The global effort towards making a Muon Collider

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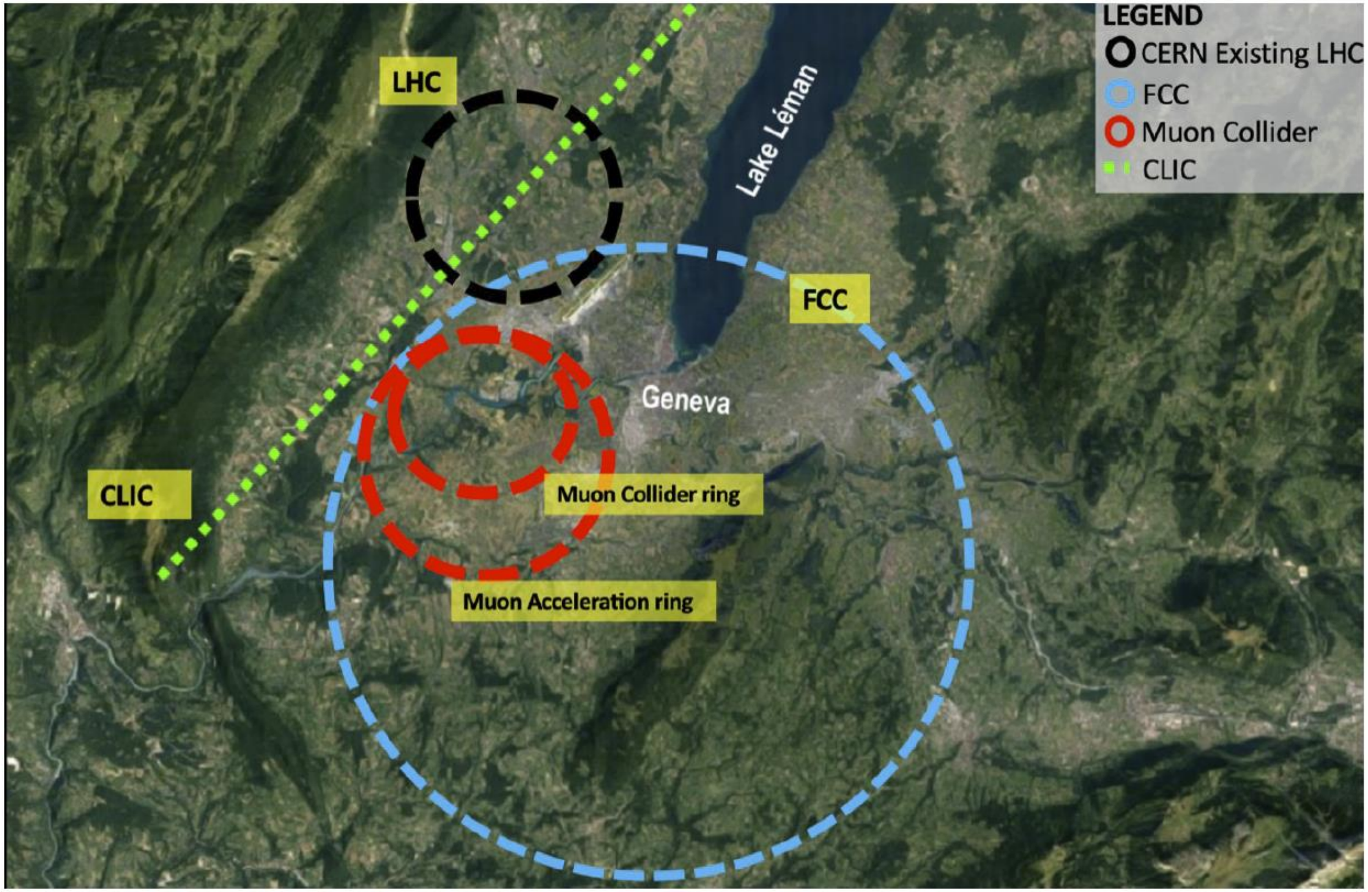
Outline

- Motivation
- History of Muon Colliders
- Accelerator design for Muon Colliders
- Technology requirements for Muon Colliders
- Current & future work

Why muons?

- **Muons** can be more beneficial than **protons**
  - Muons are elementary particles and all their energy in a collision is used
  - As a result the equivalent energy reach of muon collisions is about x7 times higher than in proton collisions. That allows Muon Colliders to x7 smaller compared to protons ones
- **Muons** can be more beneficial than **electrons**
  - Muons are ~200 times heavier than electrons therefore no synchrotron radiation. This makes acceleration in rings possible up to many dozens of TeV instead of just 300-500 GeV
  - For the same reason, no bremsstrahlung – and small dE/E at the interaction region of O(0.1%) vs O(10%) in e+e-
  - Some cross sections prefer higher mass (e.g. S-channel reactions scale as m^2)

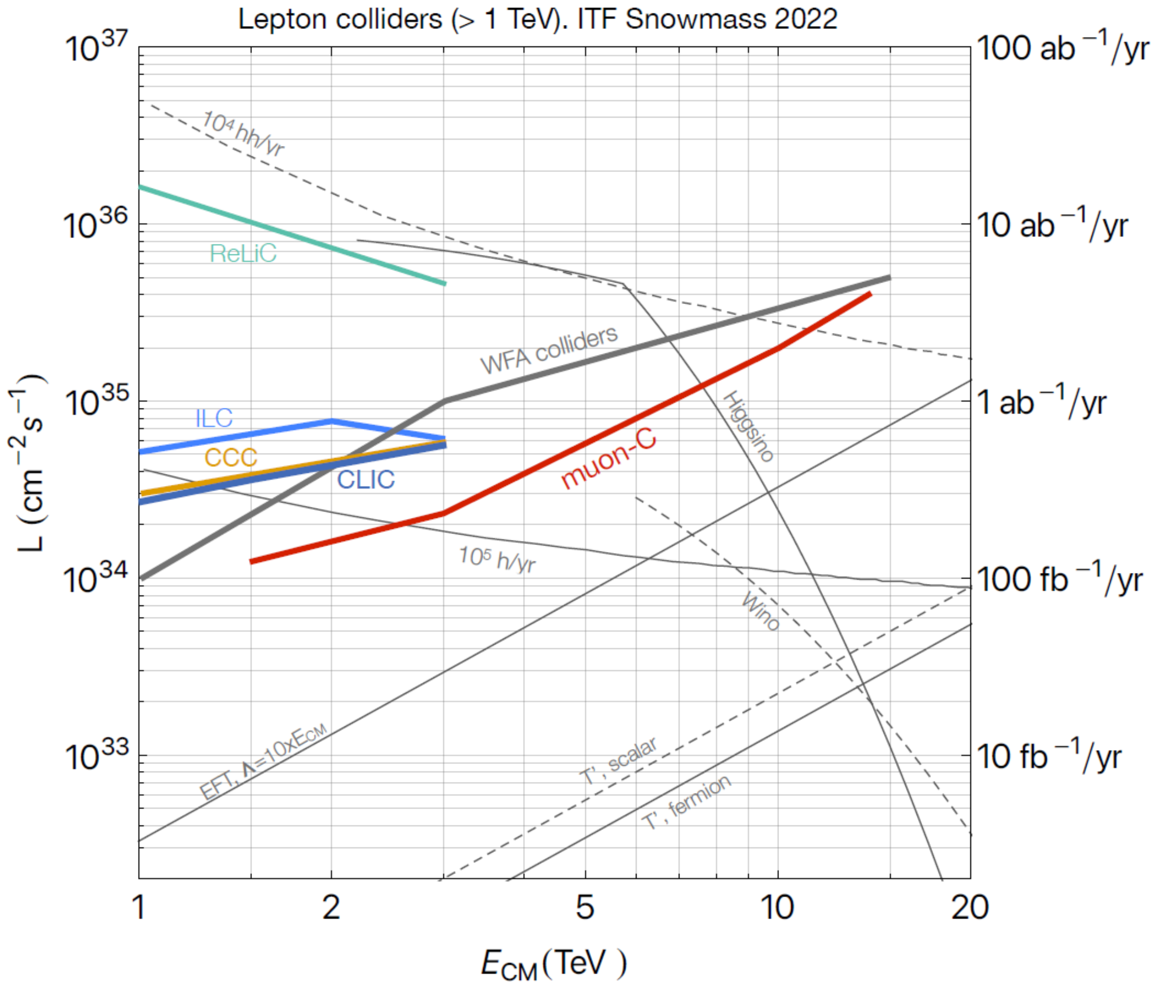
Compactness



- A Muon Collider offers a precision probe of fundamental interactions, in a smaller footprint as compared to electron or proton colliders

Efficiency

More details: Snowmass'21 ITF report



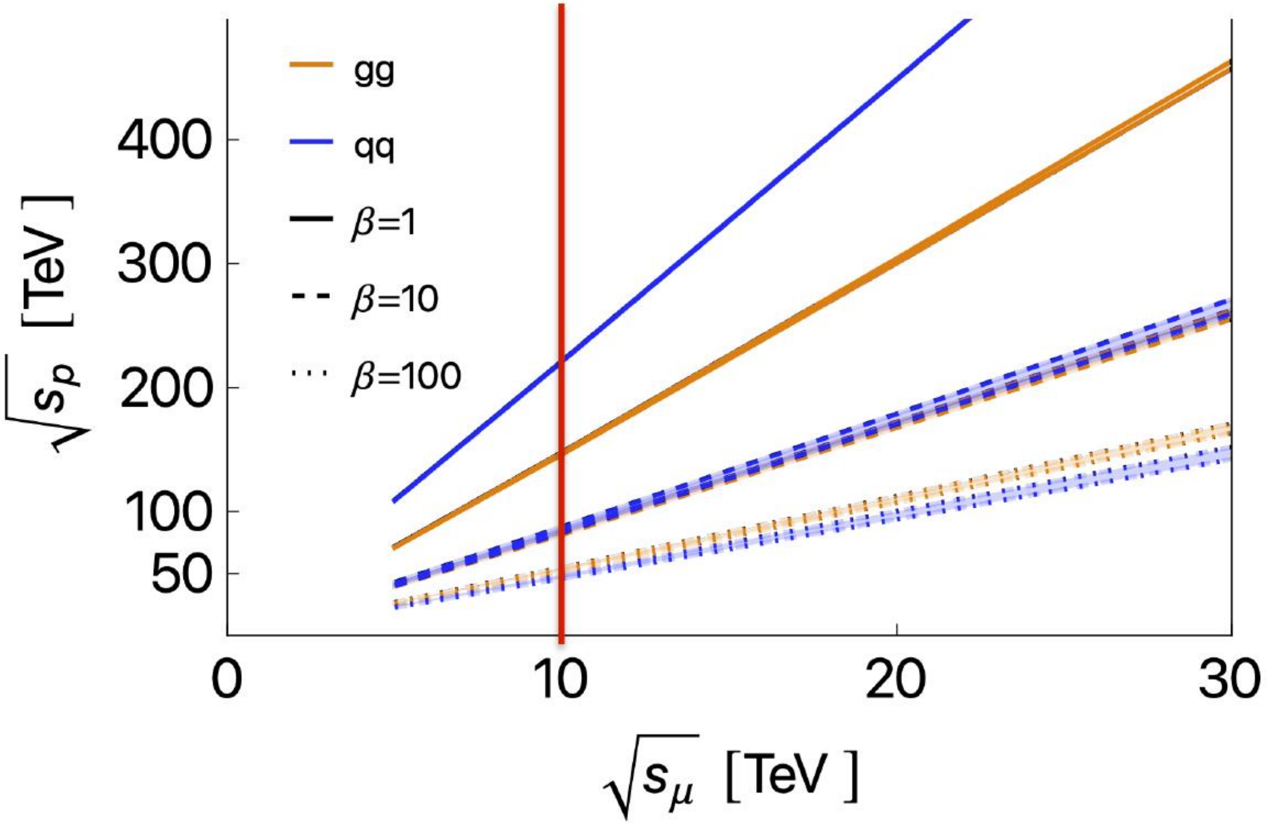
Electric power:
~450-1000 MW
Cost: ~18-80 $B

Electric power:
~320 MW
Cost: 12-18 $B

- In a **Muon Collider**, luminosity improves substantially with energy

Energy reach

More details: arXiv:2209.01318



- A 10 TeV muon collider can go beyond 100 TeV pp depending on the process

History (1)

- **1960s:** First mention of Muon Colliders in the literature
- **1990s-2010:** Design studies through US institutional collaborations
- **2011-2016:** Muon Accelerator Program (MAP) was approved and supported by DOE to address key feasibility issues of a MC
  - Focused on a proton-driver based solution
  - End-to-end design for a Neutrino Factory & a 125 GeV Higgs Factory. Considered colliders at 1.5, 3 and 6 TeV
- **2021:** CERN Council has charged the EU Laboratory Directors Group to develop the Accelerator R&D Roadmap for next decade
  - Formation of a Muon Panel that assessed MuC challenges and defined prioritized work with resource estimates

History (2)

- **2022:** Muon Colliders become part of the European Accel. R&D Roadmap:
  - International Muon Collider Collaboration (IMCC) has formed, hosted at CERN for now
- **2022:** US Snowmass study reveal strong interest on Muon Colliders:
  - Presented the Muon Collider Forum Report: a coherent vision for Muon Colliders from the US perspective
  - Proposed and presented a National Collider Initiative
  - **Received strong support from the global community**
- **2023:** Formation of the US Muon Collider R&D coordination group:
  - Initiated and supported by the Fermilab directorate
  - It's goal was to provide input to the P5 panel on Muon Collider research
  - Its ASK was presented at two P5 town-hall meetings (BNL and SLAC)

2021 Snowmass Process in the US

- Happens roughly once a decade
- A two year long scientific study process to determine future directions for the particle physics in US, together with international partners
- Work done in 10 frontiers + several cross-frontier groups
- Final reports available:
  - Snowmass report: arXiv:2301.06581
  - EF report: arXiv:2211.11084, AF report: arXiv:2209.14136
  - Muon Collider Forum Report: arXiv:2209.01318

