Motivation for a multi-TeV Muon Collider

[Towards a muon collider, Eur. Phys. J. C 83 (2023) 864]

International MUON Collider Collaboration

Strong interest in **high-energy, high-luminosity lepton collider**
- combines **precision physics** and **discovery reach**
- application of hadron collider technology to a lepton collider

Muon collider promises **sustainable** approach to the **energy frontier**
- limited power consumption, cost and land use ➔ **site evaluation and reuse of existing tunnels**

Technology and **design advances** in past years
- reviews of the muon collider concept in Europe and US found **no insurmountable obstacle**
- **identified required R&D**, documented in accelerator R&D Roadmap
- first parameters' report submitted October 2023

Aim at **10+ TeV** and potential initial stage at **3 TeV**

NEW OPTION: initial 10 TeV stage at reduced luminosity

Interim report https://arxiv.org/abs/2407.12450

Strong support by P5 Report @ December 2023

NEW
European Strategy for Particle Physics Update

Input documents due by March 31 2025

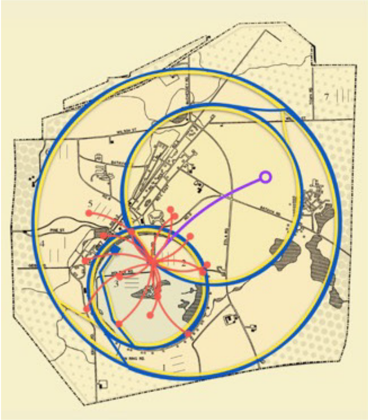
Council approval expected June 2026

US P5 – International partnership

Stability of the program requires implementing the framework for our international partnerships!

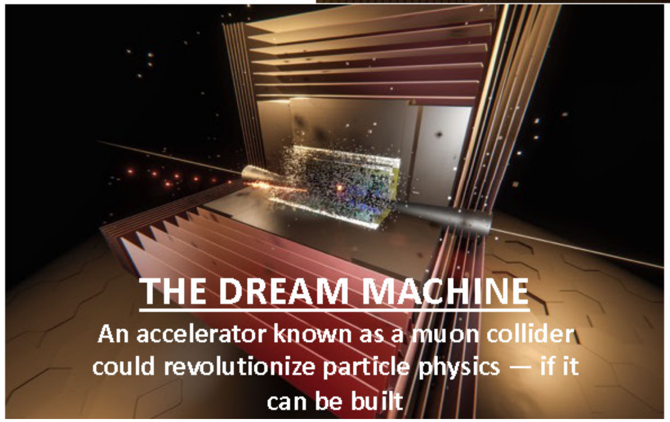
Parallel to the R&D for a Higgs factory,
the US R&D effort should develop a 10 TeV pCM collider (design and technology), ….

The US should participate in the International Muon Collider Collaboration (IMCC) and take a leading role in defining a reference design.
We note that there are many synergies between muon and proton colliders, especially in the area of development of **high-field magnets**. R&D efforts in the next 5-year timescale will define the scope of test facilities for later in the decade, paving the way for initiating **demonstrator facilities within a 10-year timescale** (Recommendation 6).



INAUGURAL US MUON COLLIDER COMMUNITY MEETING

FNAL – August 9, 2024



Key Challenges of the facility

Proton driver production
Baseline @ International Design Study

International MUON Collider Collaboration

10+ TeV
completely new
regime
to explore!

