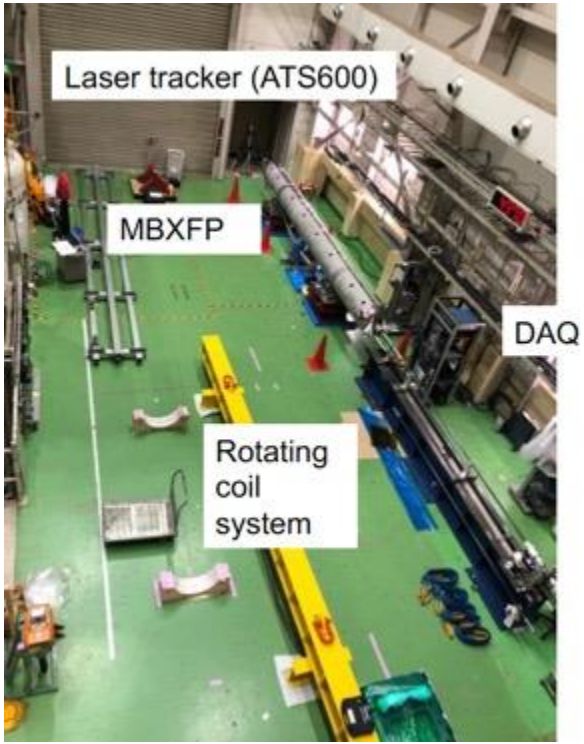
Magnetic measurements for the 1st series of D1: MBXF1

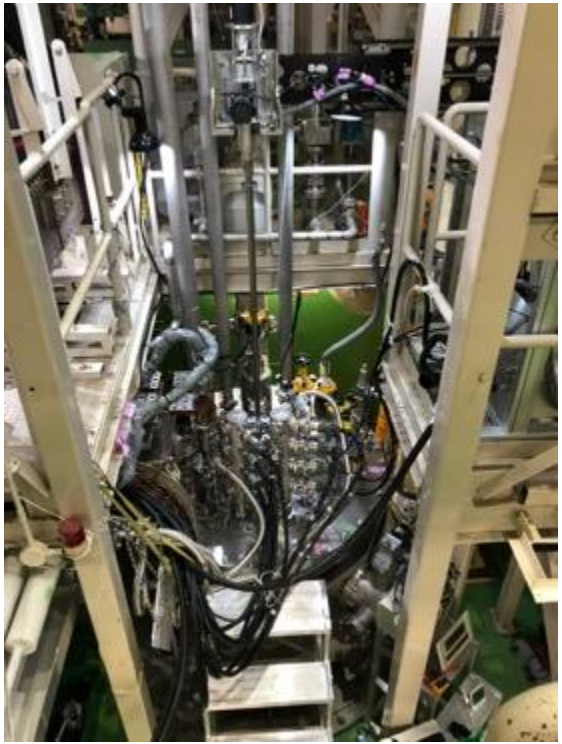
Kento Suzuki

WP3meeting, 23.06.07

Magnetic measurements at KEK

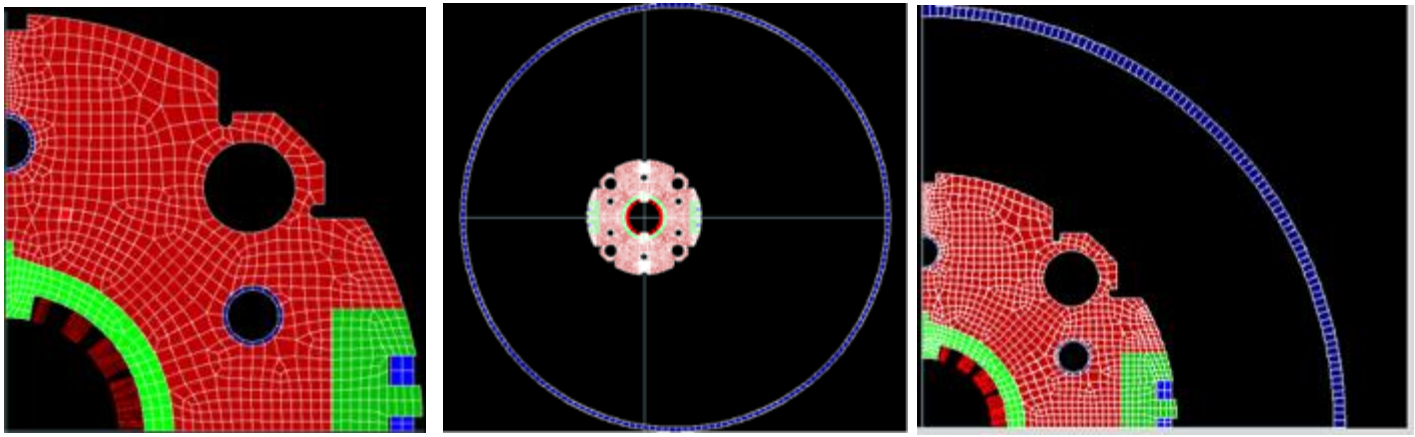


Horizontal system for warm MM



Vertical system for warm/cold MM

D1 magnetic models



w/o Cryostat	KEK pit	CERN cryostat
Horizontal bench	Vertical test stand - Off-centered by 150mm	Used for design - Centered*

(*) Actual cryostat is off-centerd by 54mm
but not taken into account for our design

EDMS: 2045899

Magnetic design goal for the D1 series

ACCEPTANCE CRITERIA

ACCEPTANCE CRITERIA OF KEK IN-KIND CONTRIBUTION (SEPARATION DIPOLE D1)

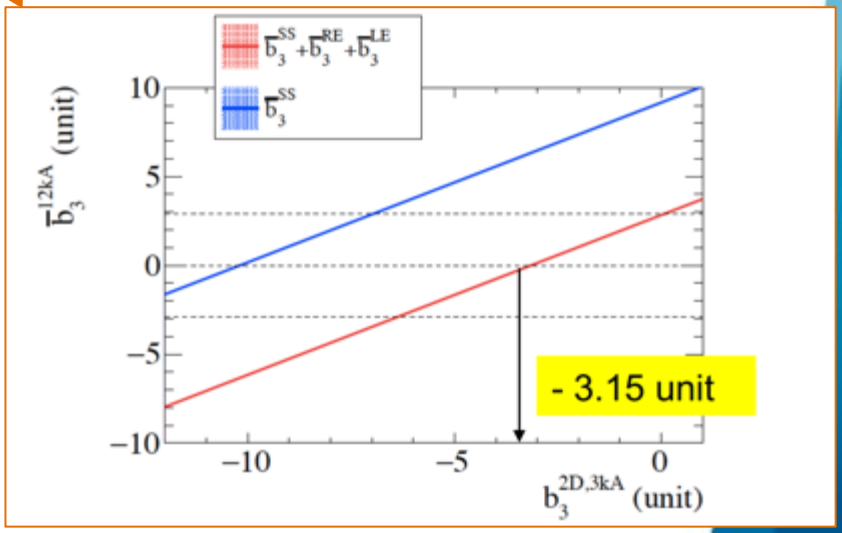
Limit on integral at nominal field

	lower limit	upper limit
b_2	-0.800	0.800
b_3	-2.900	2.900
b_4	-0.500	0.500
b_5	-1.500	1.500
b_6	-0.240	0.240
b_7	-0.660	0.660
b_8	-0.110	0.110
b_9	-0.260	0.260
b_{10}	-0.030	0.030
b_{11}	-0.076	0.076
a_2	-0.800	0.800
a_3	-2.900	2.900
a_4	-0.500	0.500
a_5	-1.500	1.500
a_6	-0.240	0.240
a_7	-0.660	0.660
a_8	-0.110	0.110
a_9	-0.260	0.260
a_{10}	-0.030	0.030
a_{11}	-0.076	0.076

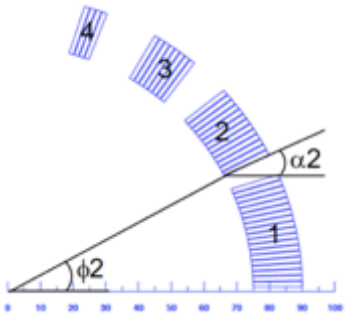
K.Suzuki et al. IEEE TASC vol30, no.4 June 2020, 4002706

$$B_{\mathrm{ref}} \cdot \int_{SS} b_3(z)dz \simeq B_{\mathrm{ref}} \cdot \int_{SS} b_3(z=0)dz + \Delta\bar{b}_3^{\mathrm{shape}} = B_{\mathrm{ref}} \times \left(b_3^{\mathrm{2D,3kA}} + \underbrace{\Delta b_3^{\mathrm{geom}}}_{+3.51} + \underbrace{\Delta b_3^{\mathrm{3kA\to 12kA}}}_{+2.02} + \underbrace{\Delta b_3^{\mathrm{3D,\ 3kA}}}_{+0} \right) \cdot \int_{SS} dz + \underbrace{\Delta\bar{b}_3^{\mathrm{shape}}}_{+4.10} \quad (5)$$

Design parameter



Magnetic design goal for the D1 series



Cross sectional design tuned by Roxie

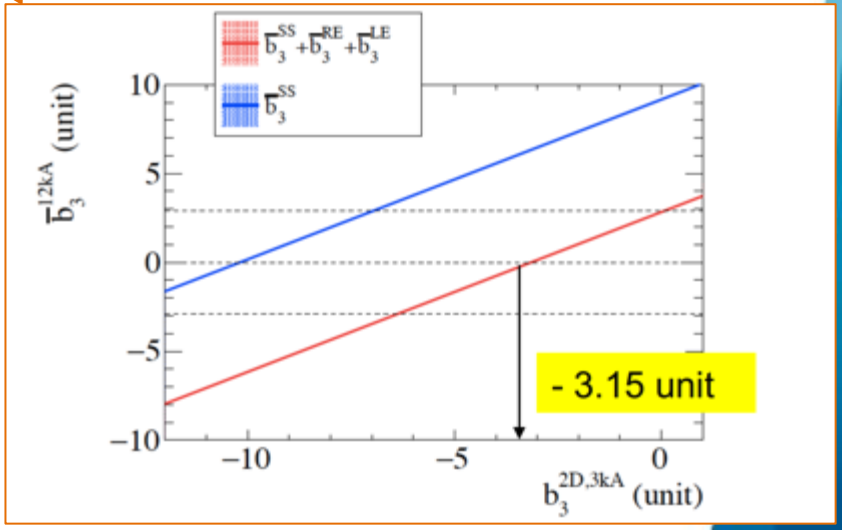
	Parameters for design
ϕ1	1.1680
ϕ2	27.8471
ϕ3	50.3830
ϕ4	70.7156
α2	27.5527
α3	52.5639
α4	70.3048
Azimuthal insulation thickness (mm)	0.1297

1.9K, 3kA

b3	-3.15011
b5	-2.99980
b7	0.01068
b9	0.03186
b11	0.09035
b13	-0.64140
b15	-1.07244

$$B_{\mathrm{ref}} \cdot \int_{SS} b_3(z)dz \simeq B_{\mathrm{ref}} \cdot \int_{SS} b_3(z=0)dz + \Delta\bar{b}_3^{\mathrm{shape}} = B_{\mathrm{ref}} \times \left(b_3^{\mathrm{2D,3kA}} + \Delta b_3^{\mathrm{geom}} + \Delta b_3^{\mathrm{3kA\to 12kA}} + \Delta b_3^{\mathrm{3D,\ 3kA}} \right) \cdot \int_{SS} dz + \Delta\bar{b}_3^{\mathrm{shape}} \quad (5)$$

