Crab Cavity Design Options

Double Quarter Wave (DQW)

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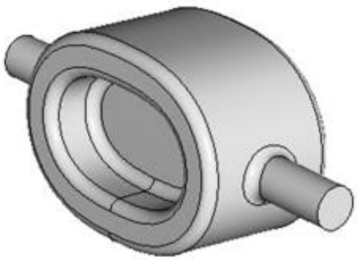
DQW Design Evolution



HL-LHC

- 400 MHz
- Vertical kick
- With waist
- Elliptical profile

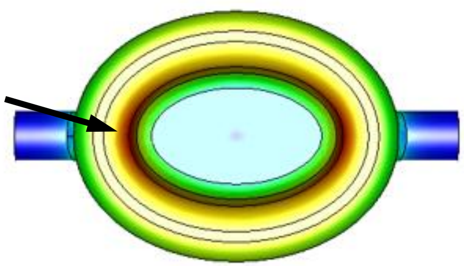
… No clearance issues, ease fab, reduce cost →

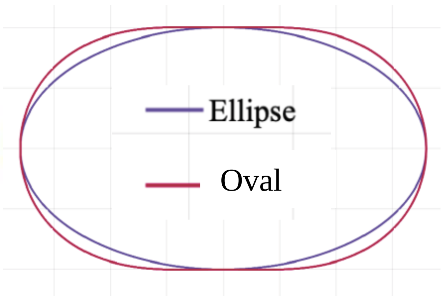
…Further reduce peak fields →

EIC

- 200, 400 MHz
- Horizontal kick
- Flat walls
- “Cassini” oval profile

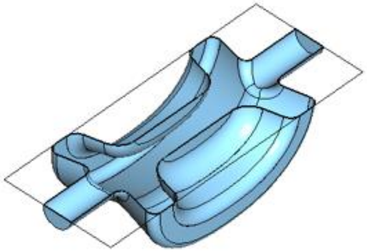
Max. peak surface H





ILC = HL-LHC + EIC

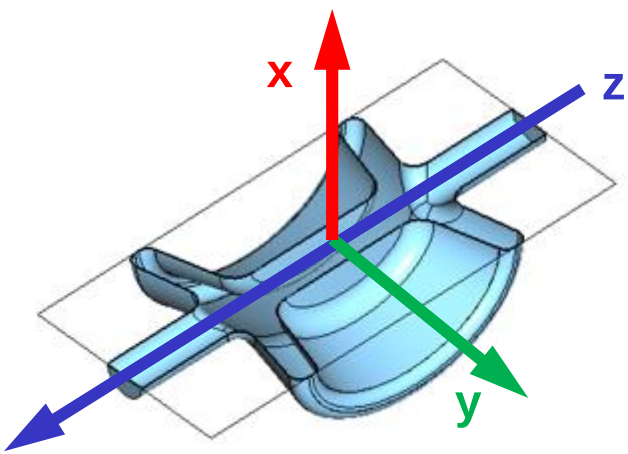
- With waist, “Cassini” oval profile

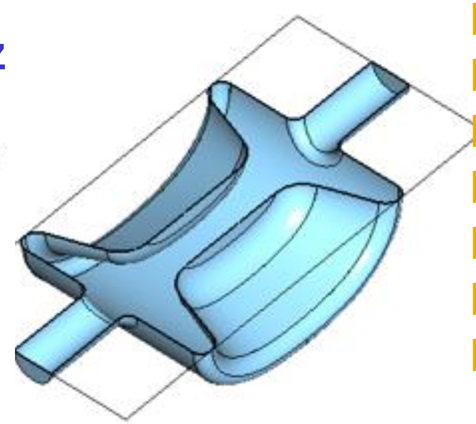


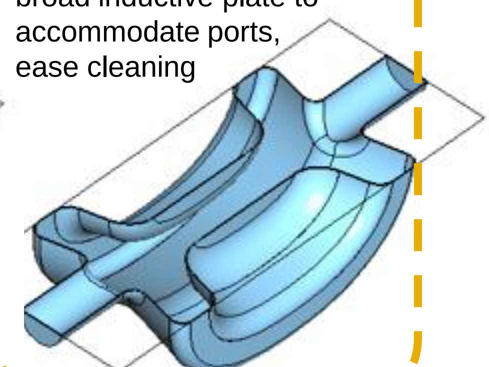
Comparison Between Cavity Models

	LHC-type DQW (B05)	EIC-type DQW (A42)	LHC+EIC-type (C02)
Aperture, capacitive plate distance (mm)	20	20	20
Profile	Elliptical, with waist	Oval, straight walls	Oval, with waist
Dimensions: L x W x H (mm)	95 x 100 x 88	115 x 98 x 82	117 x 76 x 97
Circuit Rt/Q (Ohm)	309	333	311
