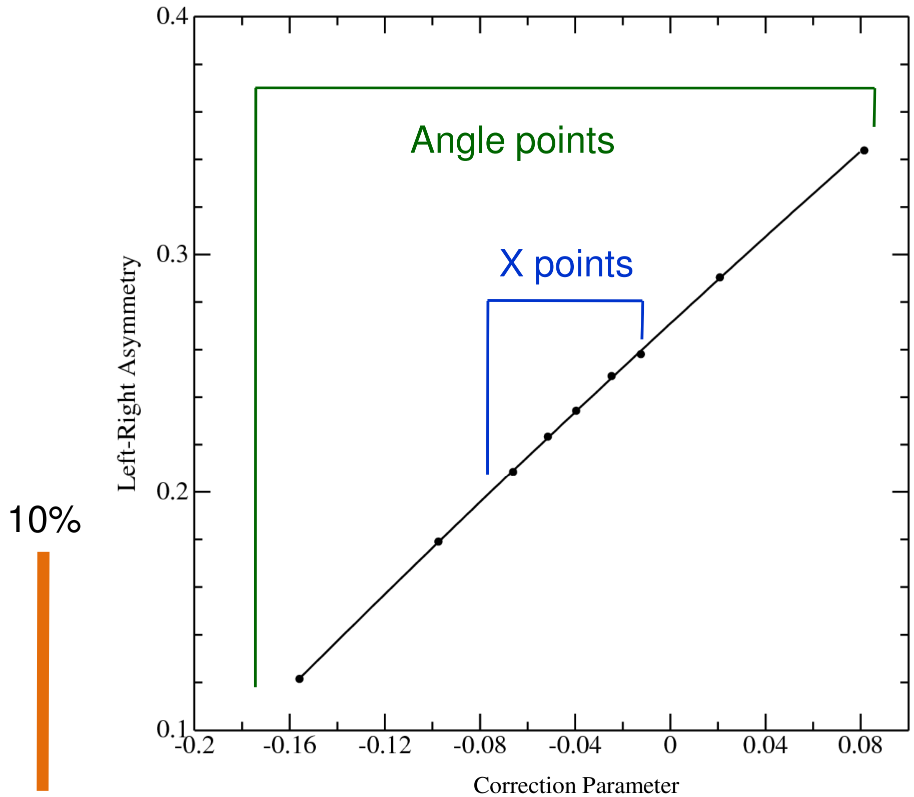
1 Rate and geometry effects are separable.

Make a linear fit to the data from the stores. Assume the zero rate point is independent of rate and can be used for the analysis of geometry effects.

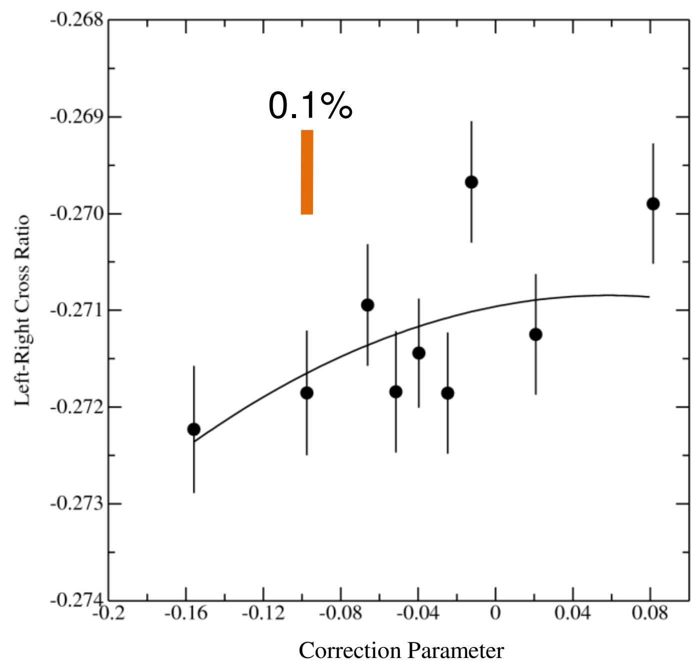


Use the slope for the study of rate effects (pileup).

Polarimeter Development
COSY results



For the cross ratio, second order effects are smaller.