Snowmass 2021

- Had several townhall meetings along several institutions in the US
- Next step is the Particle Physics Project Prioritization Panel (P5) deliberation
  - We expect report later this fiscal year

Snowmass Muon Collider Forum

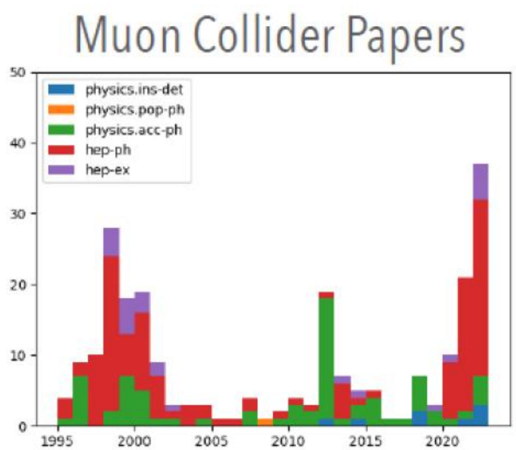
- The forum established a strong collaboration between the AF+EF+TF frontiers for Muon Collider (MuC) research
  - Goal was to make a strong physics case for MuC and inform the community
  - Monthly meetings and dedicated workshops for 18+ months before Snowmass
  - Lined-up a plan for Muon Collider R&D in the US
  - Identified synergies with other programs
  - Published all findings as a "**MuC Forum report**" and presented it in the Snowmass meeting: ~180 authors, 50+% are early career scientists
- Forum conclusions:
  - No fundamental showstoppers identified
  - BUT engineering challenges exist
  - R&D is needed to improve a MuC risk profile
  - **This R&D should start now!**

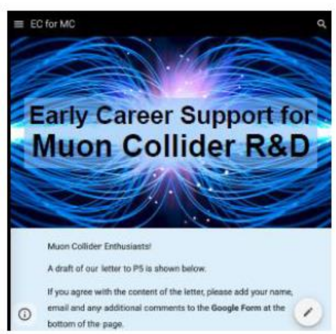
Cross-Frontier Report Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Muon Collider Forum Report

Enthusiasm about Muon Colliders is surging in US

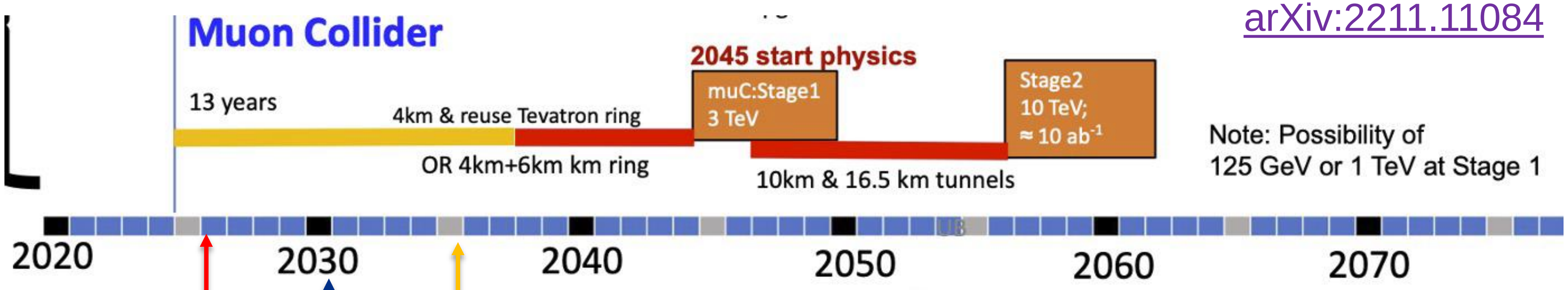
- MuC was the most studied machine during Snowmass. Many new results & papers, propagated to the EF vision.





US timeline & vision as presented at Snowmass

arXiv:2211.11084



Develop an initial design for a first stage TeV-scale MC in the US (pre CDR)+ Support relevant detector R&D (2025-2030)

Demonstrate principal risk mitigation and deliver CDR for a first stage TeV-scale MC (2030-2035)

Demonstrate readiness to construct and deliver TDR for a first TeV-scale MuC. Ramp up funding support for relevant detector R&D (2035-2040)

- The actual project start time is subject to:
  - Successful outcome of the proposed extensive R&D program
  - Availability of funding + resources, host laboratory, and international agreements
- **Development will take a long time – need to start now**

International Effort

- In 2020, following the 2018 European Strategy process, Laboratory Director's Group initiated a Muon Collider feasibility study
- In 2022, the International Muon Collaboration (IMCC) was formed and hosted at CERN
- Several US universities started to join, many more expressed interest
- IMCC planning assumes a significant US participation to develop the baseline project and the best siting option (including US siting)

International MUON Collider Collaboration

https://muoncollider.web.cern.ch/

IMCC 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

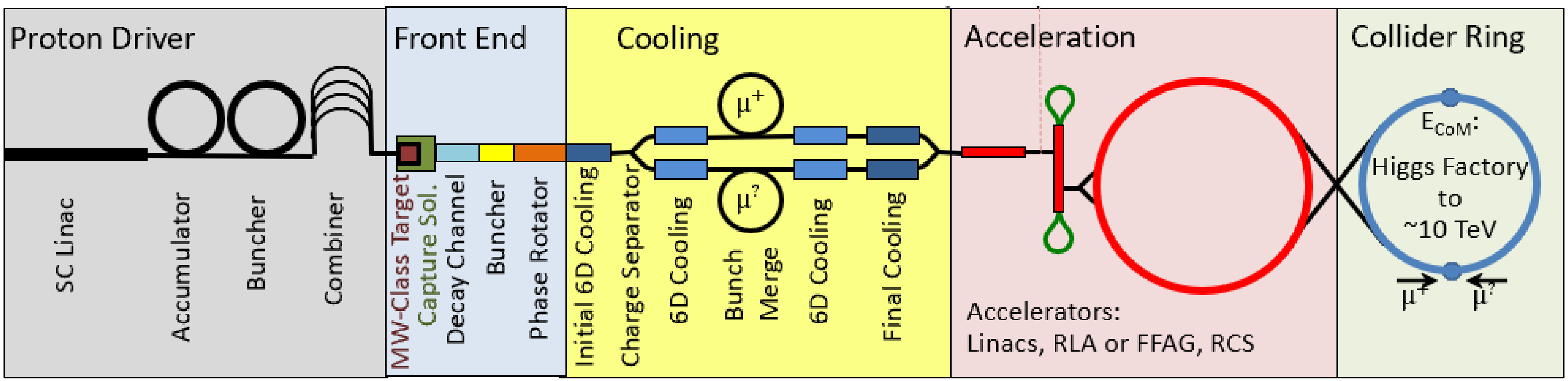
- Tentative parameters based on MAP study, might add margins
- Achieve goal in 5 years
- FCC-hh to operate for 25 years
- Aim to have two detectors

Feasiblity addressed, will evaluate luminosity performance, cost and power consumption

Start → Goal

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	µm	25	25	25
$\sigma_{x,y}$	µm	3.0	0.9	0.63

Machine overview



Muon production target

MW-scale proton driver

Capture 200 MeV bunches

Ionization cooling to reduce 6D emittance

Acceleration to TeV scale energy

Collider ring for counter propagating muons

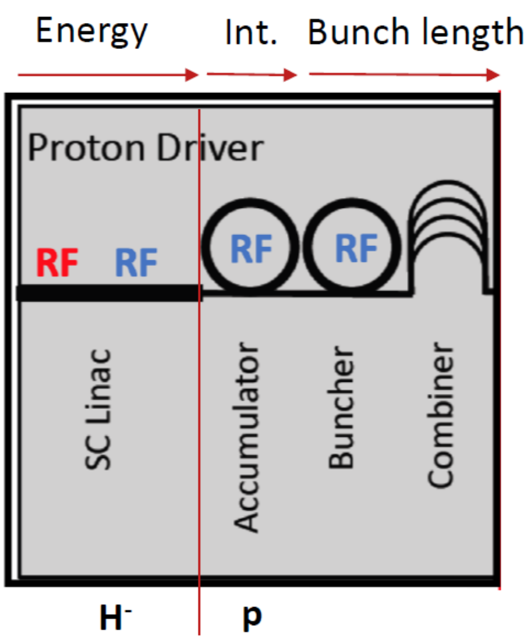
Luminosity for a MuC

- **Luminosity** is a measure of the collider efficiency
  - Given by

$$L = \frac{N_+ N_- n_C f}{4\pi\sigma_x\sigma_y}$$

- **High** charge per muon bunch of each sign
  - Requires a powerful proton driver, high-yield production target & fast acceleration
- **Small** transverse beam size
  - Requires beams with a low transverse emittance
  - Requires very strong focusing magnets in the IR
- **Many** collisions in the collider ring
  - Requires strong dipole magnets to minimize the collider ring radius

MuC proton driver: Concept & technology needs



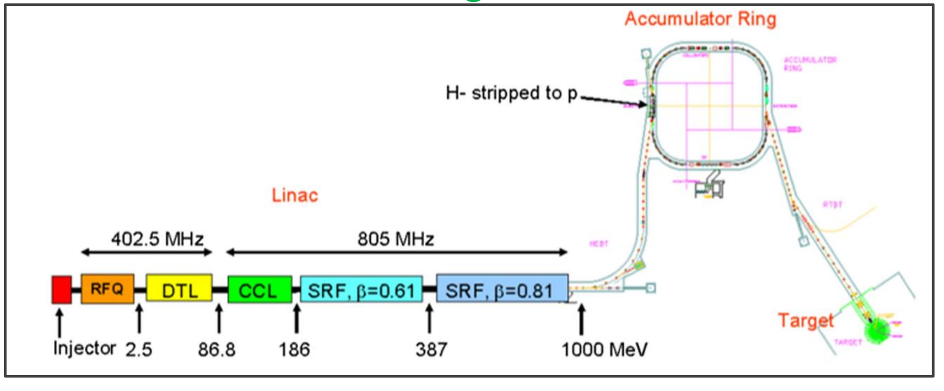
- Technology requirements for MuC driver:
  - Linac capable to deliver ~5 GeV, ~10^{14} H- in ~ 1 ms
  - Accumulator ring to create four, 20 ns bunches of protons with H- injection stripping
  - Buncher to create ~ns scale pulses
  - Combiner system that delivers the beam to target
  - Alternative: A solution of using a rapid cyclic synchrotron instead of a multi-GeV linac is also viable

- Peak performance: **1-4 MW** proton beam @ **5-20 GeV**, compressed to **1-3 ns** bunches at a **5-10 Hz** frequency

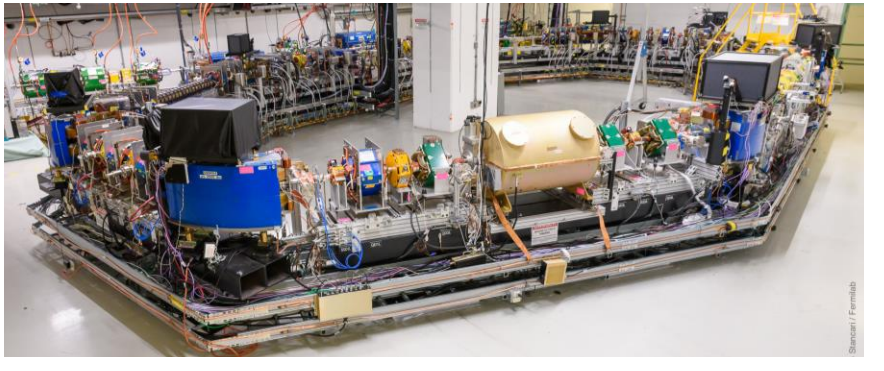
MuC proton driver: Moving forward

- Proton driver does not require new technology or breakthroughs
- However it requires a detailed beam dynamics study of the several concepts involved
  - Examples: injection stripping, ~ns bunch compression, combiner trombones
- US facilities that can provide key proof-of-principle proton-driver tests for a MuC R&D program have expressed interest!

