



FUTURE CIRCULAR COLLIDER

How the FCC-ee could look like? *FCC-ee Arc Half-Cell 1:1 Mock-up project*

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Outlines

1. What is an arc half-cell? And why this demonstrator?
2. Details concerning the 1:1 mock-up
3. A short functional demonstrator
4. Conclusion



Towards approval of the FCC

→ 2013 Update of European Strategy for Particle Physics:

- *“CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines.”*
- **FCC Conceptual Design Reports (2018/19)**

→ 2020 Update of European Strategy for Particle Physics:

- *“Europe, together with its international partners, should investigate technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.”*
- **FCC Feasibility Study leading to Final Report (2021/25)**

→ 2026/28 Next process of Update of European Strategy for Particle Physics:

- Importance of Feasibility Study documentation and **demonstrators!**

Which demonstrators?

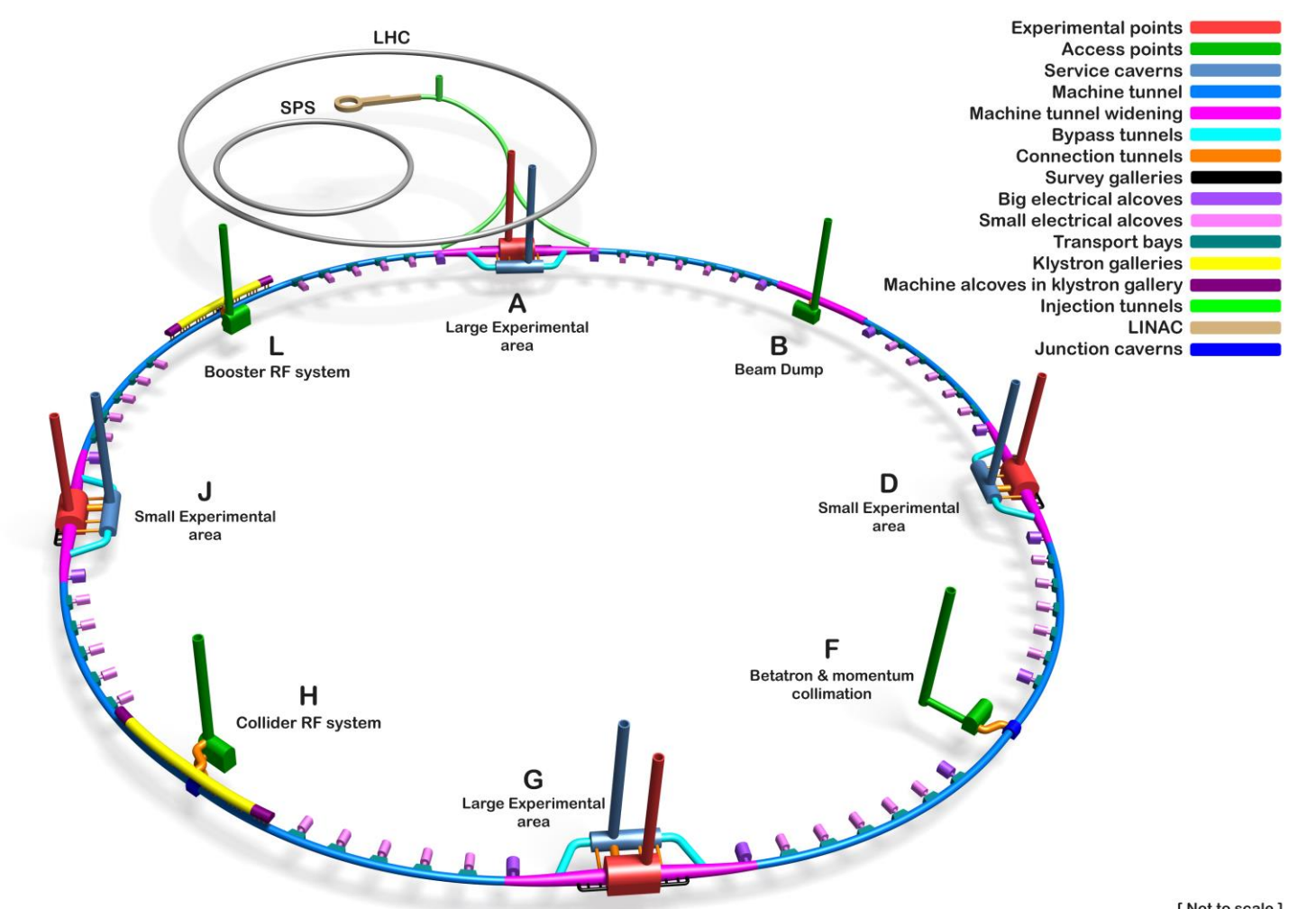
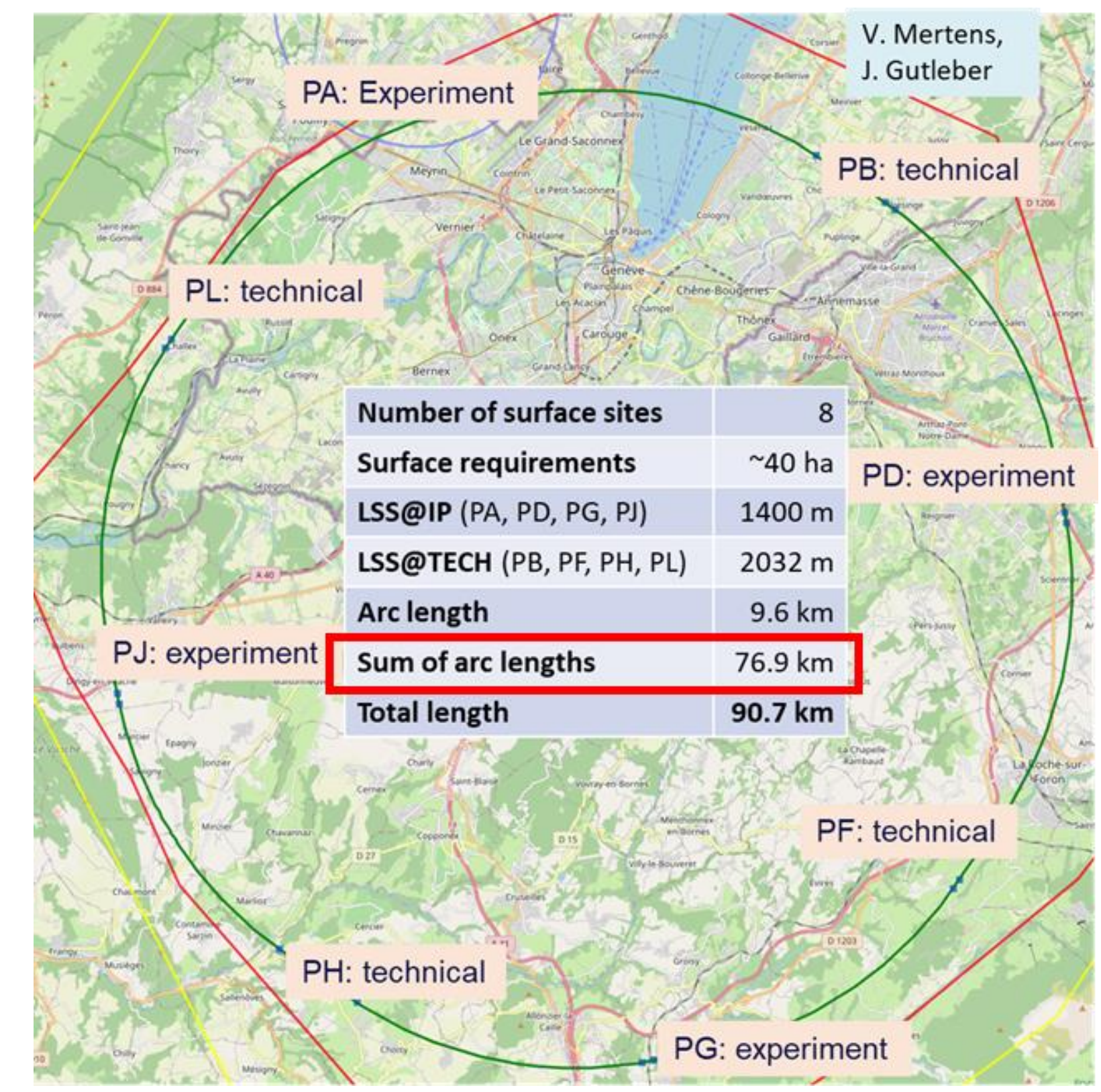
Arc half-cell = most recurrent assembly of mechanical hardware in the accelerator → **77 km** over **90 km** are arc cells (about **85 %**)

Objectives:

→ **Test aspects** related to:

- Cost
- Integration
- Assembly
- Stability inspection
- Security / Safety
- Fabrication, machining capabilities for critical components
- Transport
- Installation
- Alignment
- Maintenance
- Safety

→ **“Visual” driver** for FCC stakeholders, visitors and collaborating researchers



[Not to scale]

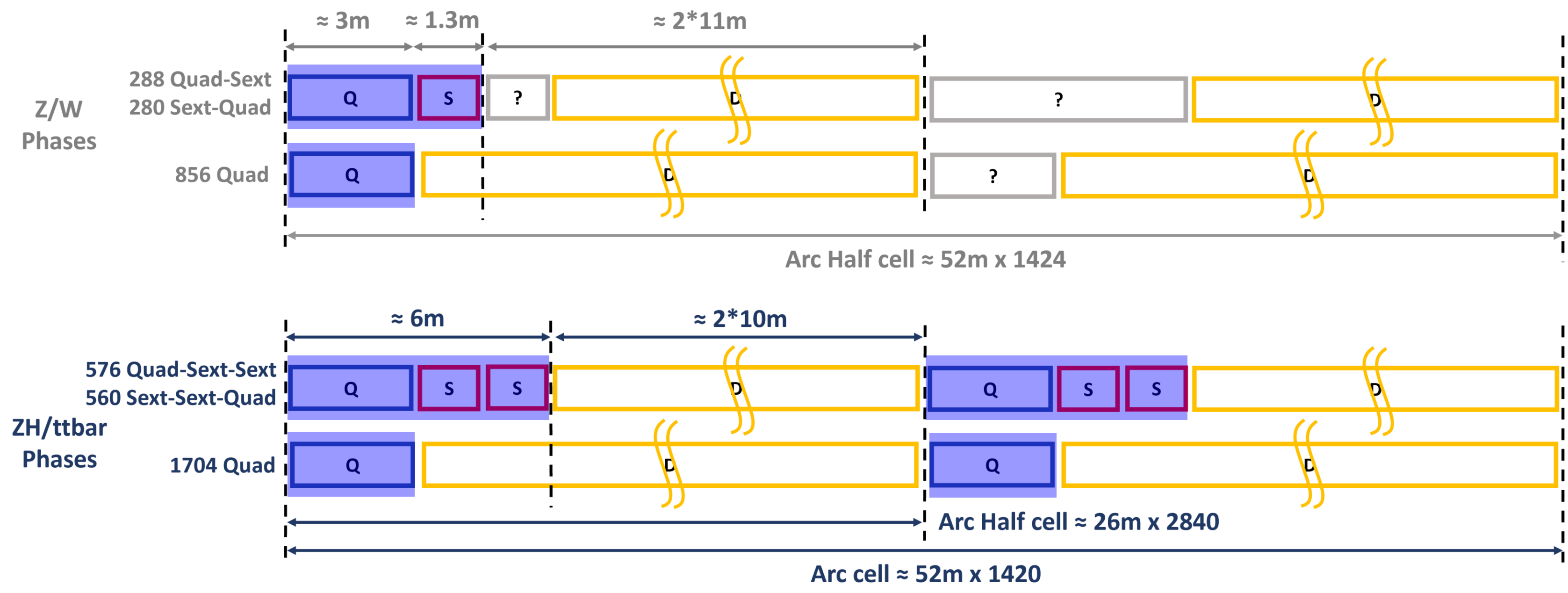
What is an arc half-cell?

