VAX prototyping, procurement, installation, alignment & operation

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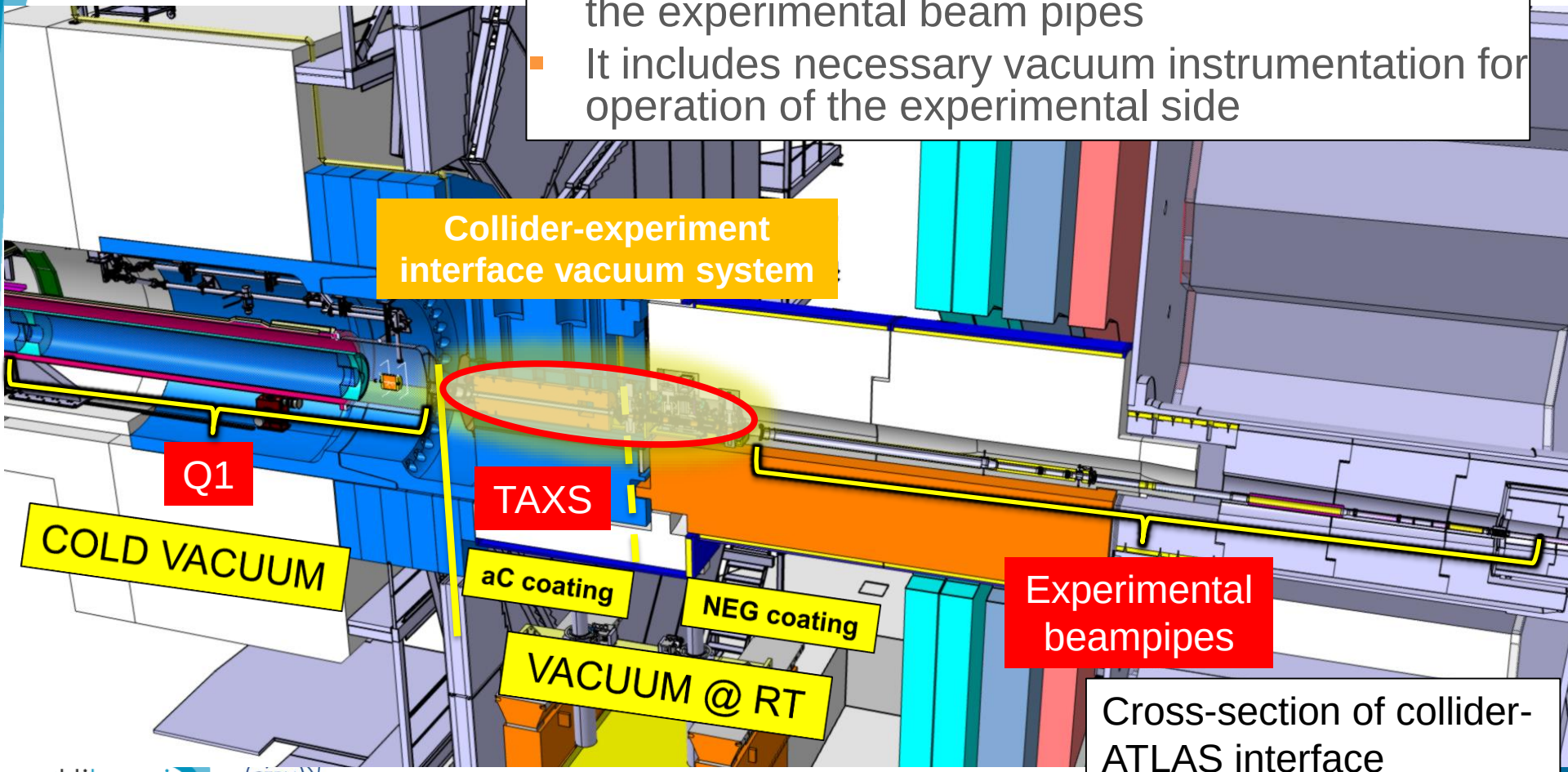
1. Introduction to vacuum system of collider-experiment interface and item identification

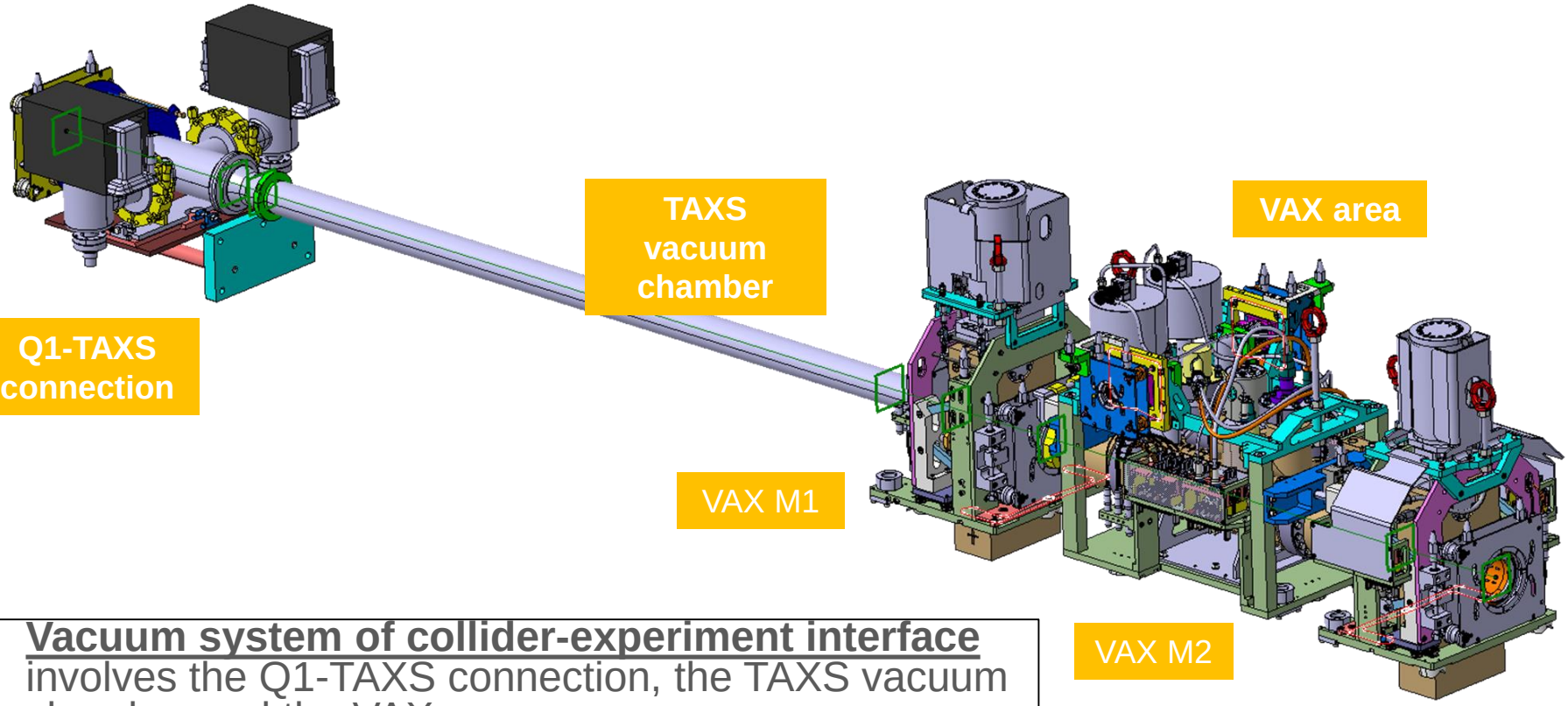
HL-LHC vacuum system of collider-experiment interface – ATLAS example

- **Vacuum system of collider-experiment interface** connects the vacuum system of Q1 (through the cold-warm transition - CWT) with the experimental beam pipes
- It includes necessary vacuum instrumentation for operation of the experimental side



Cross-section of collider-ATLAS interface

Main subsystems of HL-LHC collider-experiment interface vacuum system



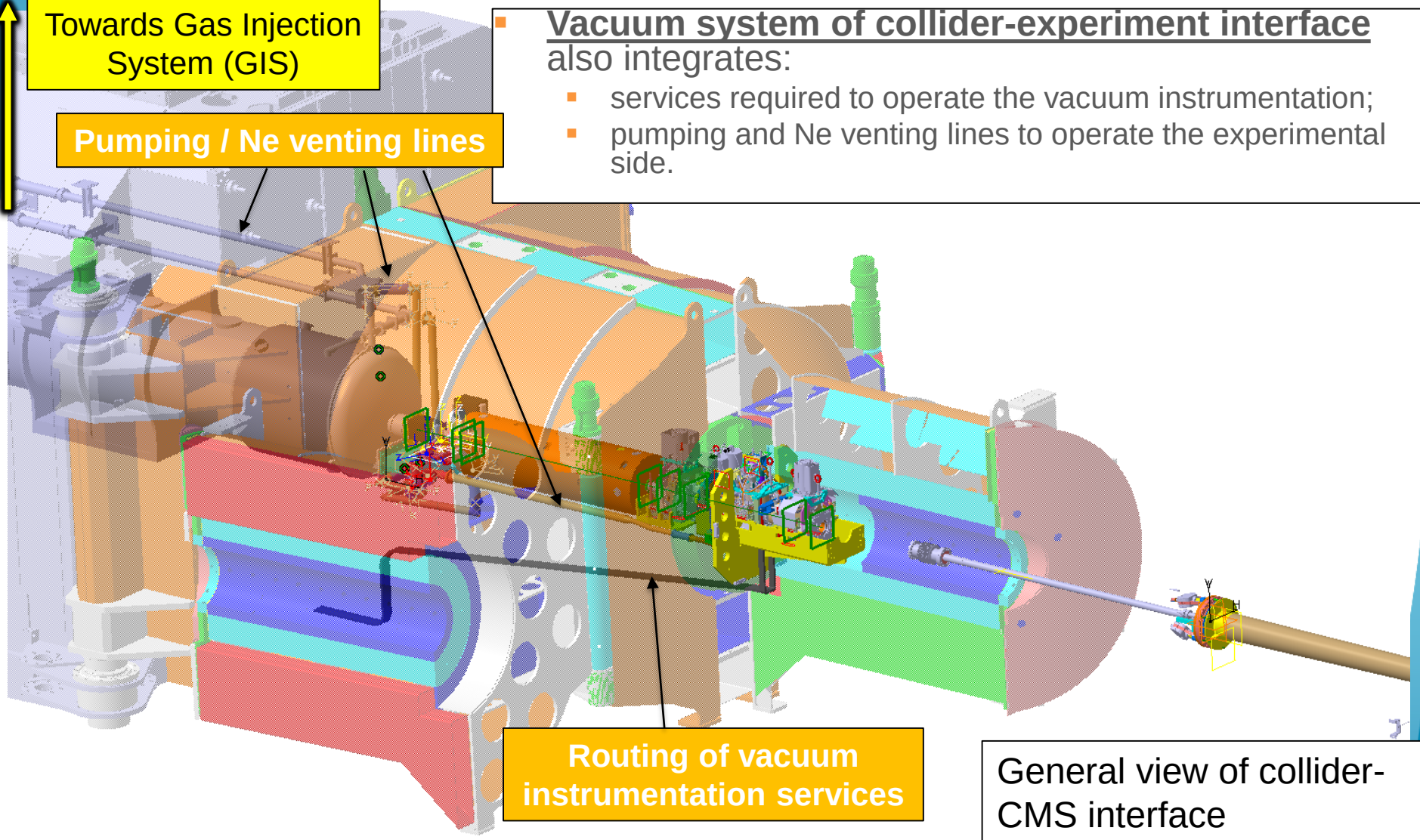
- **Vacuum system of collider-experiment interface** involves the Q1-TAXS connection, the TAXS vacuum chamber and the VAX area
- **VAX area (Vacuum Assembly for eXperimental area)** refers to the full vacuum connection between TAXS and the experimental chambers
- Similar approach for IR1 (ATLAS) and IR5 (CMS)

Pumping / Ne venting lines for HL-LHC vacuum system – CMS example

Towards Gas Injection System (GIS)

Pumping / Ne venting lines

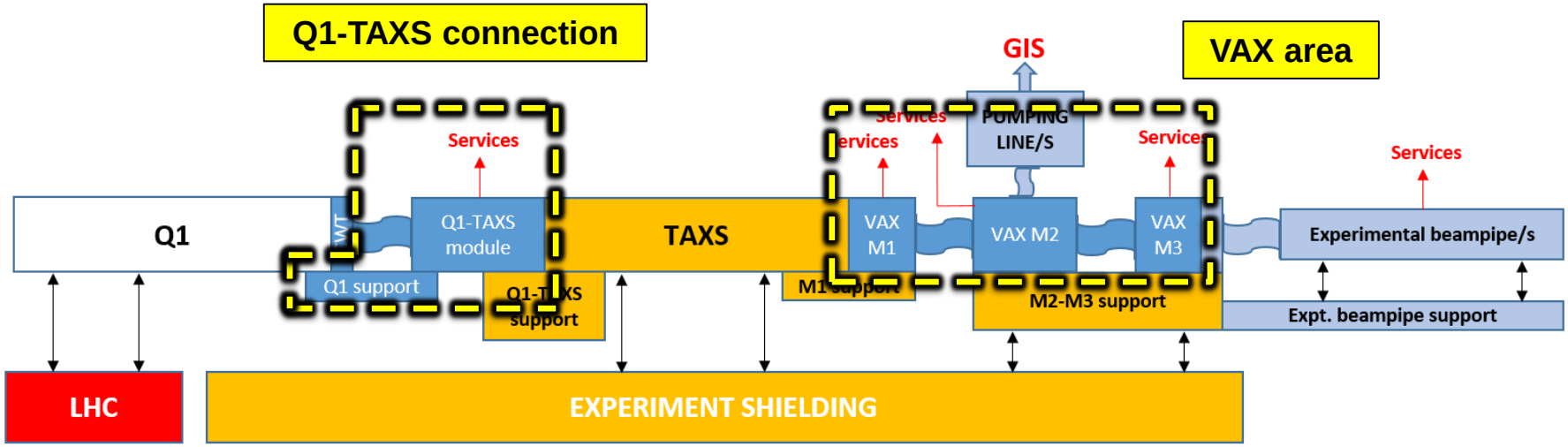
- **Vacuum system of collider-experiment interface** also integrates:
  - services required to operate the vacuum instrumentation;
  - pumping and Ne venting lines to operate the experimental side.



Routing of vacuum instrumentation services

General view of collider-CMS interface

Subsystem and item identification



Block diagram of collider-experiment interface

Roadmap and schedule before installation

	2021				2022				2023				2024				2025				Comments
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Q1-TAXS MODULE									*	*											
TAXS CHAMBER																					In-kind contribution
VAX M1																					
VAX M2																					
VAX M3																					
PUMPING LINES																					
GIS																					

* No double external bellows

- Conceptual design
- Final design
- Prototype supply + assembly
- Prototype test + design upgrade
- Bake-out and vacuum tests (TBC)
- Series supply + assembly
- Acceptance test

First vacuum qualification tests (TBC)

First orders for series supplies

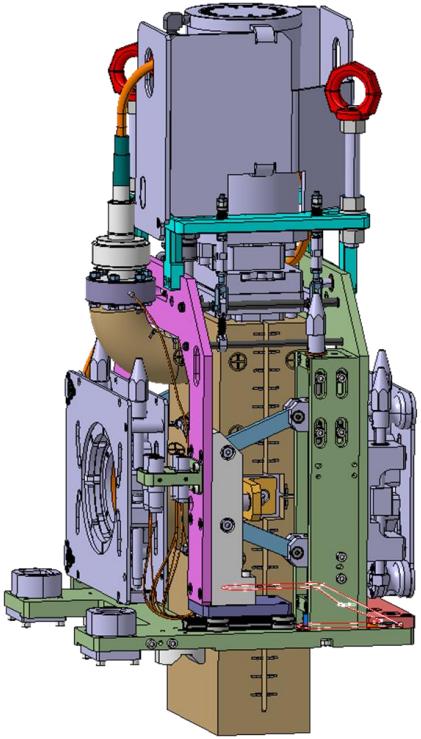
First acceptance tests

To achieve the objectives of the roadmap there are still several open points to solve

2. VAX prototyping and tests status

VAX module status

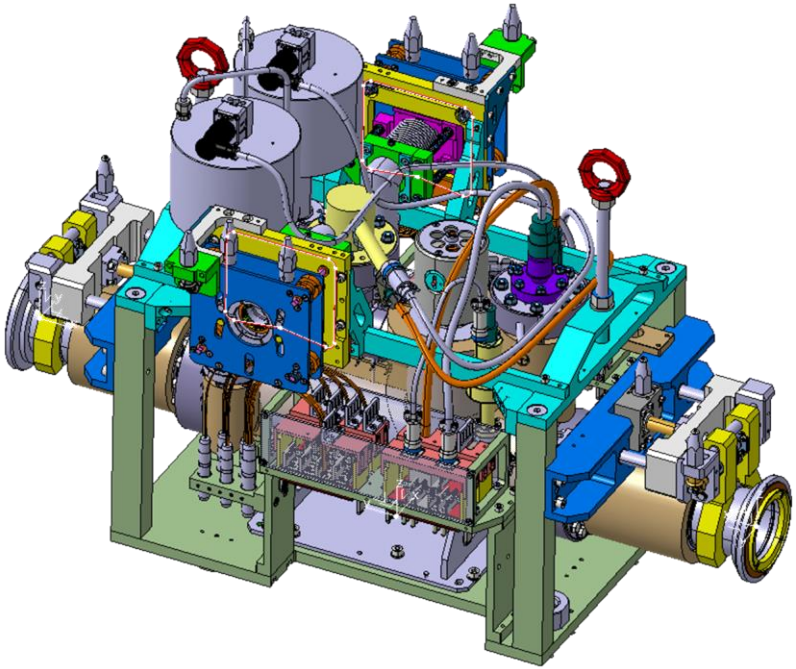
M1 current baseline does not assemble STAUBLI connectors



