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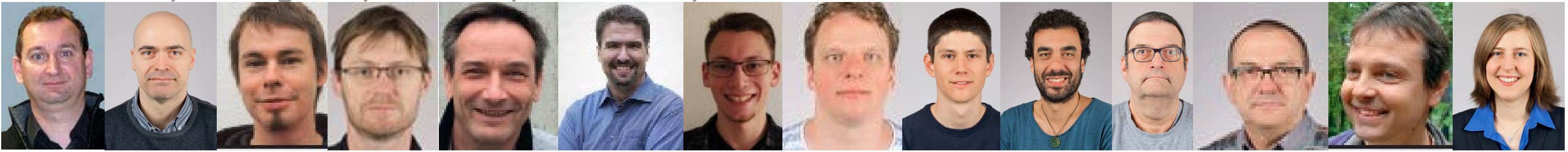
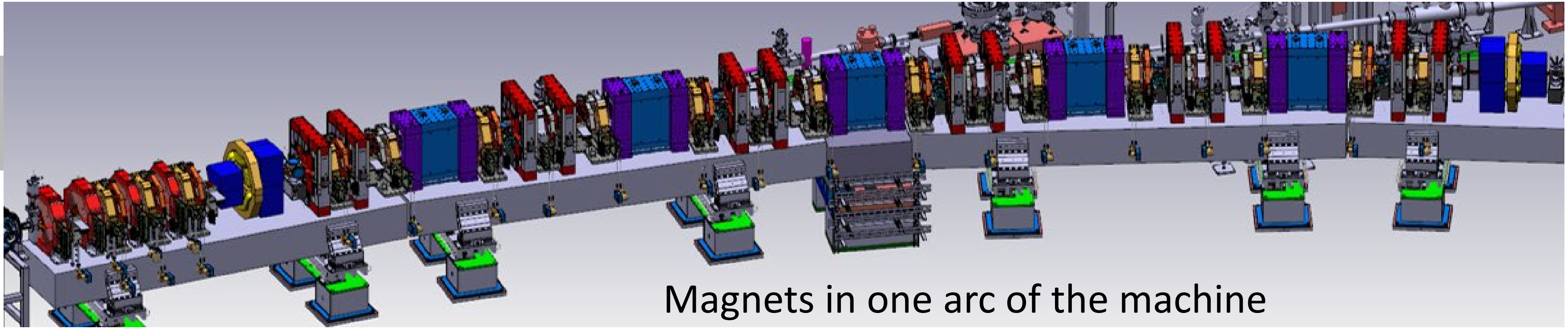


# SLS 2.0 Magnets

2nd PerMaLIC Workshop, 03.11.2022

# Magnets for SLS2.0- the challenges



Magnets in one arc of the machine

- High Magnet numbers (1154 magnets),16 different types
- Very limited space for high number of magnets
- Compact combined function magnets, small apertures, small gaps (22 mm)
- High field superconducting magnets
- Tight schedule for magnet delivery (end of 2023)

# List of Magnets

## Permanent Magnets

| | | |
|---|---|---|
| BN | 56 | Dipole |
| VB | 96 | Quad |
| VBX | 24 | Quad |
| AN | 120 | Quad |
| ANM | 24 | Quad |
| BE | 24 | Dipole |
| VE | 24 | Quad |
| 2T BS | 4 | Dipole |

Total : 372

## Electromagnets

| | | |
|---|---|---|
| QP | 55 | Quad |
| QPH | 53 | Quad |
| SXQ | 24 | 6-Poles |
| SX | 264 | 6-Poles |
| OC | 264 | 8-poles |
| CHV | 120 | Steerer |

Total: 780

## Superconducting Magnets

5T BS 2 Dipoles

BS=Superbend

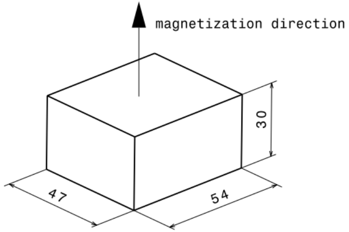
Total: 2

84 dipoles und 228 quadrupoles with PM technology

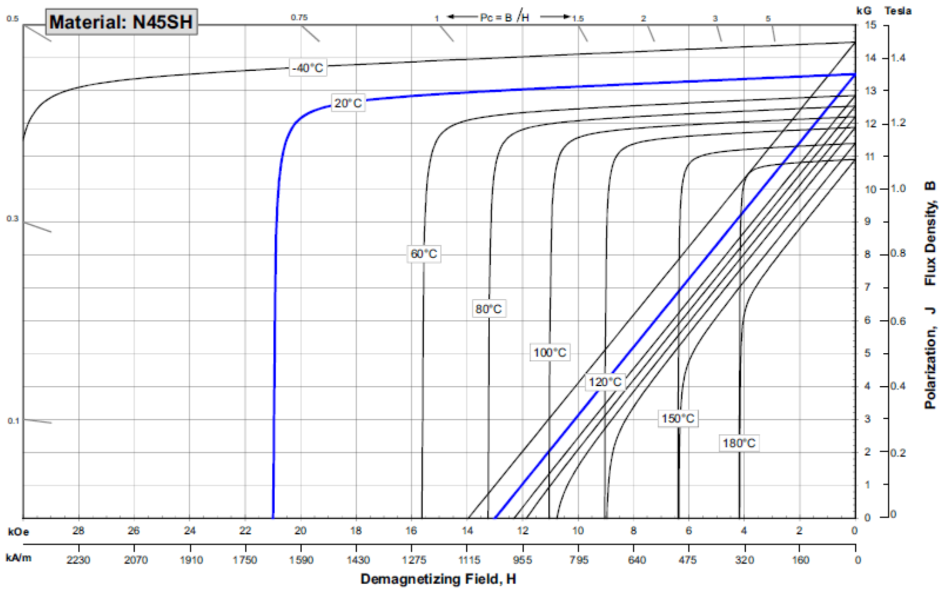
# Permanent Magnets

We converged on one block size: 30 mm x 47 mm x 54 mm

Ordered PM blocks: 34000



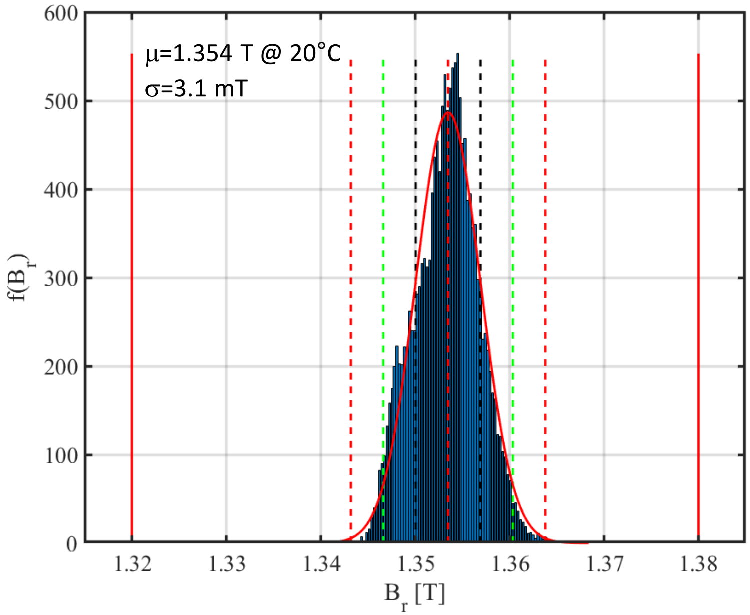

| Description | Value | |
|---|---|---|
| Nominal size of Permanent Magnet block | 30 mm x 47 mm x 54 mm | |
| Direction of magnetization | Along 30 mm block size | |
| Max. deviation of the magnetization direction wrt the orthogonal to the surface of the block [degree] | 2.5 | |
| Remanent flux density at 20°C, $B_r$ [T] | $B_r = 1.35$ | $B_{r,max} = 1.38$ |
| | | $B_{r,min} = 1.32$ |
| Coercive field (typical value), $H_{cB}$ [kA/m] | $H_{cB} = 1015$ | $H_{cBmax} = 1050$ |
| | | $H_{cBmin} = 979$ |
| Intrinsic coercive field, $H_{cJ,min}$ [kA/m] | 1592 | |
| Energy product at 20°C (typical value), $BH_{max}$ [kJ/m³] | 350 | |
| Reversible temperature coefficient of induction, $\alpha(B_r)$ [%/°C] | -0.120 | |
| Reversible temperature coefficient of intrinsic coercitivity, $\alpha(H_{cJ})$ [%/°C] | -0.535 | |
| Heat treatment temperature [°C] | 100 | |
| Weight of one block [kg] | 0.57 | |

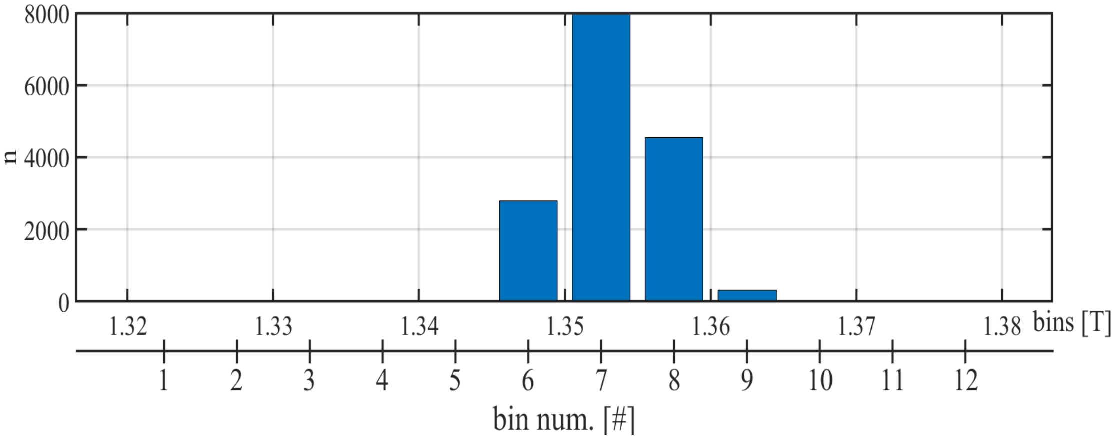


# Permanent magnet blocks

The first shipment batch arrived at PSI this month: 48 pallets, about $10^4$ magnets.

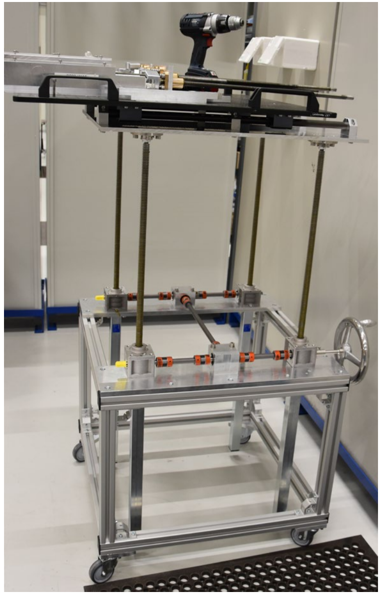
All in all the company produced already 21212 PM blocks (62% of total production).



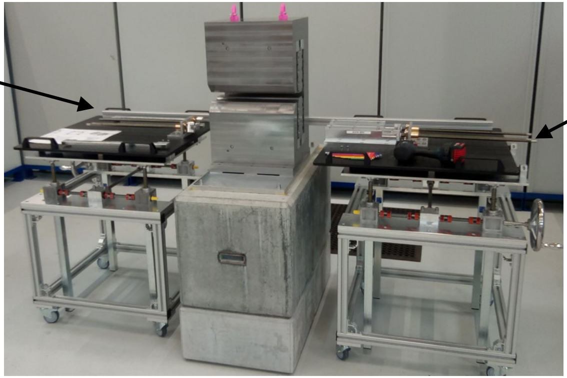
# Permanent magnets: assembly tools

Lifting table



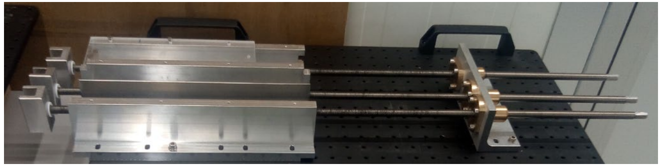
Assembly table mounted around the BN magnet.

Compensating screws



Forward screws

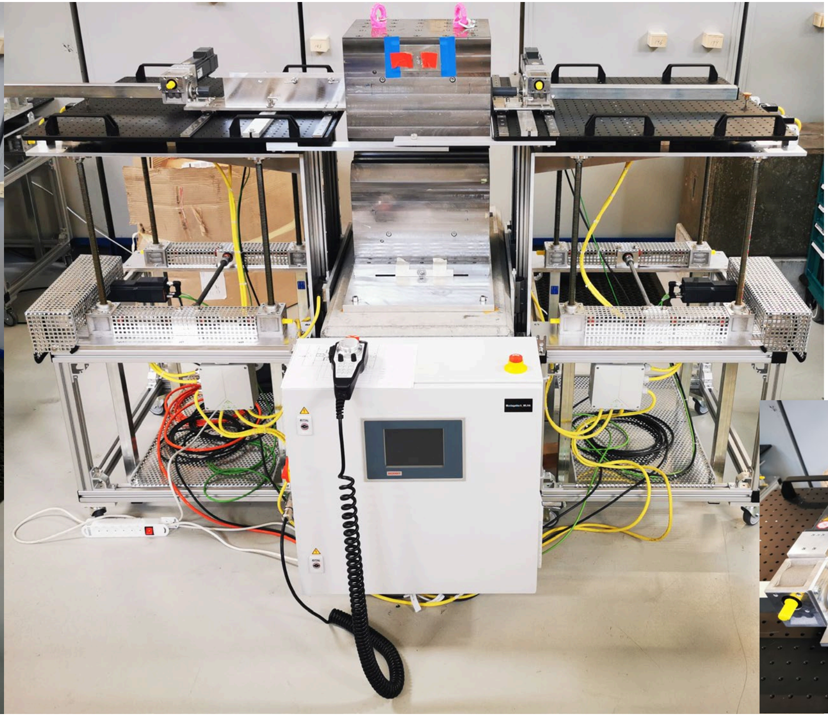
Detail of the insertion rods.

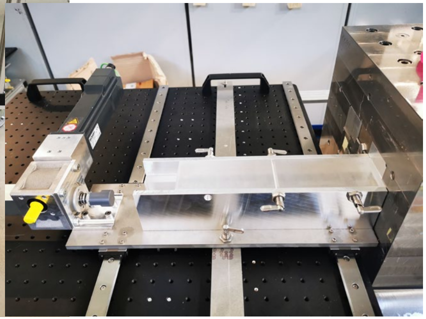


Insertion rods Ready to assemble the BN magnet (on the left) and the ANM magnet (on the right).

# Permanent magnet blocks

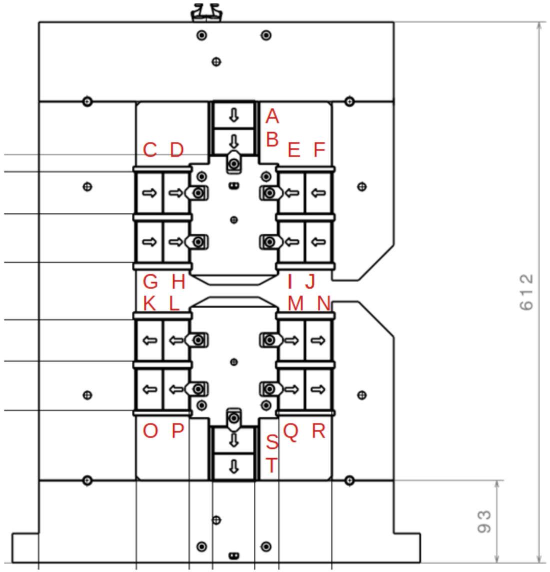
The mounting table is ready for the serial production.

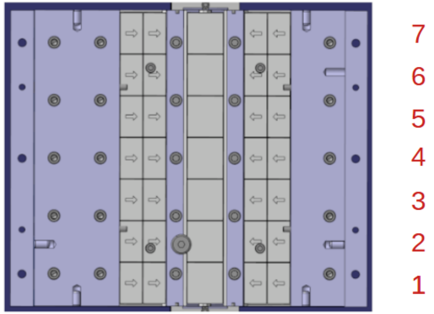




# Permanent magnet blocks

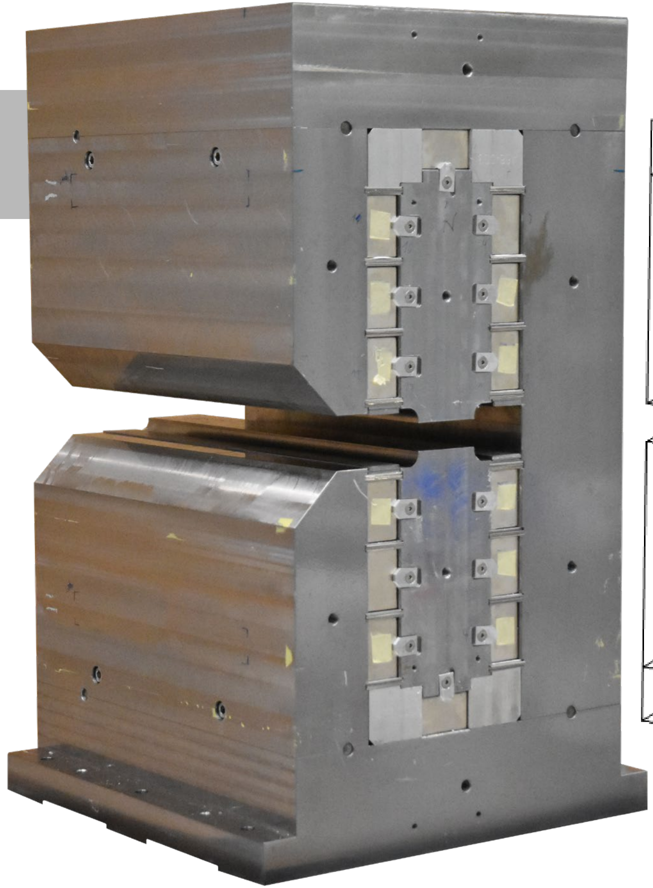
The mounting table is ready for the serial production.

