SPEAR 3 DCCT

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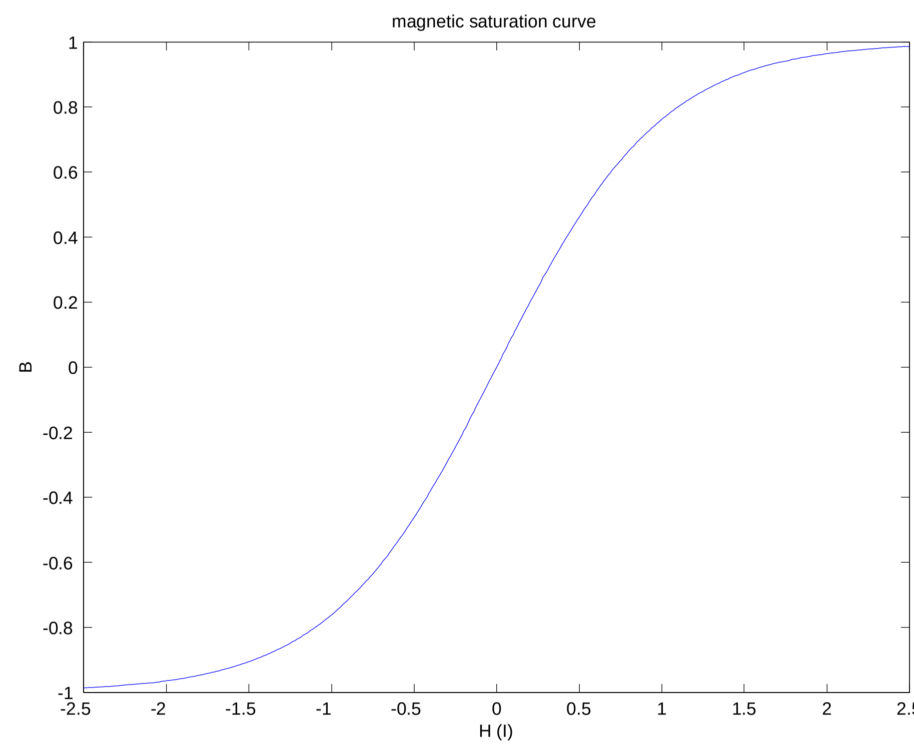
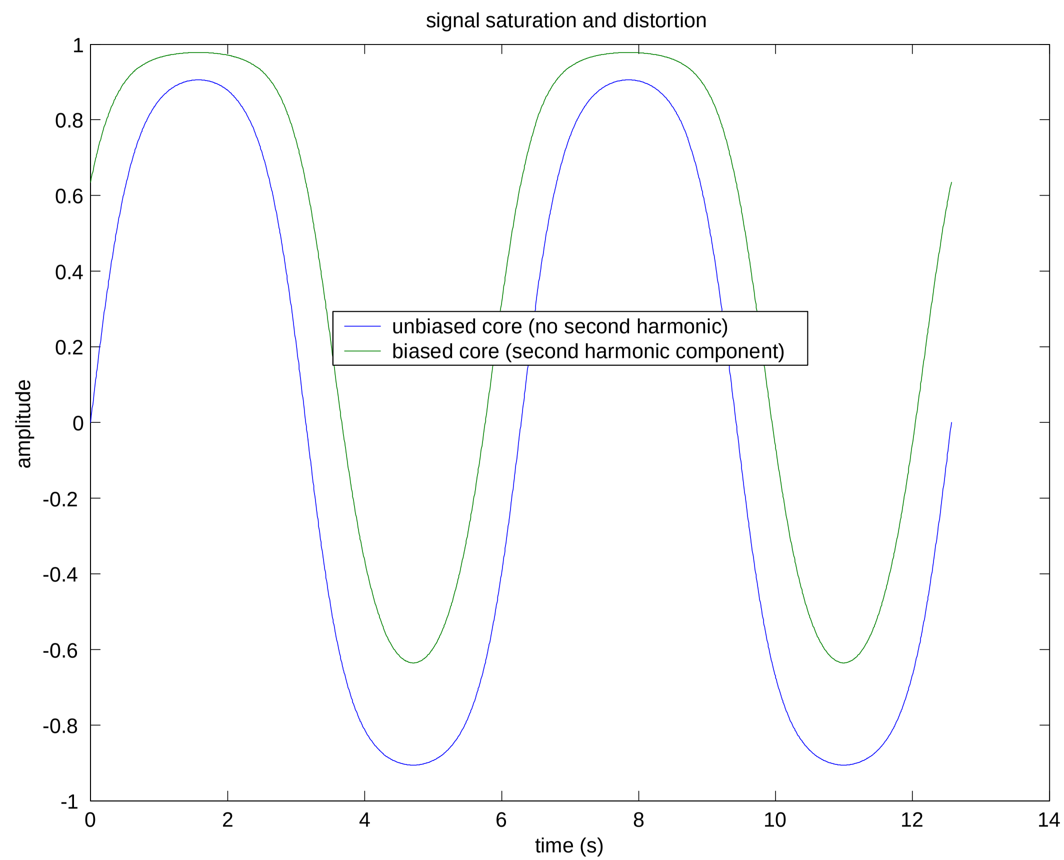
1 Outline

