3.9 GHz components design

Speaker: Nikolay Solyak (from behalf of LCLS-II design team)

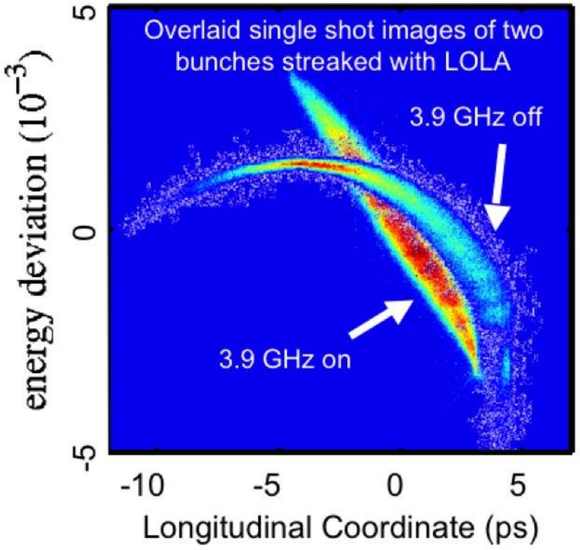
3.9GHz Review, FNAL, May. 26, 2016

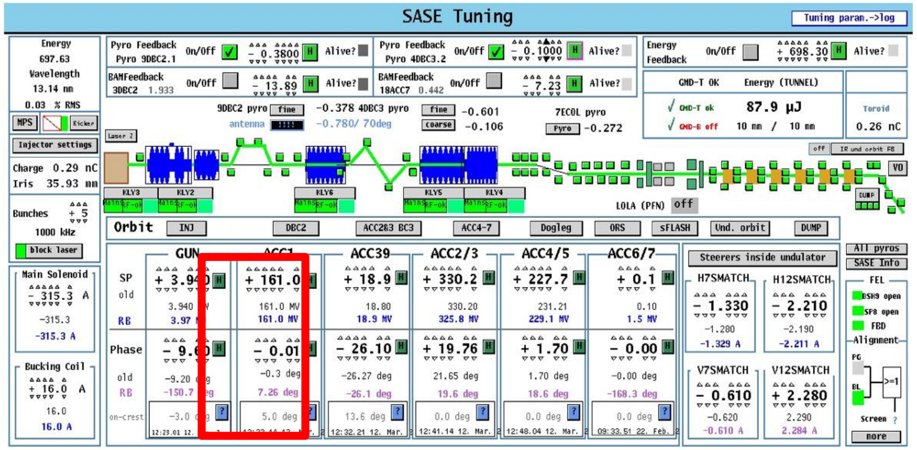
Outline

- 3.9 GHz system functionality
- Requirements
- Cavity design modification
- HOM design
- Coupler design
- Heating issues
- Frequency Tuner
- BPM; Gate-valve; HOM absorber.
- Conclusion

FLASH and XFEL - ACC39 performance

- ACC39 routinely operates at 18.9 to 19.7 MV/m
  - *Capable of operation at 22 MV/m*
    - *Limitation set by thermal interlocks – concern about compromising HOM's on cavities 3 & 5 (trimmed 2-post style)*
- Amplitude stability ≤ 2x10^{-5} pulse-to-pulse
- Phase stability ≤ 0.003° pulse-to-pulse





Energy 697.63
Wavelength 13.14 nm
0.03 % RMS

Charge 0.29 nC
Iris 35.93 mm

Bunches + 5
1000 kHz

Pyro Feedback Pyro 9DBC2.1 On/Off ☑ - 0.3800 Alive?
BAMFeedback 3DBC2 1.933 On/Off ☐ - 13.89 Alive?
Pyro Feedback Pyro 4DBC3.2 On/Off ☑ - 0.1000 Alive?
BAMFeedback 18ACC7 0.442 On/Off ☐ - 7.23 Alive?
Energy Feedback On/Off ☐ + 698.30 Alive?

9DBC2 pyro -0.378
antenna -0.780/ 70deg
4DBC3 pyro -0.601 / -0.106
7ECOL pyro -0.272

GMD-T OK
√ GMD-T ok
√ GMD-B off
Energy (TUNNEL) 87.9 µJ
10 mm / 10 mm
Toroid 0.26 nC

LOLA (PFN) off

Main Solenoid - 315.3 A
-315.3
-315.3 A

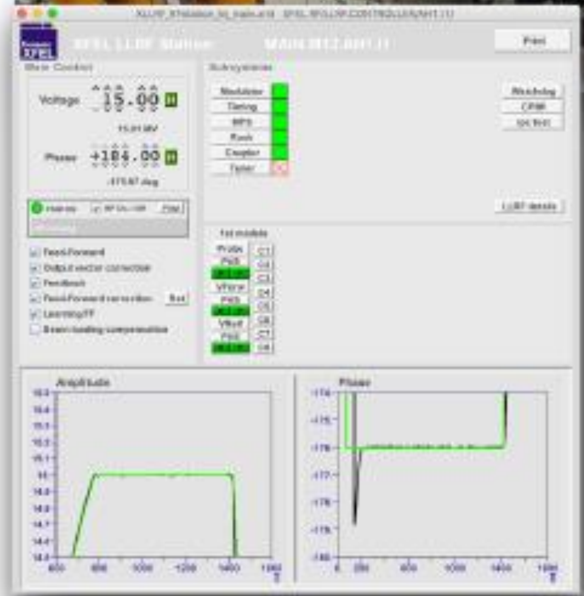
Bucking Coil + 16.0 A
16.0
16.0 A

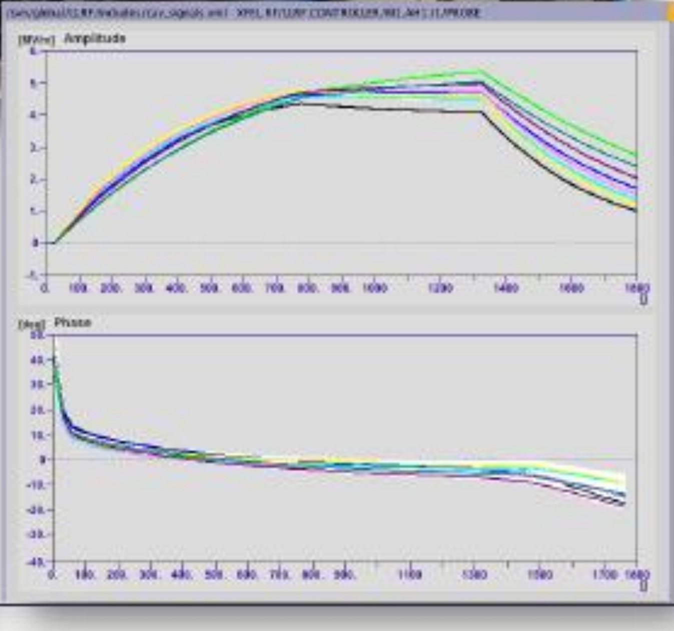
	GUN	ACC1	ACC39	ACC2/3	ACC4/5	ACC6/7
SP	+ 3.94	+ 161.0	+ 18.9	+ 330.2	+ 227.7	+ 0.1
old	3.940	161.0 MV	18.80	330.20	231.21	0.10
RB	3.97	161.0 MV	18.9 MV	325.8 MV	229.1 MV	1.5 MV
Phase	- 9.6	- 0.01	- 26.10	+ 19.76	+ 1.70	- 0.00
old	-9.20	-0.3 deg	-26.27 deg	21.65 deg	1.70 deg	-0.00 deg
RB	-150.7	7.26 deg	-26.1 deg	19.6 deg	18.6 deg	-168.3 deg
on-crest	-3.0	5.0 deg	13.6 deg	0.0 deg	0.0 deg	0.0 deg
	12:23.01 12.		12:32.21 12. Mar.	12:41.14 12. Mar.	12:48.04 12. Mar.	09:33.51 22. Feb.

	H7SMATCH	H12SMATCH	V7SMATCH	V12SMATCH
SP	- 1.330	- 2.210	- 0.610	+ 2.280
old	-1.280	-2.190	-0.620	2.290
RB	-1.329 A	-2.211 A	-0.610 A	2.284 A

N.Solyak

Third harmonic module AH1 (INFN, Milano)



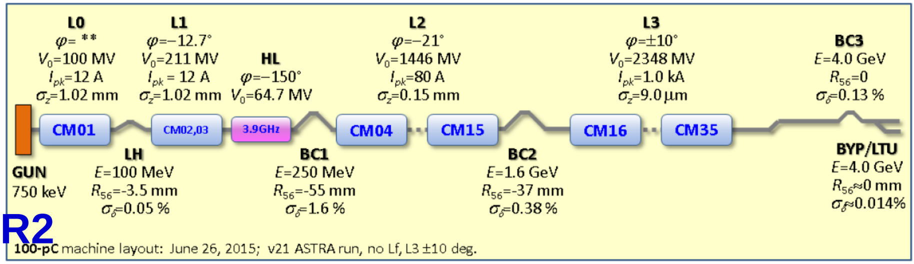


- **18 December 2015:** First *rough* calibration
  - Nominal pulse structure Fill Time: 750 us
  - Flat Top: 650 us
  - Gradient well above nominal 30 MV of VS voltage
  - First quench > 45 MV
- **10 February 2016 :**
  - QL aligned well within the 10% requirement
  - Phases within 15°
- **16 February 2016 :** Back on beam
  - Moved to -180° (wrt on-crest), calibration with beam energy

LCLS-II
36MV/CM

For details on SC modules see D.Reschke's talk on Thursday THYB01 on 'Performance of Superconducting Cavities for the European XFEL'

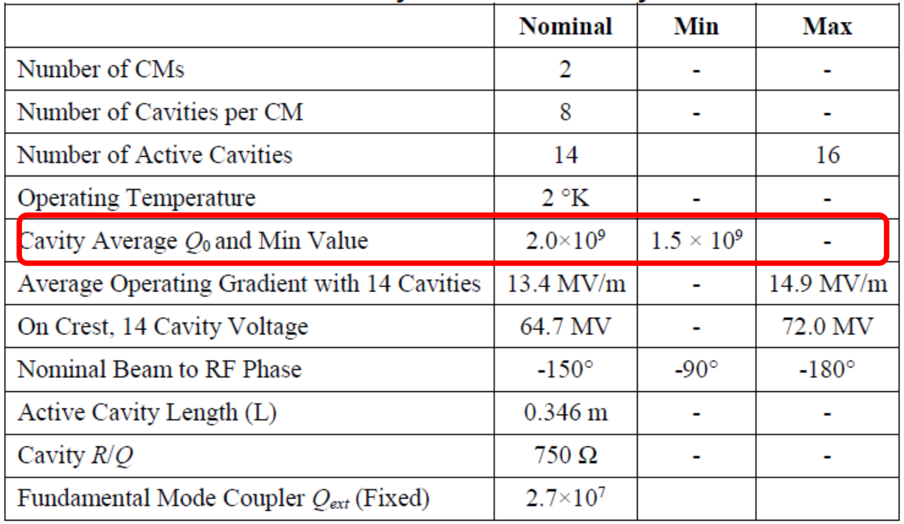
LCLS-II reqs.(PRD and FRD)



100-pC machine layout: June 26, 2015; v21 ASTRA run, no Lf, L3 ±10 deg.

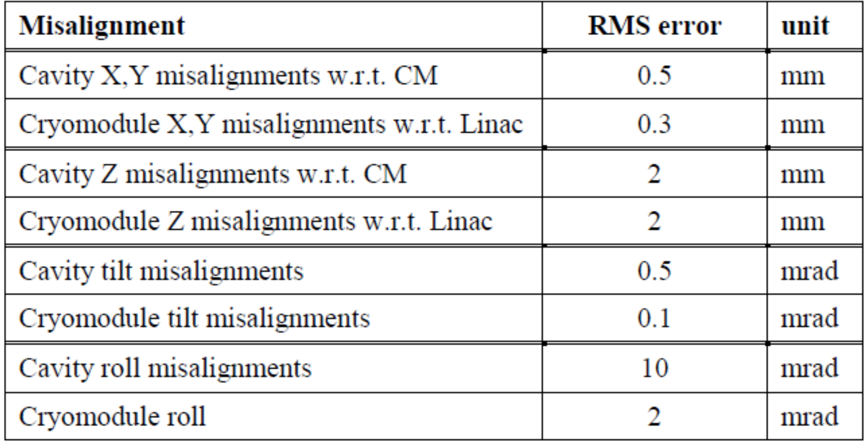
SCRF 3.9 GHz Cryomodule LCLSII-4.1-PR-0097-R2

Table 1. Main 3.9 GHz Cryomodule and Cavity Parameters.



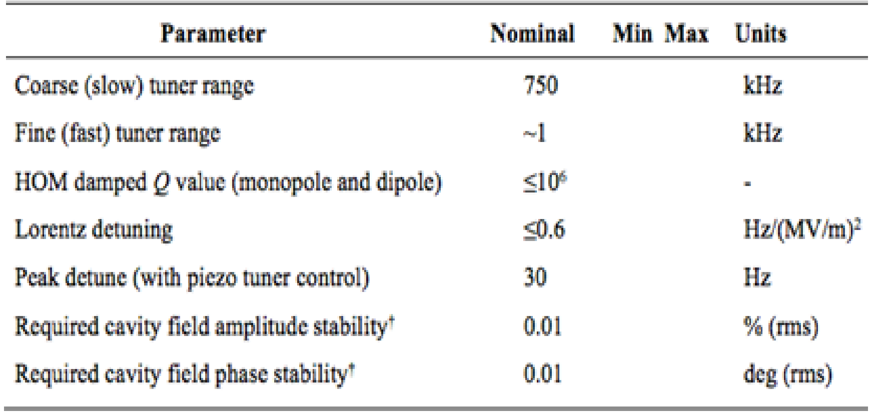
	Nominal	Min	Max
Number of CMs	2	-	-
Number of Cavities per CM	8	-	-
Number of Active Cavities	14		16
Operating Temperature	2 °K	-	-
Cavity Average Q_0 and Min Value	2.0×10^9	1.5 × 10^9	-
Average Operating Gradient with 14 Cavities	13.4 MV/m	-	14.9 MV/m
On Crest, 14 Cavity Voltage	64.7 MV	-	72.0 MV
Nominal Beam to RF Phase	-150°	-90°	-180°
Active Cavity Length (L)	0.346 m	-	-
Cavity R/Q	750 Ω	-	-
Fundamental Mode Coupler Q_{ext} (Fixed)	2.7×10^7		

Table 2. Alignment Tolerances for the 3.9 GHz Cryomodules



Misalignment	**RMS error**	**unit**
Cavity X,Y misalignments w.r.t. CM	0.5	mm
Cryomodule X,Y misalignments w.r.t. Linac	0.3	mm
Cavity Z misalignments w.r.t. CM	2	mm
Cryomodule Z misalignments w.r.t. Linac	2	mm
Cavity tilt misalignments	0.5	mrad
Cryomodule tilt misalignments	0.1	mrad
Cavity roll misalignments	10	mrad
Cryomodule roll	2	mrad

