Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

1.3GHz WOW type crab cavity for ILC

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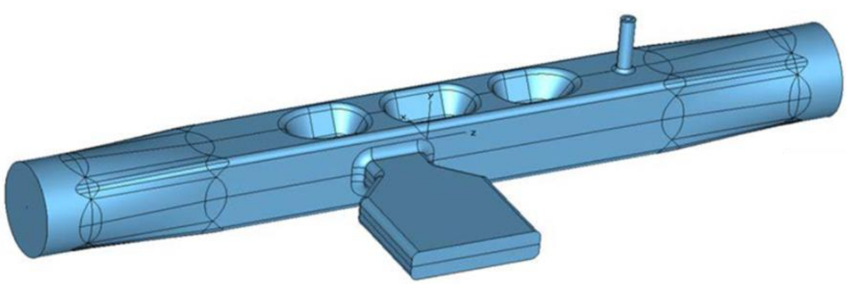
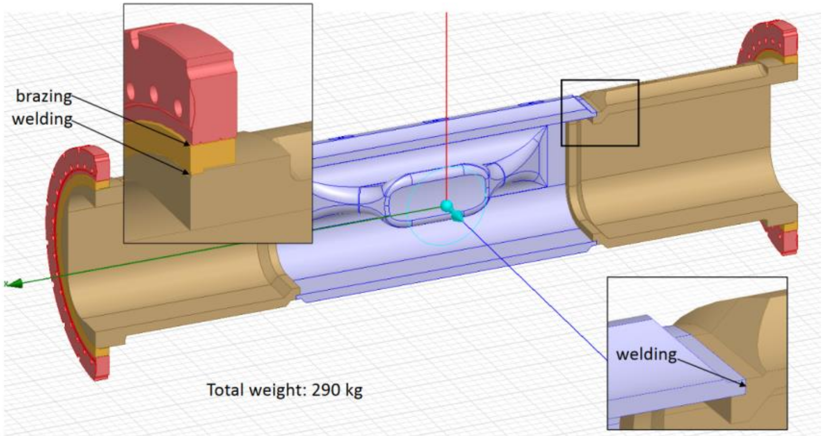
WOW type crab cavity

- Crab cavity with wide open waveguides (WOW) was proposed back in 2014 in HOMSC meeting by Fermi Lab colleagues (Quasi-waveguide Multicell Resonator: QMiR).
- CERN colleagues proposed WOW type crab cavity for LHC & FCC in 2015.
- EIC proposed to use WOW+RFD as a backup solution for 394MHz crab cavity.



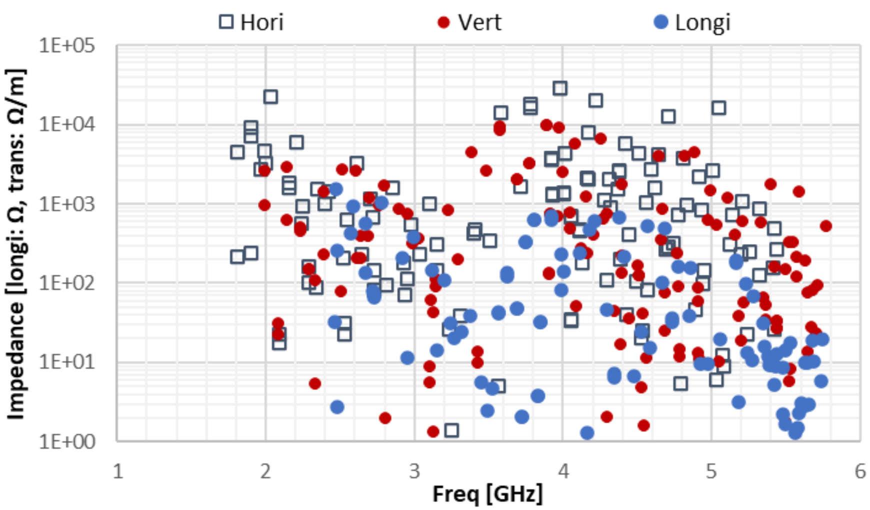


https://indico.fnal.gov/event/7942/contributions/104178/attachments/68128/81727/HOM_Free_Deflecting_Cavity.pdf
https://inspirehep.net/files/40359296b280f1cdd0a2b1cb94e33785

EIC WOW type

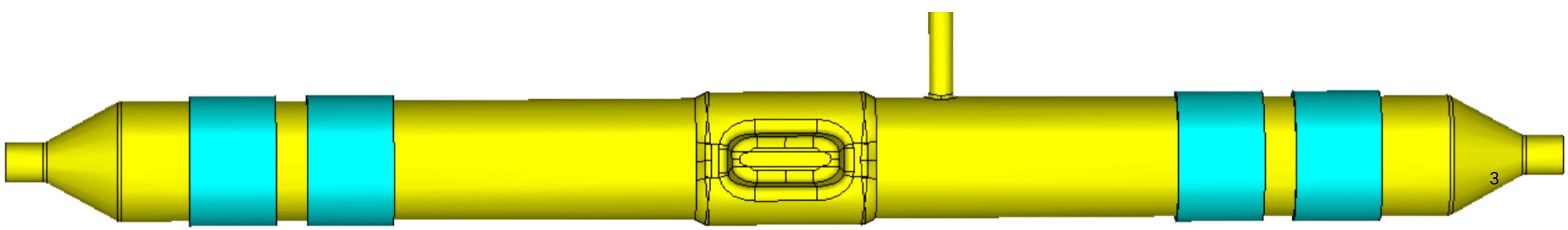
(Scaled to 1.3GHz)

- Two SiC absorbers on each side.
- 30.3mm gap & 94mm pipe.
- Vt: 1.27MV, Epk: 50.4MV/m, Bpk: 80.0mT. Can be improved.
- Max imped, longitudinal: 1.5e3Ω, transverse: 2.9e4Ω/m.
- Needs 6 cavities for 7.4MV.