For the **current optics baseline** of the collider (GHC optics), the cells are **different** for the **Z/W phases** and the **ZH/ttbar phases**.

An arc half-cell =

- + **Short Straight Section (SSS):** 1 Quadrupole + (0, 1, 2 Sextupoles) + ... (correctors, BPM, etc.) → elements standing on a common girder, pre-aligned on the surface. *Length 3 to 6 m*
- + **Dipole region:** obtained by a sequence of dipole. *Length 20 to 46 m*

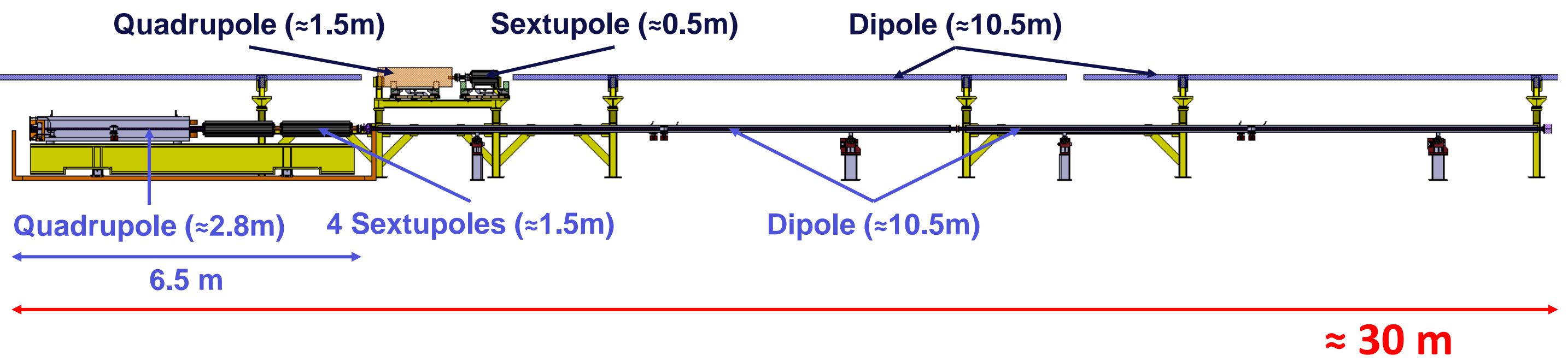
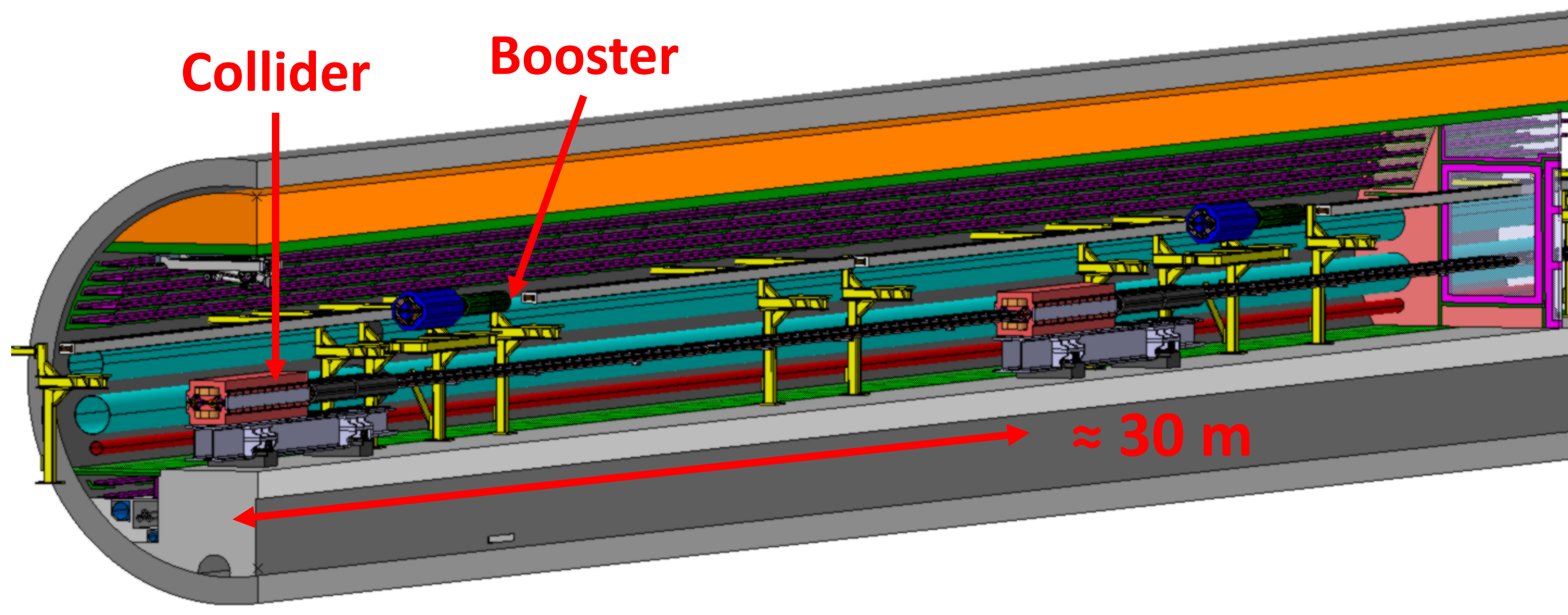
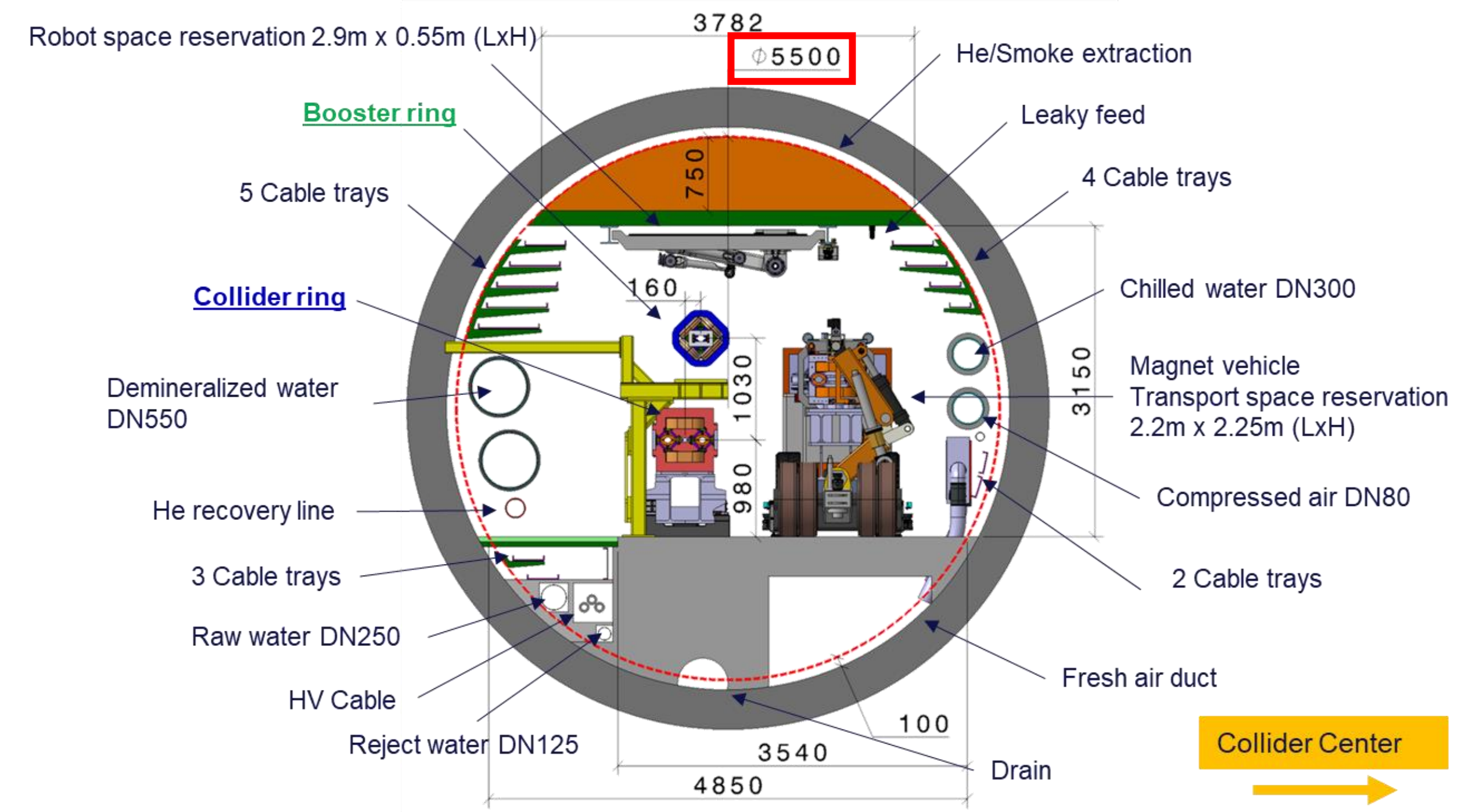
COLLIDER OPTICS



