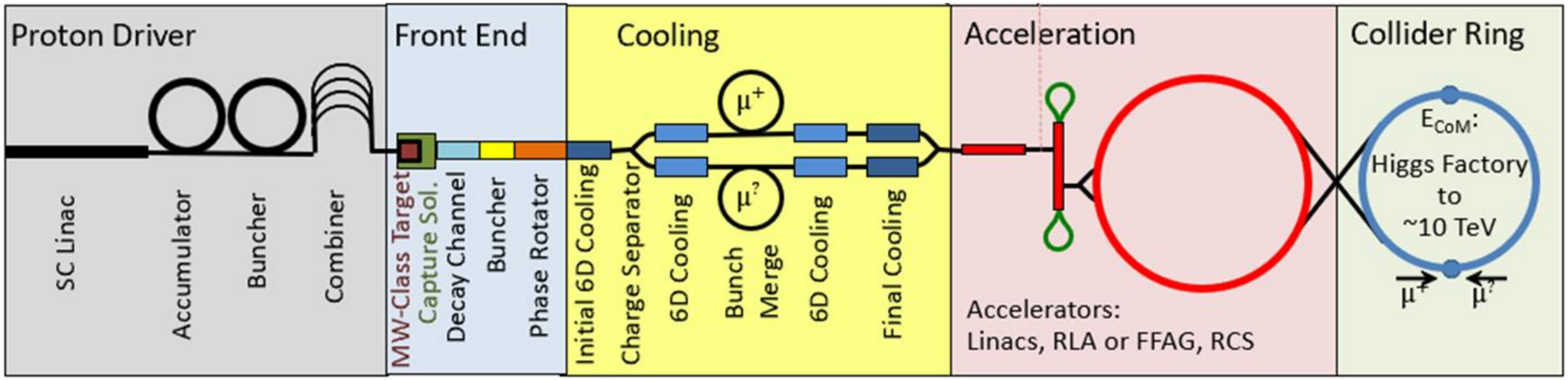
Demonstrator overview

Diktys Stratakis (Fermilab)
US Muon Collider Annual Meeting
August 8, 2025

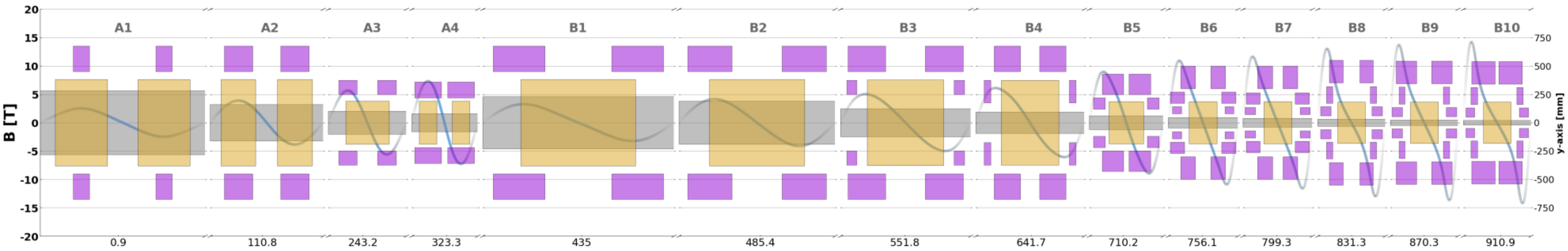
Muon Collider overview



Subsystems: Costs and Risks *2024

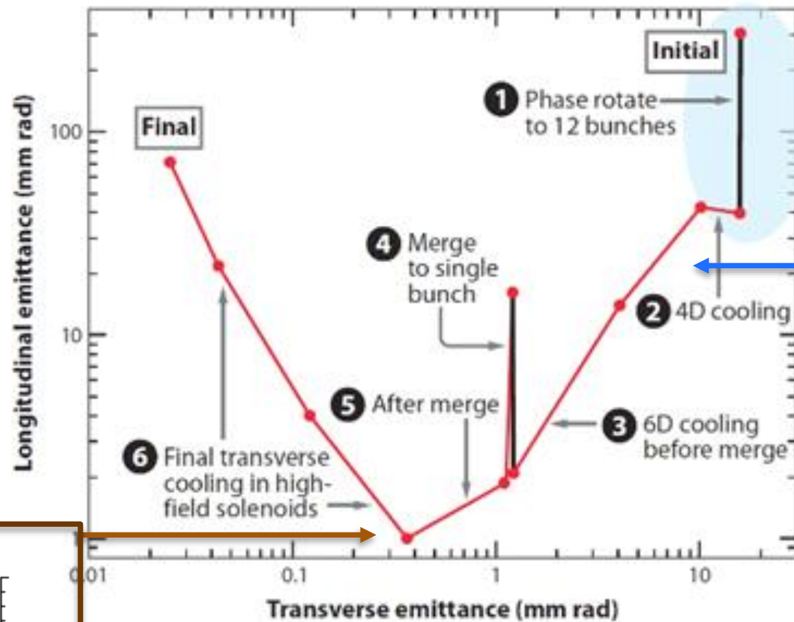
	Approx. % of the Total Cost	Approx. Luminosity Risk Factor
Proton Driver and Targetry	15 - 20 %	10^{1-2}
Muon Cooling	10 - 15 %	10^{3-4}
Acceleration	30 - 60 %	10^{1-2}
Collider	25 - 40 %	10^{0-1}
TOTAL	**12 - 18 B$** *ITF?	**10^{5-9}**