BNL/SLAC joint effort

- Adjacent cavities can share SiC absorbers.
- Total 4.74m.
- Further optimization to lower the peak fields (less cavity number)

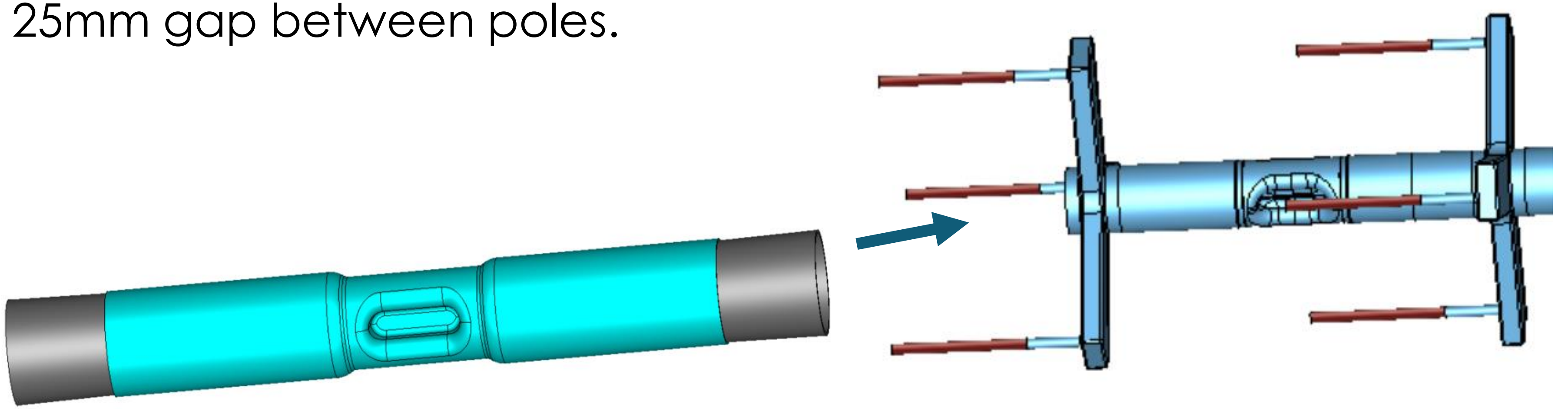


Two major changes in specs

- Minimum gap from 20mm to 25mm, number of cavities increases from 4 (1.85MV/cavity) to 5 (1.48MV/cavity).
- Installation length from 3.8m to 3.25m, and then back to 3.8m.

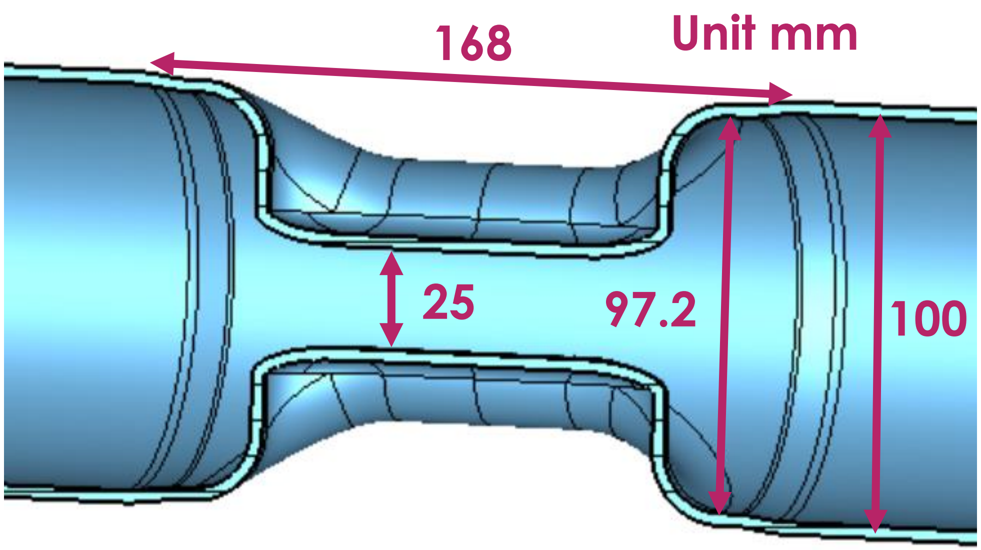
Design considerations

- RFD cavity shape, with WOW and ~~beam line absorbers (BLA)~~ Nb waveguide (WG) to coax absorbers on both sides.
  - WG to coax can be shorter than BLA.
  - WG to coax can joint with cavity using either indium seal or Cu gasket.
  - Fundamental mode can attenuate in WG.
  - While both of them are detachable from cavity.
- First transverse HOM at ~1.8GHz, first longitudinal HOM at ~2.3GHz.
- Choose 100mm ID WOW
  - with cutoff frequencies at 1.758GHz for TE_{11} and 2.297GHz for TM_{01}.
  - It is a good size for gate valve, no need for tapering.
  - it is also the beampipe size for EIC crab cavities.
- 25mm gap between poles.



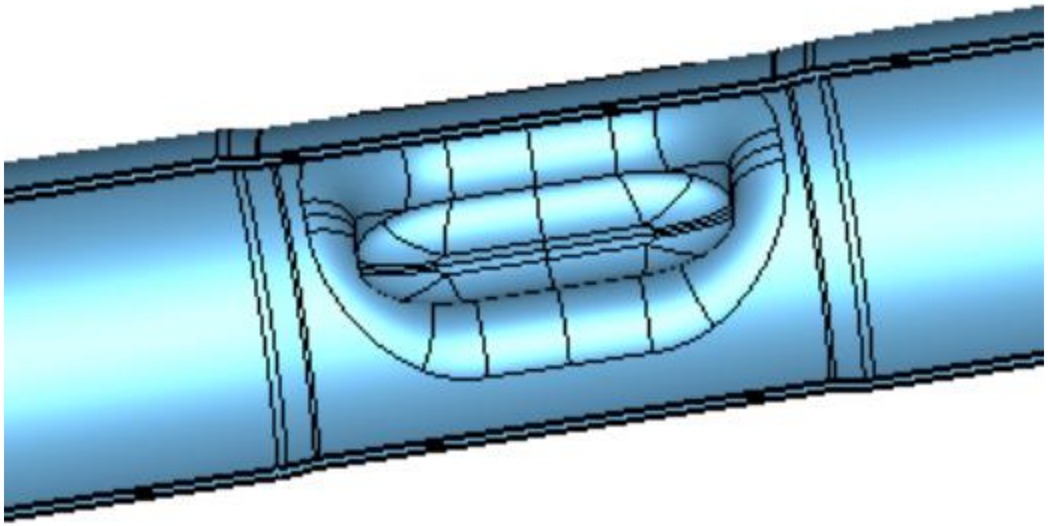
Cavity parameters

Property	Value
Operating frequency [GHz]	1.300
1st longitudinal HOM [GHz]	2.299
1st transverse HOM [GHz]	1.765
E_p/E_t with $E_t=V_t/(\lambda/2)$	3.24
B_p/E_t [mT/(MV/m)]	5.75
B_p/E_p [mT/(MV/m)]	1.77
G [Ω]	130.9
R/Q [Ω]	454.3
R_tR_s [Ω^2]	59446



