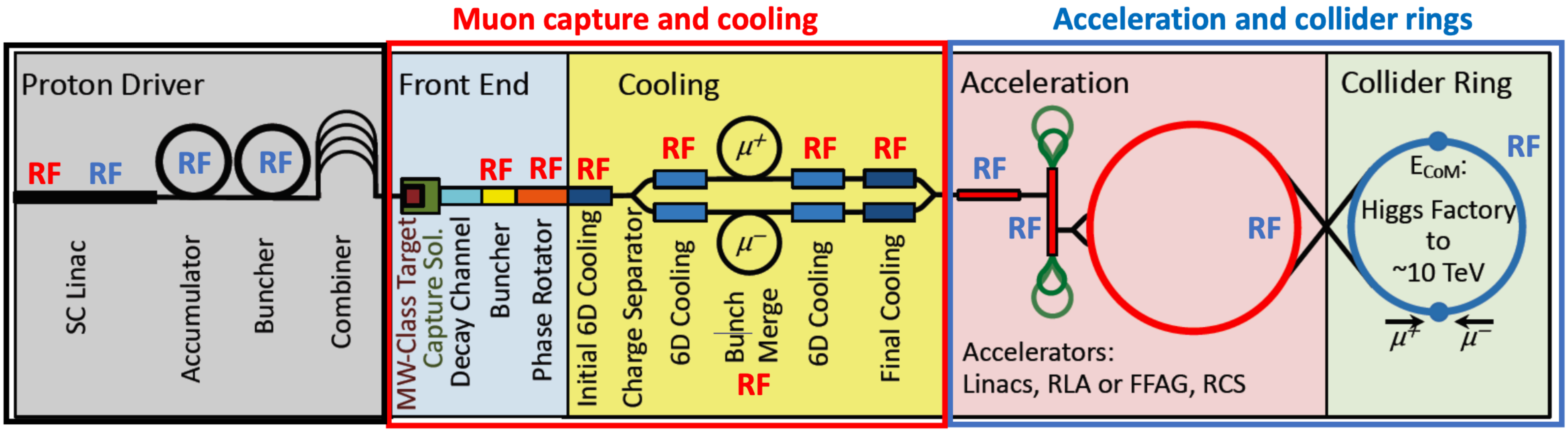
Introduction and Objectives of the BD-WG

- Introduction and Overview
- Programme
- Participants
- Objectives

Introduction and Overview



Courtesy of A. Grudiev et al.

Introduction and Overview

- Summary of RF systems

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	RLA	RCS	Ring	IMC	Acceleration
Reference expert			F.Gerigk		?	D.Neuffer	C.Rogers	D.Stratakis	C.Rogers	A.Bogacz		S.Berg	E.Gianfelice		
Beam (system exit)	Energy	GeV/c	0.16	5	5	0.255	0.255	0.255	0.255	1.25	62.5	1500	1500		1500
	# 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	1.5E-02	1.9E-03	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02		
	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		120	367	7182	32	52	360	2694	?	11074	149000
	RF length	m	46	237		30	105	1274	151	82	1364	2802	?	6091	30000
	Frf	MHz	352	704	4 ?	326to493	325	325-650	20-325	325	650-1300	1300	800	4 to 1300	12000
	Grf	MV/m	1-3.7	19 - 25		20	20 to 25	19-28.5	7.2-25.5	20	25 to 38	35	?	7 to 35	100
	Aperture	mm	28	80		?	?	?	?	300	150	75	120	?	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		434	2618	30447	1836	1640	50844	98062	250	1.92E+05	3.00E+06
	Energy gain	MeV	160	4840		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		99	429	1172	43	52	360	2024	0	4.43E+03	8.5E+06
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		1.00E-01	1.00E-01	1.00E-01	1.00E-01	3.00E-02	5.90E-02	7.25E-01	1.48E+01		2.44E-04
	Prf/Power Source	MW	11.7	1.93						1	1				136
	Total Power Sources	#	17	244		30				52	341			?	74400
	Installed Peak RF Power	MW	34	275		164	515	1407	52	52	341	2429	2.38E-02	5269	5.06E+08
	Average RF power	MW	0.27	2.13		0.05	0.21	0.59	0.02	0.01	0.11	14.88	0.00	18.27	104
	Wall plug power (η=0.6)	MW	0.45	3.55		0.08	0.36	0.98	0.04	0.01	0.18	24.81	0.00	30.46	337

