Demonstrators for Technical Developments and Physics Synergies

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Rutherford Appleton Laboratory

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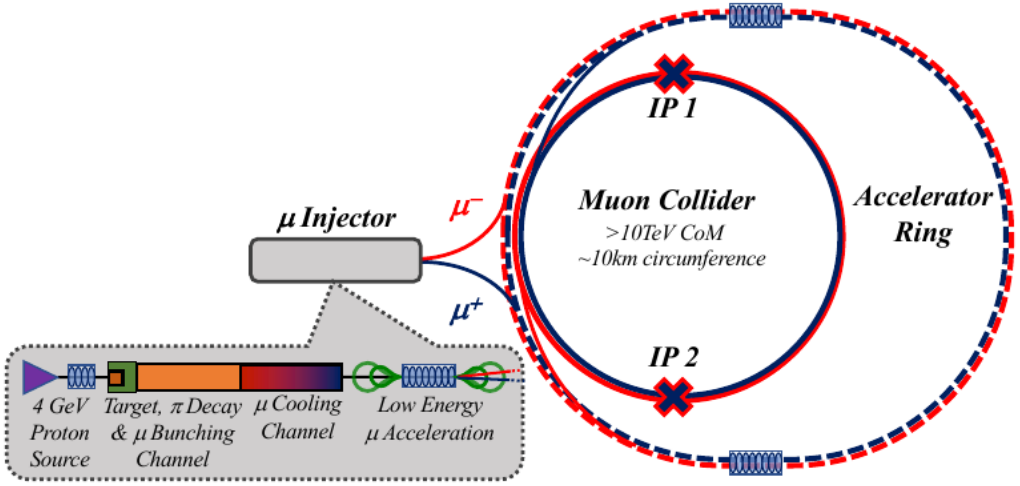
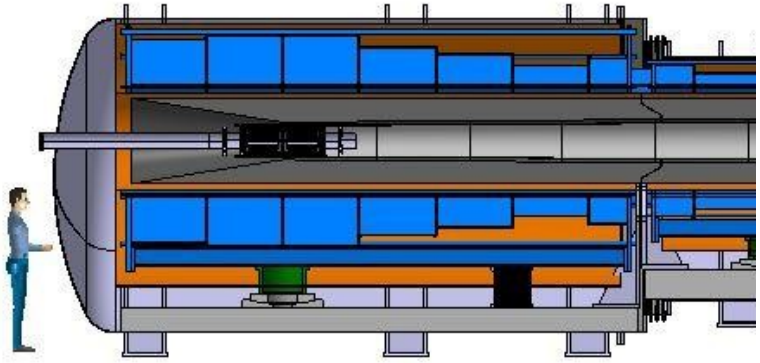
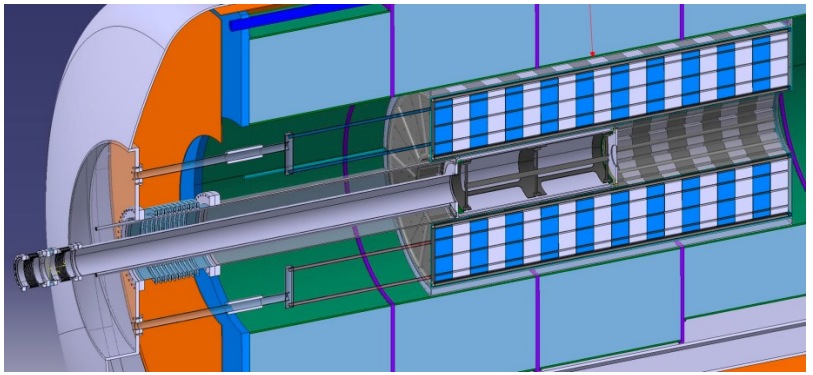
Muon collider



- Muon collider R&D path provides important contribution to non-collider experimental programme
- Two beam demonstration studies are considered
  - Cooling demonstrator & nuSTORM
  - High power targetry & CLFV
- Exquisite non-collider physics programme at the collider
  - E.g. Nuclear physics programme using high energy neutrinos
  - E.g. High power proton beam dump experiments
  - Discussions have just started

MuC Target

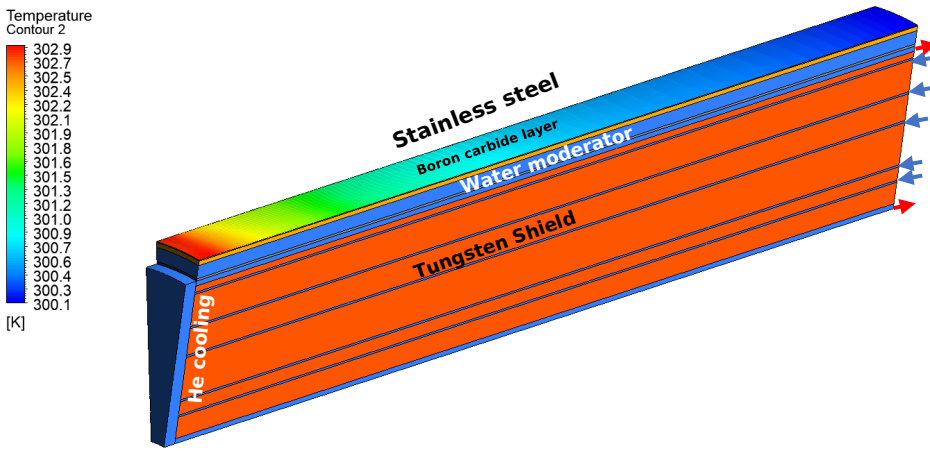




- Protons on target → pions → muons
  - Graphite target takes proton beam to produce pions
    - Back up options under investigation
  - Heavily shielded, very high field solenoid captures π^+ and π^-
- Challenge: Solid target and windows lifetime
- Challenge: Energy deposition and shielding of solenoid