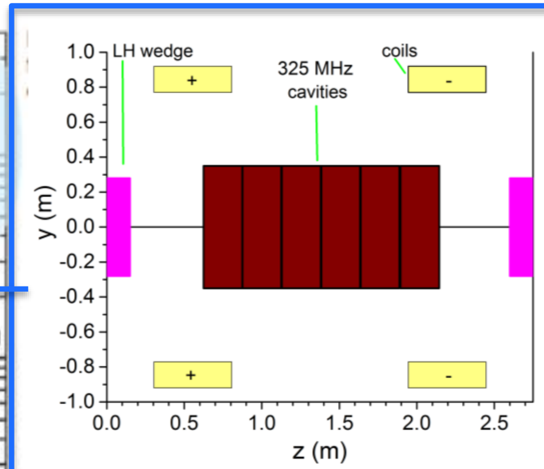
Ionization cooling channel



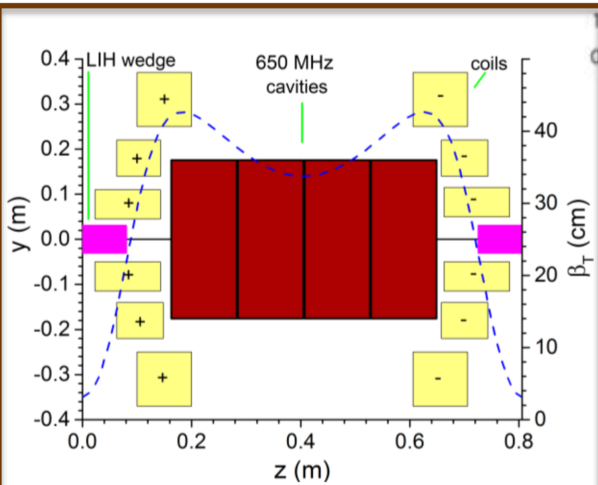
- Total length: 945 m
- Total # of solenoids: 3026
- On axis field from 2.5 T to 14.3 T (in Lattice)
- Free bore 1.5 m to 90 mm

