Building the Magnets of Tomorrow: Research on accelerator magnets at PSI

S. Sanfilippo and D. Martins Araujo

for the PSI magnet section

Magnet section in the PSI Large Resarch Infrastructures

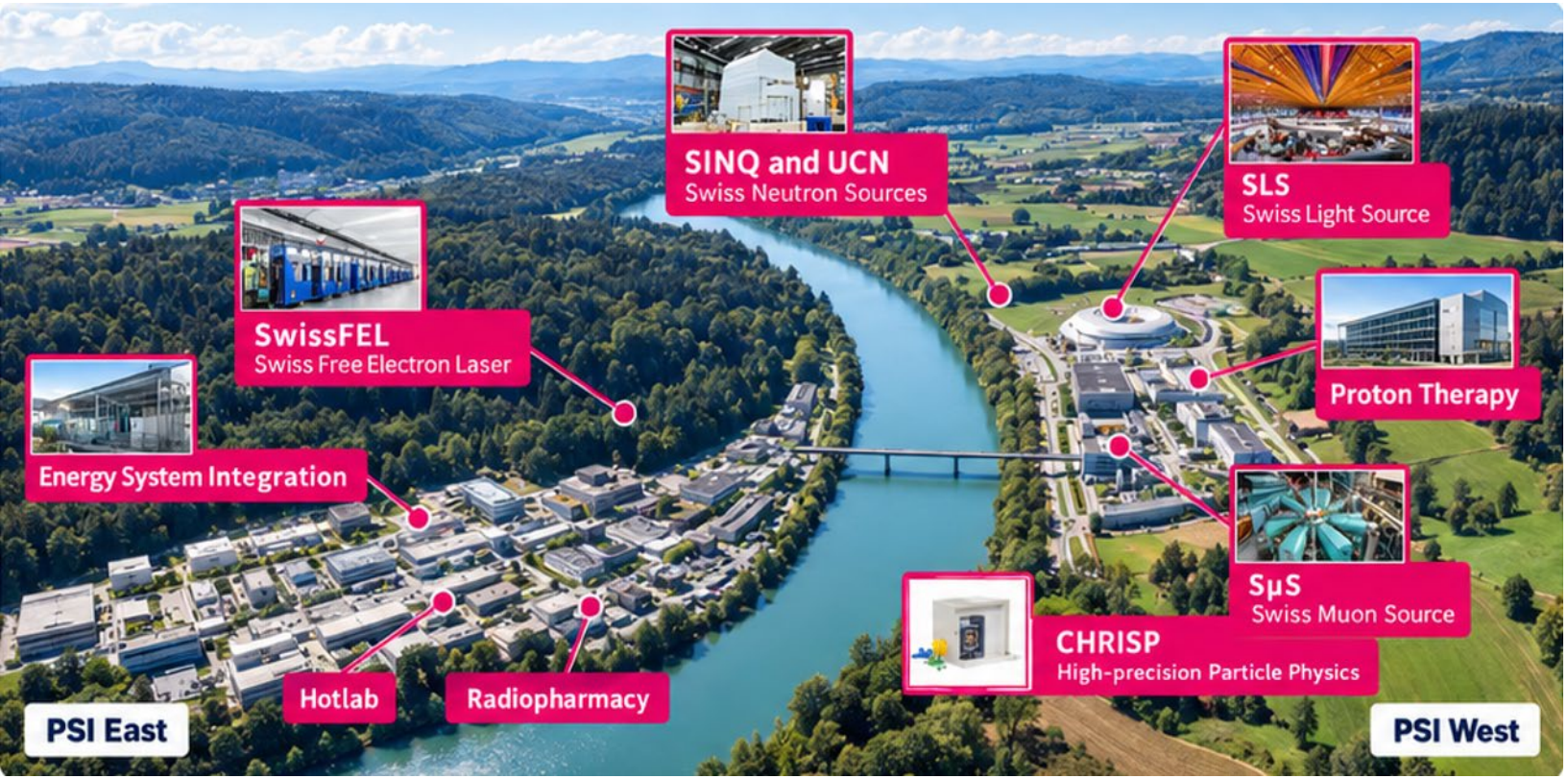
- Focus 1: Energy-Efficient Magnets for PSI Research Facilities
- Focus 2: Magnetic Measurement Systems
- Focus 3: CHART – High-Field Magnet Technologies & HTS Magnets for Fusion (PSI–Proxima Fusion Cooperation)

4th Swiss ITER Suppliers meeting / PSI / 5th November 2026

Paul Scherrer Institute at a glance

Large-scale research infrastructure for science, society and innovation

PSI



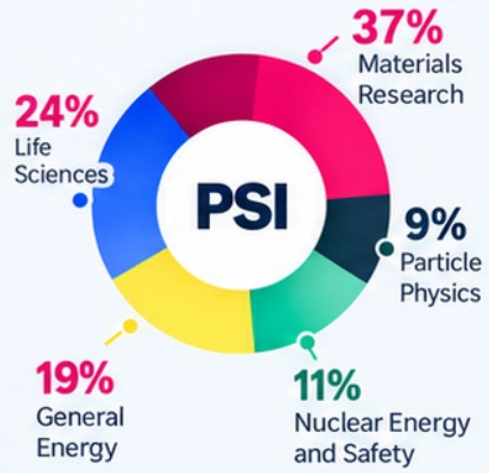
PSI IN NUMBERS

2,300 Employees

6 Major research facilities

~2,200 Researchers hosted in 2025

RESEARCH AREAS



Park Innovaare: industry link

Ecosystem: start-ups, spin-offs, SMEs and R&D departments of established companies



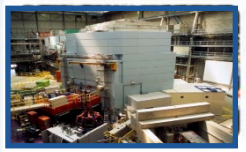
ACCELERATOR-BASED LARGE RESEARCH FACILITIES



SLS 2.0
Light source



SwissFEL
X-ray free-electron laser



SINQ
Neutron source



SμS
Muon source



CHRISP
Particle physics (UCN, pions, PIF ...)

