Towards a Muon Collider

E. Métral (many thanks to Daniel Schulte and all IMCC colleagues)

International MUON Collider Collaboration

CERN

$$m_\mu = 105.7\ MeV/c^2$$
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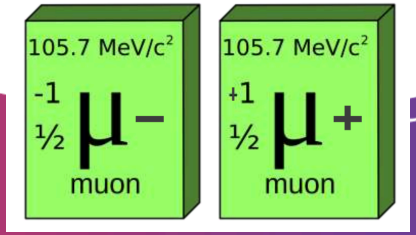

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- Executive summary
- Introduction
- Overview: Novelties, challenges, etc.
- Timelines and milestones
- Conclusion and next steps

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Executive summary

=> Go to https://e-groups.cern.ch/e-groups/ and search for groups with “muoncollider” to subscribe to the mailing lists!

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- Addressing these challenges requires the development of **innovative concepts and demanding technologies**

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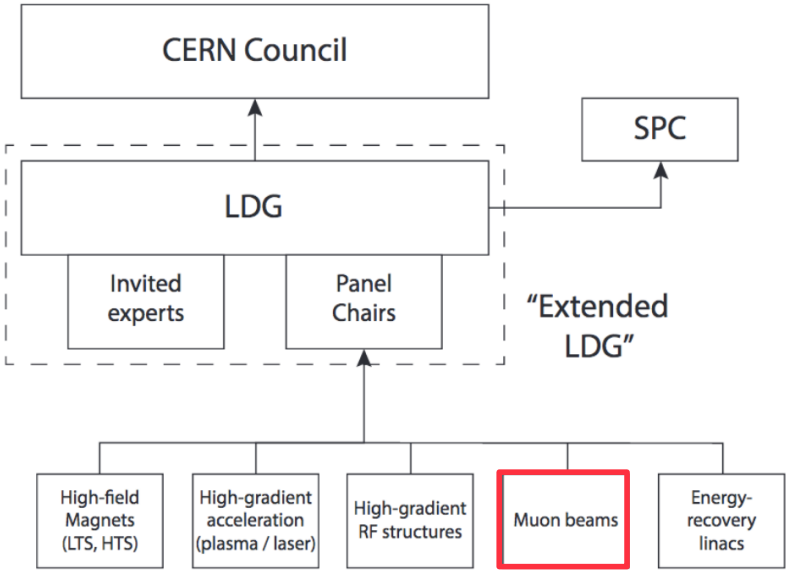
- In response to this, the Laboratory Directors Group (**LDG**), which represents the large European Particle Physics Laboratories, has initiated an **IMCC** to study the concept

Introduction

European Accelerator R&D Roadmap

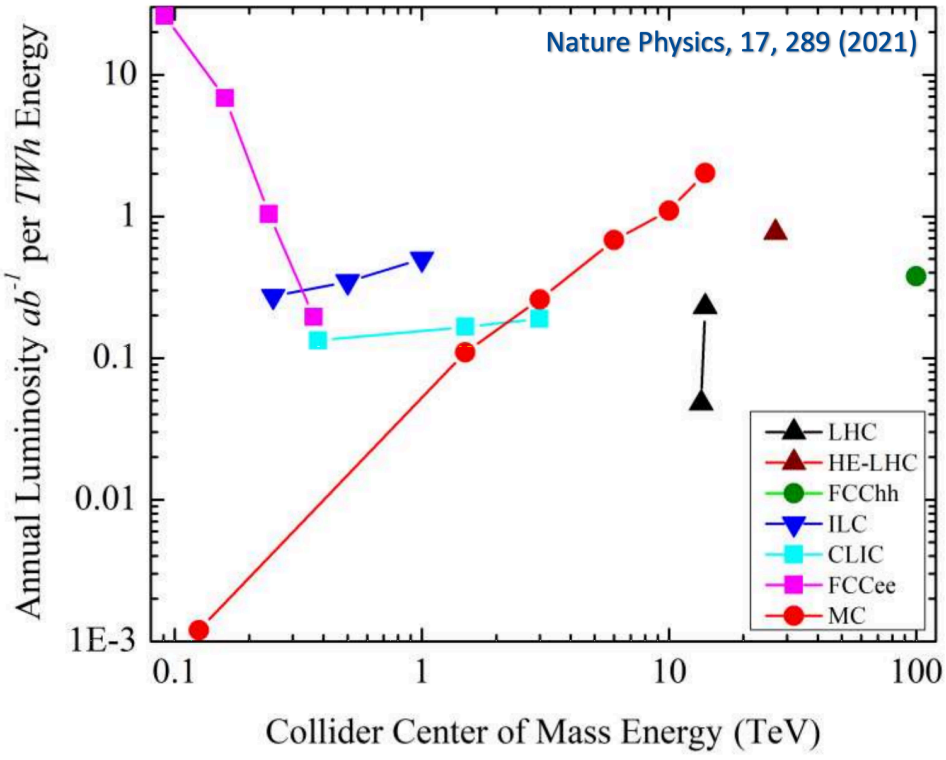
LDG: directors of the largest European Laboratories