VAX M1: common to IR1 and IR5

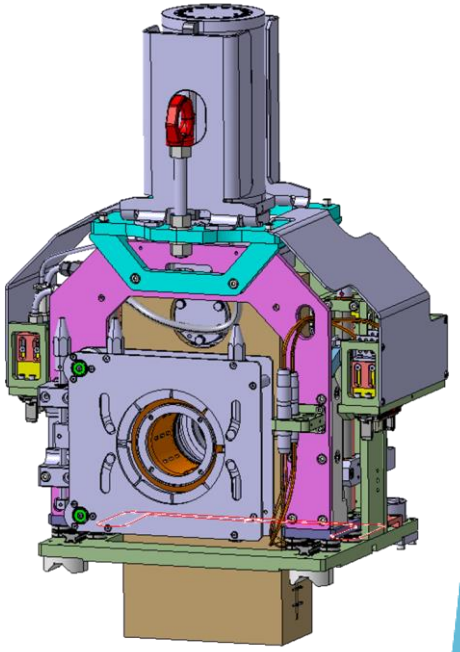
Prototype released → testing ongoing

M2 current baseline does not assemble ion pumps



M2 (IR5 version): similar BUT different between IR1 and IR5

Design for final prototype pending of decision on vacuum layout and Q1-TAXS connection design

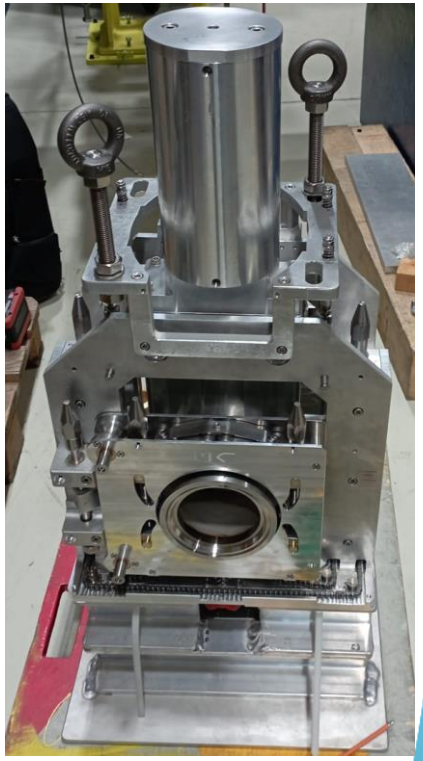


M3: common to IR1 and IR5

Prototype released → testing ongoing

VAX M1 – prototyping and tests

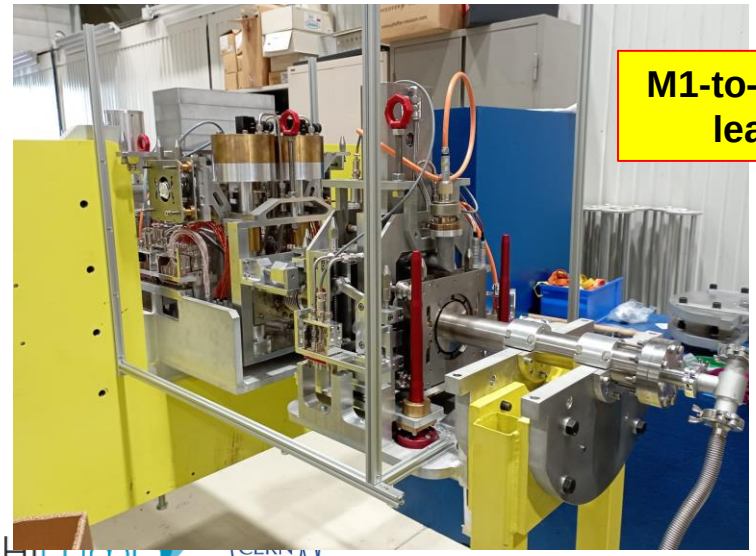
- Handling
  - ATLAS: test to be repeated → re-adjustment of handling eye-bolt height following conclusions of previous tests
    - Methodology OK
    - Sling configuration TBC
  - CMS: OK
- Accessibility to remote operation
  - ATLAS: test to be repeated → confirm accessibility at TAXS side (with new sling configuration), **including envelope of services and pumping lines**
  - CMS: OK
- Remote operation → ATLAS and CMS:
  - Test for vacuum flange closure to be repeated → New functionalities integrated on the robotic tooling: number counting + higher torque to minimum tightening level (final tightening made manually on previous tests)
  - **Test including cabling manipulation** → No automatic STAUBLI connection according to last design baseline
- **Sector valve AND bake-out jacket integration** → ATLAS and CMS:
  - Bake-out tests (SIMILAR TO VAX M3)
    - Standard bake-out jacket solution
    - Alternative solution under study (TBC)
  - Vacuum tests (COMMON TO VAX M3)
  - **Integration of upgraded design** to enhance assembly process in order to facilitate maintenance and internal pre-alignment (COMMON TO VAX M3)



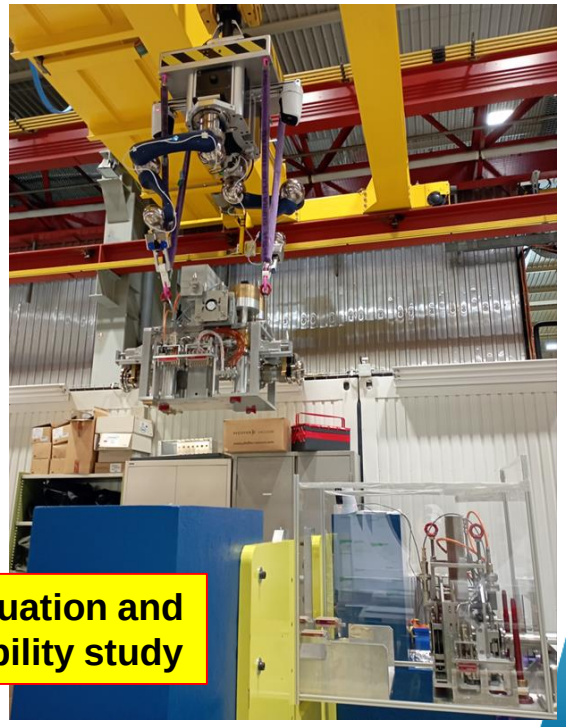
- **Bake-out jacket received**
- **Sector valve delivery foreseen by mid-October 2022 following reliability problems on external edge-welded bellows of actuation system during cycling tests → PROBLEM IS APPARENTLY IDENTIFIED AND CYCLING TESTS ON NEW DESIGN ARE ONGOING**

VAX M2 – prototyping and tests

- Final design is pending on decision of vacuum layout
  - Prototype made with dummy loads of vacuum chamber and instrumentation;
  - Prototype included all key features for remote connection: STAUBLI connectors, quick vacuum connectors for pumping lines, bellows retraction mechanism with quick vacuum connector
- Handling → ATLAS and CMS:
  - **Tests to be repeated with cabling of STAUBLI connectors on both female and male sides**
  - Tests to check electrical and pneumatic continuity after quick connection
- Accessibility to remote operation → ATLAS and CMS, OK
- Remote operation → ATLAS and CMS:
  - Test for guiding system of bellows retraction mechanism to be repeated → tests so far OK
  - **Integration and tests of vacuum connection to pumping lines**
- **Main vacuum chamber, vacuum instrumentation AND bake-out jacket integration** → ATLAS and CMS:
  - Bake-out tests
    - Standard bake-out jacket solution
    - Alternative solution under study (TBC)
  - Vacuum tests



M1-to-TAXS vac. chamber leak tightness test



M2 remote actuation and robot accessibility study

VAX M3 – prototyping and tests

- Handling → ATLAS and CMS:
  - **Tests to be repeated with cabling of STAUBLI connectors on both female and male sides**
  - Tests to check electrical and pneumatic continuity after quick connection
- Accessibility to remote operation → ATLAS and CMS, OK
- Remote operation → ATLAS and CMS:
  - Test for vacuum flange closure to be repeated → New functionalities integrated on the robotic tooling: number counting + higher torque to minimum tightening level (final tightening made manually on previous tests)
- **Sector valve AND bake-out jacket integration** → ATLAS and CMS:
  - Bake-out tests (SIMILAR TO VAX M1)
  - Vacuum tests (COMMON TO VAX M1)
  - **Integration of upgraded design** to enhance assembly process in order to facilitate maintenance and internal pre-alignment (COMMON TO VAX M1)

M3 remote installation in cavern

M3 remote actuation and robot accessibility study

3. VAX procurement

Material availability acc. to baseline planning and last TAXS installation proposal at ATLAS

	2021				2022				2023				2024				2025				Comments	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4		
Q1-TAXS MODULE									*	*												(a)
TAXS CHAMBER																					In-kind contribution	(b)
VAX M1																						(c)
VAX M2																						(d)
VAX M3																						(d)
PUMPING LINES																						(e)
GIS																						(TBC)

* No double external bellows

- Conceptual design
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- Series supply + assembly
- Acceptance test

a) Q1 installation starts in June 2027 → if TAXS installation for ATLAS is approved (by June 2026) ⇒ **Q1-TAXS module** requires to be installed at TAXS between both → conservative approach is to have **material to be ready by Q1 2026**

b) mechanical production is through in-kind contribution (or WP8), but surface treatments and vacuum acceptance tests require to be made before installation. Material is to be ready during TAXS assembly process, foreseen along Q3 2025 if TAXS installation for ATLAS is approved (by June 2026) → conservative approach is to have **material to be ready by Q2 2025**

c) Not really necessary until vacuum commissioning of triplet vacuum subsector – last magnet to be installed by October 2027 → anyway, same approach as Q1-TAXS module can be considered, **material to be ready by Q1 2026**

d) VAX installation (except M1) is foreseen along Q3/Q4 2028 → conservative approach is to have **material to be ready by Q4 2027**

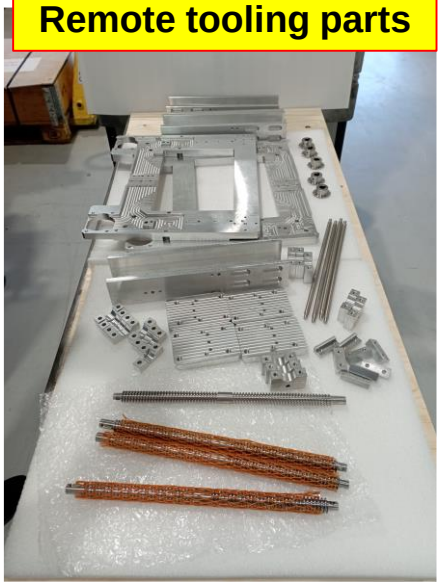
e) Open point for ATLAS. Planning to be studied to check slots (not before June 2026) → conservative approach is to have **material to be ready by Q1 2026 (TBC)**

For CMS it applies the same logics as for TAXS chamber → conservative approach is to have **material to be ready by Q2 2025**

VAX M1-M2-M3 procurement (I)

- **General mechanics (remote tooling, support components, etc.):** design details being upgraded but procurement should be <6 months (raw material + production) → should not be an issue
- **Vacuum instrumentation:** based on standard known material → should not be an issue
- **Vacuum chambers and inserts:** raw material considered as a potential bottleneck due to extended delivery time → already supplied for the series components of the consolidated designs (everything except for M2 vacuum chamber)
  - Cu-OFE bars and Cu-OFS tubes for inserts
  - Tube in SS 316-L
  - Bar in SS 316-LN for vacuum quick flanges
- **Bake-out material:** baseline is to use standard bake-out jackets (design established for M1and M3, and almost defined for M2), but alternatives are under study. For standard material, procurement is estimated to be <6 months (raw material + production) → should not be an issue

Remote tooling parts



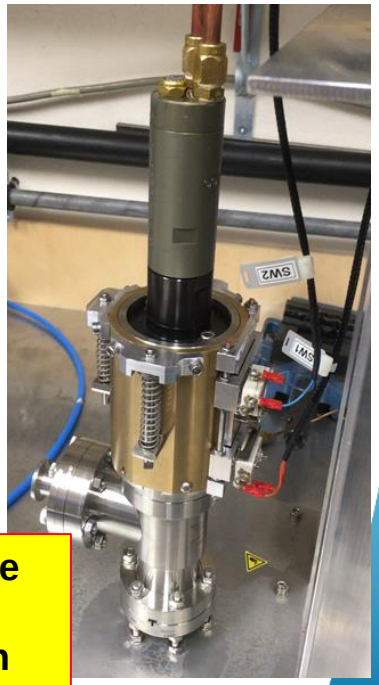
Vacuum chambers and inserts

VAX M1-M2-M3 procurement (II)

- **Sector valves** → dedicated all-metal valve. Current delay is >1 year due to unexpected technical problems and extended raw material delivery (inside VAT), for a delivery time of >1 year. Technical problems seem to be solved but require confirmation: most solid information by the end of 2022. Supply under blanket contract B1501/TE, currently extended until at least June 2023. **Supply of series to be done under current blanket contract**
- **Right-angle valves** → final solution is still under evaluation (see slide 37). **Decision should be taken by Q2 2023** if extension of supply blanket contract B1502/TE is guaranteed until at least end of 2023.
- **Bellows**: planned to be supplied through an annex to order CA9102154 for the supply of HL-LHC plug-in modules and beam screen assemblies. Over-cost is inside the scope of the corresponding DR (#8594569)
  - aC coating tests under preparation with dimensionally similar bellows
  - Final version as per HL-LHC WG on Alignment (March 17th 2021). Solution endorsed following 32nd Meeting of the HL-LHC Technical Coordination Committee
- **Local services** → pneumatics tubing and hard-rad cabling. TBC but should not be an issue

VAX sector valve

Vacuum bellows



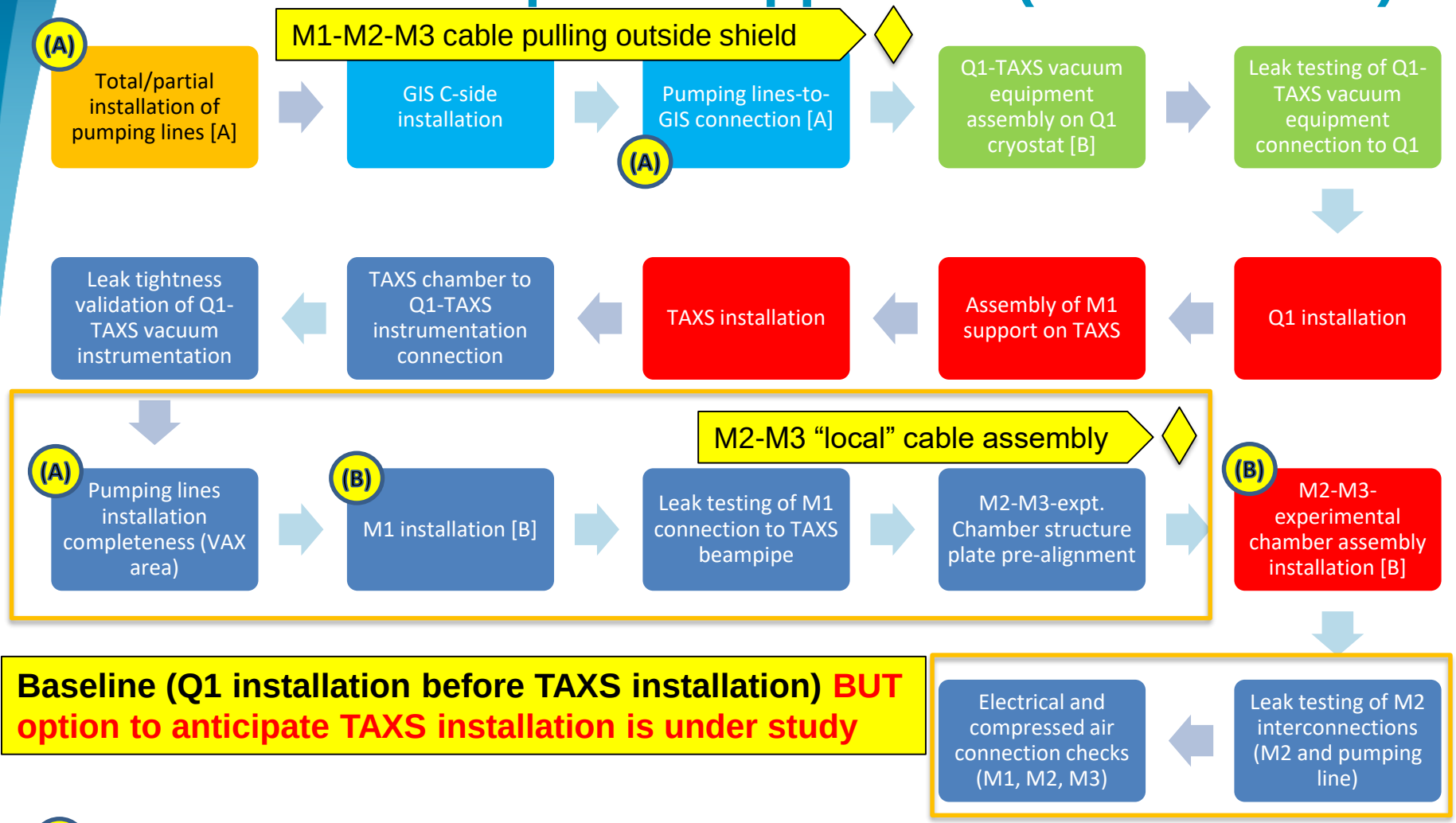
Manual angle valve with prototyped external actuation

