

# Magnetic measurements on MBHSP102

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# Outline

- MM systems (ambient and cryogenic temperature)
- Performed measurement cycles
- Results
  - Straight section
    - TF
    - Allowed multipoles
    - Other multipoles
    - Comparison with ROXIE model
    - Comparison with MBHSP101
    - Ramp-rate dependency
  - Integral field
  - Cold/Warm correlation
- Conclusions

# Measurement system 300 K

- 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 (radius 22 mm, length 1.2 m)
- Flexible software Framework for Magnetic Measurements (FFMM)

Number of turns	(-)	256
Inner width	(mm)	13.41
Inner length	(mm)	1195.6
Groove thickness	(mm)	1.4
Magnetic surface	(m <sup>2</sup> )	3.37
Center radius	(mm)	21.33

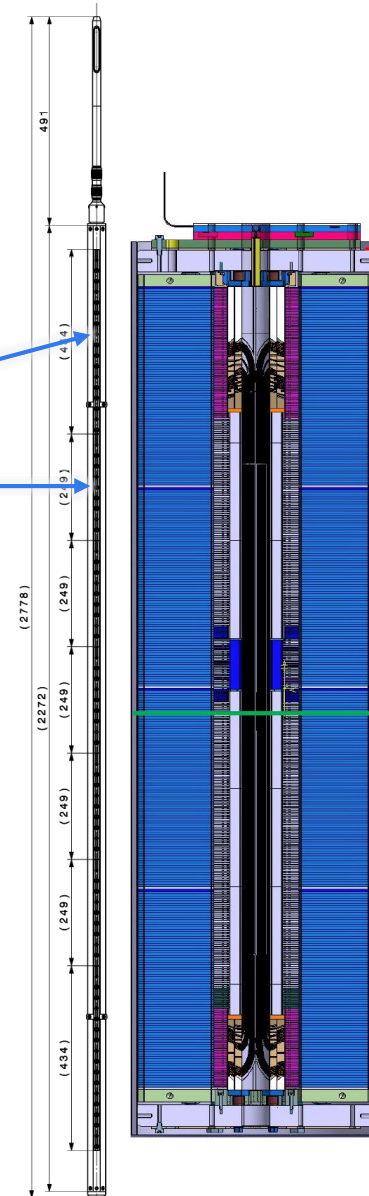
**A measurement is the average over 1.2 m**



# Measurement system 1.9 K

- Flexible software Framework for Magnetic Measurements (FFMM)
- Fast Digital Integrators (FDI)
- Motor + encoder + slip-ring unit (MRU)
- Vertical rotating shaft in liquid He

Number of turns	-	36	36
Inner width	mm	10.3	10.3
Inner length	mm	431.5	246.5
Groove thickness	mm	0.57	0.57
Magnetic surface	m <sup>2</sup>	0.17	0.10
Center radius	mm	21.5	21.3

