IN-VACUUM COLD MEASUREMENT BENCH DEVELOPMENT

For the CPMU upgrade programme at Diamond Light Source

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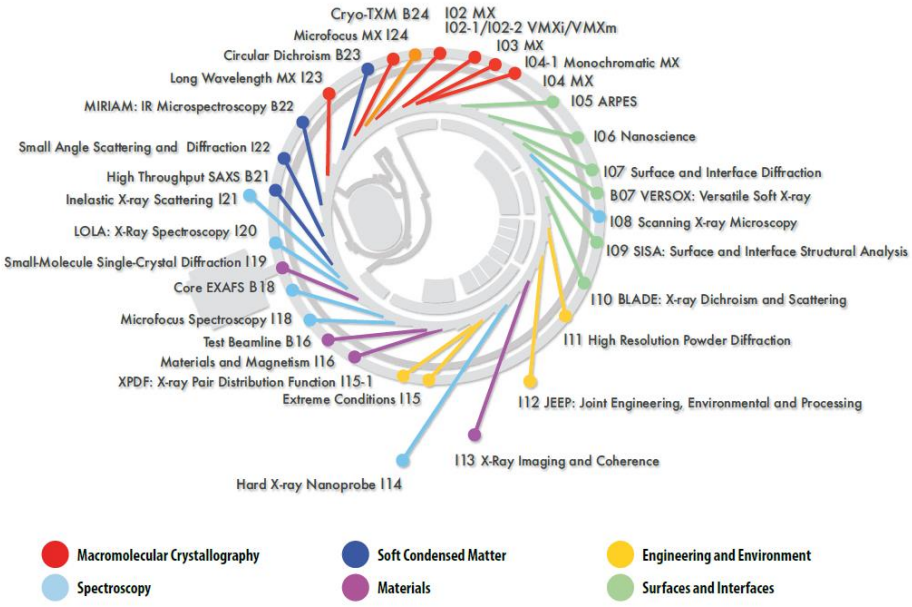
CPMU upgrade programme

- All straight sections filled
- Plans for up to 6 beamlines to upgrade to CPMUs
  - Factor of 2-4 increase in brilliance at 12.6 keV
  - Factor of 2-3 increase in flux (standard white beam slit aperture) at 12.6 keV
- DII upgrade (2025-2026) – further demand

Beamline	Current λ_u [mm]	Periods	CPMU λ_u [mm]	Periods
I24	21	95	17.6	113
I03	21	95	17.6	113
I14	23	85	17.6	113
I04	23	85	17.6	113



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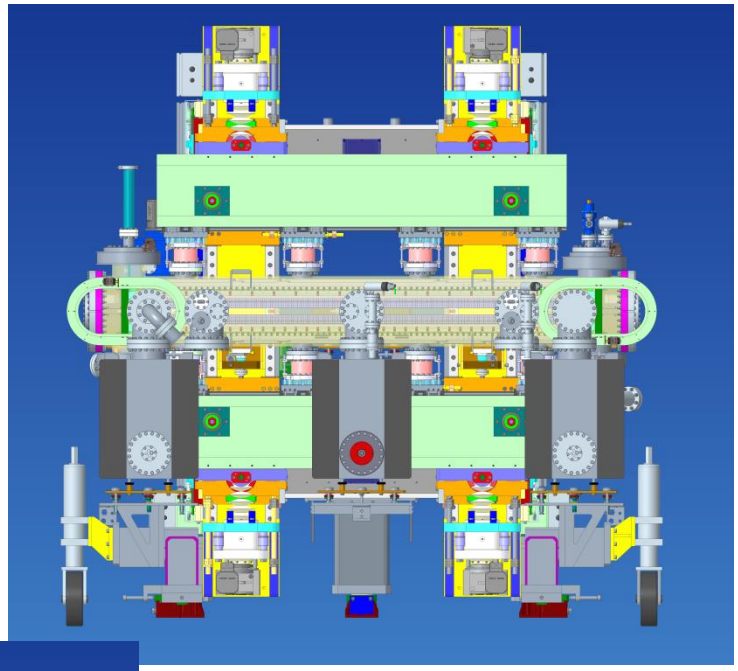
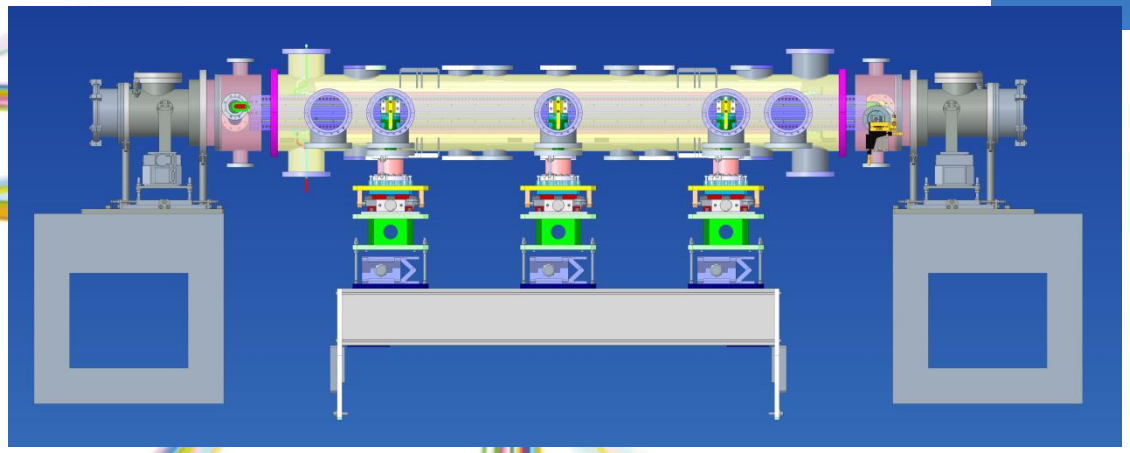
The cold bench

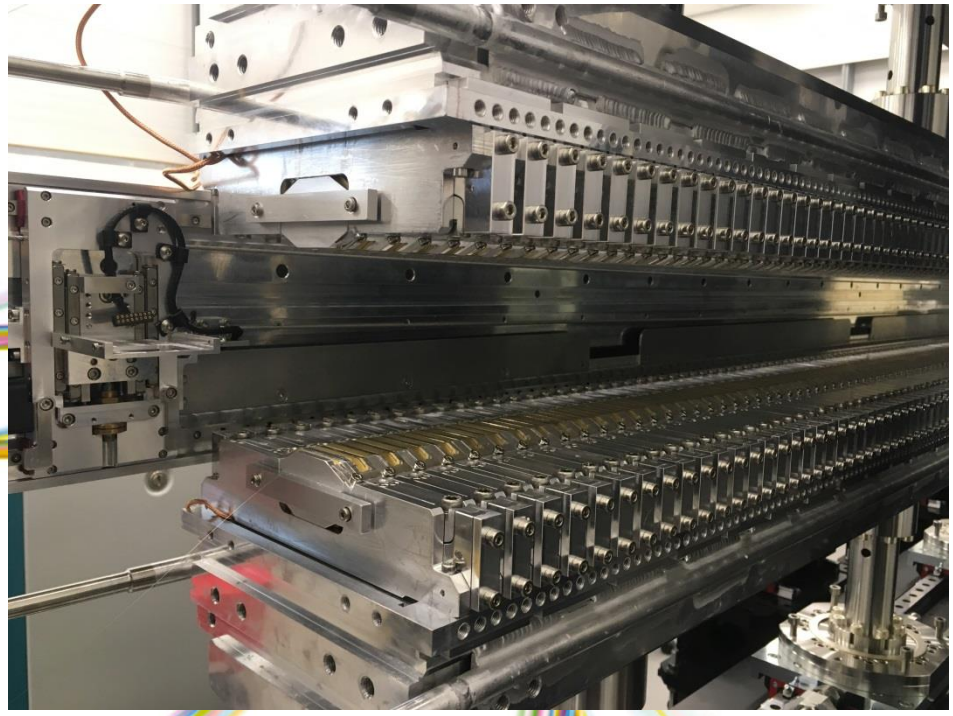
- CPMU may change when cold
- Hall probe & stretched wire
- Bench mounted on 3 columns through ion pump/vacuum gauge ports
- Platform attached to lower beam
- Extra end vessels for laser, feedthrough and wire mounts