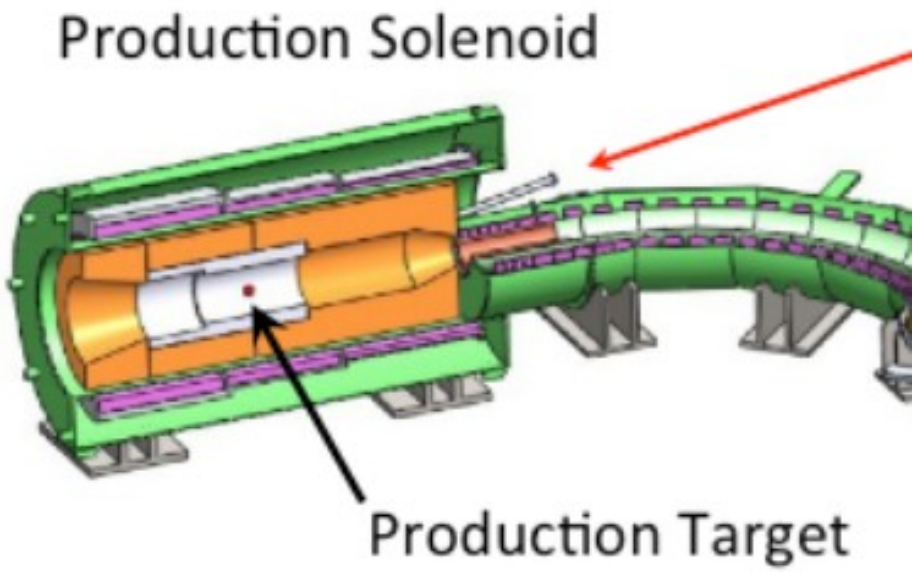
Magnet options

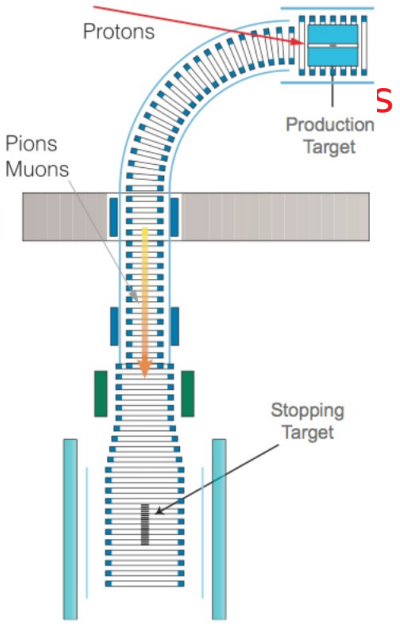
- Investigating force-flow cooled HTS cable
  - Operation at 20 K → more efficient cryo plant
  - Smaller footprint and stored energy than LTS
- Also strong synergy with
  - Fusion
  - UHF Magnets for science
- Radiation hardness under study
  - Propose workshop in Spring



Synergy with cLFV

mu2e

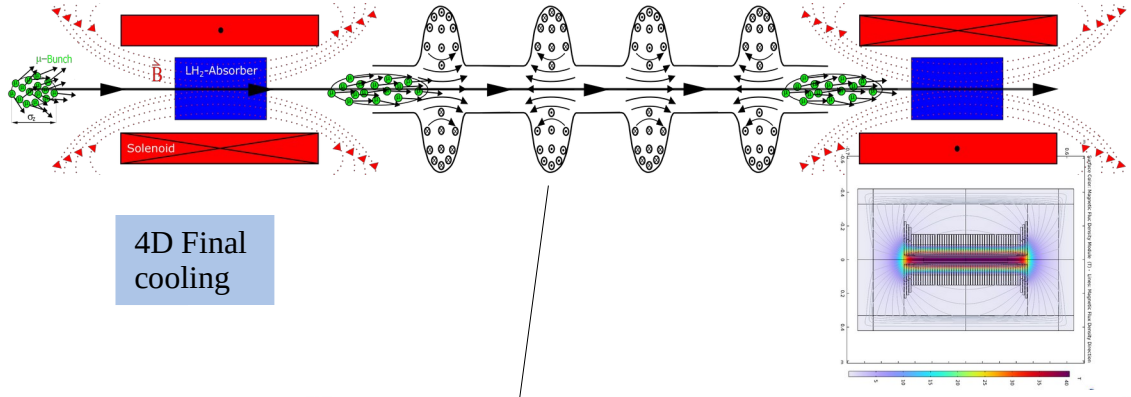




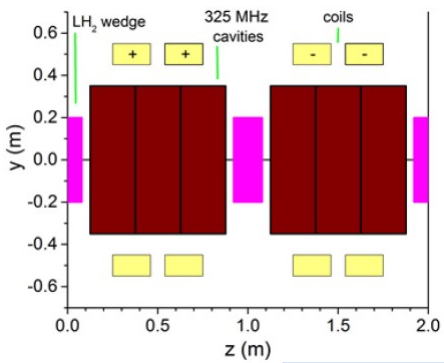
【 COMET Phase-I 】

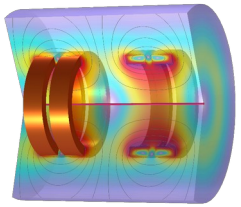
- Muon-to-electron conversion experiments
  - Look for rare decay processes
- Under construction now
- R&D for phase 2 in progress
- Target station similar to MC target
  - But lower power, lower field
- Excellent opportunity to test ideas on target station

