Material for Discussion on Muon Collider Plan

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Objective and Scope

Objective:

In time for the next European Strategy for Particle Physics Update, the study aims to establish whether the investment into a full CDR and a demonstrator is scientifically justified.

It will provide a baseline concept, well-supported performance expectations and assess the associated key risks as well as cost and power consumption drivers. It will also identify an R&D path to demonstrate the feasibility of the collider.

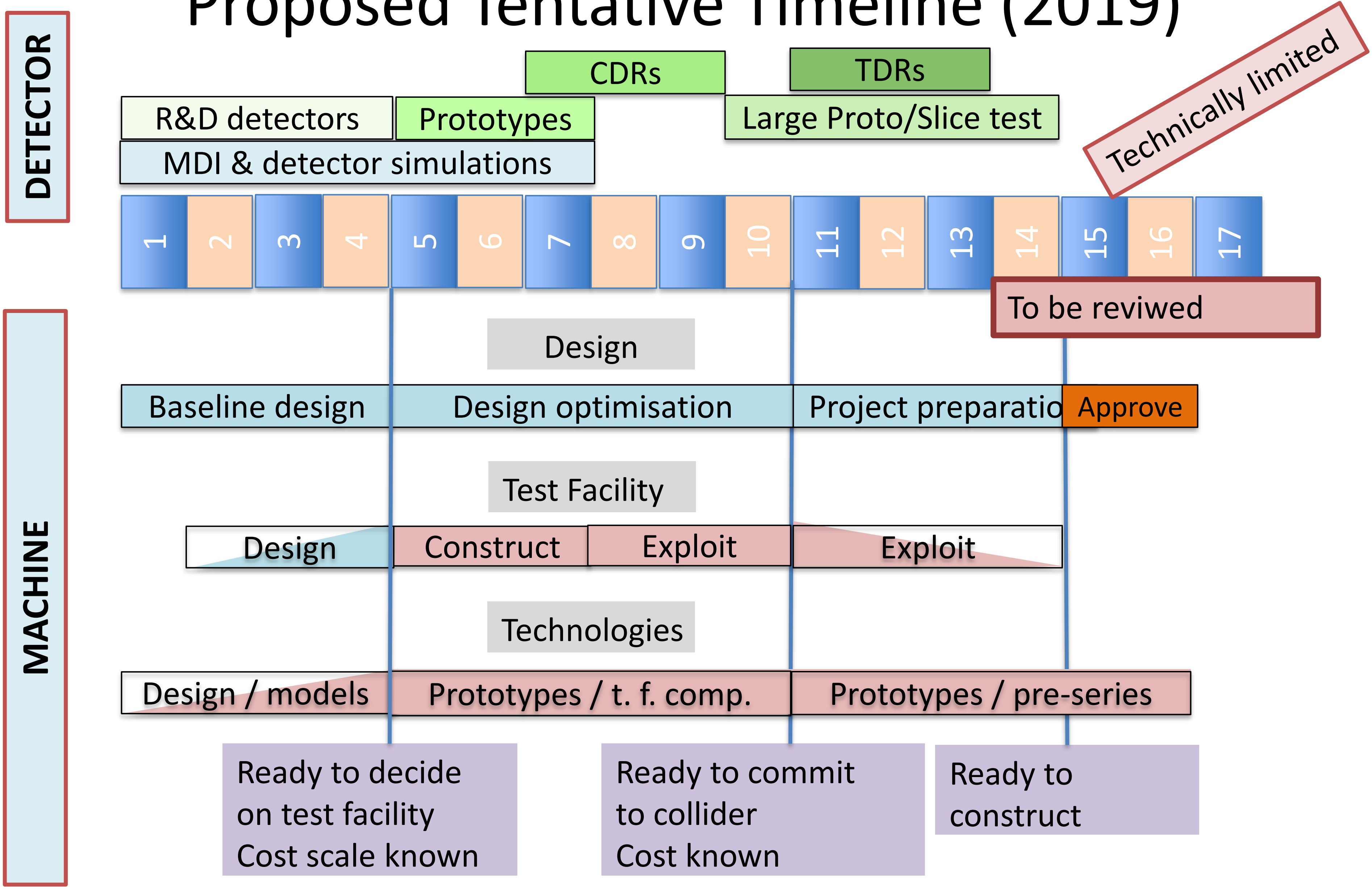
Deliverable:

Report assessing muon collider potential and describing R&D path to CDR

Scope:

- Focus on two energy ranges:
  - 3 TeV, if possible with technology ready for construction in 10-20 years
  - 10+ TeV, with more advanced technology
- Explore synergy with other options (neutrino/higgs factory)
- Define R&D path

Proposed Tentative Timeline (2019)



DETECTOR

CDRs

TDRs

Technically limited

R&D detectors

Prototypes

Large Proto/Slice test

MDI & detector simulations

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

To be reviwed

MACHINE

Design

Baseline design

Design optimisation

Project preparatio

Approve

Test Facility

Design

Construct

Exploit

Exploit

Technologies

Design / models

Prototypes / t. f. comp.

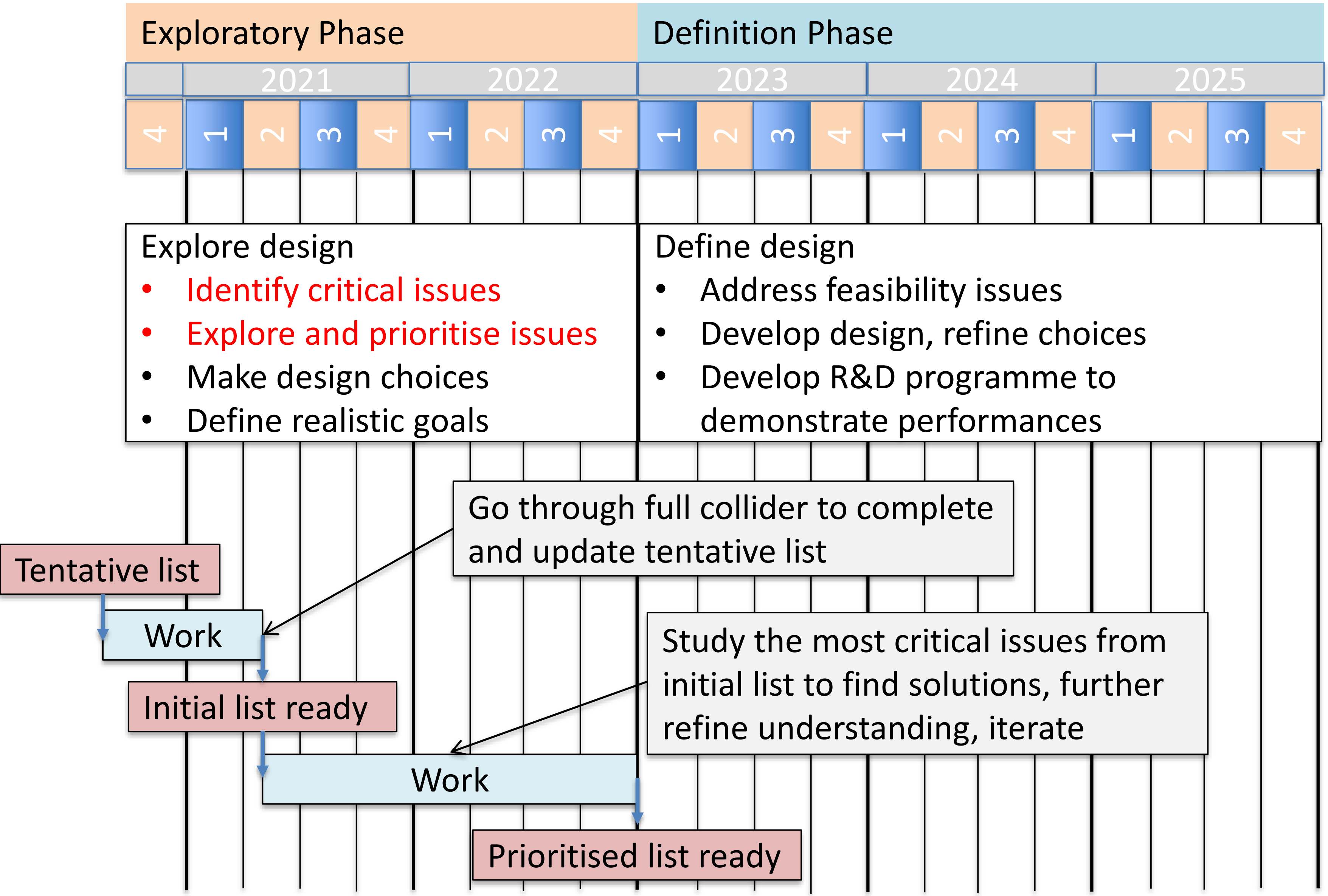
Prototypes / pre-series

Ready to decide
on test facility
Cost scale known

Ready to commit
to collider
Cost known

Ready to
construct

Tentative Timeline



Exploratory Phase

Definition Phase

2021
2022
2023
2024
2025

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Explore design
- Identify critical issues
- Explore and prioritise issues
- Make design choices
- Define realistic goals

Define design
- Address feasibility issues
- Develop design, refine choices
- Develop R&D programme to demonstrate performances

Tentative list

Work

Go through full collider to complete and update tentative list

Initial list ready

Work

Study the most critical issues from initial list to find solutions, further refine understanding, iterate

Prioritised list ready

Exploratory Phase – Key Topics

- Impact on the environment
  - The neutrino radiation and its impact on the site. This is known to require mitigation strategies for the highest energies.
  - Power consumption (accelerating RF, magnet systems, cooling)

- The impact of machine induced background on the detector, as it might limit the physics reach.

- High-energy systems that might limit energy reach or performance
  - Acceleration systems, beam quality preservation, final focus

- High-quality beam production
  - Target and target area
  - Cooling, in particular final cooling stage that does not yet reach goal

Tentative Target Parameters

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

Based on extrapolation of MAP parameters

