EP R&D WP8,

Future Plans

21st June 2022

M. Mentink (EP/ADO) on behalf of WP8

Where are we coming from?

Advanced Magnet Powering (Prioritized, in time for LS2)

- CMS Free-wheeling diode for increased magnet availability: Completed
- ATLAS Toroid Snubber for breaker arc suppression: Completed

Reinforced Super Conductors and Cold Masses (on hold)

- (Limited effort) Cryogenic compatibility studies of 3D printed structures (cold masses, coil suspension, support structure): On-going

New 4 T General Purpose Magnet Facility for Detector Testing

- Conceptual design study: Well-advanced (See talk Shuvay Singh)
- Construction of cryogenic test station for conductor and coil demonstrator testing: Well-advanced
- Aluminum-stabilized HTS demonstrator conductor for superconducting busbars and cooling-efficient high-temperature transparent superconducting magnets, including novel quench protection method for HTS-based coils, and towards coil design: On-going (See talk Anna Vaskuri)

Innovation in Magnet Controls, Safety & Instrumentation

- Optical position measurement for high-resolution field mapping: On-going
- Mosfet-based flux pump for current generation and cryogenic power savings: On-going

Where do we want to go?

To develop the technology and expertise needed for superconducting detector magnet projects (NA 4T dipole, BabyIAXO, Alice-3, CLIC, FCC-ee, FCC-hh, …)

Challenges:

- The typical development and construction time-line for a (very) large superconducting magnet is 10-20 years. For example, CMS solenoid, from CDR to TDR (core team of 20 persons): 3 years, from TDR to commissioning-on-surface: 10 years, so a long-term strategic view would be needed to ensure that the required superconducting detector magnets do not delay the projects → Long-term strategy should be formulated.

- Superconducting detector magnets can last for decades (For example: ATLAS H8 Morpurgo Superconducting dipole since 70s) and expertise disappears over time → Training of the next generation of specialists is important, and cost-effective demonstrator studies can contribute towards this objective.

- Conduction-cooled superconducting detector magnets require aluminum-stabilized Nb-Ti/Cu conductors, which are no longer commercially available → Investigate aluminum-stabilized conductor production for the purpose of enabling detector magnet projects.

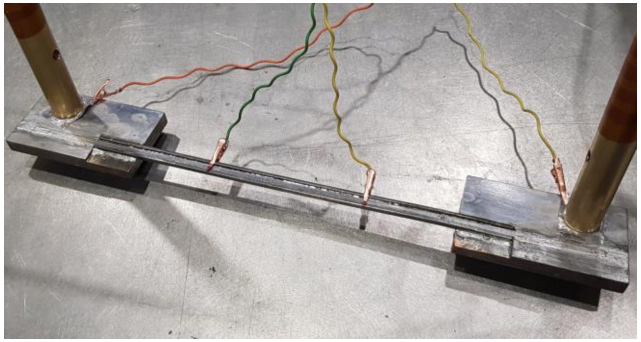
HTS-based aluminum-stabilized conductor technology

On-going: Study of aluminum-stabilized HTS-based conductors (see talk Anna Vaskuri)

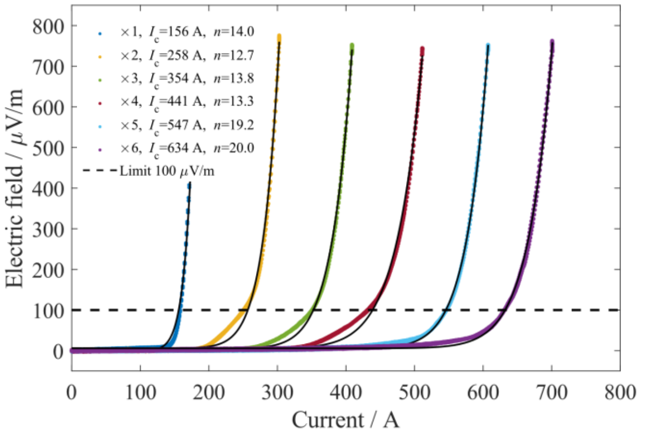
- Motivation: HTS-based conductors (ReBCO and Bi-2223) offer alternative to the superconducting detector magnet workhorse superconductor Nb-Ti
- HTS is relatively expensive, but technological developments are on-going in recent years, whereas Nb-Ti was optimized some decades ago
- In addition to increased field strengths, HTS allows operation at elevated temperatures, allowing substantial cryogenic cost savings and reduced energy consumption, which is compatible with the CERN objective of sustainable science.
- HTS is expected to give enhanced particle transparency
- Near-term use: Busbars, current leads
- Long-term use: Superconducting coils

