2017 - 2018 SPS Crab Cavity Validation Run: Status and Issues

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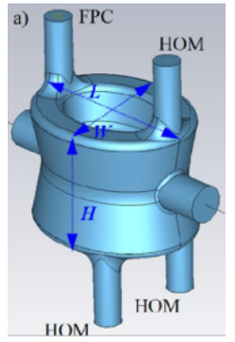
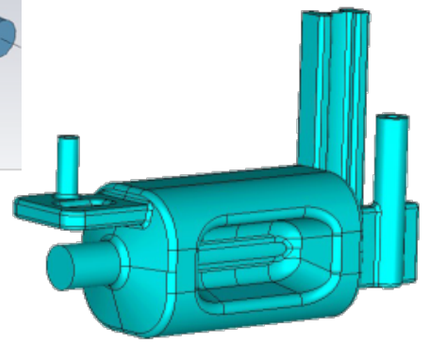
20/11/2014 4th Joint HiLumi LHC-LARP Annual Meeting

Post HL-LHC Review Conclusions (May 2014)

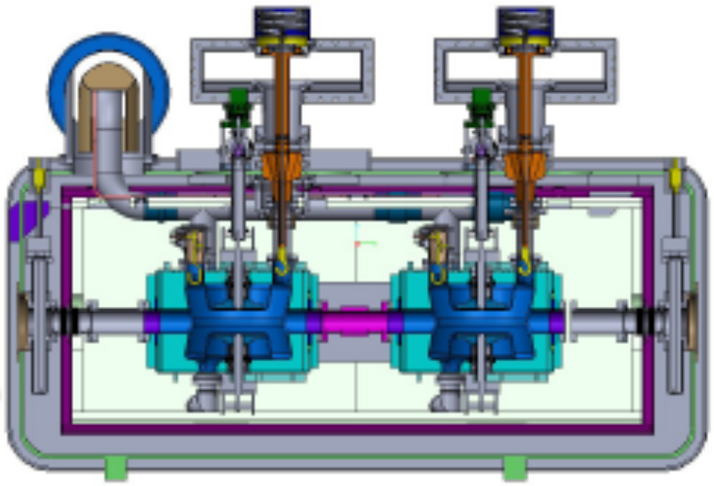
- **SPS Test is of Crab cavity Prototypes is critical**
  - Prepare for 2 cavity types to be tested in the SPS before LS2
  - Validation of crab functionality + assessment of machine protection issues

- **Crab Cavity prototypes to be tested in SPS**
  - Double Quarter Wave design
  - RF Dipole design





- **SPS Crab Cavity Installation**
  - 2 cavities of the same type in a common cryomodule
  - Cryomodules must be easily exchangeable
  - Cavities operate at 2 Kelvin
  - Cryomodule must be remotely movable in/out of beam



SPS Crab Validation Run: What is to be tested

- **Demonstration of cavity deflecting field (amplitude and phase control) with proton beam including injection, energy ramp and coast at energies ranging from 26-450 GeV.**
- **Verification and control of cavity field (amplitude and phase), frequency, tuning sensitivity, input coupling, power overhead and HOM signals.**
- **Establish operational cycle with crab cavities and demonstrate the possibility to operate w/o crab cavity action (make them invisible) by both counter-phasing the two cavities or by appropriate detuning.**
- **Measurements of beam orbit centering, crab optics and bunch rotation with available instrumentation such as BPMs and head-tail monitors.**
- **Demonstrate Multi cavity feedback operation**
- **Demonstrate robust 2-cavity cryomodule operation – trigger quench in one cavity without inducing quench in the other**
- **Verification of machine protection aspects and functioning of associated slow and fast interlocks.**
- **Test HOM coupler operation with high beam currents and associated power levels as a function of filling scheme, instability thresholds for deflecting and higher order modes and impedance measurements of the crab cavities.**
- **Measurable emittance growth induced by the crab cavities**

Taken directly from the WP4 PDR

SPS Crab Validation Program: 5 Steps

- **Validation Run requires dedicated SPS MD time**
  - **LHC injection and SPS Fixed Target beams not possible when crabs in**
- **Measurement programme broken in to 5 categories**
  1. Cavity setup, conditioning, beam injection and initial cavity operation
  2. Long Term Effects: Coasting Beam [120 -270 GeV]. Low Intensity
  3. Short Term Effects: Cycling Beam: [26-450 GeV]. Low intensity
  4. Machine Protection Issues and Quench studies
  5. High Intensity Studies

- Each MD step: 2 to 3 slots of 8hrs with beam

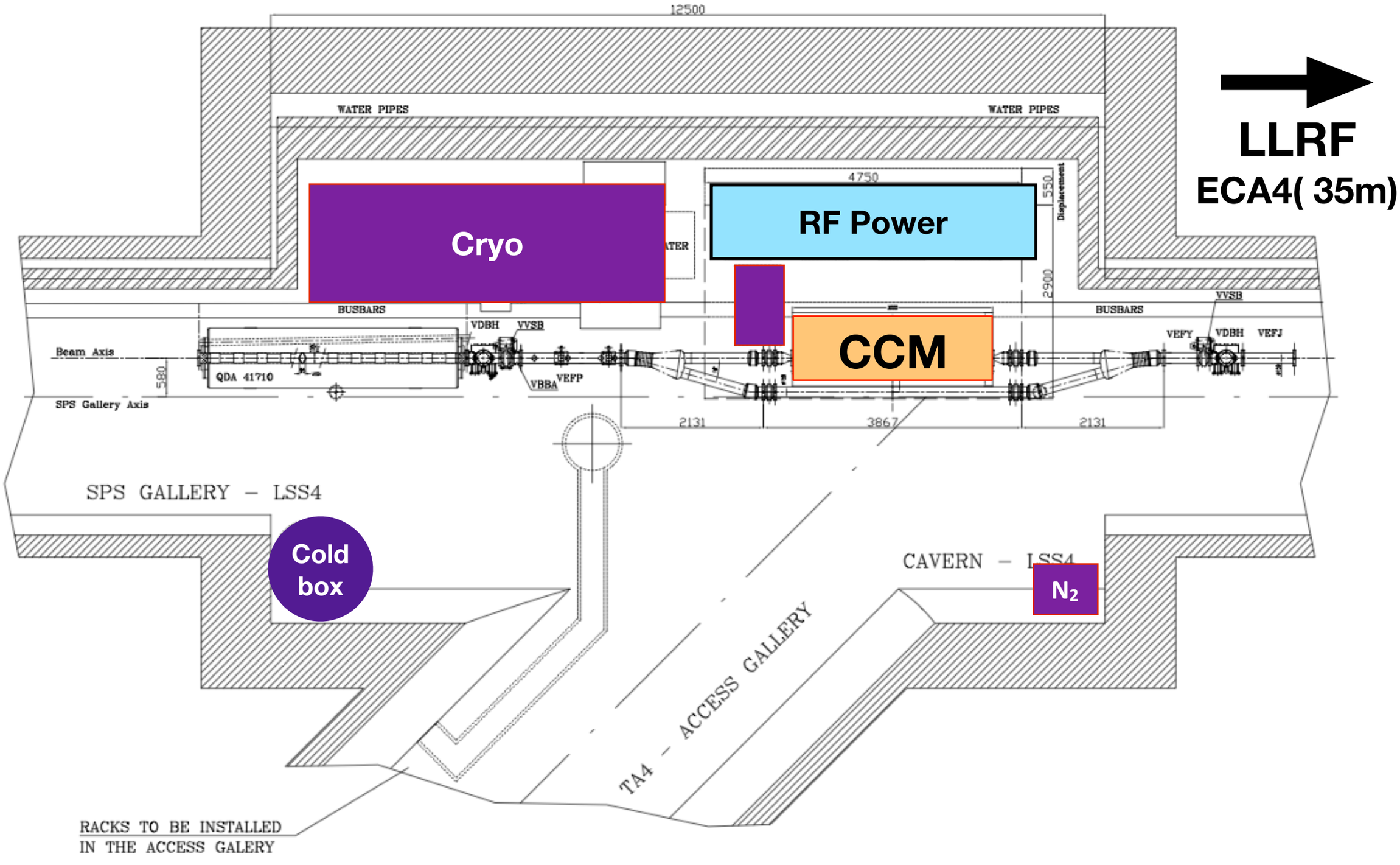
- Validation of test of 1 cavity type:

~12 slots of 8hrs of dedicated MD time spread over 1 year

- Its necessary to be installed for 2017 SPS run.