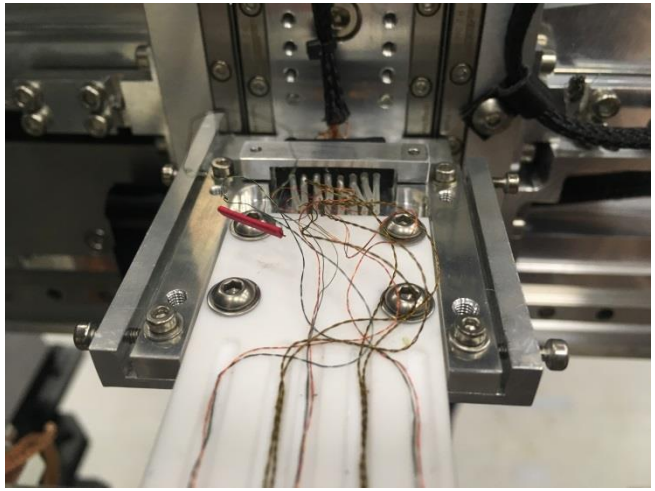


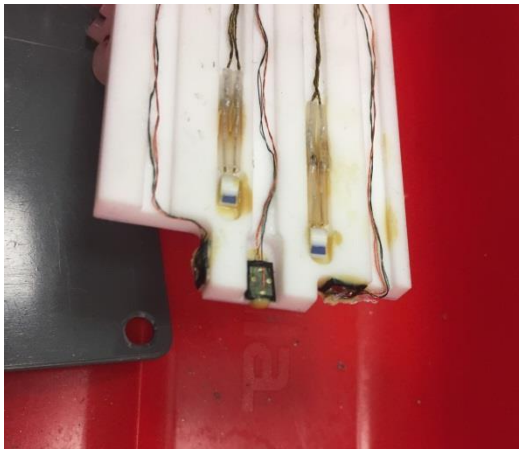


Hall probes

- 3 x 1D AREPOC HHP-SU probes
  (3 mm x 4 mm x 0.9 mm)
- Active area: 20 µm x 20 µm
- 2 x PT100s (only 1 used)







- Macor plate 3 mm thick
- Probes glued in place
- Soldered connections

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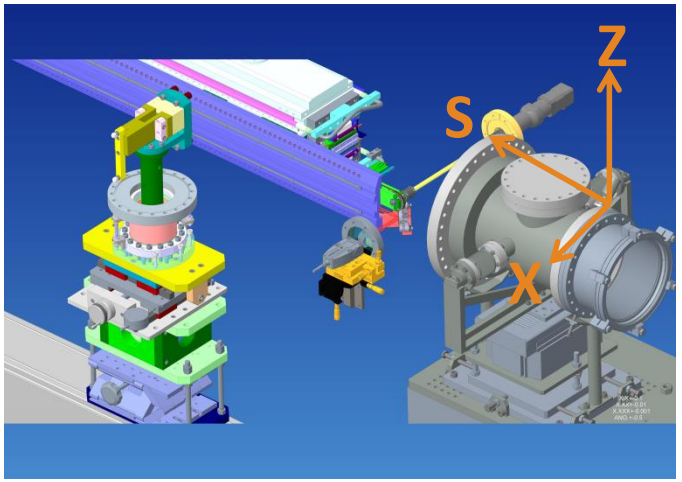
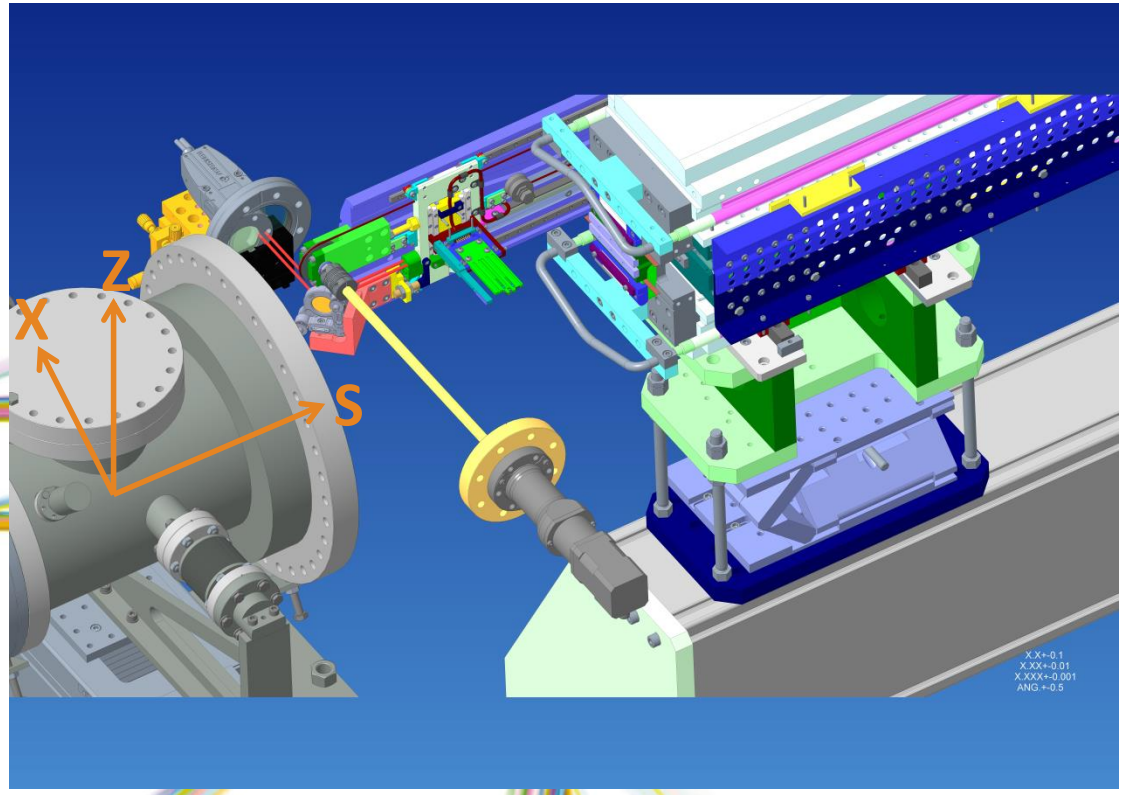
Hall probe design

- Stepper motor, linear rail & pulley cable
- Laser interferometer for position & triggering
- Ramp to park for wire measurements
- Limit switch for homing – 3 µm repeatability





- Height and X pos. set in gap approx. using telescope
- Laser aligned with combination of laser adjustment & bench adjustment

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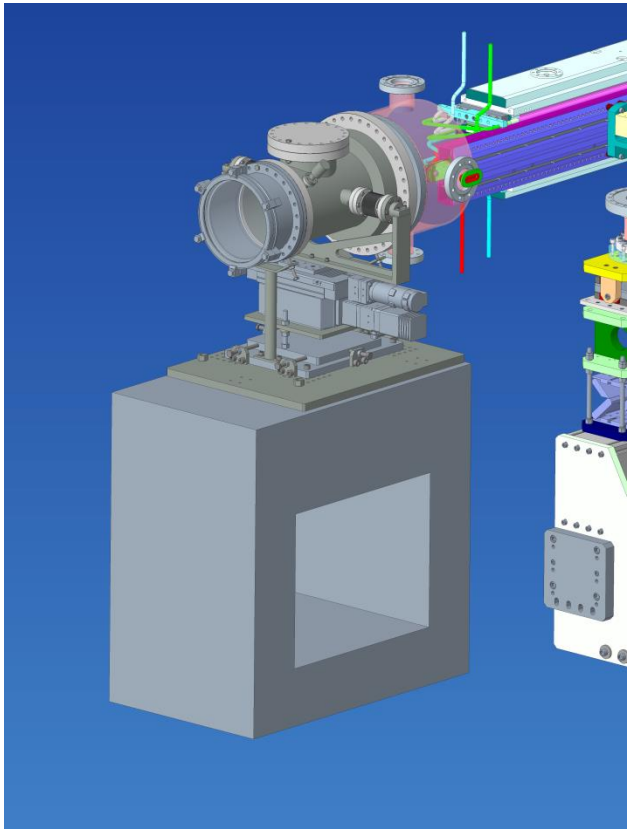
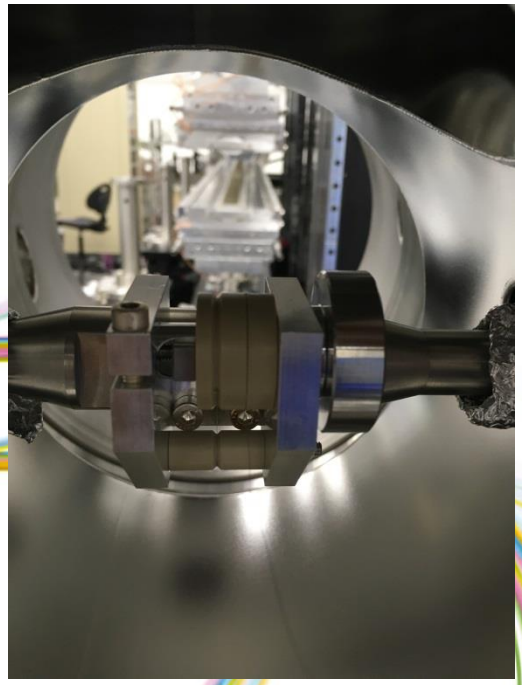
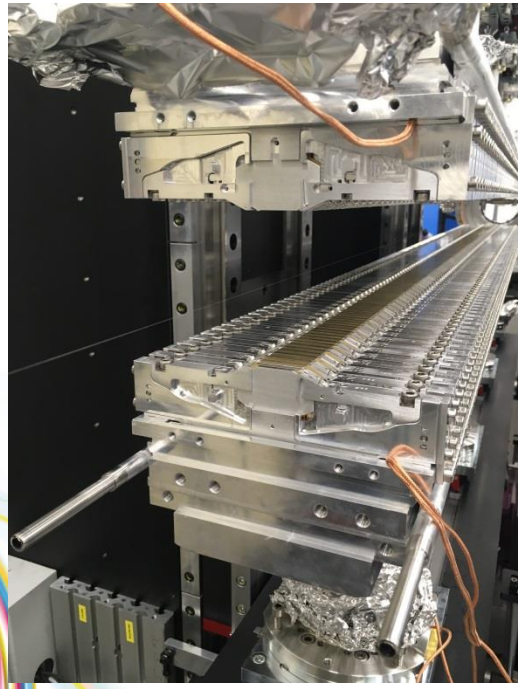
The stretched wire

