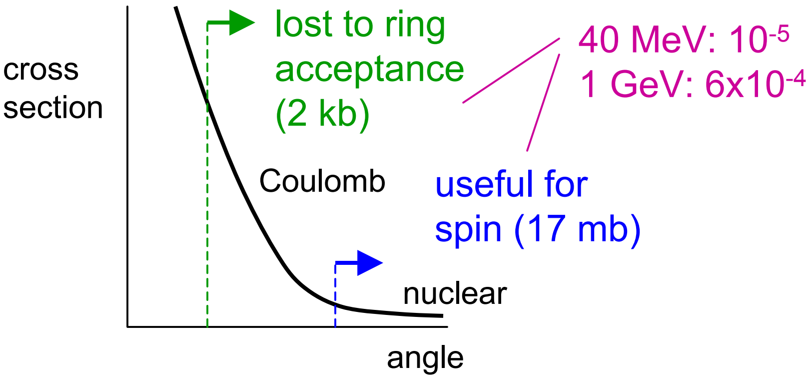
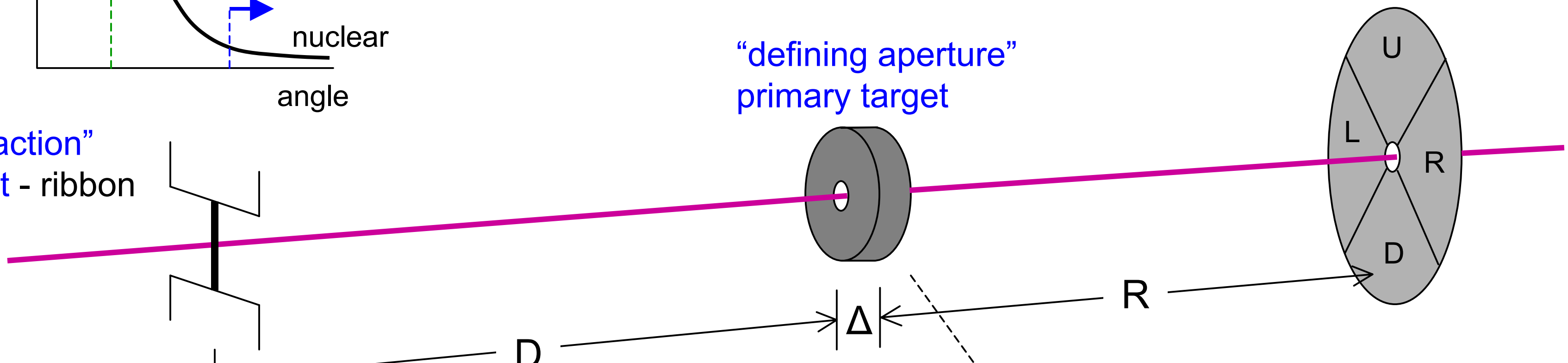
EDM polarimeter



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

(POMME efficiency several percent)



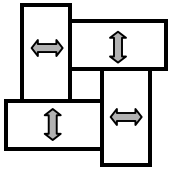
Target could be Ar gas (higher Z).

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. Everything 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 Polarization

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

The magnetic substates

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

are fractionally populated.

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

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

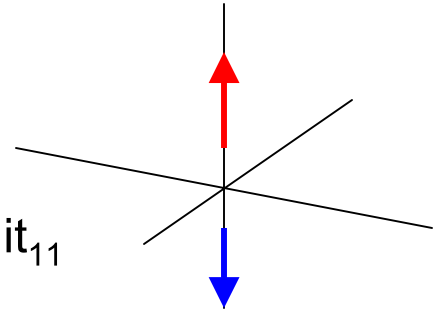
The difference of any *f* from 1/3 produces a polarization:

