Crab Cavities: progress towards SPS

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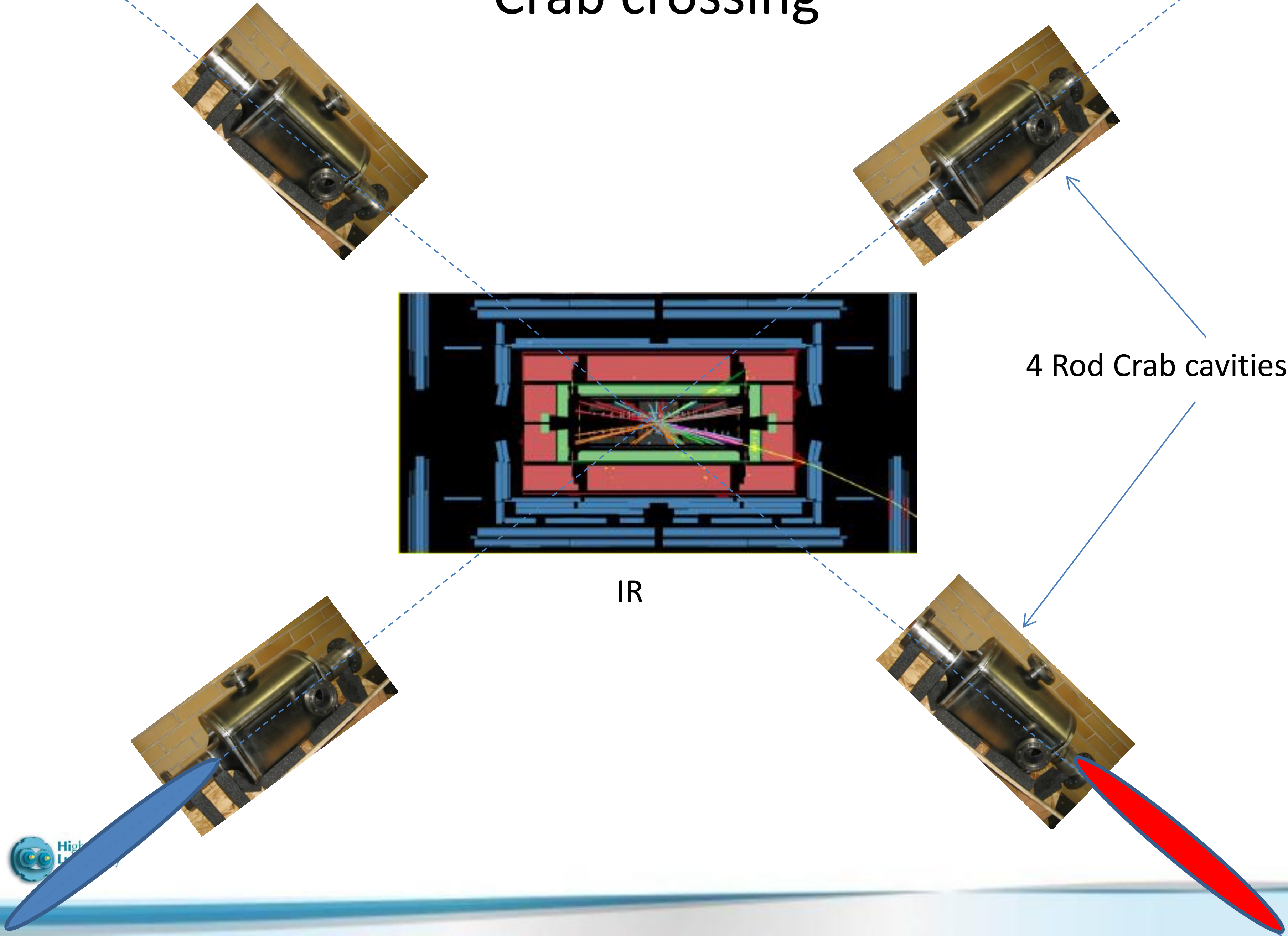
On behalf of WP4 team

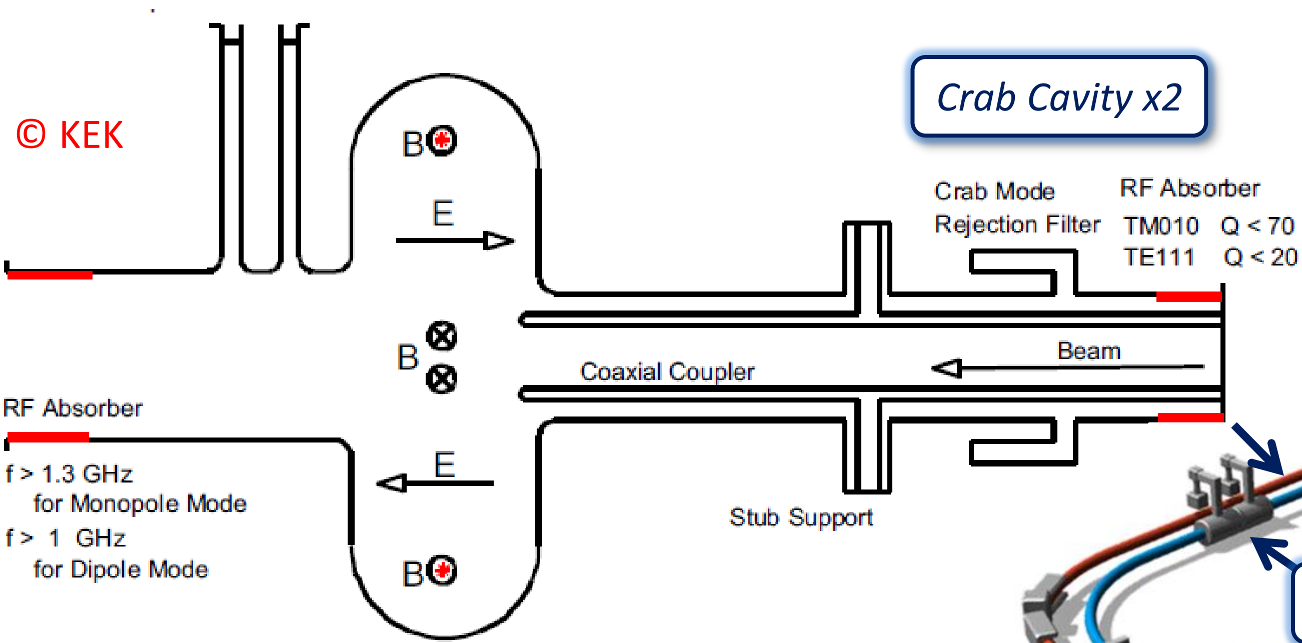
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

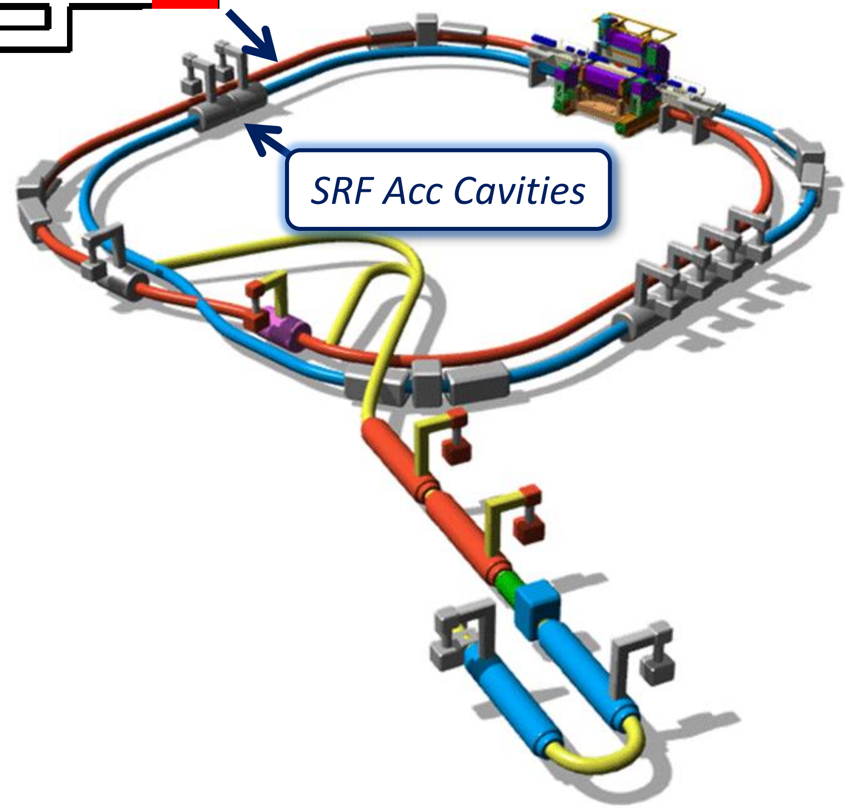
Logo's

Crab crossing



KEKB Crab Cavity (Crab cavities come home)



