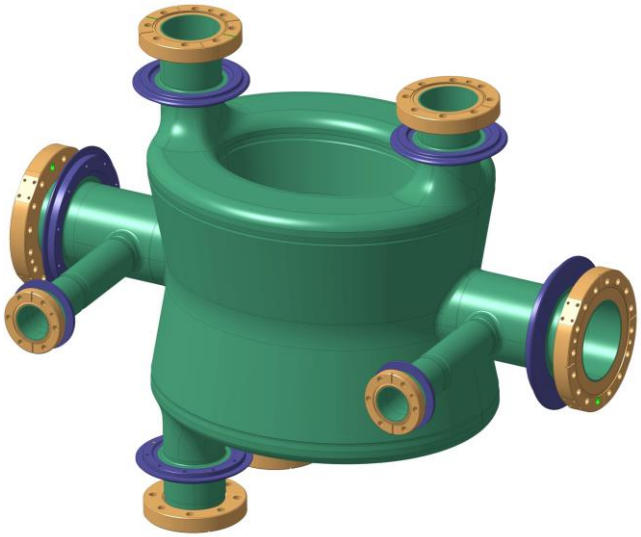
HL-LHC WP4 Strategy for Crab Cavities Cryomodules

Ofelia Capatina (CERN) on behalf of the
WP4 collaboration members

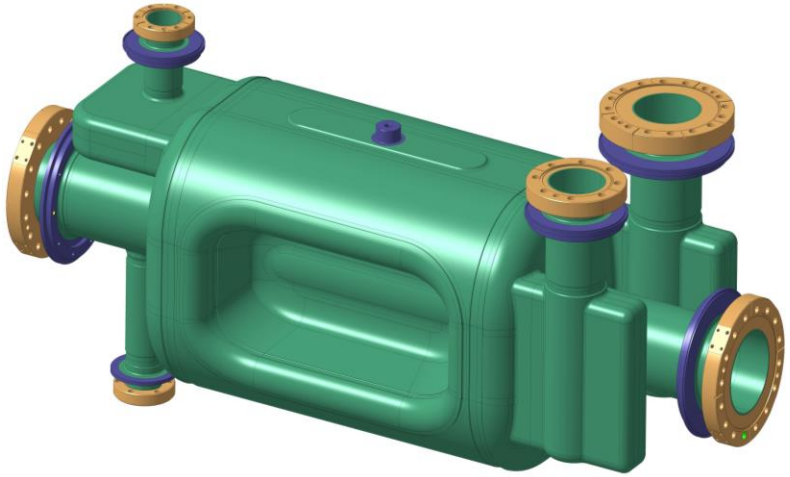
International review of the HL-LHC Crab Cavity system, 19/06/2019

HL-LHC Crab Cavity types

- For HL-LHC, superconducting compact RF crab cavities will be used to compensate the geometric angle (500 μrad) at ATLAS and CMS.
- Two types of cavities required (vertical, horizontal)
  - Baseline : adopt both cavity types and exploit their natural RF topology
    - Note: Both cavities could have been used in the other plane

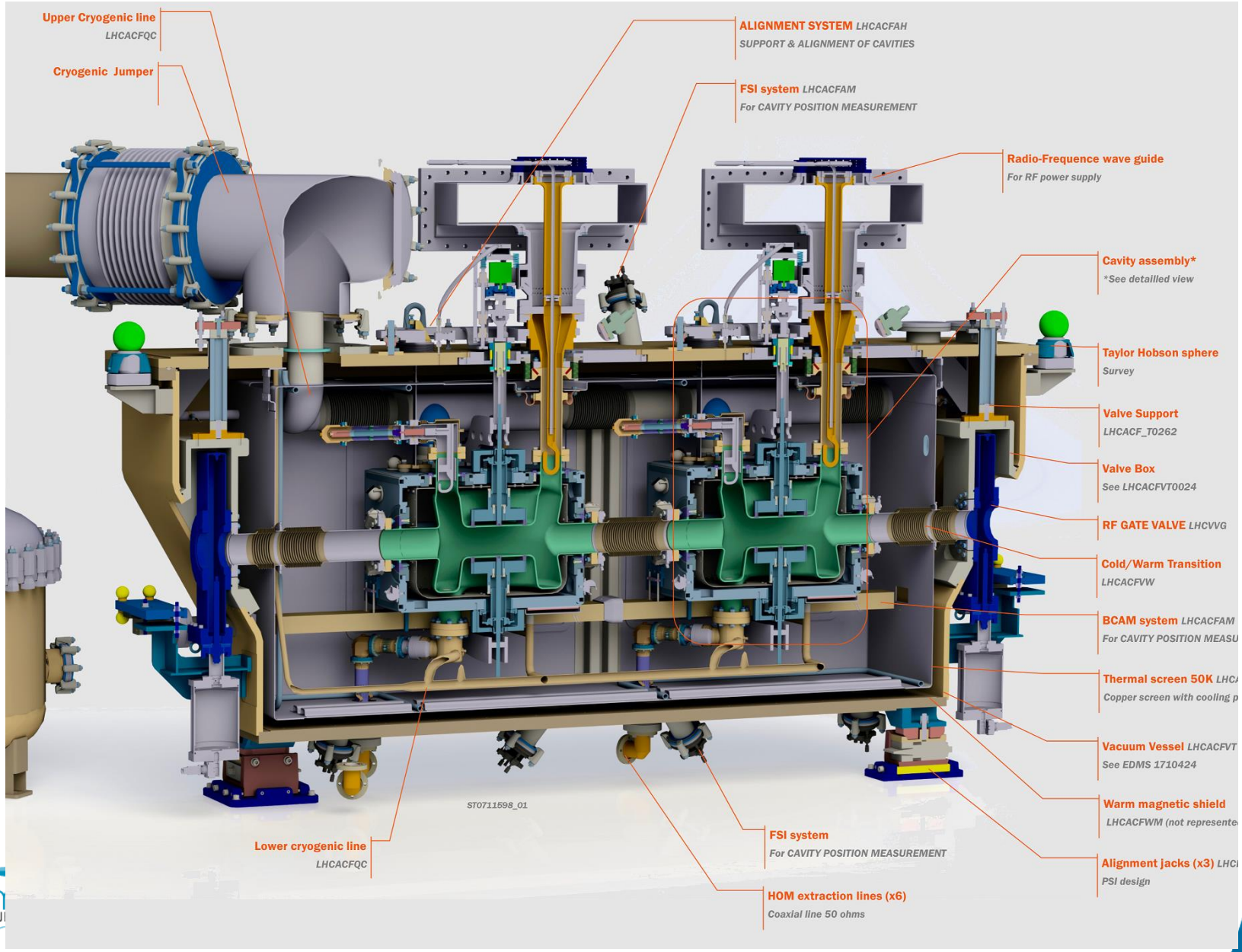


Double Quarter Wave (DQW) cavity – Vertical – to be used in Point 5 (CMS)



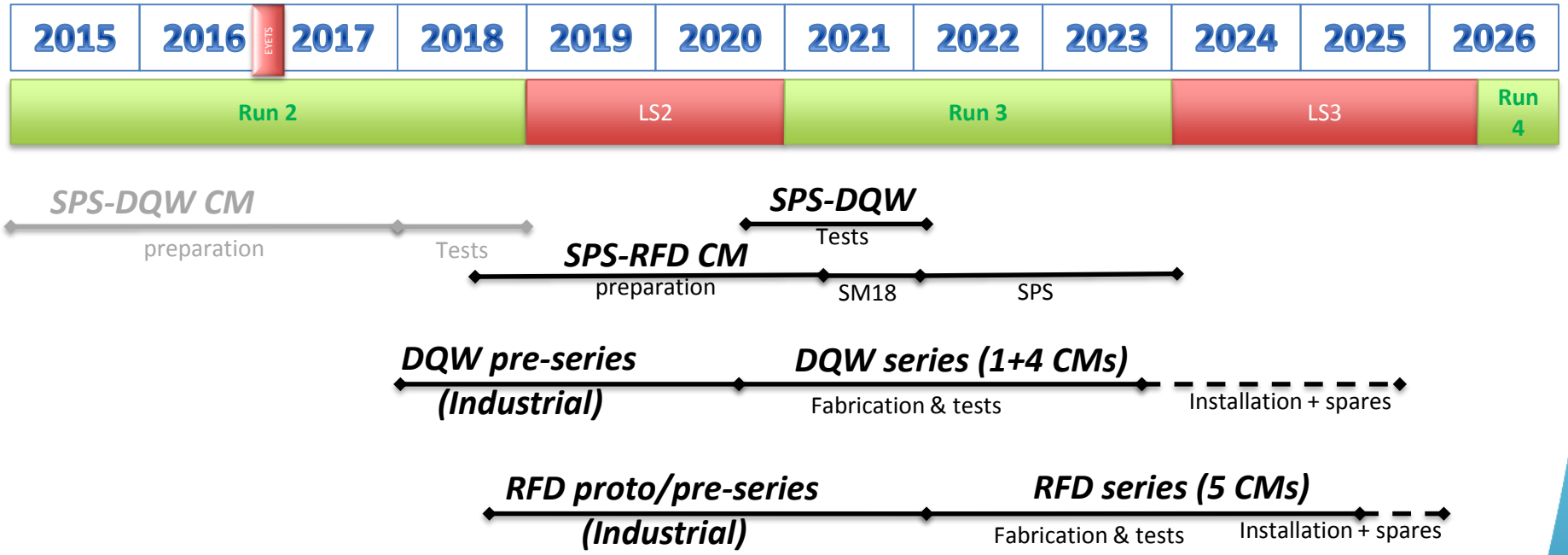
RF Dipole cavity – Horizontal – to be used in Point 1 (ATLAS)

