saGDH Analysis Update

Target Analysis

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Polarized Helium-3 Collaboration Meeeting

CEBAF Center F224-5, October 18, 2006

Outline

1. saGDH HALOG Search Engine
2. MySQL <-> ROOT interface to Database
3. EPICS variables in the Data Stream
4. Polarization Gradients and Beam Depolarization
5. Polarimetry Issues
6. Outlook

EPICS Variables in the Data Stream

163 variables read every 3, 5, or 30 seconds including:

1. Beam Current Data
2. HRS Current and Field Data
3. Beam Energy
4. Helicity Pattern Info
5. Beam Positions at 10 different BPMs
6. “Correction Coil” Currents
7. Septum Power Supply and Set Current
8. Helmholtz Coil Currents

Surprising things it does NOT have:

1. **Beam Half-Wave Plate Readback (IN or OUT)**
2. **Septum Readback Current**

Polarization in Two Chambered Cells

Equilibrium Pumping Chamber Polarization:

$$P_p^\infty / P_p^\infty(I=0) \;=\; \left(1 + f_t \tau_{\rm su}^0 \Gamma_{\rm beam}\right)^{-1}$$

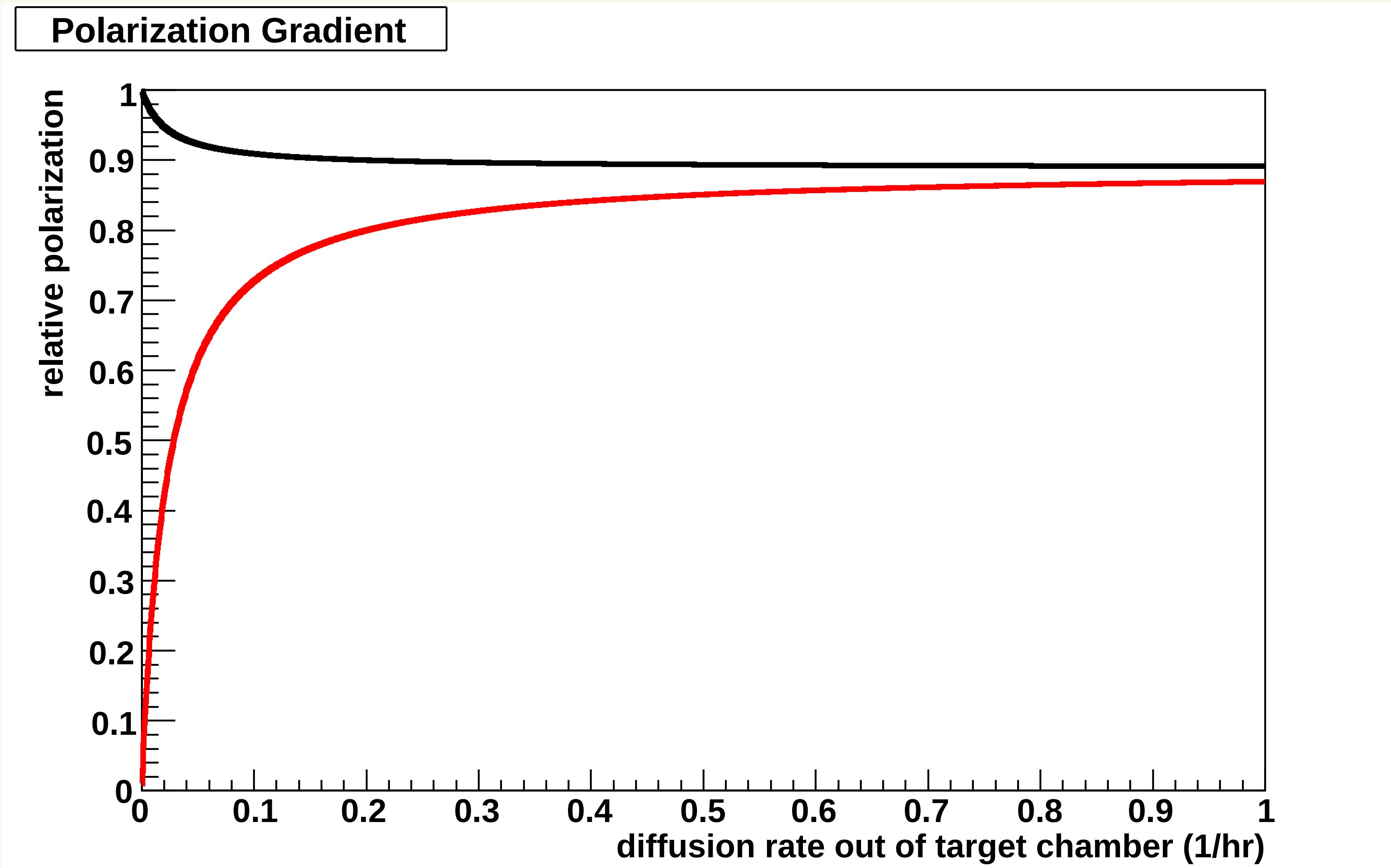
Equilibrium Target Chamber Polarization:

$$P_t^\infty / P_p^\infty \;=\; \left(1 + \frac{\Gamma_t^0 + \Gamma_{\rm beam}}{D_t}\right)^{-1}$$

1. f_t = fraction of nuclei in target chamber
2. $\tau_{\rm su}^0$ = spin up time constant without beam
3. $\Gamma_{\rm beam}$ = beam depolarization rate
4. Γ_t^0 = spin relaxation rate in target chamber
5. D_t = diffusion rate out of target chamber

Relative Equilibrium Polarizations

Pumping Chamber Target Chamber



Estimating Rates

1. Atomic ions created by the electron beam depolarize nuclei:

$$\Gamma_{\text{beam}} = \Gamma_{\text{ion}} n_a \approx \left(\frac{1}{40\text{ hrs}}\right) \cdot \left(\frac{I}{10\ \mu\text{A}}\right) \cdot \left(\frac{2\text{ cm}^2}{A_{\text{tc}}}\right)$$

   where Γ_{ion} is the ionization rate per atom and n_a is the mean number of nuclei depolarized.

2. The ionization rate can be estimated from the Bethe-Bloch collisional energy loss formula.

3. **Phys. Rev. A, 38, p4481-7 (1988)** gives formulas for estimating n_a. In our case, $n_a \approx 0.5 \pm 0.1$.

4. The diffusion rate exiting the target chamber is:

$$D_t = \left(\frac{1}{1.2\text{ hrs}}\right) \cdot \left(\frac{90\text{ cm}^3}{V_{\text{tc}}}\right) \cdot \left(\frac{A_{\text{tt}}}{0.5\text{ cm}^2}\right) \cdot \left(\frac{6\text{ cm}}{L_{\text{tt}}}\right)$$

Polarization Gradients

1. Relative gradient without beam:

$$\Delta_0 = (3\% \text{ rel.}) \cdot \left(\frac{V_{\mathrm{tc}}}{90 \text{ cm}^3}\right) \cdot \left(\frac{0.5 \text{ cm}^2}{A_{\mathrm{tt}}}\right) \cdot \left(\frac{L_{\mathrm{tt}}}{6 \text{ cm}}\right)$$

2. Relative gradient due to beam:

$$\Delta_{\mathrm{beam}} = (4\% \text{ rel.}) \cdot \left(\frac{I}{15\ \mu\text{A}}\right) \cdot \left(\frac{L_{\mathrm{tc}}}{40 \text{ cm}}\right) \times \left(\frac{0.5 \text{ cm}^2}{A_{\mathrm{tt}}}\right) \cdot \left(\frac{L_{\mathrm{tt}}}{6 \text{ cm}}\right)$$

3. Decrease beam current I, target chamber volume V_{tc} and length L_{tc}, transfer tube length L_{tt}, and/or increase transfer tube cross sectional area A_{tt}.

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- Doh!?! Only the water constant is changing, what is going on?

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- Low field to high field sweep is different from high field to low field sweep.
- $\rightarrow$ The NMR lineshape for water is roughly but not exactly the sqrt of a Lorentzian.
- Analytic form of lineshape can be derived from the Bloch Eqs making a few approximations.