- Supplied by Danfysik
- X and Z stages on concrete blocks
- Ti alloy wire – minimise sag
- Tensioned to 50 Hz, but Keithley acts as a low-pass filter anyway





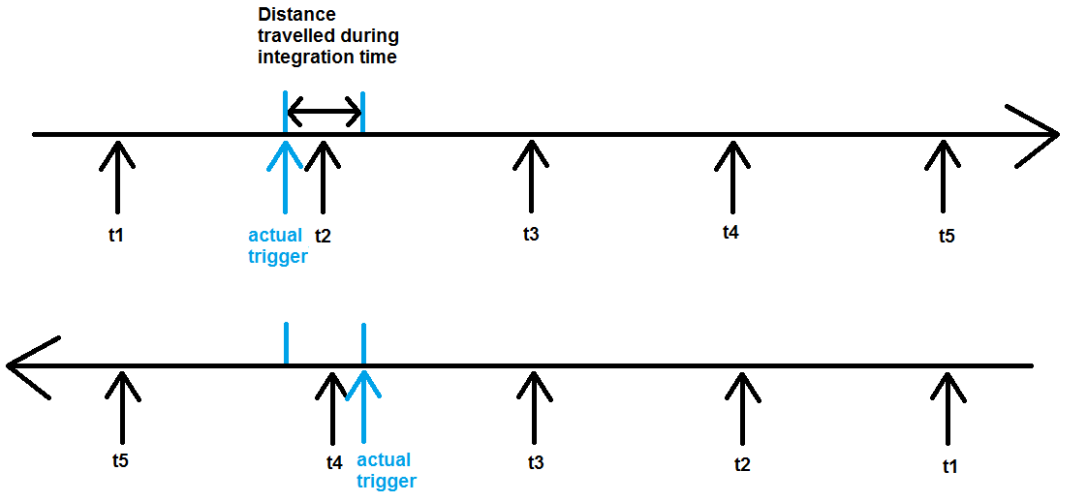


Stretched wire scans

$$I_z^{meas}(x_i) = \frac{\overline{V_i}}{N\overline{v_x}}$$

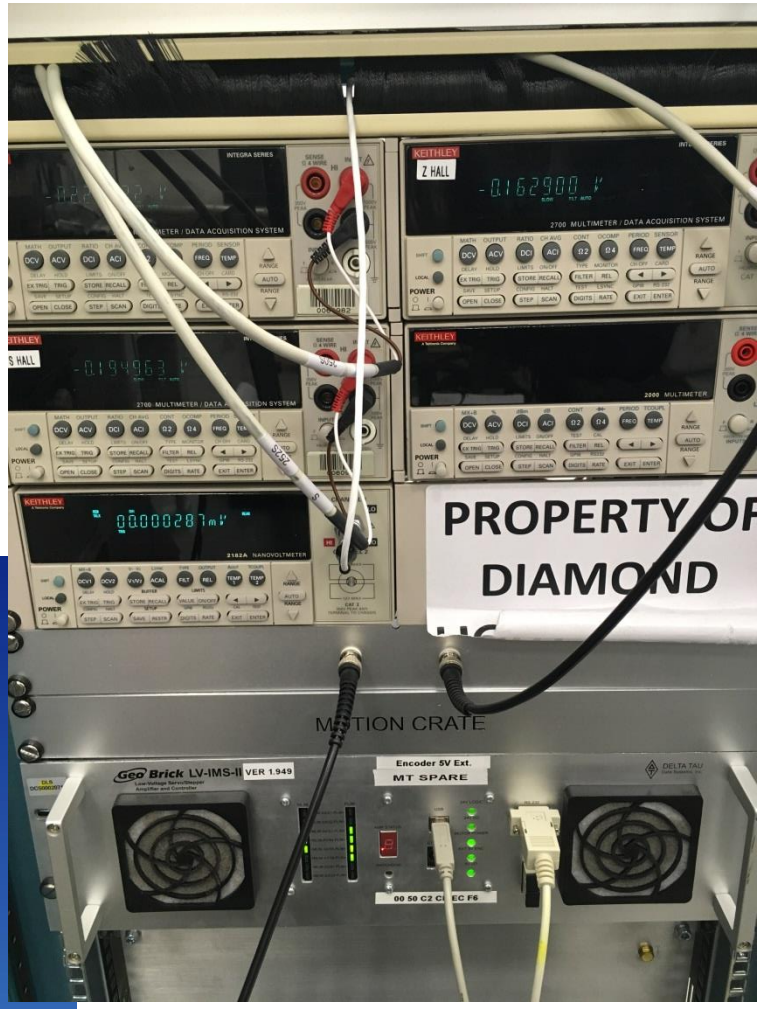
$$I_x^{meas}(z_i) = \frac{\overline{V_i}}{N\overline{v_z}}$$

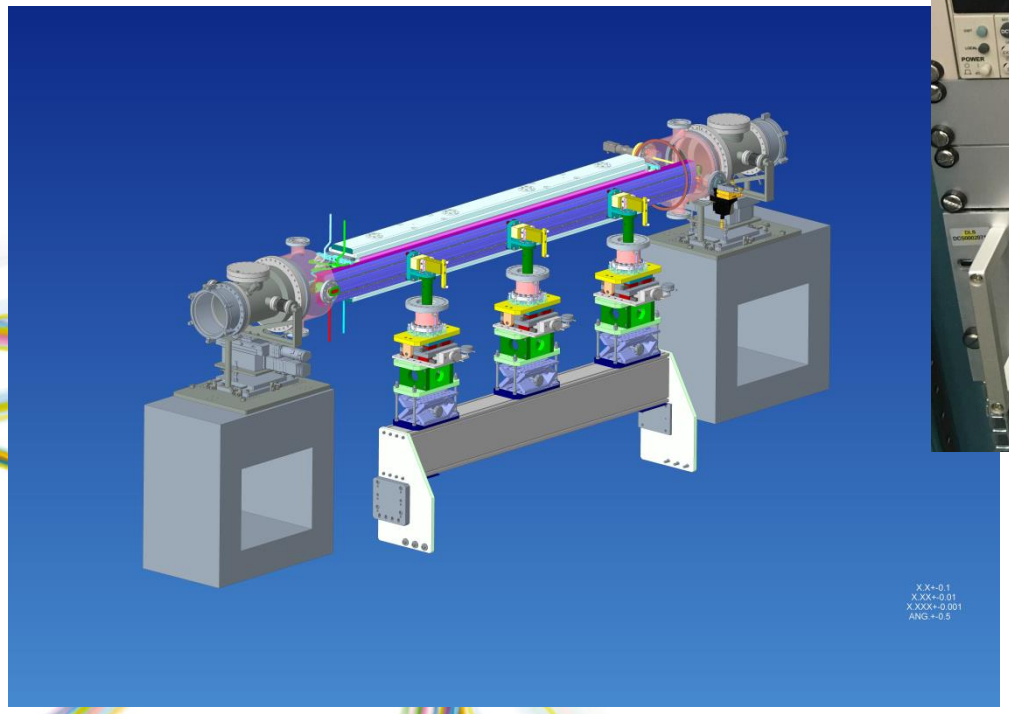
- Field integrals to correct field maps from Hall probe
- Iz measured in x sweep (15 mm/s, S = 15 nV/G·cm)
- Ix measured with vertical movement (4 mm/s, S = 4 nV/G·cm)
- Triggers (positional) need to match up in both directions
- Integration time = 20 ms (PLC = 50 Hz)
- Repeat 10 times to average, st.dev. = 0.08 G·m (increasing repeats doesn't improve st. dev. further)



