Muon cooling demonstrator - R&D programme and beam

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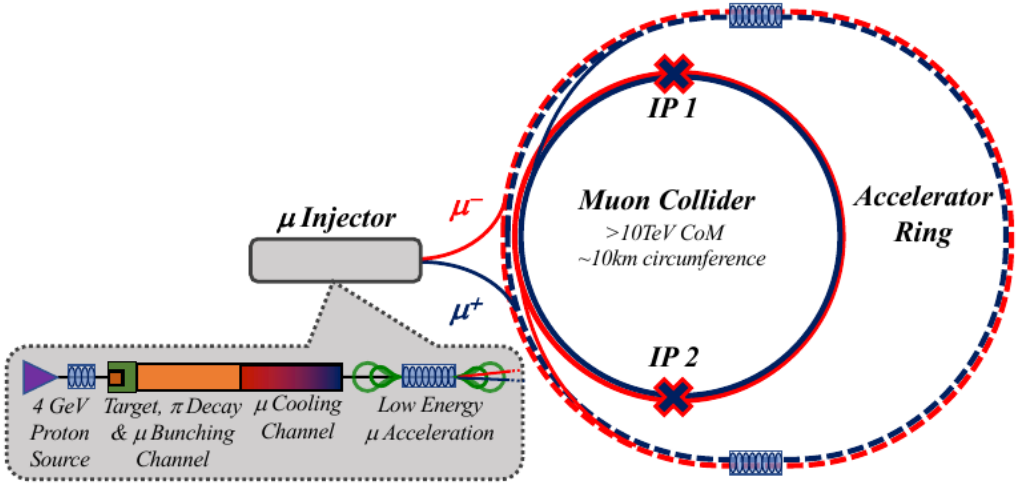
Muon collider

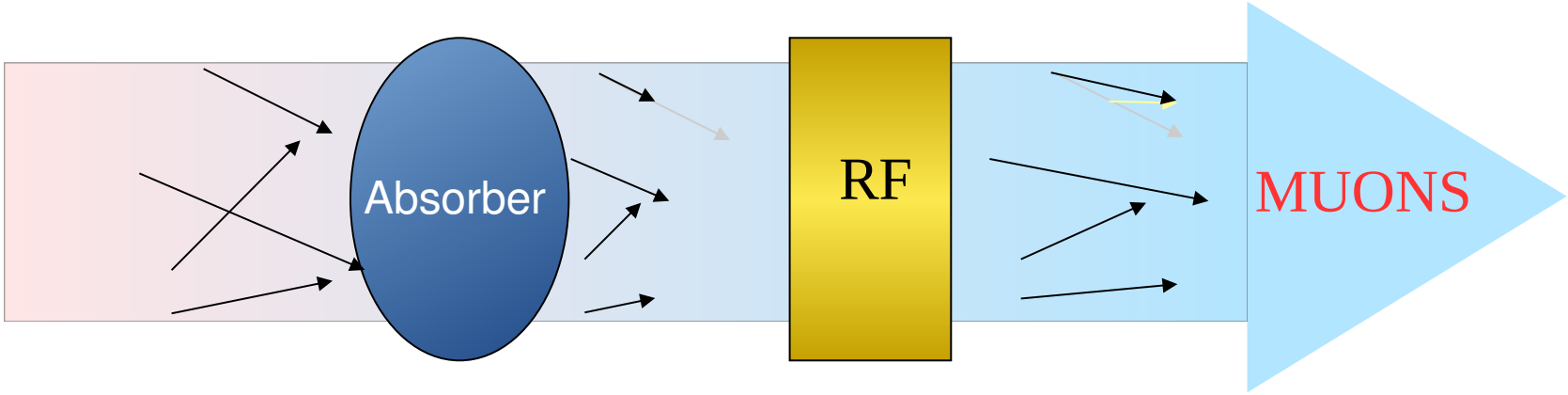


- Muon collider R&D path provides key contribution to non-collider experimental programme
- This talk → cooling demonstrator
- What will it do?
- What is on the way?

Administrative Things

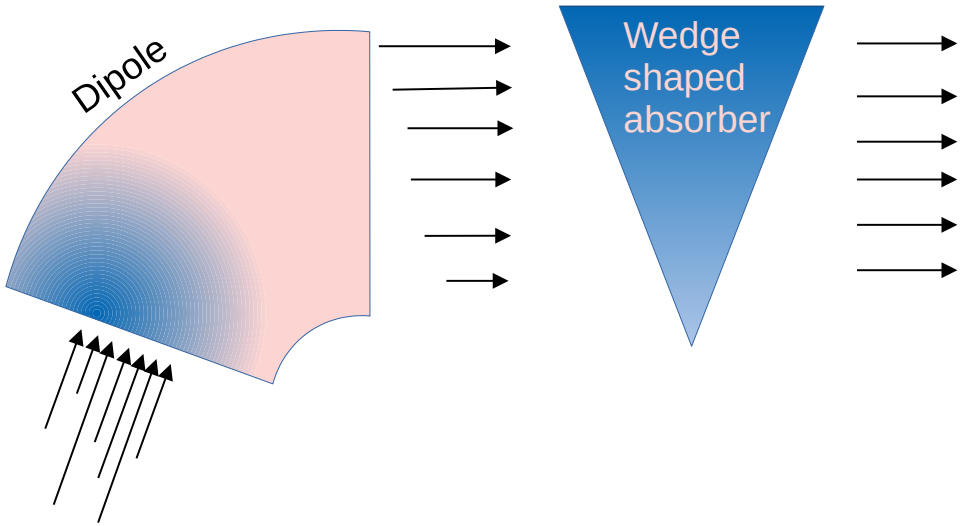
- Some administrative things:
  - We hope that the synergies forum will be monthly
  - Rough plan, TBC:
    - September – Neutrinos
    - October – Rare processes and BSM
    - November – Facilities and Infrastructures
- Comms
  - Mailing list muoncollider-synergies@cern.ch
  - Search in https://e-groups.cern.ch/e-groups/EgroupsSearch.do
  - Indico area https://indico.cern.ch/category/17069/

