Magnetic measurements on MBH dipoles (models and prototype)

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Outline

- Background information
  - Coils, magnets and strands
  - Strategy
  - Instrumentation
- Measurement results
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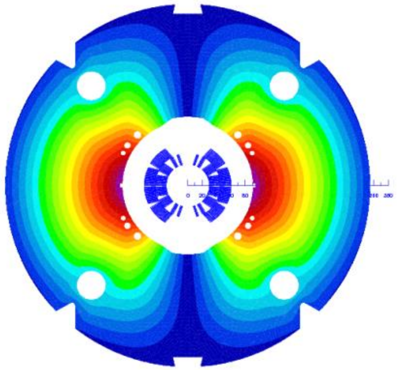
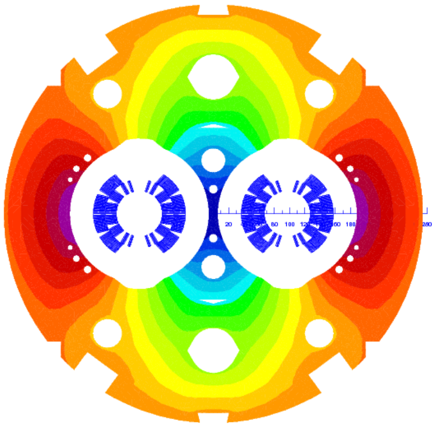
    - TF and field quality (geometric)
  - Cryogenic temperature
    - TF and saturation, b3 and persistent currents
    - Field quality (saturation, persistent currents)
    - Other effects
- Summary

R_{ref} = 17 mm



Background information



Coils, magnets, and conductors

Coil	Magnet	Strand
105	SM101	RRP 108/127
106	SP101, SP102, DP101	RRP 108/127
107	SP101	RRP 108/127
108	SP102, DP101	RRP 132/169
109	SP103, DP101, DP102	RRP 132/169
111	SP103, DP101	RRP 132/169
112	SP104, DP102	RRP 132/169
113	SP104	RRP 132/169
114	SP105, DP102	RRP 150/169
115	SP105, DP102	RRP 150/169
116	SP106	RRP 150/169
117	SP106	RRP 150/169

Coil	Magnet	Strand
CR4	PROTO1- AP1	RRP 132/169 & 150/169
CR5	PROTO1- AP1	RRP 132/169 & 150/169
CR6	PROTO1- AP2	RRP 108/127
CR7	PROTO1- AP2	RRP 108/127

Measurement strategy

- Measurement with rotating coils (cross calibrated with stretched wire)

- Ambient temperature
  - **Central and integral field at ±20 A**
    - After collaring (CC)
    - After shell welding (CM)

- Cryogenic temperature
  - **Central and integral field up to nominal**
    - Standard program
      - At 1.9 K
        - Machine simulation cycle after pre-cycling at 50 As^{-1}
        - Stair-step cycle
        - Ramp-rate study
    - Extended program (option)
      - At 4.3 K
        - Machine simulation cycle (limited flattop current)

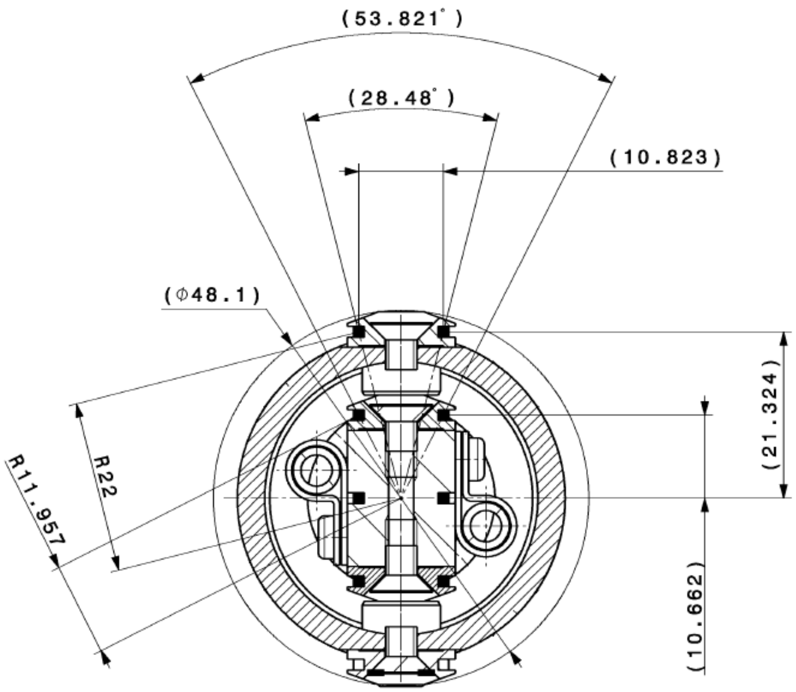
Shafts for models at ambient temperature

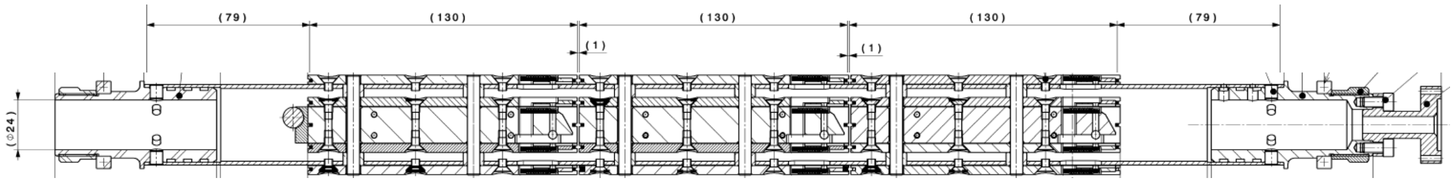
Shaft design 1

- 3 sectors, L = 130 mm/each
- 5 tangential coils/sector
- Measurement radius 22 mm
- Horizontal position

