EP R&D Day
WP8 Detector Magnets

Program Proposal 2024-2028

Benoit CURE, Matthias MENTINK

20 February 2023

Content

WP8 - Scope & Historical Overview

→ *WP8 on Magnet Detector R&D launched in 2020 with* ***3 major R&D areas*** *(scope reduced compared to the initial plan to meet the available budget).*

Scope for years 2020-2024

8.1 Advanced Magnet Powering

8.2 Reinforced Super-Conductors and Cold Masses

Delayed for financial reasons, considering the expected costs of prototyping

Re-activated in 2023 following conclusions of SDMW (unavailability of co-extrusion for Al-stab. NbTi/Cu SC in industry)

8.3 Ultra-Light Cryostat Studies **(integrated into WP4)**

8.4 New 4-Tesla General Purpose Magnet Facility for Detector Testing

8.5 Innovation in Magnet Controls, Safety Systems & Instrumentation

WP8 - Members in 2022

Members of the team:

Fellows: Shuvay Singh, Anna Vaskuri

Technical Students: Weronika Głuchowska (part), Robert Jurco (part)

Trainees: Dennis Klaassen, Jeop Van Den Eijnden

Staff: Alexey Dudarev, Matthias Mentink, Nicola Pacifico, Benoit Cure

And support from EP, EN and TE teams.

WP8.1 – Advanced Magnet Powering - Past results, overview

Original workplan

Scope for years 2020-2024

- Magnet powering and protection
- Free wheel systems and persistent mode current switch
- Energy extraction studies and quench protection
- Studies applied to WP8.4.

Resources: (½ fellow + 1 technical student) / year over 2020-2022

Deliverable 2020 – mid 2022:

- Feasibility studies and reports.
- Conceptual Design reports based on simulation, technical designs, construction of demonstrator models and testing.

Results

Activities 2020- mid 2022

1. Quench protection studies and modelling, applied to the 4-T magnet studies,
2. Snubber studies for implementation on Atlas Barrel Toroid,
3. Commissioning of CMS free wheel system,
4. Study of persistent mode current switch,
5. Study of flux pump.

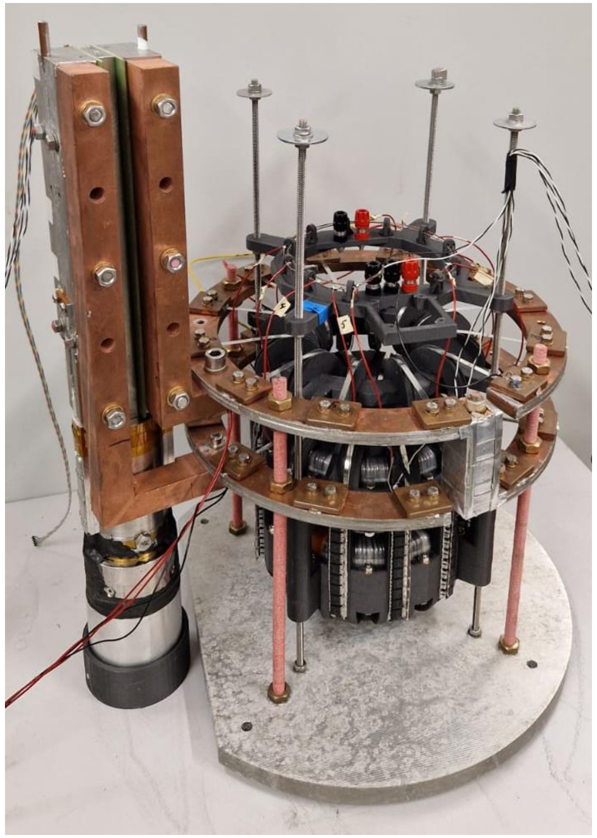
Resources: (½ fellow + 1 technical student + trainee) / year over 2020-2022

Results 2020 – start of 2023:

- Feasibility studies and reports : done (1-2-4-5)
- Computational simulations: done (1-2-4-5)
- Conceptual design reports based on simulation: done (2-4-5); construction of demonstrator models and testing : done (2), in progress (5)
- Implementation and final testing campaign : done (2-3-4)
- Quench simulations, benchmarked against existing magnets
- Flux-pump demonstrator: On-going with encouraging first results

WP8.1 – Past results, examples

Snubber system for ATLAS Toroid circuit, for arc-suppression during slow-dumps



Flux-pump demonstrator, operating in liquid nitrogen

WP8.2 – Reinforced Super-Conductors and Cold Masses, Past results

Within context of EP R&D WP8.2 (High-strength aluminum-stabilized conductors)

- Was originally foreseen, but not implemented due to budget constraints
- Results:
  - Participation in the 2022 Snowmass process, on the topic of future superconducting detector magnets and the associated conductor needs
  - Organization of a workshop "Superconducting Detector Magnet Workshop" on 12/9/22, co-organized with KEK and hosted at CERN in hybrid format
    - EP Seminar, summarizing the workshop 23/9/22
    - Featured at the BSB forum and in the CERN courier

Superconducting detector magnets for high energy physics

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KEYWORDS: Superconducting detector solenoid; Aluminum-stabilized conductor; Indirect cooling; Inner coil winding technique.

2022 Snowmass process on superconducting detector magnets

Snowmass 2021 Whitepaper, in Accelerator Frontier - 7 Accelerator Technology - Magnets
arXiv:2208.13349v2 [physics.acc-ph] 1 Dec 2022
[Seattle Snowmass Summer Meeting 2022 (16-26 juillet 2022): Accueil · INDICO-FNAL (Indico)](https://indico.fnal.gov/event/22303/)
https://indico.fnal.gov/event/22303/

arXiv:2203.07799v1 [physics.ins-det]
To be published in a Special Issue "Snowmass Accelerator Frontier" of the Journal of Instrumentation (JINST)

Superconducting Detector Magnet Workshop, Sep 2022

https://indico.cern.ch/event/1162992/

EP Detector Seminar:
https://indico.cern.ch/event/1200637/

WP8.4 – New 4-Tesla General Purpose Magnet Facility for Detector Testing, Past results

Original workplan

Scope for years 2020-2024

- Conceptual design study of a 4-T magnet for a test beam facility

Resources: ½ fellow / year over 2020-2022

Deliverable 2020 – mid 2022:

- Magnet design.
- Magnet subsystem design (cryogenics, powering, cryostat, yoke, support system)

Results

Activities 2020- start of 2023

1. Definition of technical requirements,
2. Studies of magnet layout and stray field
3. Definition of conductor and cold mass
4. Study of cryogenics

Resources: ½ fellow (2020-22)+ 1 technical student (2021)

