Muon Collider
WP7 - Magnets

Luca Bottura, F. Boattini, B. Caiffi, S. Mariotto, L. Quettier, M. Statera
on behalf of the Muons Magnets Working Group

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WP7 objective and broad scope

- The objective of this work package is to address **feasibility and technology limits**, assess **technology readiness** and **R&D timeline** for the magnet and powering systems. The leading topics are:
  - Maximum field and free bore of the solenoids for the target, capture and cooling complex
  - Feasibility of the fast accelerator chain
  - Design options and performance limits for the magnets of the collider complex
- We address the above topics through a combination of:
  - [Review and] conceptual design work
  - Targeted tests
  - Specific characterization measurements
- Exploit synergies with other fields (high magnetic field science, NMR, fusion) and programs (EU High-Field Magnets R&D, US-MDP)

WP7 milestones

Milestone	Description	Month	Witness
M7.1	Report on solenoids and TPL experiments	12	Report
M7.2	Report on RCS and HCS configurations	24	Report
M7.3	**Workshop on ultra-high-field solenoids**	**30**	**Indico site**
M7.4	Report on HTS fast-cycled magnets	32	Report
M7.5	Report on high-field collider magnet design	33	Report
M7.6	Report on solenoid conceptual design	34	Report
M7.7 ~~(M7.8)~~	**Workshop on high-field collider magnets**	**42**	**Indico site**
M7.8 ~~(M7.9)~~	Report on footprint, power and cost model	44	Report
M7.9 ~~(M7.10)~~	Report on R&D and impact	44	Report

WP7 deliverables

Deliverable	Description	Month	Date
D7.1	Preliminary report on muon collider magnets	33	November 2025
D7.2	Consolidated report on muon collider magnets	45	November 2026

WP7 participants

Beneficiaries (CERN through UMIL)

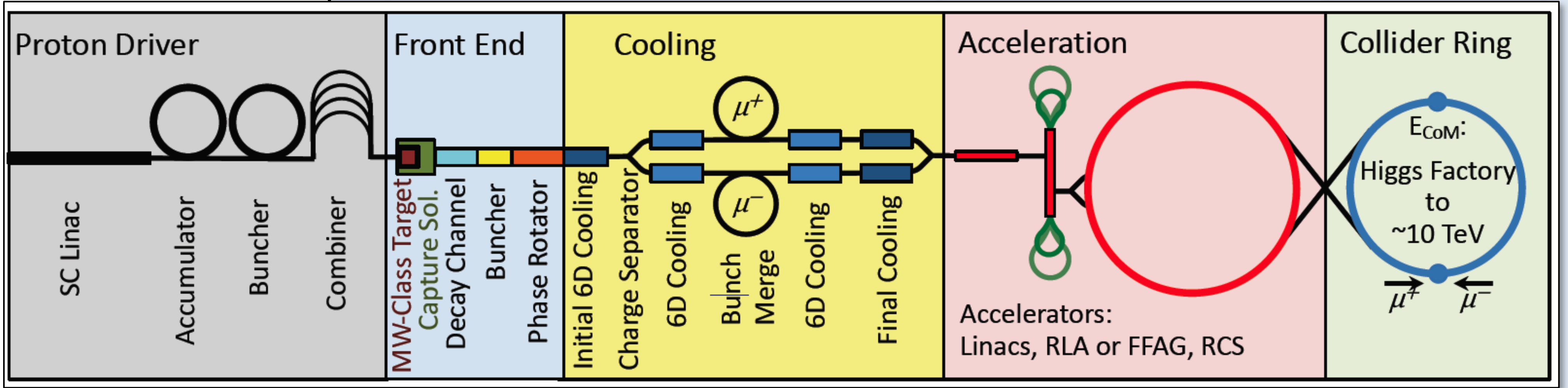
Institute	EU FTE-month
CERN	0 (+63)
CEA	18 (+18)
INFN	32 (+32)
SOTON	42 (+42)
TUDa	15 (+15)
UTWENTE	14 (+14)
UMIL	8 (+8)
PSI	
UNIGE	
KIT	
CNRS	
UNIBO	

