Muon Collider Status

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On behalf of the International Muon Collider Collaboration

SB Meeting, CERN, January 2024

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

Important Milestones

Parameter Document (submitted October 2023)

- Establishes a set of basic parameters and how they are derived
- Good basis to harmonise and identify trade-offs
- Concise version has been submitted as milestone to EU
- Longer version will be published, also explains derivation of parameters

Interim Report (due by **end of February 2024)**

- Part of the European Accelerator R&D Roadmap and MuCol deliverable
- Help to increase support from Council and other funding agencies
- Report progress since Roadmap
- Manage expectation for next reports, specify what can and cannot be done by 2026
- Prepare key elements of the R&D, e.g. RF test stand, demonstrator site
- Cover physics, detector, accelerator and technologies
- Very compact, <4 pages per area
- Would like IAC to review

Interim Report Key Messages

- Good progress in studies
  - Many examples
- Strong interest in the collaboration
  - E.g. EU Design Study, US P5 recommendation
- Substantial increase in resources
  - Thanks to EU Design Study
  - More resources in institutes (e.g. CERN MTP)
  - US will contribute but in the longer run
- Still not at required level
  - Manage expectations for 2025/2026
- Synergies
  - Strong synergies exist; in particular, HTS magnet development, strong impact on society
- What will we need in the future?
  - RF test stand, demonstrator etc.
  - Technology developments

Interim Report Structure

Executive Summary

Implementation Considerations

Physics Potential

Physics, Detector and Accelerator Interface

Detector

Accelerator design

Accelerator technologies

Synergies

R&D programme development

Collaboration Development

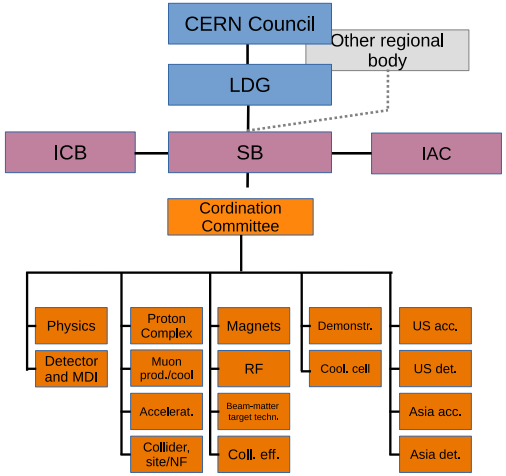
Contents

Finalising report
Start editing to be ready for IAC
Final deadline end of February

US P5: The Muon Shot

P5 endorses muon collider R&D
”This is our muon shot”

Consider FNAL as a proponent to host
Recommend joining the IMCC



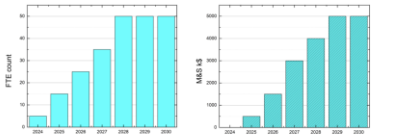


Figure 2: FTE and M&S profiles for accelerator R&D corresponding to the first phase of the program. We assume here that funding can start in 2024. The M&S is in FY23 dollars and escalation is not included in these estimates.

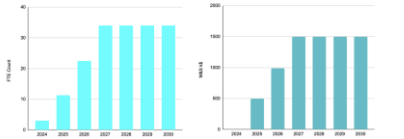


Figure 3: FTE and M&S profiles for detector R&D corresponding to the first phase of the program. We assume here that funding can start in 2024. The M&S is in FY23 dollars and escalation is not included in these estimates.

Request formulated by 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

We welcome the US community

Already participation, also in leadership

- Will increase and reorganise in 2024

Ambition of US to host collider is excellent news, makes study more robust

US Integration

As already planned, we will **revise the distribution of R&D efforts and the organisation with your help in 2024**, reflecting the US efforts and resources. We look forward to **understanding US vision of the US participation**, both in R&D areas and organisation.

