Muon Collider Overview and Workshop Purpose

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for the International Muon Collider Collaboration

Synergy workshop, Orsay, June 2023

This project has received funding from the European Union's Research and Innovation programme under GA No 101094300.

Goal of Synergy Workshop

- Feel that the muon collider has important synergy with other programmes, e.g.
  - Muon sources, neutrino physics, proton beams, targets, …

- Would like to more concretely identify the synergy
- Then find a way to join forces where possible
  - Exchange of information, workshops, …
  - Maybe try to find common activities or even funding

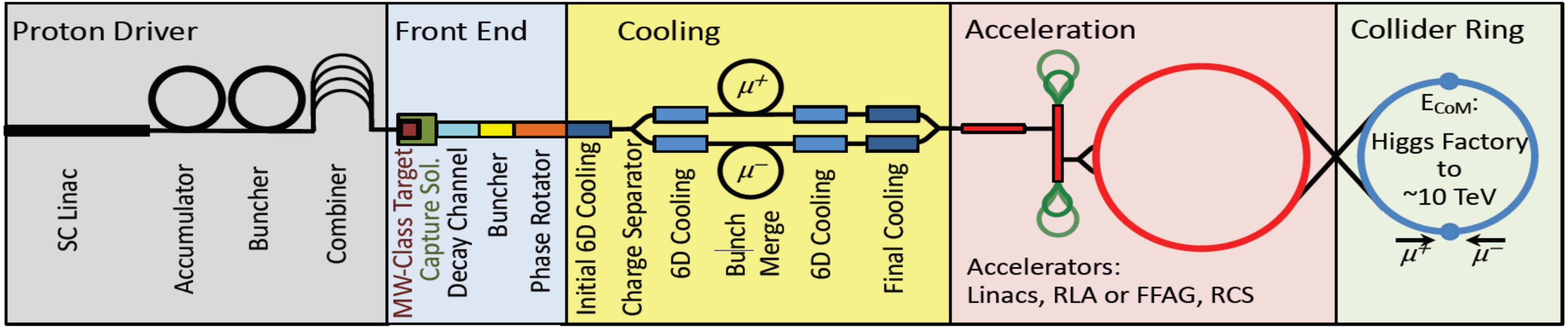
- Goal of the workshop is to explore the potential opportunities and to foster collaboration

Muon Collider Overview

Muon collider has been studied in the US (“MAP”), experiments have been performed in the UK (“MICE”) and some alternatives have been considered at INFN (“LEMMA”)

Renewed interest thanks to **technology and design advances** and new goal of **very high-energy, high-luminosity lepton collisions**

Would be easy if the muons did not decay
Lifetime is $\tau = \gamma \times 2.2\ \mu s$



Short, intense proton bunch

Protons produce pions which decay into muons muons are captured

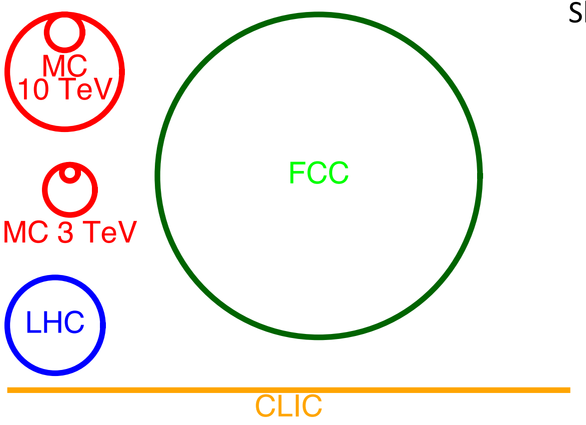
Ionisation cooling of muon in matter

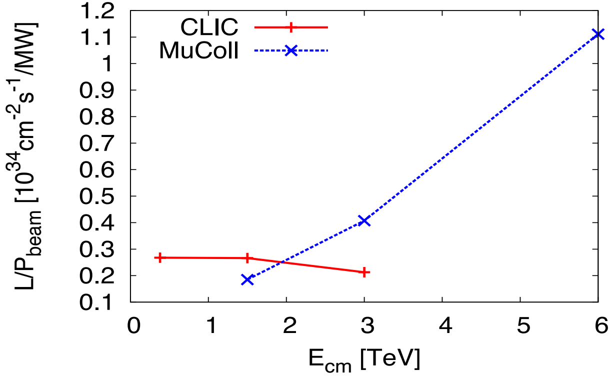
Acceleration to collision energy

Collision

Muon Collider Promises

US Snowmass Implementation Task Force: Th. Roser, R. Brinkmann, S. Cousineau, D. Denisov, S. Gessner, S. Gourlay, Ph. Lebrun, M. Narain, K. Oide, T. Raubenheimer, J. Seeman, V. Shiltsev, J. Straight, M. Turner, L. Wang et al.





	CME [TeV]	Lumi per IP [$10^{34}cm^{-2}s^{-1}$]	Years to physics	Cost range [B$]	Power [MW]
FCC-ee	0.24	8.5	13-18	12-18	290
ILC	0.25	2.7	<12	7-12	140
CLIC	0.38	2.3	13-18	7-12	110
ILC	3	6.1	19-24	18-30	400
CLIC	3	5.9	19-24	18-30	550
MC	3	1.8	19-24	7-12	230
MC	10	20	>25	12-18	300
FCC-hh	100	30	>25	30-50	560

Judgement by ITF, take it *cum grano salis*

Goal and Accelerator R&D Roadmap

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http://arxiv.org/abs/2201.07895

Muon collider is on European **Accelerator R&D Roadmap**

- Reviews in Europe and US found **no insurmountable obstacle**

Implementing workplan

- Goal: **Project Evaluation Report** and **R&D Plan** to next ESPPU/other processes
- 10+ TeV collider, potential 3 TeV initial stage
- CERN has budget in MTP, hosting a collaboration
- Design Study supported by EC, Switzerland, UK and partners contribute
- Strong interest in US community to join

Key work

- Design of critical beam complex
- Address technologies
- Prepare demonstrator

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.

$\sqrt{s}$	$\int \mathcal{L} dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

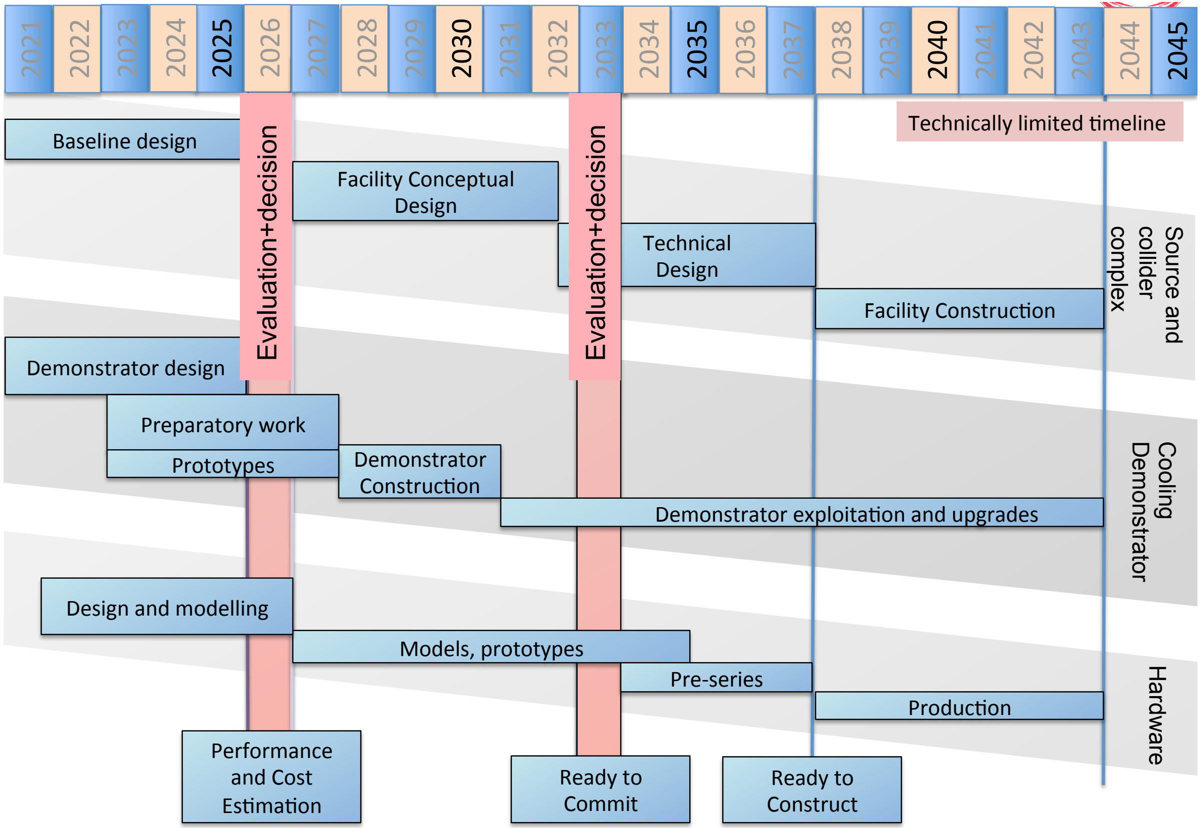
Roadmap: Technically Limited Timeline

To be reviewed considering progress, funding and decisions

Muon collider important in the long term

Fastest track option with important ramp-up of resources to see if muon collider could come directly after HL-LHC
- Compromises in performance, e.g. 3 TeV

Needs to be revised but do not have enough information at this point for final plan



Initial Target Parameters

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Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

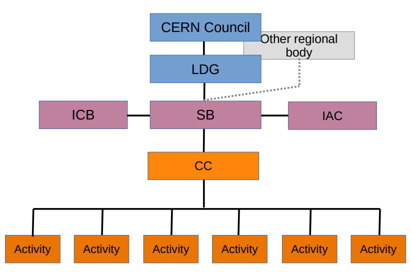
Note: currently focus on 10 TeV, also explore 3 TeV

- Tentative parameters based on MAP study, might add margins
- Achieve goal in 5 years
- FCC-hh to operate for 25 years
- Aim to have two detectors

Parameter	Unit	3 TeV	10 TeV	14 TeV	CLIC at 3 TeV
L	**10^{34} cm^{-2}s^{-1}**	**1.8**	**20**	**40**	**2 (6)**
N	10^{12}	2.2	1.8	1.8	
f_r	Hz	5	5	5	
P_{beam}	**MW**	**5.3**	**14.4**	**20**	**28**
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	