Muon Cooling

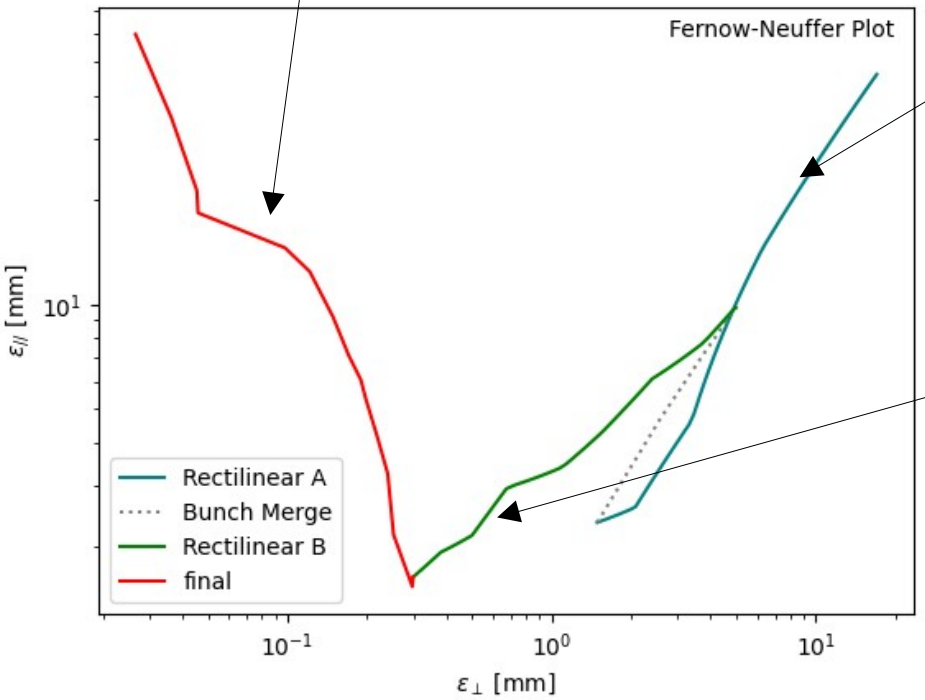


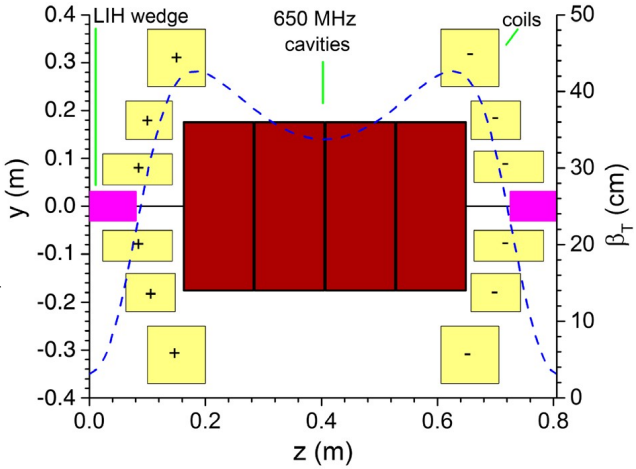
4D Final cooling

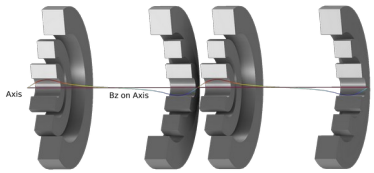




Rectilinear cooling







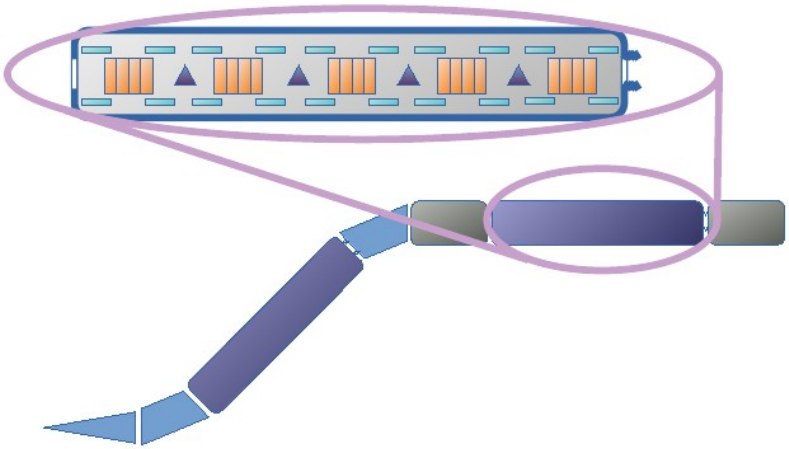
Facilities Council

Cooling Demonstrator Programme

International MUON Collider Collaboration

RF Test programme, with upgradeable magnet configuration, to test novel RF technologies

Prototype of a cooling vacuum vessel to test magnet, absorber and RF integration



Full cooling vacuum vessel with beam

Full cooling lattice with beam

MUCOOL Cavity R&D

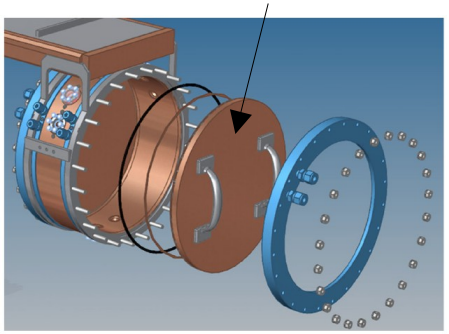
- Cooling requires strong B-field overlapping RF
  - B-field → sparking in RF cavities
- Two technologies have demonstrated mitigation

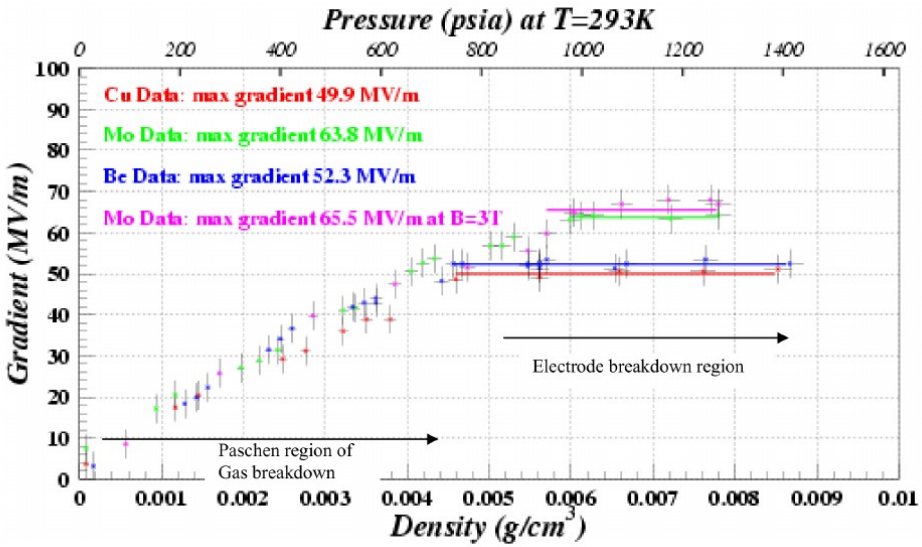
Bowring et al, PRAB 23 072001, 2020

Material	*B*-field (T)	*E*-field (MV/m)
Cu	0	24.4 ± 0.7
Cu	3	12.9 ± 0.4
Be	0	41.1 ± 2.1
Be	3	$> 49.8 \pm 2.5$

