Lessons Learnt from CMS Mock-ups

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Index

- Short glossary
- Main functions of a physical mock-up
- Complementarity of real mock-ups and CAD models
- Examples of mock-ups for CMS Upgrade (HL-LHC)
- Mock-up of the CLIC VTX for CFD benchmarking
- Considerations on a mock-up for FCC-ee IR
- Conclusions

Short Glossary

- Digital model: CAD rapresentation of a region of interest
- Prototype: first version of a device from which evaluate its performances and/or manufacturing process
- Mock-up: physical recontruction of a limited region of interest. It origins from a simplified digital model of the region of interest and may include prototypes of components, 3-D printed elements as «space holders», realistic supports and masses for deformation and vibration studies, cables and other services, alignment targets, etc…

Main functions of a physical mock-up

- Geometrical integration – envelopes checks
- Functional integration (e.g. cooling, vibration, etc.)
- Installation sequence
- Alignment & survey
- Maintenance scenario & personnel training
- Cost and manpower estimate for final realization
- Outreach

Complementarity of real mock-up and CAD model

- Extension and coverage
- Fast modelling with high level of details
- Parametric design
- Numerical simulations
- Ease to share
- Feasibility studies
- Real scale measures of mechanical & thermal behaviour
- Tolerances evaluation, alignment & survey issues
- Maintenance & Operation assesment
- Training of personnel
- Cost and labour estimate for final realization
- Outreach purposes

Examples of mock-ups for CMS Upgrade

Despite the obvious differences between p-p and e-e MDIs, the exemples of mock-ups here presented are intended to give a broad view on their scope, their realization and the lessons learnt that may be useful also in the case of the FCC e-e Interaction Region design.

- Beampipe support
- Tracker Upgrade
- Calorimeter Upgrade

Beampipe support

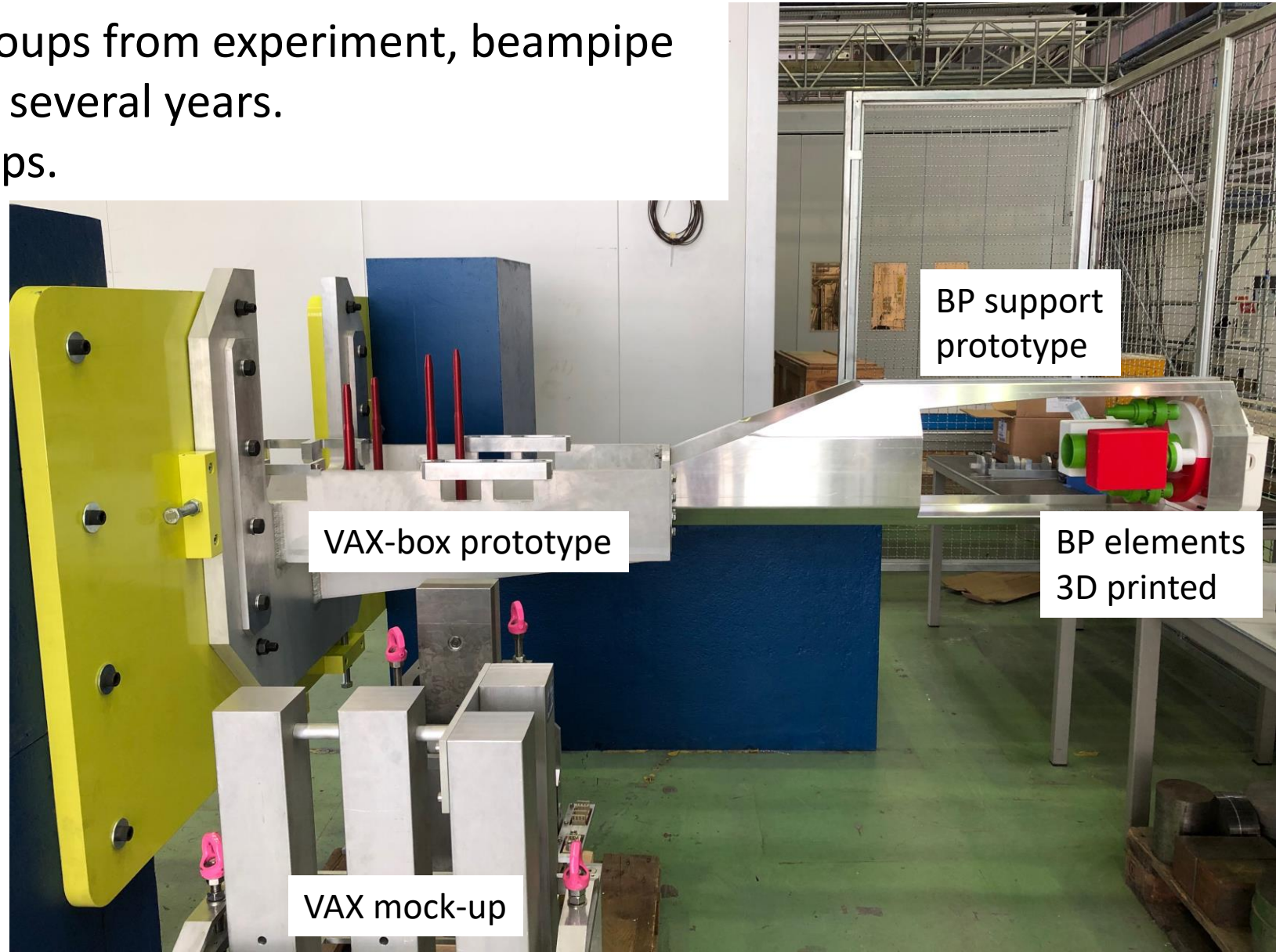
- Phase 2 Beampipe has a new support at 15.7m from I.P. It allows a quicker opening of CMS Endcaps, avoiding the installation of a cantilevered beam from the FIN.
- The new BP support interfaces with the new VAX-box (designed by EN-EA) and holds several Beampipe components (vacuum pump, bellow & adjusting frame) designed by TE-VSC.

Reasons for a mock-up:

- Check interfaces and tolerances with the VAX-Box designed by EN-EA.
  - A prototype of the VAX-Box was already available.
- Check installation sequence of TE-VSC components.
  - 3D-printing of main elements to check interferences & installation sequence.

Beampipe support mock-up in b.186

Collaboration of three different groups from experiment, beampipe and machine. It is still in use, after several years.
Cost shared among the three groups.



Beampipe Support Mock-up

- Lessons learned.
  - Useful synergy between CAD models & physical mock-up.
  - Very effective to debug small interferences, difficult to spot on CAD models (e.g. access with tools & wrenches)
  - Change of installation sequence decided later in the game by TE-VSC was quickly checked with the first mock-up and led to a re-design of the BP support.
  - Mock-up helped in optimizing fabrication process for the final BP support.