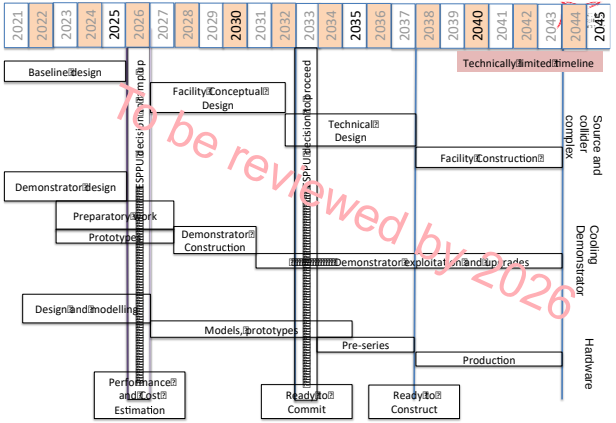
Several US institutes are already members of the IMCC and members of the US community are already engaged in important roles. We understand that it will take some time to ramp up the US effort. Three R&D areas are particularly critical for the timely implementation of a muon collider

- The development of **superconducting magnets** in the different parts of the accelerator. […]
- The development of the **muon production and cooling technology and its demonstration** in a facility. Developing more than one site option will make this effort more robust and US participation to the technology is essential.
- The **detector concept and technologies R&D**. The muon collider will reach lepton collision energies beyond those studied for other approaches, such as CLIC. The detector design and technologies will be challenging and should consider novel concepts of hard- and software. It appears to be prudent to develop alternative concepts to a good level of detail to ensure that we can take full advantage of the muon collider.

Physics considerations for implementation scenarios, consistent with the interest in all regions

- relative merits of an energy staging versus a luminosity staging;
- the overall physics performance and complementarity of a high-energy muon collider and a low energy Higgs factory;
- the complementarity of a high energy muon collider and a proton collider.

Started Reviewing Timeline



- Uncertainties:
  - physics case (e.g. HL-LHC),
  - society development,
  - budget profile
  - …

- Goal:
  - Identifying shortest possible timeline, switch on before 2050
  - Technically limited, success-oriented schedule
  - Not a “man on the moon” but main “next project” priority

- On the critical path
  - Muon cooling technologies and integration
  - Magnet technology
  - Detector technologies

Magnet Roadmap

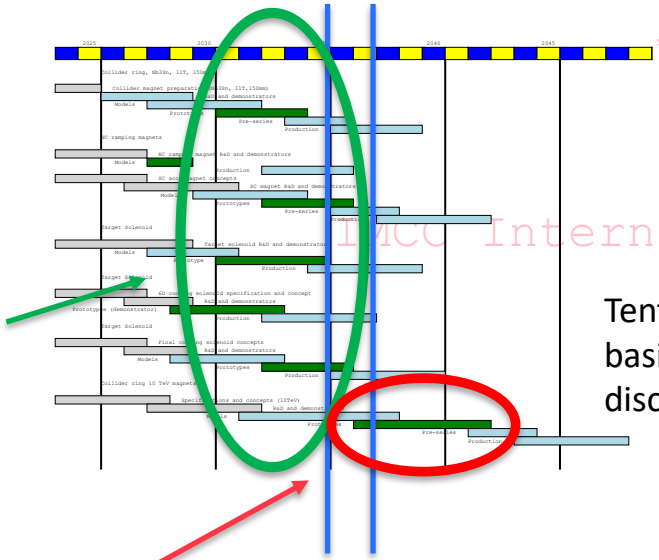
Assume: Need prototype of magnets by decision process

Consensus of experts (review panel):

- Anticipate technology to be **mature in O(15 years):**
  - **HTS solenoids** in muon production target, 6D cooling and final cooling
    - HTS tape can be applied more easily in solenoids
    - Strong synergy with society, e.g. fusion reactors
  - **Nb_3Sn 11 T magnets** for collider ring (or HTS if available): 150mm aperture, 4K
- This corresponds to 3 TeV design
- Could build 10 TeV with reduced luminosity performance
  - Can recover some but not all luminosity later

Still under discussion:

- Timescale for 10 TeV HTS/hybrid collider ring magnets
- For second stage can use **HTS or hybrid collider ring magnets**



2036+2037 decision process

Strategy:

- HTS solenoids
- Nb_3Sn accelerator magnets
- HTS accelerator magnets

Seems technically good for any future project

Staging Approaches

Assumptions:

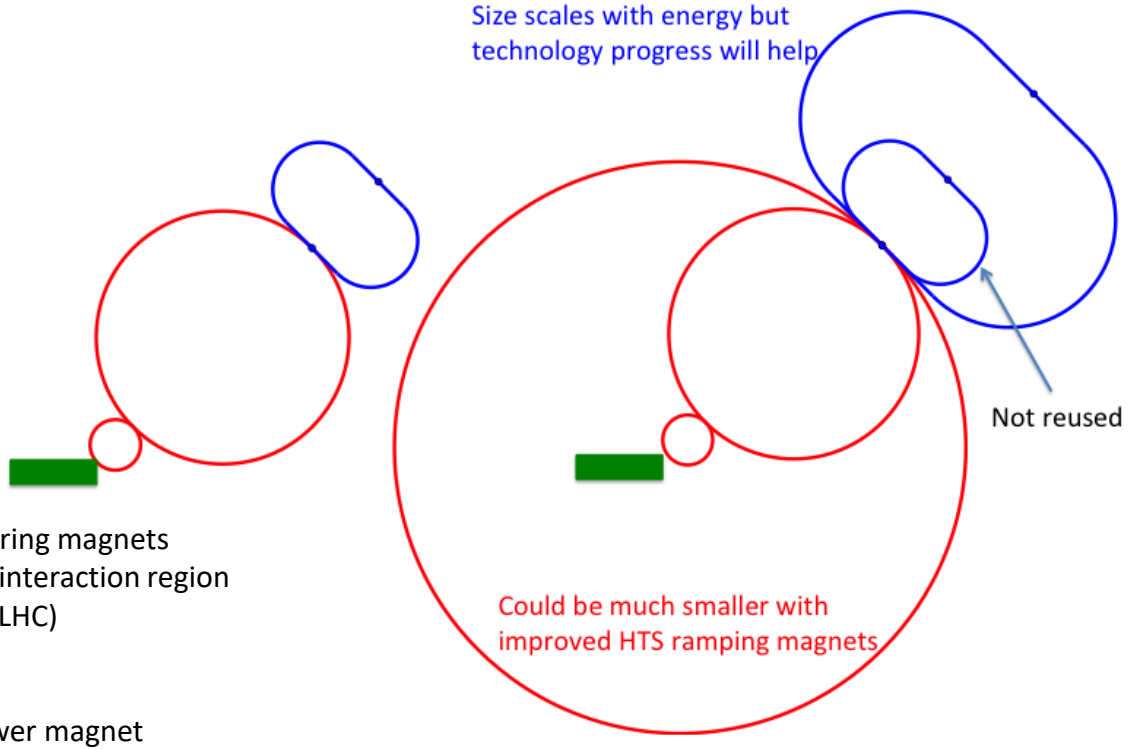
- In O(15 years):
  - HTS technology available for solenoids
  - Nb_3Sn available for collider ring
- In O(25 years):
  - HTS available for collider ring

Scenario 1: Energy staging

- Start at lower energy (e.g. 3 TeV)
- Build additional accelerator and collider ring later
- Requires less budget for first stage
- 3 TeV design takes lower performance into account

Scenario 2: Luminosity staging

- Start at with full energy, but less performant collider ring magnets
- Main sources of luminosity loss are collider arcs and interaction region
  - Can recover interaction region later (as in HL-LHC)
  - But need full budget right away
  - Some luminosity loss remains (O(1.5))
  - More power for the collider ring required (lower magnet temperature)