Integration





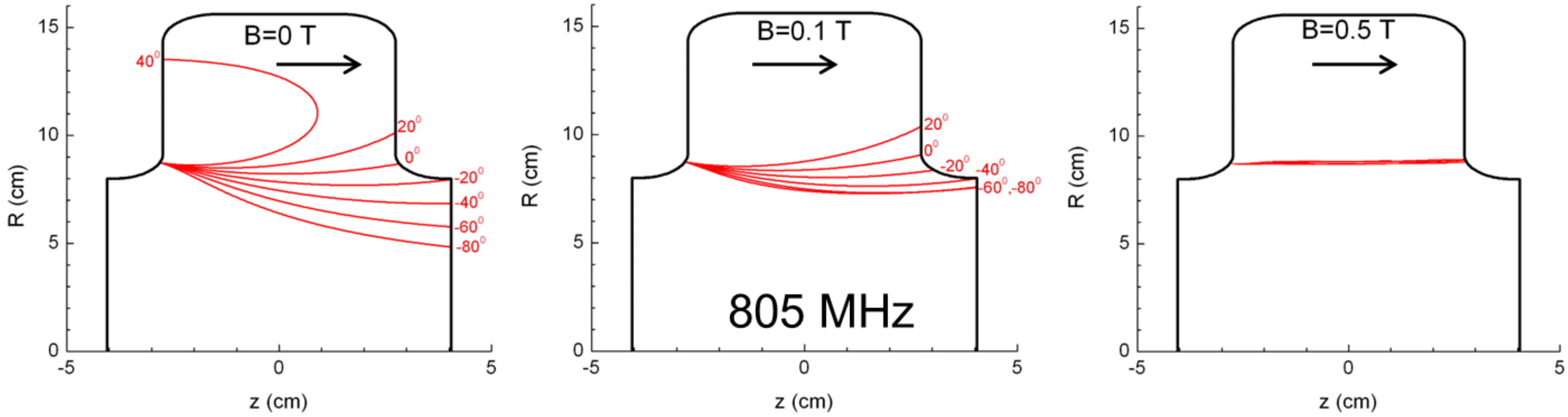
Early cell ("easy") – 2T peak

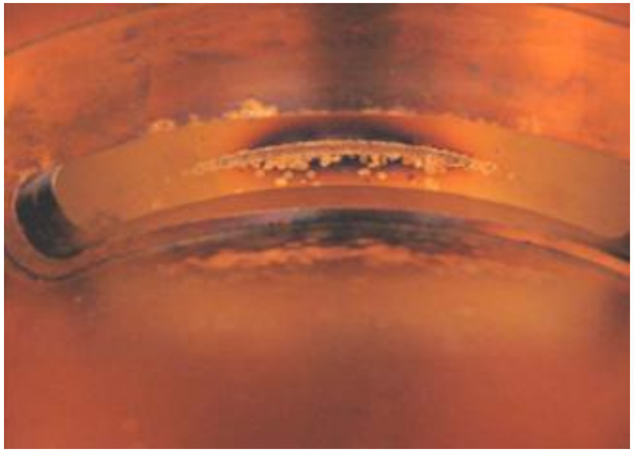


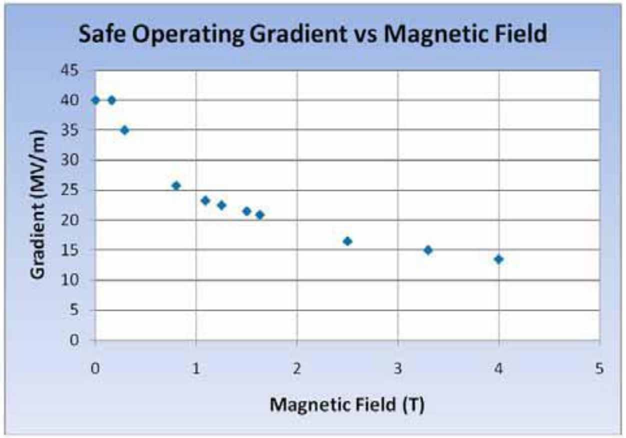
Late cell ("hard") – 14 T peak

Fermilab

Cavities in B-fields








Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

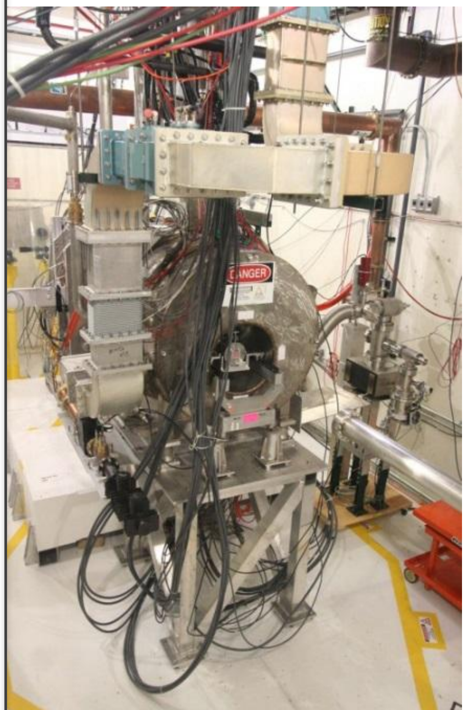
journal homepage: www.elsevier.com/locate/nima

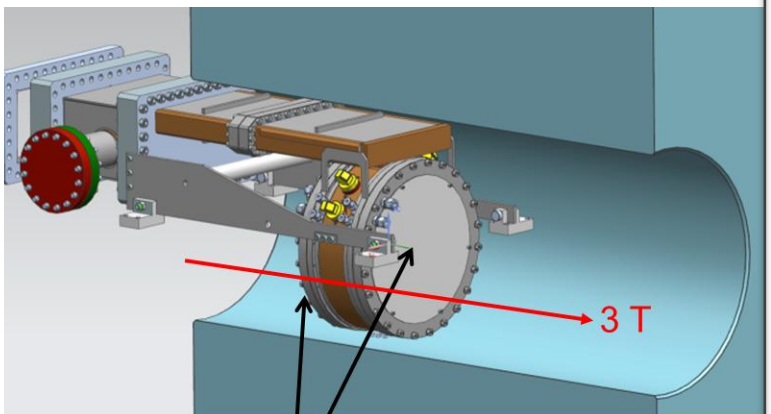
Effects of external magnetic fields on the operation of high-gradient accelerating structures

Diktys Stratakis *, Juan C. Gallardo, Robert B. Palmer

Cavities in B-fields

Vacuum cavities

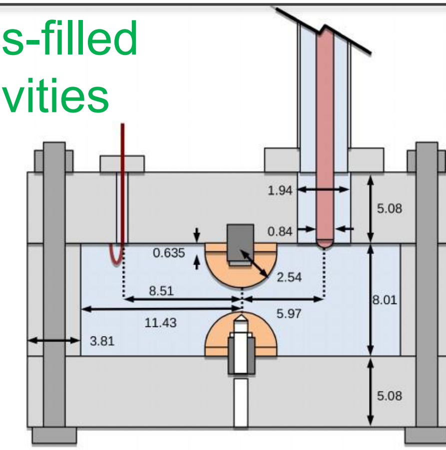


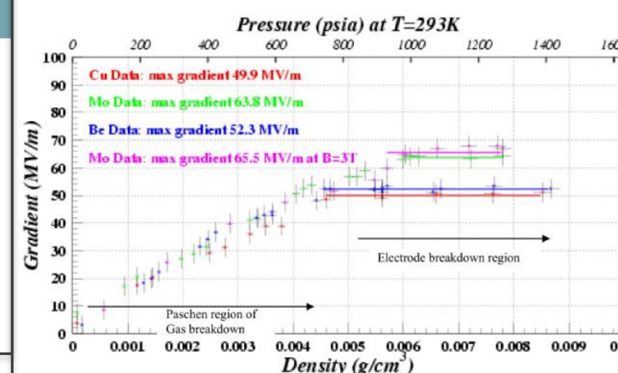


removable plates (Cu, Al, Be)

Material	B-field (T)	SOG (MV/m)	BDP ($\times 10^{-5}$)
Cu	0	24.4 ± 0.7	1.8 ± 0.4
Cu	3	12.9 ± 0.4	0.8 ± 0.2
Be	0	41.1 ± 2.1	1.1 ± 0.3
Be	3	$> 49.8 \pm 2.5$	0.2 ± 0.07
Be/Cu	0	43.9 ± 0.5	1.18 ± 1.18
Be/Cu	3	10.1 ± 0.1	0.48 ± 0.14

