International MUON Collider Collaboration

# Muon Collider Magnet Technology Options Internal Review

L. Bottura, L. Quettier and S. Fabbri,
on behalf of the MuCol Task Leaders and the Muons Magnets Working Group
21/6/2023

# Scope of the review

- The Muon Collider study aims at preparing a **(pre)conceptual design** for the next iteration of the European Strategy (2025-2027), which will include a consistent accelerator complex design
- The present baseline poses significant challenges and calls for **advances in magnet technology**
- We have formulated a *plan of action*, and selected specific solutions that appear to be **attractive for the muon collider, but not only**

We are presently at the beginning of this work, and we wish to have your opinion on the plan and the choices taken for the study

# Questions to the experts

- Q1: Are all critical magnet systems identified, including the true performance drivers, with no missing area ?
- Q2: Is the evaluation of technology options complete and appropriate ? Specifically, are there viable options that have not been considered, or not evaluated correctly ?
- Q3: Are the selection of options to be studied in detail, and the ranking of priorities, justified and appropriate for the objectives of a pre-conceptual report, due by end 2025 ?
- Q4: Is the work program proposed matching the above ambitions ?

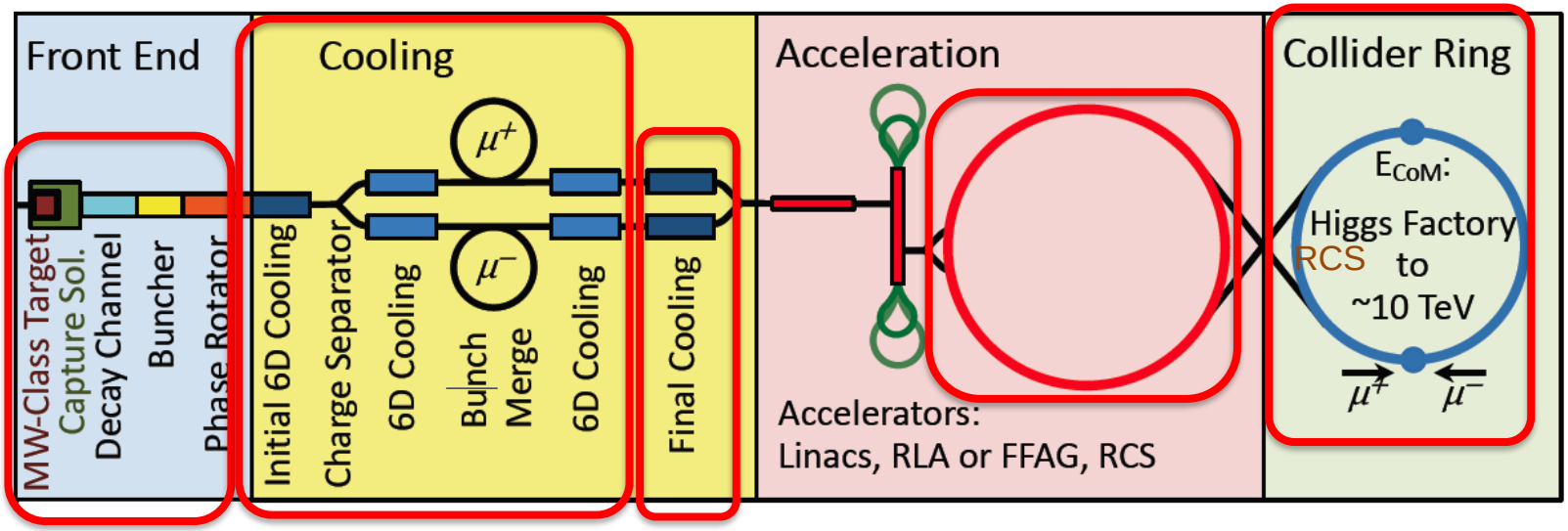
The result will be a report that we can release as part of the study (both IMCC and MuCol)

# Muon Collider magnet "specs"

Target solenoids
Field: 20 T… 2T
Bore: 1200 mm
Length: 18 m
Radiation heat: ≈ 4.1 kW
Radiation dose: 80 MGy

6D Cooling solenoids
Field: 4 T … 19 T
Bore: 90 mm … 600 mm
Length: 1 km (x 2)
Radiation heat: TBD
Radiation dose: TBD