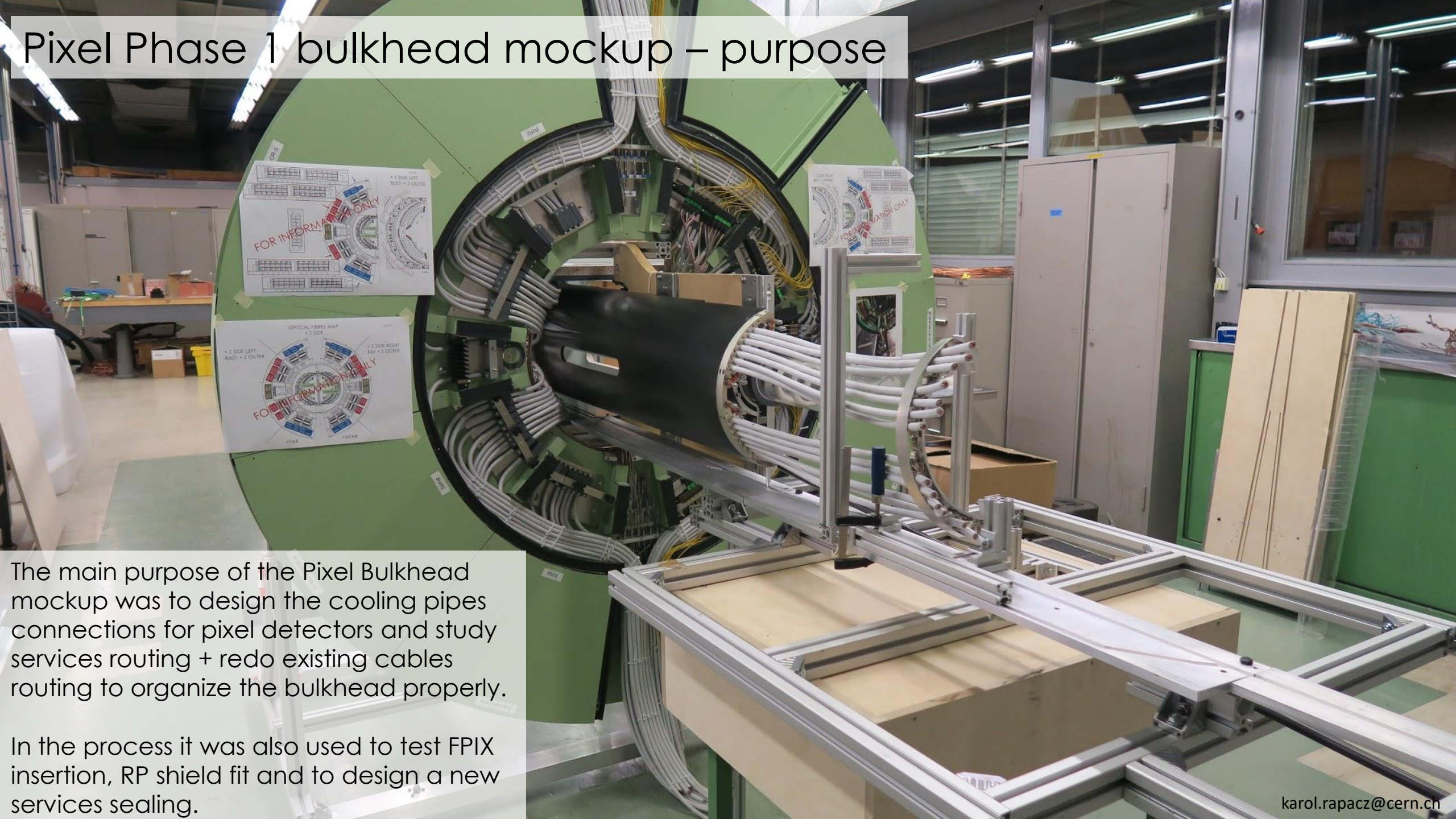
  - Long process to get the (small) space requested in b.186.

Tracker Upgrade

Contribution from N. Bacchetta & K. Rapacz

- Several mock-ups were built ahead of the construction of the present Tracker in the period 2004-2007
- Some extensively re-worked and expanded for the Phase I Pixel project
- We are building a set of brand-new mock-ups for Phase 2, namely (4 main mock-ups foreseen at the moment):
  1. PP1 and PP1-to-Tracker service channel + Tracker/BTL interface to Tracker channel and seals.
  2. Tracker service channel (cooling) thermal studies mock-up
  3. New Tracker bracket region and EB cabling mock-up
  4. Bulk-head replica for Pixel + ITST + Pixel nose region

Pixel Phase 1 bulkhead mockup – purpose



The main purpose of the Pixel Bulkhead mockup was to design the cooling pipes connections for pixel detectors and study services routing + redo existing cables routing to organize the bulkhead properly.

In the process it was also used to test FPIX insertion, RP shield fit and to design a new services sealing.

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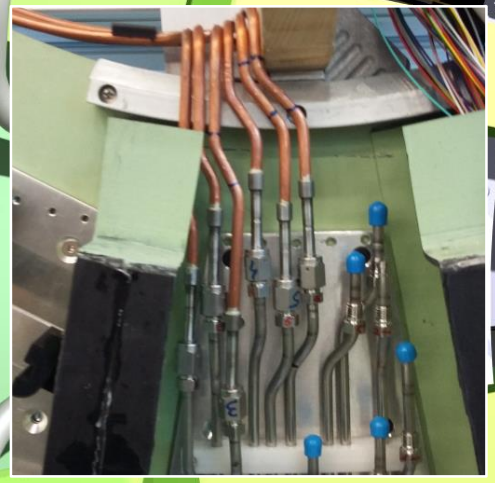
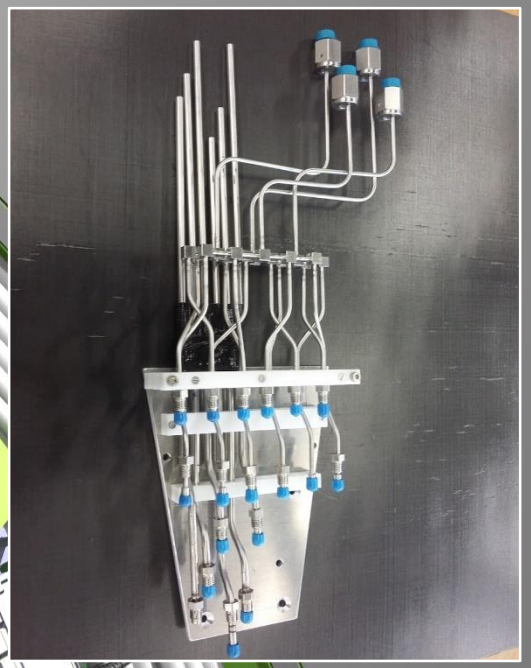
Mockup – CAD models workflow

All the ideas were iterated multiple times in CAD and then at the mockup to get the confidence that models are realistic





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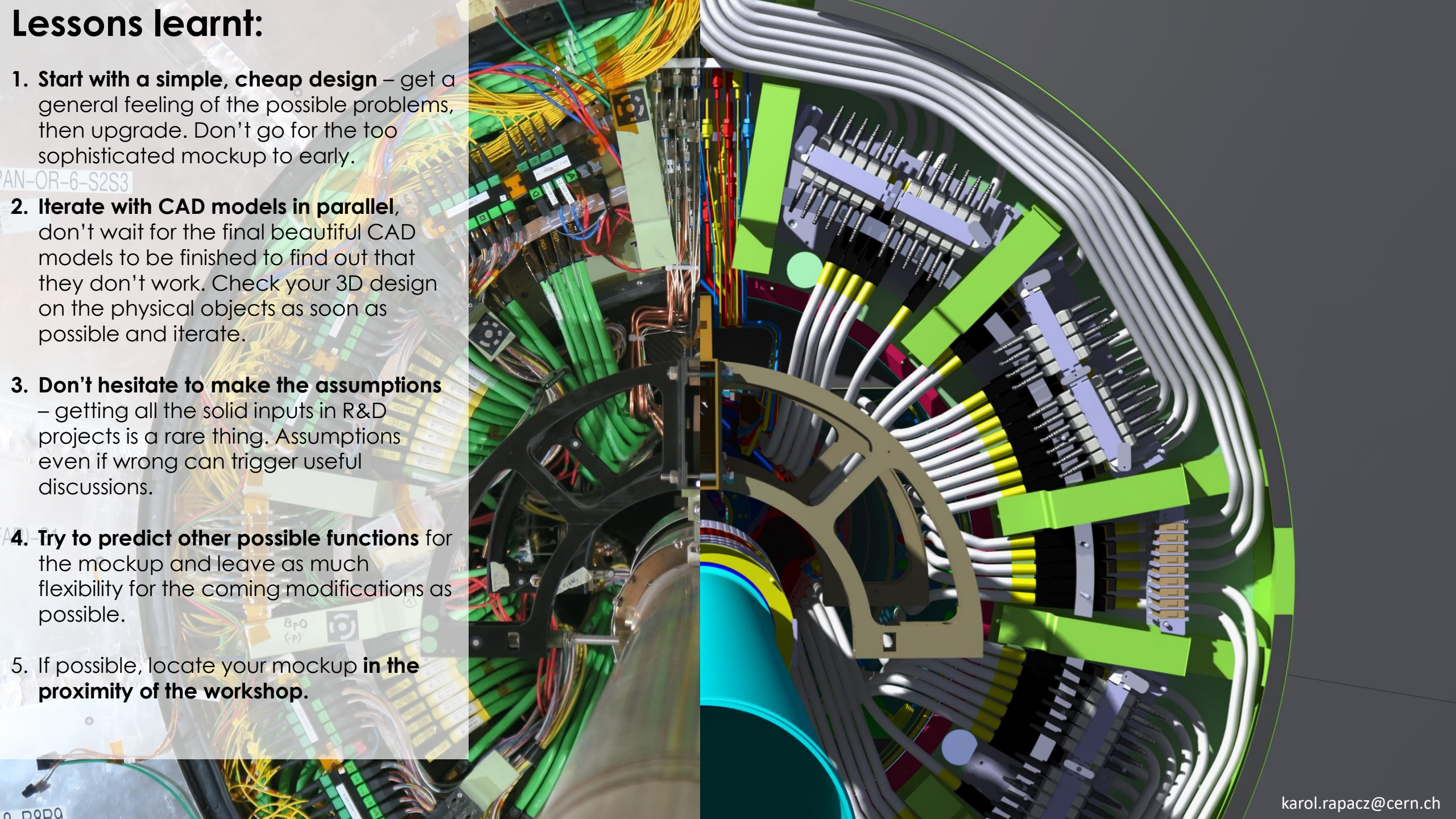
Lessons learnt:

1. **Start with a simple, cheap design** – get a general feeling of the possible problems, then upgrade. Don't go for the too sophisticated mockup to early.
2. **Iterate with CAD models in parallel**, don't wait for the final beautiful CAD models to be finished to find out that they don't work. Check your 3D design on the physical objects as soon as possible and iterate.
3. **Don't hesitate to make the assumptions** – getting all the solid inputs in R&D projects is a rare thing. Assumptions even if wrong can trigger useful discussions.
4. **Try to predict other possible functions** for the mockup and leave as much flexibility for the coming modifications as possible.
5. If possible, locate your mockup **in the proximity of the workshop.**



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Tracker Upgrade (cont'd)

Contribution from N. Bacchetta & K. Rapacz

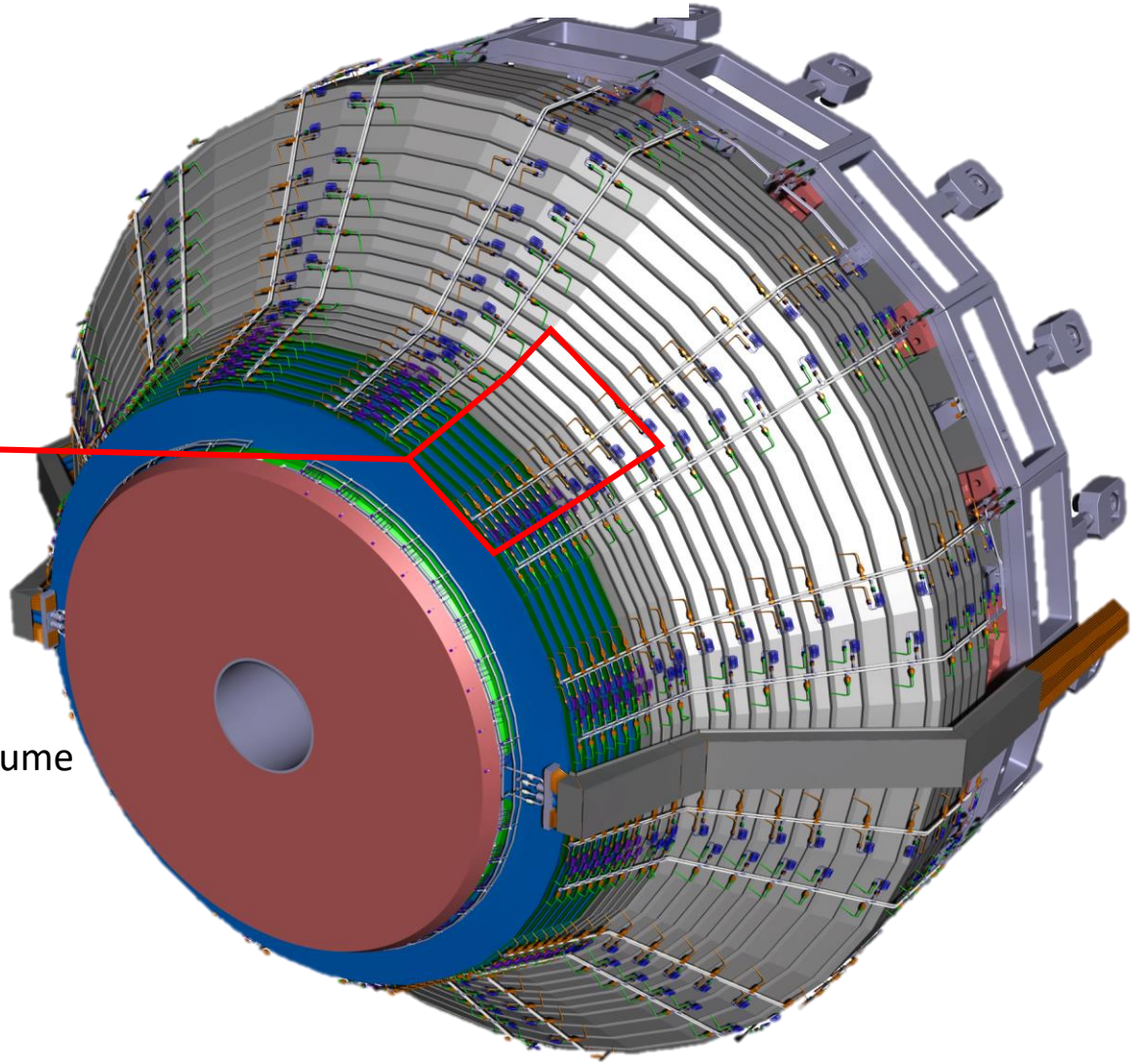
- Trade-off between cost, effort, flexibility, durability and precision vs usefulness
- In general experience shows that mock-ups are very useful for several reasons:

a. Manufacturing and putting together real parts almost as in realistic environment allows for a better understanding of the challenges to be faced (e.g. construction and installation point of view)

b. Practice service installation, sequence, anchoring points, etc.

c. Very useful to show people what work lays ahead once the region will not be accessible.

Calorimeter Upgrade / 20-degree mock-up



Scope of the mock-up:
- First estimation of the services volume/thickness inside detector's cold-volume