Gas-filled cavities



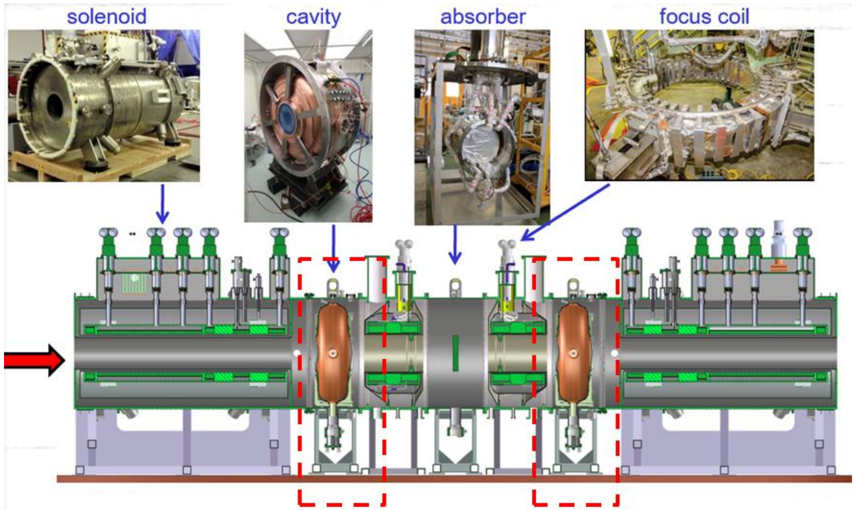


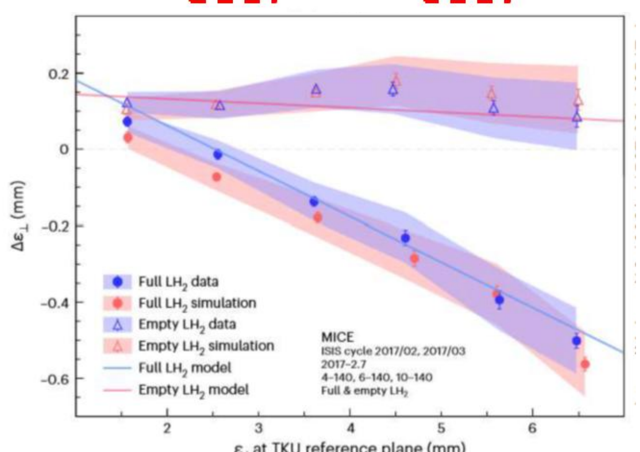
Need B> 3T

Principle verification

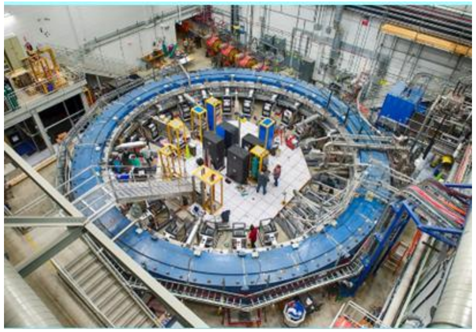
- Physics of ionization cooling has been demonstrated in two occasions

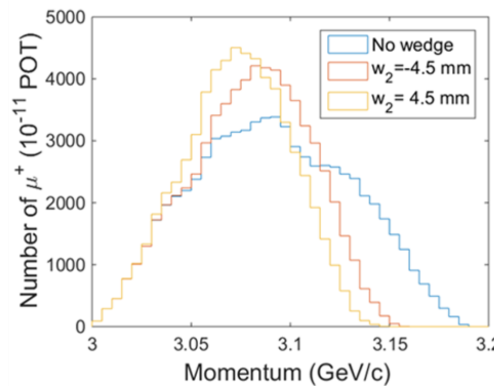
MICE Experiment

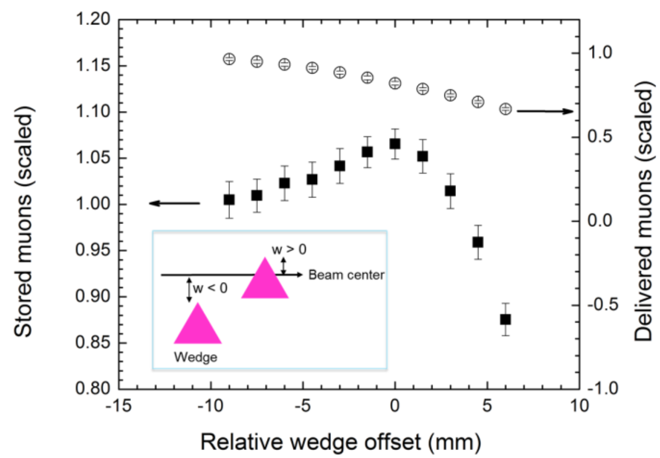


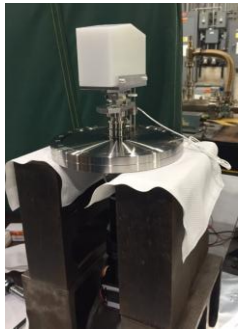


Fermilab Muon g-2 Experiment







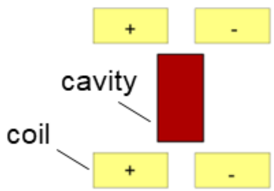


Benefits of a cooling demonstrator

- Benchmark a realistic cooling lattice
  - This will give us the input, knowledge, and experience to design a real, operational cooling channel for a MuC
- It will advance magnet technology since we will design, prototype and test solenoids similar to those needed for a MuC
  - Synergistic with fusion reactors and axion dark matter searches
- It will advance rf cavity technology since we will design, prototype and test NC cavities similar to those need for a MuC
  - Opportunity to develop efficient klystrons that can be useful for future colliders
  - Opportunity to develop technology towards very high-gradient rf cavities for future colliders