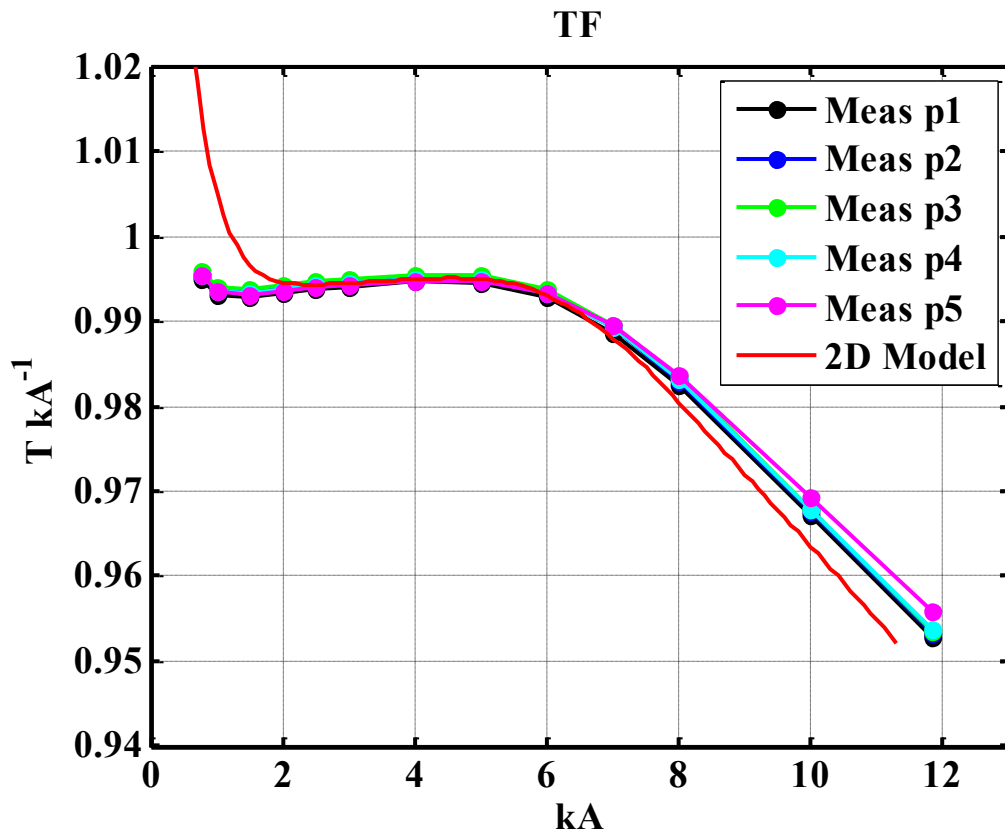


**A measurement is the average over 250 mm**

# Performed measurement cycles

- At 1.9 K
    - Stair-step cycle
    - 3x machine simulation cycles
    - Ramp-rate study at 20, 50, and 100 A s<sup>-1</sup>
    - Long flat-top (10 h) before a machine cycle
  - No measurements at 4.3 K
- } Standard program

# Transfer function



- Measurements and ROXIE model in agreement for geometric TF
- Saturation overestimated by the model (+55 units)
- Measurement results on MBHSP101 and MBHSP102 are consistent

# Transfer function

Possible sources of error:

## Iron properties

Using data from LHC production the discrepancy decrease by 20 units (from ~70 to ~50 units)

