Synergy of US and International Muon Collider Collaboration

Daniel Schulte and Mark Palmer for the Muon Beam Panel

Introduction

The MAP collaboration in the US has been developing the muon collider

- also with MICE in the UK as an experimental demonstration

But the support faded with the last P5 process

In Europe the interest grew with the last strategy update for particle physics

- Led to initiation of International Muon Collider Collaboration
- and to integration of muon collider in European Accelerator R&D Roadmap
- Hope now that also the US and others will join
  - after the P5, but at some level before

Since 2021, CERN provides a budget for the muon collider

- not at the level as for CLIC or AWAKE

So a slightly funny situation

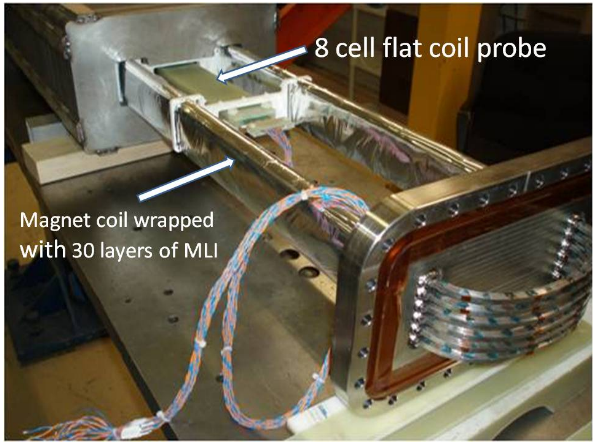
- US is still ahead in expertise
- But we can (start) working on the muon collider
- However makes integration of new and old efforts probably easier

Illustration: US and UK Technologies

FNAL
12 T/s HTS
0.6 T max

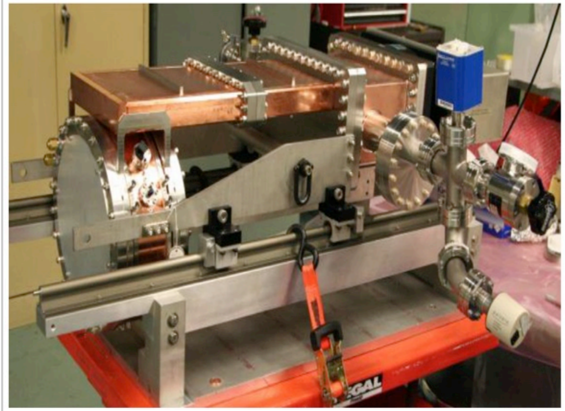
now 290 T/s

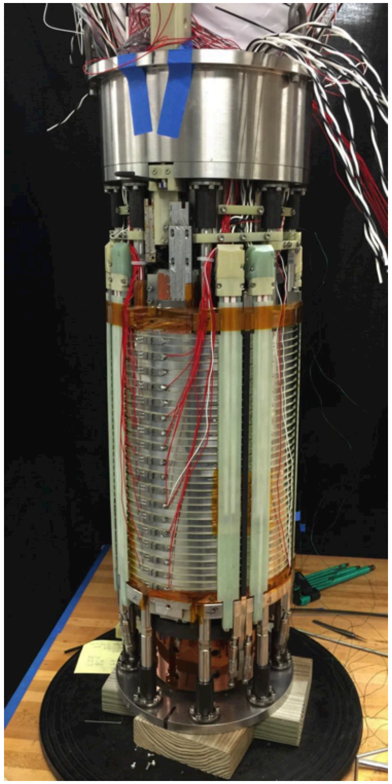
Test of **fast-ramping normal-conducting magnet** design



MuCool: >50 MV/m in 5 T field

Two solutions
- Copper cavities filled with hydrogen
- Be end caps

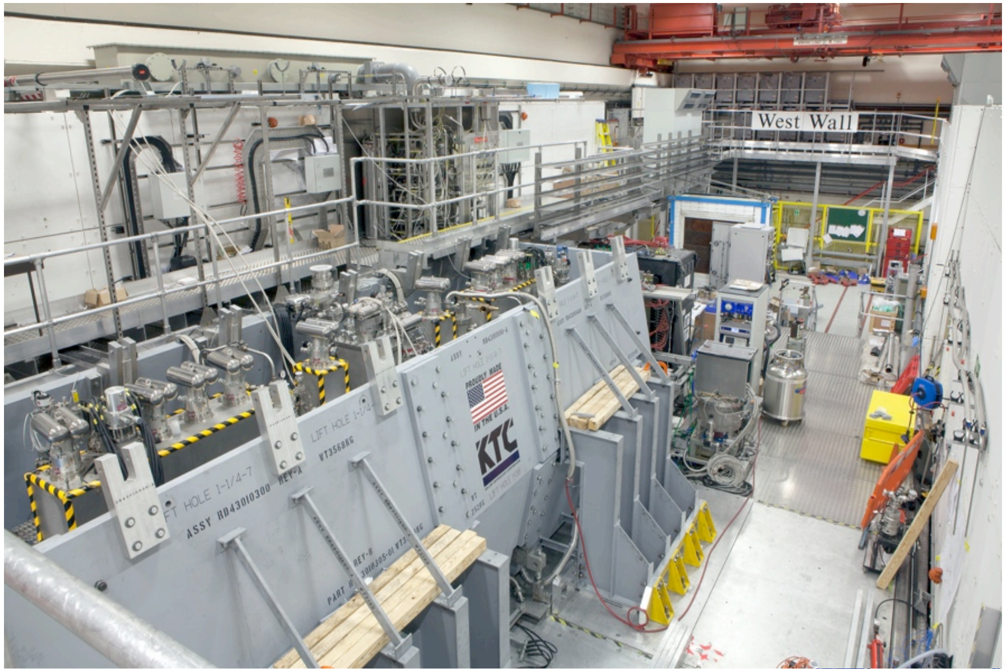




NHFML
32 T solenoid
with HTS

Planned efforts
to push even
further

MICE (UK) Muon cooling principle



International Muon Collider Collaboration

Initiated:

By the Laboratory Directors Group (LDG) that represents large European Laboratories
LDG has been approved by CERN Council
But international collaboration, using European planning process as a tool

Goal

In time for the next European Strategy for Particle Physics Update, aim to **establish whether the investment into a full CDR and a demonstrator is scientifically justified** Will also provide the input for other strategy process, in particular next Snowmass/P5

Scope

- Focus on two energy ranges:
  - **3 TeV**, if possible with technology ready for **construction in 15-20 years**
  - **10+ TeV**, with more advanced technology, **the unique potential of the muon collider**
- Explore synergies (neutrino facility/higgs factory)
- Define **R&D path**

Scope will be adjusted according to the need of the collaborators

- e.g. a site filler in the US

International Muon Collider Collaboration

International MUON Collider Collaboration

Muon Collider Study

Memorandum on Cooperation
for the Muon Collider (MC) Study

THE INSTITUTES, LABORATORIES, UNIVERSITIES AND FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM ON COOPERATION AND CERN AS THE HOST ORGANIZATION **("**the Participants**")**

Whereas

If you can, please sign the MoC (you can contact me or Alexia)