Muon Collider Community

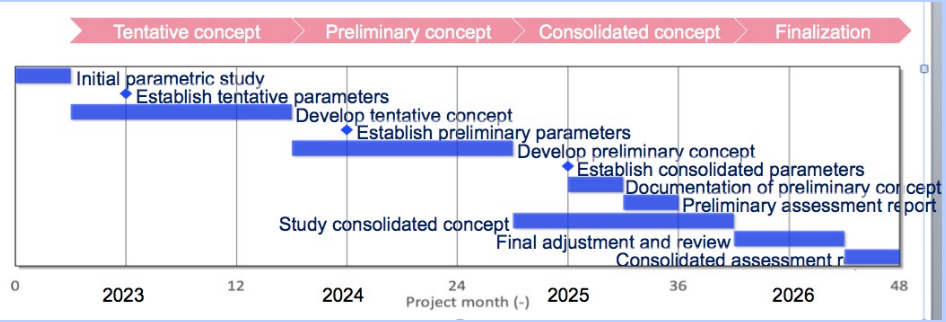
Formed **collaboration** hosted by CERN to implement R&D Roadmap for CERN Council



60+ partners, 40+ already signed MoC

EU Design Study approved

(EU+Switzerland+UK and partners)



Plan to participate to **HORIZON-INFRA-2024-TECH**

Goal: prepare experimental programme, e.g. **demonstrator, prototypes, …**

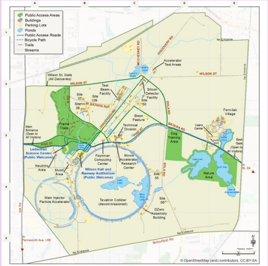
TIARA wants magnet proposal

US Snowmass has **strong support**

- to contribute to R&D
- as a collider in the US

Lia Merminga appointed team to prepare P5 ask

Some first contacts with others



MoC and Design Study Partners

IEIO	**CERN**
FR	**CEA-IRFU**
	CNRS-LNCMI
DE	DESY
	Technical University of Darmstadt
	University of Rostock
	KIT
IT	**INFN**
	INFN, Univ., Polit. Torino
	INFN, Univ. Milano
	INFN, Univ. Padova
	INFN, Univ. Pavia
	INFN, Univ. Bologna
	INFN Trieste
	INFN, Univ. Bari
	INFN, Univ. Roma 1
	ENEA
Mal	**Univ. of Malta**
BE	***Louvain***

UK	**RAL**
	UK Research and Innovation
	University of Lancaster
	University of Southampton
	University of Strathclyde
	University of Sussex
	Imperial College London
	Royal Holloway
	University of Huddersfield
	University of Oxford
	University of Warwick
	University of Durham
SE	**ESS**
	University of Uppsala
PT	**LIP**
NL	**University of Twente**
FI	**Tampere University**
LAT	**Riga Technical Univers.**

US	**Iowa State University**
	Wisconsin-Madison
	Pittsburg University
	Old Dominion
	BNL
China	***Sun Yat-sen University***
	IHEP
	Peking University
EST	***Tartu University***
AU	**HEPHY**
	TU Wien
ES	**I3M**
	CIEMAT
	ICMAB
CH	**PSI**
	University of Geneva
	EPFL

KO	**KEU**
	Yonsei University
India	***CHEP***
IT	**INFN Frascati**
	INFN, Univ. Ferrara
	INFN, Univ. Roma 3
	INFN Legnaro
	INFN, Univ. Milano Bicocca
	INFN Genova
	INFN Laboratori del Sud
	INFN Napoli
US	FNAL
	LBL
	JLAB
	Chicago
	Tenessee

US P5 Ask

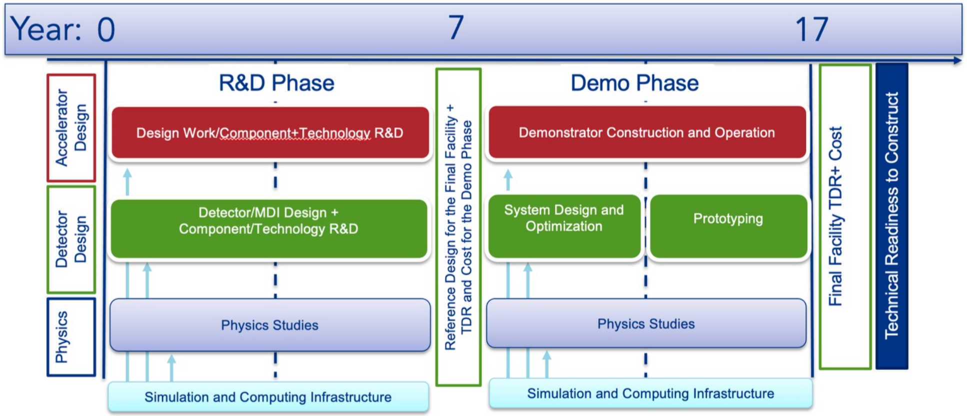
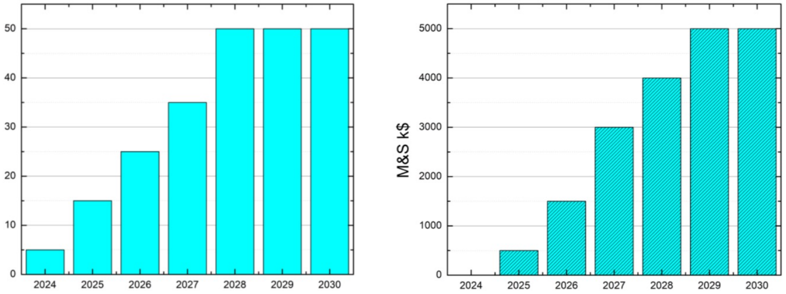


Figure 1: A sketch of the proposed muon collider R&D timeline, along with high-level activities, milestones, and deliverables.



: FTE and M&S profiles for accelerator R&D corresponding to the first phase of the . We assume here that funding can start in 2024. The M&S is in FY23 dollars and n is not included in these estimates.

S. Jindariani, D. Stratakis, Sridhara Dasu et al.
Goal is to contribute as much as Europe
Start of construction a bit later than in Roadmap
Will try to harmonise/define scenarios once US joins

Total resources would approach Roadmap

- Some increase in Europe and Asia assumed
- 1-2 years delay
- But profile is different

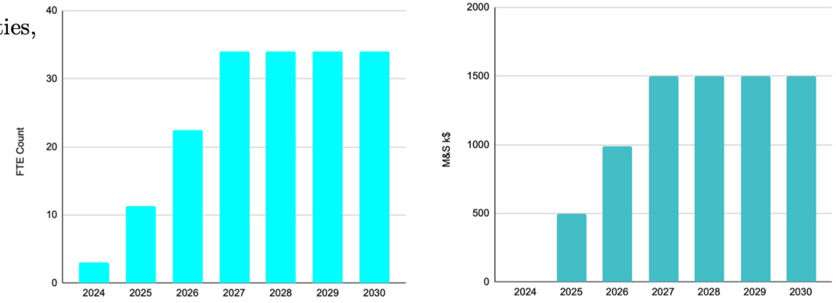
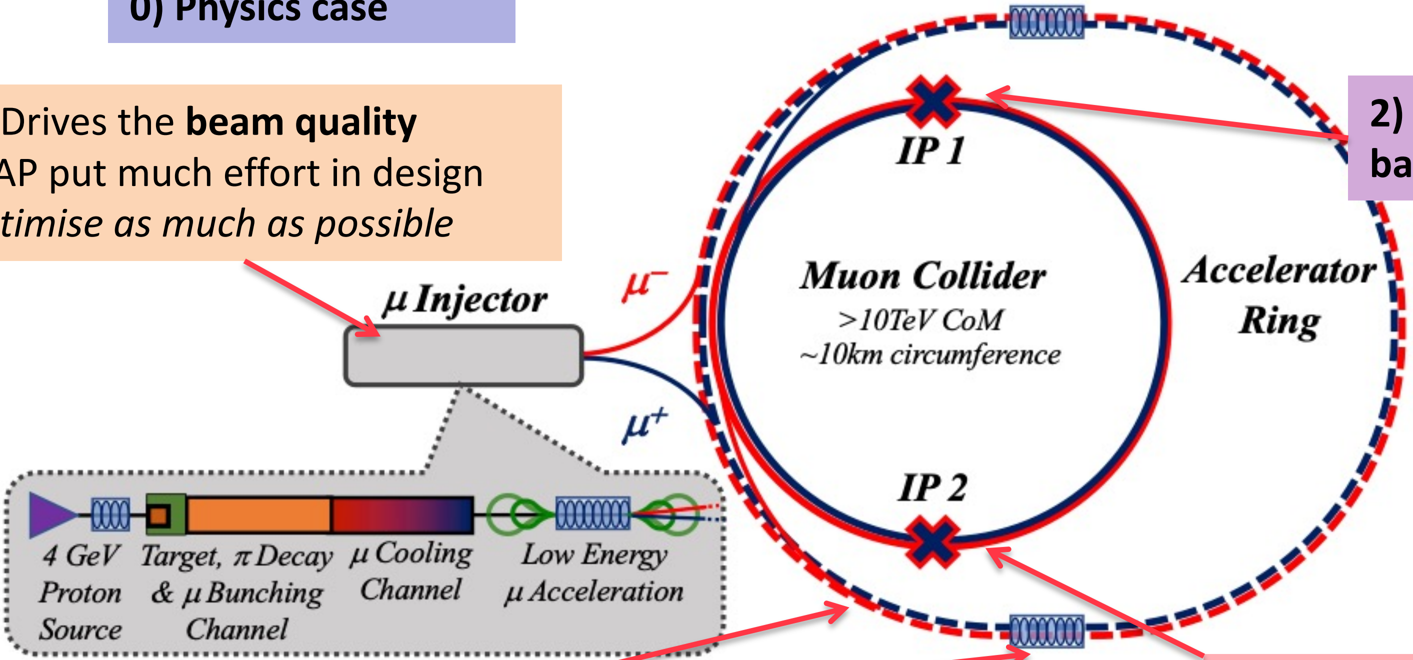


Figure 3: FTE and M&S profiles for detector R&D corresponding to the first phase of the program. We assume here that funding can start in 2024. The M&S is in FY23 dollars and escalation is not included in these estimates.

