The case for a Muon Collider

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Graduate symposium

Science and Technology Facilities Council
ISIS Neutron and Muon Source

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Collider comparison

Machine	Budget – according to Snowmass'21 ($) 2023 prices	Centre of mass energy (TeV)	Maximum circumference /length (km)	Completion date	Will I be dead before it runs?
FCC-ee	13 - 20bn	0.37	~100km	2045	No
FCC-hh	34 – 56bn	100	~100km	Construction starts in 2060s	Maybe?
CLIC	7.8 – 13.5bn	0.38	~11km		
Muon collider - 3	7.8 – 13.5bn	3	~30km	2045*	No
Muon collider - 10	13.5 – 20bn	10	~30km	?	?

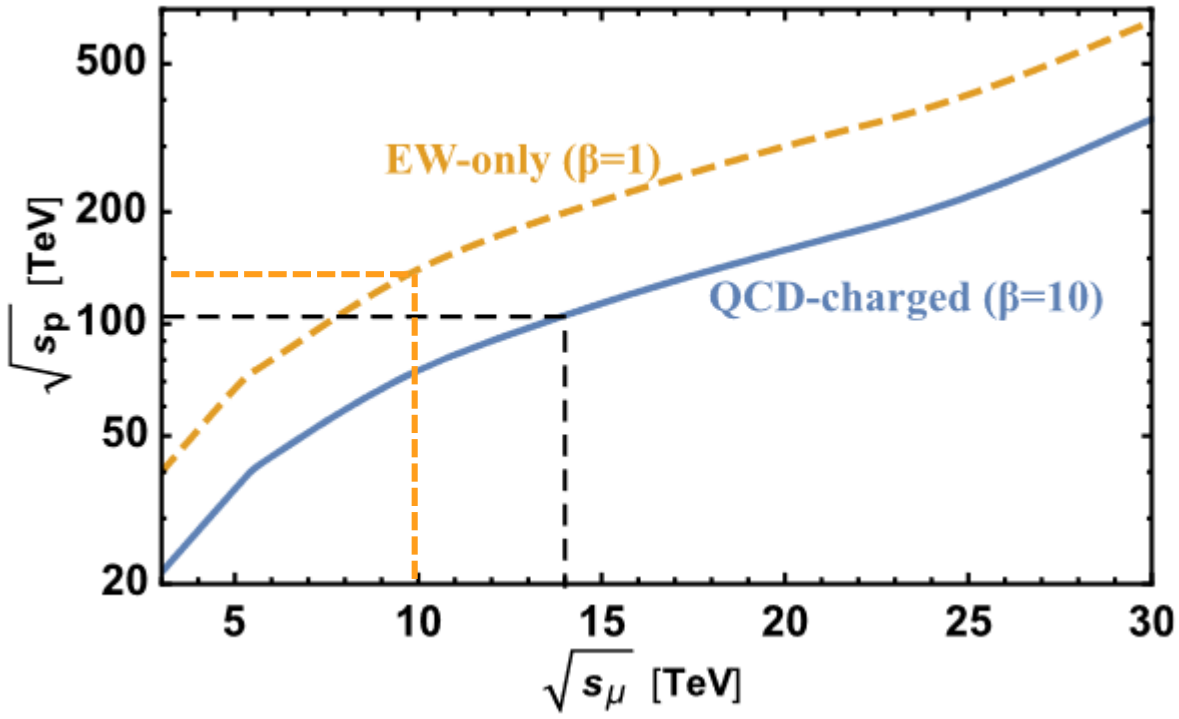
* Technically limited timeline

- FCC week - Funding options and integration of the FCC ee construction and operation in CERN's financial plan Florian Sonnemann, CERN
- Report of the Snowmass 2021 Collider Implementation Task Force - On the feasibility of future colliders: report of the Snowmass'21 Implementation Task Force, Roser et al
- Towards a muon collider. *The European Physical Journal C*, *83*(9), 864

Why muons?

- A lepton collider with out the drawback of synchrotron radiation.
- Unlike protons the entire centre of mass energy is available for the collision.

The equivalent proton collider energy needed to match a muon collider.