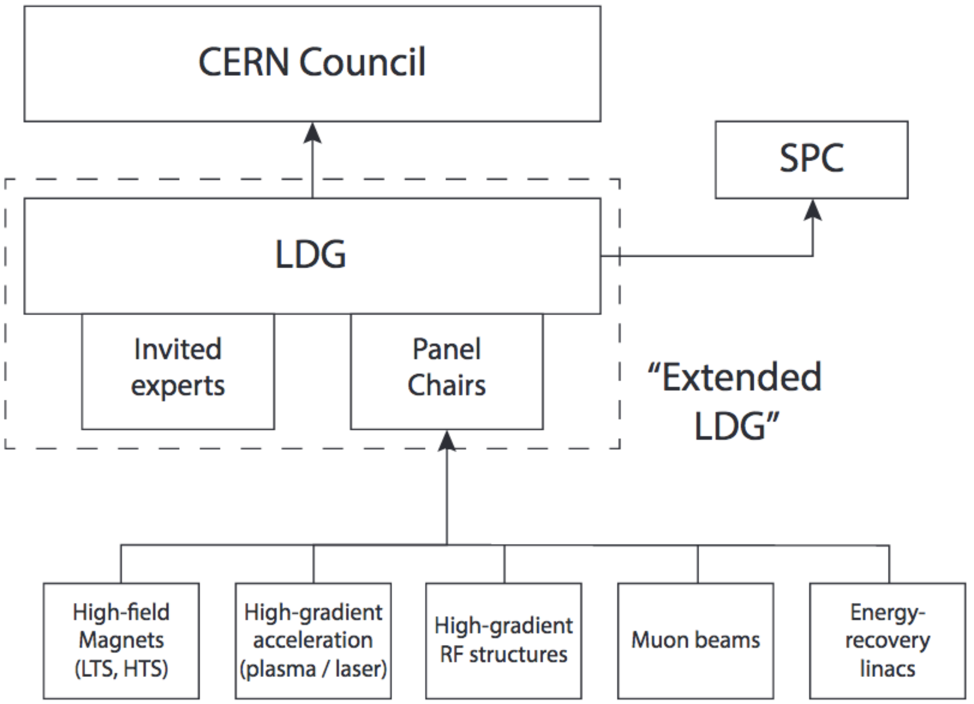
If not, we are preparing how you can still participate to the collaboration board but with no voting rights (in principle foreseen in MoC)

- But need clear way to be in or not

Best effort and not legally binding

European Accelerator R&D Roadmap

CERN Council charged Laboratory Directors Group (LDG) to deliver European **Accelerator R&D Roadmap** by the end of 2021



Panels

- Magnets: P. Vedrine
- Plasma: R. Assmann
- RF: S. Bousson
- Muons: D. Schulte
- ERL: M. Klein

Muon Beam Panel members: Daniel Schulte (CERN, chair), Mark Palmer (BNL, co-chair), Tabea Arndt (KIT), Antoine Chance (CEA/IRFU) Jean-Pierre Delahaye (retired), Angeles Faus-Golfe (IN2P3/IJClab), Simone Gilardoni (CERN), Philippe Lebrun (European Scientific Institute), Ken Long (Imperial College London), Elias Metral (CERN), Nadia Pastrone (INFN-Torino), Lionel Quettier (CEA/IRFU), Tor Raubenheimer (SLAC), Chris Rogers (STFC-RAL), Mike Seidel (EPFL and PSI), Diktys Stratakis (FNAL), Akira Yamamoto (KEK and CERN)
Contributors: Alexej Grudiev (CERN), Donatella Lucchesi (INFN-Padua), Roberto Losito (CERN), Andrea Wulzer (EPFL, CERN, Padua)

Roles of panel members and contact persons at https://muoncollider.web.cern.ch/organisation

Accelerator R&D Roadmap

- Aimed at CERN Council and European funding agencies
  - has importance beyond CERN as a laboratory

- A strong link exists between the interim collaboration and the muon beam panel
  - **the panel aimed beyond Europe**

- Muon collider evaluation and work programmes are based on community meeting and panel expertise spelled out challenges and status

- Identified work to be done and specified two scenarios (request from LDG) to address them
  - The aspirational programme contains basically all that the working groups identified
  - Aimed to have a minimal programme to be 2-3 times larger than the CERN contribution
  - Hard to define the border
  - We decided to spell out the aspirational programme and mark what is missing in the minimum programme
  - The minimum is a reduction of our ambition
    - but still do not yet have all the resources in place

- **Should be considered seed of global talk**

https://arxiv.org/ftp/arxiv/papers/2201/2201.07895.pdf

Community Working Group Convener

Conveners list

Radio-Frequency (RF): Alexej Grudiev (CERN), Jean-Pierre Delahaye (CERN retiree), Derun Li (LBNL), Akira Yamamoto (KEK).
Magnets: Lionel Quettier (CEA), Toru Ogitsu (KEK), Soren Prestemon (LBNL), Sasha Zlobin (FNAL), Emanuela Barzi (FNAL).
High-Energy Complex (HEC): Antoine Chance (CEA), J. Scott Berg (BNL), Alex Bogacz (JLAB), Christian Carli (CERN), Angeles Faus-Golfe (IJCLab), Eliana Gianfelice-Wendt (FNAL), Shinji Machida (RAL).
Muon Production and Cooling (MPC): Chris Rogers (RAL), Marco Calviani (CERN), Chris Densham (RAL), Diktys Stratakis (FNAL), Akira Sato (Osaka University), Katsuya Yonehara (FNAL).
Proton Complex (PC): Simone Gilardoni (CERN), Hannes Bartosik (CERN), Frank Gerigk (CERN), Natalia Milas (ESS).
Beam Dynamics (BD): Elias Metral (CERN), Tor Raubenheimer (SLAC and Stanford University), Rob Ryne (LBNL).
Radiation Protection (RP): Claudia Ahdida (CERN).
Parameters, Power and Cost (PPC): Daniel Schulte (CERN), Mark Palmer (BNL), Jean-Pierre Delahaye (CERN retiree), Philippe Lebrun (CERN retiree and ESI), Mike Seidel (PSI), Vladimir Shiltsev (FNAL), Jingyu Tang (IHEP), Akira Yamamoto (KEK).
Machine Detector Interface (MDI): Donatella Lucchesi (University of Padova), Christian Carli (CERN), Anton Lechner (CERN), Nicolai Mokhov (FNAL), Nadia Pastrone (INFN), Sergo R Jindariani (FNAL).
Synergy: Kenneth Long (Imperial College), Roger Ruber (Uppsala University), Koichiro Shimomura (KEK).
Test Facility (TF): Roberto Losito (CERN), Alan Bross (FNAL), Tord Ekelof (ESS,Uppsala University).