## Packing factor of the yoke laminations

Its effect is up to ~15 units

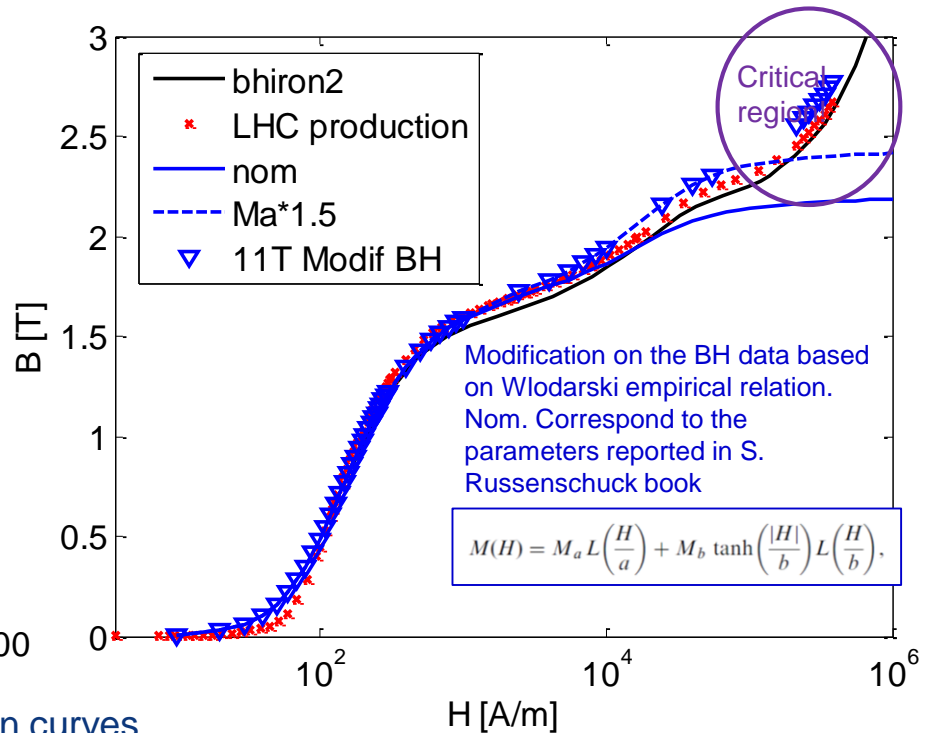
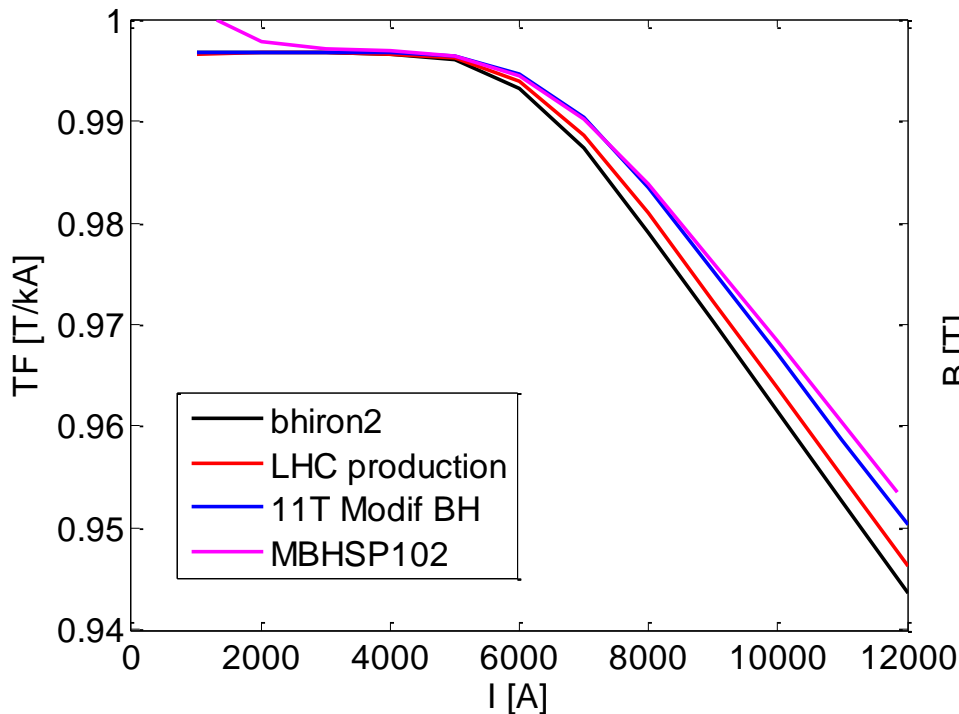
## Geometric

Rather big displacements needed to explain 50 units (350  $\mu\text{m}$  smaller coil gives ~15 units)

