Seconda Giornata Acceleratori – Catania

Muon Collider

update

Dario Giove (MI-LASA), Donatella Lucchesi (UniPD e PD),
Lucio Rossi (UniMI e LASA), ***Nadia Pastrone*** *(TO) et al.*

Gruppi **INFN** *in* ***RD_MUCOL @ CSN1*****:** 110 persone/19FTE

BA BO FE GE MI MIB LNF LNL LNS NA PD PV RM1 RM3 TO TS

MDI, Crystals/Targets, and New activities for the Accelerator Facility Design Study

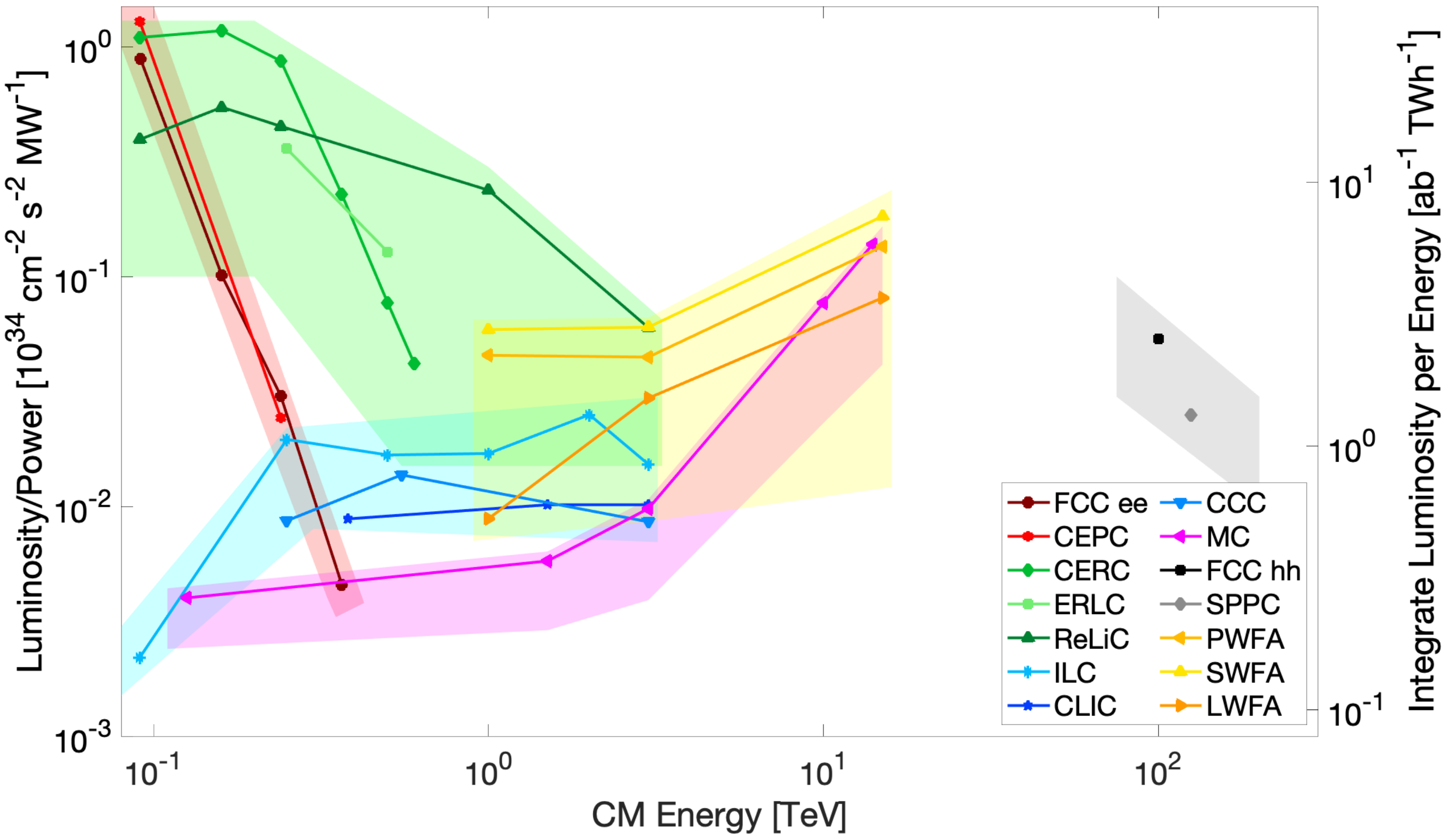
INFN-LNS , 3 marzo 2023

MuCol

HORIZON-INFRA-2022-DEV-01-01

Energy efficiency of present and future colliders

Thomas Roser et al., [Report of the Snowmass 2021 Collider Implementation Task Force](), Aug 2022



The effective energy reach of hadron colliders (LHC, HE-LHC and FCC-hh) is approximately a factor of seven lower than that of a lepton collider operating at the same energy per beam.

MuCol

MUST

IMCC MTP

INFN R&D

2020
- EPPSU
- IMCC Design Study@ CERN

2021
- Snowmass21
- Roadmap R&D Accelerator ➔ Muon Panel
- Roadmap R&D Detector ➔ Muon Collider @ 10 TeV
- AIDAinnova Detector R&D

2022
- 5 arXiV document to Snowmass
- Snowmass Muon Collider Forum report
- First IMCC Annual Meeting @ CERN
- Request for support to INFN GE

2023
- **EU INFRA-DEV project MuCol ➔ 4 years**
- EPJC paper submitted
- Second IMCC Annual Meeting @ IJCLab
- U.S. P5
- EU Roadmaps implementation

2024

2025

2026

2027
- EU Strategy

...
- U.S. Strategy

International Design Study facility

Proton driver production as baseline

- **Focus on two energy ranges:**

3 TeV technology ready for construction in 10-20 years

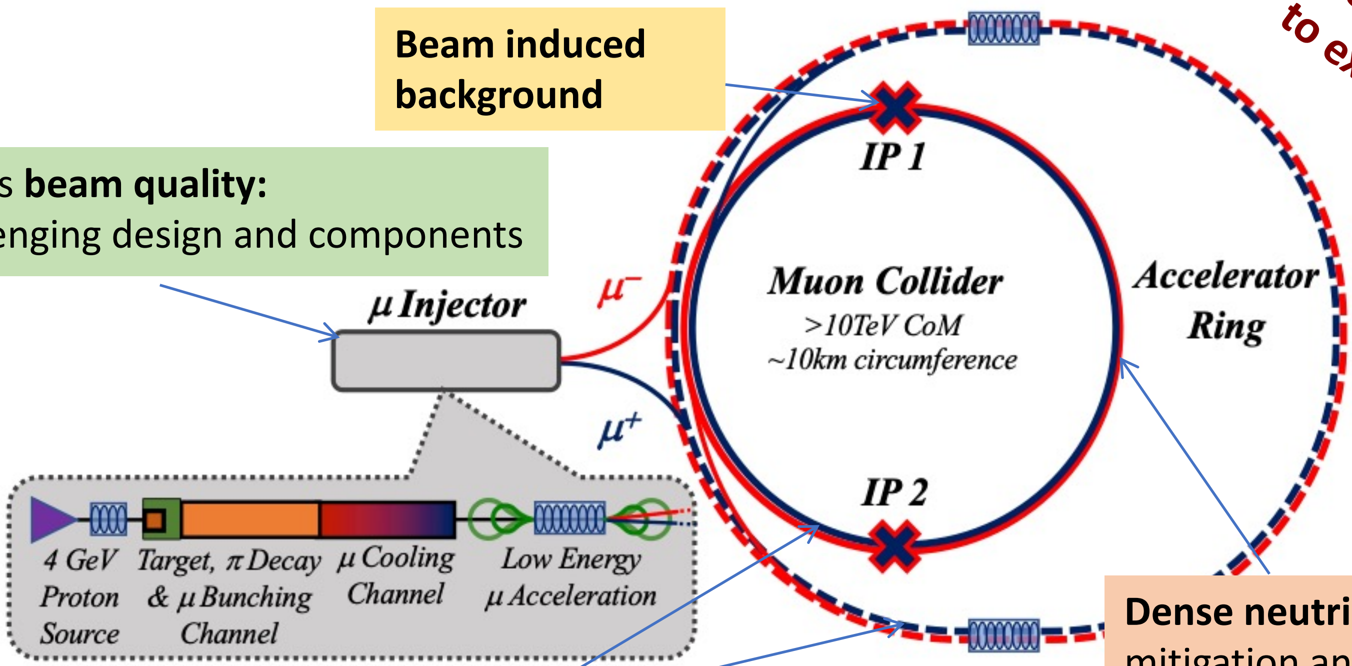
10+ TeV with more advanced technology

10+ TeV completely new regime to explore!

Web page: http://muoncollider.web.cern.ch

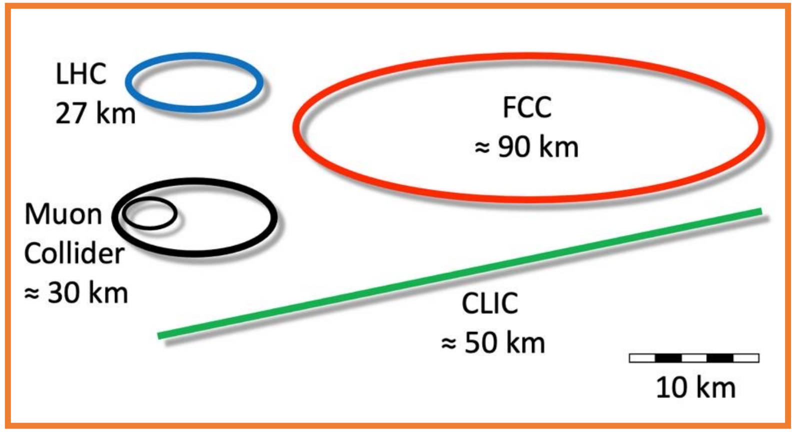
Beam induced background

Drives **beam quality:** challenging design and components



Dense neutrino flux mitigation and site

Cost and **power** consumption drivers, limit energy reach
e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring



[Muon Collider Forum Report](#) **Sept 2022**

Key Challenge Areas

- **Physics potential** evaluation, including **detector concept and technologies**
- Impact on the environment
  - **Neutrino flux mitigation** and its impact on the site (first concept exists)
  - **Machine Induced Background** impact the detector, and might limit physics
- **High-energy systems** after the cooling (acceleration, collision, ...)
  - Fast-ramping magnet systems
  - High-field magnets (in particular for 10+ TeV)
- **High-quality muon beam production**
  - Special RF and high peak power
  - Superconducting solenoids
  - Cooling string demonstration (cell engineering design, demonstrator design)
- **Full accelerator chain**
  - e.g. proton complex with H- source, compressor ring ➔ test of target material

High energy complex requires known components
➔ synergies with other future colliders

