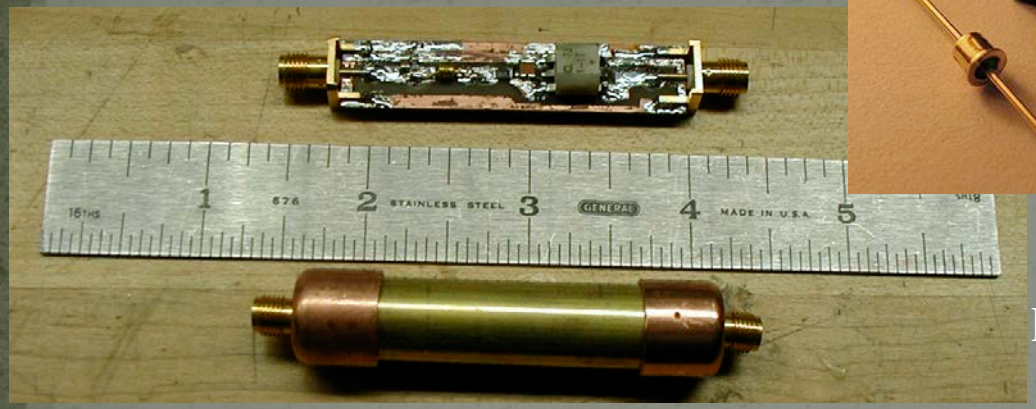
Proximity Detection Oscillator: High-Precision, Contactless Resistivity Measurements

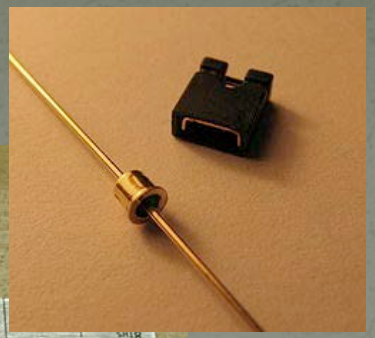
Chuck Mielke

Los Alamos NATIONAL LABORATORY EST. 1943

NATIONAL SCIENCE FOUNDATION

Overview



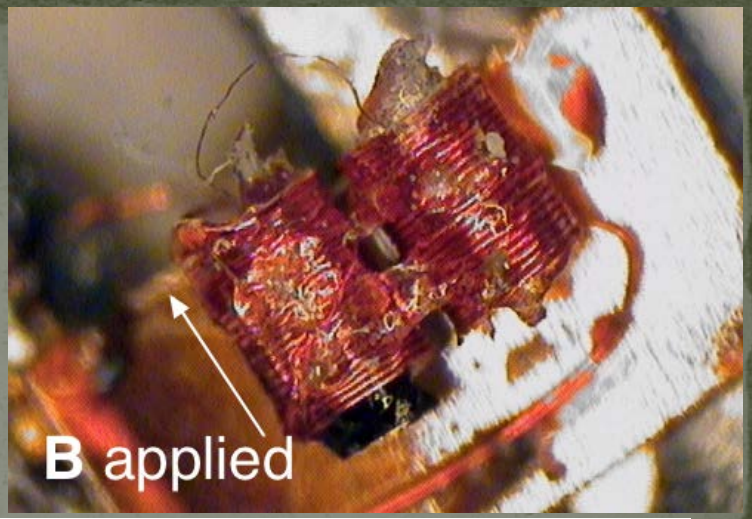


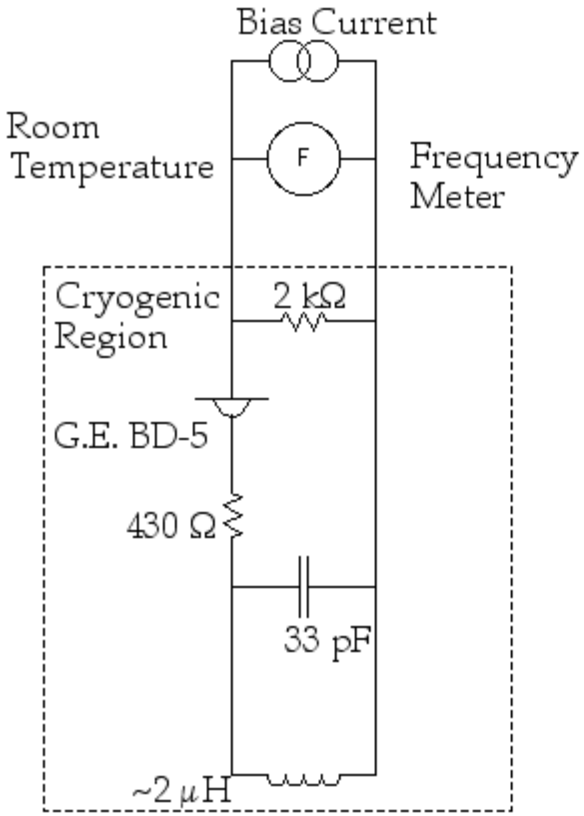
Leo Esaki (inventor of the tunnel diode)

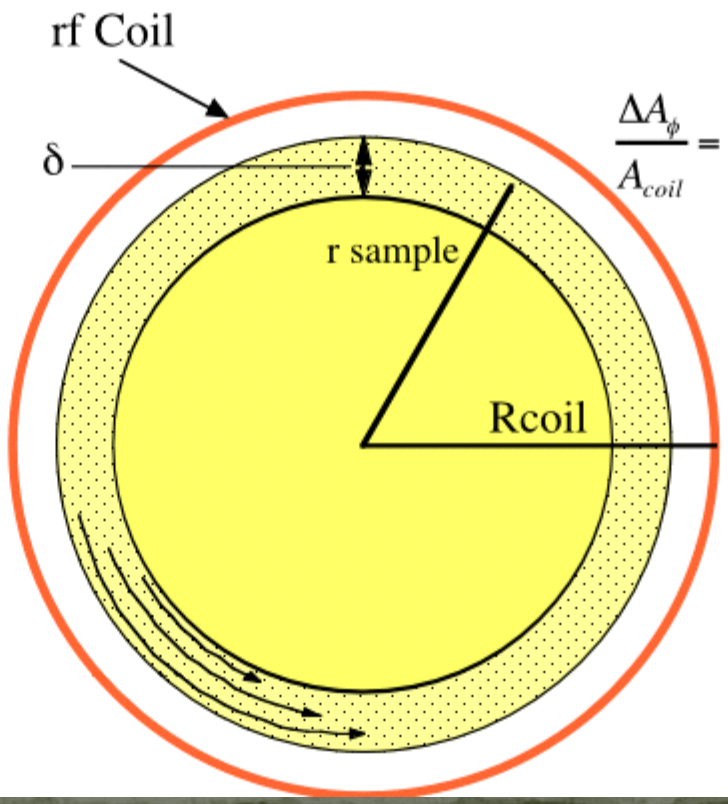
- Proximity Detector Oscillator (Prox Box or PDO)
  - How is this related to the Tunnel Diode Oscillator (TDO)
  - What is special about the PDO
    - Where did it come from & Why
- The PDO in use
  - Extreme pulsed field environments & their challenges
  - Success in the extremes
  - Opportunities!

Theory of How it Works

C. Mielke J. Phys.: Condens. Matter **13 (2001) 8325.**







$$\frac{\Delta A_\phi}{A_{coil}} = 2\frac{\Delta f}{f_0}$$

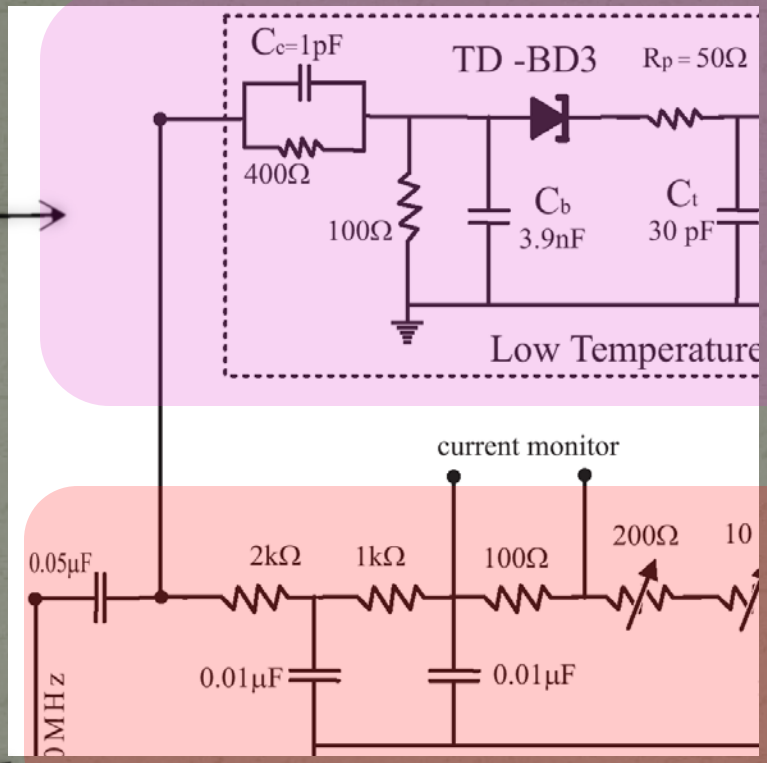
$$\frac{\Delta A_\phi}{A_{coil}} = \frac{\pi r_s^2 - \pi(r_s - \delta)^2}{\pi R_{coil}^2} = \frac{2\delta r_s}{R_{coil}^2}$$

$$\delta = \frac{R_{coil}^2}{r}\frac{\Delta f}{f_0}$$

$\Delta f \approx 500$ kHz
f_0=20 - 50 MHz
R_{coil}= 375 μm
$r_{sample} \approx$ 300 μm

