MC BD WG WP structure summary

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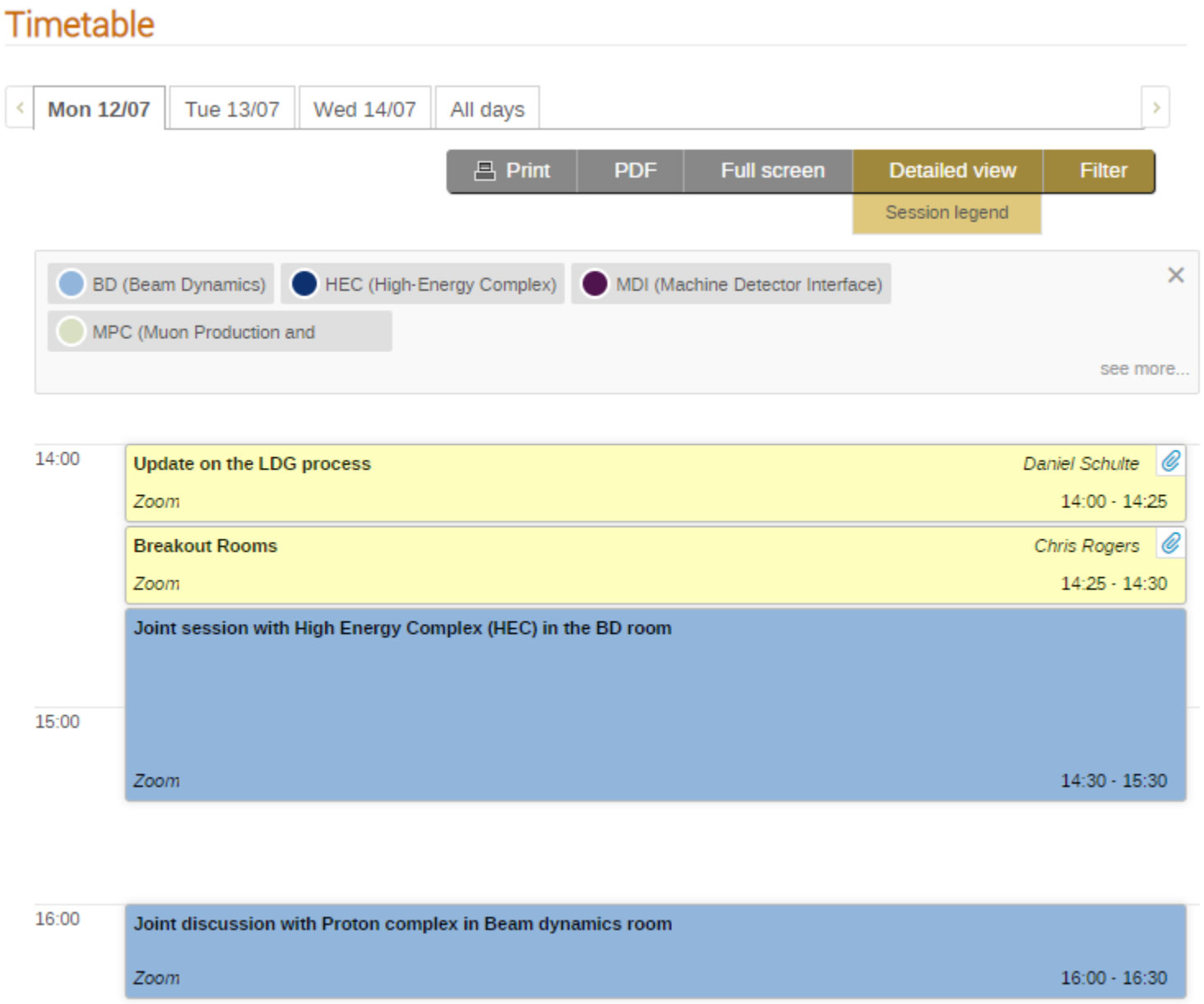
2021/07/13

2nd Muon community meeting

Viewgraphs not shared – all errors and misstatements responsibility of Tor R.