Courtesy of S. Izquierdo Bermudez

# Transfer function

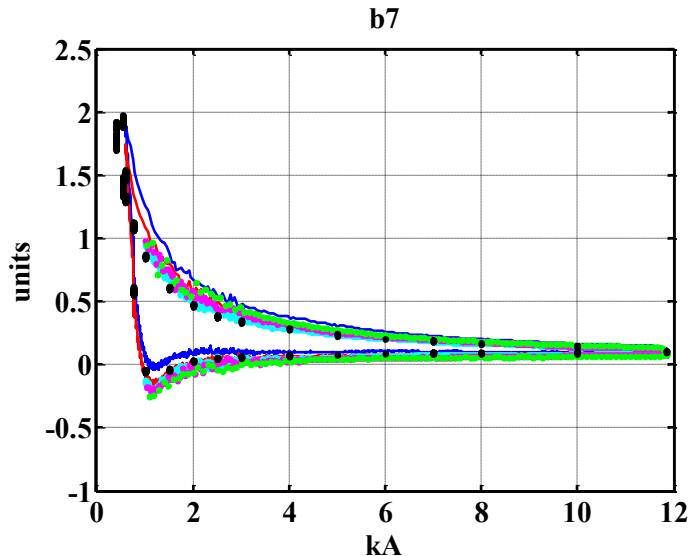
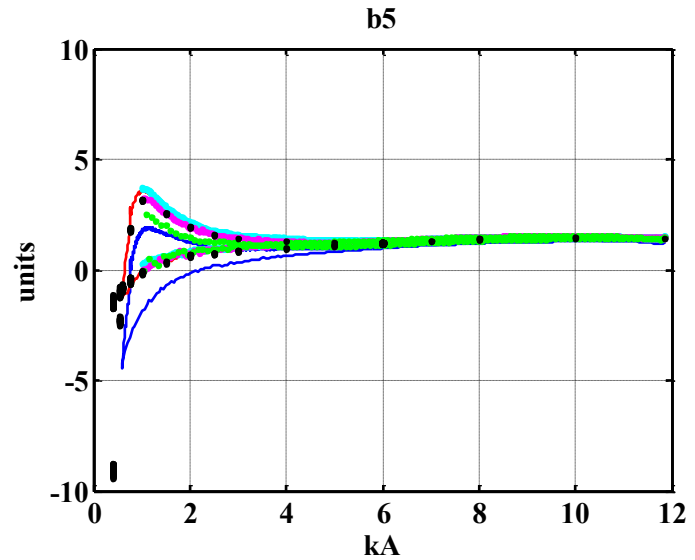
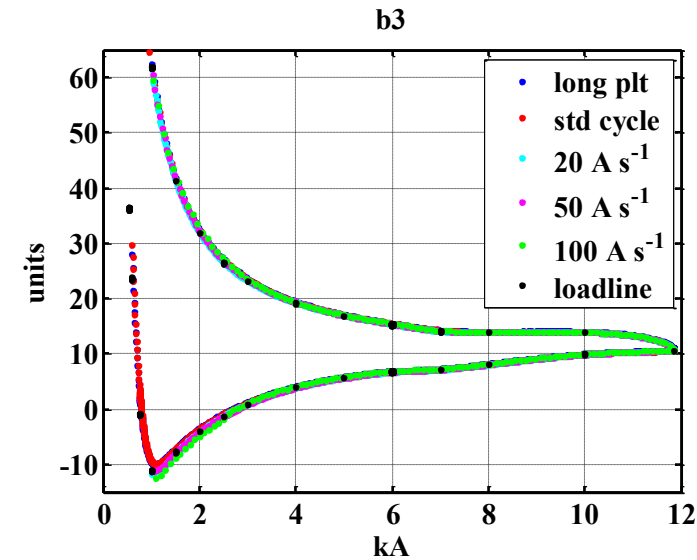
- The main source of error is the magnetic properties of the iron:
  - Discrepancy ~ **80 units** using ROXIE bhdata2
  - Discrepancy ~ **55 units** using LHC production data
  - Discrepancy ~ **15 units** using a modified bh data based on [1]



