Polarimetry:
General Considerations

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JEDI Collaboration

EDM kickoff meeting
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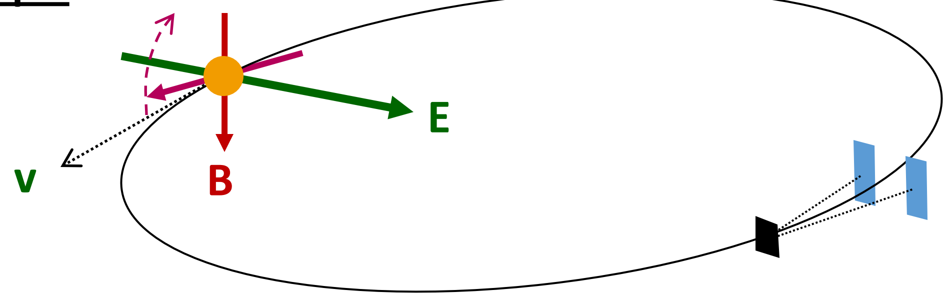
CERN

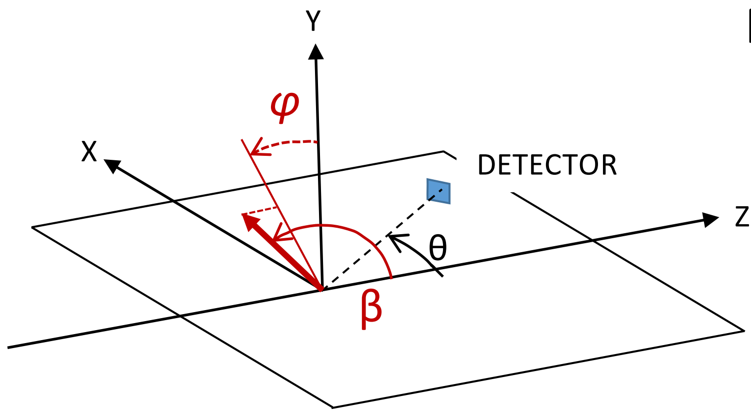
EDM experiment concept

Frozen spin (p, d, ^3He, …)

Signal is changing vertical polarization component between early and late in the beam store.



Polarimeter uses asymmetry in elastic scattering from carbon.



Polarized cross section

$$\sigma_{POL}(\theta) = \sigma_{UNP}(\theta)\left[1 + p_Y A_Y \cos(\varphi)\sin(\beta)\right]$$

$$-1 \le p_Y \le 1, \quad -1 \le A_Y \le 1$$

Asymmetry — 2 sides — Spin-flip

$$\varepsilon = p_Y A_Y = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

NIM A **664**, 49 ('12)

Eliminates 1st order errors.
With calibration and an index, correct for higher orders (10^{-5}).

or combine sides and spin flip

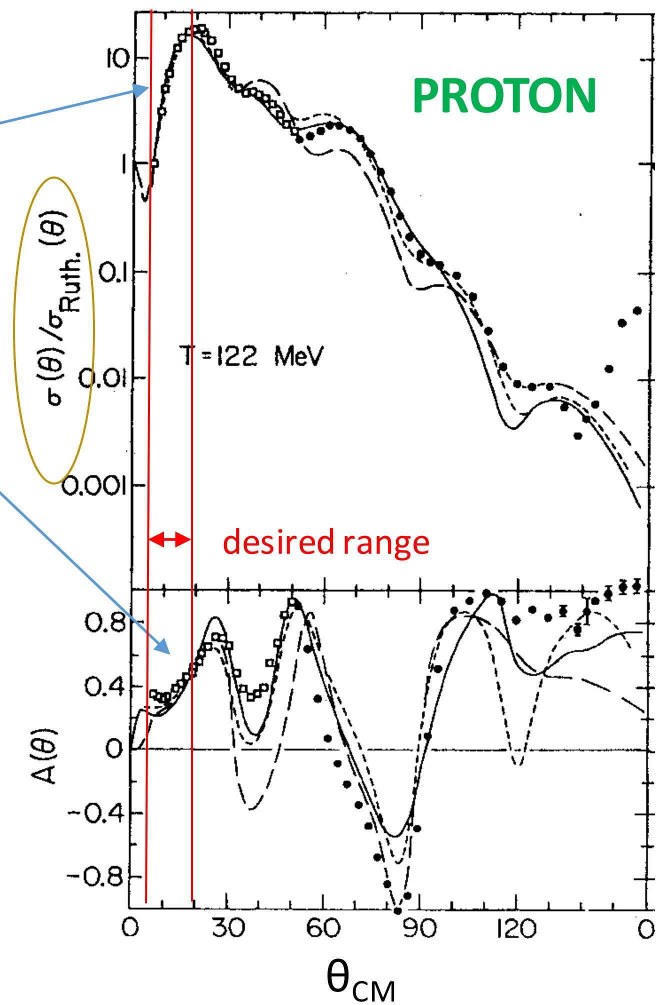
$$\varepsilon = \frac{r-1}{r+1}, \quad r^2 = \frac{\sigma_{L+}\sigma_{R-}}{\sigma_{L-}\sigma_{R+}}$$

"cross ratio"

Spin sensitivity of elastic scattering from carbon (spin-orbit force):

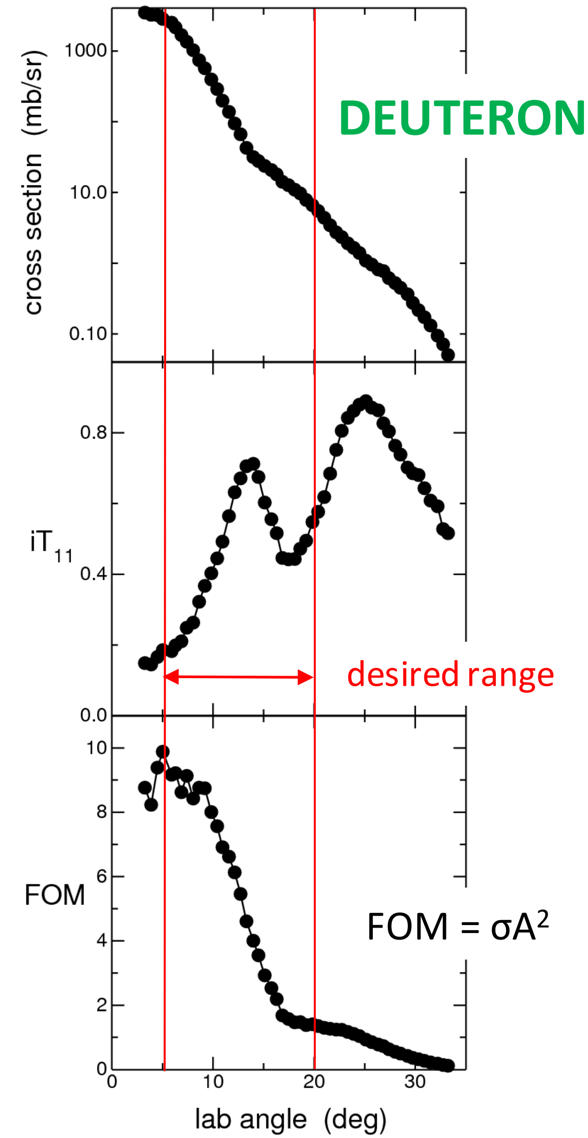
Concentrate on forward angles where cross section and analyzing power are both large.

NOTE: It is not necessary to restrict acceptance to the elastic channel; other reactions show similar sensitivity. Detectors may be simple.



PRC **27**, 459 ('83)

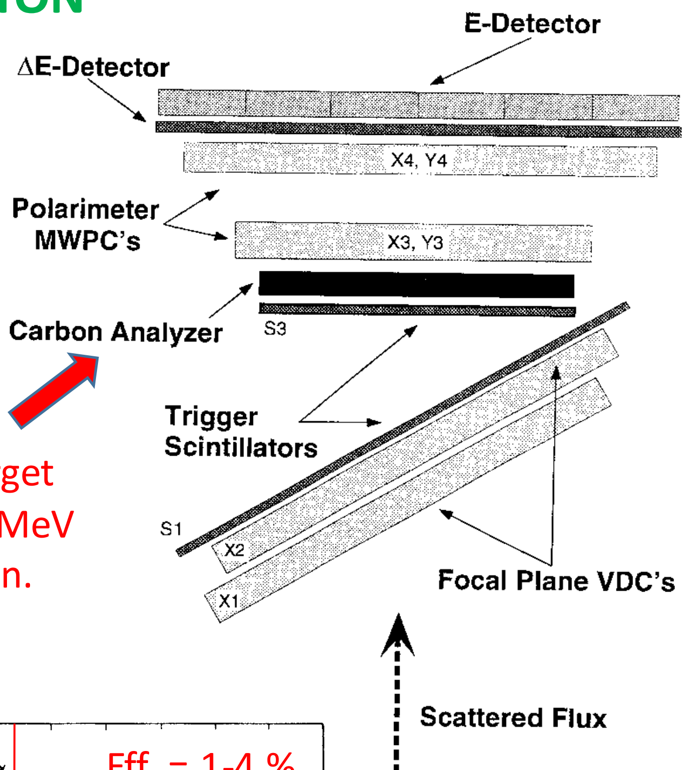
d+C elastic, 270 MeV



PL B **549**, 307 (2002)

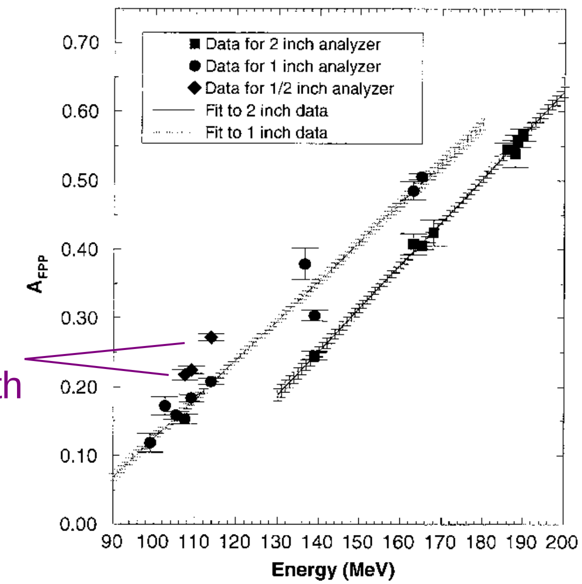
Use K=600 spectrometer focal plan polarimeter at Indiana as a model for thick target operation.

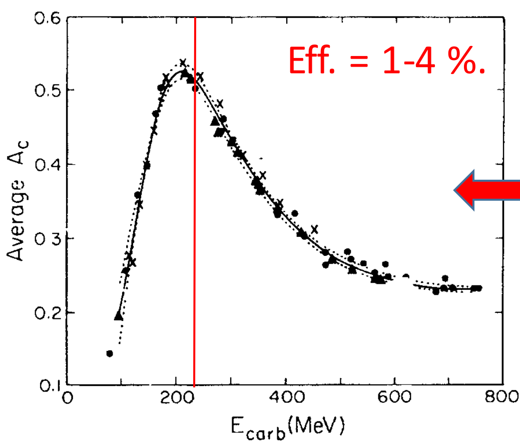
PROTON



5-cm target for 200-MeV operation.

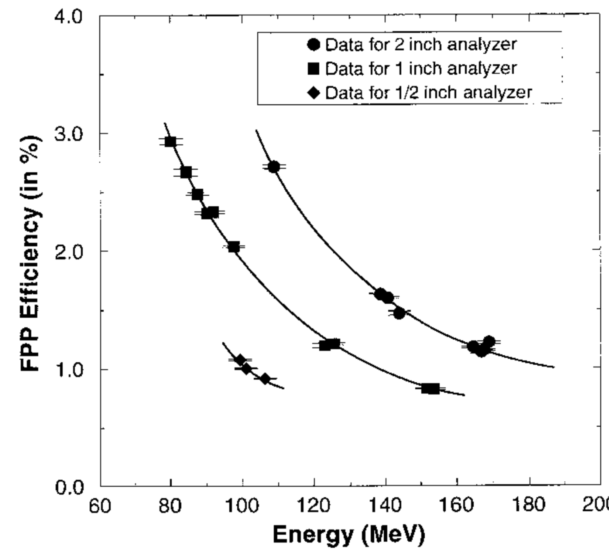
figure of merit is better with thinner target: σA^2





Eff. = 1-4 %.