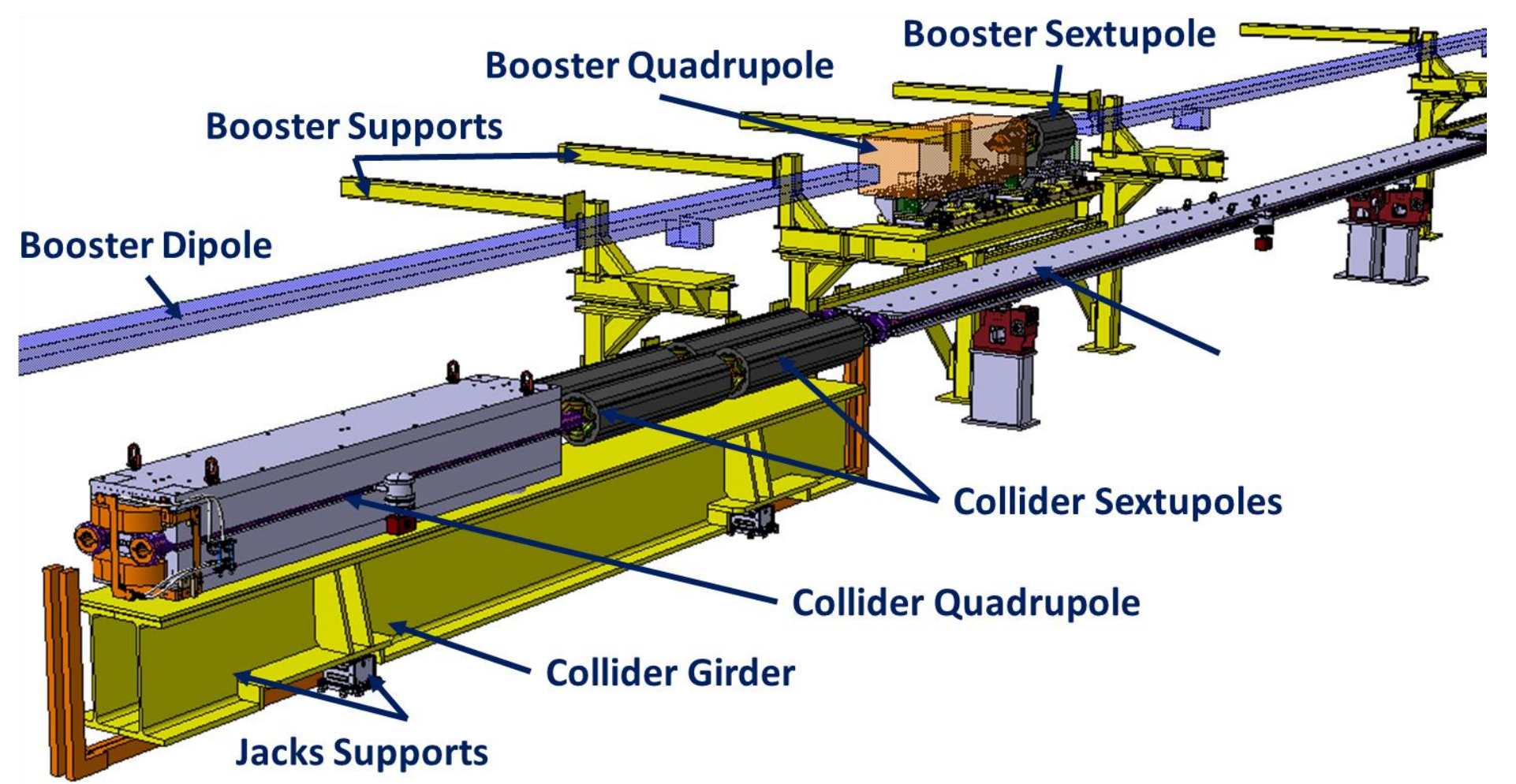
Z/W Phases
 Arc half-cell length = 52 m
 Unit = about 1500

ZH/ttbar Phases
 Arc half-cell length = 26 m
 Unit = about 3000

How does an arc half-cell look like?



Short Straight Section = SSS



What about the 1:1 Mock-up?

WHEN?

- **During 2025:** Installation of the first version of the Mock-up
- **Following years:** Possible evolution of the mock-up

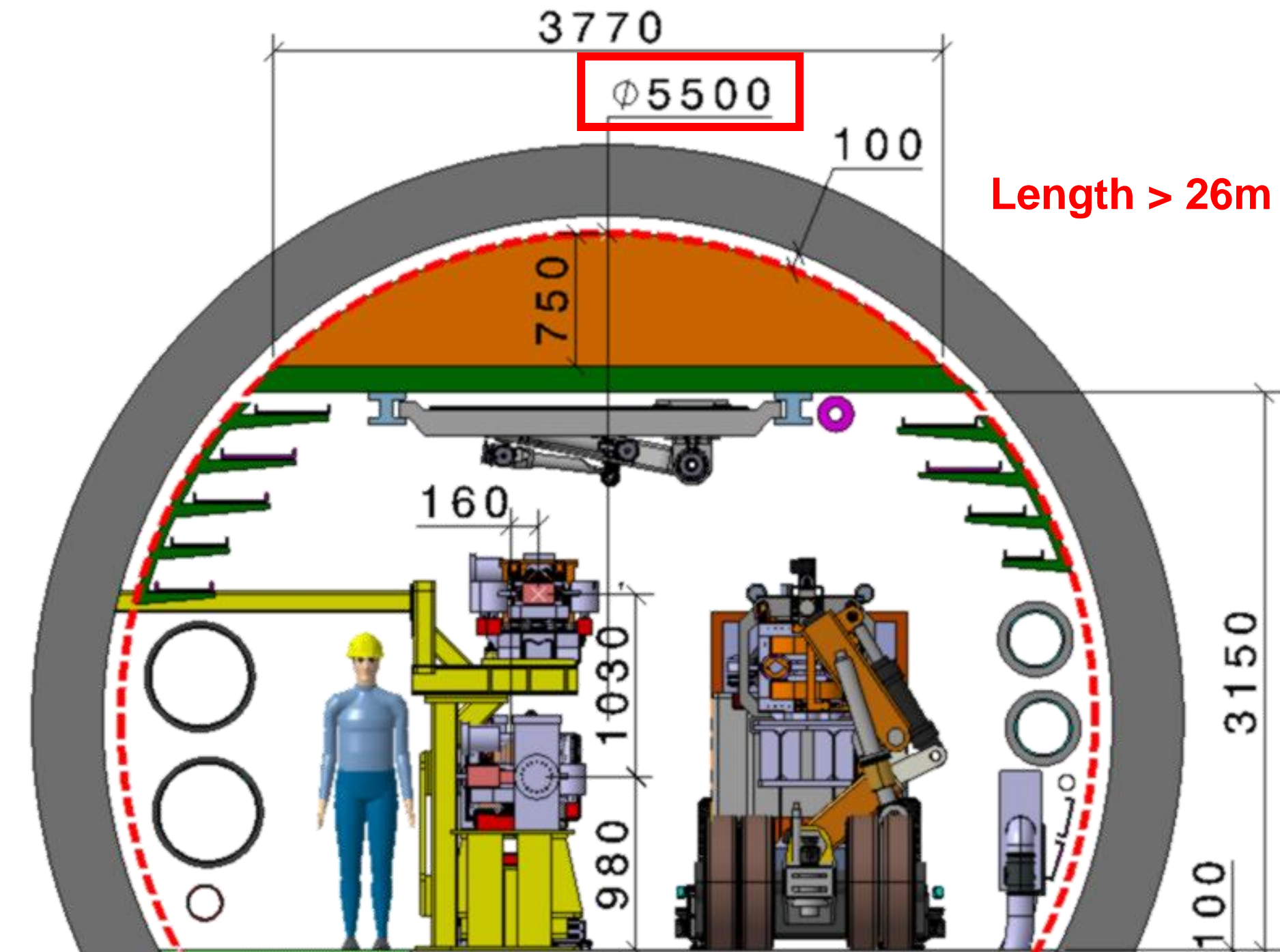
WHY?

Short term objective = A mock-up allowing to test the integration of simplified elements within a short timeframe.

- Detailed study of the integration of elements
- Analysis of access and compatibility with safety requirements
- Test of alignment strategy and mechanical stability

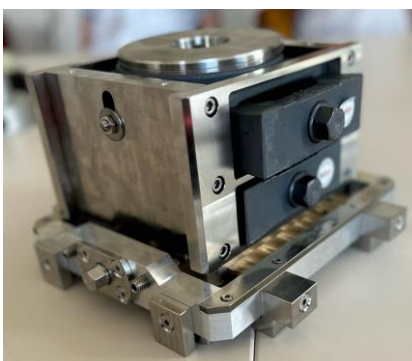
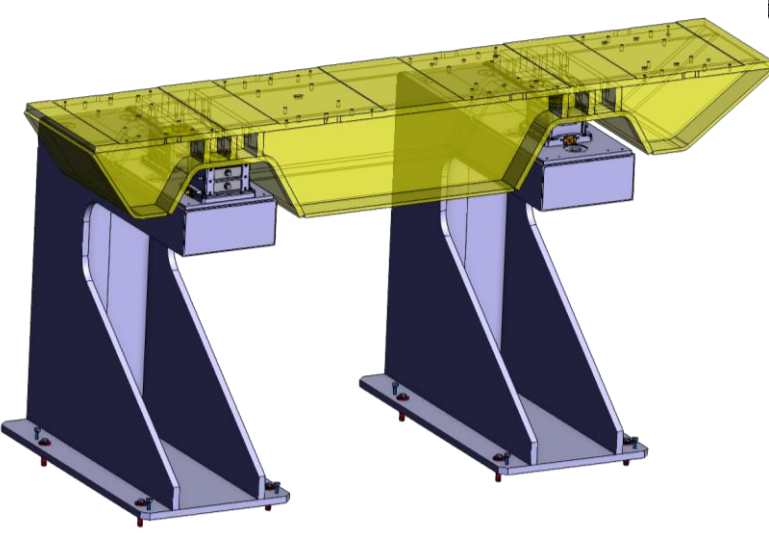
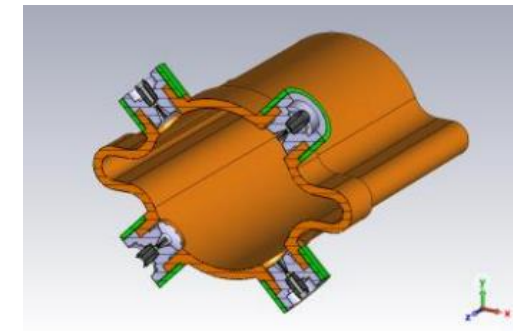
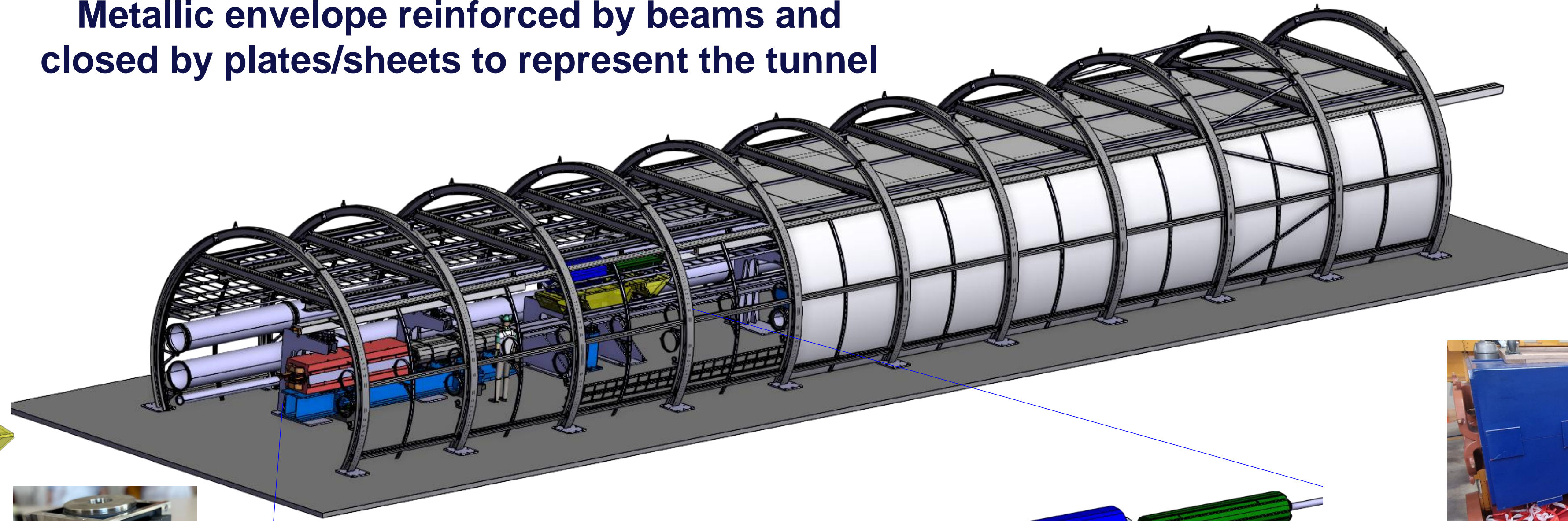
And: outreaching! (“Visual” demonstrator for FCC stakeholders).