Accelerator R&D Roadmap

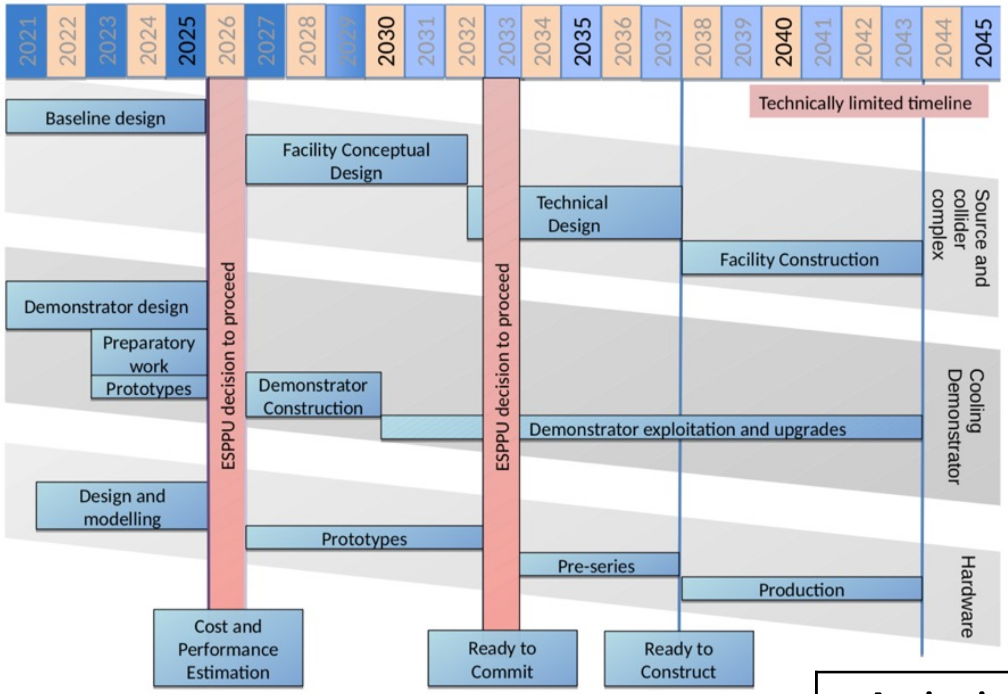
Bright Muon Beams and Muon Colliders

Panel members: **D. Schulte**,(Chair), M. Palmer (Co-Chair), T. Arndt, A. Chancé, J. P. Delahaye, A.Faus-Golfe, S.Gilardoni, P.Lebrun, K.Long, E.Métral, **N.Pastrone**, L.Quettier, T.Raubenheimer, C.Rogers, M.Seidel, D.Stratakis, A.Yamamoto
Associated members: A. Grudiev, R. Losito, **D. Lucchesi**

International MUON Collider Collaboration

presented to CERN Council in December 2021
published https://arxiv.org/abs/2201.07895
now under implementation by LDG + Council…

Technically limited timeline



Development path to deliver a 3 TeV muon collider by 2045

Scenarios

Aspirational		Minimal	
[FTEy]	[kCHF]	[FTEy]	[kCHF]
445.9	11875	193	2445

~70 Meu/5 years

Roadmap Plan

MDI

Dipoli/solenoidi ad alto campo (Nb3Sn, HTS?)

Cavità RF SC e NC

Cooling cell Dimostratore

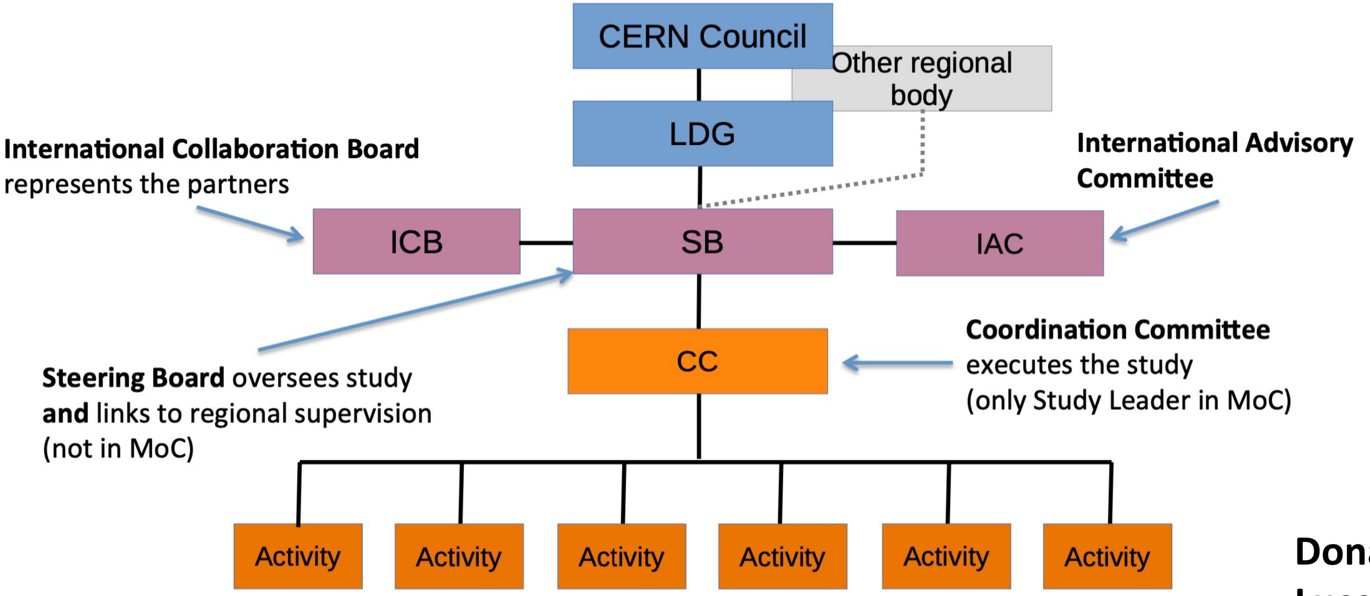
Label	Begin	End	Description	Aspirational [FTEy]	Aspirational [kCHF]	Minimal [FTEy]	Minimal [kCHF]
MC.SITE	2021	2025	Site and layout	15.5	300	13.5	300
MC.NF	2022	2026	Neutrino flux mitigation system	22.5	250	0	0
MC.MDI	2021	2025	Machine-detector interface	15	0	15	0
MC.ACC.CR	2022	2025	Collider ring	10	0	10	0
MC.ACC.HE	2022	2025	High-energy complex	11	0	7.5	0
MC.ACC.MC	2021	2025	Muon cooling systems	47	0	22	0
MC.ACC.P	2022	2026	Proton complex	26	0	3.5	0
MC.ACC.COLL	2022	2025	Collective effects across complex	18.2	0	18.2	0
MC.ACC.ALT	2022	2025	High-energy alternatives	11.7	0	0	0
MC.HFM.HE	2022	2025	High-field magnets	6.5	0	6.5	0
MC.HFM.SOL	2022	2026	High-field solenoids	76	2700	29	0
MC.FR	2021	2026	Fast-ramping magnet system	27.5	1020	22.5	520
MC.RF.HE	2021	2026	High Energy complex RF	10.6	0	7.6	0
MC.RF.MC	2022	2026	Muon cooling RF	13.6	0	7	0
MC.RF.TS	2024	2026	RF test stand + test cavities	10	3300	0	0
MC.MOD	2022	2026	Muon cooling test module	17.7	400	4.9	100
MC.DEM	2022	2026	Cooling demonstrator design	34.1	1250	3.8	250
MC.TAR	2022	2026	Target system	60	1405	9	25
MC.INT	2022	2026	Coordination and integration	13	1250	13	1250
			Sum	445.9	11875	193	2445

Organization after the Roadmap

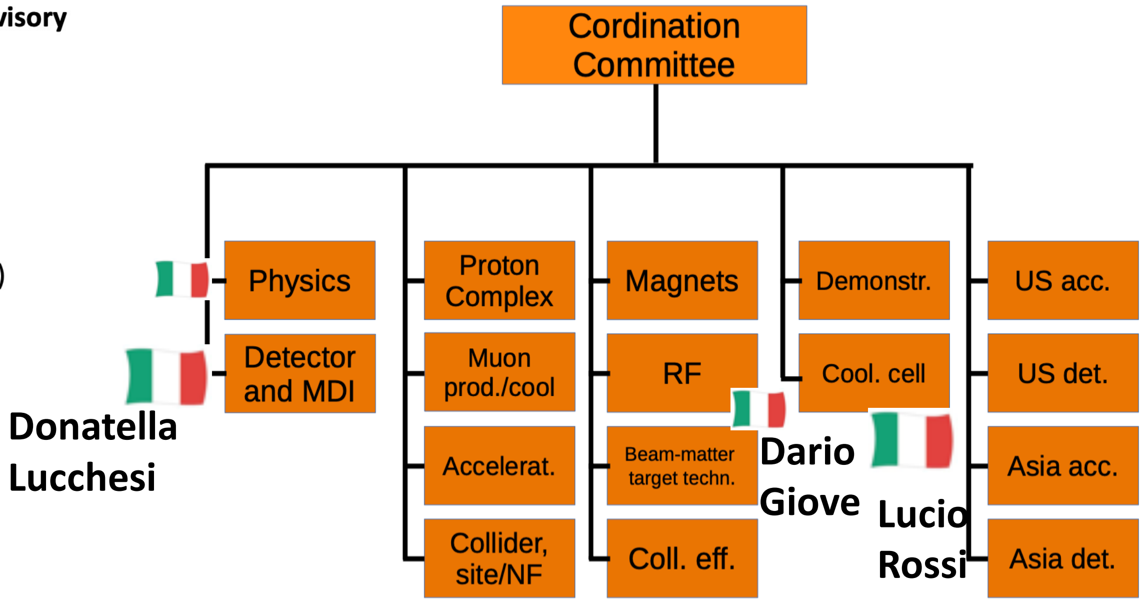
- Study Leader **Daniel Schulte**
  - Deputies: **Andrea Wulzer, Donatella Lucchesi, Chris Rogers**

CERN is host organisation, can be transferred to other partner on request of CERN and with approval of ICB
Will review governance in 2024, US could join at that time

- **Collaboration Board (ICB)**
  - Elected chair : **Nadia Pastrone**
- **Steering Board (SB)**
  - Chair **Steinar Stapnes**,
  - CERN members: Mike Lamont, Gianluigi Arduini,
    + ICB representatives, ICB chair and SL and deputies
- **International Advisory Committee (IAC)** *still to be formed*



Coordination Committee



MoC signed by CERN CEA INFN STFC-RAL ESS IHEP and different universities in EU, US, China

Design Study activities: EU project MuCol

Total EU budget: 3 Meu start March 1 '23 – 4 years
18(+14) beneficiaries (associated)

HORIZON-INFRA-2022-DEV-01-01:
Research infrastructure concept development

International MUON Collider Collaboration

INFN 510 keu **UniMI** 300 keu **UniPD** 100 keu + associate partners: UniBO, UniPV

MuCol study will produce a coherent description of a novel particle accelerator complex that will collide muons of opposite charge at the energy frontier. The study will target a centre-of-mass energy (ECM) of 10 TeV with 3 TeV envisaged as a first stage.