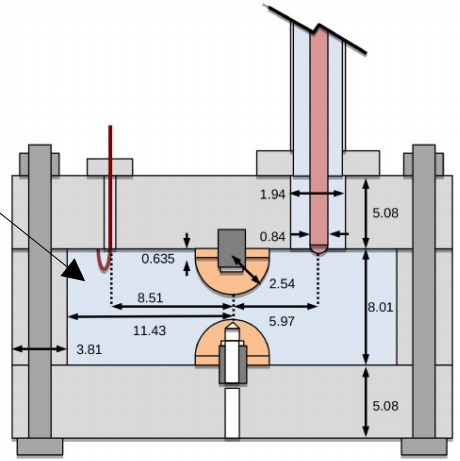
Double vs Cu cavity in 0 T

Changeable Cu/Be walls



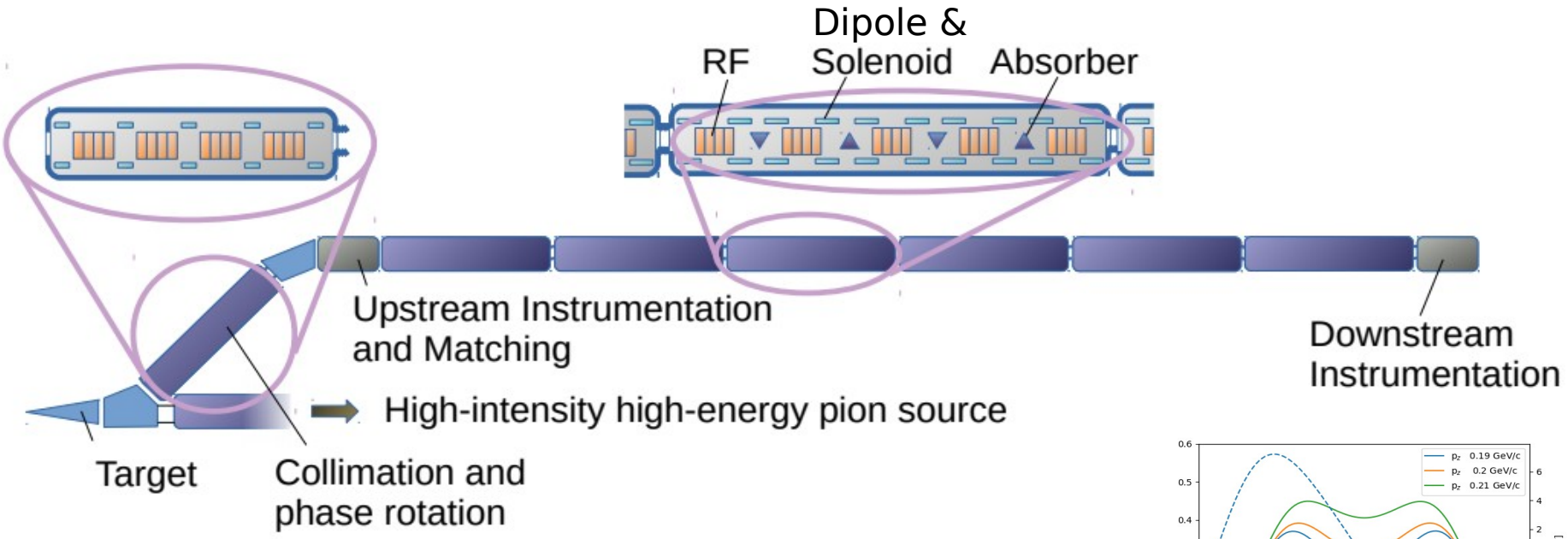


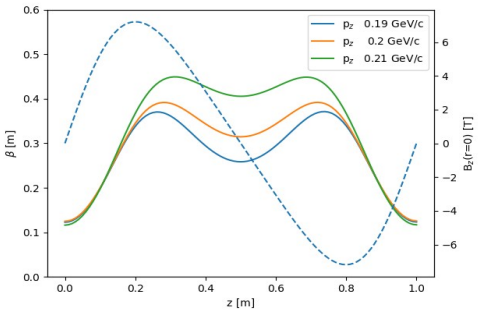
High Pressure gas

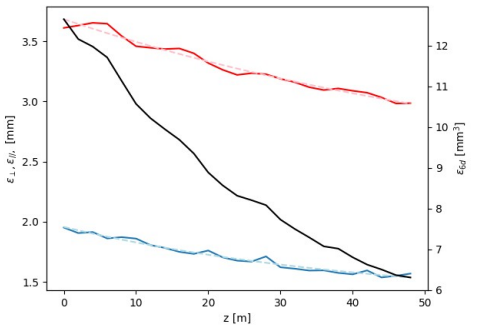


Freemire et al, JINST 13 P01029, 2018

Cooling Demonstrator



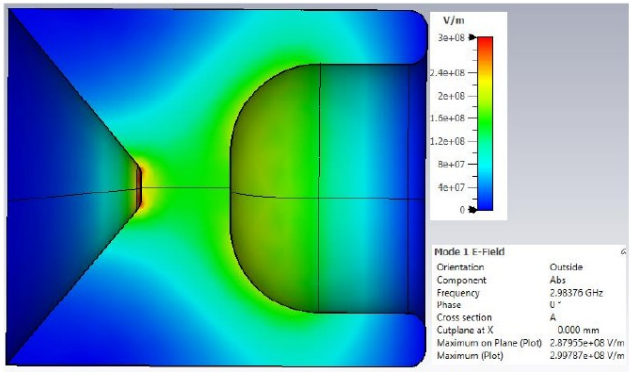




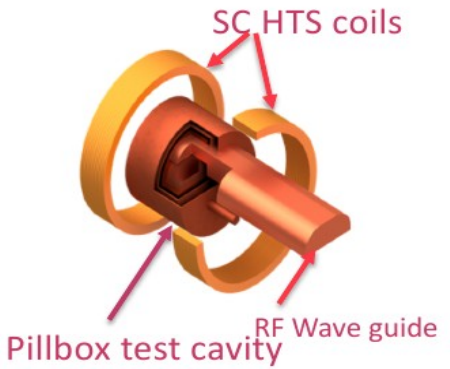
- Cooling demonstrator design in progress
  - Preliminary cooling design - **done**
  - Preliminary phase rot./collimation - **done**
  - Working now on target and transport
    - Consider switchyard for high energy pion beam
- Investigating synergy with muSR/low energy muons

