Series Measurements of the SLS2.0 Longitudinal Gradient Bends Magnets

Challenges and Results

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Summary

- The SLS2.0 Arc
- The Triplet’s Magnets (The LGB)
- Measurements’ Challenges & Requirements
- Measurement Procedures
- Series Measurements Results
- Conclusions

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The SLS2.0 Arc

On Wednesday you are going to visit the tunnel!

- **SLS2.0 keeps the same footprint of SLS-> magnets density along the ring increases of a factor 3.8**
- An SLS2.0 arc is based on a multi-bend achromatic structure (7BA)->emittance reduction by a factor ~40
- The multi-bend design is implemented through Longitudinal Gradient Bends magnets-> Triplets in the PSI jargon
- Each arc has 5 triplets installed

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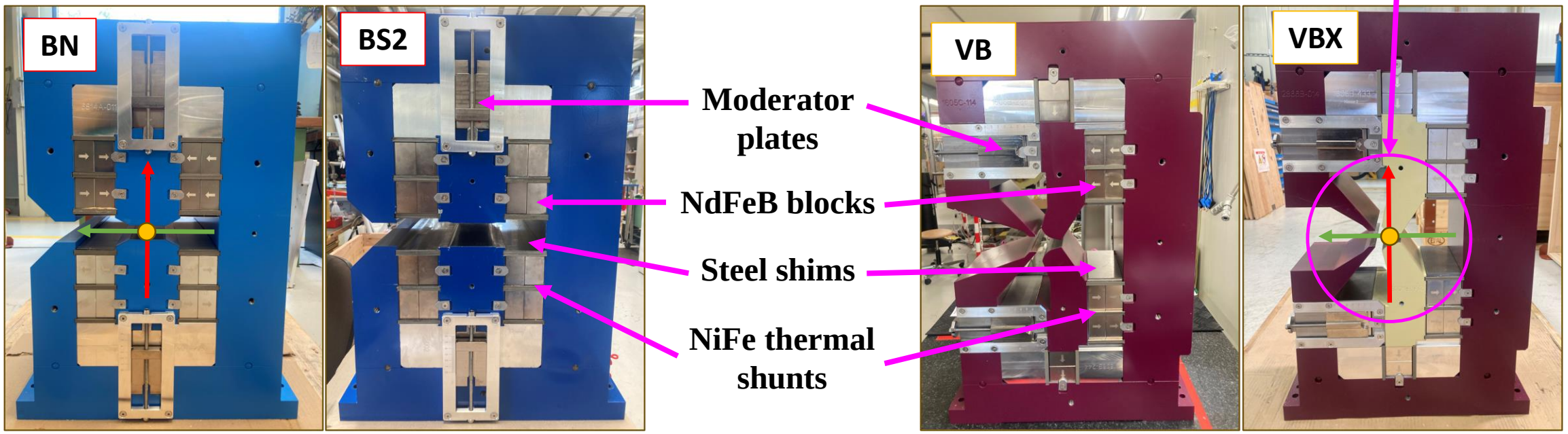
Triplet's Permanent Magnets



- **BN and BS2**
- BN is a normal dipole (56)
- BS2 is a longitudinal gradient dipole (4)

- **VB and VBX**
- VB is a combined function: quadrupole+dipole (96)
- VBX is a combined function: quadrupole+ dipole (24)

Arc type	Triplet 1	Triplet 2	Triplet 3	Triplet 4	Triplet 5	Number of Arcs
1	VBX(I)-BN^1-VB^1	VB^2-BN^2-VB^2	VB^2-BN^2-VB^2	VB^2-BN^2-VB^2	VB^3-BN^3-VBX(O)	8
2	VBX(I)-BN^1-VB^1	VB^2-BN^2-VB^2	VB^4-BS2-VB^4	VB^2-BN^2-VB^2	VB^3-BN^3-VBX(O)	4

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Measurements' Challenges

❖ **Main Challenges**

- Each individual magnet must be tuned according to the standalone requirements (see also C. Zoller talk)
- As an assembly an extra tuning step is needed to accommodate for cross-talk effects (see also R. Riccioli talk)
- **From beam dynamics**: the Triplet integral function must be tuned with an overall uncertainty of $2 \cdot 10^{-3}$ (or 20 (u)) relative to the nominal design (1 (u) = 10^{-3})
- Specific tuning parameters depending on the triplet type
  - VB-> 4 sets of tuning paraments
  - VBX-> 2 sets of tuning paraments
  - BN-> 3 sets of tuning parameters
  - BS2-> 1 set of tuning parameters

(true also for other SLS2.0 magnets)

- Several measurements steps: time consuming

❖ **Defining Requirements**

- The cross-talk effect, due to extreme dense lattice, obliges to optimize a Triplet as a full assembly with neighbours (iterative process)
- From an optimized triplet the magnetic axis of the single magnets must be extracted
- Each single magnet must be simulated as a standalone entity
- From field maps, simulations of the measurement process are carried out to calculate the design parameters for the tuning and adjustment of magnets (field quality and integral quantities)
- Each single step needs careful revision to avoid pitfalls

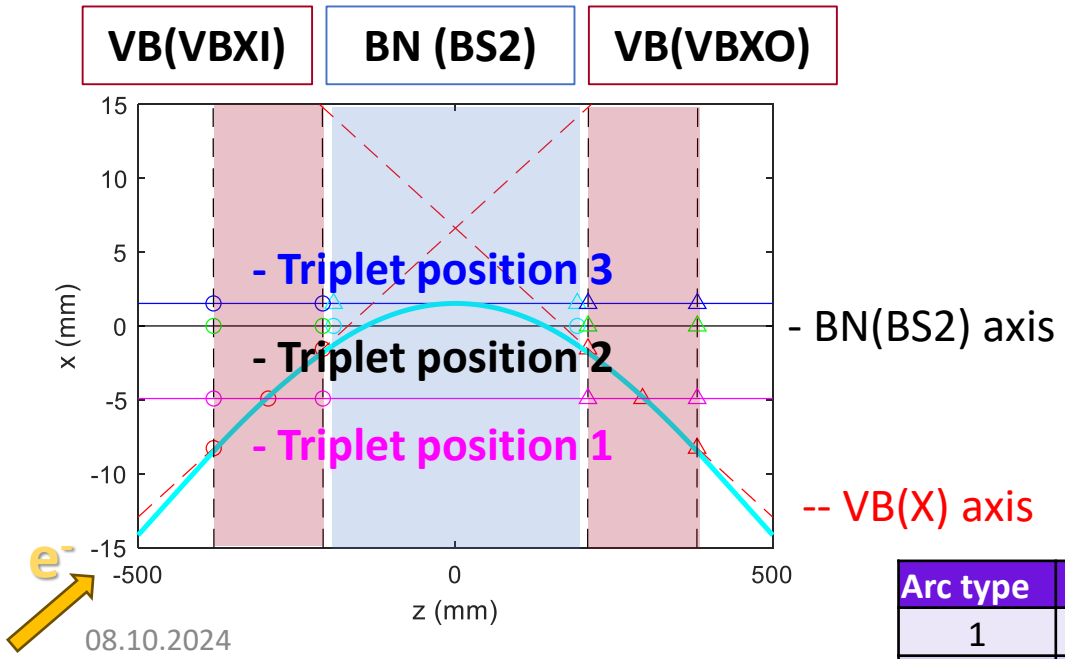
Measurements' Requirements (1)

❖ **Systems Requirements**

- VB(X): Rotating Coil (RC) and Moving (Stretched) Wire (MV_W) systems
- BN(BS2): Moving (Stretched) Wire
- Assembled Triplet: Moving (Stretched) Wire
- Each of the above steps needs survey operations

❖ **Magnetic Axis definition (Triplet alignment)**

- Definition of the magnets' axis from ideal particle trajectory relative to mechanics



- VB's axis: line parallel to the mechanical axis that minimizes the L2 distance with the particle trajectory inside the magnet

❖ **Desing Parameters: standalone (field quality->see slides 14-17)**

Magnet name	∫Dipole (Tm)	∫Gradient (T)	x0 (mm)	
VBX(I)	-0.15244	5.5740	-0.435	0.8 m
VB^1	-0.15669	7.0332	1.080	
VB^2	-0.15358	6.9398	1.261	
VB^3	-0.15640	7.0011	1.025	
VB^4	-0.15100	6.8722	1.413	
VBX(O)	-0.15240	5.5726	-0.435	
BN^1	-0.57086		0	1.5 m
BN^2	-0.57265		0	
BN^3	-0.57149		0	
BS2	-0.57698		0	

❖ **Desing Parameters: Triplets->Integrals for MV_W meas. at Positions 1 to 3 over 1.5 m (slide 24)**