MC BD WG parallel session



16:30 – 18:30 Continued meeting with HE Complex

Critical issues and R&D on BD

Summary of the challenges for the Beam Dynamics Working Group

Conveners: R. Ryne, T. Raubenheimer and E. Métral

Even if everything needs to be done quickly with muons (due to the short lifetime), many issues can happen with high bunch charges and high impedances (which is the case here with the many RF stations all along the muon collider chain) and many aspects need to be carefully studied. The BD-WG identified and prioritized 12 R&D items (many thanks to all participants, MAP experts, Daniel and Mark):

Criticality 1 (high):

1) New beam dynamics regime during acceleration
2) Opposite sign bunches – beam crossing and wakes
3) Design of the full chain (acceleration in particular)
4) Radiation mitigation by moving the beam / magnets in the collider
5) Collective instabilities during ionization cooling

Criticality 2 (medium):

6) FFAs as an alternative to pulsed synchrotrons
7) Longitudinal and transverse beam dynamics studies in the collider
8) Development of simulation tools

Criticality 3 (low):

9) Halo formation and beam losses in the Proton Driver
10) Check of all cooling studies with a second code
11) Are sextupoles needed in pulsed synchrotrons?
12) Impedance models

210707 Muon Beam Dynamics Studies

Goal:

Google Doc listing tasks and relationships

Develop a credible design concept Muon Collider with cost estimate, upgrade path, and demonstration facility requirements by December 2025 based on reasonable assumptions on technology development. Costing and final documentation will require at least roughly 12 months although updates can be accommodated through Fall 2025.

Requires complete beamline description with lattices with critical technologies identified and ideally have start-2-end tracking of full system to demonstrate luminosity performance (subsystem tracking may be sufficient). Identify outstanding challenges with possible mitigation approaches.

Most tasks listed here are the responsibility of the High Energy Complex group. Some of the early tasks are responsibility of Parameters, Proton Complex, Front End groups. Beam Dynamics has no direct responsibility.

Output developed through interactions with High Energy Complex and Proton Complex. Still need to discuss with Cooling group.

Most details summarized in HE Complex discussion

Muon Collider Parameters

Tentative IMC 3 TeV
(based on MAP potential transmission factors)

IMC	3 TeV	Particle Transmission		Dilution/Cooling Factor: Transverse emittances		Dilution/Cooling Factor: Longitudinal emittances		Beam Energy	Number of bunches	Particles per bunch	Norm transv emittance	Norm. long. emittance	Bunch length	Beam Power
5	Rep rate (Hz)							GeV	#	E12	μrad-m	mrad-m	mm	W
	Driver	0.153 at 8GeV						5	1	376.89			600 (2ns)	1.5E+06
	Target & Front End	0.0956						0.255	12	36.04	15000	45	85.2	8.8E+04
Cooling	Initial Cooling	0.72	0.108	0.2	0.003	0.22	2.182	0.255	12	25.77	3000	10	85.2	6.3E+04
Cooling	Charge separator	0.90		1.05		1.05		0.255	12	23.19	3150	10	85.2	5.7E+04
Cooling	6D cooling before merge	0.72		0.5		0.20		0.255	12	16.58	1575	2	85.2	4.1E+04
Cooling	6D merge	0.88		2		4.00		0.255	1	14.59	3150	8	92.3	3.0E+03
Cooling	6D cooling after merge	0.44		0.067		0.23		0.255	1	6.42	211	2	92.3	1.3E+03
Cooling	Final cooling & Re-Accel	0.61		0.188		52.00		0.255	1	3.91	40	98	92.3	8.0E+02
Acceleration	Injector Linac	0.92	0.568	1.05	1.159	1.05	1.159	1.25	1	3.60	42	103	46.2	3.6E+03
Acceleration	RLA1	0.92		1.02		1.02		5	1	3.32	42	105	23.1	1.3E+04
Acceleration	RLA2	0.85		1.02		1.02		62.5	1	2.83	43	107	23.1	1.4E+05
Acceleration	RCS1	0.90		1.02		1.02		303	1	2.54	44	109	23.1	6.2E+05
Acceleration	RCS2	0.92		1.02		1.02		750	1	2.34	45	112	23.1	1.4E+06
Acceleration	RCS3	0.95		1.02		1.02		1500	1	2.22	46	114	23.1	2.7E+06
Collider	IP	0.99		1.02		1.02		1500	1	2.20	47	116	5.0	2.6E+06
Front End to IP		6.10E-02		3.12E-03		2.58								