R&D challenges: Basic conductor technology investigation (on-going), commercial production of long lengths (long-term), quench detection and protection (on-going), coil winding (long-term)

→ Towards characterization at variable temperature and magnetic field, and then towards a conceptual coil design, including quench protection studies



Experimental HTS-based aluminum-stabilized conductor



Critical current measurements at 77 K

North-Area 4 T dipole: Split-coil solenoid demonstrator (1/2)

Towards table-top demonstrator of a Nb-Ti/Cu split-coil solenoid

Motivation:

- Conceptual design of North-Area 4 T dipole is well-advanced (see talk Shuvay Singh), but how to check aspects of the conceptual design and move beyond it?
- Split-coil solenoid demonstrator, helps to test superconducting detector magnet concepts in a comprehensive (from coil winding to vacuum vessel) but cost-effective manner
- To ensure that all the details that don't appear in a conceptual design (current leads, joints, busbars, cryogenics, vacuum vessel etc.), are designed, implemented, and tested
- To provide a training platform for the next generation of superconducting detector magnet experts
- Step towards cost-effective intermediate-size superconducting detector magnets as needed by the CERN community, and would be useful for conductor and (small) detector component testing

This includes:

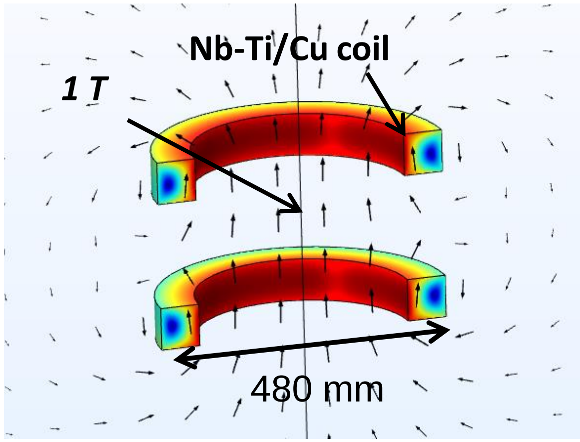
- Coil winding
- Current leads and busbars
- Quench detection and protection
- Cryogenics and thermal shield
- Vacuum vessel
- Mechanics
- Testing

North-Area 4 T dipole: Split-coil solenoid demonstrator (2/2)

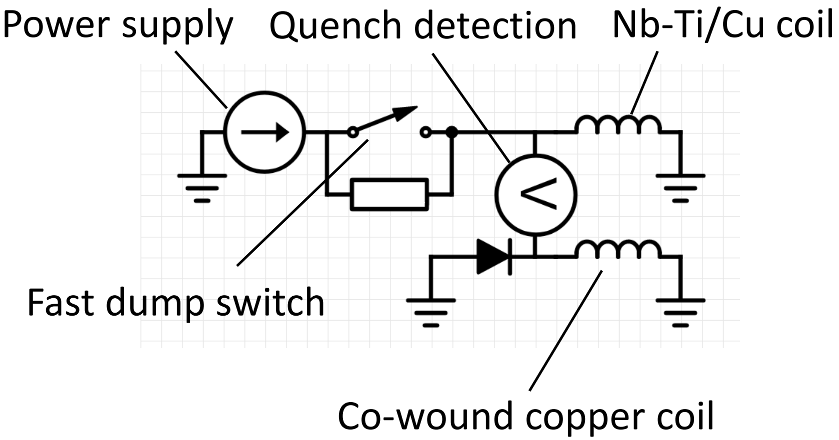
Specifics:

- Coil winding (with EP-DT-EF support): Co-wound coils features insulated Nb-Ti/Cu and Cu conductors
- Quench protection:
    - Novel quench detection concept featuring intrinsically-optimal inductive balancing, for reduced quench detection complexity
    - Novel quench protection concept featuring inductive energy transfer between coupled coils resulting in low voltages and very homogeneous quench behaviour
- Cryogenics, thermal shield, current leads: Stand-alone cryogenics utilizing a cryo-cooler, with HTS-based current leads for thermal efficiency
- Mechanics: Lorentz forces are mainly handled by conductor, with net forces between coils to be resolved by support structure
- Vacuum vessel: Could make interesting test case for WP4 vacuum vessel technology, to be discussed