Workpackage Overview

Label	Begin	End	Description	Aspirational [FTEy]	Aspirational [kCHF]	Minimal [FTEy]	Minimal [kCHF]
MC.SITE	2021	2025	Site and layout	15.5	300	13.5	300
MC.NF	2022	2026	Neutrino flux mitigation system	22.5	250	0	0
MC.MDI	2021	2025	Machine-detector interface	15	0	15	0
MC.ACC.CR	2022	2025	Collider ring	10	0	10	0
MC.ACC.HE	2022	2025	High-energy complex	11	0	7.5	0
MC.ACC.MC	2021	2025	Muon cooling systems	47	0	22	0
MC.ACC.P	2022	2026	Proton complex	26	0	3.5	0
MC.ACC.COLL	2022	2025	Collective effects across complex	18.2	0	18.2	0
MC.ACC.ALT	2022	2025	High-energy alternatives	11.7	0	0	0
MC.HFM.HE	2022	2025	High-field magnets	6.5	0	6.5	0
MC.HFM.SOL	2022	2026	High-field solenoids	76	2700	29	0
MC.FR	2021	2026	Fast-ramping magnet system	27.5	1020	22.5	520
MC.RF.HE	2021	2026	High Energy complex RF	10.6	0	7.6	0
MC.RF.MC	2022	2026	Muon cooling RF	13.6	0	7	0
MC.RF.TS	2024	2026	RF test stand + test cavities	10	3300	0	0
MC.MOD	2022	2026	Muon cooling test module	17.7	400	4.9	100
MC.DEM	2022	2026	Cooling demonstrator design	34.1	1250	3.8	250
MC.TAR	2022	2026	Target system	60	1405	9	25
MC.INT	2022	2026	Coordination and integration	13	1250	13	1250
			Sum	445.9	11875	193	2445

Table 5.5: The resource requirements for the two scenarios. The personnel estimate is given in full-time equivalent years and the material in kCHF. It should be noted that the personnel contains a significant number of PhD students. Material budgets do not include budget for travel, personal IT equipment and similar costs. Colours are included for comparison with the resource profile Fig. 5.7.

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Workpackage Overview

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Roadmap Deliverables

Three main deliverables are foreseen:

- a Project Evaluation Report that assesses the muon collider potential as input to the next ESPPU; (Note since this is a European document we have to deliver end of 2025. However, we want to feed into all relevant processes)
- an R&D Plan that describes a path towards the collider;
- an Interim Report by the end of 2023 that documents progress and allows the wider community to update their view of the concept and to give feedback to the collaboration.

[..] The availability of the Interim Report will coincide with the expected time when the strategy process in the US will arrive at its conclusion.

Project Evaluation Report

The **project evaluation report** will contain an assessment of whether the 10 TeV muon collider is a promising option and identify the required compromises to realise a 3 TeV option by 2045. In particular below would be addressed.

- What is a realistic luminosity target?
- What are the background conditions in the detector?
- Can one consider implementing such a collider at CERN or other sites, and can it have one or two detectors?
- What are the key performance specifications of the components and what is the maturity of the technologies?
- What are the cost drivers and what is the cost scale of such a collider?
- What are the power drivers and what is the power consumption scale of the collider?
- What are the key risks of the project?