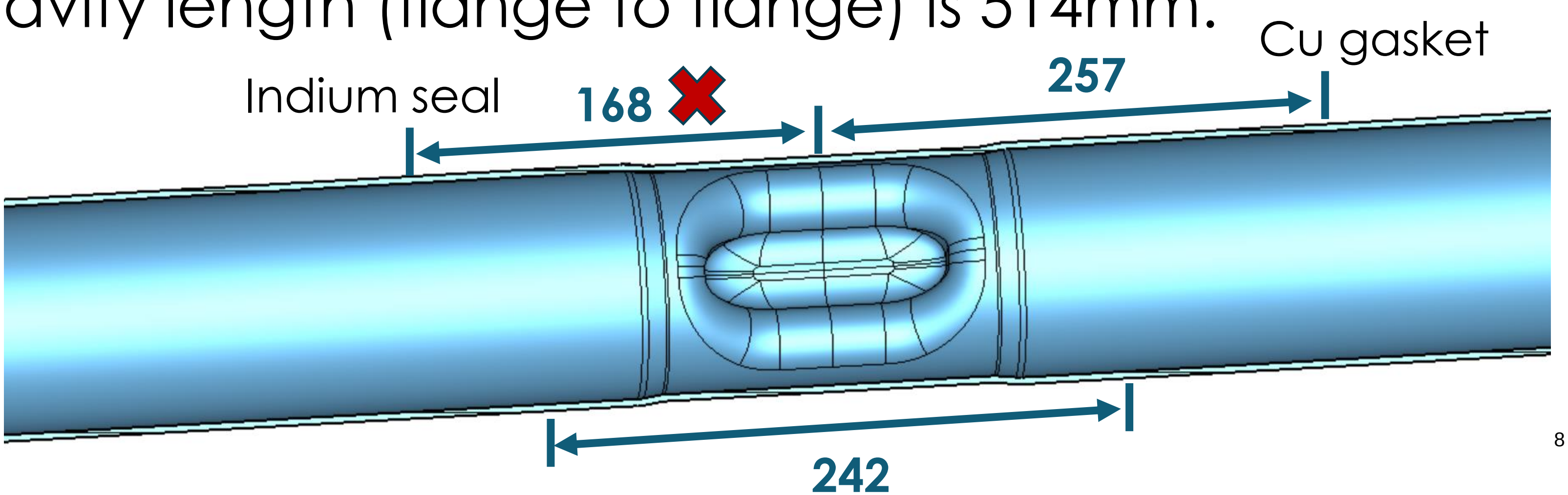
Peak fields

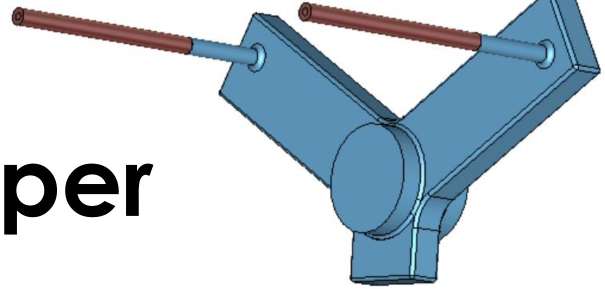
- Needs 1.845MV for 125GeV case and 7.4MV for 500GeV case.
- 5 cavities for 500GeV, meaning 1.48MV per cavity, corresponding to 41.6MV/m E_{pk} and 73.8mT B_{pk}.
- With this we need 2 cavities for 125GeV.
- With 45MV/m E_{pk} and 80mT B_{pk}, cavity could operate at 1.60MV, with a total of 8.0MV from 5 cavities.



Interfaces

- Cavity helium vessel is placed at 8mT magnetic field Under nominal voltage. Length of helium vessel can be as short as 242mm.
- Indium seal is placed at 2.5mT, located at 168mm from cavity center.
- Cu gasket is placed at 220A/m, located at 257mm from cavity center.
- We will use Cu gasket, indium seal is NOT used.
- Cavity length (flange to flange) is 514mm.

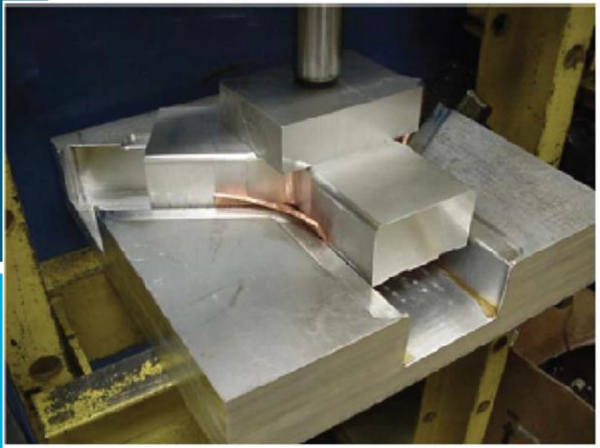


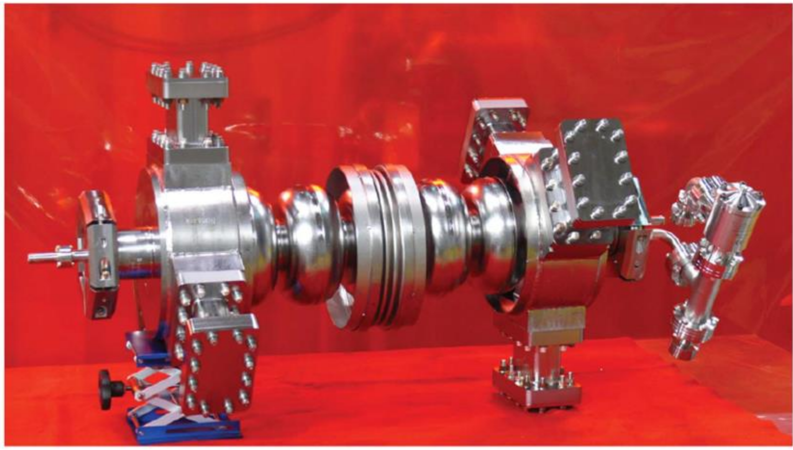


Waveguide to coax damper

- Similar study for both 197MHz and 394MHz EIC crab cavities.
- 86.2mm x 32.3mm rectangular WG to 7/16 coax (port ID 16.2mm), 3 WGs evenly distributed on circular pipe.
- Simple identical E-probes are used.
- Connection to cavity could be either indium seal or Cu gasket.
- To save space, we can add a few corrugations on the circular pipe so that we do not need bellows between cavities.
- Considering to electrically short 1 WG to reduce the number of coax on each circular pipe from 3 to 2. (top picture)
- Similar to JLab ERL-FEL damper.

