Development and characterization of an accurate rotating-coil scanner

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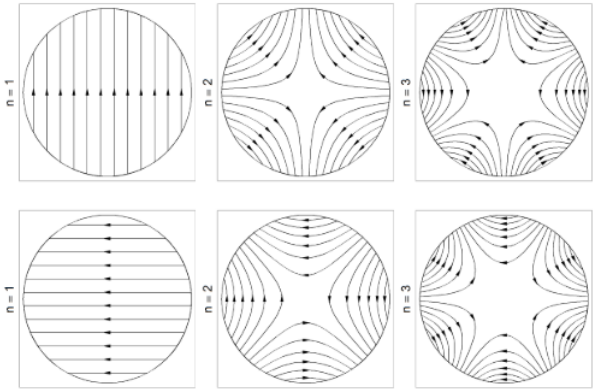
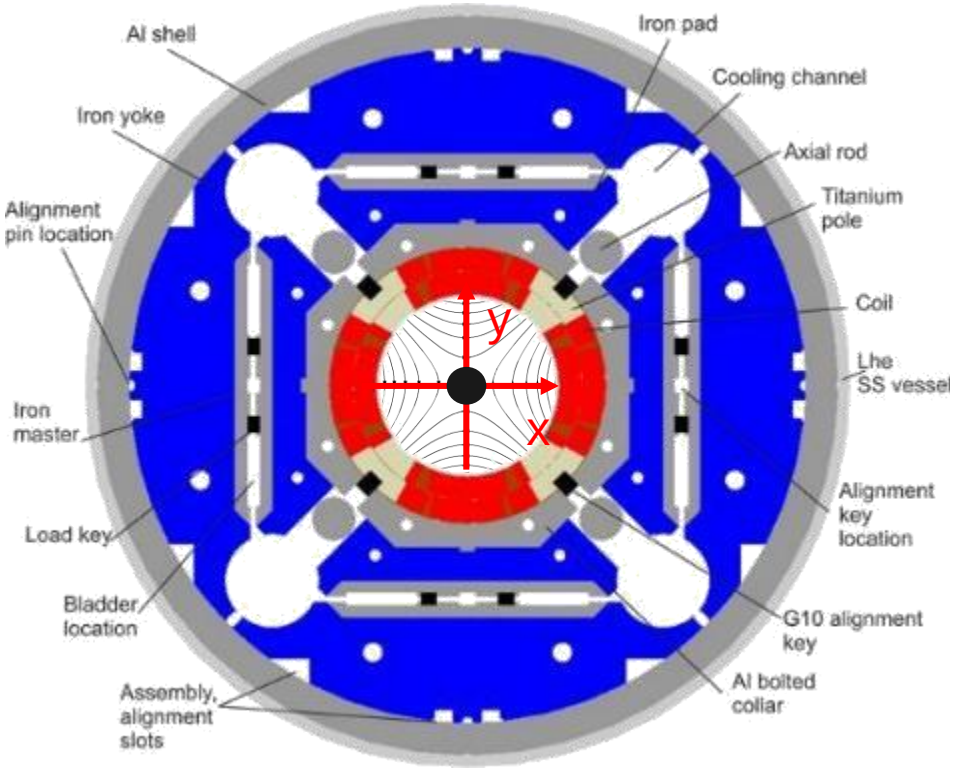
Magnetic measurements

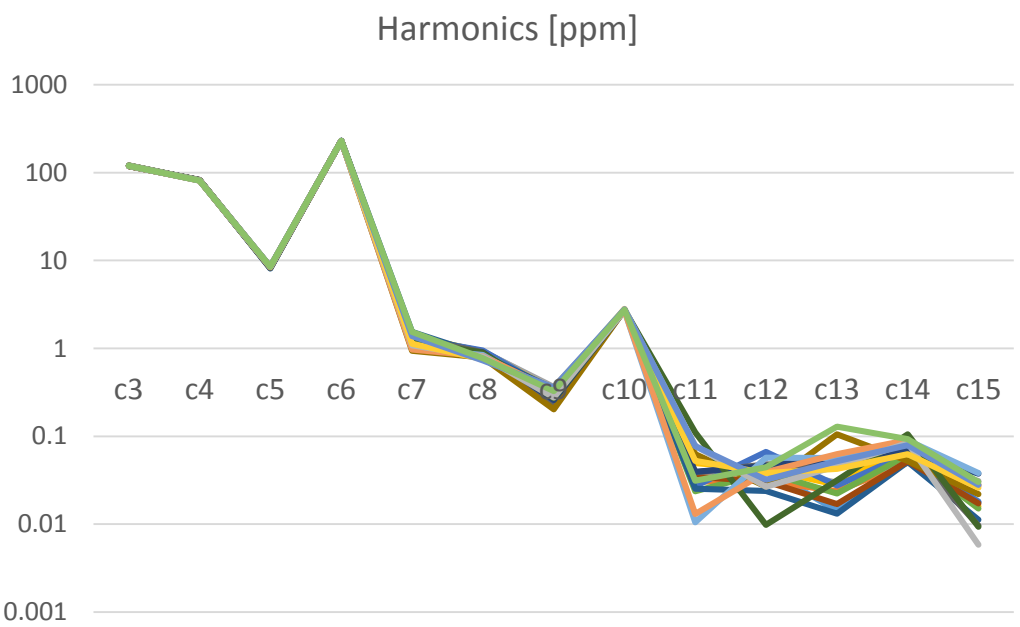
- Field strength
- Field orientation
- Magnetic axis
- Field harmonics

