Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high Ql (6e7) conditions

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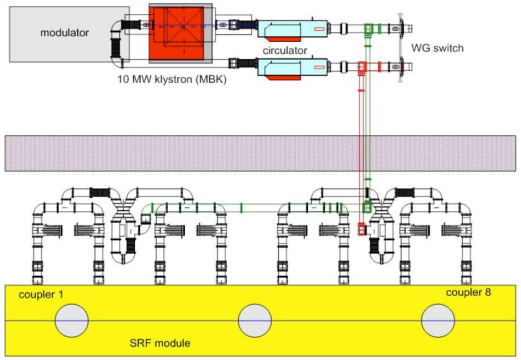
Agenda

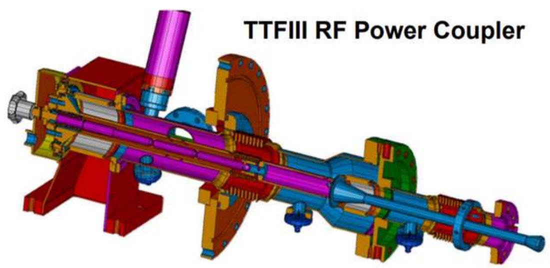
1. *Introduction,*
2. *Motivation,*
3. *Challenges in this solution*
4. *Control mechanisms used*
5. *Performance results*
6. *Summary.*

Motivation

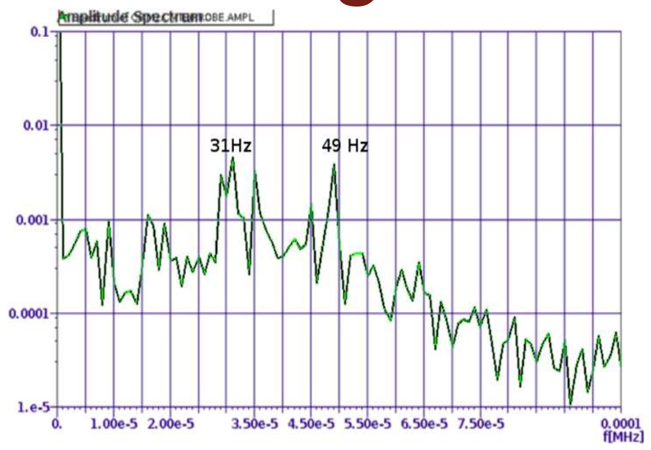
- High gradient operation of superconducting resonators in CW,
- Evaluation of cryomodule setup (CMTB env.) feasibility for CW/LPO, VS and single cav. operation
- Different mechanical and RF effects determination (effects not visible in the short pulse work regime)
- Various operation conditions scenarios evaluation.

	FLASH	XFEL	CW I	CW II	CW III
Ql value	3,00E+06	4,60E+06	2,00E+07	4,00E+07	6,00E+07
Half BW [Hz]	216,67	141,30	32,50	16,25	10,83
Input Power [W] @ 16 MV/m	2,08E+04	1,36E+04	3,13E+03	1,56E+03	1,04E+03
Input Power [W] @ 25 MV/m	5,09E+04	3,32E+04	7,63E+03	3,81E+03	2,54E+03

