Double Quarter Wave Crab Cavity Design and Plans

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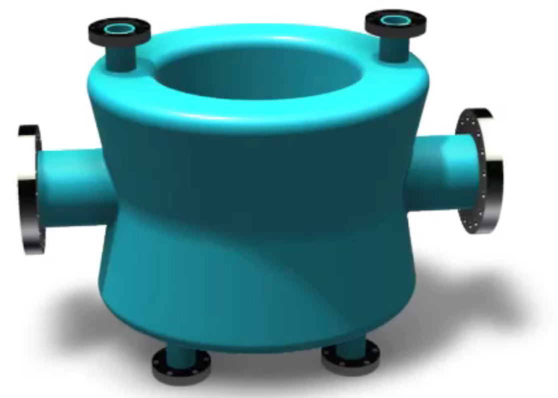
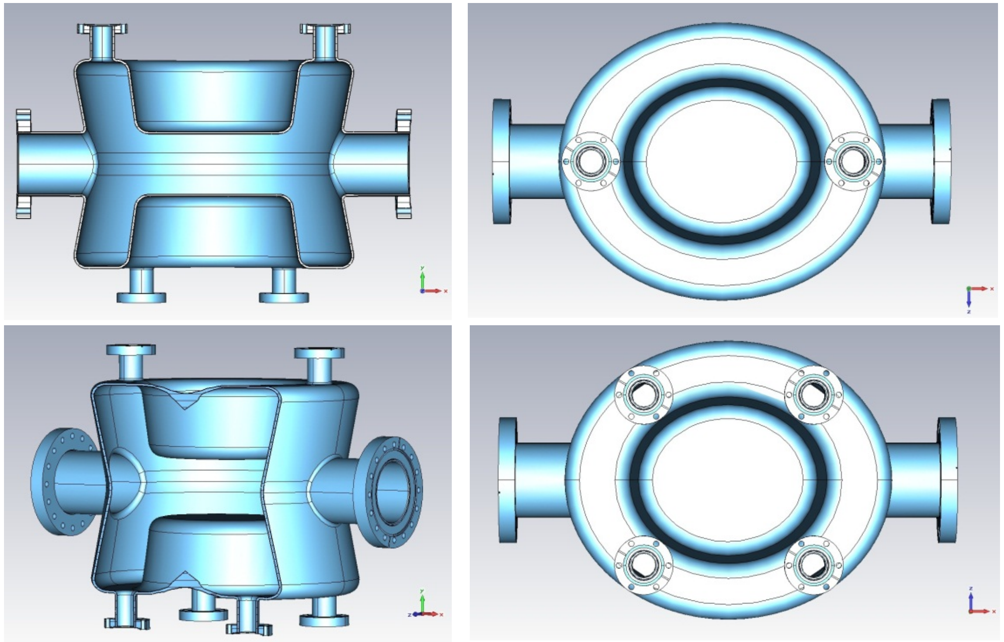
2/17/2014

Outline

- Proof of Principle (PoP) Double Quarter Wave Crab Cavity (DQWCC)
  - Cavity Design
  - Cold Tests
- SPS DQWCC
  - Cavity Design
  - Couplers
  - Helium Vessel, Tuner, Cryostat Design
- Future Plans
- Summary

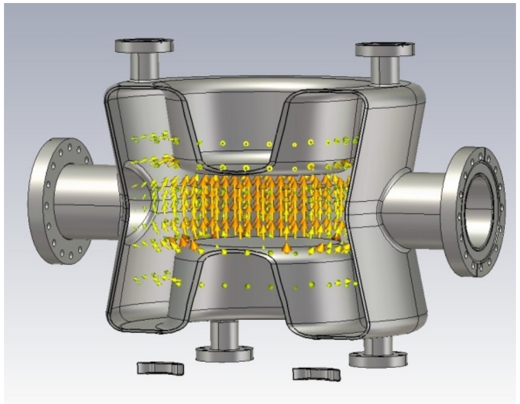
The Proof of Principle

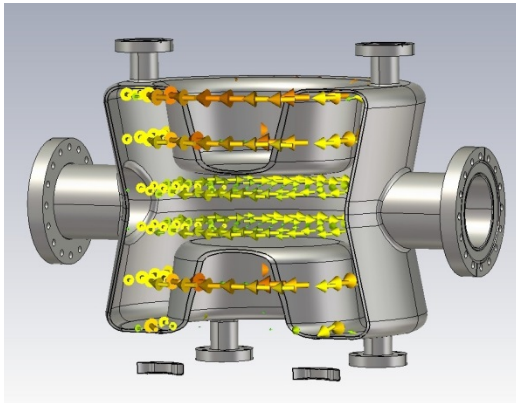




	Crabbing (fundamental) mode freq.	1st HOM	Cavity length	Cavity width	Beam pipe diameter	Deflecting voltage
Unit	MHz	MHz	cm	cm	cm	MV
DQW crab cavity	400	579	38.4	14.2	8.4	3.3

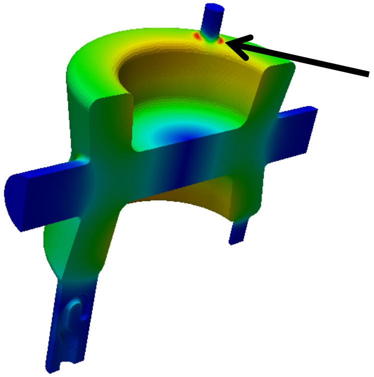
Cavity Parameters





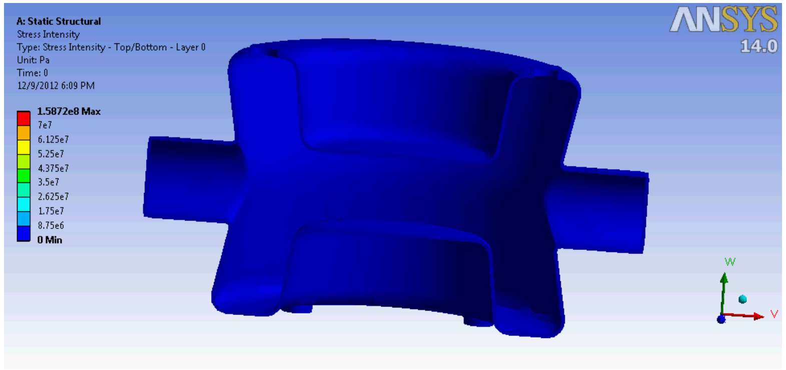
Electric field (top) and magnetic field (bottom) of the fundamental mode.