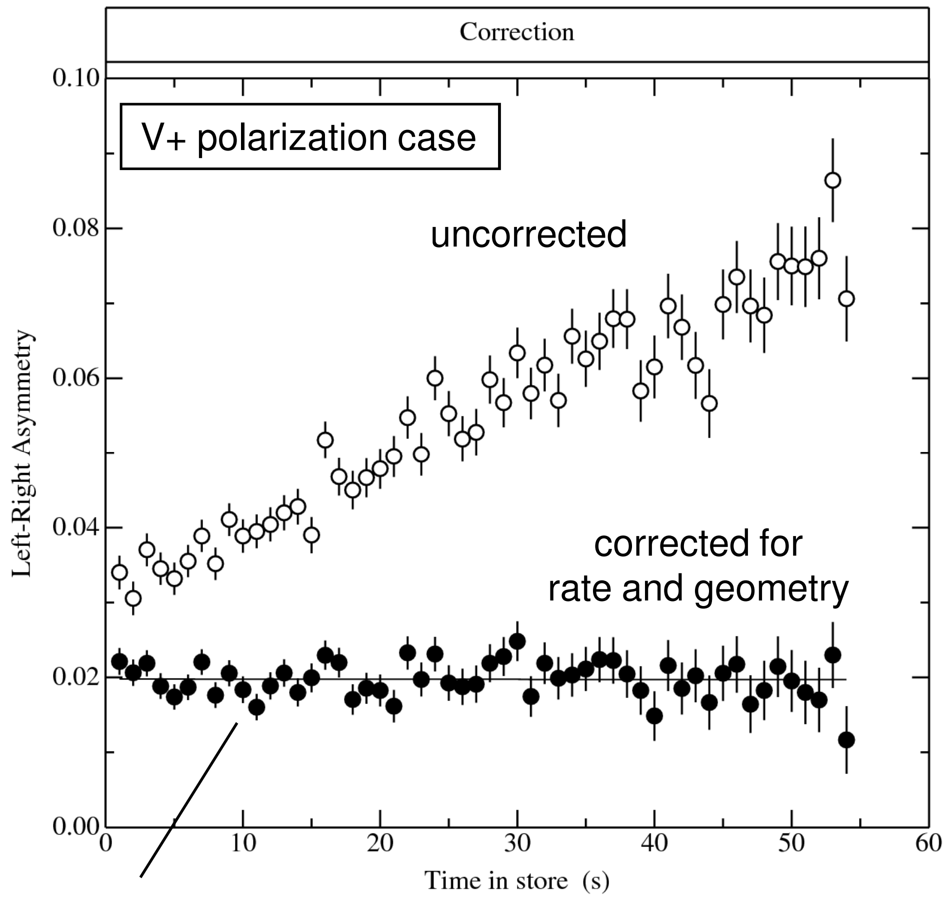


2 Corrections for X and θ match.
One index can be used for both.

Analyzing power A_y = 0.35 (front).

Polarimeter Development
COSY results

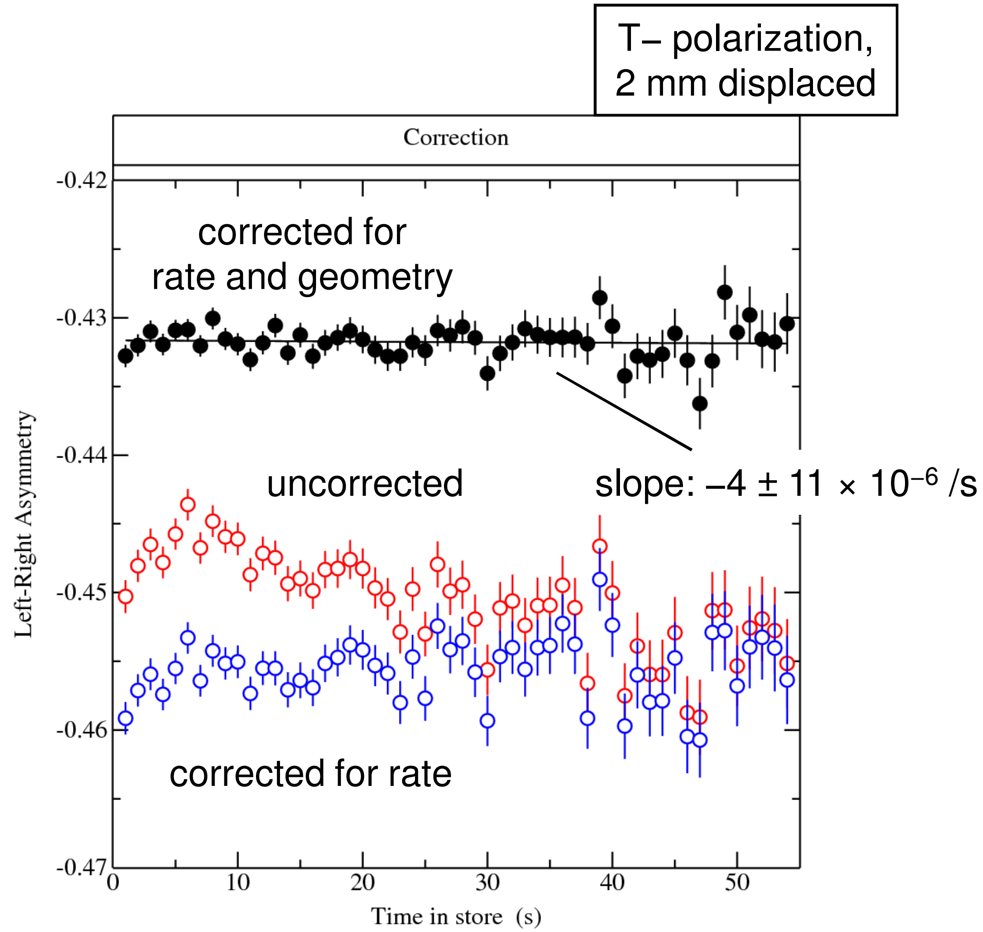
Tests were made with the beam shifting by 4 mm during the store.



slope: $-1.4 \pm 28 \times 10^{-6}$ /s

Polarimeter Development
COSY results

Tests were made with high rate and displaced beam.