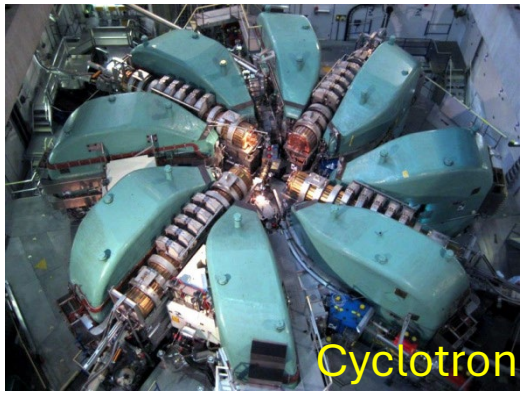


PROSCAN
Proton therapy

Magnets in operation at PSI in 2026

Magnets in Operation at PSI

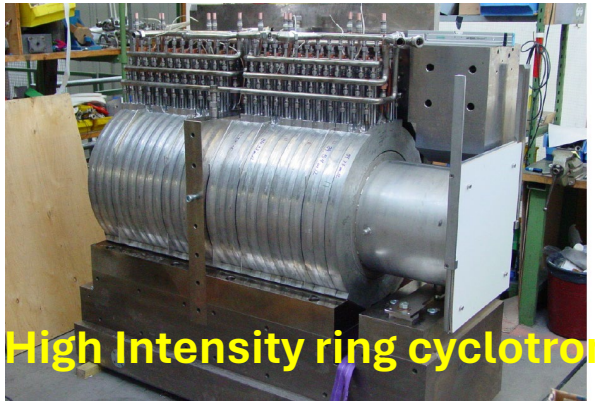
Machine	*Magnet number*	*In operation since*
HIPA	300	1974 (Ring) 1984 (Inj. II) 1996 (SINQ)
PROSCAN	100	2004
Gantry 3	*13*	*2017*
SwissFEL	*373*	*2017&2021*
SLS2.0	*1019*	2025
Total	*1805*	
HIMB TATTOOS	*34*	*2027 & 2029*

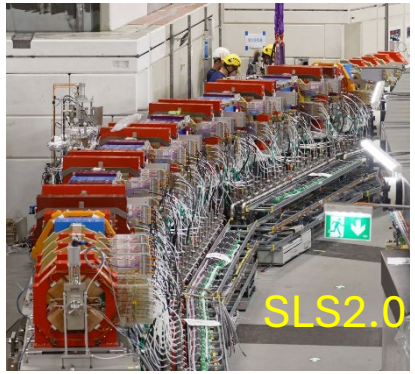












80 % are Electromagnets - 372 Permanent Magnets (SLS2.0)+ one superconducting cyclotron

Magnet section mission

CORE MISSIONS

Magnets for PSI research facilities

Design, construction and qualification of magnets for future large-scale facilities

Superconducting technologies

Efficient, high-field magnets based on advanced superconducting technologies

Testing and Magnetic Metrology

Magnet assembly, testing and magnetic measurement systems

Research and Industrial Collaboration

Joint R&D with academia, research laboratories and industry- link with Park Innovaare

FULL LIFECYCLE ENGINEERING CAPABILITIES

- Design and Engineering
- Manufacturing and assembly
- Testing @ room and cryogenic temperatures & magnetic qualification
- Operation and maintenance

OPERATIONAL RESPONSIBILITY → Absolute priority

minimising downtime through preventive maintenance, efficient repairs and critical spare parts

~ 30 specialists and students across four groups, combining engineering, technical development and research expertise.

Superconducting Magnet R&D Roadmap (simplified)

PSI

High field magnet technologies up to 20 T

Efficient and sustainable magnets

Enabling technologies & infrastructure

Coils
Sub-scales
Demonstrators
Magnets

Design, manufacturing & tests

Magnet architecture
Cables
Winding tools
Heat treatment
Impregnation
Assembly
Cooling & powering
Quench detection
Performance
Field quality

High-field magnet technologies for FCC, fusion and sustainable accelerators

CHART Swiss Accelerator Research and Technology

Synergies

SC Magnets for PSI's operating research facilities and their upgrades

MORE SCIENCE — LESS ENERGY
with LTS & HTS technologies

The efficiency and sustainability dilemma for present and future research infrastructures at PSI and around the world

↑ SCIENTIFIC PERFORMANCE

Higher beam intensity
Higher magnetic fields
More compact & powerful facilities

Upgrades must deliver more science.

PSI
≈140 GWh electricity / year

THE DILEMMA

Higher Performance and lower energy consumption

↓ ENERGY & FOOTPRINT

Lower electricity demand
Lower cryogenic losses
Lower lifecycle impact

Sustainability must improve at the same time.

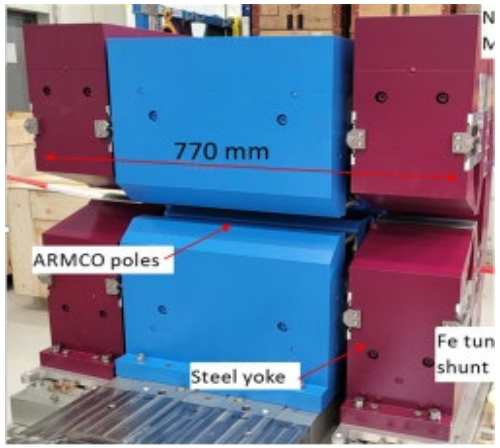
How can future research infrastructures increase accelerator performance without increasing their energy and environmental footprint?

