# Muon Collider

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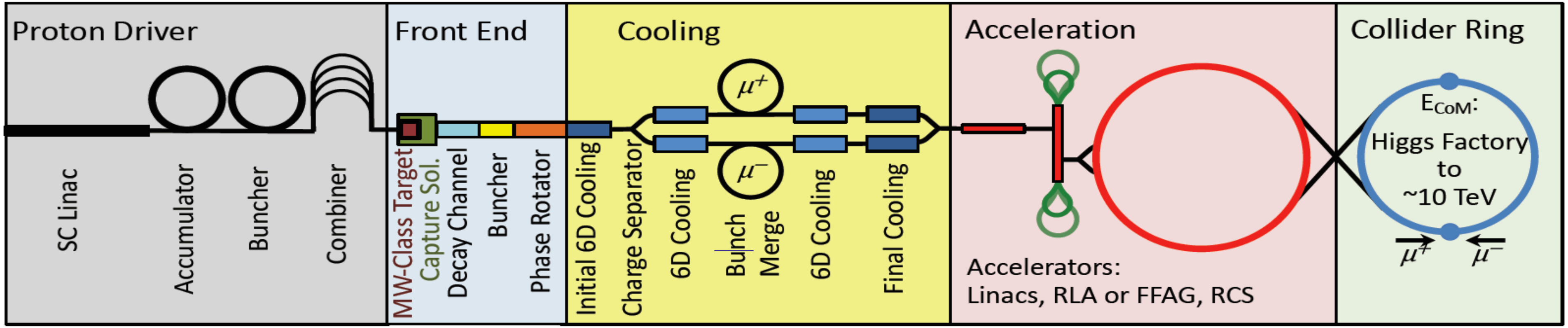
for the International Muon Collider Collaboration

CERN
March 2023

# Collider Concept

Fully driven by muon lifetime, otherwise would be easy




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

Thanks to MAPS

# Motivation and Goal

Previous studies in US (now very strong interest again), experimental programme in UK and alternatives studies by INFN

New strong interest in **high energy, high luminosity lepton collider**
- Combines **precision physics** and **discovery reach**

Muon collider promises **sustainable** approach to the **energy frontier**
- limited power consumption, cost and land use

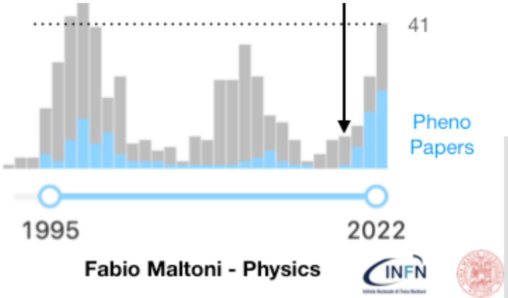
**Technology** and **design advances** in past years
- reviews in Europe and US did not find any showstoppers

Goal is
- 10+ TeV collider
- potential initial energy stage (e.g. 3 TeV)
- higher energies to be explored later

# A new Interest in Muon Colliders

## From, e.g., Snowmass21 EF report draft:

*"A 10-TeV scale muon collider with sufficient integrated luminosity provides an energy reach similar to that of a 100 TeV proton-proton collider. [...] muon and hadron colliders have similar reach and can significantly constrain scenarios motivated by the naturalness principle. [...] Multi-TeV muon colliders will have the benefit of excellent signal to background [...] One of the key measurements from the multi-TeV colliders is the one of the Higgs self-coupling to a precision of a few percent, and the scanning of the Higgs potential."*




from F. Maltoni at IMCC Annual Meeting

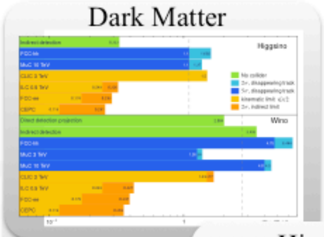
A. Wulzer, F. Maltoni, P. Meade et al.

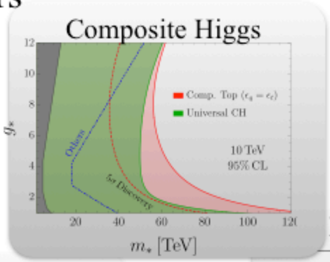
O(150) authors, 15 editors, 100 papers

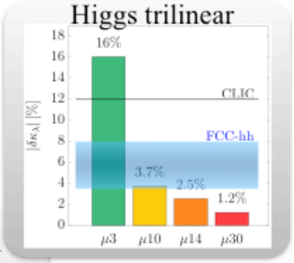
International
UON Collider
Collaboration

## Selected summary plots, from Snowmass21 reports:

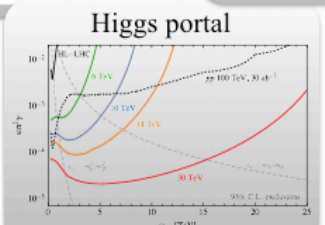
2 IMCC reports, plus Muon Collider Forum report. Total of 15 editors, ~150 authors, based on ~100 papers from 3 past years





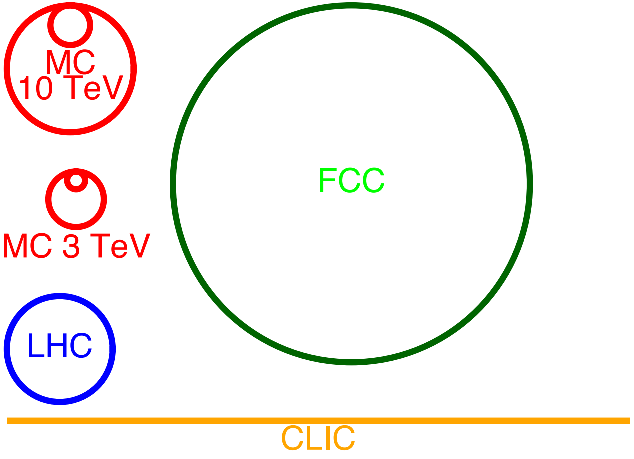


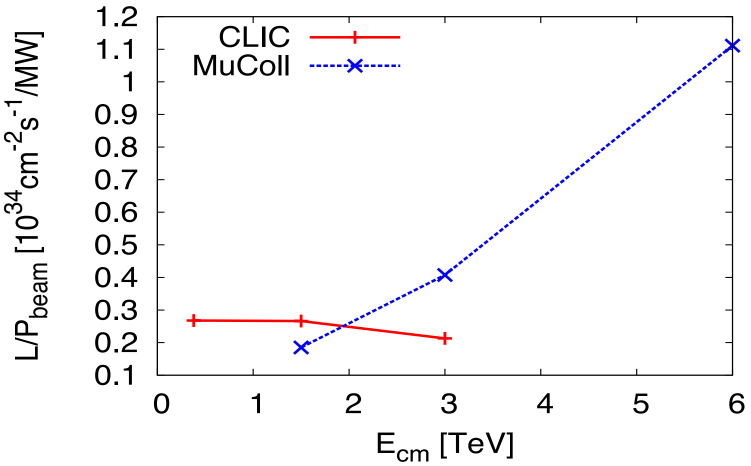

Higgs couplings

| | HL-LHC | HL-LHC +10 TeV | HL-LHC +10 TeV + $ee$ |
|---|---|---|---|
| $\kappa_W$ | 1.7 | 0.1 | 0.1 |
| $\kappa_Z$ | 1.5 | 0.4 | 0.1 |
| $\kappa_g$ | 2.3 | 0.7 | 0.6 |
| $\kappa_\gamma$ | 1.9 | 0.8 | 0.8 |
| $\kappa_{Z\gamma}$ | 10 | 7.2 | 7.1 |
| $\kappa_c$ | - | 2.3 | 1.1 |
| $\kappa_b$ | 3.6 | 0.4 | 0.4 |
| $\kappa_\mu$ | 4.6 | 3.4 | 3.2 |
| $\kappa_\tau$ | 1.9 | 0.6 | 0.4 |
| $\kappa_t^*$ | 3.3 | 3.1 | 3.1 |

* No input used for $\mu$ collider

# Sustainability




CLIC is highest energy proposal with CDR

- No obvious way to further improve linear colliders (decades of R&D)
- Cost 18 GCHF, power approx. 500 MW

Rough rule of thumb:

- cost proportional to energy
- power proportional to luminosity

**Muon Collider goals (10 TeV),** challenging but reasonable:

- Much **more luminosity** than CLIC at 3 TeV **($L=20\times10^{34}$, CLIC: $L=2\times10^{34}/6\times10^{34}$)**
- **Lower power consumption** than CLIC at 3 TeV ($P_{beam,MC}=0.5\ P_{beam,CLIC}$)
- **Lower cost**

**Staging** is possible
**Synergies** exist (neutrino/higgs)
Unique opportunity for a **high-energy, high-luminosity lepton collider**