Cold bench control

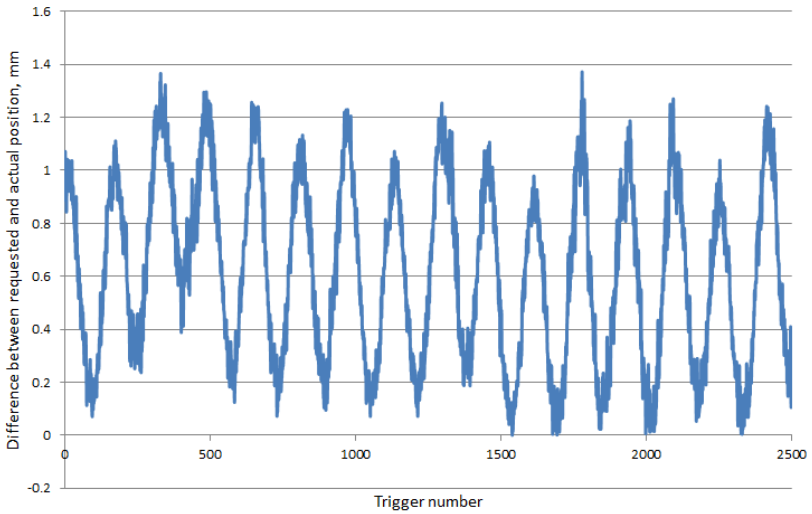
- 3 x 1D hall probes -> Keithley 2700
- Stretched wire -> Keithley 2812A
- PT100 -> Keithley 2700
- Stepper motors controlled by Geobrick (Delta Tau)

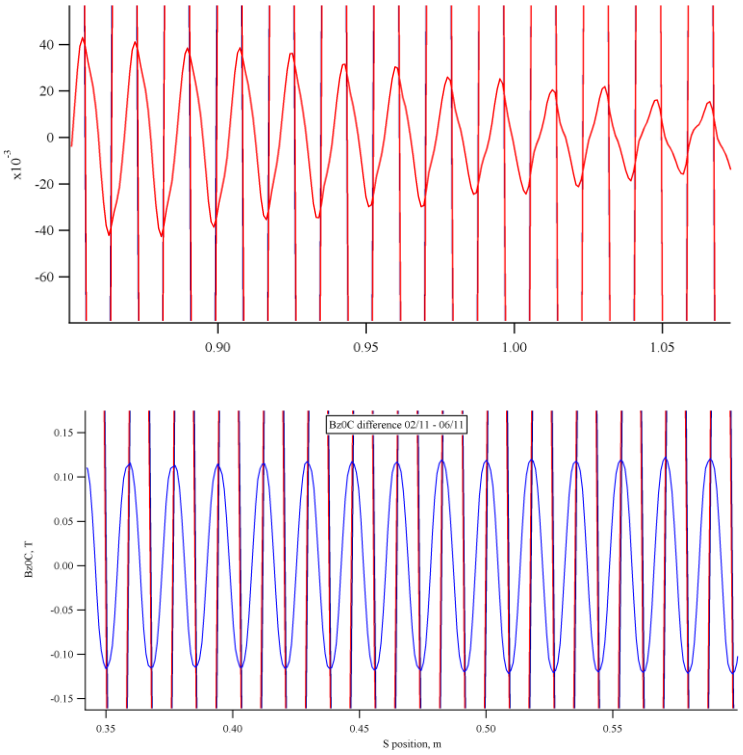




Hall scan repeatability

Large difference between motor position and encoder position during on-the-fly scans:
offset + cyclical behaviour

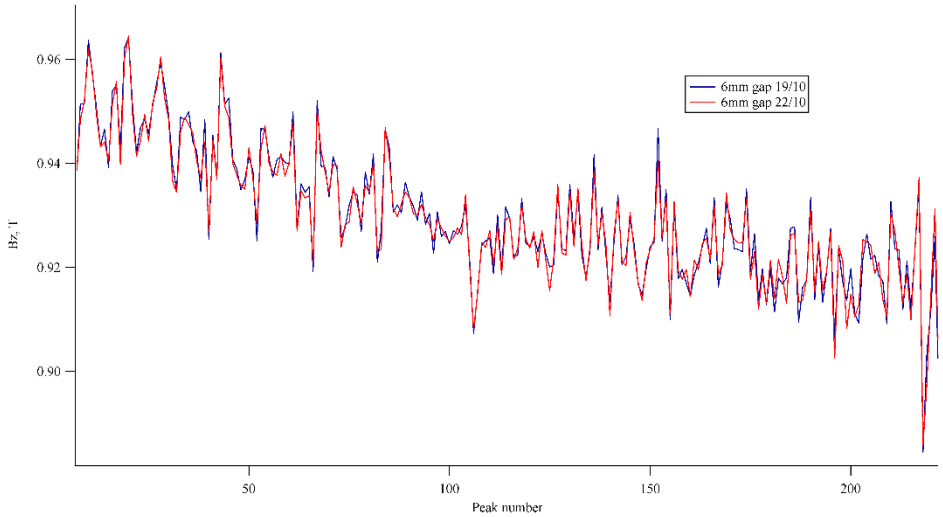


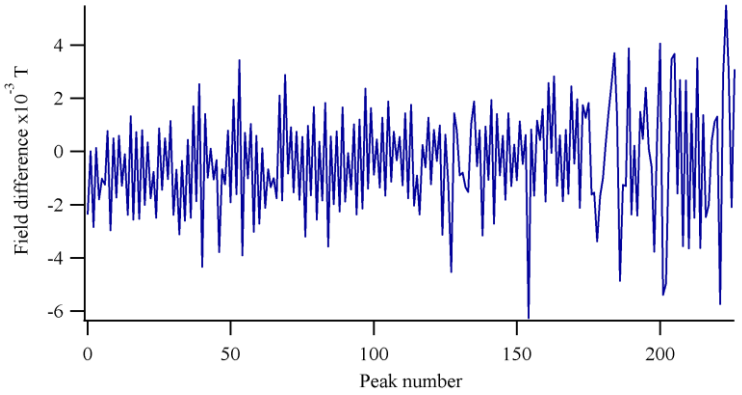


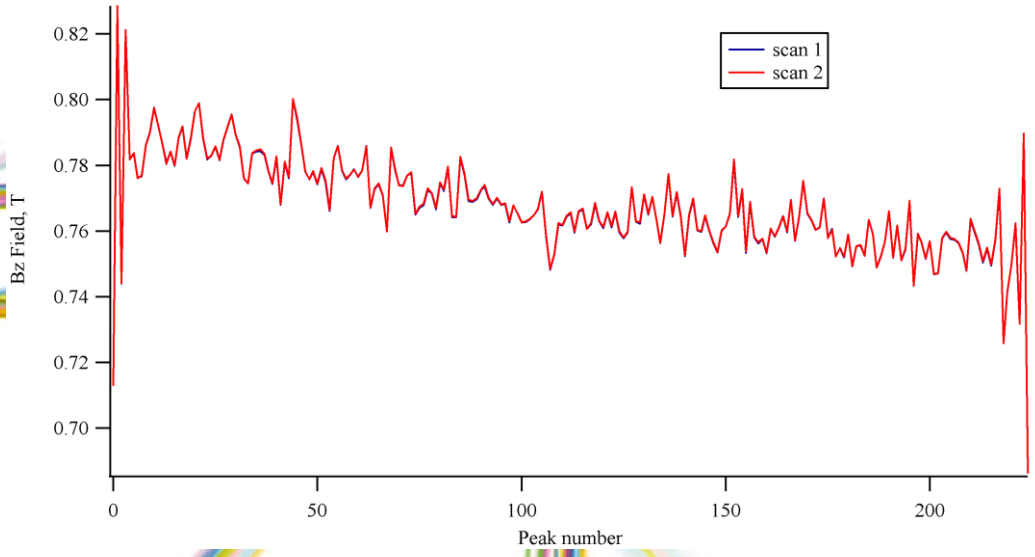
- Wavelength of laser adjusted for vacuum
- Temperature adjustment of field

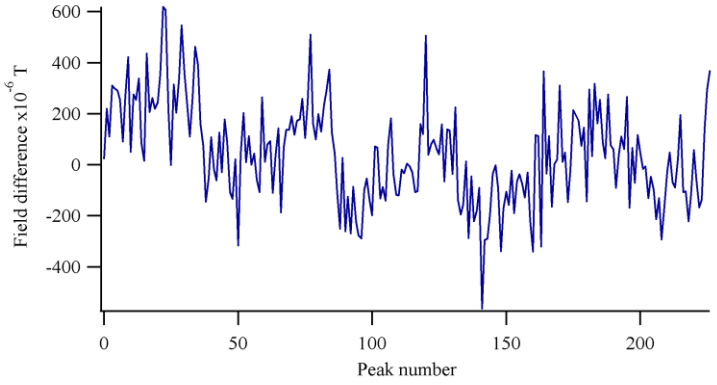
Hall scan repeatability

Step scan reduces vertical oscillation of probe but some position differences remain -> look at peak field only