Accelerator magnets
Field: ±1.8 T (NC), < 10 T (SC)
Rate: 400 Hz (NC), SS (SC)
Bore: 100 mm(H) x 30 mm(V)
Length: 3 m … 5 m (x 1500)
Radiation heat: ≈ 3 W/m
Radiation dose: TBD




Final Cooling solenoids
Field: > 40 T (ideally 60 T)
Bore: 50 mm
Length: ≈ 500 mm (x 17)
Radiation heat: TBD
Radiation dose: TBD

Collider ring magnets
Field: 16 T peak (IR 20 T)
Bore: 150 mm
Length: 10 m … 15 m (x 700)
Radiation heat load: ≈ 5 W/m
Radiation dose: ≈ 20…40 MGy

# Muon Collider magnet "catalog"

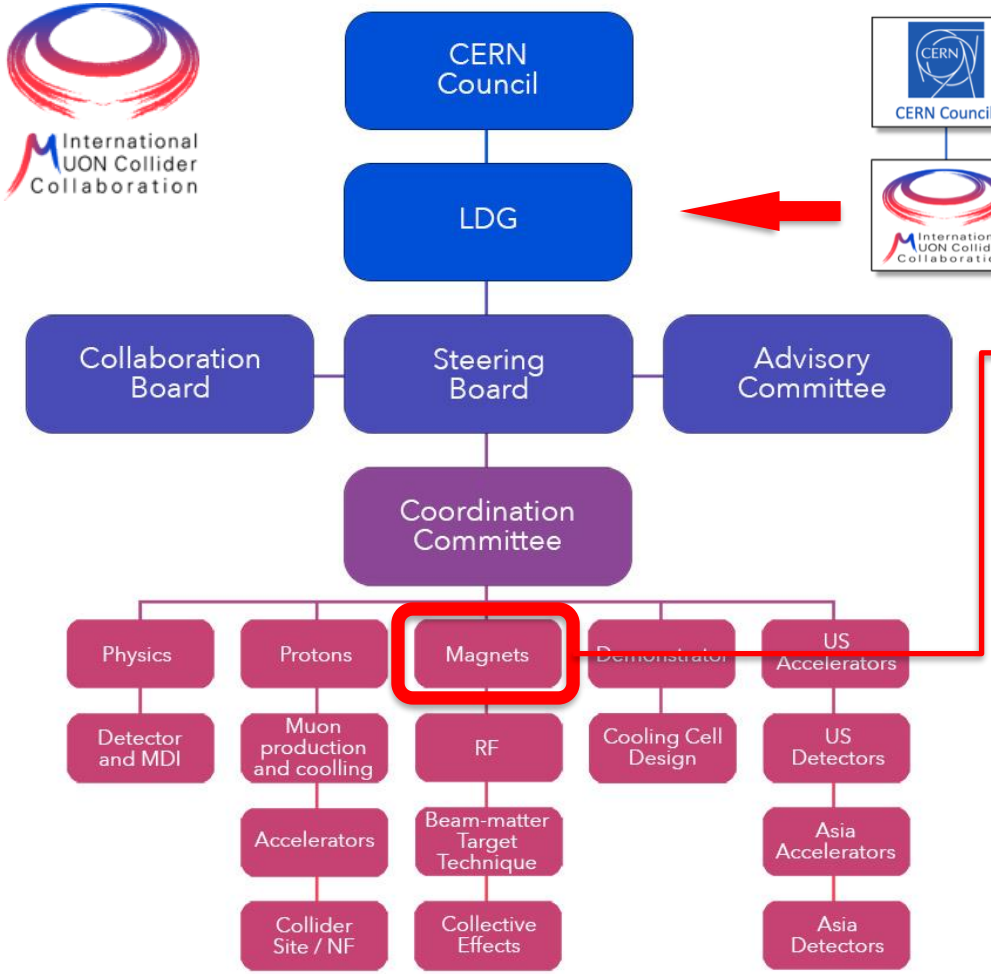
International MUON Collider Collaboration