Average analyzing power as a function of beam energy. Note peak is close to magic momentum !!!

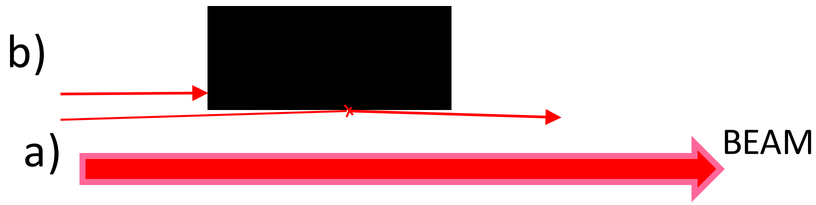


Fraction of the incoming flux that is used for a measurement.

Target Options

1 Thick material at edge of beam. Drive beam to target. Particles make single pass.

"Extraction" is a 2-step process.



The beam is below the target.

a) A particle touches the underside, scatters down, and begins to oscillate.
b) On some later turn, it strikes the front face away from the edge (~0.2 mm).

This produces full efficiency (given EDDA detectors in use at the time).

Target produces significant down-up false asymmetry (~ −0.2).

Polarization in halo may not reflect rest of beam.

2 Thin material in beam. Particles make multiple passes through target.

Target options:
- fiber (carbon) passing through beam
- gas/cluster jets
- pellet targets

There is added loss out of acceptance.

Tests show efficiencies within x10 of thick target.

Studies as a function of target design or thickness have not been done.

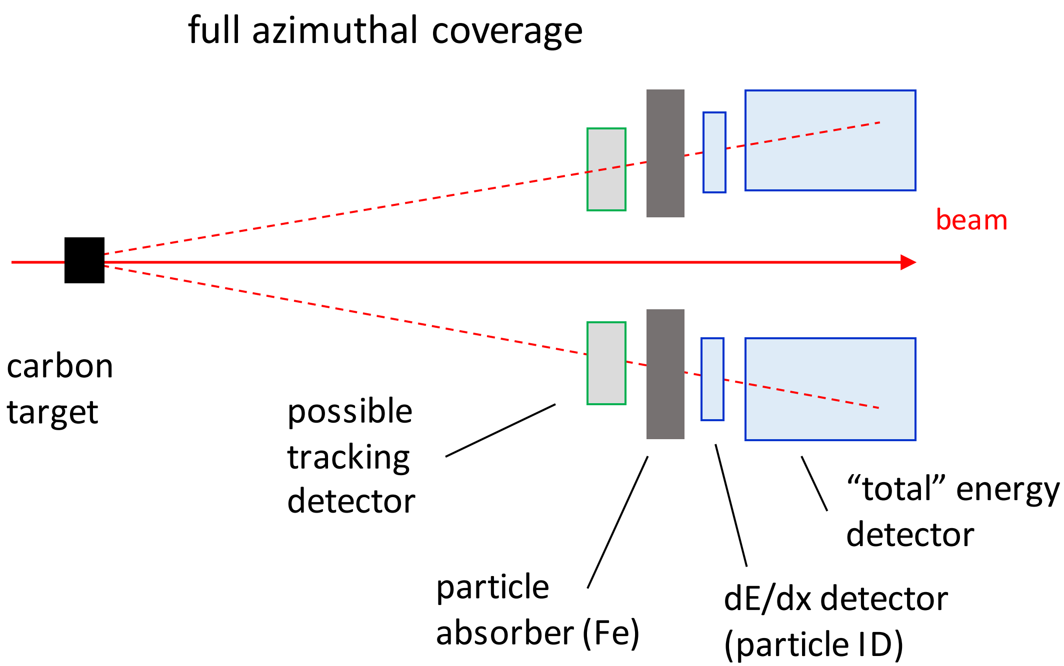
This needs work.

Opens up study of beam profile, polarization profile.

This requires additional tracking detectors.

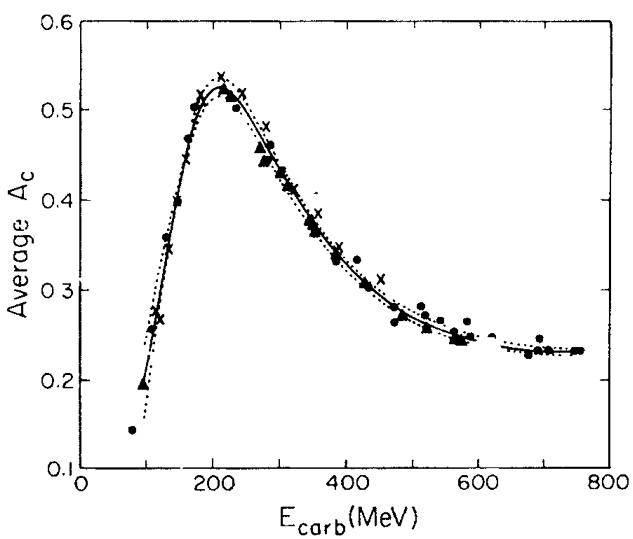
May not offer full efficiency.

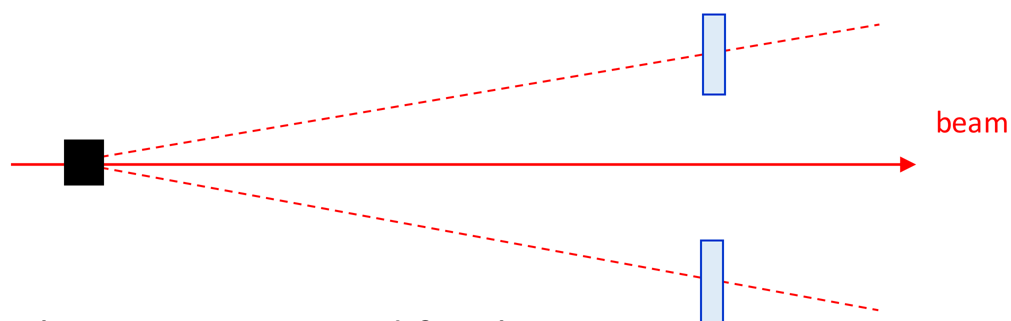
Polarimeter features might include:



The energy threshold would be set to optimize the figure of merit. Care must be taken so that the threshold is not dependent on counting rates.

For the **PROTON**, things have historically been rather simple. The situation is clean enough that only a ΔE is needed.

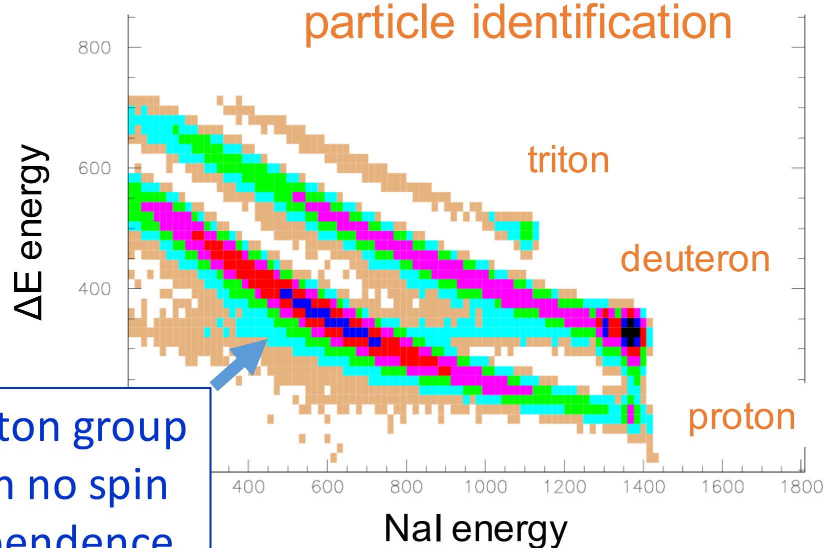




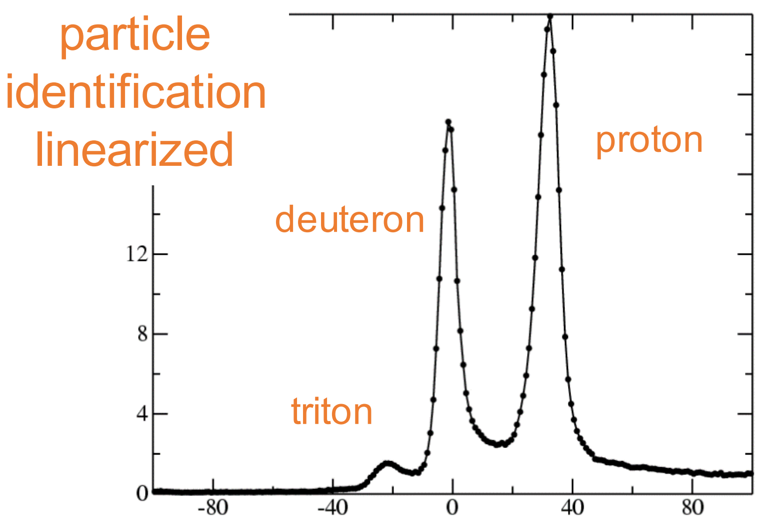
This setup was used for the double scattering work at TRIUMP and LAMPF.

The deuteron situation is more complicated because of breakup.

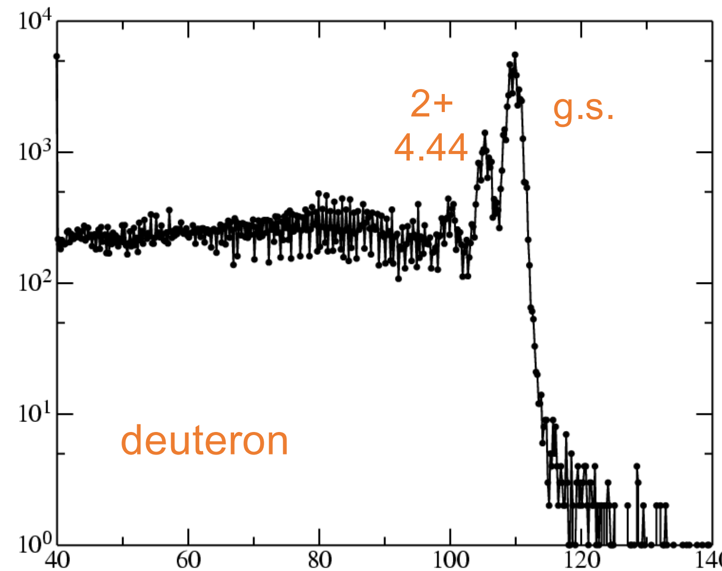
Sample spectra (110 MeV, 27°)

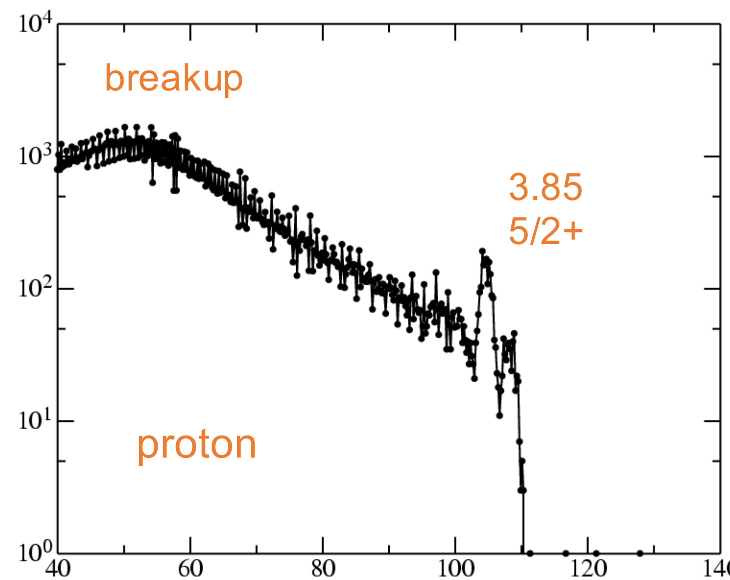


Proton group with no spin dependence.