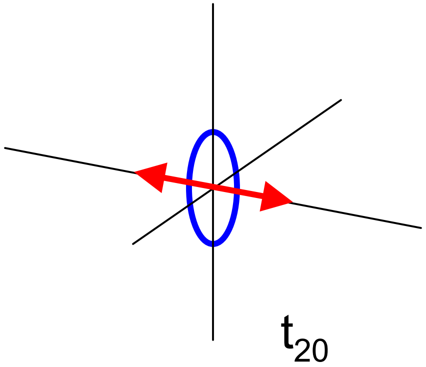
$$vector: \quad p_z = f_1 - f_{-1}$$

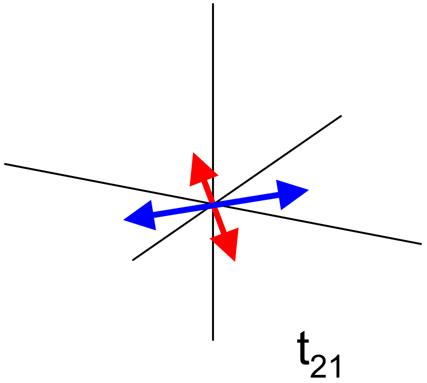
$$tensor: \quad p_{zz} = 1 - 3 f_0$$

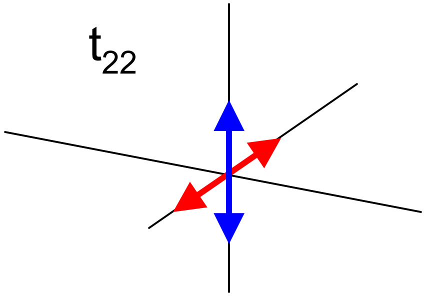
🟥 positive

🟦 negative

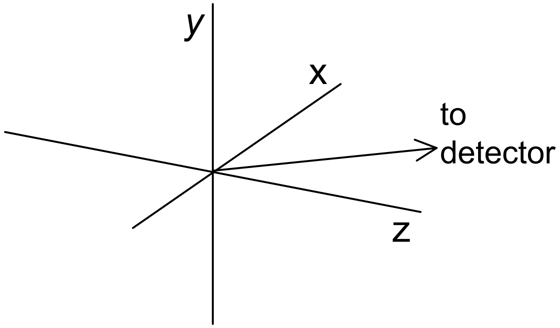






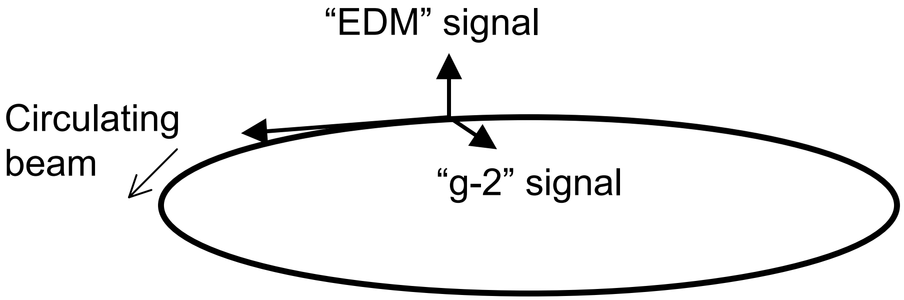


Standard coordinate system



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

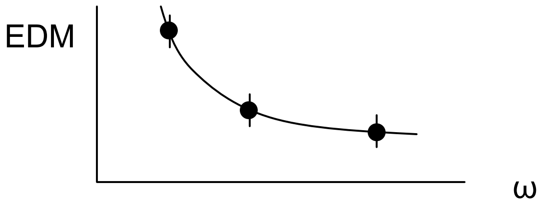
Problem (for spin=1 deuteron):
- small cancellation error + small t_{21}
  makes false EDM signal
- error about $1:10^{10}$, too large to control

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

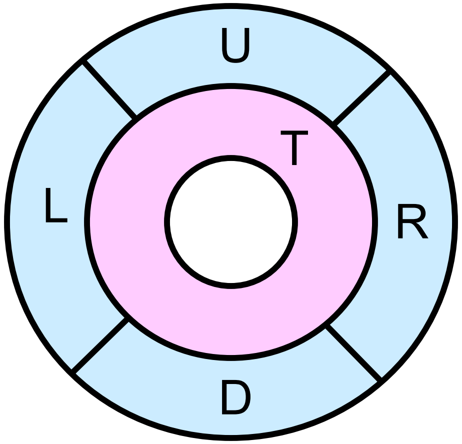
Model set up to look at this
Work started
No problems yet…
Now is good time for suggestions…