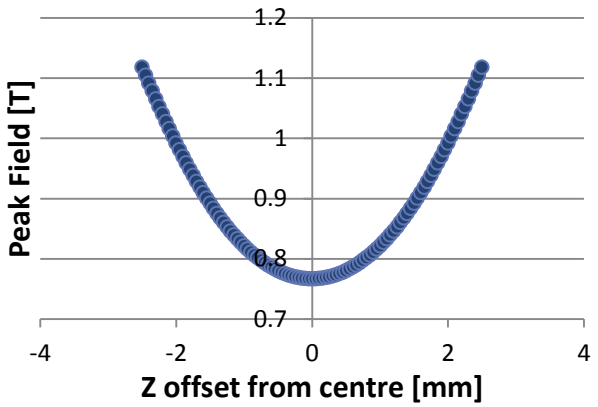


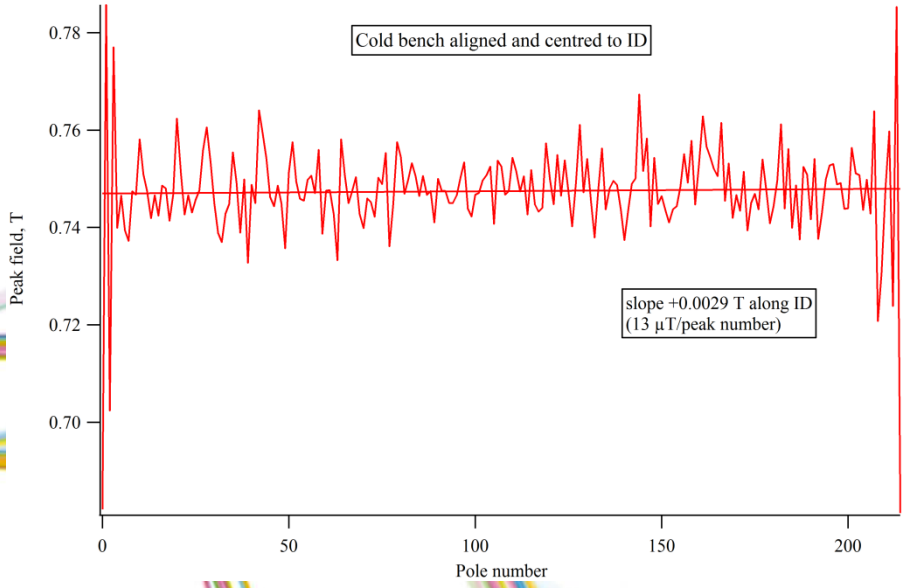


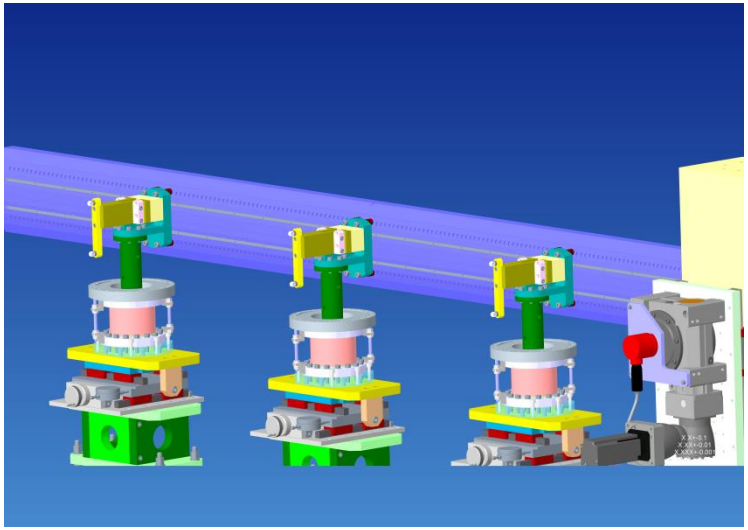


Hall probe alignment

- Manual x and z adjustment of bench on 3 columns
- Set roughly central in gap – magnet beams offset and tilted around probe (limited by the allowable tilt on the ID)







Could not tilt ID further – tilt protection system

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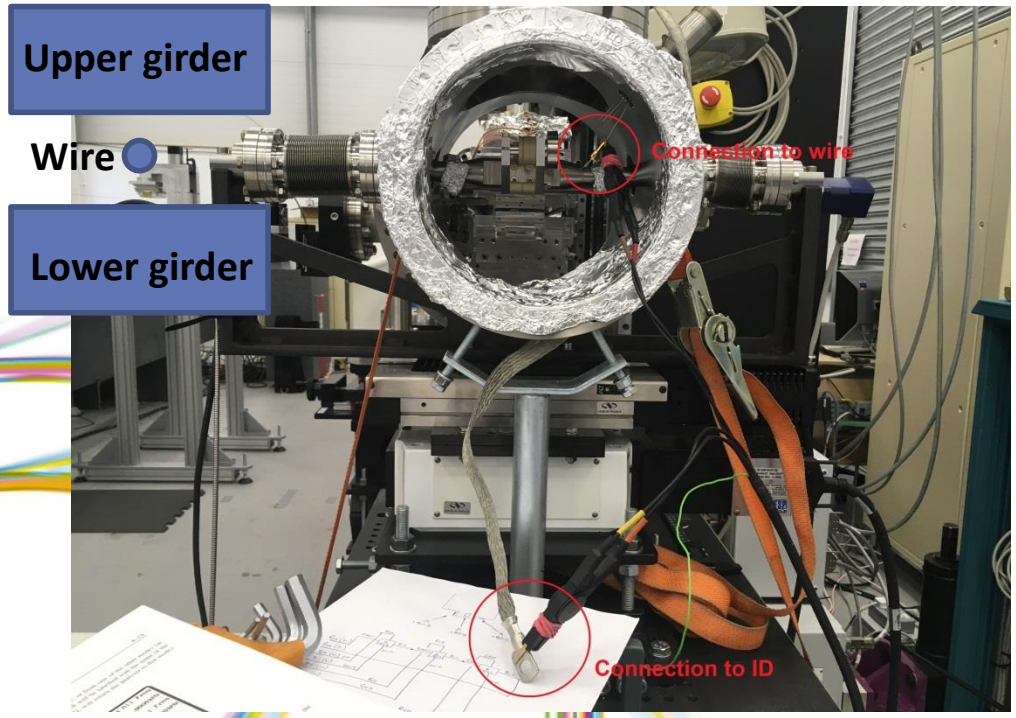
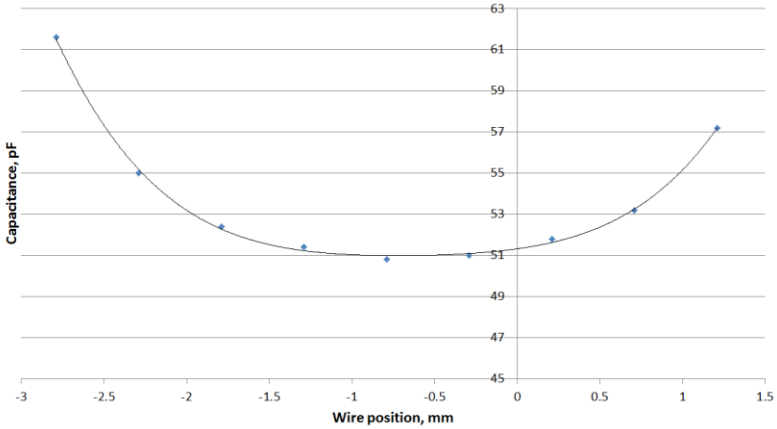
Stretched wire alignment

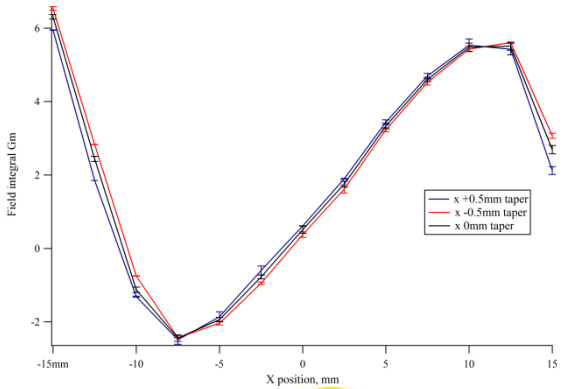
$$C = \frac{2\pi l \epsilon_0 \epsilon_r}{cosh^{-1}\frac{h}{r}}$$

$$C_{total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}}$$

- Capacitance measurements: 2 x wire over ground plane for Z height and taper
- Levelled in x using bubble level (50µm/1m)
- X taper has minimal effect on Iz







