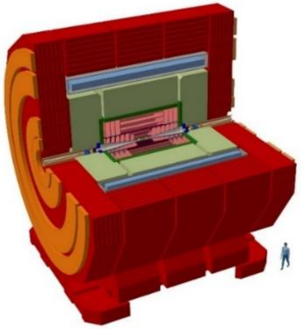
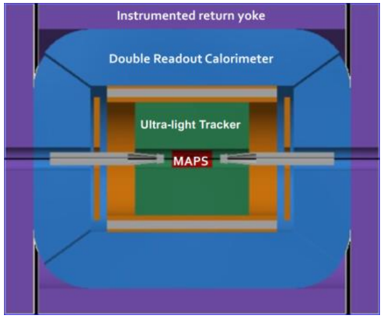
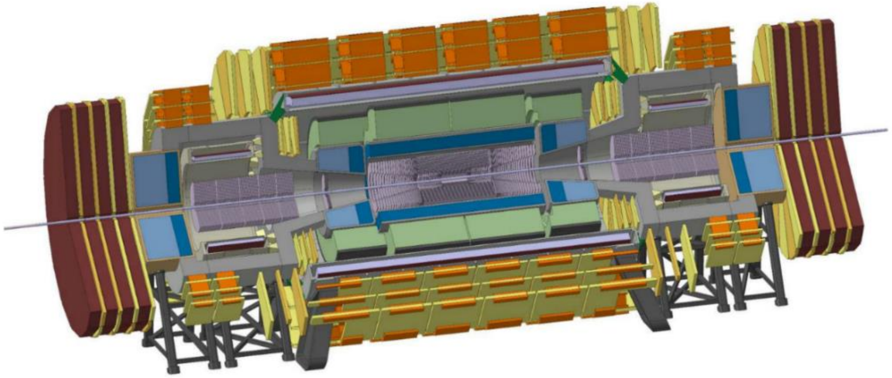
# WG8 - Detector Magnets

**Benoit Cure and Herman ten Kate**
on behalf of WG8 members





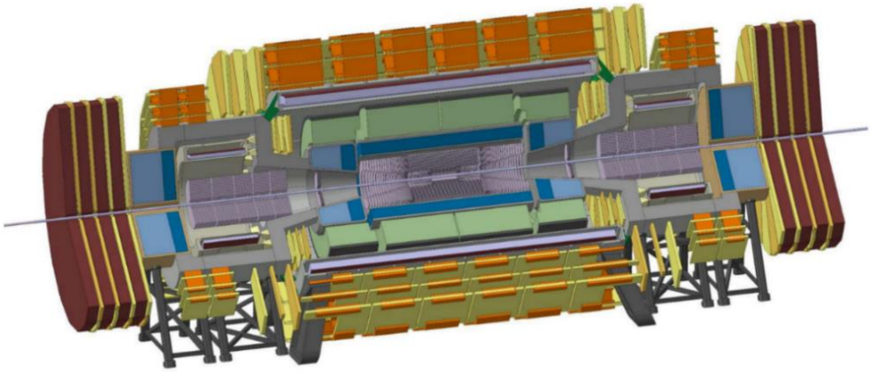



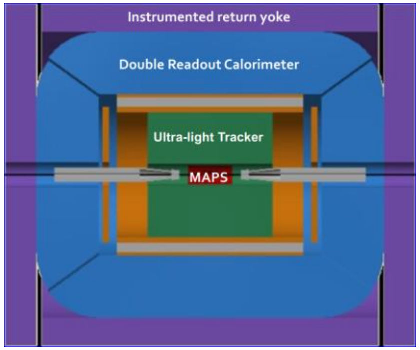
EP_R&D, $2^{nd}$ workshop, September 25, 2018

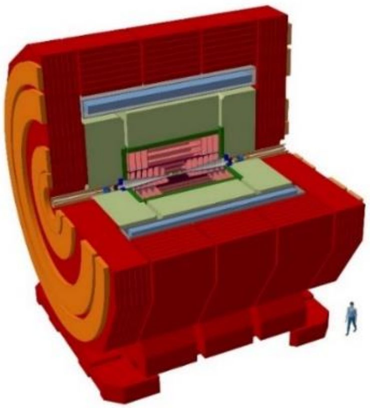
# Introduction

EP department magnet R&D will focus on developments:

- that are critical to HEP detector magnets,
- that could present show-stoppers for next generation detector magnets,
- that are not already done elsewhere,
- and where the EP department plays a crucial role.