- Zero flux transducer theory
- Circuitry details
- $SPEAR\,3$ DCCT design
- System resolution and lifetime calculations

2 Zero Flux Transducer Theory

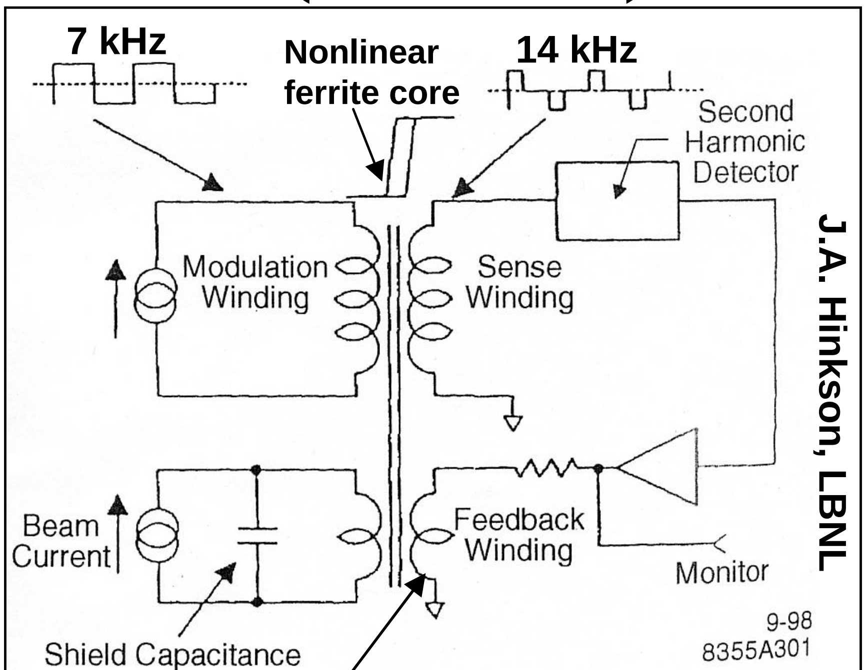


- Magnetic elements are non-linear
- Magnetic flux density, **B**, saturates with increasing magnetic field, **H**



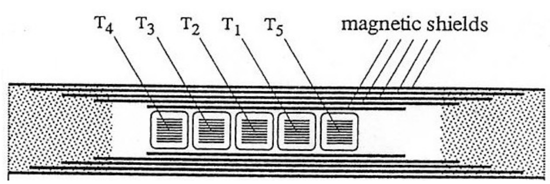
- If magnetic element is biased, $\langle \mathbf{H} \rangle \neq 0$, 2^{nd} harmonic distortion occurs
- 2^{nd} harmonic distortion detects net flux in element
- Sense 2^{nd} harmonic and feedback control current through element until $\langle \mathbf{H} \rangle = 0$

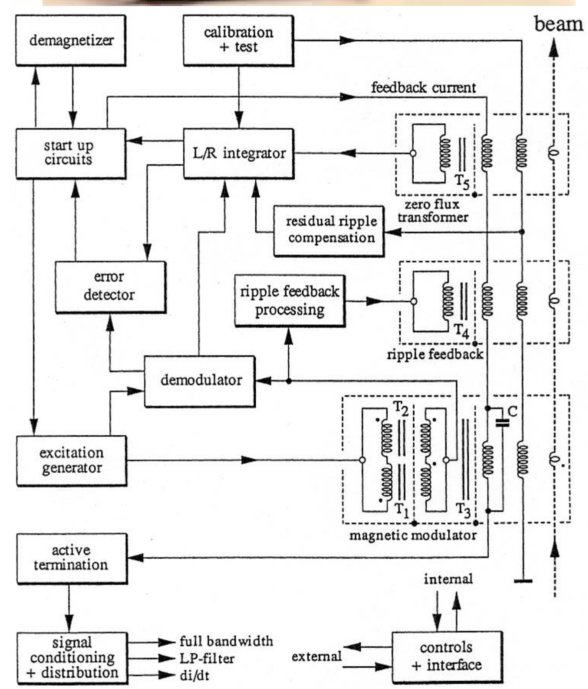
DCCT (or PCT) circuit



The DC bias current is adjusted to remove the 2nd harmonic (14 kHz) response of toroid. The beam current is proportional to the DC bias current.

