International MUON Collider Collaboration

CERN

Test Facility Session Summary

Roberto Losito
CERN-ATS-DO

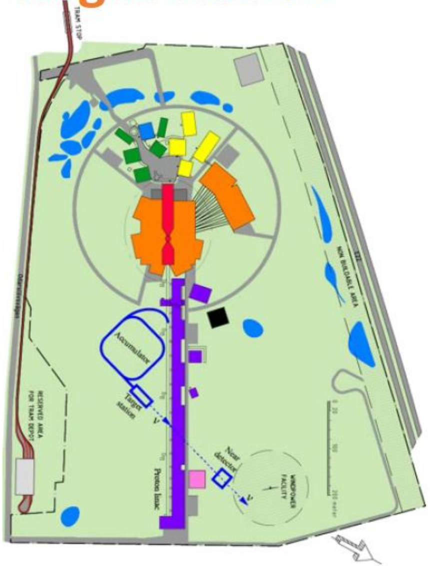
2nd Community meeting of the International Muon Colliders Design Study – 12-14 May 2021

- 2 facilities discussed
  - ESS proposing the design study of a compressor associated to the ESSnuSB Study
    - The ESSnuSB study already ecompasses an accumulator ring, shortening the pulse down to ~1 μsec. Need to add a compressor to reach ~2 nsec
    - Goal would be to test a target station at $10^{14} \div 10^{15}$ ppp.
  - A Cooling test facility to be built at CERN

International MUON Collider Collaboration

ESS NEUTRINO SUPER BEAM

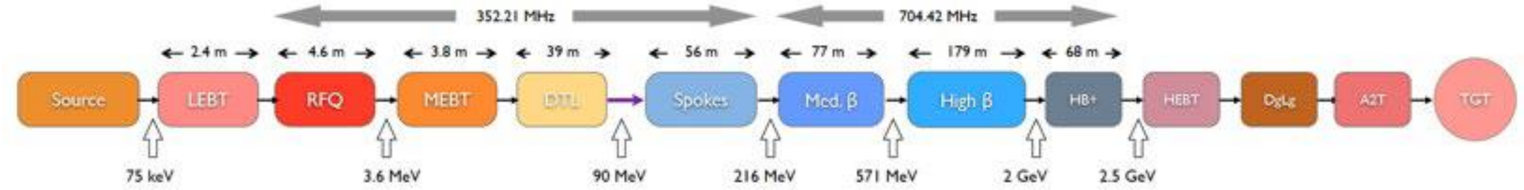
Proposal for a design study of a test facility for the Muon Collider Proton Complex based on the ESS linac and the ESSnuSB accumulator and target station

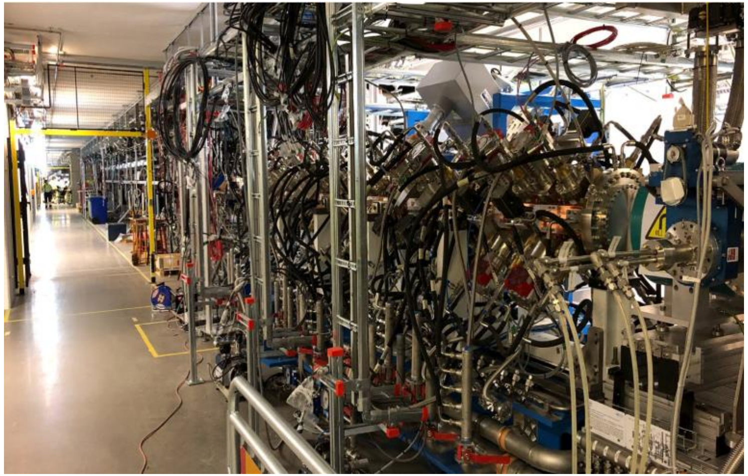


Tord Ekelof Uppsala University

The ESS linac

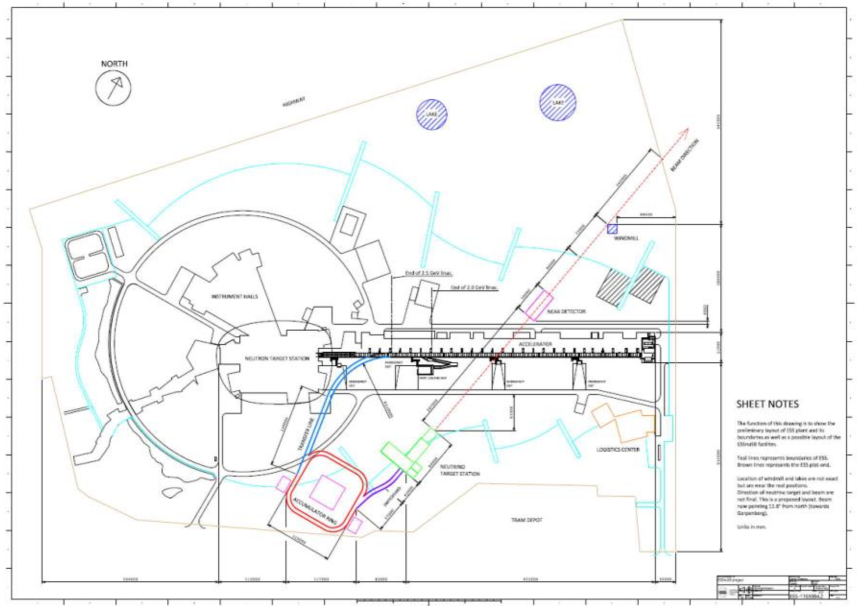
The ESS linac, currently under construction in Lund in Sweden, has as design parameters 2 GeV, 5 MW, 14 Hz and 10^{15} protons per pulse, which are similar to those of the SPL and also of the current design parameters for the Muon Collider.

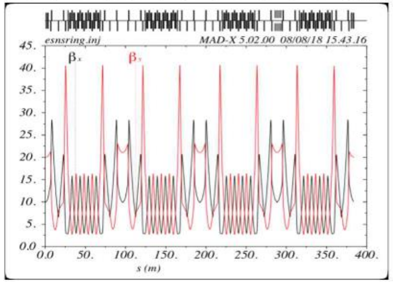


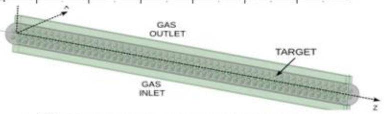


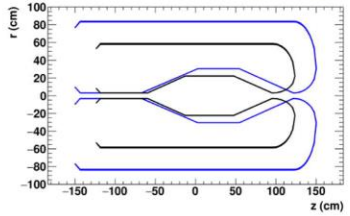
The ESSnuSB Accumulator Ring and Target Station

The EU design study includes an accumulator ring, into which the 4 chopped H- pulses shall be injected In sequence. Each of the four 1.3 µs proton bunches of 2.5×10^{14} protons extracted in sequence from the accumulator shall be guided to one of four laterally separated granular Titanium He-cooled targets, each surrounded by a focussing horn. The Conceptual Design Report of this 4-years Design Study is currently being finalized and will be published in January 2022.





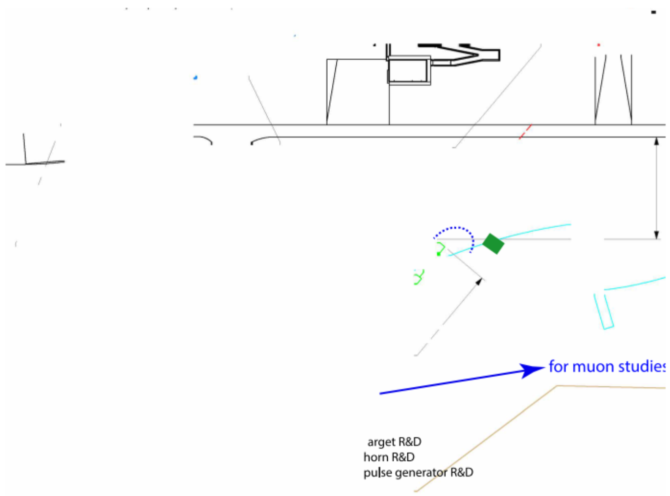




Complementary Design Study of Muon Collider Proton-Complex Test-Facility

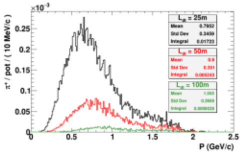
It is proposed that during the next period 2022-2025 of the Design Study, the study be enlarged in scope to include also how the already studied design of the upgrade of the ESS linac, the design of the accumulator ring and the design of the target station can be widened to encompass also the requirements of the Muon Collider.

This implies the conceptual study of, inter alia, an alternative chopping scheme for the linac, of the accumulator acceptance, rf system, timing and optics, of a design from scratch of a compressor/bunch rotation ring and of a separate target station with a target and capture system (horn or solenoid) that can stand the ns-long bunches of 10^{15} protons, using the ESSnuSB 2.5×10^{14} protons/ 1.3 µs/1.25 MW target design as staring point. Design is stages possible, i.e. fist making a 10^{15} protons/ 1.3 µs/5 MW target design.

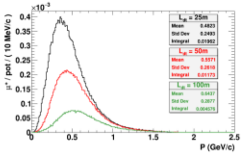


Accumulator ring to be complemented with a Compressor ring

Pion momentum distribution in a 4m x 4m aperture



Muon momentum distribution in a 4m x 4m aperture



Proposal for a EU Horizon Europe Design Study 2022-2025

We are planning to submit in Spring 2022 a proposal to EU Horizon Europe for a Design Study of features of the ESSnuSB design not yet studied during 2019-2021, like the civil engineering, licensing and safety required at the ESS and Far Detectors sites, preparation of the ESSnuSB R&D phase and a conceptual design study of a 0.5 GeV nuSTORM race track ring for low energy neutrino cross-section measurements with the aim to deliver an Technical Proposal in 2025.