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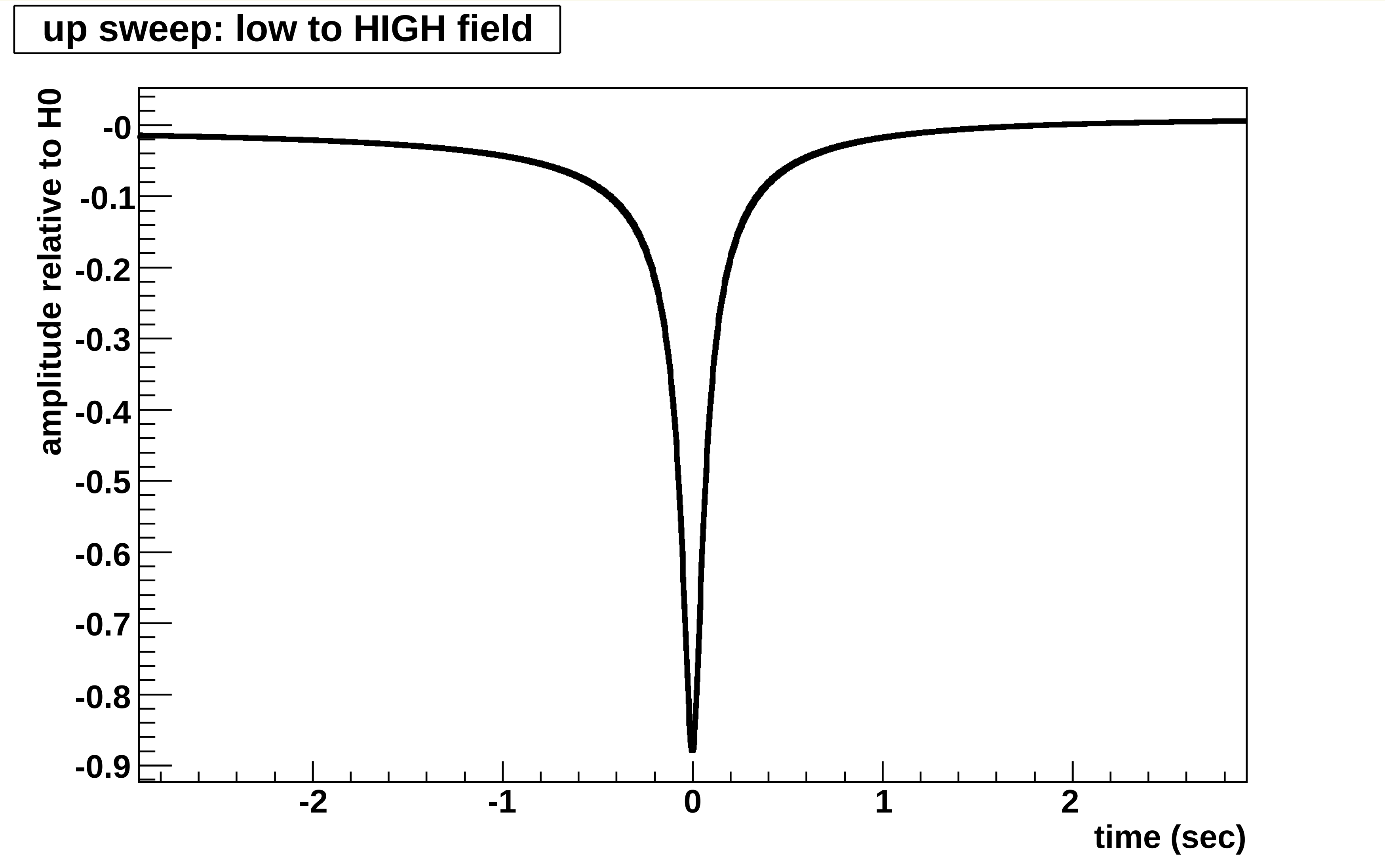