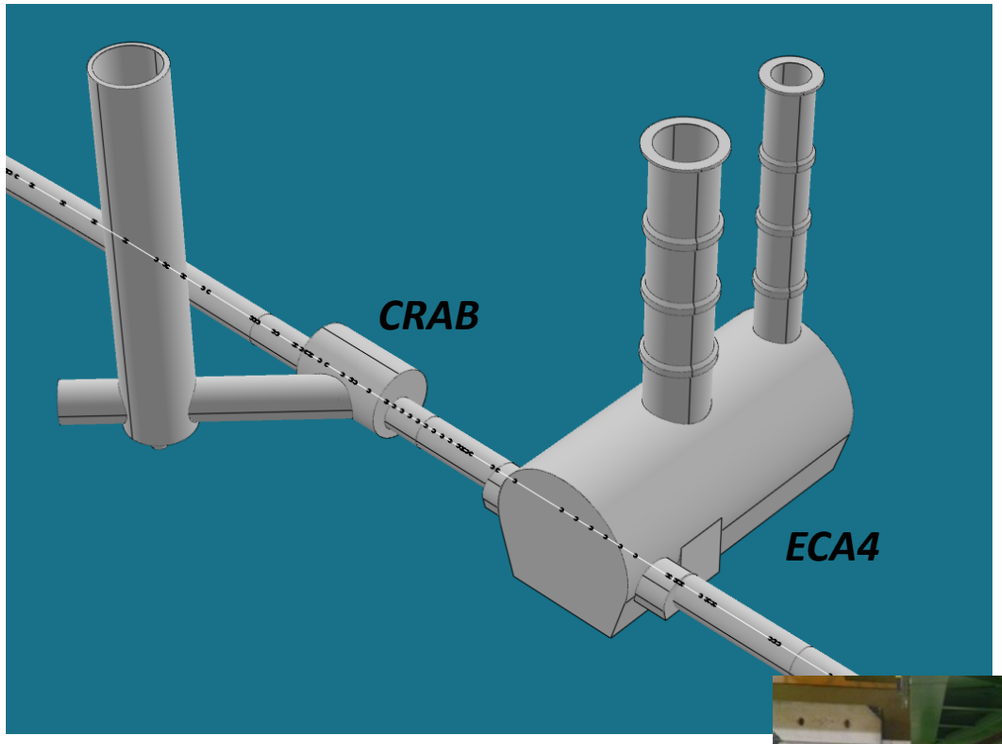
SPS Crab Integration Considerations

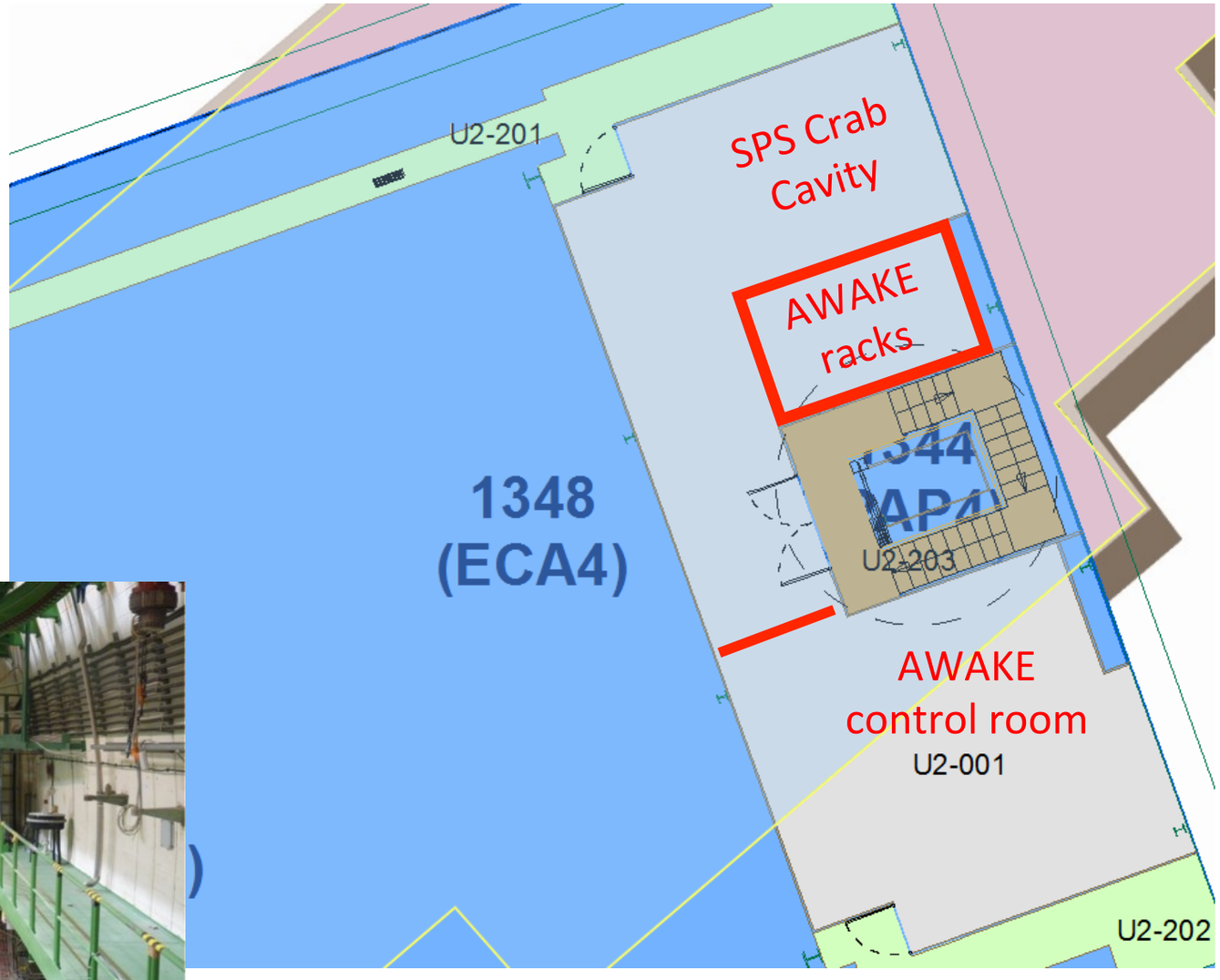
Baseline SPS location: SPS LSS4

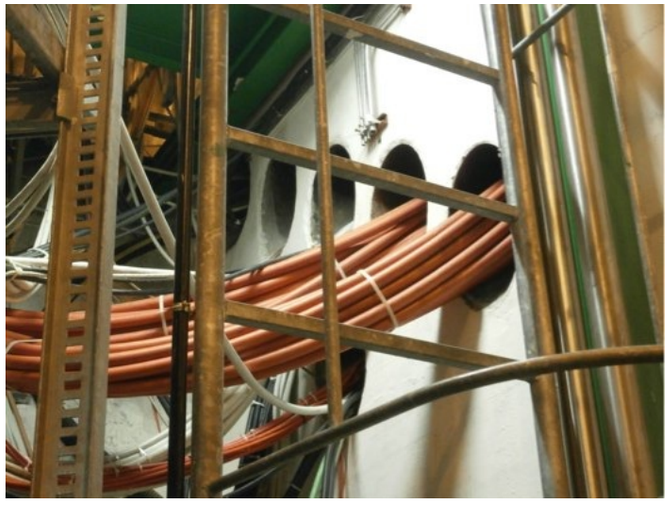


SPS Crab Control Room

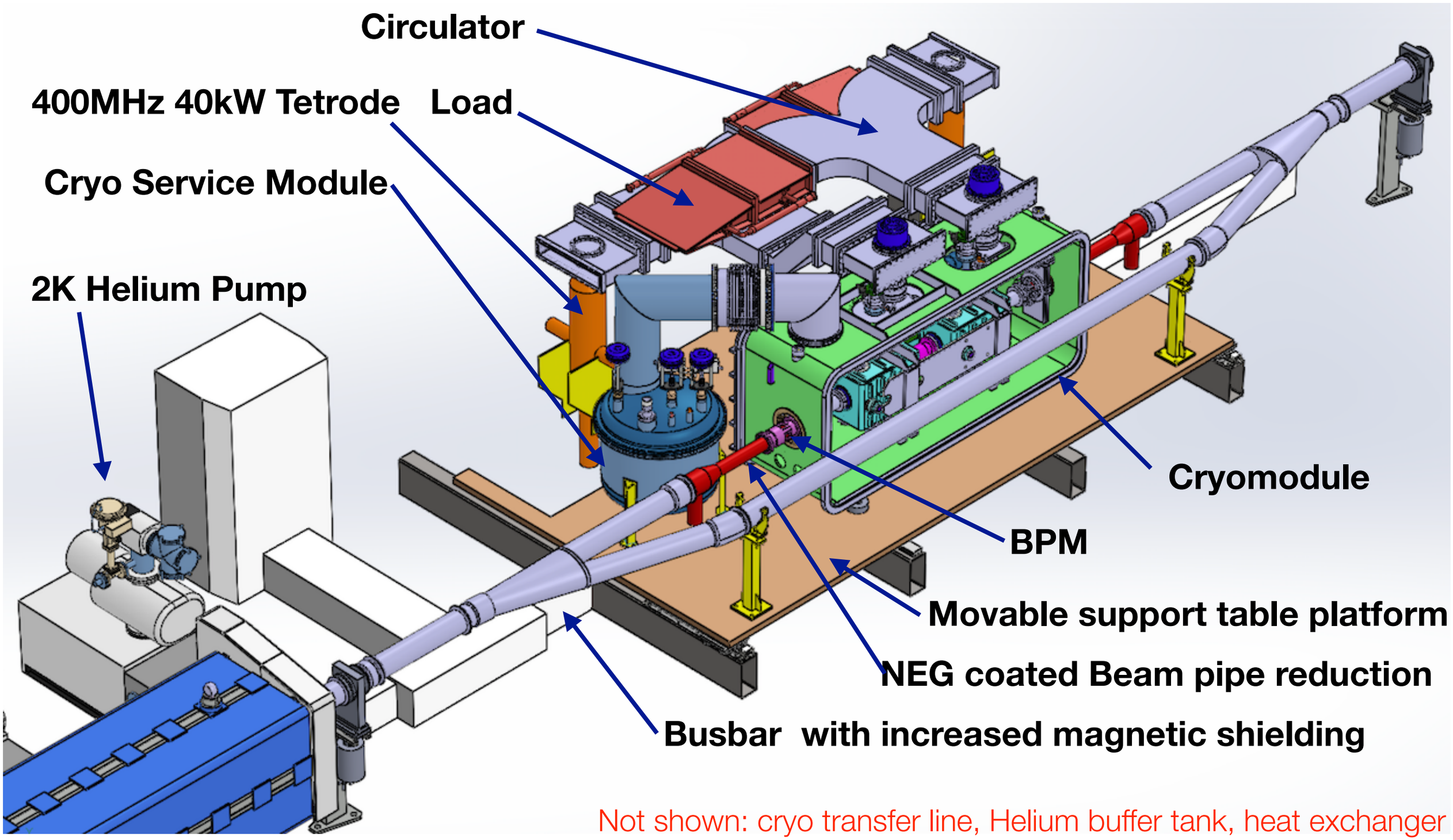
- **Crab Control room: Share ECA4 level -2 with AWAKE**
  - Space for up to 7 racks in barracks + rack space walkway in ECA4 Cavern
  - Cable routing through the ECA4-ECX4 shielding not yet understood