Polarimeter Development
COSY results

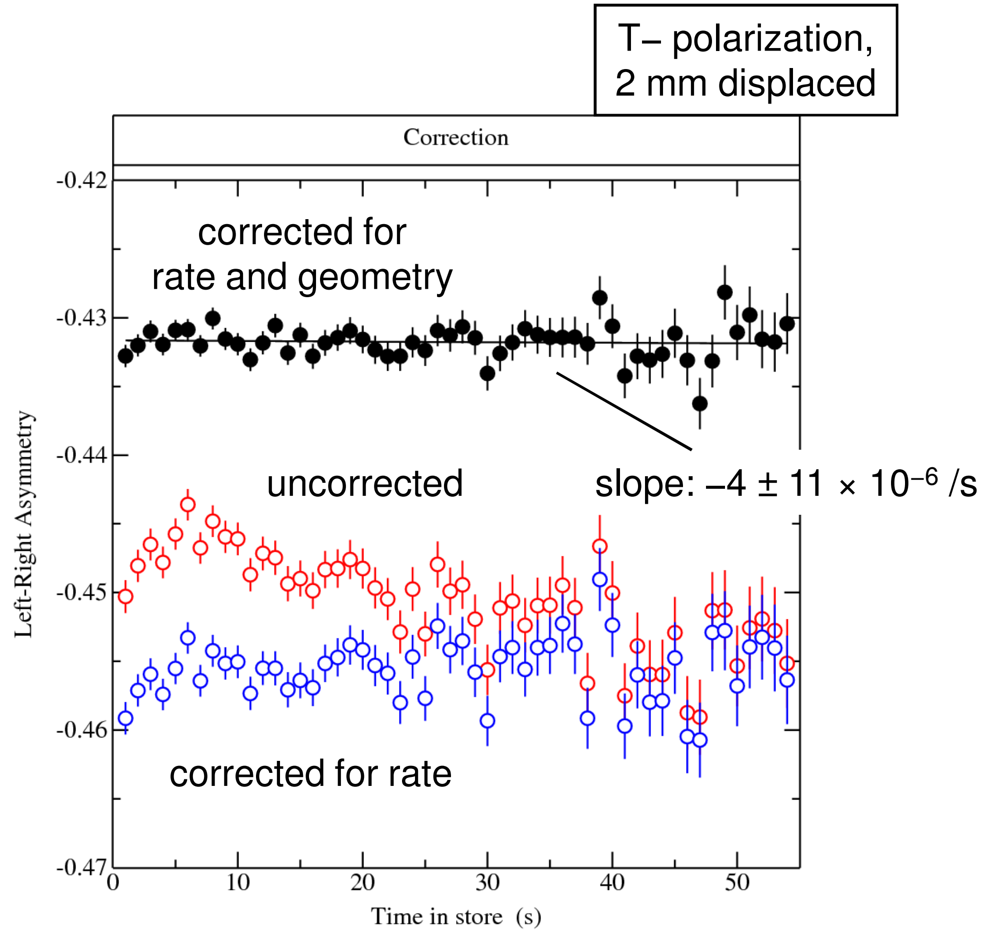
Tests were made with high rate and displaced beam.

3 Corrections work.

Scaling down:

For deuteron EDM ring:
position changes < 10 μm
initial vertical ε < 0.01
gives control of systematics to < 30 ppb, well under requirement.

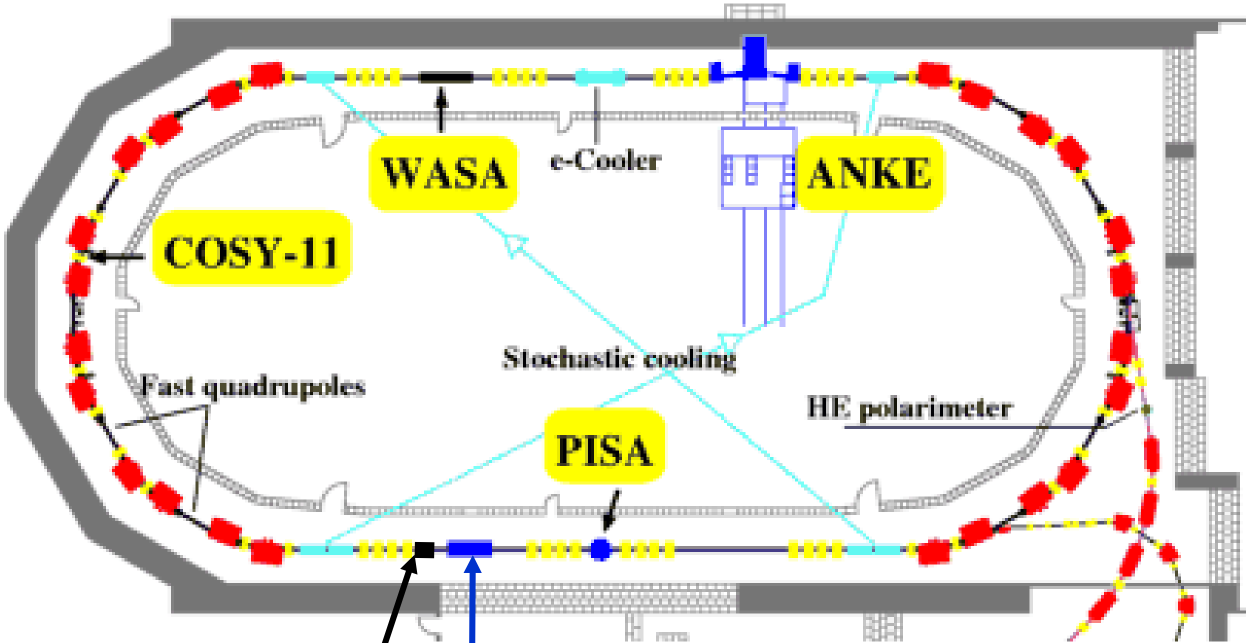
cross ratio:
A'/A = 0.0055
ε = 0.01
Δp = 0.05
use $(A'/A)\varepsilon^2\Delta p$