Long term objective = An evolving mock-up allowing **equipment groups to install and test their equipment** → we are designing the envelope and supports to be able to host, in a future, the full-size/weight functional elements



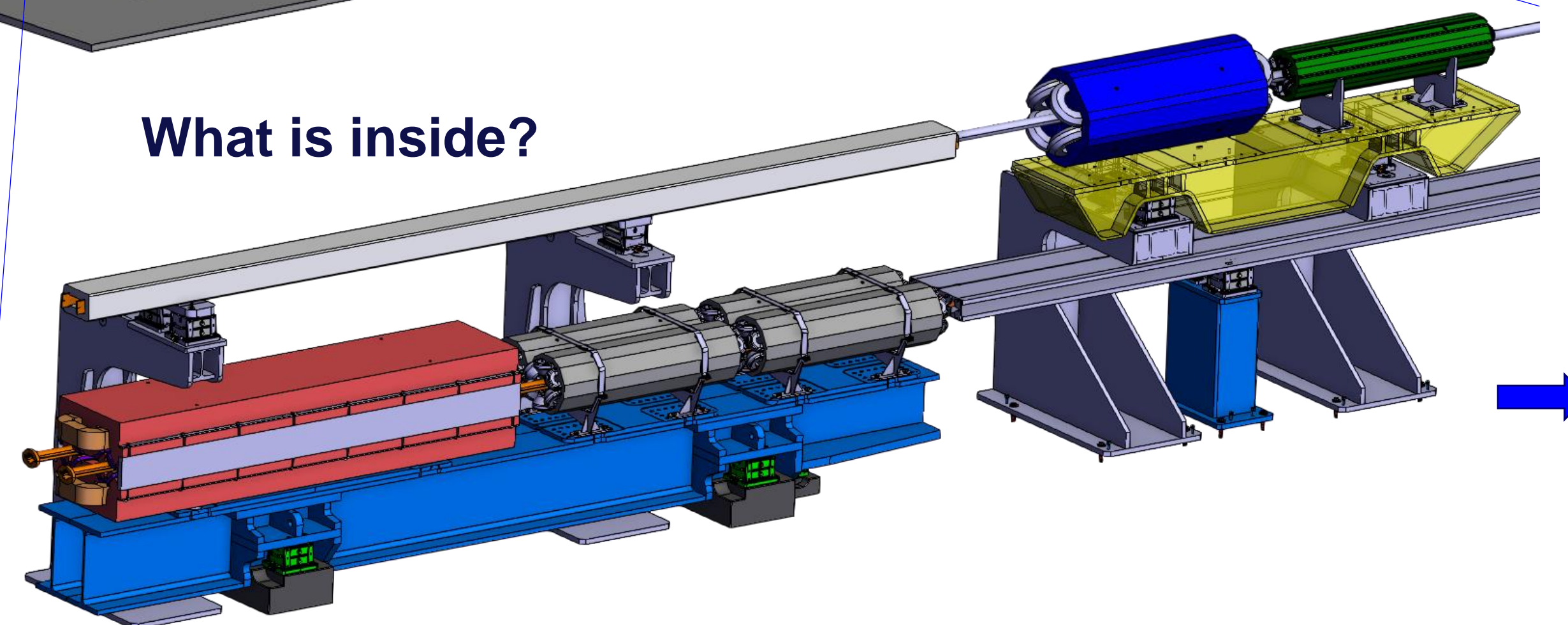
How the 1:1 Mock-up will be built?

Metallic envelope reinforced by beams and closed by plates/sheets to represent the tunnel



Real supporting systems

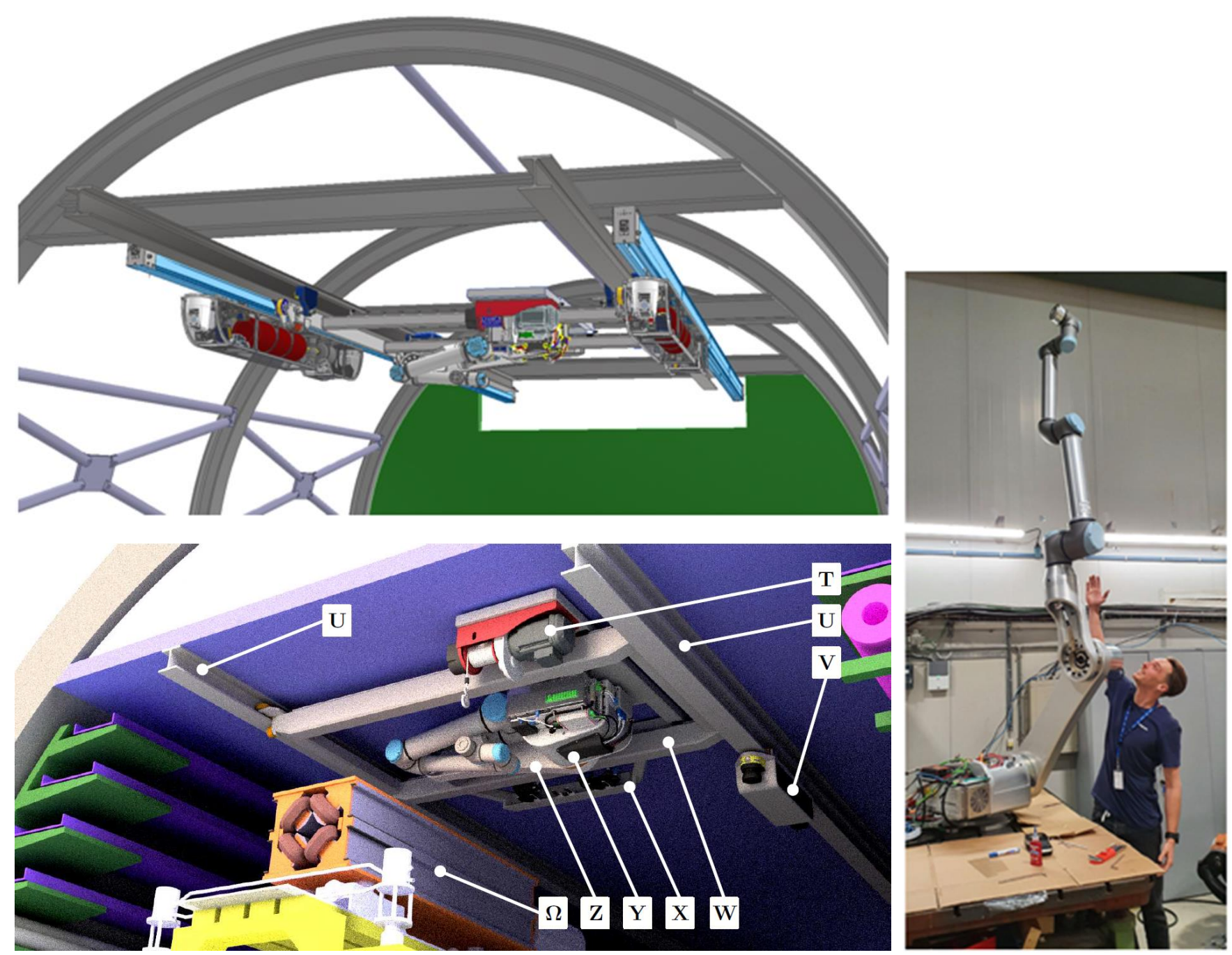
What is inside?



