Modeling Systematic Error Effects for a Sensitive Storage Ring EDM Polarimeter

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The Challenge

Measure polarization changes during store with sensitivity approaching 10^{-6} for 10^{-29} e·cm sensitivity to deuteron EDM.

Absorb systematic changes during store from beam position or angle drifts and rate changes.

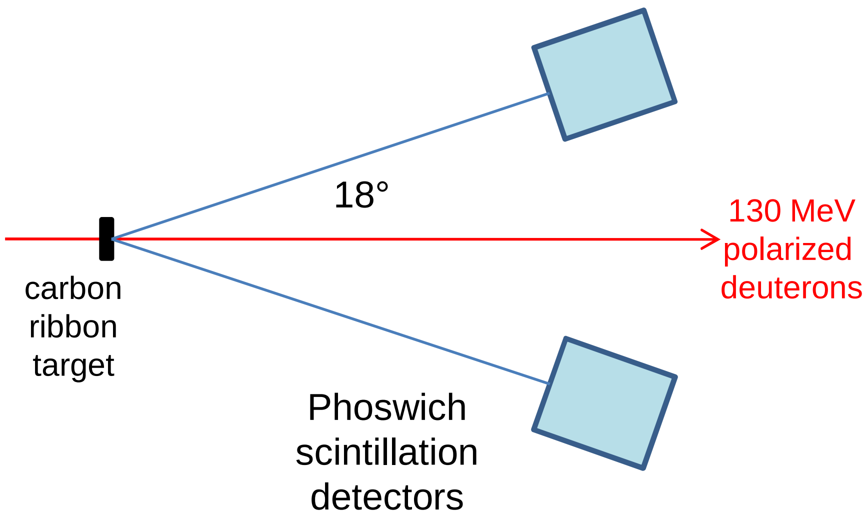
Present polarization analysis schemes cancel errors only at first-order in the error (displacement/angle change).

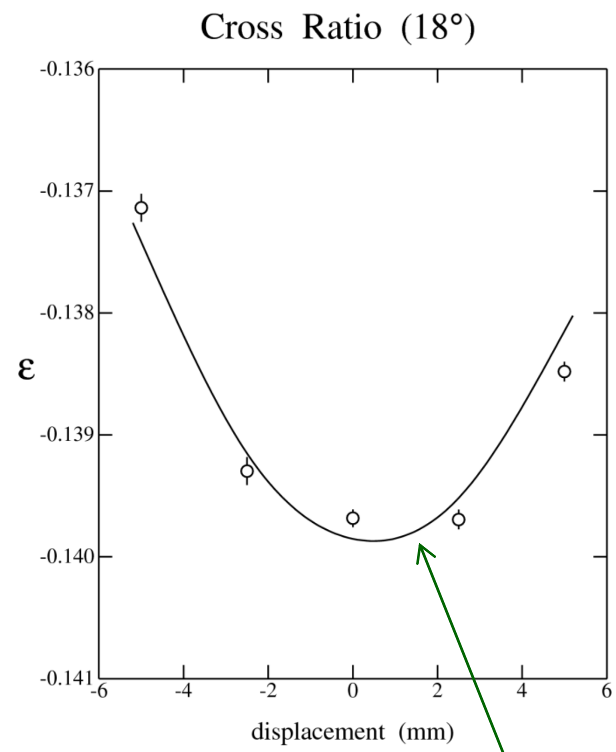
Engineering Runs

KVI (Groningen), 2007

COSY (Jülich), 6/2008, 9/2008, 6/2009

Tests made at the KVI (2007)





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

Best method: “cross ratio”, “square root” method

$$\varepsilon = \frac{3}{2} pA = \frac{r-1}{r+1} \qquad \text{where} \qquad r^2 = \frac{L(+)R(-)}{L(-)R(+)}$$

This method fails at second order in 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

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

What to do?

NOTE: Cross ratio must be supplemented with corrections specific to polarimeter.
Database at p = 1 GeV/c too slim to use as a guide.

Build (or borrow for demonstration) an “EDM” polarimeter.

Calibrate spin dependence and sensitivity to *large* systematic errors (X or θ).

Correct data (off-line or in real time) based on an “index” parameter.

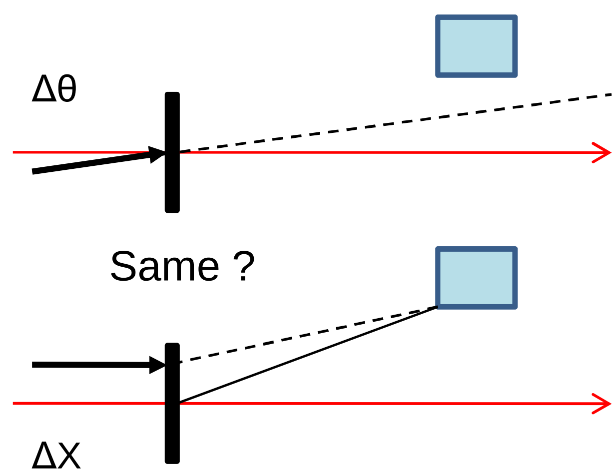
Index parameter for geometrical errors:

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

Uses same information as polarization, but in a different combination. One could also use other beam position monitors.

Open Issues:

- Is one index enough for X and θ?
- Are there any unexplained effects outside the range of this model?
- What happens when conditions change? What is affected?

