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Ciro Calzolaio :: Carolin Zoller :: Stéphane Sanfilippo :: Paul Scherrer Institut

Superconducting Longitudinal Gradient Bends for the Upgrade of the Swiss Light Source and Magnet Infrastructure Development at PSI

Seminary at CEA Saclay, 15/05/2019

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Paul Scherrer Institute (PSI)

- Largest research institute for natural and engineering sciences within Switzerland
- Three main fields of research: matter and materials, energy and the environment and human health
- Develops, builds and operates complex large research facilities
- Employs 2100 people
- ~2500 visiting scientists using facilities for experiments
- Part of the ETH Domain that also includes ETH Zurich and EPFL Lausanne
- Financed by the federal Government

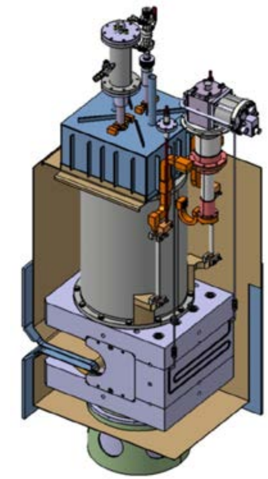
Paul Scherrer Institute (PSI)

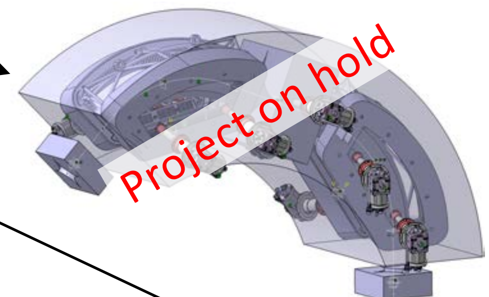
← Basel   Germany ↑   Aarau/Bern ↓   Zurich →

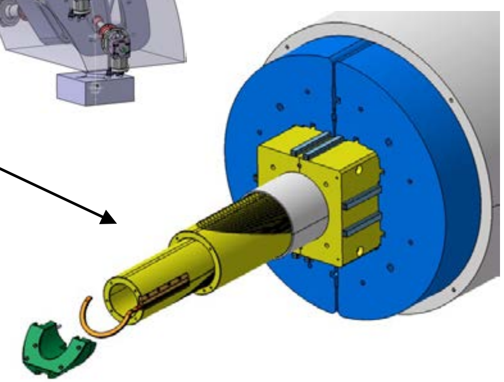
Superconducting magnet activities at PSI

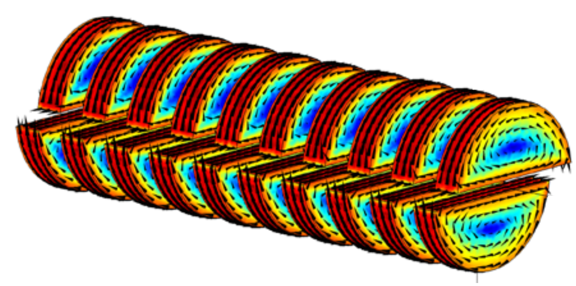
- Development of superconducting magnets:
  - Compact superbend magnets for light sources
  - Magnets for medical applications
  - High field magnets for FCC
  - 10 mm period HTS undulator

- Activities:
  - Magnetic and mechanical design
  - Fabrication (new infrastructure under development)
  - Test at operating conditions









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Outline

- Magnet infrastructure at PSI
- Motivation SLS-2
- Superconducting superbend magnets
- Conclusion and outlook

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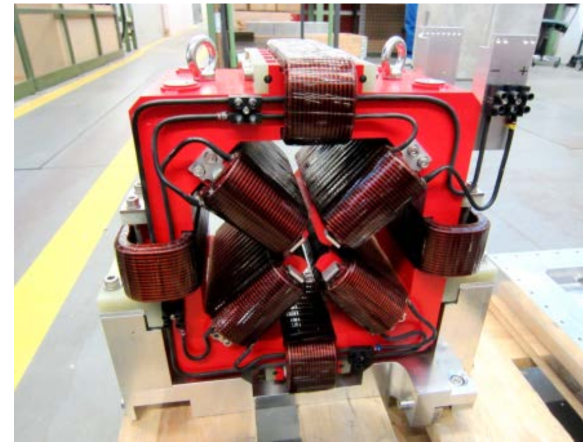
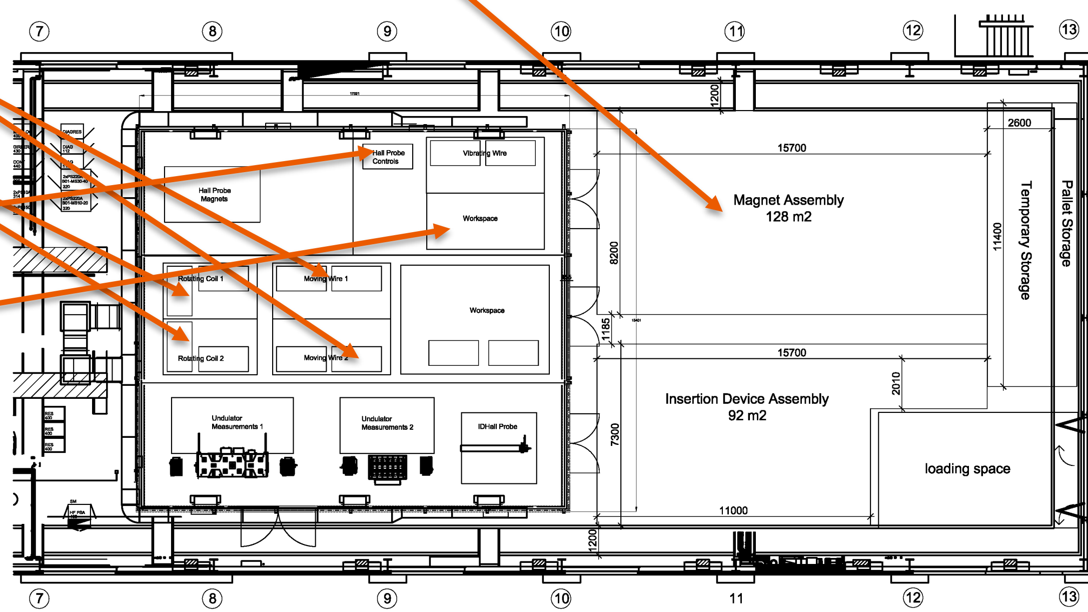
Magnet infrastructure at PSI

NC magnet and PM lab (600 m^2)

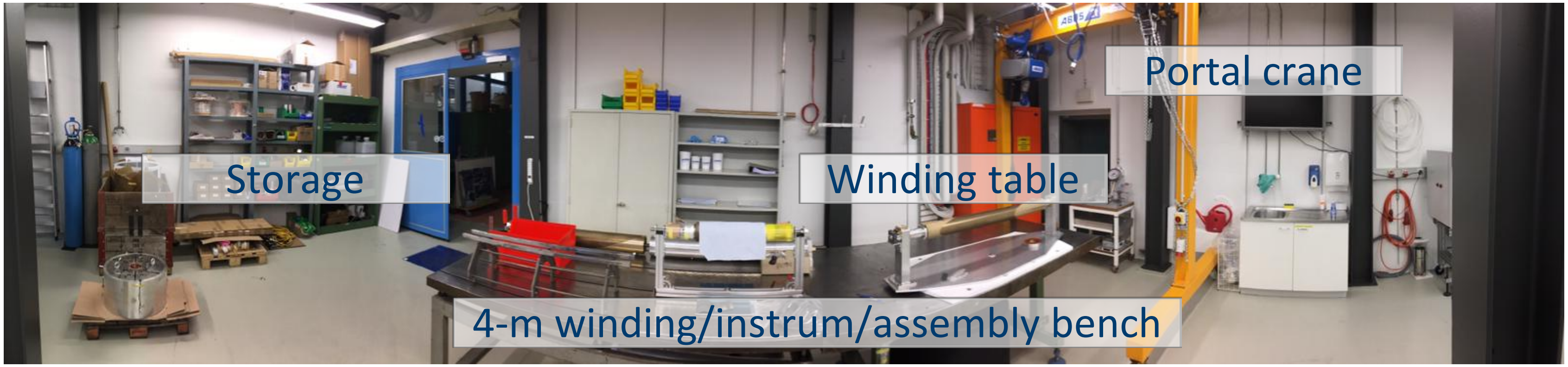
- Magnet assembly
  - –NC electromagnets
  - –Permanent magnets



- Magnetic measurements
  - –Moving wire
  - –Rotating coil
  - –Hall probe
  - –Vibrating wire

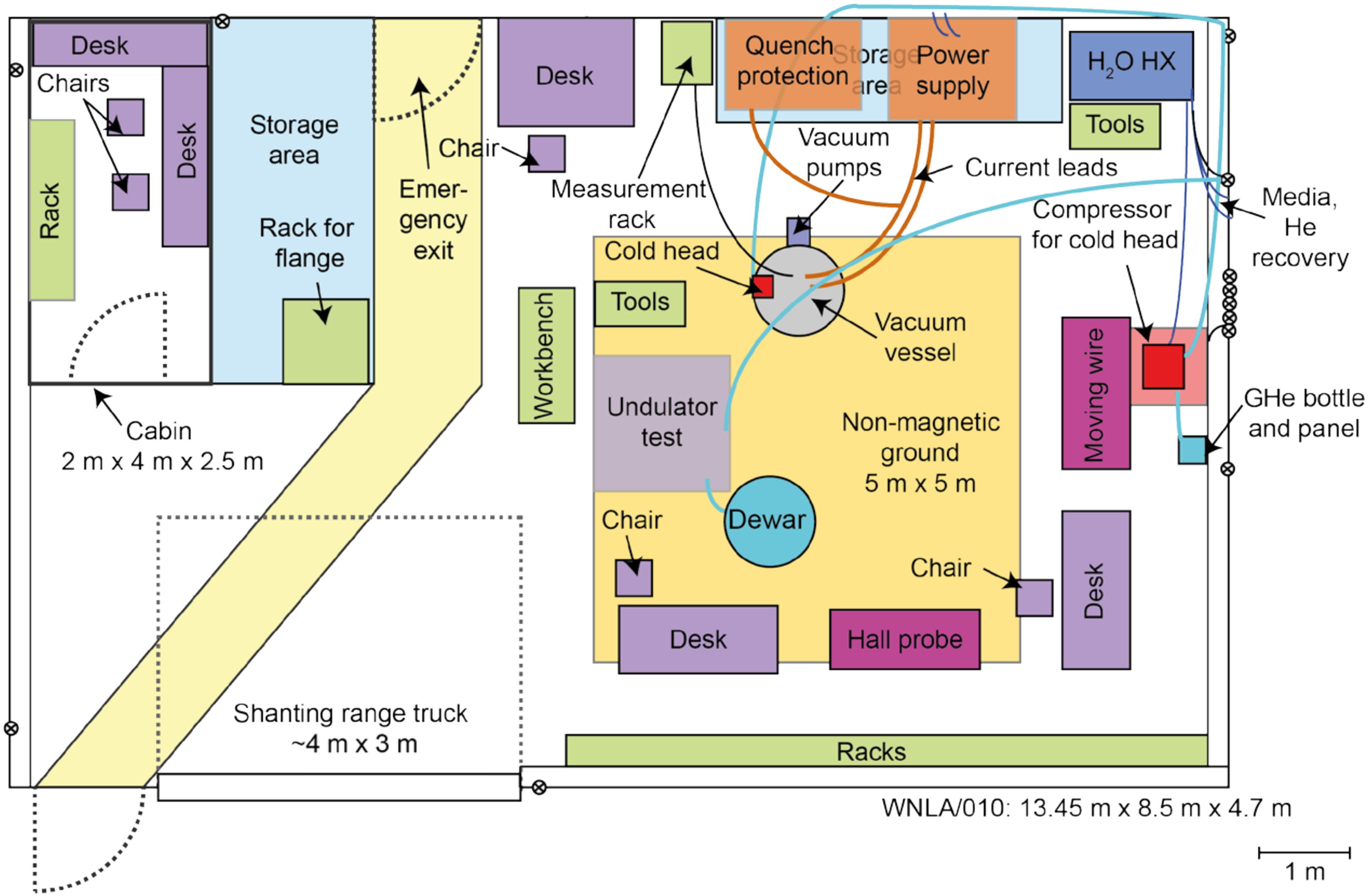


Lab for construction of SC Nb_3Sn magnets (CHART)