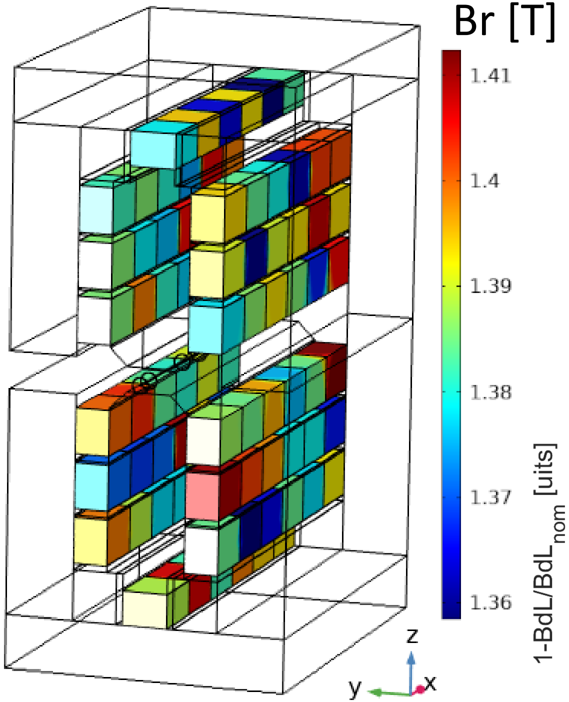


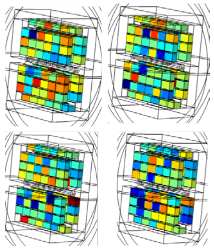



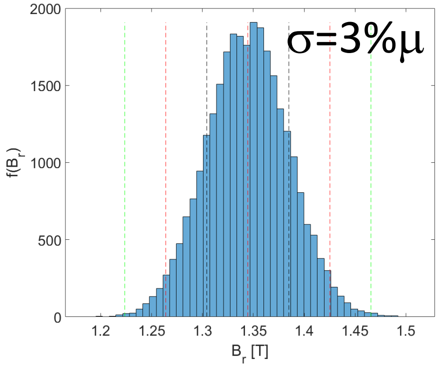
# Test of BN magnet

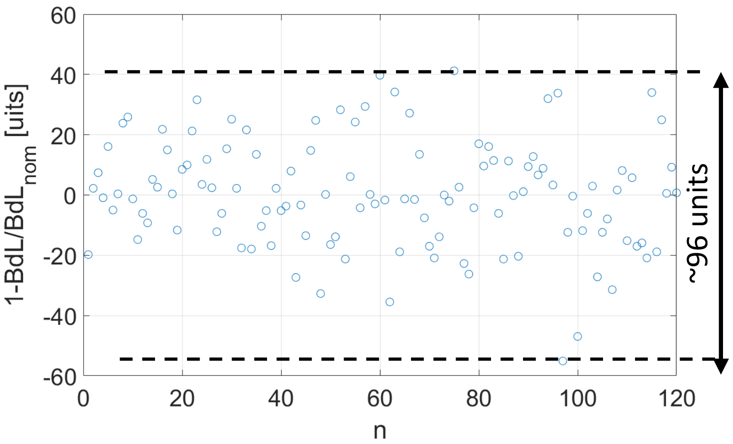
## BN Prototype: random filling with PM magnets





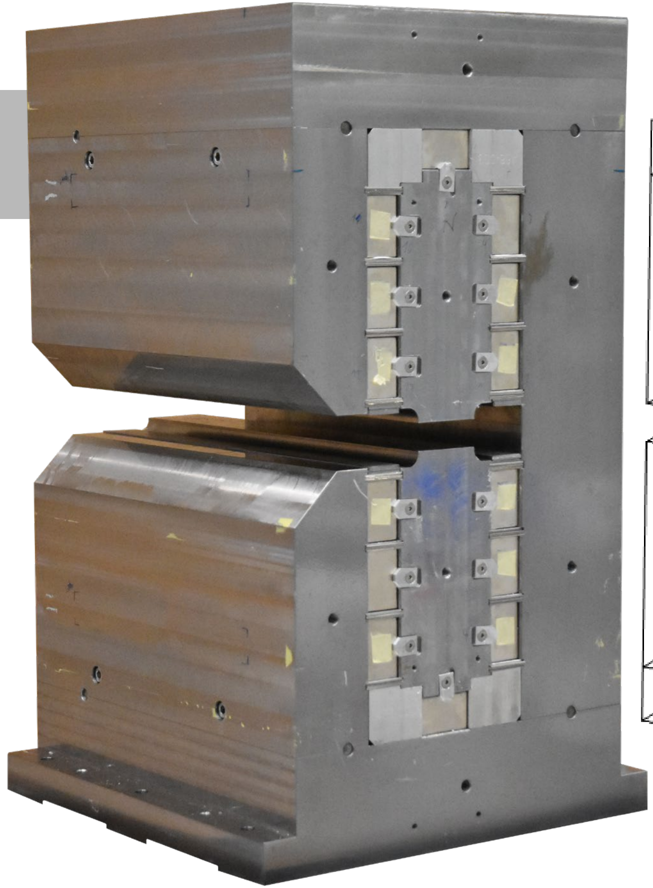



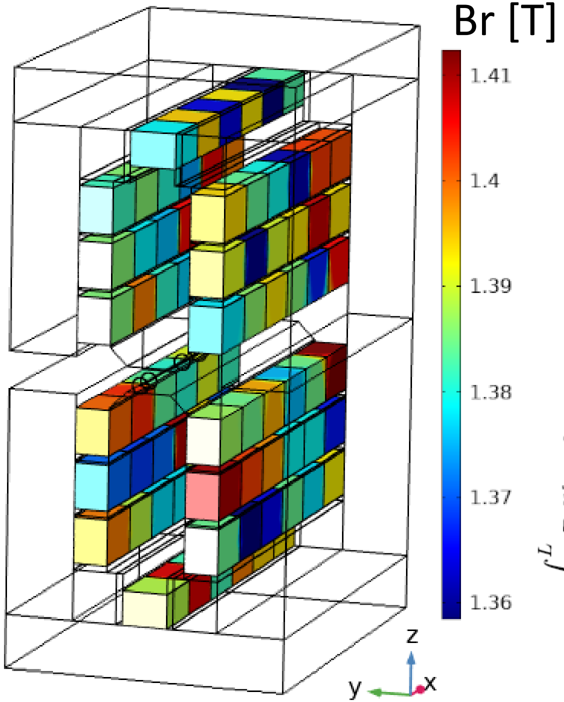


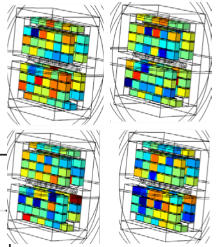



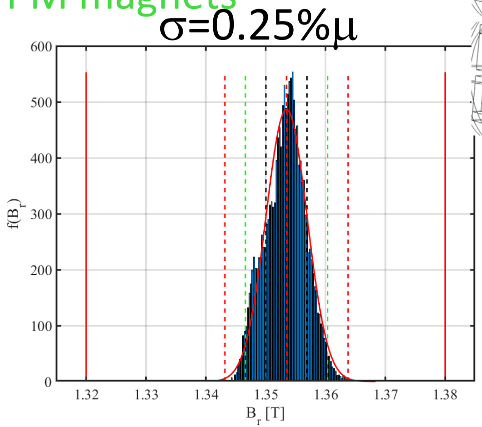
# Test of BN magnet

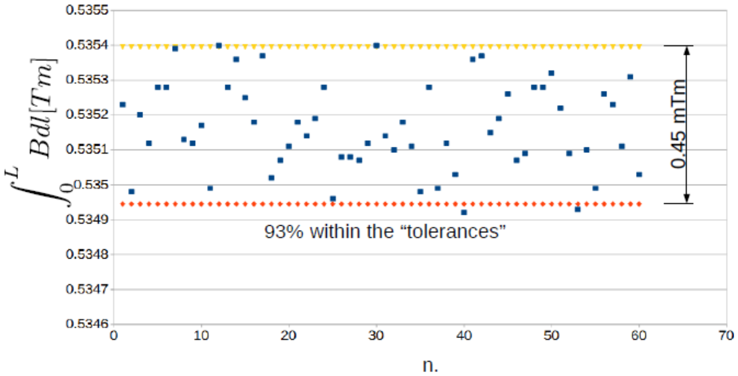
## BN Prototype: random filling with PM magnets





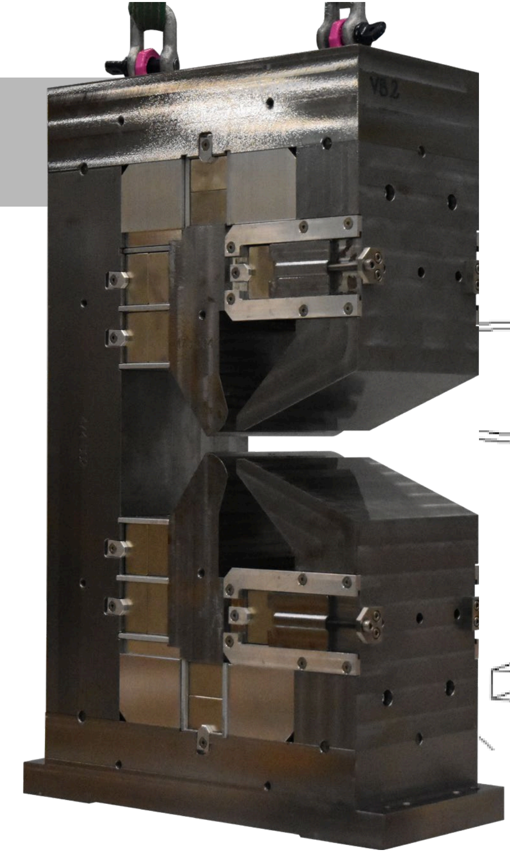



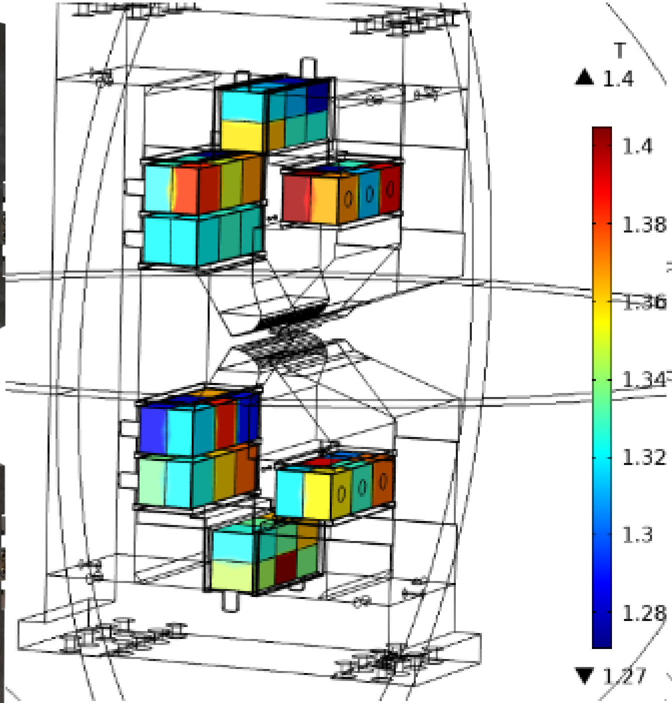


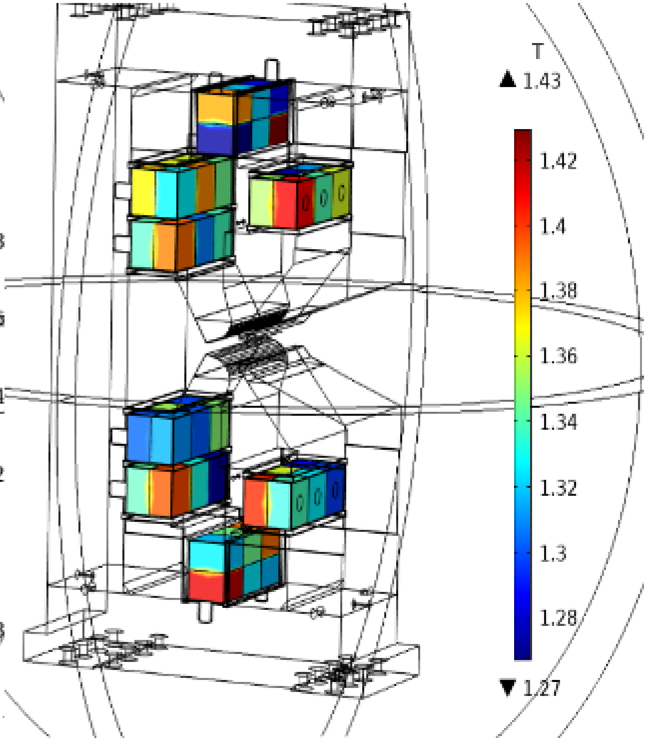



# Test of VB magnet

## **VB** Prototype: random filling with PM magnets





# Test of VB magnet

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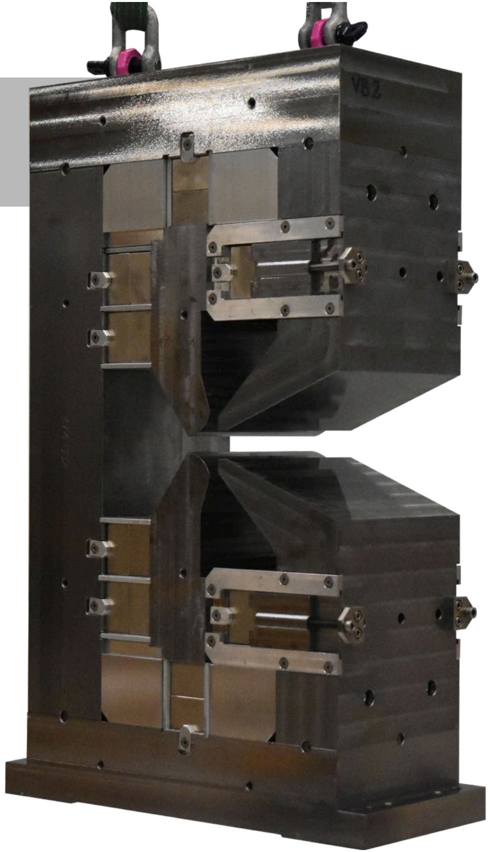
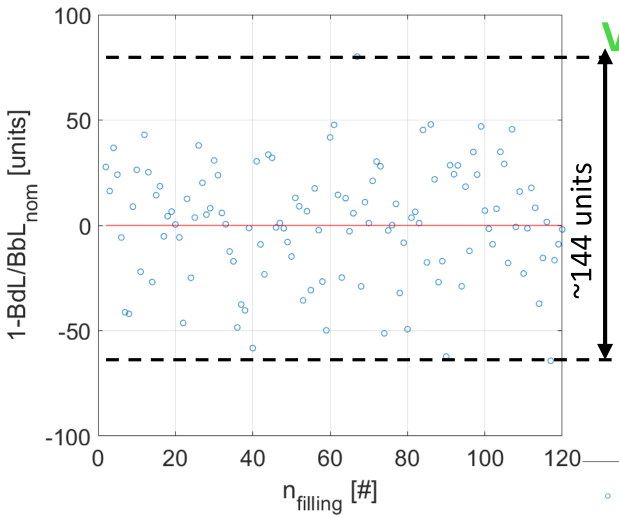
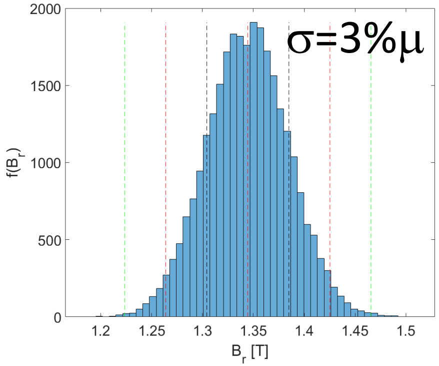
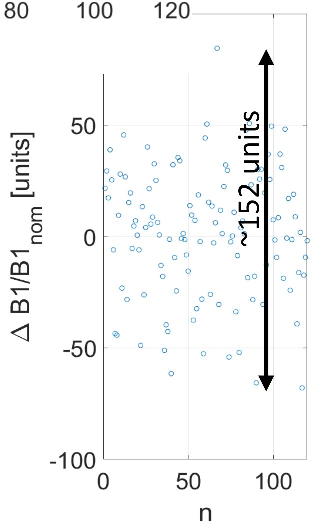
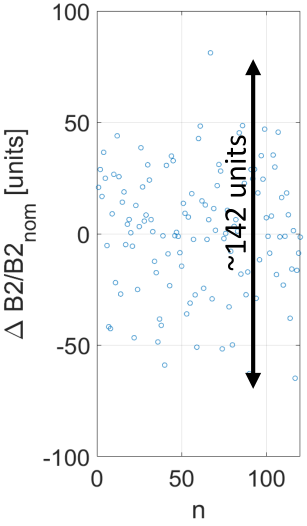


