FCC RF Coordination Meeting

October 19, 2016

Fellow requests (November ’16)

Type: FELL	**From:** 01/03/2017	**To:** Initial duration: 30 m
Organic Unit: BE-RF	**Supervisor:** Elena Chapochnikova	
Title: RF studies Beam Dynamics FCC		
Description: Until now, FCC BD study has been concentrating on single-bunch stability for electron beams, modelling quantum excitation and radiation damping in BLonD. Coupled-bunch is equally important, if not more so, if we want to move forward with the RF system design. The fellow will participate to the study of the beam dynamics apsects and limits for FCC ee- and hh- machines.		

Type: FELL	**From:** 01/03/2017	**To:** Initial duration: 30 m
Organic Unit: BE-RF	**Supervisor:** Walter Venturini Delsolaro	
Title: Thin film studies		
Description: Nb/Cu thin film technology is of prime interest for the FCC ee- and hh- machines. Its application could reduce the installation and running costs of the cryogenic system as well as the cost of cavities and cryomodules. The fellow will participate to the preparation and the characterisation of samples and cavities.		

Type: FELL	**From:** 01/01/2017	**To:** Initial duration: 30 m
Organic Unit: EN-MME	**Supervisor:** Gilles Favre	
Title: High velocity forming of SRF structures		
Description: Continuation of Elisa Cantergiani’s work on: - Thorough understanding of the electro-hydraulic forming process applied to copper and niobium geometries for Superconducting RF structures. - Characterisation and modelisation of copper and niobium for fast forming. - Production of a niobium and copper functional structure		

- Both fellows have been accepted => select your candidates asap
- Elisa’s replacement is accepted
- Please prepare PhD and technical student request asap

FCC RF WP news

- 1 RF SCENARIOS AND PARAMETERS LAYOUT (N. SCHWERG)
  - 1.1 RF SCENARIOS AND PARAMETERS LAYOUT FOR FCC_EE
  - 1.2 RF SCENARIOS AND PARAMETERS LAYOUT FOR FCC_HH
- 2 CAVITY DESIGN AND BEAM INTERACTION (A. BUTTERWORTH)
  - 2.1 CAVITY IMPEDANCE AND HOMS
  - 2.2 ACCELERATING CAVITY DESIGN AND HOM COUPLERS
  - 2.3 2ND HARMONIC CAVITY DESIGN AND HOM COUPLERS

On the agenda today

- 3 CAVITY MATERIAL AND PERFORMANCE (WALTER VENTURINI DELSOLARO)
  - 3.1 CAVITY MATERIAL AND PERFORMANCE
- 4 CAVITY FABRICATION (MIKKO KARPINNEN)
  - 4.1 CAVITY FABRICATION
  - 4.2 HIGH VELOCITY FORMING OF SUPERCONDUCTING RF STRUCTURES
- 5 COLLABORATION AGREEMENT CERN/LNL/STFC (KE2722/BE/FCC) (P. CHIGGIATO)
  - 5.1 FRAMEWORK FOR SCIENTIFIC COLLABORATION IN SUPERCONDUCTING RF CAVITIES TECHNOLOGY

November

- 6 CRYOMODULE CHALLENGES (KARL SCHIRM)
  - 6.1 CRYOMODULE DESIGN
  - 6.2 FUNDAMENTAL POWER COUPLERS
  - 6.3 CRYOMODULE DESIGN
- 7 EFFICIENCY OF RF POWER GENERATION (I. SYRATCHEV)
  - 7.1 DEVELOPMENT OF VERY HIGH EFFICIENCY KLYSTRONS (HEIKA)
  - 7.2 DEVELOPMENT OF ALTERNATIVE HIGH EFFICIENCY RF POWER DEVICES – THE RESOTRODE INITIATIVE
  - 7.3 HIGH EFFICIENCY KLYSTRONS DEVELOPMENT & CONSTRUCTION

