Status of ELENA B-train

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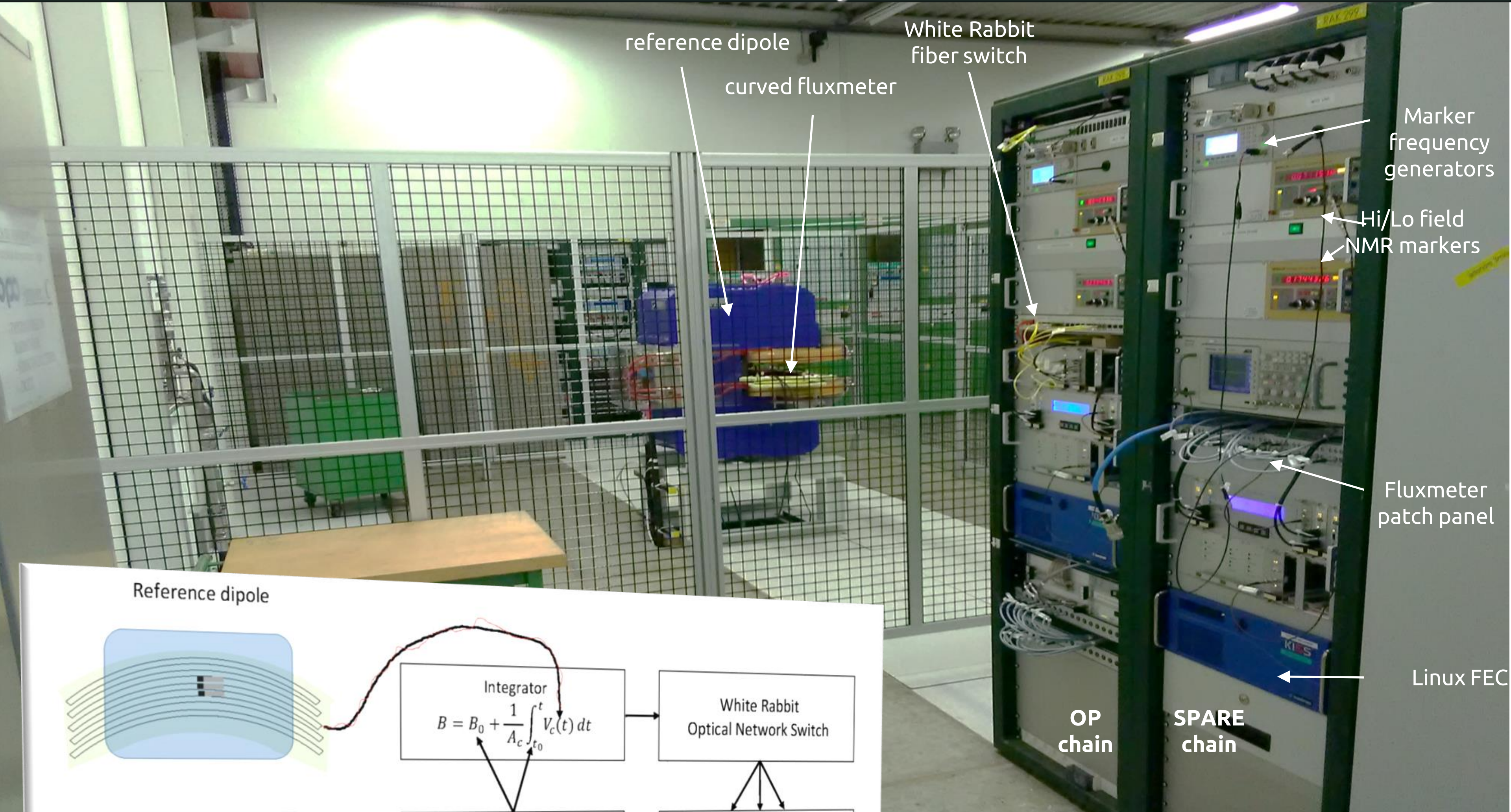
TE/MSC/MM

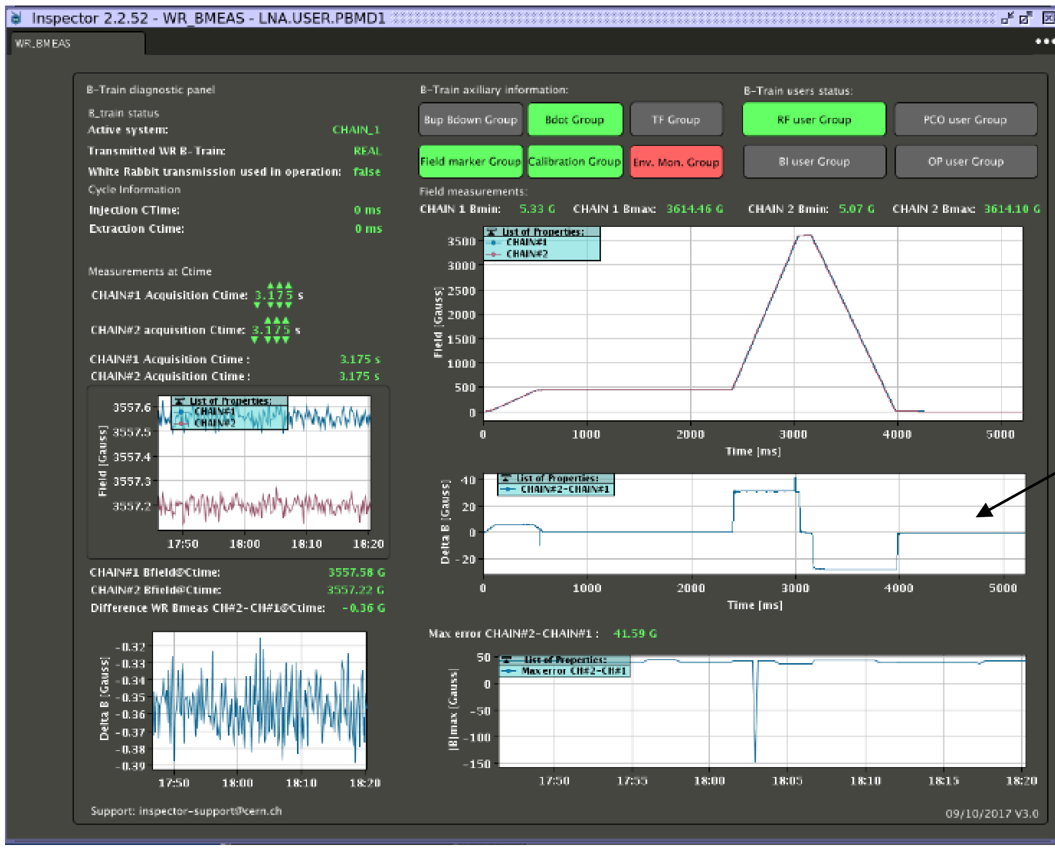
1. **Status, performance and issues**
2. **Activity during YETS and plans for the restart**