# 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 | |
| $\varepsilon_L$ | MeV m | 7.5 | 7.5 | 7.5 | |
| $\sigma_E$ / E | % | 0.1 | 0.1 | 0.1 | |
| $\sigma_z$ | mm | 5 | 1.5 | 1.07 | |
| $\beta$ | mm | 5 | 1.5 | 1.07 | |
| $\varepsilon$ | μm | 25 | 25 | 25 | |
| $\sigma_{x,y}$ | μm | 3.0 | 0.9 | 0.63 | |

# Accelerator R&D Roadmap

International MUON Collider Collaboration

European Roadmap and Snowmass process

- **no insurmountable obstacle** identified
- less mature than other options

Full funding scenario deliverables by next ESPPU/other processes

- **Project Evaluation Report**
  - key performance, risk, cost and power drivers
  - site considerations (CERN and elsewhere)
- **R&D Plan**
  - describes a path towards the collider;
  - key element is **demonstrator concept**
- **Interim Report** (2023)

Allows to make **informed decisions**

http://arxiv.org/abs/2201.07895

| Label | Begin | End | Description | Aspirational | | Minimal | |
|---|---|---|---|---|---|---|---|
| | | | | [FTEy] | [kCHF] | [FTEy] | [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 |

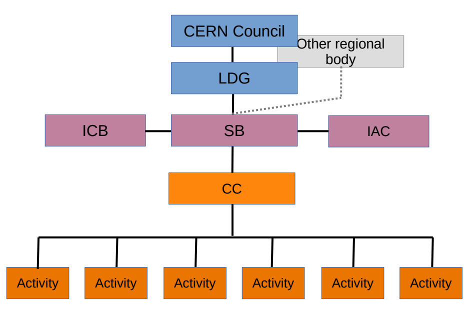
**Table 5.5:** The resource requirements for the two scenarios. The personnel estimate is given in full-time equivalent years and the material in kCHF. It should be noted that the personnel contains a significant number of PhD students. Material budgets do not include budget for travel, personal IT equipment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

Current funding only allows addressing subset
Attempting to secure more funding

# Muon Collider Community

International MUON Collider Collaboration

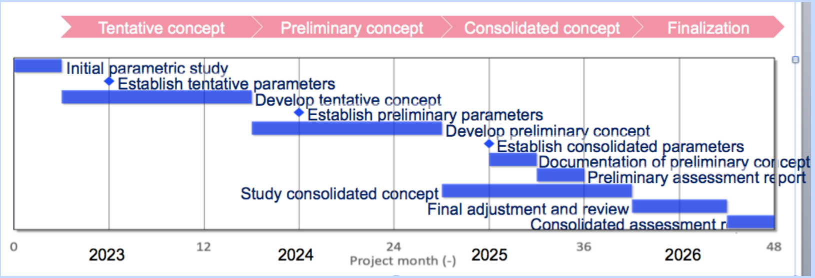
Formed **collaboration** to implement and R&D Roadmap for CERN Council




50+ partner institutions
30+ already signed formal agreement

**EU Design Study just started,** 32 partners, O(3+4 MEUR)

(EU+Switzerland+UK and partners)

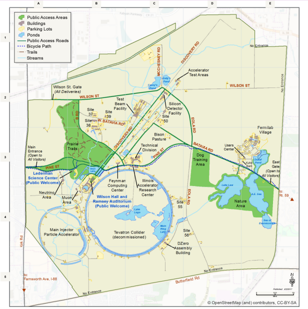



Plan to apply in 2024 for **HORIZON-INFRA-2024-TECH**
Goal: prepare experimental programme, e.g. **demonstrator, prototypes, …**

**US Snowmass** has **strong support**

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

Now P5 and EPP2024 are ongoing
Planning potential contributions



# US Snowmass

**Strong interest** in the US community in muon collider
- want funding for **R&D**
- like to **host a muon collider**

T. Roser et al.

**Implementation task force**:
- MC 10 cost range **12-18G$**
- MC 10 power **O(300 MW)**
- MC 3 cost range **7-12 G$**

Take it **cum grano salis**
- have to do our study to make robust scale estimates

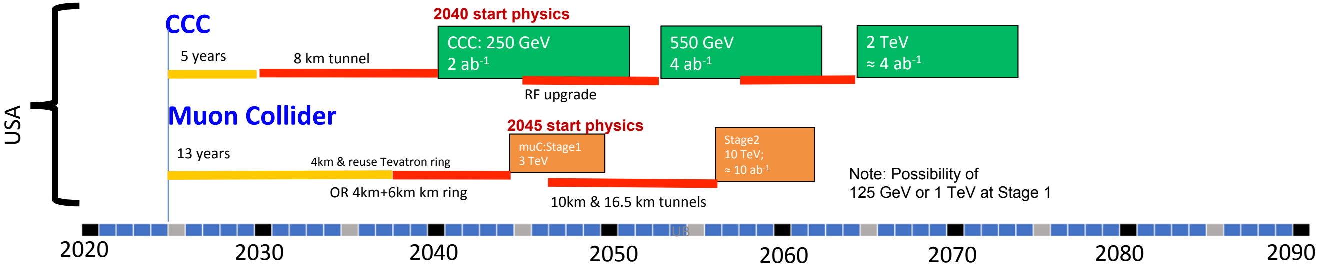
**Possible scenarios of future colliders**

Proton collider
Electron collider
Muon collider

Construction/Transformation
Preparation / R&D

Original from ESG by UB
Updated July 25, 2022 by MN

**Proposals emerging from this Snowmass for a US based collider**



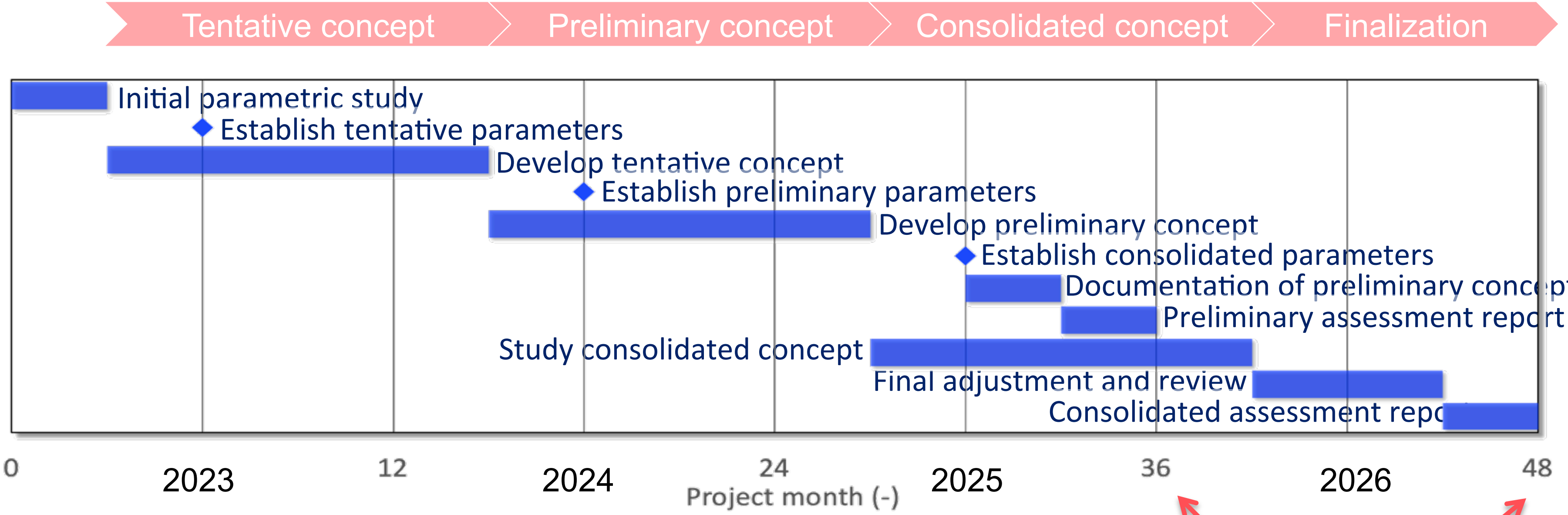

- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or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