Shaft design 2, the same but

- 1 sector, L=1200 mm





Measurement system at ambient temperature

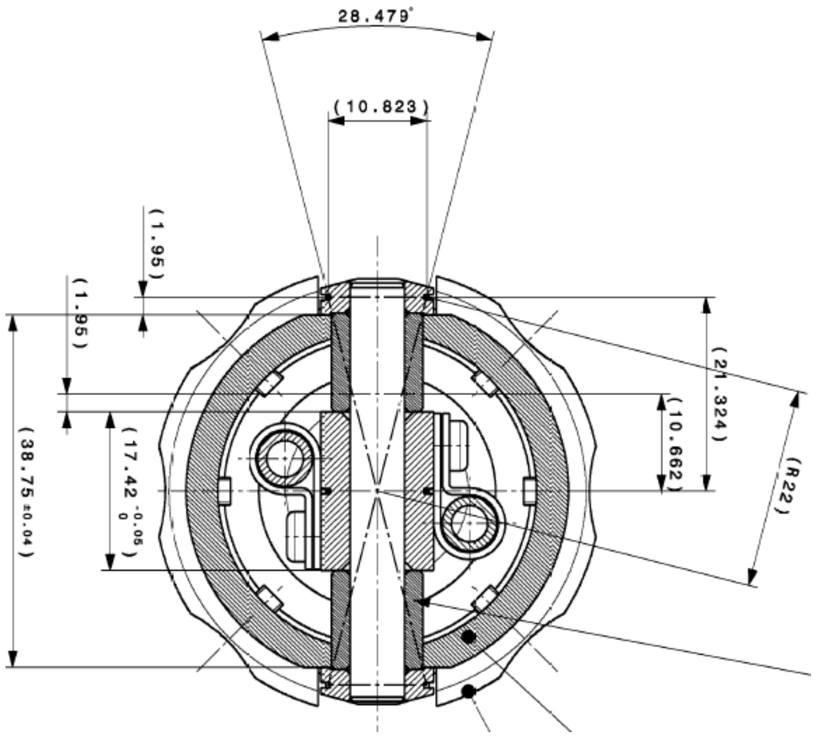
- Motor + encoder + slip-ring unit (MRU)
- Fast Digital Integrator (FDI)
- FuG low voltage power supply (40 V, 20 A)
- DCCT Hitec MACC-plus
- Search coil shafts

<u>A measurement is an average over 1200 mm (or 130 mm fro the scanning)</u>

Measurements in 3 positions:	Shaft centered	->	central field
	Two adjacent positions	->	integral field

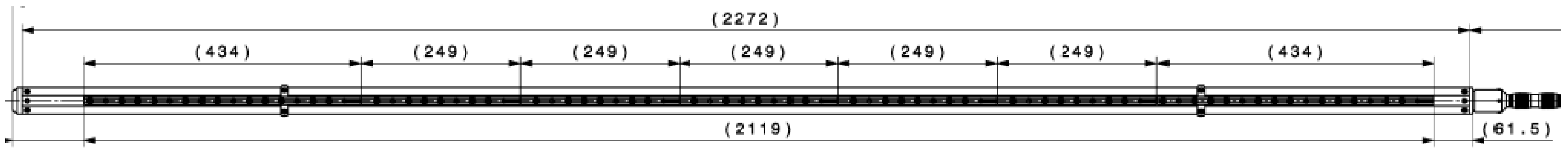
Z-scan with short shaft

Shaft for models at cryogenic temperature



Design

- 7 sectors, total length 2.1 m
- Dipole compensation scheme (3 tangential coils/sector)
- L = 434 mm to cover the coil heads, end field and splice region
- L = 249 mm in the straight part
- Measurement radius of 22 mm
- Full rotation symmetry for high rotation speed
- Possible use for quench location



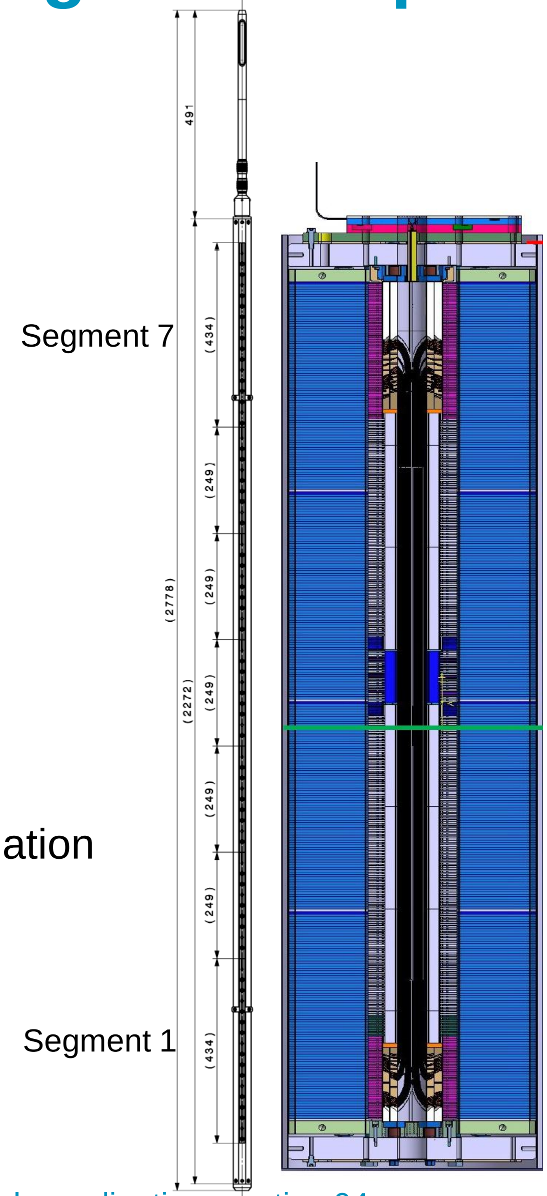
Measurement system at cryogenic temp.

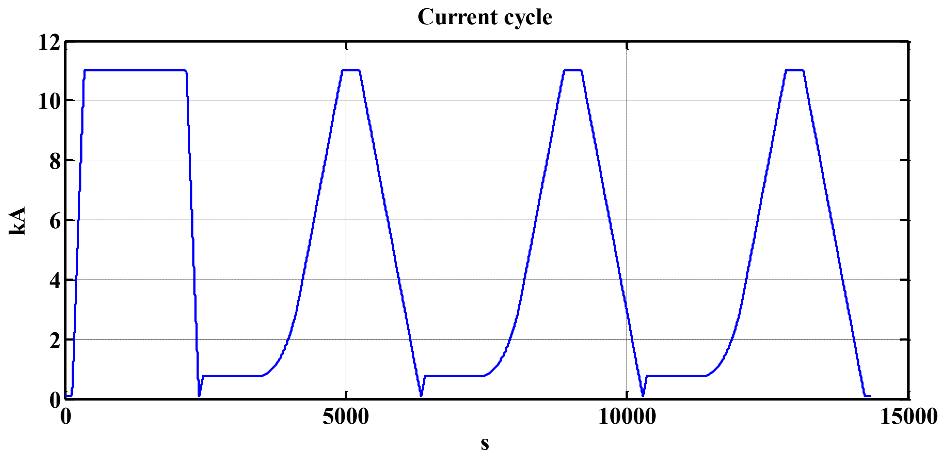
- **Fast Digital Integrators (FDI)**
- **Motor + encoder + slip-ring unit (MRU)**
- **Vertical shaft rotating in liquid He**