The main outcome of MuCol will be a **report** documenting the facility design that should demonstrate that:

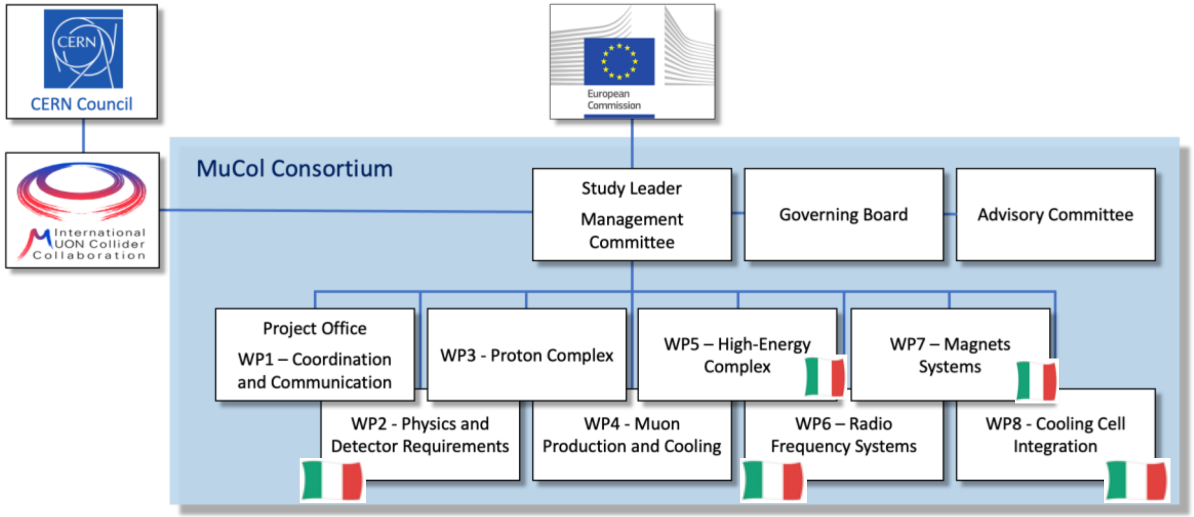
- the **physics case** of the muon collider is sound and **detector systems** can yield sufficient resolution and rejection of backgrounds;
- there are **no principle technology showstoppers** that will prevent the achievement of a satisfactory performance from the accelerator or from the detectors side;
- the muon collider provides **a highly sustainable energy frontier facility** as compared to other equivalent colliders;
- **exploiting synergies with other scientific and industrial R&D projects**, a valuable platform to provide Europe a leading edge not only in terms of discovery potential, but also for the development of associated technologies.

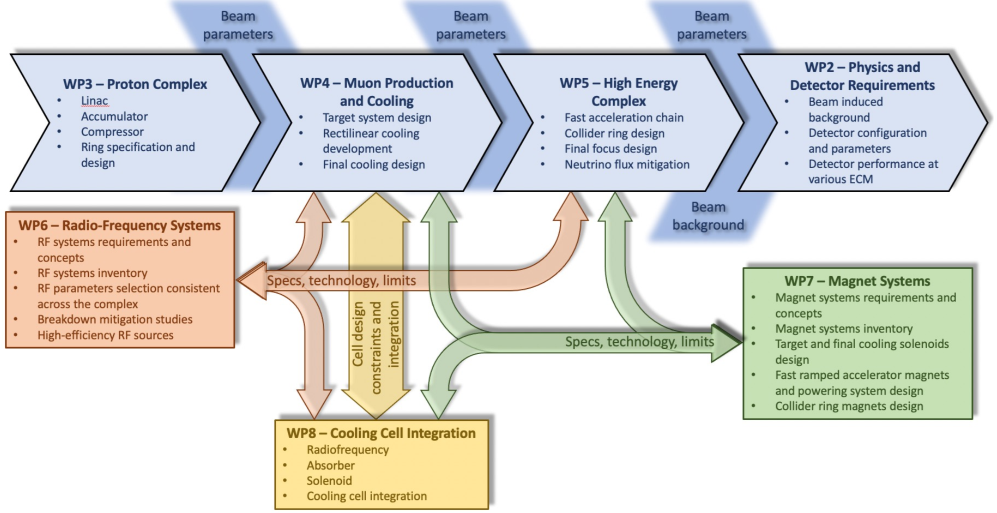
The final report will include a thorough assessment of benefits and risks of the accelerator and detector complex, including an evaluation of the scientific, industrial and societal return beyond high-energy physics, the cost scale and sustainability of the complex and the impact arising from an implementation on the CERN site.

Design Study activities: EU project MuCol

HORIZON-INFRA-2022-DEV-01-01:

Research infrastructure concept development





MUon collider STrategy network - MUST

INFN - CERN (+BINP) – CEA – IJCLAB – KIT – PSI – UKRI – (BNL-USA not beneficiary)

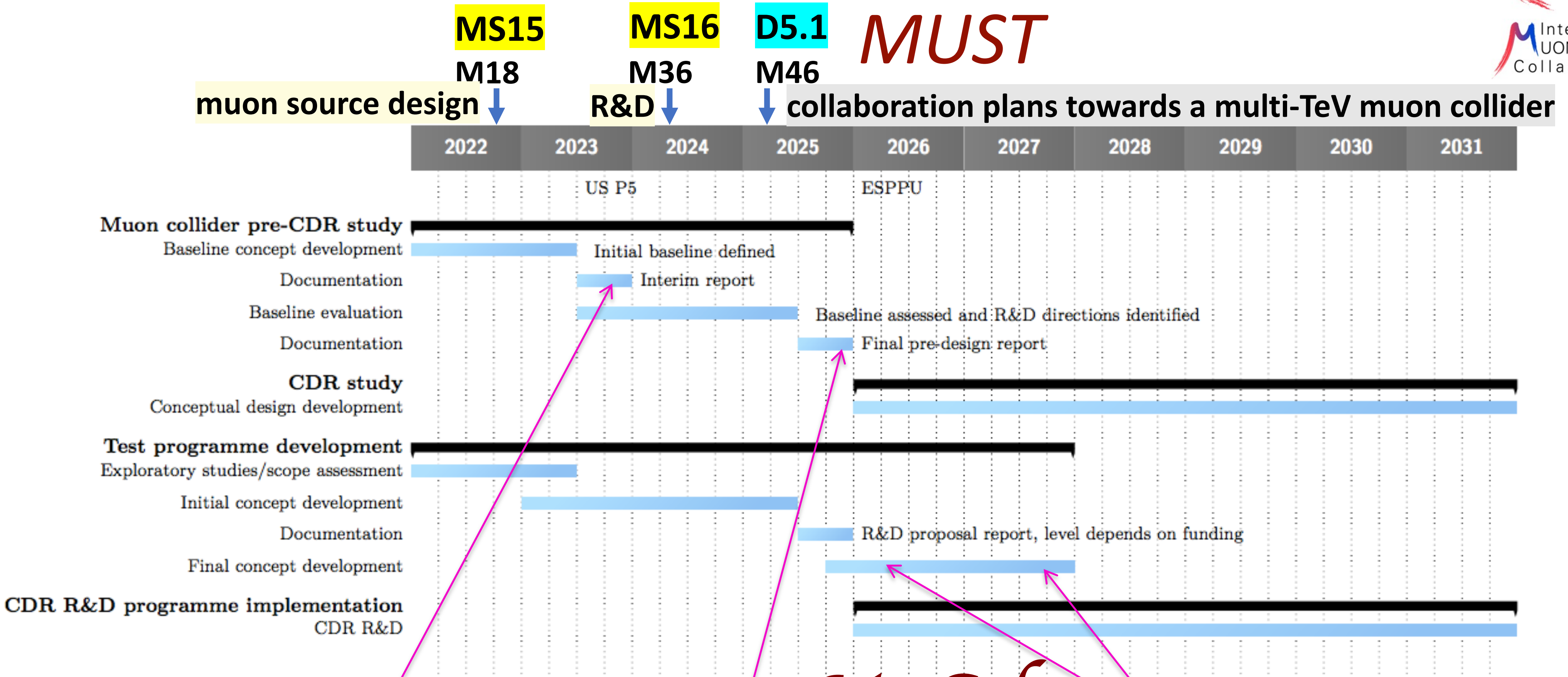
Task 5.1: MUon colliders STrategy network (MUST) M1 – M48

- Support the effort to **design a muon collider** and to **project and plan the required R&D**
- **Consolidate the community** devoted to develop an international future facility
- Prepare the platform to **disseminate** the information (website, meetings, tools)

Synergies on material targets and thin windows

- **MS15:** International workshop on muon source design **M18** ➔ *Report*
- **MS16:** International workshop to define R&D plans **M36** ➔ *Report*
- **D5.1:** International collaboration plans towards a multi-TeV muon collider **M46**

MuCol R&D Program



2023
Interim Report to gauge progress
Initial baseline defined

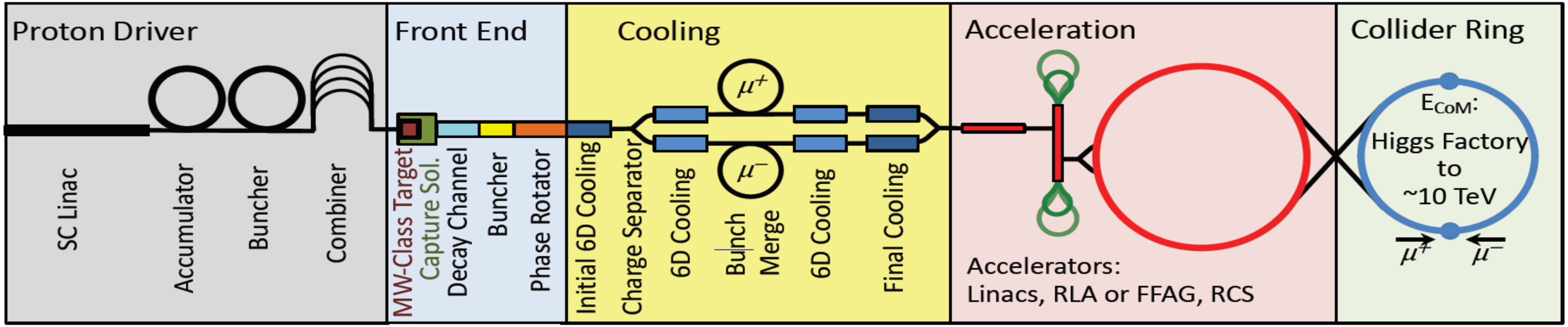
MuCol

2025
Assessment Report

2025-2027
R&D plan will be refined

Collider Concept

Fully driven by muon lifetime, otherwise would be easy



Short, intense proton bunch

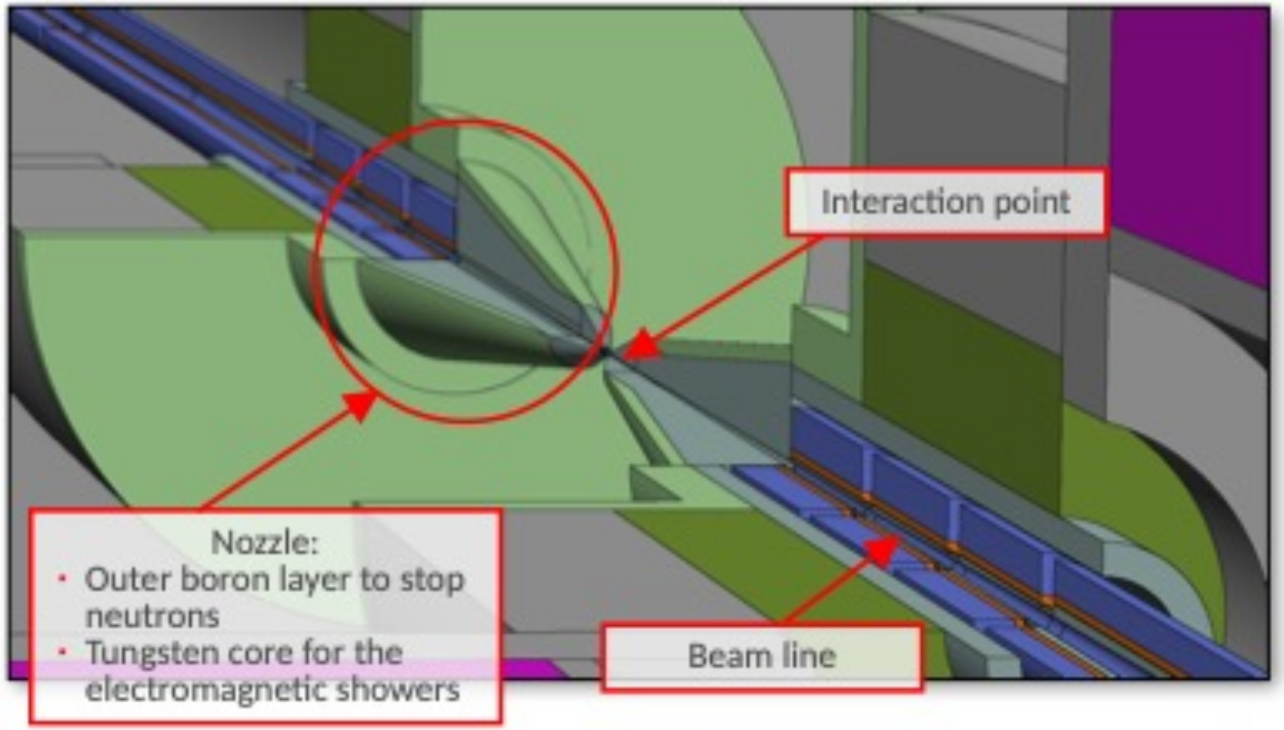
Protons produce pions which decay into muons muons are captured