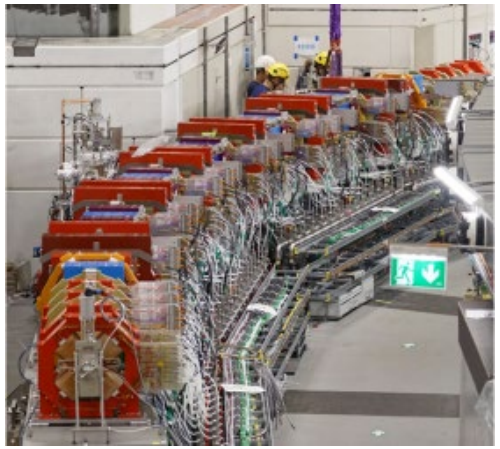
CHART&SMILE&HTS4SRI **LTS& HTS magnets + efficient cryogenics + smart powering + sustainability-by-design**

A systemic approach integrating innovation, scientific performance, energy efficiency, and environmental responsibility

The pioneering example : the SLS2.0 storage ring

PERMANENT MAGNETS

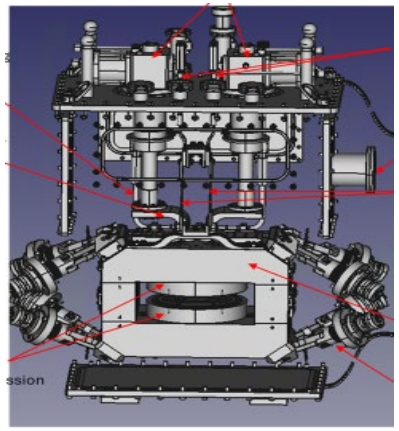


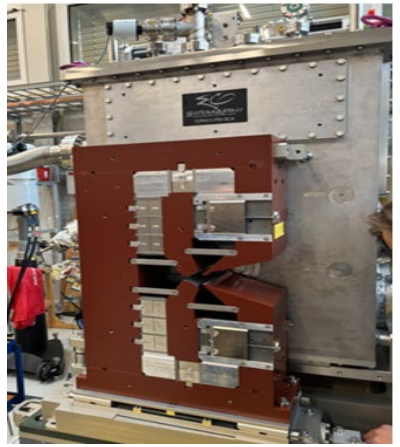


372 /1143 (total)

NdFeB permanent magnets* (2025)

SUPERCONDUCTING SUPERBENDS





2 × 5 T

NbTi Superbends (installation end of 2026)

MAGNET POWER RATING

800 kW → **250 kW**

0.5 Meur/annual saving

–69%

- 3.8 GWh/a

Next step : upgrade with additional HTS conduction cooled dipole superbend

* Supported by the Swiss program ProKilowatt

the SMILE initiative : Technological framework

Superconducting **M**agnets to **I**mprove **L**arge research facility **E**fficiency at PSI

Explore the operating limits of HTS magnets to improve PSI facility performance, compactness and energy efficiency

HTS MAGNET TECHNOLOGY — INVESTIGATION FRAMEWORK within PSI operation

Magnet configuration	Operating envelope	Key technological challenges
Moderate/low fields DC magnets	Magnetic field < 8 T	Thermal stability, cryogenic efficiency, field quality, quench detection and protection.
Compact superferric AC magnets	Low field ≤ 2.5 T; high ramp rates	AC losses & field quality:
Large-aperture solenoids	Large magnetic volumes	Mechanical forces, field uniformity, cooling.
Radiation-exposed HTS magnets	Dose rate up to few Gy/s	Radiation tolerance, insulation integrity, lifetime reliability.

Explore the potential of HTS technologies to improve magnet performance, compactness and energy efficiency under the PSI operating conditions.
Modelling studies, technology development and implementation in selected PSI's magnets

SMILE Research Activities

Superconducting **M**agnets to **I**mprove **L**arge research facility **E**fficiency at PSI

Three complementary activity poles

POLE 1

Efficient DC magnets

HIPA

Incl. radiation qualification
magnet design & assembly

POLE 2

Compact AC magnets

HTS cable and coil studies

Numerical & experimental AC-loss studies on coils

POLE 3

Efficient magnet cooling

Pulsating Heat Pipes (PHP)

PHP modelling and HTS-coil validation

Targets : Dipoles of HIPA (~2 T) and TATTOOS – 7T HTS solenoid for Mu-EDM project

https://intranet.psi.ch/de/uem/aktivitaeten

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some topics included in the EU-funded project HTS4SRI (2026–2030)

EU Project (HORIZON-INFRA-2025-01-TECH-01) : HTS4SRI – Overview, Partners & Roadmap

A four-year European project: High-Temperature Superconductors for Sustainable Research Infrastructures

PSI

Project at a glance

Duration:	4 years (2026–2030)
Start:	1st September 2026
Coordinator:	PSI
Participants:	8 partners + EU
Budget:	7.57 M€ total
EU contribution:	5.0 M€
In-kind	2.57 M€
Work Packages:	6

Our partners

8 institutions+ EU support • A common vision for sustainable research infrastructures

UNIVERSITÀ DEGLI STUDI DI MILANO

INFN Istituto Nazionale di Fisica Nucleare

CERN

Horizon EU 101292103 HTS4SRI

Ciemat

cea

BRUKER

GSI Helmholtzzentrum für Schwerionenforschung

PSI

Our 5 objectives

A sustainability-driven pathway from HTS technology development to accelerator-scale validation

01 ADVANCE HTS MAGNET TECHNOLOGY
TRL 3 → 6 • Average energy savings of 50% compared with resistive magnets over their duty cycle.