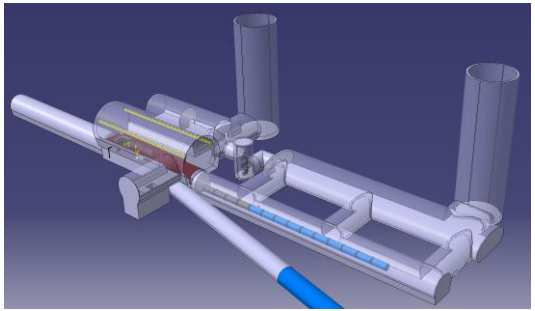


Demonstrator Site Study

Cooling demonstrator is a key facility
Different sites are being considered

- CERN, FNAL, ESS …
  - Discussed at ACE at FNAL
  - Currently consider two site options at CERN
- J-PARC also interesting as option

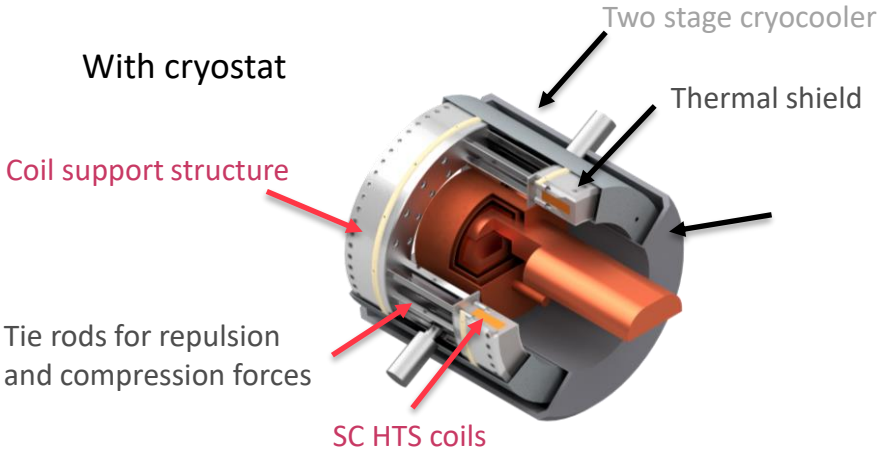
Plan workshop to discuss options



Are developing **schedule**

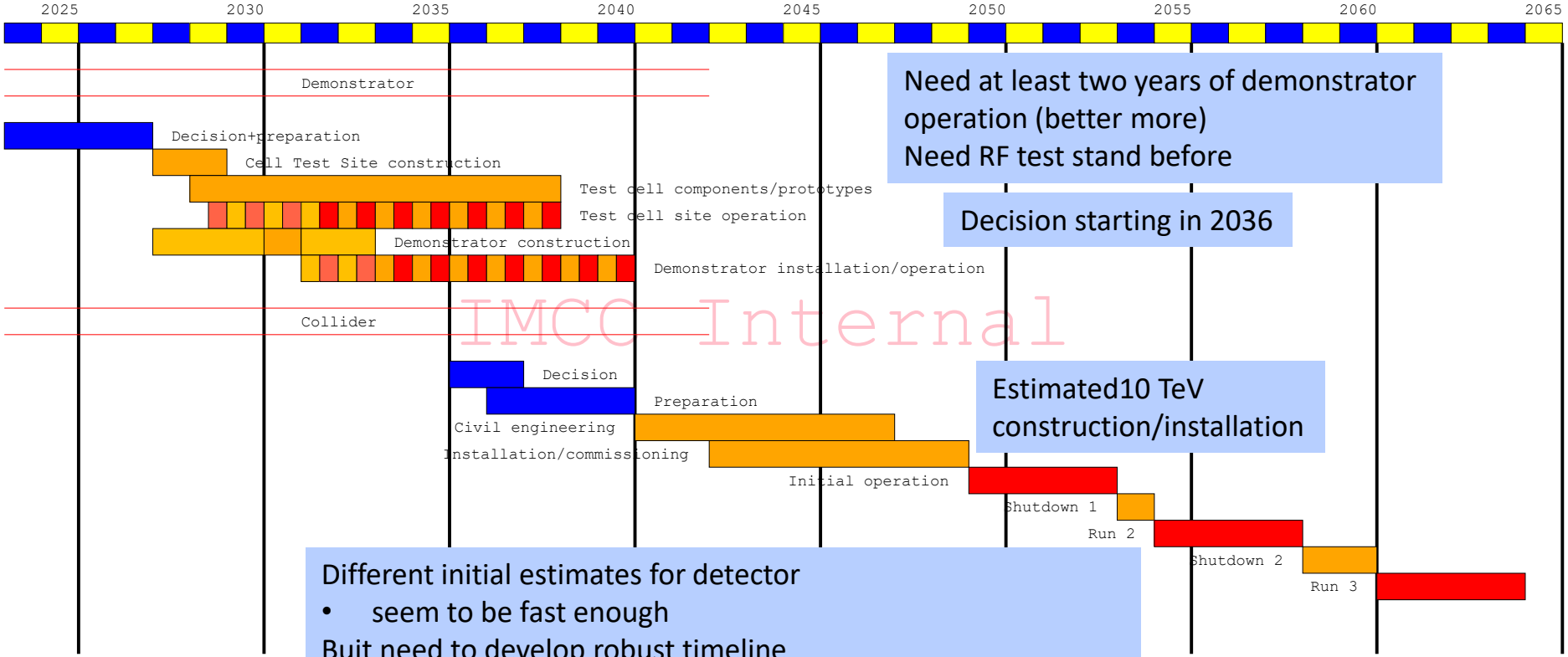
- Site dependence exists
- Need some infrastructure early
  - Infrastructure to test RF cavities in magnetic field
  - Discussion on facilities at **STFC, INFN, CEA**, …
  - Funding required
- Also understand decision making, administrative procedures, civil engineering, …