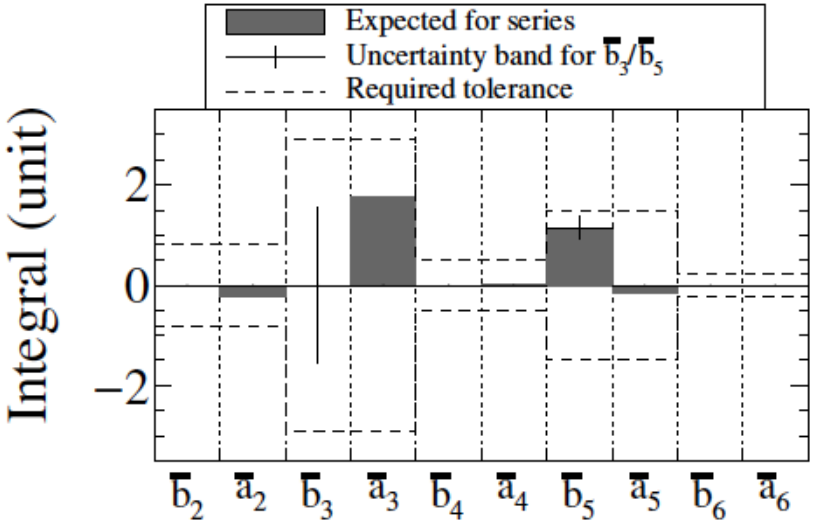
+3.51 +2.02 +0 +4.10

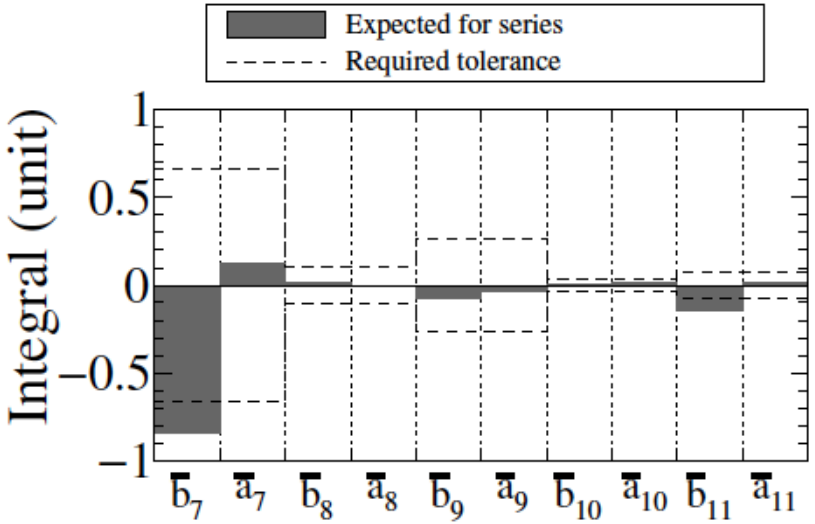


Magnetic design goal for the D1 series

Expected field integral at CERN cryostat

K.Suzuki et al. IEEE TASC vol.32, no.6 Sept 2022, 9000407



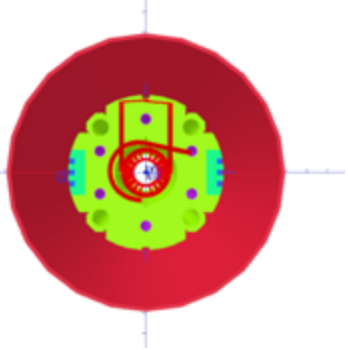


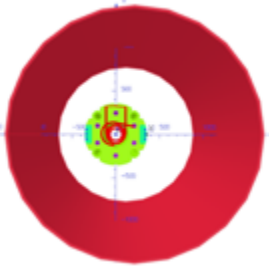
Remark I: Environmental effect

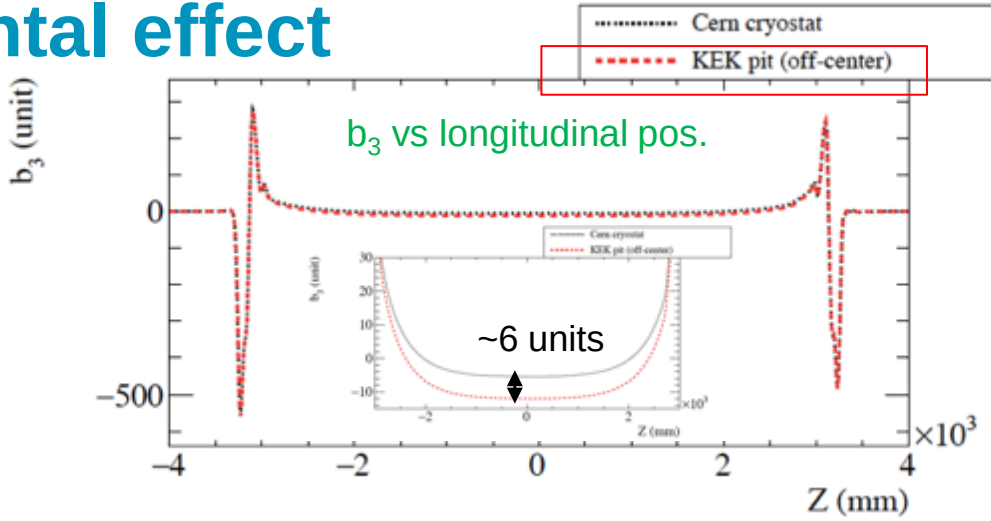
CERN cryostat

KEK pit

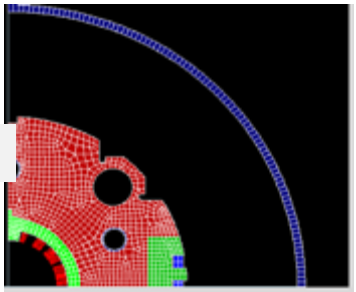
Opera3D

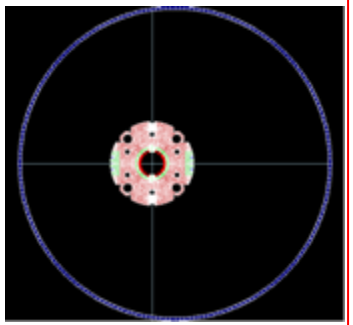


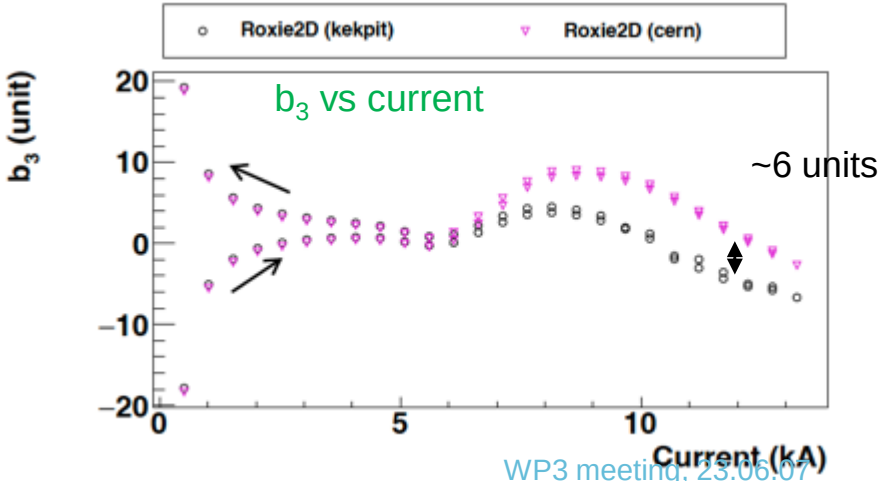




Roxie2D







Remark II : Contribution from “coil-end field”

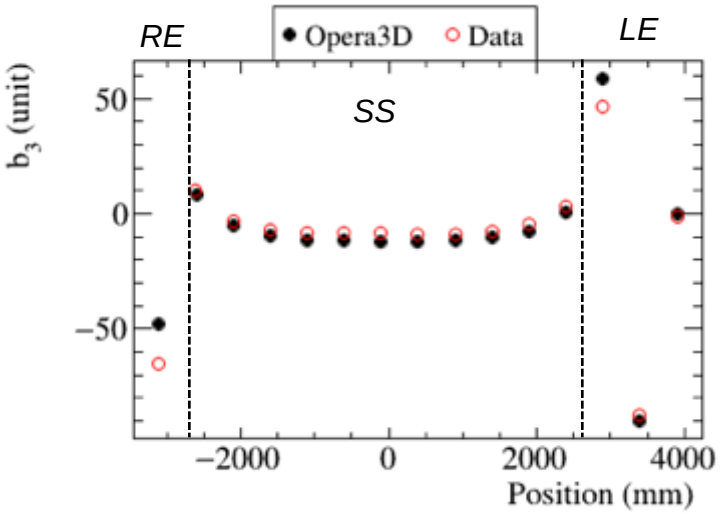
https://indico.cern.ch/event/1269740/contributions/5378345/attachments/2644433/4577520/2023-03-22_Room%20temperature%20magnetic%20measurements%20of%20D1%20cold%20mass%20prototype.pdf

By Mariano Pentella

Measurement results - 4

	b_n					a_n				
N	Central	Average SS	Std.	Integral	ROXIE	Central	Average SS	Std.	Integral	ROXIE
2	0.87	0.58	0.33	0.69	0.00	-1.67	-1.70	0.67	-1.89	0.00
3	-4.12	-4.22	0.70	-14.88	-2.19	0.09	-0.05	0.19	1.60	0.00
4	0.18	0.14	0.12	0.16	0.00	-0.37	-0.42	0.06	-0.46	0.00
5	2.81	2.70	0.26	2.66	3.51	0.16	-0.02	0.14	-0.13	0.00
6	0.10	0.04	0.07	0.04	0.00	-0.02	-0.04	0.04	-0.05	0.00
7	1.09	1.12	0.07	0.84	1.05	0.02	0.02	0.09	0.16	0.00
8	0.03	0.01	0.02	0.01	0.00	0.15	0.14	0.04	0.15	0.00
9	0.74	0.74	0.03	0.39	0.61	-0.02	-0.01	0.04	-0.02	0.00
10	0.01	0.01	0.01	0.01	0.00	0.11	0.10	0.02	0.11	0.00
11	0.08	0.08	0.01	-0.08	0.04	0.00	0.01	0.02	0.02	0.00
12	0.00	0.00	0.01	0.00	0.00	0.05	0.04	0.01	0.04	0.00
13	-0.68	-0.68	0.01	-0.80	-0.68	0.02	0.02	0.01	0.02	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	-1.11	-1.10	0.02	-1.23	-1.18	0.01	0.03	0.03	0.03	0.00

Prototype result at CERN (warm)



Prototype result at KEK (1.9K, 12.11 kA)

Discrepancy observed at coil end, resulting in negative offsets to the b_3 integral

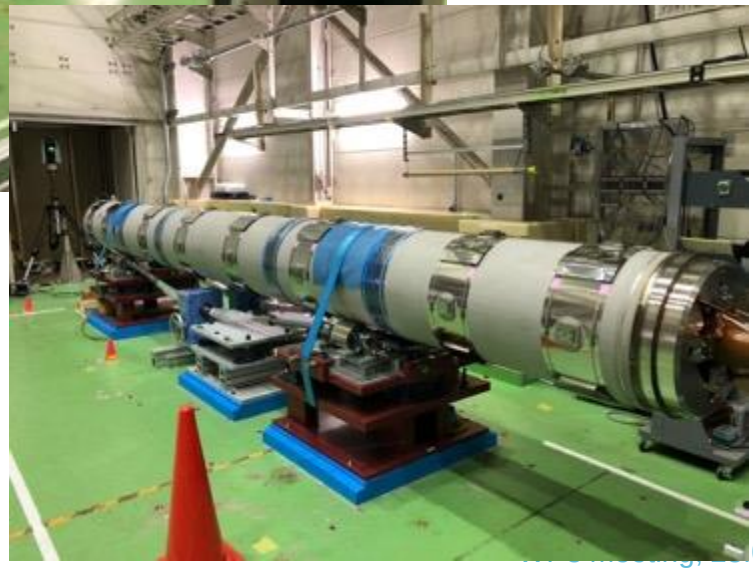
Test schedule

- MBXF1 reception : 3/16
- Horizontal MM (*I*=15A): 3/17 – 3/24
- Vertical MM in the 1st thermal cycle :
  - Room temperature (*I*=10A) : 4/10
  - 1.9 K temperature (*I*=687A-12110A) : 5/10 – 5/16