Cryomodule with 2 identical cavities



General plans

- 2 cryomodules for SPS tests
  - 1 cryomodule with 2 identical cavities (type «vertical» - DQW)
    - Tests in SPS in 2018 and 2021
  - 1 cryomodule with 2 identical cavities (type «horizontal» - RFD)
    - Tests in SPS in 2022
- 8 cryomodules (4 of each type) for installation in LHC during LS3
  + 2 spares (1 of each type)

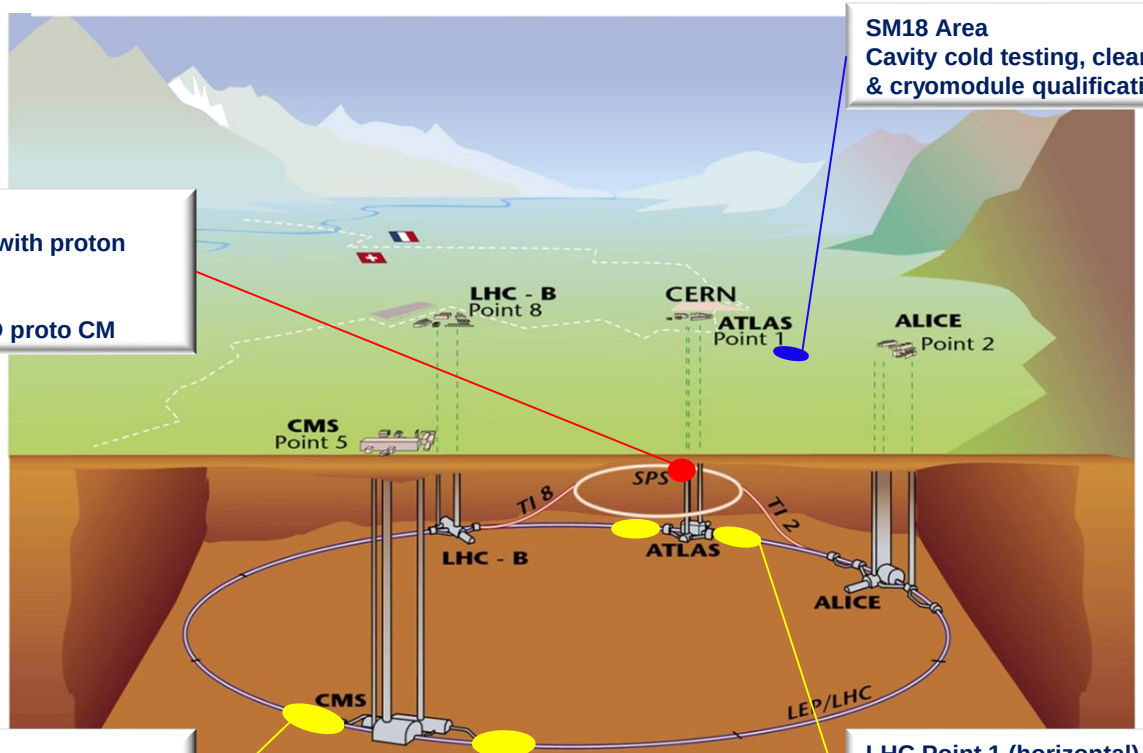


CERN locations

SM18 Area
Cavity cold testing, clean room facilities & cryomodule qualification

SPS BA6
Test Prototype Modules with proton beam

1 DQW proto CM + 1 RFD proto CM



LHC Point 5 (vertical)
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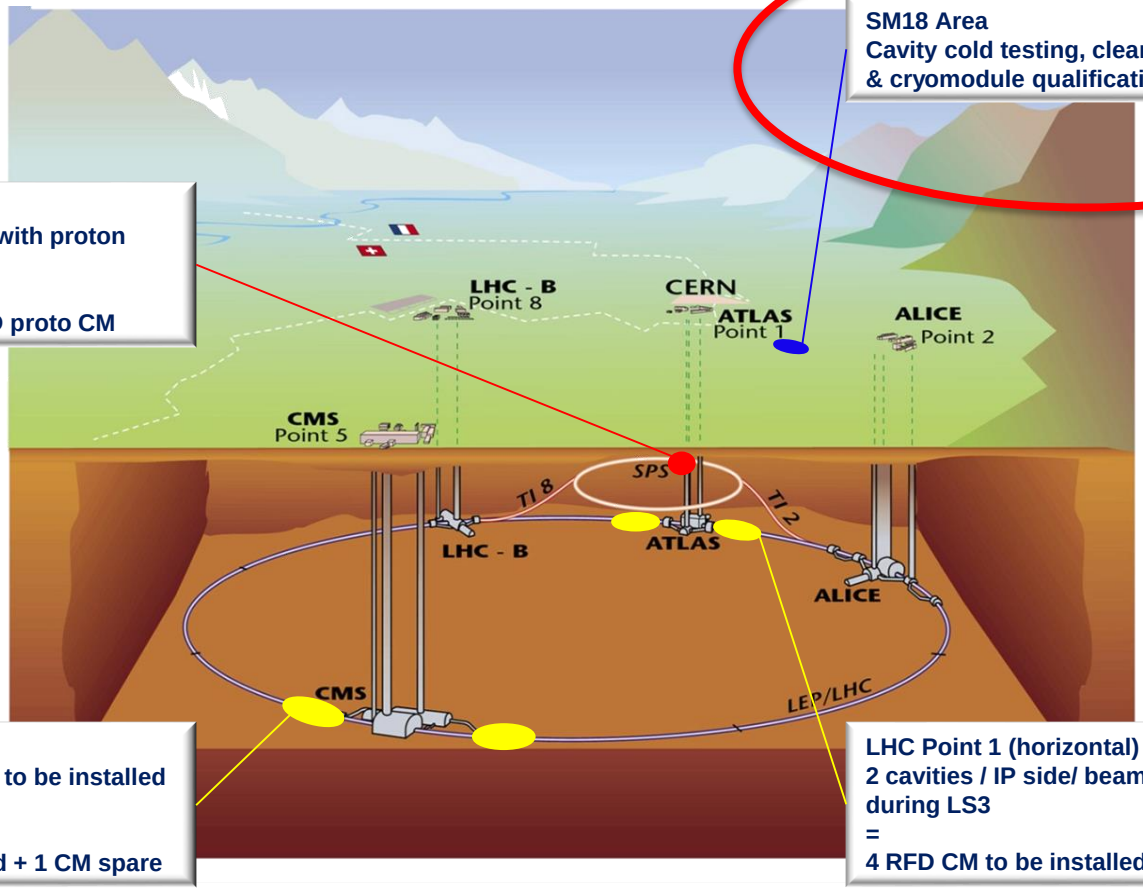

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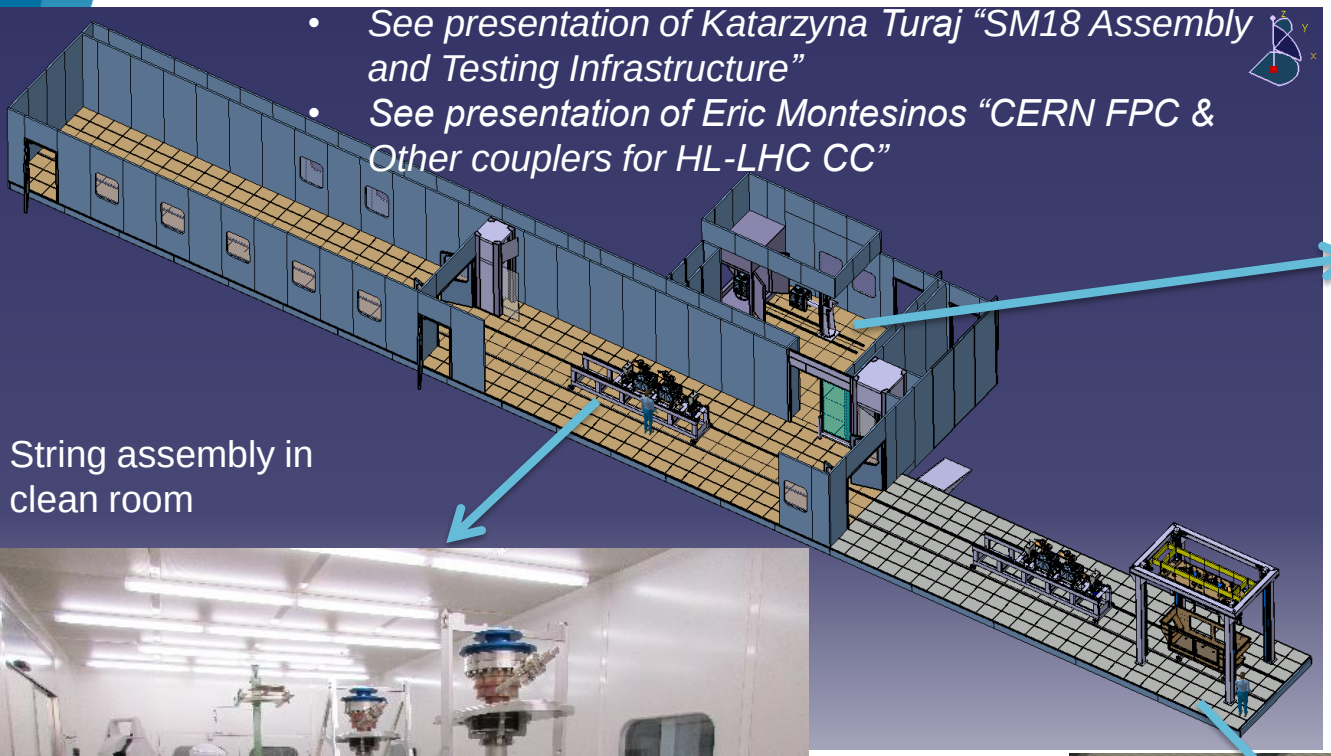
SM18 – vertical cold test of cavities

