INTEGRATION CHALLENGES IN COLLIDER DETECTORS FOR PARTICLE PHYSICS

The examples of the CMS experiment Tracker and High-Granularity Calorimeter for High-Luminosity LHC operation

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LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
LHC 27 km


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ATLAS
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SPS 7 km
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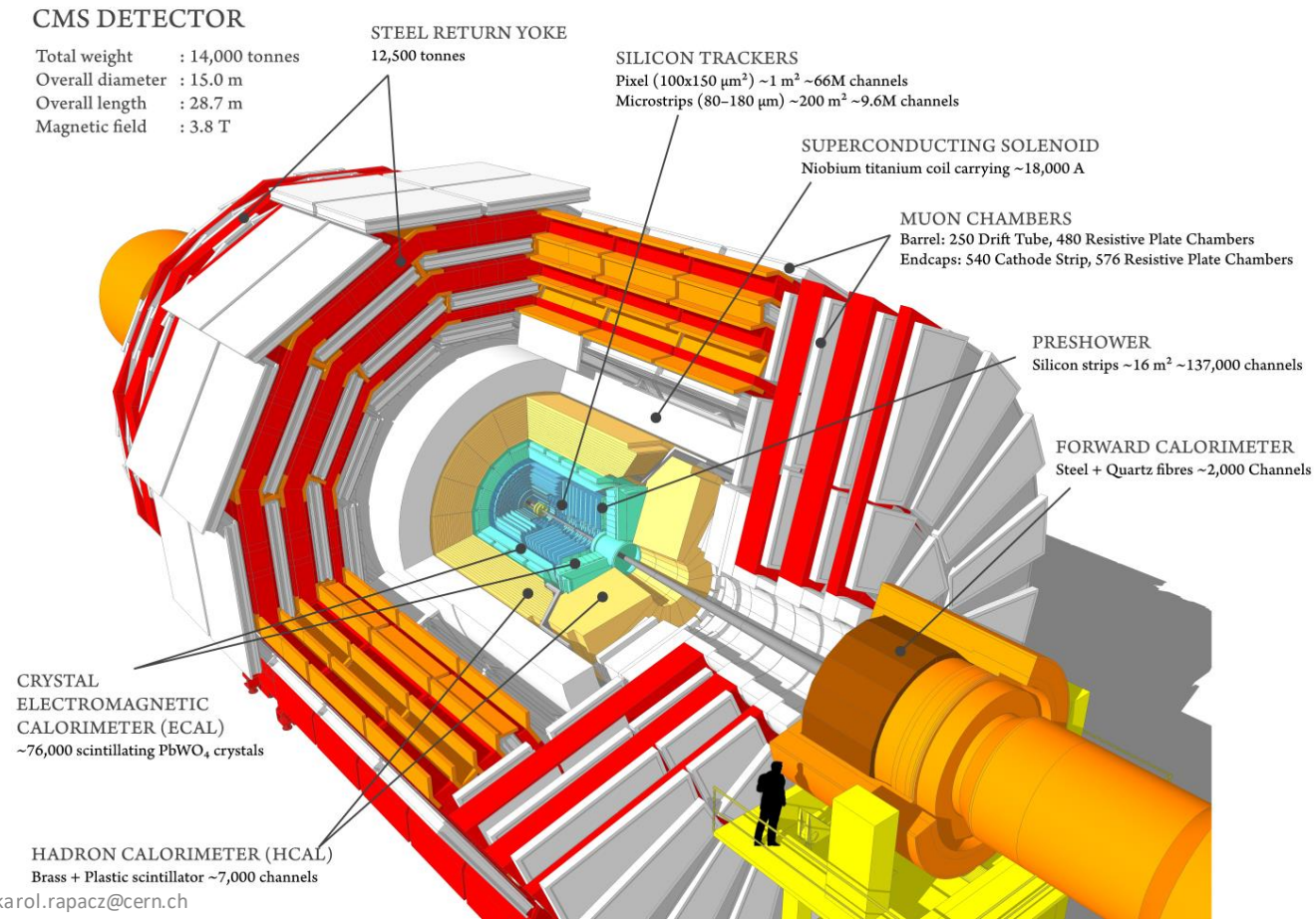
LHC 27 km

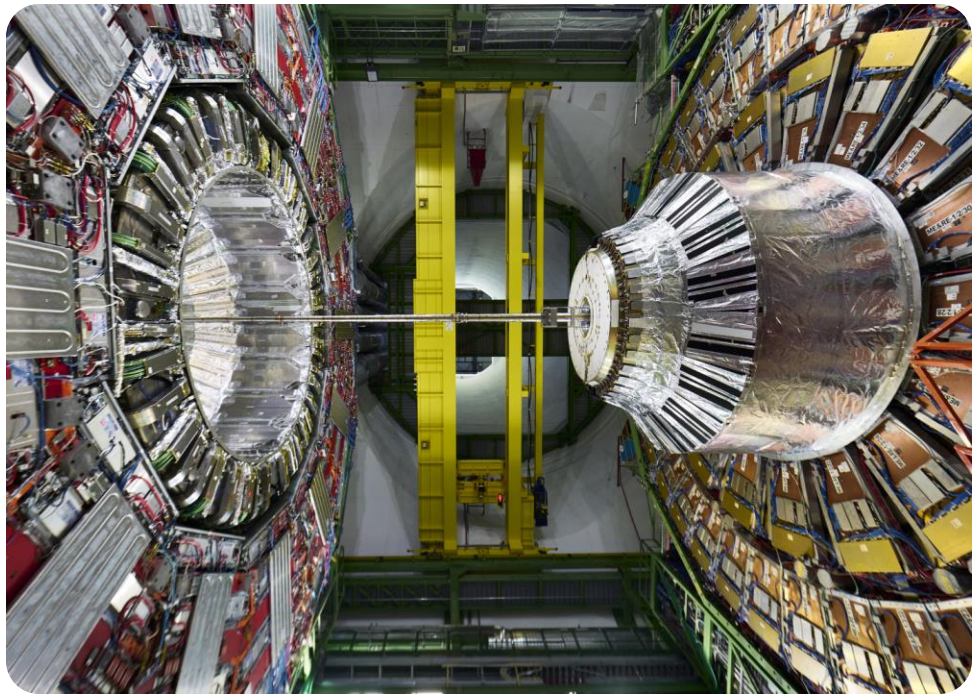
Challenge counter:

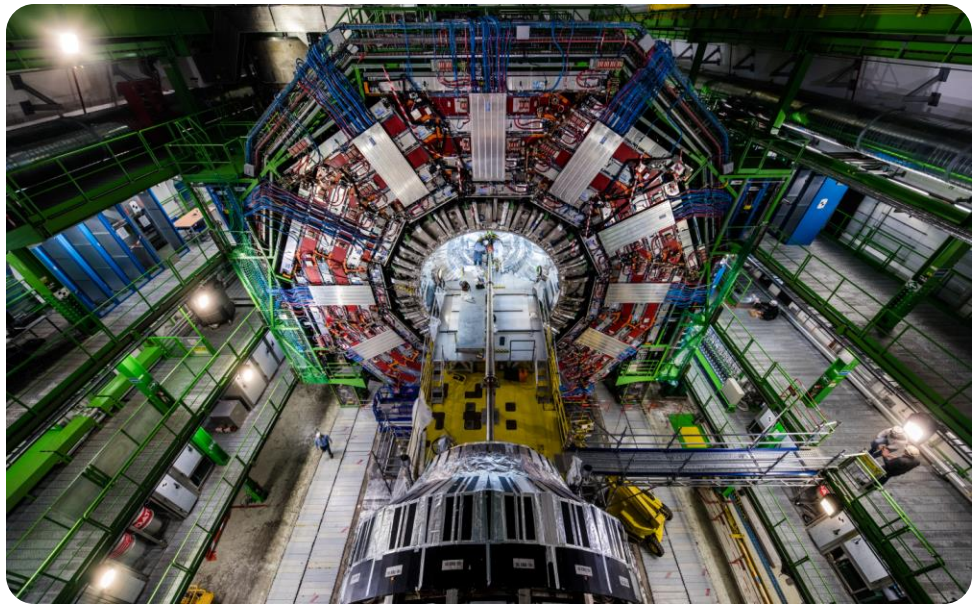
Challenge counter:

- Location

What is CMS?







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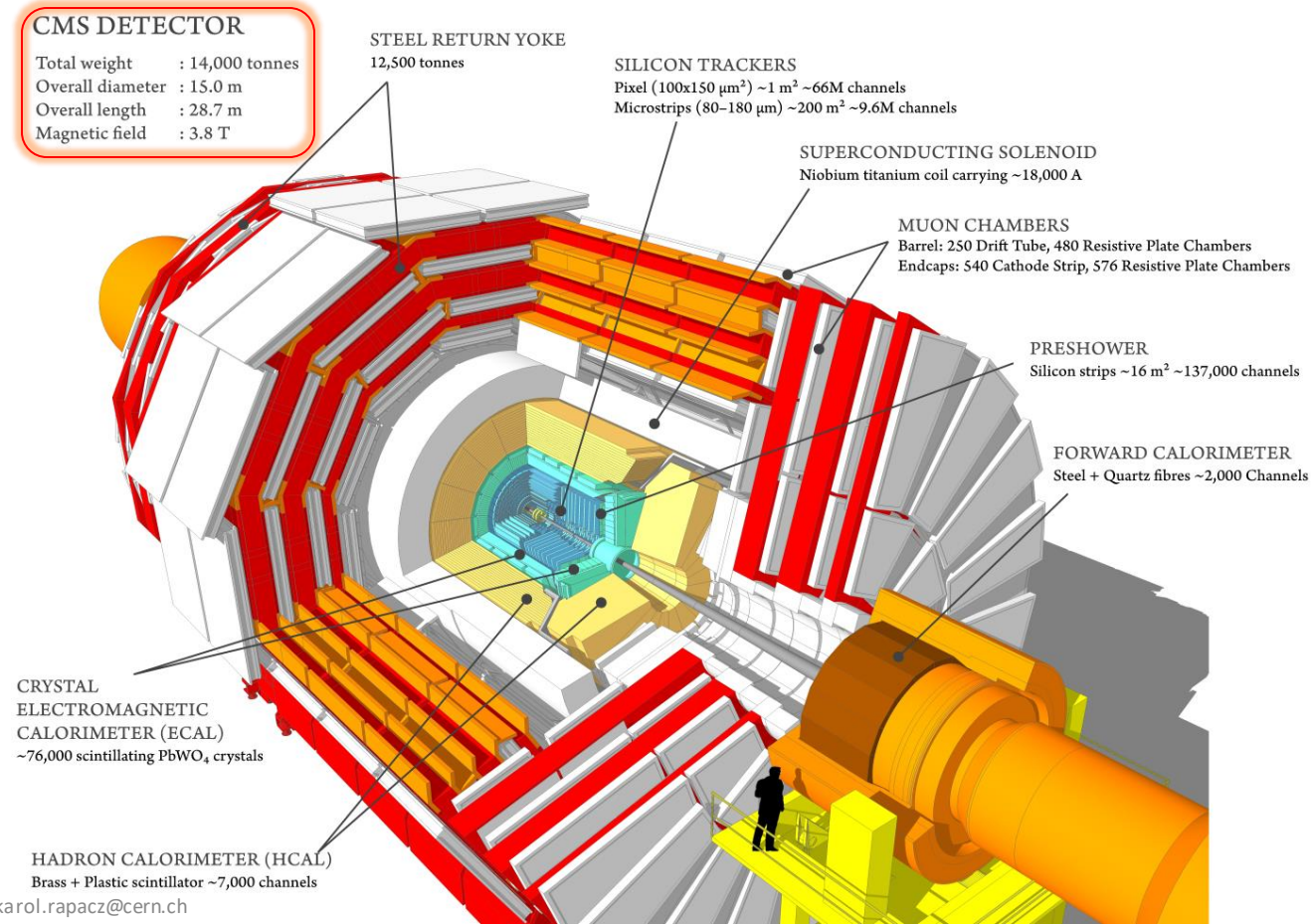

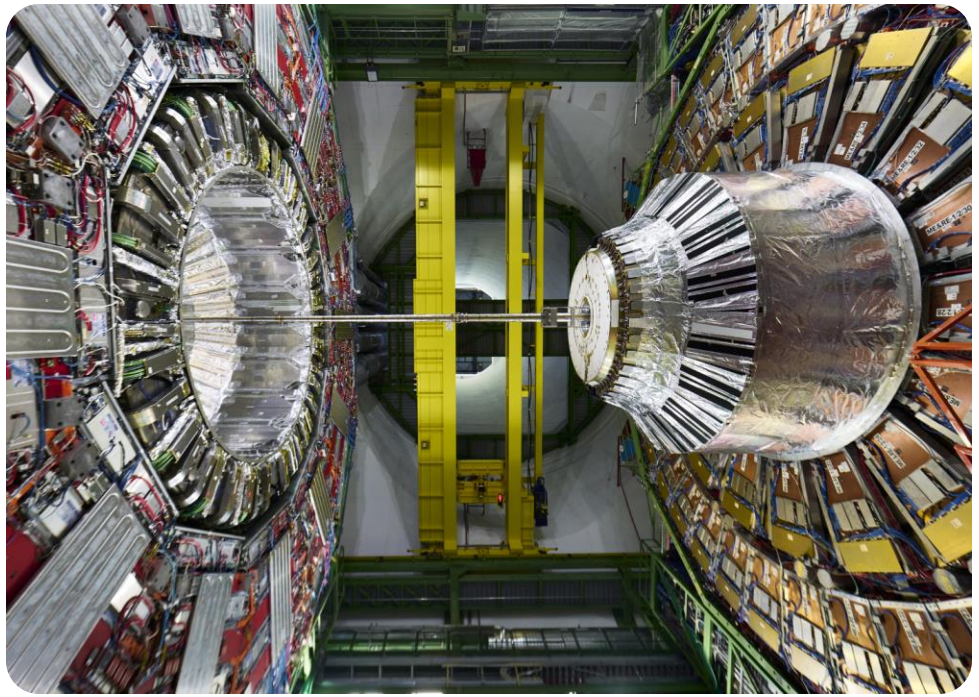

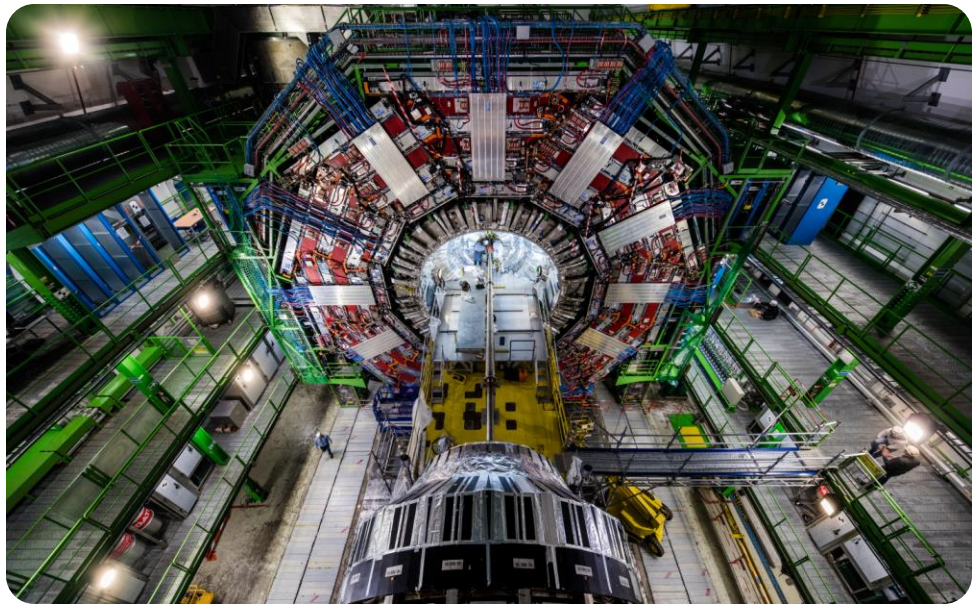

Challenge counter:

- Location
- **Size**

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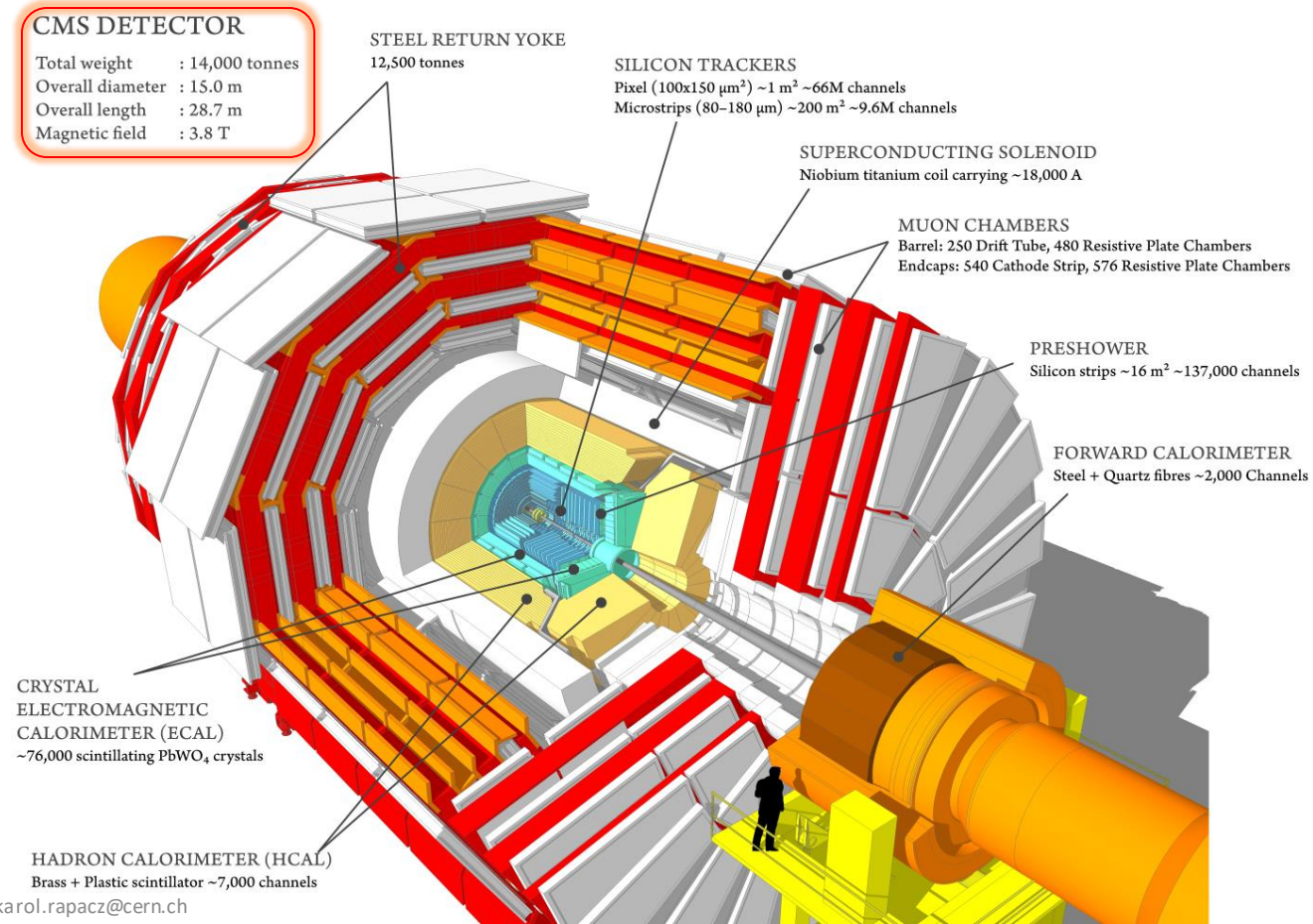
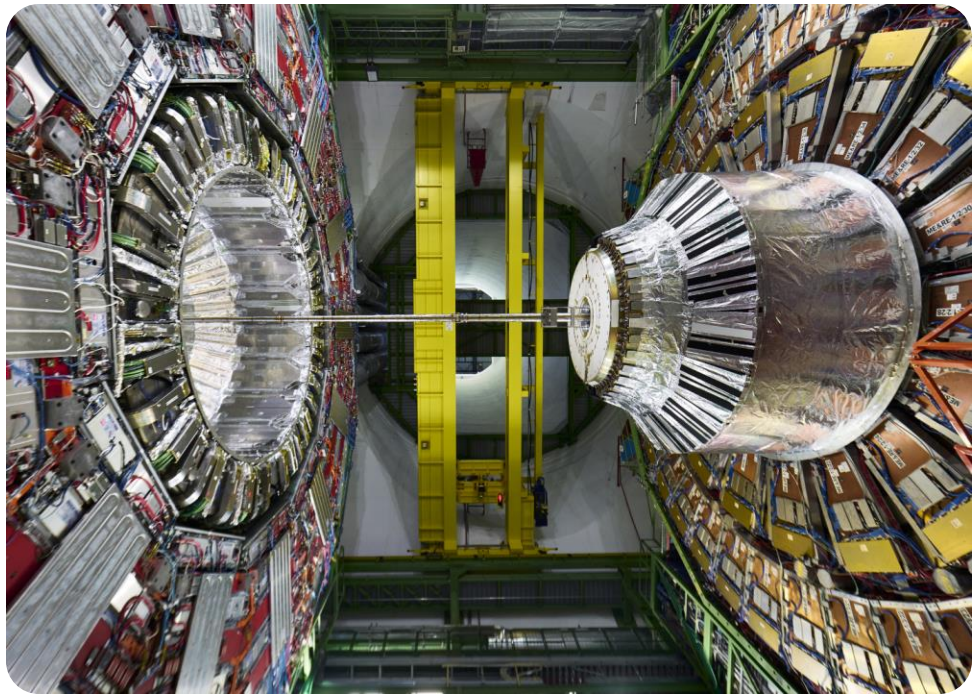
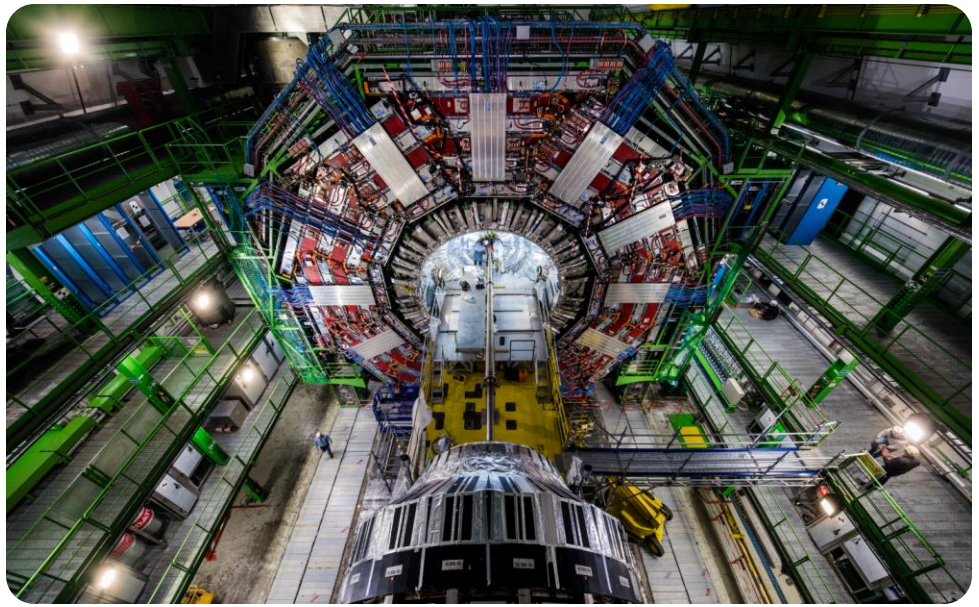


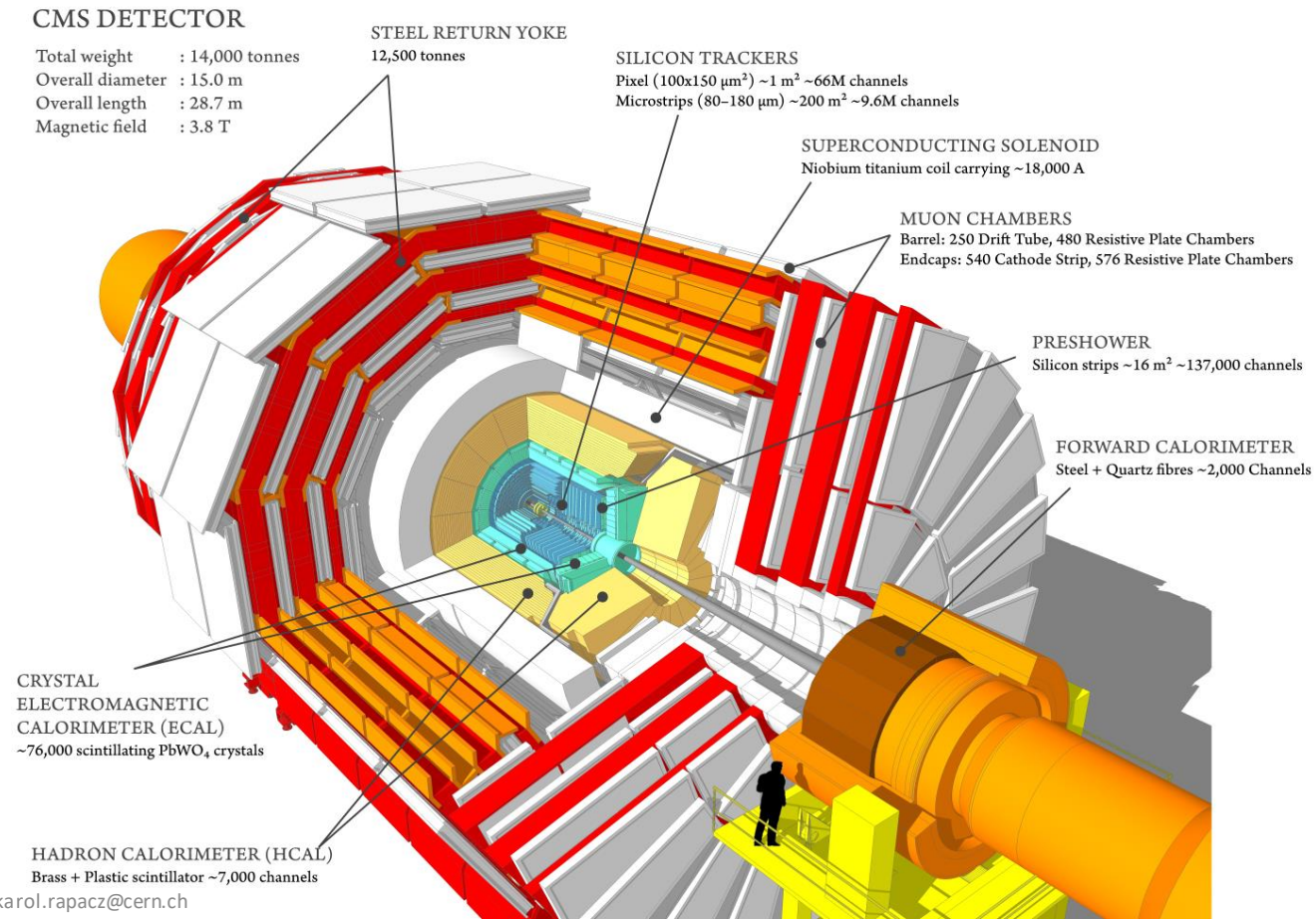


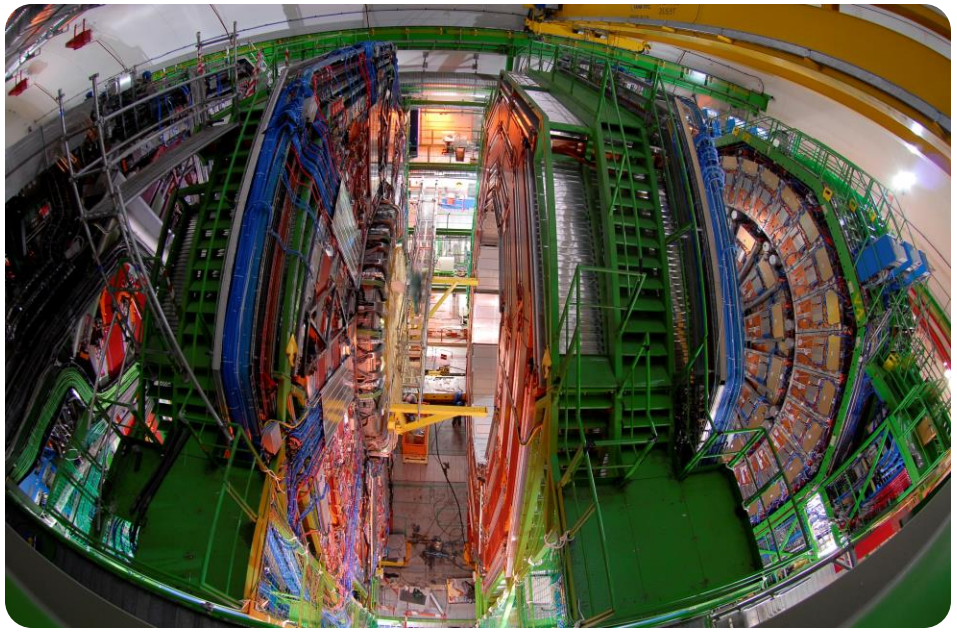


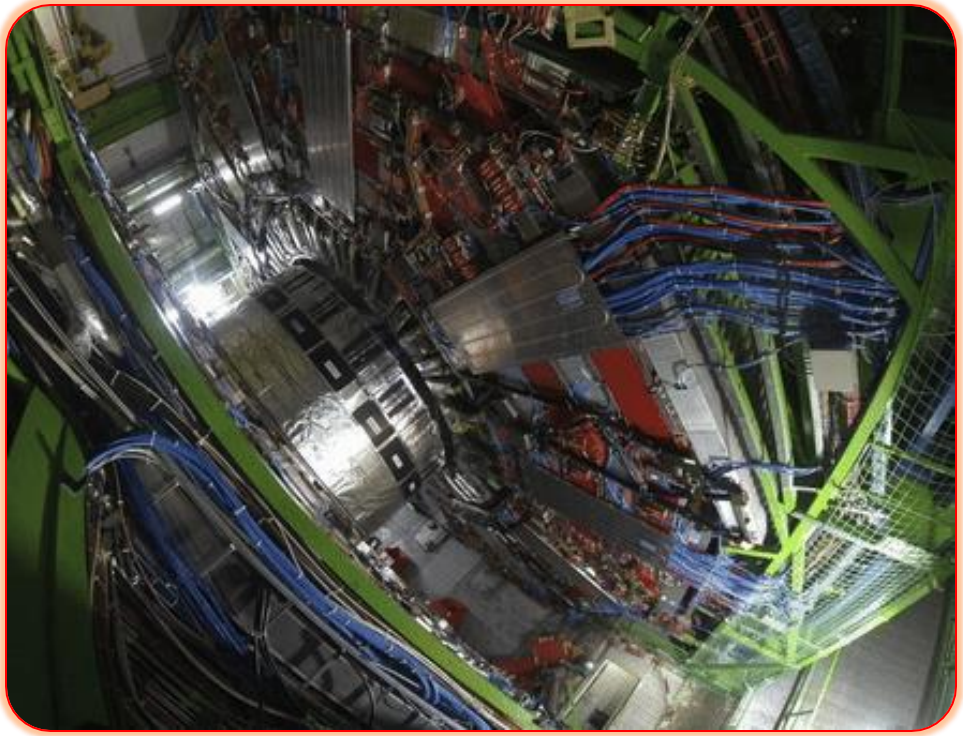
Challenge counter:

- Location
- **Size**
- **Weight**

What is CMS?