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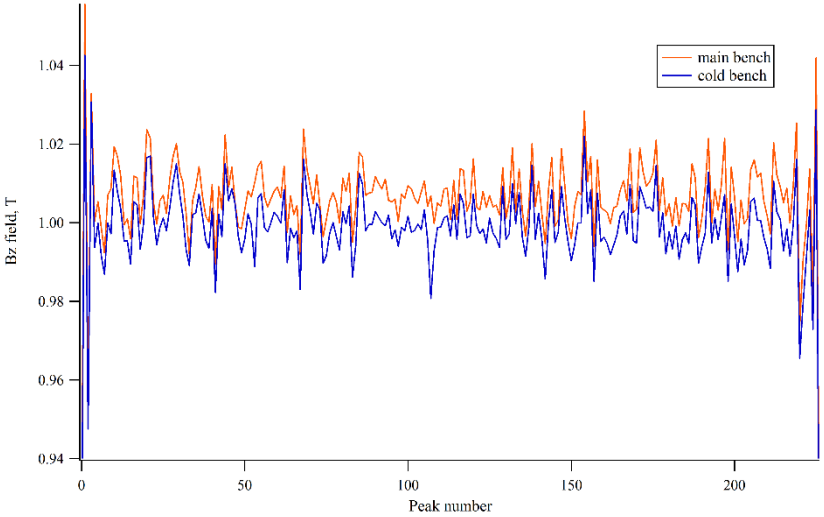
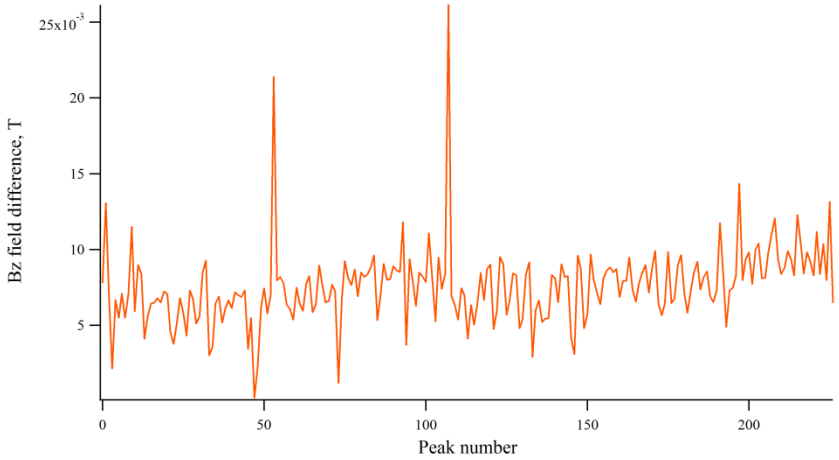
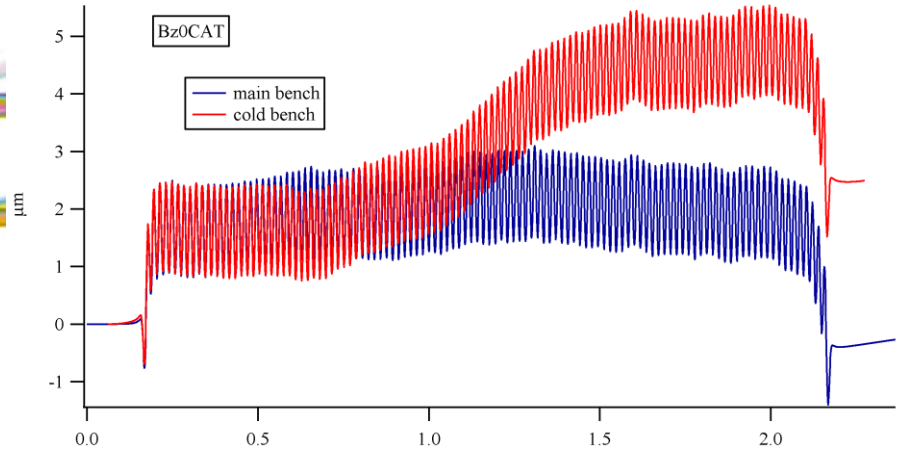
Hall scan comparison with lab bench







- Lab Hall probe bench from ESRF
- Higher field from main bench – main Hall probe not centred as well/calibration issue
- Spikes in difference plot point to real changes in the ID
- Changes reflected in horizontal trajectory

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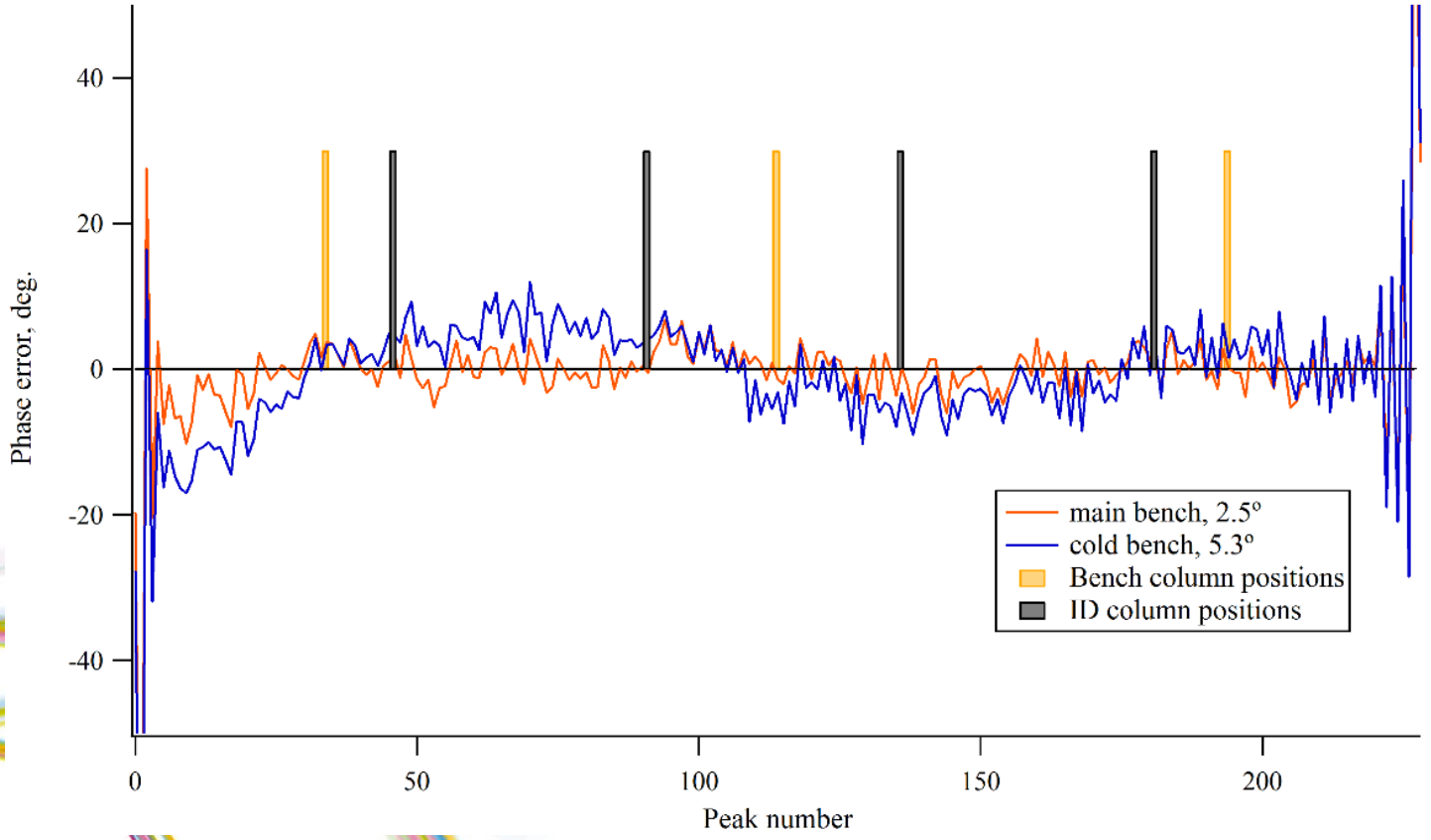
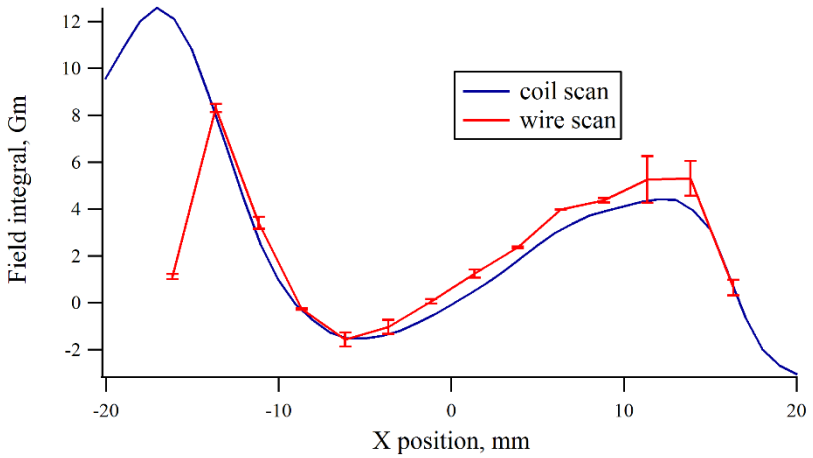
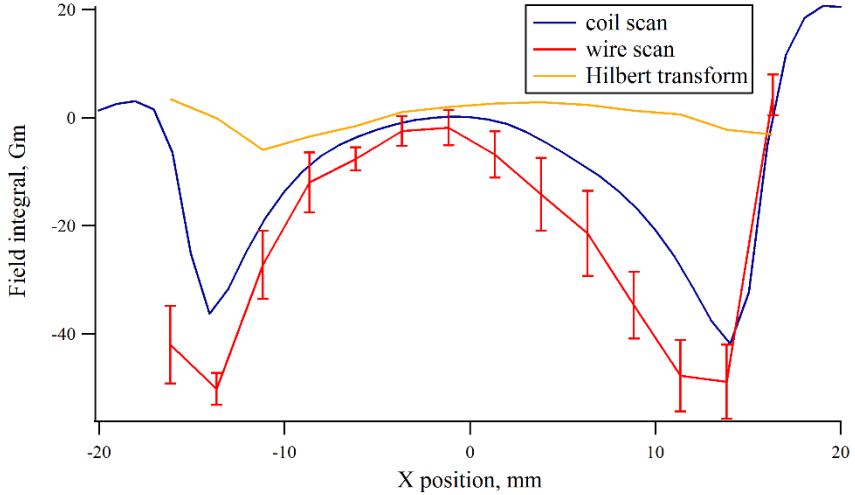
Hall scan comparison with lab bench