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



Introduction

Power efficiency



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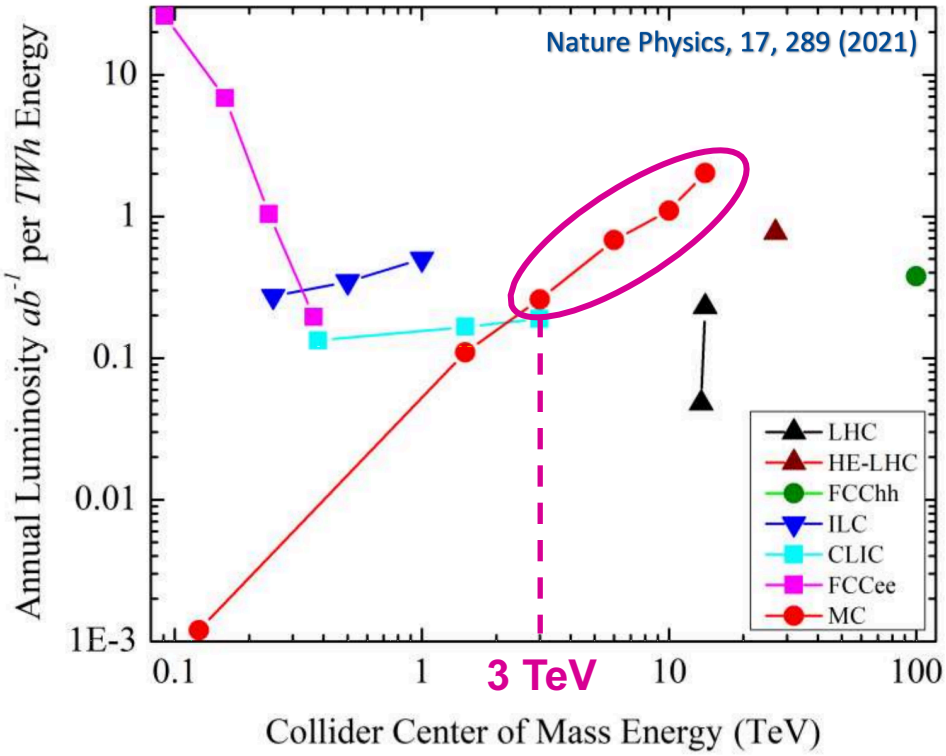
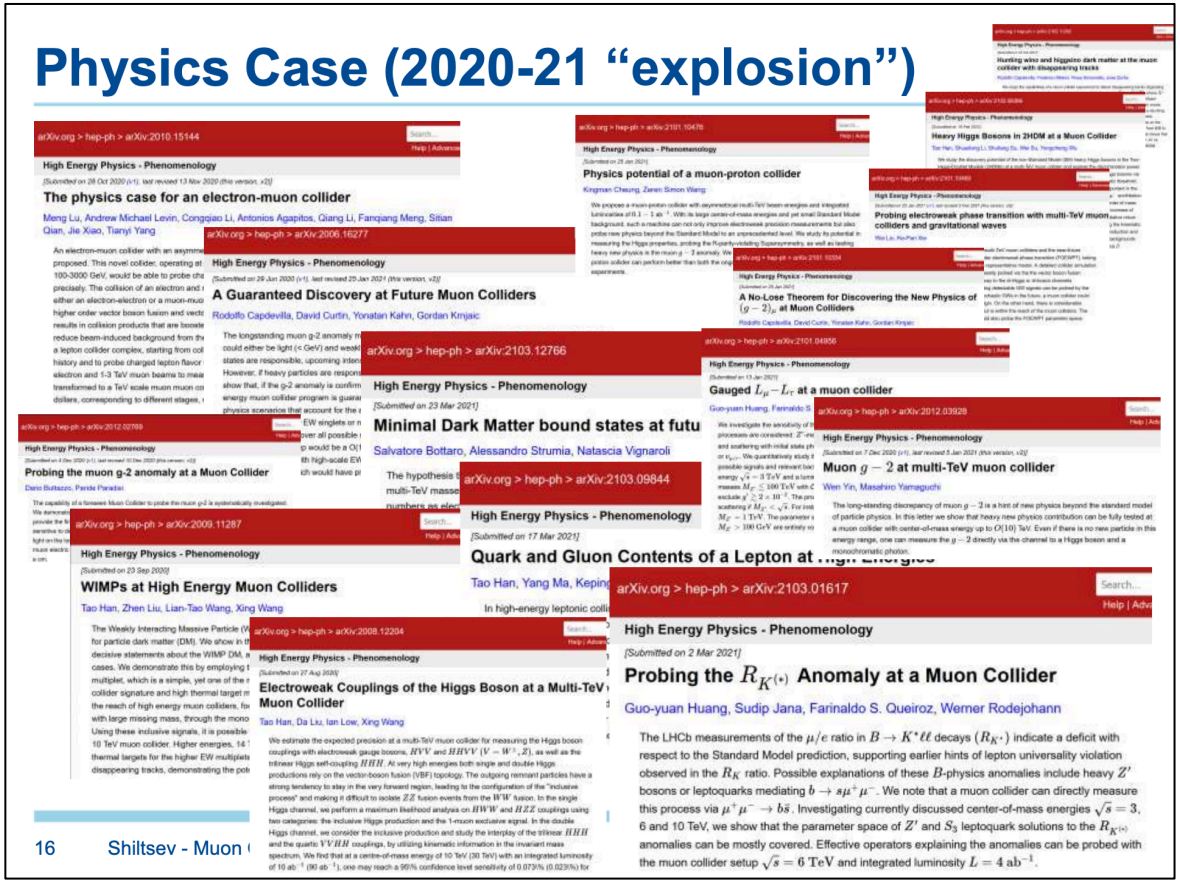


Introduction

Physics Case (2020-21 "explosion")



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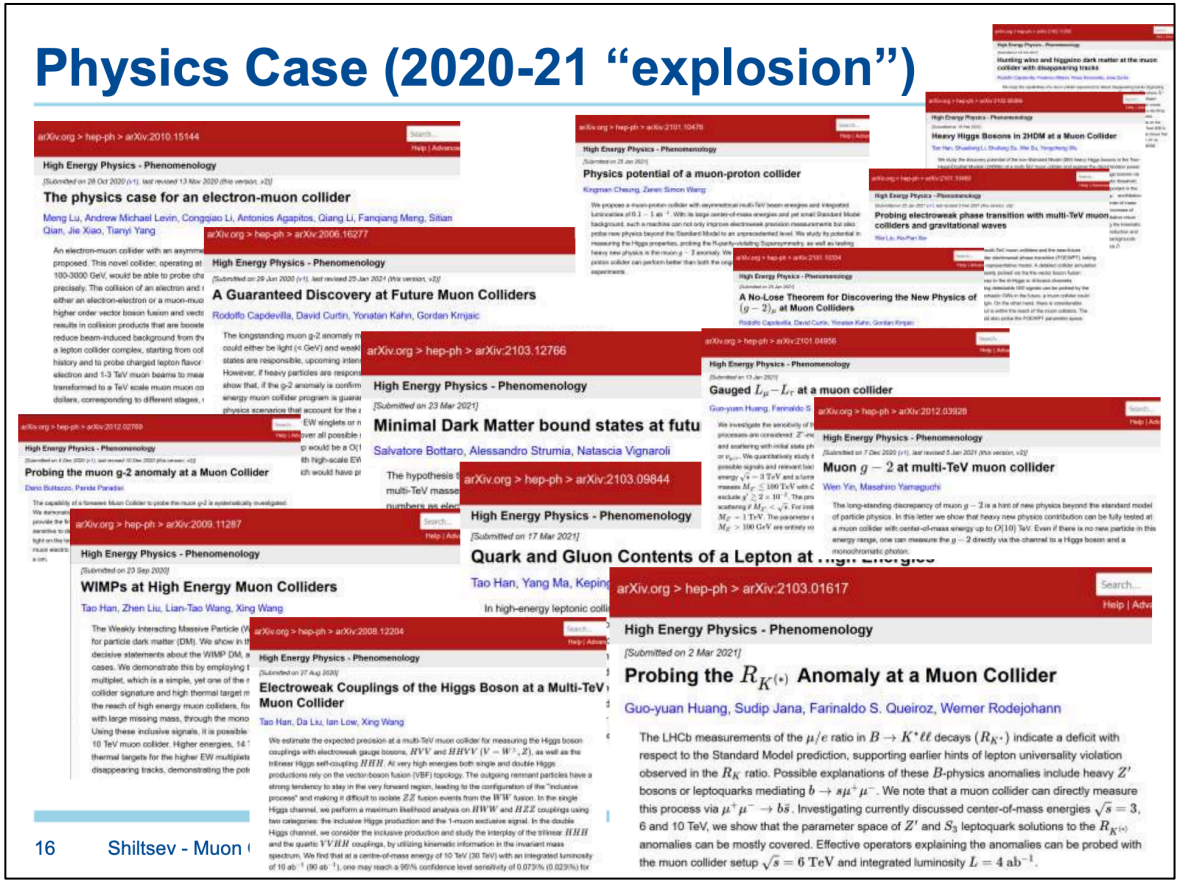

- Many physics studies
- A MC at 3 TeV offers already very good physics possibilities (compared to CLIC)!