| Complex | Sector | Sub-Sector | Magnet Type | Field | Gradient | Aperture | Gap | Width | Length | Number | Ramp time | Field rate | Homogeneity | Persistance | Beam power deposition | Magnet Technology | | Comments | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (T) | (T/m) | (mm) | (mm) | (mm) | (m) | (-) | (s) | (T/s) / (T/m/s) | (units) | (units/s) | (kW/m) | Preferred Option | Other Options | | |
| Target and Capture | Target | | solenoid | 15 | | 2400 | | | 2 | 1 | 21600 | 0.0007 | 100 | | 1 | LTS | | baseline 15 T, 2.4 m bore design, assumes 6 hours ramp-up time and 5 kW deposited total power | |
| | | | solenoid | 5 | | 150 | | | 0.5 | 1 | 1 | 5.0000 | 100 | | 100 | NC | | baseline 5 T resistive insert | |
| | Capture and decay channel | | solenoid | 20 | | 600 | | | 1.5 | 1 | 21600 | 0.0009 | 100 | 0.1 | 5 | HTS | | option based on a HTS cable, reduced bore and shielding, operating at 10...20 K | |
| | | | solenoid | | | | | | | | | | | | | TBD | | | |
| | Chicane | | | | | 860 | | 100 | 0.18 | 41 | | | | | | | | | Parameters assumed in C. Rogers past simulations |
| Cooling | Pre-Bunch-Merge | A1-1 | solenoid | 2.4 | | 900 | | 100 | 0.21 | 264 | 21600 | 0.0001 | 100 | 0.1 | | TBD | | cell A1 | US MAP Baseline |
| | | A2-1 | solenoid | 3.5 | | 820 | | 130 | 0.26 | 260 | 21600 | 0.0002 | 100 | 0.1 | | TBD | | cell A2 | |
| | | A3-1 | solenoid | 4.8 | | 540 | | 110 | 0.11 | 428 | 21600 | 0.0002 | 100 | 0.1 | | TBD | | cell A3 | |
| | | A4-1 | solenoid | 6.1 | | 440 | | 140 | 0.09 | 352 | 21600 | 0.0003 | 100 | 0.1 | | TBD | | cell A4 | |
| | Post-Bunch-Merge | B1-1 | solenoid | 2.6 | | 1540 | | 150 | 0.5 | 40 | 21600 | 0.0001 | 100 | 0.1 | | TBD | | cell B1 | US MAP Baseline |
| | | B2-1 | solenoid | 3.7 | | 1000 | | 150 | 0.36 | 64 | 21600 | 0.0002 | 100 | 0.1 | | TBD | | cell B2 | |
| | | B3-1 | solenoid | 4.9 | | 820 | | 150 | 0.37 | 108 | 21600 | 0.0002 | 100 | 0.1 | | TBD | | cell B3 | |
| | | B4-1 | solenoid | | | 350 | | 200 | 0.092 | 100 | 21600 | 0.0003 | 100 | 0.1 | | TBD | | cell B4 | |
| | | B4-2 | solenoid | 6 | | 820 | | 240 | 0.32 | 100 | | | | | | | | | |
| | | B5-1 | solenoid | 9.8 | | 226 | | 88 | 0.1 | 182 | 21600 | 0.0005 | 100 | 0.1 | | TBD | | cell B5 | |
| | | B5-2 | solenoid | | | 434 | | 165 | 0.196 | 182 | | | | | | | | | |
| | | B6-1 | solenoid | 10.8 | | 168 | | 92 | 0.1 | 154 | 21600 | 0.0000 | 100 | 0.1 | | TBD | | cell B6 | |
| | | B6-2 | solenoid | | | 430 | | 160 | 0.177 | 154 | | | | | | | | | |
| | | B7-1 | solenoid | 12.5 | | 100 | | 74 | 0.1 | 100 | 21600 | 0.0005 | 100 | 0.1 | | TBD | | cell B7 | |
| | | B7-2 | solenoid | | | 420 | | 145 | 0.17 | 100 | | | | | | | | | |
| | | B8-1 | solenoid | | | 90 | | 65 | 0.12 | 122 | 21600 | 0.0006 | 100 | 0.1 | | TBD | | cell B8 | |
| | | B8-2 | solenoid | 13.6 | | 280 | | 80 | 0.08 | 122 | | | | | | | | | |
| | | B8-3 | solenoid | | | 500 | | 120 | 0.1 | 122 | | | | | | | | | |
| | Final Cooling | Option 1 | solenoid | 30 | | TBD | | | 0.5 | 17 | 21600 | 0.0014 | | | 0 | HTS | | baseline design from US-MAP | US MAP Baseline |
| | | | solenoid | 40 | | TBD | | | 0.5 | 17 | 21600 | 0.0019 | 100 | 0.1 | 0 | HTS | | HTS NI option, including aperture margin | |
| | | | solenoid | 60 | | TBD | | | 0.5 | 17 | 21600 | 0.0028 | 100 | 0.1 | 0 | HTS | | HTS NI option, including aperture margin | |
| Accelerator | RCS1 | | dipole | 1.8 | | | 30 | 100 | 8.08 | 432 | 7.35E-04 | 2448.980 | 10 | | | NC | | | |
| | RCS2 | | dipole | 10 | | 100 | | | 2.4 | 288 | 1000 | 0.010 | 10 | | | LTS | | | |
| | | | dipole | 1.8 | | | 30 | 100 | 6.06 | 432 | 1.80E-03 | 1000.000 | 10 | | | NC | | | |
| | RCS3 | | dipole | 10 | | 100 | | | 2.6 | 288 | 1000 | 0.010 | 10 | | | LTS | | | |
| | | | dipole | 1.8 | | | 30 | 100 | 5.05 | 432 | 1.80E-03 | 1000.000 | 10 | | | NC | | | |
| | RCS4 | | dipole | 10 | | 100 | | | 2.6 | 288 | 1000 | 0.010 | 10 | | | LTS | | | |
| | | | dipole | 1.8 | | | 30 | 100 | 5.05 | 432 | 8.46E-03 | 212.716 | 10 | | | NC | | | |
| Collider | Arc | | dipole | 10 | 300 | 150 | | | | | 1000 | 0.010 | 10 | | 0.5 | HTS | | | |
| | IR | | quadrupole | | 466.32 | 171.4 | | | 2 | 4 | 1000 | 0.000 | 10 | | | HTS | | IQF1 | |
| | | | quadrupole | | 376.93 | 212.2 | | | 2 | 4 | 1000 | 0.000 | 10 | | | HTS | | IQF1a | |
| | | | quadrupole | | 300.71 | 266 | | | 2 | 4 | 1000 | 0.000 | 10 | | | HTS | | IQF1b | |
| | | | quadrupole | | 191.41 | 417 | | | 13.6 | 4 | 1000 | 0.000 | 10 | | | HTS | | IQD1 | |
| | | | quadrupole | | 214.03 | 411.2 | | | 5 | 4 | 1000 | 0.000 | 10 | | | HTS | | IQF2 | |