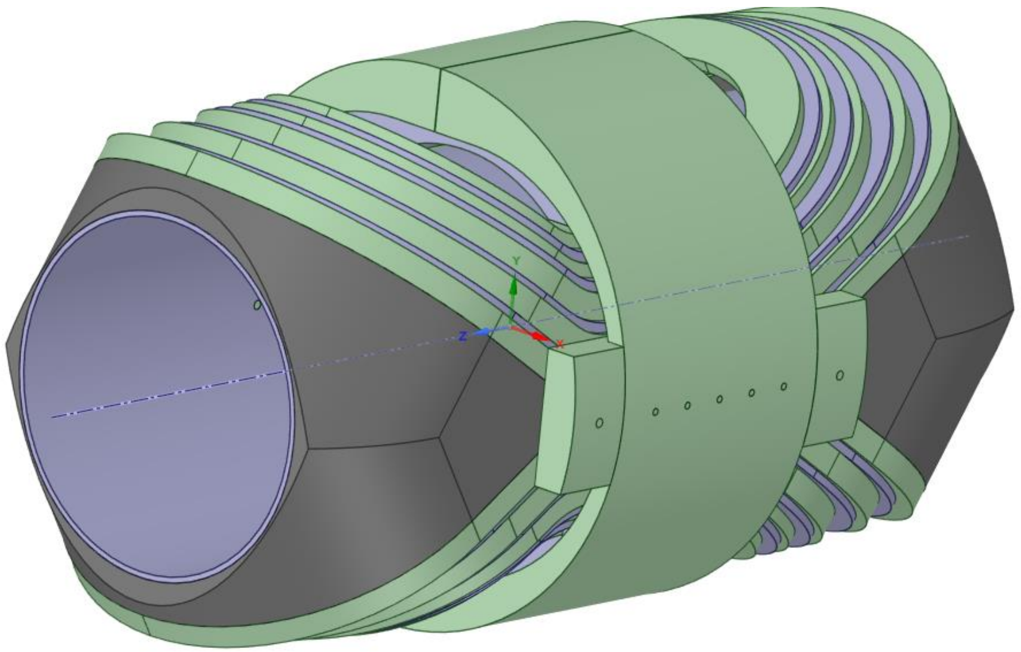
Results 2020 – start of 2023:

- Magnet concepts: done, reported and published.

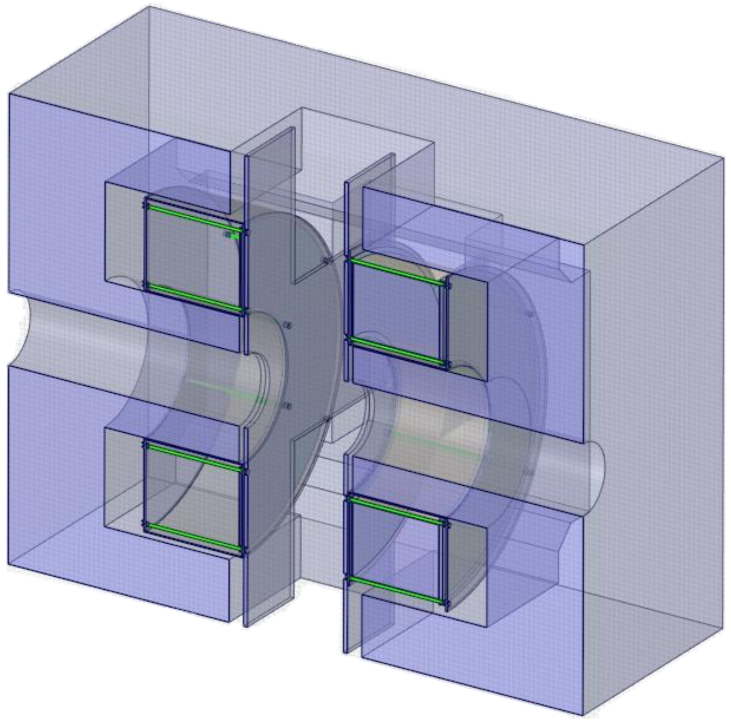
  Two options studied, Split coil solenoid and Dipole (Magnadon). Conductor and winding defined: pancake winding of reinforced Al-stabilized NbTi conductor. Final conceptual report currently being written.
- Magnet subsystem studies on:

  Inner cryogenics, powering system, yoke, cryostat, support system.

WP8.4 – Examples



“Magnadon” preliminary conceptual design of a 4 T superconducting dipole



4 T split-coil solenoid conceptual design

WP8.5 – Innovation in Magnet Controls, Safety Systems & Instrumentation, Past Results

Original workplan

Scope for years 2020-2024

- Quench protection in HTS: fast detection, sensitivity, low voltage;
- Magnet controls : requirements, identification of future systems;
- Instrumentation: magnetic measurement, interfaces CAN FD.
- Applied to the 4-T magnet beam test facility to test and qualify these systems.

Resources: activity starting from mid 2021 with 1 fellow + 1 technical student

Deliverable mid 2021 – mid 2022:

- Magnet control system needs.
- Testing and reporting.
- Simulation, prototyping with new instrumentation.

Results

Activities 2021 – start 2023

1. New testing setups for HTS tape characterisations.
2. Assembly of a new low-T test bench facility with SC magnet for SC cable measurements and further prototype testing.
3. Scrutiny of emerging optical technologies in position measurement for potential application to field-mapping.
4. Study of an innovative insulation system.

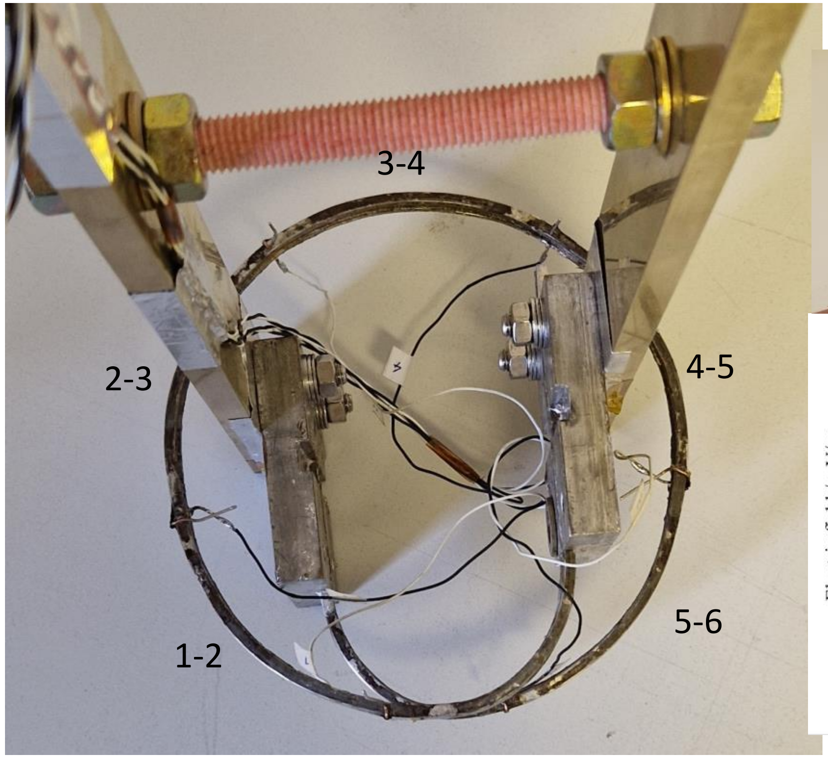
Resources: 1 fellow / year from Oct. 2021 + 1 TS (2022)

Results 2021 – start of 2023:

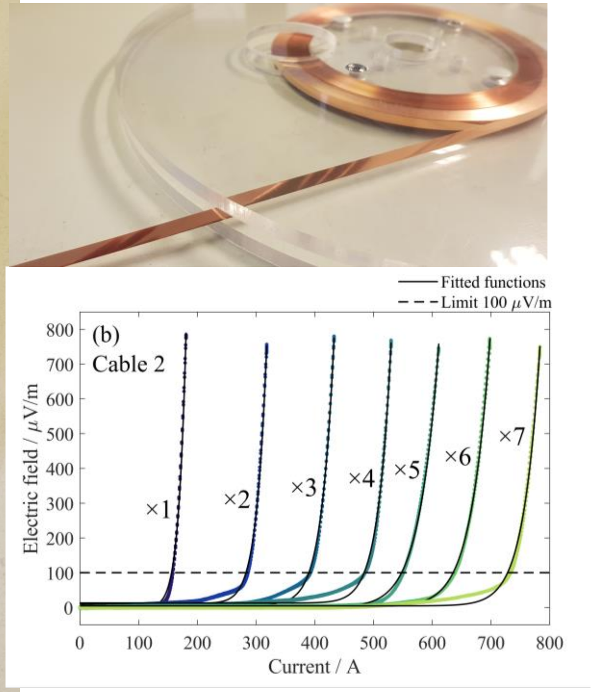
- HTS studies: in progress

  Prototype conductor was fabricated
  Extensively tested at 77 K showing no degradation
- Helium test setup with 5 T solenoid, completed with strong EP-DT support, and first test with HTS conductor at 4.2 K, 5 T completed
- Report on optical technologies with discussion on applications and level of accuracy: done.