Note: The study will have to verify that these parameters can be met

Develop emittance budgets

Initial Organisation: IRAP

“Interim R&D Advisory Panel”

The IRAP will work during the initial phase of the study, mostly in two subgroups: one on detector and physics, one on the accelerator complex. Its mandate is to:

- propose initial detector performance specifications
- establish a list of critical issues for the detector
- suggest initial priorities for the identified critical issues
- propose the scope of the work on the most critical issues
- propose initial accelerator complex performance specifications
- establish a list of critical issues for the accelerator complex
- suggest initial priorities for the identified critical issues
- propose the scope of the work on the most critical issues

Members representing large laboratories and communities as well as critical technical expertise

- include all regions

Critical Issues Include:

- **Advanced detector concepts and technologies**, requiring excellent timing, granularity and resolution, able to reject the background induced by the muon beams.
- **Advanced accelerator design** and beam dynamics for high luminosity and power efficiency.
- **Robust targets and shielding** for muon production and cooling as well as collider and detector component shielding and possibly beam collimation.
- **High field, robust and cost-effective superconducting magnets** for the muon production, cooling, acceleration and collision. High-temperature super-conductors would be an ideal option.
- **High-gradient and robust normal-conducting RF** to minimise muon losses during cooling.
- High rate **positron production** source and high current positron ring (LEMMA).
- **Fast ramping normal-conducting, superferric or superconducting magnets** that can be used in a rapid cycling synchrotron to accelerate the muons and efficient power converters.
- **Efficient, high-gradient superconducting RF** to minimise power consumption and muon losses during acceleration.
- **Efficient cryogenics systems** to minimise the power consumption of the superconducting components and minimise the impact of beam losses.
- Other accelerator technologies including high-performance, compact **vacuum systems** to minimise magnet aperture and cost as well as fast, robust, **high-resolution instrumentation**.