Since asymmetry depends only on count rates and calibration coefficients, we get results in real time.

Polarimeter Development

μ-solenoid test



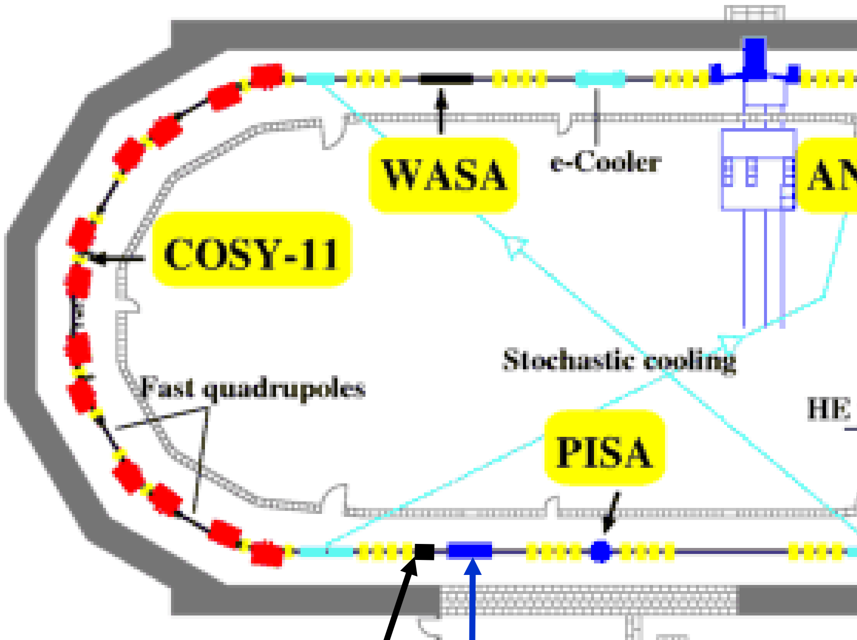
add 60-turn solenoid
to ring running 100A

EDDA

polarity known
only to COSY

Polarimeter Development

μ-solenoid test

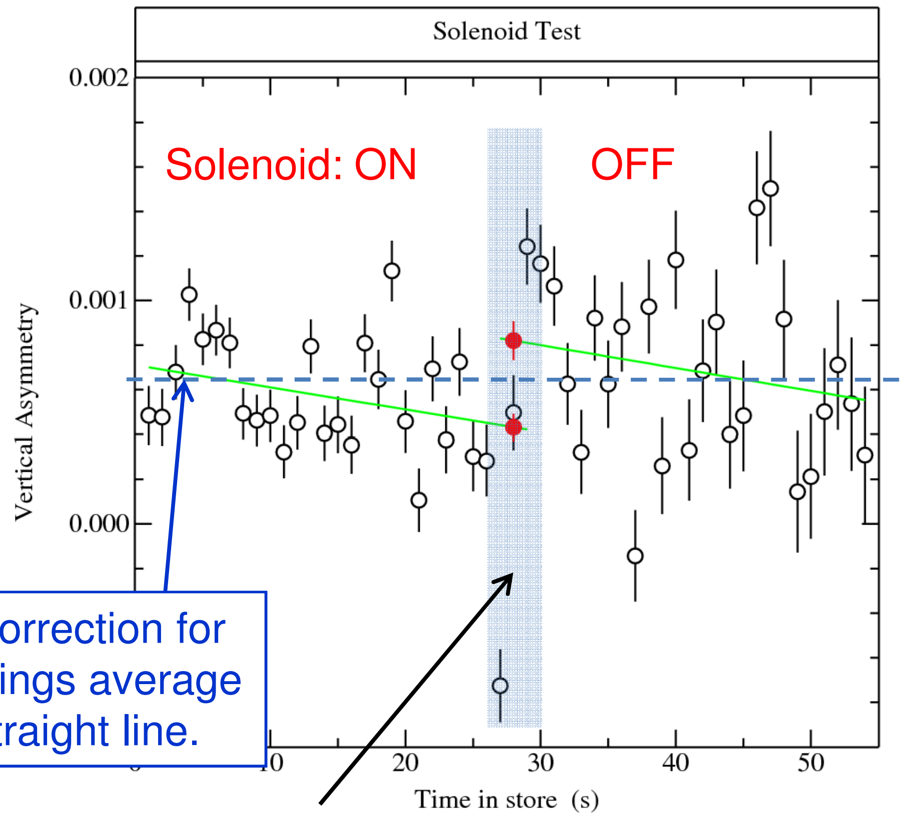


add 60-turn solenoid to ring running 100A

EDDA

polarity known only to COSY

data sample from rear detector



Data correction for rate brings average onto straight line.