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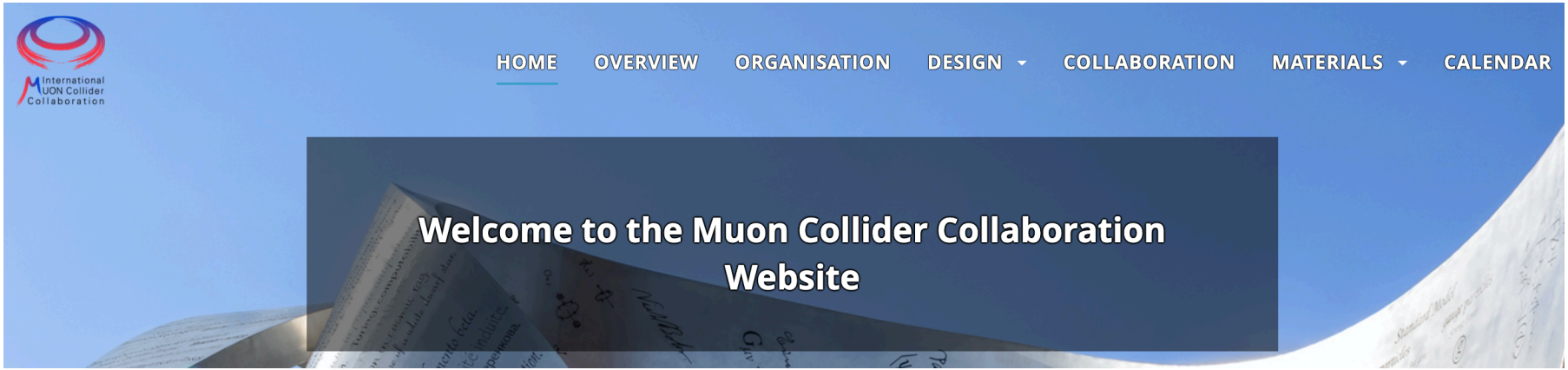
- It will provide a **baseline concept**, well-supported performance expectations and assess the **associated key risks as well as cost and power consumption drivers**
- It will also identify an **R&D path to demonstrate the feasibility of the collider**

Introduction

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



Introduction

Introduction: MAP

USEFUL LINKS

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MICE

LEMMA

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=> The current muon collider baseline concept was developed by the MAP collaboration, which conducted a focused program of technology R&D to evaluate its feasibility

Introduction: MICE

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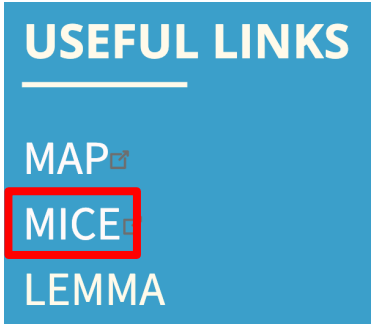

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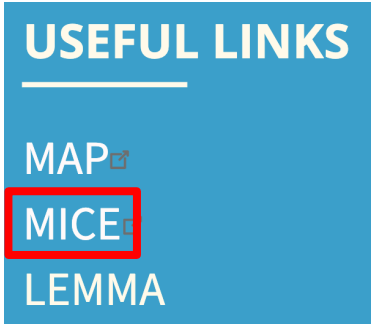
Introduction: MICE



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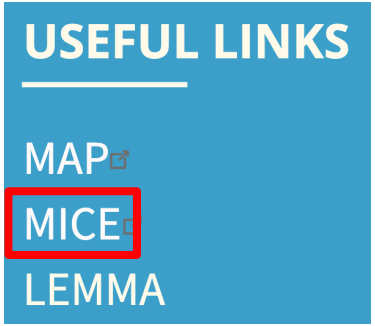

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  => M. Bogomilov et al. Demonstration of cooling by the muon ionization cooling experiment. Nature, 578, 2020

International MUON Collider Collaboration

Introduction: LEMMA

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- **Difficulty to achieve high muon beam current and hence competitive luminosity** => Novel ideas are required to overcome this limitation

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- MBP works with **collaboration and community meetings**

Introduction: 2021 meetings

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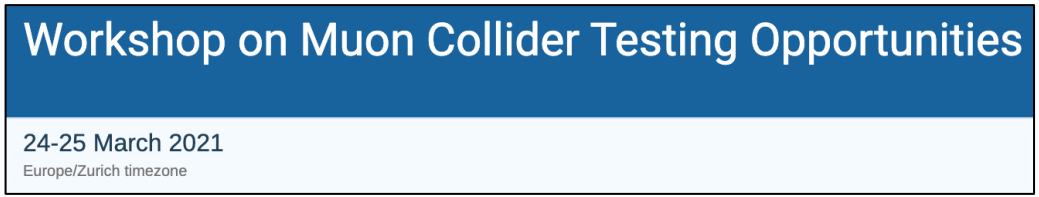
https://indico.cern.ch/event/1016248/



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Workshop on Muon Collider Testing Opportunities

24-25 March 2021
Europe/Zurich timezone

https://indico.cern.ch/event/1030726/

1st Muon Community Meeting

20-21 May 2021
Zoom
Europe/Zurich timezone

Introduction: 2021 meetings

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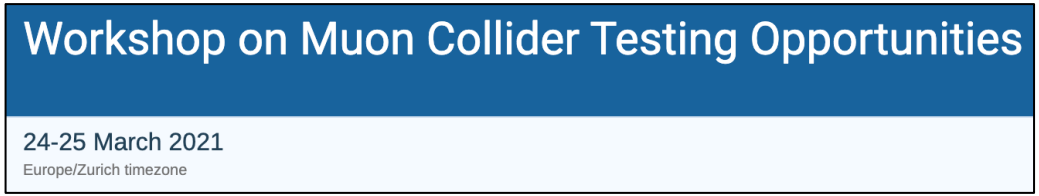

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Identify R&D challenges, first scope

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12-14 July 2021
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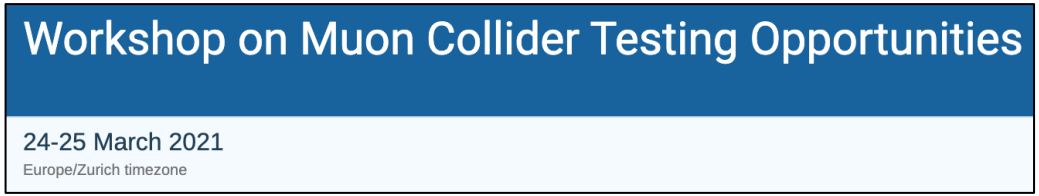

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https://indico.cern.ch/event/1043242/

2nd Muon Community Meeti…

Identify the R&D for next five years

12-14 …
E… Zurich timezone

https://indico.cern.ch/event/1062146/

3rd Muon Community Meeting

Should be 06-08/10/2021

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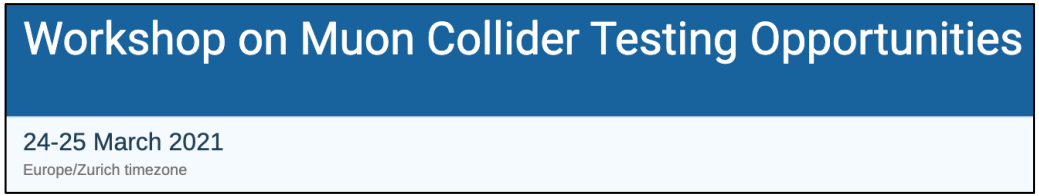

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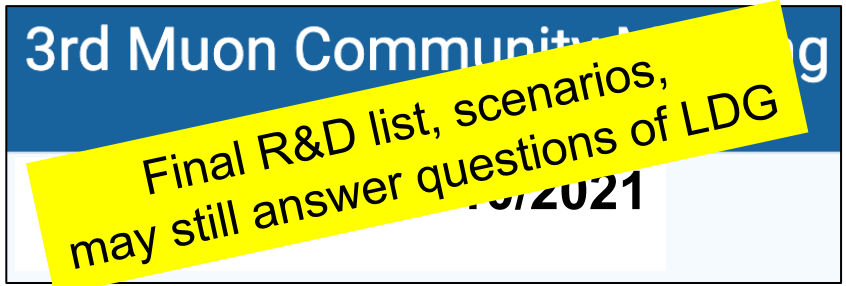