Courtesy of
J.P. Delahaye et al.
(20/05/21)

Introduction and Overview

- RF system for muon capture and cooling

Region	Length [m]	N of cavities	Frequencies [MHz]	Gradient [MV/m]	Magnetic field [T]	Peak RF power [MW/cav.]
Buncher	21	54	490 - 366	**0 - 15**		1.3
Rotator	24	64	366 – 326	**20**		2.4
Initial Cooler	126	360	325	**25**	**2**	**3.7**
Cooler 1	400	1605	325, 650	**22, 30**	**2-3, 4-6**	
Bunch merge	130	26	108 - 1950	**~ 10**		
Cooler 2	420	1746	325, 650	**22, 30**	**2-5, 8-13**	
Final Cooling	140	96	325 - 20			
Total	**~1300**	**3951**				=> **~12GW**

It is a very large and complex RF system with high peak power

Courtesy of A. Grudiev et al.

Introduction and Overview

International MUON Collider Collaboration

◆ RCS chain parameters

	Based on Neuffer, Shiltsev, JINST 13 (2018) T10003							
	Speed of light	c_0	[m/s]	299792458				
	Electron charge	e_0	[10^{-19}C]	1.602176634				
	Muon rest mass	m_μ	[MeV]	105.6583755				
	Muon lifetime (at rest)	τ_μ	[µs]	2.196981122				
			Unit	**RCS-LE (SPS)**	**RCS-ME (LHC)**	**RCS-HE (LHC)**	**RCS-HE (new)**	**Remark**
	Injection energy	E_{inj}	**[TeV]**	**0.063**	**0.3**	**1.5**	**1.5**	
	Ejection energy	E_{ej}	**[TeV]**	**0.3**	**1.5**	**10**	**10**	
	Muon survival rate	N_{ej}/N_{inj}		**0.9**	**0.9**	**0.9**	**0.9**	
	Circumference	$2\pi R$	[km]	6.912	26.659	26.659	50.000	
	Pack fraction		[]	0.67	0.71	0.71	0.80	
	Bending radius	ρ	[km]	0.741	3.026	3.026	6.366	Bending radius from SPS and LEP, ISR see E. Keil, ISR-TH/72-20
	Total straight section length	l_{SS}	[km]	2.254	7.643	7.643	10.000	
	Injection Bending field	B_{inj}	[T]	0.283	0.331	1.653	0.786	
	Ejection Bending field	B_{ej}	[T]	1.350	1.653	11.022	5.240	By far too large bending field for 10 TeV in LHC tunnel
	Injection relativistic mass factor	γ_{inj}	[]	596	2839	14197	14197	
	Injection relativistic mass factor	γ_{ej}	[]	2839	14197	94645	94645	
	Revolution frequency	f_{rev}	[kHz]	43.38	11.25	11.25	6.00	
Linear ramp	Gradient for survival	G	[MV/m]	2.38	2.45	2.89	2.89	Constant acceleration with linear energy increase
Linear ramp	Acceleration time	T_{acc}	[ms]	0.33	1.63	9.82	9.82	
Linear ramp	Number of turns	n_{turn}		14	18	110	59	
Linear ramp	**Maximum energy gain per turn**	ΔE	**[GeV]**	**16.42**	**65.33**	**77.00**	**144.43**	**No overvoltage!**
Linear ramp	**Average gradient per straight length**	$\Delta E/l$	**[MV/m]**	**7.286**	**8.547**	**10.075**	**14.443**	
Sinusoidal ramp	Maximum gradient for survival	G	[MV/m]	4.12	4.28	5.25	5.25	During maximum ramp rate
Sinusoidal ramp	Aceleration time	T_{acc}	[ms]	0.30	1.47	8.48	8.48	
Sinusoidal ramp	Number of turns	n_{turn}		13	17	95	51	
Sinusoidal ramp	**Maximum energy gain per turn**	ΔE	**[GeV]**	**28.50**	**114.05**	**139.93**	**262.45**	**No overvoltage!**
Sinusoidal ramp	**Average gradient per straight length**	$\Delta E/l$	**[MV/m]**	**12.642**	**14.923**	**18.308**	**26.245**	

Courtesy of H. Damerau et al.