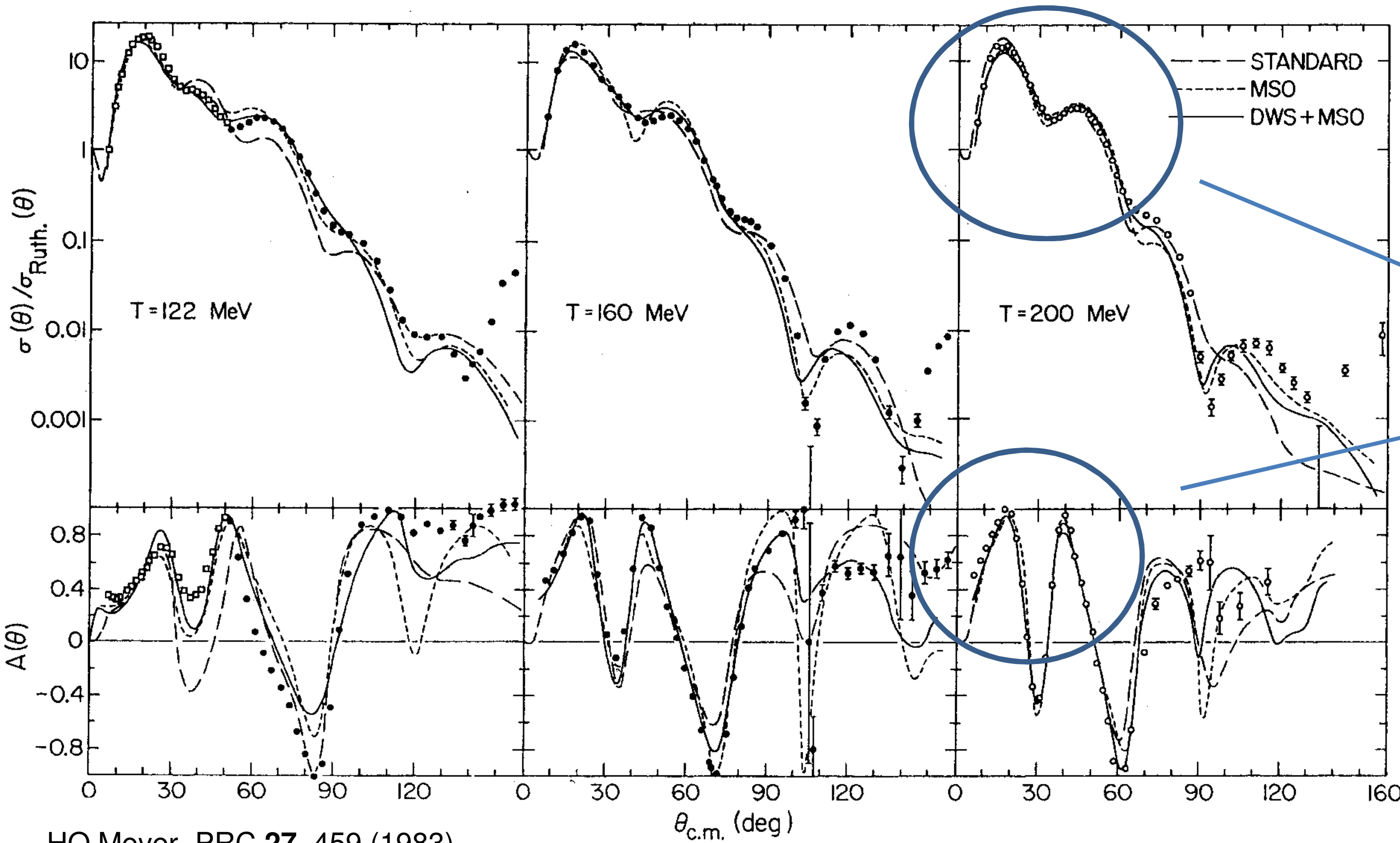
data excluded while magnet ramps

Prediction:	0.87 mrad
Measured:	1.4 ± 0.4 mrad

Polarity agrees!

Polarimeter Development
Protons

proton + carbon elastic scattering



HO Meyer, PRC **27**, 459 (1983)

Near 230 MeV the forward cross section and analyzing power are favorable.