Traditional TDO experimental setup in dc field

At low temperature



At room temperature

Oscillation condition

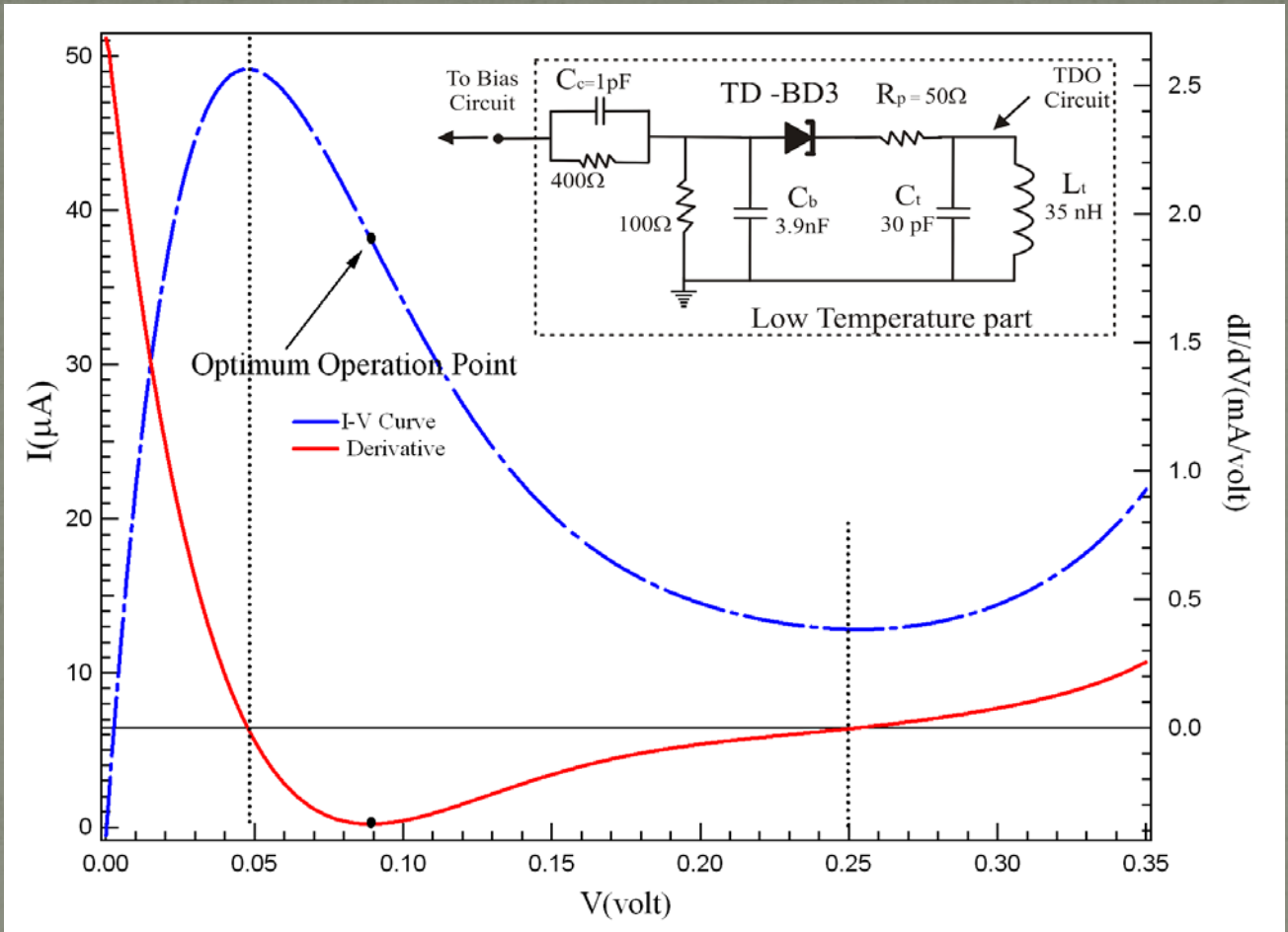
$$Z_0 \geq |R_p + R_n|$$

With small coils, circuit needs to be cooled down

C. T. VanDegrift. Rev. Sci. Instrum, 46(3):599, October 1975

Los Alamos NATIONAL LABORATORY EST. 1943

dB/dt makes the TDO challenging

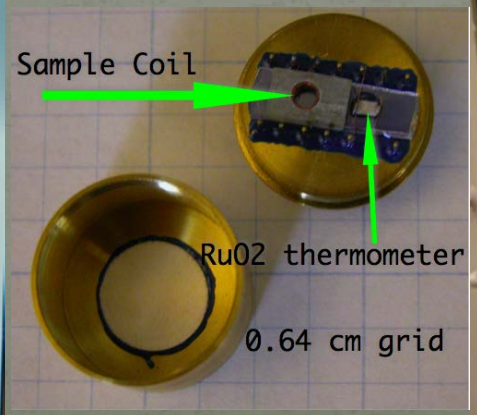


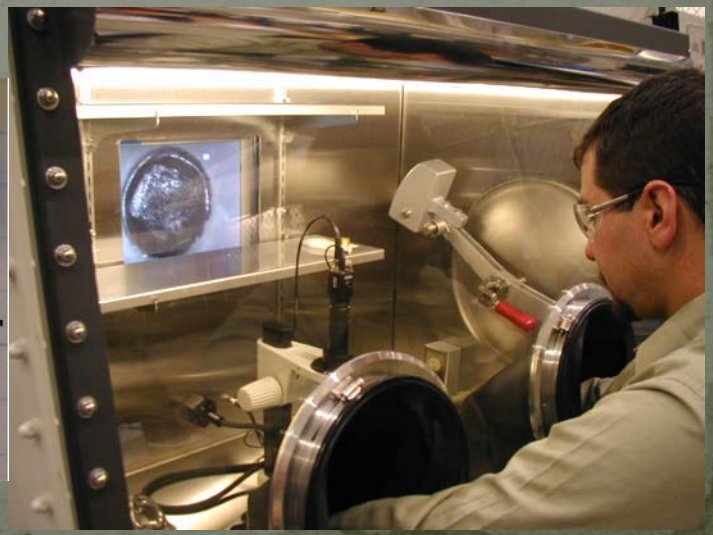
$V_{induced}$ = *60 mV for 1 mm*^{2} area in 60T magnet

Bias dependence of the TDO couples electrical noise to frequency.
Extreme case of being kicked outside operating range by dB/dt.

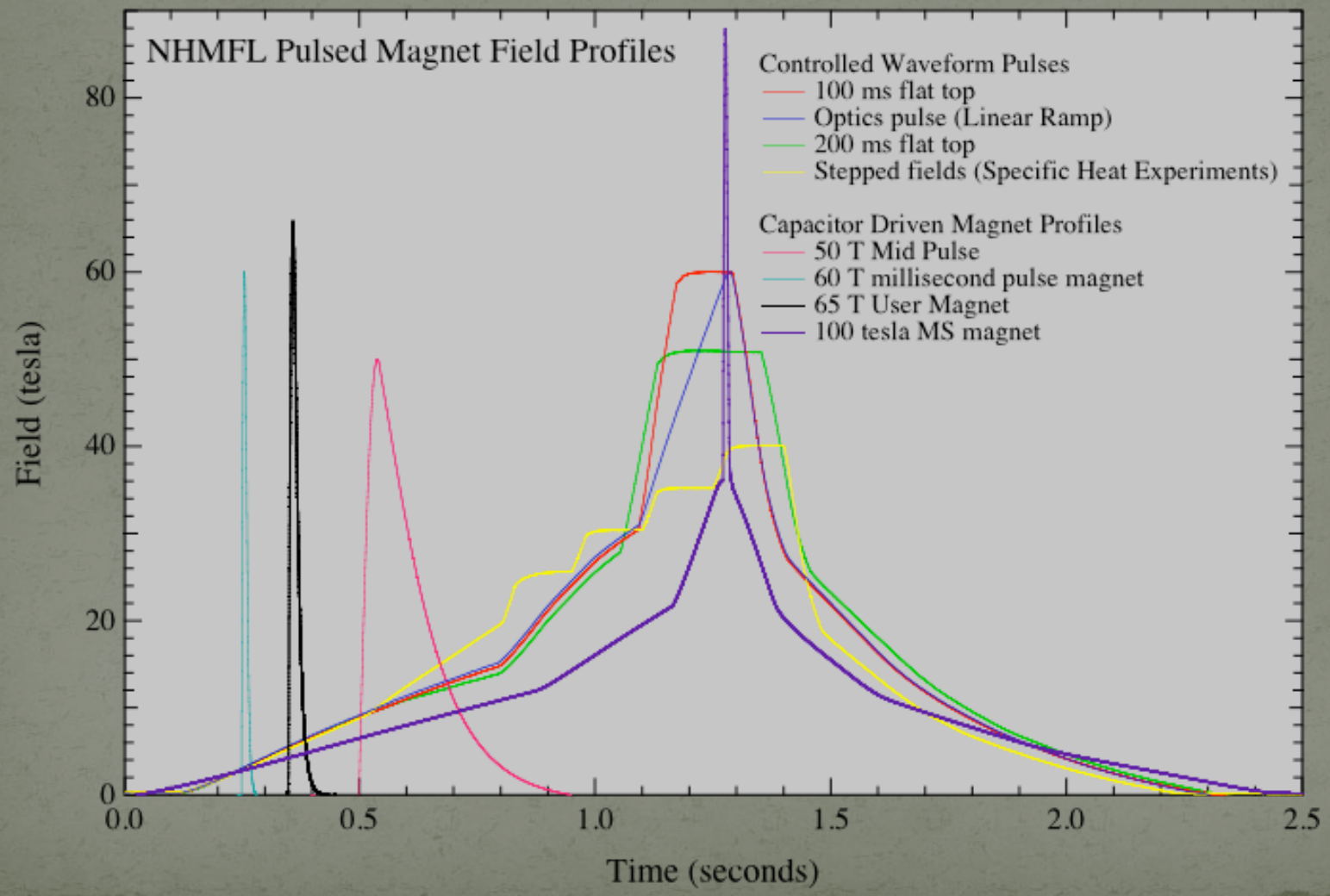
The Right Method can solve problems…

- Very small and delicate samples
- Surfaces that oxidize
  - May be toxic or simply air sensitive
    - Ce, Pu, U, HTcs many, many other interesting systems…
- In pulsed magnets the *Rate of Change* (i.e. dB/dt) can destroy an experiment…. Not just figuratively