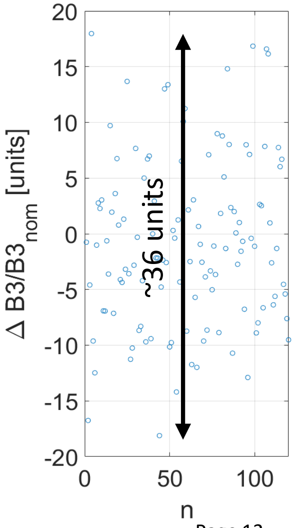



## VB Prototype: random filling with PM

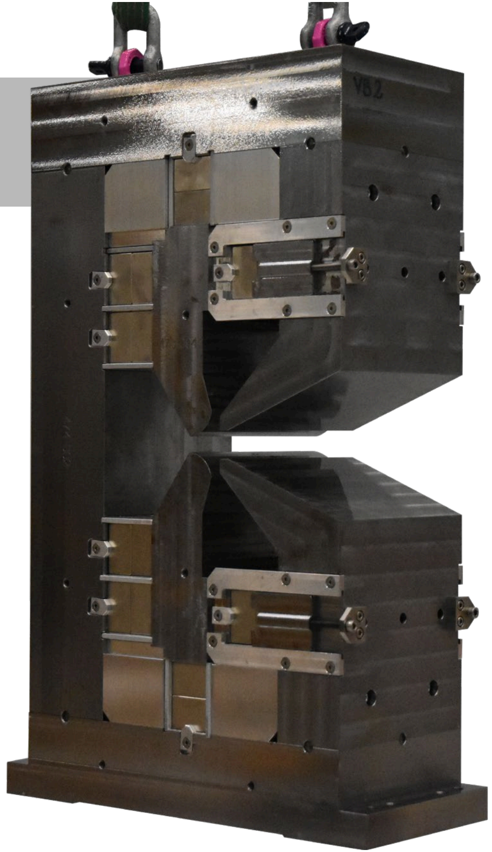


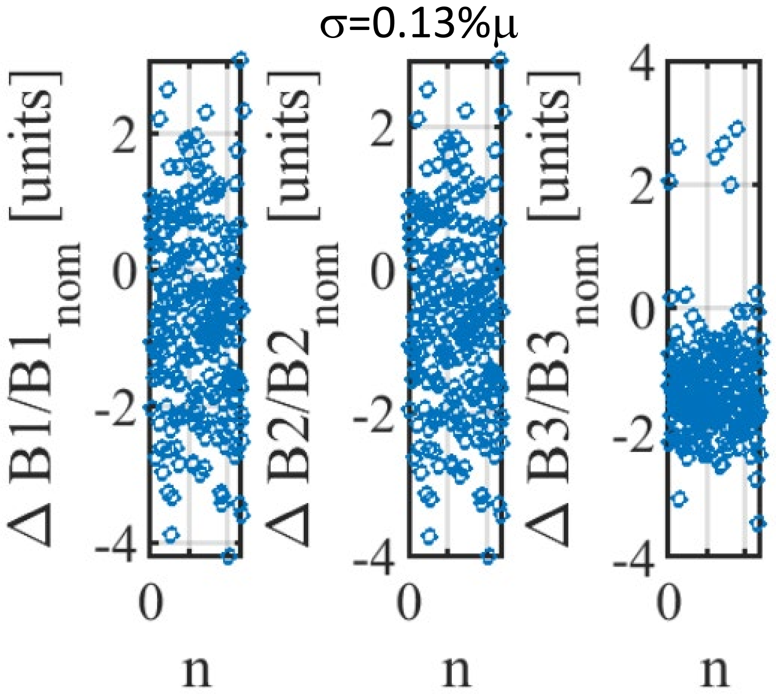



# Test of VB magnet



VB Prototype: random filling with PM magnets




By combining the PM blocks of the different bins, we aim to uniform the field quality of the different magnets.

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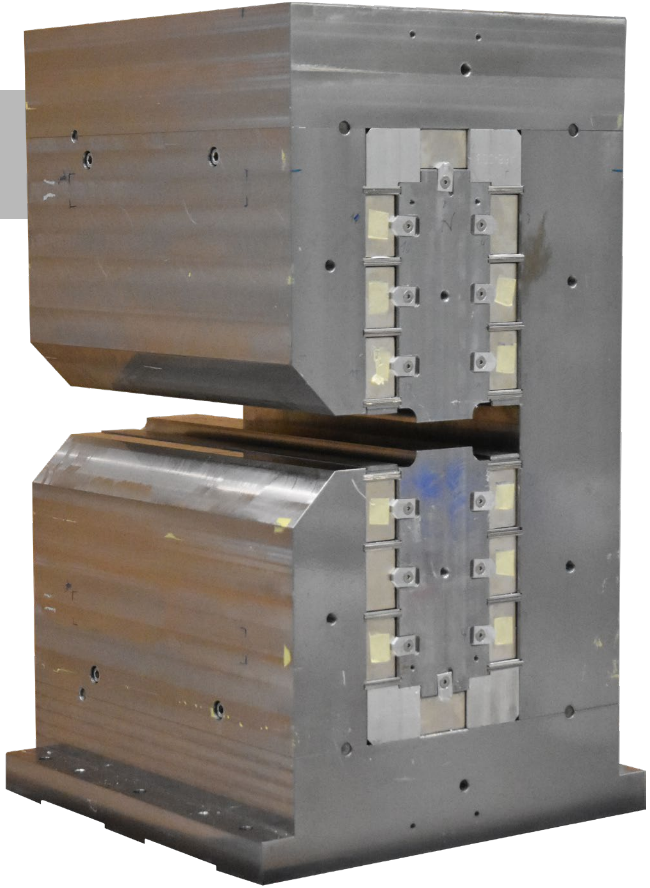
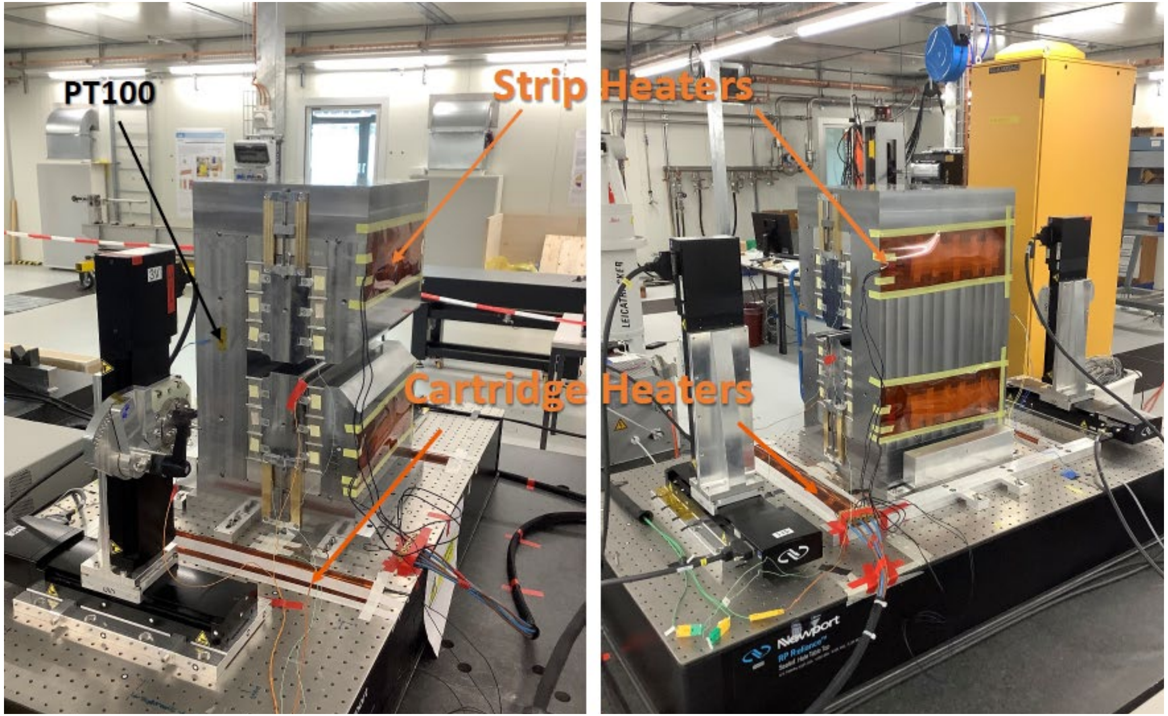
# Test of BN magnet

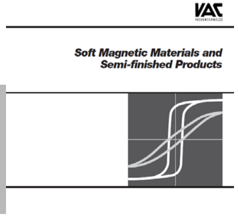
## BN Prototype





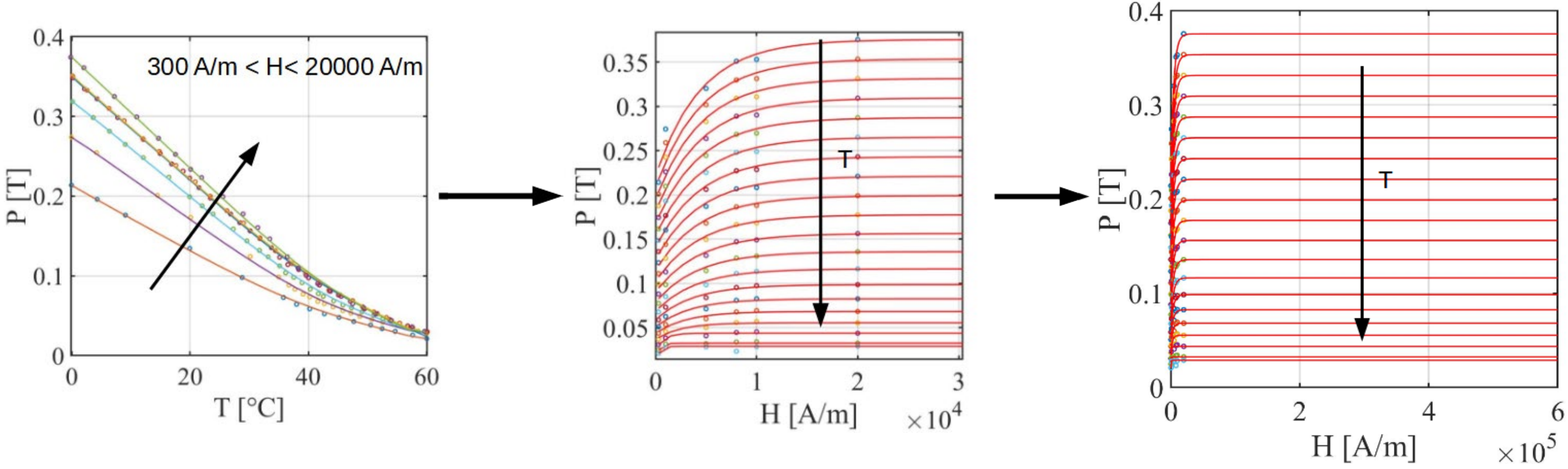

Moving wire measurements

# NiFe thermal shunts



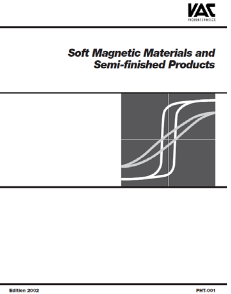

$$\vec{B} = \mu_0 \mu_r(T, H)\vec{H} = \mu_0 \vec{H} + \vec{P}(T, H)$$

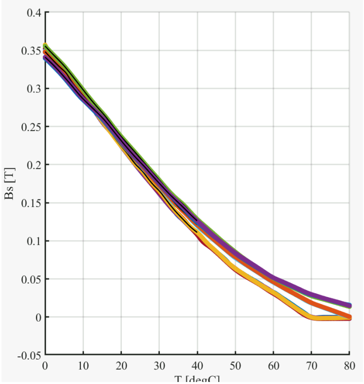
$$P(H) = B_s(T) \cdot (1 - ae^{-bH})$$

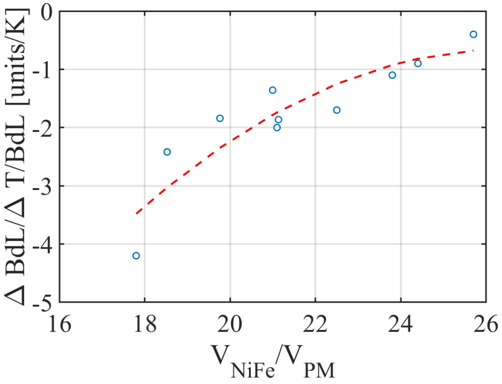


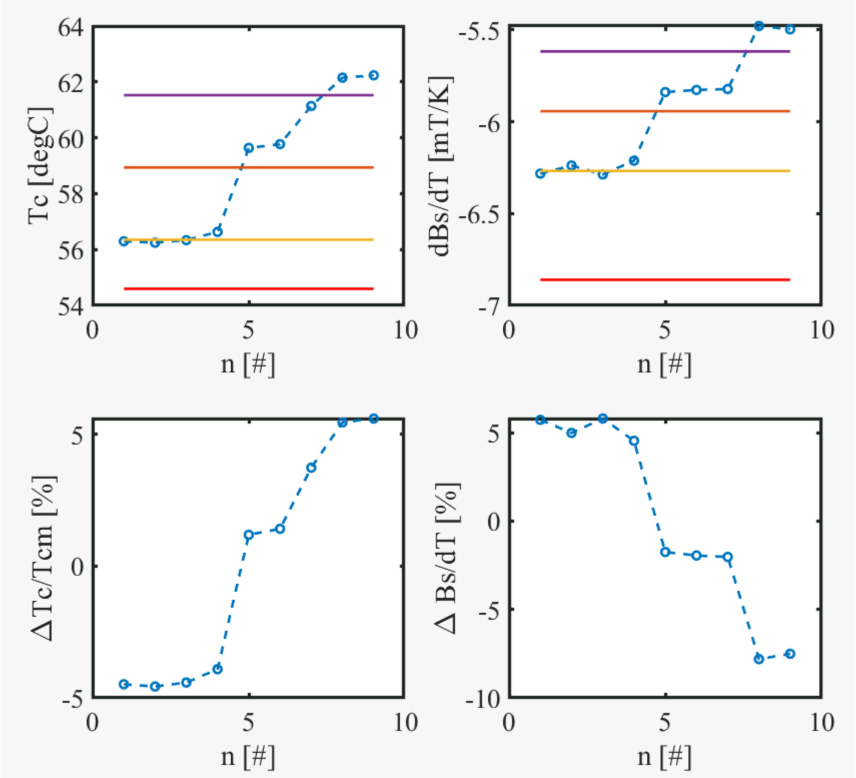

The temperature in the tunnel won't be uniform: we try to minimize as much as possible the temperature dependence of the permanent magnets. Goal: d $\int Bdl$ /dT/$\int Bdl_{ref}$ ≈ -1 units/K.

# NiFe thermal shunts



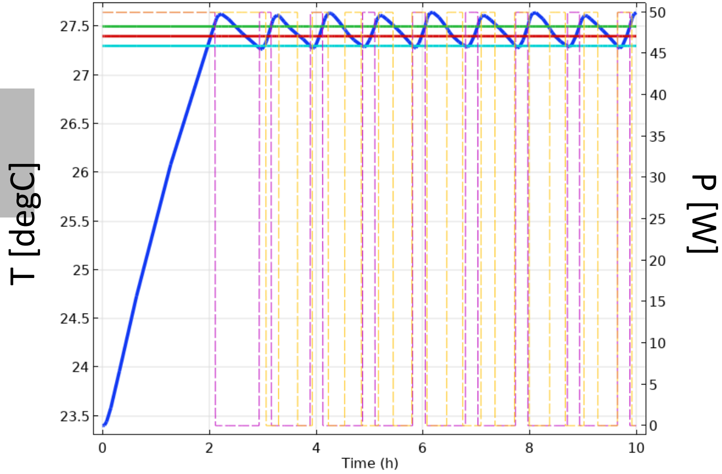



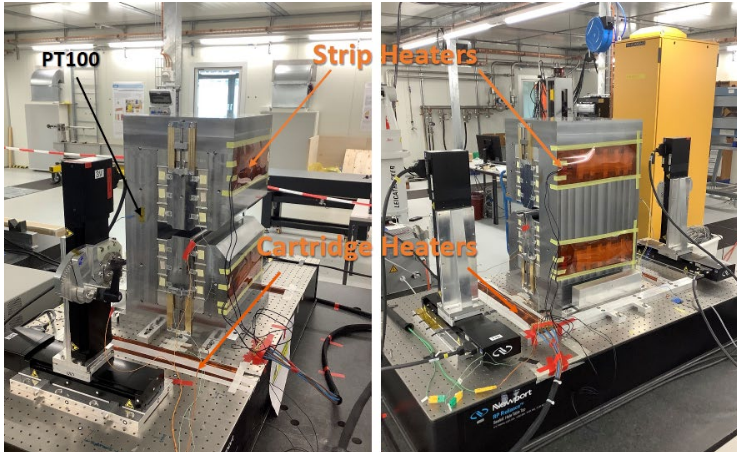



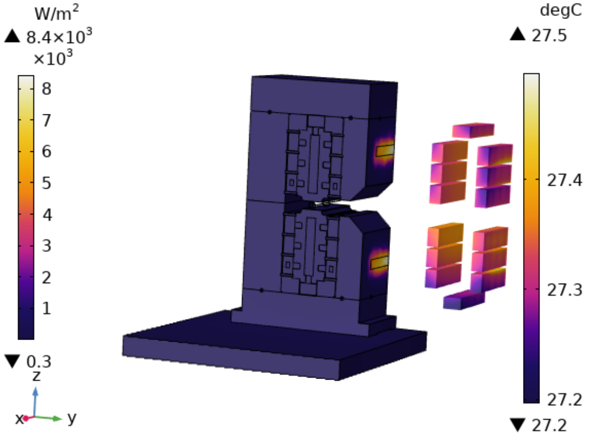

It will also be necessary a sorting of the NiFe plates as the different production batches have different Ni content (from 30.08% to 30.13%) and therefore different Curie Temperatures.

