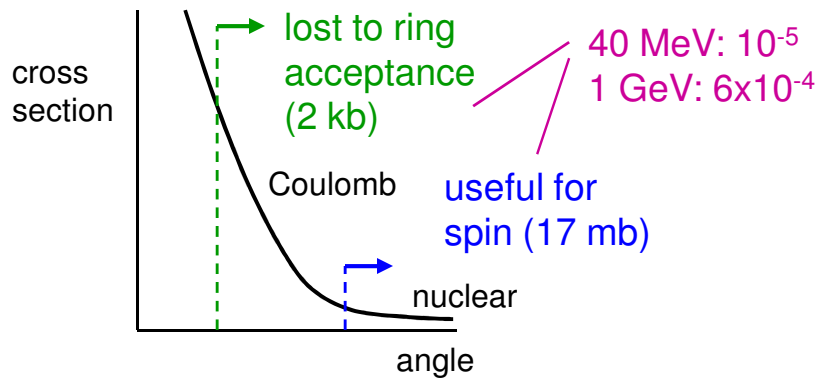


EDM polarimeter



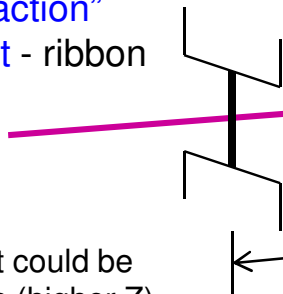
IDEA:

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

(POMME efficiency several percent)

detector system

“extraction” target - ribbon

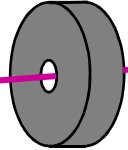


Target could be Ar gas (higher Z).

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

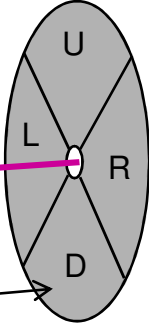
Events must imbed far enough from hole to not multiple scatter out of primary target, thus $\Delta \ll D$. Δ , which is a large fraction of the deuteron range, sets scale for polarimeter.

“defining aperture” primary target



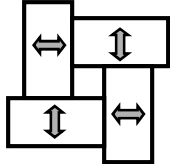
Hole is large compared to beam. Everything that goes through hole stays in the ring. (It may take several orbits to stop scattered particle.)

R



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

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



Deuteron Polarization

“Ion Source” usually has a good axis of quantization.

The magnetic substates

$$m = 1, 0, -1$$

are fractionally populated.

$$f_1, f_0, f_{-1}$$

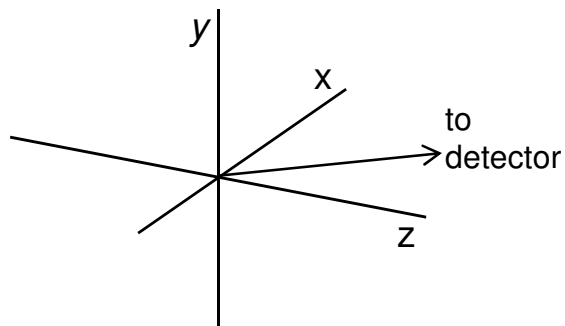
$$f_1 + f_0 + f_{-1} = 1$$

The difference of any f from $1/3$ produces a polarization:

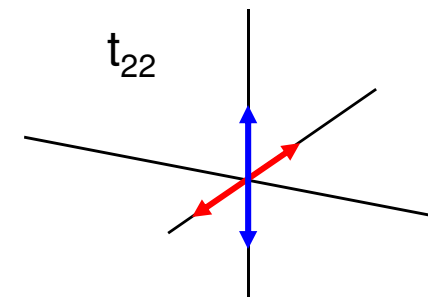
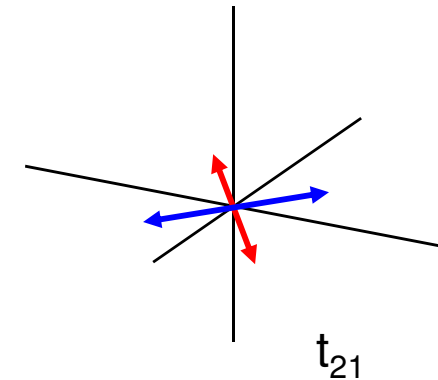
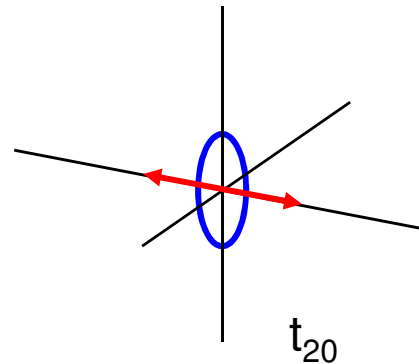
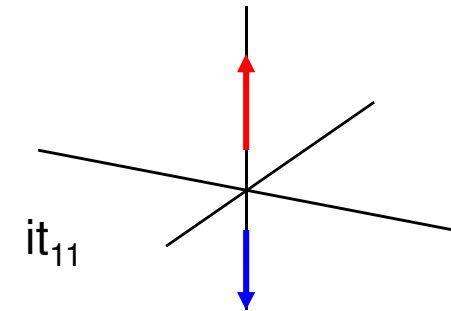
$$\text{vector: } p_z = f_1 - f_{-1}$$

$$\text{tensor: } p_{zz} = 1 - 3f_0$$

Standard coordinate system

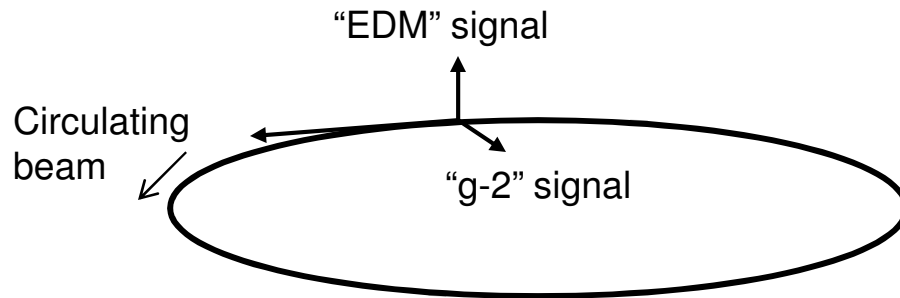


■ positive
■ negative



Systematic Polarimeter Errors

Ed Stephenson
July 30, 2003



Simple Plan:

use E-field to cancel g-2 precession
allow EDM component to grow
measure EDM with left/right asymmetry

Problem (for spin=1 deuteron):

small cancellation error + small t_{21}
makes false EDM signal
error about $1:10^{10}$, too large to control

Alternate Plan:

get close to cancellation,
but allow polarization to precess
run polarimeter continuously
measure all deuteron components,
Fourier analyze results

Does this work?

no longer a simple calculation

Model set up to look at this

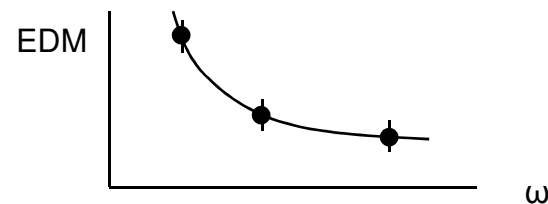
Work started

No problems yet...

Now is good time for suggestions...