The plan would be to include resources in the requested budget for a conceptual design study of the Muon Collider proton-complex test-facility described above.

HORIZON-INFRA-2022-DEV01

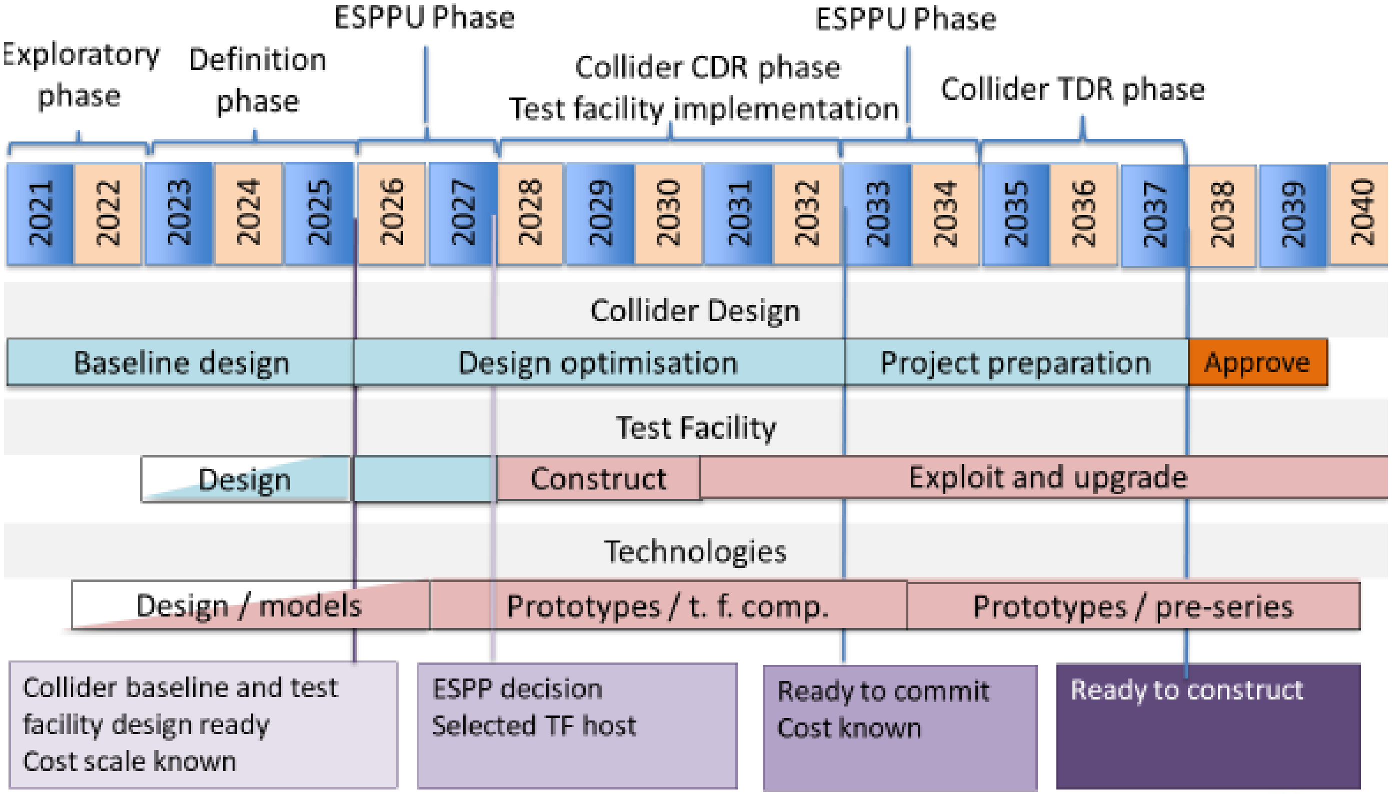
Developing European Research Infrastructures to maintain global leadership

Deadline: **24 March 2022**

Topics	Type of Action	Budgets (EUR million)	Expected EU contribution per project (EUR million)	Number of projects expected to be funded
		2022		
Opening: 10 Nov 2021 Deadline(s): 24 Mar 2022				
HORIZON-INFRA-2022-DEV-01-01	RIA	24.00	1.00 to 3.00	10
Overall indicative budget		24.00		

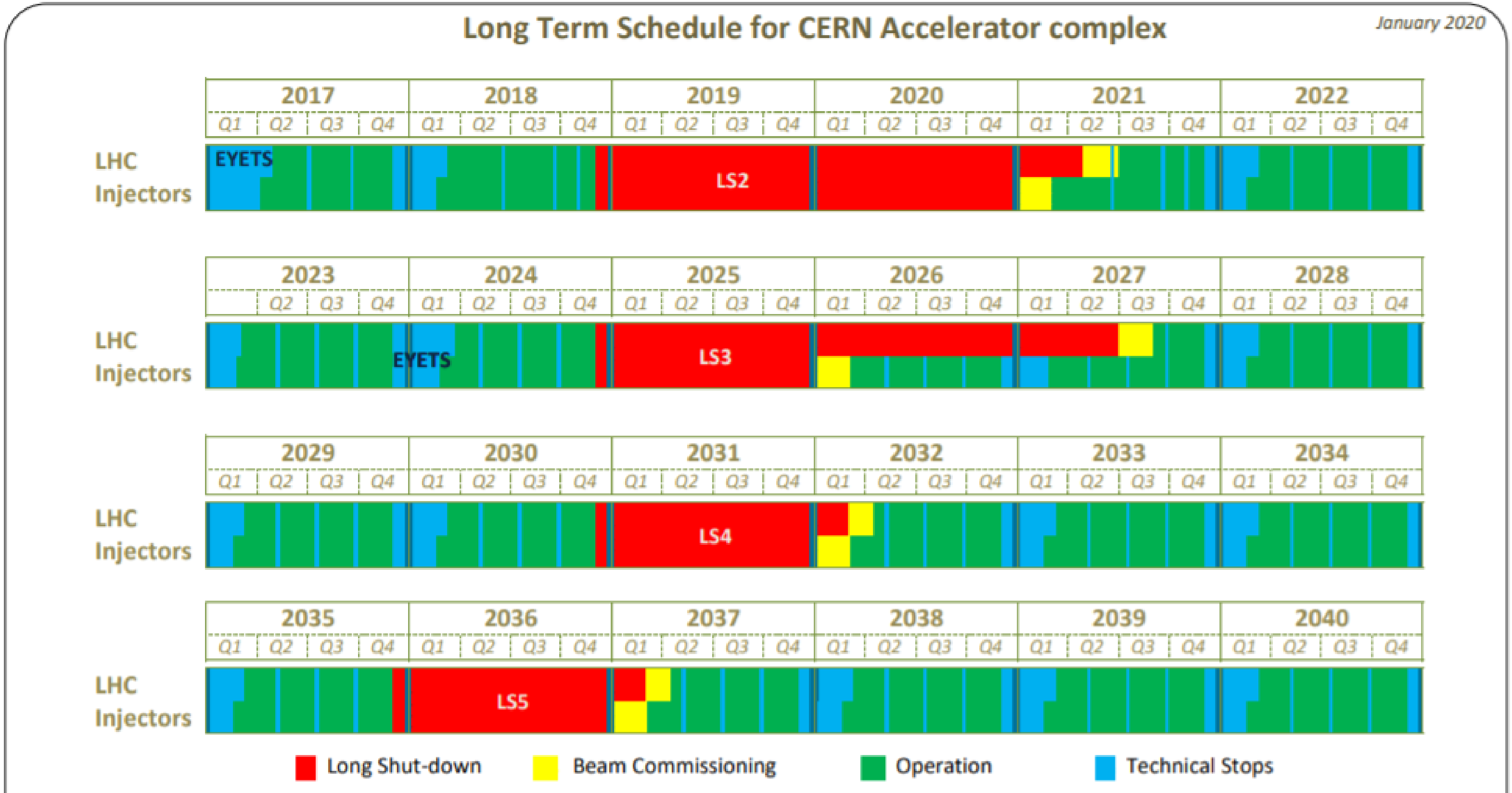
CERN FACILITY

Technically Limited Long-Term Timeline

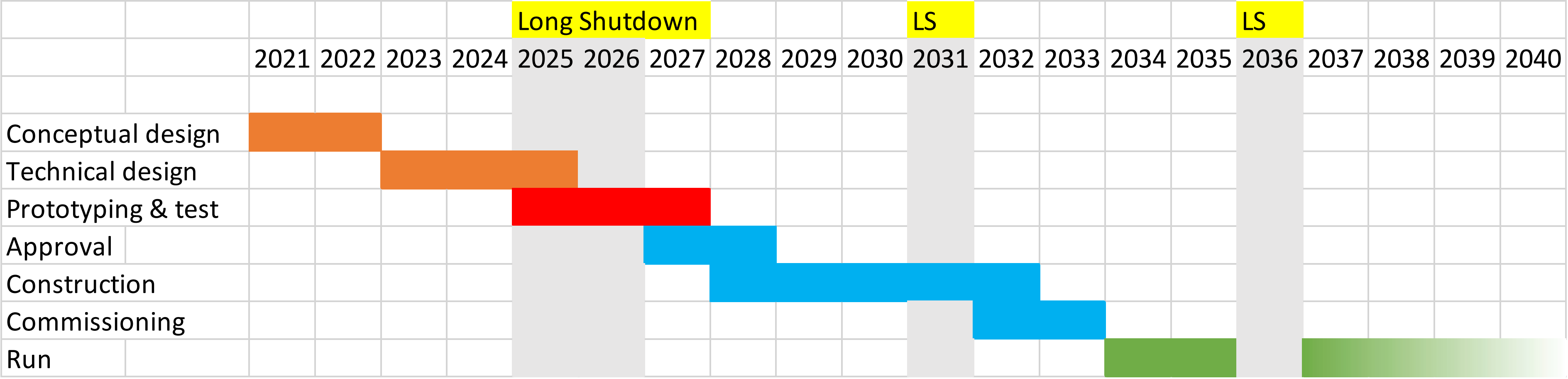


EDMS No.	REV.	VALIDITY
2311633	1.0	RELEASED

REFERENCE
ACC-PM-MS-0004



Proposed Workpackage Timeline (test Facility at CERN)