Muon demonstrator staging

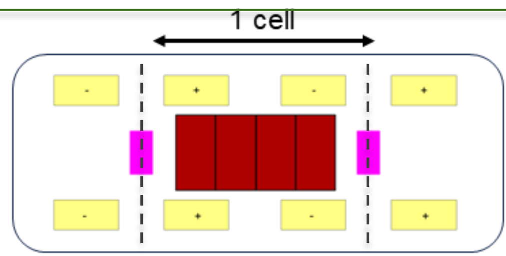
Phase-I



RF studies in B-fields

Material studies & cryogenic Cu

Phase-II

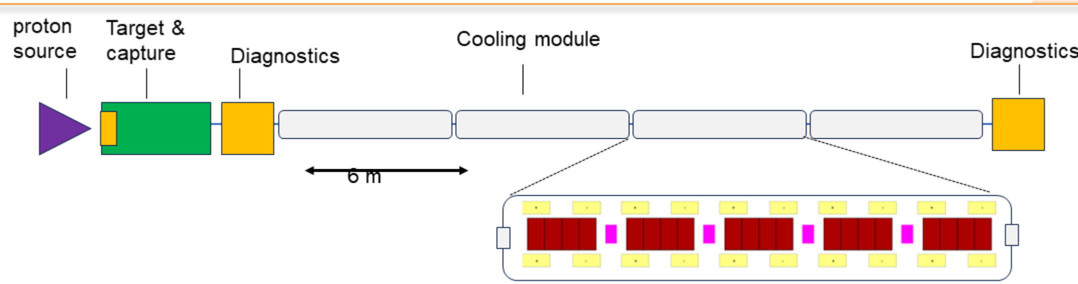


Cell integration studies

Cell resembles late 6D cooling stages

Reuse components from Phase I

Phase-III



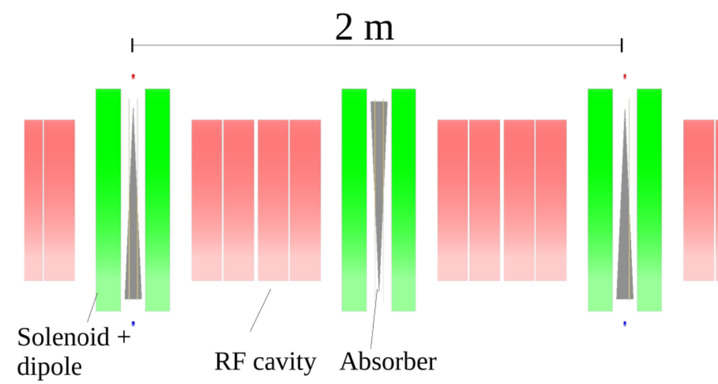
Full demonstrator with beam

Coils producing 7T axial fields

Potential to achieve 50% 6D cooling

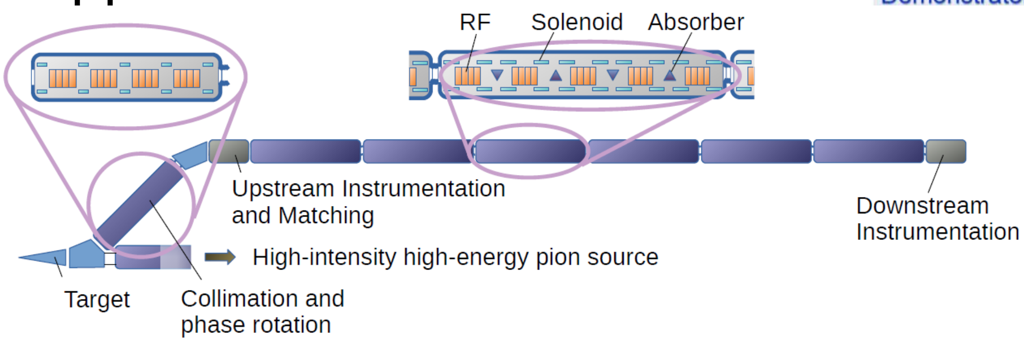
Full demonstrator with beam

- Design in progress
  - Muon source, target and transport
  - Beam transport
  - Cooling channel
- Investing synergies with other applications



Cooling System	
Cell length	2 m
Peak solenoid field on-axis	7.2 T
Dipole field	0.2 T
Dipole length	0.1 m
RF real estate gradient	22 MV/m
RF nominal phase	20°
RF frequency	704 MHz
Wedge thickness on-axis	0.0342 m
Wedge apex angle	5°
Wedge material	LiH

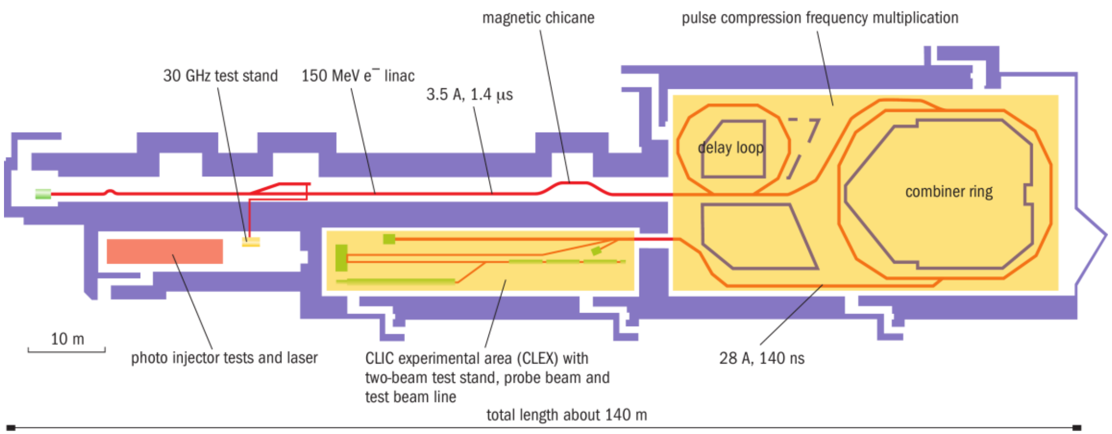
	Muon energy, MeV	Total length, m	Total # of cells	B_max, T	6D emm. reduction	Beam loss, %
Full scale MC	200	~980	~820	2-14	x $1/10^5$	~70%
Demonstrator	200	48	24	0.5-7	x 1/2	4-6%