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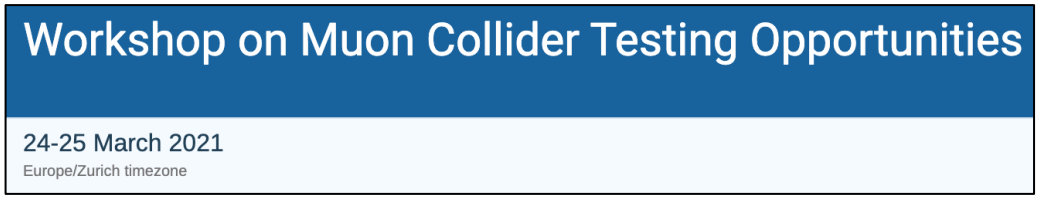

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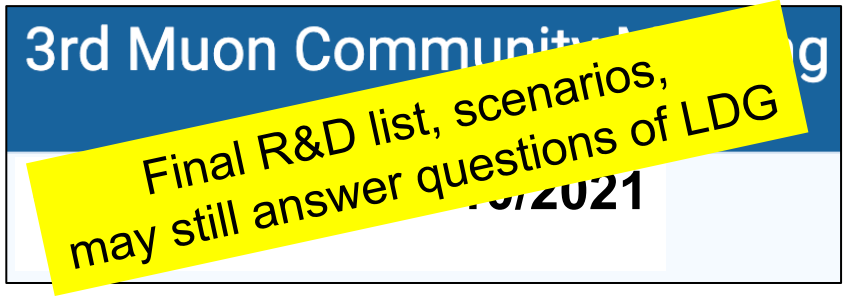

=> See more info at https://muoncollider.web.cern.ch/events-calendar

International MUON Collider Collaboration

Overview: Novelties, challenges, etc.

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Idea

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→ pions

→ muons

→ μ- μ+ collider

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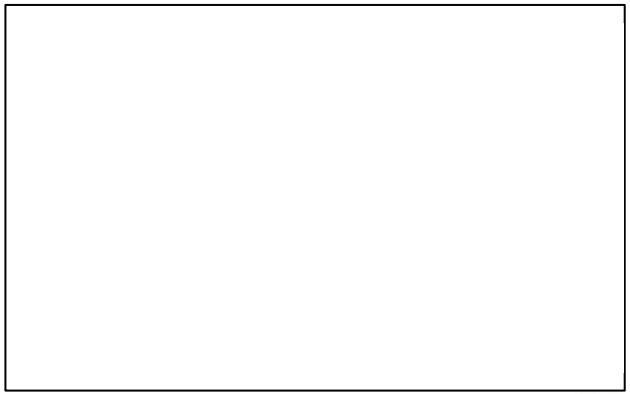
4 main challenges (of decaying particles)



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International MUON Collider Collaboration

Published: 28 July 1977

Measurements of relativistic time dilatation for positive and negative muons in a circular orbit

J. Bailey, K. Borer, F. Combley, H. Drumm, F. Krienen, F. Lange, E. Picasso, W. von Ruden, F. J. M. Farley, J. H. Field, W. Flegel & P. M. Hattersley

Nature **268**, 301–305 (1977) | Cite this article

Abstract

The lifetimes of both positive and negative relativistic ($\gamma = 29.33$) muons have been measured in the CERN Muon Storage Ring with the results $\tau^+ = 64.419\ (58)\ \mu s$, $\tau^- = 64.368\ (29)\ \mu s$ The value for positive muons is in accordance with special relativity and the measured lifetime at rest: the Einstein time dilation factor agrees with experiment with a fractional error of 2×10^{-3} at 95% confidence. Assuming special relativity, the mean proper lifetime for μ^- is found to be $\tau_0^- = 2.1948(10)\ \mu s$ the most accurate value reported to date. The agreement of this value with previously measured values of τ_0^+ confirms CPT invariance for the weak interaction in muon decay.

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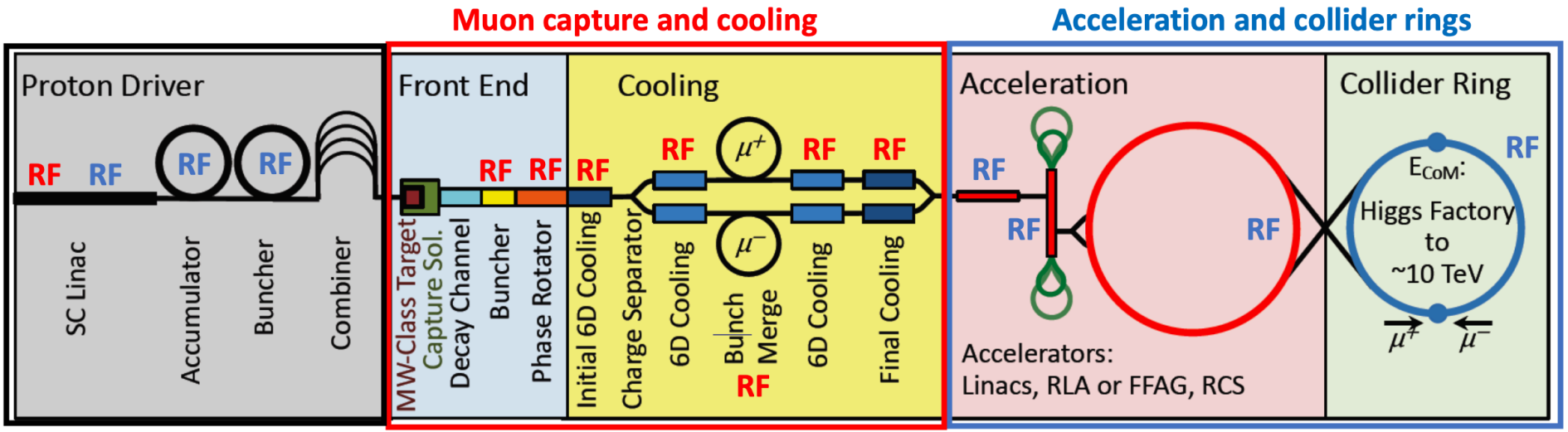
~ 150 ms at 7 TeV

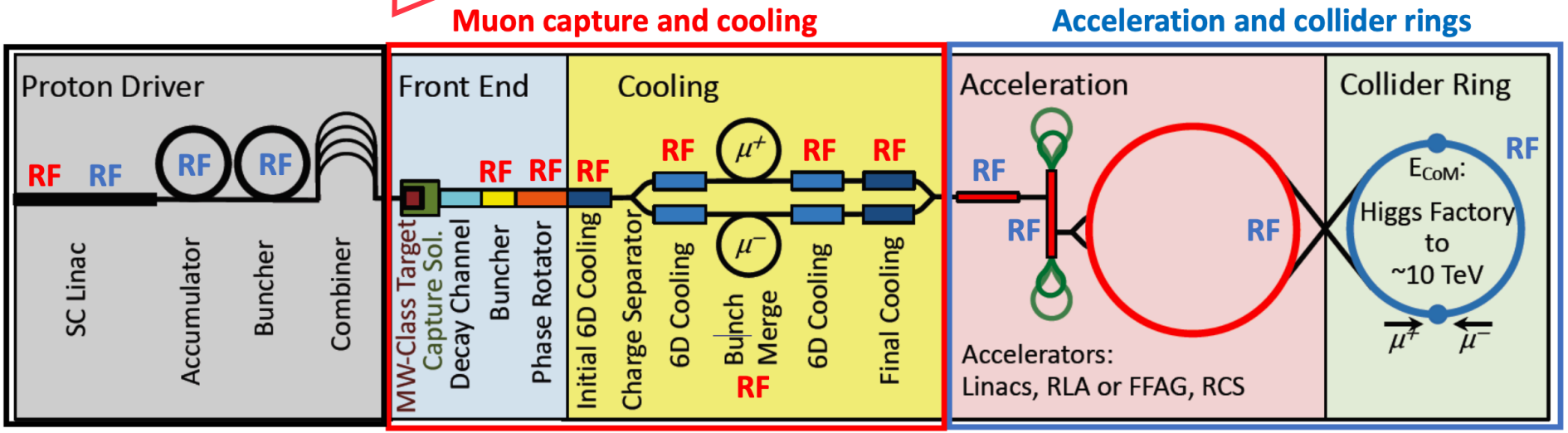
Full chain and associated main challenges