ELENA B-train system



Safety concern: replacement of non-standard key to 193-R-408 still pending → door is left OPEN

- OP system has been calibrated according to nominal values for PBMD2 cycles in September ⇒ 3 mm radial offset need to be applied
- SP system is being used in the shadow of normal operation (mostly …) to test the new absolute calibration

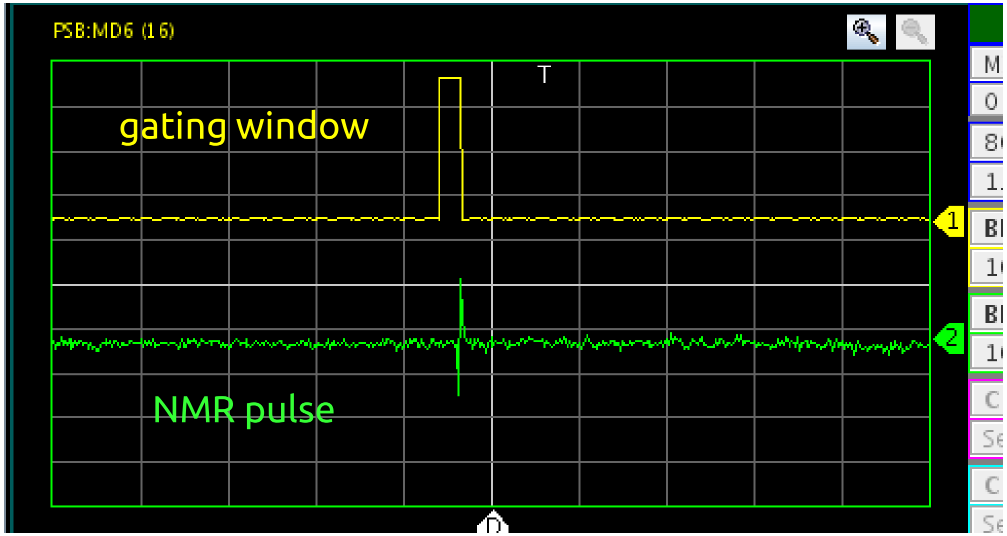


Synch problem in FESA acquisition from different FECs

(difference OP/SP is wrong!)

Inspector diagnostic interface

- Missing marker pulses in Sep were traced back to misaligned NMR gating window → please do tell us when the cycles are modified in a way that affects the time when B=450 G (low marker) or B=3400 G (high marker) are reached
- 2.4% rounding error in the gain found and corrected (NB irrelevant for "traditional" calibration by trial and error)
- For the moment we still need "zero" cycles (PMD3) to be reserved for ADC calibration (coil input shorted). NB these are recognized by name
- New PCB fluxmeter: dropped due to the two only suppliers found being incapable of providing large-scale boards with acceptable quality
- Switching to negative polarity cycles: automatic switching of the PT2025 teslameter is implemented, but needs to be tested

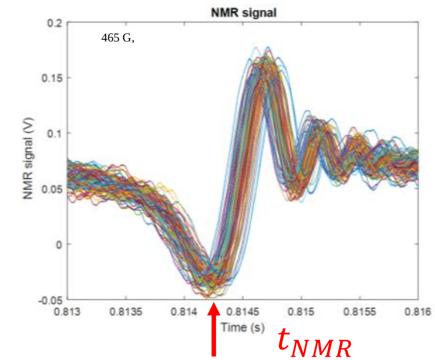


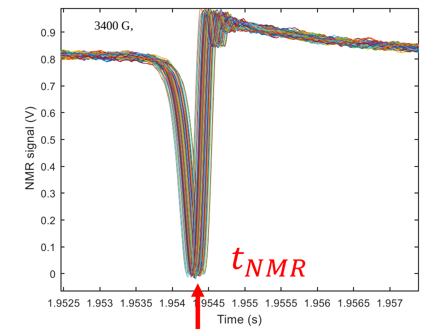
TRIGGER SIGNAL REPEATABILITY FOR VARIOUS COMBINATIONS OF B AND $\dot{B}$

B (mT)	$\dot{B}$ (mT/s)	$B/\dot{B}$ (s)	$\sigma_{t_{NMR}}$ [ms] OP	$\sigma_{t_{NMR}}$ [ms] SP	$\sigma_{B(t_{NMR})}$ [μT] OP	$\sigma_{B(t_{NMR})}$ [μT] SP	$\sigma_{B(t_{NMR})}/B$ [10^{-4}] OP	$\sigma_{B(t_{NMR})}/B$ [10^{-4}] SP
43.0	151	0.284	0.037	0.036	5.6	5.5	1.30	1.28
44.5	151	0.294	0.047	0.047	7.1	7.1	1.60	1.60
45.0	151	0.297	0.054	0.059	8.2	9.0	1.82	2.00
44.5	76	0.588	0.063	0.062	4.8	4.7	1.08	1.06
45.0	76	0.594	0.075	0.075	5.7	5.7	1.27	1.27
46.5	58	0.800	0.057	0.055	3.3	3.2	0.71	0.69
44.5	41	1.077	0.067	0.065	2.8	2.7	0.63	0.61
45.0	41	1.090	0.104	0.109	4.3	4.5	0.96	1.00
46.5	31	1.490	0.108	0.099	3.4	3.1	0.73	0.67
340	584	0.582	0.0039	0.0044	2.3	2.6	0.07	0.08
340	443	0.767	0.0056	0.0067	2.5	3.0	0.07	0.09
340	195	1.744	0.0138	0.0137	2.7	2.7	0.08	0.08

$$\sigma_{B(t_{NMR})} = \frac{dB}{dt}\sigma_{t_{NMR}}$$

NB conservative evaluation, does not take into account current and magnet repeatability





- NMR marker repeatability (OP/SP): 0.09 G (@ 450 G) **0.03 G** (@ 3400 G)
- Integrator drift (OP/SP): **0.02 ± 0.01 G/s**
- Overall reproducibility @ injection: **0.04 G** (OP) 0.7 G (SP)
- Difference OP-SP: -0.7 ± 0.7 G ($3\cdot10^{-4}$)

