Systematic Polarimeter Errors

Ed Stephenson
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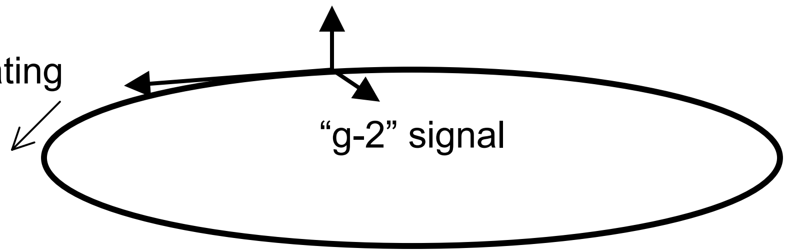


Simple Plan:
- use E-field to cancel g-2 precession
- allow EDM component to grow
- measure EDM with left/right asymmetry

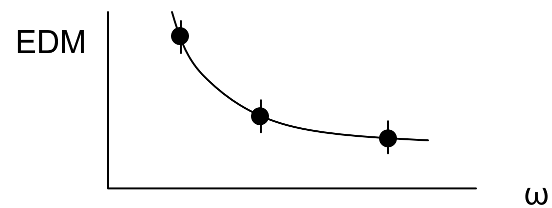
Problem (for spin=1 deuteron):
- small cancellation error + small t_{21} makes false EDM signal
- error about $1:10^{10}$, too large to control

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

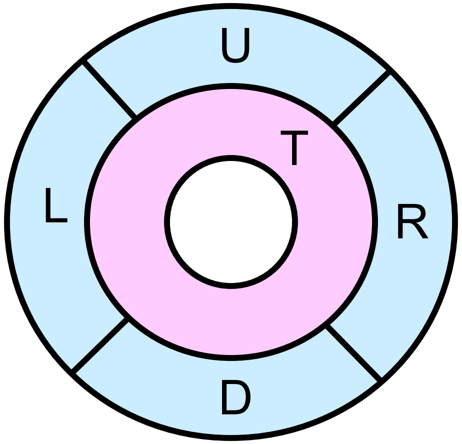
Model set up to look at this
Work started
No problems yet that exceed 10^{-26} e•cm
Now is good time for suggestions…

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



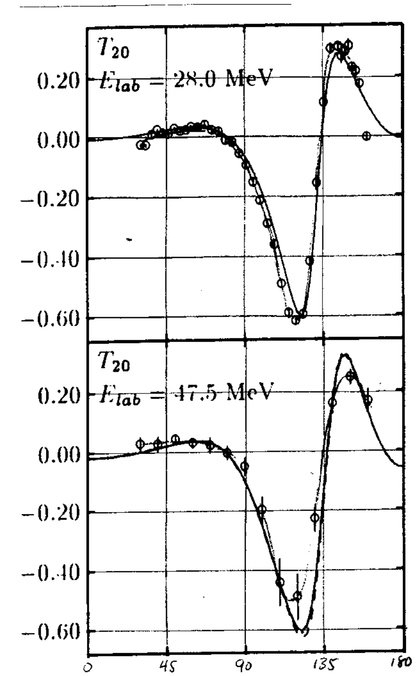
- eliminates first-order problems (all flat) from:
  - injected normal component
  - polarimeter rotation
  - etc.
- other big terms determine unknown ω_{g-2} (ω varies from shot to shot)

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

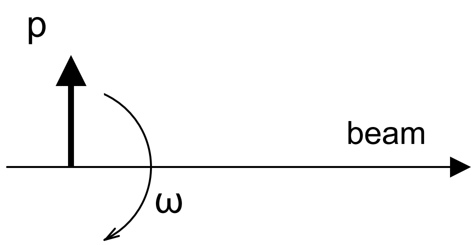
Model of the experiment:
Deuterons precess at determined rate
- produces detector count rates with errors
- all effects included exactly
- systematic errors added exactly

Wall of ignorance
All 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?

