Magnetic noise in Virgo

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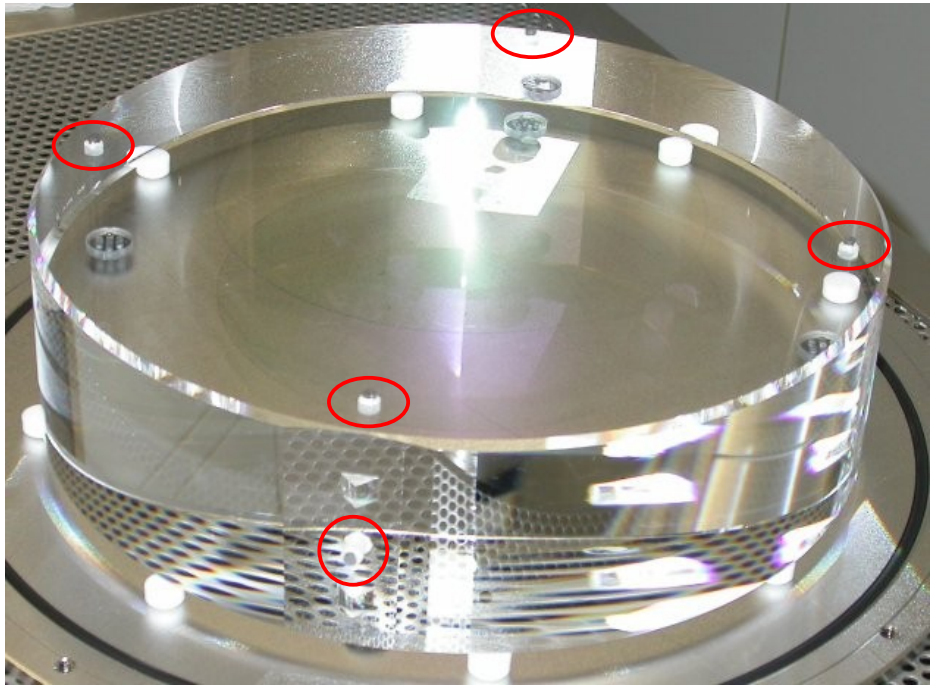
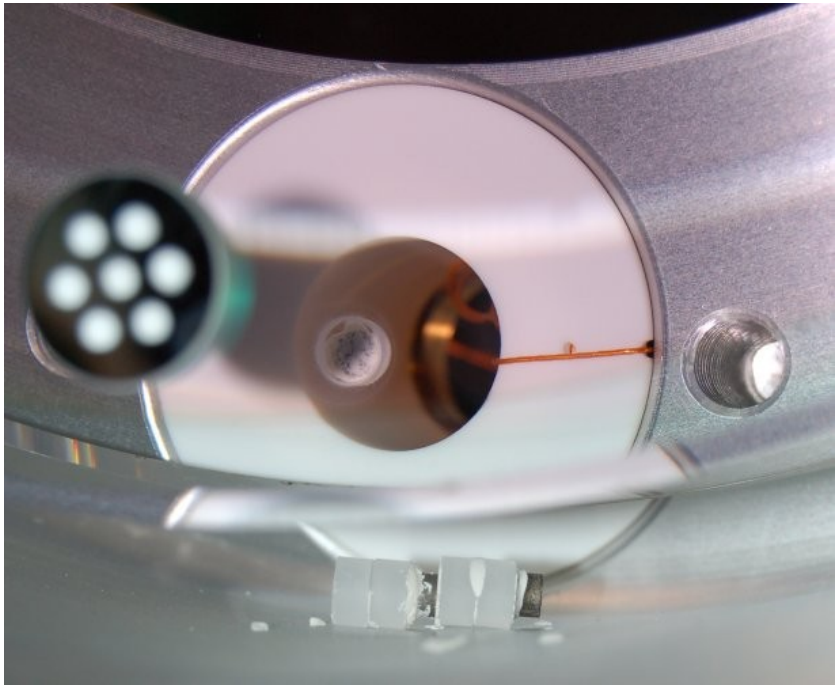
Introduction





- 6 magnets per mirror (SmCo)
  - 4 on back surface (parallel for input, anti-parallel for end)
  - 2 lateral (some missing)
- Effects on sensitivity:
  - Coupling to environmental magnetic field
  - Damping by eddy currents → lowered Q pendulum → thermal noise

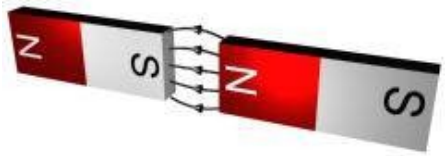
Magnetic injections

- Big coil (8000 turns), 2.5m from mirror
- Typical fields of 10-100 nTesla at mirror position
- Signal generator, amplifier, current monitor
- Magnetometers
- Hall-probe
- 3 orientations of coil
- Observe effect in dark fringe

Theory

- Torque due to field

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$



- Force due to gradient

$$\vec{F} = \left(\vec{\mu} \cdot \nabla\right) \vec{B}$$

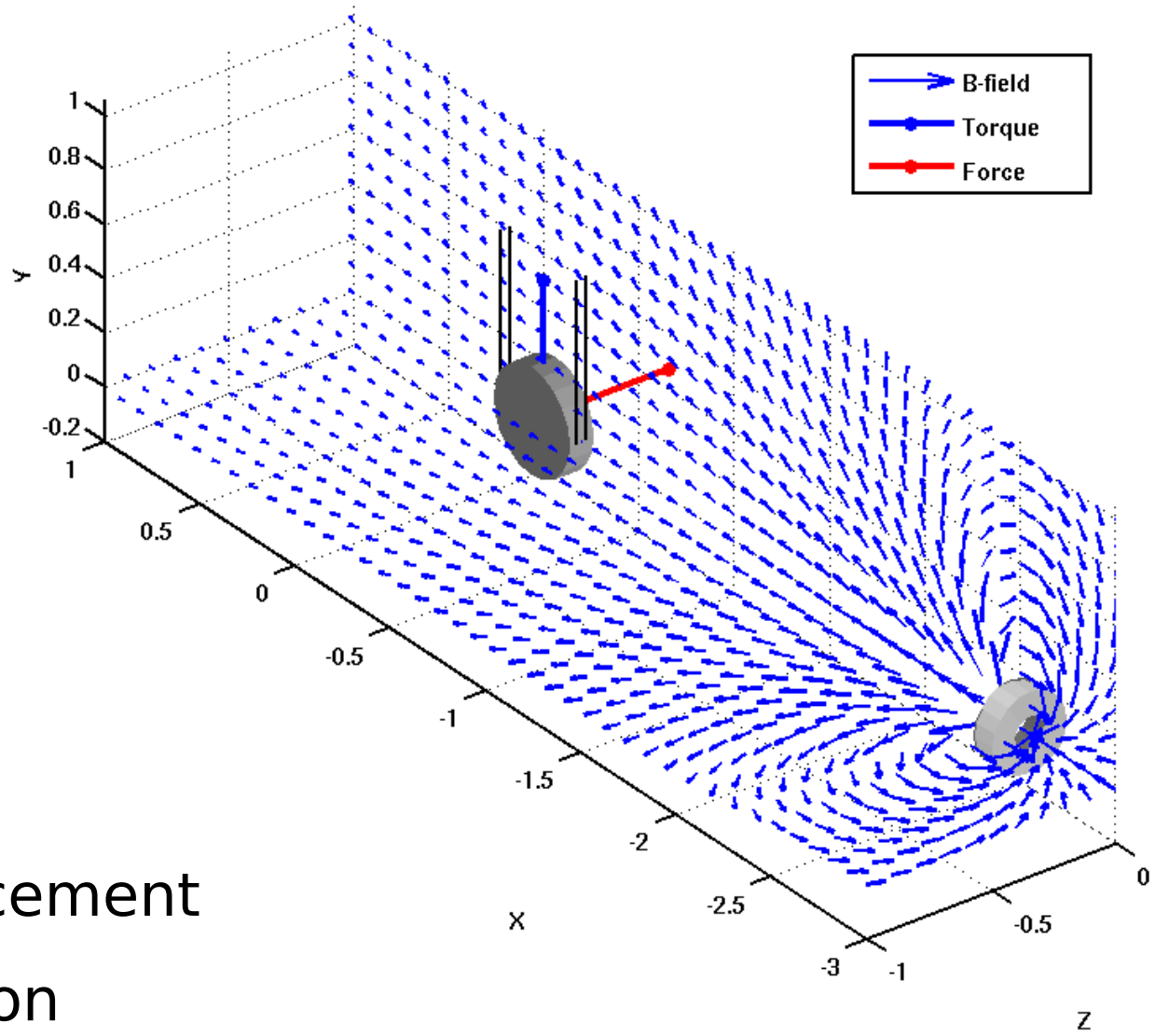
- Combine forces/torques for all magnets

$$\vec{F}_{total} = \sum_i \vec{F}_i \qquad \vec{\tau}_{total} = \sum_i \vec{\tau}_i + \sum_i \vec{r}_i \times \vec{F}_i$$