Geometric factor (Ohm)	80	82	97
Epk (MV/m) at 1.86 MV	50	56	55 ←
Bpk (mT) at 1.86 MV	99	81	84 ←
First HOM (GHz)	1.74 (z)	1.98 (z)	2.18 (z) ←

Added advantages: broad inductive plate to accommodate ports, ease cleaning







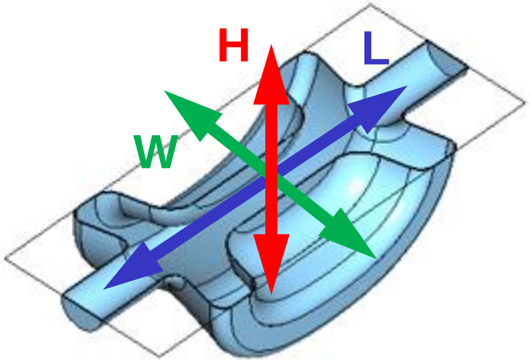
DQW Aperture Study

All LHC+EIC DQW type with oval (Cassini) profile and waist.

Aperture (mm)	30*	25* (NEW)	20
Dimensions: L x W x H (mm)	126 x 91 x 106	117 x 82 x 104	117 x 76 x 97
Circuit Rt/Q (Ohm)	153	211	311
Geometric factor (Ohm)	104	102	97
Epk (MV/m) at 1.86 MV	63	58	55
Bpk (mT) at 1.86 MV	109	99	84
First HOM (GHz)	1.84 (z)	2.00 (z)	2.18 (z)

* Peak fields may be further reduced with refined optimization

#cavities for 125 GeV (Total Vcc = 1.86 MV)		2	
#cavities for 500 GeV (Total Vcc = 7.4 MV)		6	



* with adopted max. allowable peak fields of 45 MV/m and 80 mT

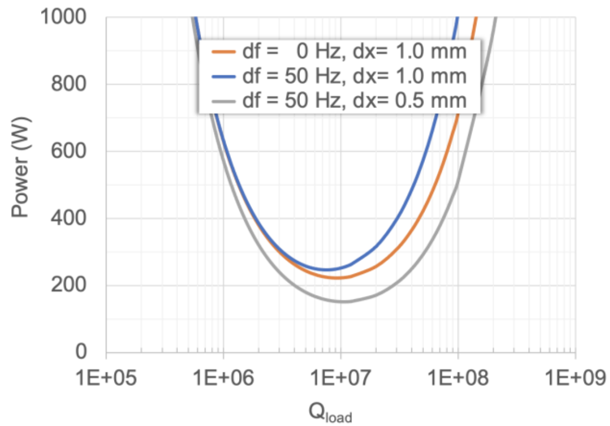
Power Requirement

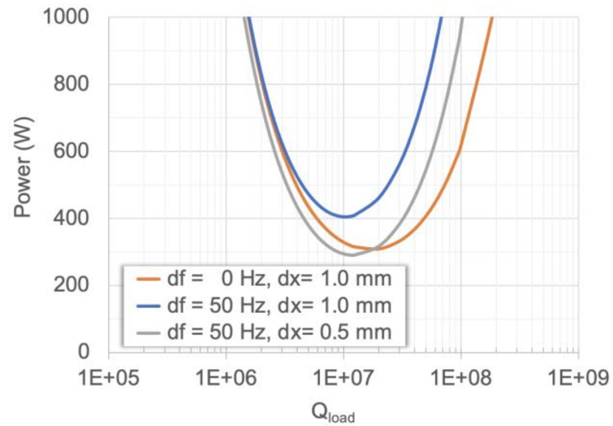
Input power required by detuned ($\Delta\omega$) crab cavity ($\varphi_b = 0$) loaded by offset beam (y):