## Introduction Detector Magnet Main Characteristics (few challenges)

| Collider | FCC-hh | FCC-hh | FCC-hh | FCC-ee | FCC-ee | CLIC | LHC | LHC |
|---|---|---|---|---|---|---|---|---|
| Detector concept | baseline | baseline | alter-native | IDEA | CLD | baseline | CMS | ATLAS |
| Magnet type | central solenoid | forward solenoid | forward dipole | central solenoid | central solenoid | central solenoid | central solenoid | central solenoid |
| Location w.r.t. calorimeter | behind | N/A | N/A | in front | behind | behind | behind | in front |
| B-field (T) | 4 | 4 | 4 Tm | 2 | 2 | 4 | 3.8 | 2 |
| Inner bore radius (m) | 5.0 | 2.6 | N/A | 2.1 | 3.7 | 3.5 | 3 | 1.15 |
| Coil length (m) | 19 | 3.4 | N/A | 6 | 7.4 | 7.8 | 12.5 | 5.3 |
| Current (kA) | 30 | 30 | 16.6 | 20 | 20 or 30 | ~20 | 18.2 | 7.7 |
| Current density A/mm2 | 7.3 | 16.1 | 27.6 | ?? | ?? | 13 | 12 | |
| Stored energy (GJ) | ~12.5 | 0.4 | 0.2 | ~0.2 | ~0.5 | ~2.5 | 2.3 | 0.04 |
| Mat. budget incl. cryostat | | | | ~1 $X_0$ | | <1.5 λ | | |
| Cavern depth (m) | ≤ 300 | ≤ 300 | ≤ 300 | ≤ 300 | ≤ 300 | ~100 | 100 | ~75 |

# Introduction

During the first workshop, WG8 presented:

- the on-going activities within EP on detector magnets together with the foreseen challenges ahead (H. ten Kate),
- the requirements for specific applications and the associated generic R&D studies (B. Curé).

Since then, following few rounds of discussion within WG8 and EP internal review by the Steering Committee, **5 R&D activities** have been identified and detailed with work plans, milestones and deliverables.

The activities are described in the general report on the CERN EP department R&D program on Experimental Technologies.

They are all included in Work Package 8.

# WG8 - Proposed activity list

## Studies in the frame of Work Package 8:

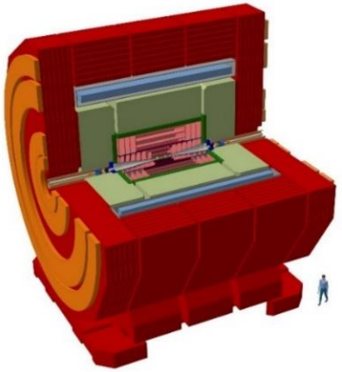
**8.1 Advanced Magnet Powering for High Stored Energy Detector Magnets,**

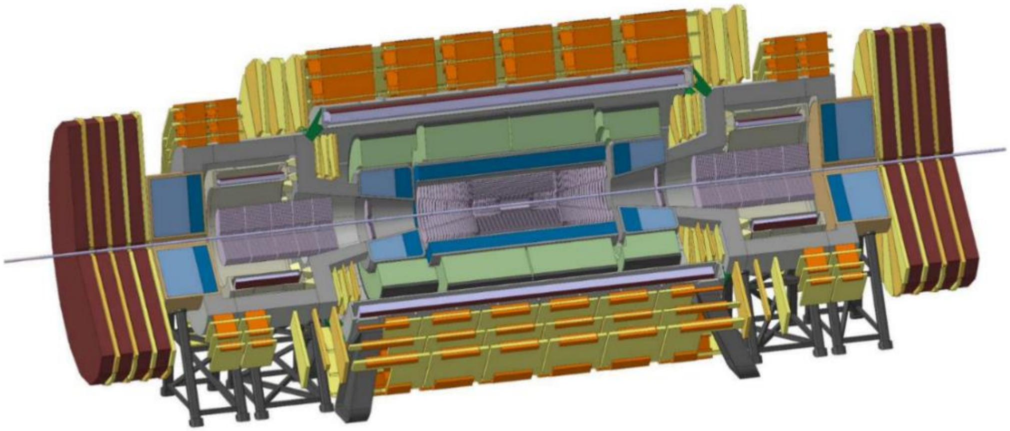
**8.2 Reinforced Super-Conductors and Cold Masses,**