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Examples: Magnet Challenges

- Final cooling solenoid (O(50 T))
  - ultimate field, luminosity proportional to field and need only few small solenoids
  - hardware tests (cable tests to start)

- Fast-ramping magnets in accelerator ring
  - normal or superconducting
  - site size, cost and power consumption driver, (test of superconducting cables)
  - power converters with energy recovery

- Collider ring arc magnets
  - high-field, cost-effective, dealing with beam loss
  - integrated study with loss team (shielding, optics, cooling)

- Final quadrupoles
  - high-field, large aperture, limit luminosity

- Target solenoid
  - large aperture, high-field, high radiation area, machine protection

- 6D cooling solenoids
  - high-field, robust, cost-effective, integration in cooling cell

- Other magnets

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Example: Collider Ring Magnet Shielding

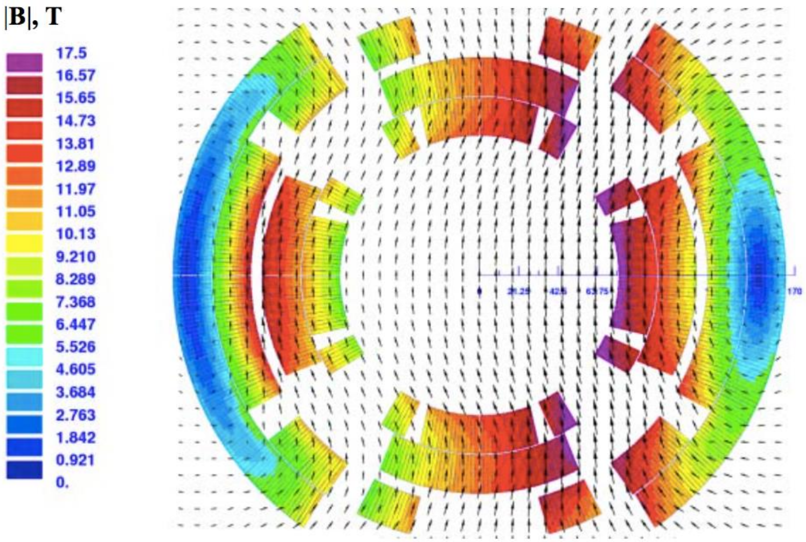
Need **minimum field-free distance** between magnets and **combined function magnets** to minimise neutrino radiation by minimising the path with no bending

High field dipoles to minimise collider ring size and maximise luminosity

Need to protect from O(400 W/m) **beam loss**

- 1/3 of beam energy
- large aperture and shielding
    - 150 mm in MAP at 3 TeV, 30-50 mm shielding
- open mid-plane magnets can be considered (but still some power lost in magnets)
- efficient cooling
- consider collimators to localise losses

Combined function magnet design



V.V. Kashikhin et al.

Design Choice Examples

- Two options for high-energy accelerator (FFA and RCS)
  - RCS depends on fast-ramping magnets and energy recovery
  - FFA needs high-field magnets and lattice design
    - typically low effective bending field
  - Need enough maturity of both designs to compare
  - The ring is probably the most costly system of the collider

- Accelerator RF frequencies and design

- Collider ring arc dipoles
  - Open midplane or large aperture to deal with radiation
  - Technology choice for 3 and 14 TeV

- Beam parameters all along the collider

- Muon source

- …

Physics and Detector

Physics at 10+ TeV is in uncharted territory

- need important effort, theorists are motivated

Explore what can be done to develop physics case, also in comparison to other options