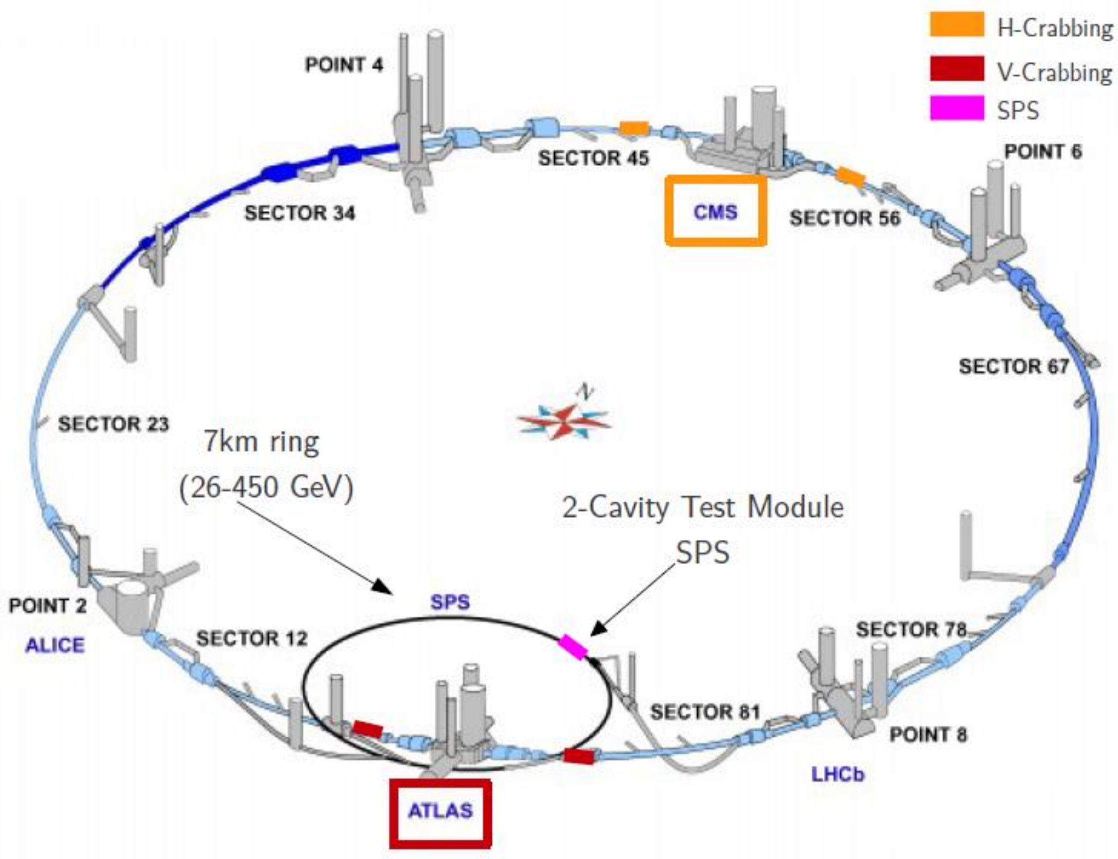


- **509 MHz squashed elliptical cavity**
- **LOM picked up by coaxial coupler, controlled by the insertion of the coaxial**
- **Choke structure to reject crabbing mode**
- **Low Q_{ext} for HOMs guarantees low impedance**
- **Multipacting easily processed in coaxial structure**
- **HOM power 16 kW/cavity, absorbed by ferrites**

High Luminosity LHC

Introduction

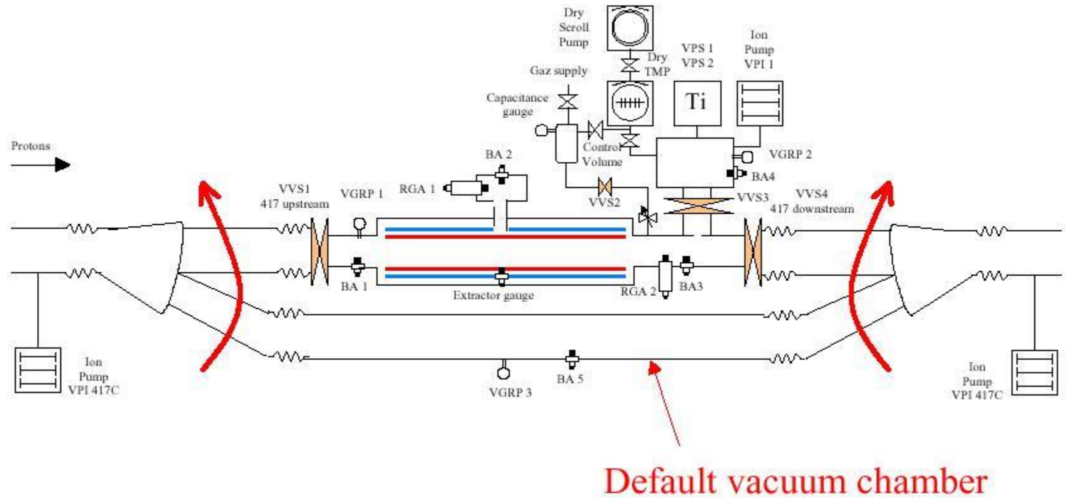
- For HL-LHC we consider crabs at ATLAS and CMS, each with two sets of crab cavities per beam per IP (total 32 cavities plus spares)
- We also will install two crab cavities in the SPS as a test beam.



High Luminosity LHC

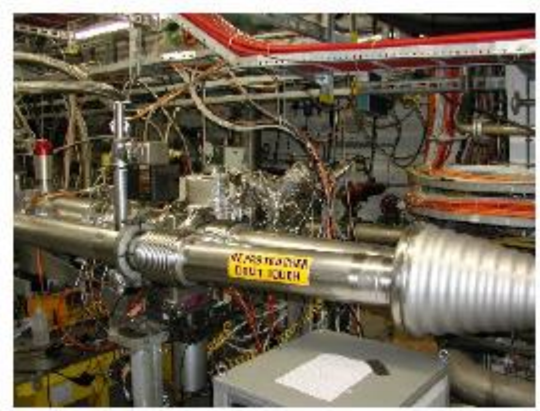
SPS Beam Tests

Crabs have never been tested on hadron beams and LHC is not a testbed.
COLDEX location in the SPS has a bypass line that could serve as a hadron crab cavity test location prior to LHC.



Goals of SPS test (before LS2):

- Cavity validation with beam (field, ramping, RF controls, impedance)
- Collimation, machine protection, cavity transparency
- RF noise, emittance growth, non-linearities,
- Instrumentation & interlocks



SPS Test Program And Objectives

Objectives:

- Demonstration of cavity deflecting field 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 and test operational cycle with crab cavities.
- Demonstrate the possibility to operate w/o crab cavity action (make them invisible) by both counter-phasing the two cavities or by appropriate detuning (to parking position) at energies ranging from 26-450 GeV.
- Measurements of beam orbit centering, crab dispersive orbit and bunch rotation with available instrumentation such as BPMs and head-tail monitors.
- Demonstrate MFB operation.
- Demonstrate non-correlated operation of two cavities in a common CM – trigger quench in one cavity without inducing quench in the other.
- Define and implement interlock hierarchy. Verification of machine protection aspects and functioning of slow and fast interlocks.
- Test HOM coupler operation with high beam currents, different filling schemes and associated power levels. Measurement of impedance and instability thresholds for nominal mode and HOMs.
- Measure emittance growth induced by the crab cavities as far as possible.

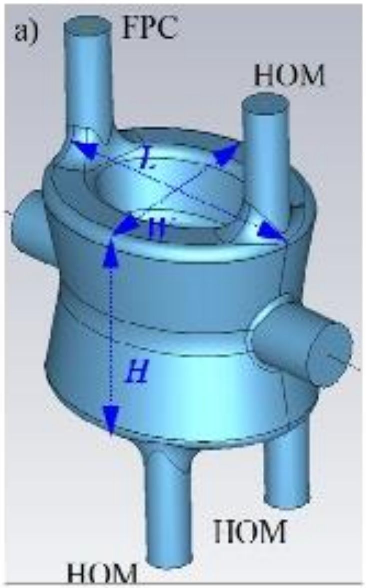
Timeline

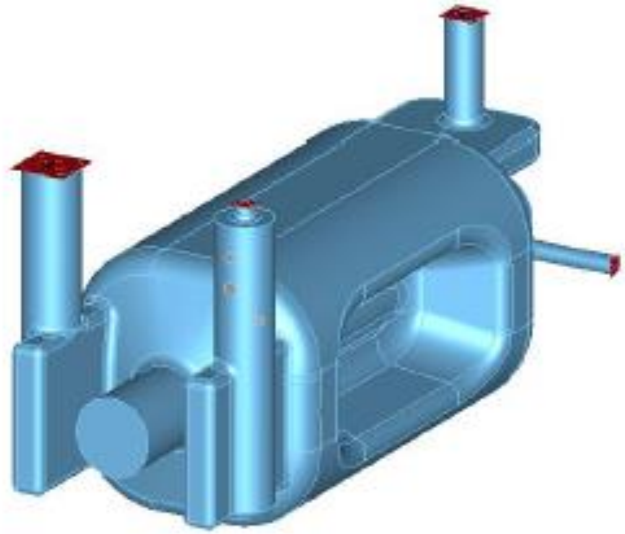
2013-2014	2015-2016	2017-18	2019-2020	2021-2023	2023-24
Cavity Testing & Prototype Cryomodule design	SPS Cryomodule Fabrication	SPS Beam Tests	LHC Pre-series Cryomodule Construction & Testing	LHC series Cryomodule Construction & Testing	LHC Installation