- Currently looks promising
  - Assuming we and the funding agencies are determined



Timeline Considerations

Only a basis to start the discussion, will review this year



Need at least two years of demonstrator operation (better more)
Need RF test stand before

Decision starting in 2036

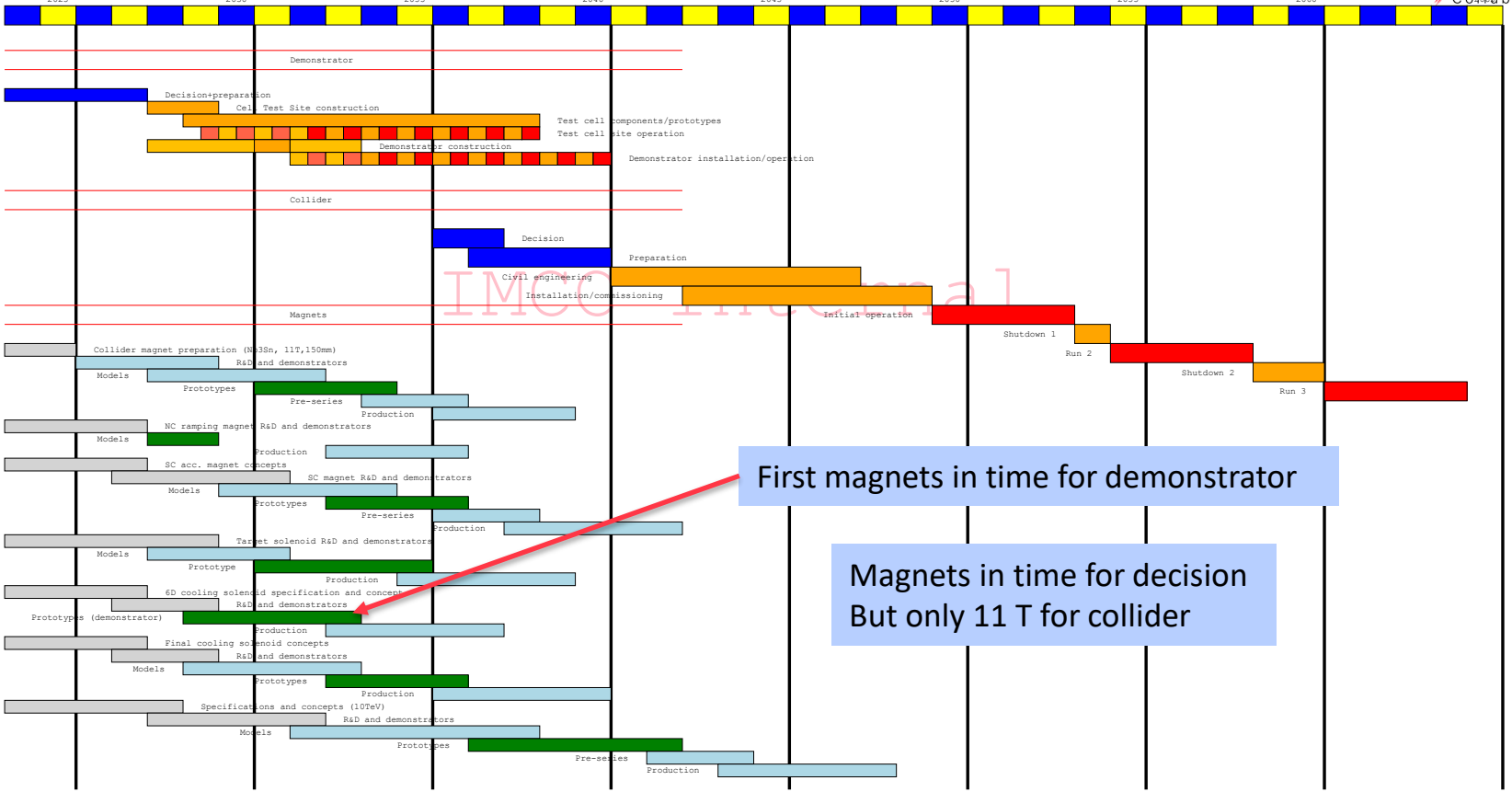
Estimated10 TeV construction/installation

Different initial estimates for detector
- seem to be fast enough

Buit need to develop robust timeline

Timeline Considerations

Only a basis to start the discussion, will review this year



First magnets in time for demonstrator

Magnets in time for decision
But only 11 T for collider

Costing Effort

Starting cost estimate
- Develop PBS for the whole project, considering PBS for FCC and CLIC
- But are very limited in resources, compared to other efforts

PBS will allow to
- Identify where information is available
- Understand uncertainty of estimate

Planned work
- Some bottom-up estimates for key unique components
  - E.g. fast-ramping magnets and power converter
- Generic and scaled estimates for other components
  - Where possible with the relevant groups but do not have a dedicated budget for the group personnel

New EU Proposal

INFRA-2024-TECH-01-01
Discussed in TIARA

L. Bottura with help from M. Calvi, S. Casalbuoni, X. Chaud, C. Darve, F. Debray, K. Foraz, R. Losito, L. Garcia Tabares, J.M. Jimenez, E. Lelievre, J.M. Perez, L. Rossi, D. Schulte, P. Vedrine, M. Vretenar

- **Research and Innovation action**: EU expects proposals in the range of 5…10 MEUR from consortia with at least 3 ESFRI/ERIC. Total budget 62 MEUR
- **EU-MAHTS**: European **M**agnet technology **A**dvances through **HTS**, for science and societal applications:

WP1: Management and Communication
WP2: Strategic Roadmap
WP2: Inductry Cooperation
WP4: HTS Magnet Application Studies
WP5: Materials and Technologies
WP6: All-HTS Ultra-high Field Solenoid Demonstrator (40T)
WP7: All-HTS Split Solenoid (10T class)
WP8: All HTS Small Period Undulator (2T)
WP9: Test Infrastructures