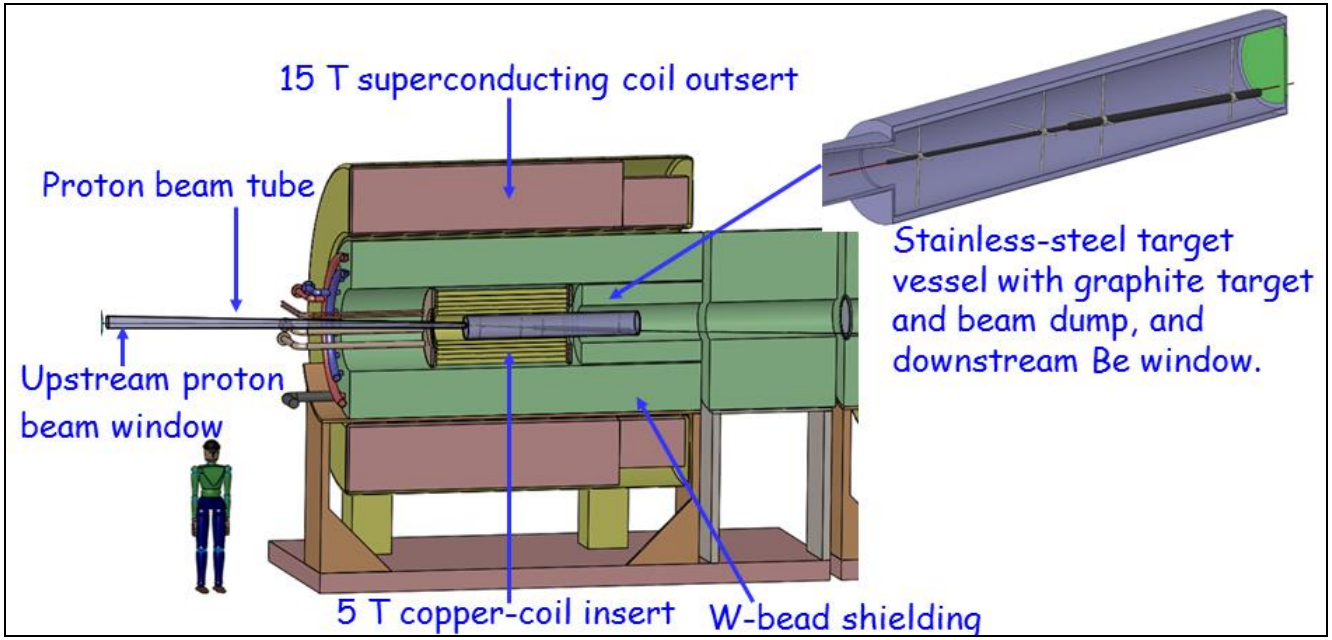
SNS linac @ Oak Ridge



FAST/ IOTA @ Fermilab



MuC target: Concept & technology needs



- Technology requirements for MuC targets:
  - Target materials that produce high muon yield
  - Placement in a high-field solenoid (15-20T) to maximize capture
  - Materials tolerant to thermal shock and fatigue from MW-scale beams
  - Shielding system that protects the capture magnet and surrounds
  - Large solenoid aperture to allow for shielding

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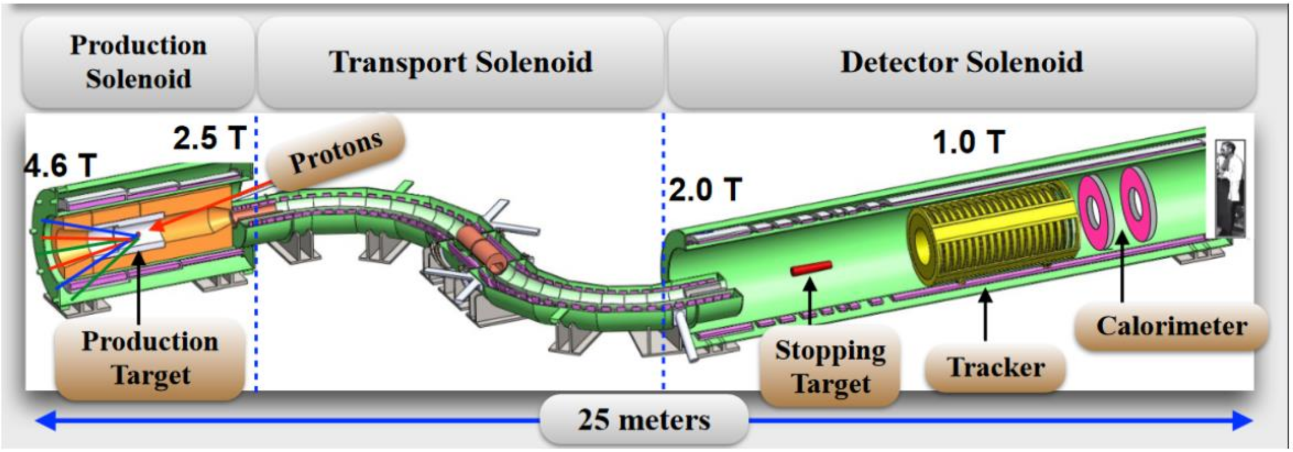
MuC target: Path forward (1)

- In 2007, a proof-of principle test **validated** the concept with a liquid Hg target. **Technology was OK** but some safety concerns (ref)
- Recent work shows **promising results** with graphite or tungsten but **still significant** R&D is needed to confirm that (ref)
- This fact, combined with the strong demand of high-power targets puts the MuC in a **synergistic path** with many future experiments
  - One example is the Fermilab Mu2e experiment



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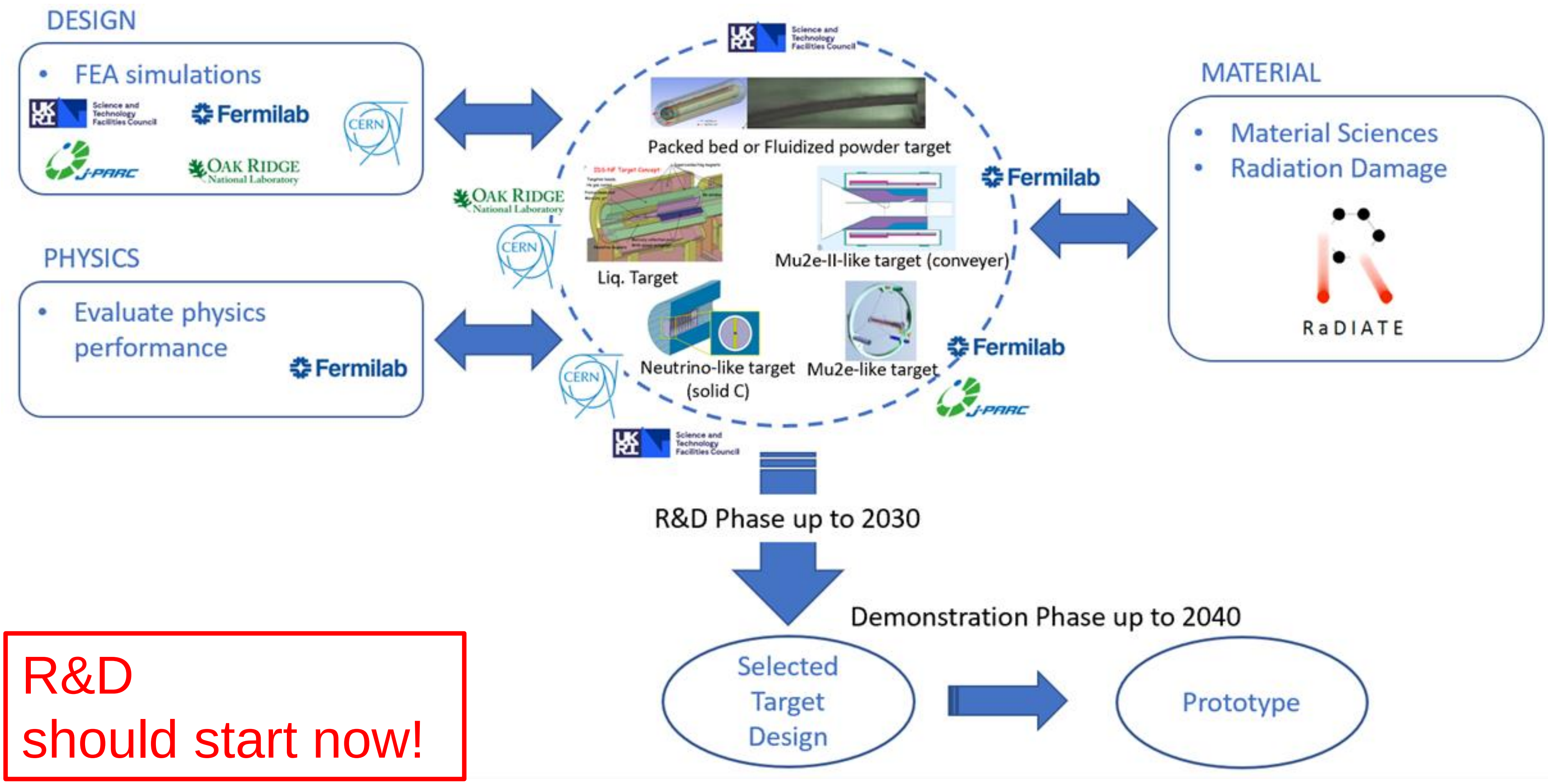
Muon Collider target: Path forward (2)

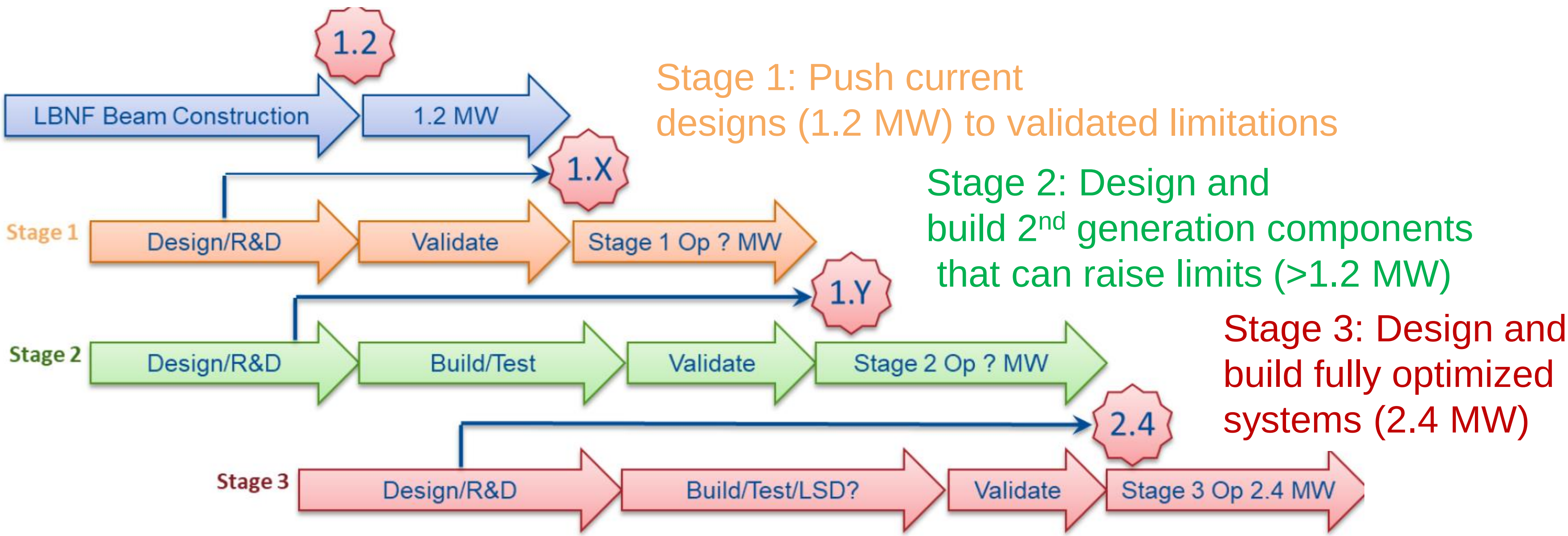
- MuC targetry is included in the proposed GARD High Power Targetry Roadmap (ref) with a plan to have a prototype in the **late 2030s**



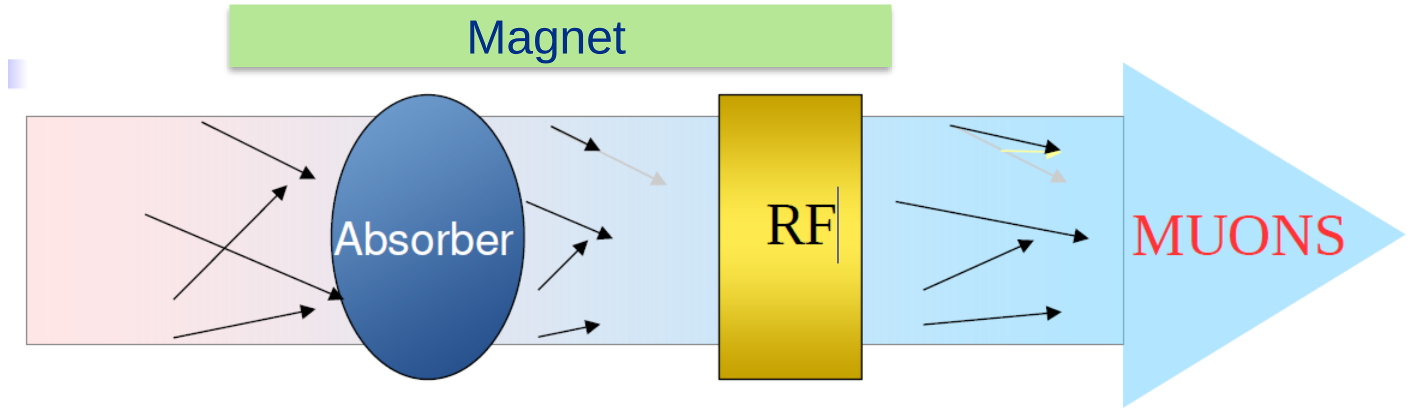
R&D
should start now!