Does not seem consistent, needs to be checked

(for comparison: magnet's transfer function repeatability = $3.5\cdot10^{-5}$ (-))

$$V_c = \frac{1}{1 - \frac{R_c}{R_{in}}}(V_{in} - V_0)$$

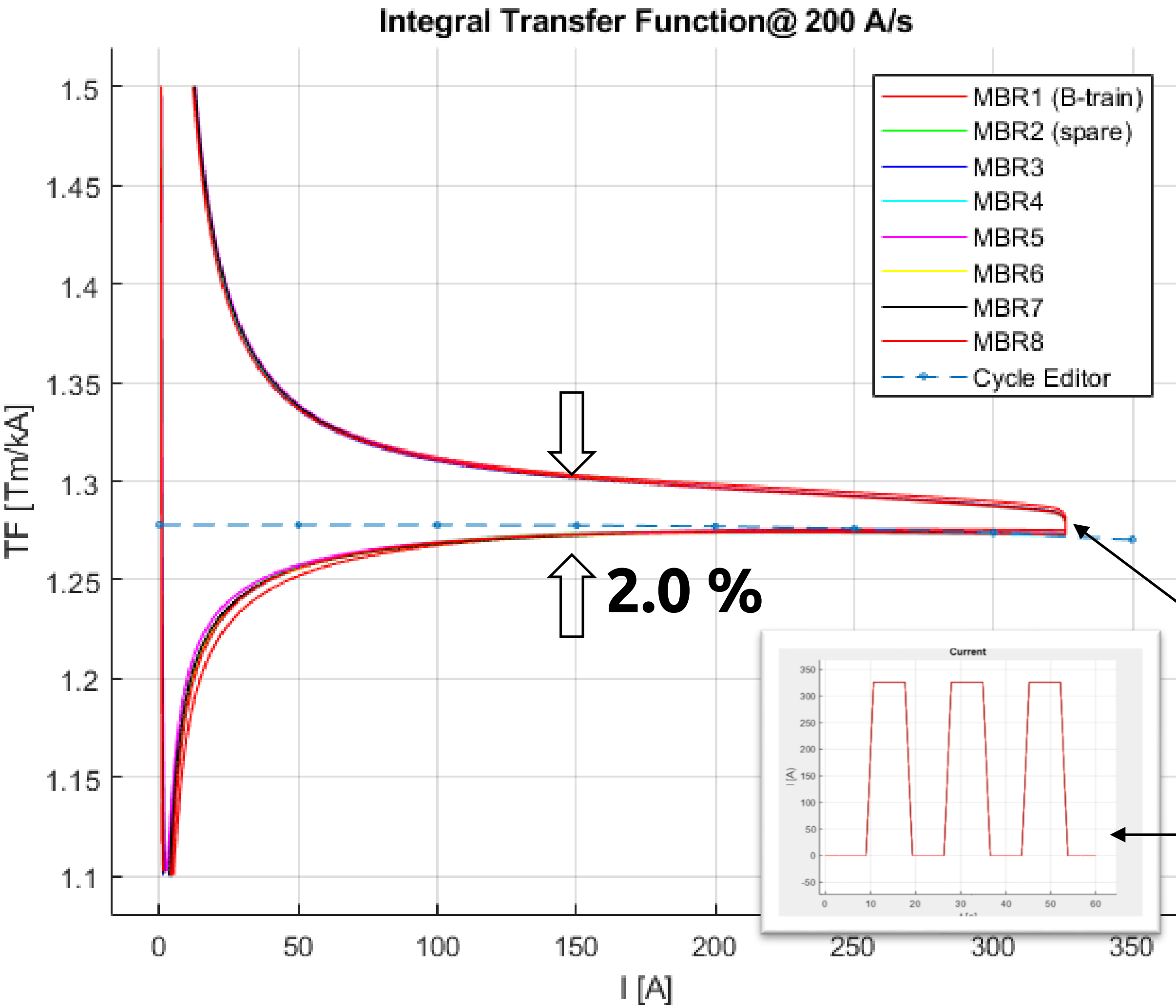
- V_c: coil voltage
- V_{in}: measured voltage
- V_0: voltage offset (source of integrator drift)
- $\frac{R_c}{R_{in}}$: resistance ratio coil (5 kΩ) to integrator input

$$\bar{B}(t) = \frac{1}{l_0}\frac{Bd\ell_{ring}}{N_{BM}Bd\ell_{ref}}(1+\varepsilon)\left(B_{marker}l_m + \frac{1+\eta}{w_{eff}}\int_{t_{marker}}^{t} V_c\,dt\right)$$

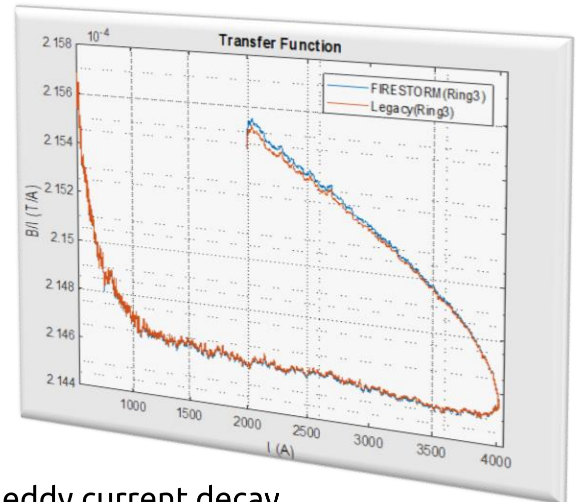
- $\bar{B}(t)$: average field over the ring distributed via WR
- $l_0 = \frac{2\pi R_0}{N_{BM}}$
- $\frac{Bd\ell_{ring}}{N_{BM}Bd\ell_{ref}}$: 1+α = field integral ratio ring average to reference magnet
- $(1+\varepsilon)$: coil geometry factor includes impact of transverse position and finite width (harmonic field content)
- η: coil correction factor non-ideality sources: error on w_{eff}, electronic gain …
- l_m: magnetic length
- w_{eff}: effective coil width (2.82058 m)
- $\left(B_{marker}l_m + \frac{1+\eta}{w_{eff}}\int_{t_{marker}}^{t} V_c\,dt\right)$: integrated field measured by the coil in the reference magnet
- $(1+\varepsilon)\left(\ldots\right)$: integrated field along the nominal beam orbit (in the reference magnet)
- $\frac{Bd\ell_{ring}}{N_{BM}Bd\ell_{ref}}(1+\varepsilon)\left(\ldots\right)$: integrated field along the nominal beam orbit (in the ring)

