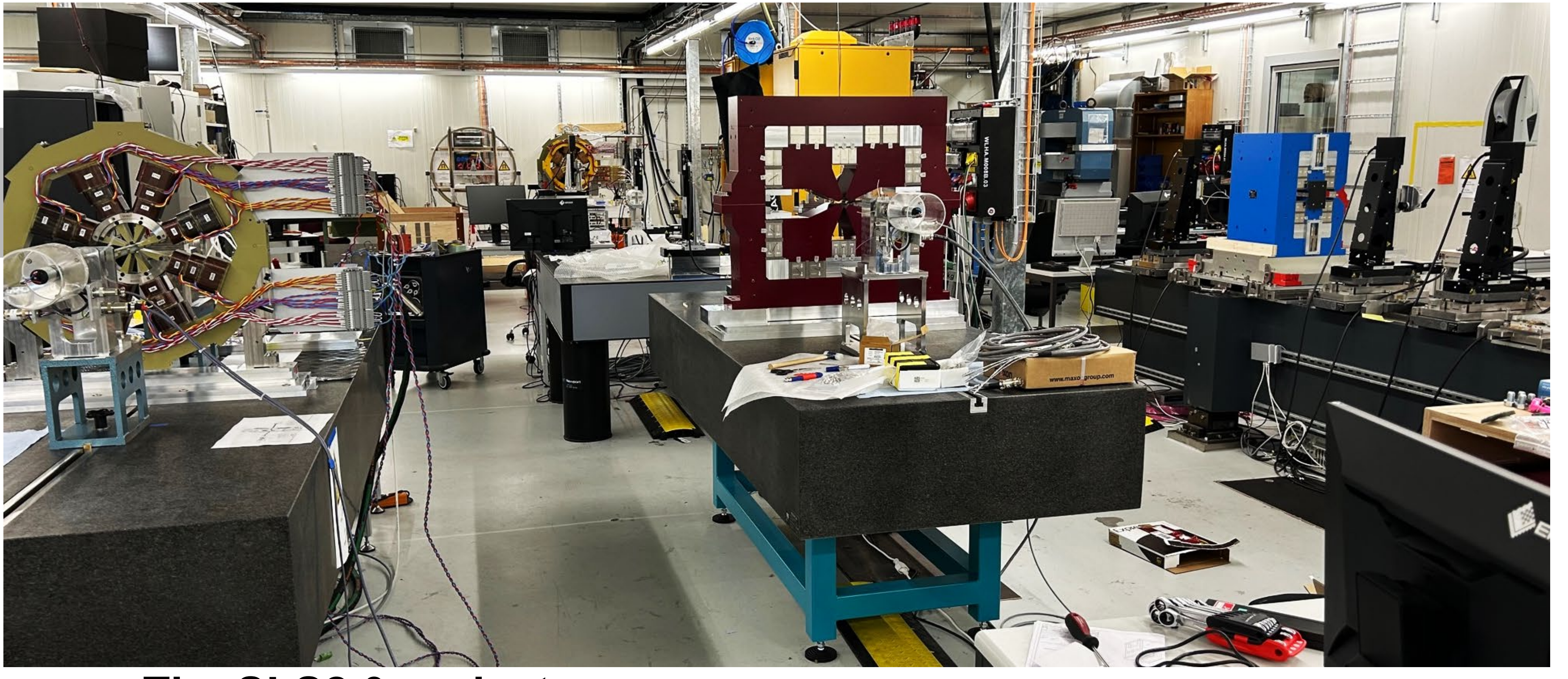
Ciro Calzolaio on behalf of the Magnet Section :: Paul Scherrer Institut

PM Accelerator Magnets for SLS2.0

6th LEAPS Annual Meeting 2023
October 18 – 20, 2023
Synchrotron SOLEIL

Outline

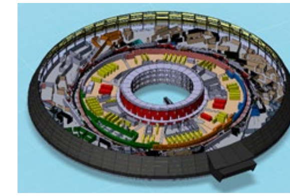


- The SLS2.0 project
- Status: Magnet production & magnetic measurements-phase 1
- Phase 2- superconducting magnets
- Review and outlook

PAUL SCHERRER INSTITUT PSI

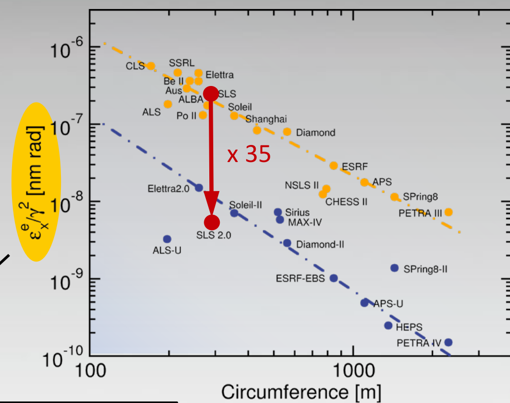
Upgrade of the SLS - SLS2.0

https://www.psi.ch/fr/media/sls-20



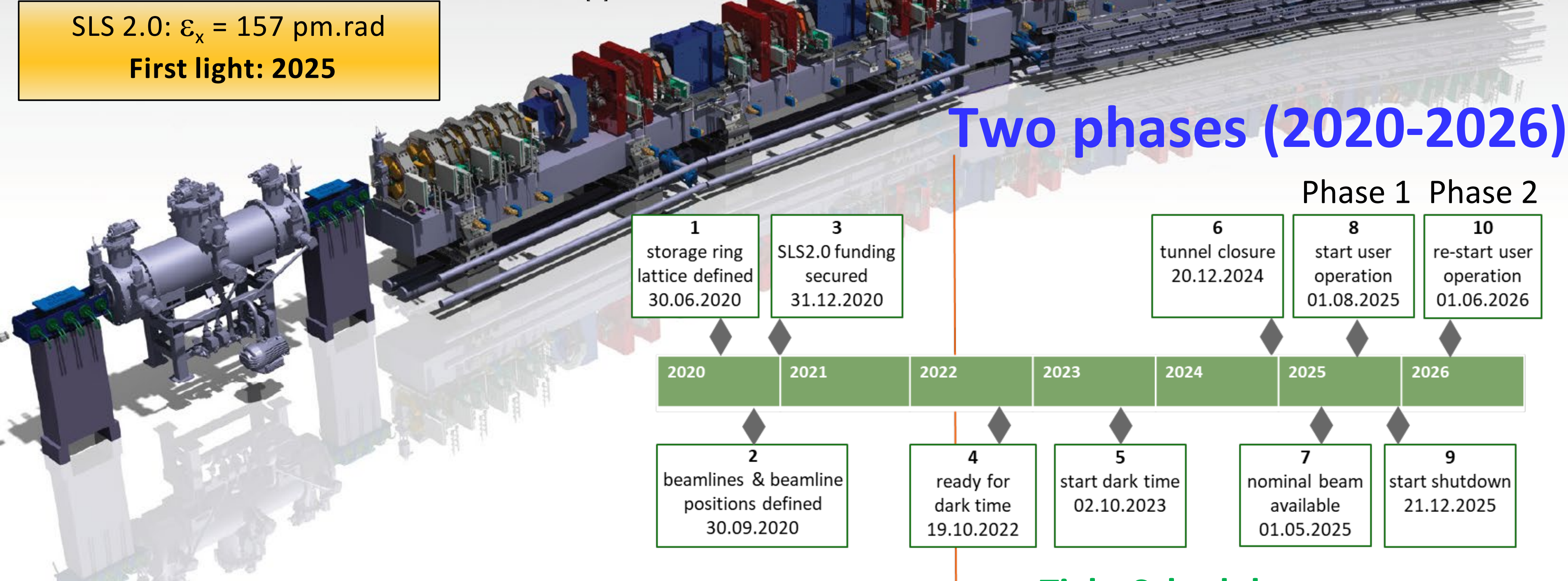
$$\mathcal{B} = \frac{\text{flux}}{\text{emittance}}$$

Brilliance



SLS 2.0: ε_x = 157 pm.rad

First light: 2025



Two phases (2020-2026)

Phase 1 Phase 2

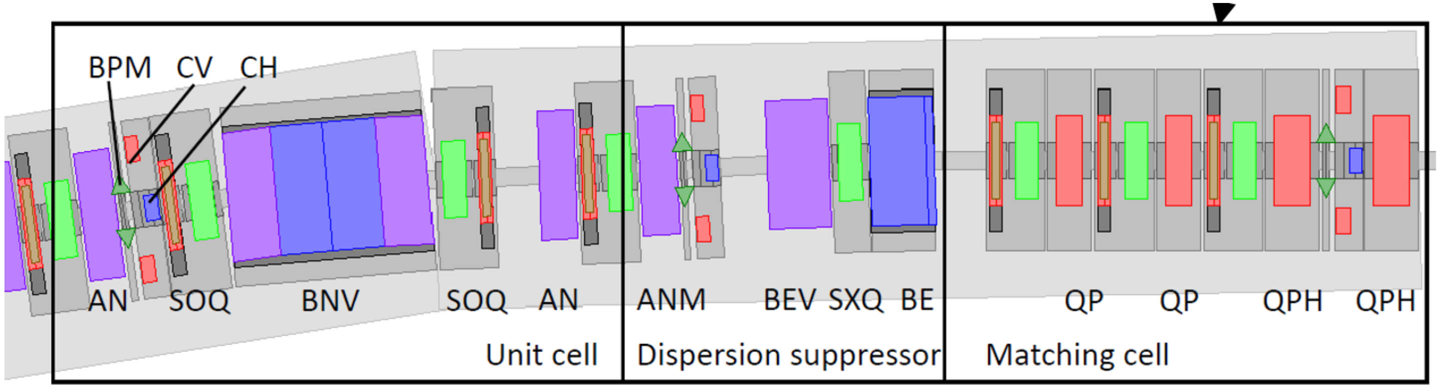
2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

1. storage ring lattice defined 30.06.2020
2. beamlines & beamline positions defined 30.09.2020
3. SLS2.0 funding secured 31.12.2020
4. ready for dark time 19.10.2022
5. start dark time 02.10.2023
6. tunnel closure 20.12.2024
7. nominal beam available 01.05.2025
8. start user operation 01.08.2025
9. start shutdown 21.12.2025
10. re-start user operation 01.06.2026

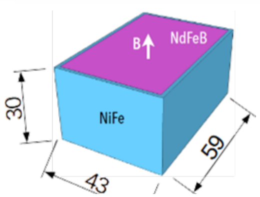
12.4.2022

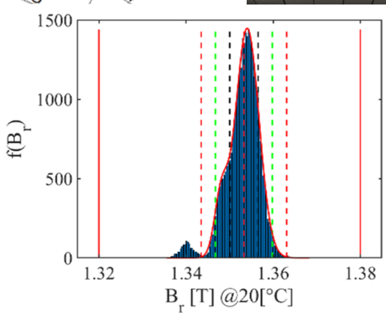
Tight Schedule

Magnet list for the SLS upgrade



34 000 NdFeB blocks
16.6 tons





Permanent Magnets

BN	56	Dipole
BS	4	Dipole
VB	96	Quad
VBX	24	Quad
	Triplet	60
AN	120	Quad
ANM	24	Quad
BE	24	Dipole
VE	24	Quad
	Total : 372	