We aim to do this within existing EP R&D budget allocation



1 T split-coil solenoid



Proposed electrical circuit

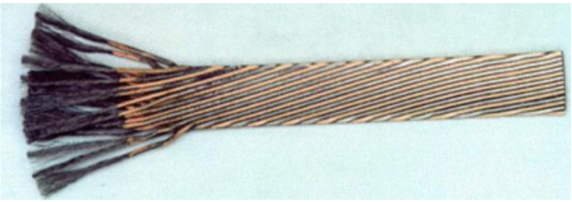
Aluminum-stabilized Nb-Ti/Cu conductor (1/2)

Challenge:

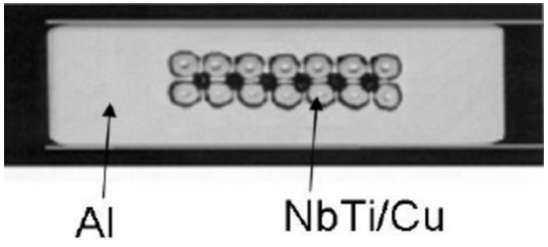
- Similar to existing superconducting detector magnets (ATLAS, CMS, …), future superconducting detector magnets require aluminum-stabilized Nb-Ti/Cu conductors, which are presently no longer commercially available

- Why not use individual Nb-Ti/Cu strands or accelerator magnet conductors instead?
    - Superconducting detector magnets develop internal voltages during quench, voltage amplitude is inversely proportional to operating current, and, for insulation purposes, the maximum voltage is practically limited to < 1000 V → Large detector magnets require large operating currents, and so cabling of strands is unavoidable (→ Rutherford cables)

    - Superconducting detector magnets are typically conduction-cooled, where aluminum ensures the thermal, electrical, and mechanical stability of the superconductor, temporarily carries the current during a quench, and provided needed heat capacity. **Aluminum-stabilized conductors is a niche technology**, and accelerator magnet technology (where conductor is in direct contact with helium and the stored magnetic energy is much smaller) does not work for superconducting detector magnets

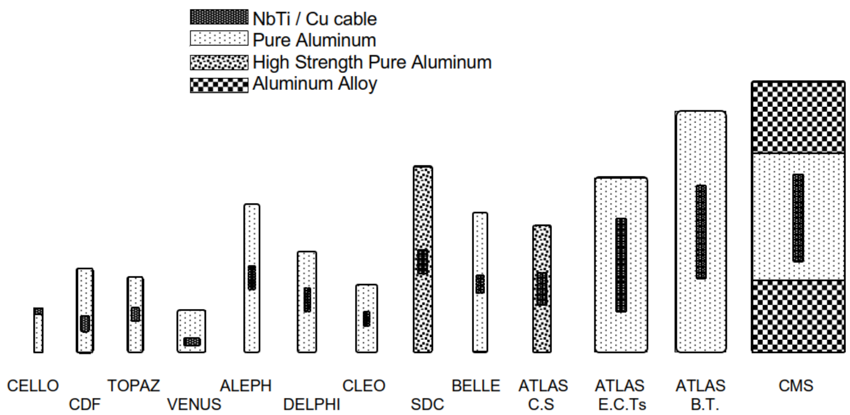


Nb-Ti/Cu Rutherford cable



Rutherford cable encased in pure aluminum

Aluminum-stabilized Nb-Ti/Cu conductor (2/2)



Aluminum-stabilized conductors used for various superconducting detector magnets (Source: Snowmass white paper '22)

indico.cern.ch/e/sdmw

Workshop on superconducting detector magnets, to be held later this year at CERN, with emphasis on aluminum-stabilized Nb-Ti/Cu conductor availability

- To address lack of commercial availability, we are organizing a workshop together with KEK on superconducting detector magnets later this year at CERN with world-wide colleagues and industry
- **Must-have technology for present and future superconducting detector magnet projects (BabyIAXO, Alice-3, CLIC, FCC-ee, FCC-hh, …)**
- **Request: To fund aluminum-stabilized Nb-Ti/Cu conductor development, as was originally foreseen (EP R&D WP8.2)**