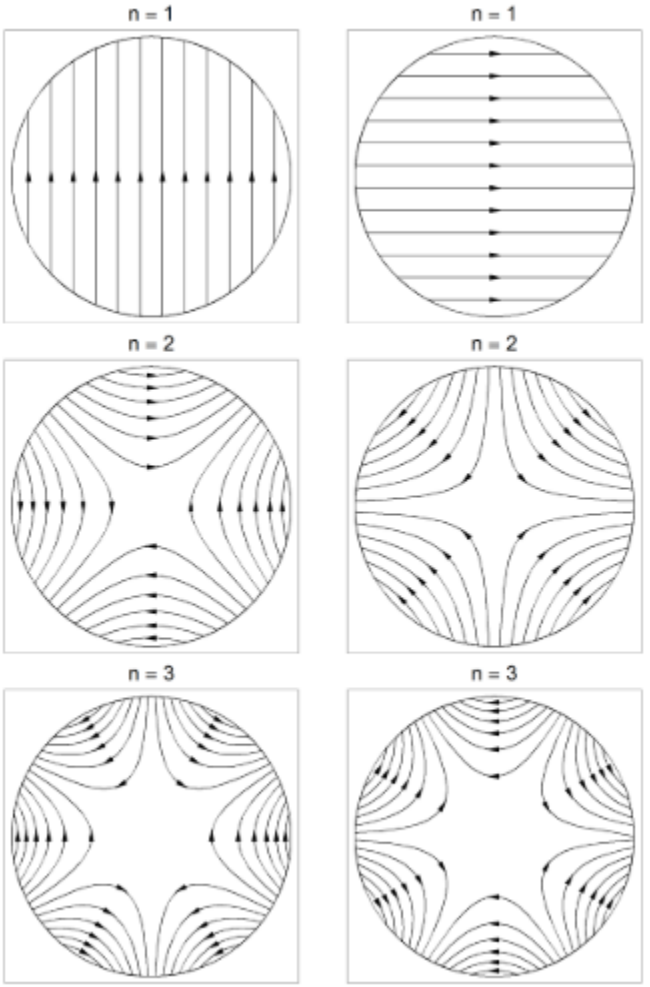




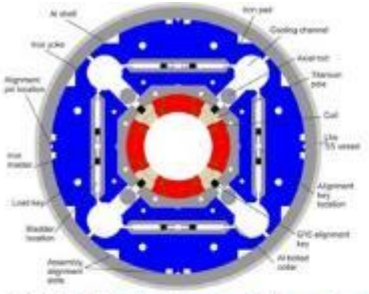
Field multipole expansion

$$B_y + iB_x = B_N \sum_{n=1}^{\infty} \left(b_n(r_0) + ia_n(r_0)\right)\left(\frac{z}{r_0}\right)^{n-1}$$

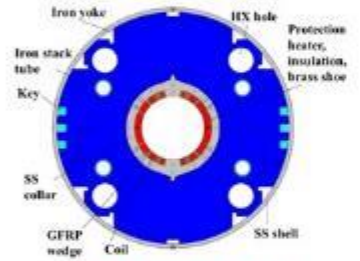




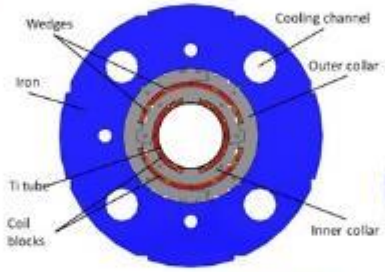
HL-LHC insertion region magnets



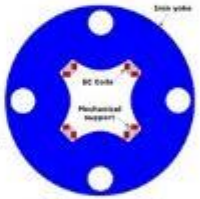
Triplet [G. Ambrosio, P. Ferracin et al.]



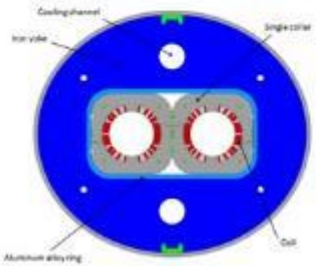
D1[T. Nakamoto et al.]



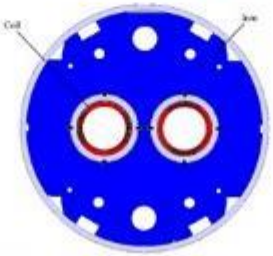
MCBXF [F. Toral, et al.]



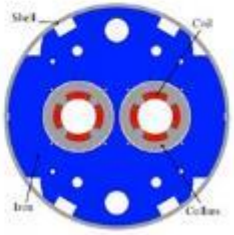
Skew quad [G. Volpini, et al.]



D2 [P. Fabbricatore, S. Farinon]



D2 correctors [G. Kirby, J. Rysti]



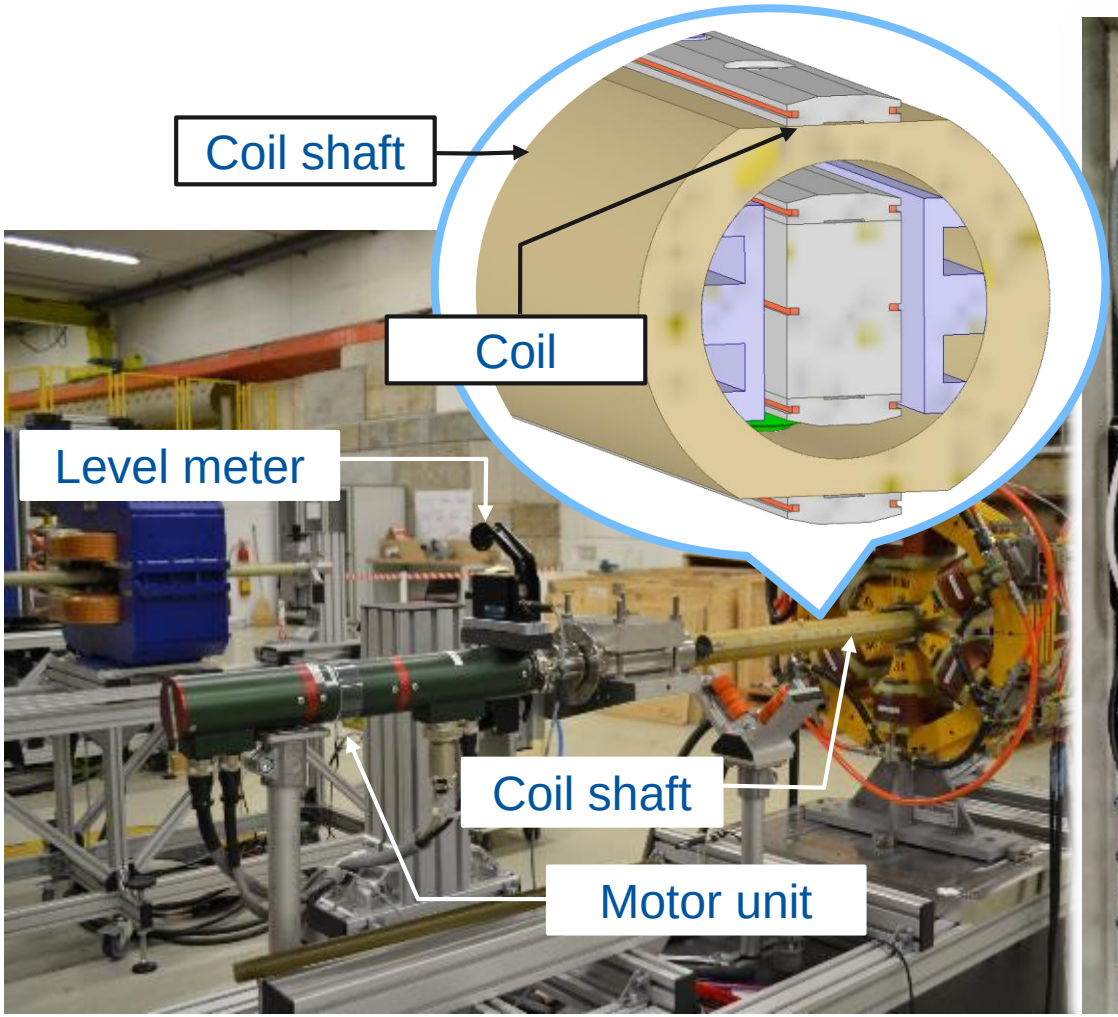
MQYY [J. M. Rifflet, M. Segreti, et al.]