MAP collaboration

Full chain and associated main challenges

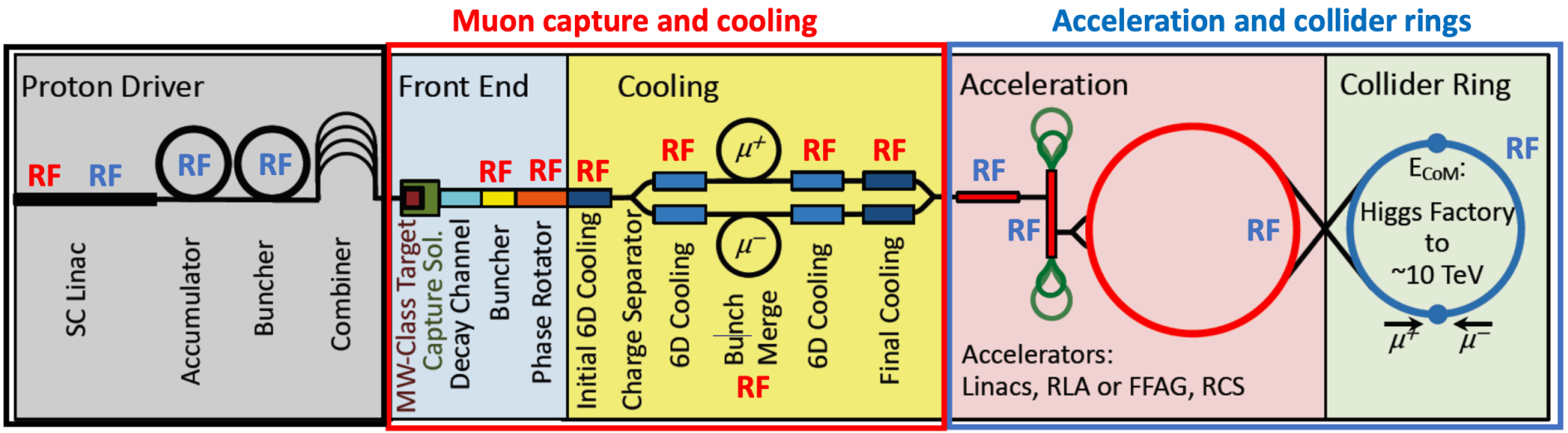
High (few MW) beam power, short (1-2 ns) bunch length, low (5 Hz) RepRate on a Target



MAP collaboration

Full chain and associated main challenges

Ionisation cooling in matter (due to short time scale)

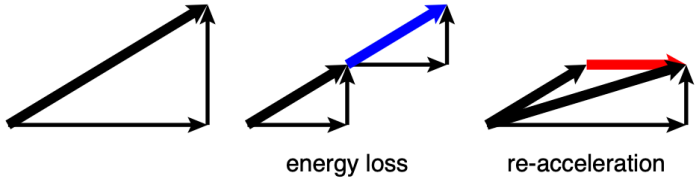


MAP collaboration

Full chain and associated main challenges

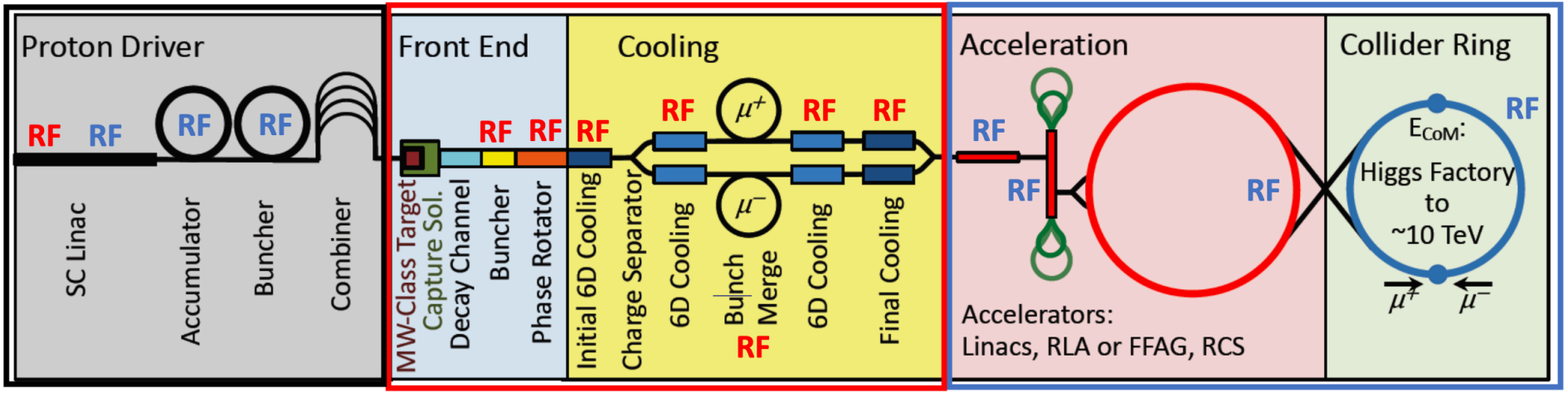
International MUON Collider Collaboration

=> Sequence of absorbers and RF cavities in high B



Muon capture and cooling

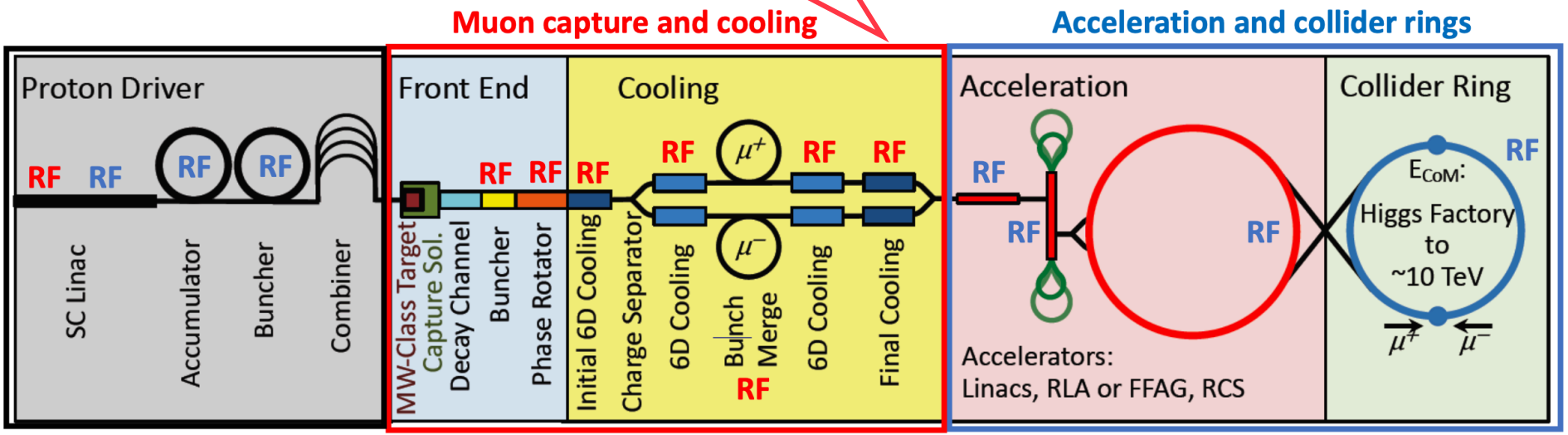
Acceleration and collider rings



MAP collaboration

Full chain and associated main challenges

Final Cooling limited by highest achievable B for solenoids: 30 T => ~ 50 T?



