
WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

Stéphane Sanfilippo on behalf of the magnet section :: Paul Scherrer Institut

PSI Magnet Section activities: Horizon 2020 and beyond

International Magnetic Measurement Workshop 21 @ESRF

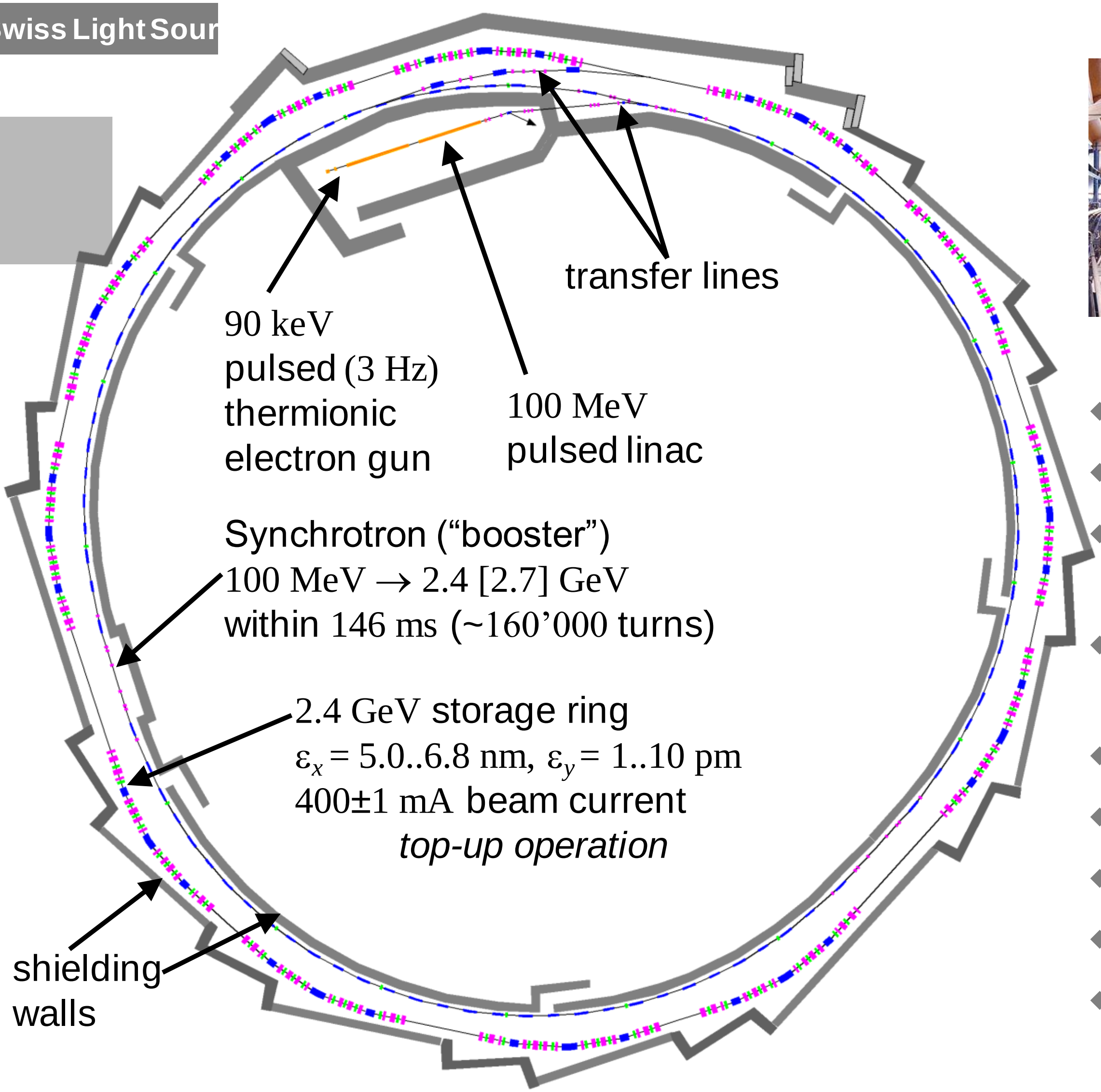
Outline

- Overview of the main projects (2019-2024)
  - Magnets for the upgrade of the Swiss Light Source
  - High field superconducting magnets (CHART phase 2)

- Infrastructure and magnetic measurement system development

SLS now ... to SLS 2.0 in 2024

Swiss Light Sour



transfer lines

90 keV
pulsed (3 Hz)
thermionic
electron gun

100 MeV
pulsed linac

Synchrotron (“booster”)
100 MeV → 2.4 [2.7] GeV
within 146 ms (~160’000 turns)

2.4 GeV storage ring
$\varepsilon_x = 5.0..6.8$ nm, $\varepsilon_y = 1..10$ pm
400±1 mA beam current
top-up operation

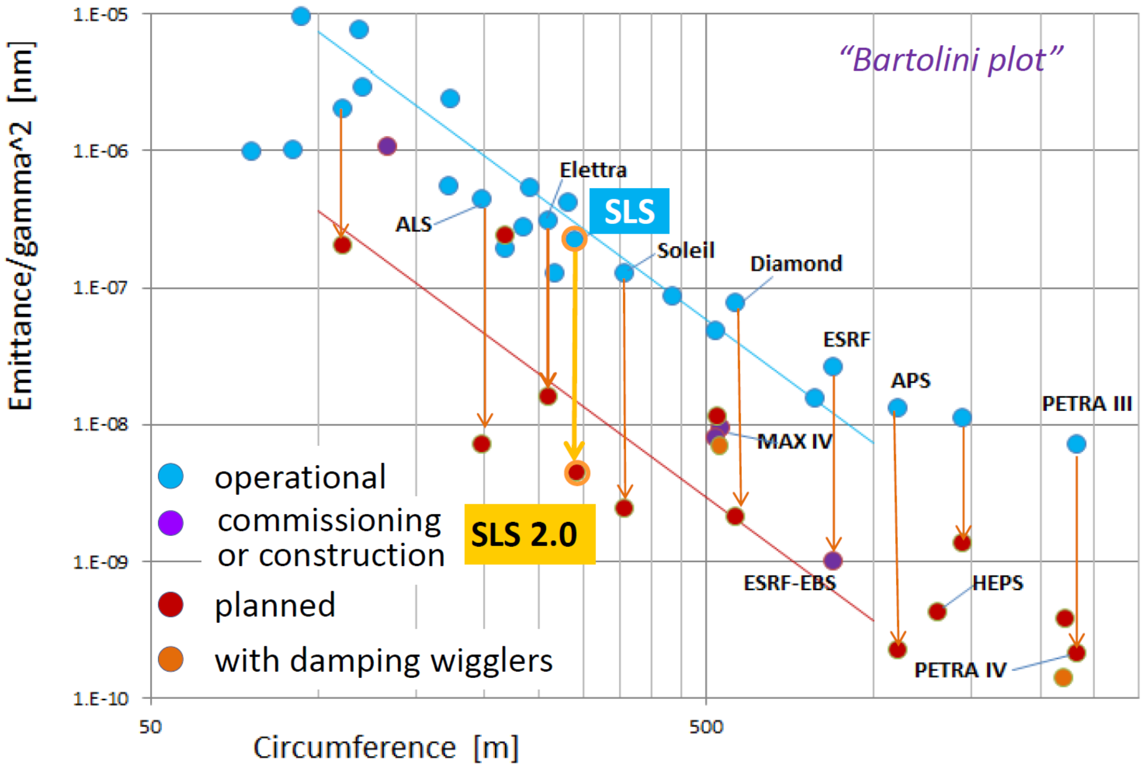
shielding
walls

- Energy of 2.4 GeV
- 288 m circumference
- 12 × TBA (triple bend achromat) lattice
- straight: 6 × 4 m, 3 × 7 m, 3 × 11.5 m
- 3 NC 3T super-bends
- Horizontal emittance 5.5 nm
- Vertical emittance ≈ 5 pm
- User operation since June 2001
- 18 beam lines in operation

Swiss Light Source upgrade SLS 2.0

Emittance normalized to energy vs. circumference

$\varepsilon_x \propto (\text{Energy})^2 / (\text{Circumference})^3$



Theoretical Emittance scaling

$\varepsilon \propto \gamma^2 C^{-3}$

$\ln\frac{\varepsilon}{\gamma^2} = K - 3 \cdot \ln C$

$K \approx 2 \rightarrow \approx -1$

improvement ×20

↓ upgrade projects

A. Streun (December 2018)

Project Goals :

– Replace SLS with significantly lower emittance design ($\varepsilon_x = 5500$ pm → 125 pm)

–Competitive with other machines coming on-line (MAX-IV, NSLS2, ESRF Upgrade, PETRA 3..)