7 segments: 5 short in the middle + 2 longer on the ends

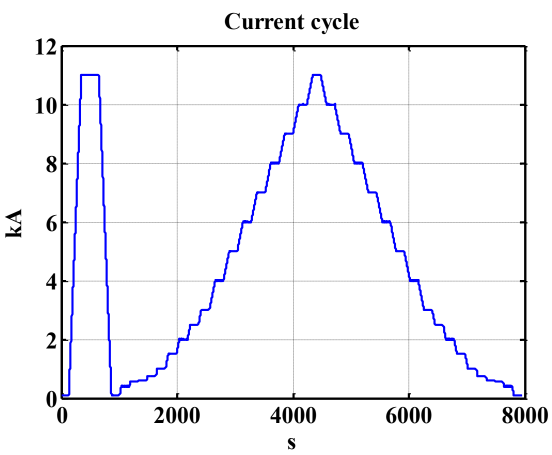
<u>A measurement is an average over 250 mm (432 mm)</u>

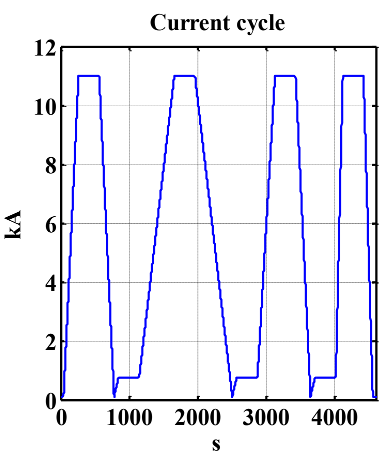
The shaft cannot be translated along the magnet after installation