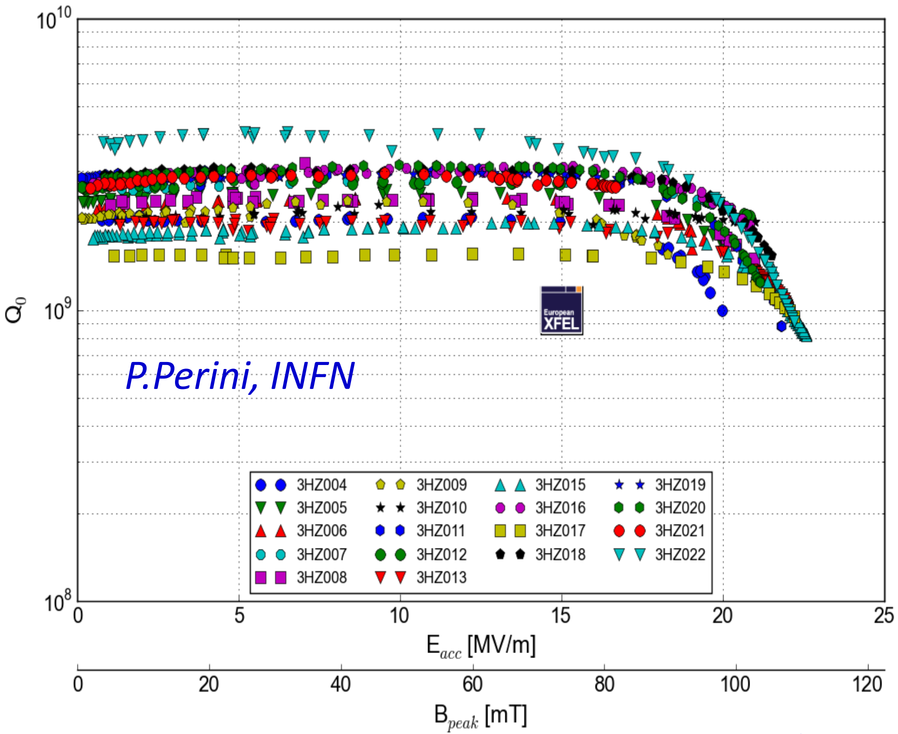
Table 3. Tuning/stability requirements



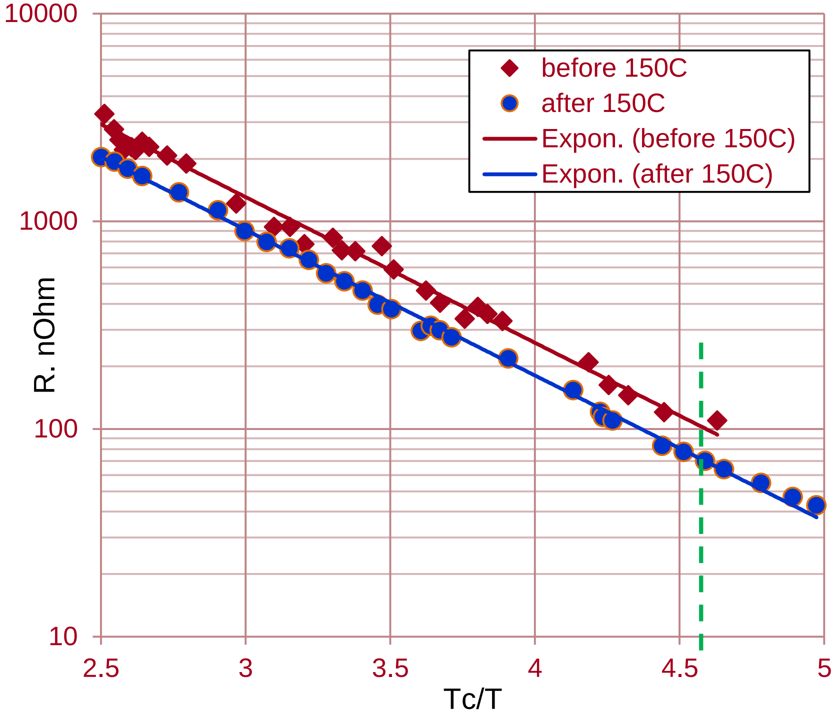
Parameter	Nominal	Min	Max	Units
Coarse (slow) tuner range	750			kHz
Fine (fast) tuner range	~1			kHz
HOM damped Q value (monopole and dipole)	≤10^6			-
Lorentz detuning	≤0.6			Hz/(MV/m)^2
Peak detune (with piezo tuner control)	30			Hz
Required cavity field amplitude stability†	0.01			% (rms)
Required cavity field phase stability†	0.01			deg (rms)

- Two CMs; 8 cavity / each
- 9 Cu plated bellows
- Coupler orientation as per XFEL
- ~150 W heat load/cryomodule (2K)
- BPM at downstream end (1.3GHz type)
- No magnet

Cavity gradient and Q0 requirements (recent data from XFEL cavity production)



P.Perini, INFN



<u>Recent XFEL production cavities (INFN-Zenon);</u>

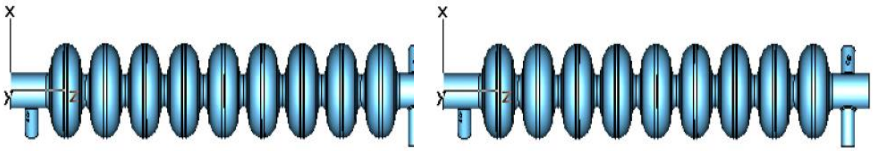
- At 2K the all cavities have Qo in range ~(2-3)·10^9 (except 2)
- No field slope up-to ~17 MV/m; Quench at 20-23 MV/m, VTS
- No Q degradation after welding to HV

Risk: LCLS-II cavity (cw) requirements more stringent than XFEL (pulse) !!!

➔ Require Prototyping and Testing

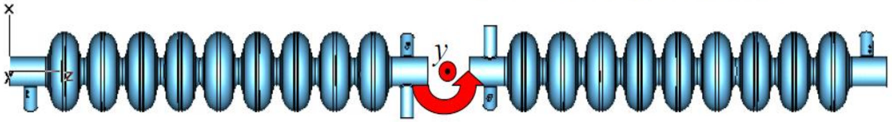
Effect of large field asymmetry and cavity orientation

3.9 GHz Cryomodule Options



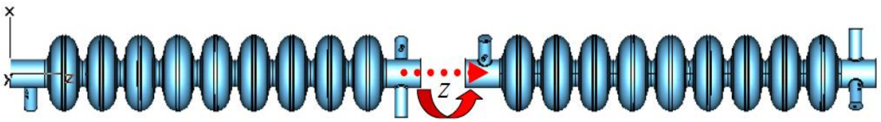
1.3GHz like Cryomodule Layout:

yrot=180 deg of cavities

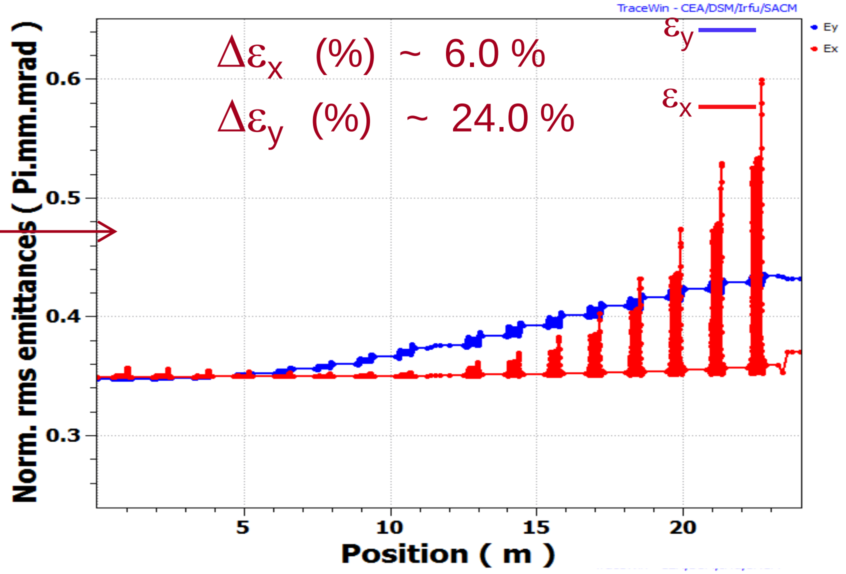


FLASH-like Cryomodule Layout:

zrot=180 deg of cavities

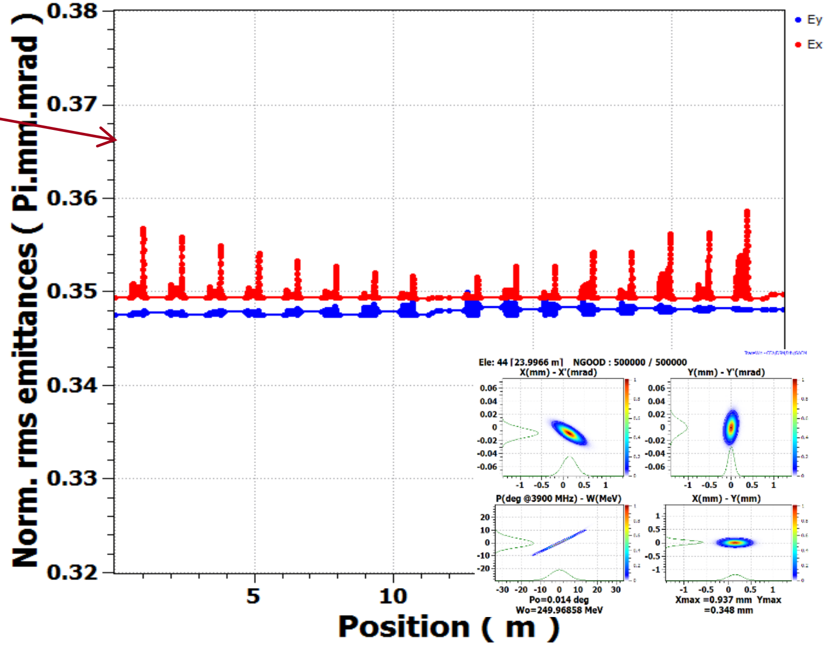


XFEL/LCLS2 Cryomodule Layout



$\Delta\varepsilon_x$ (%) ~ 6.0 %

$\Delta\varepsilon_y$ (%) ~ 24.0 %



	1.3GHz-like	XFEL
$\Delta\varepsilon_x$ (%)	6 .0	0.09
$\Delta\varepsilon_y$ (%)	24.4	0.15

Emittance growth in 3.9 GHz system

Cavity/coupler design issues and proposed modifications for LCLS-II CW operation

- Cavity, bellows and Helium vessel
- HOM coupler
- Power Coupler
- Blade-Tuner with piezo

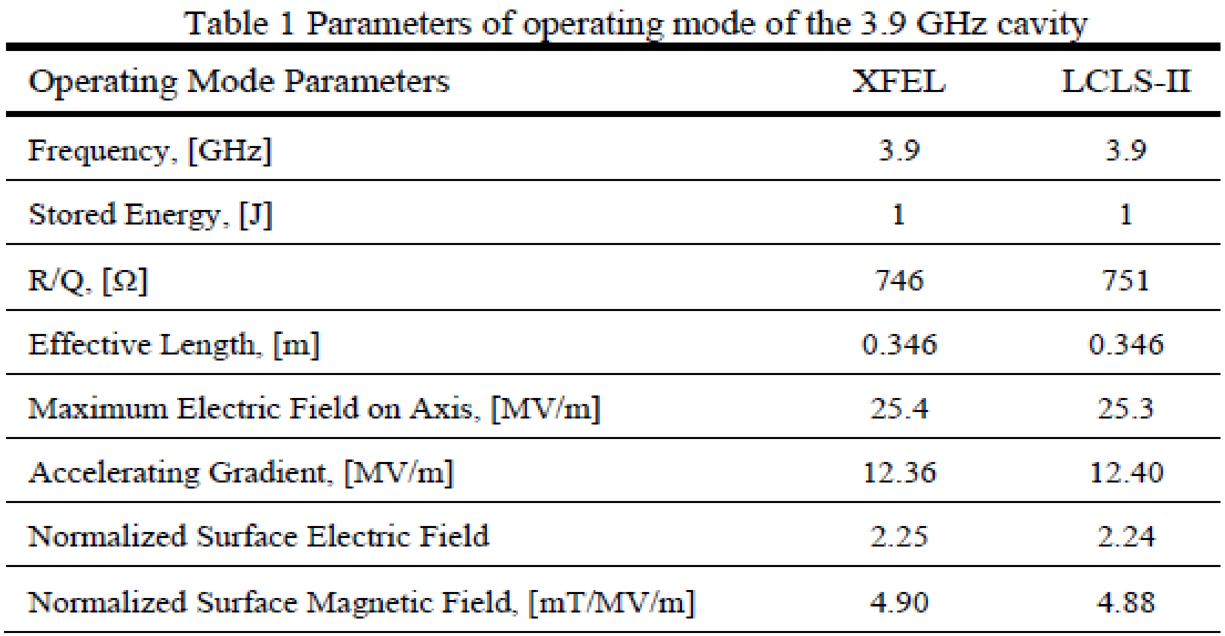
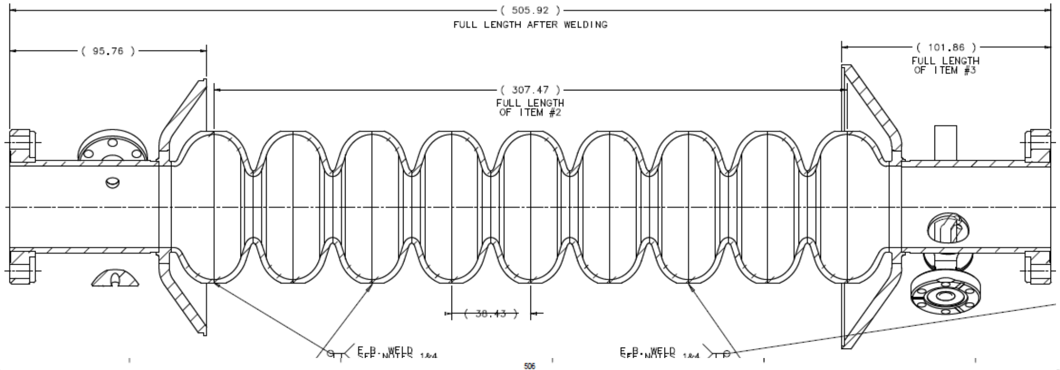


Table 1 Parameters of operating mode of the 3.9 GHz cavity

Operating Mode Parameters	XFEL	LCLS-II
Frequency, [GHz]	3.9	3.9
Stored Energy, [J]	1	1
R/Q, [Ω]	746	751
Effective Length, [m]	0.346	0.346
Maximum Electric Field on Axis, [MV/m]	25.4	25.3
Accelerating Gradient, [MV/m]	12.36	12.40
Normalized Surface Electric Field	2.25	2.24
Normalized Surface Magnetic Field, [mT/MV/m]	4.90	4.88

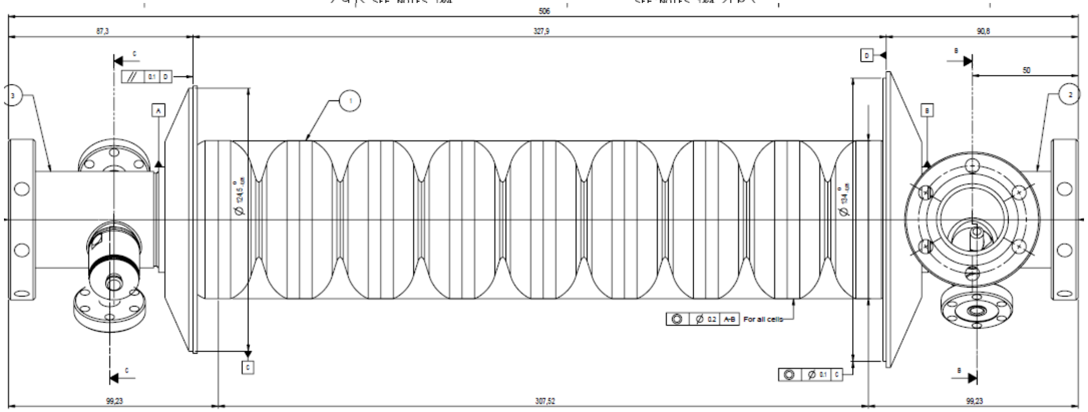
Cavity drawings: FLASH → XFEL → LCLS-II

FNAL/FLASH design



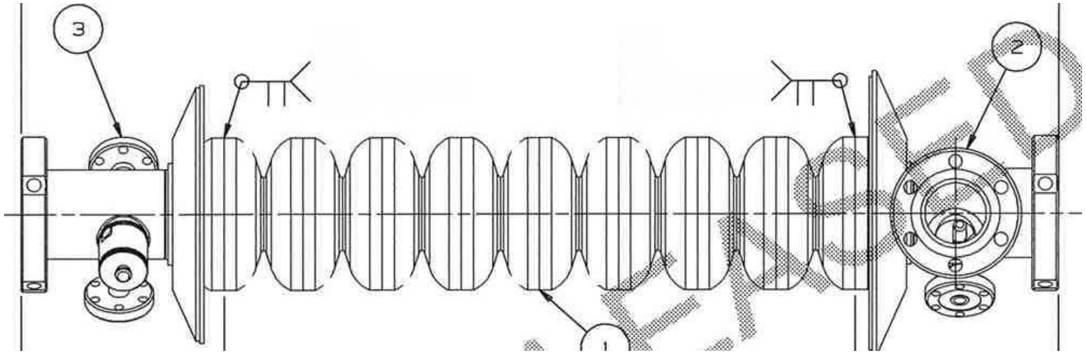
INFN/Zenon modification

(starting point for LCLS2)



LCLS-II:

Additional modifications to meet requirements.



LCLS-II 3.9 GHz cavity design

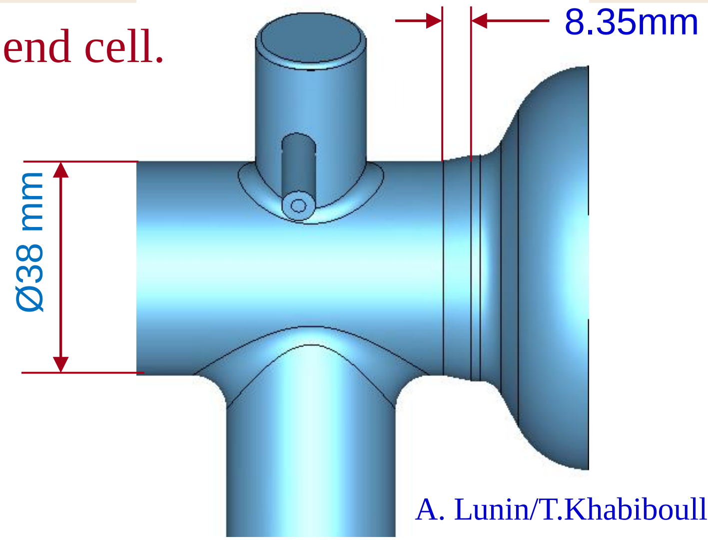
- INFN = modified FNAL design of the cavity for XFEL project. Modifications are done to simplify/improve production (Zenon) and tuning. Drawings and 3D models are available (thanks INFN team)
- CW operation in LCLS-II is more severe regime for the cavity. Some minor modifications are needed to reduce risks and eliminate tuning and heating problems.