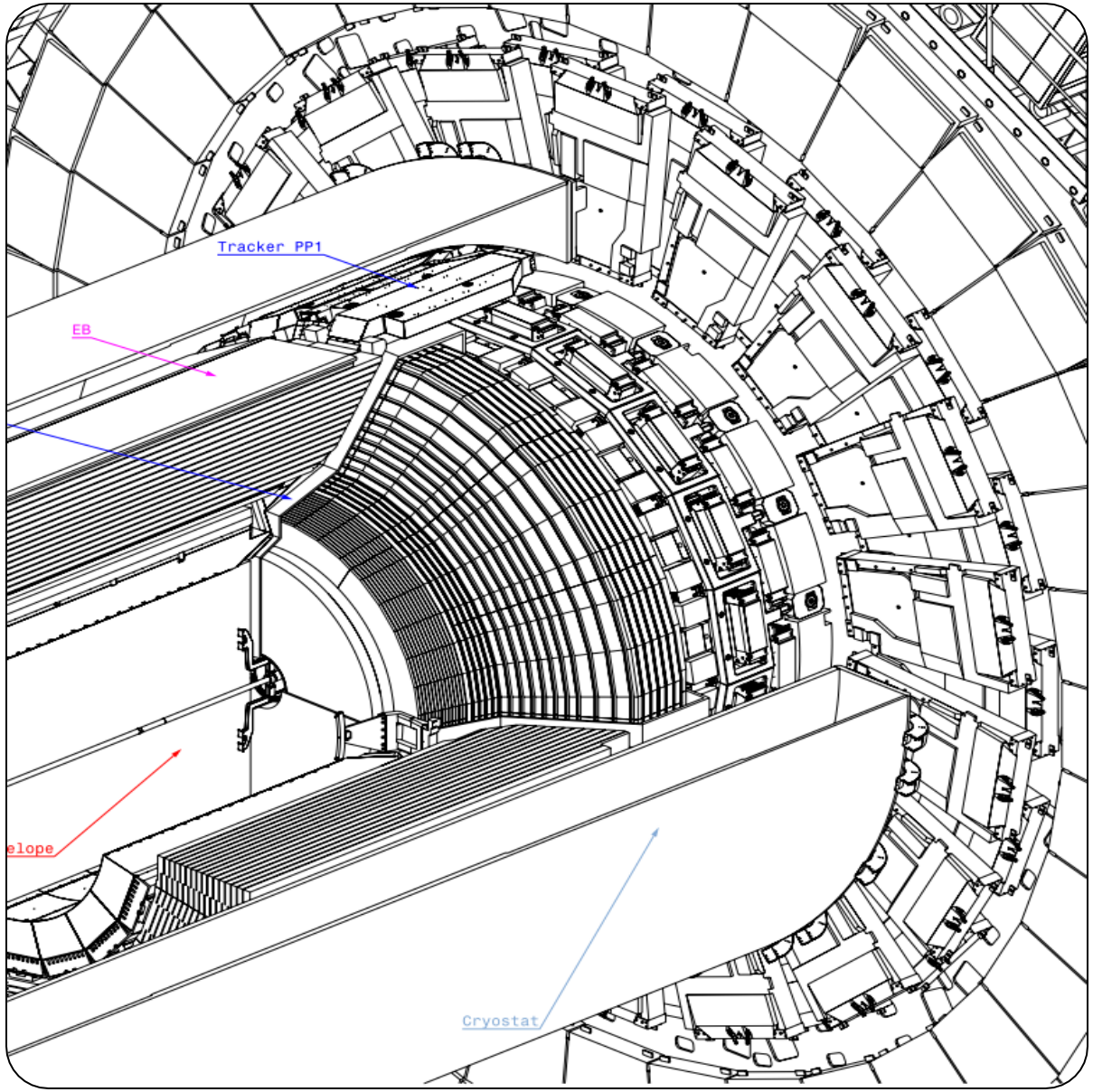


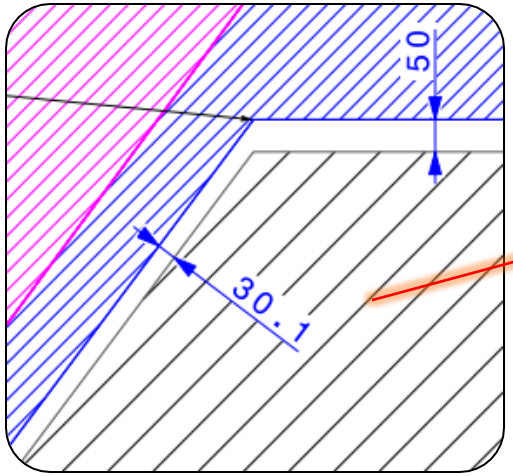


Challenge counter:

- Location
- Size
- Weight
- **Motion!**

Compactness of Compact Muon Solenoid



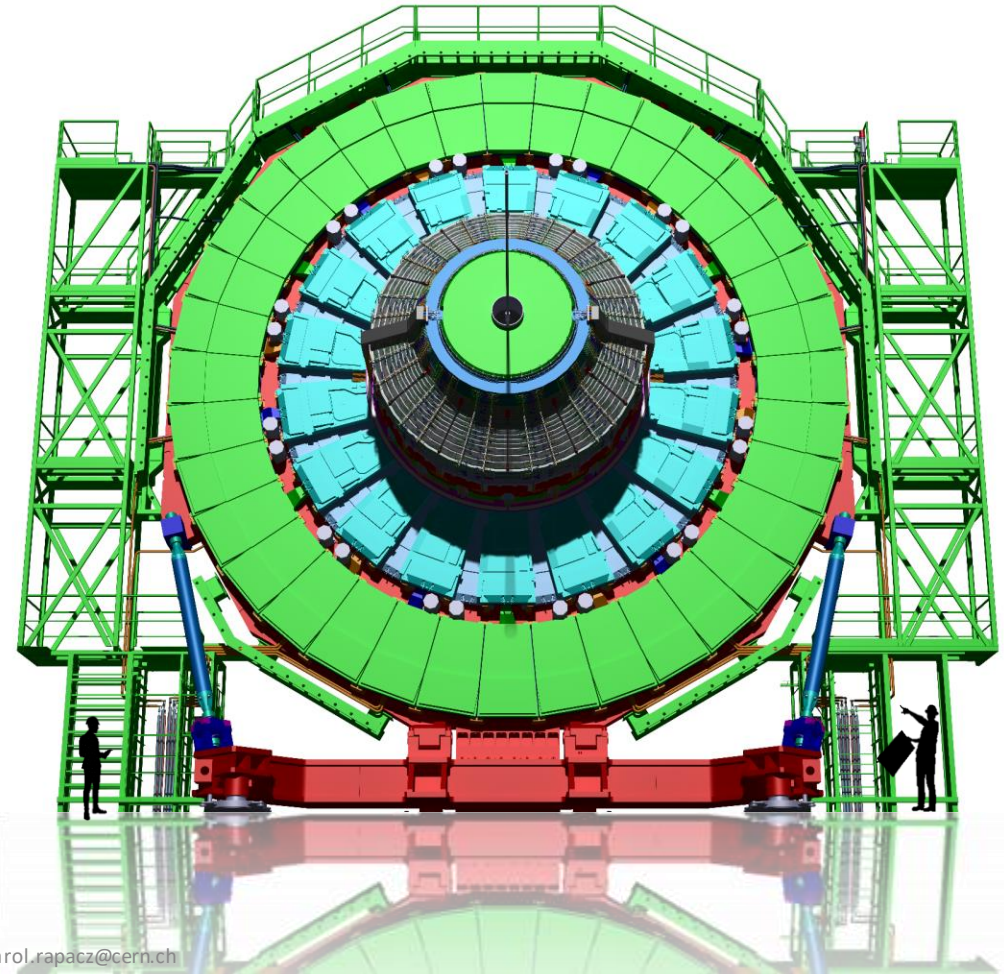


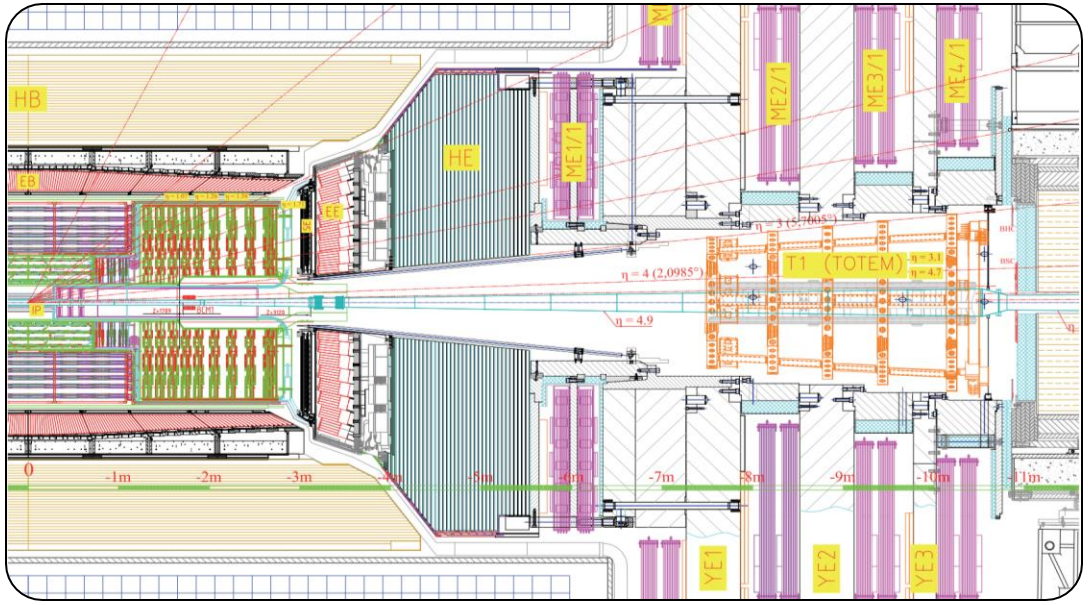
Typical few centimeter gaps between frequently moving detectors weighing ~ 1400 tonnes!

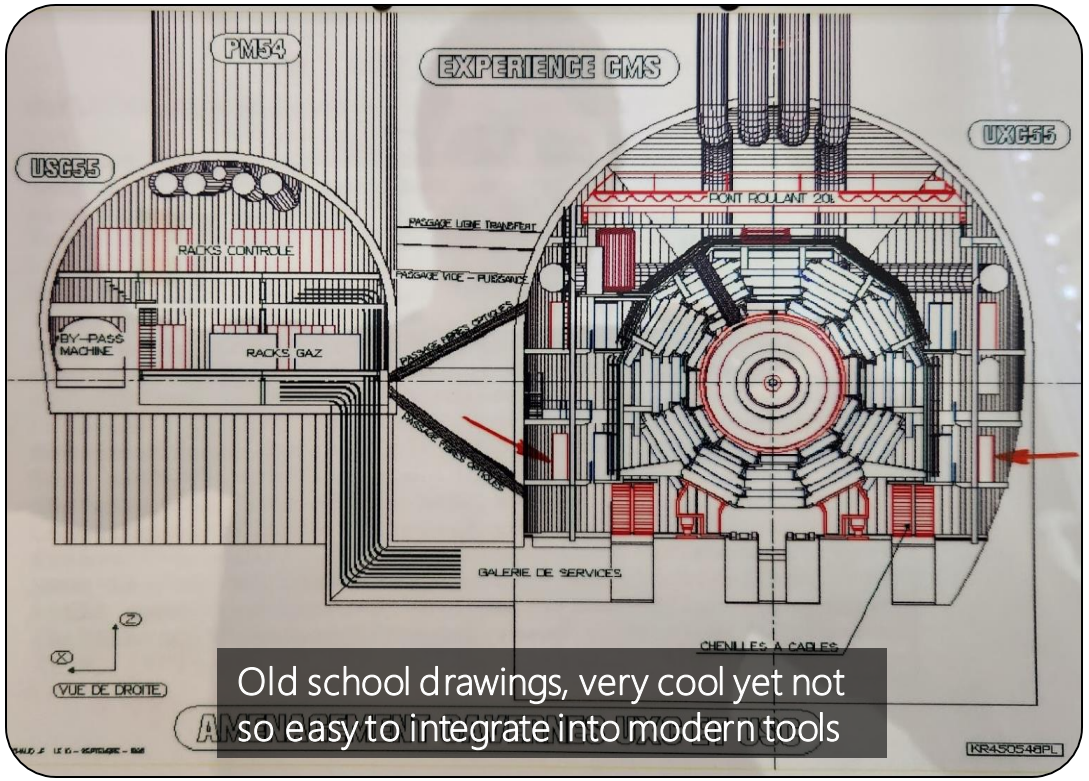
Challenge counter:

- Location
- Size
- Weight
- Motion
- **Tight Envelopes**

Detector envelopes definition



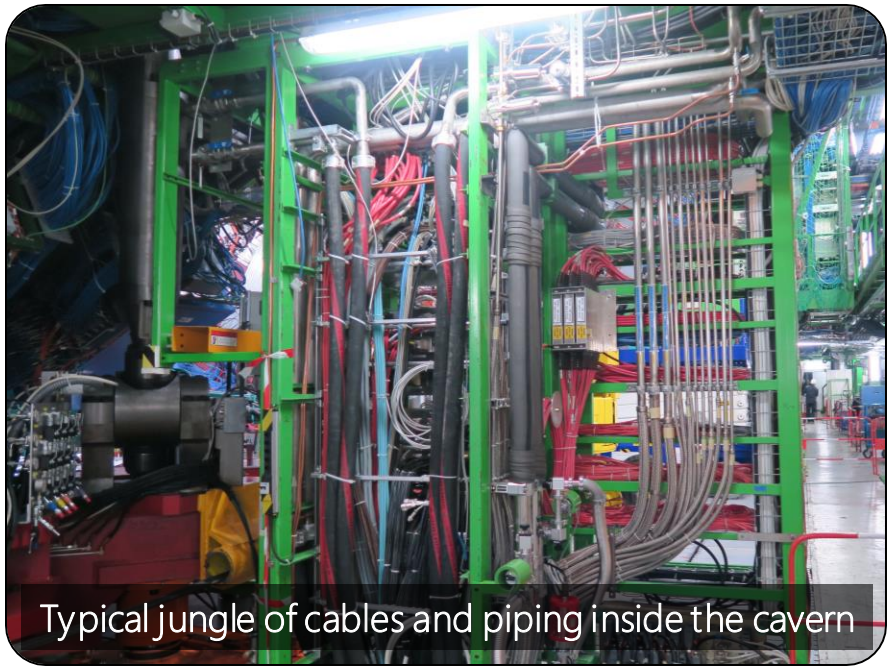




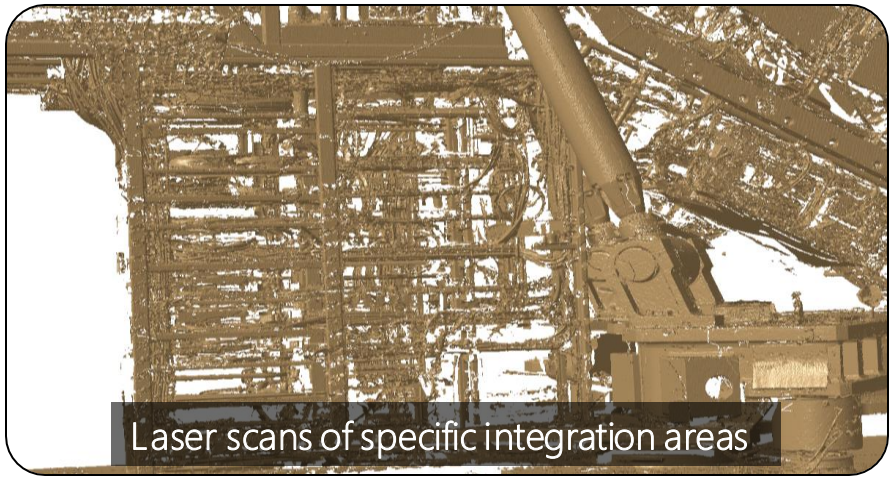
Challenge counter:

- Location
- Size
- Weight
- Motion
- Tight Envelopes
- **Inputs**

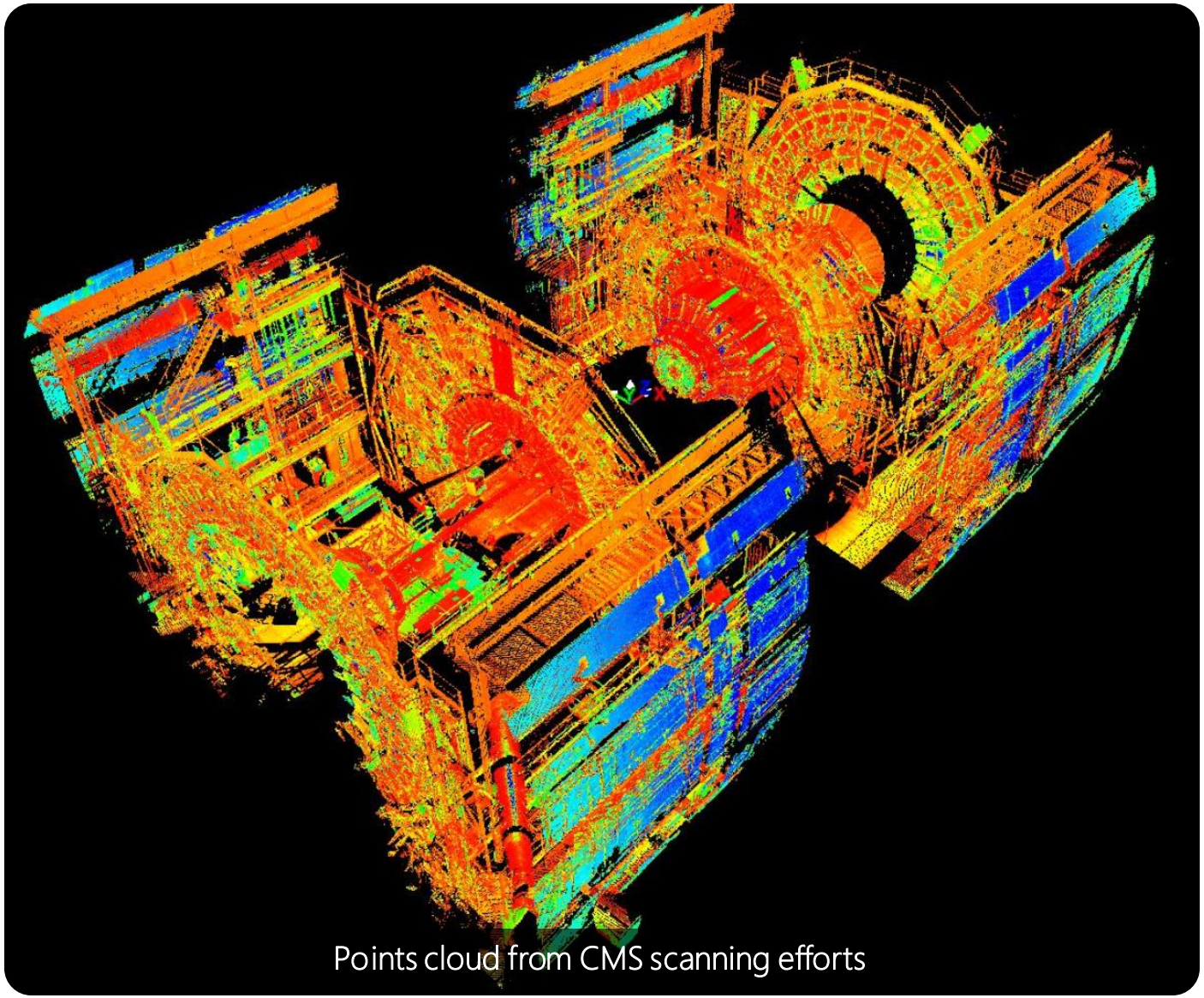
Detector envelopes debugging



Typical jungle of cables and piping inside the cavern



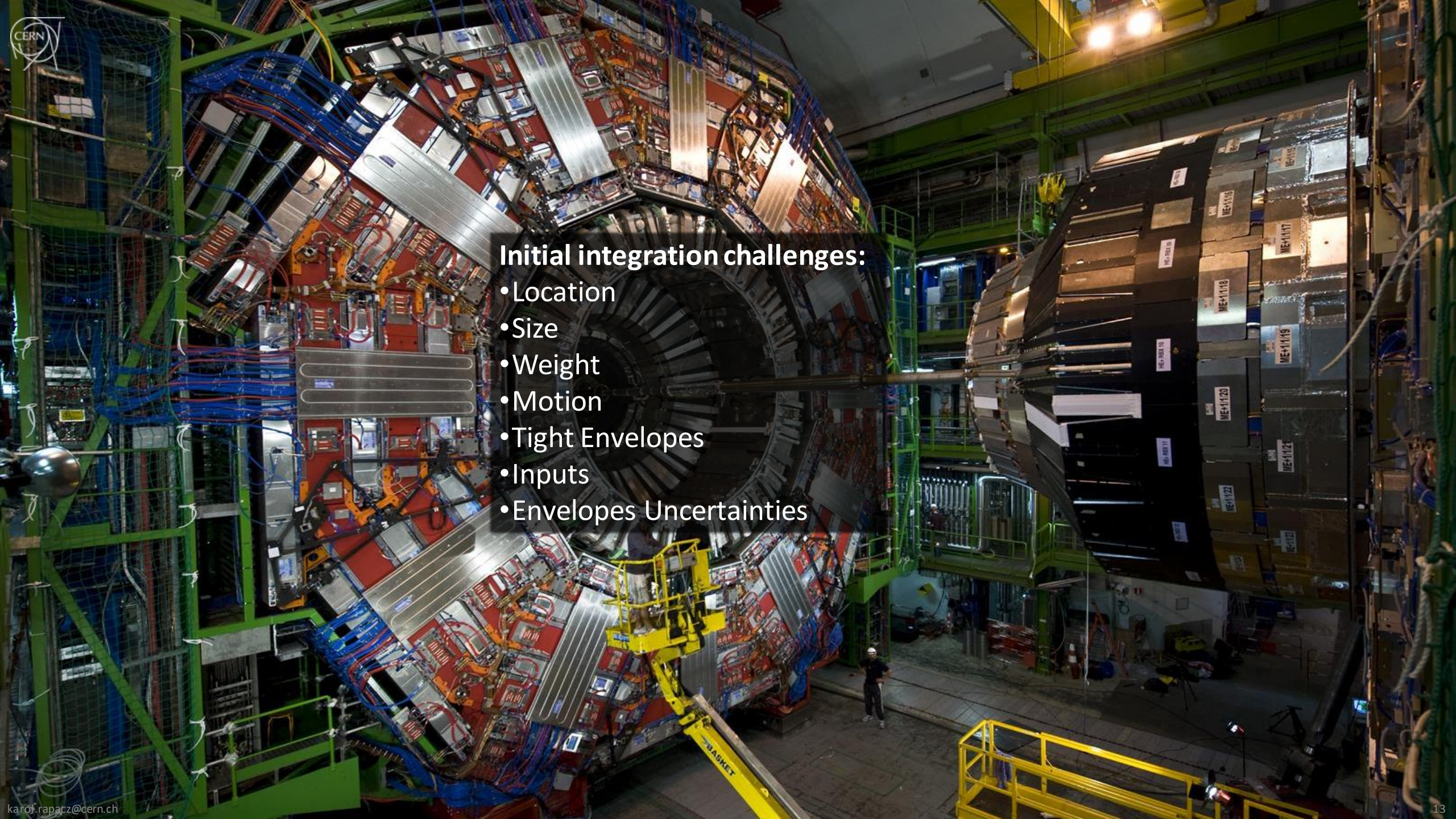
Laser scans of specific integration areas



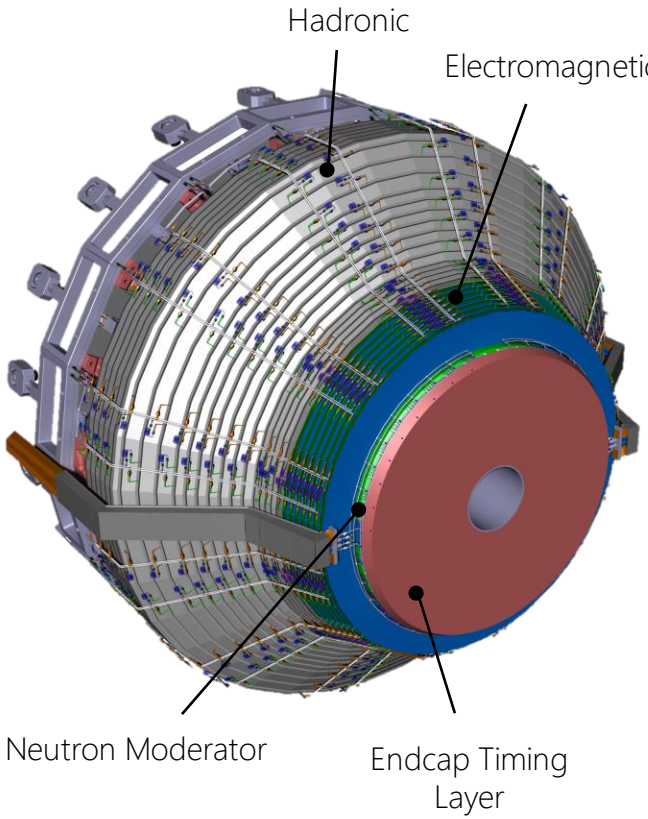
Points cloud from CMS scanning efforts

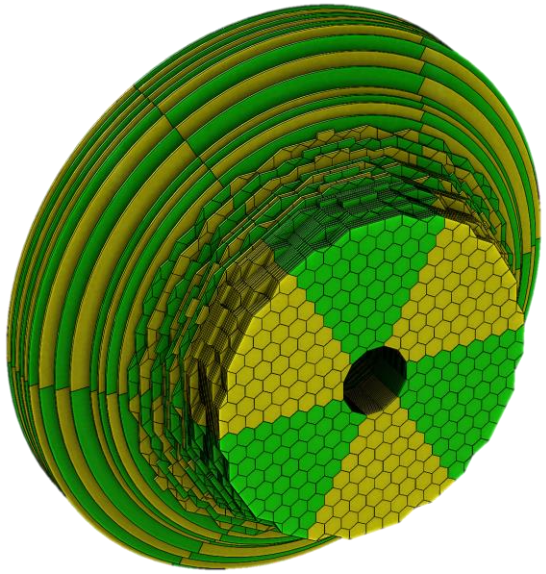
Challenge counter:

- Location
- Size
- Weight
- Motion
- Tight Envelopes
- Inputs
- **Envelopes Uncertainties**


Initial integration challenges:
•Location
•Size
•Weight
•Motion
•Tight Envelopes
•Inputs
•Envelopes Uncertainties

HGCAL – High Granularity Calorimeter





'Active' Part of HGCAL

Key Parameters:
HGCAL Covers $1.5 < \eta < 3$
~220 tonnes per endcap

CLICK **HERE** TO SEE SHORT HGCAL ASSEMBLY ANIMATION

Active Elements:
- Hexagonal modules based on silicon sensors in the high-radiation regions of the detector.
- Scintillating tiles with SiPM (Silicon Photo-Multiplier) readout in the lower radiation regions.

~30000 modules containing 620m^2 silicon sensors (8" hex wafers).
~4000 boards containing 370m^2 of scintillators.
~6M si channels

Challenge counter:

- Location
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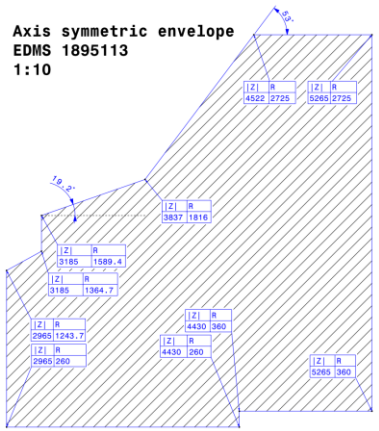
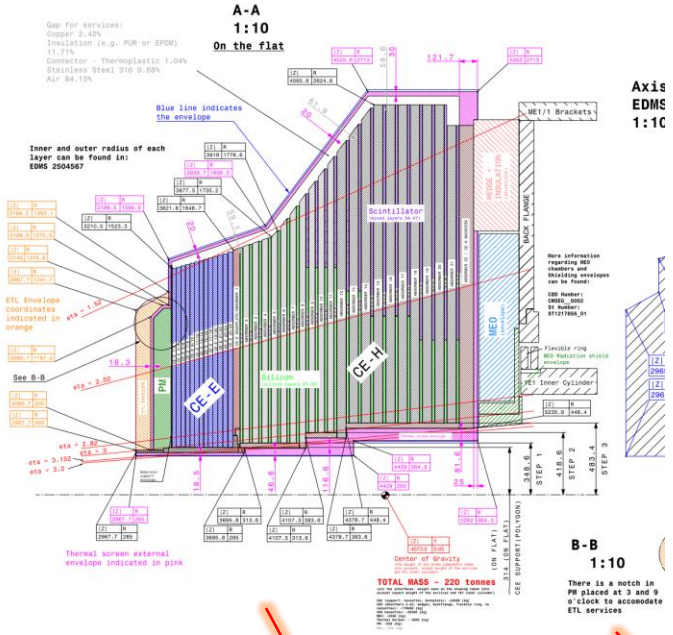
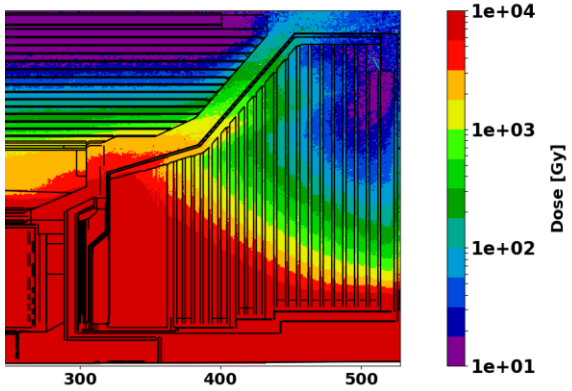
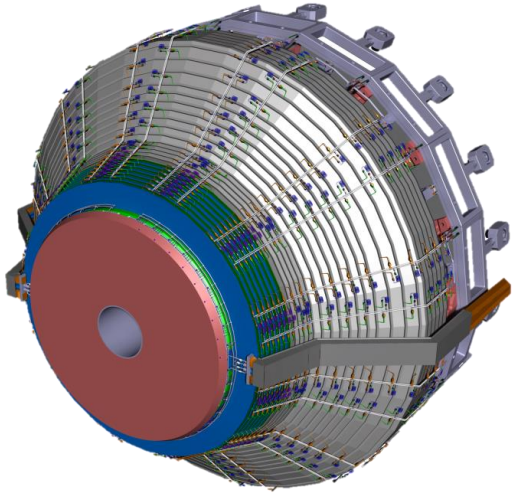
Typical detector development workflow



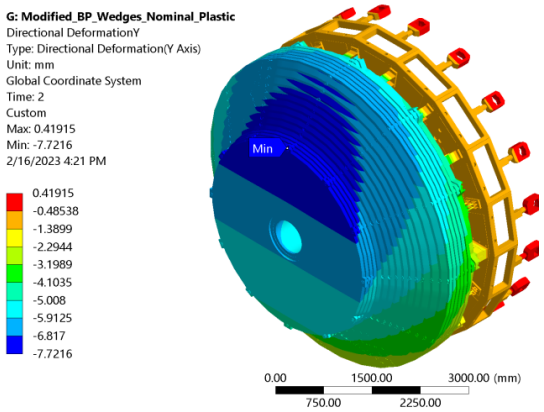




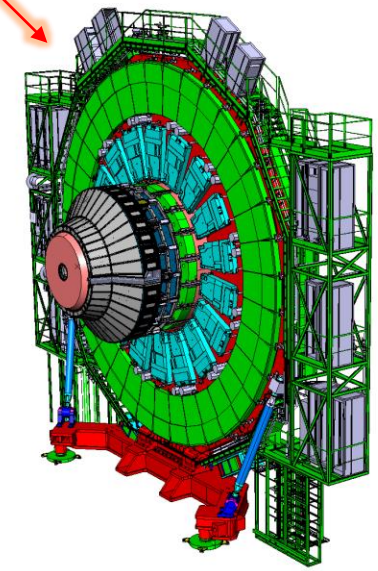
Fluka simulations



Boundary conditions for detailed CAD design



Input for FEM studies



CAD geometry for integration checks

Challenge counter:

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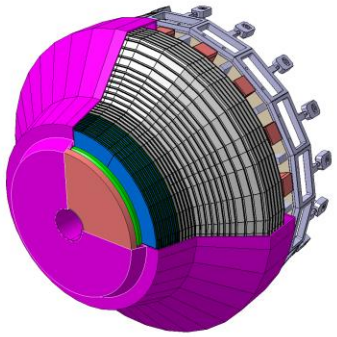
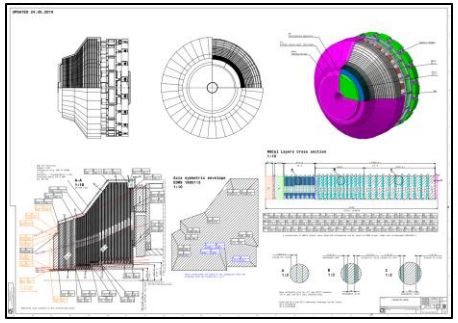
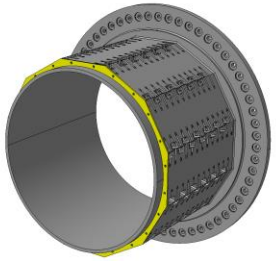
CAD workflow

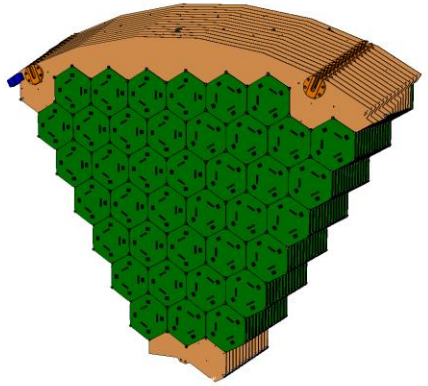




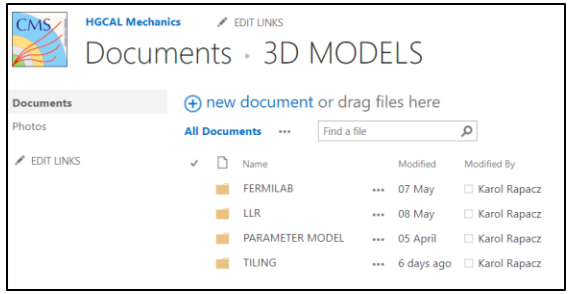
SUBSYTEM DESIGNERS
1. Take inputs from parameter model, drawings and tiling

feedback

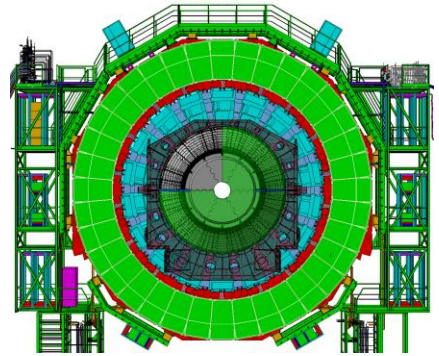




SUBSYTEM DESIGNERS
2. Create detailed 3D design based on the inputs



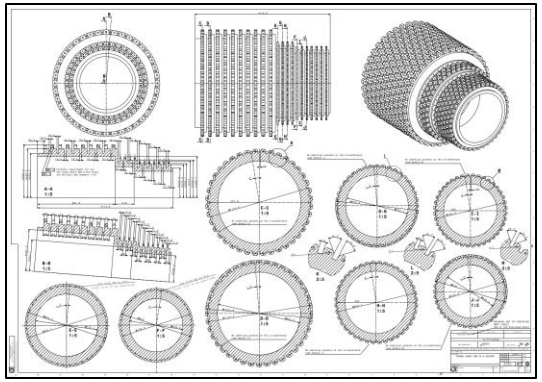
SUBSYTEM DESIGNERS
3. Share 3D models in .stp on sharepoint and EDMS