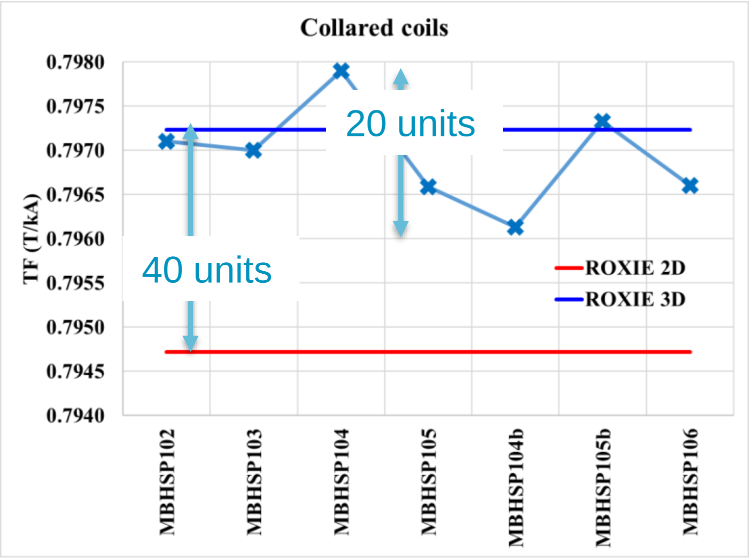


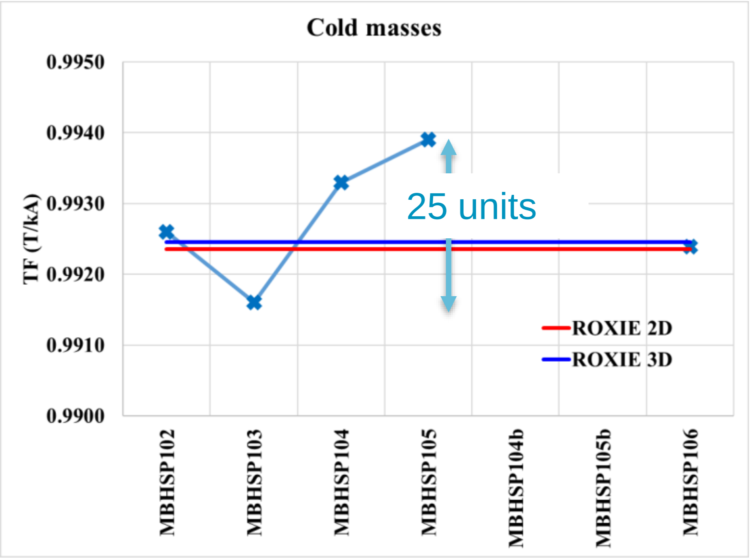
Selection of results

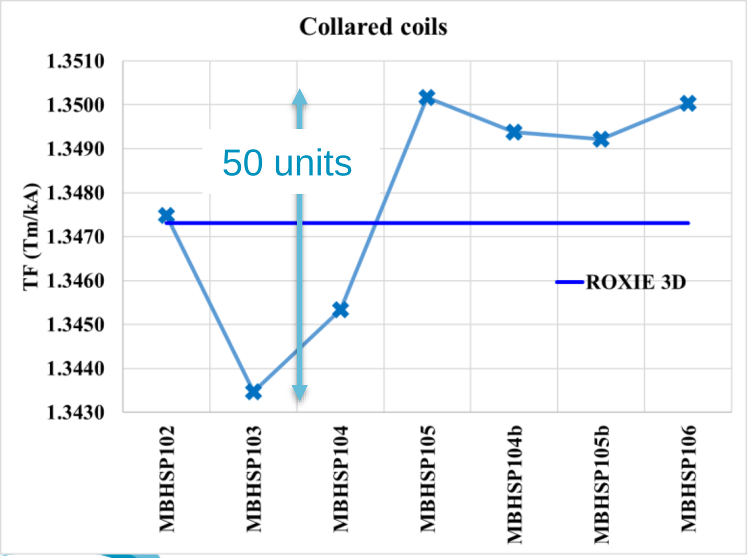


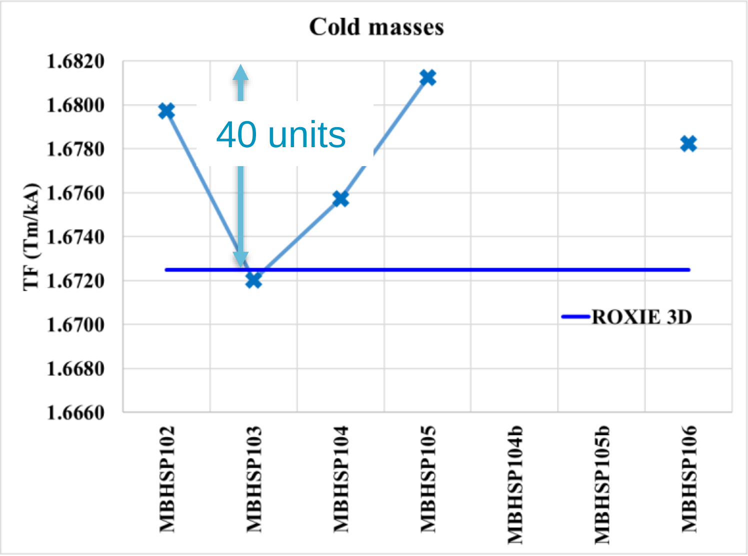


Ambient temperature: TF of short models





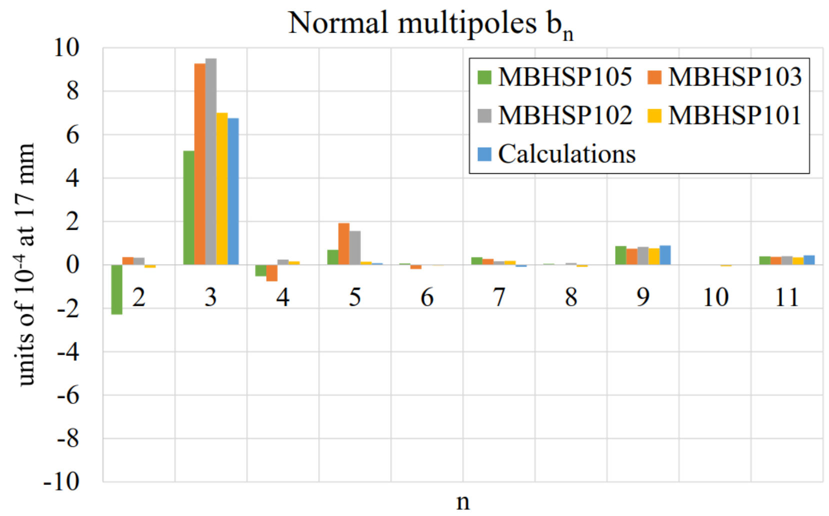


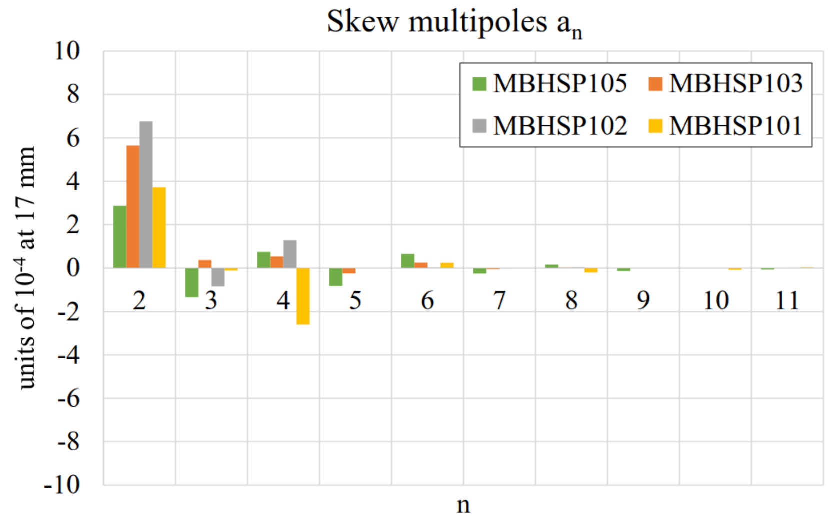


Ambient temperature: TF of full-length prototype

TF central	Collared coil			Cold mass		
	MM	ROXIE	DIFF	MM	ROXIE	DIFF
	T/kA		units	T/kA		units
HCMBH_CR1	0.7945	0.7947	-2			
HCMBH_CR2	0.7939		-10			
HCMBH_CR3	0.7938		-11			
HCLMBHB_CR1 - Ap1 (CR2)				0.9896	0.9922	-26
HCLMBHB_CR1 - Ap2 (CR3)				0.9896		-26
TF integral	**Collared coil**			**Cold mass**		
	MM	ROXIE	DIFF	MM	ROXIE	DIFF
	Tm/kA		units	Tm/kA		units
HCMBH_CR1	4.2213	4.2272	-14			
HCMBH_CR2	4.2209		-15			
HCMBH_CR3	4.2255		-4			
HCLMBHB_CR1 - Ap1 (CR2)				5.2352	5.2391	-7
HCLMBHB_CR1 - Ap2 (CR3)				5.2342		-9

Ambient temperature: multipoles on short models



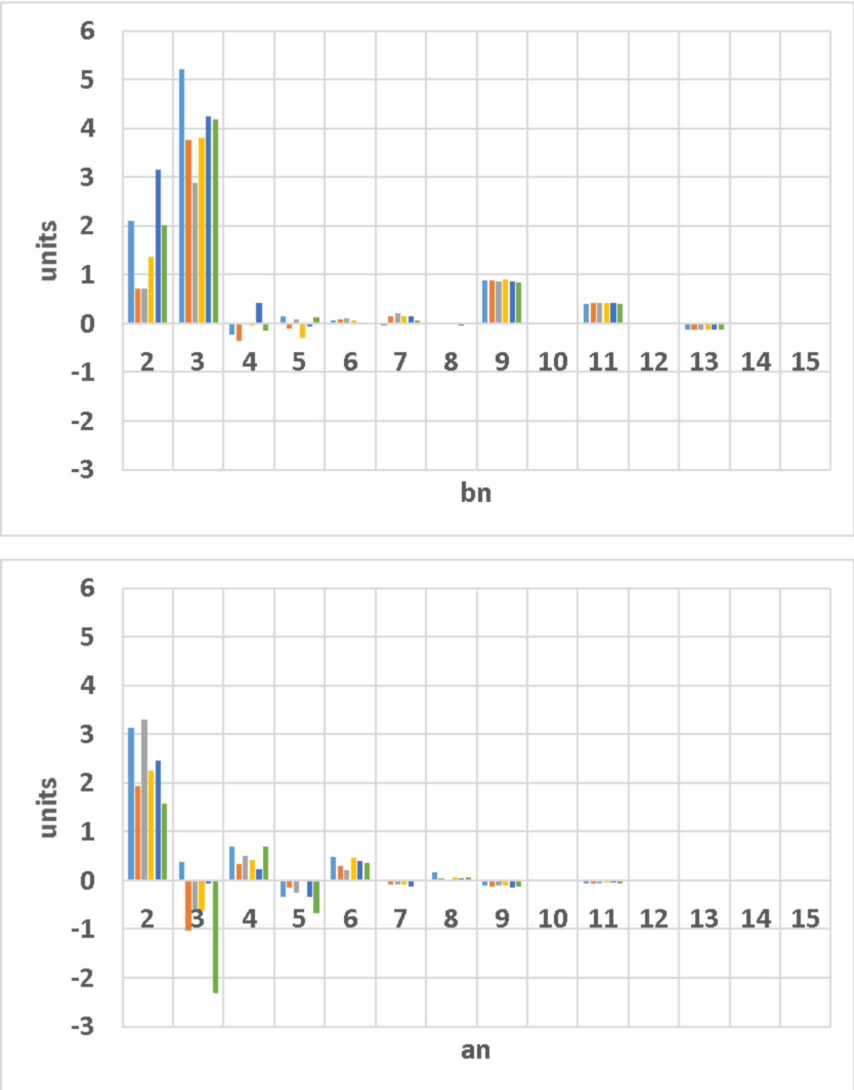


FIELD QUALITY on short models:

