2nd **Annual Meeting**, Trieste April 20 - 2023

MUon collider STrategy network - MUST

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

Task 5.1

.... It will serve as the common ground for a
growing international muon-collider collaboration

MUST *will support to establish an* ***international collaboration*** *and develop an* ***optimized R&D roadmap*** *towards a future muon collider, including the definition of* ***optimum test facilities and possible intermediate steps***

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Task structure and objectives

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)

ESPPU

[..] an ***international design study*** *for a* ***muon collider***
unique opportunity *to achieve a multi-TeV energy domain*

MUST can play a crucial role

- **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**

International Muon Collider Collaboration
established soon after EPSSU in July 2020

Key Challenges of the facility

- **Focus on two energy ranges:**

– **3 TeV** technology ready for construction in 10-20 years

– **10+ TeV** with more advanced technology

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

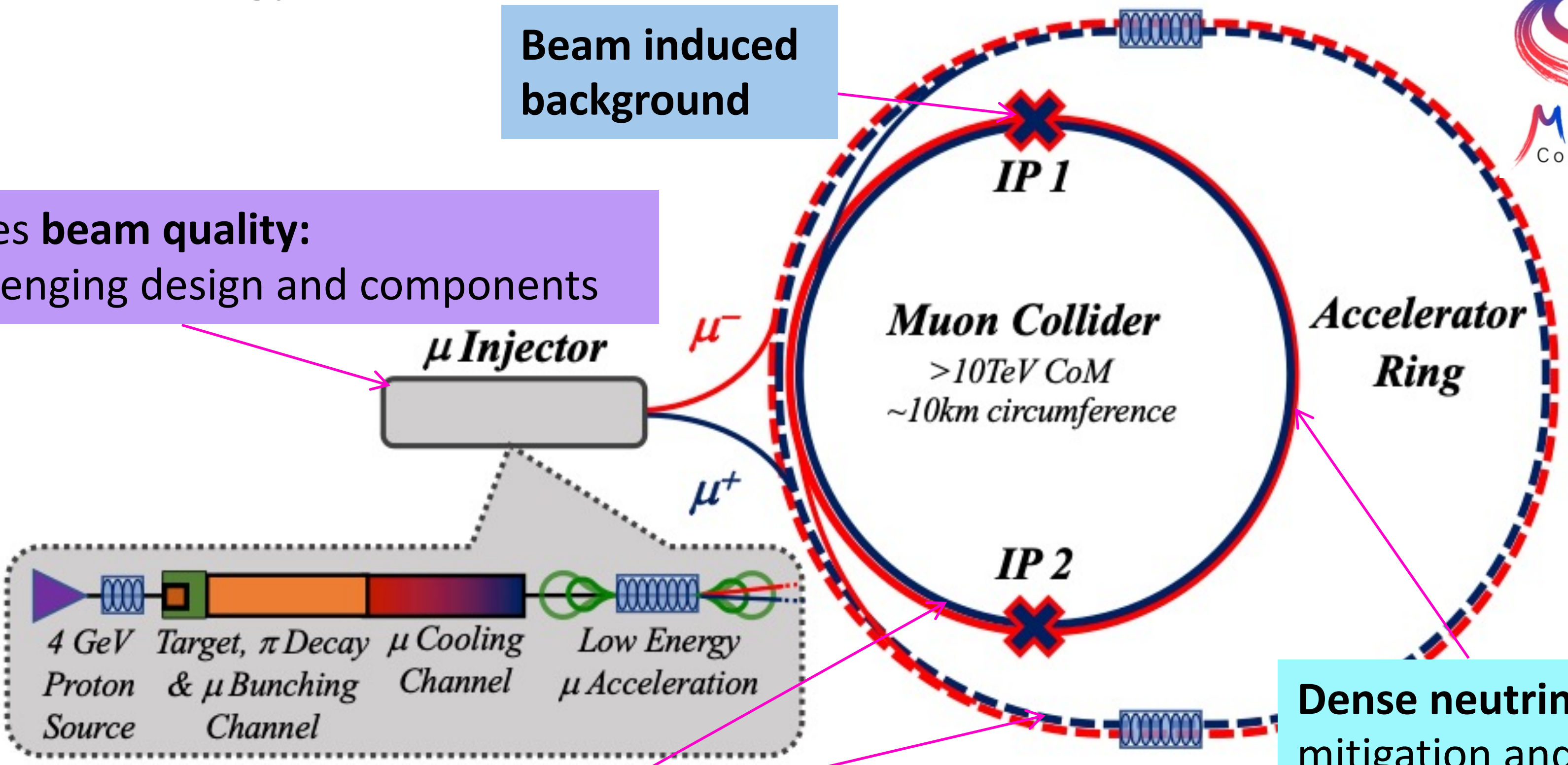
10+ TeV completely new regime to explore!