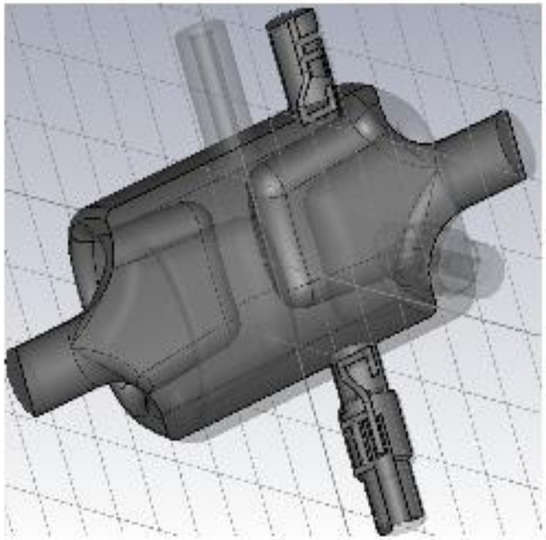
SPS test schedule

2015	Cavity manufacture and testing
End 2015	Cryostating
Mid 2016	SM18 Cryomodule tests
End 2016	Install Cryomodule 1 in SPS
2017	SPS Run 1
End 2017	Install Cryomodule 2 in SPS
2018	SPS Run 2

Cavity options



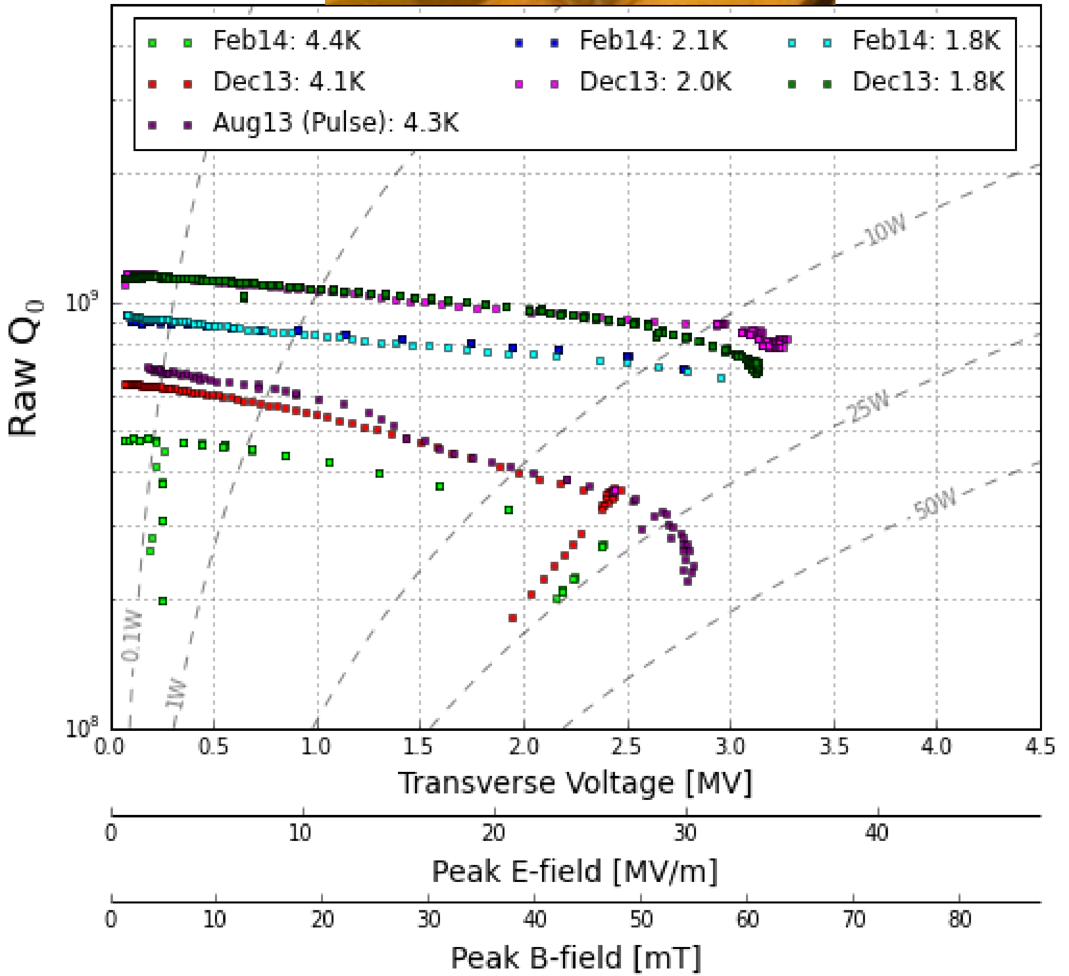




- At the last HiLumi meeting we had three cavity design options
- Double quarter-wave (DQW)
- RF Dipole (RFD)
- Four Rod (4R)

4R- test results

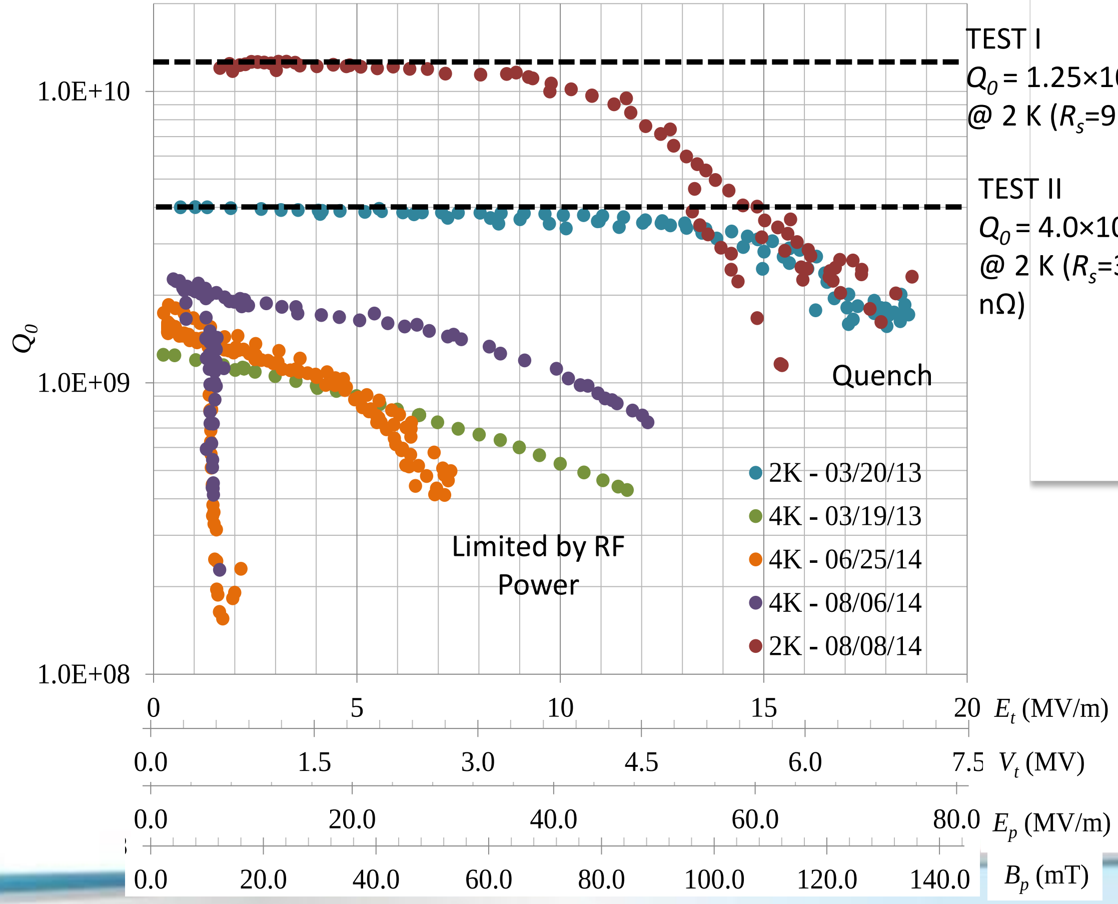
- The 4R CC was tested at CERN and achieved the design gradient.
- In initial tests the Q was rather low, this turned out to be due to the pick-up probes
- Recent testing has shown Q values more consistent with expectations.