Size of the mock-up, location:
~ 1m x 1m x 0.5m, location B28/S019 – workshop

Timeline and resources estimate for preparation and exploitation.
- Finished

Cost estimate:
~2000CHF for materials

Utility needs:
- None

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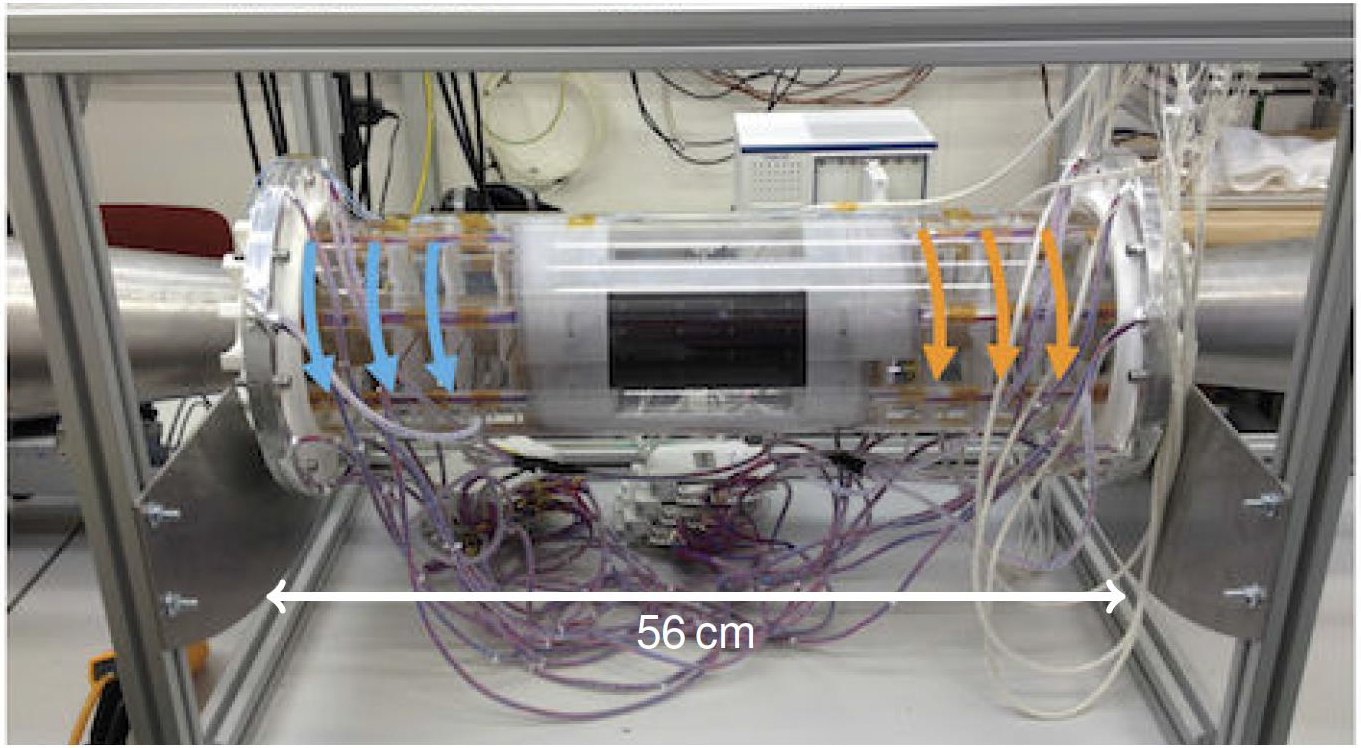
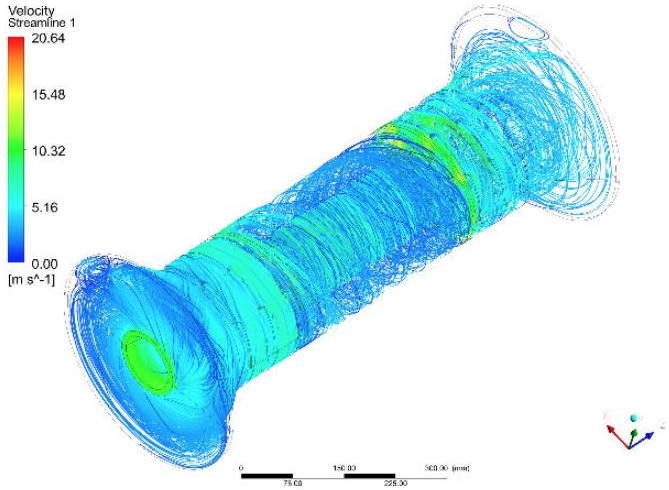
Mock-up of the CLIC VTX for CFD benchmarking



(a)



(b)

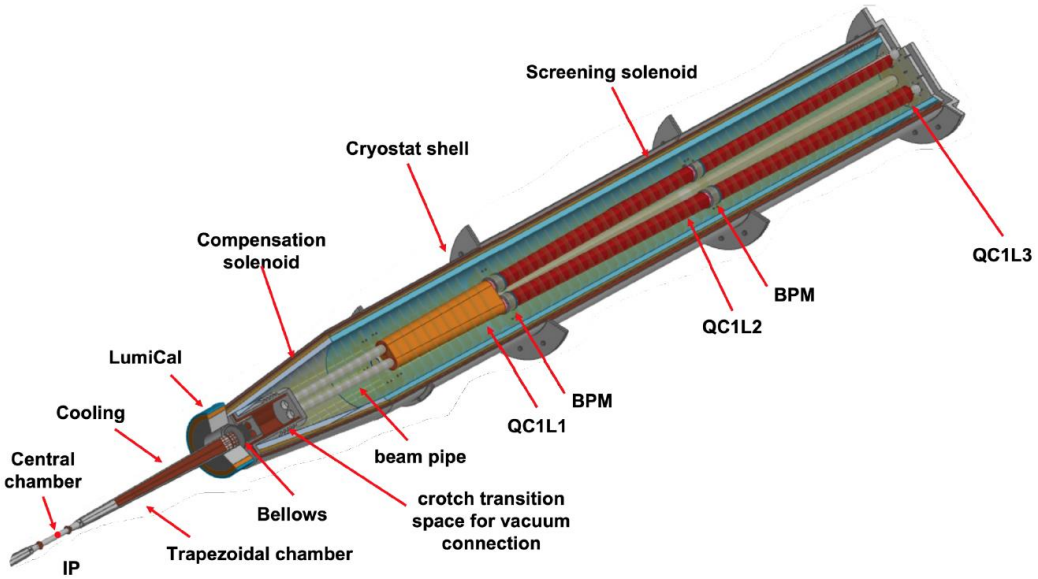
Real scale mock-up (a) of the CLIC VTX detector to study the performance of the air-flow cooling concept and compare the result with the computational fluid dynamics (CFD) simulations (b), showing the velocity streamlines of the forced air-flow insode the detector volume *(courtesy F. Duarte Ramos).*

Considerations on a mock-up for FCC-ee IR

A mock-up of the FCC e-e MDI region will be useful for the finalization of the system engineering of the IR and, in particular, for the scope of:

1) Addressing all the issues related to the assembly like:

- Possible conflicts of components and/or difficulties in components assembling
- Establishing the optimal assembling sequence
- Finalizing the dimensioning of all the components as close as possible to the requirements of the final design
- Anticipate potential problems of access to IR, especially after significant irradiation of massive components (LumiCal, Quads & Cryostat, etc…)

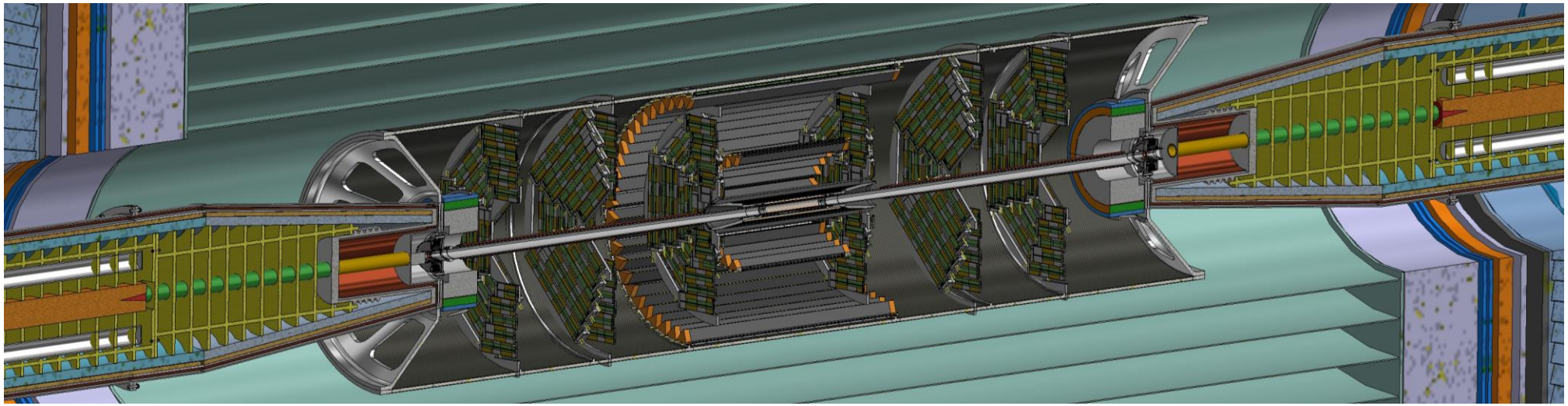


Considerations on a mock-up for FCC-ee IR (cont'd)

2) Test some critical functionality on real scale prototypes (e.g. Beampipe cooling, etc.)

3) Addressing all critical issues related for instance to the overall mass of the systems, like deformation, long and short-term stability of the system, including ad-hoc passive and active system to reduce vibrations

4) A realistic full-scale mock-up is also a way of converging to one single solution when many options exist on the table and an effective way of promoting a project!