Proton driver production
Baseline @ International Design Study

International MUON Collider Collaboration

Beam induced background

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



Dense neutrino flux mitigation and site

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

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

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Accelerator Key Challenge Areas

- **Physics potential** evaluation, including **detector concept and technologies**

- Impact on the environment
  - The **neutrino flux mitigation** and its impact on the site (first concept exists)
  - The **machine induced background** impact the detector, and might limit the 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 (cooling cell engineering design, demonstrator design)

- **Full accelerator chain**
  - e.g. proton complex with H- source, compressor ring ➔ test of target material

> - Some technology challenges more important at 10 than at 3 TeV
>   - higher dipoles fields in collider (O(15 T))
>   - stronger final focus quadrupoles (O(18-20 T))
>   - shorter bunches in cavities of last accelerator ring
>   - more performant accelerator ring systems to cut length and cost

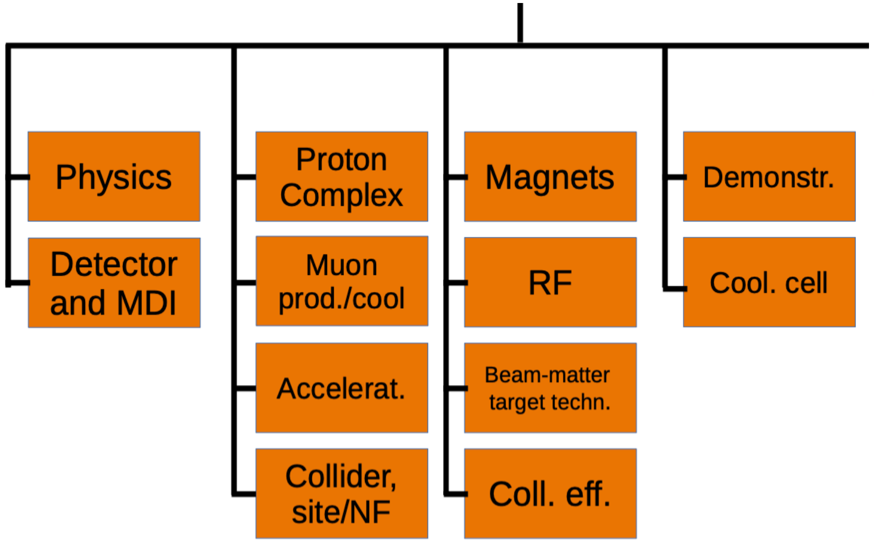
Roadmap implementation

The panel has identified a development path that can address the major challenges and deliver a 3 TeV muon collider by 2045

http://arxiv.org/abs/2201.07895

Scenarios

Aspirational		Minimal	
[FTEy]	[MCHF]	[FTEy]	[MCHF]
446	12	193	2.5
65 MCHF/5 years		27 MCHF/5 years	



International MUON Collider Collaboration

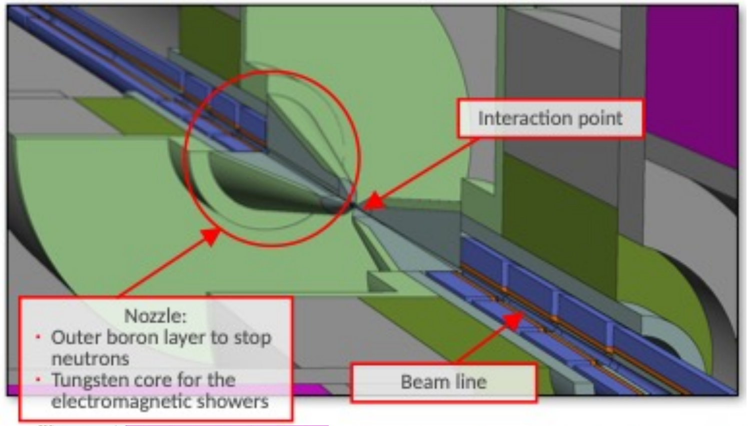
Label	Begin	End	Description	Aspirational [FTEy]	Aspirational [kCHF]	Minimal [FTEy]	Minimal [kCHF]
MC.SITE	2021	2025	Site and layout	15.5	300	13.5	300
MC.NF	2022	2026	Neutrino flux mitigation system	22.5	250	0	0
MC.MDI	2021	2025	Machine-detector interface	15	0	15	0
MC.ACC.CR	2022	2025	Collider ring	10	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

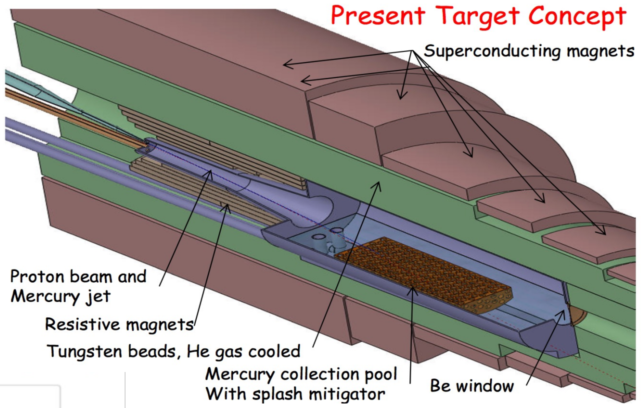
Table 5.5: The resource requirements for the two scenarios. The personnel estimate is given in full-time equivalent years and the material in kCHF. It should be noted that the personnel contains a significant number of PhD students. Material budgets do not include budget for travel, personal IT equipment and similar costs. Colours are included for comparison with the resource profile Fig. 5.7.