- Calculate displacement

$$z = \frac{F_z}{m\omega^2} \qquad z = \frac{\tau_y D_x}{I_y \omega^2}, z = \frac{\tau_x D_y}{I_x \omega^2}$$

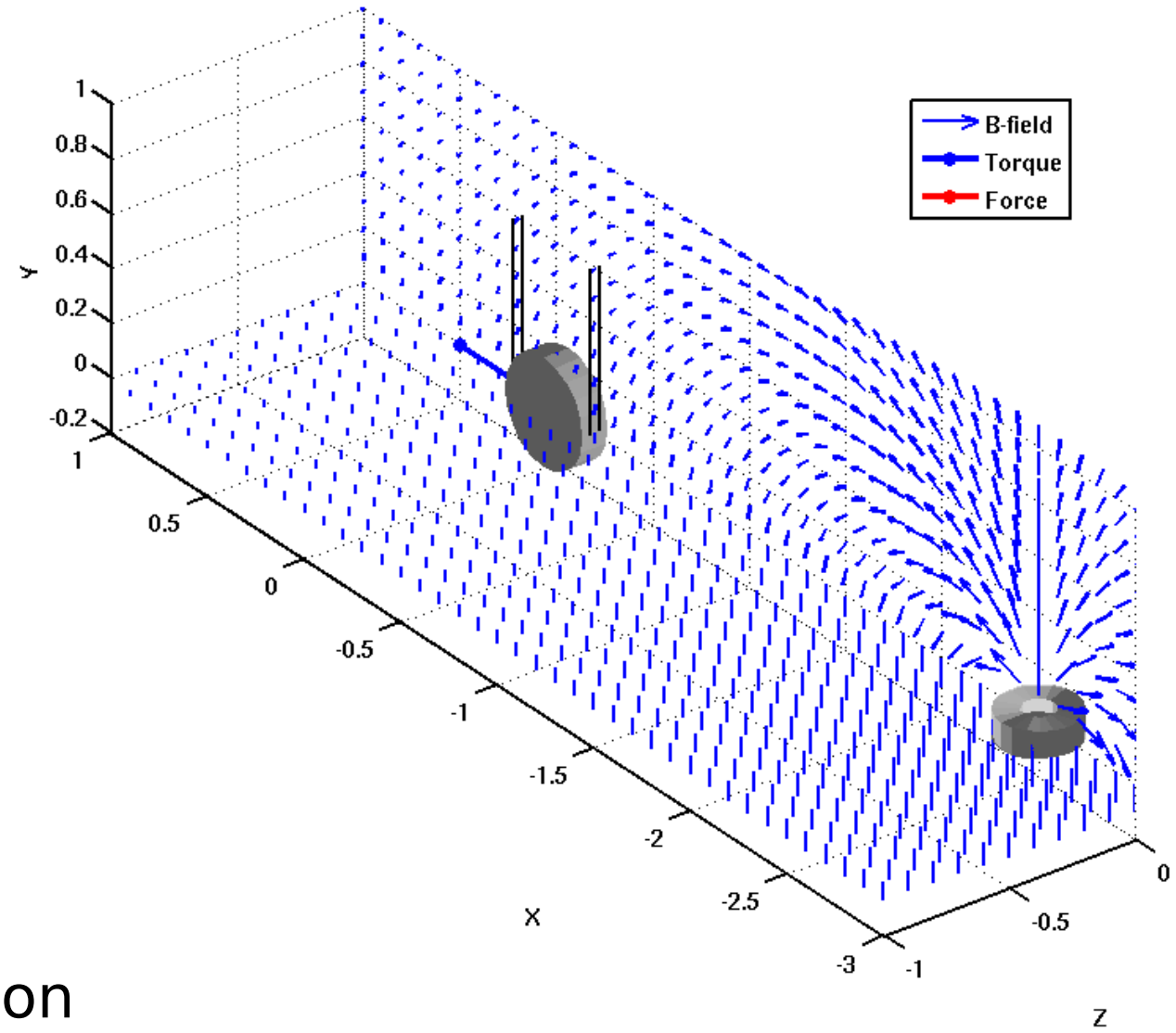
Coil along X



z displacement

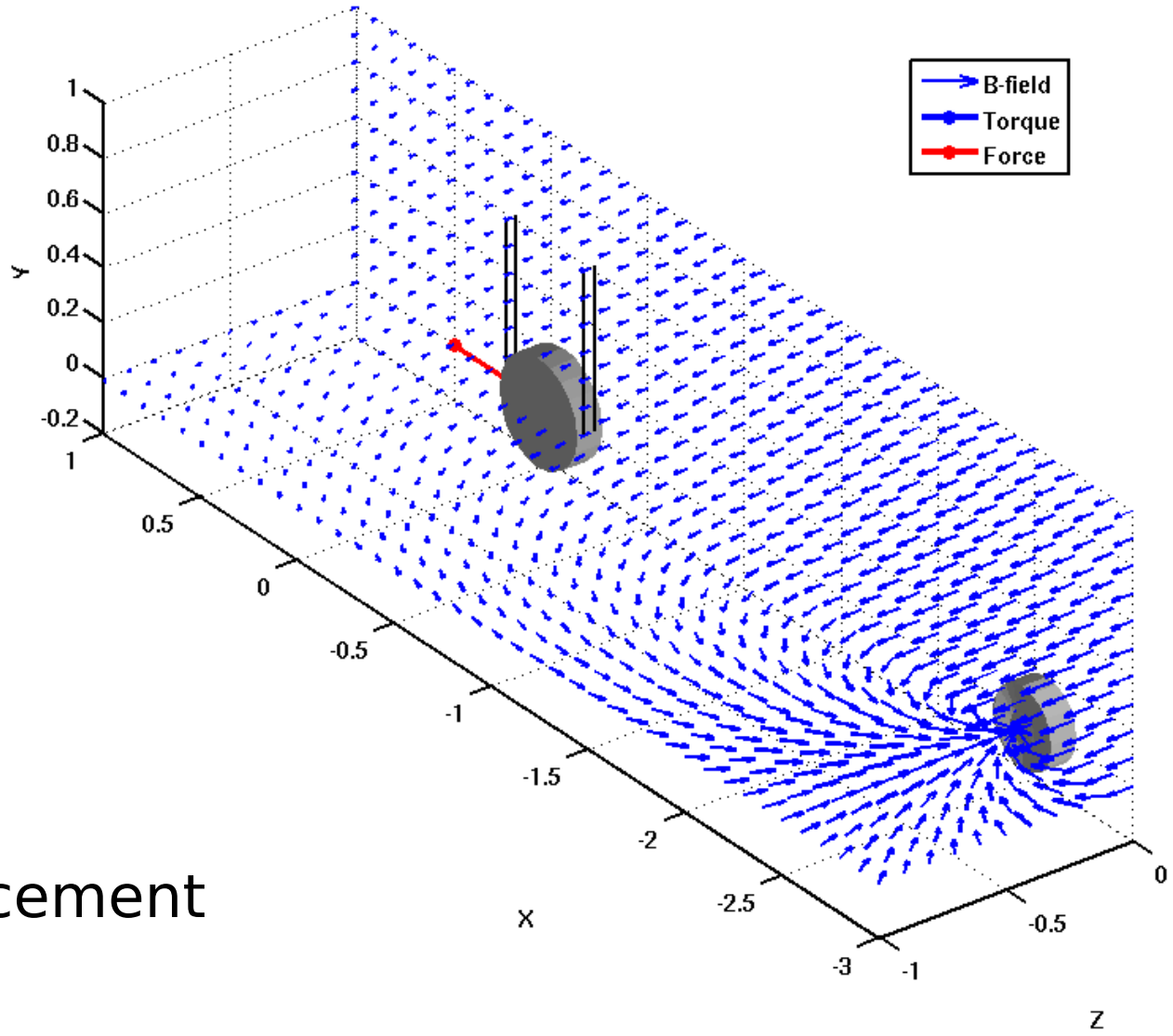
ty rotation

Coil along Y



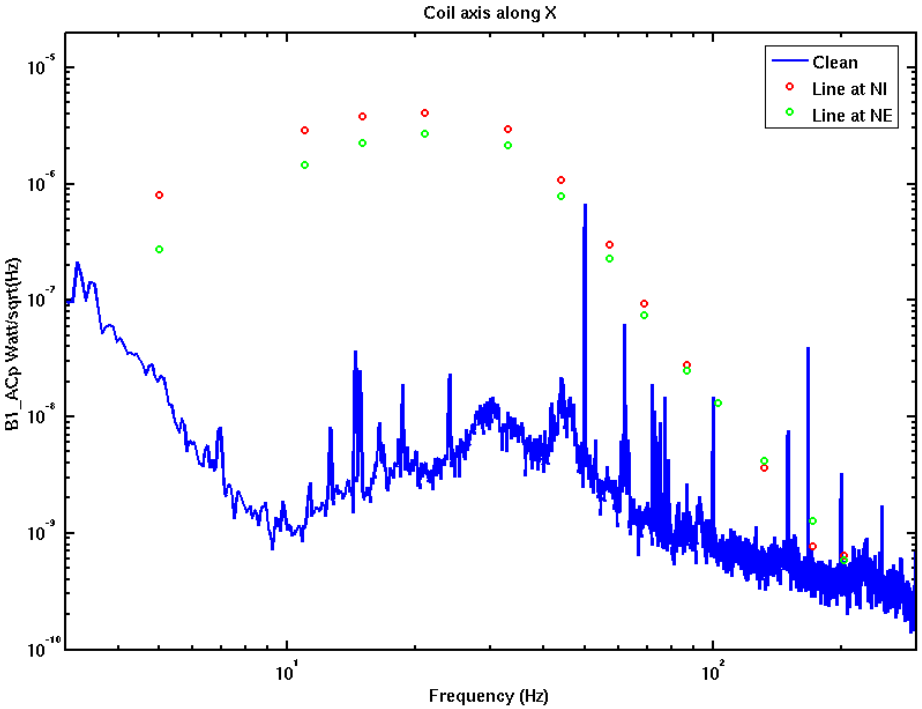
tx rotation

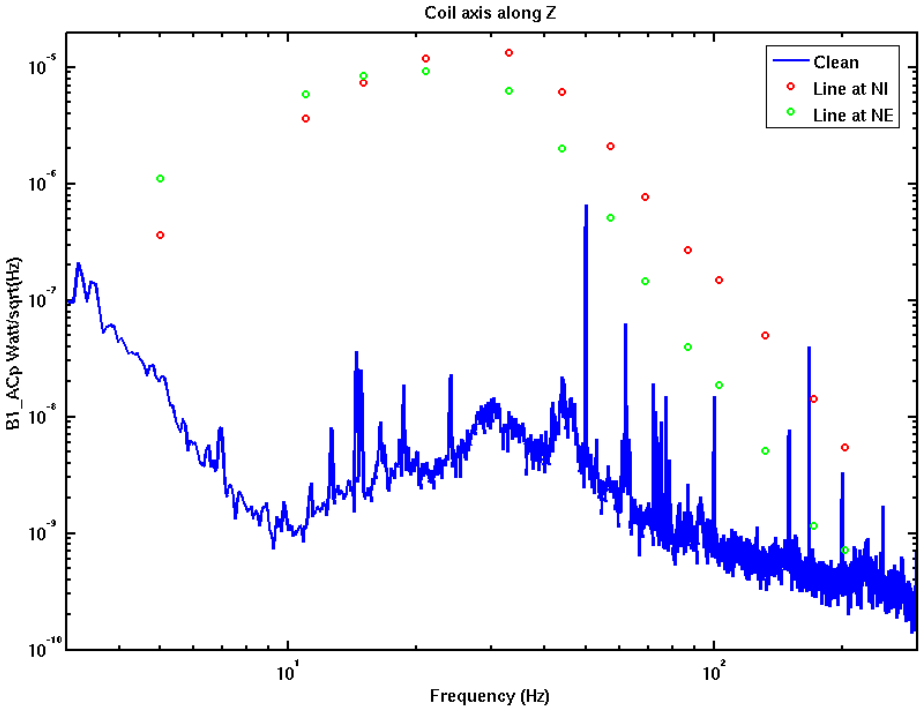
Coil along Z



x displacement

Results



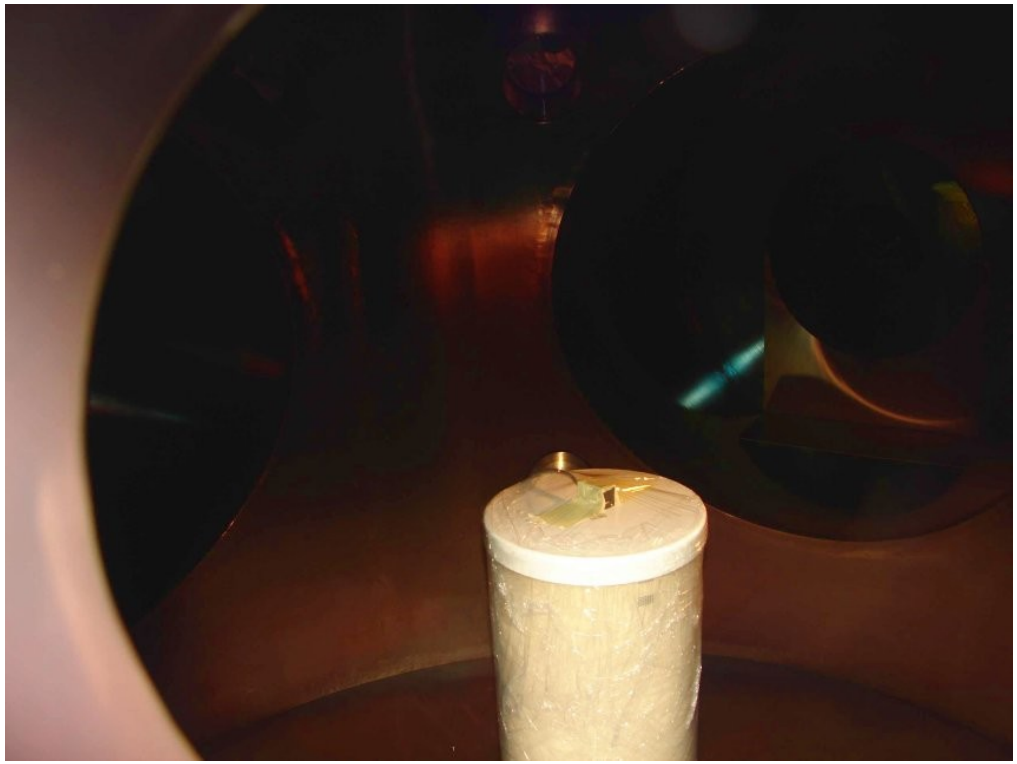