- EU funding is matched by equal internal effort at all beneficiaries
  - CERN does not require EU funds
- Exploting program synergies with KEK, Kyoto University and US-MDP
- Some significant contributions already received from F4E and TUT

WP7 Organization

Task 2 (M. Statera)
Target, Capture and Cooling Magnets

Task 4 (S. Mariotto, B. Caiffi)
Collider Ring Magnets



Task 3 (F. Boattini)
Fast Cycled Accelerator Magnets

Task 1 (L. Bottura, L. Quettier)
Technical Coordination and Integration

The Team and the work – 1/4

WP7 - Magnet Systems

Task 1 (L. Bottura, L. Quettier)
Technical Coordination and Integration

Task 2 (M. Statera)
Target, Capture and Cooling Magnets

Task 3 (F. Boattini)
Fast Cycled Accelerator Magnets

Task 4 (S. Mariotto, B. Caiffi)
Collider Ring Magnets

- Participants
  - **CERN** (LB, SF)
  - CEA (LQ)
- Activities
  - Periodic meeting of the "muons magnets Working Group"
  - Machine configuration ("magnet catalogue")
  - Interface to physics, radiation, vacuum, cryogenics, safety and RP
  - Review of radiation hardness of superconductors and insulation systems (joint activity with radiation studies)
  - Documentation and reporting

The Team and the work – 2/4

WP7 - Magnet Systems

Task 1 (L. Bottura, L. Quettier)
Technical Coordination and Integration

Task 2 (M. Statera)
Target, Capture and Cooling Magnets

Task 3 (F. Boattini)
Fast Cycled Accelerator Magnets

Task 4 (S. Mariotto, B. Caiffi)
Collider Ring Magnets

- Participants
  - **INFN** (MS, SS)
  - CEA (LQ, PhD)
  - CERN (AD, BB, TM, LB, AK, CA, AB)
  - *CNRS-LNCMI (XC)*
  - *F4E (AP, PT)*
  - *KIT (TA)*
  - *PSI (JK)*
  - *SOTON (YY, post-doc)*
  - TWENTE (HTK, AK, SO)
  - *UNIGE (CS)*
- Activities
  - Review concepts and options for the target and final cooling solenoid
  - Establish mechanical and protection limits of HF and UHF solenoids
  - Conceptual design of solenoids
  - Testing of electro-mechanical properties and limits:
    - HTS tapes and stacks
    - HTS single- and stacked-pancakes

The Team and the work – 3/4

WP7 - Magnet Systems

Task 1 (L. Bottura, L. Quettier)
Technical Coordination and Integration

Task 2 (M. Statera)
Target, Capture and Cooling Magnets

Task 3 (F. Boattini)
Fast Cycled Accelerator Magnets

Task 4 (S. Mariotto, B. Caiffi)
Collider Ring Magnets

- Participants
  - **CERN** (FB, LB, SF, TECH)
  - UNIBO (MB, PR, RM)
  - *CNRS-LNCMI (JB)*
  - TWENTE (HTK, AK)
  - TUDa (HVG, post-doc)
- Activities
  - Power converter conceptual design and optimization, including energy storage
  - Components tests (capacitors)
  - Conceptual design and 2D optimization of resistive magnets for RCS, including options
  - Detailed 2D/3D analysis of resistive magnets for RCS, including saturation, end effects, anomalous loss
  - Conceptual design of SC magnets for RCS
  - Study of HTS options for pulsed magnets
  - Testing of properties and limits:
    - Magnetic properties of iron in the relevant frequency range
    - Ageing tests of capacitors

The Team and the work – 4/4

WP7 - Magnet Systems

Task 1 (L. Bottura, L. Quettier)
Technical Coordination and Integration

Task 2 (M. Statera)
Target, Capture and Cooling Magnets

Task 3 (F. Boattini)
Fast Cycled Accelerator Magnets

Task 4 (S. Mariotto, B. Caiffi)
Collider Ring Magnets

- Participants
  - **INFN** (SM, BC, DN)
  - CERN (LB)
  - UNIMI (SM)
  - *TUT (TS)*
- Activities
  - Establish limits of SC dipoles and quadrupoles, considering LTS and HTS as well as combined function options
  - Agree on arc dipole specification
    - Field and gradient
    - Aperture
    - Nested/asymmetric windings
    - Operating conditions
  - Conceptual design of main arc magnet