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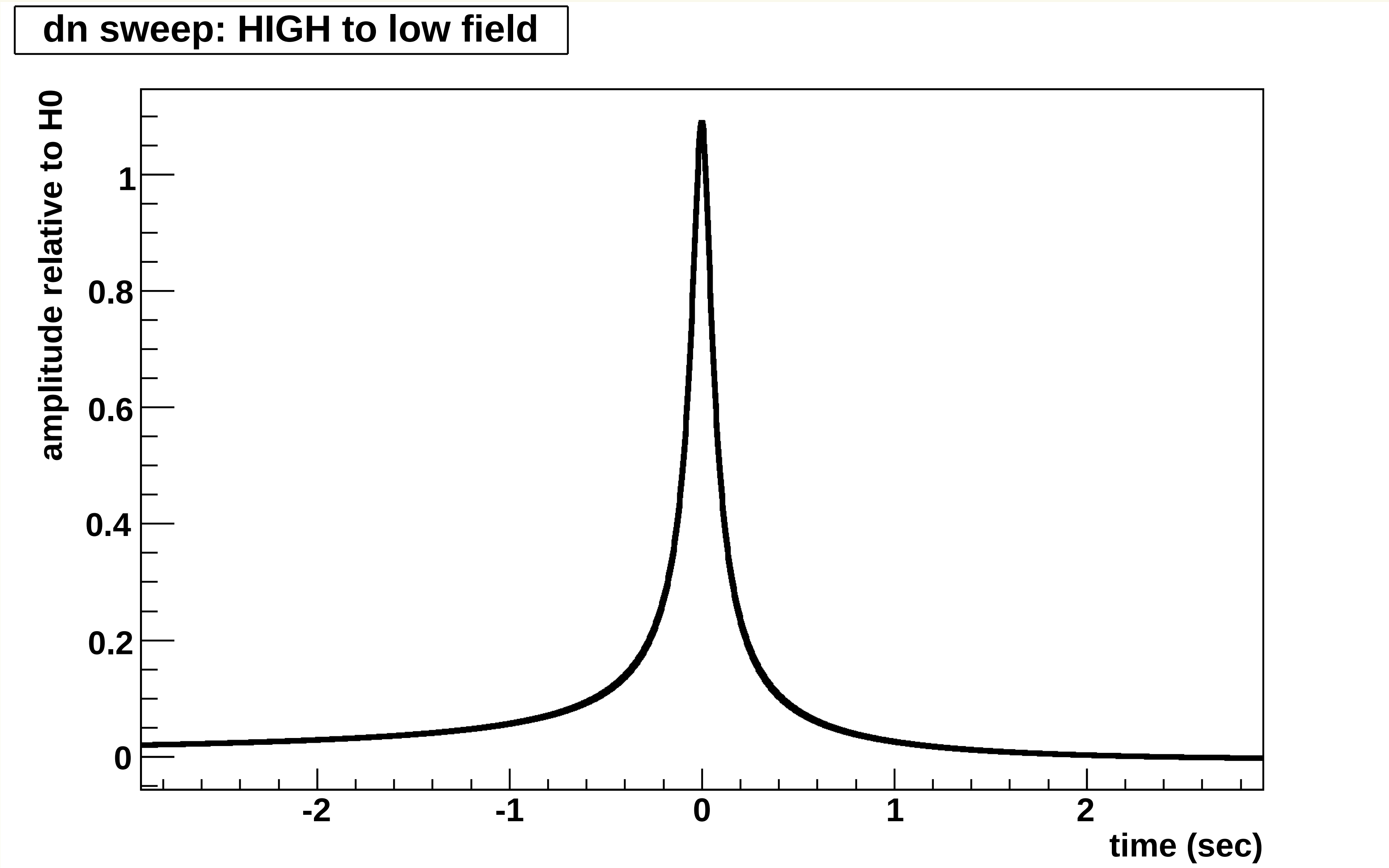

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- Could it possible that Princeton or Caltech might be <u>wrong</u>!
- Don’t be silly! They are both basically right...

Fitting Techniques

fit	sweep rate	up	down	norm
$\sqrt{L}$	-	-	-	Bloch Eqs for up & dn peaks
$f\sqrt{L}$	$\alpha = +\alpha_0$	1.0	adjust	Bloch Eqs for up peak
"	"	~~adjust~~	~~adjust~~	~~Bloch Eqs for up peak~~
"	$\alpha = \pm\alpha_0$	1.0	1.0	$P_{\rm th}$ at steady H_0

$$V(t) \;=\; f(t,\alpha)\sqrt{L(t,|\alpha|)} = V(0)\cdot P(t)/P_n$$

$\Rightarrow$ "Norm": What percent polarization P_n does the voltage measured at resonance $V(0)$ equal?