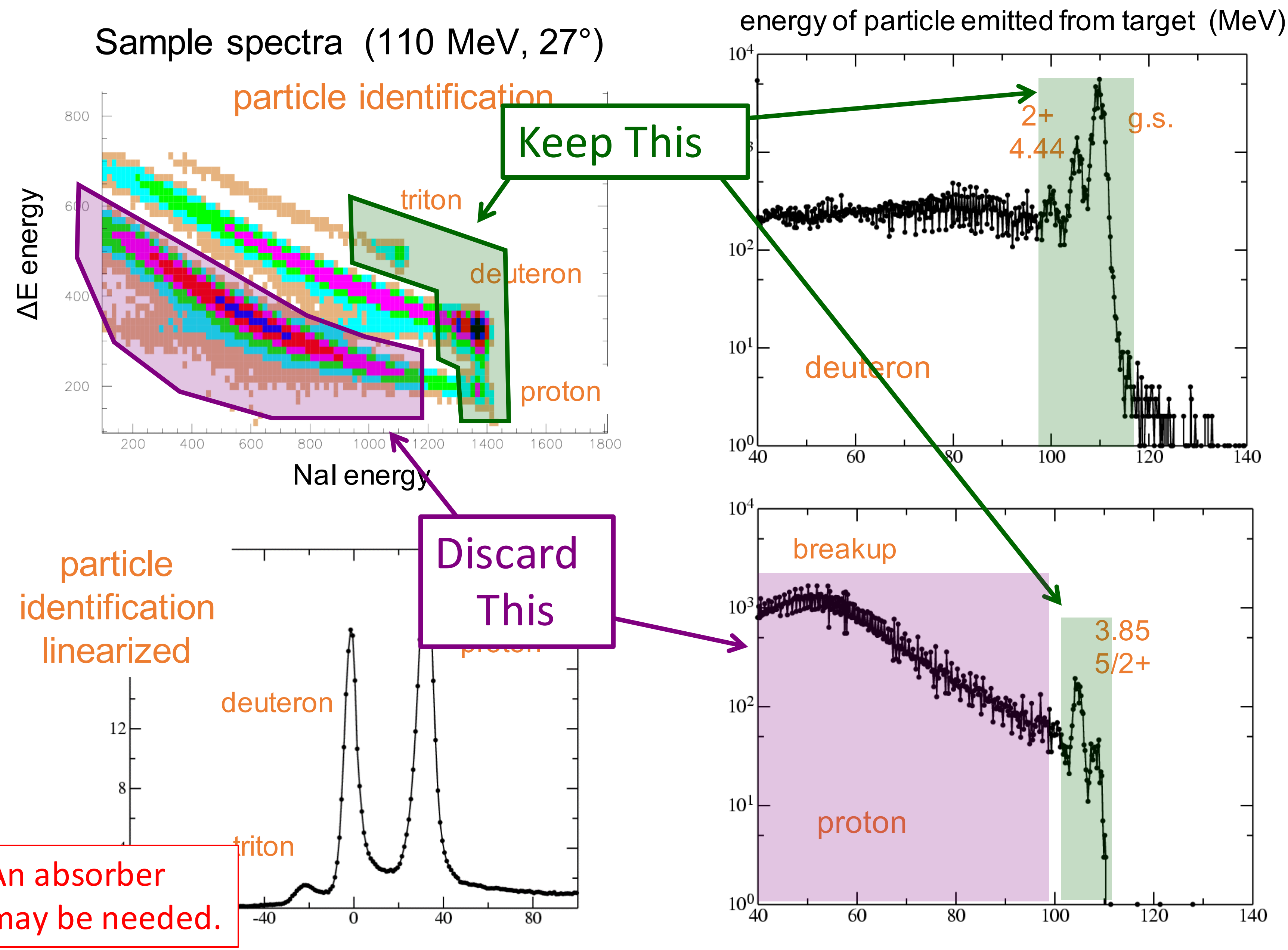


energy of particle emitted from target (MeV)





What would we include in a polarimeter signal?



An absorber may be needed.

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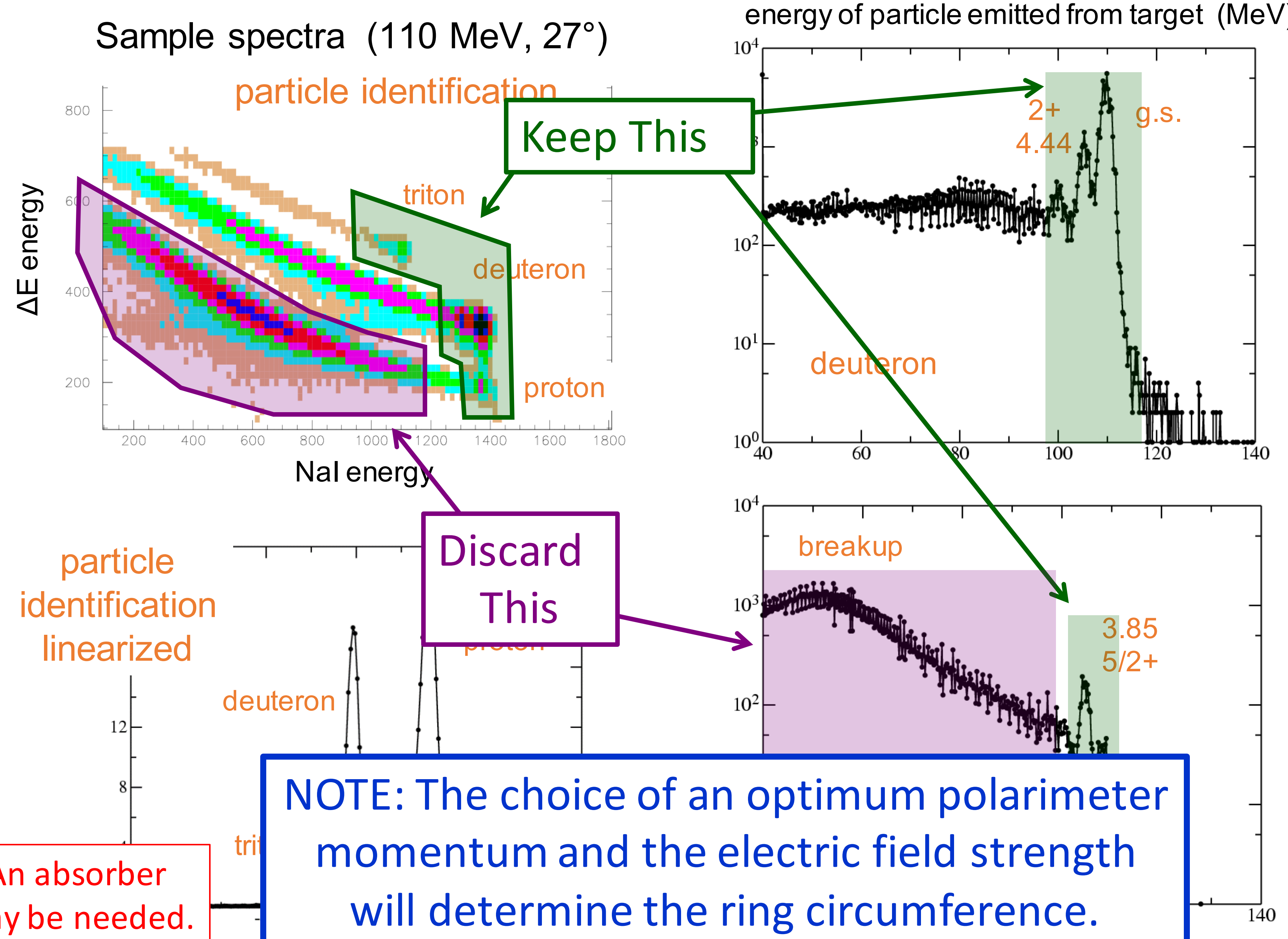
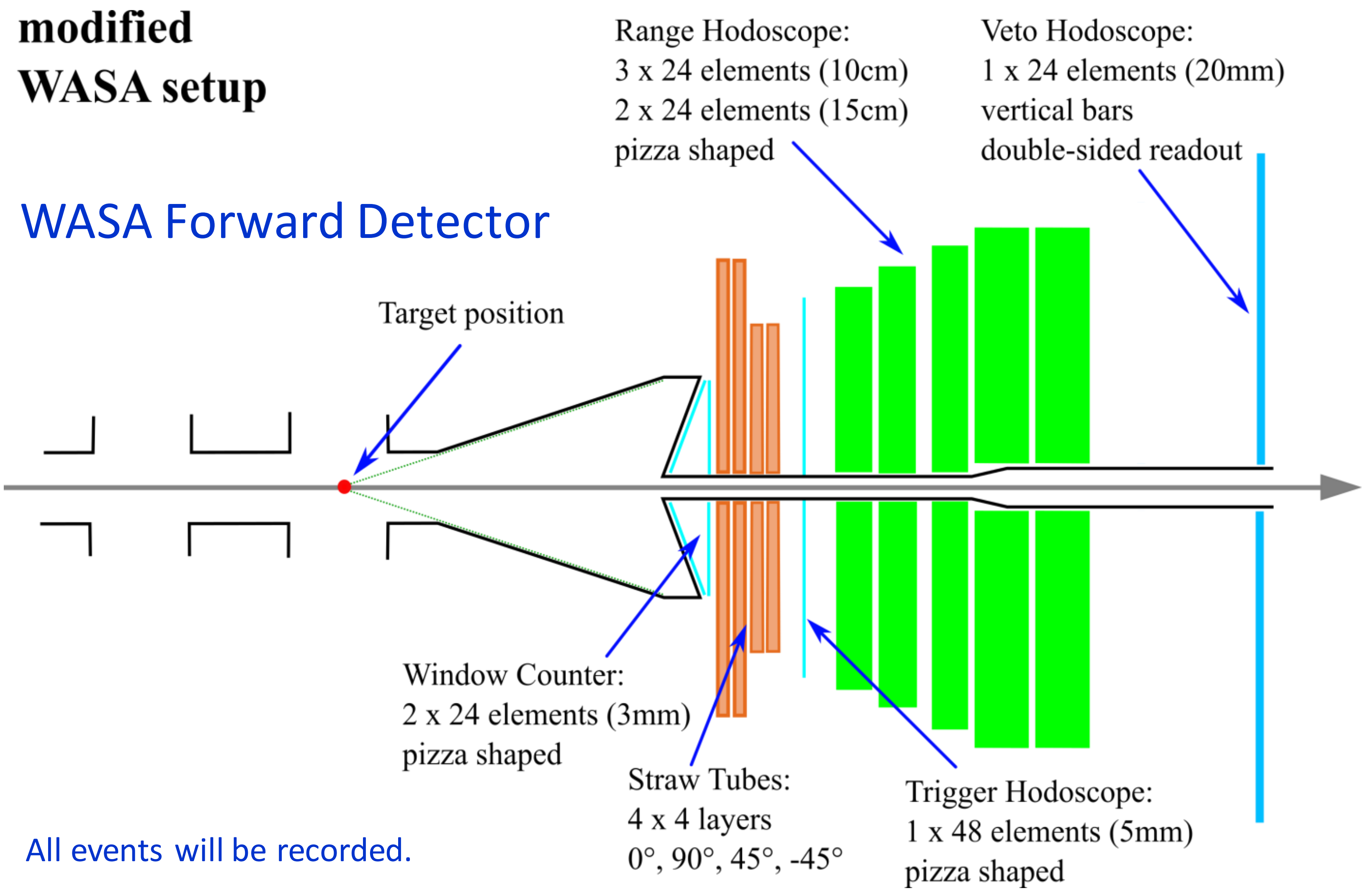


NOTE: The choice of an optimum polarimeter momentum and the electric field strength will determine the ring circumference.

An absorber ay be needed.

Plans for 2017-2018: data base experiments

Deuteron case was run in November-December, 2016.