Proposed Workpackage Description (2021-2025)

- **A beam test facility is key to demonstrate items of critical importance to achieve the required luminosity in the Muon Collider, namely, 6D cooling, the integrated engineering of the cooling cells.**

- **The workpackage deliverable will the design and cost estimate of a test Facility including:**
  - Muon production and capture, including collimation and momentum selection at a level of at least 10^6 muons per pulse
  - 6D cooling based on HFOFO rectilinear cooling, including full conceptual engineering design of the cell.
  - Study eventual alternative cooling schemes as defined by the Muon Production and Cooling working group
  - Coordinate the site dependent studies, entirely funded by each interested laboratory, in order to provide a full cost estimate for a given test facility
  - Collaborate with the other working groups to establish a list of ancillary test facilities (e.g. high power targets, RF, magnets, Proton Beam preparation etc…) in order to avoid duplication of efforts and ensure optimal use of resources.
  - The muon production working group will be asked to assess whether one can use in a first stage a horn instead of a Superconducting solenoid in order to reduce cost.
  - Synergy with other facilities/experiments to be investigated

Proposed Workpackage Tasks

- **Simulations & Engineering design**
  - Proton beam preparation and evolution (Accumulator, compressor, mainly connection to Proton Complex WG)
  - Extraction and transfer line
  - Infrastructure (civil Engineering and services)
  - *Muon production (target+horn)*
  - *RP, Remote handling, waste management, environmental impact (if necessary).*
  - *Momentum selection, collimation & proton beam dump*
  - Cooling based on schemes developed by the cooling, RF and Magnet WG
  - Beam Instrumentation
  - Synergy (ESS, NuStorm, Enubet…)

Proposed Workpackage Resources for CDR/TDR

Task	Staff [pm]	postdoc [pm]	student [pm]	Cash [kEUR]	Comment
Proton beam preparation	-	-	-	-	Funded and coordinated by proton Complex WG
Extraction and transfer line					Funded (and coordinated) by CERN
Civil Engineering & Infrastructure					Funded and coordinated by CERN
Muon Production					
RP, Remote handling, waste management, environmental impact (if necessary).					Funded and coordinated by CERN
Momentum selection, collimation & proton beam dump					
Cooling					
Beam Instrumentation					
Synergy					Funded by CERN and Synergic experiments/facilities.

Chiara Bracco, CERN

International MUON Collider Collaboration

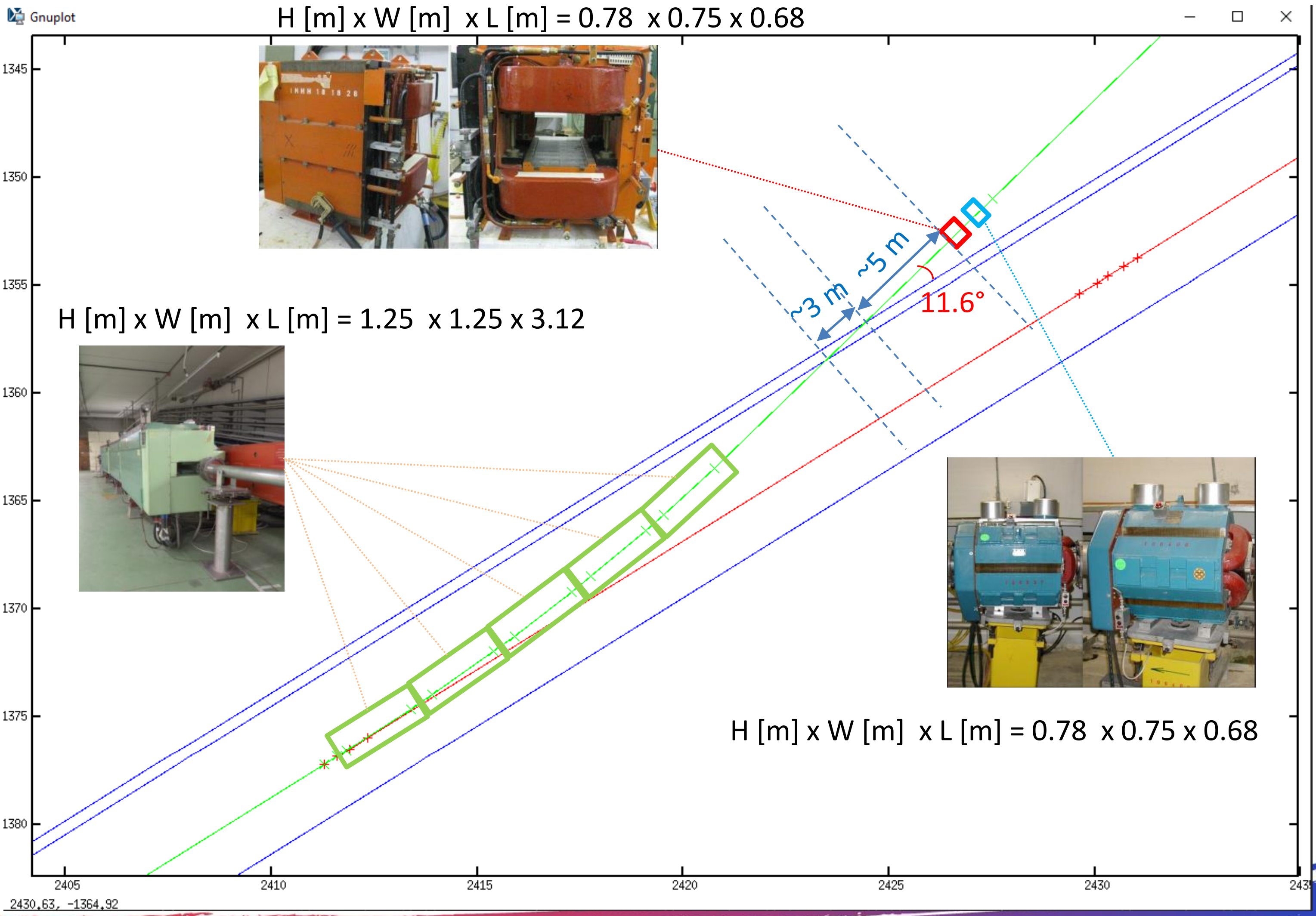
TT10 Branching

TT10: Transfer line from PS to SPS

First question: left or right?

The need of a junction cavern for this branching would constraint CE works to LS

Any way to avoid digging a junction cavern? ➔ have a as sharp as possible angle between line and tunnel walls!



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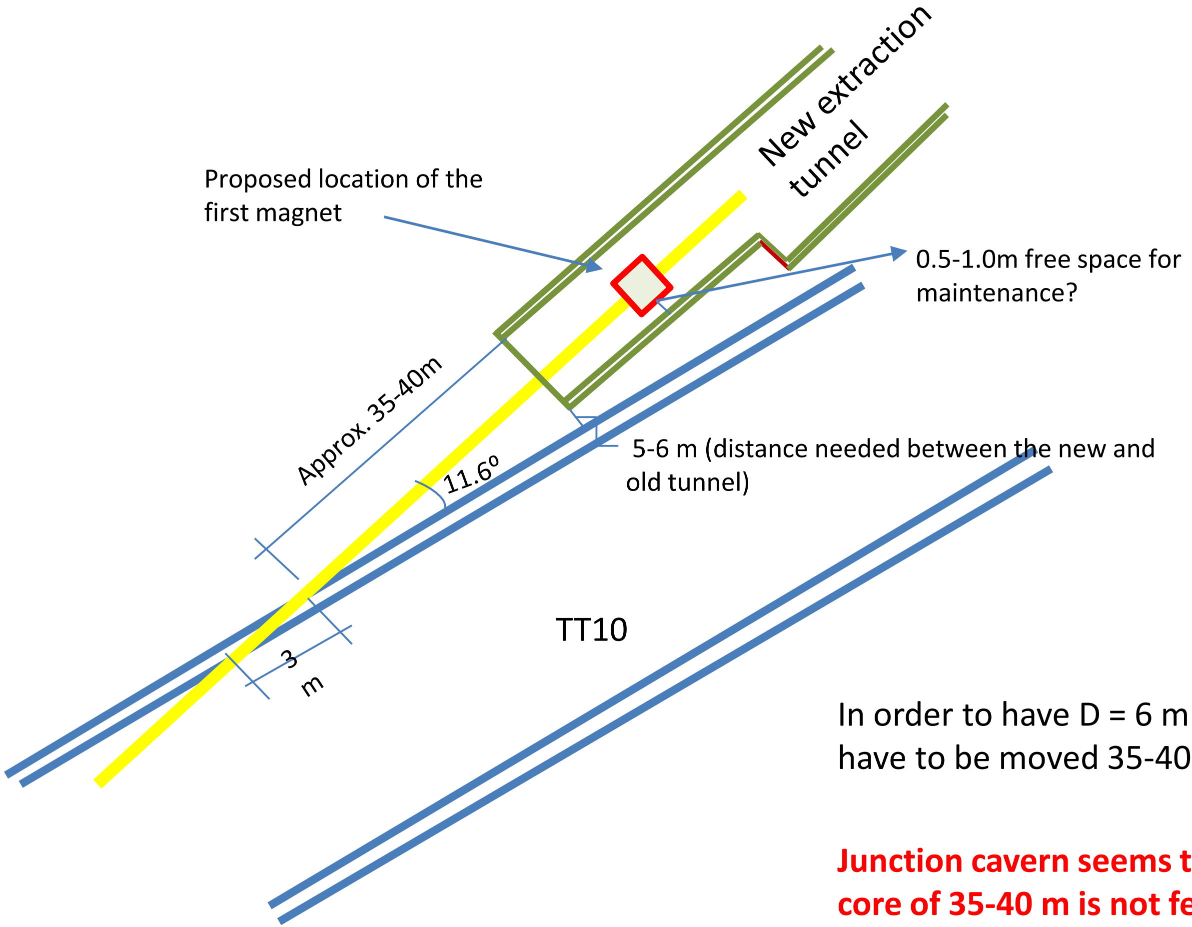
Courtesy of K. Balazs

In order to allow the structural integrity of the existing and new tunnel we would need to keep a certain distance between the two. This distance it is marked with "D", in our case the TT10 being 4 m wide that would mean approximately 5-6m distance between the two tunnels in the first 10-15 m, but in order to confirm we need to do a proper alignment drawing to see the exact dimensions.