HGCal INTEGRATION
4. Cross check in the assembly model

feedback

If no discrepancies



SUBSYTEM DESIGNERS
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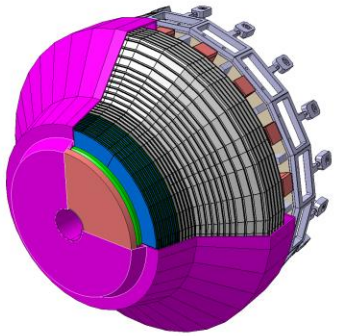
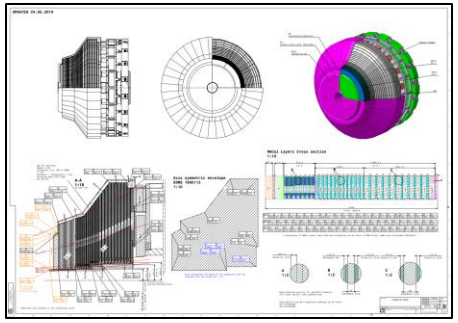
CAD workflow





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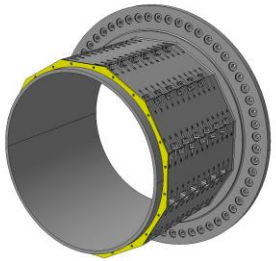

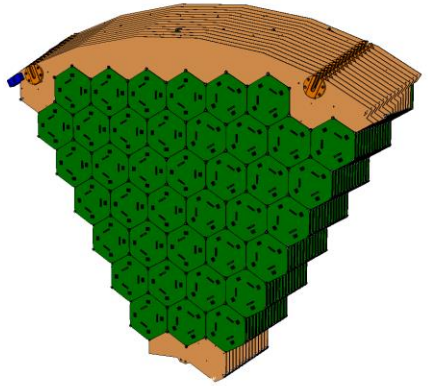

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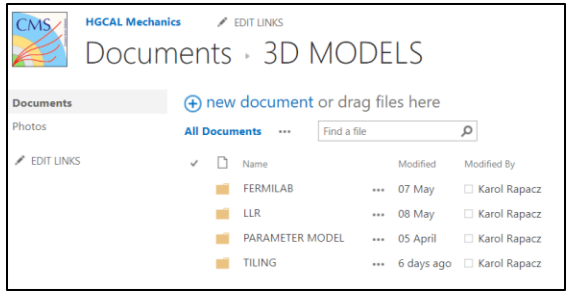

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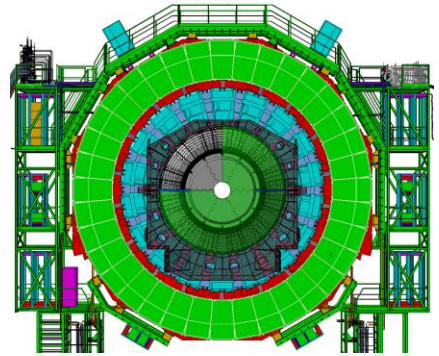

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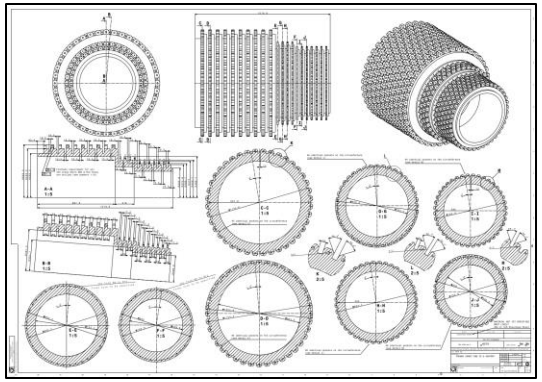

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HGCAL specific:

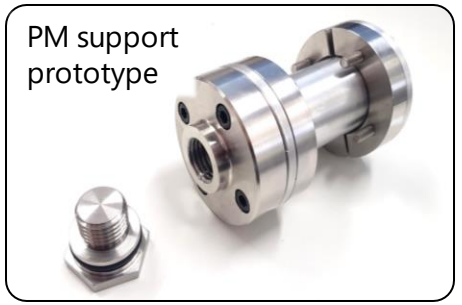
- **CAD Repositories**
- **Formats Compatibility**
- **Files sizes**

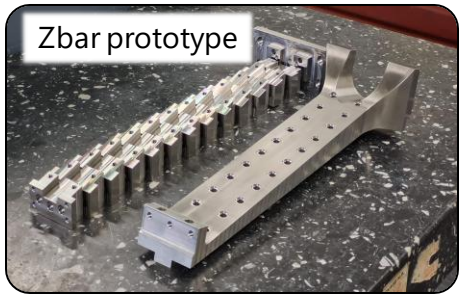
CAD is not enough! Prototyping is still necessary

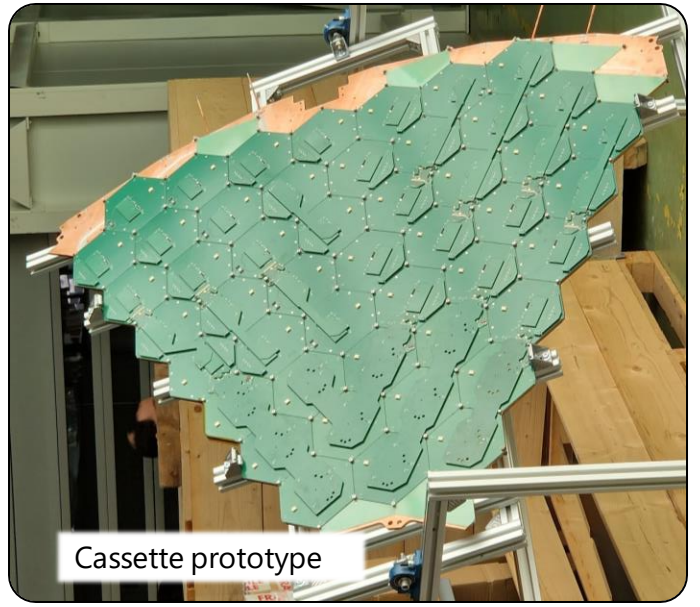
- When feasible, CAD designs are always verified using prototypes.
- Critical interfaces are examined at a 1:1 scale and subjected to as realistic a manufacturing process as possible.
- For other designs, only selected elements require prototyping to achieve full validation.
- Depending on the requirements, prototypes undergo various checks, including:

- Verification of the assembly process
- metrology
- load testing and comparison with FEM
- thermal testing and comparison with FEM
- leak and pressure testing


Wedge support prototype


PM support prototype

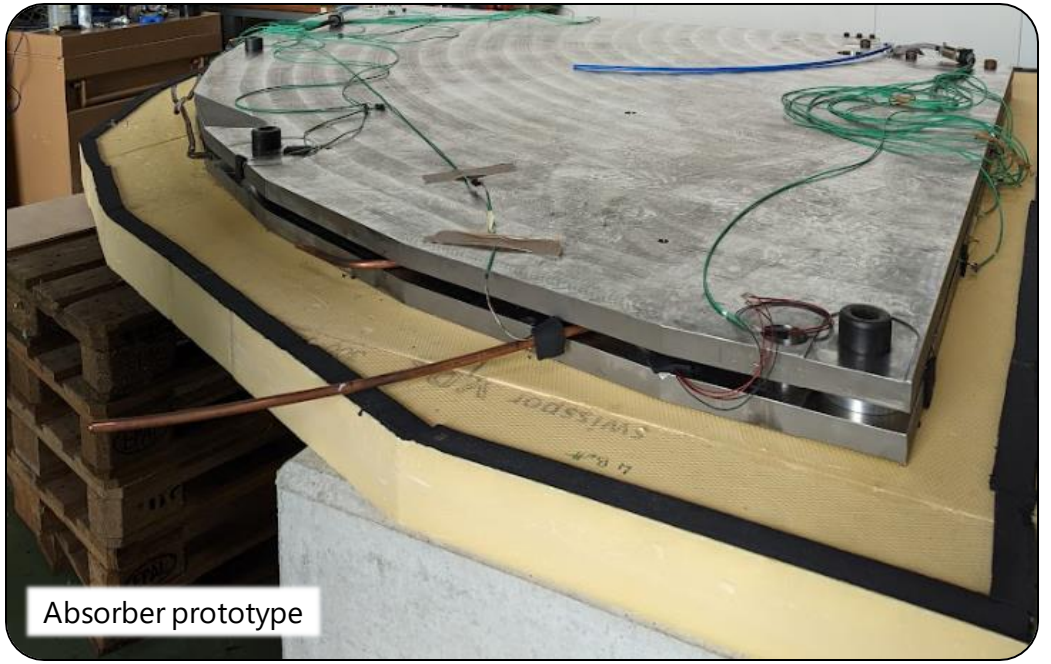

Zbar prototype


Cassette prototype


CO2 manifold prototype


Thermal screen panels prototype


CO2 transfer line prototype


Absorber prototype

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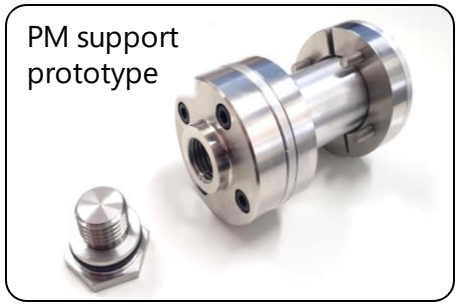
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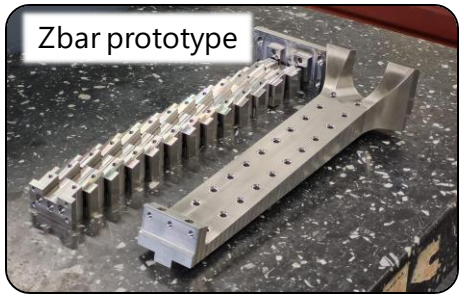
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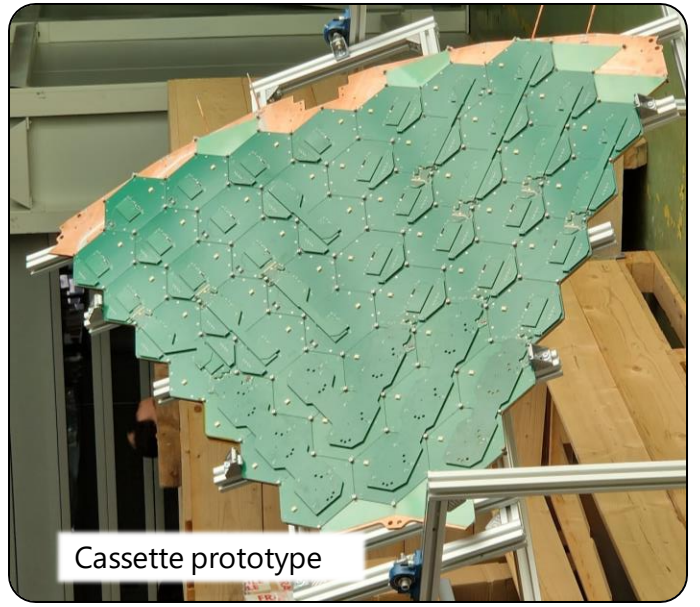
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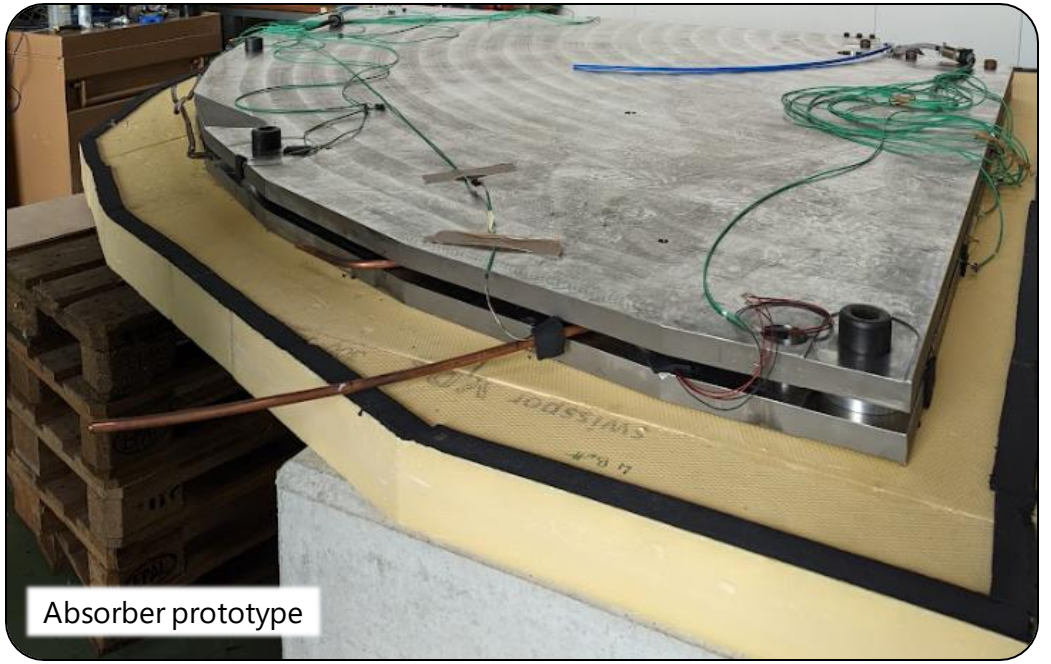

Absorber prototype

Challenge counter:

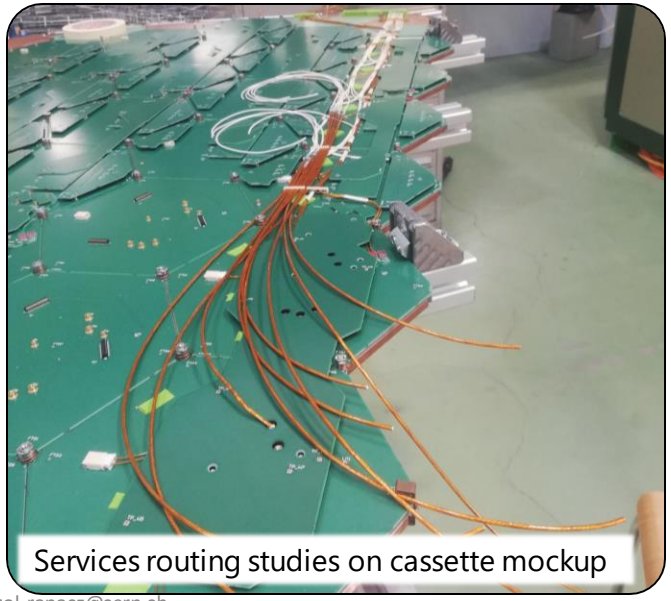
- Location
- Size
- Weight
- Motion
- Tight Envelopes
- Inputs
- Envelopes Uncertainties

HGCAL specific:

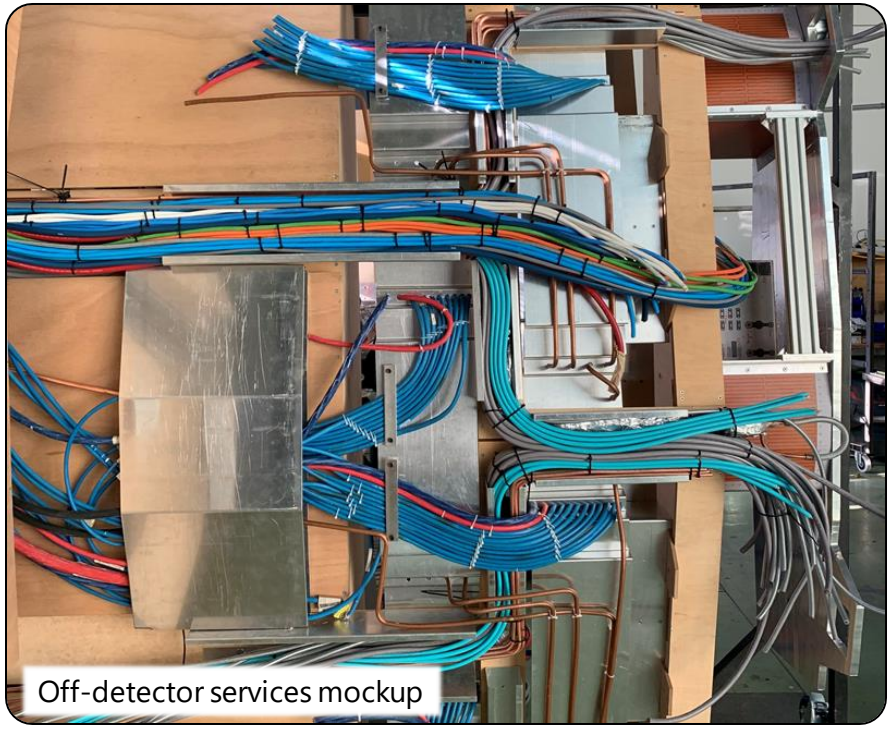
- CAD Repositories
- Formats Compatibility
- Files sizes
- **Realistic tolerances**
- **Machinibility**