Courtesy: Bob Rimmer



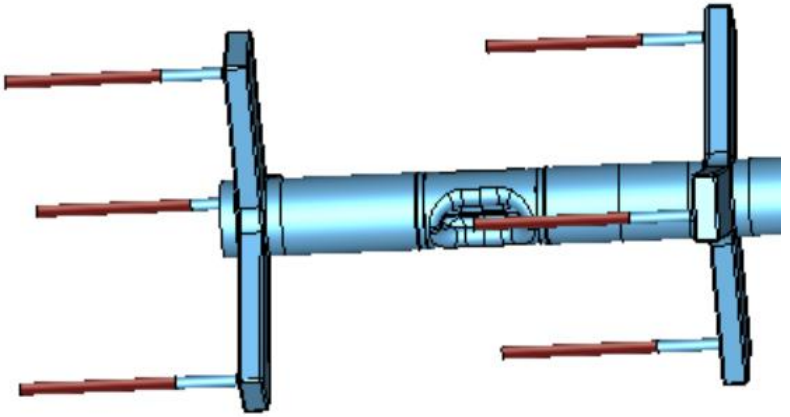


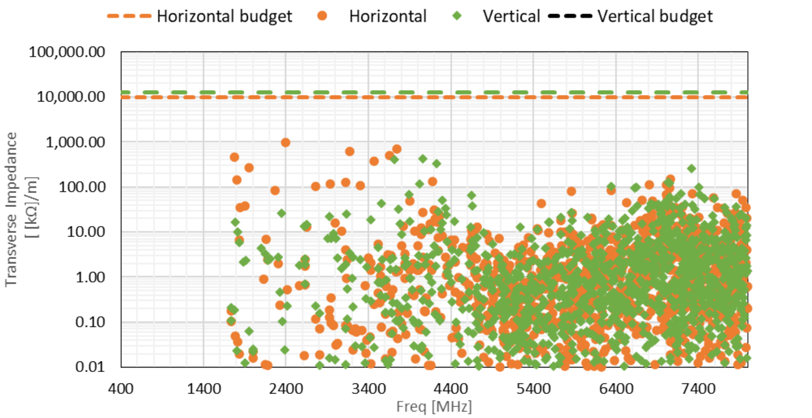
Fundamental loss on HOM absorber

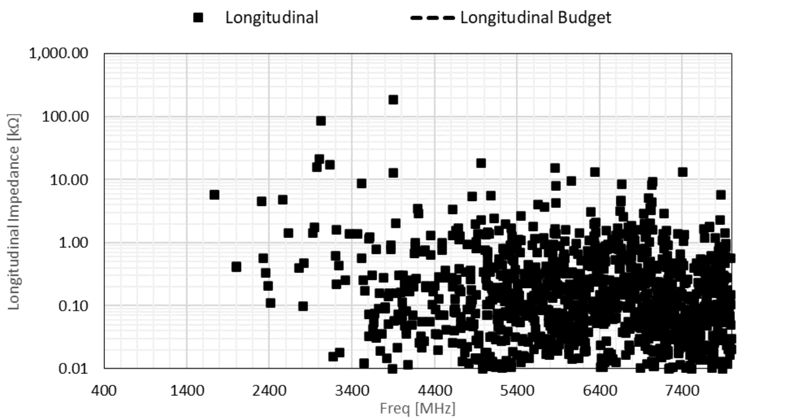
- At 1.48MV, the RF loss of the fundamental mode on each HOM absorber needs to be <0.1W since it is planned to use 4K thermal anchor to cool down the absorber.
- With 454.3Ω R/Q. the Q should be >4.8e10.
- Waveguide 0.245m long from the beam center.
- 0.1W each on two of the absorbers, and 0.024W each on the other two, total 0.25W.
-

Impedances

- First round of simulation with one damper unit on each side, beampipes are with electrical boundary condition.
- Max horizontal impedance 0.99MΩ/m, max vertical impedance 0.43MΩ/m, 1/10 of the budget (9.76MΩ/m horizontal and 12.34MΩ/m vertical), all numbers are per cavity.
- Max longitudinal impedance 186kΩ per cavity, further optimization can be done if needed.
- Simulation on full structure (5 cavities with 6 damper units) with open boundary on beampipe will follow.
- Possible to reduce absorbers on each damper unit from 3 to 2.