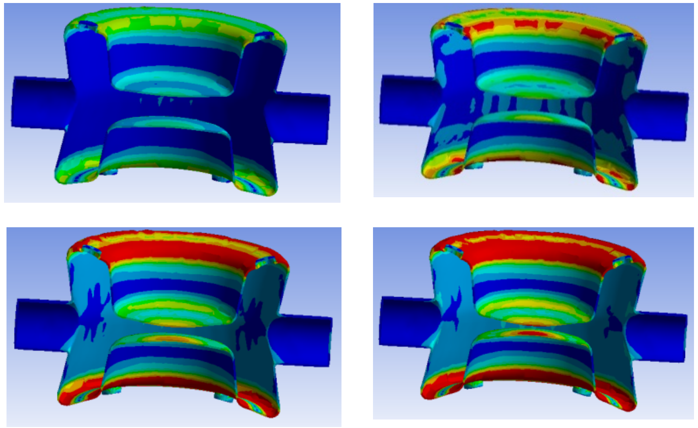
	Unit	DQWCC
Fundamental Mode Frequency	MHz	400
Nearest Mode Frequency	MHz	579
Vertical Deflection Voltage	MV	3.3
Rt/Q (Fund. Mode)	Ohm	400
Epeak	MV/m	44
Bpeak	mT	60 on cavity 79 on port blending
Energy Content	J	12



Peak field on port blending region. Improved in SPS prototype cavity design, see later slides.

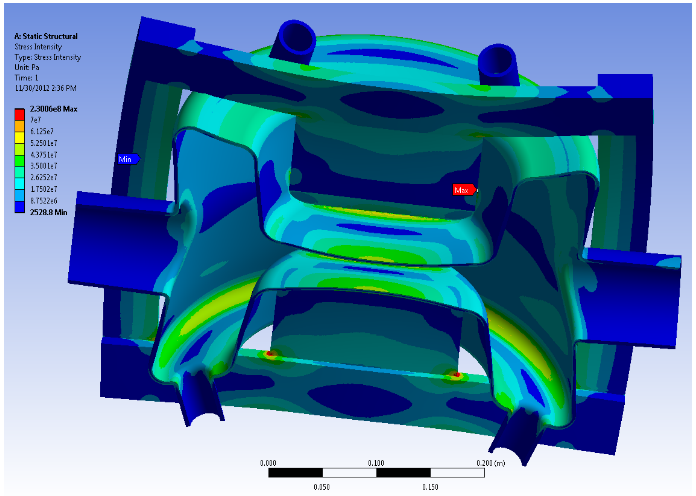
Cavity Stress Analysis





Bare cavity without stiffening frame

- Pressure: 2e5 Pa (2 bar) outside, vacuum inside. Requirement for PoP Cavity.
- Fixed Support: One side of beam port.
- Stiffening plates and frames are added to the cavity for vertical cold tests.
- The material for stiffening components can be either Nb or Ti.



Cavity stress with stiffening frame

Multipacting study

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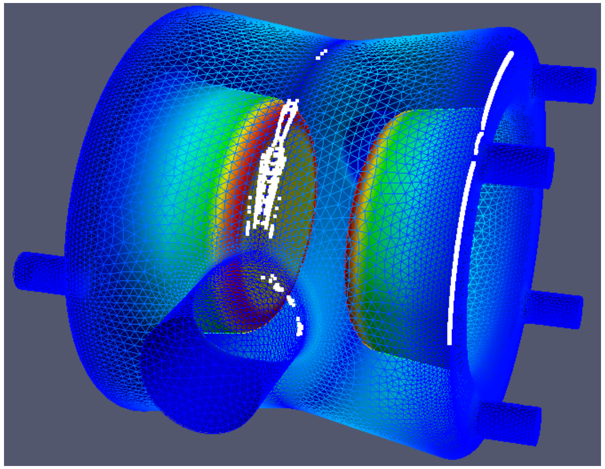

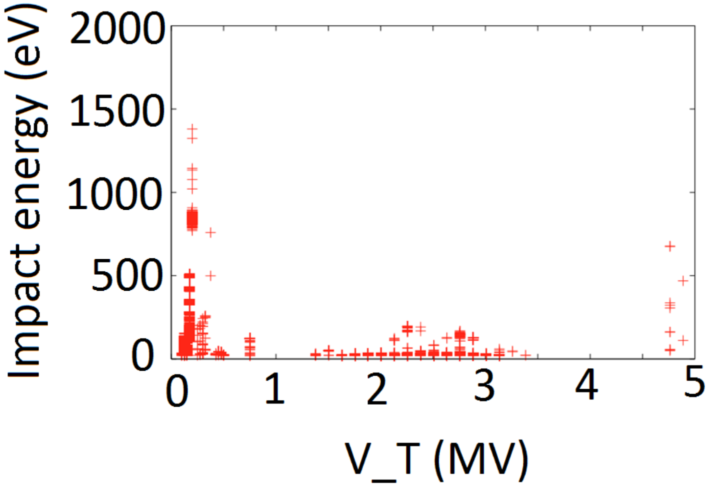

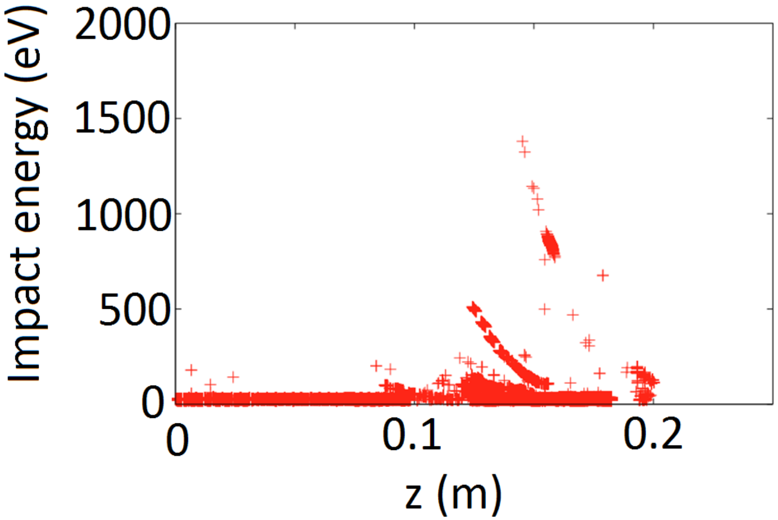

Small multipacting (MP) region was found around the waist of the cavity at ~0.1 MV of deflection voltage. Verified and processed during vertical tests.