Ferrite core Xsection



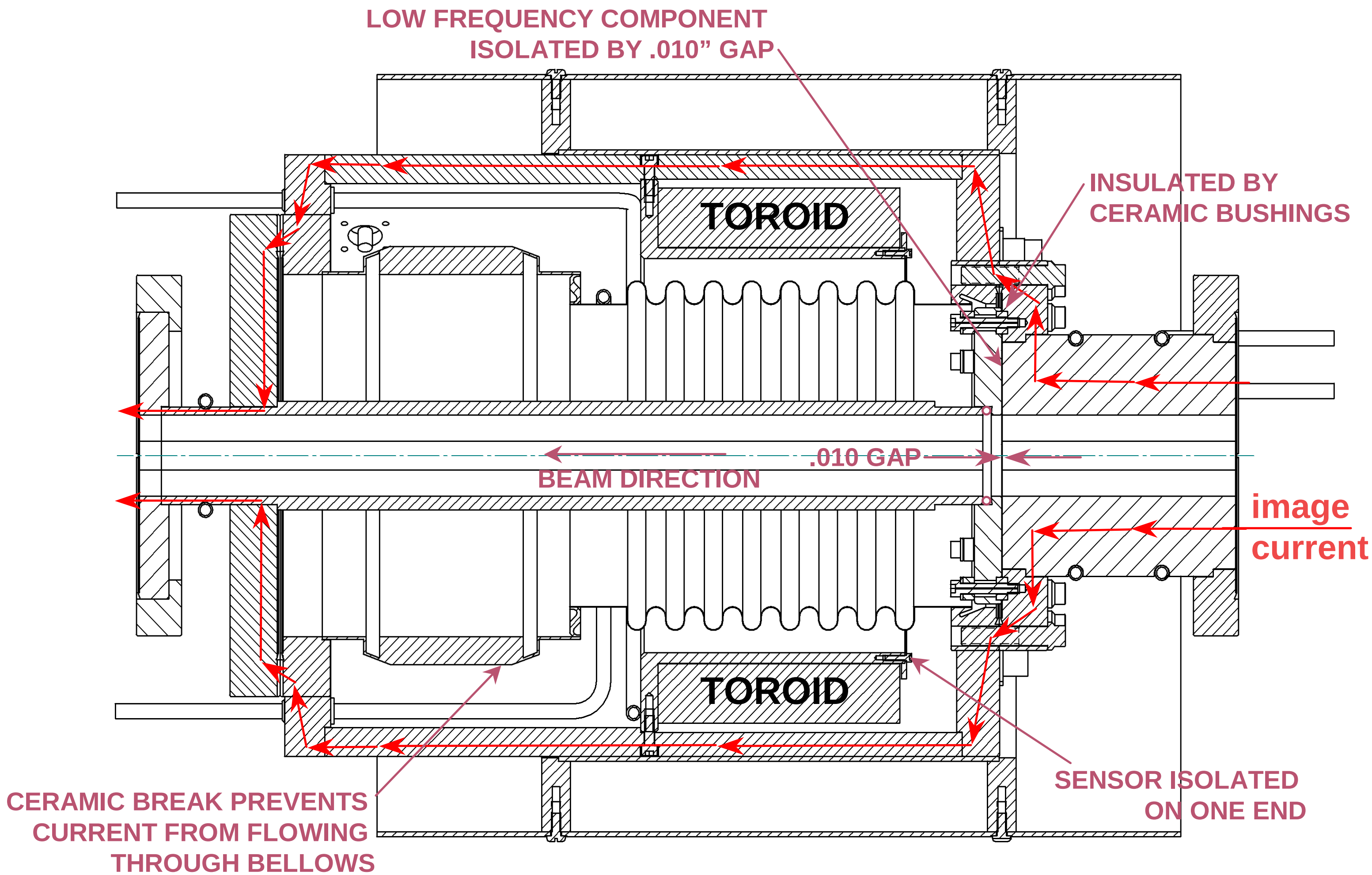


Simplified circuit, K. Unser, 1992

3 SPEAR 3 DCCT Design

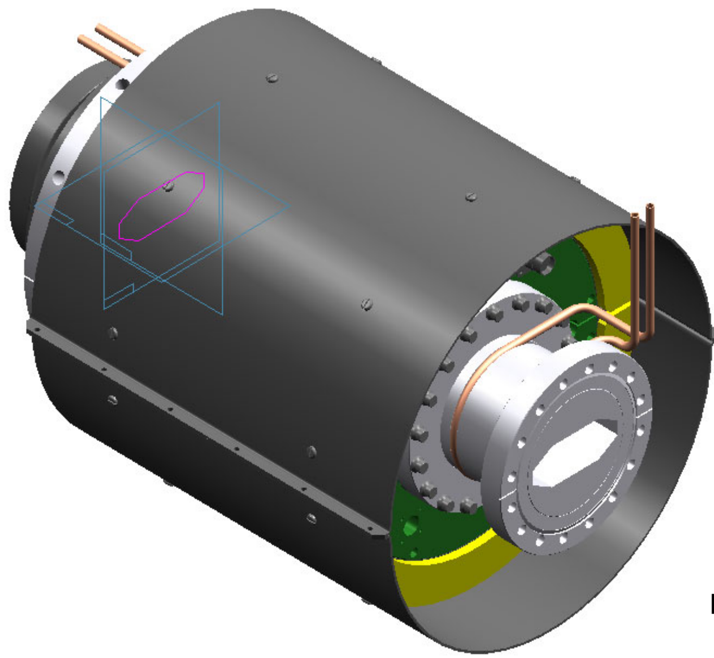
- Beam carries image current along with it
  - Image current on vacuum chamber wall
  - Need the beam current, but not the image current, to pass through the toroid
- Need a break in the metallic chamber wall, but still want to minimize beam impedance
  - Small gap in vacuum chamber
- Keep as much of the toroid out of the ring vacuum as possible
  - Place large ceramic break inside toroid inner diameter