# EU Design Study Timeline

International MUON Collider Collaboration



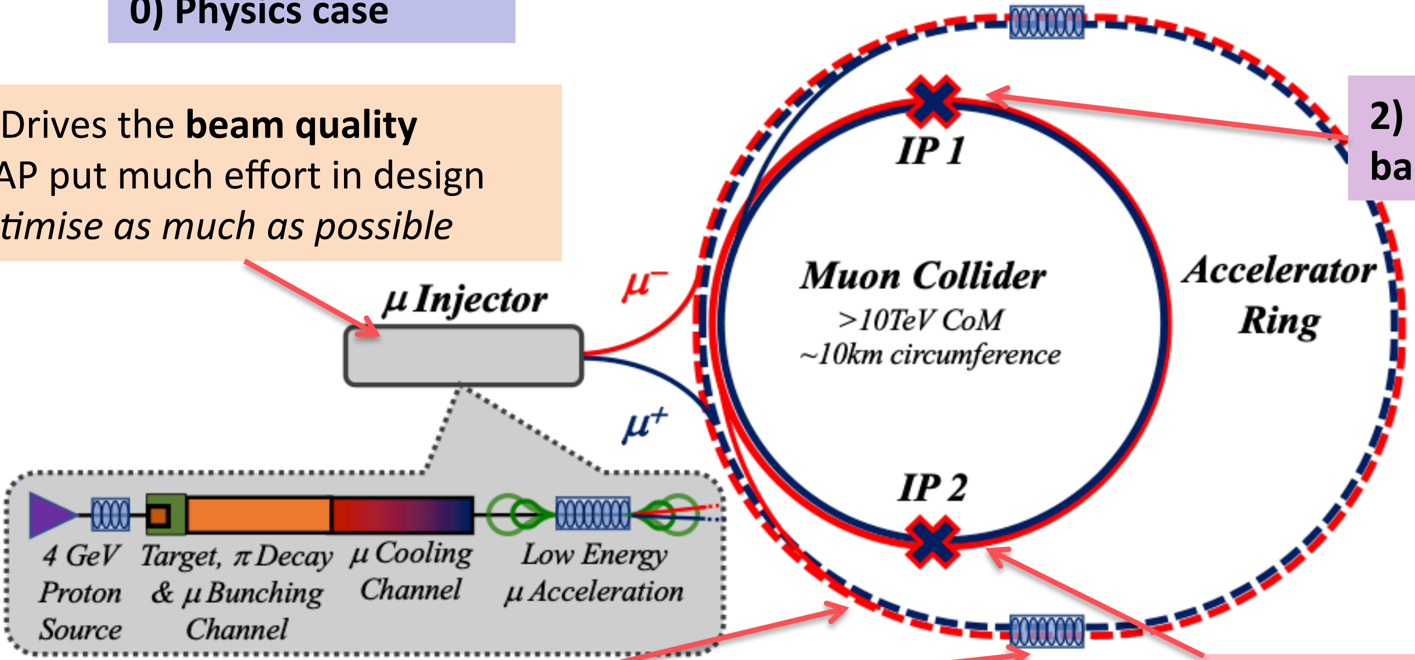

Next ESPPU ?

Representative of overall workplan

# 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**

# Physics and Detector Studies

International MUON Collider Collaboration

Details on physics case, detector and accelerator can be found in

- Snowmass white papers https://indico.cern.ch/event/1130036/
- EPJC report in preparation

**Used tentative detector performance specifications** in form of DELPHES card

- based on FCC-hh and CLIC performances, including masks against beam induced background (BIB)
- Please find the card here: https://muoncollider.web.cern.ch/node/14

M. Selvaggi, W. Riegler, U. Schnoor, A. Sailer, D. Lucchesi, N. Pastrone, M. Pierini, F. Maltoni, A. Wulzer et al.

Initial detector simulation studies at 1.5 and 3 TeV indicate that this is a **good model**

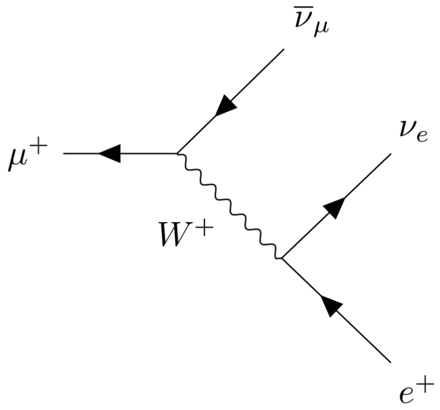
Now moving to 10 TeV

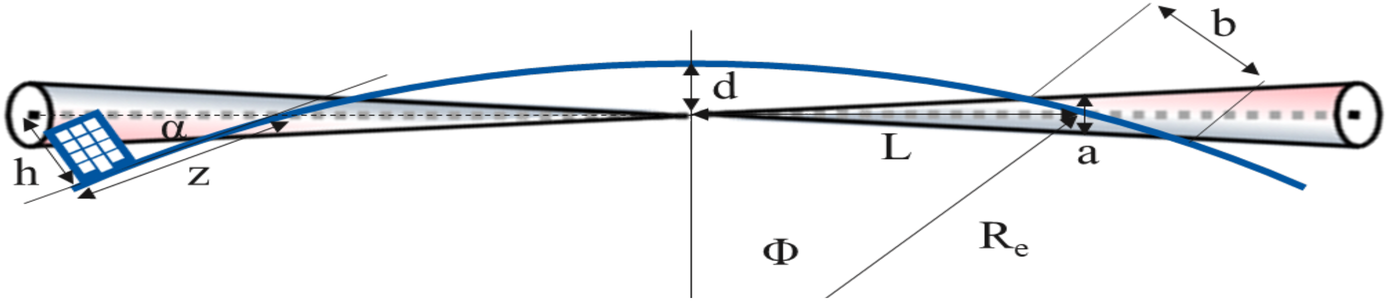
D. Lucchesi et al.

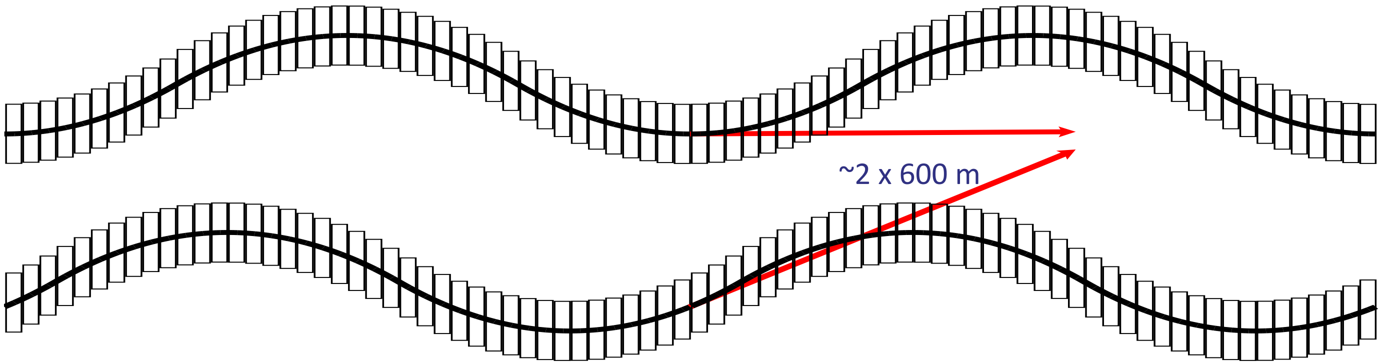
If you are interested to contribute please contact me or the responsible deputies:

**Andrea Wulzer (Physics)** and **Donatella Lucchesi (Detector and MDI)**

# Muon Decay and Neutrino Flux

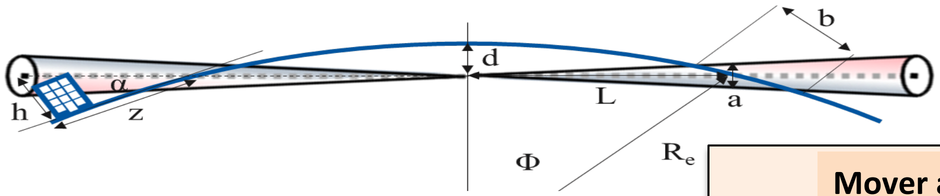


# Neutrino Flux

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**




International
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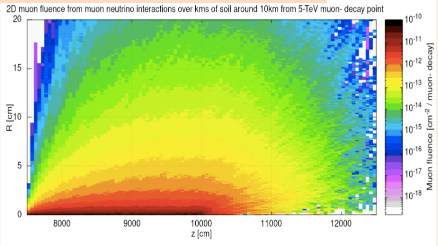
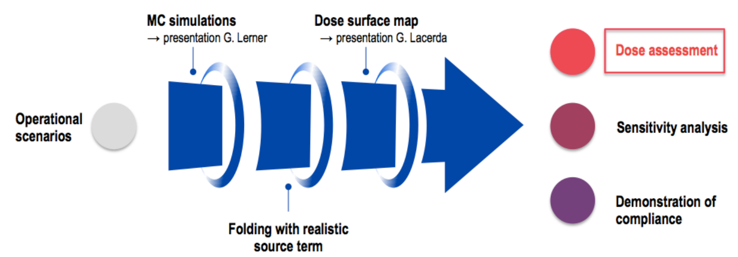
Collaboration