Electromagnets

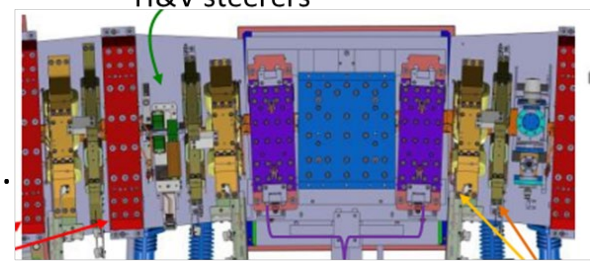
QP	55	Quad
QPH	53	Quad
SXQ	24	6-Poles
SX	264	6-Poles
OC	264	8-poles
	SOQ	264
CHV	112	Steering
	Total: 780	

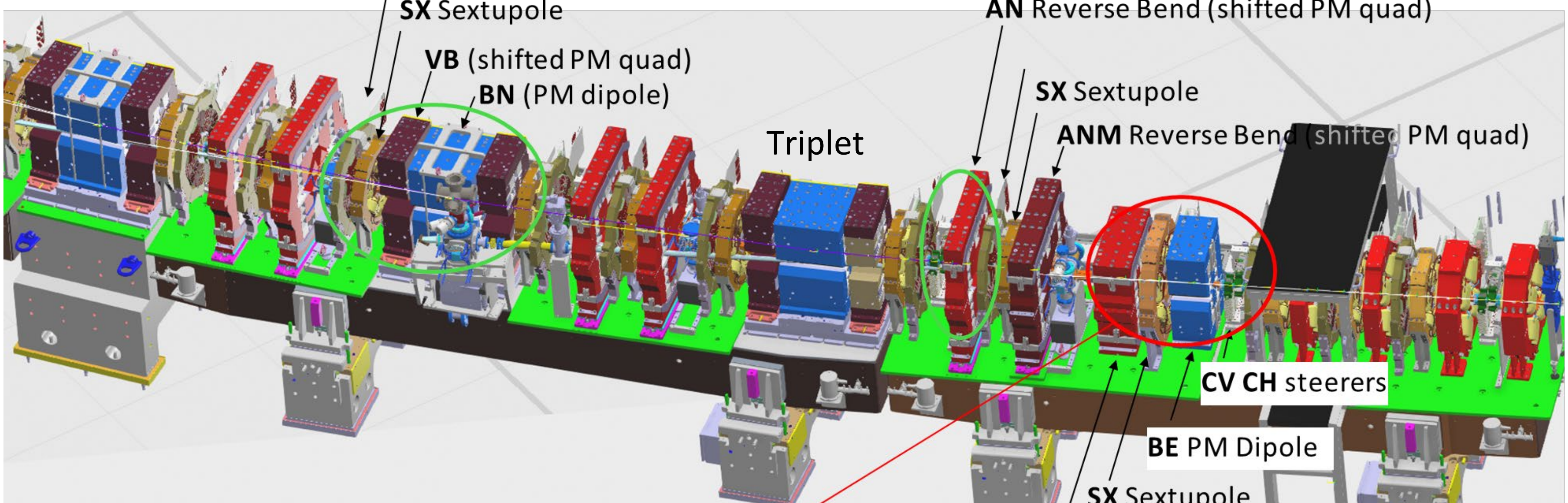
1152 + two 5 T superconducting superbends (phase 2)

SLS2.0 magnets : the challenges

- High field and gradients (>1T).
- **Combined function magnets**
- **Tight tolerances** (field quality 0.01….0.1 %; aligment below 30 micrometers)
- Three types of magnets (electro/**permanent**/superconducting)
- High number of magnets , **16 different types**
- **Dense packing of magnets** (Cross-talk issues).
- Tight schedule for the design, the production and the measurements.

Lack of space !





SLS2.0 magnets : the production path

PAUL SCHERRER INSTITUT PSI

In House | Supplier | In House

Electromagnets

Design + CAD specifications → Magnets manufactured by the supplier → Reception tests & Prototypes & & 100 % magnetic qualifications at PSI

Permanent Magnets (NdFeB)

Specifications for → NdFeB blocks produced and measured by the supplier → few % cross check (Helmholtz)

NdFeB blocks produced and measured by the supplier → Prototypes & 100 % magnet assembly at PSI

Design + CAD+ specifications → Iron yoke, thermal shunts manufactured by suppliers → Prototypes & 100 % magnet assembly at PSI

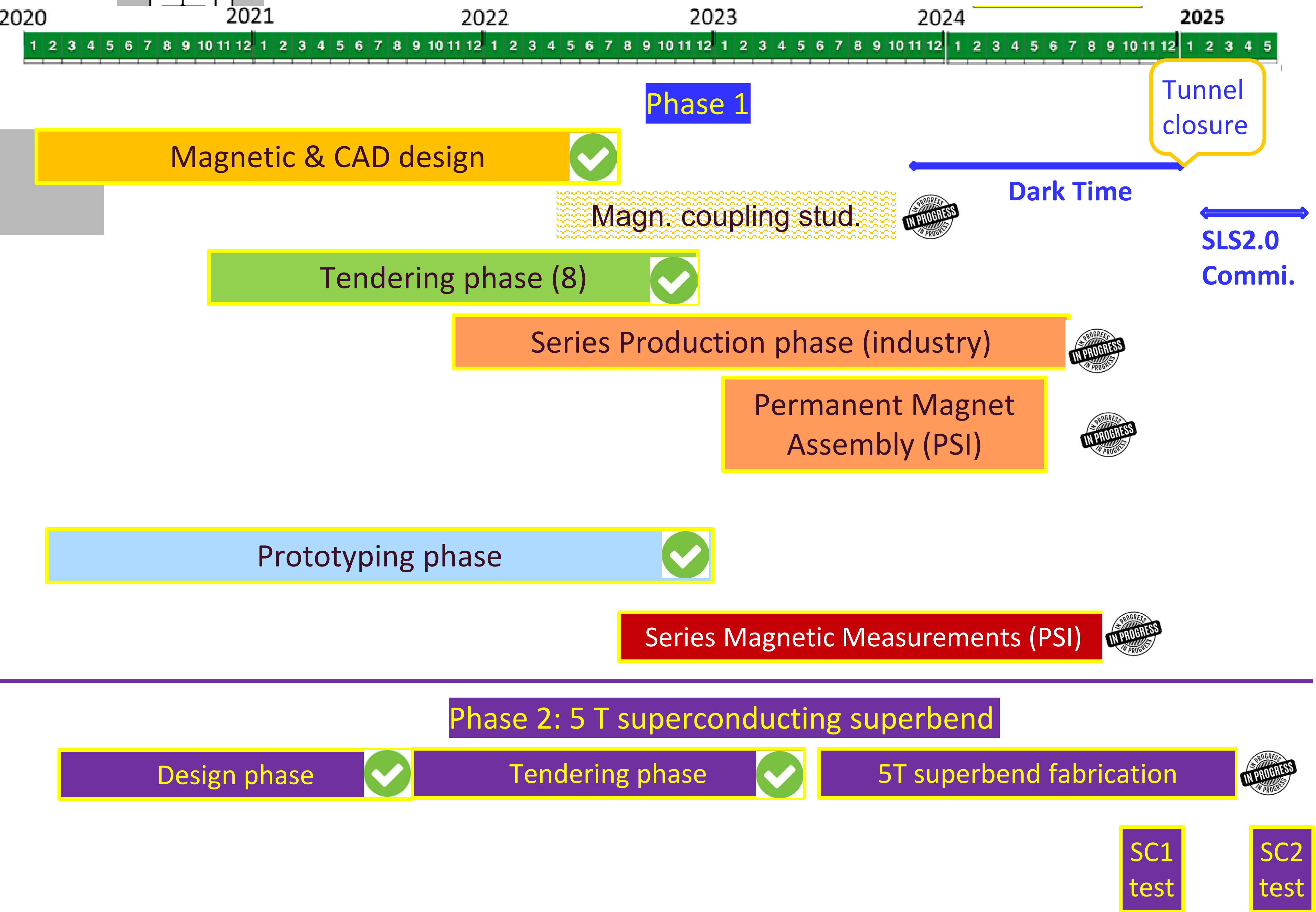
Prototypes & 100 % magnet assembly at PSI → 100 % Magnetic qualifications at PSI

5 T superbends

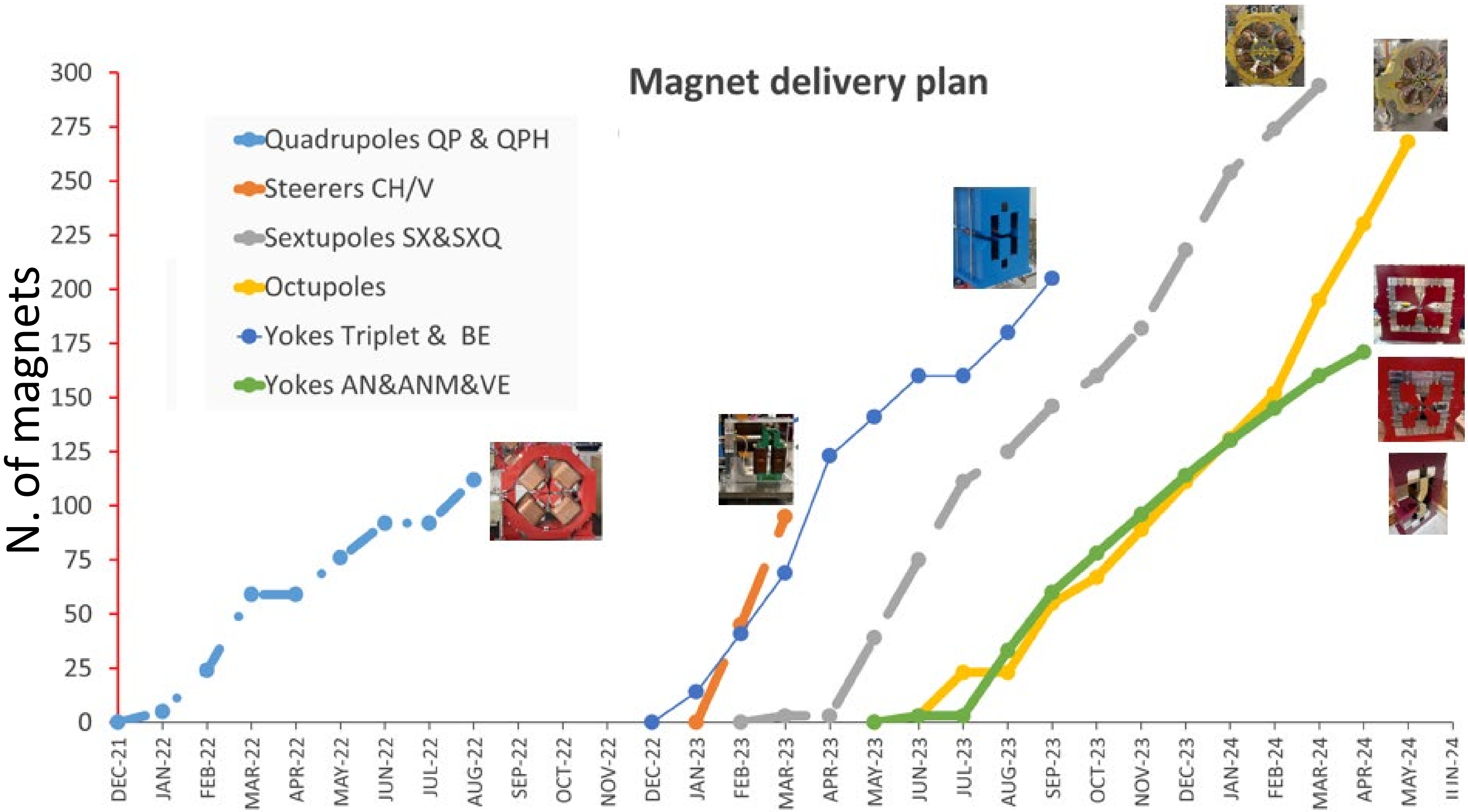
Design + specifications → Magnets manufactured by the supplier → Power tests at 4.2 K and magnetic tests at PSI

