HOW TO BUILD A FUTURE COLLIDER?

Speaker: Francesco Fransesini

How to build a future collider?

I don’t know, of course…

…but I will try to explain why it is so difficult from engineering point of view.

What must we consider to built a future collider?

- Safety → Develop safe concepts.
- Sustainability → Reduce the environmental impact.
- Feasibility → Identify challenges and propose solutions.
- Affordability → Cost optimisation to respect the budget.
- Performance → Reach physics objectives.
- Mounting → Integration and alignment.
- Scheduling → The activities plan is crucial.
- Components design → Each components of the system require a design.
- Maintenance → All systems must last for decades.
- Infrastructure → The tunnel and services needed for the collider.
- Ad libitum → Every moment the things to be considered increase.

How to build a future collider?

To consider and respect each of the previous aspects, we need at least the following ingredients:

1. Manpower → The more important thing at each level of the project is **the human resources**, from management to the design. To achieve results respecting budget and time schedule the only way is to create a solid working group, well organized and correctly sized. It is important the correct distribution of senior and young, in order to **use the previous experiences to built the future**.

2. Existing Technologies → **The existing technologies are essential**, in fact, it is necessary to **understand how the problems have been resolved** and what kind of performances have been achieved in the present.
By studying the used solutions, it is possible to understand the **strengths and the weaknesses of each process.**

3. New Technologies → **New technologies are the base of a future project**. The last discoveries and inventions are necessary to project FCC in the future and to be able to achieve the result that is impossible with the existing technologies but feasible with the new ones. It is essential to investigate the latest ideas to understand how they can be developed for the project.

4. Future Technologies → In such a long term project, it is essential to consider the development of the technologies and the path that each technology will follow in the next years, intending to prevent what type of technologies we will have in the next year. It is important to **leave an open door to the future** with the idea of **integrating the new technologies during the project, during the building, without any fear of change**.

1 Manpower

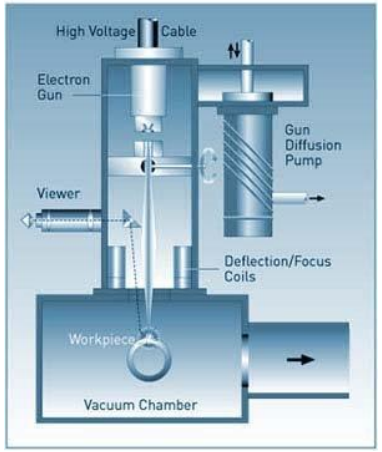
Presented by Michael Benedikt and Frank Zimmermann during the FCC week 2024

https://fcc.web.cern.ch/collaboration

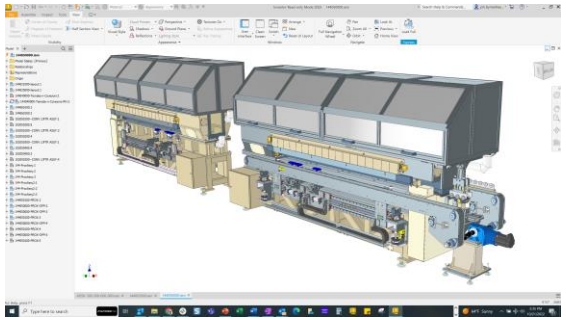
- **Particle Physicists**: Develop theoretical frameworks and experimental methodologies to explore fundamental particles and forces.
- **Accelerator Physicists and Engineers**: Design and optimize the accelerator components, such as vacuum components, magnets, radiofrequency systems, etc.
- **Cryogenic Engineers**: Develop and manage the cryogenic systems necessary for cooling superconducting magnets and other components to extremely low temperatures.
- **Civil and Structural Engineers**: Plan and oversee the construction of the extensive underground tunnels and surface facilities required for the collider.
- **Mechanical Engineers**: Design and maintain mechanical systems, including support structures, vacuum systems, and cooling mechanisms.
- **Electrical and Electronics Engineers**: Develop and maintain the complex electrical systems, including power supplies, control systems, and instrumentation.
- **Software Developers and Data Scientists**: Create software for data acquisition, processing, and analysis, as well as simulation tools for modeling experiments.
- **Project Managers**: Coordinate the various aspects of the project, ensuring timelines, budgets, and quality standards are met.
- **Environmental and Safety Specialists**: Assess and mitigate environmental impacts and ensure compliance with safety regulations throughout the project's lifecycle.