RF in Magnet Test Programme

- Studying options to test RF cavities in B-field
  - Possibility at Daresbury lab, INFN LASA, CEA Saclay, CERN
  - 3 GHz tests likely possible
- No resource to test RF at design frequency
  - Large bore solenoid with appropriate RF equipment does not exist
  - Significant cost to bring RF source
- Investigating synergy with axion searches



Bare coils and RF cavity



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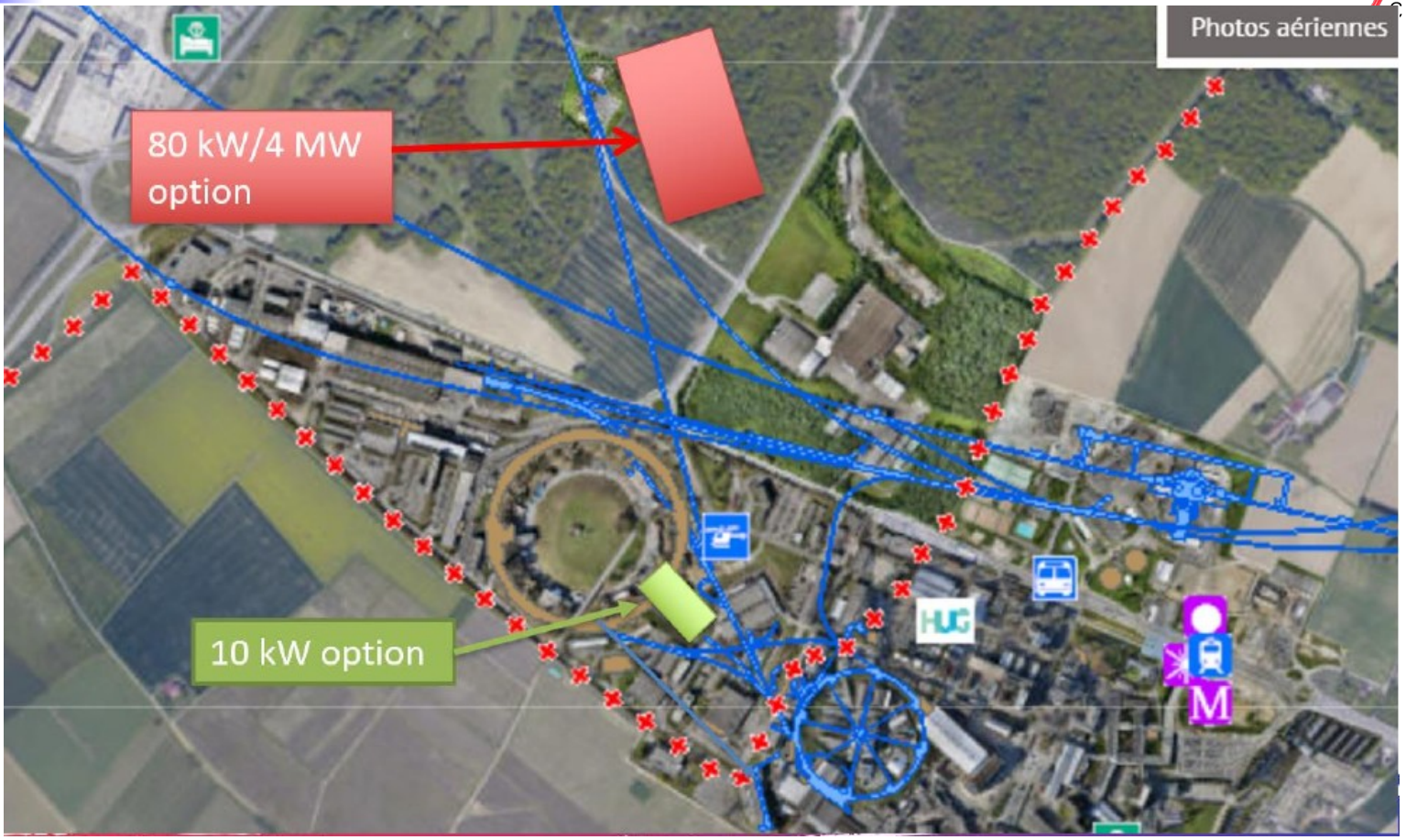
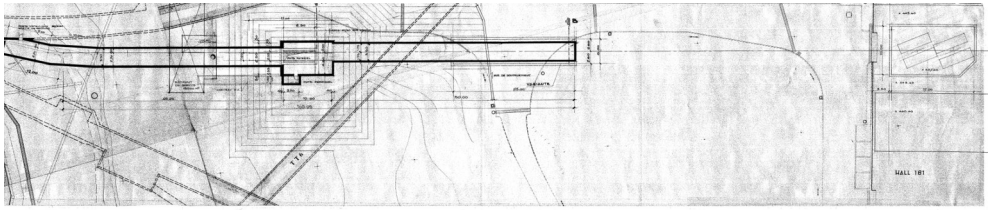
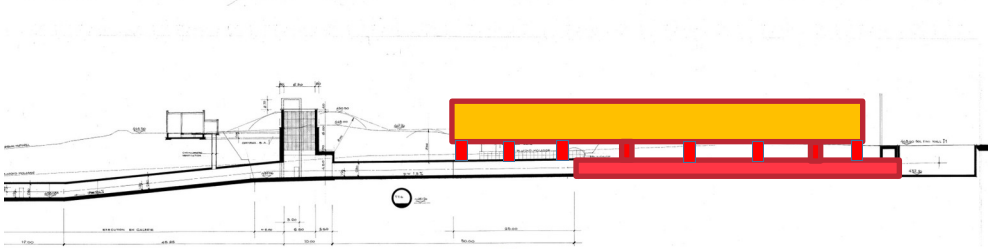
CERN Siting Options