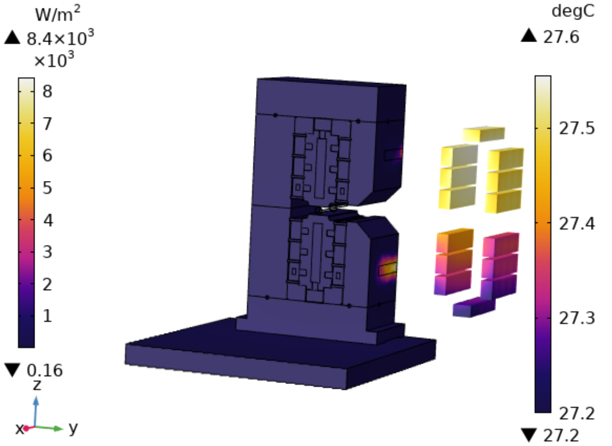
# Test of BN magnet

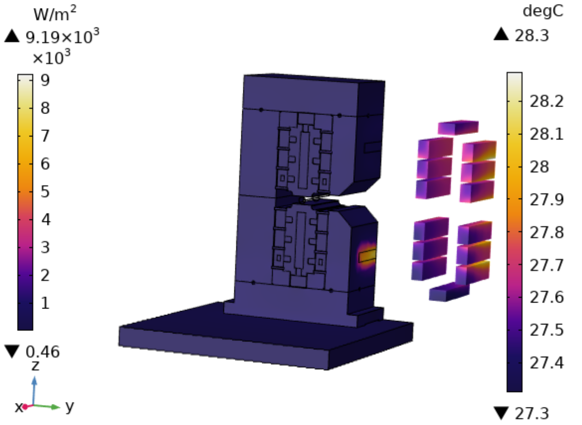
## BN Prototype



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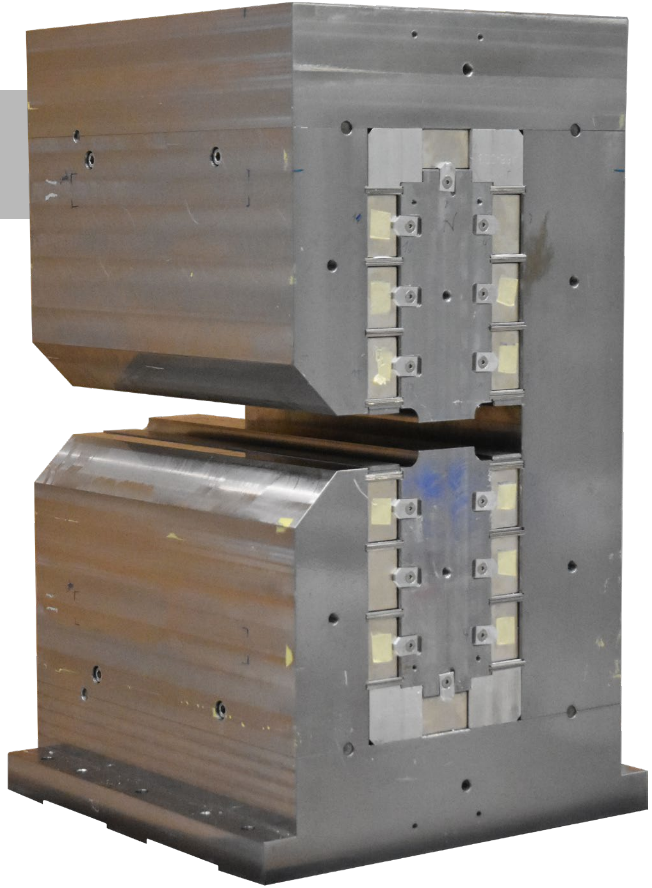
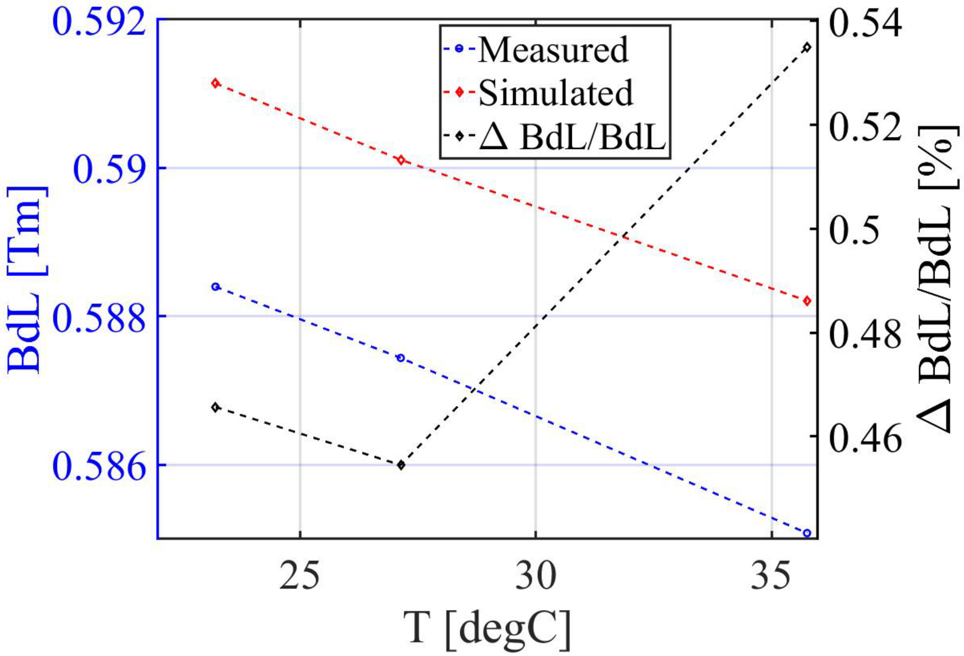
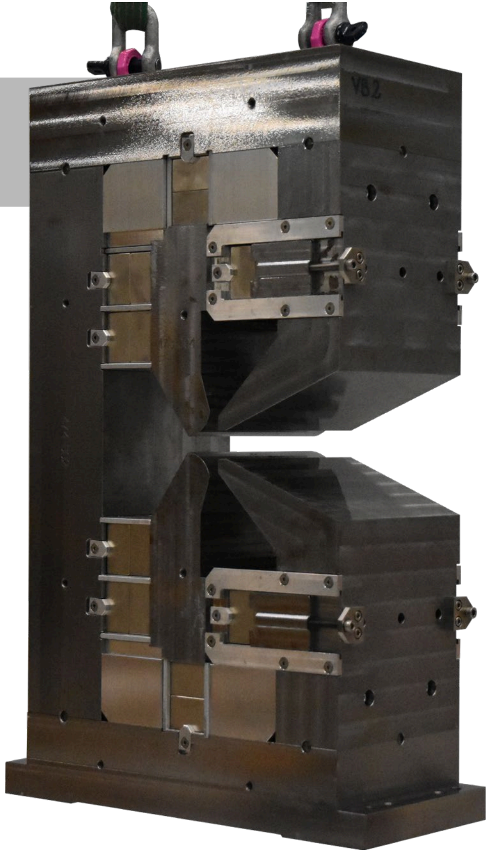
# Test of BN magnet