$\mathcal{L} = (E_{CM}/10\text{TeV})^2 \times 10\ ab^{-1}$

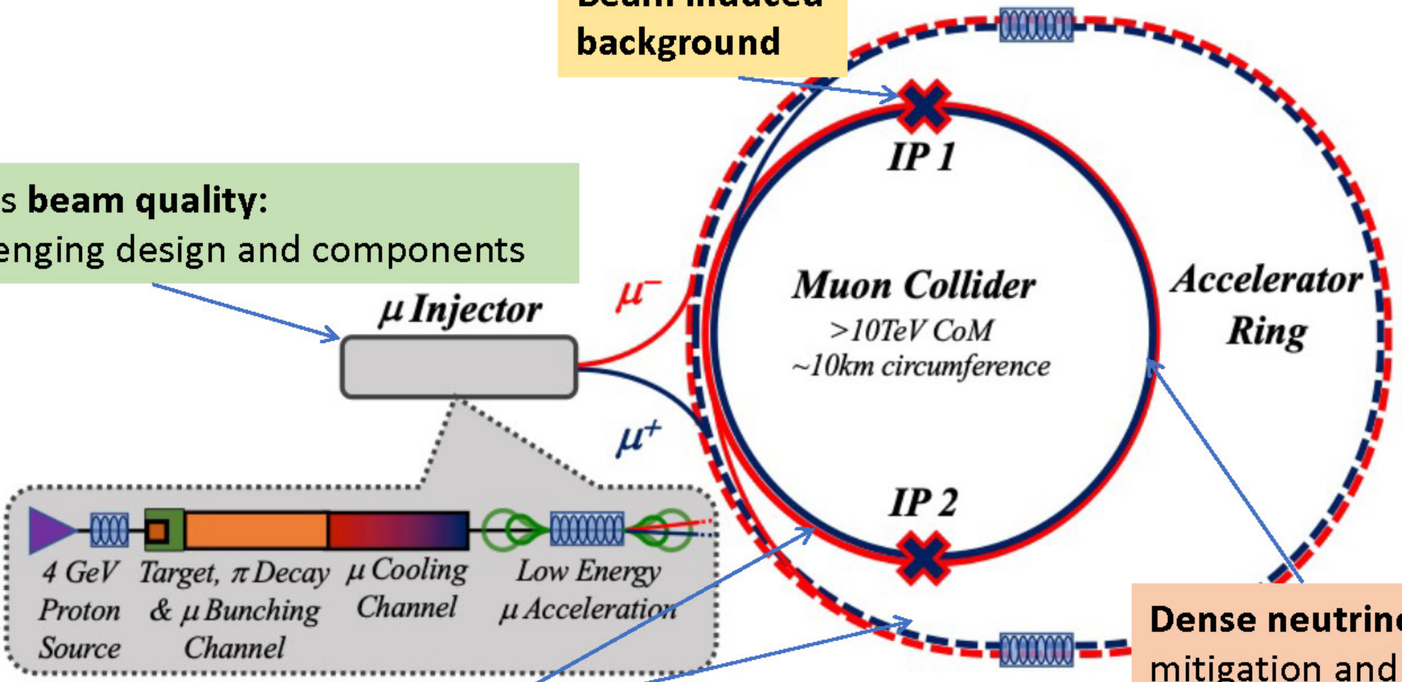
@ 3 TeV ~ 1 ab^{-1} 5 years

@ 10 TeV ~ 10 ab^{-1} 5 years

@ 14 TeV ~ 20 ab^{-1} 5 years

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

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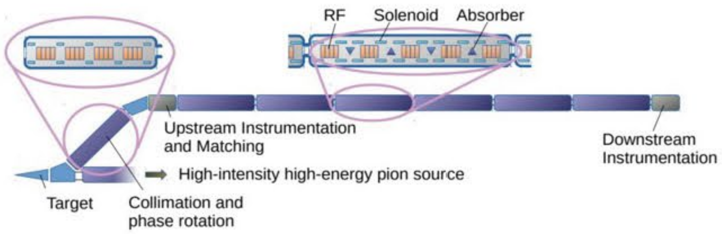
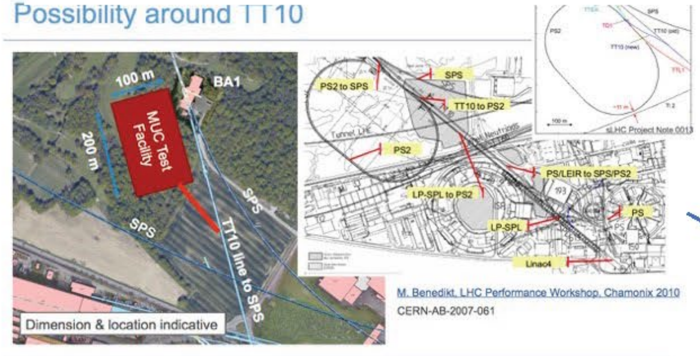
Demonstrator Facility: a crucial step forward!



