International Muon Collider

RF systems
Specifications and Issues

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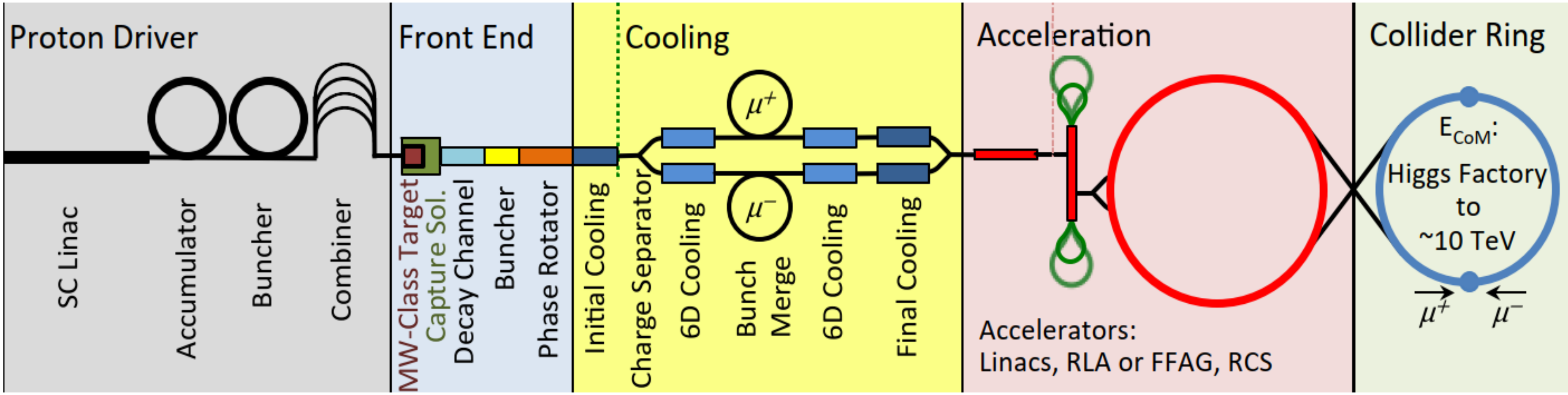
Many thanks to the reference experts:
F.Gerygt, D.Neuffer, D.Stratakis, C.Rogers, A.Bogacz, S.Berg, E.Gianfelice-Wendt

International
UON Collider
Collaboration

RF systems along the IMC complex



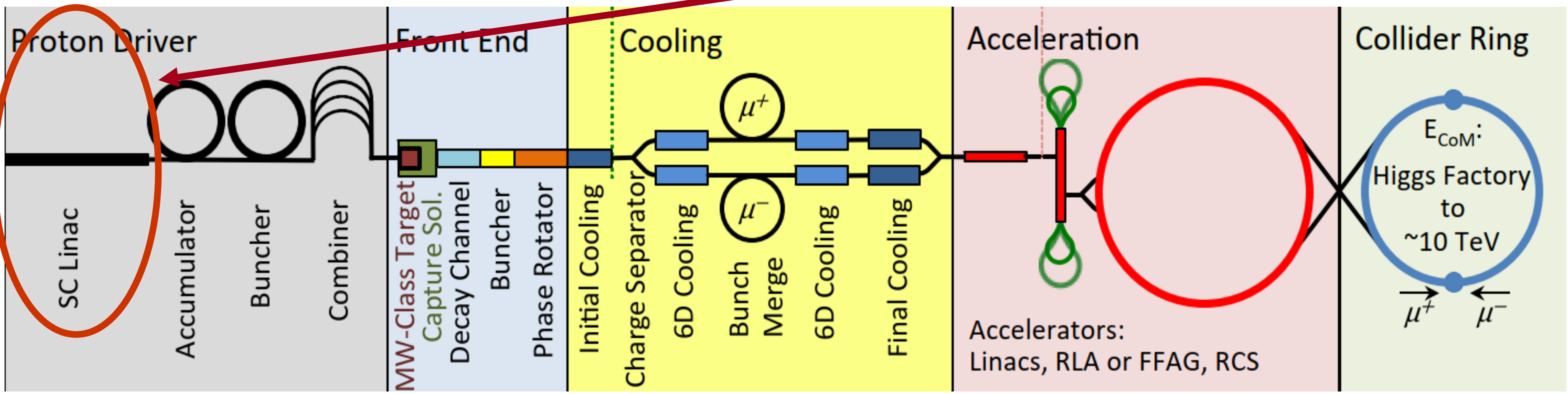
RF = multiple fonctions in multiple systems
Normal-Conducting, Super-Conducting