Introduction and Overview

- Target parameters for the Muon Collider ring

Courtesy of D. Schulte

Tentative target parameters
Scaled from MAP parameters

Comparison:
CLIC at 3 TeV: 28 MW

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

Parameter	Symbol	Unit	3 TeV c.m.	14 TeV c.m.
Speed of light	c	[m/s]	299792458	
Electron charge	*e*	[10^{-19}C]	1.60	
Muon rest mass	mmu	[MeV]	105.66	
Muon lifetime (at rest)	taumu	[μs]	2.20	
Energy	E	[TeV]	1.5	7
Gamma			14197	66251
Circumference	C	[km]	4.5	14
Revolution frequency	frev	[kHz]	66.6	21.4
Revolution period	Trev	[μs]	15.0	46.7
Muon lifetime		[ms]	31	146
		[turn]	2078	3117
Average Beta function		[m]	50	50
Beta function at the IP	betaIP	[mm]	5	1.07
Rms bunch length	sigmaz	[mm]	5	1.07
Norm. transverse emittance	epsNorm	[microm]	25	25
Un-norm. transverse emittance	eps	[microm]	0.00176	0.00038
Average rms transv. bunch size	sigmatAvg	[microm]	296.7	137.4
Rms transv. bunch size at the IP	sigmatIP	[microm]	3.0	0.6

Introduction and Overview

- IMCDS website: https://muoncollider.web.cern.ch/welcome-page-muon-collider-website
- Organisation: https://muoncollider.web.cern.ch/organisation

International Muon Collider Design Study

HOME OVERVIEW ORGANISATION DESIGN COLLABORATION MATERIALS CALENDAR

- General Parameters
- Lattices
- Beam Dynamics
- RF
- Magnets
- High-Energy Complex +
- Muon Production and Cooling +
- Proton Complex
- Radiation Protection and other Technologies
- MDI
- Physics
- Detector
- LEMMA source

MUON BEAM PANEL

0) Integration, project, reserve: Daniel Schulte (CERN) and Mark Palmer (BNL).

1) Muon production and cooling: Chris Rogers (STFC-RAL) and Diktys Stratakis (FN

2) Muon acceleration and collision: Antoine Chance (IRFU) and Angeles Faus-Golf

3) Magnets: Lionel Quettier (IRFU) and Tabea Arndt (KIT).

4) RF: Jean-Pierre Delahaye (CERN retiree) and Akira Yamamoto (CERN/KEK).

5) Particle-matter interaction: Simone Gilardoni (CERN) and Nadia Pastrone (INF

6) Beam dynamics: Tor Raubenheimer (SLAC/Stanford University) and Elias Metra

7) Other systems and issues: Philippe Lebrun (European Scientific Institute) and

8) Other muon beam opportunities: Ken Long (Imperial College London).

9) LEMMA: Nadia Pastrone (INFN-Torino) and Angeles Faus-Golfe (IJClab).

CONTACT PEOPLE

- Role:

- They should help the panel to do its duty.
- They should dispatch questions to relevant experts.
- They are responsible for ensuring that an answer is provided.

- List for Design

- ***Parameters***: Daniel Schulte.
- ***High-energy complex***: Alex Bogacz (linacs), Shinji Machida (FFA), Antoine Chance (RCS), Christian Carli (collider), Anton Lechner (shielding).
  - ***Muon production and cooling***: Chris Rogers, Marco Caviani, Chris Densham.
  - ***Proton complex***: Ilias Efthymiopoulos, Frank Gerigk.
  - ***Test facility***: Roberto Losito.
  - ***Beam Dynamics***: Elias Metral.
  - ***LEMMA***: Marica Biagini.