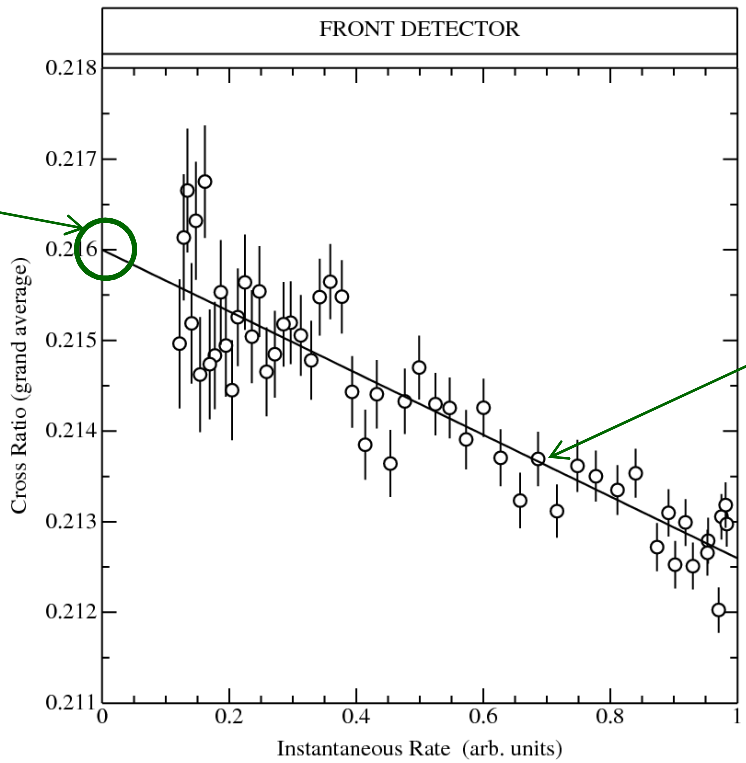


Build a model framework of parametrized effects to investigate issues

Include only what you need…

First, separate rate and geometry effects.

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.

Each point is a specific observable that depends on polarization and ΔX or Δθ.

Geometry model

Parameters we know we need to include:

EDDA Analyzing power: A_y and $A_T = \frac{\sqrt{6}T_{22}}{\sqrt{8} - p_T T_{20}}$

Polarizations: p_V and p_T for the states V+, V−, T+, T−

There is some information available from the COSY Low Energy Polarimeter.

Logarithmic derivatives: $\frac{\sigma'}{\sigma}, \frac{\sigma''}{\sigma}, \frac{A_y'}{A_y}, \frac{A_y''}{A_y}, \frac{A_T'}{A_T}, \frac{A_T''}{A_T}$

Solid angle ratios: L/R D/U (D+U)/(L+R)

Total so far: 19 parameters

Parameters we found we needed:

Rotation of Down/Up detector (sensitive to vertical polarization): θ_{rot}

X – Y and $\theta_X - \theta_Y$ coupling (makes D/U sensitive to horizontal errors): C_X, C_θ

Ratio of position and angle effects (effective distance to the detector):

$X/\theta = R$

Tail fraction: multiple-scattered, spin-independent, lower-momentum flux that is recorded only by the “right” detector (to inside of ring)

F = fraction F_X, F_θ sensitivities to position and angle shifts

Total parameters: 26

Fitting revealed continuous ambiguity involving L/R and (D+U)/(L+R) solid angle ratios, the tail fraction, effective detector distance, and all polarizations.

Choice was to freeze L/R solid angle ratio for front rings at one.

Quality of the fit

$$\varepsilon = \frac{L-R}{L+R}$$

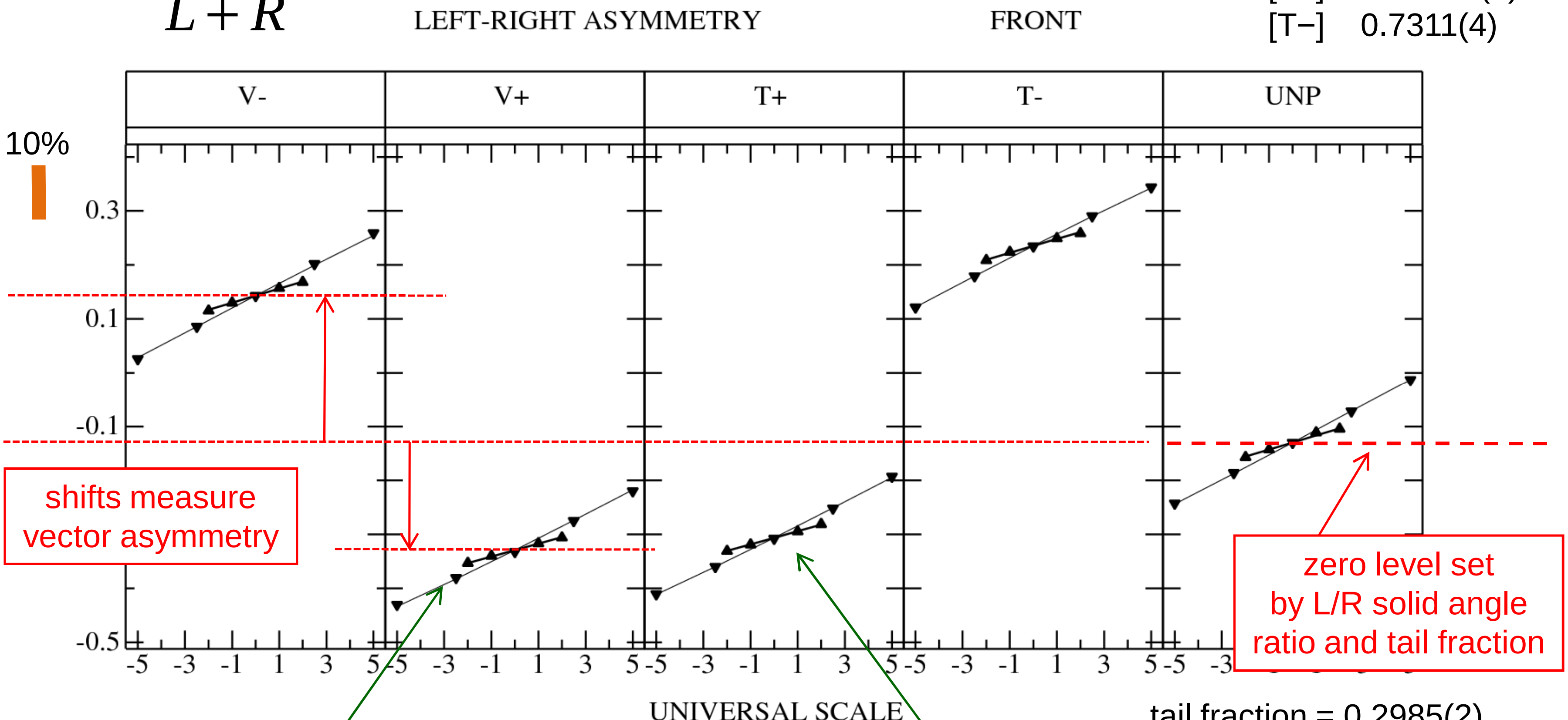
Group 5

Vector Analyzing Power

$A_y = 0.349(6)$

Vector Polarization p_y

[V−] 0.5370(4)
[V+] −0.3954(4)
[T+] −0.3399(4)
[T−] 0.7311(4)



tail fraction = 0.2985(2)
with L/R solid angle ratio = 1

slopes given by $\left(\frac{\sigma'}{\sigma}+\frac{A'}{A}\right)\varepsilon^2-\frac{\sigma'}{\sigma}$