Features of Alternate Plan:

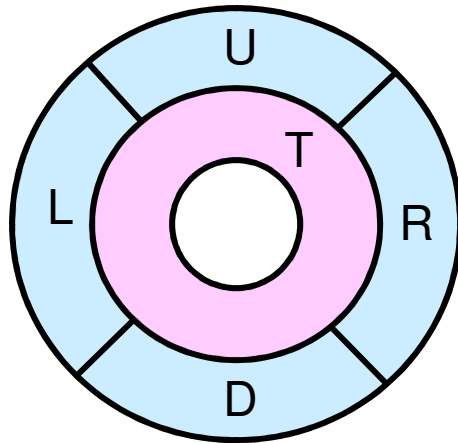
loss of precision in cancellation made up in data
EDM signal goes as $1/\omega_{g-2}$



eliminates first-order problems (all flat) from:
injected normal component
polarimeter rotation
etc.

other big terms determine unknown ω_{g-2}
(ω varies from shot to shot)

Polarimeter “mock-up”



Use hydrogen as the target

For simplicity, consider 5 detectors
inner ring (T) allows luminosity
to be separated from t_{20} if the
angular distribution contains both
signs of T_{20} , which it does →

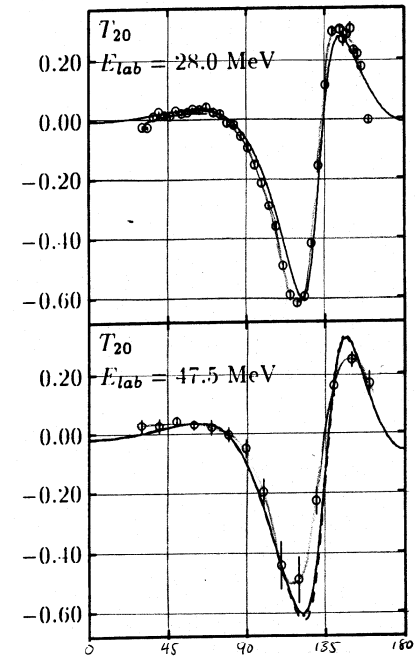
At any time (even with spreading)
the beam is specified with four
parameters:

T_{10} : vector polarization

T_{20} : tensor polarization

β : polar angle of spin axis

φ : azimuthal angle of spin axis



Each polarimeter data time slice can be used to obtain:

$$S = L + R + D + U + 4T$$

$$\Delta_{LR} = (L - R) / S$$

EDM term
appears here

These can all be obtained
for a single spin state.

$$\Delta_{DU} = (D - U) / S$$

$$\Delta_{20} = (L + R + D + U - 4T) / S$$

$$\Delta_{22} = (L + R - D - U) / S$$

Differences between opposite
spin states can cancel some
systematic errors.

How to make the model:

Go through a list of imaginable errors:

- detector rotation
- depolarization of the beam
- binning (aliasing) effects
- tensor polarization
- etc.

Singly or in groups, do you get something that mimics an EDM signal or masks it with noise? If so, at what level?

Techniques that are trouble:

Algebraic expansion:

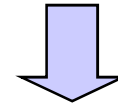
- the system has signals of the order of 1/3
- EDM is less than 10^{-4}
- many orders needed to get a check

Monte Carlo:

- too many events for needed statistics

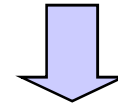
Model of the experiment:

Deuterons precess at determined rate
produces detector count rates with errors
all effects included exactly
systematic errors added exactly



Wall of ignorance

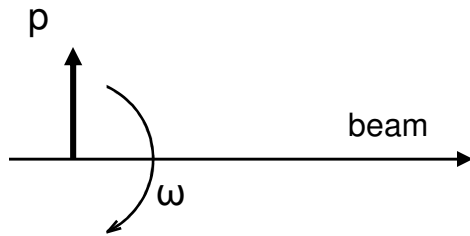
All setup variables lost
Only count rates remain



Fourier series analysis program:

Turn rates into polarizations
Extract series coefficients as a
function of θ_{g-2}
Is there a problem?