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



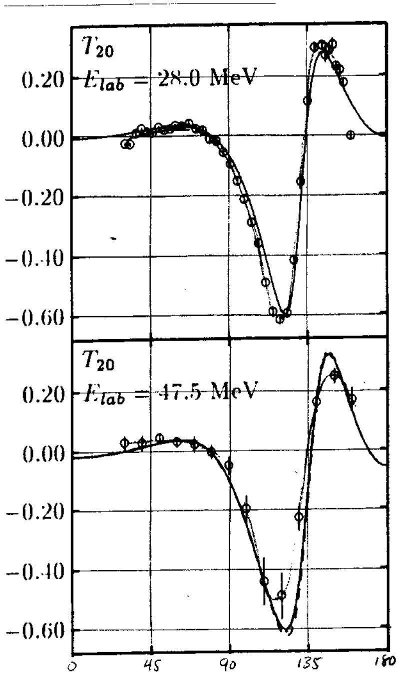
- eliminates first-order problems (all flat) from:
  - injected normal component
  - polarimeter rotation
  - etc.
- other big terms determine unknown ω_{g-2}
  (ω varies from shot to shot)

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:

- τ_{10}: vector polarization
- τ_{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

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

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

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

These can all be obtained for a single spin state.

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

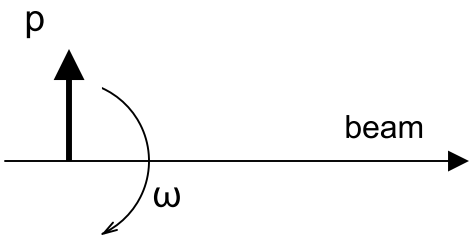
Monte Carlo:
- too many events for needed statistics

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 shapshot at regular
intervals (say every 10 ms)
Compute count rate in each detector
Change count rate randomly based on
statistics for that rate

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

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

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

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

where

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

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

Count rates:

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

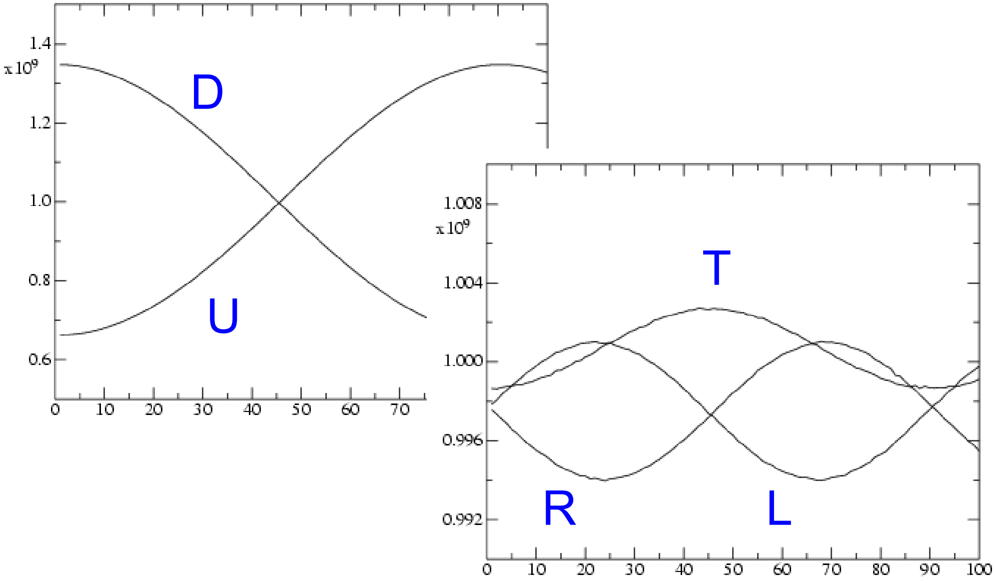
$$C_R =$$

$$C_D =$$

$$C_U =$$

$$C_T =$$

etc. with angles rotated as
needed for each detector



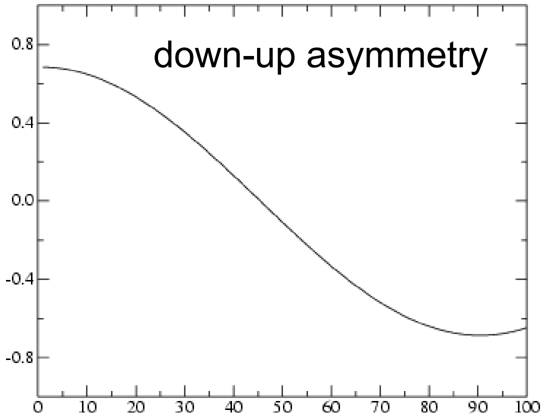
Typical Output

function of time

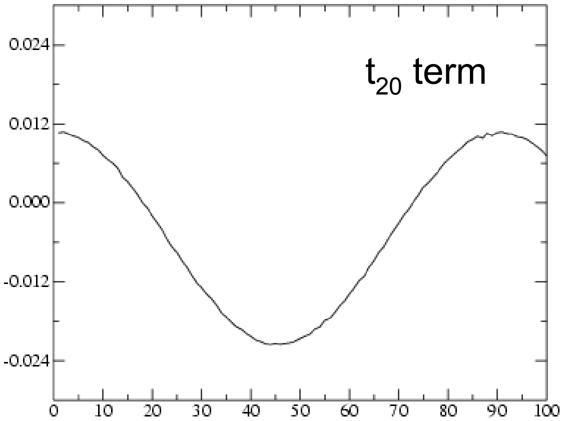
$$\vartheta = \theta_0 + \bar{\theta} t$$