100 % of Permanent Magnets assembly in house
100 % of magnets magnetically measured at PSI

Magnet development Overview (Phase 1+2)



Mass production delivery plan



Forecast based on planned delivery batches from the companies

Delivery split in small batches of 20-30 magnets

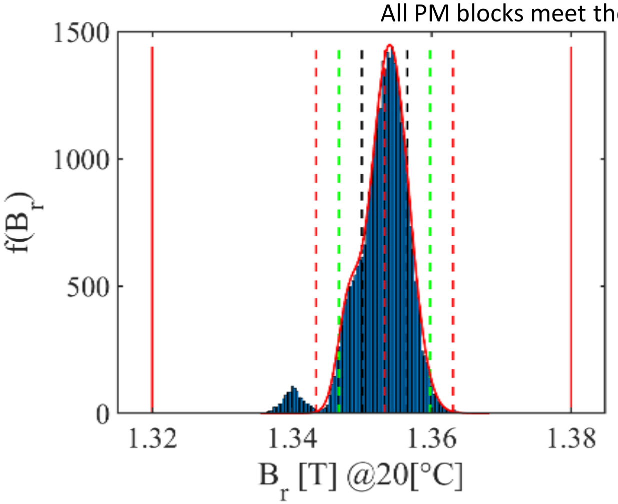
End of the delivery: June 2024

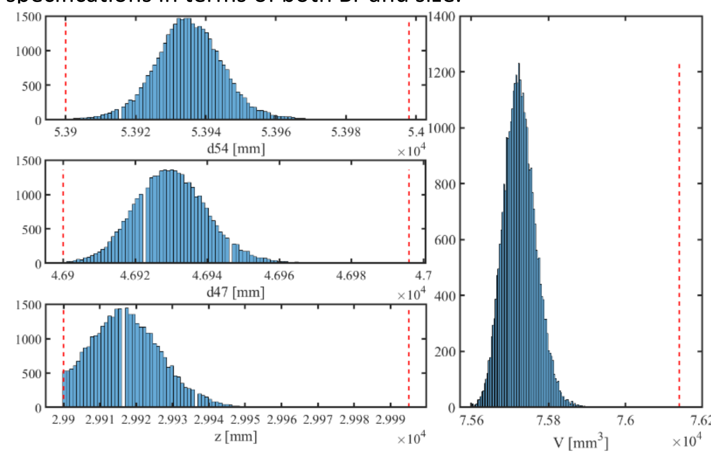
Delivery : permanent magnet blocks

All the permanent magnet blocks were delivered at PSI (34000)

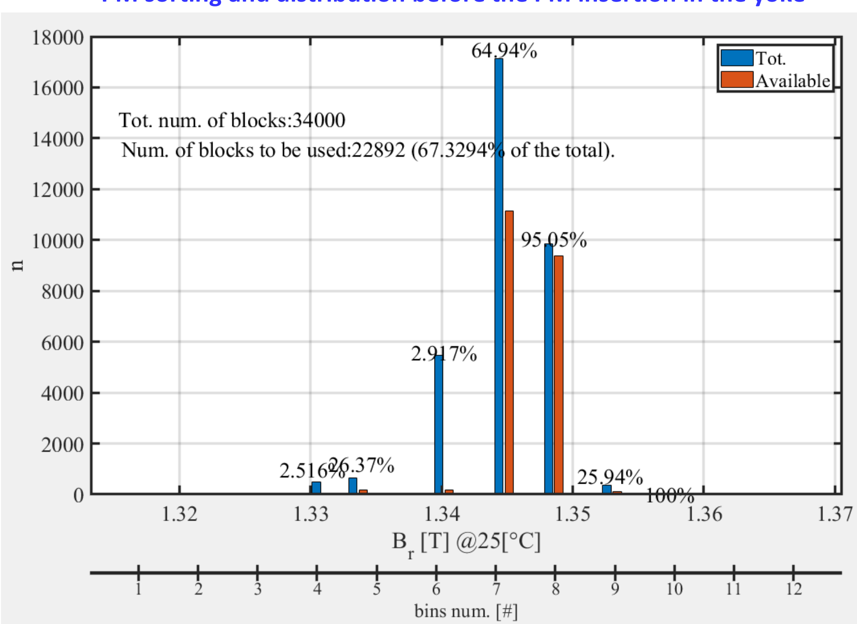
Magnetization and Distribution within the specs- difference on 0.32 % in measurements

All PM blocks meet the specifications in terms of both Br and size.

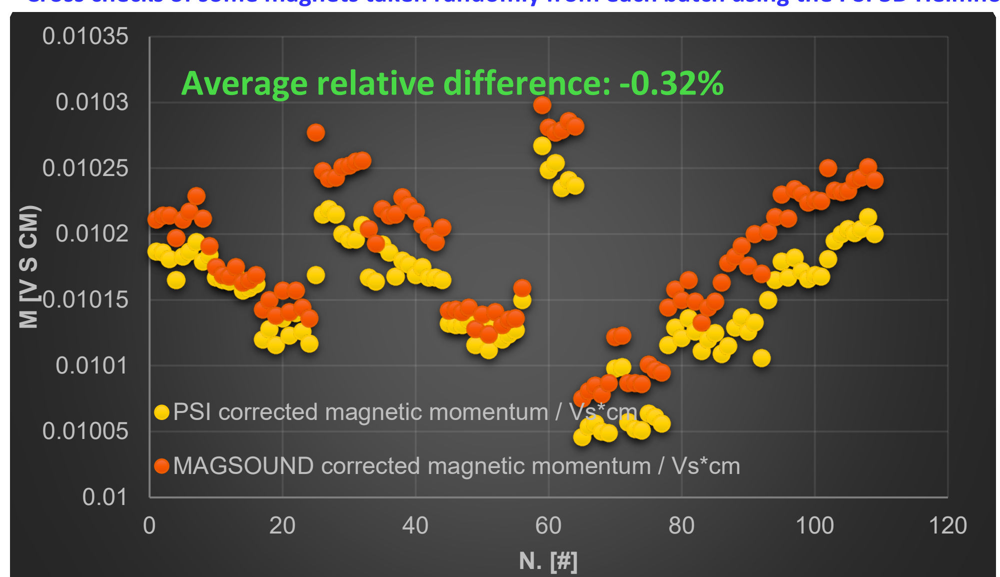




PM sorting and distribution before the PM insertion in the yoke



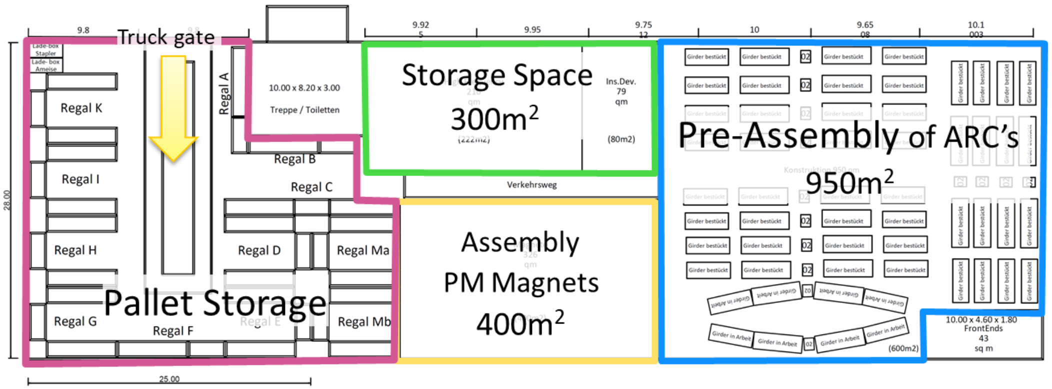
Cross checks of some magnets taken randomly from each batch using the PSI 3D Helmholtz



Assembly facility for permanent magnets in PSI

PAUL SCHERRER INSTITUT PSI

Challenge: Assembly of the 372 Permanent Magnets by PSI staff !