Crab Zone Layout



Not shown: cryo transfer line, Helium buffer tank, heat exchanger

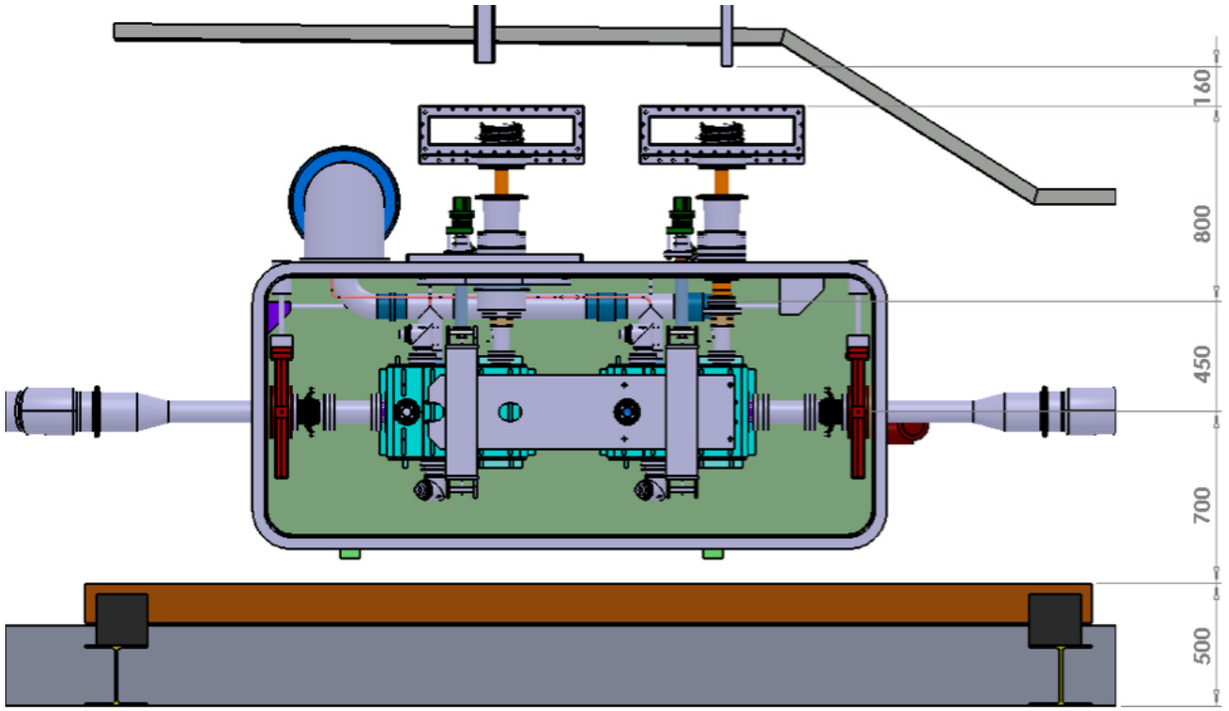
- **Baseline Integration model being assembled with Integration Office**

Overview of Status: SPS crab cavity run

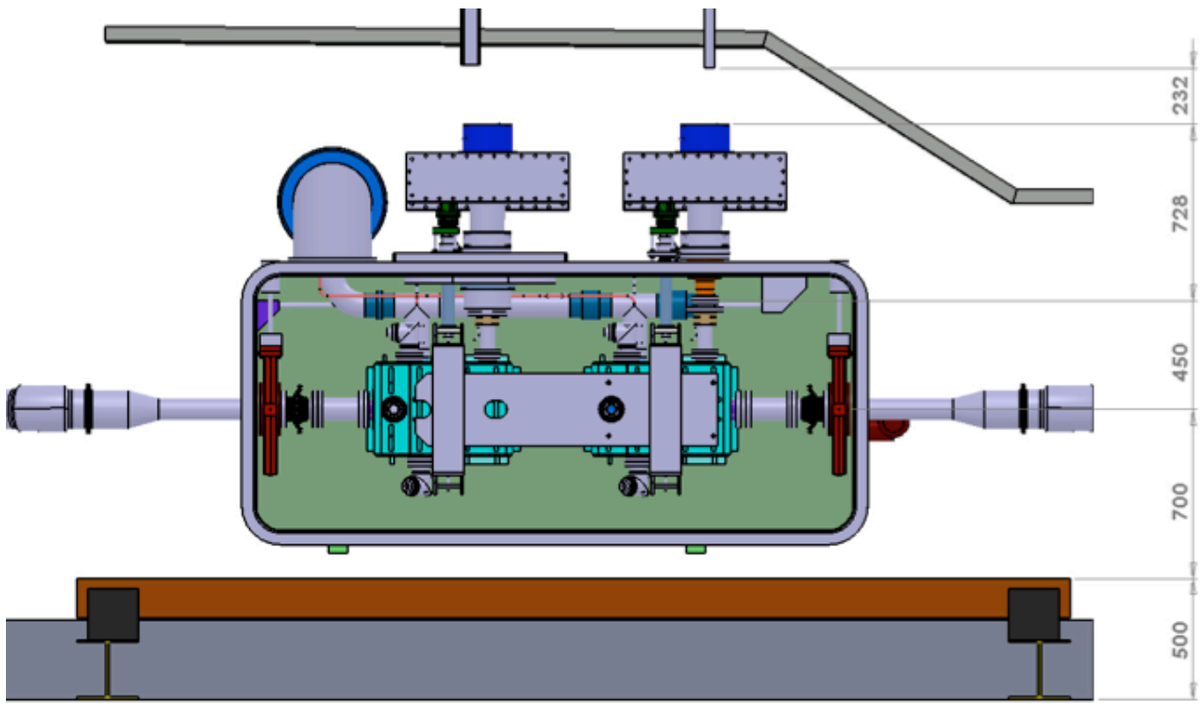
- **SPS Cavities:**
  - DQW design released for production: **October 2014**
  - RFD design to be released for production: **December 2014**
- **Cryomodule + Cryo 2K service module**
  - Conceptual design expected **end of December 2014**
- **Crab LSS4 Integration**
  - September 2014: integration model launched with CERN Integration Group
- **Cryogenics in LSS4: Heat load is still an issue**
  - During LS1: Helium pumps with services installed.
- **Beam line**
  - Conceptual models of Y-Chamber, support table and BPMs done
    - Preparing to launch technical designs needed for ECR
- **RF Power**
  - Cabling requirements specified and Tetrodes under test
  - Integration model of BA4 and ECA4 area need to be launched
- **LLRF + Controls**
  - LLRF:Ultra fast FB loop not needed => tetrode integration options?

Crab Installation Considerations: Space

- **Installation: Vertical height constrained by existing cable trays**
  - Some (mostly empty) cable trays will have to be dismounted/modified
  - Installation of power coupler and wave guide is the space constrained step



Installation: Power coupler + waveguide connection to Cryomodule



Installed crab cavity system

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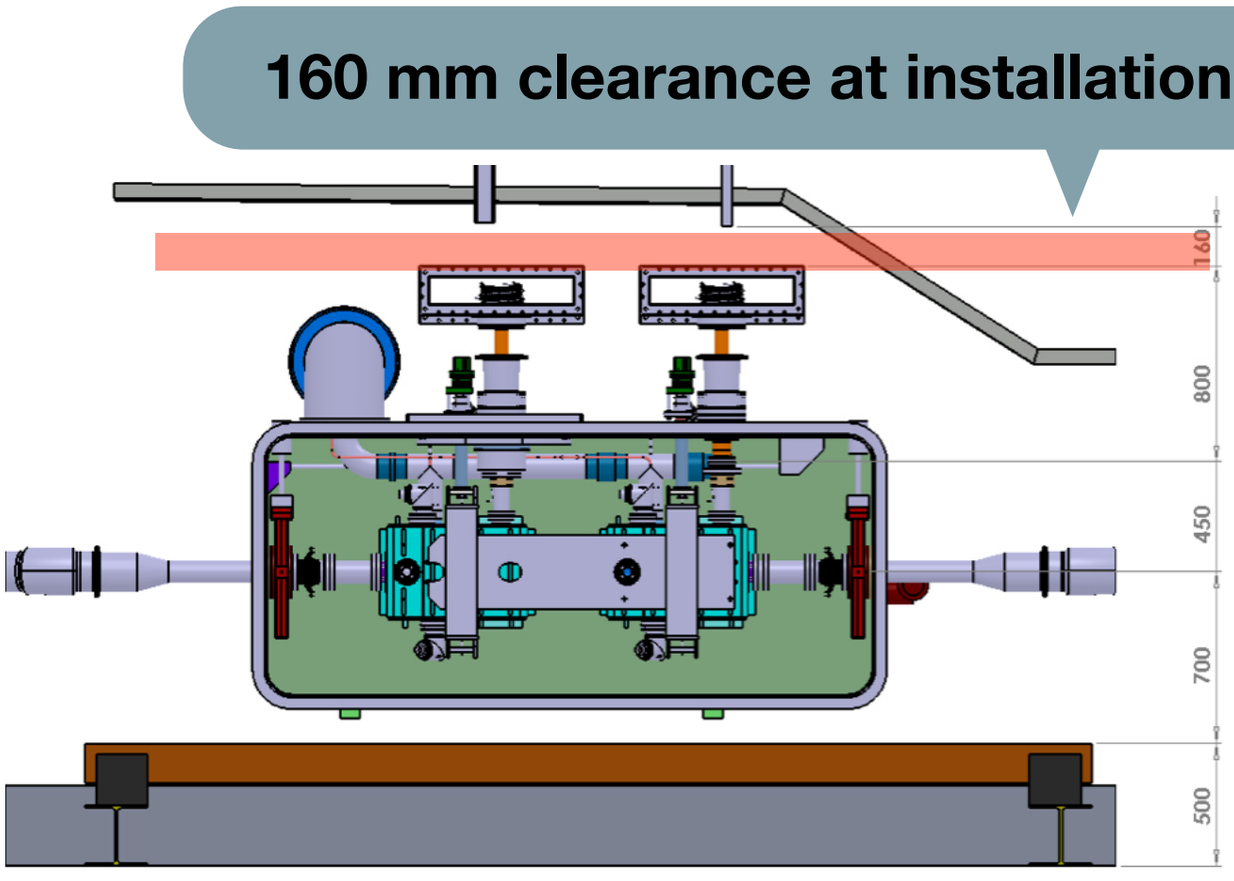