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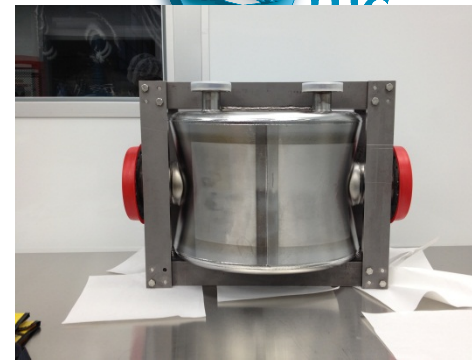
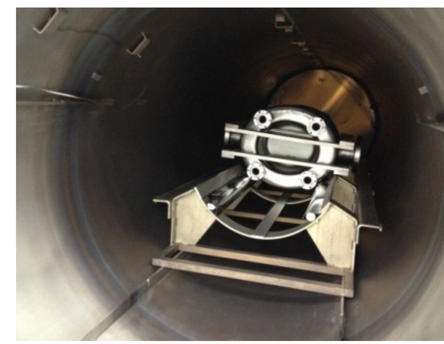
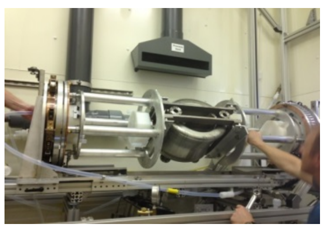
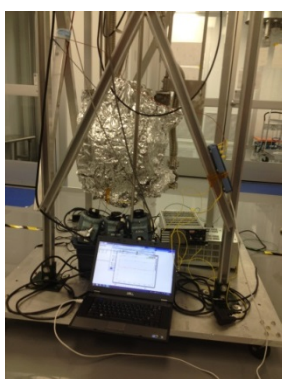
PoP Cavity
Fabrication & Preparation





Test I





Test II

PoP cavity test results (1st)

- 1st cooled down test done in June 2013.
- Multipacting (MP) was found for the region of 0.07-0.16 MV and was easily conditioned through. The MP did not come back after the conditioning.
- Q_0 measured at 3×10^8
- Q_0 did not improve by cooling down from 4.2 to 2 K.
- V_t reached 1.34 MV, limited by the RF power amplifier.
- Further chemistry cleaning and niobium plated flanges helped decrease the heating issue in the cavity.

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PoP cavity test results (2nd)