[1] Z. Wlodarki. Analytical description of magnetization curves



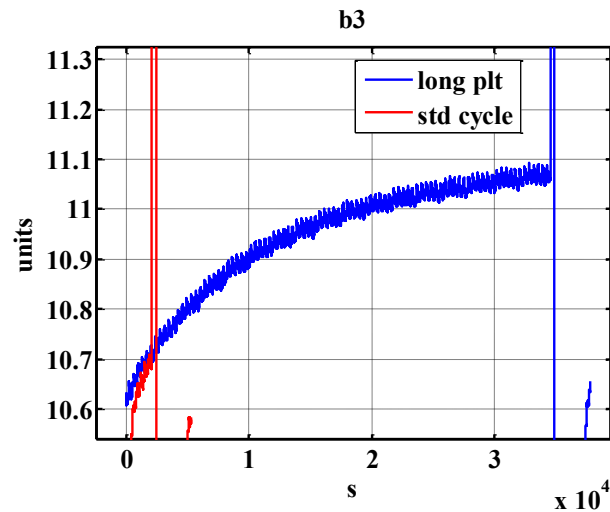
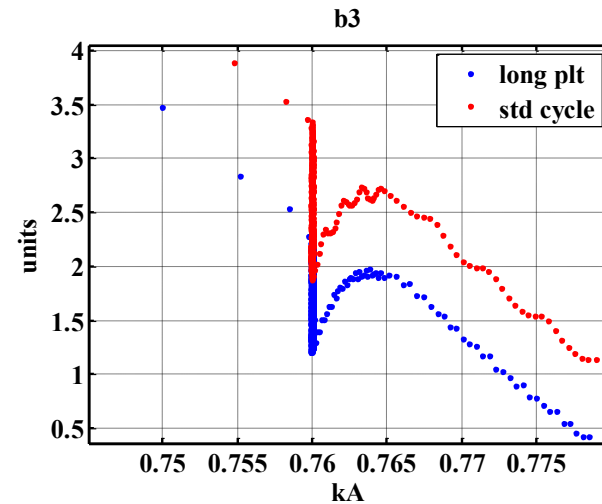
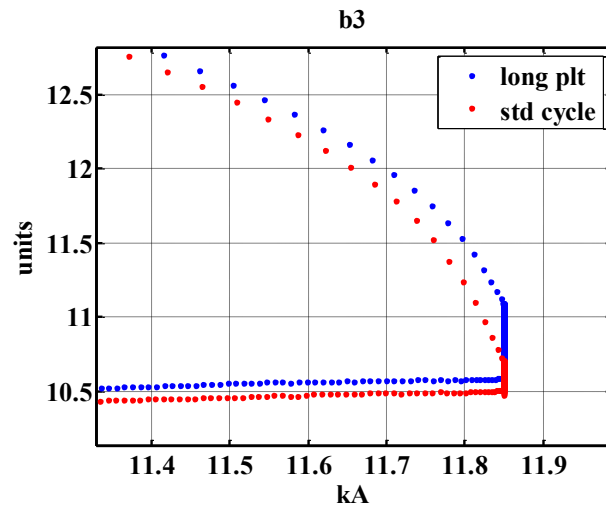
# Allowed multipoles



- b3 changes by ~22 units during ramp
- Offset on allowed multipoles after long plateau at nominal

Reference radius 17 mm

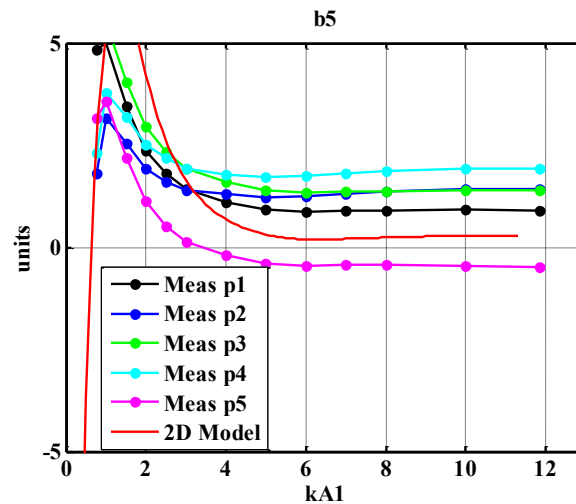
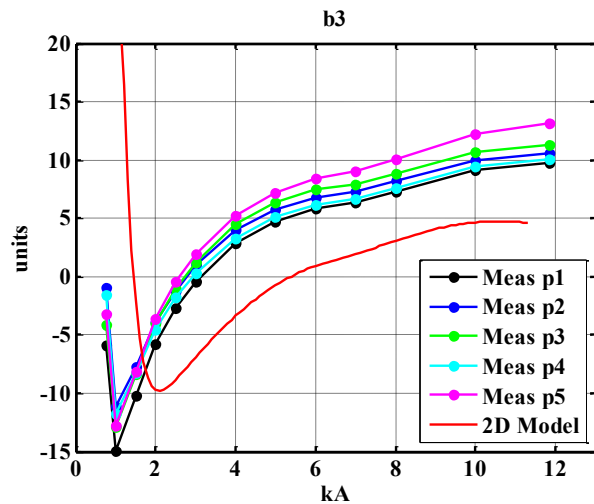
# Allowed multipoles