Ionisation Cooling



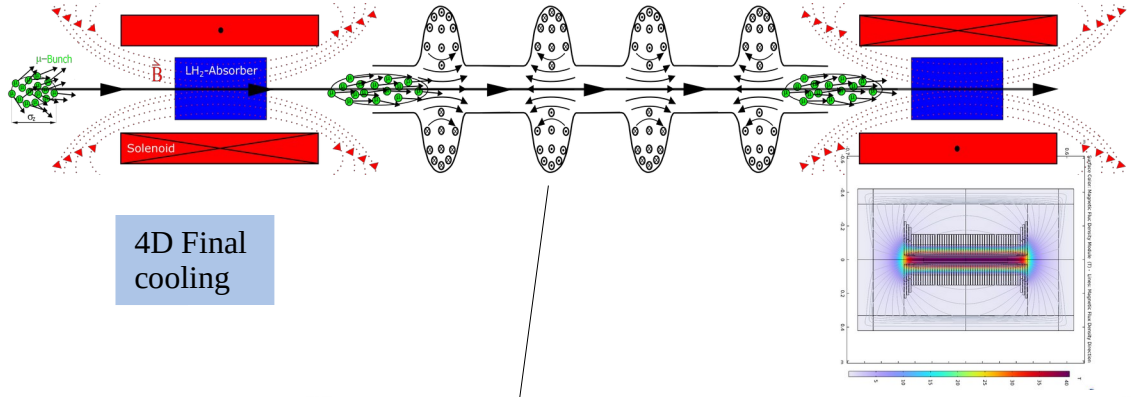
- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more straight
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing
  - Mitigate with low-Z materials
  - Equilibrium **emittance** where MCS completely cancels the cooling

Emittance exchange

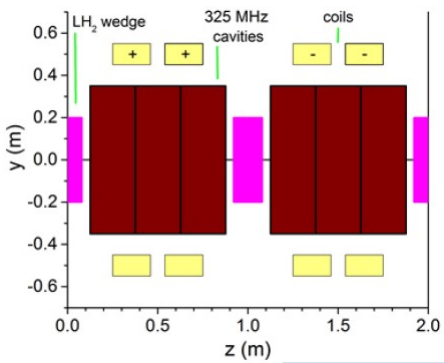


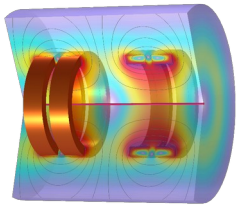
- Initial beam is narrow with some momentum spread
  - Low transverse emittance and high longitudinal emittance
- Beam follows curved trajectory in dipole
  - Higher momentum particles have higher radius trajectory
  - Beam leaves dipole wider with energy-position correlation
- Beam goes through wedge shaped absorber
  - Beam leaves wider without energy-position correlation
  - High transverse emittance and low longitudinal emittance