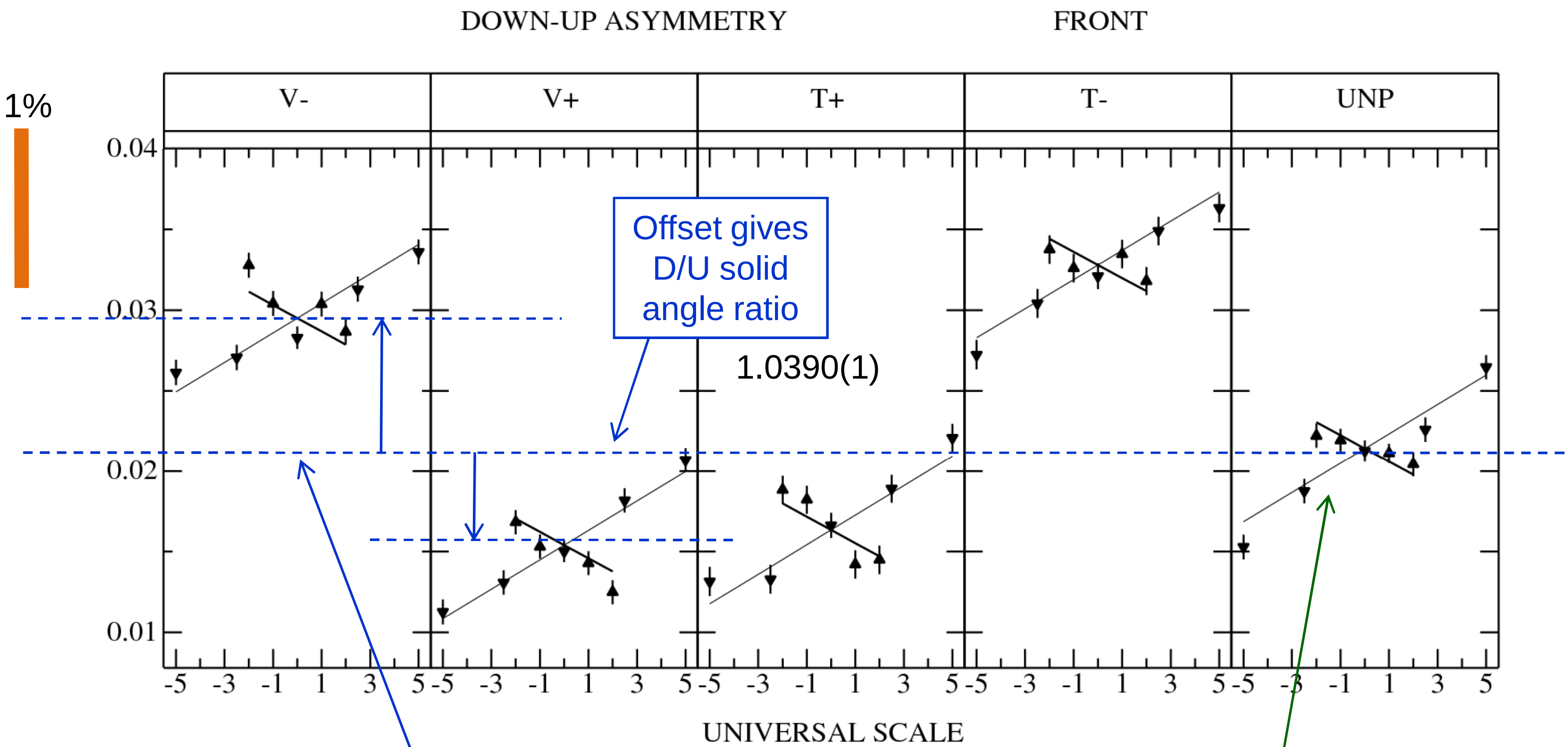
$\frac{\sigma'}{\sigma} = -0.02562(9) \quad \frac{A'}{A} = 0.0055(3) \quad \frac{1}{rad}$

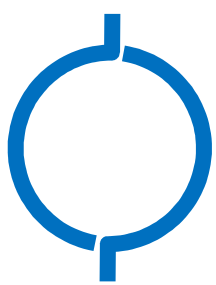
slope difference measures “effective” distance to detector

X/θ = 52.4(8) cm

$$\varepsilon = \frac{D-U}{D+U}$$

Group 5





Broken symmetry of ring detectors creates false rotation in vertical asymmetry and sensitivity to polarization.

rot = 0.0278(5) rad

Beam X – Y and $\theta_X - \theta_Y$ coupling connects to horizontal beam motion

X coupling = −0.031(5)
θ coupling = 0.036(2)