02 OPTIMIZE THE HTS ECOSYSTEM
Radiation-hard REBCO • Coil design • Cryogenics • Efficient powering (Cryogenic Electronic Power Supply)

03 SUSTAINABILITY BY DESIGN
Life Cycle Assessment • Sustainability-Integrated Design & Manufacturing Practices

04 DEMONSTRATE AT ACCELERATOR SCALE
SIS18 quadrupole • 4 T TATTOOS Dipole • FCC-ee combined-function magnet

05 BUILD KNOWLEDGE & SKILLS
HTS community • Training • Guidelines • European synergies with EPITA and iRIIS

Maturation Pathway

TRL 3 → TRL 4 → TRL 5 → TRL 6

Technology development → accelerator validation

HTS4SRI target: validated demonstrators at TRL 6

3 Flagship Demonstrators

GSI / SIS18	HTS large-aperture quadrupole coils
PSI / TATTOOS	4 T HTS dipole
CERN / FCC-ee	HTS combined-function Q-S magnet

TECHNOLOGY SUCCESS
Our demonstrators work.
We achieve TRL 6 and deliver validated, high-performance HTS magnet solutions.

TRANSITION SUCCESS
Research infrastructures are ready to use our solutions.
We create the confidence, evidence and tools for adoption by RIs at scale.

Innovative Magnetic Measurement Systems:
Magnetic metrology of superconducting toroidal-field coil

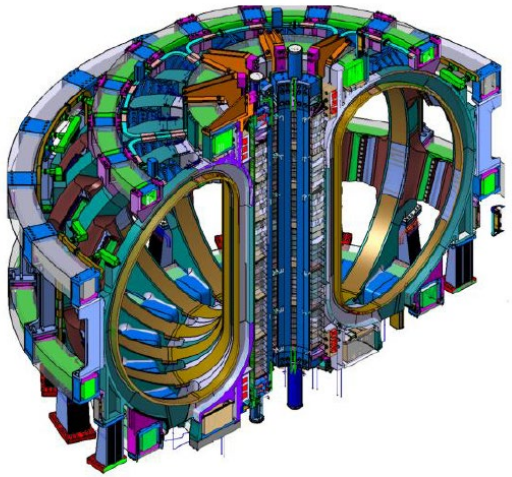
PSI

PSI CERN

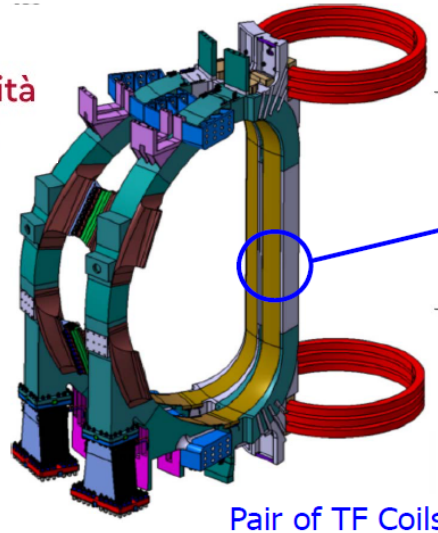
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L-Università ta' Malta

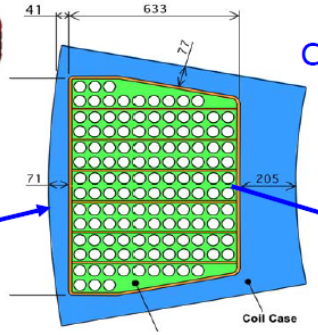
ITER toroidal-field magnet system Project work: 2013–2015



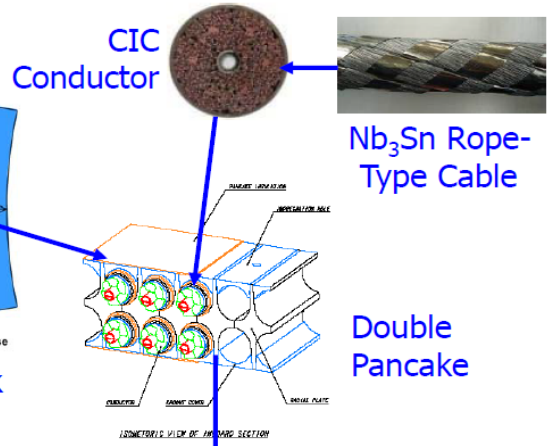
18 toroidal-field coils



Pair of TF Coils



Winding Pack



- Main assembly steps: wind, react, transfer and impregnate.



Stainless Steel Radial Plate

Fluxmeter with PCB coils
Lock in
Laser tracker

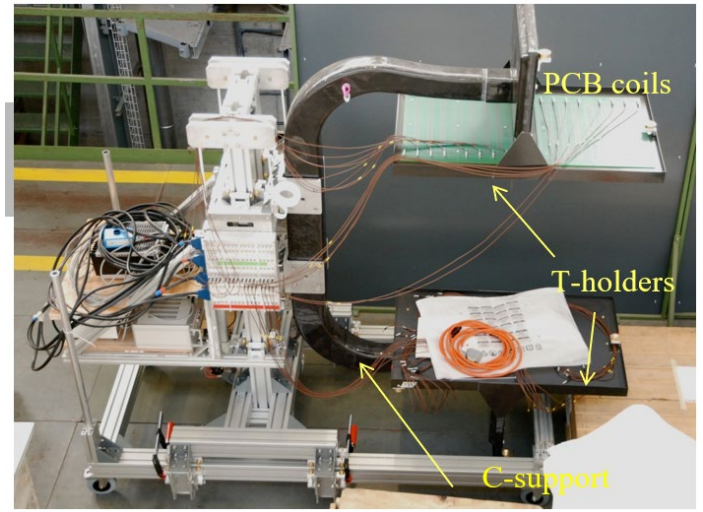
→ Meas. 0.3 Hz, T=300 K
Br(z) and Bz(r) profiles