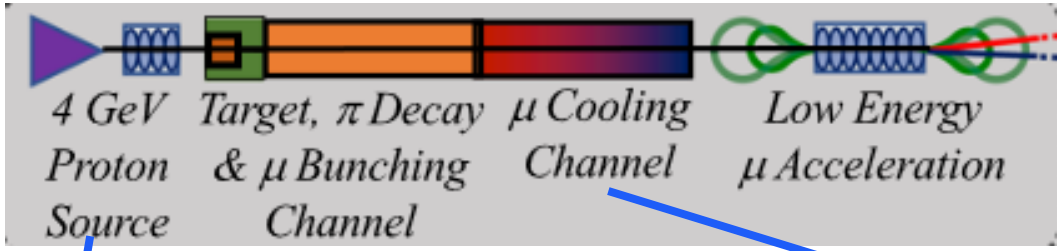


Towards a muon collider. *The European Physical Journal C*, *83*(9), 864

The obvious problem…

- Why hasn’t this been done already?
- Of course, muons decay in ~ 2μS
- However, since the muons are accelerated their decay time is time-dilated.
- The acceleration chain must be as fast as possible…
  - One of many challenges
  - For example the LHC ramps up in energy over many hours, the muon collider acceleration time is a few milliseconds (depending on the acceleration stage)

How does it work?