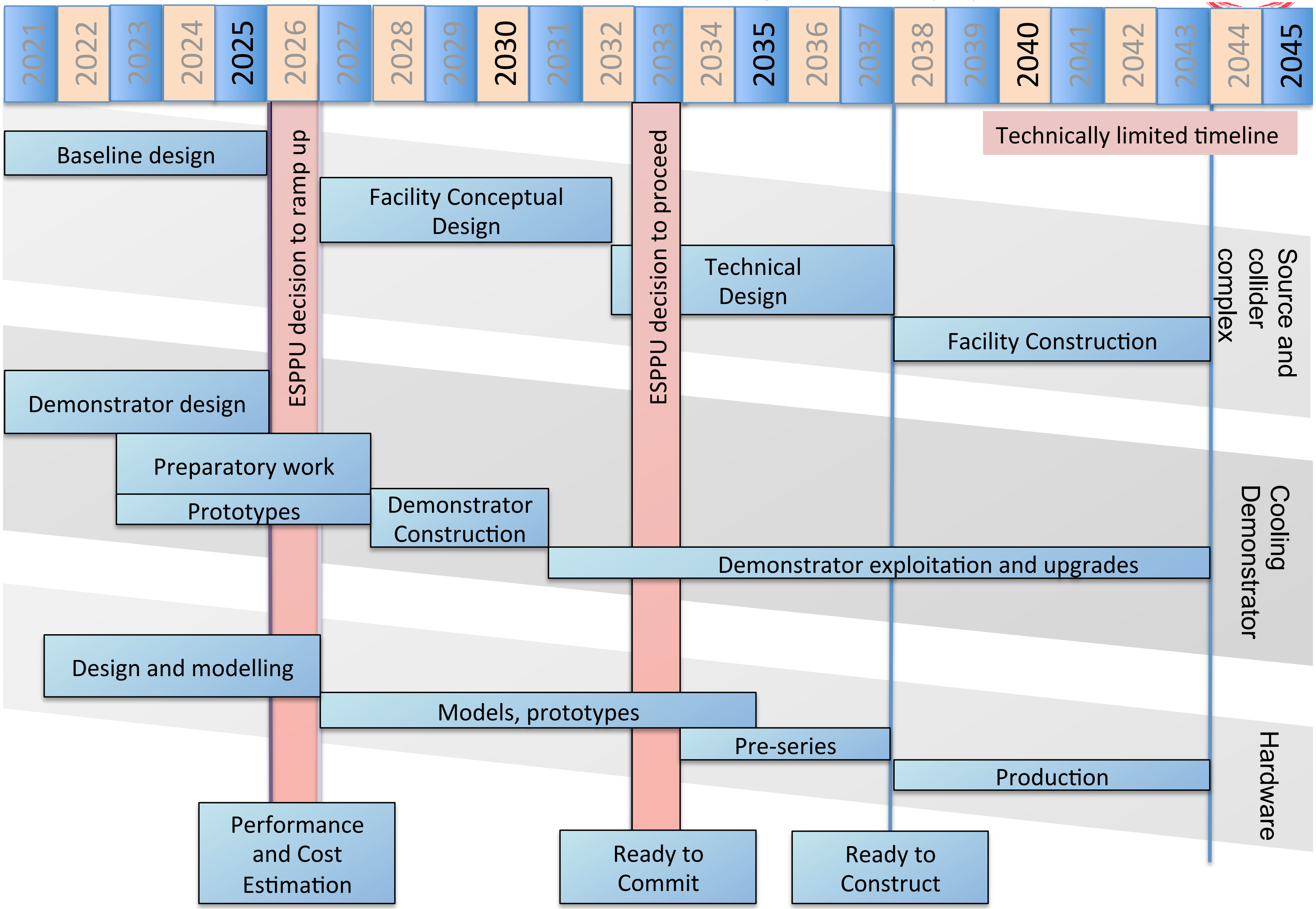
Timeline Discussions

Tentative Target for Aggressive Timeline

to assess when 3 TeV could be realised, assuming massive ramp-up in 2026

In Europe:
if higgs factory
built elsewhere

Fastest timeline
for all regions



Short-term Timeline

International MUON Collider Collaboration

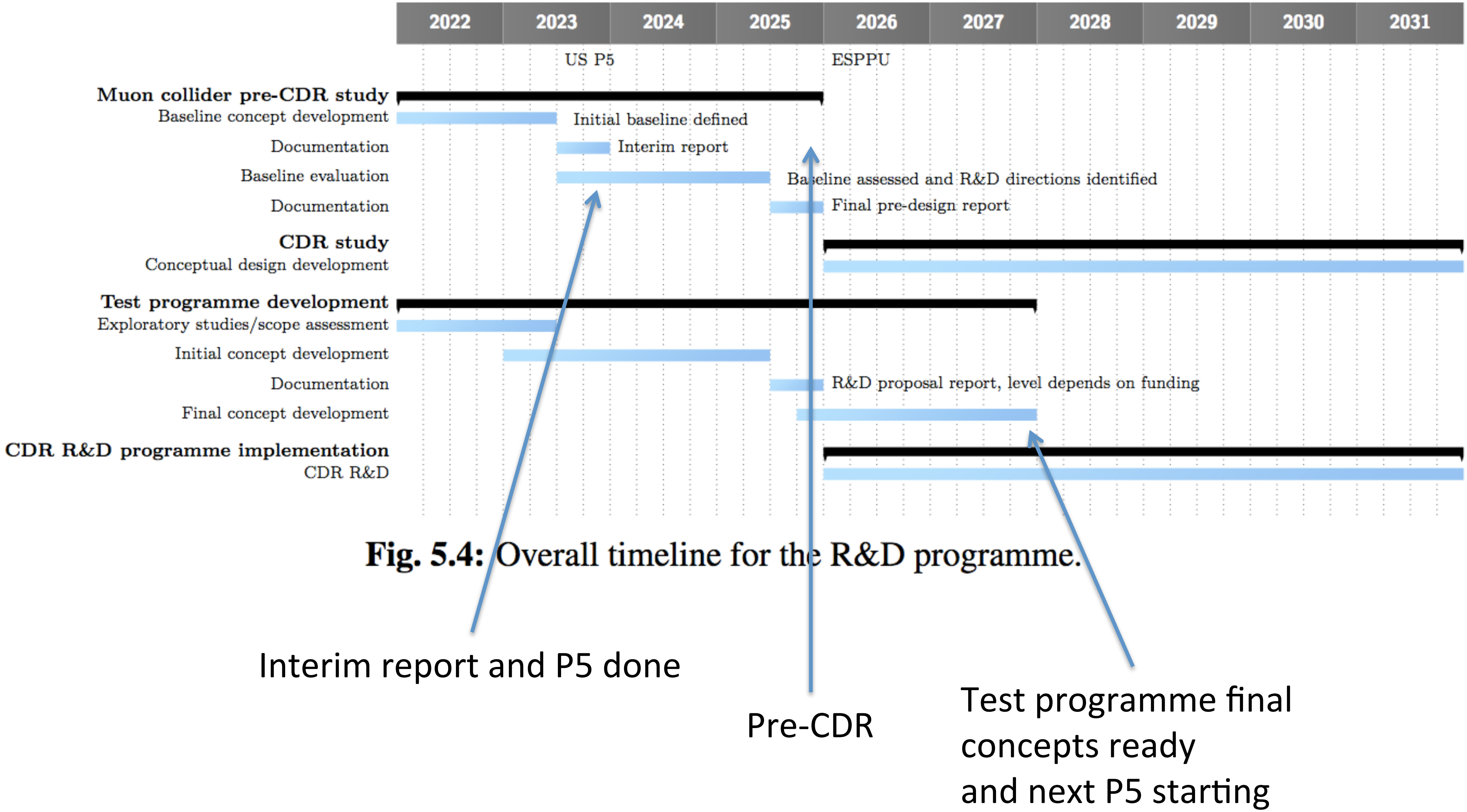


Fig. 5.4: Overall timeline for the R&D programme.

D. Newbold

LDG Recommendations

- The Roadmap is the consensus view of the community (but many detailed planning decisions are yet to come)
- Governance structures should be put in place, spanning the R&D programmes; CERN Council is the ultimate arbiter
- We should maintain a broad front -> at least the minimal programmes in each area
- Retain the capability for blue skies R&D
- Continuity of funding is more important than maximal funding; investments must be supported
- Sustainability is now a driving factor; plan in light of this
- Early science output (and impact) from the R&D is highly desirable; plan in light of this
- We need to work with industry closely, and in ways that they can accommodate
- Close and organised cooperation between major labs internationally is needed to facilitate the programme
- Trained people are the lifeblood and future of the field – ensure the supply

D. Newbold

Next Steps: Implementation

- R&D landscape is a complex mix
  - Some already-approved or ongoing projects
  - Some basic R&D areas that perhaps so far 'missed'
  - Some aspirational elements
  - Some things made possible only by external investments (plasma, ERL)
- Oversight and governance is clearly necessary
  - To ensure the R&D stays on track with the European Strategy goals
  - To provide a reporting line to CERN Council (and to give FAs confidence)
  - To scrutinise and peer-review concrete plans and proposals where needed
- Council has extended the mandate of LDG and ECFA
  - We are request to report at March Council with a implementation plan
  - This may necessarily involve some initial aspects of prioritisation
  - Several questions under active discussion now
    - What is the 'standard collaboration model' of R&D activities (MC is one example…)
    - Which are the governing bodies, and how can objectivity be ensured?
    - Should the accelerator and detector R&D be treated together or separately?
    - What is the distinct role of 'host laboratories' outside CERN in both R&D programmes?

UKRI Science and Technology Facilities Council

Next Steps

Prepare our plan with LDG and the partners, hope you can help us
Move from Muon Beam Panel to Collaboration

Also will are preparing proposal for EU co-funding

Contribute as IMCC to the Snowmass process

- General papers (Will set up a mechanism to collect names)
  - Muon collider potential
  - Muon collider accelerator complex (AF4)
- Specific papers (specific authors):
  - Muon collider potential at 3 TeV
  - Muon collider detector studies

Accelerator paper editors:
Mark Palmer, Tor Raubenheimer (tbc), Diktys Stratakis (tbc), Vladimir Shiltsev (tbc), Nikolai Mokhov (tbc), Akira Yamamoto, Jingyu Tang, Nadia Pastrone, Chris Rogers, Daniel Schulte

Will use material from Roadmap

Andrea and Donatella will propose similar structure for physics potential paper

US Effort Synergy

US has all the expertise required for the muon collider

- Actual has been leading the field
- We still use most the results as basis for our plans

⇒ Could help in any field

⇒ Your help would be welcome in any field because resources are stretched in all areas

⇒ But certainly some fields have more needs

However assume that only areas of contributions need to be identified now and the details will be defined later in the strategy process

Assume that dedicated specific effort in US is very limited until end of 2023

But could aim for collaborative efforts before

⇒ Probably focus on technologies and individual components that have high synergy (magnets etc.)