$$P_g = \frac{1}{8}\frac{|\overrightarrow{V_\perp}|^2}{(R/Q)_\perp Q_{load}} \times \left\{\left[1 + \frac{2(R/Q)_\perp \kappa y Q_{load} * I_{b0} cos\varphi_b}{|\overrightarrow{V_\perp}|}\right]^2 + [2Q_L \frac{\Delta\omega}{\omega_0} + \frac{2(R/Q)_\perp \kappa y Q_{load} * I_{b0} sin\varphi_b}{|\overrightarrow{V_\perp}|}]^2\right\}$$

ILC CC Specs v11	125 GeV, 10 Hz upgrade	500 GeV
Frequency $\omega_0/2\pi$ (GHz)	1.3	1.3
Total $V_\perp$ (MV)	1.86	7.4
I_{b0} (mA)	8.75	7.6
No. DQW cavities	2	5
$V_\perp$ per cavity (MV)	0.93	1.48
DQW $R/Q_\perp$ (Ω, circuit)	211	211
Max. offset y (mm)	0.5	0.5
Detuning $\Delta\omega/2\pi$ (Hz)	50	50

⟹ Take target Qe = 1e7, with 130 Hz bandwidth and 300 W power req.



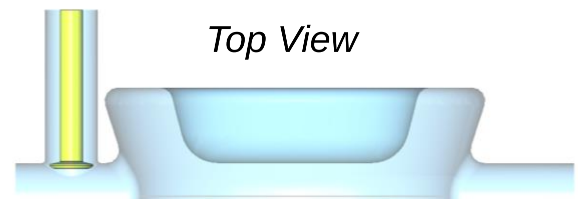


Fundamental Power Coupler

Several options inspected (all using 40 mm Ø tube for DN40 CF flange):

(1) Target **Qe = 1e7 easily obtained by hook coupler** (H) inserted in horizontal port opened at inductive plate (like LHC DQW). Low P_0 ~ 1.4 W (Vt = 0.93 MV, copper).

(2) Attempts to attain similar coupling levels with **cone-like coupler** (E) inserted in horizontal port at the beam pipe only provided Qe ~ 1e8.