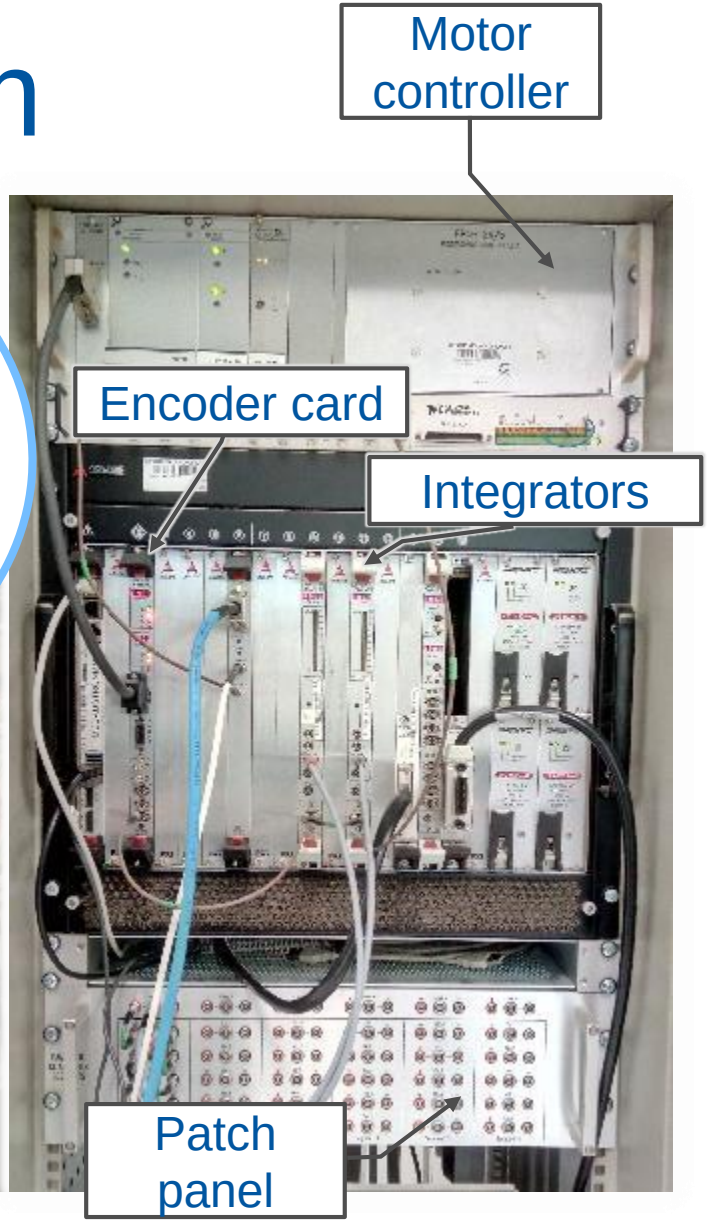
Required accuracy

Main field	100 ppm	Relative to nominal of ~8 mT locally (currently 1‰ locally)
Magnetic center	~50 µm	Referenced to magnet geometry, using laser tracker
Field angle	0.1 mrad	Or ~0.006°
Longitudinal magnetic center	1 mm	In a 10-meter-long magnet (currently 2-3 mm)
Harmonics (High order content)	1 ppm	Relative to the main field, meaning 8 nT in 8 mT field