- Minimize heating effects from beam induced RF effects on toroid
- Maintain high precision of system
  - Shield the toroid from stray fields that could bias the toroid
- Create a workable mechanical design
- $SPEAR\,3$ design by D. Arnett, N. Kurita, and J. Safranek

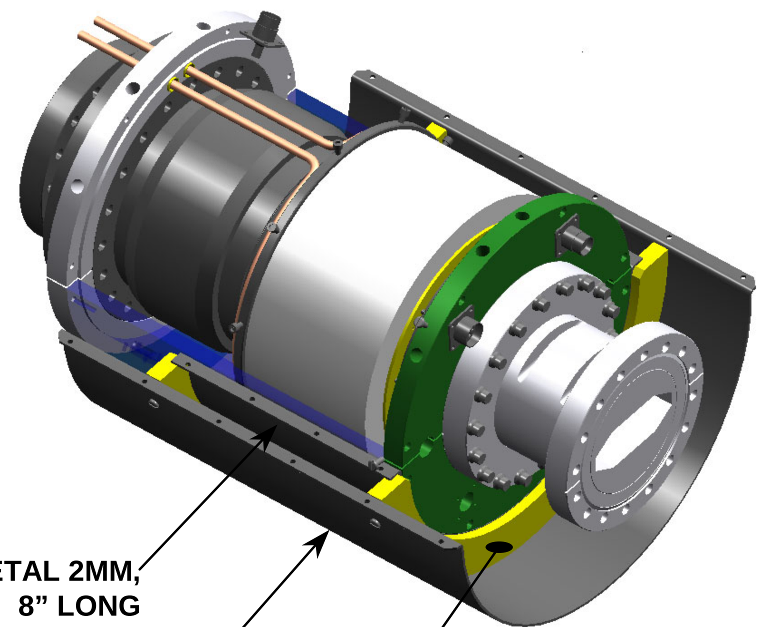
SPEAR3 DCCT



Courtesy of J. Safranek

Shielding





Courtesy of N. Kurita

4 System Resolution and Lifetime Calculations

- SPEAR current

$$\begin{aligned} 500\,\mathrm{mA} &= Q \cdot f_{rev} \\ Q &= 3.91 \times 10^{-7}\,\mathrm{C} \\ &= 2.44 \times 10^{12}\,e^{-} \end{aligned}$$