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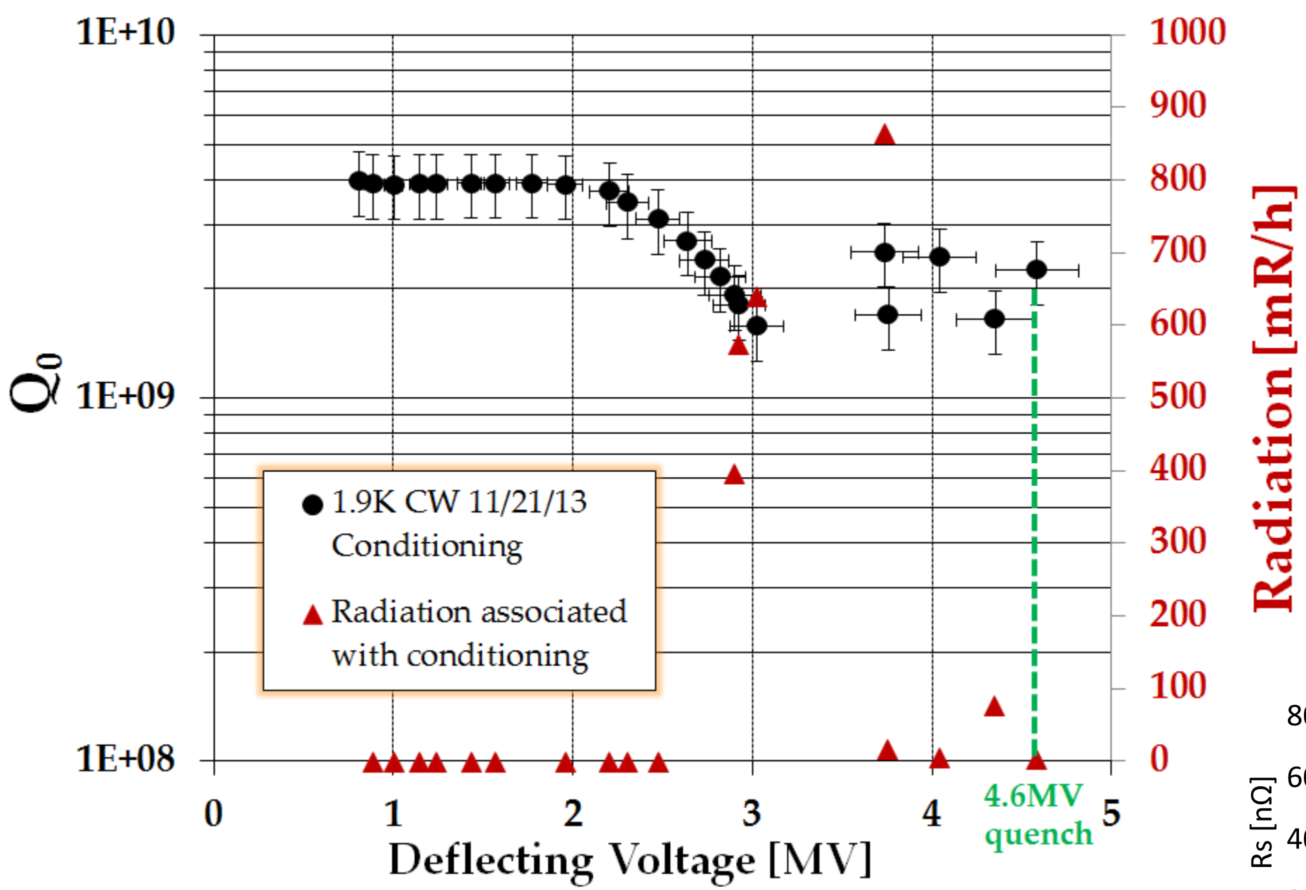
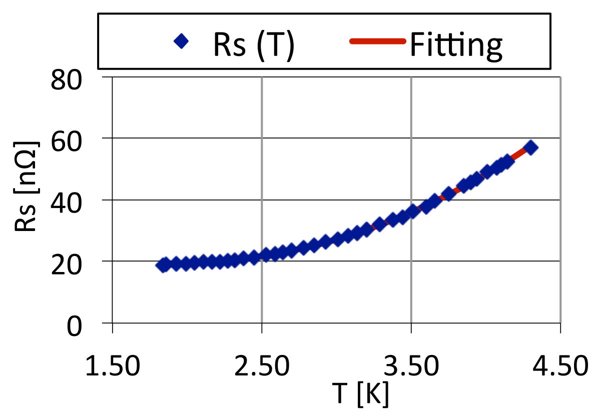
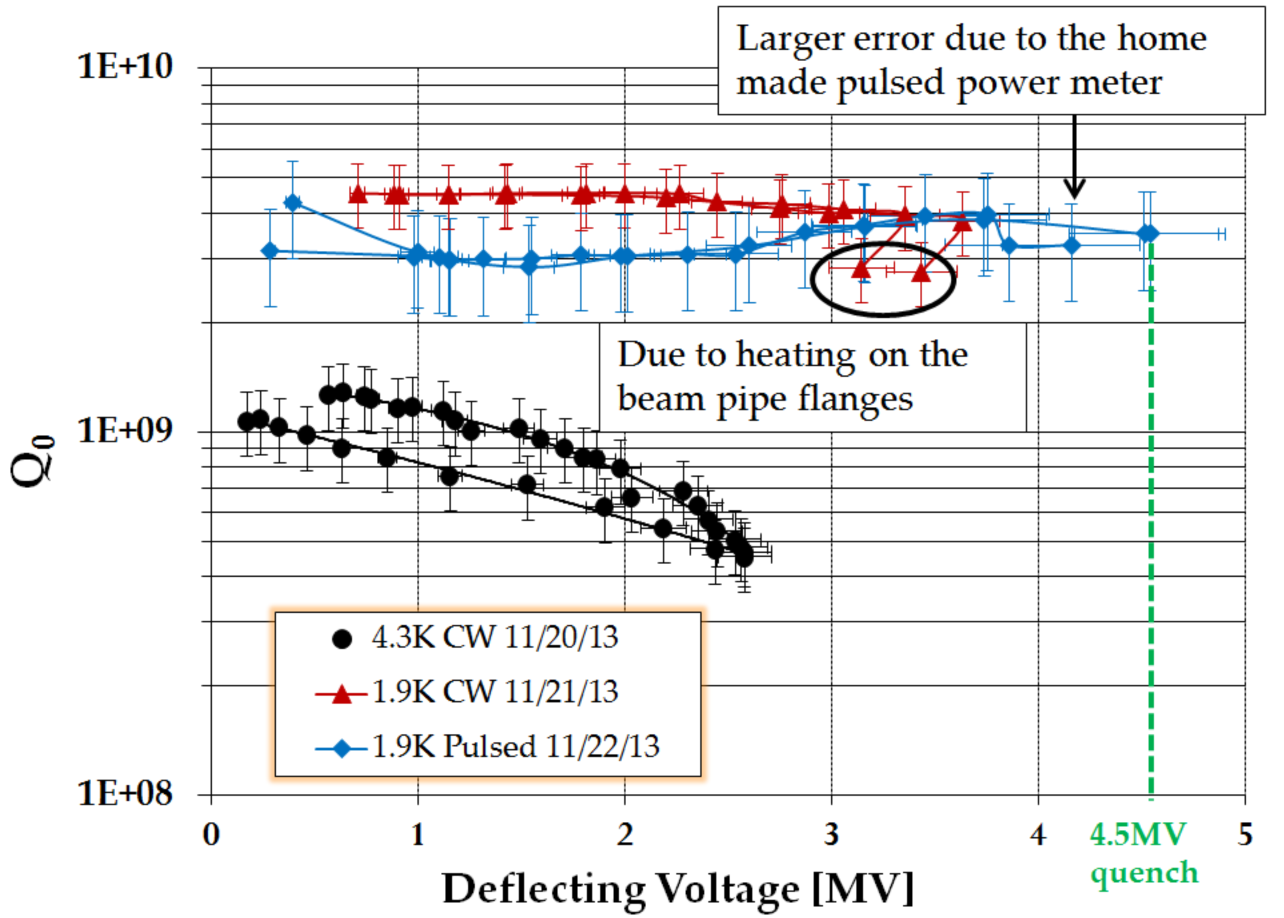


- Q_0 reached 3e9 at low field. The requirement is above 1e10.
- Q_0 decreases starting from 2MV, associating with high radiation.
- Q_0 got recovered after ~30 minutes conditioning.
- Radiation is lower than 15mR/h after the conditioning.
- Reached 4.6MV kick in CW with Q_0 above 2e9, limited by quench.
- Temperature increase on both beam pipe flanges and pickup port blending area.
- Rs at 4.3K: 57nΩ

  1.9K: 18.6nΩ
- Rres is 18.5nΩ

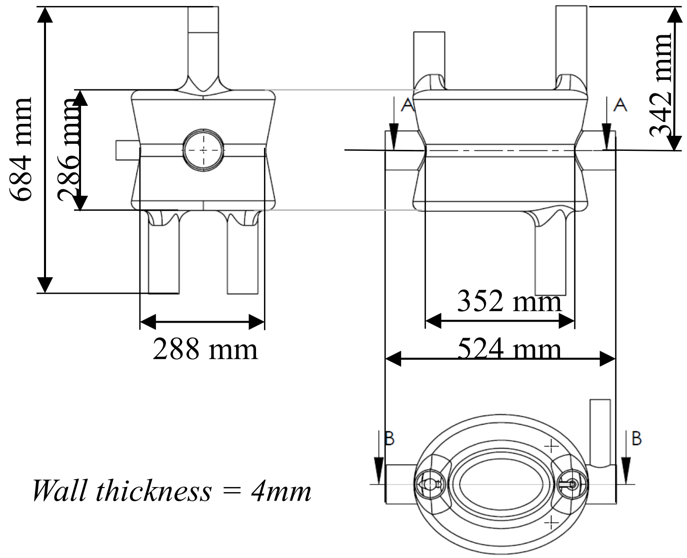


PoP cavity test results (2nd)



