Crab Cavities: Vacuum Considerations

Vacuum issues for the SPS and LHC crab cavity installations

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Technical Meeting on Vacuum for HL-LHC
5 March 2014

Acknowledgments
Marton Ady, Vincent Baglin, Krzysztof Brodzinski, Rama Calaga, Sergio Calatroni, Ofelia Capatina, Erk Jensen, Phoevos Kardasopoulos, Pierre Maesen, Eric Montesinos, Benoit Salvant.

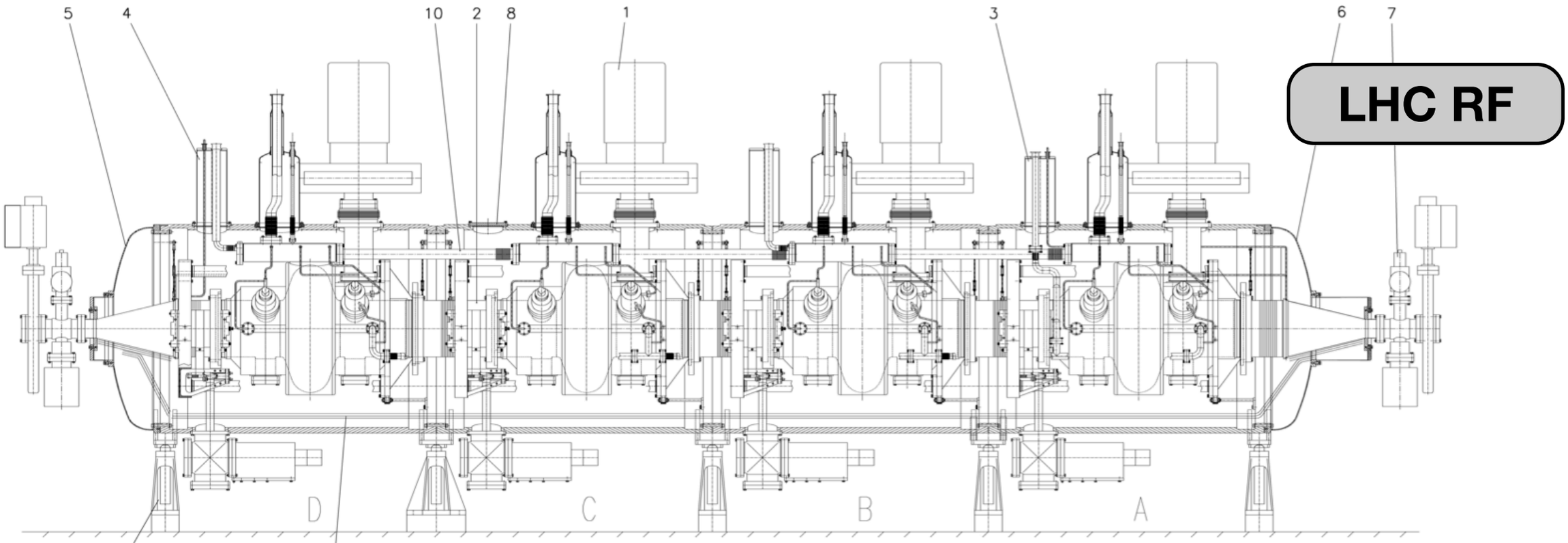
Overview: Why we want good vacuum?

- **What happens if we do not have good cavity vacuum**
  - **Fast vacuum trips due to hydrogen monolayers on cavity surfaces**
    - **Risk**: Reduced crabbing strength, increased power dissipation on cavity, long term loss of performance
  - **Thermal Loading and Quenches**
    - **Risk**: Quenches => impact on operational efficiency
  - **Excess Field Emission in the cavity**
    - **Risk**: Reduced crabbing strength, localized quench spots

- **What can cause vacuum deterioration in the cavity**
  - **Multipacting - especially around the power coupler**
    - **Risk**: Damage to power coupler, reduced operational efficiency
  - **Activation/creation of defects on cavity surface**

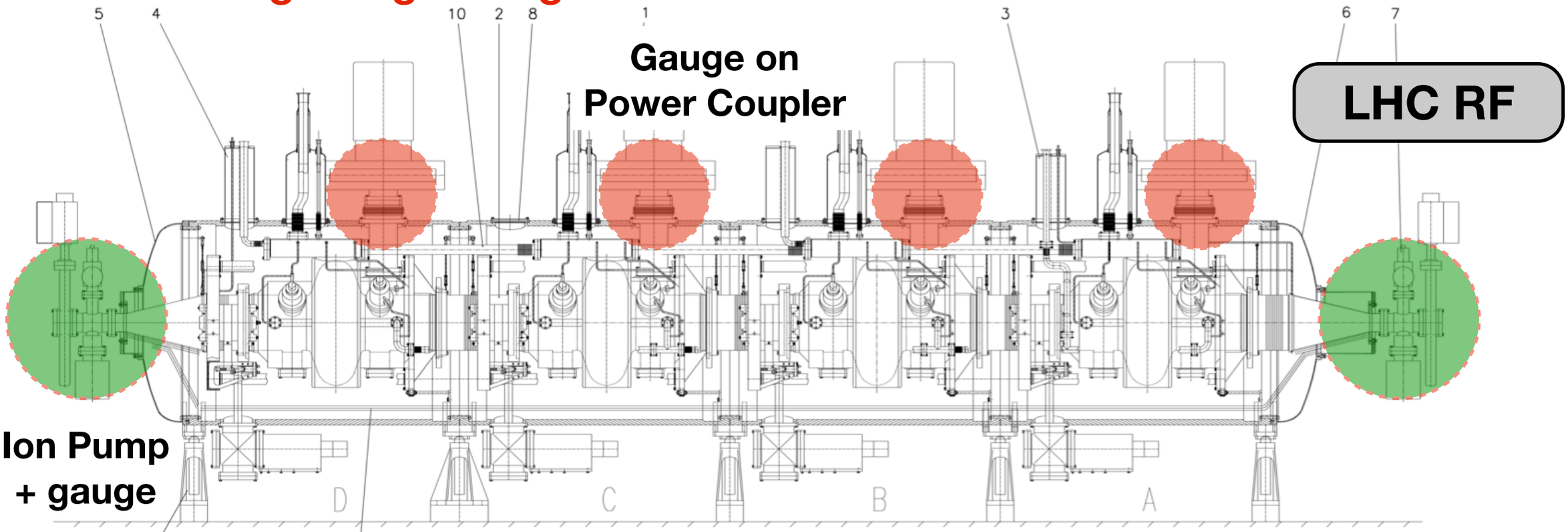
LHC: Example of pressure profile

- **Good vacuum: but sensitive to dust and to venting procedures**



LHC: Example of pressure profile

- **Good vacuum: but sensitive to dust and to venting procedures**
- **Gauges on neighbouring warm sections (NEG coated)**
    - **measures pressure at entrance to cold sections**
- **Cold section => cryo pumping of surroundings onto cavity surfaces**
- **In-situ RF conditioning: expect higher pressures around power couplers**
- **Gauges need same range as beamline gauges**
    - **Penning Gauge Range: 10^{-11} to 10^{-5} mBar**



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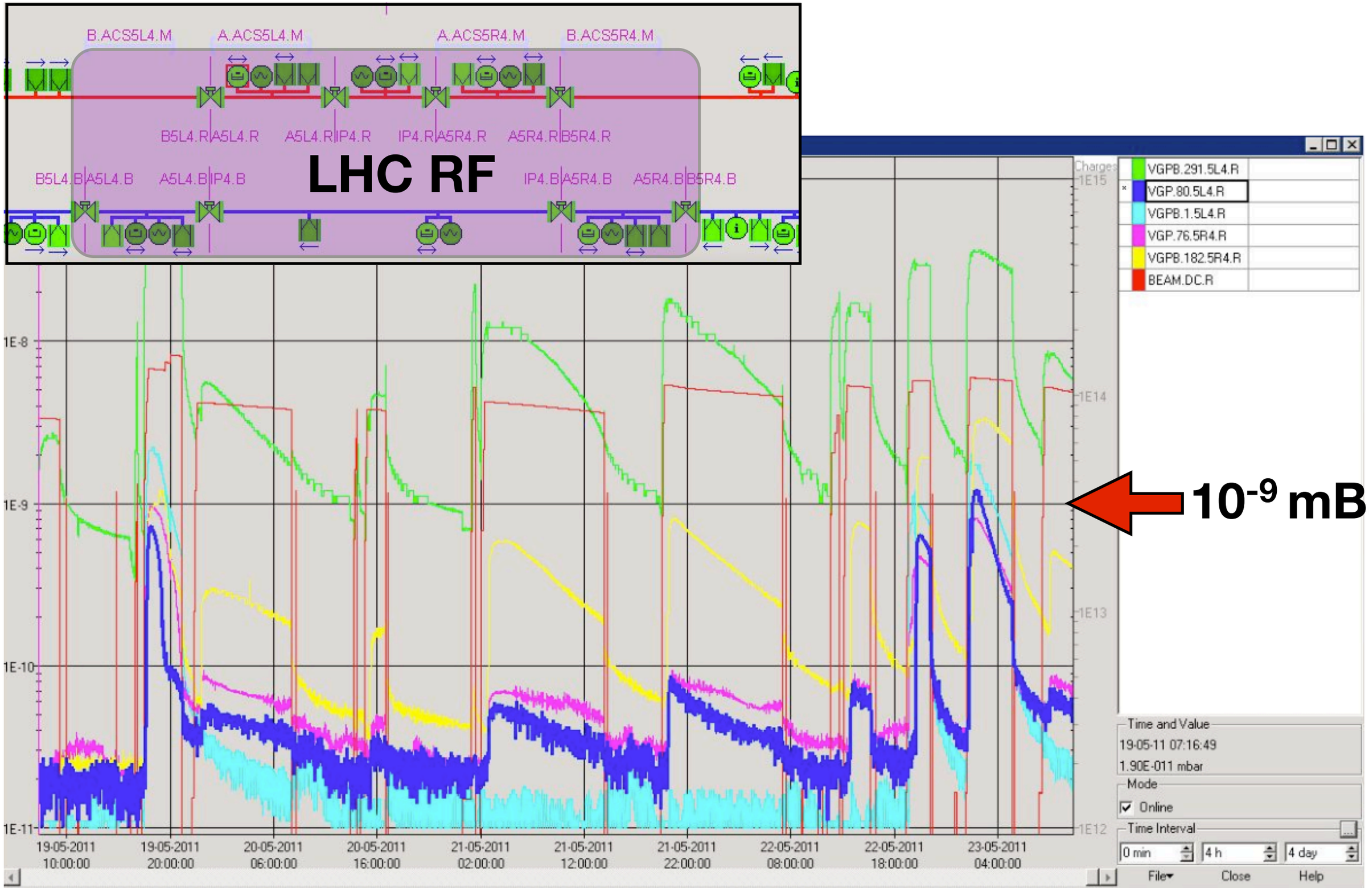