→ *Biot Savart Law*
CCL reconstruction w.r.t fiducials
δ_r and δ_z $\chi^2 = \sum_i \left(\frac{B_i^{\text{mesuré}} - B_i^{\text{calculé}}}{\sigma_i} \right)^2$

Extremely challenging target : Current Center Line (CCL) location of each coil within uncertainty of 1 mm

CCL ITER TF : measurement system validation in a double pancake prototype



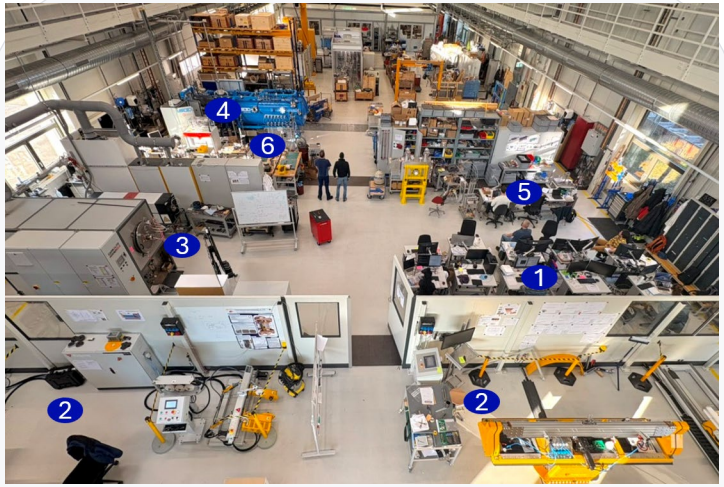


- 2 T holders with **3 modules of PCB coils** each
- Each board has **8 PCB coils**: 4.5 sqm (500 mm x 420 mm) -14 turns, 22 layers each
- **C-shape support** in carbon fiber mounted in an aluminum frame
- Signal generator, Standford Research, DS 345
- Each fluxmeter coil is wired to a switch box containing a passive RC filter.
- PXI system (2 ADC cards with 16 channels)
- **Two fiducials** per holder
- Survey made by a **laser tracker** (416 locations)

- PSI developed a full-scale fluxmeter system with PCB pick-up coils, mechanical supports, electronics and software.
- Tests at ASG La Spezia used a full-size radial plate (2014) and a double-pancake prototype (2015).
- Measurements at 0.3–1.0 Hz - CERN performed the CCL reconstruction
- reconstruction uncertainty: ±2 mm normal, ±3 mm radial→ Promising prototype results, approaching the ± 1 mm target, with further improvements identified to achieve the required accuracy.

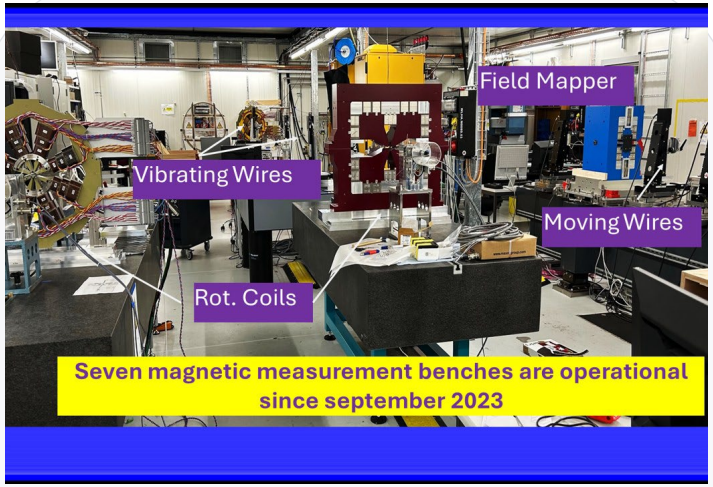
Project stopped in 2015 at the level of the prototyping-no tests for the TF series coils

Magnet Section & CHART — three complementary laboratories



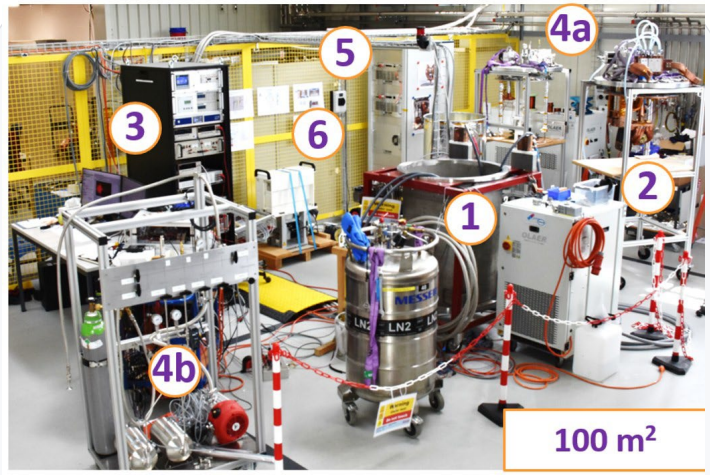
Magnet construction & assembly

CHART MagDev / LTS& HTS technologies for coils and magnets



Magnetic measurements

Field mapping & qualification



Cryogenic superconducting tests

Versatile infrastructure for coils and Conduction cooled magnets, PhP tests.
4.5K ≤T ≤65 K
In a 77 K LN2 bath

You will have the opportunity to visit the CHART MagDev during the two dedicated time slots

CHART (Swiss Accelerator Research and Technology)

CHART develops key accelerator technologies for the Future Circular Collider (FCC) while creating synergies with PSI research facilities, Swiss industry and European partners. At PSI, CHART activities span accelerator injector technologies and superconducting magnet R&D; this presentation focuses on the magnet programme.