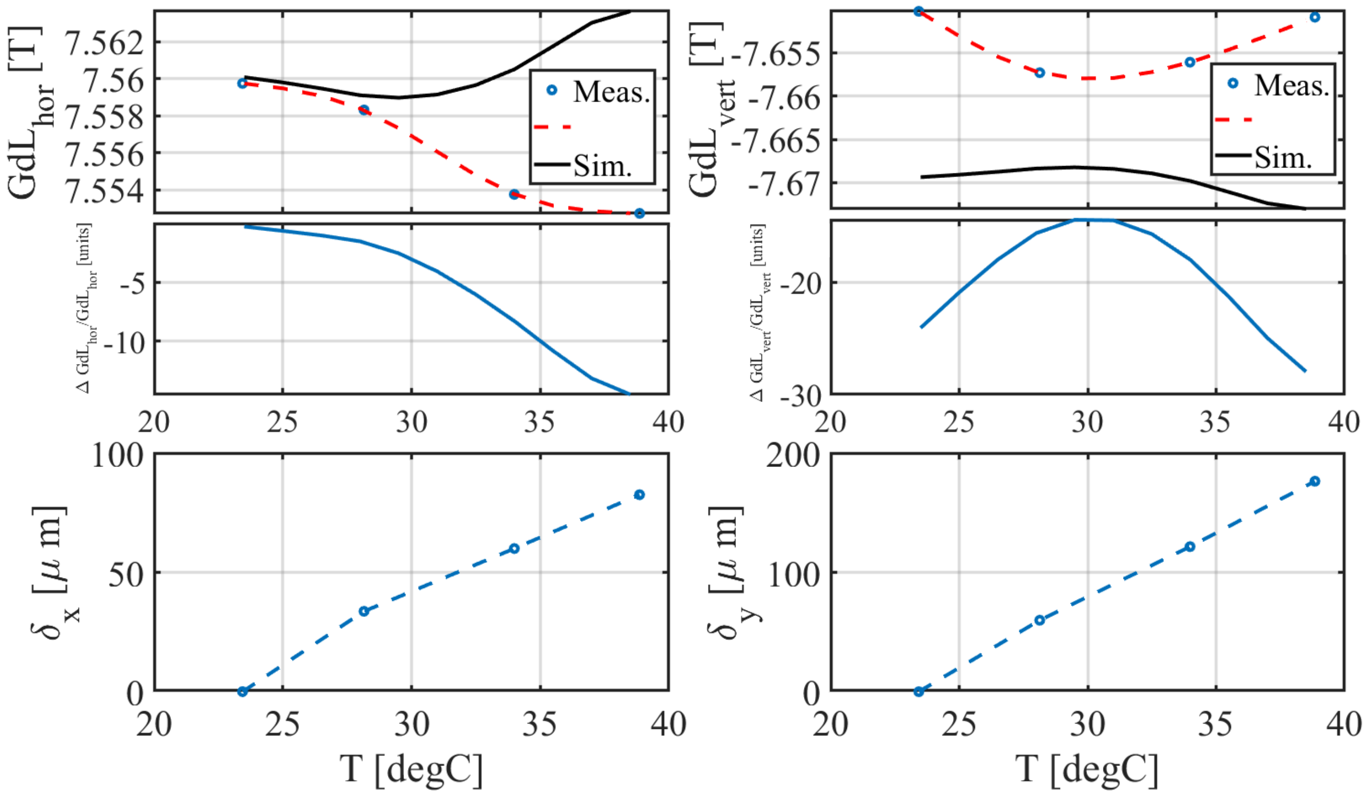
## **BN** Prototype



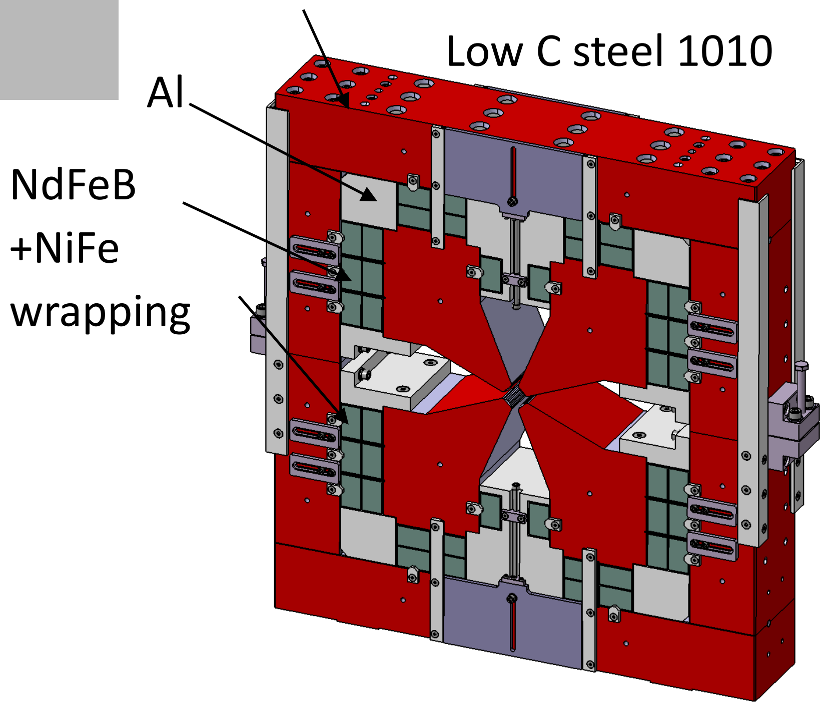


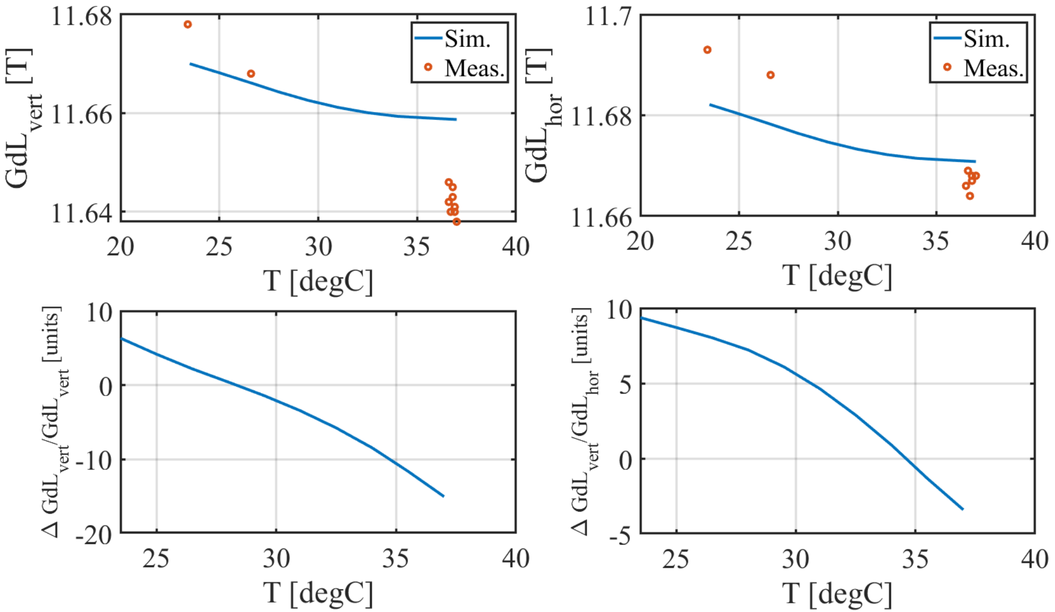
# Test of VB magnet





# Test of ANM magnet

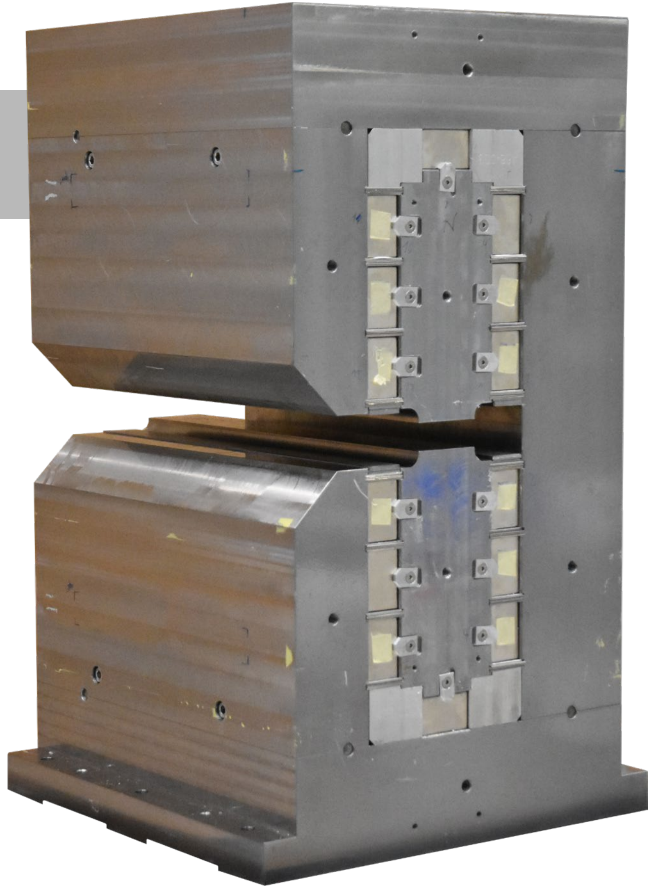


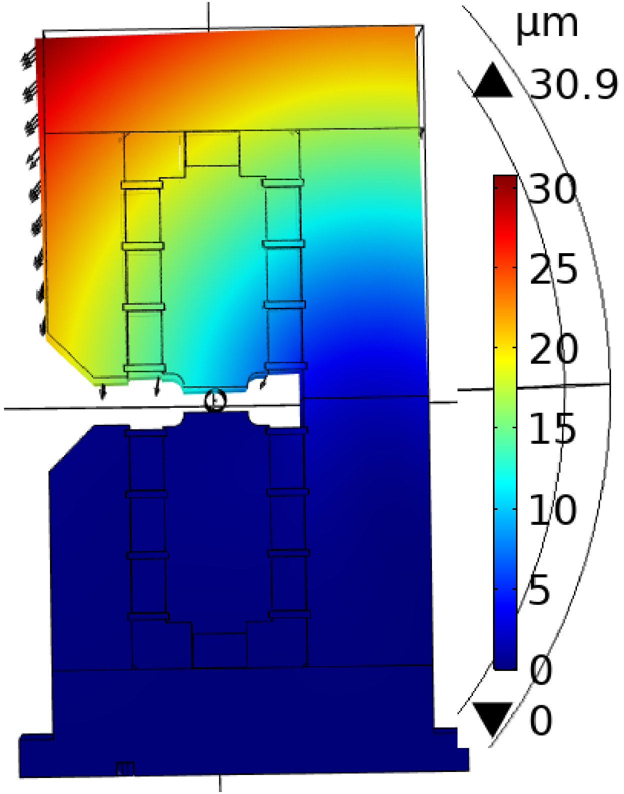



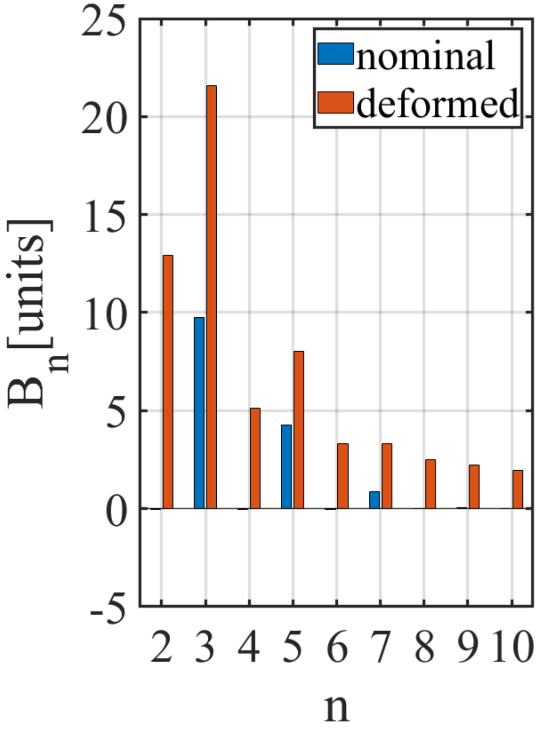

Moving wire measurements

# Test of BN magnet

## BN Prototype: deformation

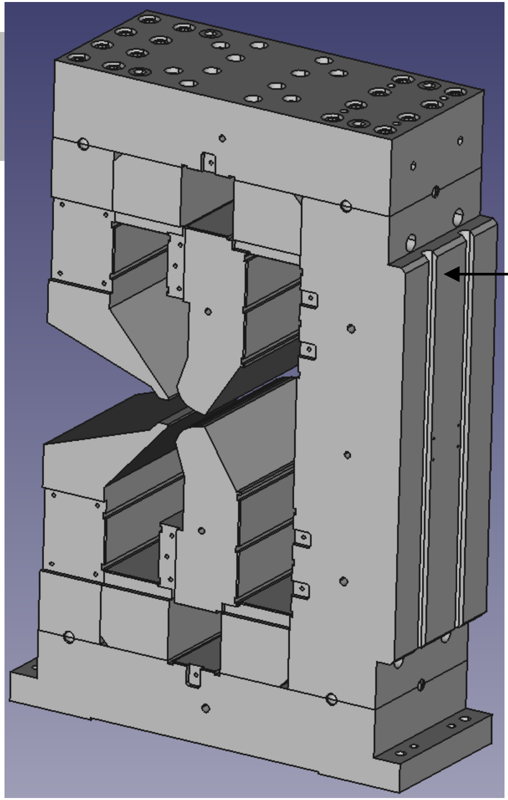




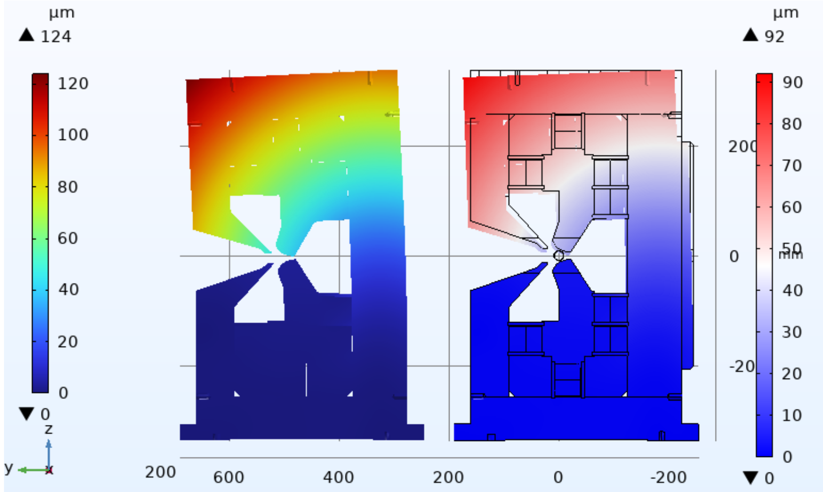




Negligible skew components.

# Stiffer yokes

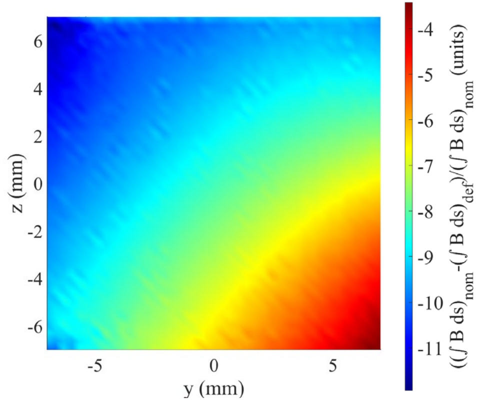


Rib to Increase VB yoke rigidity



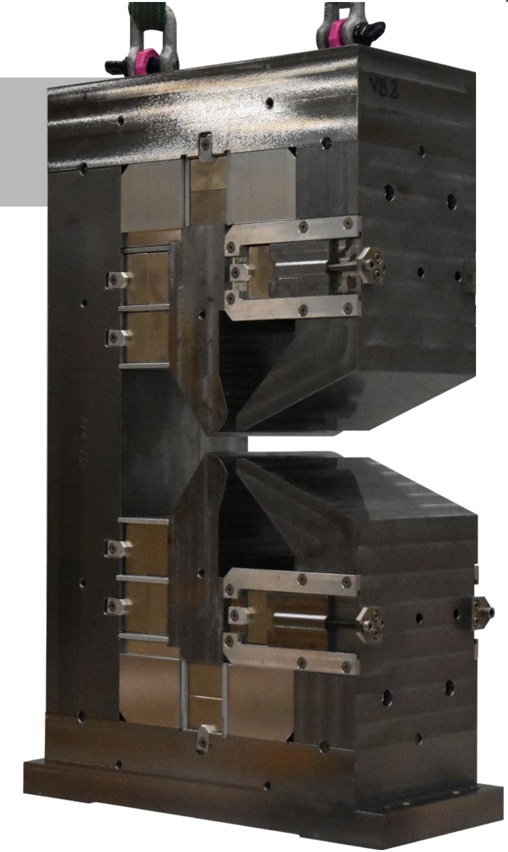

Integrated field in the good field region:

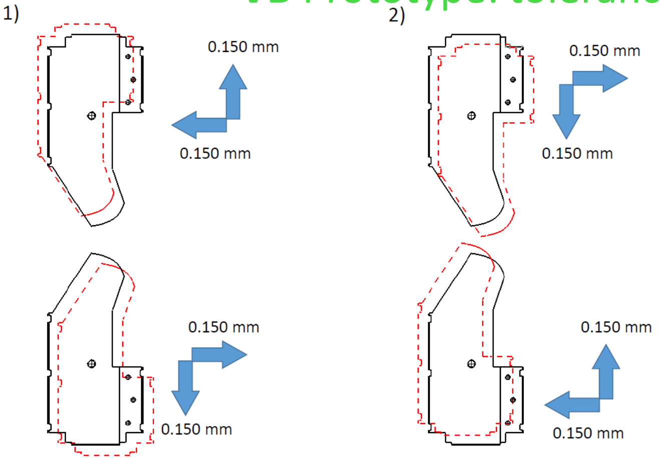
$$\left|\frac{\int Bds_{nom}-\int Bds_{def}}{\int Bds_{nom}}\right|\times 10^4 < 12[units]$$

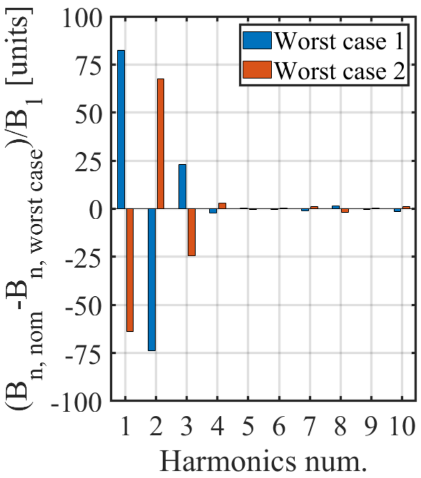


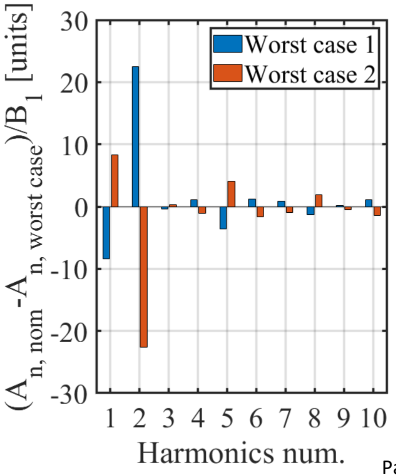
# Test of VB magnet

## VB Prototype: tolerance analysis

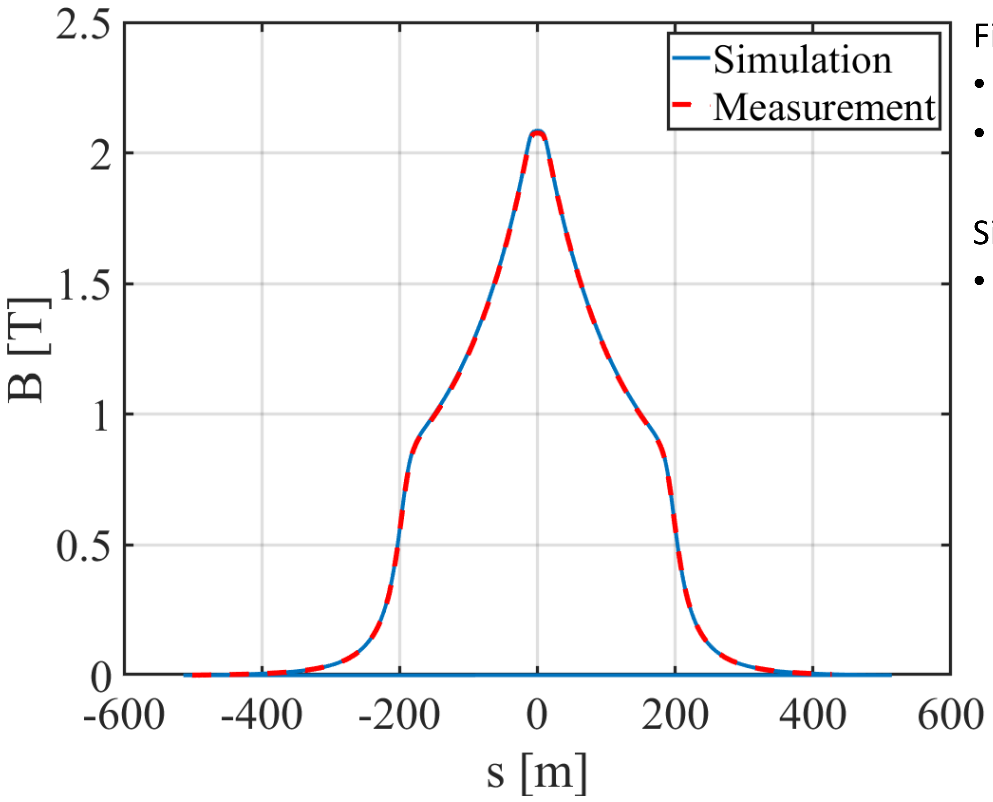




# BS2 superbend




Field integral measured (23°C) by

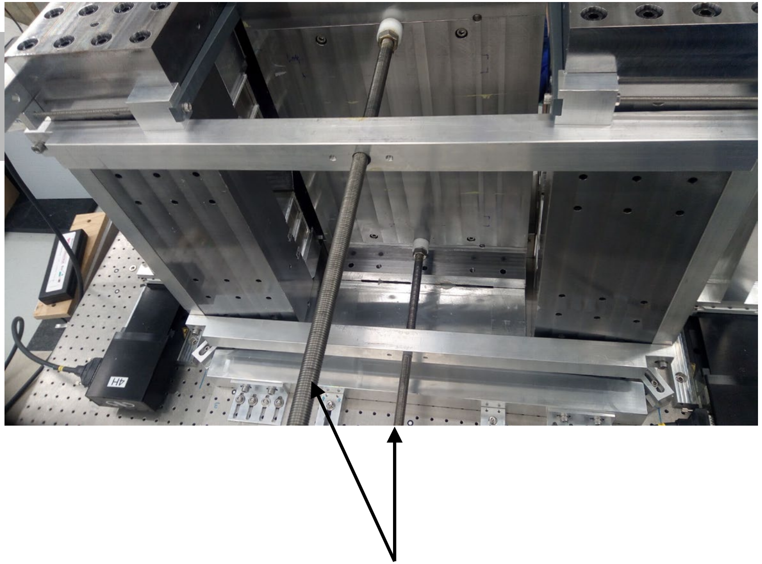
- Compact field mapper (CFM): 0.56245 Tm
- Moving wire: 0.56354 Tm

Δ~19 units

Simulated field integral at 23°C:

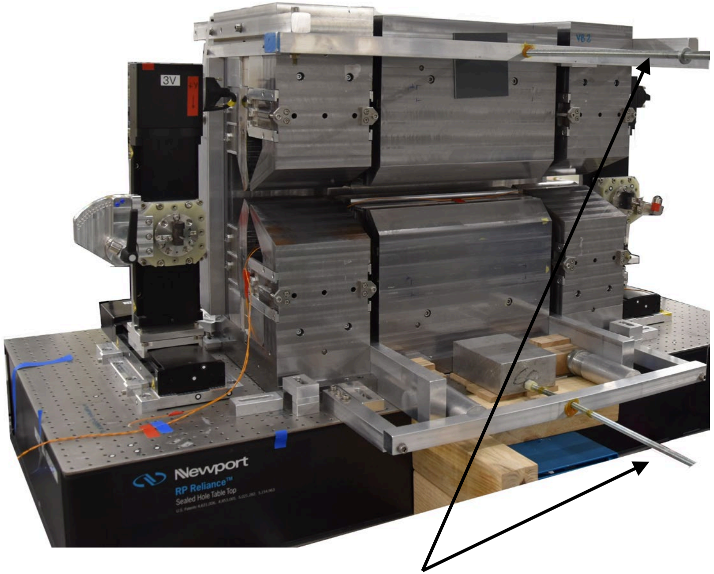
- 0.56490 Tm (+24 units with regard to moving wire, +44 units with regard to CFM).

# Permanent magnets: assembly tools



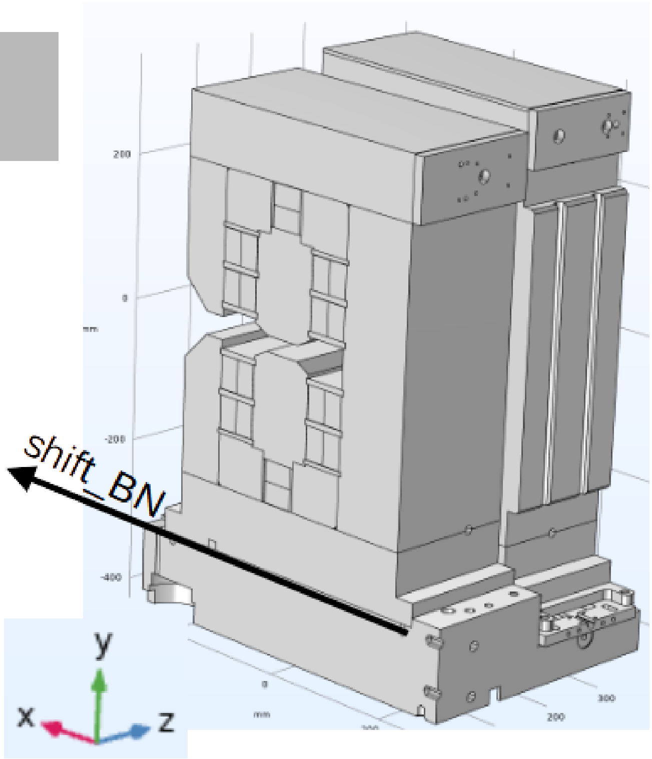
Compensating screws to guide the BN when attracted towards the VB magnets.

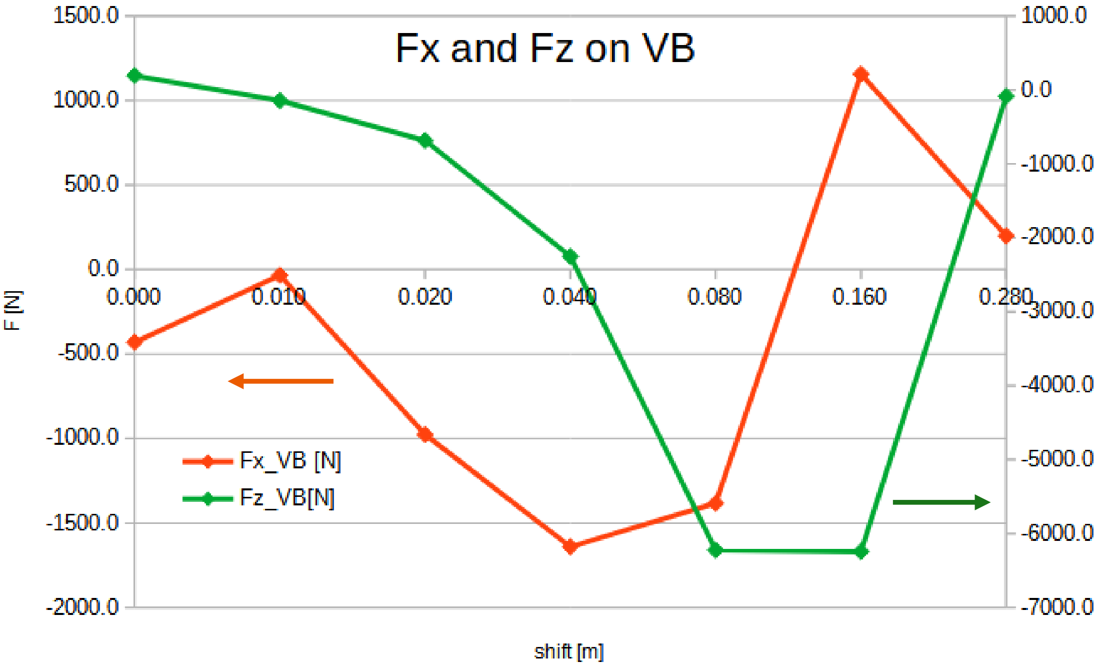
Equilibrium position: From here on we need to push the BN using the forward screws.