■ Not achievable yet ■ Achievable, using more than one system ■ Achievable now

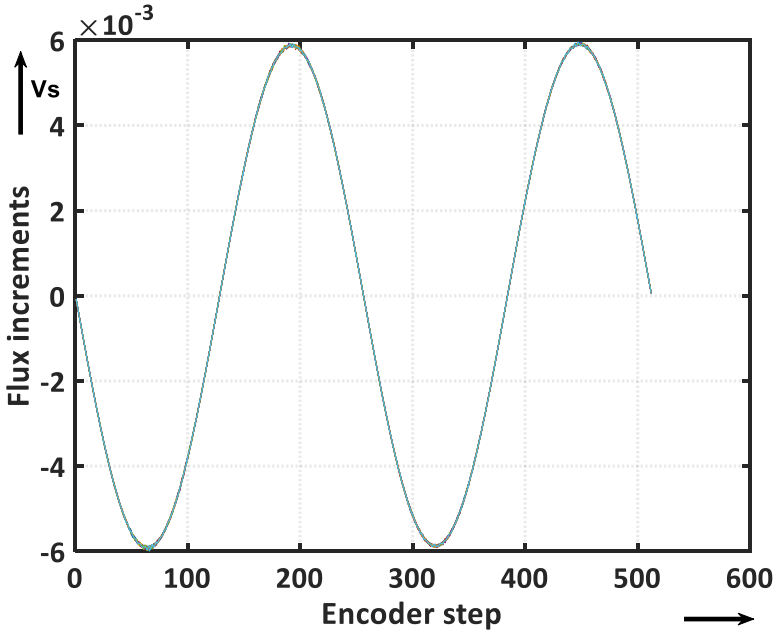
Rotating coil system





Rotating coil transducer

- Very robust data analysis:
  - Fourier transform of acquired sinusoidal signal



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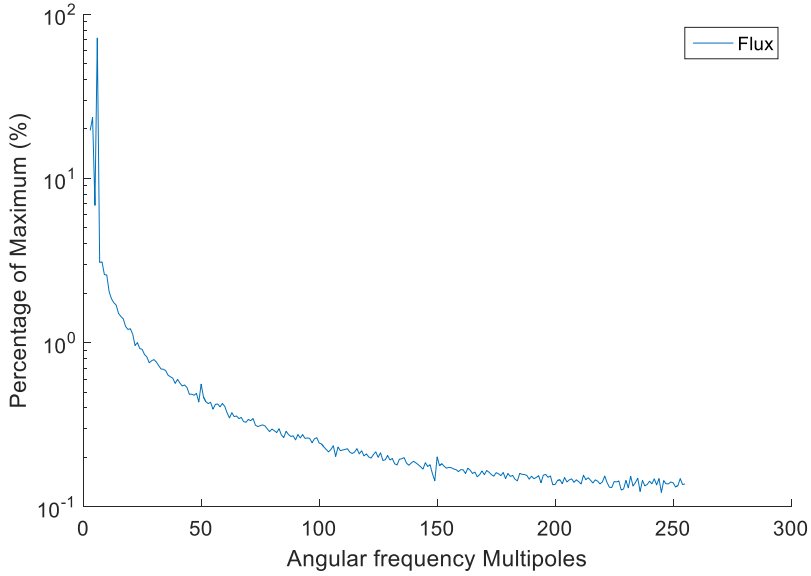
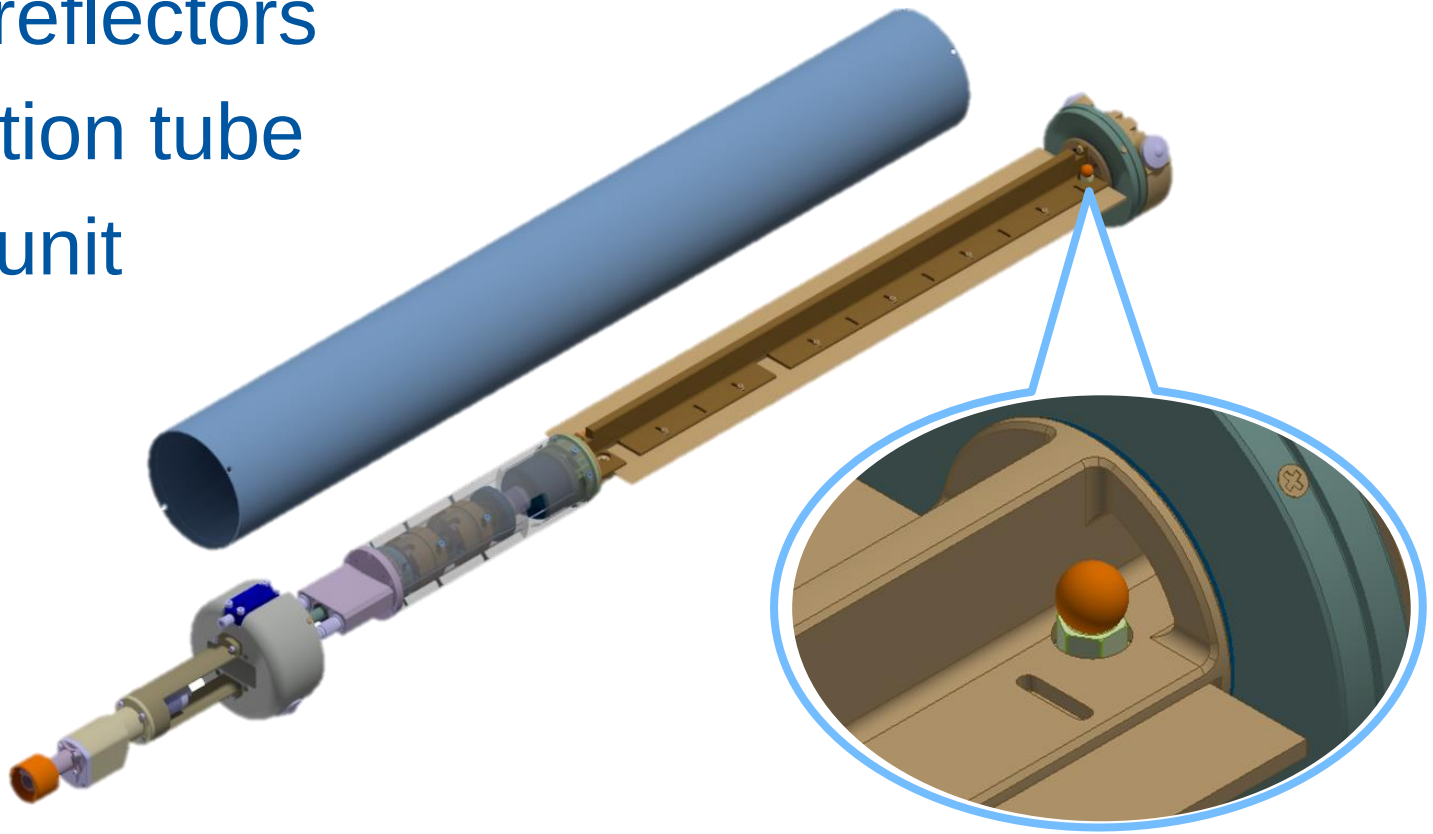
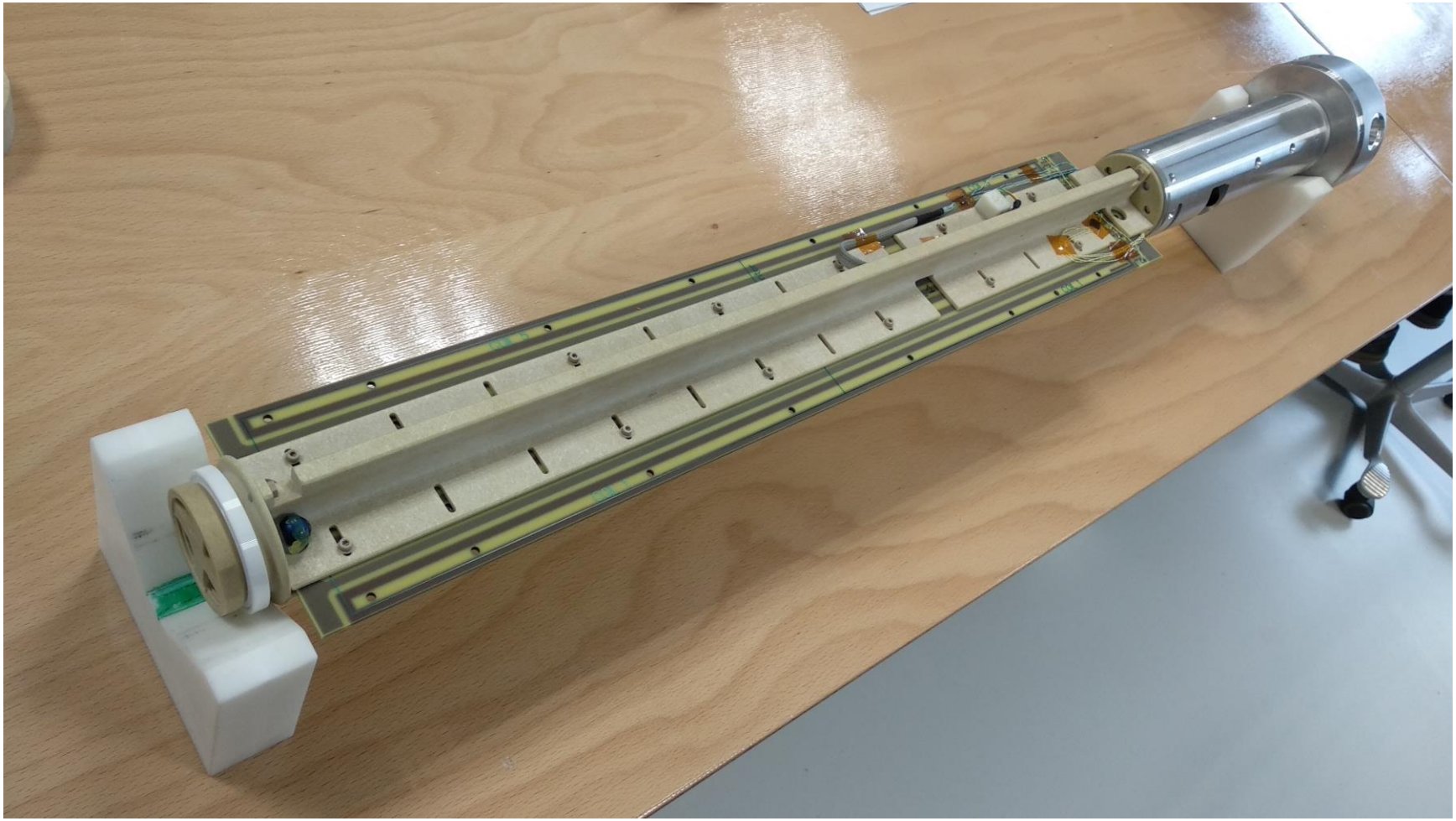