– Maintain existing building, injector, beam lines **(small ring circumference constraint)**

Challenges for the SLS 2.0 magnet design & production (1)

- Extremely dense lattice arrangement
  - total: 888 electromagnets (4 types), 450 PM magnets (7 types)

- Bending magnets (and some quads) made from permanent magnets!
  - reduced power consumption (green machine)

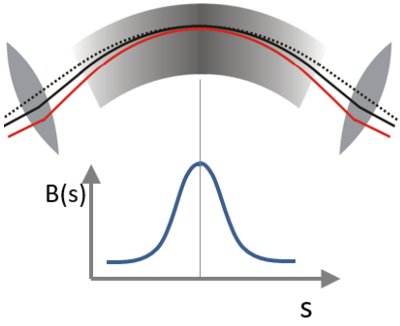
- Three superconducting bends (reaching minimum of 4 T field).
  - not from day one, but users ask for them early following beam commissioning

- Reduction in vacuum chamber cross section w.r.t. SLS: ø 18 mm.
  - Compact magnet designs require small magnet bore → need for smaller vacuum chamber

Challenges for the SLS 2.0 magnet design & production (2)

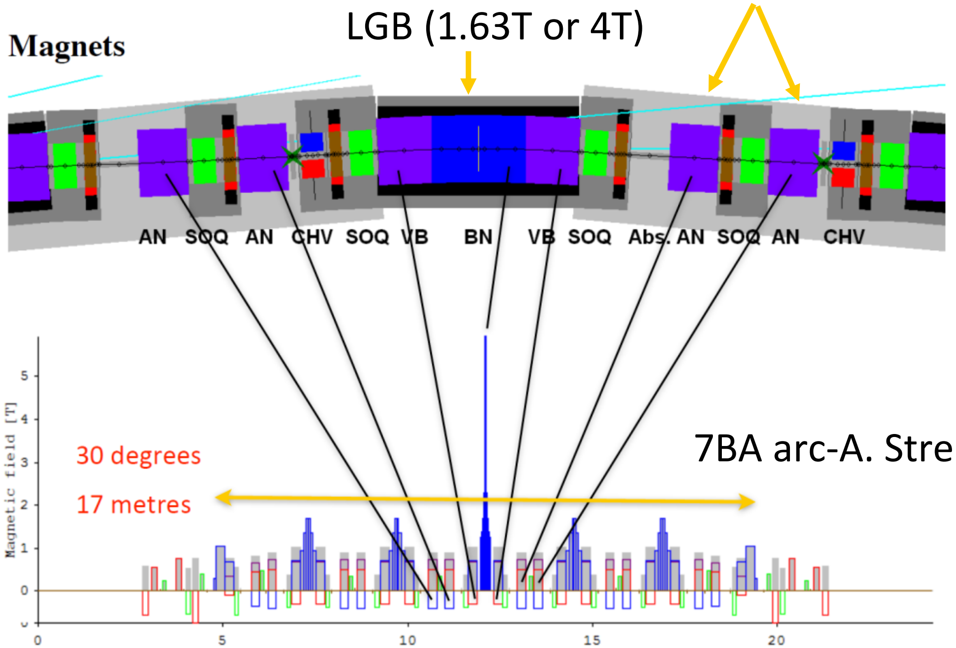
- Permanent LGB magnets with 1.63 T magnetic field peak
- SC super-bends with 4 T magnetic field peak
- Tight schedule for the design, production and measurements

(component installation from mid 2023- commissioning mid 2024)



PM off cent. quads

LGB (1.63T or 4T)

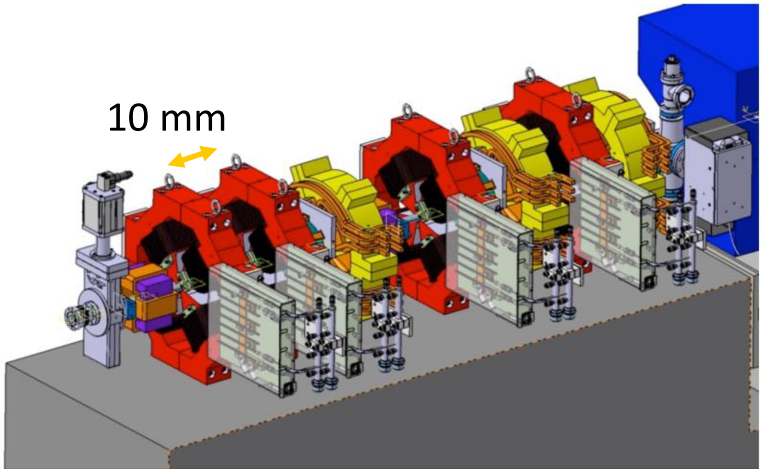


30 degrees

17 metres

7BA arc-A. Streun

Space is very tight!



S. Sidorov

Permanent Magnets for 1.6 T LGBs

Relative merits

- Compactness (transverse size)
- no power consumption
- Reliability: no cooling water vibrations, no power supply
- no maintenance

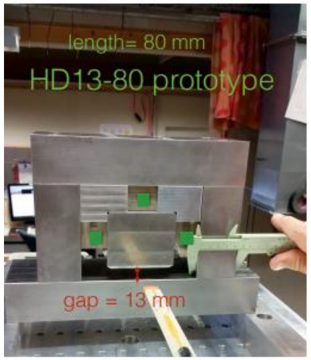
Challenges

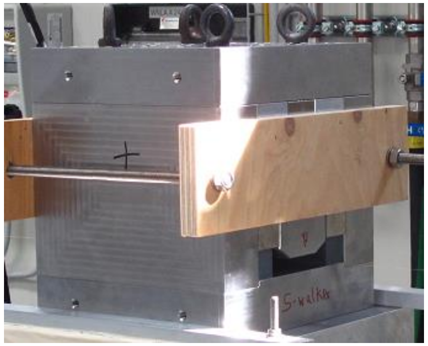
- choice of PM material (radiation damage vs. field strength)
- difficult assembly, dangerous handling, → design of assembly tools and assembly process
- cannot be opened → special mechanism to insert vacuum chamber
- Tuning difficult→ corrections by adjacent steerers and quads
- Temperature dependence

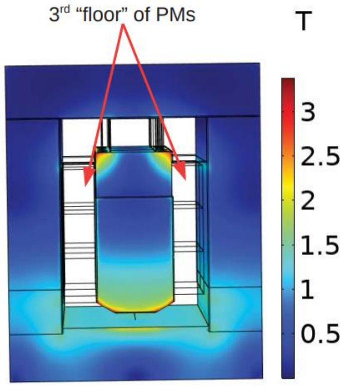
Talk Marco Negrazus

Tuesday

Prototyping period (magnets+assembly tools) from 2018 up to mid-2020







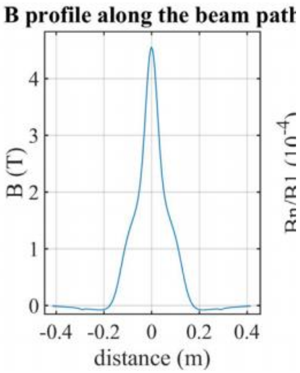
Half dipole with towers of PM blocks
9.5 mm x 32 mm x 40 mm, Br=1.1T

