Muon Cooling and Demonstrator

Workshop on FCC-ee and Lepton Collider

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https://agenda.infn.it/event

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Summary

- Muon Cooling and its challenges
- R&D program phases
- The demonstrator concept
- Implementation at CERN

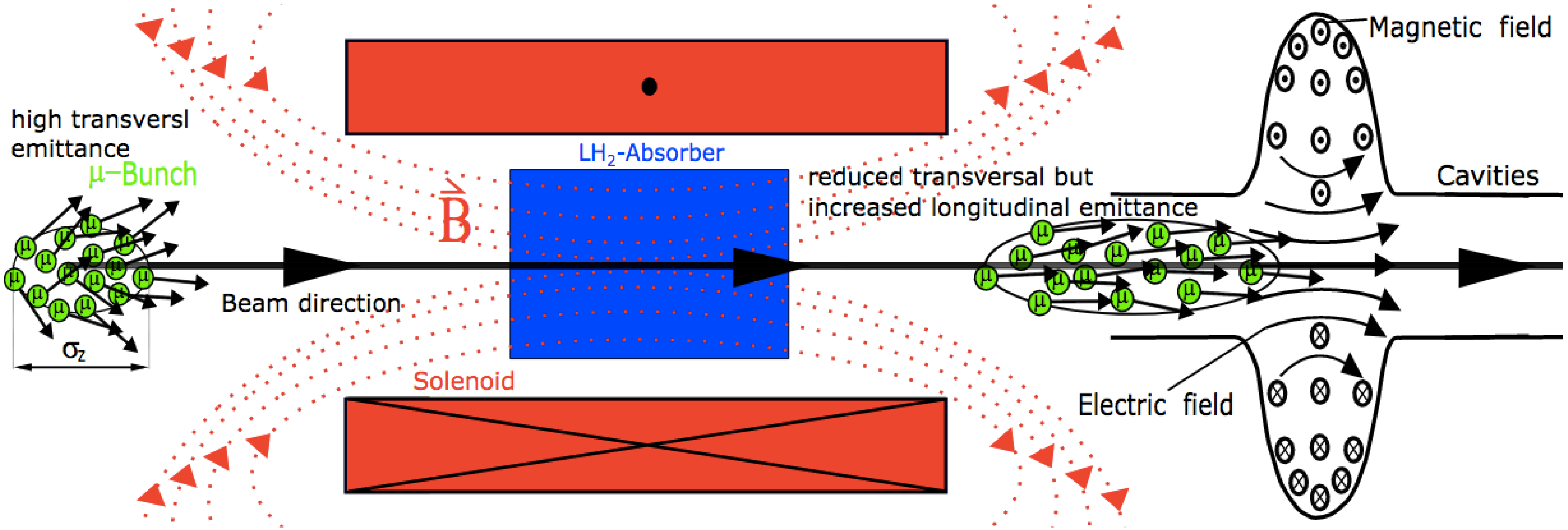
R&D programme for the muon collider

- A Muon Collider complex presents many challenges and requires a wide R&D programme for many different systems:
  - High field radiofrequency,
  - High Power targetry
  - HTS magnets
  - Fast pulsing magnets
  - Vacuum windows
  - Absorbers
  - …

- In the following slides I will present the part of R&D necessary to demonstrate that the requirements for muon cooling can be achieved.

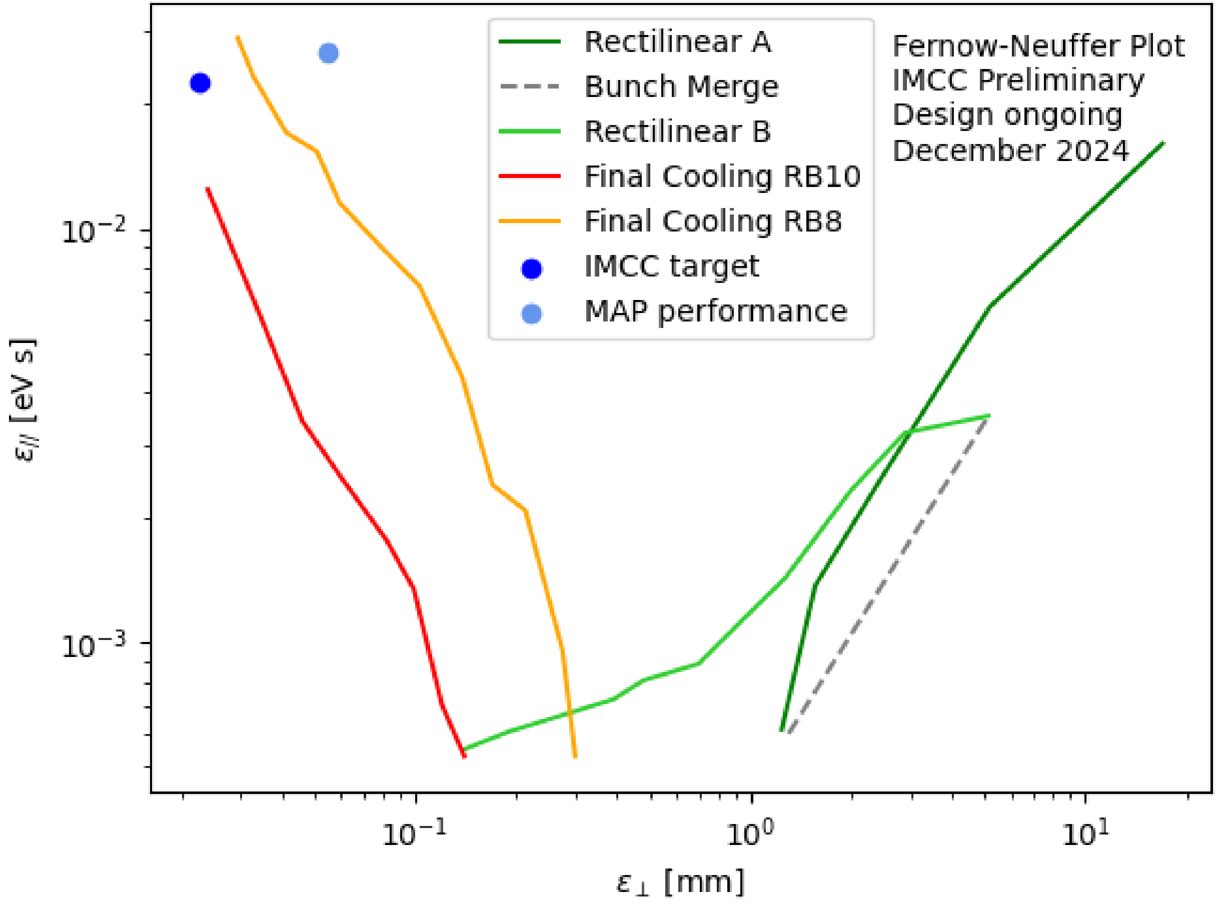
Muon Cooling and its challenges

- Cooling is necessary after production to reduce the 6D emittance of the captured beam



