EU Project MuCol Status and Plans

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CERN

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WP1
Coordination and Communication

- All Deliverables (D) and Milestones (M) achieved and declared on EU portal
- D & M falling in summer over the entire project have been moved to end of October of the corresponding year (list in spare slides)
- Few Associated Institutes didn’t sign yet the Consortium Agreement…

WP2

Physics And Detector Requirements

1) Software and detector training

MuCol: training on detector design and physics performance tools

International UON Collider Collaboration

5–6 Jul 2023
CERN
Europe/Zurich timezone

Enter your search term

- 46 participants in person and remote
- Presentations and hands-on sessions very well attended

	Introduction to the MuCol project and tutorial goals	Donatella Lucchesi	40/S2-C01 - Salle Curie, CERN	13:30 - 13:45
	Description of the actual detector	Davide Zuliani	40/S2-C01 - Salle Curie, CERN	13:45 - 14:05
14:00	Introduction to the software	Karol Krizka	40/S2-C01 - Salle Curie, CERN	14:05 - 14:30
	Hands on: Event generation examples	Donatella Lucchesi et al.	40/S2-C01 - Salle Curie, CERN	14:30 - 15:00
15:00	Coffee Break		40/S2-C01 - Salle Curie, CERN	15:00 - 15:30
	Hands on: detector simulation	Lorenzo Sestini	40/S2-C01 - Salle Curie, CERN	15:30 - 16:15
16:00	Hands on: event reconstruction	Laura Buonincontri	40/S2-C01 - Salle Curie, CERN	16:15 - 17:00
17:00	Hands on: event analysis	Chiara Aime'	40/S2-C01 - Salle Curie, CERN	17:00 - 17:45

09:00	Beam Induced background description	Nazar Bartosik	40/S2-C01 - Salle Curie, CERN	09:00 - 09:20
	Hands on: Beam Induced Background overlay to physics event	Nazar Bartosik	40/S2-C01 - Salle Curie, CERN	09:20 - 09:55
10:00	Hands on: Modify the detector geometry	Lorenzo Sestini	40/S2-C01 - Salle Curie, CERN	09:55 - 10:30
	Coffee Break		40/S2-C01 - Salle Curie, CERN	10:30 - 11:00
11:00	Open hands on: from beginners to advanced		40/S2-C01 - Salle Curie, CERN	11:00 - 12:30
12:00				

WP2
Physics And Detector Requirements

2) Definitions of requisites for detector design at $\sqrt{s} = 10$ TeV

Detector magnet for 10 TeV MuC

5 October 2023
CERN
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Videoconference

Contacts
donatella.lucchesi@cern...

The design of a possible detector for a 10 TeV center of mass energy muon collider requires the definition of possible detector magnet configurations and technologies . The presence of the beam-induced background shielding structure complicates the magnet design. This meeting brings together detector, machine-detector interface and magnet experts to start the discussion on possible configurations of the complete interaction region.

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Time	Session	Speaker	Location	Duration
09:00	Introduction		4/3-006 - TH Conference Room, CERN	09:00 - 09:10
	Detector requirements at a 10 TeV muon collider	Massimo Casarsa	4/3-006 - TH Conference Room, CERN	09:10 - 09:40
	Discussion		4/3-006 - TH Conference Room, CERN	09:40 - 09:50
	MDI Requirements	Daniele Calzolari	4/3-006 - TH Conference Room, CERN	09:50 - 10:20
10:00	Discussion		4/3-006 - TH Conference Room, CERN	10:20 - 10:30
	Coffee Break		4/3-006 - TH Conference Room, CERN	10:30 - 11:00
11:00	Superconducting Technology for Future Colliders and Detectors	Prof. Akira Yamamoto	4/3-006 - TH Conference Room, CERN	11:00 - 11:30
	Status and plans of aluminium stabilized conductor R&D at CERN for detector magnets	Benoit Cure	4/3-006 - TH Conference Room, CERN	11:30 - 11:55
12:00	The 3.6 T CLIC-like superconducting solenoid for the Muon Collider	Matthias Mentink	4/3-006 - TH Conference Room, CERN	11:55 - 12:20
	Discussion		4/3-006 - TH Conference Room, CERN	12:20 - 12:30
	Lunch Break			
	Detector magnets survey	Andrea Bersani	4/3-006 - TH Conference Room, CERN	15:15 - 15:40
16:00	Discussion and decision on possibilities to use on detector(s) concept			

We received several suggestions and recommendations on how to proceeds on magnet assumptions.