1. First two methods listed above: set $P_n = P(0)$ and then solve full Bloch equations numerically to get $P(0)$.
2. Last method: simply set $P_n = \chi H_0$.
3. Method 3: Not even wrong...

Fits to Simulated data

fit	data	up	dn
$f(+\alpha)\sqrt{L}$	-	$+1.01$	-1.25
$f(-\alpha)\sqrt{L}$	-	-0.80	$+0.99$
$f(+\alpha)\sqrt{L}$	flip	$+1.01$	-1.26
$f(-\alpha)\sqrt{L}$	flip	-0.80	$+0.99$
$\sqrt{L}$	-	-0.87	$+1.08$

Simulated data obtained from numerical solution to Bloch equations with $T_1 = 3.0$ s, $T_2 = 2.7$ s, $|\alpha| = 1.2$ G/s, $H_1 = 60$ mG, 1% gaussian noise, and a normalization of $P_n = \chi H_0$.

Ratio of Constants

$$
\begin{aligned}
\frac{C_{\mathrm{W}}}{C_{\mathrm{E}}} \propto & \left(\frac{P_{\mathrm{W}}}{V_{\mathrm{W}}}\right)\left(\frac{\Phi^{\mathrm{W}}_{\mathrm{tot}}}{\Phi^{\mathrm{H}}_{\mathrm{tc}} G^{\mathrm{H}}_{\Phi}}\right)\left(\frac{1}{B_{\mathrm{He}}}\right)\left(\frac{G^{\mathrm{W}}}{G^{\mathrm{H}}}\right)_{\nabla}\left(\frac{G^{\mathrm{W}}}{G^{\mathrm{H}}}\right)_{\tau} \\
& \times \left(\frac{P_{\mathrm{pc}}}{P_{\mathrm{tc}}}\right)\left(\frac{\kappa_0 T_{\mathrm{tc}}}{T_{\mathrm{pc}}}\right)\left(\frac{G^{\mathrm{W}}}{G^{\mathrm{H}}}\right)_{Q}\left(\frac{G^{\mathrm{W}}}{G^{\mathrm{H}}}\right)_{p}(\rho_{\mathrm{W}})
\end{aligned}
$$

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Density of liquid water, ρ_{W}, is well known.

Ratio of Constants

$$\frac{C_{\rm W}}{C_{\rm E}} \propto \left(\frac{P_{\rm W}}{V_{\rm W}}\right)\left(\frac{\Phi^{\rm W}_{\rm tot}}{\Phi^{\rm H}_{\rm tc}G^{\rm H}_{\Phi}}\right)\left(\frac{1}{B_{\rm He}}\right)\left(\frac{G^{\rm W}}{G^{\rm H}}\right)_{\nabla}\left(\frac{G^{\rm W}}{G^{\rm H}}\right)_{\tau}$$
$$\times\left(\frac{P_{\rm pc}}{P_{\rm tc}}\right)\left(\frac{\kappa_0 T_{\rm tc}}{T_{\rm pc}}\right)\left(\frac{G^{\rm W}}{G^{\rm H}}\right)_{Q}\left(\frac{G^{\rm W}}{G^{\rm H}}\right)_{p}(\rho_{\rm W})$$

Ratios of preamp settings, G_p, is well known.

Ratio of Constants

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Ratio of Q-curve gains, G_Q, appear very stable.

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κ_0/T_{pc} varies by about 6% from 200 to 300 Celsius.

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Need to look at details of polarization gradient for saGDH, but it is at most 5 to 6 percent.

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Need to look at time constant lineshaping effects, G_τ. A $\tau = 30\ \mathrm{ms}$ reduces the helium signal height by about 10%, but I think that the effect is nearly the same for the water lineshape.

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Have started to look into gradient effects in the helium line-shape and EPR. Two EPRs done at 0 septum current are consistent with those done at higher septum currents. Nothing obvious stands out, but more work needs to be done.

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I have made sure that am I using the correct transition in the analysis. Some EPRs have slopes, but I believe that is under control. Other than that, I have not looked into other systematic effects.