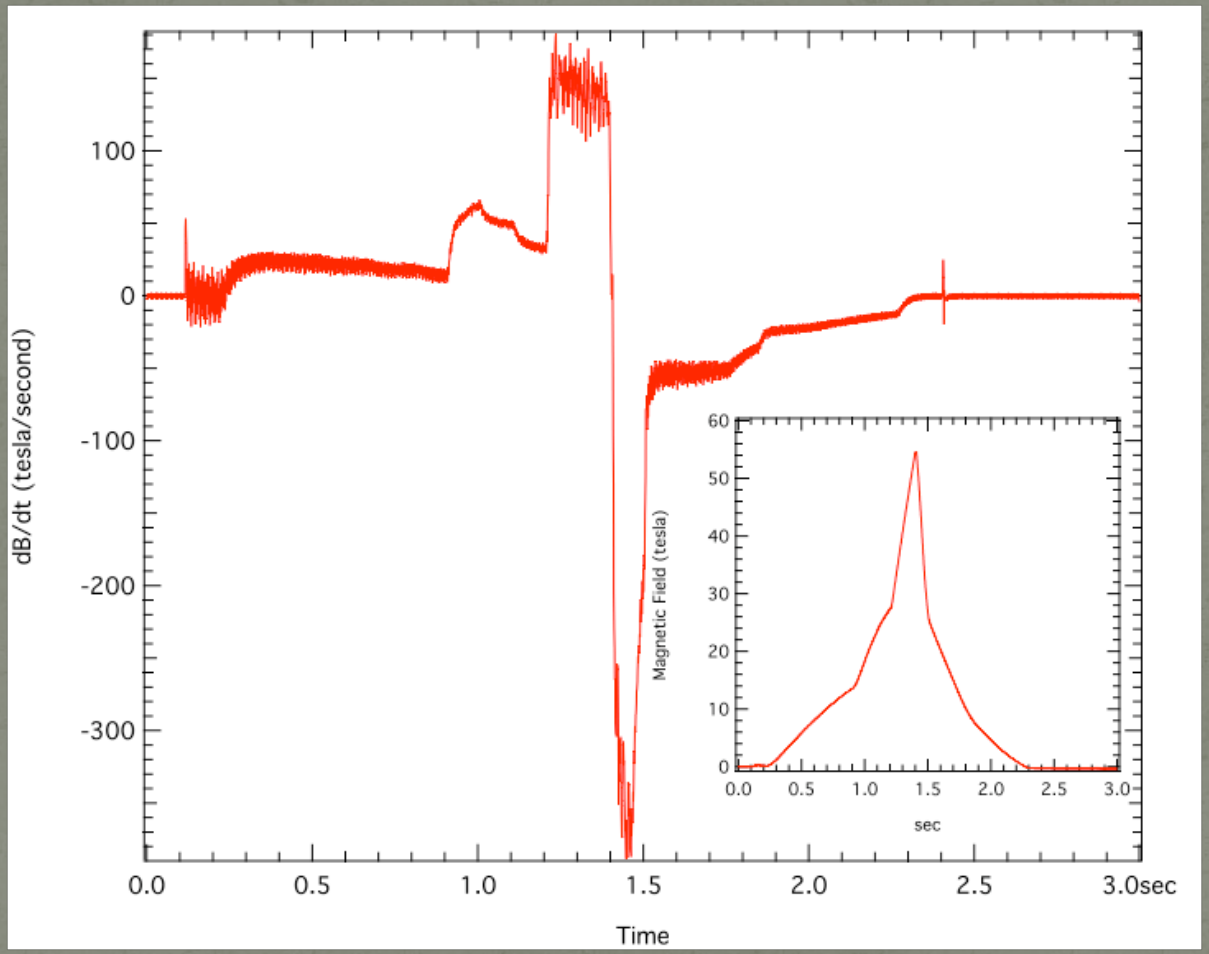




Pulsed Magnet Waveforms

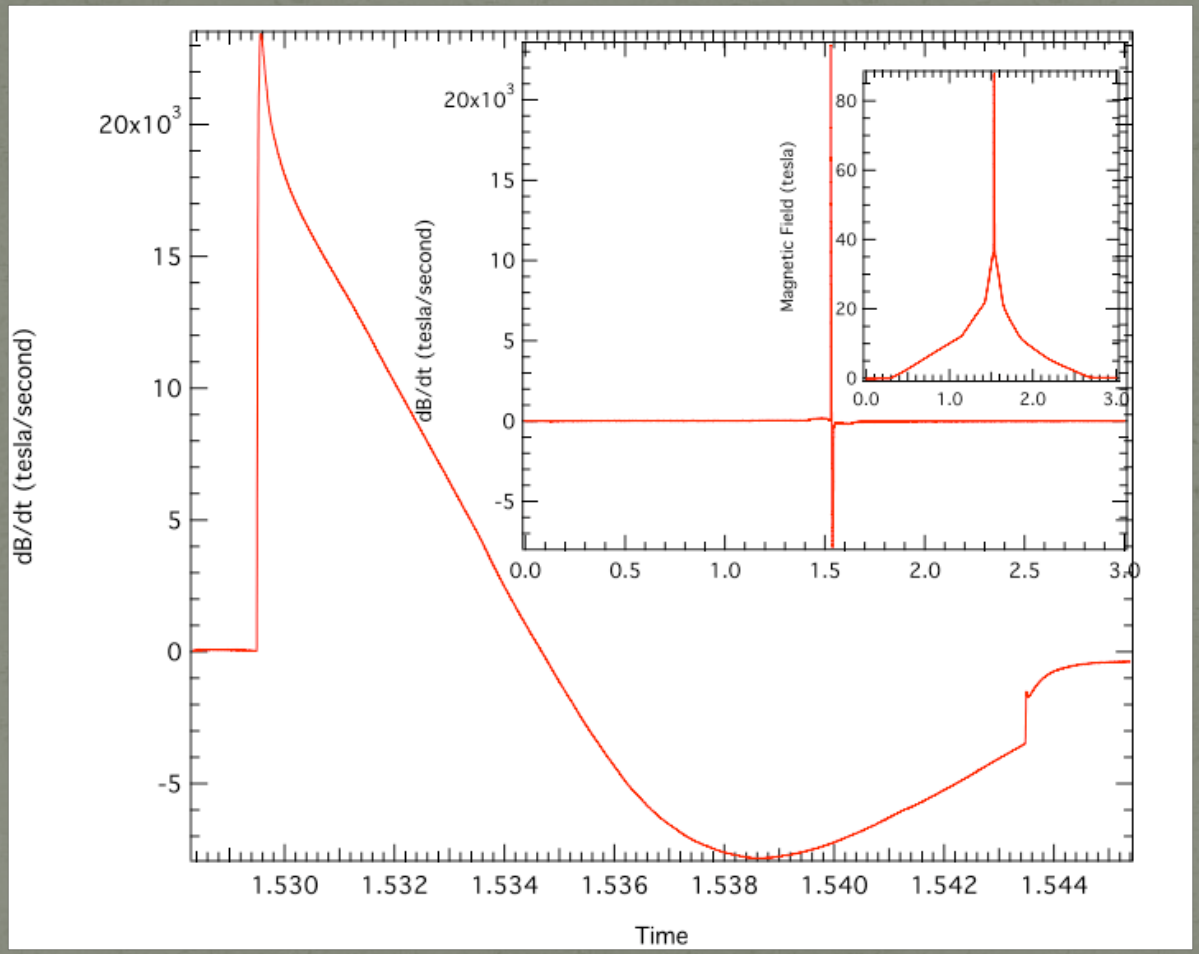


How big is dB/dt?



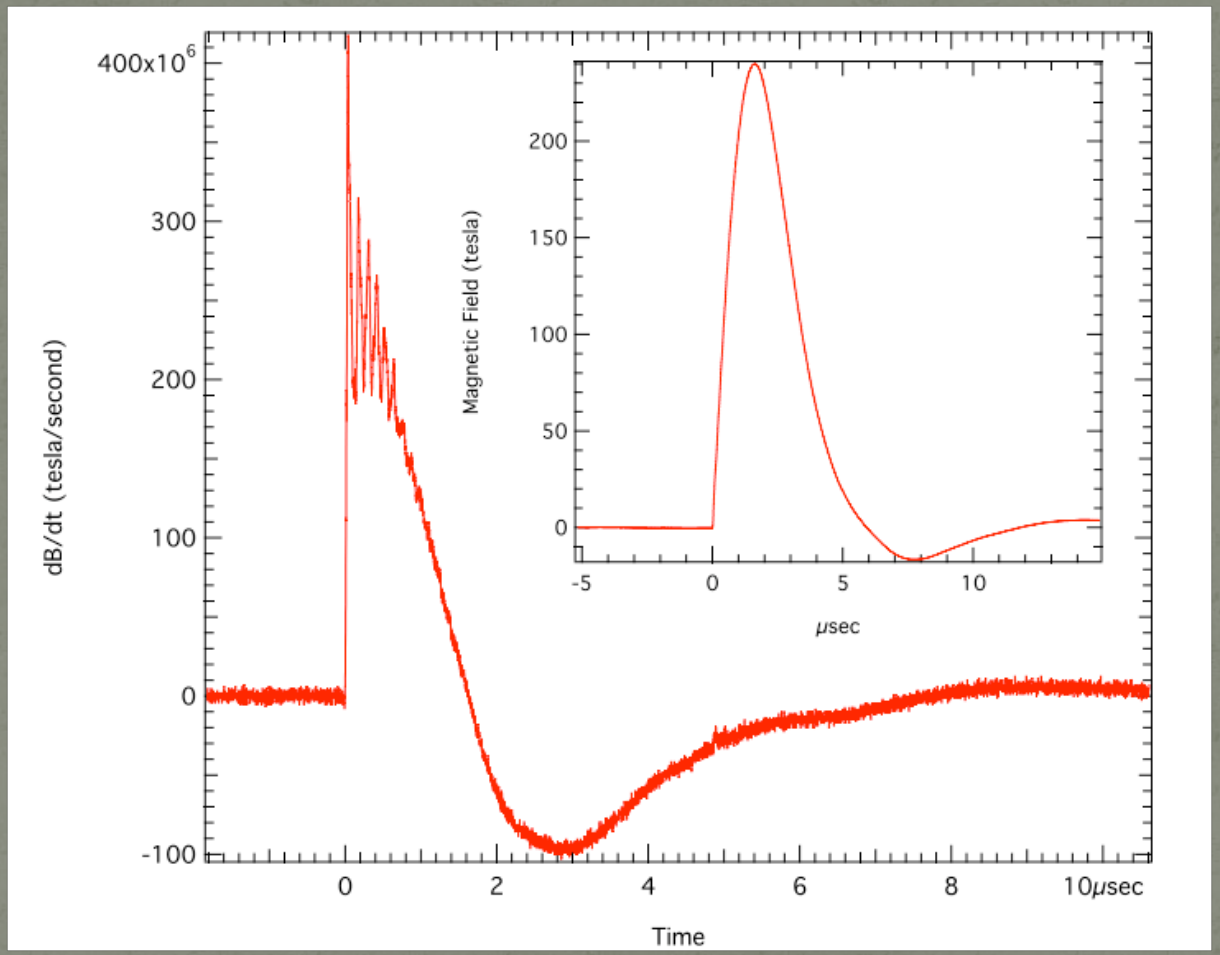
60T Long Pulse Magnet

How big is dB/dt?



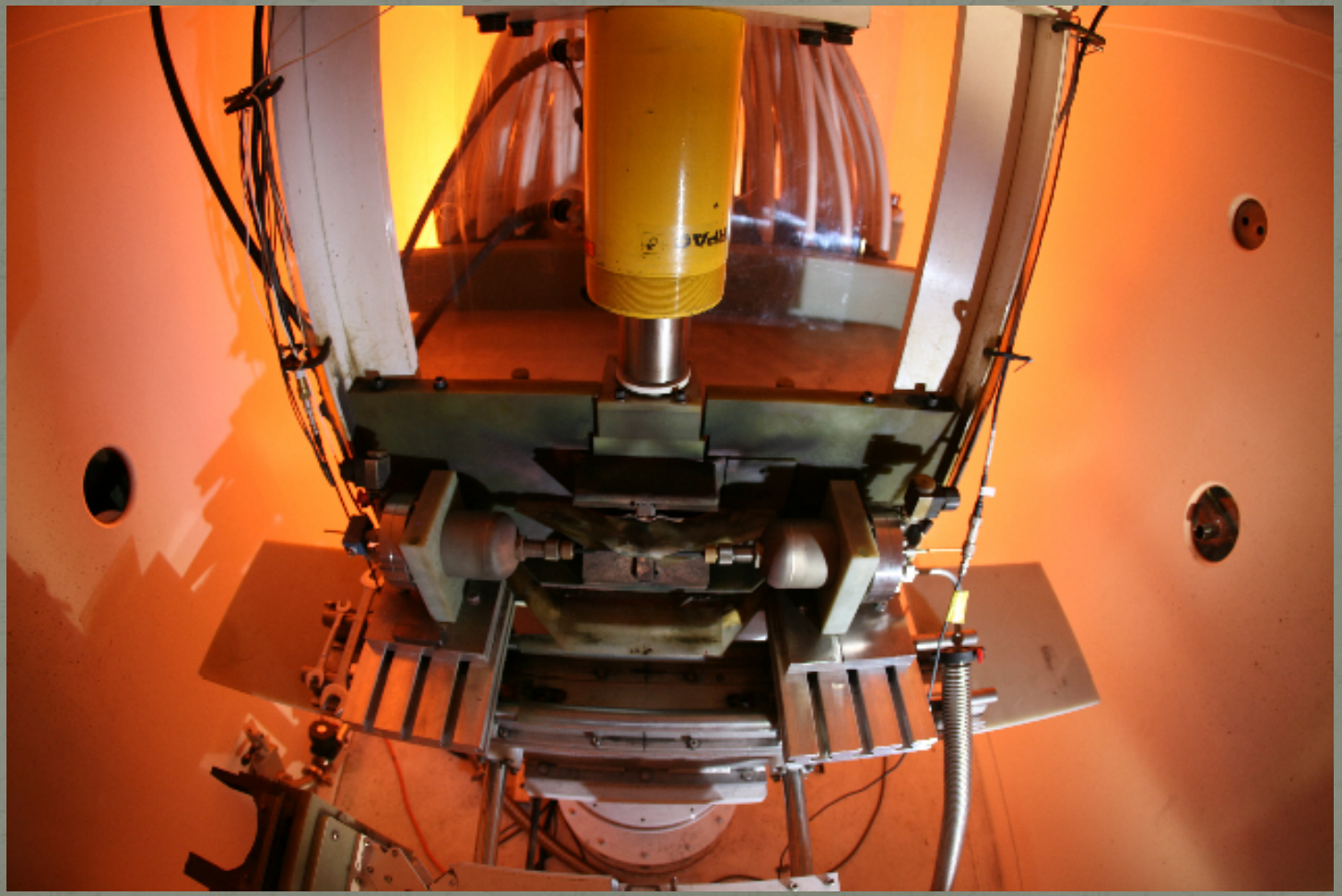
100 T Multi-Shot Magnet

How big is dB/dt?