- **Proton driver (LinacNC, LinacSC, Accumulator, Compressor),**
- **Front-End (RF Buncher, Phase Rotator),**
- **Cooling (initial, bunch separation, 6D before merge, bunch merge, 6D after merge, final),**
- **Acceleration (RLA, RSC and/or FFAG)**
- **Collider ring**

IMC RF systems references

System	Sub-System	Reference	Expert	Rapporteur
Driver	H-Linac	Project X Conceptual Design	Project X	-
		SPL conceptual Design	SPL	F.Gerigk
	Accumulator&Comp.	RAST Vol. 7 (2014) 137–15	R.Palmer	-
Front-End		2017 JINST 12 T11007	D.Neuffer	D.Neuffer
Cooling	Initial Cooling	2018 JINST 13 P08013	Y. Alexahin	C.Rogers
	Charge separator	THPH019 at PAC2014	C.Yoshikawa	D.Stratakis
	6D cooling Before&after merge	2017 JINST 12 P09027 PRST-AB 18, 031003 (2015)	D. Stratakis	
	Bunch merge	PRAB 19, 031001 (2016) by Yu Bao	Y.Bao	
	6D « helical »	arXiv:1806.00129 [physics.acc-ph]	K. Yonehara	-
	Final Cooling	PRST Ac.Beams 18 (2015) 9, 091001	H. Sayed	C.Rogers
		PAC2011 thobn2	R. Palmer	
		2017 JINST 12 T07003	D. Neuffer	
Acceleration	Injector Linac	2018 JINST 13 P02002	A. Bogacz	A.Bogacz
	RLAs (to ? GeV)	2018 JINST 13 P02002	A. Bogacz	A.Bogacz
	RCSs (to 1500 GeV)	arXiv:0707.0302v1 [physics.acc-ph] 2 Jul 2007	D.Summers S. Berg	S. Berg
	FFAG	?	S. Berg	-
Collider		2018 JINST 13 P11002 + lattice files	Y.Alexahin	E. Gianfelice-Wendt

Proton Driver: Linac



System	Sub-System	Expert	Rapporteur	Reference
Driver	H-Linac	Project X	-	Project X Conceptual Design
		SPL	F.Gerigk	SPL conceptual Design
	Accumulator	R.Palmer	-	RAST Vol. 7 (2014) 137–15

Link to Proton Driver Template: F.Gerygk

https://www.dropbox.com/s/y19p11l9bulk1ck/RF%20specifications%20MC%20Driver%20Linac%20FG_JPD.xlsx?dl=0

Driver linac based on SPL

FNAL context, MAP based on project X (8GeV/4MW at 12Hz)

European context, IMC (4 to 5 GeV? Multi-MW at 5Hz?)