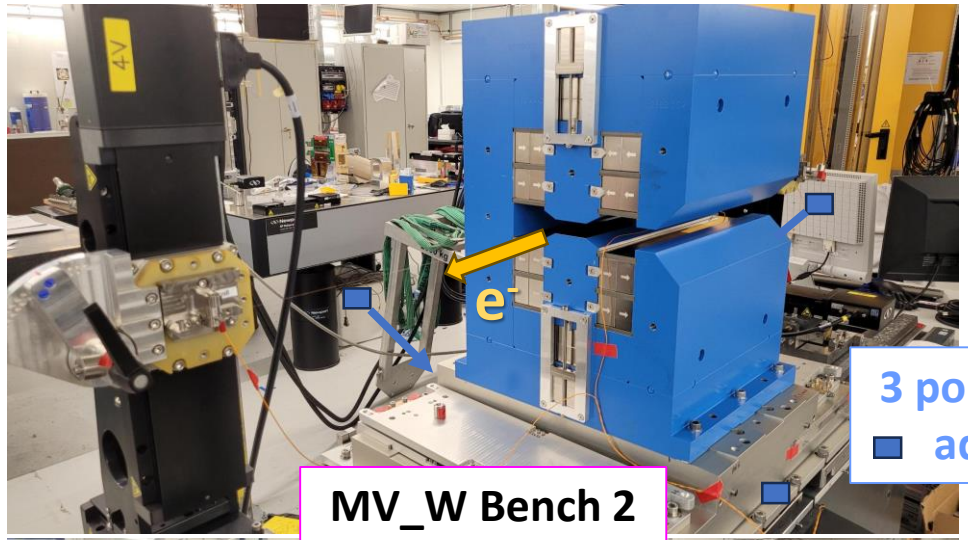
Arc type	Triplet 1	Triplet 2	Triplet 3	Triplet 4	Triplet 5	Number of Arcs
1	VBX(I)-BN^1-VB^1	VB^2-BN^2-VB^2	VB^2-BN^2-VB^2	VB^2-BN^2-VB^2	VB^3-BN^3-VBX(O)	8
2	VBX(I)-BN^1-VB^1	VB^2-BN^2-VB^2	VB^4-BS2-VB^4	VB^2-BN^2-VB^2	VB^3-BN^3-VBX(O)	4

Measurements' Requirements (2)

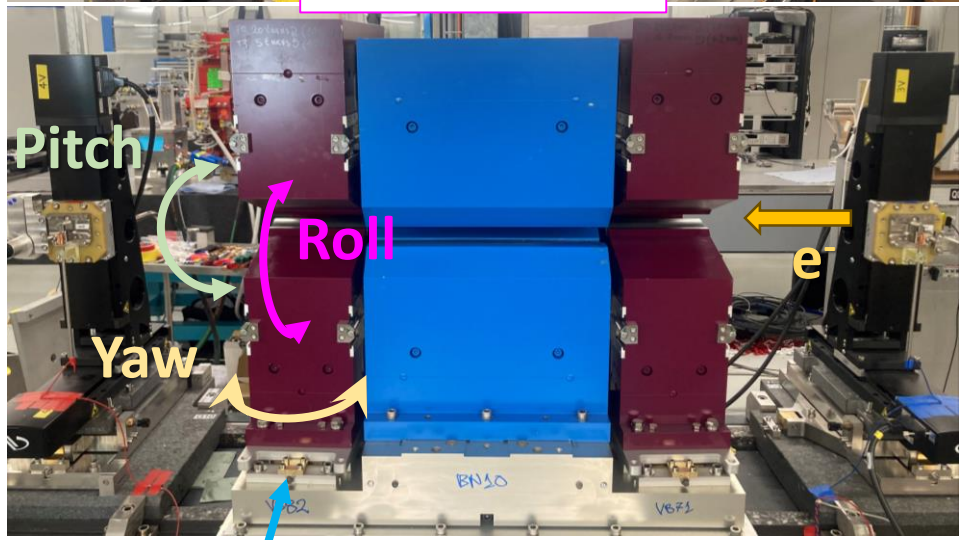
- RC Bench 2 (0.5 m): Tuning VB(X) magnets
- MV_W Bench 1 (0.8 m): VB(X) axis measurements
- MV_W Bench 2 (1.5 m): BN/BS2 and Triplet tuning

RC Bench 2

MV_W Bench 1



MV_W Bench 2



3 points plane adjustment

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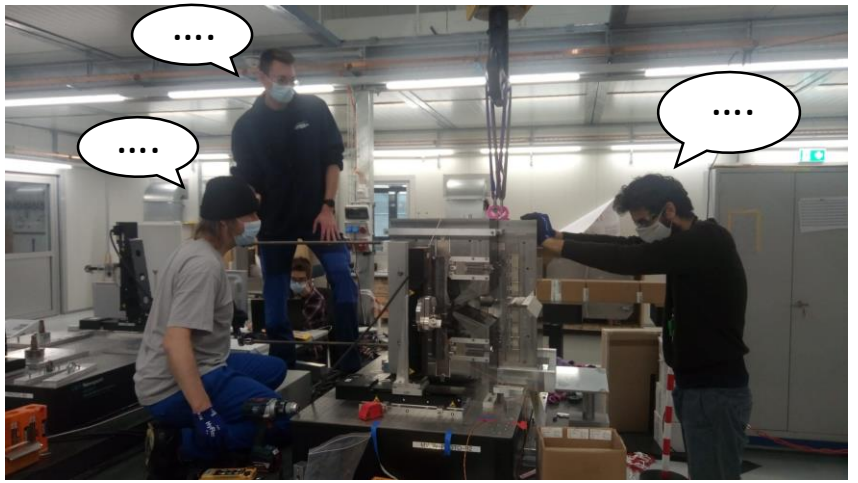
Triplet Measurement Procedures

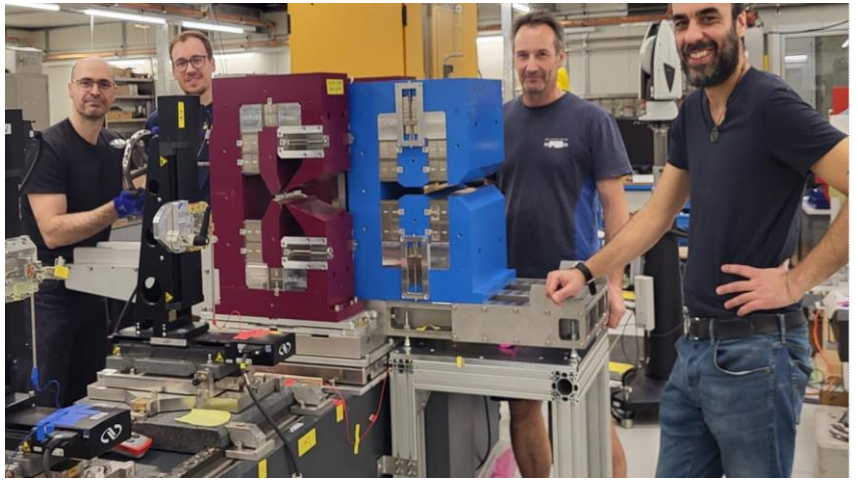
TRIPLET ASSEMBLY PROCESS

- **Step 1: VB and VBX measured and tuned with Rotating Coil**
  - 2 Steps measurement
    - Reference position: Adjustment of field value
    - Flip position: evaluation of magnet roll
    - Fiducialization with hexagon arm: referencing magnetic axis 'estimation' to magnet fiducials
- **Step 1: BN and BS2 measured and tuned with Moving Wire**
  - Fiducialization of the mechanical axis on a reference granite table (AT960 Hexagon)
  - ALignment on measurement bench: transfer of axis for stages starting position definition (AT960 Hexagon)
  - Measurement: Adjustment of field value
- **Step 2: VB and VBX axis measurement with Moving Wire**
  - Fiducialization of magnet's fiducials on reference granite table (AT960 Hexagon)
  - Roll angle alignment on Moving Wire bench (AT960 Hexagon)
  - Transfer of magnetic axis from Rotating Coil for initial wire positioning
  - Measurement: magnetic axis search
  - Fiducialization with AT960 Hexagon: referencing magnetic axis to magnet fiducials
- **Step 3: Triplet measurement and adjustment with Moving Wire**
  - Assembly of the Triplet
  - Alignment of the 3 magnets by survey team using fiducialization data from Step 1 (BN,BS2) and Step 2 (AT960 Hexagon)
  - Cross check of alignment, AT960 Hexagon, and calculations of initial wire set of starting positions
  - Measurement and tuning
  - Fiducialization with AT960 Hexagon: referencing Triplet magnetic axis to the magnets' assembly fiducials
  - **Cross the fingers until first beam :)!**

Prototyping phase (COVID era….)