4. VAX installation

VAX installation – some key points

- ATLAS
  - M1 is installed on its support individually
    - M1 to be installed without STAUBLI and manual connection outside the shields
  - M2 and M3 are pre-installed on surface on their support and then installed together with the VJ experimental chamber support as a whole
    - M1 support remains in place at every shutdown or technical stop
    - M2-M3 modules and supports are removed at every LS
  - Routing of pumping lines is outside the shield
  - New GIS is to be assembled at C-side → **baseline is to install symmetrically wrt A-side**
  - Access to Q1-TAXS area is only possible through the LHC tunnel
- CMS
  - Modules are installed individually on their corresponding supports
    - Supports remain in place at every shutdown or technical stop
    - M1 to be installed without STAUBLI and manual connection outside the shields
  - Routing of pumping lines is through TAXS

Installation sequence approach (ATLAS case)

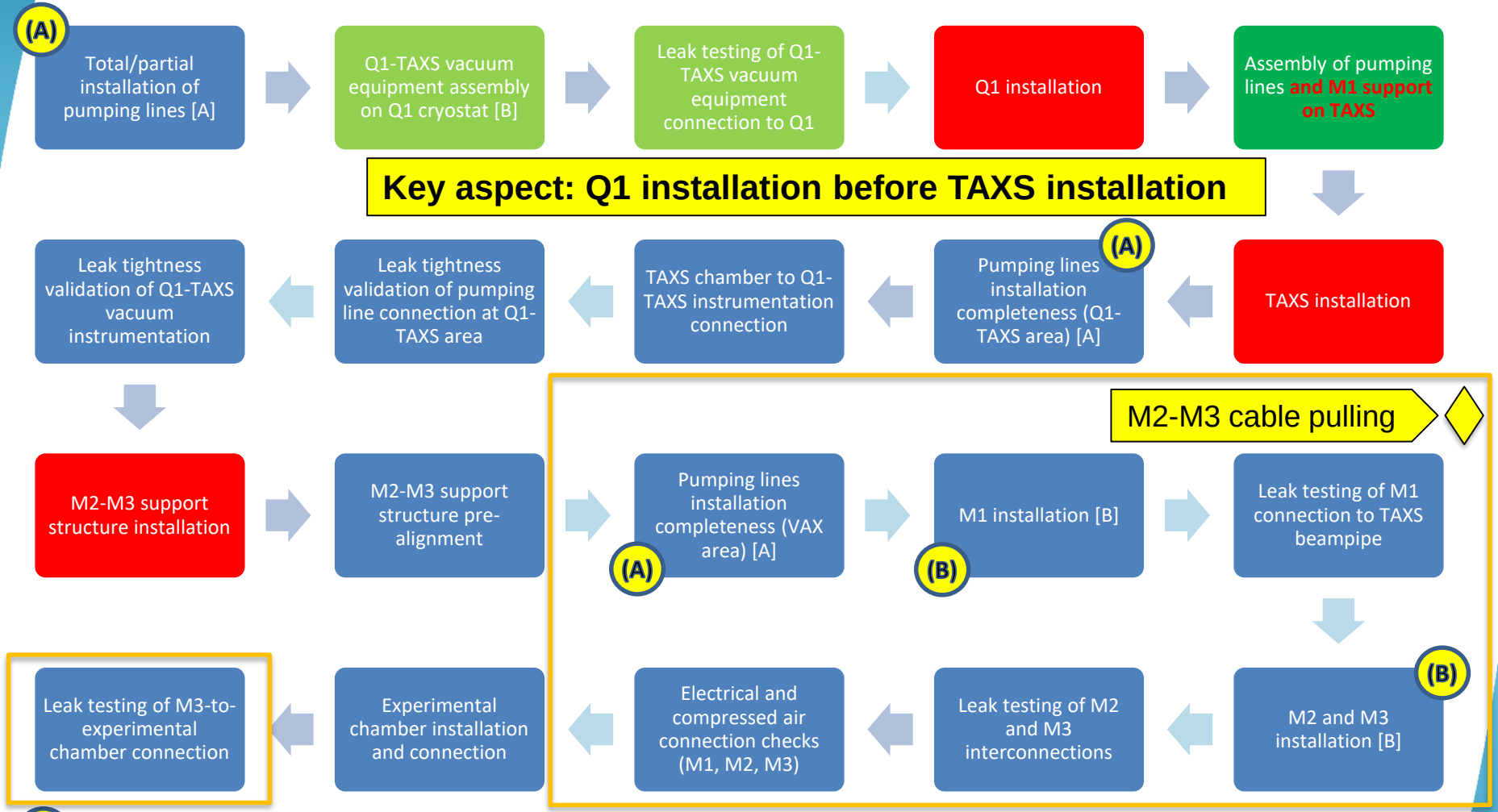


Baseline (Q1 installation before TAXS installation) BUT option to anticipate TAXS installation is under study

(A) Leak tightness validation of pumping lines installed + checking and commissioning of existing bake-out

(B) Module assembled and verified leak tight on surface. If applicable, bake out already verified on surface

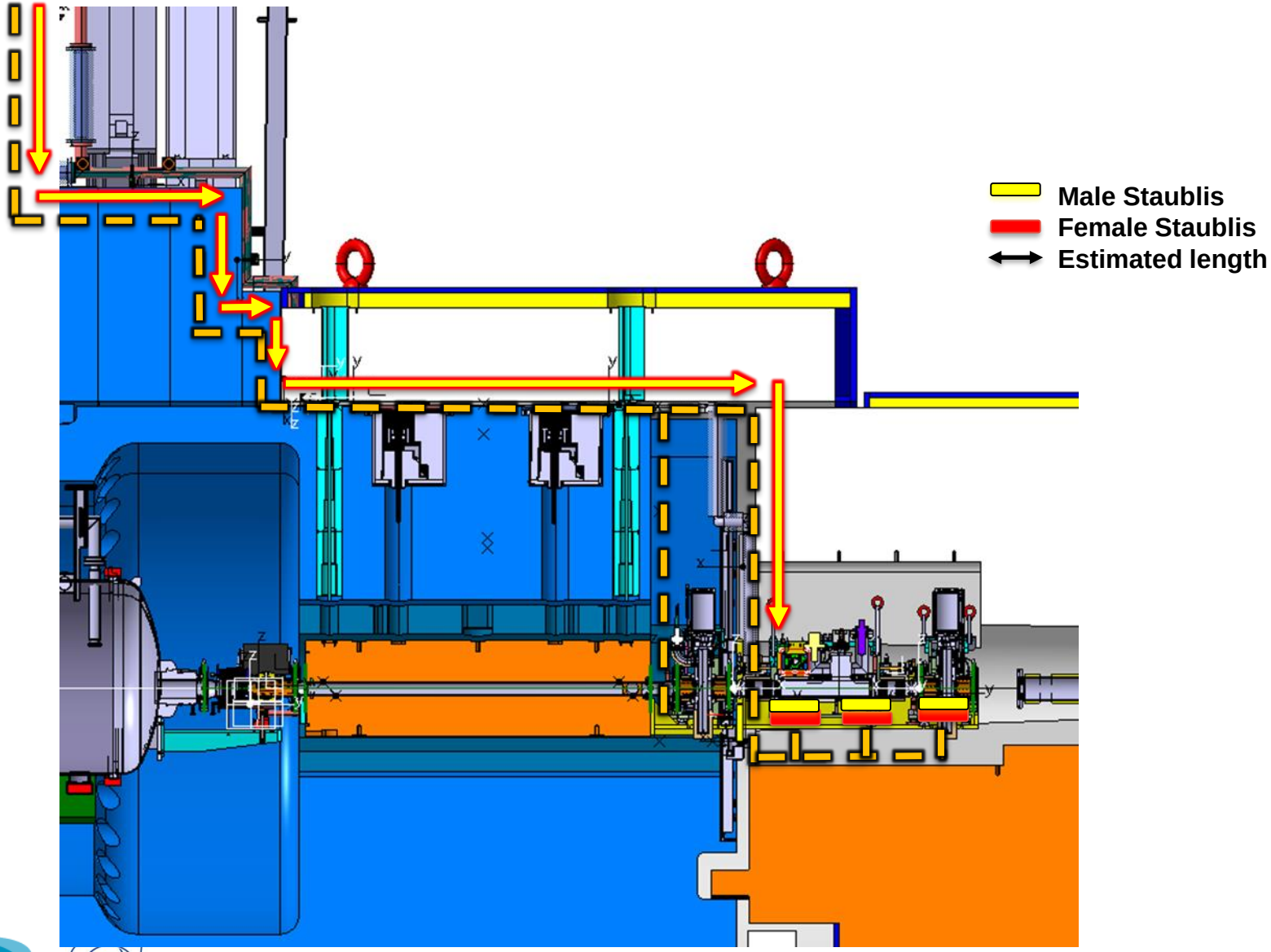
Installation sequence approach (CMS case)



(A) **Leak tightness validation of pumping lines installed + checking and commissioning of existing bake-out**

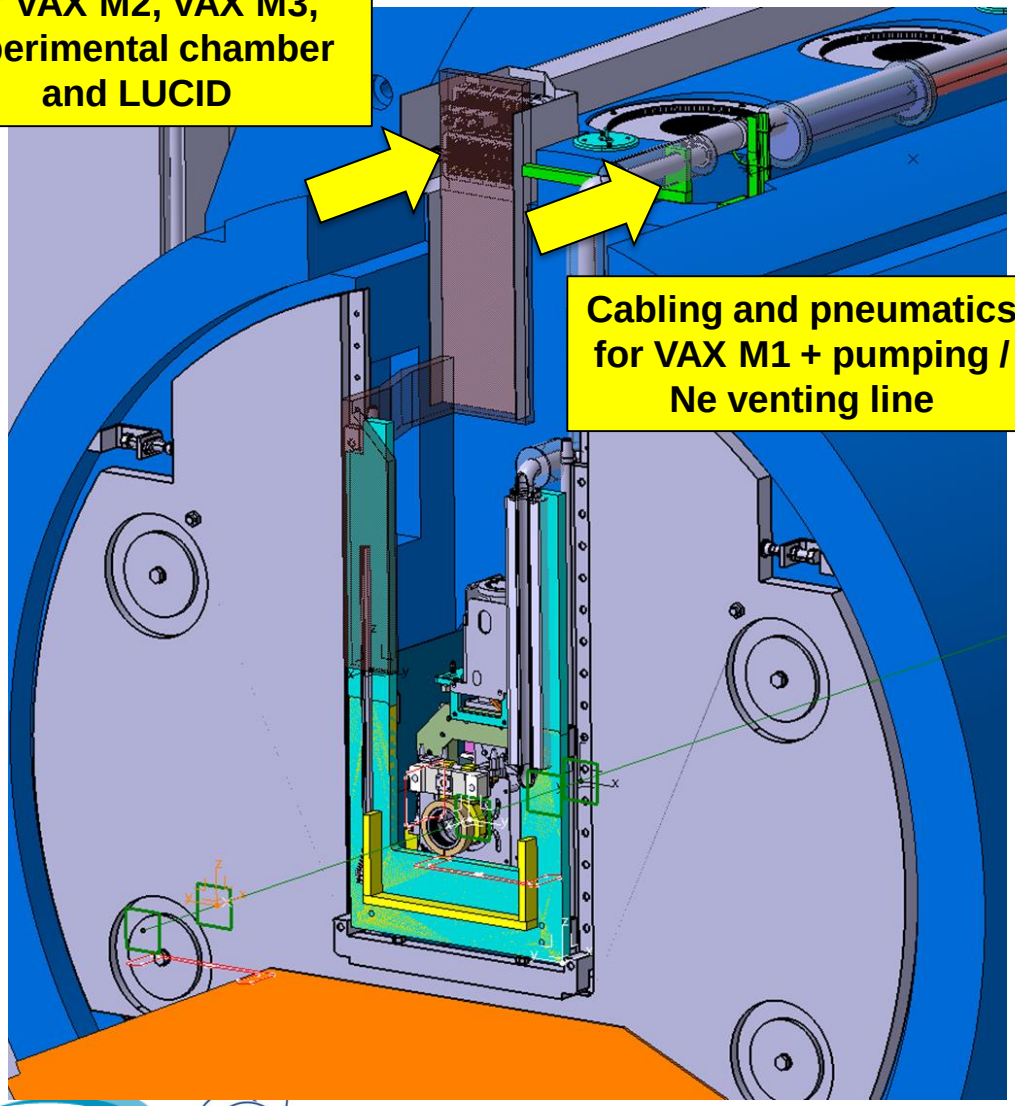
(B) **Module assembled and verified leak tight on surface. If applicable, bake out already verified on surface**

VAX services integration – ATLAS

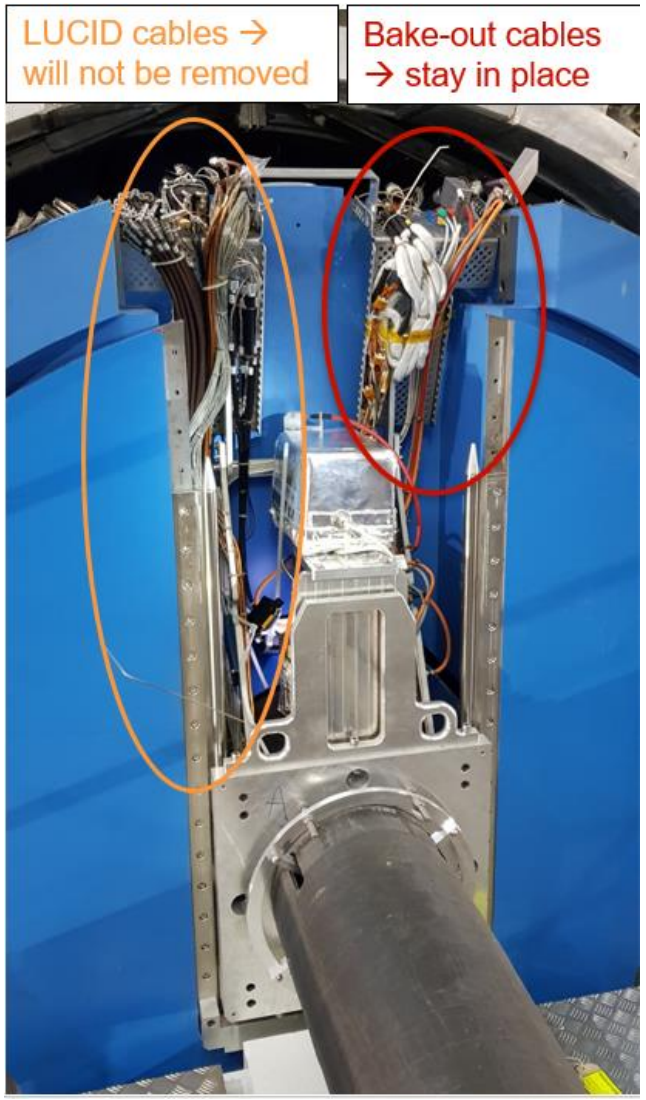


VAX services routing baseline – ATLAS

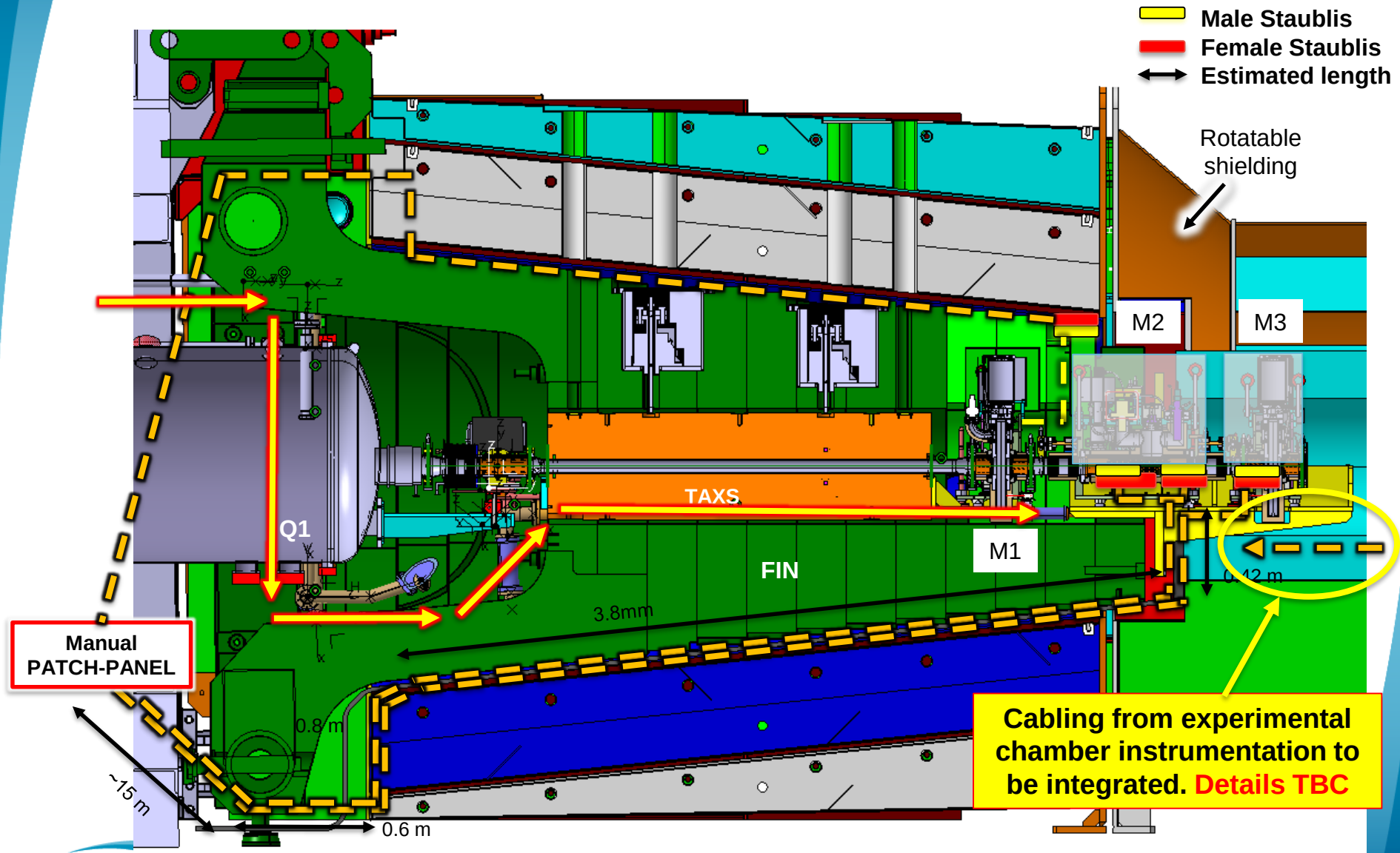
Cabling and pneumatics for VAX M2, VAX M3, experimental chamber and LUCID