Fermilab ACE program (proposed to P5)

- In the next decade, LBNF plans to use protons which will operate at 1.2 MW to start and will be upgradable to 2.4 MW
- Fermilab Accelerator Complex Evolution (ACE) aims a Main Injector upgrade to deliver >1.2 MW by 2032
  - Will include a rigorous **target R&D program for 2+ MW** beam powers
  - This program will **extremely benefit** the targetry R&D for a MuC

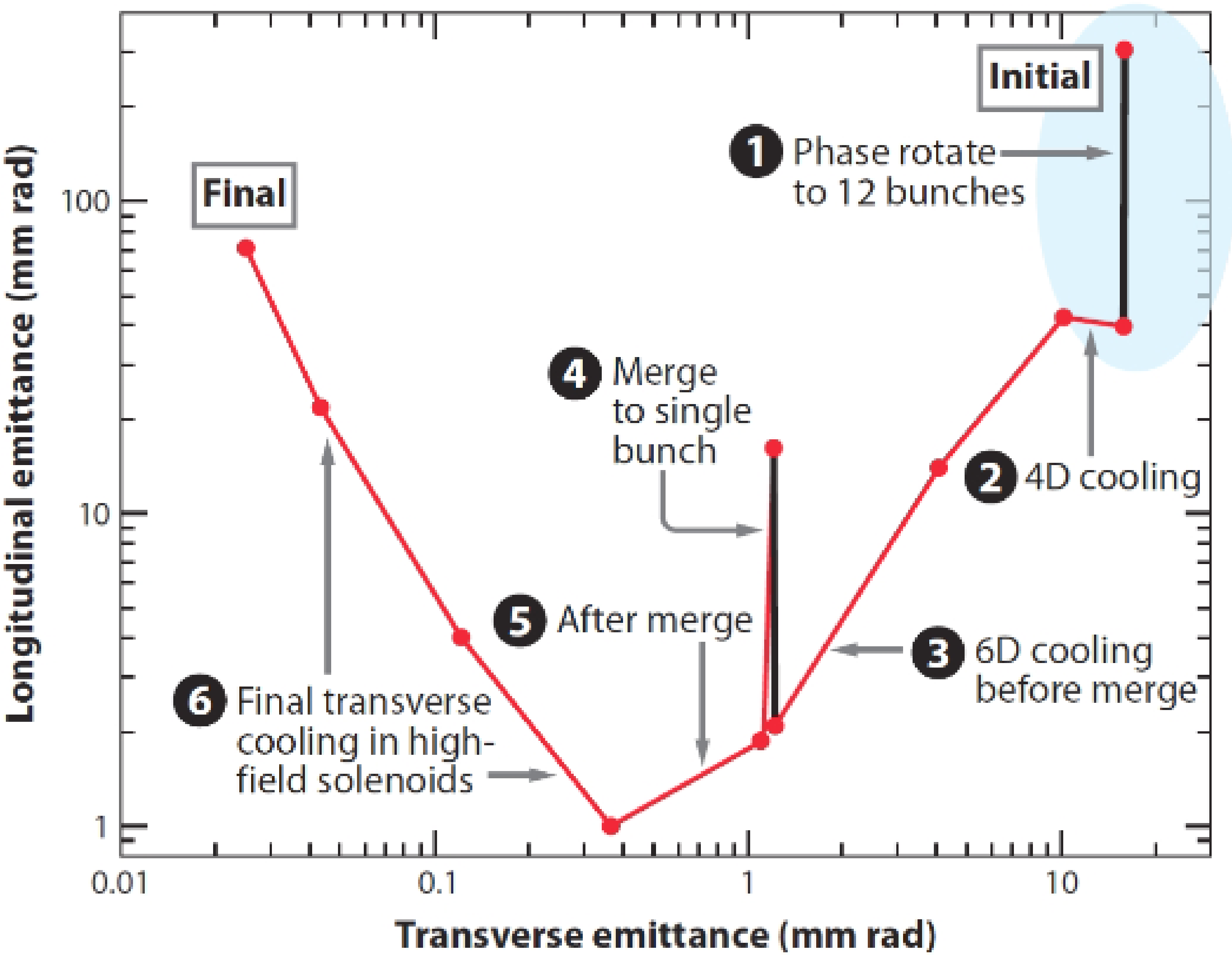


MuC cooling – Concept & technology needs



- Technology requirements for MuC cooling:
  - Large bore solenoidal magnets: From 2 T (500 mm IR), to 20+ T (50 mm IR)
  - Normal conducting rf that can provide high-gradients within a multi-T fields
  - Absorbers that can tolerate large muon intensities
  - Integration: Solenoids coupled to each other, near high power rf & absorbers)

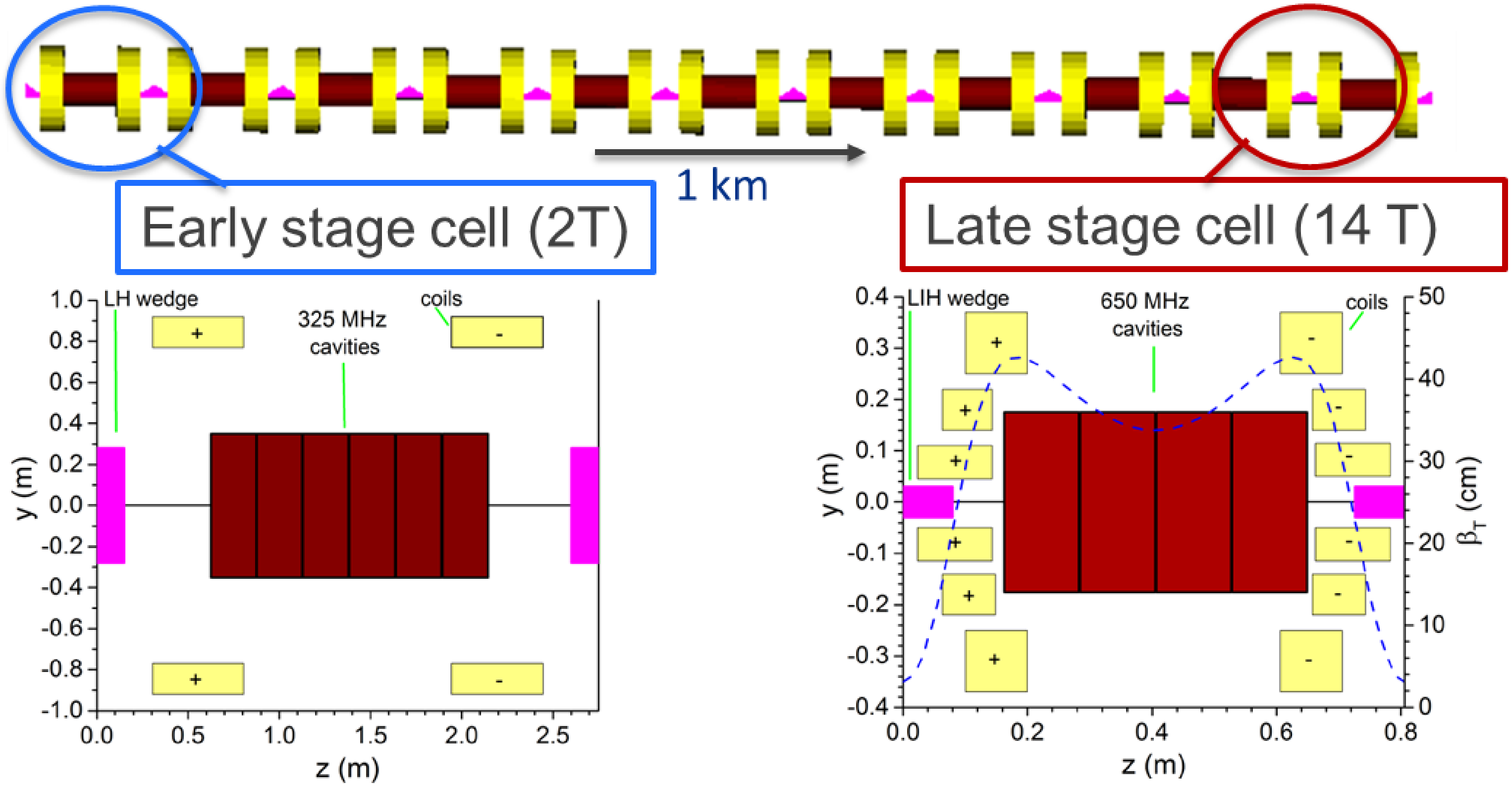
Baseline for muon cooling



6D emittance reduction by 6 orders of magnitude

Muon cooling: Past experience

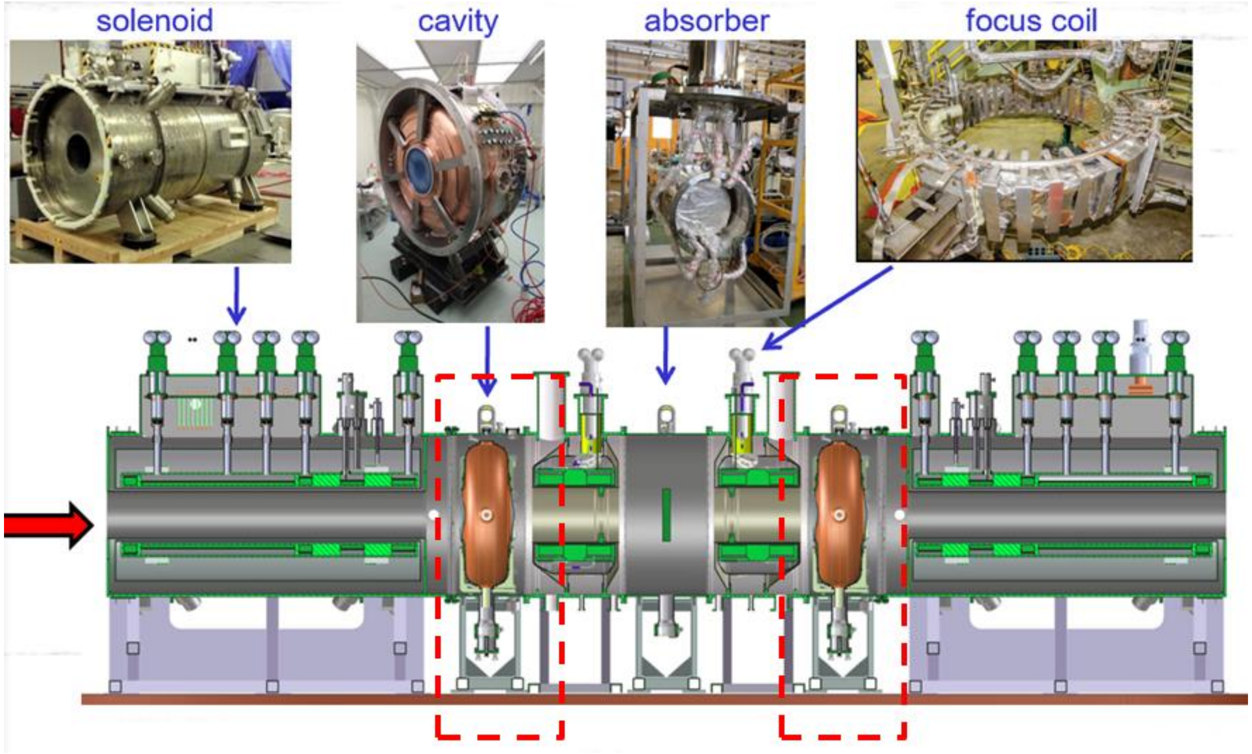
- Lattice designs have been developed for MuC ionization cooling
  - Magnetic field has to progressively increase to enhance cooling



Interplay of several parameters. Room for improvement exist!

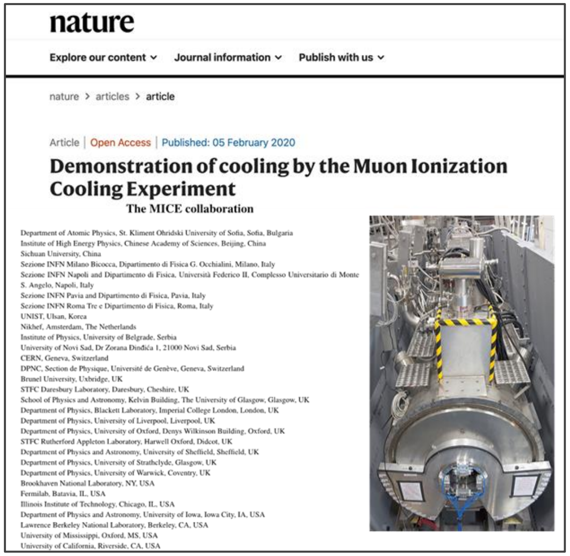
Muon Collider cooling: Past experience

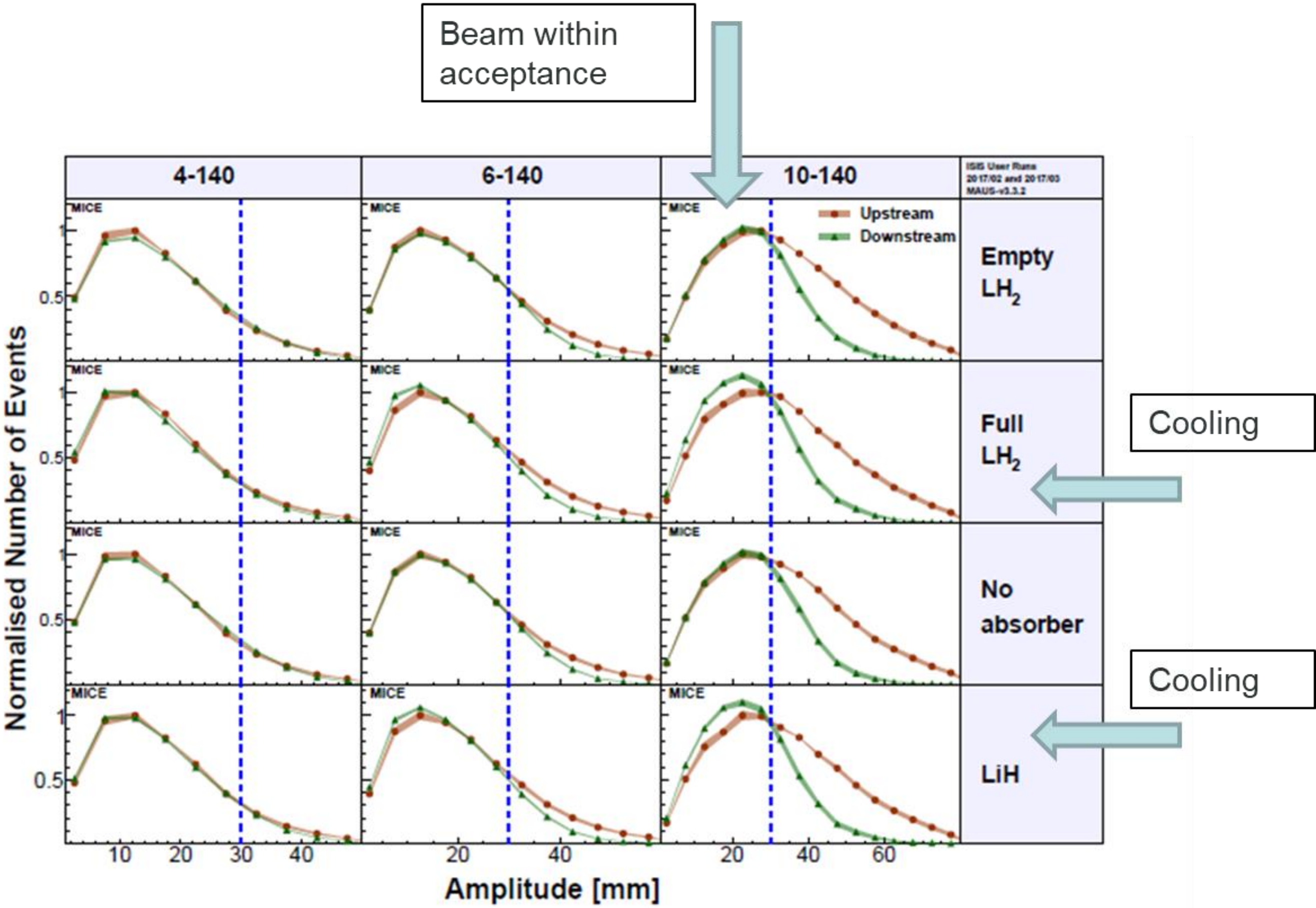
- Muon Ionization Cooling Experiment (MICE) at Rutherford Appleton Lab (UK) demonstrated ionization cooling for the first time!
- A sample lattice was build and showed O(10%) **transverse cooling**



Muon Collider cooling: Past experience

- Tested with two different absorbers: LH_2 and LiH
- More particles move to the core with absorbers (cooling!)