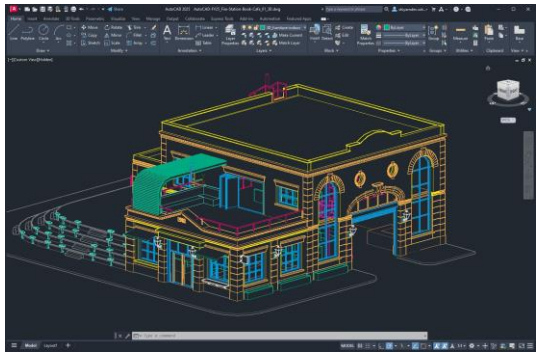
2 Existing Technologies

- Ordinary manufacturing techniques (milling, turning, welding)

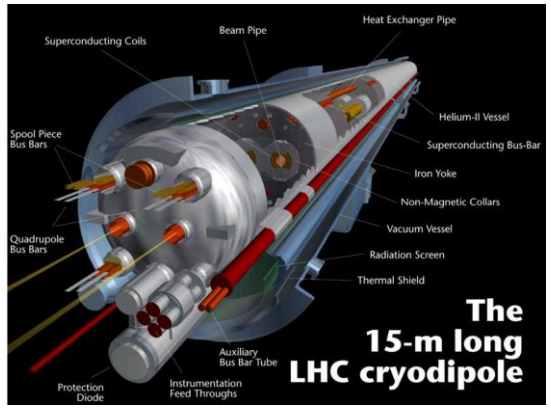


- Ordinary engineering design process (CAD, CAM, FEM)





- Usual accelerator components



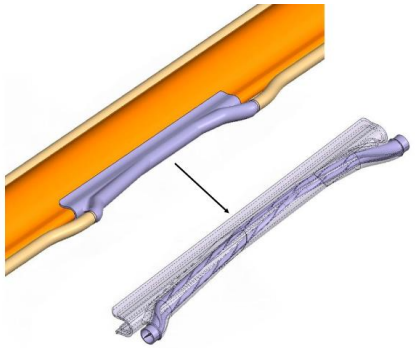
3 New Technologies

- Additive manufacturing → allows to create more complex geometries, needed when it is important to achieve specific requirements.

Cold-spray for Beam Position Monitors (BPM)

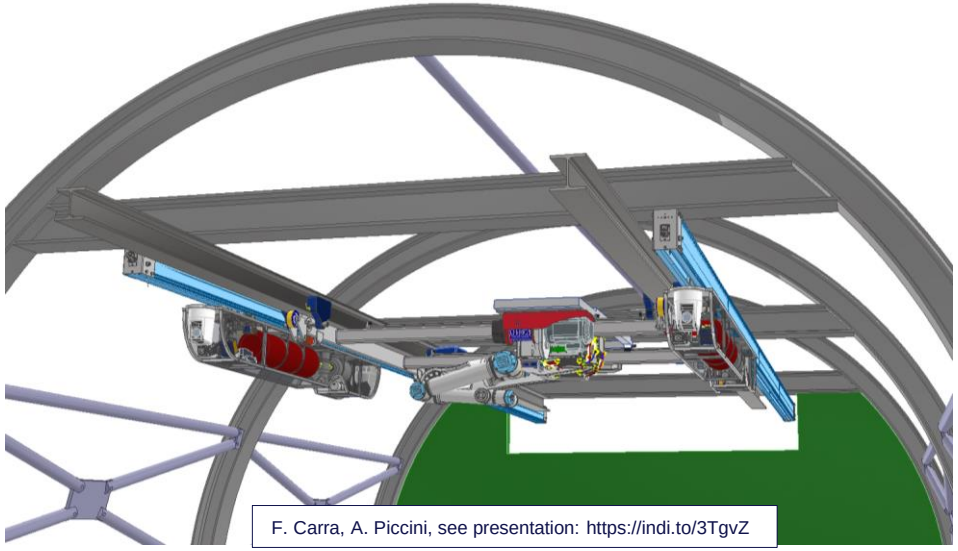
Courtesy C. Garion, M. Morrone

Synchrotron Radiation Absorber 3D printed



Courtesy C. Garion, M. Morrone

- Robotics →
  - **Operational Safety** - Protect workers from dangerous interventions (radiation exposure, etc.)
  - **Availability - Corrective & preventive maintenance** increasing maintainability/ Predictive maintenance increasing reliability
  - **Emergency/safety** - Technical/Medical Emergencies, Situation Awareness, Detect and engage hazards.