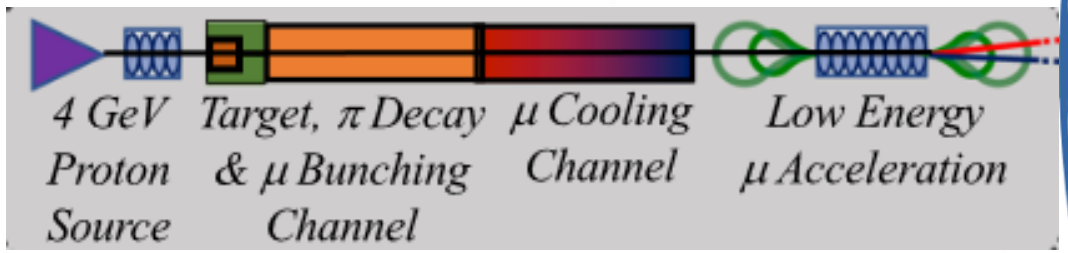


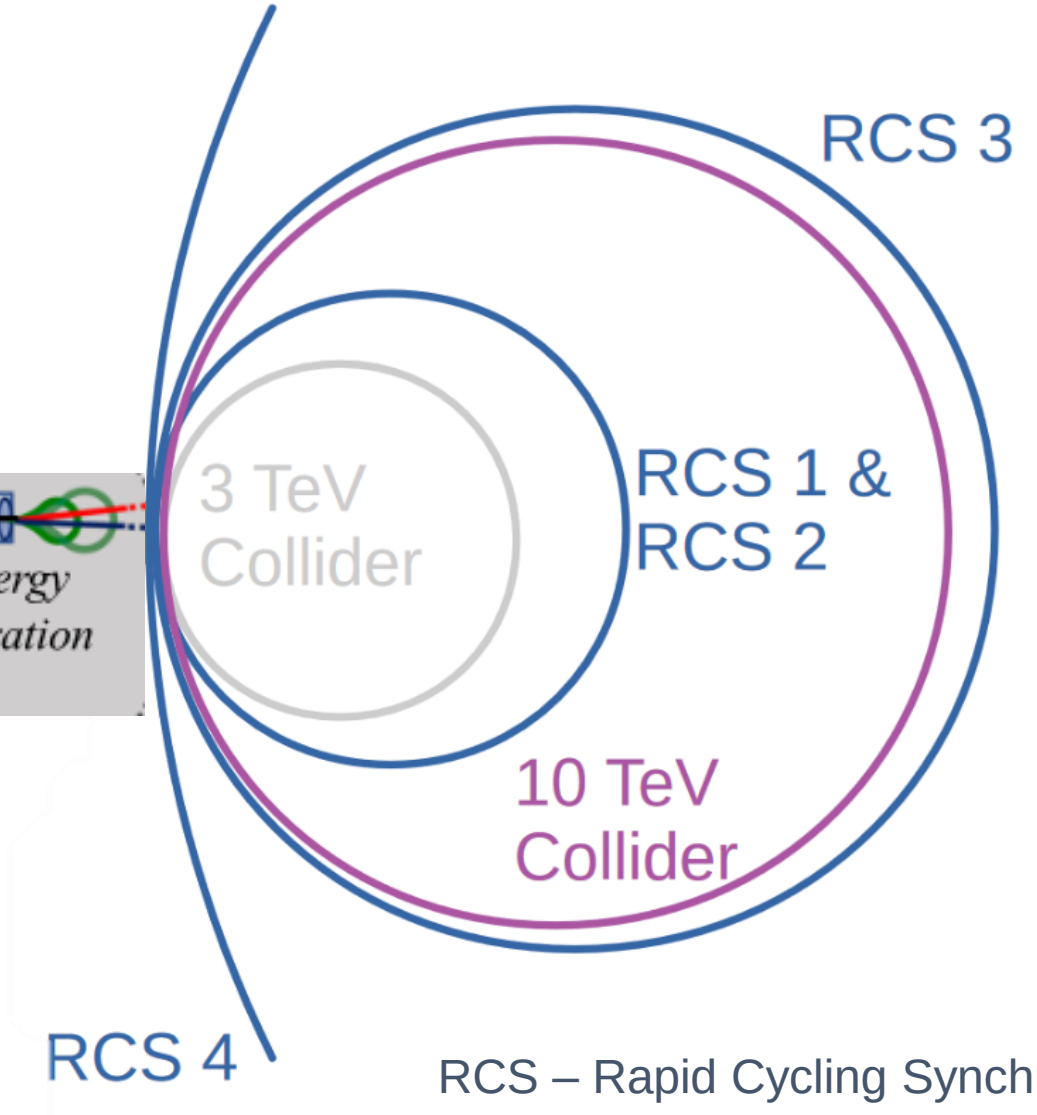
ISIS-II scale proton source

- Muon cooling was demonstrated at the MICE experiment at ISIS.

Demonstration of cooling by the Muon Ionization Cooling Experiment – MICE collaboration, 2020

How does it work?





RCS – Rapid Cycling Synchrotron

Physics reach

- High sensitivity than even FCC-hh for some BSM candidates in a 10 TeV muon collider.
- Wimp candidates are accessible for 10 TeV MuC

- A 3 TeV muon collider can access similar physics to CLIC and FCC-ee and some physics unique to muon-muon collisions.

- Difficult to access heavy particles that carry only QCD interactions – proton colliders are better suited to this

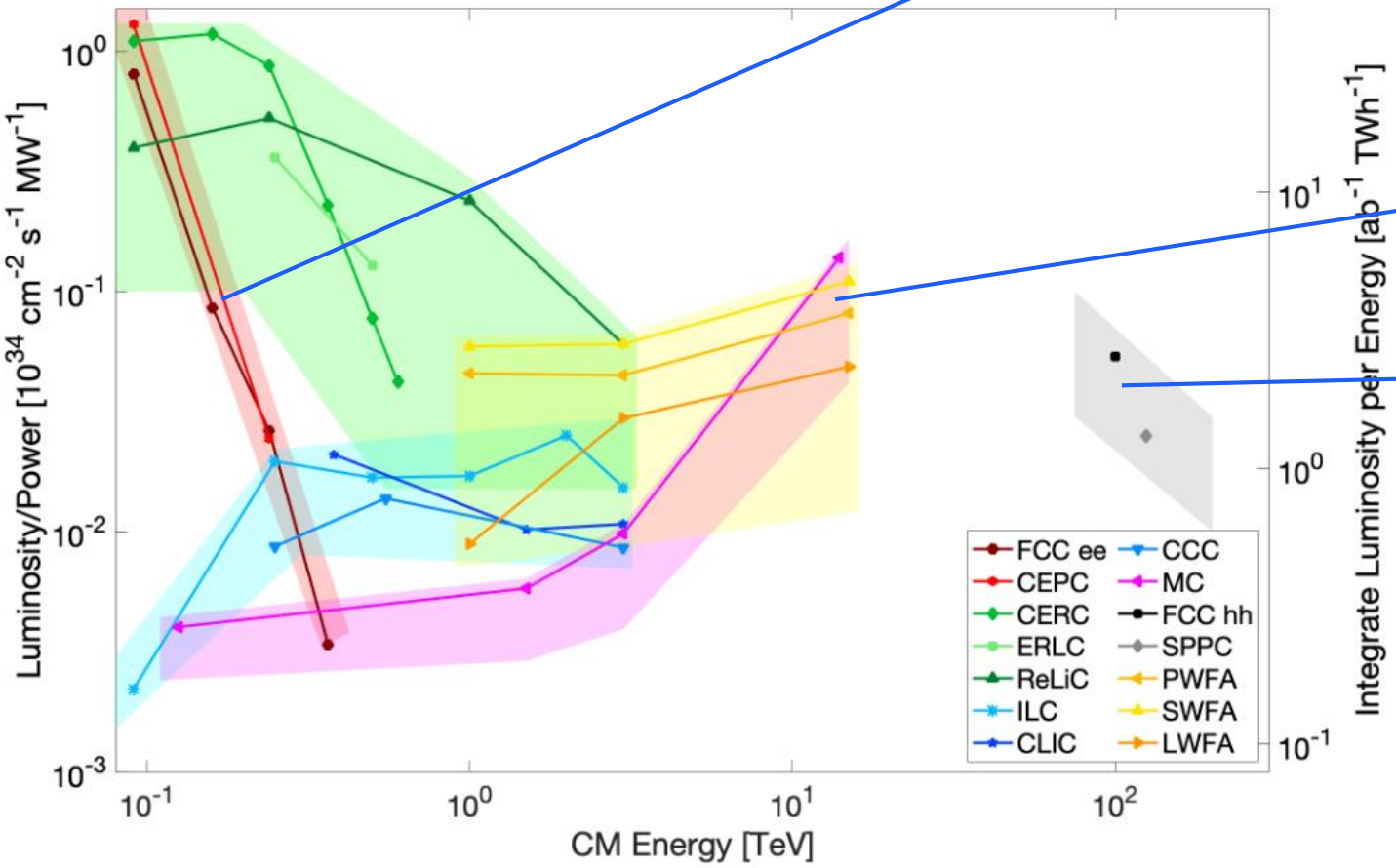
The physics case of a 3 TeV muon collider stage, Jorge De Blas et al, Snowmass 2021