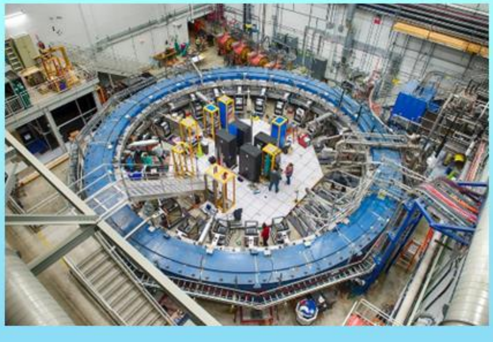


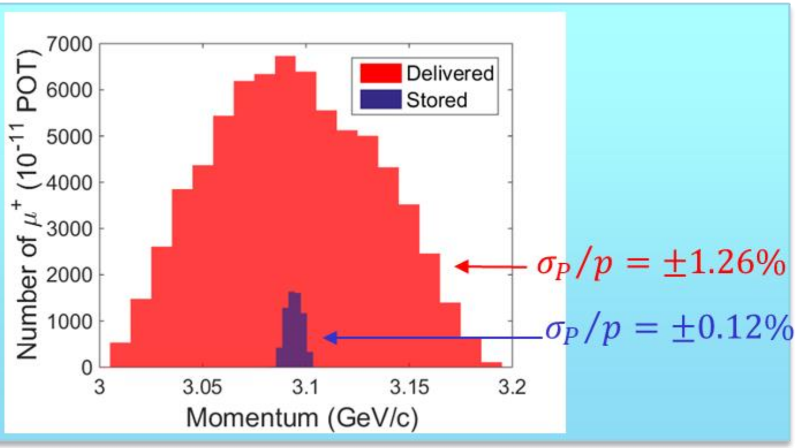


Muon Collider cooling: Past experience

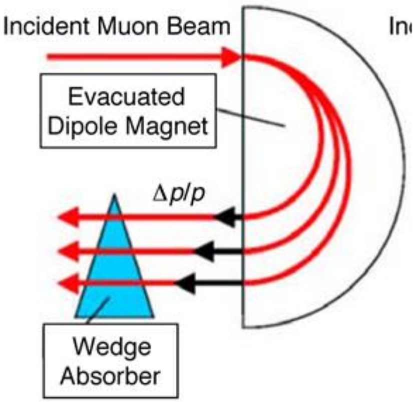
- Demonstrated **longitudinal ionization cooling** using the Fermilab Muon g-2 Experiment storage ring

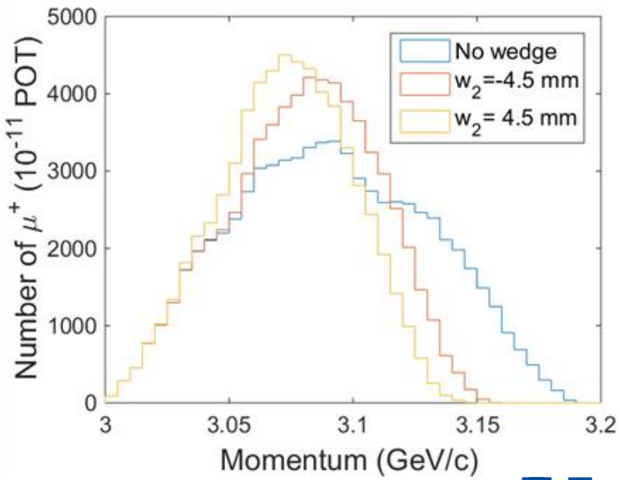
CURRENT SCHEME





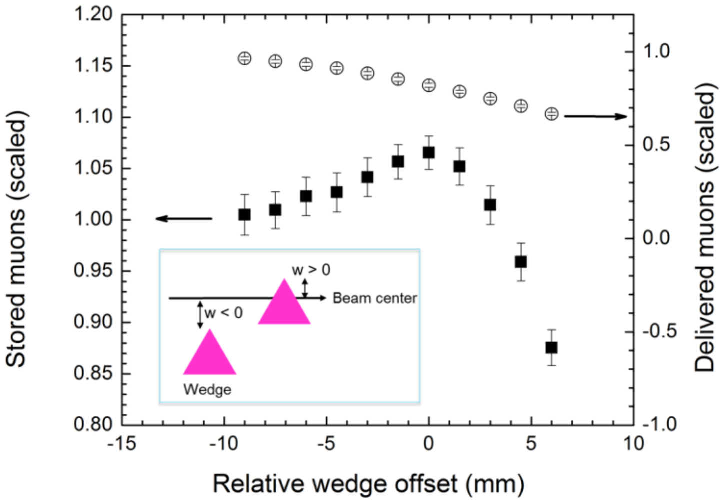
IMPROVED SCHEME

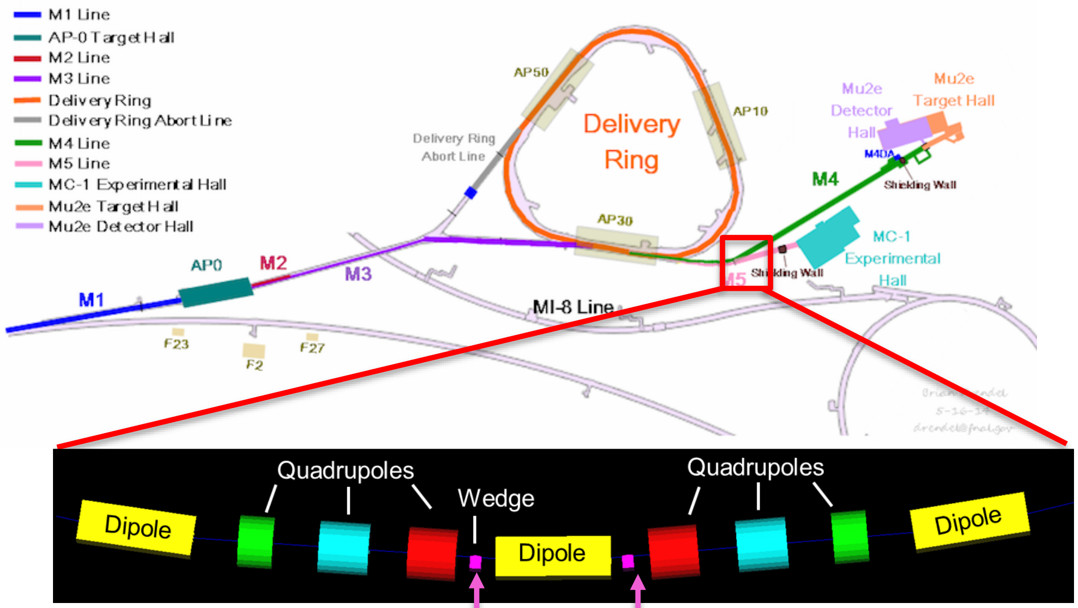


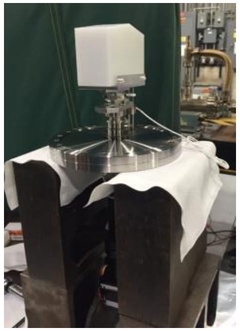


Muon Collider cooling: Past experience

- Proof-of-principle: Demonstrated a gain up to 8% in stored muons with a polyethylene wedge.







LDRD at Fermilab
Laboratory Directed Research and Development

Muon g-2 cooling: Thanks to several students!

Nick Amato (2019)
Master's Thesis, **NIU** (Syphers)
Title: Improved momentum spread for precision experiments using wedges

Lauren Carver (2019)
Fermilab Intern
Title: Modeling a wedge absorber for the g-2 Experiment

Jerzy Manczak (2018)
Fermilab Intern
Title: Modeling a wedge absorber for the Mu2e Experiment

Joe Bradley (2017)
Fermilab Intern
Title: Material & geometry study of a wedge absorber for the g-2 Experiment

Grace Roberts (2020)
Fermilab Intern
Title: Optimizing injection for a wedge based Muon g-2 Experiment

Ben Simons(2020)
NIU grad. student
Title: Tuning beam optics for the Muon Campus

PHYSICAL REVIEW ACCELERATORS AND BEAMS 22, 053501 (2019)

Application of passive wedge absorbers for improving the performance of precision-science experiments

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Nuclear Inst. and Methods in Physics Research, A 962 (2020) 163704

Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

Realistic modeling of a particle–matter-interaction system for controlling the momentum spread of muon beams

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A parametric analysis for maximizing beam quality of muon-based storage ring experiments

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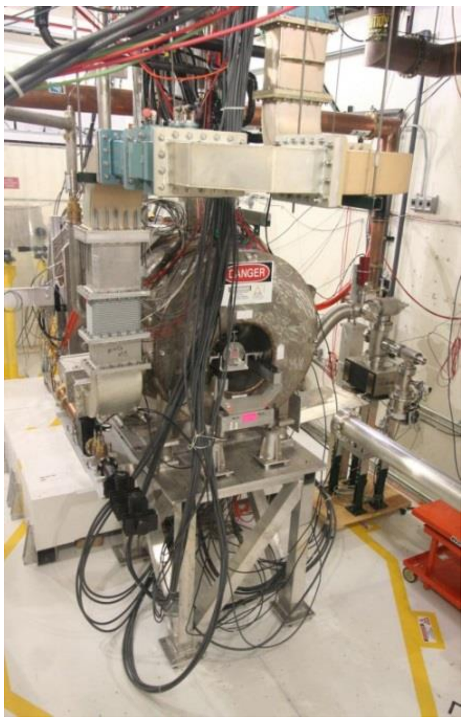
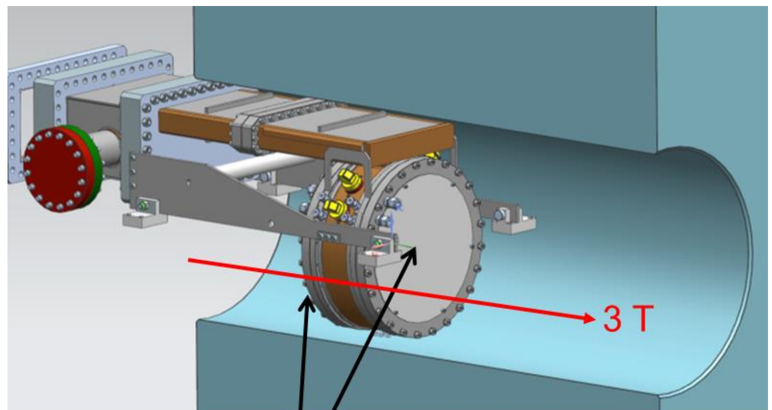
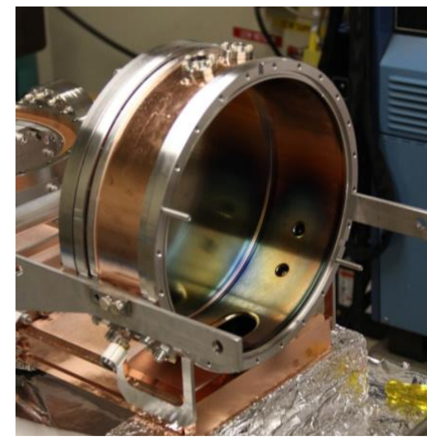
MuC cooling: Past experience

- Cooling designs need placement of cavities within multi-T B-fields
  - Limits the technology to normal conducting NC) cavities
  - Some evidence that the B-field makes operation of these cavities difficult
- Behavior of NC cavities in B-fields (up to 3 T) was tested at Fermilab







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

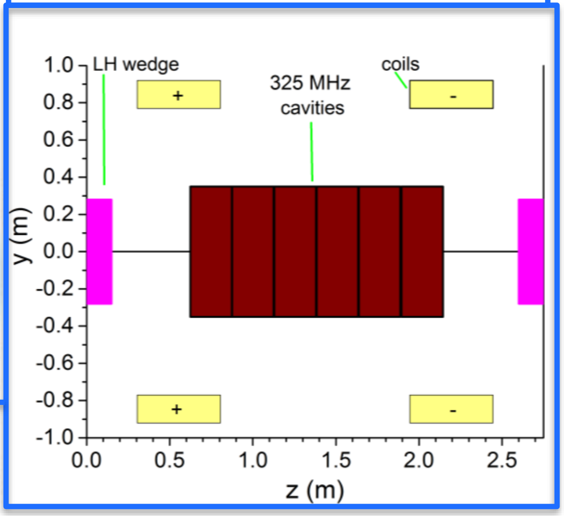
No change in gradient!

Tests at higher B-fields are needed!