- **proposed to be based on SPL (5 GeV/40mA/4MW) design on CERN site**
- **its low energy part (normal conducting) up to 160MeV corresponding to:**
  - **now operating at CERN (Linac4 LP) although at low rep frequency (2Hz)**
  - **would require modest upgrading from 2 to 5Hz at low cost with the same current of 40mA (Linac4 HP).**
- **Its high energy part (super-conducting) corresponding to:**
  - **the ESS linac with a beam energy of 2.5 GeV/50mA/5MW at 14Hz**
  - **strongly inspired from the SPL design**
  - **could serve as an excellent demonstrator with similar beam current.**
  - **presently being built with first beam available from 2022**

SPL, Accumulator and Compressor designs to be adapted to IMC:
Especially its transformation from H+ to H-

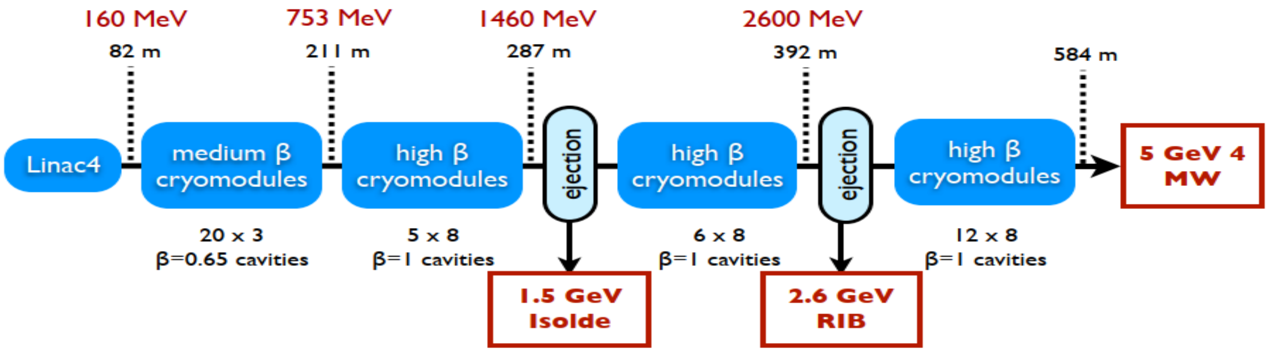
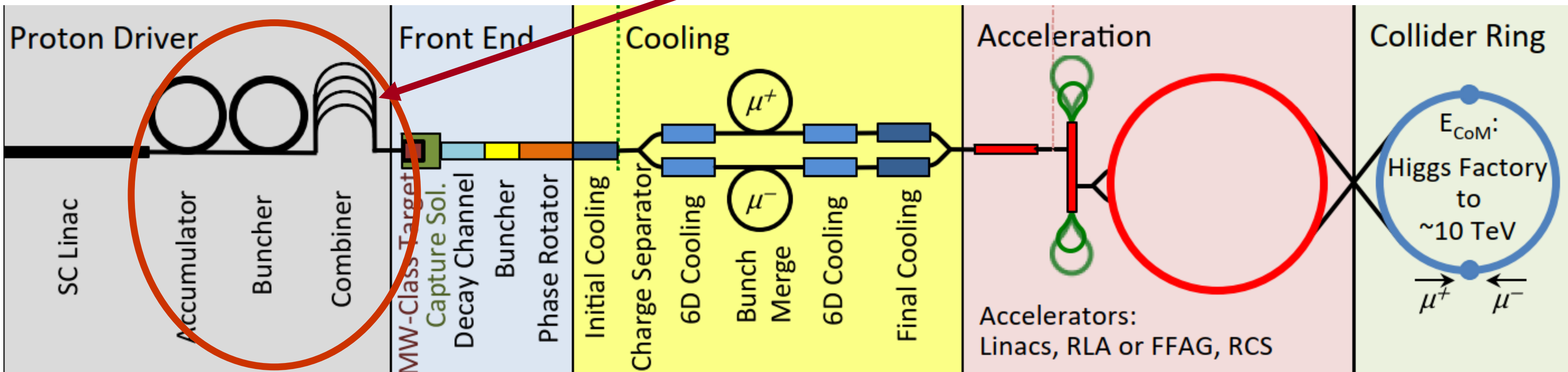