Key Challenges

0) Physics case

4) Drives the **beam quality**
MAP put much effort in design
optimise as much as possible



2) Beam-induced background

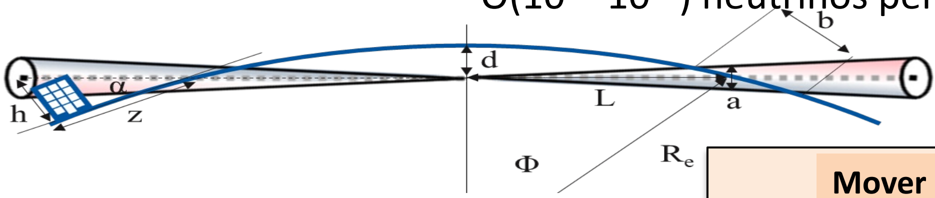
1) Dense neutrino flux
mitigated by mover system and site selection

3) Cost and **power** consumption limit energy reach
e.g. 35 km accelerator for 10 TeV, 10 km collider ring
Also impacts **beam quality**

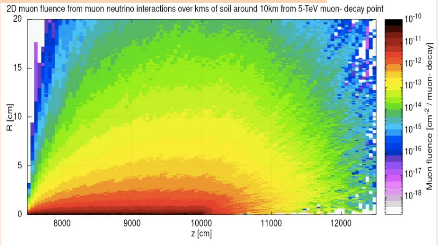
Neutrino Flux

Goal: **similar to LHC**: limit neutrino flux to have **negligible impact**, “fully optimised” (10% of MAP goal)
Verify performance of concept to be good for 14 TeV

O(10^{11}-10^{12}) neutrinos per second

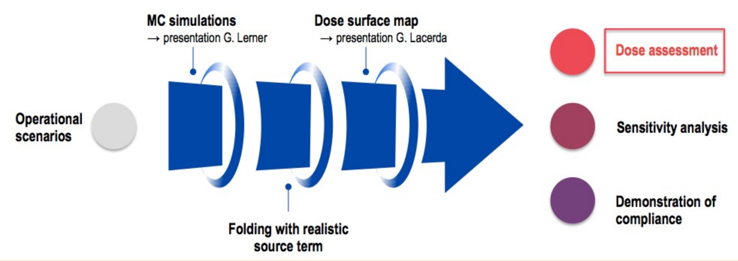


FLUKA dose studies



G. Lerner, D. Calzolari, A. Lechner, C. Ahdida

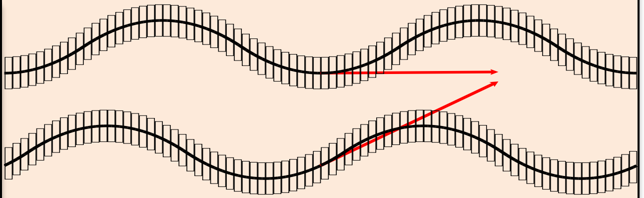
Conformity Verification Scheme



C. Ahdida, P. Vojtyla, M. Widorski, H. Vincke

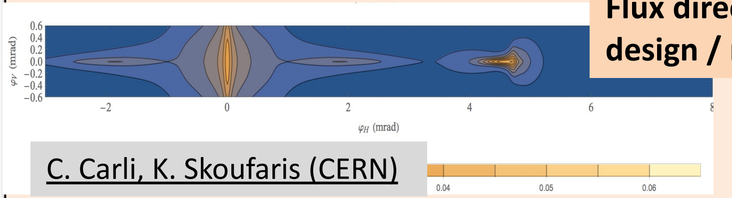
X

Mover and support system



F. Bertinelli et al. (CERN, Riga)

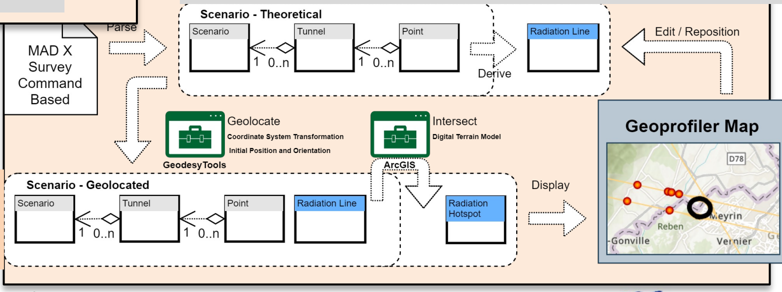
Flux direction map / lattice design / mover impact on beam



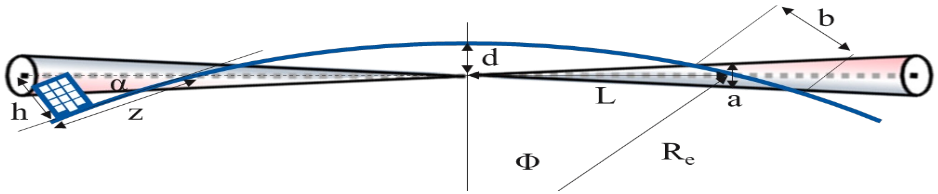
C. Carli, K. Skoufaris (CERN)

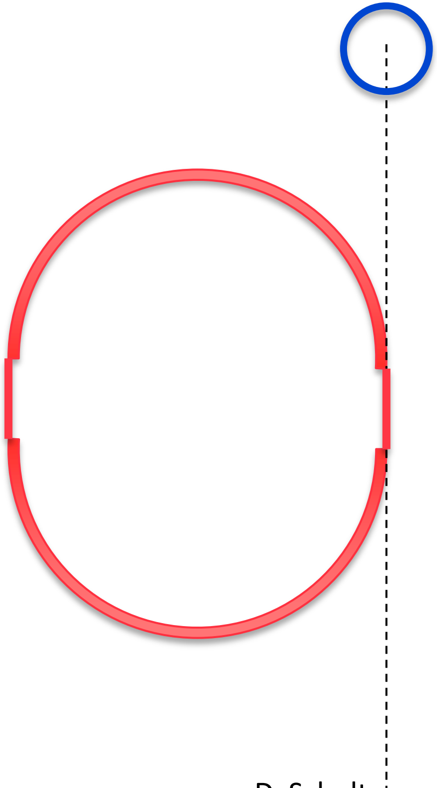
Mitigation: Site choice tool

G. Lacerda, Y. Robert, N. Guilhaudin (CERN)



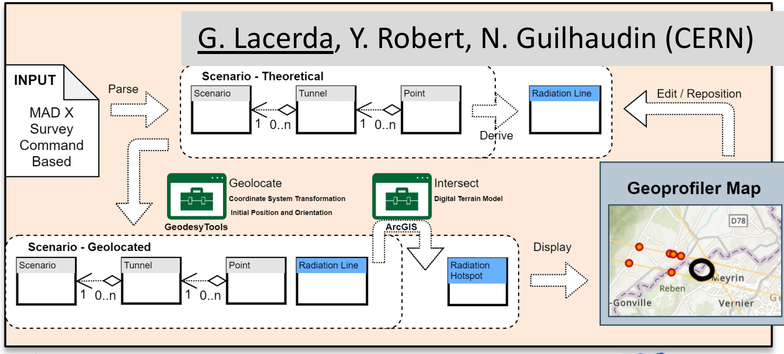
Neutrino Flux





O(10^{11}-10^{12}) neutrinos per second
Plan to either dilute or likely aquire the land around this spot

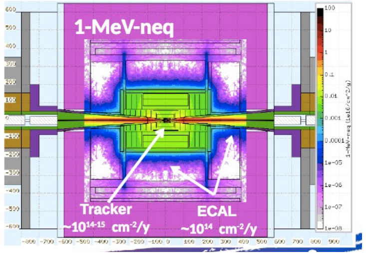
Important to know if this is helpful becsause depends on the lattice design



Muon Collider R&D Examples

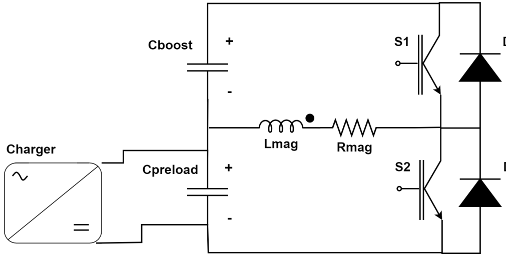
Detector studies
- 10 TeV design
- Beam-induced background

Promising but more work required

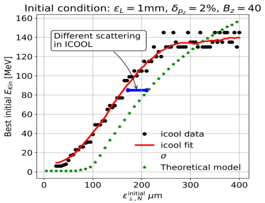


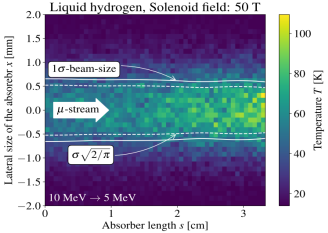
Efficent power converters

Energy recovery for fast-ramping magnets

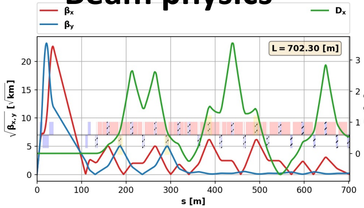


Muon ionisation cooling



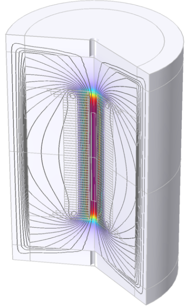


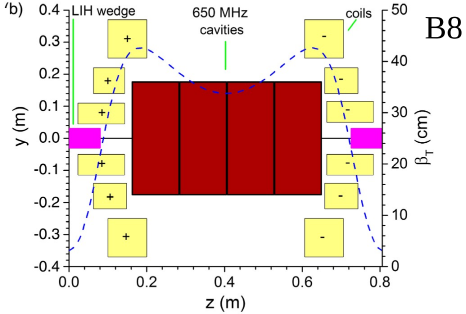
Beam physics



High-field HTS solenoids

40 T HTS solenoid

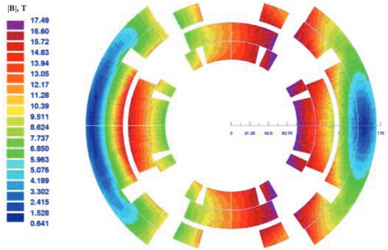




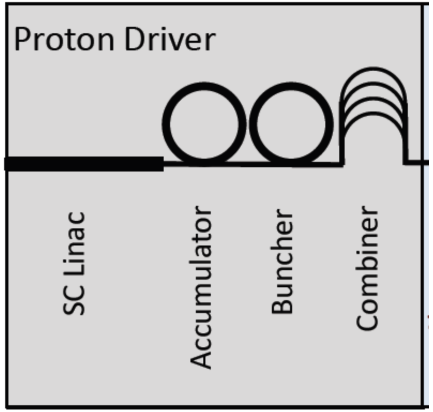
Cooling Cell Design

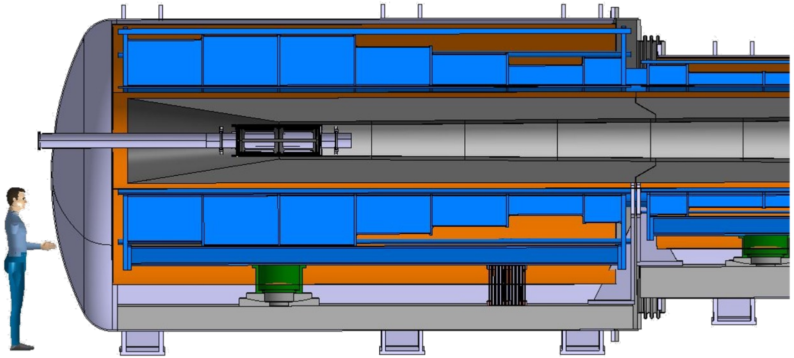
RF in magnetic field

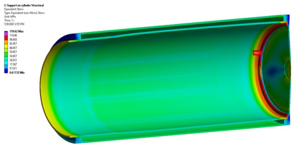
High-field dipoles (HTS or Nb_3Sn)