Series (intermediate steps not shown …)



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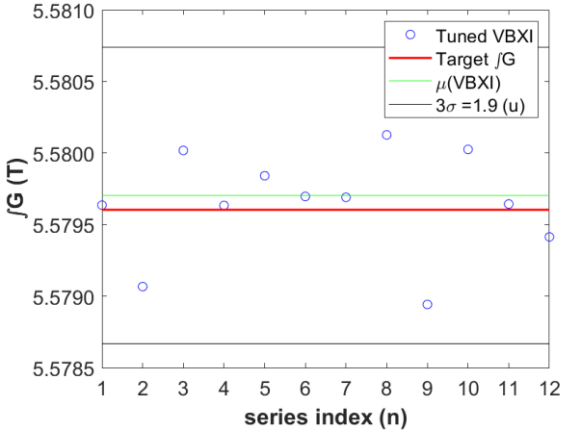
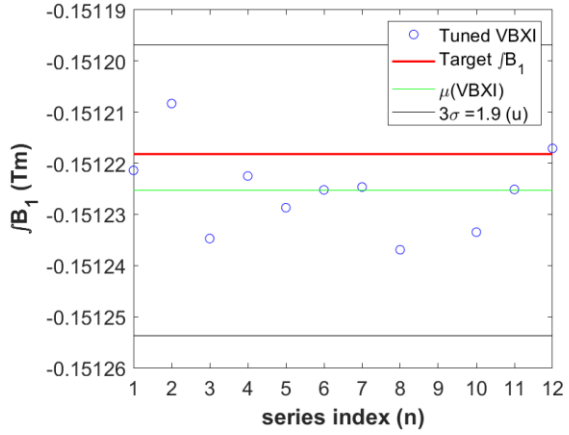
RC measurement Results: VBX(I) and VB^1

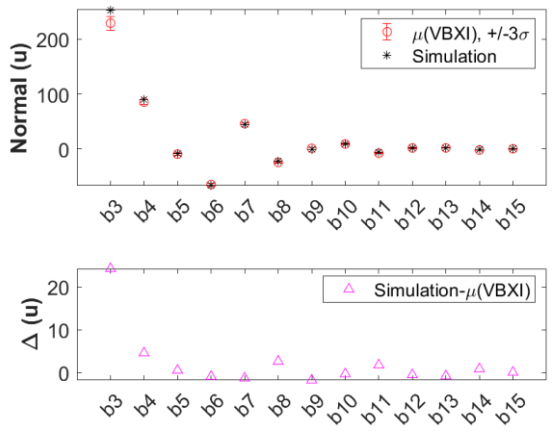
VBX(I)



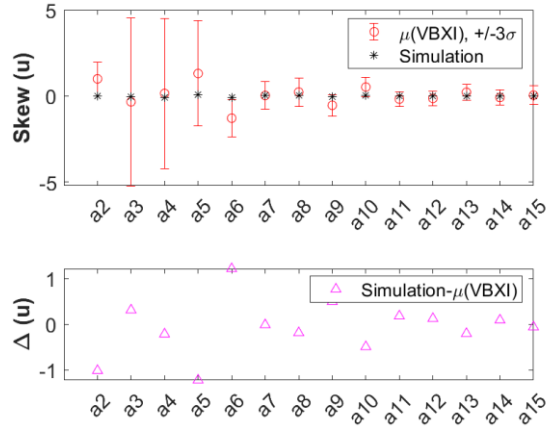
- **Tuned Integral B2/R_{ref} @ 8.8 mm**



- **Tuned Integral B1 @ 8.8 mm**

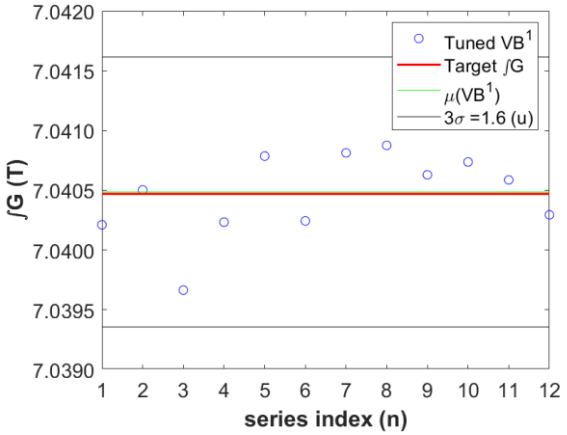


- **Normal harmonics vs Simulated one**

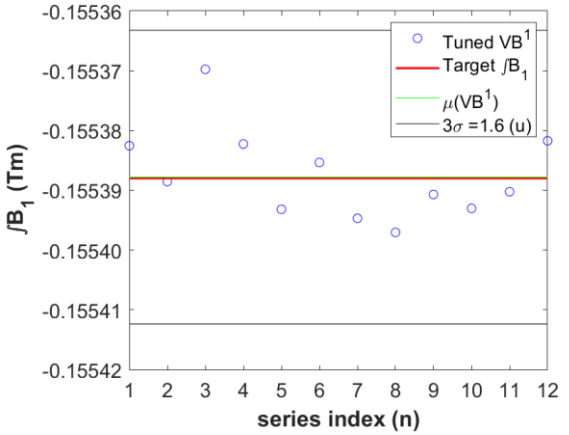


- **Skew harmonics vs Simulated one**

VB^1



- **Tuned Integral B2/Rref @ 8.8 mm**



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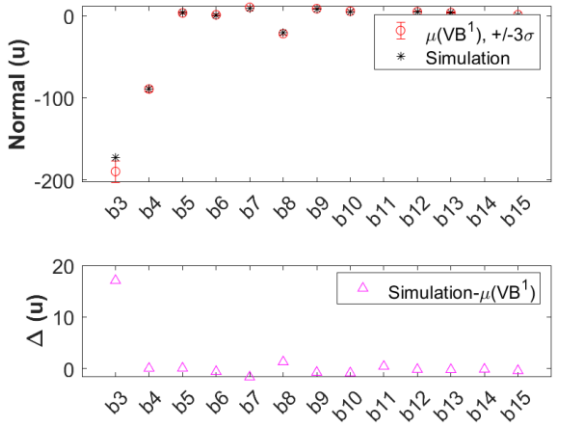

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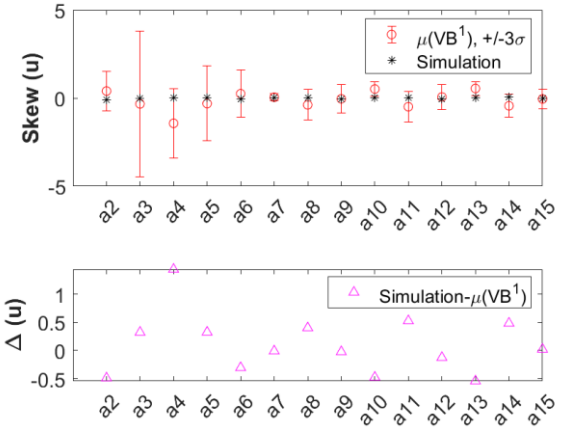
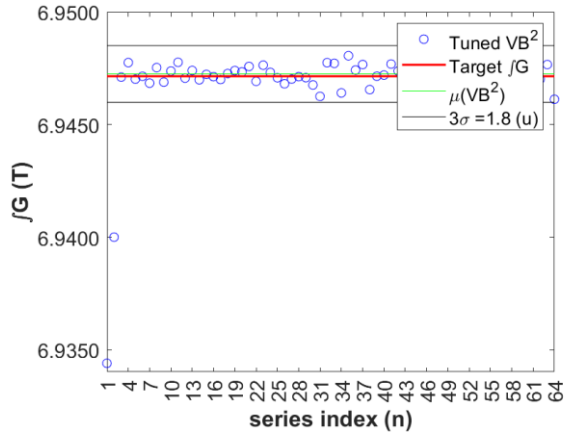


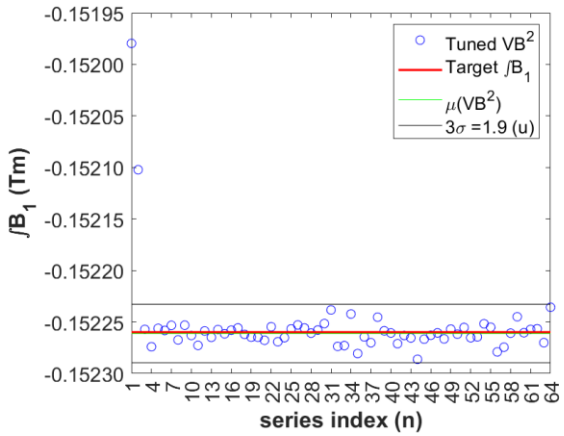
- **Skew harmonics vs Simulated one**

RC measurement Results: VB^2 and VB^4

VB^2



- **Tuned Integral B2/R_{ref} @ 8.8 mm**



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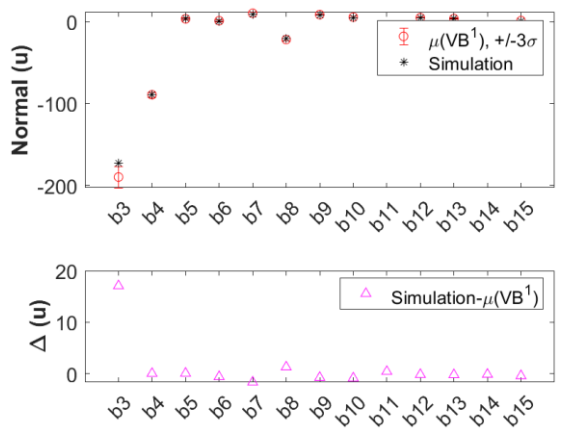
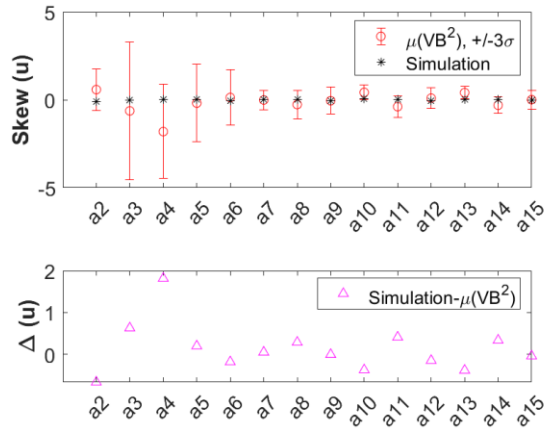
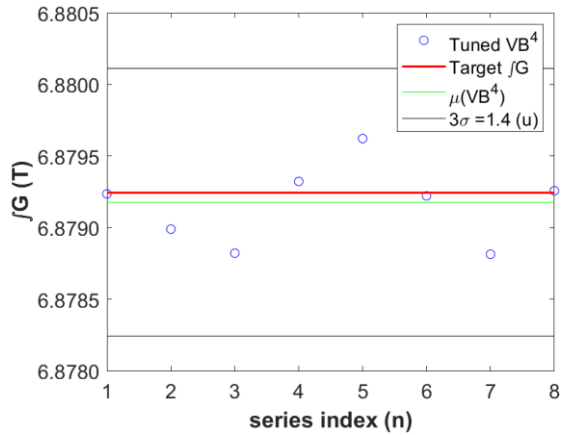