The calibration coefficients α, ε, η, ℓ_m are functions of:
current (or field) level, current history, ramp rate, sensor position

Series measurements - integrated dipole



To compare: mid-range hysteresis width in the PSB = **0.5 %**

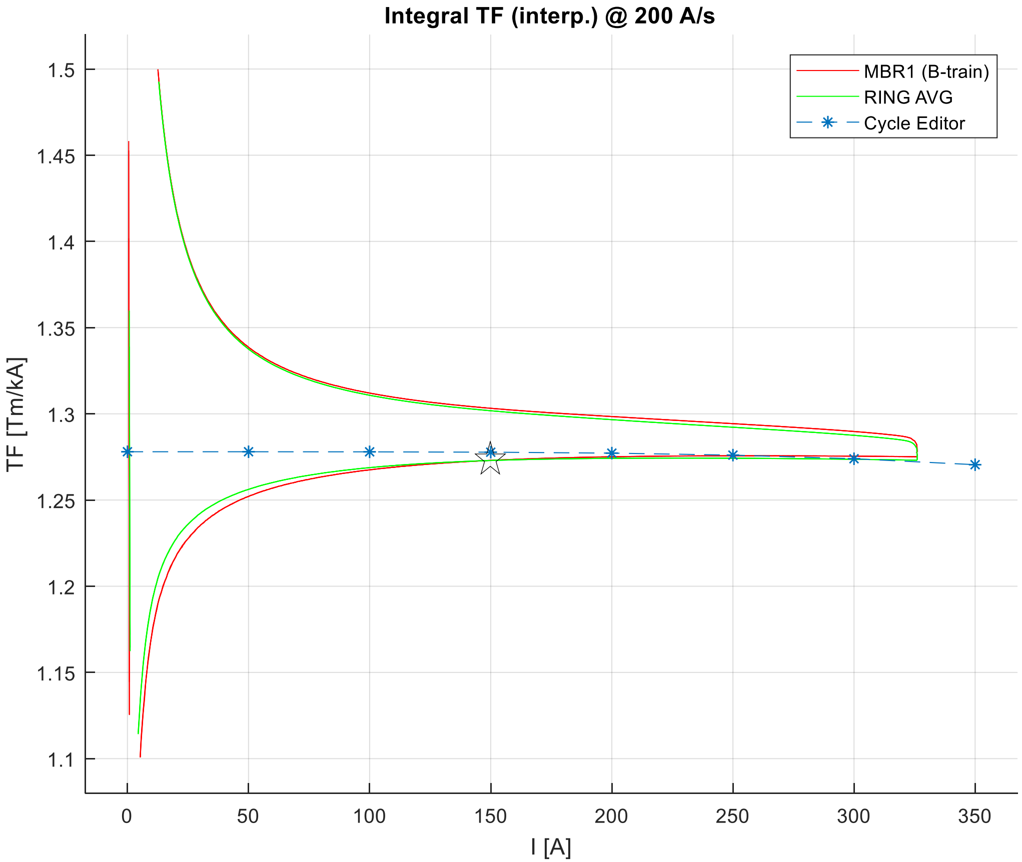


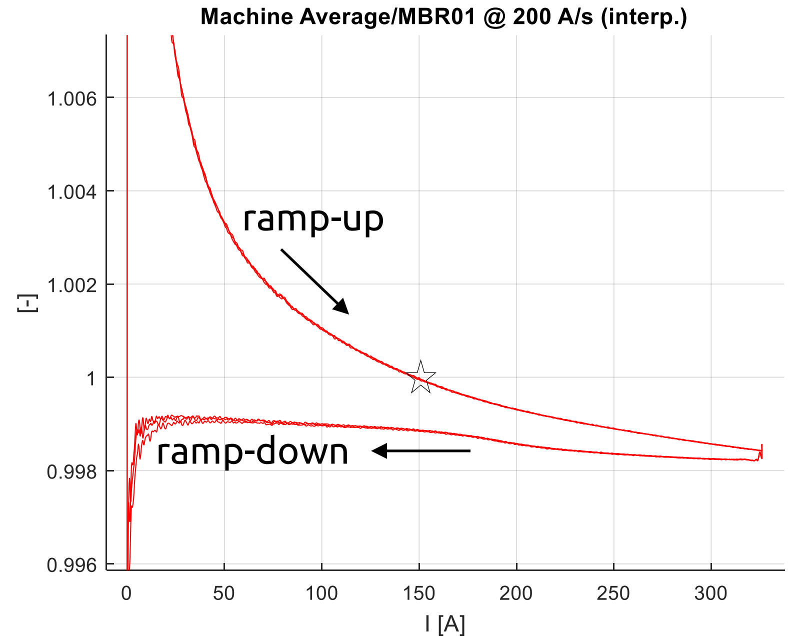
eddy current decay at constant current

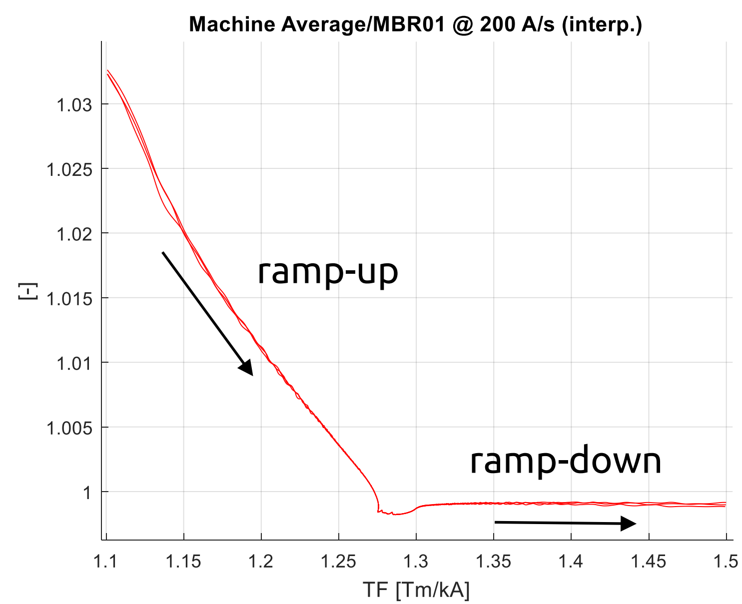
Current cycles during series tests 0-326 A, 200 A/s (pre-cycles, drift corrected, residual field measured)