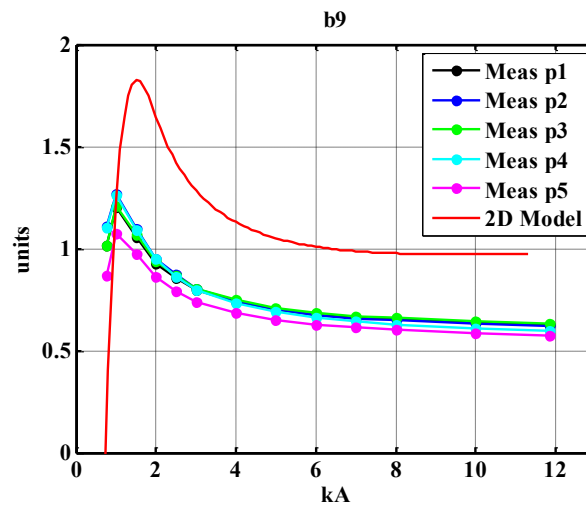
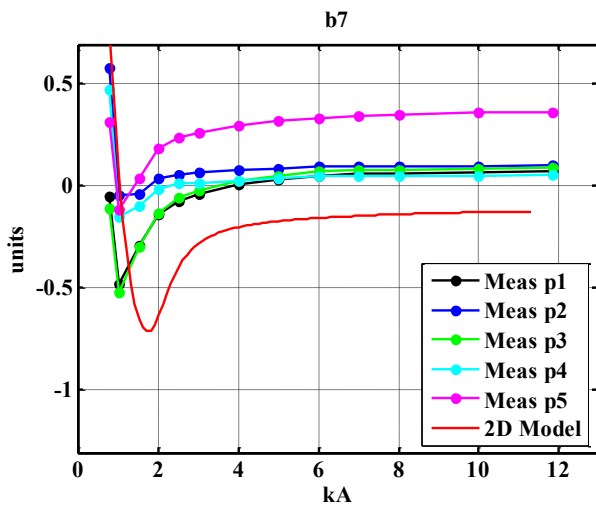
- Slow decay of b3 during long plateau at nominal ~0.5 units
- Decay at injection ~1.2 units

Reference radius 17 mm

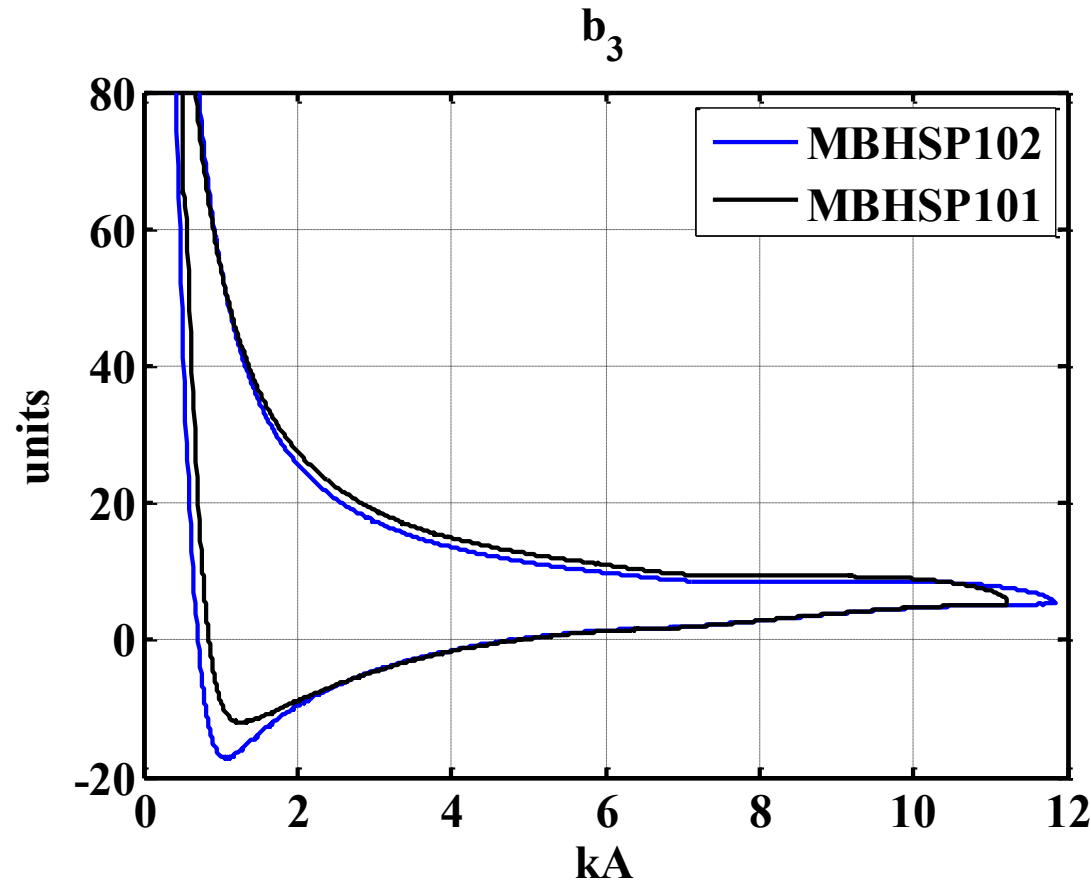
# Comparison with ROXIE (2D)