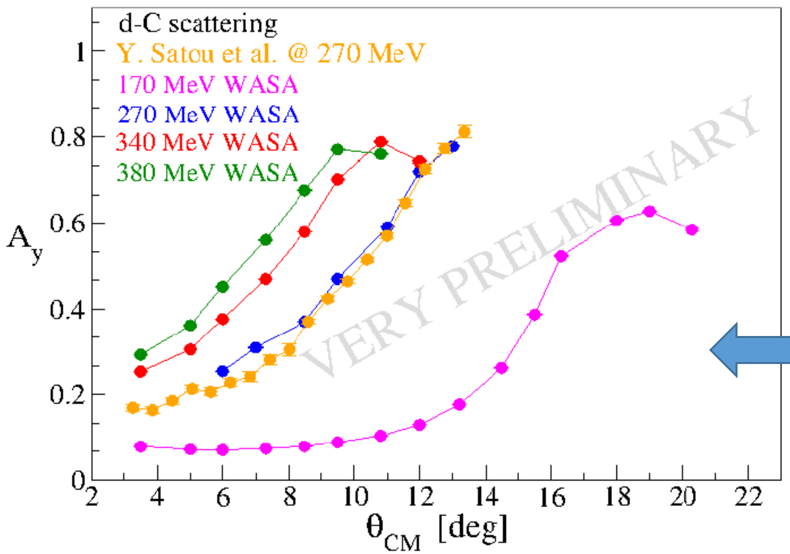


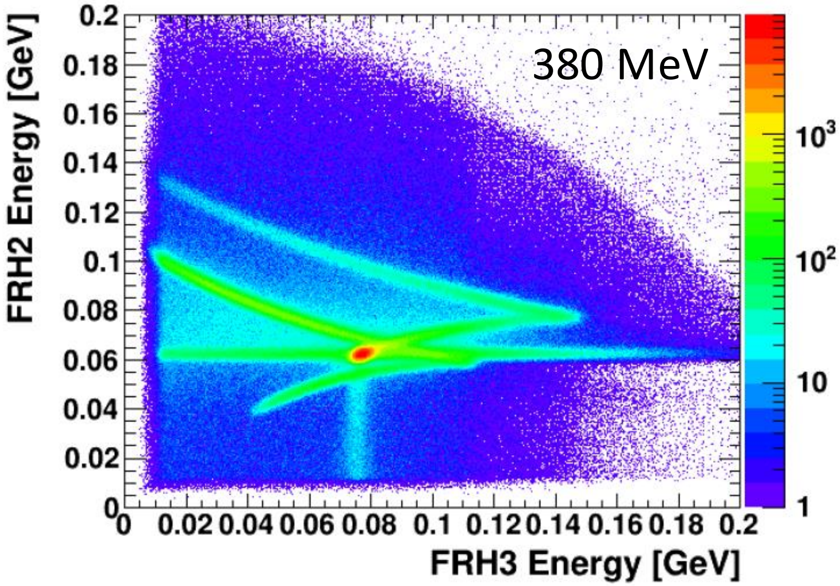
All events will be recorded.

Energies: 170, 200, 235, 270, 300, 340, and 380

Polarization: vector and tensor

Targets: C and CH_2





Preliminary data shows analyzing power peak moving forward as the energy rises !!

Take similar data with raytrace detectors: Park@Korea, Fanourakis@Demokritos

<u>Two analysis tracks:</u>

Choose energy and trigger for best use of WASA F.D. for precursor experiment.

Remove tailing in spectra, create event generator for GEANT.
Model more detailed polarimeter with raytrace detectors, absorbers, etc.

Repeat for protons.

Plans for 2017-2018: applications for spin feedback

COSY ring not capable of frozen spin: Deuterons precess at 121 kHz at test energy.

Instead, mark each event with the clock time, unfold the precession in the DAQ.

Magnitude of in-plane polarization obtained from sideways component, D/U asym.

In a series of time bins, we obtain the magnitude and phase of the polarization.

The next step is feedback to the ring rf: change precession rate or current phase.

Applications:

1) In EDM experiment, hold polarization along velocity of the beam. Now $\sigma \sim 0.2$ rad.
2) In precursor experiment, synchronize polarization to rf Wien filter.
3) In EDM experiment, rotate polarization to sideways to measure magnitude. Then put it back. Do a full rotation to calibrate or check systematics.

Note that for deuterons there is the possibility to use tensor polarization as a monitor. One has to understand correlations with vector to eliminate spurious L/R effect.

NOTE: All polarimeters must be set up for both beam directions (CW vs. CCW).

Extra pages

Plan for handling geometry and rate errors

considering that beam properties are continuously changing
error correction must respond in real time

1 Use as robust a scheme as possible:

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).

Cross ratio: $pA = \varepsilon = \frac{r-1}{r+1}$ $\quad r^2 = \frac{L(+)R(-)}{L(-)R(+)}$

But this fails at second order in the errors.

2 Measure sensitivity of all observables to geometry and rate errors.

Choose index variables for all error types.

Build a model that explains all effects. Does it have a simple dependence in terms of the index variables?

Other observable options (3 more):

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

Good! Sees geometry errors, not p.

2) ~~$\chi = \frac{t-1}{t+1}$ $\quad t^2 = \frac{L(+)R(+)}{L(-)R(-)}$~~

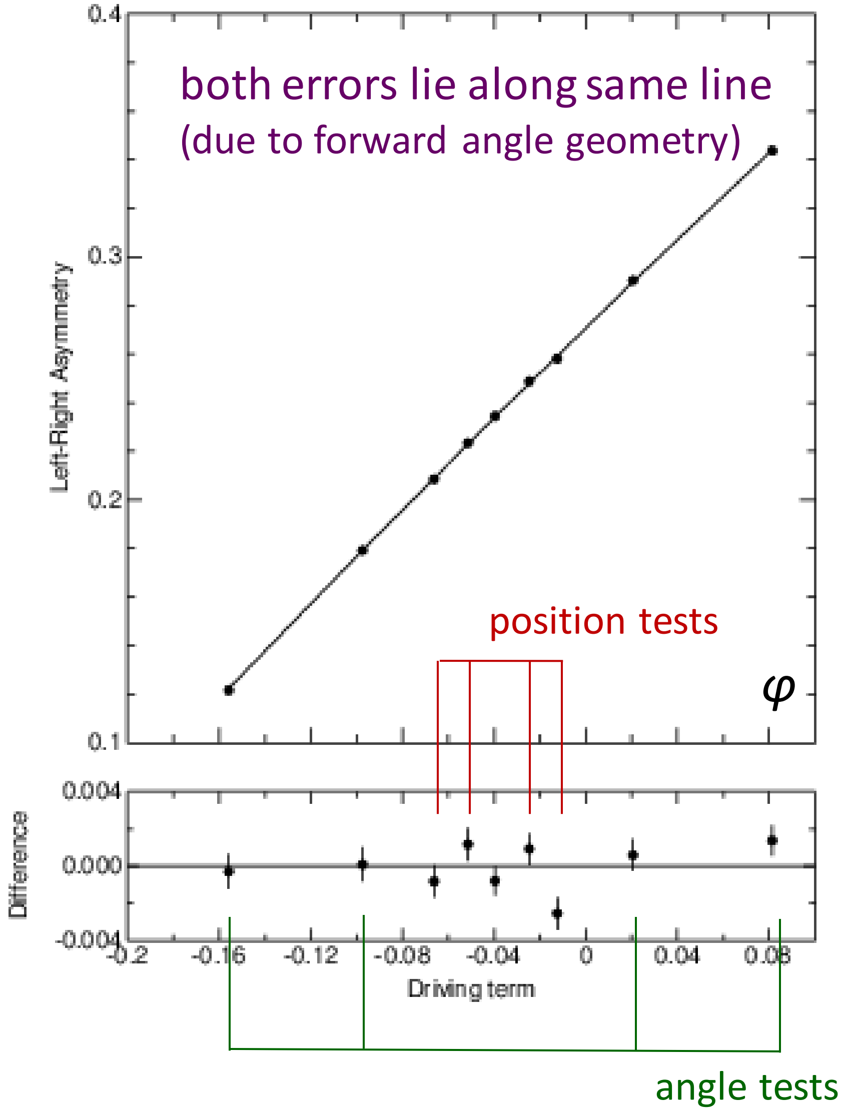
Useless! Sees luminosity difference.

3) $W = L(+) + R(+) + L(-) + R(-)$

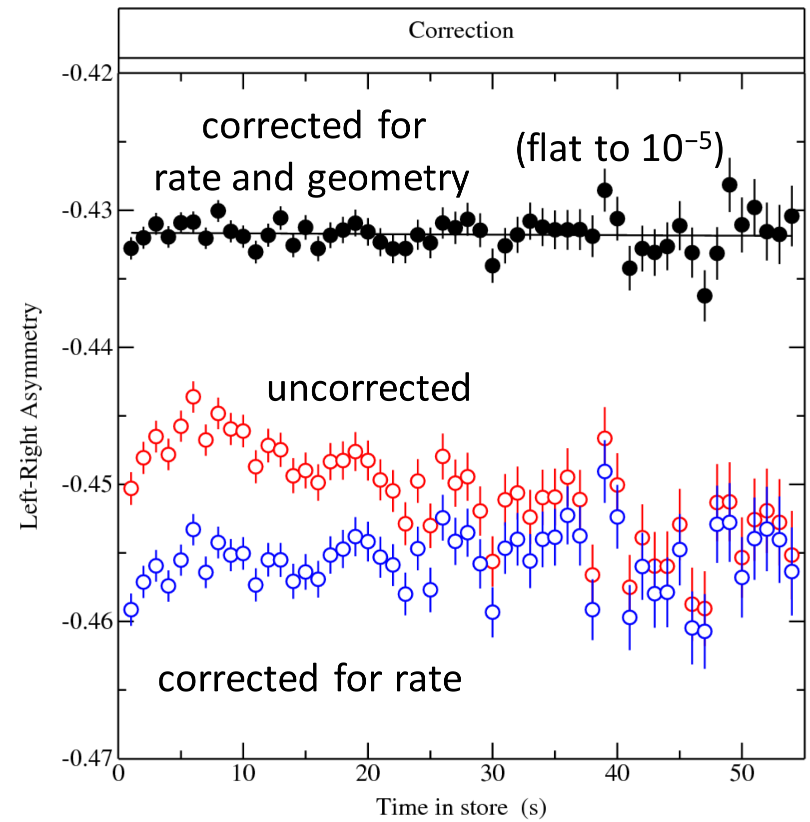
Good for rate effects!

Does this work? (Test by comparing position and angle sensitivity.)

data from 2009 long run



test with constant polarization

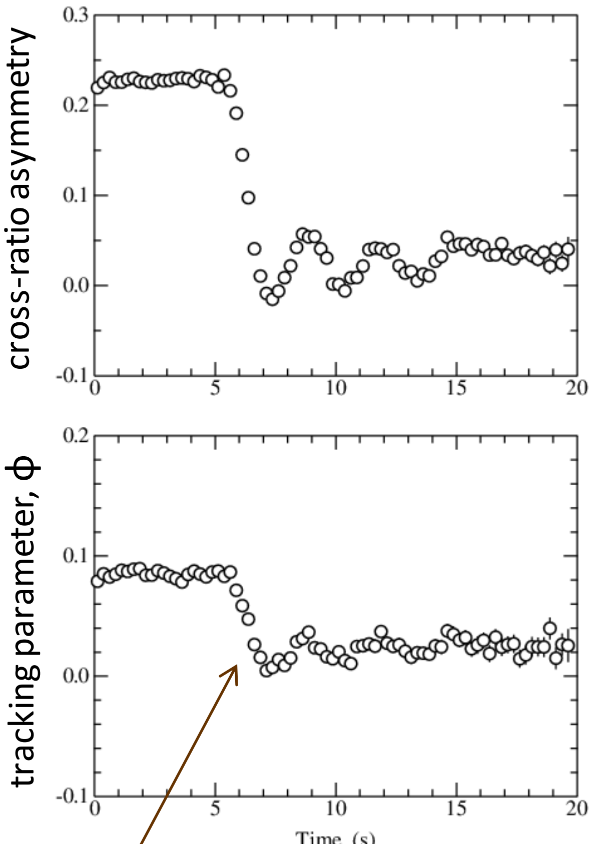


Application to data with errors shows correction in real time.

What about a varying polarization signal?

What happens when the polarization itself is changing?