Infrastructure and People



400 m^2 laboratory for currently 15 (Nov 2026) lab members


Douglas Araujo


André Brem


Matteo Crescenti


Joep Van den Eijnden


Jaap Kosse


Jungtae Lee


Thomas Michlmayr


Marek Mosat


Colin Müller


Kirtana Puthran


Sascha Röthlisberger


Dmitry Sotnikov


Anna Stampfli


Inês S. P. P. Yoshizawa


Alejandro C. Zurita

Additional researchers across PSI contribute to CHART activities through shared funding.

Rapid prototyping with Low-Temperature Superconducting (LTS) magnet

HFM High Field Magnets Programme

CHART Swiss Accelerator Research and Technology

PSI



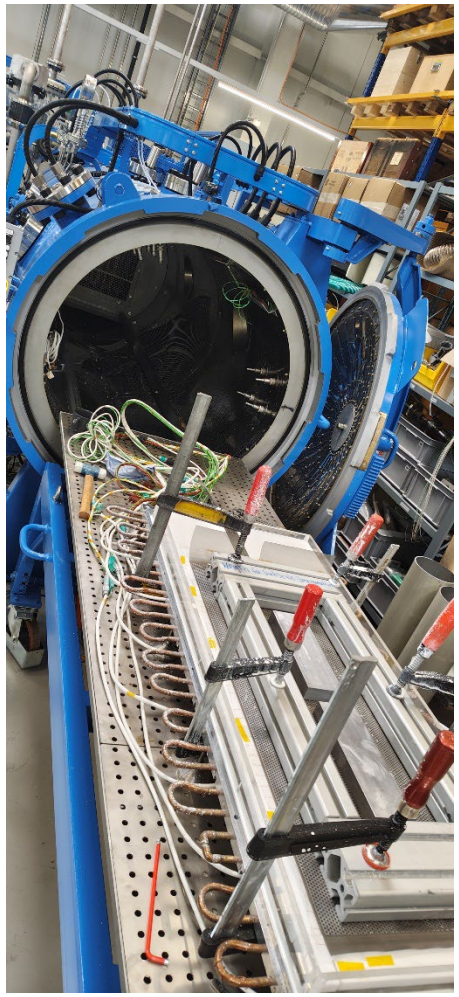
BOX program

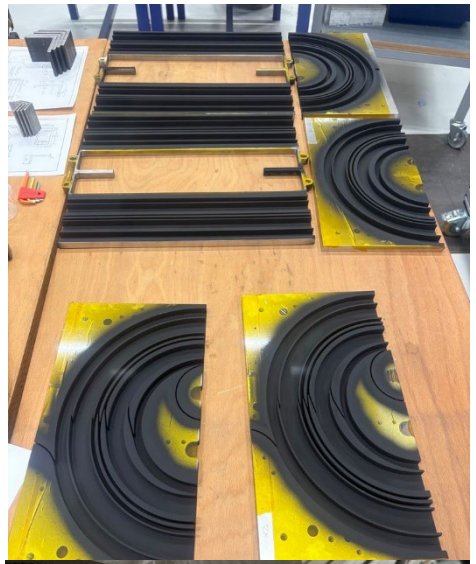
UNIVERSITY OF TWENTE.

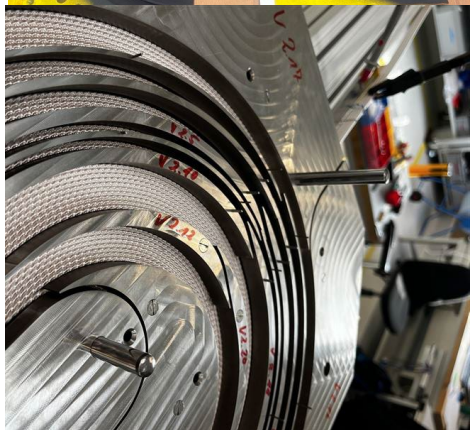


BNL

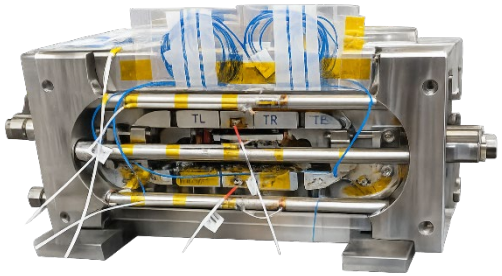
BigBOX







Subscale magnet



Winding tooling

CERN



SMACC

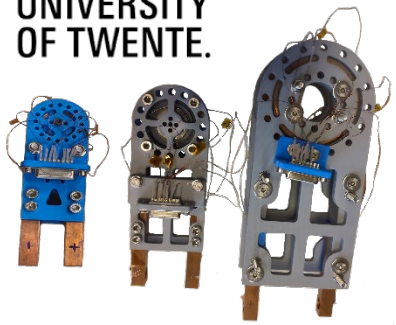
Rapid prototyping with High-Temperature Superconducting (HTS) magnet