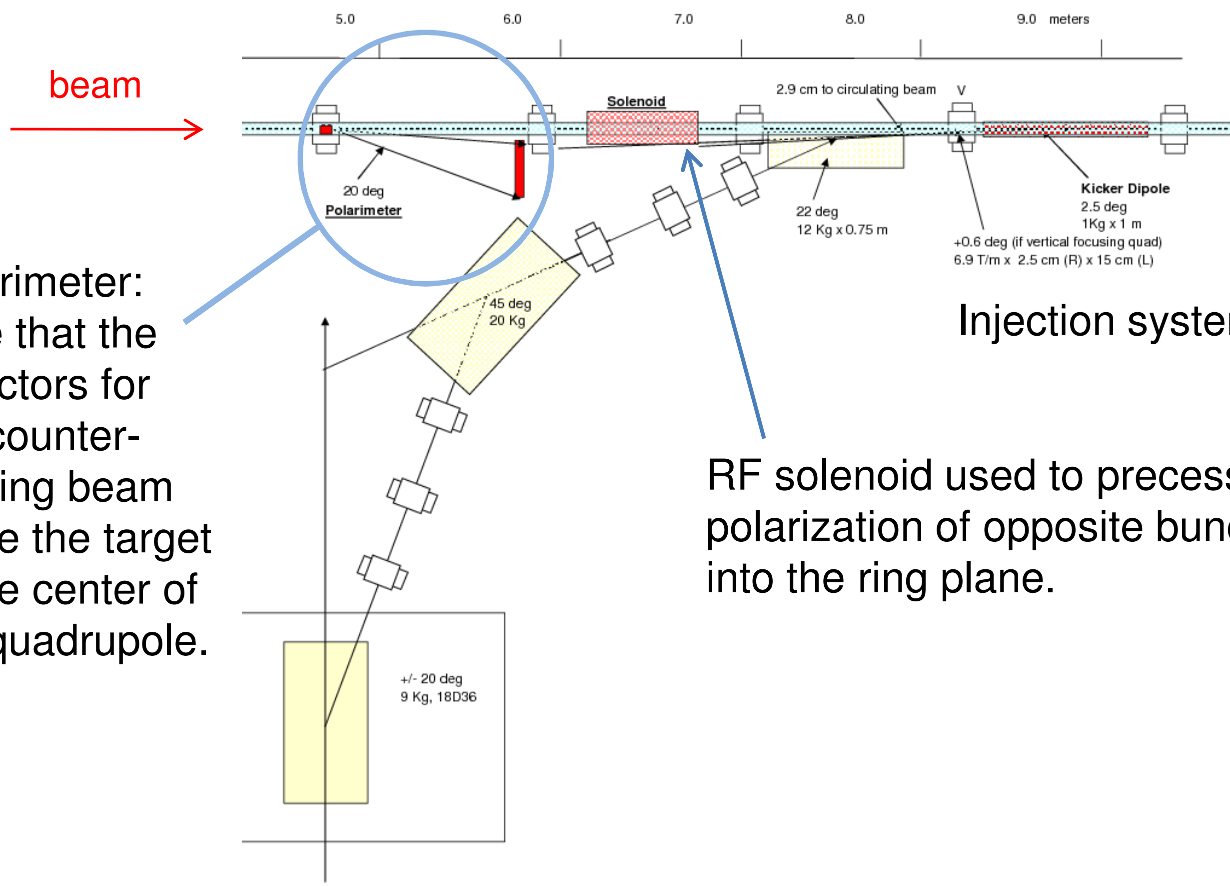
We can expect: efficiency ~ 1.1 % (over 2π)
analyzing power ~ 0.6

with some selection on elastics

Polarimeter Development

Polarimeter

Location of polarimeter in (half of) storage ring straight section



Polarimeter:
Note that the detectors for the counter-rotating beam share the target at the center of the quadrupole.

Injection system

RF solenoid used to precess polarization of opposite bunches into the ring plane.

