Vibration Measurements in Superconducting Quadrupoles

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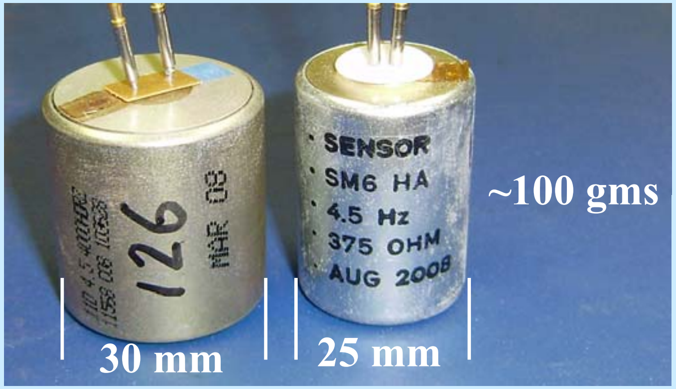
Introduction

- Issue of vibrations in the final focus quadrupoles is of considerable importance for machines with nm-size beams.
- Superconducting magnets can potentially have vibrations driven by the cryogenics, making it essential to study vibrations under cold conditions.
- Such measurements are non-trivial due to very low temperatures of the cold mass, limited space available in the cryostat for instrumentation, etc.
- Considerable work has been done at BNL over the last several years to study vibrations of cold masses.
- Some of the more recent work is presented here.

Tools Available at BNL

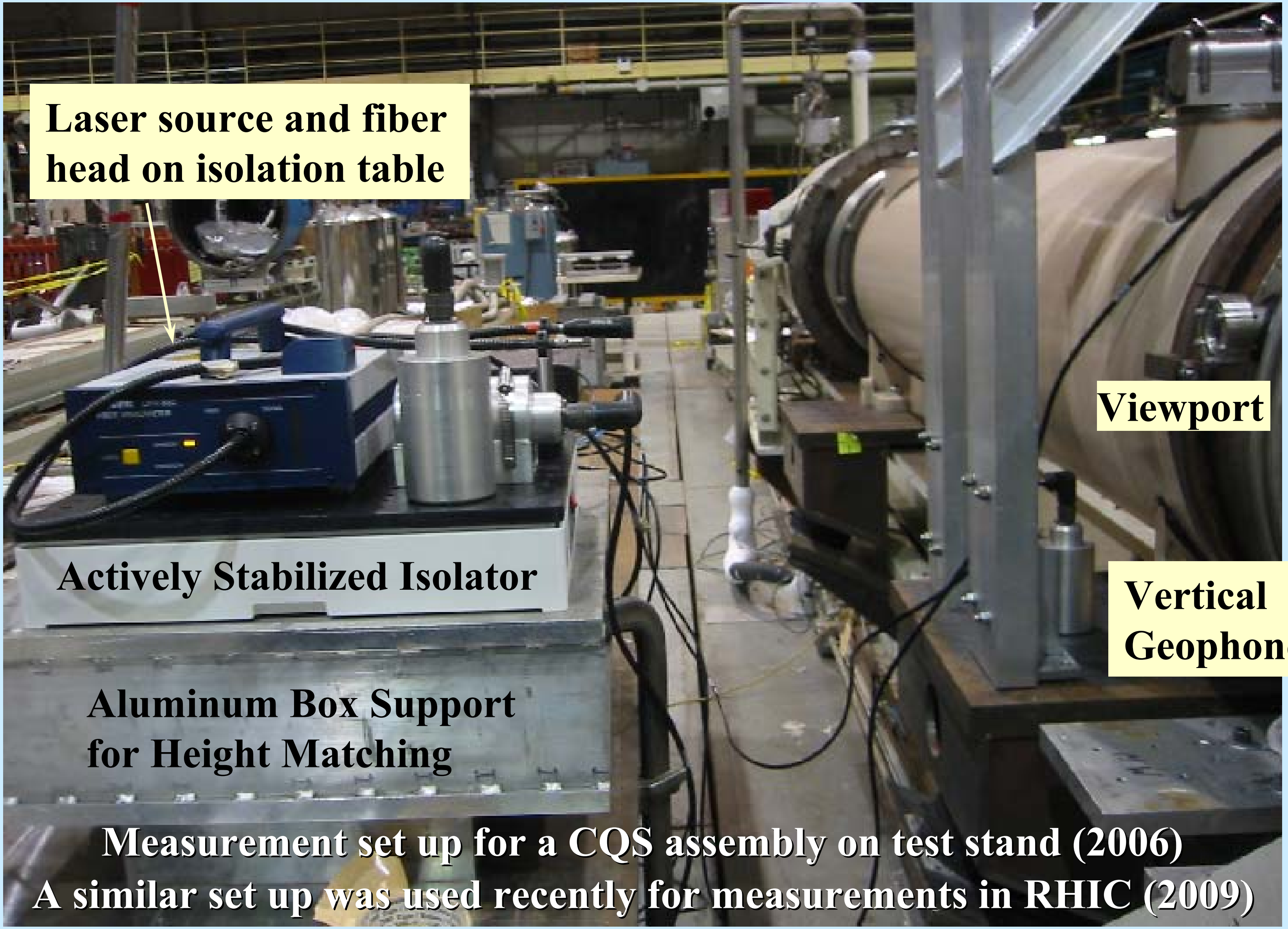
1 Hz Geophones (L4): High sensitivity; Easy to calibrate without external reference; Can be used to benchmark other techniques. Very bulky; can not work cold, or in magnetic fields.



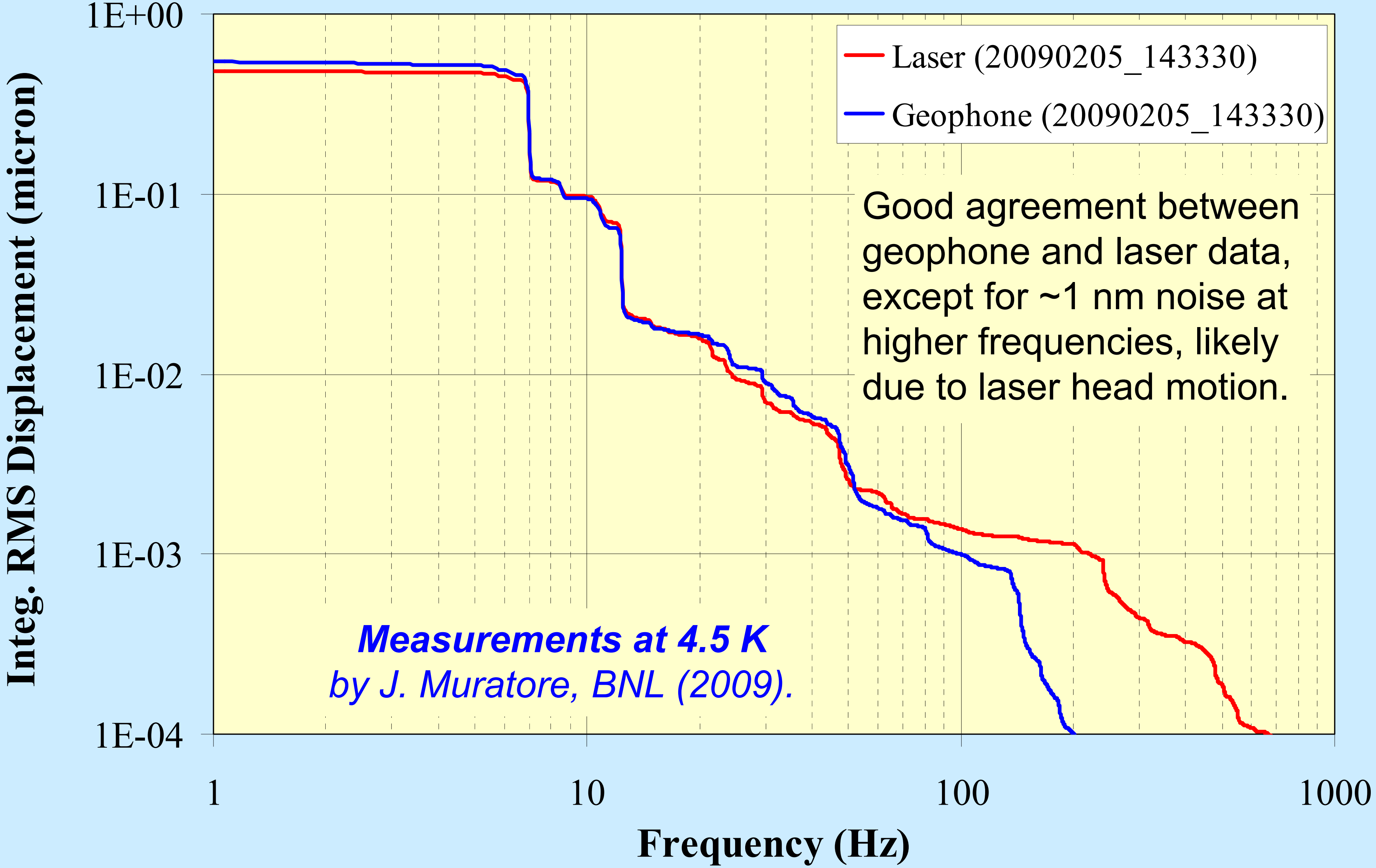
4.5 Hz Geophones: SM6 & GS11(V) can work at LHe temperatures, relatively small. Can not work in magnetic fields; still need significant space in the cryostat.
(Used at DESY; Recently installed in RHIC to measure IR quadrupole vibrations.)