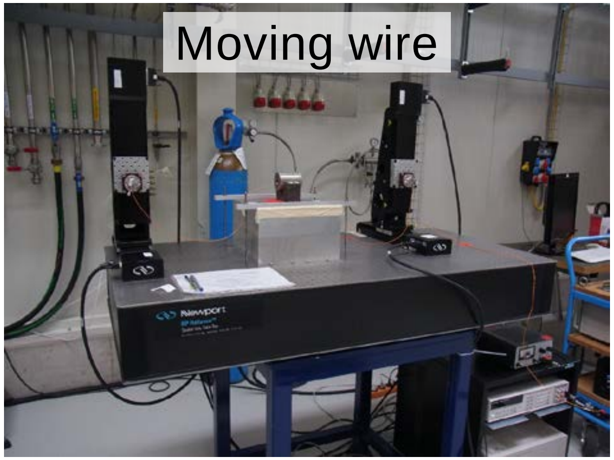


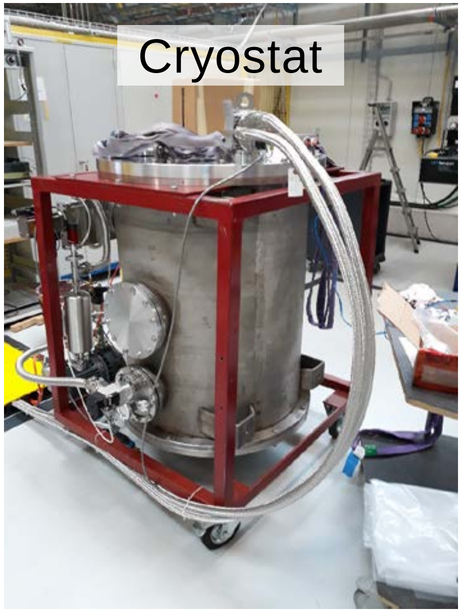
- Upgrade of infrastructure for CHART Phase II in preparation (400 m^2)

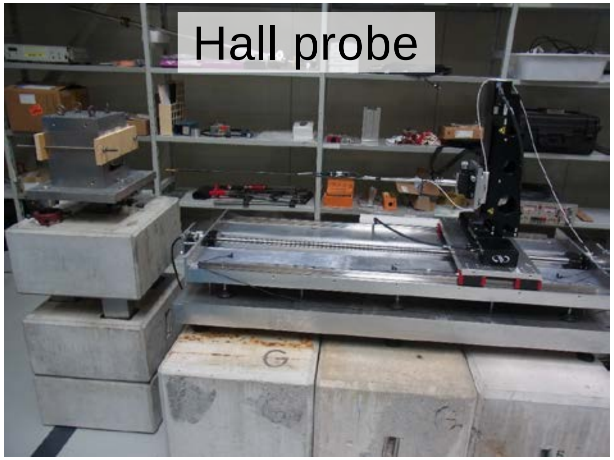
Lab for tests of SC magnets and components (100 m^2)



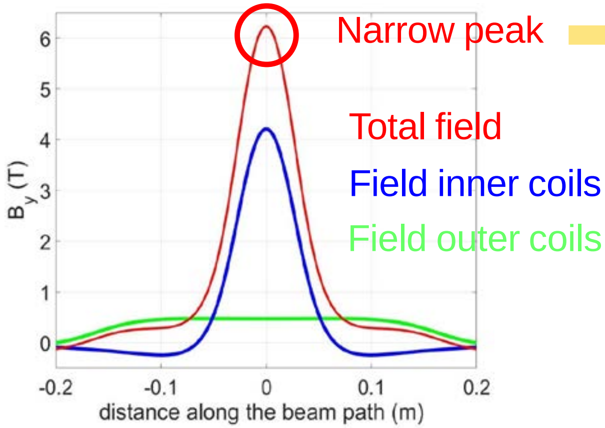
Lab for tests of SC magnets and components ($100\ m^2$)





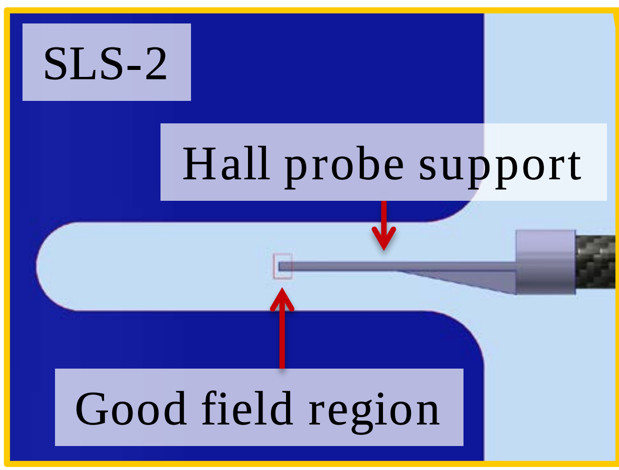


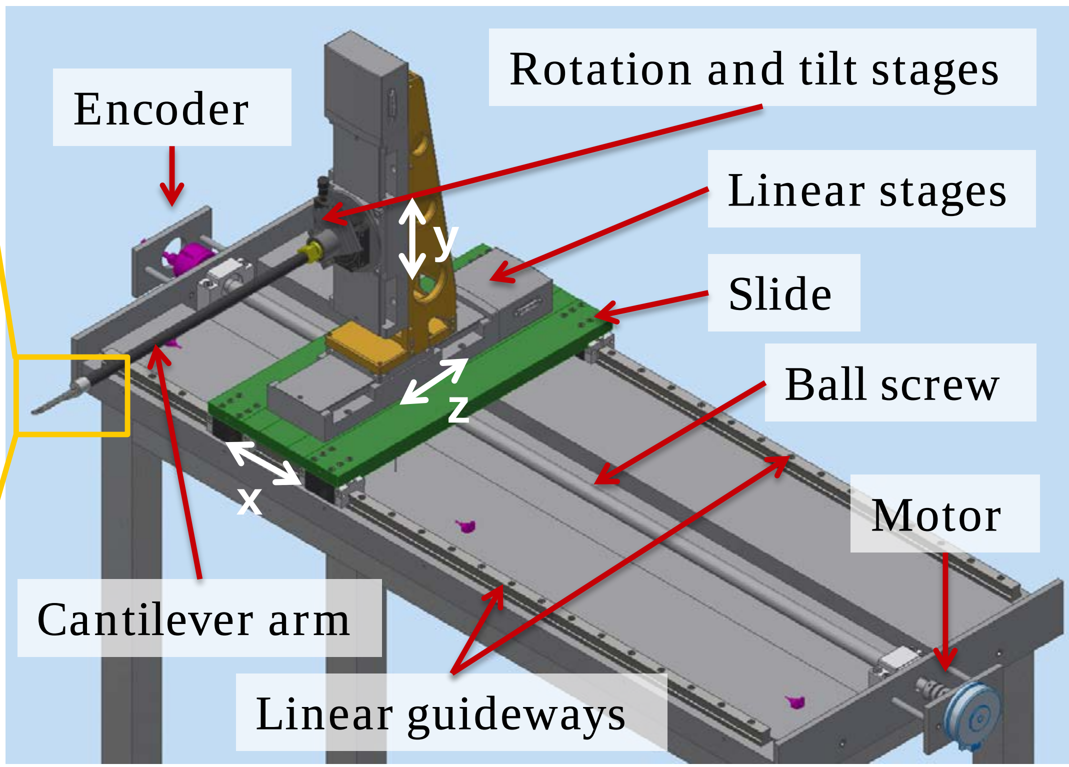
Measurement system for inhomogeneous high-intensity magnetic fields



Challenges: Measurement of the field gradient

- in 3 dimensions
- with accuracy 0.1 % of field range
- With 200 measurement points and increments of 1 mm

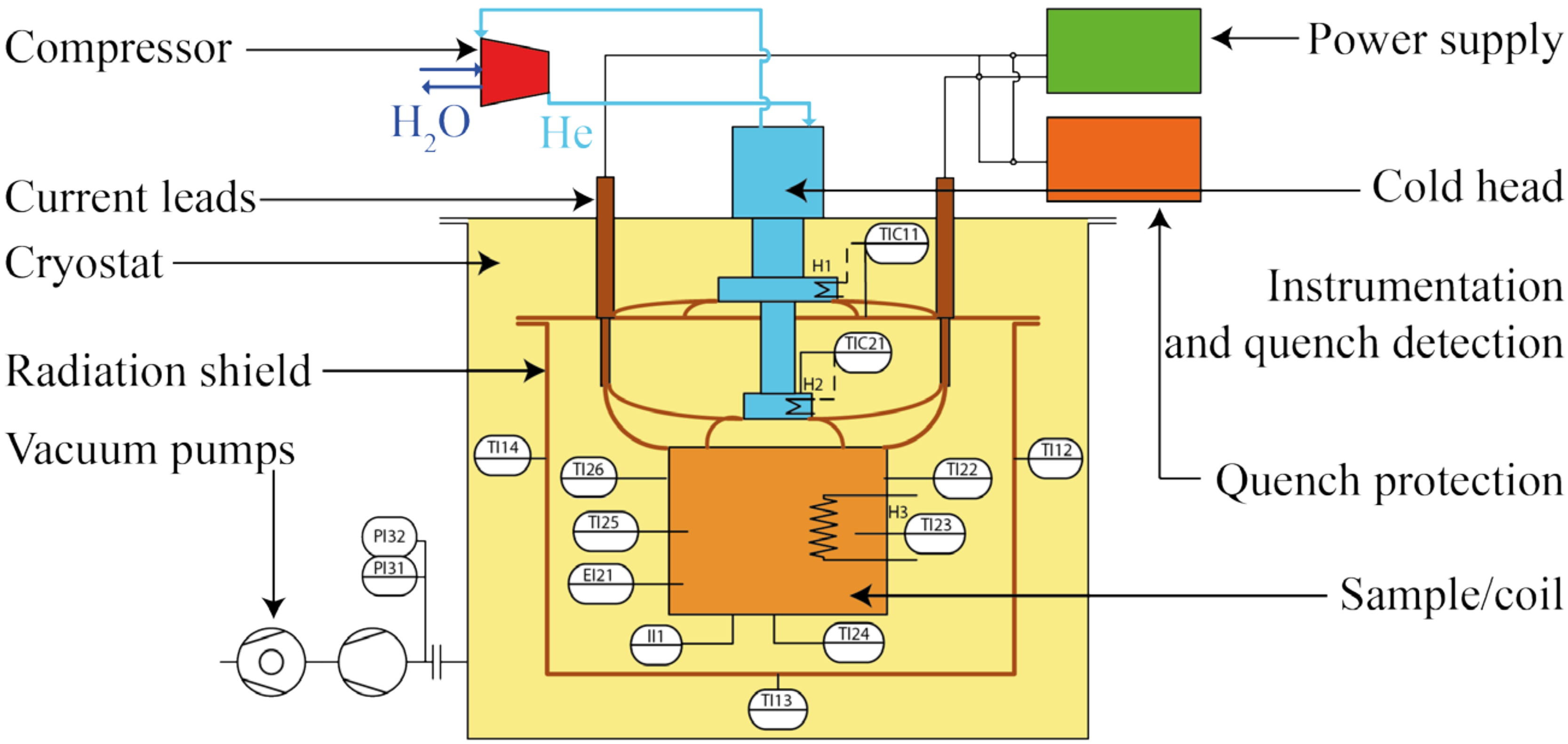




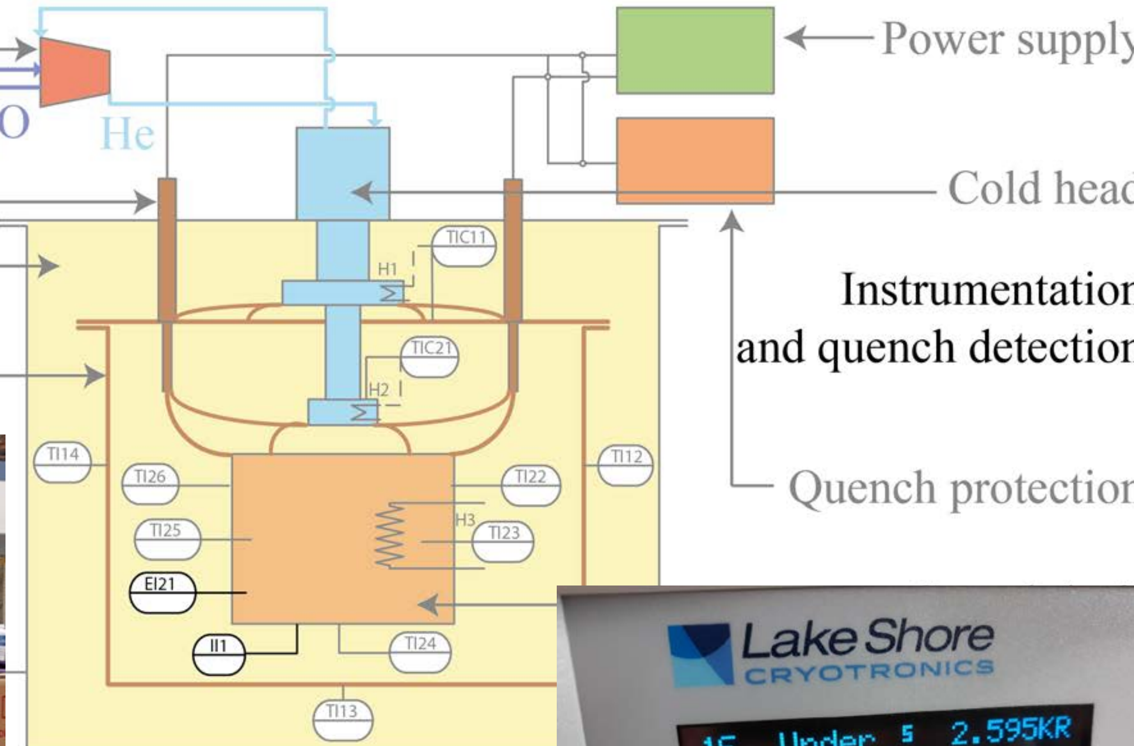
Positioning of the probe: highest accuracy necessary