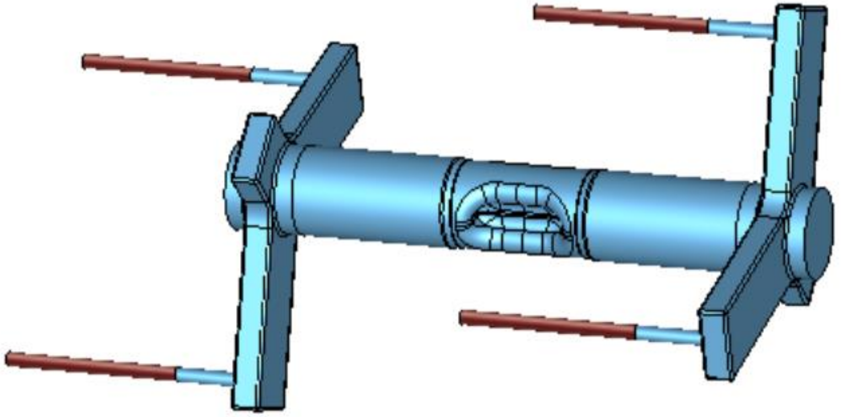


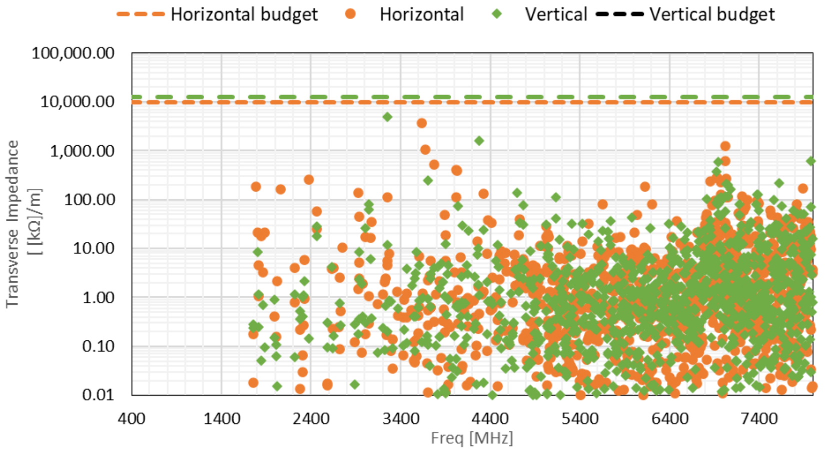


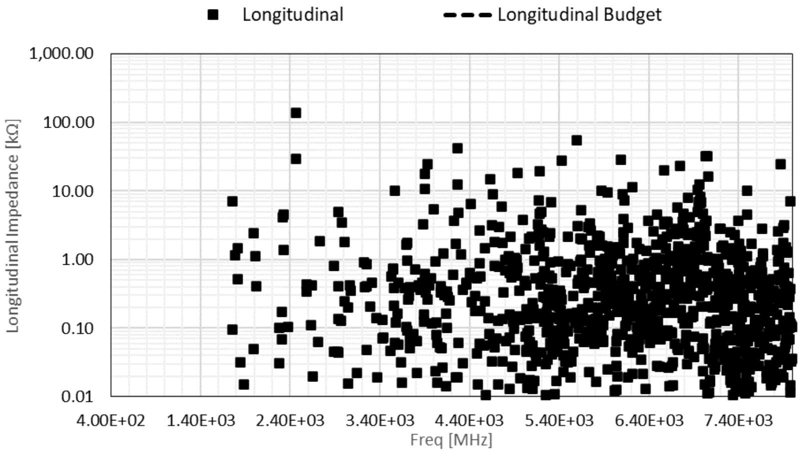


Impedances (2)

- Two coax absorbers on each damper unit.
- Max longitudinal impedance 139kΩ per cavity.
- Max horizontal impedance 3.65MΩ/m and max vertical impedance 4.87MΩ/m, within the impedance budget.
- Further optimization can be done if needed.
- Simulation on full structure (5 cavities with 6 damper units) with open boundary on beampipe will follow.

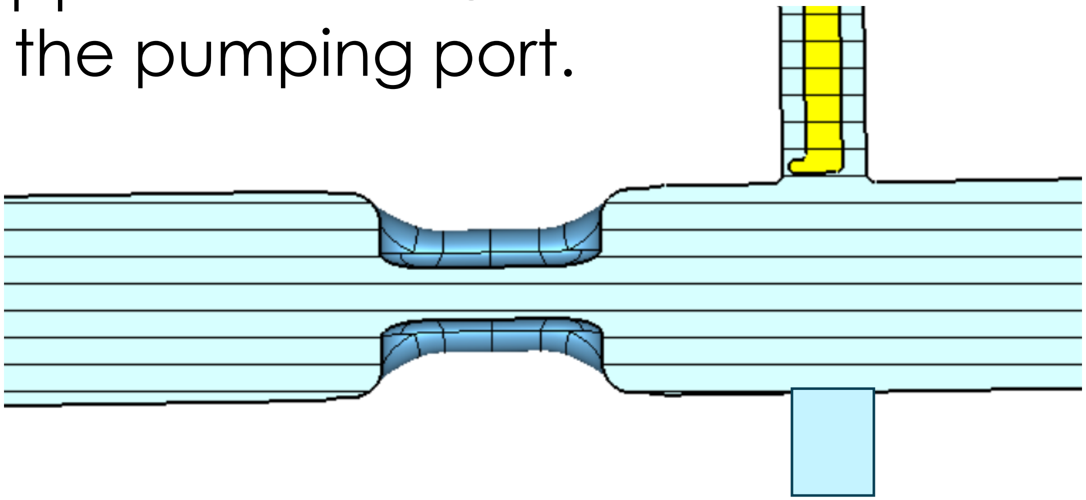






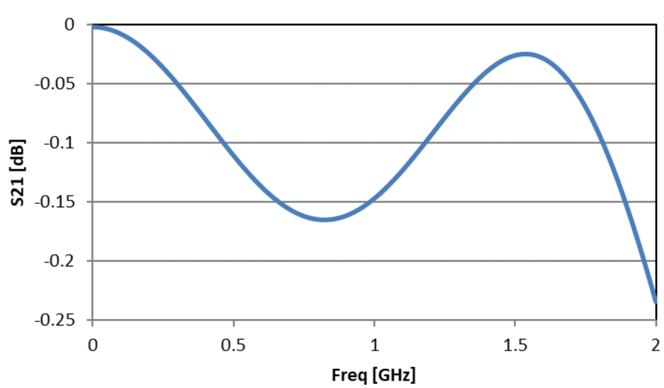
FPC

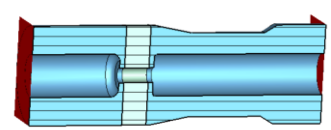
- Horizontal E-probe FPC outside the helium vessel.
- Assuming 0.5mm offset, 200Hz frequency shift and 10mA peak current, at 1.48MV we need 3e6 coupling and 850W power.
- Less than 2W power dissipation on the inner rod, conduction cooling is enough, coax to waveguide transition or quarter wave stub for water/gas cooling is not needed, which leads to a simple design.
- Another port opposite to FPC to balance the field, and to serve as the pumping port.