Test schedule

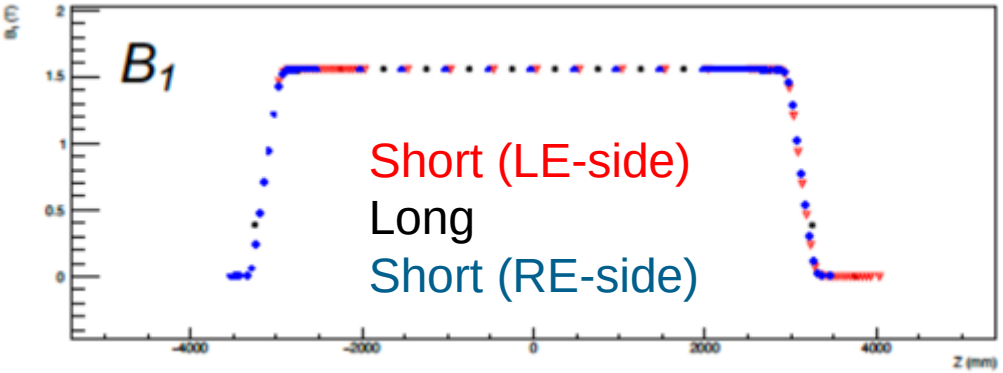
- MBXF1 reception : 3/16
- **Horizontal MM (*I*=15A): 3/17 – 3/24**
- Vertical MM in the 1st thermal cycle :
  - Room temperature (*I*=10A) : 4/10
  - 1.9 K temperature (*I*=687A-12110A) : 5/10 – 5/16

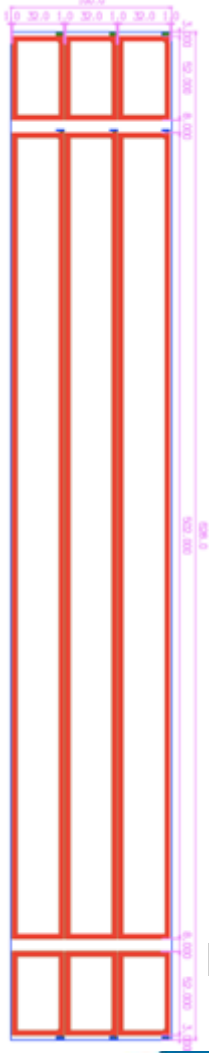
Preparation work during horizontal MM (3/17)



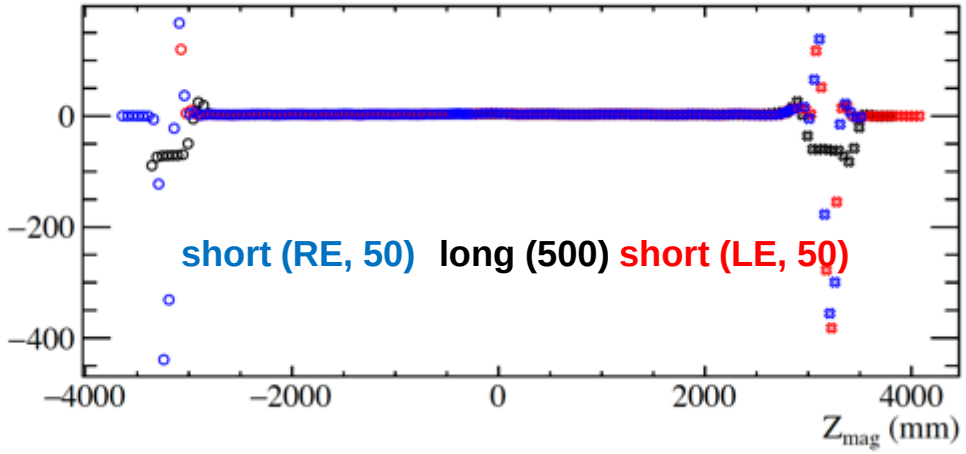
Rotating coil for the horizontal MM

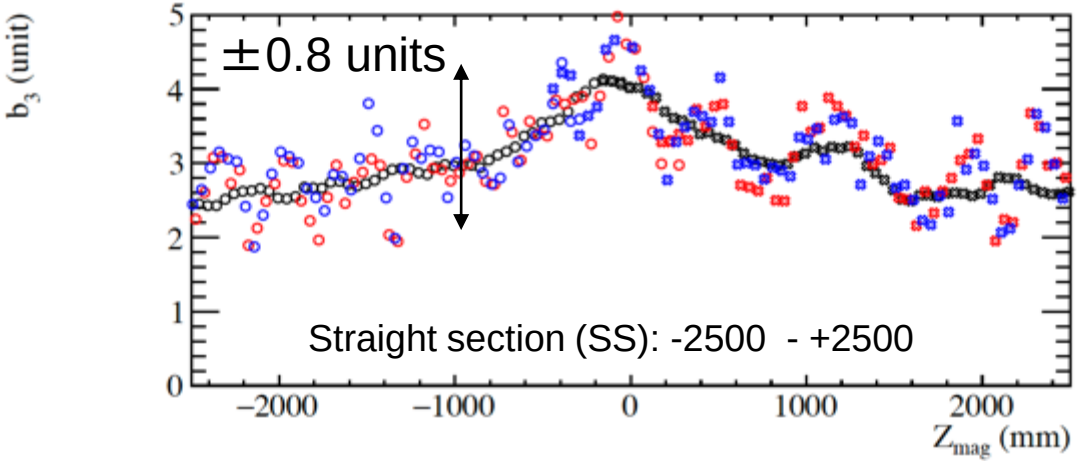
- Common layout with the vertical MM system
  - A long coil (500mm) sandwitched by two short ones (50mm)
  - Long coil for integral measurement
  - Short coils for profile measurement
- Measurement procedure : EDMS 2747312
  - https://edms.cern.ch/document/2747312/1
- Expected coverage:





Measured b_3 profile





- The first check of the field profile along the entire coil of MBXF1
- b_3 in the SS has a 'bump' and a peak around the magnet center
- Variation of ±0.8 units observed for the SS in the long coil measurement
  - This is not the first feature in the full-scale magnet
  - Similar feature was confirmed in the prototype too (see backup)

FQ table of MBXF1 for room temperature

RE: -3505 mm - -2505 mm
SS: -2505 mm - 2495 mm
LE: 2495 mm - 3995 mm
Central: -255 mm - 245 mm

$$\frac{\int_{\mathrm{RE}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4 \quad \frac{\int_{\mathrm{SS}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4 \quad \frac{\int_{\mathrm{LE}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4$$

n	Central		SS (average)		RE		SS		LE		Total	
	an	bn	an	bn	an	bn	an	bn	an	bn	an	bn
2	-2.79	-0.09	-3.31	0.18	-0.12	-0.40	-2.65	0.14	0.02	0.22	-2.75	-0.04
3	0.01	4.06	-0.24	3.04	0.02	-5.52	-0.19	2.43	1.92	-4.46	1.75	-7.55
4	-0.46	0.12	0.08	0.05	0.03	-0.08	0.07	0.04	0.02	-0.03	0.12	-0.07
5	0.01	-2.31	0.00	-2.49	-0.04	-0.71	0.00	-1.99	-0.18	0.07	-0.22	-2.63
6	0.36	-0.05	0.09	0.15	0.04	-0.02	0.07	0.12	-0.02	0.04	0.09	0.14
7	0.05	0.46	0.09	0.37	0.02	-0.31	0.07	0.29	0.15	-0.05	0.24	-0.07
8	0.24	0.01	0.07	0.10	0.07	-0.03	0.06	0.08	0.02	0.02	0.15	0.07
9	0.00	0.23	0.03	0.17	0.01	-0.27	0.03	0.14	0.00	-0.15	0.04	-0.29
10	0.12	-0.02	0.00	0.08	0.03	-0.02	0.00	0.07	0.01	0.01	0.04	0.06
11	0.01	0.17	0.11	0.24	0.01	-0.09	0.09	0.19	0.02	-0.06	0.11	0.04
12	0.00	0.00	0.41	-0.08	0.05	-0.02	0.33	-0.07	0.02	0.00	0.39	-0.08
13	0.02	-0.70	0.23	-0.45	0.01	-0.09	0.18	-0.36	0.01	-0.07	0.20	-0.51
14	0.08	-0.02	0.77	-0.24	0.05	-0.02	0.62	-0.19	0.02	0.01	0.69	-0.20
15	-0.02	-1.06	0.23	-0.90	0.01	-0.08	0.19	-0.72	0.01	-0.09	0.21	-0.88
16	0.04	-0.04	0.62	-0.29	0.03	-0.02	0.49	-0.23	0.02	0.00	0.55	-0.25
17	-0.04	-0.67	-0.10	-0.82	-0.01	-0.06	-0.08	-0.66	-0.01	-0.06	-0.09	-0.78
18	-0.05	-0.09	-0.32	0.10	-0.02	0.01	-0.25	0.08	-0.03	0.00	-0.29	0.09
19	0.12	0.34	-0.02	0.35	0.01	0.03	-0.02	0.28	0.01	-0.01	0.00	0.30
20	-0.04	0.08	-0.05	0.03	0.00	0.00	-0.04	0.03	0.02	-0.01	-0.02	0.01

Comparison with prototype and prediction (Roxie2D)

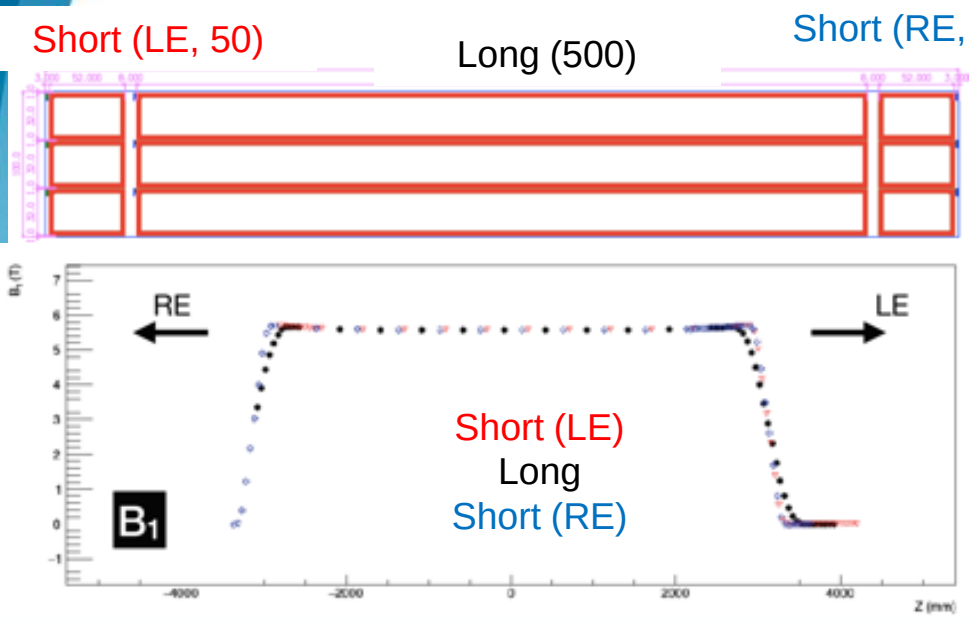
2D FQ (averaged over SS) from horizontal						Prediction by Roxie 2D (warm, woCryostat)					
MBXFP (ref)		MBXF1		MBXF1-MBXFP		Prototype		Series		Series - Proto	
an	bn	an	bn	Δan	Δbn	an	bn	an	bn	Δan	Δbn
-1.03	0.11	-3.31	0.18	-2.28	0.07	0	0	0	0	0	0
-0.19	-4.37	-0.24	3.04	-0.04	7.41	0	-2.19	0	0.73	0	2.92
-1.01	0.34	0.08	0.05	1.10	-0.29	0	0	0	0	0	0
-0.06	2.85	0.00	-2.49	0.06	-5.33	0	3.51	0	-2.86	0	-6.38
-0.41	0.19	0.09	0.15	0.50	-0.04	0	0	0	0	0	0
-0.03	1.18	0.09	0.37	0.11	-0.81	0	1.05	0	-0.26	0	-1.31
-0.17	0.15	0.07	0.10	0.23	-0.06	0	0	0	0	0	0
0.01	0.82	0.03	0.17	0.02	-0.65	0	0.61	0	-0.10	0	-0.71
0.06	0.07	0.00	0.08	-0.06	0.02	0	0	0	0	0	0
0.10	0.22	0.11	0.24	0.01	0.02	0	0.04	0	0.06	0	0.03
0.44	-0.08	0.41	-0.08	-0.03	0.00	0	0	0	0	0	0
0.24	-0.45	0.23	-0.45	-0.01	-0.00	0	-0.68	0	-0.65	0	0.03
0.82	-0.26	0.77	-0.24	-0.06	0.02	0	0	0	0	0	0
0.20	-0.97	0.23	-0.90	0.03	0.08	0	-1.18	0	-1.05	0	0.12
0.56	-0.26	0.62	-0.29	0.05	-0.04	0	0	0	0	0	0
-0.10	-0.77	-0.10	-0.82	-0.01	-0.06	0	-0.66	0	-0.69	0	-0.03
-0.31	0.11	-0.32	0.10	-0.00	-0.01	0	0	0	0	0	0
-0.01	0.37	-0.02	0.35	-0.01	-0.02	0	0.37	0	0.35	0	-0.02
-0.02	0.02	-0.05	0.03	-0.03	0.01	0	0	0	0	0	0