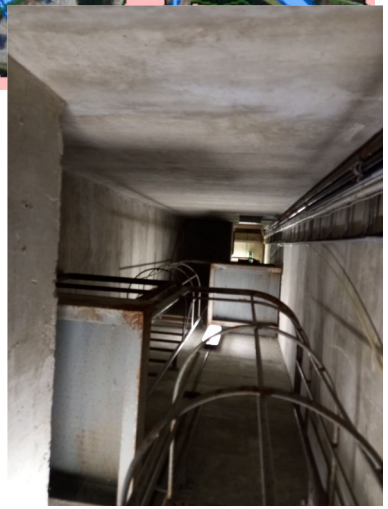


- Site options in other laboratories/regions are welcome

10 kW option







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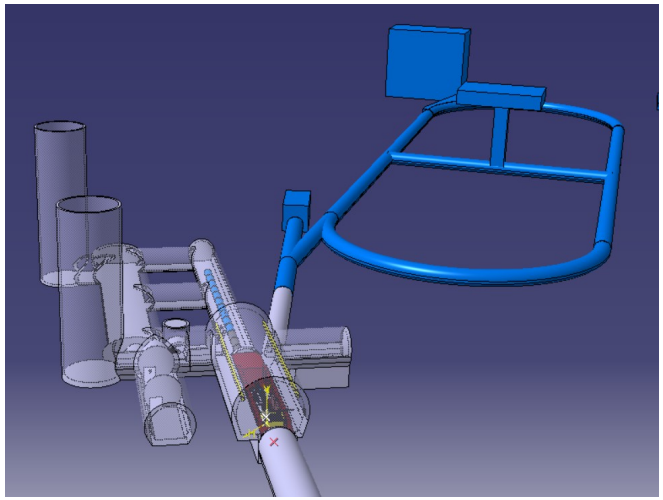
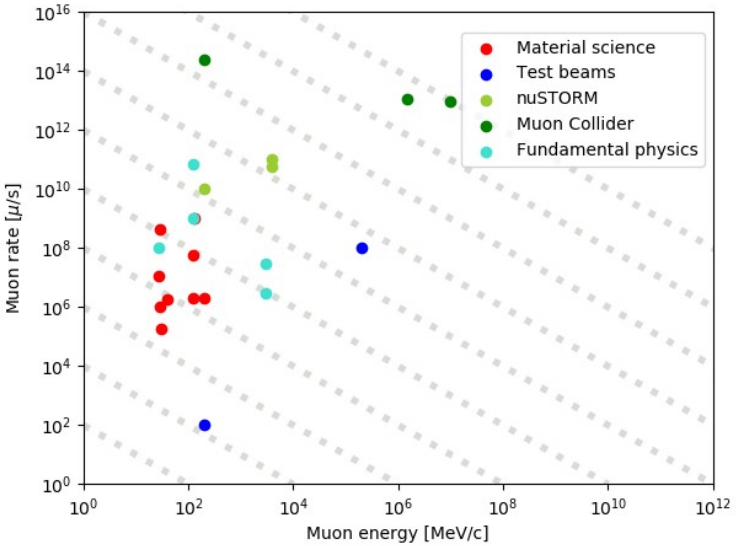
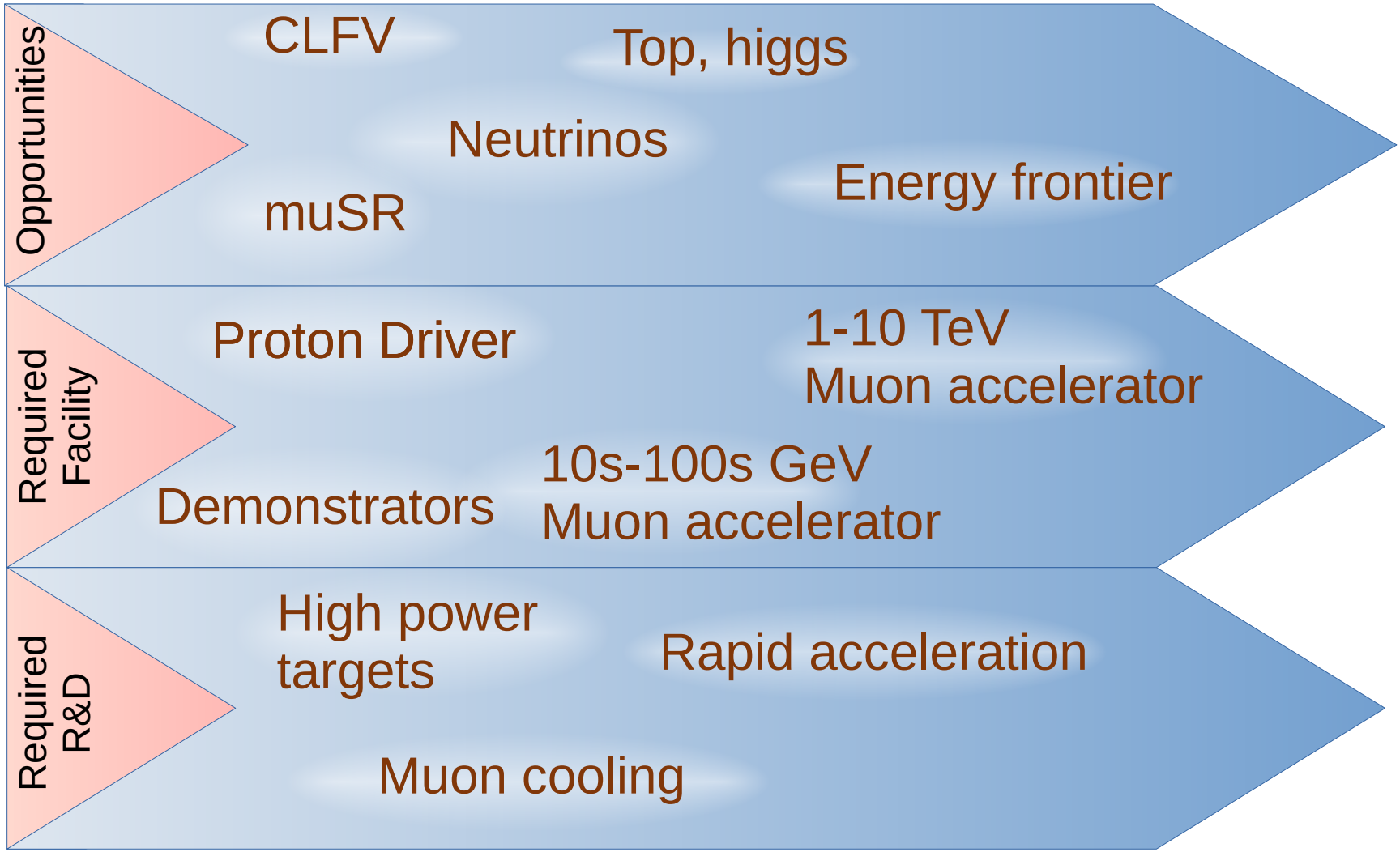
Synergy with nuSTORM