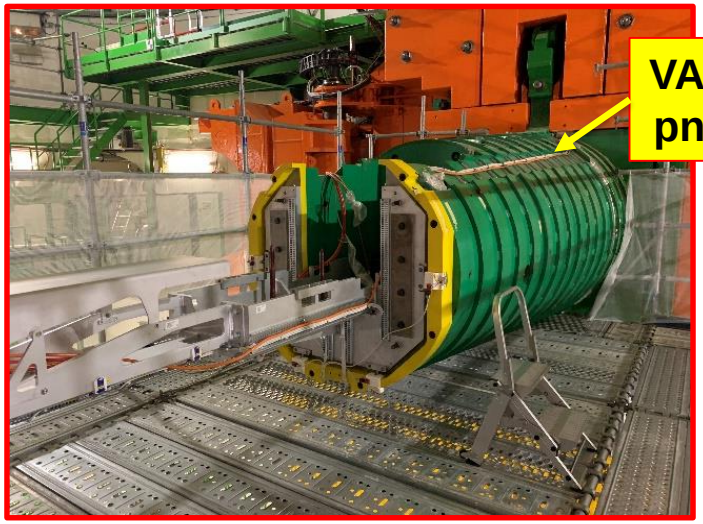
Cabling and pneumatics for VAX M1 + pumping / Ne venting line



VAX services integration – CMS

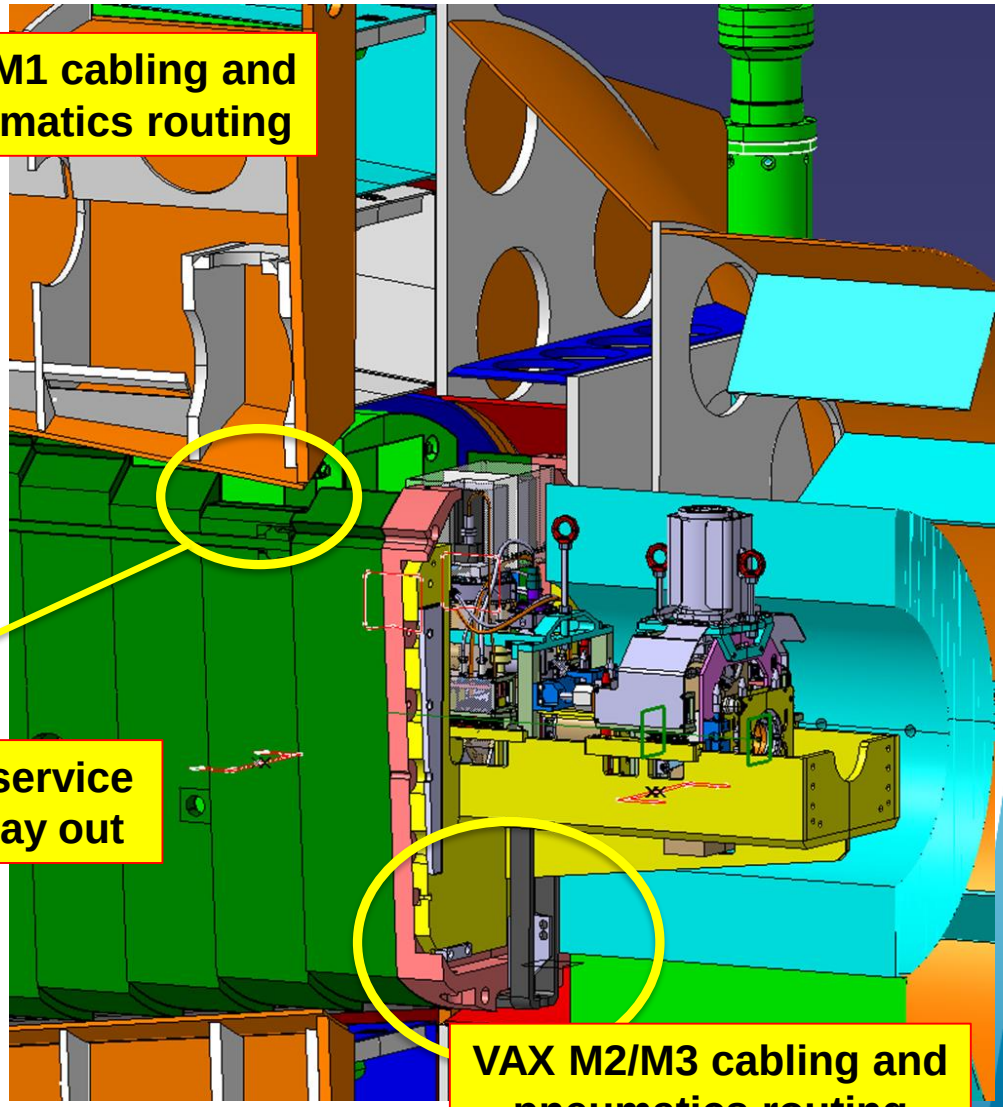


VAX services routing baseline – CMS



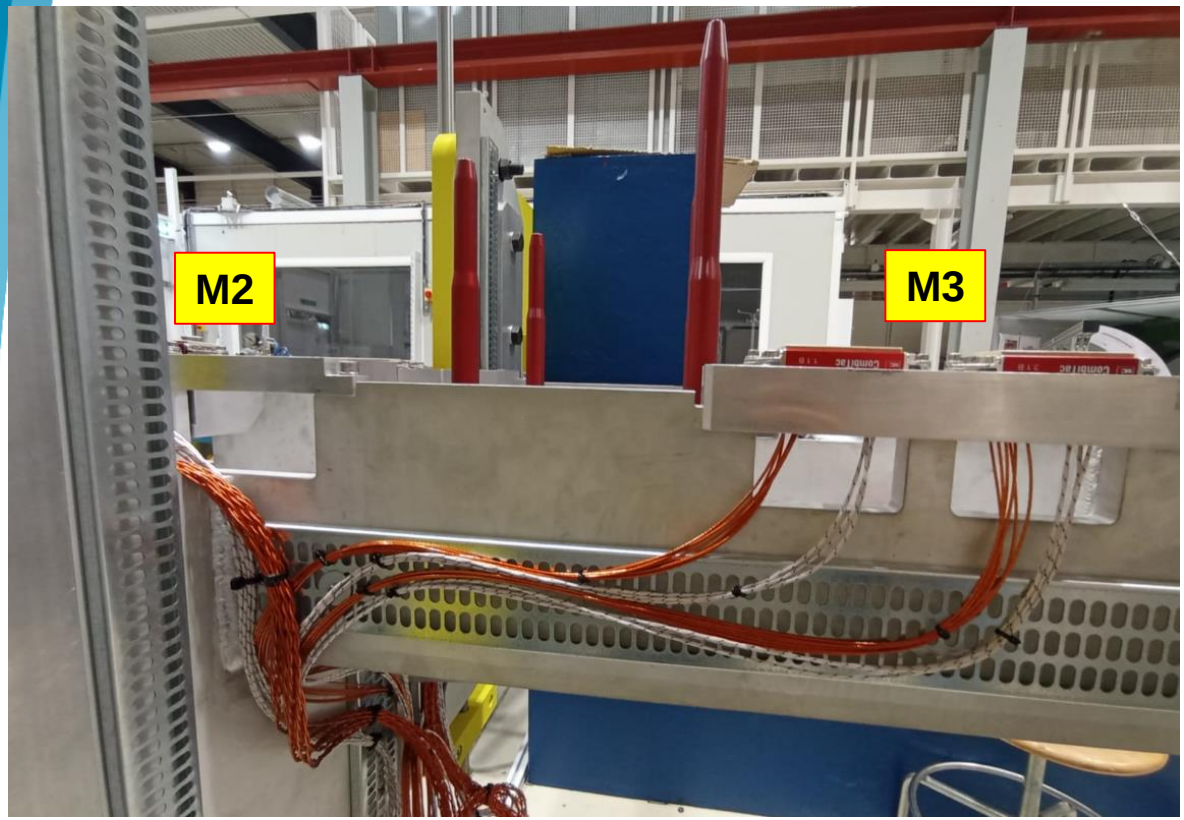
VAX M1 cabling and pneumatics routing

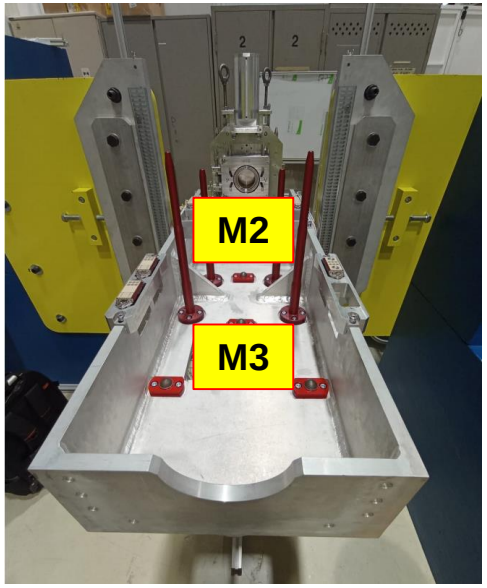
VAX M1 service shield way out



VAX M2/M3 cabling and pneumatics routing

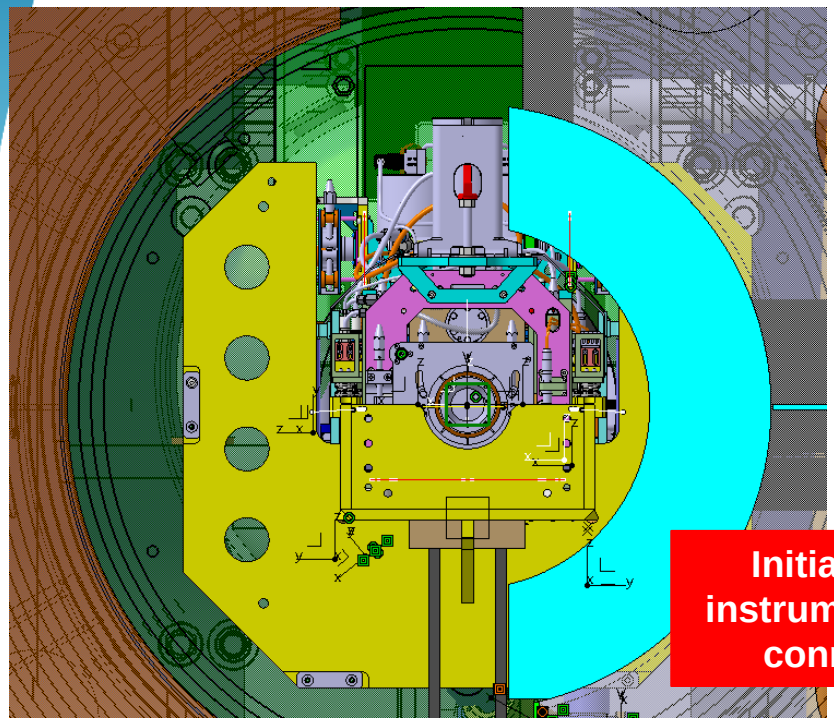
VAX services routing tests – CMS (I)



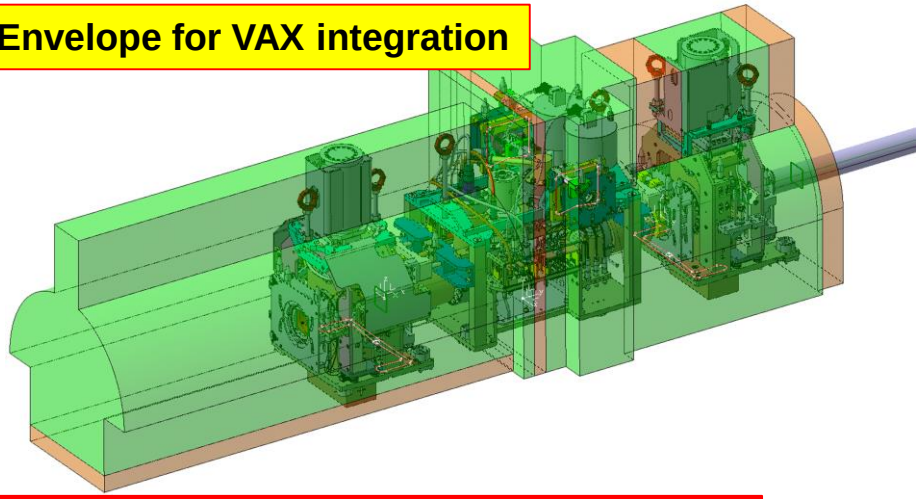


STAUBLIs for vacuum instrumentation (including pneumatics) already produced BUT not yet fully assembled → Stiffener parts under production to avoid forcing cabling pin welds

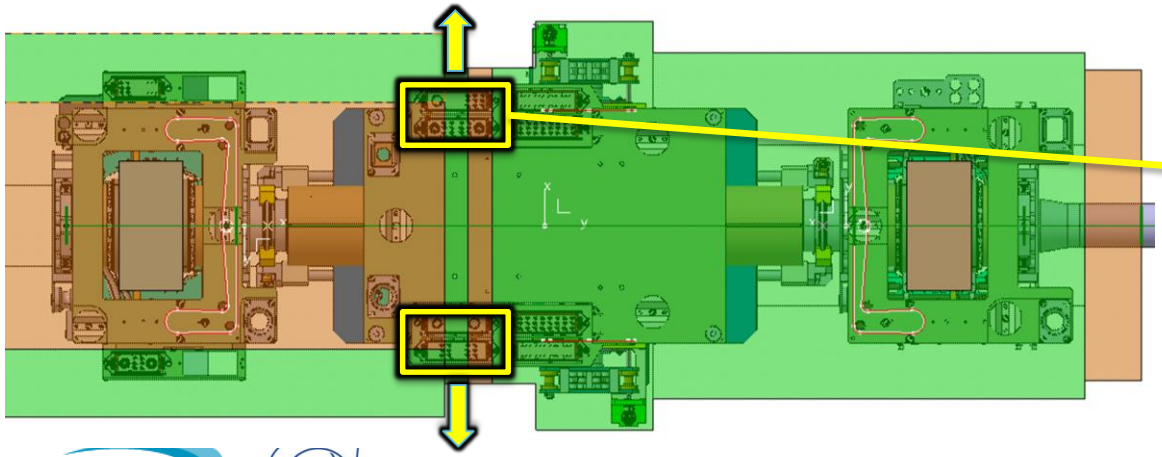
VAX services routing tests – CMS (II)

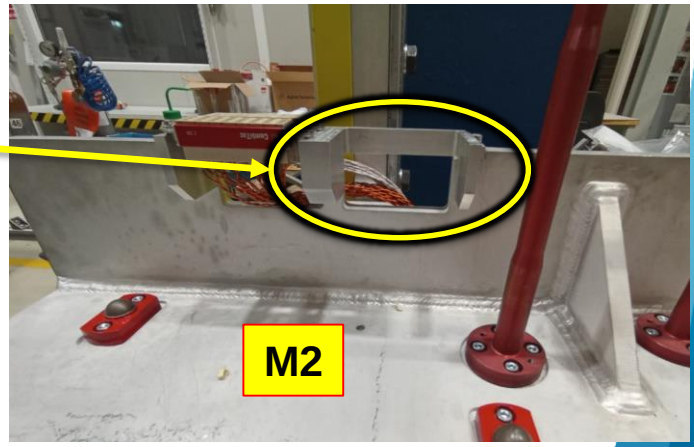


Envelope for VAX integration



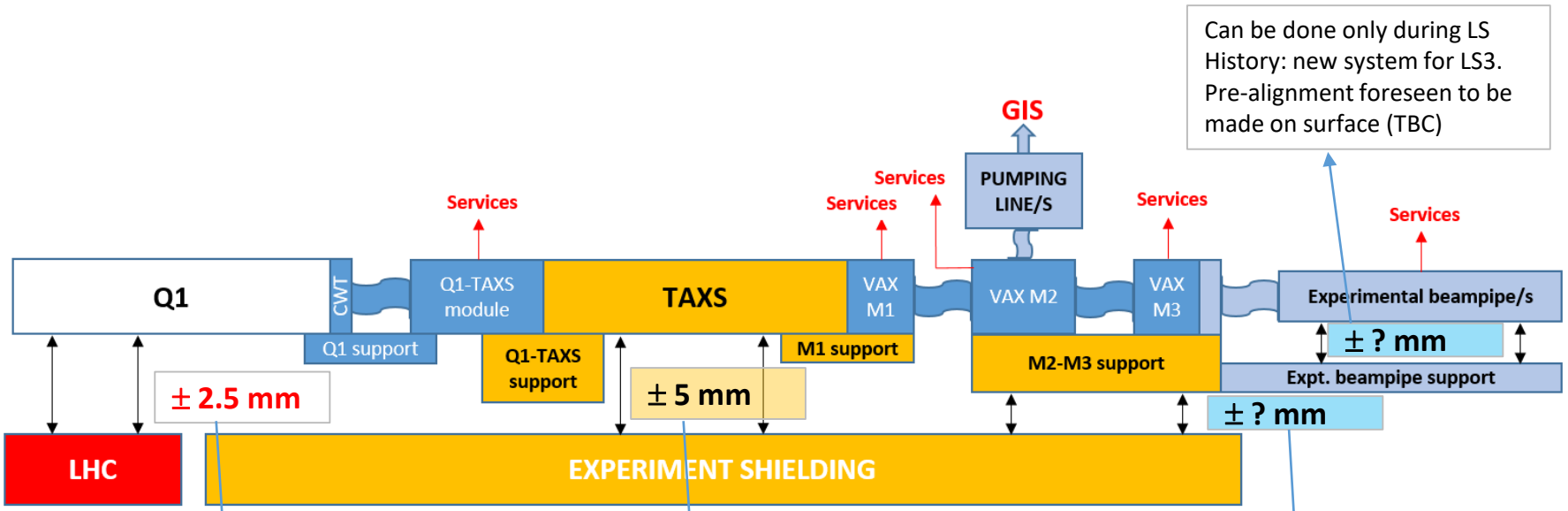
Initial assembly tests with STAUBLIs for vacuum instrumentation showed the need to move slightly the connectors → the solution looks feasible (TBC)