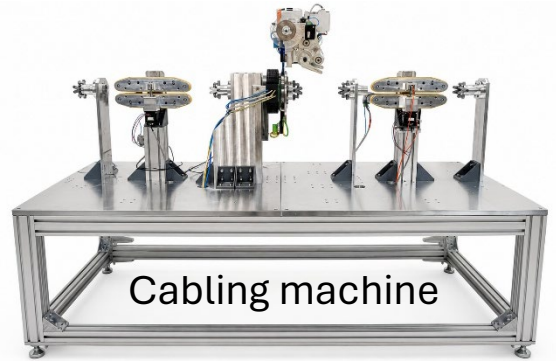
HFM High Field Magnets Programme

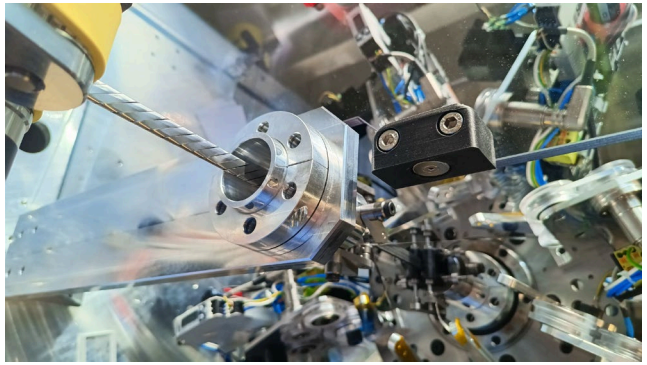
CHART Swiss Accelerator Research and Technology

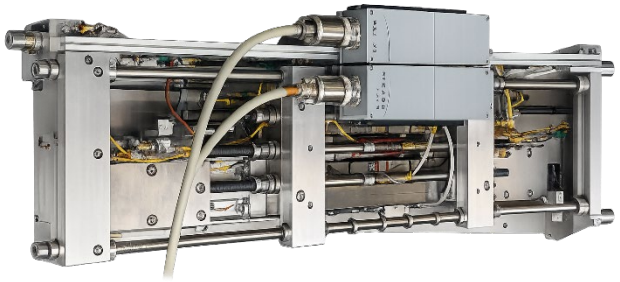
PSI

UNIVERSITY OF TWENTE.



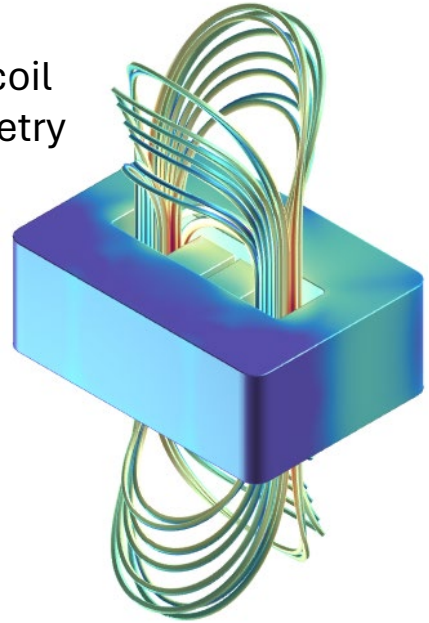






Subscale magnet tested in collaboration with the Magnet Section

New coil geometry



- Fast turnaround
- Shared components
- New magnet concepts
- Cable technologies for fusion, energy-efficient magnets, and high-energy physics.

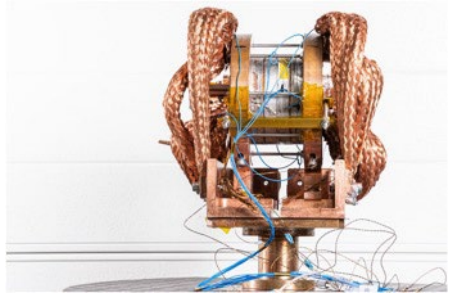
Rapid prototyping with High-Temperature Superconducting magnet

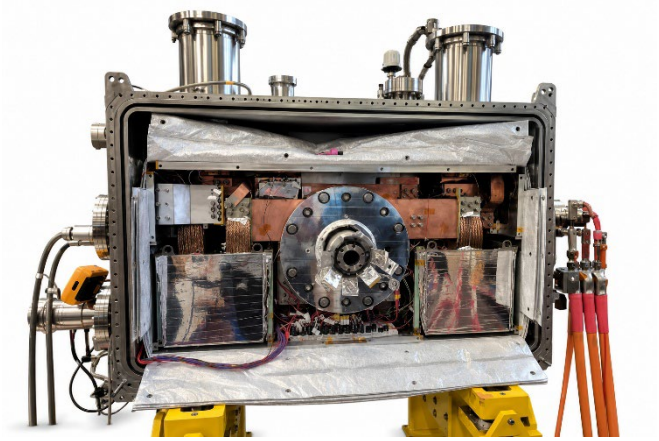
HFM High Field Magnets Programme

CHART Swiss Accelerator Research and Technology

PSI

In collaboration with Tokamak Energy

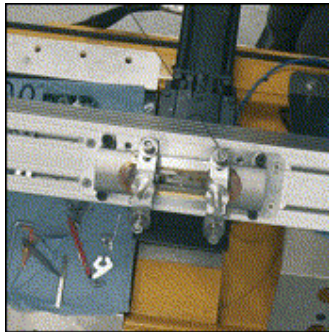






From a pioneering Non-Insulated HTS technology demonstrator to the P3 capture solenoid for FCC - potentially the first REBCO magnet operating in a particle accelerator









Prof. Jonas Huber and team

Pioneer energy-saving CHART project for FCC with Cryogenics Power Electronics System (CPES)

ETH zürich

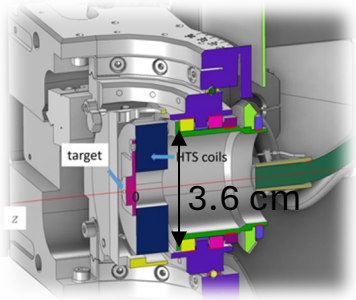
The same technology platforms create value across multiple PSI research facilities