FPC Window

- Coax window for 40mm port can be used.
- I propose to use the same as LHC DQW HOM window.
- It was tested at CERN in October 2017 (Eric Montesinos):
    - Ok: 16 kW pulsed 100 microseconds at 10 Hz with SW all phases (equivalent to 64 kW, but only with 100 microseconds every 100 milliseconds, i.e. 1/1000 average power), more than that some contact started to burn.
    - Ok: 3 kW CW TW during 4 hours
    - Ok: 4 kW CW TW during 1 hour
    - Not OK: 4 kW CW TW after 1 hour and 30 minutes

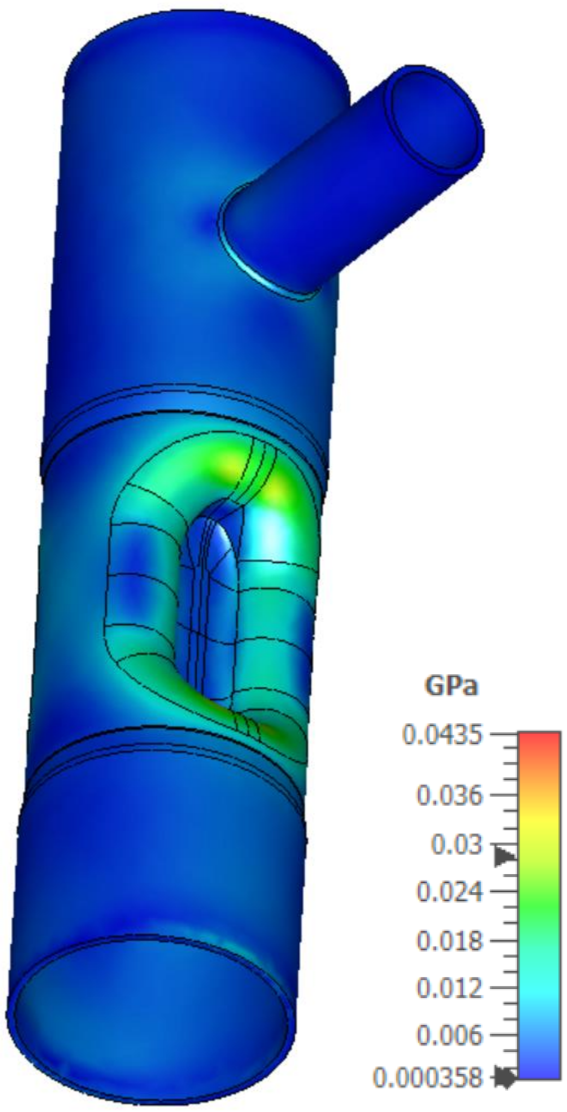




S21 of the LHC Window

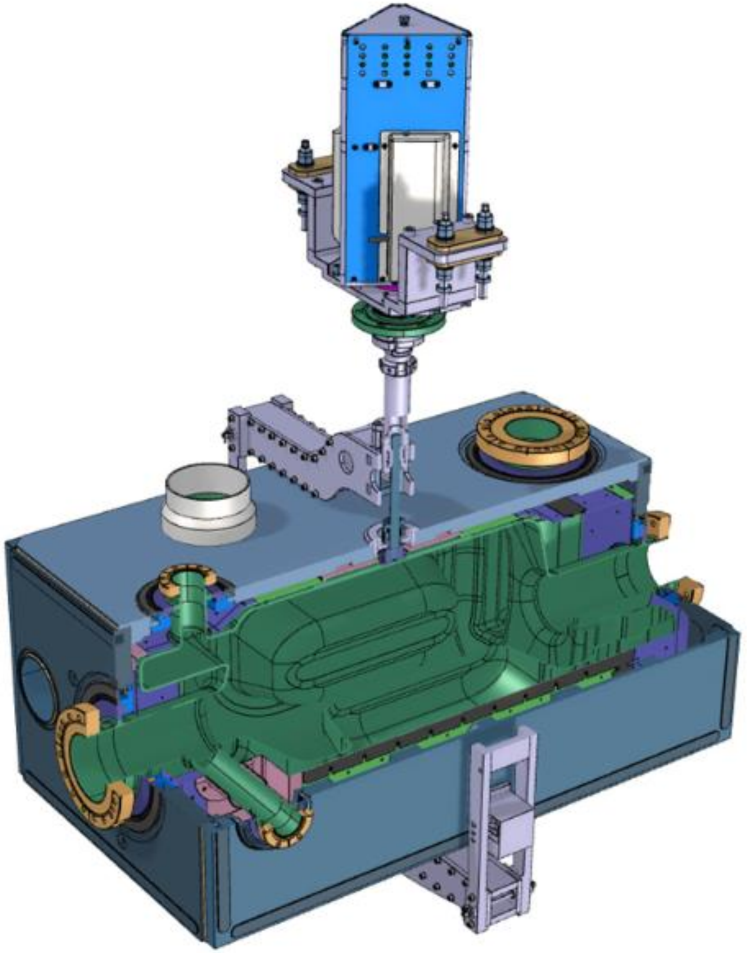
Stress analysis

- Analysis at 2.2 atm external pressure
- Nb material properties at room temperature
  - Young's modulus 82.7 GPa
  - Poisson's ratio 0.38
- Cavity thickness at 3 mm.
- Boundary conditions: Cavity constrained at beam pipes and FPC
- Allowable stress < 43.5 MPa
- Maximum stress 28MPa
- No stiffener needed



Tuner

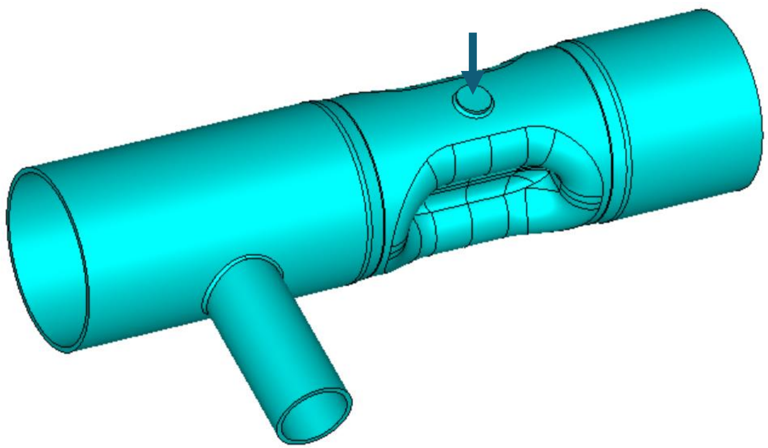
- Tuner will be similar to the LHC RFD cavity, with scissor jack tuner applying force symmetrically to the top and bottom (vertically) of the cavity.

