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

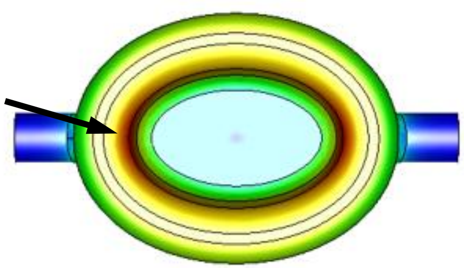
EIC

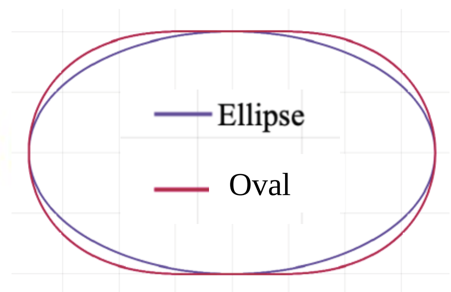
- 200, 400 MHz
- Horizontal kick
- Flat walls
- "Cassini" oval profile

… No clearance issues, ease fab, reduce cost →

…Further reduce peak fields →

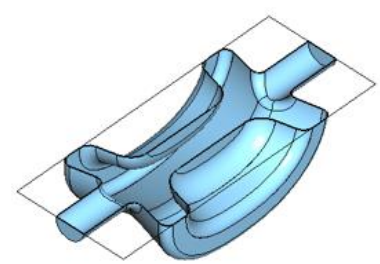
Max. peak surface H





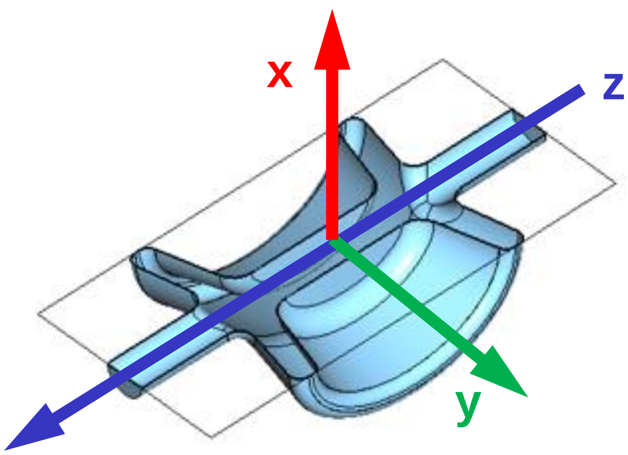
ILC = HL-LHC + EIC

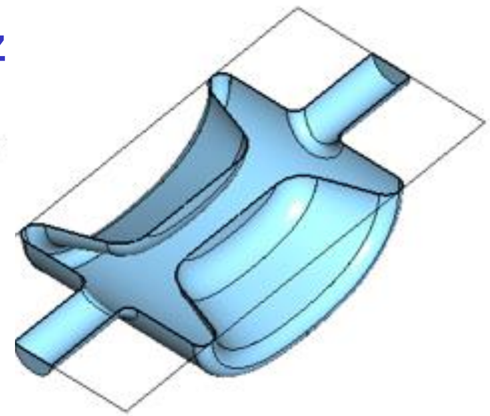
- With waist, "Cassini" oval profile



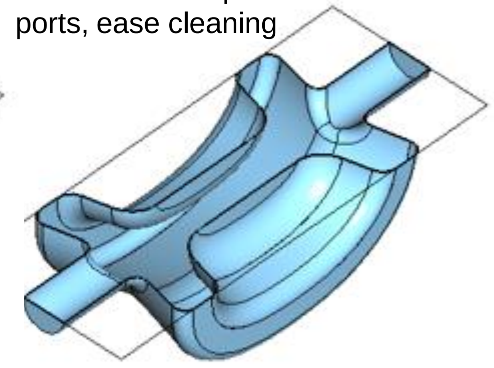
Comparison between cavity models

	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



ILC 1.3 GHz: DQW aperture study

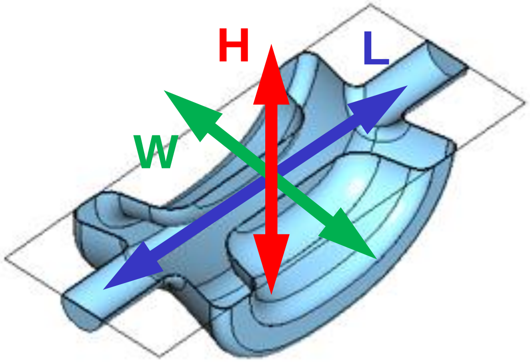
All LHC+EIC DQW type with oval (Cassini) profile and waist.