## FLUKA dose studies



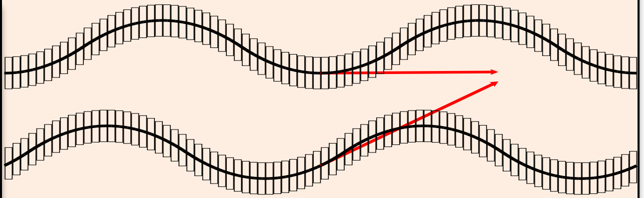

G. Lerner, D. Calzolari, A. Lechner, C. Ahdida

## Conformity Verification Scheme



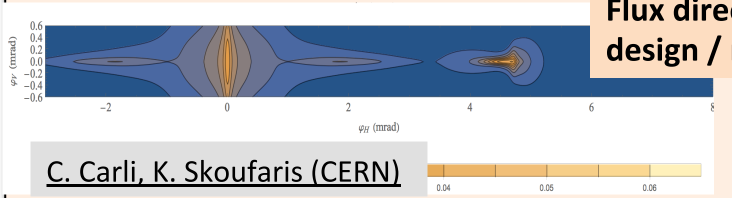

C. Ahdida, P. Vojtyla, M. Widorski, H. Vincke

## Mover and support system



F. Bertinelli et al. (CERN, Riga)

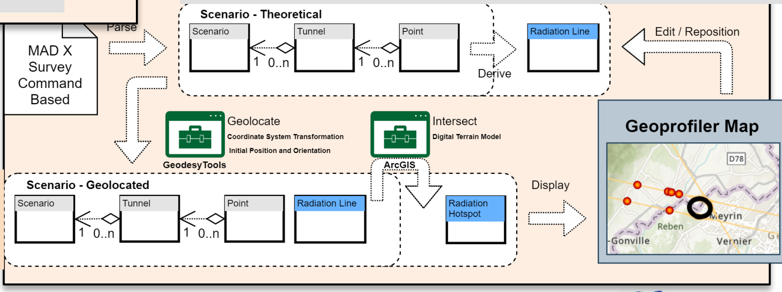
## Flux direction map / lattice design / mover impact on beam




C. Carli, K. Skoufaris (CERN)

## Mitigation: Site choice tool

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



# Muon Decay and Detector Background

Muons decay produces electrons and positrons

- Loss per unit length almost independent of energy

**Tools mostly ready** to generate background

- tentative beamline and mask, FLUKA
- tentative beam-beam for muons (GUINEA-PIG)

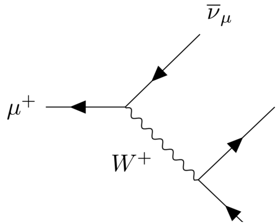
Studies at 1.5 <and 3 TeV with concept based on CLIC detector

- **Radiation level in detector similar to HL-LHC**

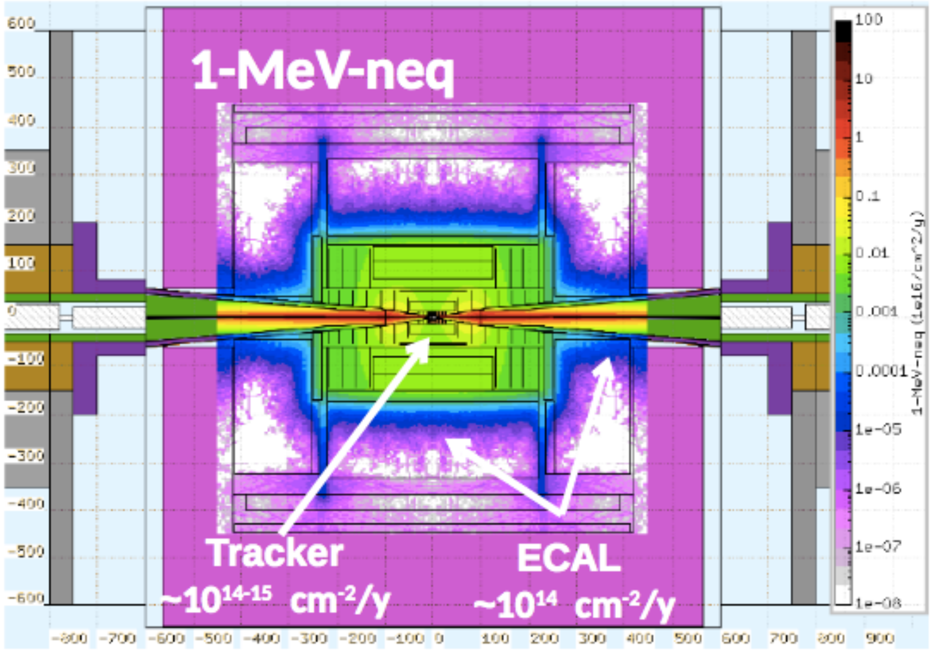
Studies with **beam-induced background** in progress

- some channels are not affected by background
- some improvement required for other channels

Concept for **10 TeV** in progress




Detector team
O(69) authors, O(150 signatories)

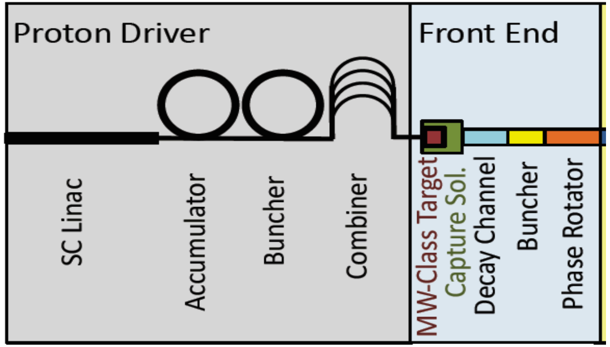


# Proton Complex and Target Area

**2 MW Proton beam power** is no fundamental issue

Some challenges in **H- source** and **compressing pulses in accumulator and combiner**

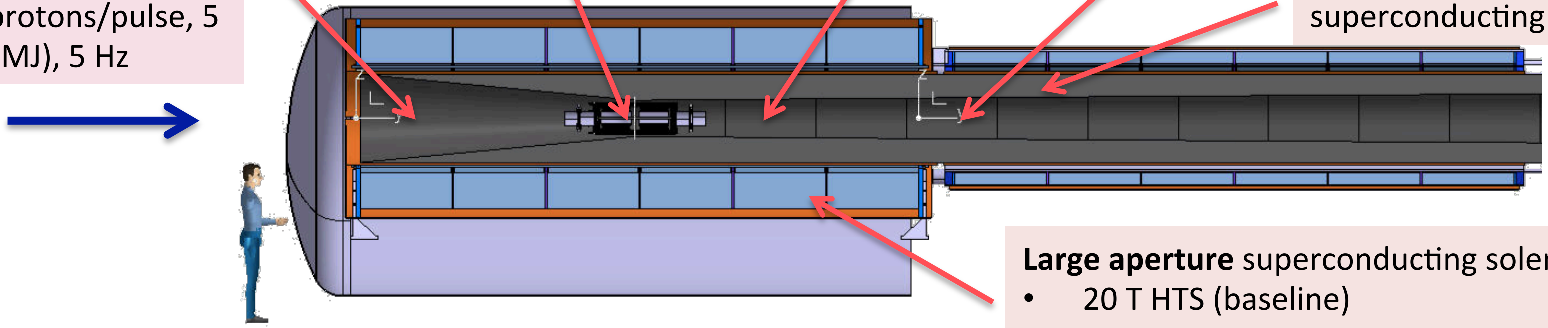
N. Milas et al. (ESS, Uppsala, CERN)