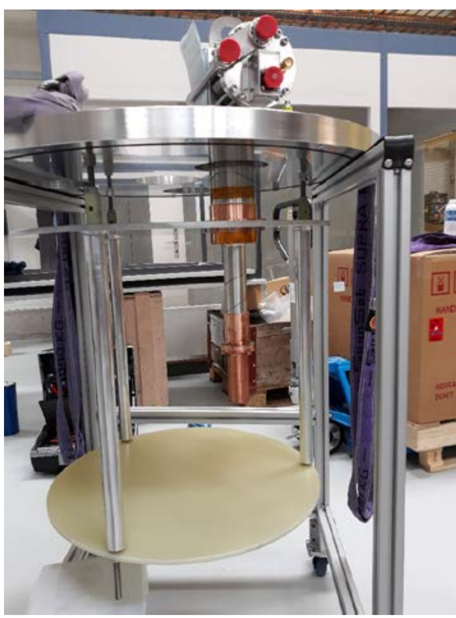
PhD Paola La Marca

Cryogenic tests of e.g. SLS-2 model coil



Cryogenic tests of e.g. SLS-2 model coil





Test stand for SC components

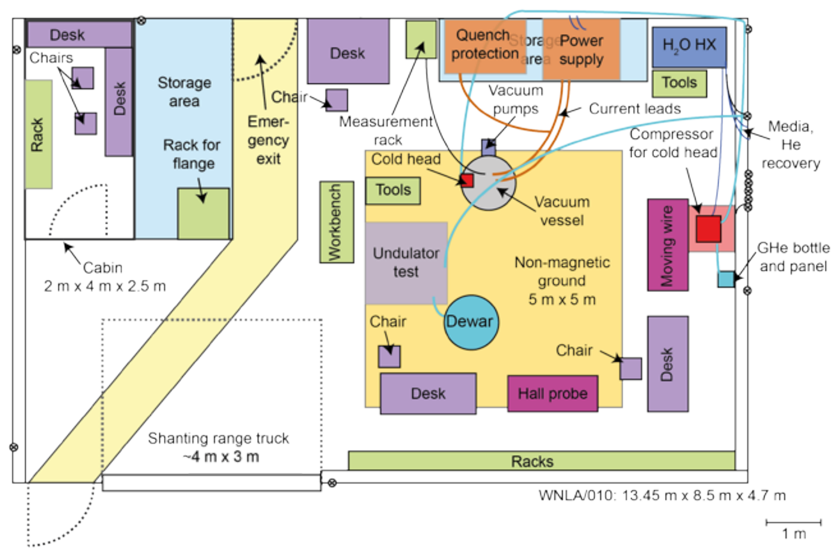
- Adjustable test stand for systems cooled with cryocoolers under **operating conditions**
- Verification effectiveness and reliability of
  - Cooling method
  - Electrical performance at cold temperatures
  - Instrumentation
  - Operation at nominal current
  - Quench detection and protection
  - Field integral
  - Magnetic profile

Timeline and outlook infrastructure

2018	2019	2020	2021	2022	2023

- Construction, infrastructure
- Commissioning test stand
- Measure-ments
- Test of SLS-2 coils, SC HTS undulators,…

- Phase I: Infrastructure
- Phase II: Test of superconducting components, coils and magnets Nb-Ti (and Nb_3Sn?)
- Phase III: Upgrade to HTS (e.g. for upgrade SLS-2 6 T superbends and SC undulators using HTS bulks or stacked tapes)



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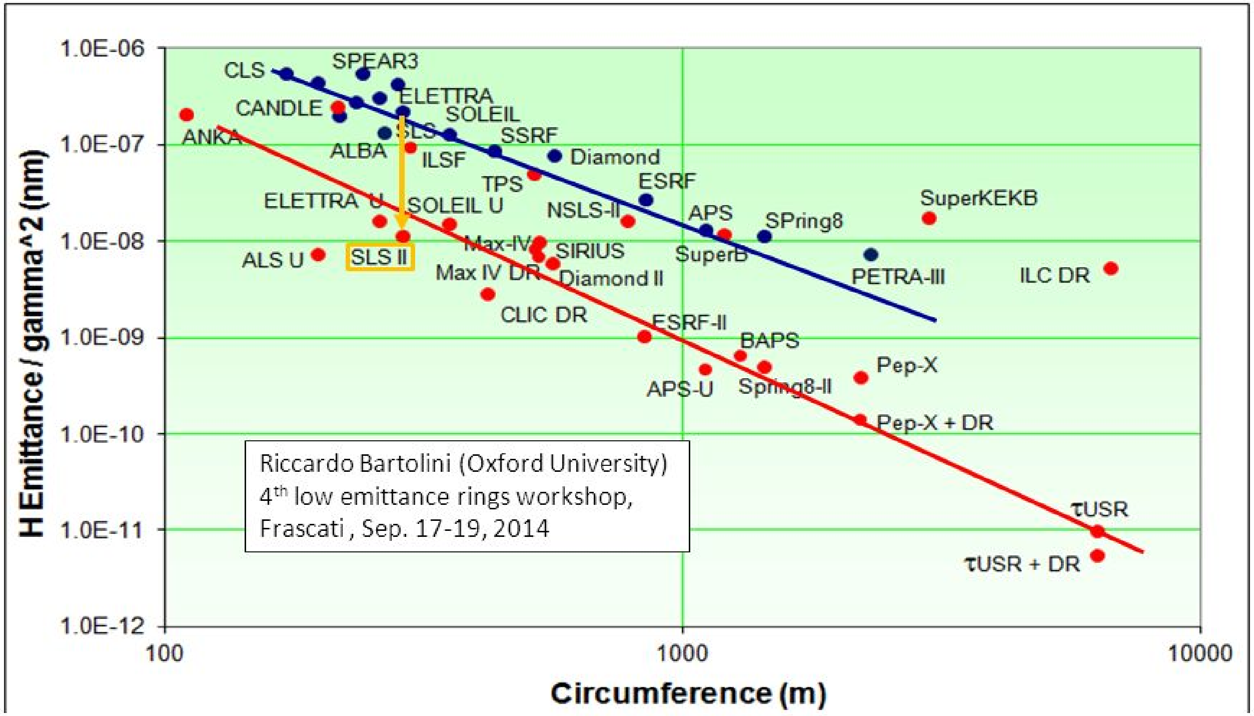
Motivation SLS-2

In order to stay competitive in future, the new storage ring has to provide a factor

> 30 lower emittance at the same circumference and beam energy.

The storage ring generational change



Storage rings in operation (•) and planned (•).
The old (—) and the new (—) generation.

Motivation SLS-2

In order to stay competitive in future, the new storage ring has to provide a factor

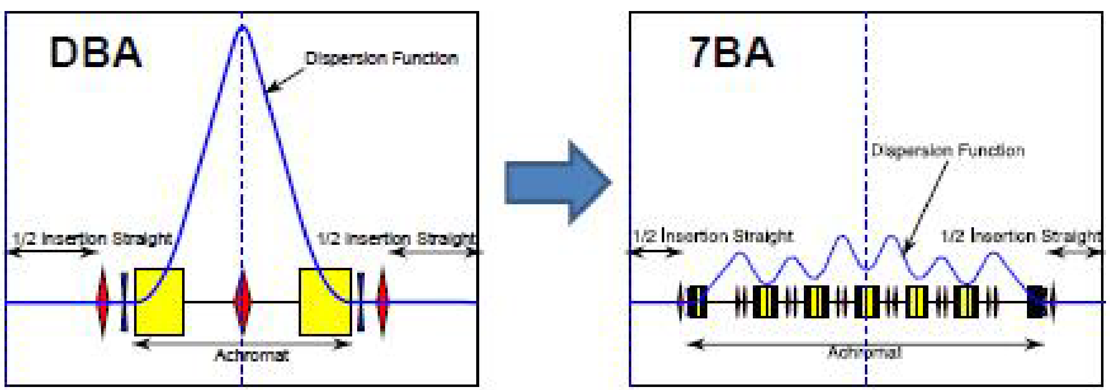
> 30 lower emittance at the same circumference and beam energy.

$$B_{average}(\lambda) \sim \frac{N_{photon}(\lambda)}{\varepsilon_x \cdot \varepsilon_y}$$

Lattice design evolution from double- and triple-bend achromats (DBA, TBA) to multi-bend achromats: increase N_D.

$$\varepsilon_x = C_L \frac{E^2}{N_D^3}, \quad \varepsilon_x \underbrace{\propto}_{\text{Fixed E}} \frac{1}{C^3}$$

C_L = lattice constant
N_D = # dipoles
C = Circumference

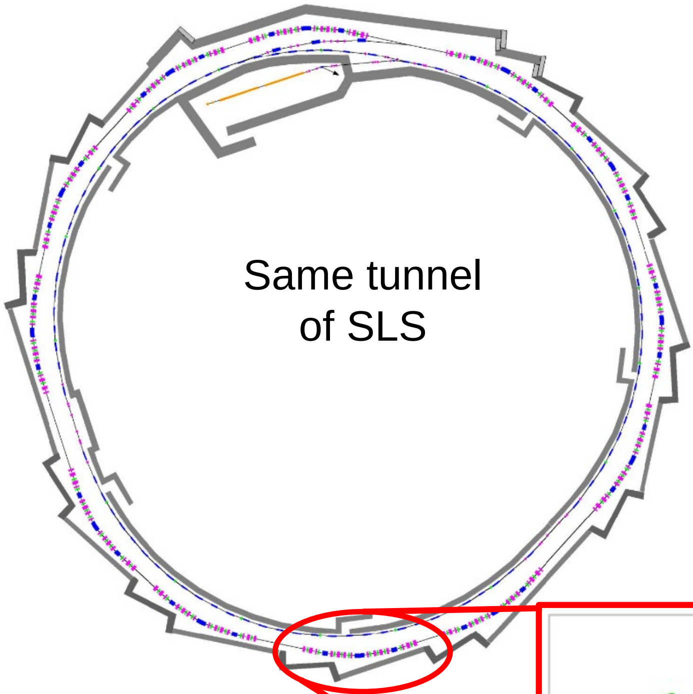


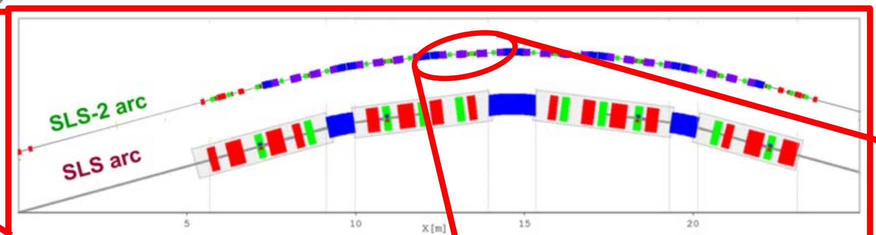
Strong Focusing and Low Dispersion

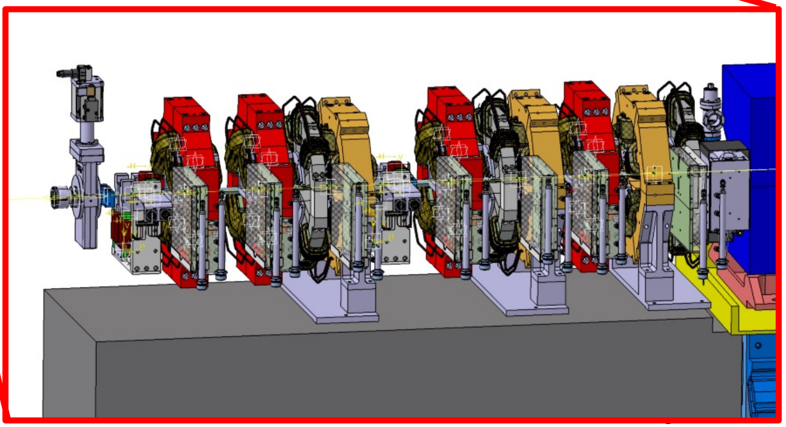
First used for MAX-IV.