High Luminosity LHC

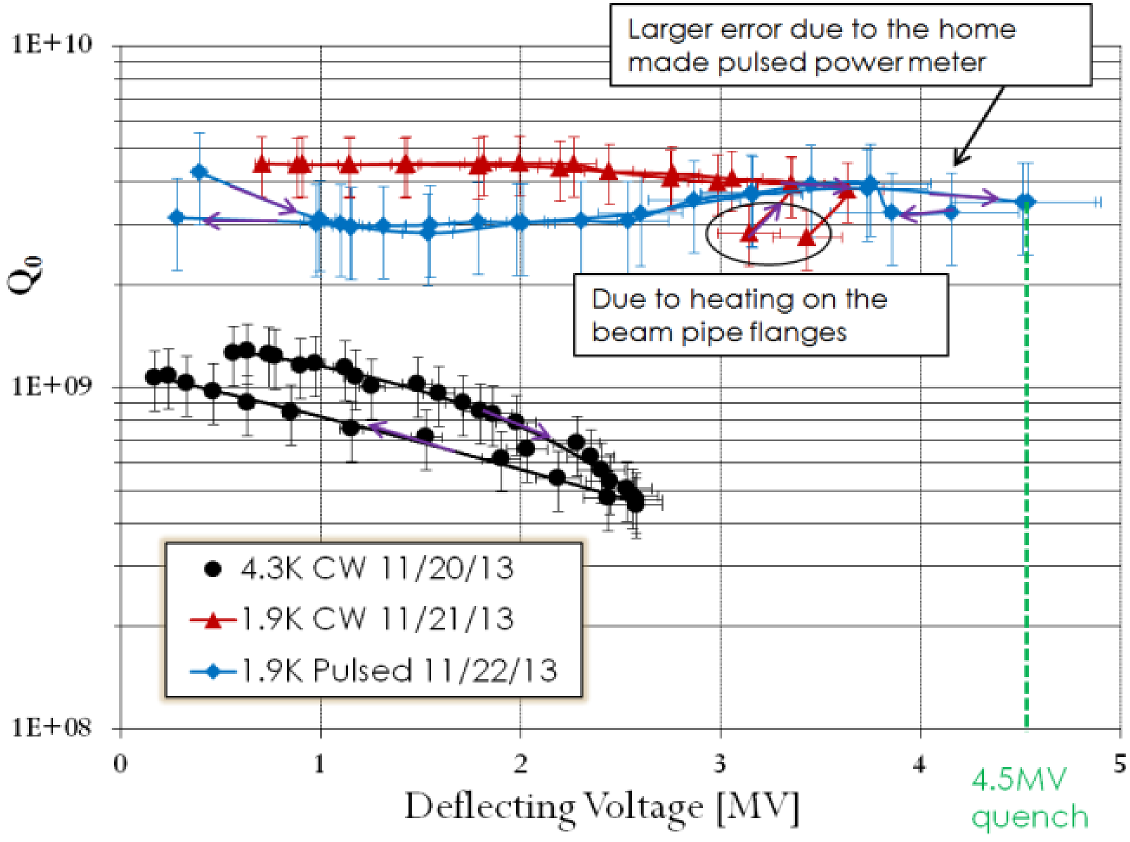
RFD Test Results

- The RFD cavity was tested at Jlab and was able to achieve a voltage far in excess of the specification (acc. phys please do not get excited and increase the required voltage).
- The cavity has now been re-tested at CERN and achieved similar results.



DQW test results

- The DQW was tested at BNL and achieved above the design spec.
- Q was reduced by the beampipe flanges, these have now been coated with Nb and will be retested at CERN imminently.

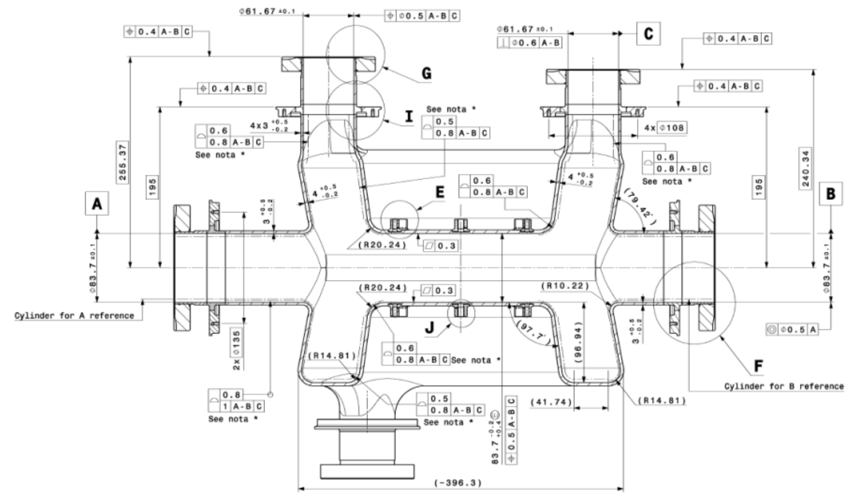


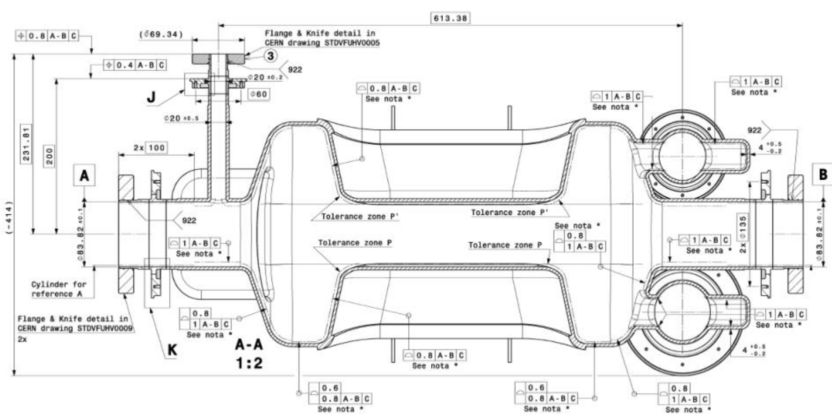
High Luminosity LHC

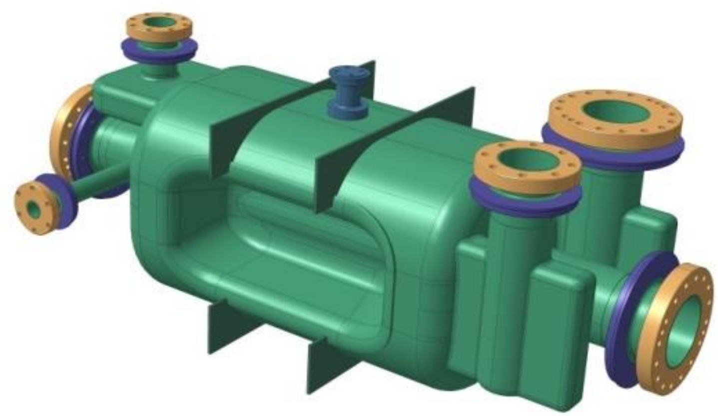
Recommendations from Technical Review

- At the LARP meeting we had a complete technical review by a committee of external experts.
- The recommendations are summarized below:
  - Recommendation to pursue only two out of the three cavities for the SPS tests (Double Quarter Wave with Coaxial HOM damping & the RF Dipole with the Waveguide HOM damping). Refocus the UK effort towards the two suggested cavities and complete the 4-Rod design at a lower priority in view of the LHC.
  - Improved project management and planning to realize the very tight schedule for the SPS tests.
  - Investigate an alternative vendor in view of the HL-LHC.

Bare cavities with interfaces



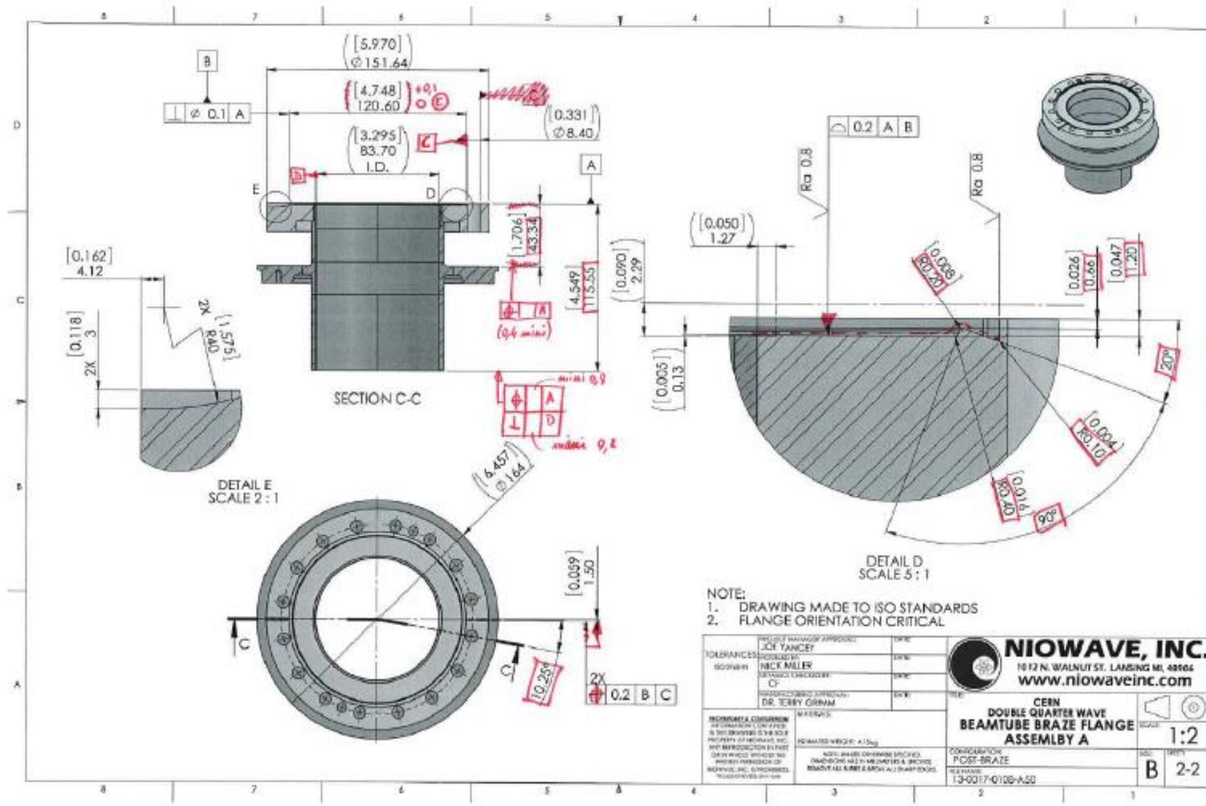




Niowave

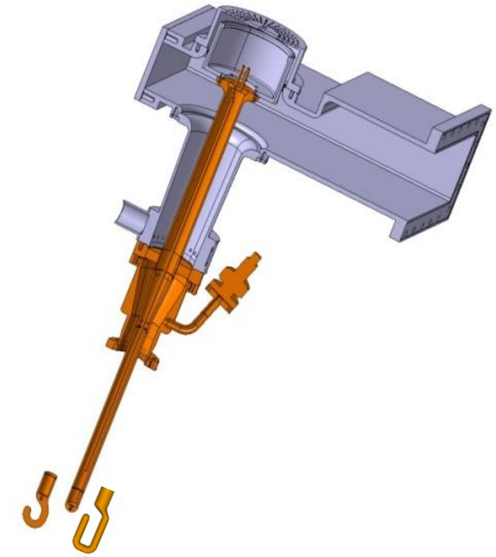
- We are advanced in the process of agreeing the manufacture and quality control with Niowave
- Very close to finalising this and start cutting (or in this case pressing) metal.