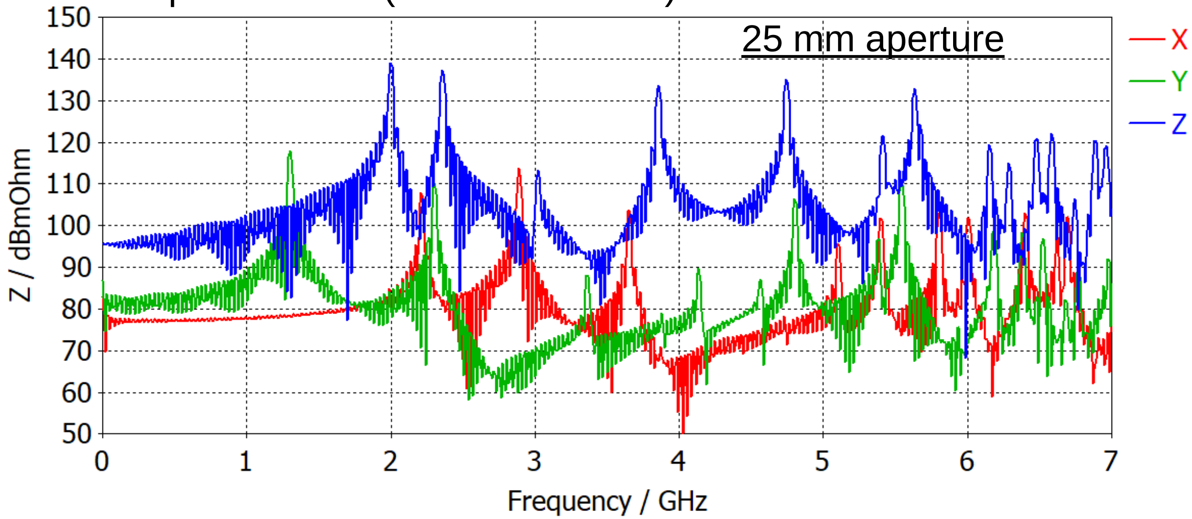


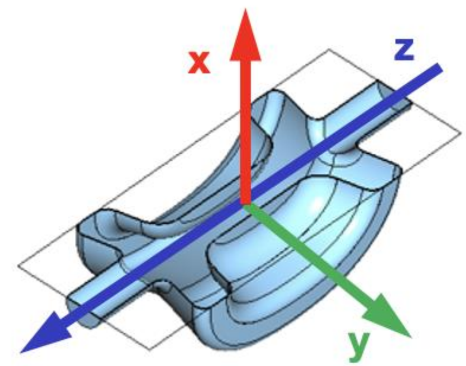
(3) A **pringle-like coupler** (E) provided similar results as option (2).

(4) Explored coupling levels offered by **ice cream scoop coupler** inserted in (preferable) vertical port at the beam pipe with insufficient Qe ~ 1e10. Further studies ongoing drawing from EIC DQW design experience.

Mode Spectra w/o HOM Couplers

Freq TE11 cutoff (25 mm diameter) = 7 GHz





HOM #	Freq (GHz)	R/Q (circuit)	Type
(1)	2.00	43 Ω	Long. (z)
(2)	2.21	23 Ω/m	Vert. (x)
(3)	2.30	28 Ω/m	Hor. (y)
(4)	2.36	31 Ω	Long. (z)
(5)	2.89	26 Ω/m	Vert. (x)

Impedance threshold [ILC CC Spec v13]	Total	Per cavity (5 cavities)
Zx (MΩ/m)	48.8	9.8
Zy (MΩ/m)	61.7	12.3
Zz	TBD	--

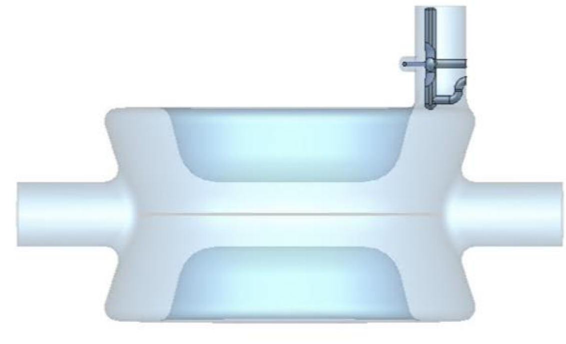
⟹ Damping required of about 3 orders of magnitude.

HOM Coupler Design

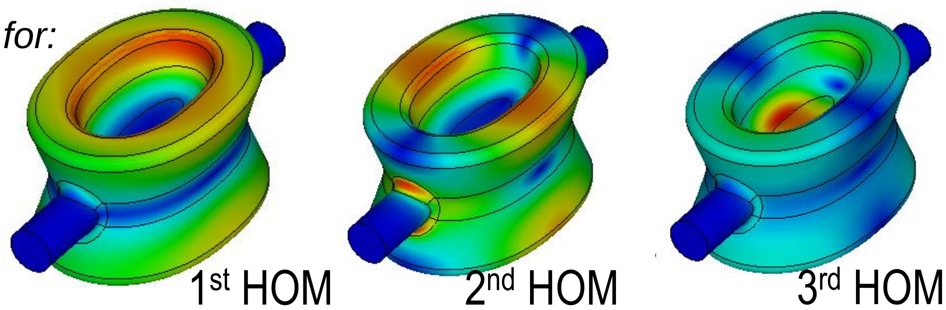
Three main approaches under consideration:

(1) Install **HOM couplers in horizontal ports** opened at inductive plate (H-coupling like LHC DQW).