Forward screws to push the BN in position

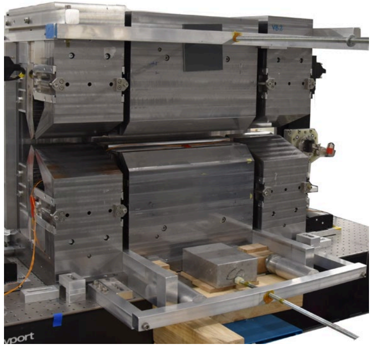
# Permanent magnets: assembly tools



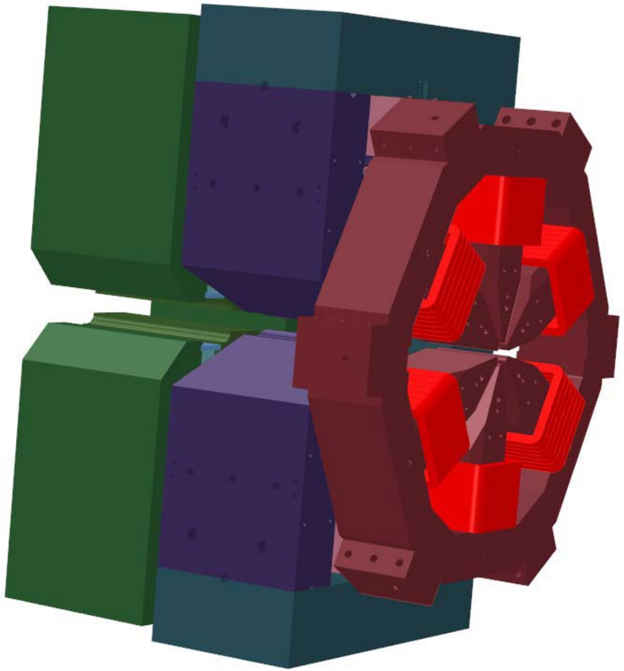



# Crosstalk issues

# Triplet(s): VB-BN-VB & VB-BS-VB



Triplet cross talk with active sextupole

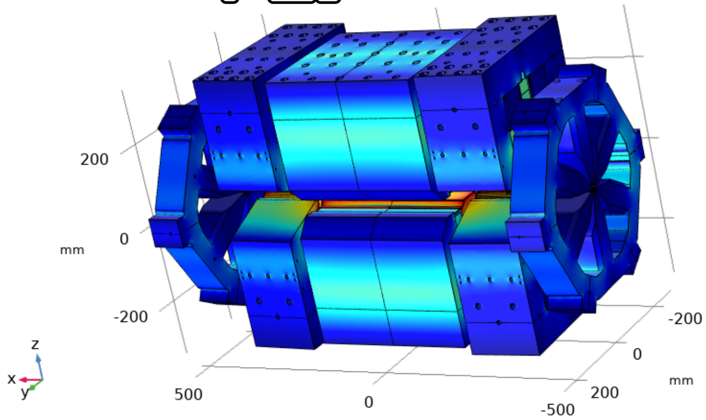


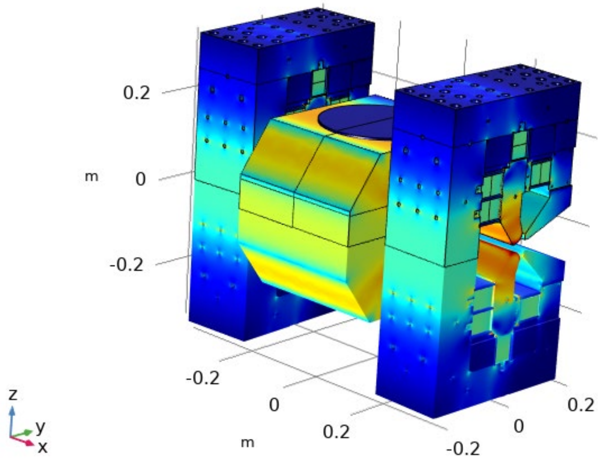
Moving wire measurements

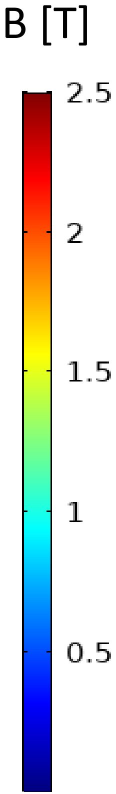
When the magnets are assembled in the triplet:

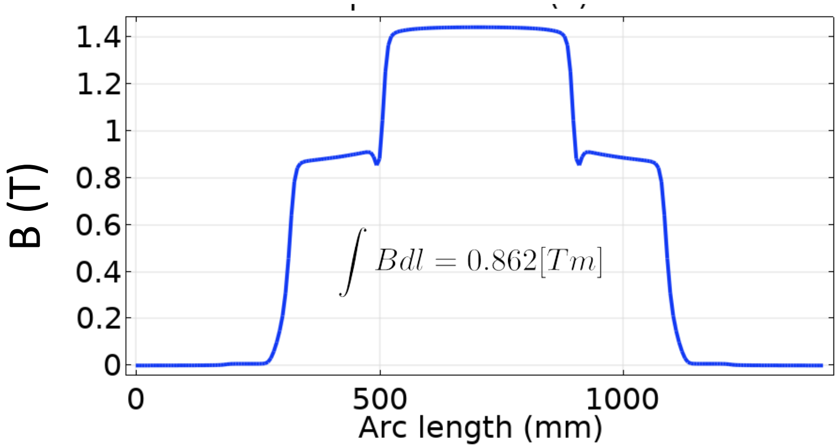
- BN dipole: 0.7% stronger;
- VB dipole: 0.47% stronger;
- VB quadrupole 0.36% stronger.

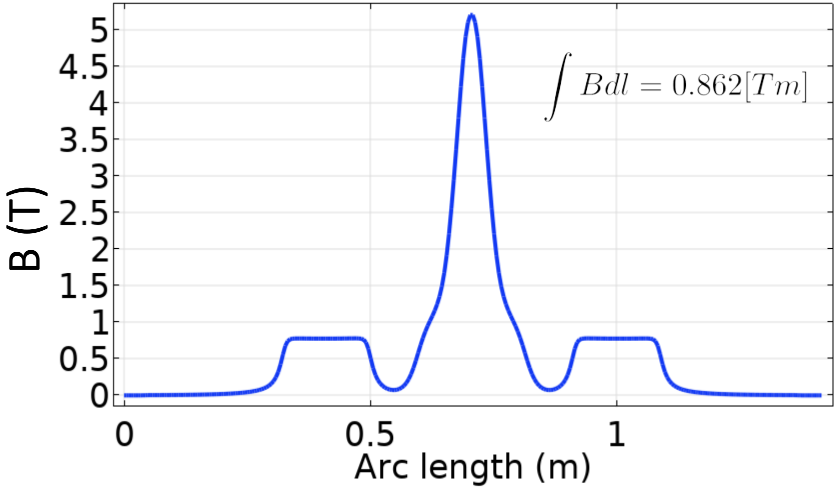
# Triplet(s): VB-BN-VB & VB-BS-VB



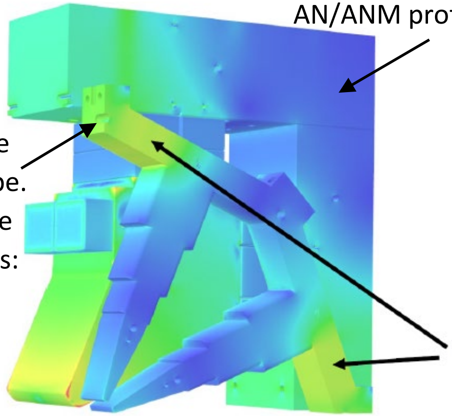



# OC magnet

AN/ANM prototype

Octupole Prototype. Ret. Yoke thickness: 30mm



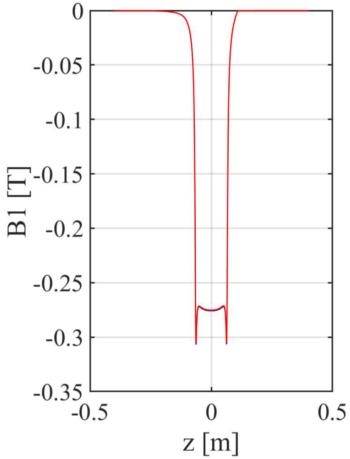
B > 1.8 T

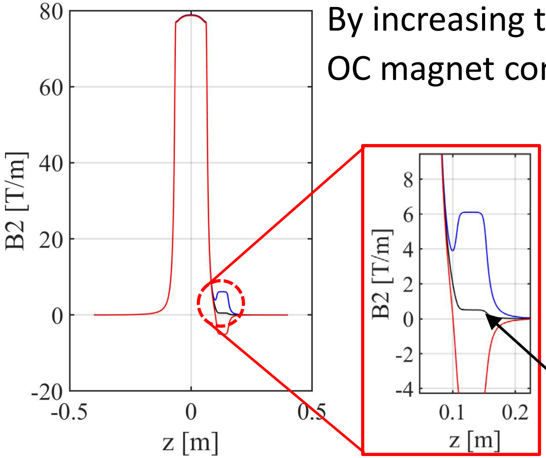
AN(M) prototype alone: 83.9 T/m

AN(M) + OC (30 mm iron to iron distance): 79.7 T/m (-5%)

Nominal quadrupole in OC: 5.6 T/m

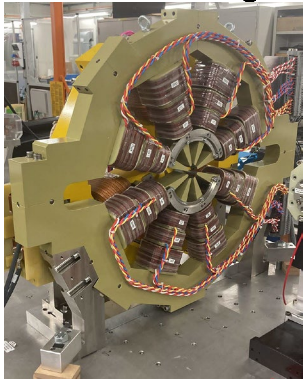
Quadrupole in the OC magnet coming from the AN(M) magnet: 8.8 T/m.



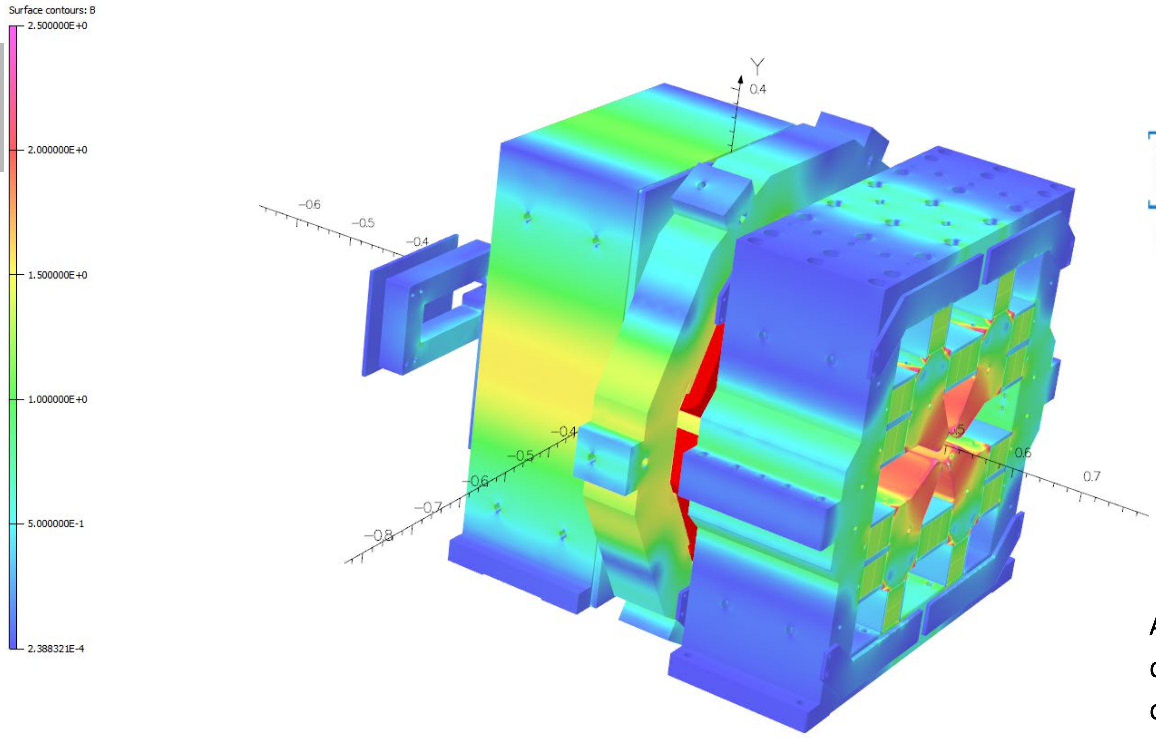

By increasing the OC return yoke thickness to 72.7 mm the quadrupole in the OC magnet coming from the cross-talk with the AN magnet dropped to 0.5 T/m.

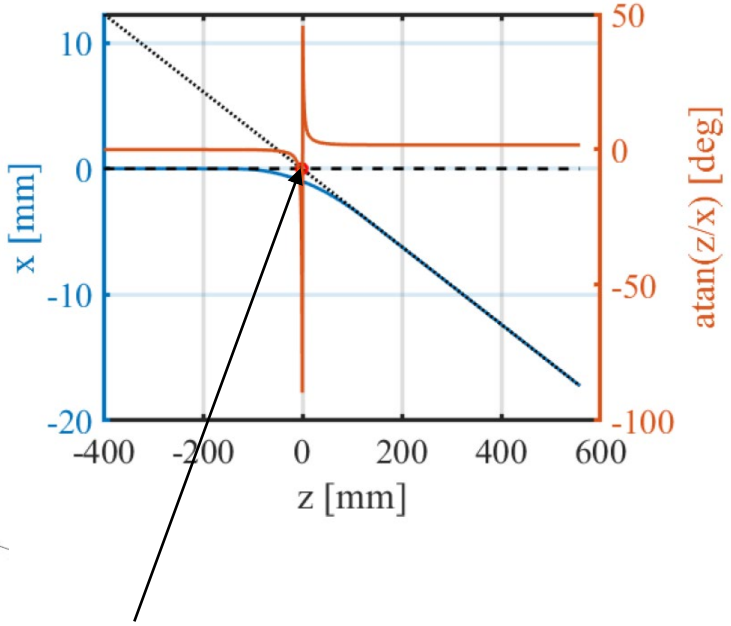
0.5 T/m coming from the AN magnet



<u>The 3rd OC prototype with wider yoke will be measured in the coming weeks.</u>

# CHV-BE-SXQ-VE




As a consequence of the cross talk among the different magnets, the vertex point of the BE dipole is shifted by 4.2 mm.

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# Summary

- Several modifications were applied to the different magnets to cope with cross talk problems.

- All the WTOs have been published;
- The delivery time for some magnets has still to be confirmed;

- All the QP and QPH magnets have been tested. All the magnets are within the specifications.

- Next important milestones
  - Test of the 3rd octupole prototype (wide body + thicker yoke + heat treatment);
  - Axis determination of the SOQ assembly;
  - Test of the triplet VB-BN-VB including the mechanical support.