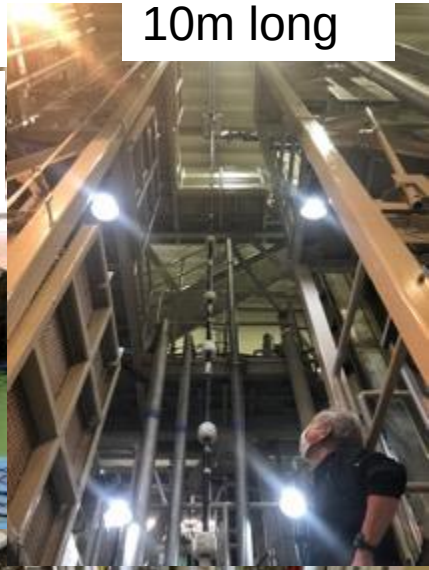
- 4.5 units increase was observed in b_3, which is higher than Roxie2D's expectation
- 3.3 units offset was observed in a2, which was already confirmed and reported in the previous WP3 meeting (23.02.10)
- Good improvement observed for the other harmonics

Test schedule

- MBXF1 reception : 3/16
- Horizontal MM (*I*=15A): 3/17 – 3/24
- **Vertical MM in the 1st thermal cycle :**
  - Room temperature (*I*=10A) : 4/10
  - 1.9 K temperature (*I*=687A-12110A) : 5/10 – 5/16

Vertical Magnetic Measurement System



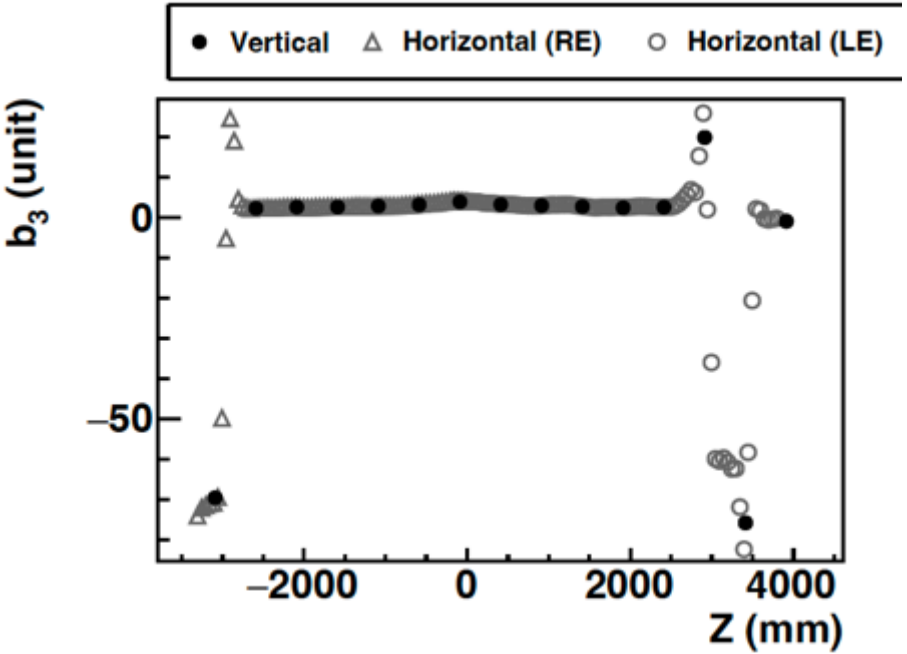


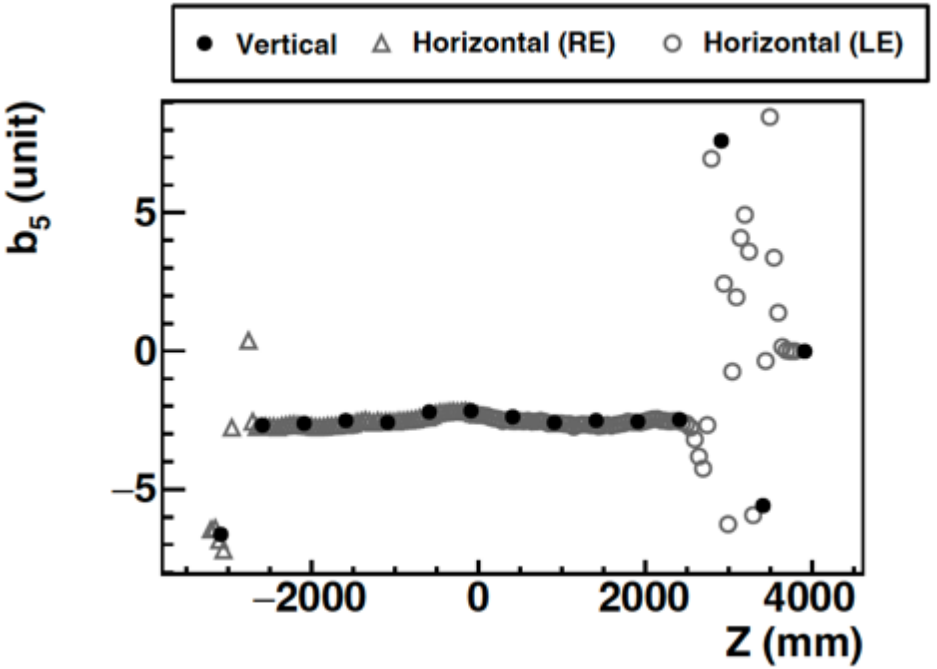
- PCB design
  - Common layout with the horizontal one
- Shaft extension was completed before the prototype test
  - Attached a 1.7m-long extension to enlarge the measurement coverage for the full scale (7m-long) magnet

Test schedule

- MBXF1 reception : 3/16
- Horizontal MM (*I*=15A): 3/17 – 3/24
- **Vertical MM in the 1st thermal cycle :**
  - **Room temperature (*I*=10A) : 4/10**
  - 1.9 K temperature (*I*=687A-12110A) : 5/10 – 5/16

Comparison w/ horizontal results -b3 / b5 profile

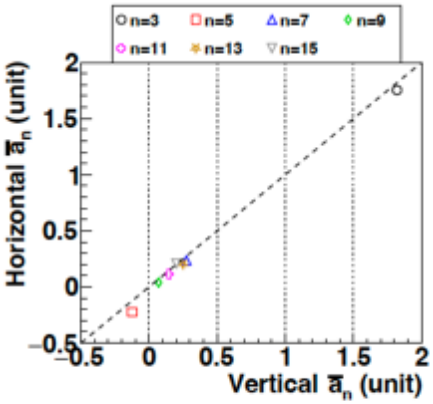


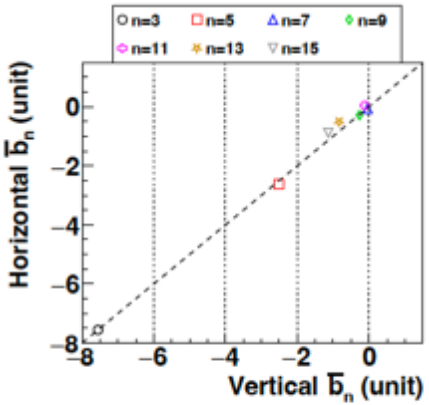


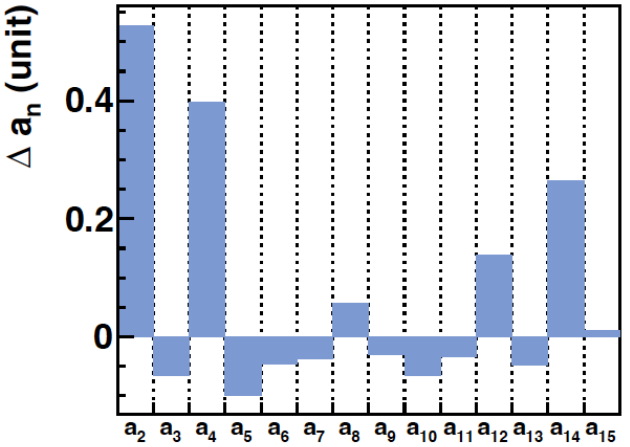
- Measured profiles are consistent with the horizontal results

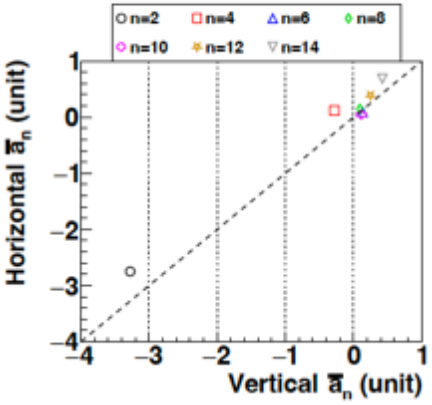
Comparison w/ horizontal results

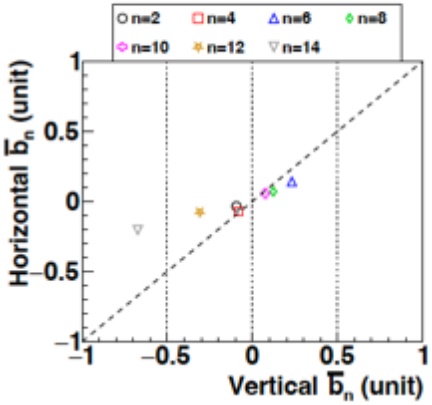
Integral

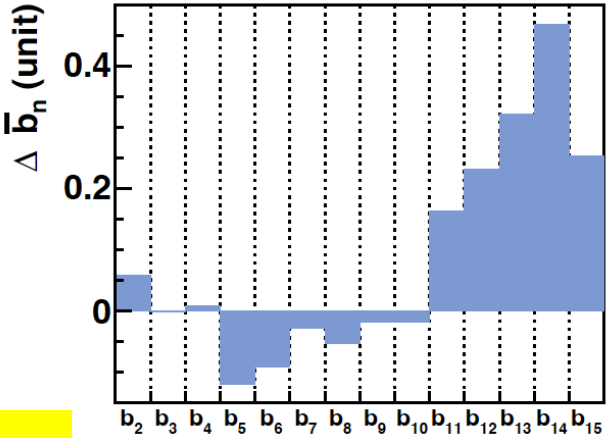










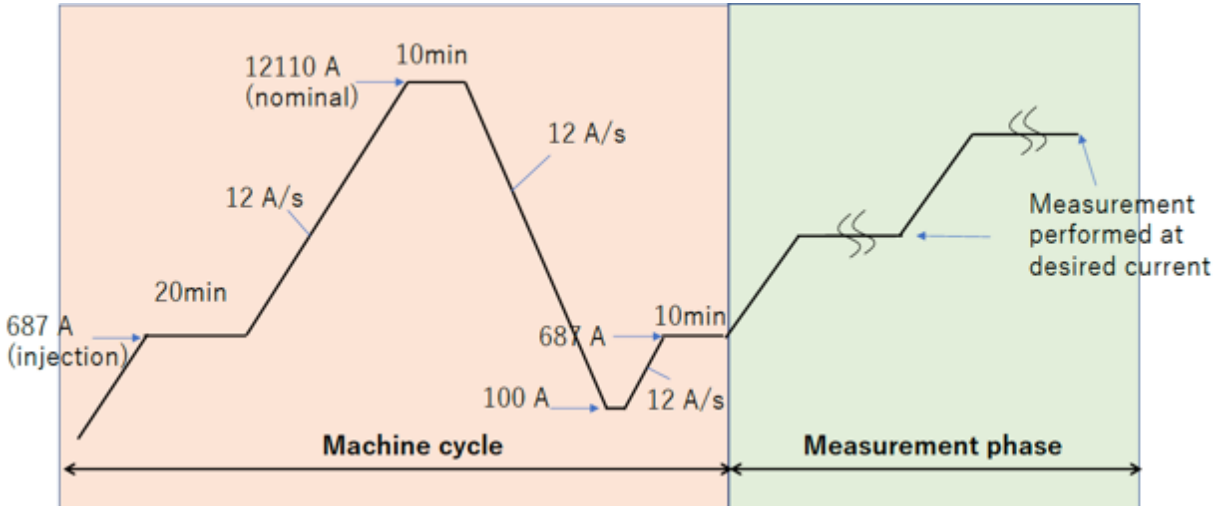


- Differences of measured harmonics are within 0.5 units

Test schedule

- MBXF1 reception : 3/16
- Horizontal MM (*I*=15A): 3/17 – 3/24
- **Vertical MM in the 1st thermal cycle :**
  - Room temperature (*I*=10A) : 4/10
  - **1.9 K temperature (*I*=687A-12110A) : 5/10 – 5/16**