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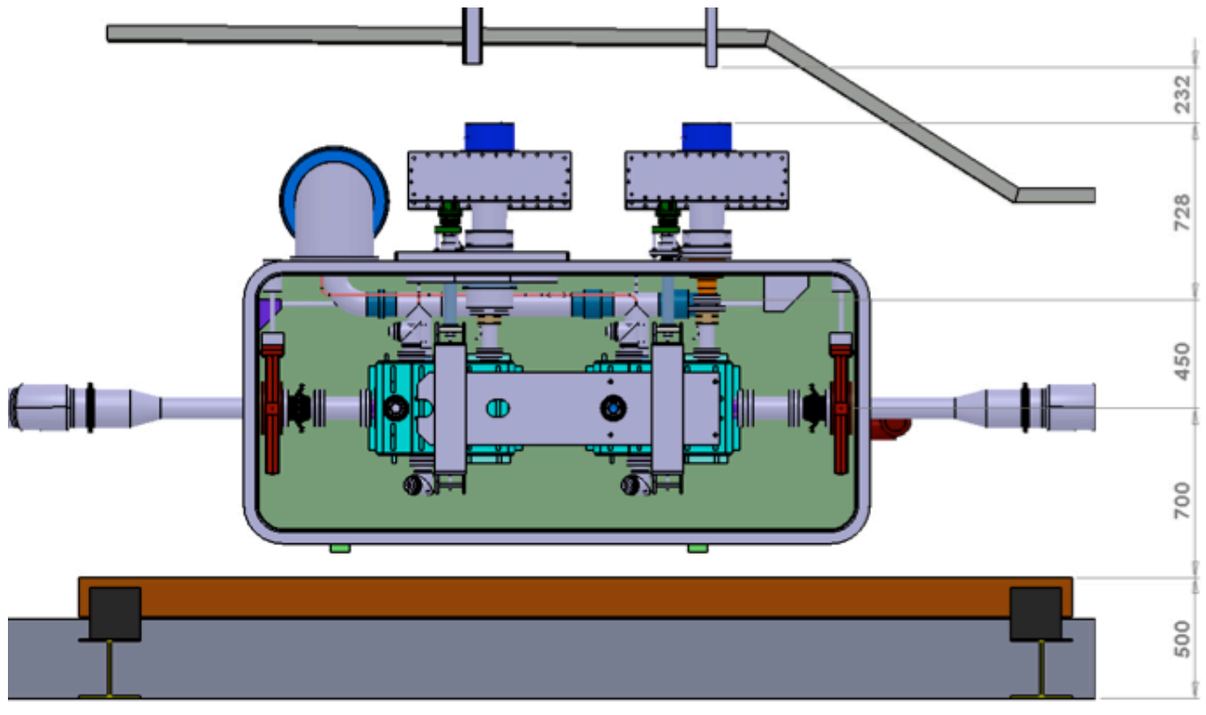
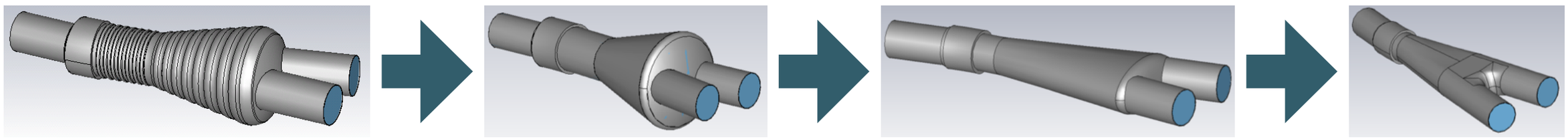


Installed crab cavity system

Beam Line Considerations: New Y-Chamber

- **Cryo module size => new Y-chamber design required**
  - **Opportunity taken to improve impedance design**
    - **Design presented and endorsed by Impedance Working Group**
      - No significant impedances within beam spectrum (< 1.5 GHz)
      - Propagating modes do not reach cavity due to aperture reduction
    - **Propagating modes into SPS reduced wrt existing design**

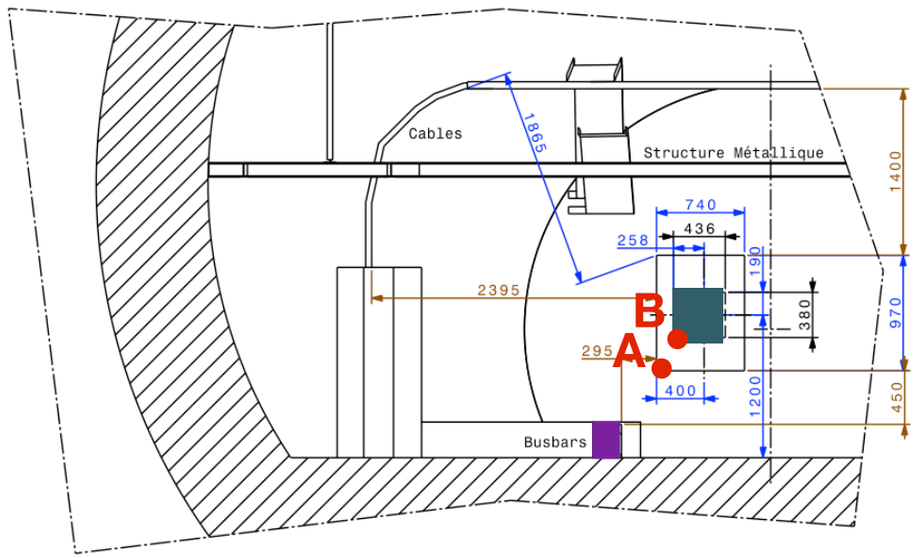


Model	Z	Zx (kOhms/m)	Zy (kOhms/m)
Installed 12 Degree Y-Chamber	*2.8*	*0.33*	*0.31*
Proposed 16 Degree Y-Chamber	*0.43*	*0.21*	*0.85*

- **Preparing to hand over to prepare Vacuum group for mechanical design, design approval, and manufacture.**

Beam Line Considerations: Ambient Magnetic Field

- **Requirement**
  - Ambient field < 1uT at cavity
- **Initial 2D simulation results**
  - consider only main magnet busbars
- **Identify most critical position.**
  - **Pt A**: Outer surface of cryomodule
  - **Pt B**: Outer surface of He Vessel
- **Source of ambient magnetic field: SPS main magnet busbars**
  - Take worst operational case => 2 x normal operational levels



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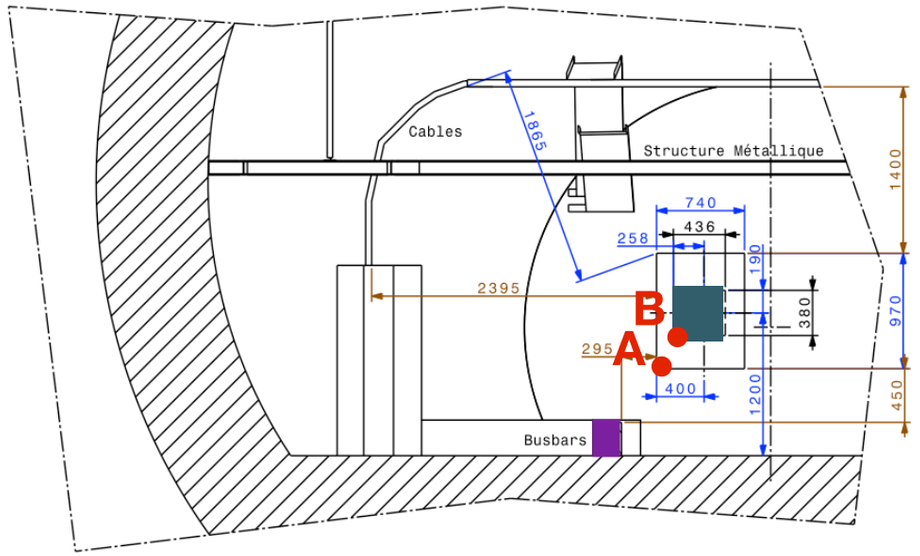