- List for Technologies and Infrastructure

- ***RF***: Alexej Grudiev.
- ***Magnets***: Lionel Quettier.
- ***Power converter***: Davide Aguglia, Fulvio Boattini.
- ***Beam instrumentation***: Manfred Wendt.
- ***Vacuum***: Jose Antonio Ferreira Somoza.
- ***Alignment***: Helene Mainaud-Durand.
- ***Cryogenics***: Rob van Weelderen, Patricia Tavares Coutinho Borges De Sousa.
- ***MDI***: Donatella Lucchesi (MDI), Anton Lechner (shielding/MDI), Christian Carli.
- ***Radiation protection***: Claudia Ahdida, Markus Widorski.
- ***Civil engineering***: John Osborne, Youri Robert.

Introduction and Overview

International
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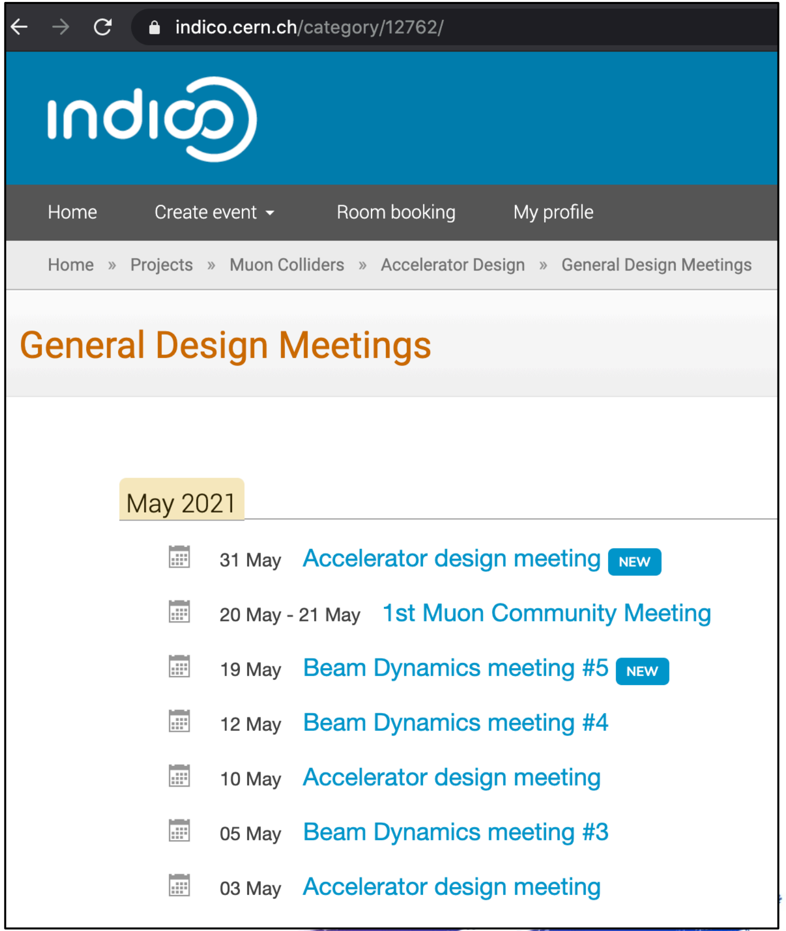
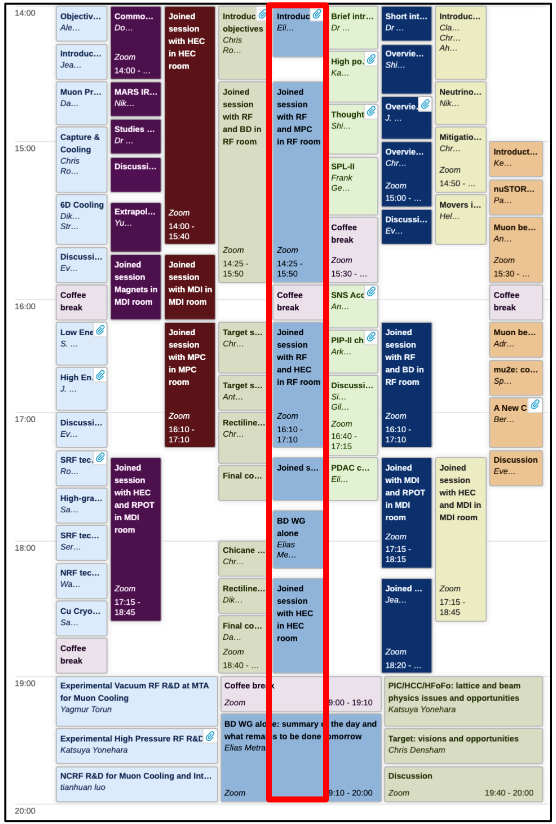
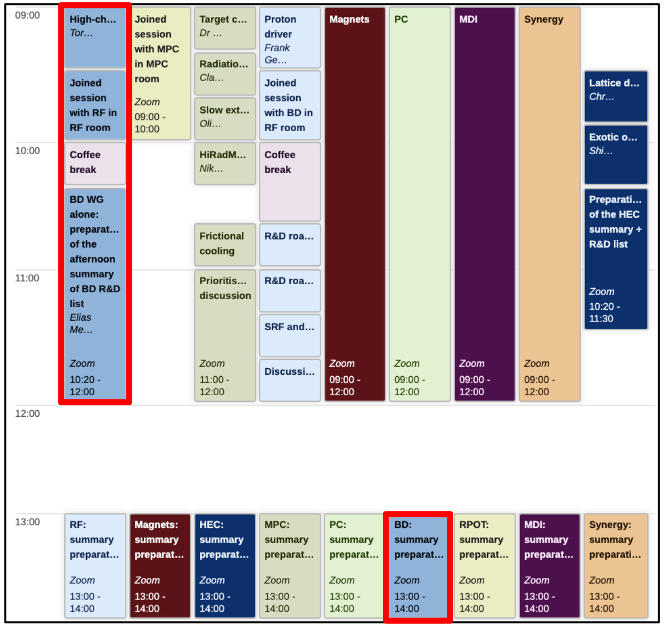
- Direct link to the indico site for Accelerator Design Meetings (from Daniel Schulte, on Monday afternoons) and Beam Dynamics Meetings => https://indico.cern.ch/category/12762/