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)	5

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



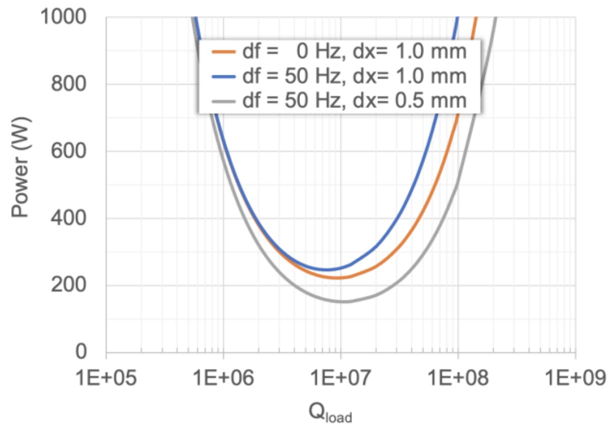
ILC 1.3 GHz: Power Requirement

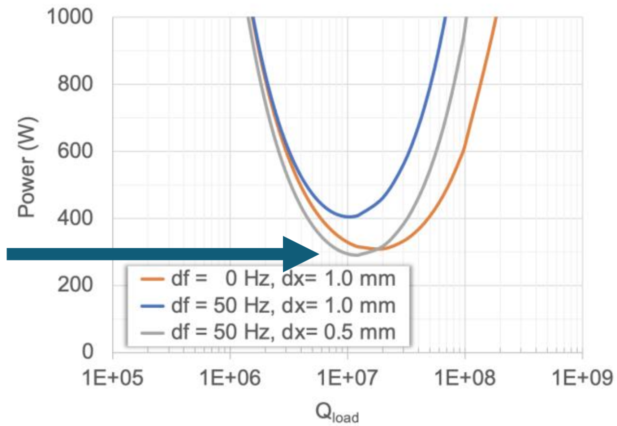
Input power required by detuned ($\Delta\omega$) crab cavity ($\varphi_b = 0$) loaded by offset beam (y):

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

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.



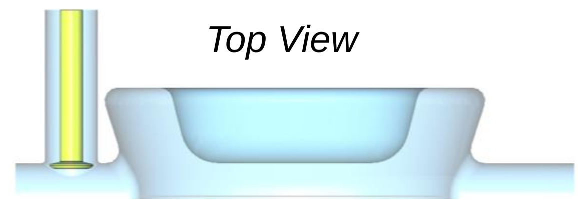


ILC 1.3 GHz: FPC

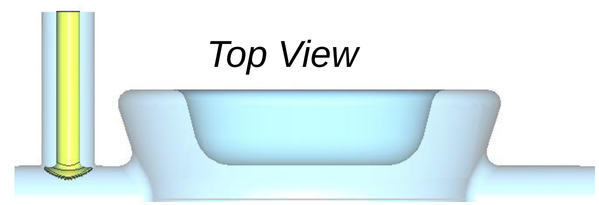
Several options inspected (all using 40 mm ø tube for DN40 CF flange):

(1) Target **Qe = 1e7 easily obtained by hook coupler** (H) inserted in horizontal port opened at inductive plate of DQW (like LHC DQW). .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.