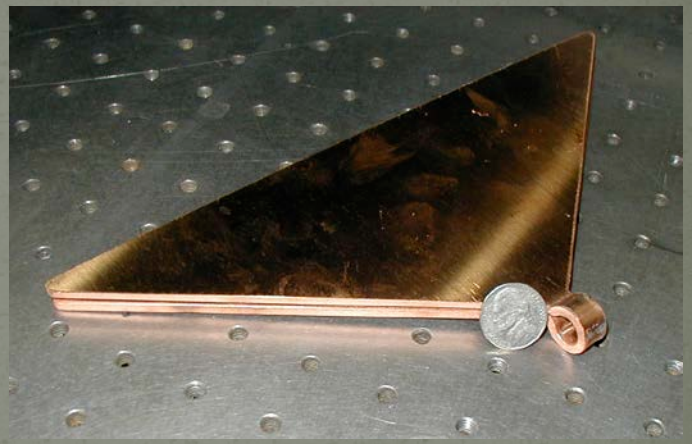


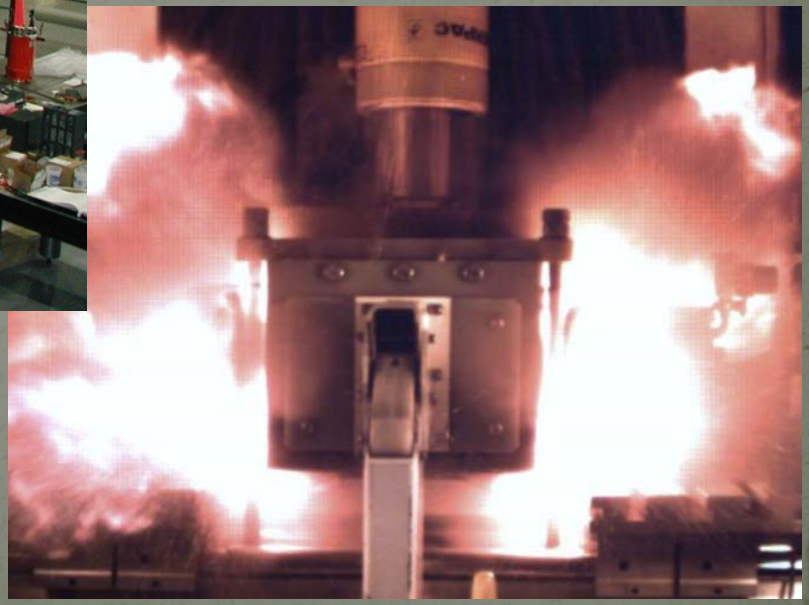
Single Turn Magnet

The Single Turn



Single Turn Magnet System

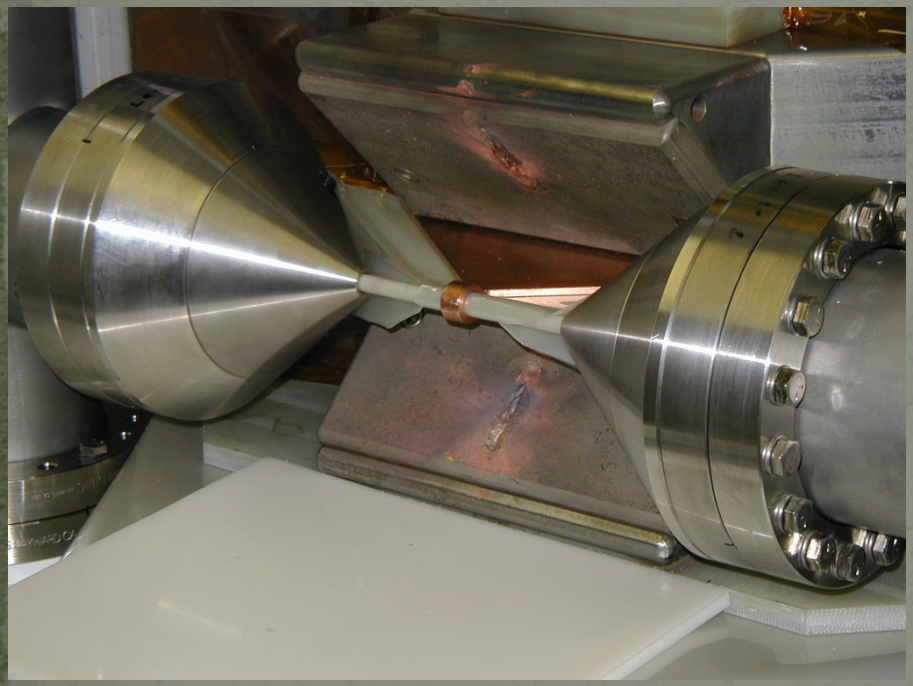




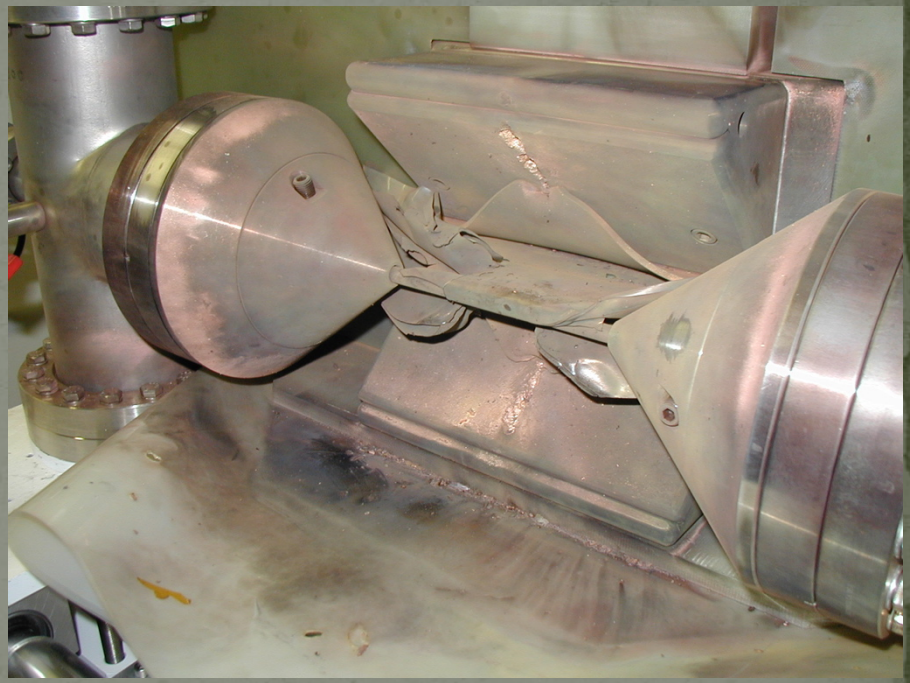
What do we HAVE to sacrifice?

- TIME
- The Magnet
- Sample cross section
- Some diagnostics

Probe & sample survive

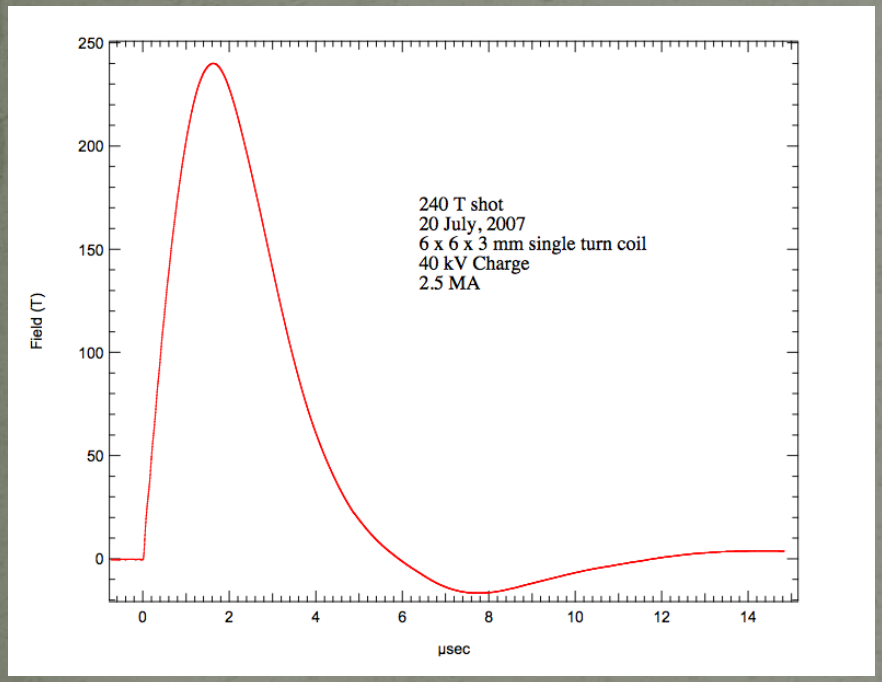


Before



After

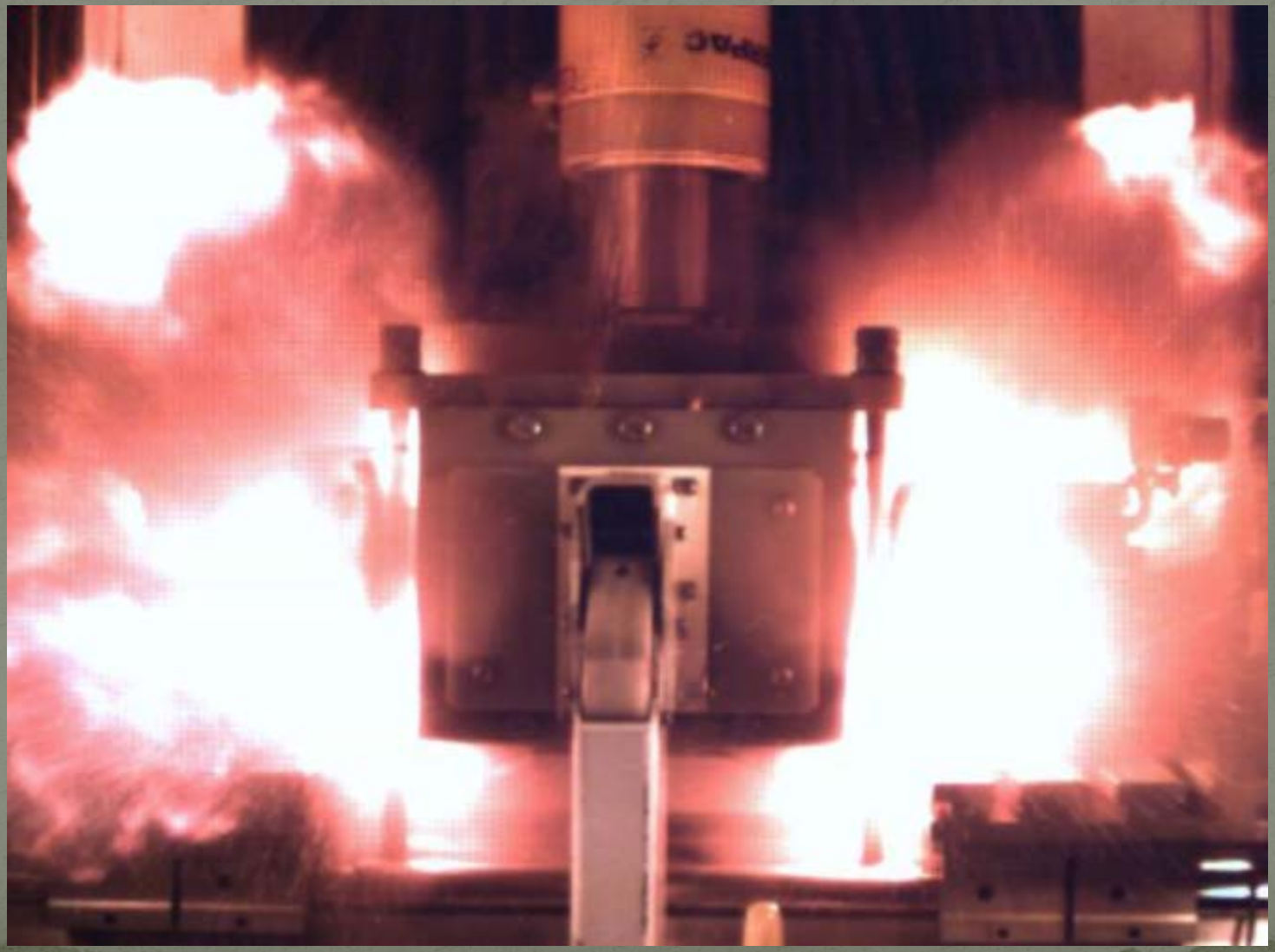
Reaching beyond 100 T



Still Frame from a 240 T shot at the NHMFL-PFF (Los Alamos)