Dual beam fiber optic Laser Doppler Vibrometer: High sensitivity, Non-contact, absolute or differential measurements. Tested extensively at BNL.
Laser heads must be stabilized; Line of sight with retroreflector tape on object needed.

Laser Vibrometer Setup for RHIC Quad



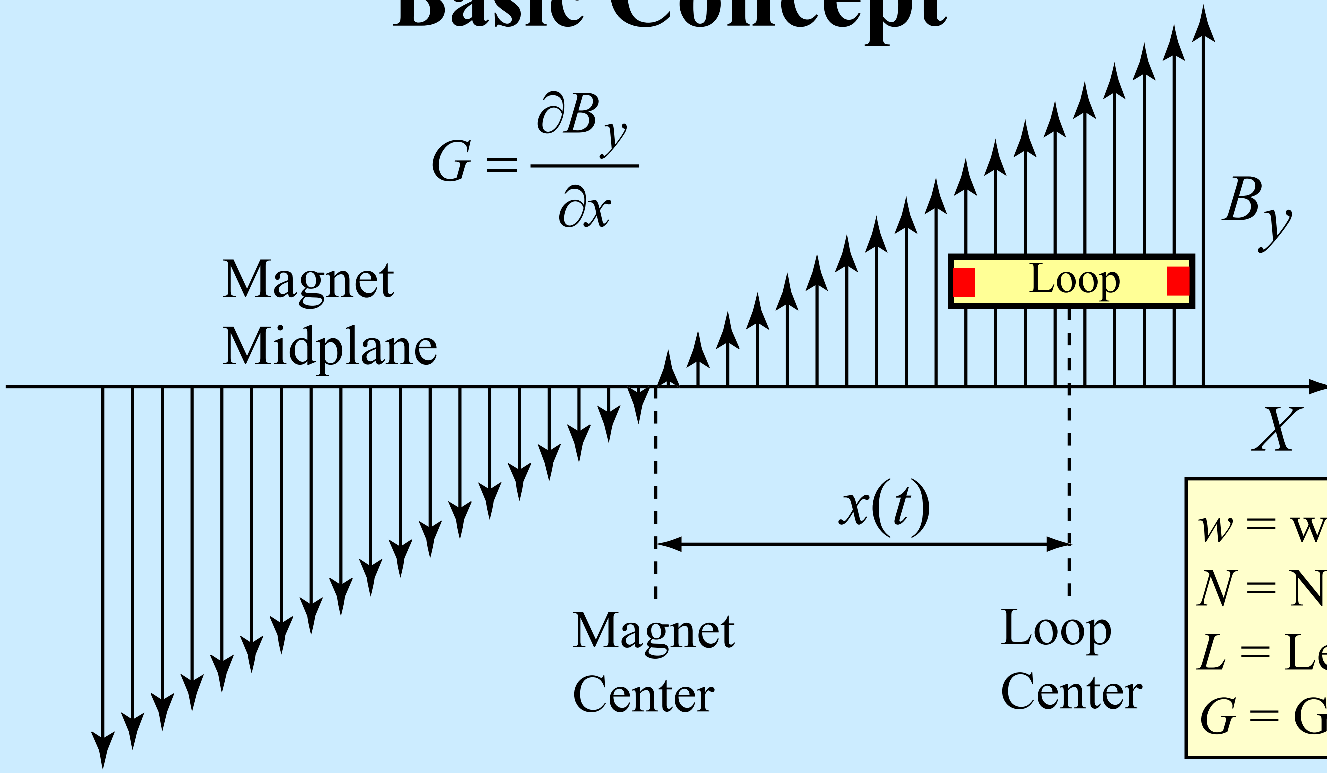
Laser Vibrometer Vs Geophones in RHIC IR



Measuring Quadrupole *Field Center* Motion

- Place a flat loop of wire in the quadrupole aperture.
- The amount of flux linked through the loop is proportional to the offset of the loop center from the quadrupole field center.
- A relative motion of the field with respect to the loop center will produce a change in flux, and hence a voltage signal.
- Analysis of the voltage signal provides the velocity spectrum.
- Two, or more, loops can be used to monitor both horizontal and vertical motion.

Basic Concept



w = width
N = No. of turns
L = Length
G = Gradient

$$V(t) = wNLG \cdot \dot{x}(t)$$ (assuming G is constant)

CERN Coil: 2500 turns; 13.5 mm x 125 mm; $wNL \sim 4\ \text{m}^2$
$V(t) \sim 400$ V/(m/s) at 100 T/m => More than a Mark L4 geophone

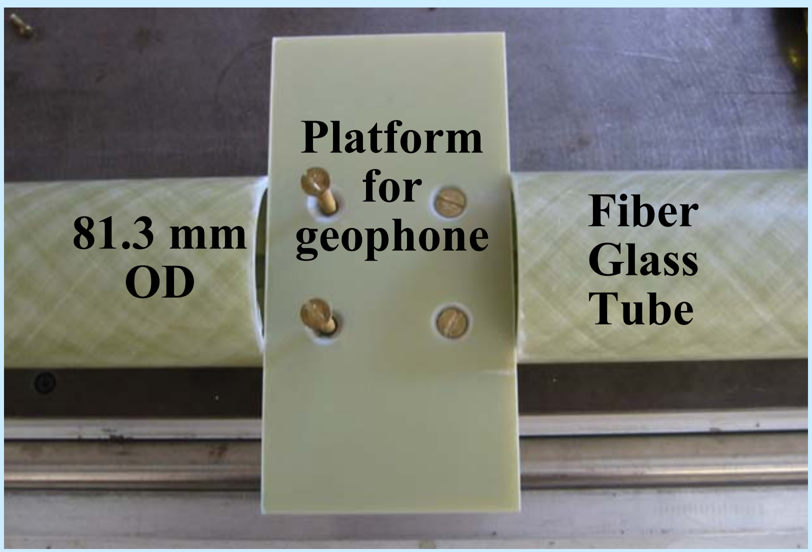
It is not easy to make such a coil with small enough wire bundle cross section!
(Help from CERN is acknowledged.)