Data Generator



Inject P sideways (in ring plane)
 Allow to precess at ω for 1 second
 EDM precession is added by
 integrating longitudinal component (p_z)
 Take polarization snapshot at regular
 intervals (say every 10 ms)
 Compute count rate in each detector
 Change count rate randomly based on
 statistics for that rate

$$it_{11} = \tau_{10} \frac{1}{\sqrt{2}} \sin \beta \cos \phi$$

$$t_{20} = \tau_{20} \frac{1}{2} (3 \cos^2 \beta - 1)$$

$$t_{21} = \tau_{20} \sqrt{\frac{3}{2}} \sin \beta \cos \beta \sin \phi$$

$$t_{22} = \tau_{20} \sqrt{\frac{3}{8}} \sin^2 \beta \cos 2\phi$$

where

$$\tau_{10} = \sqrt{\frac{3}{2}} (f_+ - f_-)$$

$$\tau_{20} = \sqrt{\frac{1}{2}} (1 - 3f_0)$$

Count rates:

$$C_L = C_0 (1 + 2it_{11} iT_{11} + t_{20} T_{20} + 2t_{21} T_{21} + 2t_{22} T_{22})$$

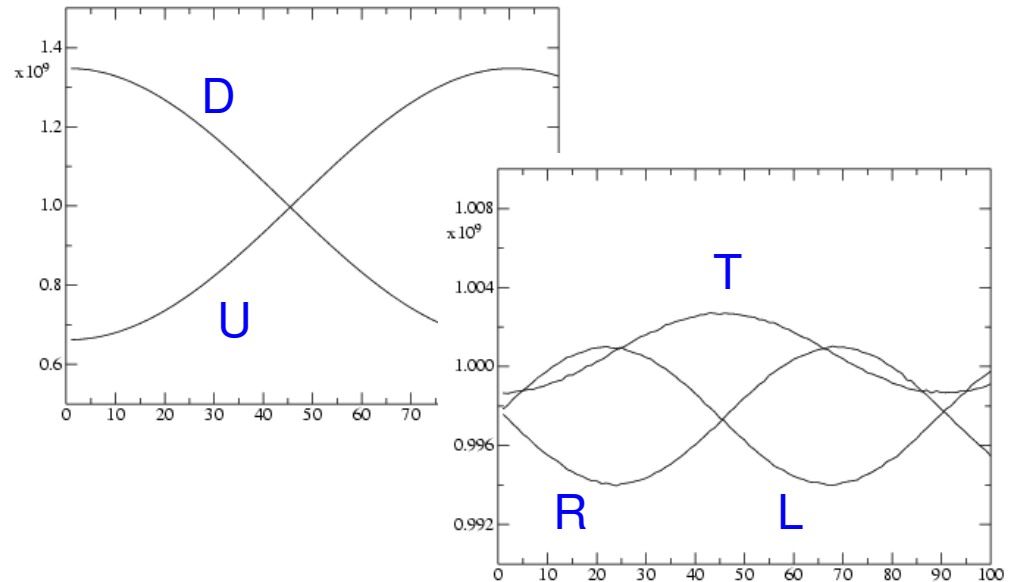
$$C_R =$$

$$C_D =$$

$$C_U =$$

$$C_T =$$

etc. with angles rotated as
 needed for each detector

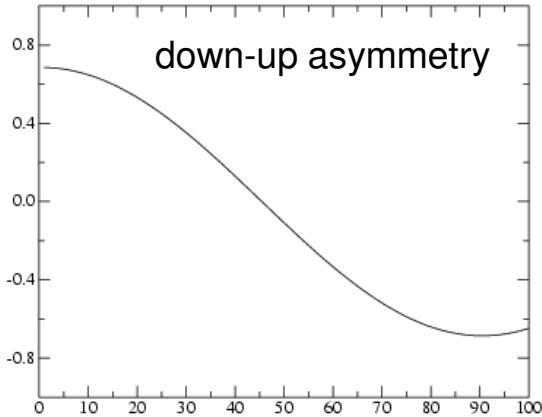


Typical Output

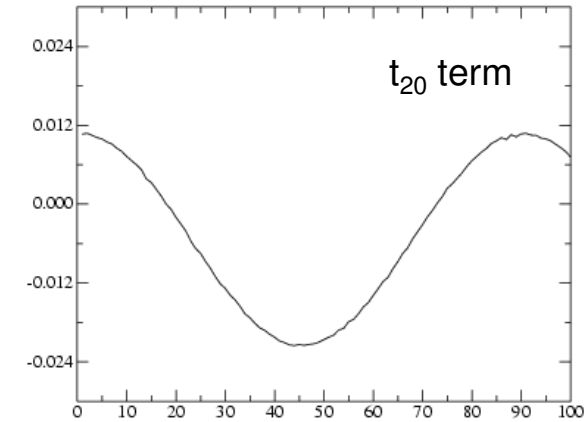
function of time

$$\vartheta = \theta_0 + \bar{\theta}t$$

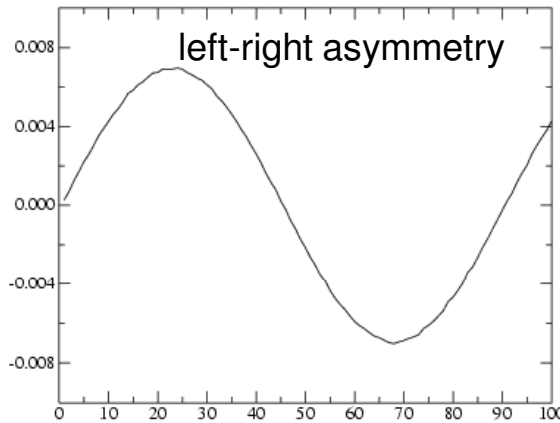
/ spin injection angle
| spin precession rate



$$\Delta_{DU} = A_1 \cos \vartheta + A_2 + A_3 \sin 2\vartheta$$



$$\Delta_{20} = A_7 (3 \sin^2 \vartheta - 1) / 2$$



$$\Delta_{LR} = A_4 10^{-4} \cos \vartheta + A_5 10^{-4} + A_6 \sin 2\vartheta$$

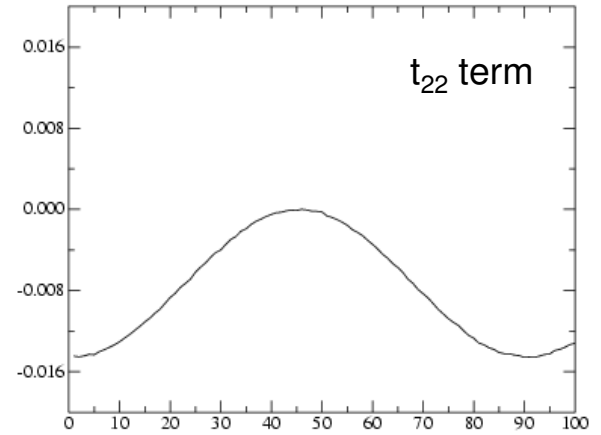
EDM term

+ A₆ sin 2ϑ

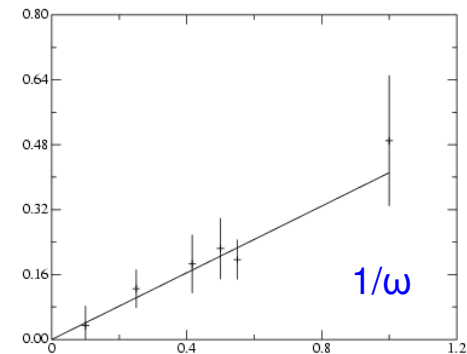
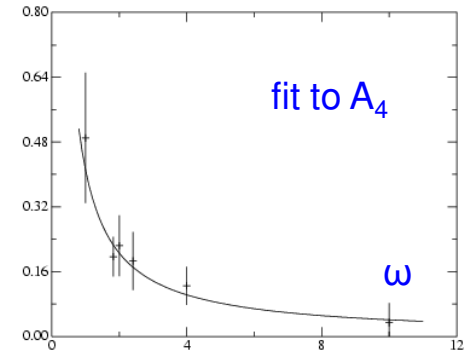
t₂₁ term