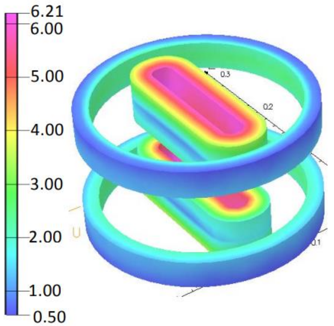
Superconducting LGB (4T minimum)

- Space constraints (longitudinal space: 415 mm; Vacuum chamber OD: 20 mm)
- Sharp peak (FWHM < 75mm) & short field integral (0.63 Tm)
- Open geometry (C-shape): Synchrotron radiation+ changing the magnet without touching the vacuum chamber

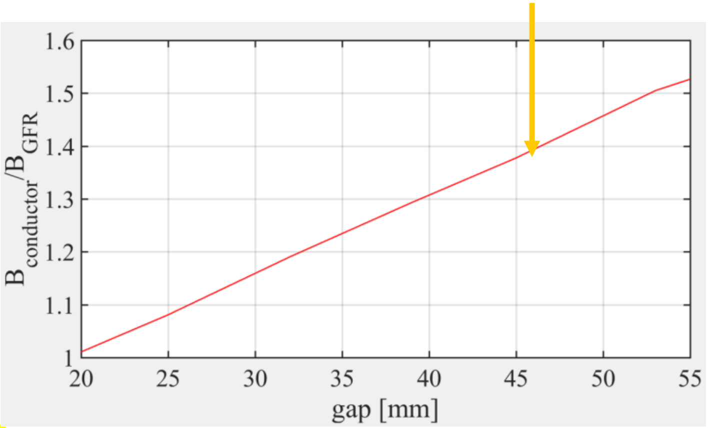
- large gap (46 mm)
- Conduction cooling with 1 cryo-cooler (efficiency, vibration)
- High ratio $B_{@conductor}/B_{peak}$

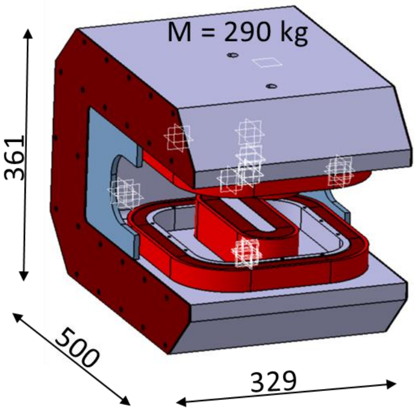
Magnetic design



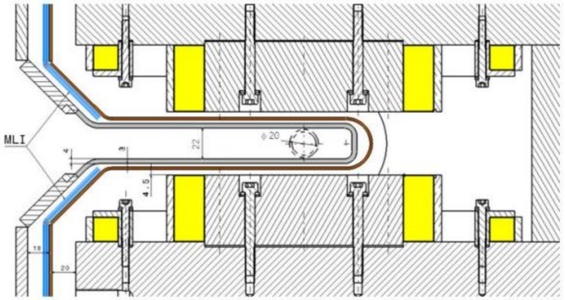


$B_{@conductor}/B_{peak} \sim 1.4$

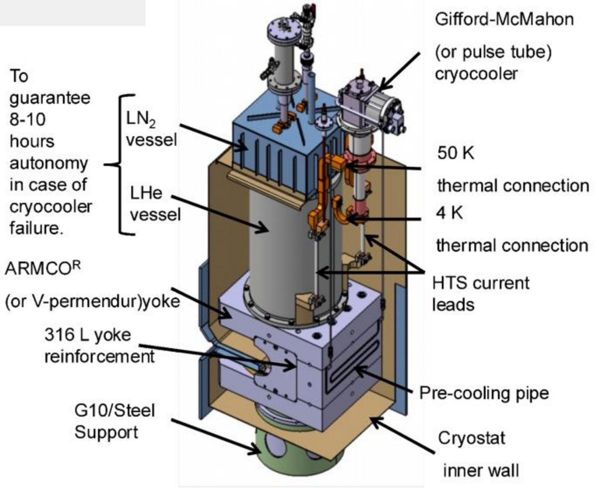




Mechanical design



	Req. space [mm]
Vacuum chamber OD	20
Vacuum chamber to cryostat (x2)	2
Cryostat walls (x2)	8
Cryostat to th. shield distance (x2)	6
th. shield walls (x2)	2
th. shield to coil distance (x2)	8
Tot.	46



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

LN_2 vessel

LHe vessel

Gifford-McMahon (or pulse tube) cryocooler

50 K thermal connection

4 K thermal connection

HTS current leads

ARMCO^R (or V-permendur)yoke

316 L yoke reinforcement

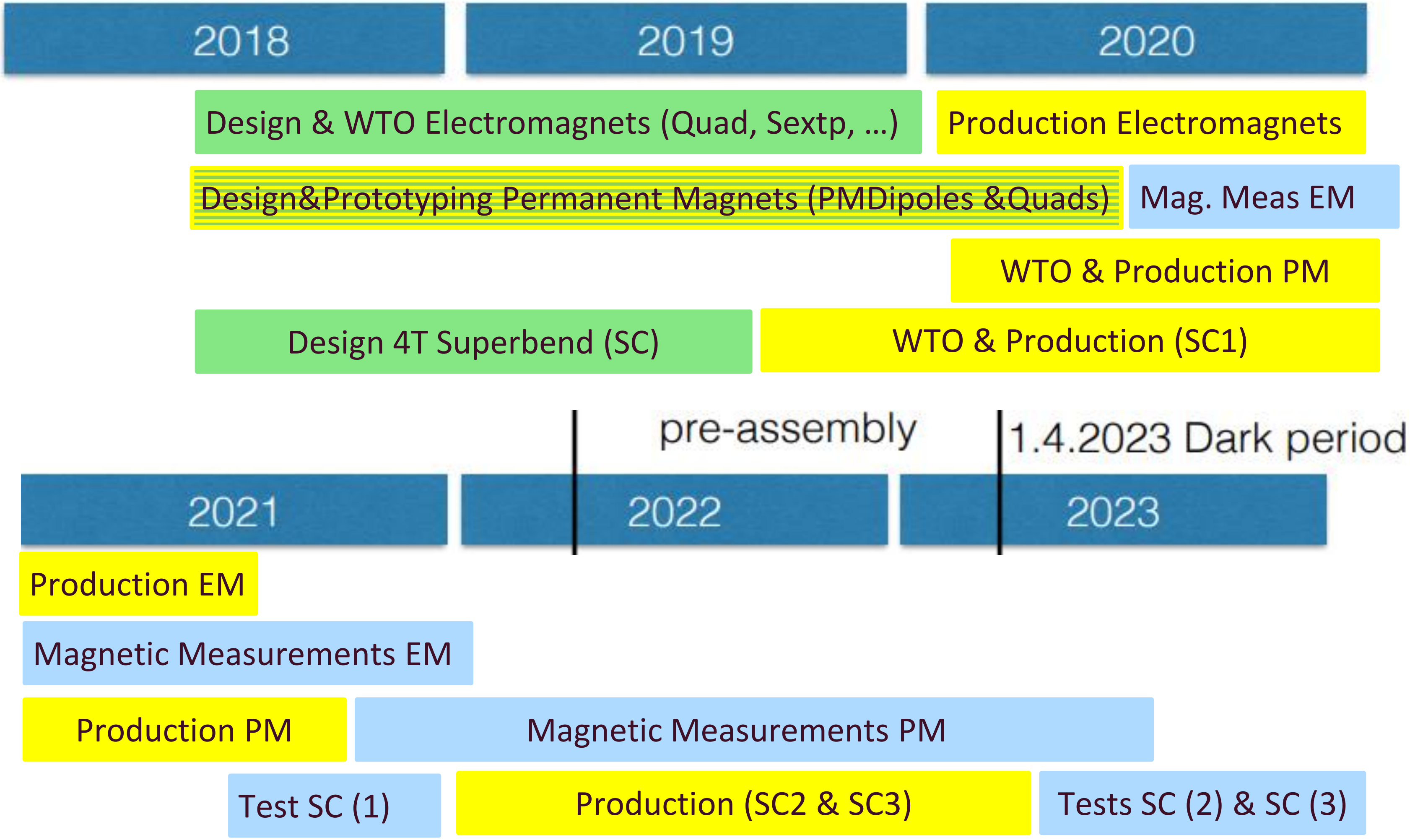
Pre-cooling pipe

G10/Steel Support

Cryostat inner wall

C. Calzolaio

Tight Schedule (status June 2019)