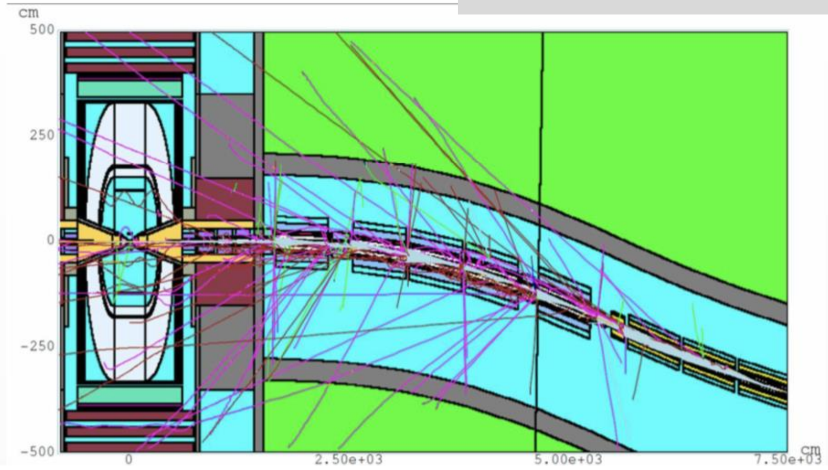
Need to include realistic assumptions about the detector performance

- use synergies with technologies that will be developed for other detectors
- identify additional needs for muon collider

Main detector challenge in machine detector interface (MDI)

At 14 TeV: 40,000 muons decay per m and bunch crossing
At 3 TeV: 200,000 muons per m and bunch crossing

D. Lucchesi et al.



Detector must be designed for robustness

- effective masking
- high granularity
- fast timing
- clever algorithms

Detailed design of machine is required for this

Some Collaboration Discussions (Machine)

France

- CEA: RCS accelerator ring, RF, high-field solenoid
- CNRS: GUINEA-PIG, maybe wandering snake with Annecy

UK

- Cooling, FFAGA, (final focus), could do some source work

Germany

- KIT, Darmstadt, magnets, cooling
- Rostock: high-energy acceleration, MPI: muon cooling
- DESY waiting for discussion

Italy

- INFN: MDI, collective effects, magnets, targets, LEMMA

Switzerland

- beam-beam (EPFL), some more interest to be discussed

Spain

- some interest in the physics, need to follow up on machine

Sweden, Norway

- Uppsala some interest (proton complex), ESS would require add. funding, Oslo

Austria

- some interest in physics, student on machine

US

- SLAC, JLAB, providing old design files

Sorry to have started mainly in Europe
CERN is going to be reorganised …
Need to discuss with other regions

Meetings / Working Groups

Project meeting

- Includes physics, detector and machine
- Report about important progress in the project
- Present and discuss important decisions
- Half-day long
- Every few months
- Next one maybe end of October/beginning of November

Design meeting

- Follow the overall design of the accelerator facility
- Facilitate contacts between all accelerator activities
- Allow to have technical discussions in a common timeslot
- Specialised accelerator and technology working groups will report here
- Timeslot Monday 16:00 CET
- Weekly/biweekly
- Typically one main subject, but also short news

Specialised working groups

- Spawn in the design meeting, as needed
- Design the machine and its components
- Organise their meetings according to the preferences of their members

Accelerator Themes/Working Groups

- **MDI**
- **High-energy complex**
- **Muon cooling**
- **Target area**
- **Proton complex**
- **LEMMA specific activities**
  - generally integrate with other working groups (e.g. targets)
  - LEMMA is an alterative

- **Magnets (and power converters)**
- **RF (normal and superconducting)**
- **Targets, shielding, collimation, vacuum, cooling, …**
- **Technologies: Exploratory technology review: Instrumentation, beam transfer, …**

- **Beamdynamics, simulation codes, …**
- **Layout, environment, infrastructure**

First Meetings

Date	Subject	Comment
21.09.	MDI, experimental insertion and collider ring	Youri Alexahin passed away
24.09.	Muon cooling	replacing 28.09.
28.09 ?	Magnets	Topical technical meetings to allow starting to (informally) agree on distribution of work; should help submitting funding proposals
?	Superconducting RF	
?	Targets	
5.10.	High-energy acceleration	