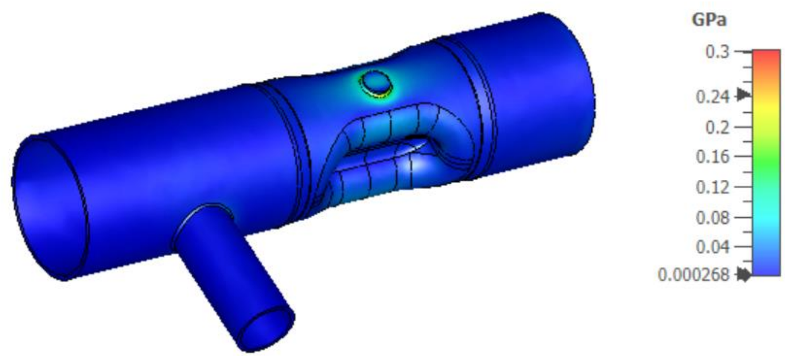


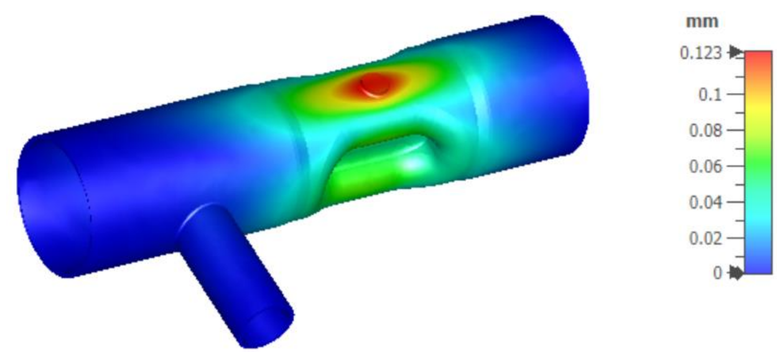
Tuning analysis

- Nb material properties at cryo temperature
  - Young’s modulus –123 GPa
  - Poisson’s ratio –0.38
- Cavity thickness at 3 mm.
- Boundary conditions –Cavity constrained at beam pipes and FPC
- Allowable stress < 0.3 Gpa

- Force 2.5 kN on each side (8MPa on 20mm diameter disk)
- Maximum stress 0.24 GPa
- Displacement 0.12 mm each side
- Tuning sensitivity 10.2 MHz/mm
- Tuning range 2.5 MHz







Pressure sensitivity

- Nb material properties at cryo temperature
  - Young's modulus –123 GPa
  - Poisson's ratio –0.38
- Cavity thickness at 3 mm.
- Boundary conditions –Cavity constrained at beam pipes, FPC.
- Allowable stress < 0.3 Gpa

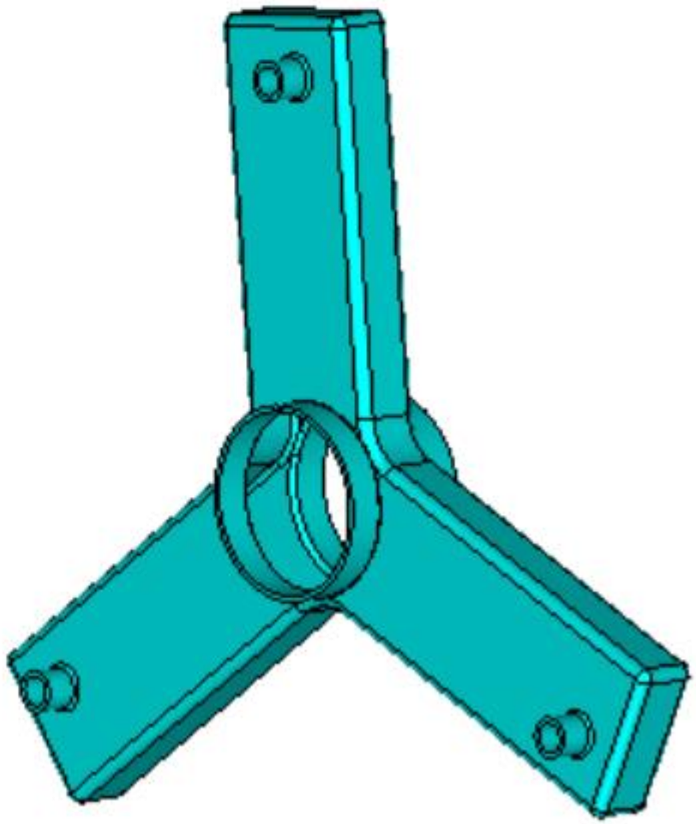
- Apply 1mBar
- Displacement 2.3e-5 mm on the pole each side
- Pressure sensitivity 725Hz/mBar
- Pressure sensitivity 308Hz/mBar with tuner fixed.
- Stiffener is needed in case further improvement is required.

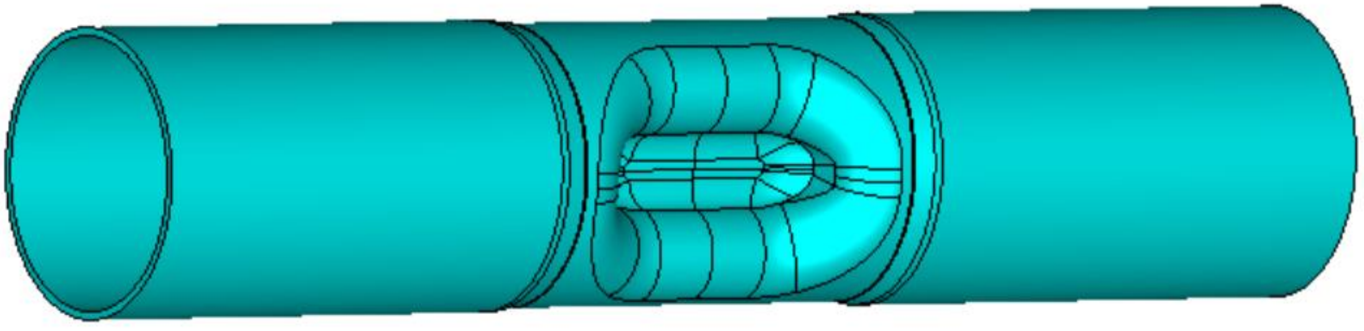
Lorentz force detuning

- Nb material properties at cryo temperature
  - Young's modulus –123 GPa
  - Poisson's ratio –0.38
- Cavity thickness at 3 mm.
- Boundary conditions –Cavity constrained at beam pipes, FPC.
- Lorentz force detuning -1.51kHz/MV^2.
- At 1.48MV, it is -3.31kHz.
- Can be compensated by tuner.