Proposed modifications in cavity RF design.

- **Issue #1:** Frequency of lowest dipole mode trapped in coupler end of the cavity is too close to operating mode frequency, 3.9 GHz. As a result the tuning of notch frequency is difficult and 3.9 GHz frequency power leak is significant.
  Solution: Move away frequency of this mode
  Modification: Reduce beam pipe and bellow diameter from 40 to 38mm.
- **Issue #2 :** Overheating of the HOM antenna (quench ~20MV/m at cw/VTS)
  Modification: Increase length of bump
- *Issue: Heating of bellow between cavities*
  Modification: reduce bellow ID from 42 to 38mm

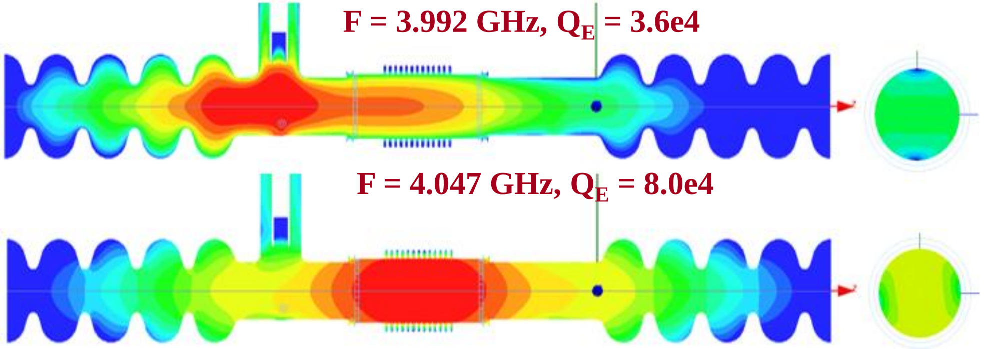
Reduce beam pipe diameter from 40mm to 38mm.

- No modification of cavity cells.
- Add small conical transition between beam pipe and end cell.



A. Lunin/T.Khabiboulline

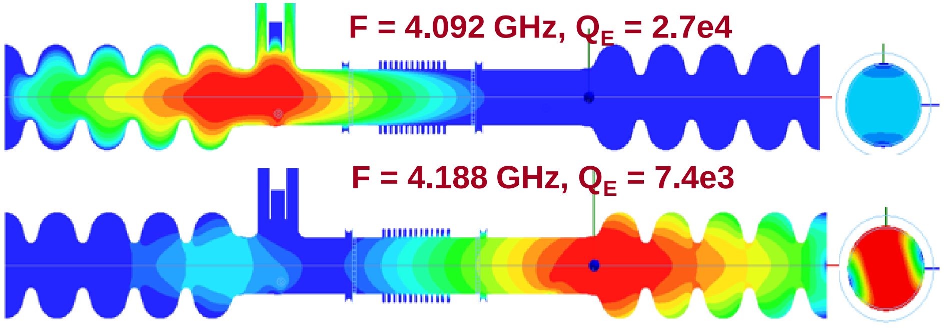
FLASH: Lowest Dipole HOMs. Beam Pipe Ø 40 mm and Bellows Ø 42 mm.



F = 3.992 GHz, Q_E = 3.6e4

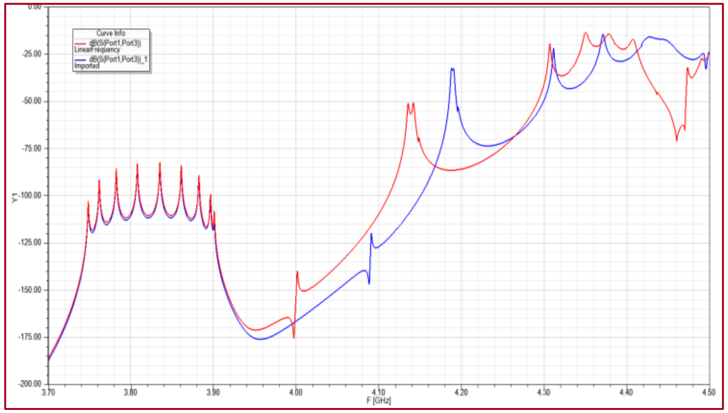
F = 4.047 GHz, Q_E = 8.0e4

LCLS2: Lowest Dipole HOMs. Beam Pipe Ø 38 mm and Bellows Ø 38 mm.



F = 4.092 GHz, Q_E = 2.7e4

F = 4.188 GHz, Q_E = 7.4e3



In current design lowest mode is closer (min ~10-20 MHz vs. 100MHz in simul.) to operat. mode

Lowest dipole mode frequency shifted by **100 MHz** up away from operating mode frequency.

Modification of HOM coupler

- Reduce penetration of antenna inside HOM to reduce heating → F-part modification

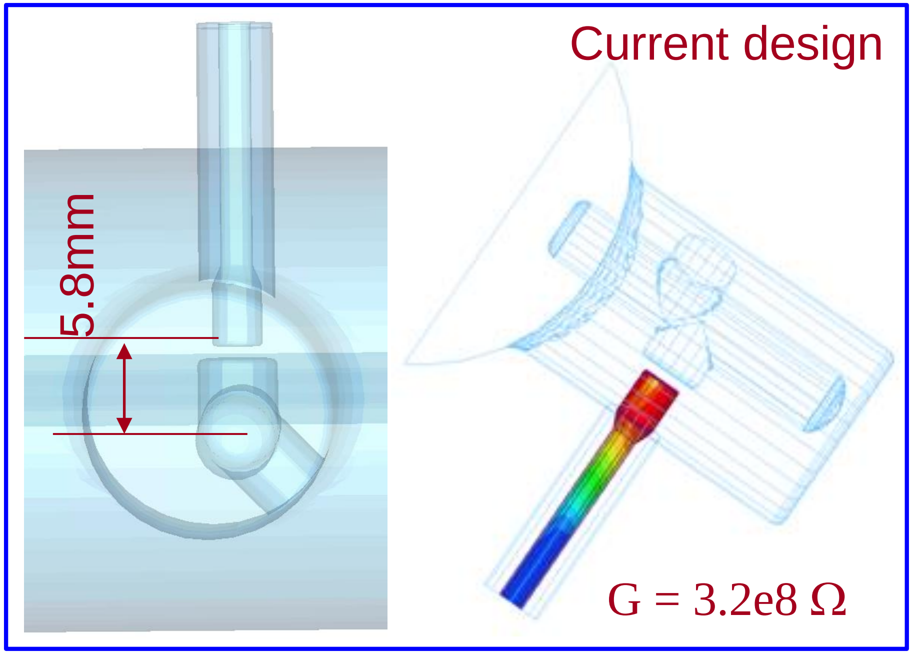
- Increase wall thickness on the top of HOM can to prevent cracks and vacuum leak

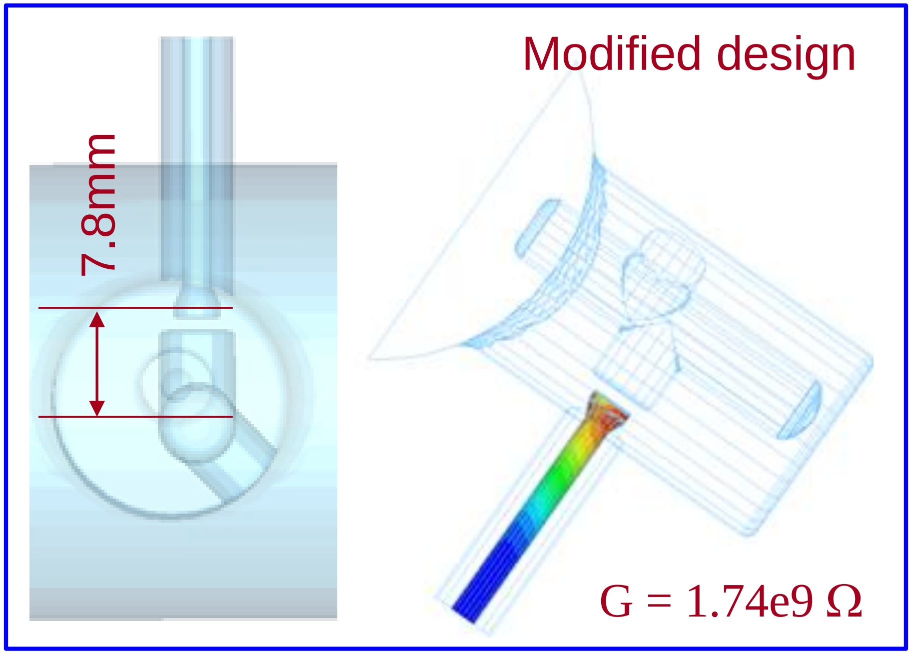
- To modify length of HOM feedthrough

  (choice of feedthrough design: Fermilab vs. XFEL)

HOM F-part modification to reduce antenna heating

Reduce penetration to beam pipe. Increase length of bump in F-part

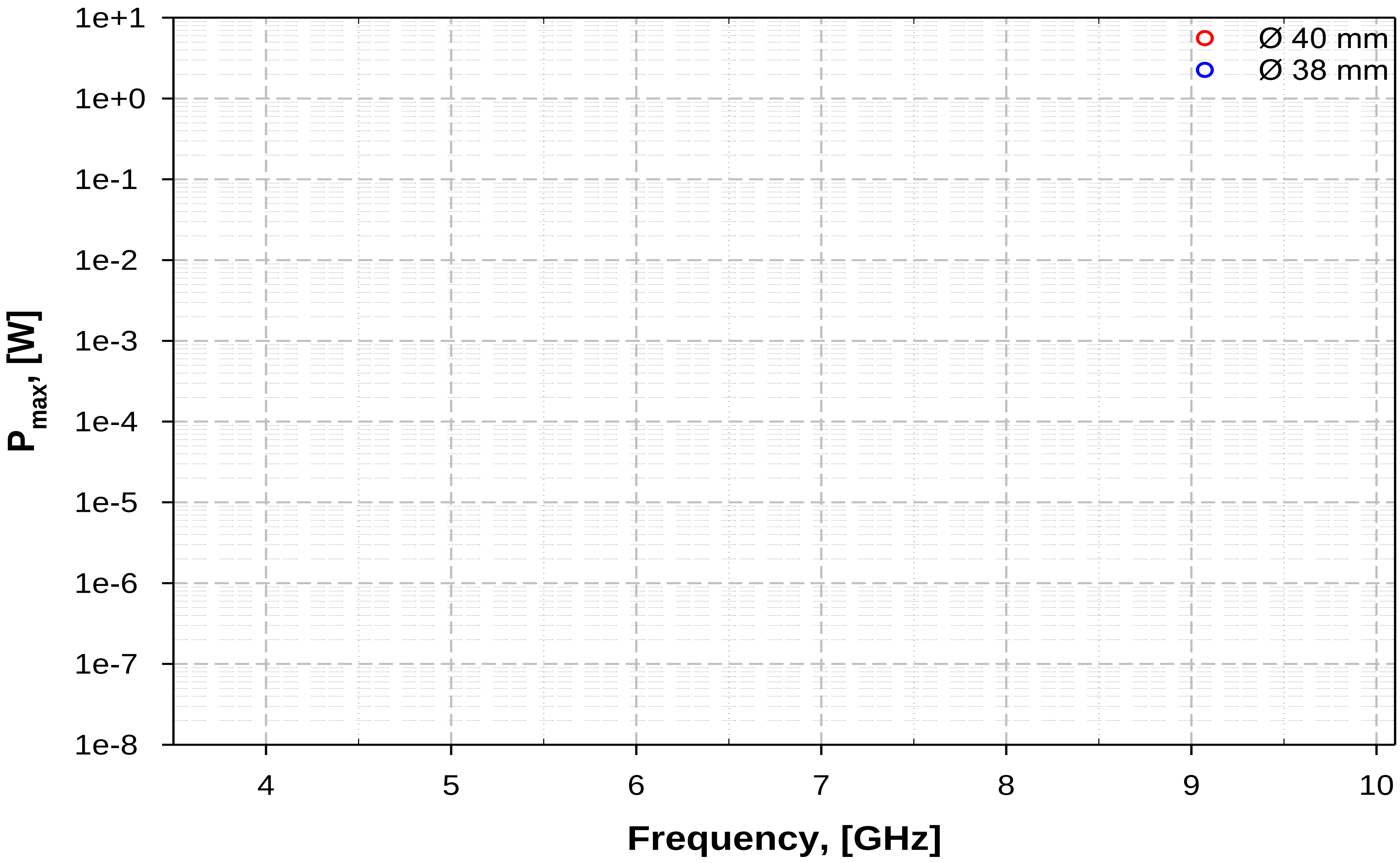




A. Lunin/khabiboulline

- **Current design HOM antenna quenches at ~20 MV/m in VTS. Expected that quench limit will even lower in CW regime at HTS and CM.**
- **RF power dissipation on HOM antenna reduced by factor of 5.4 after modification**

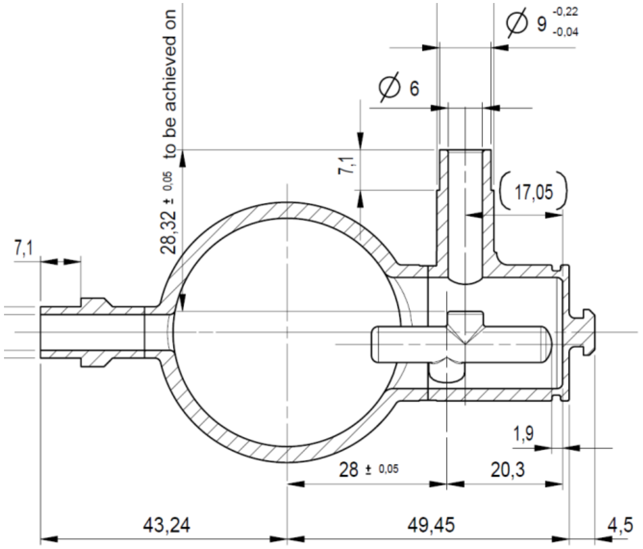
HOMs Resonant Losses in the 3.9GHz LCLS-II cavity (run #1)

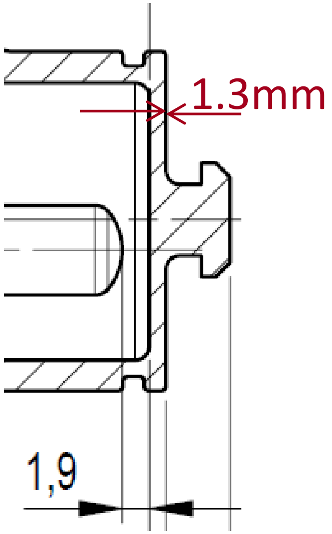


HOM can thickness increase from 1.0 mm to 1.3 mm.