A. Lechner, M. Calciani, C. Densham, L. Bottura et al.

Protons → Target → Pions → Muons

5 x $10^{14}$ protons/pulse, 5 GeV (0.4 MJ), 5 Hz



**Thick shielding** of superconducting solenoid

**Large aperture** superconducting solenoid
- 20 T HTS (baseline)
- 15 T $Nb_3Sn$ plus 5 T inner booster solenoid

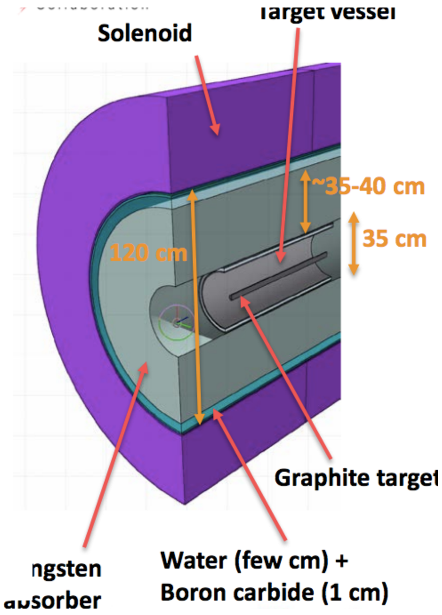
# Target Design

**Baseline:**

- **Graphite target (2 MW)**

**Alternatives for higher power:**

- **Liquid lead**
- **Fluidised tungsten**

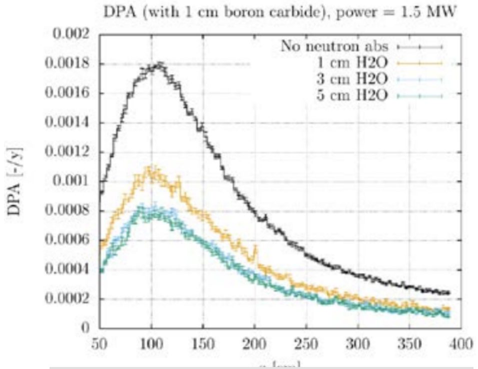



Shielding protects solenoid

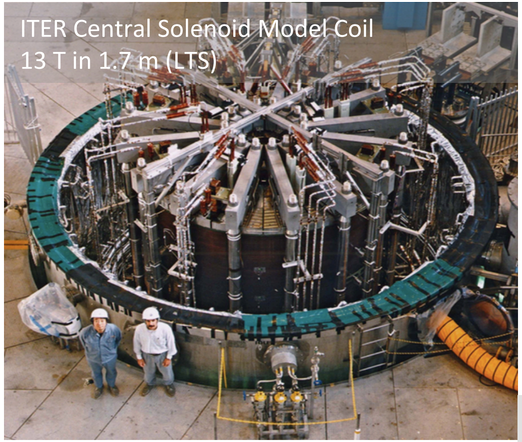
Rui Franqueira Ximenes, M. Calviani et al.

C. Densham et al. (UK)

Stress in graphite appears OK



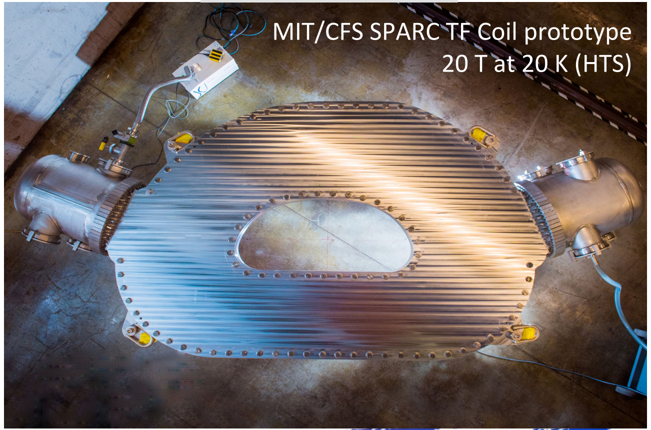

Rui Franqueira Ximenes et al.



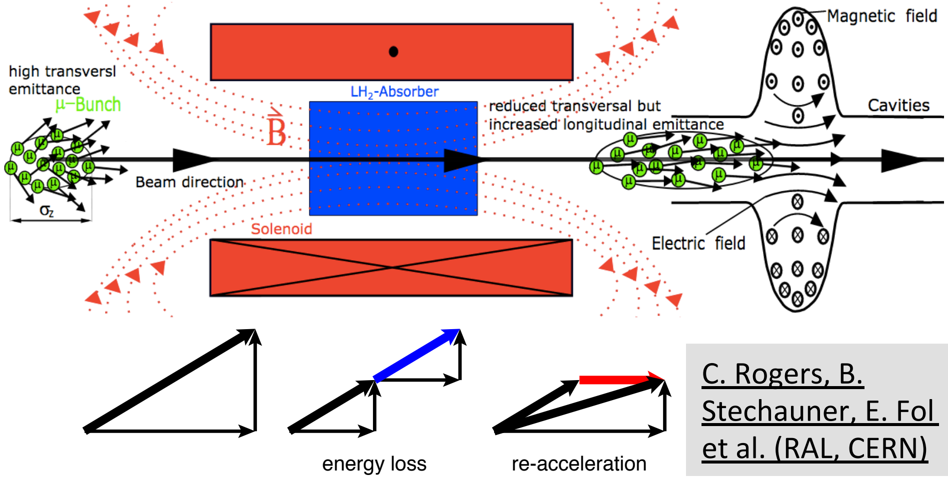

15 T $Ni_3Sn$ solenoid similar to ITER central solenoid

Work on 20 T HTS design started

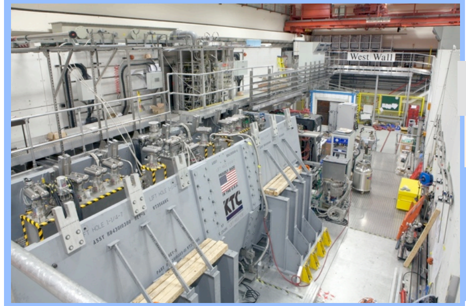
L. Bottura et al.



# Muon Cooling




C. Rogers, B. Stechauner, E. Fol et al. (RAL, CERN)



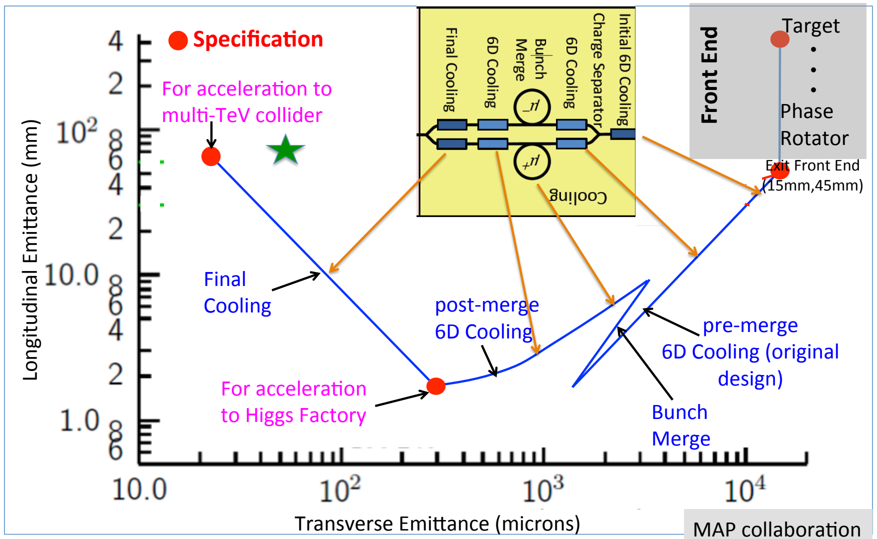
MICE Collaboration

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

Principle demonstrated with no RF
Use of data for benchmarking is still ongoing

MAP designs almost achieve 10 TeV goal

- miss factor two for final cooling



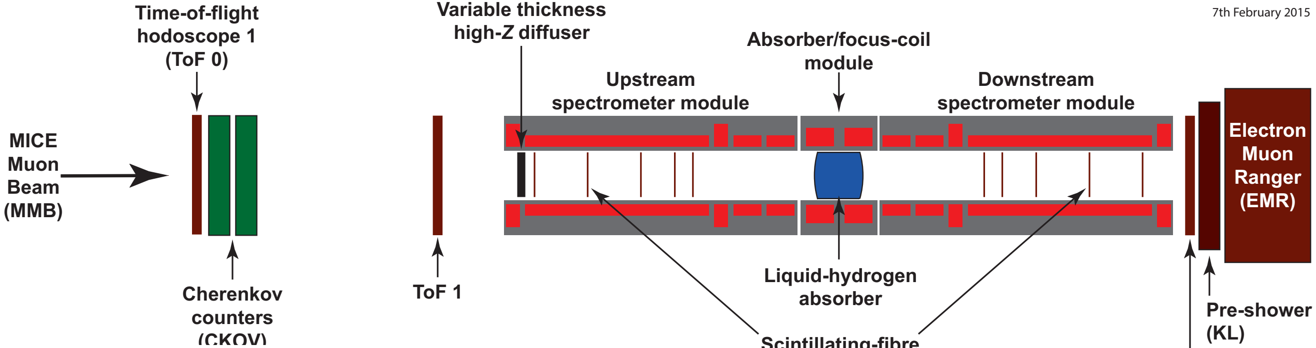

MAP collaboration

**Integration/optimisation** of design
Integrating **improved technologies**
**Collective effects**

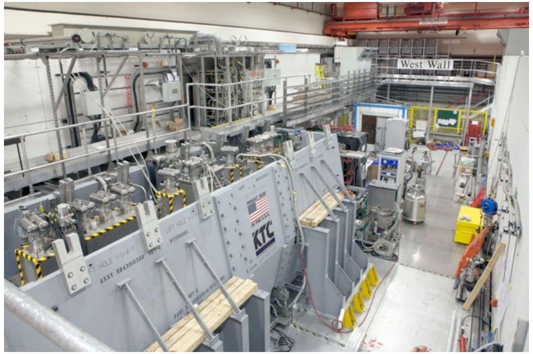
C. Rogers et al. (RAL, CERN)