Practical Difficulties to be Solved

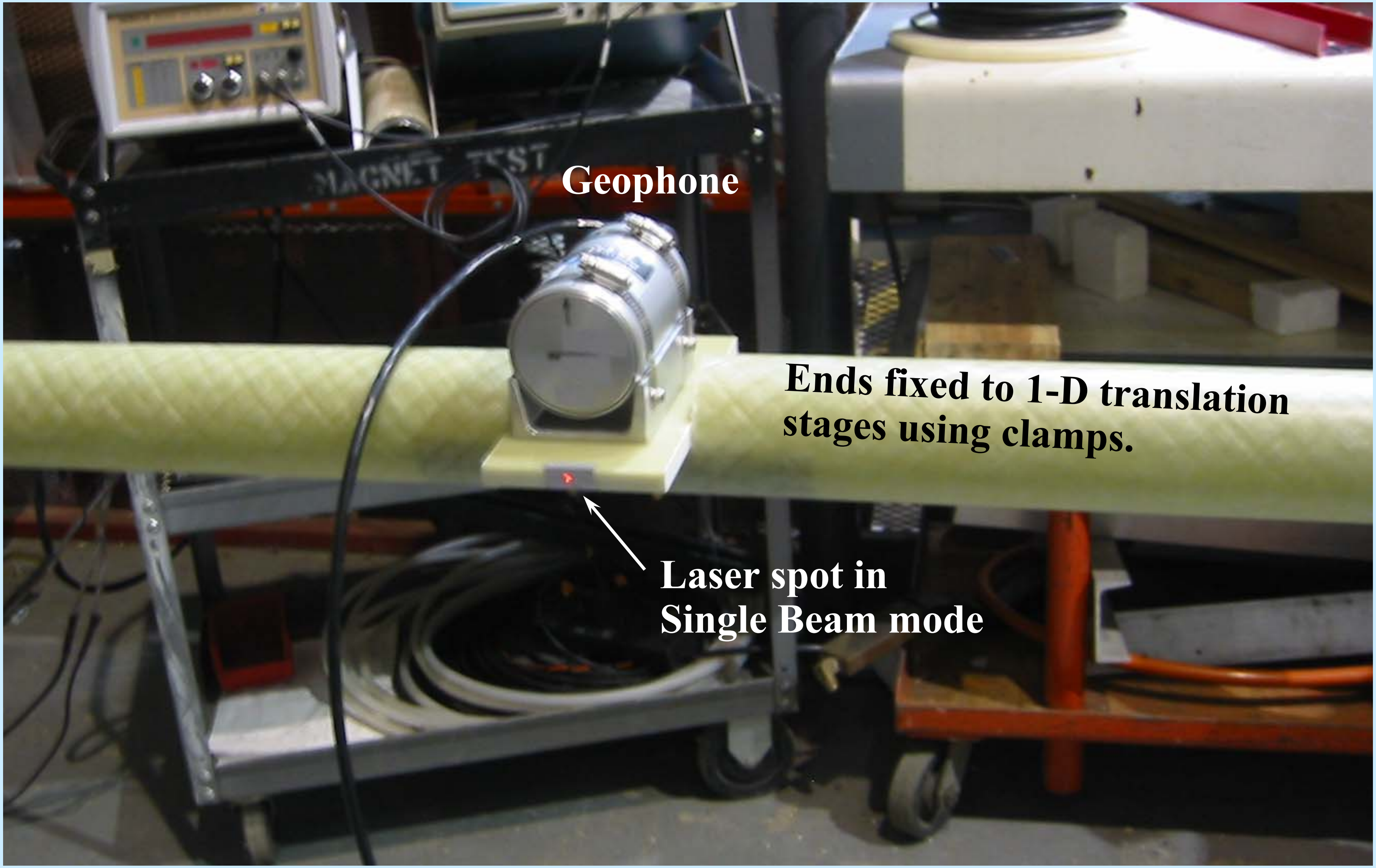
- Signal may also be produced if the quadrupole field changes with time, e.g. due to power supply ripple.
- Signal due to ripple may drown the signal due to field motion if the loop is not well centered.
- Signal only tells the relative motion of the pick up coil and the field. How does one know where the pick up coil is?
- Minimize, and characterize, the motion of the pick up coil $\Rightarrow$ Most challenging task!
- Issues of signal strength Vs. noise for very small motion ~ nm.