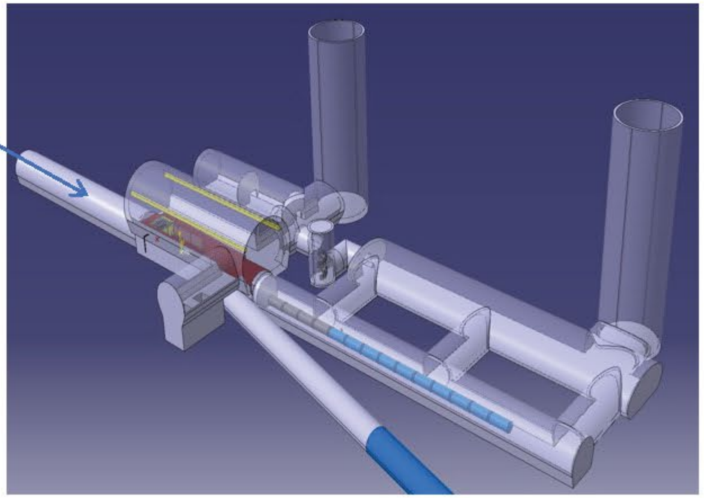
Planning **demonstrator** facility with muon production target and cooling stations

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

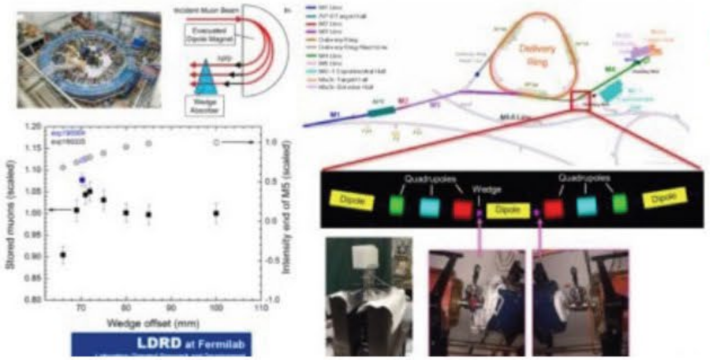
- could combine with **NuStorm** or other option



@ CERN



@ FNAL



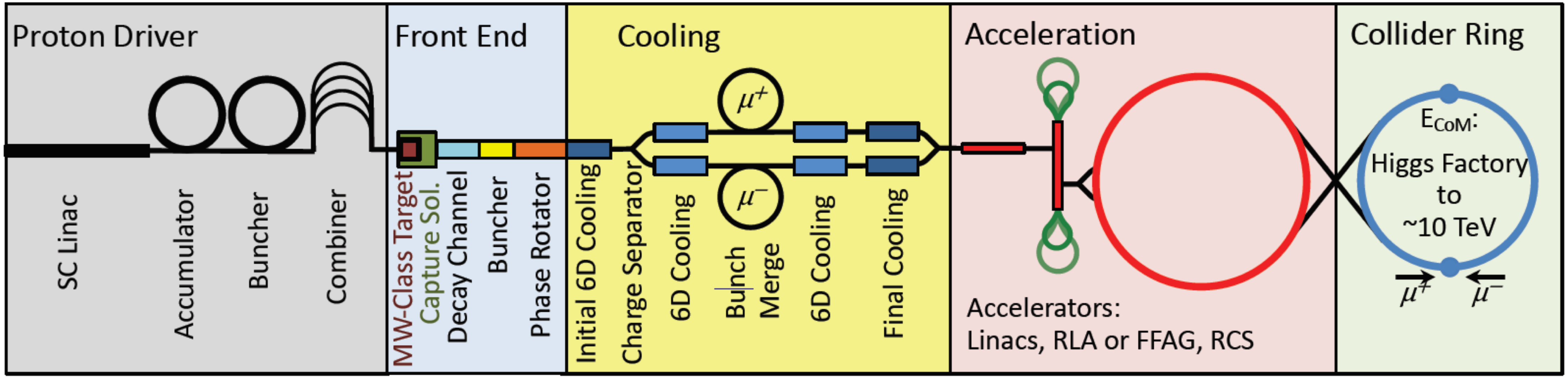
[International Muon Collider Collaboration: Demonstrator Workshop](#)