⇒ Actually for the next two years happy to have the support from experts ton ensure that we define performance specifications that are realistic goals

Hopefully, after the P5 we can then go full speed ahead

Key Challenge Areas

10+ TeV is uncharted territory

- **Physics potential** evaluation, including d**etector concept and technologies**
- Impact on the environment
  - The **neutrino flux mitigation** and its impact on the site (first concept exists)
- The impact of **machine induced background** on the detector, as it might limit the physics reach.
- **High-energy systems** after the cooling (acceleration, collision, …)
  - Fast-ramping magnet systems
  - High-field magnets (in particular for 10+ TeV)
- **High-quality muon beam production**
  - Special RF and high powering systems
  - Superconducting solenoids
  - Cooling string demonstration (cooling cell engineering design, demonstrator design)
  - Full power target demonstration
- **Proton complex**
  - H- source, compressor ring

“Educated Guess” of Vladimir, with comments

- Theory and MDI work – with EF and TF
  - We need to strengthen this key area
- Machine design: optics and beam physics issues, incl. ~~neutrino hazard and~~ neutrino flux mitigation
  - Neutrino flux impact benchmarking, impact on beam operation and technologies are common
  - All lattice designs can be common for all energies, with exception of last accelerator and collider rings
  - Could find a very efficient setup
- Proton driver accumulator and bunch compressor design – synergy with post-PIPII FNAL complex
  - Would appreciated help in proton complex design for the collider in collaboration with ESS
- Muon cooling IMCC magnet, RF & diagnostics design work
  - We have tasks for each technology and we plan to design a muon cooling module for the test facility
  - also have to work on absorbers (including windows)

“Educated Guess” of Vladimir, with comments

International MUON Collider Collaboration

- Muon acceleration RF – simulations and exp test beam loading in ILC-type cavities at FNAL FAST
  - we are looking into beam loading effects, tests are good, should consider other frequencies when possible
- Muon acceleration fast cycling 500-1000 T/s HTS magnet prototypes
  - should also consider field range, normal conducting magnets are also critical (10kT/s)
- 12-16 T dipoles design and tests, incl. mechanical tilt – synergetic with the US MDP
  - Yes. should also consider NbTi for 3 TeV and HTS for 10 TeV. Is 20 T feasible?
  - I guess mechanical tilt is neutrino flux mitigation? Very important.
- 2-4 MW proton target design and development – with GARD targets
  - a number of technologies to be considered: graphite, fluidized tungsten, liquid metal, …
- MC Target magnet design - synergetic with IMCC
  - in particular the shielding and the stress are important
- Final cooling solenoids design and HTS short magnets tests – synergetic with US MDP
  - yes

"Educated Guess" of Vladimir, with comments

International MUON Collider Collaboration

- Final focus quadrupoles – design extension beyond US LARP/LHC AUP
  - yes
- (Later) compile (pre-) CDR, come up with semi-engineering "bottom-to-top" cost estimates O(50%) range for a) various options of high energy MC; b) objecvtives, cost and timeline of the post-CDR US MC R&D program 2030-2036
- Do you consider test facility in US? Shall there be one common effort for test facilities or one per site?
- We need a new test stand for the muon cooling RF (magnetic field is unique, CEA might go for one in the long run))
- Targets and absorbers require experimental work
- Need also to include other fields of expertise
  - cryogenics, vacuum, …
- May need to think how we can prepare cost estimate for efficient use in all regions

Physics Potential

- Making the physics case
  - proving that the collider is useful
  - at different energy stages
  - considering other facilities

- Detector and MDI
  - proving that we can realise the physics potential
  - detector performance requirements
  - technologies
  - dealing with background

There is plenty of room for contributions

- and we already see very important contributions

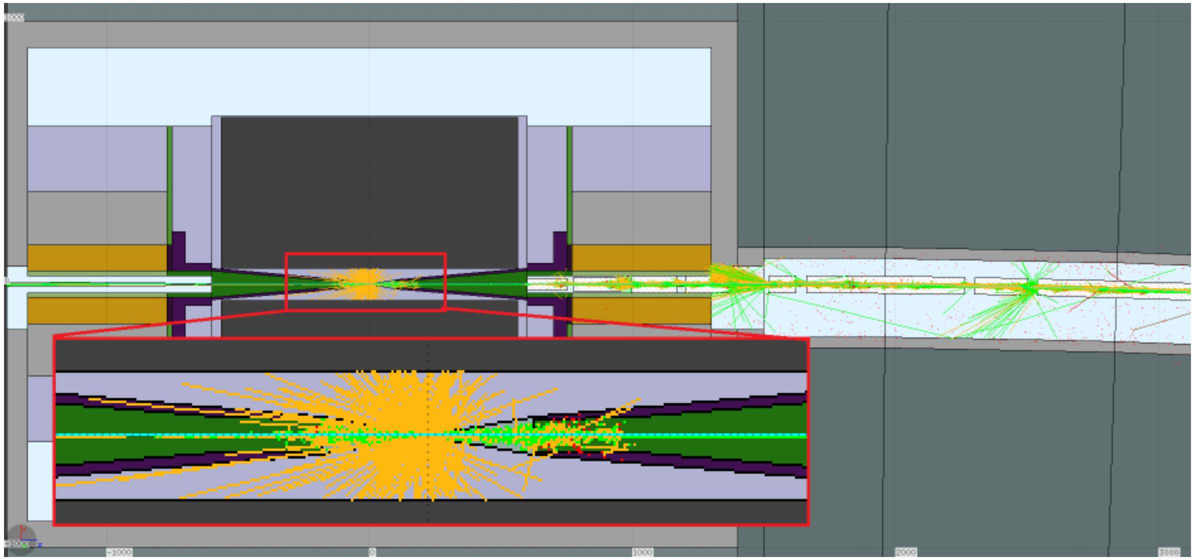
This is obviously for the global user community to develop

Should define one common forum for the theory, the detector and the technology

Machine Detector Interface

Main background sources

- Muon decay products (40,000 muons/m/crossing at 14 TeV)
- Beam-beam background
- Note: background reduces while beam burns off



Simulation tools for loss along beam line exist (D. Lucchesi et al.)

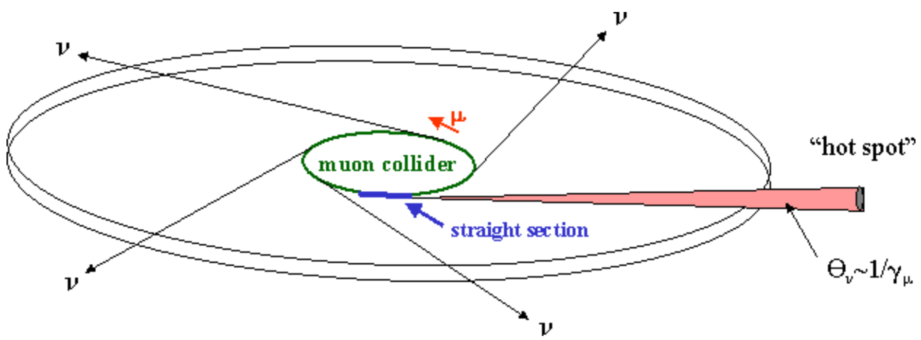
Will develop systems for higher energies

Tasks:

- Further develop the simulation tools to predict the background in the detector.
- Further develop the masking system to mitigate the background in the detector.
- Develop a tool to study the beam-beam background.
- Developing the interaction region lattice considering the impact on background.