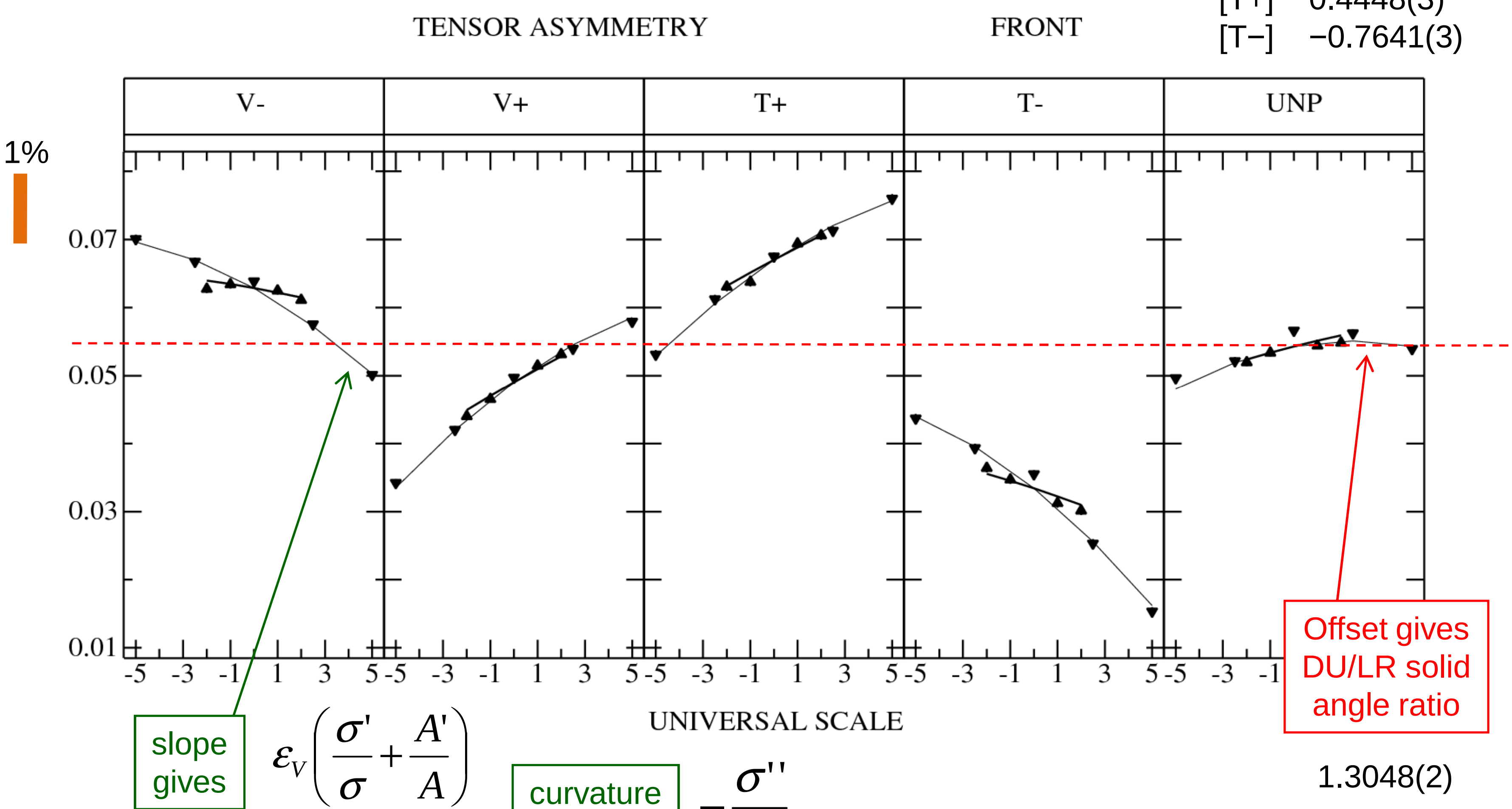
$$\varepsilon = \frac{D+U-L-R}{D+U+L+R} = \frac{\sqrt{6}\,p_T T_{22}}{\sqrt{8} - p_T T_{20}} \cong \frac{1}{2} p_T A_T$$

Group 5

Tensor Analyzing Power
A_T = 0.0721(2)

Tensor Polarization p_T

[V−]	0.1580(3)
[V+]	−0.0841(3)
[T+]	0.4448(3)
[T−]	−0.7641(3)



$$\varepsilon_V \left(\frac{\sigma'}{\sigma} + \frac{A'}{A} \right)$$

curvature gives $-\frac{\sigma''}{\sigma}$

0.00029(1) 1/rad^2

1.3048(2)

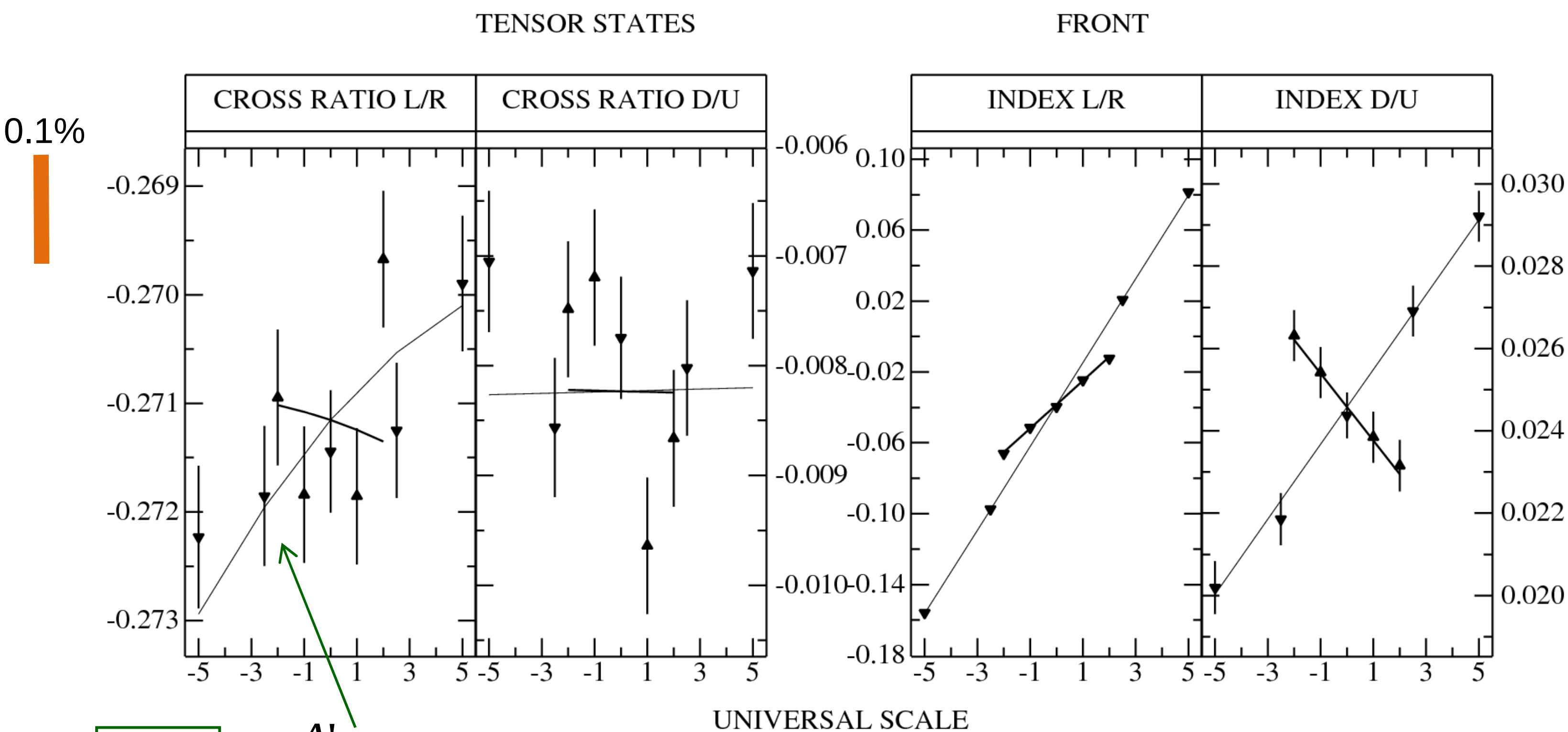
difference from one compensates for tail fraction