Polarimeter Development

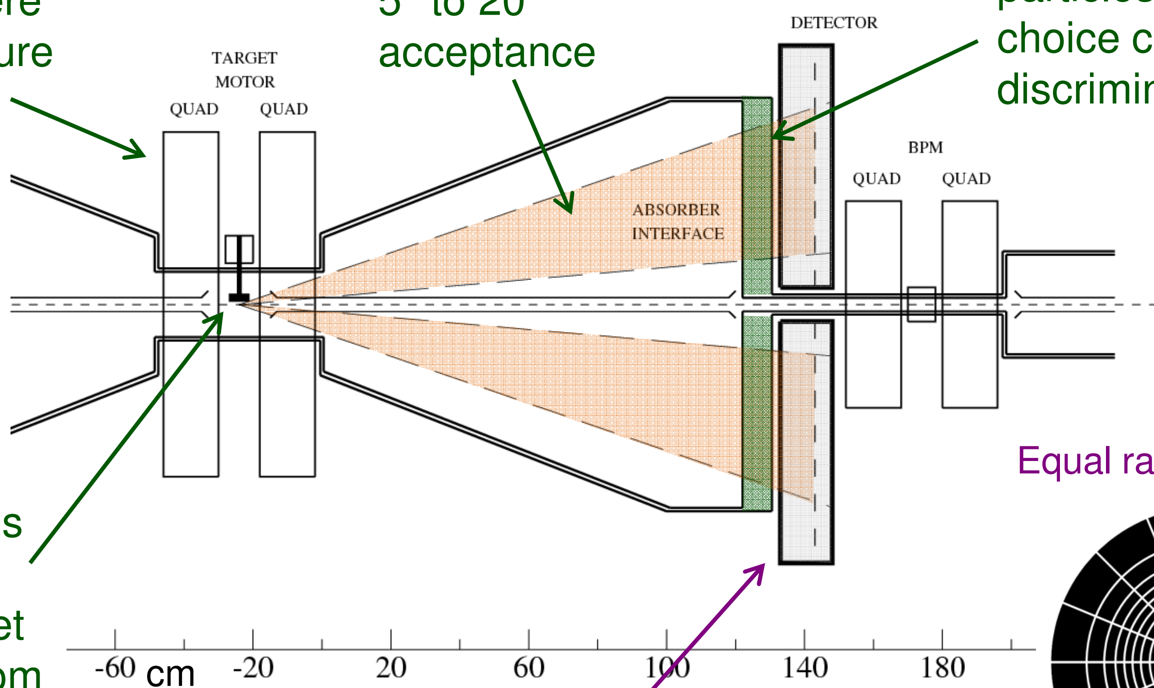
Polarimeter

(Half) Polarimeter in the ring:

Quadrupoles here are larger aperture for clearance.

5° to 20° acceptance

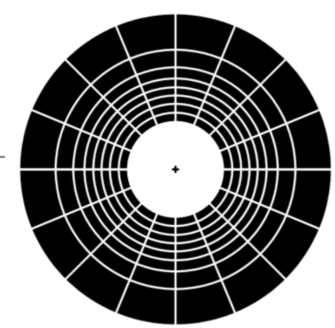
Absorber to remove low analyzing power particles. (Detector choice can also give discrimination.)



One target is shown. We want a target available from at least the left, right, up and down directions.

Generic detector:
- (?) Multi-resistive plate chamber
- (?) Micro-megas
- (?) Gas electron multiplier
- (?) …other

Equal rate readout pads



Rate = 800 /s/pad

In one store: $\delta\varepsilon = 1.5\times10^{-4}$

Polarimeter Development

Polarimeter

MRPC
Frascati, U. Rome

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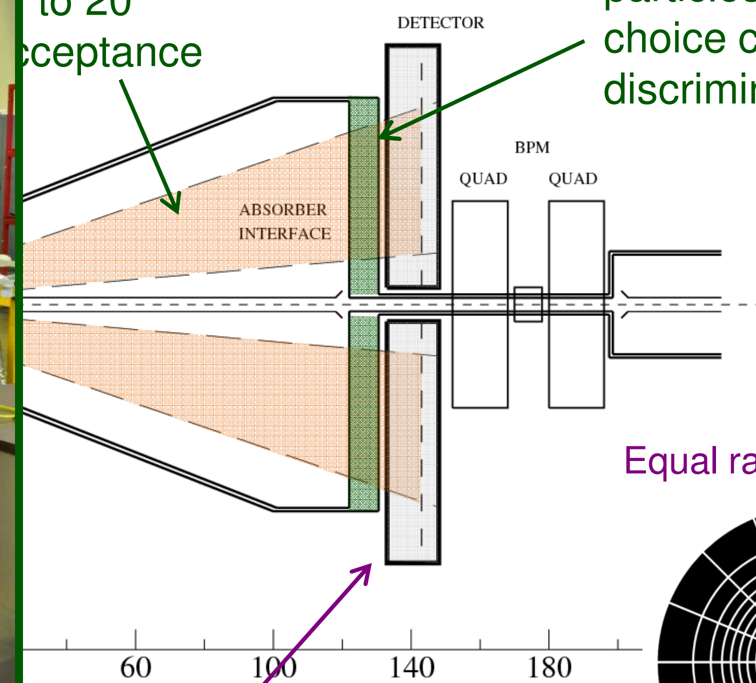

detector:
ti-resistive plate chamber
ro-megas
electron multiplier
ther

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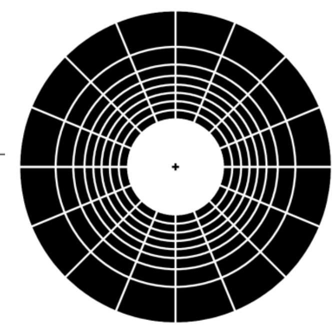