WP8.5 – Examples



Aluminum-stabilized High-Temperature-Superconducting prototype conductor, tested at 4.2 K in a 5 T back-ground field



Results at 77 K

Cryogenic test station featuring 5 T solenoid

Reports / publications

Publications:

- MT-27 - IEEE Transactions on Applied Superconductivity Print ISSN: 1051-8223 Online ISSN: 1558-2515 Digital Object Identifier: 10.1109/TASC.2022.3146809, https://ieeexplore.ieee.org/document/9699420
- ASC 2022 - : IEEE Transactions on Applied Superconductivity Print ISSN: 1051-8223 Online ISSN: 1558-2515 Digital Object Identifier: 10.1109/TASC.2023.3238294, https://ieeexplore.ieee.org/document/10021975
- ASC 2022 - IEEE Transactions of Applied Superconductivity - Towards Ultra-Thin Detector Magnet Designs by Insulating Coil Windings with V2O3-Epoxy Composite

Reports:

- Strategic R&D Programme on Technologies for Future Experiments - Annual Report 2020, https://cds.cern.ch/record/2764386
- Strategic R&D Programme on Technologies for Future Experiments - Annual Report 2021, http://cds.cern.ch/record/2808204#
- Application of Optical Positioning System to Experimental Magnets Mapping," CERN Internal Report 2738363 v.1 (2022).
- ATLAS Toroidal Snubber Demonstrator Note 2021, https://edms.cern.ch/document/2466567/1
- ATLAS Toroidal Snubber and commissioning Note 2022, https://edms.cern.ch/document/2728512/1
- A Quench Analysis for the New North Area Magnet, EDMS 2508348
- A power supply for superconducting magnets using MOSFETs, EDMS 2620984
- ATLAS Toroid Snubber & Design of a 4 T Superconducting Dipole Magnet for the CERN North Area, EDMS 2682537
- EP R&D WP8 Cryogenics, future 4 T superconducting dipole user facility, EDMS 2825571
- A Power supply for superconducting magnets using MOSFETs, EDMS 2620984
- Behaviour of 3D printed materials at cryogenic temperatures, EDMS 2825574
- R&D design superconducting switch for new 4T north area magnet, EDMS 2825577

Extension Motivations

Conclusions of the Superconducting Detector Magnet Workshop

What we need to resume / do next ?

Investigate multiple approaches for Al-stabilized SC

- Cooperation with industry
  - NbTi/Cu cable, Al-co-extrusion, Assembly with Al-reinforcement
  - Cost-effective approach need to be seriously investigated
- **Laboratory own effort**, in particular on
  - **Al-coextrusion facility and own R&D for leading technology advances**

Seek for common SC and magnet design concept, even part, for cost-effective development,

Seek for worldwide cooperation among laboratories and industry

Figure out Next meeting / workshop opportunity

- Based on sufficient progress, hopefully within 1 ~ 2 years to be held in Japan or the US, according the progress in the detector magnet technology advances.

Extension Motivations

Roadmap of the ECFA (European Committee for Future Accelerators)

Detector Research and Development Themes (DRDTs) identified in the Roadmap report.

DRDT 8.1: *Develop Novel Magnet Systems*

in Chapter 8 - Integration ; 8.3 - Key technologies

Integration (Task Force 8)
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.

***The availability of the superconductor** comes quite early in the project plans.*

R&D on superconductors must be achieved well in advance of detector completion (~ 5 to 7 years).

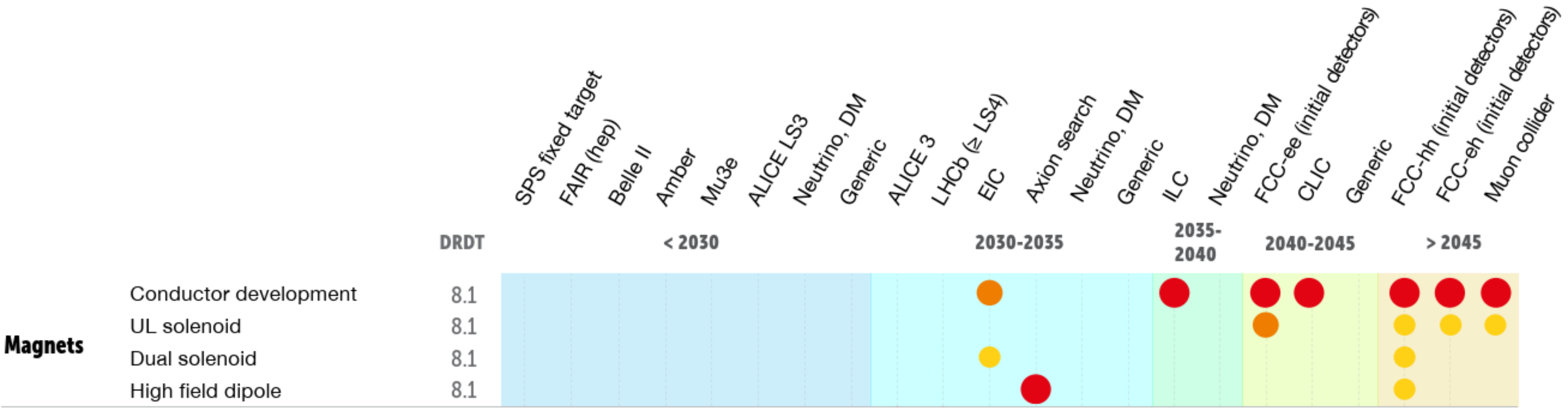


Figure 8.1: Schematic timeline of categories of diverse R&D topics [...]

Extension Motivations

Roadmap of the ECFA (European Committee for Future Accelerators)

DRDT 8.1: ***Develop Novel Magnet Systems –***

Summary of the key technologies needed, as listed in the ECFA report :

Magnets for collider experiments:

- Development of next generation of **Al-stabilized high-yield strength Rutherford cable superconductors** and prototyping for 30-40 kA large coils placed behind calorimeters.
- **R&D on conductors and prototyping for thin conductors Al/Cu/NbTi** for small coils placed in front of the calorimeters.
- Long term: development **of high temperature superconductors for coils and current leads**.
- **R&D for assemblies** with dual solenoids for magnetic shielding.

Magnet for non-collider experiments:

- large volume magnets for axion searches […],

Development of quench protection, energy extraction and high voltage designs for coils with high energy/mass ratios is also needed.

Extension Motivations

Some of the upcoming and future programs with SC detector magnets (collider and non-collider):

- **BabyIAXO (CERN input), Alice-3 (CERN), Panda (GSI/Fair), EIC (Jlab), Mu2E (FNAL), Comet (KEK), SHiP (CERN),**
- **Detectors at future colliders: ILC, CLICdet, FCC-ee/-hh, etc.**

- **Magnetic field from ~ 2 T to ~ 4T,**
- **Thin coils** within the calorimeter volume, as transparent as possible for particles,
- **Large coils** with very high stored energy and magnetic forces

Most future detector magnets will need **aluminum stabilized** and **mechanically reinforced superconductors.**

High purity aluminum stabilizer alone cannot be used (low yield strength ~ 30MPa at 4K). **Reinforced aluminum is necessary.**

→ **R&D on Al stabilized LTS needed for the benefit of the high energy physics community**

(DETECTORS for both collider and beyond collider physics).