10^{-9} mBar

Overview: Crab cavity vacuum requirements

- **Crab Cavities: Superconducting Niobium Cavities operating at 2 K.**
  - **Primary requirements on the vacuum system**
    - Cavities need to see only the best possible vacuum conditions

=> static machine vacuum < 10^{-11} mBar

=> dynamic beam induced vacuum should be < 10^{-10} mBar

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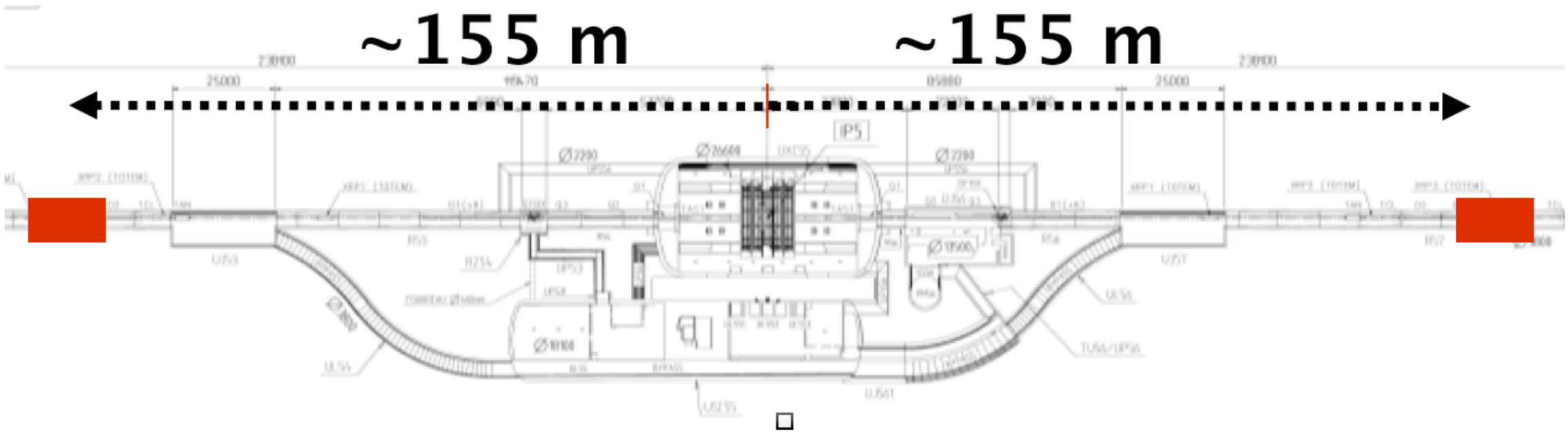
- **HL-LHC**
  - **Installation in LHC LSS1 & LSS5 during LS3**
  - **16 crab cavities per IP (4 per beam per side)**

- **Crab Cavity Validation Run in the SPS**
  - **Install in SPS for operation in 2017 and 2018**
  - **2 crab cavities in one cryo module**
  - **SPS is not baked out => machine vacuum is high vacuum (~10^{-8} mBar)**

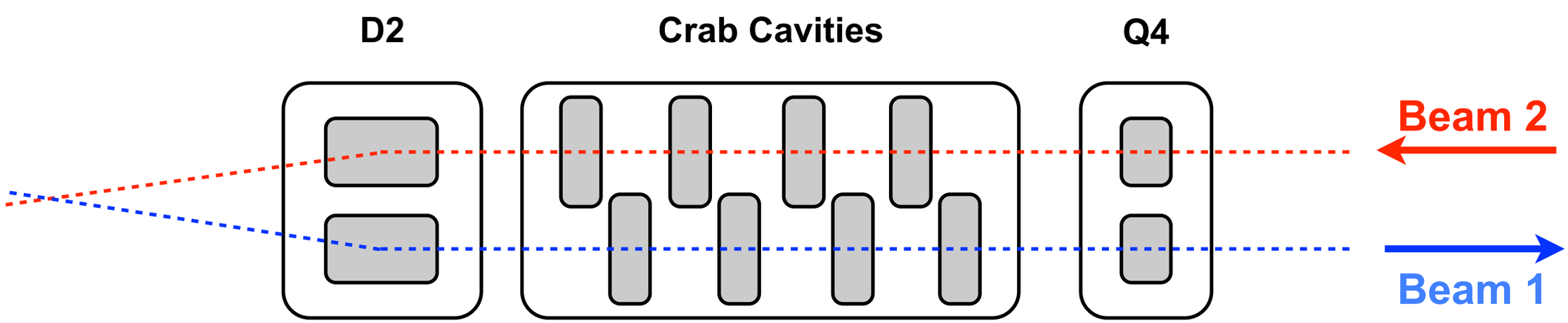
HL-LHC: Vacuum Issues

HL-LHC: Crab Cavity Installation

- **Crab cavity modules installed at ~155 m from IP1 and IP5**



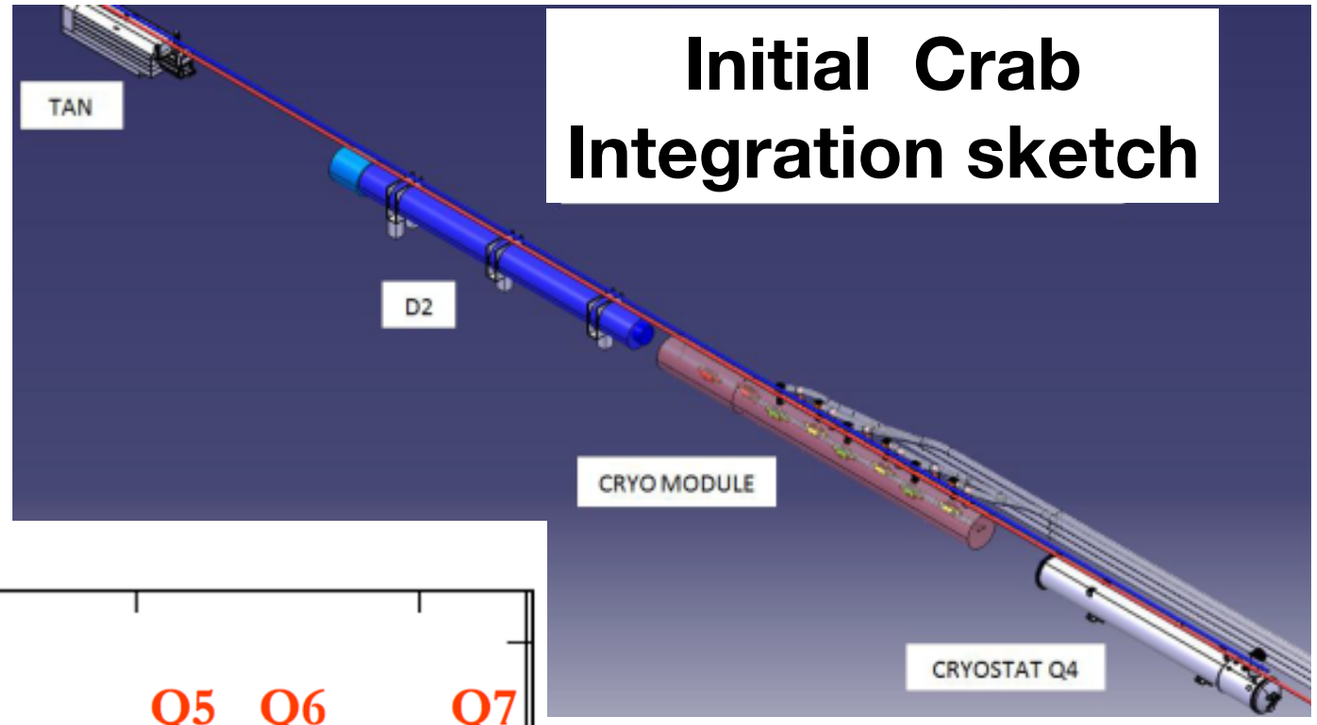
- **Crab Cavity Installation: Between the D2 and the Q4**