Vibration Pick-up Coil Assembly

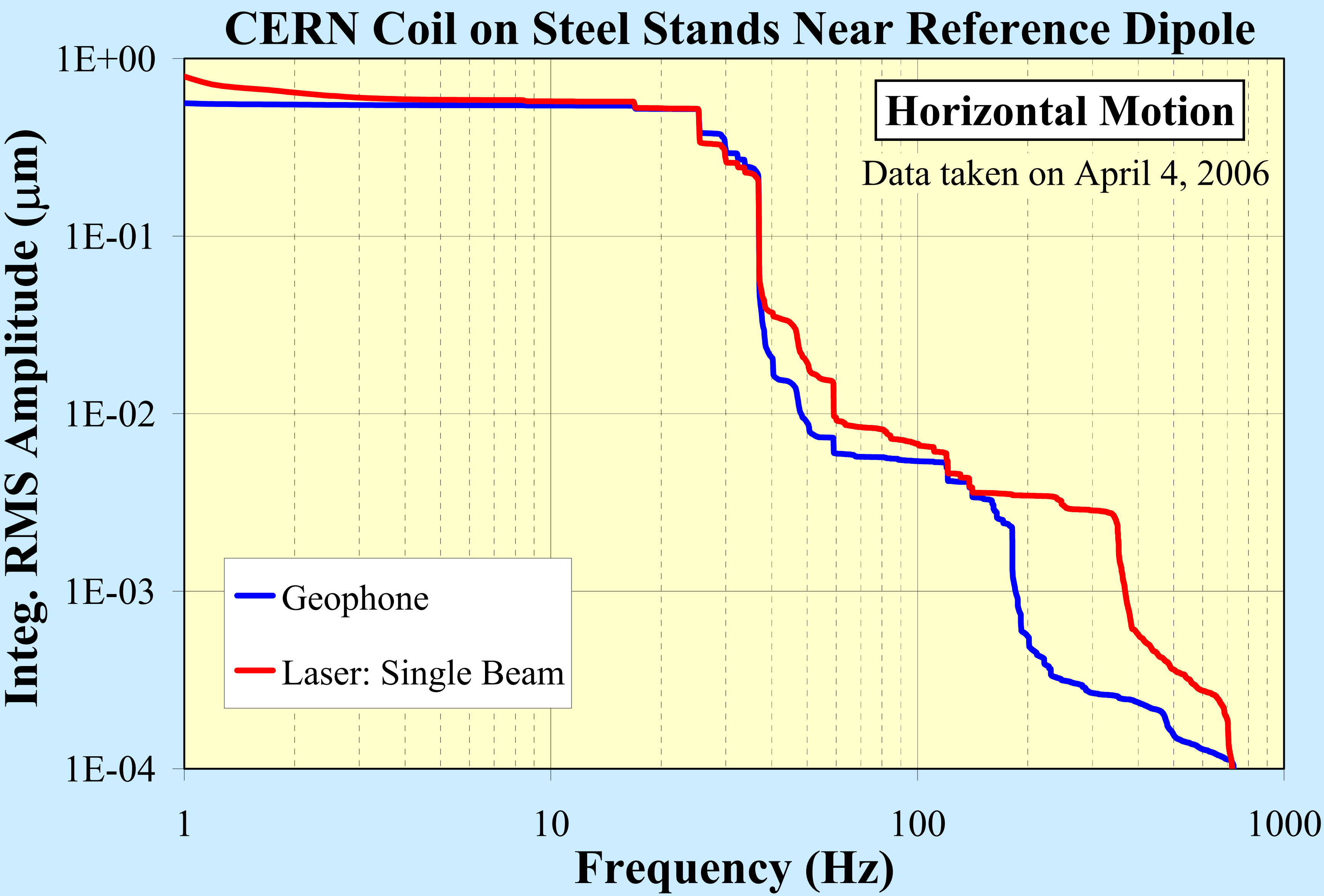
2500-turn coil from CERN



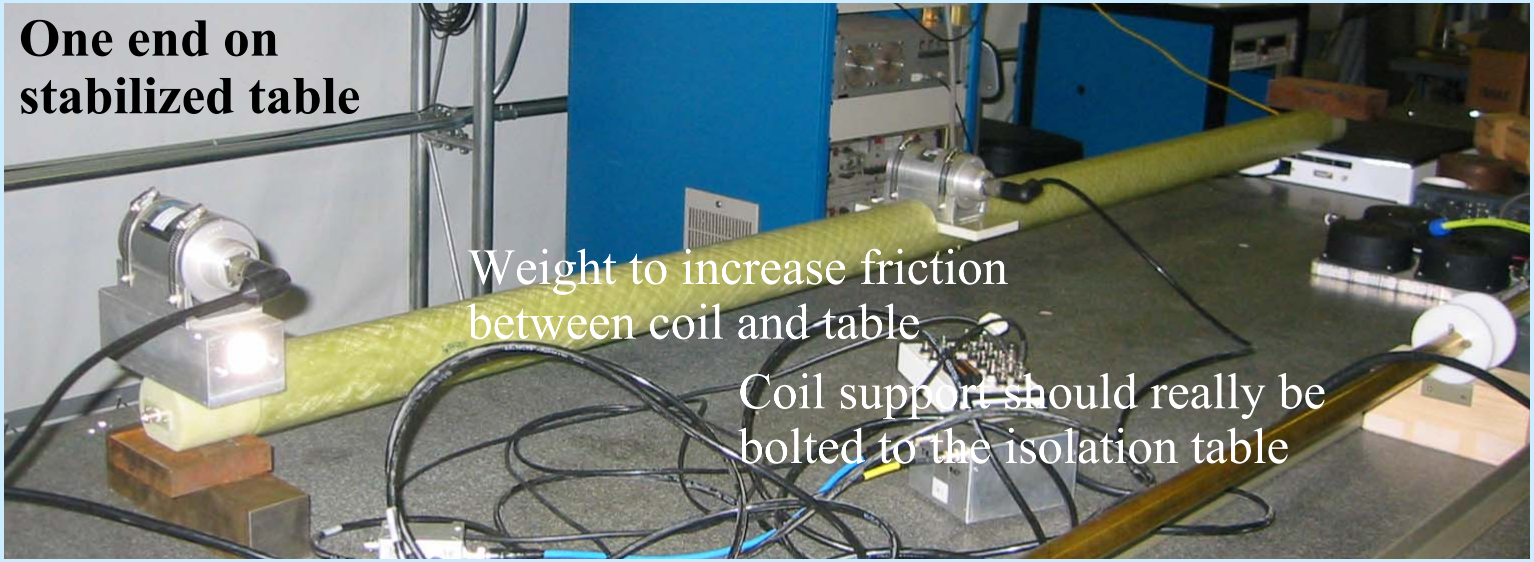
Pick-up Coil Characterization