See presentation of Katarzyna Turaj
"SM18 Assembly and Testing Infrastructure"

SM18 – CM assembly zone

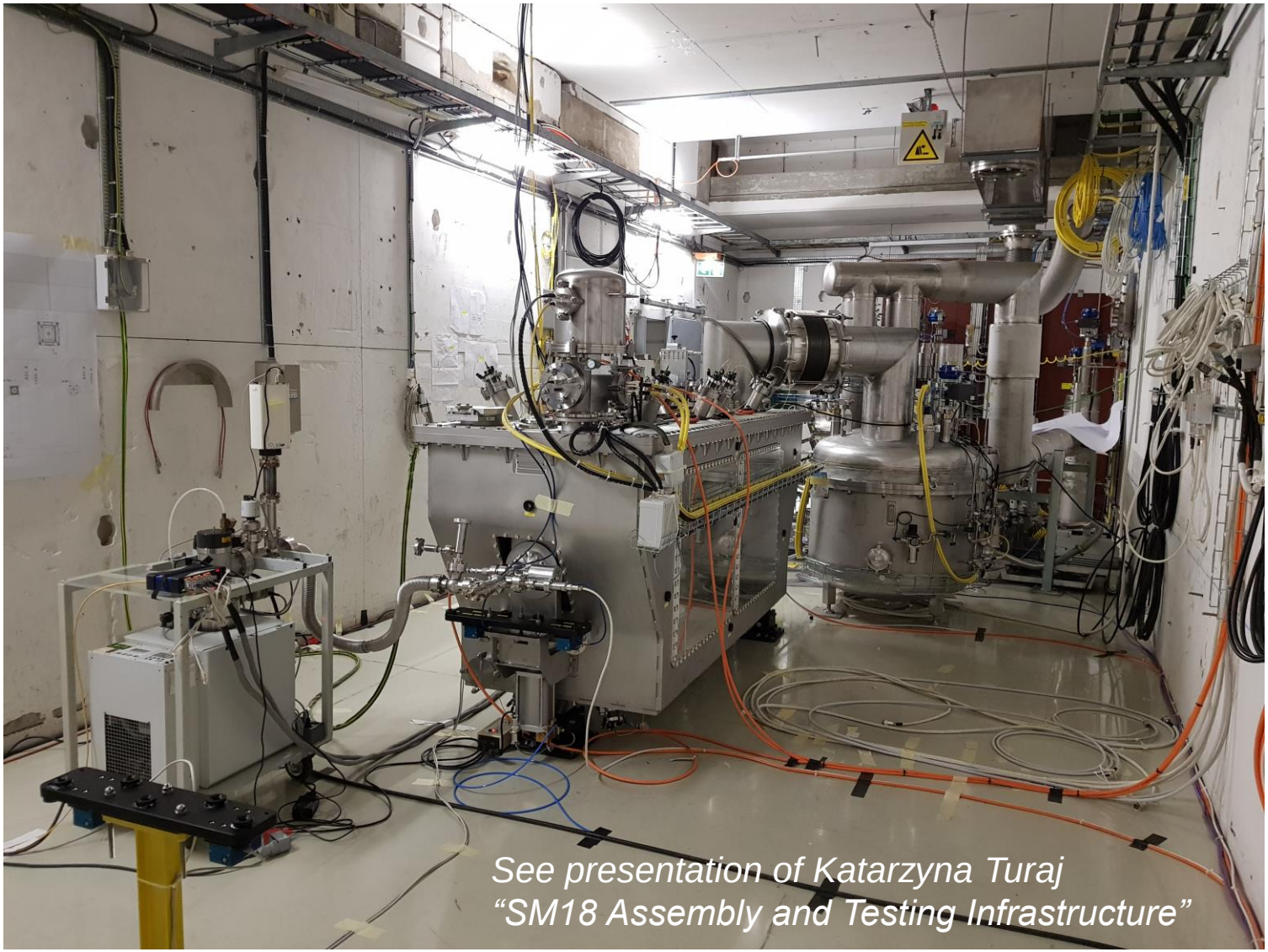
- *See presentation of Katarzyna Turaj "SM18 Assembly and Testing Infrastructure"*
- *See presentation of Eric Montesinos "CERN FPC & Other couplers for HL-LHC CC"*



String assembly in clean room

Assembly outside clean room

SM18 – bunker for CM cold test



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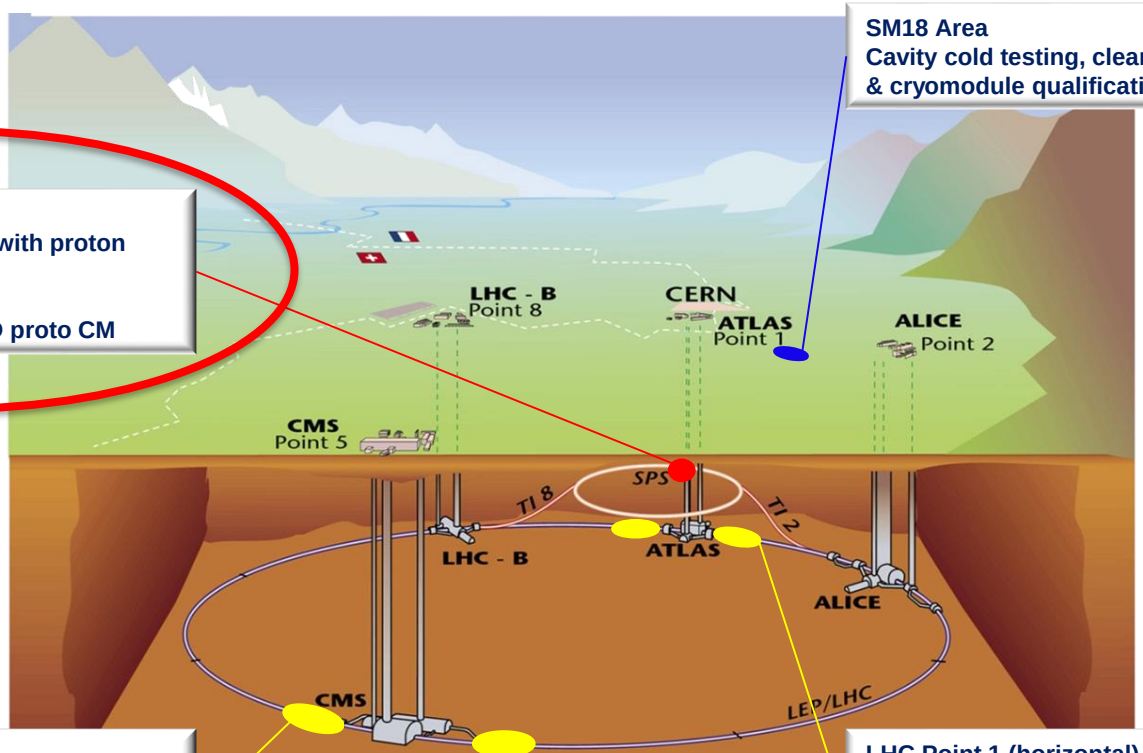