Offline: advice about search algorithms welcome

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:

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

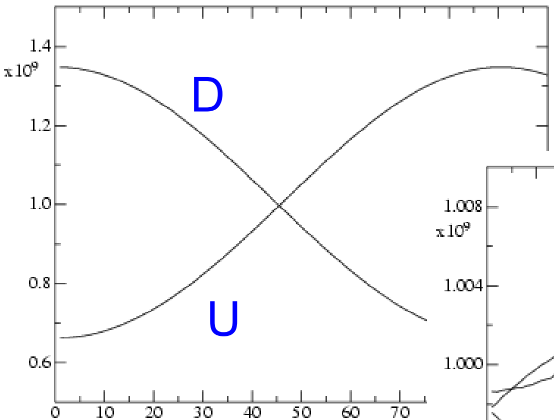
$$C_R =$$

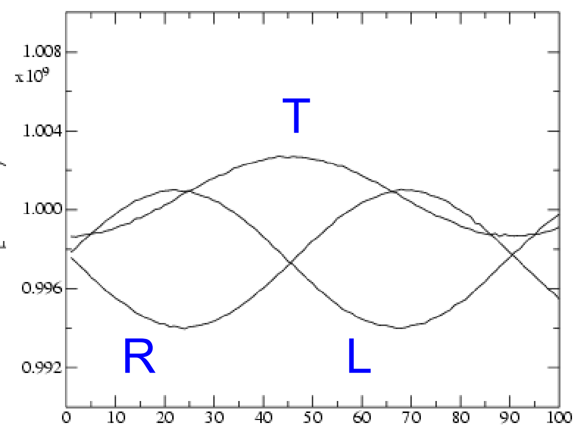
$$C_D =$$

$$C_U =$$

$$C_T =$$

etc. with angles rotated as needed for each detector





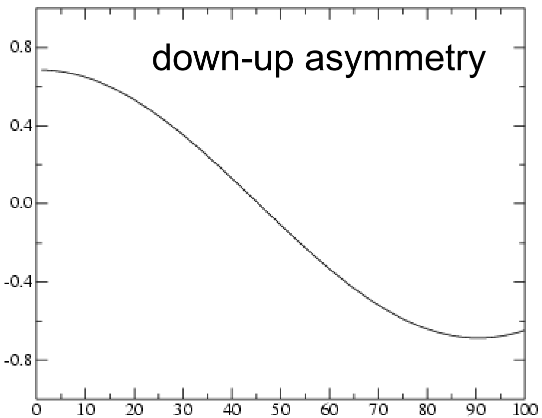
Typical Output

function of time

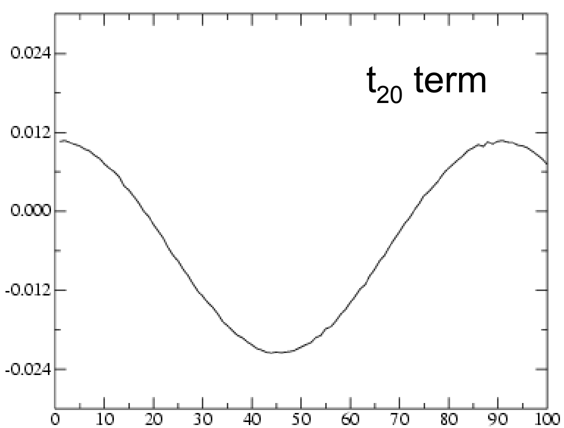
$$\vartheta = \theta_0 + \bar{\theta} t$$

spin injection angle (θ_0)

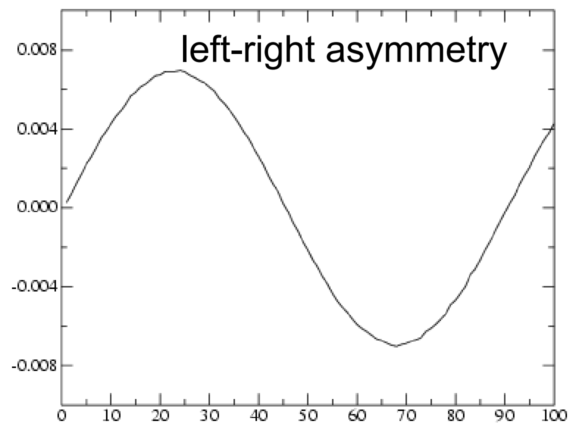
spin precession rate ($\bar{\theta}$)