T. Pieloni et al. (EPFL, CERN)

# MICE: Cooling Demonstration




7th February 2015

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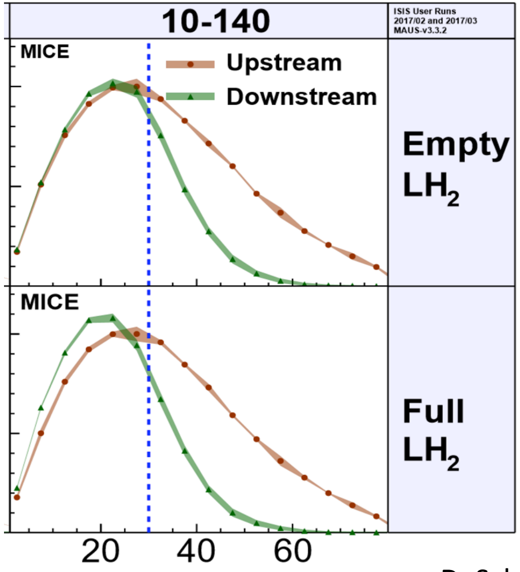



More particles at smaller amplitude after absorber is put in place

Principle of ionisation cooling has been demonstrated

Use of data for benchmarking is still ongoing

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

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

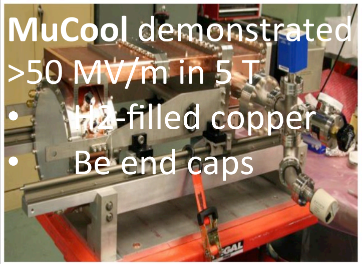
WEPOPT053

# Cooling Cell Technology

C. Marchand, Alexej Grudiev et al. (CEA, Milano, CERN, Tartu)

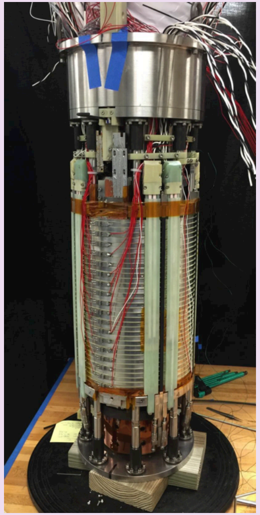
**RF cavities in magnetic field**
MAP demonstrated higher than goal gradient
Improve design based on theoretical understanding
Preparation of **new test stand**, but needs funding

- Test stand at CEA (700 MHz, need funding)
- Test at other frequencies in the UK considered
- Use of CLIC breakdown experiment considered




**Assessment of realistic goal for highest field solenoids**

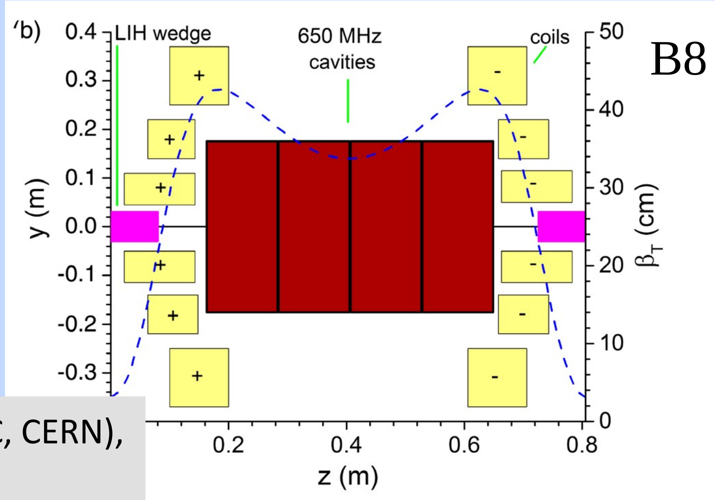
- MAP demonstrated 30 T
- now magnets aim for 40+ T
- even more can be possible



L. Bottura et al. INFN (Task Leader), CEA, CERN, LNCMI, PSI, SOTON, UNIGE and TWENTE, in collaboration with KEK and US-MDP

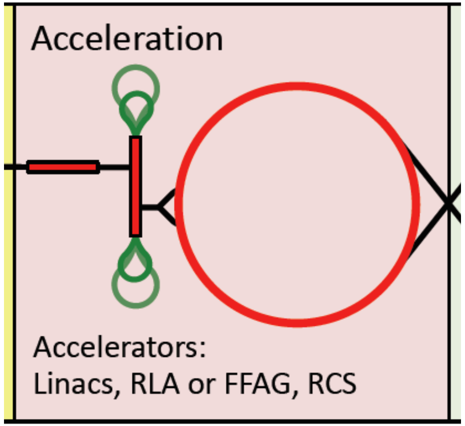
Will develop example **cooling cell integration**

- tight constraints
- additional technologies (**absorbers**, instrumentation,…)
- early preparation of **demonstrator facility**




L. Rossi et al. (INFN, Milano, STFC, CERN), J. Ferreira Somoza et al.

# Acceleration Complex

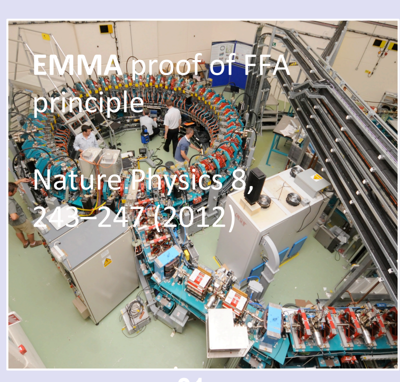



Core of baseline is sequence of pulsed synchrotron (0.4-11 ms)
Important cost and power consumption

Started

- **Integrated design of RCS** — A. Chance et al. (CEA)
  - lattice with realistic hardware specifications — E. Metral et al. (CERN)
  - collective effects
- **Concept of key components** — L. Bottura et al. (LNCMI, Darmstadt, Bologna, Twente)
  - Fast-ramping normal magnets
  - HTS alternative
  - Efficient power converters — F. Boattini et al.
  - RF with transient beam loading — H. Damerell, F. Batsch, U. van Rienen, A. Grudiev et al. (Rostock, Milano, CERN)
- Alternative FFA — S. Machida et al. (RAL)

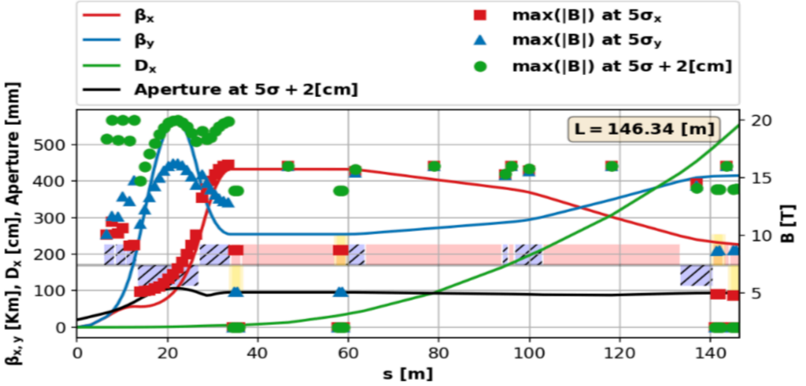
**FNAL** 300 T/s HTS magnet



# Collider Ring

MAP developed 4.5 km ring for 3 TeV with $Nb_3Sn$
- magnet specifications in the HL-LHC range

Work progressing on 10 km ring for **10 TeV collider ring**
- around 16 T $Nb_3Sn$ or HTS dipoles
- final focus based on HTS



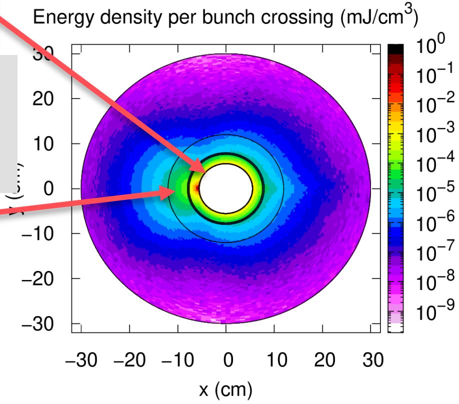

C. Carli, K. Skoufaris (CERN)

15 cm aperture for shielding to ensure magnet lifetime

Shielding

A. Lechner
D. Calzolari
(CERN)

Coil




Need stress managed magnet designs

INFN, Milano, Kyoto, CERN, profit from US

**Field choice will be reviewed for cost**

Example alternatives:
- a 6 km 3 TeV ring with **NbTi** at 8 T in arcs
- a 15 km 10 TeV ring with HL-LHC performances
- slight reduction in luminosity