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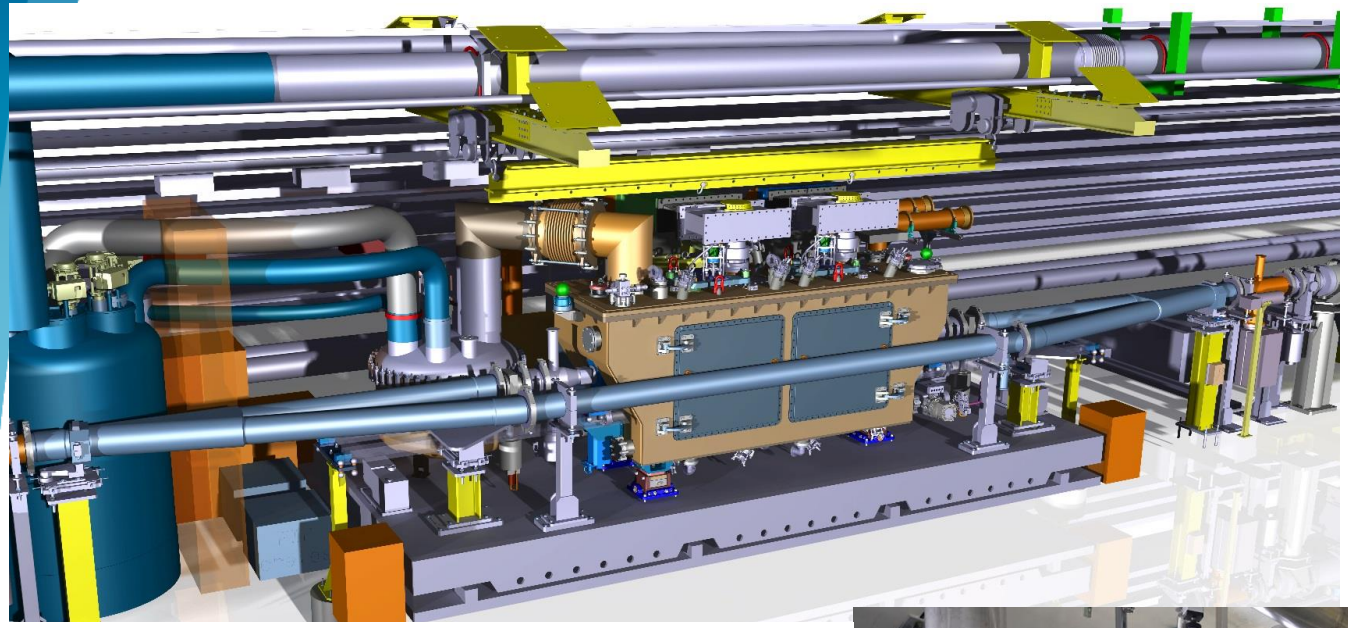

See presentation of Giovanna Vandoni
"WP4 Strategy for Integration & Services (SPS-BA6 & Interfaces)"

See presentation of Eric Montesinos
"WP4 Strategy for RF System"

See presentation of Krzysztof Brodzinski
"Cryogenics Experience from SPS"

See presentation of Chiara Pasquino
"Vacuum layout & experience from SPS"

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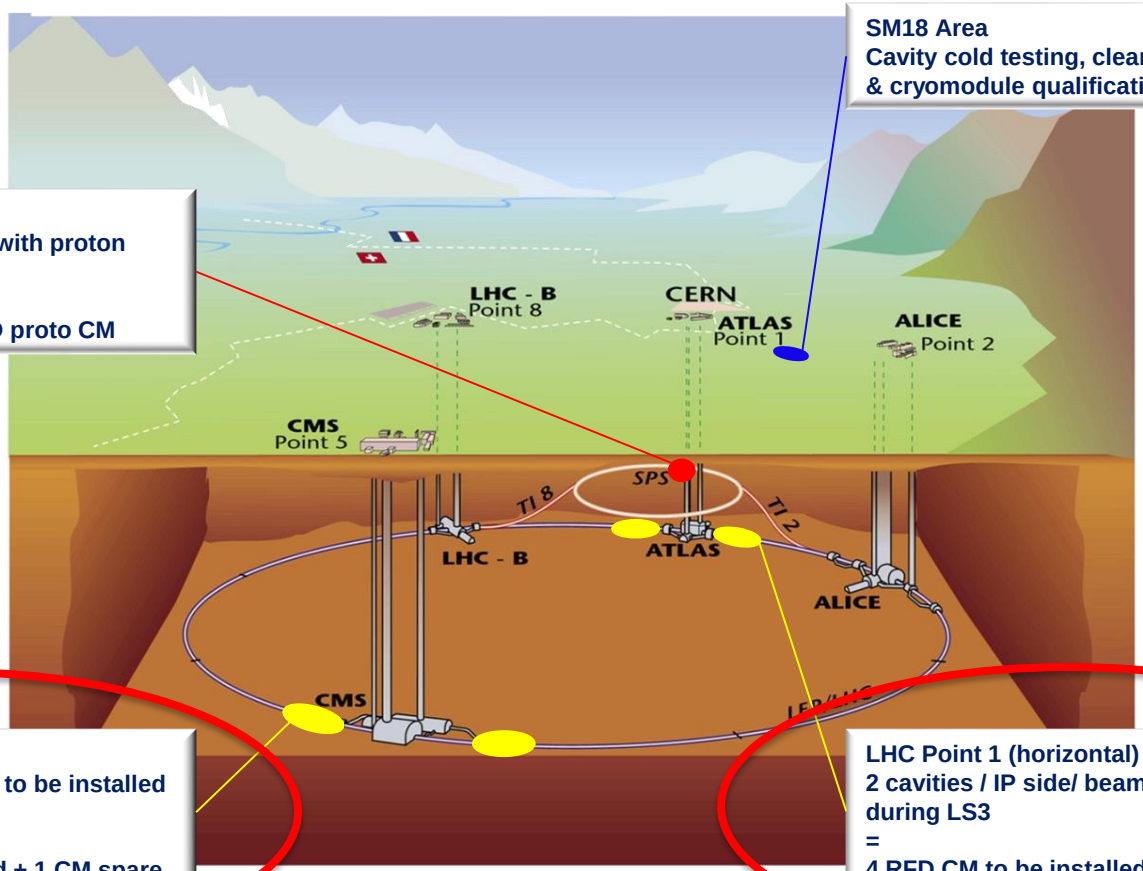

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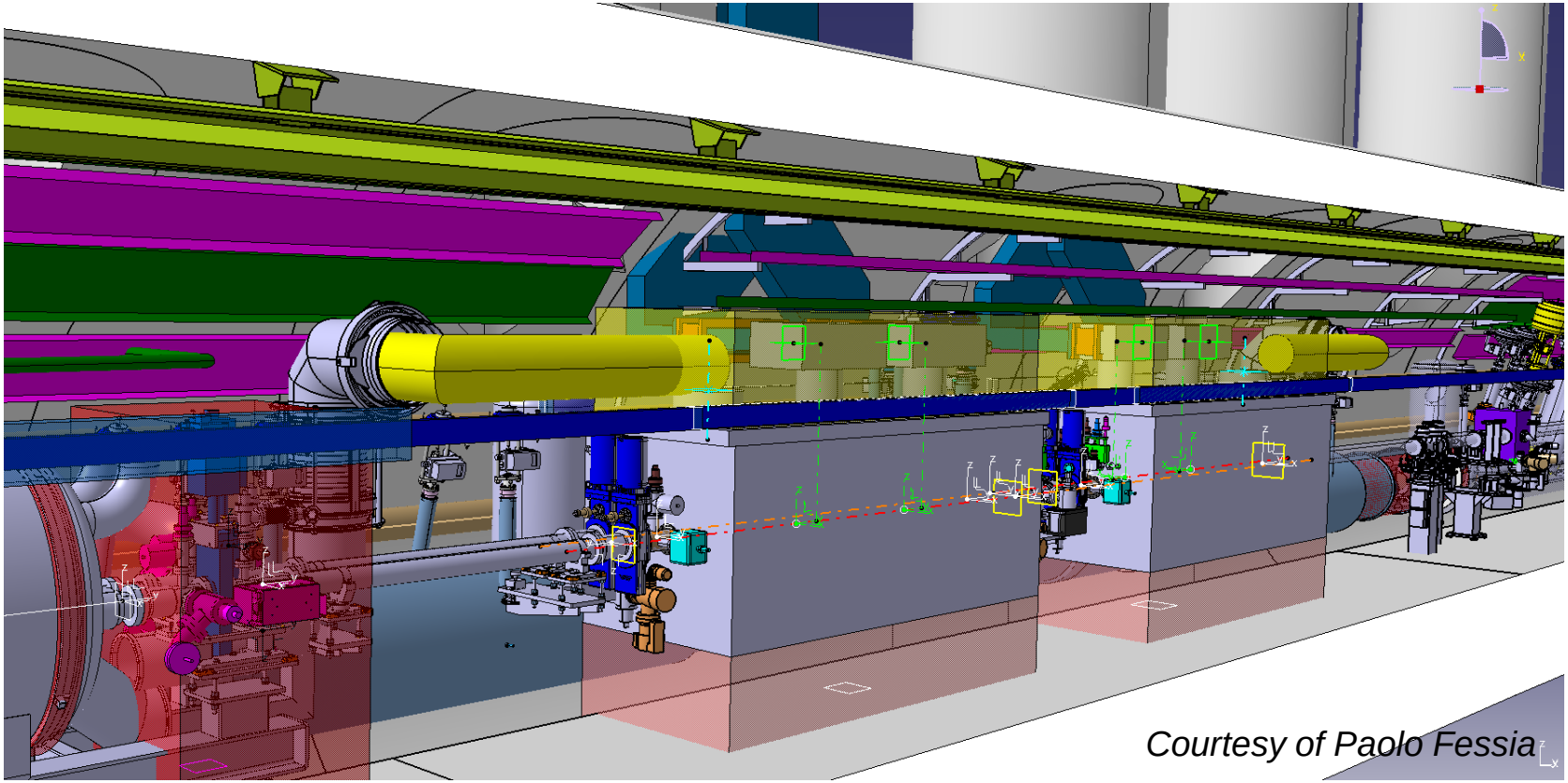
R571



See presentation of Paolo Fessia "LHC Environment Constraints & Integration"

See presentation of Krzysztof Brodzinski "Cryogenics for HL-LHC CC including sectorization"

See presentation of Germana Riddone "Vacuum for HL-LHC CC"