F. Carra, A. Piccini, see presentation: https://indi.to/3TgvZ

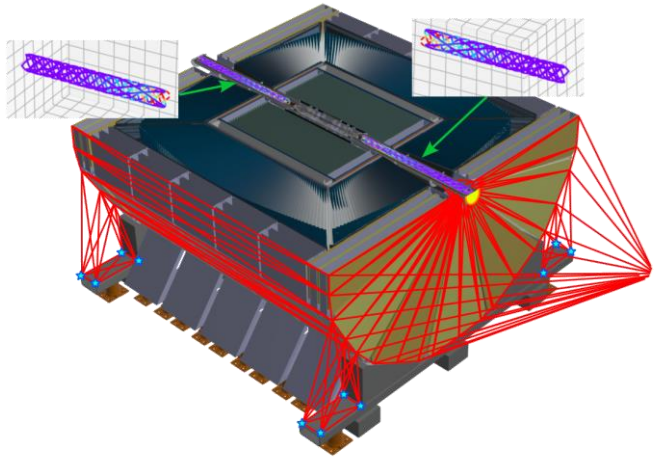
Remote Maintenance & Inspection System

Example of specific fire fighting robots: Angatec TEC800

3 New Technologies

- Alignment→ deformation monitoring system

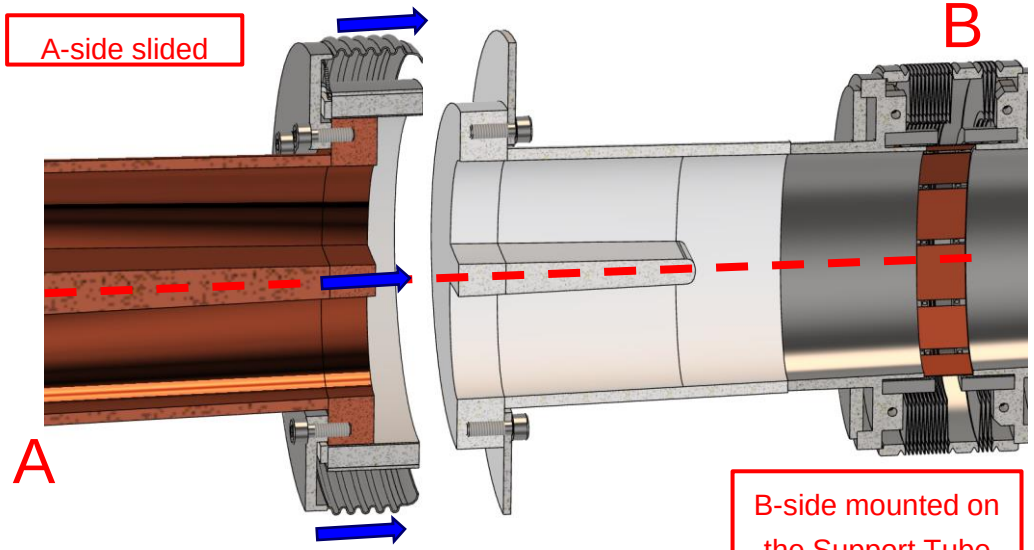
For example, in the Interaction region of FCC, the idea is to use a deformation monitoring system, to follow the alignment of the final focusing quadrupoles, coupled with an interferometric distance measurements network.