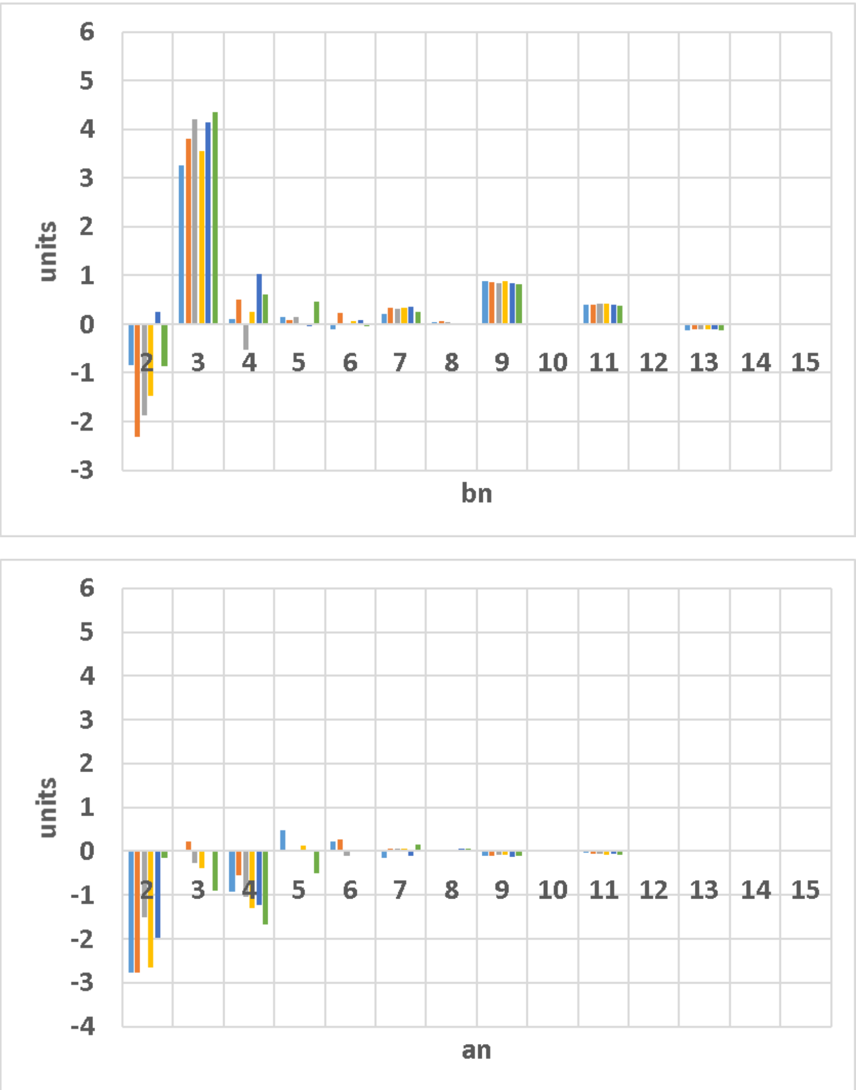
Affected by insulation thickness (different among models)