Representative dummy systems that can evolve into prototypes

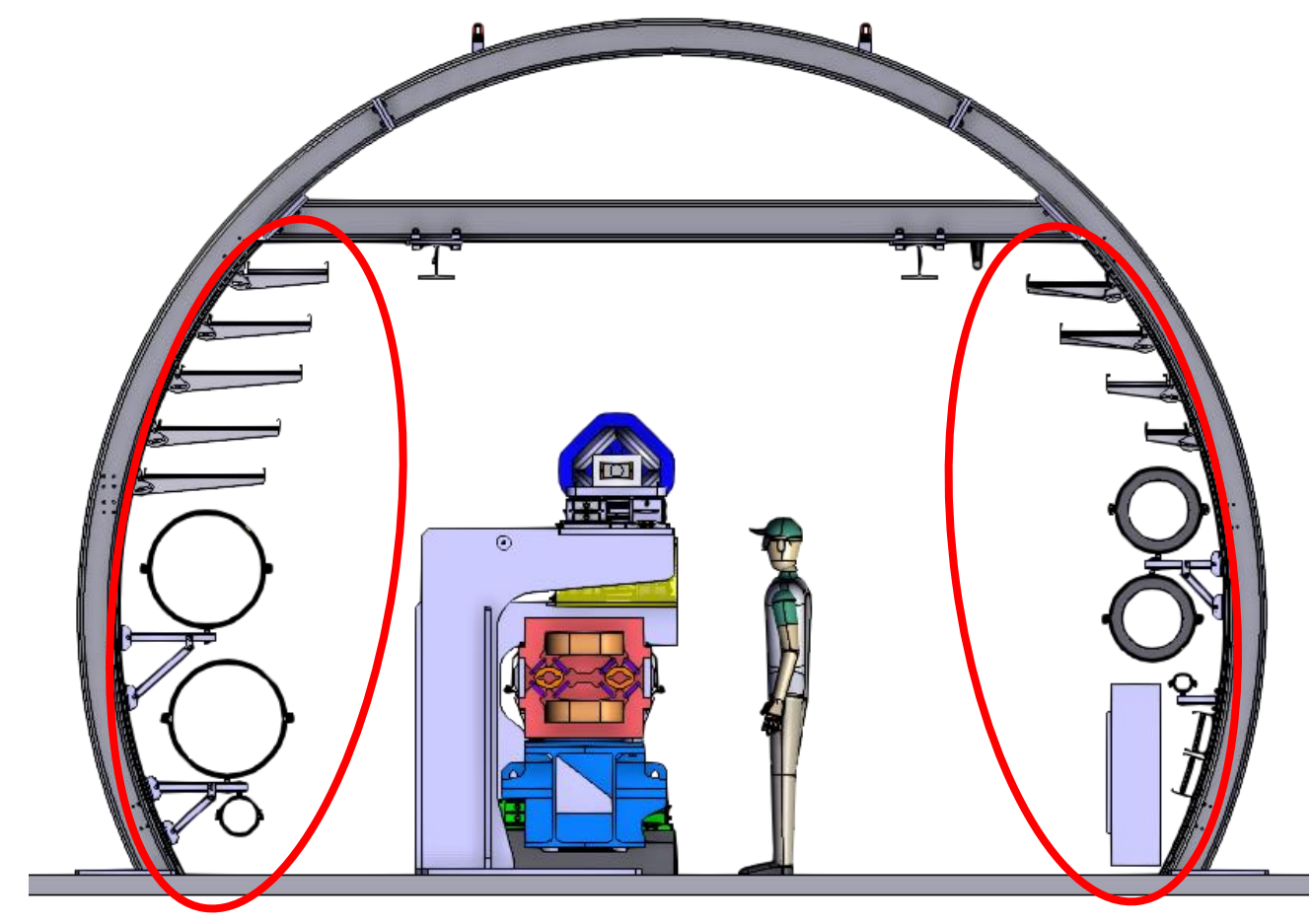
How the 1:1 Mock-up will be built?

Install a fire door to test safety aspects (HSE)

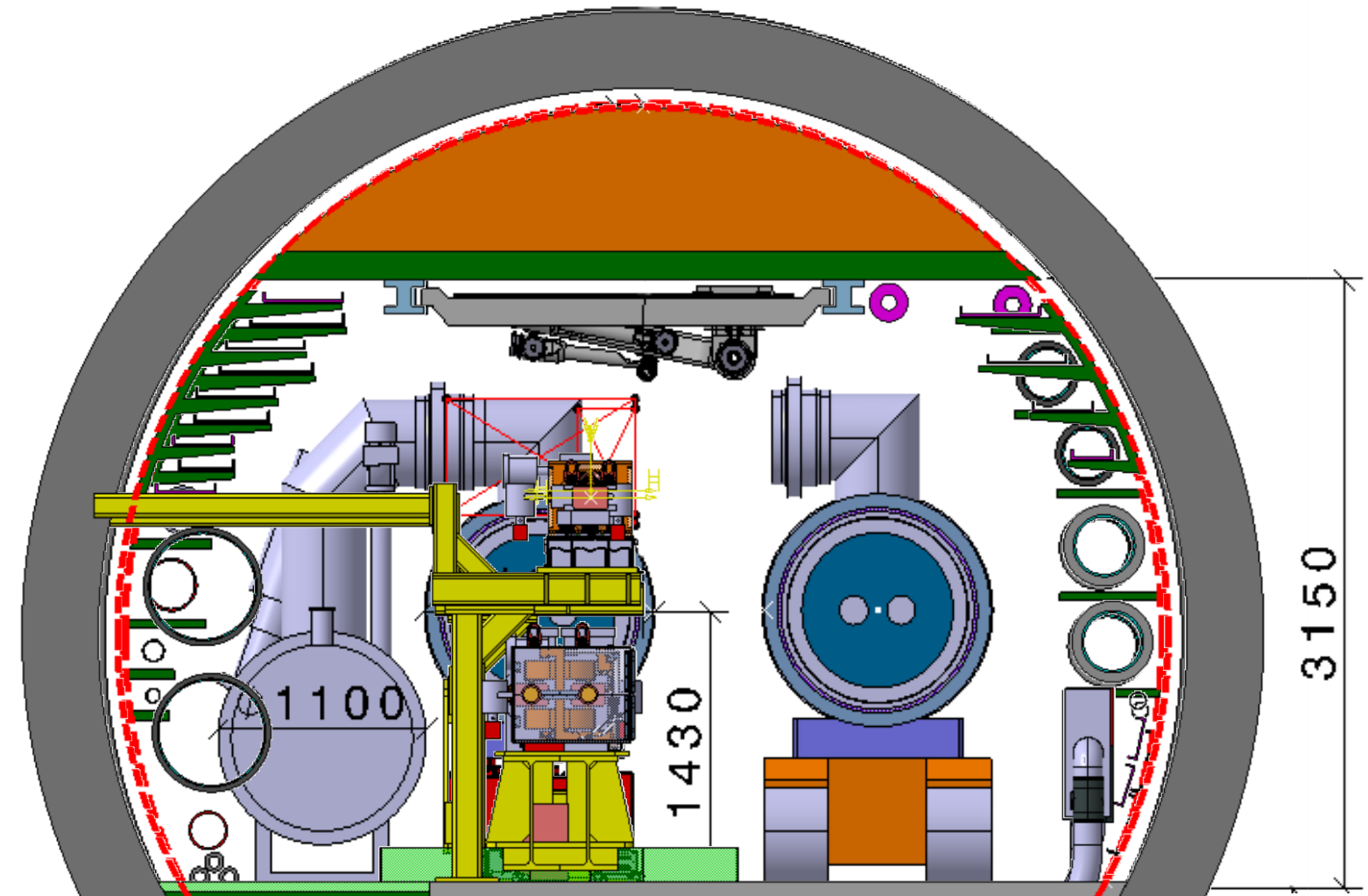


The FCC robot prototype will be installed and will move on two rails (BE/CEM)

Courtesy M. Rouchouse, H. Gamper, F. Valchkova-Georgieva, F. Carra



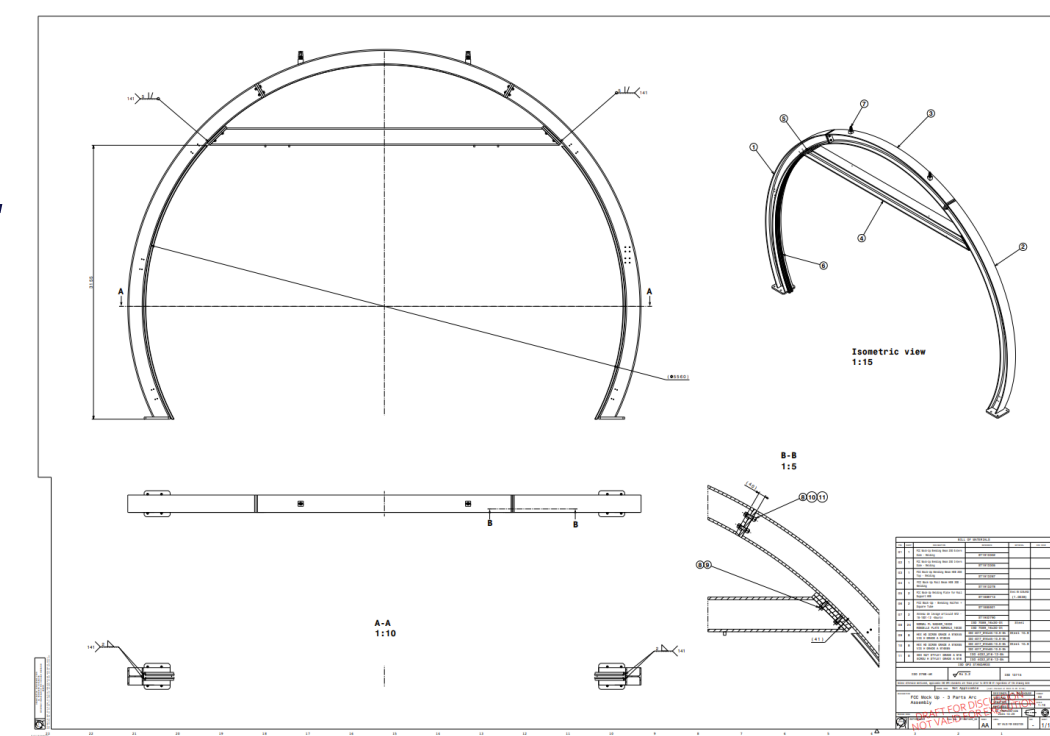
Services like pipes, cable trays will be fixed on the envelope



Use mixed reality to visualise the evolution of FCC-ee from low to high energy phase → FCC-hh

What studies does this 1:1 Mock-up involve?

- **Integration** of the mock-up inside a specific building in Meyrin site
 - *Considering the needs of transport and neighbouring building stakeholders is essential.*
- **Preparation and renovation works** on the building: *asbestos presence, lead paint, work on slabs, etc.*
- The whole project is conducted in **collaboration with HSE***
 - *Hazard identification (mechanical safety, fire safety, structural safety, working conditions etc.).*
 - *Steel structure assessment according to European standards.*
- Preparation of the **drawings** of the structure and performing all the **orders**.