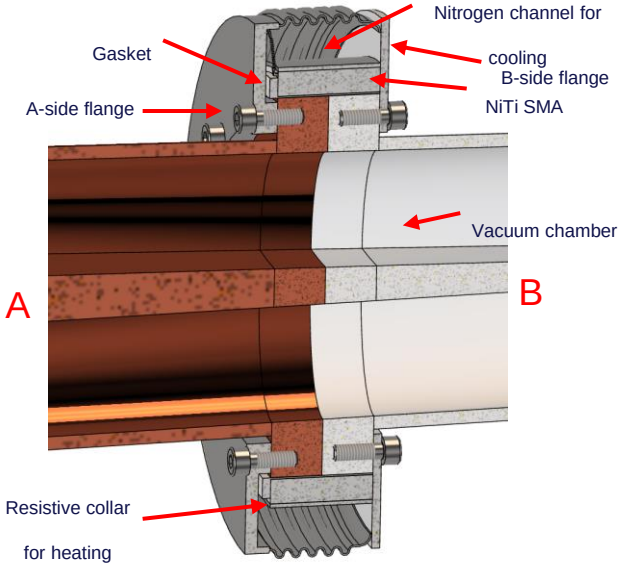


Watrelot, Léonard, Mateusz Sosin, and Stéphane Durand. "Frequency scanning interferometry based deformation monitoring system for the alignment of the FCC-ee machine detector interface." *Measurement Science and Technology* 34.7 (2023): 075006.

Watrelot, Léonard. *FCC-ee Machine Detector Interface Alignment System Concepts*. Diss. HESAM Université, 2023.

- New material → Shape memory alloy (SMA) is a material that can recover a large pseudoplastic deformation through heating. This process can be reversable using two-way shape memory alloy, this material can switch between two different shape simply by heating and cooling. In this way is possible to create a connection dismountable between two parts.

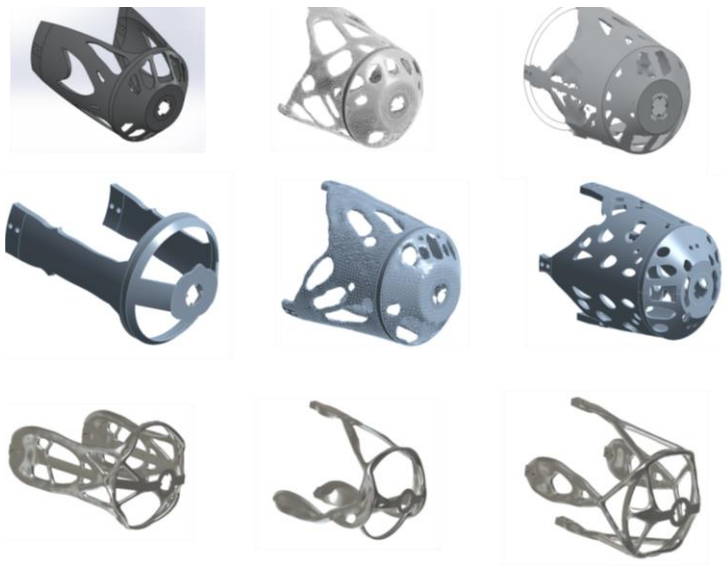


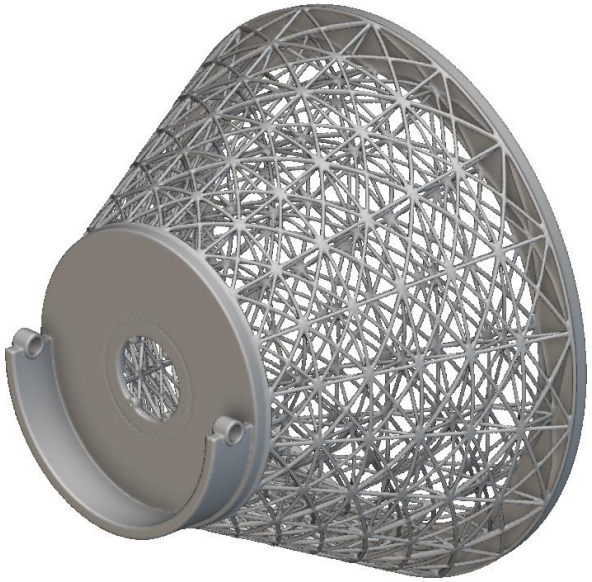


F. Niccoli, F. Fransesini

3 New Technologies

- Structural optimization → is a field of engineering and design focused on improving a structure's performance by optimizing its material distribution, shape, size, and other parameters while satisfying specific constraints. The primary goal is to create structures that are as efficient, cost-effective, and high-performing as possible.