- Q_0 at around 3~4.5e9.
- In CW mode, temperature of beam pipe flanges increase.
- Reached 4.5MV kick in pulsed mode with Q_0 always above 3e9, limited by quench, consistent with conditioning test.
- Temperature increase on pickup port blending area.
- Quench field at ~110mT, with peak E field at 52.8MV/m

Prototype For SPS

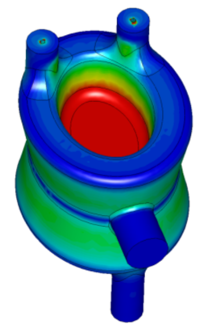


Wall thickness = 4mm

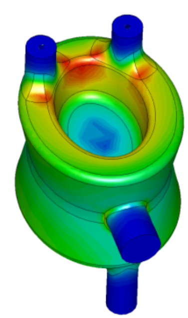
MODES			
Fundamental frequency (crab mode frequency)	f_0	400	MHz
First HOM frequency	f_1	580	MHz
FIGURES OF MERIT			
Transversal R/Q	R_t/Q	430	Ohm
Geometry factor	G	89	Ohm
FIELDS			
Maximum peak surface electric field	E_{max}	37	MV/m
Maximum peak surface magnetic field	H_{max}	69	mT
Accelerating voltage	V_{acc}	15	kV
OTHER			
Field center offset	$\mathcal{O}_{field}$	0.22	mm
Stored energy	U	10	J

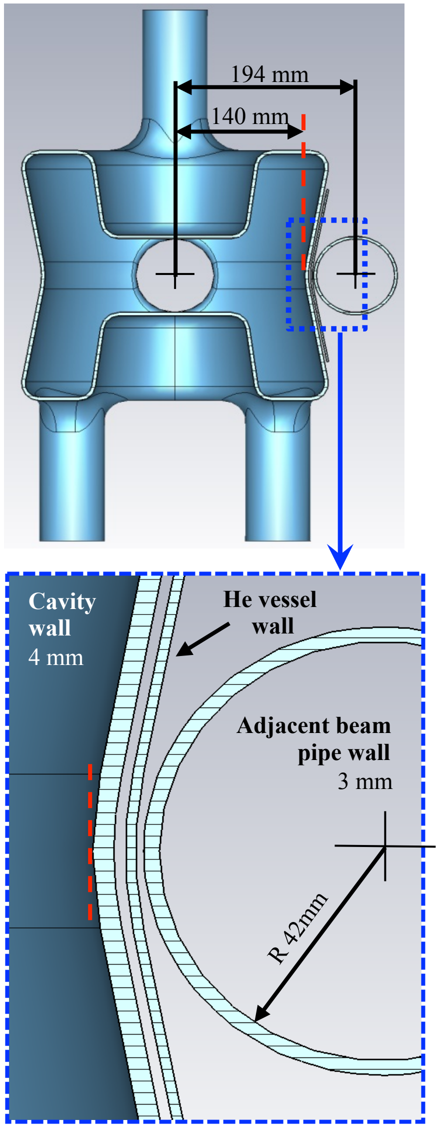
$f(0)$

Electric field

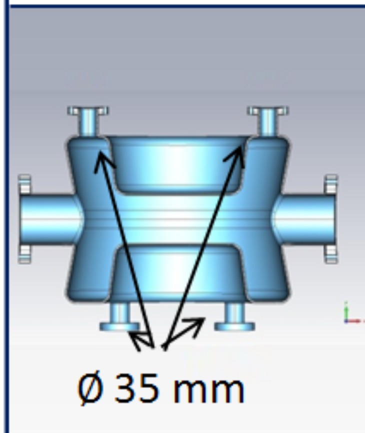
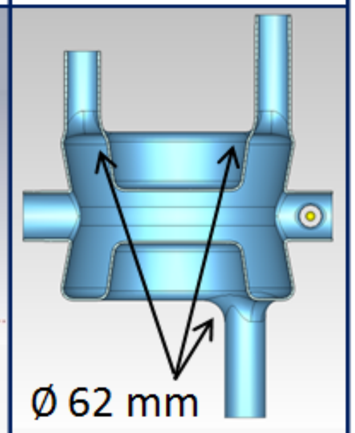


Magnetic field





Improvement in SPS Design

	PoP DQWCC	SPS DQWCC
		
R_t/Q [Ohm]	400	430
G [Ohm]	85	89
E_{max} [MV/m]	38	37
B_{max} [mT]	79	69

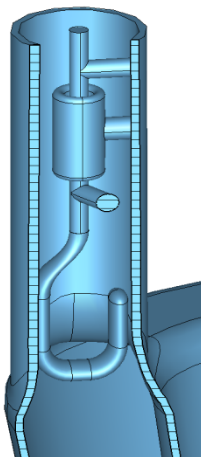
* Values scaled for Vt=3.3 MV.

The FPC port diameter was determined by CERN according to the cooling needed for the coupler. Then all ports were selected to be at the same dimension to minimize the field asymmetry.

→ Quench for **SPS DQWCC extrapolated** to About **5.3 MV** deflecting voltage using the measured quench voltage of the demo cavity (~ 14% higher voltage).