$$\varepsilon_{CR} = \frac{\sqrt{L_+R_-} - \sqrt{L_-R_+}}{\sqrt{L_+R_-} + \sqrt{L_-R_+}}$$

removes first order effects

Group 5

$$\phi = \frac{\sqrt{L_+L_-} - \sqrt{R_+R_-}}{\sqrt{L_+L_-} + \sqrt{R_+R_-}}$$



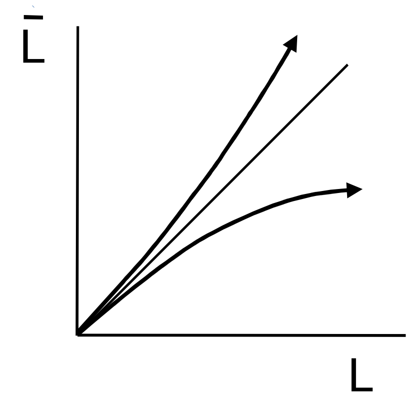
slope gives $\varepsilon_V^2 \frac{A'}{A}(p_+ + p_-)$

curvature gives $\varepsilon_V \left(\frac{A''}{A} - \left(\frac{A'}{A}\right)^2 \varepsilon_V^2 \right)$

A''/A = 0.00007(6) 1/rad^2

slopes depend on earlier first-order terms

Rate Model:



Rate effects require a non-linear response to input rate.

Detector rate $L = C\,(1 + \varepsilon)$, C = unpolarized rate

Rate effects can be $\bar{L} = L + hL^2 \ldots$

For a simple asymmetry: $\varepsilon_{exp} = \varepsilon\,[1 + hC(1 - \varepsilon^2)\ldots]$

rate dependence

For h > 0, there are excess events
(pileup, more events crossing threshold…)

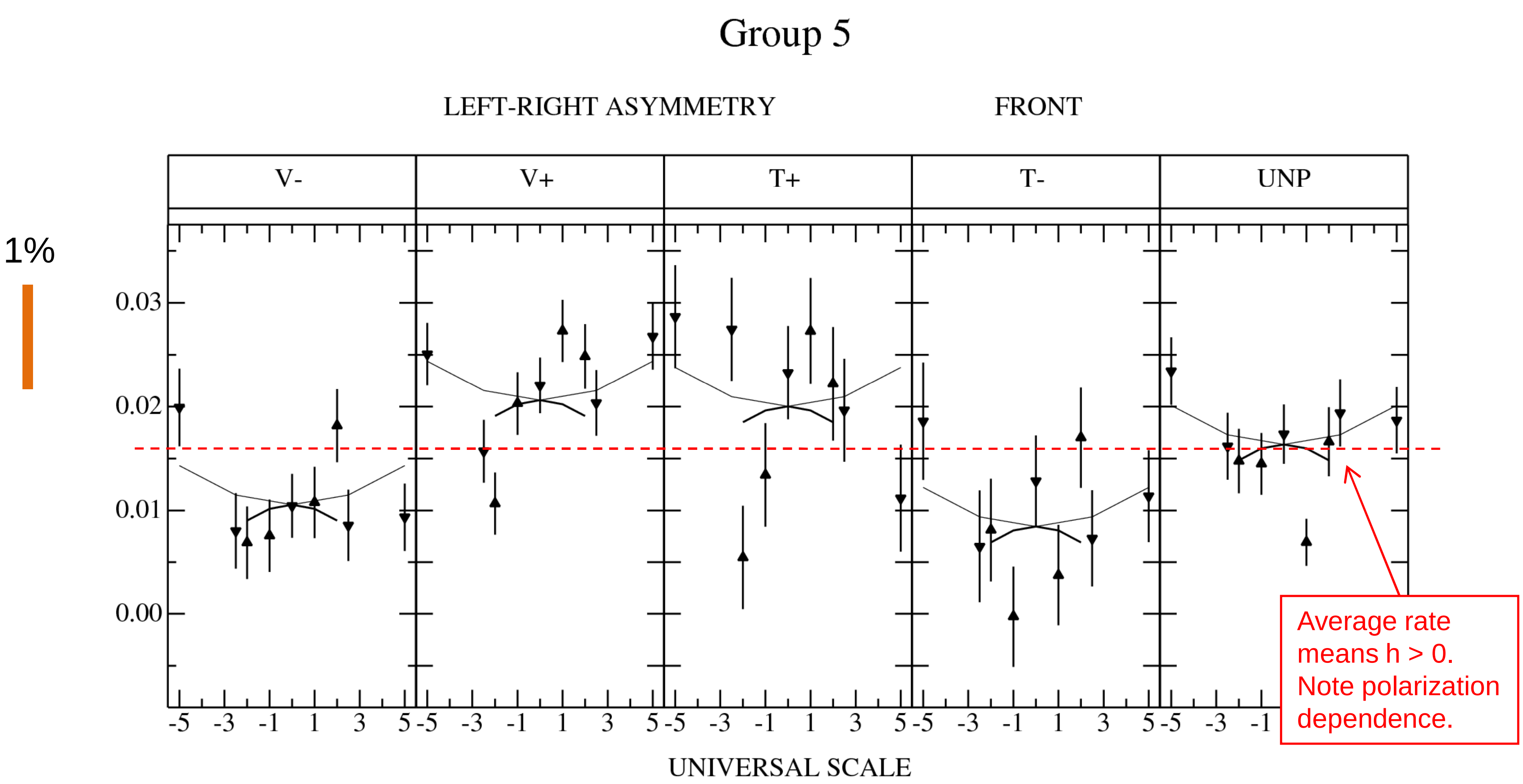
For h < 0, there are lost events
(PMT gain sag…)

This represents our case.