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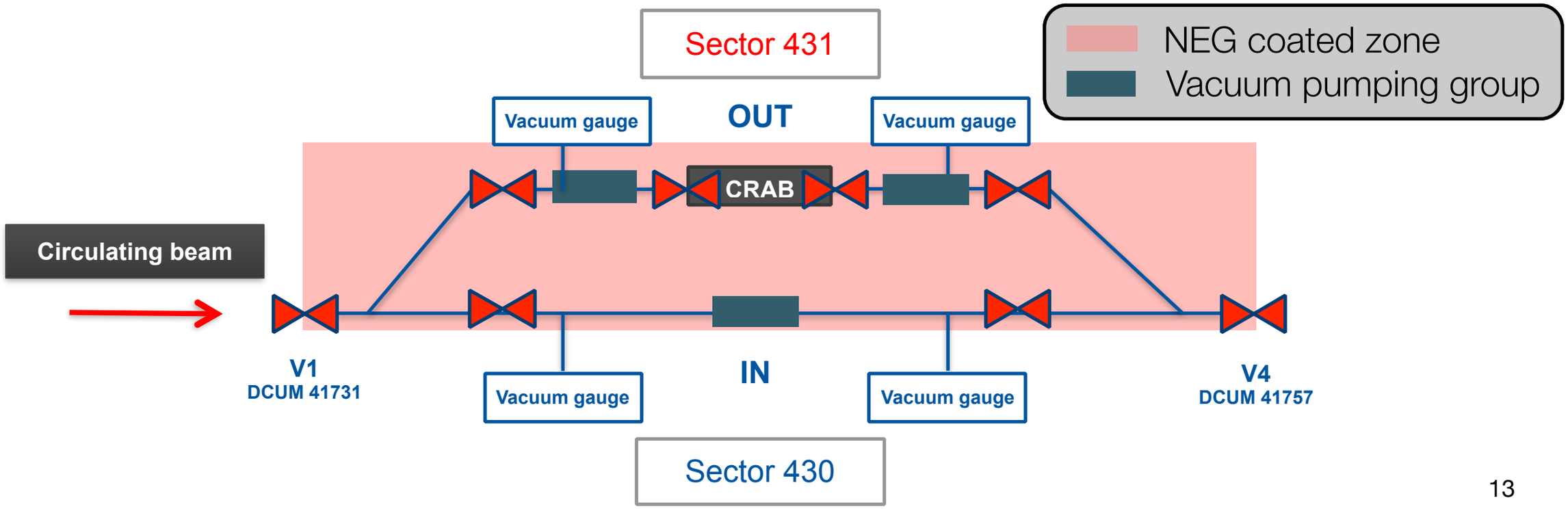
	In-Beam Transverse Stray field [mT]		Out-of-Beam Transvesre Stray field [mT]	
Busbar shielding	**Pt A**	**Pt B**	**Pt A**	**Pt B**
Stainless steel (or no cover)	0.4 **(0.57)**	0.2 **(0.39)**	0.6 **(0.85)**	0.3 **(0.51)**
Constructional steel, 2 mm thick	0.3	0.2	0.4	0.2
Constructional steel, 10 mm thick	**0.1**	**0.1**	**0.2**	**0.1**

Details: https://edms.cern.ch/document/1377806
J Bauche & A Macpherson

Measured September 2014
Error in measurement ± 20%

Beam Line Considerations: Vacuum

- **Vacuum condition required in cryo module: < 10^{-10} mbar**
  - **Vacuum conditions: should be achieved in way that mimics LHC crabs**
    - => Y-chamber, bypass, and crab beam pipe to be NEG coated
      - Large NEG cartridges required up & downstream of crab installation
    - aCarbon coatings could be applied in SPS on either side of the crab installation to mitigate influence of general SPS vacuum.
- **Vacuum valve and pump layout**
  - **This sectorisation permits rapid exchange of cryomodule**



Cryogenics: Heat Load Issues

- **Expected Heat load and required cold box capacity (with safety margin):**
  - **Total Static Heat load:**
    - 26.6 W => Required cold box capacity: 1.32*1.5 = **1.98 g/s**
  - **Dynamic Heat load:**
    - 13.4 W @ 2K + 30 W @ 80 K => Cold box capacity: 0.6*1.5 = **0.9 g/s**

- **Installed TCF20 cold box used for 4.5K COLDEX operation**
  - TCF20 Capacity: 1.1 g/s => does not have capacity for static heat load

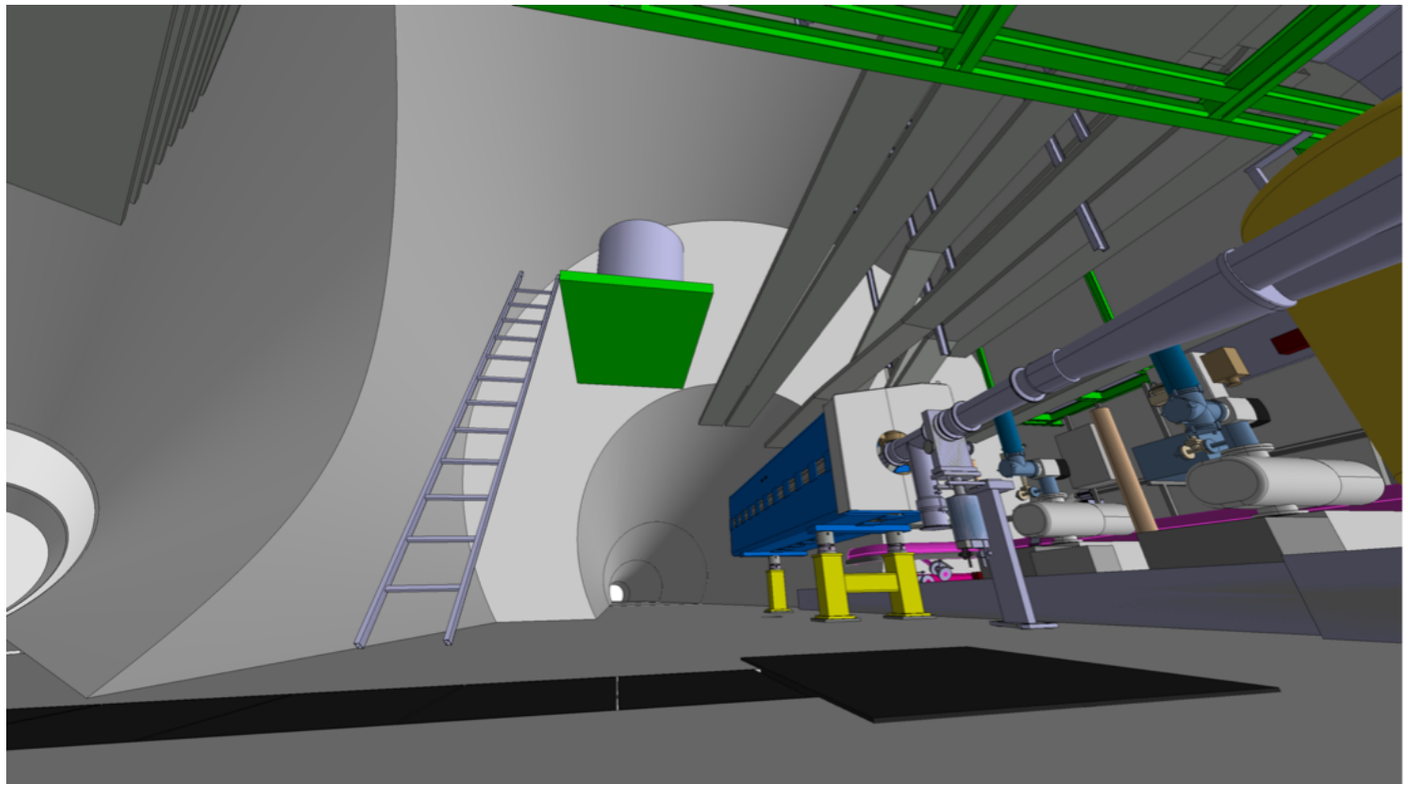
=> TCF20 must be replaced with more performant system

- **Present baseline solution: Install TCF50 from CERN cryo lab**
  - TCF50: expected maximum capacity 2.5 - 3.0 g/s
    - Integration issues to be resolved => schedule implications

- **Dynamic heat load**
  - Install buffer tank to cover dynamic heat loads over an 8-12hr period
    - Refill buffer tank over night(i.e. crab out of beam during refill)

Cryogenics: Cryo Cold Box Integration

- **TCF20 -> TCF50 upgrade: Needs to be studied in detail**
  - LSS4 installation: 4 weeks + Preparation & Surface installation: 5 months
  - Integration Issues: TCF50 is significantly larger (1.9 x 1.3 x 3.0 m)
    - Integration in LSS4 zone is difficult: cannot block SPS transport zone
    - **Integration may still be feasible => cryo team needs clear requirement.**



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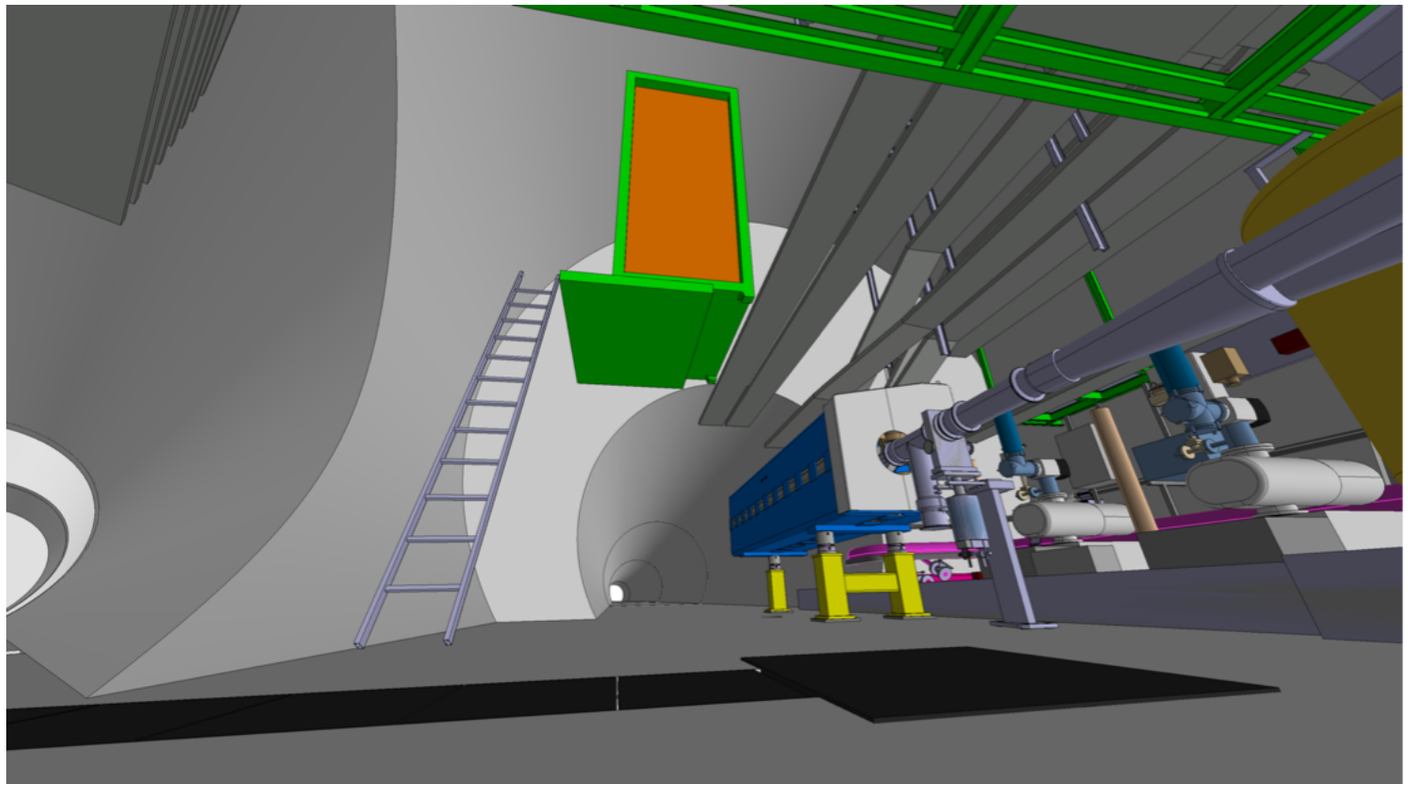