- **Normal harmonics vs Simulated one**

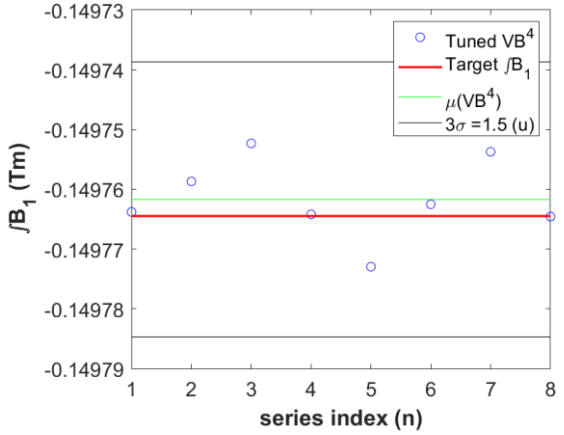


- **Skew harmonics vs Simulated one**

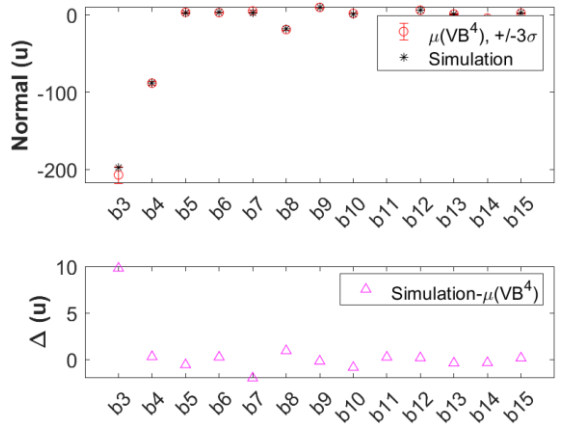
VB^4



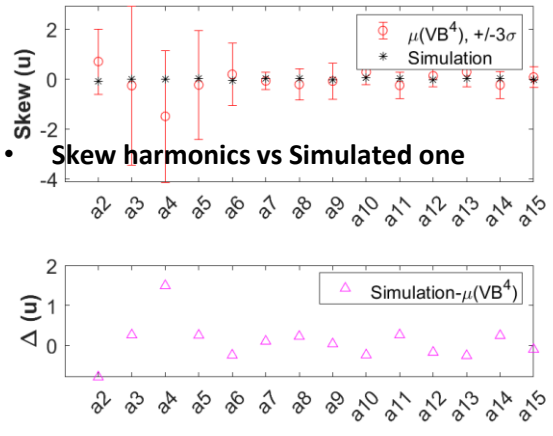
- **Tuned Integral B2/Rref @ 8.8 mm**



- **Tuned Integral B1 @ 8.8 mm**



- **Normal harmonics vs Simulated one**

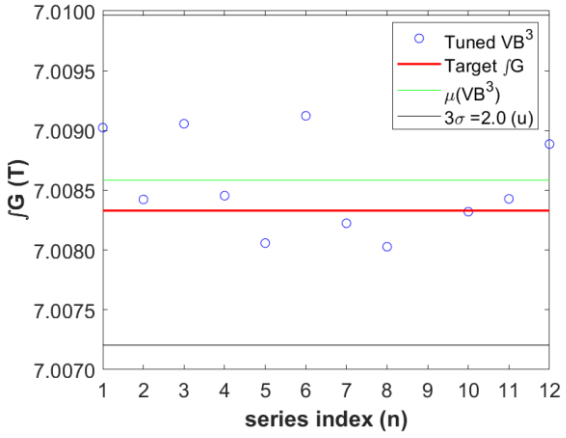


- **Skew harmonics vs Simulated one**

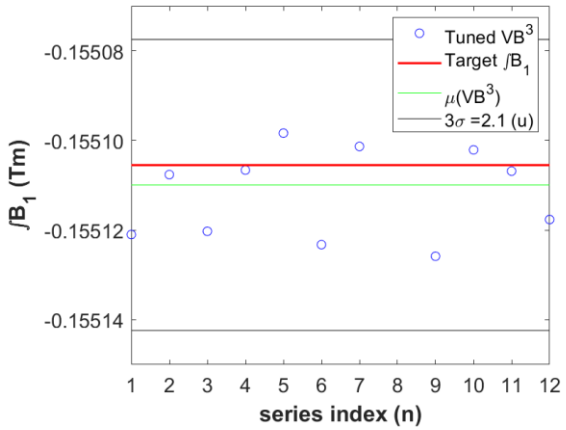
- **Skew harmonics vs Simulated one**

RC measurement Results: VBX(I) and VB^1

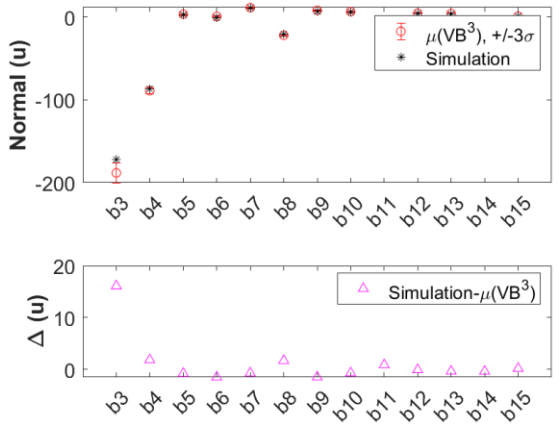
VB^3



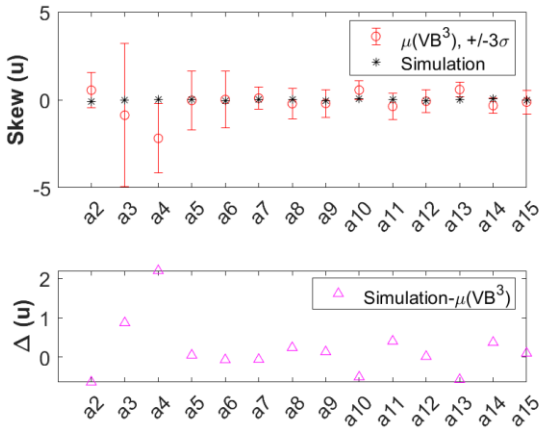
- **Tuned Integral B2/R_{ref} @ 8.8 mm**



- **Tuned Integral B1 @ 8.8 mm**

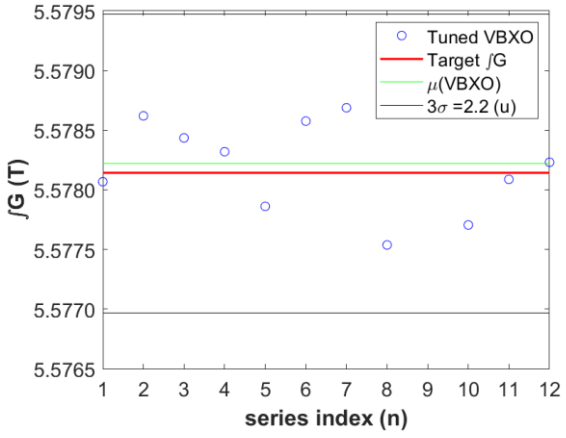


- **Normal harmonics vs Simulated one**

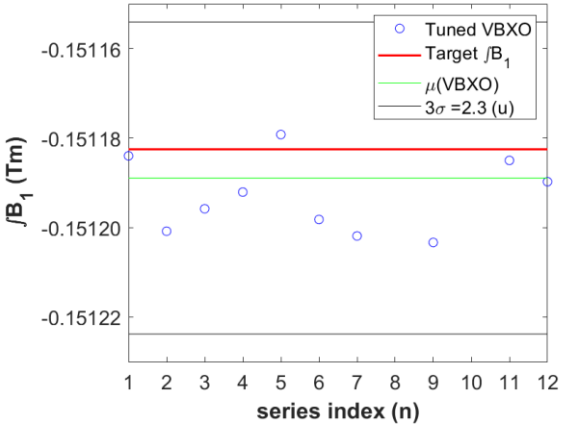


- **Skew harmonics vs Simulated one**

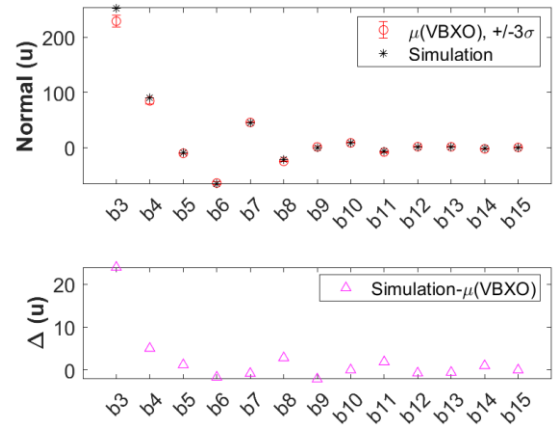
VBX(O)