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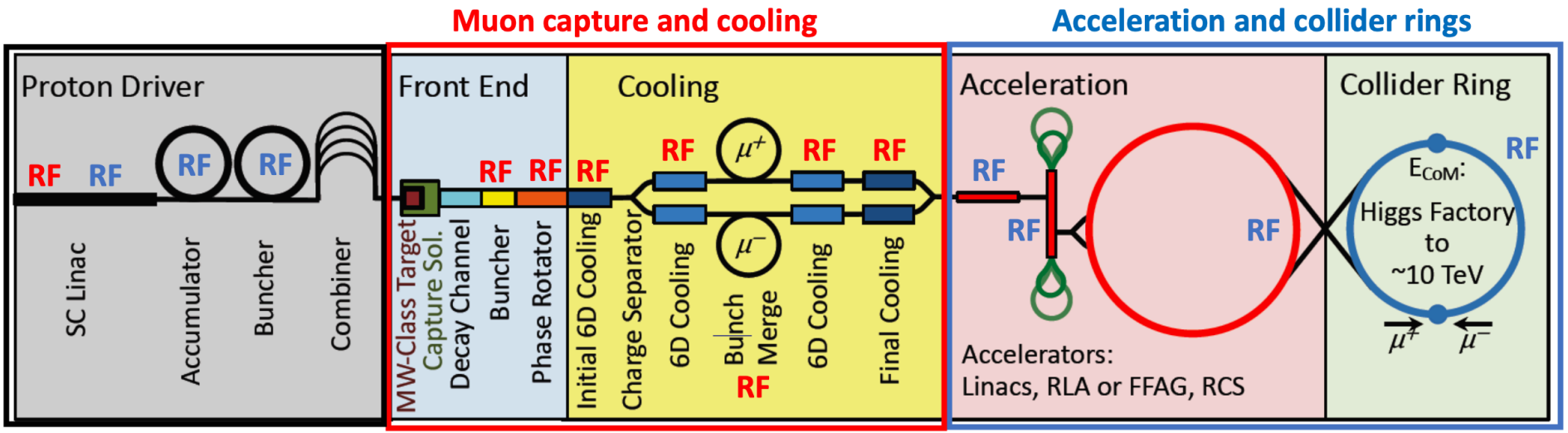
Full chain and associated main challenges

Fast acceleration from ~ 0.2 GeV/c to the TeV scale



MAP collaboration

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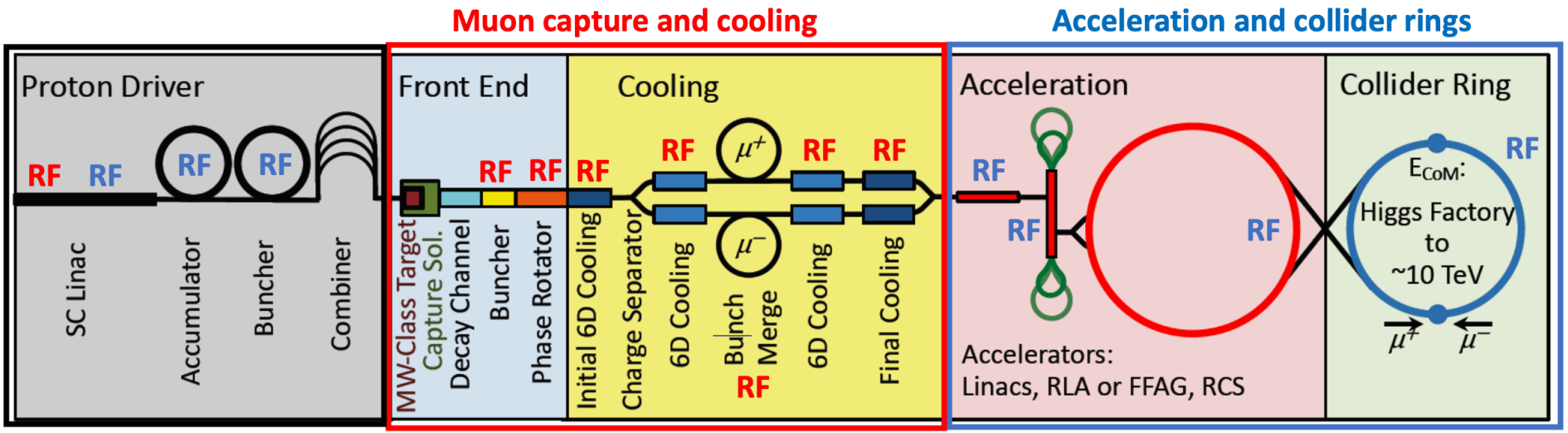
International MUON Collider Collaboration