Muon Cooling and its challenges

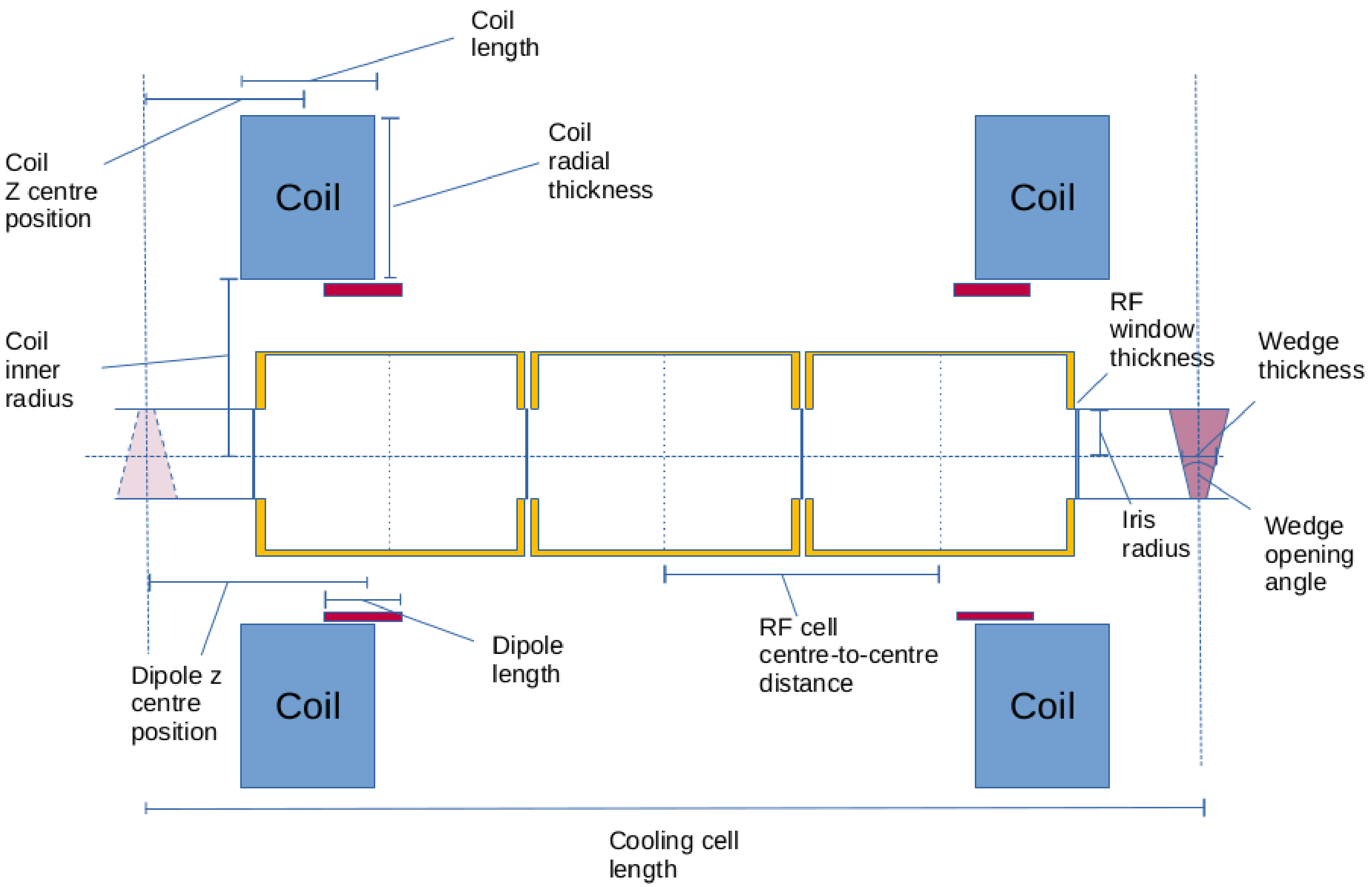
- A reduction of several orders of magnitude is necessary to achieve, in the collider, the required luminosity
- The target performance has been achieved (in simulations) by the IMCC starting from the previous work from the Muon Accelerator Program in the US



Why a demonstrator

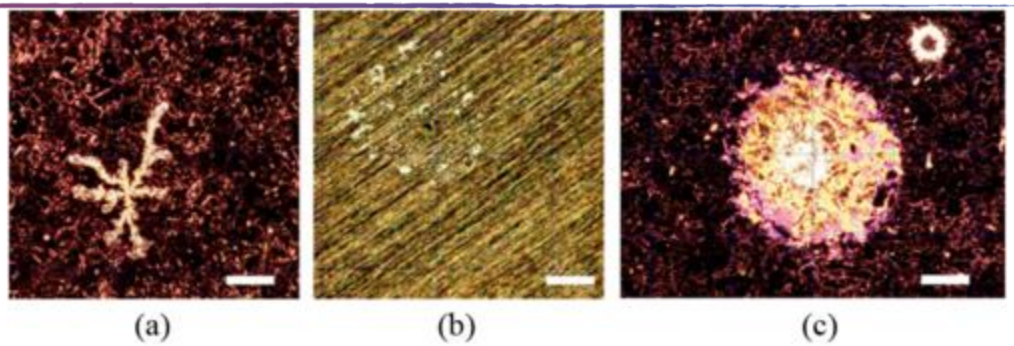
- Cooling is achieved through a complex integration of components providing different effects:

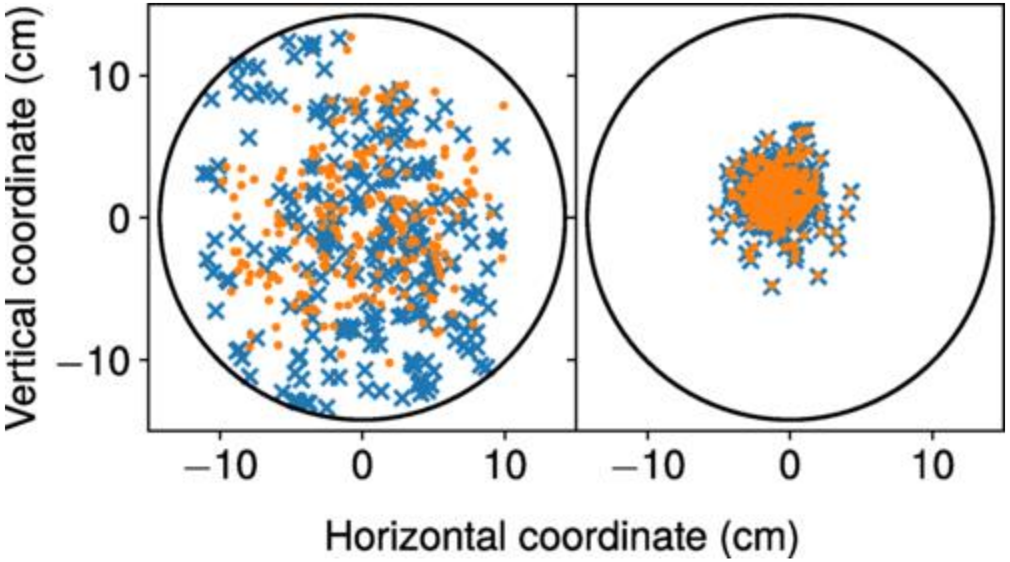
  - **Absorbers**: reduction of transverse emittance, increase of longitudinal
  - **RF Cavities**: restoring only longitudinal emittance
  - **Solenoids**: providing focusing
  - **Dipoles**: providing the proper profile of the Dispersion function.



Why a Demonstrator Programme

- ***The main issues lie with***:
  - Keeping the length of the drift spaces as small as possible, to reduce the risk of decay of muons. The limited space available in the system assembly can be a source of errors in the desired field distribution
  - RF cavities operating in magnetic fields, that is known to increase the breakdown rate
  - Achieving challenging (in operation) values for RF and magnetic fields





Operation of normal-conducting rf cavities in multi-Tesla magnetic fields for muon ionization cooling: A feasibility demonstration

D. Bowring, A. Bross, P. Lane, M. Leonova, A. Moretti, D. Neuffer, R. Pasquinelli, D. Peterson, M. Popovic, D. Stratakis, K. Yonehara, A. Kochemirovskiy, Y. Torun, C. Adolphsen, L. Ge, A. Haase, Z. Li, D. Martin, M. Chung, D. Li, T. Luo, B. Freemire, A. Liu, and M. Palmer

Phys. Rev. Accel. Beams **23**, 072001 – Published 2 July 2020

https://doi.org/10.1103/PhysRevAccelBeams.23.072001

Why a Demonstrator Programme

- **The motivation for a Cooling demonstrator is therefore twofold:**
  - Benchmarking the beam simulations in presence of a real-world field distribution (E and B)
  - Testing the assembly of components in an operational scenario, in particular related to the breakdown rate of the RF cavities in presence of a beam.

	ε_T (mm)	ε_L (mm)	ε_{6D} (mm^3)	Stage Transmission (%)	Cumulative Transmission (%)
Start	16.96	45.53	13500		100
A-Stage 1	5.17	18.31	492.60	75.2	75.2
A-Stage 2	2.47	7.11	44.03	84.4	63.5
A-Stage 3	1.56	3.88	9.59	85.6	54.3
A-Stage 4	1.24	1.74	2.86	91.3	49.6
Bunch merge	5.13	9.99	262.5	78.0	38.7
B-Stage 1	2.89	9.09	76.07	85.2	33.0
B-Stage 2	1.99	6.58	26.68	89.4	29.4
B-Stage 3	1.27	4.05	6.73	87.5	25.8
B-Stage 4	0.93	3.16	2.83	89.8	23.2
B-Stage 5	0.70	2.51	1.32	89.4	20.7
B-Stage 6	0.48	2.29	0.55	88.4	18.2
B-Stage 7	0.39	2.06	0.31	92.8	17.0
B-Stage 8	0.26	1.86	0.13	87.9	14.9
B-Stage 9	0.19	1.72	0.06	85.2	12.7
B-Stage 10	0.14	1.56	0.03	87.1	11.1

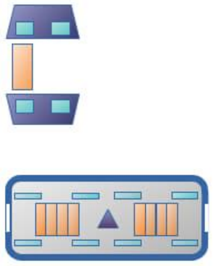
A Cooling Demonstrator programme

- The Demonstrator facility is only the last step of a R&D programme, that involves

  1. **Single cooling cell:** Design (being done through the EU project MuCol and INFN funds), construction and test
  2. **RF in Magnetic field test stand**: to study in detail breakdown phenomena
  3. **5-cooling cell assembly:** Design, construction and test
  4. **Demonstrator Facility**: to prove that cooling cells work in an operational scenario

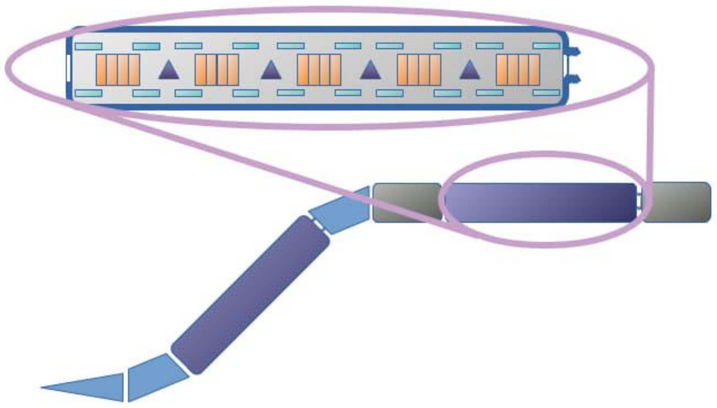
- In parallel, R&D on magnet technology, absorber technology etc.. Are also needed.
- **Level of contribution of collaborating institutes is expected to be significant**, especially in providing experts in RF, Magnet , accelerator physicists etc….