Status October 2023

BN	54/56	Dipole
BS	4/4	Dipole
BE	12/24	Dipole
VB (X)	101/120	Quad
AN(M)	6/144	Quad
VE	3/24	Quad

SLS2.0 permanent magnets

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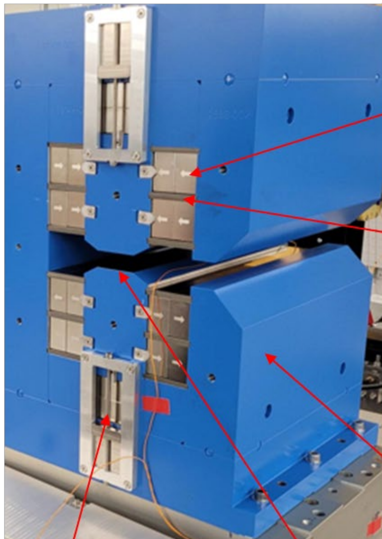
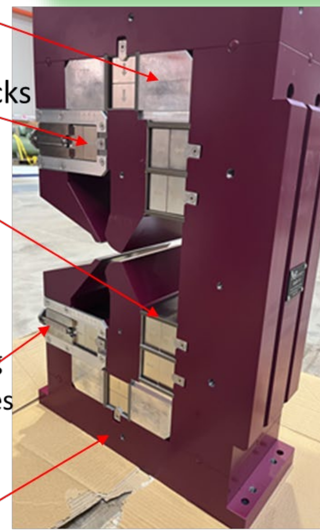
Dipole BN (56)
1.35 T; L=405 mm; G=22 mm

VB (120)
0.84 T
40.6 T/m





Al block

PM blocks

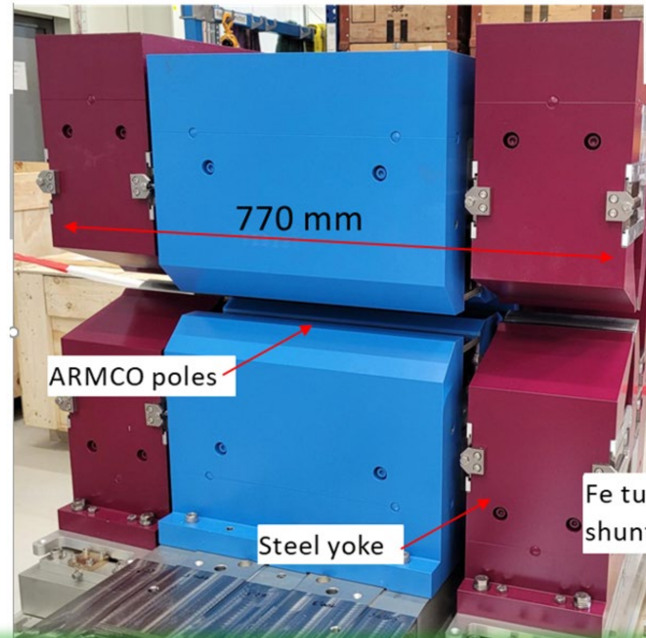
6 mm NiFe strips

Fe tunning Shunt plates

Moderator plates

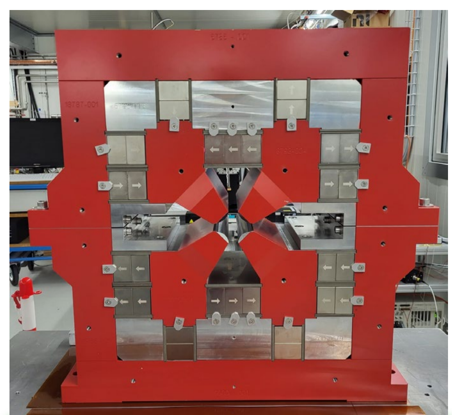
Low C steel 1010

ARMCO poles

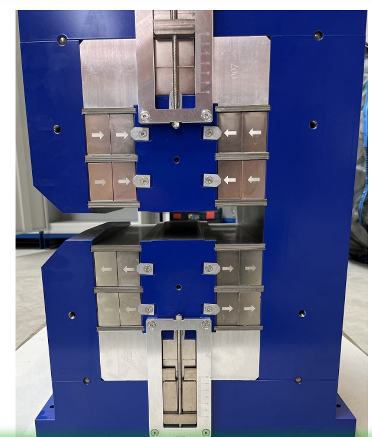


Triplet VB/BN/VB (60) , 0.861 Tm

Quadrupole AN(M) (148)
72.5-78 T/m ; Ø=22 mm



Quadrupole VE (24)
45.8 T/m; Ø=22 mm



2.1 T Superbend (4)
Gap =14 mm; L=405 mm

SLS2.0 electromagnets

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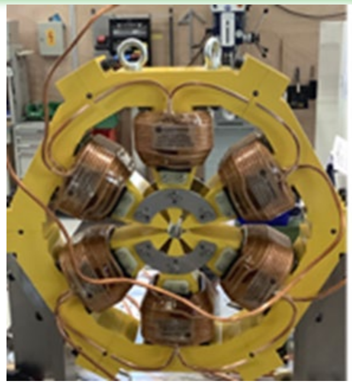
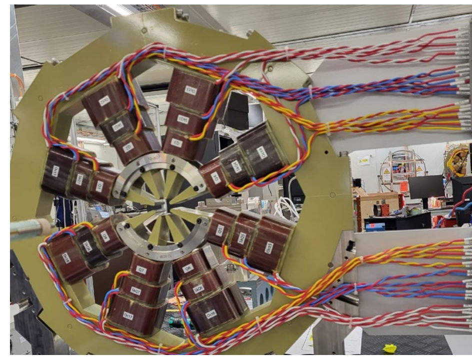
Quadrupoles (110)
93T/m-98 T/m
Ø=21 mm

Sextupoles (288-6 types)
5093T/m^2-5840 T/m^2
Ø=22 mm

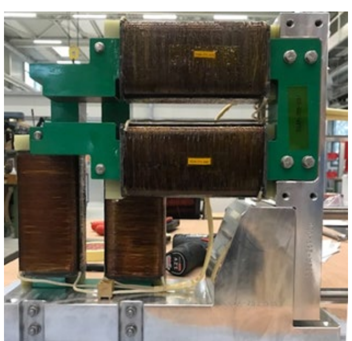
Combined functions
Octupoles (264)





24 coils
ARMCO yokes and poles
Air cooling
3 power supplies (5 A)

Steerers CH/V
44 mT; 31.4 mT



SOQ (264)

B''/2, T/m^2	5850
Aperture (Ø) sextupole, mm	22
Yoke Length, mm	84
Yoke mass, kg	93
Current, A	50
B'''/6, T/m^3	63000
B' , T/m	2.8
A' , T/m	5.6
Aperture (Ø) octupole, mm	29
Yoke Length, mm	44
Yoke mass, kg	40
Current, A	5

Magnet qualification

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Challenge : 100 % of magnets will be measured at PSI

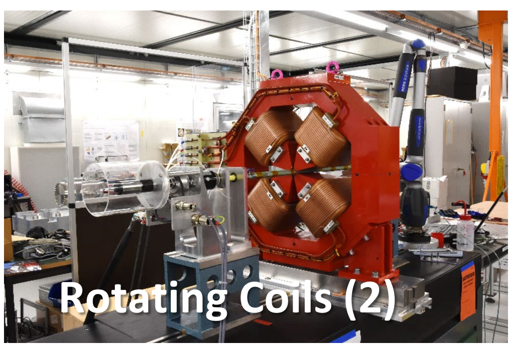
7 measuring test benches operational-80 magnets/month

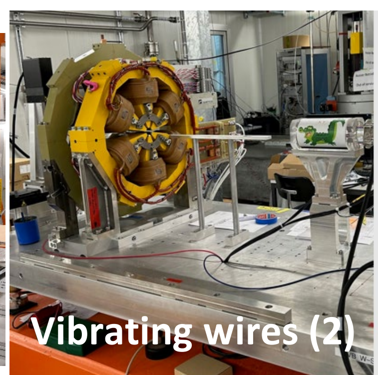
Systems (X benches)	Electro magnets	Permanent Magnets	3-5T superbend
Rotating coils (2)	Field Strength Multipoles	Field Strength Multipoles	
Moving Wires (2)		Field Strength, Magnetic axis	
Vibrating Wires (2)	Magnetic axis		
3D Field Mapper		Field Strength Maps (Few %)	Field Strength Maps