Higher order effects introduce polarization dependence.

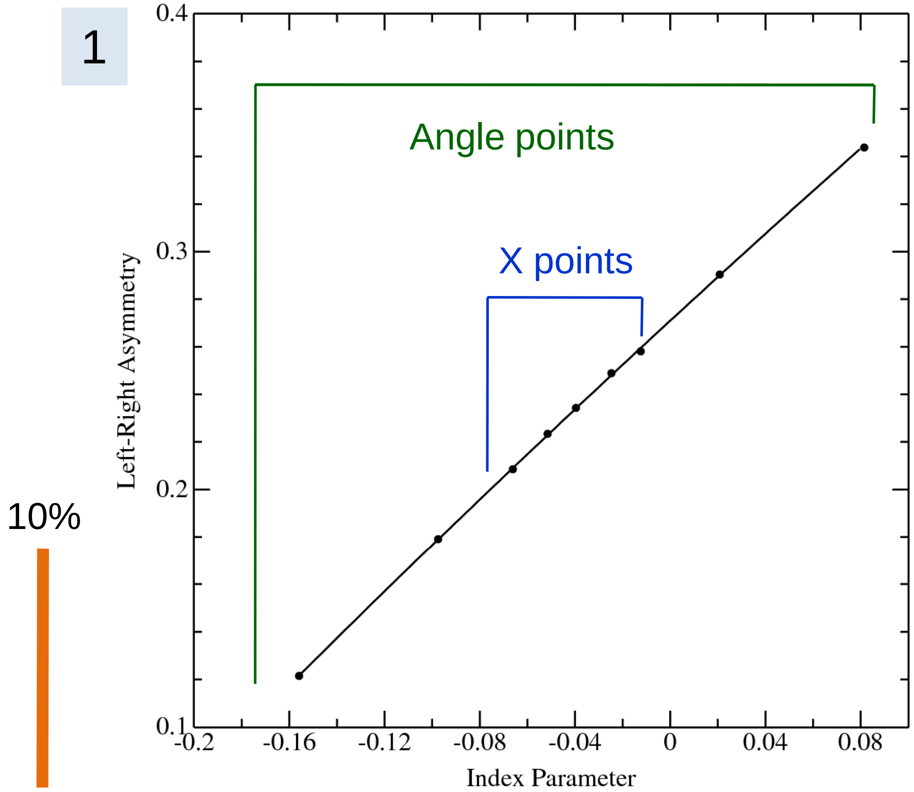
There is some evidence for quadratic X and θ dependence.
Polarization dependence not needed for cross ratio rate dependence.

Rate dependence results



Conclusions

1



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

Conclusions

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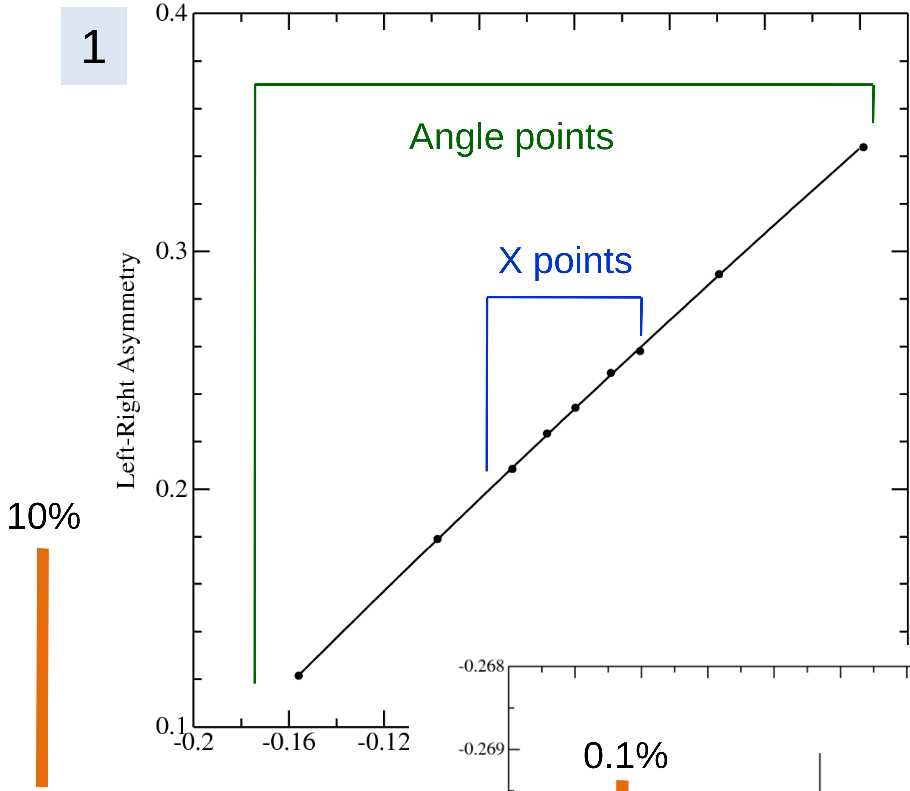