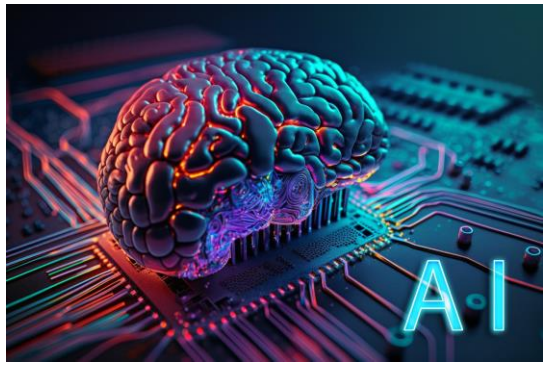


- Digital twin → is a virtual representation of a physical object, system, or process that is used to simulate, monitor, and optimize its real-world counterpart. It integrates data from the physical entity with advanced technologies such as sensors, the Internet of Things (IoT), artificial intelligence (AI), and machine learning to provide real-time insights, predictions, and decision-making capabilities.

Benefits of Digital Twins:
- **Improved Performance**: Real-time monitoring helps optimize operations.
- **Predictive Insights**: Anticipate failures or inefficiencies before they occur.
- **Cost Savings**: Reduce maintenance costs and downtime.
- **Better Decision-Making**: Simulations help assess different scenarios.
- **Enhanced Innovation**: Test and refine designs without physical prototypes.

4 Future Technologies

- The perfect integration between Artificial Intelligence and each system of the accelerator. In the following year AI will be relevant in term of technologies development. It will be crucial during the optimization phase, in fact it could be possible to predict scenarios in order to predict the best.



- Invention of new materials: in every field materials more performant are crucial:
  - increasing the mechanical resistance →to reduce the weight;
  - reducing the thermal conduction → to reduce the thickness of thermal shielding→ reduce the material budget;
  - increasing the buckling limit you can reduce the beam pipe thickness

- New data exchange technologies: WiFi N-versione, xG (after the 5G), Li-Fi, etc.

How to build a future collider?

Different fields are essential; each needs human resources, financial resources and management.

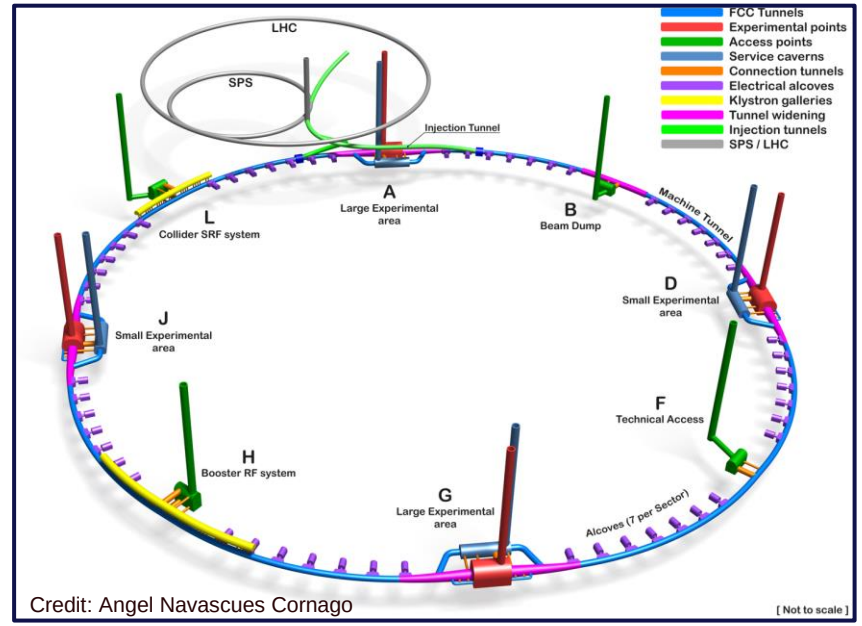
1. Civil engineering
2. Alignment
3. Safety Systems, Transport Logistics and Survey
4. Accelerator and detector components