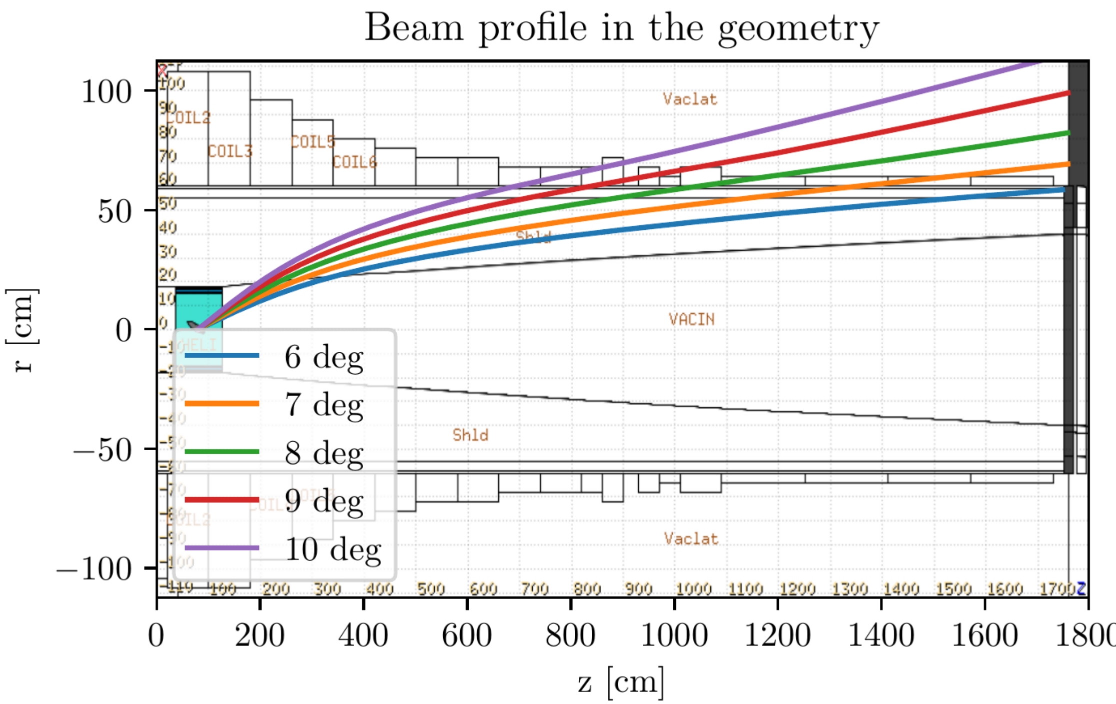
Activities starting on first concept of a base design.

WP3
Proton Complex

- PhD student started in August and looking into transport of the beam from compressor to target.
- Hiring of a postdoc to work on the compressor ring design ongoing and on final round of interview (expected start Jan 2024).
- Collecting some data from PS and Booster on merging and bunch rotation.
- Work on the tentative parameter list and interim report for MuCol and IMCC.