A Cooling Demonstrator programme



RF Test programme, with upgradeable magnet configuration, to test novel RF technologies

Prototype cooling vacuum vessel to test magnet, absorber and RF integration



Rectilinear cooling vacuum vessel with beam

Rectilinear cooling lattice with beam

Facilities

- Hardware test of the cooling cells can be hosted in the CTF3 building:
  - Most of the technical infrastructure is available,
  - Negligible modifications are needed in the civil engineering structure.
  - Cryogenics can initially be provided at reduced cost with cryocoolers (at least for the single cell).

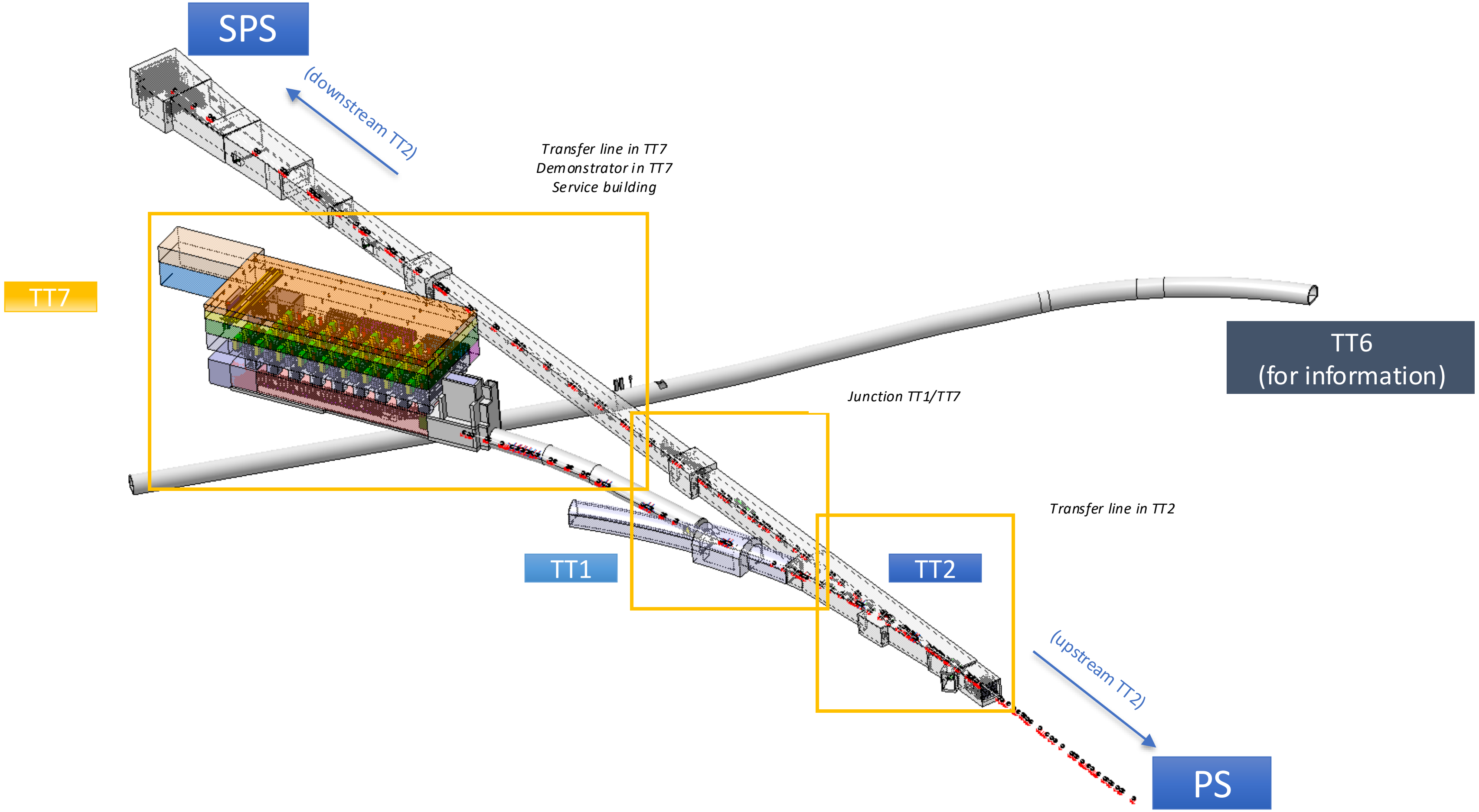
- For the demonstrator with beam we are studying two possibilities
  - TT7 (old PS neutrino beam tunnel)
  - CTF3

TT7 Facility

- The main advantage of installing a muon beam in **TT7** lies with the fact that **it does not require a new beam extraction in the PS**