More to come:
High energy collider arcs
Target and capture area
Proton complex

Mailing Lists

Dedicated mailing lists for specialised meetings

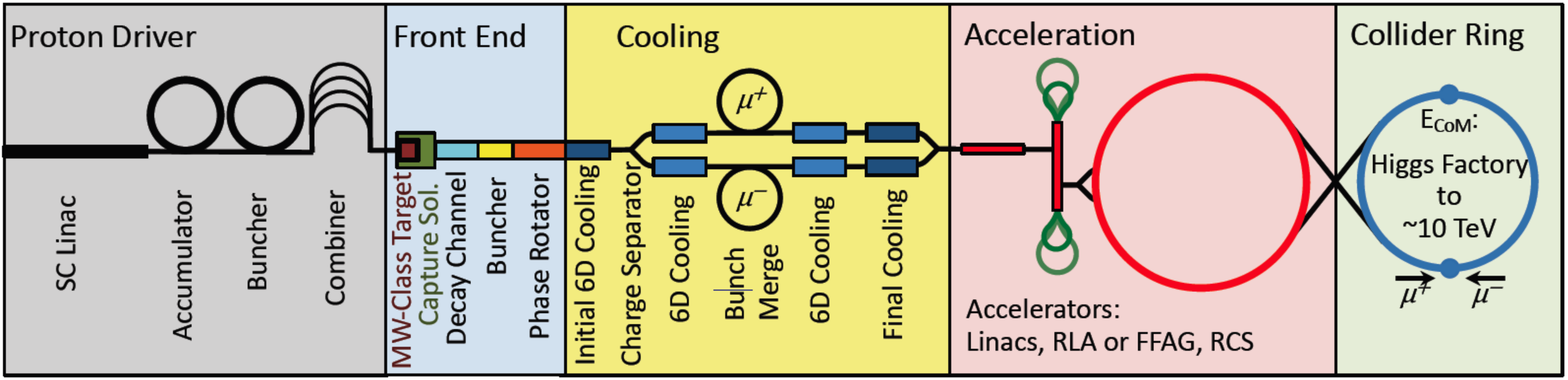
Please register for the mailing lists interesting for you
- Go to http://e-groups.cern.ch/
- Sign in with your institute (you find a list at the bottom of the sign-in page)
- Then search for “muoncollider”
- In the line “muoncollider-yourinterest” hit the subscribe button.

You can also unsubscribe in the same way (the button will be labeled “unsubscribe” if you are on the list).

Currently we have
- Cooling complex
- high-energy complex
- Magnets
- RF
- Particle interaction with matter: target, shielding etc.

Will put up the other mailing lists

High-energy Complex

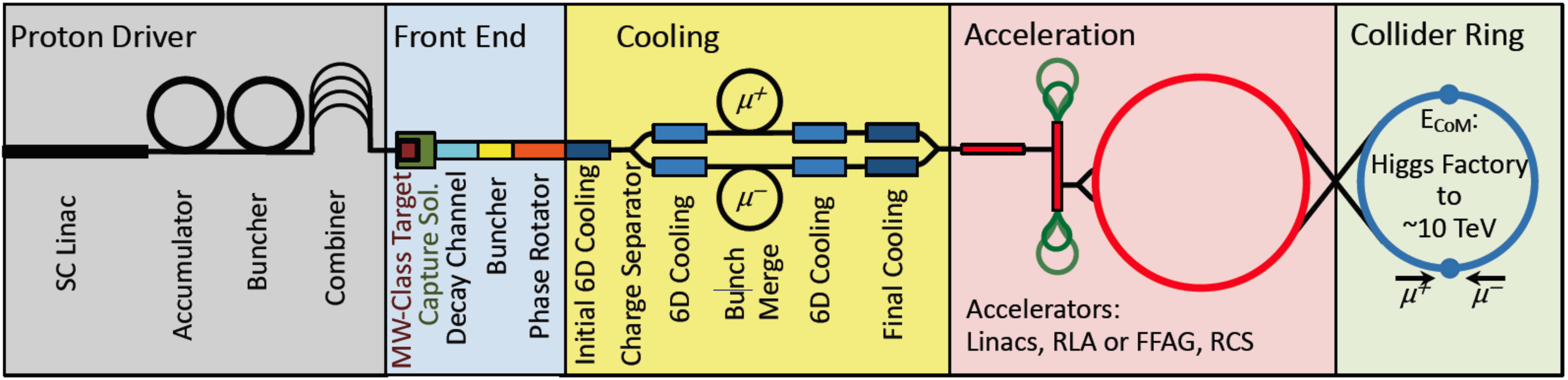


Areas
- Initial acceleration
- FFA
- RCS
- Recirculating linac
- Collider ring
- Experimental insertion