Active common working group
but need more US support also on the physics study side
INFN and CERN are active, JAI is interested
Contact Donatella Lucchesi (INFN), Sergo Jindariani (FNAL)

Site



Key ingredient of site is neutrino flux
Goal is to reach impact levels similar to LHC

Tasks:

- Verify requirements and models of the impact of the neutrino flux.
- Assess whether the mechanical system to mitigate the neutrino flux from the arcs can fulfil legal requirements and the achieve the target flux level level.
- Verify that the system will not compromise the beam operation.
- Define the strategy to mitigate the neutrino flux from the experimental insertions.
- Develop a tool to identify the surface areas that would show neutrino radiation based on the lattice design.
- Identify a potential orientation of the collider ring considering neutrino flux and geology.
- Estimate the civil engineering cost scale.

CERN has to cover specific radiation protection issues for its site
Other potential hosts will have to do the same (e.g. FNAL?)

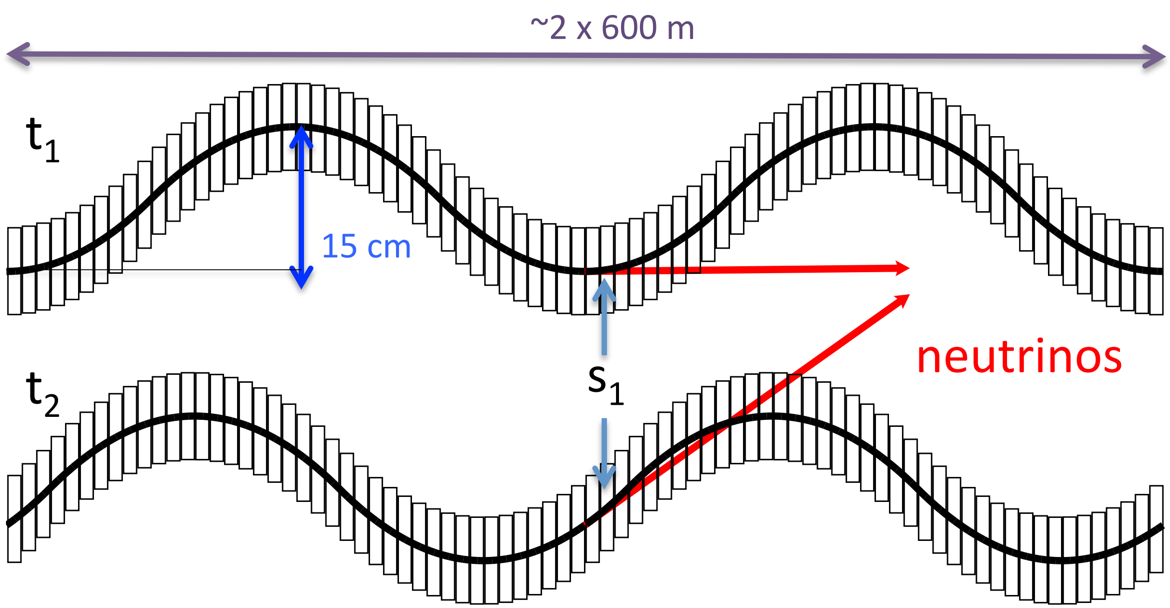
Benchmarking of codes requires US support
Verification of hardware and beam operation is common to all sites
Contact Claudia Ahdida (CERN), Christian Carli (CERN)

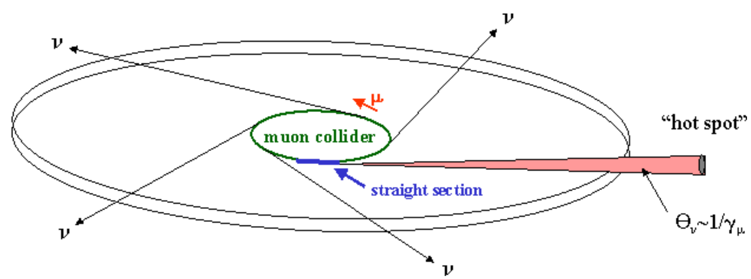
Neutrino Flux Mitigation System

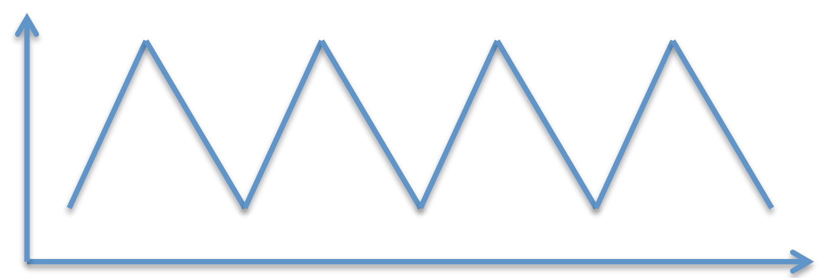
Tasks:

- Develop a concept of the mechanical flux mitigation system and of the alignment system required to control it. This includes high-accuracy, large stroke movers, alignment of the tunnel reference system to the surface and mechanical deformations and misalignments of the beam line components due to the movers

CERN has interest, but not clear that we will have the resources







Accelerator Design I

Tasks:

- A lattice for the experimental insertion and arcs of the collider ring addressing the key high-energy challenges
- A lattice for the arcs of the pulsed synchrotrons that accelerate the muon beam to full energy.
- A concept for the system of linacs that provide the initial acceleration after the muon cooling.
- A concept for the key systems of the proton complex, and in particular the systems that combine the bunches from the proton beam pulses into single, high-charge bunches.
- Assessment of the limitations arising from collective effects along the whole complex.
- Exploration of alternative concepts for muon and proton acceleration and the collider ring, in particular using FFAs.

Accelerator Design II

Tasks:

- An improved concept for the final muon cooling system, which failed to achieve the emittance target by a factor two in the MAP study.
- An improved and chained concept for the cooling systems before the final cooling, which achieve the largest emittance reduction factor.
- Exploration of alternatives for the final muon cooling.
- Consideration of the engineering aspects of the muon cooling module design and its impact on beam dynamics.
- Assessment of the limitations arising from collective effects along the whole complex.

Interest: CERN covers most of collider ring, UKRI-STFC for alternative optics, BNL for collider ring
Accelerators: BNL (FFA + RCS), CEA (RCS), IJCLab-In2p3 (RLA), JLAB (Linac), UKRI-STFC (FFA), RAL (cooling), ESS and Uppsala (protons)

US help would be welcome, in particular for initial linacs, alternatives and to complement European efforts
An area where discussions are extremely useful

Contact: Christian Carli (CERN) for collider ring, Antoine Chance (CEA) for acceleration, Chris Rogers (RAL) for muon cooling, Natalia Milas (ESS), Elias Metral (CERN) for collective effects

Fast-ramping Magnet Systems

Tasks

- Concept of powering system
- Concept of normal conducting magnet
- Test of magnetic material for fast ramping
- Design of alternative superconducting magnet
- Test of HTS cables for fast ramping

Normal and superconducting magnets have to be looked at

Obviously the US already is leading most of this

Can contribute in all those areas

Currently CERN contribution on power converters, maybe EPFL on material and magnet

Contact Luca Bottura (CERN)

Target System and Area

Tasks:

- Assessment of feasibility of the target, specifically:
- Development of a target concept:
- Design of the target including:
- The experimental programme:
- The development of a programme to demonstrate target performance in the CDR phase and beyond. This could use infrastructures at CERN or ESS. Or FNAL

Absolut

Contact Marco Calviani (CERN), Chris Rogers (RAL)

RF Systems

Tasks:

- A concept for the **normal-conducting accelerating** cavities of the muon cooling complex
  - only US developed them sofar
- A concept for the longitudinal beam dynamics and the RF systems in the high-energy muon beam acceleration complex, which uses superconducting cavities.
  - started some activity at CERN
- Design and construction of a test stand that allows measurement of the gradient and breakdown rate of the muon cooling cavities in a high magnetic field. (Only a cheap version reusing 3 T MICE solenoids and ESS klystrons at CEA is included.)
  - unfortunately the test stand at FNAL does not exist any more
- The cavity design for the test module.
- A powering system concept for the muon cooling and acceleration system. In particular, the muon cooling requires short, high-peak-power pulses, similar to the CLIC drive beam.