@ FNAL October 30 – November 1, 2024

Scientific studies, technological developments and experimental facilities for RF electrical fields embedded in high DC magnetic fields for advanced accelerating structures

Dario Giove -*INFN-LASA –Milano*
on behalf of the proposal group (mainly LASA & LNF)

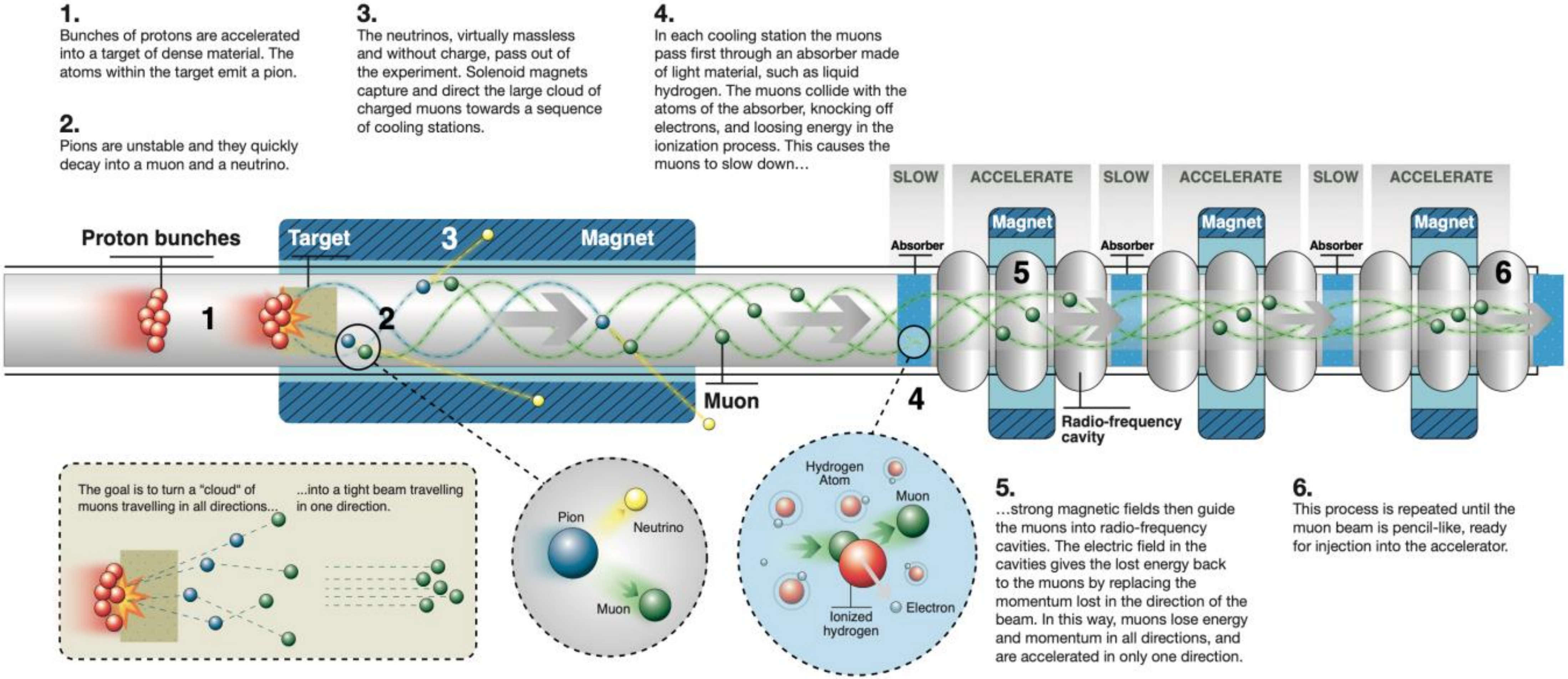
Muon collider and RF system challenges



The main challenges of a muon collider design are those arising from the short muon lifetime, which is 2.2 μs at rest, and the difficulty of producing large numbers of muons in bunches with small emittance.

The purpose of the cooling cell is to provide a reduction of the normalized transverse emittance by almost three orders of magnitude (from 1 × 10−2 to 5 × 10−5 m-rad), and a reduction of the longitudinal emittance by one order of magnitude of the Muon Beam generated by the collision of a proton beam with a production target, resulting in a shower of pions that will then decay into muons. Pions are generated with a large angular spread, and a large momentum spread as well.

Cooling Cell Scheme



Ionization Channel Parameters