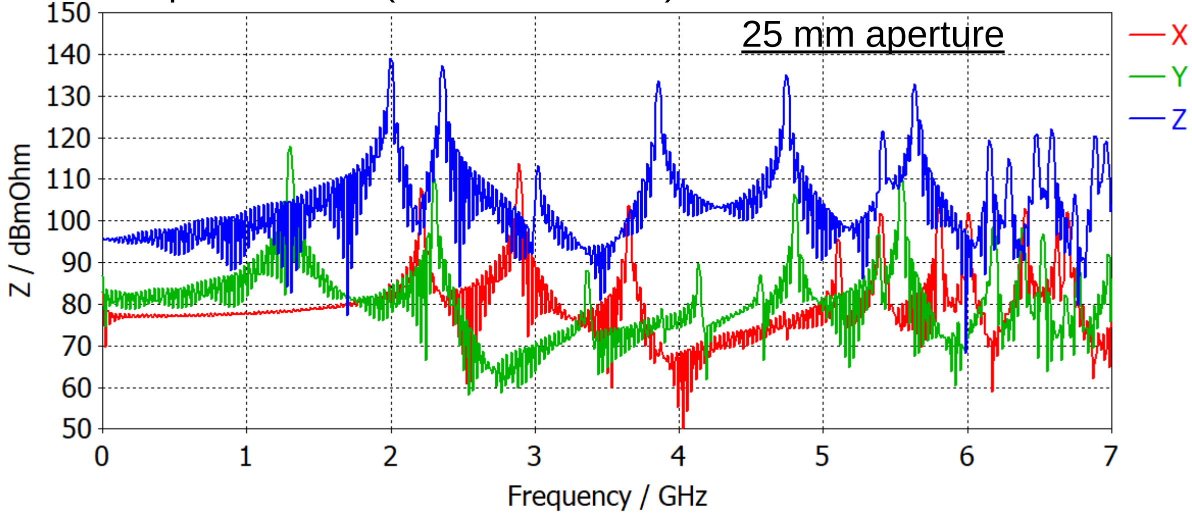
(3) A **pringle-like coupler** (E) provided similar results as option (2).

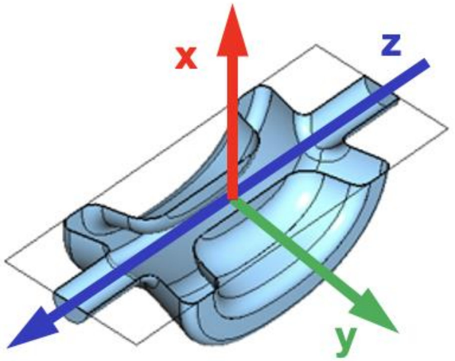


(4) Explored coupling levels offered by **ice cream scoop coupler** inserted in (preferable) vertical port at the beam pipe with insufficient Qe ~ 1e10. Further studies ongoing drawing from EIC DQW design experience.

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.

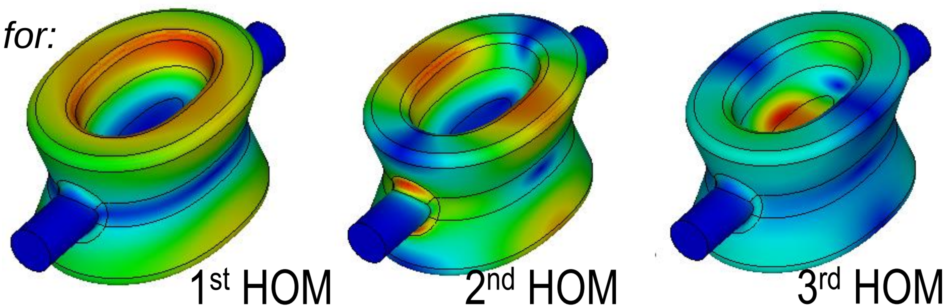
ILC 1.3 GHz: HOM Couplers

Three main approaches under consideration:

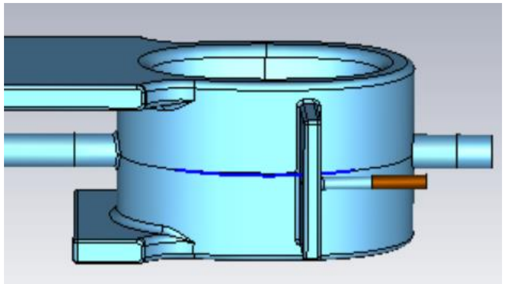
(1) Install **HOM couplers in horizontal ports** opened at inductive plate (H-coupling like LHC DQW).