Total weight

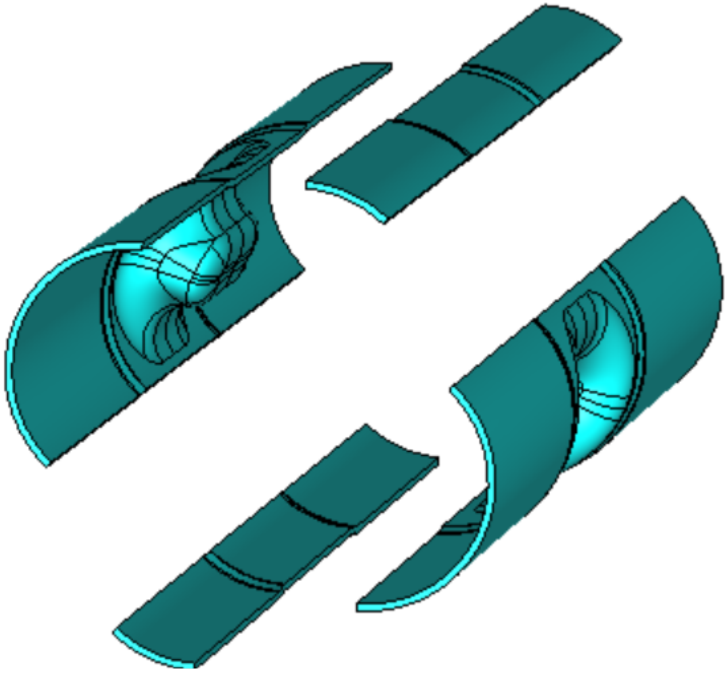
- 3mm sheet
- Cavity 4.4kg
- Damper unit 4.7kg
- For 125GeV, 2 cavities + 3 damper units, total 22.9kg
- For 500GeV, 5 cavities + 6 damper units, total 50.2kg
- May further reduce with 2 coax absorbers per damper unit

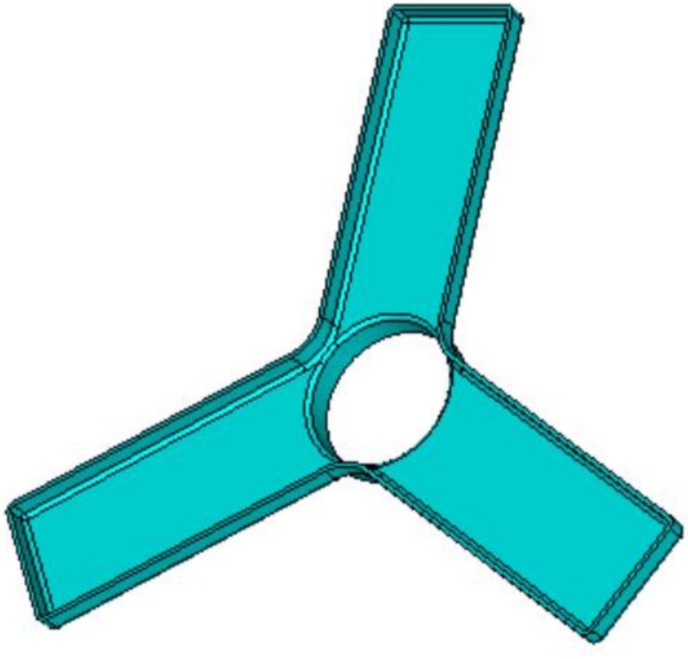




Fabrication

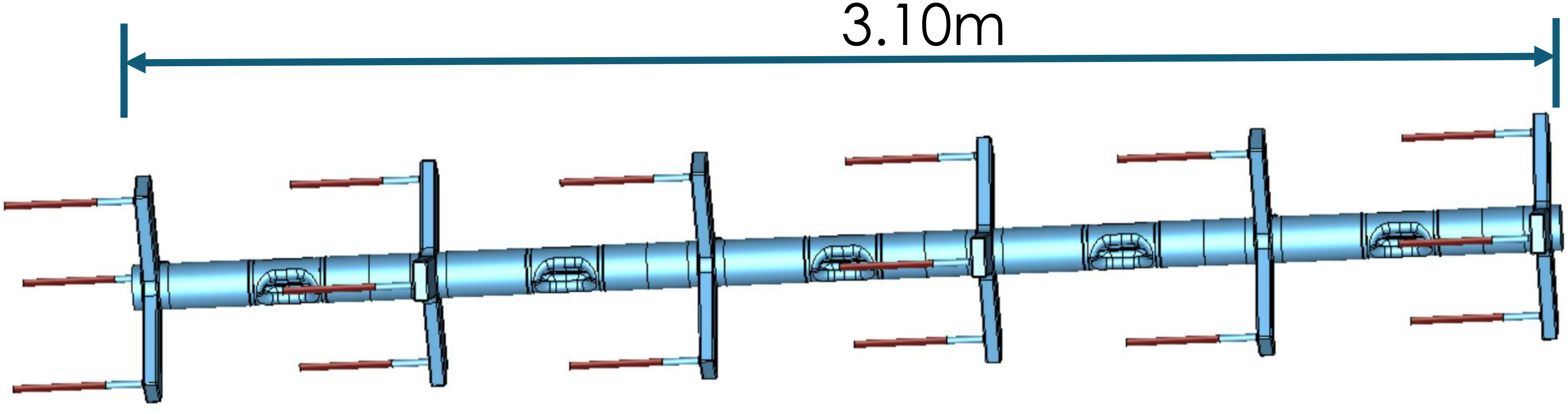
- Three dies:
  - Two for cavity
  - One for damper unit
- Then holes will be added for FPC/vacuum ports and HOM coax ports





Cavity string (estimation)

- One cryomodule with 5 cavities and 6 damper units.
- Simple design with single cell cavities and damper units between cavities.
- Total length can be 3.10m.
- Space reserved for cold-warm bellows and two valves.
- 2 cavities for 125GeV and 5 cavities for 500GeV.



Summary

- WOW + RFD is a good candidate for ILC.
- Simple (robust) cavity with helium vessel design, with FPC/PU/HOM damper all outside the helium vessel.
- Demountable HOM units that connect to the cavity beampipe. HOM units can also be EB welded to the cavity, still outside the helium vessel.
- Total length can be managed within 3.8m.
- Finished preliminary cavity design.
- Optimization on cavity/damper unit is on-going.
- More effort on ancillaries (FPC/PU, HOM damper, RF window, amplifier, tuner etc) is needed.
- Could be a good joint effort.