December

Baseline table

Machine specific	FCC_hh (Elena	Z - baseline			Z - "more aggressive"			W		
Ebeam [GeV]		45.5			45.4			80.0		
Ibeam [mA]		1450.0			1450.0			152.0		
Nb bunches		91500			30180			5162		
RF voltage [GV]	0.032	0.20			0.40			0.80		
Energy loss/turn [GeV]		0.034			0.034			0.33		
Bunch Length (mm)		3.00			1.60			3.00		
	FCC_hh (Elena	Z - baseline			Z - "more aggressive"			W		
Technology&design										
cavity choice	1 cell, 400M	1 cell, 400M	2 cells, 400	2 cells, 800	1 cell, 400M	2 cells, 400	2 cells, 800	1 cell, 400M	2 cells, 400	2 cells, 800MH
technology	Nb/Cu	Nb/Cu	Nb/Cu	Nb	Nb/Cu	Nb/Cu	Nb	Nb/Cu	Nb/Cu	Nb
frequency [MHz]	400	400	400	800	400	400	800	400	400	800
Nb cells/cavity	1	1	2	2	1	2	2	1	2	2
Eacc [MV/m]	**10**	**6**	**3**	**20**	**6**	**10**	**20**	**10**	**10**	**20**
R/Q [Ohm/cell]	87	87	85	85	87	85	85	87	85	85
k_cav// [V/pC]	0.10	0.39	0.78	1.10	0.39	0.78	1.10	0.39	0.78	1.20
k_taper// [V/pC]	0.10	1.70	1.70	3.30	1.70	1.70	3.30	1.70	1.70	0.68
k_CM// [V/pC]	1.00	5.46	7.02	11.50	5.46	7.02	11.50	5.46	7.02	6.66
Pfpc max [kW]	500	500	500	400	500	500	400	500	500	400
G [Ohm]	297	297	297	297	297	297	297	297	297	297
Rs [nOhm]	94	94	94	23	94	94	23	94	94	23
Qo (=G/Rs)	3.1E+09	3.1E+09	3.1E+09	1.3E+10	3.1E+09	3.1E+09	1.3E+10	3.1E+09	3.1E+09	1.3E+10
Operating Temp [K]	4.5	4.5	4.5	2	4.5	4.5	2	4.5	4.5	2
Carnot efficiency	1.52%	1.52%	1.52%	0.67%	1.52%	1.52%	0.67%	1.52%	1.52%	0.67%
Cryo efficiency [%]	30%	30%	30%	20%	30%	30%	20%	30%	30%	20%
RF system parameters										
Lcell [m]	0.375	0.375	0.375	0.1875	0.375	0.375	0.1875	0.375	0.375	0.1875
Lacc [m]	0.375	0.375	0.75	0.375	0.375	0.75	0.375	0.375	0.75	0.375
Vcell [MV]	3.75	2.25	1.13	3.75	2.25	3.75	3.75	3.75	3.75	3.75
Vcav [MV]	3.75	2.25	2.25	7.50	2.25	7.50	7.50	3.75	7.50	7.50
Pbeam [MW]		49.3	49.3	49.3	49.3	49.3	49.3	50.16	50.16	50.16
matched Qext	2E4 - 9E4	1.0E+05	5.4E+04	1.8E+05	2.1E+05	3.6E+05	3.6E+05	6.9E+05	7.0E+05	7.0E+05
BW @ matched Qext		3813	7450	4470	1906	1117	2235	582	568	1137
Nb cells	32	89	178	53	178	107	107	213	213	213
Nb cavities	**32**	**89**	**89**	**27**	**178**	**53**	**53**	**213**	**107**	**107**
Dyn Losses/cavity [W]	**51.4**	**18.5**	**9.5**	**25.9**	**18.5**	**105.2**	**25.9**	**51.4**	**105.2**	**25.9**
RF system active length [m]	12	33	67	10	67	40	20	80	80	40
RF system length [m]	**57**	**158**	**191**	**34**	**316**	**115**	**95**	**379**	**229**	**136**
Pcryo dyn [kW] @ operating temp	1.65	1.65	0.84	0.69	3.29	5.61	1.38	10.97	11.23	2.76
Pcryo stat [kW] @ operating tem	0.34	0.95	1.15	0.20	1.89	0.69	0.57	2.27	1.38	0.82
Pcryo HOM [kW] @ operating te	0.77	4.18	5.38	8.81	12.68	16.30	26.71	0.81	1.05	0.99
Pcryo dyn+HOM [kW] @ RT	0.5	1.28	1.36	7.08	3.50	4.80	20.92	2.58	2.69	2.80
Pcryo stat [kW] @ RT	0.1	*0.21*	*0.25*	*0.15*	*0.41*	*0.15*	*0.42*	*0.50*	*0.30*	*0.61*
Pcryo tot [MW] @ RT	**0.6**	**1.5**	**1.6**	**7.2**	**3.9**	**4.9**	**21.3**	**3.1**	**3.0**	**3.4**
Pcav [kW] (optimum)	**500**	**555**	**555**	**1849**	**277**	**924**	**924**	**235**	**470**	**470**
Phom/cav [kW]	0.8	3.0	6.0	8.4	9.1	18.1	25.5	0.6	1.2	1.8
Phom/CM [kW]	7.7	41.8	53.8	88.1	126.8	163.0	267.1	8.1	10.5	9.9