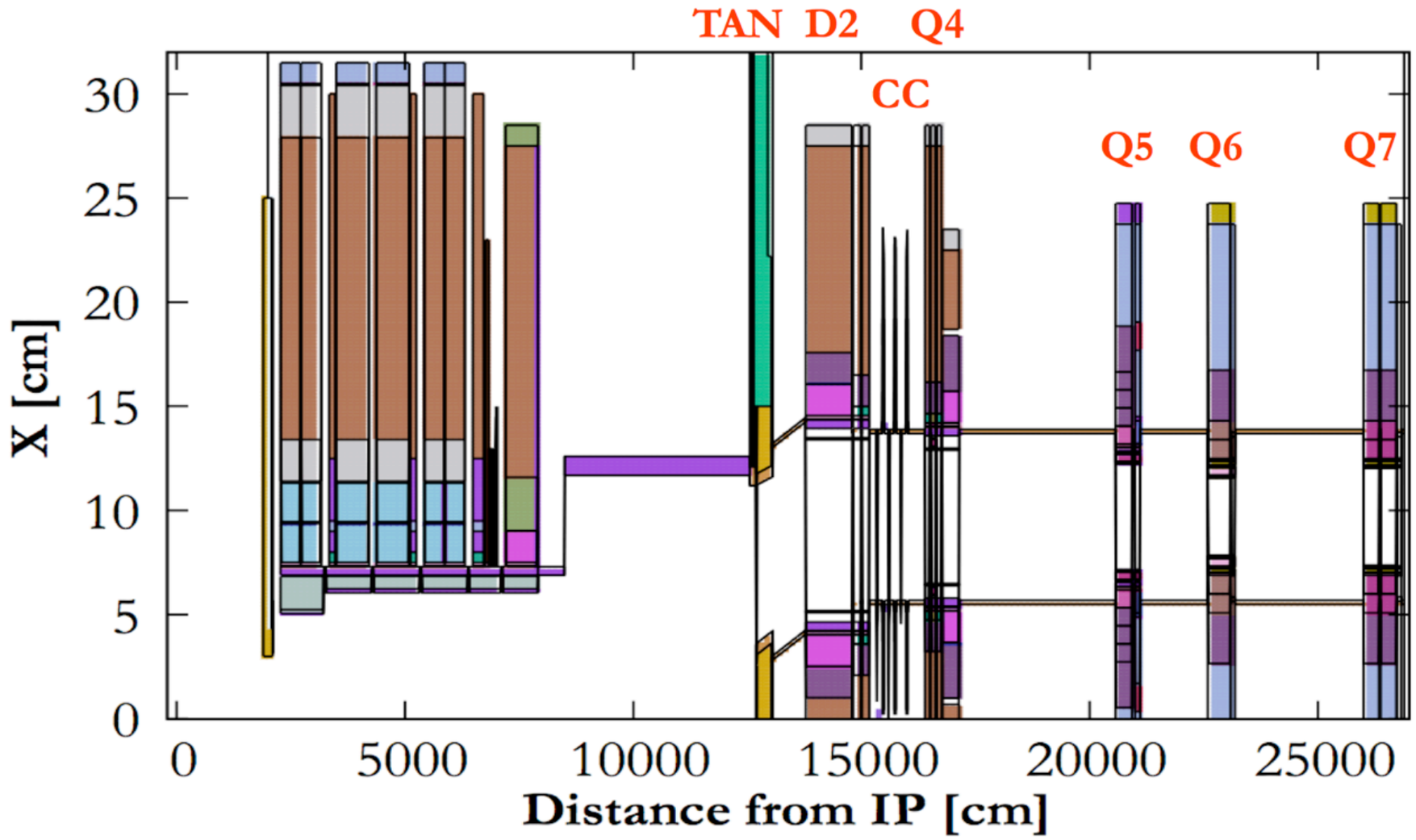


HL-LHC: Crab Cavity Installation

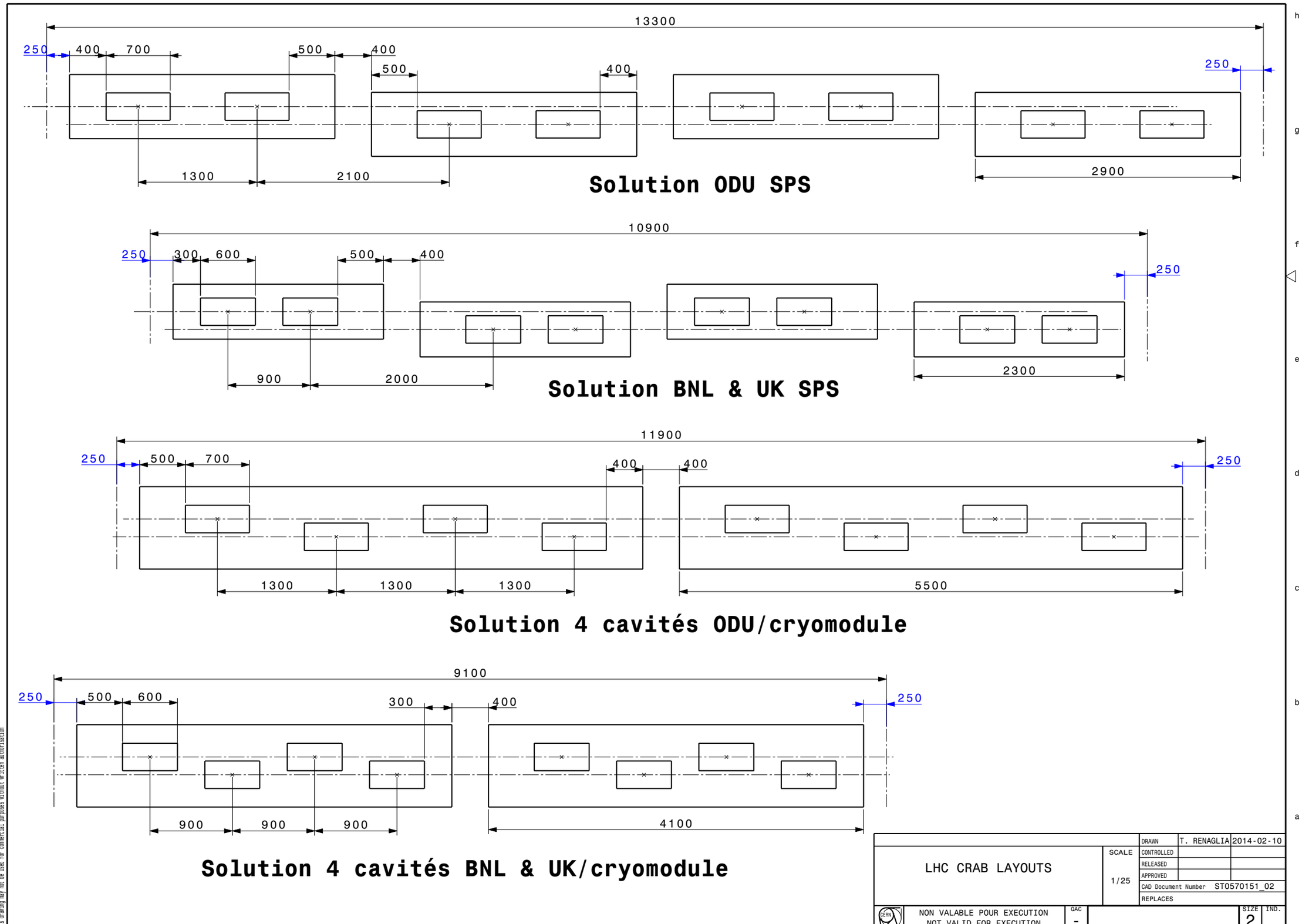
Total length for Crab Cavity Cryomodule string (8 cavities):

= ~13.5 m





HL-LHC: Crab Cavity Layout Possibilities



HL-LHC: Vacuum issues

- **Crab Cavity Cryomodule**
  - **Conceptual Design not yet realized**
    - 1 module (8 cavities) **or** 2 modules (4 cavities each) **or** 4 modules **…**
  - **Modules fully conditioned in SM18 prior to installation in LHC**
    - Requires: all beamline components baked out + (warm) RF conditioning of crabs cavities?

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- **Crab Cavity Installation**
  - **Modules transported and installed under vacuum (P_{Cav} <10^{-7}mBar)**
    - Requires isolation valve on each end of a module
  - **Connection to machine vacuum:**
    - **Crab cavities should not cryo-pump the beam line** => Isolation valves opened **only when cavities cold and machine vacuum at compatible level**
    - Requires ion pump at each end of a crab cavity cryomodule string
      - Add pumps if multi-module string + compatible D2-Q4 space constraints

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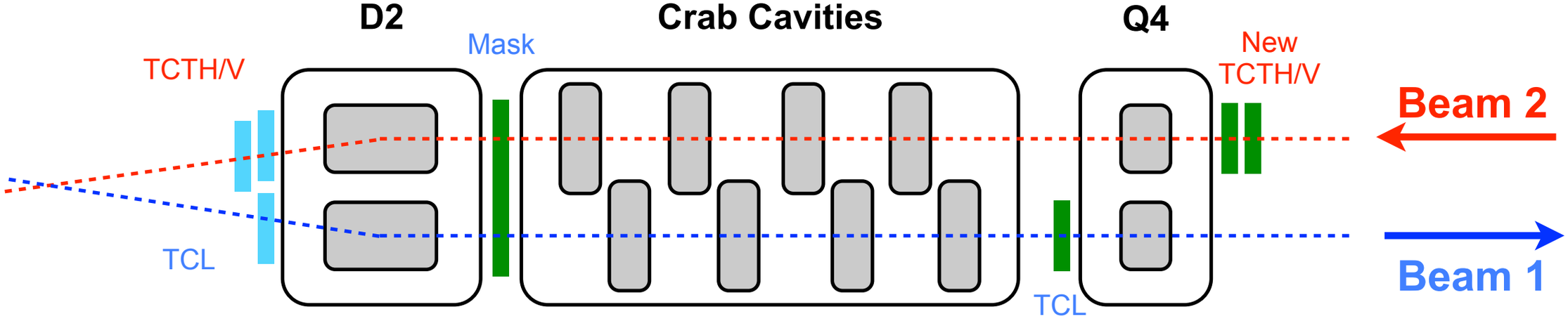
  - **Under study: Addition of TCTs + TCLs + masks at Q4 & D2**
    - **Provides protection but risk pollution into crabs**
      - **NB: no collimator equip around RF at IP4**



Additional debris protection (masks) for crab **Vertical TCL to protect D2** **Additional TCT-like collimators protecting Q4**