Ionisation cooling of muon in matter

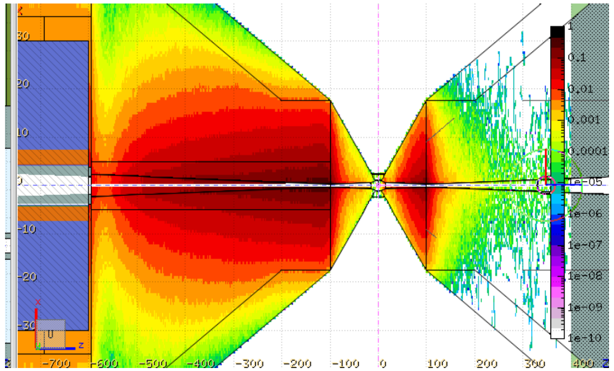
Acceleration to collision energy

Collision

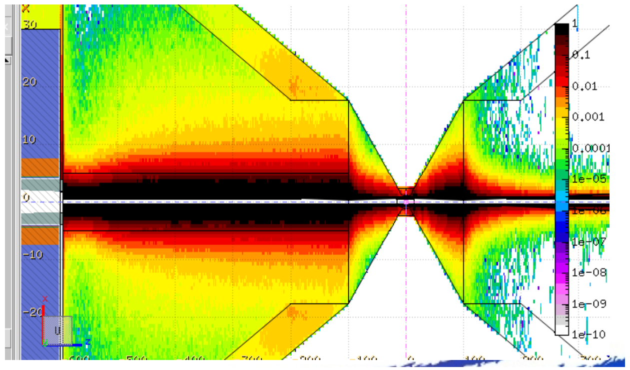
Machine Detector Interface – MDI



Neutron fluence



Photon fluence



1) Muon decay along the ring
2) Incoherent e^+e^- production during bunch crossing at IP
3) Beam halo losses

- At low energy, $\sqrt{s} = 3$ TeV, **1)** dominates
  Studies performed with MAP configuration
- At high energy, $\sqrt{s} \approx 10$ TeV, **1), 2), 3)** under evaluation

The machine elements, MDI and interaction region must be properly designed and optimized @ each collider energy

FIRST preliminary study @ 10 TeV performed using nozzle design @ 1.5 TeV

MDI – Milestones, Deliverables, Collaborations

MDI WG: *C.Carli, A. Lechner,* ***CERN****, N. Mokhov, S.Jindariani,* ***FNAL****, D.Lucchesi, N.Pastrone,* ***INFN***
with N. Bartosik, M. Casarsa, F. Collamati, L. Sestini et al.

International MUON Collider Collaboration

Collaboration

- **INFN:** PD, RM1, TO, TS
- **CERN**
- **UK**
- **FNAL** (after P5)

	Milestones (M) e Deliverables (D)	Date
M1	Report on beam-induced background at center of mass energy 3 TeV	**Q4 2023**
M2	Report on beam-induced background at center of mass energy 10 TeV	**Q4 2024**
D1	Beam-induced background files available in Open Access	**Q2 2025**
M3	Report on software description for beam-induced background generation and results with optimized nozzles at different center of mass energies	**Q4 2025**

IMCC:
Coordination MDI – absorber optimization – background on detector studies

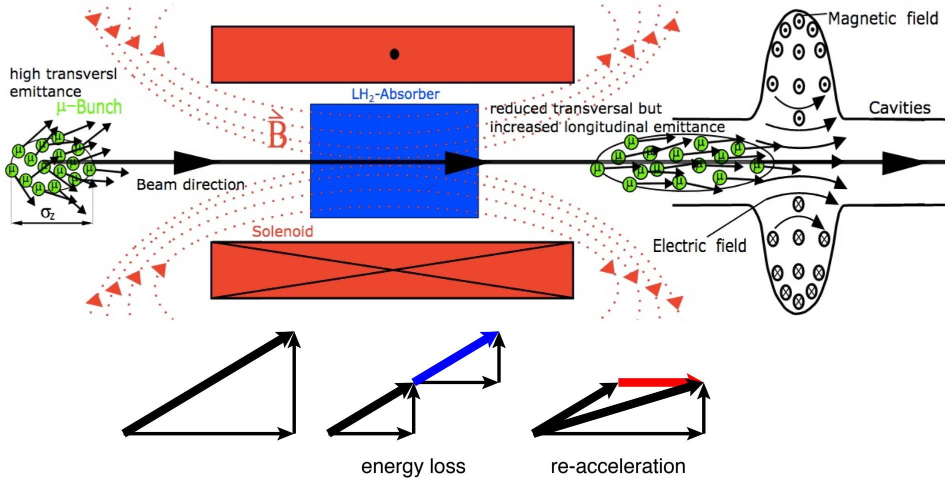
MuCol:

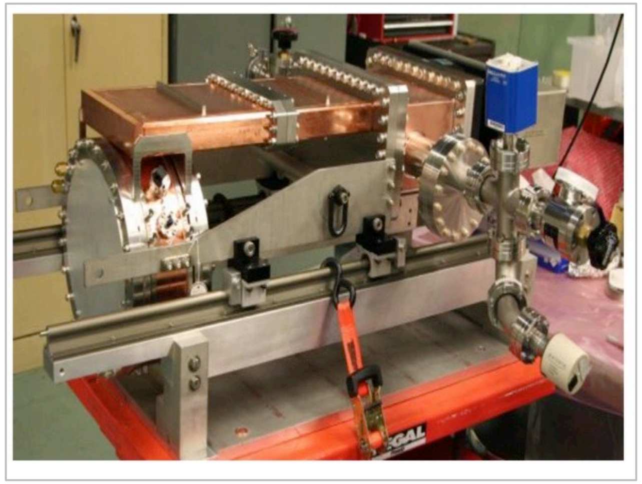
- **WP2 Physics and Detector requirements:** machine interaction point – detector design **leader D. Lucchesi**
- **WP4 High Energy Complex:** task MDI design and background to experiment

Advanced assessment of beam-induced background at a muon collider
F. Collamati, C. Curatolo, D. Lucchesi, A. Mereghetti, P. Sala *et al.* 2021 *JINST* **16** P11009

➔ IPAC 2023

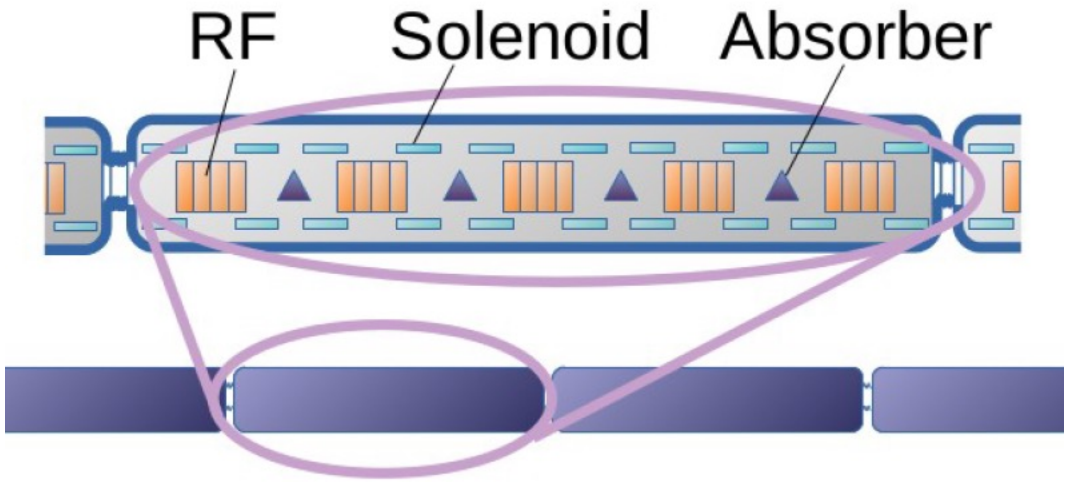
Ionizing Cooling Cell design and integration





MuCool: demonstrated cavity with >50 MV/m in 5 T solenoid

- H2-filled copper cavities
- Cavities with Be end caps

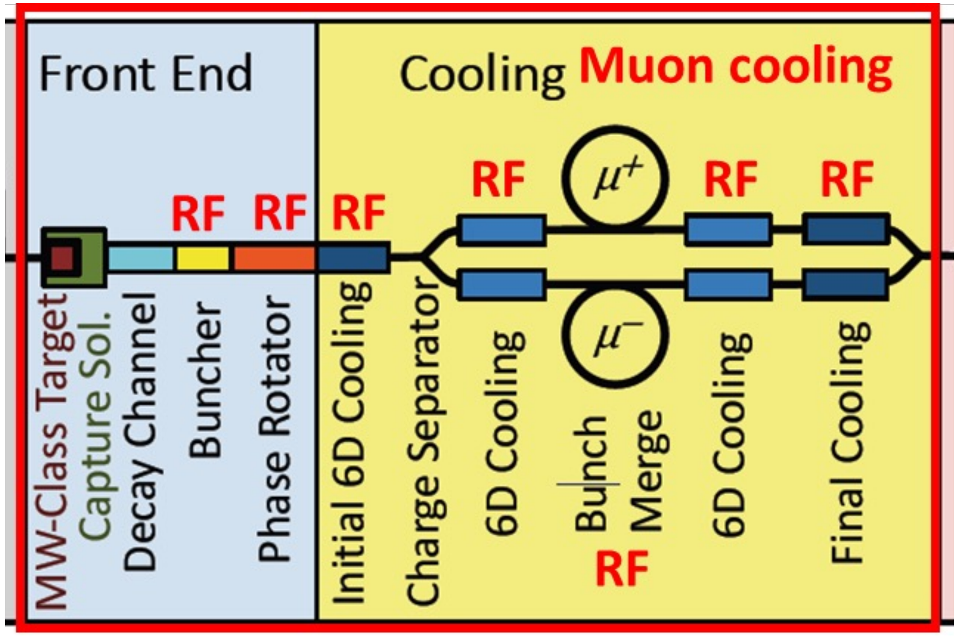


- normal-conducting RF cavities
- high field solenoidal magnets

Need to develop full cooling demonstrator

NC RF system for muon capture and cooling

Region	Length [m]	N of cavities	Frequencies [MHz]	Peak Gradient [MV/m]	Peak RF power [MW/cav.]
Buncher	21	54	490 - 366	**0 - 15**	1.3
Rotator	24	64	366 – 326	**20**	2.4
Initial Cooler	126	360	325	**25**	**3.7**
Cooler 1	400	1605	325, 650	**22, 30**	
Bunch merge	130	26	108 - 1950	**~ 10**	
Cooler 2	420	1746	325, 650	**22, 30**	
Final Cooling	140	96	325 - 20		
Total	**~1300**	**3951**			=> **~12GW**