Machine specific	H					t				
Ebeam [GeV]	120.0					176.0				
Ibeam [mA]	30.0					6.6				
Nb bunches	770					78				
RF voltage [GV]	3.00					10.00				
Energy loss/turn [GeV]	1.67					7.55				
Bunch Length (mm)	3.00					3.00				
	H					t				
Technology&design										
cavity choice	1 cell, 400M	2 cells, 400M	4 cells, 400	2 cells, 800	5 cells, 800	2 cells, 400	4 cells, 400	2 cells, 800MHz, bu	5 cells, 800MHz, bu	
technology	Nb/Cu	Nb/Cu	Nb/Cu	Nb	Nb	Nb/Cu	Nb/Cu	Nb	Nb	
frequency [MHz]	400	400	400	800	800	400	400	800	800	
Nb cells/cavity	1	2	4	2	5	2	4	2	5	
Eacc [MV/m]	**10**	**10**	**10**	**20**	**20**	**10**	**10**	**20**	**20**	
R/Q [Ohm/cell]	87	85	85	85	85	85	85	85	85	
k_cav// [V/pC]	0.39	0.78	1.56	1.20	3.00	0.78	1.56	1.20	3.00	
k_taper// [V/pC]	1.70	1.70	1.70	0.68	0.68	1.70	1.70	0.68	0.68	
k_CM// [V/pC]	5.46	7.02	10.14	6.66	13.86	7.02	10.14	6.66	13.86	
Pfpc max [kW]	500	500	500	400	400	500	500	400	400	
G [Ohm]	297	297	297	297	297	297	297	297	297	
Rs [nOhm]	94	94	94	23	23	94	94	23	23	
Qo (=G/Rs)	3.1E+09	3.1E+09	3.1E+09	1.3E+10	1.3E+10	3.1E+09	3.1E+09	1.3E+10	1.3E+10	=G/Rs
Operating Temp [K]	4.5	4.5	4.5	2	2	4.5	4.5	2	2	
Carnot efficiency	1.52%	1.52%	1.52%	0.67%	0.67%	1.52%	1.52%	0.67%	0.67%	=T/(300-T)
Cryo efficiency [%]	30%	30%	30%	20%	20%	30%	30%	20%	20%	
RF system parameters										
Lcell [m]	0.375	0.375	0.375	0.1875	0.1875	0.375	0.375	0.1875	0.1875	[illegible]
Lacc [m]	0.375	0.75	1.5	0.375	0.9375	0.75	1.5	0.375	0.9375	[illegible]
Vcell [MV]	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	[illegible]
Vcav [MV]	3.75	7.50	15.00	7.50	18.75	7.50	15.00	7.50	18.75	[illegible]
Pbeam [MW]	50.1	50.1	50.1	50.1	50.1	49.83	49.83	49.83	49.83	[illegible]
matched Qext	2.6E+06	2.6E+06	2.6E+06	2.6E+06	2.6E+06	8.9E+06	8.9E+06	8.9E+06	8.9E+06	[illegible]
BW @ matched Qext	155	151	151	303	303	45	45	90	90	[illegible]
Nb cells	800	800	800	800	800	2667	2667	2667	2667	[illegible]
Nb cavities	**800**	**400**	**200**	**400**	**160**	**1333**	**667**	**1333**	**533**	[illegible]
Dyn Losses/cavity [W]	**51.4**	**105.2**	**210.5**	**25.9**	**64.7**	**105.2**	**210.5**	**25.9**	**64.7**	[illegible]
RF system active length [m]	300	300	300	150	150	1000	1000	500	500	[illegible]
RF system length [m]	**1420**	**860**	**480**	**510**	**294**	**2867**	**1933**	**2367**	**980**	[illegible]
Pcryo dyn [kW] @ operating temp	41.13	42.10	42.10	10.35	10.35	140.32	140.32	34.51	34.51	[illegible]
Pcryo stat [kW] @ operating tem	8.52	5.16	2.88	3.06	1.76	17.20	11.60	14.20	5.88	[illegible]
Pcryo HOM [kW] @ operating te	0.21	0.27	0.40	0.26	0.54	0.13	0.19	0.12	0.26	[illegible]
Pcryo dyn+HOM [kW] @ RT	9.05	9.27	9.30	7.91	8.12	30.74	30.76	25.80	25.90	[illegible]
Pcryo stat [kW] @ RT	*1.86*	*1.13*	*0.63*	*2.28*	*1.31*	*3.76*	*2.54*	*10.58*	*4.38*	[illegible]
Pcryo tot [MW] @ RT	**10.9**	**10.4**	**9.9**	**10.2**	**9.4**	**34.5**	**33.3**	**36.4**	**30.3**	[illegible]
Pcav [kW] (optimum)	**63**	**125**	**251**	**125**	**313**	**37**	**75**	**37**	**93**	[illegible]
Phom/cav [kW]	0.2	0.3	0.6	0.5	1.2	0.1	0.3	0.2	0.6	[illegible]
Phom/CM [kW]	2.1	2.7	4.0	2.6	5.4	1.3	1.9	1.2	2.6	[illegible]