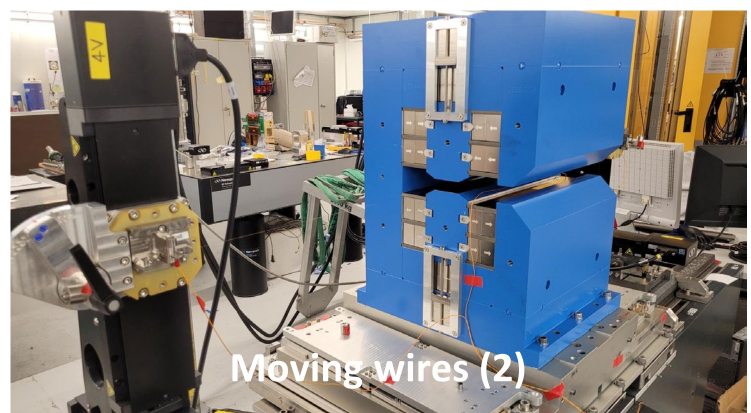
Accuracy : 1/1000

Reproducibliity : 1/10000

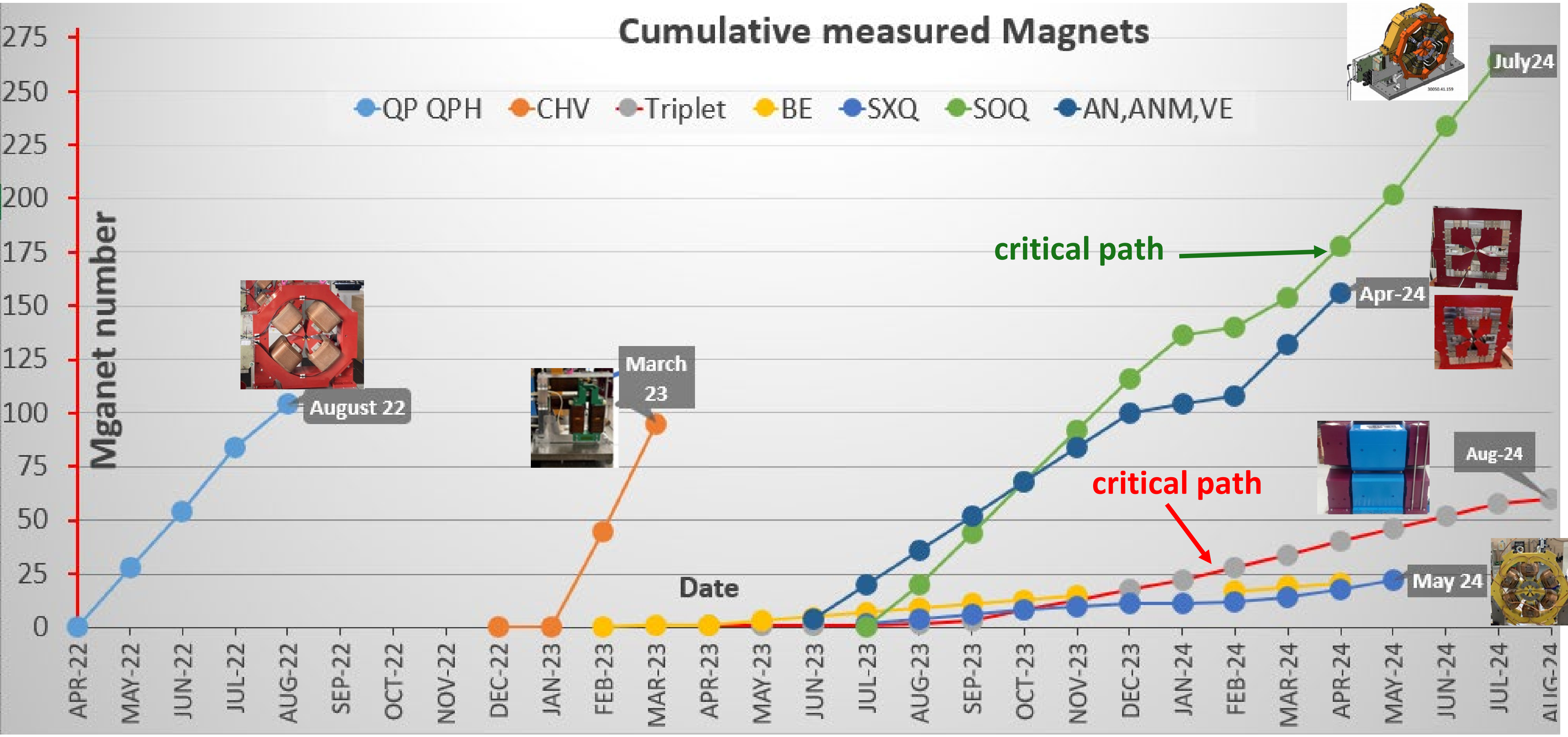
Axis : < 30 micrometers







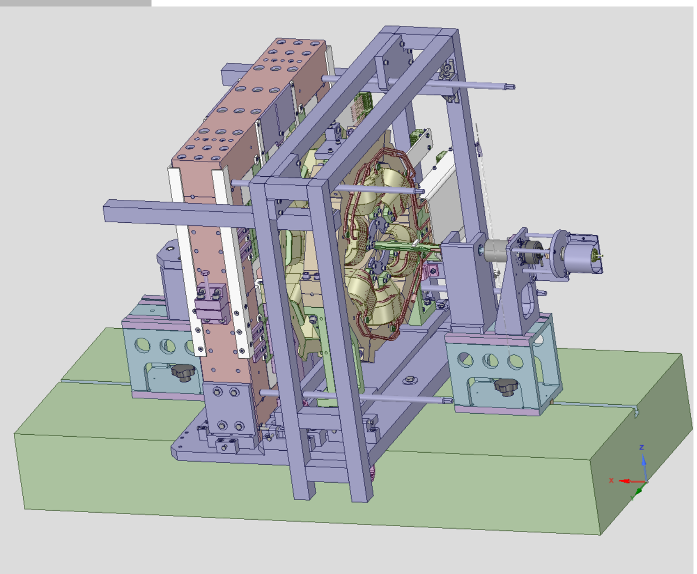
Magnetic qualification of the series magnets

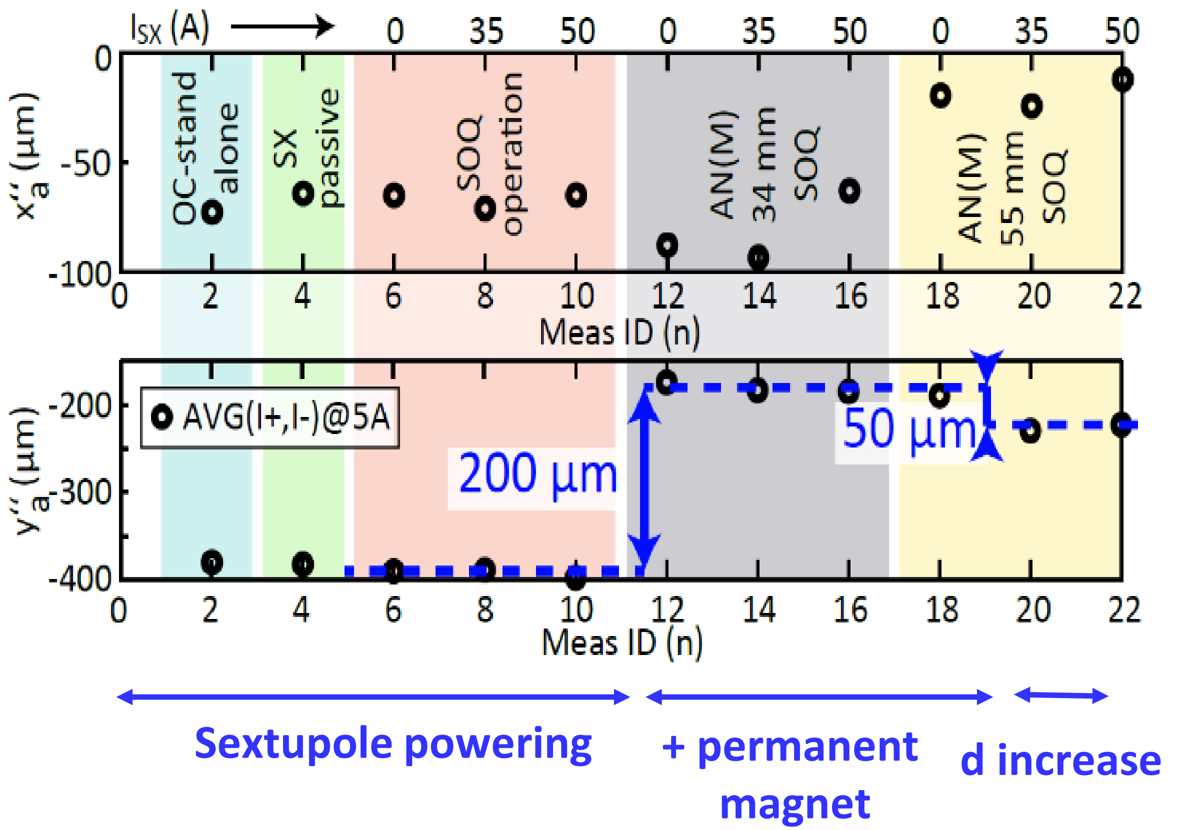


Very aggressive schedule
All the 7 benches operational
Parallelization of measurements

Challenge : Magnetic Coupling effect (Octupole axis)

→ OC magnetic axis position dependence with the sextupole powering and the neighboring permanent magnet (in that case AN(M) quadrupole)
→ test of an increase distance d=OC-ANM yoke on the axis shift





- Magnetic axis (x'',y'') measured using the Normal or Skew Quad function
- Confirm the ''final'' quadrupole design of the quadrupole (pole, yoke)

- Sextupole powering : almost no effect
- Permanent magnet influence: shift ~200 µm
- Reduced shift to ~150 µm, increasing the distance d by 20 mm

Challenge : Alignment and tuning of the triplets with the moving wires

Simulation including cross-talk (once for all)

a. Extract the nominal field integral of the stand alone dipole for magnet shimming

b. Extract the horizontal & vertical field gradient components G_{hor}, G_{ver} and the nominal integrated field gradient G for stand alone quads.

Single magnet measurement and optimization

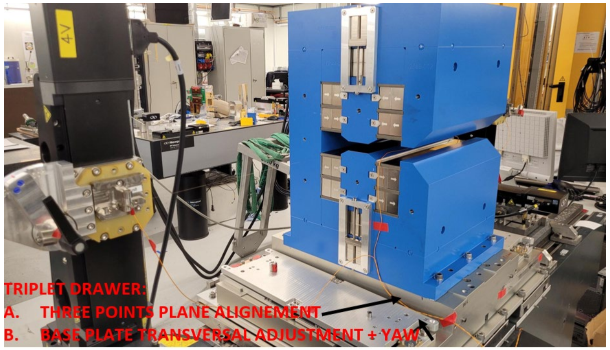
a. Dipole field integral (wire1) and shimming to **$\int B_1 dl = -0.5699$ (Tm)**

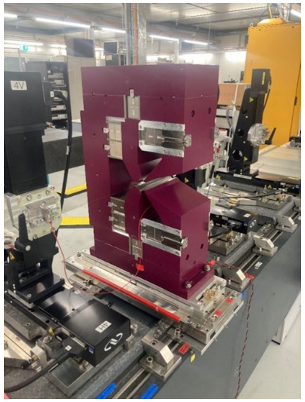
b. Nominal integrated field gradient and shimming to **$\int G dl = 7.0184$ (T)** and multipoles **(Rotating coil)**

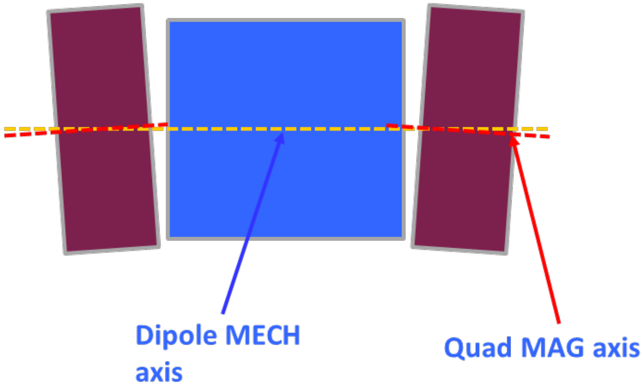
c. Magnetic axis position of each Quad (wire 1)

Triplet assembly and alignment

1. **The dipole mechanical axis (MECH) define the nominal axes of triplet magnets**
2. Quads are positioned on the drawer; a **preliminary alignment** is carried out on the two Quads vs. the nominal axes (wire 2)
3. **Dipole is installed** on the triplet; **final tuning** of the drawer and Quads (wire 2)
4. The resulting integral of the assembled triplet is recorded as control parameter







Phase 2: 5 T superconducting superbend

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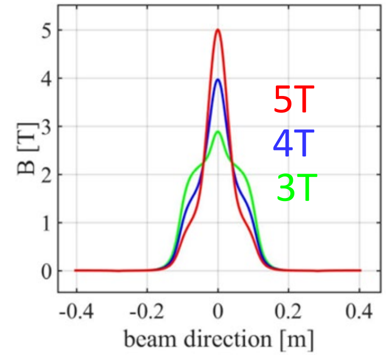
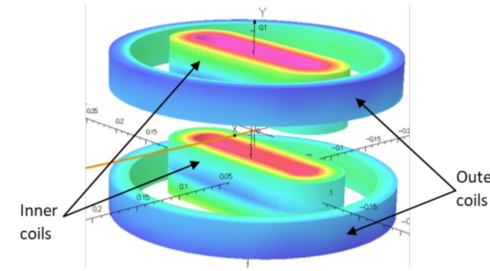
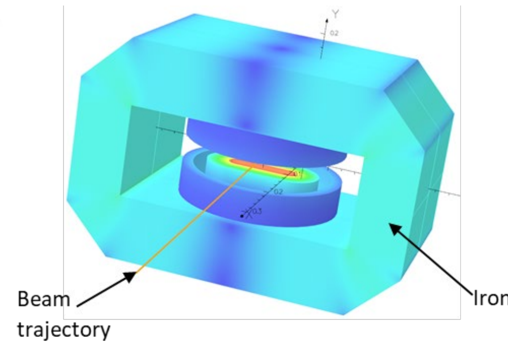
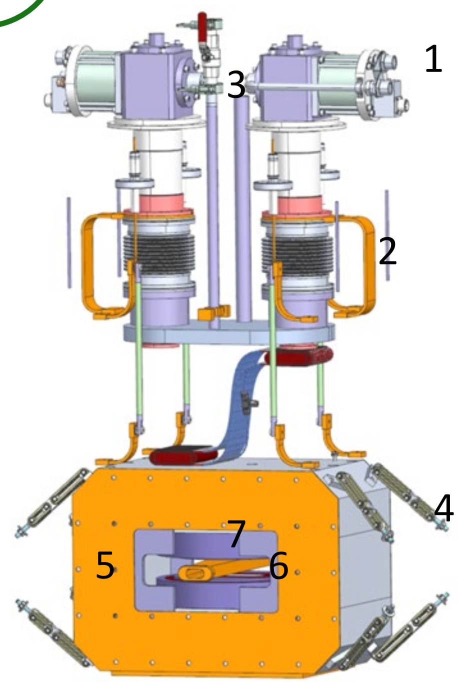
- Conduction cooled concept (2 cryocoolers)
- 2 pairs NbTi coils (racetrack, solenoidal)
- Two 200 A power supplies to adjust current (field)
- T_{op}~4.5 K
- 2 HTS -110 current leads (500 A@64K)
- ARMCO yoke (close geometry)
- Beam pipe included in the magnet assembly