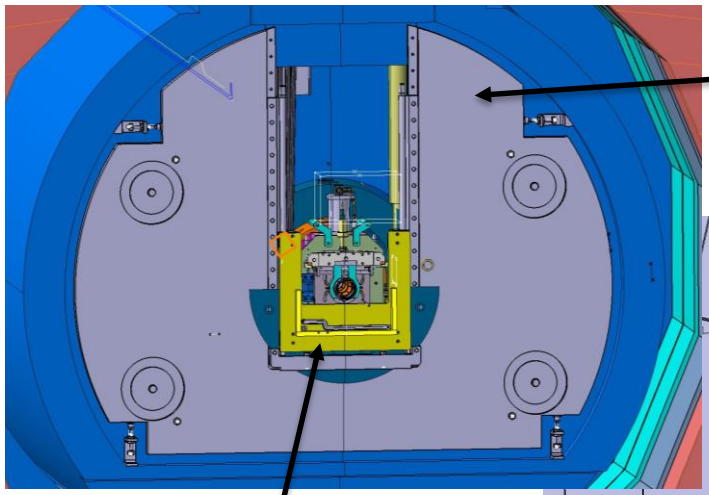
5. VAX alignment

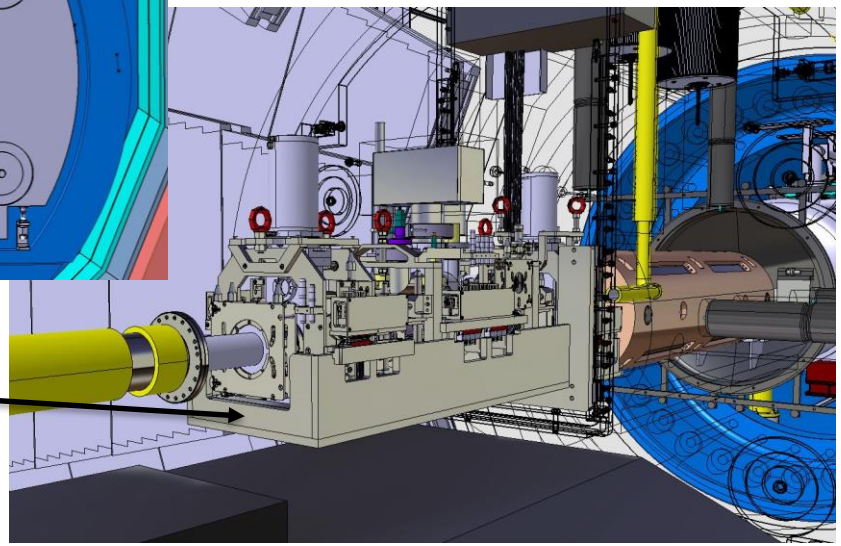
Alignment

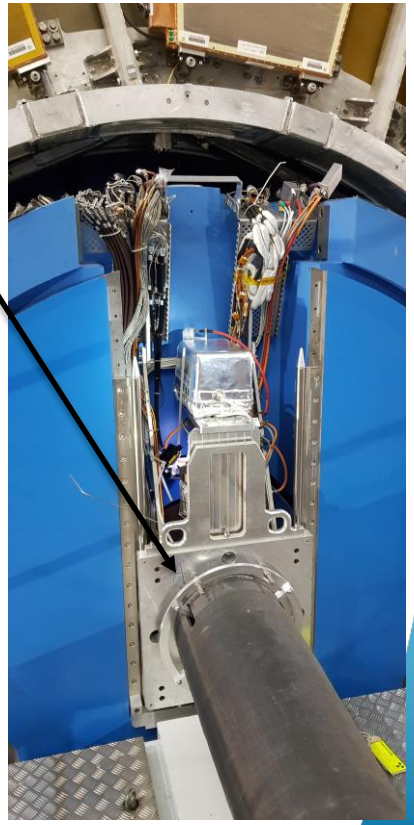

Can be done only during LS
History: new system for LS3.
Pre-alignment foreseen to be made on surface (TBC)
GIS
PUMPING LINE/S
Services
Services
Services
Services
Services
Q1
CWT
Q1-TAXS module
TAXS
VAX M1
VAX M2
VAX M3
Experimental beampipe/s
Q1 support
Q1-TAXS support
M1 support
M2-M3 support
Expt. beampipe support
± ? mm
± 2.5 mm
± 5 mm
± ? mm
LHC
EXPERIMENT SHIELDING
FRAS: can be operated during a RUN or at least during TS, (E)YETS and LS
Can be done during LS and, eventually, (E)YETS
History: re-alignment made few times in ATLAS; only one time in CMS (TBC)
Resolution of alignment measurement between Q1 and TAXS, 0.5 mm ⇒ when misalignment is >0.5 mm, LHC asks for re-alignment
Can be done only during LS
History: re-alignment never made both in ATLAS or CMS

TE-VSC alignment - ATLAS

- Alignment made through central plate → new VAX support structure to be compatible with plate and new VJ cone support
  - I/F to WP8 for VAX M1-M2 support, TBC
- Alignment and assembly methodology to have impact on maintenance scenarios, and subsequently on cabling and pumping/venting lines (see next presentation)

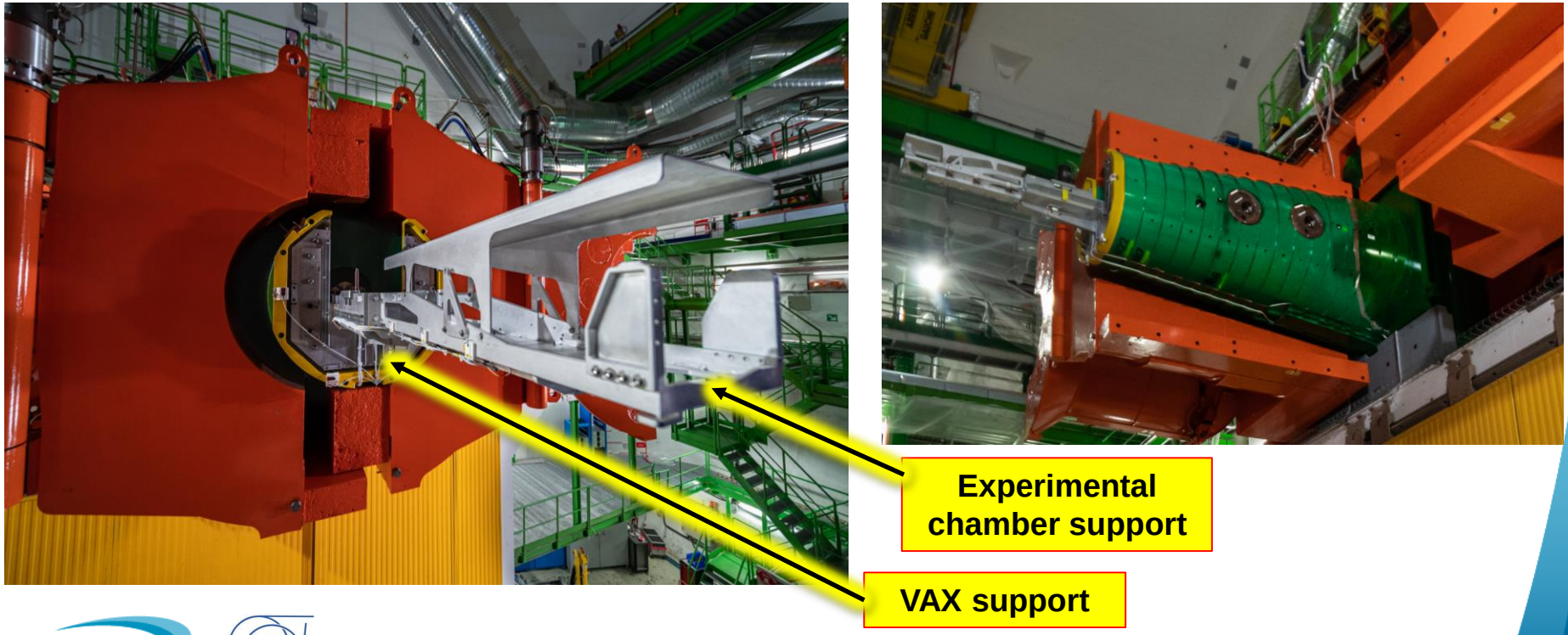






TE-VSC alignment - CMS

- Alignment made through VAX support → new transition to experimental chamber to be assembled as fix point on VAX support
  - I/F to WP8 for VAX M1-M2 support already defined
- Baseline is that VAX M1-M2 support remains in place → after support alignment, no TE-VSC re-alignment is foreseen

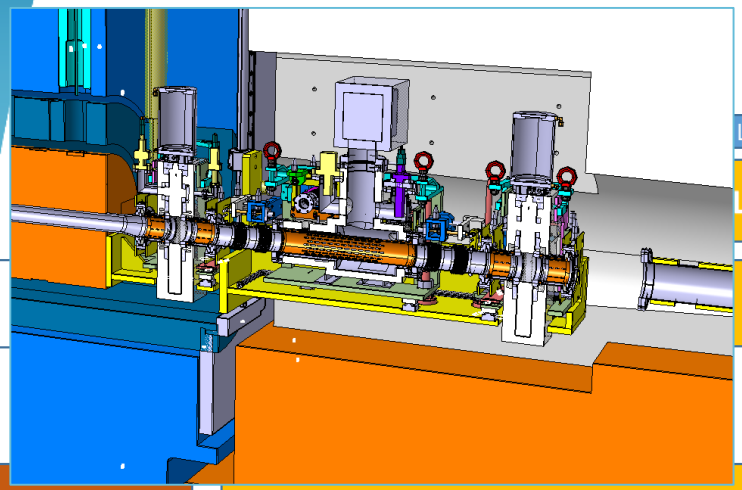


6. VAX operation

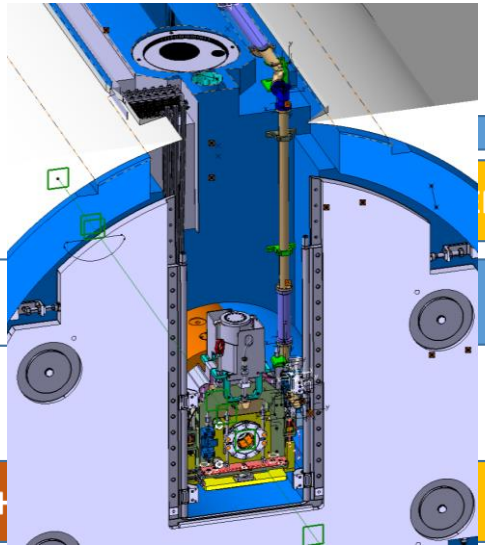
VAX operation – key aspects

- Interventions during TS
  - No recurrent or preventive actions are foreseen
  - Corrective maintenance could be envisaged (case-by-case) **with impact on planning**
- Interventions during YETS, (E)YETS
  - ATLAS:
    - **Ne venting + re-pumping of experimental chambers are systematically made → no bake-out is necessary BUT VAX M2 right-angle valves require to be operated**
    - No parts are removed
    - Corrective maintenance could be integrated in VAX specific components BUT it would require full vacuum conditioning (involving bake-out)
  - CMS:
    - **Ne venting + re-pumping of experimental chambers can be requested**
    - No parts are removed
    - Corrective maintenance could be integrated in VAX specific components BUT it would require full vacuum conditioning (involving bake-out)
- Interventions during LS
  - ATLAS:
    - **Removal of M2-M3 support and experimental chambers are required → it requires further re-assembly + full vacuum conditioning (involving bake-out)**
    - Corrective maintenance of VAX M1 could be envisaged
    - Corrective maintenance of VAX M2 and M3 can be made on surface
  - CMS:
    - **Removal of experimental chambers is required (VAX M1-M2-M3 remain in place) → it requires further re-assembly + full vacuum conditioning (involving bake-out)**
    - Corrective maintenance of VAX M1-M2-M3 could be envisaged