Technologies
- Accelerating RF (all acceleration)
- Fast ramping magnets (RCS)
- Power converters for fast-ramping magnets (RCS)
- FFA magnets (FFA)
- Collider ring arc magnets (combined function, high losses)
- Protection of magnets, vacuum, shielding, neutrino radiation

Seems logical to combine first:
Radiation problem worst in collider but also relevant in accelerator
RF worst in accelerator but also relevant for collider
…

Muon Cooling



Areas

- initial cooling
- 6 D cooling stages
- bunch merge
- final cooling

Review MAP design and optimise it

- some technology performance better than expected
- final cooling did not reach emittance target
- any emittance reduction makes machine better

Technologies

- RF
- magnets
- targets
- …

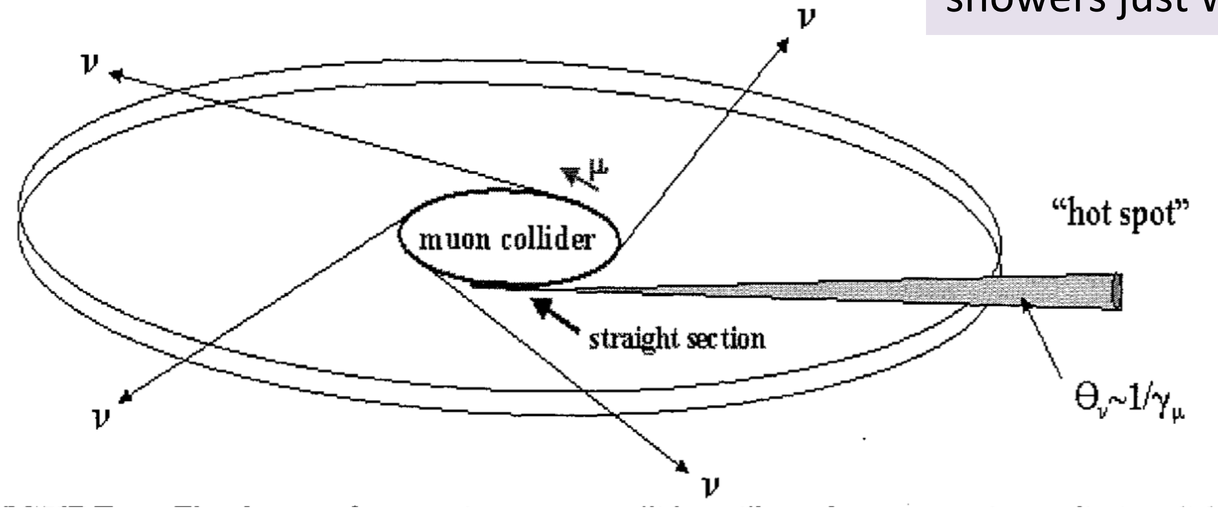
Conclusion

- Go through subjects in design meeting
  - spawn dedicated working groups as required
- First meeting of key technologies soon
- Plan first project meeting
  - maybe in November?
- Prepare IRAP
  - to propose R&D priorities and scope
  - provide also input to the LDG, which will develop a roadmap

Reserve

Note: Neutrino Radiation Considerations

Neutrinos from decaying muons can produce showers just when they exit the earth



Particularly bad in direction of straights
Mitigated by owning the land at exit

But also an issue in the arcs

Becomes more important at higher energies (scaling E^3)

US study concluded that 6 TeV parameters are OK

Reasonable goal maybe 0.1 mSv/ year, but has to be verified

For 1.5 + 1.5 TeV 40 m depth is required for arcs

LHC effective depth is 23 m in worst direction

For 7 + 7 TeV 500 m depth requires factor 8 improvement