D. Einfeld *et al.*, Proc. PAC 95, Dallas TX

Motivation SLS-2







The new lattice requires very compact components.

A lot of combined function magnets are required:

- 120 off axis quads;
- 288 octupoles-quads;
- …

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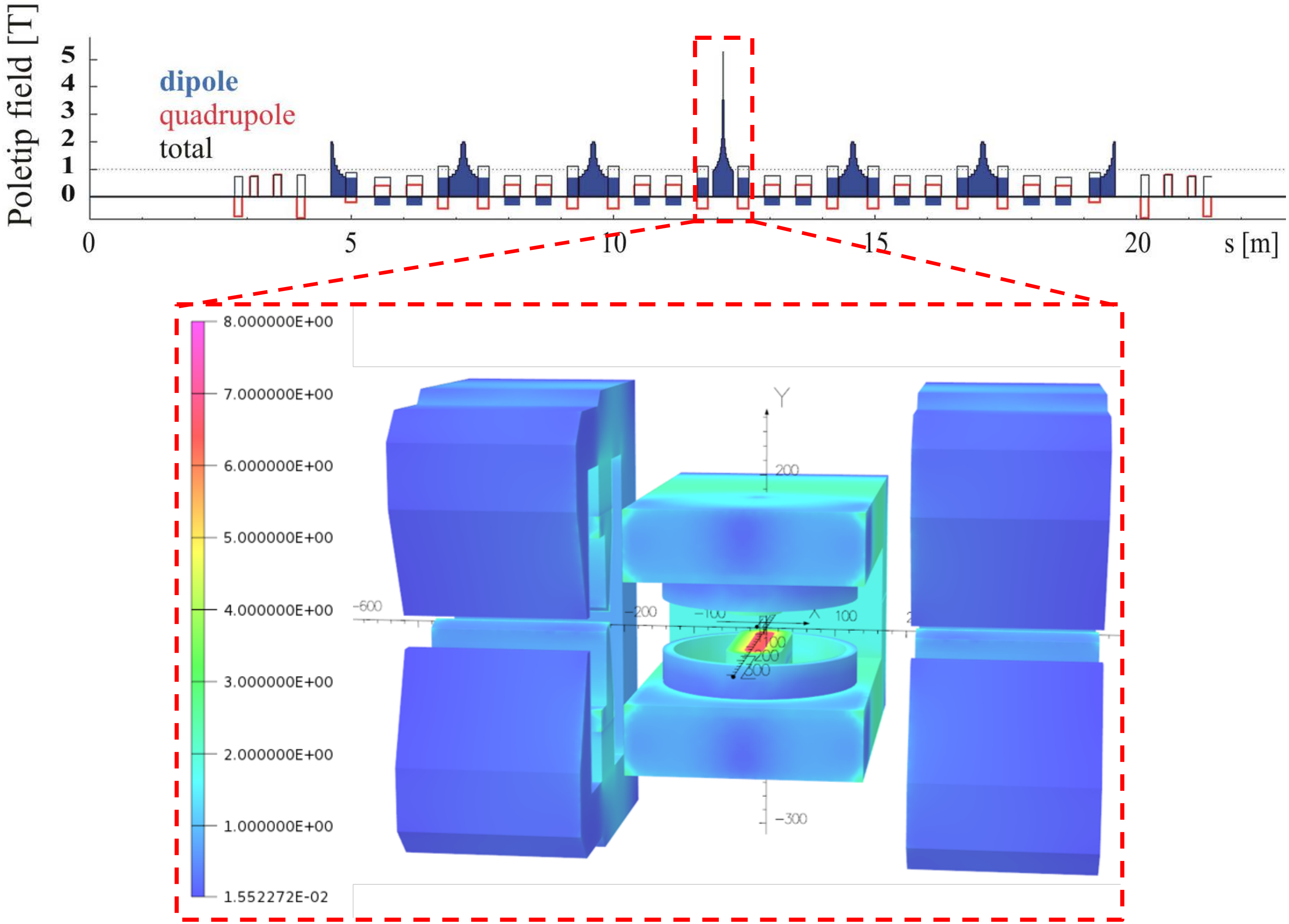
Superconducting superbend magnet(s)



Superconducting superbend magnet(s)

Specifications

- Narrow B-field profile: FWHM < 75mm;
- Peak field in the GFR > 4T;
- $\int Bdl = 0.54Tm$ (as for all the RT dipoles);
- Available longitudinal space: 430 mm;
- Vacuum chamber OD: 24 mm (possibilities to reduce the OD under discussion).

Consequences

- B field enhancement > 1.4;
  - 4T peak → Nb-Ti;
  - 6T peak → Nb3Sn
  - > 6T peak → HTS?
- Conduction cooling system;

Additional Constraints

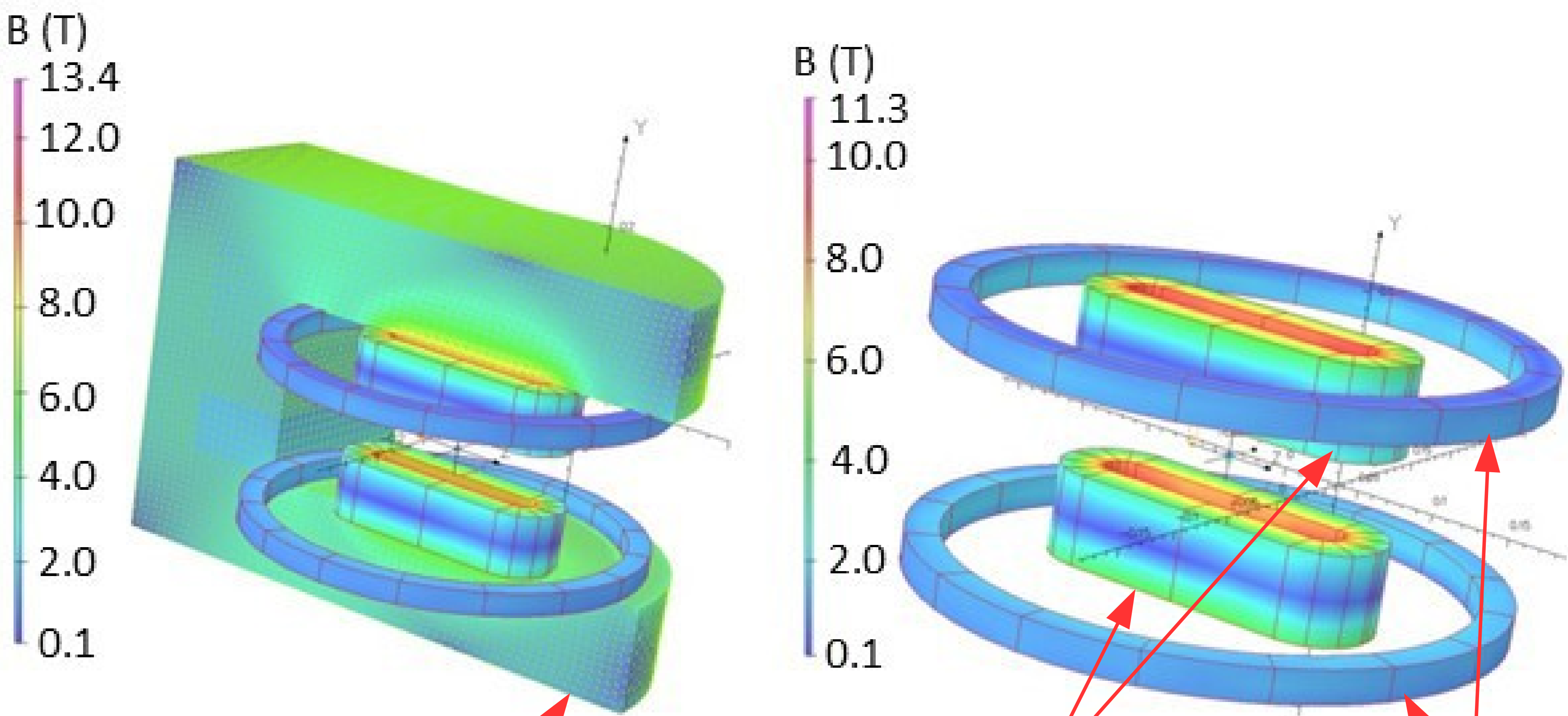
(valid for all the magnets)

- **<u>Installation strategy in the tunnel</u>**;
- Necessity to evacuate the synchrotron radiation.

- C-shaped magnet (open geometry);
  - Mechanical rigidity;
  - Stray field.

Superconducting superbend magnet(s)

Magnetic concept



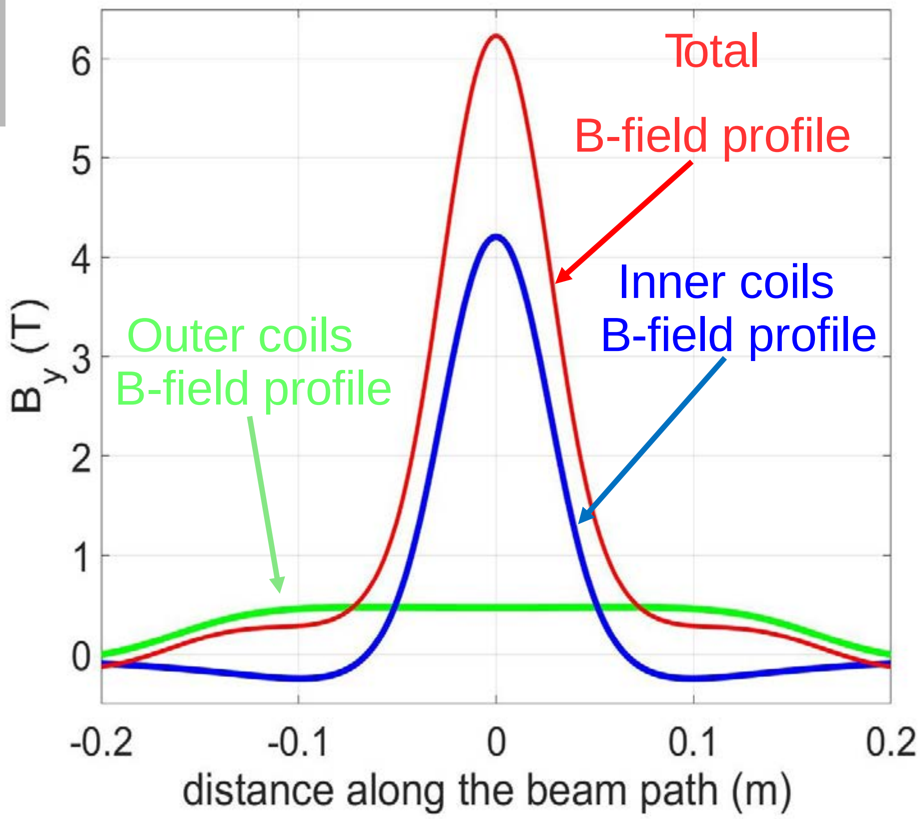
ARMCO[R] yoke to enhance the field in the GFR and to reduce the stray field