Physics reach

FCC-ee and CEPC

Muon Collider

FCC-hh



Report of the Snowmass 2021 Collider Implementation Task Force - On the feasibility of future colliders: report of the Snowmass'21 Implementation Task Force, Roser et al

The problems*

- Certainly a higher risk option than FCC but… no 100km tunnel.

- Magnet ramping.
- Radiation load.
- Neutrino flux.
- Detector background.
- Muon cooling + demonstrator.
- ISIS-II scale high intensity proton source required.

*No particular order and not exhaustive of course.

Muon Collider Forum Report K. M. Black et al. Snowmass 2021

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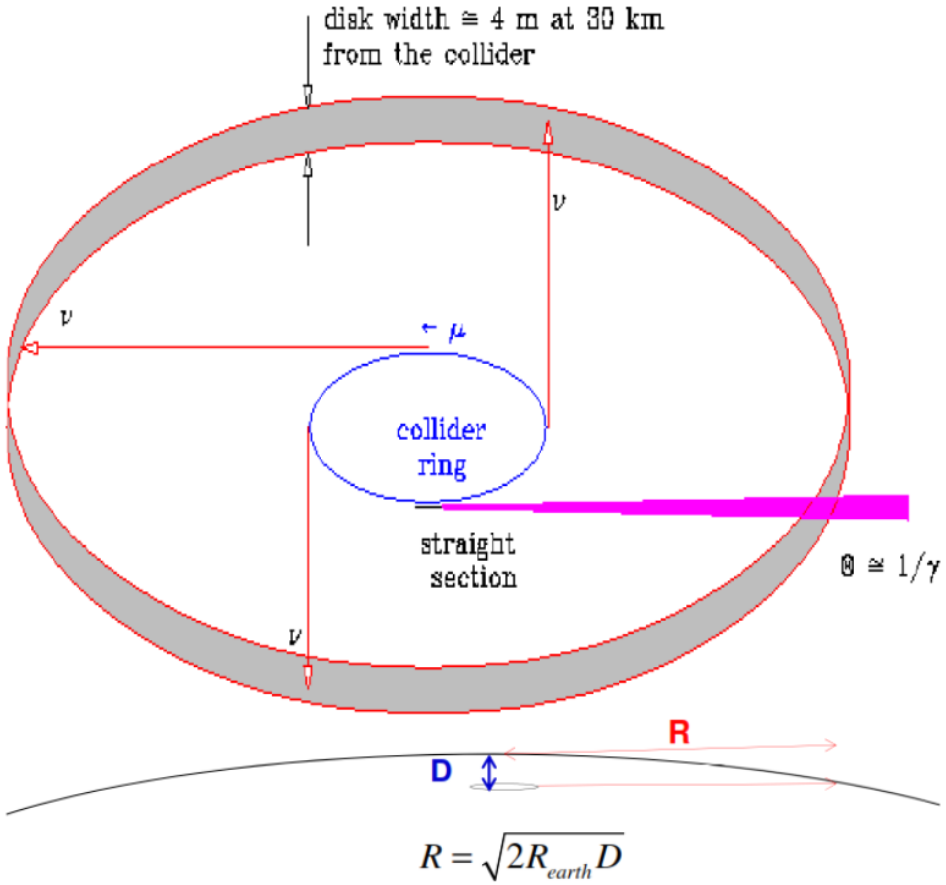
The neutrino flux from straight sections in the collider ring



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Muon Collider Forum Report K. M. Black et al. Snowmass 2021

Summary

- FCC ee physics at a lower cost
- Potential for FCC hh physics in the 10 TeV collider
- No 100km tunnel construction
- Emphasised in the US P5 report!

References

- MICE collaboration. Demonstration of cooling by the Muon Ionization Cooling Experiment. Nature 578, 53–59 (2020). https://doi.org/10.1038/s41586-020-1958-9
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