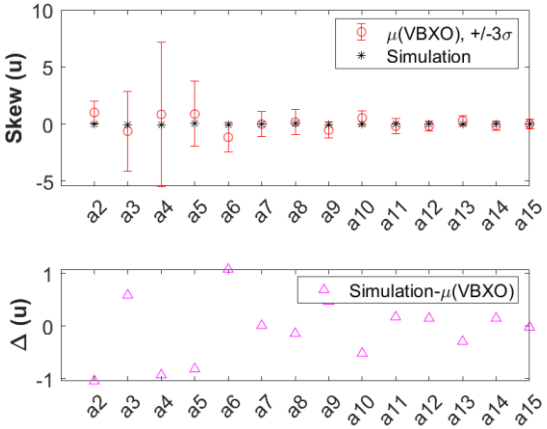
- **Tuned Integral B2/Rref @ 8.8 mm**



- **Tuned Integral B1 @ 8.8 mm**

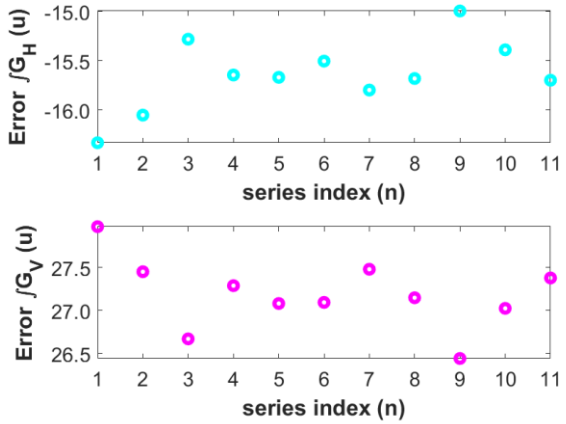


- **Normal harmonics vs Simulated one**

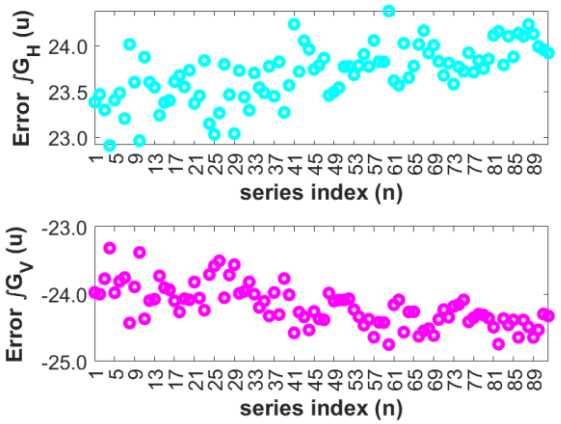


- **Skew harmonics vs Simulated one**

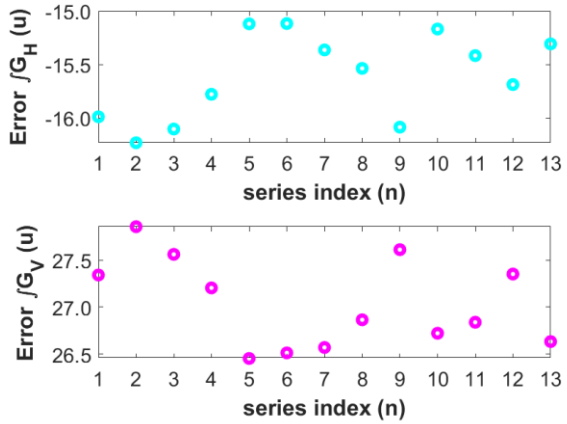
RC measurement Results: MV_W Correction(d=6.36mm)



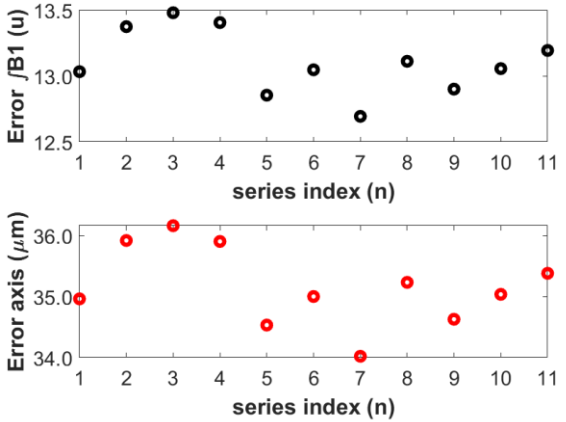
- **VBX(I) gradient error MV_W measurements**



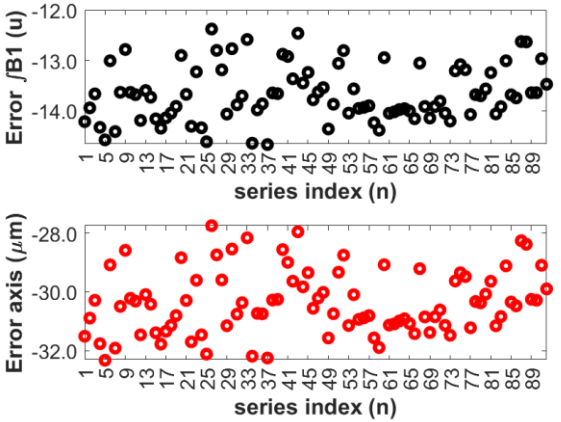
- **VB1, VB2, VB3, VB4 gradient error MV_W measurements**



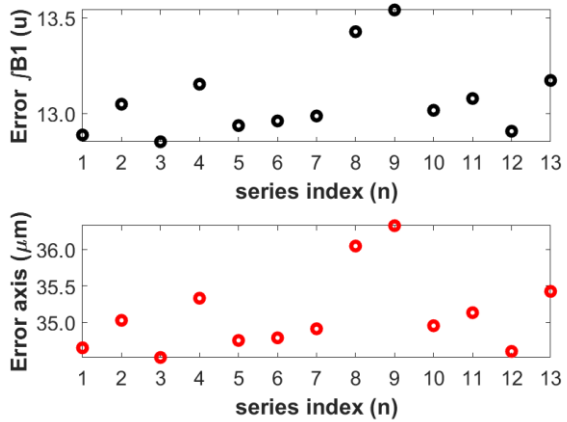
- **VBX(O) gradient error MV_W measurements**



- **VBX(I) dipole error**
- **Axis error**



- **VB1, VB2, VB3, VB4 dipole error**
- **Axis error**



- **VBX(O) dipole error**
- **Axis error**

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- **Series Measurements Results: Moving Wire-> BN, VB, and VBX**
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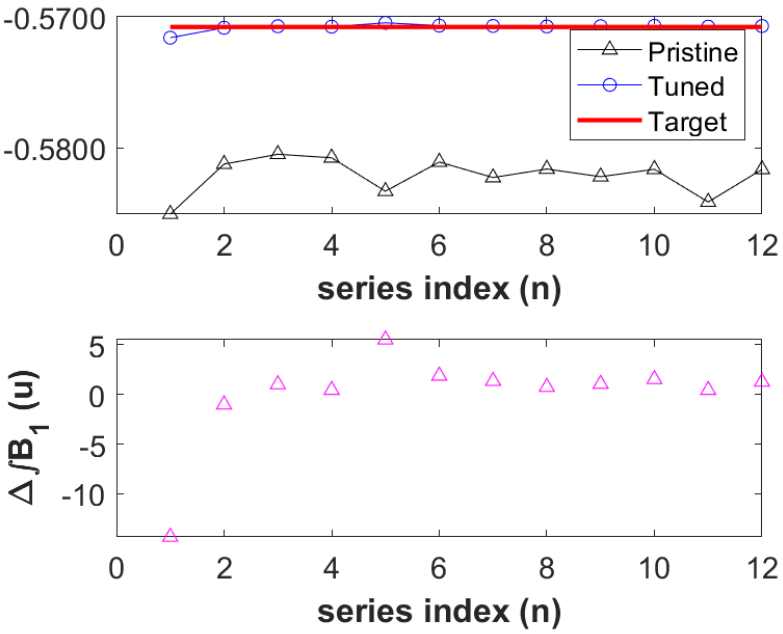
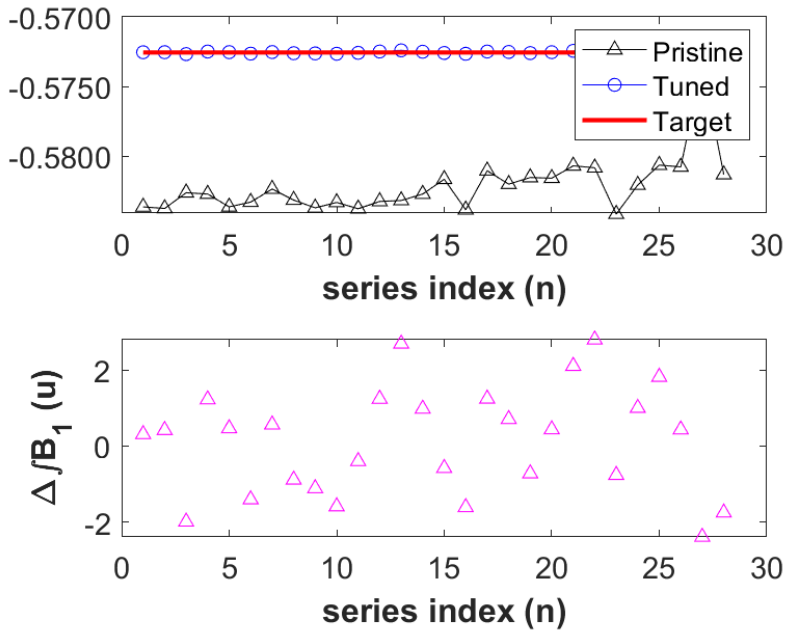
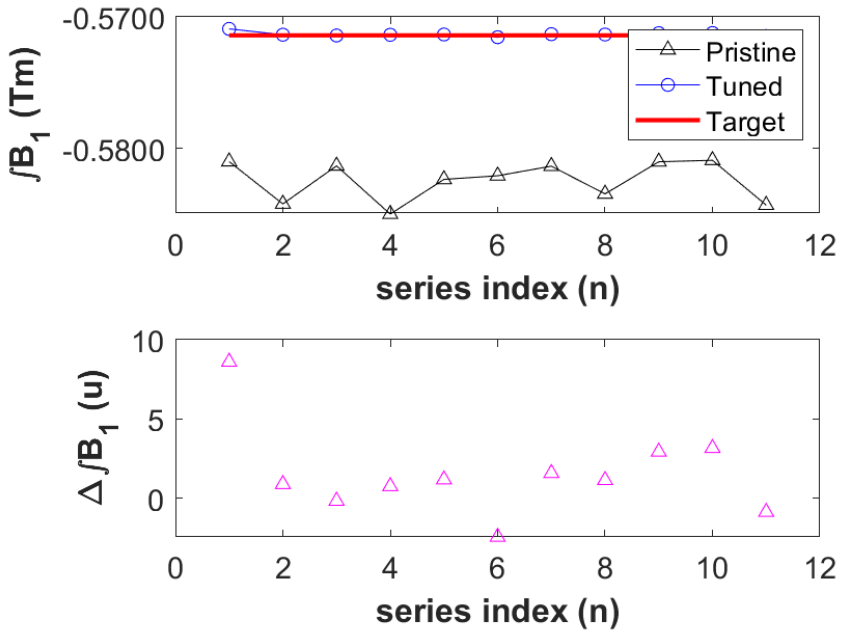
Moving Wire (d=6.36mm) Measurement Results: BN