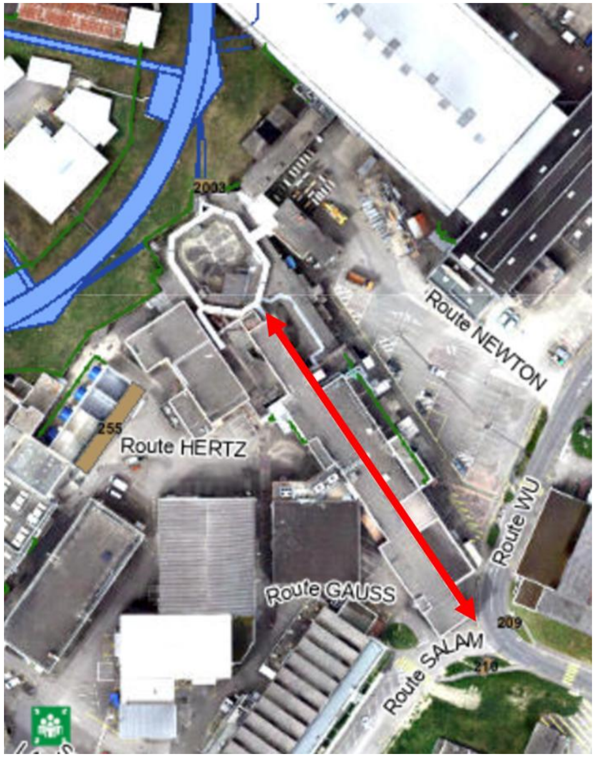


C. Rogers, Phys. Sci. Forum **2023**, 8(1), 37

Candidate locations at CERN

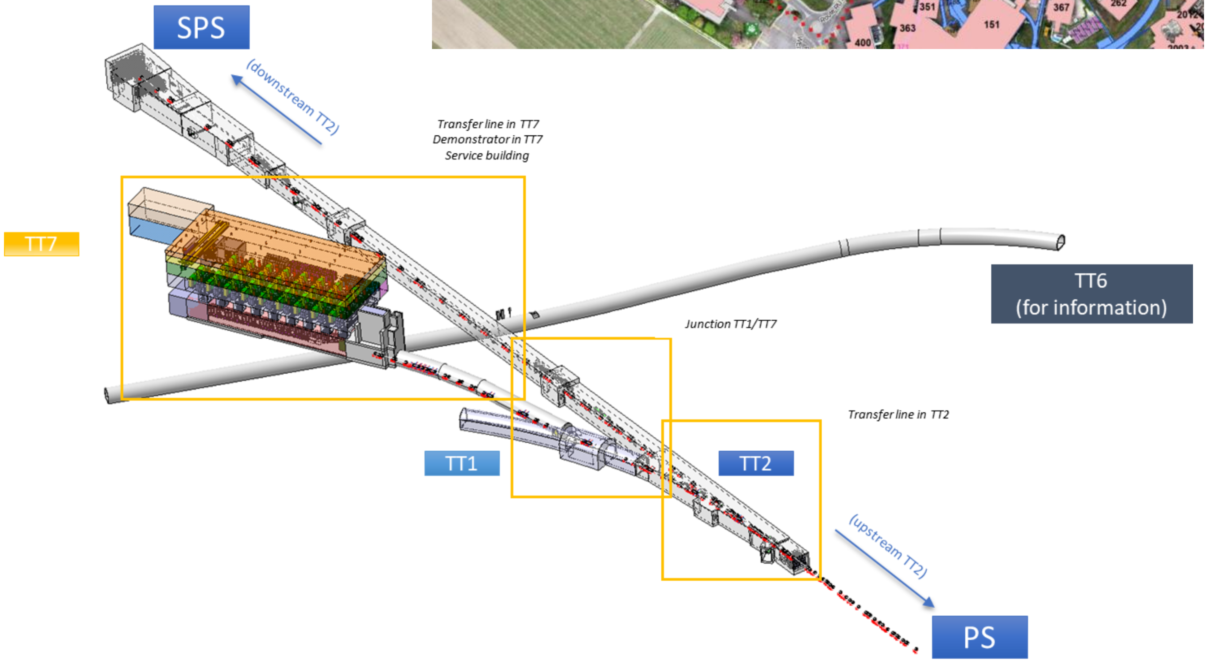
- CTF3 area
    - No extraction in the PS
    - ~ 100 m tunnel available
    - Limited to < 10 kW average beam power
    - **~ 2 × 10^6 muons/bunch**
    - Klystron gallery available