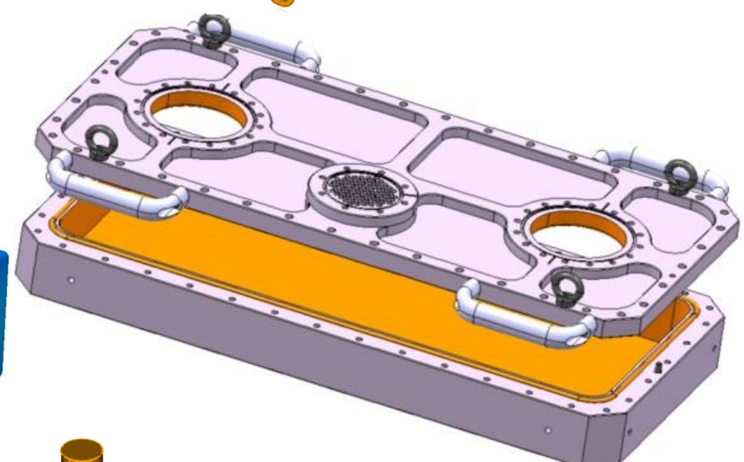
Production prints: specific comments



Power Coupler

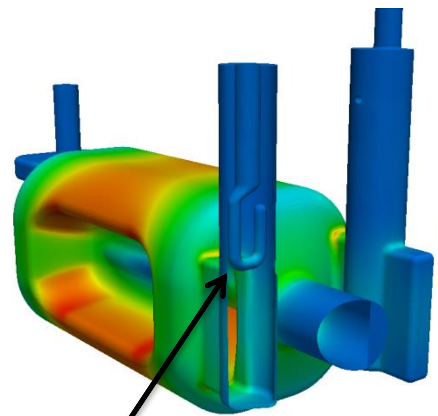
- The first milestone is to develop the couplers and start testing in a test box. This activity is well advanced and all parts are at CERN.
- Some optimisation was needed to reduce the power deposited in the tip as heat.



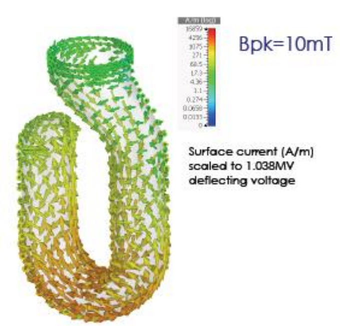


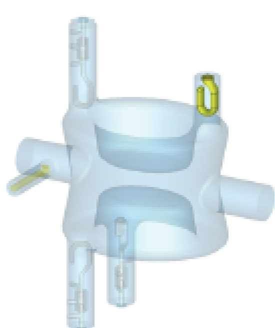
LATEST NEW VERSION
Increased f_m to enlarge coupling. Hook does not need to penetrate so deep into port tube.

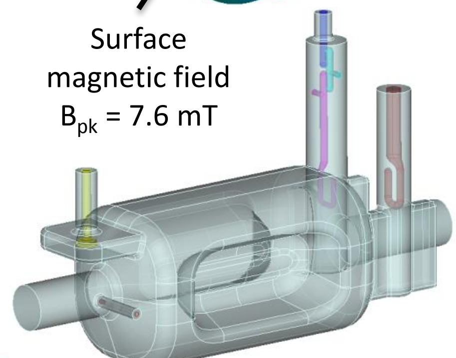
Q_{ext}^{FPC}	--	4.87e5
P_0^{FPC}	W	106

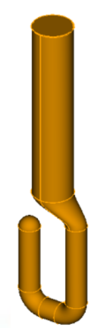


Surface magnetic field B_{pk} = 7.6 mT



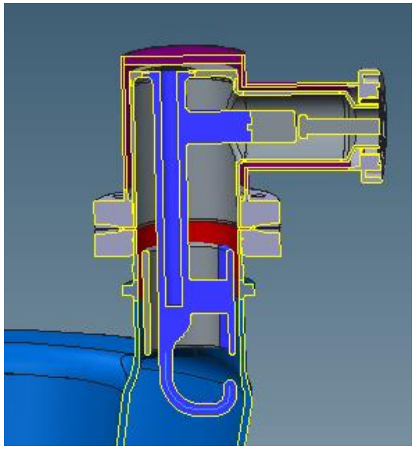


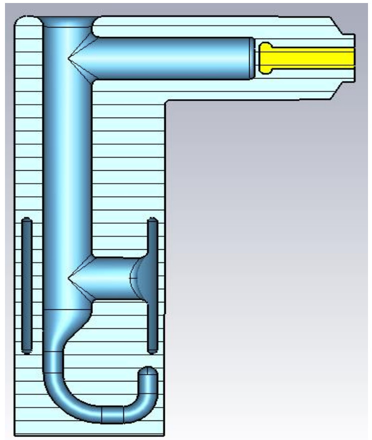


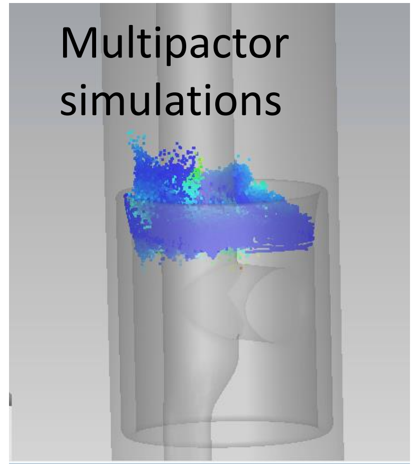


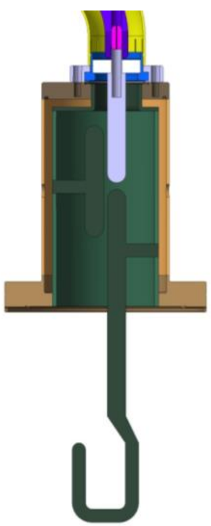
Q_{ext} (FPC)	--	5.0e5
P_0 (FPC)	W	69

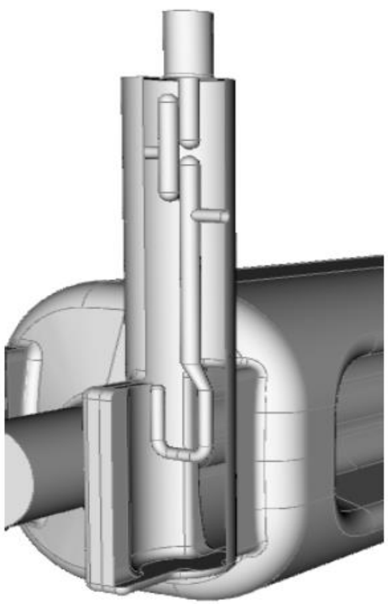
HOM Couplers

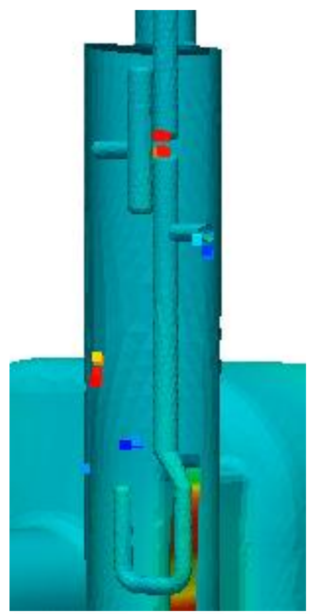








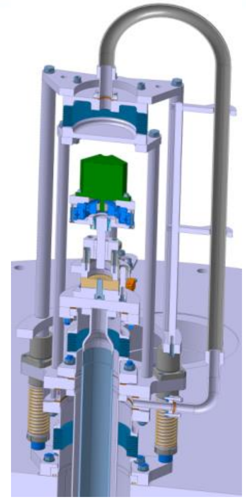


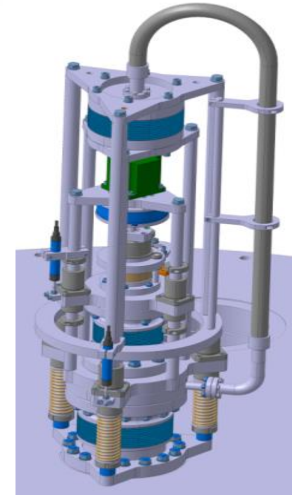


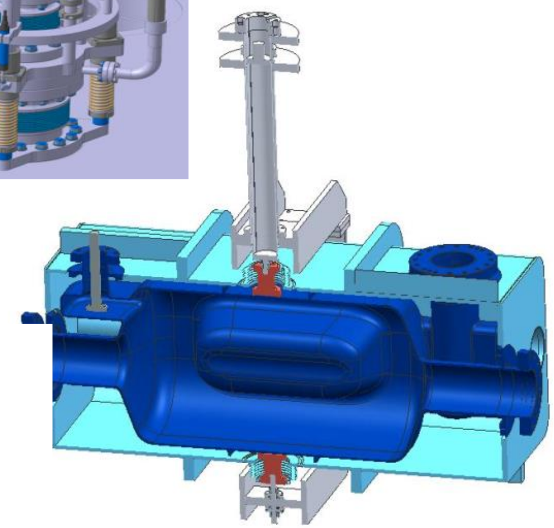
- The committee felt the highest risk item was the HOM couplers.
- These are complex due to the limited space available.
- The couplers are just about ready to release for quotes
- Comprehensive RF, multipactor, impedance and thermal /mechanical calculations are complete.