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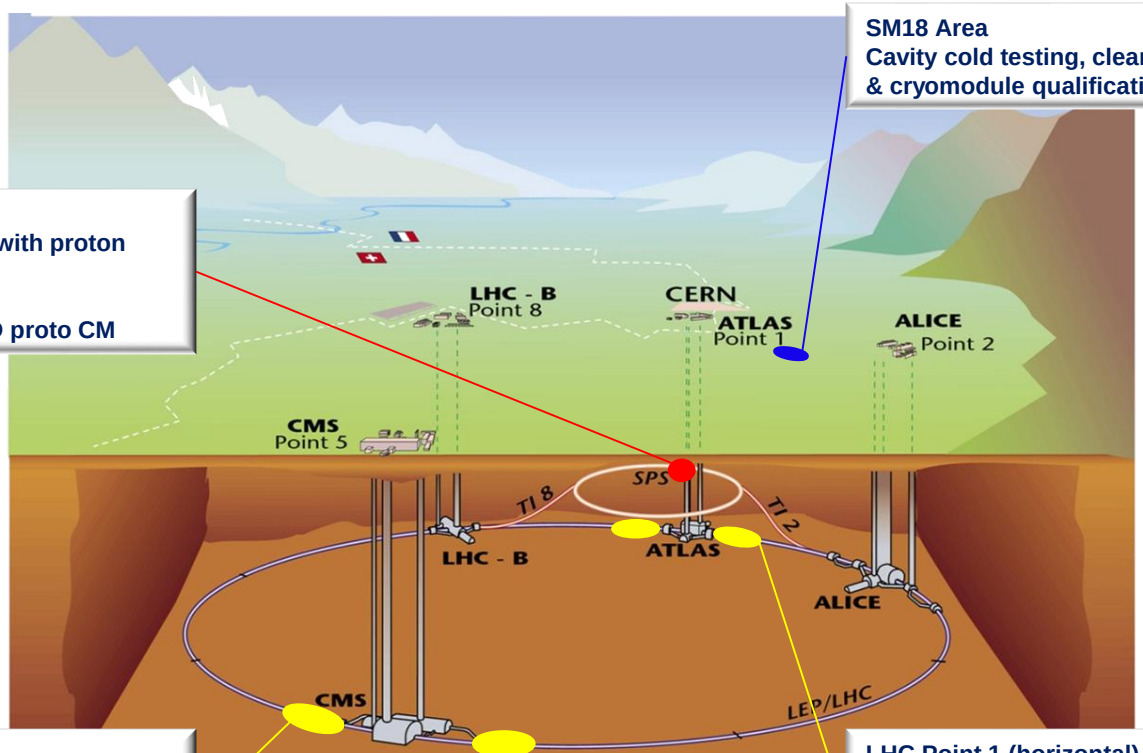

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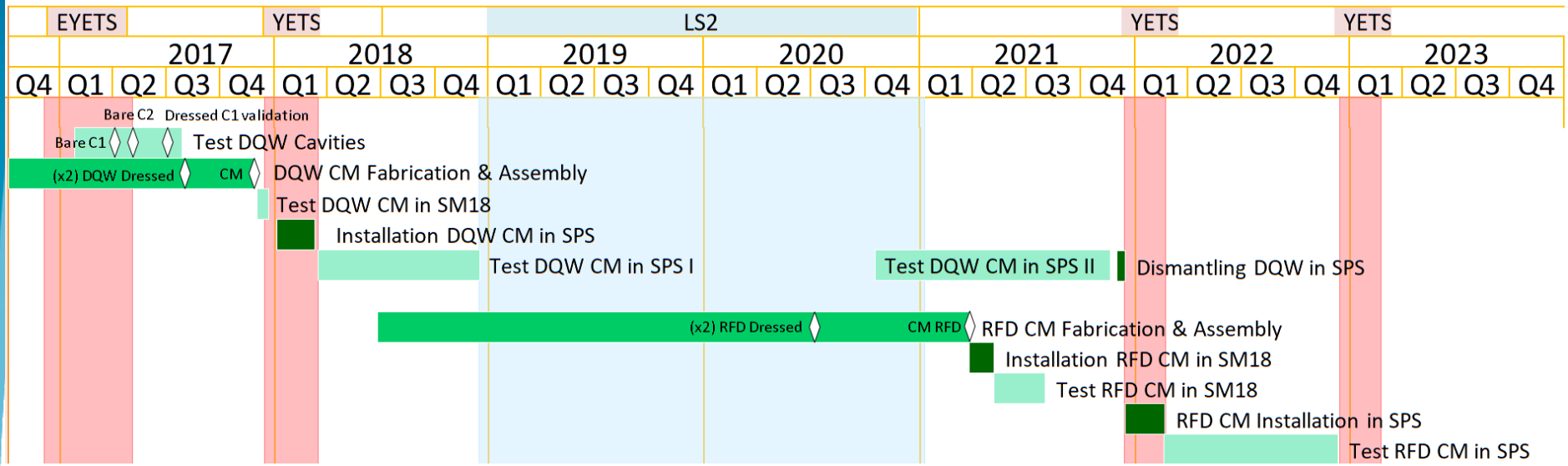
“Akira’s table”

	SPS		HL-LHC	
Type	DQW	RFD	DQW	RFD
Cavities from	CERN	CERN	RI (CERN contract)	ZANON (US-AUP contract)
Cryomodule from	CERN	UK (under UK1)	1 x CERN (first) 4 x UK (under UK2)	5 x TRIUMF