Conclusions

- First and most important: define the scope of the mock-up, then make a deep evaluation of its design, the manufacturing methods, the installation, the different functionality tests, etc.
- Define the different mock-up materials, as function of their scope (e.g. if it is just to represent a volume, make it in plastic or wood, if it is needed to evaluate vibration modes, mass and stiffness are important).
- A physical mockup changes with time, as the needs of physicists and engineers -> it shall be designed for its evolution in time.
- Evaluate the need for general utilities (e.g. crane, cooling, power, sensors, dry air, gas ….) and the proximity of a workshop.
- Draft a timeline and a resources estimate for the muck-up preparation and exploitation.

Back-up slides

Old Tracker mock-ups

PP1 and TK channel mock-up (2006)

PP1 and TK channel mock-up (2014)

HB RBX (2014)

Unexpected use for the mockup

In the process additional purposes for the mockup were found.

Insertion test for FPIX detector:

- Lack of the space to fix the cooling connections when FPIX detector is already installed, forced us to connect the pipes to the detector before insertion is done. This required tests to be done for which mockup was not entirely designed for.

RP shield:

- RP shield fitting was also study at the mockup. Weight of the shield put some strain on the mockup design.

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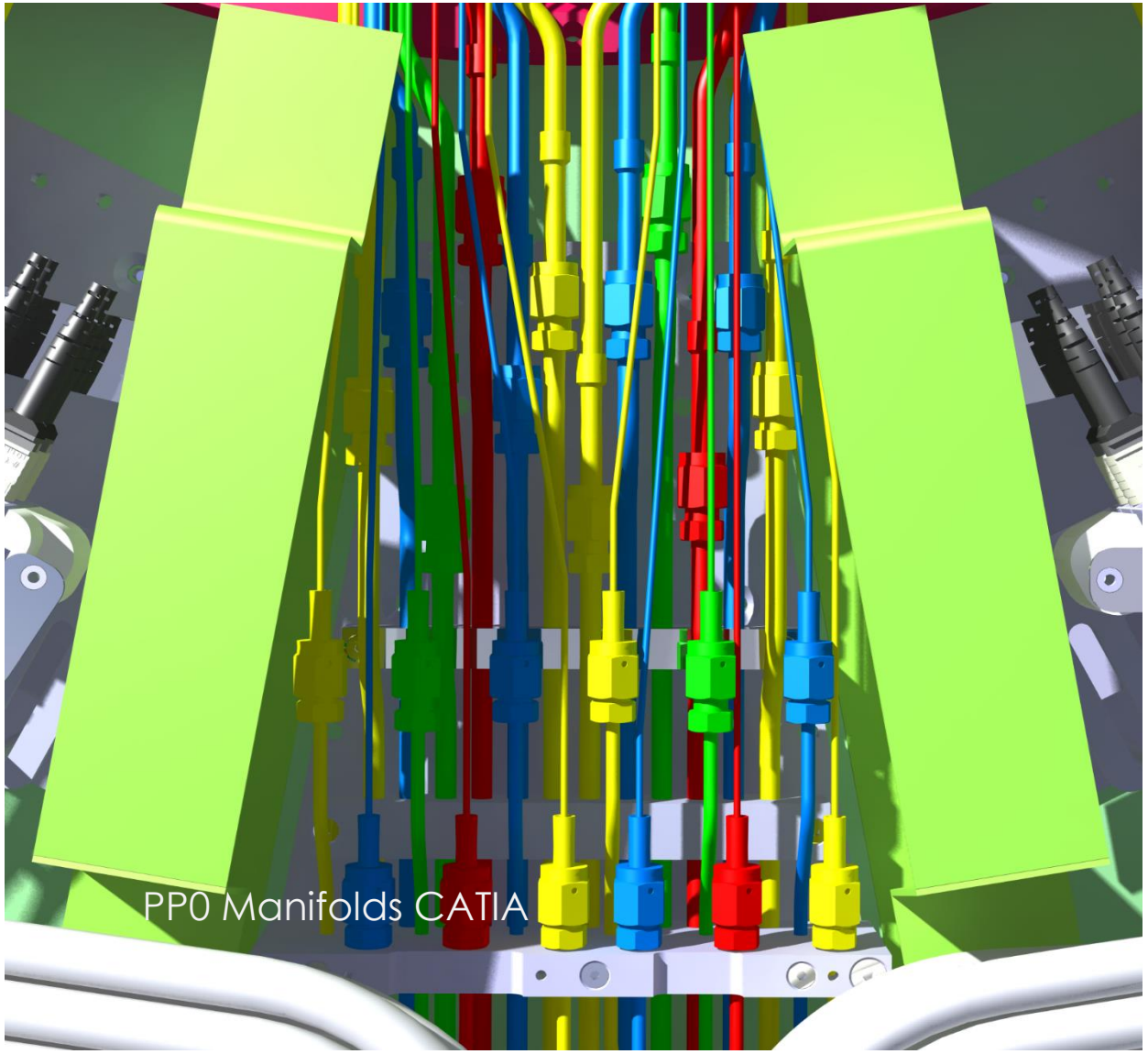
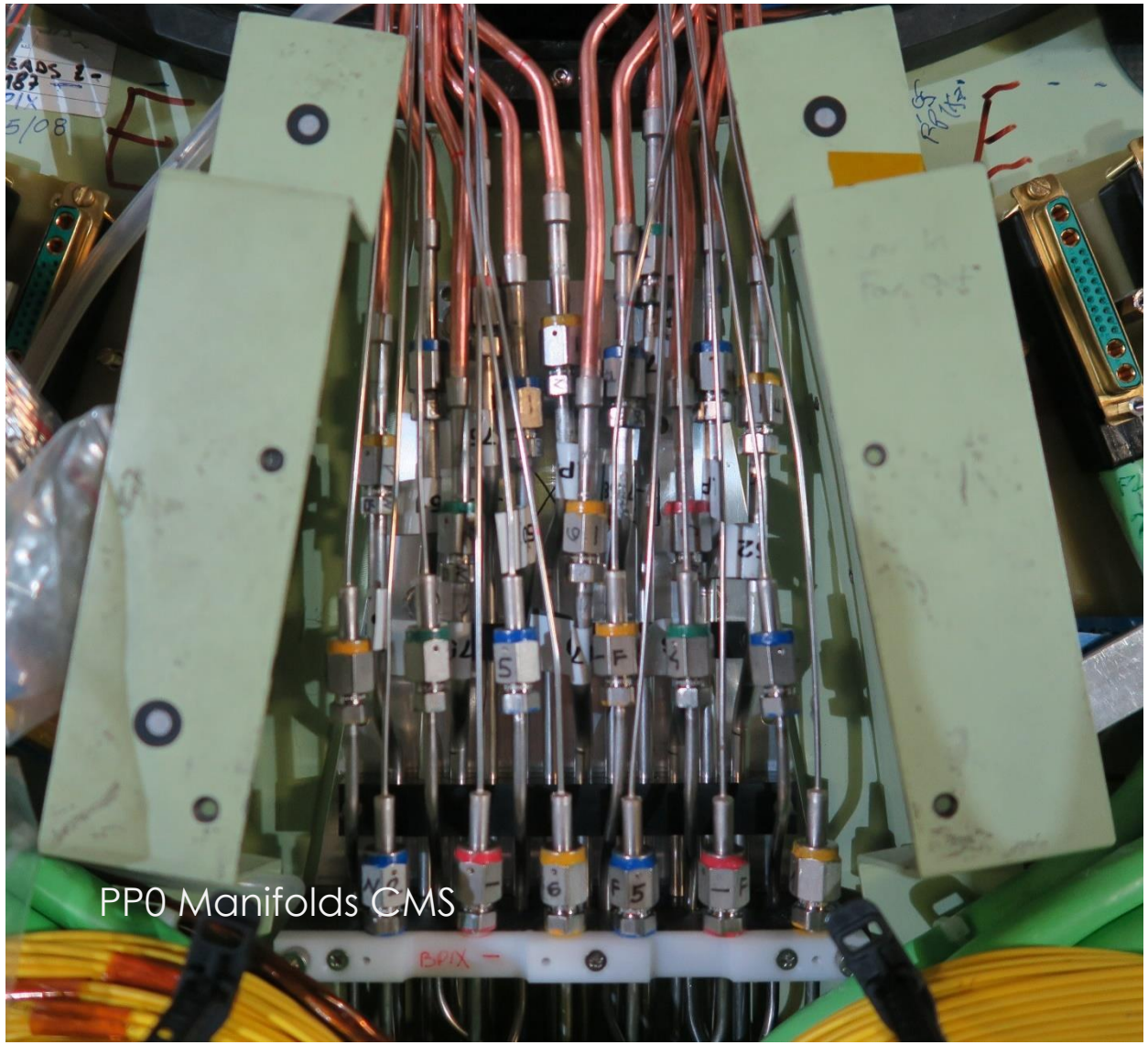
Benefits of the mockup