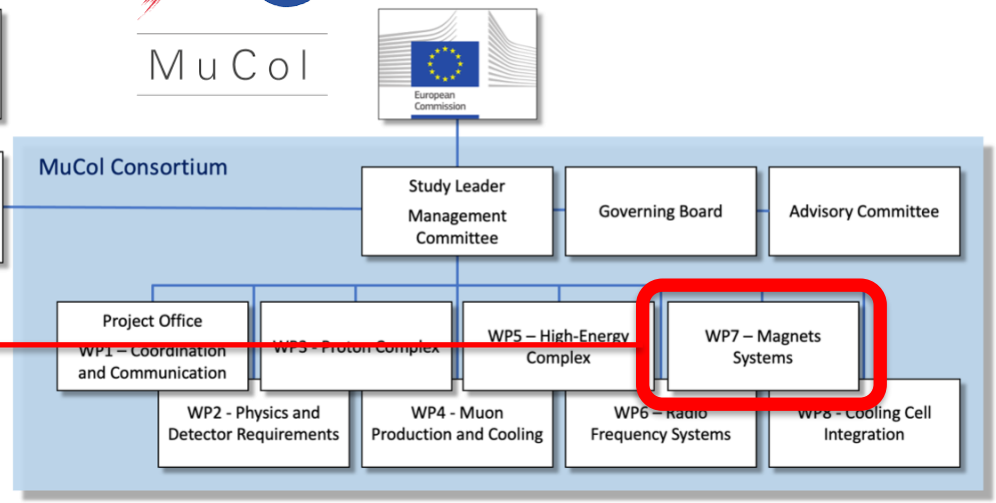
- This is a first step towards building the machine configuration, as necessary to have the basis for a calculation of cost and power

# Project organization

## International Muon Collider Collaboration




## MuCol EU Design Study




- The magnet work packages of IMCC and MuCol **are in essence the same**, with identical tasks and workplan.
- Activities are followed-up mainly through the “muons magnets Working Group” (mmWG)