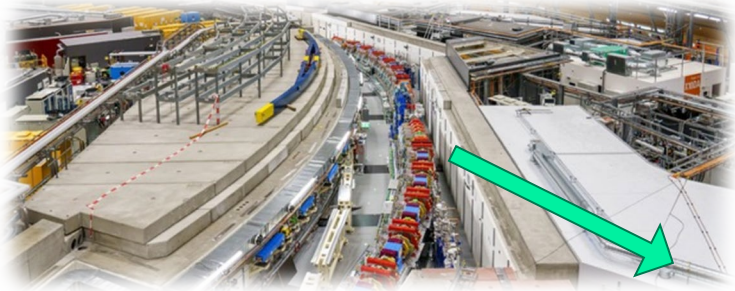
Swiss Accelerator Research and Technology

- CHART developments enabled a split-solenoid demonstrator (up to 18 T) for SINQ.
- The same platform supports a compact solenoid for the ADDRESS2.0 beamline at SLS 2.0.
- The CHART HTS4 project established the know-how that is now paving the way for future REBCO superconducting magnet applications in PSI accelerators.













Partnership with Proxima Fusion

To accelerate magnet development, Proxima Fusion established its magnet R&D division in Park InnovAare, with laboratory spaces on and off PSI campus, next door to the EPFL-SPC Sultan facility.

The CHART MagDev laboratory contributes with experience, infrastructure, and technology development that de-risks the Alpha demonstrator. *PSI participates in the steep learning curve in REBCO technology*.

Extension of the partnership beyond the SMC coil to be signed in June.

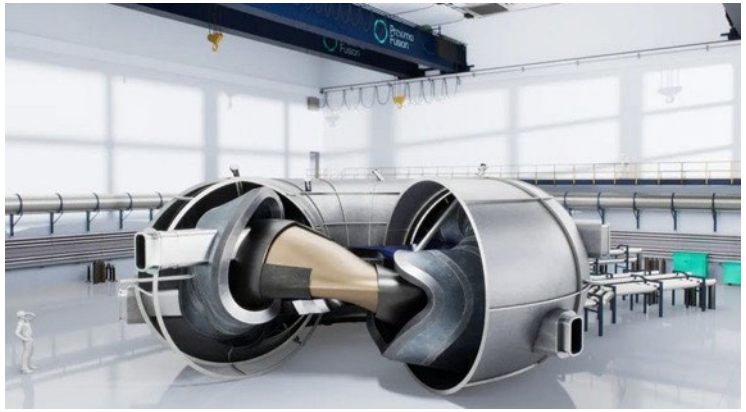

Kultur, Gesellschaft & Wissen

Milliarden für die Energie der Sonne



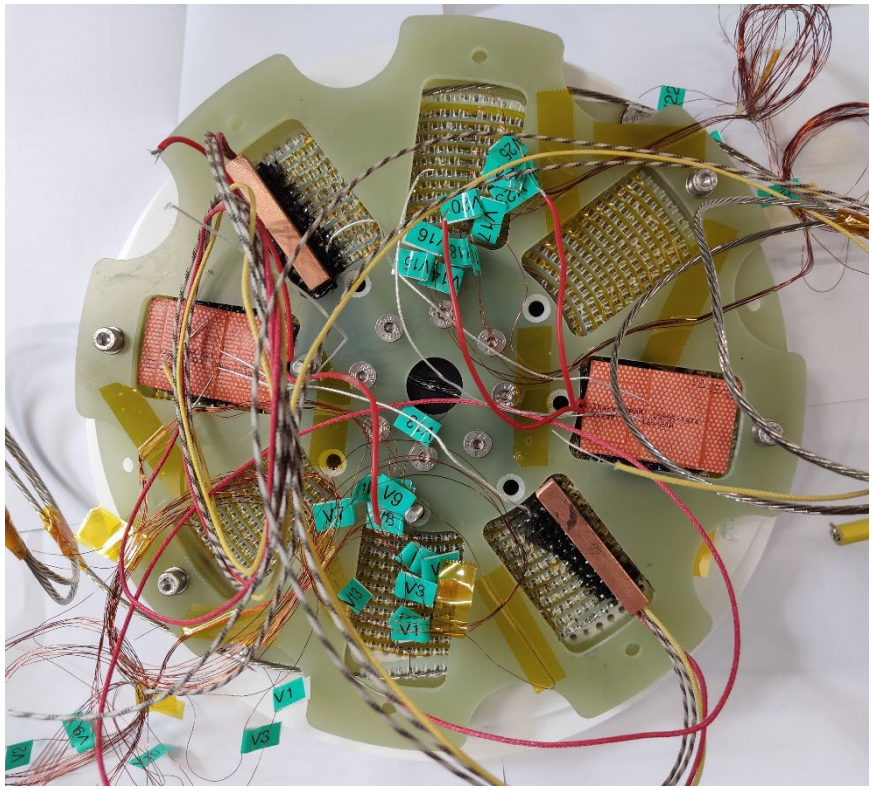






Cold Superconducting Switch R&D

- Quench-protection concept based on distributed cold superconducting switches and local energy extraction.
- Parallel assessment of three switch technologies: Nb-Ti/CuNi, MgB_2, and REBCO.
- Development of compact bifilar superconducting switches for currents exceeding 40 kA.
- Investigation of stability, switching dynamics, heater efficiency, and current commutation.
- Technology directly applicable to next-generation fusion and high-field accelerator magnets



Cold superconducting switch


Thank you very much for your attention