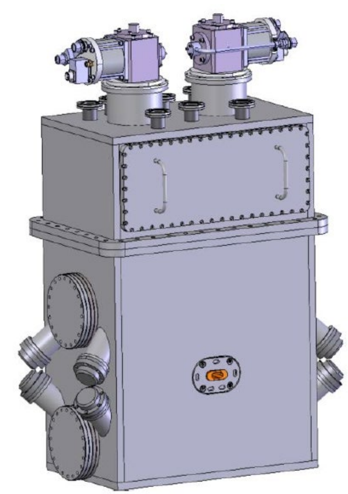




	Main magnet components
1	2 cryocolers RDK-415D
2	Thermal connections
3	Current leads (Cu+HTS)
4	Suspension straps
5	Armco Yoke
6	Vacuum chamber
7	Pair of NbTi coils inside the Al precompression ring



Cold mass



Cryogenic power tests and magnetic measurements @ PSI in a dedicated test stand

Summary and perspectives

Challenges

- More than 1000 magnets of three types are designed, produced and measured of the upgrade of the Swiss Light Source at the Paul Scherrer Institut.
- The use of series permanent magnets, the density of the magnets and the combined function make the magnetic design and the measurement complicated .
- The tight schedule imposes the construction of an infrastructure at PSI for the assembly, magnetic measurements and the cryogenic tests.

Status- October 2023

- The design and tendering phases are over; contracts signed.
- 45 % of the magnets are delivered at PSI.
- Aggressive magnetic measurement plan – **80** individual magnets per month starting fall 2023.
- All the seven test benches are operational.
- The magnetic qualification is on-going.

Next important milestones

- Series measurements of the SOQ magnetic axis.
- All magnets qualified till **September 2024**
- Phase 2: Test of the first superconducting superbend Fall 2024.

PAUL SCHERRER INSTITUT

PSI

Thank you

for your attention

Many thanks to:

S. Sanfilippo, M. Aiba, J.Bächle, P. Berger, M. Boege, P. Bucher, R. Deckardt, K. Dreyer, M. Duda, R. Erne, R. Felder, A. Gabard, F. Guarascio, T. Höwler, G. Montenero, B. Ronner, R. Riccioli, S. Roger, S. Sidorov, M. Sieber, Y.Studer, V. Vrankovic, R. Widmer, C. Zoller;

Workshop announcement-2024
HTS modeling 2024 –Paul Scherrer Institut

HTS Mod 2024
10-13 June 2024
https://indico.psi.ch/event/14456/

HTS 2024 - 9th International Workshop on Numerical Modelling of High Temperature Superconductors

10–13 juin 2024
Parkhotel Bad Zurzach, Switzerland
Fuseau horaire Europe/Zurich

Entrer le texte à rechercher

- Accueil
- Rough Programme
- Important dates
- Venue
- Accommodation
- Past workshops
- Committees

Contact
silvia.bacher@psi.ch

9th International Workshop on Numerical Modelling of High Temperature Superconductors

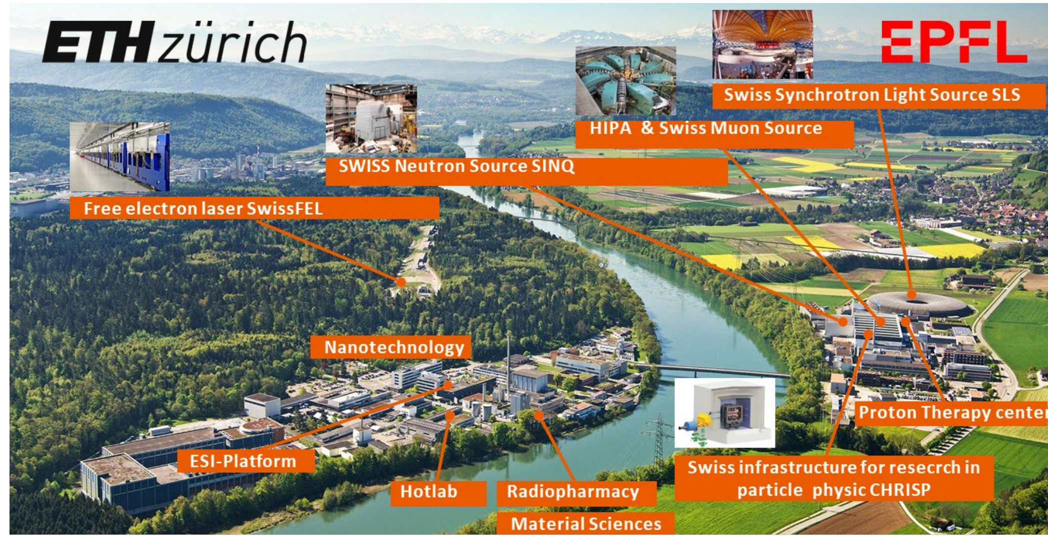
W E L C O M E

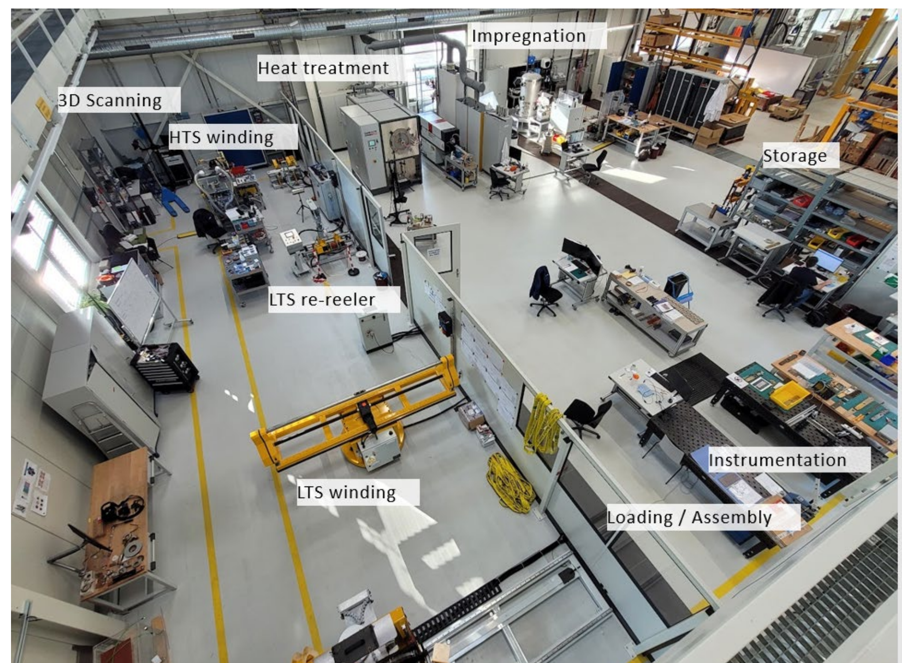
The research and development of modelling tools and approaches is a fundamental subject in applied superconductivity.

High Temperature Superconducting (HTS) materials raise complex challenges in the design and prediction of devices behaviour due to their thermal and electromagnetic dependencies and non-linearities, hysteresis, anisotropy, high wire aspect ratio and interaction with other functional materials.

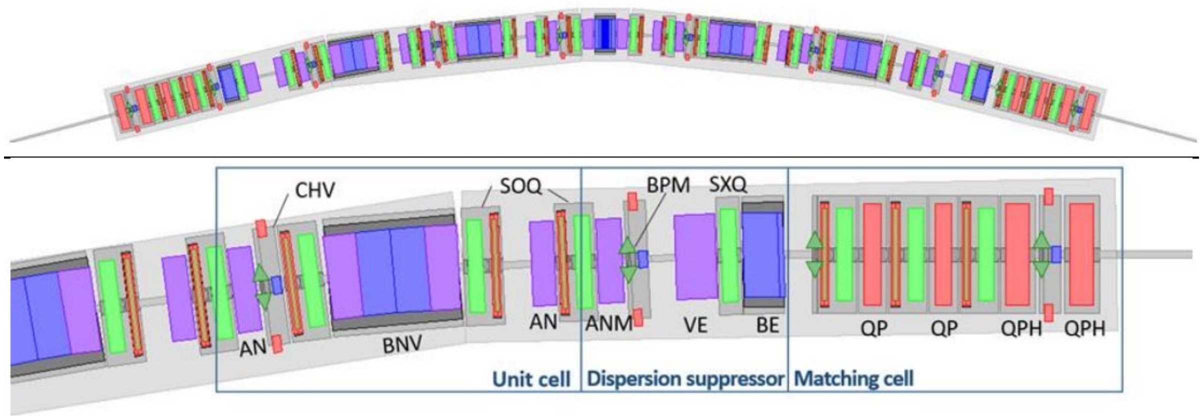
For this 9th edition, the topics of the workshop are organized into three main categories:

Modelling Fundamentals





Reminder: Magnet nomenclature



AN = ANti bend (Reverse Bend), Combined function (Shifted quadrupole)

ANM/VE/BE= Modified AN/VB/BN for dispersion suppressor (PM magnets)

BNV = Triplet , **BN** dipole + 2x**VB** combined function magnets

BS : 2T PM Magnet , replacing BN in 4 positions

CHV = Hor. corrector **CH** and Ver. corrector **CV** assembly

SOQ = Sextupole (**SX**) and Octupole (**OC**) assembly

SXQ = Stand alone sextupole

QP/QPH = Matching section quadrupoles

Courtesy M. Aiba

SLS2.0 vs SLS: Permanent magnets for energy savings

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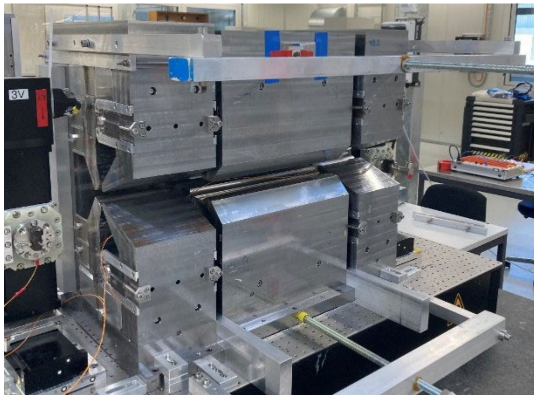
SLS2.0 Triplet = VB-BN-VB