Services. Pain in the neck …

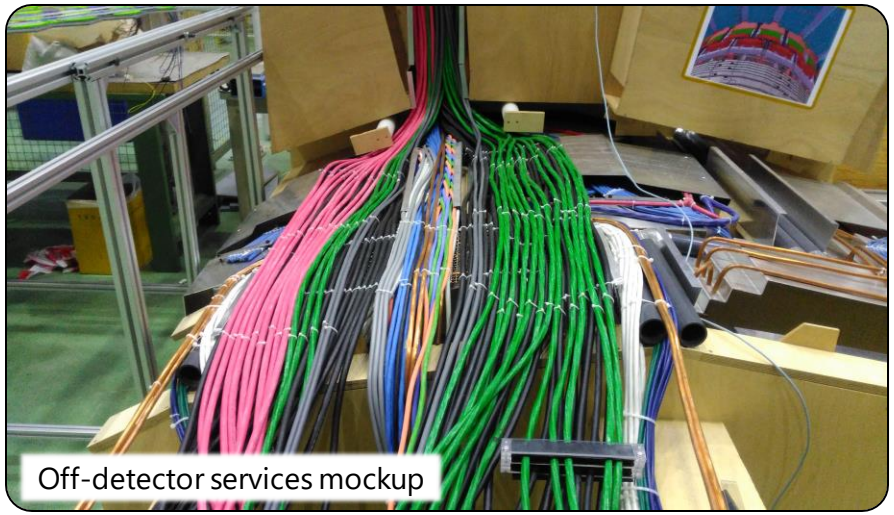
- Generating detailed CAD models isn't always practical, this applies especially to complex cable routing
- Mockups are usually the fastest and most practical way to evaluate services layout and routing
- practicality and ergonomics assessment



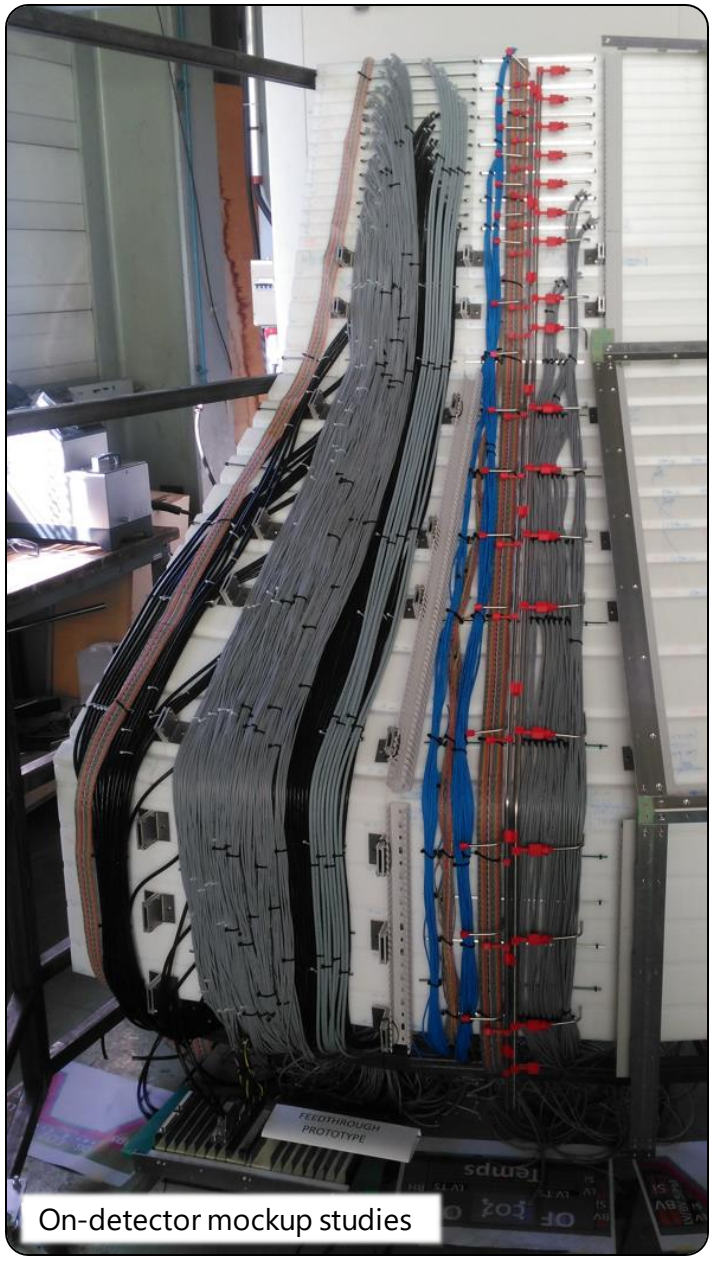
Services routing studies on cassette mockup



Off-detector services mockup



Off-detector services mockup



On-detector mockup studies

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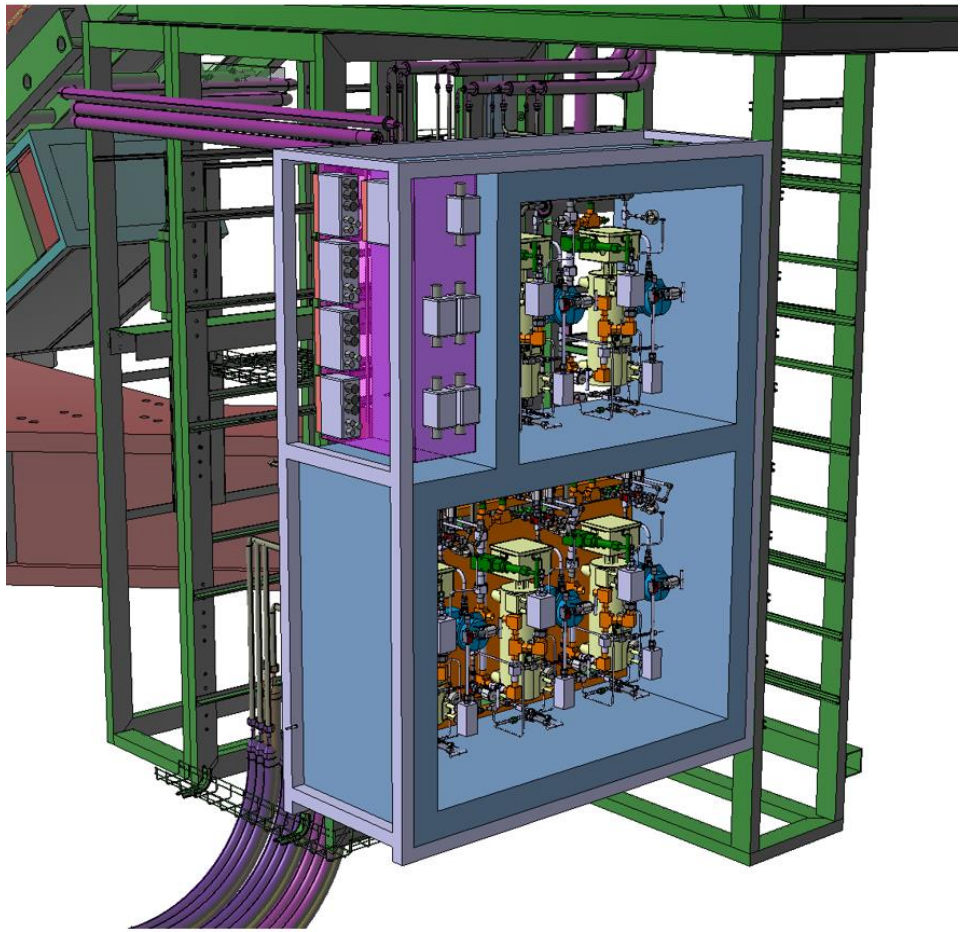
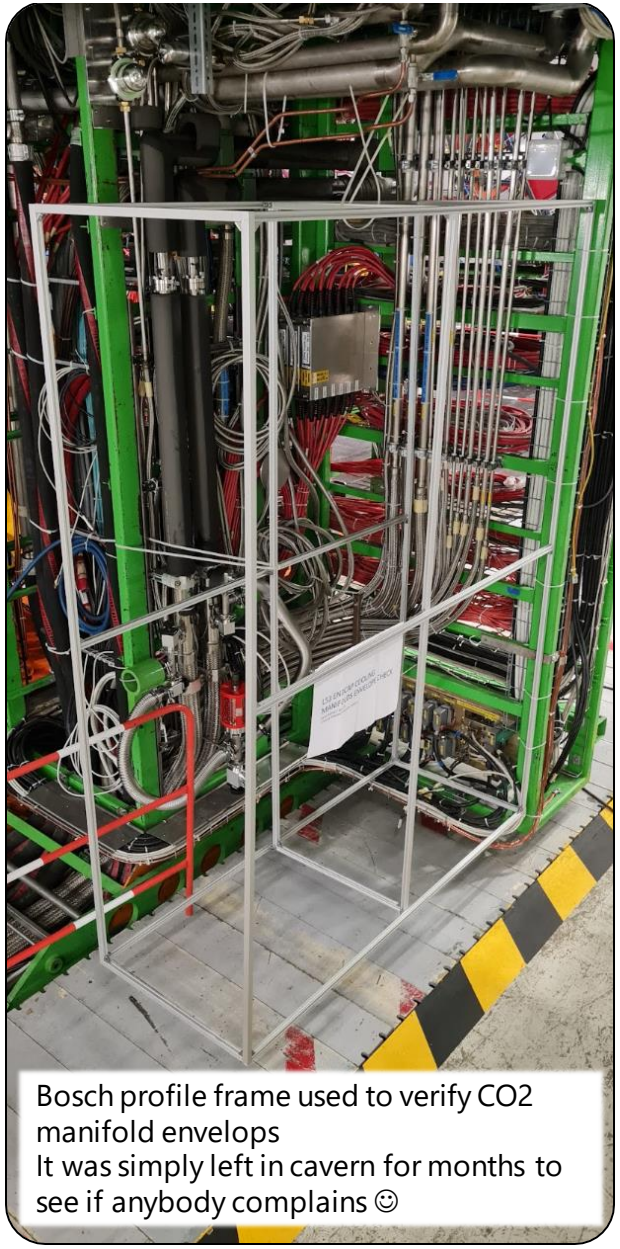
- **Services modelling**
- **Ergonomics**

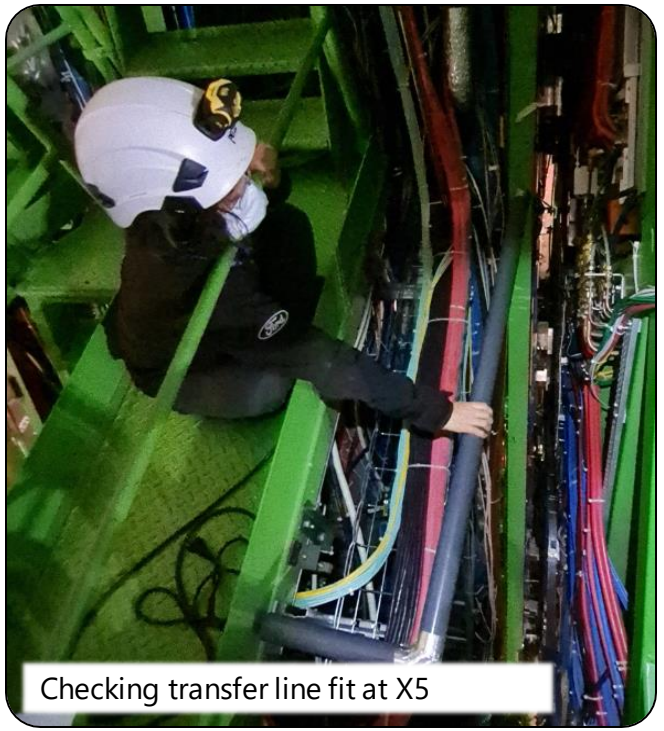
Even more down to earth integration tricks!

- Many interfaces are very difficult to model realistically
- Already existing design might be 20+ years old and simply doesn't exist in CAD repository
- Pictures or laser scans can be also used to compare CAD models with actual state
- Sometimes it's more practical to create simple mockups and verify them on site

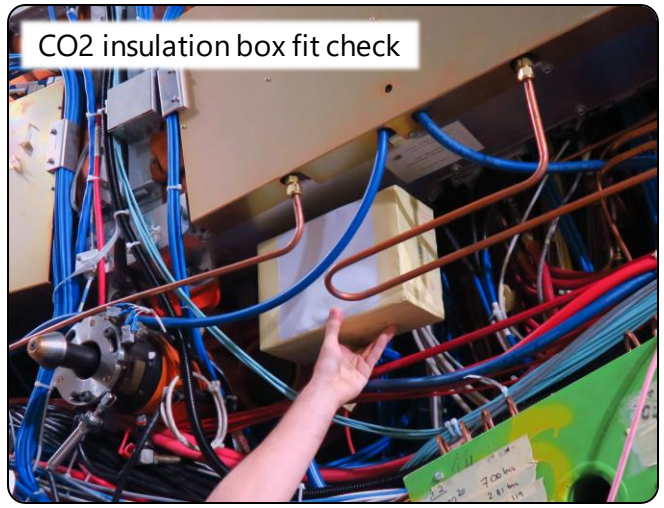




Bosch profile frame used to verify CO2 manifold envelops
It was simply left in cavern for months to see if anybody complains ☺