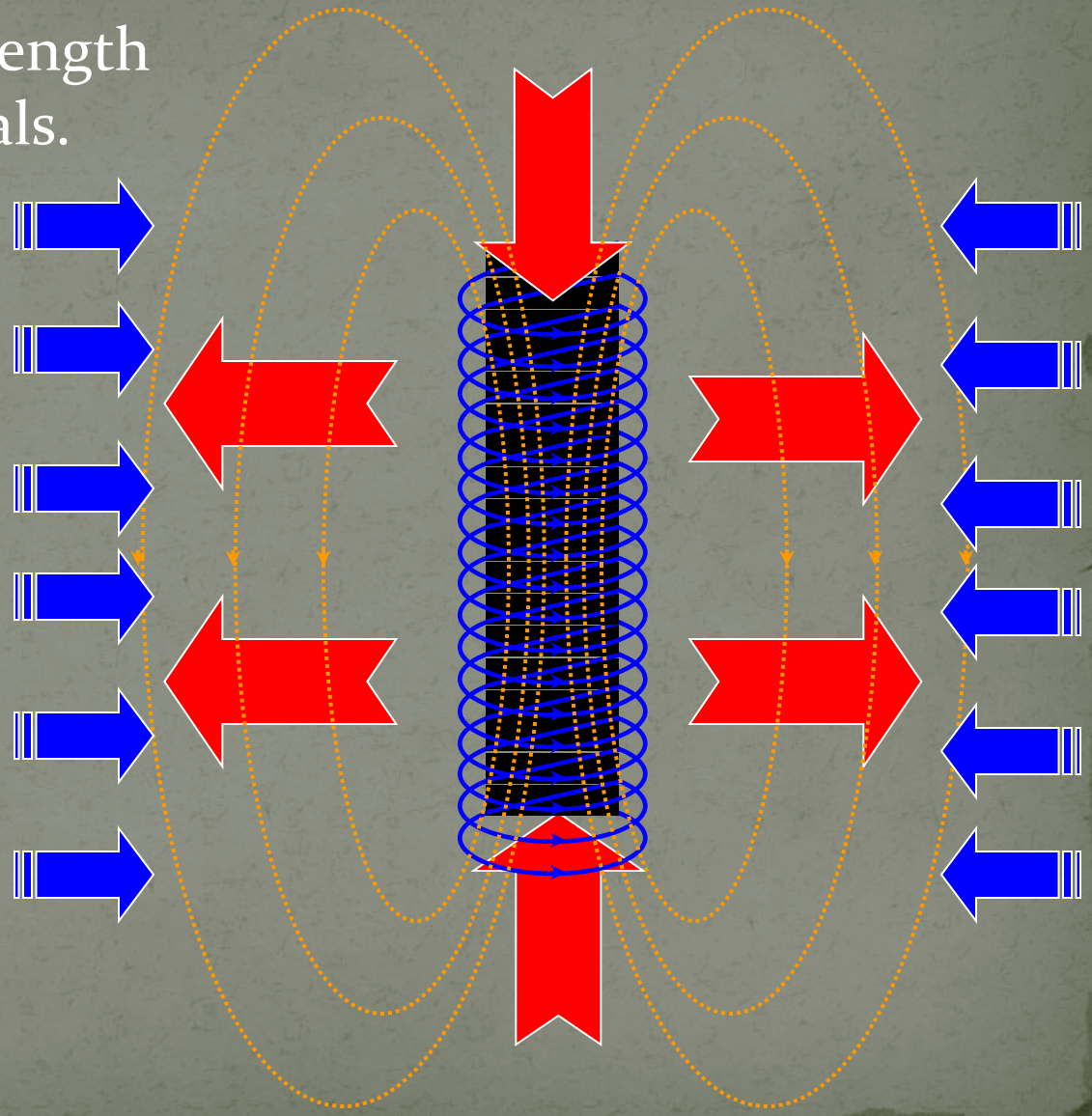
The Best way to reach fields above 100 tesla and not destroy the sample

NHMFL – Los Alamos
High Speed Video (1000 fps, 175 T shot)



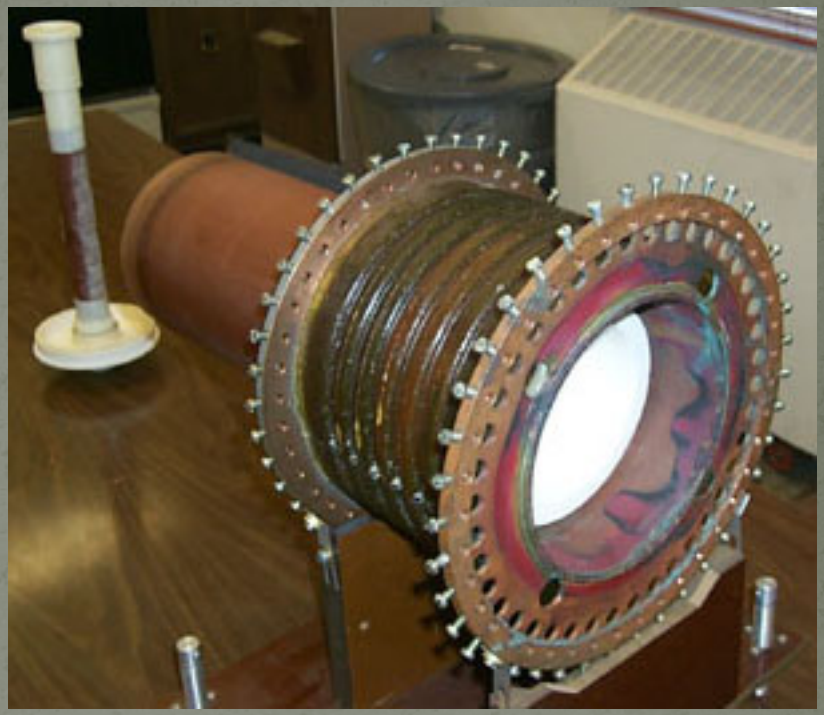
We want more FIELD

Going far beyond the strength of all reinforcing materials.



Use explosives to generate bigger forces to squeeze the magnetic field

Multi-stage flux compression.

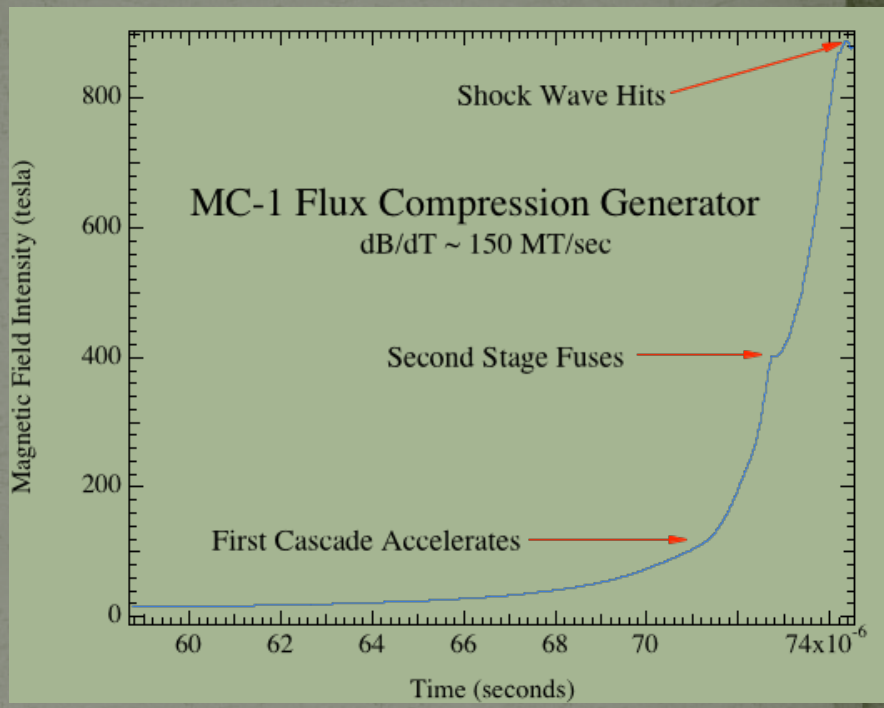


- Russian Design "MC1" FCG
- 800 to 1000 tesla
- 20 kg shaped explosive

~ 200 MJ of energy

The MC1 shot *Los Alamos*

Only way on Earth to reach these fields



You only get one chance!