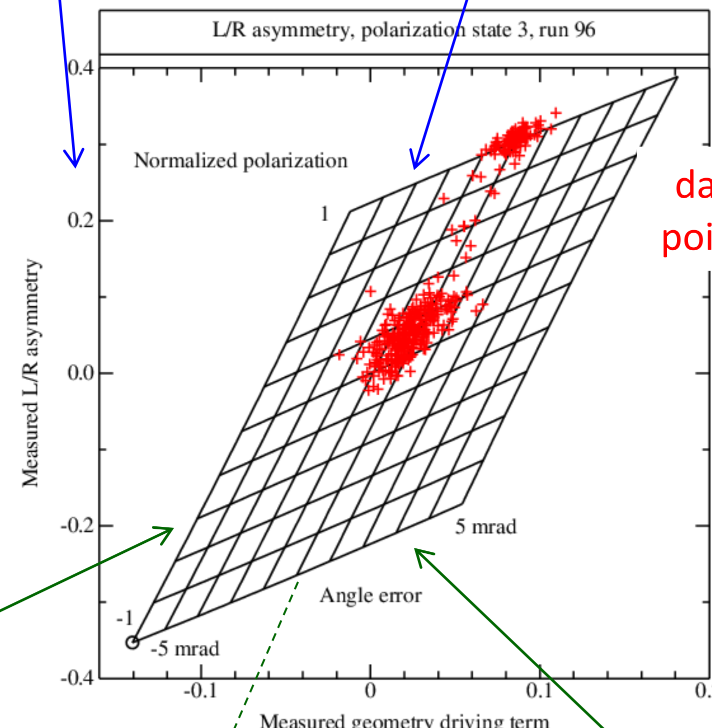
First data available in 2011 from runs made with RF solenoid on spin resonance.



The error indexing parameter also contains some remnant of the signal (from unequal state polarizations).

data

The model can also address this situation, projecting the data from the lab system onto the corrected system.



data points

0

Axis renormalized, as model knows about polarization.

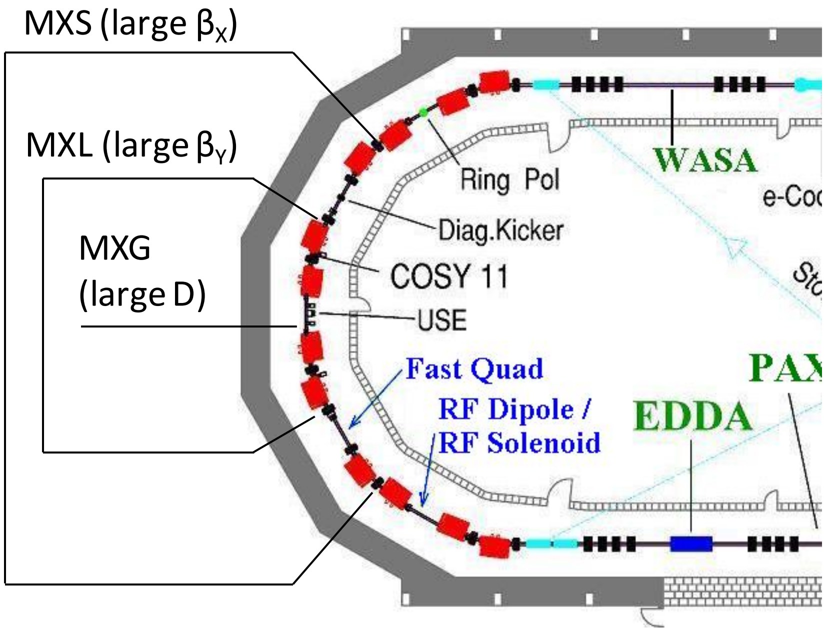
Other axis shows scatter in the systematic error

Field correction study

Learn to measure horizontal polarizationas it rotates at 120 kHz (deuterons).

Can sextupole corrections remove second-order contributions to decoherence.

Three sextupole magnet families:



New data acquisition procedure – time stamp every event

Count turn number (bunched beam) → distribution of turn number fraction yields beam distribution

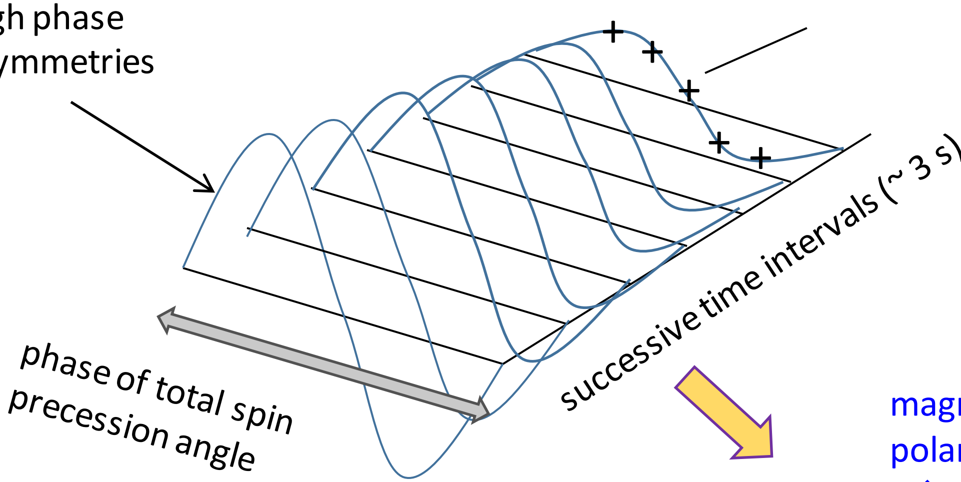
Compute total spin precession angle

Bin by phase around the circle → based on integral part of turn number

Compute asymmetry in each bin

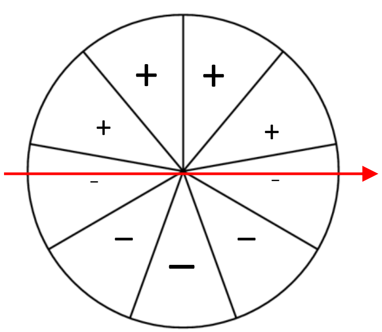
smooth curves through phase bin asymmetries

these curves determined by asymmetry measurements for 9 angle bins

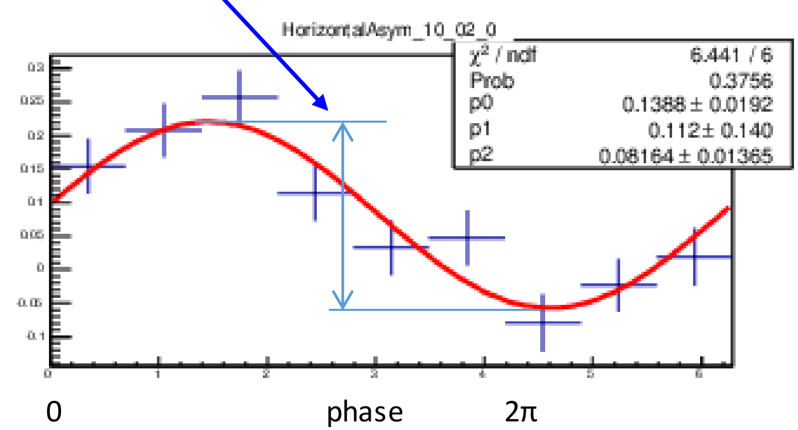


correcting phase slip from one bin to the next adjusts the spin tune

magnitude gives horizontal polarization

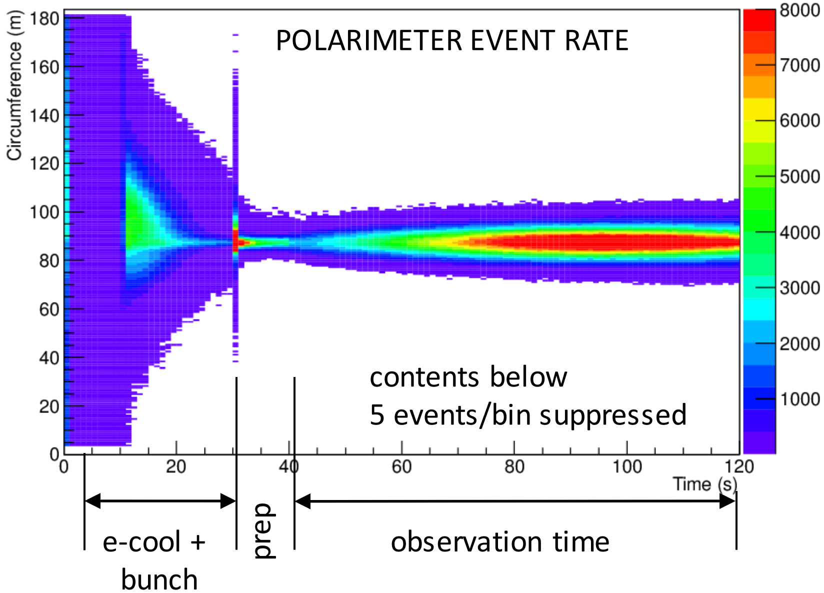


As the polarization rotates the down-up asymmetry reflects the sideways projection of the polarization.

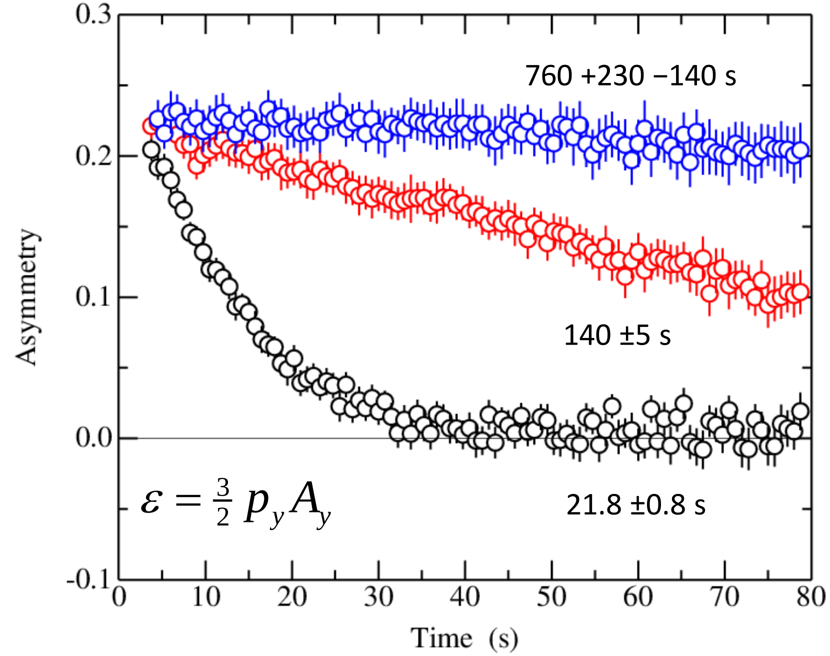


Sample data

Distribution of beam around the ring as a function of time in the store.

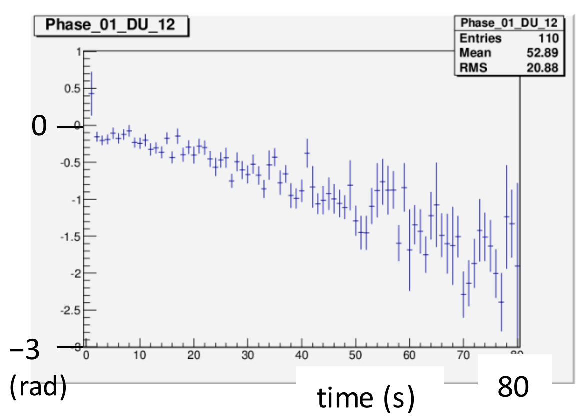


Sample measurements of horizontal polarization loss (corrected for positive bias)



Times are exponential decay rates.

phase in a single store with fixed spin tune



Program searches for highest amplitude in a narrow range.

To get maximum asymmetry stationary in one angle bin, spin tune must be accurate to < 1e-6. Normal scatter is usually < 1e-7.

Best error in phase is ~ 3° /s.

Downward slope means spin tune wrong by 3e-8 (δ ~ 10%).

EDM ring requirement is 1e-9 from feedback.