Within the two main sections, 6D rectilinear cooling and final cooling there are about 20 different types of cells with various geometry, length, gradients, magnetic field strength and frequency. In order to decide which one is the more interesting to be designed in details, one has to look not only at scientific considerations, but also to practical aspects that would ensure the maximum result for the investment to be done.

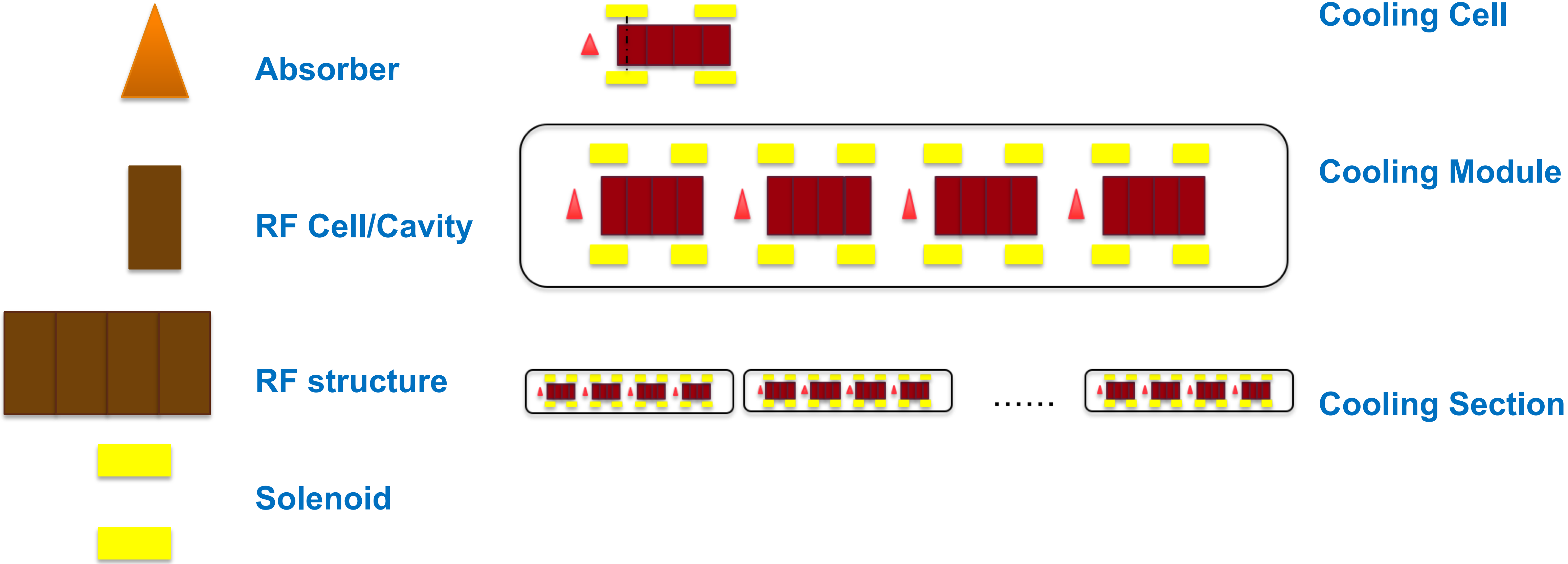
➢ Cooling cells parameters (updated)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10
Cell length (m)	2.3	1.8	1.4	1.1	0.8	0.7	0.7	0.65	0.65	0.632
Stage length (m)	55.2	61.2	77.0	70.4	53.6	49	34.3	48.1	31.85	42.33
Pipe radius (cm)	23	19	12.5	9.5	6	4.5	3.7	2.65	2.2	2.1
$B_{z,max}$ (T)	3.1	3.9	5.1	6.6	9.1	11.5	13.0	15.8	16.6	17.2
Transverse beta β_T (cm)	35	30	20	15	10	6	5	3.8	3	2.7
Dispersion (mm)										
On-axis wedge length (cm)	37	32	24	20	12	11	10	7	7.5	7
Wedge apex angle (deg)	110	120	115	110	120	130	130	140	140	140
Wedge window thickness (μm)	100	100	100	100	50	20	20	20	10	10
RF frequency (MHz)	352	352	352	352	704	704	704	704	704	704
Number of RFs	6	5	4	3	5	4	4	4	4	4
RF length (cm)	25	22	19	22	9.5	9.5	9.5	9.5	9.5	9.5
Maximum RF gradient (MV/m)	21.01	22.68	24.27	25.03	23.46	30.48	30.22	25.76	17.49	20.22
RF phase (deg)	28.22	30.91	29.76	29.48	23.81	19.65	18.31	14.37	19.42	14.69
RF inner-radius (mm)	326.2	326.2	326.2	326.2	163.1	163.1	163.1	163.1	163.1	163.1
RF window thickness (μm)	50	50	50	50	50	20	20	20	10	10