2018 | 2019 | 2020

Design & WTO Electromagnets (Quad, Sextp, …)

Production Electromagnets

Design&Prototyping Permanent Magnets (PMDipoles &Quads)

Mag. Meas EM

WTO & Production PM

Design 4T Superbend (SC)

WTO & Production (SC1)

pre-assembly

1.4.2023 Dark period

2021 | 2022 | 2023

Production EM

Magnetic Measurements EM

Production PM

Magnetic Measurements PM

Test SC (1)

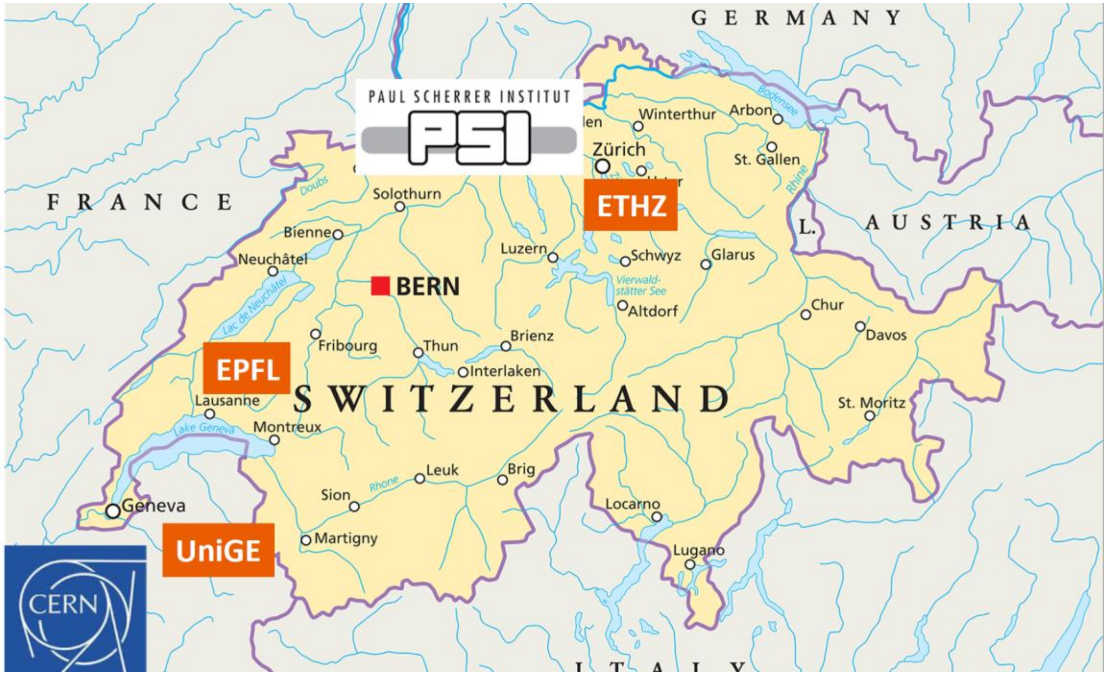
Production (SC2 & SC3)

Tests SC (2) & SC (3)

- Prototyping phase for the PM Magnets up to Mid 2020
- Magnetic measurements: EM up to mid 2021; PM 2022-2023
- Commissioning in 2024 without SC superbends

CHART= Collaboration of Swiss Accelerator Research and Technology centers

- ❑ Future accelerator technologies, emphasis: high field magnets
- ❑ Accelerator concepts for synchrotron light sources, medical and industrial applications
- ❑ Three areas of research
  - ○ Superconducting magnets
  - ○ Particle collider design
  - ○ Laser and THz acceleration



Leonid Rivkin

Commitments from Swiss Secretary of Research and Innovation, ETHZ, EPFL, PSI, UniGE and CERN to fund these activities up to 2023

Area of Superconducting Magnets
Phase 1 (2016- 2019)

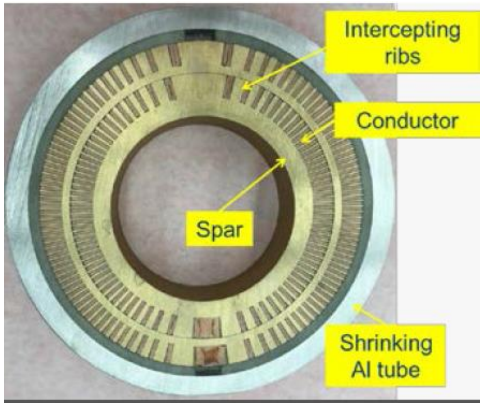
Goals:

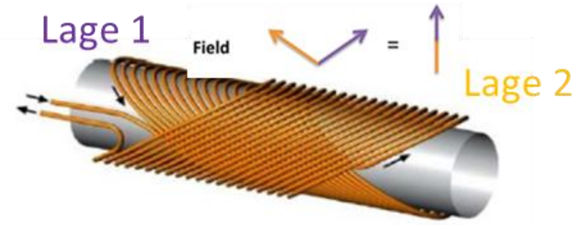
1. the development (design and prototype) of a 16 T dipole magnet with Canted Cosine Theta (CCT) technology as an option for the FCC hadron collider main magnet;

2. the development of reaction-resistant splicing techniques for Nb_3Sn magnets for FCC

CCT design = Two oppositely tilted solenoids:

Pure dipole field , solenoid component cancelled





Area of Superconducting Magnets
Phase 1 (2016-2019)- PSI SC Magnet Lab

Nb_3Sn technology introduced at PSI

90 m^2 laboratory refurbished, equipped, commissioned

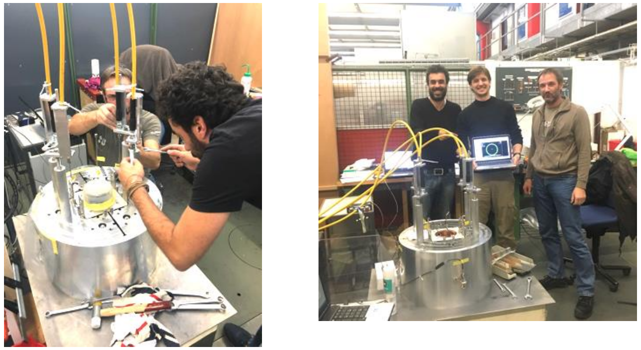
B. Auchmann

Area of Superconducting Magnets
Phase 1 (2016-2019)- CCT Model

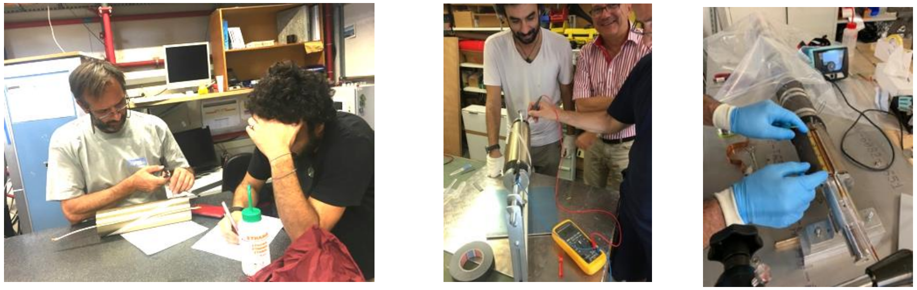
CCT technology transferred from LBNL, adjusted towards FCC criteria

Production of the first 2 layers CCT model CD1 (cold test at LBNL end of 2019?)