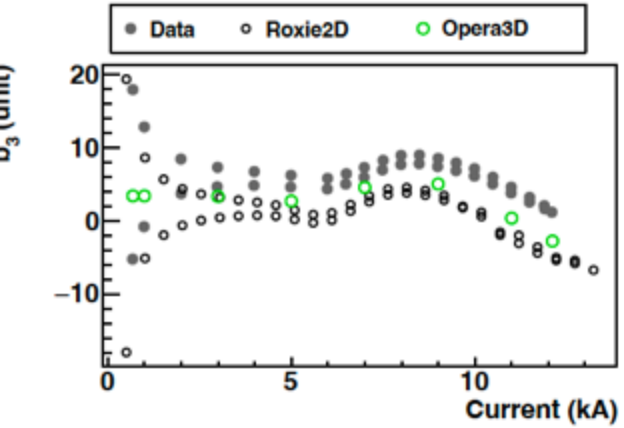
Measurement procedure

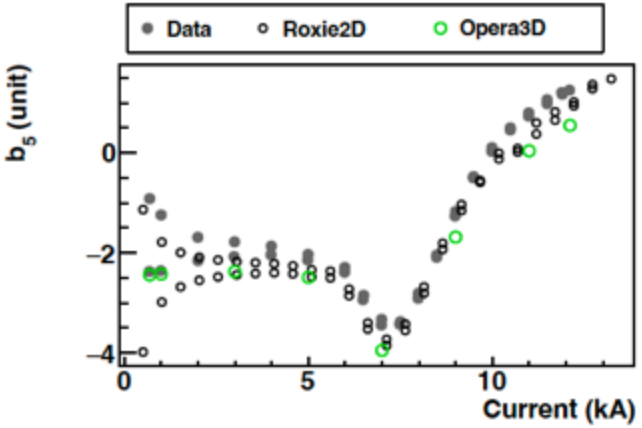


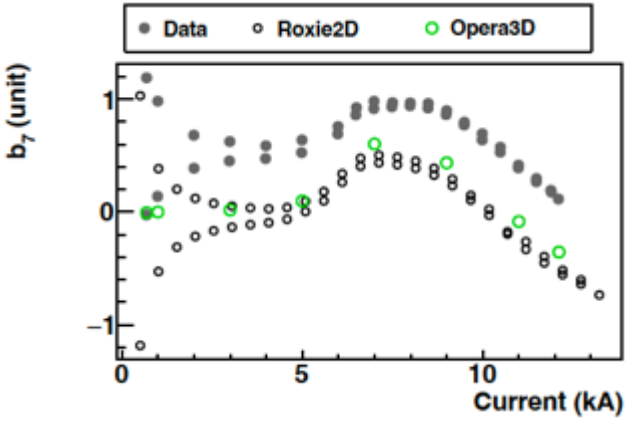
- Before the measurements we perform ’Pre-cycle’ so the NbTI cable experiences its magnetization up to the nominal field
- Ramp rate, which was originally set to 10 A/s, was changed to **12A/s** according to the HL-LHC circuit parameters(*)
  - Accordingly out test plan was modified

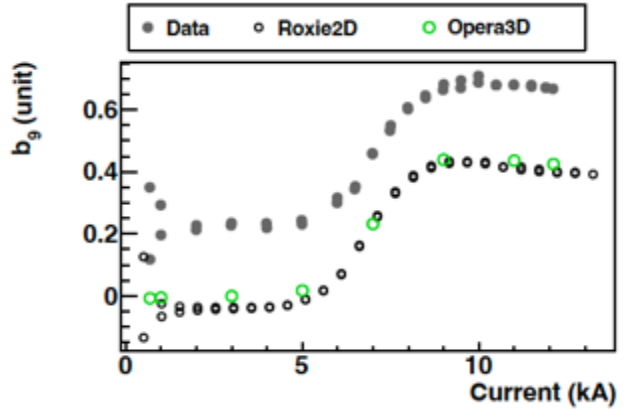
(*)https://cds.cern.ch/record/2298764/files/CERN-ACC-2017-0101_revised.pdf

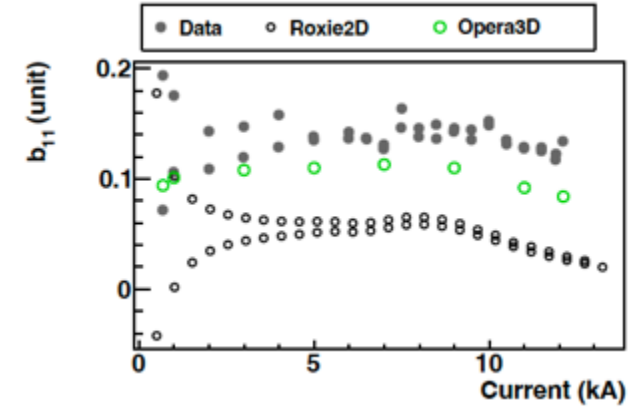
DC loop at the Z center for allowed normal (n=3-13)

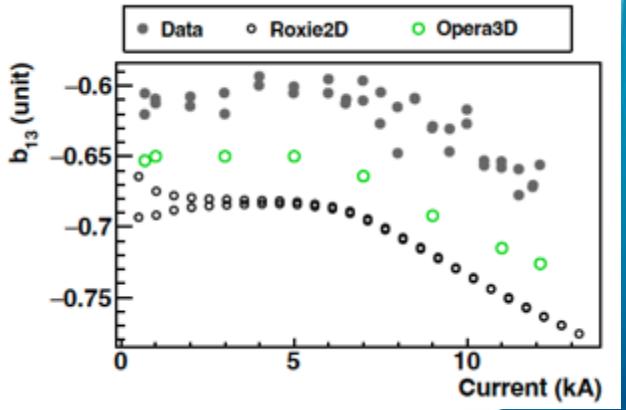




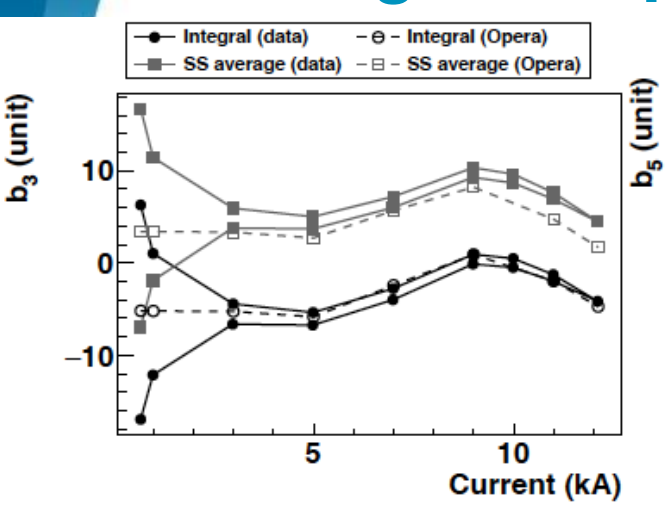


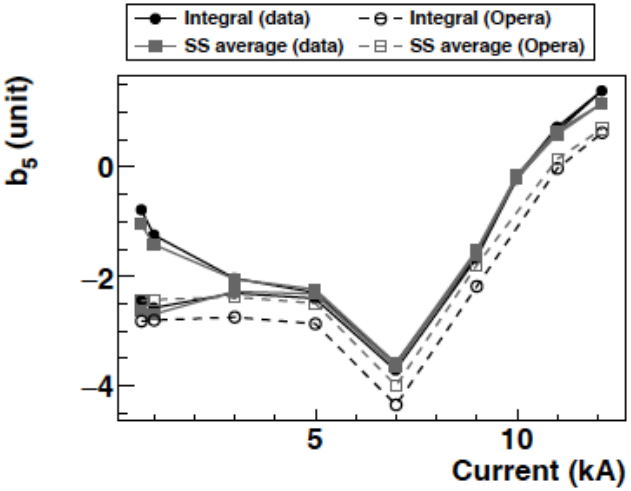


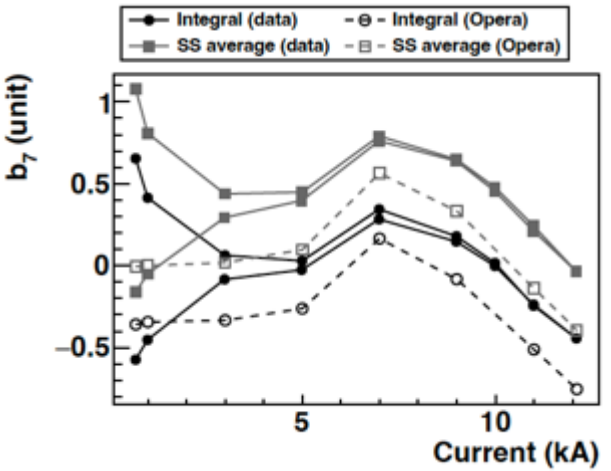


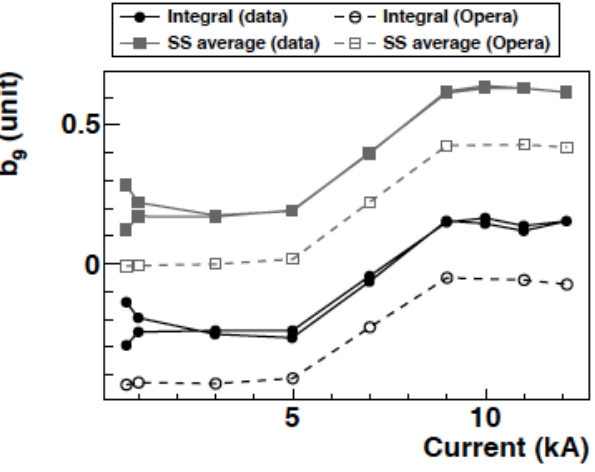


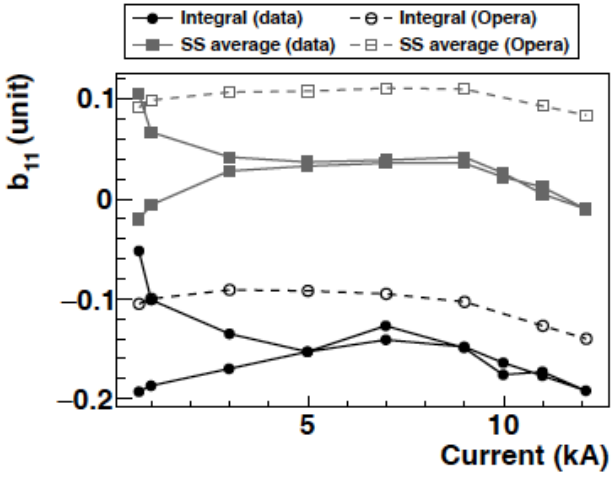
Integral loop for allowed normal (n=3-13)