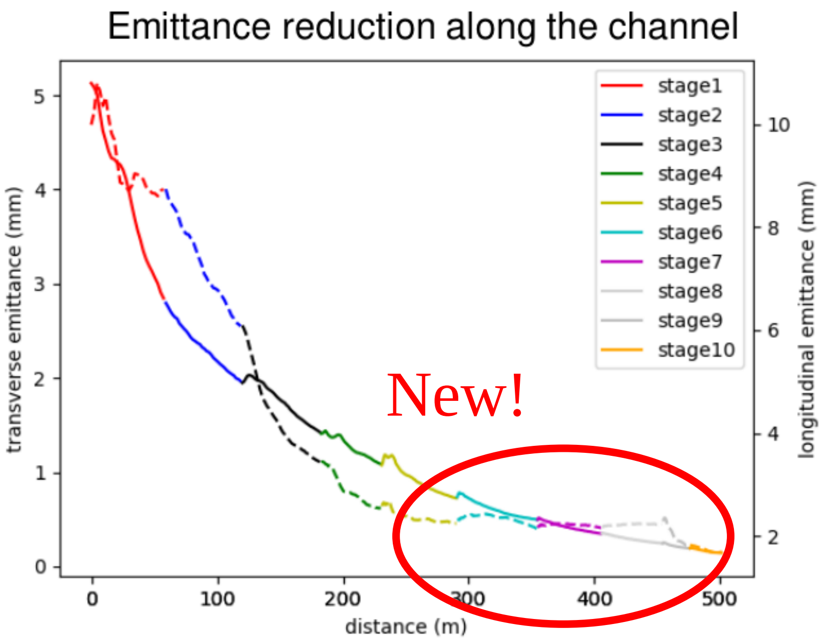
WP4
Muon Production & Cooling

- Established preliminary radial build
- Optimising dose levels, heat load etc to shielding and magnet
  - Close liaison with magnets team
  - Discussion around 60 vs 70 cm magnet bore
- Looking at beam window
- Looking at spent proton beam extraction



WP4
Muon Production & Cooling

- Lattice optimisation ongoing
- Rectilinear cooling (Zhu Ruihu)
  - Drive optimisation
- Final cooling (Elena Fol, Bernd Stechauner)
  - Improved scattering model in RFTrack
  - Implement realistic RF
    - Phase rotation and acceleration of muon beam



WP5 - High Energy Complex

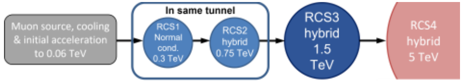
Parameter table

- A first parameter table is proposed for the high-energy acceleration.
  - The RCS4 is the most preliminary and needs more studies to be consolidated.
  - The needed total dipole length and RF voltage are evaluated and can be a first step for costing considerations.
  - The optics is based on FODO cells and should be reviewed.
  - The acceleration ramp is quasi-linear and may evolve.
- Future versions of the parameter table should include also an FFA alternative.
- We need to continue the discussions to see how to marry RF, magnet, powering, costing, vacuum, collective effects, and optics considerations.

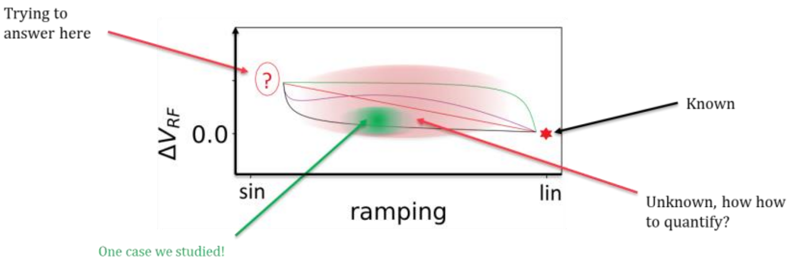
Parameter	Symbol	Unit	RCS1	RCS2	RCS3	RCS4
Hybrid RCS	-	-	No	Yes	Yes	Yes
Repetition rate	f_{rep}	[Hz]	5	5	5	5
Circumference	$2\pi R$	[m]	5990	5990	10700	35000
Injection energy	E_{inj}	[GeV/u]	63	314	750	1500
Ejection energy	E_{ej}	[GeV/u]	314	750	1500	5000
Energy ratio	E_{ej}/E_{inj}	-	4.98	2.39	2.00	3.33
Assumed survival rate	N_{ej}/N_{inj}	-	0.9	0.9	0.9	0.9
Acceleration time	τ_{acc}	[ms]	0.343	1.097	2.37	6.37
Revolution period	T_{rev}	[μs]	20.0	20.0	35.7	117
Number of turns	n_{turn}	-	17	55	66	55
Required energy gain per turn	ΔE	[GeV]	14.8	7.9	11.4	63.6
Average accel. gradient	G_{acc}	[MV/m]	2.44	1.33	1.06	1.83
Number of bunches/species	-	-	1	1	1	1
Bunch population	N_{inj}/N_{ej}	$[1 \times 10^{12}]$	2.7/2.43	2.43/2.2	2.2/2.0	2.0/1.8
Vertical norm. emittance	$\epsilon_{v,n}$	[mm]	25	25	25	25
Horiz. norm. emittance	$\epsilon_{h,n}$	[mm]	25	25	25	25
Long. norm. emittance $\sigma_E \times \sigma_t$	$\epsilon_{l,n}$	[eVs]	0.025	0.025	0.025	0.025
Tot. straight section length	L_{str}	[m]	2335	2336	3976	10367
Total NC dipole length	L_{NC}	[m]	3655	2539	4366	20376
Total SC dipole length	L_{SC}	[m]	0	1115	2358	4257
Max. NC dipole field	B_{NC}	[T]	1.80	1.80	1.80	1.80
Max. SC dipole field	B_{SC}	[T]	-	10	10	16
Ramp rate	$\dot{B}$	[T/s]	4200	3282	1519	565
Main RF frequency	f_{RF}	[MHz]	1300	1300	1300	1300
Max RF voltage	V_{RF}	[GV]	20.9	11.2	16.1	90