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Flux calculations are tricky and I am still looking into this.

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I believe I am now fitting the lineshape correctly. The up and down peaks are very sensitive to the T_1 used in the analysis, BUT the average is very insensitive: the average changes by 0.32% per second of T_1. I am worried about whether we are letting the spins reach equilibrium, see plots.

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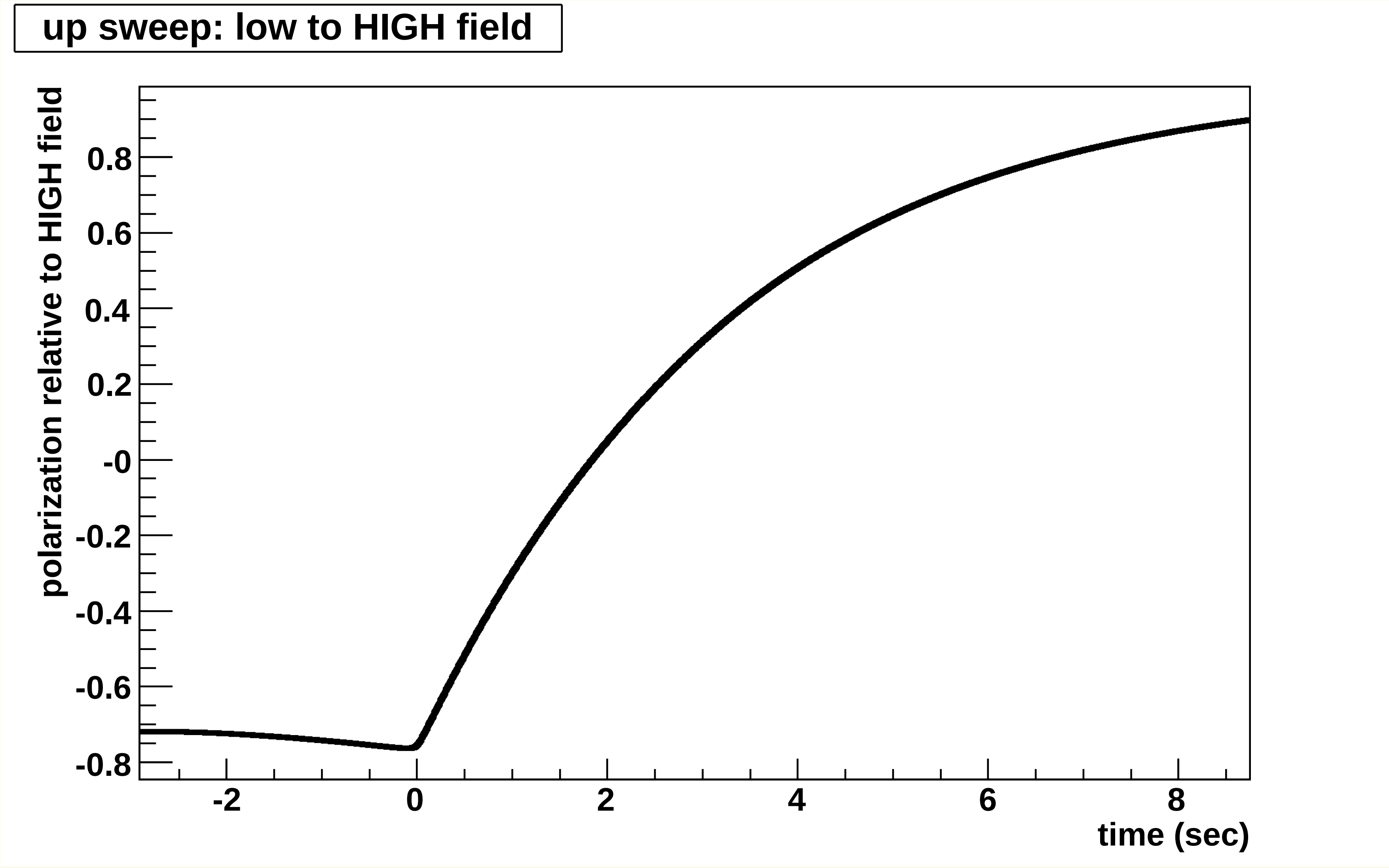