Safety factor to be applied according to EN 1993-1-1 and EN 1990

One safety factor should be applied on the resistance of the material and safety factors should be applied on the actions while verifying the ultimate state: "Static equilibrium (EQU)"

2.4.3 Design resistances
 (1) For steel structures equation (6.6c) or equation (6.6d) of EN 1990 applies:

$$R_d = \frac{R_k}{\gamma_M} = \frac{1}{\gamma_M} R_k (\eta_1 X_{k1}, \eta_2 X_{k2}, \dots, \eta_n X_{kn}, \alpha_d) \quad (2.1)$$

 where R_k is the characteristic value of the particular resistance determined with characteristic or nominal values for the material properties and dimensions
 γ_M is the global partial factor for the particular resistance
 NOTE: For the definitions of $\eta_1, \eta_2, X_{k1}, X_{k2}, \dots, X_{kn}$ and α_d see EN 1990.

2.4.4 Verification of static equilibrium (EQU)
 (1) The reliability format for the verification of static equilibrium in Table 1.2 (A) in Annex A of EN 1990 also applies to design situations equivalent to (EQU), e.g. for the design of holding down anchors or the verification of uplift of bearings of continuous beams.

6 Ultimate limit states
6.1 General
 (1) The partial factors γ_{M2} as defined in 2.4.3 should be applied to the various characteristic values of resistance in this section as follows:
 resistance of cross-sections whatever the class is: γ_{M2}
 resistance of members to instability assessed by member checks: γ_{M2}
 resistance of cross-sections in tension to fracture: γ_{M2}
 resistance of joints: see EN 1993-1-8
 NOTE 1: For other recommended numerical values see EN 1993 Part 2 to Part 6. For structures not covered by EN 1993 Part 2 to Part 6 the National Annex may define the partial factors γ_{M2} ; it is recommended to take the partial factors γ_{M2} from EN 1993-1-8.
 NOTE 2B: Partial factors γ_{M2} for buildings may be defined in the National Annex. The following numerical values are recommended for buildings:
 $\gamma_{M2} = 1.00$
 $\gamma_{M2} = 1.25$

On the material
 $\gamma_{M2} = 1.25$

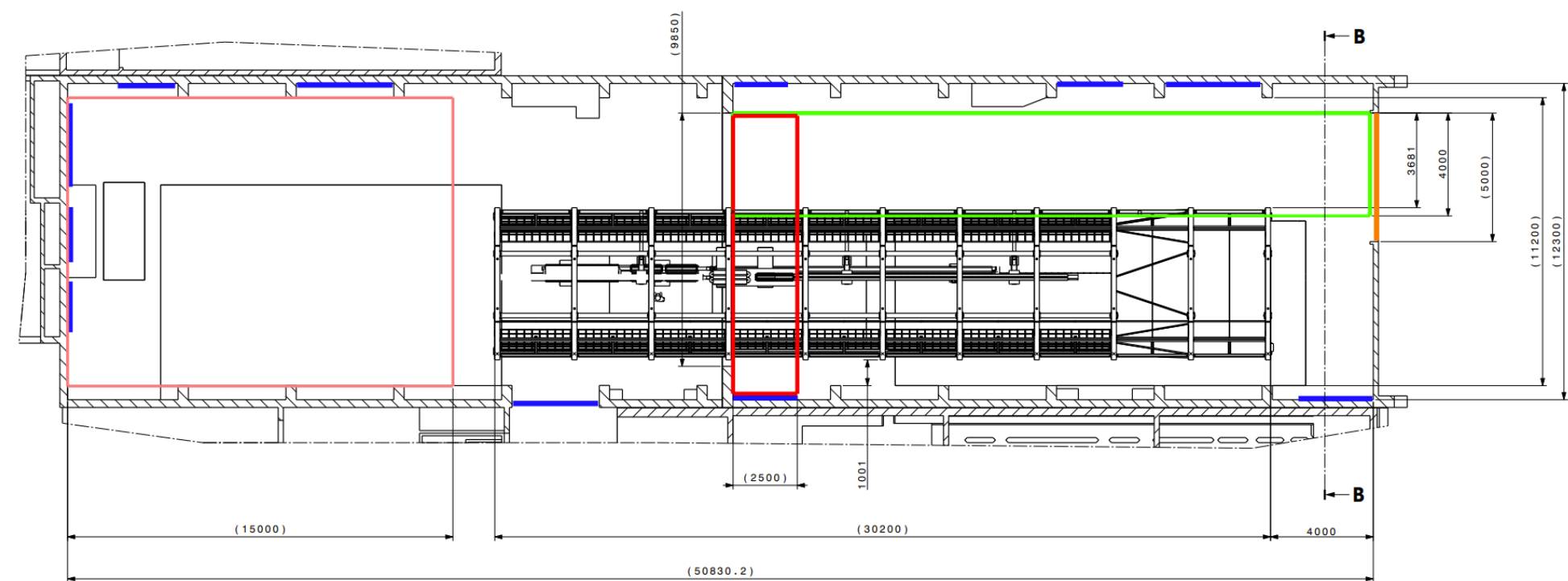
Table A1.2(A) - Design values of actions (EQU) (Set A)

Permanent and transient design situations	Permanent actions		Leading variable action (*)	Accompanying variable actions	
	Unfavourable	Favourable		Main (if any)	Others
(Eq. 6.10)	$\gamma_{G,inf} \gamma_{G,sup}$	$\gamma_{G,inf}$	$\gamma_{Q,1} \psi_{0,1} \psi_{1,1}$	$\gamma_{Q,2}$	$\gamma_{Q,3} \psi_{0,3}$

(*) Variable actions are those considered in Table A1.1.
 NOTE 1: The γ values may be set by the National Annex. The recommended set of values for γ are:
 $\gamma_{G,inf} = 1.00$
 $\gamma_{G,sup} = 0.90$
 $\gamma_{Q,1} = 1.50$ where unfavourable (0 where favourable)
 $\gamma_{Q,2} = 1.30$ where unfavourable (0 where favourable)
 $\gamma_{Q,3} = 1.35$
 $\gamma_{Q,3} = 1.50$ where unfavourable (0 where favourable)
 $\gamma_{Q,3} = 1.20$ where unfavourable (0 where favourable)
 provided that applying $\gamma_{Q,3} = 1.00$ both to the favourable part and to the unfavourable part of permanent actions does not give a more unfavourable effect.

For permanent and unfavorable actions + structural members
 $\gamma_{G,sup} = 1.35$

- █ = Access door
- █ = Main door
- █ = RF storage area
- █ = Truck access
- █ = Power converter handling



*Occupational Health & Safety and Environmental Protection

In parallel: a short functional demonstrator

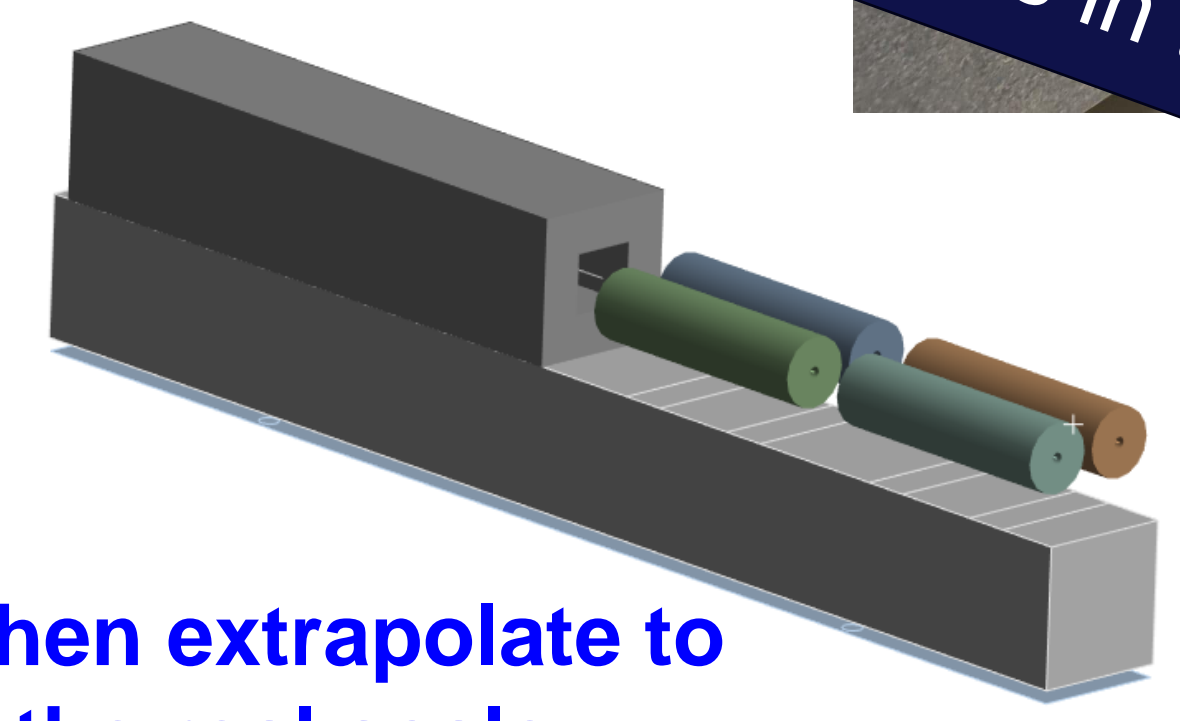
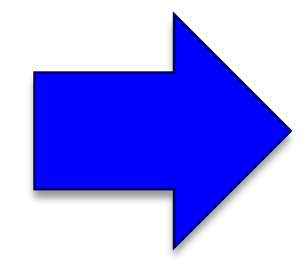
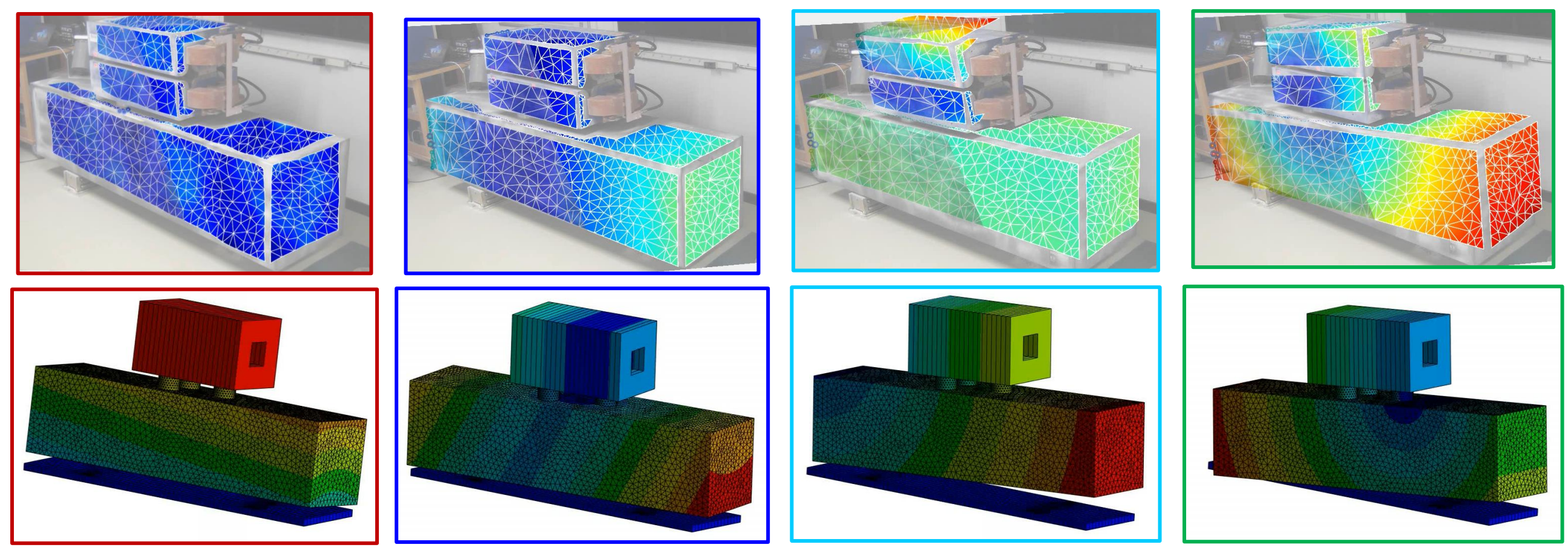
→ **WHY?** To know how the different elements of the SSS affect stability.
Do we have a fundamental problem of **dynamic stability**?
To obtain **first and fast feedback** for the design and at low-cost.