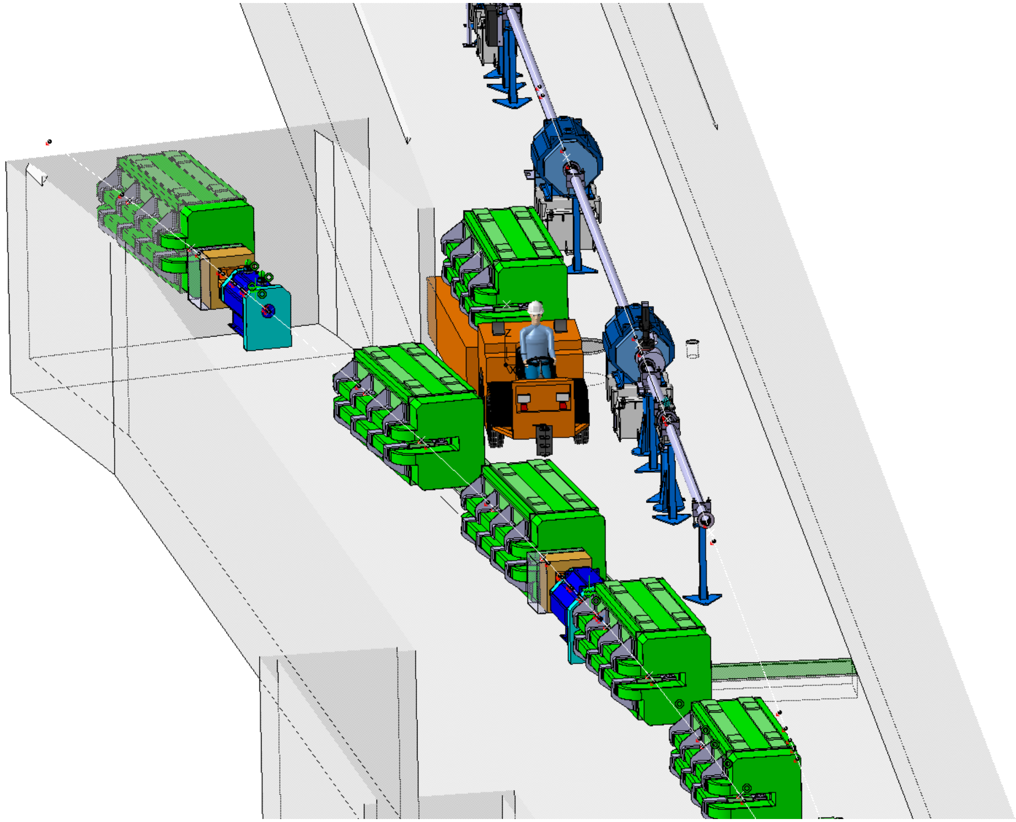
- A pre-study has found no showstoppers, although a few critical points need to be addressed by a proper CDR work.

TT7 Facility

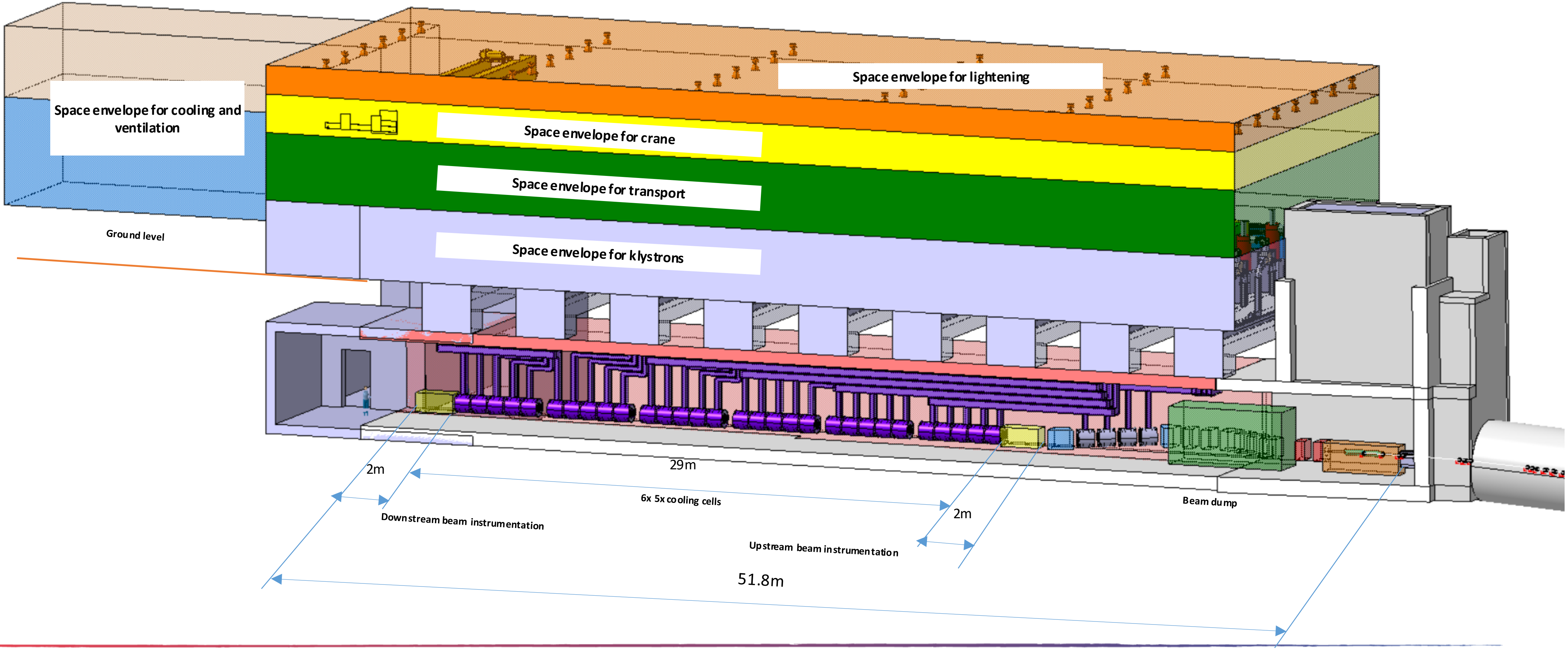


TT7 Facility

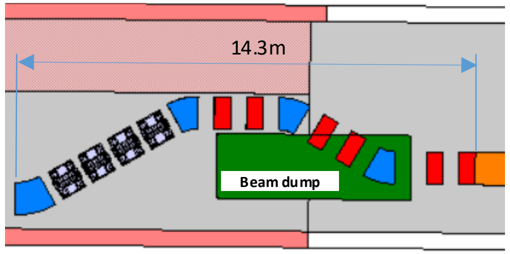
- There are a few issues to solve with the passage of personnel and materials, but no major issue.