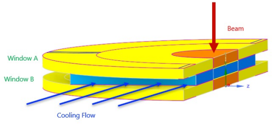


Proton Complex and Target









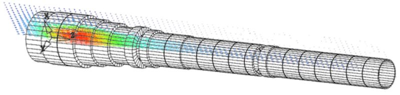
2 MW proton beam 5 GeV
5 Hz from the combiner

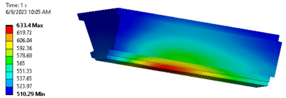
Will explore parameters to optimise proton compolex and target

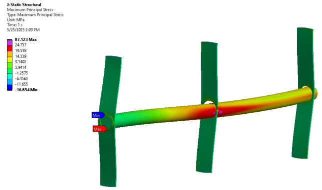
Will explore higher power

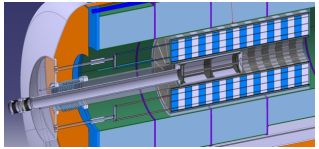
Graphite target baseline with tungsten shield for surrounding solenoid

Good progress on 20 T HTS solenoid design, stress in target, vessel, shielding, more to be done for the window









CDR Phase, R&D and Demonstrator Facility

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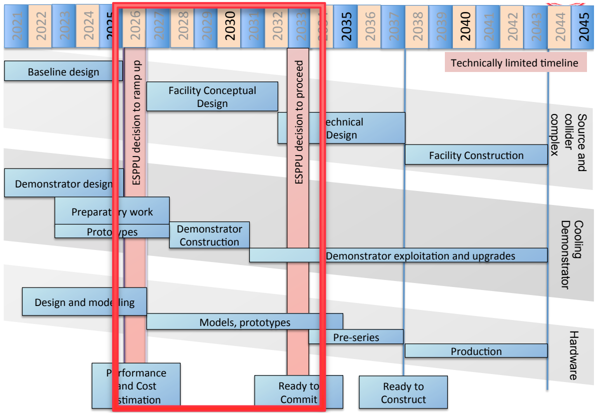
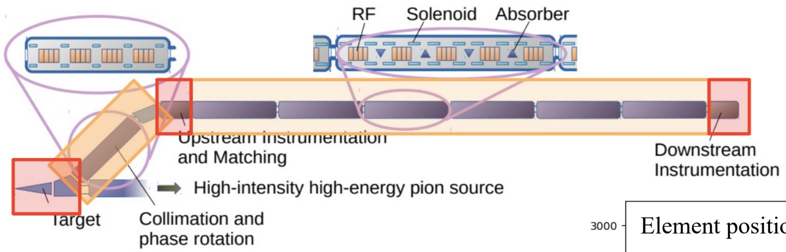


Broad R&D programme can be distributed world-wide

- Models and prototypes
  - Magnets, Target, RF systems, Absorbers, …
- CDR development
- Integrated tests, also with beam

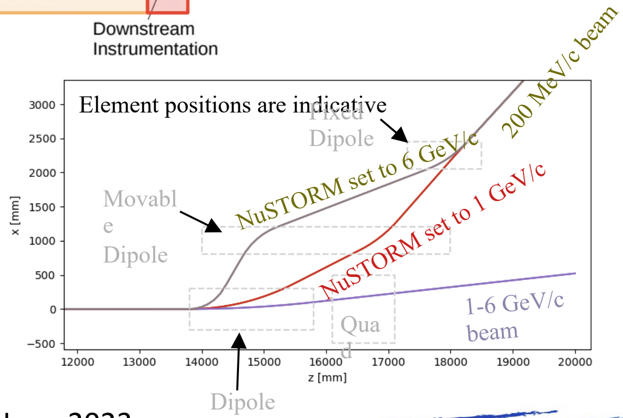
Integrated cooling demonstrator is a key facility

- look for an existing proton beam with significant power



Different sites are being considered

- CERN, FNAL, ESS are being discussed
- J-PARC also interesting as option
- **FNAL is considering this in the ACE**



Could be used to house physics facility

- Are trying to explore what are good options

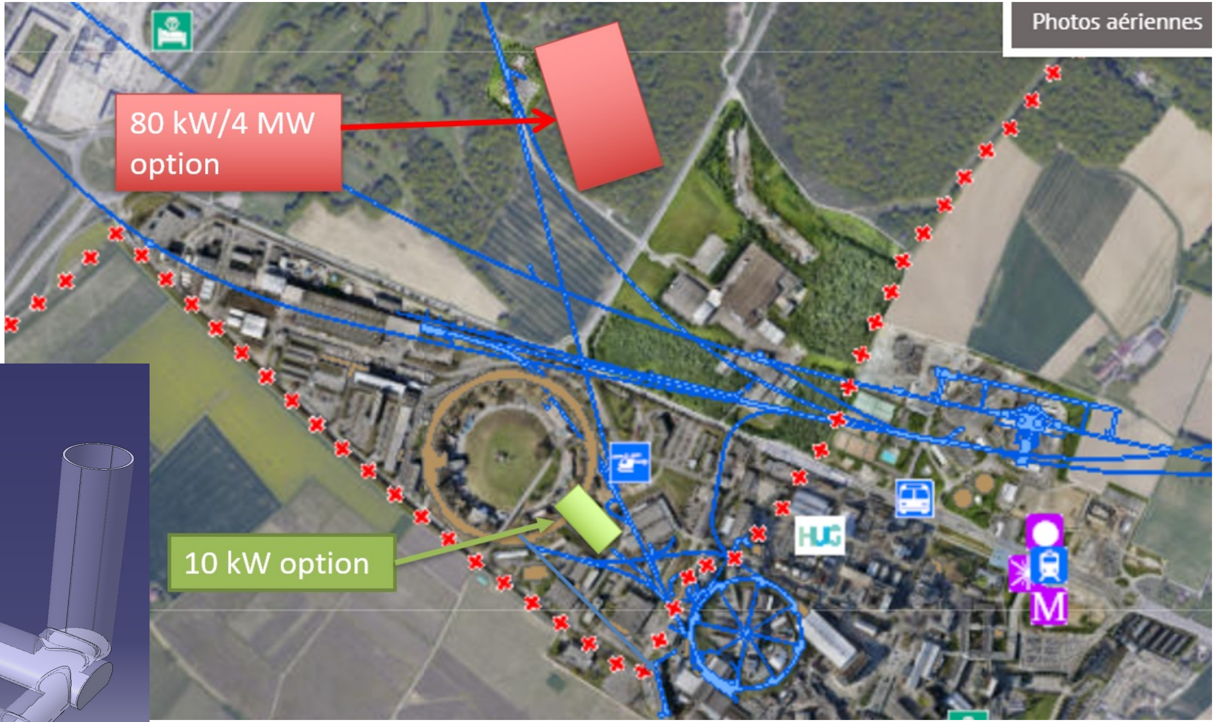
Example CERN Locations

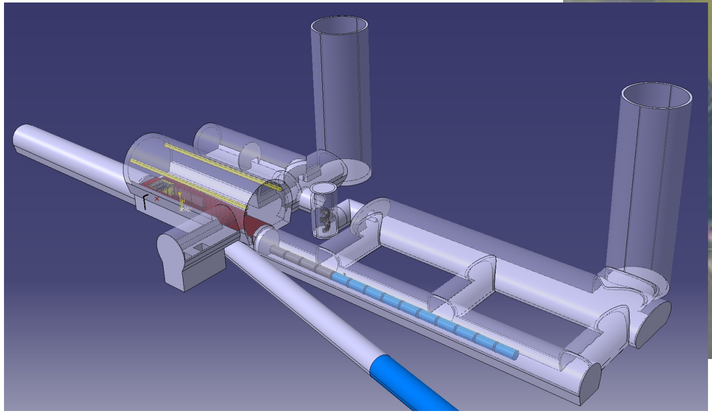
nTOF-like beam from PS:

- 1 pulse of 10^{13} p at 20 GeV per 1.2 s
- i.e. 27 kW, maybe O(100kW) possible

If SPL were, installed could use its beam, e.g. 5 GeV, 4 MW

Can branch muons to physics facility





Conclusion

- Muon collider unique opportunity for high-energy, high-luminosity lepton collider
- Currently working toward 10+ TeV, potential 3 TeV intermediate stage explored
- Collaboration exists, expected to increase
- Develop and R&D programme including demonstrator
- Feel that there is important synergy with other facilities

http://muoncollider.web.cern.ch To join contact muon.collider.secretariat@cern.ch

Reserve

Muon Collider Luminosity Scaling

Fundamental limitation

Requires emittance preservation and advanced lattice design

Applies to MAP scheme

$$\mathcal{L} \propto \gamma \langle B \rangle \sigma_\delta \frac{N_0}{\epsilon \epsilon_L} f_r N_0 \gamma$$

High energy

High field in collider ring

Large energy acceptance

Dense beam

High beam power

Luminosity per power increases with energy
Provided technologies can be made available