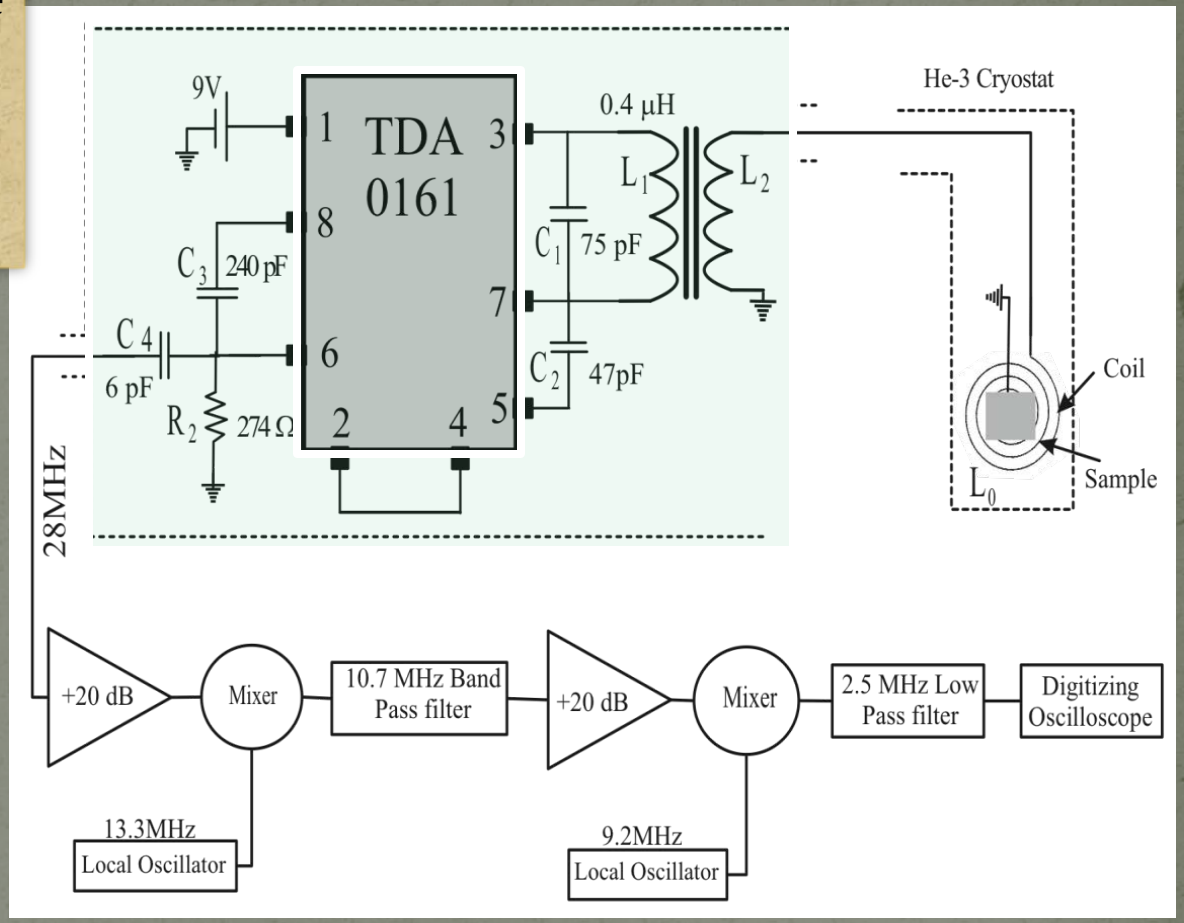
The PDO Circuit

The PDO operation is insensitive to voltages induced by pulsed magnetic fields due to its wide operating voltage range (5 to 35 volt) where TDO (~100mV).

Less sensitive to the interference from the pulsed field environment

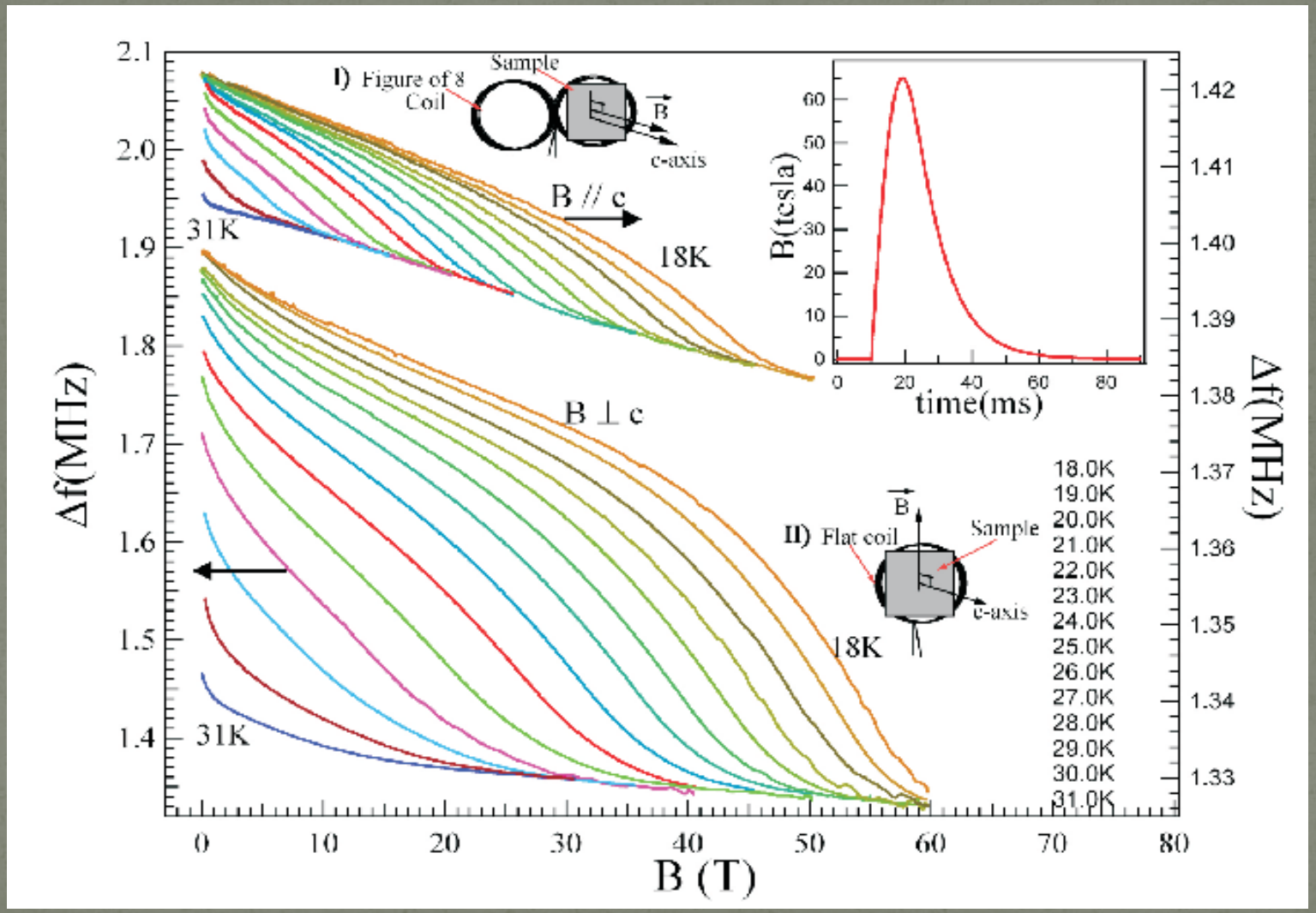
No voltage tuning is required (always Oscillating).

High stability frequency during the pulse.



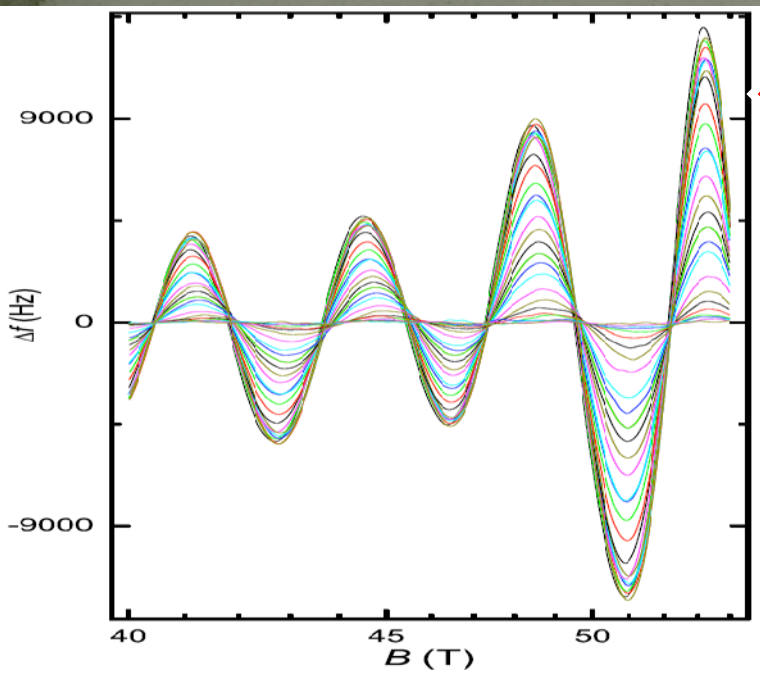
M. M. Altarawneh, C. H. Mielke and J. S. Brooks. Rev. Sci. Instrum., **80**, June 2009

PDO used for Studying superconductivity in $Ba_{0.55}K_{0.45}Fe_2As_2$

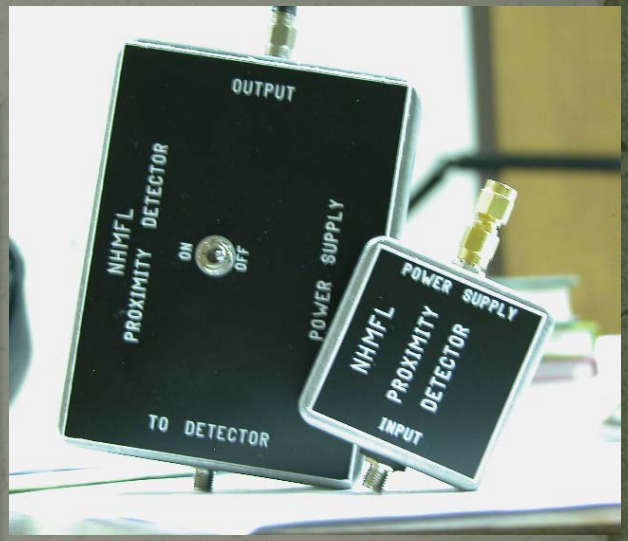


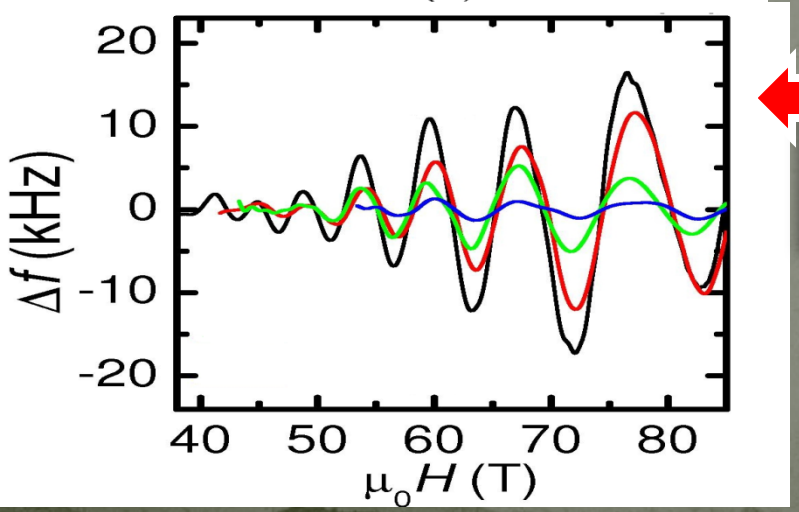
M. M. Altarawneh et al., Phy. Rev. Rapid Comm., 2008.

The PDO is used to perform rf measurements at very high magnetic fields



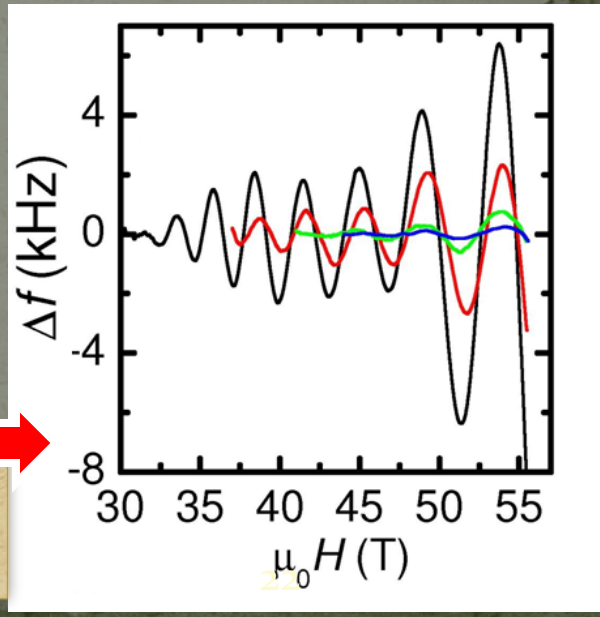
This data was collected for a High-temperature superconducting sample (*HTS*) in the 60 T long pulse magnet at LANL.