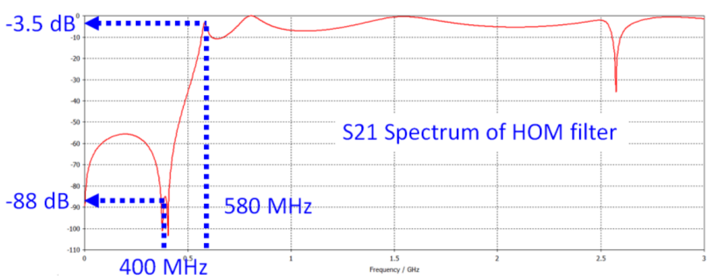
Couplers

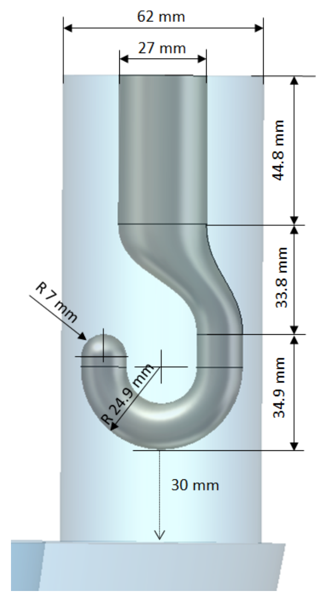
- Three (3) Higher Order Mode (HOM) couplers are proved by simulation to be sufficient for damping. The coupler hook and filter will be actively cooled by liquid helium, and the analysis is undergoing at CERN.
- Fundamental mode coupler (FPC) is designed for providing coupling with Qext 1e5 to 1e6, and peak magnetic field at the same level of the cavity. The FPC waveguide, cooling, and power input will be provided by CERN.
- Pick-up coupler should bring minimum disturbance to the cavity field symmetry and ~ 1 W of power for the low level control system.



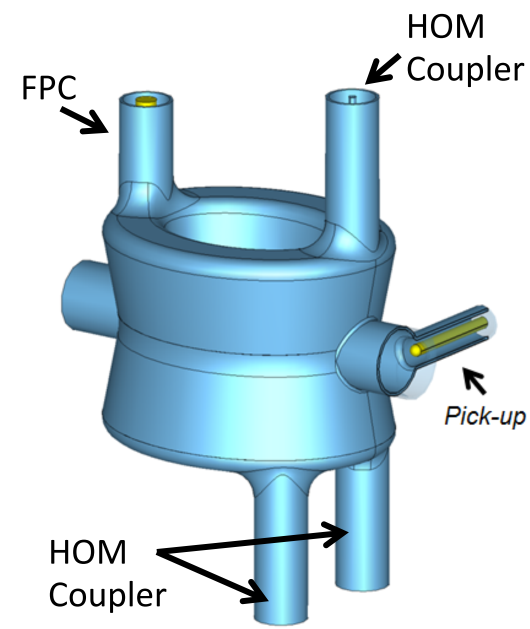
HOM coupler and filter

The maximum magnetic field on the HOM coupler is 50 mT, and the coupling to the first HOM is 471.



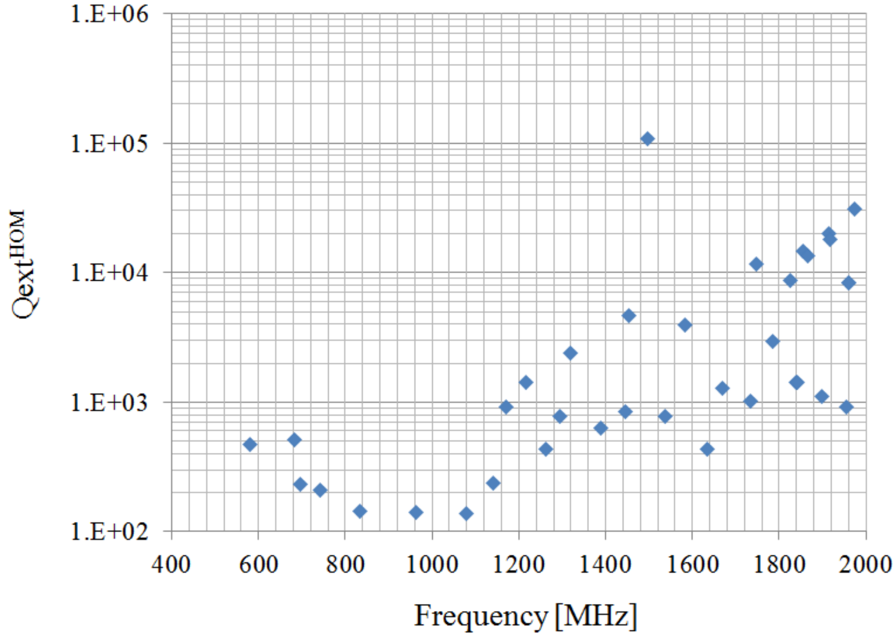


FPC hook: *Qext $^{f(0)}$ = 6×10^5, 40 kW power supply is enough to feed the cavity*



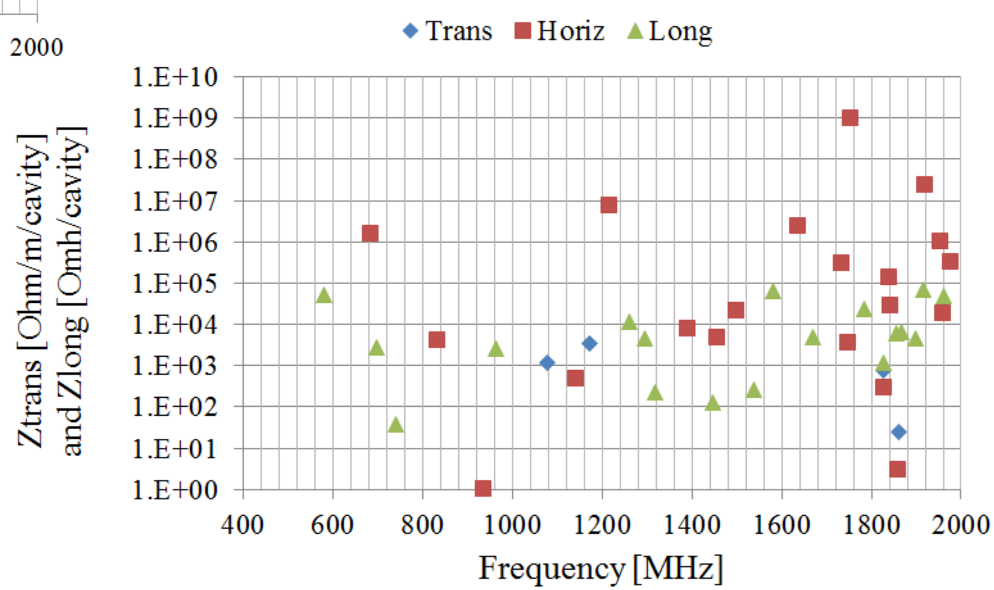
Pick-up antenna: Qext $^{f(0)}$ about 3×10^{10}, enough to extract about 1W of fundamental mode.