25.4.2024 by Ruiu Zhu

Terminology

Before to discuss the panorama of the open points related to RF and the activities carried out in the last year, a definition of the terminology that we will use in the discussions has been defined.



ESPP November 2022

Il MAC ha prodotto un documento con raccomandazioni che è stato sottoposto alla valutazione finale della Giunta Esecutiva (GE).

La GE, seguendo le raccomandazioni del MAC, ha approvato cinque dei progetti proposti, definendo per ciascuno di essi le risorse che potranno essere fornite (marzo 2023) .

Il Progetto dedicato al Muon Collider si articola in quattro Working Packages (WPs):

1. WP1 – Machine Detector Interface (MDI)
2. WP2 - Ionizing Cooling Cell design and integration: - normal-conducting RF cavities - high field solenoidal magnets
3. WP3 - Superconducting RF cavities: fast frequency tuner system
4. WP4 - High Field dipole Magnets technologies

L'aspetto innovativo è presente in ogni WP, le sfide tecnologiche sono molto ambiziose e qualora raggiunte l'avanzamento delle conoscenze rappresenterebbe un valore aggiunto nel campo degli acceleratori in generale. Il piano di lavoro appare molto dettagliato e articolato puntualmente per ogni WP.

ESPP- Budget since 2023
(delays due to administrative reasons)

Status @ 21 march 2024

Funds received :
HTS tape: 150 Keuro
RF: 70 Keuro

Funds spent
HTS tape: 150 kEuro
RF: 33 Keuro (co-financed new Network Analyzer)

Funds residual: 37 Keuro

Status @ 21 march 2024

Orders to be placed in 2024 :

DC test components: 20 Keuro
NC RF laboratory upgrade: 30 Keuro
Samples of different materials, coating: 30 Keuro
704 MHz/3 GHz cavities prototypes: 70 Keuro

Additional fund request in 2024 of 120 Keuro has been accepted in October 2024

ESPP- New proposal in September 2024

Breakdown rate studies of normal conducting structures operating at electric fields > 30 MV/m up to 100 MV/m embedded in magnetic fields up to 10 T (mostly with E and B fields parallel to each other) represents one of the most exciting and relevant areas in the development of new proposals for accelerating machines.