Extension Motivations

→ **Reinforced aluminum stabilized NbTi/Cu superconductor:**

Baseline designs of future large magnet detectors benefit from the previous manufacturing breakthroughs of the CMS solenoid and the Atlas Central Solenoid.

CMS:

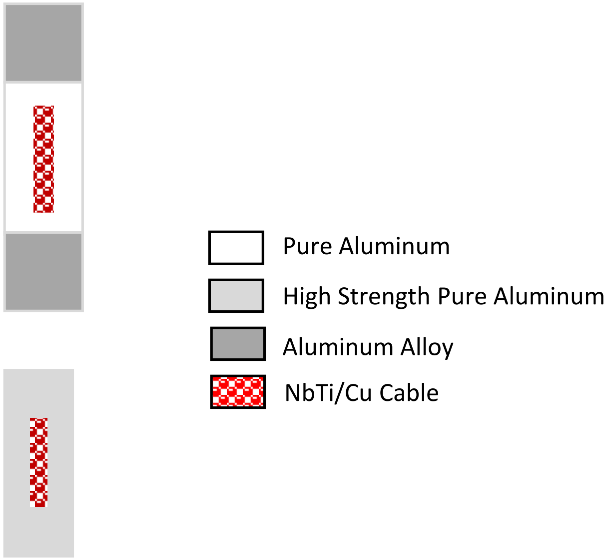
Coextrusion of Rutherford cable in High purity aluminium stabilizer

+ Electron beam welded aluminum alloy profiles on coextruded conductor.

ATLAS-CS:

Coextrusion of Rutherford cable in micro-alloyed aluminum stabilizer, either crystallization/precipitation state (Ni-doped) or solid solution state (Cu/Mg-doped)

+ Cold working of coextruded conductor.



→ Technology not available at present.

→ One coextrusion line identified and under development in industry in China (Wuxy Toly Electrics Works Co., Ltd.), together with cabling machine for Rutherford cable (a project with IHEP-China). **Presentation at SDMW.**

→ This technology has to be re-established and applied to the variety of conductors for detector magnet.

Program from 2024 to 2028

Building on the 1st phase of the program, 2020-2024.

WP8.1 - Advanced Magnet Powering for high-stored energy detector magnets

WP8.2 - Aluminum-stabilized reinforced Superconductors

WP8.4 - Demonstrator magnets, to demonstrate technology for future superconducting detector magnets

WP8.5 - Magnet Controls and Instrumentation

WP8.1 - Advanced Magnet Powering for high-stored energy detector magnets

Sustainability and cost-efficient powering systems with reduced energy consumption are aimed for the next generation of superconducting detector magnets.

Proposed activities : (Continuation of works done during 1st R&D phase on powering system demonstrators and testing)

Design of powering systems for detector magnet applications, with the use of High Temperature Superconductors (HTS) e.g. ReBCO tapes.

- Prototypes of current leads, flux pumps, persistent mode switches
- Study and prototyping of HTS-based aluminium-stabilized cable prototypes

Objectives:

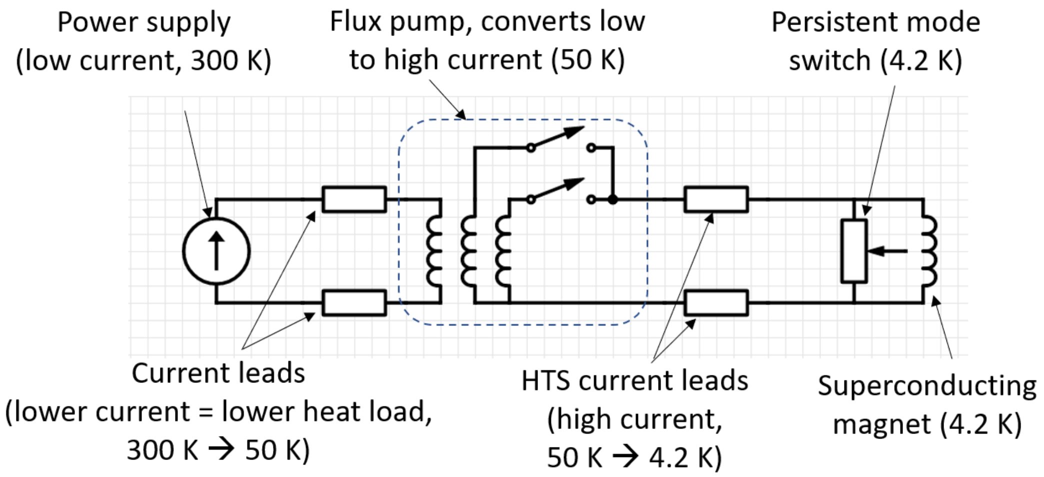
- Given that getting current into magnets determines a substantial fraction of the cryogenic budget, work on powering technology giving minimal cryogenic heat load, moving beyond the present state-of-the-art for superconducting detector magnets
- HTS-based aluminum-stabilized conductors: Of interest for busbars connecting coils, but also for the coils themselves. Advantage: Allows for much higher operating temperature (= lower cryogenic cost) and higher magnetic fields in the bore, albeit presently at higher capital cost for the conductor itself

WP8.1 – Example of application: How to get current into superconducting detector magnets?

Sustainability and cost-efficient powering systems with reduced energy consumption are aimed for the next generation of superconducting detector magnets.

How to get high current into a superconducting detector magnet in a cryogenically efficient way?

- Traditional approach: High-current generation at room temperature, normal-conducting current leads down to 4.2 K, resulting in a significant heat load
- To reduce cryogenic load:
  - Flux pump, generates high current at 50 K
  - HTS-based current leads, to get current from 50 to 4.2 K (something similar is used for the LHC)
  - High-current persistent mode switch: Normal-conducting during magnet charging and subsequently fully superconducting
- Each of these reduces cryogenic power consumption, and they can be combined for minimal cryogenic load



Powering Circuit optimum configuration

WP8.1 - Advanced Magnet Powering for high-stored energy detector magnets

Timeline

2024	HTS conductor and current lead demonstrator assembly and test.
2025	Persistent switch and flux pump study and prototyping (for test facility : 5kA)
2026	HTS powering system demonstrator design and assembly.
2027	HTS powering system demonstrator testing.
2028	Study for a large scale magnet application, evaluation, outlook and conclusion.

Resources

WP8.1	Goods & consumables (kCHF)	Students	Fellows
2024	40	1	
2025	30	1	
2026	30	0.5	1
2027	20	0.5	1
2028	20		1

WP8.2 - Aluminum-stabilized reinforced SC

Strong need identified for aluminum-stabilized superconductor prototyping up to pre-industrialization, for CERN programs and associated projects, and more largely for the HEP community.

Scope: to identify and propose manufacturing routes, in view of producing sample lengths that can be adapted for scaling up to production for future detector magnet conductors.

Objectives:

Set up a coextrusion & coldwork development line for:

- R&D on aluminum-stabilized NbTi/Cu superconductors (to be able to resume production),
- Future developments and applications of this technology.