Scanner prototype

- PCB coils
- Retro-reflectors
- Protection tube
- Motor unit

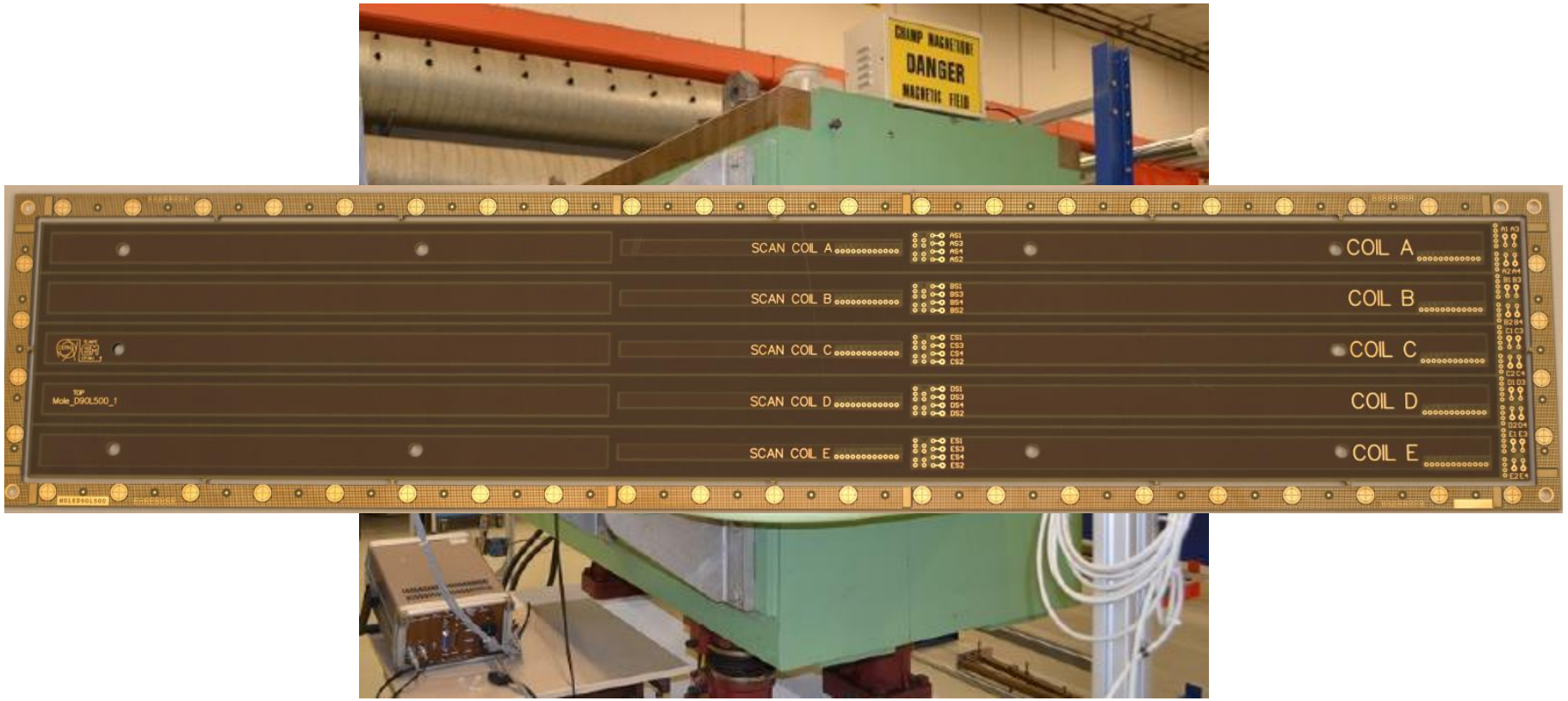


Scanner prototype



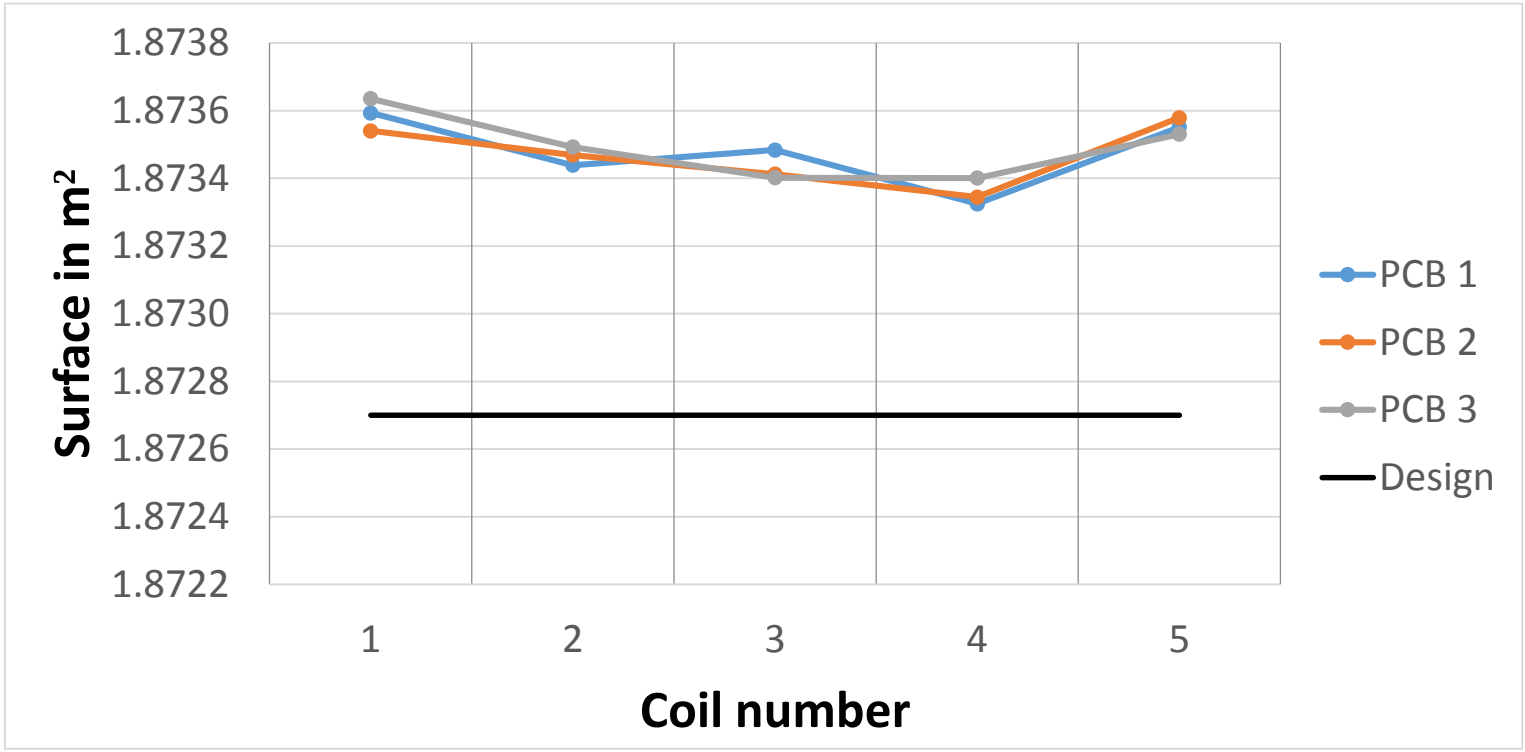
PCB coil calibration

- Coil surfaces are calibrated in a dipole magnet with a well known field profile.



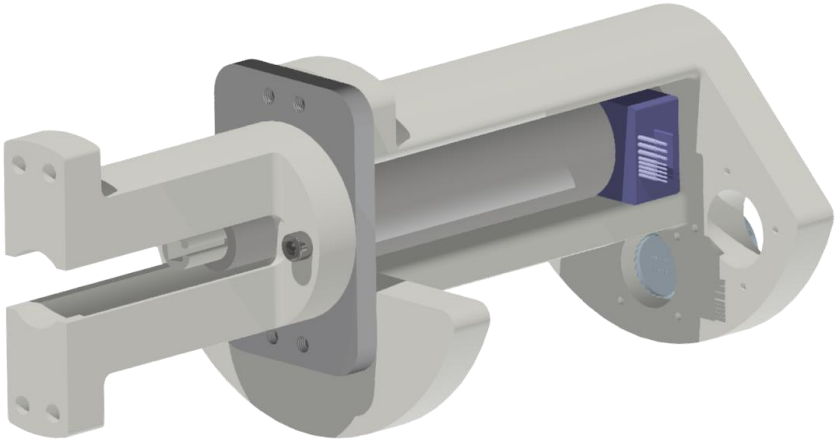
PCB calibration

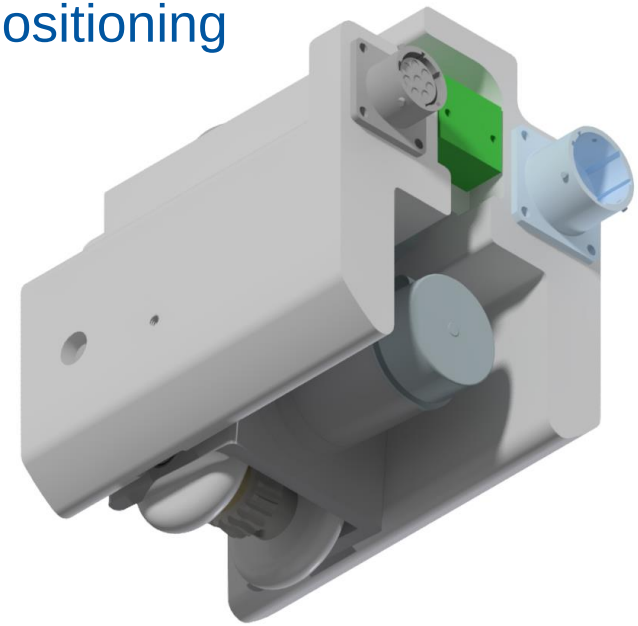
- Results at the limit of calibration accuracy