**Thanks for your attention**

# Wir schaffen Wissen – heute für morgen

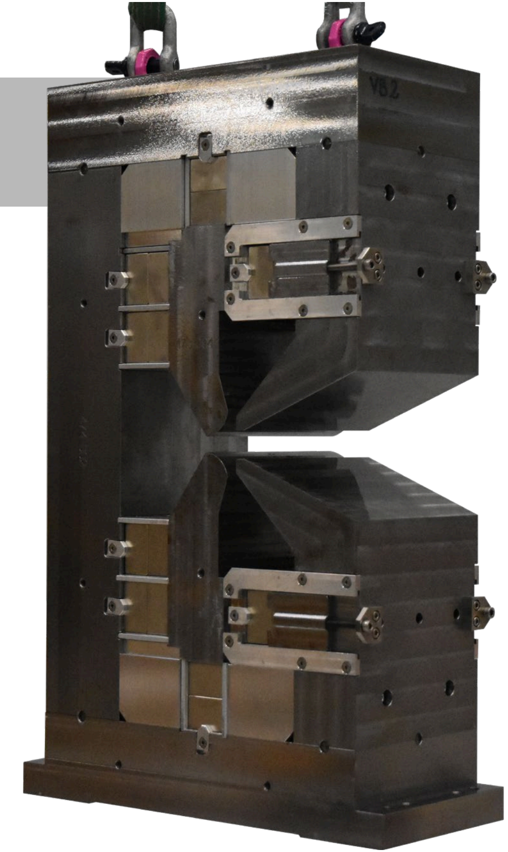
**Many thanks to:**

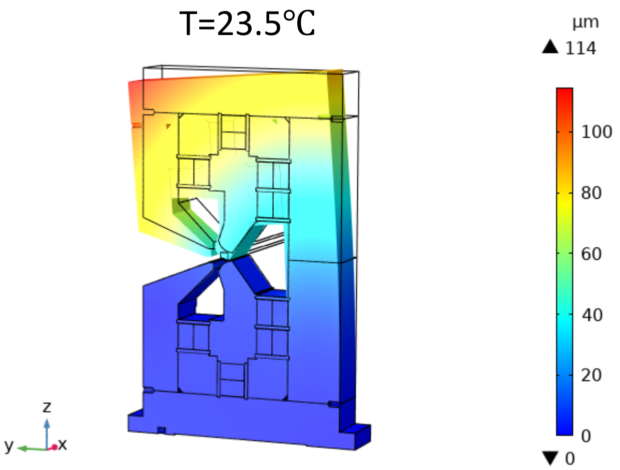
- S. Sanfilippo
- A. Gabard
- S. Hellmann
- M. Duda
- R. Hübscher
- G. Montenero
- M. Negrazus
- S. Sidorov
- V. Vrankovic

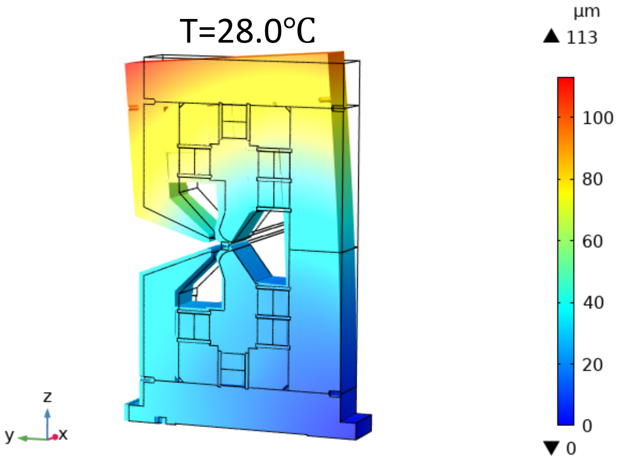
# Backup slides

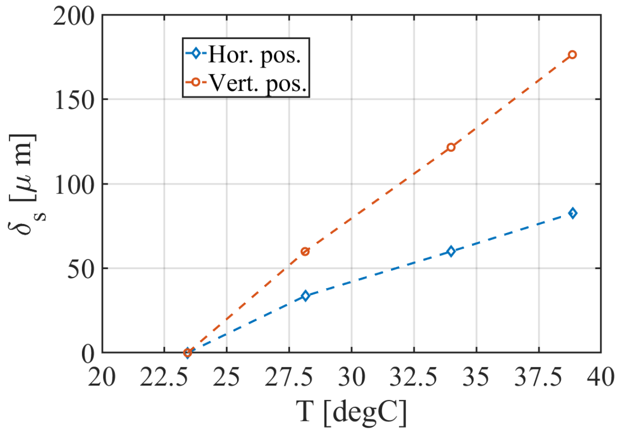
# Test of VB magnet

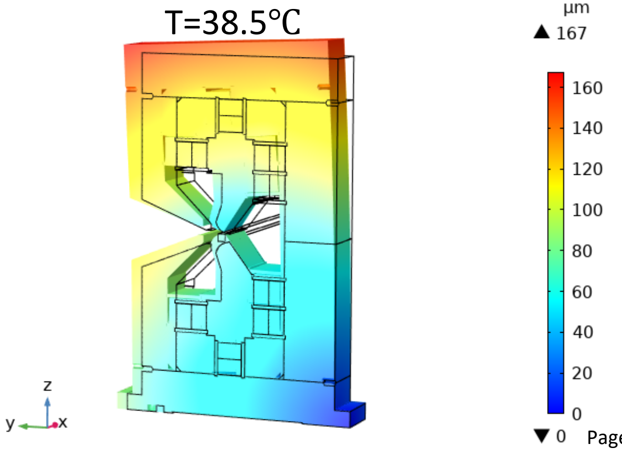
## VB Prototype: deformation



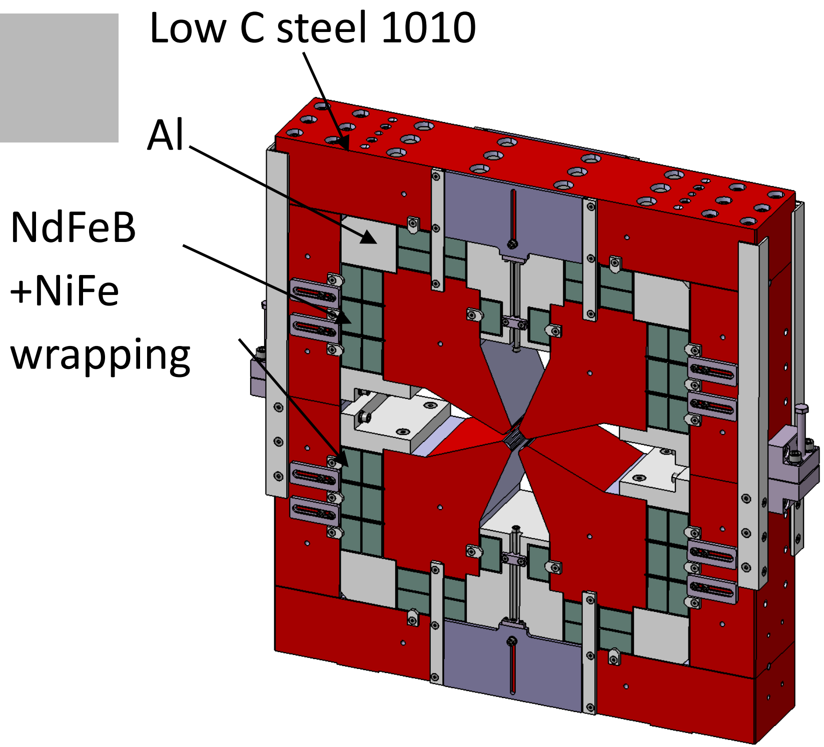


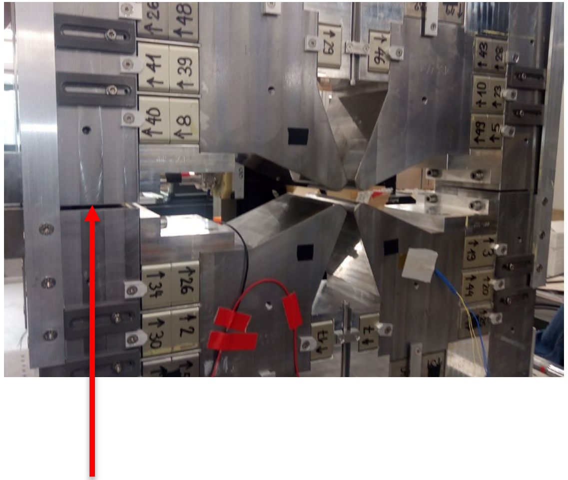



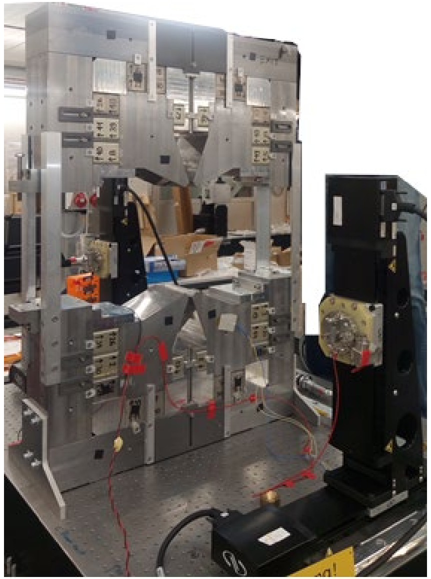



# Test of ANM magnet





- ~20 mm opening by using the screws (about 10 Nm) before pulling with the crane;
- The integrated quadrupole changed by about 5 units by opening and closing the magnet.

# Prototyping electromagnets

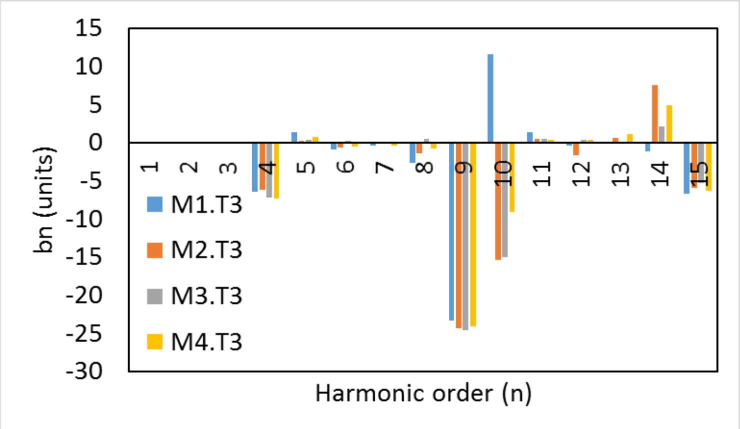
# SX prototype measurements (G10 19 mm coil shaft)

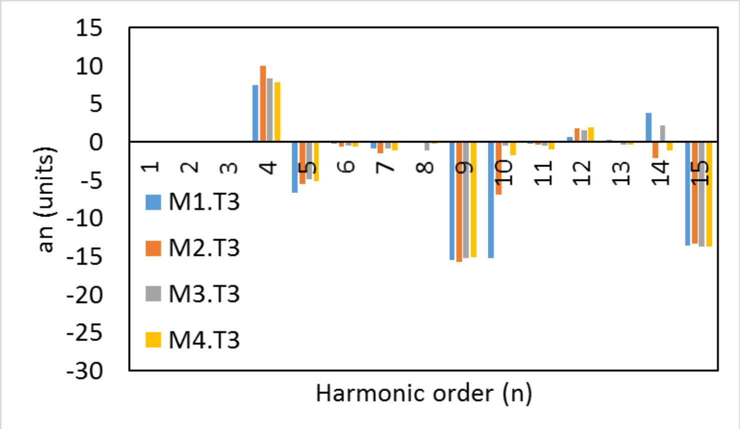

- ○ **Rotating Coils: coils from CERN with dipole and quadrupole bucking**
- ○ **50 A Delta Elektronika PS–> no degaussing available-> measured sextupole field integral ~2% higher then TDR specs (5865.5 T/m2)**
- ○ **Field errors from design: b9=-27 (units) and b15=-28 (units)**

**Next steps:**

- **Use high accuracy PSI WLHA power supply for (i) degaussing and (ii) powering of the magnet**
- **Use the new RC measurement bench-> PCB rotating coil sandwiched in a MACOR shaft (digital bucking of sextupole will be available)**

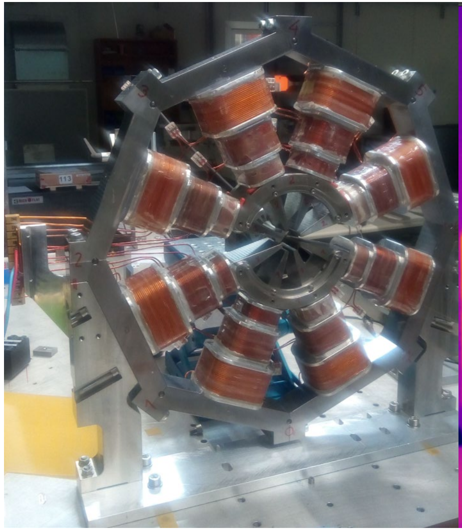
**Normal and Skew harmonics on repeated measurement runs**

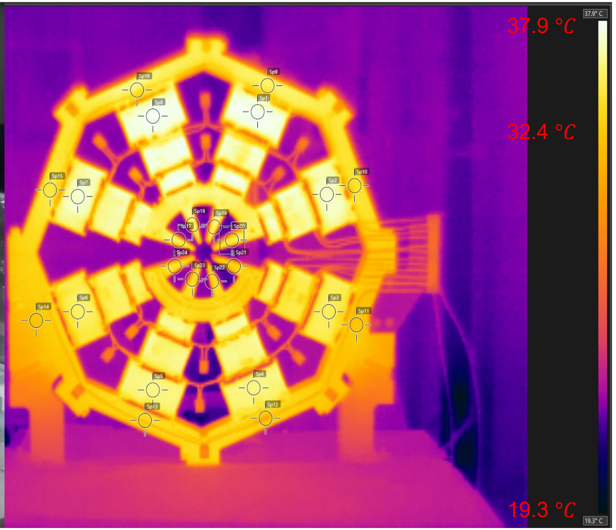



Magnetic design confirmed

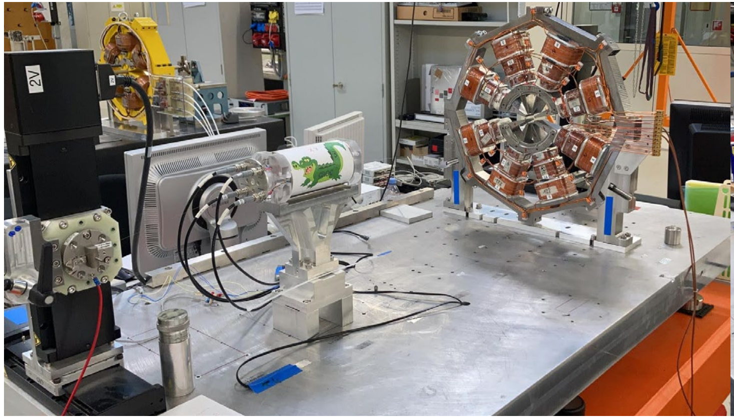
# OC magnet

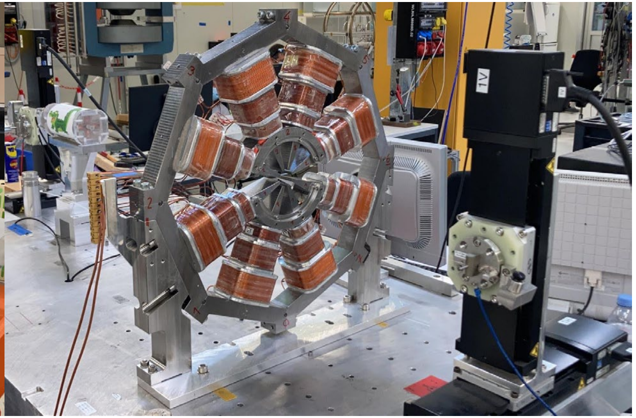





Temperature measurement
OC magnet's coils

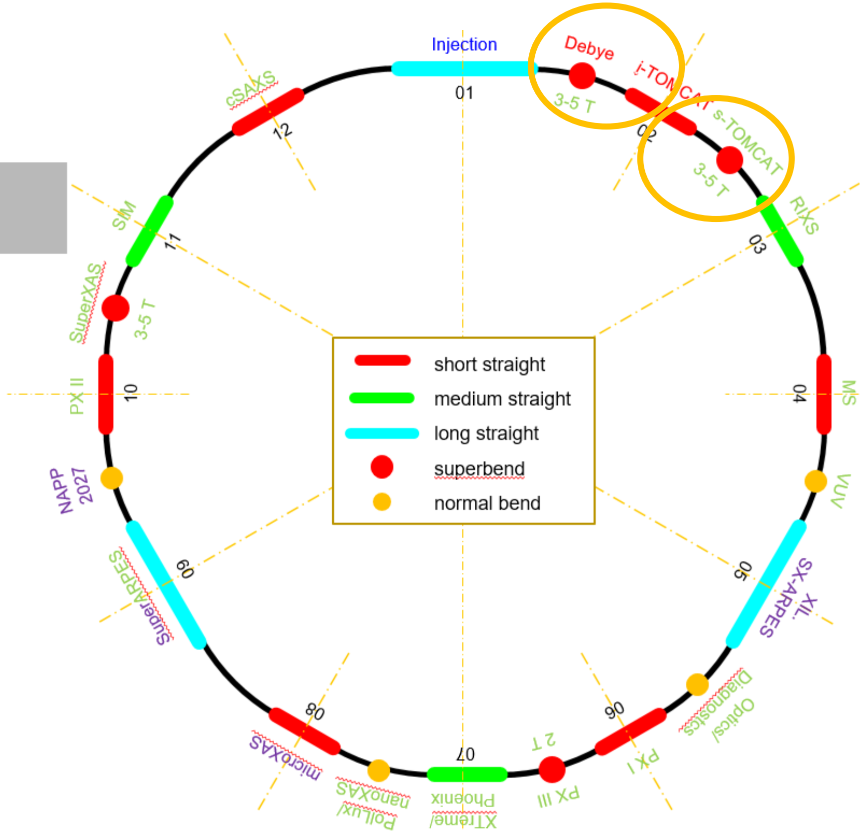
Acceptable temperature range
$(32.4℃ \leq T_{coils} \leq 37.5℃)$





OC on the bench ready
to be measured

# Superbends for the SLS upgrade




4 PM based superbend magnets:

- I-XAS (“Debye”)
  - Arc 1
  - to be upgraded to 3-5 T variable or 5 T fixed
- s-TOMCAT
  - Arc 2
  - To be upgraded to 5 T (…and then to 8 T)
- SuperXAS
  - Arc 10
- PX III
  - Arc 6

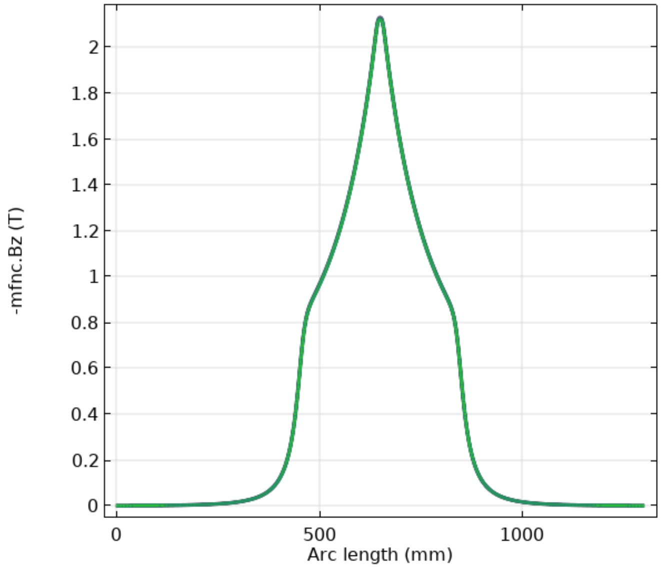
*) Phil Willmott, SLS 2.0 Beamlines & Photonics :: PSIM, 8th April 2021