Constant current for required luminosity scaling

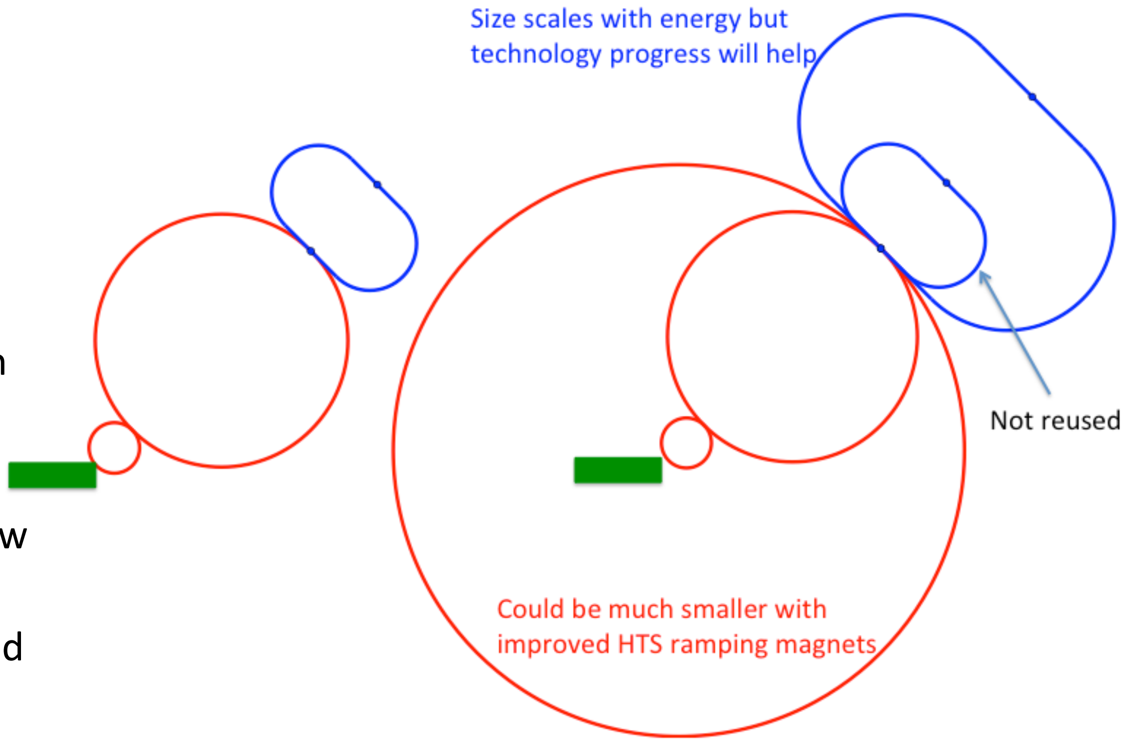
Staging

Ideally would like full energy right away, but staging could lead to faster implementation

- Substantially less cost for a first stage
- Can make technical compromises
  - e.g. 8 T NbTi magnets would increase collider ring from 4.5 to 6 km and reduce luminosity by 25%
- Timeline might be more consistent with human lifespan

Upgrade adds one more accelerator and new collider ring

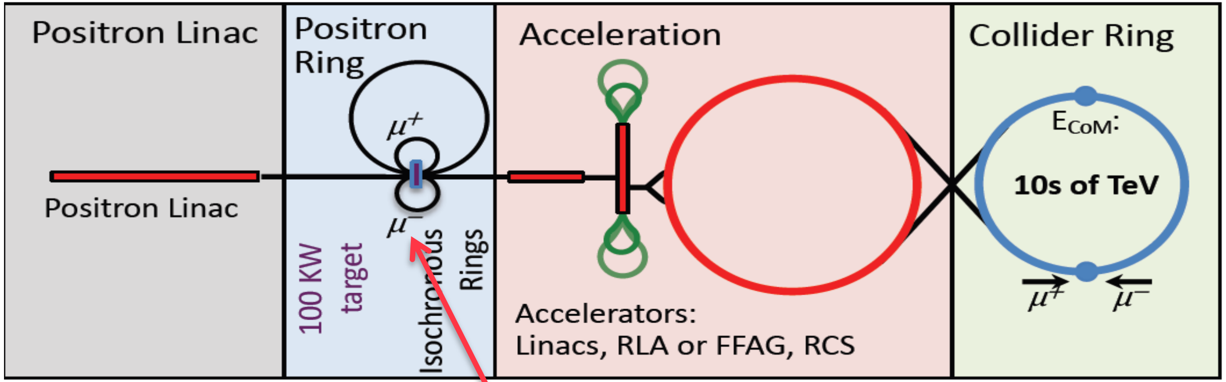
- only first collider ring is not being reused



Alternatives: The LEMMA Scheme

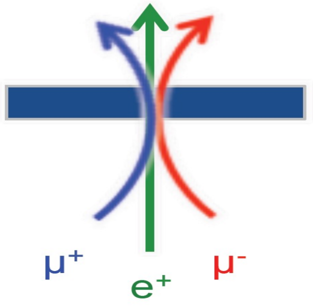
LEMMA scheme (INFN) P. Raimondi et al.

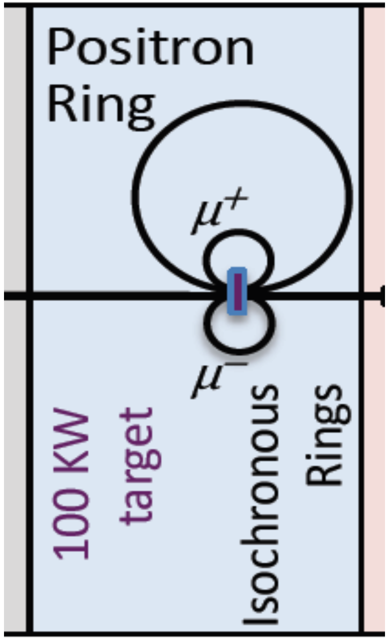
Note: New proposal by C. Curatolo and L. Serafini needs to be looked at
- Uses Bethe-Heitler production with electrons



45 GeV positrons to produce muon pairs
Accumulate muons from several passages

$$e^+e^- \rightarrow \mu^+\mu^-$$





Excellent idea, but nature is cruel

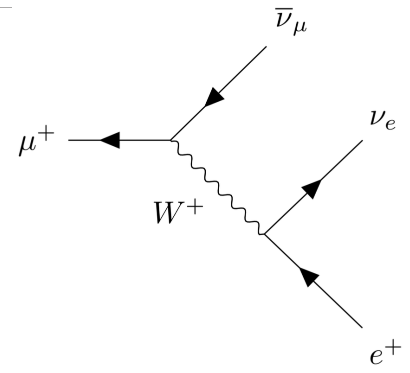
Detailed estimates of fundamental limits show that we require a very large positron bunch charge to reach the same luminosity as the proton-based scheme

$\Rightarrow$ **Need same game changing invention**

Muon Decay

MuCol

International MUON Collider Collaboration



About 1/3 of energy in electrons and positrons:

Experiments needs to be protected from **background** by masks

- simulations of 1.5, 3 and 10 TeV
- optimisation of masks and lattice design started
- first results look encouraging
- will be discussed at ICHEP

Collider ring magnets need to be shielded from losses

Losses elsewhere will also need to be considered but are less severe

D. Lucchesi, A. Lechner, C Carli et al.

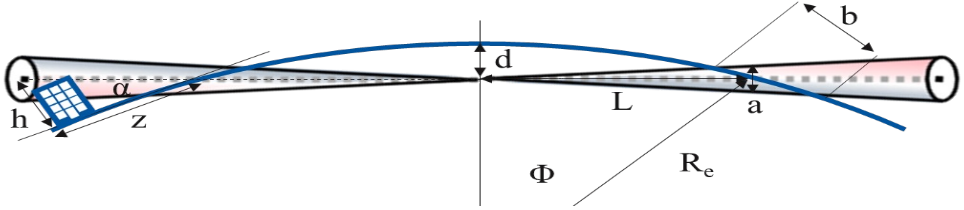
Neutrino flux to have negligible impact on environment

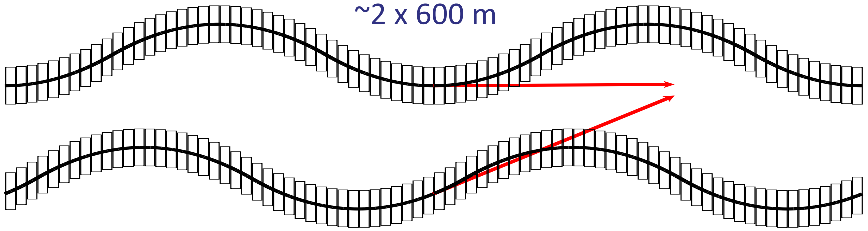
- want to be **negligible** (same level as LHC)
- opening cone decreases, cross section and shower energy increase with energy

Above about 3 TeV need to make beam point in different vertical directions

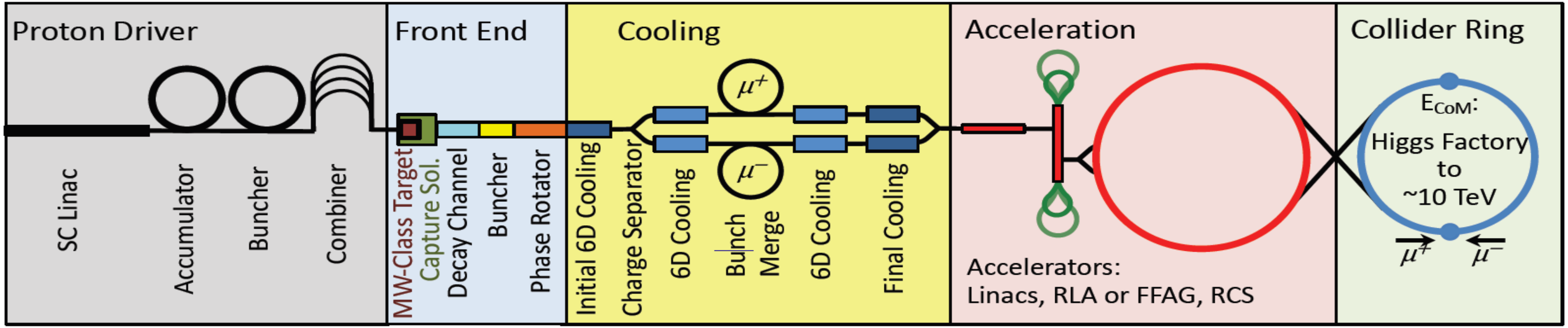
Mechanical system with 15cm stroke, 1% vertical bending

Length of pattern to be optimised for minimal impact on beam





Key Challenges



Proton complex
- Compressing protons to few bunches

Target
- Target
- Solenoid

Cooling channel
- Channel design
- Solenoids
- RF in magnetic field
- Absorbers
- Integration

RCS
- Beam dynamics
- Ramping magnets
- Power converter
- RF system

Collider ring
- Optics
- Magnets
- Neutrino flux
- Detector background

Roadmap

In **aspirational scenario** can make **informed decisions**:

Three main deliverables are foreseen:

- a **Project Evaluation Report** for the next ESPPU 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 the questions 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?
- an **R&D Plan** that describes an R&D 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.