1 Civil engineering

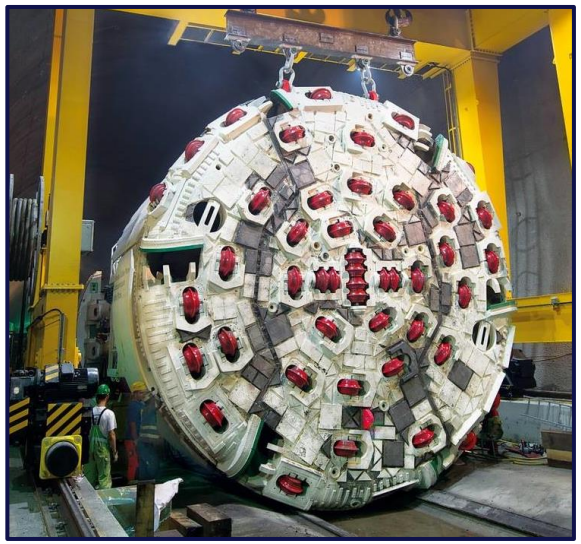
The civil engineering job regards not only the building construction but also the construction of the tunnel.

It is important:

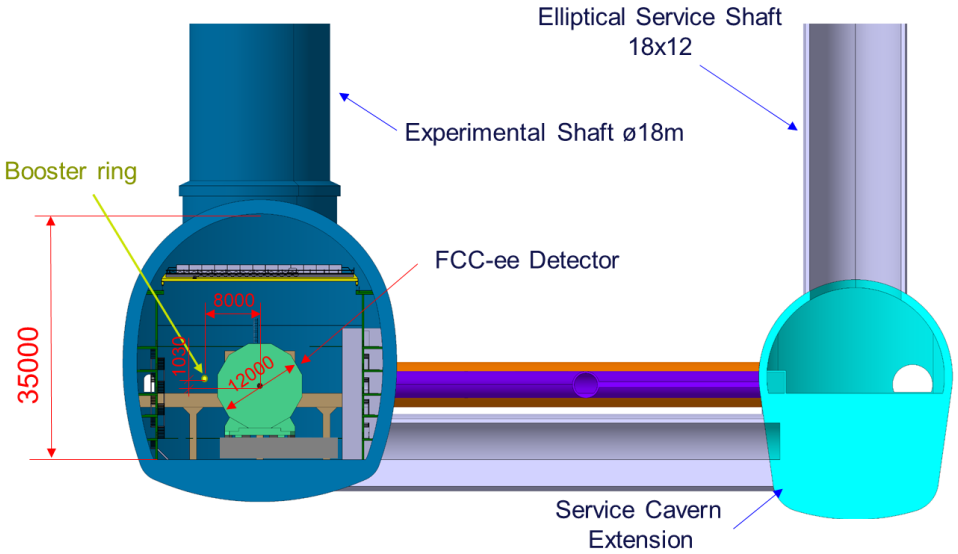
- to respect the budget and the time scheduling.
- reuse the material extract from the ground to respect the sustainability principle.



Credit: Angel Navascues Cornago



TBM (tunnel boring machine)



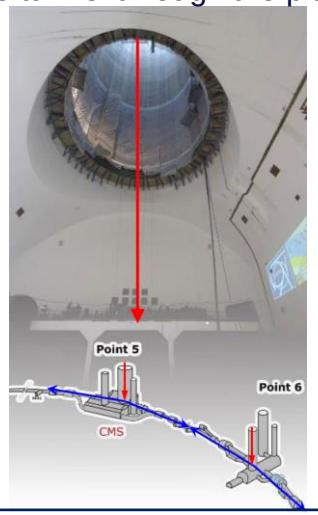
Multi-service vehicles

2 Alignment

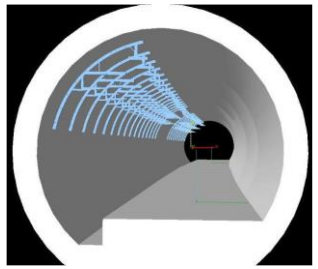
Courtesy of Léonard Watrelot

Alignment starts always from the surface …

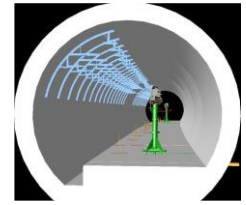
… then is transferred to the tunnel through the pits



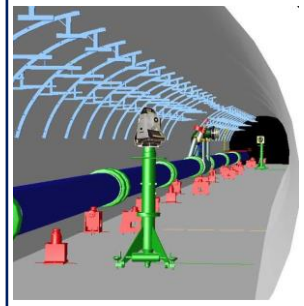
Intervention while the tunnel is still empty, installation of the reference network.