WP5 High Energy Complex

Ramp optimization



- **20 September 2023: First meeting art CERN dedicated to Impact of RCS acceleration ramp shape on magnets and RF**



Courtesy: F. Batsch and H. Damerau

- **2 powering circuits are being considered (full-wave and switched resonances).**
- **Some cost model (RF and powering) is under development. Clearly, the choice of the ramp has a big impact on the total cost.**
- **Next steps: Integrating in a python environment the different scaling laws (costing, powering, optics, RF,…) to reduce the number of free parameters and improve the optimization process.**

WP6
RF

- The activities of the WP6 proceed during the first months of the project focusing on some specific elements related to objective of each of the subWP.

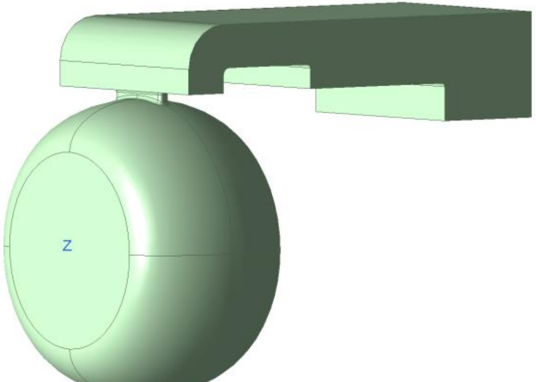
- WP 6.1 specifically addressed different approaches to the analysis of the problems related to the HOM of the SC cavities involved. The study of specific aspects relating to these cavities was addressed in a general sense with an overview of the skills available in the components involved.

- WP 6.2 focused on carrying out an overview of possible technologies to be applied to the construction of RF cavities for the cooling system. In parallel, in concert with WP4, we focused on the definition of the main parameters (frequency, aperture, ...) as well as how these derive from the beam dynamics in the channel.

- WP 6.3 is probably the WP where the most part of the efforts concentrated. Computer simulations and theoretical analysis have been carried out to outline and face the problems related to the coexistence of high electric RF fields in strong magnetic fields. The requirement to carry out deep analysis on the experimental side to define the technologies to be used in such application has been deeply discussed. A pulsed DC test set is under realization at INFN Milano and a couple of different RF cavities (with related power couplers) have been electromagnetically designed to be used in a test stand based on a SC solenoid and one of these cavities.

- The pulsed DC test set has been conceived taking into account the experience made at CERN on a similar bench.
- The innovative feature of this new test set is that we may apply the pulsed DC voltage along with a static magnetic field up to 1 Tesla.
- We will expect to get more and more data on materials and surface treatments.