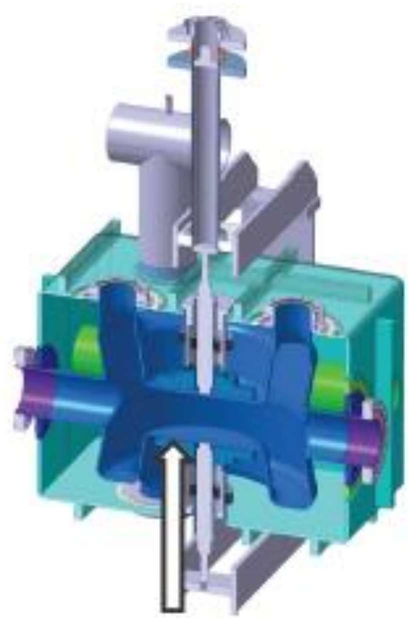
Tuner

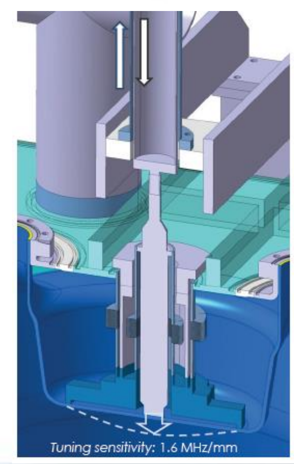
- Both cavities use the same tuner mechanism which uses the actuator from the Jlab scissor-jack tuner.
- This compresses the cavity vertically to alter the frequency.
- CERN are now planning an actuator test in SM18 in Feb 2015.





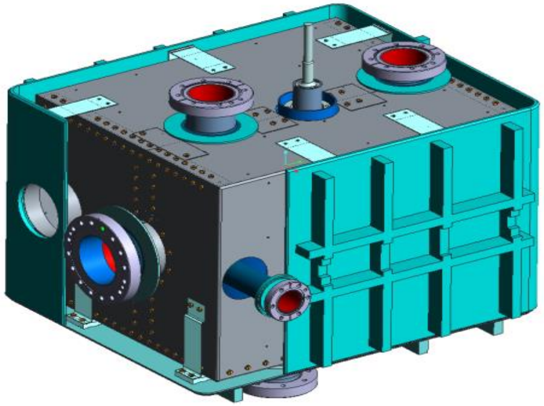


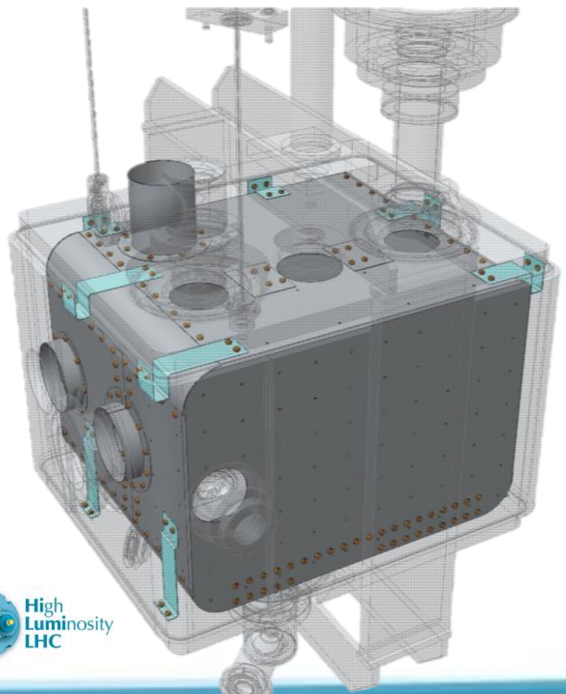




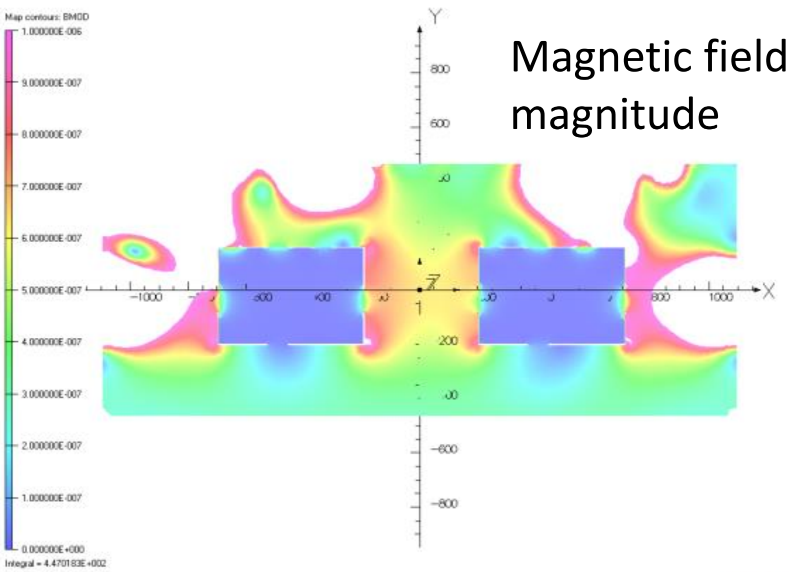
Magnetic shielding

- The cavity must be shielded from the earths magnetic field to less than 1 μT. Due to the large apertures in the LHe vessel this requires both an internal and external shield.
- The internal shield is inside the LHe vessel and works at cryogenic temperatures.