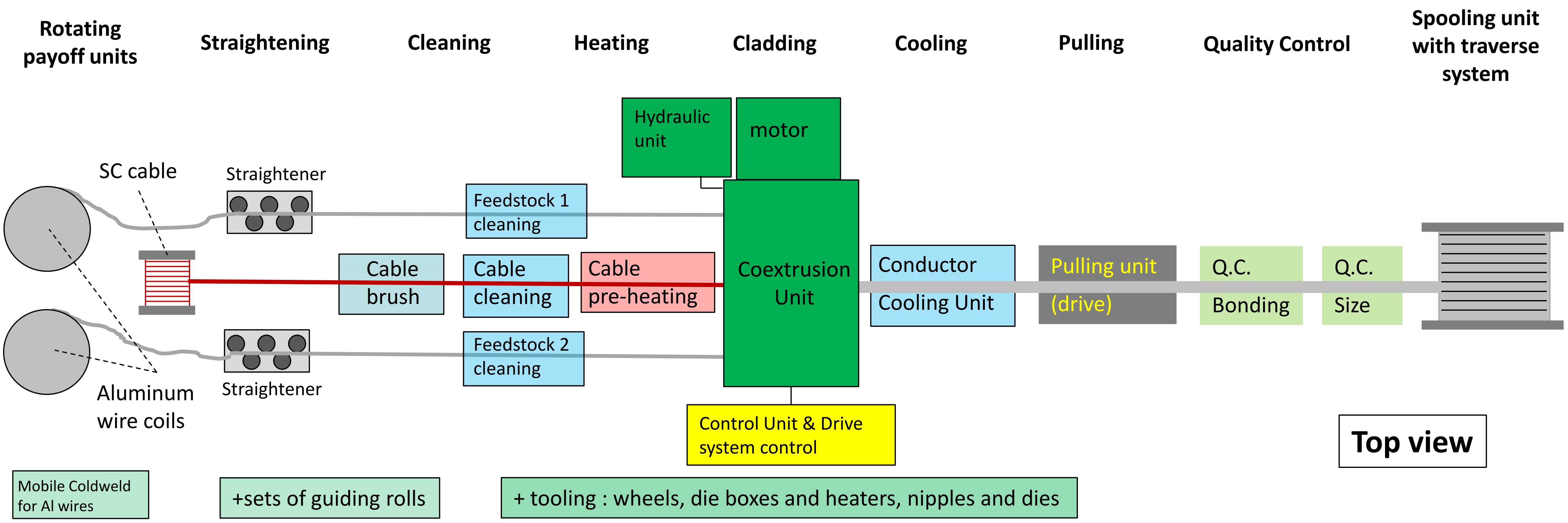
Two options:

Option A- with industrial partner **or** **Option B- in a lab (CERN?)**

WP8.2 - Coextrusion Development Line

Typical sketch of a complete coextrusion line (with inputs from KEK)

- About 25~30 m x 10m minimum (<u>not including</u>: delivery, services and storage space areas)
- Infrastructure : electrical power, water service (chiller?), compressed air, N2 (or Ar) gas line, overhead crane (> 5 tons)

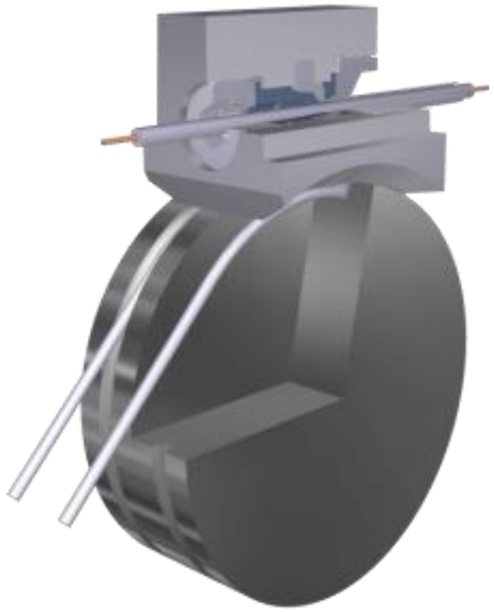


WP8.2 - Coextrusion Development Line

Aim is to use **continuous** process such as **Conform Cladding** (machine supplier BWE, UK)

Such a process was successfully applied to Atlas CS, Mu2e coils (Furukawa, JP, *discontinued*) , Panda conductor R&D (Russia, *stopped*).

BWE Ltd, Beaver Industrial Estate,
Ashford, Kent, TN23 7SH, England



WP8.2 - Cold Work Development line

Prototyping led in the past with short samples for material property studies [1, 2].

R&D requested to characterize :

- **Multiple pass process,**
- **Tension force applied on conductor,**
- **Conductor lubrication during the process.**
- **Monitoring of Process and conductor parameters,**
- **Conductor electrical and mechanical properties**

Such a process was successfully applied to Atlas CS (Hitachi, JP).

[1] S. Sgobba, et. al., "Toward an Improved High Strength, High RRR CMS Conductor," in *IEEE Trans. on Applied Superconductivity*, vol. 16, no. 2, pp. 521-524, June 2006.

[2] S. A. E. Langeslag et. al., "Characterization of a Large Size Co-Extruded Al-Ni Stabilized Nb-Ti Superconducting Cable for Future Detector Magnets," in *IEEE Trans. on Applied Superconductivity*, vol. 23, no. 3, June 2013, Art no. 4500504.

Example of equipment (Criotec, ENEA, IT):

- 50-ton, actively driven, four-roll Turks head mill (DEM SpA),
- Used for production of the ITER cable-in-conduit [Della Corte et al., 2013].

WP8.2 - Aluminum-stabilized reinforced SC

The WP8.2 R&D program will cover the activities needed:

- to set up **coextrusion & coldwork development line**, including:
  - **Investigation and definition** of the industrial equipment required for the processes (such as coextrusion equipment + tooling for brushing, cleaning, heating, on-line QA, cooling, specific instrumentation, cold weld, etc).
  - **Procurement of tooling** for preliminary testing, together with **material (aluminum, superconducting cable).**
- to produce **Al-stabilized conductor demonstrator lengths**,
- To **test conductor samples** : mechanical destructive testing, electrical testing (Ic, RRR), metallurgical tests (hardness, interdiffusion layer), at RT and 4K, etc. Typical test program to be drafted.

In 2023, the activity starts aiming at :

- **Identifying** potential industrial partner(s) (CERN Member States + Associated M.S. + UE)
- **Studying feasibility** to install such a facility at CERN,
- Writing a **technical proposal** with cost basis.

WP8.2 - Aluminum-stabilized reinforced SC

Since Autumn 2022, continuing in 2023:

Regular meetings on Aluminum stabilized NbTi conductors,

- following the SDMW.
- about once a month with representatives from:
  - ➢ **CERN** : **EN**-MME, **EP**-Magnet, **TE**-MSC,
  - ➢ **KEK**.

In progress:

- **Cost estimate** of a new production line (Conklad™ process), with inputs from KEK+CERN.
- **Contacts with industry:**
  - ➢ (co)extrusion machine suppliers (mostly UK). UK CERN-ILO contacted.
  - ➢ Positive feedback from DE CERN-ILO ("preliminary interest").
  - ➢ One contact in industry (DE): project submitted to their management, waiting feedback.
  - ➢ Contact with Swiss company that did ATLAS and CMS conductors. Attempt to follow up on their future plans.
  - ➢ Market survey envisaged, documents in preparation.