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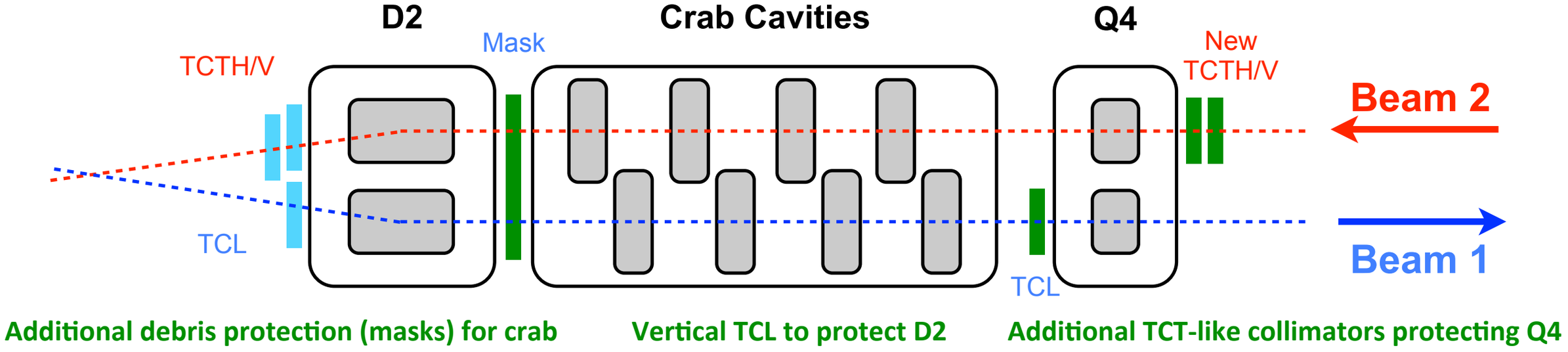

- **Protection of Cavity vacuum:**
  - **Is it assumed fast closing vacuum valves are not accepted for HL-LHC?**
    - Implies interlock cavity operation on neighborhood vacuum level

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  - **Installed in LSS4 of SPS for test in 2017**
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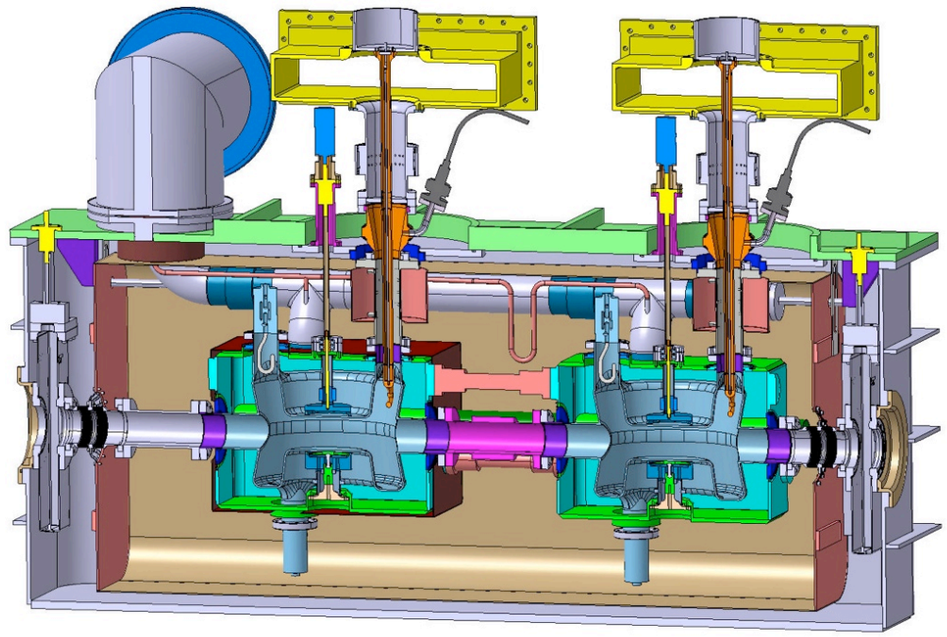
  - **Cavities to be operated at 2K**
  - **Cryomodule ~3m in length**



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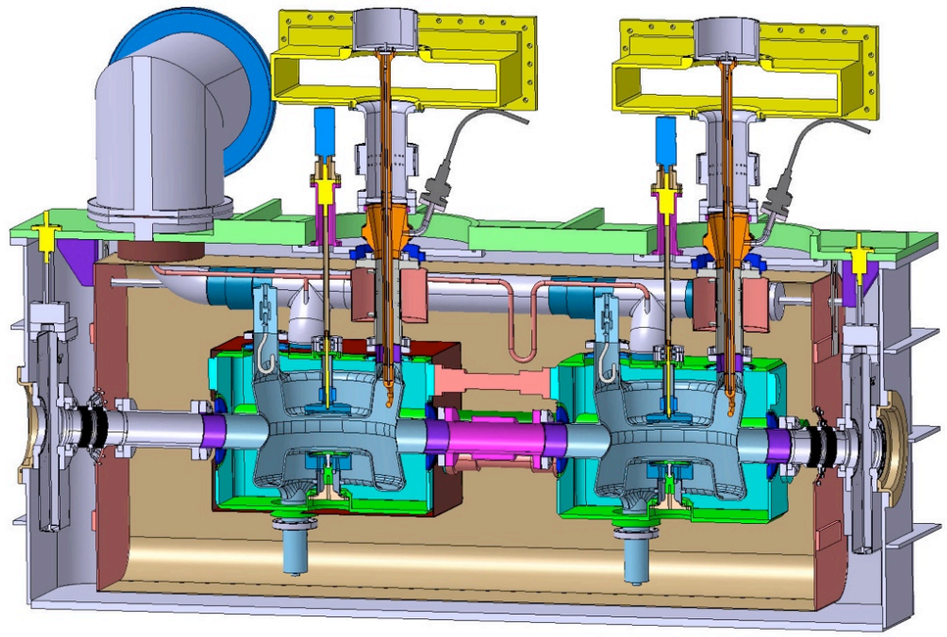
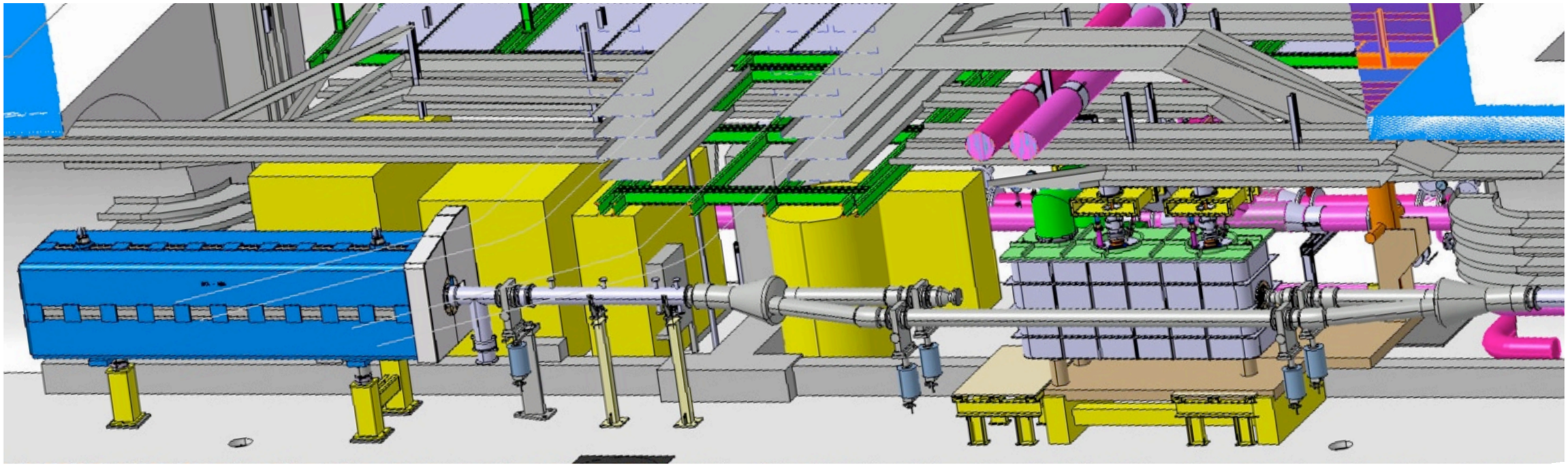


- **Crab Cavities Installed after 2015 COLDEX Run**
- **Requires CODEX to be completely de-installed by end of 2015**