Pixel detectors Services installation was very challenging, but long hours invested at the mockup allowed to go through the process smoothly





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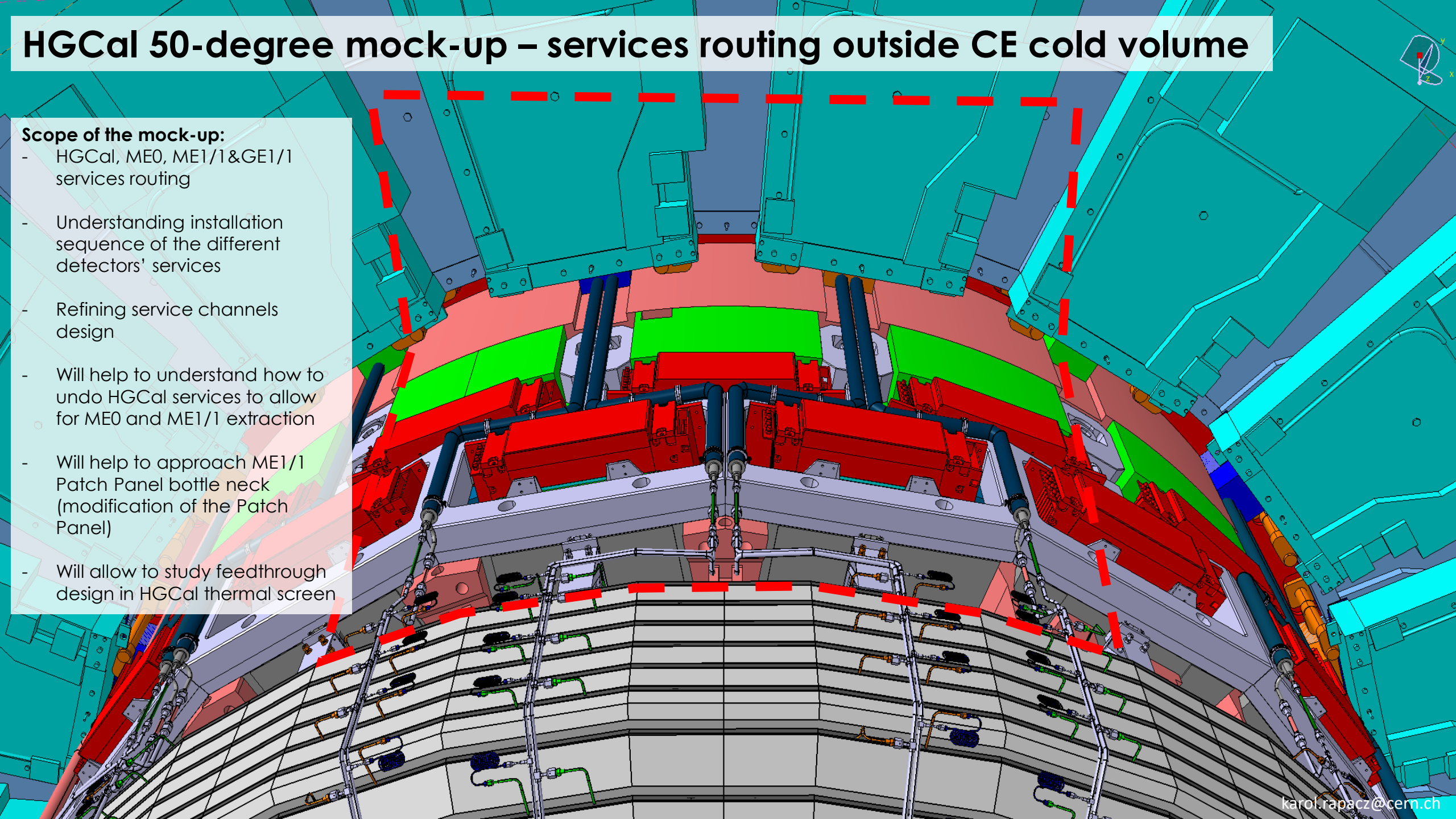
HGCal 50-degree mock-up – services routing outside CE cold volume



Scope of the mock-up:

- HGCal, ME0, ME1/1&GE1/1 services routing
- Understanding installation sequence of the different detectors' services
- Refining service channels design
- Will help to understand how to undo HGCal services to allow for ME0 and ME1/1 extraction
- Will help to approach ME1/1 Patch Panel bottle neck (modification of the Patch Panel)
- Will allow to study feedthrough design in HGCal thermal screen

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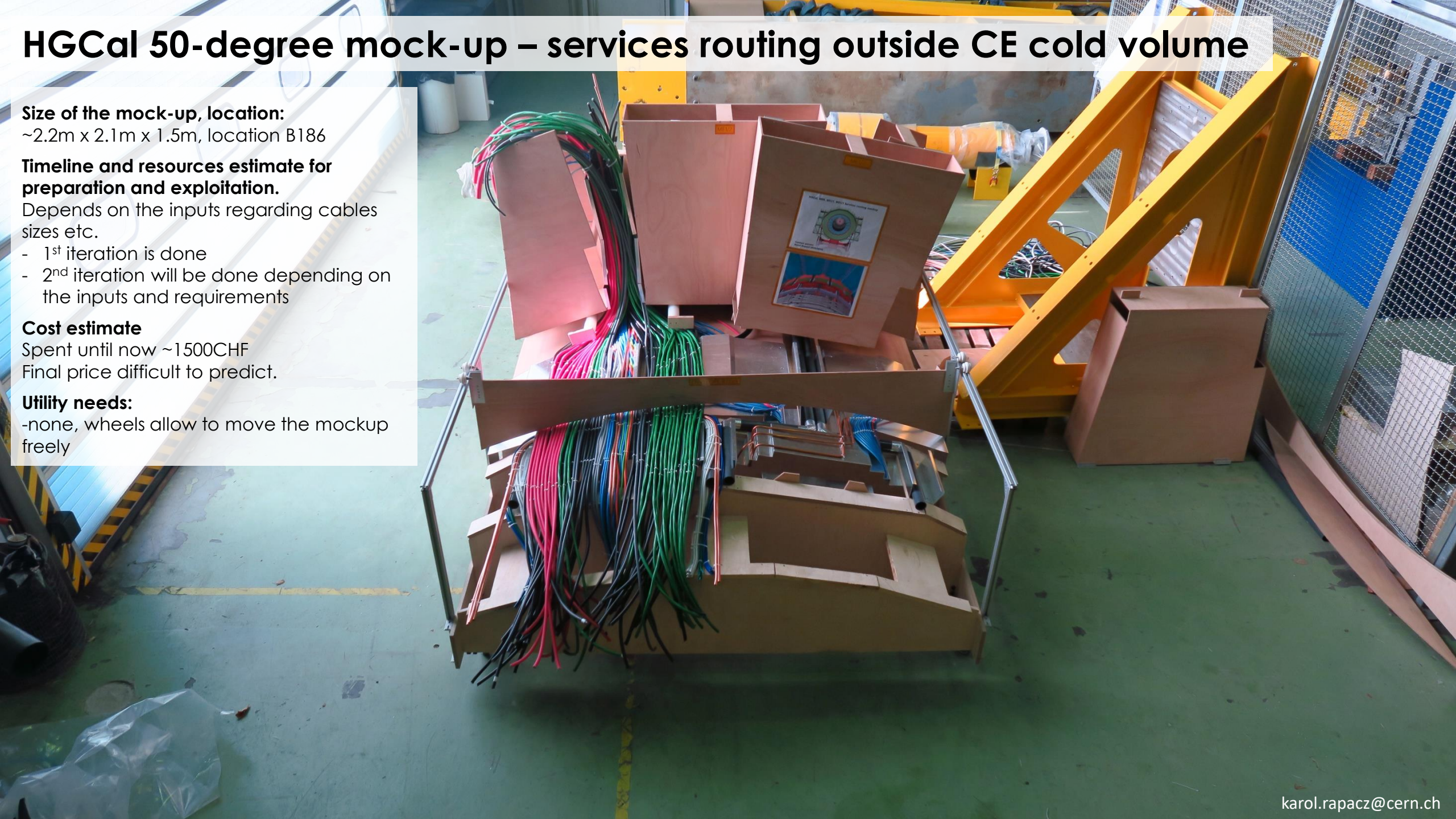
HGCal 50-degree mock-up – services routing outside CE cold volume