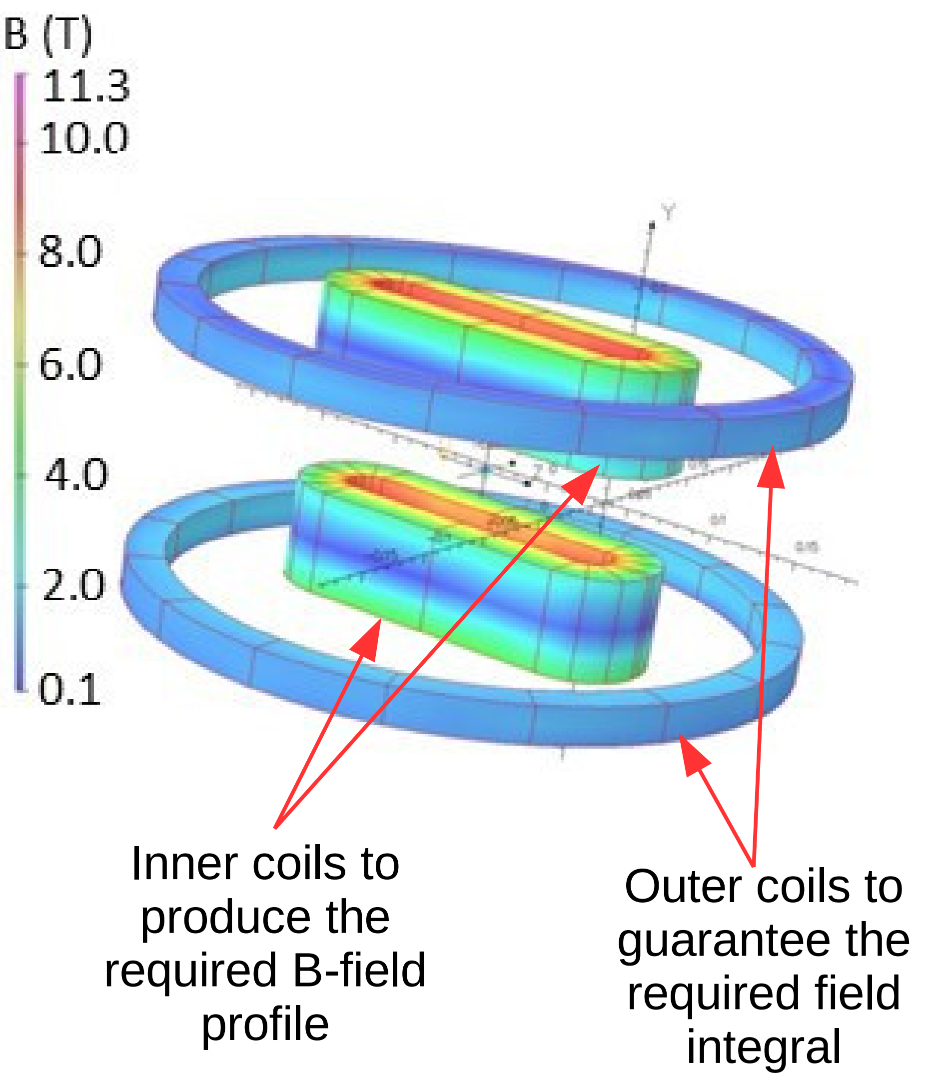
Inner coils to produce the required B-field profile

Outer coils to guarantee the required field integral

Superconducting superbend magnet(s)

Magnetic concept

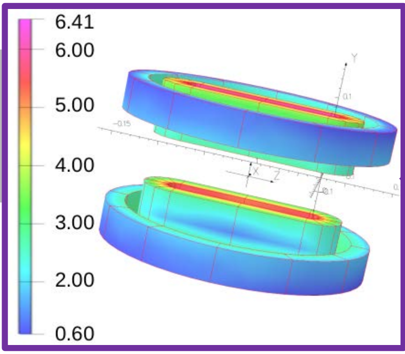




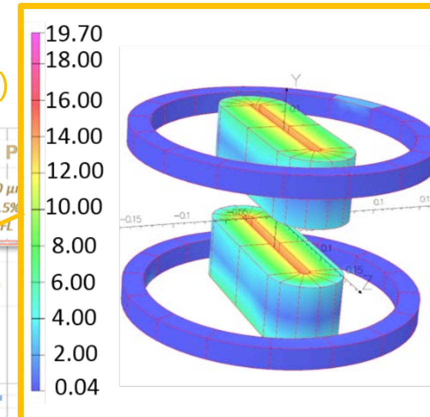
Superconducting superbend magnet(s)

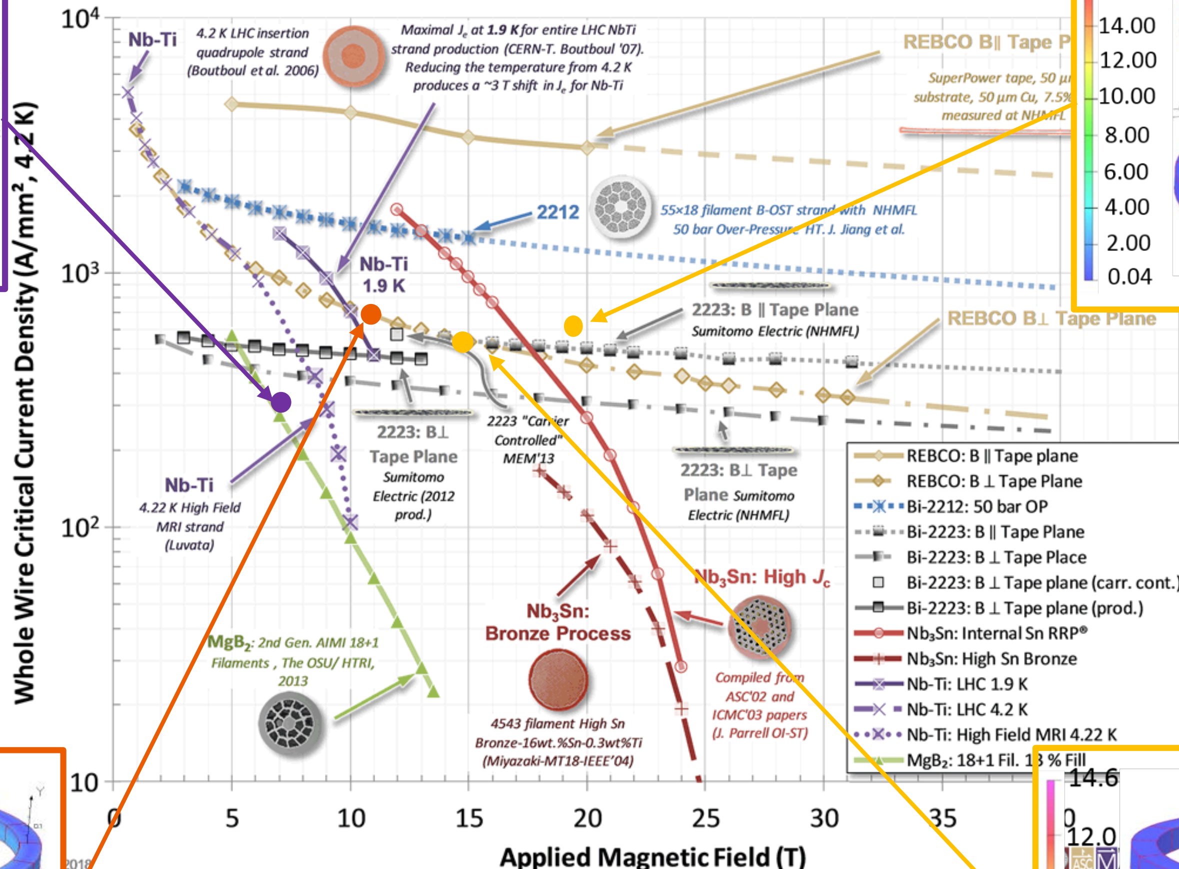
305 A/mm² @ 6.30T →

Nb-Ti (4.3T peak, 0.54Tm)

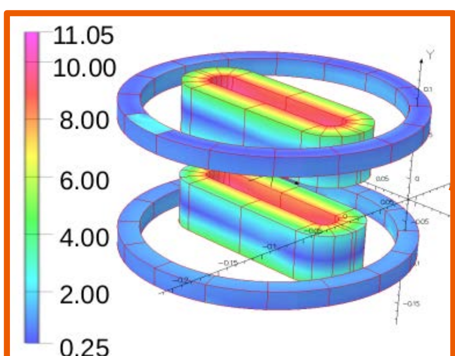


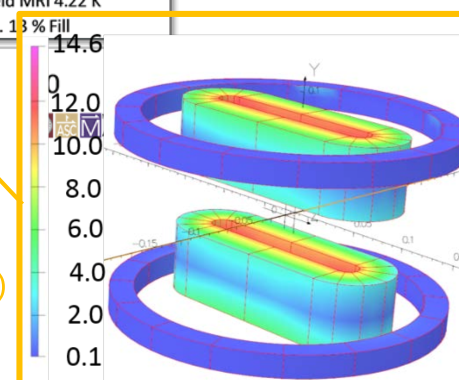
644 A/mm² @ 19.70T→
HTS (7.72T peak, 0.54 Tm)





676 A/mm² @ 11.05T →
Nb_3Sn (6.2T peak, 0.54Tm)



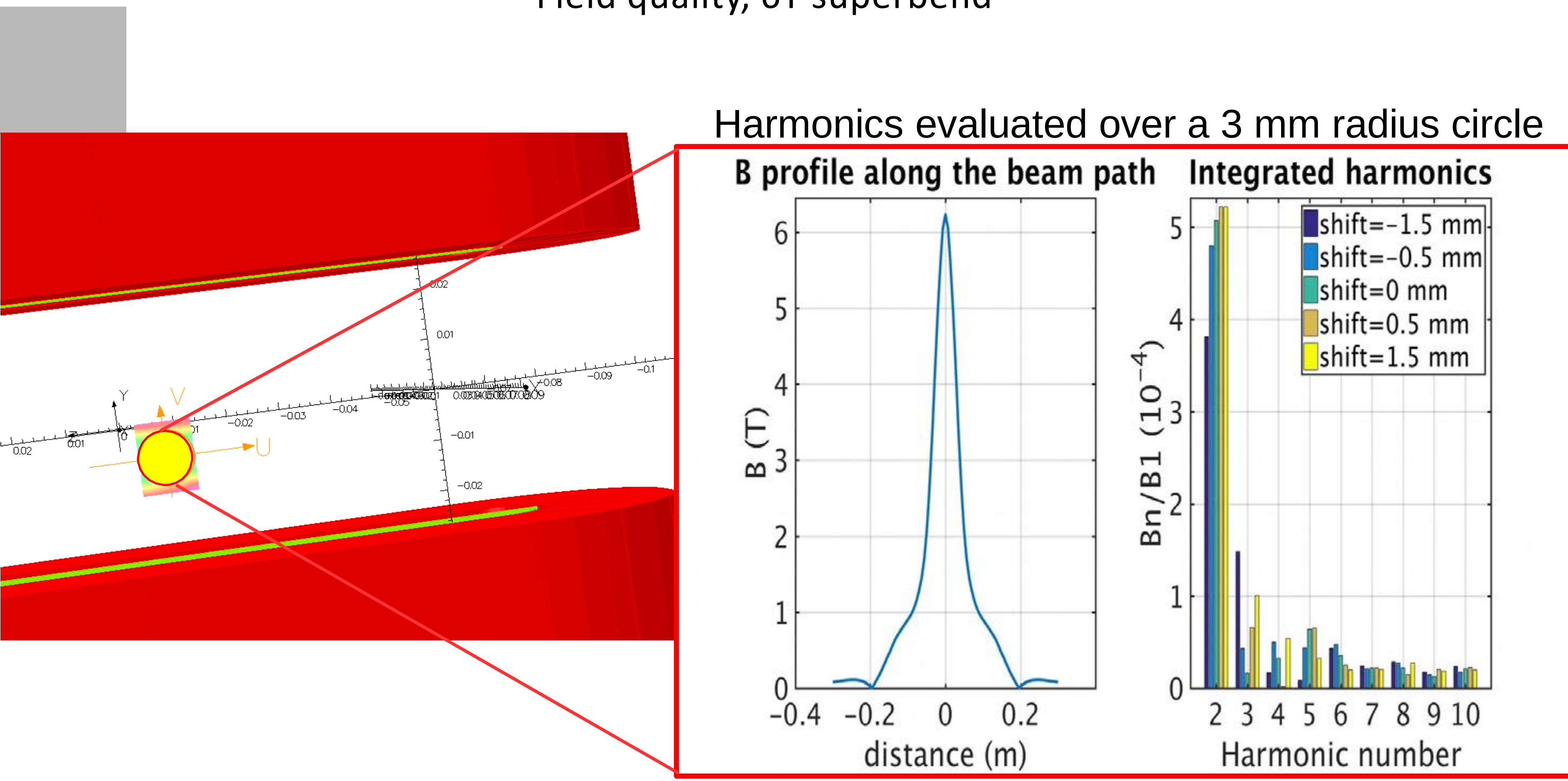


495 A/mm² @ 14.60T →
HTS (7.3T peak, 0.54 Tm)

Superconducting superbend magnet(s)