While the tunnel is still empty, marking for all the jacks

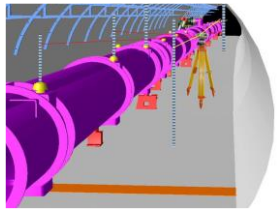


Installation and prealignment of all the jacks

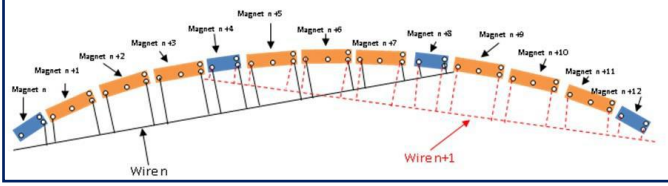


Fiducialisation : Transfer of the reference axis on fiducials (= point references on the object).

First alignment of the components in the tunnel.



“Smoothing” of the alignment, so the components are on a smooth line with no “steps”.



Maintenance of the alignment as often as required.
(as challenging as the initial installation due to the new constraints appearing with the operation of the machine)

Note :
These alignment steps are heavily time-consuming and very repetitive. FCC will be in a way bigger scale, requiring R&D to automatize as much as possible these operations.

3 Safety Systems

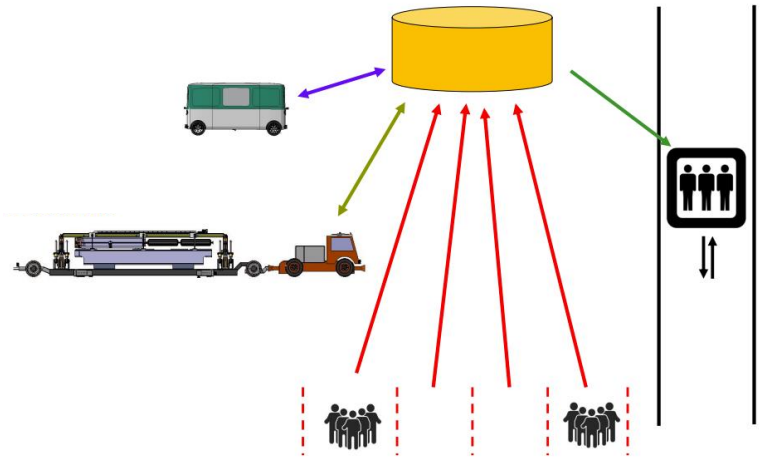
It is important to pay attention to the safety system:

- Access control;
- Fire detection system
- ODH (Oxygen deficiency hazard) detection system

→ Active safety system, evacuation plan, training, etc.

3 Transport Logistics and Survey

Courtesy of R. Rinaldesi

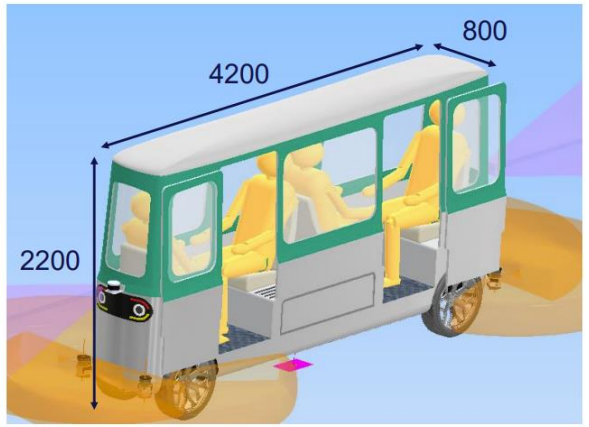


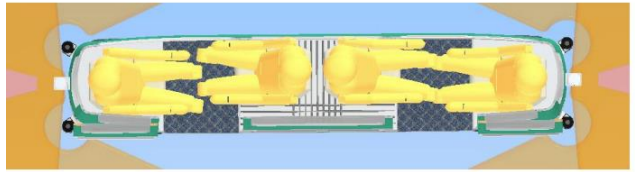
Centralized traffic management

It is crucial to know how to move personnel and goods in the tunnel and it is something that has to be investigated at the beginning, in order to foresee the space and the required tools inside the tunnel.