Fig. 2.1: Layout of superconducting linac with intermediate extraction

Proton Driver
Accumulator & Compressor



System	Sub-System	Expert	Rapporteur	Reference
Driver	H-Linac	Project X	-	Project X Conceptual Design
		SPL	F.Gerigk	SPL conceptual Design
	Accumulator	R.Palmer	-	RAST Vol. 7 (2014) 137–15

No detailed design in spite of a challenging accelerator complex:

- **Merging 1.5E6 Linac bunches into a single bunch 5E14 H+ / 2ns on target.**
- **Pulse compression by a factor 1E6 !**
- **Very low RF frequency: few MHz?**

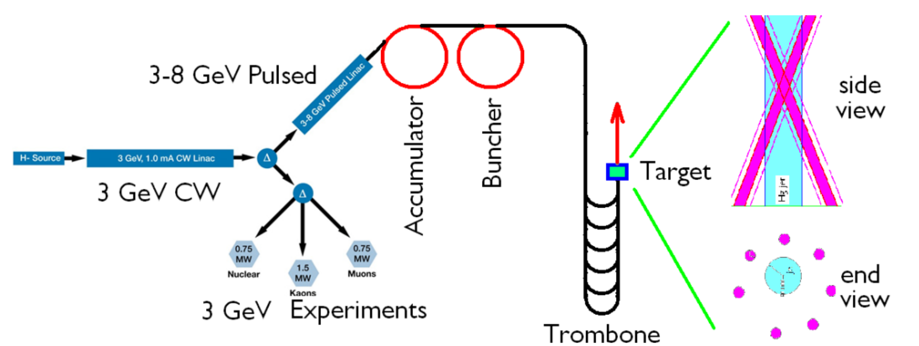
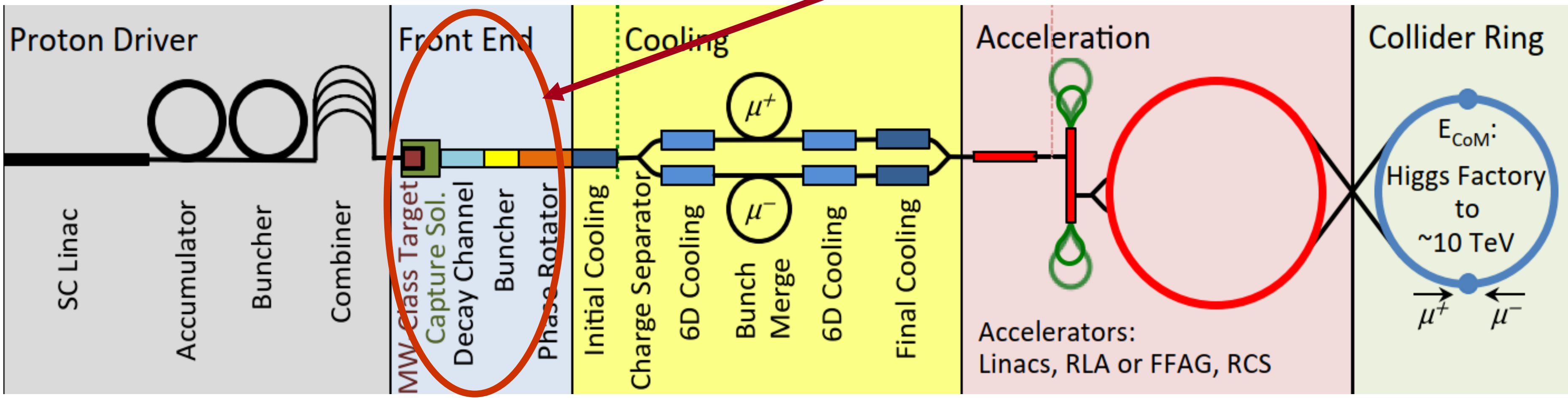


Figure 3: Schematic of Project X proton accelerator upgraded for use as a Muon Collider proton driver.