- Filter can be TESLA-like.
- May require several HOM couplers at different locations to extract all the required HOMs.

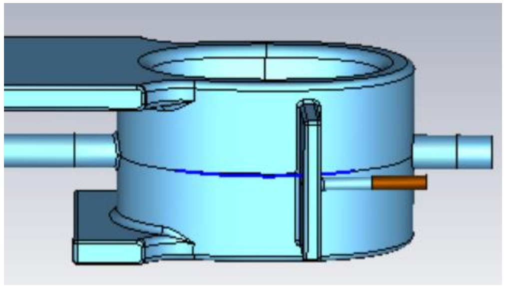


H-field for:



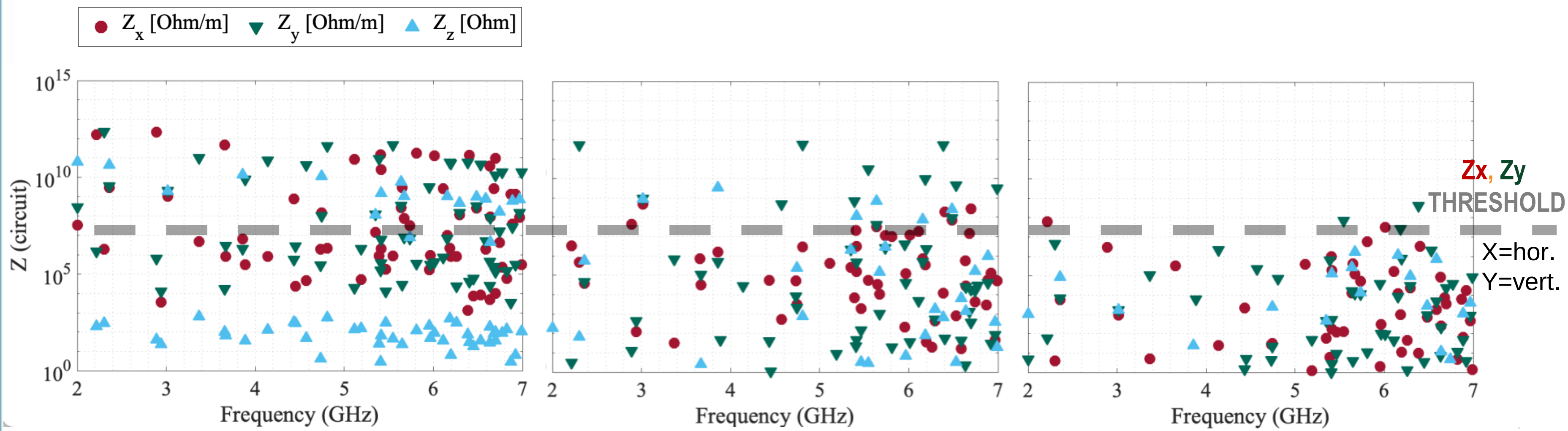
(2) Due to high frequency of the 1st HOM, a **WG or WG stub coupled to an antenna**.

[Rectangular WG with a ~ 75 mm has $f_{c,TE10}$ = 2 GHz.]



(3) A combination of options (1) and (2).

HOM Coupler Option (1)