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

H-field for:

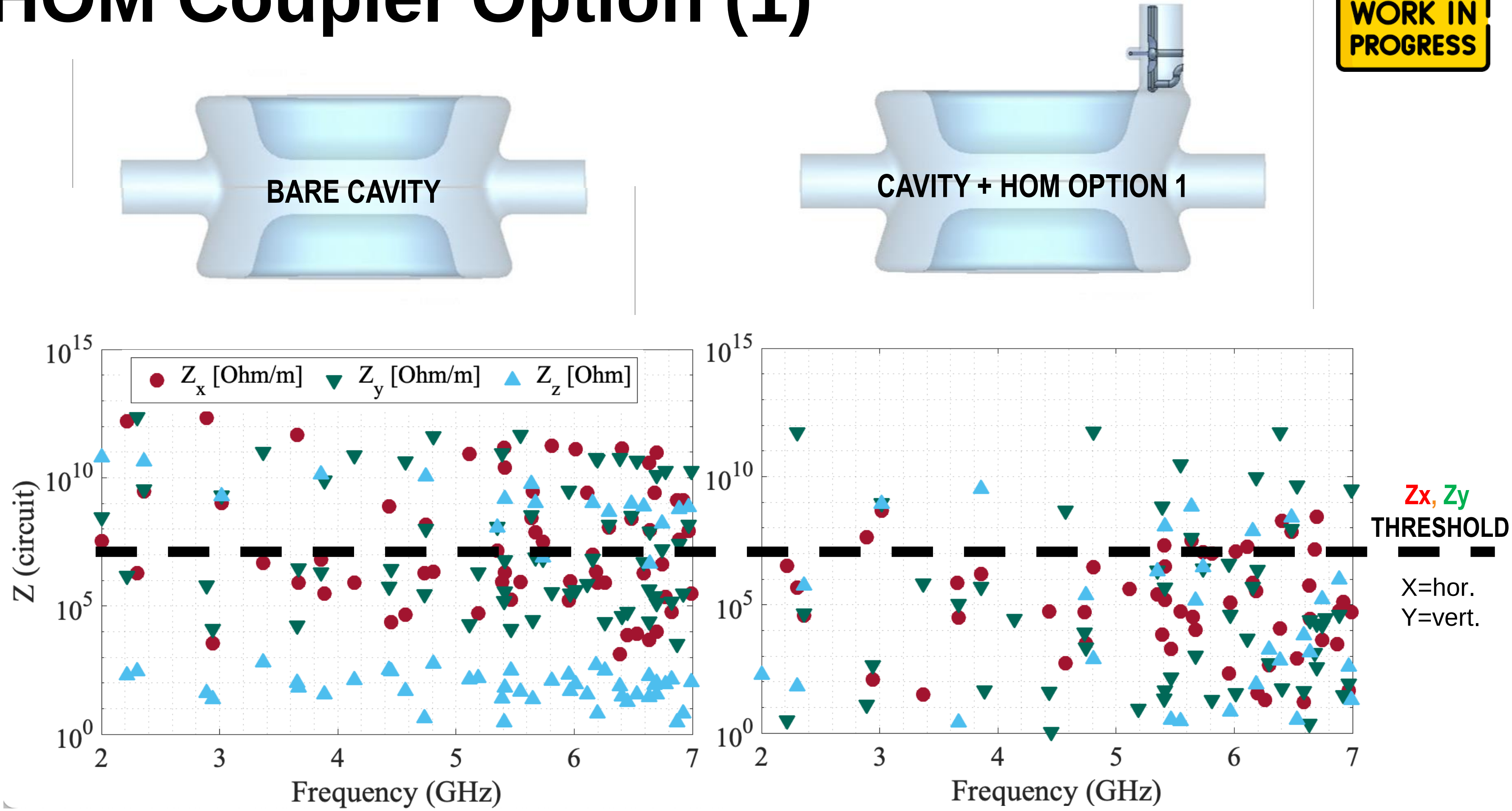


(2) Due to high frequency of the 1st HOM, a **WG or WG stub coupled to an antenna**.
[Rectangular WG with a ~ 75 mm has $f_{c,TE10}$ = 2 GHz.]



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

HOM Coupler Option (1)