Contact Alexej Grudiev (CERN), Claude Marchand (CEA)

High-field Magnets

Tasks:

- Develop realistic target parameters for
  - target solenoid (20 T, large aperture)
  - 6D cooling solenoids (HTS?, 20-25 T)
  - final cooling solenoid (small bore, 50 T?)
  - collider ring magnets
- Cable tests and model design and testing (mainly for solenoids)
- Conceptual design of target solenoid

US is world-leading in this field

CEA, KIT have interest in solenoids, are contacting more partners

Toru Ogitsu (KEK-CERN) is interested in collider ring

Contact Luca Bottura (CERN) for details

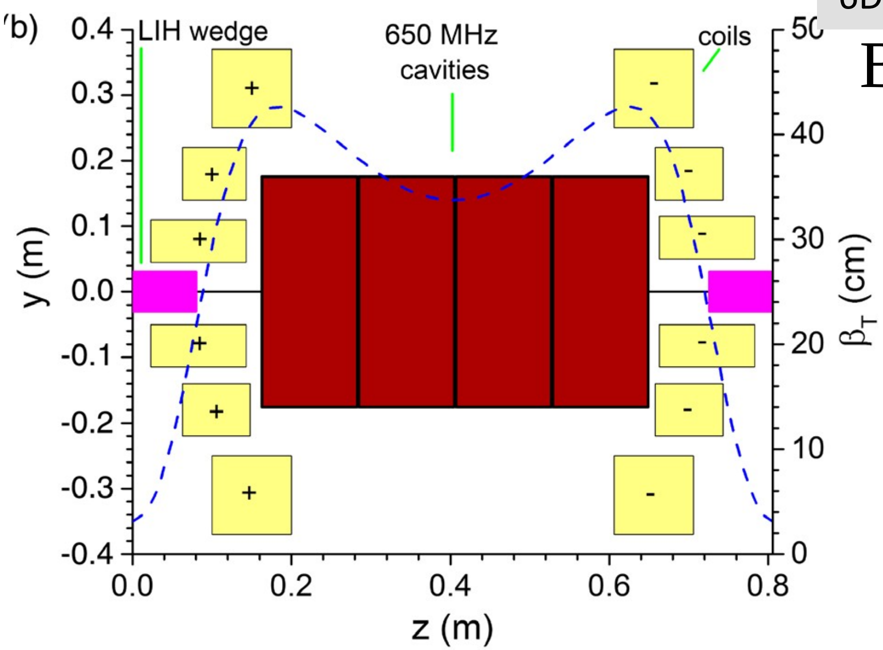
Muon Cooling Test Module

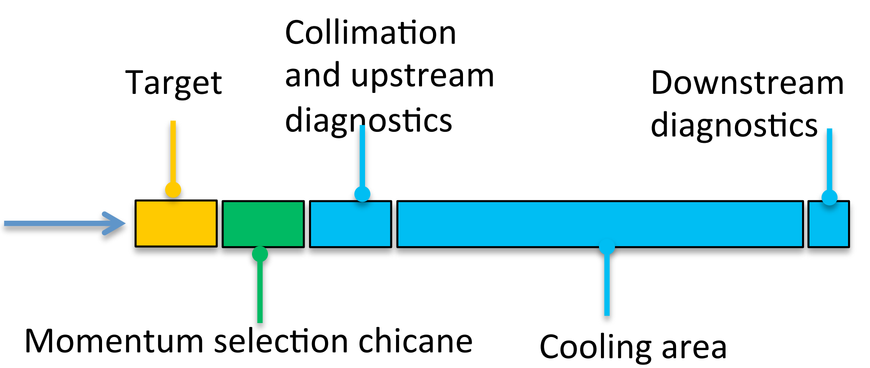
Tasks:

- Assessment of technological challenges of 6D cooling cell.
- Conceptual design of technical systems for 6D cooling cell:
  - mechanical engineering;
  - adaptation of RF design;
  - adaptation of magnet design;
  - cryogenics design;
  - vacuum design;
  - beam instrumentation.
- Integrated conceptual design of the 6D cooling cell.

All the design is from the US
Interest: INFN, STFC, CEA, CERN, US?

6D cooling





Contact: Roberto Losito (CERN)