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Polarimeter Development

Polarimeter

Micro-Megas
INP Demokritos, Saclay, BNL

(Half) Polarim

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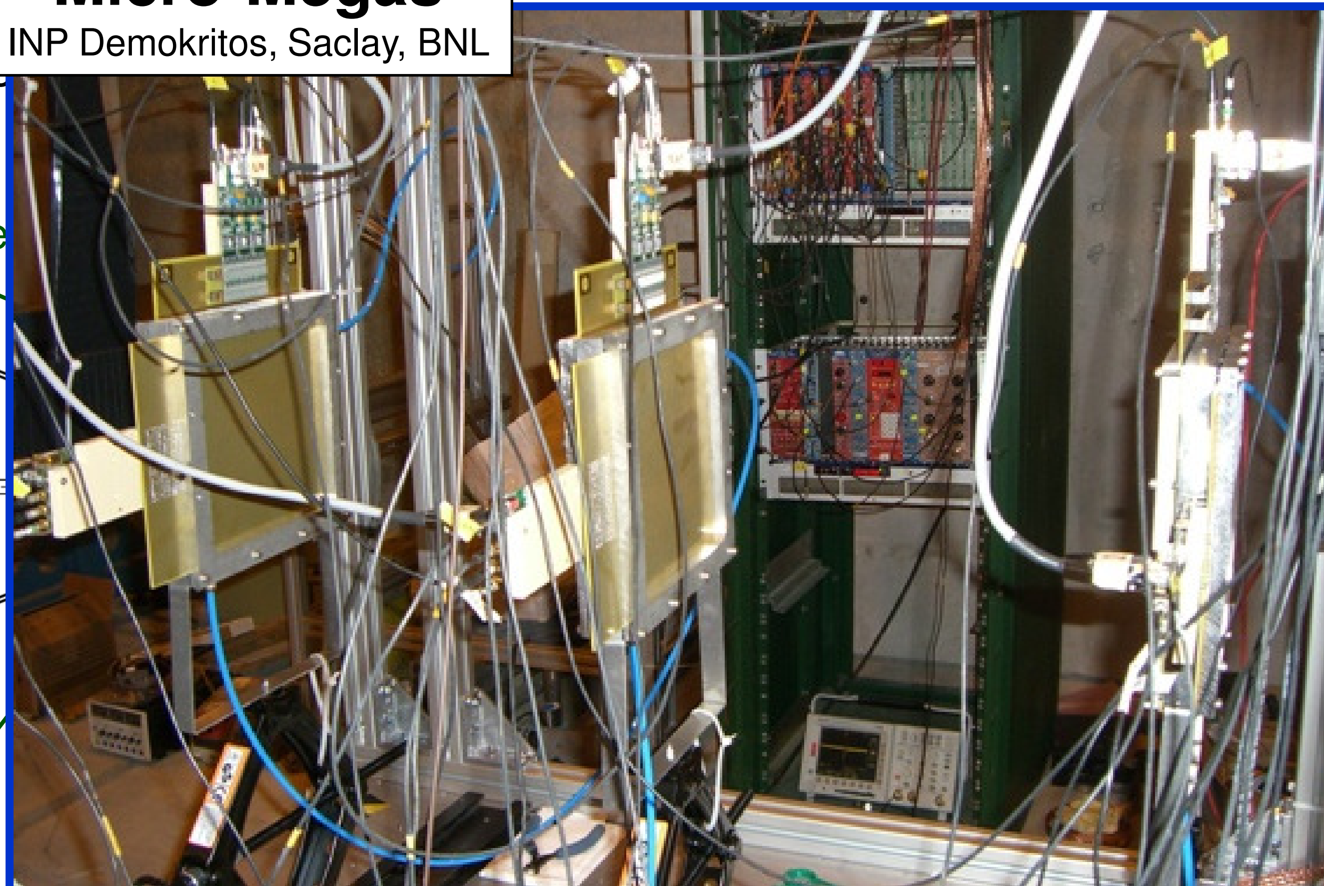

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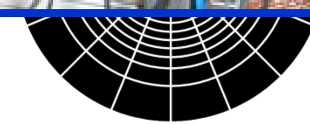

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Polarimeter Development
R & D 3-year Plan

Goals (milestones)

Produce a working EDM polarimeter for the ring

Year 1: Simulation and design of proton polarimeter
- Database creation (cross section and analyzing power)
- Monte Carlo simulation
- Engineering design (including electronics)

Detector selection
- Prototype tests (COSY, KVI, IUCF…)
- Inclusion in Monte Carlo simulation

Year 2: Construction
- Parts procurement, machine shop, assembly

Installation (at COSY)

Year 3: Commissioning and calibration
- Design verification
- Operating point determination
- Measurement of systematic error sensitivity

Polarimeter Development

R & D 3-year Plan

Resources needed:

Note: This is an opportunity for separate funding through Indiana University or other EDM Storage Ring institutions.

		Costs (k$) with IU overhead
Personnel	post-doc	300
	student	140
Travel		140
Construction	design	60
	fabrication	160
Other (add ~1/4)		200
TOTAL		**1,000**

Polarimeter Development
EDM Polarimeter Team

Polarimeter Development Team: (participating at COSY)

Indiana: Ed Stephenson*, Astrid Imig (BNL)

KVI-Groningen: Gerco Onderwater*, Marlène da Silva e Silva, Klaas Brantjes, Duurt van der Hoek, Wilburt Kruithoff, Oscar Versolato

COSY Jülich: Ralf Gebel, Andreas Lehrach, Bernd Lorentz, Dieter Prasuhn, Hans Stockhorst

BNL: Vasily Dzordzhadze, Don Lazarus, Bill Morse, Yannis Semertzidis

Regis U.: Fred Gray

Frascati: Paolo Levi Sandri, Graziano Venanzoni

U. of Rome: Francesco Gonnella, Roberto Messi, Dario Moricciani

Thanks to: Olaf Felden (COSY), Frank Hinterberger (Bonn), Rudolf Maier (COSY), Hans Ströher (COSY), Univ. Münster

* Spokespersons for polarimeter development