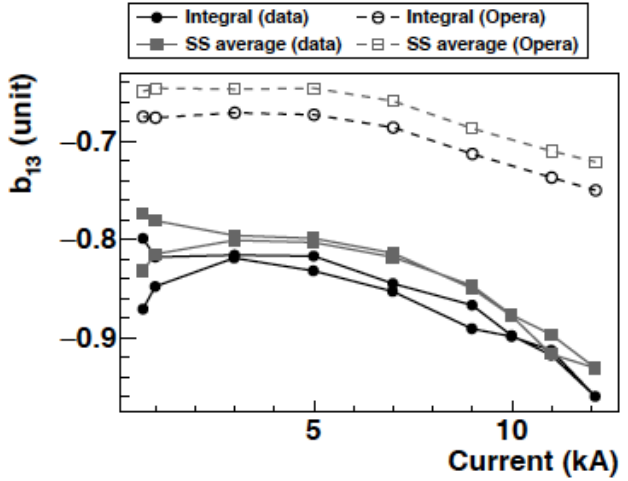












FQ table of MBXF1 for $I_{nominal}$ (12.11kA)

RE: -3353 mm - -2853 mm
SS: -2853 mm - 2648 mm
LE: 2648 mm - 4148 mm
Central: -250 mm - 250 mm

$$\frac{\int_{\mathrm{RE}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4 \quad \frac{\int_{\mathrm{SS}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4 \quad \frac{\int_{\mathrm{LE}} B_n(z)dz}{\int_{\mathrm{total}} B_1(z)dz} \times 10^4$$

n	Central		SS (average)		RE		SS		LE		Total	
	an	bn	an	bn	an	bn	an	bn	an	bn	an	bn
2	-3.92	0.05	-3.88	0.31	-0.41	0.09	-3.41	0.28	-0.02	-0.25	-3.84	0.11
3	-0.07	1.19	-0.30	4.48	0.13	-5.08	-0.26	3.94	2.04	-3.01	1.90	-4.15
4	-0.46	0.07	-0.59	0.38	-0.07	0.07	-0.52	0.33	-0.04	0.15	-0.63	0.55
5	0.01	1.25	0.06	1.16	0.02	-0.25	0.05	1.02	-0.13	0.62	-0.06	1.39
6	0.30	-0.06	0.15	0.09	-0.02	0.07	0.13	0.08	0.02	-0.02	0.13	0.14
7	0.05	0.12	0.10	-0.04	0.03	-0.36	0.09	-0.03	0.16	-0.05	0.28	-0.44
8	0.24	0.03	0.07	0.27	-0.03	0.09	0.06	0.24	-0.03	-0.05	0.00	0.27
9	0.03	0.67	0.06	0.62	0.03	-0.28	0.06	0.54	0.01	-0.11	0.09	0.15
10	0.14	0.02	0.06	0.05	-0.02	0.03	0.05	0.05	0.00	-0.05	0.04	0.03
11	0.00	0.13	0.06	-0.01	-0.01	-0.11	0.06	-0.01	0.04	-0.07	0.09	-0.19
12	0.01	-0.12	0.11	-0.41	0.00	0.02	0.10	-0.36	0.00	-0.06	0.11	-0.40
13	-0.02	-0.66	0.08	-0.93	0.00	-0.07	0.07	-0.82	0.02	-0.07	0.09	-0.96
14	-0.09	-0.25	0.15	-0.78	0.00	0.01	0.13	-0.69	0.01	-0.07	0.14	-0.76
15	-0.03	-1.15	0.06	-1.36	0.01	-0.03	0.05	-1.20	0.02	-0.08	0.08	-1.31
16	-0.08	-0.21	0.09	-0.53	0.01	0.01	0.08	-0.46	0.00	-0.05	0.08	-0.51
17	0.02	-0.77	-0.03	-0.63	-0.01	-0.01	-0.03	-0.56	0.00	-0.01	-0.03	-0.58
18	0.08	0.10	-0.04	0.29	0.00	0.01	-0.03	0.26	-0.02	0.01	-0.05	0.28
19	0.00	0.38	0.00	0.38	0.00	0.00	0.00	0.33	0.00	0.03	-0.01	0.37
20	-0.01	0.02	0.00	0.02	0.00	-0.01	0.00	0.02	0.00	-0.01	0.00	-0.01

b_3 Summary

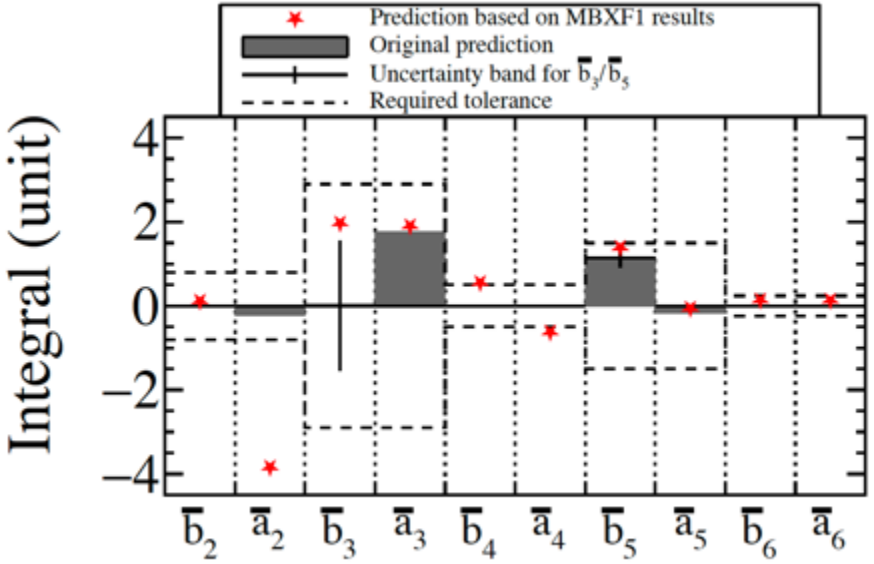
		Opera3D (for series)	MBXFP1	**MBXF1**	MBXF5
Horizontal by portable MM system			-4.87	**1.96**	1.00
Horizontal warm	Central		-4.12	**4.06**	
	SS average			**3.04**	
	Integral			**-7.55**	
Vertical, warm	Central				
	SS average		-4.37	**2.90**	
	Integral		-14.38	**-7.55**	
Vertical, 12.11kA	Central	-2.74	-8.51	**1.19**	
	SS average	1.70	-4.25	**4.48**	
	Integral	-4.72	-12.31	**-4.15**	
CERN (prediction)	Central	3.74	-2.03	**7.67**	
	SS average	7.98	2.03	**10.77**	
	Integral	-1.55 / +1.40	-6.19	**1.97**	

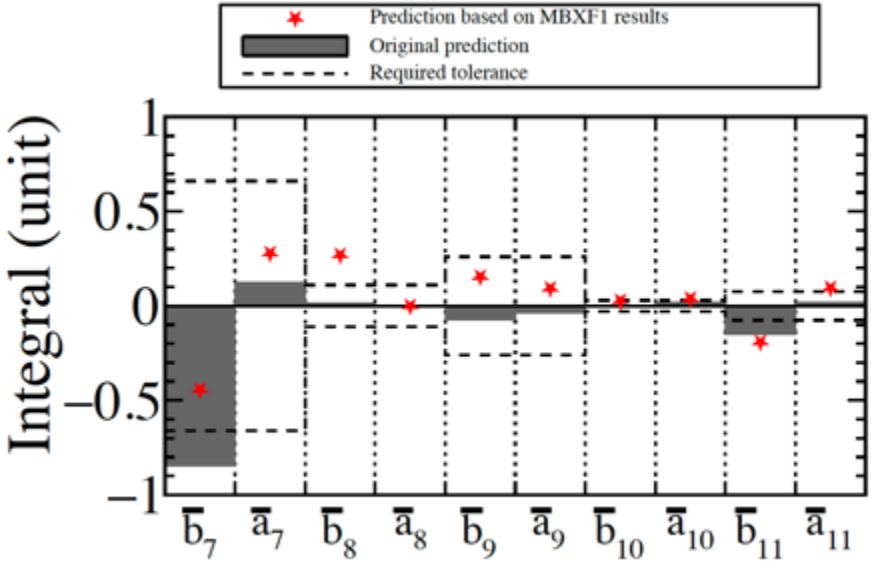
Error band defined by comparison between proto. and simulation

b_5 Summary

		Opera3D (for series)	MBXFP1	**MBXF1**	MBXF5
Horizontal by portable MM system			2.86	**-2.34**	-2.49
Horizontal warm	Central		2.90	**-2.31**	
	SS average			**-2.49**	
	Integral			**-2.63**	
Vertical, warm	Central				
	SS average		2.85	**-2.43**	
	Integral		2.31	**-2.51**	
Vertical, 12.11kA	Central	0.55	6.72	**1.25**	
	SS average	0.70	6.76	**1.16**	
	Integral	0.63	6.51	**1.39**	
CERN (prediction)	Central	0.77	6.94	**1.47**	
	SS average	0.94	7.01	**1.40**	
	Integral	0.89	6.78	**1.66**	

Predicted FQ in the LHC cryostat





- Almost all the harmonics are within the requirement !

Plan for MBXF MM

- MBXF1
  - After the 2nd thermal cycle we plan to perform the horizontal MM to confirm reproducibility
    - July 2023
- MBXF5
  - The horizontal MM is planned after the reception, foreseen in this summer.
    - Detailed schedule will be decided later
- MBXF2
  - The warm MM is planned after yoking but ground insulation issue is not fixed yet
    - Detailed schedule will be decided later

Summary

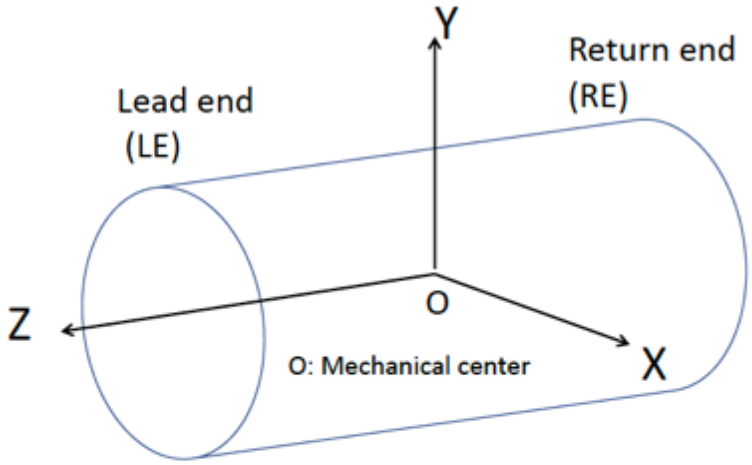
- The first magnetic measurements at the KKE test benches were completed for both room and 1.9 K temperatures.
- Measured multipoles (integral) were comparable with the predictions by Opera, except for a_2 which is slightly bigger than expectation (-3.8 units)
- The multipoles (integral) in the LHC cryostat were estimated based on the MBXF1 results, most of which were confirmed to be within tolerance
- The detailed MM plans for MBXF5 and MBXF2 will be decided later.