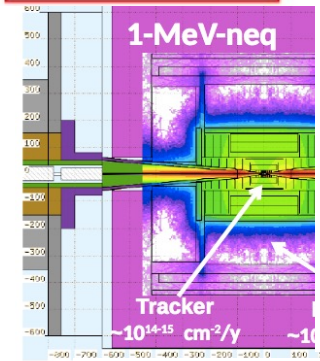
Summary of activities

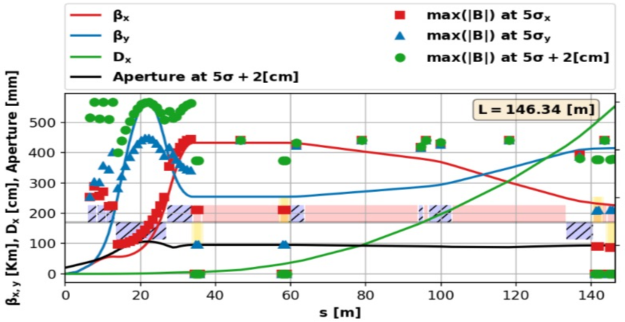
➔**Each Machine component WP is working to identify challenges and R&D plans:**

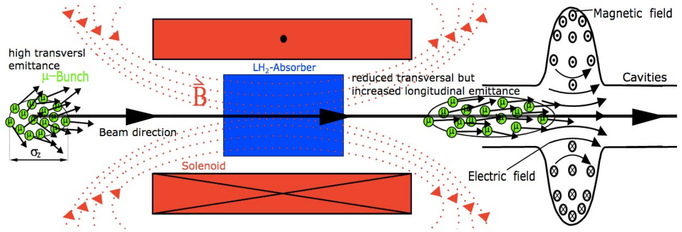
- Physics and MDI
- Proton complex
- Target design
- Muon Cooling
- Accelerator Complex
- Collider Ring
- RF Technology
- Magnet Technology
- Cooling cell integration
- Demonstrator

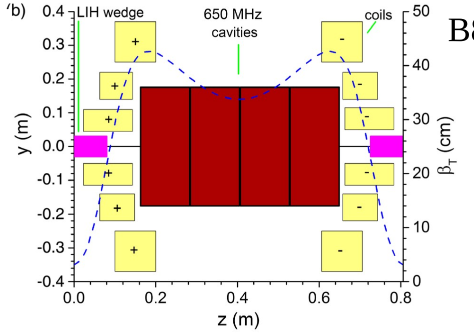












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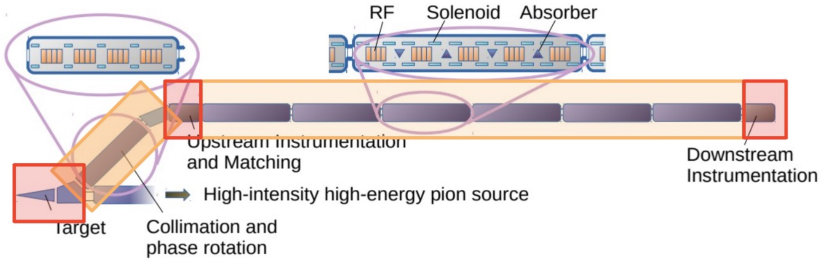