Ambient temperature: multipoles on prototype

AP1-CR2 z-scan

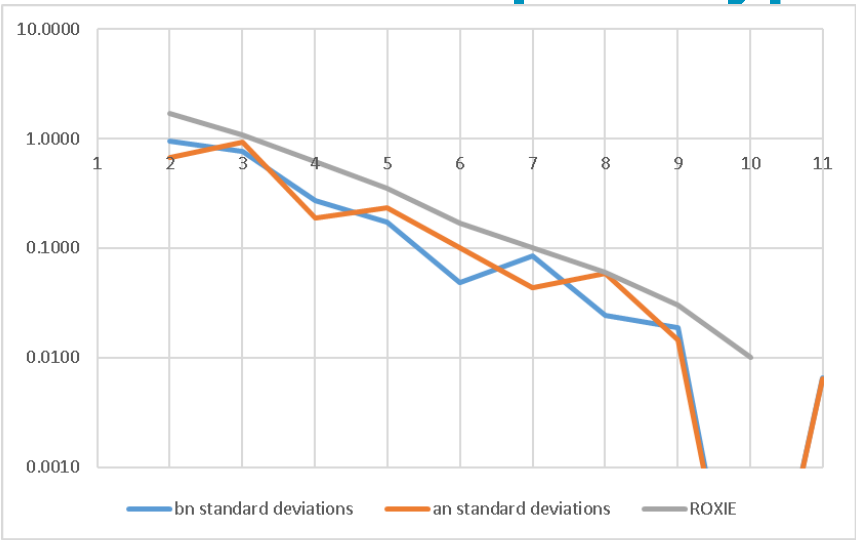


AP2-CR3 z-scan



Ambient temperature: random components on prototype

Ap1-CR2

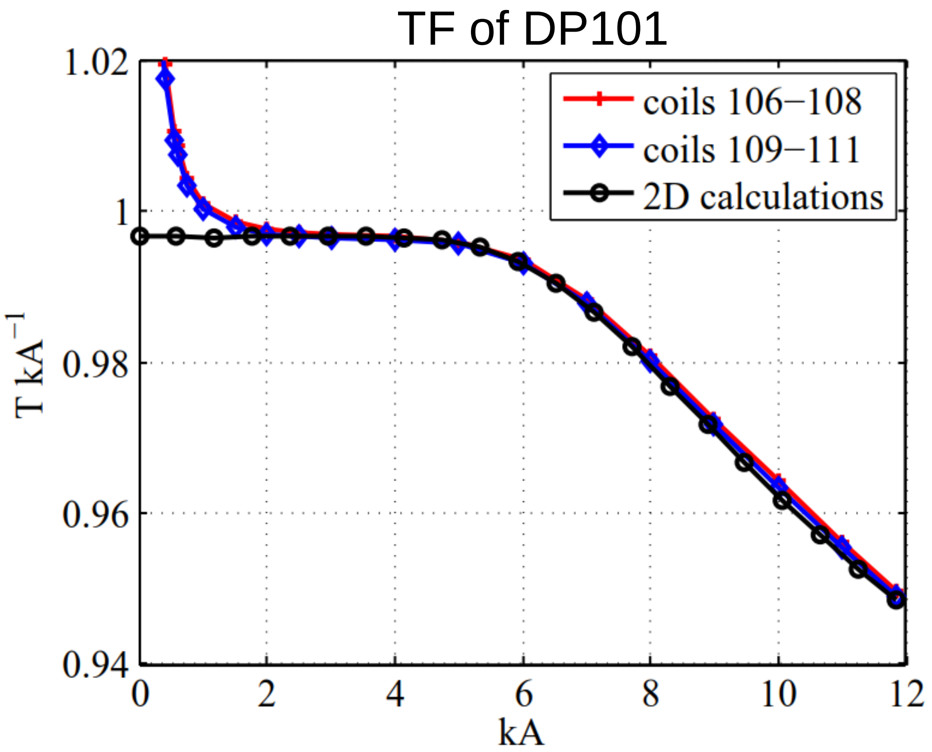


Ap2-CR3

ROXIE:
Calculations of random block displacements with σ = 60 μm

Random components seems to be larger than NbTi technology, but not enough statistic

Cryogenic temperature 1.9 K: TF and saturation

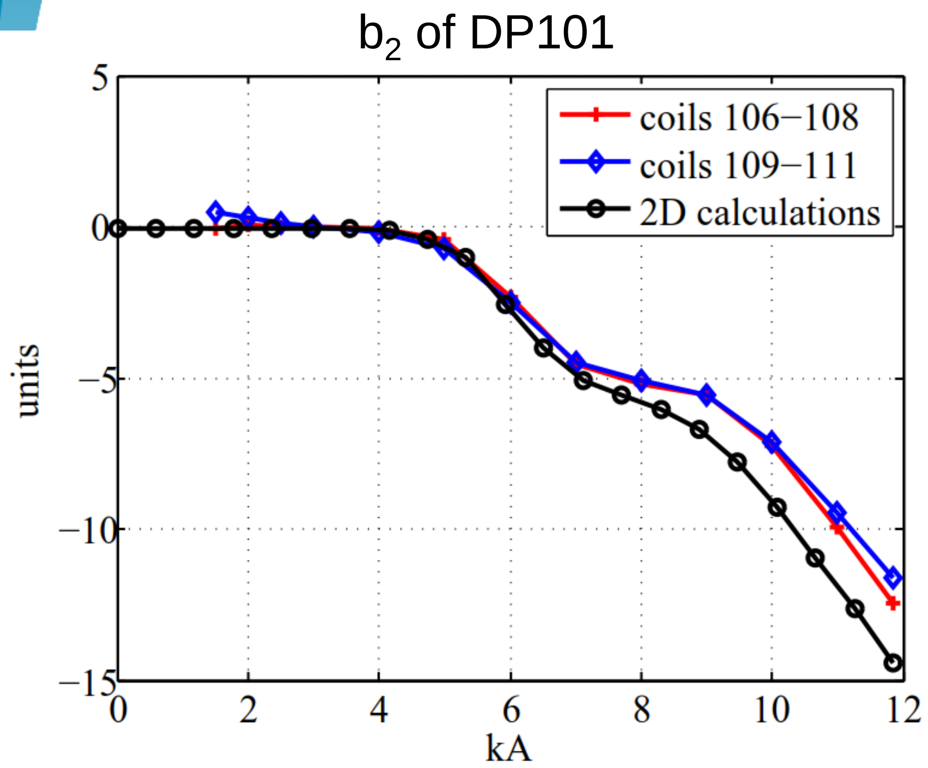


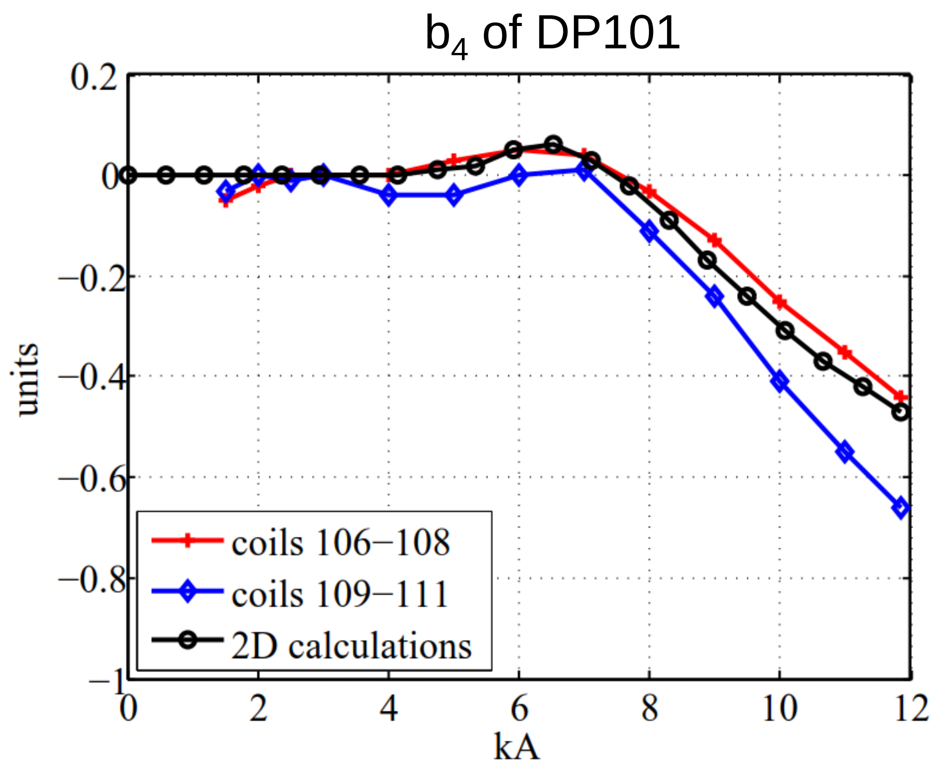
Central TF in agreement with model in terms of

- Geometric
- Saturation

Mismatch calculations/mm for saturation on single aperture models seems to be related to 3D effects