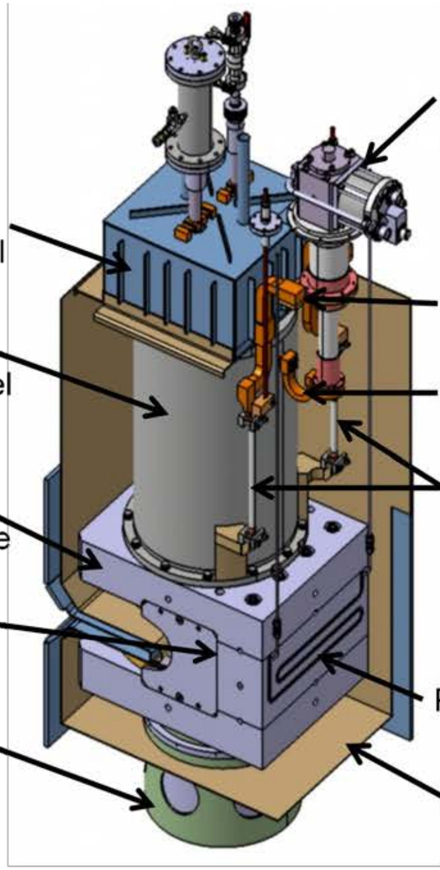
Field quality, 6T superbend

Harmonics evaluated over a 3 mm radius circle



Superconducting superbend magnet(s)

Superbend, main components

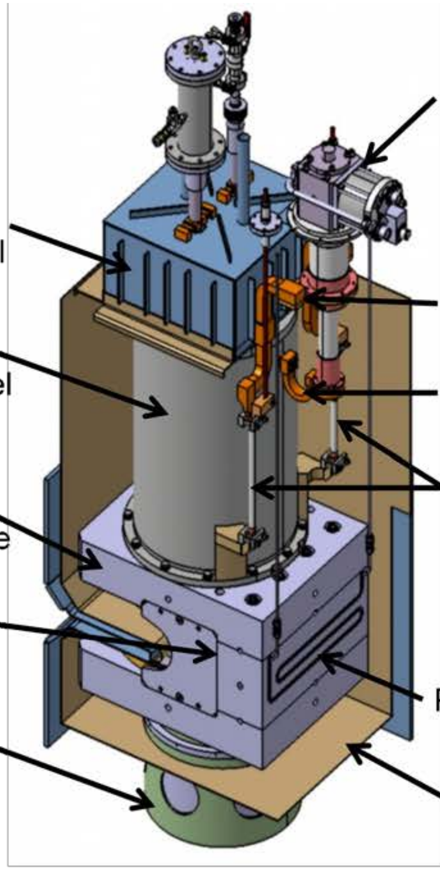


	Outer coils	Inner coils
Conductor type:	Nb-Ti	Nb_3Sn (RRP)
Insulation:	Formvar	S-glass
I_c @ 4.2 K (A)	752 @ 5T	810 @ 12T
Magnetic energy (kJ) (1 coil)	3.8	16.6
Inductance (mH) (1 coil)	50	210
Current per turn (A)	400	400
N. turns (1 coil)	200	1485
Extraction Voltage (V) (τ_{damp}=0.4s)	340	140
Horizontal aperture (mm)		53
Peak field at conductor (T)	2.8	11.3
Peak temperature (K)	4.2	4.3

Superconducting superbend magnet(s)

Superbend, main components

To guarantee 8-10 hours autonomy in case of cryocooler failure.



ALS Superbend Magnet System

J. Zbasnik[†], S. T. Wang[††], J. Y. Chen[††], G. J. DeVries[†], R. DeMarco[†], M. Fahmie[†], A. Geyer[†], M. A. Green[†], J. Harkins[†], T. Henderson[†], J. Hinkson[†], E. H. Hoyer[†], J. Krupnick[†], S. Marks[†], F. Ottens[†], J. A. Paterson[†], P. Pipersky[†], G. Portmann[†], D. A. Robin[†], R. D. Schlueter[†], C. Steier[†], C. E. Taylor[†], R. Wahrer[††]

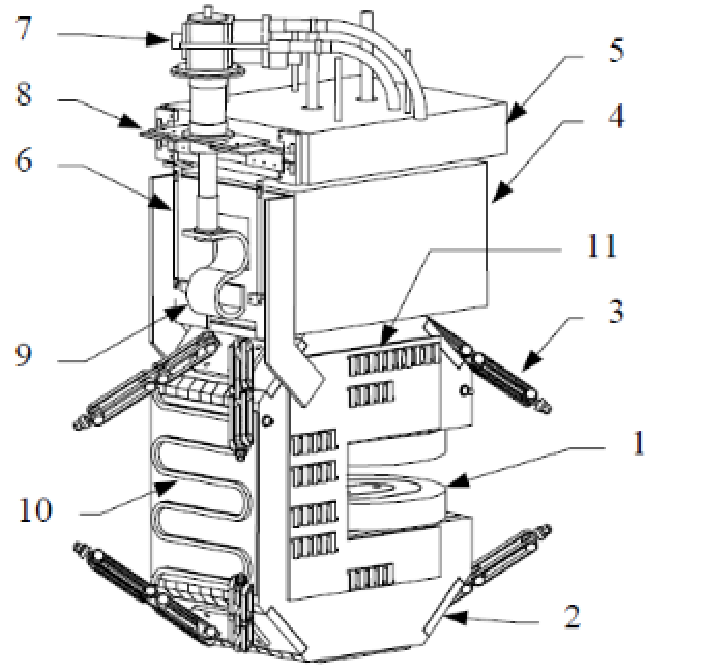


Fig. 1. Superbend cold mass assembly: 1 – superconducting coils with steel poles, 2 – laminated steel yoke, 3 – suspension straps, 4 – LHe vessel, 5 – LN_2 vessel, 6 – HTS leads, 7 – cryocooler, 8 – 50 K thermal connection, 9 – 4 K thermal connection, 10- cooldown tube, 11 – warmup heater.

October 4, 2001 marked the completion of the Superbend Project — the biggest upgrade to Berkeley Laboratory's

Advanced Light Source (ALS)

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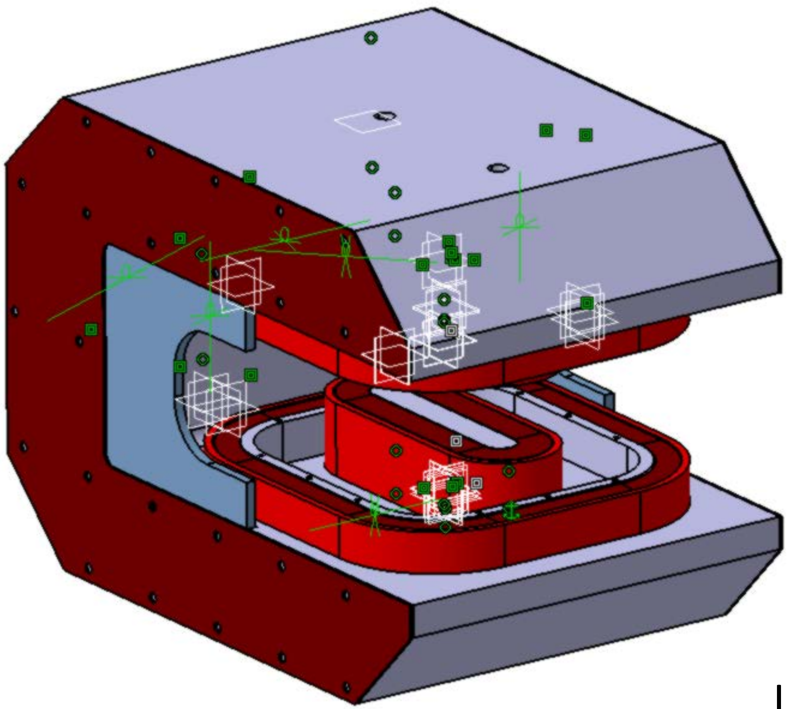
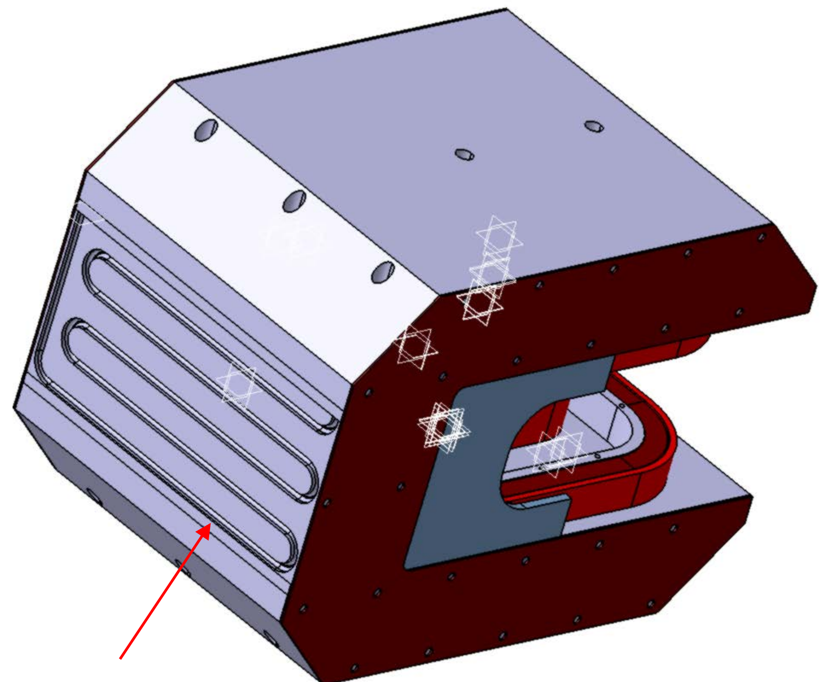
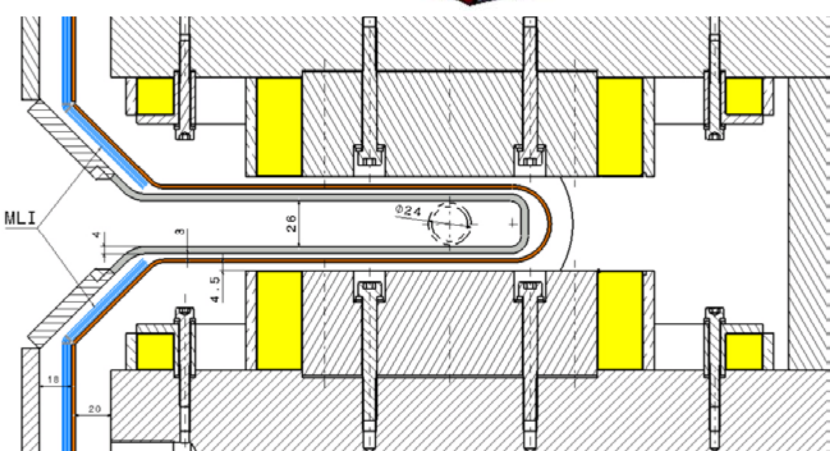
Superconducting superbend magnet(s)

Superbend, cold mass anchored to the 2^{nd} stage





LN_2 precooling pipe.