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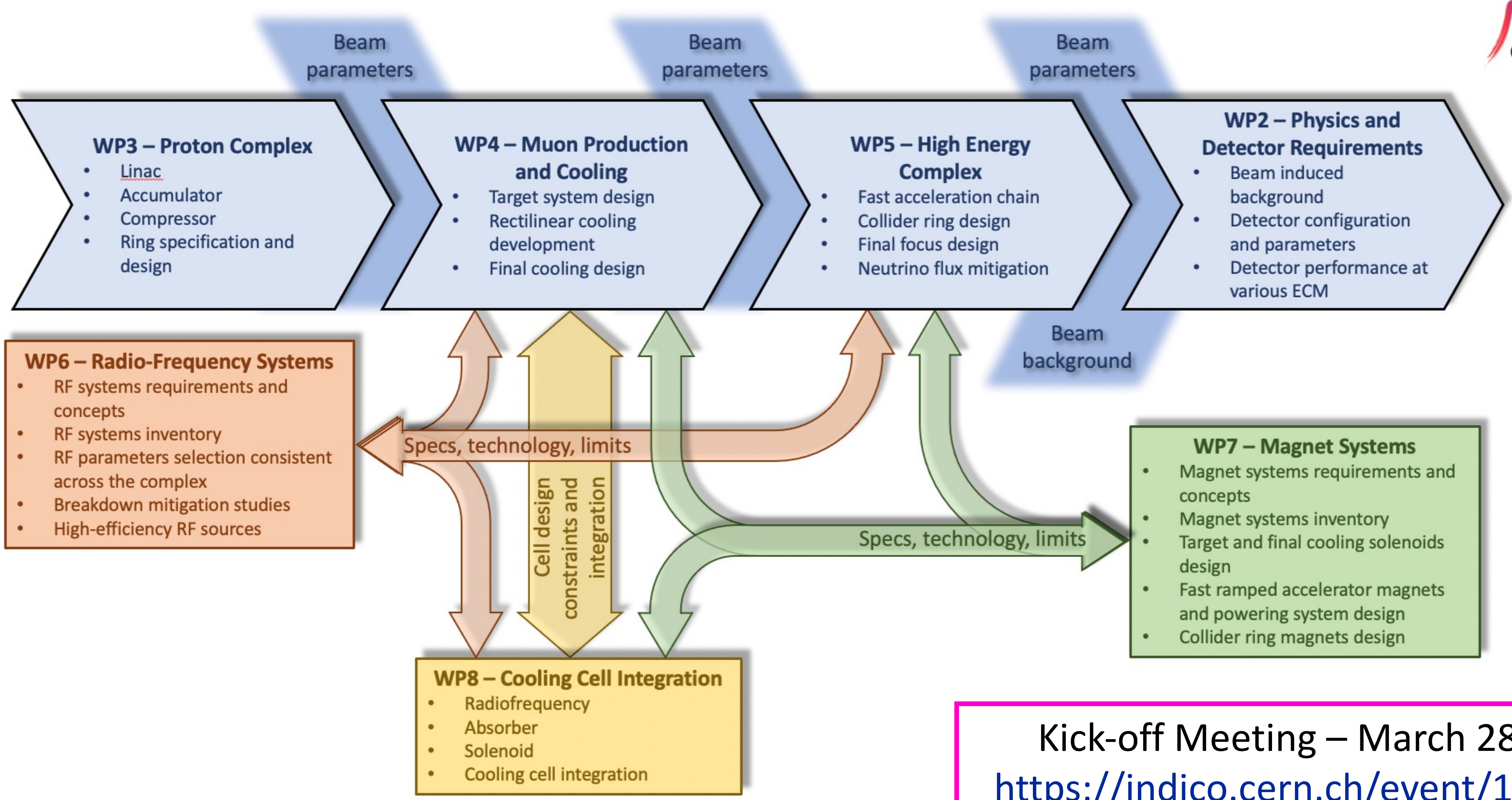
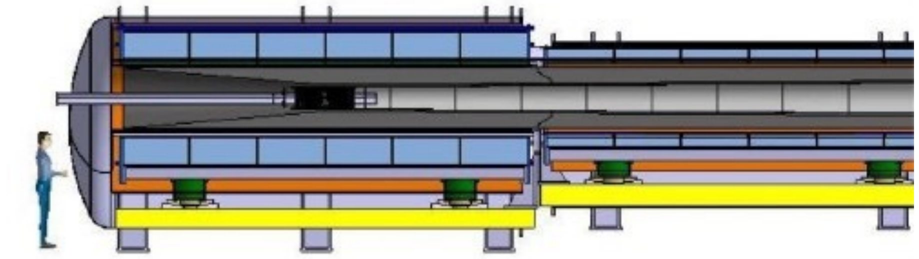
MuCol EU INFRA-DEV project



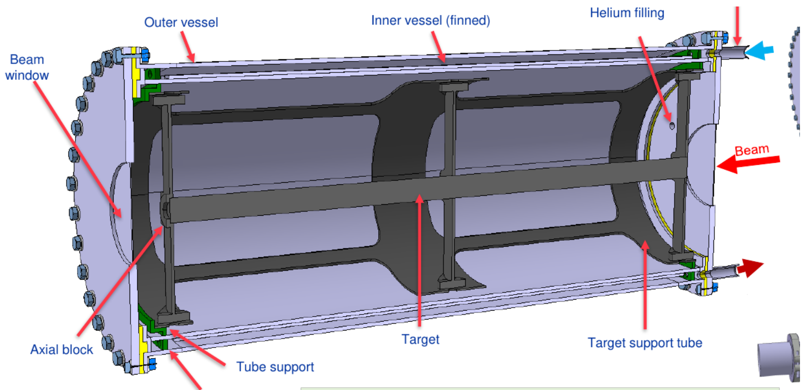
Kick-off Meeting – March 28 2023
https://indico.cern.ch/event/1219912/

Target and Cooling cell

- Baseline: solid graphite target
  Protons → π → μ
  ~15-20 T solenoid field to capture pions
  High radiation environment
  Challenges with target damage
  Challenge to shield the solenoid



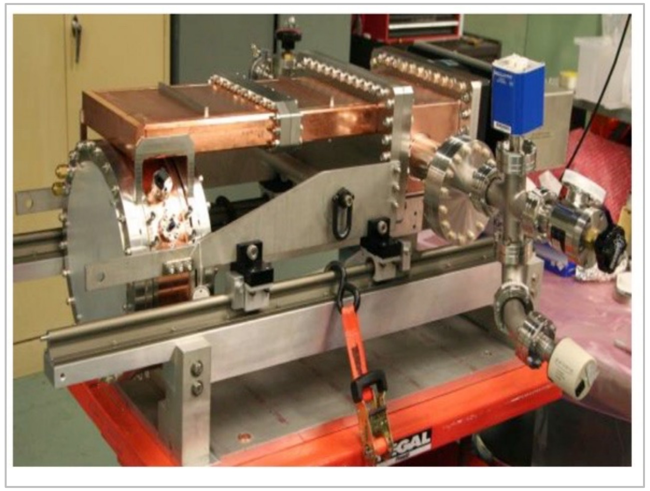
The muon source is a key part of the muon collider facility
In many parts, the system is entirely novel system