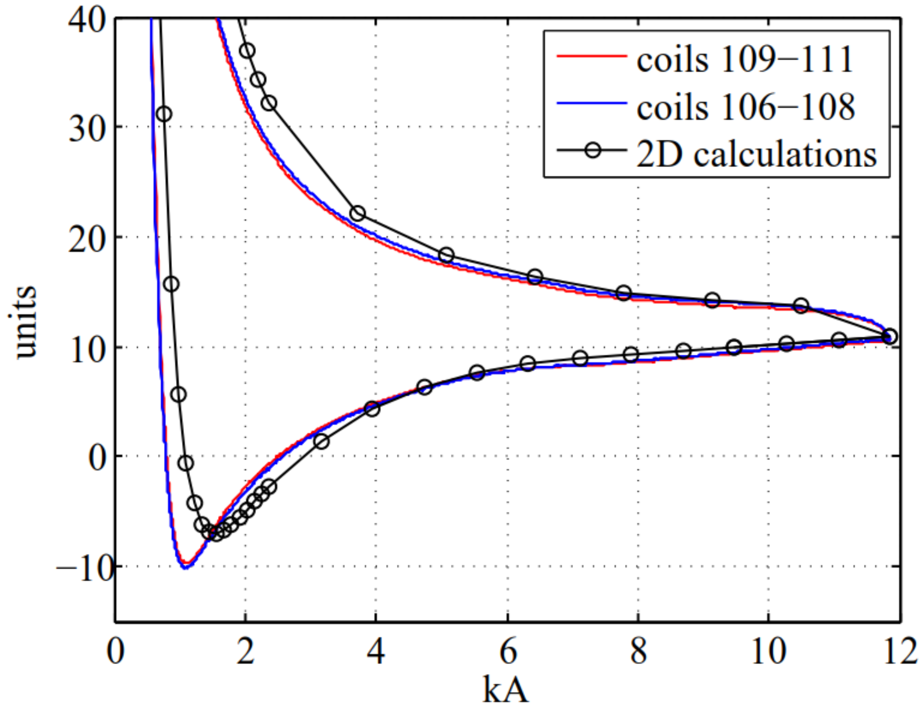
Cryogenic temperature 1.9 K: b2, b4 and saturation





Saturation affects mainly b2 and b4 (apart TF):
Predicted by calculations at unit level

Cryogenic temperature 1.9 K: b3 and persistent currents



PERSISTENT CURRENTS effects:

- More than 20 units of change from injection to nominal
- Difficult to compute, flux jumps difficult to model

Cryogenic temperature 1.9 K: Ramp-rate effects

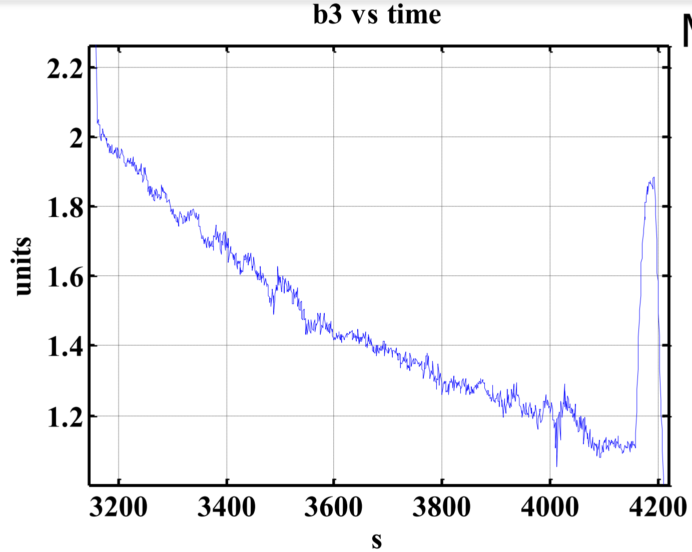
		MBHDP101 Ap 1 (Coils 106/108) at 5 kA ramping up								
A s^{-1}		**10**	**20**	**40**	**80**					
T kA^{-1}		TF								
		0.9945	0.9946	0.9948	0.9949					
A s^{-1}		**10**	**20**	**40**	**80**		**10**	**20**	**40**	**80**
units		bn					an			
2		-1.7	-1.7	-1.6	-1.4		2.9	2.7	2.5	2.0
3		6.2	6.3	6.3	6.5		1.2	1.2	1.1	0.8
4		-0.2	-0.3	-0.3	-0.3		0.1	0.0	0.0	-0.3
5		1.3	1.3	1.3	1.3		0.0	0.0	0.0	-0.1
6		-0.1	-0.1	-0.1	-0.1		-0.2	-0.2	-0.2	-0.2
7		0.1	0.1	0.1	0.1		0.1	0.1	0.1	0.1
8		0.0	-0.1	0.0	0.0		0.1	0.1	0.1	0.1
9		0.7	0.7	0.7	0.7		-0.1	-0.1	-0.1	-0.1
10		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0

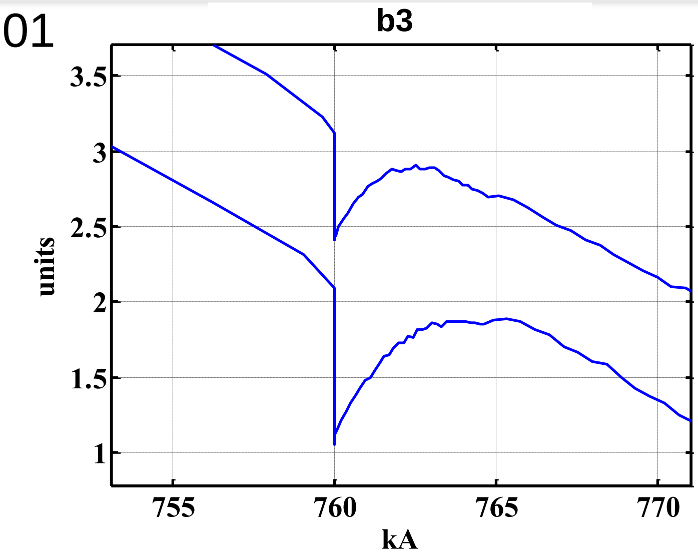
Nominal ramp-rate is 10 A s^{-1}

Relatively small ramp-rate effects as expected because of the cored cable

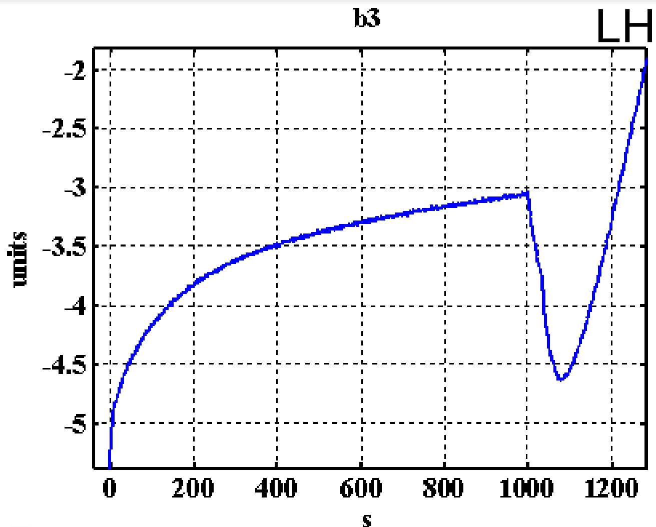
Cryogenic temperature 1.9 K: Decay and snapback