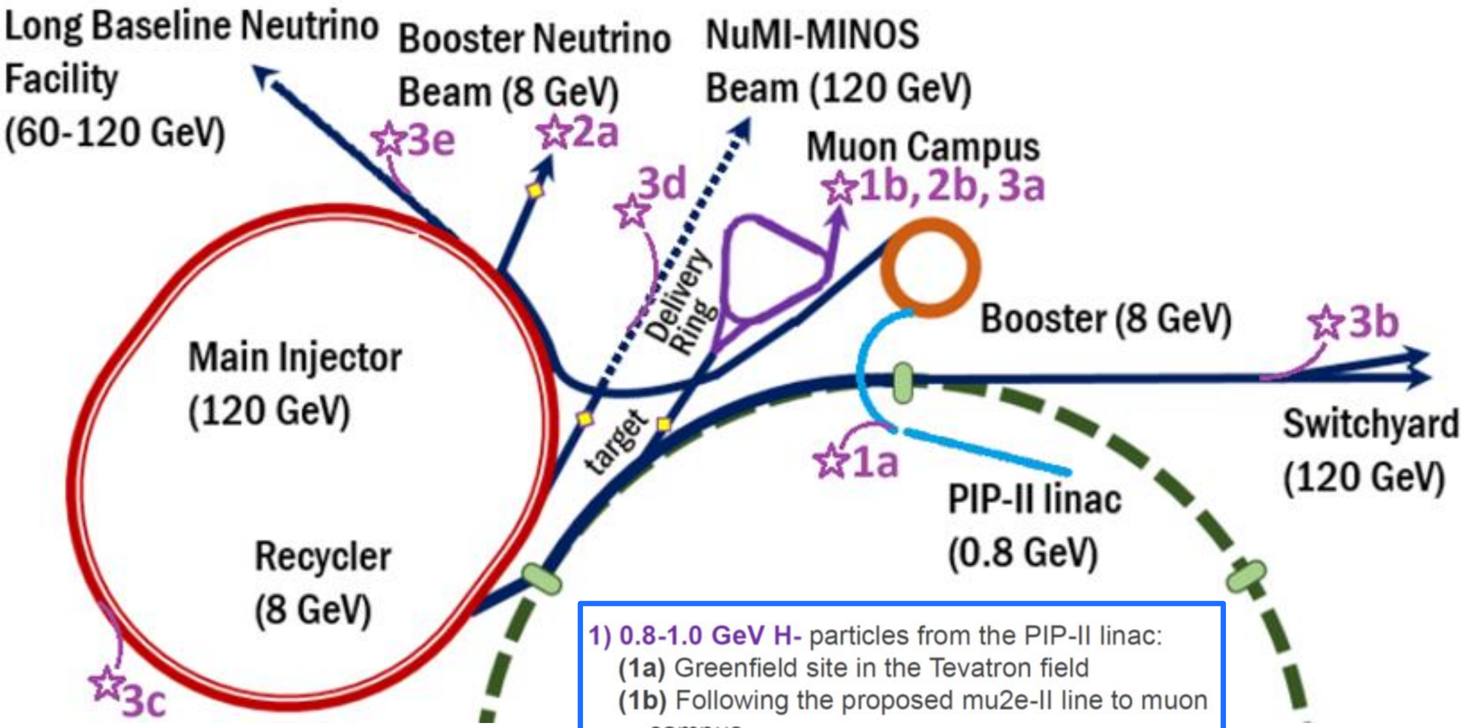


Candidate locations at CERN

- **TT7 tunnel**
  - Does not require a new beam extraction in the PS
  - **Muon intensity lower than CTF3 (under study)**



Candidate locations at Fermilab

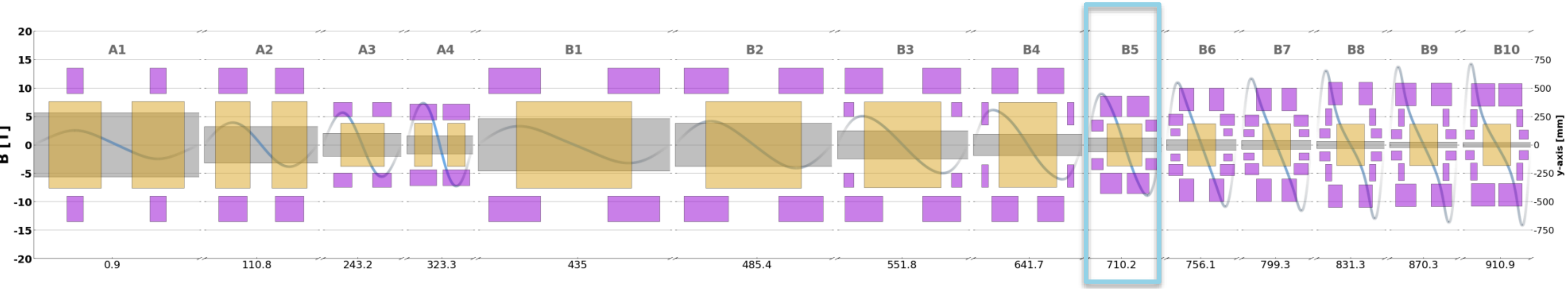


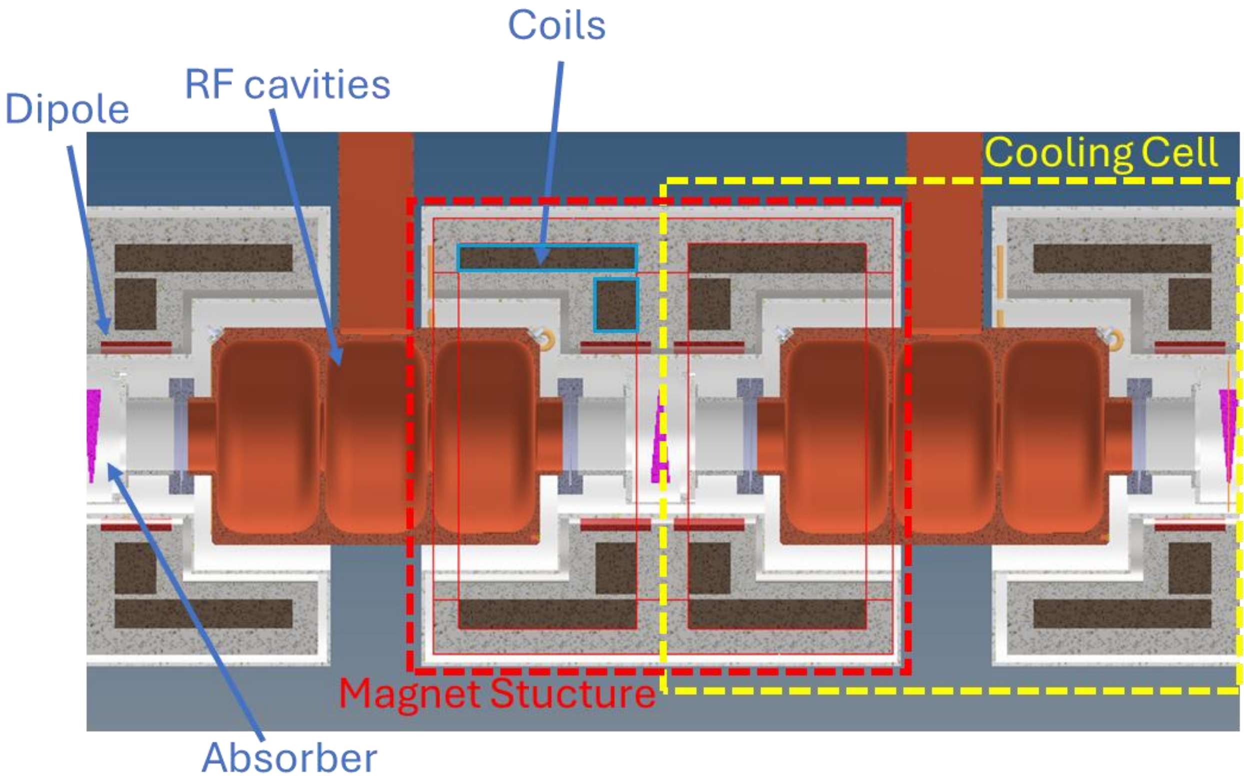
1) **0.8-1.0 GeV H-** particles from the PIP-II linac:
- **(1a)** Greenfield site in the Tevatron field
- **(1b)** Following the proposed mu2e-II line to muon campus.