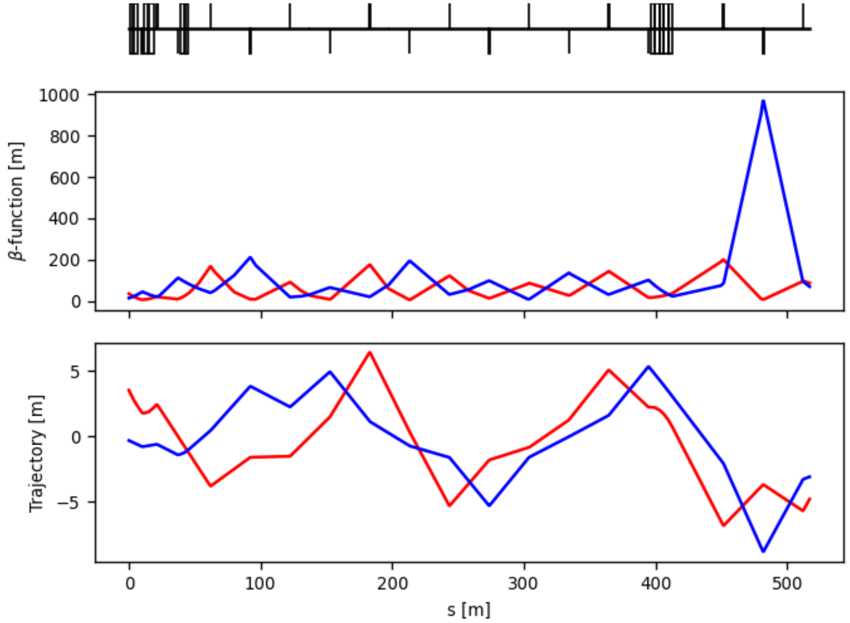


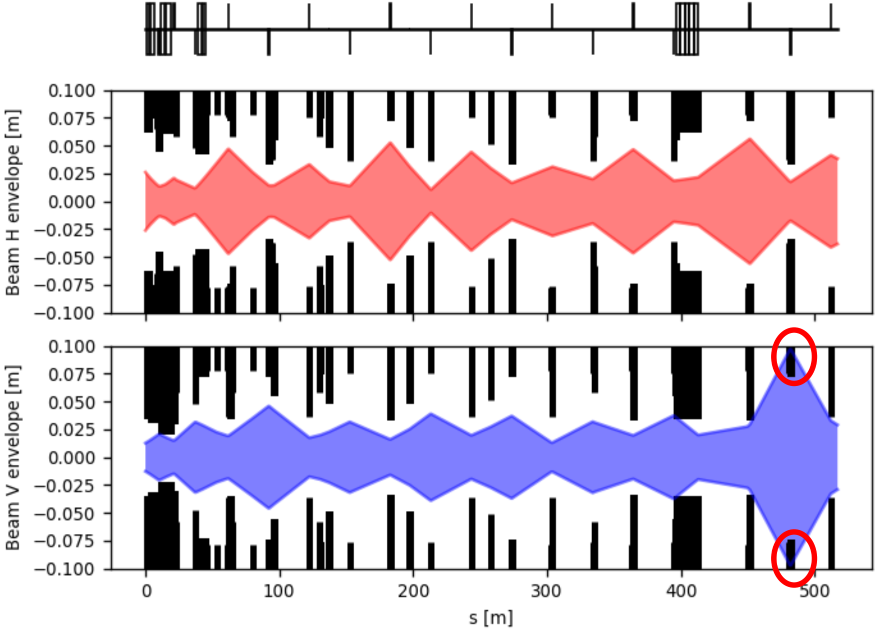
In order to have D = 6 m the corrector+quadrupole magnets have to be moved 35-40 m more downstream

Junction cavern seems to be needed since also drilling a core of 35-40 m is not feasible

First glance at optics and Aperture

Moving Corrector+Quadrupole 25 m more downstream ➔ already out of aperture





Layout

Rui Franqueira Ximenes, CERN

Layout components of the Demonstrator:

- Target & Horn (first stage) and potentially superconducting solenoid at a later stage
- Momentum selection chicane
- Collimation & diagnostics area
- Muon Cooling area
- Downstream diagnostics area

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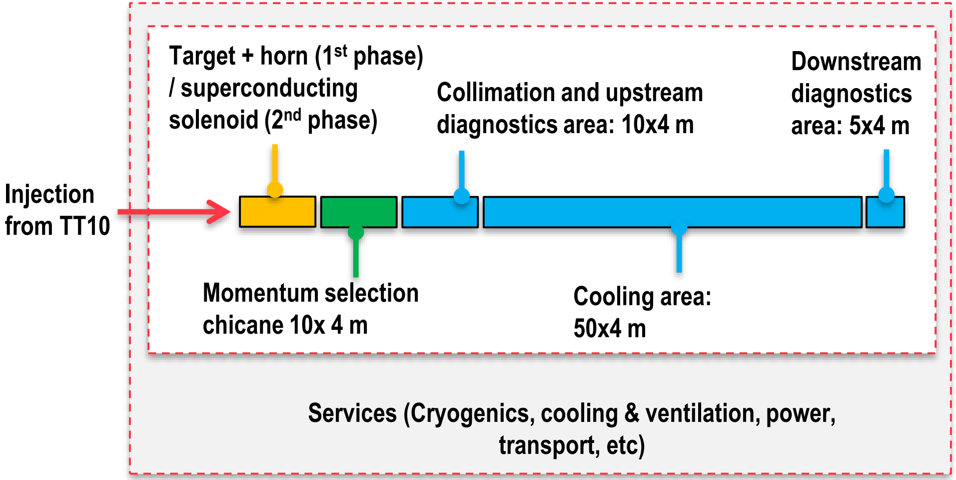
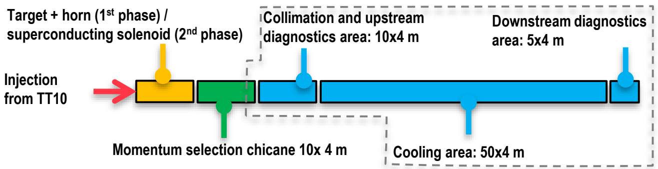
- Service areas (Cooling & ventilation, cryogenics, power, transport, etc…)
- Radioactive storage
- *Branch to other experiments* ?
- … other??