- Lines injected from 5 to 200 Hz
- Easily visible in the dark fringe
- Use dipole model for coil to calculate transfer function

Results

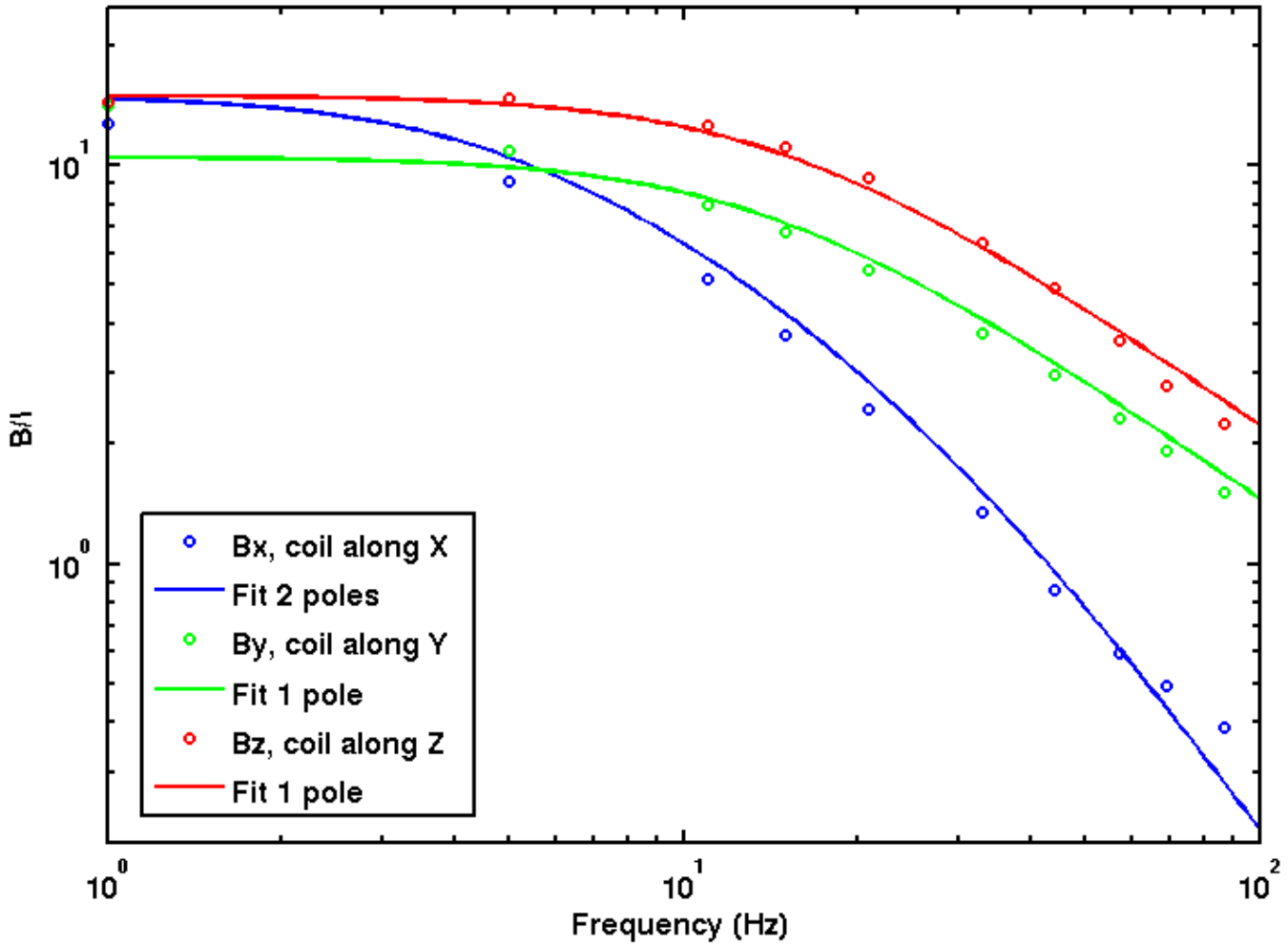
- Measurements not consistent with simple model
  - Ratio anti-parallel vs parallel smaller than expected
  - Model: X is most sensitive
  - Measurement: Z is most sensitive
  - Strange frequency dependence
- Experiment with beam mis-centering
  - Rotation observed for wrong orientation