It is a very large and complex RF system with high peak power

RF cavities in the Cooling Channel

The performance of a normal conducting cavity may degrade when the cavity is operated in strong magnetic fields (Operational experience and numerical studies)

➔ the magnetic fields cause RF cavity breakdown at high gradients

relevant technical challenge for the design of a high-efficient ionization cooling channel

RF cavities has been designed, built and demonstrated stable operation at ~10 MV/m

Data: mainly 201 MHz and 805 MHz cavities with different surface quality enhancements and low Z materials

INFN proposed contribution is:

- Design the compact multiple-cavity module, with efficient frequency tuning and RF power feeding systems.
  In the cooling channel, the voltage in each segment requires multiple cavities or one LINAC with multiple cells.
  In order to have strong solenoid fields, the cavity design should be as compact as possible in the transverse direction
- Study the possibilities offered by improved copper surface qualities, new copper based alloys or low Z materials as Berillium to improve the braeakdown properties of a NC cavity
- Look into a suitable RF frequency choice (in the range 3000 to 325 MHz) to define a trade off between the above discussed phenomena and the magnet design

To contribute to the proposal of a demonstrator of a cooling channel section

For 2023 we get a small funding from CSN1 to evaluate the possibility to carry out some tests on selected materials and polishing technologies on a DC HV (10 MV/m) test set up in magnetic field (1 T) @ LASA.
This may be considered as the starting point of a more ambitious program.

International
MUON Collider
Collaboration

1. study of innovative materials to create electrodes to be tested with a high DC static field in the presence of a magnetic field of at least 1 T or higher
2. study of surface finishing and cleaning techniques for the above materials
3. DC high static field test in the presence of a magnetic field of at least 1 T or higher
4. design of single cells at different frequencies in the 650-1300 Ghz range to verify the feasibility of structures with a reduced number of brazing (against joining techniques that allow the parts to be removed)
5. low frequency test
6. high power tests
7. test in magnetic fields of at least 5 T of single cells with RF power.

R=2.405c/2pf

f0 = 352 MHz, Rc = 326.2 mm;
f0 = 704 MHz, Rc = 163.1 mm;
f0 = 1500 MHz, Rc = 76.6 mm;
f0 = 3000 MHz, Rc = 38.3 mm.

A **common laboratory at LASA** could be envisage for the **low-power qualification of these cavities.**

With new and dedicated staff resource, it could also take care of transferring and increasing the know-how available in the context of LLRF systems and integrate with similar national and international initiatives.

The activities listed above, in the face of a recent survey, met the interest of the groups working on NC RF cavities of the following structures:

- **LNS** (e.m. design power coupler design)
- **NA** (e.m. design)
- **MI** (e.m. design, measurements, tests and sample preparation)
- **LNL** (limited to the analysis part of the surface finishes of materials)

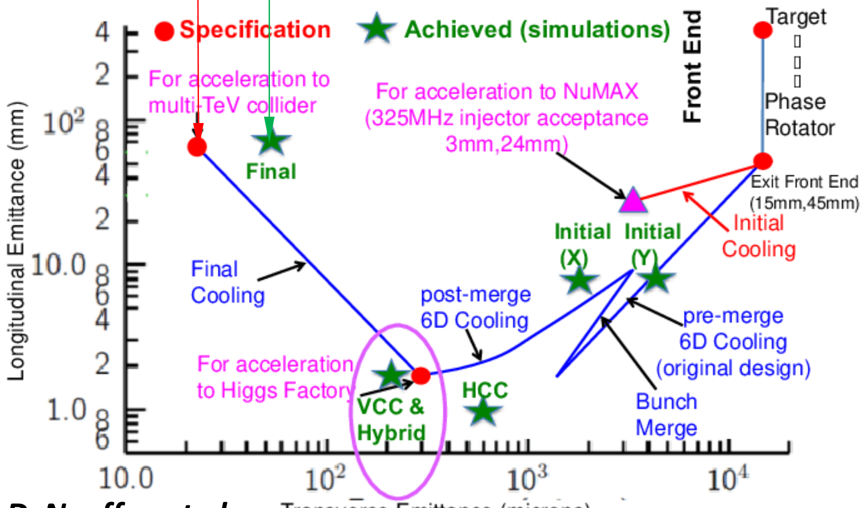
To date, there is a defined involvement with **CEA** for which Dario Giove is deputy leader on the WP dedicated to the RF of the cooling channel of the European proposal.

Cooling solenoids

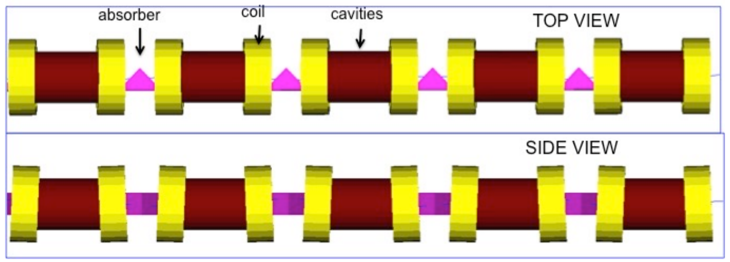
40…60 T required

30 T assumed in MAP

***A field of 40 T (minimum), up to 60 T (target) is needed** to meet emittance specification at the end of the cooling stage*



D. Neuffer, et al.



- **Muon cooling**

  1km 2 T to 14 T
- **Final cooling**

  8.5 m – 40 T or 60 T

- The conceptual design of UHF solenoids has started, exploring limits of performance (field and stress), operating efficiency (temperature), lean and compact designs (mass and cost)
- **We are defining a *Solenoid Coil Demonstrator* (SCD), a representative test configuration (20 T, 50 mm, 500 MPa) to support the conceptual design with a strong experimental basis. This configuration could be a basis for collaborative work across laboratories**
- Some SCD per year will be needed (manufacturing and testing).
- Each SCD requires approximately 150 m of 12 mm HTS tape
- **HTS tape, initially in the range of 1 to 1.5 km (12 mm) is the single most critical item to start manufacturing and experimental work**

***Solenoids for a muon collider need to be compact** (reduce cost), **mechanically strong** (withstand extraordinary e.m. forces) **and well protected against quench** (large stored energy)*

- **Define initial experimental needs by performing material characterization**
- **Provide material for the manufacturing of the first SCD's**

Targeted R&D is required to address these challenges

CERN, INFN, Univ di Twente (NL), Univ. di Ginevra, KIT, CEA

Programme 2024-2026

- 2024
  - Test coil at the Variable Temperature Facility (VTF) in preparation 2022-2023
  - **Design magnete SC HTS: 1 in MgB2 and 1 in REBCO to be integrated with RF**
    Operating temperature: 10-20 K
    @ RF 650 MHz → large apert.→ 2-3 T
    @ RF 1.3 GHz → smaller aperture → 3- 5 T
  - Plan to build two magnets
    - HTS conductor (half REBCO Half MgB2) : 10 km → ~ 0.5 M€
    - HTS Magnet fabrication: → ~1.3 M€ (with cooling system)
- 2025-26 follow up fabrication
- 2026 cold test (single mode ➔ with RF)
- REBCO Technologgies are the same for ring magnets (task leadership INFN)

Partecipating institutes

CERN-EP, Contact person: A. Dudarev

LNCMI, contact person: Dr. X. Chaud, Dr. F. Debray

PSI, contact person: Dr. B. Auchmann

University of Geneva,

contact person: Prof. C. Senatore

INFN LASA, contact person: Marco Statera

University of Southampton,

contact person: Prof. Y. Yang

University of Twente, Prof. A. Kario

CEA, Dr. L. Quettier

Ionizing Cooling Cell design and integration

Milestones (M) e Deliverables (D)		Date
M1	Definition of characteristics of HTS tape, Tech Specs for placing the order for 1 km tape	**Q2 2023**
M2	Tests on materials for high Voltage Breakdown	**Q4 2023**
D1	Report on Kilpatrick limit vs RF frequency. Mitigation procedures to improve breakdown limit	**Q4 2023**
M3	Set-Up of the RT RF laboratory for RF field measurements @LASA	**Q1 2024**
M4	Experimental characterization of existing 3 GHz copper cavities	**Q2 2024**
D2	Report on proposed RF cavities properties for the cooling channel and their mechanical design	**Q3 2024**
M5	Study of the em behavior of a 650 MHz and of a 3 GHz cavity with suitable power couplers and simulating a static RF thermal load	**Q4 2024**
D3	Report on applicable scaling rules for RT RF cavities properties	**Q4 2024**
D4	Construction of the model coils for technology validation of the split coil design	**Q2 2025**
D5	Design of a proposal for the experimental setup of a complete cooling channel	**Q4 2025**

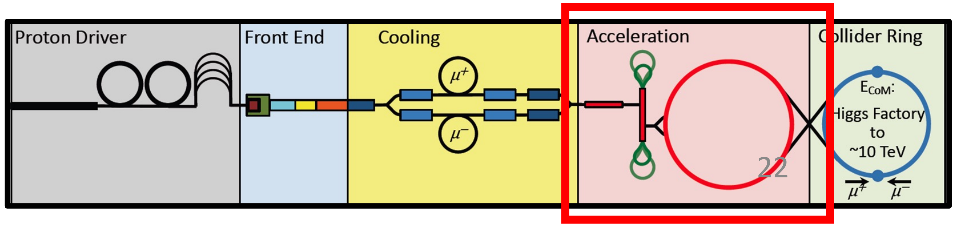
Baseline concept of the RF system for acceleration of the High Energy Complex

International MUON Collider Collaboration

- Provide a **preliminary design concept** for the SRF cavities for acceleration in the Rapid Cycling Synchrotrons (RCS) of the HEC of the muon collider.
  - For the acceleration stage of the HEC, the short muon lifetime requires the highest possible acceleration rate to reach energy gains on the order of 10 GeV per turn. This is foreseen to be provided with **very high voltage SRF cavities**.
- **Select a suitable cavity technology**, including the accelerating cavity type, shape and main RF frequency, the cavity material and its possible surface treatments will be determined for this system.
- **Strong transient beam loading** effects, as well as **strong wake field effects** due to the very high intensity of the muon bunches will also have to be addressed in the cavity optimization.
- In cooperation with beam dynamics working package, a **full set of parameters for the RF cavities** that address longitudinal beam dynamics and stability will be established (R/Q, Vmax, k_{loss}…) for the fundamental mode and HOMs' suppression.
- This will provide **input specifications** for the **design concept of the RCSs cavities**
- At present, **reference cavity** is the **TESLA 1.3 GHz** operated at **30 MV/m.**

HE Complex

Multiple RF station along Acc. Ring with
1.3 GHz, pulsed SRF cavity, are being studied by Batsch at al.