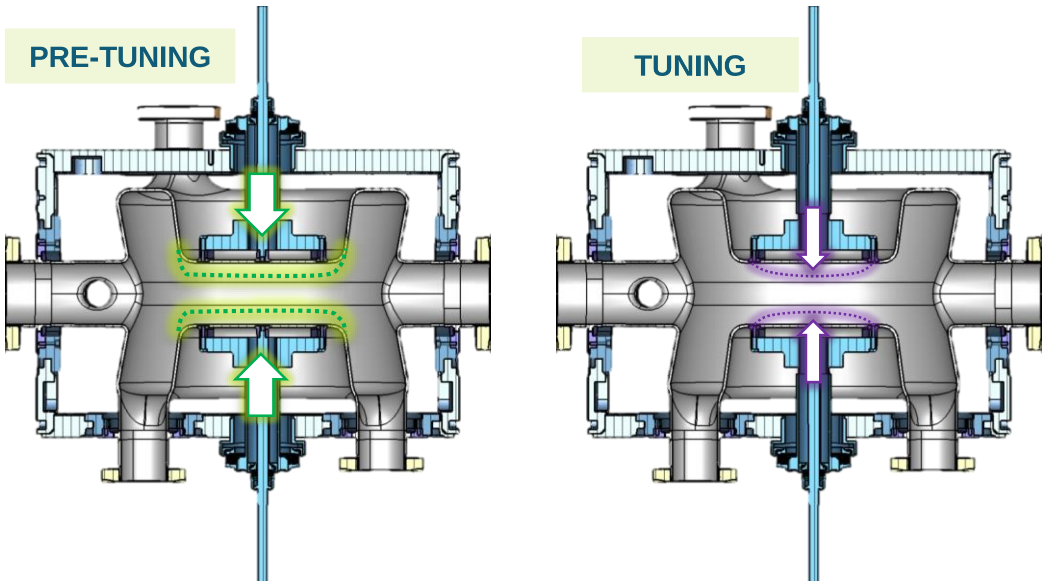


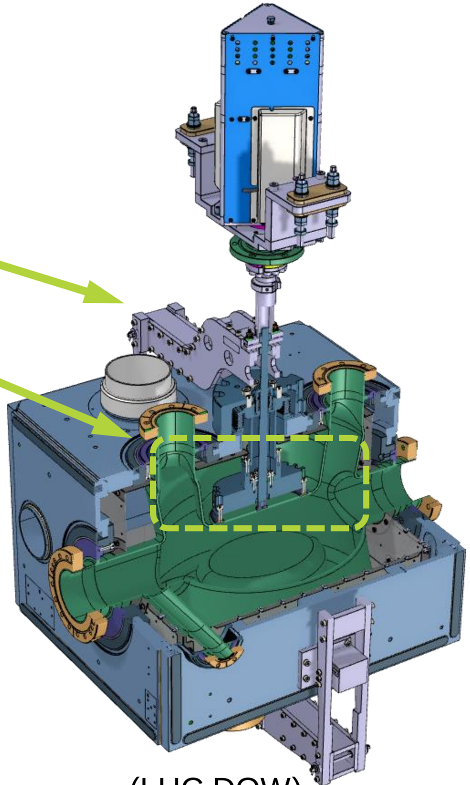
- **[Promising first results](#)** for 1.3 GHz ILC DQW with single HOM coupler and TESLA filter and successful coupling scheme of LHC. DQW motivated the use of **several HOM couplers** at different locations **on inductive plate**.

Tuner Concept

Active tuning realized by scissor-jack frame connected to the push-pull tuning systems of both capacitive plates.

- Designed to ensure symmetric displacement of the plates and hence **preserve E-field center location.**
- Enables **asymmetric pre-tuning** and **symmetric tuning**.





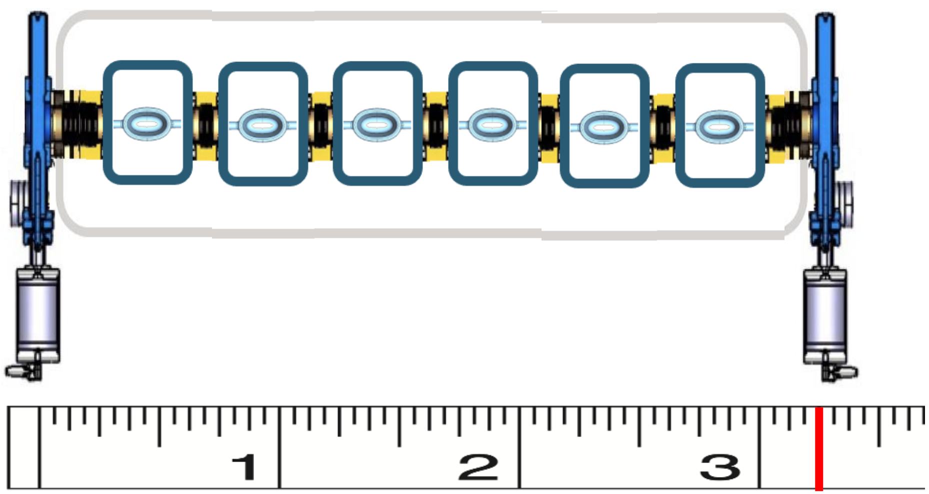
(LHC DQW)