Winding



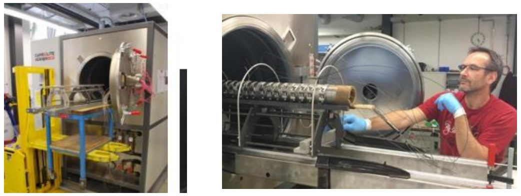
Assembly



Instrumentation

Inner layer

The two layers



Thermal treatment

Impregnation

The PSI SC magnet team

Area of Superconducting Magnets Phase 2 (2019-2023)

Nb3Sn Magnets

Design, build, and test superconducting-magnet models according to FCC design study

- Build the CCT option of a 16-T Nb3Sn dipole short model for FCC-hh
- Develop 2-m-long prototypes of 16-T Nb3Sn dipoles up to the pre-industrialization stage
- Superconducting wire production development (FCC specification)

High Temperature Superconducting (HTSC) Magnets

Design, build, and test high temperature superconducting-magnet models according to CERN and PSI strategic goals in view of future application for the FCC magnets:

- Develop technologies for HTS based accelerator magnets
- Design, build, and test an HTS variant of the SLS 2.0 superbend magnet
- Design, build, and test several periods of an HTS undulator magnet

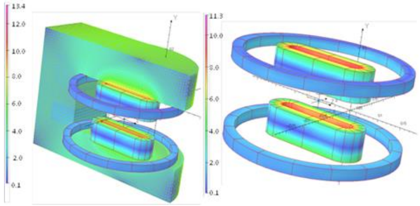
Infrastructure

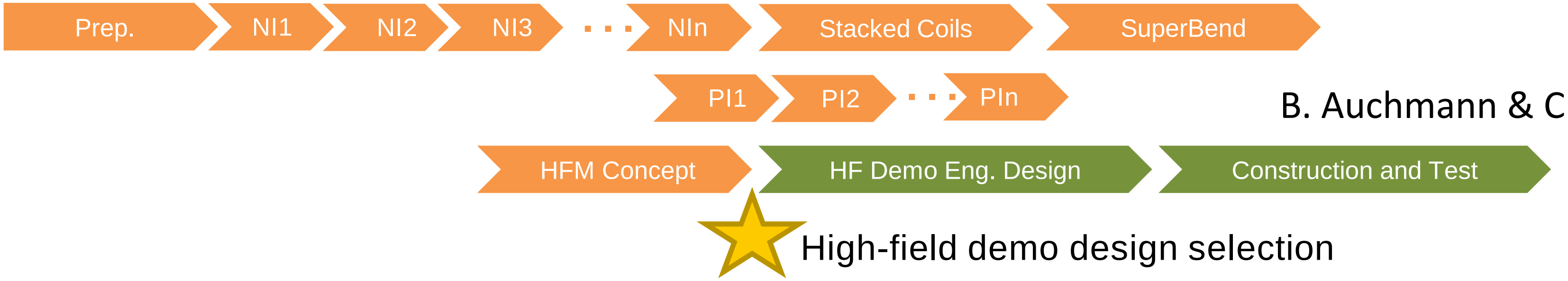
To establish the infrastructure needed to build and test all aspects of FCC-hh, HE-LHC magnets and other SC accelerator magnets

Example: HTS SLS2.0 SuperBend

- Upgrade of the SC superbend for SLS2 with higher fields (>6T)
- An LTS version will be built first in industry for the SLS2 machine
- R&D on HTS coils with fast turn-around (1....10)
  - Round pancakes → single-layer racetracks → stacks of pancakes/racetracks
  - Testing in LN_2 and at the PSI cryogen-free test station (self field)
- R&D development on cooling system using Pulsating Heat Pipes
- Design, construction and test→ of HTS Super-Bend magnet

→ Tools and experience for High Field accelerator magnets for FCC





High-field demo design selection

B. Auchmann & C. Calzolaio

Magnet infrastructure development at PSI (2019-2020)

Construction SC magnets

Construction and test NC, PM magnets and IDs

Test SC magnets

Infrastructure

Infrastructure for SLS2 magnets, insertion devices and SC magnets

1-WLHA building: to normal-conducting magnet workshop, field-quality measurements, insertion devices assembly and magnetic measurements (600 m^2)

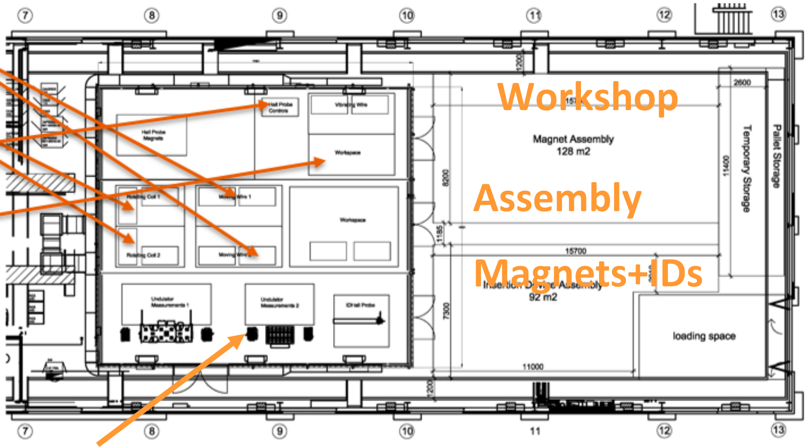
2-Extension for a ~400 m^2 laboratory space for CHART phase 2 (SC magnet production)


April 2019

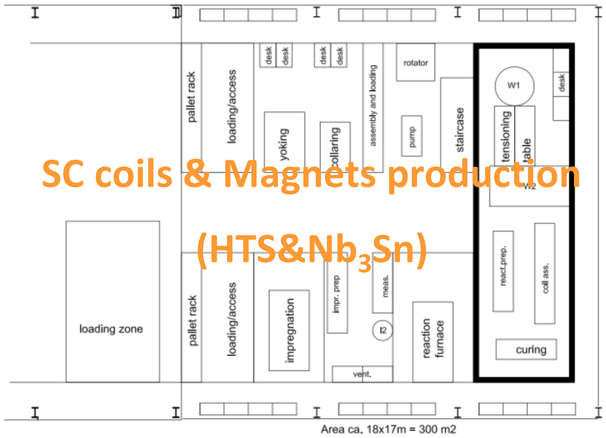

April 2019

Magnetic measurements (magnets+ID)