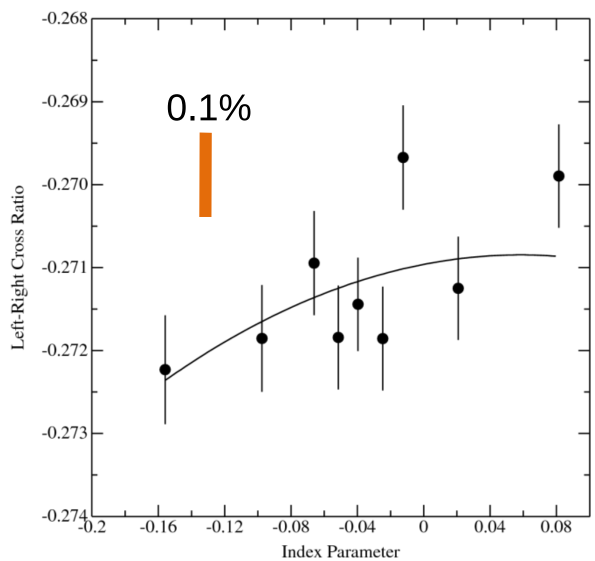

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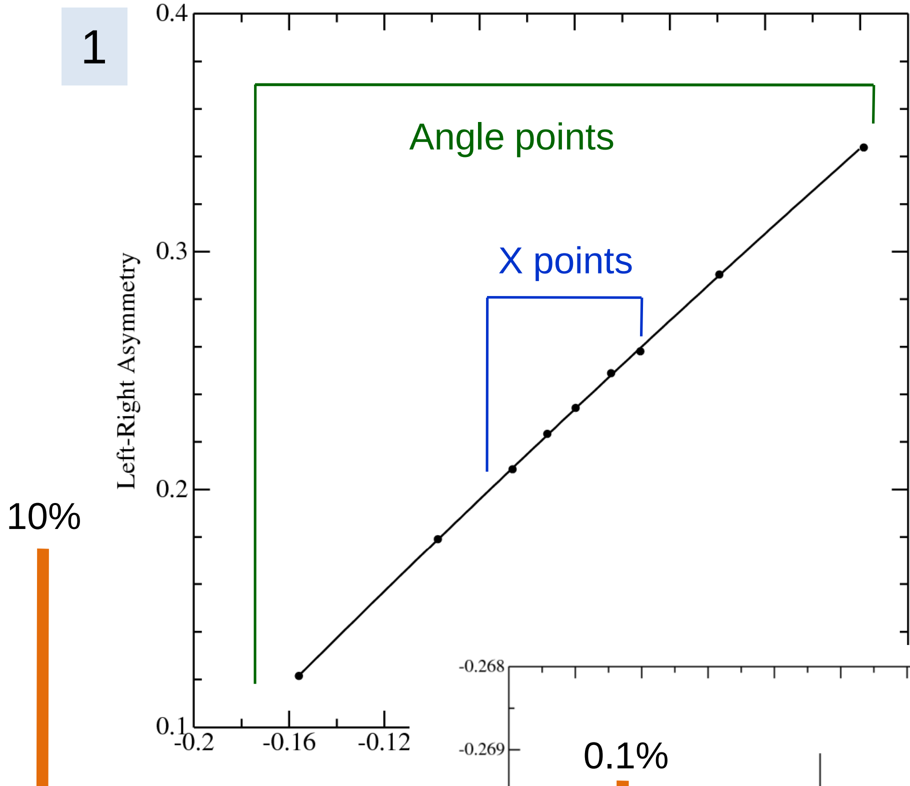