Shielding of vacuum chamber



- Inject fields with coil placed in front of SR chamber
- Hall-probe on plastic tube inside SR, bottom almost closed

Shielding of vacuum chamber

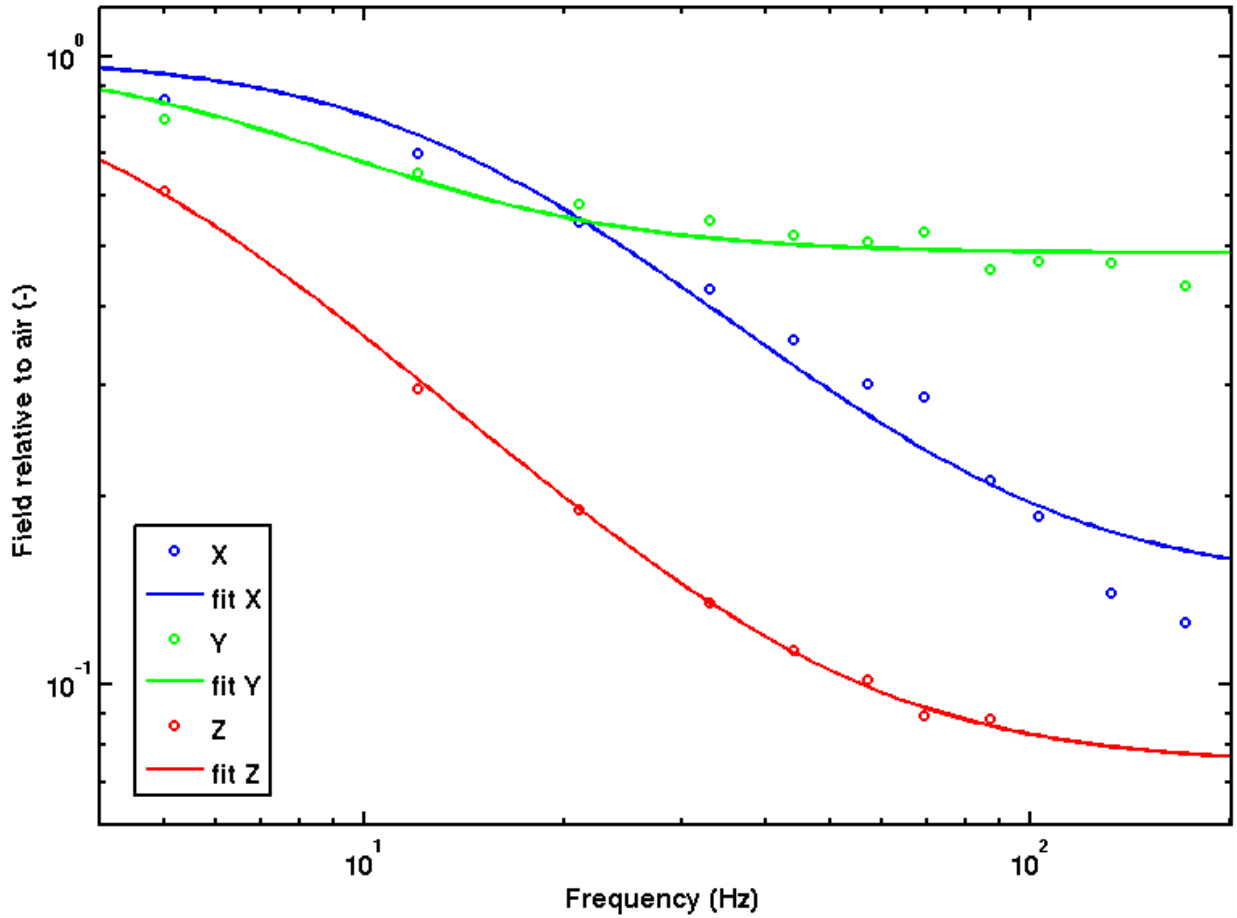


- Y and Z: 1 pole, X: double pole
- Shows up in transfer function to dark fringe

Reference mass

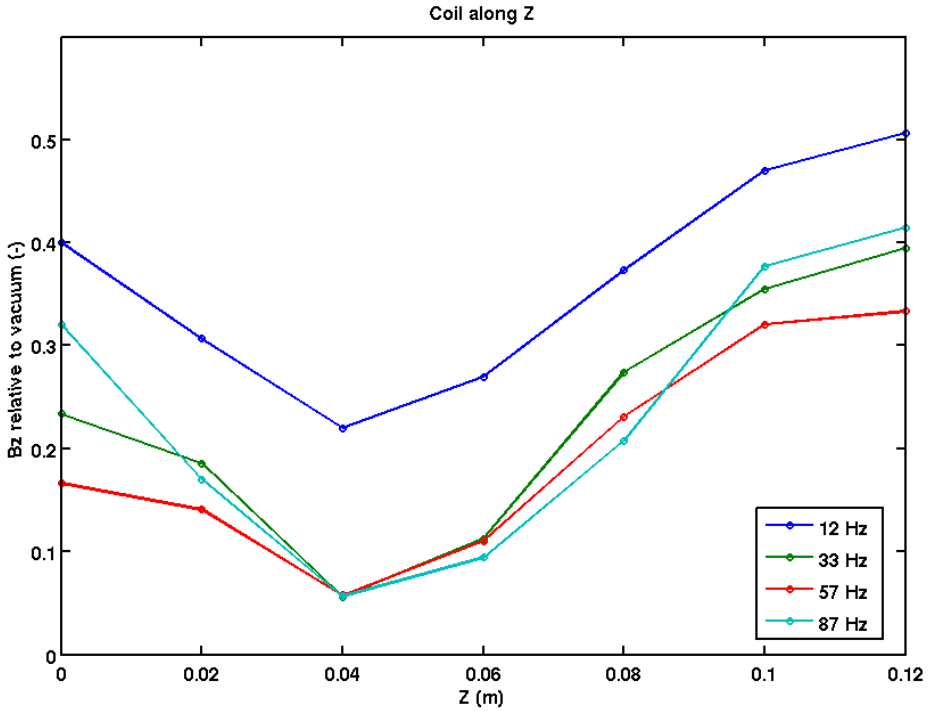
- Measurements with spare reference mass
- Compare field inside with field outside
  - as function of frequency
  - as function of Z (gradient dBz/dz)

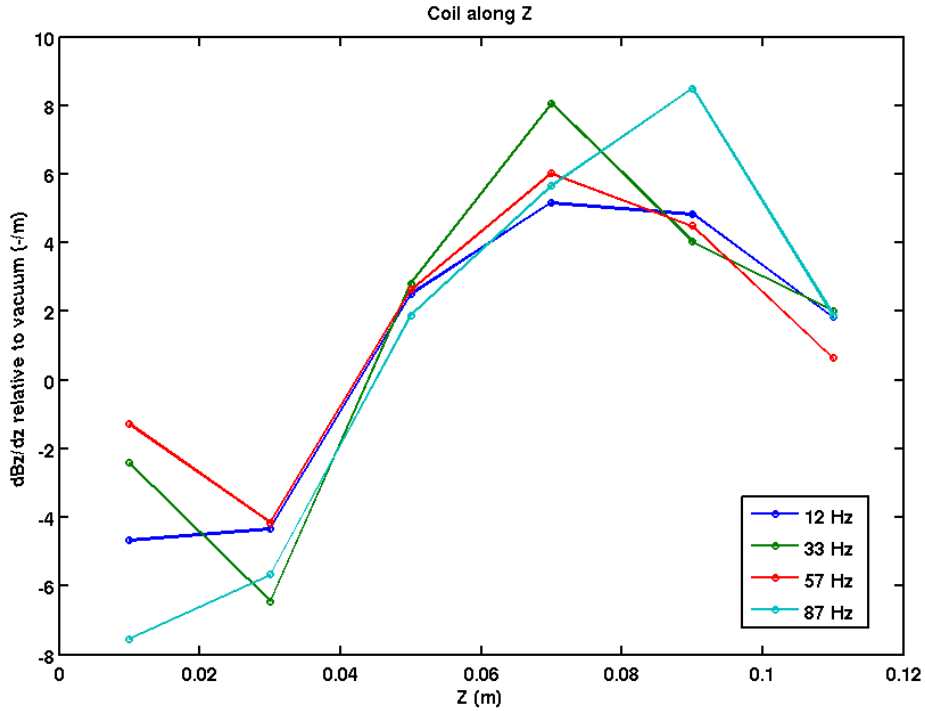
Reference mass



- Frequency dependent shielding, largest for Z
- Can be fitted with 1 pole, 1 zero

