MC RF WG WP structure summary

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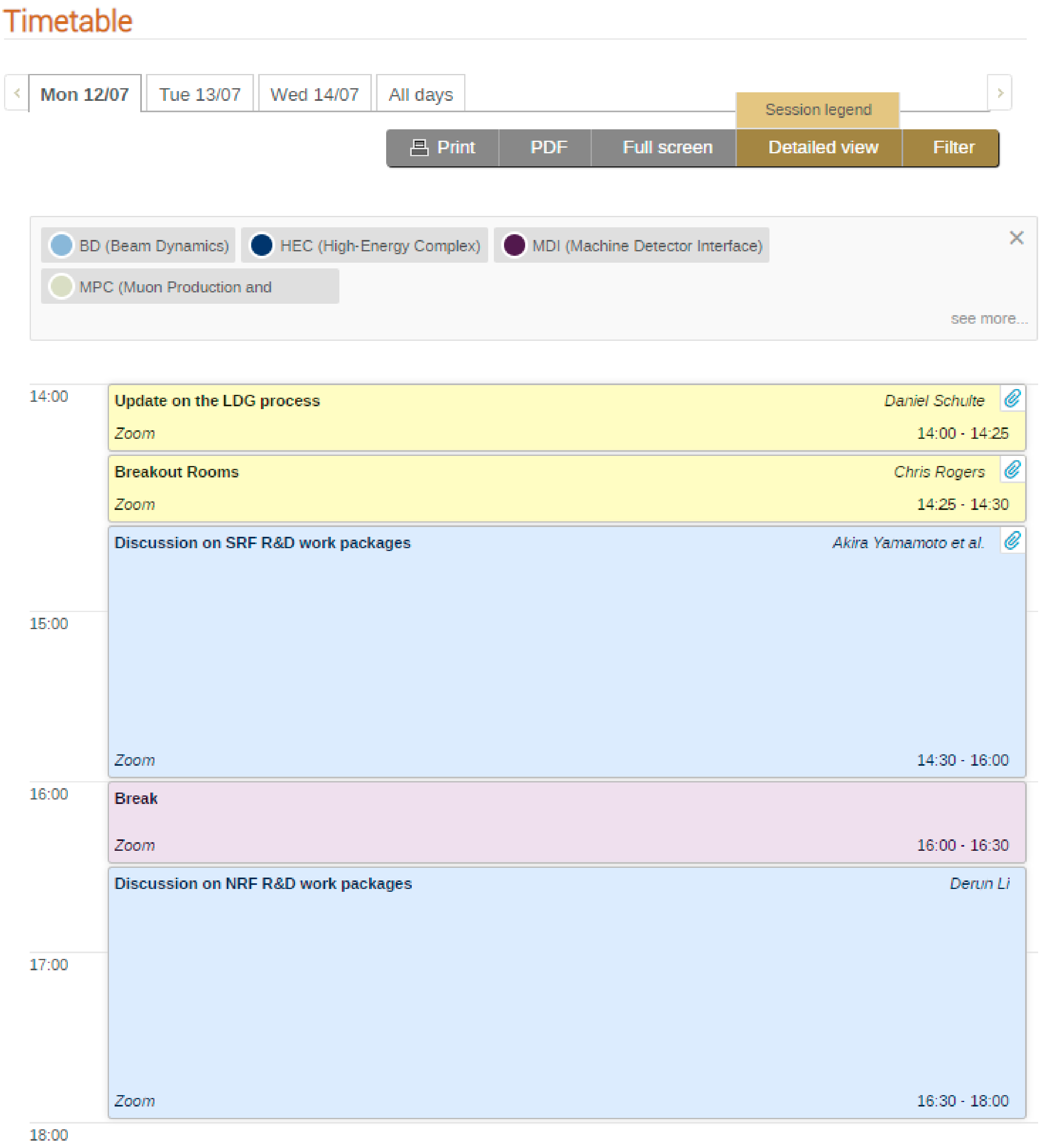
2nd Muon community meeting