HOM table

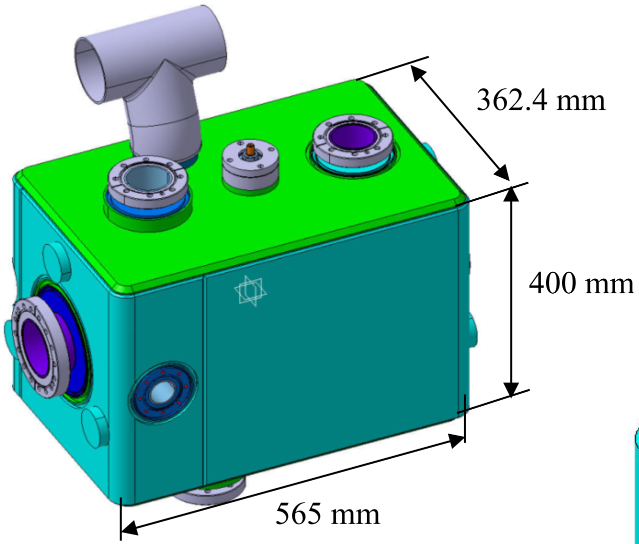


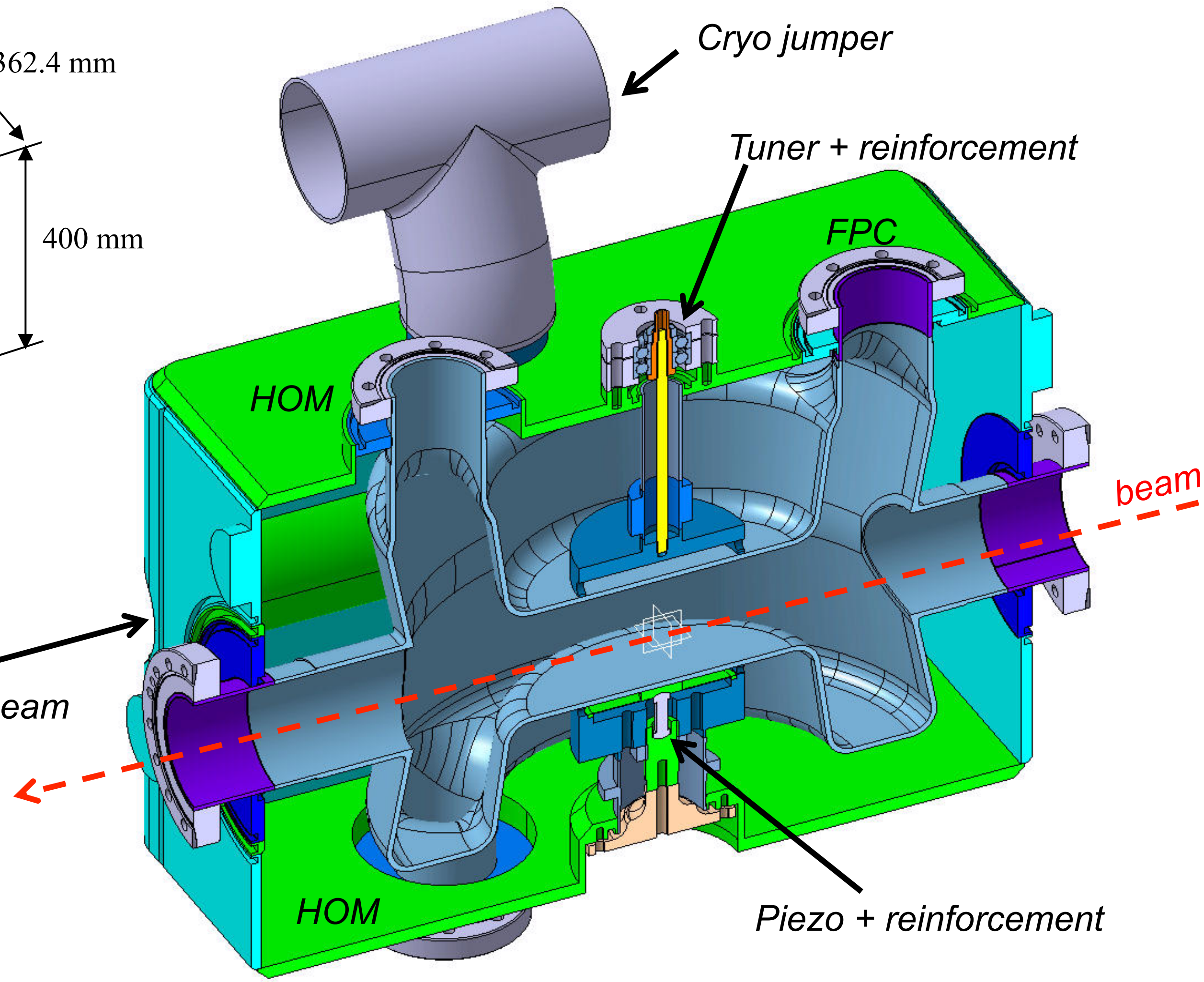
- The HOMs are coupled out with the design of the coupler hook shown in the.
- The external Q of the first HOM is 471, which is much lower than the limit of 1000. The Qext shown here is before the filter.
- The mode at 1.5 GHz with Qext above 1e5 has a very small R/Q of 6e-3 Ohm.

The impedance of each HOM is calculated accordingly. We will collaborate with beam dynamics study at CERN to validate the design.