- The picture below report the RF design for a 3 GHz cavity which may be inserted in a SC solenoid with a bore of nearly 350 mm. The design of the solenoid will provide a field up to 7 Tesla while the electric fields may reach a value of 50 MV/m.



WP7
Magnets

- Review held during annual meeting, preliminary report presented to the Community
- Working at precising responsibilities and refining parameters for the parameter list (see next slide)

WP7
Magnets

Muon Collider magnet "team"

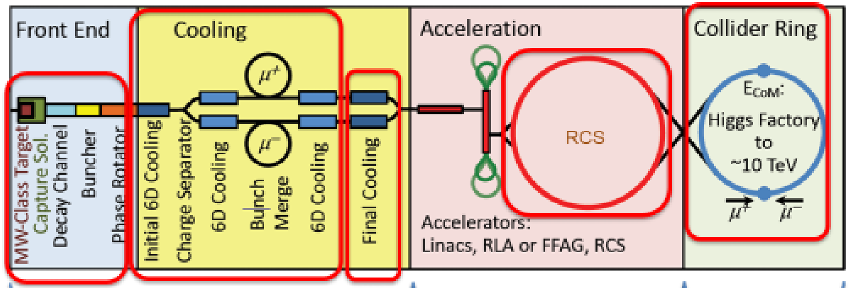
CERN
F4E (Barcelona)
EUROFusion (Garching)

INFN
CERN
UMIL
KIT

CERN
INFN
CEA
CNRS
PSI
UniGE
SO'TON
UniTwente

CERN
UniBO
TUDa
UniTwente
UniMalta
HEIA-FR
UniLaval

INFN
UMIL
CERN
TUT



Task 7.2
M. Statera (INFN)

Task 7.3
F. Boattini (CERN)

Task 7.4
S. Mariotto (UMIL, INFN)
B. Caiffi (INFN)

WP7
Magnets

Magnet development targets

Complex	Magnet	Aperture (mm)	Length (m)	Field (T)	Ramp rate (T/s)	Temperature (K)
Target, decay and capture channel	Solenoid	1200	19	20	SS	20
6D cooling channel	Solenoid	90…1500	0.08…0.5	4…15	SS	4.2/20
Final cooling channel	Solenoid	50	0.5	> 40	SS	4.2
Rapid cycling synchrotron	NC Dipole	30x100	5	± 1.8	4200	300
Rapid cycling synchrotron	SC Dipole	30x100	1.5	10	SS	4.2/20
Collider ring	Dipole	160…100	4…6 (1)	12…16	SS	4.2/20

(1) depends on sagitta vs. aperture (see US-MAP studies)

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WP8
Cooling Cell

- Working on the definition of the prototype cooling cell to be designed

- Training on the design of the RF-in-magnetic-field test stand

- First preliminary ideas will be presented and discussed in a workshop at CERN on 18 and 19 January in order to collect feedback from the community. Design work will then start

WP8
Cooling cell

- C. Rogers, NuFact 22

MDPI

Article

A Demonstrator For Muon Ionisation Cooling

Chris Rogers [1]

[1] Rutherford Appleton Laboratory; chris.rogers@stfc.ac.uk

Abstract: The muon collider is an excellent prospect as a multi-TeV lepton collider, with the possibility for high luminosity and reach to 10 TeV or more. In order to realise such luminosity, high beam brightness is required. Ionisation cooling, which was demonstrated recently by the Muon Ionization Cooling Experiment (MICE), is the technique proposed to realise sufficient brightness. MICE demonstrated transverse emittance reduction of incident beams having relatively high emittance and without beam reacceleration. The international Muon Collider Collaboration proposes a Demonstrator for Muon Cooling that will demonstrate six-dimensional emittance reduction over a number of cooling cells, operating at beam emittance close to the ultimate goal for the muon collider. Together with a full R&D programme this will pave the way for construction of a muon collider. In this paper, initial considerations and possible implementations for the Demonstrator are discussed.