MC RF WG parallel session

Discussion on SRF
Chair: Akira Yamamoto
5 participants

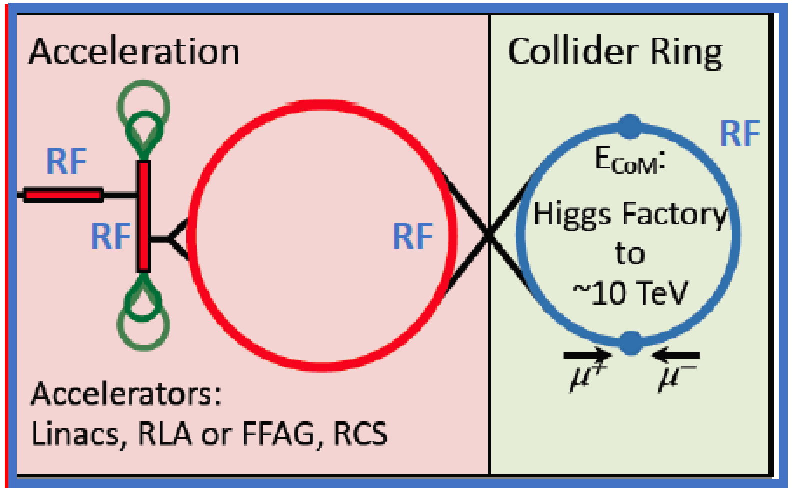
Discussion on NRF
Chair: Derun Li
3 participants



Super conducting RF (SRF) system for muon acceleration to high energy

- SRF system for high efficiency and highest acceleration rate to minimize the muon decay losses on the way to very high energies: ~10TeV

  - High charge, short bunches,
  - High efficiency at high gradient
  - Manufacturing quality
  - Longitudinal and transverse stability



Summary of 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

SRF system parameters and challenges

- SRF system for **high efficiency** and **highest acceleration rate** to minimize the muon decay losses on the way to very high energies: ~10TeV
  - **Large bunch charge in the linacs:** 3.6 x 10^{12} μ => **576 nC**
  - **Large bunch charge in the rings:** 2.2 x 10^{12} μ => **352 nC**
  - **Short bunch length in the collider:** **1.5 mm**
  - Highest possible gradient : $\geq$ 35 MV/m ?
  - **Power efficiency:** **> 70 % ?**
  - **High energy gain per turn in the rings:** **?**
  - **High level of radiation:** **?**
  - **Stray magnetic field :** **?**

Critical issues and R&D on SRF

- **Design of the RF system:** including acceleration, longitudinal beam dynamics, wake-fields, bunch length, and energy spread control for RF cavity design.
- **High gradient:** at low frequency multi cell cavities: **>> 20 MV/m ?, @ 325, 650 MHz** with seeking for common SRF cavity frequency **beneficially applicable to various project with saving synergy.**
- **Technology choice: Bulk vs Coating**; Different materials: **Nb, (Nb3Sn, HTS**, …) in 5 yrs
- **Cavity type(shape) and Surface Treatment:** for high gradient and high Q (low loss factor)
- **Pulsed operation:** Lorenz force detuning in pulsed (strong transient) mode.
- **RF power sources:** pulsed, high peak power, high efficiency: > 70 % ?
- **Tolerance:** to external (stray) magnetic field, … Which level?
  - With common motivation with HTS beam-screen under ≥ 16 T for the FCC-hh
- **Tolerance:** to the radiation and beam loss
- **Power couplers:**

SRF WP1: Baseline design of the RF system for acceleration to high energy: Design study