- Very large hysteresis compared to other machines (mostly attributable to low-field operation)
- This is especially important for a decelerator (even more for so for cycles including both acceleration and deceleration)
- Important difference between ring and reference magnet (MBR01)

Integrated dipole: ring vs. MBR01

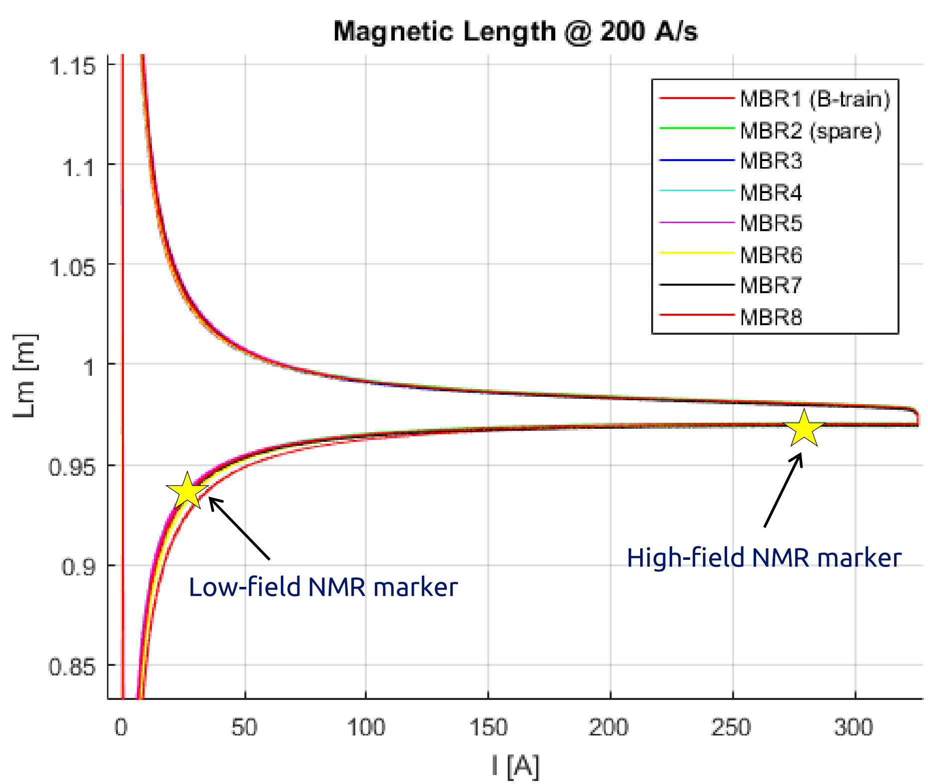


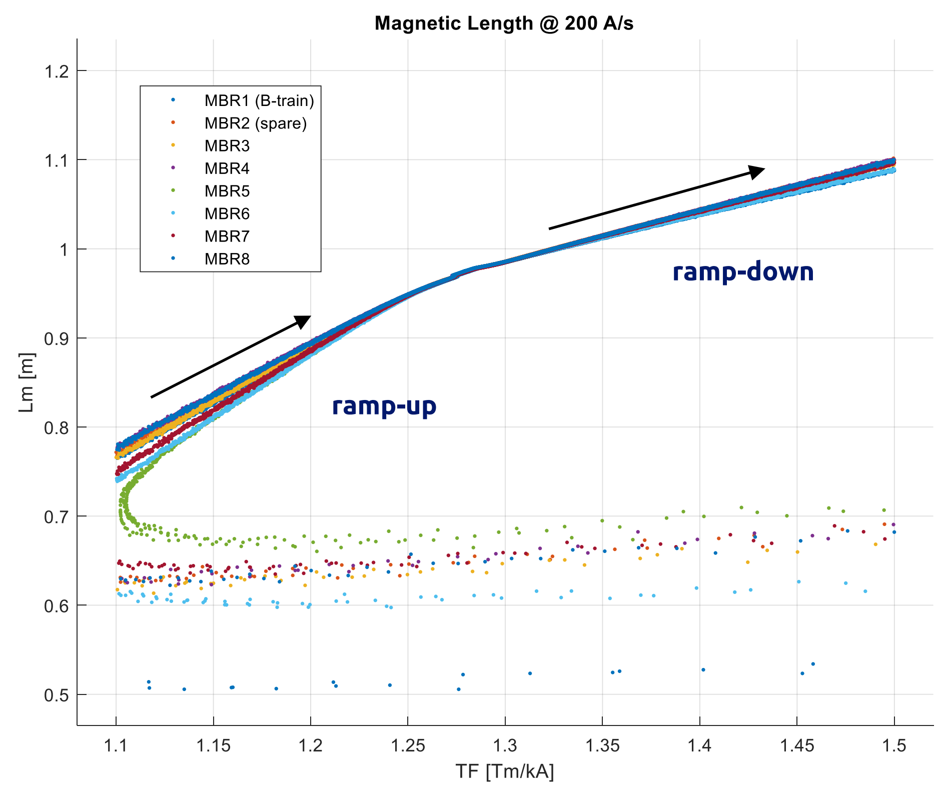




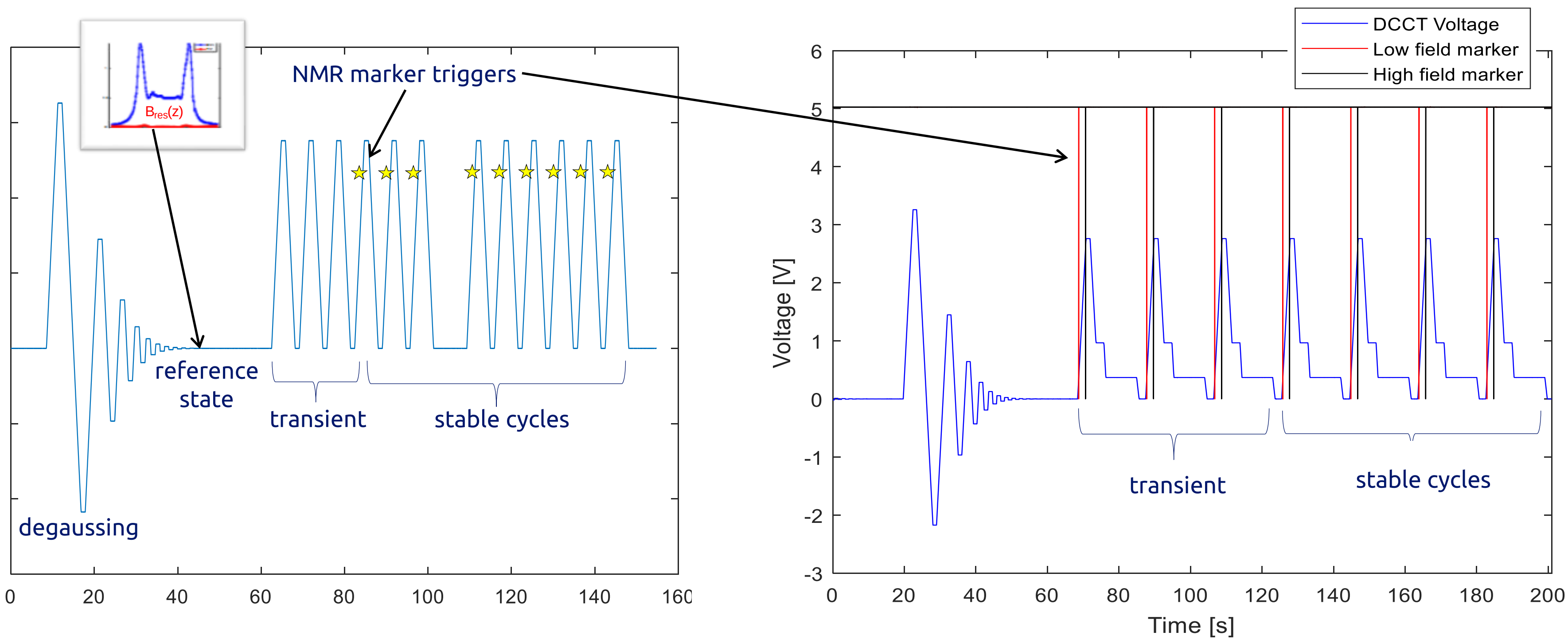
- TF used in cycle editor close to ramp-up at high field
- Reference magnet can be higher or lower than ring average – large variation on ramp-up (acceleration)
- More stable value <1 on ramp-down
- Re-pameterization vs. TF looks much nicer
- Large uncertainty contribution to the model !

- $$\ell_m(I) = \frac{1}{B_0(I)} \int_{-\infty}^{\infty} B(I,s)\,ds$$
- Basic parameter to derive integral value from point-like marker measurement
- Strongly hysteretic behavior ⇒ FESA property must be adjusted if the working point changes
  almost ±10% variation in the range of interest !
- Re-parametrization as a function of the Transfer Function looks much simpler – may simplify both manual and automatic implementations





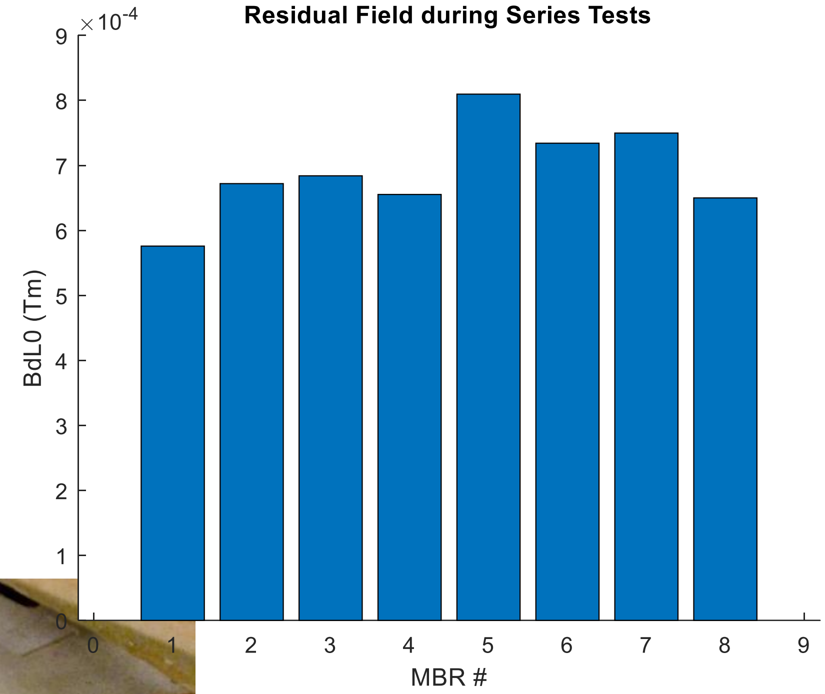
- Aim: use **all available information** to provide absolute $Bd\ell$ with **rigorous uncertainty estimation** → rational error bounds for subsequent adjustments
- *In-situ* approach: re-measure $Bd\ell$ of reference magnet in the precise conditions found during operation; derive directly the integration constant $(B_{marker}\ell_m)_{t_{NMR}}$
- Field integration without a marker, by bringing the magnet to a known reference state
- Accurate offline drift correction based on field stability on plateaux/repeated full cycles
- Tests were made with different types of cycles, analysis in progress