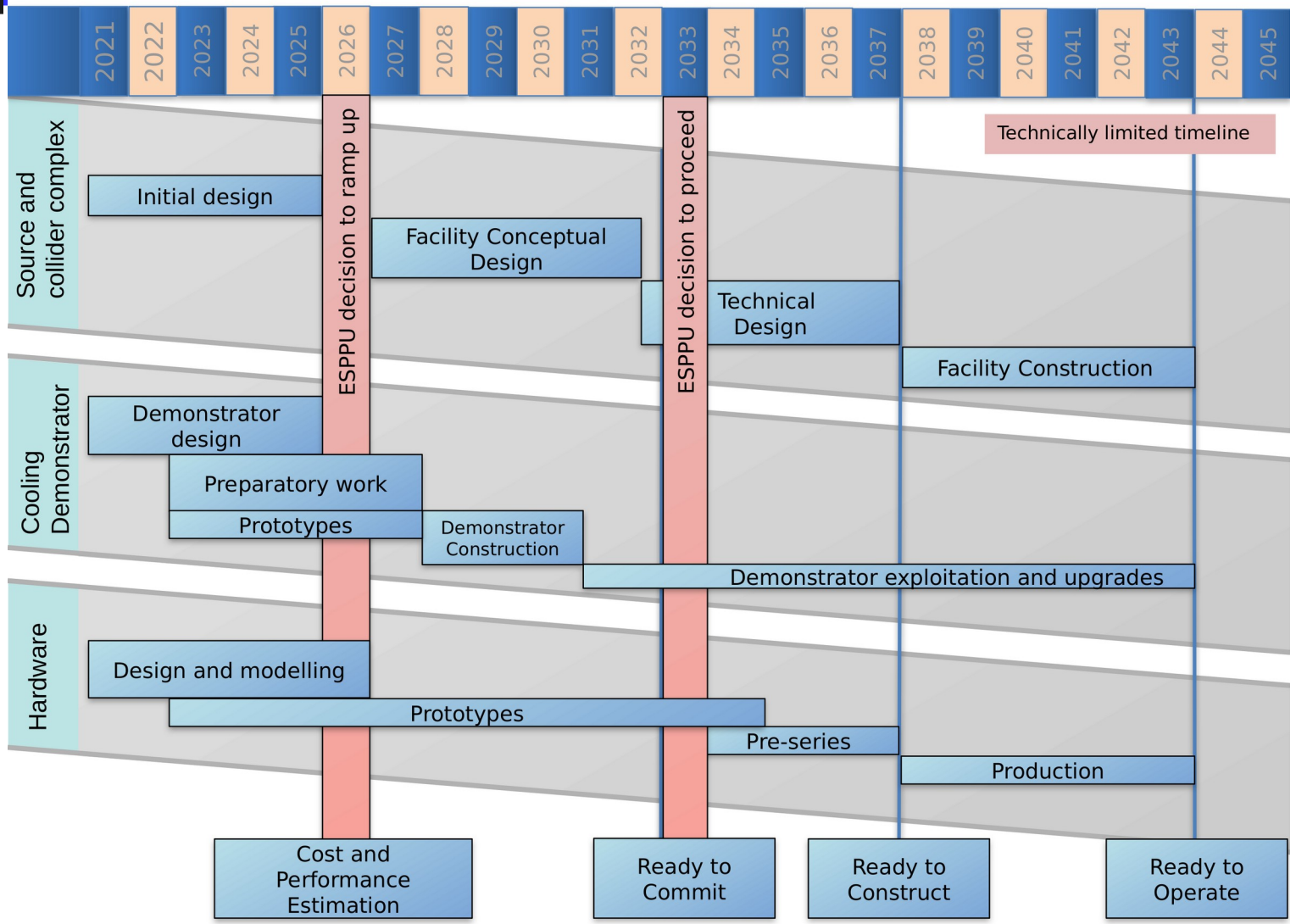


- NuSTORM → “next scale” muon facility
  - FFA-based storage ring (no acceleration)
  - Muon production target and pion handling
  - Possibly shared with cooling demonstrator
- Aim to measure neutrino-nucleus cross-sections
  - E.g. reduce neutrino oscillation experiment resolutions
  - Nuclear physics studies
  - Sensitivity to Beyond Standard Model physics
- Only possible at the 80 kW/4 MW site

R&D Roadmap


Opportunities
CLFV
Top, higgs
Neutrinos
Energy frontier
muSR
Required Facility
Proton Driver
1-10 TeV
Muon accelerator
Demonstrators
10s-100s GeV
Muon accelerator
Required R&D
High power targets
Rapid acceleration
Muon cooling

Timeline


2021
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2043
2044
2045
Technically limited timeline
Source and collider complex
Initial design
Facility Conceptual Design
Technical Design
Facility Construction
ESPPU decision to ramp up
ESPPU decision to proceed
Cooling Demonstrator
Demonstrator design
Preparatory work
Prototypes
Demonstrator Construction
Demonstrator exploitation and upgrades
Hardware
Design and modelling
Prototypes
Pre-series
Production
Cost and Performance Estimation
Ready to Commit
Ready to Construct
Ready to Operate

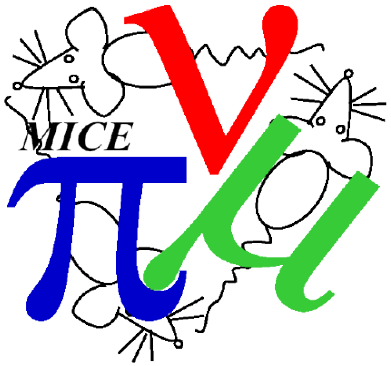
What we need

- Cooling demonstrator is on facility critical path
  - RF test stand highly desirable
    - Validate/extend MUCOOL R&D in a “Demonstrator-like” environment
    - O(700 MHz) MW-scale RF source
    - O(500 mm) aperture solenoid with 7 T “split” field operation
    - RF bunker
  - Would like to start preparing the “10 kW” test area
    - Clean up TT7 test area
    - Fast extraction and beam transfer line installation
    - Need to consider timing/availability in LS3 and suitable resourcing