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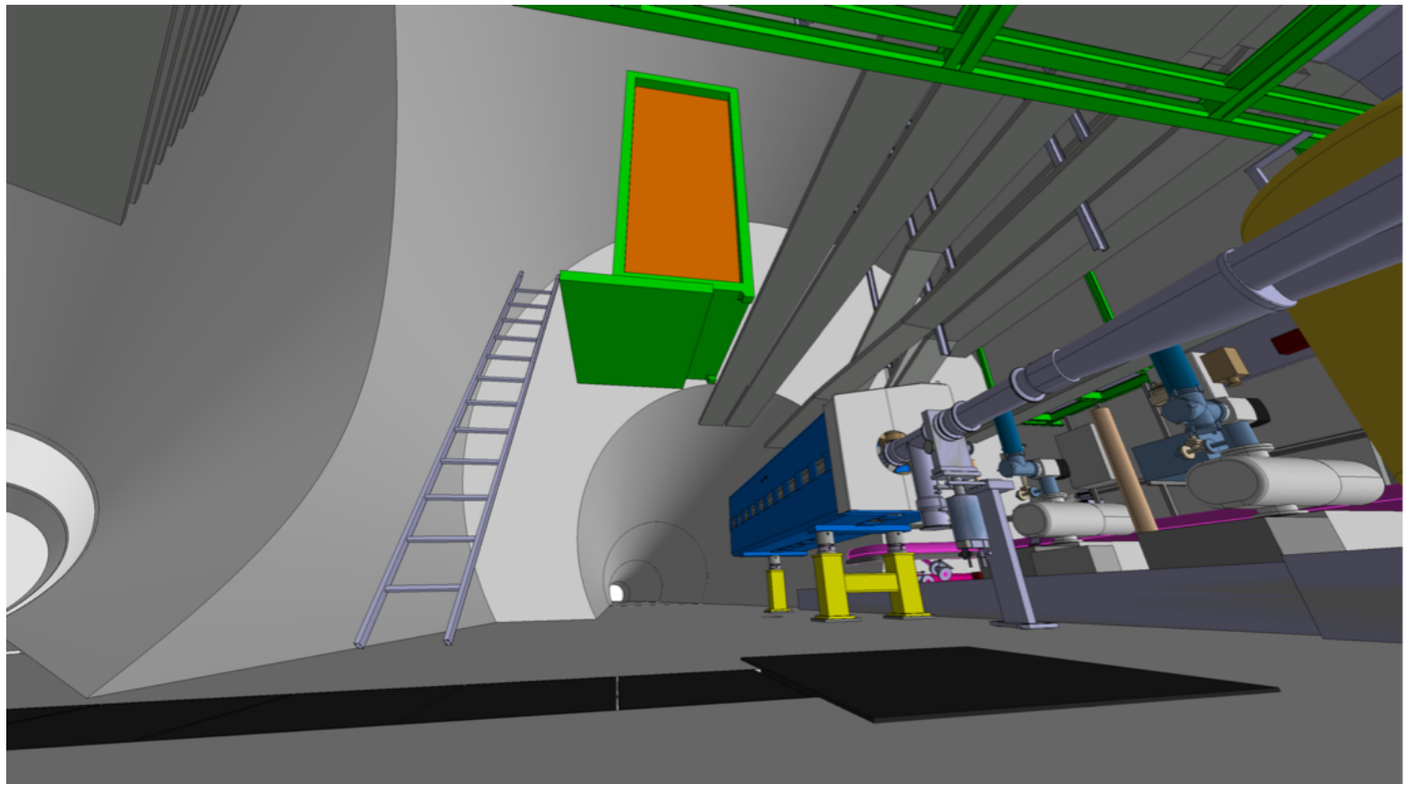
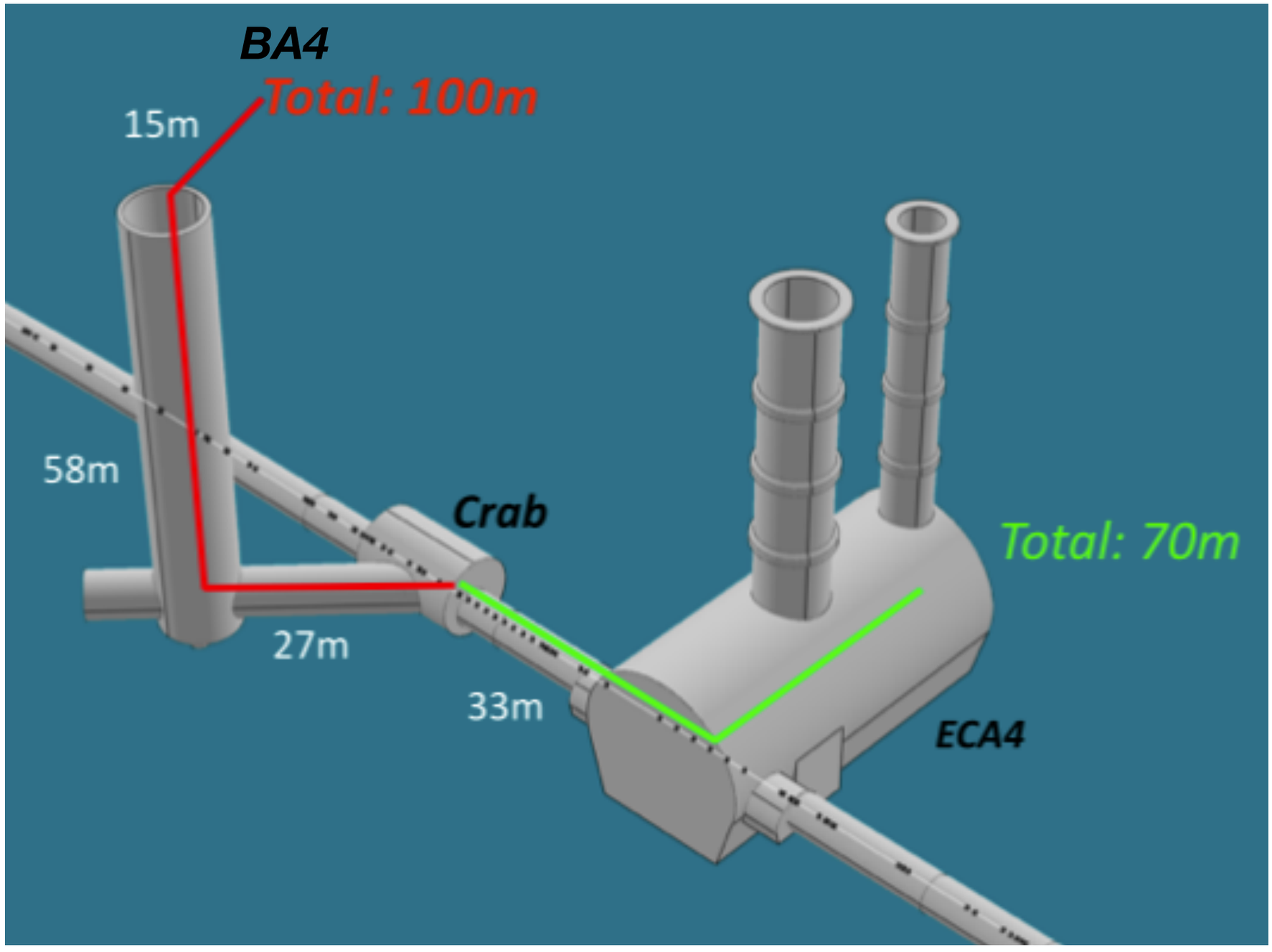


Alternatives:

- **If not possible to install in LSS4 => TCF50 has to go to ECA4 or BA4**
- **Is it sensible to consider relocating to another SPS location? …**