**8.3 Ultra-Light Cryostat Study,**

**8.4 New 4-tesla General Purpose Magnet Facility for Detector Testing,**

**8.5 Innovation in Magnet Controls, Safety Systems & Instrumentation.**

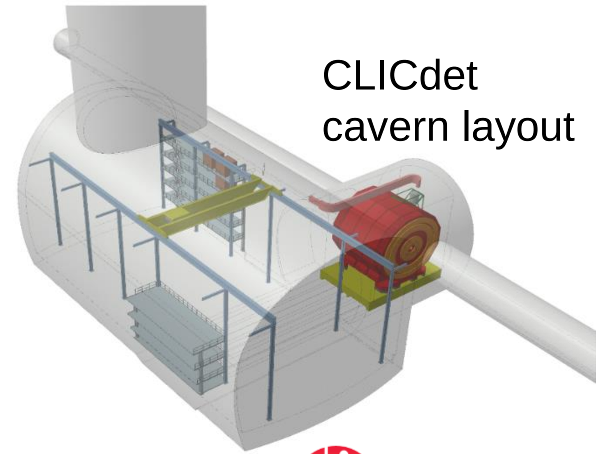




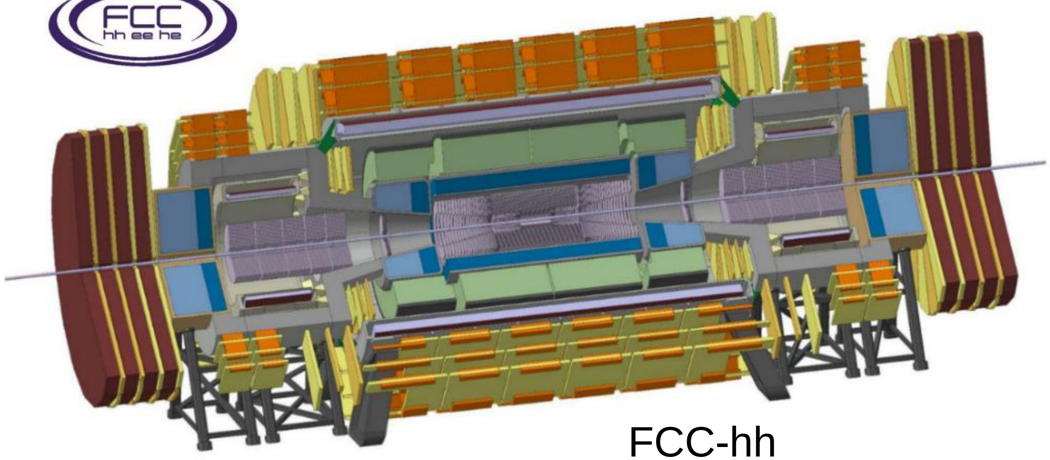
## Advanced Magnet Powering for high stored energy detector magnets

Next generation of HEP experiments will be built with different environment and infrastructure:

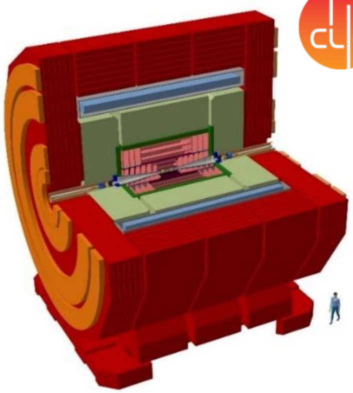
- Deeper experimental caverns,
- Specific garage positions for maintenance,
- Larger dimensions,
- Larger stored energies,
- Large magnet current up to 40 kA.



CLICdet cavern layout



FCC-hh



CLICdet

# WP8 activity 8.1

## Advanced Magnet Powering for high stored energy detector magnets

**Studies are needed to define the technical requirements for powering and quench protection circuits and associated cooling.**

Technical solutions shall be demonstrated to power the magnets:

- In a stable and sustainable manner,
- Fulfilling requirements for magnetic field stability,
- Reducing magnet downtime to ensure B-field availability for data taking,
- Addressing maintenance scenario,
- Minimizing energy consumption.

# WP8 - Activity 8.1

## Advanced Magnet Powering for high stored energy detector magnets

**WG8 has identified the 6 following issues considered as essential for achieving better magnet system performance:**

1) Compact and Fast Protection Current Breakers,

2) Free Wheel System (FWS) limiting magnet charge cycles and allowing faster recoveries,

3) Persistent mode Current Switch (PCS) allowing large energy savings and less magnet down time,

4) Compact, high performance Quench Protection Dump Units,

5) Maximum Energy Extraction Studies allowing much faster magnet recovery,

6) Requirements for Cryogenics HTS Current Bus Lines allowing remote on-surface powering.

## Advanced Magnet Powering for high stored energy detector magnets

### *1) Compact and Fast Protection Current Breakers:*

Considering:

- Magnet with large current → need of large breakers with poles connected in // → space must be available → issue for integration solutions with detector on-board platform.
- Redundancy and sturdiness are key requirements.

→ Define the requests for the given specific time constants of future magnets.

→ Technical solutions are to be identified.

Example: CMS – 20 kA switch breakers for powering and discharging lines.