WORK IN PROGRESS

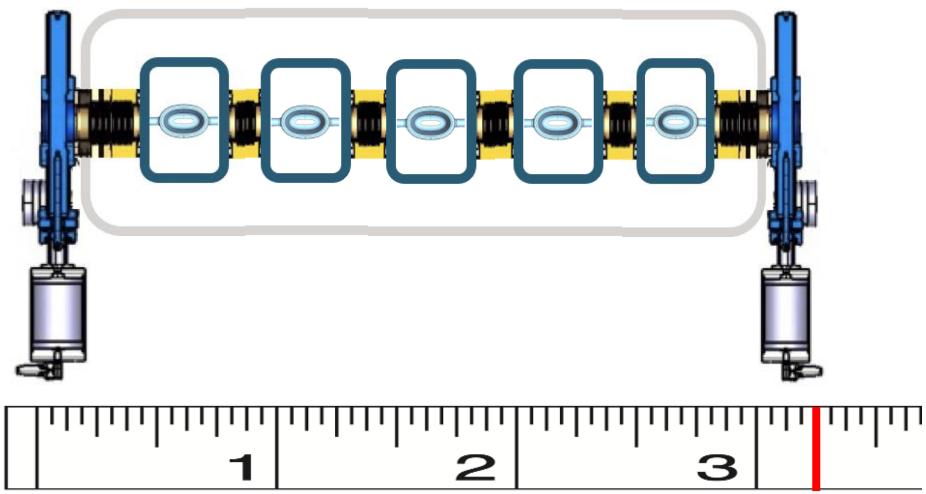
Promising first results for 1.3 GHz ILC DQW with single HOM coupler and TESLA filter **but some work ahead** to define adequate HOM extraction system.

Brookhaven National Laboratory

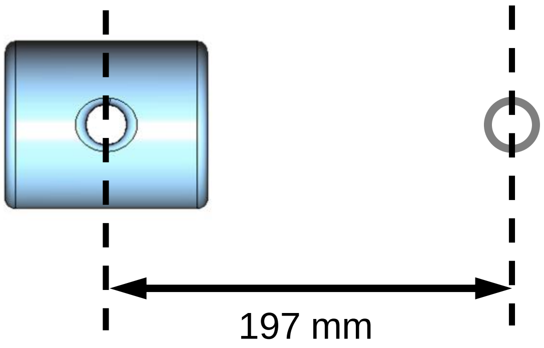
Integration: cryomodule, 2^{nd} beam pipe

- For 1 TeV CoM beam scenario, **5 DQW cavities** are sufficient to **provide a 7.4 MV crabbing kick at 1.3 GHz**.
- Length available of **3.25 m enough for crab cavities and other necessary components** (cold-warm transitions, gate valves, etc.).
- Sufficient **clearance to 2^{nd} beam pipe for coupler integration**.

Side view, 5 DQW in cryomodule



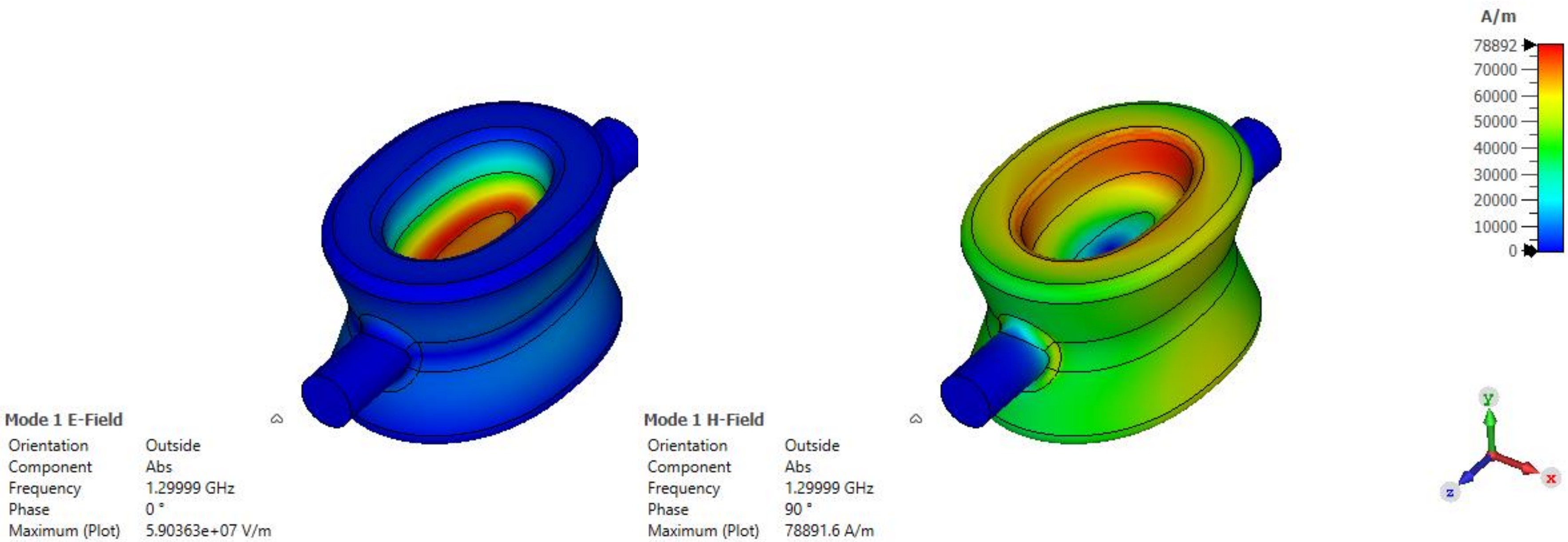
Front view, distance to 2^{nd} beam pipe