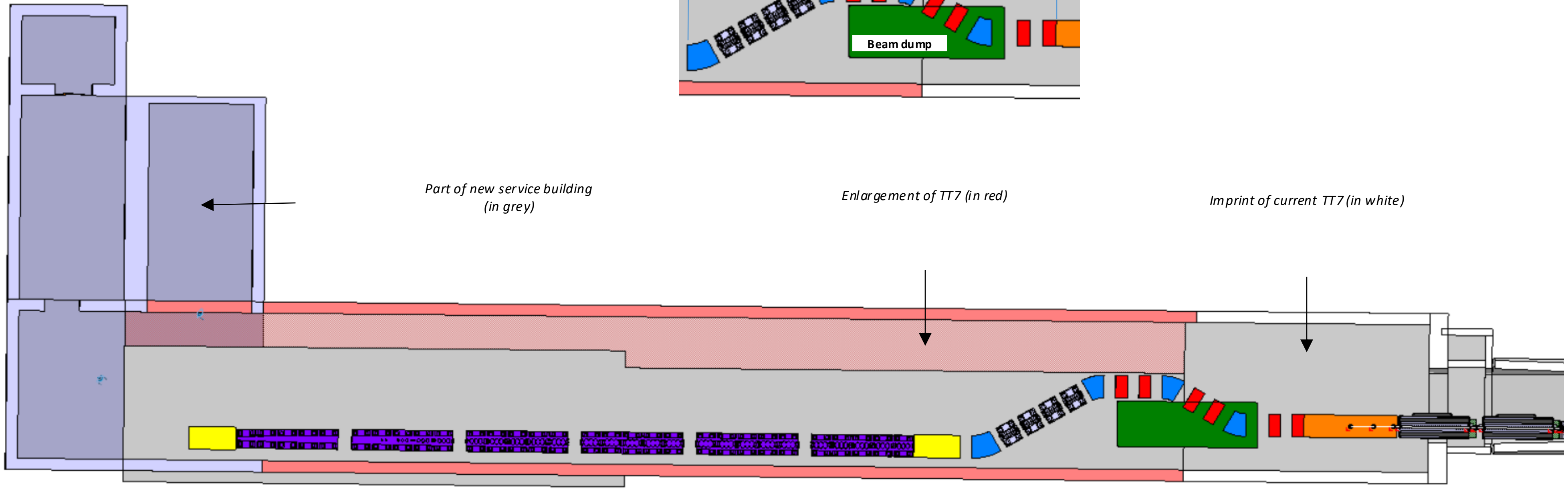


TT7 Facility



Optimization of transfer line components' position is required or beam dump's volume to solve interference



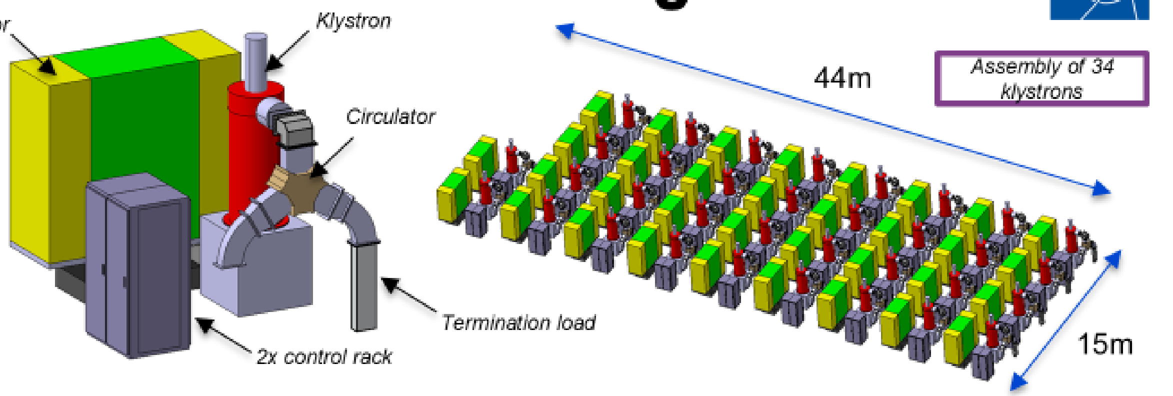


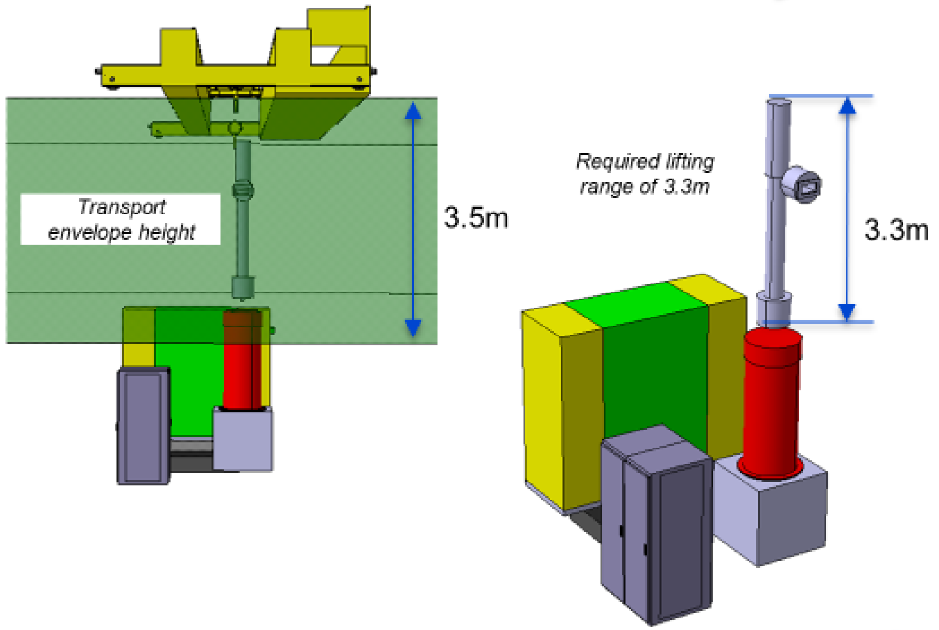
Integration – required service building

Integration study is based on CLIC RF L-band klystron (Canon E37503)

Parameters of integrated klystron	Units	CERN specification
RF frequency	MHz	999.516
Peak RF power	MW	20