ATLAS

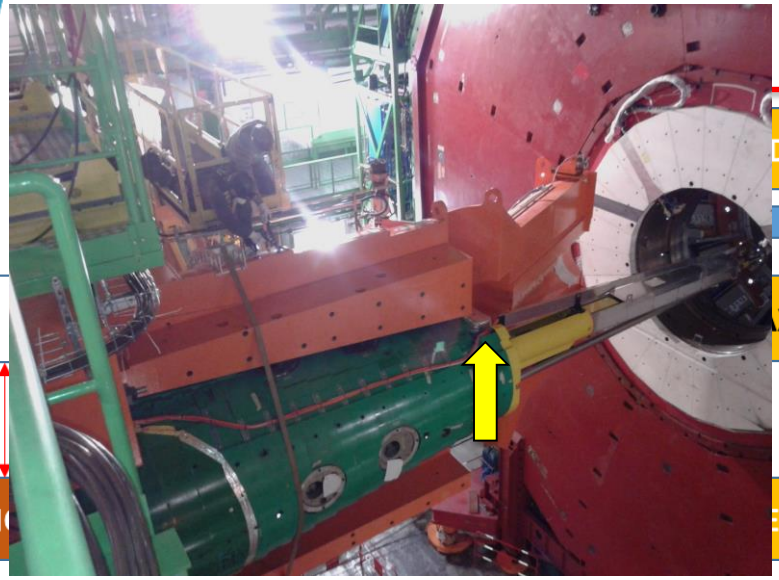


FINAL CONFIGURATION (SHIELDING NOT SHOWN) – (E)YETS CONFIGURATION



LS CONFIGURATION

CMS - Configurations



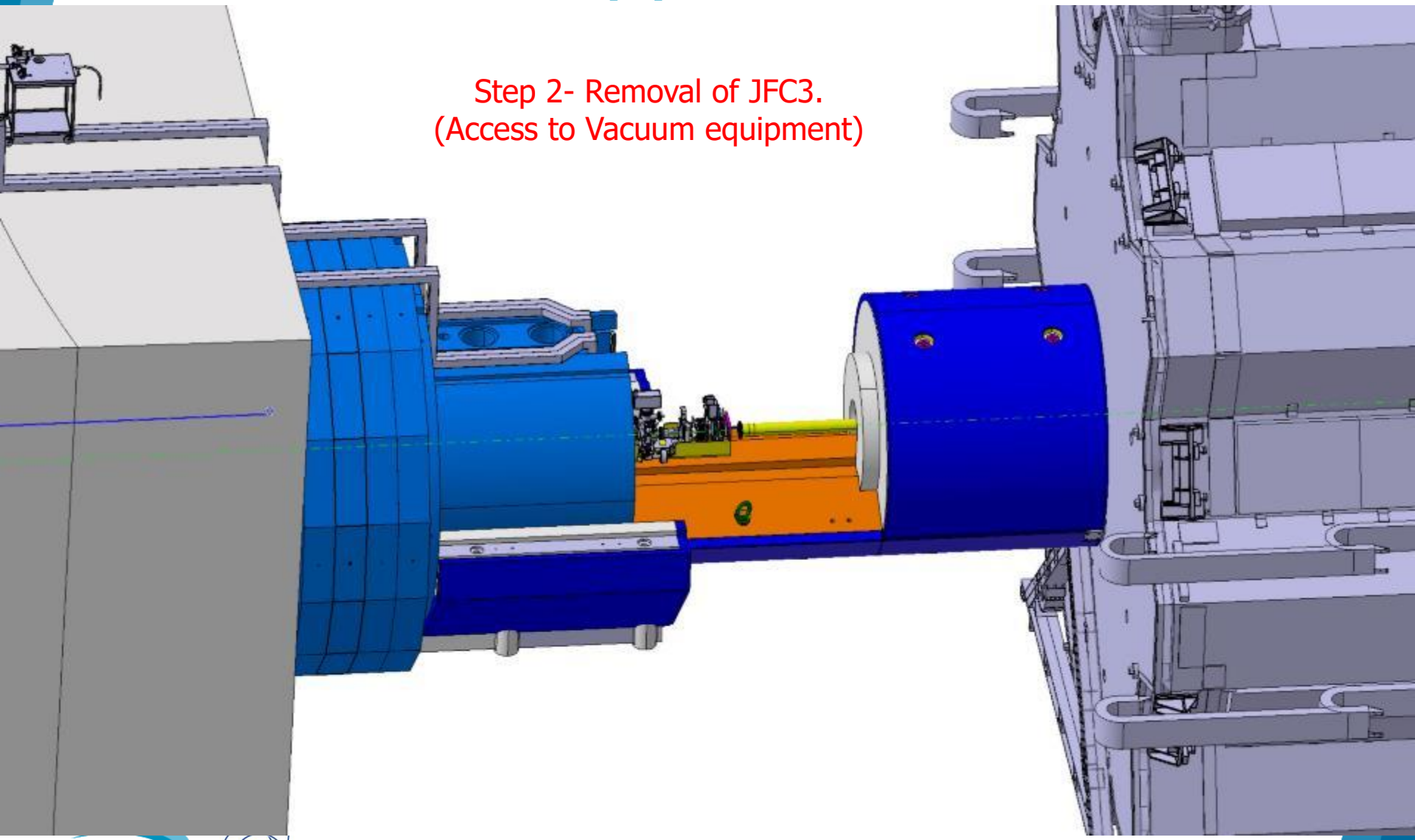
FINAL CONFIGURATION (SHIELDING NOT SHOWN) – (E)YETS CONFIGURATION

LS CONFIGURATION

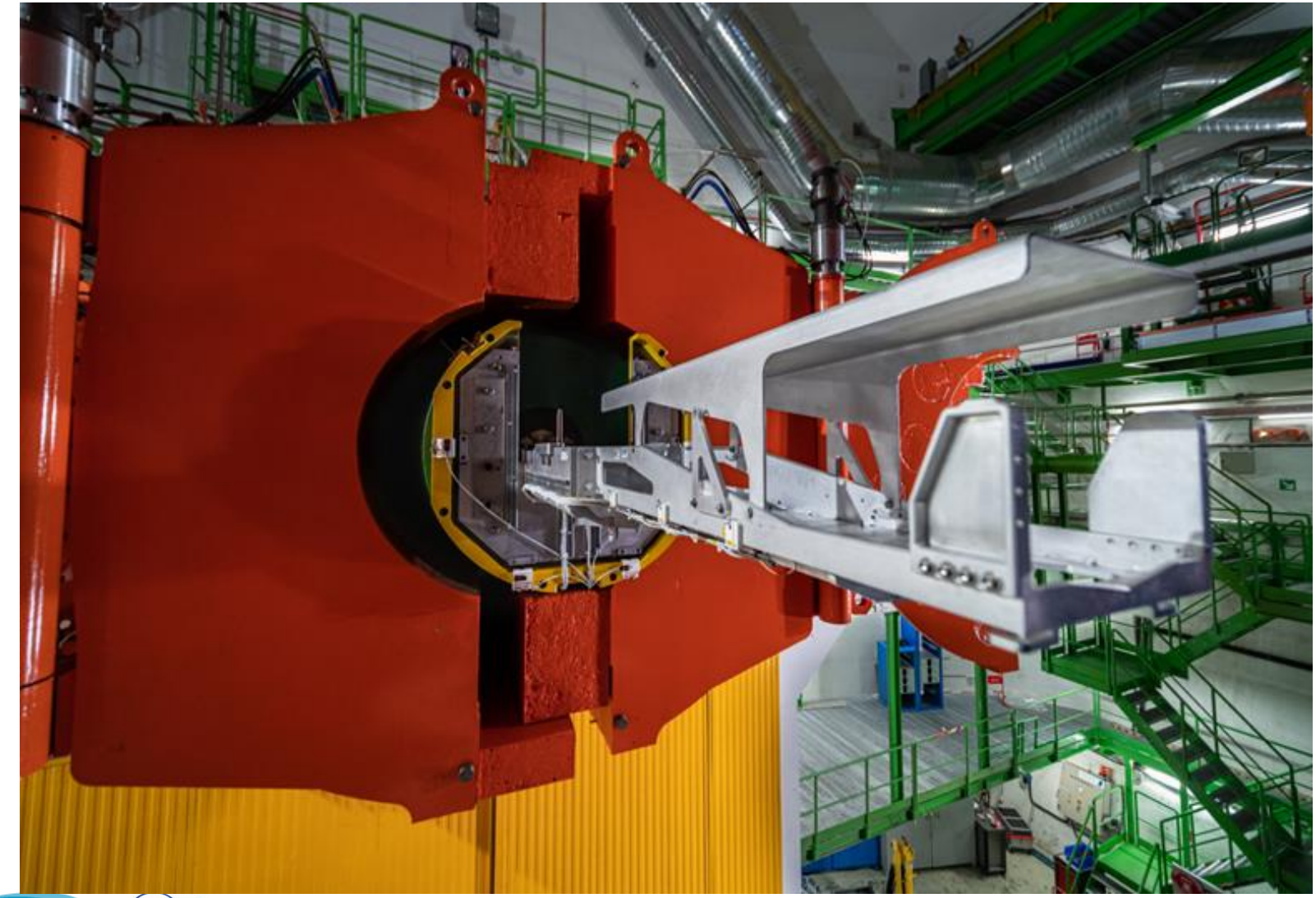
VAX M2 – operation of right-angle valves

- The impact in case of malfunctioning or failure is not so severe as for the sector valves, due to redundancy construction and the absence of interlock to the operation
- The use of the right-angle valves is limited to the YETS, (E)YETS and LS
- Four alternatives are open at the moment → **decision to be based on risk analysis and operation scenarios**
  - Standard pneumatically operated right-angle valve
    - Reliable solution**, limited by radiation hardness**: VAT guarantees 1 MGy at standard operation, while analyses show a cumulated dose for LS7 of ~10 MGy
    - **The use would require a systematic maintenance at every LS (TBC if also in an intermediate YETS) involving the venting of the vacuum and the further conditioning**
  - Manually operated right-angle valve
    - Including permanent external remote operation
      - **Prototype must be consolidated and qualified → difficult to get the level of reliability of a VAT actuation system BUT there is a gain in radiation hardness**
      - The actuation system is independent of the valve → maintenance does not involve vacuum venting and further conditioning
    - With non-permanent remote operation (through robotic actuation)
      - **Requires to be checked with the experiments and integrated in the corresponding plannings → could be especially critical on the YETS, (E)YETS**
      - No maintenance problems are envisaged
  - Pneumatically operated right-angle valve with similar actuation system to that of the sector valve
    - **TBC by VAT; high cost and long delivery time are expected**
    - **No action until having qualified the actuation system of the sector valves (TBC)**

Access to VAX M2 in ATLAS during YETS, (E)YETS



Access to VAX M2 in CMS during YETS, (E)YETS



7. Summary of main open points

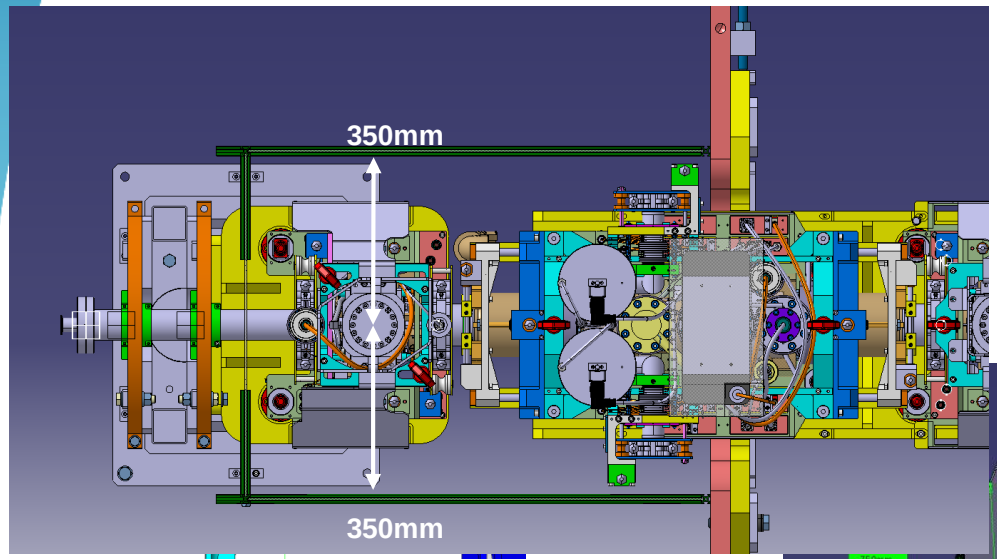
Summary of main open points

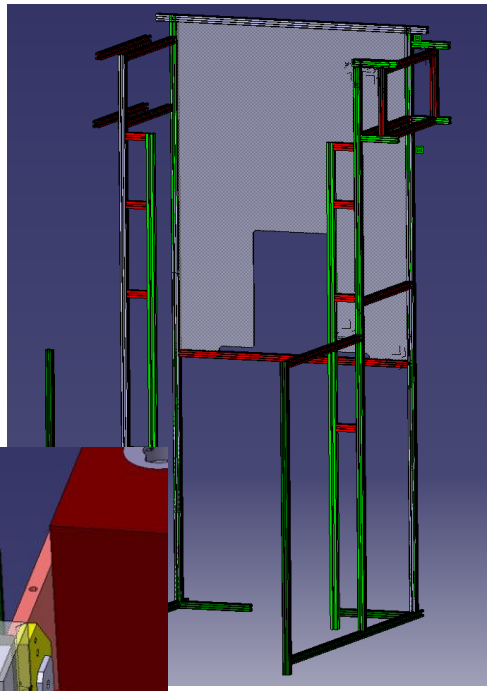
- VAX M1 and M3 modules are well defined but require to close the following open points:
  - Reliability problems of actuation system of sector valve (by VAT);
  - Confirmation of tight closure by the robotic system;
  - Accessibility to TAXS chamber connection in ATLAS;
  - Handling and installation of cabling at M1;
- VAX M2 design is not fully finished. It requires to solve the following:
  - Freezing of vacuum layout;
  - Choice of best right-angle valve alternative;
- Actions required for all VAX M1, M2 and M3:
  - Freezing of cabling routing and details from external devices (LUCID and experimental chambers);
  - Confirmation of final baking system.

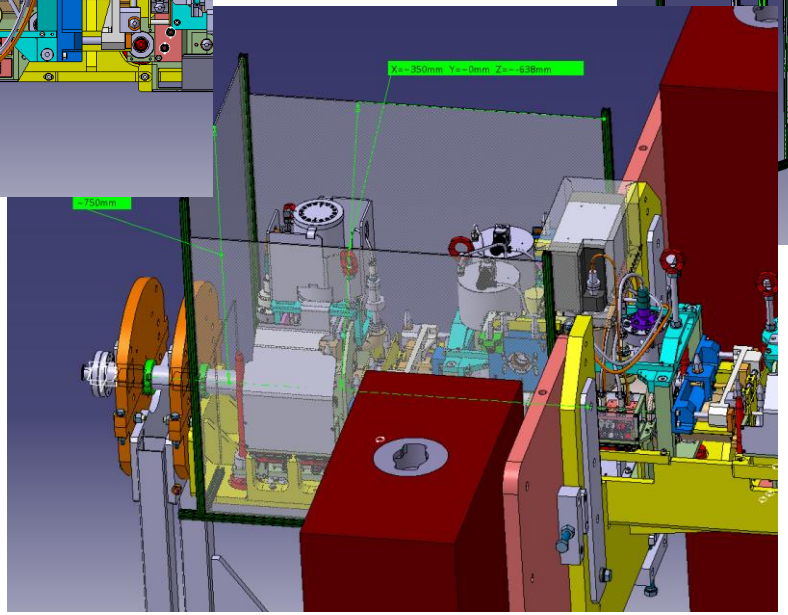
Thanks for your attention

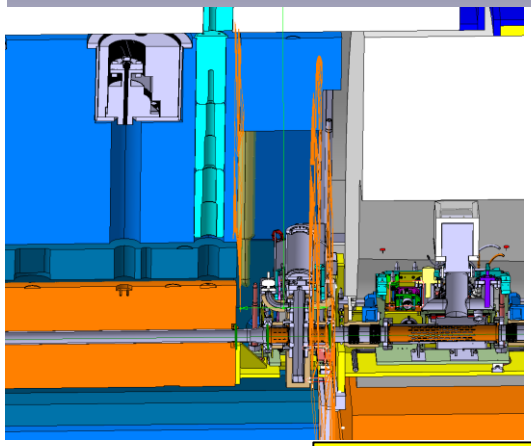
Special thanks to Rita, Frederic, Herve, Josef, Alessio, Giuseppe, Vincent, Cedric, Oliver, Ruth, Antonio, Francisco and many others

ATLAS test configuration





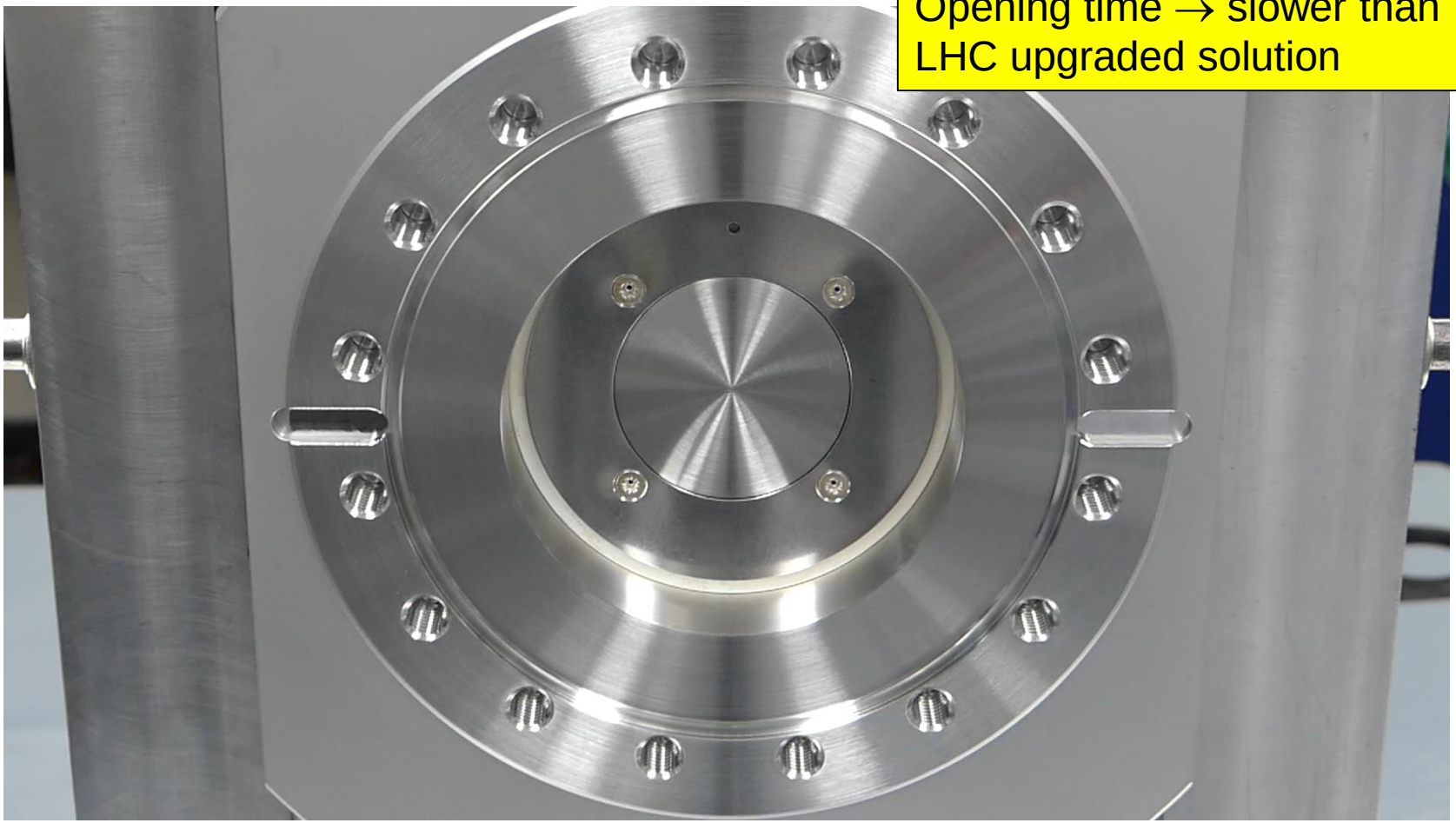




Test mock-up is based on CMS configuration → OK for ATLAS configuration as it is more favourable for VAX module installation purposes, except for M1 accessibility ⇒ <u>mock-up upgraded at M1 level to integrate ATLAS M1 constraint</u>

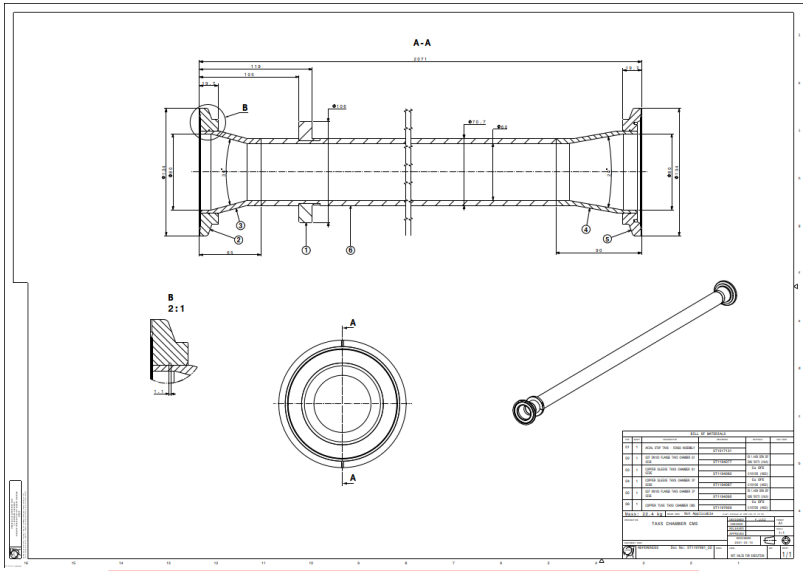
VAX sector valve – VAT qualification

Closure time → slightly faster than LHC upgraded solution
Opening time → slower than LHC upgraded solution