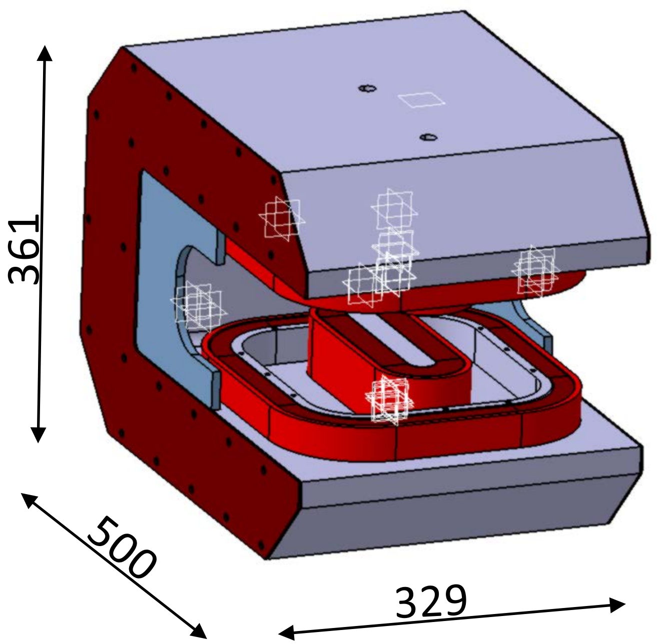
Large vertical aperture to allow the installation of the magnet in the section:

Very high field enhancement:

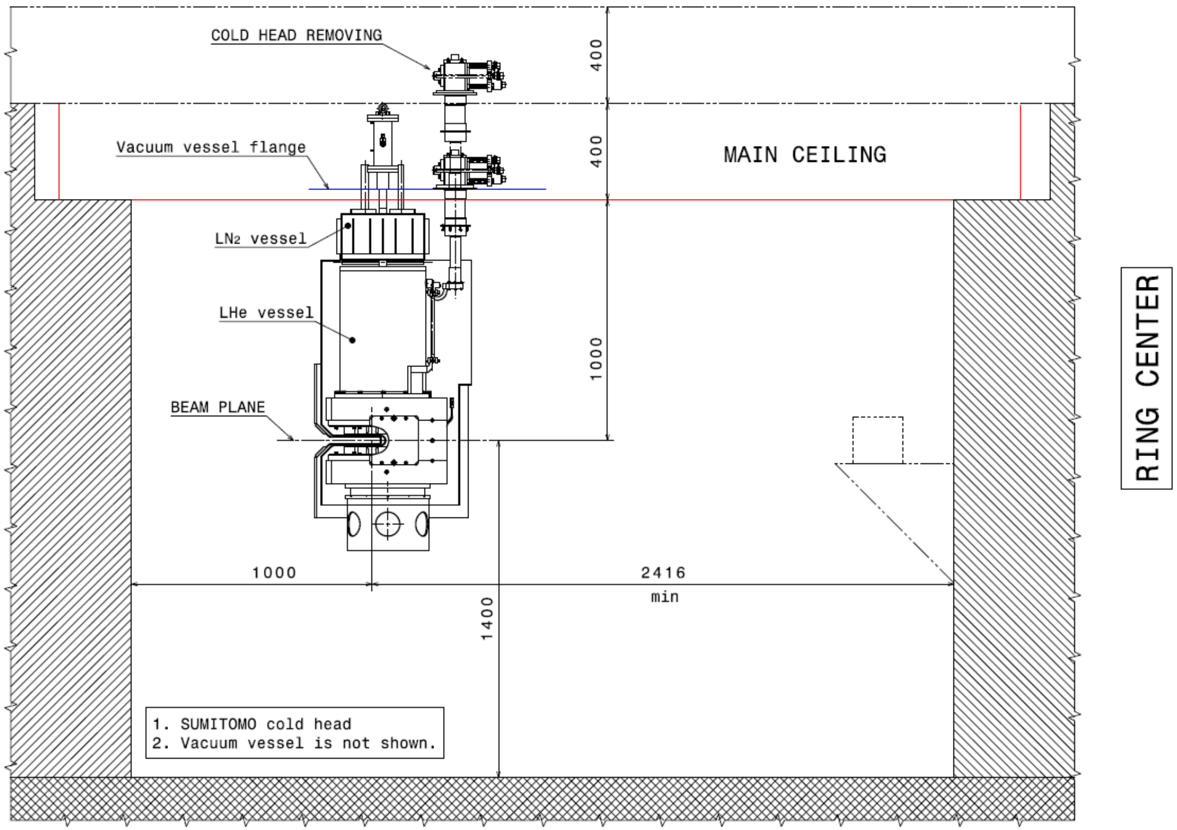
- 1.45 @ 4T peak;
- 1 .78 @ 6T peak;
- ~2 @ >7.8 T.

Superconducting superbend magnet(s)

Superbend, cold mass anchored to the 2nd stage

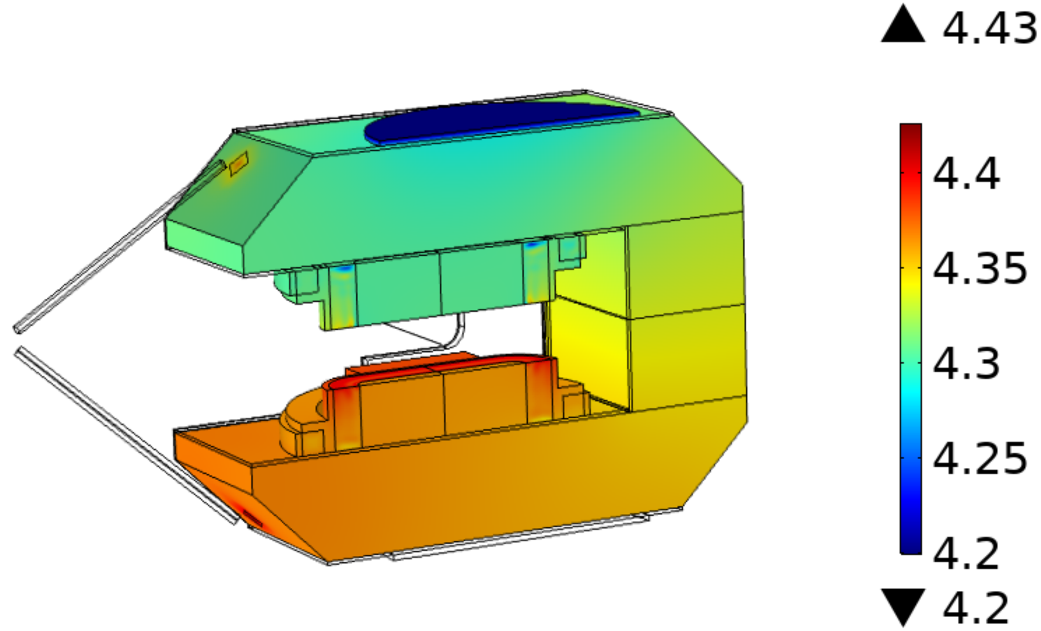


M = 290 kg

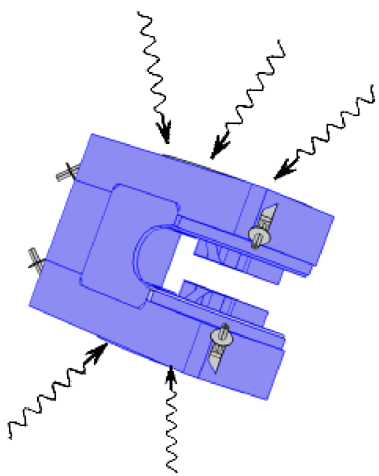


Superconducting superbend magnet(s)

	Power (W)
MLI, 50 K $\rightarrow$ 4.2 K	0.04
MLI, 300 $\rightarrow$ 4.2 K	0.068
Splices	0.026
Current leads	0.26
Conduction through the support	0.22
TOT.	0.62

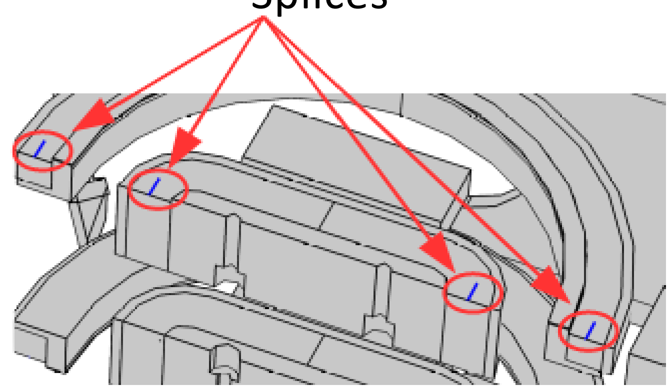


Radiation from the 50 K shield

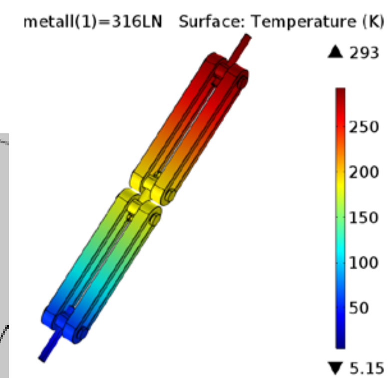


Radiation from the Warm bore

Splices



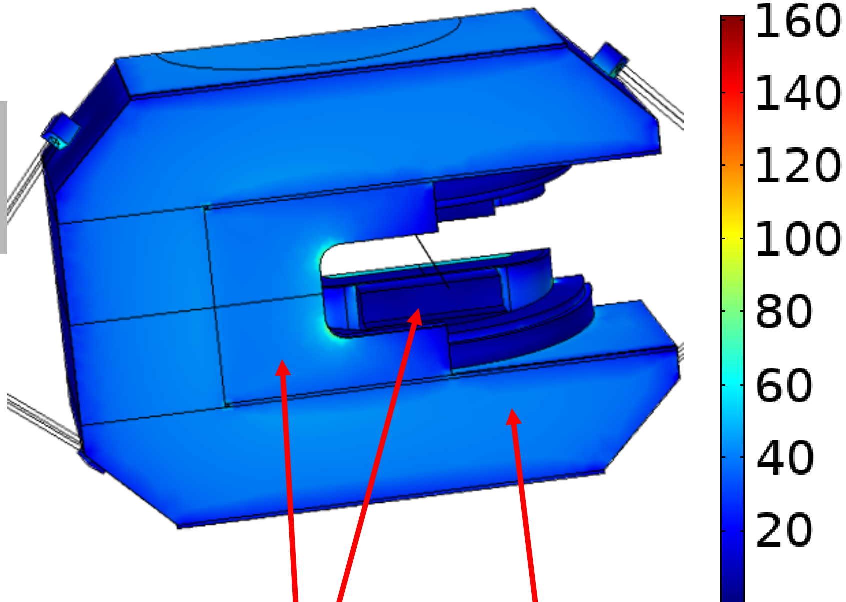
Suspension straps



Superconducting superbend magnet(s)

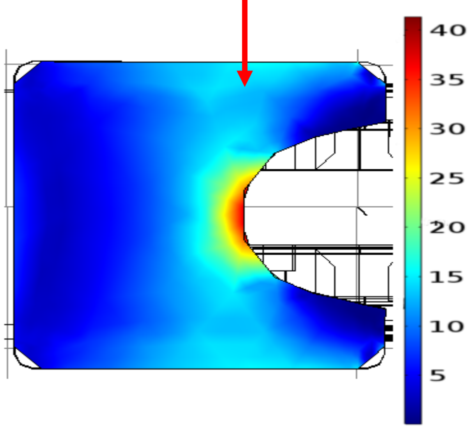
Mechanical structure

Material	Yielding stress (MPa) @ 4.2 K
316LN	860-1000
CuBe	260 (@ 77 K)
Armco®	940 (@77 K)