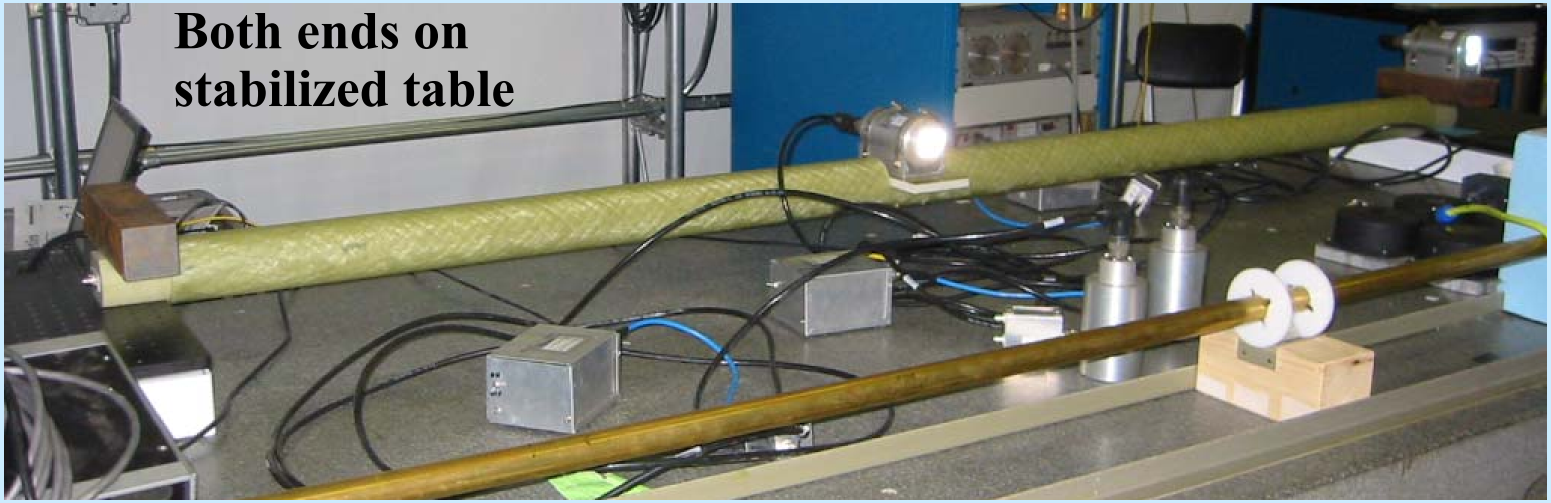


Pick-up Coil Characterization

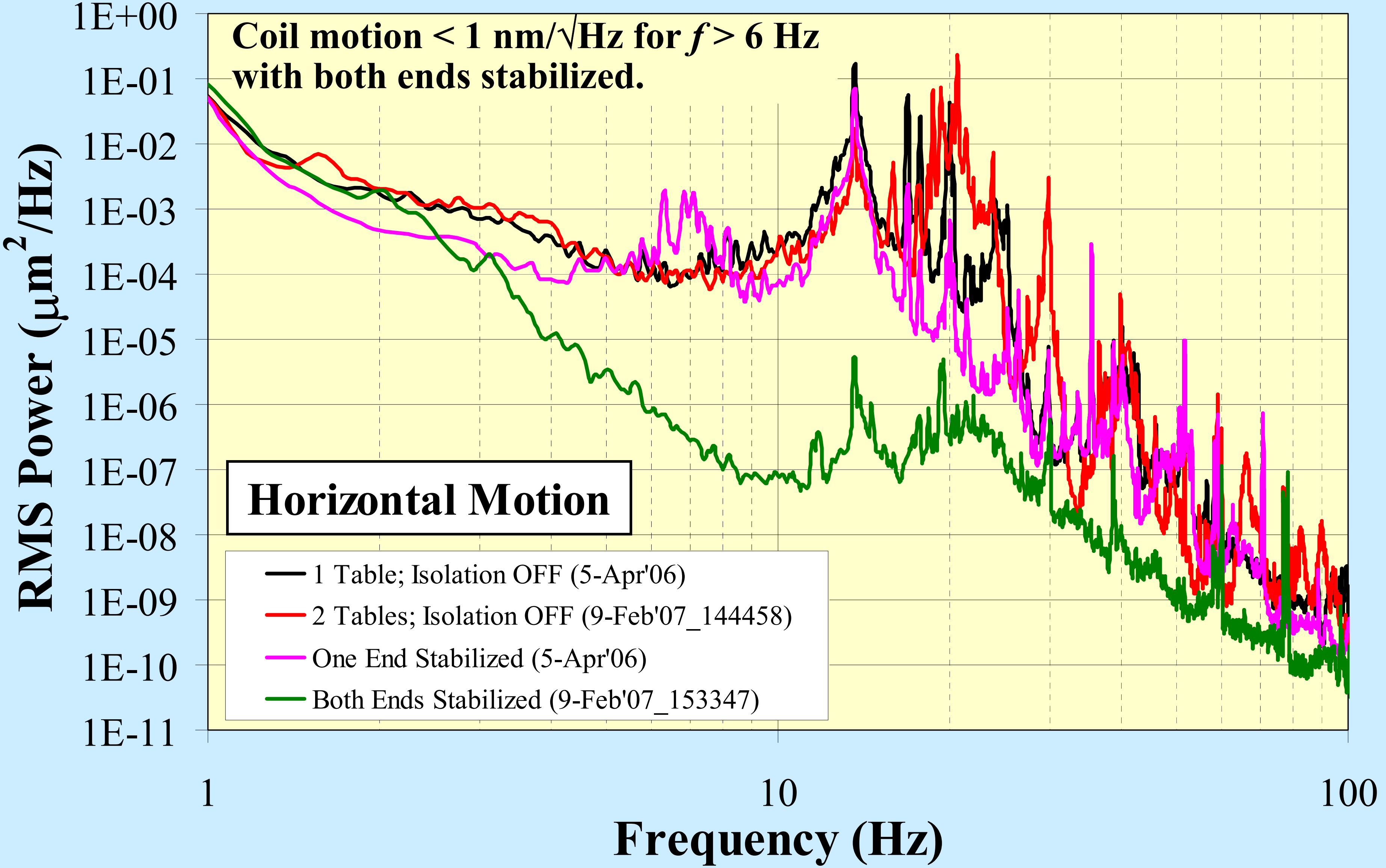


Pick-up Coil Stabilization (Crude!)