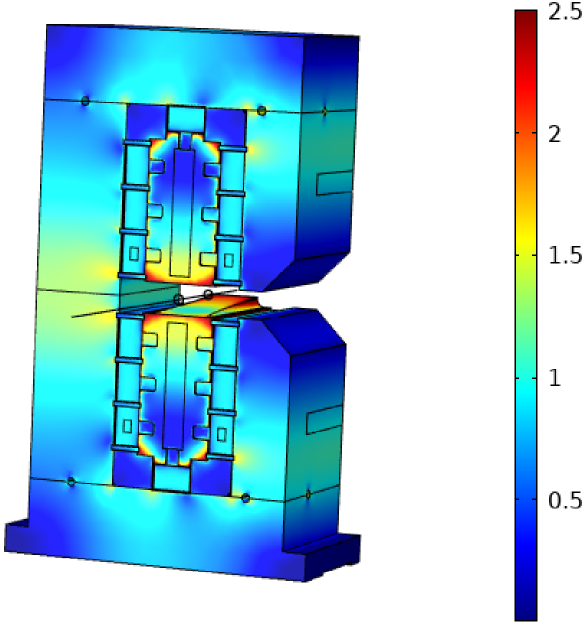
# 2 T superbend

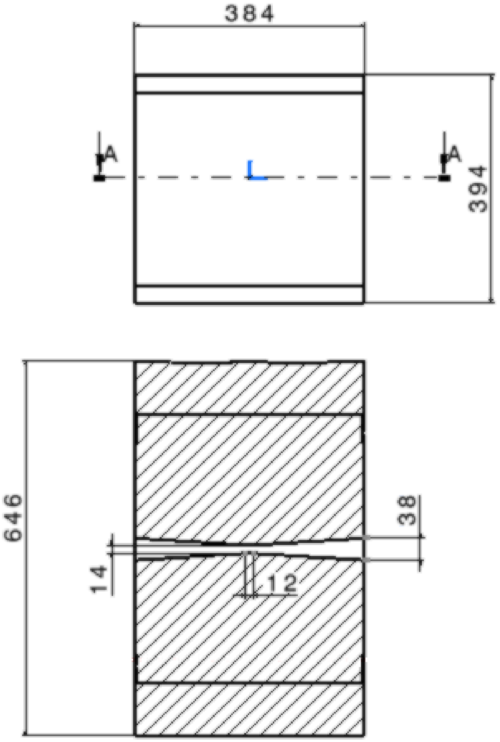
Similar design as BN

- PM size : 30 x 47 x 54 mm$^3$
- 98 blocks (like for BN)
- Pole to pole distance reduced to 14 mm
- $\Delta$(BdL)/(BdL)$_{ref}$/$\Delta$T =-4.3 units/K

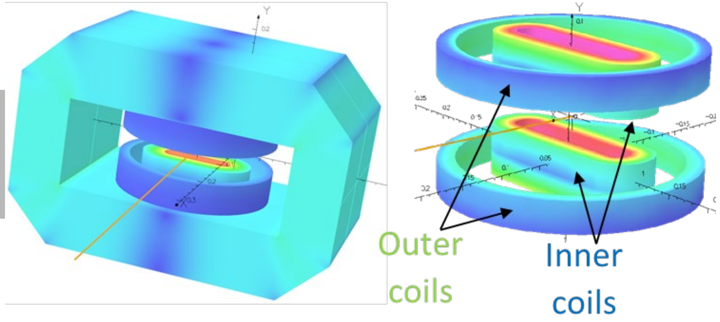
The design will be modified according to the lesson learned with the BN magnet.



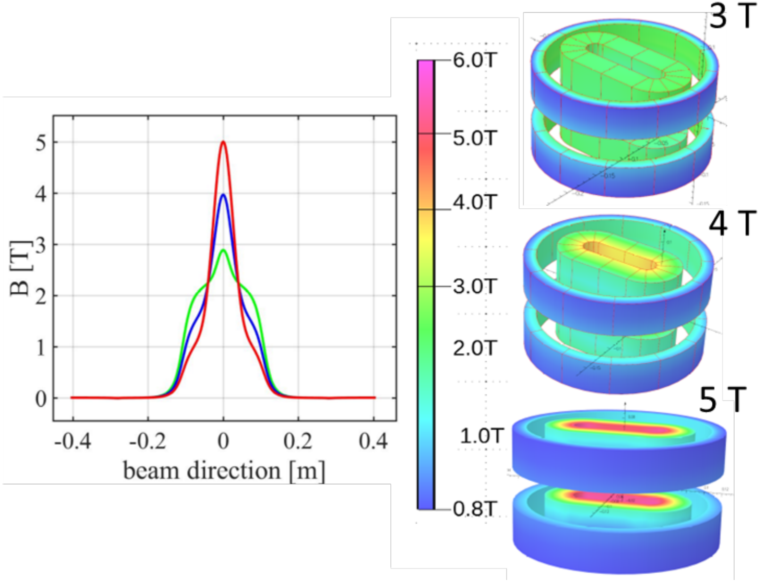



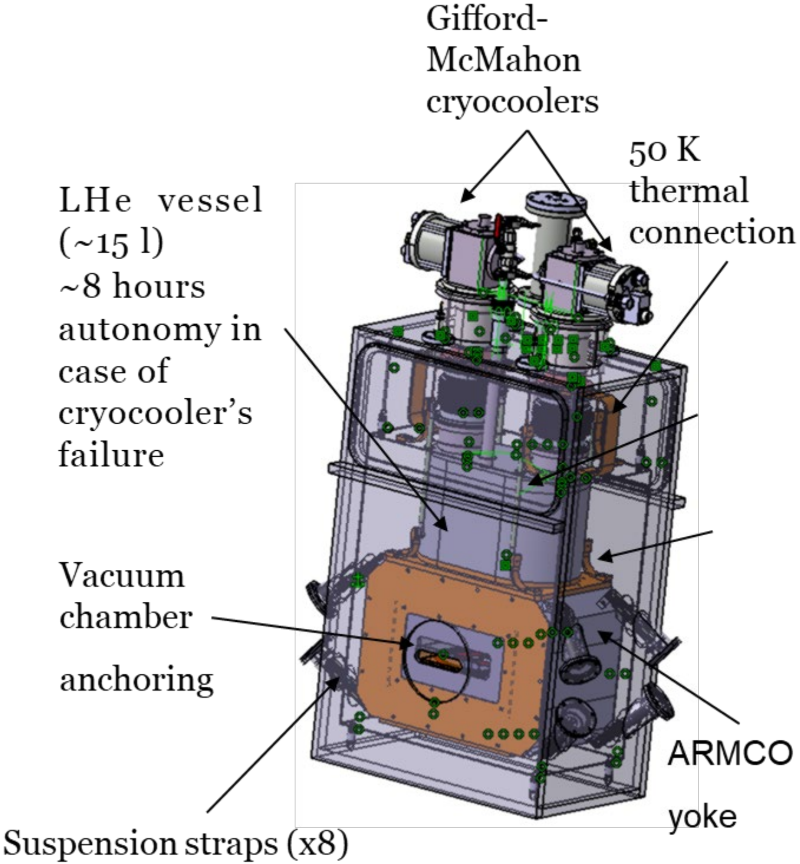



# SC superbends –magnetic & mechanics




Closed shape confirmed



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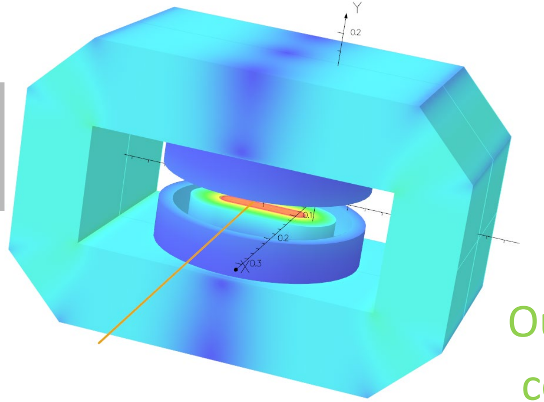
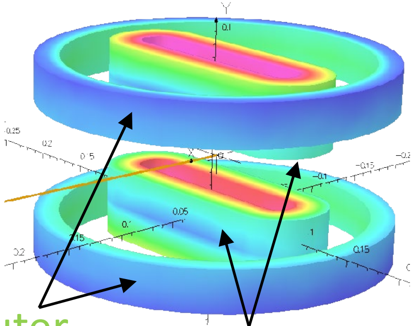
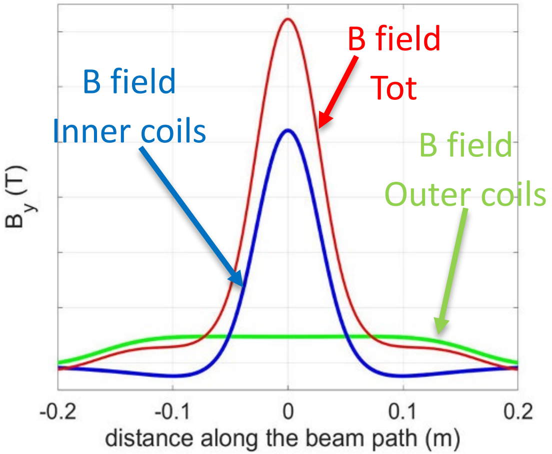
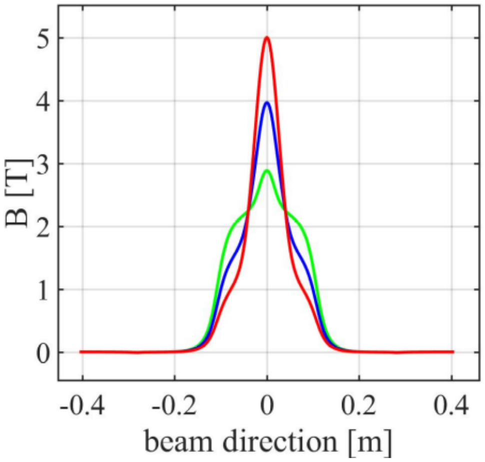
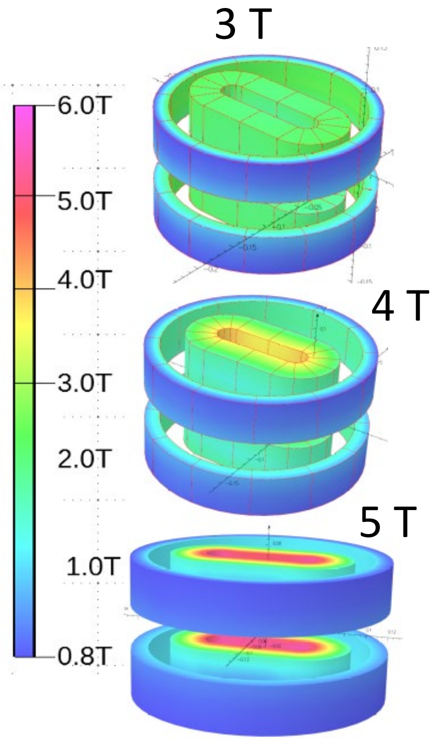
# 5.3 SC superbends –magnetic & mechanics





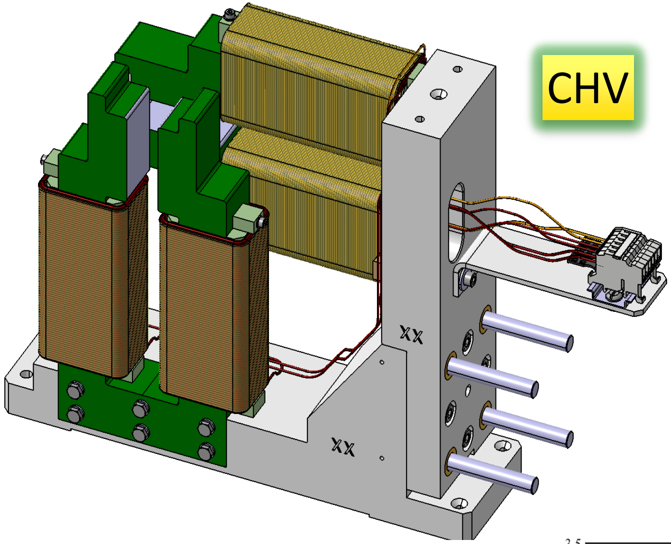



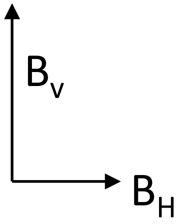



# 2.3 Status of the magnet design

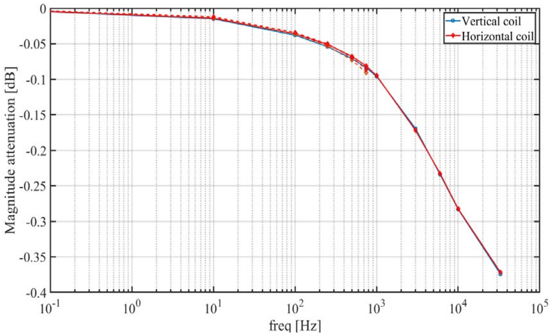
## CHV Corrector Magnet (conventional electromagnet)

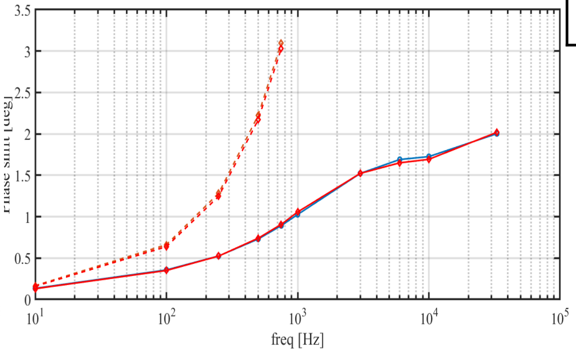



CHV



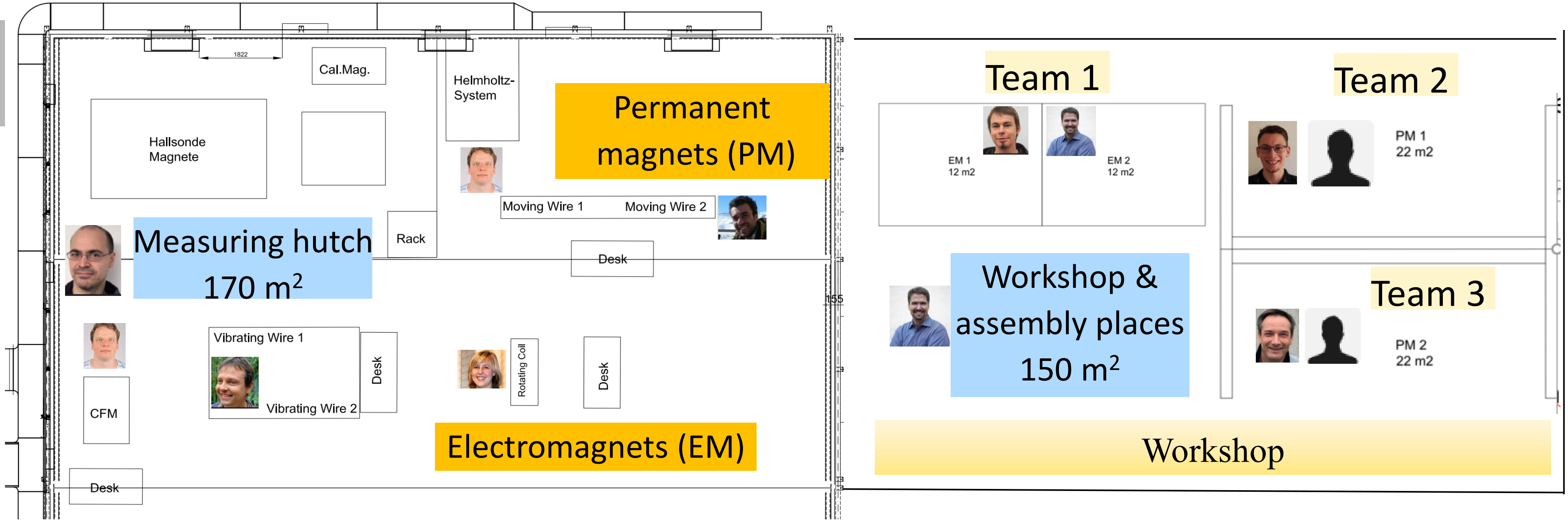

| | |
|---|---|
| Aperture, mm | 25 |
| Total Length, mm | 95 |
| Integral B.dL, mTm | 2 x 3.6 |
| Maximal deflection, mrad | 2 x 0.4 |
| Laminations (mm) | 0.35 |
| Turns number (3 pairs of coils) | 4*161+2*81 |
| Current, A | 5 |
| Total power (W) | 28 |
| Weight (kg) | 22 |
| Quantity | 115 |




| | |
|---|---|
| Magnetic Design | Completed |
| CAD Design | Completed |
| WTO Call for Tender | Completed |

# 6.3 Infrastructure
## PSI magnet Laboratory




| | |
|---|---|
| Building | Completed |
| Measurement benches | Ready and commissioned |
| Workshop & Assembly benches | Completed Mid-2021 |