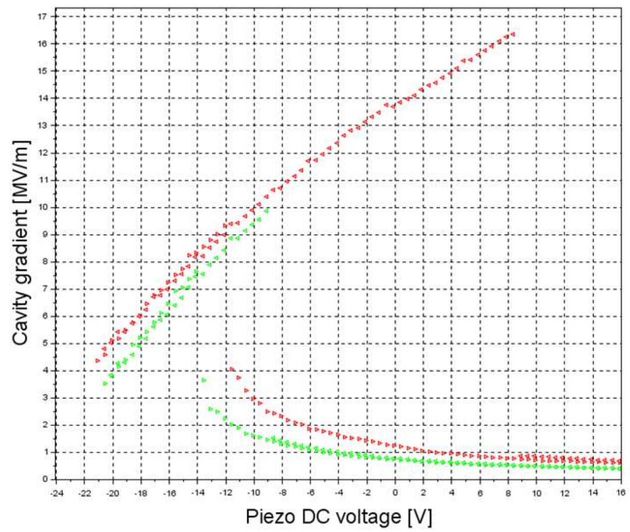




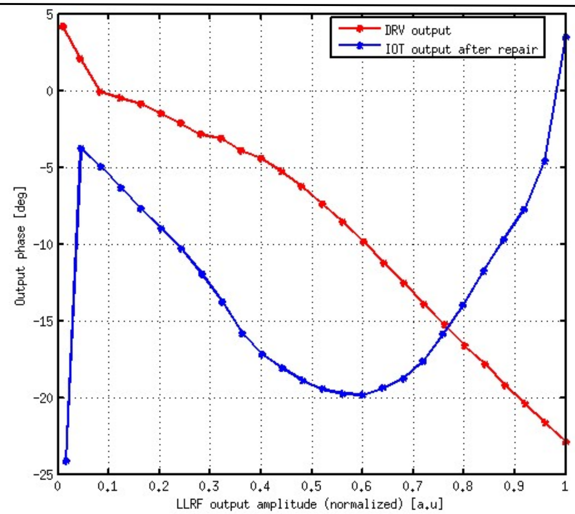
Challenges



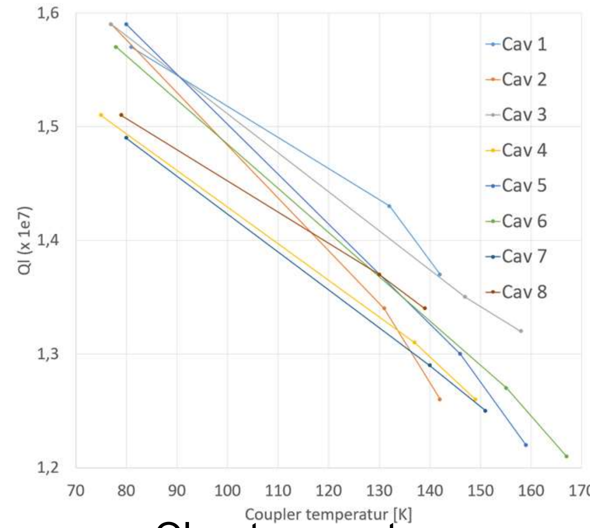
Microphonics



Static drop



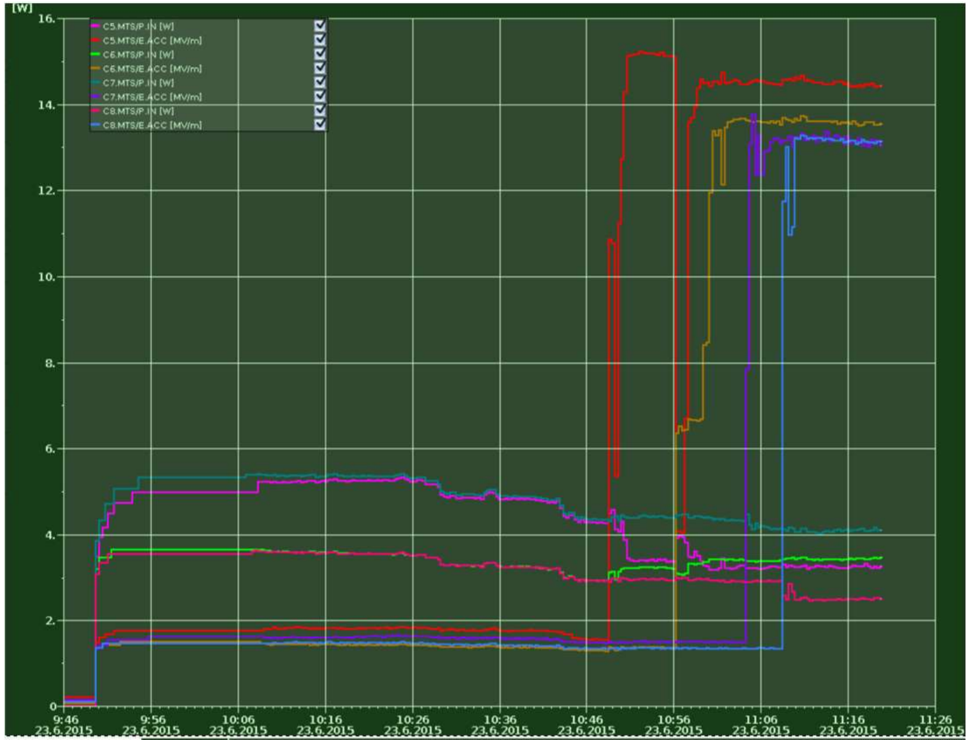
HPC (IOT) nonlinearity



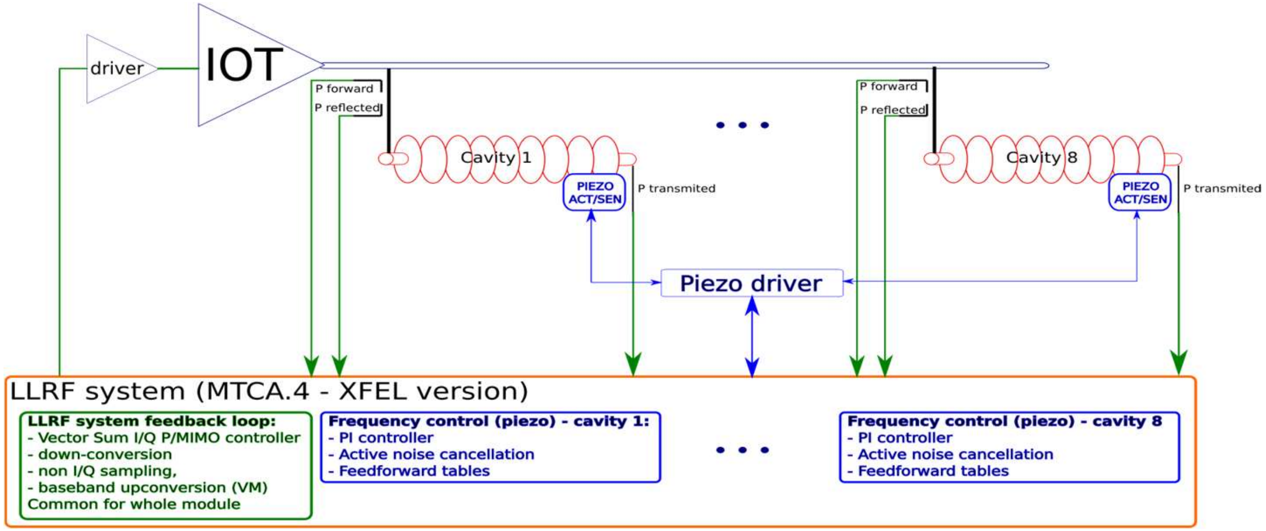
Ql vs temperature

Some other system limitations

- Coupling between cavities -> full reflection from one structure changes conditions for neighboring resonators,
- Limited cryo system capacity -> heat load up to 120 W,
- Couplers overheating -> temperature have been kept below 160 K limit,
- Vacuum pumps oscillations.



CW - LLRF system setup



- RF field regulation loop:
  - P and MIMO controller,
  - similar to short pulse with 4,5MHz feedback sampling,
- Cavity frequency regulation:
  - DC voltage offset,
  - PI controller (mainly I component used) for low freq (<10Hz) regulation,
  - ANC based solution for persistent microphonics effects reduction