The lack of experimental data and, as a consequence, the difficulties to develop and verify theoretical models of the involved phenomena must be addressed in a short period and this requires a significant effort involving an approach that will start from material science up to accelerator related advanced technologies.

The present proposal represents a unique opportunity in the area due to the possibility to take advantage in a short period of already existing testing facilities at LNF for RF power studies and the knowledge process under development at LASA related to the design of suitable magnet structures and RF cavities.

ESPP- New proposal in September 2024

The proposal arises from a series of activities already underway for several years **both at LNF and at LASA** and for which it is necessary to make a qualitative leap in the related studies in order to continue to maintain an adequate level of leadership at a global level.

At **LNF** the development of RF structures operating in C and X band has achieved impressive results in the maximum electrical field sustained in the past years. **The possibility to test in a devoted facility these structures resulted in the acquisition of a leading role in the international panorama**.

At **LASA** the design of normal conducting cavities with frequencies ranging from 650 MHz up to 3 GHz has been carried out for different accelerator projects. The construction of full scale prototypes was carried out with Italian companies allowing the development and maintenance of adequate technologies. **The completion of testing facilities underway allows to play a valuable role in projects such as the Muon Collider or ERL related components. The study, construction and technological developments related to high filed SC magnets represent the major activity underway at LASA.**

ESPP- New proposal in September 2024

Design, specify and build (internally or commissioning to a company) a SC magnet feeded by a cryocooler and with a useful bore of 120 mm **to be used in the LNF TEX** facility for testing C and X band structures about the breakdown rate obtainable. The magnet will provide up to 4 T of magnetic field over a length of 200 mm.

Design, specify and build (commissioning to a company) **a couple of prototypes of single cells and power couplers** running at 704 MHz and 1 GHz and aimed for the Muon Collider (MC) project. These components will be tested at **low power in the RF laboratory under development at LASA within the previous ESPP funding**.

Design, specify and build (commissioning to a company) **a prototype of a full 3 RF cells element running at 704 MHz as the basic building block of the MC demonstrator structure**. Carry out low power tests at LASA and high power RF tests in a laboratory to be identified.

Design and build **a RF power coupler (up to few MW) for a 704 MHz and 1 GHz 3 RF cells structure.**

ESPP- New proposal in September 2024

Design, specify and develop **a structure able to integrate a 7 T HTS based SC magnet with a full 3 RF cells elements as a prototype of the first cooling cell of the MC demonstrator structure**.

Continue **the technological developments underway at LASA and at LNL for the best materials and surface manipulation techniques to increase the breakdown rates and start studies that using the experimental results will allow to develop suitable theoretical studies of these phenomena**.

ESPP- New proposal in September 2024

The elements described in this proposal may be considered suitable for the laboratories involved and for their ambition to play a relevant role in the accelerator international community.

The budget foreseen for the whole project is of the order of 2.0 MEuro.

ESPP- New proposal in September 2024

LNF: the activity will be mainly developed at the RF test stand (named TEX) equipped with C-band (5,7 GHz) and X band (12 GHz) power stations. The facility is manned by a dedicated team. To enlarge the scientific goal to include the study of breakdown rate of C-band and X-band accelerating structures in high solenoidal B-field the team requires at least **a reinforcement of 1 FTE with the profile of an RF engineer.**

LASA: in order to continue and advance in the ongoing activities and in others such as those described here, **the laboratory requires to resume a basic service structure similar to what it had at the time of its establishment** (and which has been eroded over the years for various reasons that have also prevented its reconstitution). This structure shall include: mechanical design service: 2 people; workshop service: 2 people; experiment assistance service (mechanical, electrical and electronic): 3 people; plant engineering: 2 people

From the point of view of the researchers and technologists involved it is believed that **at least 3 figures are necessary** to give perspective to the laboratory.