Summary

- The technical work is well defined for all areas: the preparation of the EU MuCol proposal provided a great introduction to the challenges and topics, as well as learning and *team building*
- We are still seeking for the best distribution of some practical tasks to profit best from expertise and infrastructure (volunteering welcome)
- Direct synergy exists with other programs worldwide (HFM, US-MDP, KEK, Kyoto) open to external partners
- The connection to other fields of science and societal applications is STRONG and we already profit from it (fusion, high-field science, power applications)

Task 7.2 - proposal

- CERN-EP
  - Contribution to development of HTS technology for UHF solenoids
  - Contact person: A. Dudarev

  Design 40T: B. Bordini, T. Mudler, A. Bertarelli, C. Accettura

  Baseline studies for HF solenoids: S. Fabbri, J. Pavan
- LNCMI
  - Contribution to target and cooling solenoid design and development
    - Power balance and optimization of a hybrid target solenoid
    - Support for testing in LNCMI HF test facilities (samples and coils)
  - Contact person: Dr. X. Chaud, Dr. F. Debray
- PSI
  - Contribution to target and cooling solenoids design and technology R&D
    - Instrumentation and analysis of NI coils (in synergy with other projects that provide the coils)
    - Powered samples to test mechanical limitations (NOTE: need to brainstorm)
    - Integrated conceptual target-magnet design, in close iteration loops with particle-shower simulations
  - Contact person: Dr. B. Auchmann

  Instrumentation for test coils (vtap, protection schemes and devices)
- University of Geneva
  - Measurements in support to R&D on HTS
    - Electro-Mechanical characterization and limits at high field (NOTE: need to brainstorm)
  - Contact person: Prof. C. Senatore

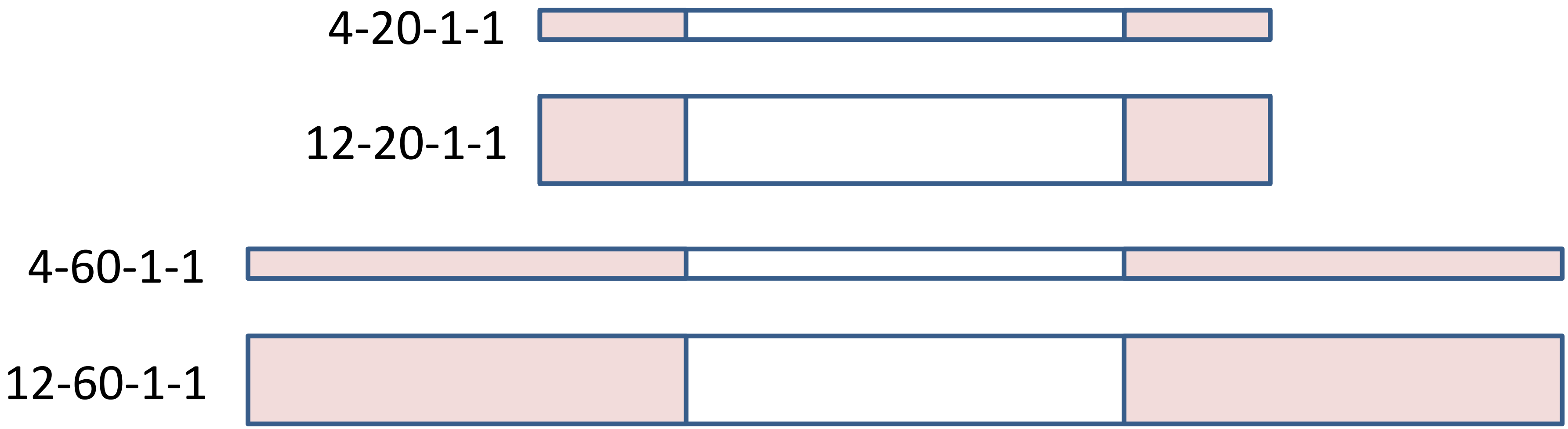
  Ic measurements vs internal stress (compressive and tensile)
- INFN LASA
  - Critical current measurement
  - Contact person: Dr. Marco Statera