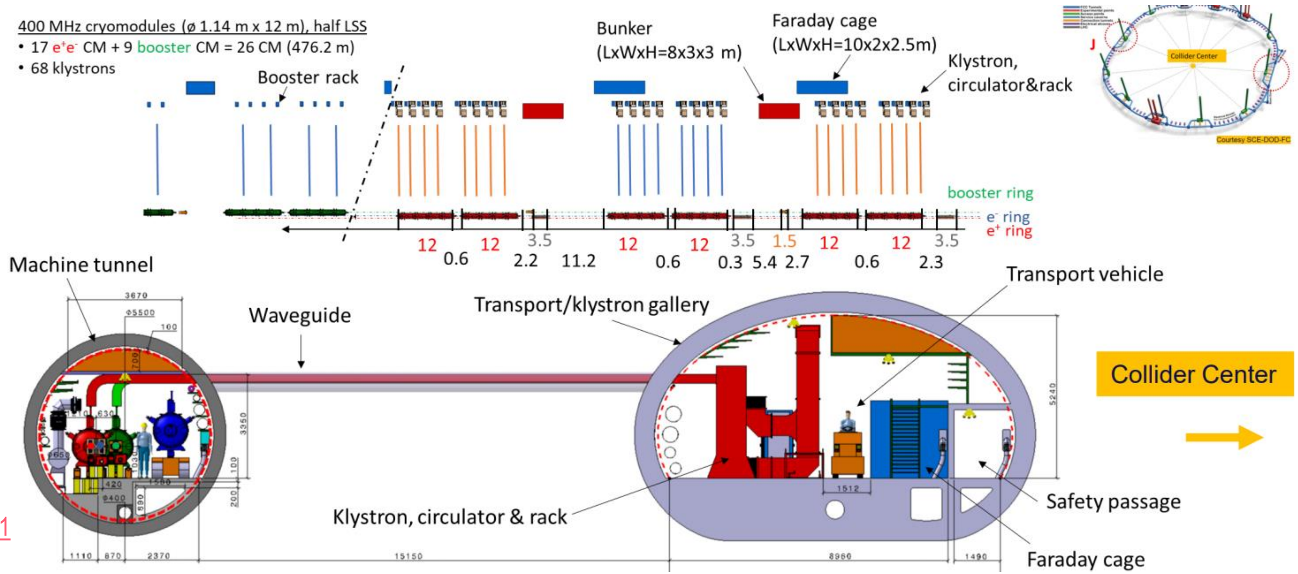


*Indicative dimensions by C. Rogers

Layout ideas

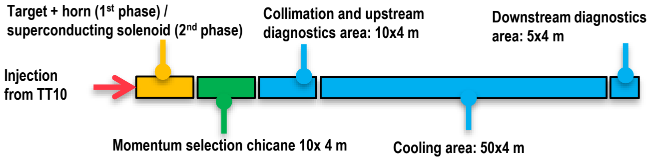


Muon Cooling Area - FCC e⁺e⁻ Crymodules tunnel & klystrons gallery



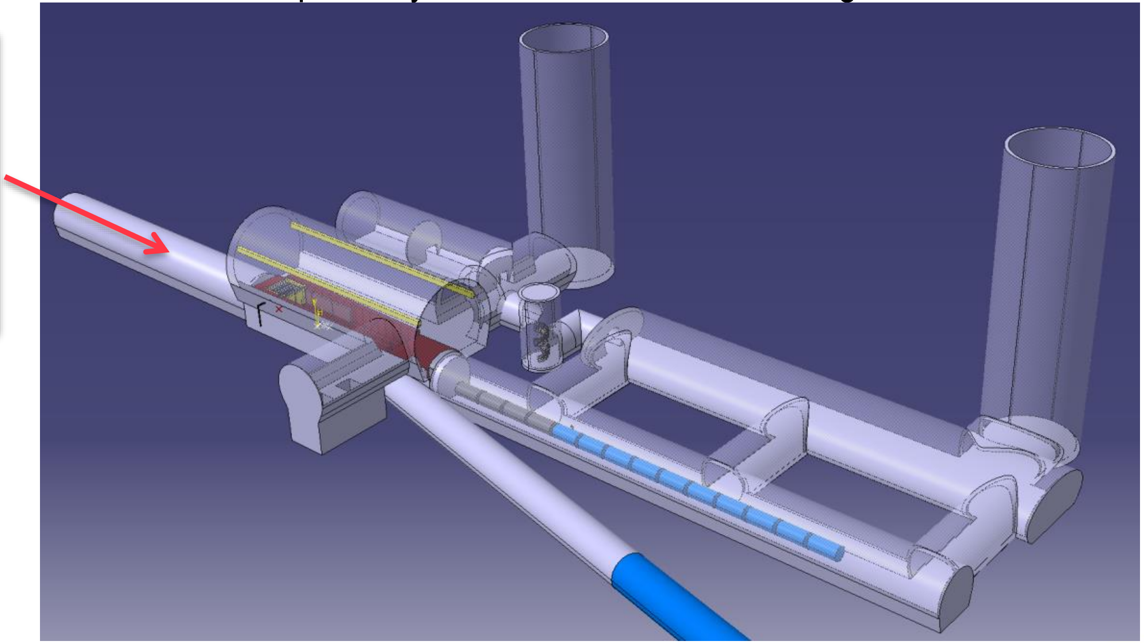
Jean-Pierre Corso, Integration of the FCC, FCC Week 2021

Conceptual layout

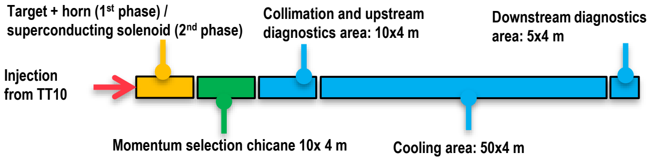


MUC Demonstrator VERY Conceptual layout → To be taken with a “grain of salt”

CERN TT10 branch



Conceptual layout



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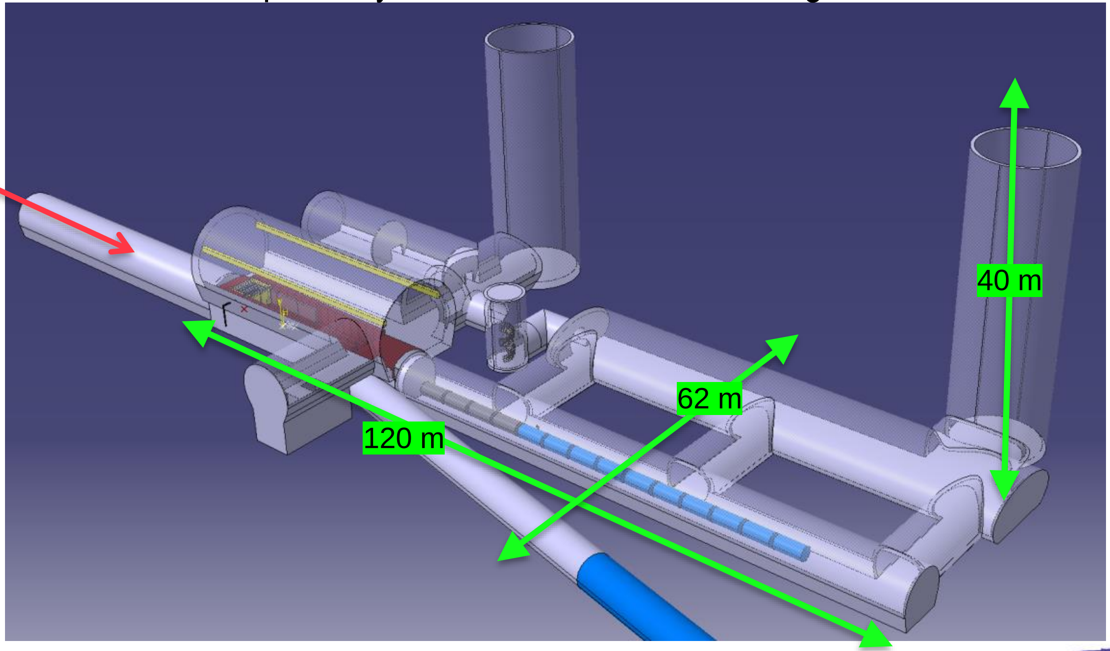
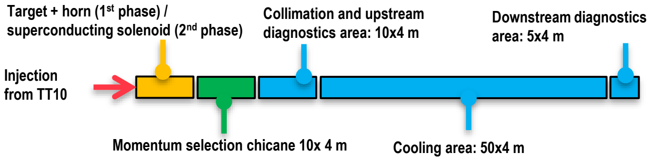


Indicative dimensions. Model is very flexible at this stage

Conceptual layout



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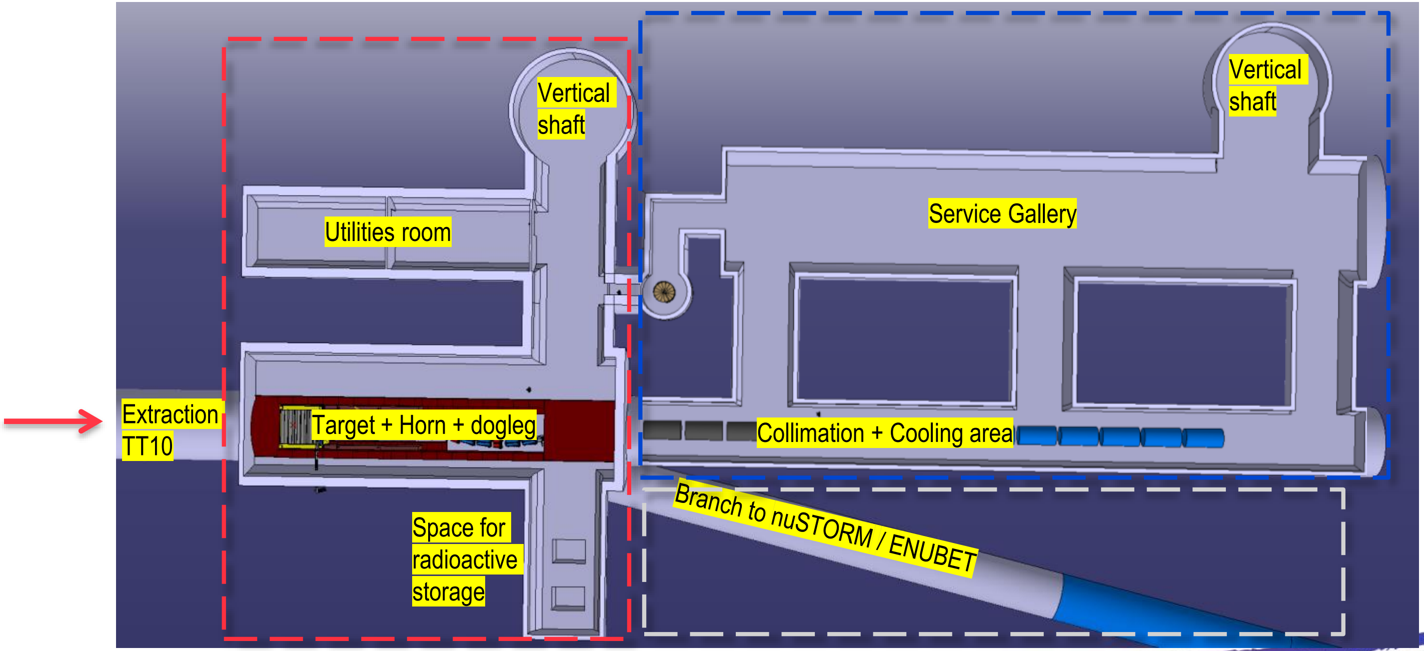
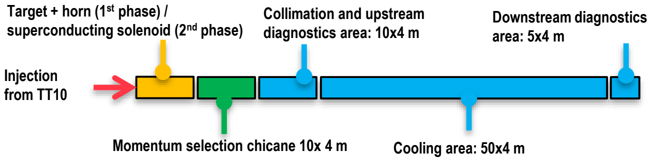