- Offset of +5 units on b3
- Offset on other allowed multipoles
- Discrepancy on persistent currents



# Comparison with MBHSP101



- Offset added on data from MBHSP102
- Larger persistent currents on MBHSP102

# Ramp-rate dependence

		20 A s <sup>-1</sup>	50 A s <sup>-1</sup>	100 A s <sup>-1</sup>		20 A s <sup>-1</sup>	50 A s <sup>-1</sup>	100 A s <sup>-1</sup>	
n		Δ Bn				Δ An			
2		-0.01	-0.07	-0.06		-0.13	-0.31	-0.42	mT
3		0.08	0.16	0.27		-0.02	0.02	0.06	
4		0.01	0.02	0.04		-0.08	-0.14	-0.19	
5		-0.07	-0.04	0.01		-0.03	-0.01	-0.01	
6		0.00	0.01	0.03		0.01	-0.01	-0.03	
7		0.01	0.01	0.02		0.00	0.00	0.00	
8		0.00	0.01	0.04		0.00	-0.01	0.00	
9		0.01	0.00	-0.01		0.00	0.01	0.01	

- $\Delta C_n = C_n^{dynamic}(I) - C_n^{static}(I) \Big|_{I=5\text{ kA}}$
- **Small effects: the cored cable is well performing**

Reference radius 17 mm

# Other multipoles

n	300 K at 20 A		1.9 K at 5 kA on three segments						$\sigma$	
	1.2 m		seg3		seg4		seg5			
	bn	an	bn	an	bn	an	bn	an	bn	an
2	0.33	6.76	1.75	2.73	1.22	3.56	0.69	3.67	0.53	0.51
3	9.50	-0.84	11.32	-1.78	11.82	-1.38	10.75	0.25	0.54	1.08
4	0.24	1.28	0.54	0.19	0.32	-0.33	-0.29	-0.20	0.43	0.27
5	1.56	-0.02	1.17	-0.59	1.39	0.20	1.65	0.58	0.24	0.60
6	0.00	0.03	-0.01	0.13	0.19	-0.42	0.09	-0.24	0.10	0.28
7	0.16	-0.02	0.16	-0.22	0.10	-0.07	0.12	-0.06	0.03	0.09
8	0.08	0.03	0.03	-0.04	0.05	-0.09	0.03	0.05	0.01	0.07
9	0.83	0.00	0.63	-0.13	0.64	0.02	0.62	0.22	0.01	0.18
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.40	0.02	0.22	-0.04	0.19	0.05	0.17	0.16	0.03	0.10
12	-0.06	0.01	-0.03	0.06	-0.06	0.04	-0.07	0.02	0.02	0.02
13	-0.10	0.00	-0.11	-0.01	-0.11	0.00	-0.11	0.00	0.00	0.01
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
15	-0.02	0.00	-0.02	0.00	-0.02	0.00	-0.02	-0.01	0.00	0.01