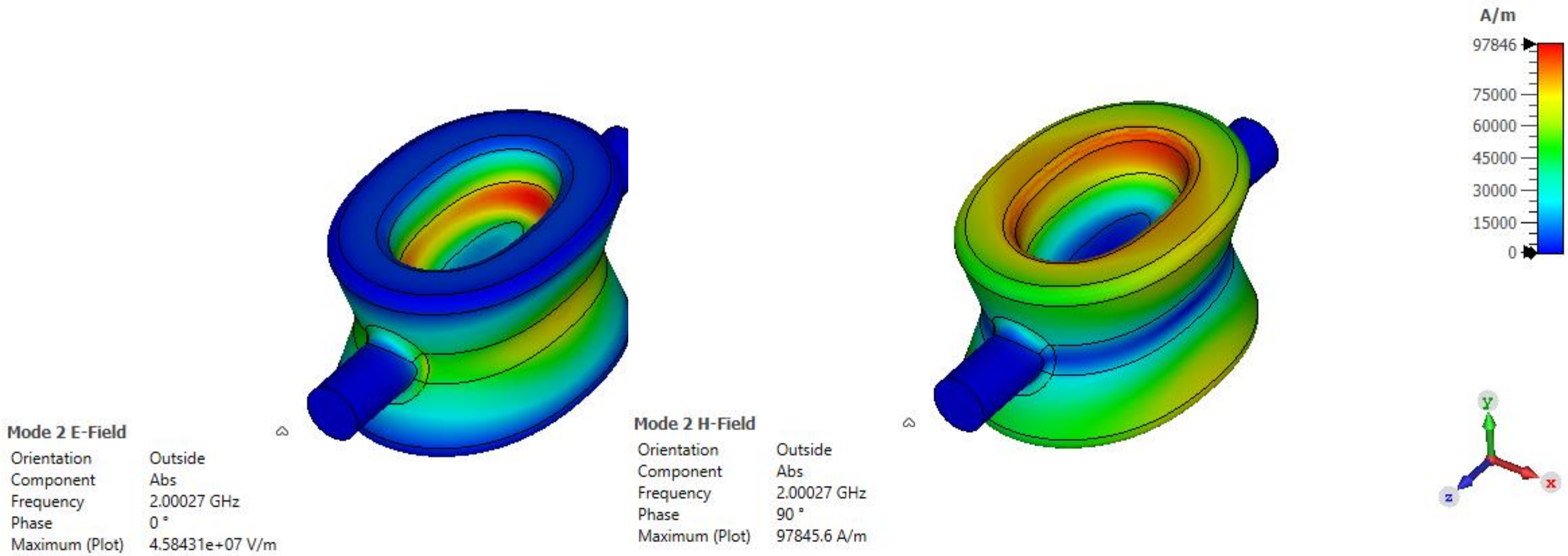
Summary and Overview

- 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**: coupler design and integration, multipacting, mech. analysis.