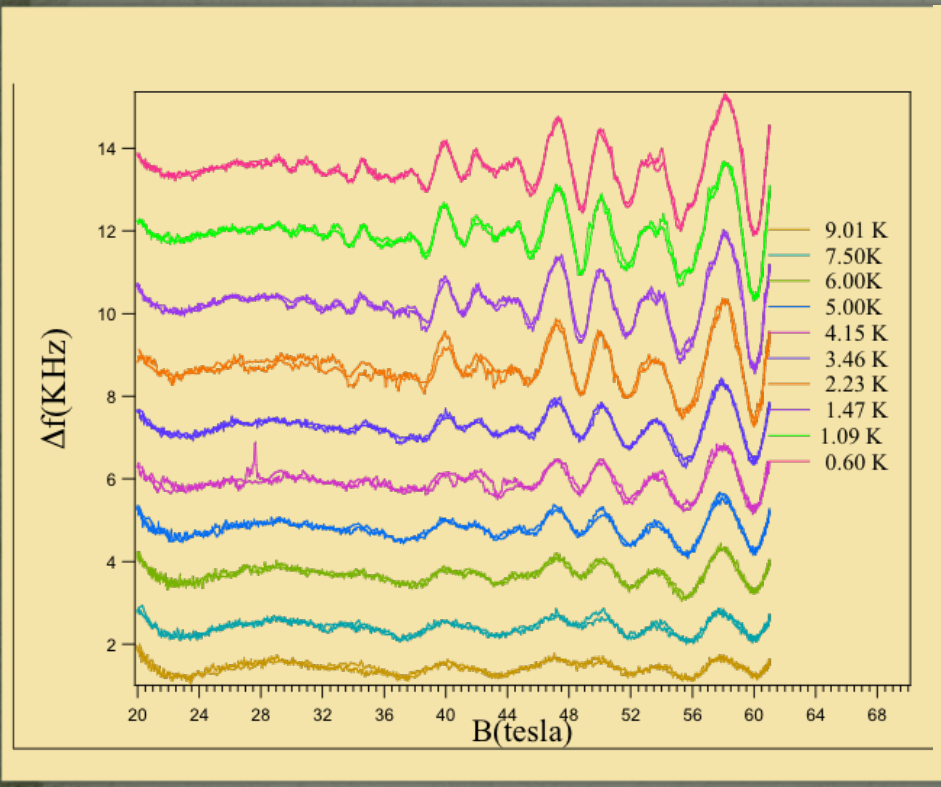


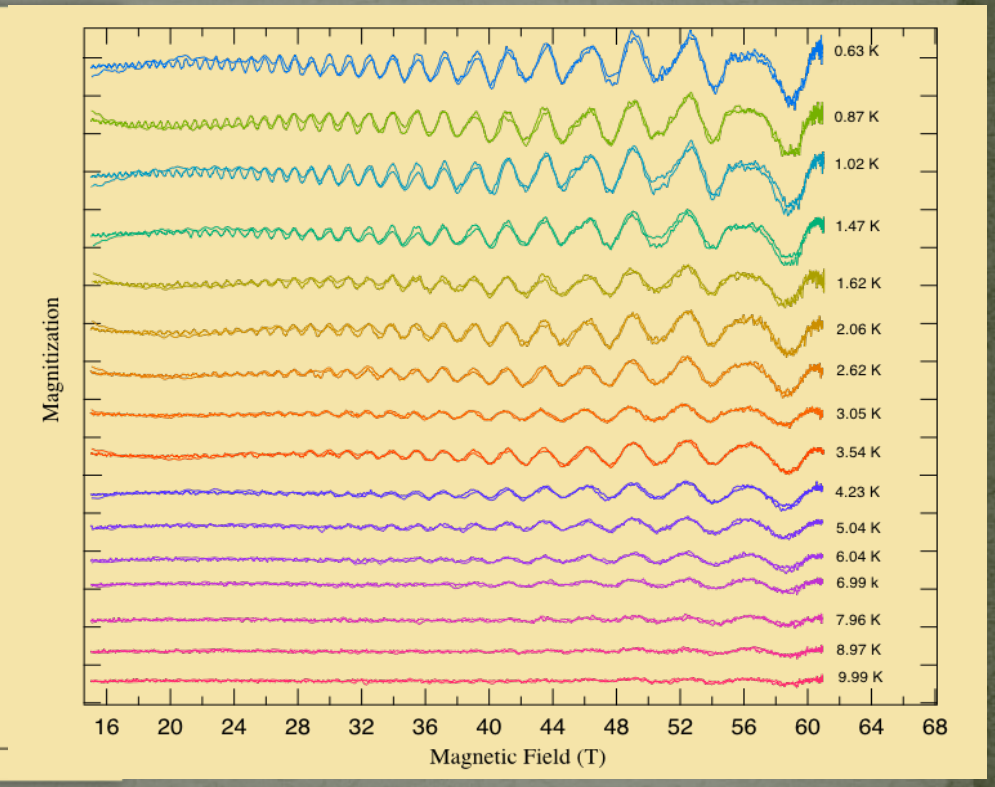
•The PDO is used in 100T magnet too.

•The PDO is used in 65T.

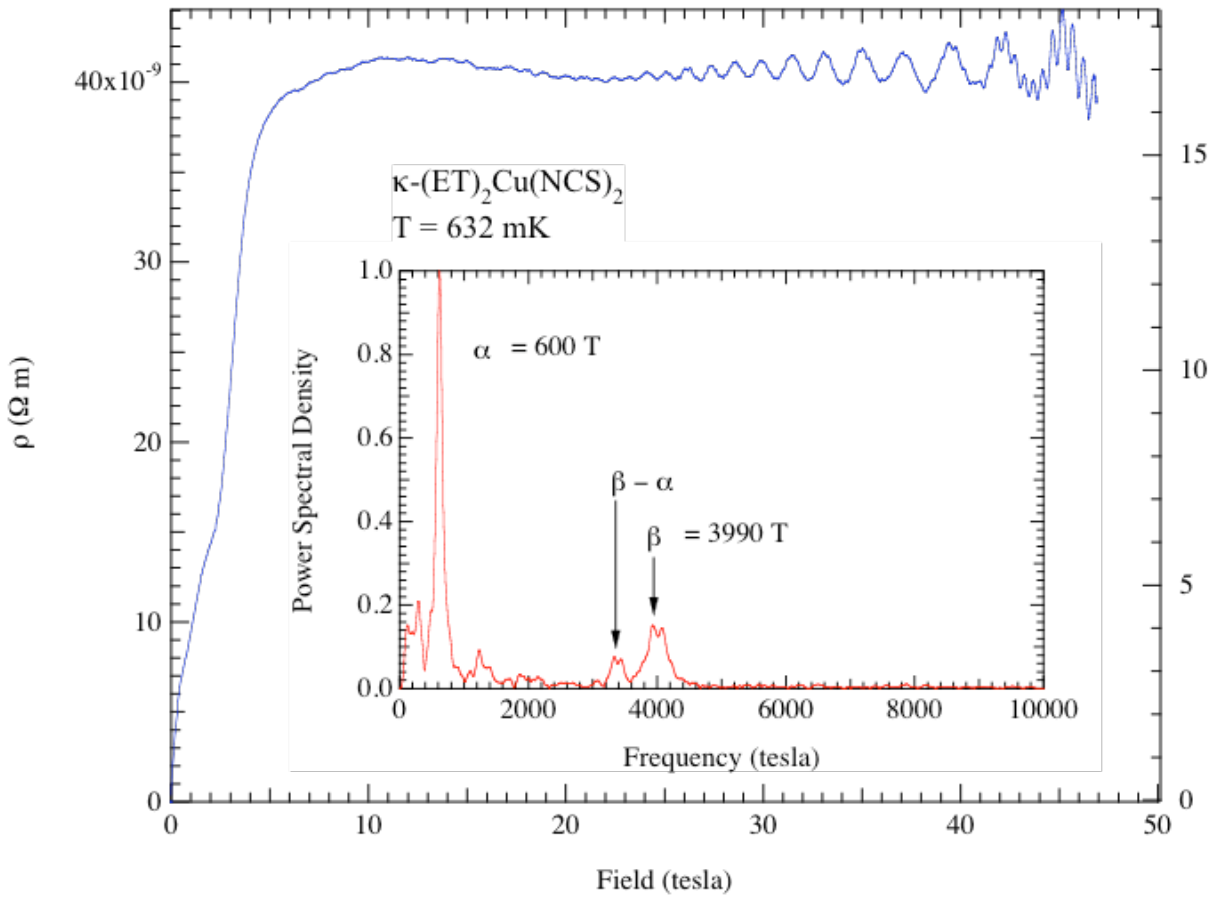


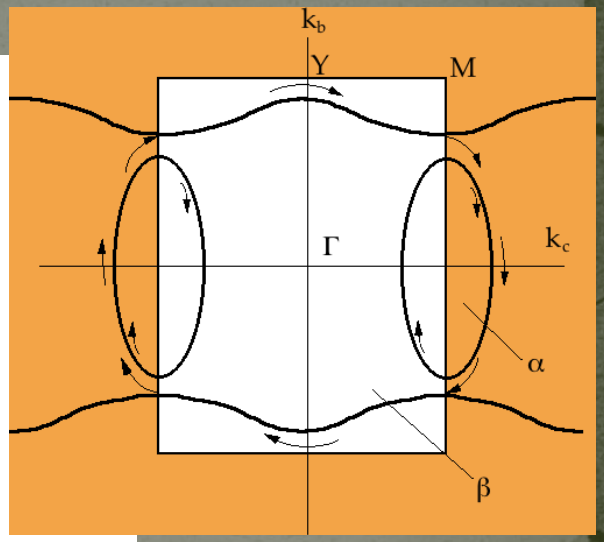
USb2 Measured with the PDO and a Magnetometer