Expected sensitivity of polarization lifetime (inverse) to sextupole strength

$$\frac{1}{\tau_{SCT}} = |A + a_1 S + a_2 L + a_3 G|\theta_X^2 + |B + b_1 S + b_2 L + b_3 G|\theta_Y^2 + |C + c_1 S + c_2 L + c_3 G|\sigma_P^2$$

natural value

sensitivities

sextupole currents (MXS, MXL, MXG)

drivers: emittance, sync. osc.

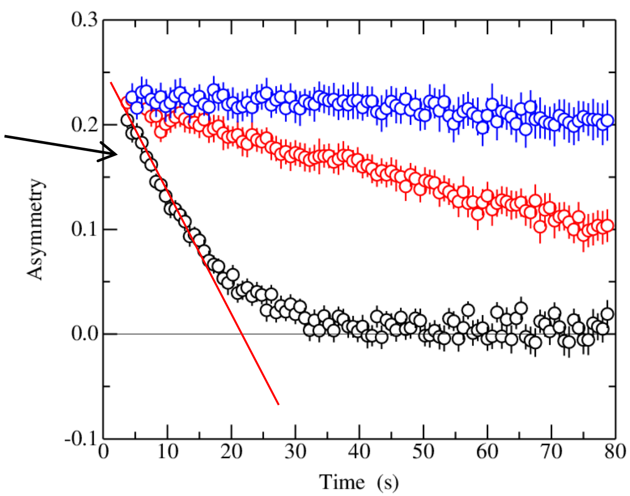
1 Set chromaticities to zero (X and Y). Make horizontally wide beam.

2 Measure initial polarization slopes.

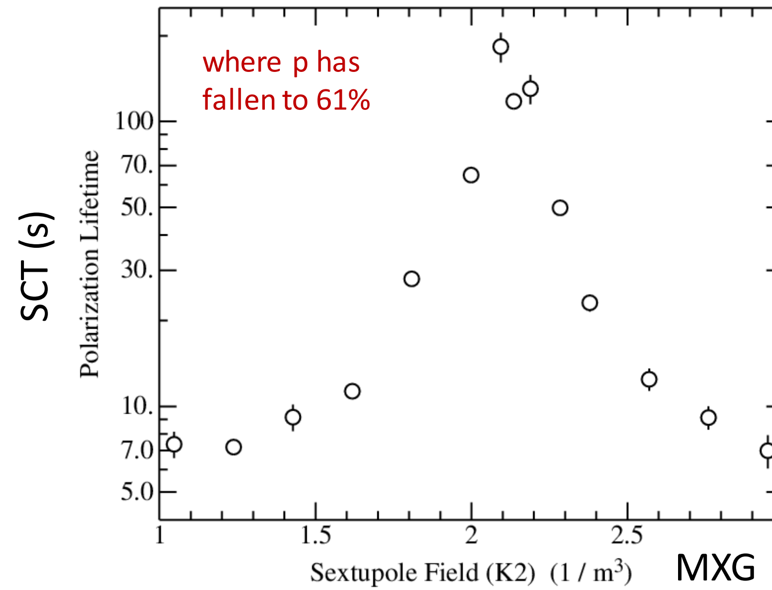
Make linear fit to early part.

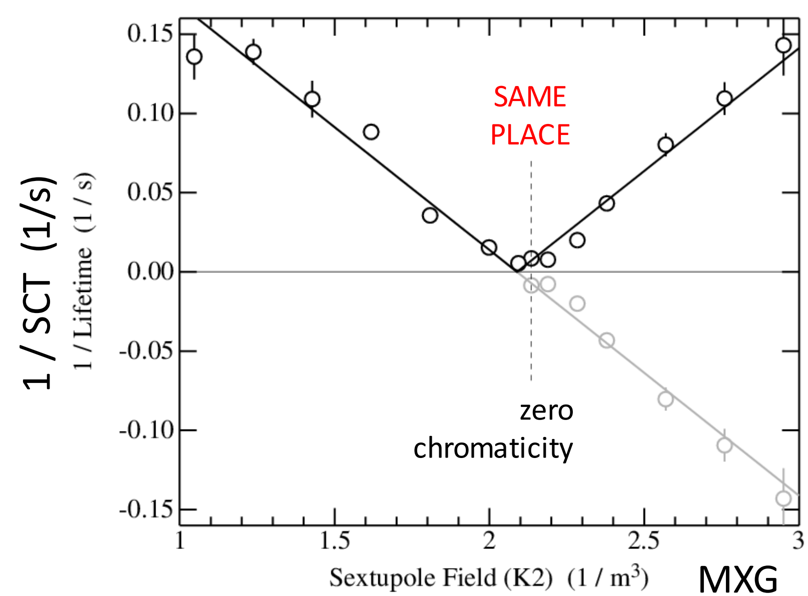
$$\varepsilon = a_0 + a_1 t$$

$$SCT = -\frac{a_0}{a_1}$$



3 Repeat for changing MXG.





Can we maximize the polarization lifetime using all 3 sextupole families?

Use two machine setups to separately check:

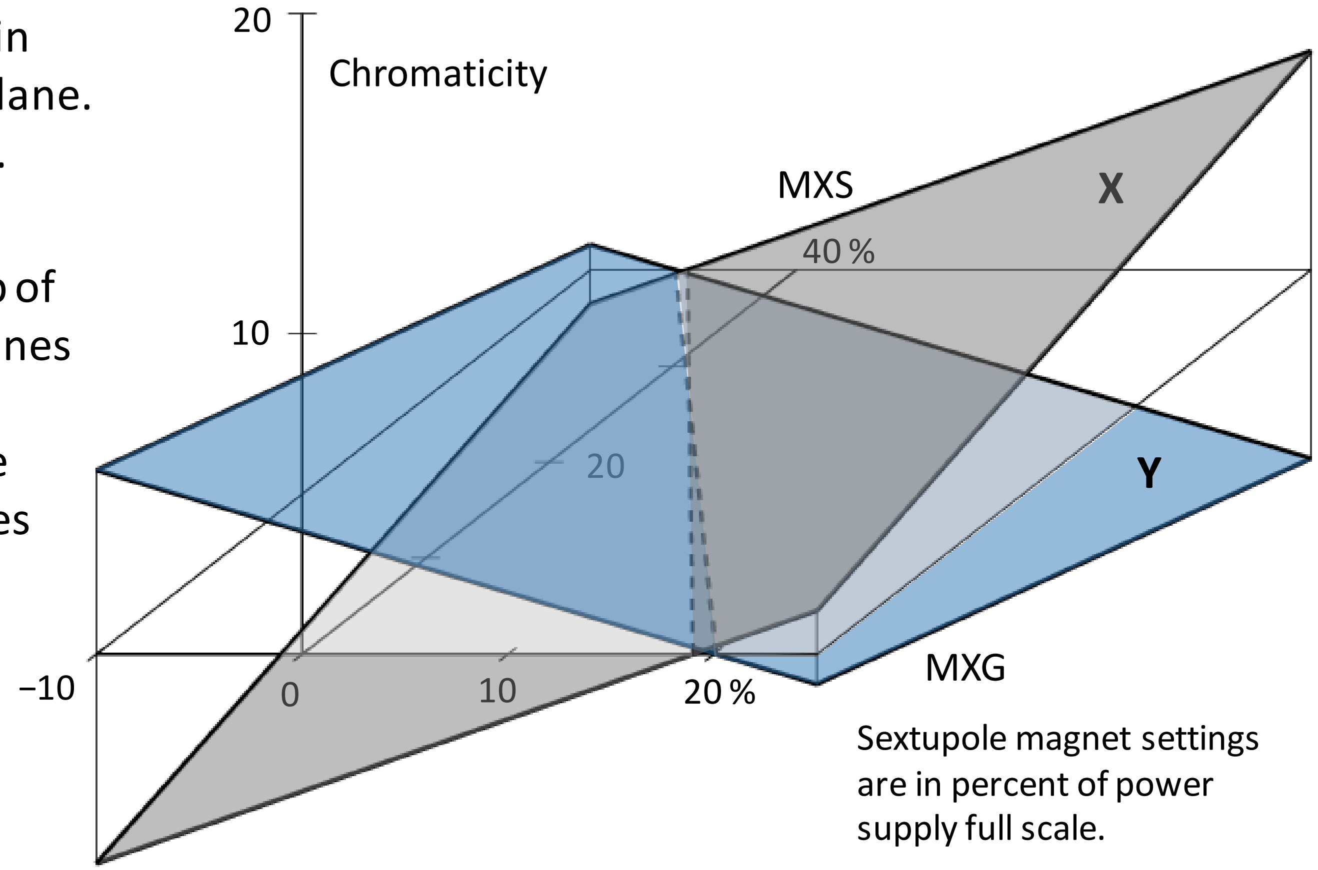
[1] horizontal emittance. E-cool and bunch together, then heat with white noise.

[2] synchrotron Δp/p. E-cool first, bunch second. No horizontal heating.

Extraction onto polarimeter target uses vertical white noise (always present).

Chromaticity in MXG x MXS plane. MXL = −2.0 %.

Note the overlap of the two dotted lines that represent the places where the chromaticities vanish.



Sextupole magnet settings are in percent of power supply full scale.

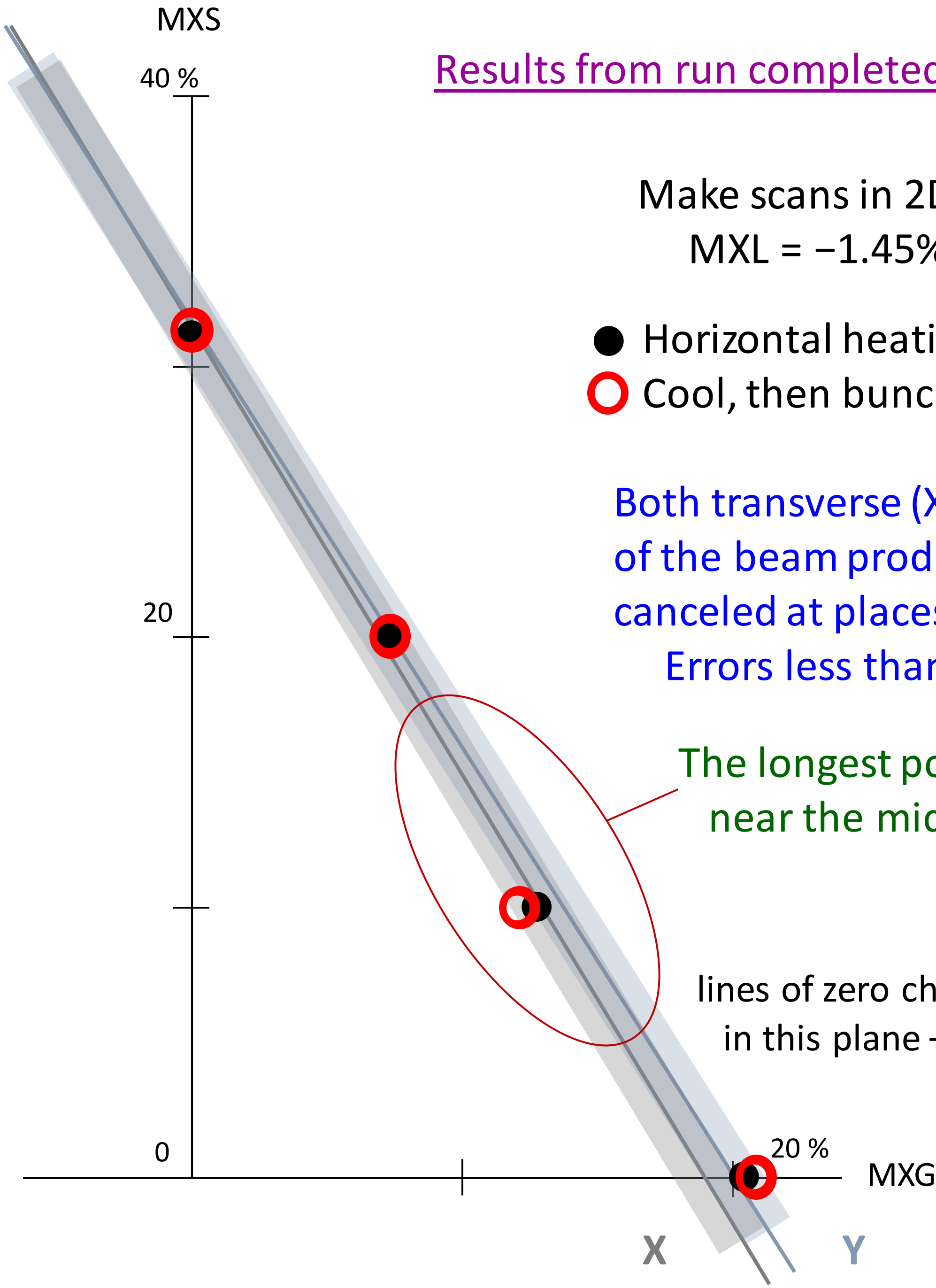
Results from run completed in August, 2014.