WP8.2 - Aluminum-stabilized reinforced SC

Timeline – preliminary (tentative) plan

Phase 1 (2023): **Studies and plan** ~ < 1 year

1. Contact with industry,
2. Technical proposal,
3. Detailed test program,
4. Cost basis with resources.

→ **Decision on either option A or option B → target : by second half 2023.**

Phase 2 (2024): **Tendering process:** ~1 year **+ off-the-shelf equipment procurement**

Phase 3 (2025): **Coextrusion machine procurement, equipment test and setup, first tests:** ~1 year

Phase 4 (2026): **R&D line for prototyping**

The successful completion of this project will depend on the availability of additional external funds to the EP R&D WP8 budget.

WP8.2 - Aluminum-stabilized reinforced SC

To be looked at:

- Determine if the project is relevant to next EU grants for research infrastructure.
- Project can be open to other institutes to enlarge contributions (Desy? GSI-FAIR? Others?), preliminary contacts with Desy, GSI, to be further explored…

It is in the institutes (or collaborations) own interest to re-establish the coextrusion of Al-stab SC for their projects:

- A joint coordinated effort would be more cost effective than separate repeated exercises (time consuming effort with non negligible costs).
- A sustainable solution shall be preferred, as projects do not follow one another regularly (and may be subject to changes).
- Keeping in mind Al-stab. superconductor is very low volume production compared to the volumes handled in the cable industry, where the competition is strong.

WP8.2 - What is next (what are the prospects)

Case 1:

- An industrial partner in CERN MS +AMS with the machinery available is identified and willing to work on this project.
- Activity can start relatively quickly, on a short term, contractual aspects to be clarified.
- Relatively flexible if more than one company is identified.
- R&D could be performed with the WP8.2 budget to some extent. More funds may be requested from Institutes willing to join.
- Will this company be available in 10-20 years ???

Case 2:

- An industrial partner without the machinery (but experience in this field) may be interested.
- Same as case 1, except that much more investment is needed (machinery and services, manpower).
- Contractual aspects more complex (responsibility for design, installation, operation, maintenance, equipment ownership).
- Availability in 10-20 years ???

Case 3:

- No industrial partner easily identified. Continue searching…???
- Consider setting up a test facility inside an institute. Investment is similar to case 2, space is needed, less contractual constraints, benefit from in-house expertise of KEK. All activities in-house (design to operation), with industrial support (e.g. manpower).
- Sustainable for long period (need of a secured in-house technical specialist on long term).

Investigations in 2023 will tell us about the perspectives. It is not a fast process…

Support from EN-MME and TE-MSC is very much appreciated (and needed). Same with KEK for the valuable inputs into this project since the beginning.

WP8.2 - Aluminum-stabilized reinforced SC

Timeline

2023	Material (Alu + SC) and prototyping with industry.
2024	Material (Alu + SC) and equipment procurement and delivery. Equipment setup and test.
2025	Testing of coextrusion line component with trials using short lengths, for validation before the co-extrusion prototyping phase.
2026	First short prototype lengths manufactured. Quality control testing on samples.
2027	Coextrusion and coldwork of Al-doped conductor prototype samples.
2028	Long length prototype manufacturing and reporting.

Resources

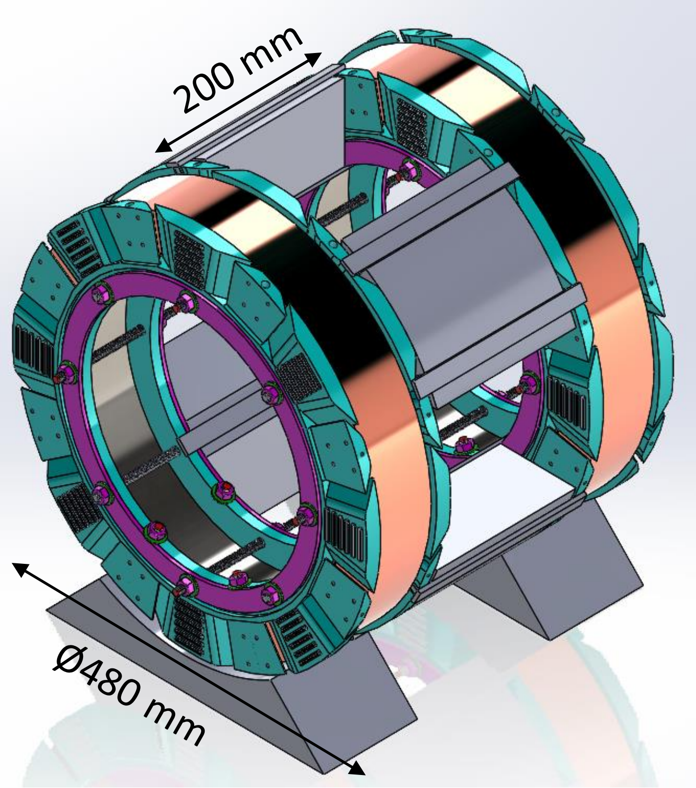
WP8.2	Goods & consumables (kCHF)	Students	Fellows	Longer term investment
2023	100			
2024	100	0.5		500
2025	100	0.5	1	~~2000~~
2026	100	0.5	1	300
2027	100	0.5	1	
2028	100	1		

WP8.4 – Demonstrator magnets, to demonstrate technology for future superconducting detector magnets

Cost-effective demonstrator magnet, from conductor to vacuum vessel and everything in between

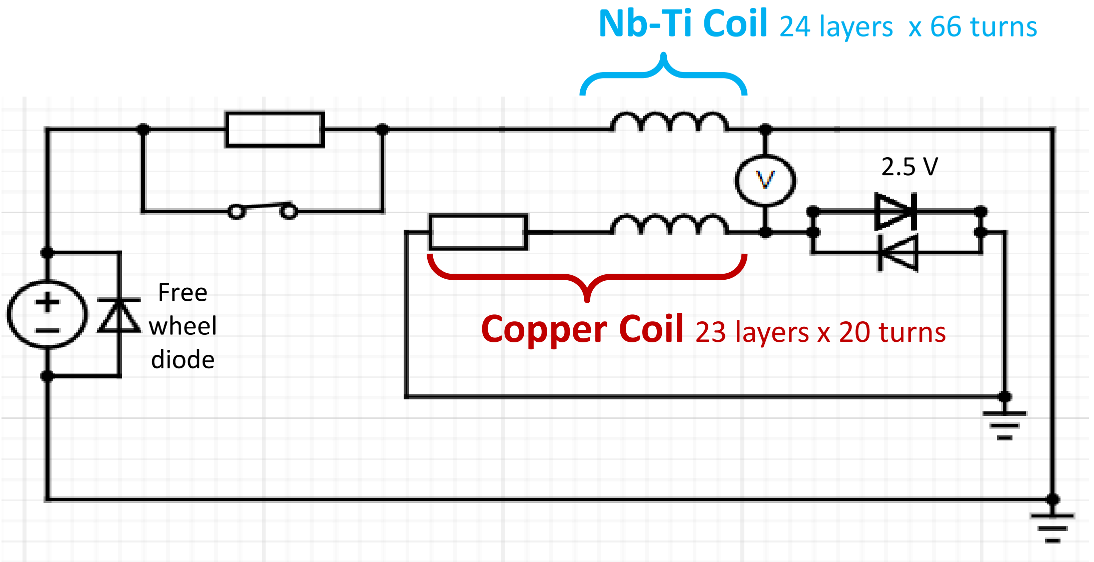
- Superconducting detector magnets are complex devices, where all of the following has to be correct: Conductor, cold mass mechanics, coil suspension, cryogenics, thermal shield and MLI, vacuum vessel and vacuum pumps, quench detection and protection, current leads and power supply, controls
- Moreover, for cost and scheduling reasons, the first superconducting detector magnet must work at the first try