Muon Cooling

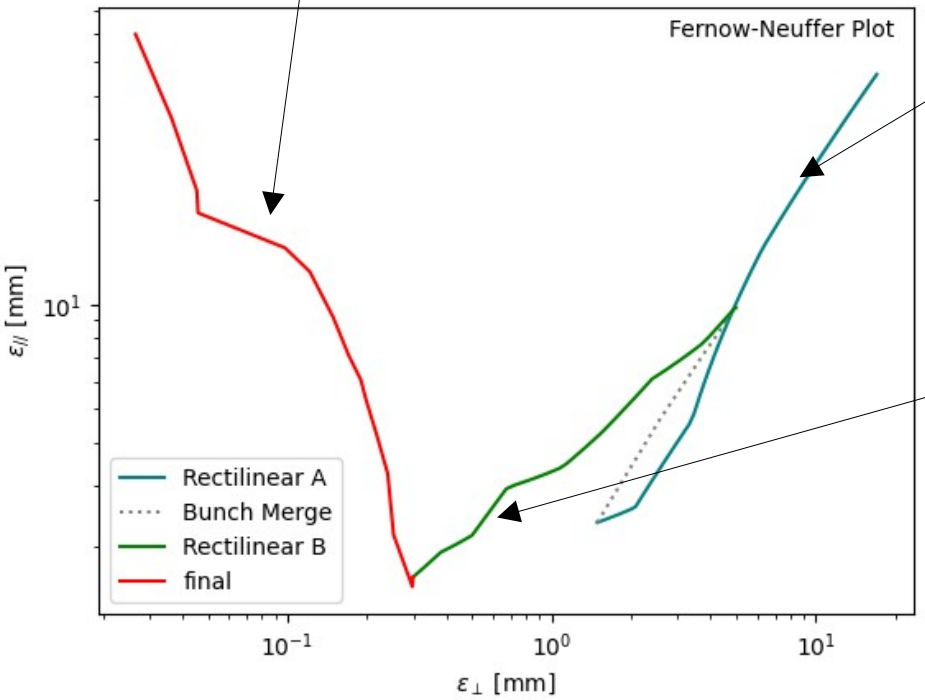


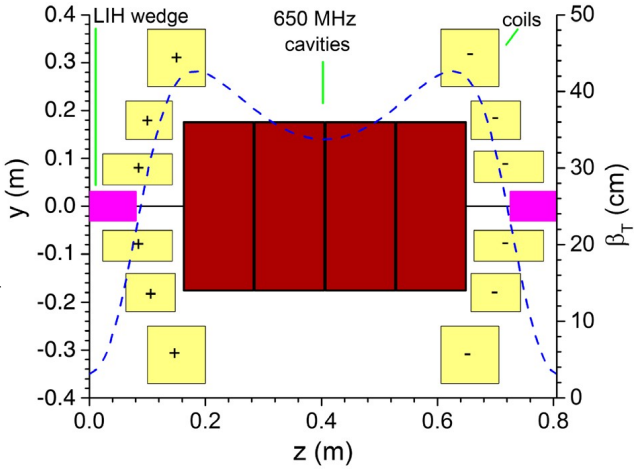
4D Final cooling

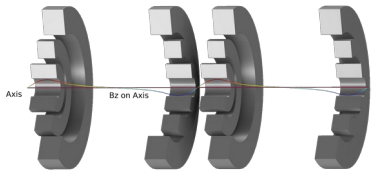




Rectilinear cooling

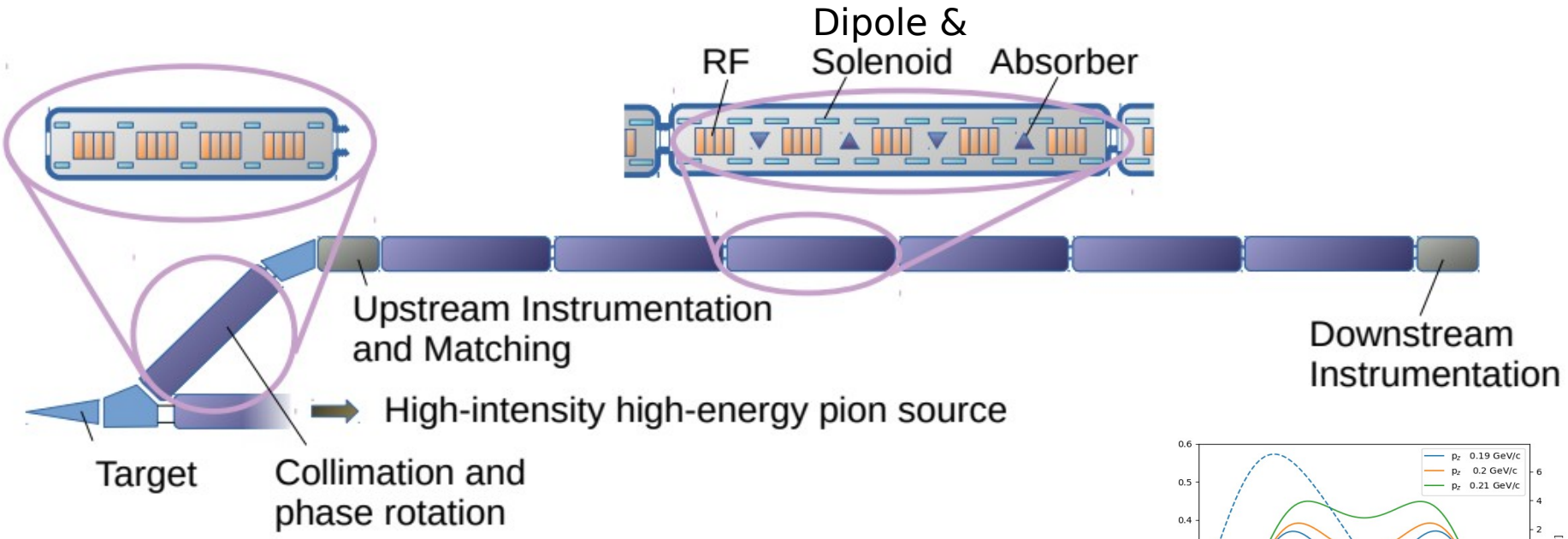




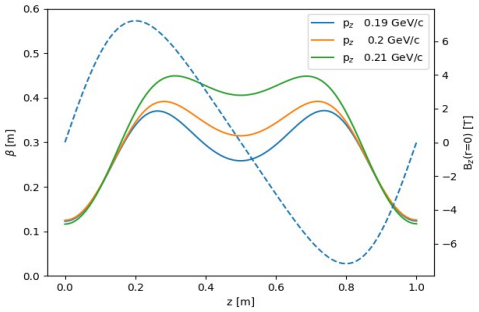


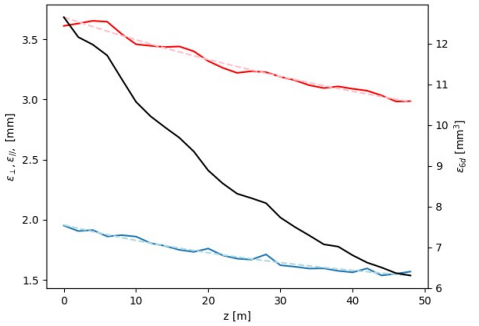
Cooling Demonstrator

International MUON Collider Collaboration



- Build on MICE
  - Longitudinal and transverse cooling
  - Re-acceleration
  - Chaining together multiple cells
  - Routine operation