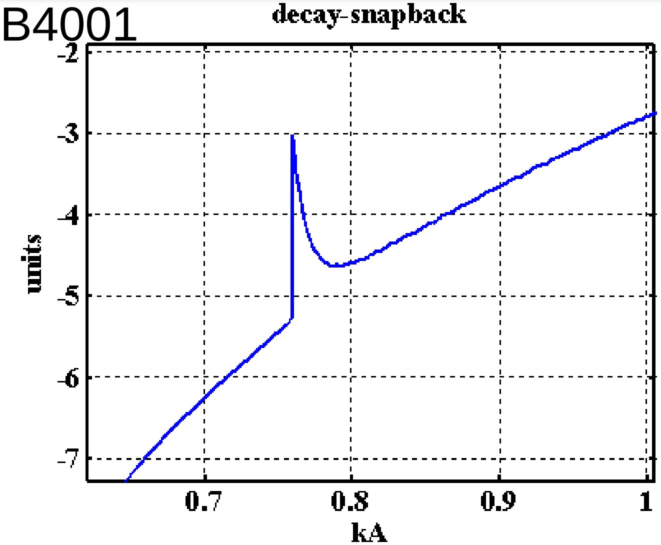
MBHDP101



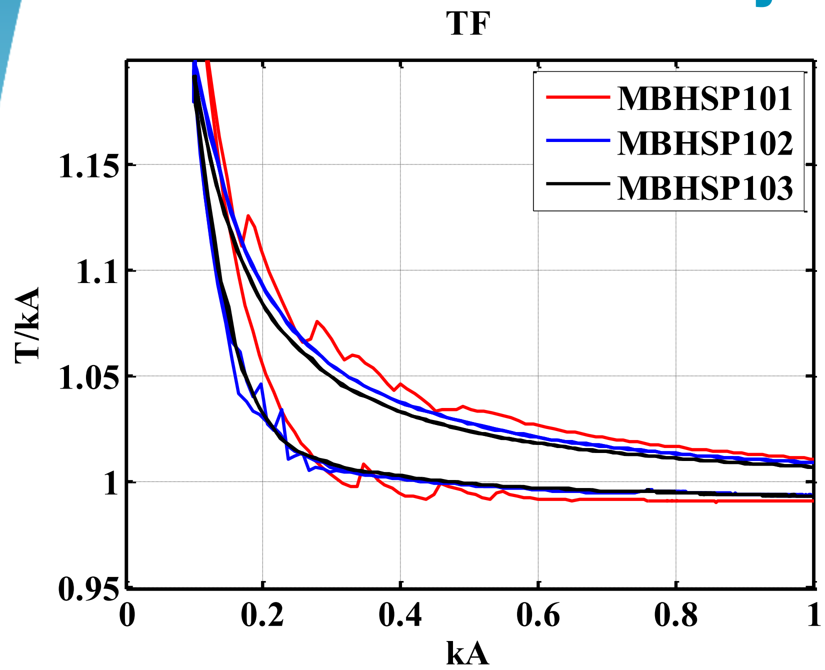


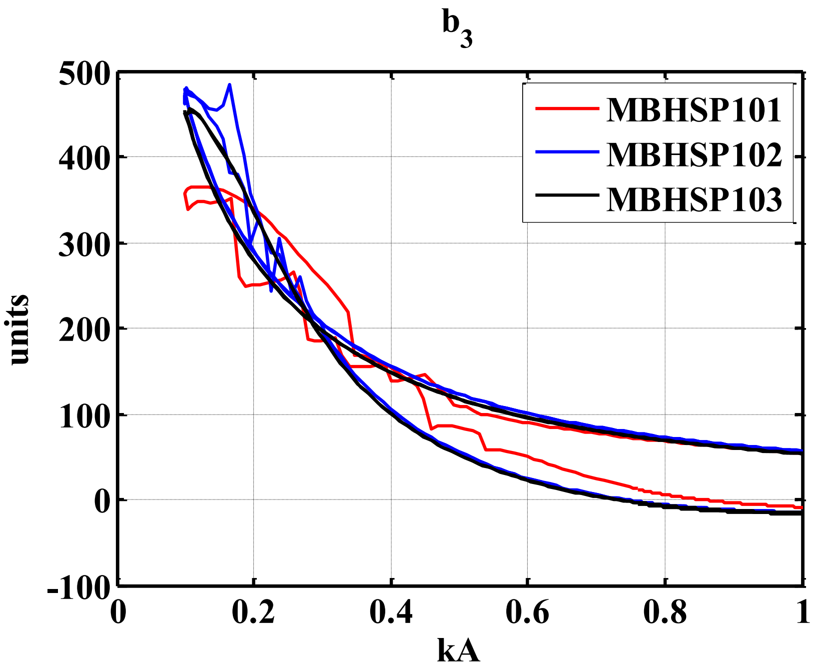
LHC dipole MB4001





Cryogenic temperature 1.9 K: Effects of flux jumps





At low current, noise on the measured magnetic field can be associated with flux jump

Larger on MBHSP101 and almost invisible on MBHSP103

Cable RRP 108/127 shows stronger effects because of larger filaments

Summary

- **Magnets measured up to now:**
  - 6 single aperture and 2 double aperture models
    - Ambient temperature
    - Cryogenic temperature
  - One full length prototype
    - Ambient temperature

- **Main results**
  - TF in general agreement with the calculations
    - Fine tuning of the calculations
  - Field quality
    - Geometric
      - Affected by insulation thickness on short models
      - Improvement on the prototype
    - Persistent current effects
      - ~25 units of change on b3 from injection to nominal
    - Saturation effects
      - Large saturation as expected on b2 and b4
    - Random component
      - In line with random block displacements with σ = 60 µm
    - Ramp rate
      - Small effects due to cored cable
    - Decay and snapback at injection
      - Small effect, inverse direction consistently measured at 1.9 K at CERN
    - Flux jumps effects visible below injection on the first models