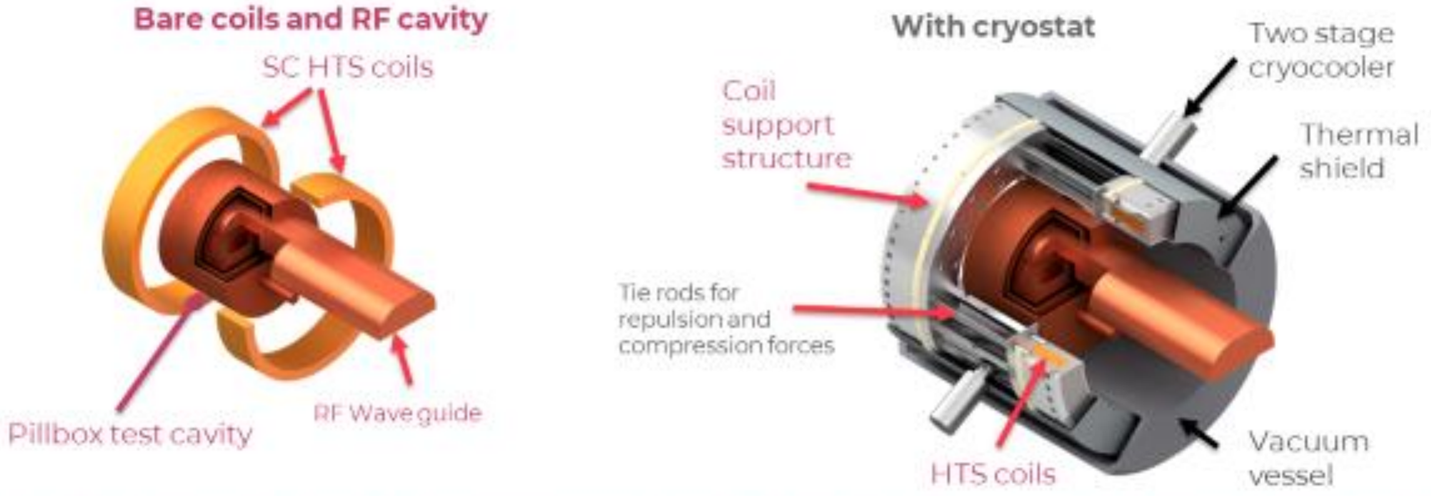
Keywords: collider; cooling; muon

Table 1. Hardware parameters for the Demonstrator.

Beam Preparation System	
Parameter	**Value**
Cell length	1 m
Peak solenoid field on-axis	0.5 T
Collimator radius	0.05 m
Dipole field	0.67 T
Dipole length	1.04 m
RF real estate gradient	7.5 MV/m
RF nominal phase	0° (Bunching)
RF frequency	704 MHz
Cooling System	
Parameter	**Value**
Cell length	2 m
Peak solenoid field on-axis	7.2 T
Dipole field	0.2 T
Dipole length	0.1 m
RF real estate gradient	22 MV/m
RF nominal phase	20°
RF frequency	704 MHz
Wedge thickness on-axis	0.0342 m
Wedge apex angle	5°
Wedge material	LiH

WP8
Cooling Cell

First sketch of RFMF test stand split coils, single cryostat 700 mm free bore



The construction of a test stand is an important push toward the definition of a baseline technology Beside being a **key tool for RF tests**. However the first rough evaluation was in the **4 M€ range...**