Total number of triplets: 60

BN: By=1.35 T; VB: GdL=-40.64 T/m

Total Weight=1250 kg

60 Triplets ~Total P=<u>0 W</u>

SLS BX Dipole

Total number of BXs:12
By=1.39 T ; I=407 A; R= 58 mΩ;
Weight=2950 kg
Cooling= 16 l/min

BX: P= 58 mΩ x $(407\ A)^2$= <u>~9.6 kW</u>

12 BX ~ Total P: <u>116 kW</u>

SLS dipoles : 116 kW x 6800 operating hours ; 789 MWh per year

Savings for 15 Years : 11.83 GWh

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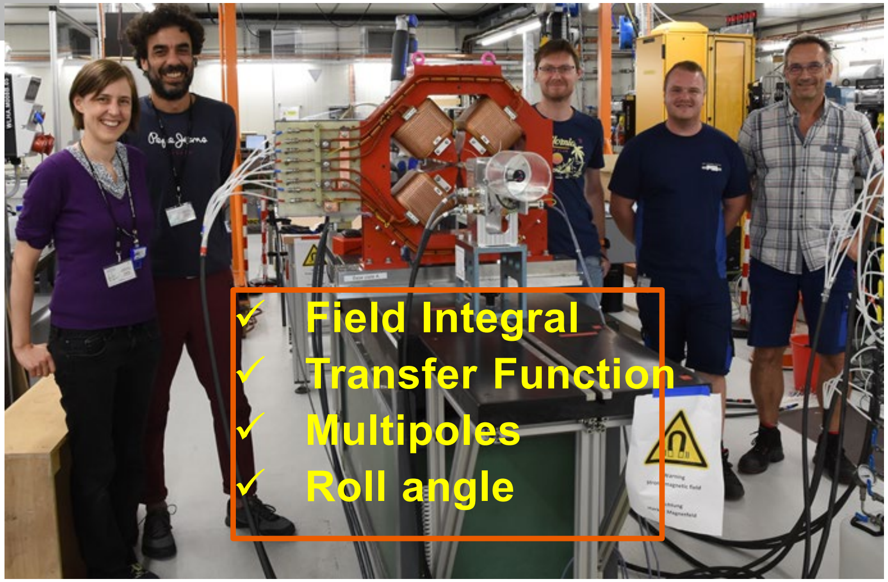
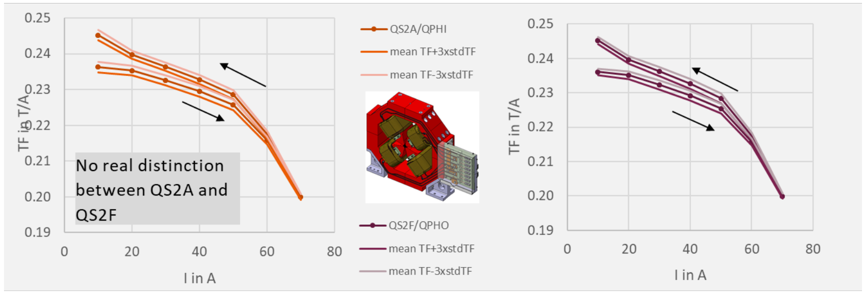
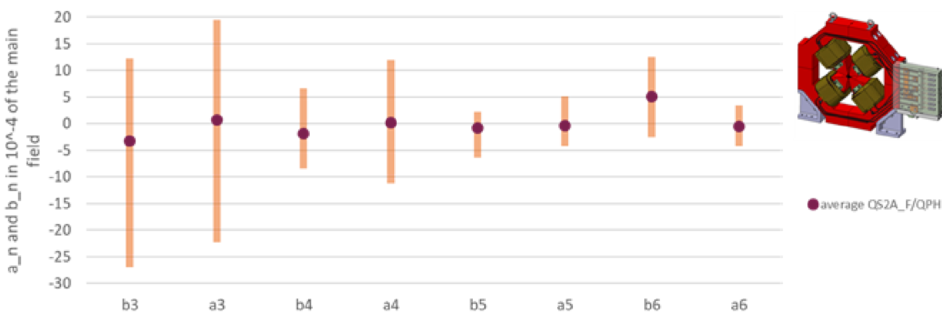
Magnetic measurements
Electroquadrupoles QP, QPH

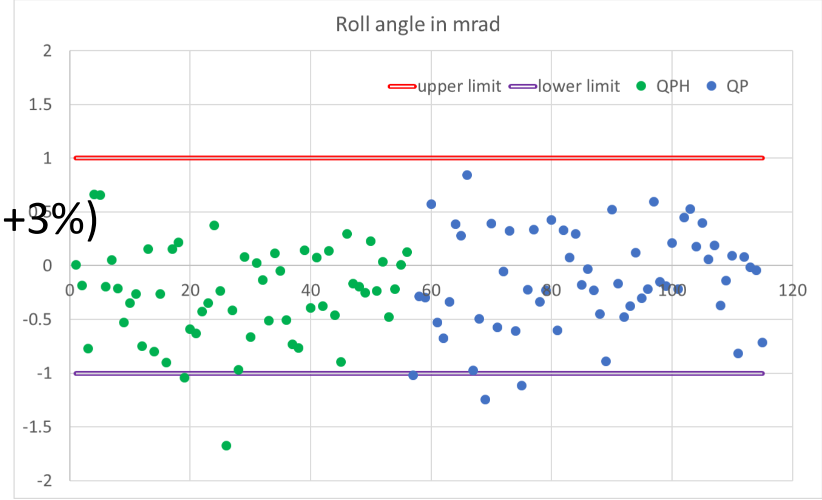
08.22

115 electro-quadrupoles delivered & measured with rotating coils









- Field integrals with comfortable margin
  - 3-4 %above the nominal values (designed for +3%)
  - spread 0.15 % - 0.2% (at 70 A)
- Multipoles below the 20 units
- Roll angles below 1 mrad- few outliners

Magnetic measurements Steerers (CHV)

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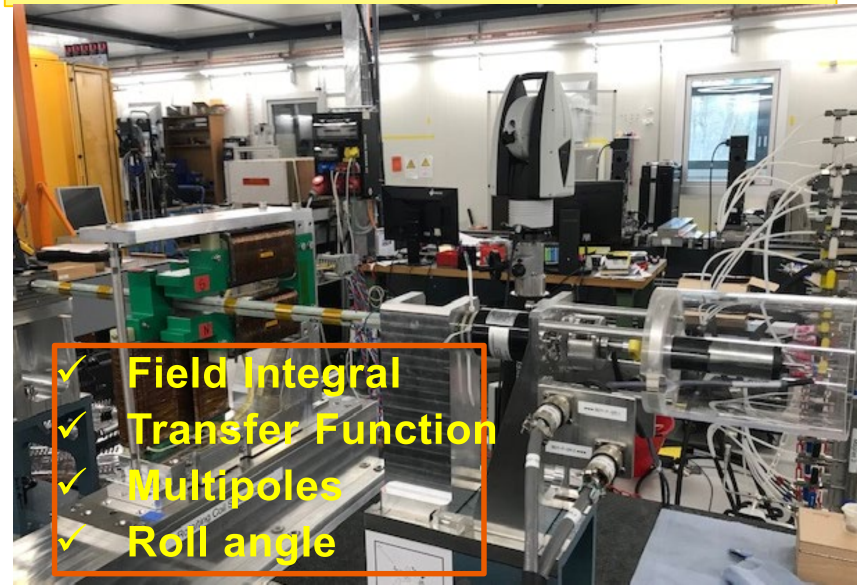
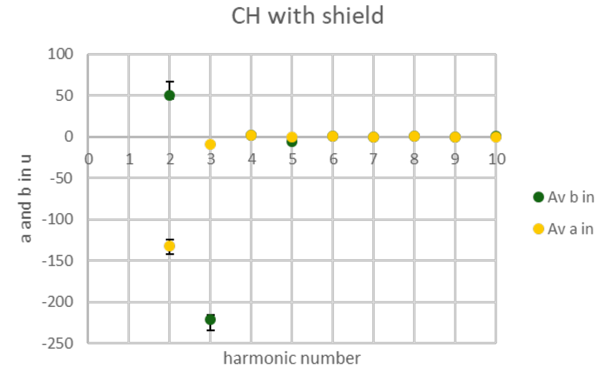
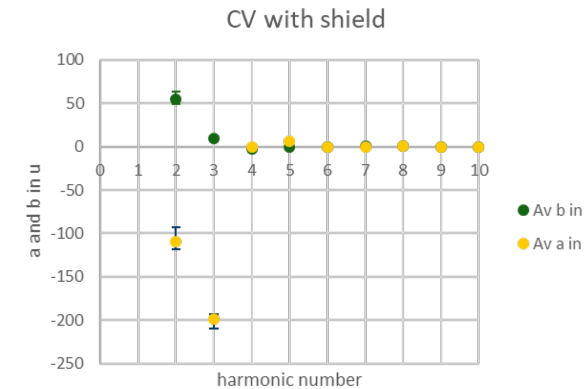
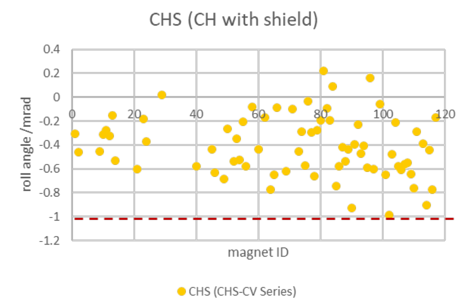
04.23

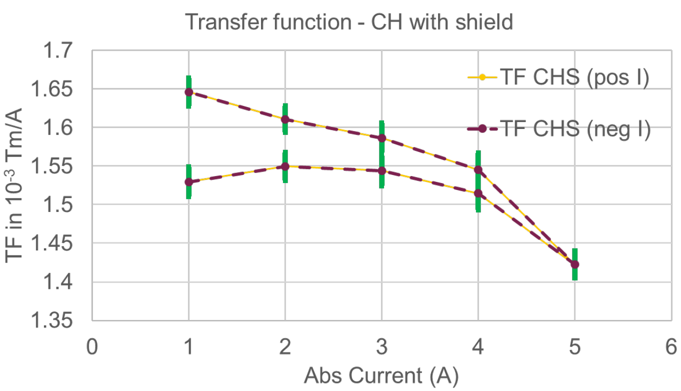
117 Steerer magnets measured

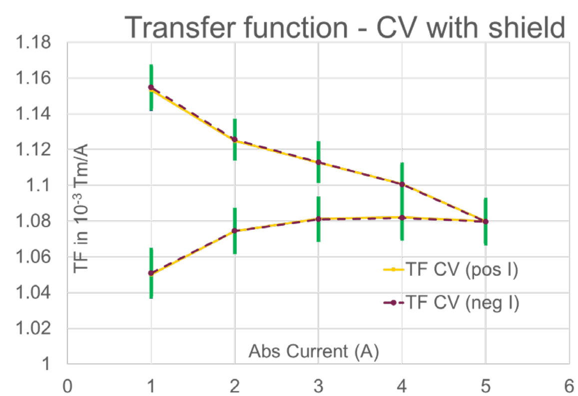


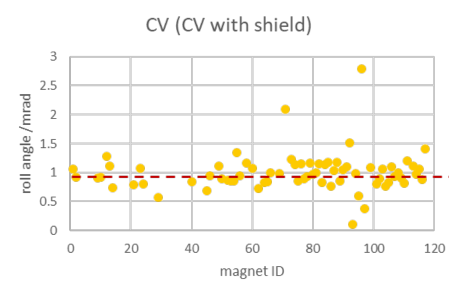












- Vertical steering & Horizontal steering strength : OK;
- Multipoles : OK , sextupole between 200 and 250 units
- Roll angles between +/-1 mrad- few outliners