Cavity choice	technology	f [MHz]	# cells	Eacc [MV/m]	R/Q [Ohm/cel	G [Ohm]			Rs [nOhm]	Operating T [K]	Pmax/FPC [kW	Qo (=G/Rs)	Bp/Eacc	Cryo efficiency
1 cell, 400MHz	Nb/Cu	400	1	10.0	87	297			94	4.5	500	3.1E+09	4.1	30%
2 cells, 400MHz	Nb/Cu	400	2	10.0	85	297			94	4.5	500	3.1E+09	4.1	30%
4 cells, 400MHz	Nb/Cu	400	4	10.0	85	297			94	4.5	500	3.1E+09	4.1	30%
2 cells, 800MHz, Nb/Cu, 4.5	Nb/Cu	800	2	10.0	85	297			288	4.5	400	1.0E+09	4.1	30%
2 cells, 800MHz, Nb/Cu, 2K	Nb/Cu	800	2	10.0	85	297			64	2.0	400	4.7E+09	4.1	20%
2 cells, 800MHz, bulk Nb	Nb	800	2	20.0	85	297			23	2.0	400	1.3E+10	4.1	20%
5 cells, 800MHz, bulk Nb	Nb	800	5	20.0	85	297			23	2.0	400	1.3E+10	5.1	20%