Phase plot affected by bench column positions

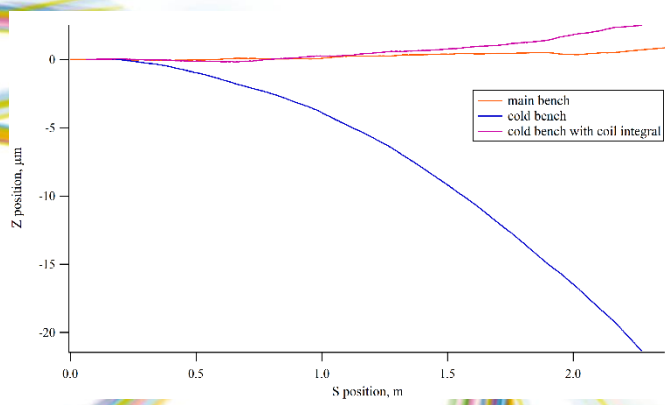
Stretched wire scan comparison





- Rotating coil from ESRF
- Error bars represent st. dev.
- Hilbert transform of Iz data should give Ix

$$F(t) = \frac{1}{\pi t} \int_{-\infty}^{\infty} \frac{f(x)dx}{x - t}$$



Central integrals:

Iz_{coil} = -0.1 G·m, Ix_{coil} = +0.1 G·m

Iz_{wire} = +0.5 G·m, Ix_{wire} = +2.0 G·m

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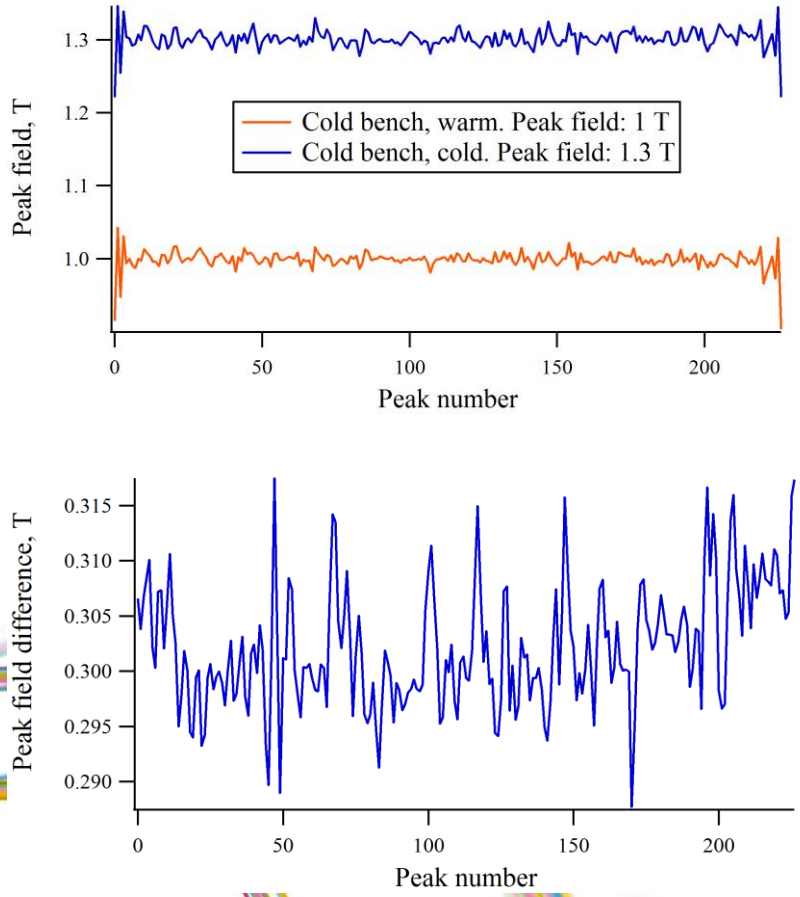
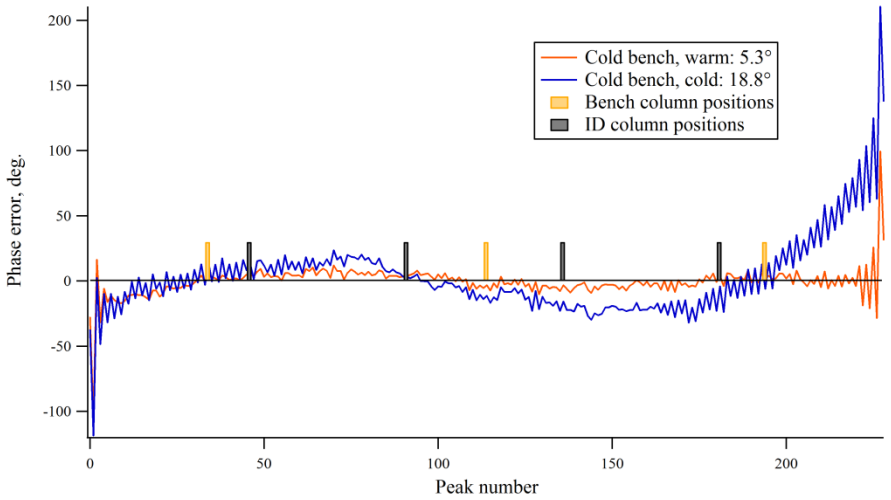
Measurements when cold



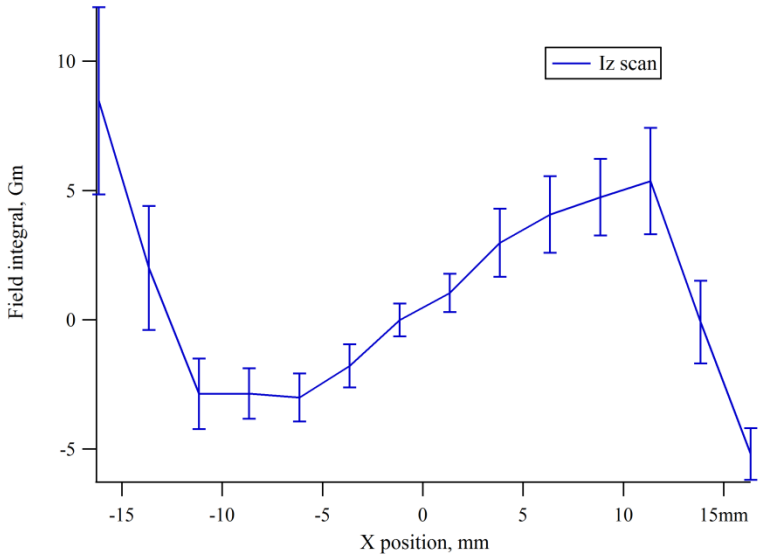
Fourier transform of field data: period decreased by 72 µm; 70 µm expected

- Laser had to be realigned slightly
- Field increase larger than expected
- Gap smaller than measured



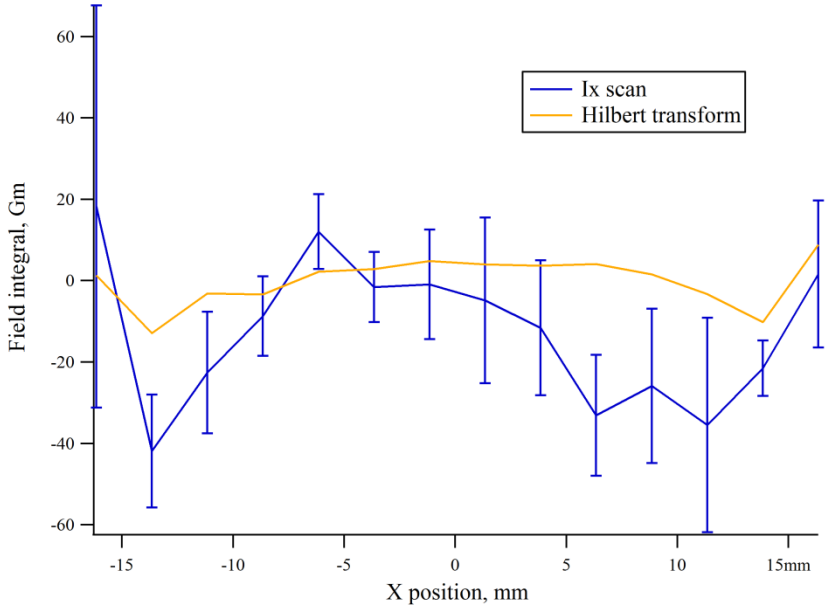
Difficult to tell if phase affected by ID columns due to effect from bench columns