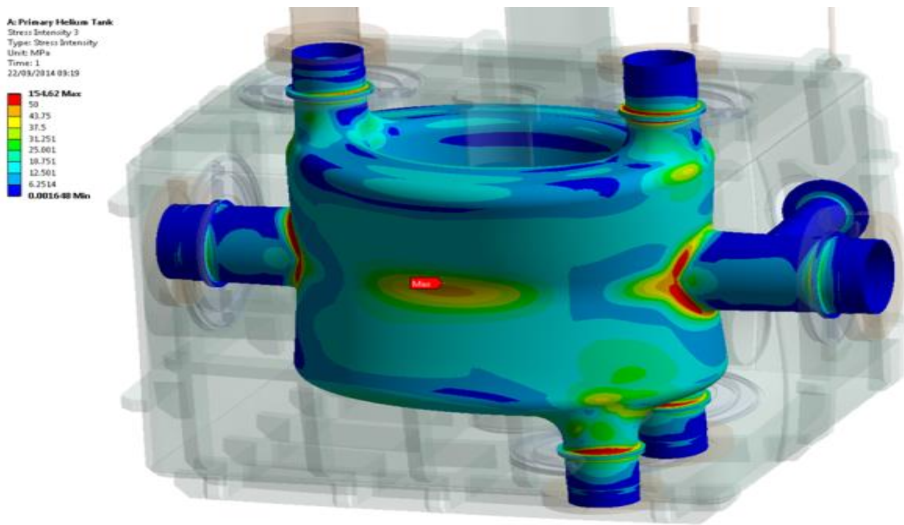


1 μT

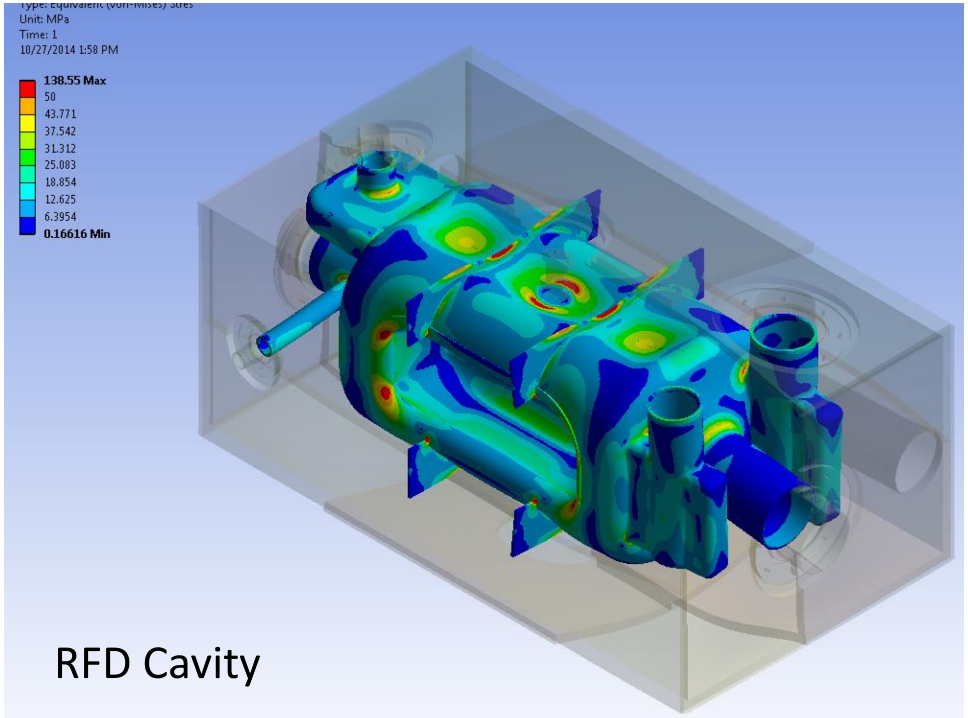


High Luminosity LHC

Stress Analysis



DQW Cavity



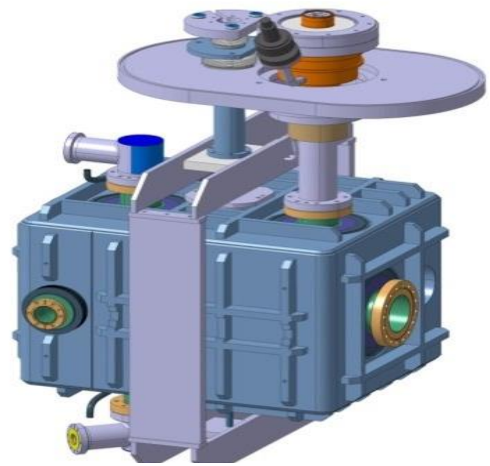
RFD Cavity

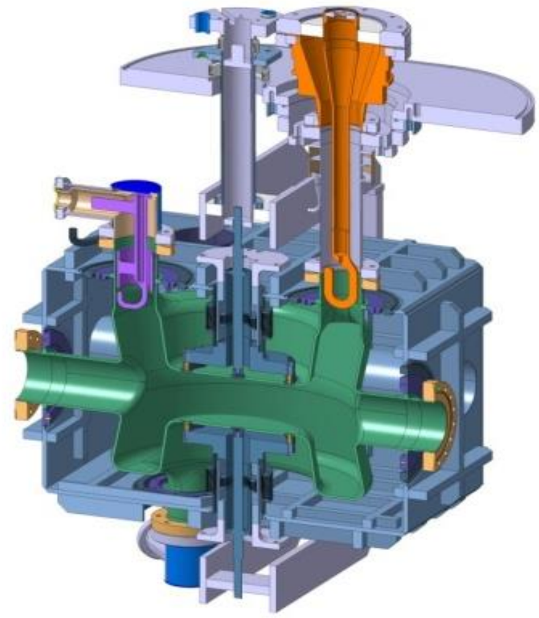
- The full system has been modelled to ensure that the stress on the dressed cavity does not exceed material limits.

Dressed cavity designs

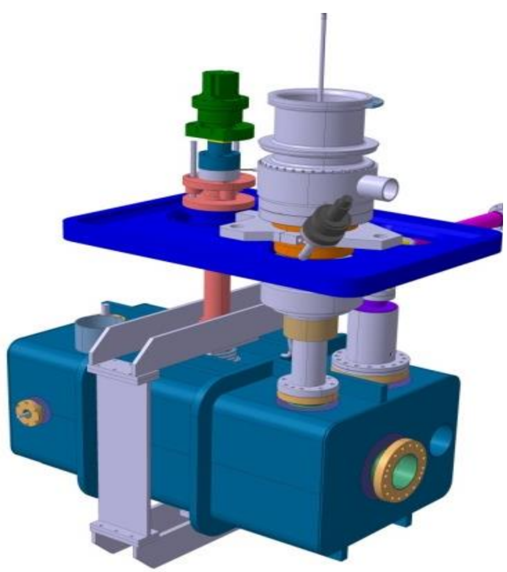
- We are now pretty close to having final dressed cavity designs.
- This includes couplers, tuners, magnetic shielding and LHe vessels.