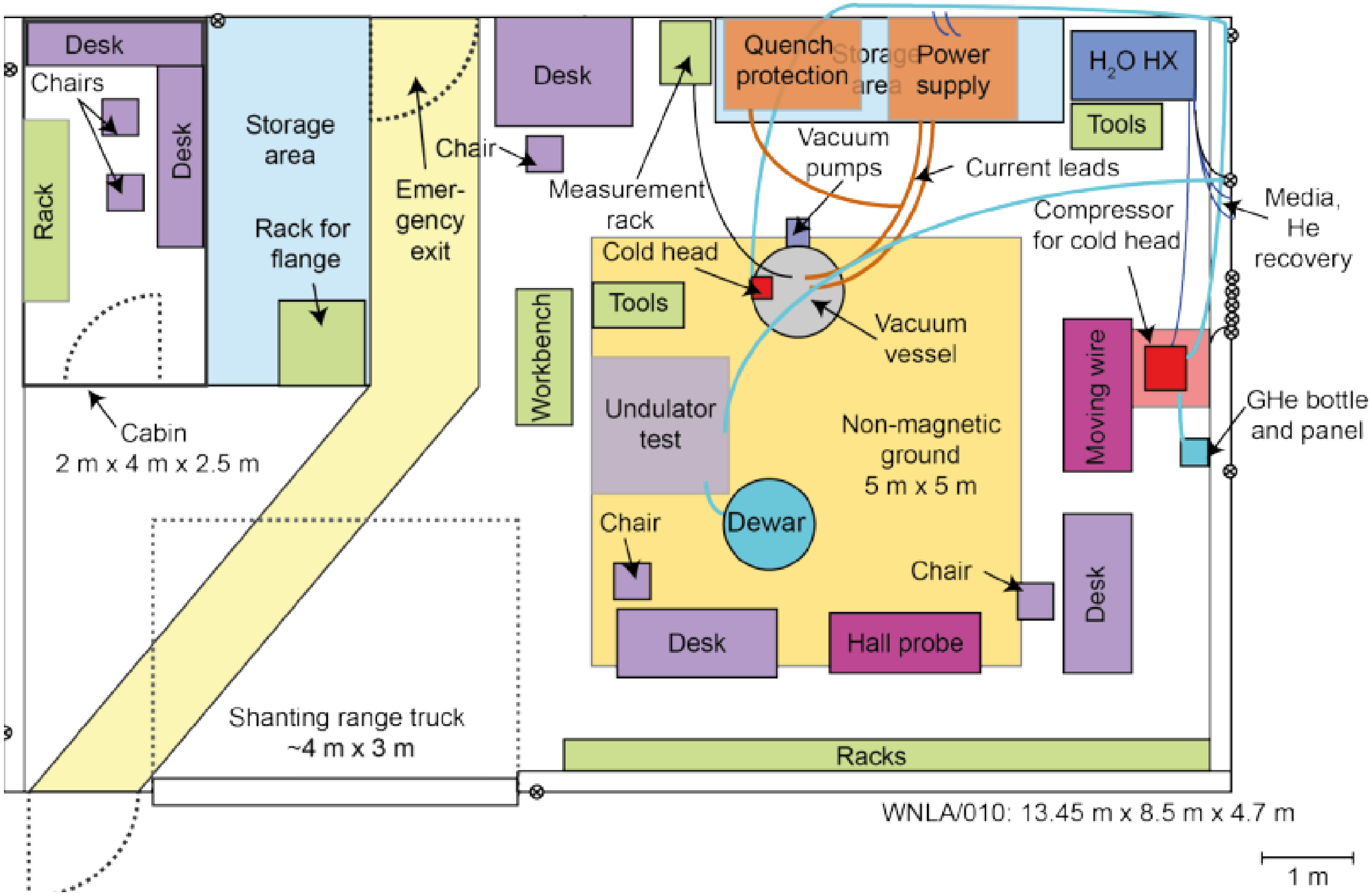
- –Moving wires
- –Rotating coils
- –Hall probes
- –Vibrating wire
- –Helmholtz coils



ID measurement systems



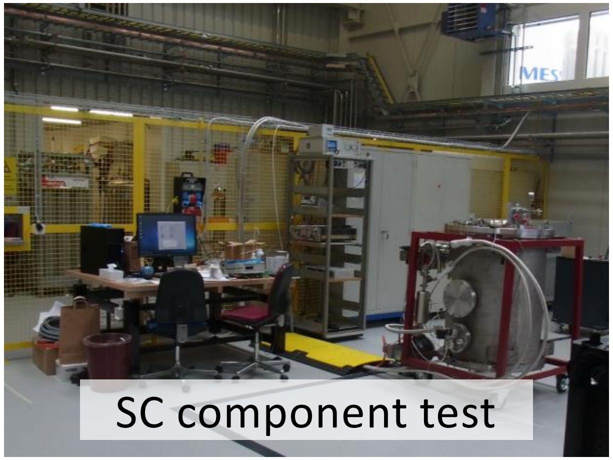
Cryogen Free Magnet Test station(100 m²) 2018-2019



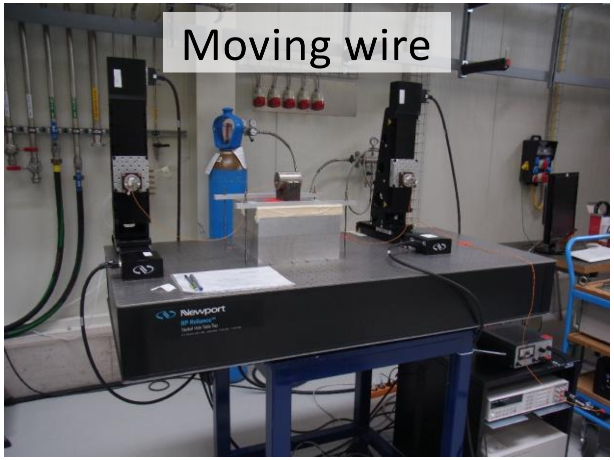
- **Tests of the SLS2 SC superbend**
- **Magn. measurement systems**
- **Tests of HTS coils**

Lab for tests of SC magnets and components (100 m²) (2018-2019) in construction


Office and storage


SC component test


Hall probe test and storage

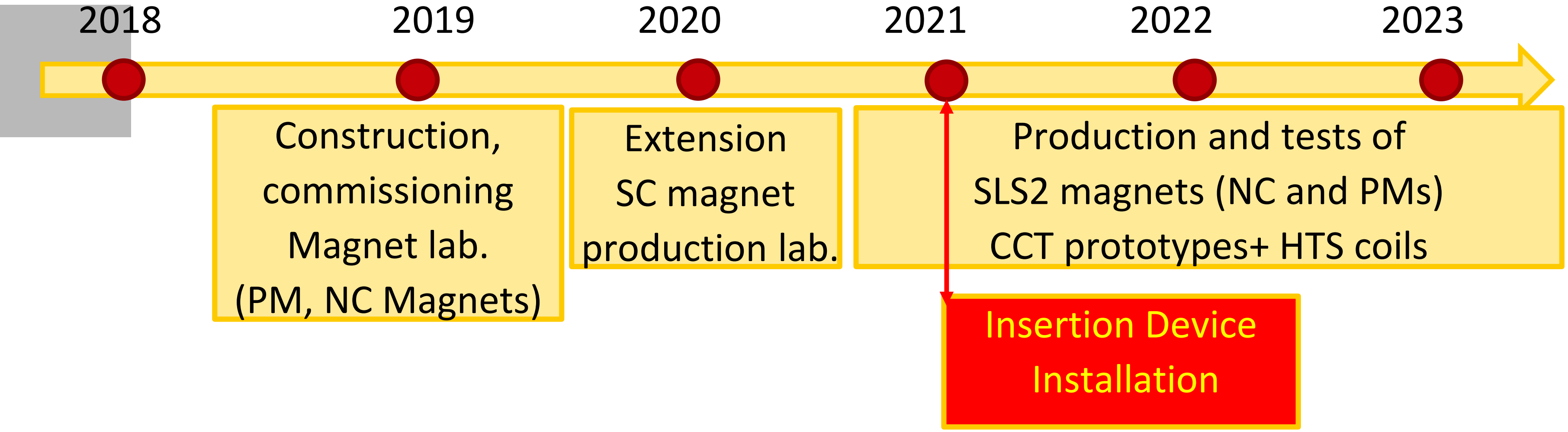

Moving wire


Cryostat


Three axis-Hall probe

Time line-Infrastructure

Mag &ID Lab



2018

2019

2020

2021

2022

2023

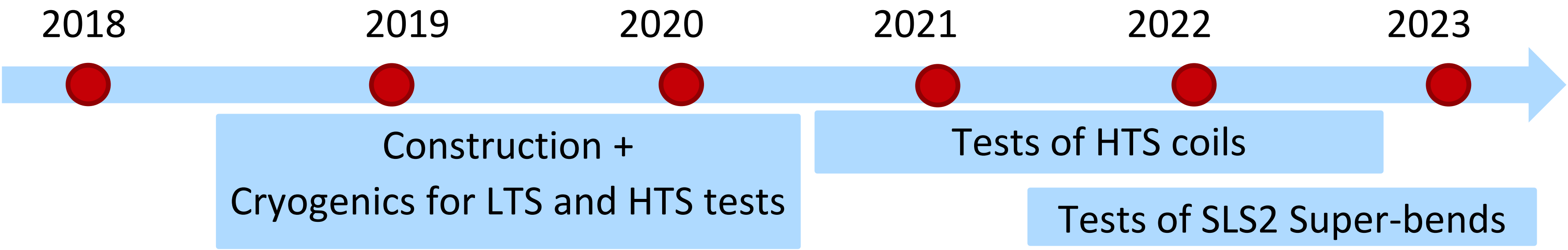
Construction, commissioning Magnet lab. (PM, NC Magnets)

Extension SC magnet production lab.