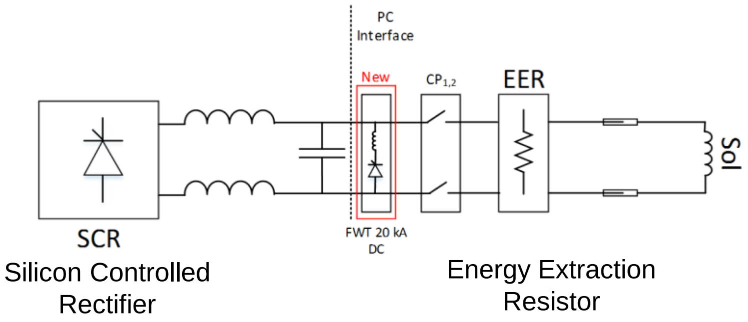
## Advanced Magnet Powering for high stored energy detector magnets

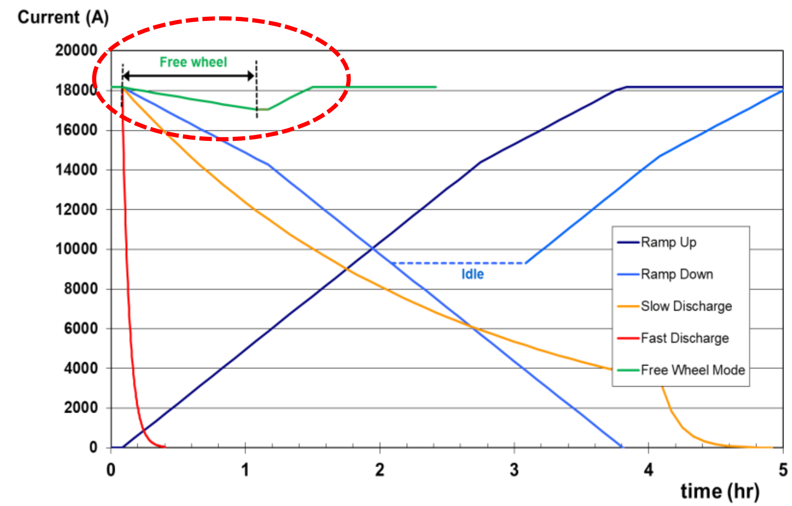
### *2) Free Wheel System (FWS) limiting magnet charge cycles and allowing faster recovery:*

- Offers large gain on magnet availability against services faults (power cut, cooling) during operation (avoid discharge & ramp up time, typically 8-12 hours), only few minutes with FWS.
- Reduces the mechanical cycling of magnet due to field on-off cycles.
- Works at room temperature with elements such as diodes, thyristors.
- FWT implemented for CMS after LS2.

→ Establish technical requirements, simulation

→ Optimize for application with large detector magnets.




Example: FWT of CMS for LS2

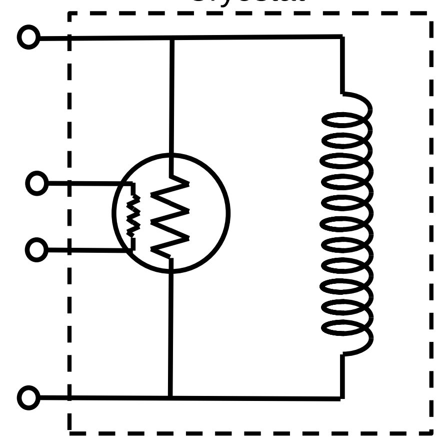
## Advanced Magnet Powering for high stored energy detector magnets

### *3) Persistent Mode Current Switch (PCS) allowing large energy savings and less magnet down time:*

Develop a high-current switch towards persistent mode, a design that can be adapted to future magnet configurations.

Reduction of power consumption (e.g. CMS power converter at nominal field ~ 150 kW).

No more voltage ripple, but compatibility of PCS with requirements on field stability must be checked (large magnets will have resistive conductor splices) :



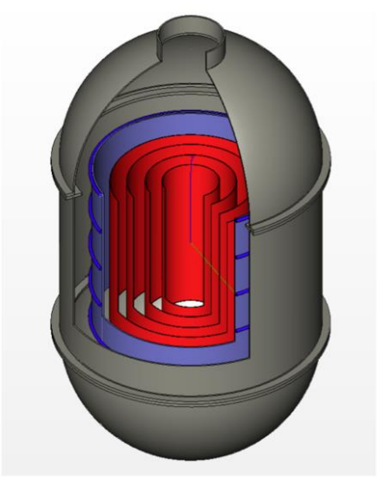

- Determine if a field decrease ΔB/B < ~ 1e-5 – 1e-4 realistic over ~x hours ?
- Is it acceptable for data analysis to have Field map B(*x,y,z,*$B_{ref.meas.}(t)$) ?
- Identify solutions for field and magnet current measurement.

- Study switch protection against quench and compatibility with magnet protection.
- The study will cover feasibility for both high and low Tc superconductors.
- Short demonstrator with either low or high Tc.