SPS cryomodules

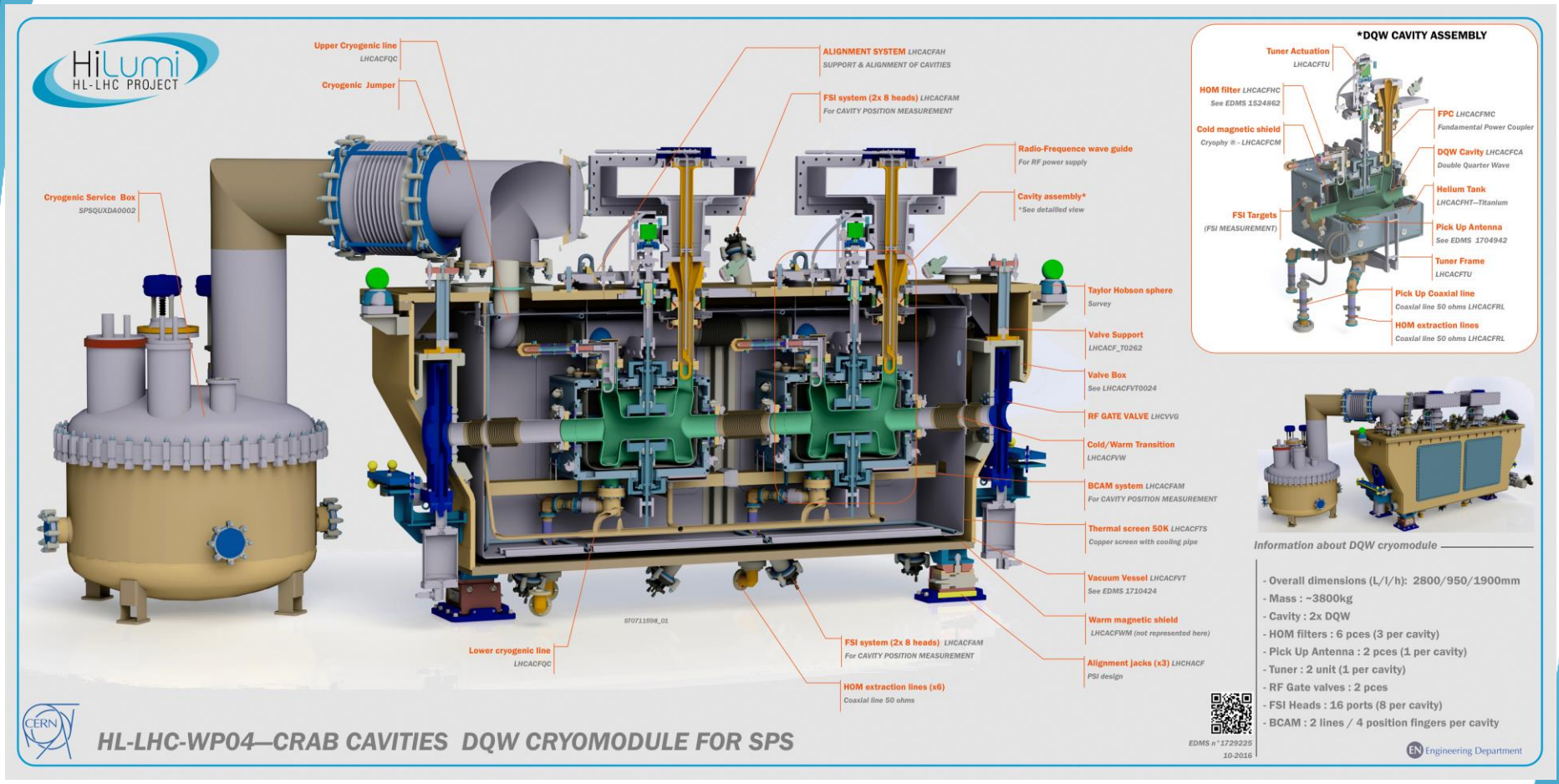
Courtesy of Marta Alcaide



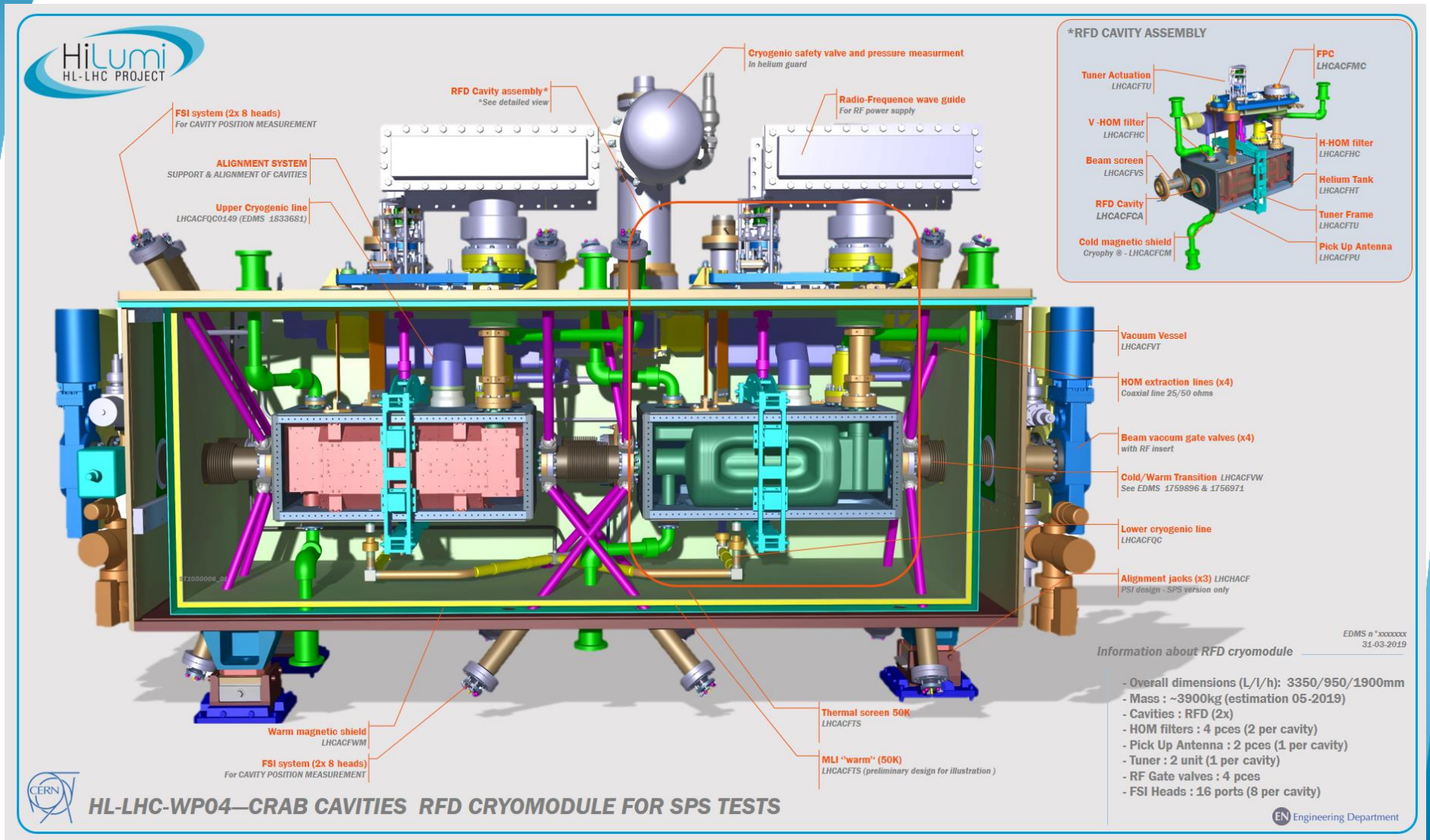
- 1 DQW cryomodule for SPS (done)
  - Design **CERN + UK + USLARP** coherent with LHC but without some components (second beam pipe, …)
  - Cavities + helium vessel + processing + ancillaries + cold test by **CERN**
  - Cold magnetic shield by **UK**
  - CM by **CERN**
  - CM cold test in SM18 prior install in SPS
  - Tested in SPS in 2018 and 2021

- 1 RFD cryomodule for SPS (ongoing)
  - Design as LHC prototype **CERN + UK + USLARP/AUP**
  - Cavities + helium vessel + processing + ancillaries + cold test by **CERN**
  - Cold magnetic shield by **UK**
  - CM by **UK** with some components by **CERN** (thermal shield, RF internal lines, beam screen, part of alignment and instrumentation, …)
  - CM cold test in SM18 in 2021
  - Test in SPS starting in 2022

DQW Cryomodule for SPS



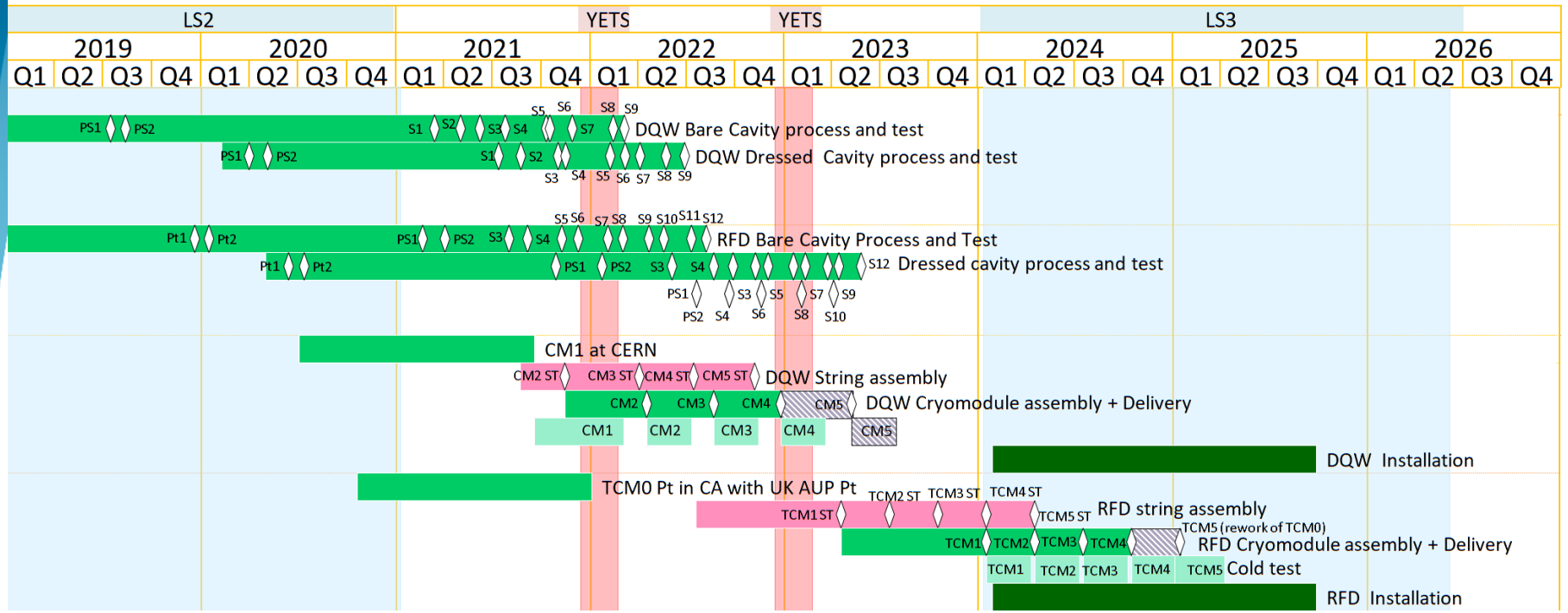
RFD Cryomodule for SPS (LHC prototype)



See presentation of Teddy Capelli "HL-LHC CC Cryomodule Design"