Front End
RF Buncher & Phase Rotator



System	Sub-System	Expert	Rapporteur	Reference
Front-End		D.Neuffer	D.Neuffer	2017 JINST 12 T11007

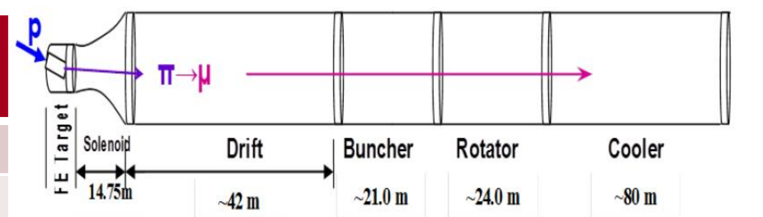
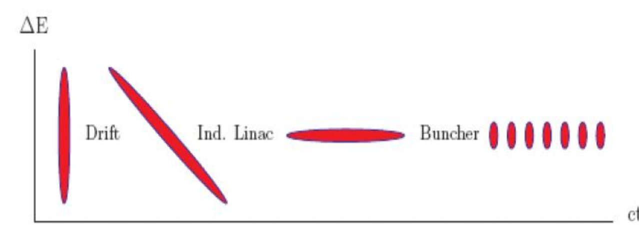


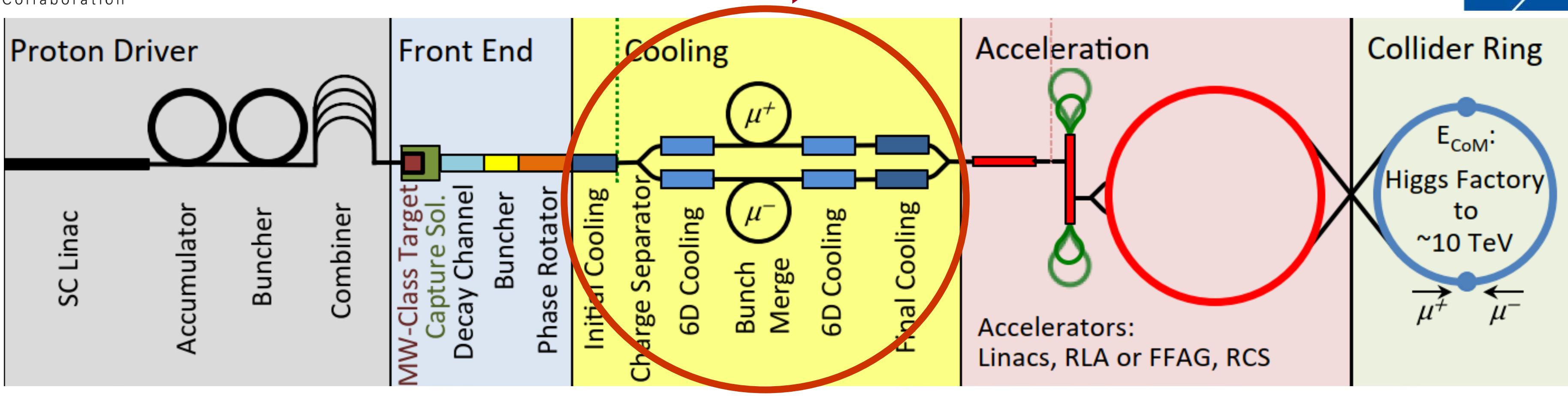
Figure 2. Overview of the MAP front end, consisting of a target solenoid (20 T), a capture solenoid (20 T to 2.0 T, 14.75 m), Drift section (42 m), rf Buncher (21 m), an energy-phase Rotator (24 m), with a Cooler (80 m).