- Provides **reinforcement** to **sensitive capacitive region**.
- Further **development requires He vessel design**.

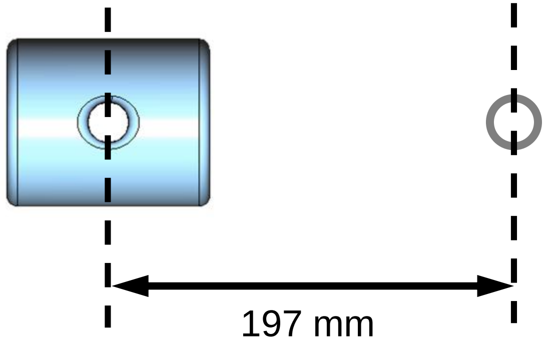
Scalability. Integration: Cryomodule, 2nd Beam Pipe

- For 1 TeV CoM beam scenario, **6 DQW cavities** are sufficient to **provide a 7.4 MV crabbing kick for 500 GeV**.
- Length available of **3.25 m enough for crab cavities and other necessary components** (cold-warm transitions, gate valves, etc.).
- Sufficient **clearance to 2nd beam pipe for coupler integration**.

Side view, 6 DQW in cryomodule



Front view, distance to 2nd beam pipe



Summary and Overview

- The **DQW** cavity is a **compact solution for the ILC crabbing system**. Two **single-cell cavities** provide **1.86 MV with safe max. peak fields**.
- Tuner and coupler integration can be borrowed from HL-LHC and EIC.
- Cavity **compactness opens the possibility of manufacturing the cavity out of ingot**, which in turn makes the port fabrication much easier and enables the implementation of port interfaces with smooth surfaces for peak field reduction. (The HOM coupler for the HL-LHC DQW was made from ingot and demonstrated good performance.)
- Fabrication and **testing of a prototype** will help the decision on how many cavities are needed to provide the required crabbing kick for ILC.
- **To be done**: refine HOM damping scheme, multipacting, multipoles, He vessel and cryomodule integration, mech. analysis.

1.3 GHz ILC DQW Crab Cavity

Parameter	Unit	Value	
Operating frequency	(GHz)	1.3	
SOM		None	
First long. HOM	(GHz)	2.00	
First trans. HOM	(GHz)	2.21	(vertical)
Ep/Et*		3.60	
Bp/Et*	(mT/MV/m)	6.14	(coupler dependent)
G		102	
Rt/Q (acc)	(Ohm)	422	
RtRs	(Ohm^2)	43044	
Vt max per cavity	(MV)	1.44	[Ep limited]
Vt operational per cavity (125 GeV)	(MV)	0.93	
No. cavities (125 GeV)		2	
Extendability (500 GeV)		6	
Number of cells		1	
Cavity diameter	(mm)	104	
Min. Aperture	(mm)	25	
Flange-to-flange length	(mm)	TBD	
FPC Loaded Q		1e7	
Loaded Bandwidth	(kHz)	0.13	
Cavity input power	(kW)	0.3	
Stored energy (at Vt operational)	(J)	0.25	
HOM impedance		TBD	[Coupling scheme under dev.]
Loss and Kick Factors		TBD	
Multipole Parameters		TBD	
Max. Stress, Max. Pressure		TBD	[Mech. support needed]
Nb per cavity	(kg)	15	