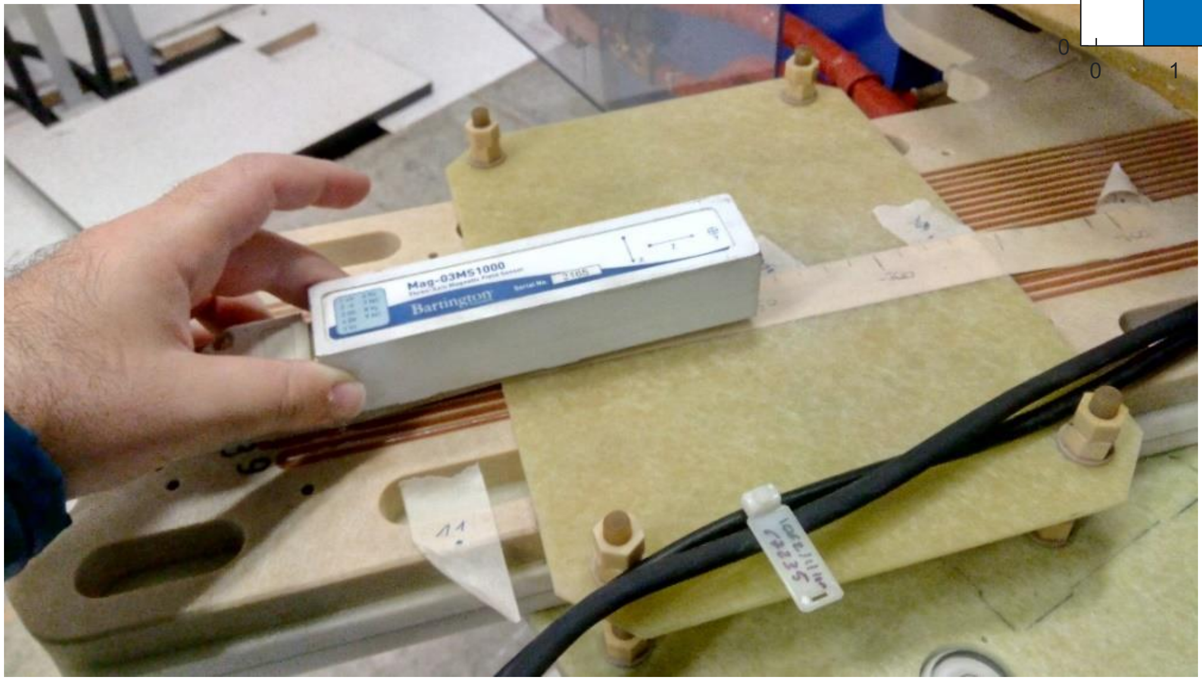


Series tests

remanent field was measured by inserting then extracting repeatedly the whole fluxmeter in the magnet gap (!)