Beneficiaries

- High Energy Physics – CERN (**ESFRI**), INFN+UMIL, CEA, CIEMAT
- Synchrotron light sources and FEL facilities – EUXFEL (**ESFRI**), ESRF (**ESFRI**), PSI
- *Nuclear physics – FAIR (**ESFRI**), GSI*
- *Strategic partnerships (under discussion): Neutron scattering – ESS (**ESFRI**), High Field Science – EMFL (**ESFRI**), LNCMI, HLD, HFML, EUROFusion, Industry*

Association planned of several other partner institutes and universities, including fusion, and a substantial participation from European Industry

Collider Site Studies

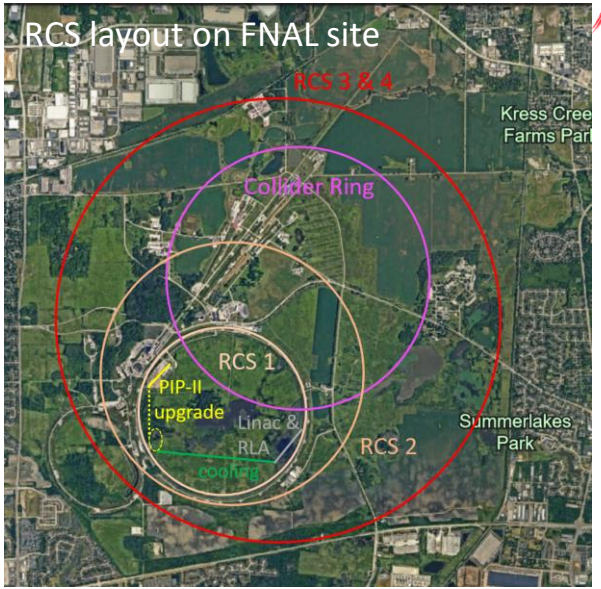
Candidate sites **CERN, FNAL,** potentially others **(**ESS, JPARC, …)

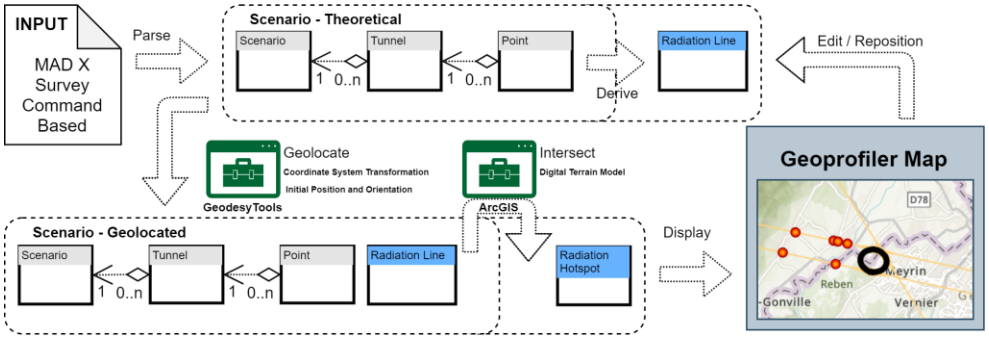
Study is mostly site independent

- Main benefit is existing infrastructure
- Want to avoid time consuming detailed studies and keep collaborative spirit
- Will do more later

Some considerations are important

- Neutrino flux mitigation at CERN
- Accelerator ring fitting on FNAL site





Potential site next to CERN identified

- Mitigates neutrino flux
  - Points toward mediterranean and uninhabited area in Jura
- Detailed studies required (280 m deep)

Conclusion

- Interim Report is on its way
  - IAC essential to help us
- Work is progressing
  - But still resource limited
  - Hope to get more support from EU and partners
- US P5 recommendation will strengthen the collaboration
  - Looking forward to have US vision of how to integrate
- Start reviewing the timeline
  - Could be having stage project operational before 2050
  - Need to work on demonstrator timeline and increasing site options
    - started planning workshop in summer
  - Need to work out detector timelines
  - Review magnet timelines, civil engineering etc.
- Start cost estimate
- Potential collider sites at FNAL and CERN, invite more site proposals

Many thanks to all that contributed

http://muoncollider.web.cern.ch