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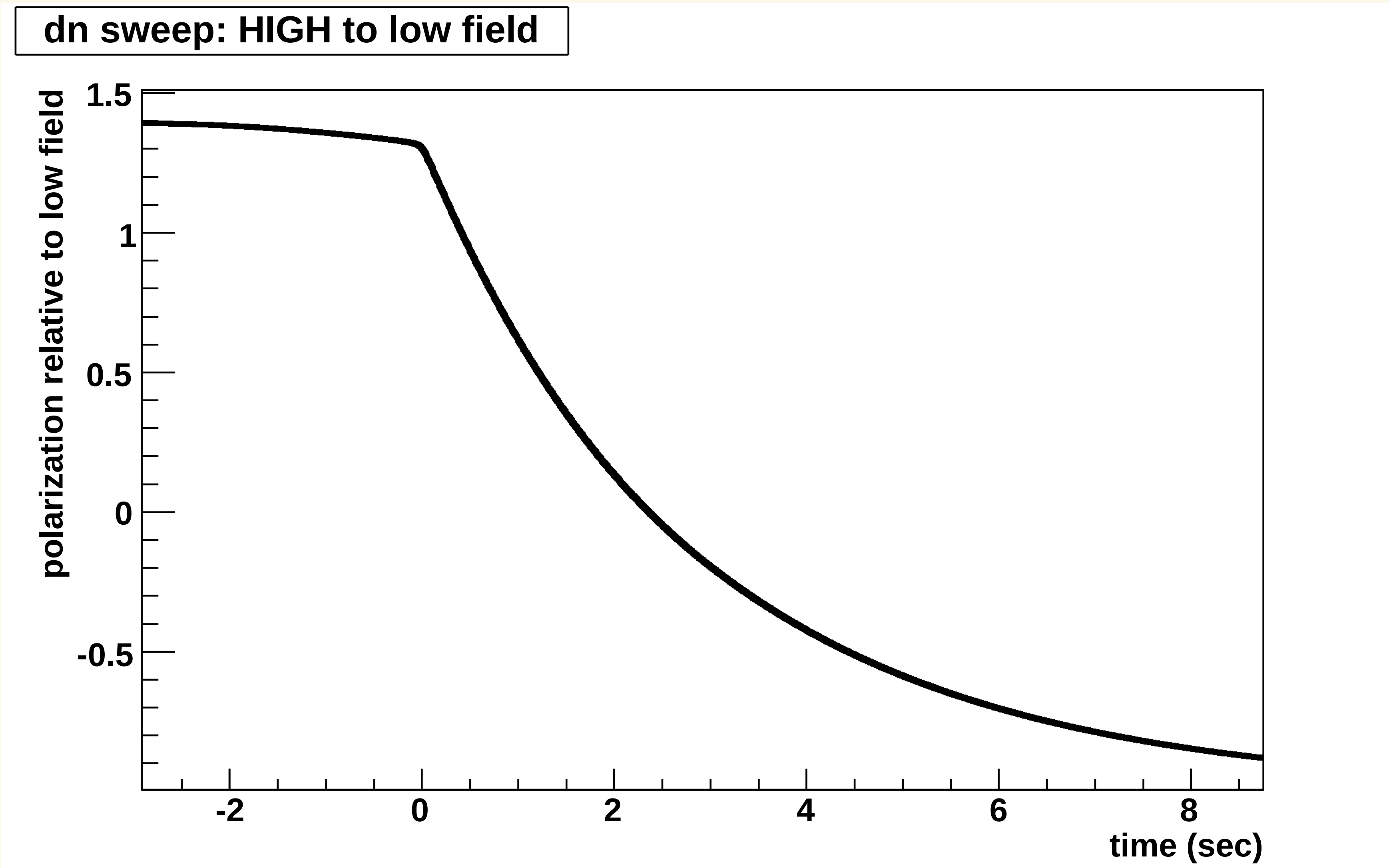

Conclusion

After a “comedy” of errors on my part, I believe that we have a 16% difference between our two methods of calibration for our polarimetry. I am still hopeful, because there are still some things I need to look at.