Link to Front End Template: D.Neuffer

https://www.dropbox.com/s/qr0rdeslanoduwz/RF%20specifications%20MC%20Front%20End%20DN%20JPD%20DN.xlsx?dl=0



Cooling

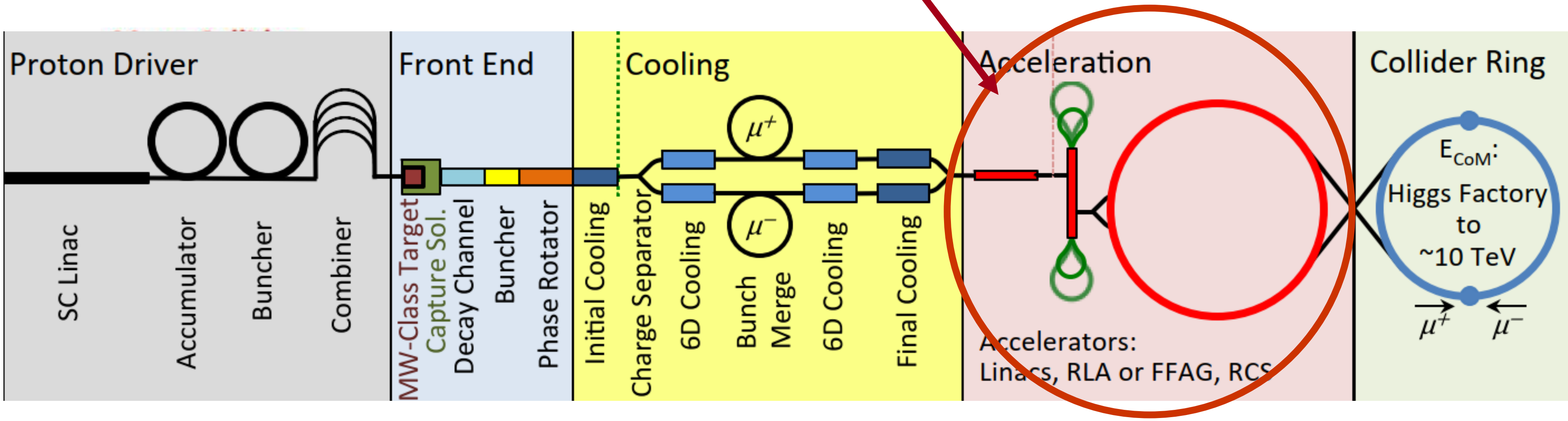


System	Sub-System	Expert	Rapporteur	Reference
Cooling	Initial Cooling	Y. Alexahin	C.Rogers	2018 JINST 13 P08013
	Charge separator	C.Yoshikawa	D.Stratakis	THPH019 at PAC2014
	6D cooling Before&after merge	D. Stratakis		2017 JINST 12 P09027
				PRST-AB 18, 031003 (2015)
	Bunch merge	Y.Bao		PRAB 19, 031001 (2016) by Yu Bao
	6D « helical »	K. Yonehara	-	arXiv:1806.00129 [physics.acc-ph]
	Final Cooling	H. Sayed	C.Rogers	Phys.Rev.ST Accel.Beams 18 (2015) 9, 091001
		R. Palmer		PAC2011 thobn2
		D. Neuffer		2017 JINST 12 T07003

Link to Cooling Template: D.Stratakis & C.Rogers

https://www.dropbox.com/s/392zyxkohoj3r5d/RF%20specifications%20MC%20Cooling%20DS%20JPD.xlsx?dl=0