Proton beam power on target for 2.2E12 μ /5Hz at IP: 1.5 MW
IP transverse/longitudinal emittances: 47/116 mm-mrad

OP: Overall parameters

1. Need to interface with the parameters group to determine reasonable initial transverse and longitudinal emittance values and dilutions. As part of this, an outline of the tuning and matching techniques should be developed for each subsystem. Subsequent iterations will be made as simulation tools and diagnostic specifications are developed to be able to confirm the initial estimates. Decay and emittance growth tolerances.
   --Timescale: September 2021. Requires agreement with Parameters and High Energy WGs.
   --Resources: unknown.

2. Need guidance on critical technologies such as SRF and magnets. Best to develop a 'list' of hardware assumptions that can be used across subsystems.
   --Timescale: September 2021. Requires agreement with Parameters and High Energy WGs.
   --Resources: unknown.

3. Develop simulation tools to verify physics with tuning and matching techniques with realistic diagnostic performance. Simulations likely divided into portions consisting of proton complex, front end, cooling, acceleration, and colliding ring. Ideally, a single tool could be developed for the entire acceleration portion including the linac, RLA's, and RCS's.
   --Timescale: September 2024. Requires initial lattices for most subsystems, responsibility for lattices largely with the HE working group (will split in tasks, not yet confirmed: Christian for collider ring, Antoine for RCS, ALex for linacs, Shinji for FFA).
   --Resources: unknown. Specs being developed.

4. Demonstrate start-to-end simulations with realistic jitter, drift, and diagnostics to verify emittance transport and collision parameters.
   --Timescale September 2025. Requires RC.4, CR.3 for start-2-end lattices and models, responsibility various.
   --Resources: unknown. Not clear that this is necessary or possible within scope of the design study.

PC: Proton Complex

1. Study collective limitations in the Compressor ring to determine limitations.
   --Timescale: 1st iteration, September 2022. Requires OP.1 and PC Energy choice.
   --Resources: 2 FTE-yr.

2. Simulate proton driver performance with existing simulation tools. Verify performance with tuning and matching techniques with realistic diagnostic performance.
   --Timescale: September 2024. Requires initial lattices for most PC subsystems, responsibility for lattices Proton Complex.
   --Resources: 2 FTE-yr.

3. Model beam halo for multi-MW proton driver and develop collimation systems.
   --Timescale: September 2025. Requires updated lattices for Proton Complex
   --Resources: unknown.

CO: Cooling

1. Develop analytic description of collective interactions in materials.
   --Timescale March 2023.
   --Resources: 2 FTE-yr.

2. Update cooling simulation tools to include 'all' effects including collective effects within and between absorbers.
   --Timescale September 2024.
   --Resources: 2 FTE-yr.

3. Using cooling channel lattice to simulate cooling system.
   --Timescale September 2024; Requires CO.2 and cooling lattice from Cooling WG.
   --Resources: unknown.

4. Develop lattice for transverse and longitudinal matching from cooling to 1st linac.
   --Timescale September 2022. Requires matching lattice, responsibility should be with muon production and cooling (to be confirmed with Chris et al.).
   --Resources: unknown.

FL: First Linac 325 MHz (255 MeV → ~1 GeV)

1. Calculate short- and long-range wakefields for 325 MHz – choose cavity technology – is it scaled from Fermilab 650 MHz or TESLA 1.3 GHz or …? Developing a new SRF cavity geometry takes time and $.
   --Timescale April 2022. Requires decision from RF group on 325 MHz cavity geometry.
   --Resources: 1 FTE-month.

2. Develop lattices for First Linac.
   --Timescale June 2022. Requires interaction with High Energy WG, reponsibility with High Energy Complex. 2 FTE-yr
   --Resources: unknown.

3. Model beam transport through linac with errors include both bunches and all wakefields.
   --Timescale September 2022. Requires use of existing tools and lattice for 1st linac, responsibility to be discussed with linac task, I would assume up the beam dynamics working group.
   --Resources: 1 FTE-yr.