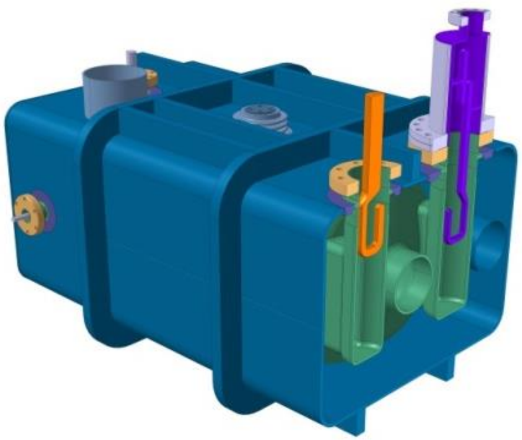
DQW



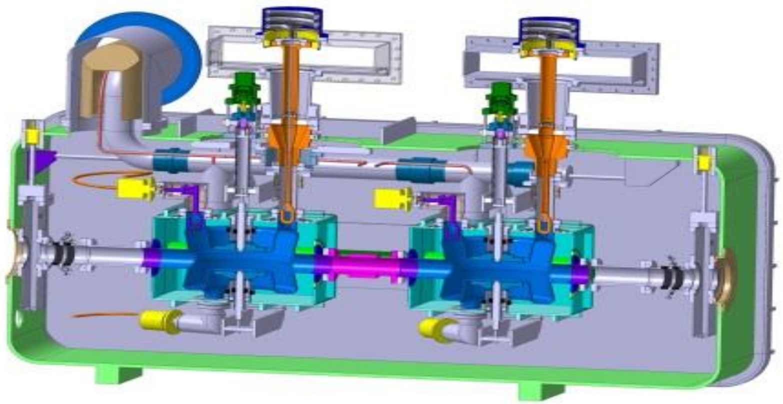


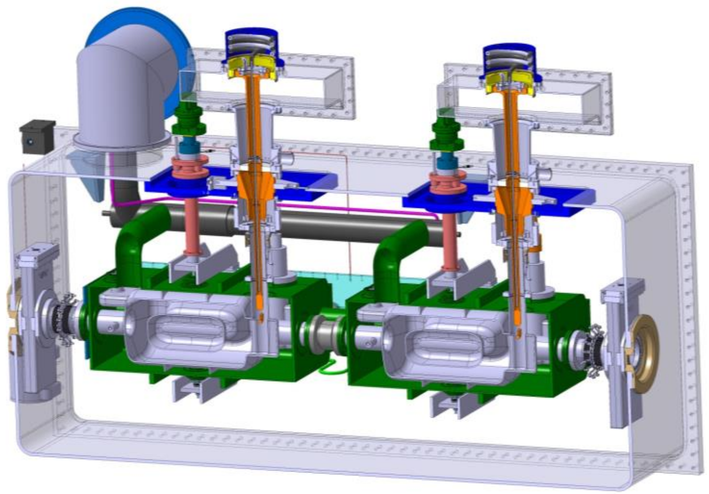
RFD



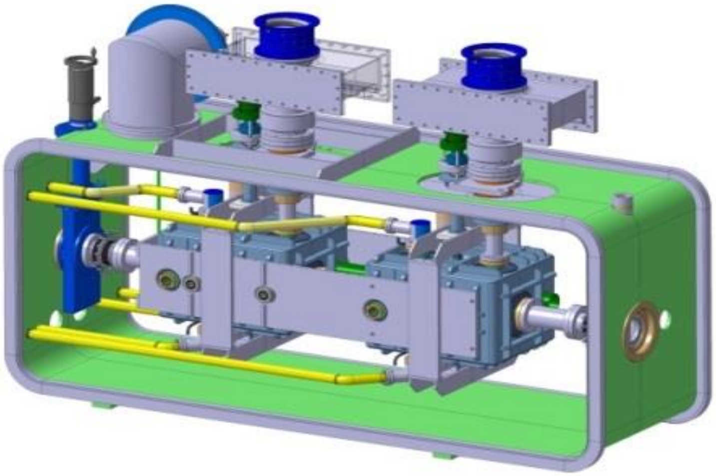


Side-loaded Cryomodules

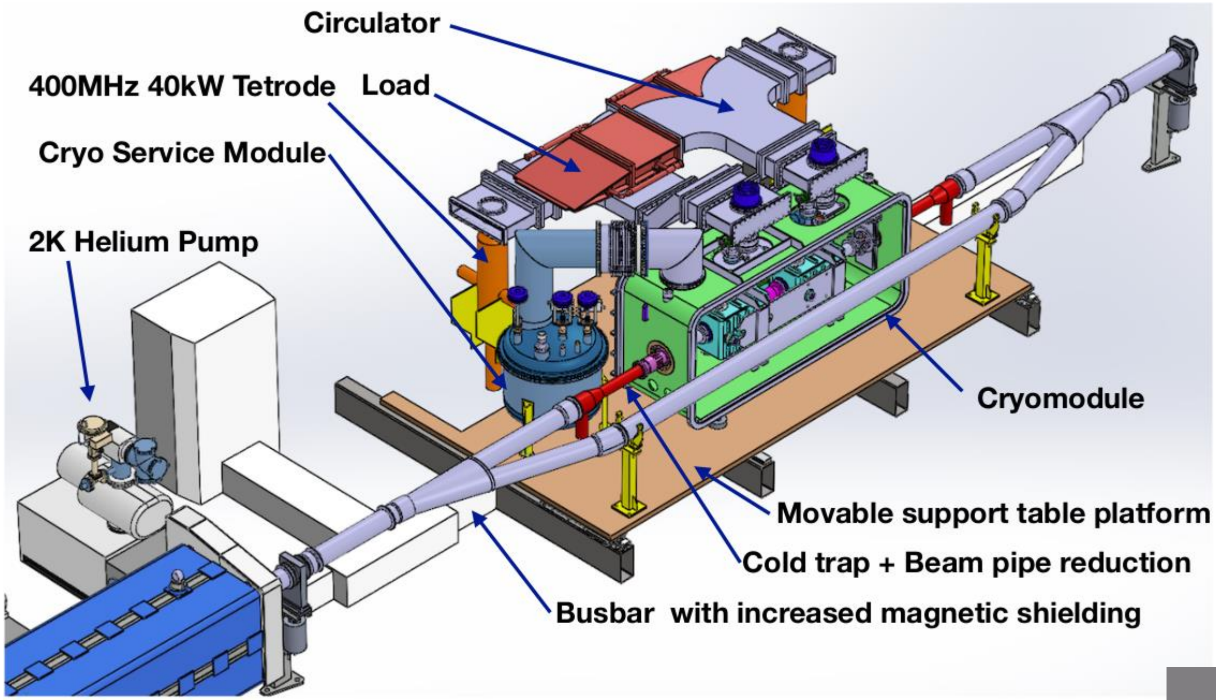




- The SPS cryomodule will contain two crab cavities.
- The design uses a novel side-loading design to allow fast access during commissioning.

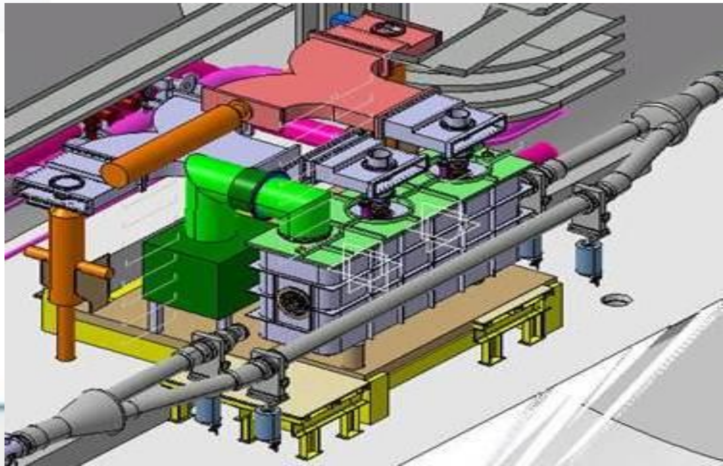


Cryomodules in SPS



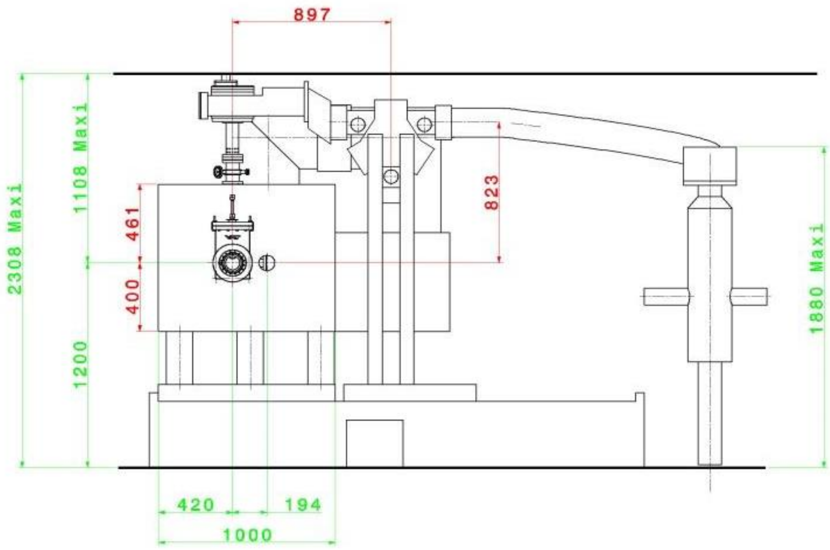
- The SPS cryomodules are mounted on a moving table so that they can be moved in and out of the beamline using a Y-chamber.

This also needed careful consideration of power and cryogenics.

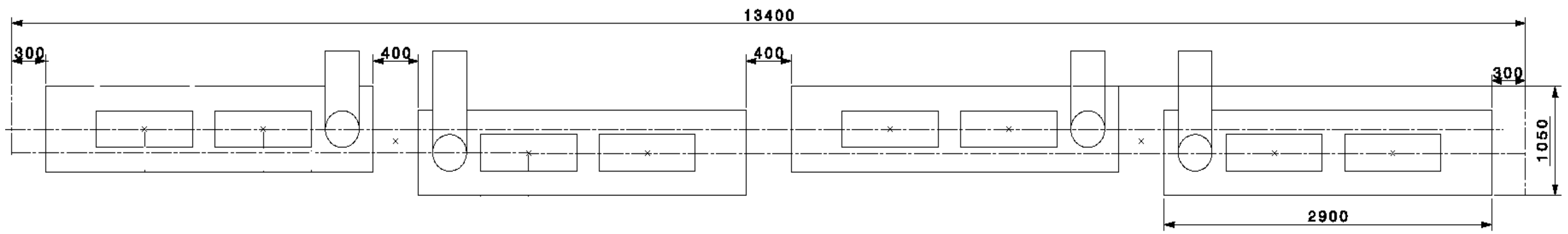


RF power

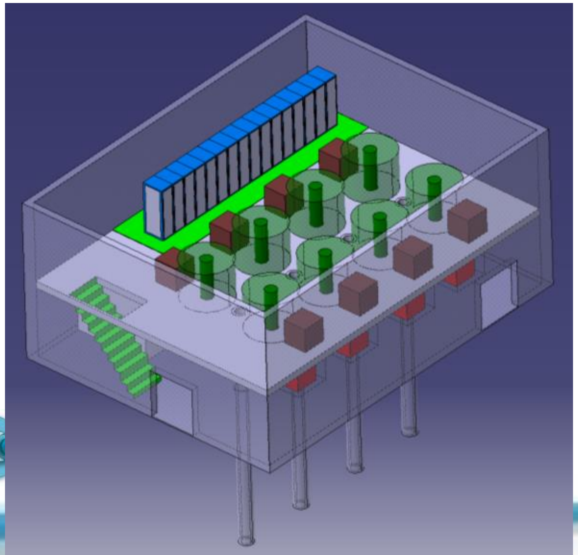
- Two LEP tetrodes will be used for the SPS tests.
- Specially designed WR2300 will feed the RF power from the Tetrode amplifiers to the respective cavity.
- Placement of the amplifiers on the movable table will depend on the full integration of the cryomodule, transmission lines and the circulator.
- Material is now at CERN and assembly will start soon.

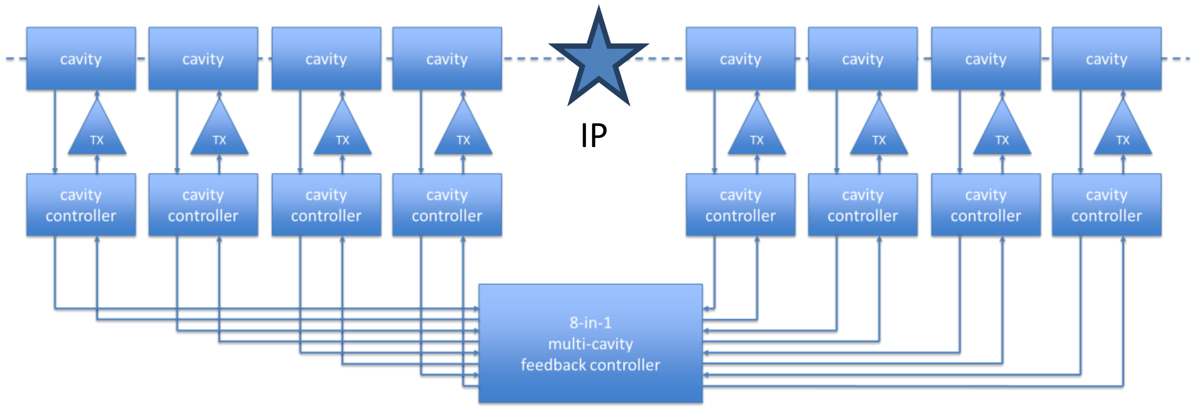


LHC Crab System



- The HPRF, LLRF and cavity layout has been considered for HL-LHC as well as for the SPS tests.





Conclusions

- There has been a down-selection to two crab cavities for SPS, the 4R design is frozen.
- The mechanical design of the dressed cavities is very nearly complete.
- The rest of the cryomodule will be finished off in the next few months.
- The manufacturing process of the bare cavities has begun at Niowave.
- The SPS experimental preparations are in full swing.
- We are on schedule to test in SM18 in 2016 and in SPS in 2017/2018.