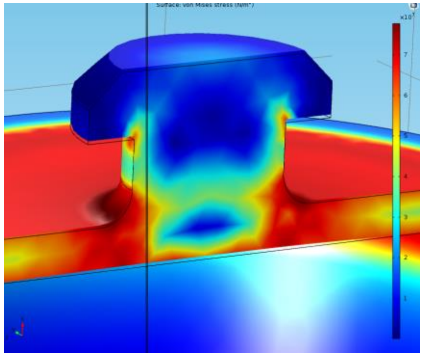
Thickness of hat is a concern:

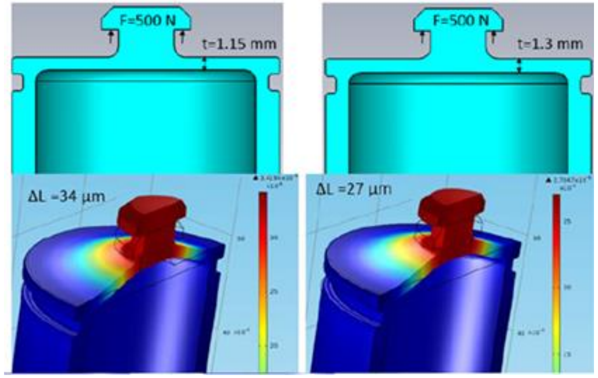
- **Was broken when h=1mm (FLASH).**
- **XFEL design has thickness of 1.15 mm → one prototype cavity has a leak.**
- **Proposal to have 1.3mm.**





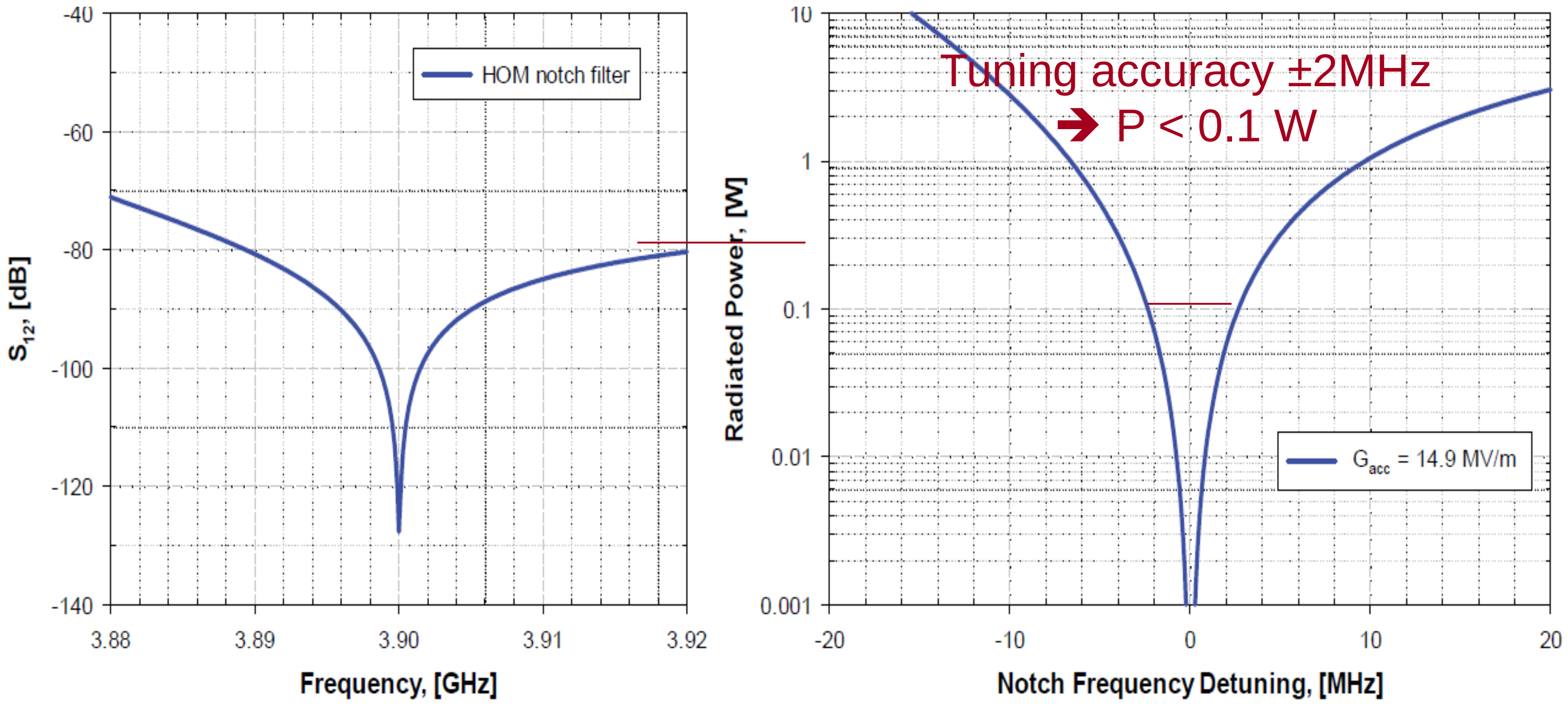
Knob pulled up by 0.1 mm





Conclusion: 1.3mm is acceptable thickness of can wall

Notch filter tuning requirements



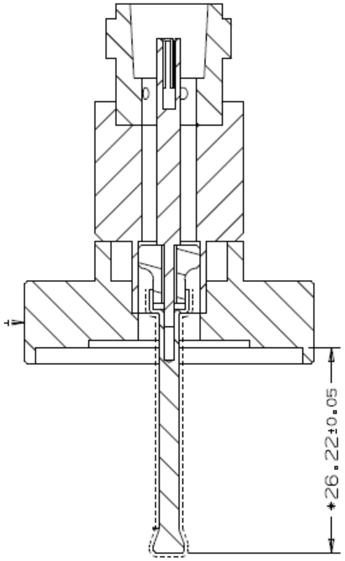
Tuning accuracy ±2MHz
➔ P < 0.1 W

Passband of the 3.9 GHz notch filter (left) and corresponding power radiated through HOM coupler at nominal accelerating gradient (right)

For 1.3 GHz HOM accuracy for notch filter frequency ~0.5MHz

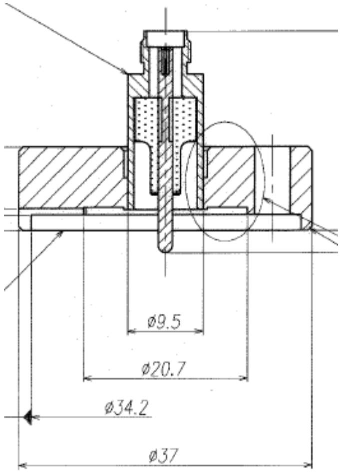
HOM and pick-up feedthrough:

XFEL design (used for 1.3GHz and 3.9 GHz)



Antennaa are modified for 3.9 GHz

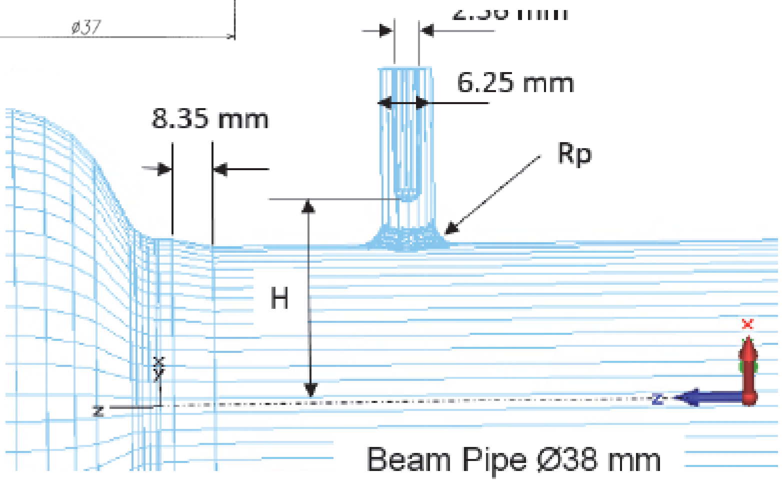
Field probe for 3.9 GHz (modified 1.3GHz design)



All feedthroughs are ordered in Kyocera for 24 cavities

$Q_{ext} = 7.5x10^{10}$

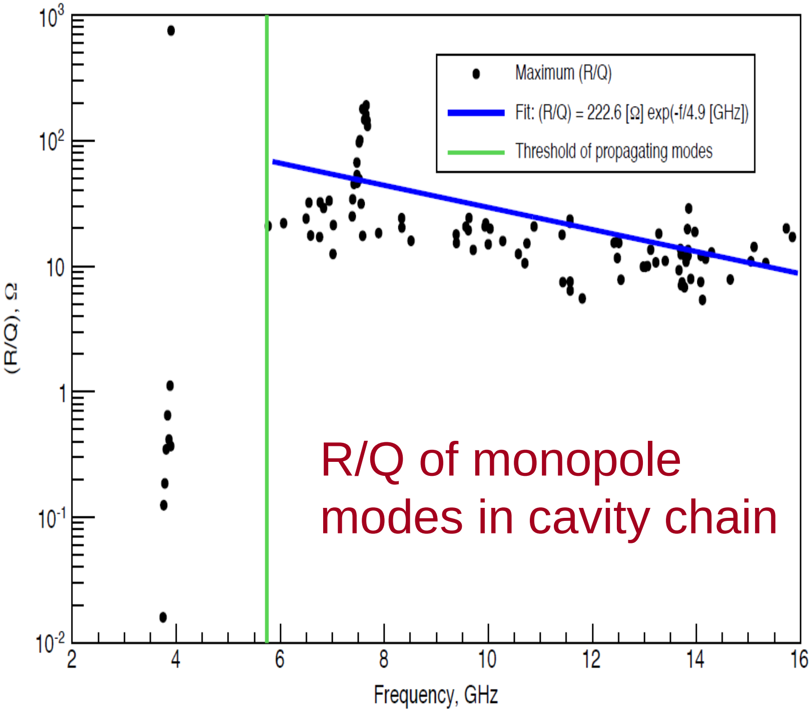
Pullout radius, (Rp)	1 mm	3 mm	6 mm
Ant. Offset, (H)	**21.9**	**22.4**	**23.4**



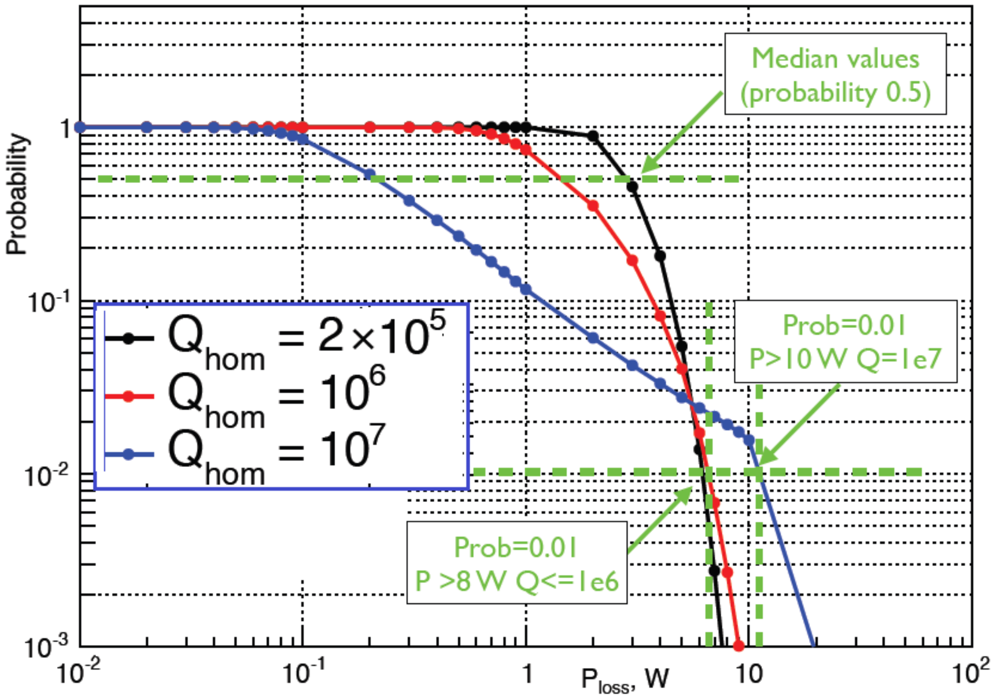
3.9 GHz: Power removed by HOM coupler

- Median P < 3 W (Q=2e5)
- Prob. 10^{-2} (in 1/100 cavities) to have P > 10 W (Q=1e7)

A. Sukhanov



R/Q of monopole modes in cavity chain



Median values (probability 0.5)

Prob=0.01 P>10 W Q=1e7

Prob=0.01 P >8 W Q<=1e6

- Simulation model includes copper plated bellows between cavities
- HOM frequencies have random distribution ~ 1MHz rms
- Max values of R/Q for each mode is used (vs. cavity to cavity distance) – overest.
- $Q_{HOM} < 10^6$ for most dangerous modes (Pmax < 7W, prob. 10^{-2} per 2 HOMs)

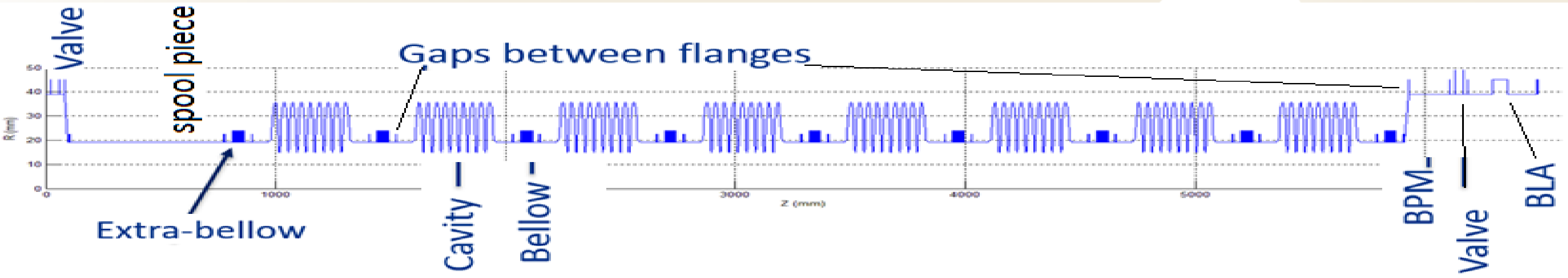
HOM antenna heating issues

- Maximum power flux to HOM coupler up to 4W:
  - ✓ < 0.5 W – leakage from operating mode
  - ✓ Max power flux to 2K is 0.1W (from power dissipated in cable)

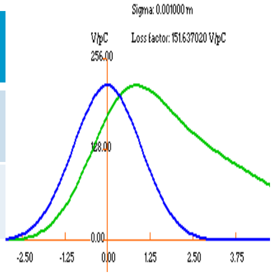
- Part of this will be dissipated in cable (0.6dB/m) and will heat HOM antenna.
- Heat removal from feedthrough (2K) and from the cable intercepts (5K and 50K) is essential part of design.

- Choice of cable and specs is part of current activity. Use the same cables as in 1.3GHz CM, but ~1m shorter.

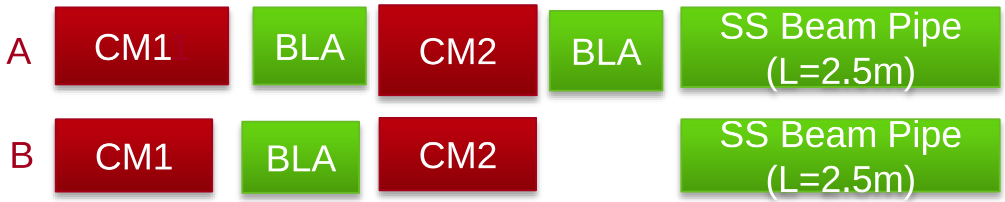
Beamline components heating: wakes



Bunch length (sigma)	1mm
8x (Cavities + bellow)	135.5 V/pC
CM (8cav/9bellow/gaps)	151.64 V/pC



Wake power (300µA; σ=1mm) is **13.65 W** per CM, and only **9.5 W** above beam pipe cut-off frequency



A CM1 BLA CM2 BLA SS Beam Pipe (L=2.5m)

B CM1 BLA CM2 SS Beam Pipe (L=2.5m)

Components in 2 CM's	Power Deposition, [W]		
	A (baseline)		B
	No HOM, PC	HOM PC	HOM PC
BLA (1 or 2)	16.2	13.5	10.5
SS tube 2.5m	1.65	1.4	2.2
Bellows (17)	0.36	0.3	0.4
Gate Valve (4)	0.6	0.45	0.7
Spool (2)	0.02	0.02	0.03
HOMC (32)	0	0.5	0.75
FPC (16)	0	2.7	4.1

