D. Martins Araujo (PSI), B. Auchmann (PSI/CERN), A. Brem (PSI), M. Daly (PSI), C. Hug (PSI), J. Kosse (PSI), L. Rivkin (CHART), H. Garcia Rodriguez (PSI), S. Sanfilippo (PSI), M. Seidel (PSI/EPFL),

Joint Annual Meeting of the Austrian Physical Society and the Swiss Physical Society, University of Innsbruck, September 1st, 2021.

High-Field Magnet Development in CHART MagDev

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

http://chart.ch
• From the application for support of the Swiss Accelerator Research and Technology Initiative (2018):
  – **CHART**, the Swiss Center for Accelerator Research and Technology, was founded to support the future oriented accelerator project *Future Circular Collider (FCC)* at CERN and the development of advanced accelerator concepts in Switzerland beyond the existing technology.
From the application for support of the Swiss Accelerator Research and Technology Initiative (2018):

- CHART, the Swiss Center for Accelerator Research and Technology, was founded to support the future oriented accelerator project Future Circular Collider (FCC) at CERN and the development of advanced accelerator concepts in Switzerland beyond the existing technology. […] The high field magnet R&D has strong synergies with PSI projects […]

- For example:
  - SuperBend magnets and undulators for PSI light sources.
  - Gantry magnets.

In return, CHART activities enjoy steadfast support from PSI magnet section.
CHART HFM Activities
• Topics of ongoing **ASC projects** in CHART:
  – WireChar – SC wire and tape characterization
  – WireDev – Nb₃Sn wire development
  – MagDev1 – SC magnet development
  – MagRes – resin development
  – MagAM – additive manufacturing for coil components
  – MagNum – numerics for design and analysis
  – HTS Bulk Undulator – Bulk REBCO undulator technology
  – FCCee Injector – injector test at SwissFEL, incl. NI solenoid

• Other ongoing CHART projects:
  – FCC / LHC Lumi
  – FCCee Beam Dynamics Simulation
  – FCChh Stability
  – FCC Geodesy
  – FCC Geology 3D Model
CHART HFM – Technology Pillars

WireChar
WireDev

MagDev1
MagDev2
FCCee Injector

**STRAND / TAPE**
LTS and HTS strand/tape
R&D, Procurement, QA

**CABLE**
Rutherford / Roebel production

**MAGNET DESIGN**
FCC-hh / HE-LHC conceptual and technical

**COIL MANUFACTURING**
Nb3Sn and HTS coils

**MECHANICAL ASSEMBLY**
Mechanical loading

**TESTING**
LTS and HTS magnet tests
CHART HFM – Enabling Technology R&D

Sustainable design and analysis workflows
Multi-scale modeling

**MagNum**

**Strand / Tape**
LTS and HTS strand/tape R&D, Procurement, QA

**Cable**
Rutherford / Roebel production

**Magnet Design**
FCC-hh / HE-LHC conceptual and technical

**Coil Manufacturing**
Nb3Sn and HTS coils

**Mechanical Assembly**
Mechanical loading

**Testing**
LTS and HTS magnet tests
CHART HFM – Enabling Technology R&D

Polymer R&D
Insulation and composite R&D
Splices and Joints
REBCO NI Coil Technology

MECHANICAL ASSEMBLY
Mechanical loading

MAGNET DESIGN
FCC-hh / HE-LHC conceptual and technical

COIL MANUFACTURING
Nb3Sn and HTS coils

CO Александр

MAGNET DESIGN
FCC-hh / HE-LHC conceptual and technical

COIL MANUFACTURING
Nb3Sn and HTS coils

MECHANICAL ASSEMBLY
Mechanical loading

MagRes
CHART HFM – Enabling Technology R&D

Additive manufacturing
Coil interfaces
Process digitization QA/QC

MagAM

STeAD / TAPE
LTS and HTS strand/tape R&D, Procurement, QA

CABLE
Rutherford / Roebel production

MAGNET DESIGN
FCC-hh / HE-LHC conceptual and technical

COIL MANUFACTURING
Nb3Sn and HTS coils

MECHANICAL ASSEMBLY
Mechanical loading

TESTING
LTS and HTS magnet tests
Subscale sample tests in background field
Quench Protection
Instrumentation and Signal Analysis
LTS Driving Questions

- How to increase the overall robustness and performance of Nb$_3$Sn technology in terms of:
  - increased field,
  - increased yield of conforming coils,
  - reduced magnet training to ultimate field,
  - resilience to operational and thermal cycles?
- To which level can the magnetic field be pushed in an economical way?
- How to reduce the manufacturing complexity and material cost?

How to demonstrate technical and financial feasibility of FCC Magnet System? (ESPPU 2020)
Caveat: CHART3 is not today an approved program. The funding envelope will determine the possible level of engagement, and a selection of activities may have to be made according to priorities.
Completion of CD1 (Canted Dipole 1) technology demonstrator, designed and built at PSI. Test at LBNL interrupted due to a cryoplant issue after first quench at 11.1 kA or 62.5% of short sample, 6 T in the bore.
Ramping up of activities in **new MagDev Lab** at PSI (400 m²). Missing items: winding table (order placed), impregnation system (procurement started).
• How to deal with high forces?

• Numerous reports of bonding failures between cable / coil-blocks and structural coil components

• Typical interface issue

• Stress management structure

Pictures by A. Zlobin
BOX (BOnding eXperiment) program with uTwente has shown a wide variety of results, from complete conductor degradation (no impregnation) to substantial training (epoxy) to no-training (wax), with 10 BOX samples manufactured and 7 tested to date. Narrow-edge pressure amounts to 100 MPa at $I_c$. Pictures by M. Daly, S. Sidorov
We are limiting ourselves to REBCO tapes due to their availability from multiple suppliers, relative robustness, low infrastructure requirements, and the proven track record.

Cost is an issue, but not one that we expect to directly address in the coming years.

Driving questions:
• Basic technology questions:
  – Which aspects of tape technology need improving?
  – cable-, coil-configuration, insulation, quench protection?
• Route to high fields:
  – hybrid HTS/LTS strategy, aiming for 20+T,
  – or an HTS-only path towards 16+T?
• Accelerator integration:
  – How reach “accelerator quality” in terms of field quality for a 20+T accelerator?
  – Operating temperature of an HTS-only accelerator?

How much progress can we achieve by the next strategy update?
HTS No-Insulation Coil Development

Pictures by M Duda

Pictures by J. Kosse

Pictures by J. Kosse

Pictures by J. Kosse and H. Garcia
Conclusion

- CHART is a Swiss research network, active in the field of superconducting accelerator magnets, contributing to the international HFM project.
- Identifying LTS and HTS driving questions
- Fast-track key technology R&D with academia and industry.
- Use fast-turnaround subscale samples and coils as innovation funnel.
- Benefit from existing infrastructure
- Increase the cross-linking among CHART members