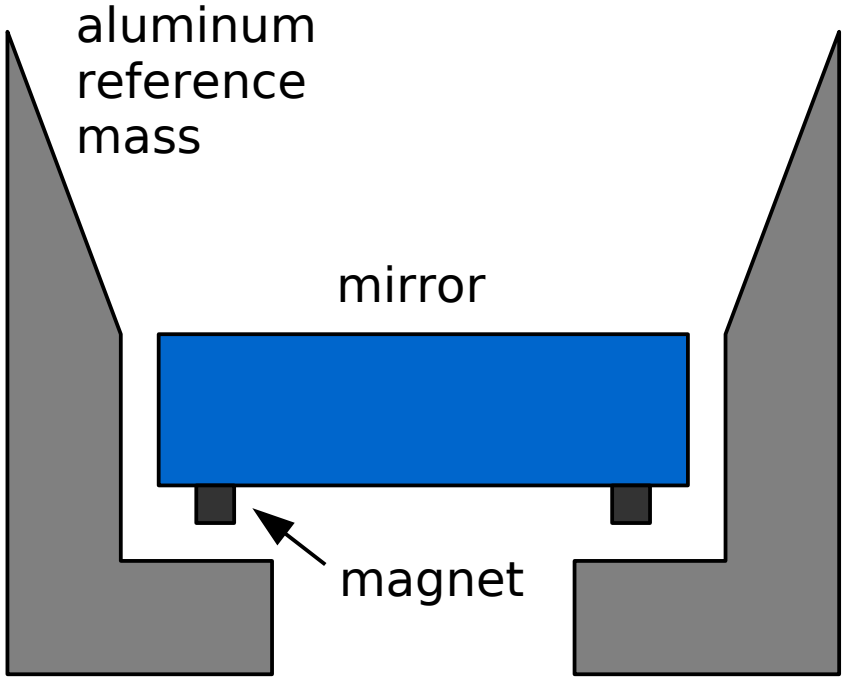
Reference mass



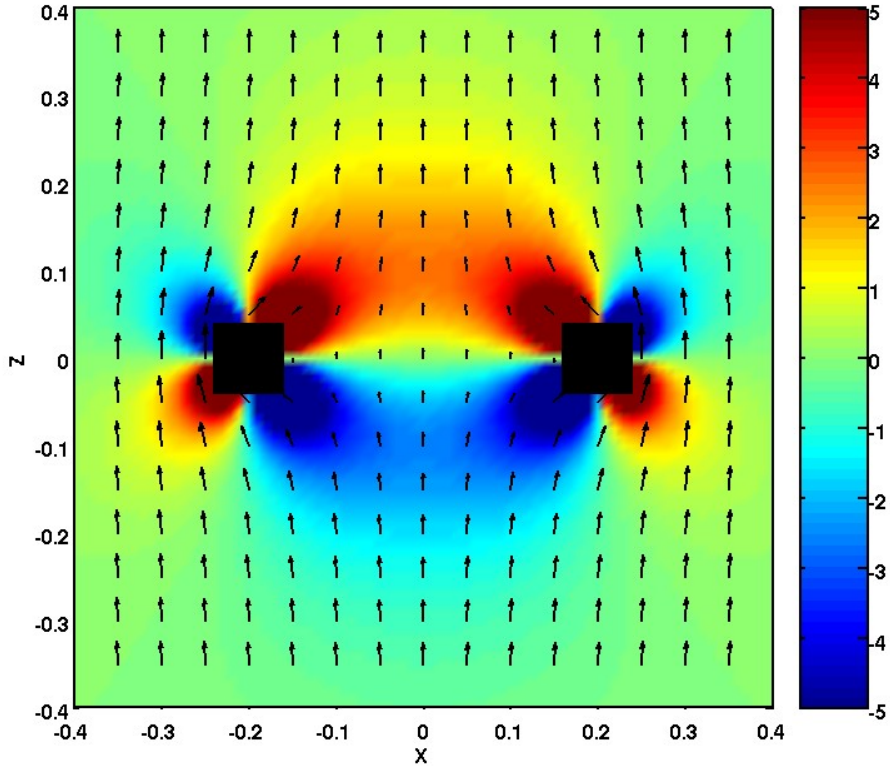


- Field is lowered very locally: induced gradient
- Magnet (z=~0.02) feels the gradient

Reference mass



thin wire loop
in uniform field

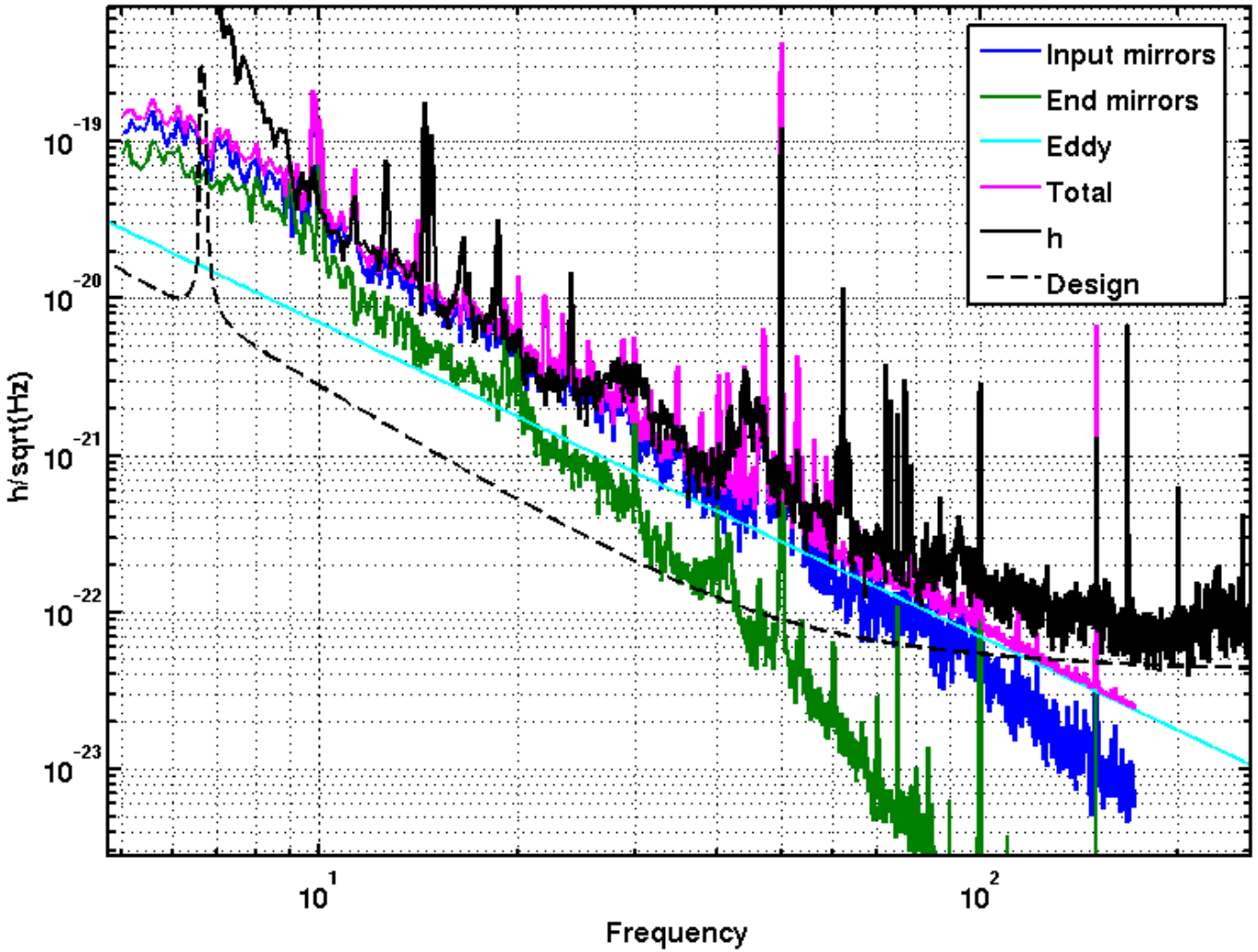


- Possible explanation:
  - Eddy currents induced in reference mass
  - Induced field partly cancels incident field
  - Local decrease of field → gradient