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



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

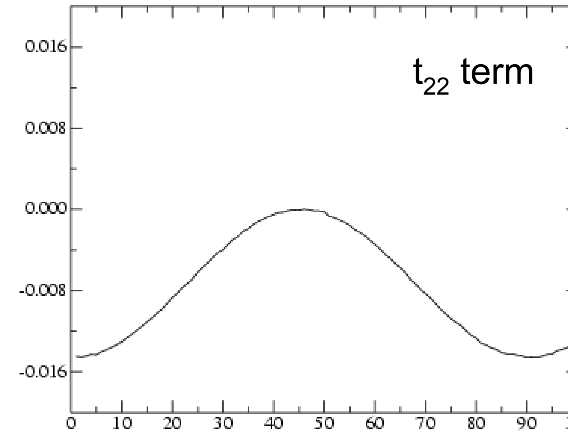


$$\Delta_{LR} = A_4 10^{-4} \cos\vartheta + A_5 10^{-4} + A_6 \sin 2\vartheta$$

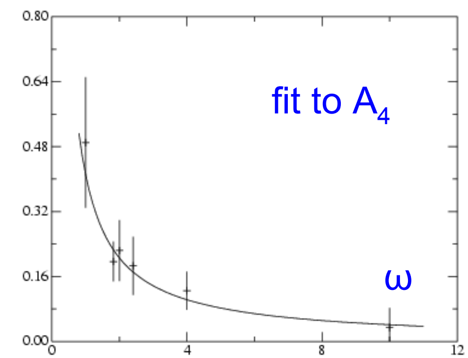
EDM term (A_4)

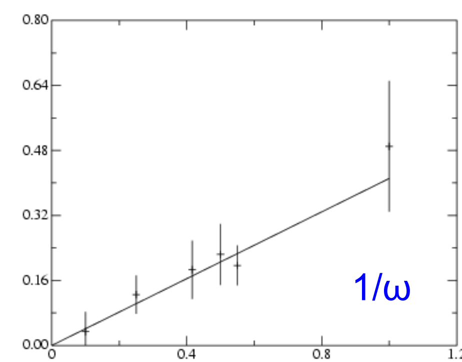
t_{21} term (A_6)

constant term needed because EDM grows from zero (A_5)



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

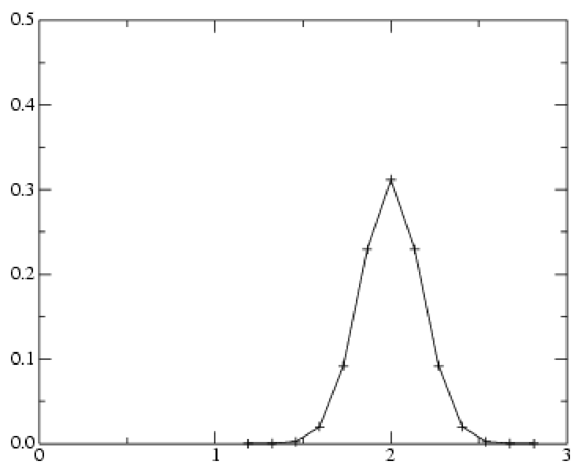




A_4 at several precession rates

Systematic error test 1: effect of ω binning

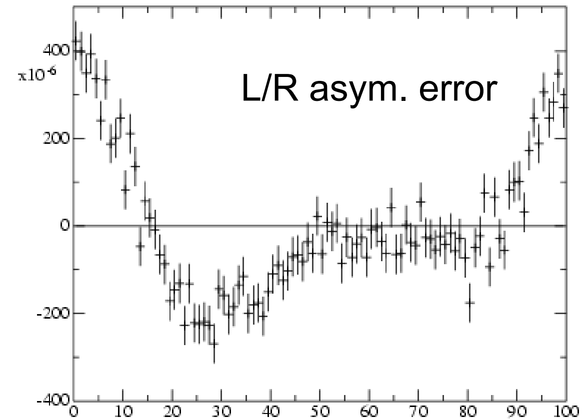
Power supply regulation means that E, B drift
To look for ω-dependence, bin each shot
What is the statistical error?
  The ring loss cross section is 2 kb.
  A 1 s beam lifetime means target is < 5 x 10^{14} /cm^2
  With a polarimeter cross section of 17 mb,
    each shot records about 2700 events.
With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



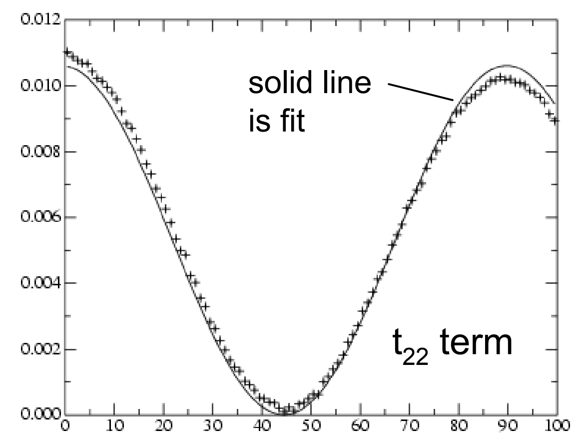
If one averages together data with this spread,
  what happens?

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:



Plan is to include depolarization function in fit.

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