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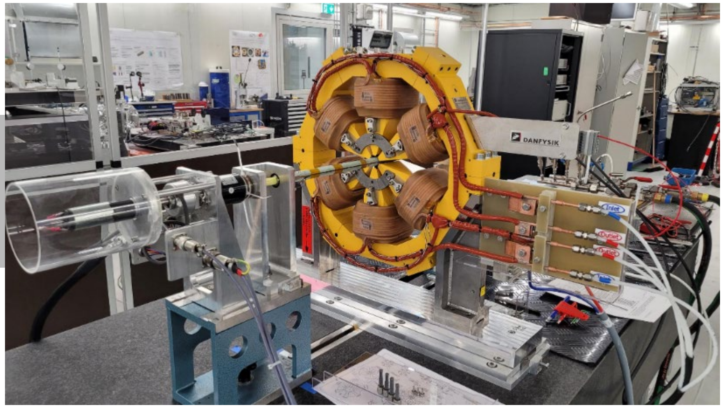
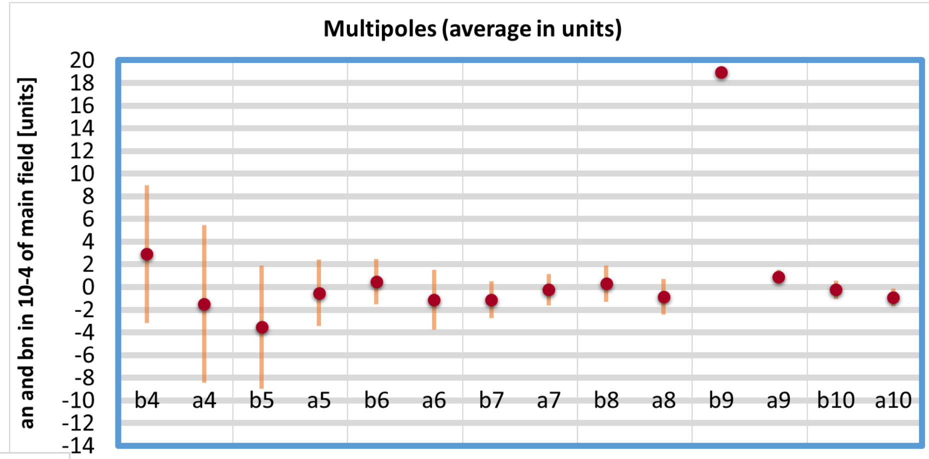
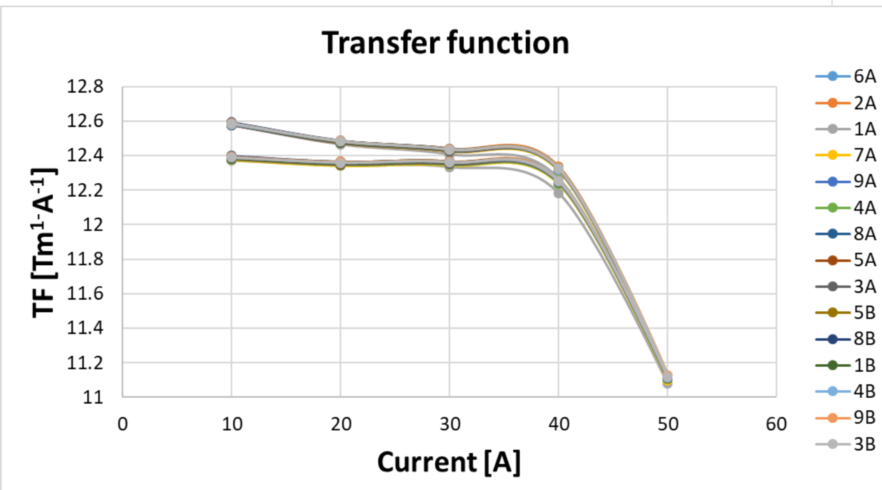
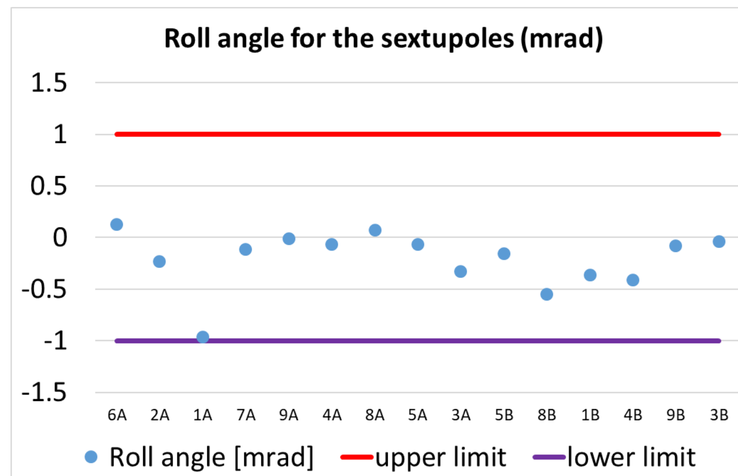
Magnetic measurements
Sextupoles- first results of field quality



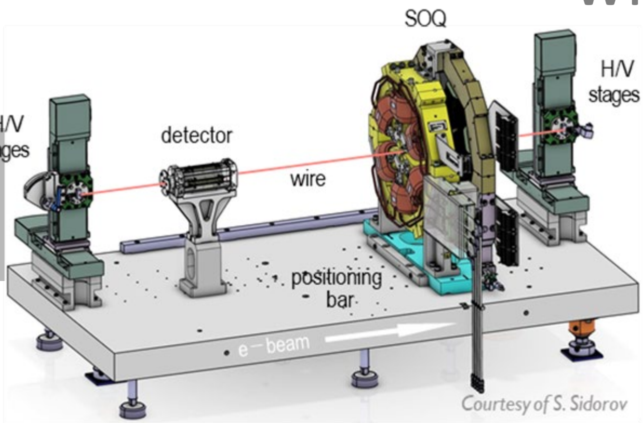






- 16 sextupoles of this type measured up to now
- Field integral (at 50 A): +2 % reserve in the field strength ; spread of 0.1 %
- b_9 <20 units

SOQ : magnetic axis alignment with the vibrating wire



MEASUREMENT PROCEDURE (MAG-MAG):

➞ SOQ on the measurement bench positioning bar

➞ determine the sextupole magnetic axis

➞ determine the octupole magnetic axis (through auxiliary quad excitation)

➞ adjust the sextupole vertically (V) if magnetic axes misalignment >30 µm

repeat until <30 µm is achieved

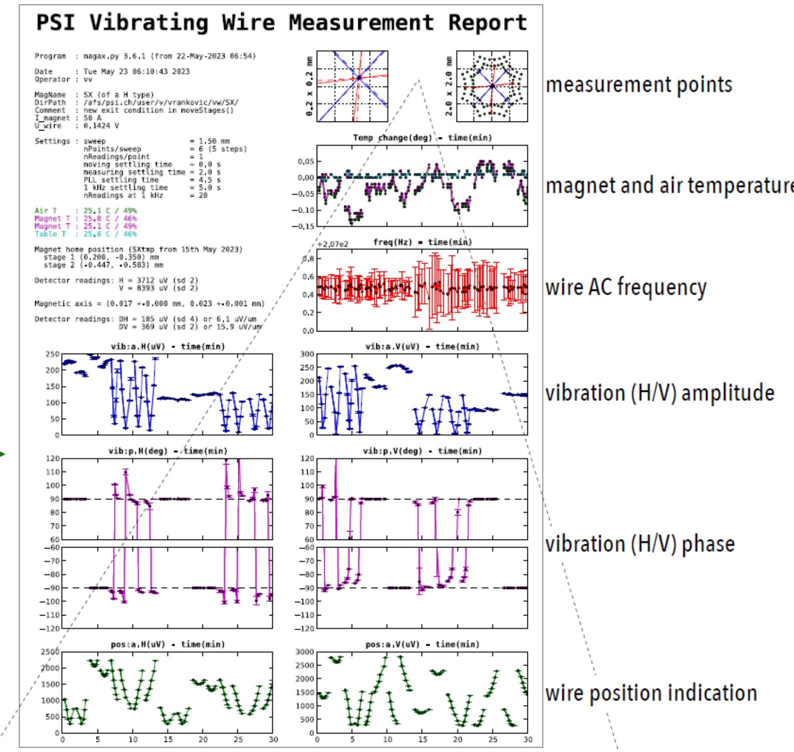
➞ adjust the octupole horizontal (H) position to align to the sextupole magnetic axis

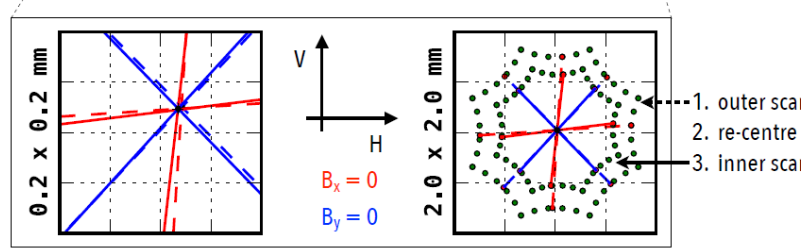
➞ fasten the sextupole-octupole fixing bracket

➞ verify the sextupole and octupole magnetic axes (with octupole quad and skew-quad functions)

➞ laser tracker fiducialisation

Courtesy ***V.Vrankovic***





| Δ[axis(Bx=0) – axis(By=0)] | ≤ 2 µm

First results Δ MECH-MAG successful on two SX: within 30 um (as expected)

“Cryogen-free” test stand- 5T superbends

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Vacuum vessel with pumps

Electronic rack

- Vacuum control/monitoring
- T control/monitoring
- U signals recording
- Quench detection system

DAQ

- 2 nV channels
- 64 high precision channels
- 64 fast sampling channels
- 10+ Cernox temp sensors
- 5+ Hall probes matrix

2kA ±10V power converter

Cryostat insert

Radiation shield

- d = 630 mm,
- h = 590… 1000 mm

Powering cables (500A single cable)

Water chiller