Acceleration



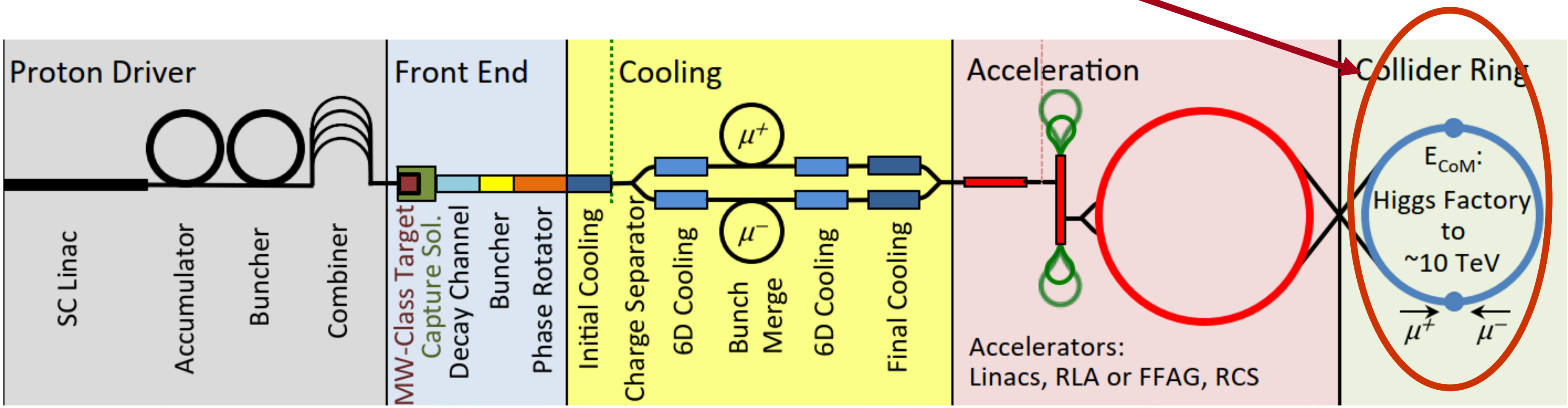
System	Sub-System	Expert	Rapporteur	Reference
Acceleration	Injector Linac	A. Bogacz	A.Bogacz	2018 JINST 13 P02002
	RLAs (to ? GeV)	A. Bogacz	A.Bogacz	2018 JINST 13 P02002
	RCSs (to 1500 GeV)	D.Summers S. Berg	S. Berg	arXiv:0707.0302v1 [physics.acc-ph] 2 Jul 2007
	FFAG	S. Berg	-	?

Links to Acceleration Templates: A.Bogacz (Linac, RLAs) & S.Berg (RCS)

Linac & RLAs: https://www.dropbox.com/s/s67phcdnak1uvpk/RF%20specifications%20MC%20RLA_AB_JPD.xlsx?dl=0

RCSs: https://www.dropbox.com/s/tr1yhnvksqfw67l/RF%20specifications%20MC%20RCS%20SB%20JPD.xlsx?dl=0

Collider Ring



System	Sub-System	Expert	Rapporteur	Reference
Collider		Y.Alexahin	E. Gianfelice-Wendt	2018 JINST 13 P11002 + lattice files

Link to Collider Ring Template : E.Gianfelice

https://www.dropbox.com/s/czsvvyclmn0vy3o/RF%20specifications%20MC%20CollisionRing_EG.xlsx?dl=0