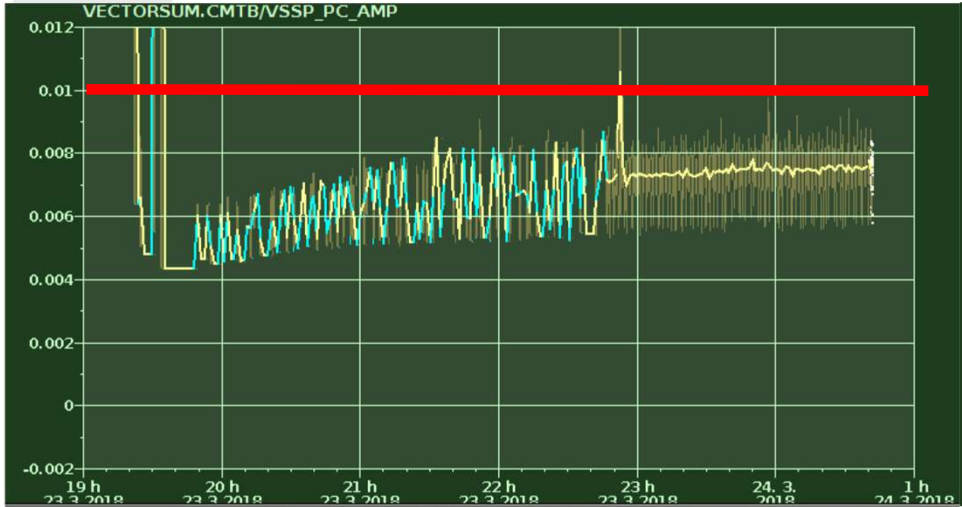
CW tests with QL ~4e7 @~15-16 MV/m

	C1	C2	C3	C4	C5	C6	C7	C8
FOR power [kW]	1.582	1.784	1.735	1.804	1.622	1.716	1.969	1.736
Gradient [MV/m]	15.98	16.63	16.46	17.02	16.67	15.20	14.56	13.14
Expected Eacc [MV/m]	16.48	17.68	17.20	17.83	16.98	17.18	15.31	13.77
Ql	41.96M	42.84M	41.68M	43.04M	43.43M	41.01M	29.11M	26.71M
FPC temp (70K)	90.37	94.27	93.78	90.67	99.99	97.36	98.20	91.99

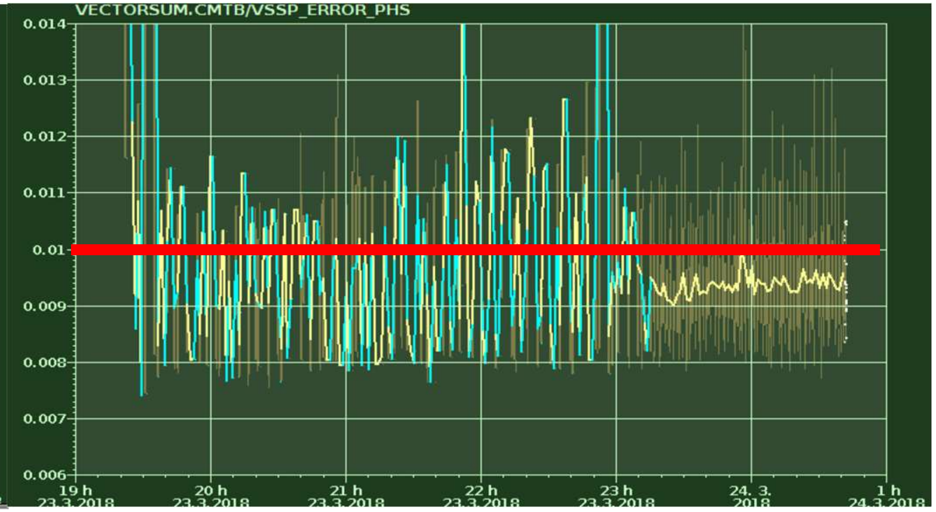
Regulation	
dA/A (%)	0.006
dP [deg]	0.009

RF feedback loop and piezo PI loop + ANC filters (30 or 50 Hz) used.

Amplitude regulation (red line – XFEL spec.)