=> RF gradient for muon survival in MV/m range with dB/dt of few kT/s



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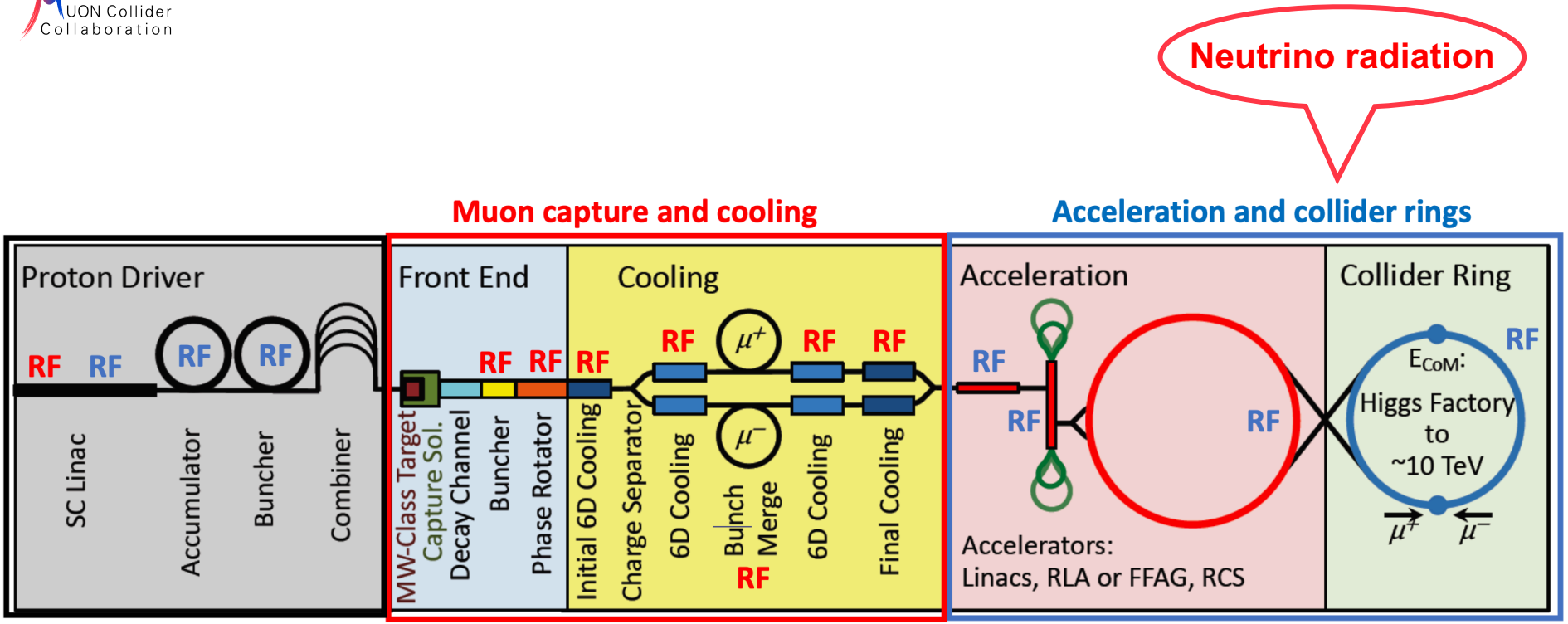
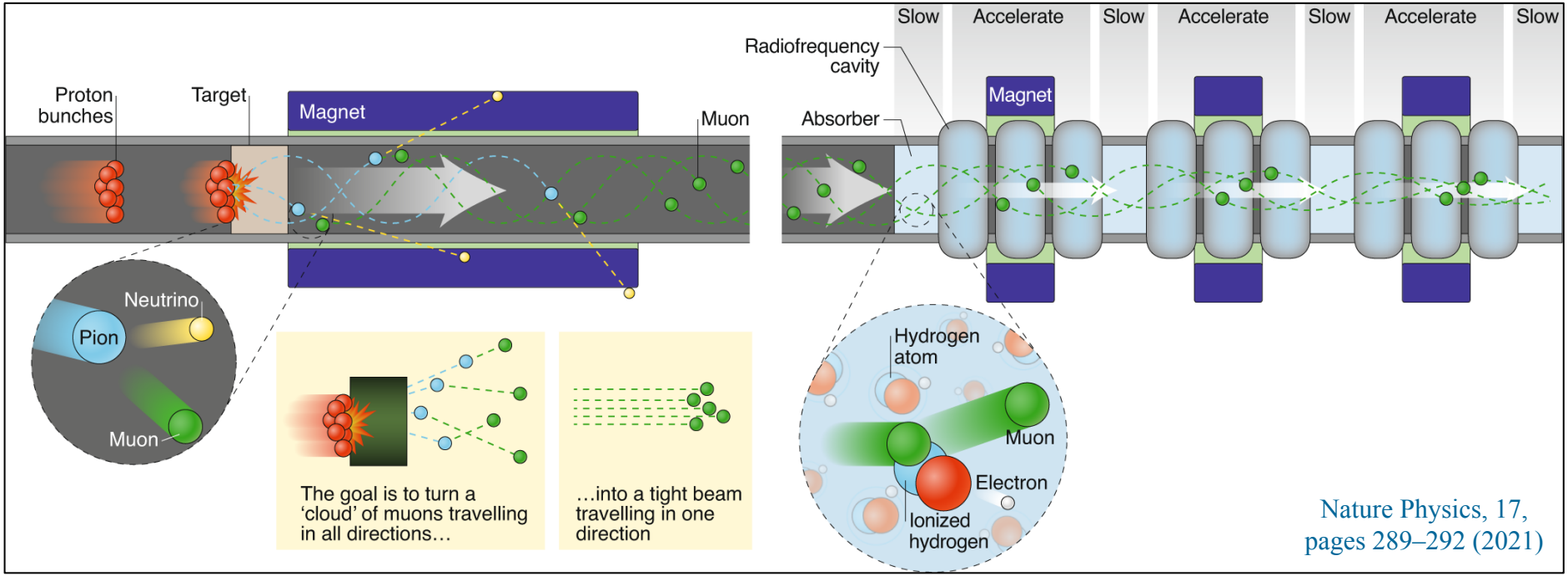


Muon production and cooling



Nature Physics, 17, pages 289–292 (2021)

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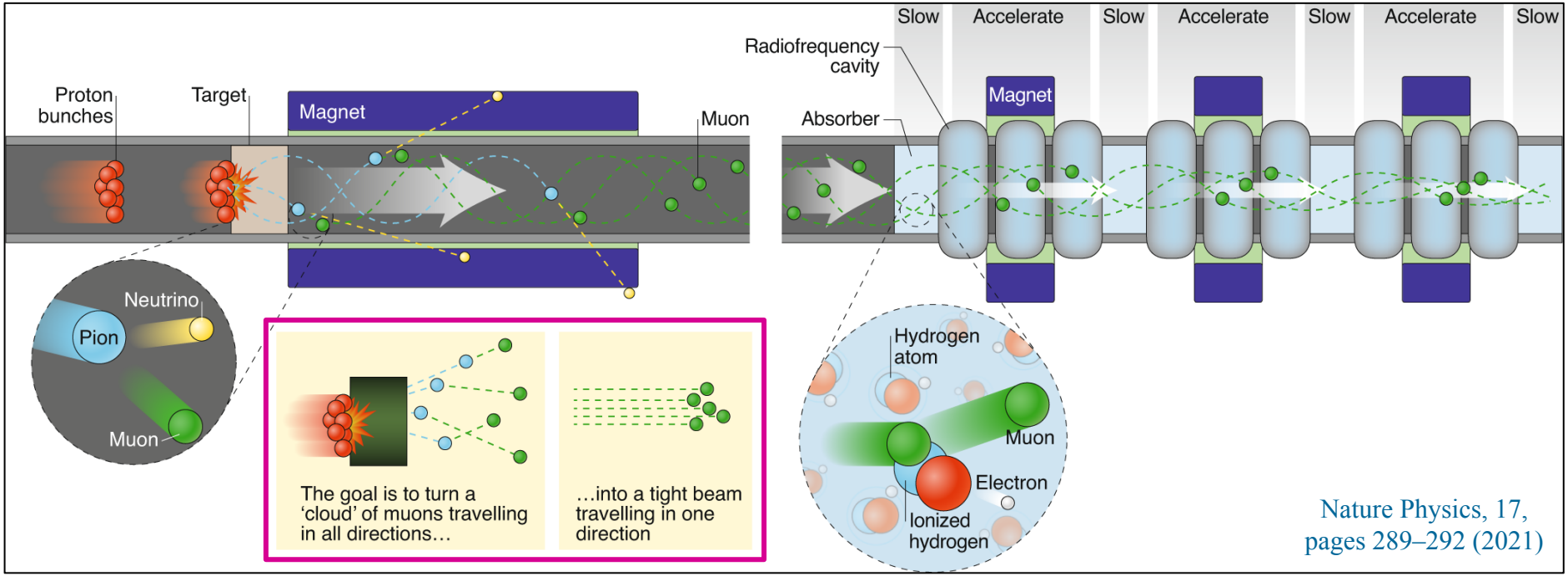

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Energy and luminosity goals for the IMCC

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

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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
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ε	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

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Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L} dt$
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Now study if these parameters lead to realistic design with acceptable cost and power