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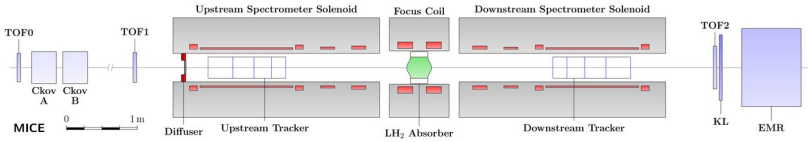
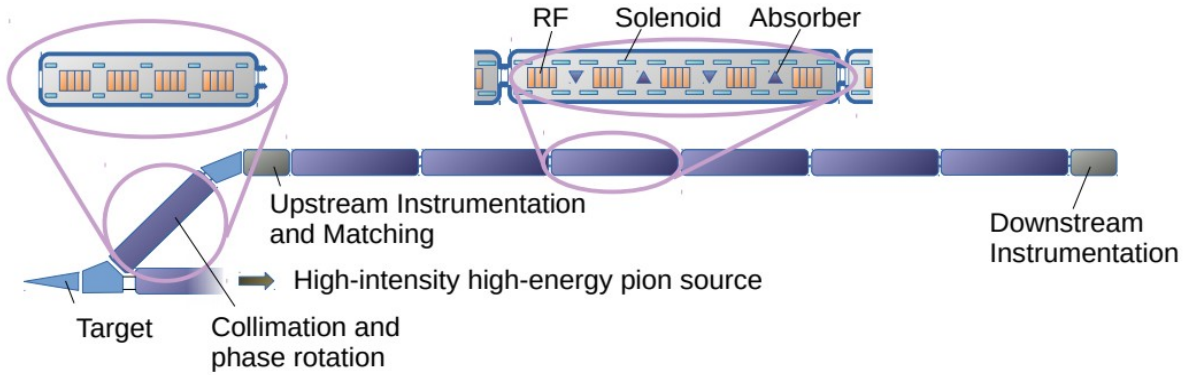
Comparison with MICE



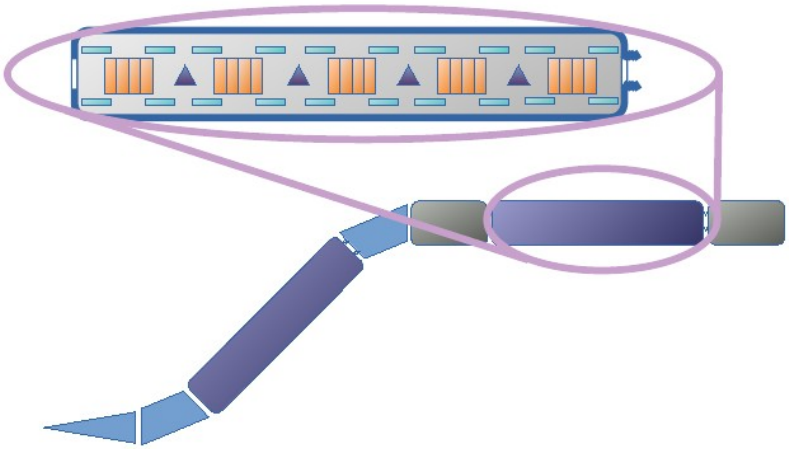


	MICE	Demonstrator
Cooling type	4D cooling	6D cooling
Absorber #	Single absorber	Many absorbers
Cooling cell	Cooling cell section	Many cooling cells
Acceleration	No reacceleration	Reacceleration
Beam	Single particle	Bunched beam
Instrumentation	HEP-style	Multiparticle-style

Demonstrator Programme

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

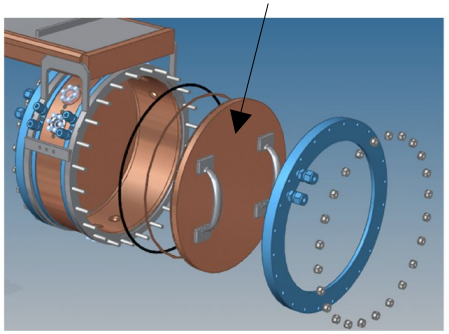
- Cooling requires strong B-field overlapping RF
  - B-field → sparking in RF cavities
- Two technologies have demonstrated mitigation:

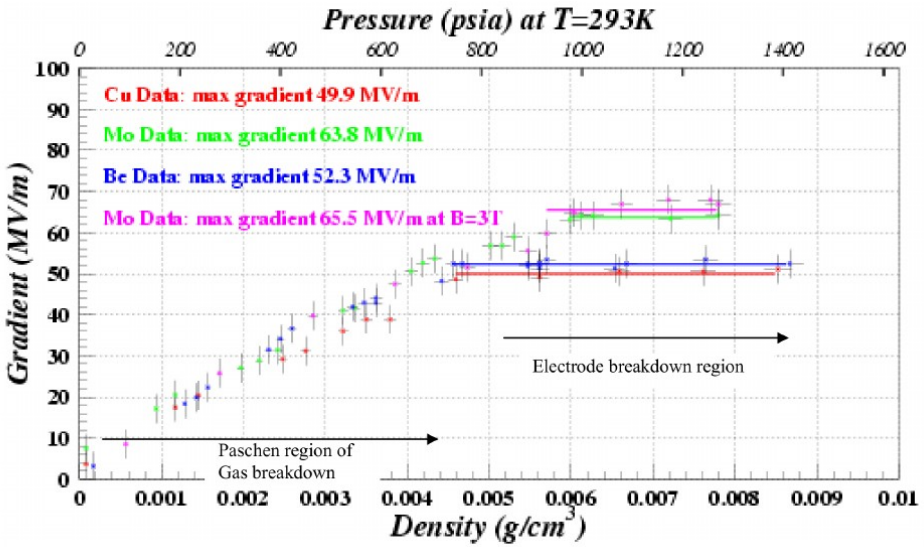
Bowring et al, PRAB 23 072001, 2020

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	$> 49.8 \pm 2.5$

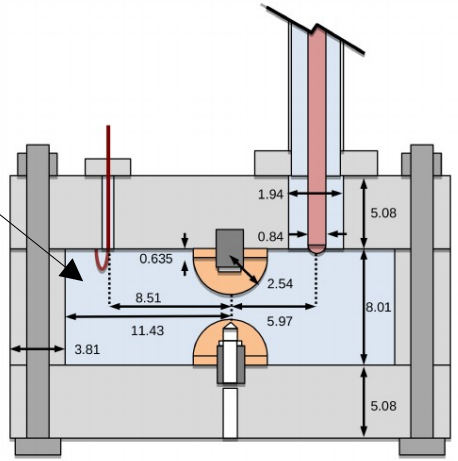
Double vs Cu cavity in 0 T

Changeable Cu/Be walls





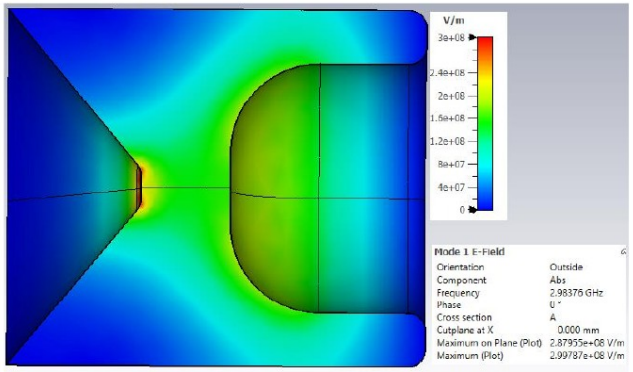
High Pressure gas



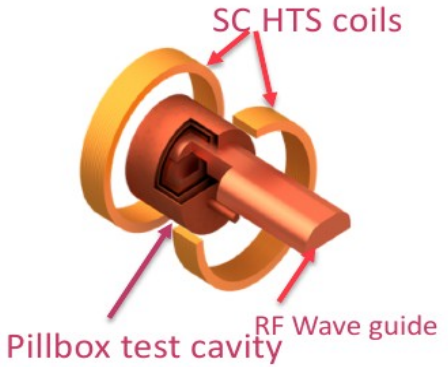
Freemire et al, JINST 13 P01029, 2018

New RF 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
    - 7 T
    - 3 GHz RF @ 50+ MV/m
- Interested in lower frequency
  - 700 MHz @ 30-50 MV/m
  - 7 T field
  - Seeking access to RF power and magnets