Measurements when cold



Iz warm = +0.5 G·m Iz cold = -0.17 G·m
Ix warm = +2.0 G·m Ix cold = +4.4 G·m

Iz st. dev. from 0.08 G·m to 1.5 G·m
Ix st. dev. from 4.7 G·m to 17.3 G·m



- Wire scans affected by vacuum pump– vibrations
- Now the Hilbert transformation seems closer to the measured data

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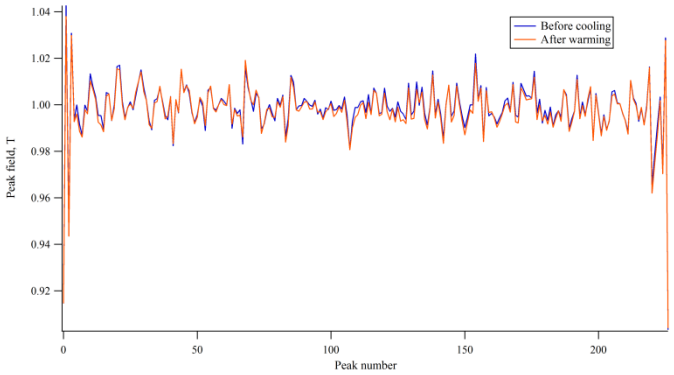
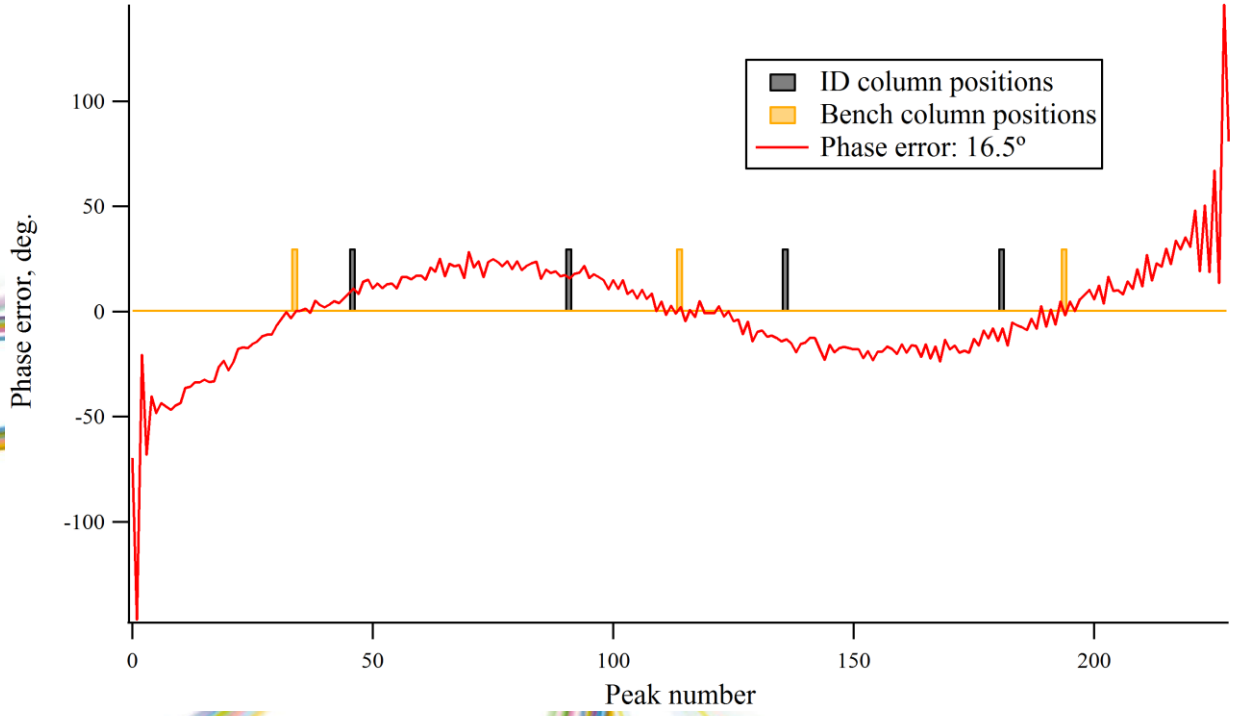
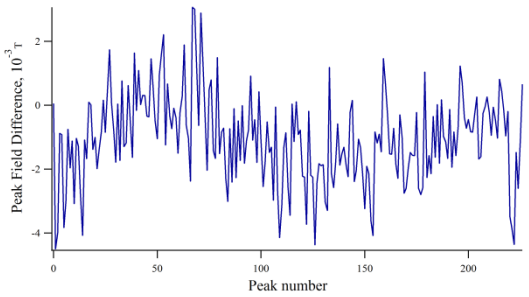
Measurements when warm (after cooling)

- Bench permanently affected by cooling
- Peak field difference up to 4 mT before & after cooling
- Phase error changes masked by bench column effects







Summary of original bench

Successes

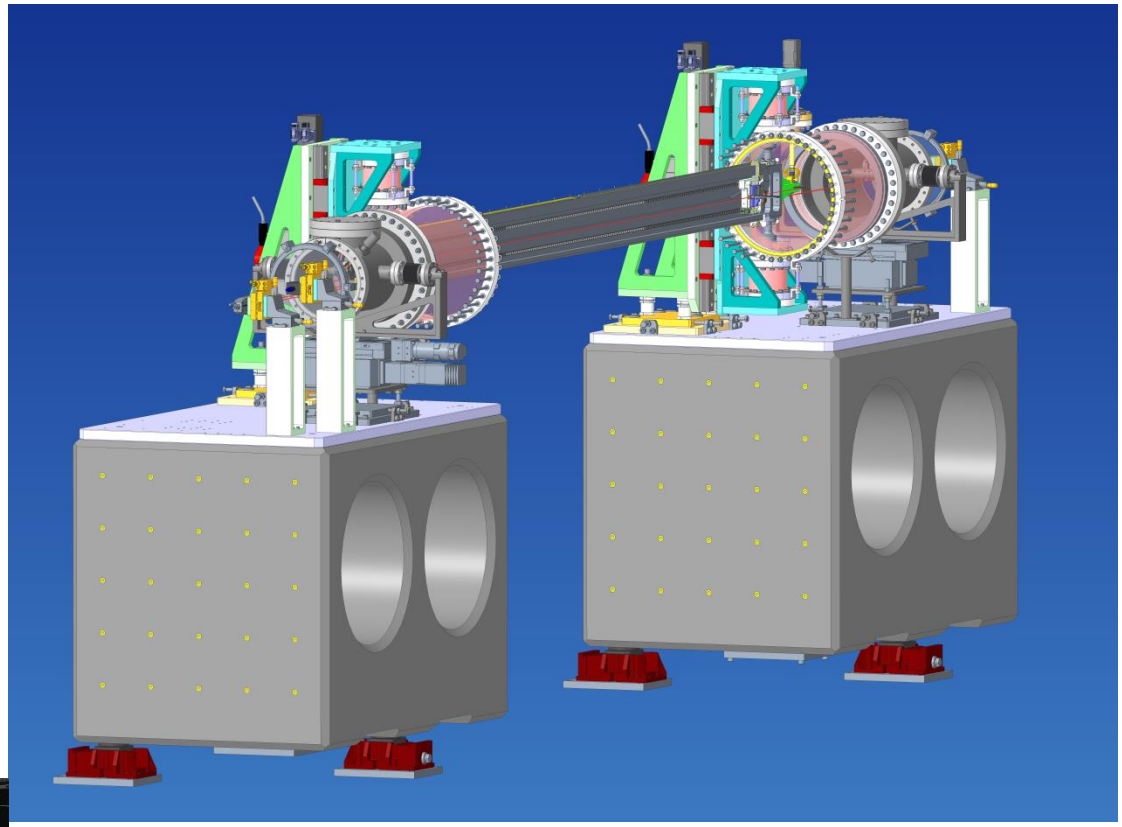
- Peak field (mostly) matched the lab bench measurements
- Able to reach good vacuum
- Works at 77K

Issues

- Pulley system too slack – can't use closed loop control or on-the-fly scans
- Thinness of the rail deforms during and after the cooling that can be seen in the measurements
- Need a more accurate way of aligning the Hall probe & measuring the gap
- Noise on wire measurements

Bench re-design

- Magnet girder re-design = more space in vessel
- Thicker rail
- Pulley running on both sides
- From 3-axis support to 2-axis
- Motorised vertical adjustment



- PSD to measure height

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