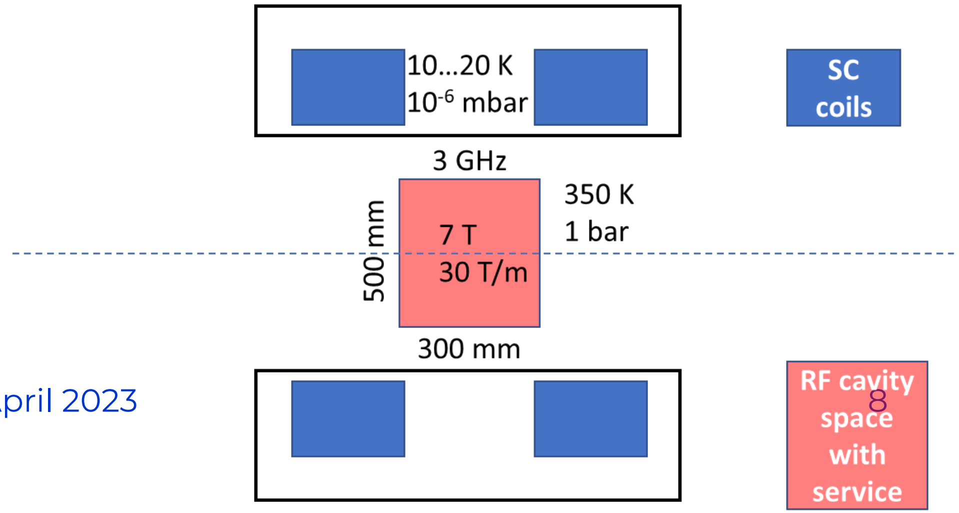


Schematic of the RFMF test facility

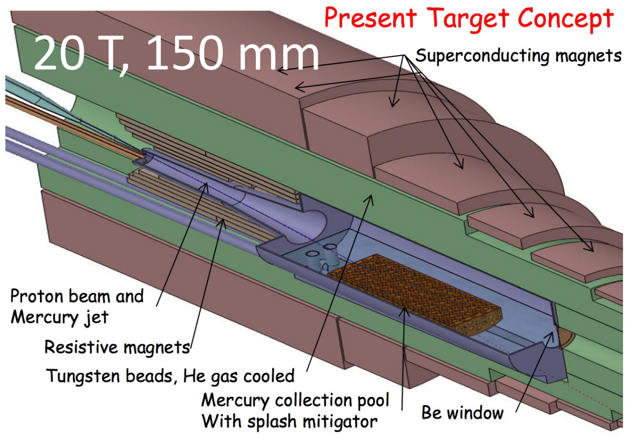
MuCool: demonstrated cavity with >50 MV/m in 5 T solenoid