SPS LSS4 Bypass Section

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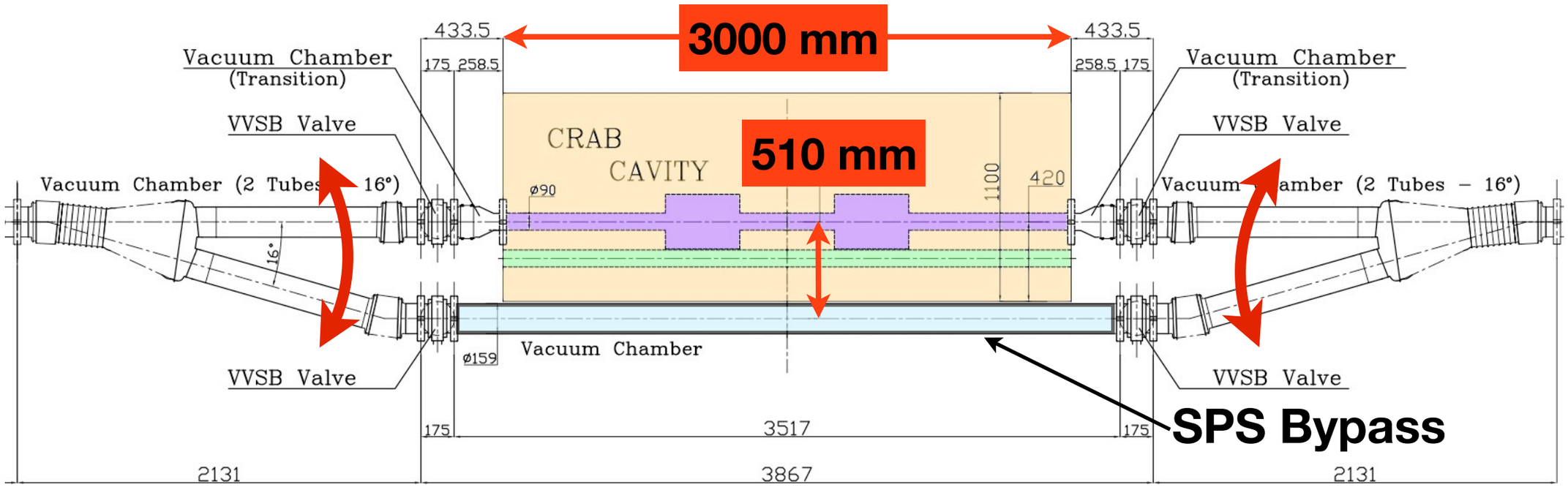
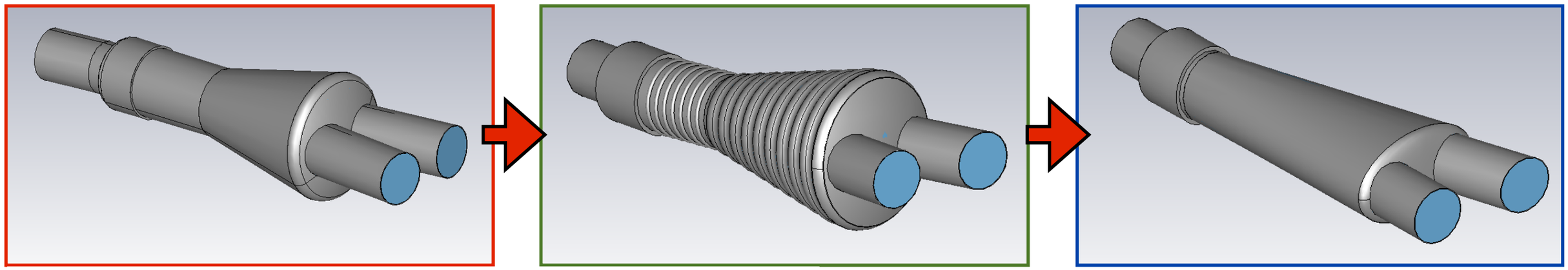
  - **Transverse separation of bypass increased from 340 to 510mm**
- **Y-Chamber redesign**
  - **Reduce impedance => impedance and HOM studies**
  - **Mechanical reliability**
    - Increased number of translation cycles => stress analysis of bellows

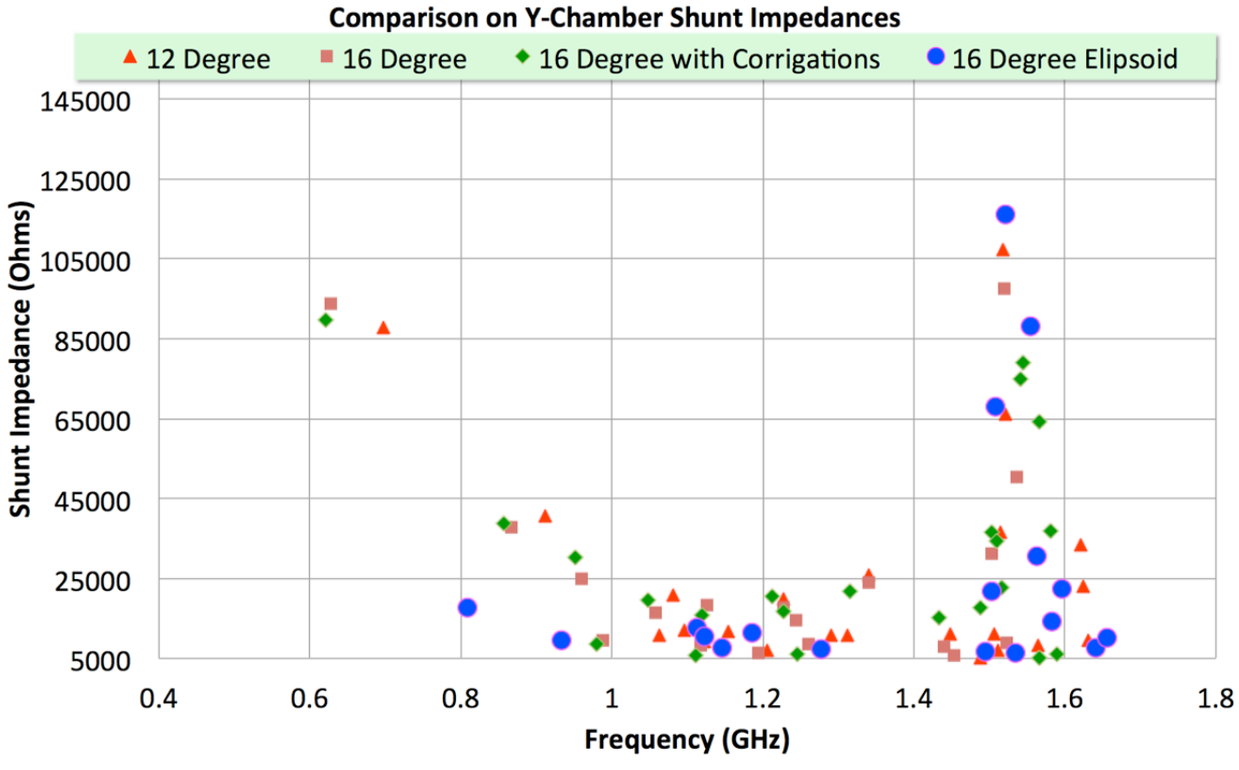


- **Remote transverse movement in/out of beam line under 20 min**

Y-Chambers: Impedance issues

- **Y-Chamber design: opening angle increased from 12 to 16 deg**
  - **Possibility of reducing impedance + increasing mechanical reliability**
  - **Question of choosing suitable and feasible mechanical design**



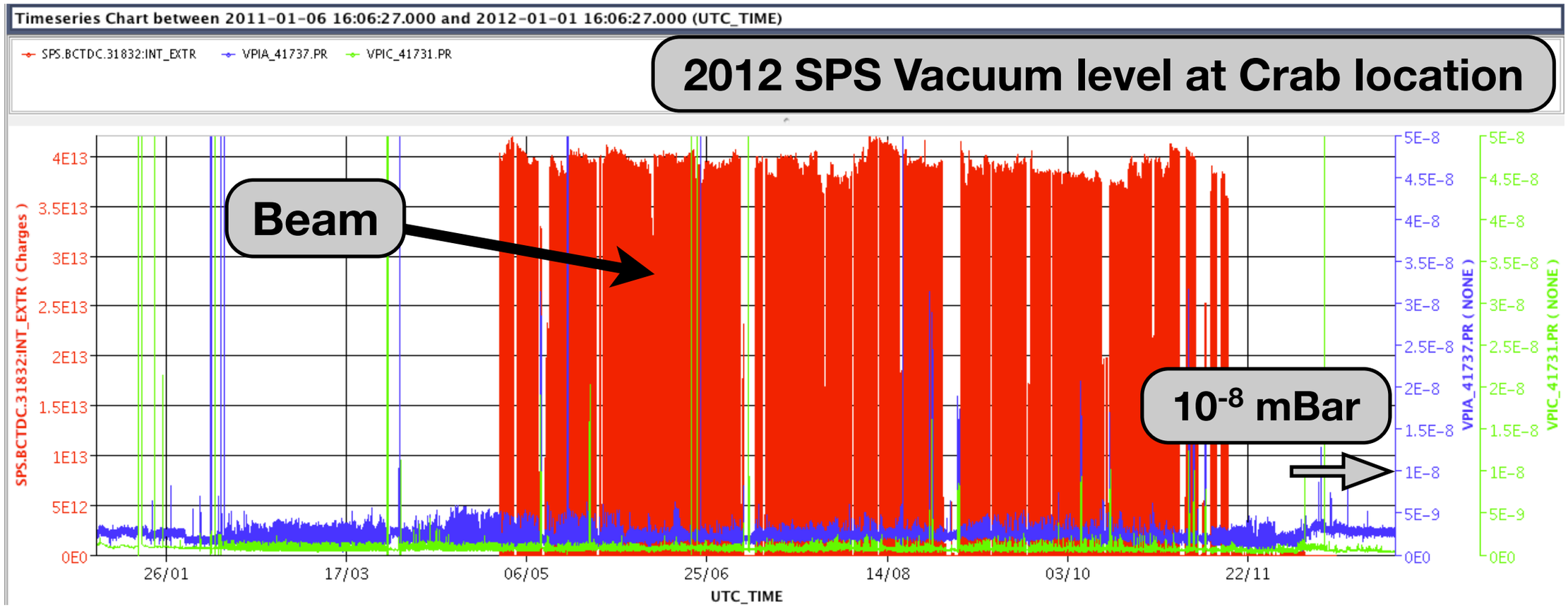


Impedance impact of new Y-Chambers expected to be small compared to SPS impedance.