Checking transfer line fit at X5



CO2 insulation box fit check

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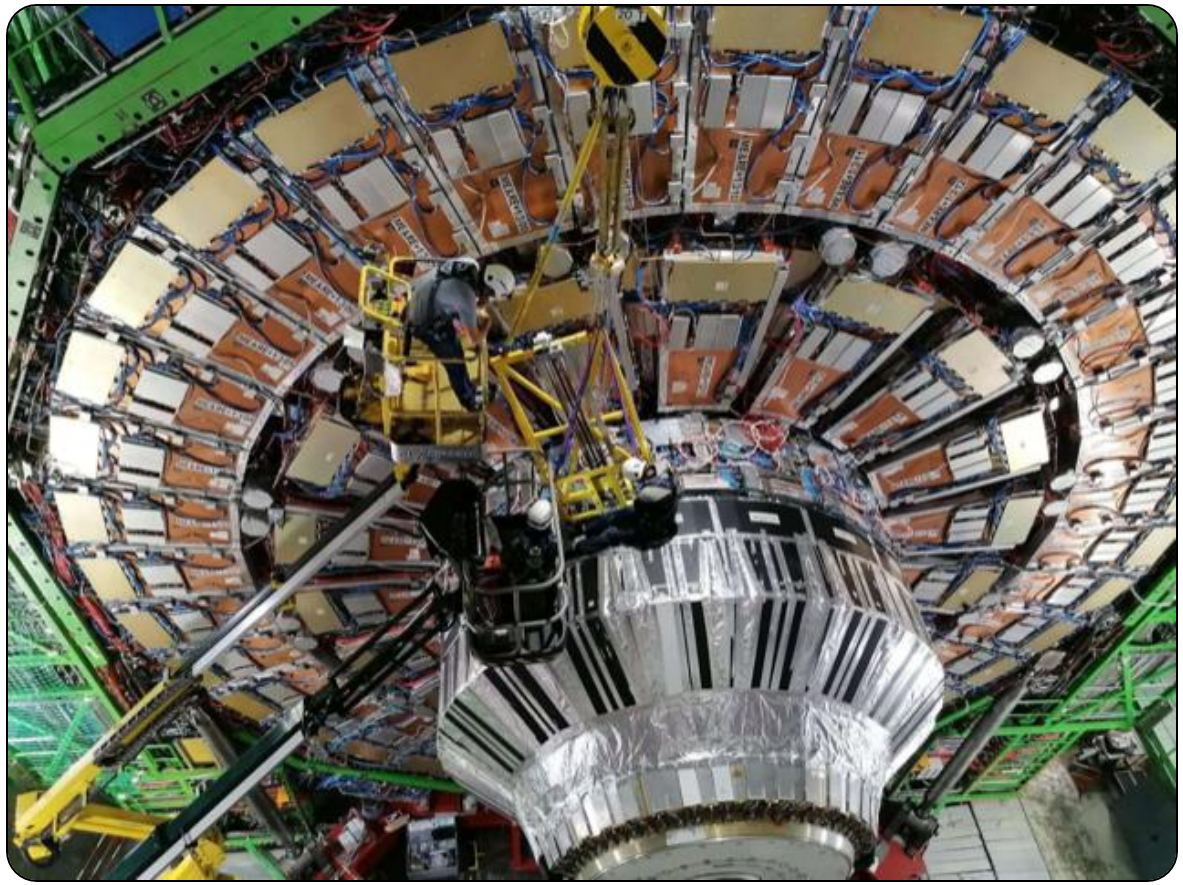
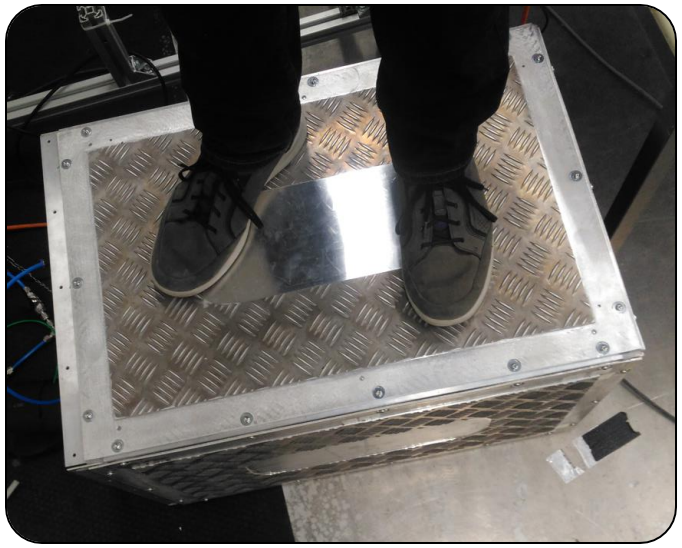
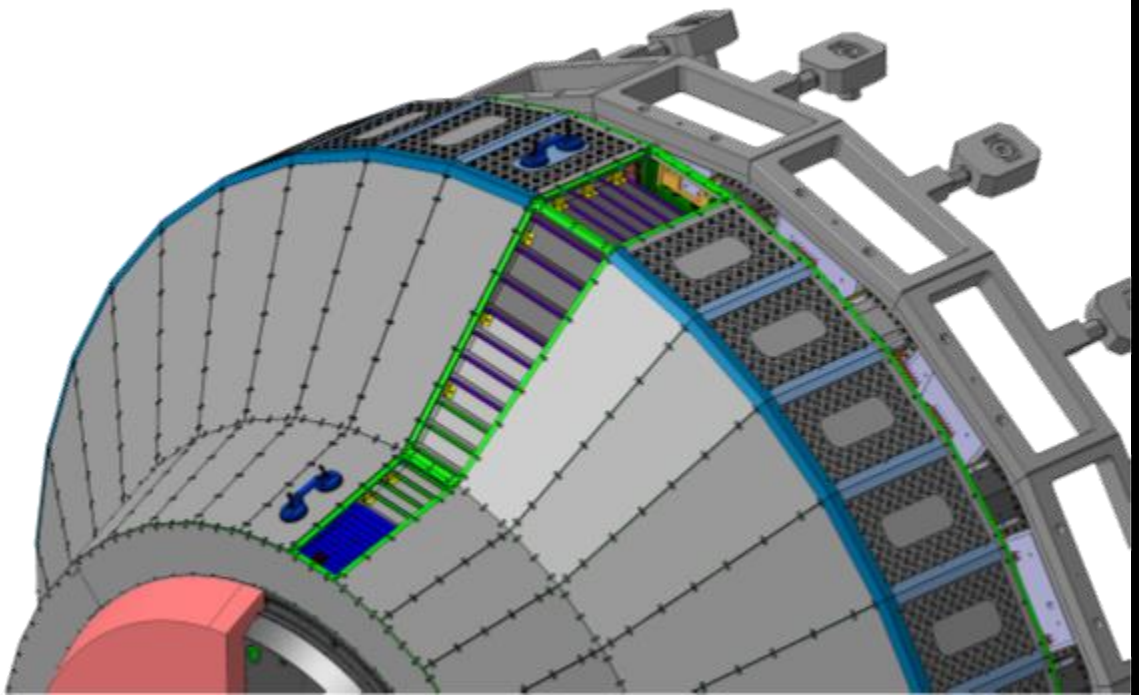
- Ergonomics
- **Operations**

Suprises

- Complex operations can produce incidents
- It's difficult to predicate user creativity
- Interfaces design should take into account out-of-the box cases
- Keep your design as modular and flexbile as possible







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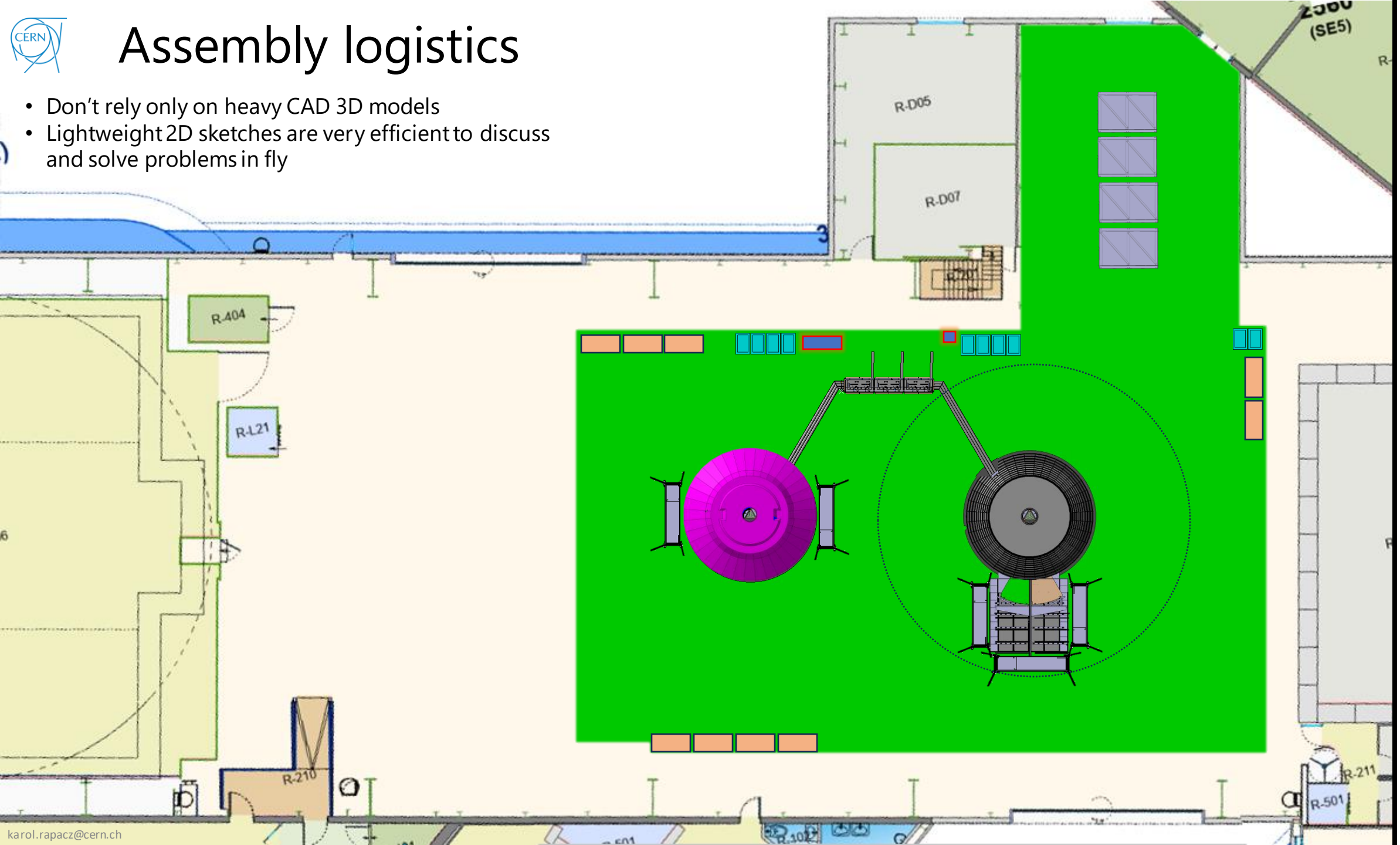
Assembly logistics

- Don't rely only on heavy CAD 3D models
- Lightweight 2D sketches are very efficient to discuss and solve problems in fly



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- Operations
- **Space requirements**
- **Dynamic changes**

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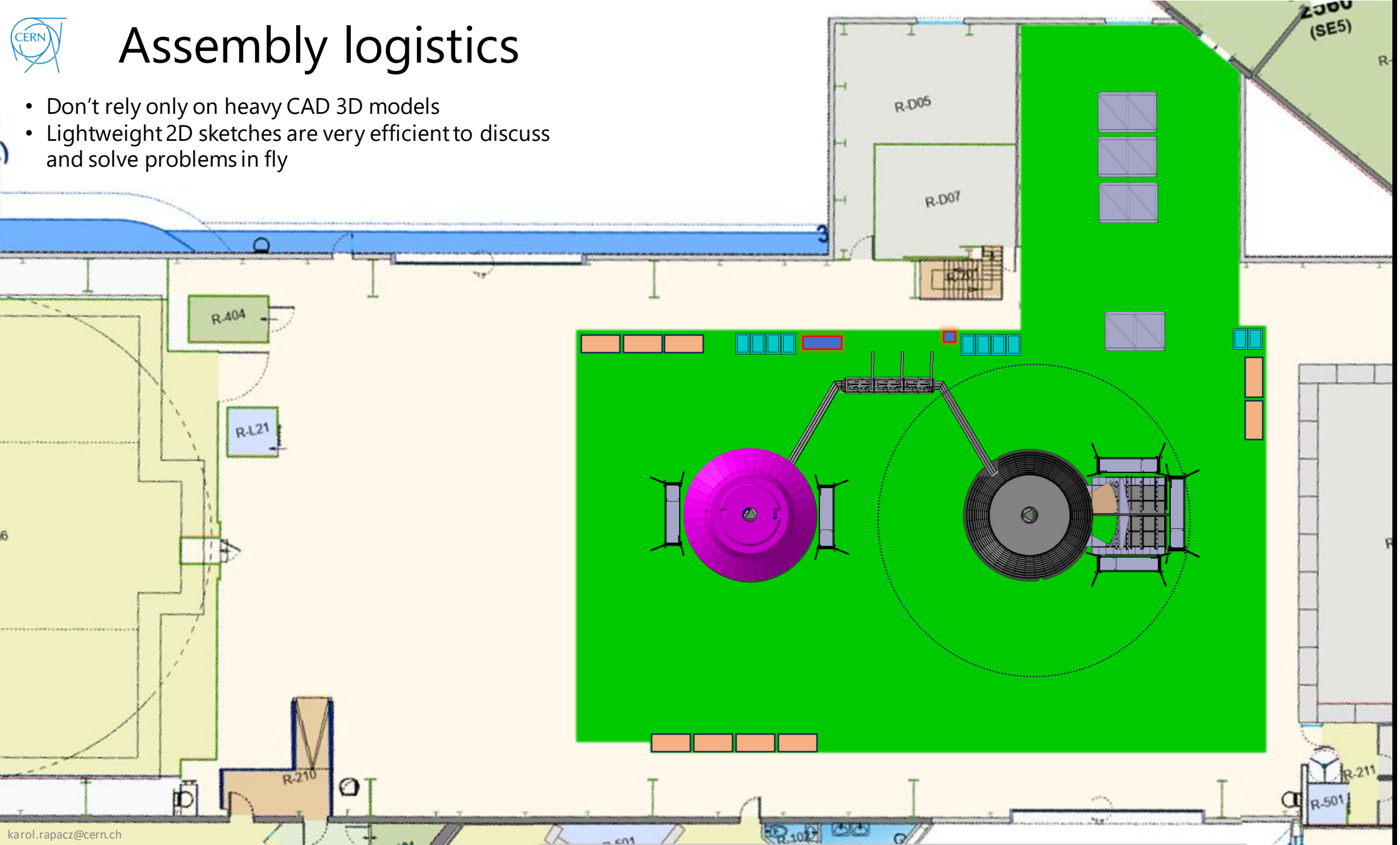

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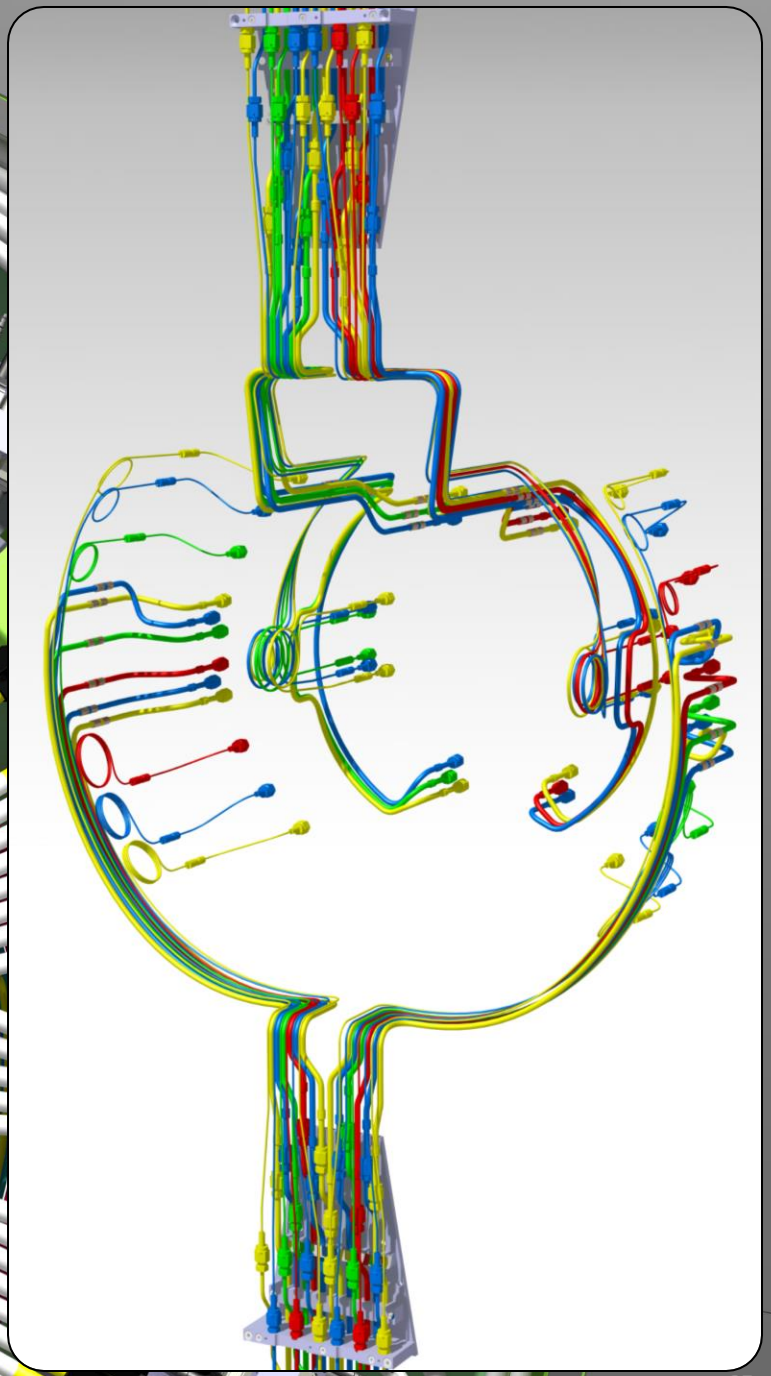
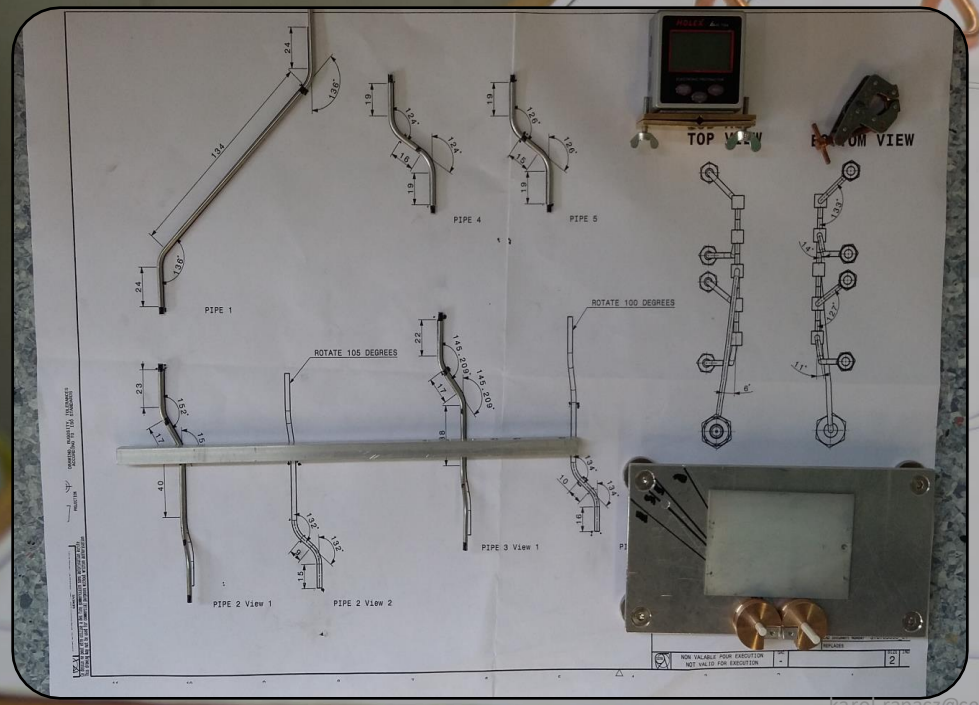
Tracker experience