Total power in 2 CMs ~19 W

Heating of bellows from operating mode RF

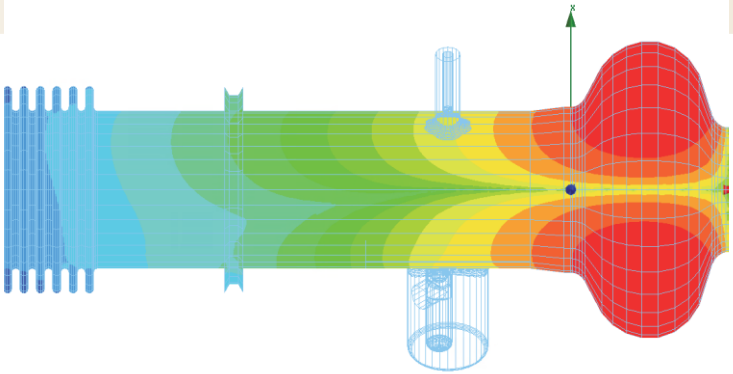
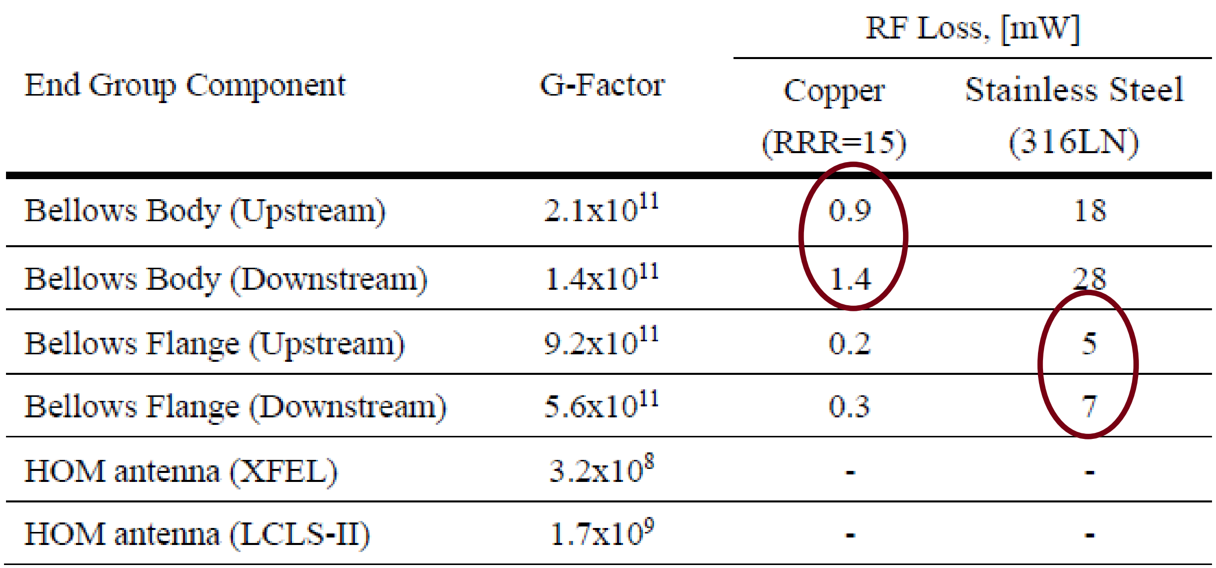
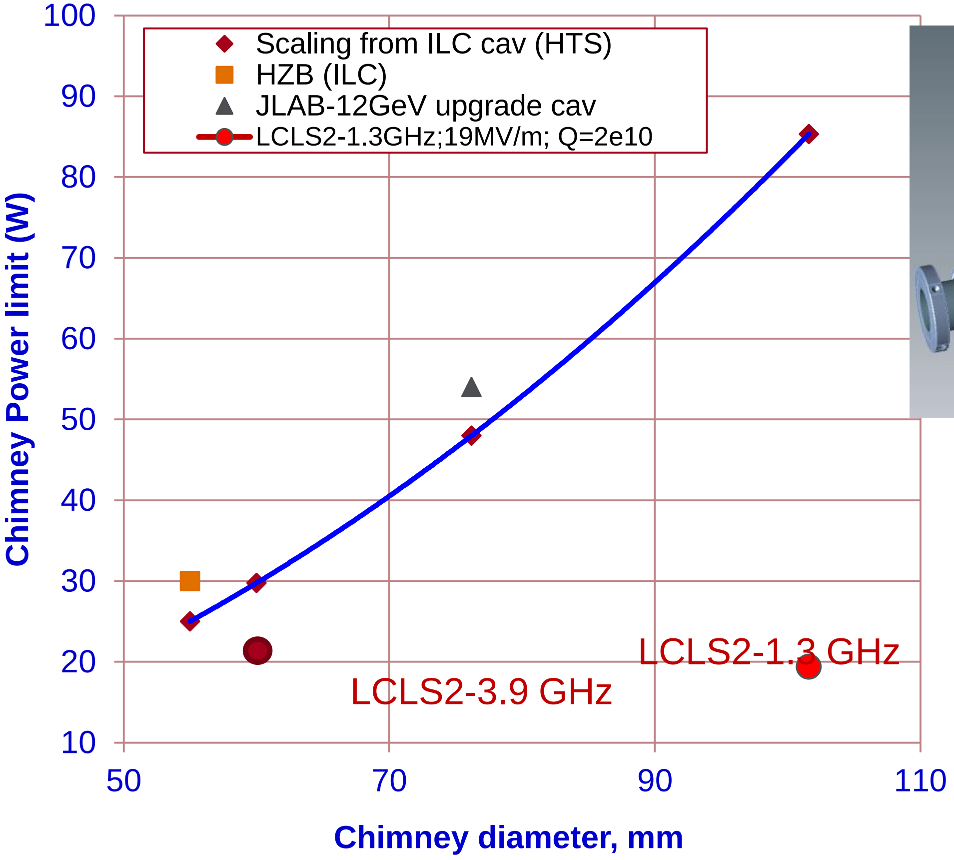


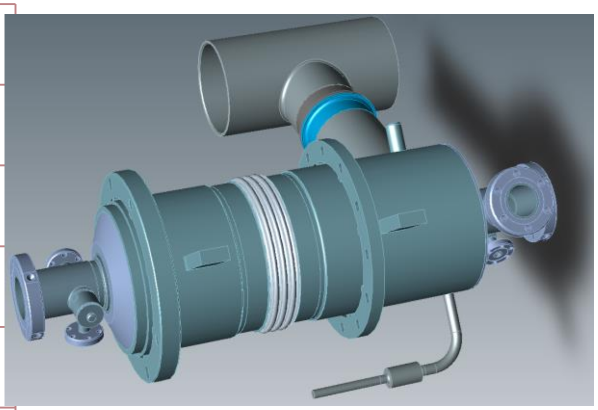
Table 2 Operating mode RF losses in the End Group at 14.9 MV/m gradient

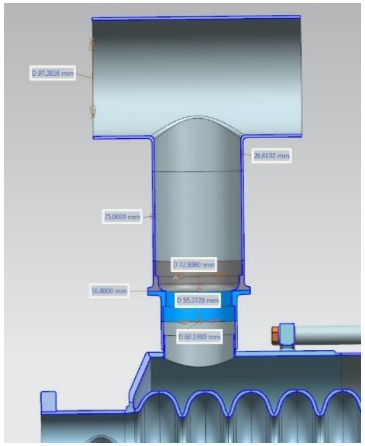


End Group Component	G-Factor	RF Loss, [mW]	
		Copper (RRR=15)	Stainless Steel (316LN)
Bellows Body (Upstream)	$2.1\text{x}10^{11}$	0.9	18
Bellows Body (Downstream)	$1.4\text{x}10^{11}$	1.4	28
Bellows Flange (Upstream)	$9.2\text{x}10^{11}$	0.2	5
Bellows Flange (Downstream)	$5.6\text{x}10^{11}$	0.3	7
HOM antenna (XFEL)	$3.2\text{x}10^{8}$	-	-
HOM antenna (LCLS-II)	$1.7\text{x}10^{9}$	-	-

Chimney Power Limit







$$P = \frac{(E_{acc} \cdot L)^2}{(R/Q) \cdot Q_0}$$ - Cryoload at 2K

	Nominal parameters	Max in CM	Max power (VTS/HTS)
E_{acc} (MV/m)	**13.4**	**14.9**	16.4 (+10%)
Q0	**2.e9**	**2.e9**	1.5e9
P/cav (W)	**14.3**	**17.7**	28.6

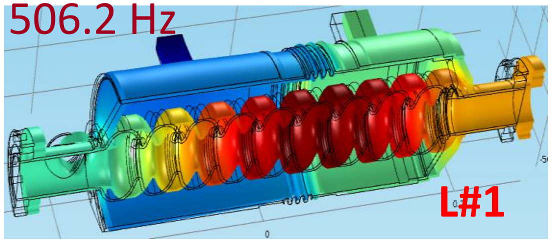
Avrg power per cavity in CM

Max power in individual cavity

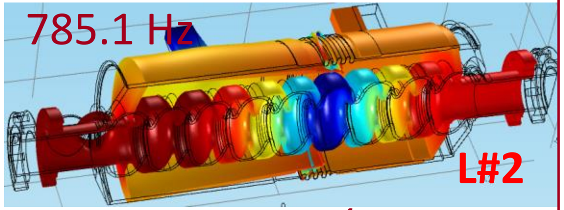
Chimney the heat load limit is at least 30 W (ID= 60.2 mm (short) → 73mm (long part))

Cavity Mechanical Resonances
(Stiffness of the Tuner = 40 kN/mm)

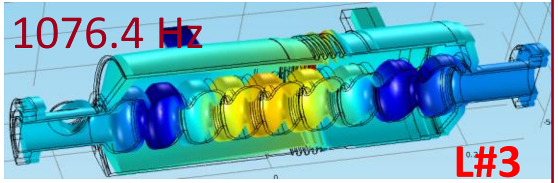
Longitudinal modes



k=0.75 Hz/µm

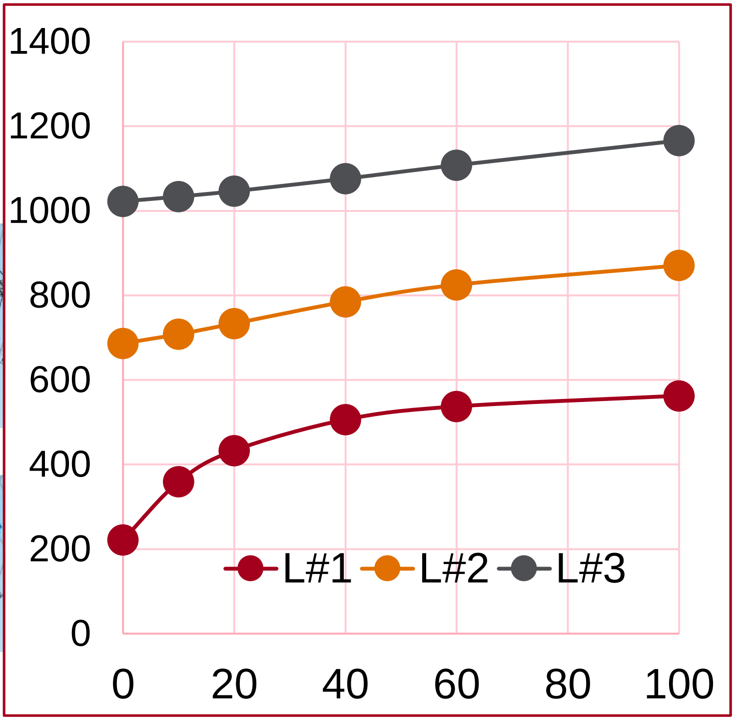


k=4.75 Hz/µm

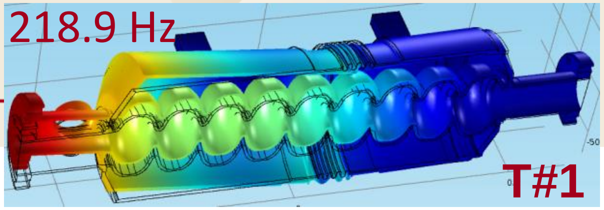


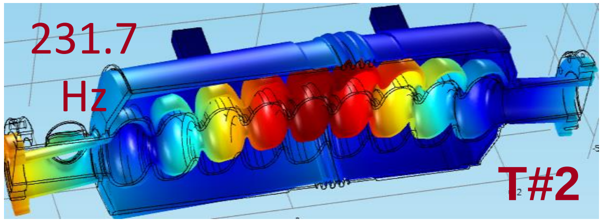
k=0.75 Hz/µm

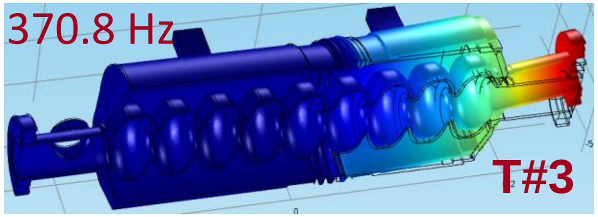
Frequencies (Hz) of Longitudinal modes L#1-L#3 vs. Stiffness of the Tuner (kN/mm)

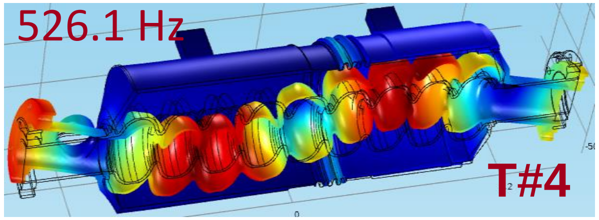


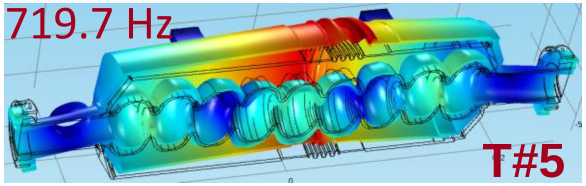
Transverse modes

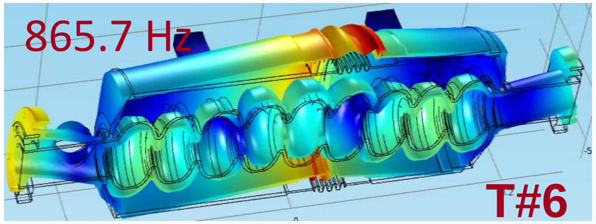






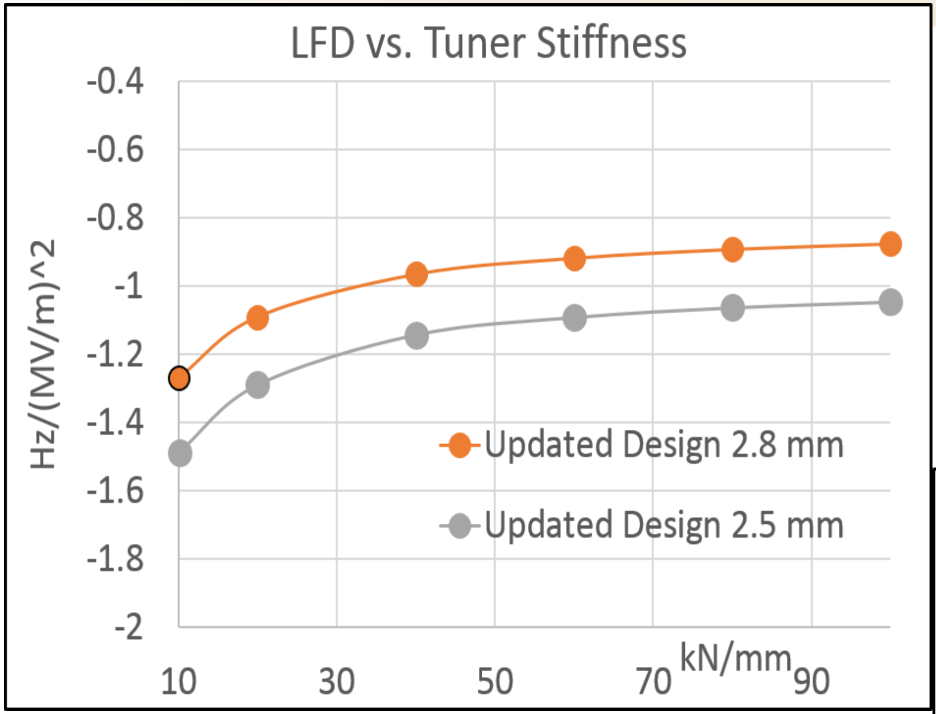




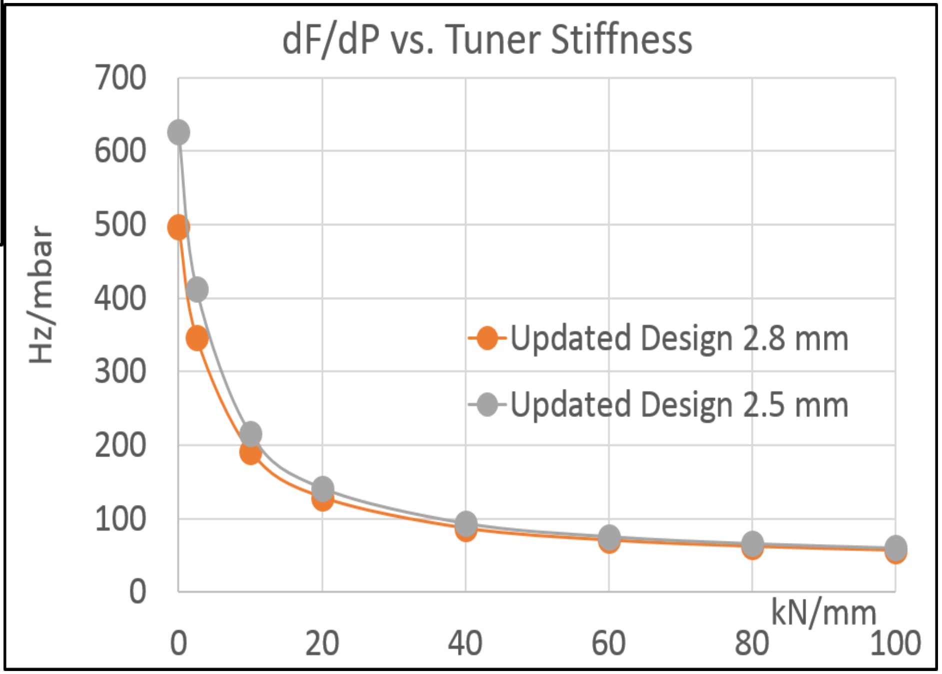


I. Gonin

Dressed Cavity LFD and dF/dP

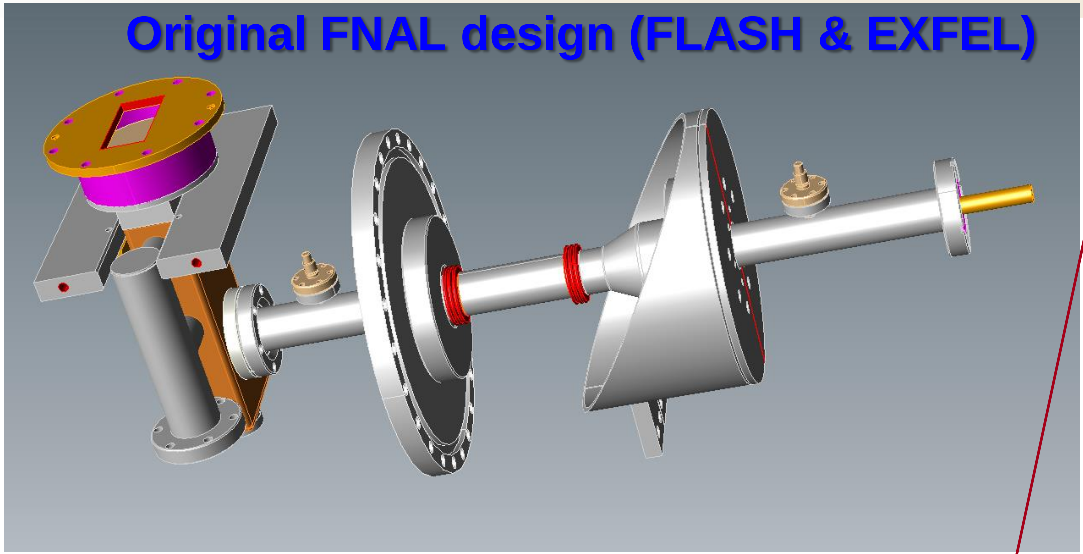


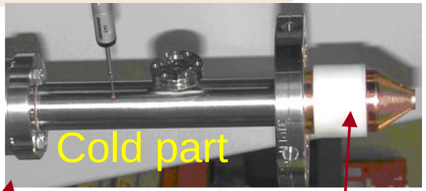
I. Gonin



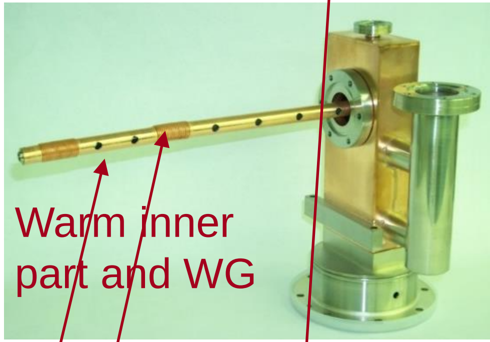
Modification of 3.9 GHz power coupler for LCLS-II CW operation