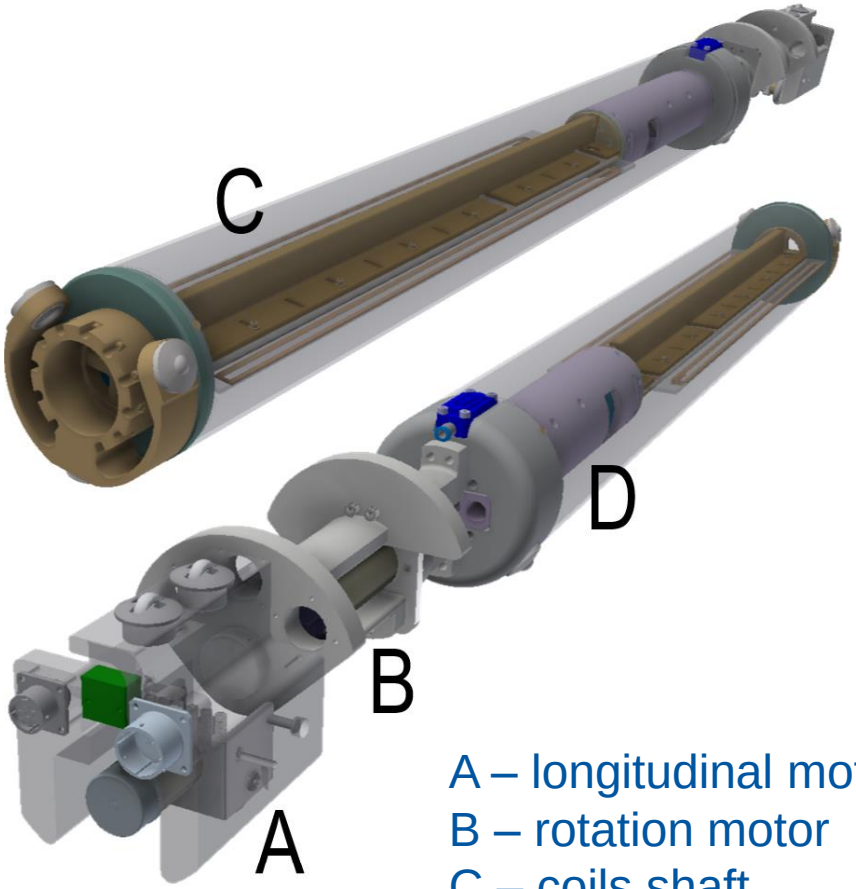
New motor unit

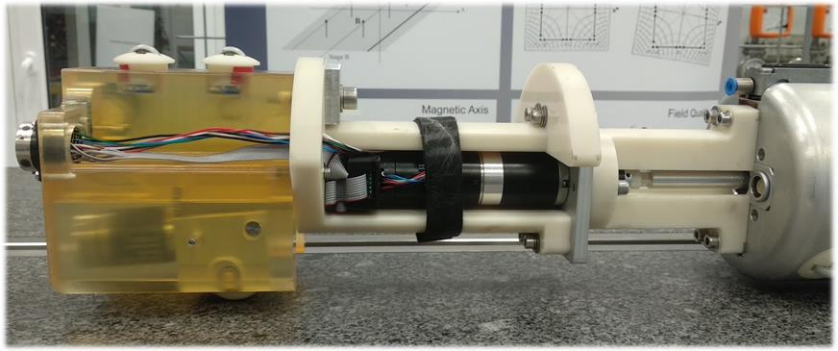
- 1st stage: electric motor with high precision encoder and tilt sensor directly on the PCB:
  - Minimal changes in the transducer required
  - Flexible, multipurpose unit for low field measurements
  - Greatly simplified and more robust leveling procedure
  - Additional motor for longitudinal positioning