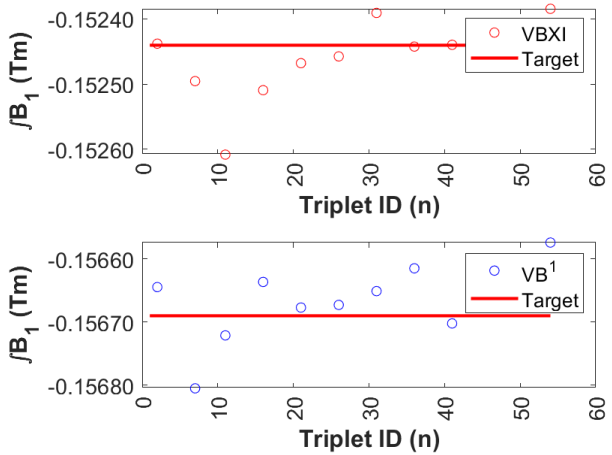




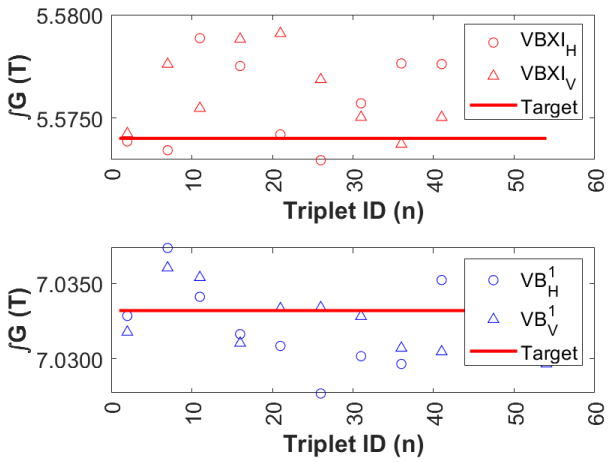


- **BN^1**
  - Tunning process
  - Residual mismatch
- **BN^2**
  - Tunning process
  - Residual mismatch
- **BN^3**
  - Tunning process
  - Residual mismatch

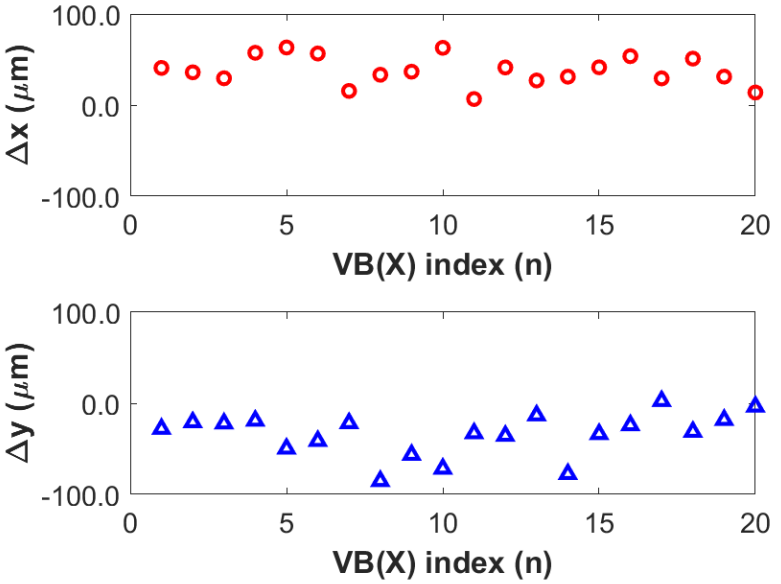
Moving Wire Measurement Results: VBX(I) and VB1



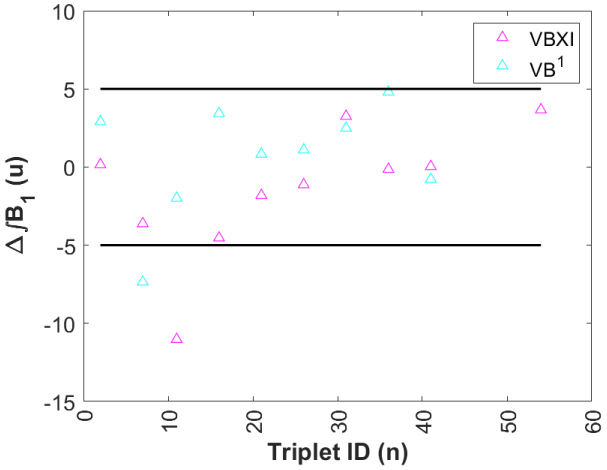
- **Dipole on axis**
- d=6.36 mm



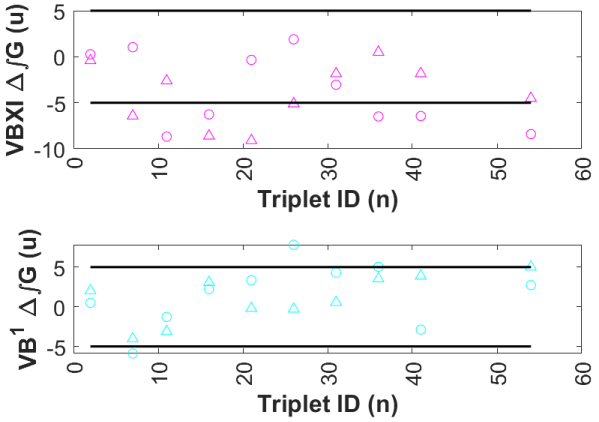
- **Gradient from Horizontal and vertical measurements**
- On axis -> d=6.36 mm



- **Initial wire offset w.r.t. magnetic axis from RC axis transfer**
- RC uncertainty below 100 µm
- Machine requirements 30 µm