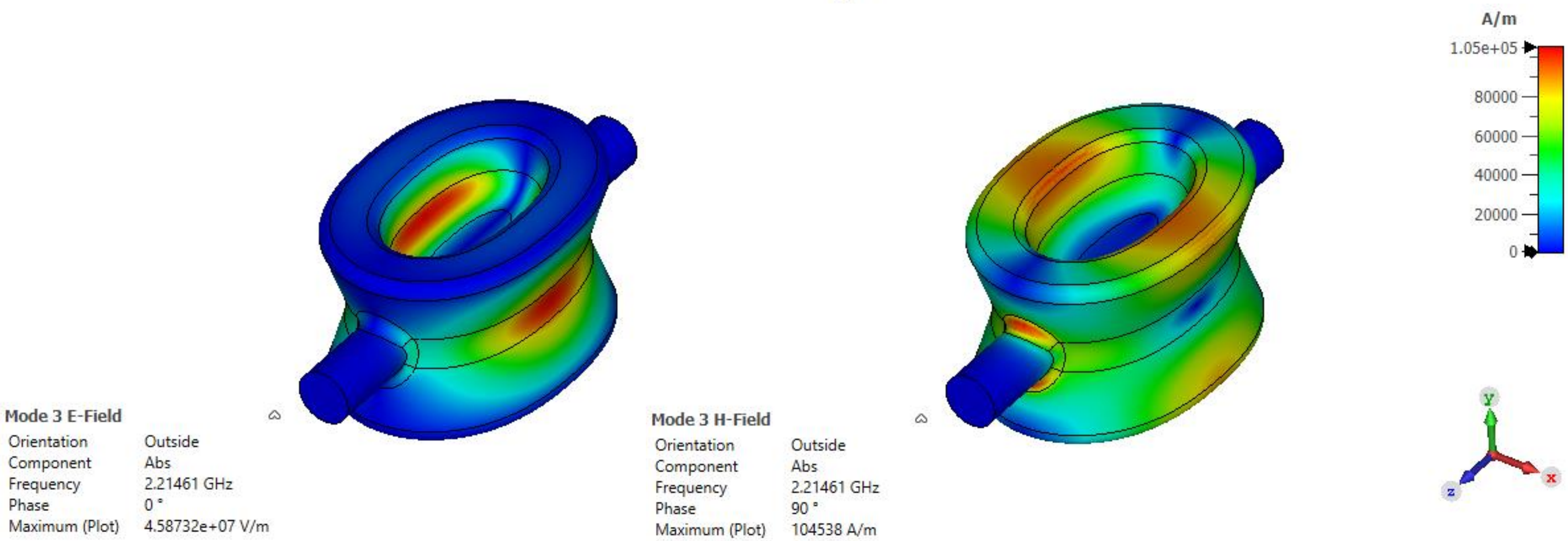
Fundamental mode, f(0)



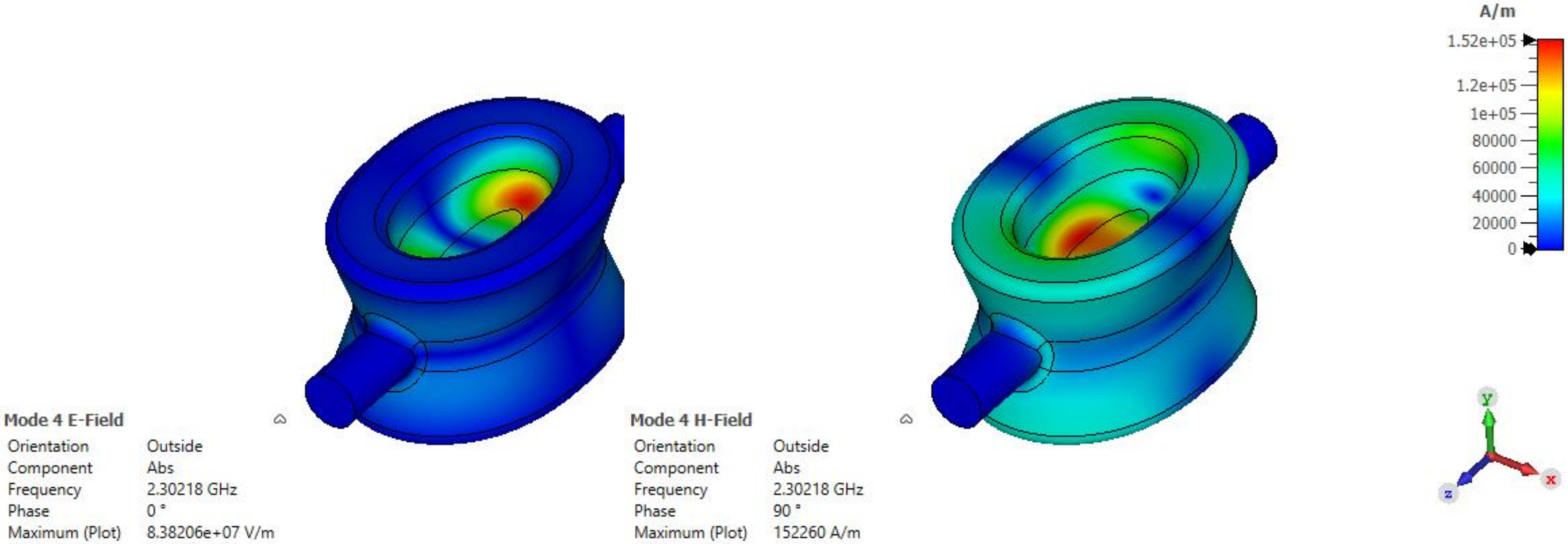
HOM01, f(1)