Benoit Salvant,
Crab Cavity Workshop, Dec 2013

SPS Vacuum conditions for Crab Cavity Run

- **Assume worst case operational conditions = 10^{-8} mBar**



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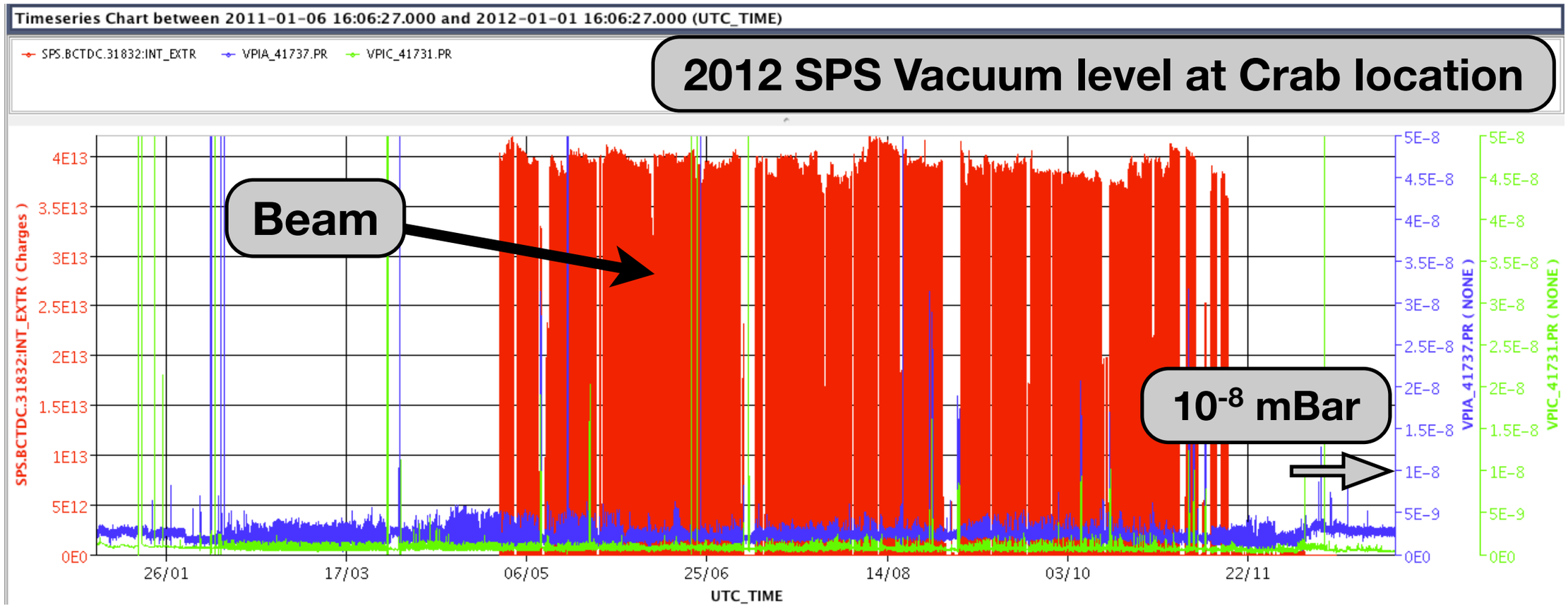

- **Necessary to improve both static and beam induced vacuum**
  - **Install Cryo-trap around Crab Cavity cryomodule**
    - Reduces: Vacuum level in Cavities to acceptable level
  - **Apply amorphous carbon coating to up/down stream of Cryomodule**
    - Suppress electron gas/e-cloud to prevent multipacting/thermal loading

Proposals for achieving the required SPS vacuum

- **Transition from warm unbaked machine to cold (2K) crab cavity zone**
  - **Main concern: Pollution of cavity from water**
    - **Deploy a cryo-trap on each side of the crab cryo module**
  - **Second concern: What about molecular species other than water**
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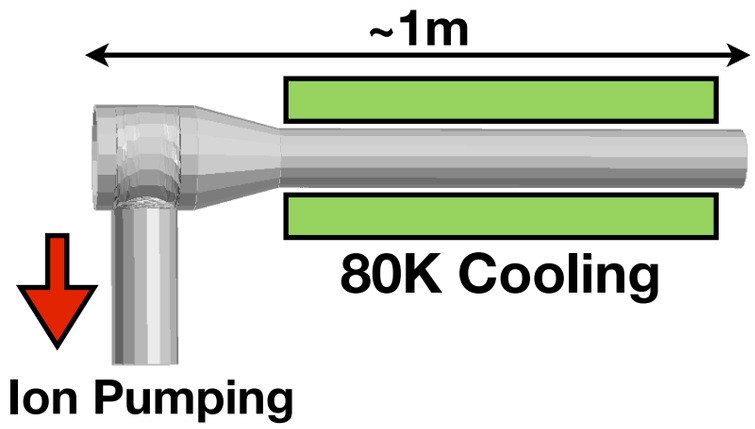
- **Crab cavity running will be limited to periods of dedicated beam time**
  - **Possibility for regular warm-up and pumping of crab location**

Achieving the required SPS vacuum

- **NEG Coating: possibility but may saturate due to SPS machine vacuum**
- **Cryo-Trap: at each end of Crab module**
    - Freeze out molecules (mostly H_2O)
    - Forms transition from std beam pipe to reduced aperture of crab cavity
    - Not a permanent SPS installation=> Installed between Y-Chambers



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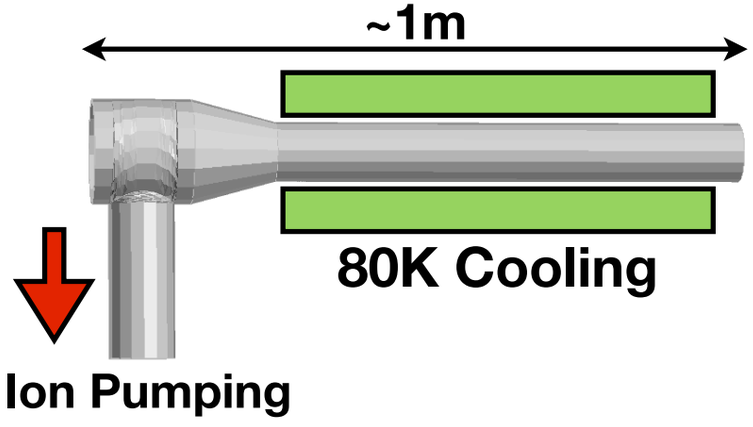
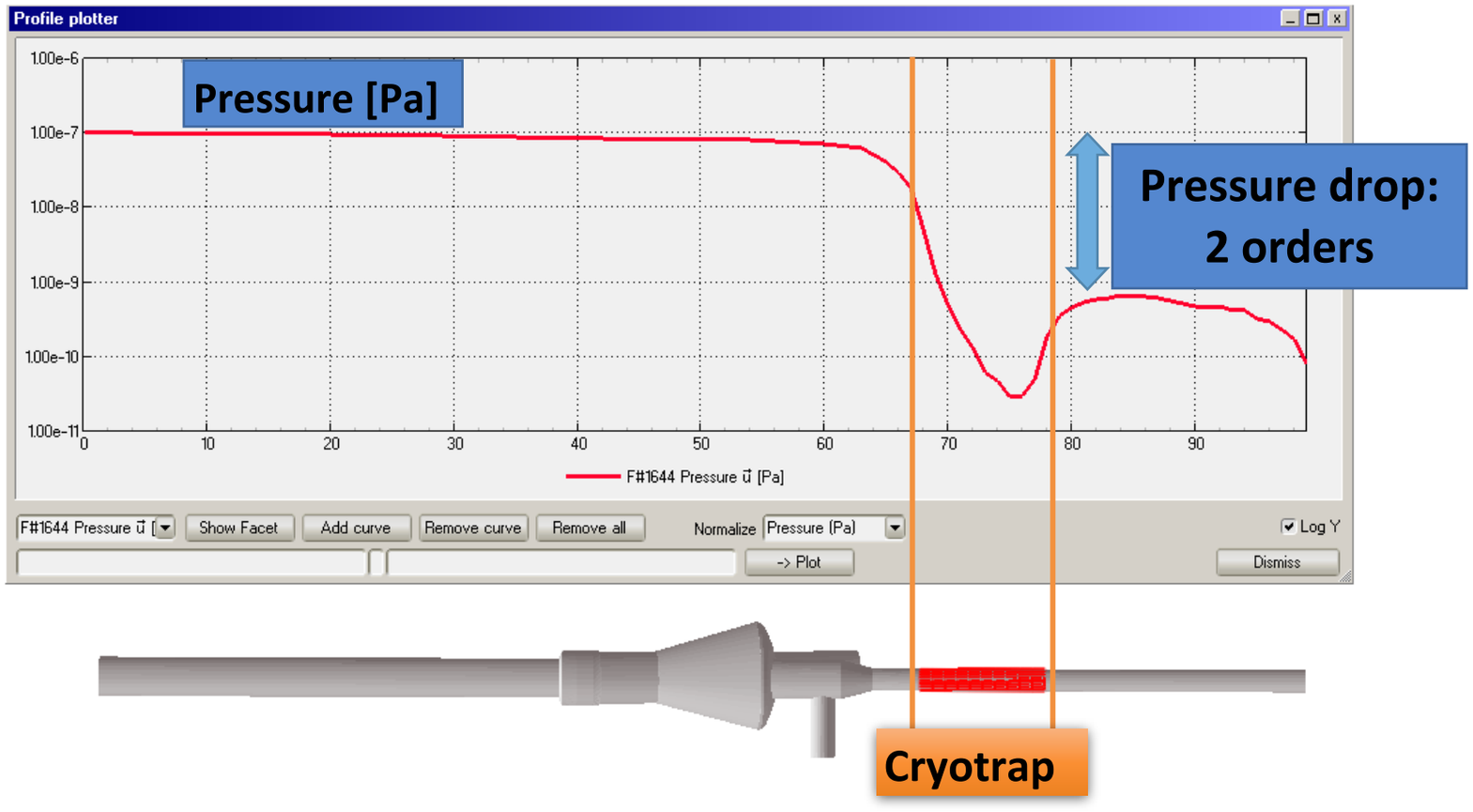


Transmission ratio

	No cryotrap	0.5m cryotrap	1.0m cryotrap
Without pump	100%	1%	0.55%
With pump	10%	0.55%	**0.2%**