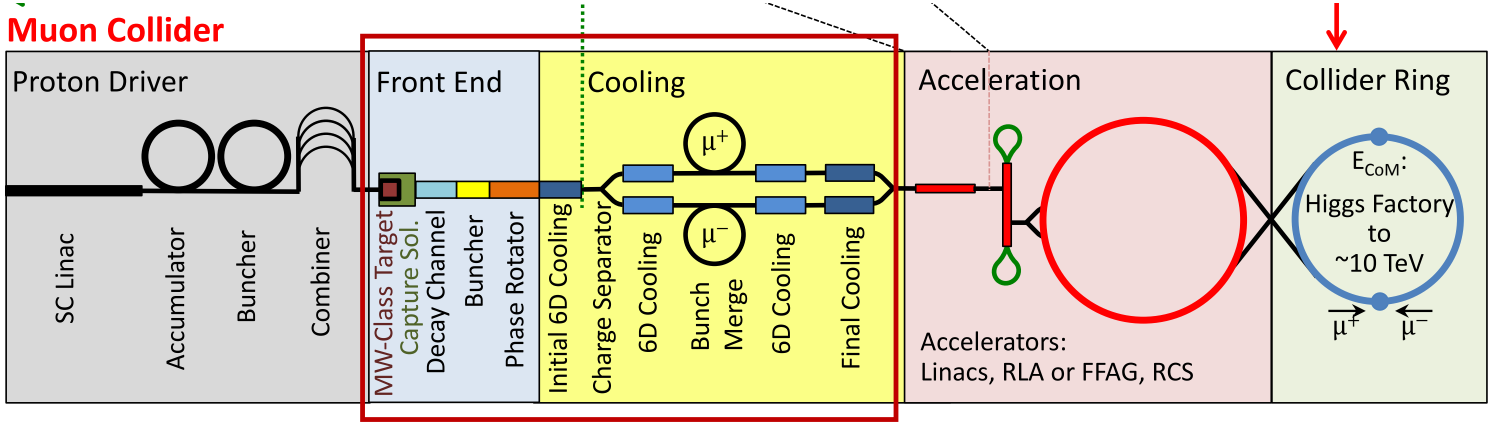
	1	2	3	4	5	input	output	EOI
1. Baseline design of the RF systems for **RCSs** including acceleration, longitudinal beam dynamics and stability, bunch length and energy spread control. a. Provide specifications for **cavity design**: **frequency**, R/Q, HOM suppression. b. Provide specification for **RF power sources**: frequency, power, …						HEC, BD, MG	PPC	CERN SY-RF
2. Calculation of **cavity parameters** for fundamental mode parameters: R/Q, Vmax; as well as for HOMs and wakes for the design work in 1.								UoR
3. RF design of the cavities for the RCSs as input to BDR								UoR
4. Design of the **RF cavities for LA and RLAs** based on the specifications from HEC and BD						HEC, BD		UoR

SRF <u>WP2</u>: High gradient SRF technology for muon accelerators. Synergy + potential prototypes

	1	2	3	4	5	input	output
1. Provide **limiting values for** RF cavity and RF system **design** from SRF State of the Art: - Gradient and Q0 at different frequencies: 325, 650, 1300 MHz - Tolerances to external (stray) magnetic fields - Tolerances to radiation and beam loss							RF
2. High gradient prototype of lowest frequency (**325 MHz)** accelerating structure to target high gradient: **>20 MV/m**							
3. RF power sources: High efficiency baseline design based on the parameter specification from WP1 to provide information on the power and cost							PPC
4. Synergy: Look for synergy in SRF technology with already ongoing projects and R&D activities. Direct them to the parameter space relevant for muon collider - High gradient at low frequencies - Tolerances to magnetic field, radiation and beam loss							RF HEC BD

Normal conducting RF (NRF) system for muon capture and cooling

- **Key Issues of NRF technology for muon capture and cooling**
  - High gradient at low frequencies
  - **In the presence of high magnetic field at multi-Tesla magnitude**
  - Large iris or Be windows;
  - High peak RF power, independently powered cavities;
  - RF sources and LLRF controls
  - Engineering challenges of system integration with RF, SC magnet, cryogenics, and etc.



Many NRF cavities

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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
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NRF system parameters and challenges

- Complex **normal conducting RF (NRF)** system, and many of the cavities need to be independently powered and controlled at many different frequencies in the ranges from 20 to 650 MHz. Majority of the cavities operate at two main frequencies: 325 and 650 MHz at high gradients in a strong magnetic field at multi-Tesla magnitude.
- **Low frequency (large cavity): 325 - 650 MHz,**
- **High gradient: 25 - 30 MV/m,**
- **Strong magnetic field: 5 - 10 T**
- **High peak current before bunch merge:** 3.6E12 μ @325MHz => **187 A**
- **Large bunch charge after bunch merge:** 7.3E12 μ => **1168nC**
- **Large beam aperture/window:**
- **High level of beam losses and decay radiation**
- **Technology is far from being mature**. The closest example is a positron capture RF cavity: high frequency, high gradient, but not in so strong magnetic field.