spin injection angle

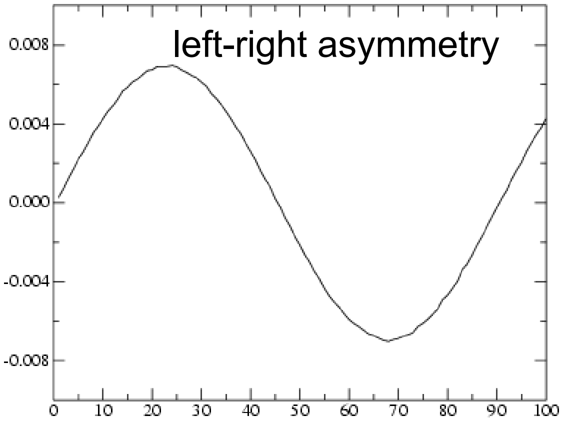
spin precession rate



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



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

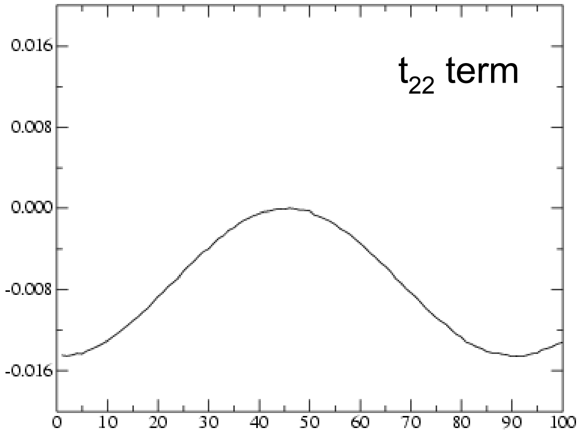


$$\Delta_{LR} = A_4 10^{-4} \cos\vartheta + A_5 10^{-4} + A_6 \sin 2\vartheta$$

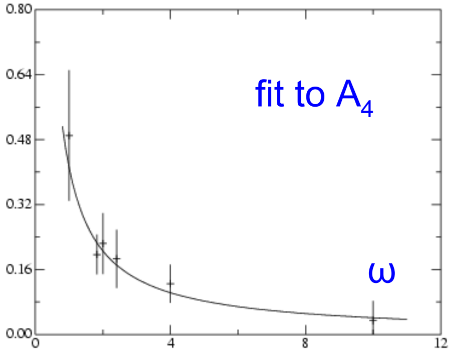
EDM term

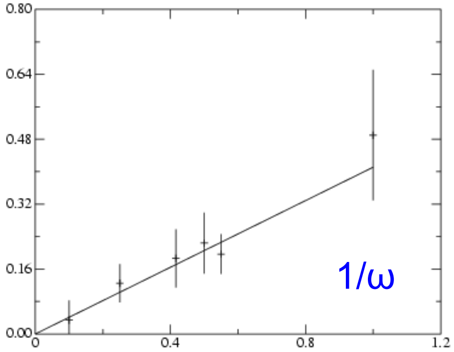
t_{21} term

constant term needed because EDM grows from zero



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

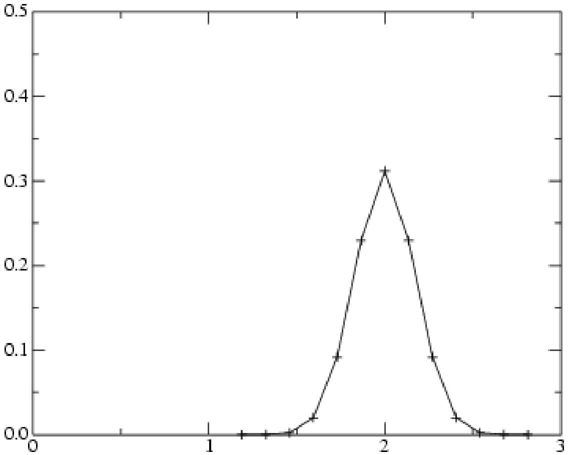




A_4 at several precession rates

Systematic error test: effect of ω binning

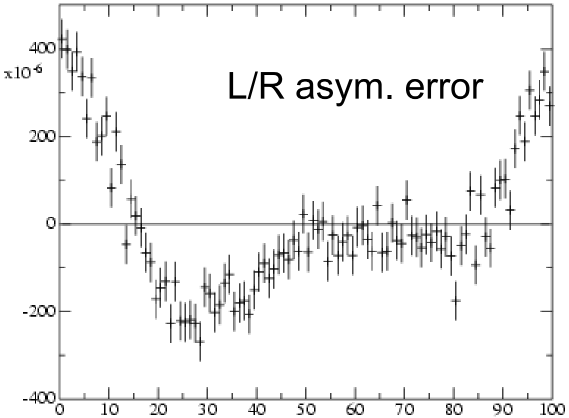
Power supply regulation means that E, B drift
To look for ω-dependence, bin each shot
What is the statistical error?
  The ring loss cross section is 2 kb.
  A 1 s beam lifetime means target is < 5 x 10^{14} /cm^2
  With a polarimeter cross section of 17 mb,
    each shot records about 2700 events.
With a δ-function ω, the recorded distribution is:



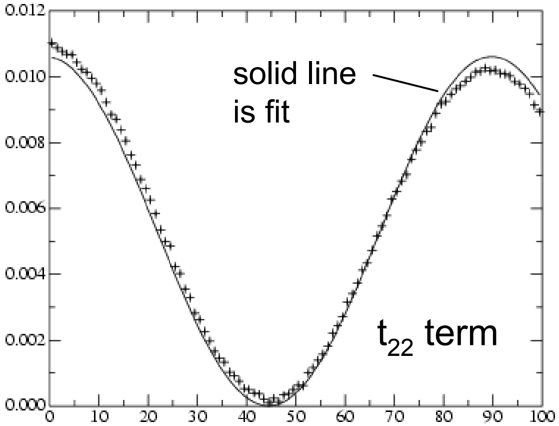
If one averages together data with this spread,
  what happens?

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.