Bare coils and RF cavity



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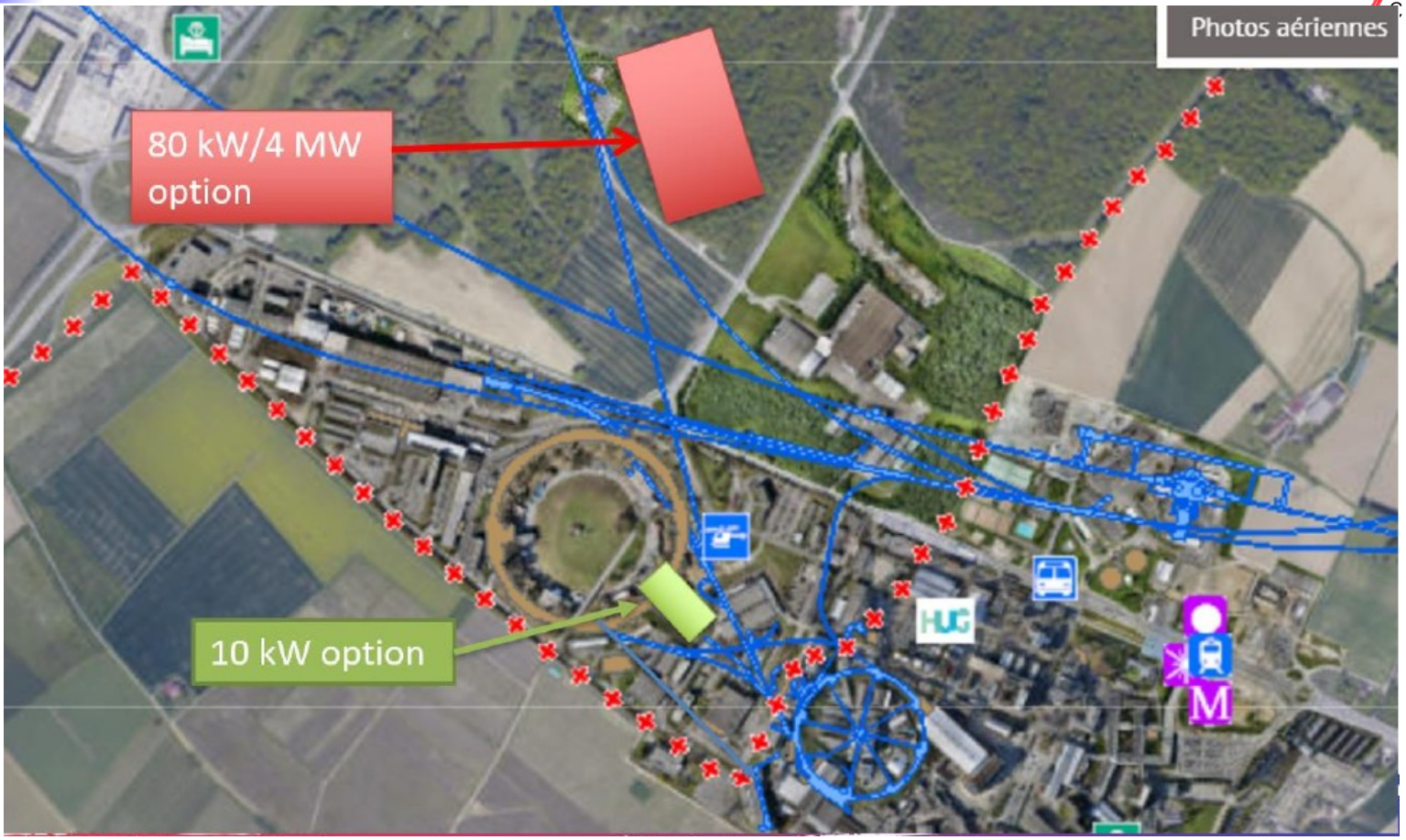
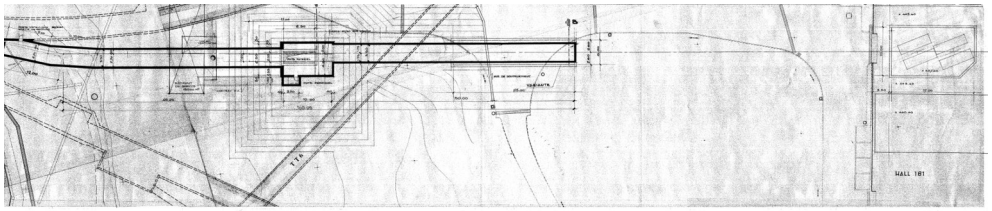
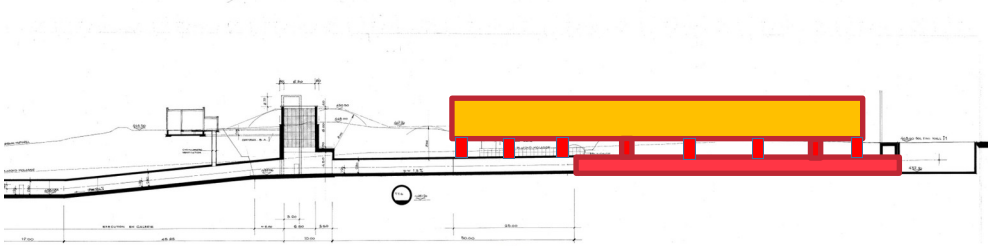
CERN Siting Options