Production and tests of SLS2 magnets (NC and PMs) CCT prototypes+ HTS coils

Insertion Device Installation

Cryogenic Test Stand



2018

2019

2020

2021

2022

2023

Construction + Cryogenics for LTS and HTS tests

Tests of HTS coils

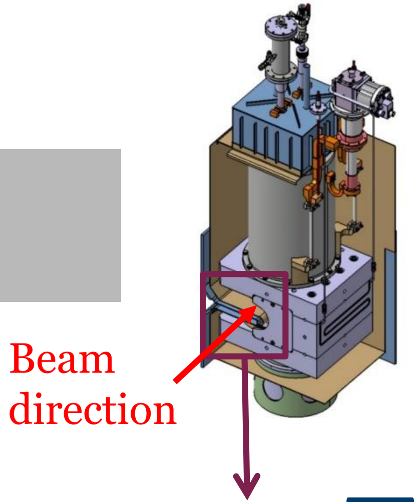
Tests of SLS2 Super-bends

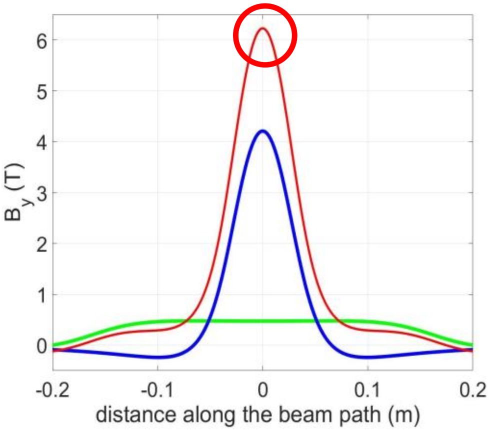
Magnetic measurement systems (SLS2)

	Strechted wire (s)	Three axis – Field Mapper (CFM)	Rotating coil(s) (∅ 19 mm)	Vibrating wire
LGB Dipoles	Field Integral	Field Maps		
Quadrupoles			Field Integral Multipoles	Magnetic axis
Sext./Octu.	Field Integral			Magnetic Axis
Steerers	Field Integral			
Dipole/ Quadrupole	Alignement			
Status systems	1 in commissioning +1 (2020)	Ready mid 2020	OK 1 spare needed	OK

All the equipment should be operational mid-2020

Compact Field Mapper for LGB dipoles (CFM)



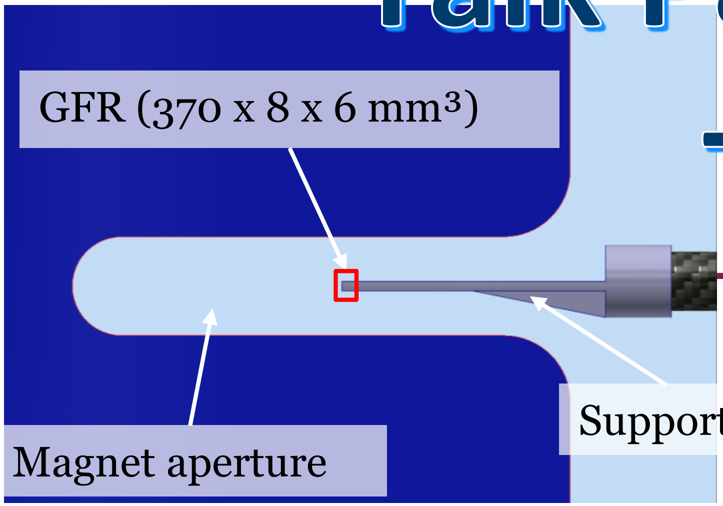


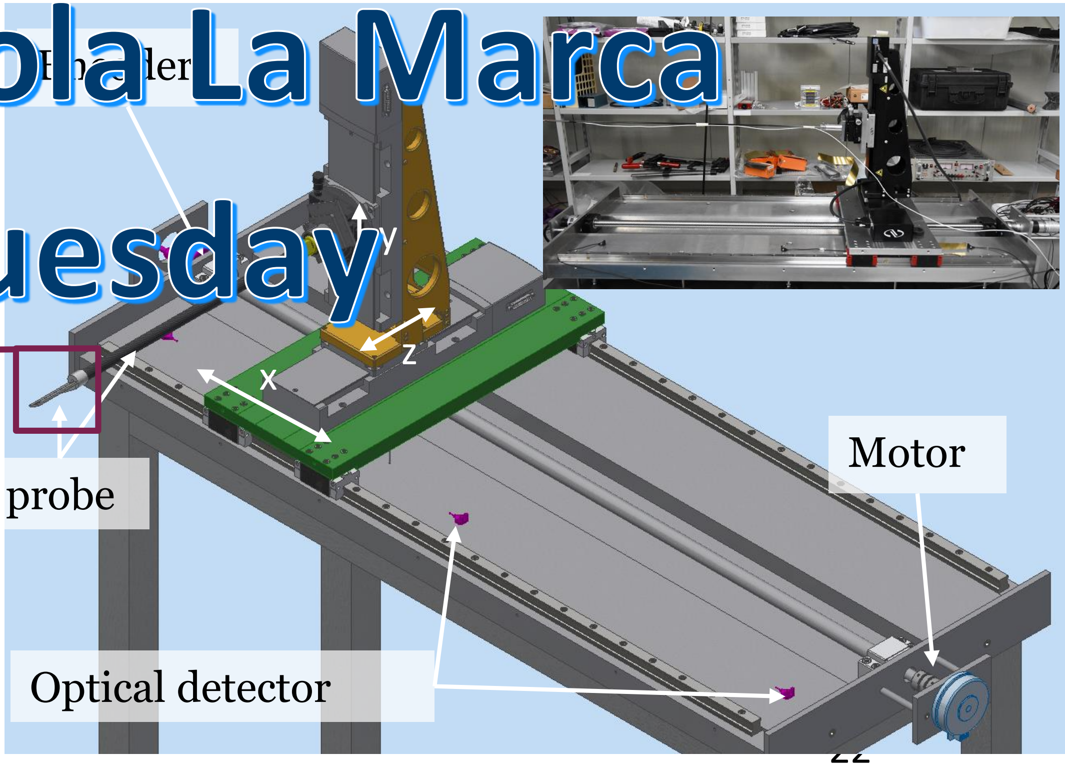
magnetic field profile

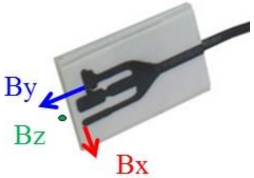
Challenges: Field gradient

- 3 directions
- accuracy 0.1 %
- 200 measurement points in 1 mm length

Talk Paola La Marca Tuesday

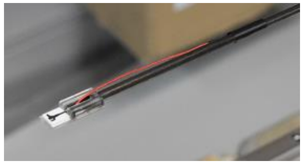






SENIS

Sensor



Rotating Coil for 16 T CCT magnet

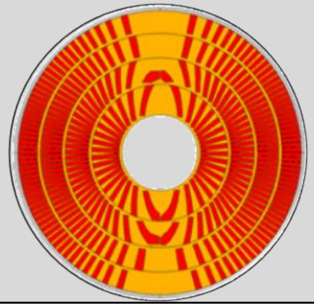
- **2-m long single aperture 16 T CCT model magnets to be measured @RT (horizontal) and @4.2 K (vertical cryostat)**
  - ✓ **Accuracy b1 ~ few units**
  - ✓ **Repeatability: few units (expected b_3 and b_5 of tens of units)**
  - ✓ **Field Quality+ field profile**

- **Measurement requirements**
  - Minimum of 5 coils segments (500 mm each) to cover the magnetic length (1.5 m) and magnet's heads
  - @300 K: avoid pre-amplification of coils signals
  - @4.2 K: rotating coil shaft in helium bath

- **Coil design**
  - Segments of **3 coils**: 2 tangential – 1 radial (1 tangential absolute; tangential-radial compensated)
  - Coil manufacturing technique: @300 K:G10 support installed on ceramic support tubes (need calibration);
  - @4.2 K: PCB coils (need calibration at warm->contraction factor correction works at cold)