Cryogenics: Cryo Cold box alternative locations

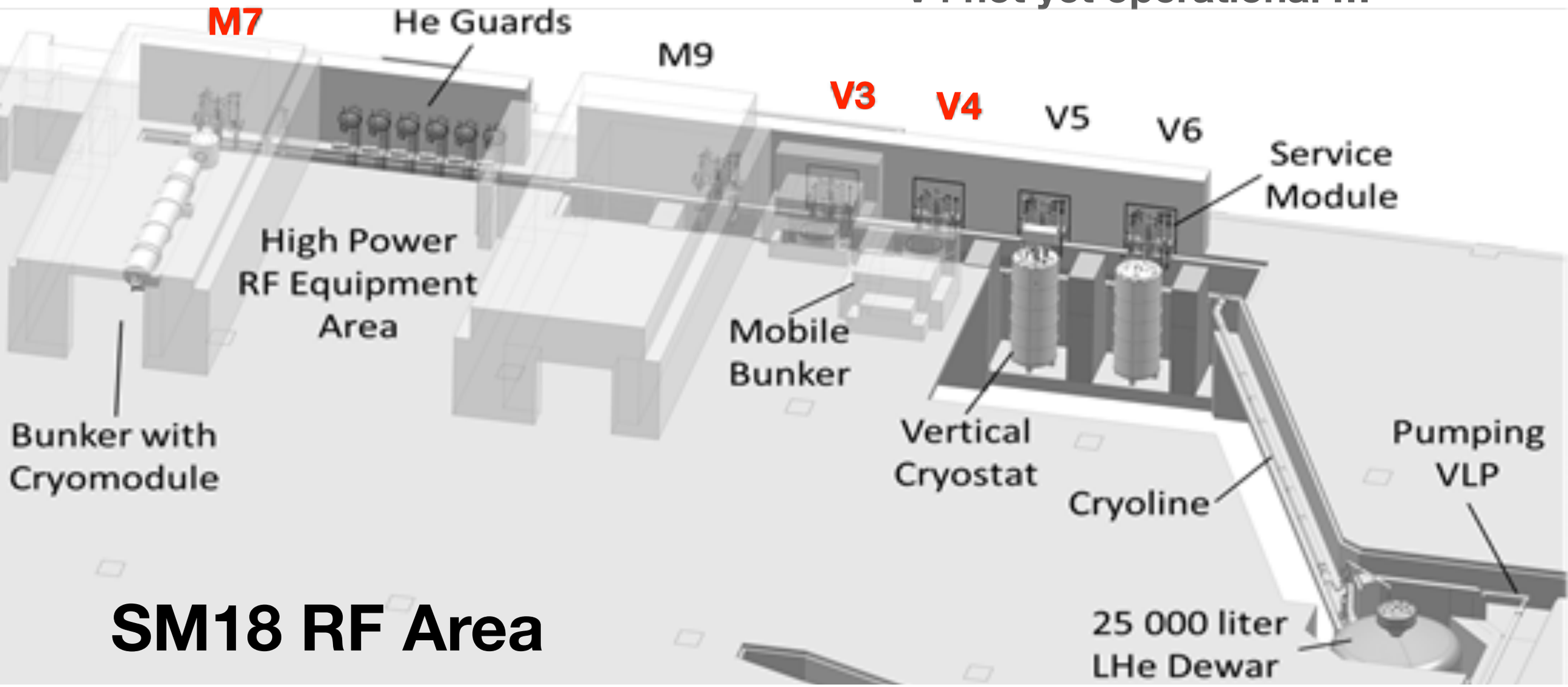
- **Relocating Coldbox to ECA4 or BA5: Need to install helium transfer line**
  - Issue of time and cost : time => time without beam + money (~4000 CHF/m)



Other Integration Issues: SM18 RF Test Facility

- SM18 Clean room
  - **Cryomodule assembly Q1 2016**
- M7 Bunker: Horizontal Tests
  - **CRAB cryomodule - 2016**

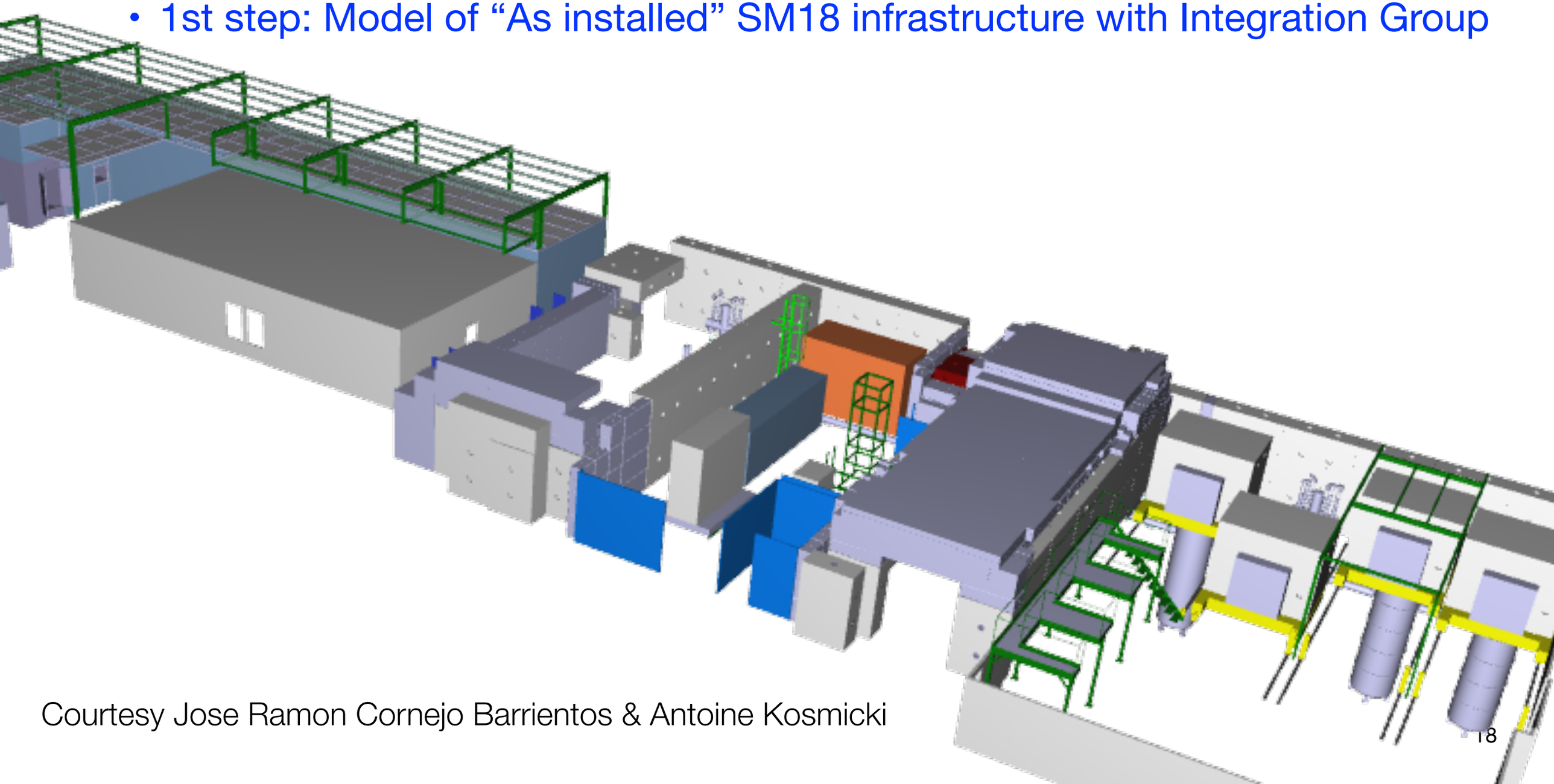
- V3 and V4 Vertical Teststand in 2014 - 2015
  - **Cavity tests: PoP Design**
  - **Quench studies**
  - **LLRF studies**
  - V4 not yet operational …



SM18 RF Area

SM18 Preparations

- **Up-grading of vertical test stand inserts for Crab testing**
  - Upgrade of V3 and V4 cryostat inserts
- **Preparations for Horizontal bunker M7 for Crab cryo module testing**
  - 1st step: Model of “As installed” SM18 infrastructure with Integration Group



Courtesy Jose Ramon Cornejo Barrientos & Antoine Kosmicki

SPS Crab Installation Schedule Considerations

SPS Crab Cavities: Preparation Schedule

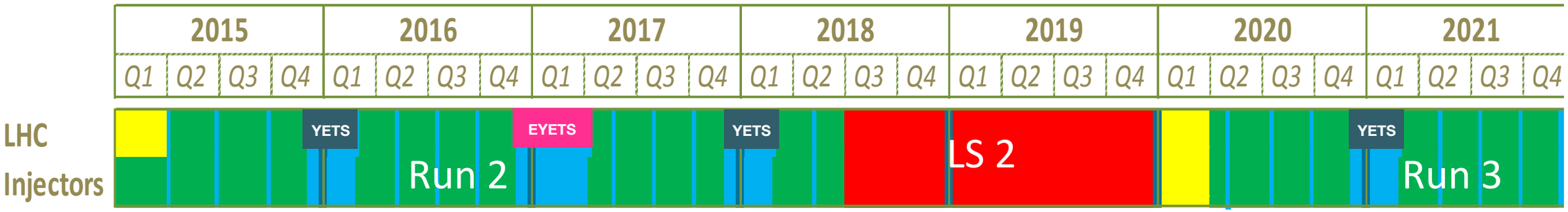
- **Assumptions**
  - **SPS crab validation run is during 2017 and 2018 SPS operation**
    - Y-Chamber essential: Remotely moveable table => dedicated beam MD
  - Two cavity types are to be tested in the SPS => two different cryo modules
    - Only one cryo module can be installed in the SPS at any one time.
  - Infrastructure and initial cryo module installation only possible in a (E)YETS

- **Schedule for cryo module preparation**
  - **Q1 of 2016**: Cryo module assembly in SM18
  - **Q2 of 2016**: Cryo module + cryo service module validation in SM18
  - **Q3 of 2016**: RF Conditioning of cryo module in SM18
  - **December 2016**: 1st Cryomodule ready to install in SPS