Simulations can predict the accelerator movement generated by ground motion, BUT Experimental benchmarking is needed to tune simulations (many uncertainties / assumptions!).



YES, considerable work is required to optimize systems in terms of stability

Validation of the short model (experimental vs numerical results)



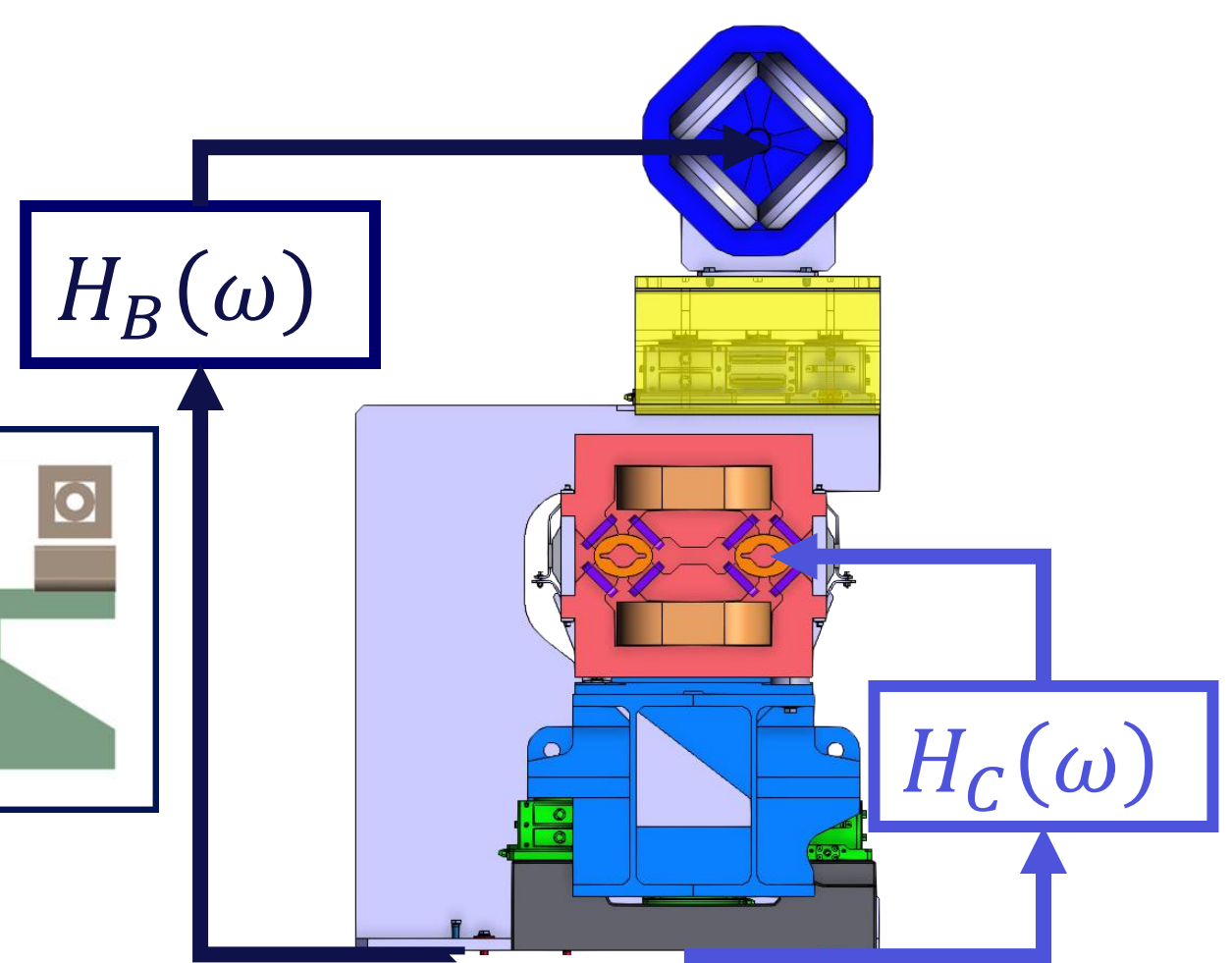
To then extrapolate to the real scale

To help optimizing the supporting structures

BOOSTER support

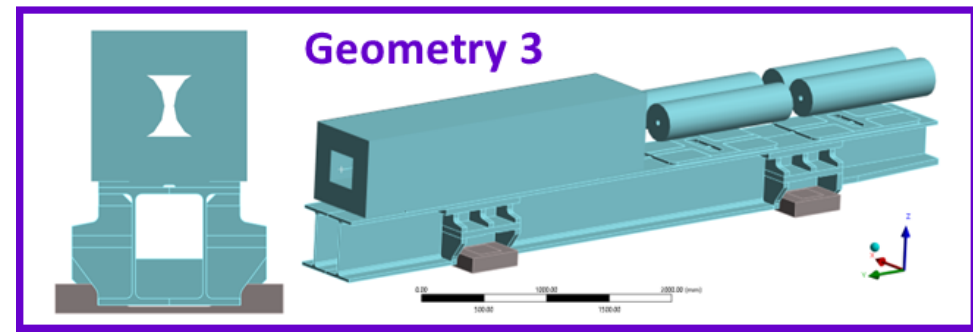
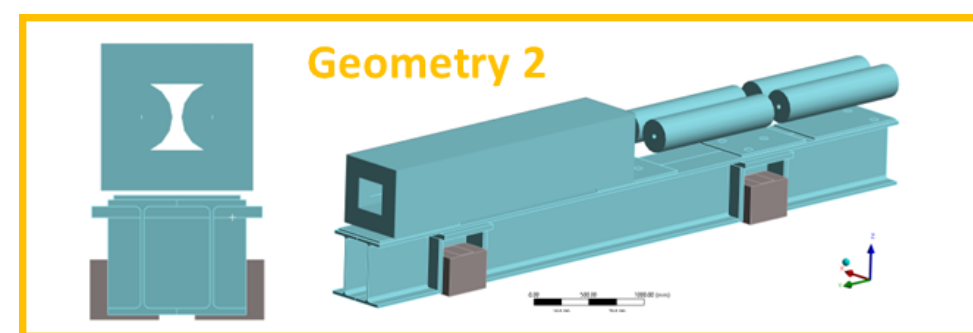
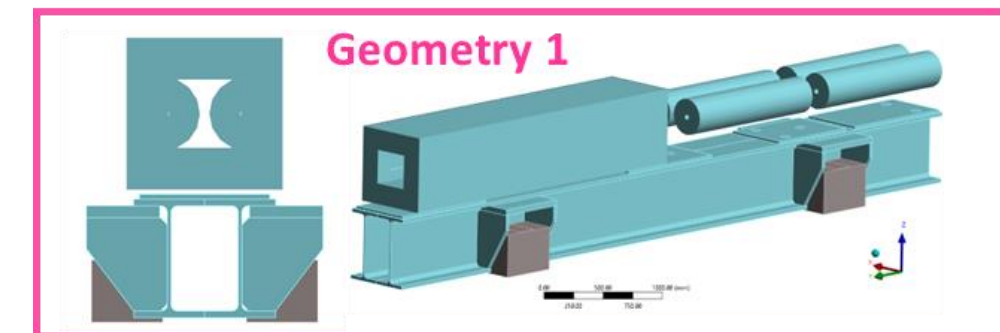
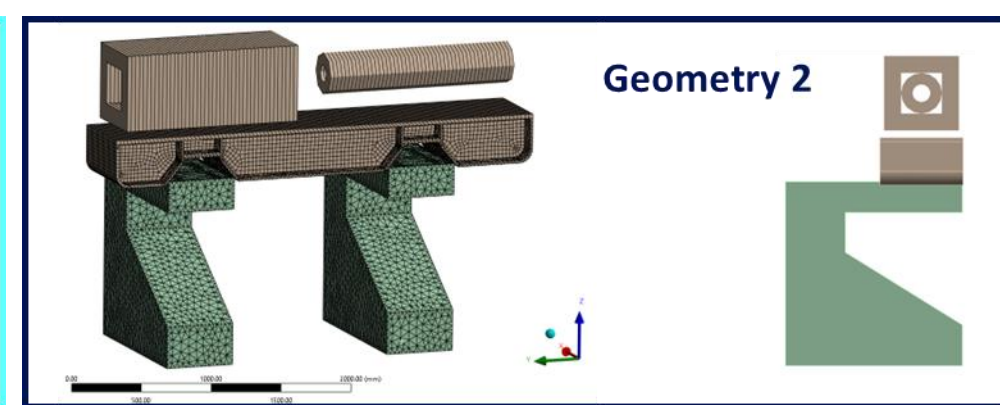
- Test / compare different:
- Geometries,
 - Fixations,
 - Etc.
 - Height,
 - Shift,