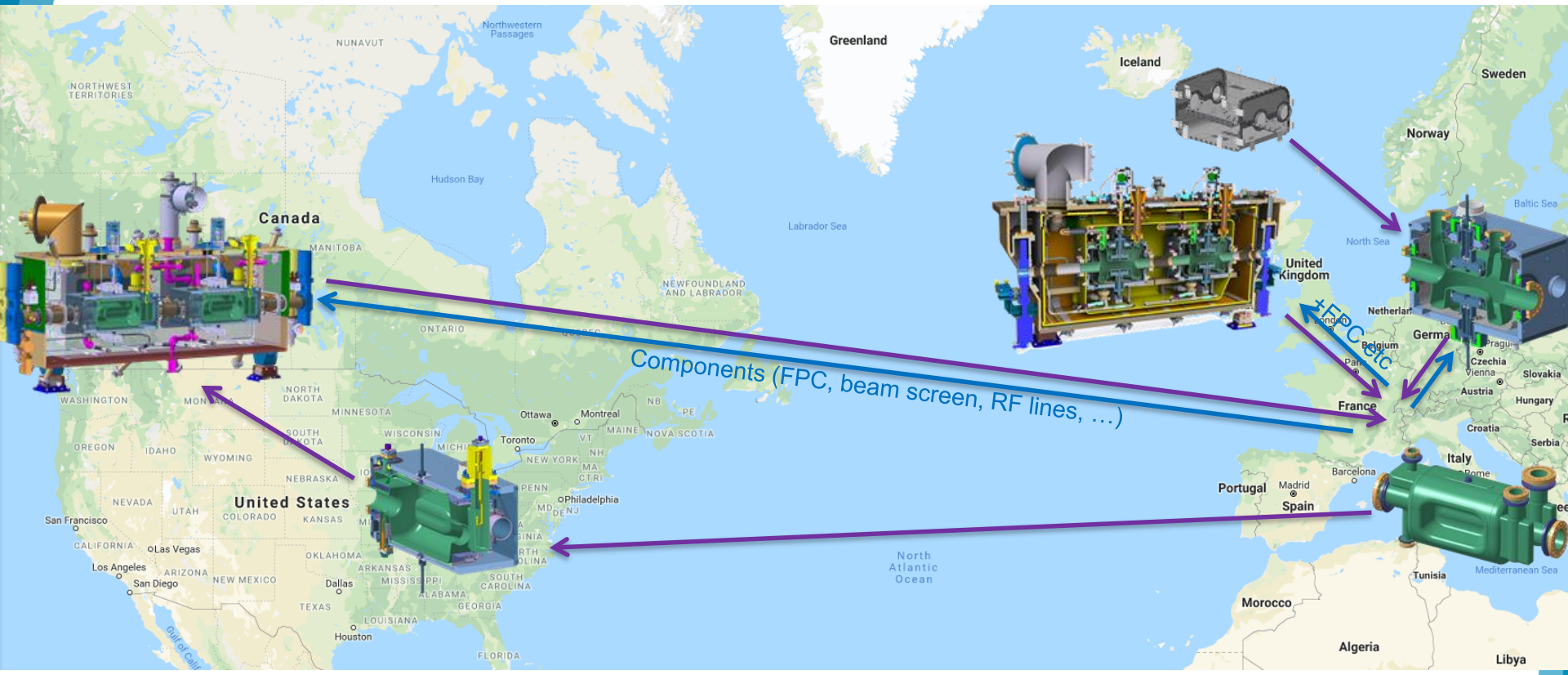
Series cryomodules

Courtesy of Marta Alcaide



- DQW cryomodules (4 + 1 spare) for LHC
  - Cavities + processing + helium vessels by Research Instruments (**DE**) under **CERN** contract
  - Cold magnetic shields by **UK**
  - HOM couplers + antennas + FPC by **CERN**
  - 1 CM by **CERN**
  - 4 CM by **UK** (STFC) with some components by **CERN** (beam screens, RF internal line, part of instrumentation and alignment…)
  - CM cold validation tests in **UK** (to what extend TBC)
  - All cavities & CM cold validation tests at **CERN**
- RFD cryomodules (4 + 1 spare) for LHC
  - Bare cavities by Zanon (**IT**) under **US-AUP** contract
  - Processing + cold magnetic shield + helium vessel + HOM couplers + antennas + cold tests by **US-AUP**
  - FPC by **CERN**
  - 5 CM by **Canada** (Triumf) with some components by **CERN** (TBC beam screens, RF internal lines…)
  - CM cold validation tests in **Canada** (to what extend TBC)
  - CM cold validation tests at **CERN**

Series cryomodules



See presentation of Kurt Artoos and Thomas Jones "Transport Aspects"
See presentation of Luca Dassa "Technical Specifications and Guidelines for Compliance with CERN Safety Rules"
See presentation of Eric Montesinos "CERN FPC & Other couplers for HL-LHC CC"
See presentation of Germana Riddone "Vacuum for HL-LHC CC"

What has been achieved so far

- In the US
  - DQW & RFD Cavities & HOMs prototyping & extensive testing demonstrated achievability of required operating parameters
    - *See presentation of Alessandro Ratti "US contribution to SPS Crab Cavity Prototypes and Lessons Learned"*

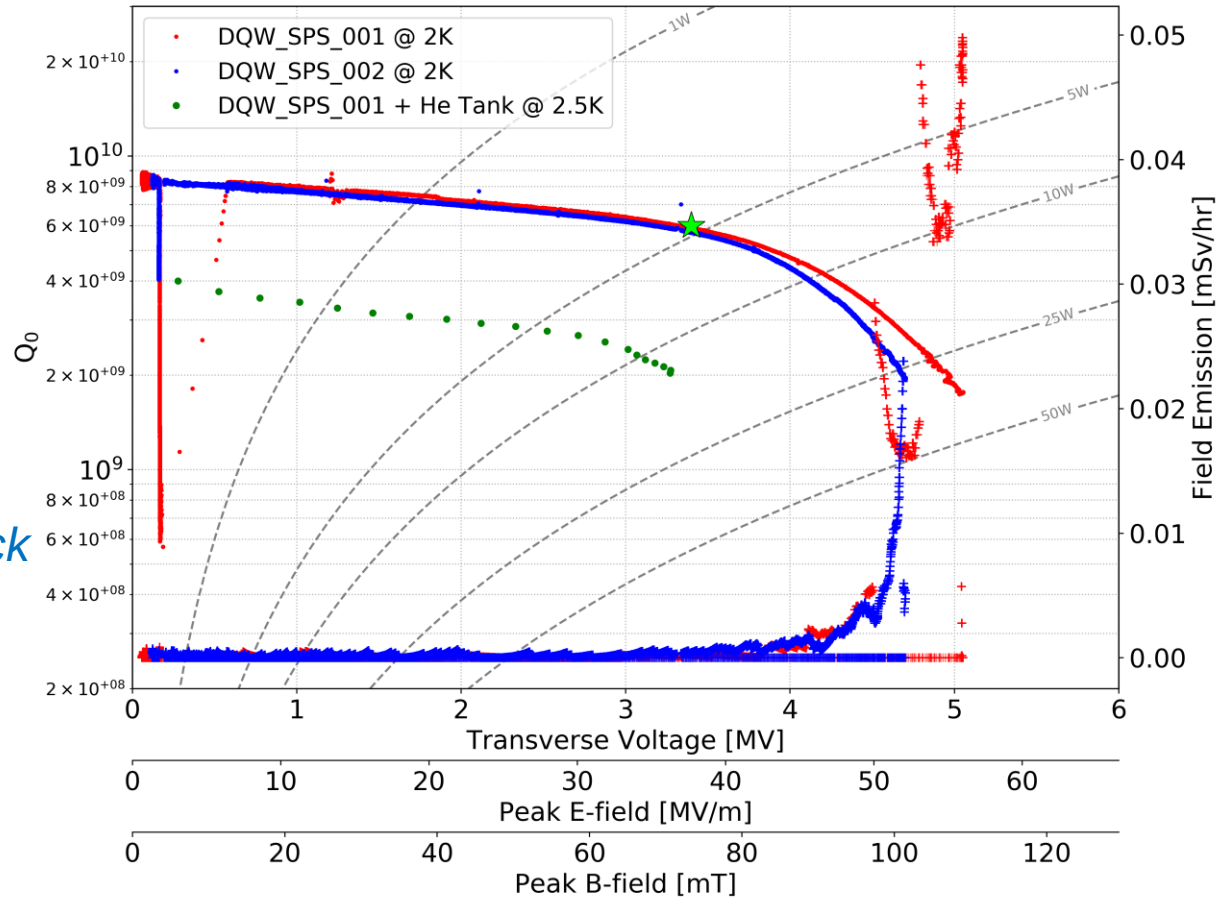
- At CERN (with UK & US contribution)
  - Successful test of individual critical components (FPC, RF internal lines, tuner, helium vessel)

  - Manufacturing of a full DQW cryomodule for SPS tests – from October 2015 to November 2017
    - Very aggressive planning successfully completed with a deviation of 2 days over a total of 25 months
      - 14 months: first bare cavity manufactured (from scratch)
      - + 1 month: second bare cavity manufactured
      - + 5 months: processing + dressing + cold test 2 bare cavities + cold test 1 dress cavity
      - + 5 months: clean room string assembly + outside clean room assembly of cryomodule ready for cold test

    - *See presentation of Marco Garlasche "CERN-Crash Program for SPS-DQW Cryomodule"*