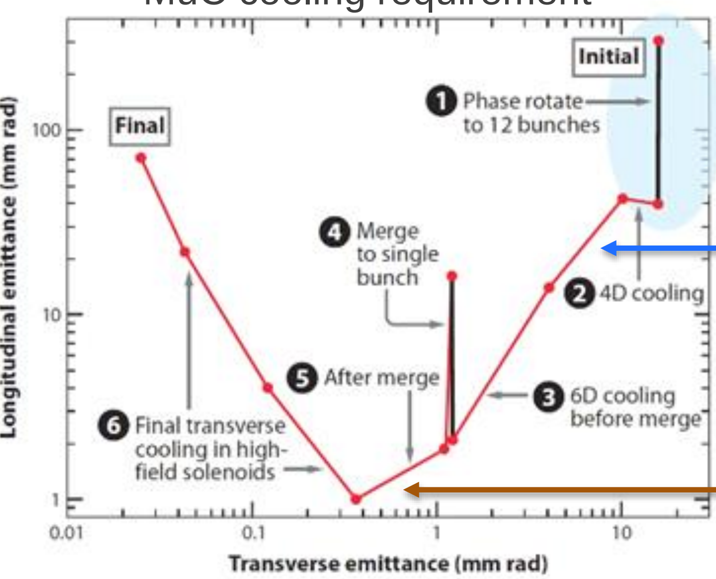
Muon Collider cooling: Path forward

- Cooling channels require **special attention**, especially the late stages which closely pack high-field magnets, absorbers, and cavities
  - Next design effort should consider **engineering aspects** on the design

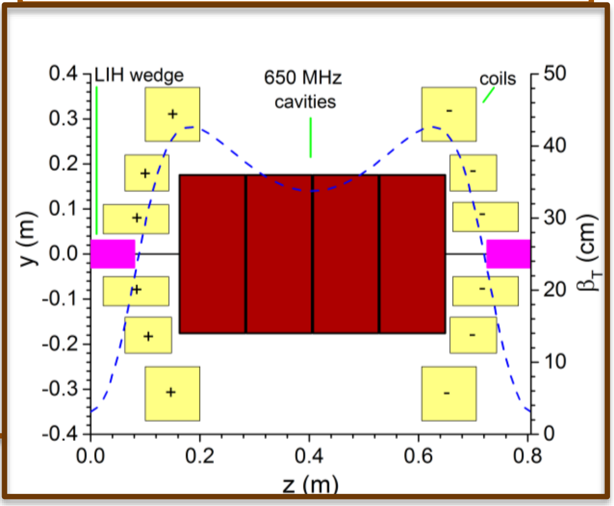
Early cell (“easy”) – 2T peak



MuC cooling requirement

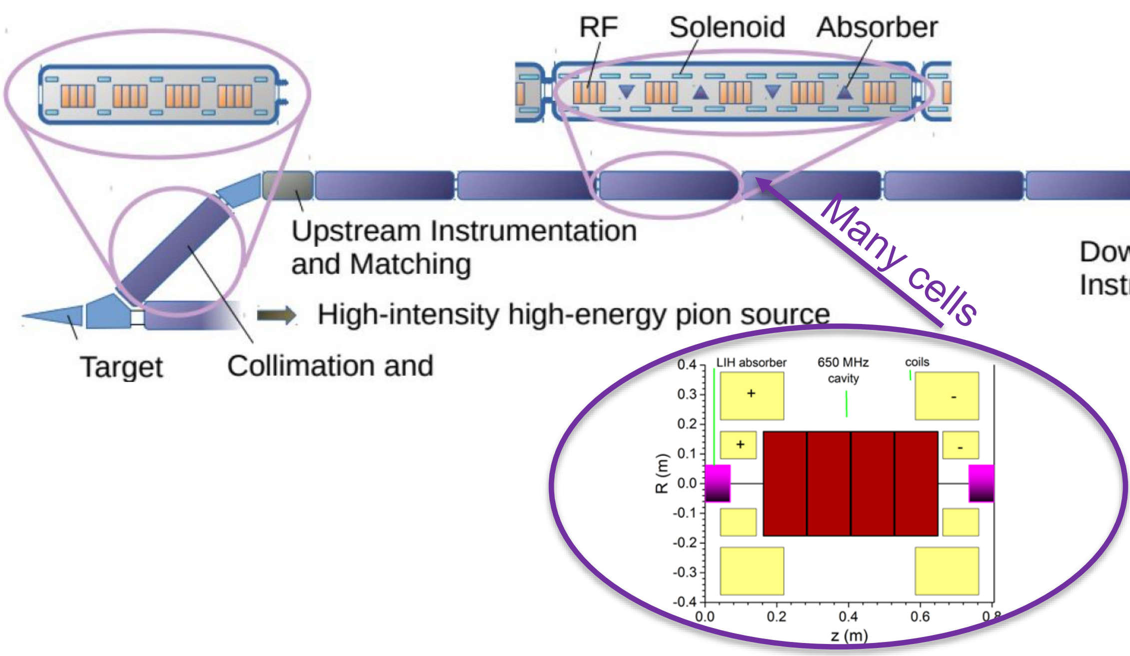


Late cell (“hard”) – 14 T peak



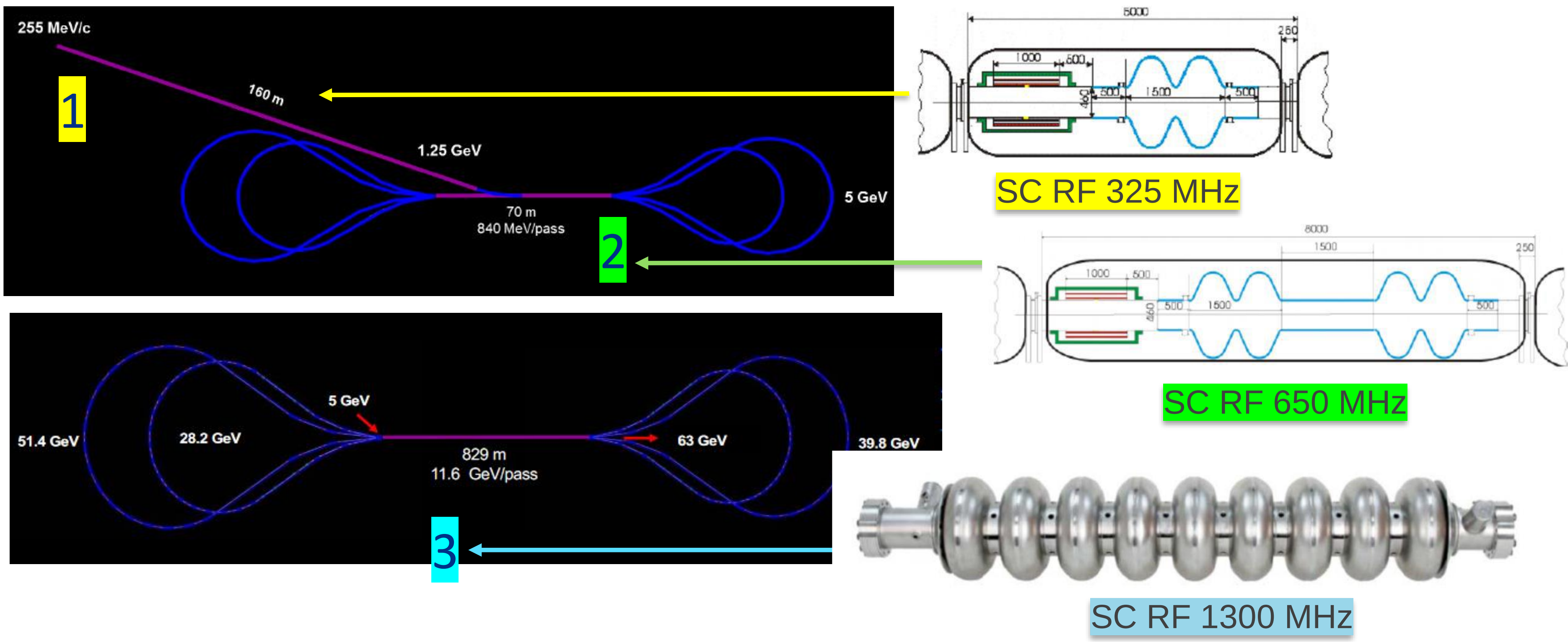
The need of a cooling demonstrator

- While the physics of ionization cooling has been shown [ref] it is **critical** to benchmark a **realistic** MuC cooling lattice
  - This will give us the input, knowledge, and experience to design a real, buildable cooling channel for a MuC
  - **Possibilities for hosting such a facility in the US exist**



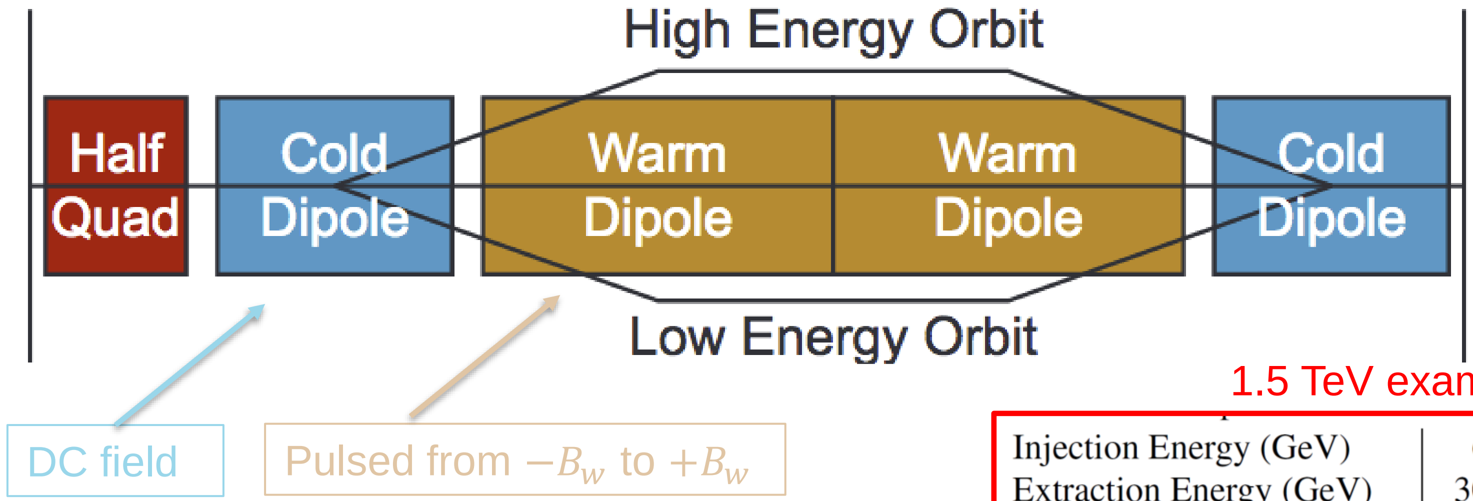
Demonstrator plan
Demonstrate operation of NC rf in B-field environment
Demonstrate forces between coils are manageable
Demonstrate performance of absorbers
Demonstrate performance of instrumentation system
Demonstrate 6D cooling with a realistic set-up

MuC GeV acceleration – Concept & technology needs



- Technologies requirements for a Muon Collider:
  - Superconducting linacs and Recirculating linear accelerators (RLAs)
  - SC RF that: (1) starts at a low frequency ~ 325 MHz, (2) operate at high-gradients

MuC TeV acceleration – Concept & technology needs

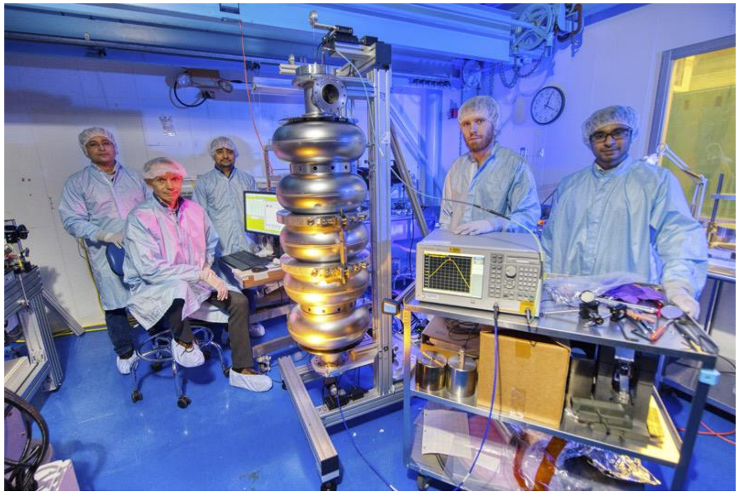


1.5 TeV example

Injection Energy (GeV)	63	303	750
Extraction Energy (GeV)	303	750	1500
Circumference (m)	5210	5210	9361
Fixed Dipole Length (m)	—	1103	2358
Ramped Dipole Length (m)	4229	3126	5240
Turns	13	25	23
Time (ms)	0.23	0.43	0.72
Cavity Power (kW)	950	950	530

- Technologies needs for a Muon Collider
  - Hybrid Rapid Cycling Synchrotron accelerators
  - Fast ramping magnets (<0.5 ms) accompanied with a 8-10 T DC magnet
  - Good energy storage and power management for pulsed magnets