Summary IMC RF systems

https://www.dropbox.com/s/2e71dj9bzomglwm/MC_RF%20Summary%20Draft.xlsx?dl=0

System			Driver			Front-End	Cooling			Acceleration			Collider	TOTAL	CLIC
Sub-system			Driver Linac H- (SPL like)		Accum &Comp	Capture& Bunching	Initial	6D (2 lines)	Final (2 lines)	Injector Linac	RLAs (2stages)	RCS (3stages)	Ring	IMC	Acceleration
Reference expert			F.Gerigk		?	D.Neuffer	C.Rogers	D.Stratakis	C.Rogers	A.Bogacz		S.Berg	E.Gianfelice		
	Energy	GeV/c	0.16	5	5	0.255	0.255	0.255	0.255	1.25	62.5	1500	1500		1500
Beam (system exit)	# bunches (μ^+ or μ^-)	#	40 mA		1	12	12	1	1	1	1	1	1		312
	Charge/bunch	E12			500	3.57	2.56	7.21	4.39	3.73	3.17	2.22	2.20		3.72E-03
	Rep Freq	Hz	5	5	5	5	5	5	5	5	5	5	5		50
	Norm Transv Emitt	rad-m				1.5E-02	3.0E-03	8.3E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05		660/20E-06
	Beam dimens. (H/V) in RF	mm	?	?	?	?	?	?	?	?	?	?	?		1?
	Norm Long Emitt	rad-m				4.5E-02	2.4E-02	1.8E-03	7.0E-03	7.0E-03	7.0E-03	7.0E-03	7.0E-03		
	Pulse/Bunch length	m	2.2 ms		0.6 (2ns)	1.1E+01	1.1E+01	9.2E-02	9.2E-02	4.6E-02	2.3E-02	2.3E-02	5.0E-03		4.4E-05
	Power (μ^+ and μ^-)	W	6.40E+04	2.2E+06	2.0E+06	1.8E+04	1.3E+04	3.0E+03	1.8E+03	7.6E+03	3.2E+05	5.4E+06	5.3E+06		2.8E+07
RF cavities	Technology		NC Linac4	SC	SC	NC	NC	NC Vacuum	NC	SC	SC	SC	SC		NC High Grad
	Number of cavities	#	23	244	2	120	367	7182	32	52	360	2694	?	11076	149000
	RF length	m	46	237	1	30	105	1274	151	82	1364	2802	?	6092	30000
	Frf	MHz	352	704	44	326to493	325	325-650	20-325	325	650-1300	1300	800	4 to 1300	12000
	Grf	MV/m	1-3.7	19 - 25	2	20	20 to 25	19-28.5	7.2-25.5	20	25 to 38	35	?	1 to 38	100
	Aperture	mm	28	80		?	?	?	?	300	150	75	120	28 to 300	2.75
	Magnetic Field	T	0	0		2	3T	1.7-9.6	1.5-4	0	0	0	0	0 to 9.6	0
	Installed RF field	MV	169	5700	4	434	2618	30447	1836	1640	50844	98062	250	1.92E+05	3.00E+06
	Beam Energy gain	MeV	160	4840	0	0	0	0	0	1250	62500	1437000	0	1.51E+06	1.50E+06
	Recirculations	#	1	1		1	1	1	1	1	4.5 to 5	13 to 23	1000	1 to 1000	1
	RF Power/pulse (η=0.6)	MW	25	220	3.E-01	99	429	1172	43	52	360	2024	1.98E-02	4425	1.2E+07
RF power sources	Technology		klystron	klystron						Klytron-IOT					Two Beam
	Cavities/Power Source	#	23	244		4				1 to 2	1 to 2				2
	RF Pulse (fill+beam) estim.	ms	2.20	2.20	3.20	0.10	0.10	0.10	0.10	0.03	0.06	0.73	14.80		0.142
	Prf/Power Source	MW	11.7	1.93						1	1				15
	Total Power Sources	#	17	244		30				52	341			?	1638
	Installed Peak RF Power	MW	34	275		164	515	1407	52	52	341	2429	2.38E-02	5269	2.46E+04
	Average RF power (η=0.6)	MW	0.27	2.13	0.01	0.05	0.21	0.59	0.02	0.01	0.11	14.88	0.00	18.28	143
	Wall plug power (η=0.6)	MW	0.45	3.55	0.01	0.08	0.36	0.98	0.04	0.01	0.18	24.81	0.00	30.46	289

Comments and recommendations

RF systems along beam lines pretty well defined

- **Mainly done by beam designer (Please check, correct and complete)**

Launch RF power systems design by RF experts

- **RF experts to be identified (volunteered)**

This meeting: Focus on identification of major issues:

- **Technical / Beam related (beam loading, instabilities) / Power consumption / Cost….**
- **Ranking (criteria?)**
- **Can they be mitigated by design review?**
- **How to address them and demonstrate their feasibility?**