Make scans in 2D MXS x MXG space with
MXL = −1.45%

- ● Horizontal heating (large X emittance)
- ○ Cool, then bunch (large synchrotron orbits)

Both transverse (X) and longitudinal spreads of the beam produce decoherence; both are canceled at places of zero chromaticity.
Errors less than the size of the symbols.

The longest polarization lifetimes are found near the middle of this range.

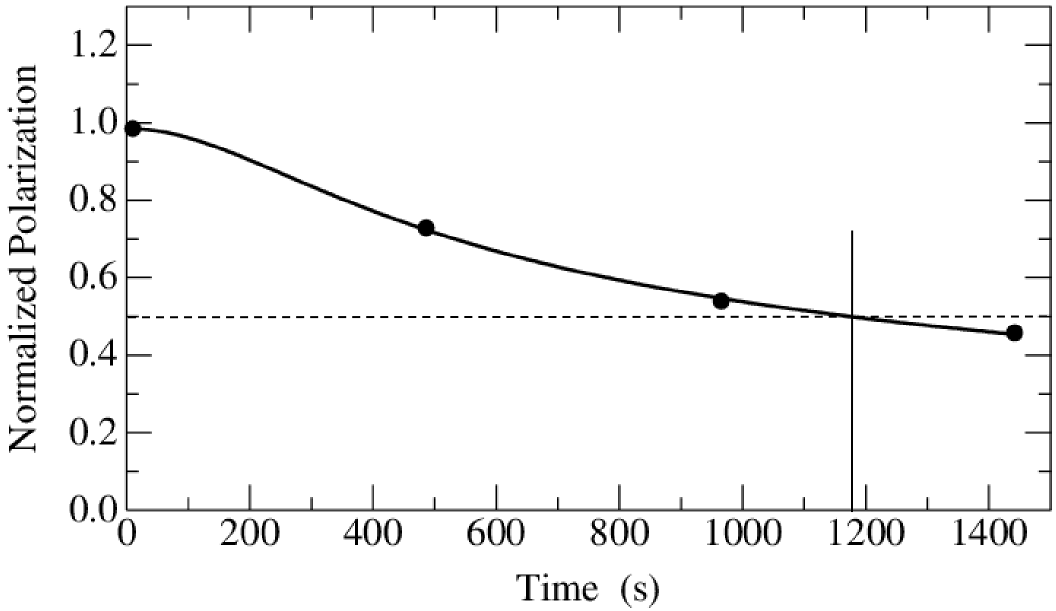


lines of zero chromaticity (X or Y) in this plane – errors ~ 1 %

Scales are in percent of power supply full range.

Longest horizontal polarization lifetime:

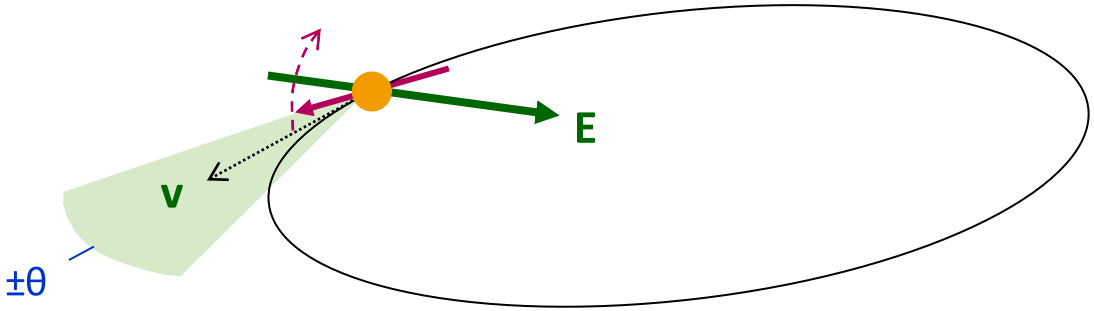
Electron pre-cooling time 75 s. No cooling afterward…



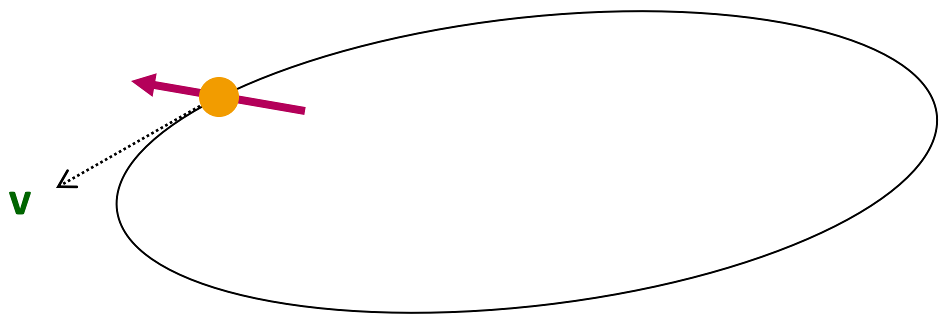
Smooth template based on Gaussian distribution of betatron amplitudes.

Half-life = 1173 ± 172 s

Requirements on polarization control:



Maintain polarization within some limited angular range on either side of the velocity for ~ 1000 s. From beginning to end, 10^{-9} precision is needed.



Periodically rotate sideways and hold for a check of the polarization. (For tensor polarized deuterons, this is possible in place.)

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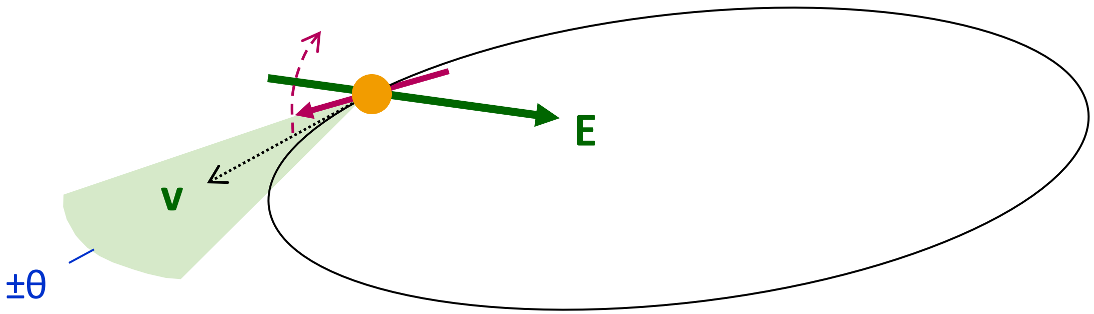

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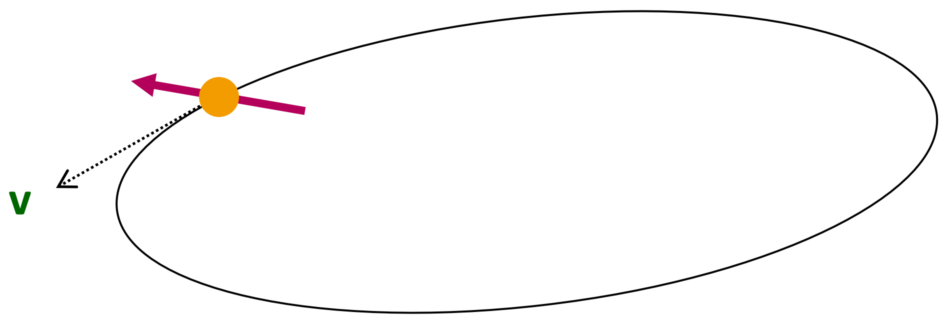


Periodically rotate sideways and hold for a check of the polarization. (For tensor polarized deuterons, this is possible in place.)

polarimeter rates (U, D, L, R)
COSY RF timing

clock TDC

DAQ

online analysis for magnitude, spin tune, and phase (from t = 0)

NEW

Calculate correction

RF frequency generator

Make 2 kinds of corrections:

1 Δf to
choose a new spin tune
regulate spin tune

2 Δf for Δt to
go to a new phase
(new direction)

Calibration of feedback to RF cavity

$$\frac{\Delta \nu_S}{\nu_S} = \frac{\Delta \gamma}{\gamma} = \beta^2 \frac{\Delta p}{p} = \frac{\beta^2}{\eta} \frac{\Delta f}{f}$$

spin tune (ν_S); revolution frequency (f)

for the deuteron beam:

$$p = 0.97\,GeV/c$$

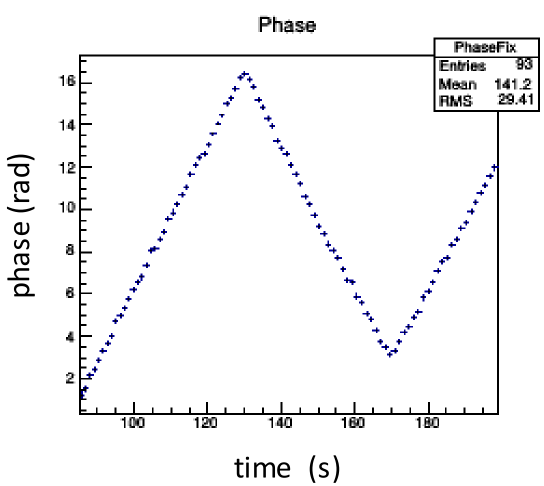
$$\beta = 0.456$$

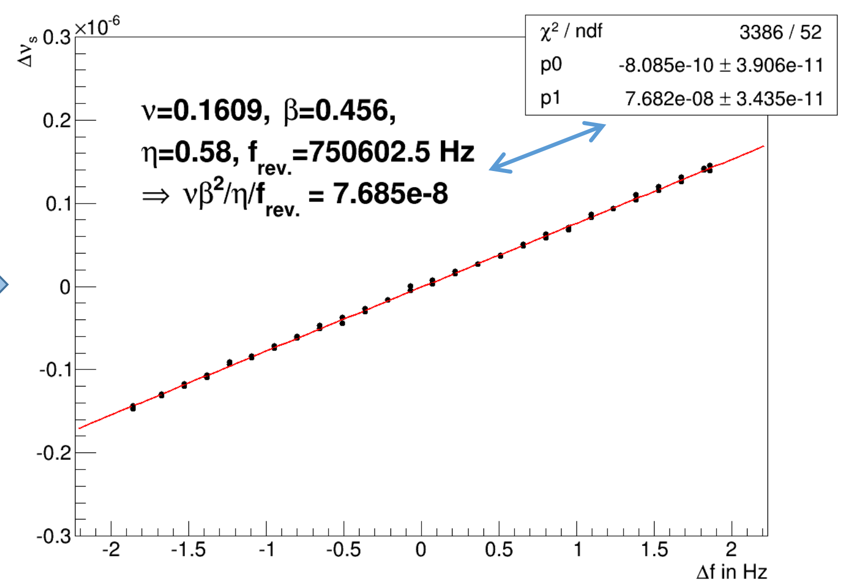
$$\eta = 0.58$$

Δf is adjustable in steps of 3.7 mHz, or $\frac{\Delta \nu_S}{\nu_S} = 2\times 10^{-9}$

$$\nu_S = \nu_0 + \frac{\partial \phi}{\partial t}$$

Initial slope is mismatch between real spin tune and reference spin tune.