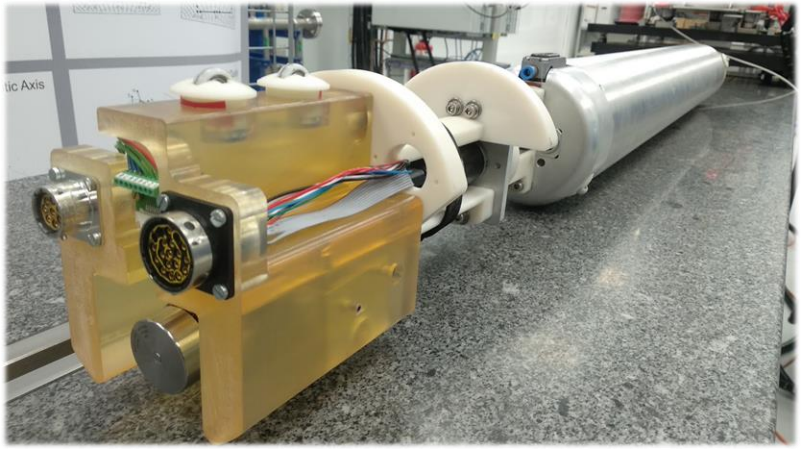




Fully automated scanner

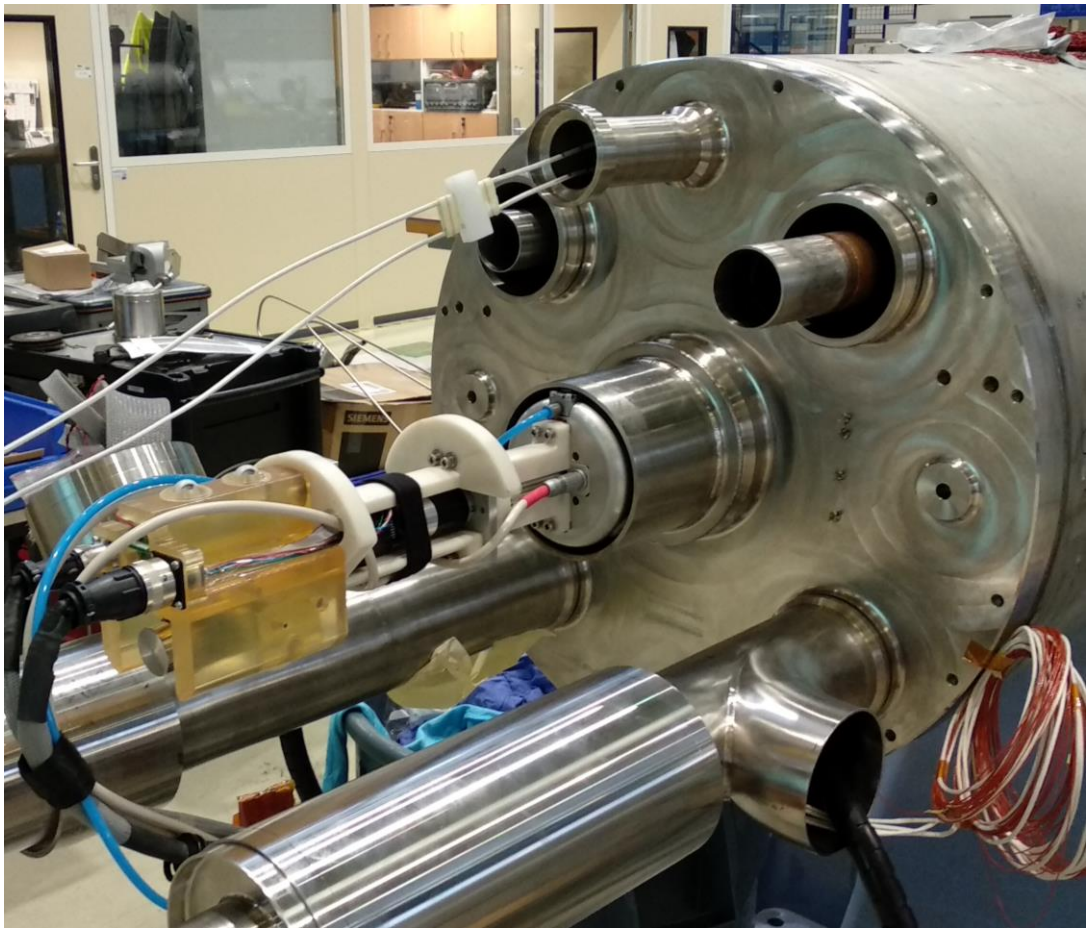




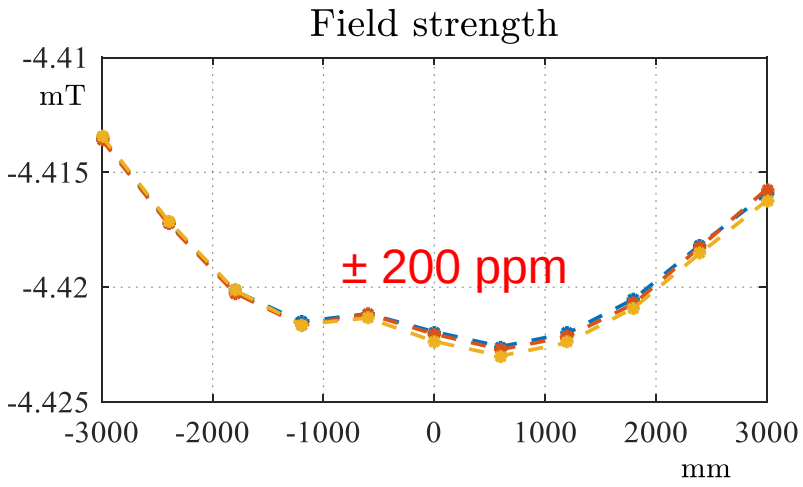


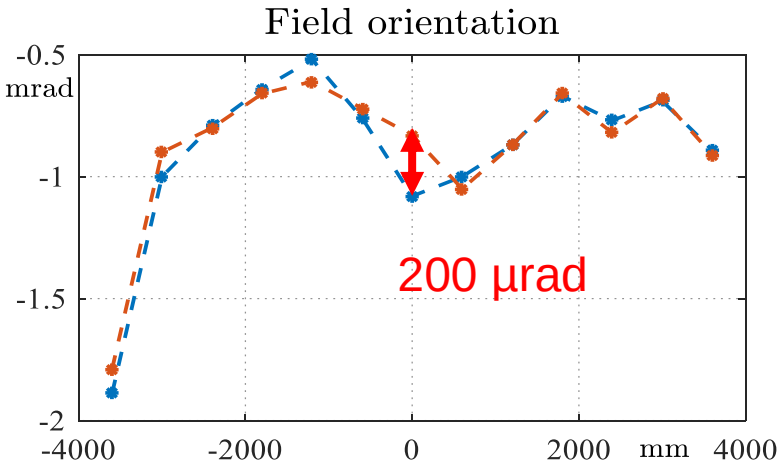
A – longitudinal motor
B – rotation motor
C – coils shaft
D – electronics base