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

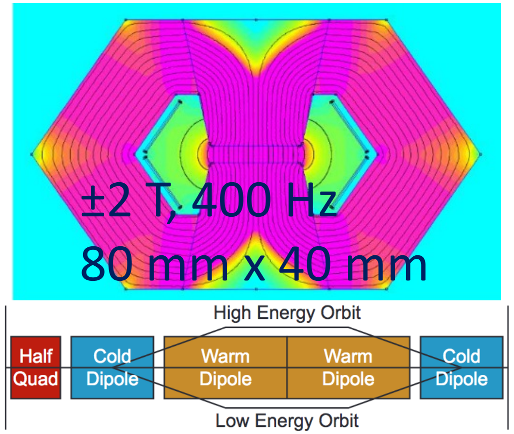




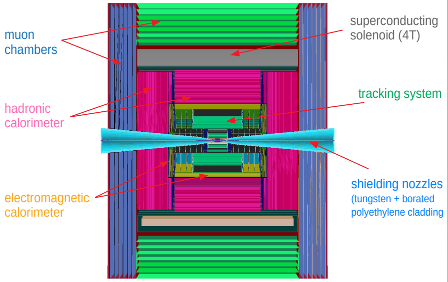
Magnets for Muon Collider



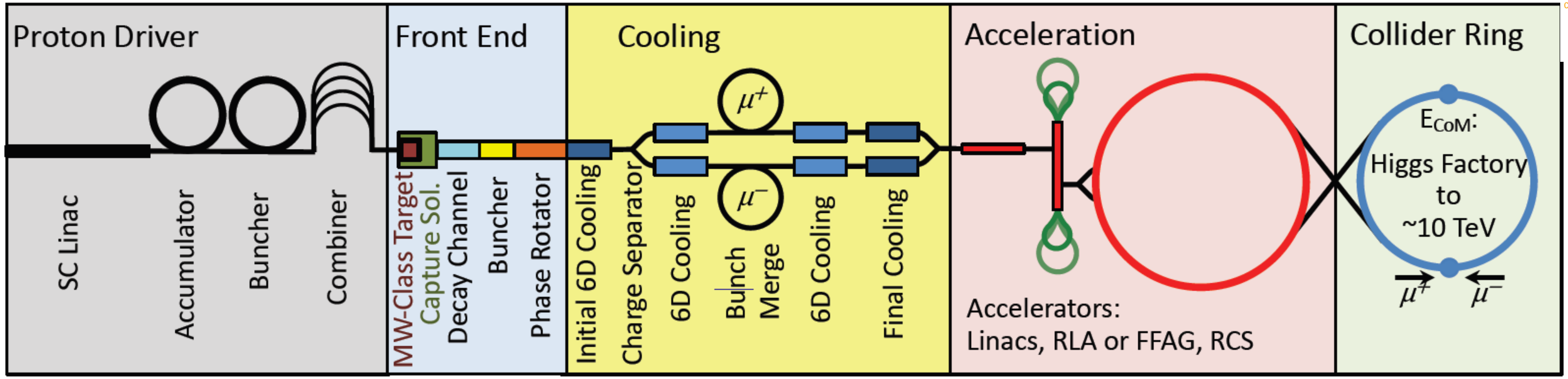
High-field and large aperture target solenoid with heavy shielding to withstand heat (100 kW/m) and radiation loads



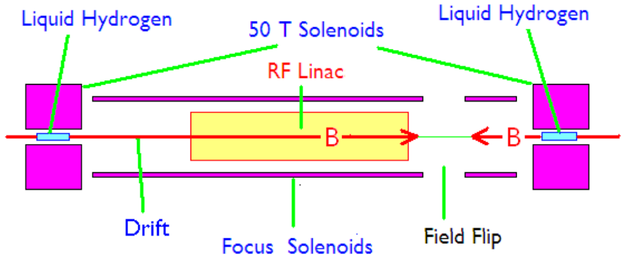
Combination of DC SC magnets (10 T) and AC resistive magnets (± 2T)



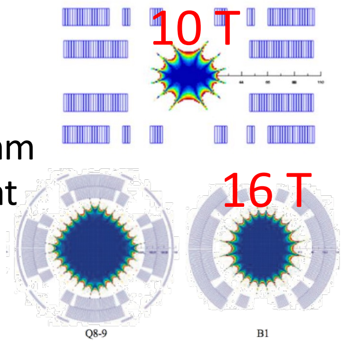
Detector Magnet to be designed for 10TeV



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



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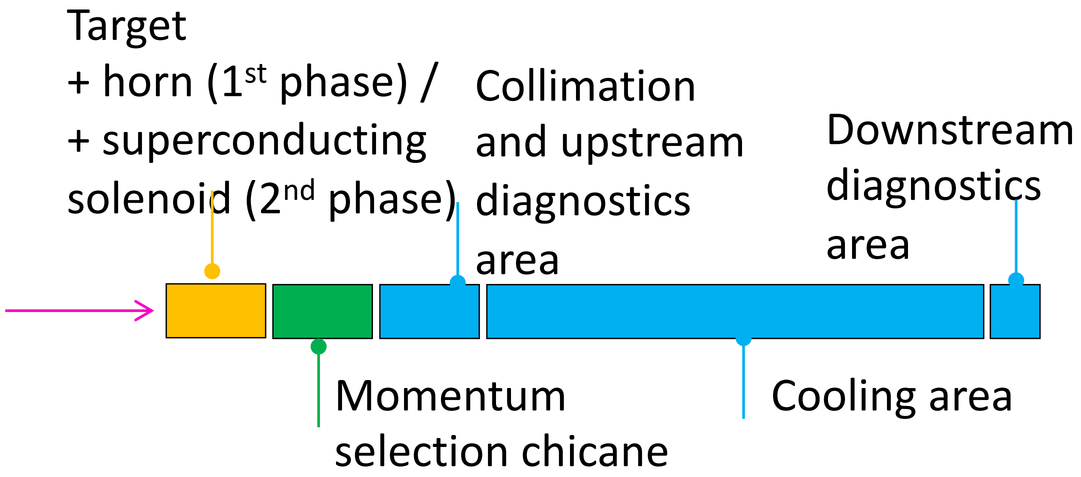
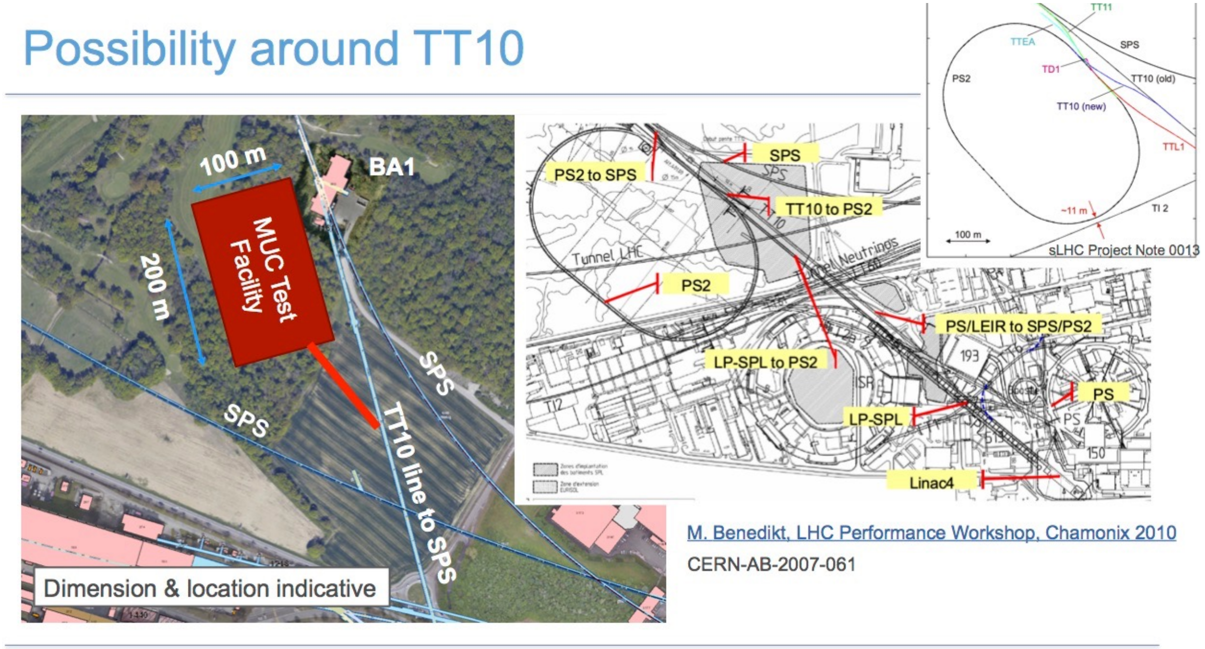
Demonstrator facility is the crucial step!