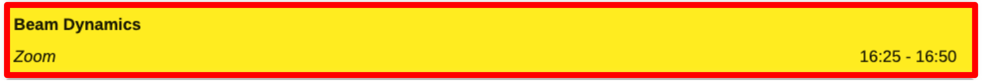


Programme

(https://indico.cern.ch/event/1030726/timetable/#all.detailed)







Participants: 39 (as of this morning) – 149 total

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Objectives

=> Charge for this 1st Muon Community Meeting:

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- The goal is to identify the R&D that has to be carried out before the next ESSU-PP to scientifically justify the investment into a full CDR for the muon collider and the corresponding demonstration programme

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- This includes R&D to develop a baseline collider concept, well-supported performance expectations and to assess the associated key risks, cost and power drivers. Further, the main components of the demonstration programme should be identified together with the corresponding preparatory work

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International MUON Collider Collaboration

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- The goal is to identify the R&D that has to be carried out before the next ESSU-PP to scientifically justify the investment into a full CDR for the muon collider and the corresponding demonstration programme
- This includes R&D to develop a baseline collider concept, well-supported performance expectations and to assess the associated key risks, cost and power drivers. Further, the main components of the demonstration programme should be identified together with the corresponding preparatory work
- The working groups should propose realistic but ambitious targets for the performance goals of the different collider systems. In particular they should consider what could be assumed for the demonstration programme, i.e. in one or more test facilities starting in 2026, as well what one can anticipate to be available in 2035-2040 for a first collider stage and in 2050 for an energy upgrade

Let's do it together for the BD part!

International MUON Collider Collaboration

CERN

Thank you for your attention