- Beam lifetime

$$\begin{aligned} I\left(t\right) &\cong I_0 \exp\left(-t/\tau\right) \\ &\cong I_0 \left(1 - t/\tau\right), \qquad t \ll \tau \end{aligned}$$

  – For $t \ll \tau$, lifetime can be found from a linear fit

- For $\tau = 40\,\mathrm{h}$ lifetime

$$\begin{aligned} N_{rev} &= 40 \cdot 60 \cdot 60 \cdot f_{rev} \\ &= 1.84 \times 10^{11} \end{aligned}$$

- Lose $\simeq 13\,e^{-}$ per revolution

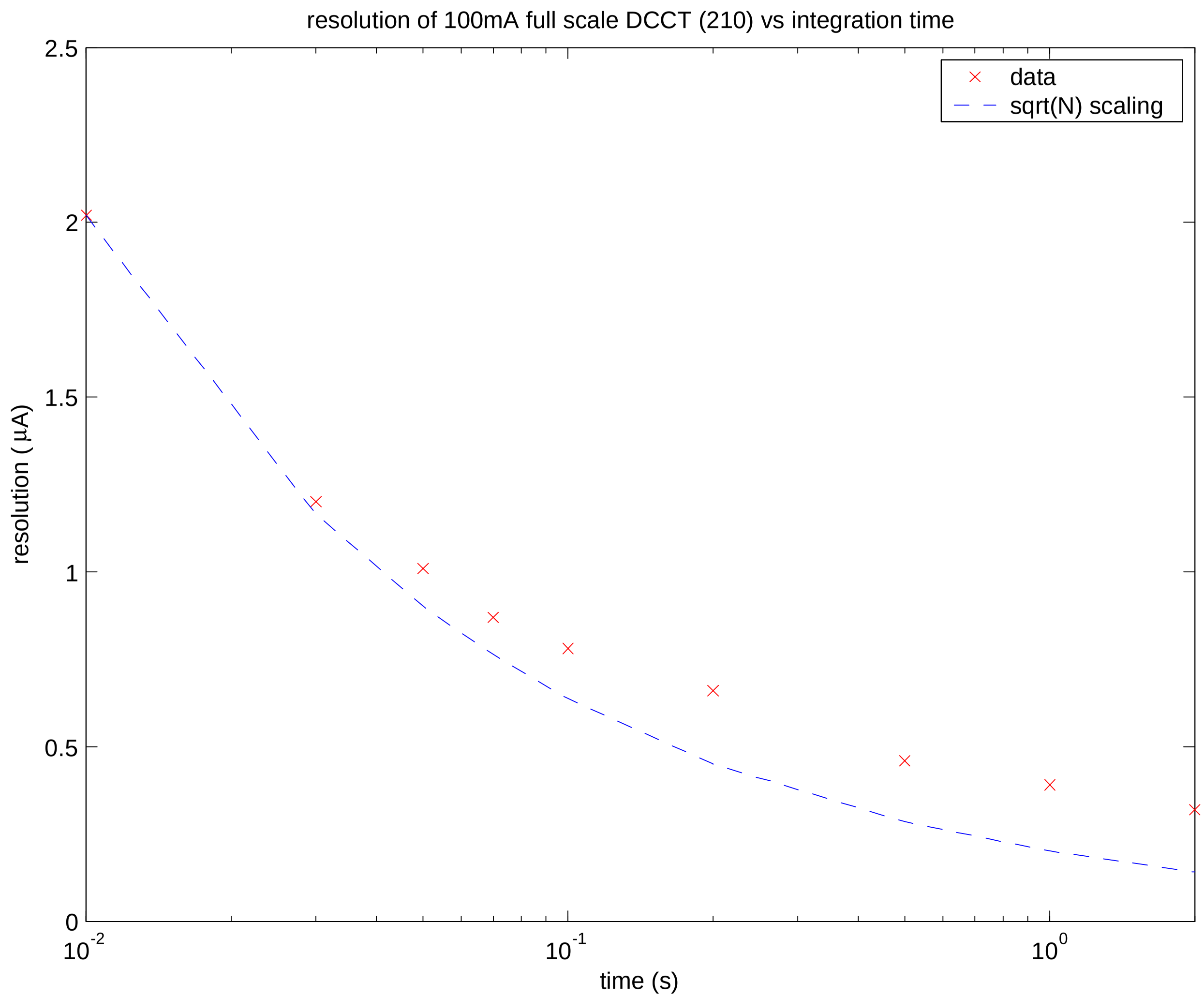
- Difference between two lifetimes

$$\begin{aligned} I_0 \left[\exp\left(-t/\tau_1\right) - \exp\left(-t/\tau_2\right) \right] &\cong I_0 \left[-t \left(\frac{1}{\tau_1} - \frac{1}{\tau_2} \right) \right] \\ &\cong -I_0 \frac{\Delta\tau}{\tau^2} t \end{aligned}$$