Reference radius 17 mm

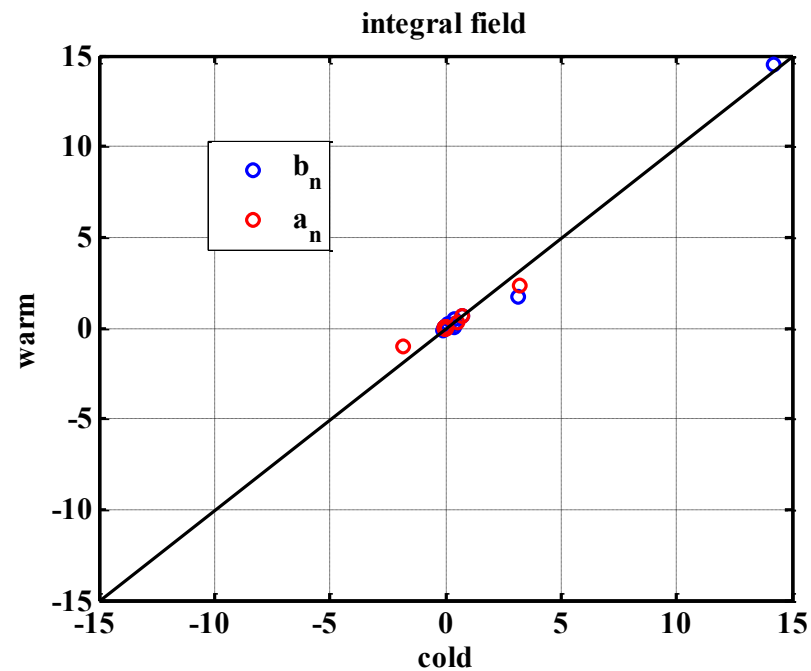
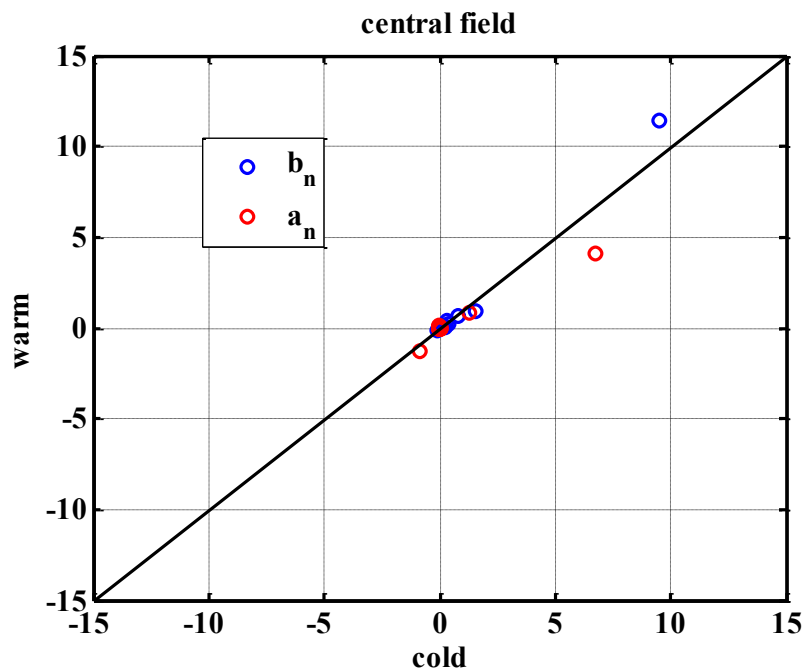
# Integral field

	300 K		1.9 K		
n	bn	an	bn	an	units at 17 mm
2	0.41	3.23	0.51	2.33	
3	14.20	-1.81	14.54	-1.02	
4	0.39	0.75	0.03	0.69	
5	3.13	0.50	1.69	0.33	
6	-0.06	-0.03	0.06	-0.07	
7	0.07	0.06	0.22	0.06	
8	0.07	0.00	0.02	0.00	
9	0.70	0.00	0.63	0.05	
10	-0.01	-0.01	0.00	0.00	
11	0.35	0.05	0.22	0.07	
12	-0.06	0.00	-0.02	0.01	
13	-0.09	0.00	-0.11	0.00	
14	0.00	0.01	0.00	0.00	
15	-0.02	0.00	-0.02	0.00	

- Multipoles in agreement with respect to measurements at 300 K.
- Thermal contraction of measurement shaft to be checked

Reference radius 17 mm

# Cold/Warm correlation



Reference radius 17 mm



# Conclusions

- MBHSP102 has been tested at
  - room temperature
  - cryogenic temperature
- Comparison with model
  - TF in agreement for geometric
  - Model overestimates saturation
  - Offset on allowed multipoles
- Cold/Warm in general agreement