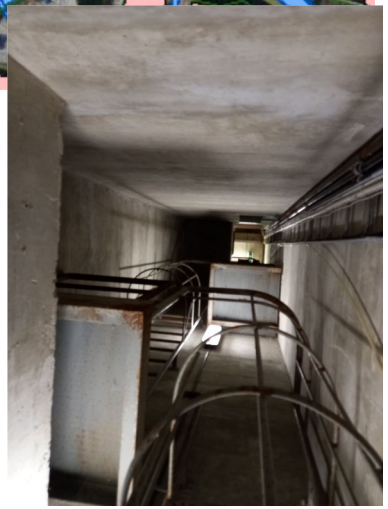


- Site options in other laboratories/regions are welcome

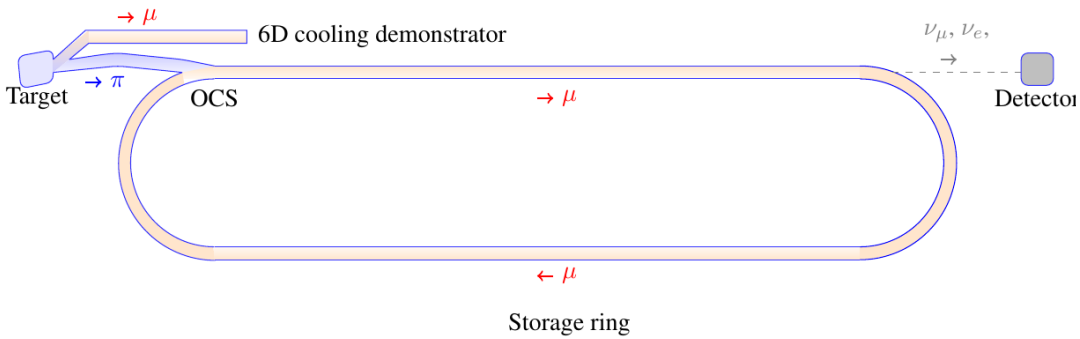
10 kW option

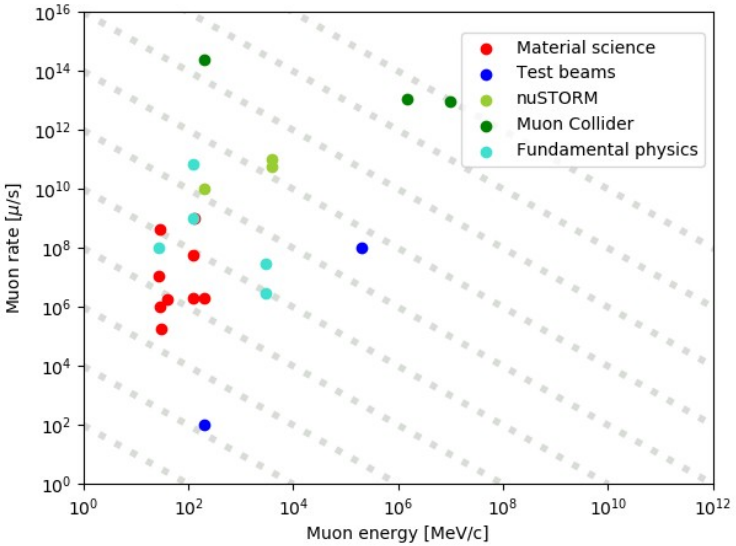






Synergy with nuSTORM

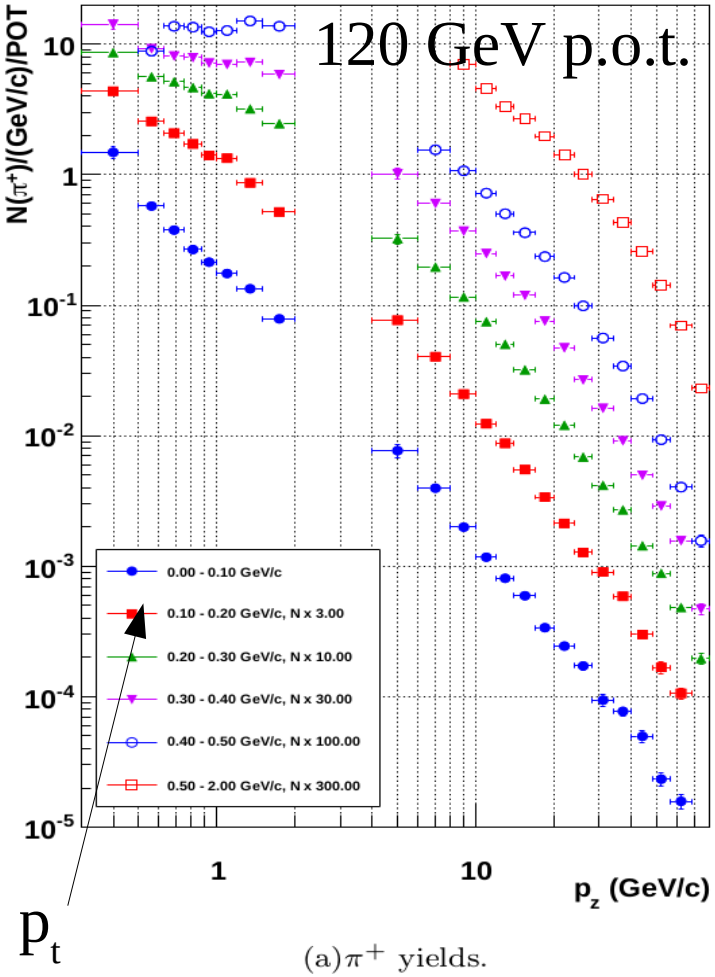




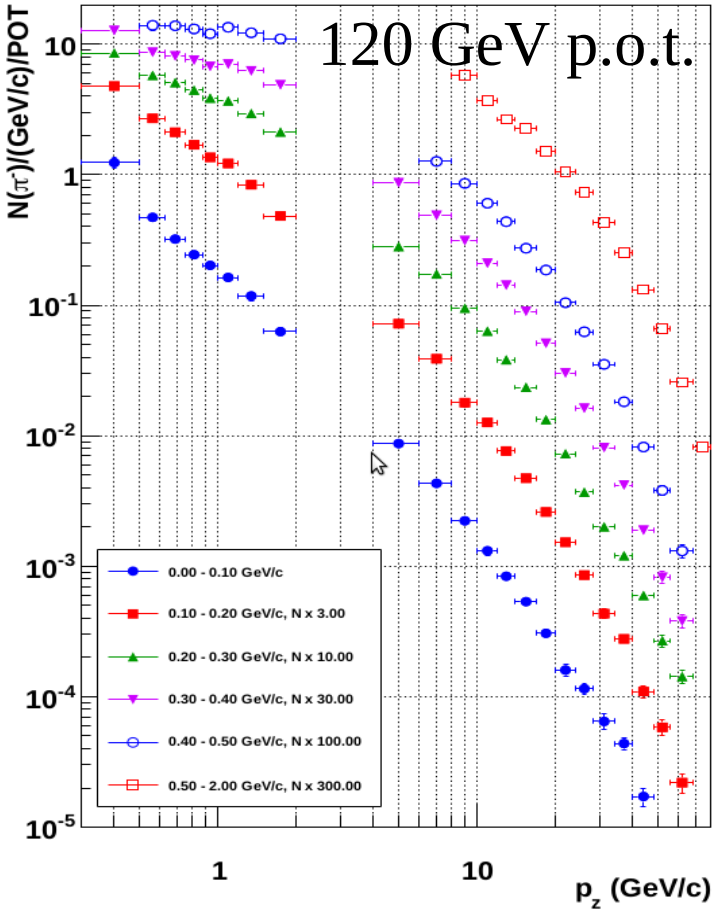
- NuSTORM → "next scale" muon facility
  - FFA-based storage ring (no acceleration)
  - Muon production target and pion handling
  - Possibly shared with cooling demonstrator
- Aim to measure neutrino-nucleus cross-sections
  - E.g. reduce neutrino oscillation experiment resolutions
  - Nuclear physics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

NuMI beam

Paley et al, Measurement of charged pion production yields off the NuMI target, PRD vol 90, 2014



(a)π^+ yields.