Conclusions

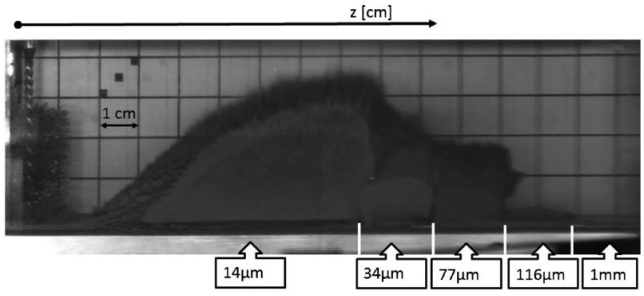
- Muon collider is an excellent candidate for post-LHC era
- Technically challenging
  - This is a good thing!
  - Would yield an entirely novel type of facility
- Beam tests are required
  - Solenoid-focused target → support CLFV programme
  - In particular ionisation cooling → cooling demonstrator
- Can support a great physics programme on the way

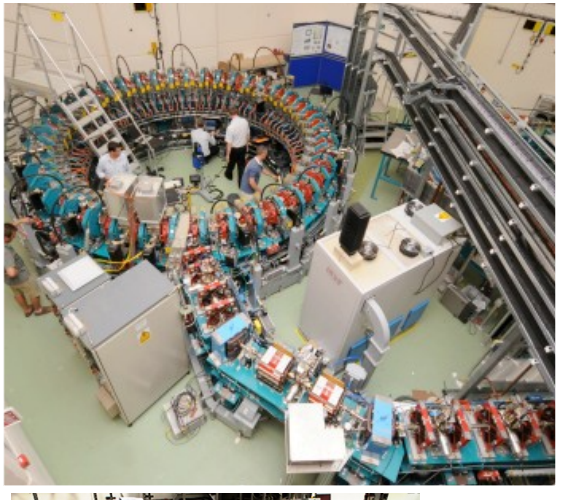
Backup

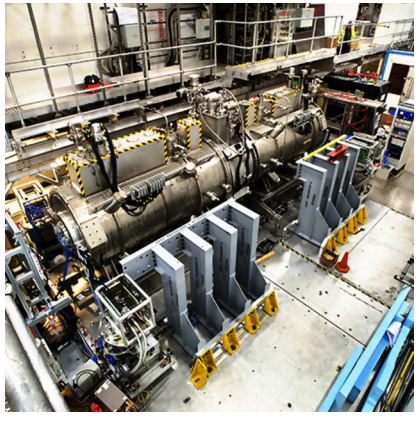


Past Muon Accelerator R&D

- Targetry
  - Graphite targets are well-known
  - Static tungsten powder bed demonstrated with beam
  - Liquid metal target demonstrated in solenoid field and with beam
  - Integration with solenoid novel
- EMMA & CBeta
  - Demonstrated fast acceleration in FFAs
- MUCOOL
  - Cavity R&D for ionisation cooling
  - Demonstrated operation of cavities at high voltage in magnetic field
- MICE demonstration of ionisation cooling







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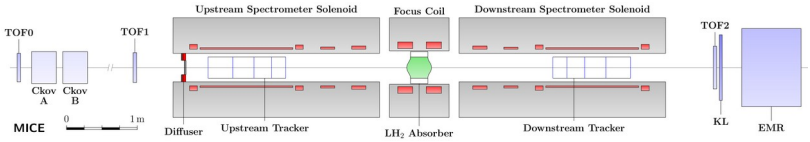
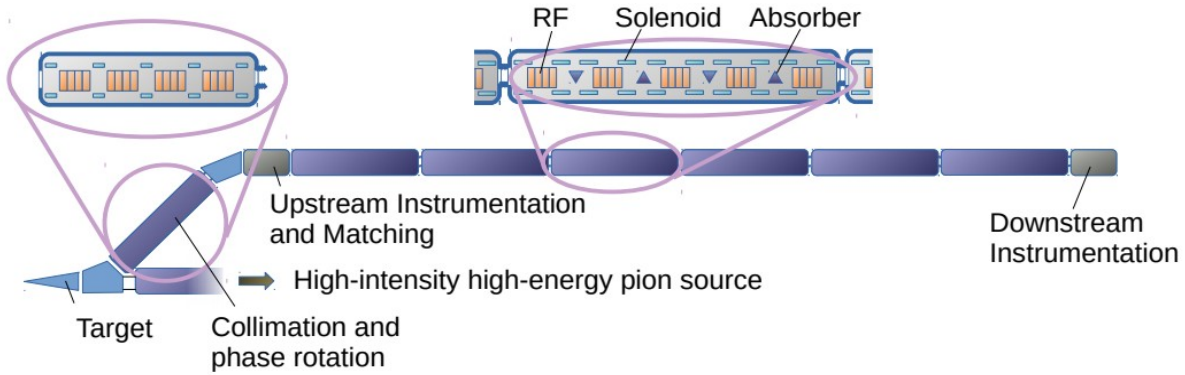
Demonstrators

- Following technologies need stand-alone tests
  - Operation of RF in magnetic fields for ionisation cooling
  - Fast ramping Rapid Cycling Synchrotron dipoles
  - High field magnets for small collider ring
  - Movable collider ring equipment to smear out neutron shower
- Following technologies need beam tests
  - Ionisation cooling technologies
  - Target in solenoid field
- Focus on the items requiring beam tests
  - Reminder of component designs
  - Overview of previous R&D
  - Consideration of useful demonstrations and synergies

Comparison with MICE





	MICE	**Demonstrator**
Cooling type	4D cooling	6D cooling
Absorber #	Single absorber	Many absorbers
Cooling cell	Cooling cell section	Many cooling cells
Acceleration	No reacceleration	Reacceleration
Beam	Single particle	Bunched beam
Instrumentation	HEP-style	Multiparticle-style