- **Expected vacuum reduction: >O(100) => P_{Cavity} <10^{-10} mBar achievable**

Summary

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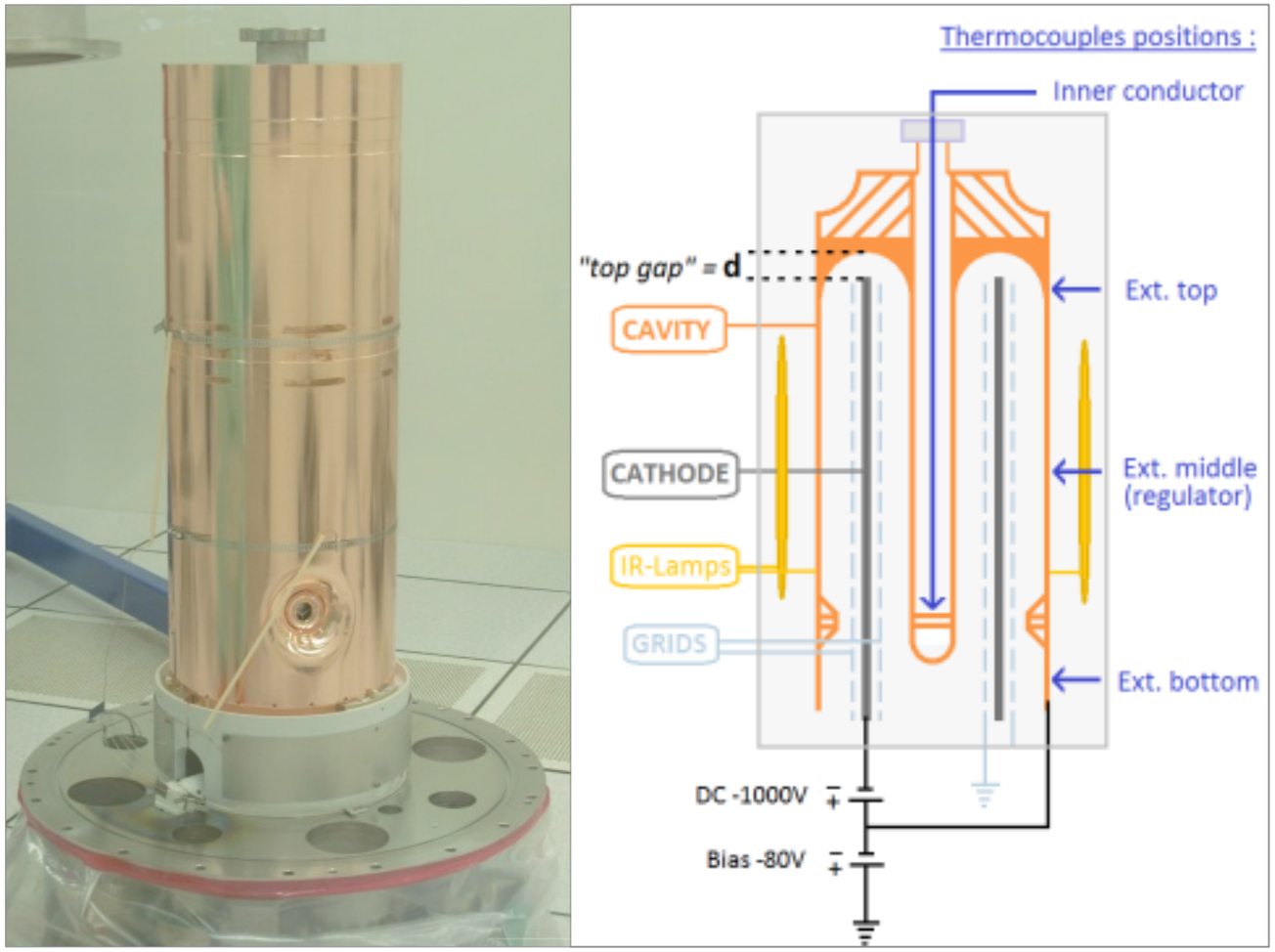
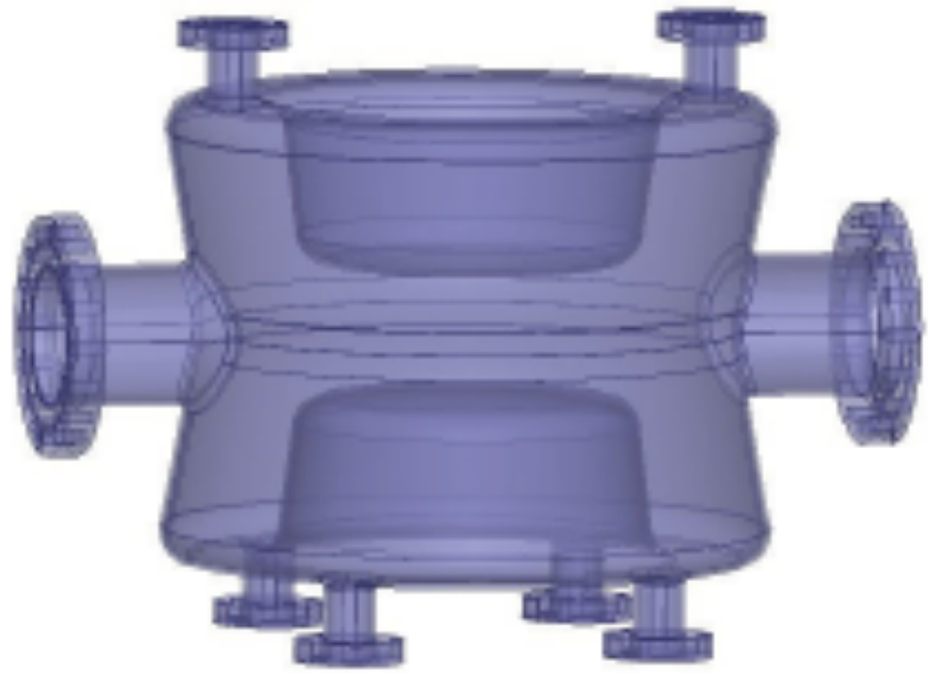
    - **Cavity protection: Need to understand if fast vacuum valves permitted**
- **SPS Crab cavity validation run in 2017-2018**
  - **Crab Cavities to use “COLDEX area” in LSS4 of SPS**
  - **Need new Y-Chamber => updated design**
  - **Proposal: Cryo-trap + pumping to reduce vacuum level in Crab vicinity**
  - **Need to minimize risk of thermal heating and multipacting**
    - **Proposal: amorphous carbon coating of beam line around crabs**