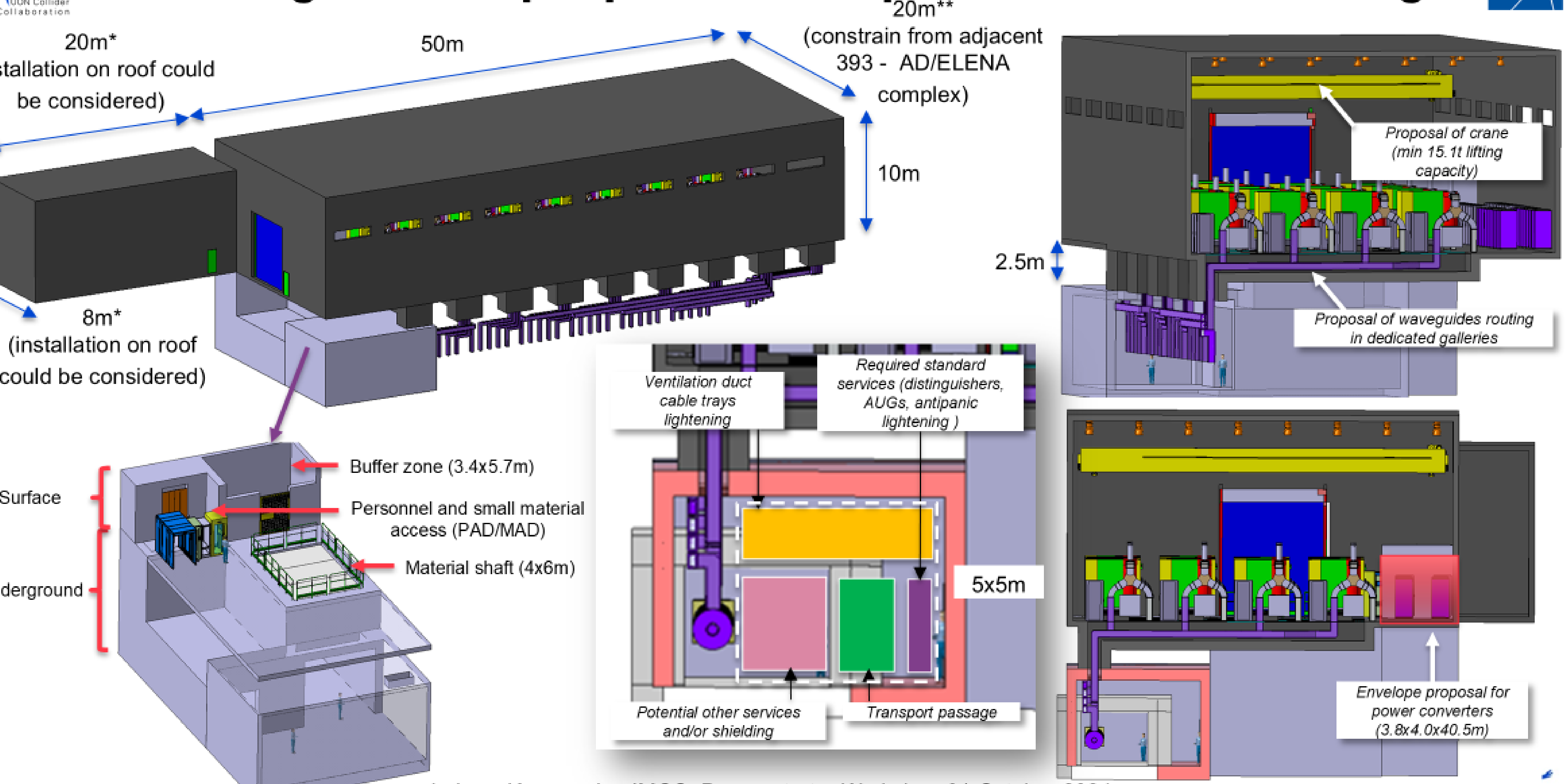
Associated components	Type
Modulator	CERN LINAC 4 type has been integrated (final size to be checked)
Circulator	Waveguide junction circulator 704.4 Mhz, 1.5 MW peak, 100kW average (CPR1150) – SPL test place at CERN
RF waveguide	WR1150 Waveguide Components On Microwave Techniques
Termination load	WR1150 Waveguide Components On Microwave Techniques