Original FNAL design (FLASH & EXFEL)




Cold part

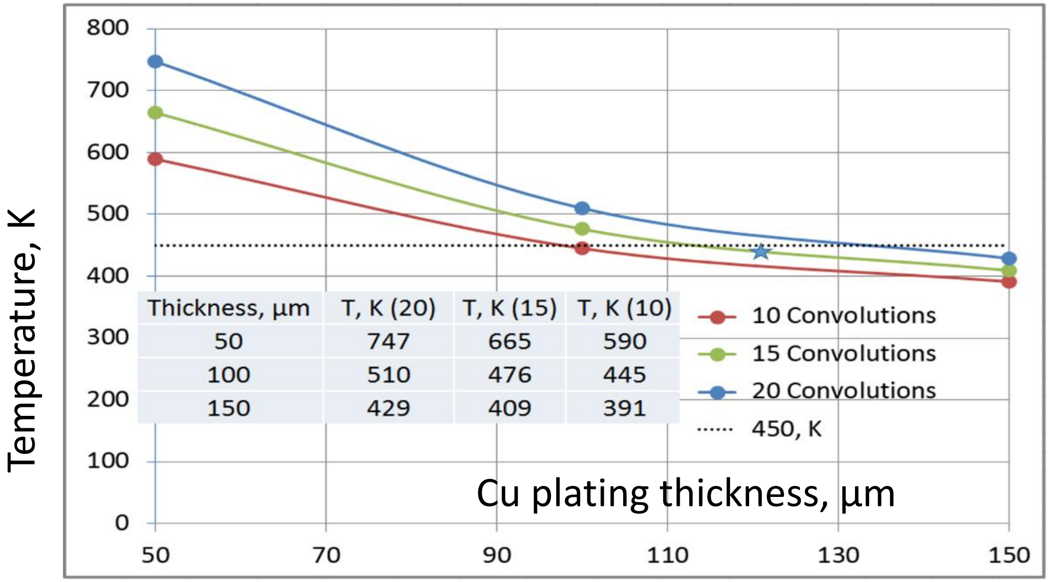

Warm outer part


Warm inner part and WG

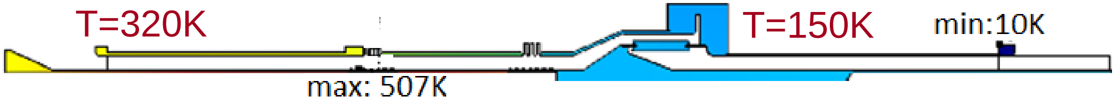
- **Coupler was designed for pulse operation (P=50kW, DF=2%).**
- **LCLS-II requirements: P_{max}=2kW cw; quasi – TW regime:**
    - W/o modification inner conductor of warm part will be overheated up to 1000 K.
  - **Proposed modifications:**
    - Shorter antenna (QL~2.7e7 vs. 1.5e6)
    - Increase thickness of copper plating on inner conductor from 30 µm to 120 µm
    - Reduce length of 2 inner bellows in inner conductor from 20 to 15 convolutions.
    - Increase thickness of ceramics in cold window to move parasitic mode away.

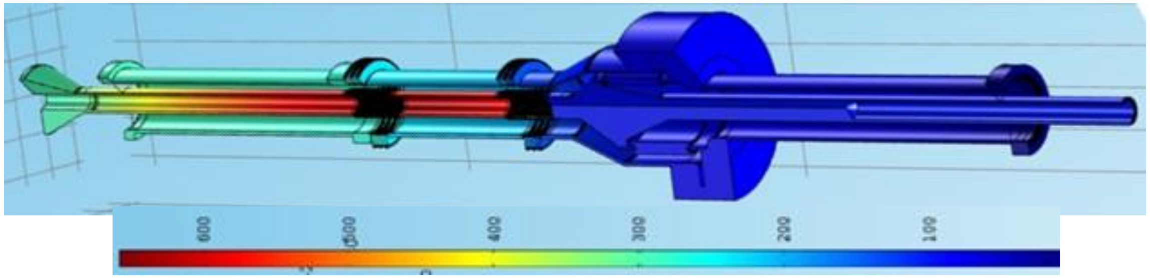
COUPLER THERMAL ANALYSIS

For solving the inner conductor overheating problem we propose to reduce the length of two inner bellows from 20 to 15 convolutions and to increase the thickness of a copper plating on the inner conductor from 30 to 120 microns.



Thickness, µm	T, K (20)	T, K (15)	T, K (10)
50	747	665	590
100	510	476	445
150	429	409	391





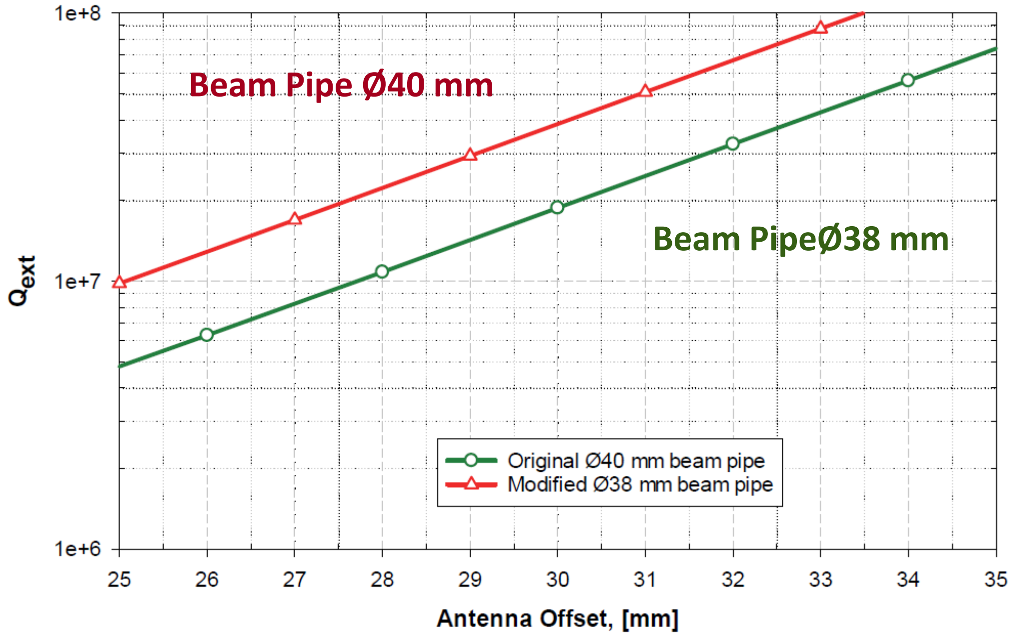
Losses (W) at 5K and 50K

SS Inner Conductor	T_{max} K	Losses @50K	Losses @5K
30 µm plating	1000	9.2	0.8
100 µm plating	507	9.3	0.8
150 µm plating	427	9.4	0.8

Assumptions

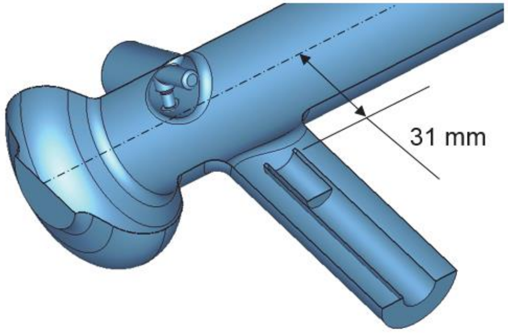
- Pin=2kW TW,
- 10µm on outer,
- RRR=50; ASE,
- 10% roughness
- ε=9.8, tan=3e-4,

Main coupler antenna configuration

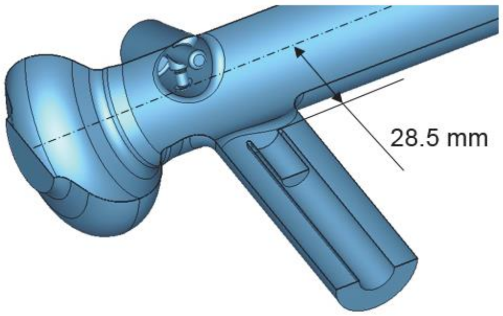


A. Lunin

Beam Pipe Ø40 mm

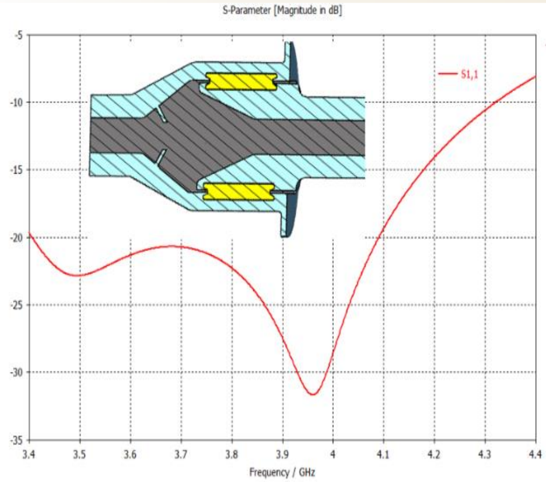


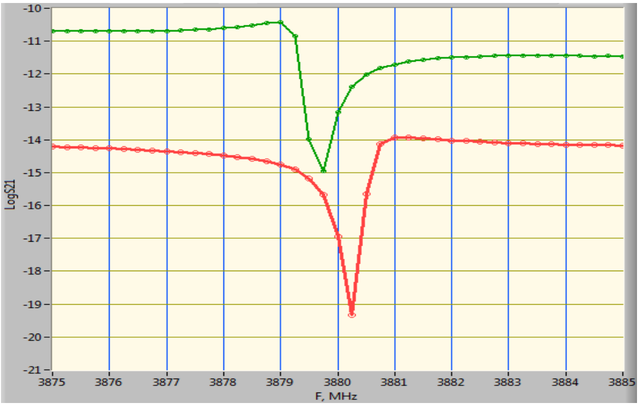
Beam Pipe Ø38 mm



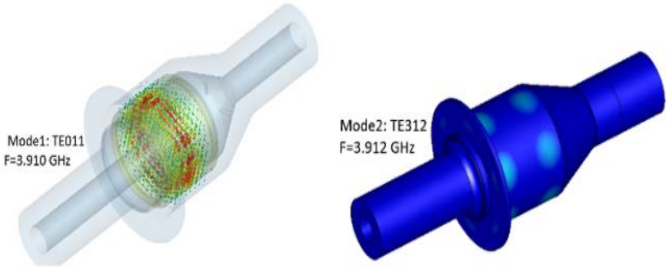
Nominal power coupler antenna positions in the 3.9 GHz cavity for XFEL (left) and LCLS-II (right);
QL=2.5e7

Trapped modes in cold ceramic window

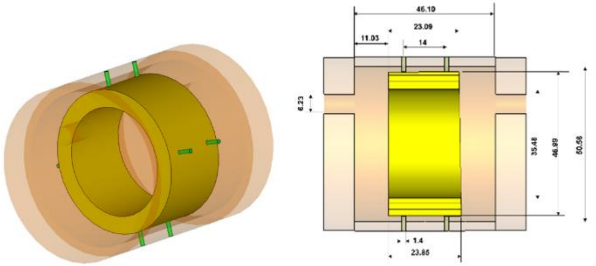




Trapped mode resonances measured in the 3rd harmonic power coupler (shift -20MHz). Transmission losses more than 3 dB, bandwidth ~ 0.5 MHz.



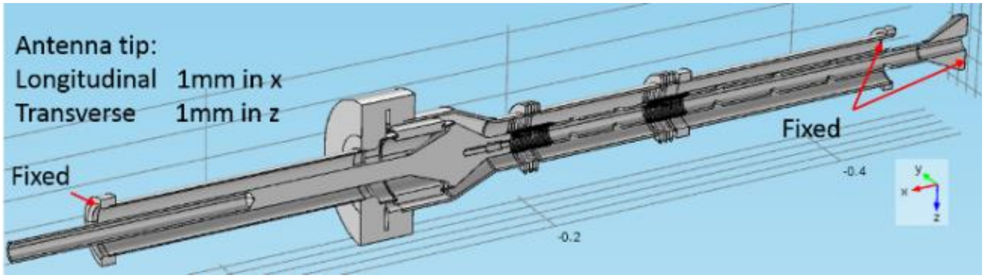
Two nearest trapped modes in the coupler ceramic window (simulations)



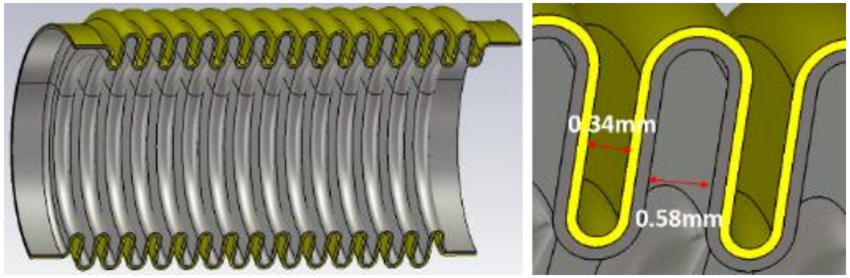
Set-up for ceramic measurement.
ε=9.71; tanδ=3.6E-4
(averaged over 5 modes)

The inner and outer diameters of ceramic changed symmetrically by 0.25 mm each, which shifts down by **33 MHz** the frequency of nearest parasitic mode and, thus, secures of **~50 MHz** isolation from the operating mode. (sensitivity of parasitic mode frequencies vs. ceramic radius is ±65.6 MHz/mm)

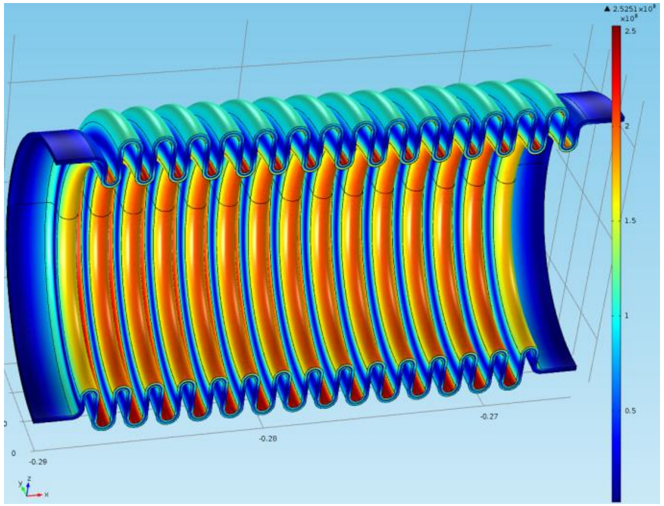
COUPLER MECHANICAL DESIGN



COMSOL solid model and mechanical boundary conditions.



Solid model of 15 convolutions stainless steel bellows with 120 µm copper plating.



Von Misses stresses for 0.5 mm longitudinal deformations of each bellows.