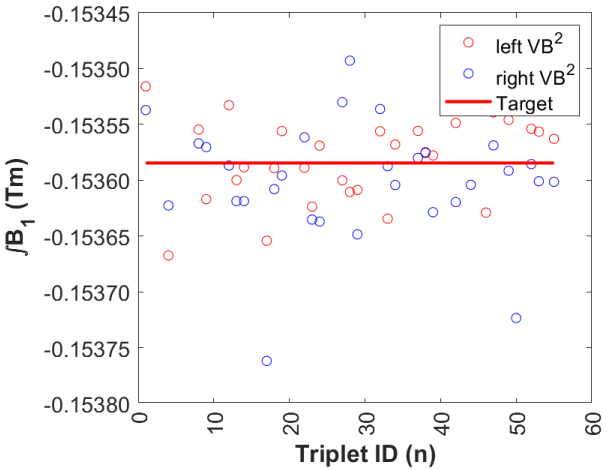


- **Correction from RC measurements**

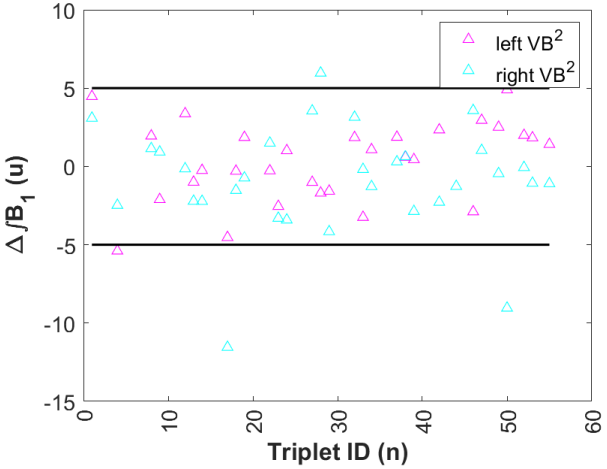


- **Correction from RC measurements**

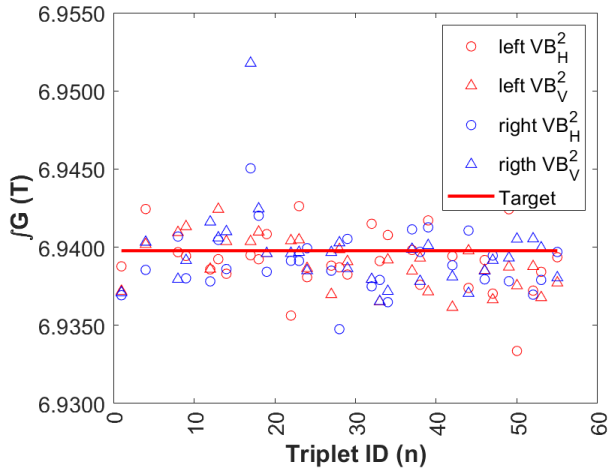
Moving Wire Measurement Results: VB2



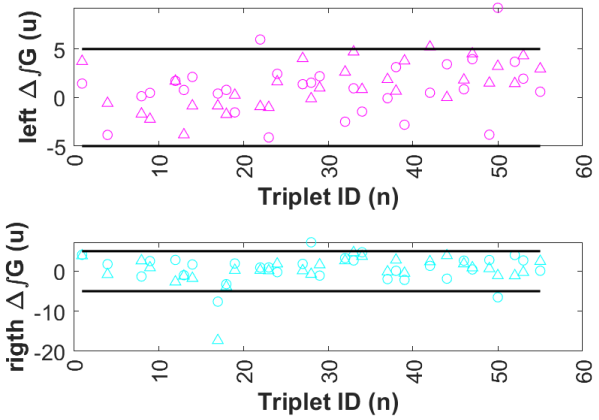
- **Dipole on axis**
- d=6.36 mm



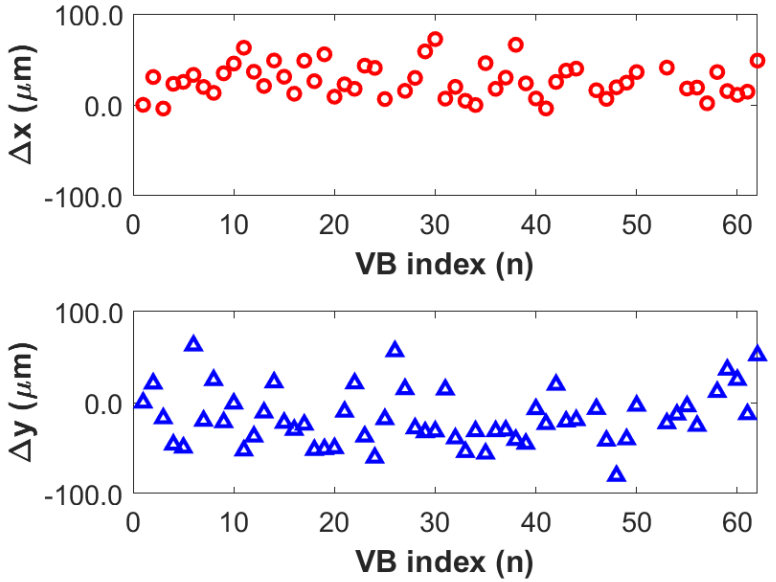
- **Correction from RC measurements**



- **Gradient from Horizontal and vertical measurements**
- On axis -> d=6.36 mm

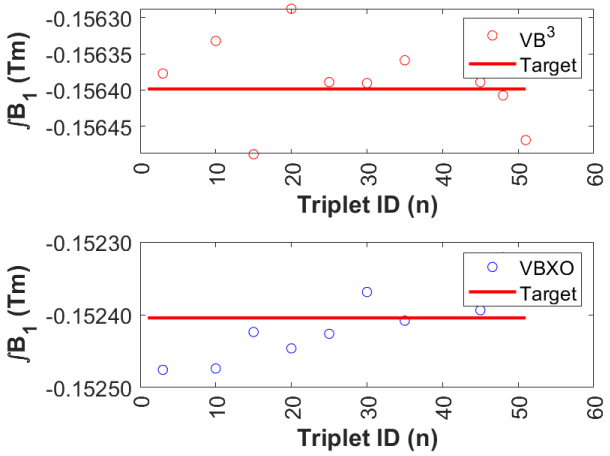


- **Correction from RC measurements**

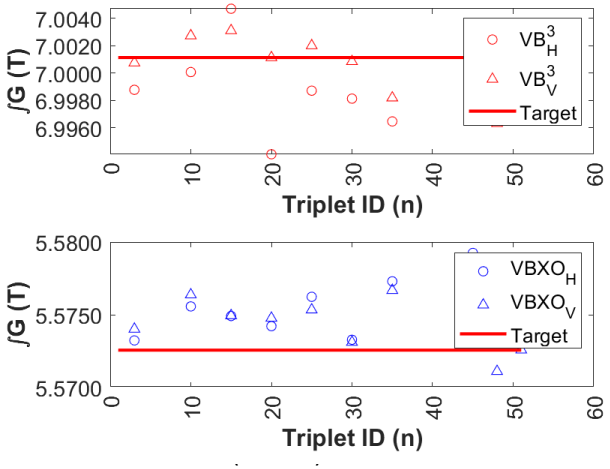


- **Initial wire offset w.r.t. magnetic axis from RC axis transfer**
- RC uncertainty below 100 µm
- Machine requirements 30 µm

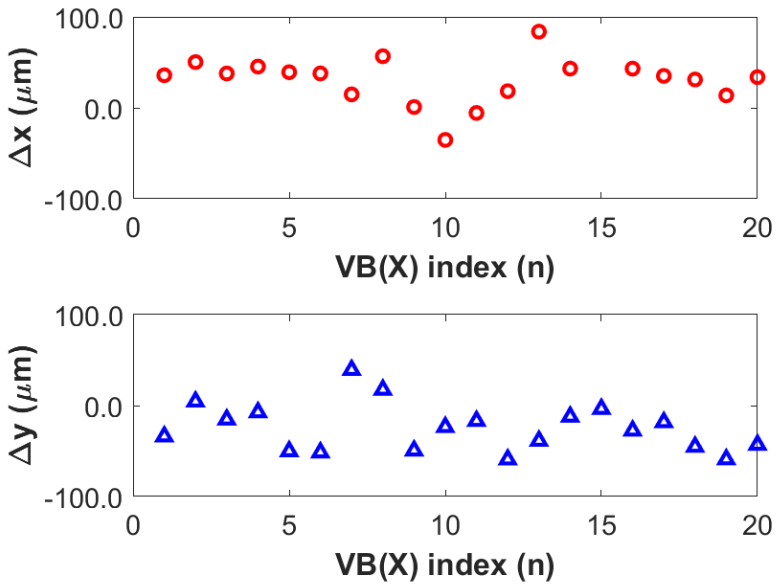
Moving Wire Measurement Results: VB and VBX(O)



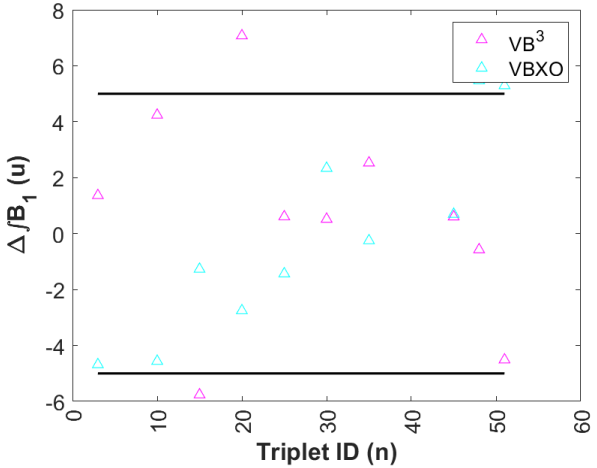
- **Dipole on axis**
- d=6.36 mm



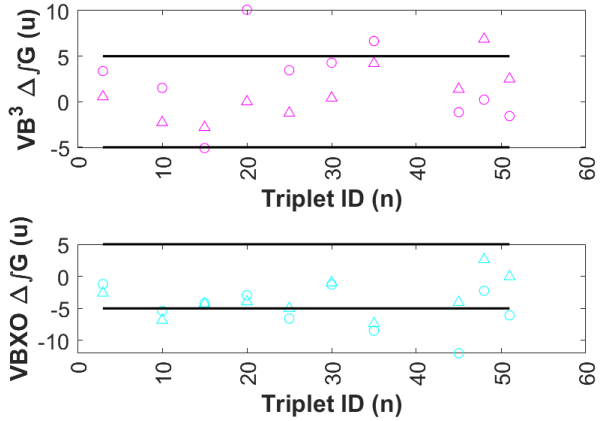
- **Gradient from Horizontal and vertical measurements**
- On axis -> d=6.36 mm