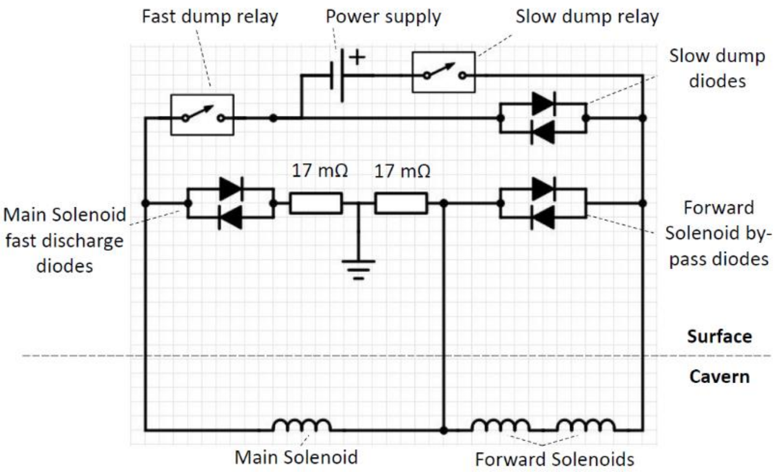
## Advanced Magnet Powering for high stored energy detector magnets

### *4) Compact, high performance Quench Protection Dump Units:*

- Study of dump circuits with passive or active cooling.
- Systems with diodes and/or resistors.
- Design taking into account operational requirements and constraints (integration, availability, recovery time, cost).



Preliminary study of a Water cooled resistor (CLICdet magnet)

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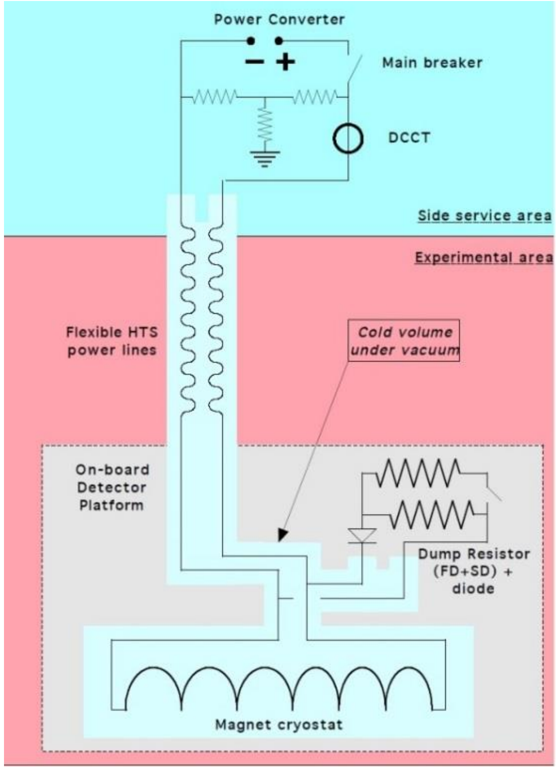



CLICdet magnet

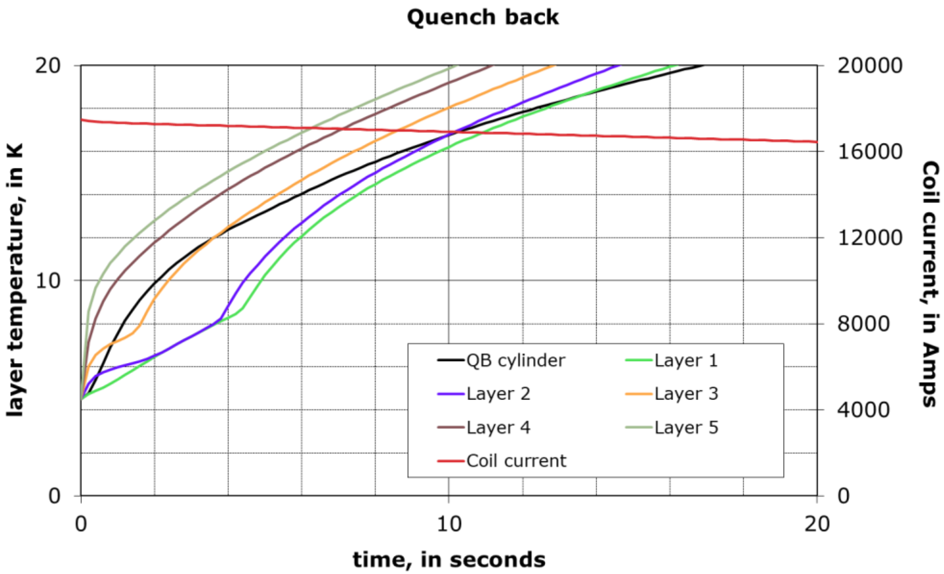
Examples of possible layouts

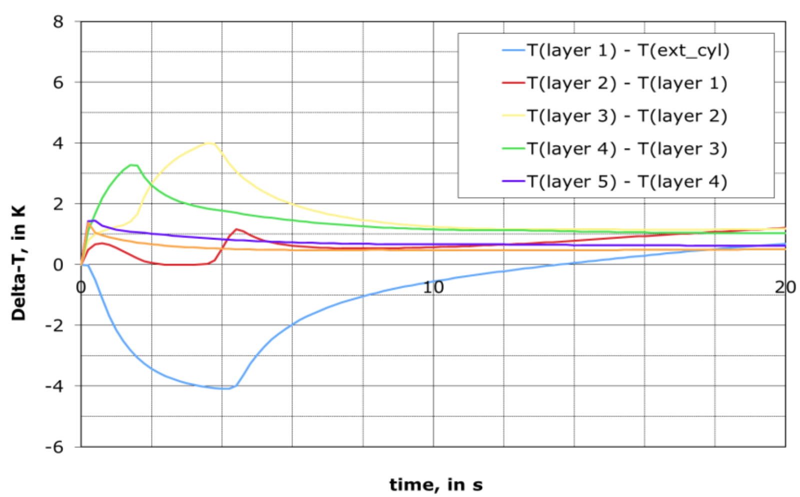
## Advanced Magnet Powering for high stored energy detector magnets