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

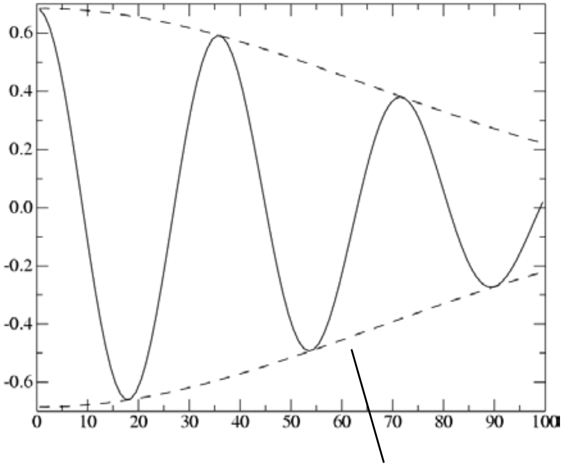
Depolarization

Reduction is convolution of cosine with Gaussian of width σ

$$atten: \quad \exp\left(-\sigma^2/2\right)$$

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

ϵ_{DU}



envelope is:

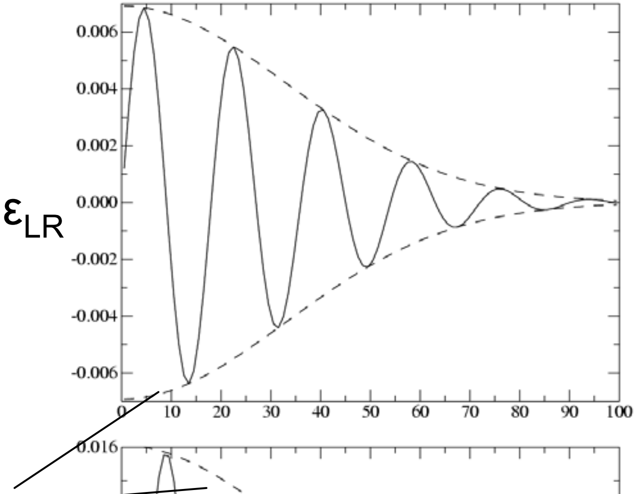
$$\exp\left(-\frac{D^2t^2}{2}\right)$$

D is added to the list of fitting parameters.

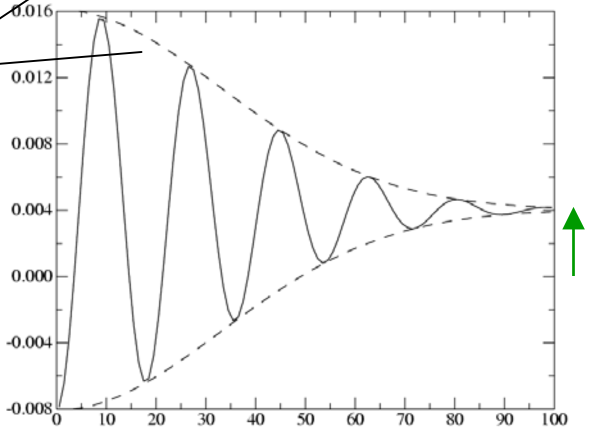
Tensor asymmetries vary twice as quickly (for this case) and attenuate twice as quickly

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

ϵ_{LR}

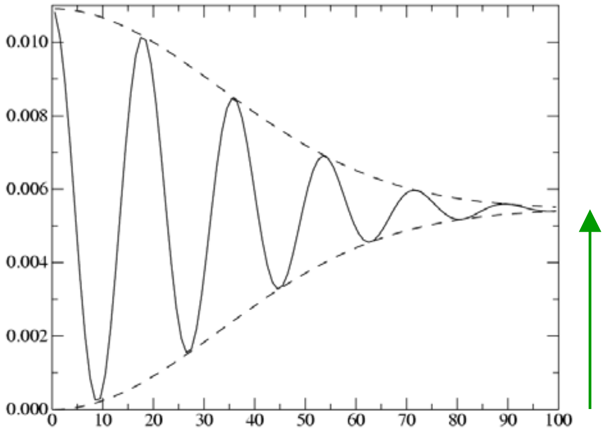


ϵ_{20}



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

ϵ_{22}



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 $1/\omega_{g\text{-}2}$
  - 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 $\omega_{g\text{-}2}$ 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 μg/cm^2

This specimen is 600 μm wide.

Widths for RHIC use extend down to 3.5 μm.

Target comparison at 2 GeV/c

	Hydrogen	Carbon
cross section into L+R pair	7.1 mb	41 mb
(integral from … to …)	2 – 11°	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 φ attenuation)		
Figure of Merit	3.0	> 0.8 3.7
target	bulky (obscures 90°)	fragile