Additional Slides on Copper Crabs with Nb Coating

Crab - QWRs: Possibility of Niobium on Copper

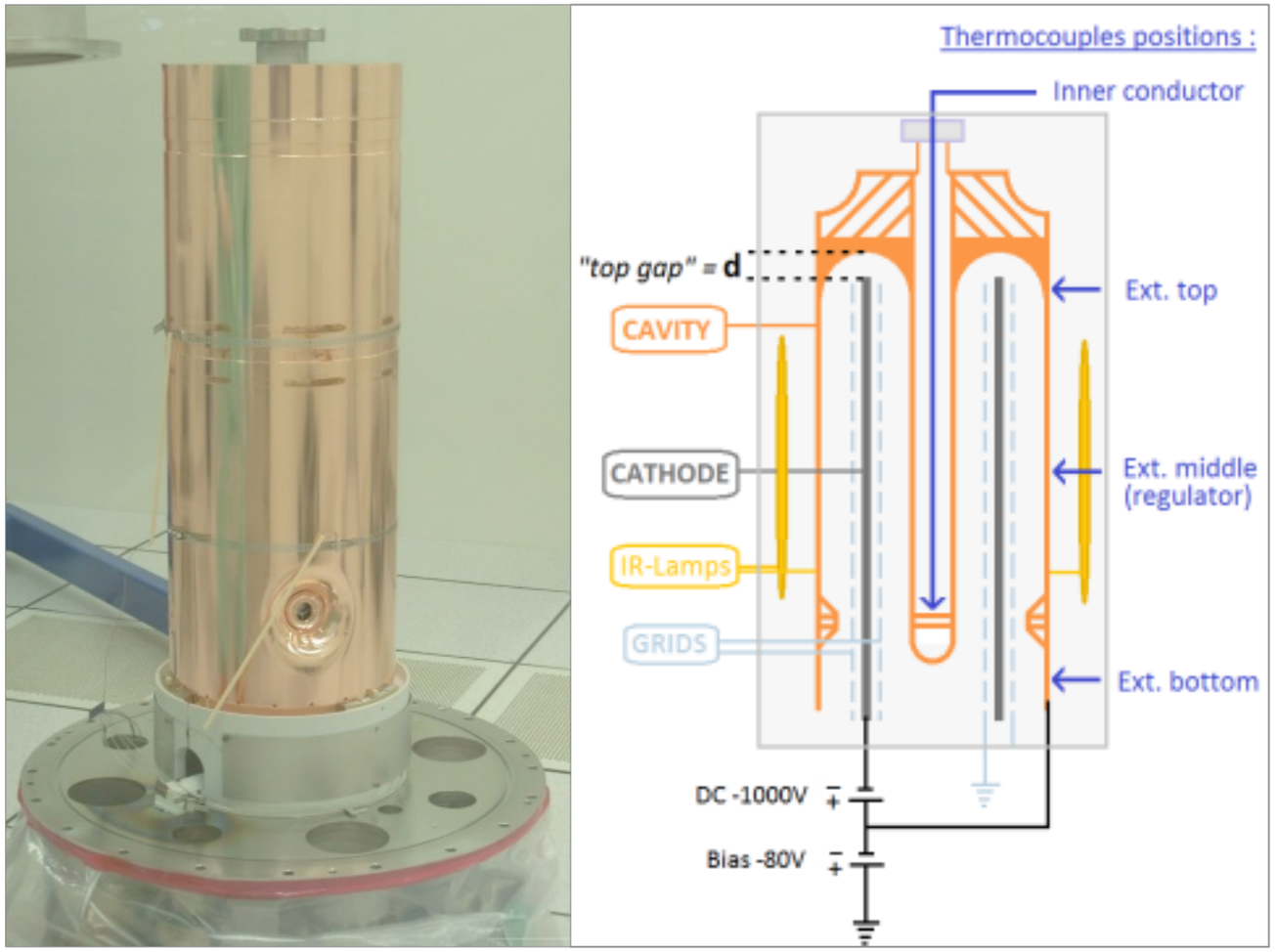


HIE-ISOLDE, coated with coaxial cathode
7 W at 6 MV/m obtained



A topological coating configuration similar to HIE-ISOLDE is possible

Crab - QWRs: Possibility of Niobium on Copper



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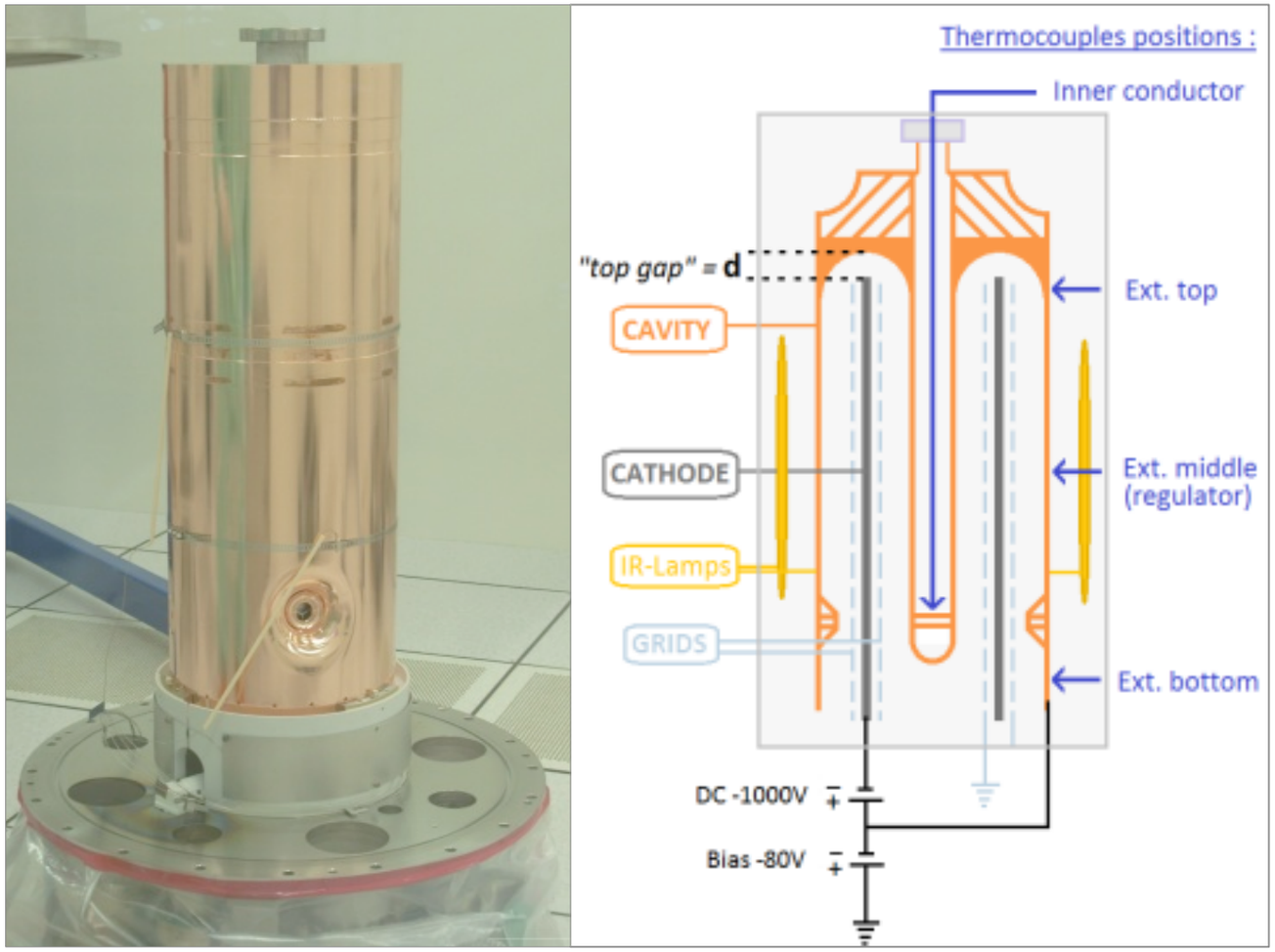

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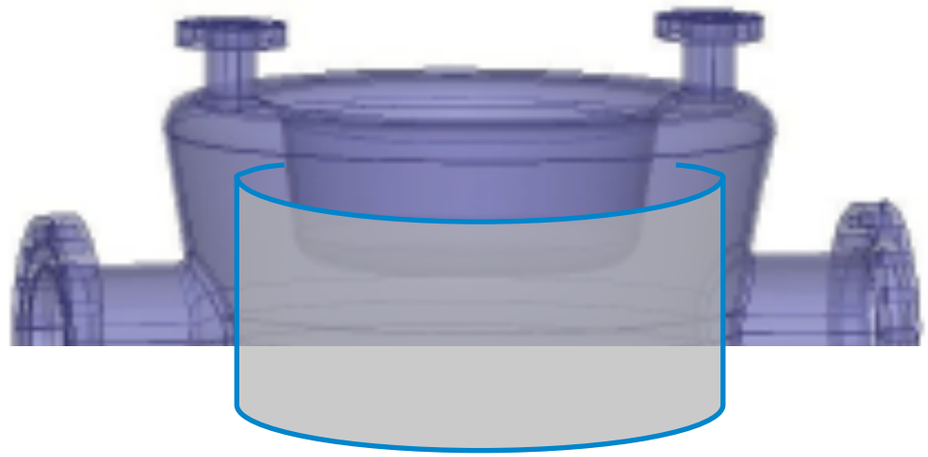

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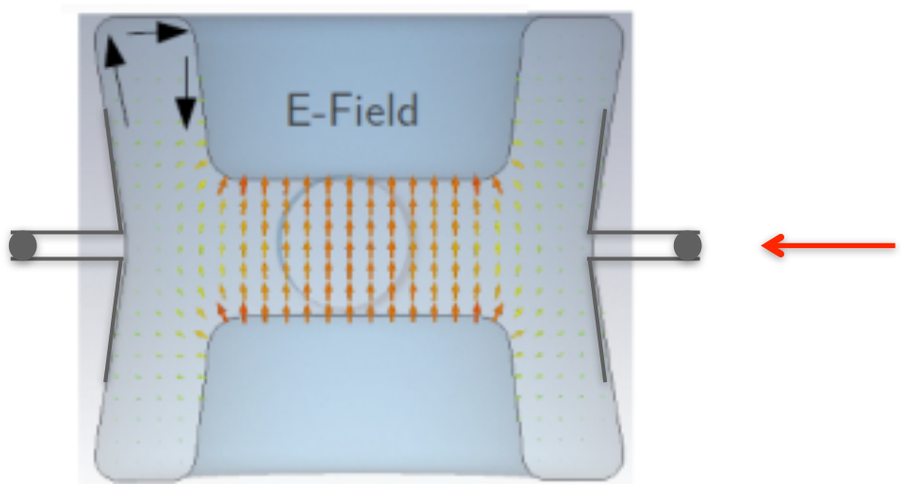
Cavity Coating: Cut + Coat + Join

- **Current of the order of few kA/m, total current a few kA**
  - RF design of beam port region can be optimized

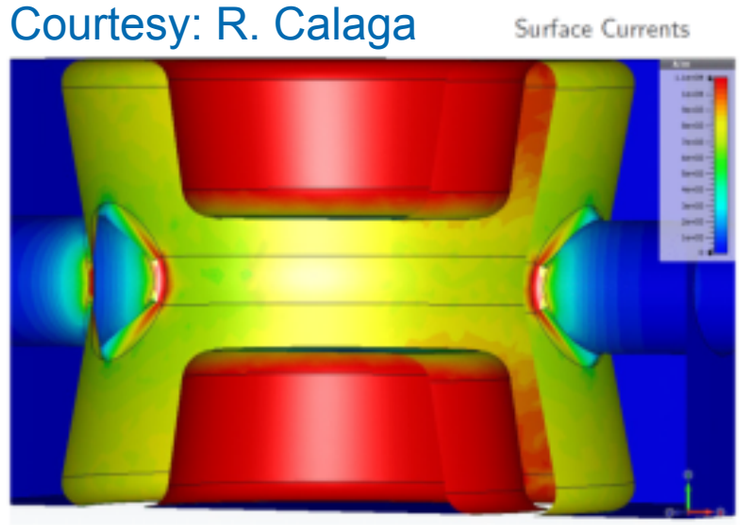
- **Maximum losses: a few watts in case of clamped connection**
  - Based on from HIE-ISOLDE experience

- **But: common vacuum cryostat required**
  - Other connection possibilities can be studied which might allow also leak tightness, thus separate vacua

Welding ?



Courtesy: R. Calaga



Short summary: Coating pros/cons

- **HIE-ISOLDE experience: required surface fields can be achieved**
- **Operate at 4.5 K, no quenches from Nb/Cu, no magnetic shielding**
- **Losses estimated at 50 W at 4.5 K,**
  - total wall plug power including cryo static losses and COP not much different compared to bulk @ 1.7 K (work in progress)
- **Expected losses from cut-and-clamp assembly are acceptable**
  - Several accelerators operate split cavities
- **Cooling by conduction is an option with copper cavities**
  - May suppress bath cyostat in favour of He circulation
- **Massive copper allows excellent stability, even at 4.5K**
  - HIE-ISOLDE micro-phonics is 0.02 Hz/mbar
- **Joining technology is presently a hot subject and needs study**
- **Common vs separate vacuum cryostat: Need study/risk analysis**