- **Initial wire offset w.r.t. magnetic axis from RC axis transfer**
- RC uncertainty below 100 µm
- Machine requirements 30 µm



- **Correction from RC measurements**

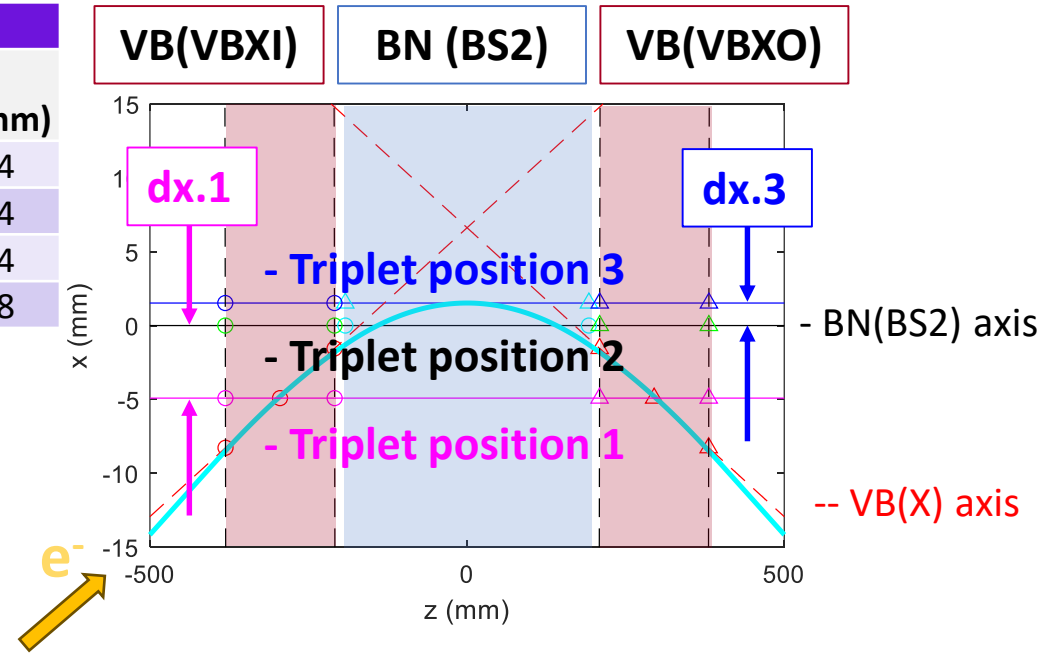


- **Correction from RC measurements**

- The SLS2.0 Arc
- The Triplet's Magnets
- Measurements' Challenges & Requirements
- Measurement Procedures
- **Series Measurements Results: Moving Wire-> Triplets**
- Conclusions

Moving Wire Measurement: Triplets Tuning

	Pos.1			Pos.2			Pos.3		
Triplet Type	∫G (T)	$\int B_1$ (Tm)	dx.1 (mm)	∫G (T)	$\int B_1$ (Tm)	dx.2 (mm)	∫G (T)	$\int B_1$ (Tm)	dx.3 (mm)
VBX(I)-BN^1-VB^1	14.002	-0.87687	-4.920	13.920	-0.80819	0	13.860	-0.78761	1.484
VB^2-BN^2-VB^2	15.356	-0.87746	-4.914	14.839	-0.80328	0	14.617	-0.78088	1.524
VB^3-BN^3-VBX(O)	13.969	-0.87709	-4.921	13.884	-0.80857	0	13.824	-0.78804	1.484
VB^4-BN^4-VB^4	15.282	-0.87619	-4.922	14.799	-0.80217	0	14.510	-0.77309	1.988

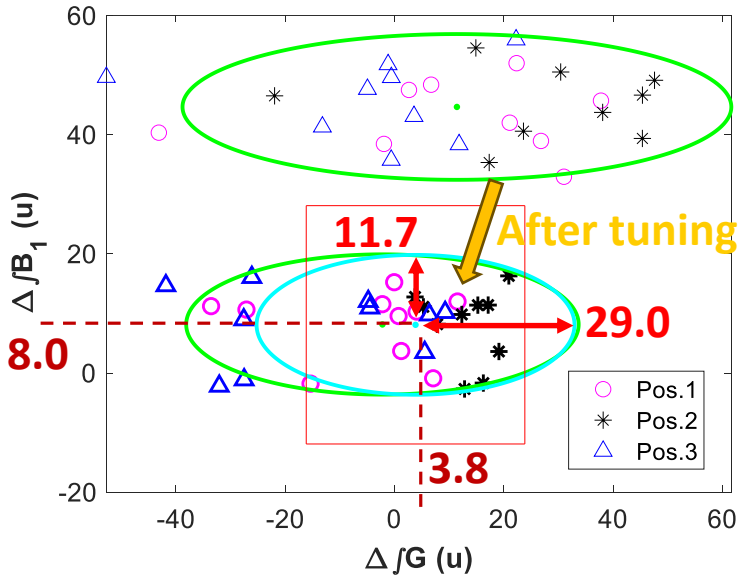


Tuning Strategy

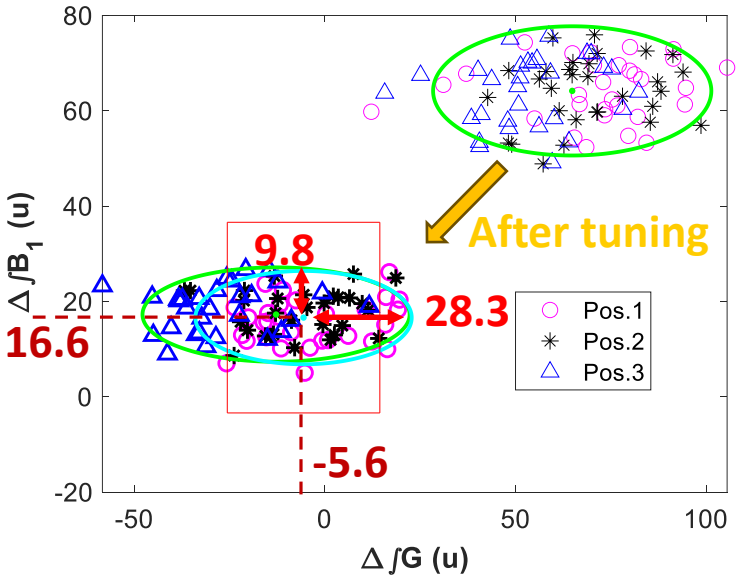
A. Initial measurement set on the calculated 3 positions
B. Differences from model assessed
C. Tuning strategy
   i. Adjust moderator plates VB(X) to minimize gradient difference
   ii. Use wire offset on the 3 positions to accommodate dipole residual mismatch

Wire displacement d=3.5 mm to minimize multipole effects

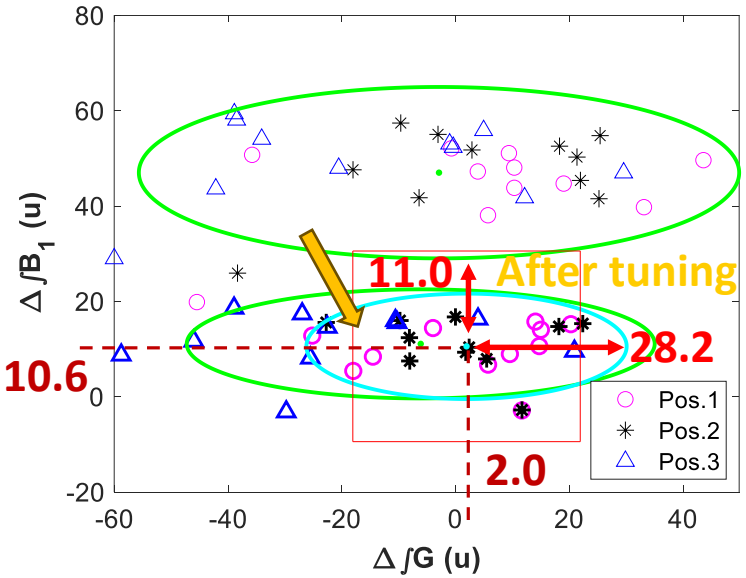
Moving Wire Measurement Results: Triplets



- **Triplets VBX(I)-BN^1-VB^1**
- Residuals of integral dipole vs gradient



- **Triplets VB^2-BN^2-VB^2**
- Residuals of integral dipole vs gradient



- **Triplets VB^3-BN^3-VBXO**
- Residuals of integral dipole vs gradient

- ✓ During series, Triplets tuning process successful mainly on position 1 and 2
- ✓ At position 3 data have a higher spread
- ✓ Systematics are within specs

- The SLS2.0 Arc
- The Triplet's Magnets
- Measurements' Challenges & Requirements
- Measurement Procedures
- Series Measurements Results: Moving Wire-> Triplets
- Conclusions

CONCLUSIONS

- A complex measurement procedure was devised and resulted effective
- A model-based Triplet tuning process gave good results
- Time schedule is going to be respected (3 triplets every two weeks since beginning of this year)
- Tomorrow Triplet 55 (hopefully) will be delivered out of 60
- It has been an incredible journey: Thanks to everybody has been involved