B O Müller

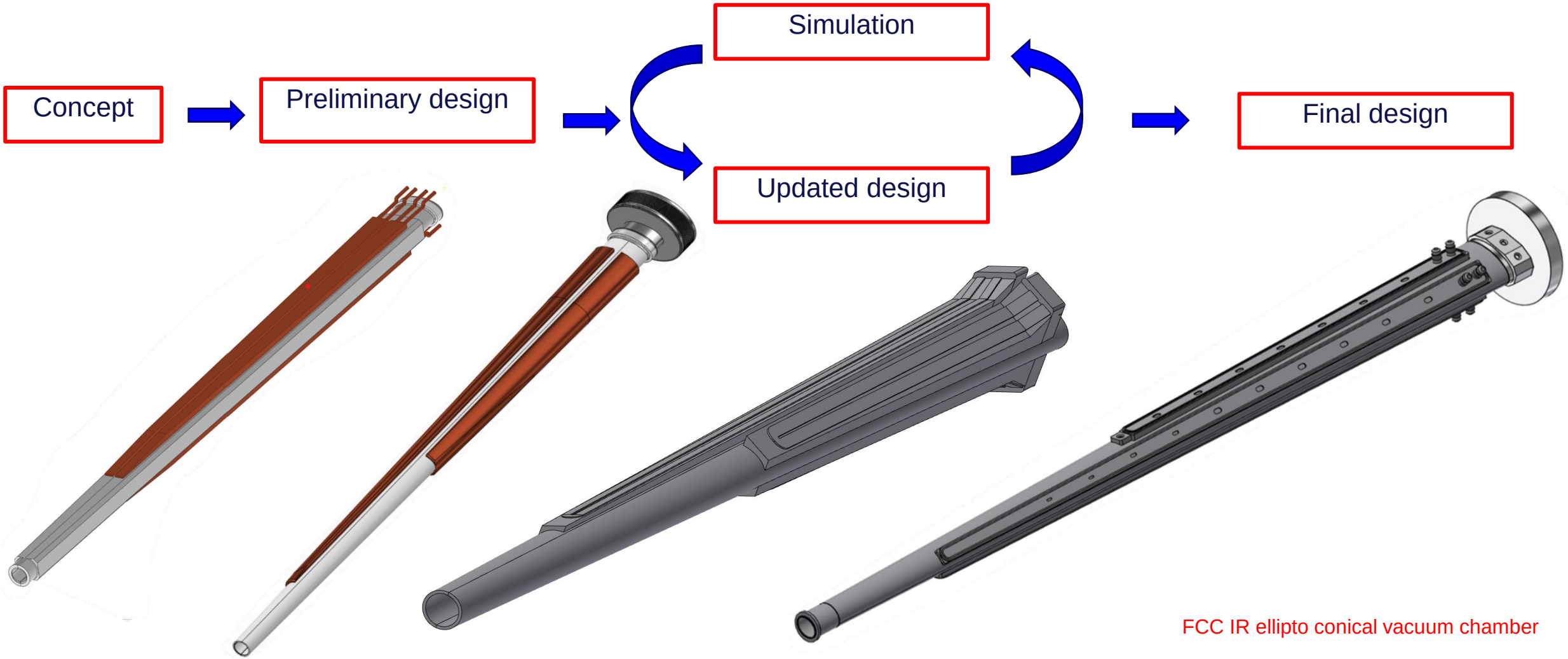
Autonomous personnel transport





4 Accelerator and detector components

Another important aspect of the question “How to build a future collider?” is the design of all the mechanical components needed, from the accelerator side and detector side.



FCC IR ellipto conical vacuum chamber

Conclusion

With this presentation, we probably know less than ever “How to build a future collider?”, but maybe we are more aware of the complexity and the ingredients needed.

- The human resources and the international collaboration are foundamental for the success of the project;
- In order to achieve the results aspected, collaboration between multidisciplinary figures such as physicists, engineers, economists, managers, etc. is necessary.
- The technologies are crucial for each step and it is important to pay attention to the future ones, to be able to include them in the future steps of the project.
- There isn’t a complete handbook with the title «How to build a future collider?”, the only way to do this is to stay aware of the progress made in each field and be able to update your own skills over the years.

INFN LNF

THANK YOU FOR YOUR ATTENTION

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