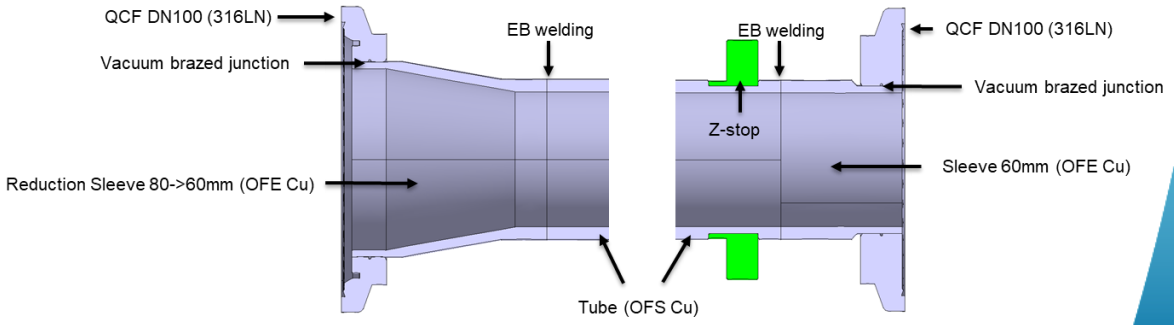


Status of Q1-TAXS vacuum chamber

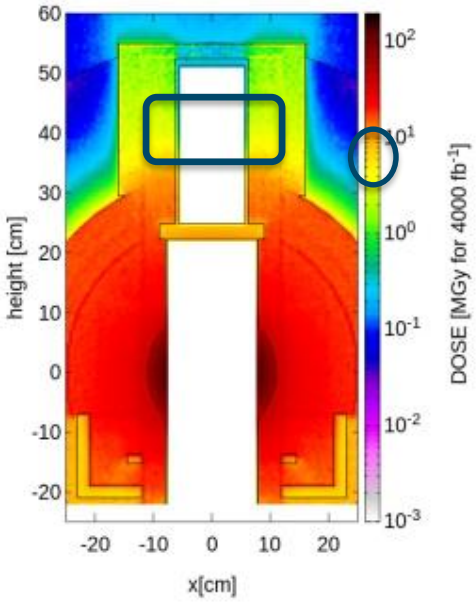
- Waiting for strategy after withdrawal of in-kind contribution (BINP)
- Synergy with TAXN chamber



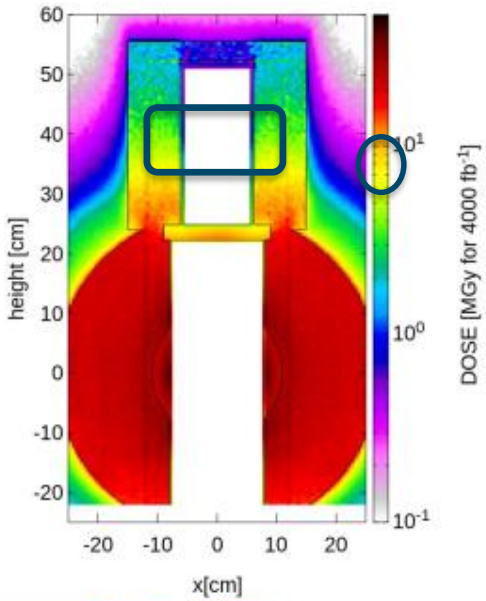
Fine tolerancing, pending



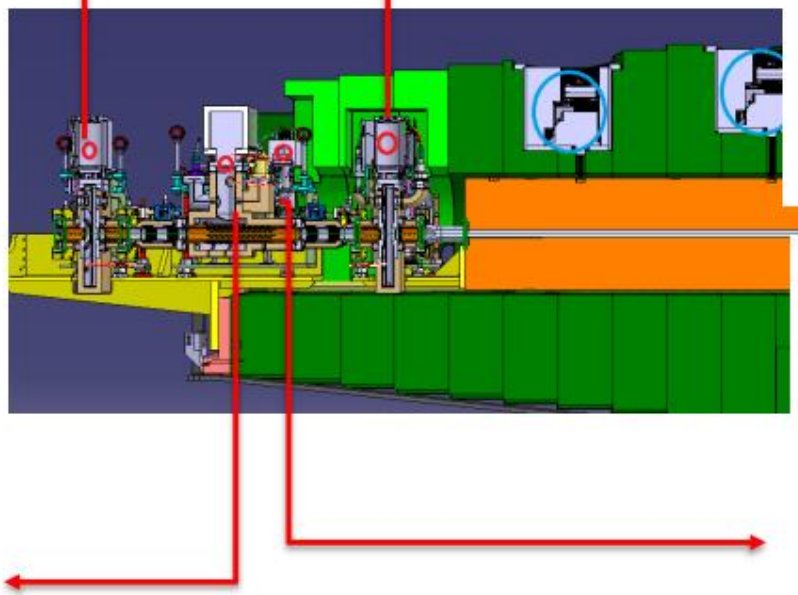
dose distribution at 17.43 - 17.44 m from IP5



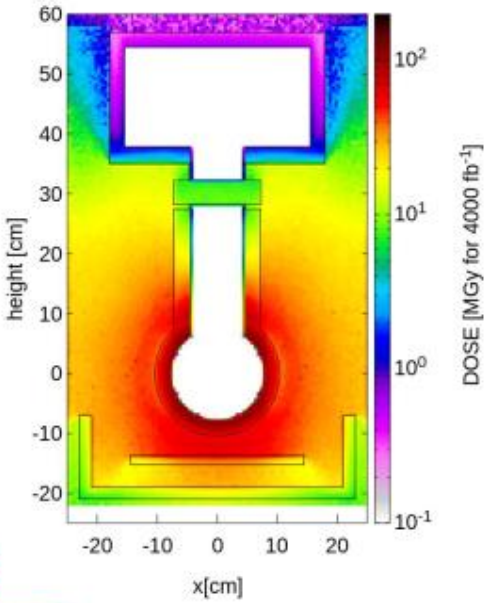
dose distribution at 18.72 - 18.73 m from IP5



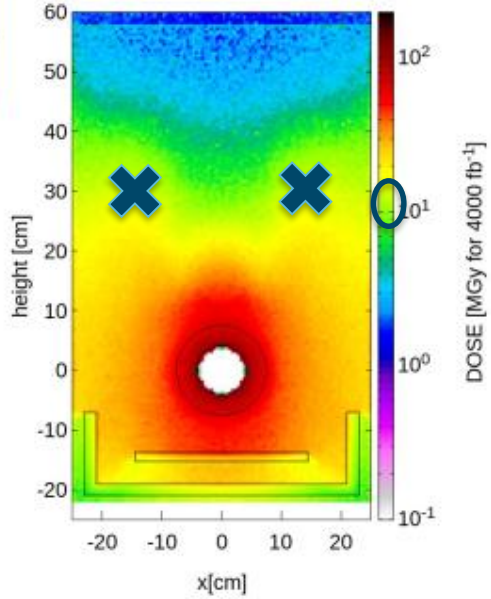
Different color scale, adapted to each region.



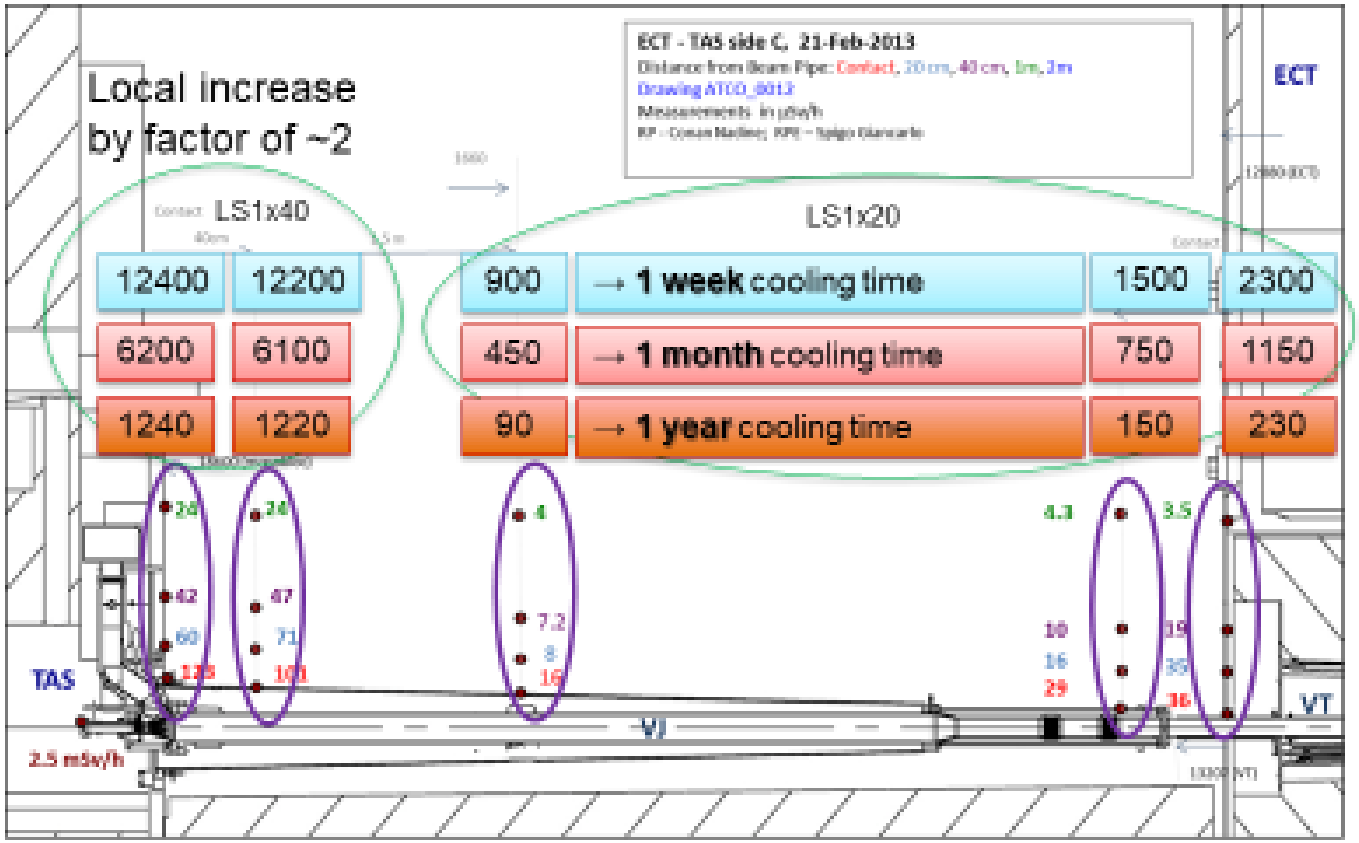
dose distribution at 18.00 - 18.01 m from IP5



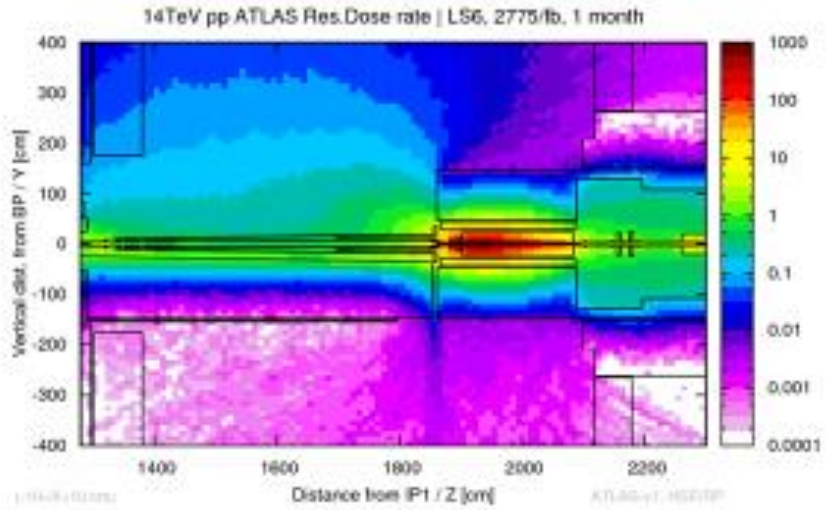
dose distribution at 18.26 - 18.27 m from IP5

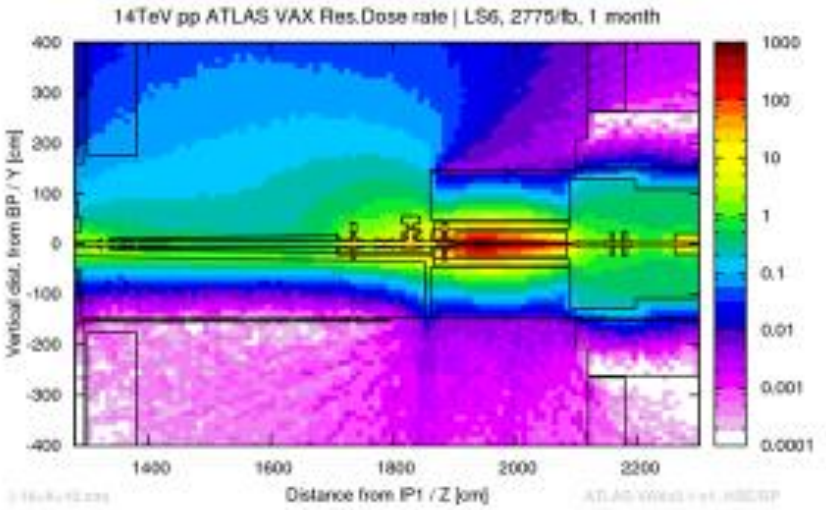


LS1 measurement
RESCALED TO $LS_{HL\text{-}LHC}$



H*(10) in mSv/h, LS6 (ATLAS)



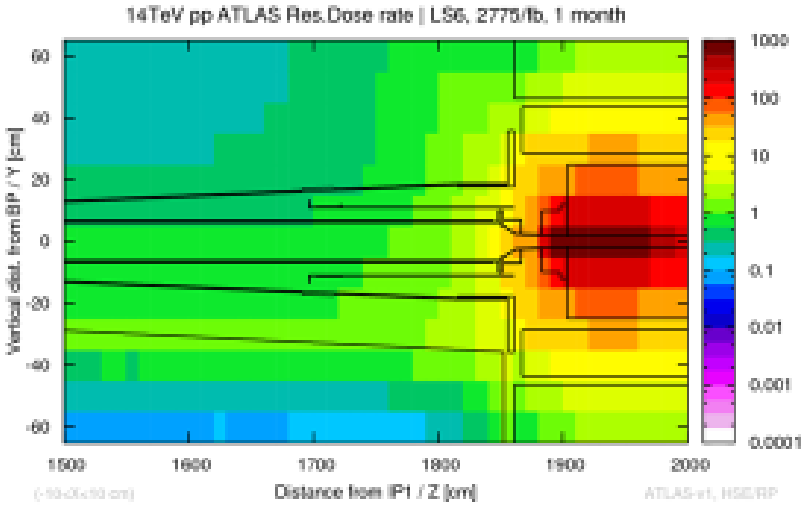


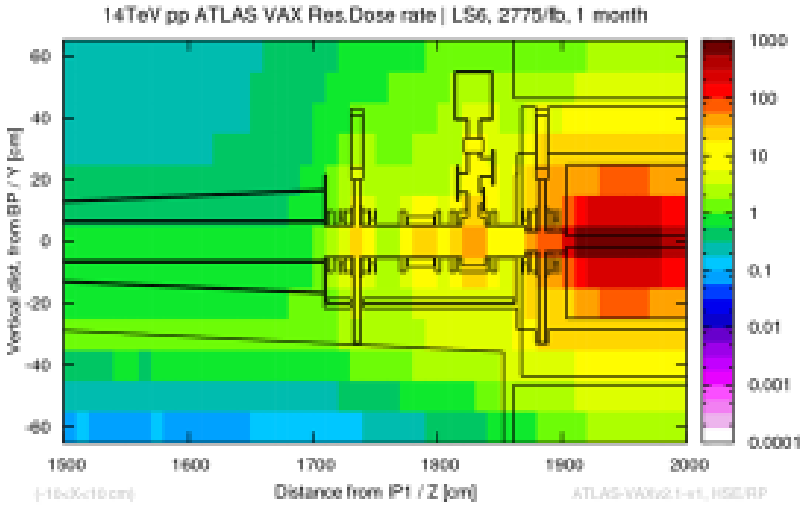
JFC2&3, JFS3U&L shielding open…

…with VAX installed

1 month cooling in LS6

H*(10) in mSv/h, LS6 (ATLAS) (zoom)