constant term needed because EDM grows from zero

A₄ at several precession rates



$$\Delta_{22} = A_8 \cos^2 \vartheta$$



Systematic error test: effect of ω binning

Power supply regulation means that E, B drift

To look for ω -dependence, bin each shot

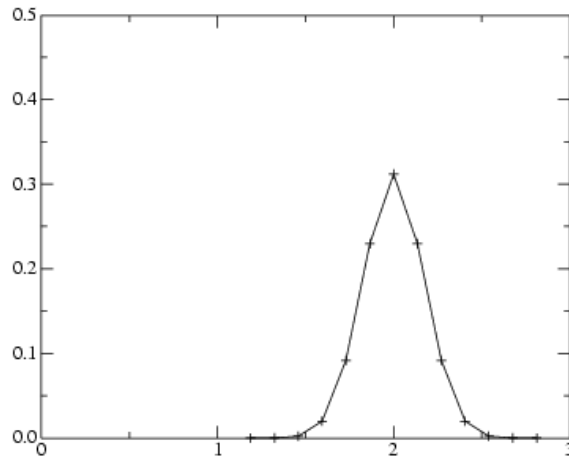
What is the statistical error?

The ring loss cross section is 2 kb.

A 1 s beam lifetime means target is $< 5 \times 10^{14} / \text{cm}^2$

With a polarimeter cross section of 17 mb,
each shot records about 2700 events.

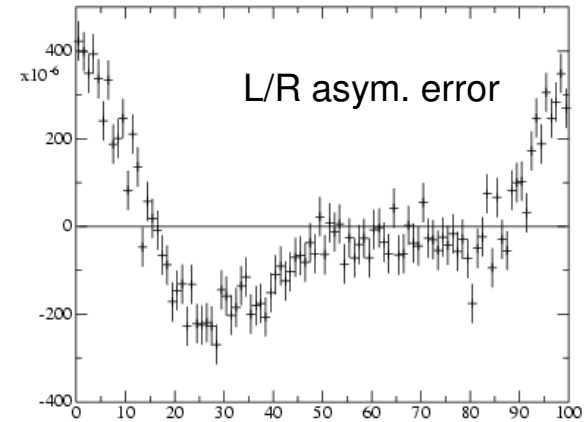
With a δ -function ω , the recorded distribution is:



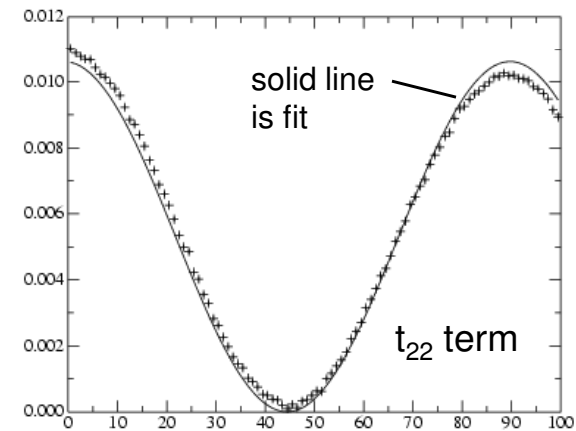
If one averages together data with this spread,
what happens?

False EDM signals appear at about the minimum
sensitivity level and that vary randomly with ω .

Problem is associated with poor fits.



Such a smearing depolarizes the data:



This comparison suggests that this effect
can be treated as a depolarization.