R&D Plan

The R&D plan will describe the R&D path toward the collider, in particular during the CDR phase, and will comprise the elements below.

- An integrated concept of a muon cooling cell that will allow construction and testing of this key novel component.
- A concept of the facility to provide the muon beam to test the cells.
- An evaluation of whether this facility can be installed at CERN or another site.
- A description of other R&D efforts required during the CDR phase including other demonstrators.

This R&D plan will allow the community to understand the technically limited timeline for the muoncollider development after the next ESPPU.

Minimal Scenario

Will allow **partially informed decisions**

- No conceptual design of neutrino flux and alignment system
- No alternative superconducting fast-ramping magnet system
- Several collider systems would (almost) not be covered, in particular
  - the linacs
  - the target complex
  - the proton complex
  - engineering considerations of the muon cooling cells
  - alternative designs for the final cooling system, acceleration, collider ring
- No RF test stand would be constructed for the muon cooling accelerating cavities
- No conceptual design of a muon cooling cell for the test programme
- No conceptual design of a muon cooling demonstrator facility
- No concept of RF power sources
- No tests/models to develop solenoid technology.

Key Technologies

Magnets

- Superconducting solenoids for target and cooling profit from developments for society
  - target solenoid comparable to ITER central solenoid fusion
  - 6D cooling solenoids similar and wind power generators, motors
  - final cooling solenoids synergetic with high-field research, NMR
- Collider ring magnets
  - profit from developments for other colliders FCC-hh, stress-managed magnets
- Fast-ramping normal-conducting magnet system
  - HTS alternative, power converter

RF systems

- superconducting RF, normal-conducting RF, efficient klystrons

Target, cooling absorbers, windows, shielding

Neutrino mitigation mover system, cooling cell integration, …

Detector

Key Technologies, cont.

RF systems

- Normal-conducting cooling cavities in magnetic field
  - profit from CLIC work
- Superconducting accelerator RF
  - profit from ILC, …
- Efficient power sources
  - profit from CLIC work

Beam-matter interaction

- Proton target
- Cooling absorbers
- Shielding (accelerator and detector)

Mechanical system

- Neutrino flux mitigation system
- Muon cooling cell integration

Collaboration Vision

IMCC is an **international** collaboration and aims to

- Enlarge the collaboration
  - Physics interest in all regions, strong US contribution to the muon collider physics and detector, interest in Japan
  - First US university have joined collaboration, try to see how to move forward, also with labs
- Combine the R&D efforts for the design and its technologies
  - Critical contributions in all relevant fields in the US
- Consider several sites for the collider
  - CERN would be one, FNAL and others should also be considered
  - A proposal with alternative sites is stronger for a single site
- Consider several sites for the demonstrators
  - E.g. Muon production and cooling demonstrator at CERN, FNAL, ESS, JPARC
  - e.g. RCS at ESRF or elsewhere
  - Target tests
  - …

Initial Target Parameters

Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Note: currently focus on 10 TeV, also explore 3 TeV

- Tentative parameters based on MAP study, might add margins
- Achieve goal in 5 years
- FCC-hh to operate for 25 years
- Aim to have two detectors

Parameter	Unit	3 TeV	10 TeV	14 TeV	CLIC at 3 TeV
L	**10^{34} cm^{-2}s^{-1}**	**1.8**	**20**	**40**	**2 (6)**
N	10^{12}	2.2	1.8	1.8	
f_r	Hz	5	5	5	
P_{beam}	**MW**	**5.3**	**14.4**	**20**	**28**
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	

US Snowmass

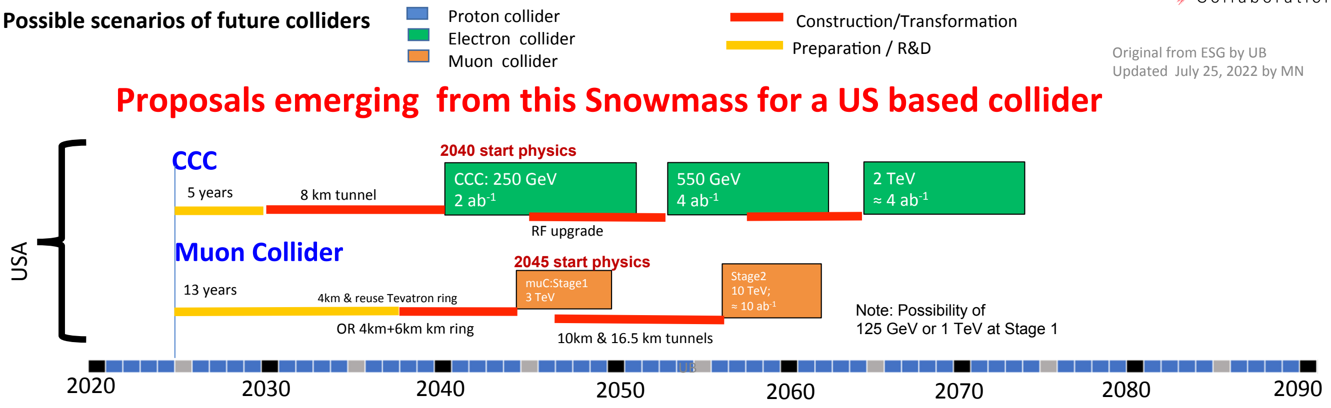
Strong interest in the US community in muon collider

- seen as an energy frontier machine
- decoupled from LC

US community wants funding for **R&D**

- **Goal: match European effort**

Community interested in the US to **host a muon collider**



- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - International Cost Sharing

Consider proposing hosting ILC in the US.

Meenakshi Narain: Energy Frontier / Large Experiments, Snowmass Community Summer Study July 17-26, 2022

US Snowmass, cont.

MuCol

International MUON Collider

Implementation Task Force

Muon Collider is a viable option for the HEP future

They made cost and power estimate for muon collider take it *cum grano salis*

Place MC in same risk tier as FCC-hh

Snowmass 2021

ITF's Look Beyond Higgs Factories

	CME (TeV)	Lumi per IP (10^34)	Years, pre-project R&D	Years to 1st Physics	Cost Range (2021 B$)	Electric Power (MW)
FCCee-0.24	0.24	8.5	0-2	13-18	12-18	290
ILC-0.25	0.25	2.7	0-2	<12	7-12	140
CLIC-0.38	0.38	2.3	0-2	13-18	7-12	110
HELEN-0.25	0.25	1.4	5-10	13-18	7-12	110
CCC-0.25	0.25	1.3	3-5	13-18	7-12	150
CERC(ERL)	0.24	78	5-10	19-24	12-30	90
CLIC-3	3	5.9	3-5	19-24	18-30	~550
ILC-3	3	6.1	5-10	19-24	18-30	~400
MC-3	3	2.3	>10	19-24	7-12	~230
MC-10-IMCC	10-14	20	>10	>25	12-18	*O*(300)
FCChh-100	100	30	>10	>25	30-50	~560
Collider-in-Sea	500	50	>10	>25	>80	»1000