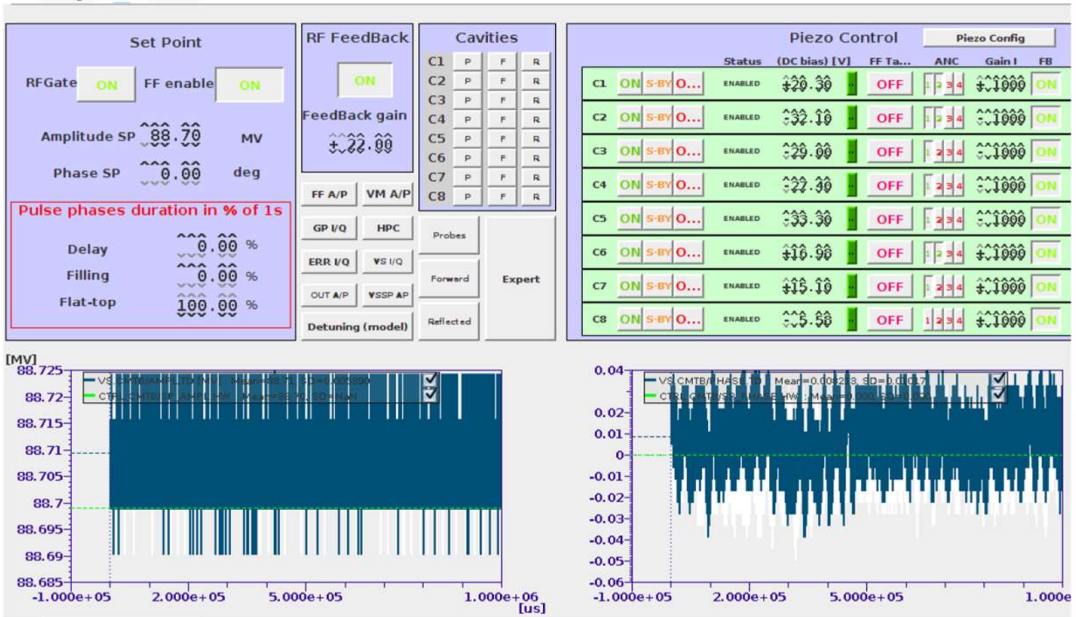


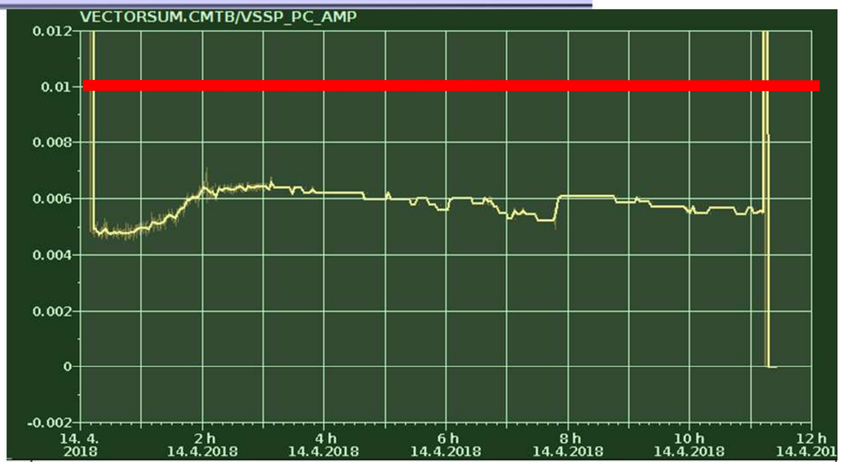
Phase regulation

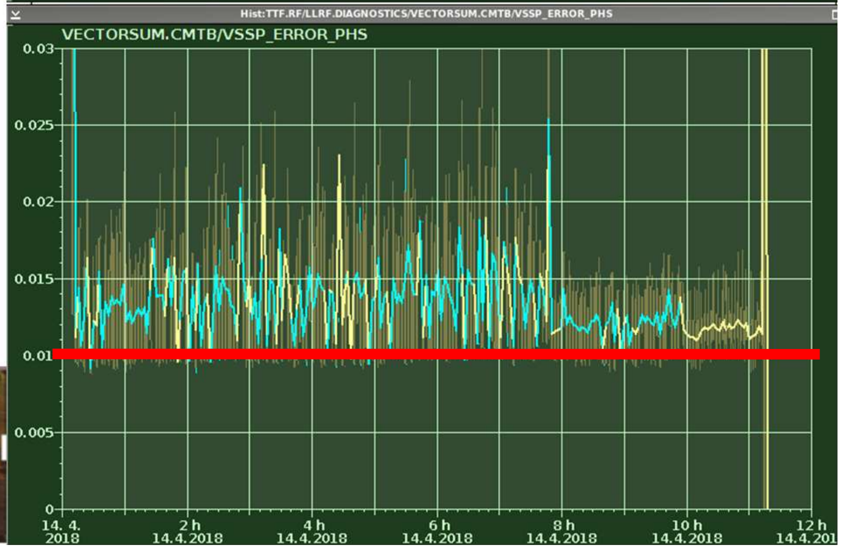


CW tests with Ql ~6e7 @~17,5 MV/m

	C1	C2	C3	C4	C5	C6	C7	C8
FOR power [kW]	1.361	1.527	1.551	1.579	1.402	1.502	1.704	1.419
Gradient [MV/m]	18.62	19.34	19.06	19.28	19.02	17.85	13.78	12.63
Expected Eacc [MV/m]	18.08	19.41	19.80	20.12	19.18	19.91	14.55	13.05
Ql	58.72M	60.28M	61.74M	62.67M	64.12M	64.5M	30.37M	29.31M
FPC temp (70K)	90.60	95.89	95.69	90.91	99.76	95.81	98.32	92.22