Superconducting RF cavities: fast frequency tuner system

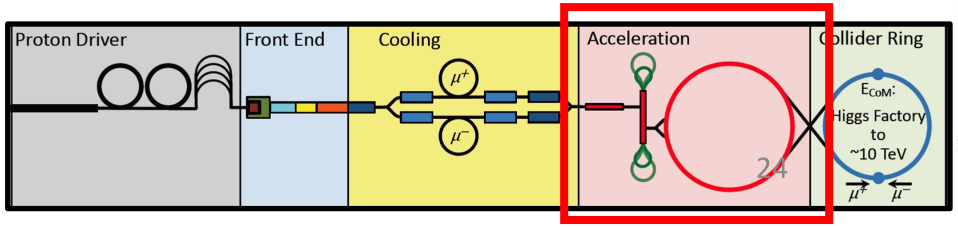
International MUON Collider Collaboration

INFN MI-LASA

Milestones (M) e Deliverables (D)		Date
M1	Select piezo actuators and driver purchased by LASA	**Q4 2023**
M2	Experimental characterization of actuators at room and cryogenic temperature	**Q2 2024**
D1	Push-Pull tuner design, report release	**Q4 2024**
M4	Purchase order issued for piezo system support and adapter parts	**Q4 2024**
D2	Installation of tuner prototype system based on Coaxial Blade tuner at LASA	**Q2 2025**
M5	Experimental characterization of the complete prototype tuner system at LASA	**Q3 2025**
D3	Simulation study of cavity + tuner system for MC, report release	**Q4 2025**

Fast ramping magnets

HE Complex



International MUON Collider Collaboration

Collaboration:
University of Bologna, CERN, University of Darmstadt, University of Twente, University of Padova, Consorzio CREATE, University of Southampton, Université Grenoble Alpes
Companies: OCEM, CB Meccanica, SAES RIAL

Marco Breschi et al.

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Resistive dipole magnets main specifications:

1) Magnetic field in the aperture about **1.8 T**
2) Magnetic field homogeneity within 10×10^{-4} in the good field region (**30 mm * 100 mm**)
3) Ramps from $-B_{max}$ to + B_{max} in **1 ms.** The objective for the value of B_{max} is 2.0 T
4) Limit the **magnet stored energy** (crucial design specification to limit the supplied power)
5) Limit the **total losses (iron + copper)**

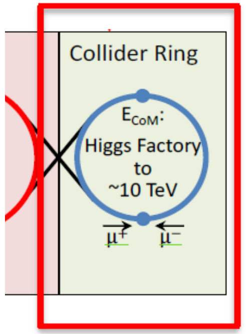
Design:

- **Power converter** design and optimization
- Design of the **resistive magnets for pulsed operation**
  - **Layout optimization** of Dipoles/Quadrupoles with different magnet configurations
  - **Simplified mathematical models** of the magnets including loss calculation integrated magnet/powering system
  - **Detailed 2D/3D transient analysis** for computation of losses in the ferromagnetic materials, effects of saturation, end plate/coils effects etc..
- Alternative **full SC (HTS) design** of fast ramping magnets

Tests:

- Magnetization and losses measurement in representative **reduced scale model of the resistive magnets**.

High Field dipole Magnets technologies



International
MUON Collider
Collaboration

Scope:

- assessing realistic performance targets for the collider magnets, in close collaboration with beam physics, machine-detector interface, and energy deposition studies
- produce Design Study Credible and Affordable
  (contain cost, energy efficient, sustainable operation)

Collaboration:

- **INFN Milano:** M. Statera, M. Prioli, E. De Matteis, R. Valente, S. Sorti
- **INFN Genova:** B. Caiffi, A. Bersani, A. Pampaloni, F. Levi, S. Farinon, R. Musenich
- **UniMI:** L. Rossi, M. Sorbi, S. Mariotto
- **CERN:** L. Bottura, A. Lechner….

- Define requirements for the **combined function collider arc magnets**:
  - dipolar magnetic field
  - gradient
  - magnet aperture
  - length

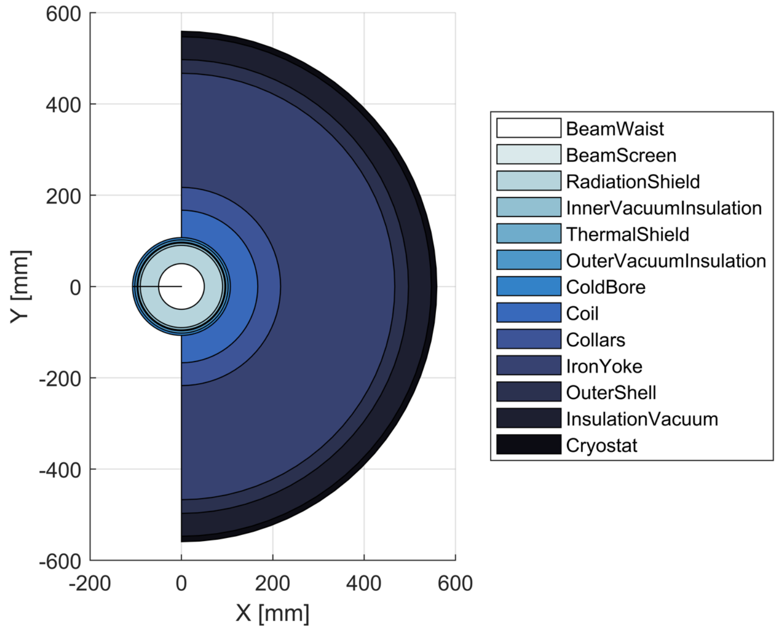
On-axis peak field(1)	10 T
On-axis peak gradient(1)	300 T/m
Bore(2)	150 mm
Magnetic length	15 m
Field Quality	10 units
Technology	LTS/HTS
Temperature range(2)	1.9/4.2 K (LTS) or 10 to 20 K (HTS)

In the current tentative specs the dipole/quad combination is NOT possible

Activity to derive (semi-analitycally) operating limits for NbTi, Nb3Sn, HTS and hybrid combinations

Radial Build

Different studies to be integrated in a unique design of the dipole layout for the collider



Preliminary Timeline

T0 +6 months
Consolidate magnet requirements

T0 + 12/14 months
Analytical expressions for cross-section

T0 +33 months
D 7.1 Intermediate Report

T0 +42 months
M 7.3 Workshop on HFM for collider

T0 +45 months
D 7.2 Consolidated report

International MUON Collider Collaboration

Milestones (M) e Deliverables (D)		Date
M1	Review of technology options	**Q2 2024**
D1	First conceptual baseline and technology selection for dipole magnets and powering system	**Q2 2025**
M2	Preliminary power and cost estimate	**Q4 2025**

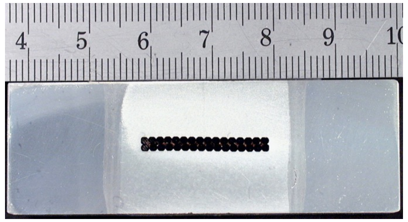
New concept for detector magnets

Strong synergy among several projects: MUCOL, FCC_ee, DUNE

Riccardo Musenich et al.

Main characteristics of superconducting magnets for particle detectors:

- Large volume
- Moderate magnetic field (0.5 to 4 T) **==> TO BE STUDIED**
- Transparency to particles is often required
- Generally, solenoidal or toroidal shape



CMS conductor

At present, only Al stabilised NbTi conductors are used for detector magnets

Fabrication of conductors requires cabling and co-extrusion, an expensive and delicate industrial process.
Currently, there are no more industries that produce Al-stabilized conductors among those that have a proven track record*

MgB_2 is an excellent material as candidate to manufacture conductors for detector magnets

MgB_2 allows operating magnets at $T > 10\ K$:

- intrinsically stable magnets more efficient cryogenics

Development of a conductor prototype for space applications (SR2S project): Titanium clad MgB_2 tape + Aluminium strip

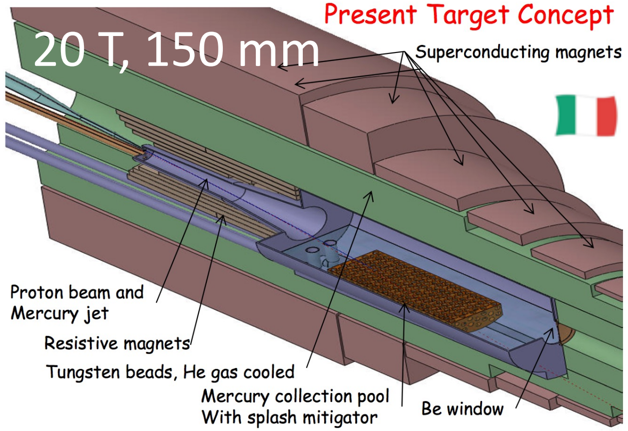
R. Musenich et al., IEEE Trans on Appl. Supercond26 (4), 2016

A remarkable example of MgB_2 wire cabling: the LHC superconducting links

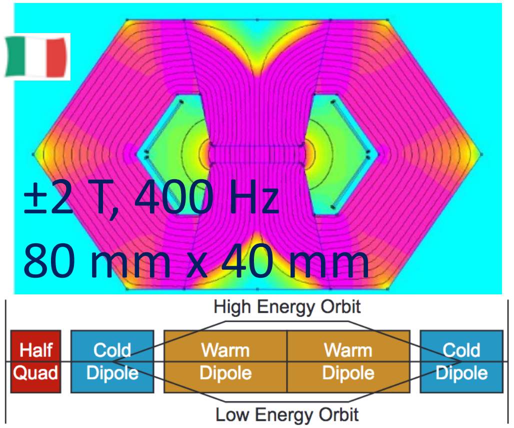
A. Ballarino, Supercond. Sci. Technol. 27 (2014) 044024

* Toly Electric, in China, is interested in the business and started producing conductors in 1.5 km length.