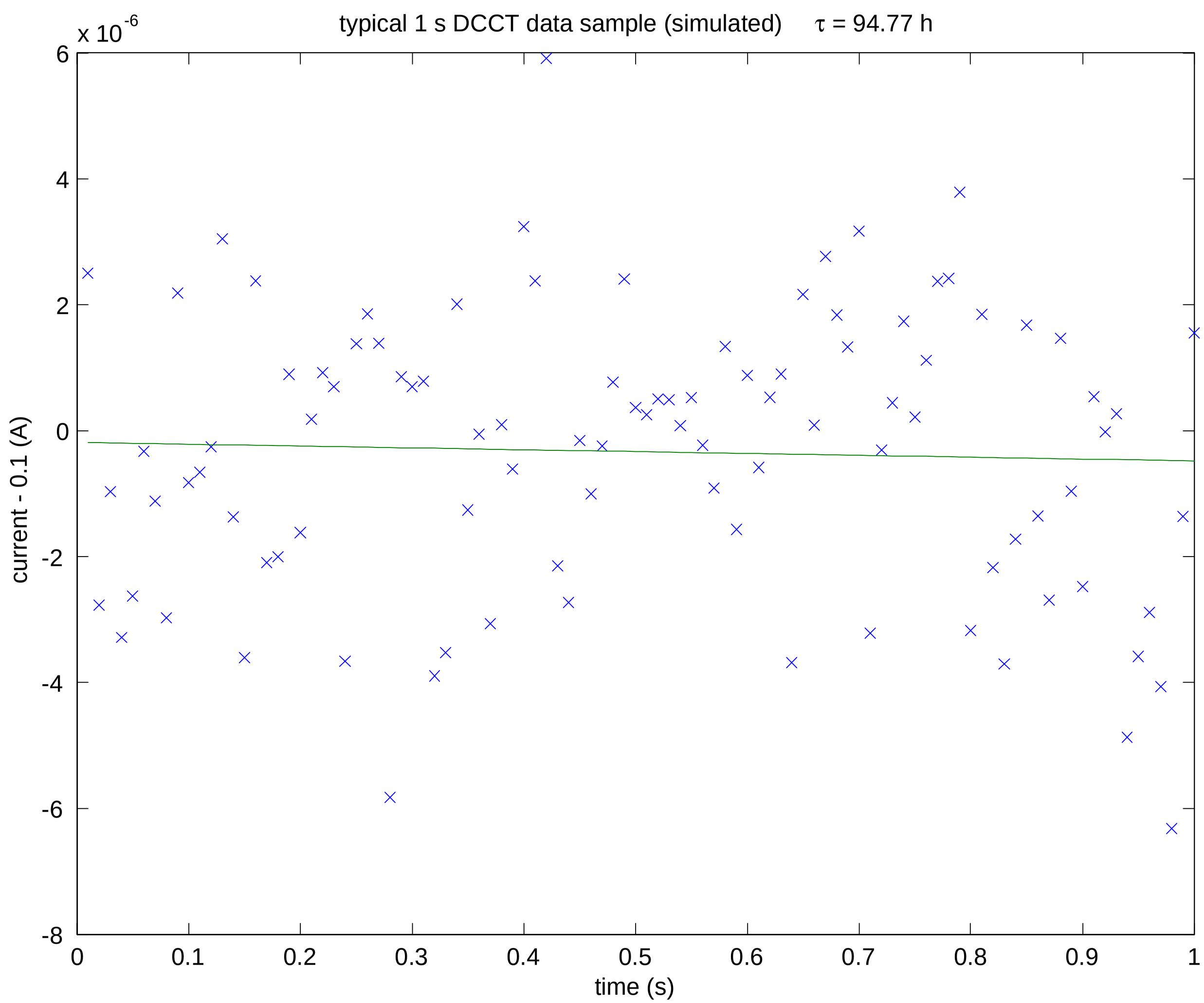
- To distinguish between different lifetimes, need to know the current to within an accuracy