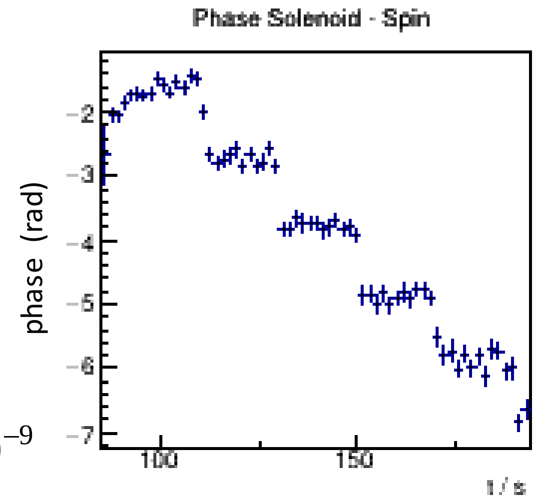
Slope match is excellent.
This tests case 1.

Calibration of feedback to RF cavity

$$\frac{\Delta\nu_S}{\nu_S} = \frac{\Delta\gamma}{\gamma} = \beta^2 \frac{\Delta p}{p} = \frac{\beta^2}{\eta}\frac{\Delta f}{f}$$

spin tune (ν_S) — revolution frequency (f)

Case 2: Making steps of 1 rad in phase



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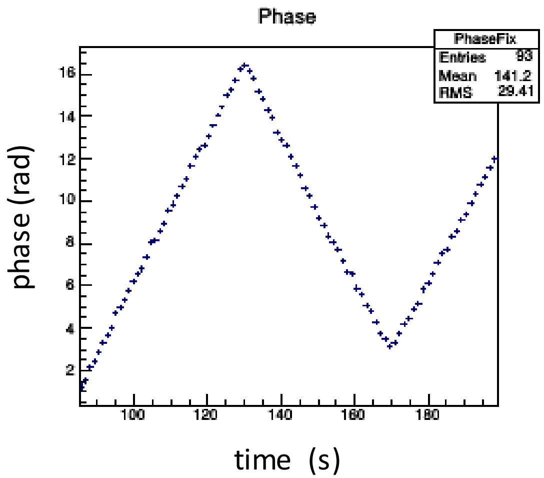
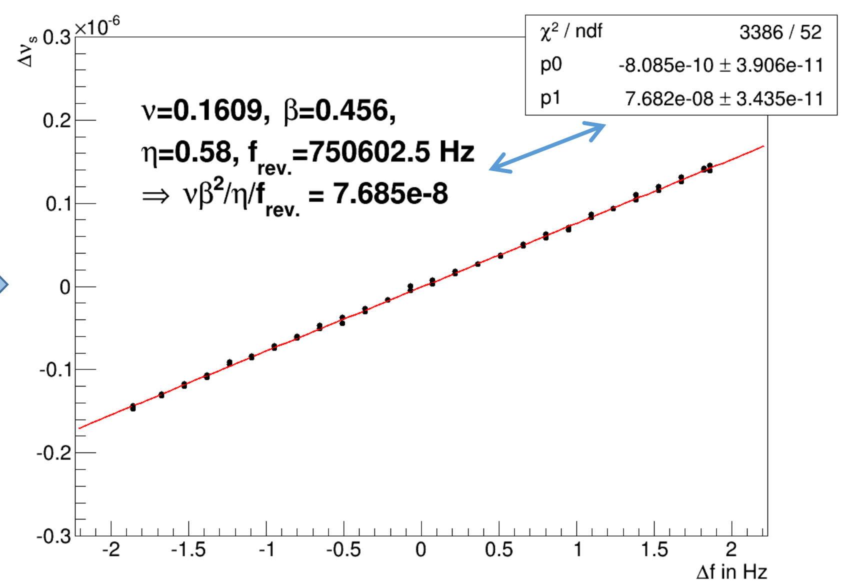
$$\nu_S = \nu_0 + \frac{\partial\phi}{\partial t}$$

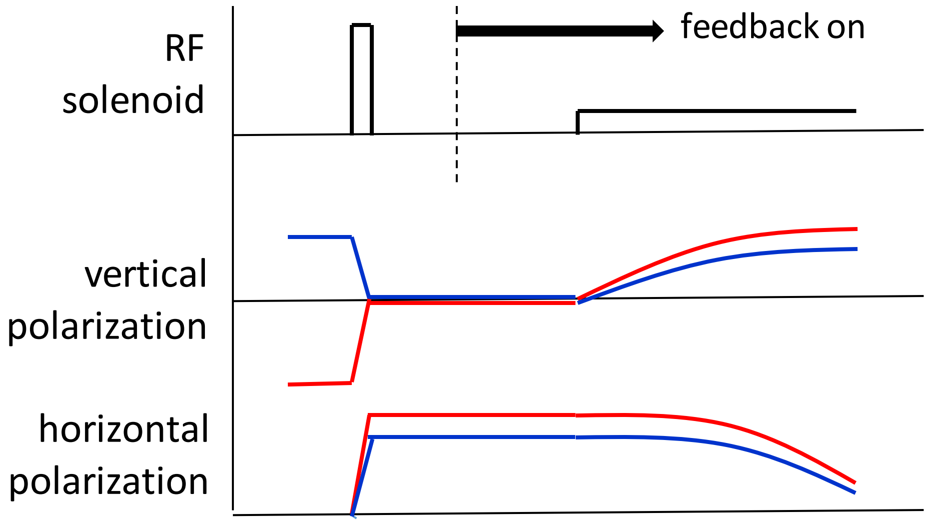
Initial slope is mismatch between real spin tune and reference spin tune.

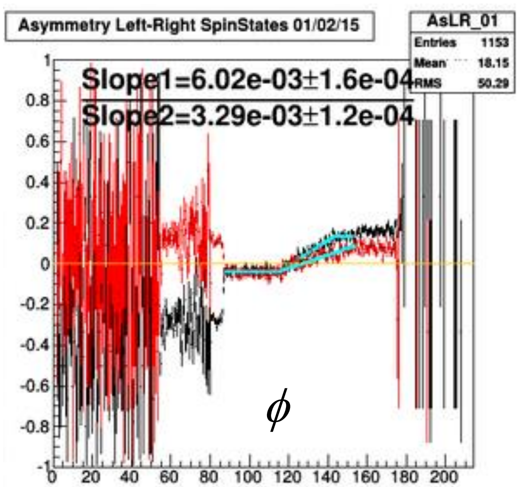


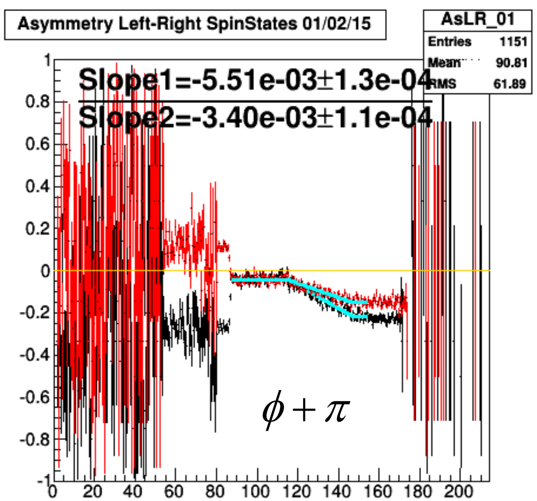


Slope match is excellent. This tests case 1.

Recapture of polarization
(working demonstration for use with RF Wien filter, etc.)

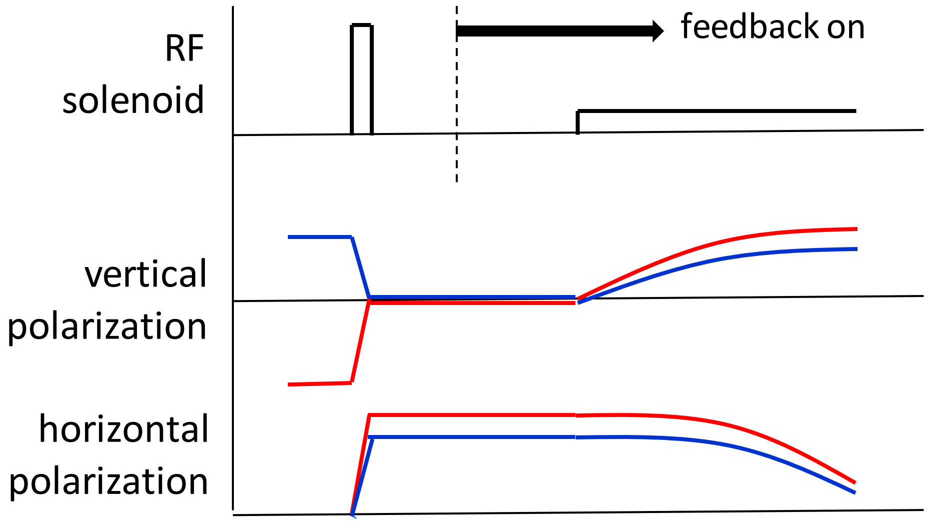


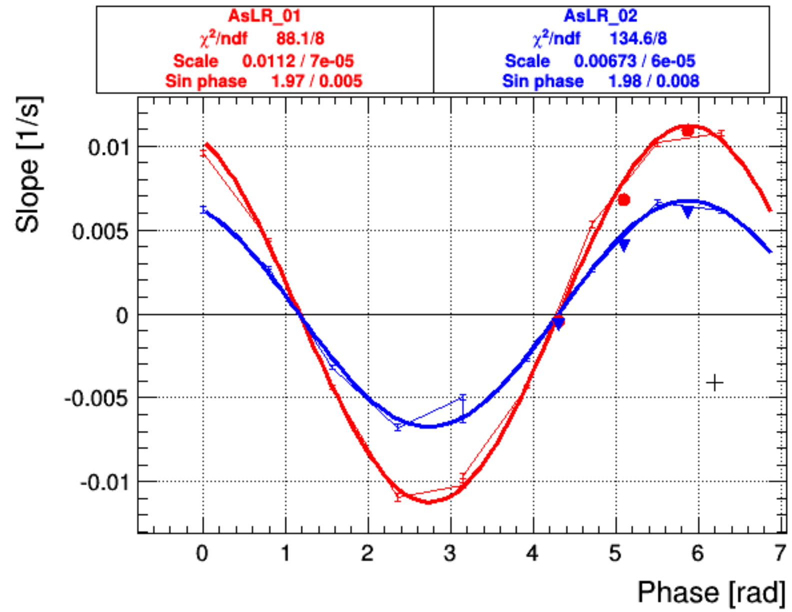


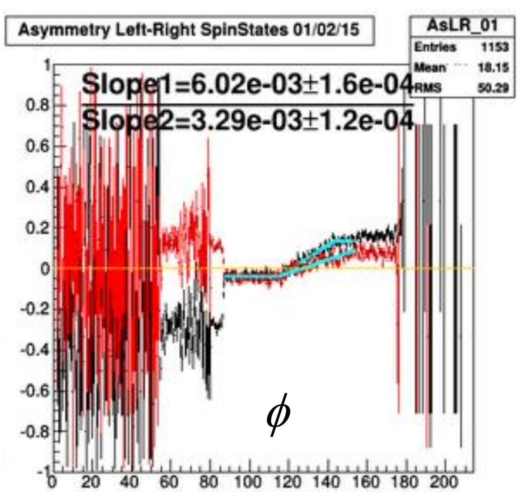


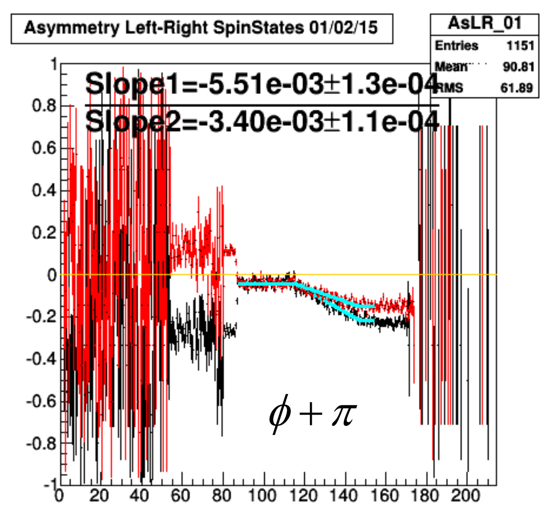
Recapture of polarization

(working demonstration for use with RF Wien filter, etc.)









Plot of initial slope as a function of the target phase for the feedback circuit.

Completes requirement for the precursor and EDM experiments.