RL: RLA's (~1 GeV → ~60 GeV)

1. Calculate short- and long-range wakefields for 650 MHz and 1.3 GHz – choose cavity technology – is it scaled from Fermilab 650 MHz or TESLA 1.3 GHz or …? Developing a new SRF cavity geometry takes time and $. Suggest that we start from existing cavity models and modify them if clearly necessary.
   --Timescale April 2022. Requires decision from RF group on MHz cavity geometries.
   --Resources: 1 FTE-month.

2. Calculate initial models of beam transport and tolerances through RLA's based on simple models. Include estimates of beam-beam crossings as well as both bunches with short and long-range wakefields. Use existing models for 650 MHz and 1.3 GHz wakefields.
   --Timescale April 2022. Requires RL.1 and OP.1 and OP.2.
   --Resources: 2 FTE-yr.

3. Develop lattices for both RLA's.
   --Timescale April 2023. Requires RL.2 and interaction with High Energy WG, responsibility with High Energy Complex.
   --Resources: 2 FTE-yr.

4. Simulate transport through RLA's. Develop tuning algorithms and verify tolerances.
   --Timescale April 2024. Requires RL.3.
   --Resources: 1.5 FTE-yr.

RC: RCS's (60 GeV → 1.5 TeV and beyond) → separate the FFA development

1. Specify parameters for RCS's
   -- Timescale December 2021. Requires OP.1 and OP.2 for input on technology, responsibilty in HE Complex working group, with parameters and technologies.
   --Resources: unknown.

2. Develop options for FFA rather than RCS
   -- Timescale April 2022. Requires OP.1 and OP.2 for parameters and technology assumptions, responsibility with High Energy Complex.
   --Resources: unknown.

3. Estimate the impact of collective effects in the RCSs and FFAs. In particular beam-beam, beam-loading, potential well distortion from short range wakes, transverse head-tail instabilities, and long-range wakes in cavities (including counter-rotating bunches) should be studied. Determine whether 1.3 GHz RF is acceptable or of lower frequencies is required. Determine whether sextupoles are required for transverse instability mitigation.
   -- Timescale 1st iteration September 2022. Requires RC.1, RC.2, and OP.1 and updated impedance model.
   --Resources: 6 FTE-yr.

4. Develop lattices for RCS or FFA's including matching between rings. Specify RF and magnetic field tolerances and alignment.
   -- Timescale April 2024. Requires RC.1, RC.2, OP.1, and OP.2, responsibility with High Energy Complex.
   --Resources: 2 FTE-yr.

5. Make physical (time)-domain simulations of RCS including both beams with beam-beam and collective effect. Iterate on designs as necessary.
   -- Timescale April 2025. Requires RC.4 and OP.3.
   --Resources: 2 FTE-yr.

CR: Collider Ring (1.5 TeV and beyond)

1. Estimate beam-beam with full lattice and collective effects; study various effects.
   --Timescale April 2022. Requires OP.1, OP.2 and decision from Parameters and High Energy WGs on circumference and general parameters including emittances and IP layout.
   --Resources: 1 FTE-yr.

2. Estimate impact of vertical trajectory modifications to reduce neutrino radiation
   --Timescale April 2022. Requires OP.1 and decision from Parameters and High Energy WGs on circumference and general parameters including emittances and IP layout.
   --Resources: 1 FTE-yr.

3. Complete Collider Ring lattice with IR, magnets, and diagnostics
   --Timescale April 2023. Requires OP.1, OP.2 and many decisions and responsibility with High Energy Complex.
   --Resources: unknown.

4. Perform (time-domain) simulations of collider ring with beam-beam, collective effects, and optics. Verify basic luminosity performance
   --Timescale April 2024. Requires CR.3 and decision from RF group on MHz cavity geometries.
   --Resources: 2 FTE-yr.

5. Optimize collimation and masking systems in collider ring to model beam losses and IR backgrounds
   --Timescale April 2025. Requires CR.3 and interaction with MDI WG.
   --Resources: unknown.

6. Simulate impact of vertical trajectory modifications to reduce neutrino radiation
   --Timescale April 2025. Requires CR.3.
   --Resources: 1 FTE-yr.