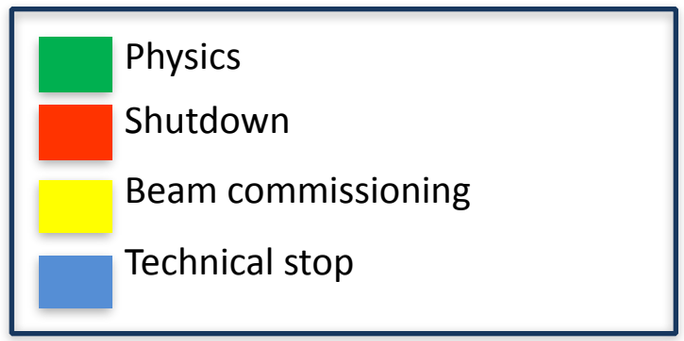
  - **Q3 2016**: Assembly of 2nd cryo module starts

SPS Schedule based on the LHC roadmap

- **Present Schedule**
  - **LS1** Finishing => LHC restart => very limited SPS access
  - **LS2** Starting in 2018 (July) => 18 months + 3 months BC
- **Machine stops**
  - Year End Technical Stop: **YETS**
  - Extended Year End Technical Stop: **EYETS**



- **Crab validation run: cryomodule 1**
- **Crab validation run: cryomodule 2**



Access periods:Year End Technical Stops

- **Installation opportunities in the SPS schedule**
  - YETS and EYETS periods
  - Technical Stops during SPS running: Each stop is limit to 4 days or less

- **Year end technical stops**
  - **YETS 2015-2016 = 3w + 2w* + 7w = 12 weeks (Beam to Beam in LHC)**
    - **This will allow approximately 4 to 5 weeks of Access in the SPS.**
  - **EYETS 2016-2017 = 3w + 2w* + 13w = 18 weeks (Beam to Beam in LHC)**
    - **This will allow approximately 10 weeks of Access in the SPS.**
  - **YETS 2017-2018 = 3w + 2w* + 7w = 12 weeks (Beam to Beam in LHC)**
    - **This will allow approximately 4 to 5 weeks of Access in the SPS.**

* Christmas break

Dates courtesy of David McFarlane SPS Technical co-ordinator

SPS Crab Cavities: Ideal Installation Schedule

- **2015-2016 YETS: Installation of infrastructure**
  - Removal of COLDEX
  - Upgrade Cryo cold box + install crab cryo infrastructure for 2K operation
  - Replace bus bar shielding, install support table + RF power
  - Installation of Y-Chamber, beam lines, and vacuum valves and pumps
- **During 2016 SPS run: Validation of infrastructure**
  - Commissioning of cryo system
  - Validation of in/out movement of support table with cold transfer lines
  - Re-confirmation of RF power operation
- **2016-2017 EYETS: Crab Installation**
  - Cryo module installation, beam line pump down, alignment of cryomodule
  - Installation of LLRF into ECA4 + cabling + deployment of control software
- **During 2017 SPS run: SPS Crab validation run**
  - 2 to 3 months of conditioning/RF conditioning
  - Crab cavity measurement programme

This schedule would be nice but is not really justifiable in terms of crab preparation milestones and wider HL-LHC program

SPS Crab Cavities: Realistic Installation Schedule

- **To be taken into account**
  - **Cryo module not ready until 2016-2017 EYETS**
  - **Cold box upgrade is substantial + likely not feasible in 2015-2016 YETS**
  - **COLDEX request to run in 2016**

- **What is a reasonable baseline scenario**
  - 2015-2016 YETS: Install of cryo cold box upgrade infrastructure
  - 2015-2016 YETS: Cabling to ECA4
  - 2016: Use SM18 M7 bunker to validate support table + RF power + Y-chamber + cryo service module + cryomodule
  - 2016-2017 EYETS:
    - Remove COLDEX. Install crab infrastructure and cryo module
    - Upgrade cryo cold box in parallel.
  - 2017: Commission and run as originally planned

This schedule is optimistic but feasible. Installation must be carefully choreographed & 2015-2016 YETS used for preparation work

SPS Revised Schedule: EYETS planning

- **Optimistic sequential planning estimate**

Activity in LSS4	How Long
Removal of COLDEX	4 days
Cryo cold box upgrade (in LSS4)	4 weeks
Installation of new bus bar shielding	4 days
Installation + alignment of support table	3 days
Installation of Tetrodes, circulators and loads	2 days
Installation of cryo 2 K infrastructure + Cryomodule	5 days
Installation of beam line + cryo connections + leak tests	3 days
Vacuum conditioning	1week
Alignment after pump down	4 days
Cabling	2 weeks
Contingency	1 week
Total Time	**13 weeks**

- **EYETS stop: 10 wks of SPS access => some work items to be in parallel**
  - **Assumes 2015-2016 YETS used for preparatory work items**

Baseline Fall Back plans

- **Baseline plan is to install in 2016-2017 EYETS into SPS LSS4**
  - Ideally cold box upgrade in 2015-2016 YETS but expect 2016-2017 EYETS

- **What happens if Cryomodule is not ready for EYETS**
  - **Option A: Install during 2017 SPS run:** two 4-5 days SPS technical stops
    - Assumes that all support infrastructure installed in EYETS
  - **Option B: Install in 2017-2018 YETS**
    - With present LS2 start date => only 1 cryo tested before LS2
    - If LS2 start moved back:
      - Possibility of swapping cryomodule in an SPS technical stop
      - Would place heavy demand on dedicated MD time during SPS run

Only realistic option for testing two different cryo modules:
Install first cryomodule in 2016-2017 EYETS

Cryo module exchange in an SPS Technical Stop

- **Minimum Time to swap a cryo module: 1 SPS technical stop of 4 days**
  - Day 1
    - Venting and removal of beam pipes -> 6hrs
    - Removal of existing Cryo module -> 4hrs
  - Day 2
    - Installation of new CM: 4hrs
    - Alignment of cryomodule: 4hrs
    - Pumpdown of beam pipe reduction transitions & Y-chambers overnight
  - Day 3
    - Remounting of bypass beam pipe: 4hrs
    - Pumping of bypass beam pipe: 24hrs

- **Things to be done once SPS beam reinstated**
  - Bakeout of beam pipe reduction transitions => to be done remotely
    - remote monitoring and only short access to remove once done
    - bakeout + reconditioning expected to take 1week

Summary

- **LSS4 of SPS is the baseline installation site**
  - Control room + LLRF in ECA4. RF power in LSS4 alcove

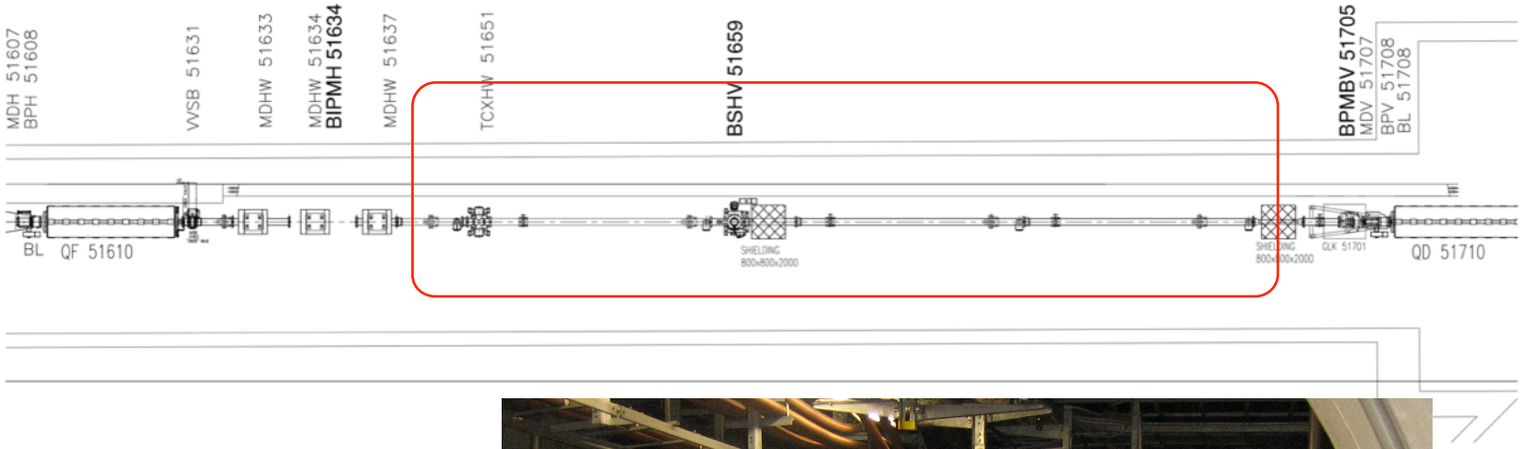
- **Revised integration/installation schedule**
  - **2016**: SM18 M7 bunker needed for infrastructure + cryo module testing
  - **All crab infrastructure installation pushed to 2016-2017 EYETS**
    - **~10 week window to install LSS4 crab infrastructure.**

- **Issues**
  - **Cryo Cold box upgrade schedule needs to be studied …**
  - Need to move Y-Chamber and support table designs into ECR phase
  - Compatibility with COLDEX: Needs confirmation on when COLDEX stops
    - COLDEX runs until EYETS then removed. Crabs installed until LS2

      - … Possibility of alternative SPS location?: to be discussed ….

Alternative SPS Crab location?

- **Very new point of discussion point**
  - **Question**: Given COLDEX program and Crabs cold box upgrade needed in LSS4, is it better to have 2 test facilities with cryogenic capacity in SPS?
- **Preliminary look at alternative locations in the SPS: Only LSS5**
  - Tunnel option: Space constraints?



- Alcove option?
  - Similar integration issues as LSS4?
  - Other users?