# The Mid-term Future

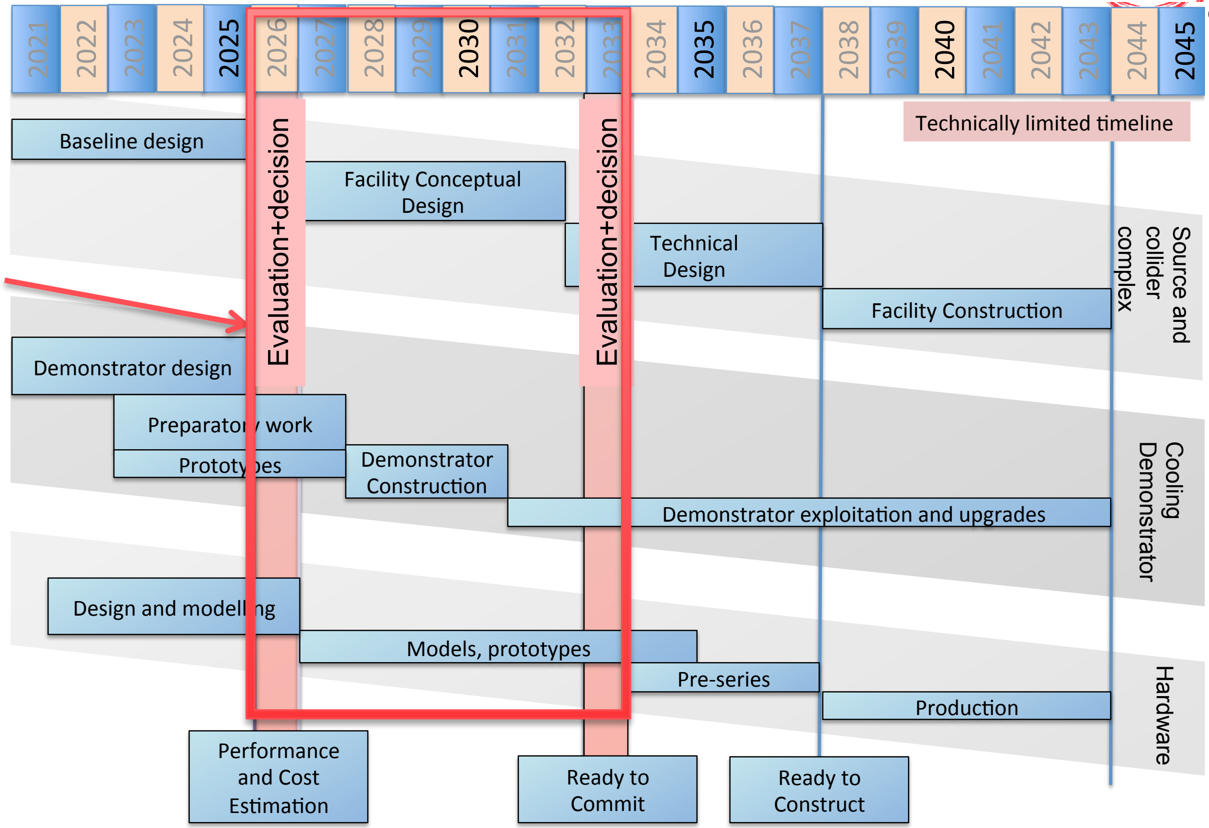
Technically limited timeline from R&D Roadmap will be reviewed as result of ongoing study

CDR phase contains prototypes, beam tests and facilities with beam

- a muon production and cooling demonstrator is important components
- targets
- hybrid RCS
- …

Can be distributed world-wide

To be reviewed considering progress, funding and decisions



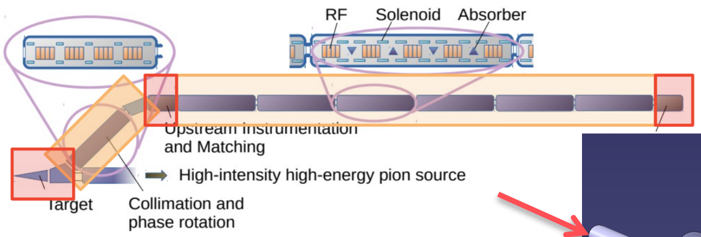
# Demonstrator(s)

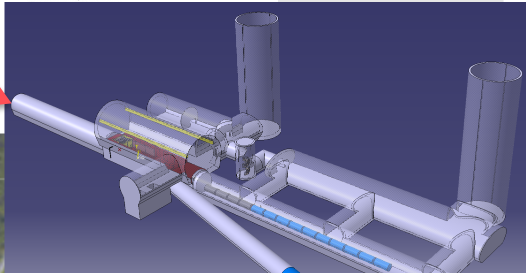
R&D efforts can be distributed over labs
- cooling demonstrator
- RF test stand
- module test stand
- …

Could also have synergies
- booster for light sources (e.g. ESRF) or proton therapy?

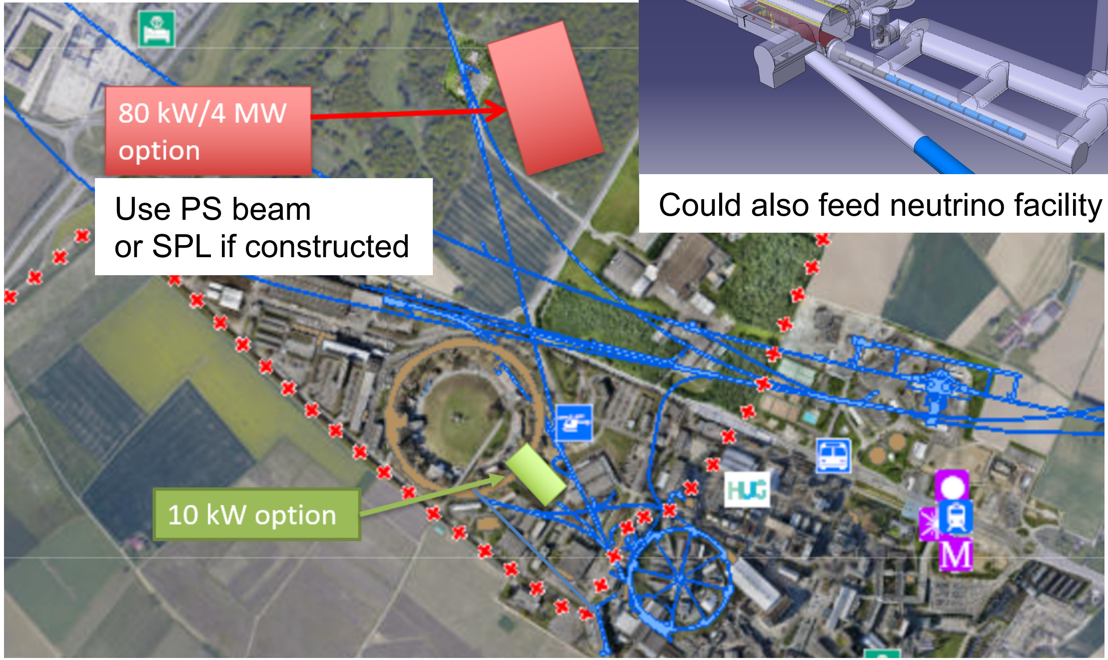
For cooling demonstrator look for an existing proton beam with significant power

Different sites are being considered
- CERN, FNAL, ESS are being discussed
- J-PARC also interesting as option



Could also feed neutrino facility



# Conclusion

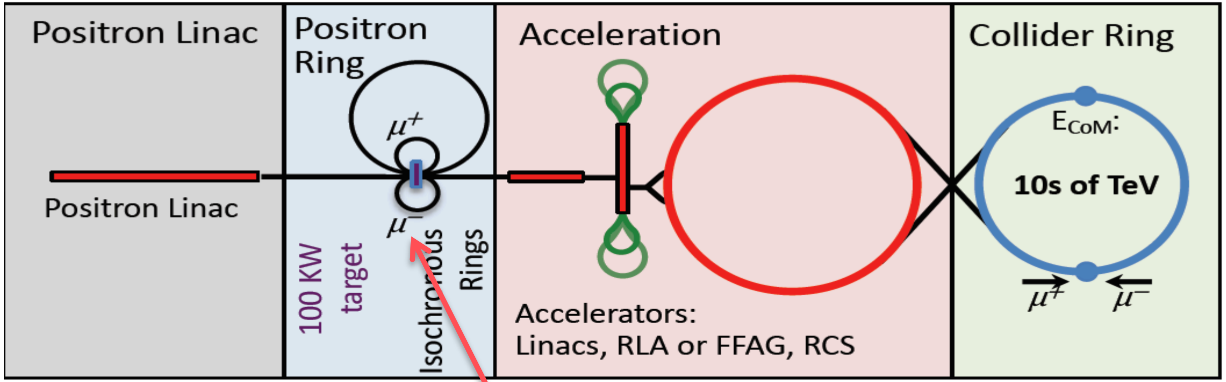
- Muon collider is unique opportunity for high-energy, high-luminosity lepton collider
    - but less mature than other options
- Currently two different options considered
    - goal of 10+ TeV, potential 3 TeV intermediate stage explored
- Collaboration exists
    - expect to still increase
    - US P5 will play an important role
- Addressing key challenges
    - Very motivated team
    - Synergy with applications for society, e.g. HTS solenoids
    - More funding required for full results to support potential claims by next ESPPU
- Working on increasing resources

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

# Reserve

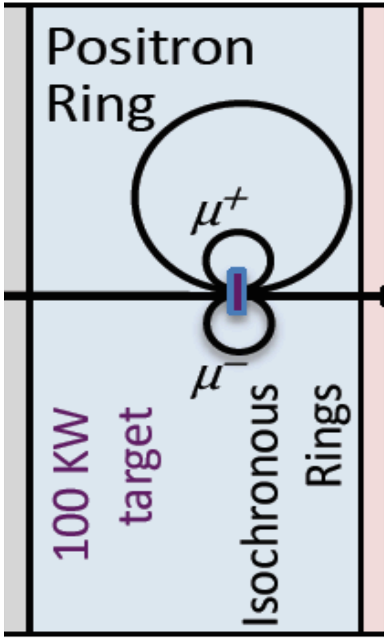
# Alternatives: The LEMMA Scheme

LEMMA scheme (INFN) P. Raimondi et al.