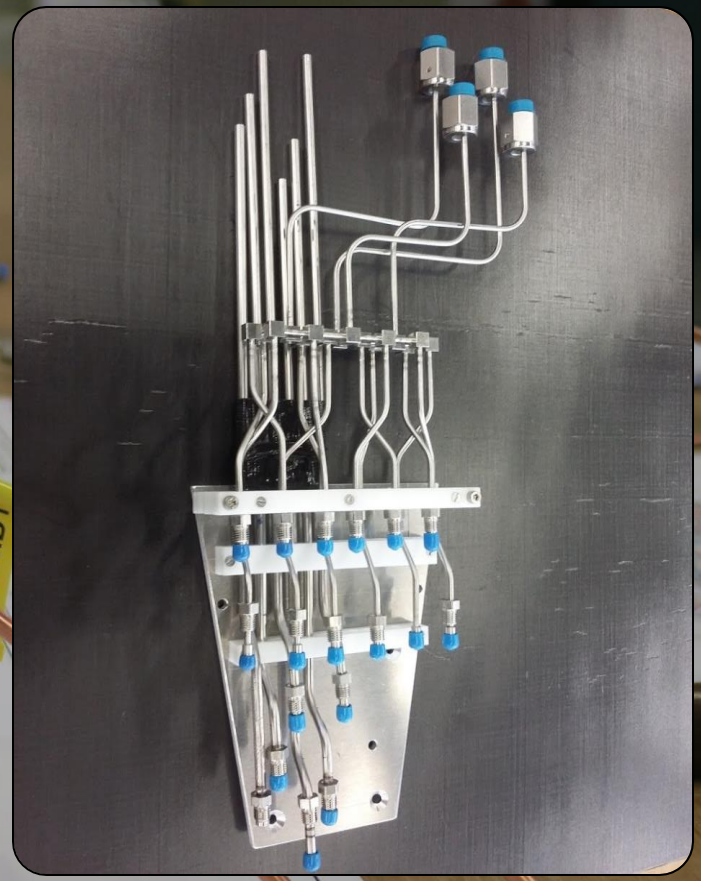
Tracker experience

Complex integration requirements

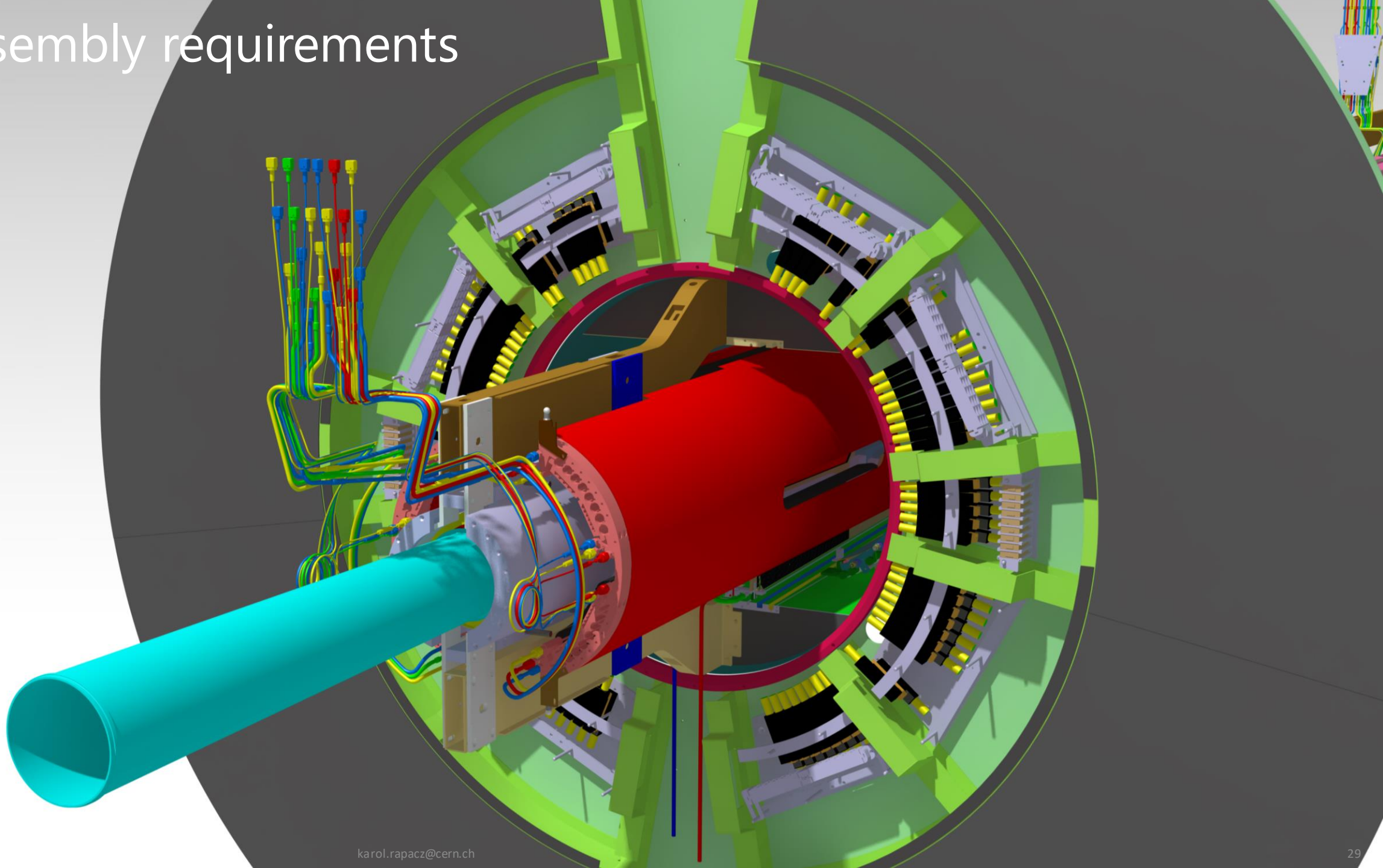


Prototyping





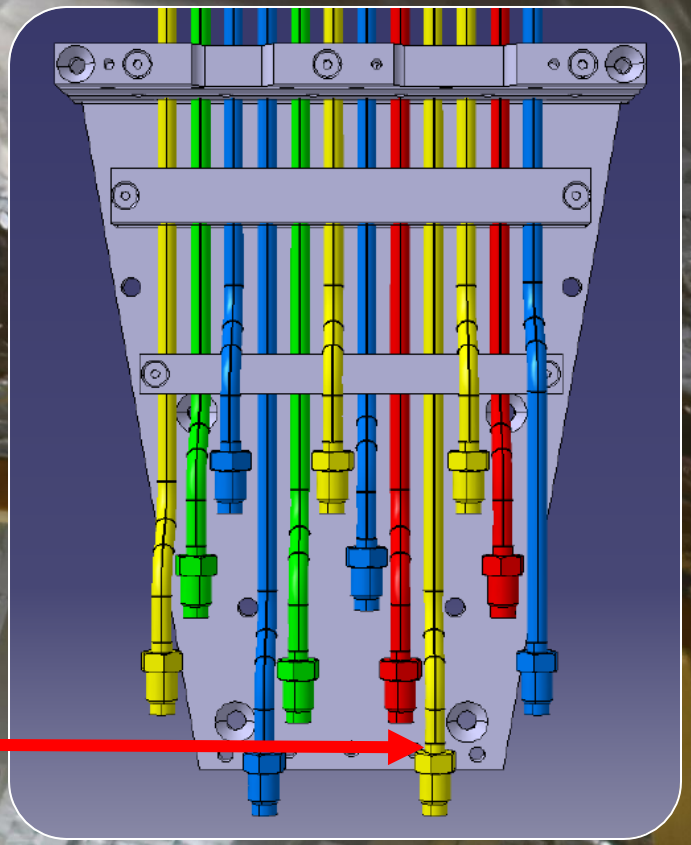
Assembly requirements



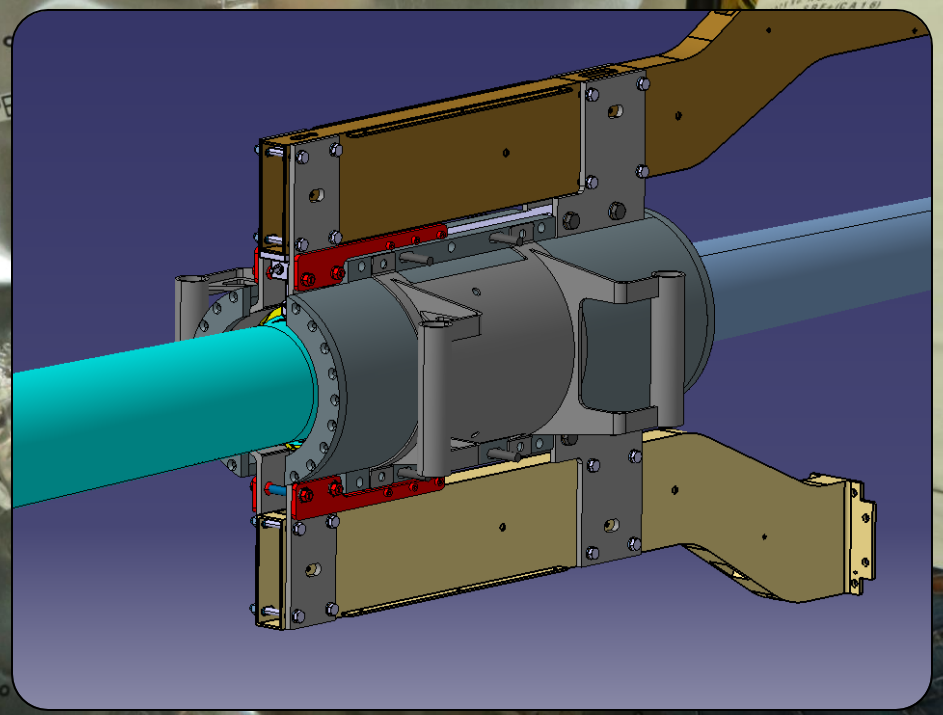
Hands-on effort

Surprises …

20 [cm] gap

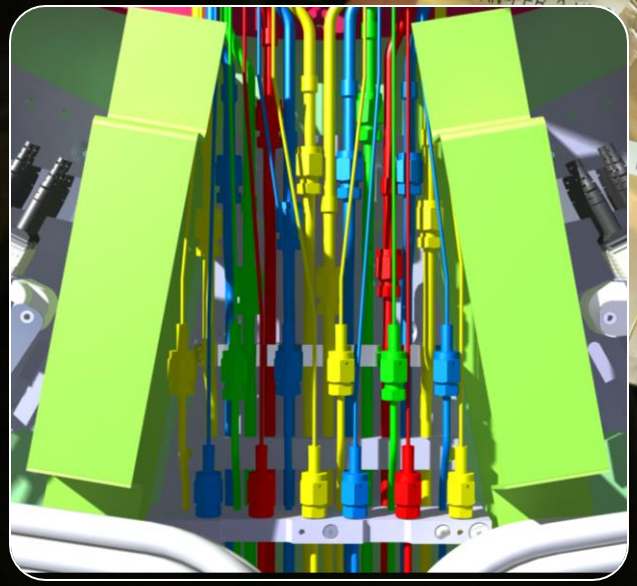


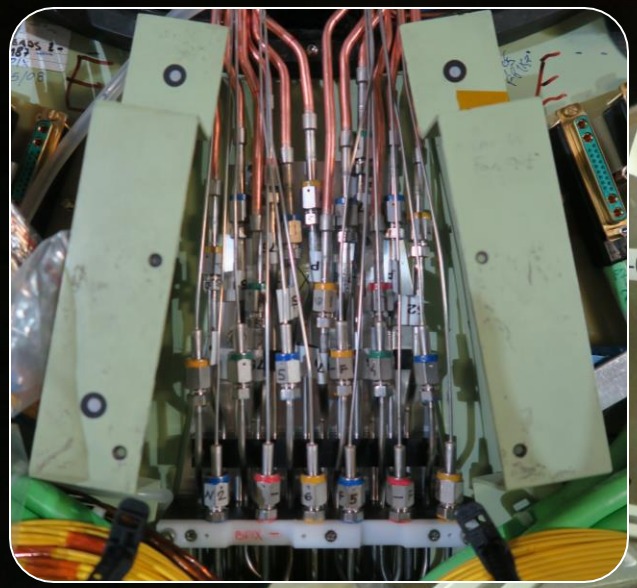
More surprises …

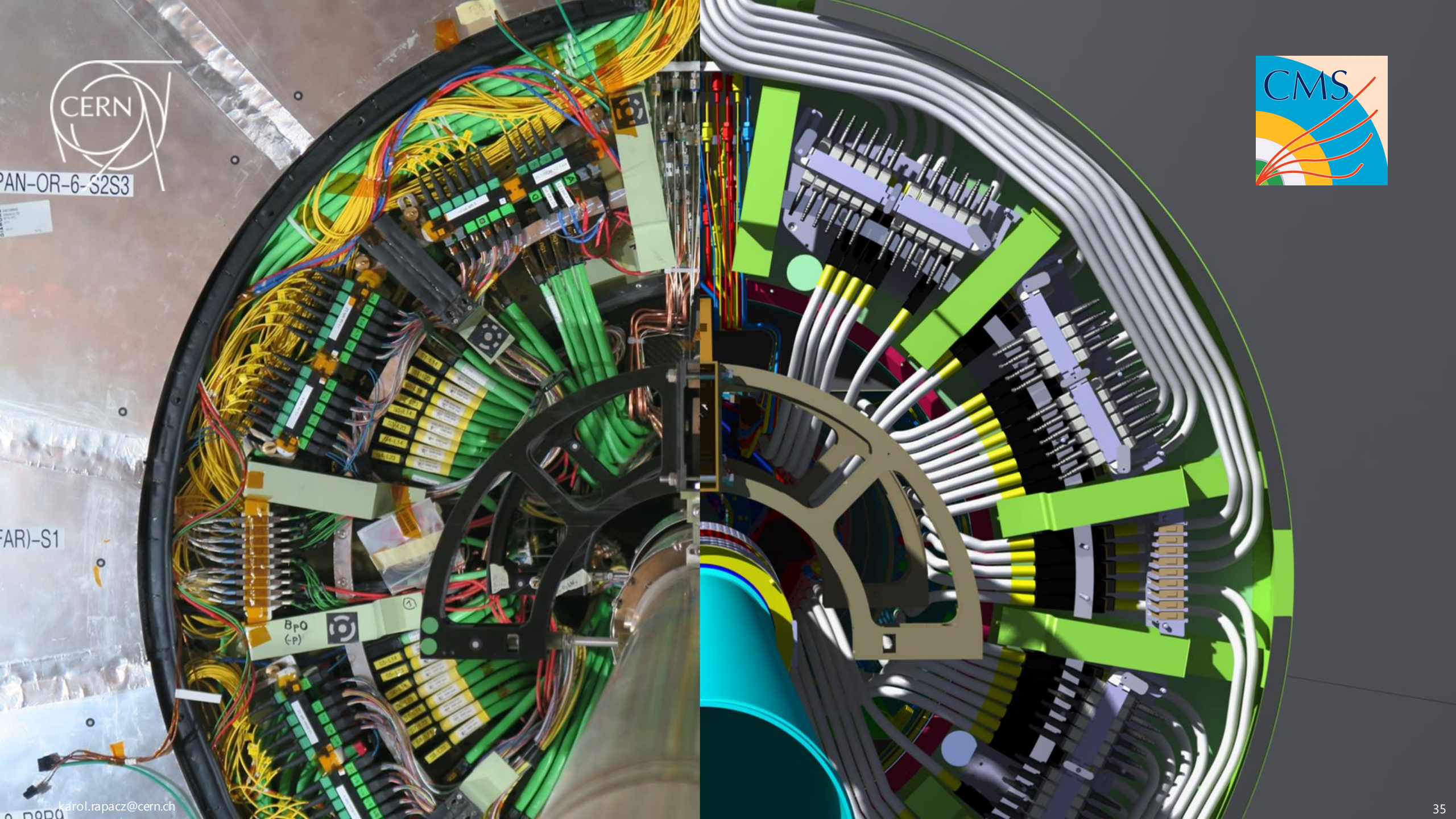


Installation!

Installation!






CERN
PAN-OR-6-S2S3
FAR)-S1
CMS

Conclusions

- Depending on the project size, investing in a dedicated integration engineer might be a very good idea.
- Setting up a simple and clear CAD workflow and file exchange system between collaborators is a must to avoid unnecessary mistakes.
- Prototyping is essential; it doesn't need to be a high-end prototype, though!
- If possible, always verify if what is built matches the inherited documentation/design.
- Don't underestimate user innovation.
- Be considerate of your future colleagues and update your design if some last-minute on-site modifications were made.

BONUS!

- 2x 1.5h rapid prototyping workshops (1st on Monday, 2nd on Tuesday)
- 3 challenges
- 3 groups of 8/9 people
- CAD, 3D printing and a lot of fun!