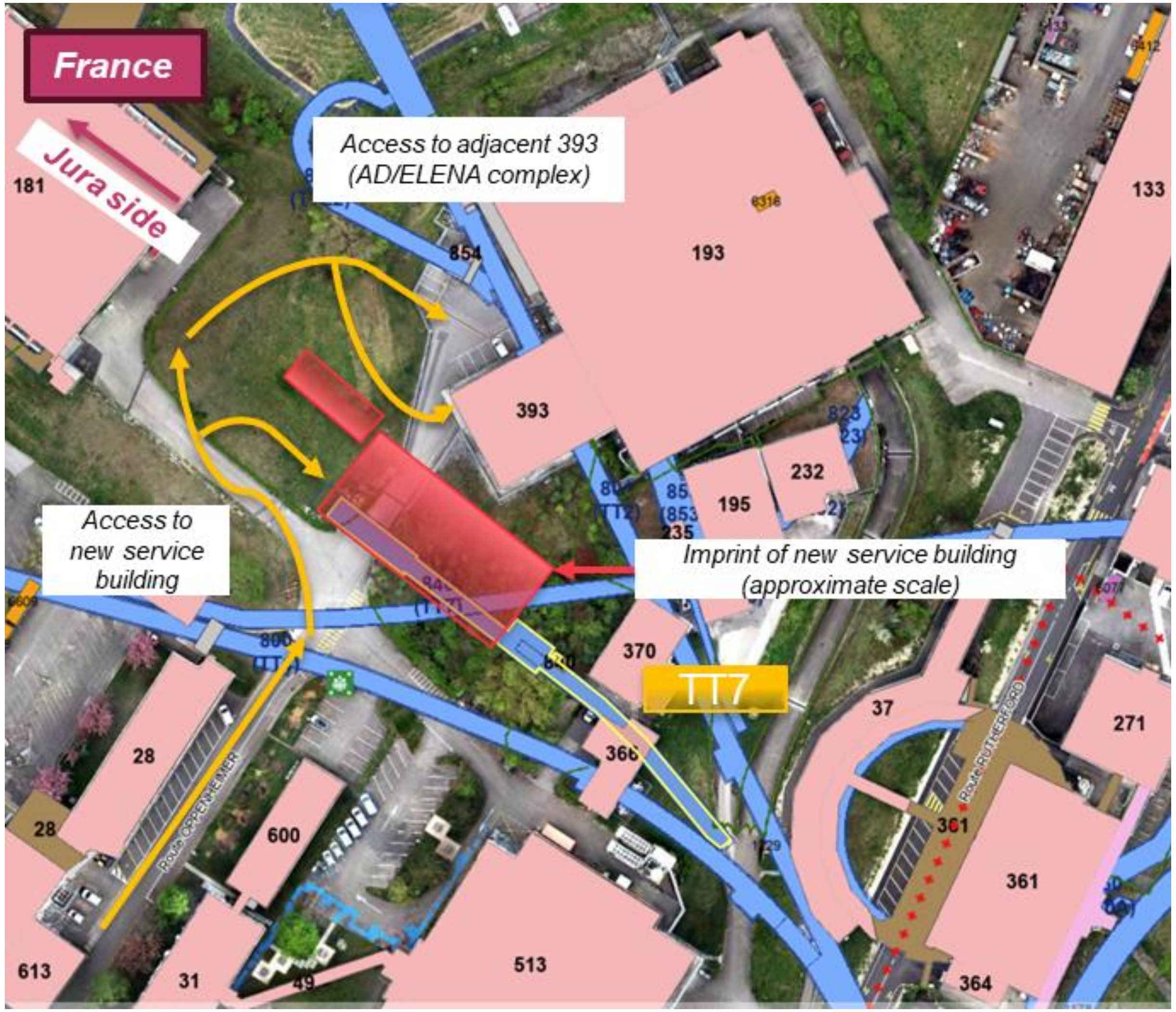


- Conclusions
  - Conservative approach has been applied in terms of space envelope
  - Quantity and space envelope required for klystrons assembly will depend on the final definition of RF frequency and power
  - Installation/maintenance scenario gives partial input on transport requirements of service building crane

Integration – proposal of required service building



TT7 Facility

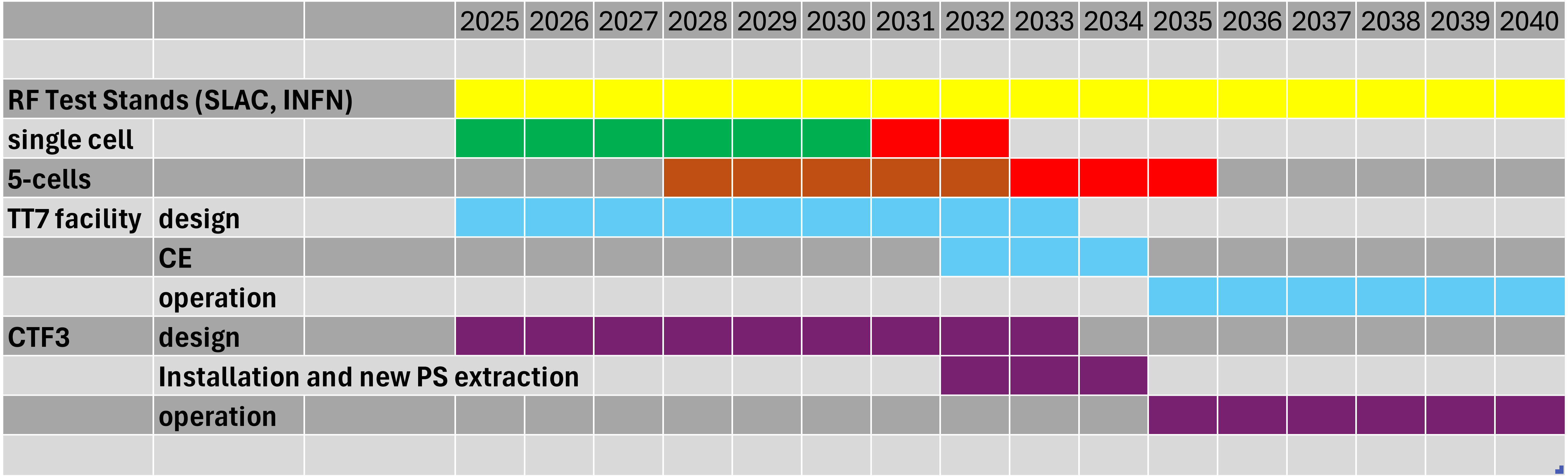


CTF3 Facility

- **Advantages**
  - ~100 m of tunnel
  - Klystron gallery already available
  - All technical infrastructure already available
  - Space available to build a proper target area and decay tube

- **Disadvantages**
  - No extraction in the PS, will need to rearrange the lattice to make room for an extraction. No beam before the end of LS4…

Tentative technically limited schedule



- TT& and CTF3 are mutually exclusive (one or the other, not both)
- Single cells and 5 cells will be tested in CTF3.

Synergies

- TT7 is too short to host a physics facility downstream.
- However if necessary (and useful) there is space to add 50m of additional tunnel (to be excavated).
- Max Intensity 10^6 muons at around 200 MeV per pulse can be provided

	Unit	Value
Transverse emittance	mm	~1 - 1.5
Longitudinal emittance	mm	~3 - 4
Beam size	mm	~10
Momentum	MeV/c	200
Momentum spread	MeV/c	< 10
Bunch length	ps	~100
Bunch intensity	-	10^5-10^6

Synergies

- The High Temperature Superconducting Magnets R&D on REBCO has a wide field of applications. Fusion is driving the market, but also medicine, materials studies etc…
  - If proven feasible, REBCO might become a choice for FCC-hh

- Development in Radiofrequency will profit any of the future projects (including FCC).
  - High efficiency klystrons, breakdown studies at high field etc…

Conclusions

- It is essential to launch immediately a serious hardware R&D programme if one wants to have results in a reasonable time scale
  - **A programme of 7 to 10 years is** necessary to build and extensively test a few cooling cells, due to the use of novel technologies (HTS)
  - **RF in magnetic field** is an issue. We know there are solutions (see MAP programme), but they have not been tested in a real operation setup (and with beam).
  - **RF test stands** are therefore essential to understand the phenomenology and to test different mitigation strategies.
  - **A collimated and dense muon beam at CERN** will be a major step towards the feasibility and a great opportunity for the muon collider community.

Thank you

International MUON Collider Collaboration

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