- How to demonstrate new technologies developed in context of EP R&D in a magnet setting?
  - → Demonstrator magnets
  - → Novel method for simplified quench detection and significantly reducing voltage during a quench, applicable for both LTS and HTS
  - → Comprehensive effort, from conductor to vacuum vessel
  - → Small and cost-effective coils, allowing step-by-step design and trial and error

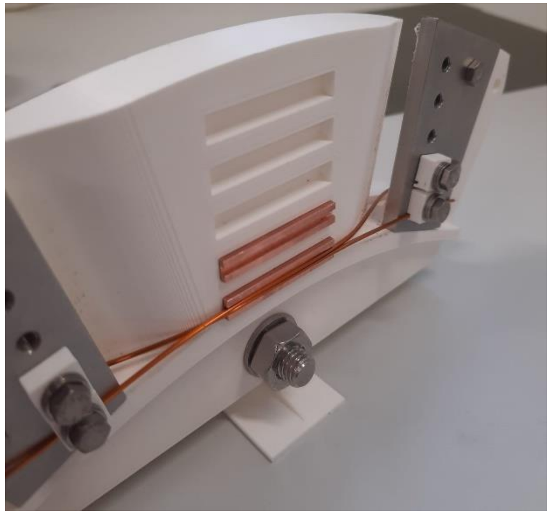


WP8.4 - Demonstrator magnets, to demonstrate technology for future superconducting detector magnets, example

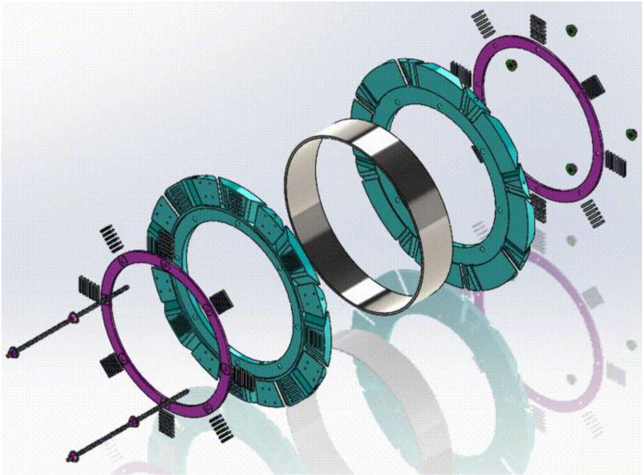
Develop and keep expertise in-house on LTS and HTS magnet design and assembly, covering various fields such as mechanics, integration, winding, splices, protection, powering, cryogenics, vacuum vessel, quench detection and protection.

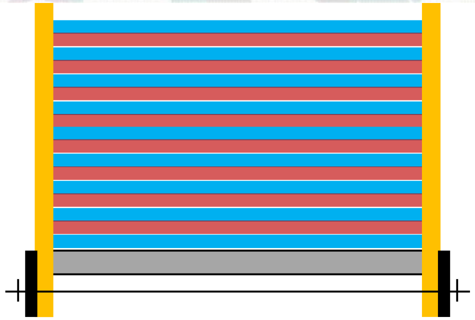


Novel method for simplified quench detection and significant reduction in voltages during quench discharge, applicable both for LTS and HTS (see back-up slides for explanation)



Layer-to-layer connection mock-up





Coil cross section scheme
2 x 24 interleaved layers and prepreg as insulation
(only 2 x 8 shown)

WP8.4 - Demonstrator magnets, to demonstrate technology for future superconducting detector magnets

Timeline

2024	Modelling of demonstrator coils, technical report. Coil winding (NbTi and HTS).
2025	Preliminary test report and final specifications.
2026	Demonstrators testing and reporting.
2027	Study for large scale magnet application and report.
2028	

Resources

WP8.4	Goods & consumables (kCHF)	Students	Fellows
2024	35		1
2025	10		1
2026	10	0.5	1
2027	10	0.5	
2028			

WP8.5 - Magnet Controls and Instrumentation

Specific instrumentation will be necessary for the works on HTS superconducting Al-stabilized cables and coils to be developed in the sub-activities of WP8.1 and WP8.4.

- **A Cryocooler test facility** will be also implemented in the laboratory of the EP magnet team in B180 to study and perform tests of refrigerant free conduction cooling of detector magnets, using Low Temperature and High Temperature Superconductor samples (HTS and LTS).
- **An HTS test setup** will be developed with anti-Dewar to test up to 70K with background magnetic field up to 5 T.
- **Specific PID control** will be developed and installed with the support of the EP-DT-DI team.

Test set up for cryo-cooler performance check in b180

WP8.5 - Magnet Controls and Instrumentation

Timeline

2024	HTS test setup development. Conceptual design with PID control & sensors.
2025	Cryocooler installation with instrumentation.
2026	Simulation and validation tests
2027	Final report.
2028	

Resources

WP8.5	Goods & consumables (kCHF)	Students	Fellows
2024	25	0.5	
2025	10	0.5	
2026	10	0.5	
2027	10	0.5	
2028			

Summary

EP R&D WP8 Program Proposal 2024-2028

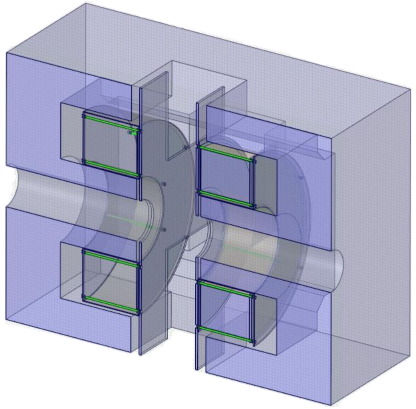
- WP8.1: Advanced Magnet Powering for high-stored energy detector magnets → For reduced power consumption and sustainable science
- WP8.2: Aluminum-stabilized (reinforced) conductor technology → Needed as enabling technology for future superconducting detector magnet projects
- WP8.4: Demonstrator magnets, to demonstrate technology for future superconducting detector magnets → Allows to demonstrate of technology developed in the context of EP R&D
- WP8.5: Magnet controls and instrumentation → In support of work-packages 8.1, 8.2, and 8.4

Thank you for your attention ☺

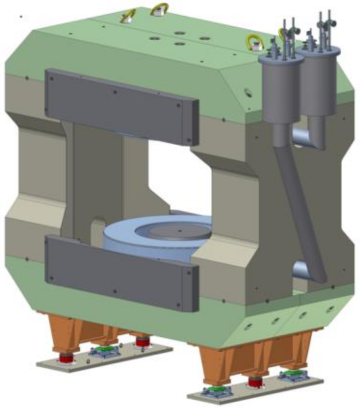
Back-up slides

WP8.4 – Extra information (1/4)

- Within the context of EP R&D WP8: Conceptual design for a large bore (~1 m) 4 T superconducting split-coil solenoid (= dipole), as a general user facility, with stored magnetic energy of 106 MJ
- For comparison: CBM dipole (Helmholtz coil), designed by the Budker institute for use at FAIR, featuring 1 T transverse field over a large bore (1.4 m), 5.2 MJ stored magnetic energy
- Also similar to M1 (3T) and the Goliath normal-conducting dipole in the North-Area
- Underlying design philosophy: Round coils, easy to wind, where the windings take most of the Lorentz force, and the support structure is there to hold the coils in place and handle the net force



Conceptual design of a 4 T superconducting dipole (EP R&D WP8)