### *5) Maximum Energy Extraction Studies allowing much faster magnet recovery:*

- Study of magnet discharge, quench propagation, fault case scenario.
- Design of protection scheme with energy extraction by quench back, heaters.

Generic studies for solenoids, with FE modelling, comparisons of solutions.



## Advanced Magnet Powering for high stored energy detector magnets

### *6) Requirements for Cryogenics HTS Current Bus Lines allowing remote on-surface powering:*

The study on SC bus-bars for detector magnets will benefit from the development done by CERN-TE Dpt.

It will be initiated at a later stage of the EP R&D program, to adapt this technology developed for HL-LHC accelerator to large detector magnets :

- Much larger time constants (~3-5h): bus bar protection issues to be studied,
- One line for one magnet only: specific conductor layout is needed to limit the self field & inductance, effect of magnet stray field,
- Characteristics of cryogenics cooling to be studied.

# WP8 - Activity 8.1

## Advanced Magnet Powering for high stored energy detector magnets

### *Deliverable and milestones:*

**Deliverables**

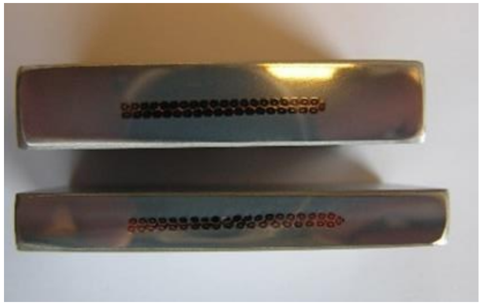
| | **date** | item |
|---|---|---|
| **Deliverables** | 12 | Feasibility Study of various Magnet Powering Modes. Recent Technology Study Report based on literature research. |
| | 24 | Technical Requirements Report and Conceptual Design Report based on Simulation and some model R&D. Selection of demonstrators. |
| | 36 | Technical design and Engineering Report. Construction of short demonstrator models and testing (2 years). |
| | 48 | Continued R&D on demonstrators and testing. |
| | 60 | Final report. |

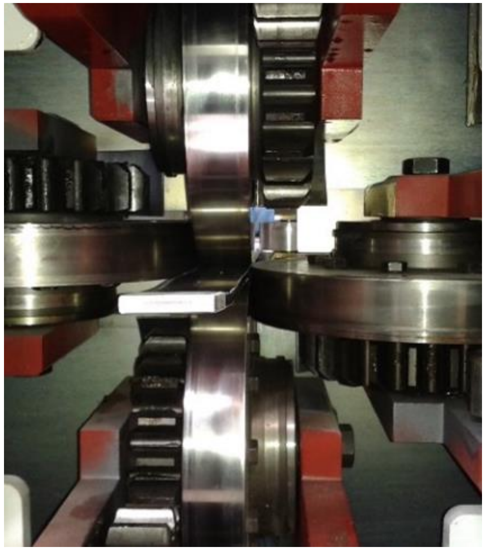
| | | |
|---|---|---|
| **Milestones** | 12 | Review of options and study report finished. |
| | 24 | Technical requirements and Conceptual Design of system and demonstrators finished. |
| | 36 | Technical design finished and construction of demonstators in progress. |
| | 48 | Test report of demonstrators. |
| | 60 | Final report, evaluation, outlook and conclusion. |

# WP8 - Activity 8.2

## Study of reinforced Super-Conductors and Cold Masses

- Study of high-yield strength Al stabilized and reinforced NbTi/Cu superconductors.
- Applied to large bore high field detector magnets,
- but also to detectors with the design goal of a 2 to 4 T solenoid cold mass with a radiation length less than 1 X0,
- and detector with a solenoid positioned inside the calorimeter, such as LHeC/FCC-eh or the FCC-ee.
- Examples are magnets for CLIC, and all variants of FCC.
- EP did a first iteration on reinforced conductor extrusion in 2011 in the frame of CLICdp.





Characterization of Al0.1wt%Ni coextruded and cold-worked conductor

# WP8 - Activity 8.2

## Study of reinforced Super Conductors and Cold Masses

**The studies will cover:**

1. Design of coils and high strength reinforced conductors, in combination with quench studies,
2. Short Conductor demonstrator manufacturing, including friction-steer and electron-beam welding exercises,
3. Sample testing to qualify conductor for use in the magnets, with measurement of mechanical and SC properties,
4. Cold mass design: minimum thickness support cylinder, new thin cooling circuits, cold mass supports and electrical connections.