Conceptual layout



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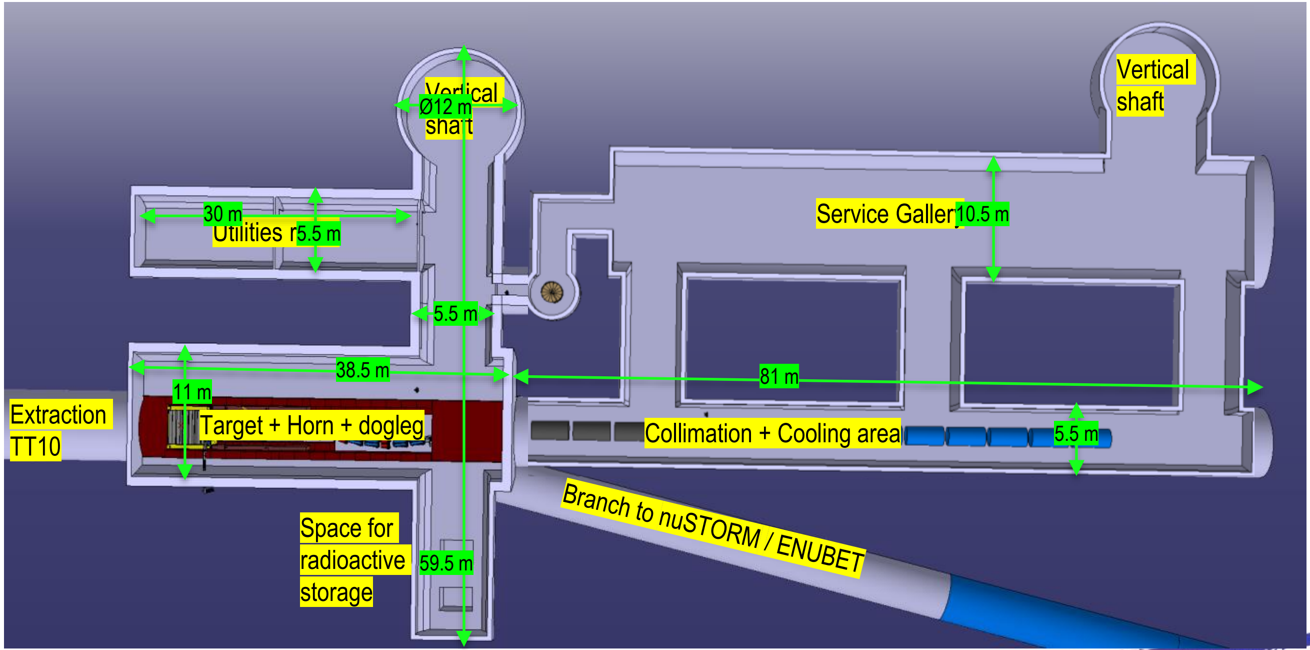

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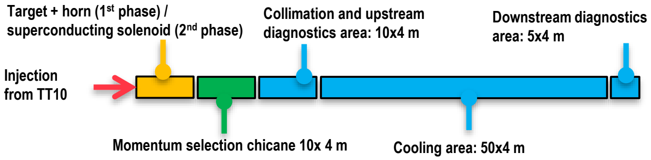

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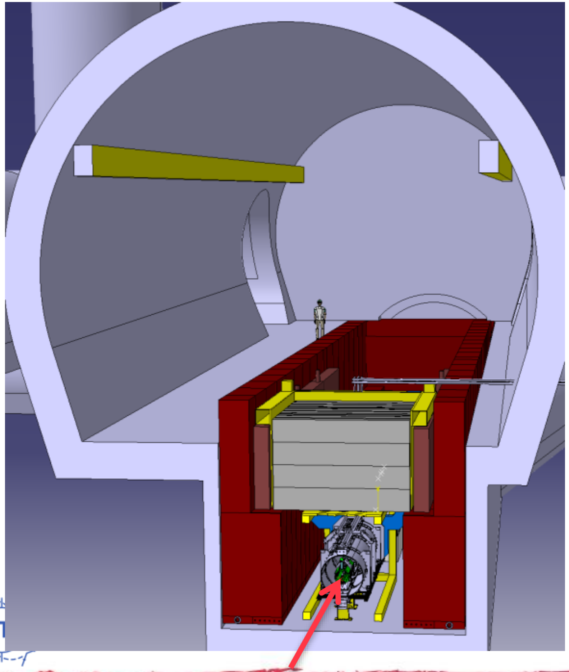
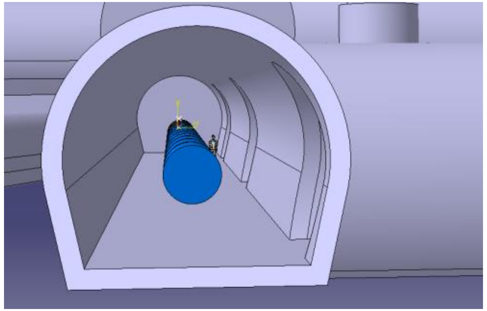
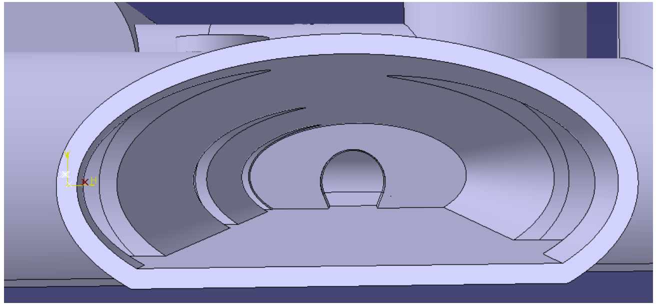


Target + Horn + chicane hall

Cooling tunnel



Services Gallery



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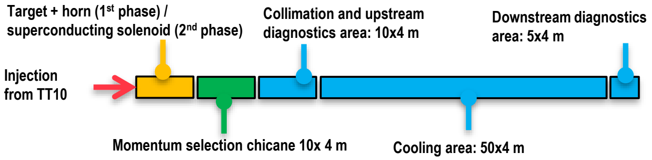
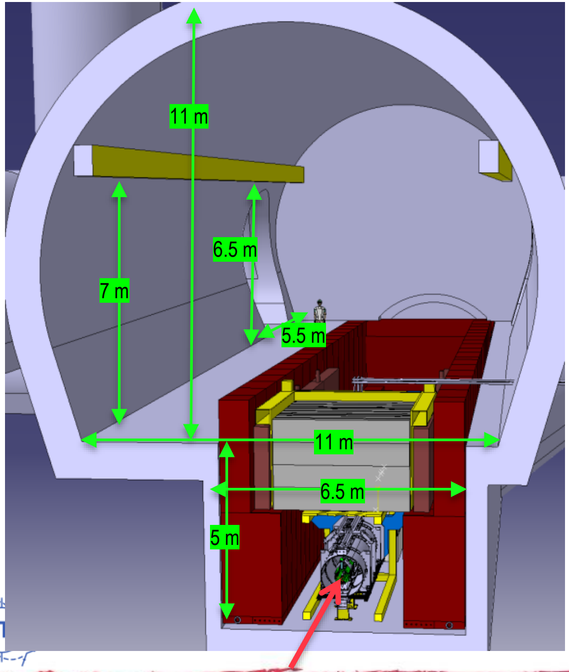
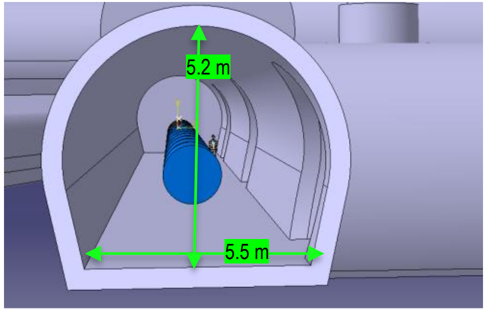


MUC Demonstrator VERY Conceptual layout → To be taken with a "grain of salt"



Target + Horn +
chicane hall

Cooling tunnel



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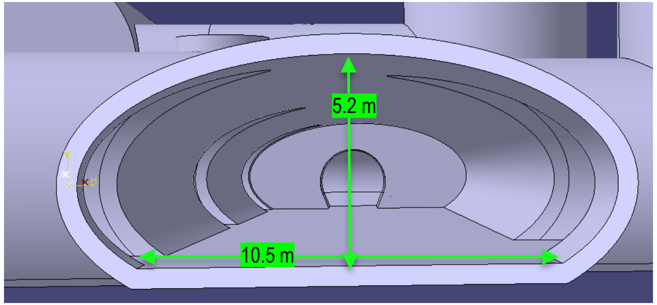
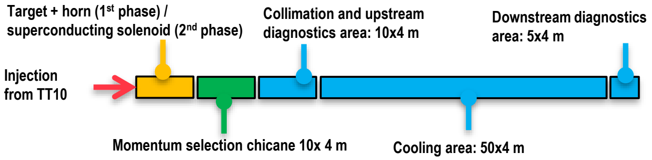