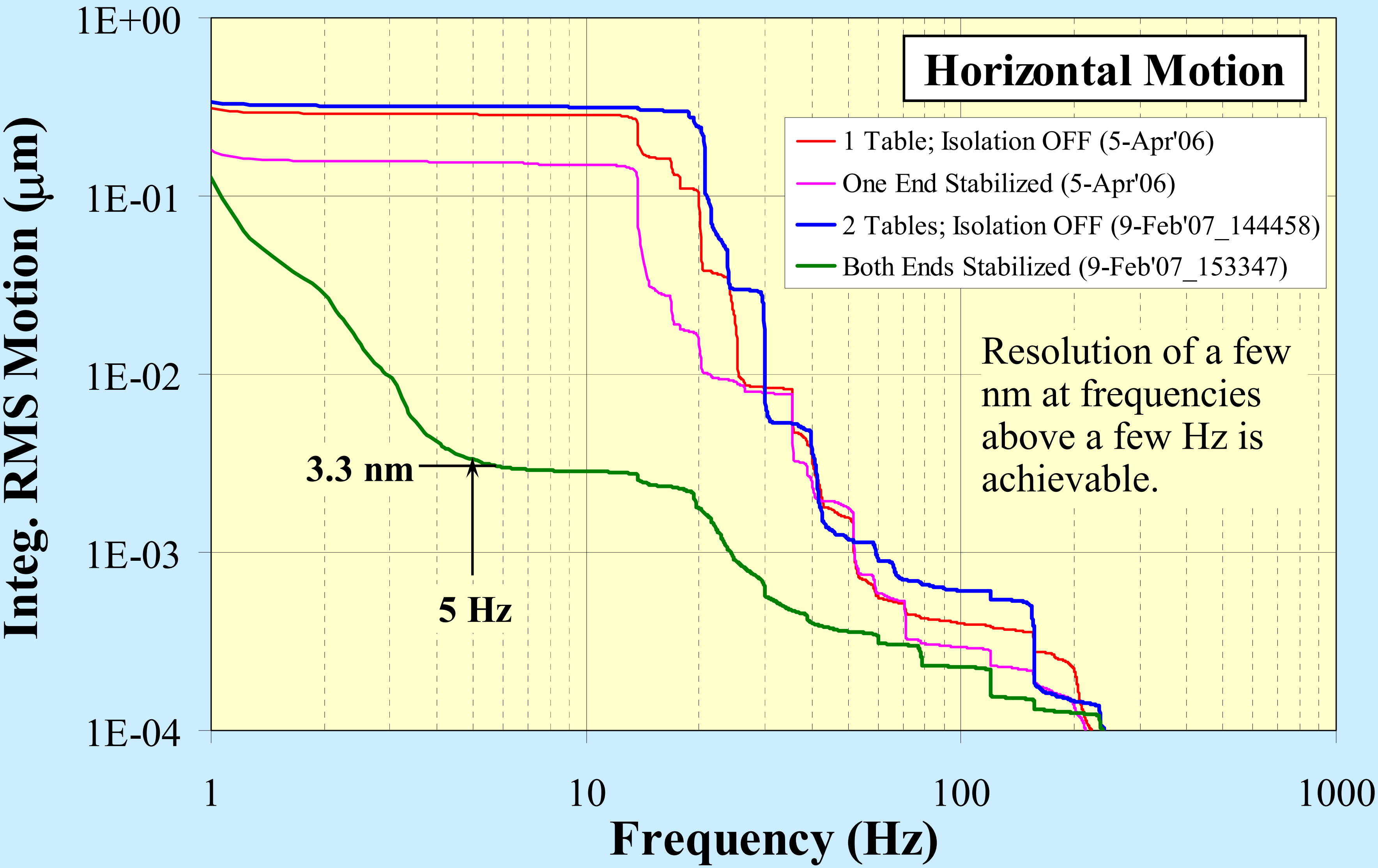




2500-turn Coil Motion With & Without Stabilization



2500-Turn Coil Motion With & Without Stabilization



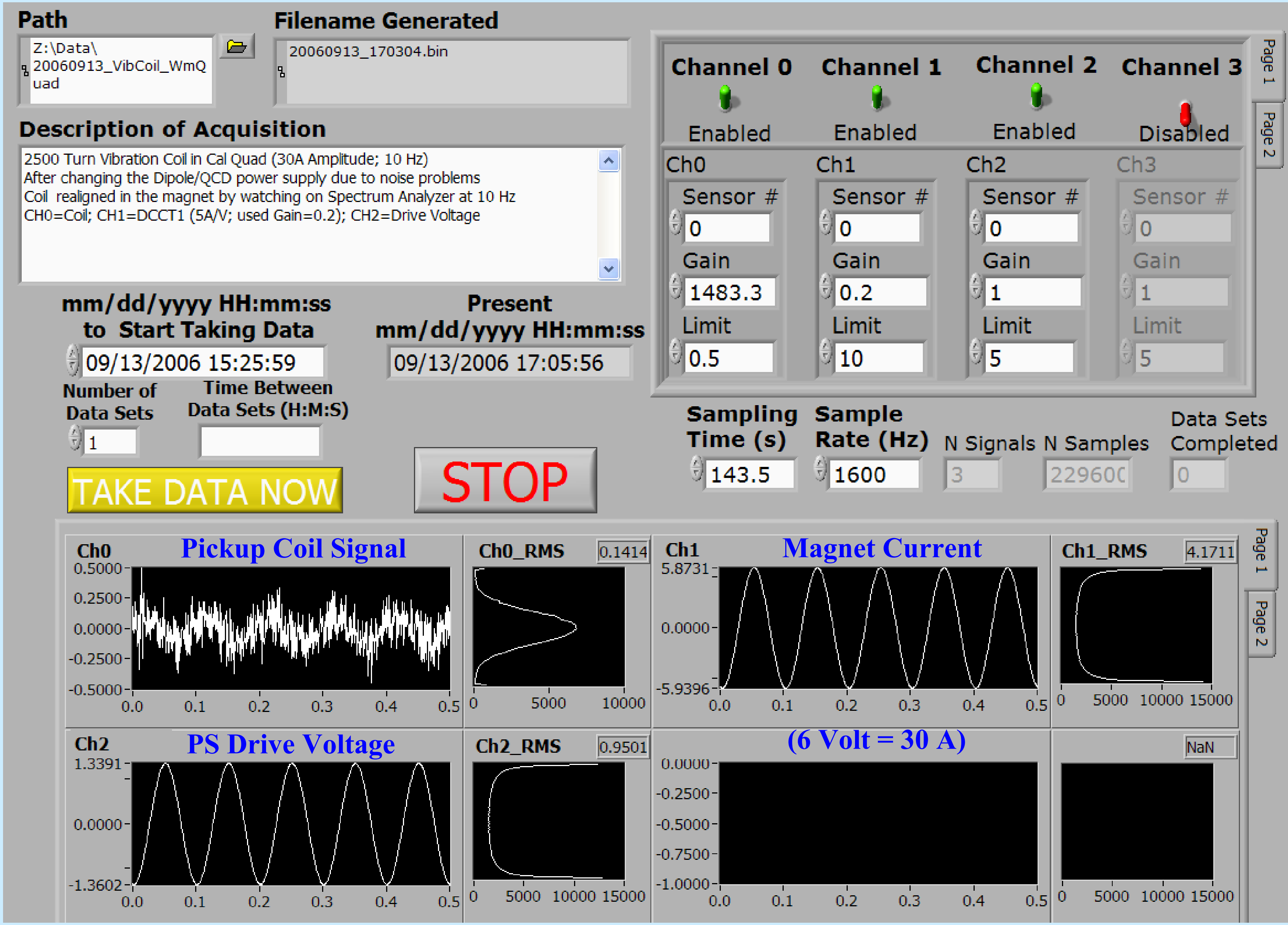
Alignment in Quad & Noise Studies

- The probe was installed in a room temperature, large bore quadrupole, normally used for calibration purposes at BNL.
- The probe was installed, ***without any stabilization***, on steel supports and a rather crude moving mechanism to align the coil.
- The magnet was excited at low fields with sinusoidal current (30 A; 0.1 T/m amplitude). This large "ripple" can be picked up if the probe is not centered in the quad.
- The pick up signal under AC excitation was used to align the probe in the quad.
- Measurements were made at 30 A DC excitation, and at 0 A to study noise.