# Muon Collider magnet “team”

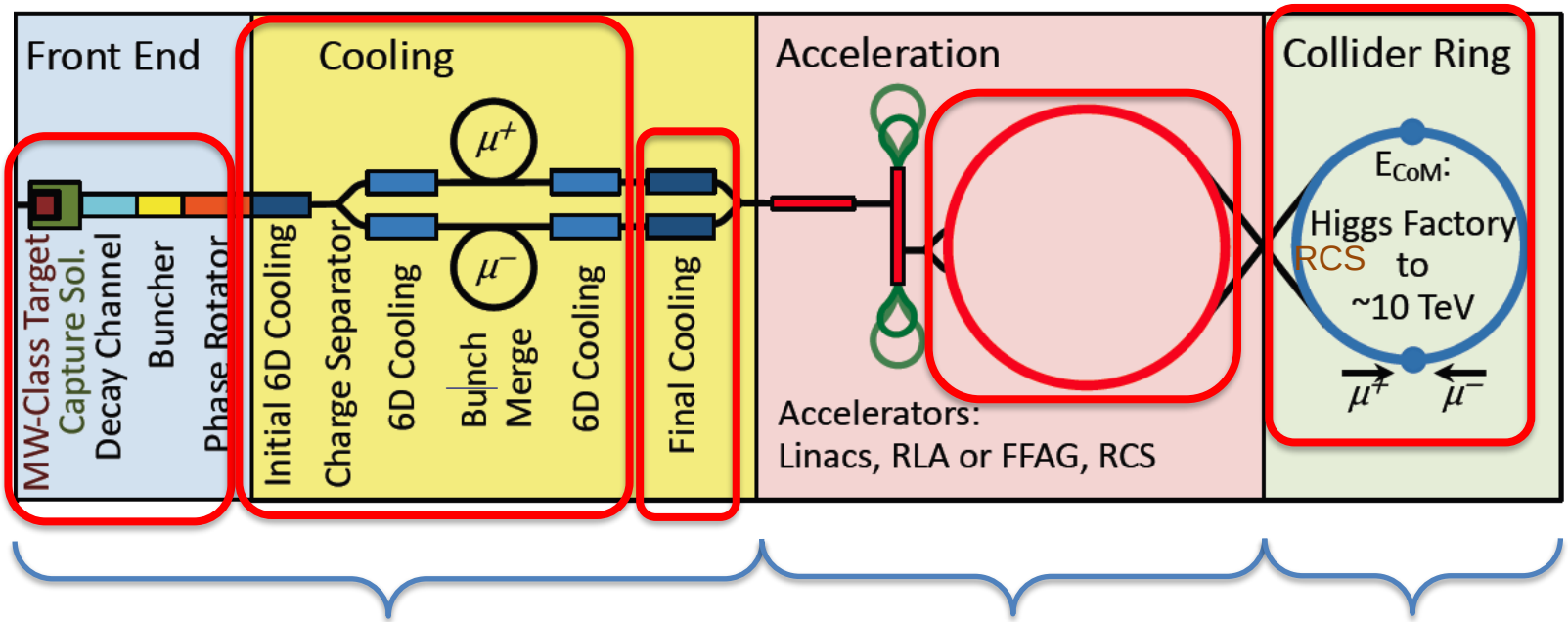
CERN
F4E (Barcelona)
F4E (Garching)