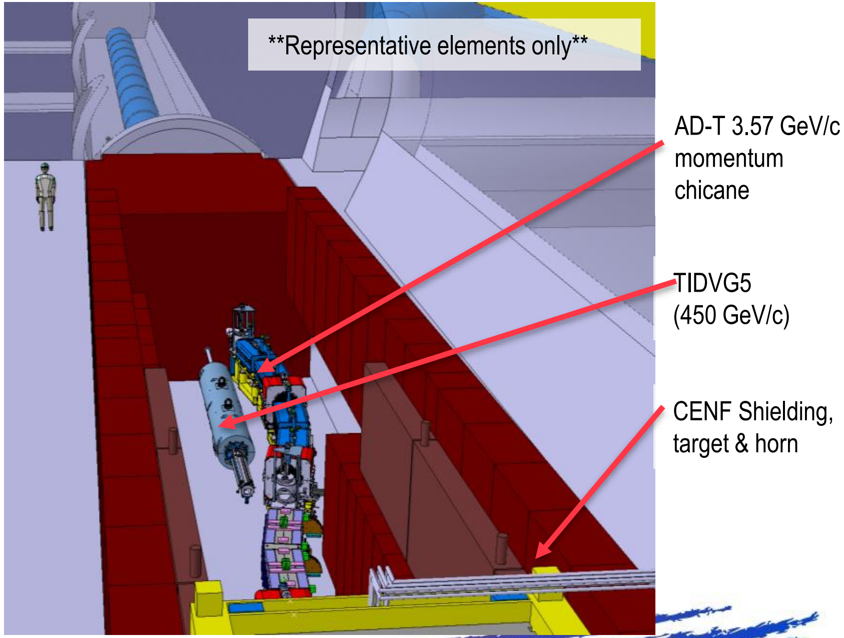
Indicative dimensions. Model is very flexible at this stage

Conceptual layout

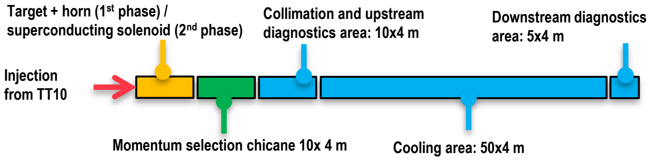


MUC Demonstrator VERY Conceptual layout → To be taken with a "grain of salt"

- Target trench like system with beam line below tunnel floor level → robust solution for radio protection
- Vertical handling with beam equipment in modules, placed in a vessel (N2) container
- Close-by radioactive storage
- Utilities in parallel gallery
- Clear separation from downstream cooling area
- Possibility to branch to other experiments
- Flexible facility with space accounted for future upgrades. At an early stage (80 kW), shielding may be reduced for cost optimization and could start with a simple target & horn. Flexibility to introduce more complex target systems depending on the progresses of the studies for the final Muon collider .

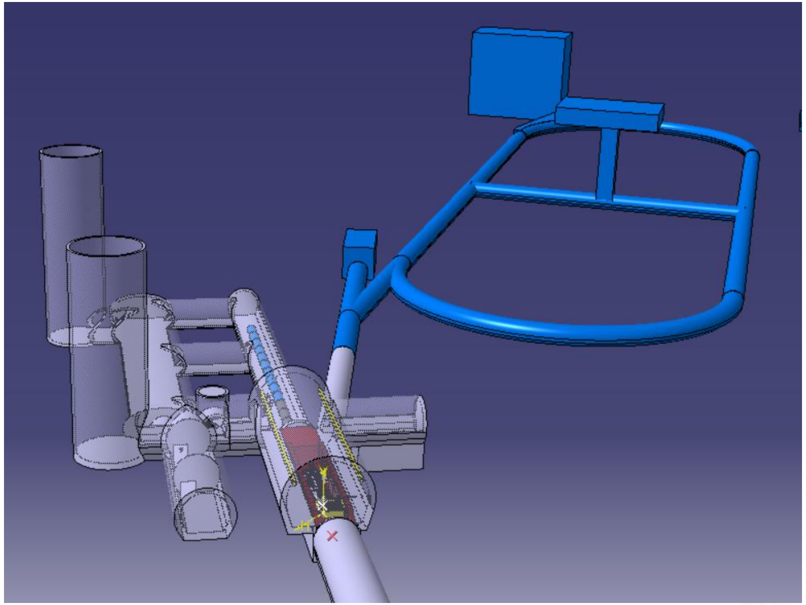


Conceptual layout

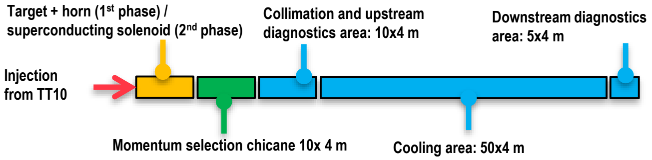


MUC Demonstrator VERY Conceptual layout → To be taken with a "grain of salt"

- The Facility is flexible enough to accommodate other experiments.
- nuSTORM and potentially ENUBET could be branched from the MUC Demonstrator Facility.
- The same target complex would be used profiting from its shielding and general target systems infrastructure, utilities, and accesses.
- The double deflection of the beamline could reduce radiation streaming towards the nuSTORM ring.
- Synergies between experiments would reduce costs on both sides.
- Is the 26 GeV/c beam from the PS appropriate for these two experiments?

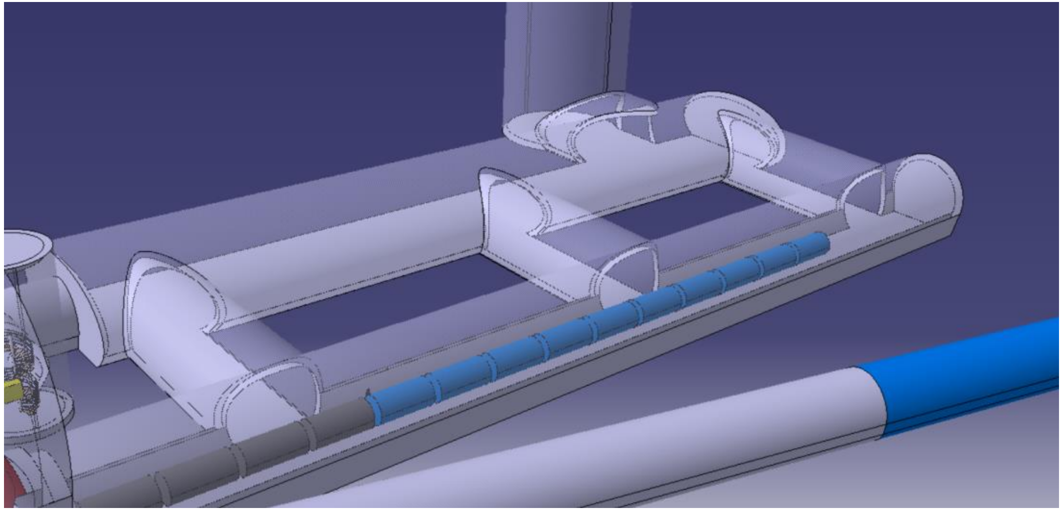


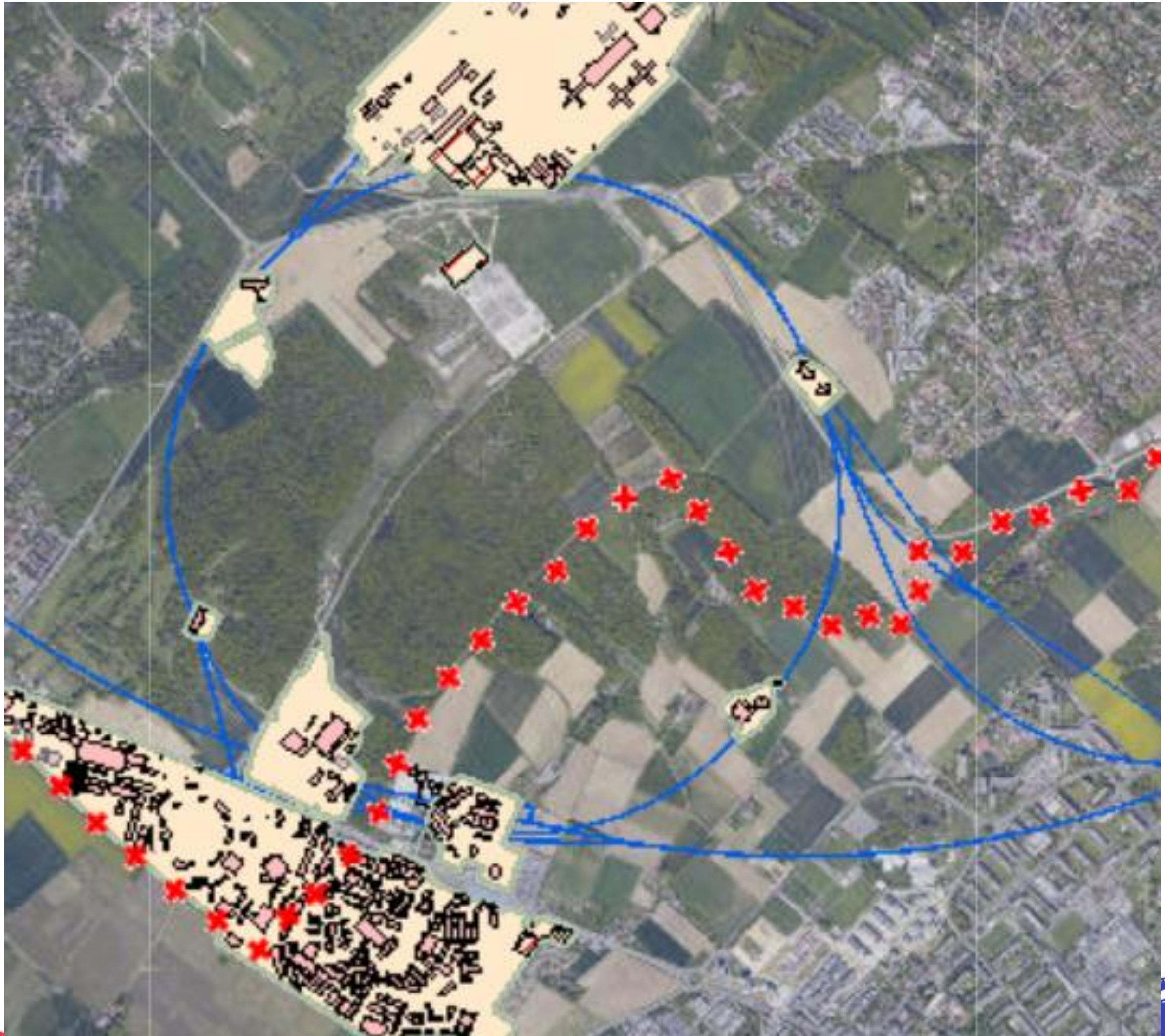
Conceptual layout



MUC Demonstrator VERY Conceptual layout → To be taken with a "grain of salt"