Design of the CBM superconducting dipole

M1 superconducting dipole

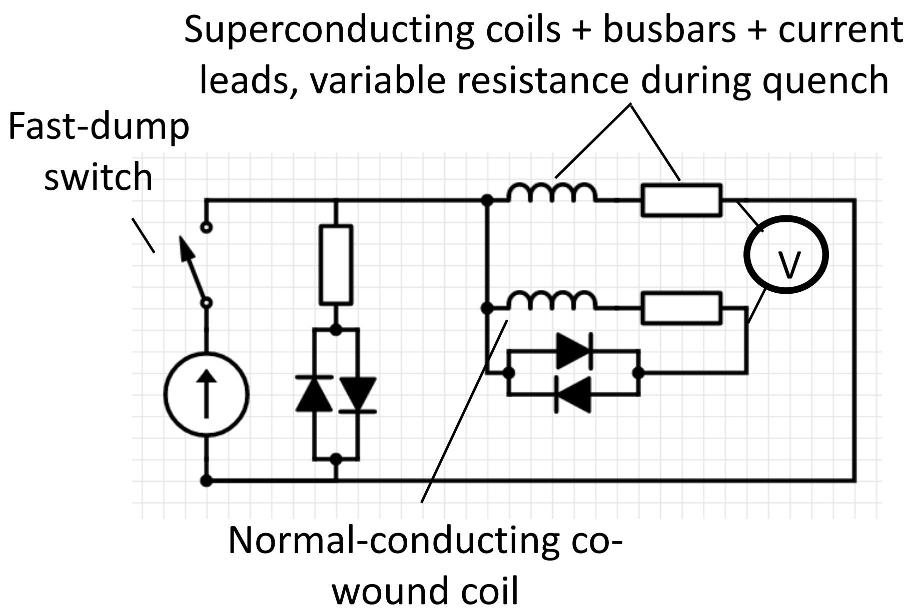
Goliath normal-conducting dipole

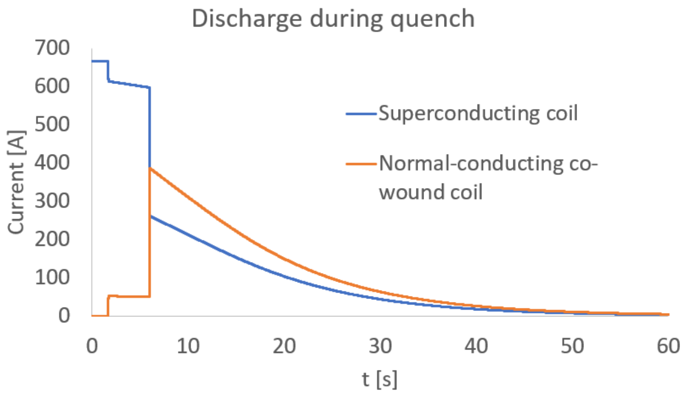
WP8.4 – Extra information (2/4)

- The CBM dipole features individual Nb-Ti strands with a cross-section of just a few mm^2, whereas for example CMS features a conductor with >1000 mm^2
- For CBM, the operating current is limited to single-wire performance (operating current of 686 A), already using one of the largest-cross-section Nb-Ti/Cu strands on the market
- With increasing magnetic field, Nb-Ti strand critical current wire performance and thus the operating current decreases
- During a quench: Challenge to quickly discharge the magnet before permanent damage occurs. Lower current and higher stored magnetic energy both result in (much) higher voltages. Therefore large superconducting detector magnets such as ATLAS and CMS feature very large conductors and large operating currents (20 kA)
- CBM dipole, relying on dump resistor: Stored magnetic energy is just 5.2 MJ, but nevertheless > 1400 V over the coils. High voltage: More challenging for internal insulation ($), more challenging for surrounding equipment ($), hazardous for humans (safety, $)
- Can we have the low operating current (compatible with single Nb-Ti strand performance), also giving lower cryogenic load (because lower current → lower load), without the high voltage during quench?

WP8.4 – Extra information (3/4)

- Concept: Co-wound coil, featuring layers of insulated superconducting (Nb-Ti/Cu) and insulated normal-conducting (only Cu) strands.
- Quench detection with 1:1 coil winding ratio (i.e. equal lengths of superconducting and normal-conducting conductors): Unlike regular superconducting magnets quench detection is done with a single voltage channel, where both the ramping voltage and the inductive noise are intrinsically strongly suppressed → Easy quench detection
- Quench protection: In case of quench detected, discharge of superconducting circuit over dump resistor, resulting in rapid current transformation to normal-conducting windings, fast and homogeneous normal-zone formation, and low internal temperatures and voltages
- With respect to regular energy-extraction (where all stored magnetic energy goes to dump resistor), >10x reduction in voltage-to-ground for identical adiabatic hotspot temperature
- How to prove that it works?





WP8.4 – Extra information (4/4)

Motivations:

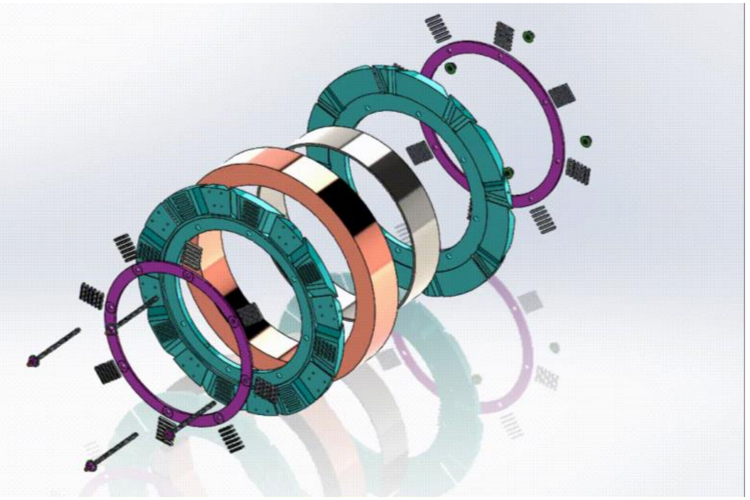
- EP Magnet Working Group mandate: “To keep the worldwide unique expertise, the working group shall maintain and expand magnet design knowledge and techniques as well as magnetic field, forces and stress calculations.”

- To have a working superconducting magnet, you need to consider all the following: Conductor, cold mass mechanics, coil suspension, cryogenics, thermal shield and MLI, vacuum vessel and vacuum pumps, quench detection and protection, current leads and power supply, controls

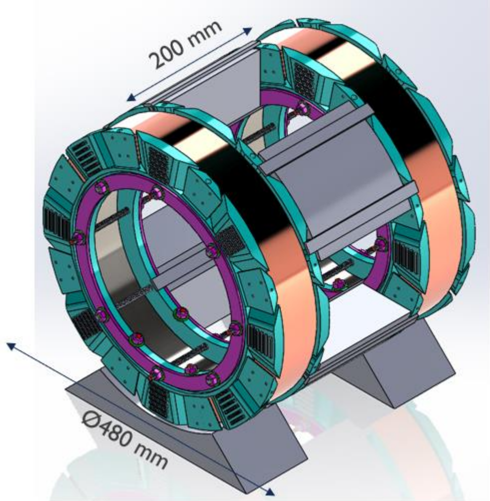
- To demonstrate that each of the above-mentioned considerations is properly considered for the new technologies developed in EP R&D WP8, a demonstrator is strongly advised, combining technologies from the various sub-packages, in a dipole which is the most challenging superconducting magnet type.

- It allows for training the next generation of magnet engineers on all aspects of superconducting magnets and associated systems

- For the purpose of having a proven design for cost-effective scalable low-complexity intermediate-size superconducting detector dipoles for the benefit of CERN and the international community



Assembly video of single coil



Split-coil demonstrator coil mass, 1 T in bore

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