Size of the mock-up, location:
~2.2m x 2.1m x 1.5m, location B186

Timeline and resources estimate for preparation and exploitation.
Depends on the inputs regarding cables sizes etc.
- 1st iteration is done
- 2nd iteration will be done depending on the inputs and requirements

Cost estimate
Spent until now ~1500CHF
Final price difficult to predict.

Utility needs:
-none, wheels allow to move the mockup freely



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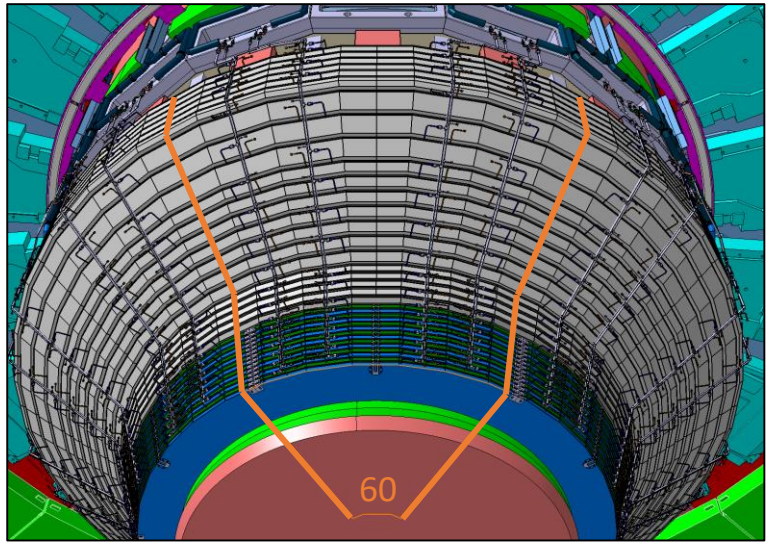
HGCal 60-degree mock-up

Size of the mock-up, location:
~2.8m x 2.1m x 1.8m, location B186

Final Weight **1000kg** overall
- 600kg Structure
- 400kg Services (estimate



Scope of the Mock-up:

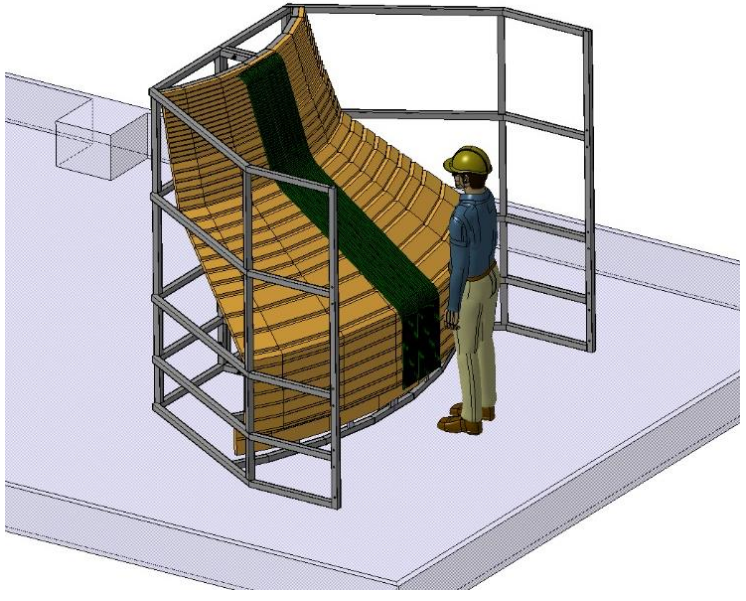
-Investigate the services installation sequence within thermal screen (services thickness, cable paths)

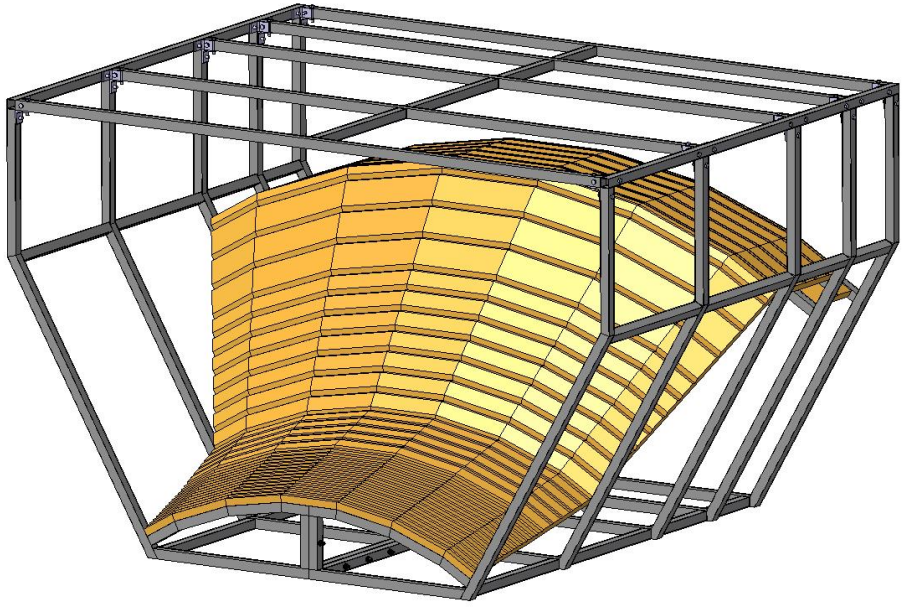
-Choice of connectors and passage through thermal screen feedthrough