What has been achieved so far

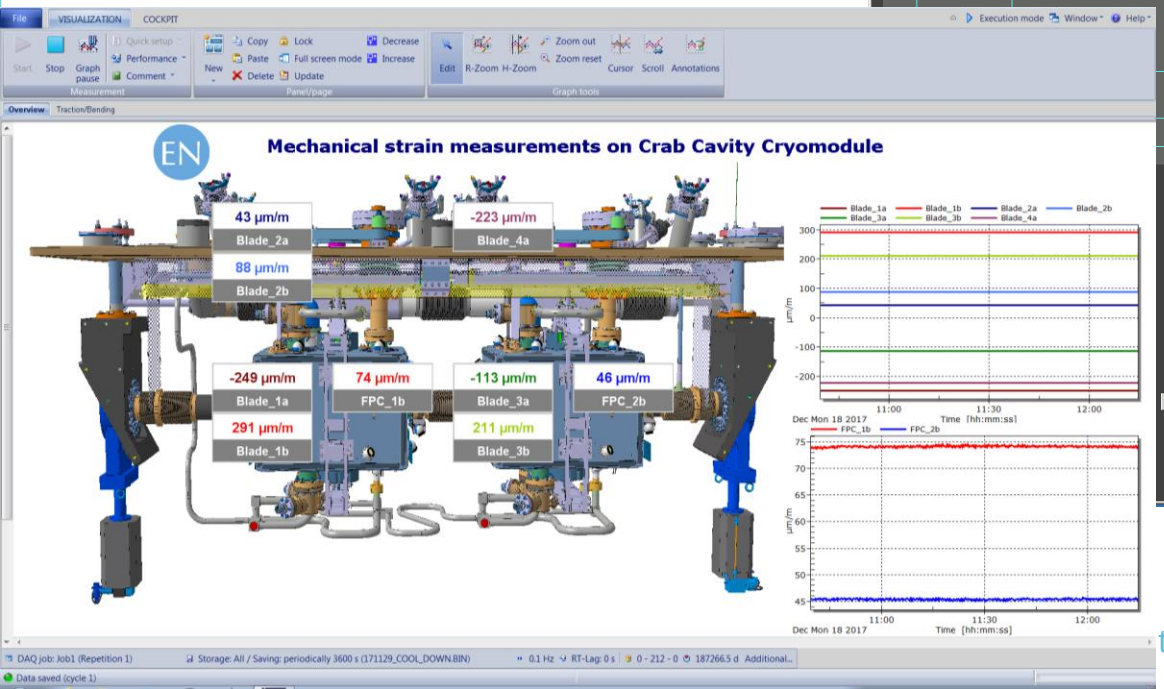
- At CERN (with UK & US contribution)
  - Number of cold test were reduced to a strict minimum to cope with the planning.
    - No time for re-processing of cavities or HOMs
    - Dynamic load of dressed cavities higher than nominal (only first dressed cavity tested)

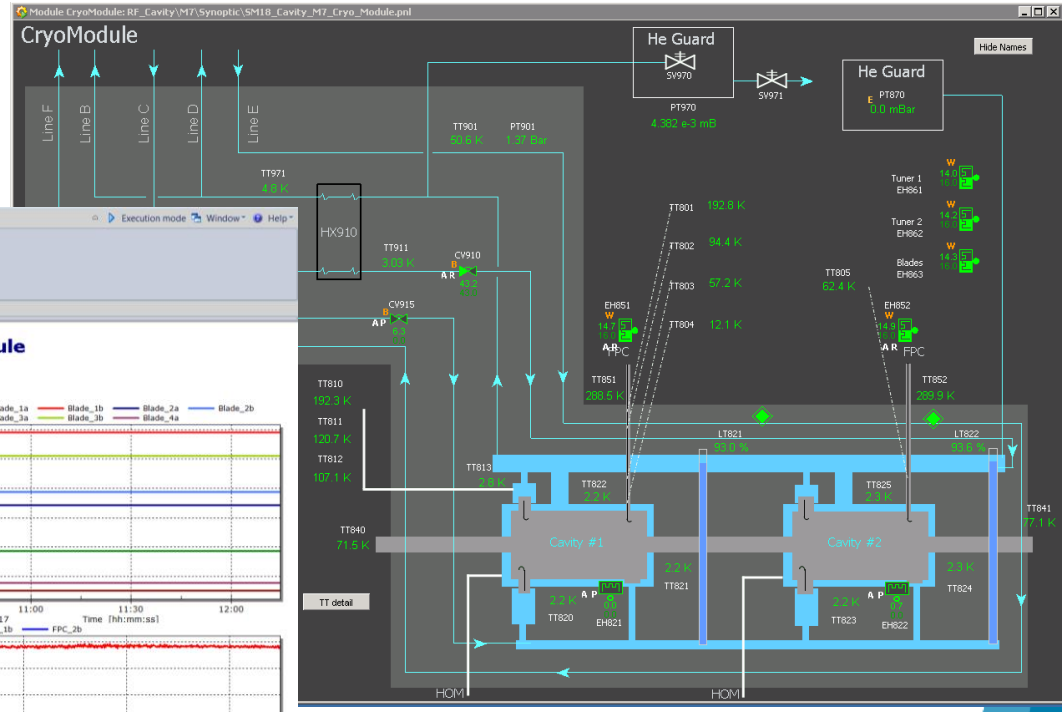


Courtesy of Alick Macpherson

What has been achieved so far

- At CERN (with UK & US contribution)
  - The DQW SPS cryomodule has been successfully tested at cold in SM18 and operated during one year in the SPS up to 2/3 of the nominal voltage in the cavities (*see presentation of Rama "SPS-CC experiments and operation Challenges/Limitations & Outlook for 2021"*). These achievements validated the main cryomodule concepts, in particular:
    - Mechanical behaviour during thermal cycles has been monitored and validated as expected





Courtesy of TE-CRG

What has been achieved so far

- Cryomodule thermal behaviour
  - Measured static loads in perfect agreement with estimated values.
  - Dynamic loads assessment (measurement vs calculations) only preliminary values, measurements need further RF operation in stable conditions.
- *See presentation of Krzysztof Brodzinski "Cryogenics Experience from SPS"*

- Tuning system operated to tune both cavities for the entire SPS frequency range
- *Presentation of Kurt Artoos "Freq Tuning System & Lessons learned"*

- Alignment performed very well
- *See presentation of Mateusz Sosin "Alignment & Monitoring from SPS to HL-LHC"*

- Static beam vacuum levels, and insulation vacuum level as foreseen
- *See presentation of Chiara Pasquino "Vacuum layout & experience from SPS"*

- QA, QC & documentation
- *See presentation of Hector Garcia Gavela "WP4 QA & QC Status, Risks & Documentation"*

- Also, several small issues were identified and addressed for the improvement of the next cryomodule generation

What's next

- Finalise the RFD SPS cryomodule and implement the strategy for the production of series cryomodules, in the frame of the international collaborations foreseen
  - Collaboration agreements already signed:
    - CERN – UK (so-called UK1) for the production of 1 SPS RFD cryomodule at STFC Daresbury with cavities and other components provided by CERN
    - *See presentation of Marco Garlasche "CERN RFD-SPS Cavity Manufacturing Status"*
    - *See presentation of Eric Montesinos "CERN FPCs & Other Couplers for HL-LHC CC"*
    - *See presentation of Teddy Capelli "HL-LHC CC Cryomodule Design"*
    - *See presentation of Thomas Jones "SPS-RFD & Series DQW Cryostating Plans"*
    - CERN – US AUP for the in-kind contribution of fully dressed series RFD cavities
    - *See presentation of Leonardo Ristori "US-AUP RFD Dressed Cavities for HL-LHC CC"*
  - Collaboration agreements under preparation:
    - CERN – UK (so-called UK2) for the production of 4 DQW series cryomodules, with cavities and other components provided by CERN
    - *See presentation of Nuria Valverde "CERN/RI DQW-Series Cavities for HL-LHC CC"*
    - *See presentation of Thomas Jones "SPS-RFD & Series DQW Cryostating Plans"*
    - CERN – Triumf for the for the production of 5 RFD series cryomodules
    - *See presentation of Robert Laxdal "Series RFD Cryostating for HL-LHC CC"*

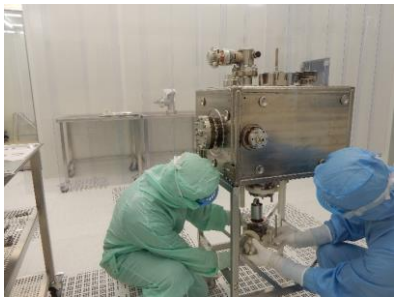
Summary

- SPS
  - DQW SPS cryomodule
    - First crab cryomodule manufactured from scratch and successfully operated during one year in the SPS - big achievement considering the important number of newly developed complex components and no time contingency
    - Tests in SPS with beam triggered cavities modifications, and some other components design modifications for next generation
  - RFD SPS cryomodule
    - Cavities manufacturing at CERN well advanced, on track for delivery to UK by mid-2020 in the frame of UK1
    - Cryomodule design update well advanced, fully compatible with the LHC
- Cavities and cryomodule series production
  - DQW and RFD (US-AUP) cavities production launched (RI and Zanon) including cavities modifications.
  - Strategy defined for the production of series cryomodules in the frame of the collaboration with Canada, UK and US
    - Canada and UK2 collaboration agreements to be finalized
    - Includes manufacturing at CERN of critical components as well as the first series cryomodule
  - CERN has manufactured both types of cavities, and it is able now to ensure a backup role if needed. The lessons learned from CERN manufacturing are shared with industry and implemented in the industrial production.

Crabs are made by very committed people.
Thanks to all colleagues of the world-wide collaboration !

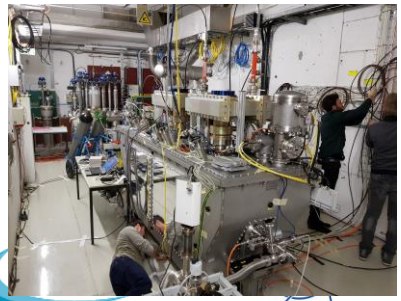
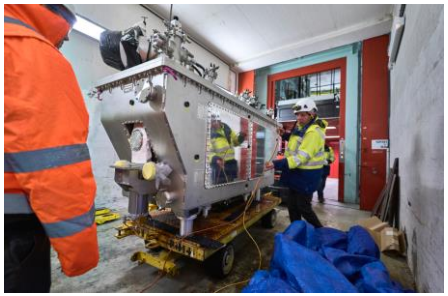








WP4 – Master planning