Fixed parameters & limits	min	val	max	note
Frev [kHz]	3			
Phom[kW]	--		4	state_of_the_art for 4 "hook" c
RF system length [m]	--		4000	FCC_ee layout: 2 x 2000m RF L
Extra length 400MHz, 800MHz	0.9	0.9		
Qext matched	?		1.00E+07	BW > 100Hz
Static Losses [W/m]		6.00		ESS CM = 13W @ 2K, LEP CM=

Fixed parameters & limits	@ 2K	@ 4.5K		
Cryo efficiency	20.00%	30.00%		L. Tavian
HOM power to Cryo	10.00%			tbc

- X-check Nikolai's model
- Extract summary tables

Power coupler requirements – summary table

Summary table

	FCC_hh	Z		W		H		t	
Ibeam [mA]	0.00	1450.00		152.00		30.00		6.60	
Nb bunches	0.00	91500.00	30180.00	5162.00		770.00		78.00	
RF voltage [GV]	0.03	0.20	0.40	0.80		3.00		10.00	
Energy loss/turn [GeV]	0.00	0.03	0.03	0.33		1.67		7.55	
Bunch Length (mm)	0.00	3.00	1.60	3.00		3.00		3.00	
frequency [MHz]	400.0	400.0	400.0	400.0	800.0	400.0	800.0	400.0	800.0
cavity technology	Nb/Cu	Nb/Cu	Nb/Cu	Nb/Cu	Nb	Nb/Cu	Nb	Nb/Cu	Nb
operating temp	4.5	4.5	4.5	4.5	2.0	4.5	2.0	4.5	2.0
Nb cavities	32.0	88.9	177.8	213.3	106.7	200.0	160.0	666.7	533.3
Nb cell / cav	1	1	1	1	2	4	5	4	5
coupler type (a priori)	movable	fixed		fixed		fixed		fixed	
power per cavity [kW]	500	555	555	235	470	251	313	75	93
Q matched	2E4 - 9E4	1.0E+05	2.1E+05	6.9E+05	7.0E+05	2.6E+06	2.6E+06	8.9E+06	8.9E+06

Cooling and cryo requirements – summary table

Summary table

	FCC_hh	Z		W		H		t	
frequency [MHz]	400.0	400.0	400.0	400.0	800.0	400.0	800.0	400.0	800.0
Ptot RF to beam [MW]	**16**	**49.30**		**50.16**		**50.10**		**49.83**	
Electrical Power									
Overall DC-RF efficiency	61%	0.72		0.72		0.72		0.72	
Plug power per beam [MVA]	**25**	**65.58**		**66.72**		**66.64**		**66.28**	
Water Cooling									
Water cooling power [kW] per RF station	756	2357.02		599.54		399.21		119.12	
Total water cooling power per beam [MW]	**24**	**62.85**		**63.95**		**63.87**		**63.53**	
Air Cooling									
Power distribution (klystron window, WG) [MW]	0.64	1.97		2.01		2.00		1.99	
Ctrl rack [MW]	0.02	0.09		0.11		0.40		0.67	
LLRF rack [MW]	0.01	0.04		0.05		0.20		0.33	
Ptot per beam [MW]	**0.66**	**2.11**		**2.17**		**2.60**		**2.99**	
Cryogenic power									
operating temp	4.5	4.5	4.5	4.5	2.0	4.5	2.0	4.5	2.0
Pcryo tot @ operating temp [kW]	2.75	7.37	22.60	14.05	4.57	49.86	13.67	157.66	48.83
Pcryo tot @ RT per beam [MW]	**0.60**	**1.61**	**4.95**	**3.08**	**3.40**	**10.91**	**10.19**	**34.51**	**36.38**