- Muon Cooling section can be extended if needed
- Experimental cavern (e.g. for low energy muons) can be foreseen downstream muon cooling tunnel

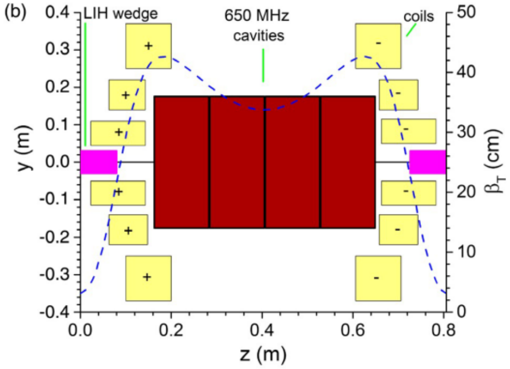


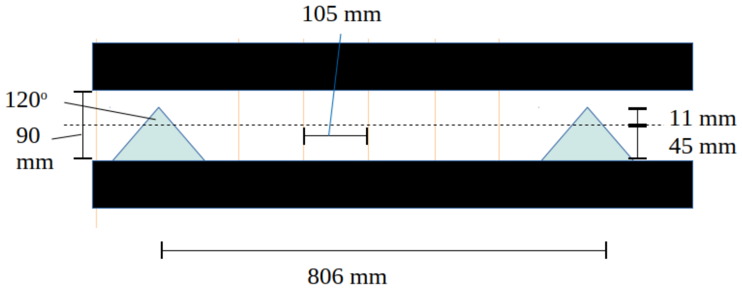


What should the facility demonstrate?

- Headlines
  - 6D cooling
  - Reacceleration
  - Cooling at low emittance (longitudinal and transverse)
- What do we need to do for CDR
  - Engineering integration
  - High-gradient RF cavity in magnetic field
  - Optics
  - High field magnets
  - Absorber infrastructure
  - Vacuum
  - Matching between different cooling cells
  - Diagnostics
  - Alignment and correction

Rectilinear B8 Lattice – as simulated



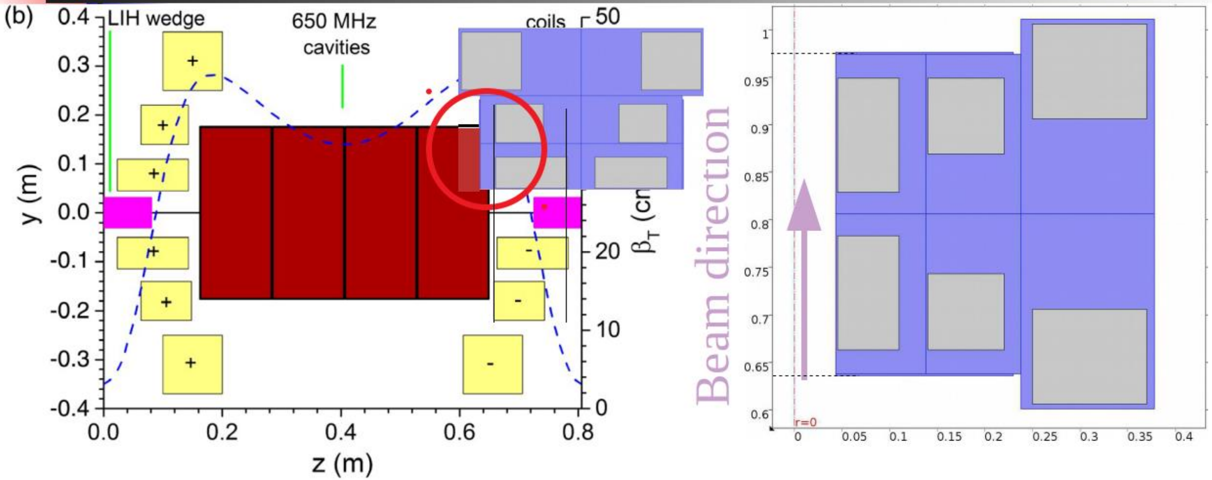


Wedge absorbers are modelled using a Lithium Hydride trapezium. Opening angle is 120° and height is 56 mm

RF windows thickness is between 20 micron. Adjacent cavities share the same window.

D. Stratakis et al, Rectilinear Six-Dimensional Ionization Cooling Channel for a Muon Collider: A theoretical and numerical study, PR ST AB 18 (2015)

Engineering Integration

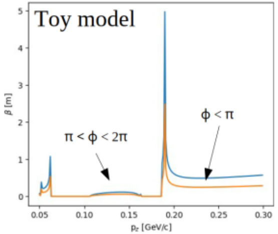


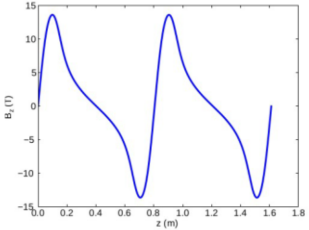
- Engineering integration
  - Note clash between the RF and the magnet
  - Cryogenic analysis was not done (but forces were)
  - Note also conflict between simulated bore and coil support
  - I guess insulating vacuum flask need to go around this?
- Challenge to bring services – vacuum, RF
- Operate RF at lN_2 temperature?
  - Make the RF → magnet interface easier?

High Gradient RF

- RF systems
  - Challenge to operate RF in high field magnet
  - Breakdown → electrons stripped from surface
- Proof-of-principle operation using Beryllium-coated windows
  - Largely seems to suppress breakdown
- Experimental results for high pressure gas filled RF encouraging
  - Practical in an accelerator?
- New concept to pulse the RF power before spark has time to build (Sergey Arsenyev)
- Significant engineering overhead to do high pressure gas cell
  - Is it something we want to invest in?
  - Note pressure window dilutes cooling effect for short lattice
    - Instrumentation in the gas volume?
- RF windows – how thick do they need to be? Radial profiling?

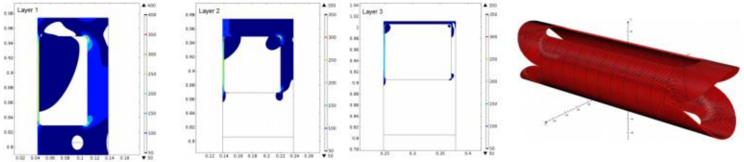
Optics questions





- How tunable is the optics
  - Can we test in both stability regions?
  - Can we tune dispersion and β? How much?
  - Can we tune wedge opening angle? How much?
  - Can we use a dual sign lattice (like HFoFo)?

High-field magnets



- High-field magnets
  - Can we manage the forces (also during unbalanced quenches/etc)?
  - Can we deal with the cryogenics?
- Quench protection
  - Neighbouring magnets strongly coupled
  - If one magnet quenches do we quench the entire line? What about in muon collider (where “line” is ~3 km of magnets)
- (Radiation load)
  - MC will have a high radiation load – needs care

Beam Instrumentation

- Muon rate is likely to be low ~ 10^6-10^7 or so
- Potential non-muon backgrounds
  - Muon decay electrons
  - Beam impurities
  - Dark currents (electrons from RF cavity surfaces)?
  - Knock on electrons (electrons knocked out of absorber/windows)?
- Beam Instrumentation:
  - Conventional BPM?
  - Scintillator screen
    - Can be non-destructive for muons
  - Phosphorescent coating on e.g. RF windows
  - Wire scanner
  - Decay electron monitoring
  - Something else?

A word on RF…

- For a facility at CERN, the choic eof the RF frequency has to take into account existing facilities
  - Need to be compatible with extraction from PS (10/20/40/80/200 MHz)
  - May have to be compatible with a future HP-SPL (350/700 MHz)
  - Shall have to be compatible with the downstream rings
  - Possibly compatible with existing infrastructure (400/800 MHz?)
- A discussion should be organized soon….

Resource requirement

- Breakdown
  - **Engineering integration**
  - High-gradient RF cavity in magnetic field – share with RF group
  - Optics studies – share with cooling group
  - High field magnets – share with magnets group
  - **Absorber infrastructure**
  - **Vacuum**
  - Matching between different cooling cells – share with cooling group
  - **Diagnostics**
  - **Alignment and correction**
  - **Collimation/beam selection**

Conclusions

- Lot of work done since last meeting, ideas more and more clear to start the real work
- Resources needed soon in almost all the systems groups
- Schedule taking into account LSs at CERN provide first beam in 2033-2034.
  - If we find sufficient budget and a brilliant idea to extract at a larger angle could be a couple of years earlier.
- ESS could host a high intensity facility to host material tests

International
UON Collider
Collaboration

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Thank you
for your attention