Noise projection

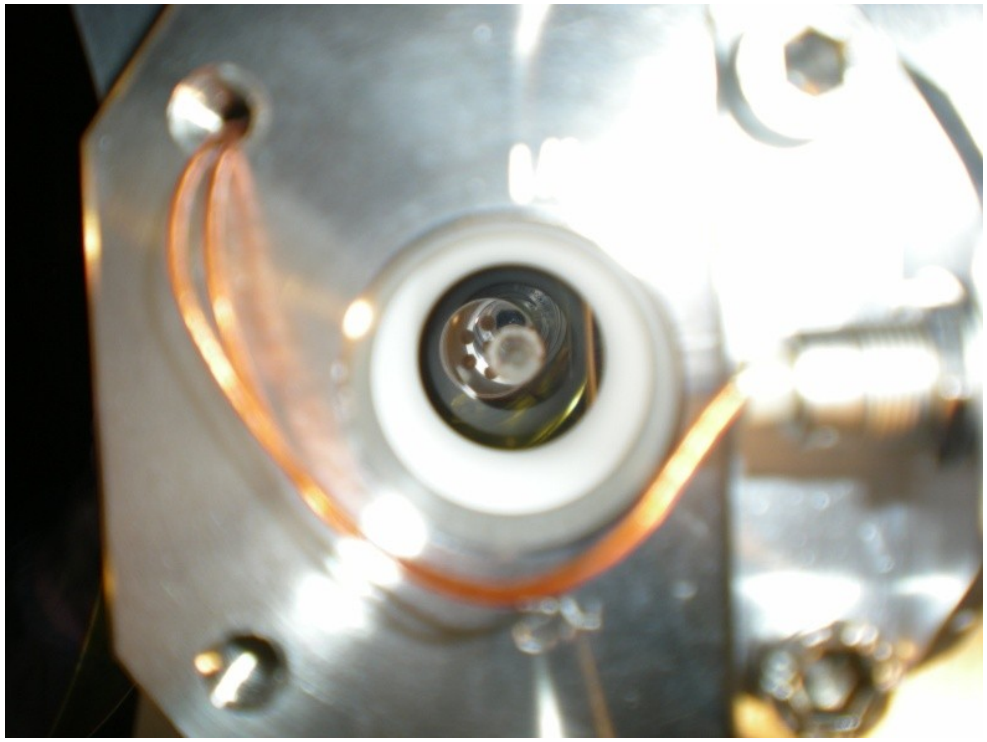
- Induced gradient by reference mass dominates → neglect environmental gradient?
- Use dipole model to calculate B-field from coil
- Assume shielding for field injected with coil and environmental field is equal
- Upper limit: max(TF) * max(magnetometer)

Noise projection



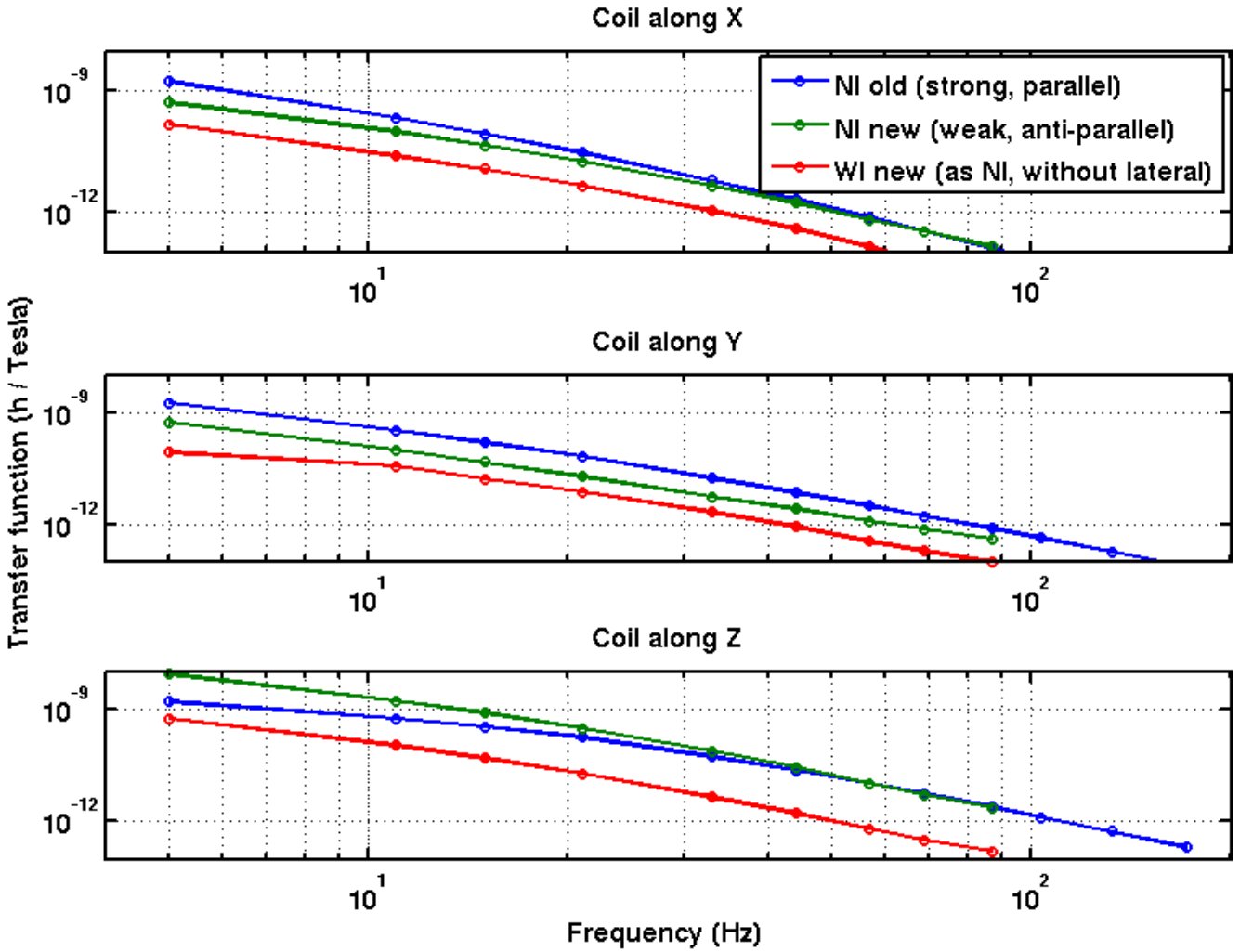
- Shape matches, but level is too high
- Some lines can be fitted by lowering with factor 3-5

Magnet replacement



- Risky operation, but successful (Punturo, Travasso et al.)
- Changed 4 magnets on both input mirrors
- Strength reduced by factor 5.5
- Orientation changed to anti-parallel