$$\frac{\Delta I}{I} = \frac{\Delta\tau}{\tau} \frac{t}{\tau}$$

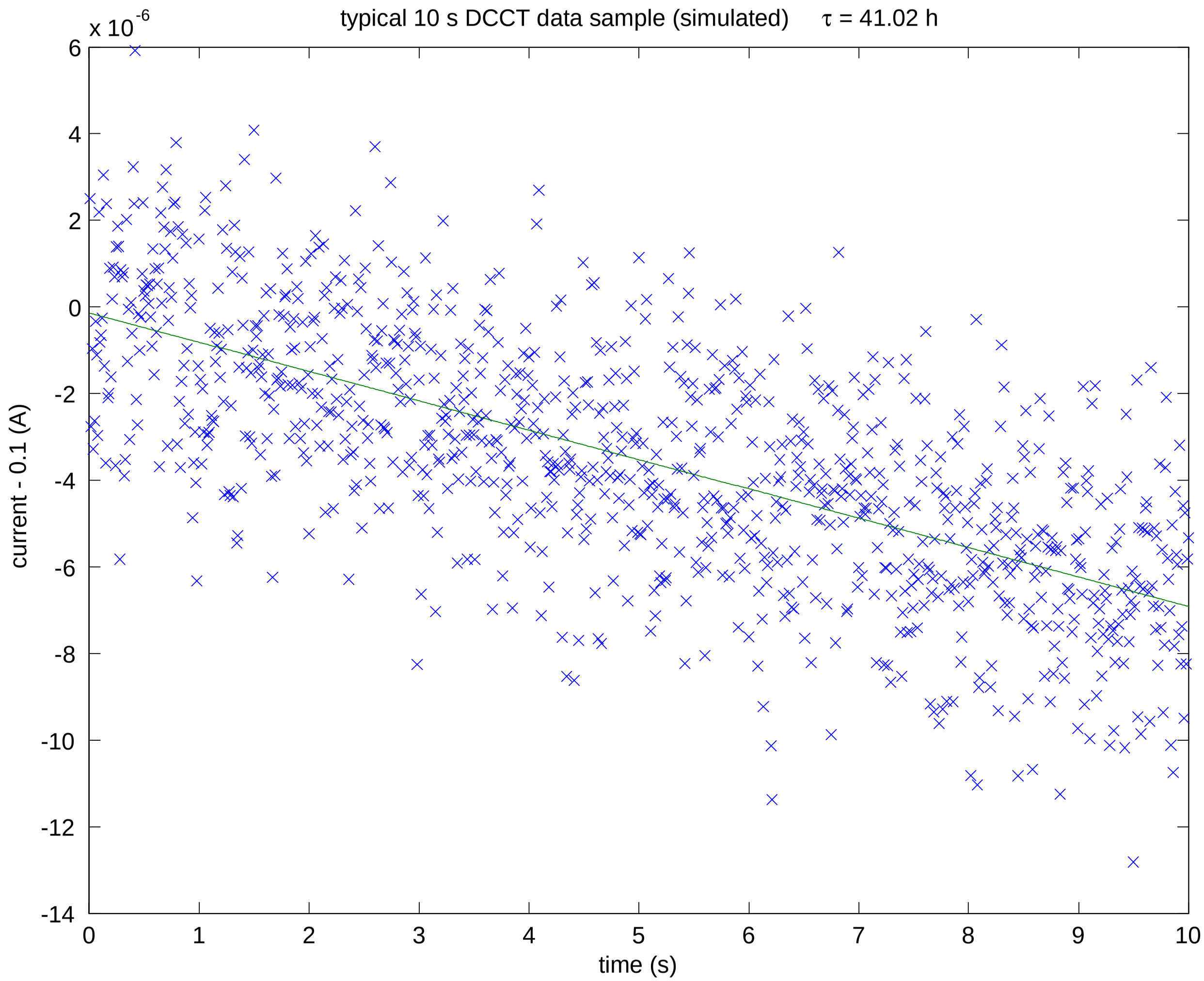
- For $\tau = 40\,\mathrm{h}$, $\tau = 144000\,\mathrm{s}$



- Bergoz electronics has resolution of $2\,\mu\mathrm{A}$ out of $100\,\mathrm{mA}$ $\left(2 \times 10^{-5}\right)$ in $10\,\mathrm{ms}$
- Noise almost decreases as $N^{-1/2}$ with increasing sample number
- Keithley DVM has 6.5 digit accuracy $\left(< 1 \times 10^{-6}\right)$ at 250 samples per second