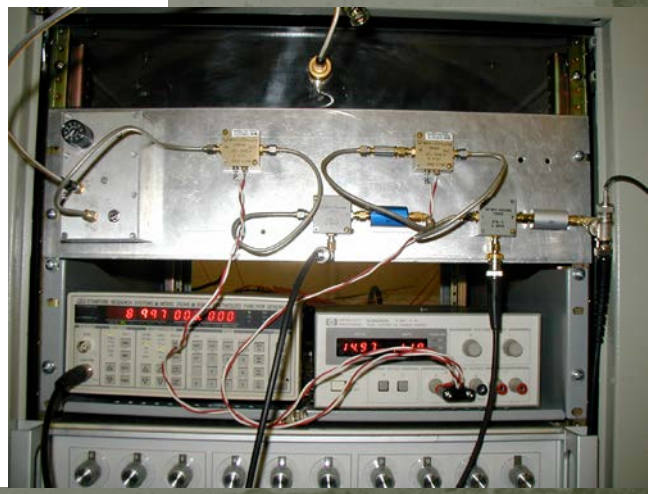




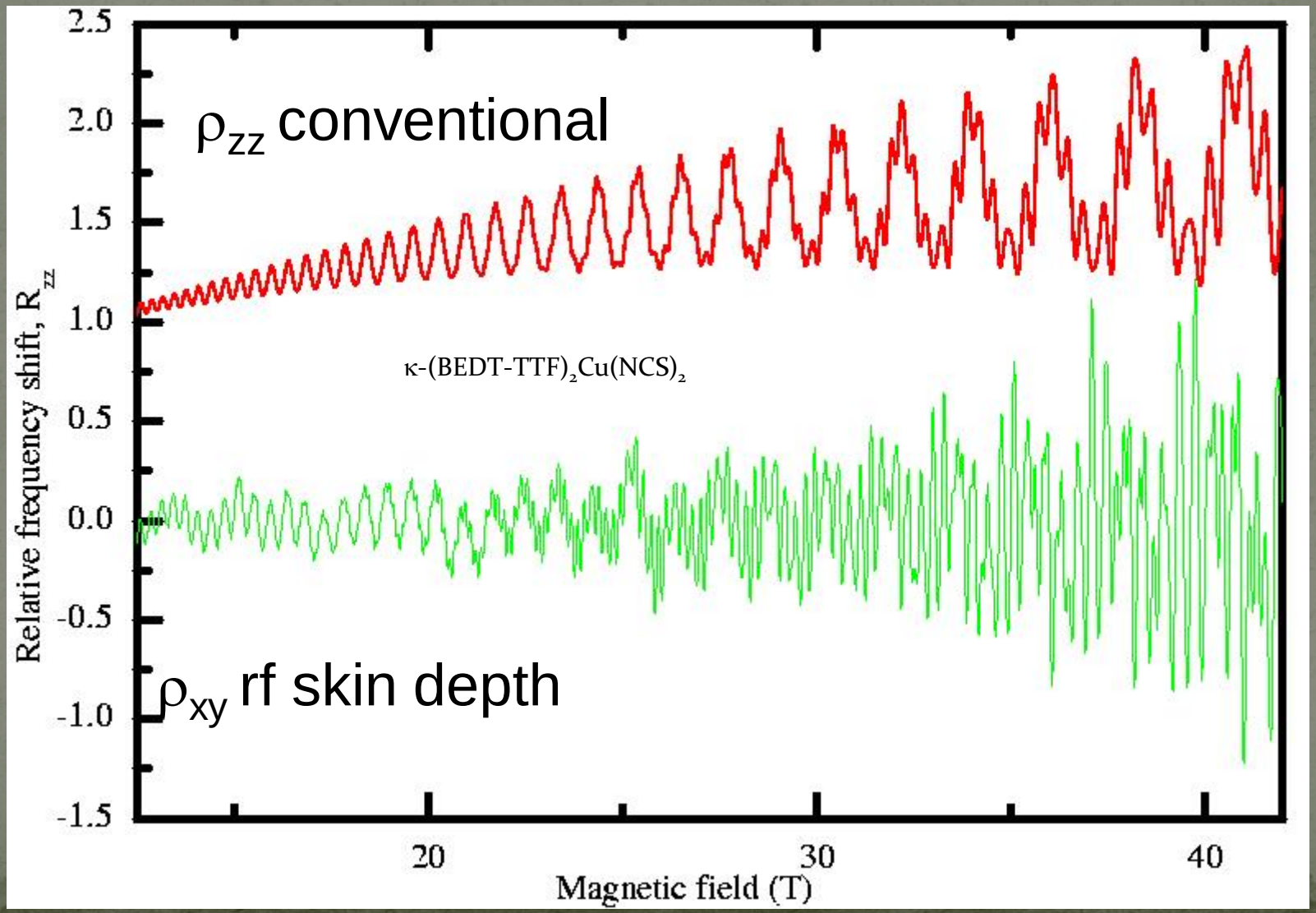
Basic Interactions Between Electrons and Magnetic Fields



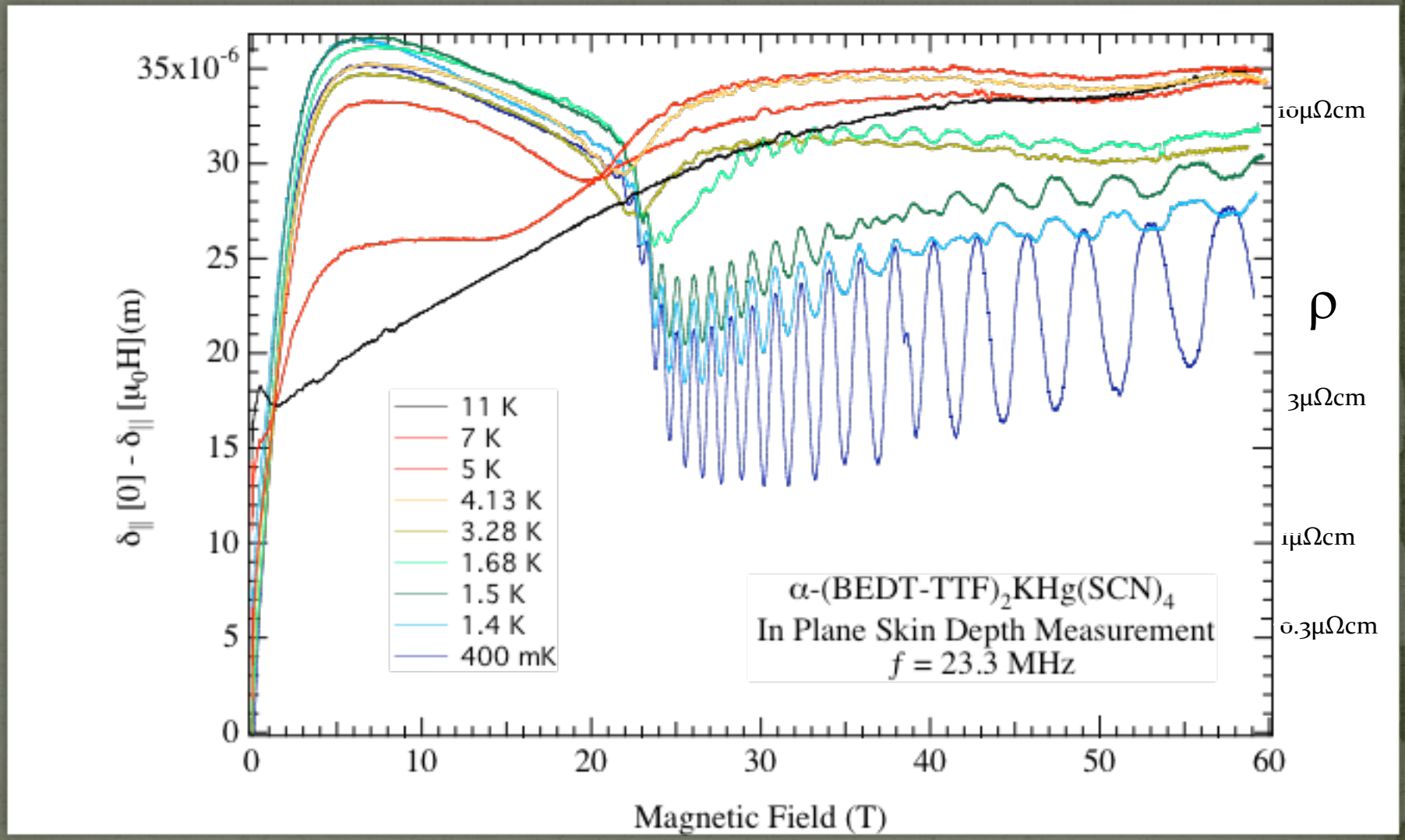




Not sensitive to weak interlayer ρ

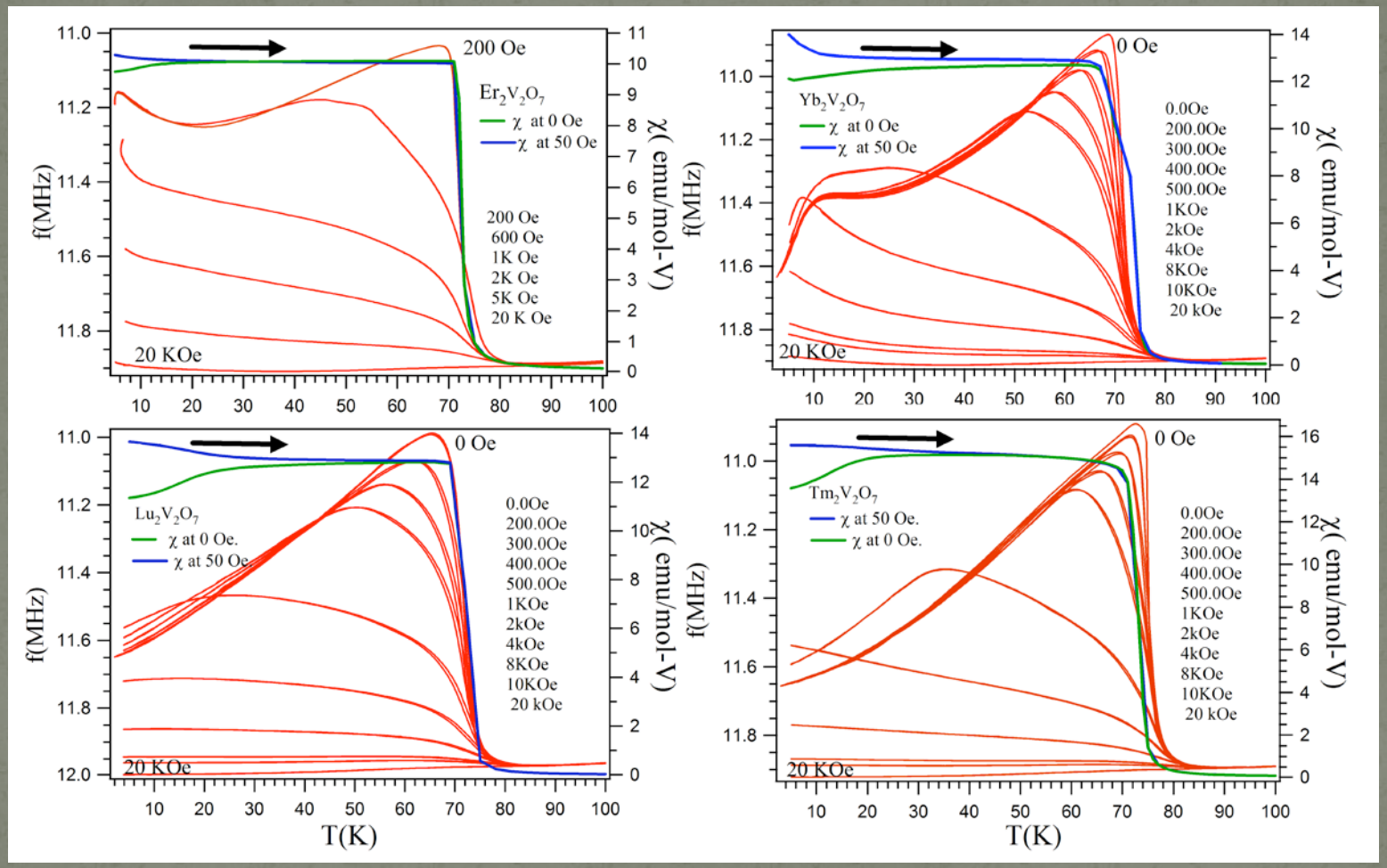


Very High Precision Measurements



C. H. Mielke, N, Harrison and J. Singleton

Can Detect Magnetic Transitions…



Summary

- The TDO or PDO can be a very sensitive and robust way to measure conductivity or magnetic signatures
- The PDO(+) is cheaper, easier, and more robust than the TDO (PDO is better for pulsed fields)
- The TDO (+) has less phase noise than the PDO and can be somewhat more sensitive

- Thanks to Moaz Altarawneh!
- See M. M. Altarawheh, C. H. Mielke, and J. S. Brooks, RSI, 80, **066104 (2009)**