Summary

- Goal: To ensure we have technology and expertise needed to contribute to superconducting detector magnet projects

- Aluminum-stabilized HTS-based conductor:
  - Long-term alternative to traditional aluminum-stabilized Nb-Ti/Cu conductor with attractive features
  - On-going: Short-length conductor development, towards testing at various temperature and field, addressing quench protection challenges, and towards conceptual design

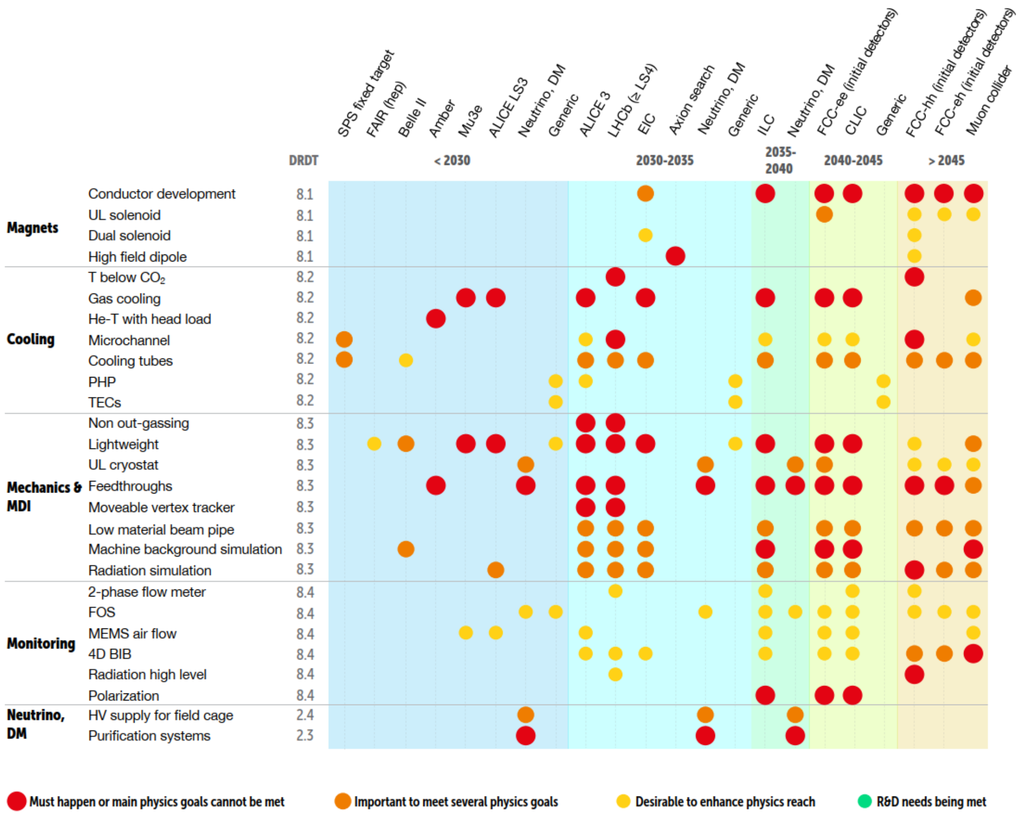
- Table-top Split-coil solenoid demonstrator:
  - Comprehensive but cost-effective effort, for training the next generation of superconducting detector magnet experts
  - Towards cost-effective intermediate-sized superconducting detector magnets as needed by the CERN community, and demonstrator itself is useful for testing conductors and small detector components
  - Novel technologies (Quench detection and protection, current leads, cryogenics, vacuum vessel)

- Aluminum-stabilized Nb-Ti/Cu conductor:
  - Traditional workhorse conductor for superconducting detector magnets
  - Must-have for present and future superconducting detector magnet projects, but no longer commercially available
  - **We request to fund WP8.2 aluminum-stabilized conductor development, as was originally foreseen, to address this issue**

- **EP R&D WP8 benefits from the contributions of various colleagues at CERN. We thank everyone for their contributions!**

ep-rnd.web.cern.ch

Back-up slide



2021 ECFA Detector Research and Development Roadmap

DRDT 8.1 - Develop novel magnet systems.
Magnet requirements are very specific to the design of the detector. Considering the very long lead time, generic R&D programmes must be established and maintained on dedicated conductors and prototyping to achieve the variety of magnet specifications.