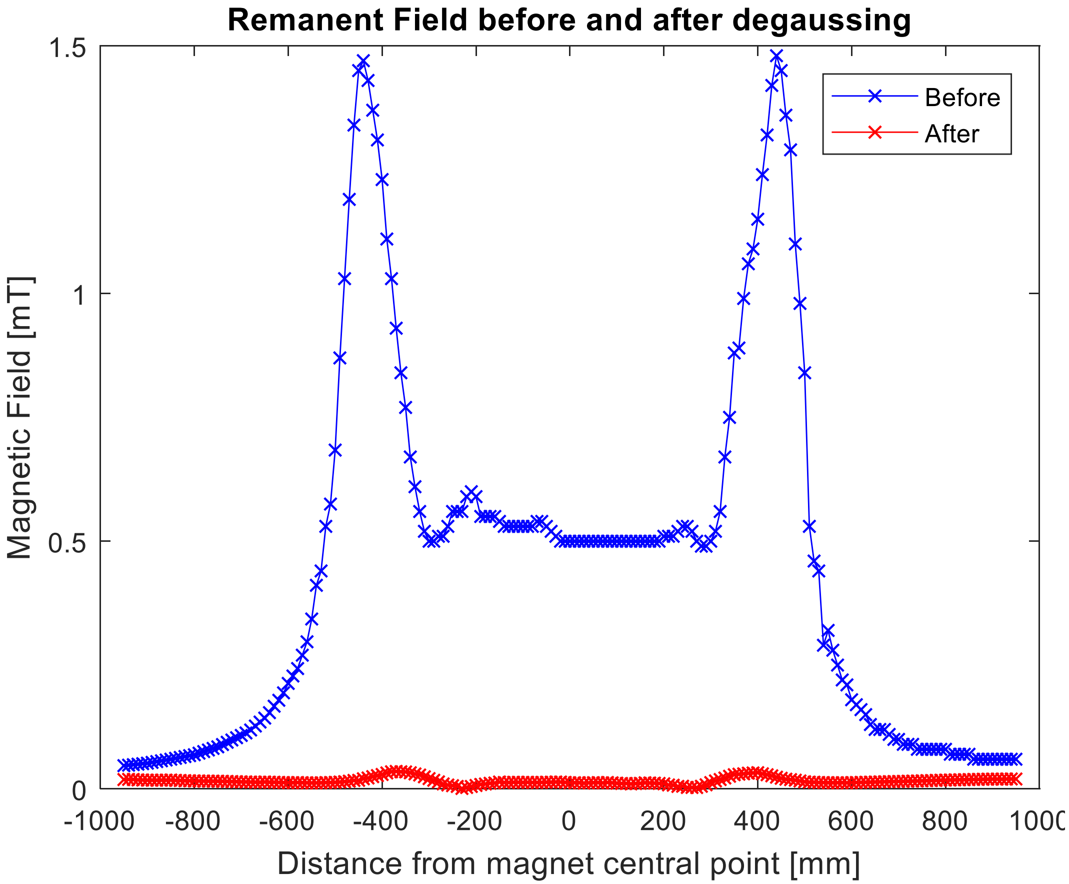
$(Bd\ell)_r$ = 0.69 ± 0.07 mTm

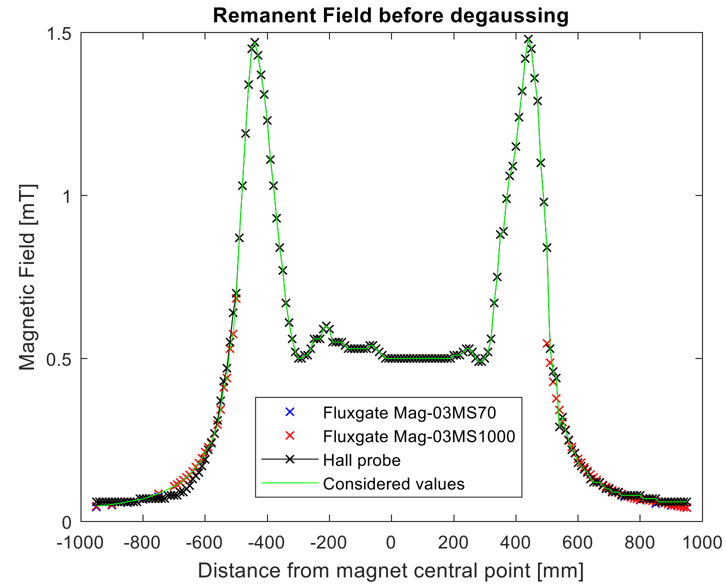


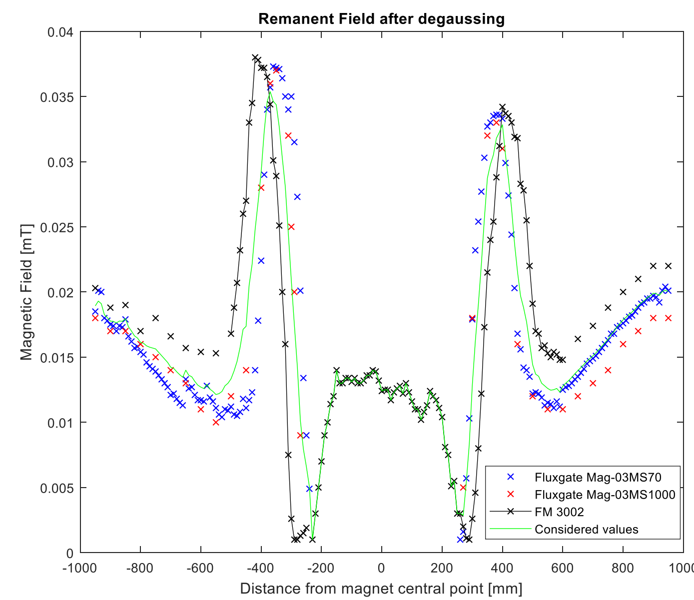


B-train tests

Measurements carried out with Metrolab Hall probe and two different Bartington fluxgate probes (1000 and 70 µT ranges)



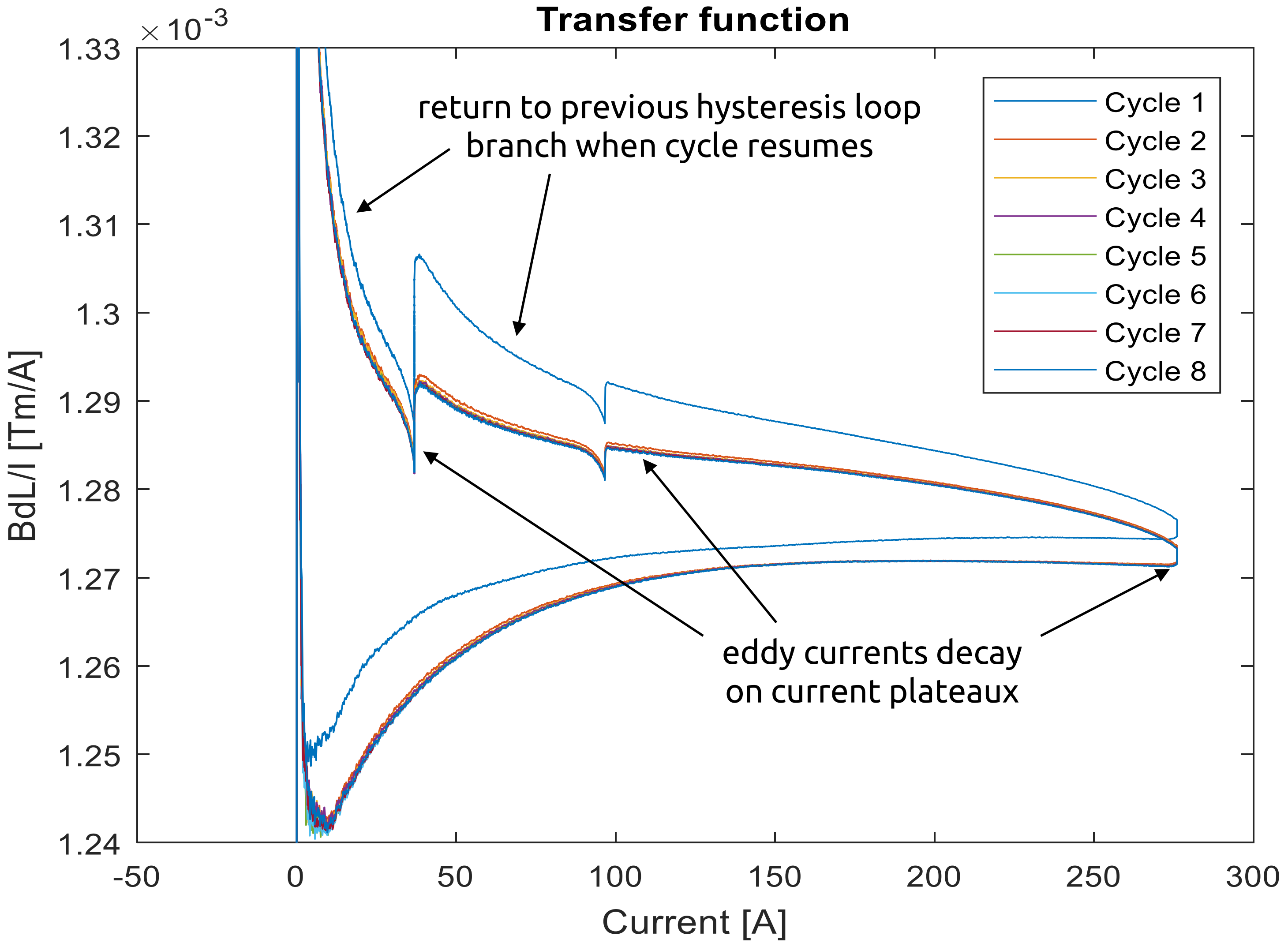




- (Nov 2016) I_{max}= 400 A: **0.45 → 0.02 mTm** (~25:1)
- (Oct 2017) I_{max}= 326 A: **0.86 → 0.03 mTm** (~29:1)

In both cases: **$(Bd\ell)_r \approx 5\text{-}8\cdot10^{-5}$** of full range needs to be taken into account

Cycle stabilization



Stable hysteresis loop achieved at the third repeated cycle
(result well in line with broader experience on similar dipoles)

- Wed Dec 20 evening: laser tracker survey with P. Bestmann (EN/ACE) of the relative position of the fluxmeter in the magnet gap (not possible before due to water pump-induced vibrations on the floor and walls !)
- Goal: determination of geometrical offset w.r.t. theoretical beam path ⇒ gain factor due to large quadrupole (~**2 G/mm @ 274 A**) to be calibrated out

Planned actions

- **Completion of the analysis** of the in-situ absolute calibration, including extrapolation from 200 A/s (series tests) to 119 A/s (operation) ramps and error propagation
- Preliminary indications: the currently distributed OP chain seems to be underestimating the peak field by about 20 G (TO BE CONFIRMED)
- We propose to **update and try the new calibration coefficients asap upon restart**
- B-train functionality that will need to be updated and tested in 2018:

  - PPM FESA properties
  - automatic field polarity switching in the PT2025 NMR teslameter
  - use of low and high markers in the same cycle
  - implementation of the new PT2026 (fast pulsed-wave NMR) as DC-mode marker
  - new in-built drift correction algorithm for long plateaux