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

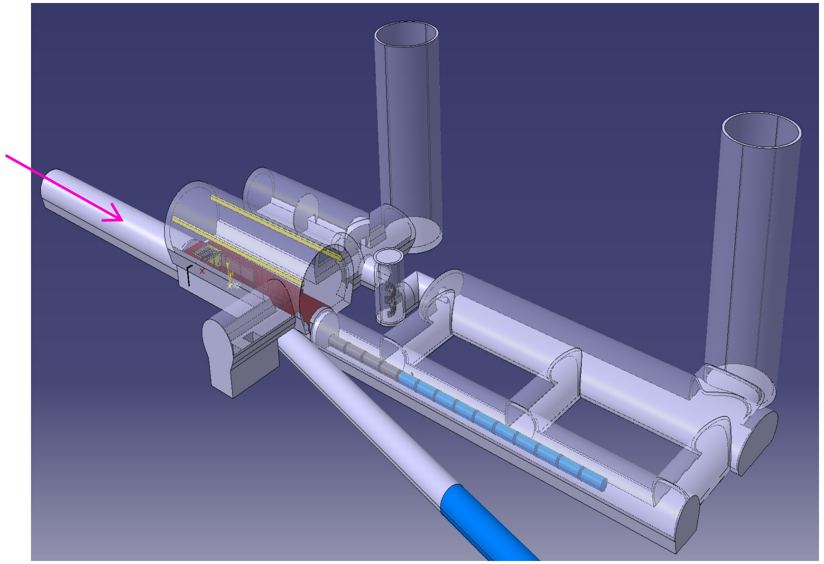
Suitable **site exists** on CERN land and can use **PS proton beam**
- could combine with **NuStorm** or other option

Any existing proton beam with significant power is considered:
- CERN, FNAL, ESS are being discussed
- J-PARC also interesting as option





@ CERN



Summary of main activities

→ **CERN** designed **first lattice at the 10 TeV centre of mass energy:** detailed IR-detector studies (**CERN/INFN**)

Machine Detector Interface (MDI) to estimate Beam Induced Background (BIB) is one of the main challenges

→ **RF and magnet technology plans are on-going**

→ **Integration of a cooling cell: a crucial step for RF and high field solenoidal magnet developments**

→ **Planning for a demonstrator is mandatory**

→ Large contributions to the U.S. Snowmass2021 Strategy process in the Muon Collider Forum:

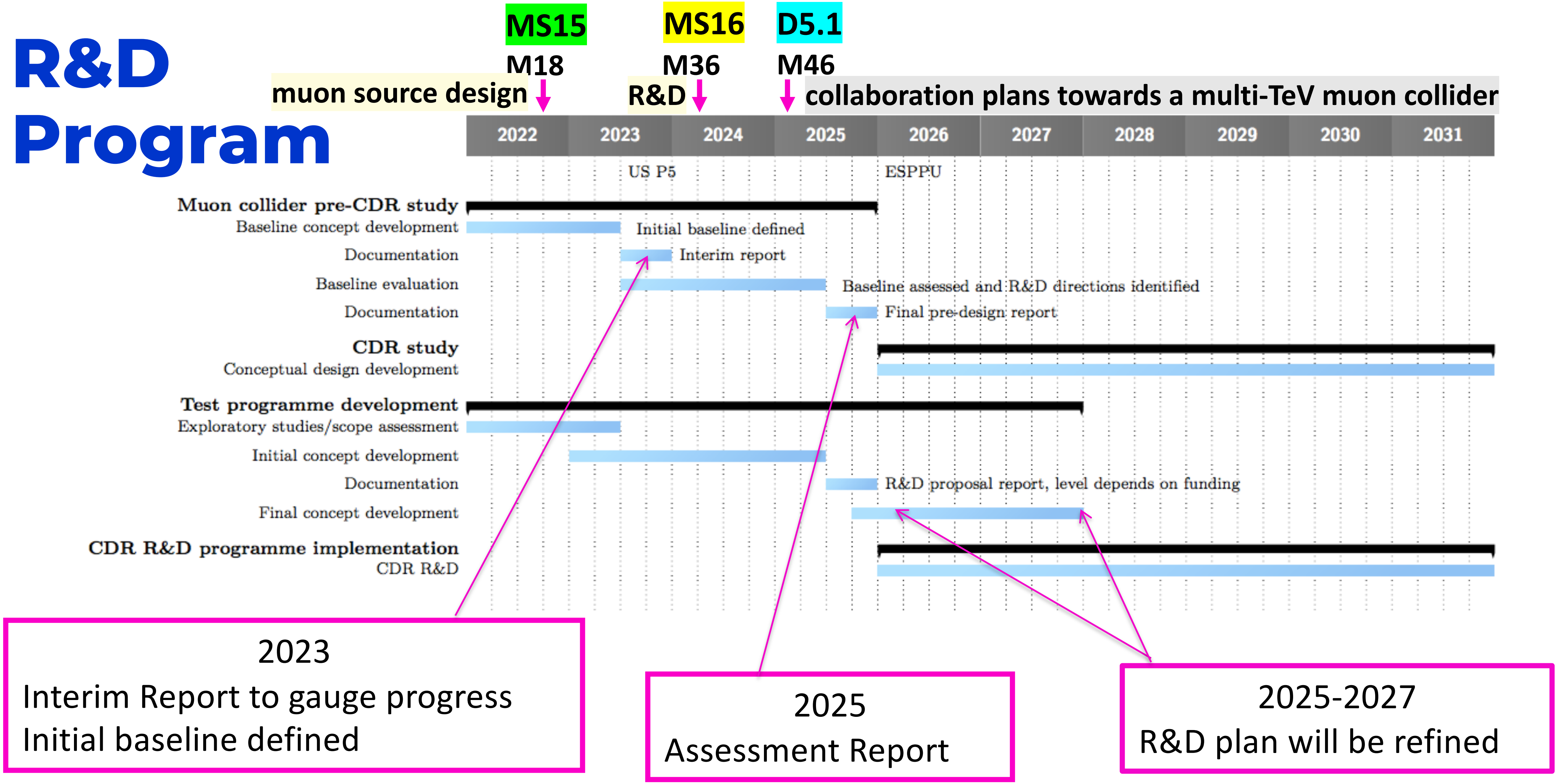
documents presented in March 2022, discussed at the Seattle Snowmass Summer Meeting (July 17-26, 2022)

→ **EPJC paper submitted** **Towards a Muon Collider**

→ the HORIZON-INFRA-2022-DEV-01 **MuCol project started March 1, 2023**

→ **P5 U.S. Strategy process on-going: further discussions and presentation at the Town Hall meetings**

R&D Program


MS15
M18
muon source design
MS16
M36
R&D
D5.1
M46
collaboration plans towards a multi-TeV muon collider
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
US P5
ESPPU
Muon collider pre-CDR study
Baseline concept development
Initial baseline defined
Documentation
Interim report
Baseline evaluation
Baseline assessed and R&D directions identified
Documentation
Final pre-design report
CDR study
Conceptual design development
Test programme development
Exploratory studies/scope assessment
Initial concept development
Documentation
R&D proposal report, level depends on funding
Final concept development
CDR R&D programme implementation
CDR R&D
2023
Interim Report to gauge progress
Initial baseline defined
2025
Assessment Report
2025-2027
R&D plan will be refined

Upcoming community events

29-31 May 2023 Venezia Muon4Future

https://agenda.infn.it/event/33270/

Workshop to start a discussion to compare results of the muon-based experiments, involving both the experimental and theoretical communities, but also applications, technologies and synergies for future facilities.

19-22 June 2023 IJCLAB Orsay 2nd Annual IMCC Meeting

https://indico.cern.ch/event/1250075/

Annual Meeting to report on the progress of the Design Study and consolidate the share of tasks among all Collaborators, including the activities within the scope of the EU-funded MuCol Design Study.

22-23 June 2023 IJCLAB Orsay Muon Collider Synergies Workshop

Please join, participate and contribute!

Looking forwards to synergies in R&D

Thanks for your attention!

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Horizon 2020 Research and Innovation programme under GA No101004730