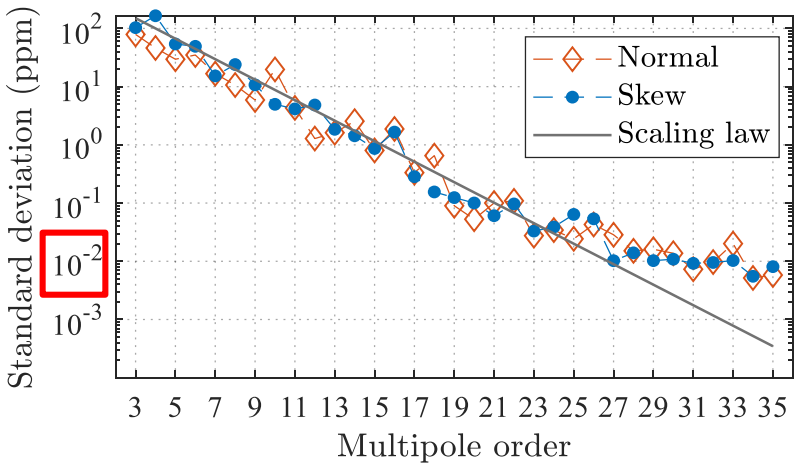
Fully automated scanner

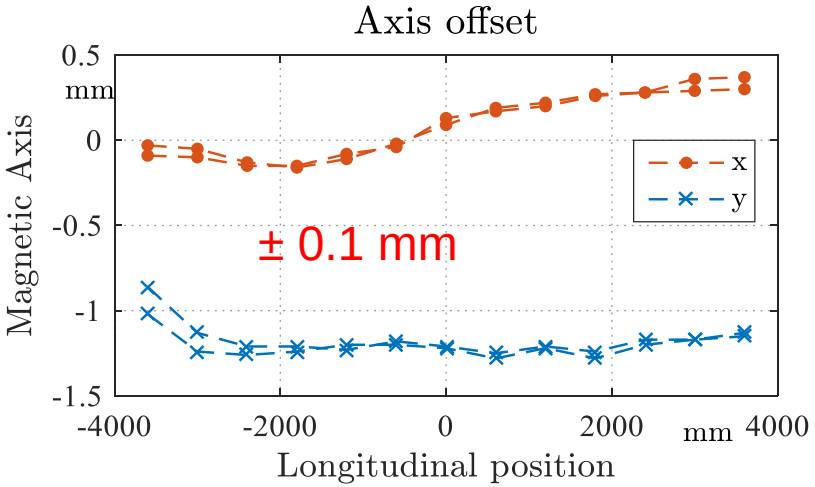


Measurement results

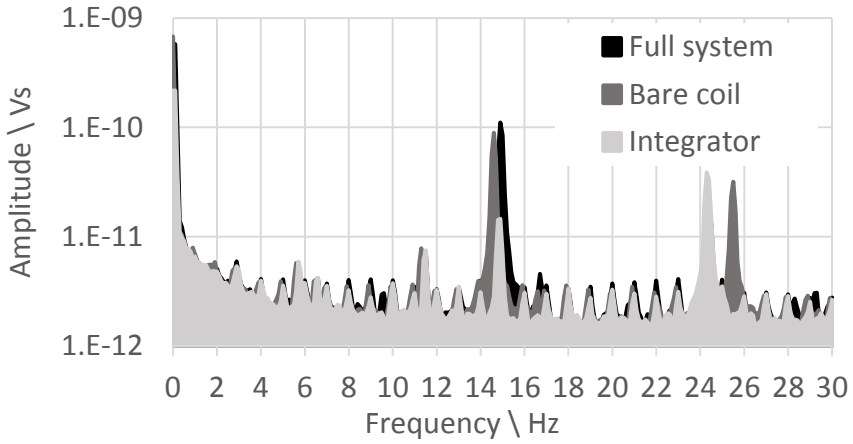








Noise of the acquisition chain

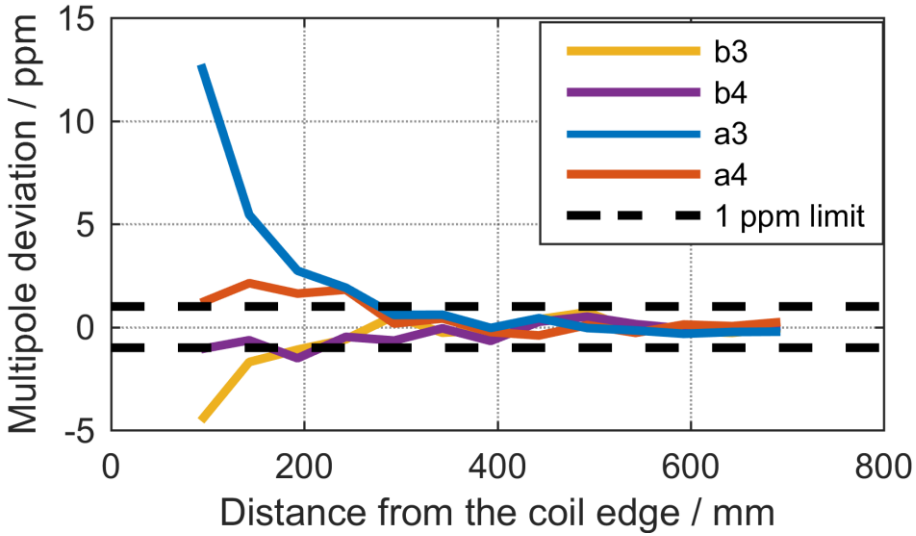


Signal-to-noise-ratio evaluation:

- SNR of the integrator:
  90-95 dB
- SNR of the absolute coil:
  75 dB
- SNR of the compensated coils:
  85 dB

Electric motor influence:

- Safe distance from a coil
  - 80 W motor: ~300 mm
  - 15 W motor: ~100 mm
- Only harmonics are significantly affected



Conclusions

- A new rotating-coil scanner design, capable of measuring all necessary quantities for HL-LHC triplet magnets in a single scan.
- Effectively substituting 2 different measurement systems, necessary for a full magnet characterization up until now.
- Full automatization of the measurement allows statistical data treatment.
- Accuracy still limited by the mechanics and environment.
- Results suggest room for possible improvements.