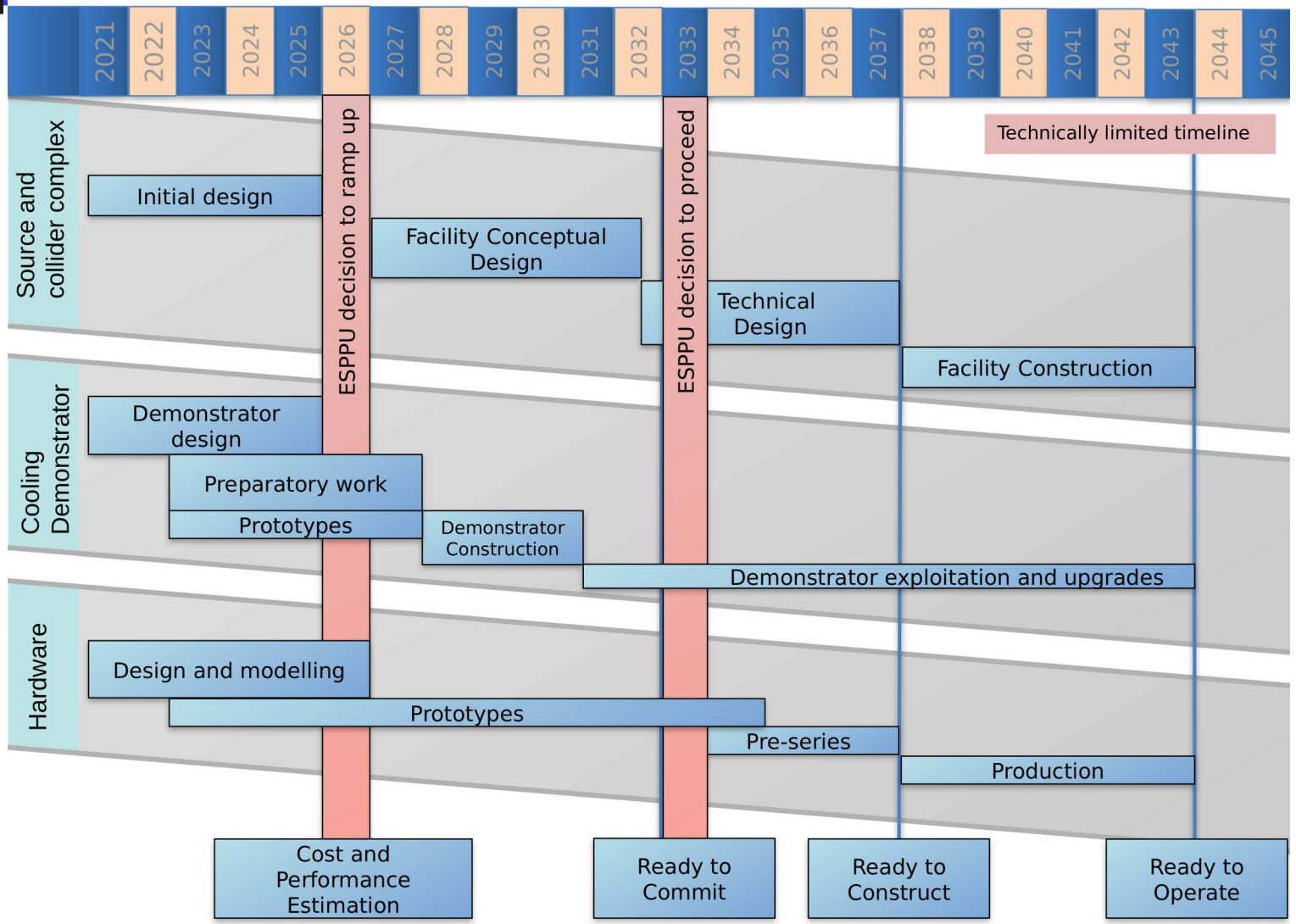
(b)π^- yields.

Assume SPS provides O(1e13) p.o.t. in 7 ns pulse

Expected muon yield

*Invoke **magic collimator fairies***
For rectilinear cooling channel:
σ(t) = 0.1 ns
σ(p) = 0.010 GeV/c
σ(px)/σ(py) = 0.010 MeV/c
σ(x)/σ(y) = 10 mm
Selection:
factor 0.01 pz selection
factor 0.1? pt selection
factor 0.01? position selection
Per single RF bucket:
0.1 ns/7 ns = factor 0.014 time selection
Adding up all RF buckets in the pulse
*0.1 ns*650 MHz = factor 0.065 time selection*
Looks like it is possible to shorten the SPS bunch length to ~ few ns
1e6 muons per RF bucket
1e7 muons per RF pulse
*Analysis in progress to understand likely yield from **PS***
More detailed calculations in progress

Timeline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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

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
  - In particular ionisation cooling → cooling demonstrator
- Can support a great physics programme on the way