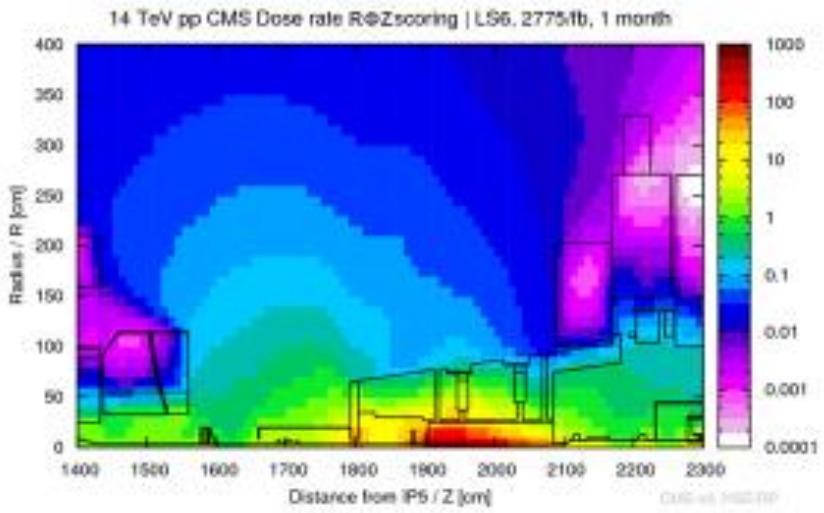


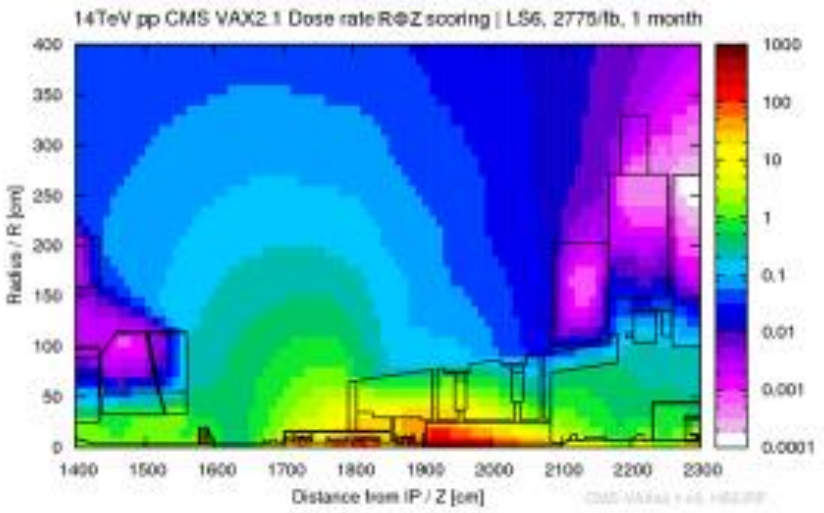


-10<X<10 cm

…with VAX installed

H*(10) in mSv/h, LS6 (CMS)





Rotating shielding open…
1 month cooling in LS6

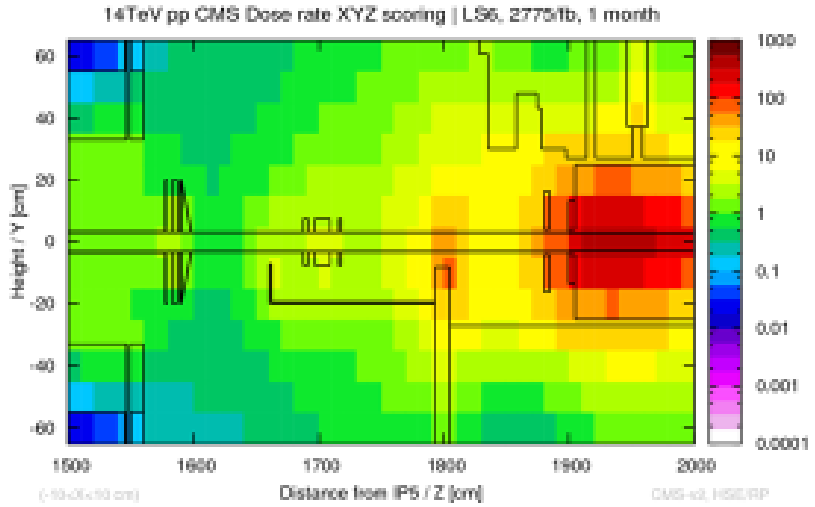
…with VAX installed

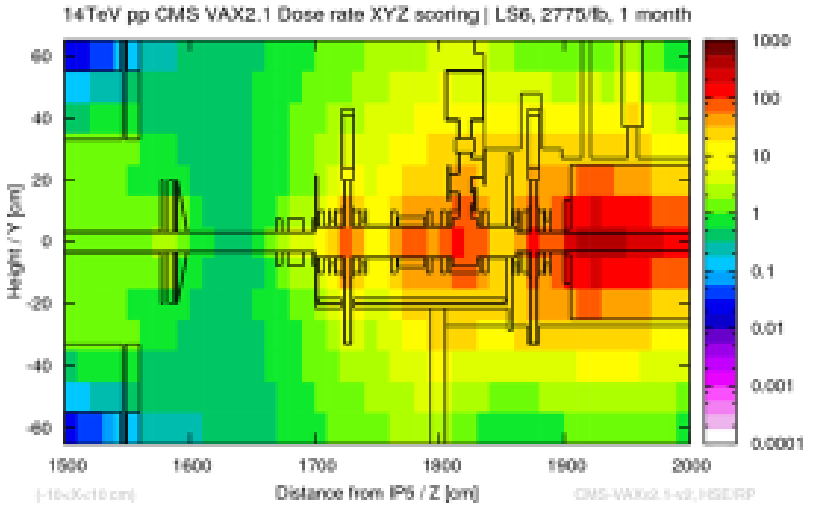
HSE
Occupational Health & Safety
and Environmental Protection Unit

7 June 2016

39th WP8 meeting

H*(10) in mSv/h, LS6 (CMS) (zoom) – XYZ





-10<X<10 cm

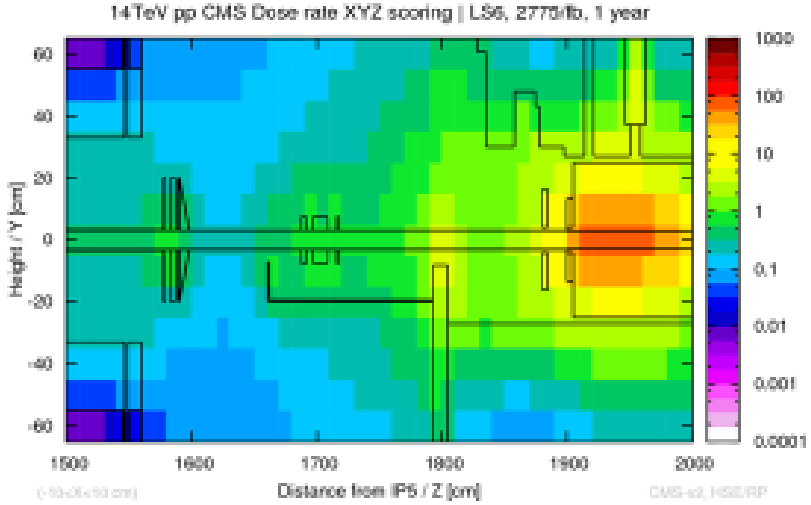
…with VAX installed

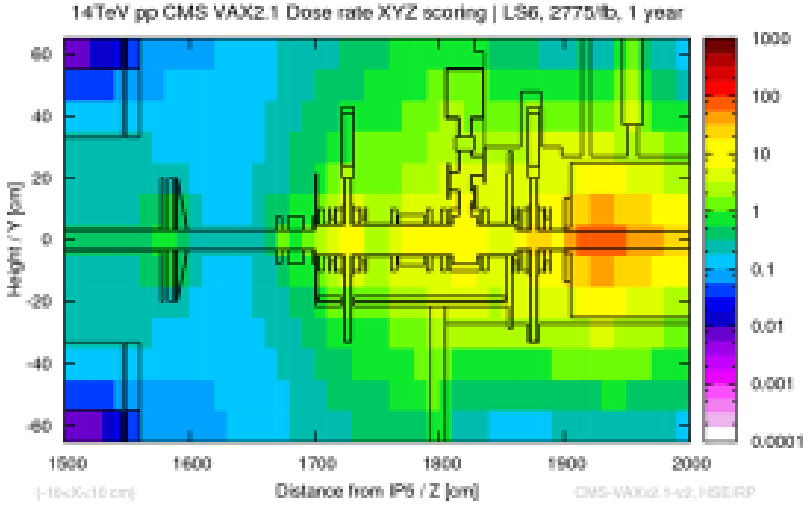
HSE
Occupational Health & Safety
and Environmental Protection Unit

7 June 2016

39th WP8 meeting

H*(10) in mSv/h, LS6 (CMS) (zoom) – XYZ



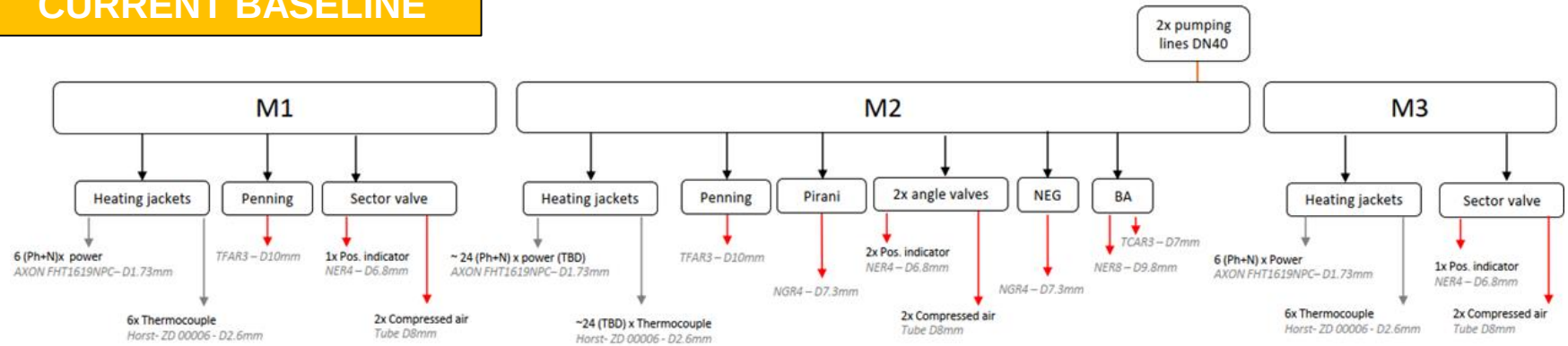


-10<X<10 cm

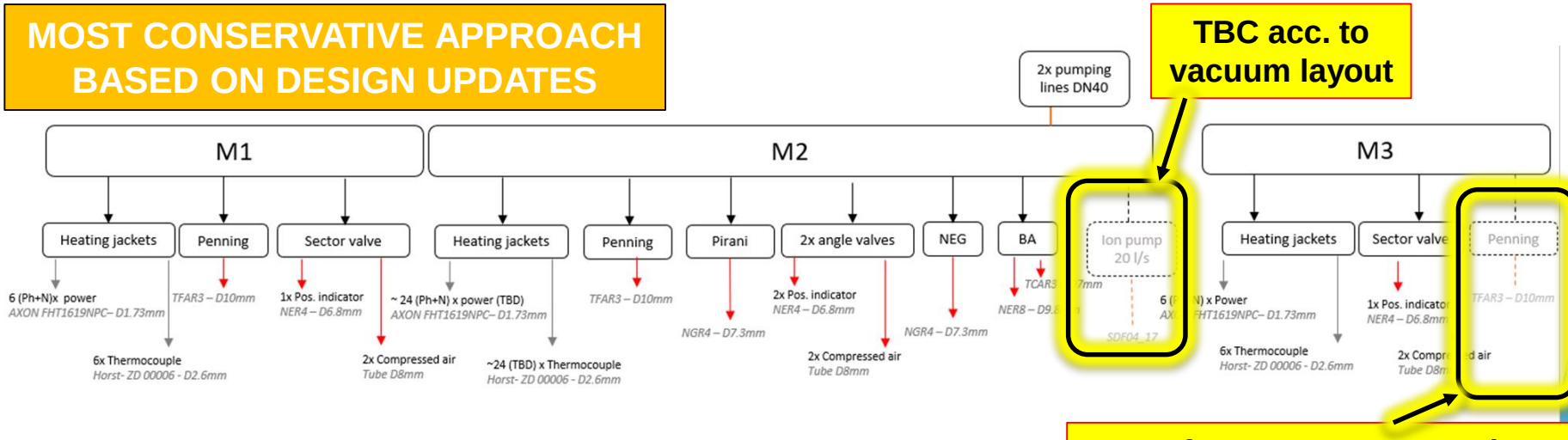
…with VAX installed

VAX module cabling needs

CURRENT BASELINE



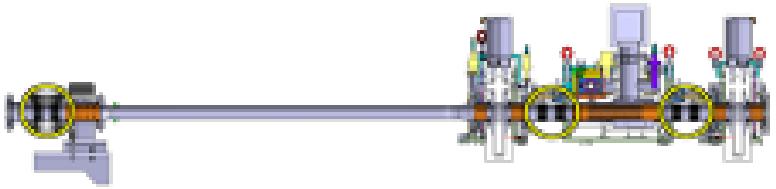
MOST CONSERVATIVE APPROACH BASED ON DESIGN UPDATES



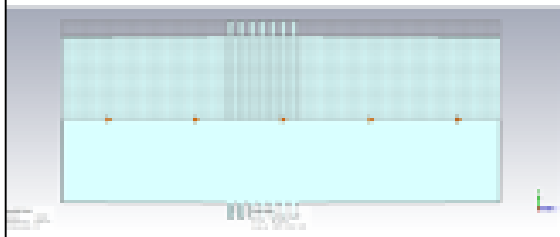
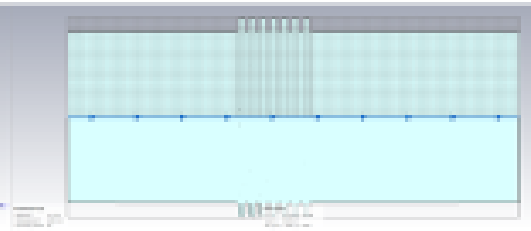
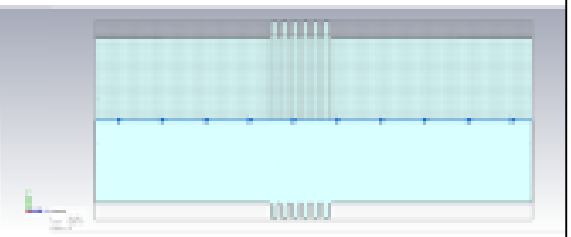
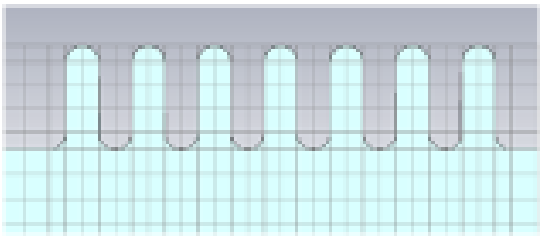
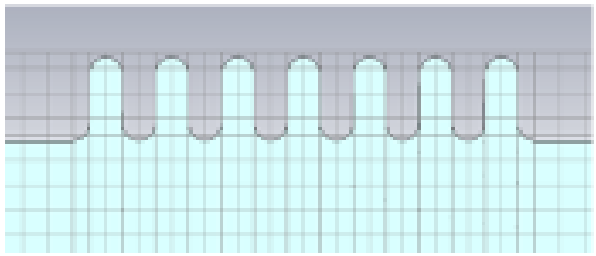
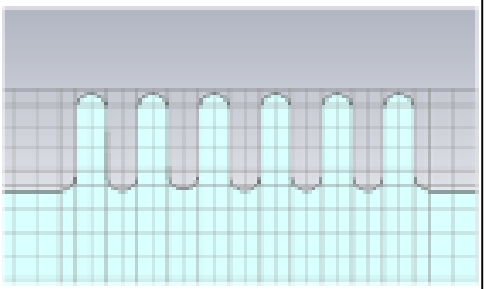
TBC acc. to vacuum layout

Input from vacuum operation, depending on instrumentation at experimental chambers

Context



- TE-VSC provided two new bellow designs "optimizing the bellows to the limit":
  - By making the bellow thinner (convolution depth smaller)
  - By making the bellow shorter (one convolution removed)

original	thinner	shorter
		
7 convolutions 8 mm convolution depth	7 convolutions 6.5 mm convolution depth	6 convolutions 8 mm convolution depth
		
	~19% reduction of convolution depth	~14% reduction of length

Conclusion

- Two options for reducing the impedance contribution of the VAX bellows were discussed:

1. shortening the bellows
2. reducing the convolution depths of the bellows ("thinner").

- Both give an improvement on the contributed impedance in both transverse and longitudinal planes in the frequency range of interest.

- Due to the stronger effect of "thinner" bellows, the Impedance WG recommends using this geometry.

11

Key maintenance points

- STAUBLI connectors make “full” sense if potential maintenance is required during (E)YETS
  - Present baseline involves use of STAUBLIs at M2 and M3
- STAUBLI at M1 would involve maintenance difficulties for the female part as access is very bad
  - Present baseline does not include STAUBLI at M1: manual cabling disconnection is required however, shielding protection is always present
- CF gasket assembly involves giving priority to one of the interface sides → current baseline gives priority to most probable maintenance intervention at M2, however, the most important driver will be again a potential maintenance during (E)YETS. At current baseline:
  - M1 disassembly involves M2 disassembly or manual intervention for CF gasket replacement (accessibility is not good)
  - M3 disassembly involves M2 disassembly or manual intervention for CF gasket replacement (accessibility is OK)
- Pinch-off and leak testing activities are not always obvious if remote operation is wished → extensive dedicated tooling would be required
- Best combination between “quick manual” and remote operation are under study

Subsystem and item identification (update and modify current image)