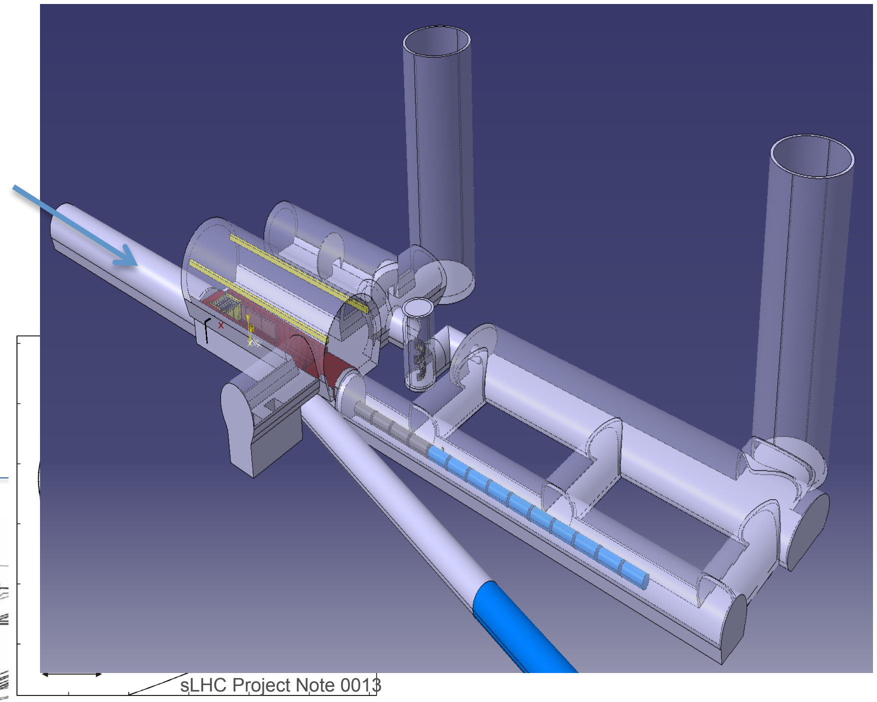
Demonstrator Facility

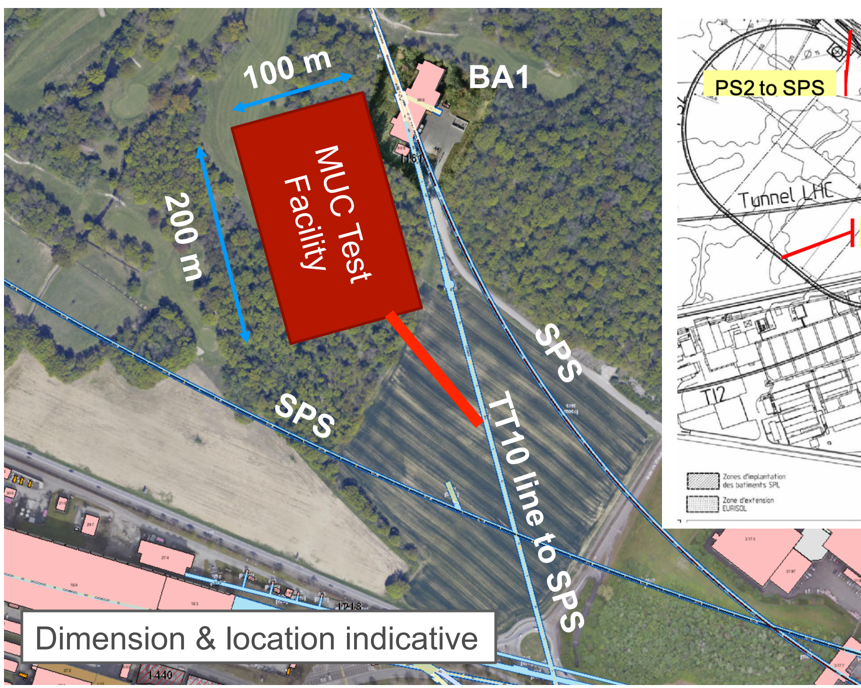
Planning demonstrator facility with muon production target and cooling stations

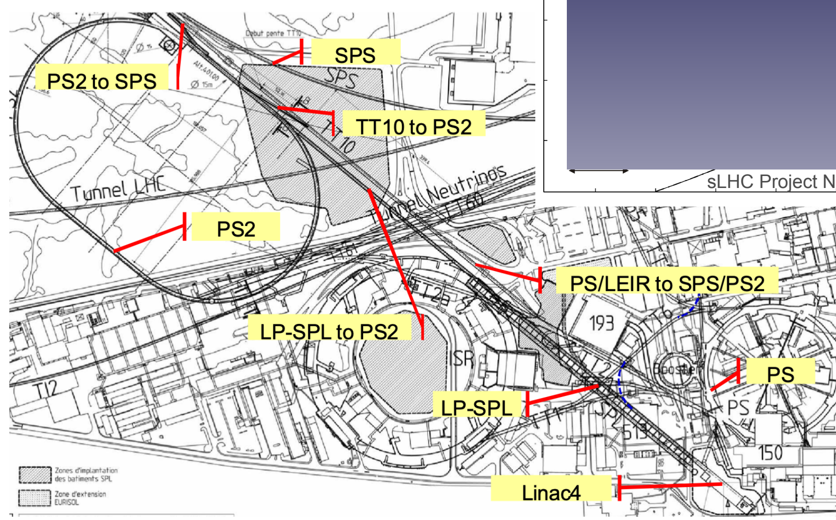
At least one suitable site on CERN land exists that can use existing proton infrastructure

Site studies will be local but demonstrator parts could be developed together

Welcome sites in other regions







sLHC Project Note 0013

M. Benedikt, LHC Performance Workshop, Chamonix 2010

CERN-AB-2007-061

Contact: Roberto Losito (CERN)

Conclusion

- Great potential for synergy exists
- How to best highlight this in the Snowmass process?
  - Contact persons to technologies?
  - Coordination of IMCC and Muon Forum white papers
- Please join the collaboration if you already can
  - If you cannot sign the MoC, we are defining how to still participate
  - Project meeting February 14-17 (https://indico.cern.ch/event/1108523/)
- Prepare collaboration on the expert level
  - have names for all areas (maybe send them to participants?)
  - some exploration of governance
- See how we can exploit technological synergies even before P5 ends
  - joining working groups and common workshops are a good start

https://muoncollider.web.cern.ch

Reserve

1. Purpose of this Memorandum

1.1. This Memorandum establishes a common basis among the Participants for the collaborative effort required for the execution of the MC Study. The MC Study and its results shall be used for peaceful purposes only.

1.2. By signing this Memorandum, the signatory becomes a Participant in the MC Study, together with the other institutes, laboratories, universities and their funding agencies who are, or who subsequently decide to become, Participants in the MC Study.

1.3. It is expressly acknowledged that, except for Articles 4.2, 4.3, 7, 9 and this Article, this Memorandum is not legally binding and each Participant's involvement in the MC Study is on a "best-efforts" basis. This Memorandum does not imply any commitment of resources. Each Participant's involvement in the MC Study is governed, as the case may be, by its internal policies and regulations and the laws to which it is subject.

2. Scope

2.1. At the date of conclusion of this Memorandum it is envisaged that the main emphasis of the MC Study shall be to establish whether the investment into a full Conceptual Design Report ("CDR") and demonstrator for a muon collider is scientifically justified. The MC Study shall provide a baseline concept for a muon collider, well-supported performance expectations and assess the associated key risks as well as the cost and electricity consumption drivers. It shall also identify an R&D path to demonstrate the feasibility of the collider and support its performance claims.

In particular, the MC Study shall focus on the high-energy frontier and consider options with a centre-of-mass energy of 3 TeV and of 10 TeV or more.

Potential synergies with other projects shall be explored and used where beneficial to the MC Study.

International Muon Collider Collaboration

3. Organization

3.1. CERN shall act as the initial host organization for the MC Study, until such time as a change to the hosting of the MC Study shall be agreed by the International Collaboration Board ("ICB") following a proposal by CERN, whereupon this Memorandum shall be amended accordingly.

3.2. The MC Study shall be executed through the following entities, each of which shall decide on its own decision-making procedures:

(i) An International Collaboration Board (ICB) whose mandate is to oversee the MC Study and channel contributions from the Participants. Each Participant shall have one representative in the International Collaboration Board. The ICB shall elect its Chair and can invite representatives of institutes that have not signed this Memorandum to participate in the discussions, without the right to vote.

(ii) An International Advisory Committee whose mandate is to review the scientific and technical progress of the Study typically on an annual basis and to submit recommendations to the ICB.

(iii) The MC Study Leader's (the "Study Leader") mandate is the overall coordination and organisation of the MC Study. He or she will be appointed by the ICB and guided by its decisions, and will act under the authority of the head of the host organization.

(iv) The term of office of the Study Leader shall be three years, renewable.

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So that partners who cannot sign the MoC can participate

Currently preparing the "constitution" of the collaboration which should define a regular case (e.g. signature of some lettre of interest)

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