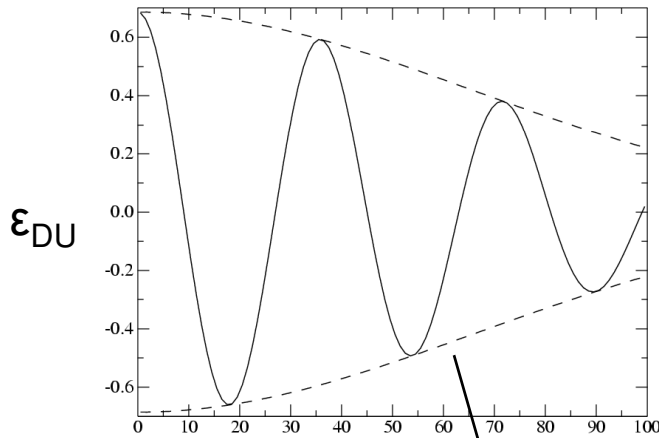
$$p(t) = p_0 \exp(-D^2 t^2 / 2)$$

Depolarization

Reduction is convolution of cosine with Gaussian of width σ

$$\text{atten: } \exp(-\sigma^2 / 2)$$

When depolarization comes from finite-width binning, $\sigma \propto Dt$.



envelope is:

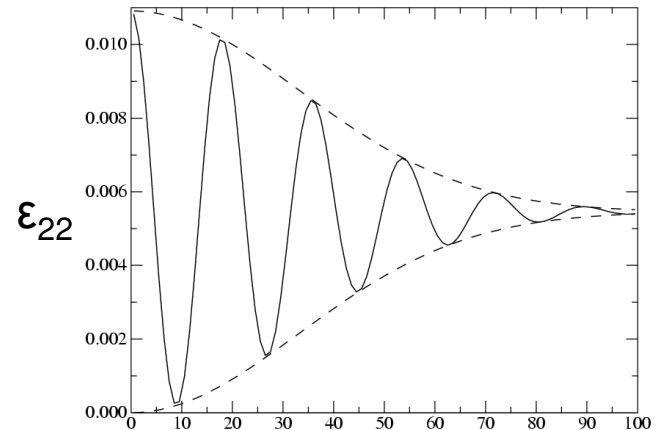
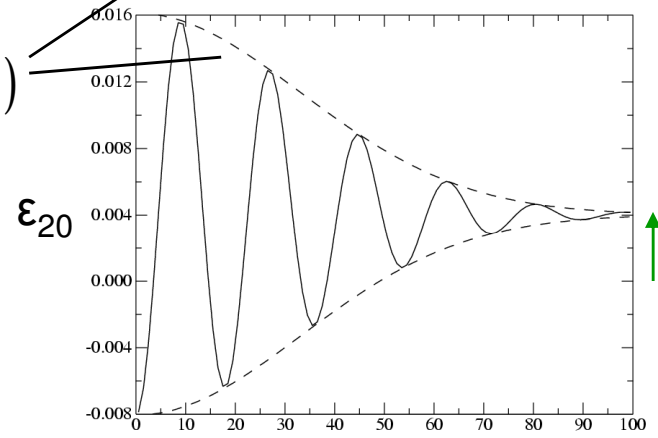
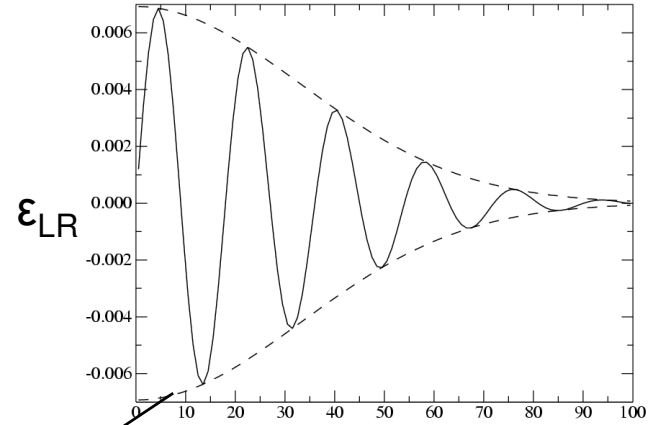
$$\exp\left(-\frac{D^2 t^2}{2}\right)$$

D is added to the list of fitting parameters.

Tensor asymmetries vary twice as quickly (for this case) and attenuate twice as quickly

$$\exp(-2D^2 t^2)$$

Beam moments t_{20} and t_{22} go to non-zero value (note arrows).