	MPa/mm
Inner conductor, transverse,	38
Outer conductor, transverse,	45
Inner conductor, longitudinal	253
Outer conductor, longitudinal	98

Summary of stresses in 15 convolutions bellows

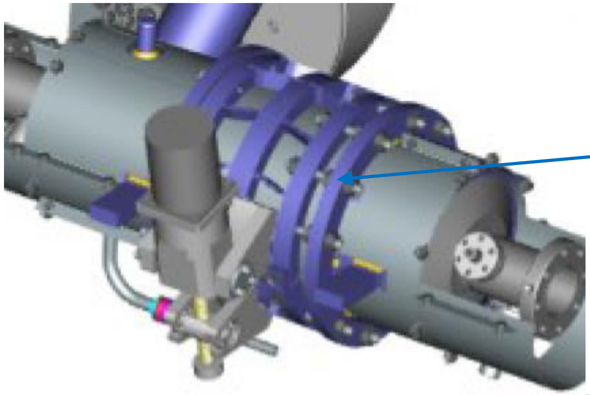
Typically copper bellow endurance limit for infinite cycles is from 83 to 166 MPa or 300 MPa for a low cycle fatigue strength CPI feed-back)

Tuner SUMMARY/STATUS

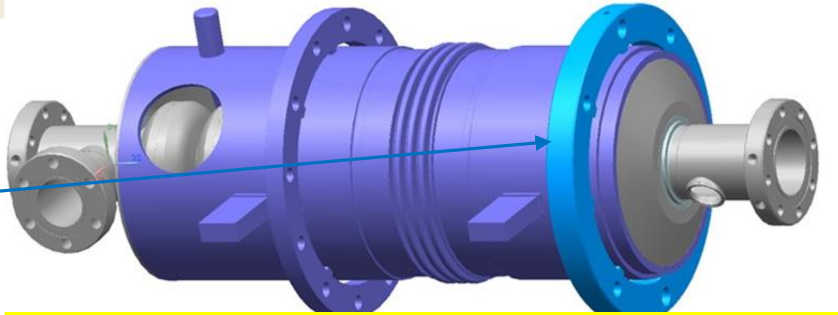
- Use XFEL 3.9GHz slim blade tuner (INFN) with minor modifications to meet LCLS-II requirements.
- Modification introduced:
  - ❖ #1 -adding fine/fast piezo tuner
  - ❖ #2 replacement of the Sanyo/HD actuator on Phytron electromechanical actuator.

Note: Piezo-capsule and Phytron actuator selected for 1.3GHz tuner.
Both active components passed several lifetime and rad. hardness tests

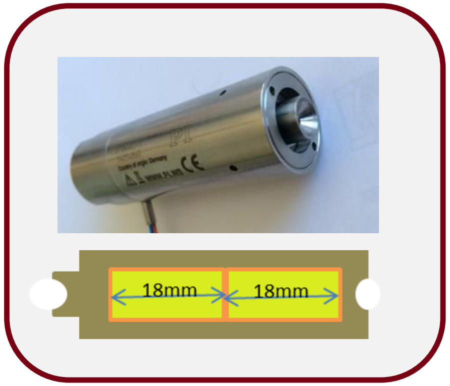
INFN slim blade tuner modifications – adding Fine/Fast (piezo) tuner

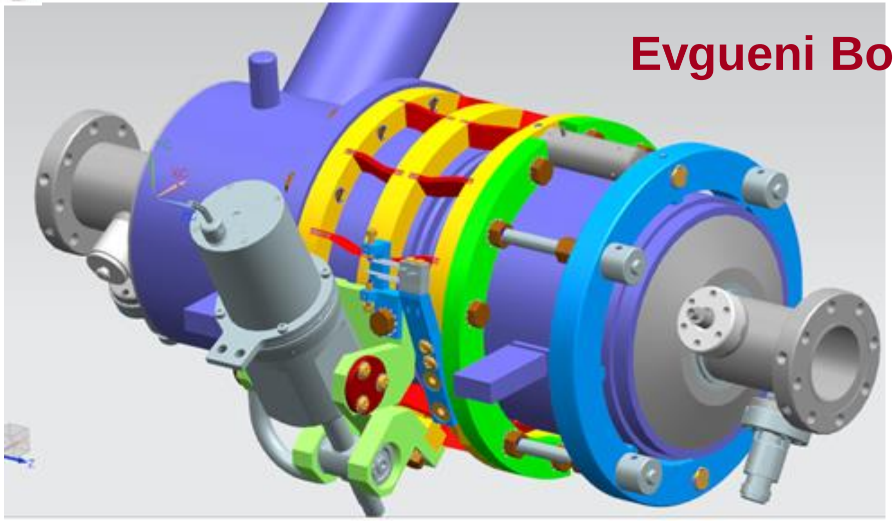


INFN (EuXFEL) tuner



Moved second ring, welded to He Vessel. to accommodate 66mm piezo-stacks

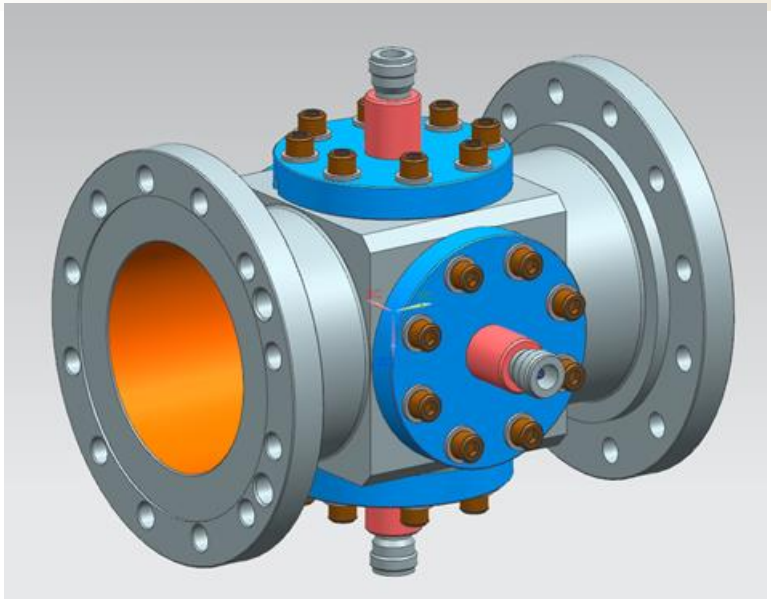




Evgueni Borissov

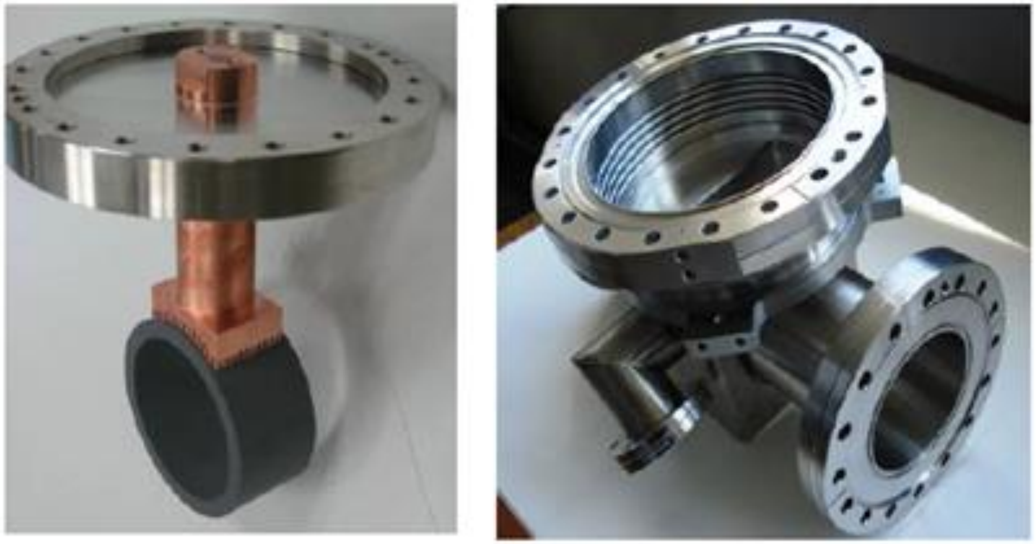
Two PI piezo-capsules (4 piezo-stacks). Will deliver more than 10kHz. Even one piezo can deliver required fine tuning stroke >1kHz.

BPM and HOM absorber



Concept: Use 1.3GHz beam line components (ID=78mm) in transition between cavity string:

- BPM,
- Gate-valve,
- Beamline HOM absorber (~10 W)



Conclusion

- Design is completed and Technology of all components exist (based on FNAL/XFEL/INFN).
- To meet LCLS-II requirements cavity, coupler, HV and tuner designs are modified to reduce risks and improve performance at cw operation.
- Simulations and studies for the dressed cavity and beamline components are done to prove proposed modifications and predict performance in LCLS-II cryostat.
- Prototypes of Cavity and Auxiliaries (Tuner, main coupler, magnetic shielding, feedthroughs,…) will be tested in HTS (DV) before major procurement starts.

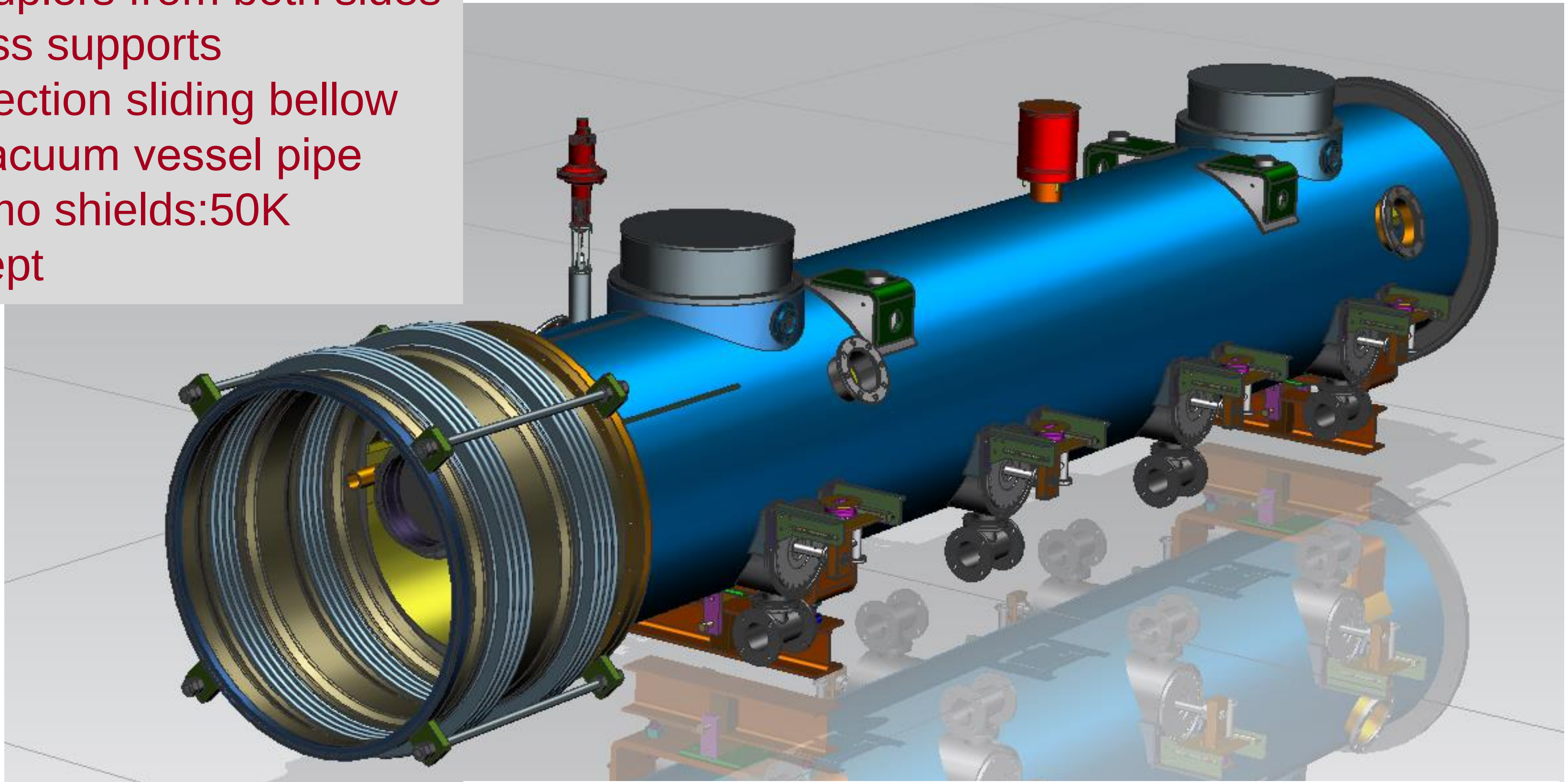
Thanks:

T.Khabiboulline, I.Gonin, A.Lunin, S.Kazakov, R.Stanek, C.Ginzburg, E.Harms, H.Edwards, C.Grimm, M.Foley, Y.Pischalnikov, T.Arkan, A.Rowe, A.Grassellino, G.Wu, O.Prokofiev, J.Ozelis, A.Saini, J.Kaluzny, S.Yakovlev, M.Hasan, T.Peterson, Y.Orlov, Y.He, E. Borissov, …

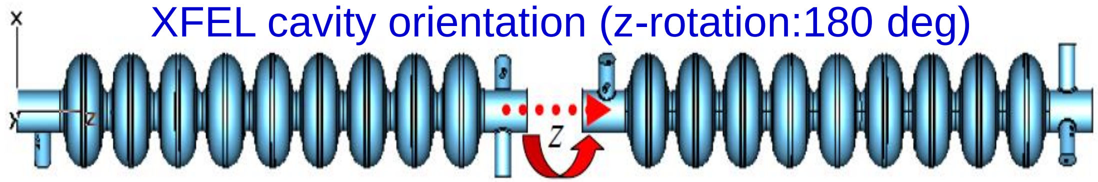
Back-up slides

LCLS-II 3.9GHz Cryomodule, (F10014857 in Team Center)

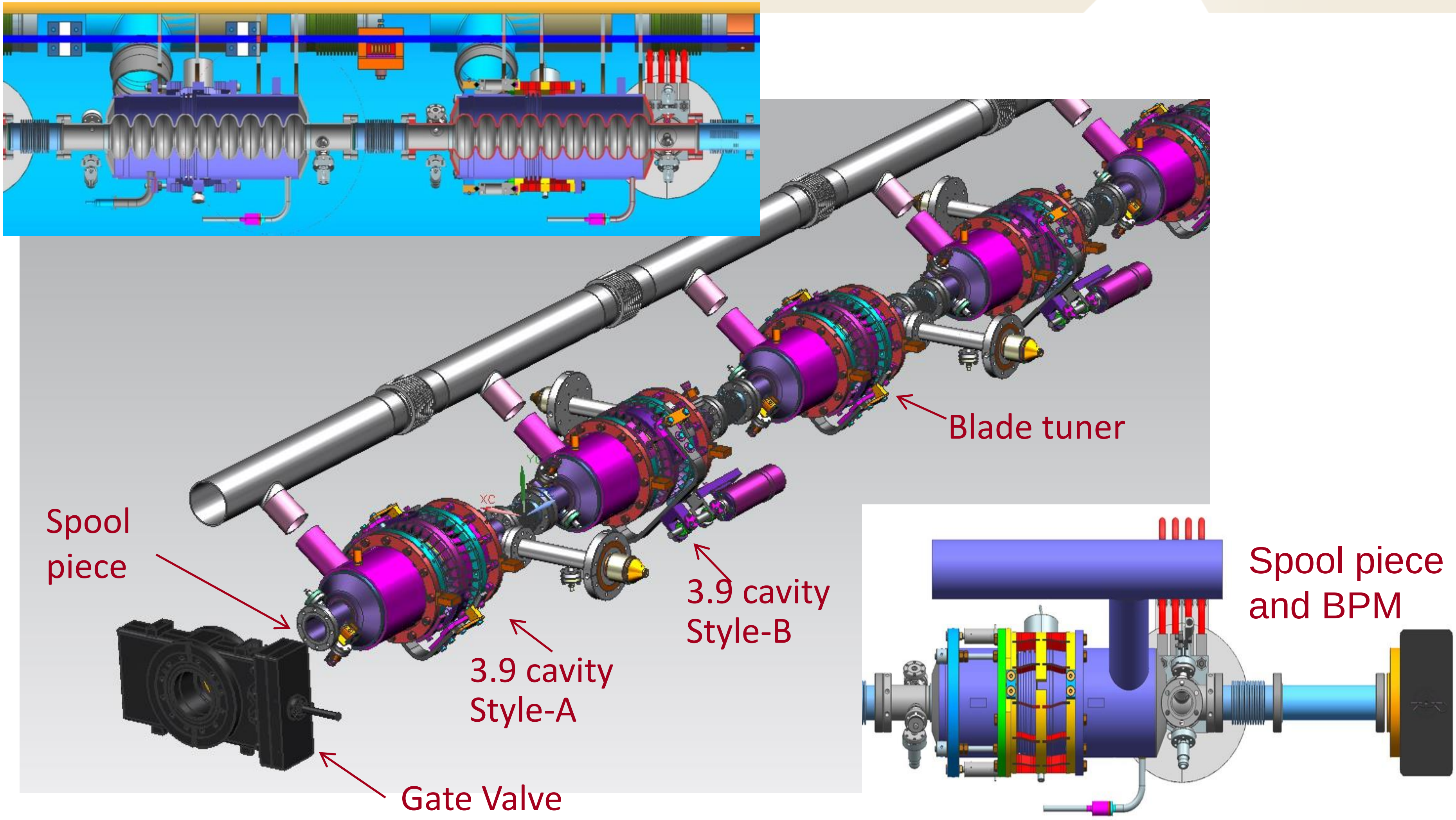
- 8 - 3.9GHz cavities
- Power couplers from both sides
- 2-coldmass supports
- Interconnection sliding bellow
- 38” OD vacuum vessel pipe
- One thermo shields:50K
- 5K intercept