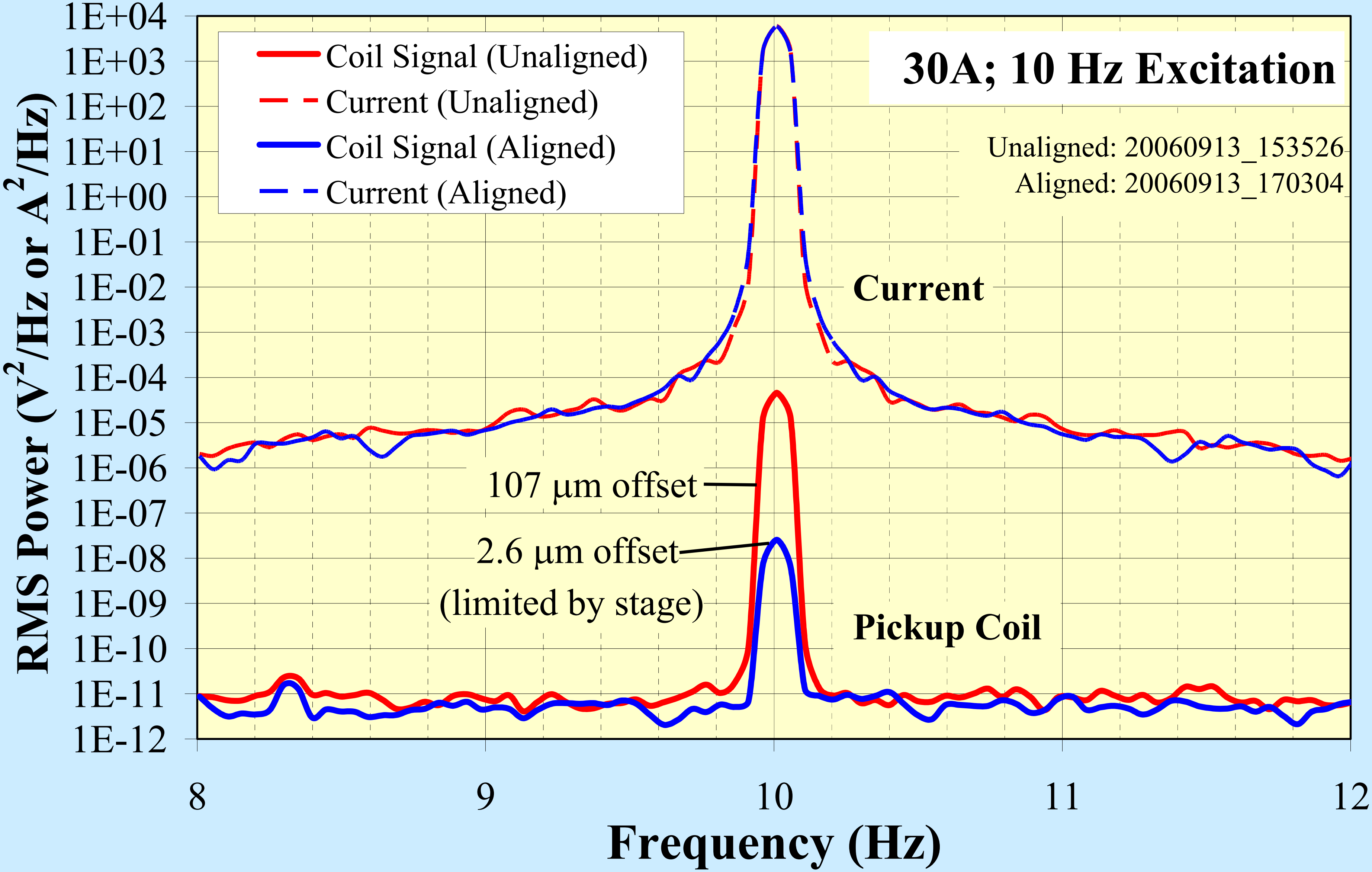
Pick-up Coil Setup in Room Temp. Quad

30 A Excitation at 10 Hz (Coil not aligned)

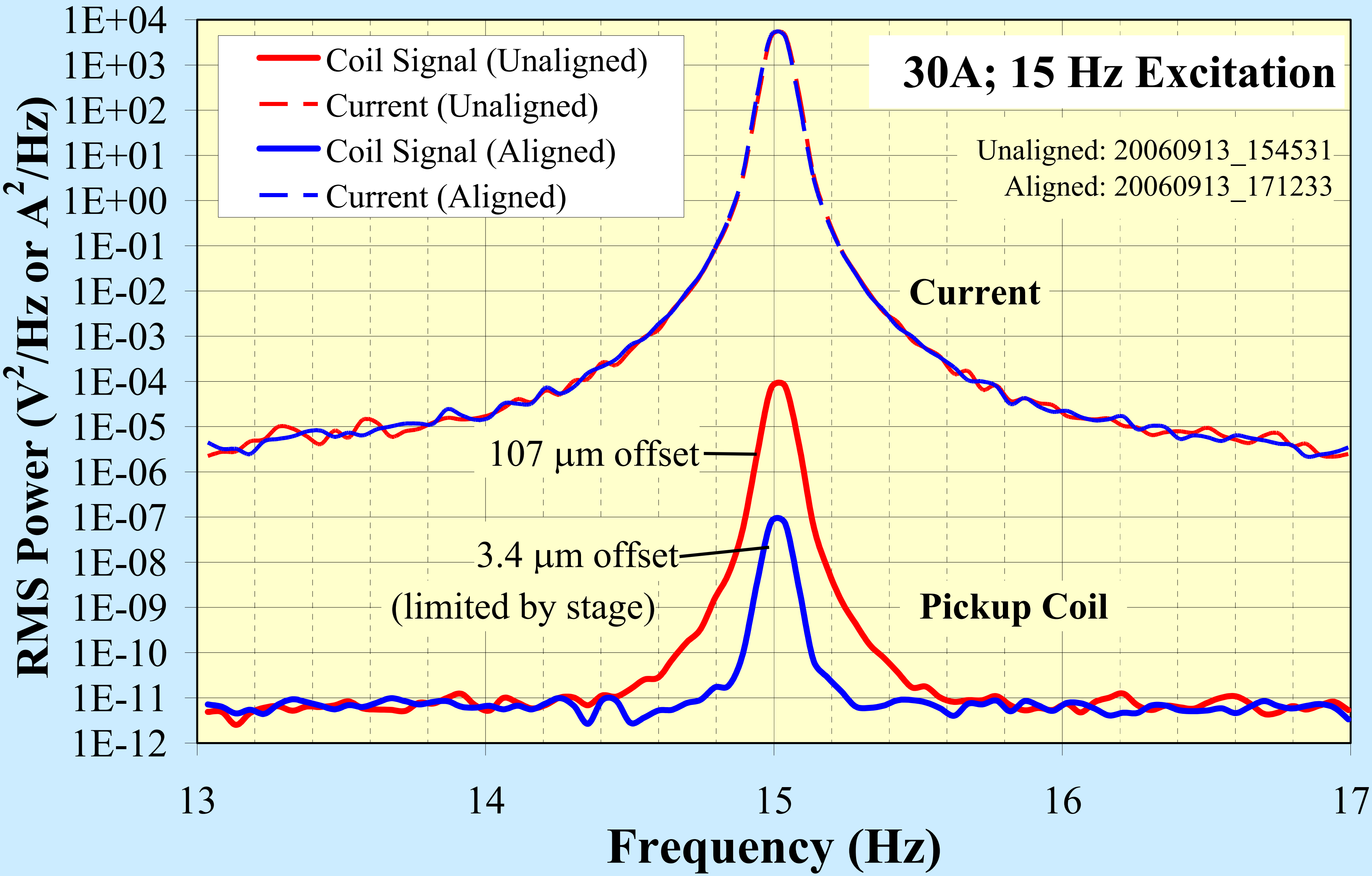
30 A Excitation at 10 Hz (Coil aligned)



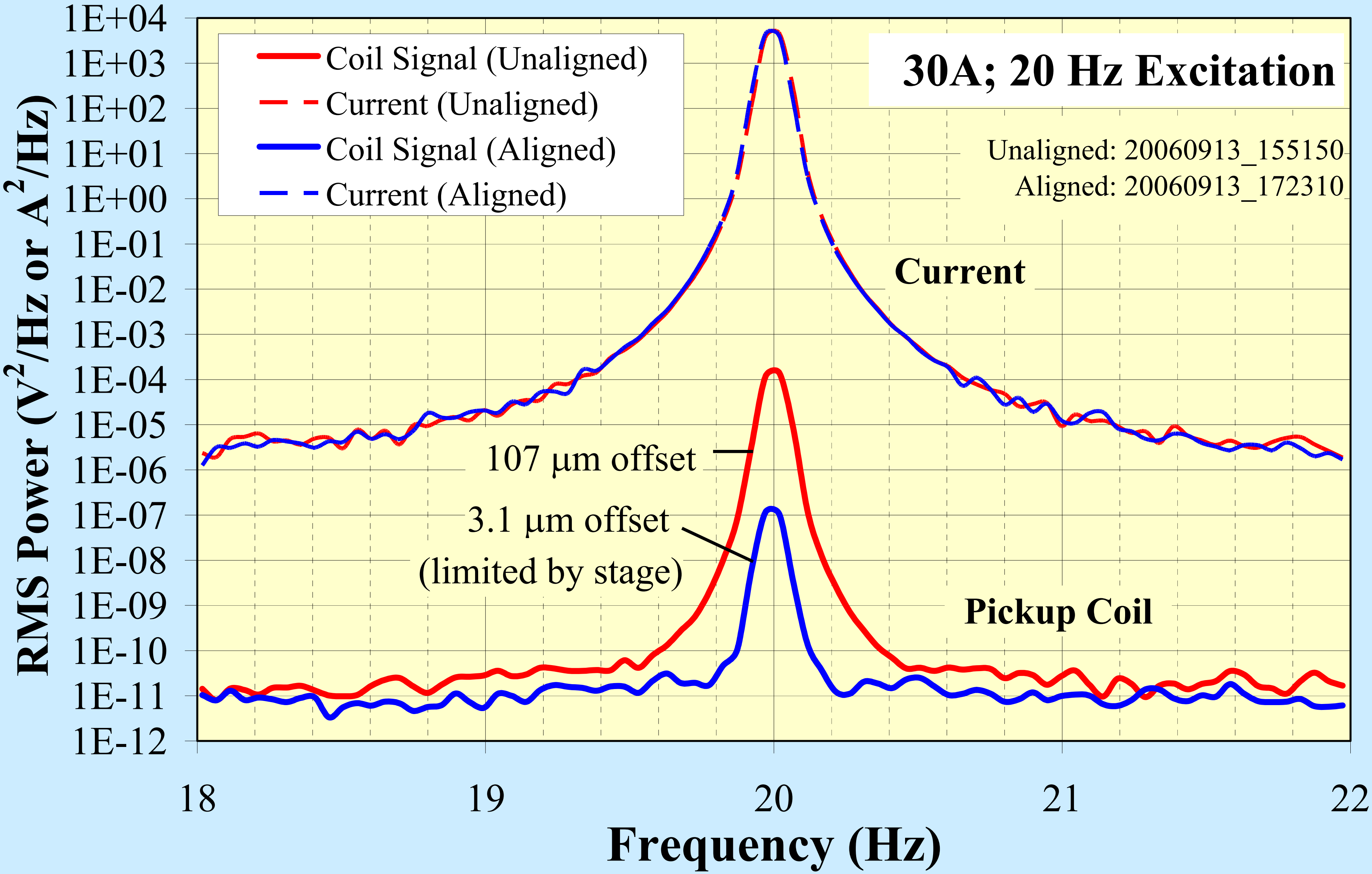
Current and Pick Up Coil Spectra in Cal. Quad