ITF Report – T.Roser, et al, arXiv:2208.06030

Thomas Roser et al

8

Muon Collider magnets

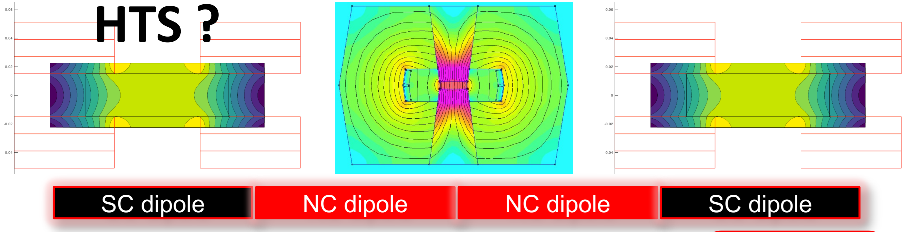
20 T, 200 mm **HTS !**

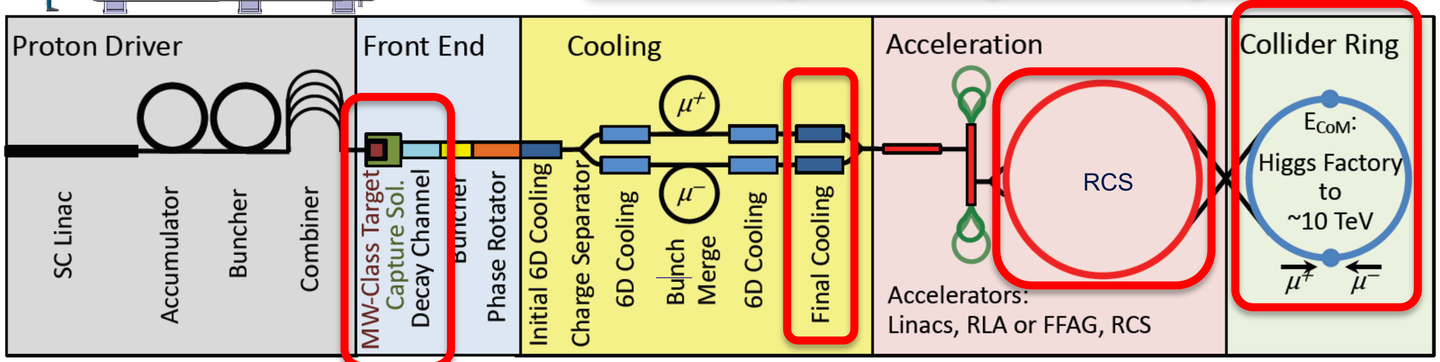
Radiation heat load ≈ 5...10 kW

Radiation dose: 80 MGy

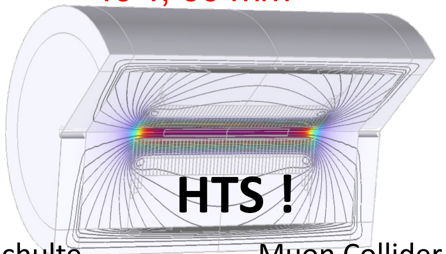
NC ±1.8 T, 400 Hz
100 mm x 30 mm

SC < 10T
100 mm x 30 mm





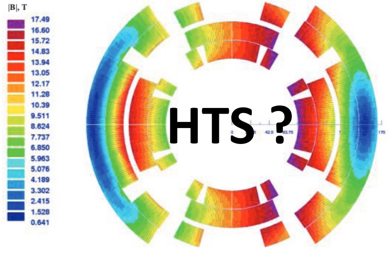
> 40 T, 60 mm



16 T peak, 150 mm

Radiation heat load ≈ 5 W/m

Radiation dose ≈ 20...40 MGy



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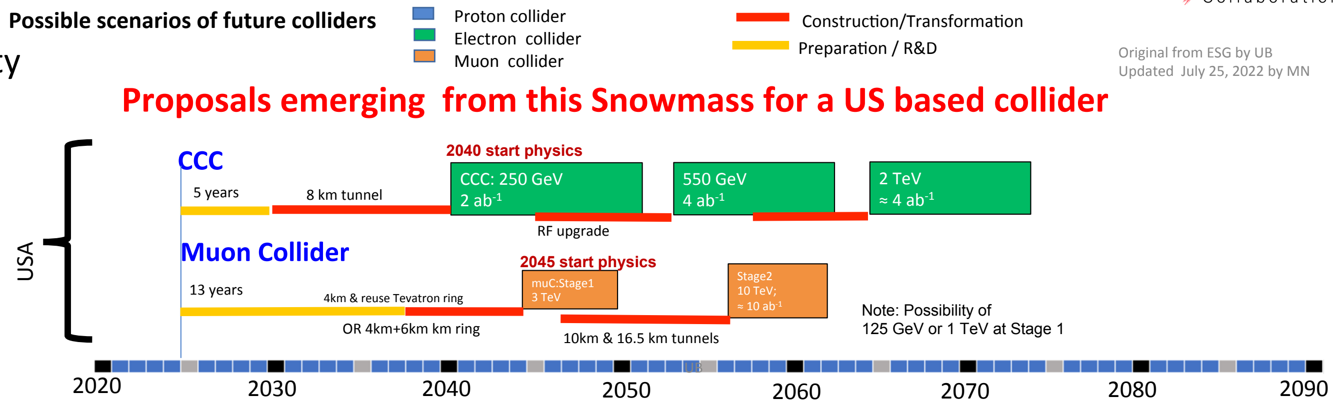

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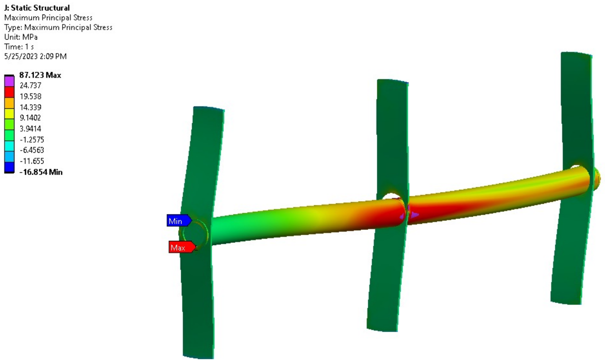
Meenakshi Narain: Energy Frontier / Large Experiments, Snowmass Community Summer Study July 17-26, 2022

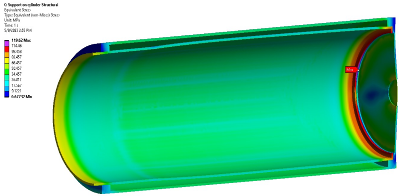
CARBON TARGET



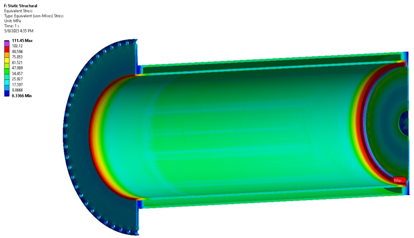
Graphite rod & supports: stress field

- Baseline updated form 1.5 to **2MW**
- Modeling **supports in the model**
- Studying **tilted beam**:
  - ✓ Effect found **positive**. Reduction of peak temperature from 3280 K (straight) to 2940 K (tilted) due to the lower energy deposition.
  - ✓ **Mechanical stresses**: stress wave expected to be “small” but **dynamic** analysis is ongoing

TARGET VESSEL



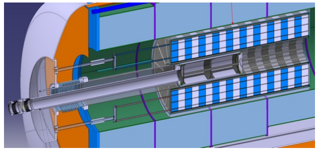
Simply supported vessel – stress field



Cantilever supported vessel – stress field

- Update to **2 MW**
- **Titanium** vessel
- Thermomechanical studies made to check the resistance to **high temperatures** and **cooling pressures**
  - ✓ Titanium vessel capable of **withstanding the requirements**
- No significant dynamic effects observed. Quasi-steady state behavior
- Two concepts being studied: simply supported cylinder and cantilever

- Evolutions from the **design**, **manufacturing & assembly** point of view of every component
- Also progress on **integration** with the **solenoid cryostat**



Coordination Committee Members

MuCol

International MUON Collider Collaboration

Physics	Andrea Wulzer
Detector and MDI	Donatella Lucchesi

Protons	Natalia Milas
Muon production and cooling	Chris Rogers
Muon acceleration	Antoine Chance
Collider	Christian Carli

Magnets	Luca Bottura
RF	Alexej Grudiev, Claude Marchand
Beam-matter int. target systems	Anton Lechner
Collective effects	Elias Metral

Cooling cell design	Lucio Rossi
Demonstrator	Roberto Losito

US (detector)	Sergo Jindariani
US (accelerator)	Mark Palmer
Asia (China)	Jingyu Tang
Asia (Japan)	tbd

A strengthening on the physics and detector side is planned

EU Design Study

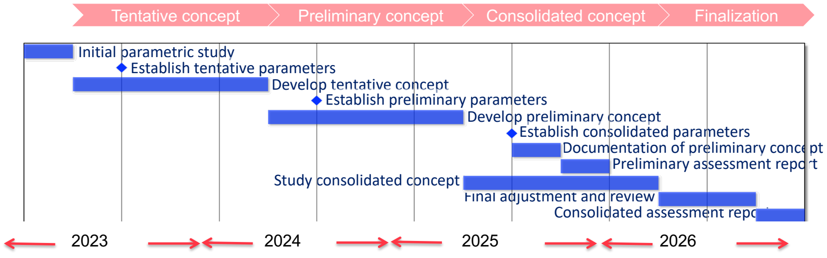
Has been approved summer 2022

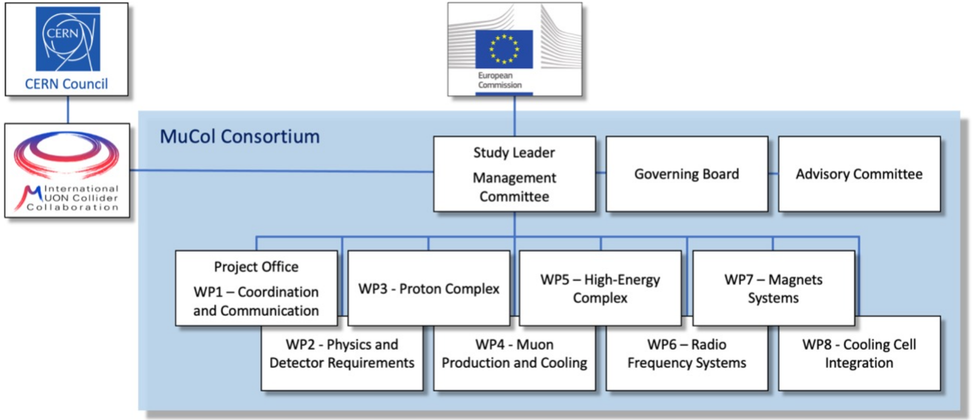
- Very helpful to kick-start collaboration

Reapproved early 2023

- It appears that there has been some issue with the refereeing of several projects, probably not directly with the muon collider

Brings 3 MEUR from the European Commission, the UK and Switzerland and about 4 MEUR from the partners
Basically nothing for CERN





Kick-off meeting in March 2023:
https://indico.cern.ch/event/1219912

Many thanks to all that contributed

https://mucol.web.cern.ch

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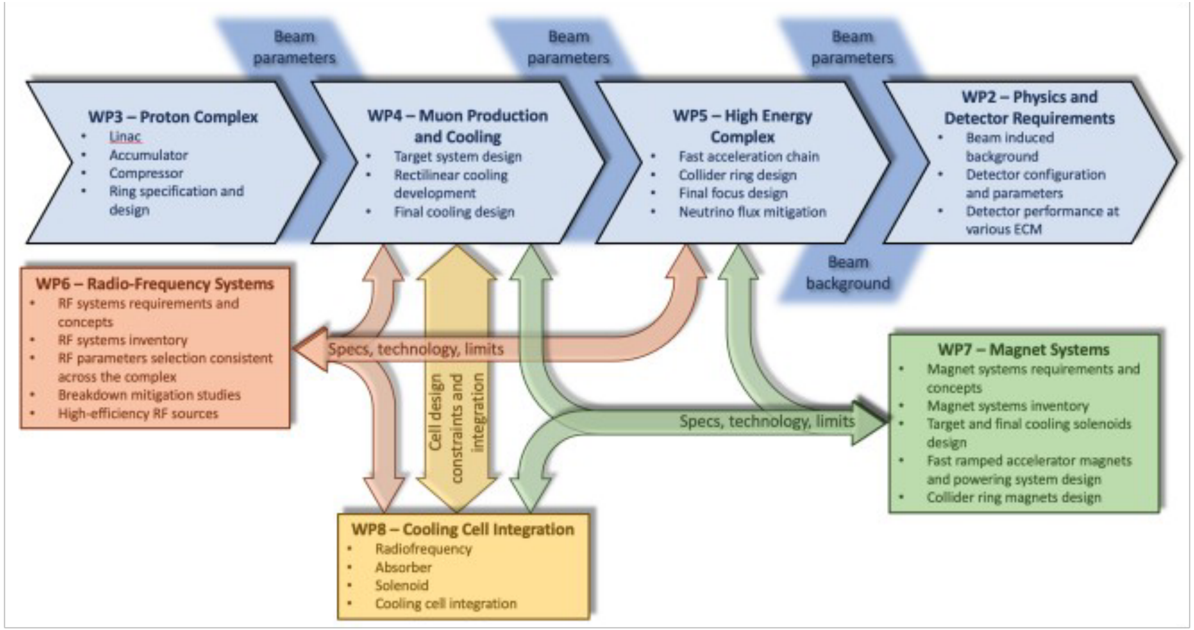
EU Design Study Work Programme