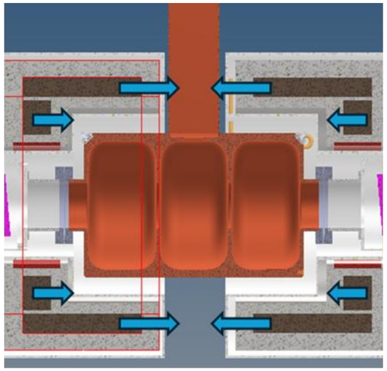
2) **8 GeV protons** from the Booster:
- **(2a)** At the present day short-baseline neutrino
- **(2b)** At present day muon campus site.

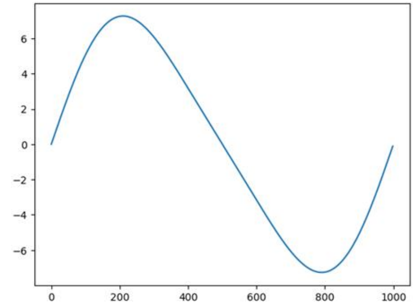
3) **8-120 GeV protons** from the Main Injector:
- **(3a)** Split off P1 Muon Campus line.
- **(3b)** Split off P1 Meson line.
- **(3c)** Split off MI Abort beamline.
- **(3d)** At the present day NuMI beamline.
- **(3e)** Split off LBNF beamline.

Choice of cooling cell?





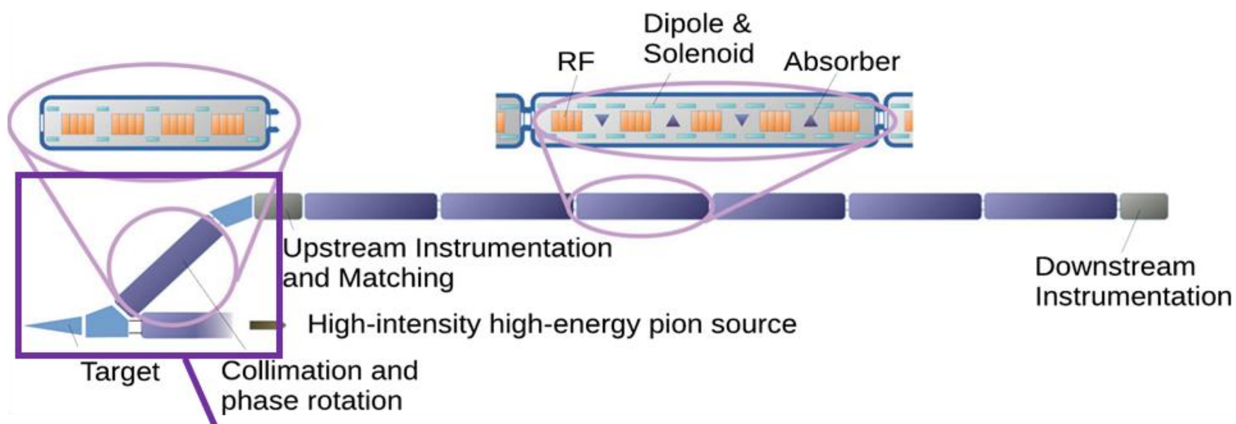


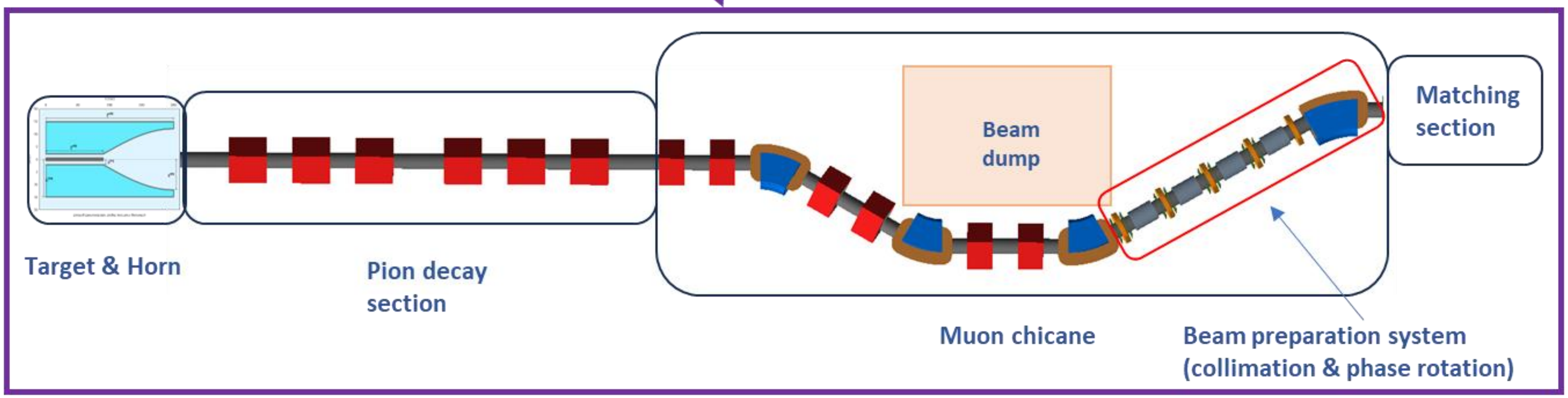


Target field on axis for a 1 m cell

Choice of capture scheme?

- Layout may vary depending on site options





LDRD at Fermilab

- Fermilab with access to high-power proton beams and technological expertise, is a good candidate for a Cooling Demonstrator
  - It requires dedicated studies for designing this facility and exploring its implementation within the Fermilab accelerator complex.
- LDRD deliverables
  - Compare sites within Fermilab for a demonstrator
  - Initial design & performance evaluation
  - Evaluation of risks
  - Initiate a cost analysis & schedule
- We are looking forward to starting the effort soon!
- More to report soon!