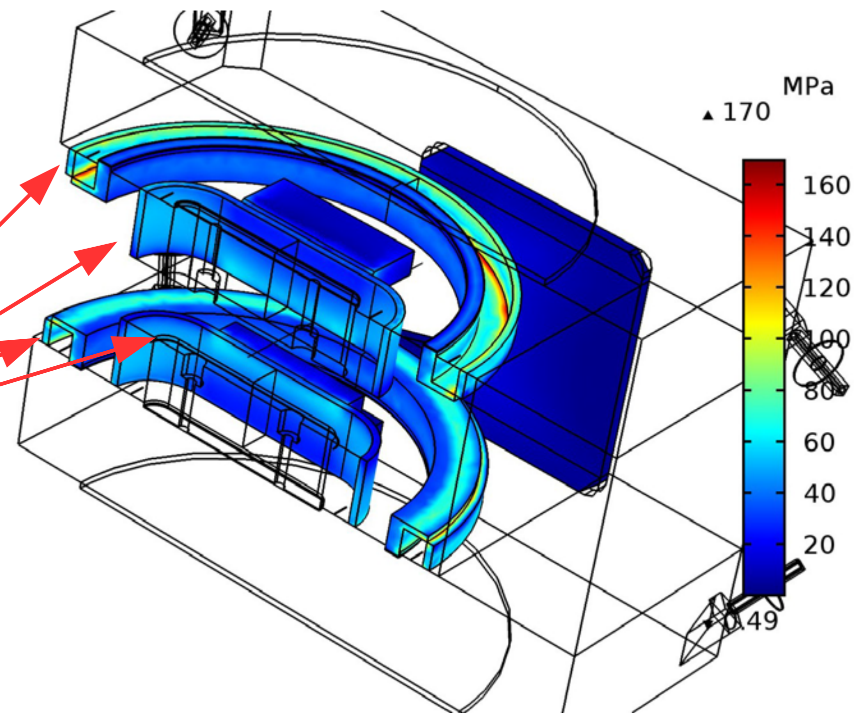


Armco®

316 LN

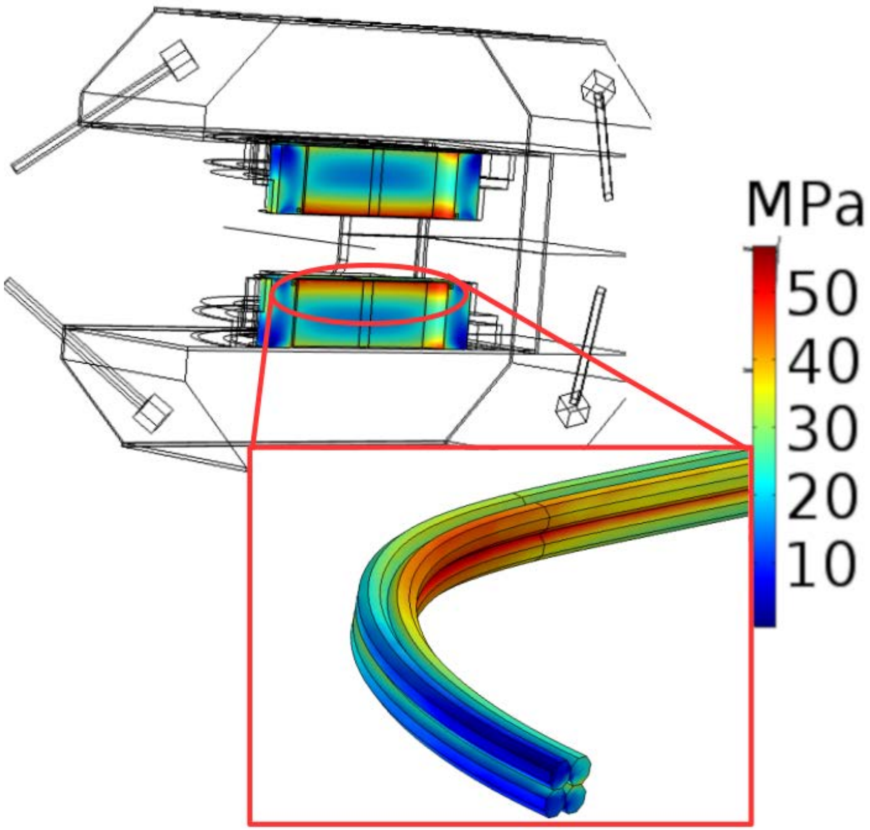


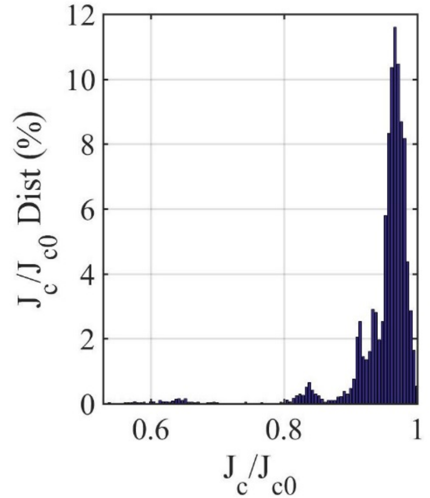
CuBe

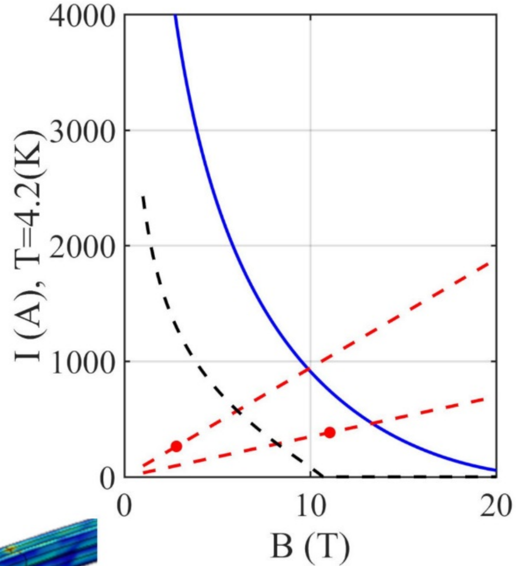


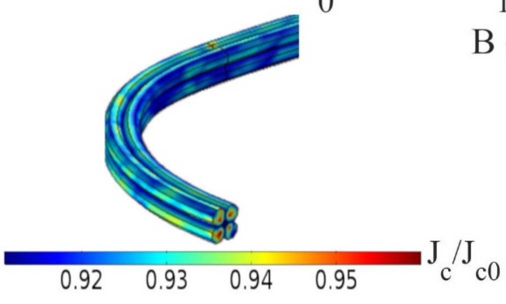
Superconducting superbend magnet(s)

Stress calculated considering:
- Lorentz forces at nominal field;
- Cool-down from 300 to 4.2 K.



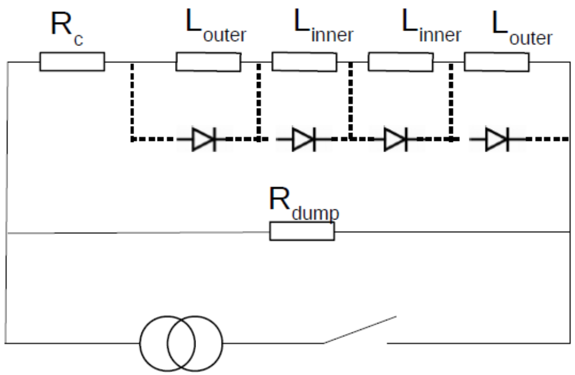






Superconducting superbend magnet(s)

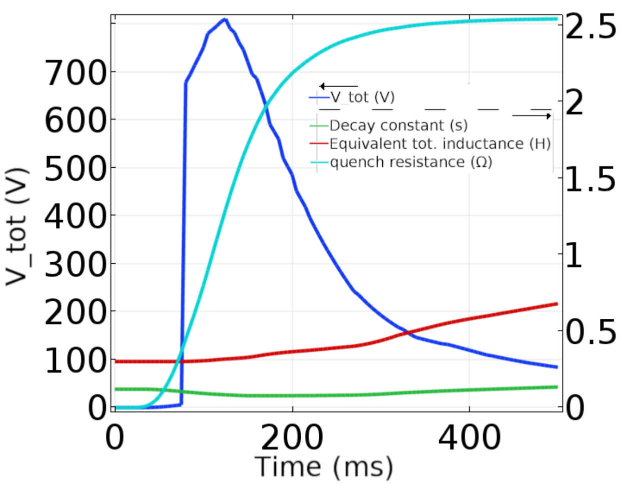
The quench protection system relies on an external dump resistor.

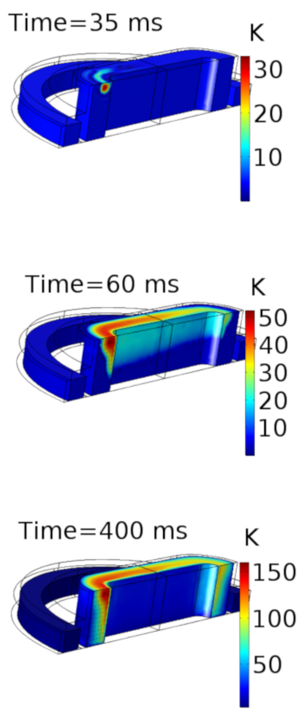


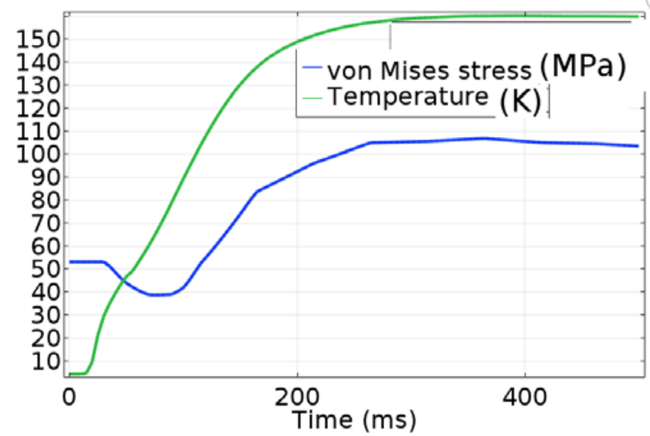
Tot. magnetic energy: 51kJ;

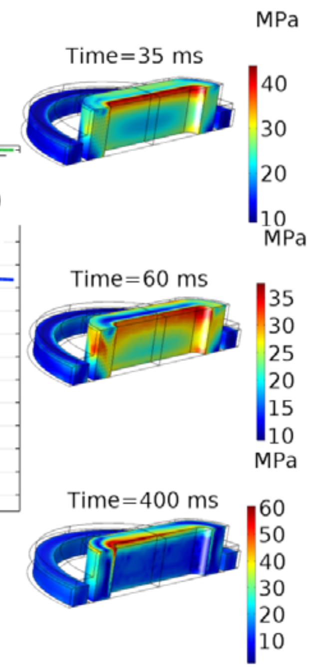
$$R_{dump} = 2\Omega$$

Extraction volt. Outer coil: 340 V;
Extraction volt. Inner coil: 140 V.

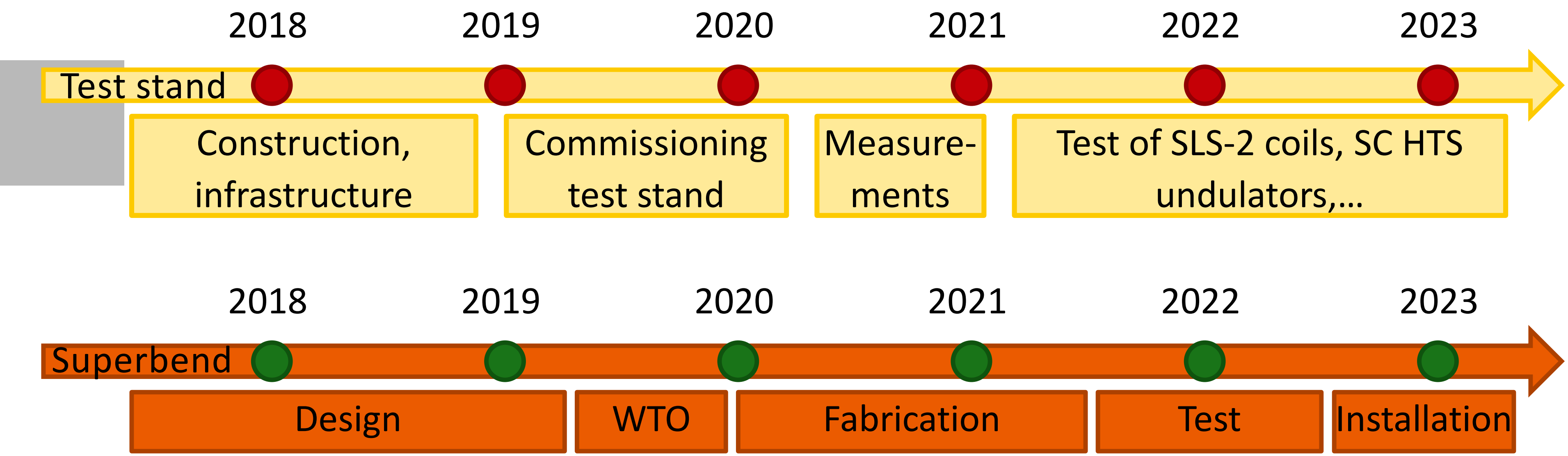








Timeline and outlook



- Collaboration possibilities:
  - Magnet design (mechanics, cooling) and construction for SC magnets like SLS-2 super-bends
  - Alternatives and complement cooling methods for Nb-Ti, Nb_3Sn and HTS magnets (PHP,...)

Thank you for your attention

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section