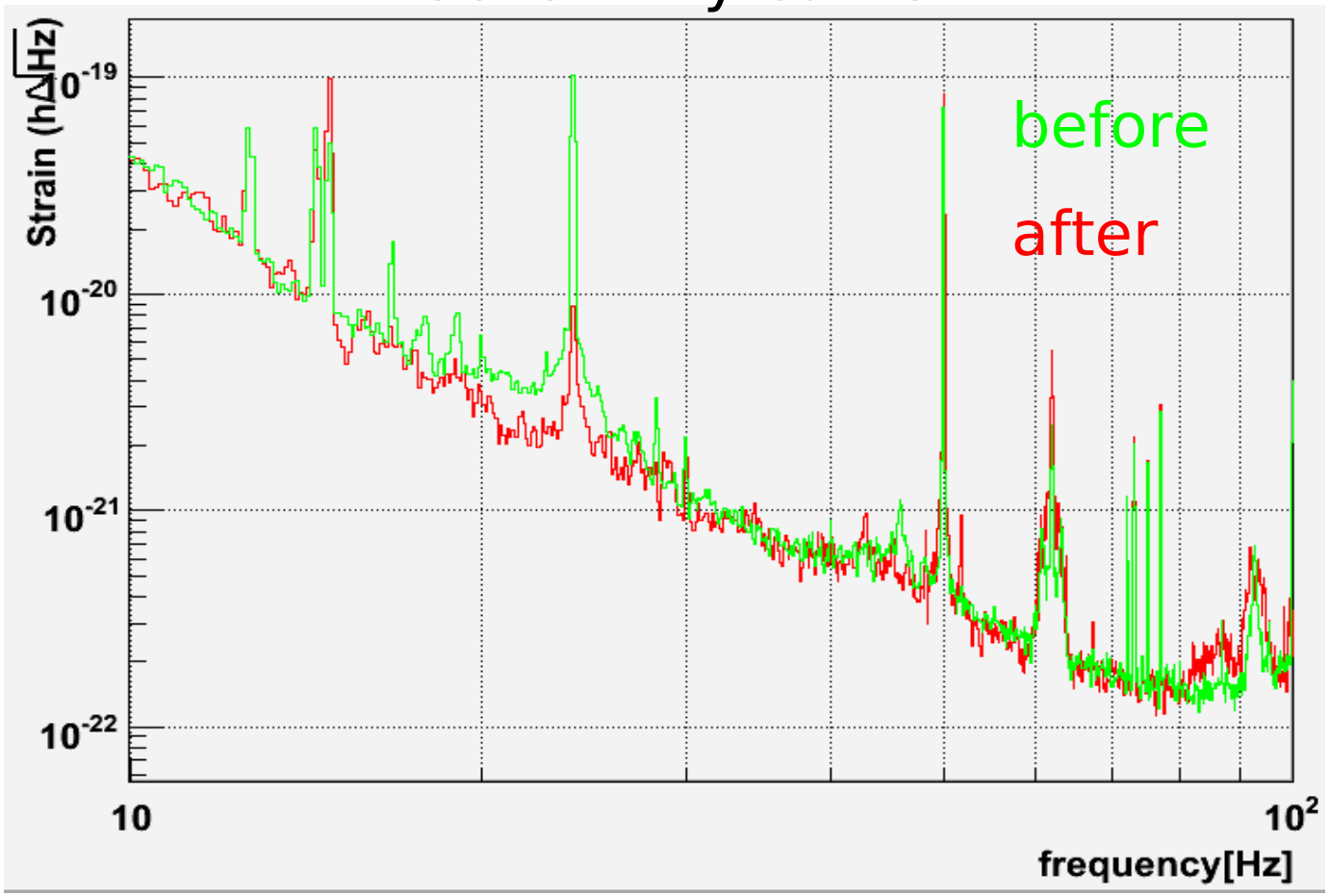
Magnet replacement



- Repeated magnetic injections
- Probably still dominated by lateral magnets

Magnet replacement

Sensitivity curve



L. Rolland

- Test with air-conditioning off
- No effect visible

Future plans

- Better explanation of measurements
  - 3D modeling of reference mass
- Preventive actions
  - Remove lateral magnets
  - Replace end-mirror magnets?
  - Remove electronics away from mirrors
  - Future mirrors: dielectric reference mass
  - Far future: electrostatic actuators?

Conclusions

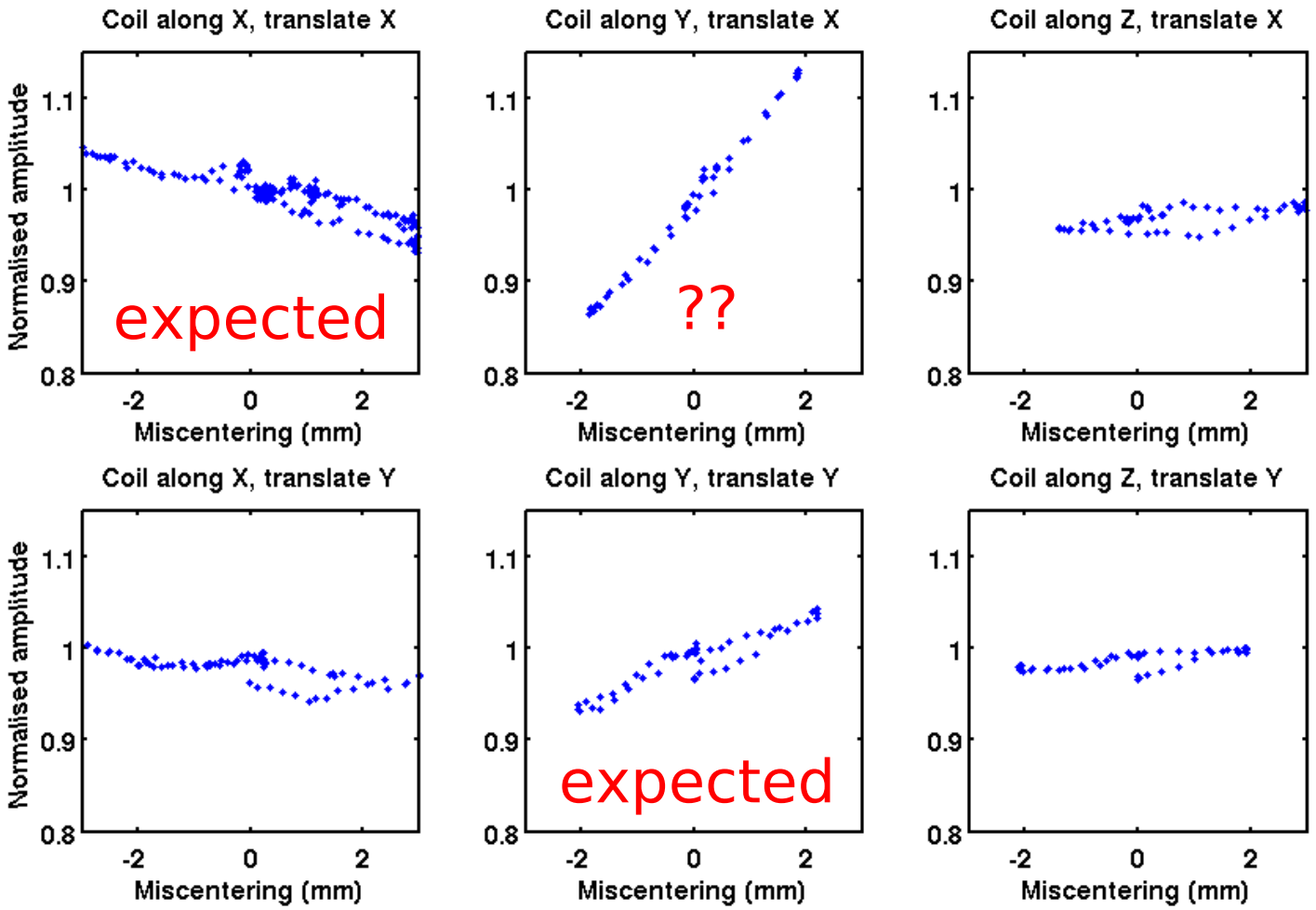
- Performed various magnetic injections
- Simple model cannot explain measurements
- Observed field distortion by reference mass, might be dominant effect
- Noise projection based on measurements, upper limit
- Probably not limiting, but might be close
- Changed magnets: no improvement observed