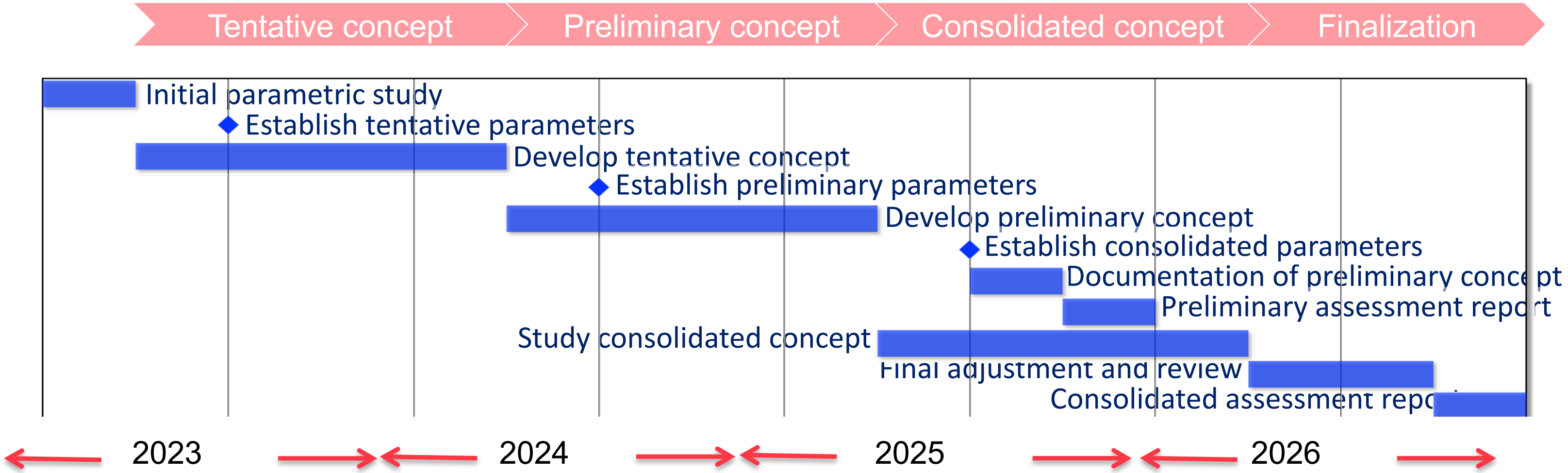
Workpackage leaders:
WP 1: R. Losito (CERN)
WP 2: D. Lucchesi (INFN, Padua)
WP 3: N. Milas (ESS)
WP 4: Ch. Rogers (RAL)
WP 5: A. Choince (CEA)
WP 6: C. Marchand (CEA)
WP 7: L. Bottura (CERN)
WP 8: L. Rossi (U. Milano)

Study Leader: D. Schulte (CERN)
Deputy Study Leader: Ch. Rogers (RAL)
Technical Coordinator: R. Losito (CERN)
Gender Advisor: E.J. Bahng (ISU)
Publications: E. Metral



Includes an important part of the work directly and much indirectly

MuCol Timeline



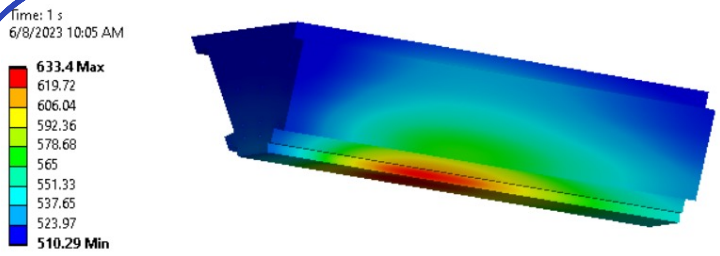
Finish February 2027

Preliminary report by early 2026, in case EU strategy takes place in 2026

Iterating on parameters ad design each year

More detail in Roberto's presentation

RADIATION SHIELDING

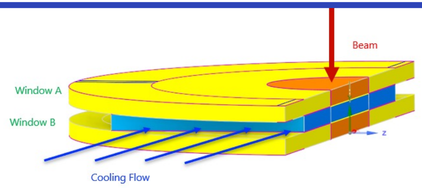


Tungsten slice – Temperature field

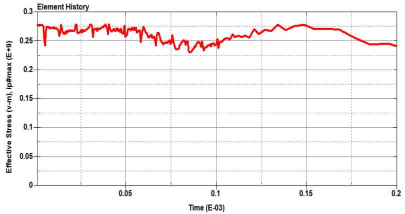
- Baseline updated to **2 MW**
- **Improved and more detailed concept** aiming for a more realistic implementation:
  Tungsten slices bounded by a stainless steel **vessel** filled with pressurized **He coolant**
- **Optimization** of the helium cooling **operational point** in function of:
  - Number of pipes
  - Diameter
  - Mass flow
  - Max. admissible flow speed & pumping power
  - Heat transfer coefficient and temperature
- **Operational Point**: Helium / ø5 mm/0.3 kg/s / 10 bar / 150 pipes

- Subsequent **thermomechanical analysis** found that **temperatures** and **stresses** are **acceptable** for tungsten (633 K at the core)
- Temperature at the **interface** with solenoid around **300 – 310 K**

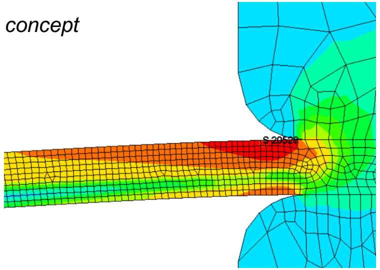
BEAM WINDOW



Cooled window concept



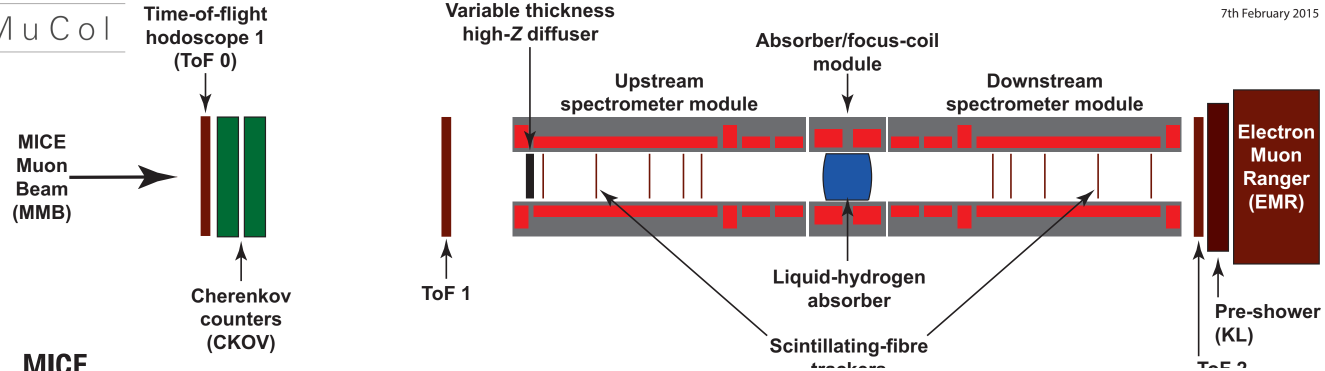
Dynamic stress waves due to one beam shot (at joint)



Stress field shape around the window joint

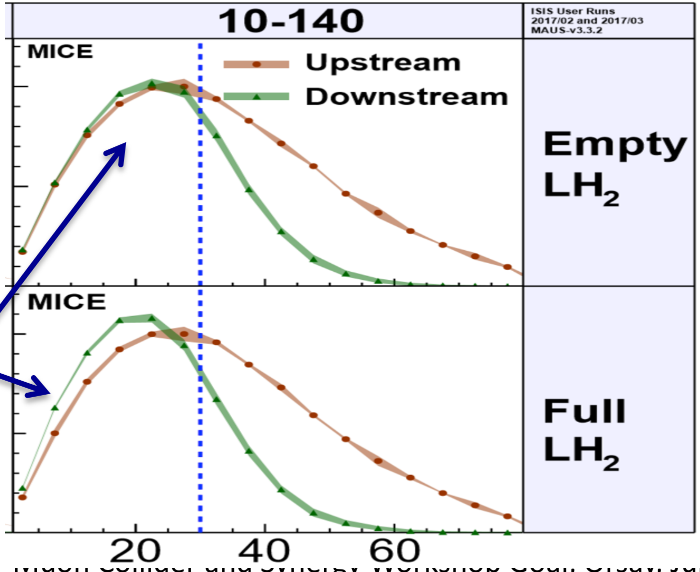
- **High requirements** in terms of energy density and cooling capabilities
- Parametric study made in function of material, thickness, and cooling pressure
- Found that **250 microns Berylium** can survive one single beam shot far from plasticity.
- There is still **little safety factor** to guarantee the **fatigue** endurance. More work will be done at this aspect
- Radiation damage is biggest challenge. Work on progress to mitigate it.

MICE: Cooling Demonstration

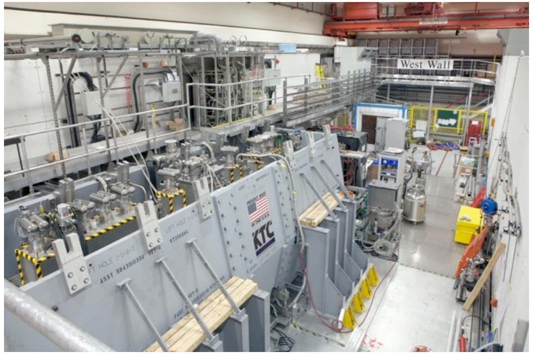


MICE

Principle of ionisation cooling has been demonstrated
Use of data for benchmarking is still ongoing



More particles at smaller amplitude after absorber is put in place



Nature vol. 578, p. 53-59 (2020)

More complete experiment with higher statistics, more than one stage required

Integration of magnets, RF, absorbers, vacuum is engineering challenge

Organisation

Collaboration Board (ICB)
- Elected chair: **Nadia Pastrone**

Steering Board (ISB)
- Chair **Steinar Stapnes**
- CERN members: Mike Lamont, Gianluigi Arduini
- ICB members: Dave Newbold (STFC), Mats Lindroos (ESS), Pierre Vedrine (CEA), N. Pastrone (INFN)
- Study members: SL and deputies
- Will add US but wait for US decision on members

Advisory Committee
- To be defined, discussion in SB

Coordination committee (CC)
- Study Leader: **Daniel Schulte**
- Deputies: **Andrea Wulzer, Donatella Lucchesi, Chris Rogers**