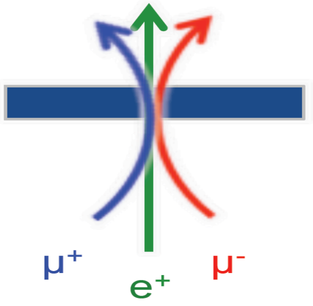

Note: New proposal by C. Curatolo and L. Serafini needs to be looked at

- 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

⇒ **Need same game changing invention**

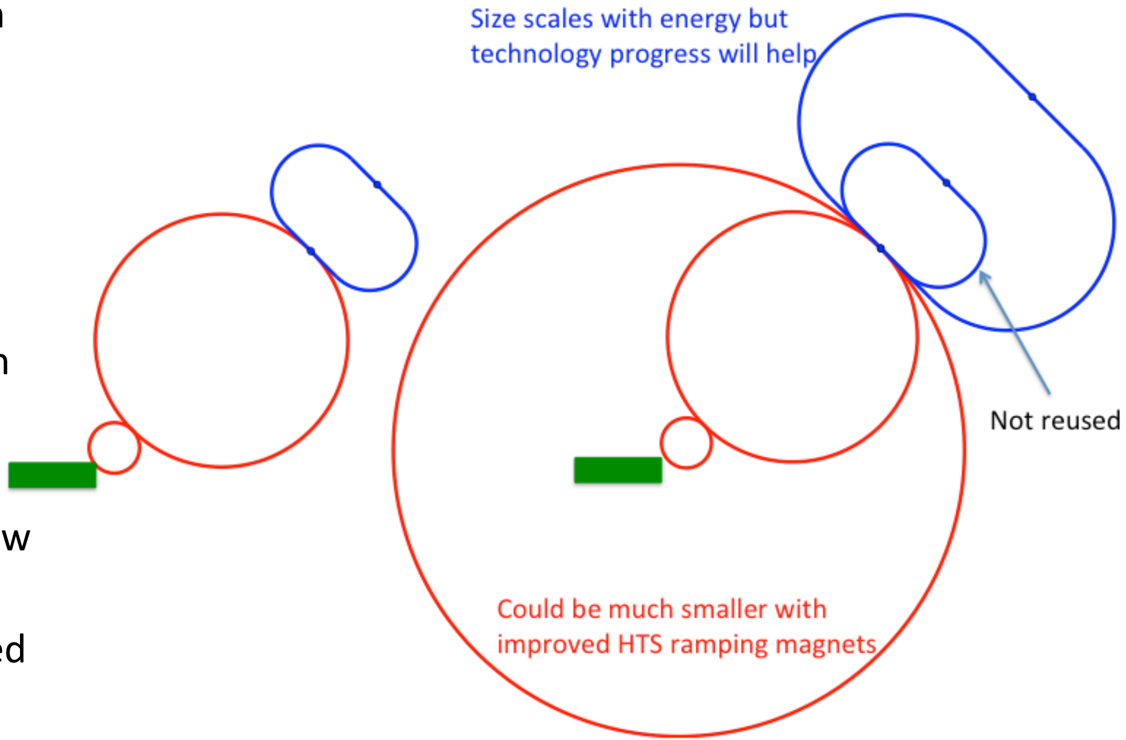
# Staging

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



# Snowmass

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

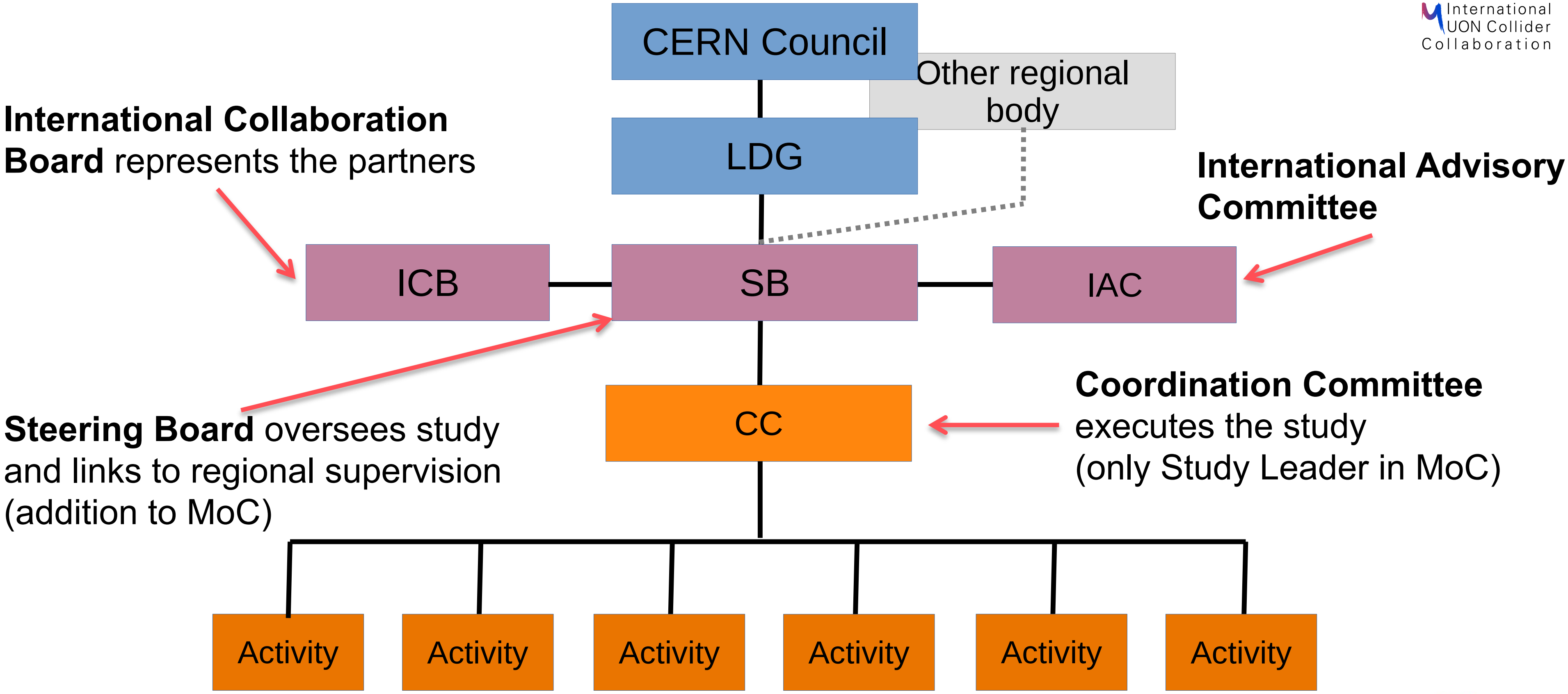
## ITF's Look Beyond Higgs Factories

| | 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

# Organisation



# Thanks

**Muon Beam Panel:** 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), Magnet Panel link, Tor Raubenheimer (SLAC), Chris Rogers (STFC-RAL), Mike Seidel (EPFL and PSI), Diktys Stratakis (FNAL), Akira Yamamoto (KEK and CERN) **Contributors:** Alexej Grudiev (CERN), Roberto Losito (CERN), Donatella Lucchesi (INFN)

**Community conveners:** *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).

**And the participants to the community meetings and the study**

# Technically Limited Timeline

Muon collider important in the long term

Prudently explore if MuC can be **option as next project**

- e.g. in Europe if higgs factory built elsewhere
- **sufficient funding required now**
- very **strong ramp-up required** after 2026
- might require compromises on initial scope and performance
  - 3 TeV