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(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
	Charge separator	0.90		1.05		1.05		0.255	12	23.19	3150	10	85.2	5.7E+04
	6D cooling before merge	0.72		0.5		0.20		0.255	12	16.58	1575	2	85.2	4.1E+04
	6D merge	0.88		2		4.00		0.255	1	14.59	3150	8	92.3	3.0E+03
	6D cooling after merge	0.44		0.067		0.23		0.255	1	6.42	211	2	92.3	1.3E+03
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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
	RLA1	0.92		1.02		1.02		5	1	3.32	42	105	23.1	1.3E+04
	RLA2	0.85		1.02		1.02		62.5	1	2.83	43	107	23.1	1.4E+05
	RCS1	0.90		1.02		1.02		303	1	2.54	44	109	23.1	6.2E+05
	RCS2	0.92		1.02		1.02		750	1	2.34	45	112	23.1	1.4E+06
	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								

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J.P.Delahaye

2

International MUON Collider Collaboration

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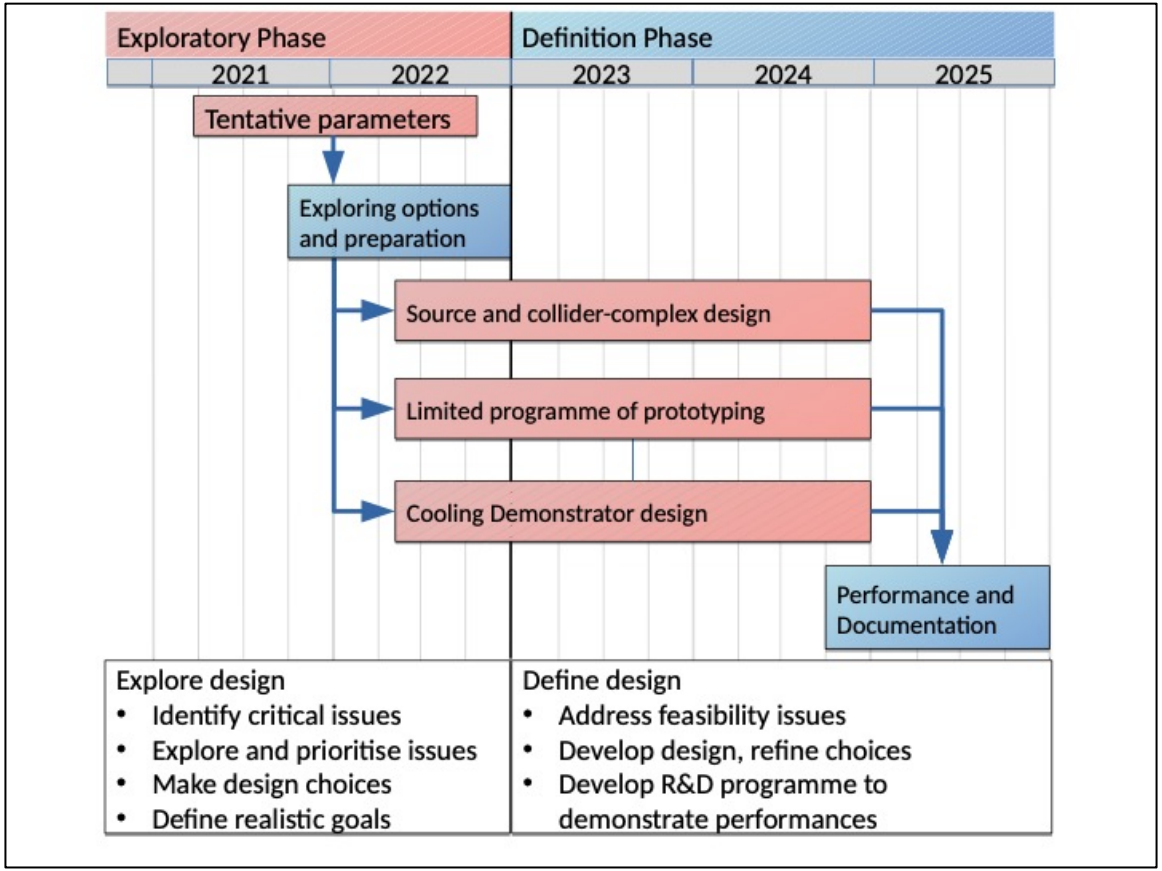
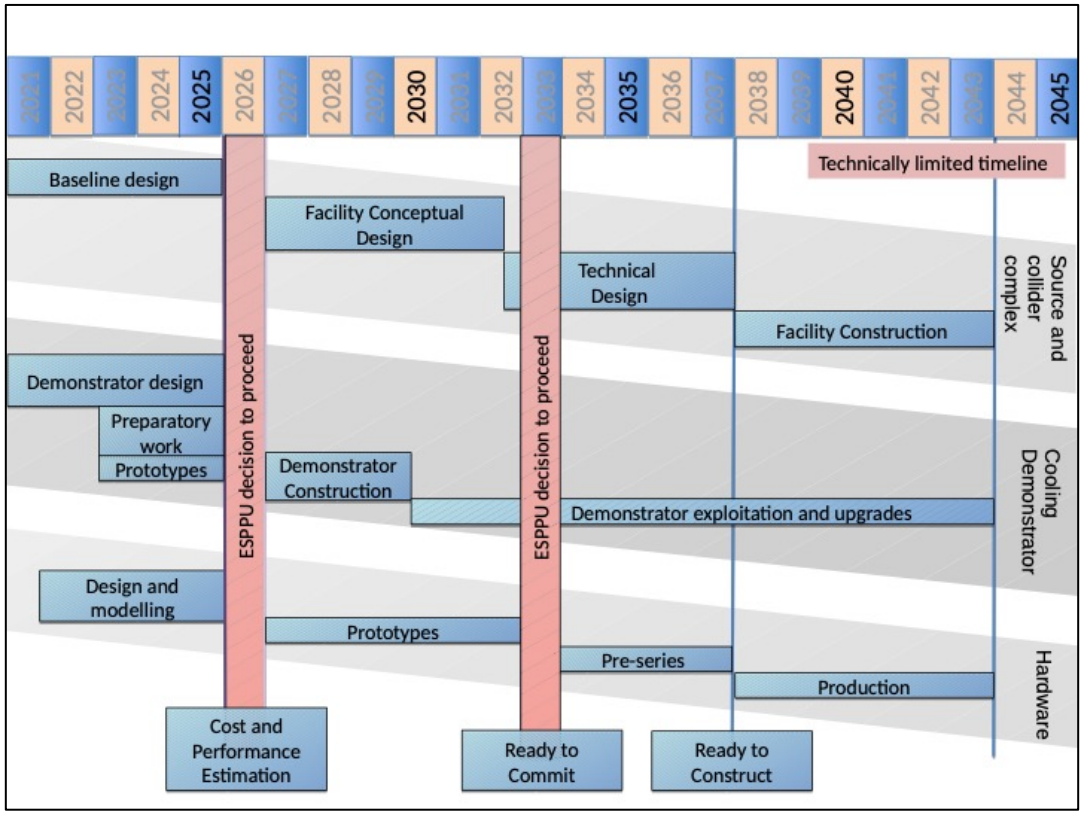
- **06-07/12/21**: SPC / Council => **LDG provides final report (to be finalised before) to Council (hoping to gain approval)**

A timeline for R&D leading to next ESPPU



A technically limited timeline for 3 TeV construction by 2045



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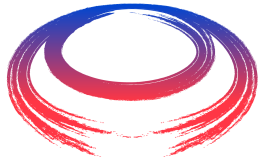
- **This R&D effort will allow the next ESPPU to make fully informed decisions**
- Based on these decisions a significant ramp-up of resources could be made to accomplish construction by 2045 and **exploit the enormous potential of the muon collider**

Quite some challenging and interesting work ahead of us!



Thank you for your attention