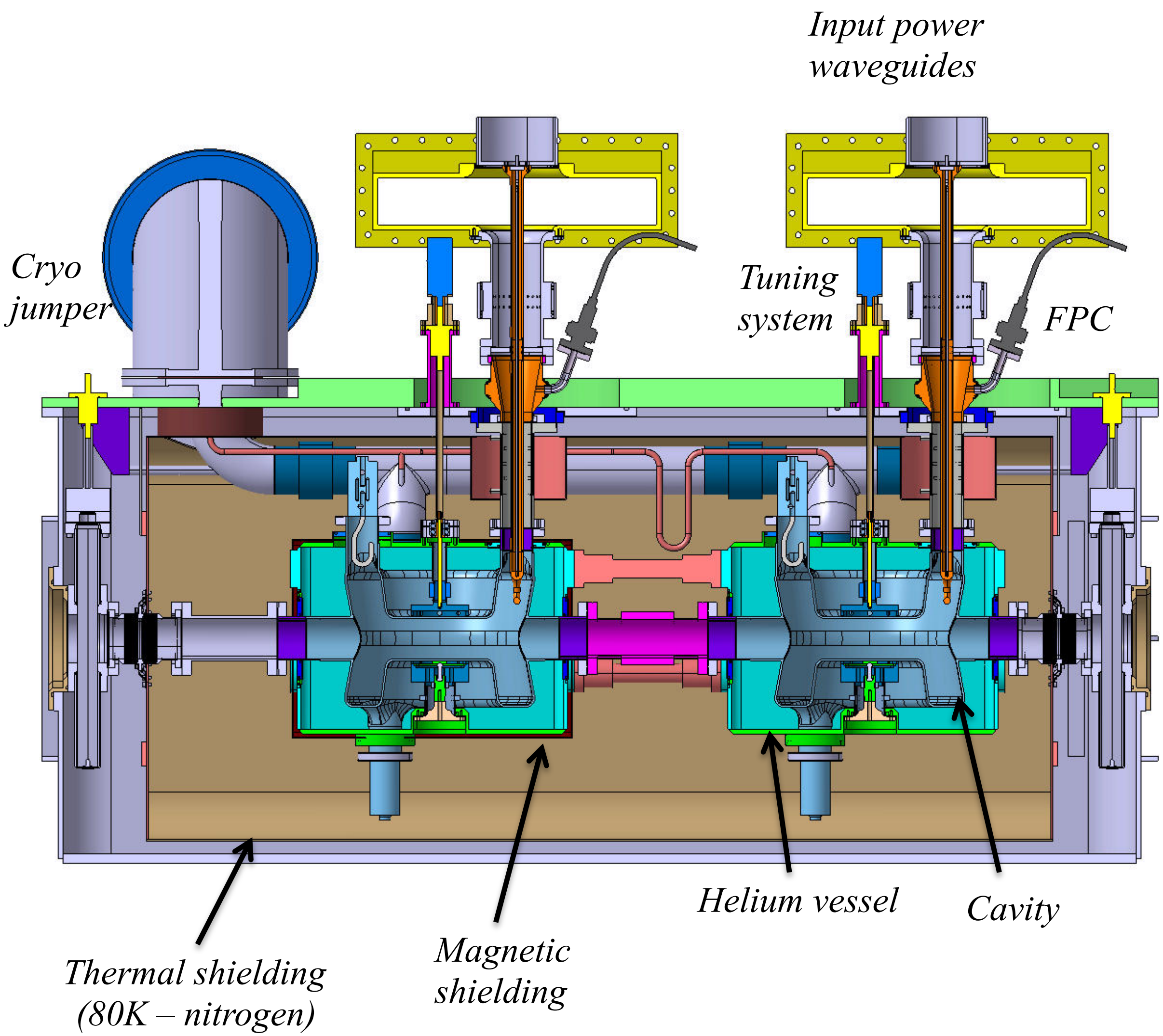


Dressed Cavity

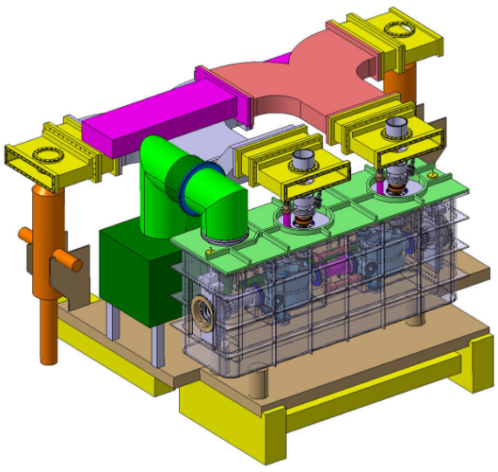




Cryostat (SPS)



The cryomodule design concept was first initiated at STFC Daresbury Laboratory（UK), then adopted and substantiated by CERN engineers.



Plans (2014)

- PoP Cavity
  - Profile measurement of PoP DQWCC (Done)
  - Static magnetic field measurement of the test dewar (Done)
  - Beadpull measurement for HOMs and off-center field
  - Cold test again at CERN
  - Test tuning system for SPS prototype cavity
- SPS Prototype Cavity
  - Rf/thermal/mechanical studies of cavity-vessel system
    - Multipacting studies and verification of fields
    - Table of frequency shifts
  - Finalize thermal-mechanical design of helium vessel and tuning
  - Send final version of design with helium vessel to Niowave in April for fabrication
  - Multipole studies
- HOM filter
  - RF design completion of HOM filter (near complete)
  - Make a 3D printing of the RF design and copper plate the surface (Done) for RF measurements
  - Thermo-mechanical design of HOM filter

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High Luminosity LHC

Plans (2015-2017)

- HOM coupler and filter
  - Finalize thermal and mechanical design.
  - Prototyping HOM coupler and filter for RF measurements at liquid He temperature.
  - Fabricate six assemblies for SPS cavities.
- SPS prototype cavity
  - Cold test both prototype cavities
  - Cold test dressed prototype cavities
  - Deliver both dressed cavities to cryomodule assembly site
  - Support SPS beam test
- LHC cavity
  - Adopt cavity for both deflection schemes (vertical & horizontal) at IP1 and IP5
  - Adopt cavity ancillaries for both deflection schemes
  - Collaborate with CERN to revisit both deflection cavity assembly specifications
  - Collaborate with CERN on alignment and other issues for LHC installation

Summary

- The PoP cavity has confirmed our design concept by achieving 4.6 MV of deflecting voltage in vertical test.
- The prototype cavity design for SPS test is coming to an end.
- It will join the helium vessel design with CERN collaboration and delivered to Niowave for fabrication in April.
- The HOM coupler and filter RF design is close to completion. Simulation will be verified with a Proof of Principle model. We will incorporate minor changes to lower surface field and suppress multipacting.
- A prototype HOM filter will be made for testing.
- Tuner and Cryomodule design is underway with close collaboration with CERN scientists and engineers.
- We are using all the resource available to us at BNL to improve our design of the entire crab cavity assembly.

Collaboration

Sergey Belomestnykh, Ilan Ben-Zvi, John Skaritka, Silvia Verdú-Andrés, Binping Xiao, Qiong Wu

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