Observations:

not dealing with CW/CCW issues
not dealing with multiple polarimeters

Ways to do experiment:

1. frozen spin: maximal signal
2. precessing spin: enriched signal
 - Cosine term, right period and phase (same as ϵ_{DU})
 - takes out constant p_y term
 - wrong period for t_{21} component
 - Amplitude that goes as $1/\omega_{g-2}$
 - takes out feed-through from ϵ_{DU}
 - Should flip with spin exactly
 - Increases data acquisition requirements
 - x 2 sine and cosine in ϵ_{LR}
 - x 2 observe ϵ_{DU}
 - x 1.2 tensor t_{20} normalization
 - x N data at multiple ω_{g-2} values

At 2 GeV/c we have data rate to spare, the experiment is DAQ limited. Polarimeters should be separate, independent.

More complicated issues:

E x B drift forces ω binning.

This creates effective depolarization

$$\sigma \propto Dt$$

When fit is bad, you get “cosine” noise.

Good fit: no noise, no cross-talk

Similar issues include:

Modulation of ω (beam induced currents on electric field plates, etc.)

Rate dependent PMT response

(Bad fits generate noise: need models)

Polarimeter “geometry” issues:

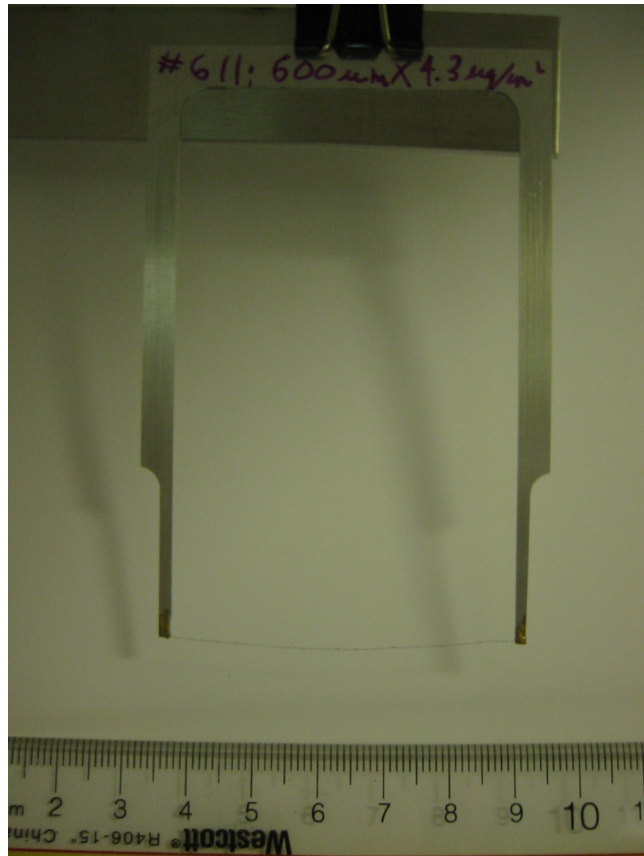
- beam position changes
- beam angle changes
- beam blow-up
- time-dependence in any of these

Carbon Fiber Target

typical thickness = $3.3 \mu\text{g}/\text{cm}^2$

This specimen is $600 \mu\text{m}$ wide.

Widths for RHIC use extend
down to $3.5 \mu\text{m}$.



Target comparison at 2 GeV/c

	<u>Hydrogen</u>	<u>Carbon</u>
cross section into L+R pair (integral from ... to ...)	7.1 mb 2 – 11°	41 mb 3 -- 13°
analyzing power iT_{11} : max	0.85	0.17 (inc.), 0.4 (exc.)
typical average	0.65	0.14 (inc.), 0.3? (exc.)
(includes $\cos \varphi$ attenuation)		\
Figure of Merit	3.0	> 0.8 3.7
target	bulky (obscures 90°)	fragile