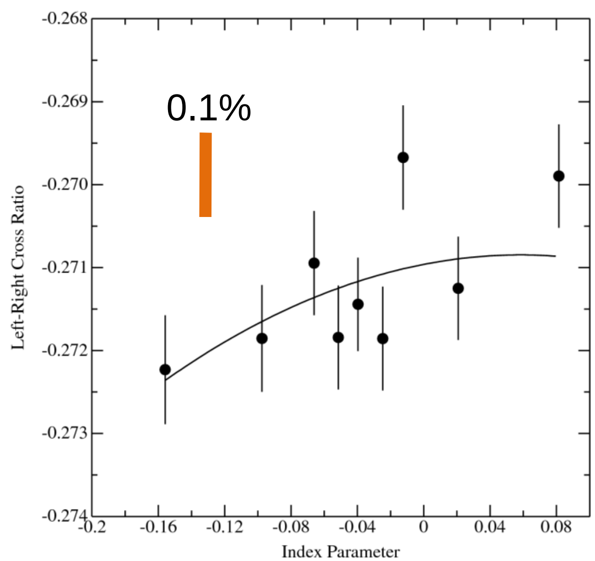

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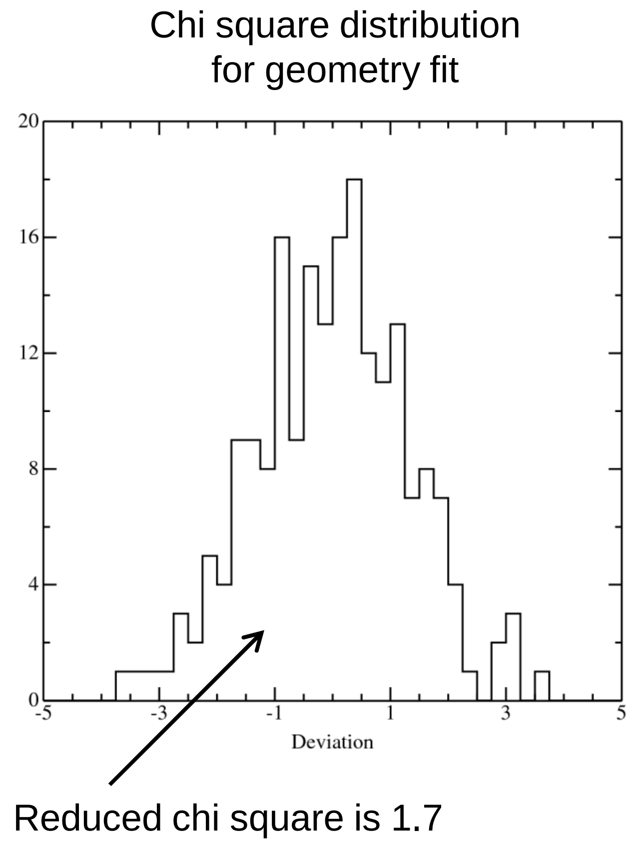
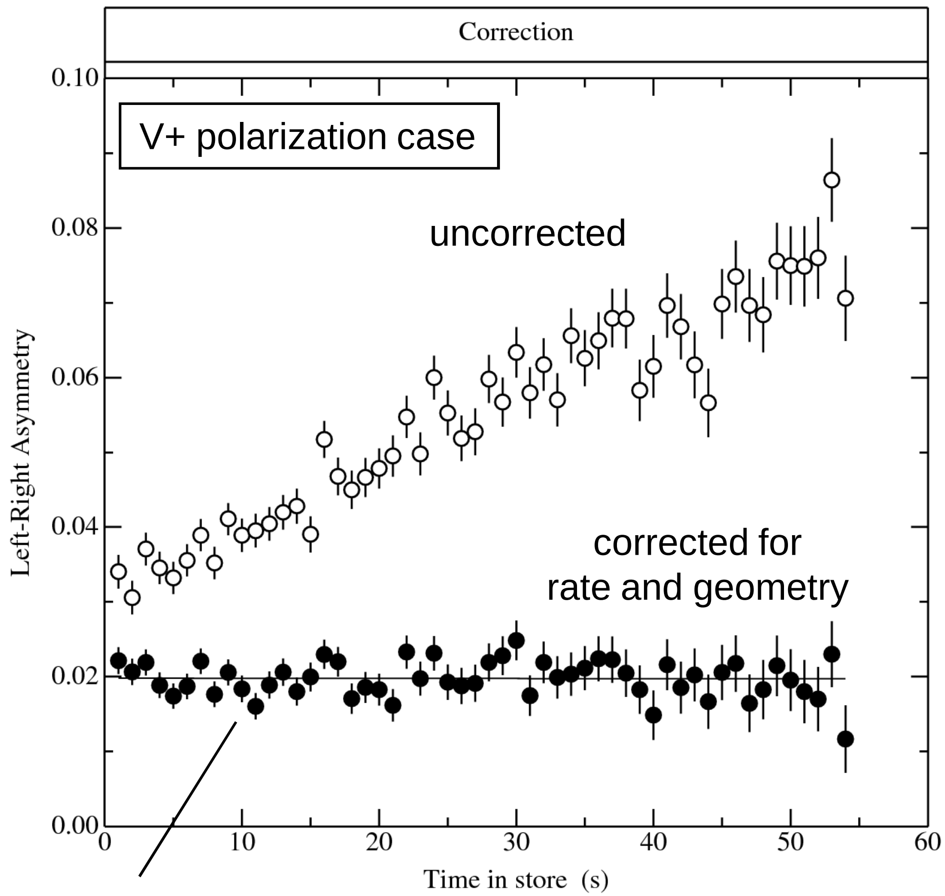
2



Reproduction of data by model is good; there are no unexplained features.

3

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



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

Corrections work.

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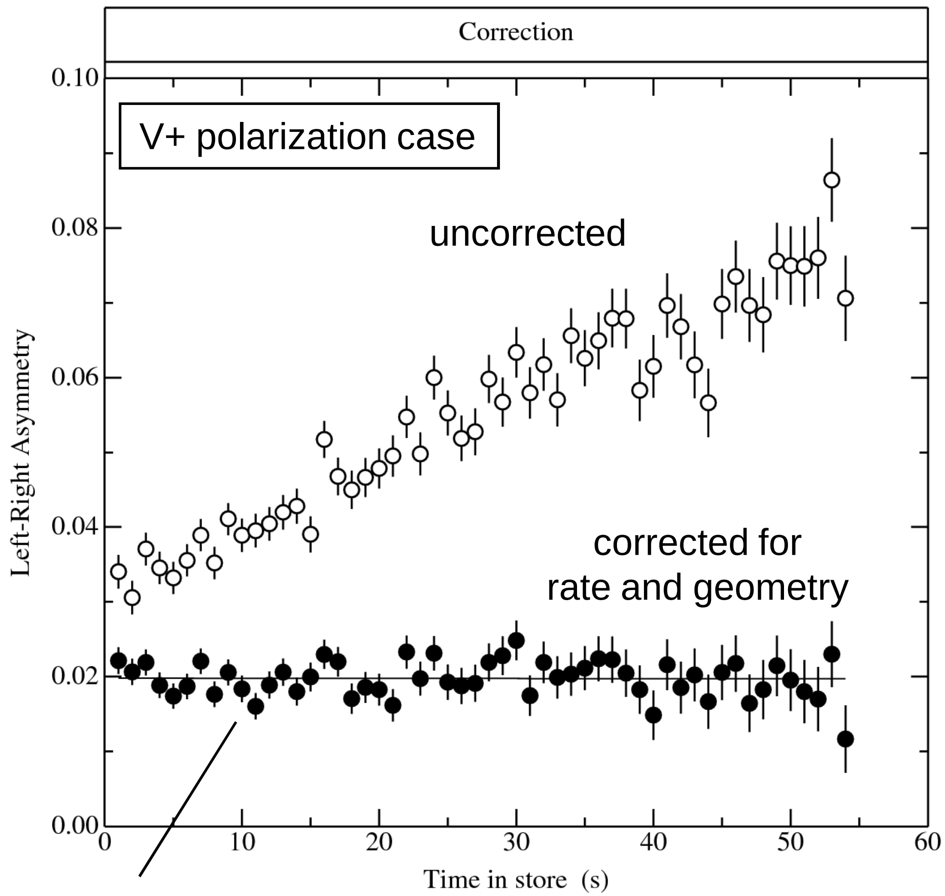

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Corrections work.

Sensitive polarimetry:

Canceling errors beyond first order requires a calibration of the error sensitivity of the polarimeter.

Model confirms that we understand the errors.

Rate and geometry errors can be tied to “index” parameters that are a part of the data.

Scaling down:

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

Polarimeter Development Team:

Indiana: Ed Stephenson*, Astrid Imig (BNL)

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Regis U.: Fred Gray

Frascati: Paolo Levi Sandri, Graziano Venanzoni

U. of Rome: Francesco Gonella, Roberto Messi, Dario Morizianni

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