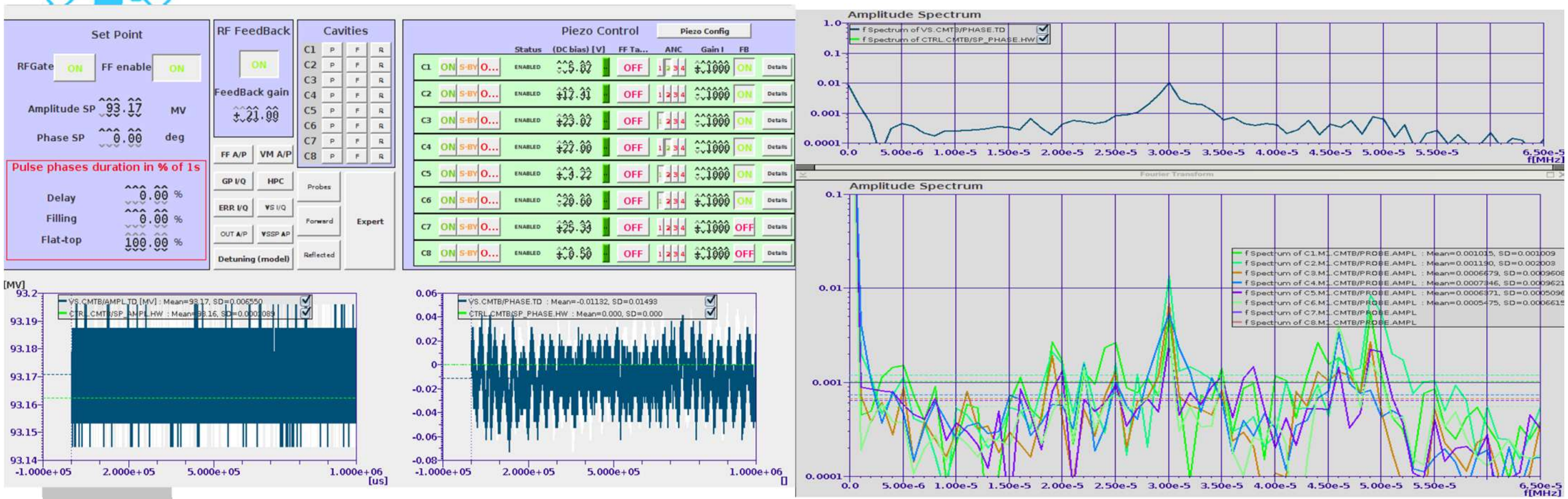


CW study with Ql~6e7 @ 20 MV/m

	C1	C2	C3	C4	C5	C6	C7	C8
FOR power [kW]	1.61	1.851	1.826	1.894	1.665	1.76	2.126	1.9
Gradient [MV/m]	20.00	20.52	20.28	20.60	20.12	18.99	0.10	0.08
Expected Eacc [MV/m]	20.14	21.69	21.71	21.69	20.38	21.19	15.63	14.30
Ql	61.55M	62.1M	63.09M	60.7M	60.94M	62.37M	28.1M	26.29M
FPC temp (70K)	1.03E2	1.13E2	1.11E2	1.07E2	1.16E2	1.11E2	99.52	93.78

VS composed from 6 cavities (last two detuned)

Achieved performance dA/A ~ 0.007%, dP ~0.01 deg



Summary

- *VS operation of the X-FEL cryomodule in CW mode that can satisfy performance criteria have been achieved,*
- *Narrow bandwidth cavity operated in high gradient may require more tuning range from fast tuners (piezos),*
- *VS focused RF loop and cavity oriented frequency tuning loop not always play together – amplitude control decoupling from phase control have to be used,*
- *There is still a place for improvement (higher gradients, improvement in phase regulation, Ql vs. temp. compensation),*
- *LPO challenges to be investigated…….*

Thank You