→ Structural and stability analysis of supports

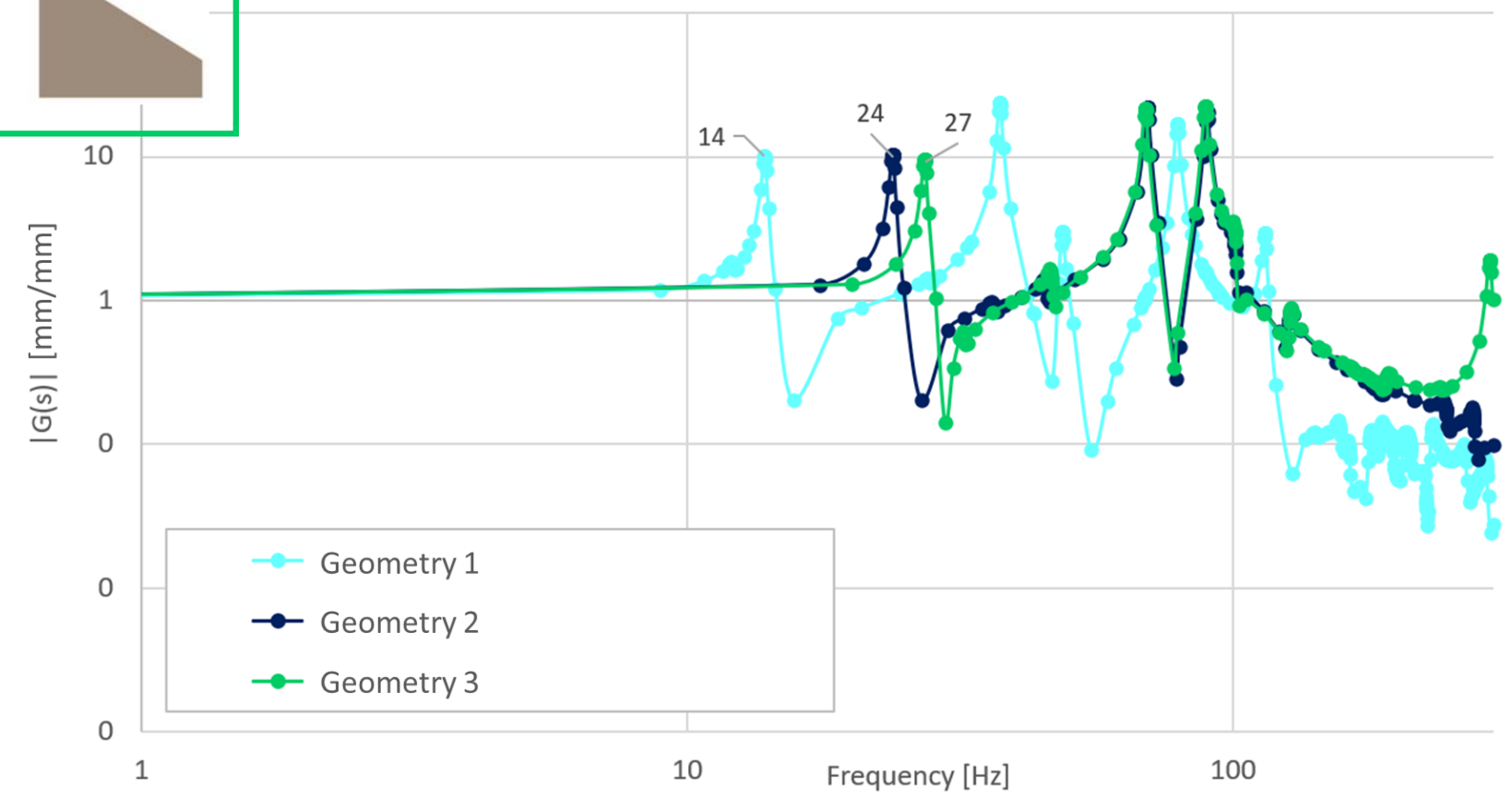


COLLIDER girder

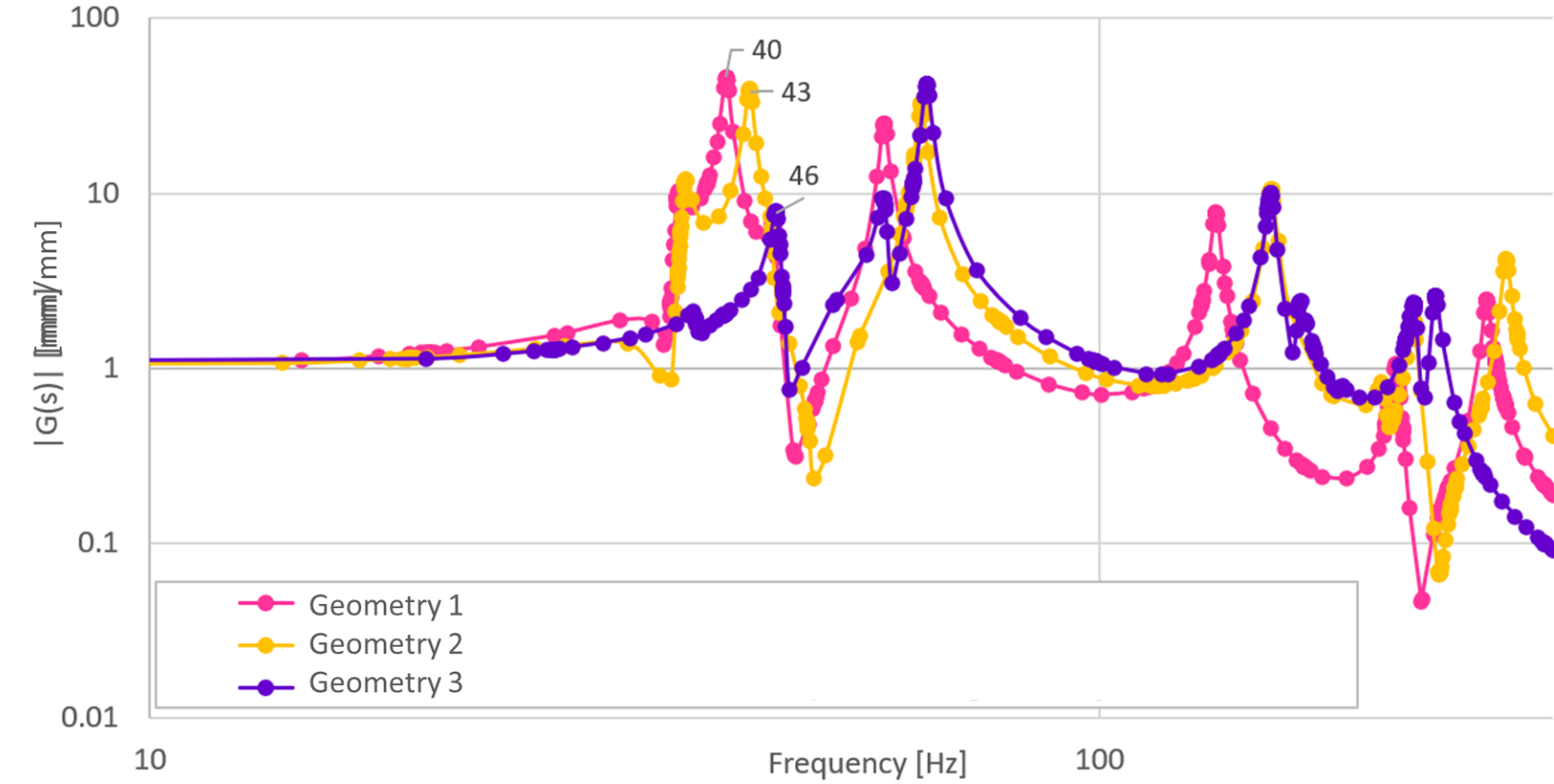
- Test / compare different:
- Geometries,
 - Material,
 - Etc.
 - Position of jacks,
 - Number/position of jacks,



Transfer function of the booster - VERTICAL

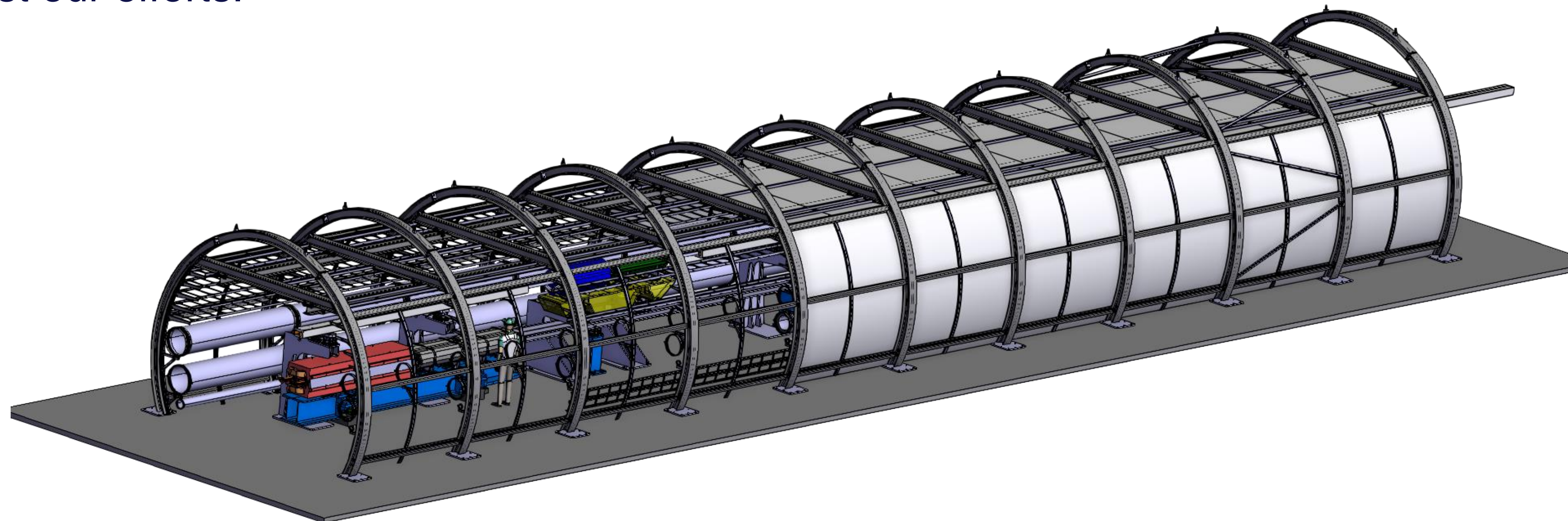


Transfer function of the collider - VERTICAL



Conclusion

- One of the important goals of the Feasibility Study is the **Mock-up of the arc half-cell** for FCC-ee.
- The design of **the mock-up structure** is finalized, and we are now ordering the different part for manufacturing, to prepare its installation.
- The **optimisation design studies** for the supporting structure account for a significant part of our work.
- These optimisation studies are completed by the **experimental campaign** allowing us to identify where to invest our efforts.





Thank you for your attention!