MuC acceleration: Path forward

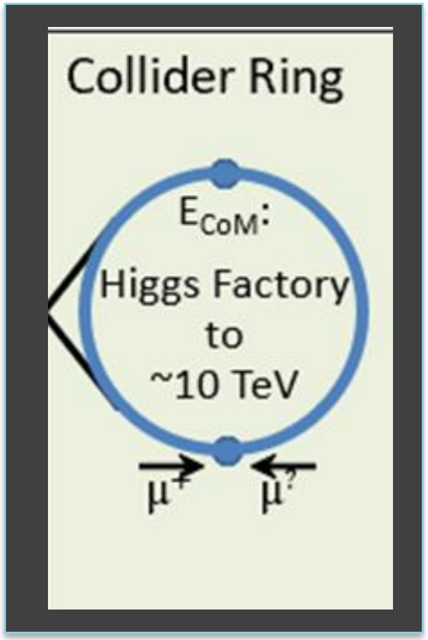


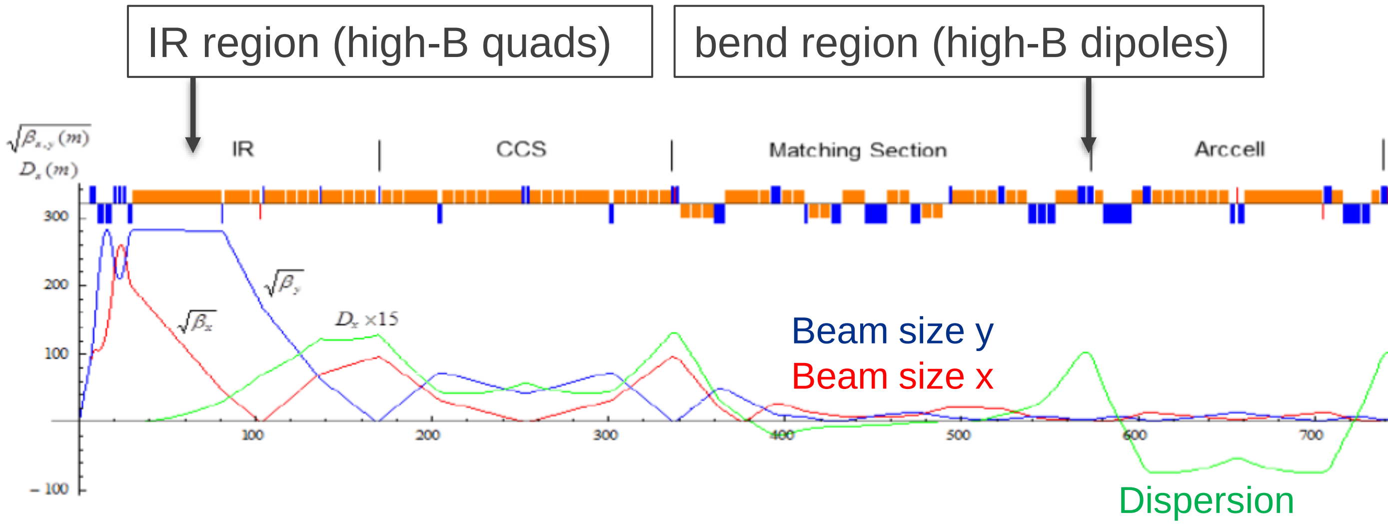
5 cell elliptical cavities @ 650 MHz for PIP-II

Cryomodule @ 1300 MHz for LCLS-II

- Develop self-consistent accelerator lattice towards a 10 TeV collider
  - Investigate the beam-cavity interactions in all parts of the accelerator
- Design and test MuC style SRF cavities (325, 650, 1300 MHz)
  - Synergy opportunities with other programs (ILC, FCC-ee)
- Proof-of-principle tests for power management for rapid cycling magnets

MuC collider ring – Concept & technology needs



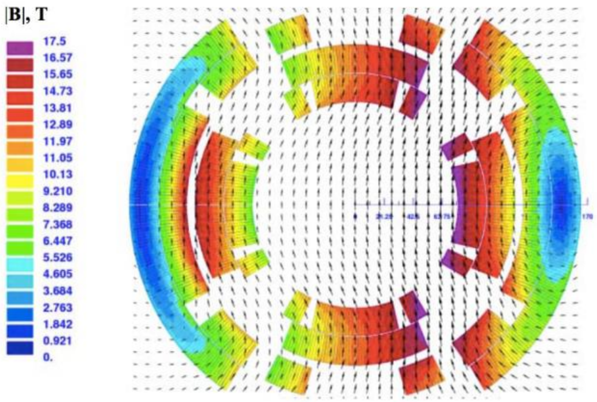


- Technology requirements for a MuC collider ring
  - Strong quadrupole focusing at IR (15-20 T for 10 TeV)
  - High-field dipoles for min. ring size & max. luminosity (12-16 T for 10 TeV)
  - Dipoles with large aperture (~150 mm) to allow for shielding
  - Mitigation system for the neutrino flux from muon decays

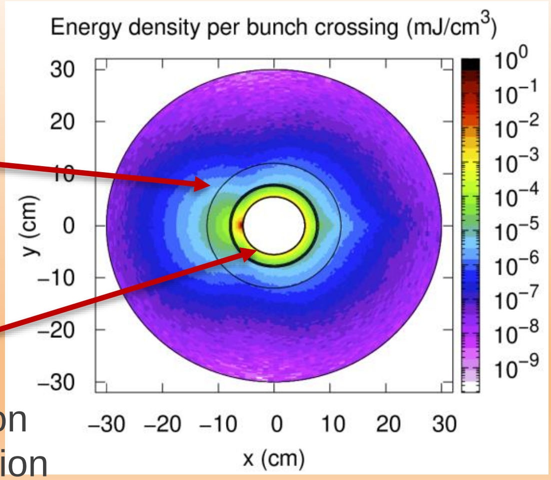
Muon Collider ring – Past experience & path forward

- Complete lattice design in place for a 3 TeV collider
  - Magnet specs are within HL-LHC range
- Parameters for a 10 TeV colliders are more demanding. Preliminary designs are in place [ref]
  - Higher dipoles fields (12-16 T)
  - IR quads in the 15-20 T range
  - **Have to push the magnet technology beyond existing limits**
- Radiation studies suggest that shielding protection for both 3 TeV and 10 TeV are **the same**

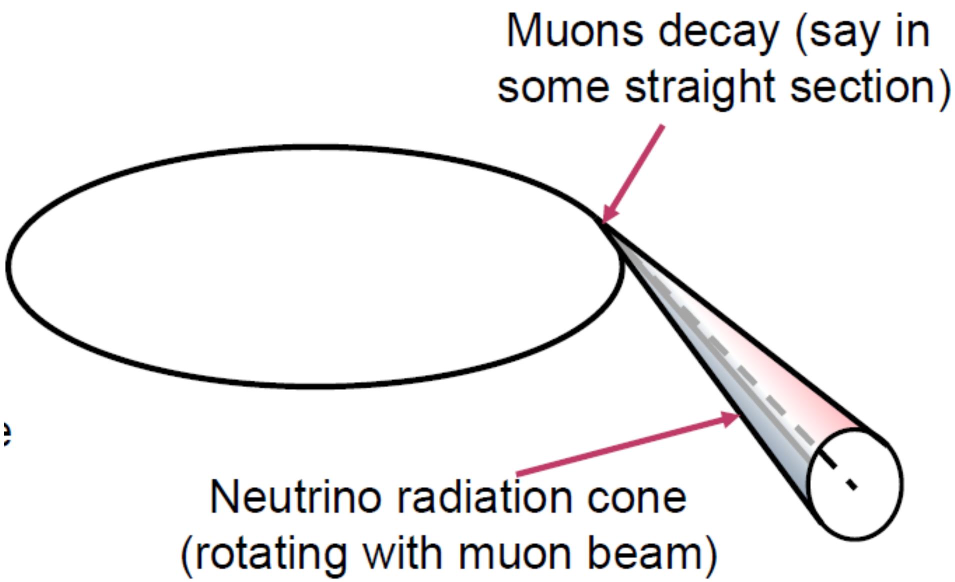
3 TeV dipole magnet

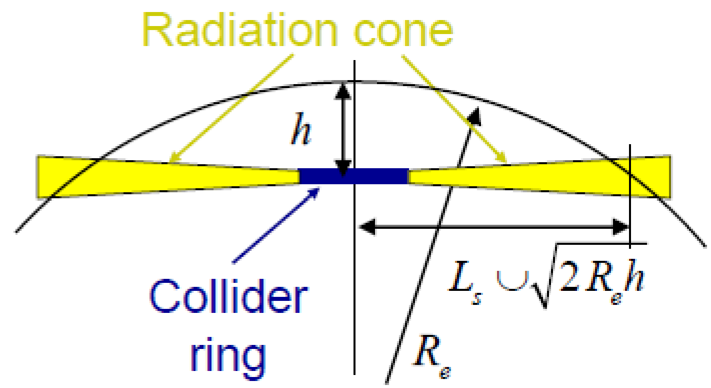


10 TeV radiation studies



Neutrino radiation

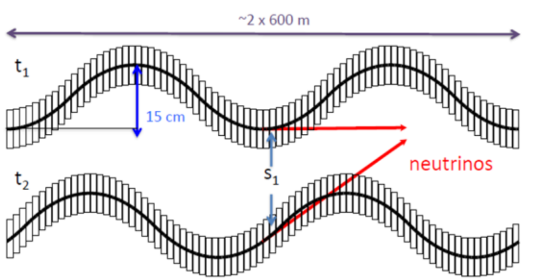




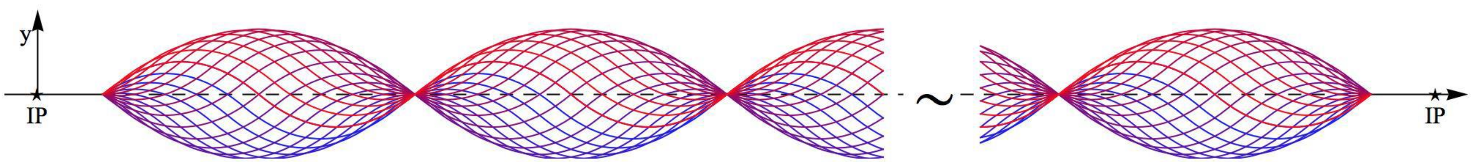
- Radiation due to neutrino beam reaching the earth
  - Narrow radiation cone for a short piece of the machine
  - Strong increase of maximum dose with muon energy
  - Matter in front does not help but makes the situation worse

Neutrino flux mitigation system

Solution: A mechanical system that will disperse the neutrino flux by periodically deforming the collider ring arcs vertically with remote movers;



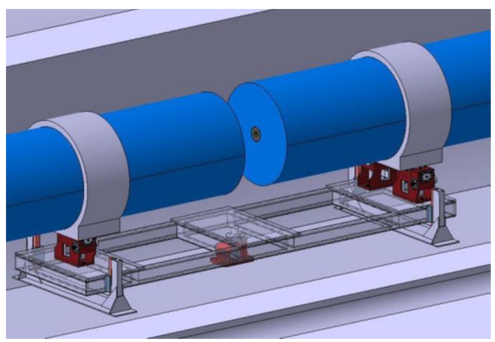
Legal limit: 1 mSv/year
MAP goal: <0.1 mSv/year
IMCC goal: <10 µSv/year
LHC : <5 µSv/year

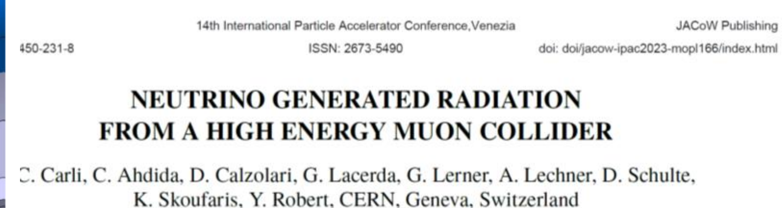


Vertical slope modulation ~ 1 mrad

Need to study mover system, magnet, connections and impact on beam

Working on different approaches for experimental insertion




14th International Particle Accelerator Conference,Venezia JACoW Publishing
450-231-8 ISSN: 2673-5490 doi: doi/jacow-ipac2023-mopl166/index.html

NEUTRINO GENERATED RADIATION
FROM A HIGH ENERGY MUON COLLIDER

C. Carli, C. Ahdida, D. Calzolari, G. Lacerda, G. Lerner, A. Lechner, D. Schulte, K. Skoufaris, Y. Robert, CERN, Geneva, Switzerland

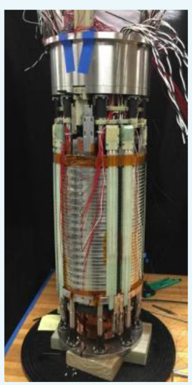
Requires significant R&D and proof-of principle tests

MuC magnet technology: Path Forward

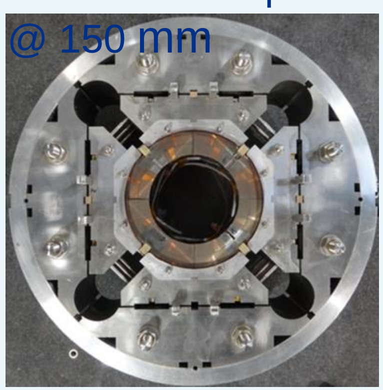
MuC section	Type	10 TeV MuC needs	Status
Cooling	Solenoid	30-50 T @ 50 mm	32 T @ 32 mm
Acceleration	Rapid cycling mag.	1.8 T @ 5 kT/s (30 mm x 100 mm)	1.8 T @ >5 kT/s (1.5 mm x 36 mm)
Collider Ring	Dipole	12-16 T @ 150 mm	11-12 T @ 120 mm
IR	Quadrupole	15-20 T @ 150 mm	11-12 T @ 150 mm

- Many synergies with other programs possible.
  - However rapid cycling magnets are unique for a MuC and need out attention!