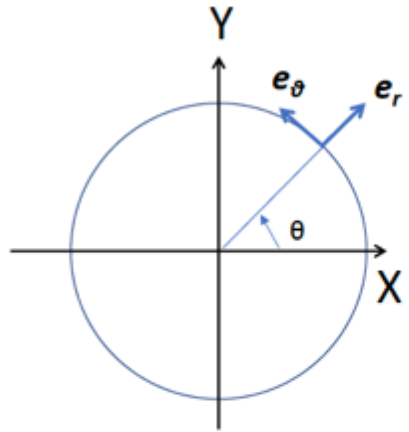
Thank you

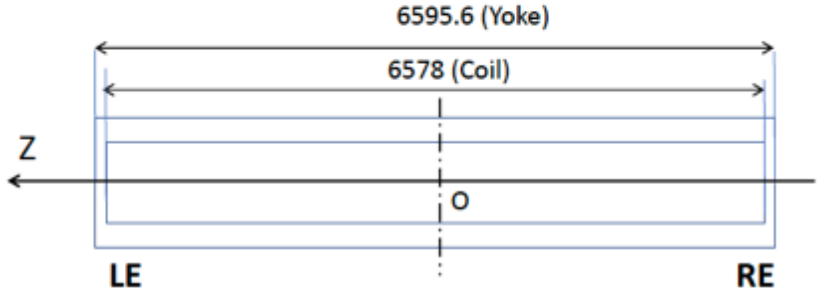
KEK

Supplement

Definition of coordinate





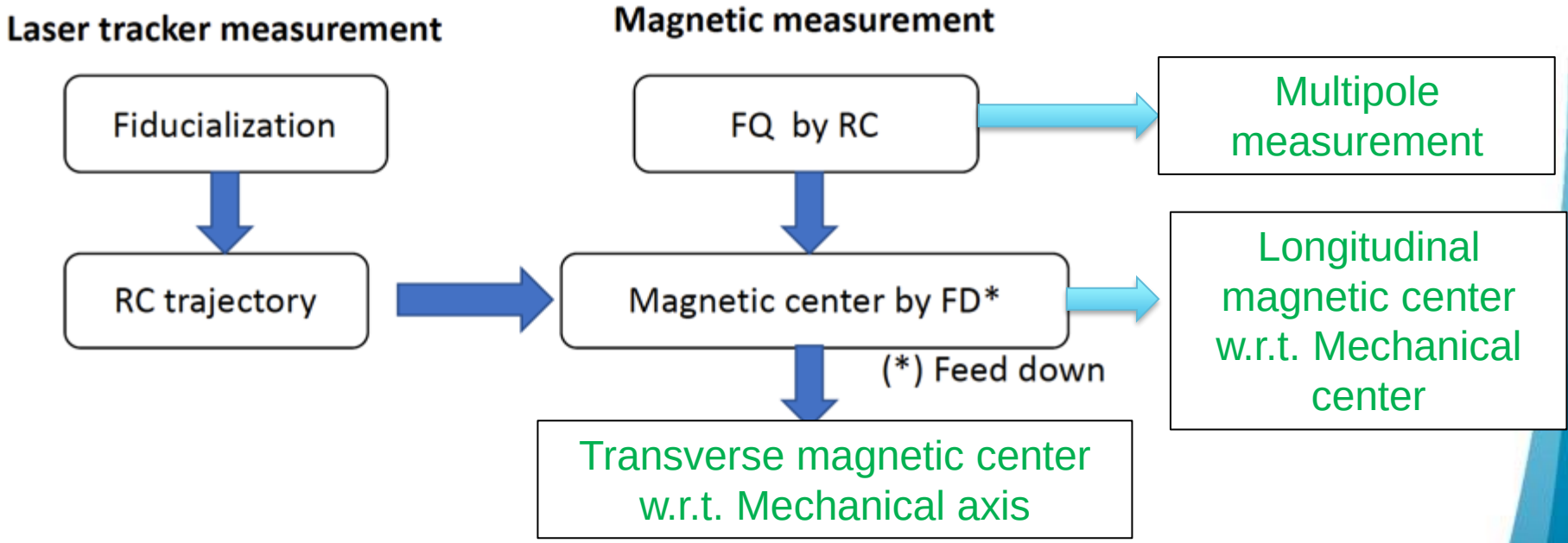


$$\vec{B} = B_\theta \vec{e}_\theta + B_r \vec{e}_r$$

$$B_\theta = \sum_n (B_n \cos n\theta - A_n \sin n\theta)$$

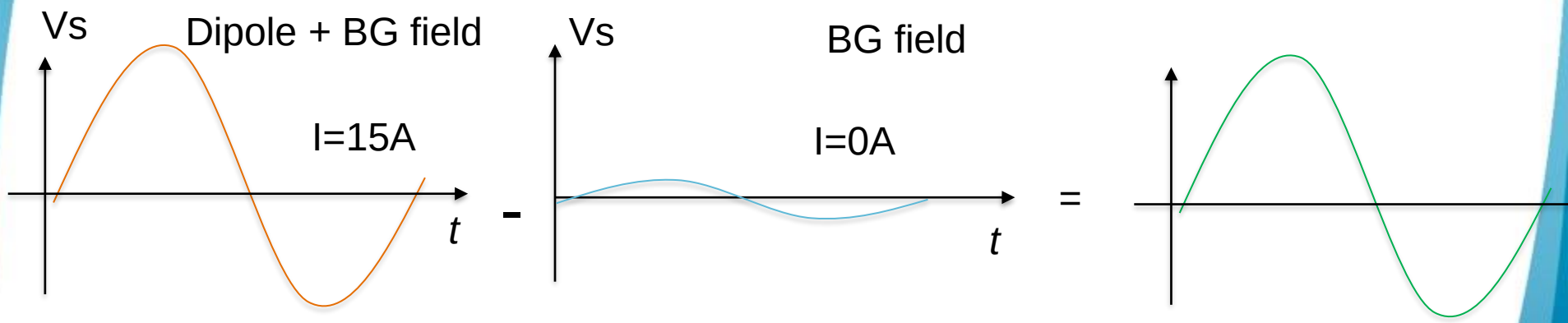
B_n: Normal、 A_n: Skew

Analysis method and outcome in horizontal MM

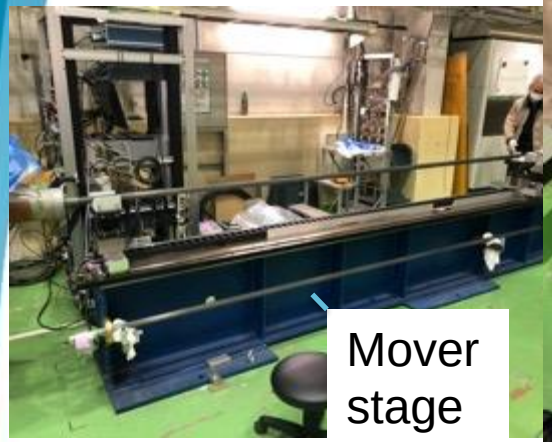


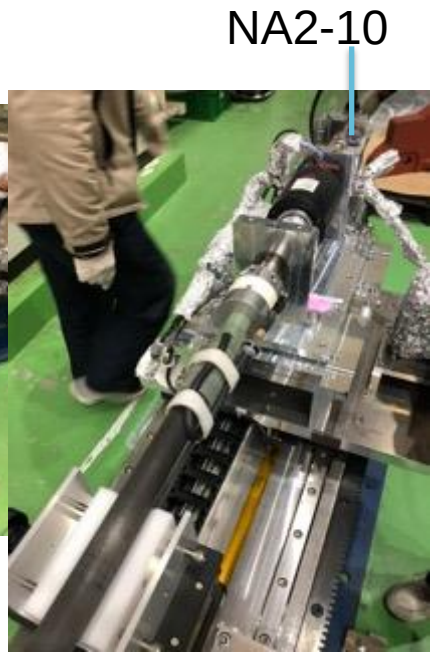
Analysis method (cont'd)

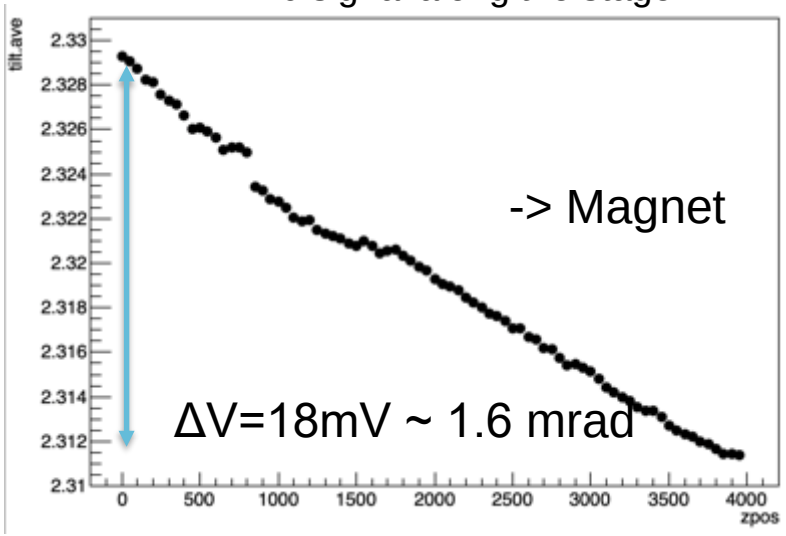
- BG elimination
  - Direct subtraction (= waveform subtraction) since MBXF1



Inclination angle of the mover stage

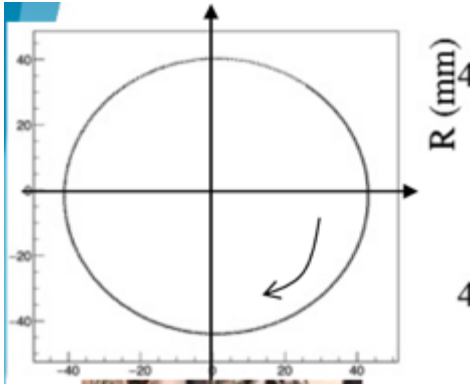


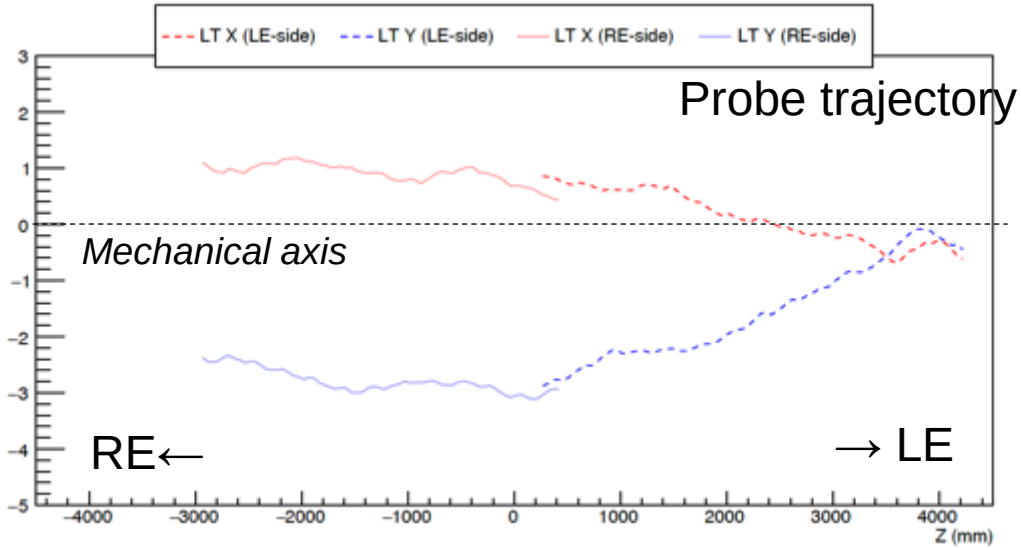




- Change in the inclination angle of the stage affects a1 measurement and thus it was used as correction for analysis

Determination of probe position (X,Y)

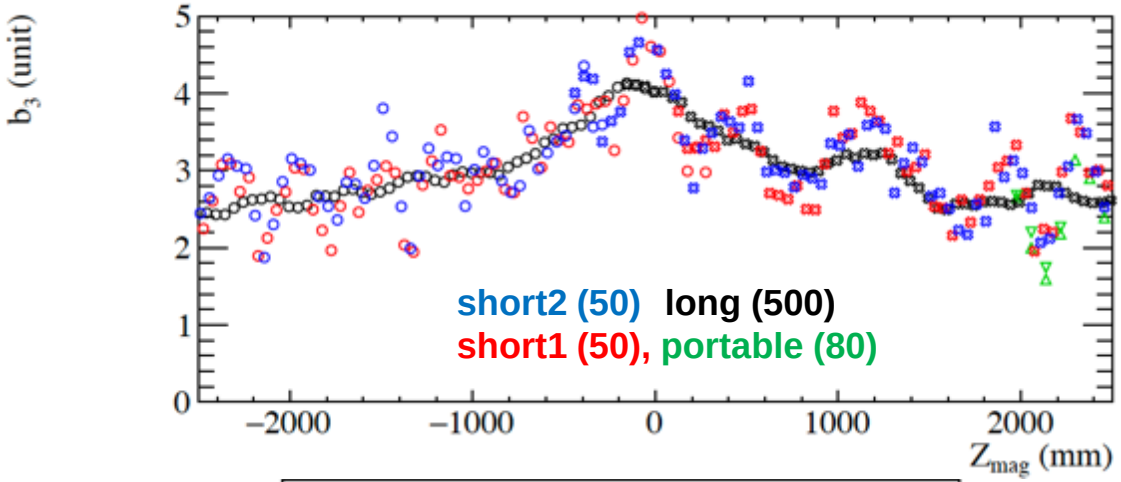




- Probe position in transverse was measured through a 0.5” SMR mounted on the probe head and a laser tracker
- The position was then transferred to the feed down analysis for determination of the magnetic center