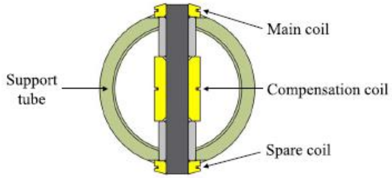
- **Some challenges**
  - @ 300 K: Optimization of a) shaft segments interconnections for high revolution speed (as high as 10 rps) and b) coil geometry for maximum sensitivity
  - @4.2 K: Design of simple and effective coil support for cold operation

16 T CCT Coils

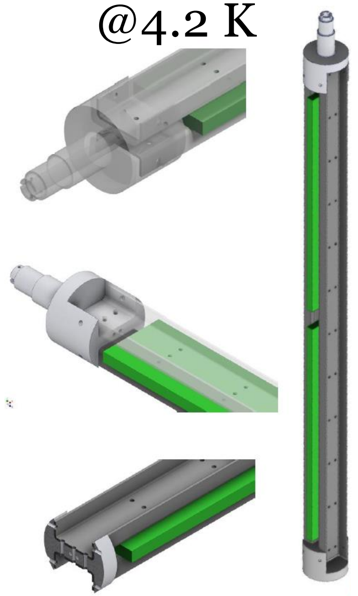


Example of CERN designs

@room temperature



@4.2 K



Challenges - summary

- Design, produce and measure a massive number of compact combined function magnets for the SLS upgrade

- Manufacture and test of High Field Magnets (16T and above)

- Technological challenges :

✓ Permanent magnet technology for LGB's up to 1.63 T
✓ SC technology for high field LGBs (4T and above) and Insertion Devices
✓ Nb3Sn and HTS technology (16 T and above)
✓ Heat transfer based on helium and nitrogen Pulsating Heat Pipes

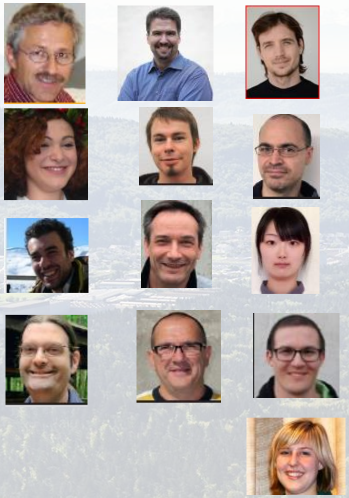
- Challenging schedule for SLS2 and CHART Phase -2

- New infrastructure ready mid-2020

- Reinforcement and diversification of the magnetic measurement system park needed before the series magnets

Wir schaffen Wissen – heute für morgen

My thanks to:

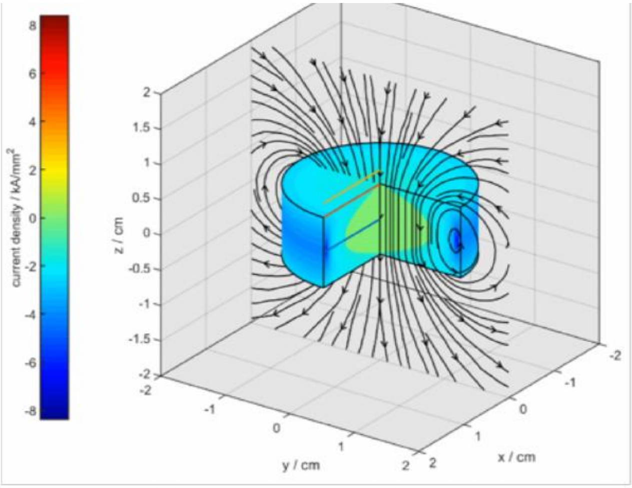


Thank you for your attention

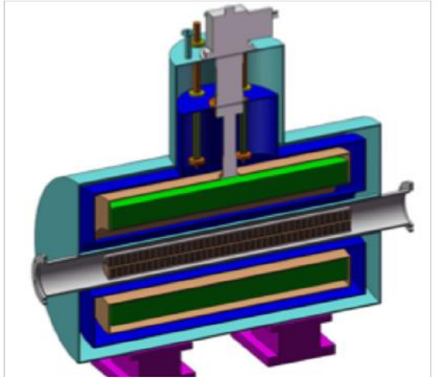
Questions?

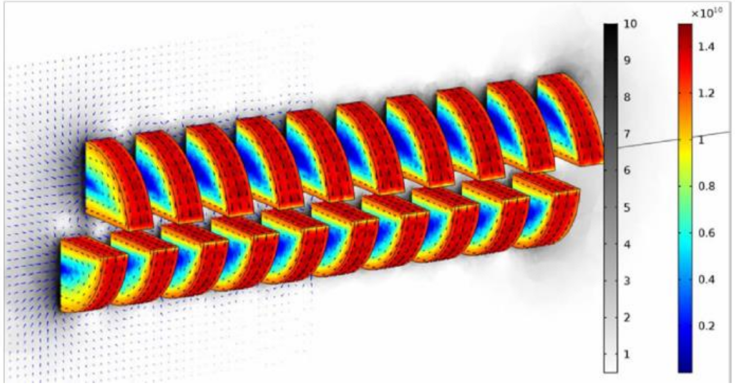
Example 2 : HTS 10 mm period undulator model

- The High-Temperature SC Undulator project is underway at the PSI Insertion-Devices group.
- Managed by M. Calvi with two post-docs.
- A collaboration agreement with the Univ. Cambridge aims at 10-periods of a 2-T, 10-mm period (4-mm gap) proof-of-concept undulator from GdBCO bulks.



- CHART2 goals:
  - Test two geometries for linearly and circular polarized light, respectively.
  - Study a hybrid solution with ferromagnetic poles added to reinforce field.
  - Test stacked tapes as alternative to bulk; decide upon final geometry.
  - Construction of 1-m-long prototype
    - in cryostat with 12-T magnetizing solenoid with an industrial partner.
    - to be tested in a PSI accelerator.

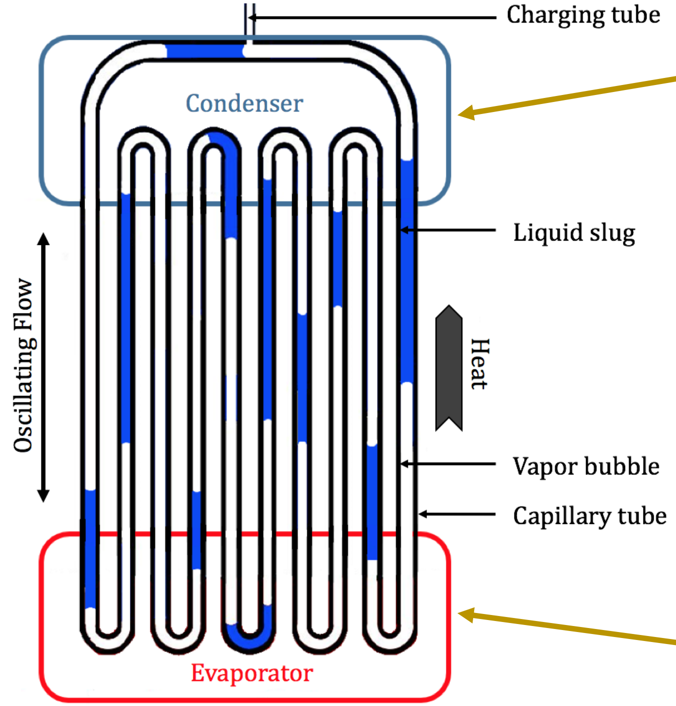




M. Calvi

Pulsating Heat Pipe (PHP)

- Passive two-phase heat transfer devices
- Using oscillatory flow of liquid slugs and vapor plugs



M. Barba, B. Baudouy et al., CEA Saclay

Connection to Cryocooler for removal of heat

Very good heat transfer

Connection to shield (nitrogen PHP) or coil (helium PHP) for cooling

Collaboration between CEA and PSI planned for HTS super-bends