This activity is foreseen at a later stage of the R&D, possibly second phase.

# Study of reinforced Super Conductors and Cold Masses

## *Deliverable and milestones:*

**Deliverables**

| date | item |
|---|---|
| 12 | Review study reinforcement options, thin cold mass design report. |
| 24 | Short sample productions, welding technology, and characterization |
| 36 | Short sample productions, welding technology, and characterization. |
| 48 | Selected conductor unit length production and coiling/bending test. |
| 60 | Reporting, evaluation and outlook. |

**Milestones**

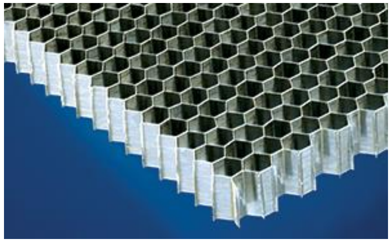
| date | item |
|---|---|
| 12 | Review study report. |
| 24 | Short sample test reports. |
| 36 | Short sample test reports. |
| 48 | Long unit test report. |
| 60 | Test coil report, final report, batch of samples made. |

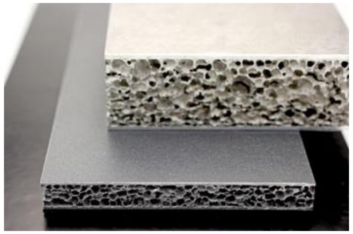
# WP8 - Activity 8.3

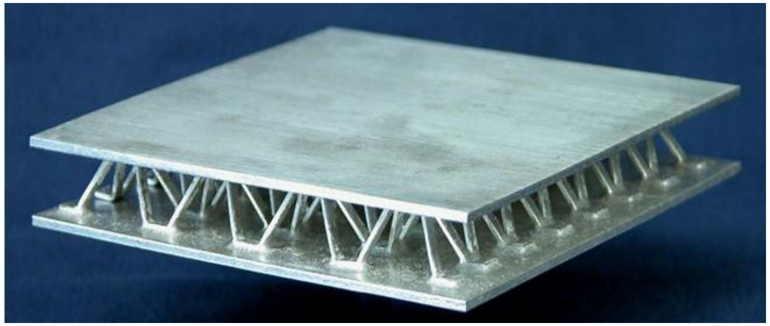
## Ultra-Light Cryostat Study

- Studies for detector magnets, calorimeter cryostats and in-detector structures in general.
- Needed to meet the design goal for minimum radiation length, thus strongly reducing material wall thicknesses and mass of next-generation cryostats.
- Carbon fiber reinforced polymeric-based composites will be explored and compared to advanced metal or hybrid honeycomb structures.
- The study is led by WP4, in cooperation with WP3.
- WP8 will provide the technical requirements for magnet cryostats.

→ Deliverables & Milestones listed in WP4







# New 4 T General Purpose Magnet Facility for Detector Testing

**Next HEP detectors are designed to work at 4 T.**

A 4-T test facility will be required in the near future and will replace or complement the old systems available at CERN on the beam-line facilities.

Within the R&D program the design of a 4-T magnet for a beam line facility is made.

Example of facilities available at CERN on beam line:


CMS-M1 (3 T)


Morpurgo (1.9 T)

# New 4 T General Purpose Magnet Facility for Detector Testing

To be used for testing and calibration (e.g. detector units, electronics, magnetic sensors, ...)

It will give access to the full range of magnetic conductions in a detector, both with a constant field value up to 4 T, and with variable field conditions that are met during ramp up or magnet discharge.

Associated tooling with remote control for the device under test is also within the scope of he study, like rotating table with rails, etc.

The facility is intended to be shared with collaborations in which EP department is contributing.

The design will include the technologies proposed in the WP8 R&D activities.

The requested characteristics will be defined together with the potential users from the CERN test beam community.

***N.B. :*** The EP R&D program will not fund the manufacturing (and operation) of such a facility.

# WP8 - Activity 8.4

## New 4 T General Purpose Magnet Facility for Detector Testing

### *Deliverable and milestones:*

**Deliverables**

| date | item |
|---|---|
| 12 | Magnet design (1 year). |
| 24 | Magnet subsystems design and integration: powering circuit, cryo, vac, |
| 36 | Demonstrators testing, control, instrumentation, powering (1 year). |
| 36 | Final Report of Design and Specification. |
| | |

**Milestones**

| | |
|---|---|
| 12 | Magnet conceptual design report. |
| 24 | Magnet Technical Specification and procurement documents. ` |
| 36 | Final report Design and Technical Specification. |
| | |
| | |