About b3 structure

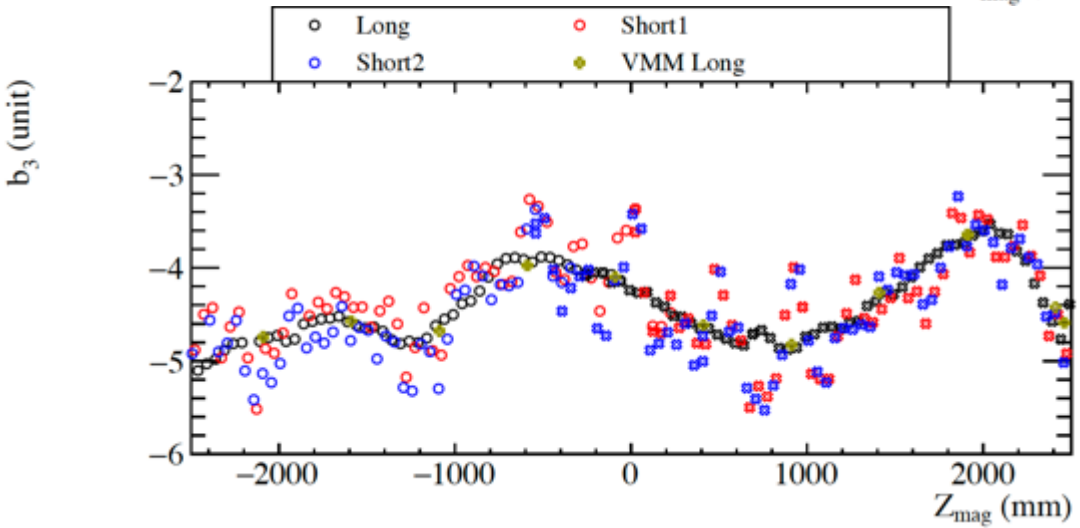
MBXF1



+/- 1.5 unit (short)

+/- 0.8 unit (long)

MBXFP

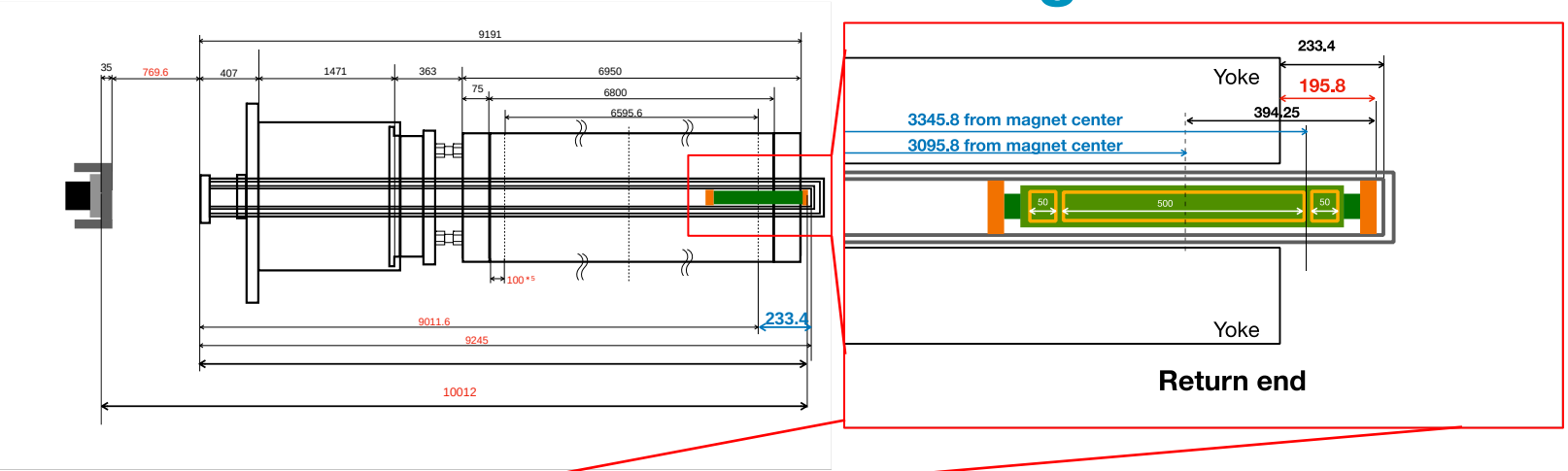


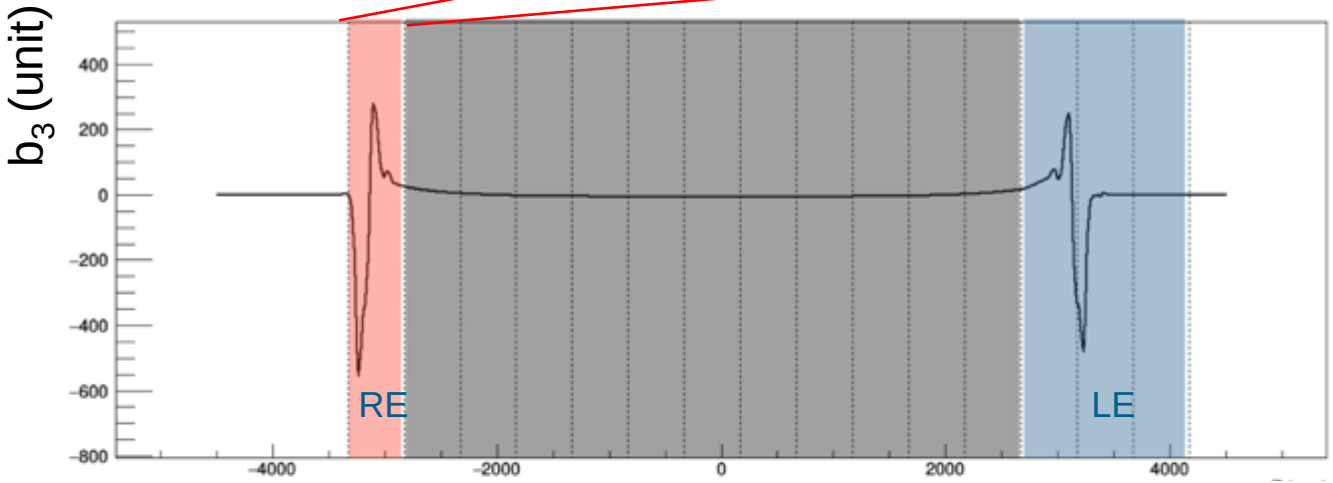
+/- 0.8 unit (long)

Horizontal MM results II – Integral

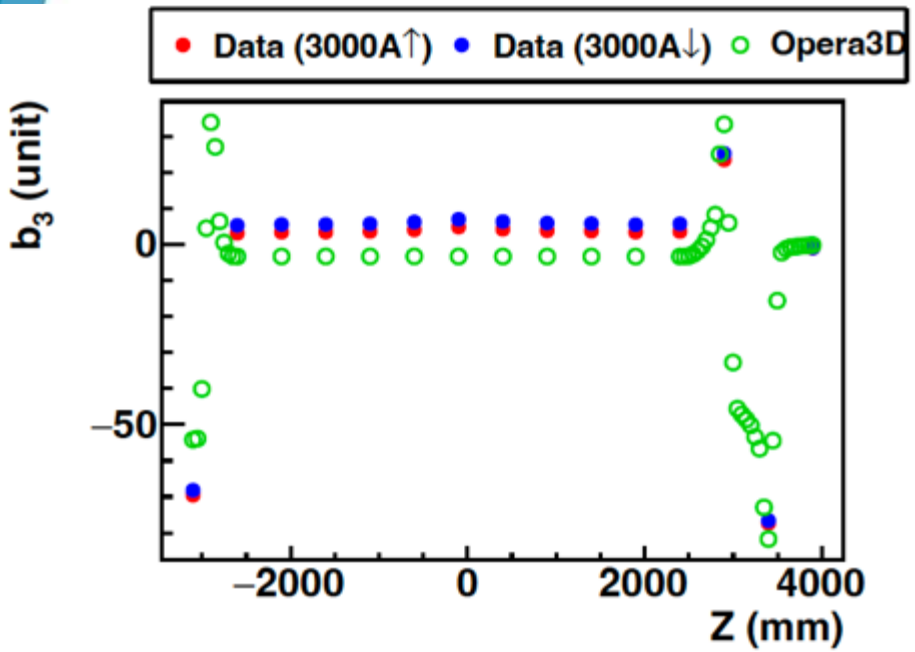
n	Data integral					
	MBXFP (vertical)		MBXF1 (horizontal)		MBXF1-MBXFP	
	an	bn	an	bn	Δan	Δbn
2	-1.94	-0.15	-2.75	-0.04	-0.81	0.11
3	1.81	-14.38	1.75	-7.55	-0.06	6.83
4	-0.56	0.63	0.12	-0.07	0.68	-0.70
5	-0.19	2.31	-0.22	-2.63	-0.03	-4.94
6	-0.08	0.35	0.09	0.14	0.17	-0.21
7	0.22	0.78	0.24	-0.07	0.02	-0.85
8	0.09	0.20	0.15	0.07	0.06	-0.13
9	0.05	0.32	0.04	-0.29	-0.01	-0.61
10	0.10	-0.01	0.04	0.06	-0.05	0.07
11	0.05	-0.18	0.11	0.04	0.07	0.22
12	0.05	-0.33	0.39	-0.08	0.33	0.25
13	0.04	-0.87	0.20	-0.51	0.17	0.36
14	0.10	-0.60	0.69	-0.20	0.59	0.40
15	0.02	-1.20	0.21	-0.88	0.19	0.32
16	0.05	-0.37	0.55	-0.25	0.49	0.12
17	0.03	-0.47	-0.09	-0.78	-0.12	-0.31
18	-0.05	0.22	-0.29	0.09	-0.24	-0.12
19	-0.03	0.35	0.00	0.30	0.03	-0.05
20	-0.03	0.02	-0.02	0.01	0.02	-0.00

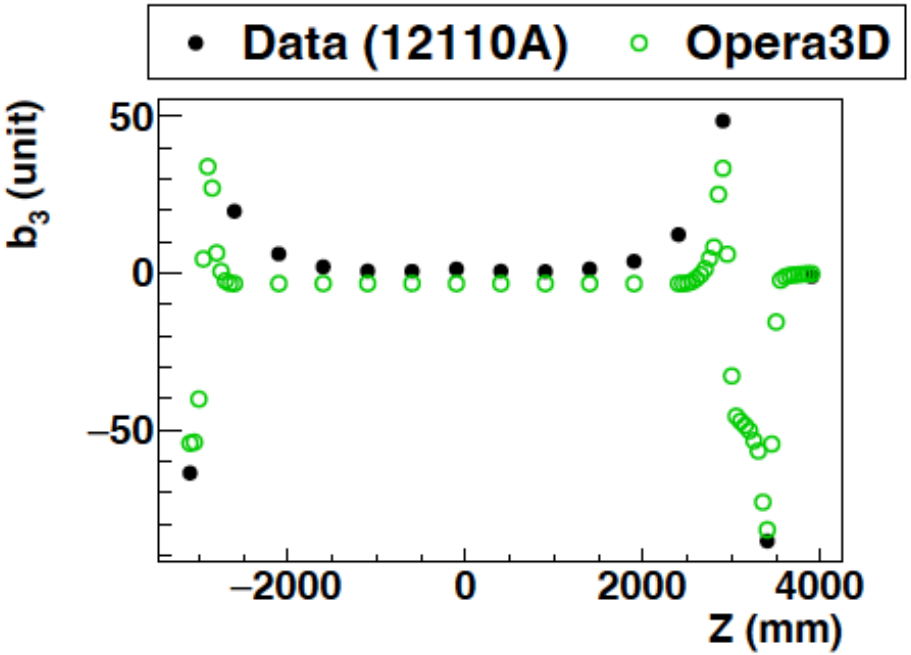
Measurement coverage





Z-scan result





Transfer function (T/kA, T·m/kA)