  Coordination

  Design of test coils devices (together with CERN, CEA, Southampton and other parties as appropriate)
- University of Southampton
  - Design of solenoids and measurement of HTS properties
  - Test in background field (10 T, 110 mm)
  - Contact person: Prof. Y. Yang
- University of Twente
  - Contribute to the design and conductor effort
    - HTS conductor design (both ReBCO and B2223) at the level of basic strand/tape, shape optimization and reinforcements
    - HTS smart innovative cabling to allow for higher current, current sharing redundancy and quench protection
    - HTS conductor characterization/review for limiting strain and cycling degradation
    - HTS coil windings with controlled resistance to smartly balance conflicting requirements of ramp loss and quench stability
    - Pancake tests and tape electro-mechanical characterization
  - Contact person: Prof. H. ten Kate (initial), Prof. A. Kario
- CEA
  - Specific interest in target and final cooling solenoid
  - Contact person: Dr. L. Quettier
- KIT (associate)
  - Specific interest in cooling solenoid and HTS tape
  - Contact person: Dr. T. Arndt
- KEK (collaborating)
  - Share design experience of capture magnets at J-PARC
  - Contact person: Dr. T. Ogitsu

R&D pancakes

- 60 mm inner diameter
- 20 mm and 60 mm thickness
- 4 mm and 12 mm tape width
- Winding variants
  - Single and double pancakes winding
  - One-, two- and many-in-hand winding
  - Stacked pancakes



NOTE: geometry variants at the various participating laboratories have similar range of dimensions

Task 7.3 Proposal

- Power converter design and optimization (CERN/LNCMI)
- Design resistive magnets for pulsed operation (UNIBO)
- Design resistive magnets for pulsed operation (TU Darmstadt)
- Design (conceptual) resistive magnets: separated dipoles for first/second harmonics (CERN)
- Design SC dipoles for the accelerator (UNIBO magnetic calculations/CERN/TWENTE Conductors technology)
- Alternative full SC (HTS) largest RCS realization (TWENTE/Fermilab)
- TESTs
  - Magnetization and losses measurement in representative reduced scale model of the magnet (TBD)
  - Ageing tests of capacitors on reduced scale samples (CERN)

Task 7.4 - Tentative proposal

3 TeV machine

- Provide a design study for the 3 TeV machine collider arc magnets
  - *if this is an interesting option for a staged strategy*

NbTi is compatible with required magnetic field

- Are combined function magnets requested also for this options?
- Nb_3Sn can also be considered, if working at 1.9 K is not an option

N.B. This technology is not scalable, magnets for 3 TeV machine or 10 TeV machine are completely different beasts, the studies will be completely different

10 TeV machine

- Provide a design study for the 10 TeV machine collider arc magnets
  - Most likely, the magnetic field required will not be compatible with Nb_3Sn
    HTS is more suitable
  - Working temperature will also constrain this choice: if we want to work @10K to reduce energy consumption, again **HTS is the way**

Task 7.4 - Schedule

Preliminary timeline

- T_0+ 6 months Consolidate magnet requirements
- T_0 + 12/14 months Analytical expressions for Magnet Cross-Section
- T_0 + 33 months D 7.1 Intermediate Report
- T_0 + 42 months M 7.3 Workshop on HFM for collider
- T_0 + 45 months D 7.2 Consolidated report

- INFN is in charge of all the aspects of the magnet design (except for protection), not R&D studies but realistic optimization of modern technology
- Finding possible synergy with other magnet groups (Berkeley, FNAL, CEA) will make it possible to explore different solutions in parallel and make the design study more credible and affordable