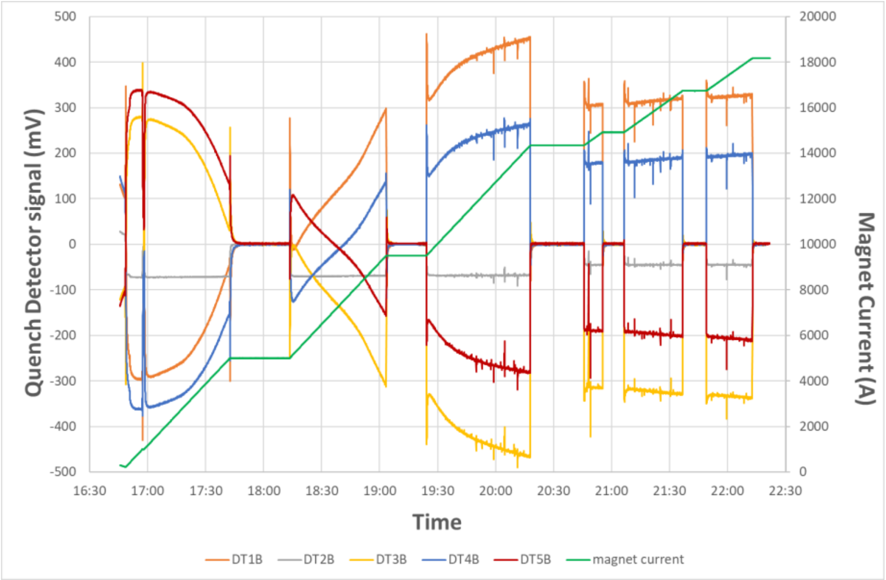
# WP8 - Activity 8.5

## Innovation in Magnet Controls, Safety & Instrumentation

**Three domains have been identified:**

1) Quench protection: requirements, sensors, electronics,
2) Magnet control: requirements, interfaces,
3) Instrumentation: magnetic measurement.

Will be applied to the 4-T General Purpose test facility study as user case.




Quench Detector signals
CMS Channel DTB

|k1.V1-k2.V2|< $V_{thr}$(1V; 2V) for 1s

## Innovation in Magnet Controls, Safety & Instrumentation

### 1) Quench protection: requirements, sensors, electronics

Quench propagation in HTS is slower than in LTS with lower resistive voltage developed.

This requests electronics with **faster response time** and **lower voltage threshold**, with **increased noise reduction**.

The study will cover problems related to:

- **Fast quench detection** systems.
- Increase of **quench detection sensitivity** at any changes of the operating current in the detector magnets due to eddy currents effect in the cold mass and high purity conductors.
- **Quench detection of low voltage elements** of magnet electrical circuit such as coil joints, superconducting bus bars and connections to the current leads where further development of the reliable fast response superconducting quench detectors is required.

# WP8 - Activity 8.5

## Innovation in Magnet Controls, Safety & Instrumentation

### 2) Magnet control : specification and requirements, interfaces

The study will provide **technical requirements for future magnet control and safety systems**:

- Expected number and type of signals, interfaces, with reduced response time, increased noise filtering.
- Identification of suitable front end and back end electronics from latest trends in SCADA technologies and data processing systems.
- Define the needs for the interfaces with other control systems (vacuum, cryogenics, beam, safety, etc.)

# Innovation in Magnet Controls, Safety & Instrumentation

## 3) Instrumentation: magnetic measurement

Topics for R&D:

- Magneto-resistive (MR) Sensors:
  - Performance,
  - Sensitivity in high fields,
  - Radiation hardness,
  - Investigation of other MR flavors.
- Motion actuation in high magnetic fields for scanning tables
  - Piezoelectric motors
- Interfaces
  - Updates to CAN (possibly CAN FD - Flexible Data-rate).

# WP8 - Activity 8.5

## Innovation in Magnet Controls, Safety & Instrumentation

### *Deliverable and milestones:*

| | date | item |
|---|---|---|
| **Deliverables** | 12 | Report on future needs for magnet control systems (1 year). |
| | 24 | Conceptual design, simulations, prototyping of new control systems and instrumentation (2 year). |
| | 36 | Simulation and validation tests (1 year). |
| | 48 | Final report. |
| | | |

| | | |
|---|---|---|
| **Milestones** | 12 | Definition of future needs for control systems, interfaces, instrumentation. Survey on the development in industry. |
| | 24 | Conceptual design completed. |
| | 36 | New controls and instrumentation validated. |
| | 48 | Final report submission. |
| | | |

# R&D on Experimental Technologies

EP R&D

## Conclusion

**Key areas for R&D were defined for supporting the development of next generation Detector Magnets for LC and FCC designed detectors:**

- Advancing Super-Conductors, cold masses and cryostats for enabling light and radiation thin magnets.
- Addressing innovations and challenges in magnet powering and controls.
- Realizing a new 4T general purpose facility for detector components testing.

✓ **A corresponding manpower and budget plan was filed covering the next 5 years.**