Mode 2 E-Field
Orientation Outside
Component Abs
Frequency 2.00027 GHz
Phase 0 °
Maximum (Plot) 4.58431e+07 V/m
Mode 2 H-Field
Orientation Outside
Component Abs
Frequency 2.00027 GHz
Phase 90 °
Maximum (Plot) 97845.6 A/m
A/m
97846
75000
60000
45000
30000
15000
0
y
x
z

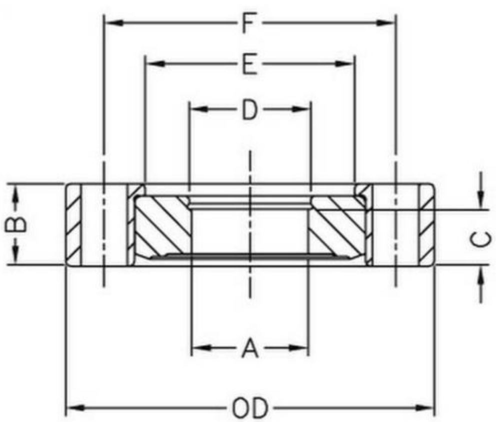
HOM02


Mode 3 E-Field
Orientation Outside
Component Abs
Frequency 2.21461 GHz
Phase 0 °
Maximum (Plot) 4.58732e+07 V/m
Mode 3 H-Field
Orientation Outside
Component Abs
Frequency 2.21461 GHz
Phase 90 °
Maximum (Plot) 104538 A/m
A/m
1.05e+05
80000
60000
40000
20000
0
y
x
z

HOM03, f(3)


Mode 4 E-Field
Orientation Outside
Component Abs
Frequency 2.30218 GHz
Phase 0 °
Maximum (Plot) 8.38206e+07 V/m
Mode 4 H-Field
Orientation Outside
Component Abs
Frequency 2.30218 GHz
Phase 90 °
Maximum (Plot) 152260 A/m
A/m
1.52e+05
1.2e+05
1e+05
80000
60000
40000
20000
0
y
x
z

https://vacgen.com/34mm-od-6mm-id-304l-rotable-bored-cf-flange



316LN (2D Forged) Rotatable Bored CF Flanges (CFRL Series)														
DN Number	OD mm	OD inch	Mounting holes	Clear Bore A mm	Flange Thickness B mm	Land Thickness C mm	Tube Counter Bore D mm	Rotatable Tube Bore E mm	BoltHole PCD F mm	Bolt Hole Diameter (or thread)	No. Of Bolt Holes	Tube Size to Fit Flange Bore	Shipping Weight (kg)	Order Code 316LN
DN16	34	1.33	Clear	6.4	7.6	N/A	6.4	19.3	27	4.3	6	6.35	0.1	CFR34-6-LN
DN40	70	2.75	Clear	40	13	4.8	41.3	41.9	58.7	6.8	6	41.27	0.3	CFR70-41-LN
DN63	114	4.5	Clear	68	17.5	8	70	71	92.1	8.4	8	69.8	0.9	CFR114-70-LN
DN100	152	6	Clear	99.4	20	9.5	101.9	104.9	130.2	8.4	16	101.6	1.7	CFR152-102-LN
DN160	203	8	Clear	149.7	22	9.5	152.6	155.7	181	8.4	20	152.4	2.6	CFR203-153-LN
DN200	254	10	Clear	200.4	24.5	9.5	203.5	206.4	231.8	8.4	24	203.2	3.7	CFR254-206-LN

All dimensions are in mm unless otherwise stated