End

Beam translation

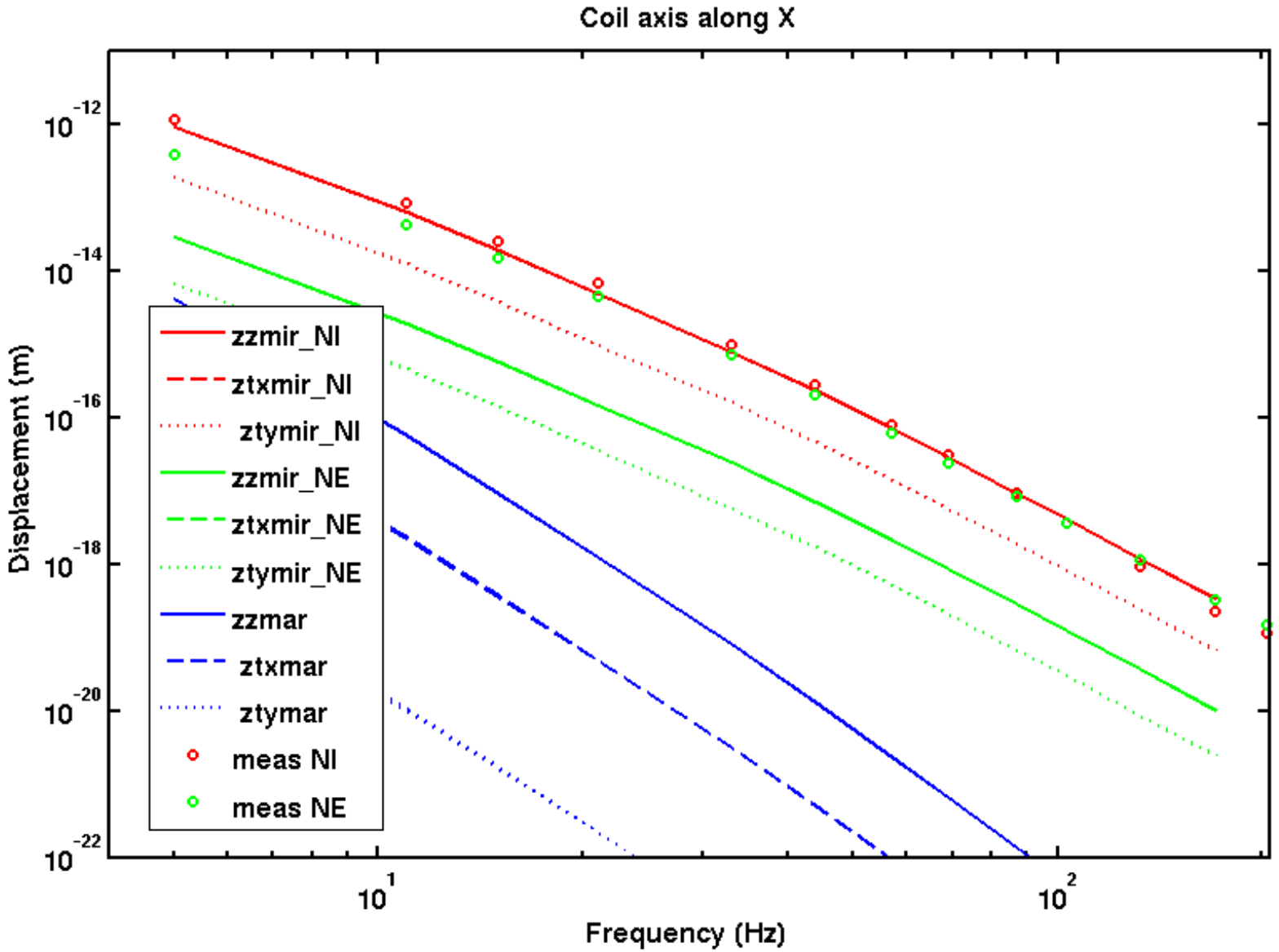
ty

tx

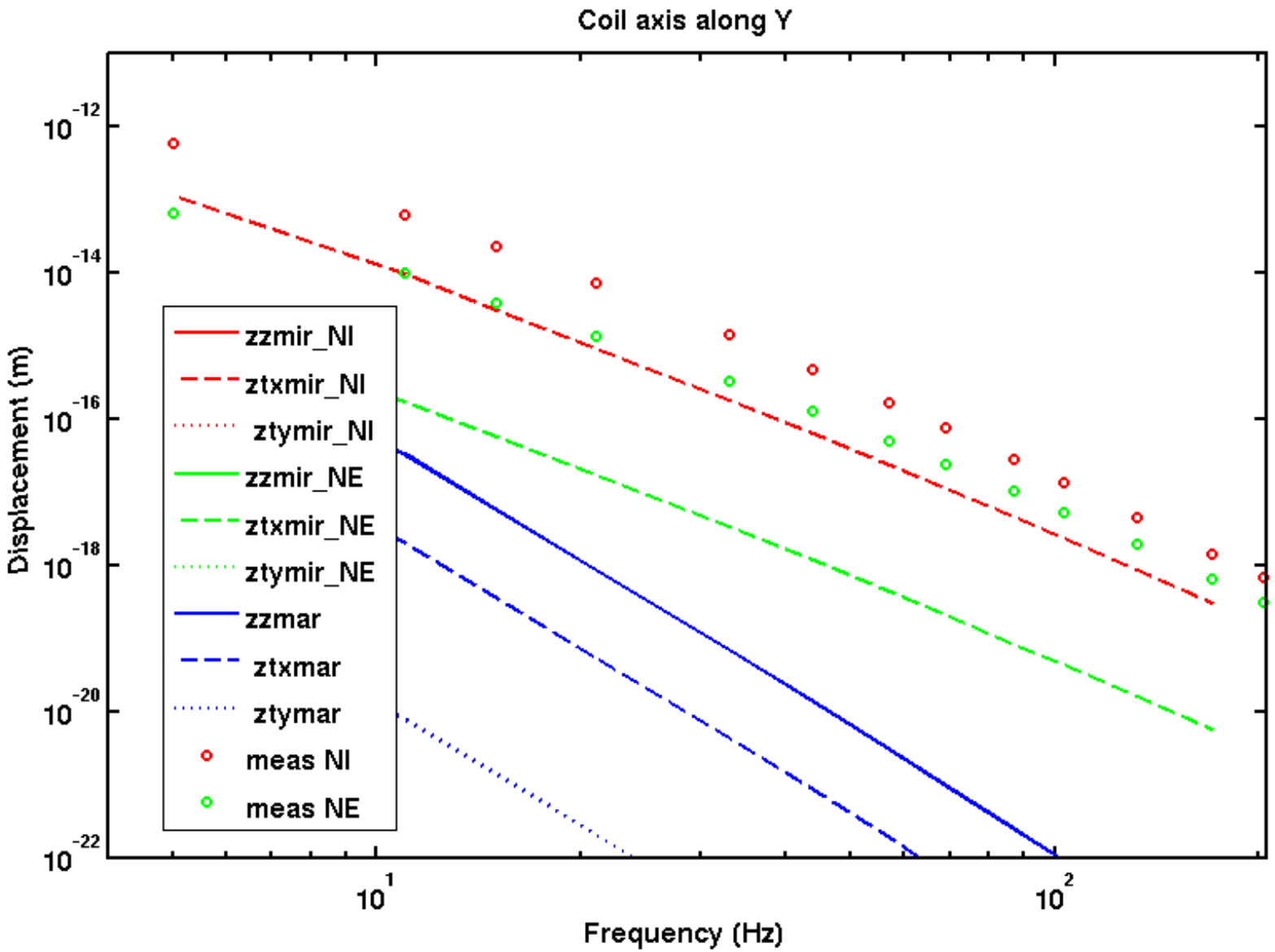


- Mis-center beam to observe rotation
- Effects not explained by simple model

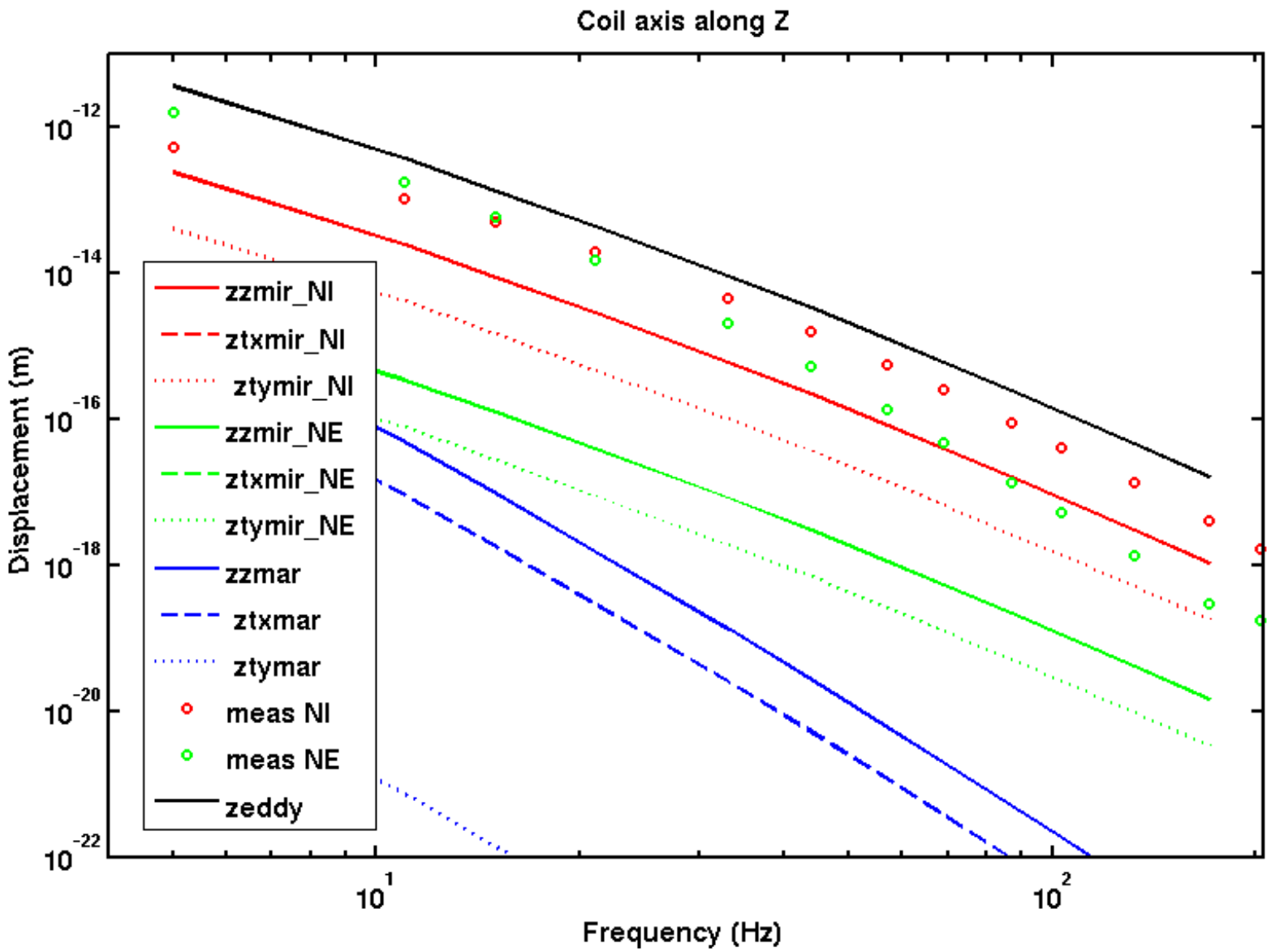
Model


Coil axis along X
Displacement (m)
Frequency (Hz)
zzmir_NI
ztxmir_NI
ztymir_NI
zzmir_NE
ztxmir_NE
ztymir_NE
zzmar
ztxmar
ztymar
meas NI
meas NE

Model


Coil axis along Y
Displacement (m)
Frequency (Hz)
zzmir_NI
ztxmir_NI
ztymir_NI
zzmir_NE
ztxmir_NE
ztymir_NE
zzmar
ztxmar
ztymar
meas NI
meas NE

Model


Coil axis along Z
Displacement (m)
Frequency (Hz)
zzmir_NI
ztxmir_NI
ztymir_NI
zzmir_NE
ztxmir_NE
ztymir_NE
zzmar
ztxmar
ztymar
meas NI
meas NE
zeddy