11 Oct. 2023 RFMF test station - WP7-WP8 MuCol meeting - L. Rossi et al.

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CERN

Thank you for your attention

Deliverables new dates

Deliverable Name	Work Package No	Lead Beneficiary	l'pc		Date
Data-management plan	*WPI*	*1 -CERN*	*DMP — Data Management Plan*	***8***	31/10/2023
Preliminary ESPPU report No. 1	WPI	1 - CERN	R — Document, report	12	29/02/2024
Preliminary ESPPU report No. 2	WPI	1 -CERN	R — Document, report	24	28/02/2025
Intermediate ESPPU report	WPI	- CERN	R — Document, report	36	28/02/2026
Consolidated ESPPU report	WPI	1 - CERN	R — Document, report	48	28/02/2027
Beam-induced background and detector configuration	*WP2*	*8 - UNIPD*	*DATA — data sets, microdata, etc*	***32***	31/10/2025
Detector performance by using physics processes	WP2	2 - DESY	R — Document, report	36	28/02/2026
Final report on parameters and initial study for the Proton Complex	WP3	11 -ESS	R — Document, report	45	30/11/2026
Development of BDSIM simulation	WP4	16 -UKRI	OTHER	24	28/02/2025
Preliminary Report on key subsystems for ESPPU input	WP4	16 -UKRI	R — Document, report	33	30/11/2025
Consolidated Report on key subsystems	WP4	16 -UKRI	R — Document, report	45	30/11/2026
Report on the collider ring design	WP5	5 - CEA	R — Document, report	44	30/10/2026
Report on the design of the HEC	WP5	5 - CEA	R — Document, report	45	30/11/2026
Report on design of high power and high efficiency RF power sources	*WP6*	*5 - CEA*	*R — Document, report*	***44***	31/10/2026
Report on RF for MCC and HEC	WP6	5 - CEA	R — Document, report	45	30/11/2026
Preliminary report on muon collider magnets	WP7	1 - CERN	R — Document, report	33	30/11/2025
Consolidated report on muon collider magnets	WP7	1 - CERN	R — Document, report	45	30/11/2026
Presentation of cooling cell conceptual design	WP8	7 - UMIL	OTHER	15	31/05/2024
Final report on cooling cell design	*WP8*	*7 - UMIL*	*R — Document, report*	***44***	31/10/2026

Milestones new Dates

Milestone No	Milestone Name	Work Package No	Lead Beneficiary	Means of Verification	Due Date (month)	Date
1	Website Available	WP1	1 -CERN	Website online	2	30/04/2023
2	Kick-off meeting	WP1	1-CERN	Indico site	3	31/05/2023
3	Tentative parameters available	WP1	1-CERN	Database	8	30/10/2023
4	First annual meeting	WP1	1 -CERN	Indico site	15	31/05/2024
5	*Preliminary parameters*	*WP1*	*1-CERN*	*Database*	***20***	30/10/2024
6	Second annual meeting	WP1	1-CERN	Indico site	27	31/05/2025
7	*Consolidated parameters*	*WP1*	*1-CERN*	*Database*	***32***	30/10/2025
8	Third annual meeting	WP1	1-CERN	Indico site	39	31/05/2026
9	Training on detector design and physics performance tools	WP2	8-UNIPD	Training material	6	31/08/2023
10	Workshop on MDI and IR design	WP2, WP5	8-UNIPD	Indico site	13	31/03/2024
11	*Release of simplified detector performance model (DELPHES card or/and similar format)*	*WP2*	*8-UNIPD*	*Model published on the website*	***20***	31/10/2024
12	Workshop on detector design and physics performance with a public lecture on Muon Collider	WP2	8-UNIPD	Indico site	25	31/03/2025
13	Publication of report of detector performance with major physics process at several ECM	WP2	8-UNIPD	Article ready for submission	48	28/02/2027
14	Mini-Workshop on pulsed magnets	WP7, WP5	5-CEA	Indico site	15	31/05/2024
15	*Tentative design of the interaction region*	*WP2, WP5*	*1-CERN*	*Optics files*	***20***	31/10/2024
16	Tentative optics of the collider ring and pulsed synchrotrons	WP5	5-CEA	Optics files	19	30/09/2024
17	Tentative design of the FFA	WP5	5-CEA	Optics files	25	31/03/2025
18	Tentative impedance budget in the collider and pulsed synchrotron	WP5	5-CEA	Dataset	26	30/04/2025
19	*Workshop on ultra-high-field solenoids*	*WP7*	*1 -CERN*	*Indico site*	***32***	31/10/2025
20	*Workshop on high-field collider magnets*	*WP7, WP5*	*1-CERN*	*Indico site*	***44***	31/10/2026
21	Cooling cell design 3D model	WP8	7-UMIL	3D model completed & Report	33	30/11/2025