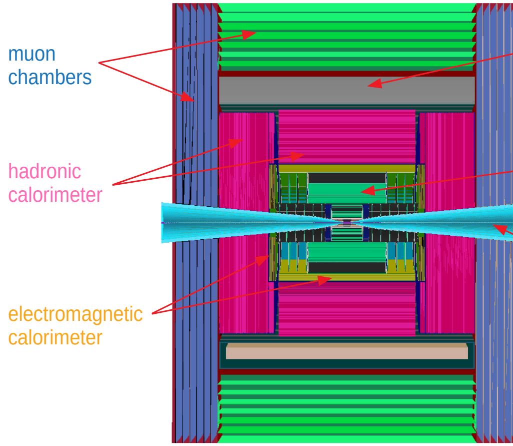
Magnet Demands @ Muon Collider



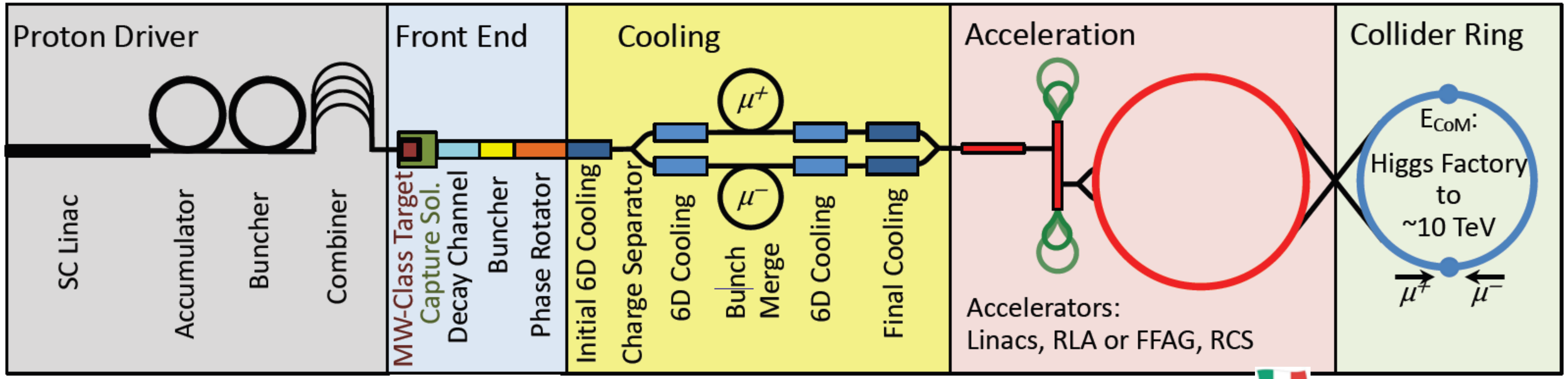
High-field and large aperture target solenoid with heavy shielding to withstand heat (100 kW/m) and radiation loads



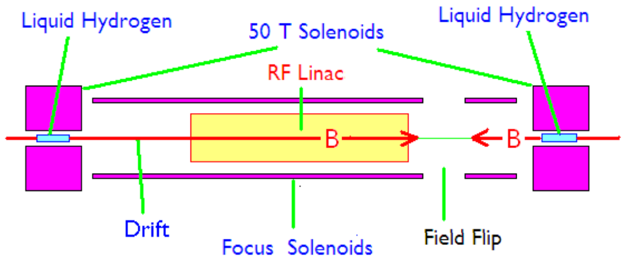
Combination of DC SC magnets (10 T) and AC resistive magnets (± 2T)



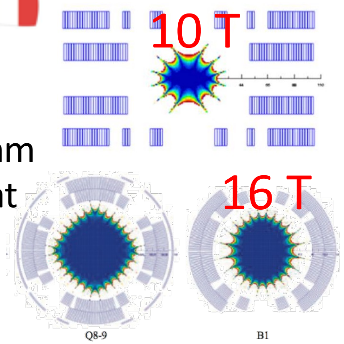
Detector Magnet to be designed for 10TeV



Ultra-high-field solenoids (40…60 T) to achieve desired muon beam cooling



Open midplane or large dipoles and quadrupoles in the range of 10…16 T, bore in excess of 150 mm to allow for shielding against heat (500 W/m) and radiation loads



Physics potential driving the future

Direct searches

Pair production, Resonances, VBF, Dark Matter, …

High-rate measurements

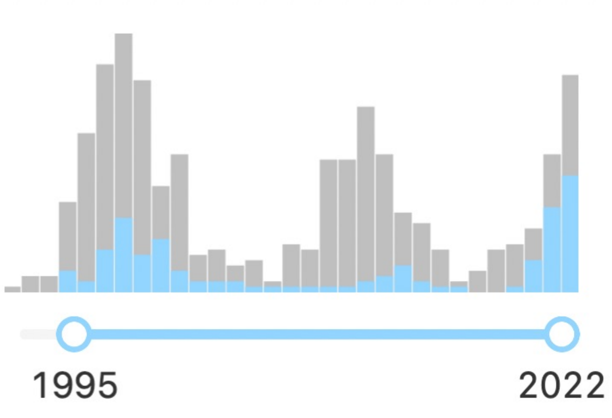
Single Higgs, self coupling, rare and exotic Higgs decays, top quarks, …

High-energy probes

Di-boson, di-fermion, tri-boson, EFT, compositeness, …

Muon physics

Lepton Flavor Universality, $b \to s\mu\mu$, muon g-2, …



Muon Collider Pheno Papers

Strong participation at IMCC activities and during Snowmass21 ➔ **new Institutes joining**

submission of white papers ➔ **EPJC paper soon**

Muon4Future

29–31 May 2023 **Venezia** - Palazzo Franchetti
Istituto Veneto di Lettere, Scienze ed Arti

Thanks for the attention!

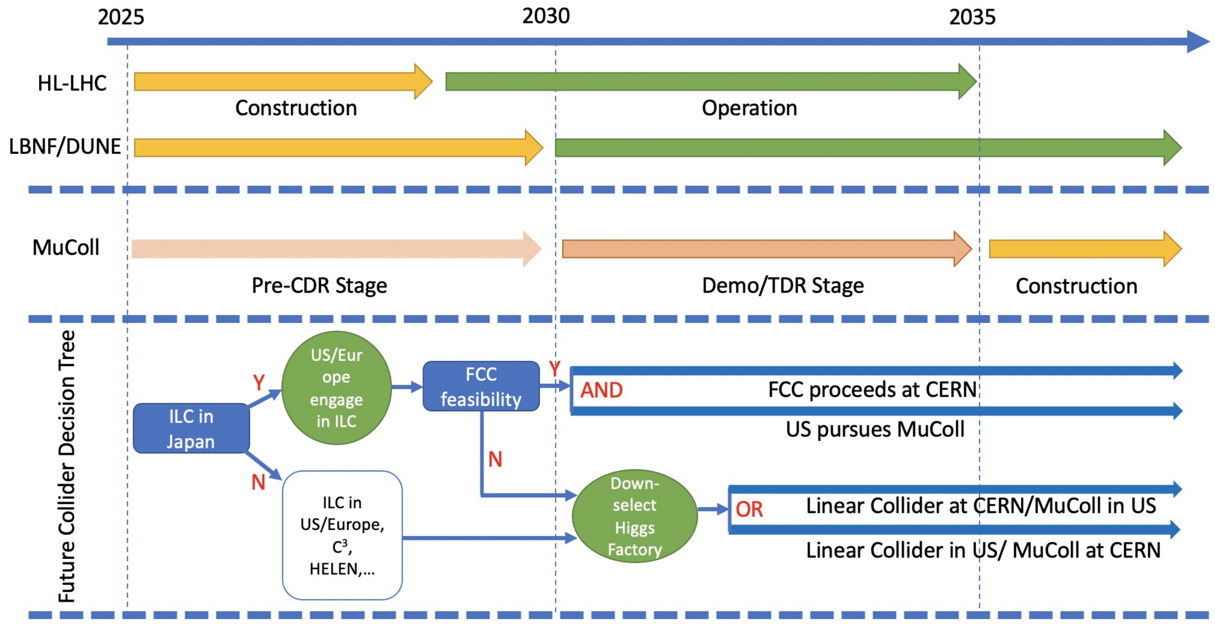
extras

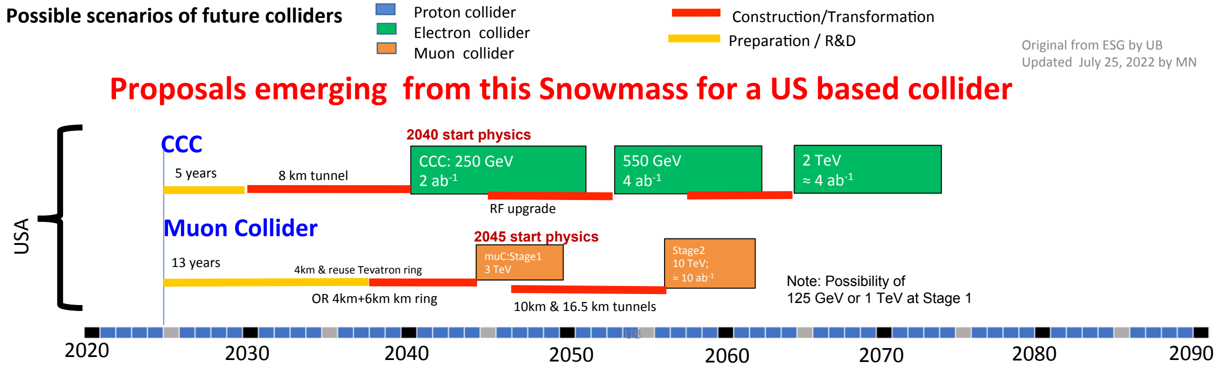
Long-term future: a multi-TeV collider

from Snowmass

- **For the next decade and beyond**
  - **2025-2030**:
    - Develop an initial design for a first stage TeV-scale Muon Collider in the US (pre-CDR)
    - Support critical detector R&D towards EF multi-TeV colliders
  - **2030-2035**: Demonstrate principal risk mitigation and deliver CDR for a first-stage TeV-scale Muon Collider
  - **After 2035**:
    - Demonstrate readiness to construct and deliver TDR for a first-stage TeV-scale Muon Collider
    - Ramp up funding support for detector R&D for EF multi-TeV colliders

Muon Collider Forum Report arXiv:2209.01318 **[hep-ex]**





- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - International Cost Sharing
- Consider proposing hosting ILC in the US.

Forum Conveners: K.M. Black, S. Jindariani, D. Li, F. Maltoni, P. Meade, D. Stratakis

Demonstrator Facility: a crucial step!

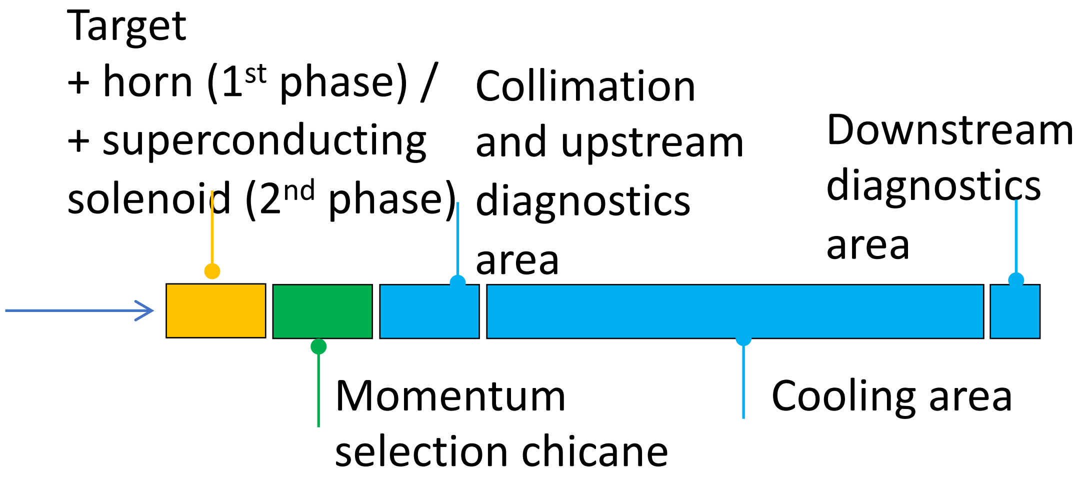
Planning **demonstrator** facility with muon production target and cooling stations