-Understand services behaviour in different orientations

-Study feedthroughs and routing services away from HGCAL

-Thermal screen design validation





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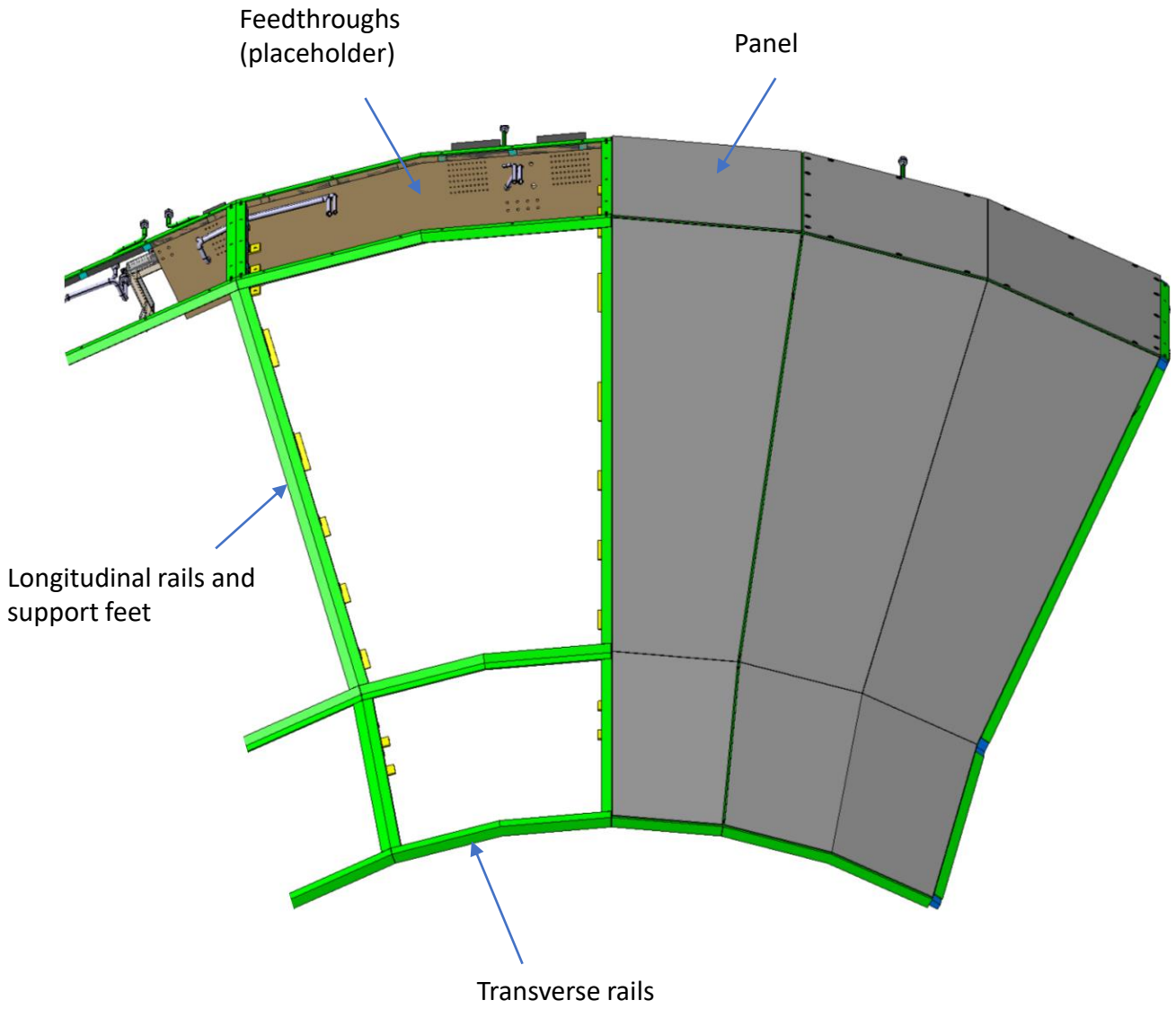
HGCAL Thermal Screen - Prototyping and Testing Activities

- Mechanical assembly test planned for outer radius thermal screen panels and rail system on 60° services mock-up, testing:
  - Fit of rail support system over 60°.
  - Fit and assembly procedure for 30° of panels.
  - Assembled panel dimensions.
  - Fit of services beneath the panels, including heating foil wiring.
  - Iteration of feedthroughs design – dimensions, services routing and connections.

- Separate prototyping and testing for all thermal screen panels is planned (including those not shown here) – sealing, mechanical loading, thermal performance.



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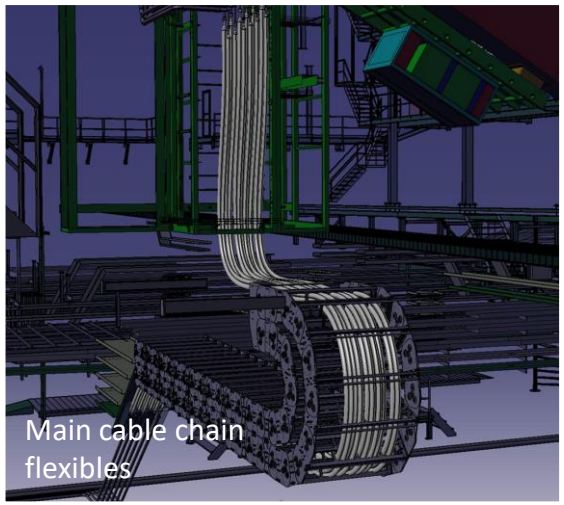
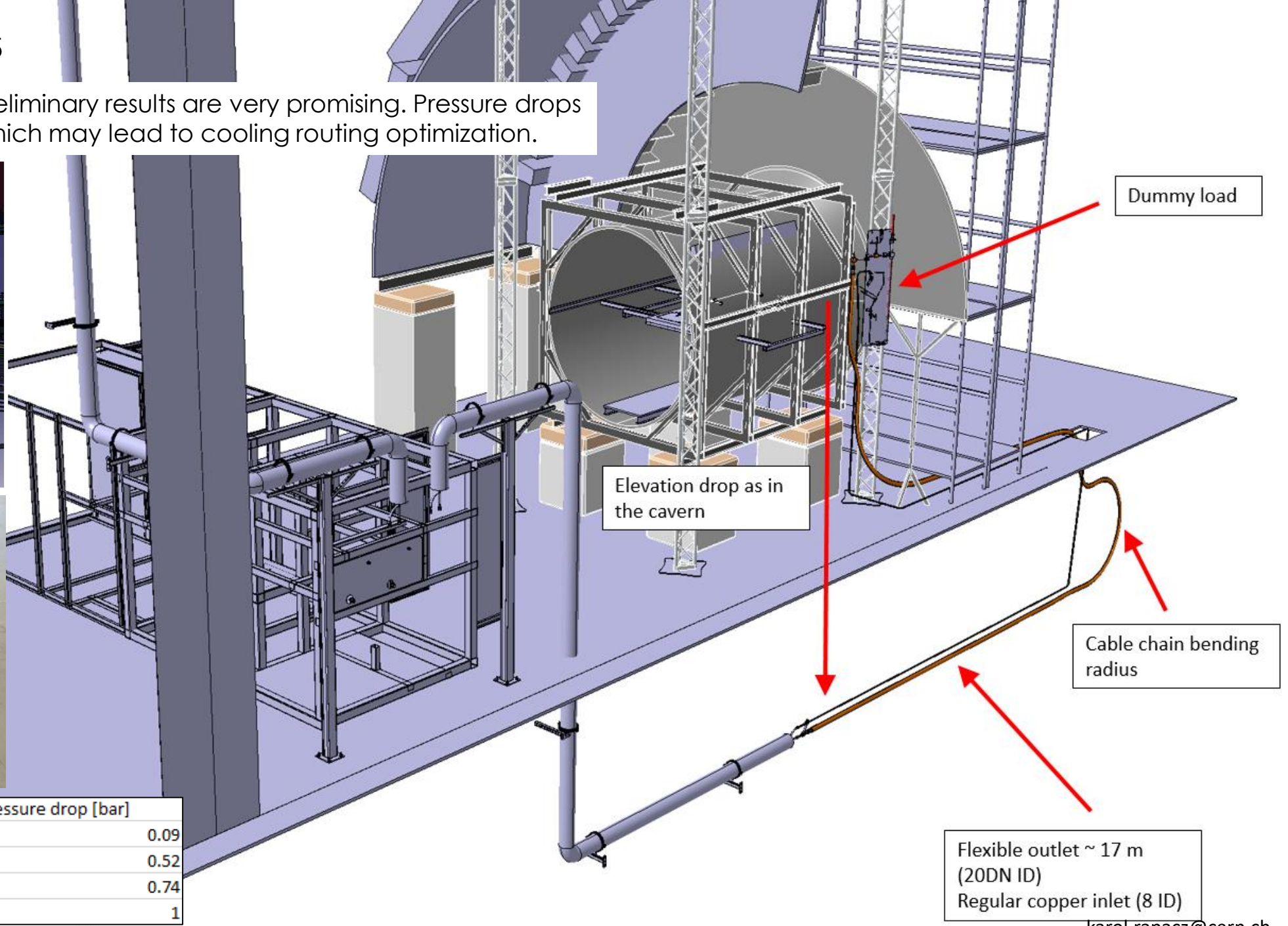
Cooling mockups

Flexible pressure drop tests, preliminary results are very promising. Pressure drops are smaller than expected, which may lead to cooling routing optimization.



Temp [C]	Flow [g/s]	Power [W]	Pressure drop [bar]
-36	40	5000	0.09
-34.6	90	10000	0.52
-35.2	101	11300	0.74
-34.5	110	12500	1



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