INFN
CERN
UniMI
KIT

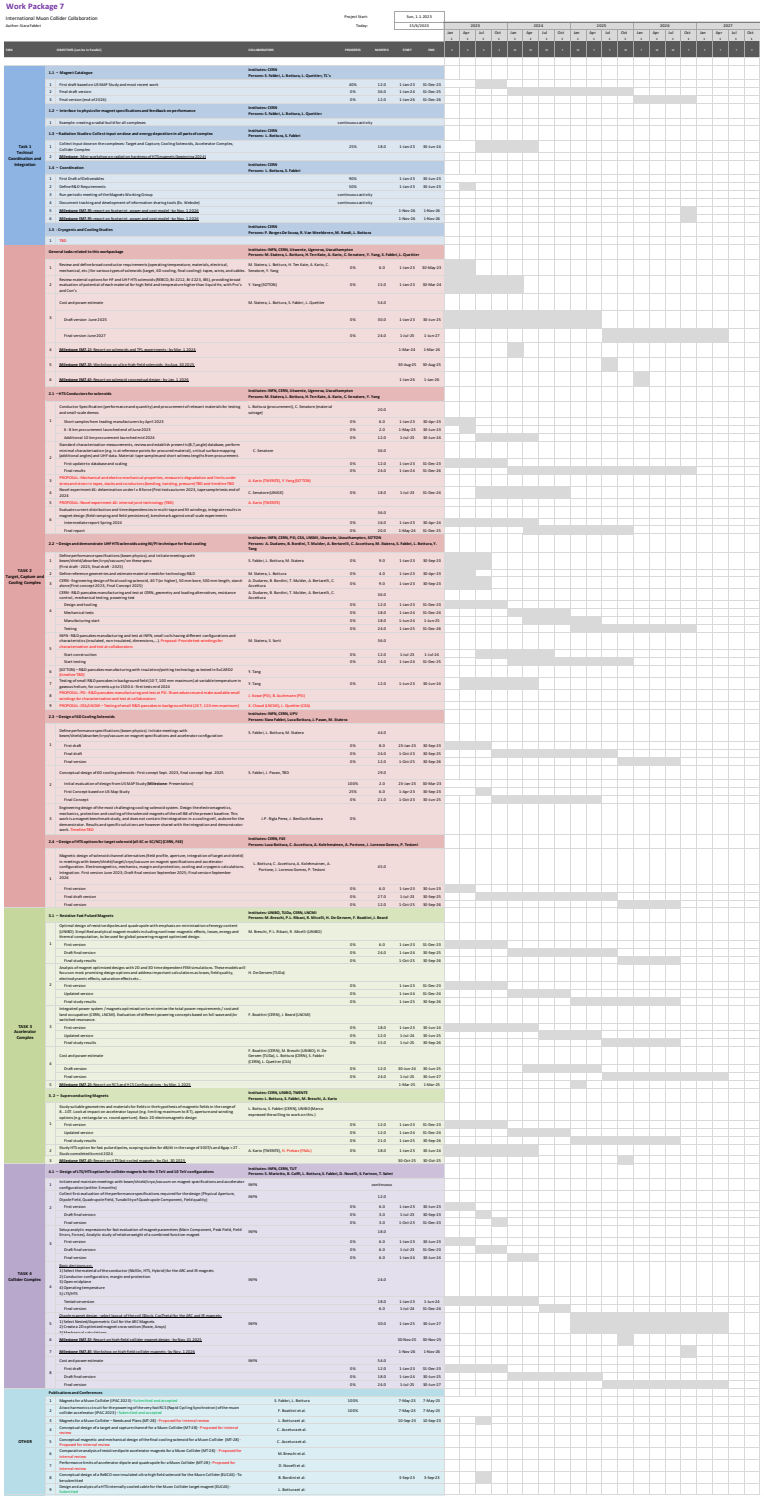
CERN
INFN
CEA
CNRS
PSI
UniGE
SO’TON
uniTwente

CERN
UniBO
TUDa
UniTwente

INFN
UniMI
CERN
TUT




Task 7.2 Task 7.3 Task 7.4




# The plan


- Activities have been defined, discussed and listed
- Deliverables
  - D7.1 – January 2026: Preliminary report on muon collider magnets
  - D7.2 – January 2027: Consolidated report on muon collider complex magnets
- Milestones
  - M7.1 – March 2024: Report on solenoids and TPL experiments
  - M7.2 – March 2025: Report on RCS and HCS configurations
  - M7.3 – October 2025: Workshop on ultra-high-field solenoids
  - M7.4 – December 2025: Report on HTS fast-cycled magnets
  - M7.5 – January 2026: Report on high-field collider magnet design
  - M7.6 – February 2026: Report on solenoid conceptual design
  - M7.7 – September 2026: Workshop on high-field collider magnets
  - M7.8 – November 2026: Report on footprint, power and cost model
  - M7.9– November 2026: Report on R&D and impact

# Logistics

- Open presentation session
  - Wednesday 21 June, 8:30-12:30
  - Pierre Lehmann Auditorium - B. 200 - IJCLab Orsay
- Panel closed session
  - Wednesday 21 June, 14:00-17:30
  - Salle Bleue - B. 200 - IJCLab Orsay
- Report and discussion at mmWG, comments and outstanding questions
  - Thursday 6 July, 15:00
  - Virtual meeting
- Open debrief at IMCC Design Meeting
  - Monday TBD, 16:00
  - Virtual meeting