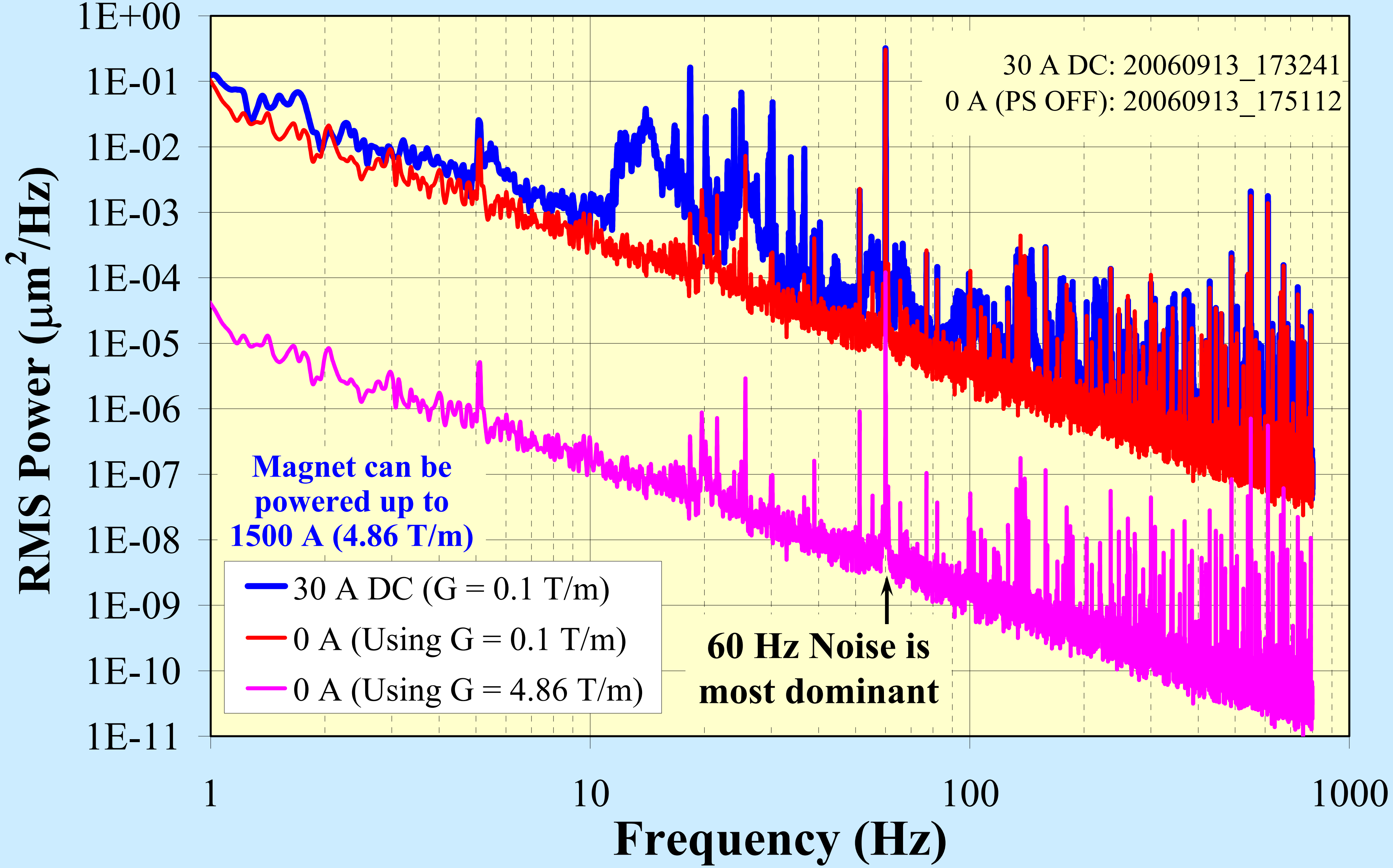
Current and Pick Up Coil Spectra in Cal. Quad



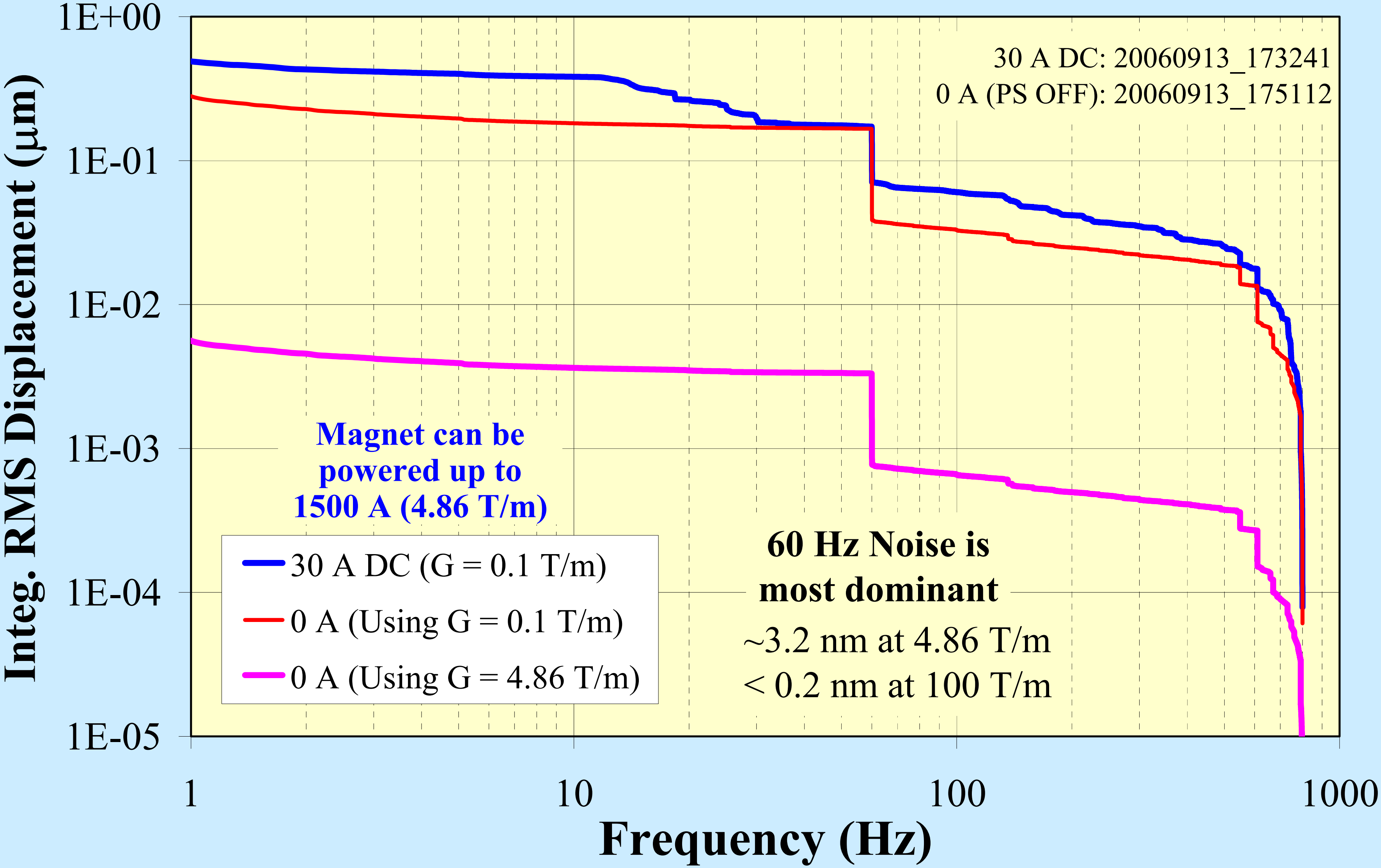
Current and Pick Up Coil Spectra in Cal. Quad



Pickup Coil Spectra in Calibration Quad (DC)



Pickup Coil Spectra in Calibration Quad (DC)



Further Work Needed/ Open Questions

- Measurements using a stabilized probe, and using better translation stages to align the probe in the quadrupole.
- Comparison of vibration spectra measured with a pick up coil and geophones in a warm magnet.
- Existing coil housing is not suitable for small aperture quadrupoles, for example, the superconducting quadrupole built at BNL for ATF2 , or the quadrupole proposed for the ILC. A smaller diameter coil housing needs to be built.
- Can a smaller diameter probe holder, suitable for the ATF2 magnet, be stabilized well enough?
- Can one build an even smaller size probe for the ILC?
- **How to support the probe without touching the magnet when no warm bore tube is available? (e.g., for ILC.)**
- A fair amount of R&D is clearly needed to make it work.

Summary

- Commercially available tools exist for good vibration measurements in warm magnets, with no space limitations.
- Most of these tools are impractical to use in magnets with limited space, or at cryogenic temperatures.
- Laser based techniques are perhaps the best choice in such cases, but require a line of sight to the cold mass.
- A pick up coil can potentially be used in any quadrupole, without need for viewports, *provided a coil of suitable size and sensitivity can be built and stabilized*.
- Very preliminary (and incomplete) studies made so far using a 2500-turn pick up coil appear to be promising.
- An ATF2-size probe could perhaps be built, but R&D is needed.
- ***It may be virtually impossible to use pick up coils in the ILC quads***, and laser based techniques may be the only option.