XFEL cavity orientation (z-rotation:180 deg)



LCLS-II. 3.9GHz Cavity String (F10014812)



Spool piece

Blade tuner

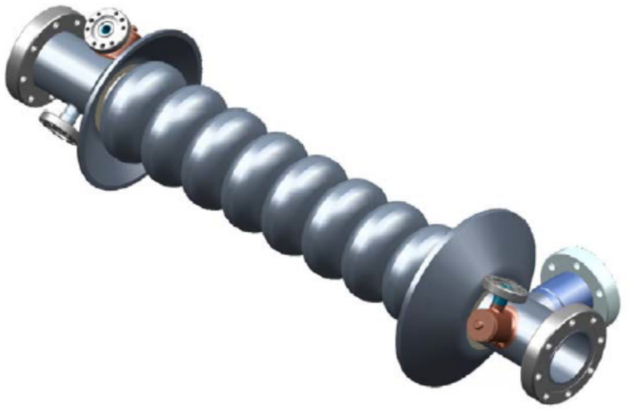
3.9 cavity Style-B

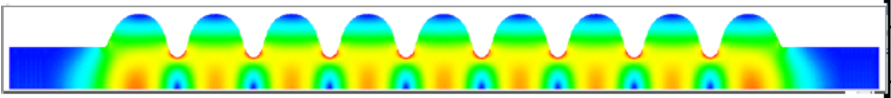
3.9 cavity Style-A

Gate Valve

Spool piece and BPM

TM_{010} Cavity general parameters

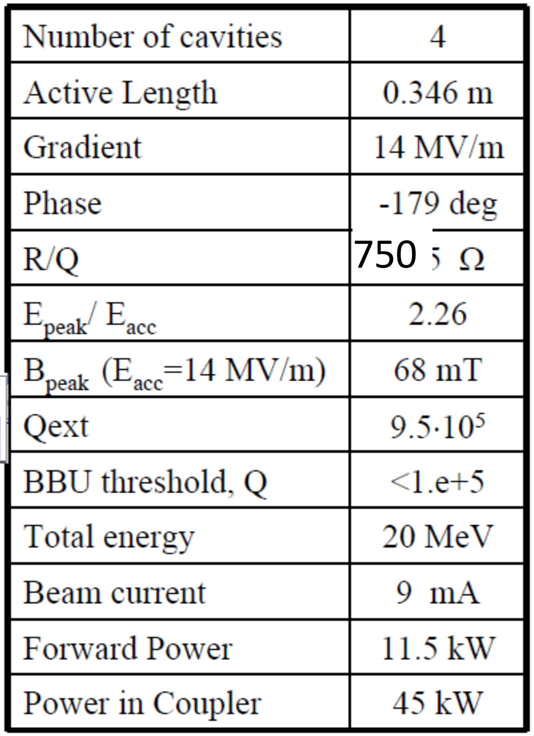




- Decreased surface fields in end cells
- Regular cells -30mm iris diameter
- End-cells iris from the tube side increased up to 40mm for better coupling with the power coupler
- Two HOM couplers are mounted in both ends
- Ports for power coupler and pick-up antenna
- 2.8 mm bulk niobium

FLASH

Parameter List for 3.9 GHz cavity:



Number of cavities	4
Active Length	0.346 m
Gradient	14 MV/m
Phase	-179 deg
R/Q	750 5 Ω
E_{peak}/E_{acc}	2.26
B_{peak} (E_{acc}=14 MV/m)	68 mT
Qext	$9.5 \cdot 10^5$
BBU threshold, Q	<1.e+5
Total energy	20 MeV
Beam current	9 mA
Forward Power	11.5 kW
Power in Coupler	45 kW

Comparison
3.9 GHz vs. 1.3 GHz:

Iris Aperture: 30mm vs. 70mm (ratio 2.34)
E_p/E_{acc} ; 2.26 vs. 2.0 (13% higher)
H_p/E_{acc}(mT/MV/m) 4.86 vs. 4.26 (14% higher)
R/Q (Ohm) 750 vs. 1000
BCS resistance ratio (f^2) (9 times higher)

Vendor	Times Microwave			Huber+Suhner				Gore Type 42
Cable Type	TFlex-401	**TFlex-401t**	SFT-304	32022	32039	SF229	**3288LM (SF329)**	Gore Type 42
Inner Cond OD [in]	0.0641	**0.062**	0.062	0.0359	0.06	?	**?**	0.089
Outer Cond ID [in]	0.208	**0.185**	0.185	0.106	0.191	?	**?**	0.196
Outer Cond OD [in]	0.249	**0.227**	0.227	0.109	0.20	?	**?**	0.225
Cable OD [in]	0.27	**0.250**	0.250	0.144	0.250	0.20	**0.20**	0.29
Material of Conductor	CuAg	**CuAg**	CuAg	CuAg	CuAg	CuAg	**AlCuAg**	CuAg
Dielectric	PTFE (ε_r=2.04)	**ePTFE**	ePTFE	Microporous PTFE	Extruded TFE	Low density PTFE	**Microporous PTFE**	ePTFE (ε_r=1.4)
Velocity %	69.5	**69.5**	76	76.3	70.3	82	**82**	
Attenuation [dB/m] at 1 GHz	0.26	**0.22**	0.22	17dB/100ft at 2GHz	12dB/100ft at 2GHz	0.18	**0.18**	0.3
Outer Braid	CuAg	**CuAg**	CuAg+ Polymide/ Al+CuAg	CuAg+ Polymide/Al +SS	CuAg+ Polymide/ Al+SS	Polymide/Al +CuAg	**Polymide/Al +AlCuAg**	CuAg+ Mechanical Shield
Jacket Material	FEP	**TEFZEL 750**	FEP	FEP	FEP	FEP	**ECTFE**	TEFZEL
Temperature Rating [C]	-65 to +125	**-55 to +200**	-55 to +200	-55 to +200	-55 to +200	-55 to +125	**-65 to +165**	-100 to 150
Shielding	>100 dB	**>100 dB**	>110 dB	>110 dB	>110 dB	>90 dB	**>90 dB**	>110 dB
Radiation Resistance [Rad]	1e5	**3e7**	1e5	1e5	1e5	1e5	**2e8**	1e8
Material of Connectors	Brass	**Brass**	Brass	Brass	Brass	Brass	**Brass**	Be Cu
Price of 3m long assemblies(min is 250)	$147	**$175**	$157	$146	$192	$266	**$341**	$756

Lead Intercepted Power (3.9 GHz)

Narrow Leads

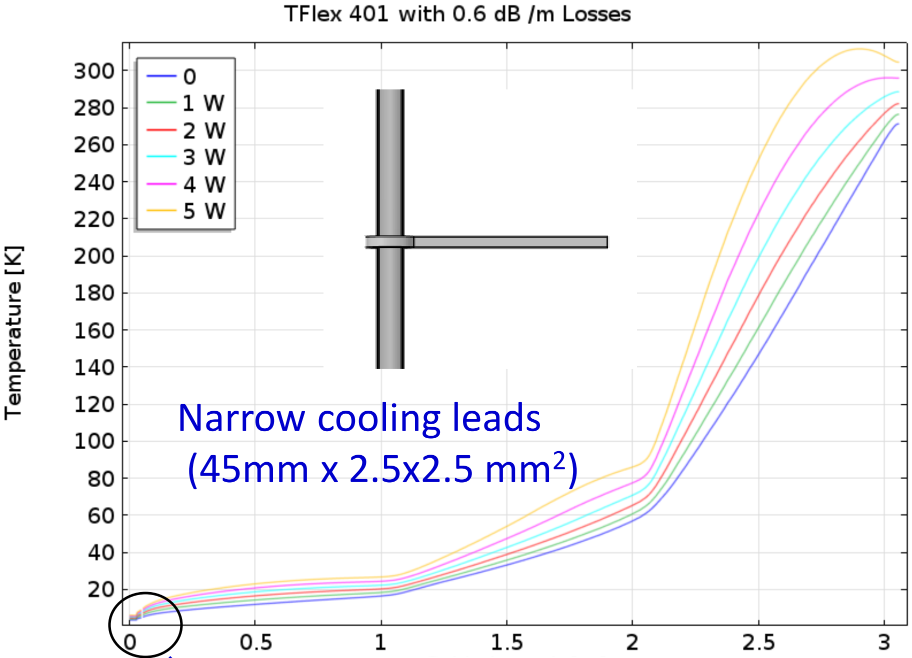
Power Flow [W]	2K	5K	50K	300K
0	6.30	189.88	287.86	-484.04
1	18.06	217.86	358.44	-394.68
2	29.84	246.19	435.51	-298.46
3	41.63	274.95	520.27	-194.23
4	53.49	304.20	614.21	-80.58
5	65.44	334.01	719.21	44.26
6	77.43	364.58	837.66	182.56
7	**89.46**	**396.08**	**972.68**	**337.22**
8	101.50	428.79	1128.35	512.10
9	113.61	462.98	1310.21	712.38
10	125.80	499.07	1525.91	945.19

Wide Leads

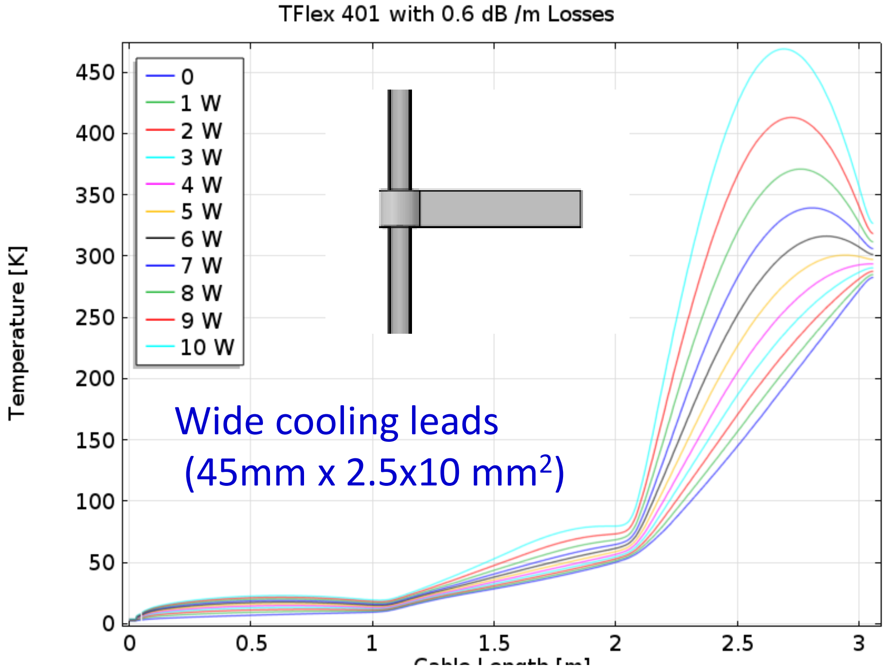
Power Flow[W]	2K [mW]	5K [mW]	50K [mW]	300K [mw]
0	9.27	164.76	242.83	-416.87
1	21.91	193.01	313.60	-326.02
2	34.61	221.87	393.03	-226.41
3	47.43	251.44	483.14	-116.22
4	60.39	281.94	586.51	6.86
5	73.47	313.74	706.51	145.86
6	86.67	347.22	847.86	304.90
7	**100.05**	**383.02**	**1017.10**	**489.75**
8	113.67	422.00	1223.63	708.57
9	127.78	465.89	1481.52	973.22
10	142.70	517.64	1812.94	1301.92

Thermal simulation for HOM cable (TFlex401)

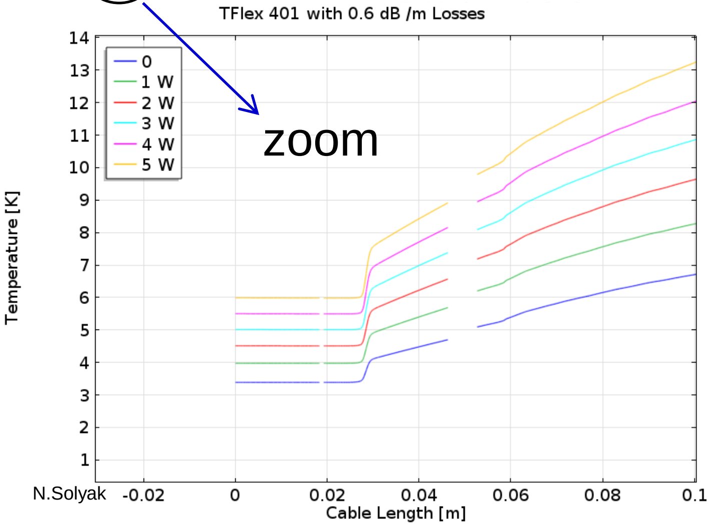
$P_{antenna}$= 9uW (140mT with modified design, 63 mT with original design)


TFlex 401 with 0.6 dB /m Losses

Narrow cooling leads (45mm x 2.5x2.5 mm^2)

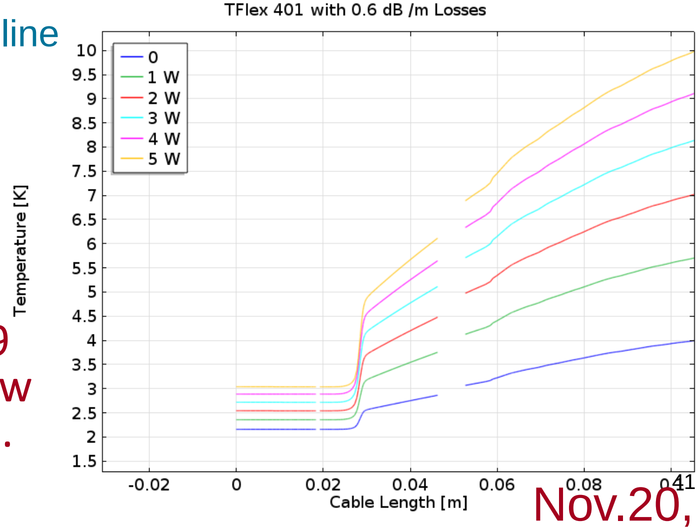

TFlex 401 with 0.6 dB /m Losses

Wide cooling leads (45mm x 2.5x10 mm^2)

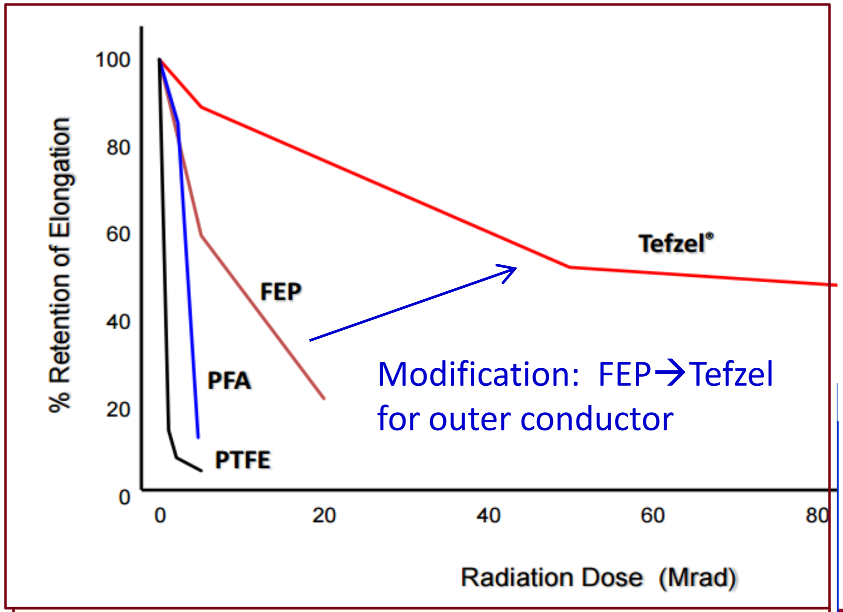

TFlex 401 with 0.6 dB /m Losses

M.Hasan/T.Khabiboulline

Cable is OK up to 9 W input power flow (80°C cable limit).


TFlex 401 with 0.6 dB /m Losses

Radiation Resistance of DuPont Fluoroplastics



Modification: FEP→Tefzel for outer conductor

TFlex 401 cable after 500 MRad γ-radiation in Sandia (7 days)

	Before Test	After Test	After Test (unfolded)
Loss [dB/m] at 1GHz	0.41	0.45	0.46
Loss [dB/m] at 3GHz	0.73	0.87	0.89

Y.Pischalnikov/T.Khabiboulline/M.Hasan

Conclusion

- New antenna design has better thermal performance
- Preliminary analysis shows that the TFlex-401t/Huber-SF329 cable used for the 1.3GHz cryo-module will work for up to 8W power flow out of the HOM ports for the 3.9GHz cryo-module
- Wide Leads are critically needed