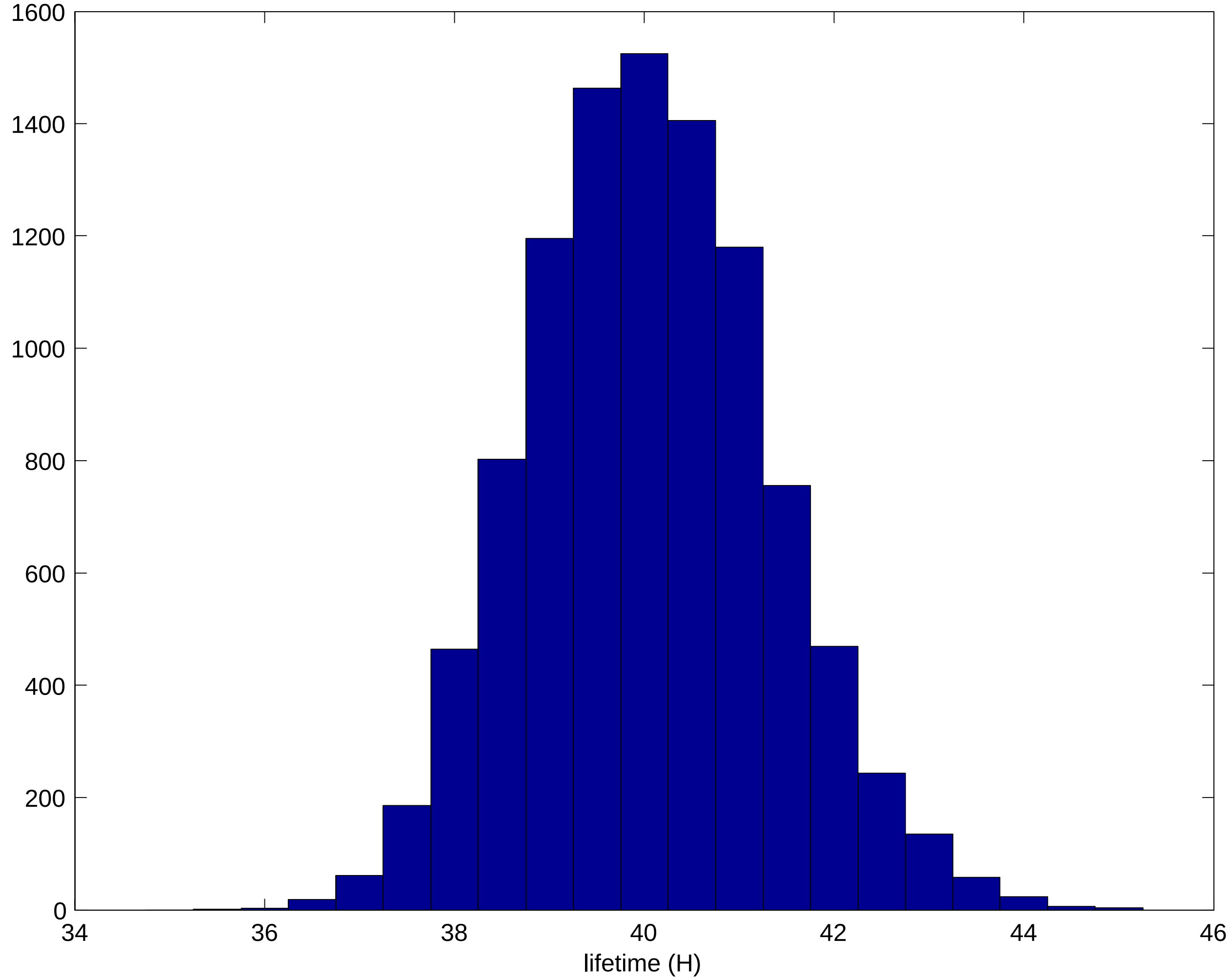


- Can aquire ~ 100 samples per second from DVM
- System noise greatly limits accuracy of lifetime calculation in $1\,\mathrm{s}$



- Accuracy becomes quite good after 1000 samples are taken in $10\,\mathrm{s}$

histogram of 10 second lifetime calculations



- $40\,\mathrm{h}$ lifetime calculations are now accurate to within 3%

5 Lifetime Calculation Summary

- Lifetime accuracy dominated by electronic noise from DCCT electronics
- Perform experiments with $100\,\mathrm{mA}$ in SPEAR so that the more sensitive scale of the electronics can be used
- $40\,\mathrm{h}$ lifetime measurements can be performed with 3% accuracy with 1000 samples in $10\,\mathrm{s}$