Critical issues and R&D on NRF

- **Gap** between **performance** of the prototype and the test cavities achieved so far must be closed. Based on the nominal parameters from the Muon Cooling WG: frequency, gradient, B-field, aperture and on the existing (and future) test results, design, build and test prototype cavities for the muon cooling test facility.

- **Achievable high gradient** in a **strong magnetic field** requires continuous R&D on: alternative materials, gas versus vacuum, operation temperatures, pulse shapes and other new ideas. This requires a dedicated test stand on a time scale before the muon cooling test facility.

- **RF power source**: Existing commercial RF power sources are by design operate at lower peak power but higher average power than what is needed for muon collider. This is driven by current applications. A new design of the RF power source targeting muon collider parameters (higher peak power, lower duty factor) and high efficiency must be pursuit.

- **Engineering design and integration:** RF, SC magnet, cryogenics, etc.

- Safety, maintenance and etc. associated with using Beryllium materials on cavity walls and beam windows.

- **Collective effects**: beam loading, single and multi-bunch must be addressed.

NRF WP1: Baseline design of the RF system for Muon cooling complex. Design study

	1	2	3	4	5	input	output
1. Collect specifications for the design of **all** RF cavities for the muon cooling complex: frequency, gradient, length, B-field, aperture (window size and thickness), …						MC	
2. Based on available knowledge both experimental and theoretical, identify best concept for achievable accelerating gradient in magnetic field: material, pulse shape, temperature, gas, …							
3. Calculate parameters of all cavities specified in 1. Provide a consistent set of parameters of **all** RF cavities and associated RF systems							PPC
4. Integration of RF cavities into cooling cell, adapting design if necessary						MC,MG ,CR, …	MC
5. Mitigation of collective effects including beam loading by design of RF cavities and RF systems						MC, BD	MC, BD

CEA, LBNL are interested

NRF WP2: Conceptual design of the RF system for Muon Cooling Test Facility (MCTF). Design study

	1	2	3	4	5	input	output
1. Collect specifications for the design of RF cavities for the MCTF: frequency, gradient, length, B-field, aperture, …						MC	
2. Design the RF cavities specified in 1 using the concept identified in WP1.2							TF
3. Design of the associated RF systems for the MCTF							TF
4. Integration of the RF cavity into the MCTF cooling cell(s) including SC solenoid, cryo, etc						MC,MG ,CR,…	TF
5. Engineering design of the cavity in its environment including cooling, thermal and mechanical stability, alignment, RF diagnostic and tuning, …							
6. Design of RF test stand for validating performance of RF cavities before installation in MCTF (simplified muon cooling cell ?)						MC,MG ,CR,TF…	TF

CEA, LBNL is interested

NRF WP3: R&D on high gradient in strong magnetic field. Potential test stand + test cavities

	1	2	3	4	5	input	output
1. Identify infrastructure available for potential use as (or setting up) an RF test stand for testing RF cavities in strong magnetic field: RF power source, SC solenoid,…							
2. Design and build RF test stand based on the available infrastructure and specified requirements.							
3. Propose test program adapted to potential test setup, considering possible limitations in terms of available frequency, power, magnetic field strength and size of a SC solenoid(s) - Materials, - Temperature - Pulse length/shape - Surface preparation for FE reduction - Gas							
4. Design and build test cavities							
5. Test the test cavities							RF, MC

CEA is interested

NRF WP4: RF power sources for muon cooling RF system. Design study + synergy

	1	2	3	4	5	input	output
1. Based on the parameters of RF cavities set target specifications for the RF power sources for Muon cooling complex						MC, RF	
2. Address potential issues including: - Large number of different frequency, - High peak power requirements - High efficiency						MC	MC
3. Baseline Design of RF power source(s) to provide information on the peak power capability, efficiency and cost							RF, PPC