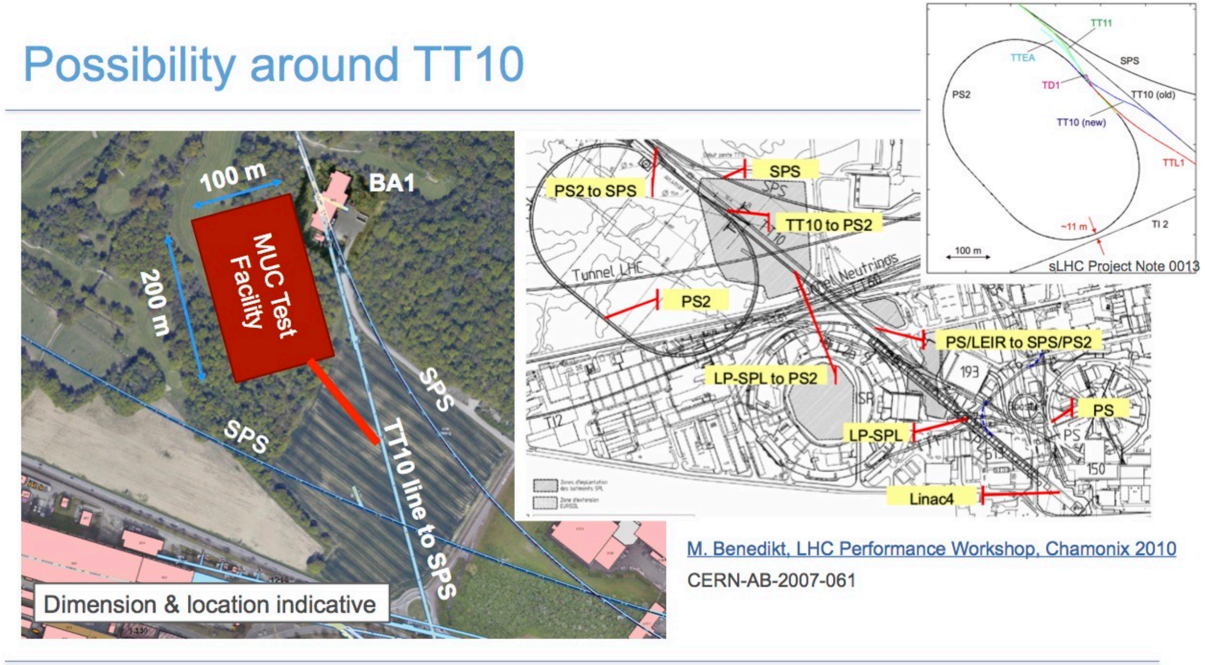
@ CERN

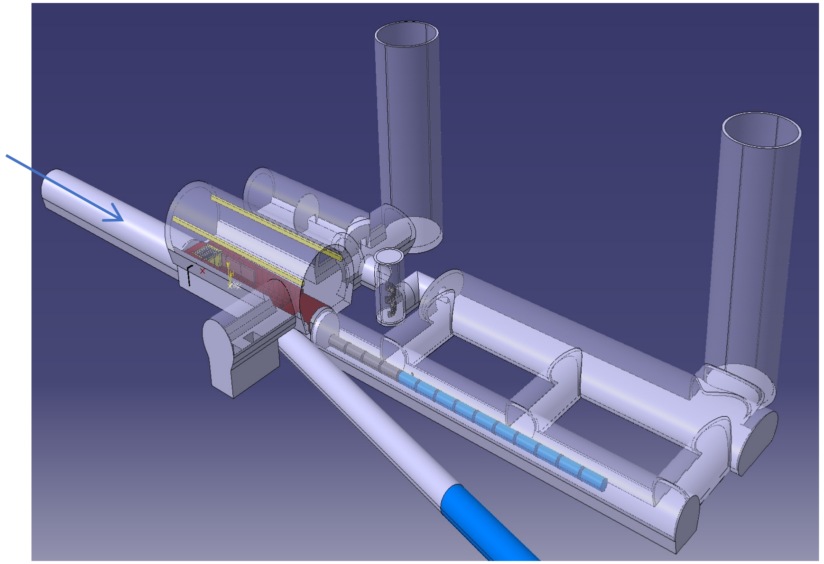
Suitable **site exists** on CERN land and can use **PS proton beam**

- could combine with **NuStorm** or other option

Other sites should be explored (FNAL?)

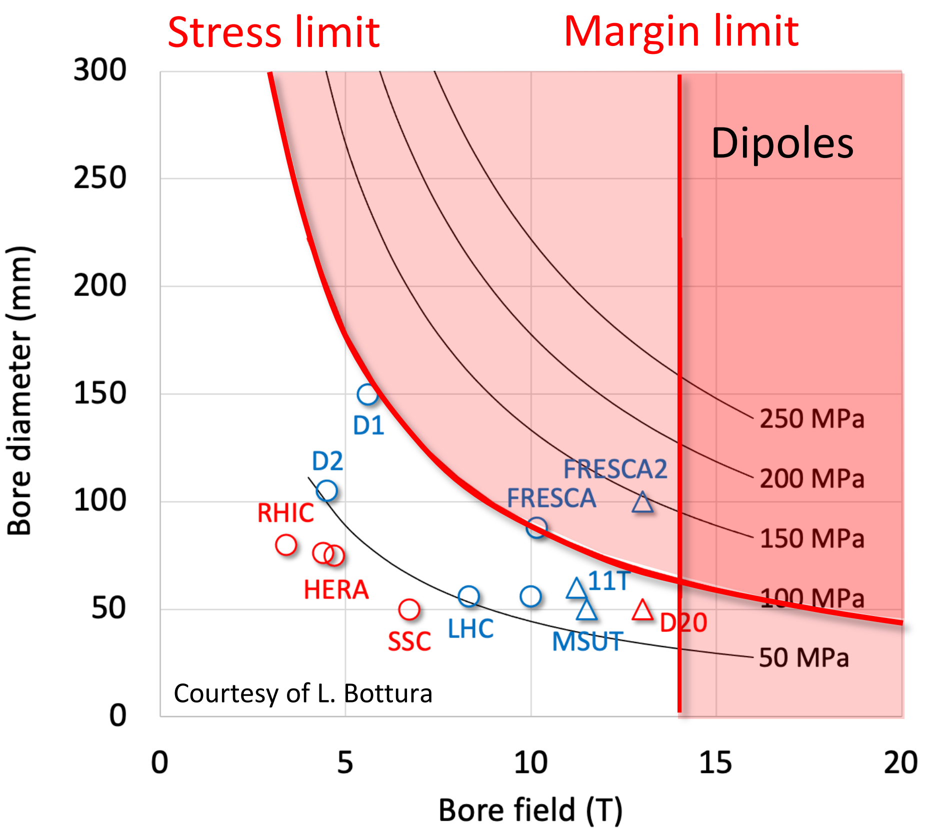


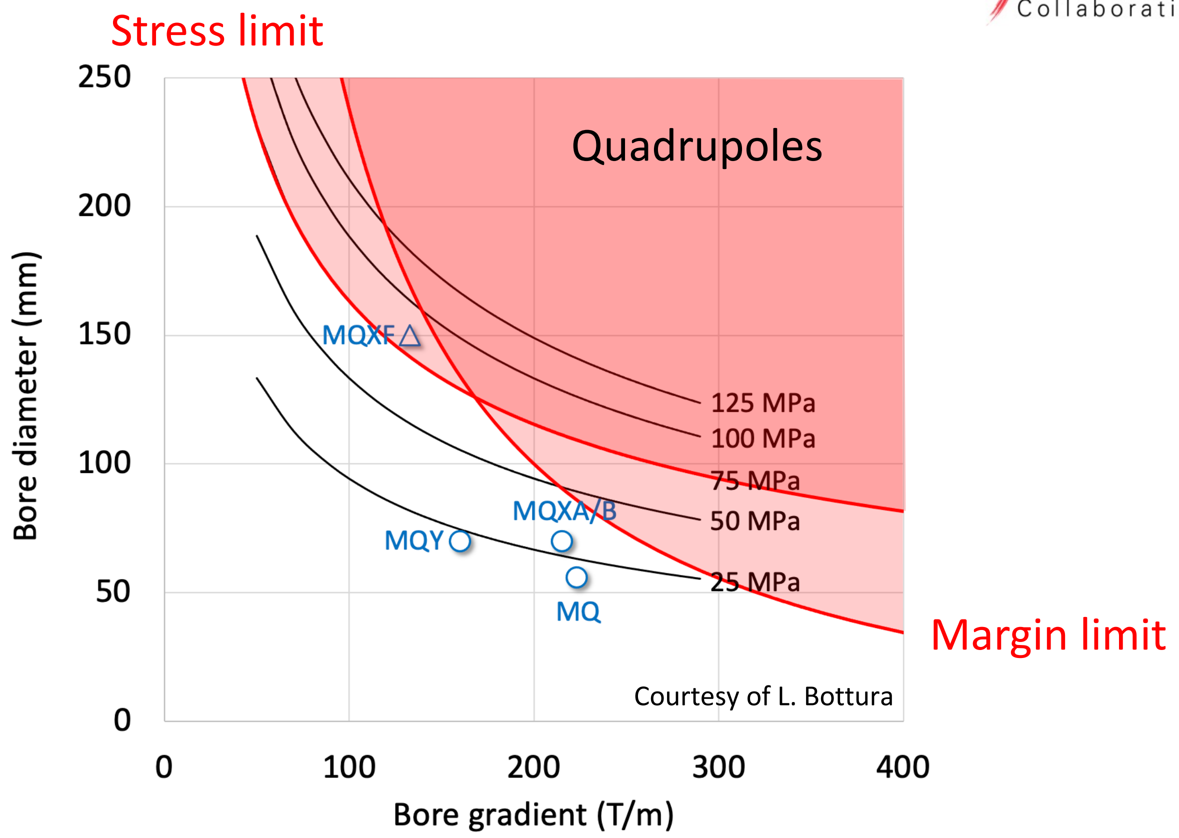




Fast evaluation of magnet parameters

International MUON Collider Collaboration





- Scope: provide analytical expression for the magnet design limits
  - Maximum field and gradient vs. magnet aperture in LTS and HTS
  - Combined function limits B+G and B/G

EU project: WP

WP 2: Physics and Detector Requirements

Leader D. Lucchesi Univ. PD + INFN (M. Casarsa) + many + + Univ. PV associated

Link to the physics and detector studies, to provide a database with Beam-Induced Background (BIB) to the physics community and maintain a simplified model of the detector for physics studies. Based on feedback from the physics community, it will provide feedback and guidance to the accelerator design.

WP 3: The Proton Complex

Leader ESS-CERN-UU

key challenge of the proton complex design, the accumulation of the protons in very high-charge bunches and determine the required basic parameters of the complex.

WP 4: The Muon Production and Cooling

Leader STFC-CERN+ UK

Production of the muons by the proton beam hitting a target and the subsequent cooling

WP 5: The High-energy Complex

Leader CEA(Antoine Chance)-CERN-STFC-INFN (F. Collamati – RM1-TO) only MDI

Acceleration and collision complex of the muons. Interaction Region and Machine Detector Interface.

EU project: WP

WP 6: Radio Frequency Systems

Leader CEA(C. Marchand)+INFN(D. Giove Deputy - MI – LNL – LNS – NA)-CERN++++

Radio Frequency (RF) systems of the muon cooling and the acceleration complex.

WP 7: Magnet Systems

Leader CERN(L. Bottura)-CERN+++ INFN(GE, MI, BO) + Univ. BO associated

Most critical magnets of the muon collider. In particular focus on the solenoids of the muon production and cooling, which are specific to the muon collider. The fast-ramping magnet system, which has ambitious requirements on power flow and power efficiency and limits the energy reach of the collider,

WP 8: Cooling Cell Integration

Leader CERN(R. Losito)+Univ. MI (L. Rossi)-STFC-INFN(M. Statera – mag. e D. Giove – RF)

Design of the muon cooling cell, which is a unique and novel design and which faces integration challenges: interact to address the challenges of the muon collider concept.