32T @ NHMFL



LHC-HL 12 T quad @ 150 mm



	Synergies				
	US-MDP	Future Colliders	Fusion	ARDAP/Industry	NSF (NMR)
Target Solenoid			■		■
Cooling Channel Solenoids					■
High Ramp Rate for RCS					
Collider Dipoles	■	■			
IR Quads		■			
Alternatives R&D					
HTS for collider magnets	■		■	■	■

Fermilab

Post-Snowmass: US Muon Collider R&D coordination group formation

- In March, R&D coordination group formed to provide input to P5
- Focus on key elements of **10 TeV accelerator & detector design**
  - Develop R&D plan, activities, budget and deliverables
  - Chairs: Sridhara Dasu, Sergo Jindariani, and Diktys Stratakis

Physics Case Development:
Patrick Meade (Stony Brook), Nathaniel Craig (UCSB)

Accelerator R&D Focus Areas:
Muon source:
Mary Convery (Fermilab), Jeff Eldred (Fermilab), Sergei Nagaitsev (JLAB), Eric Prebys (UC Davis)

Machine design:
Frederique Pellemoine (Fermilab), Scott Berg (BNL), Katsuya Yonehara (Fermilab)

Magnet systems:
Steve Gourlay (Fermilab), Giorgio Apollinari (Fermilab), Soren Prestemon (LBNL)

RF systems:
Sergey Belomestnykh (Fermilab), Spencer Gessner (SLAC), Tianhuan Luo (LBNL)

Detector R&D Focus Areas:
Tracking Detectors:
Maurice Garcia-Sciveres (LBNL), Tova Holmes (Tennessee)

Calorimeter Systems
Chris Tully (Princeton), Rachel Yohay (FSU)

Muon Detectors
Melissa Franklin (Harvard), Darien Wood (Northeastern)

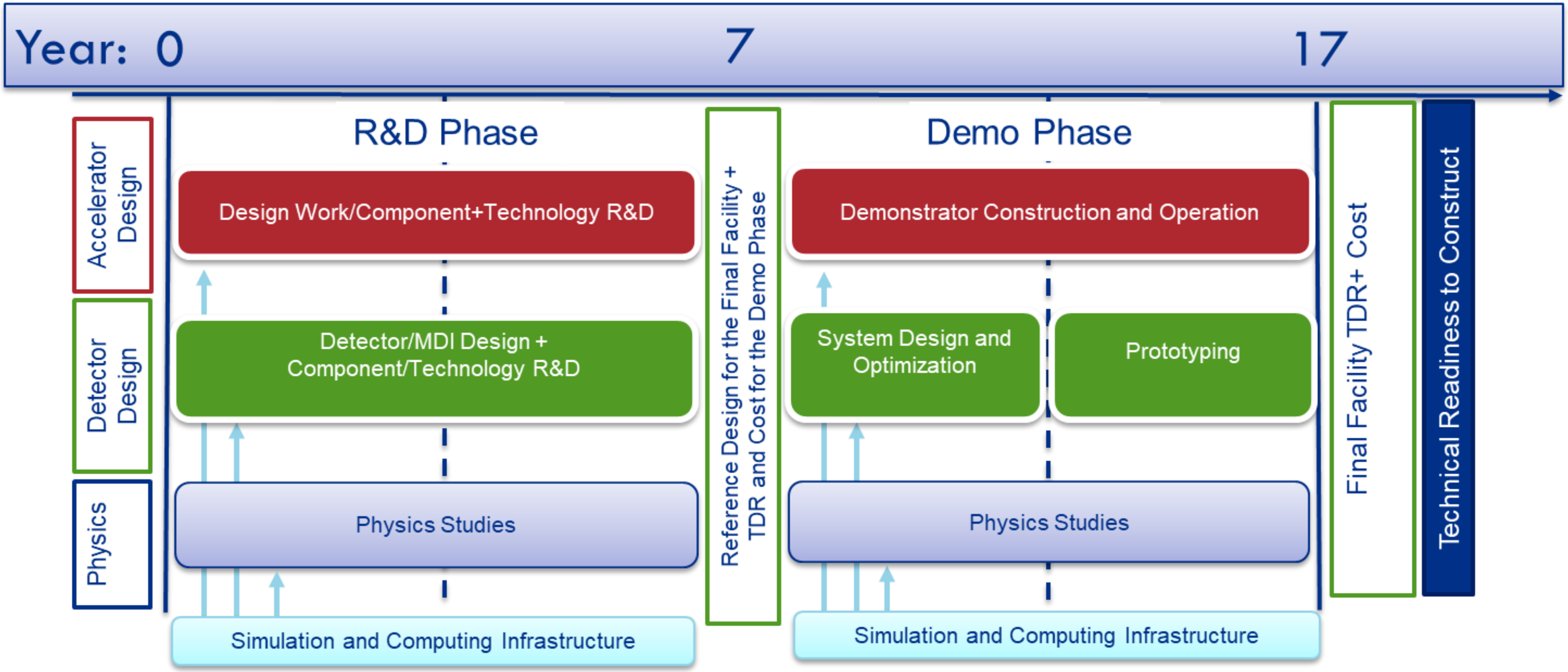
Electronics/TDAQ
Darin Acosta (Rice), Isobel Ojalvo (Princeton), Michael Begel (BNL)

MDI+Forward Detectors:
Kevin Black (Wisconsin), Karri DiPetrillo (Chicago), Nikolai Mokhov (Fermilab)

Detector Software and Simulations:
Liz Sexton-Kennedy (Fermilab), Simone Pagan Griso (LBNL)

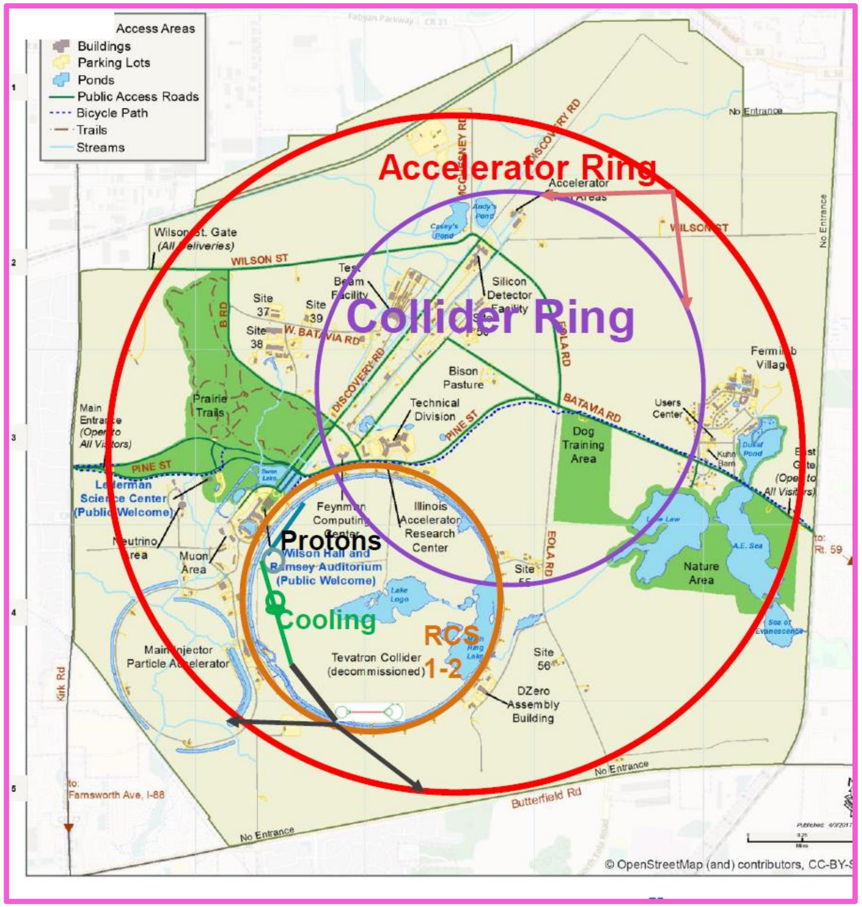
International Liaisons:
Daniel Schulte (CERN), Chris Rogers (RAL), Donatella Lucchesi (INFN), Federico Meloni (DESY)

US Muon Collider timeline



Muon Collider @ Fermilab

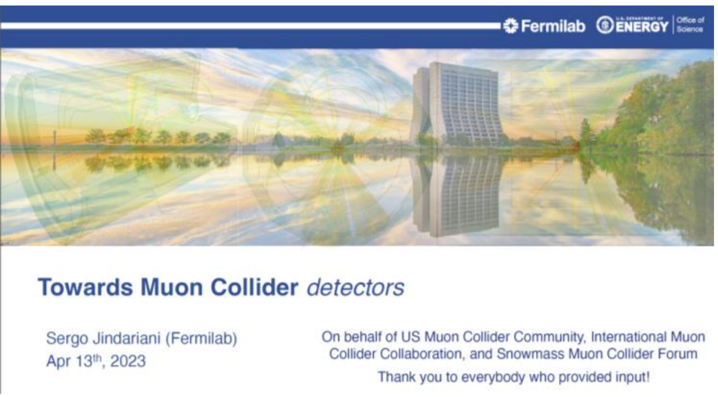
- A concept design for a Fermilab **6-10 TeV MuC** is in place
- Proton source
  - Post-ACE driver -> Target
- Ionization cooling channel
- Acceleration (3 stages)
  - Linac + RLA → **65 GeV**
  - RCS #1, #2 → **1 TeV (Tevatron size)**
  - RCS #3 → **3-5 TeV (site filler)**
- 6-10 TeV collider
  - Collider radius: 1.65 km



- In the next **5 years**, have a baseline design including the neutrino flux mitigation system

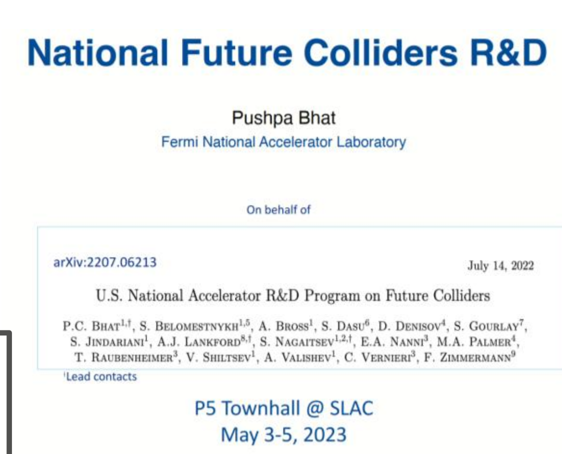
Post-Snowmass P5 Townhall Meetings

- Findings of the coordination groups were presented at two P5 Town-hall meetings



[Detector R&D plans and budget request]

[Accelerator R&D plans and budget request]



[National Collider R&D]

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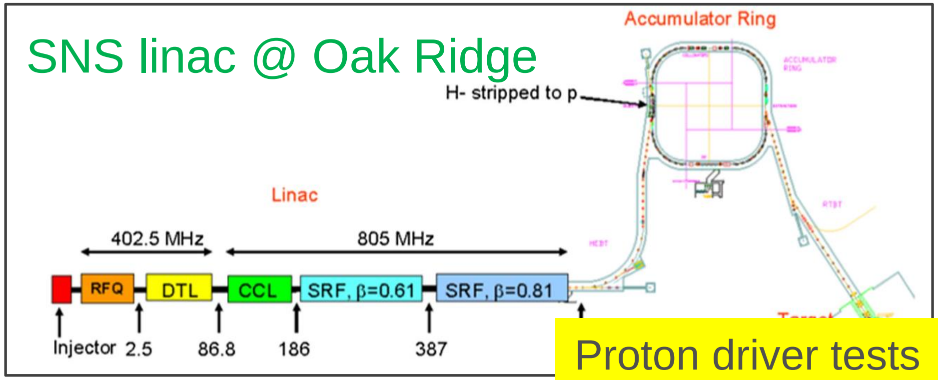
Possibilities within the US

- Several **existing US based facilities** can aid the MuC R&D program: **they expressed interest** and are currently explored

SNS linac @ Oak Ridge

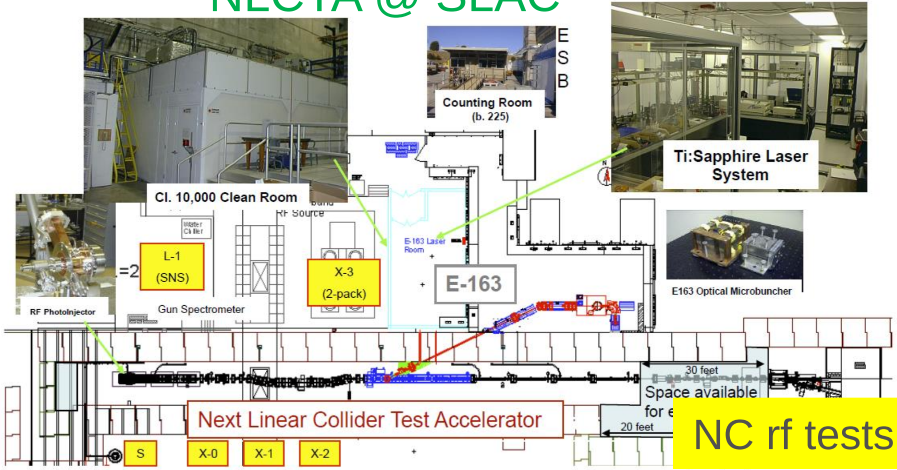


Proton driver tests

Muon Campus @ Fermilab

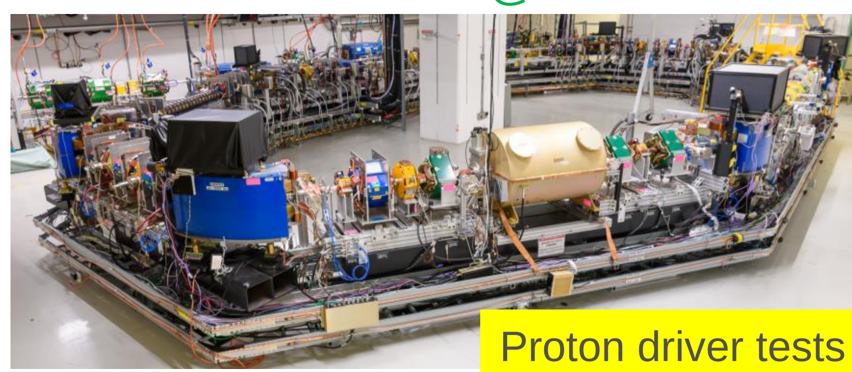
Cooling demo

NLCTA @ SLAC



NC rf tests

FAST/ IOTA @ Fermilab



Proton driver tests

Proposed MuC accelarator US R&D (next 5 years)

Some examples

Design and Simulation work

- MuC proton driver design
- Accelerator & collider designs for a FNAL MuC
- Neutrino flux mitigation for a FNAL MuC
- Ionization cooling design work

Some examples

Prototyping & tests

- Bunch compression & proton stripping
- Target material & performance studies
- Fast ramping magnet prototypes
- Low-frequency SRF cavity prototyping & testing

Some examples

Demonstrator

- Explore facility options for a full demo
- Design & prototype (if possible) 1.5 cooling cell
- Deliver a TDR for a demo facility with costs

- A 10-page **R&D summary** document submitted to P5 (link). Includes the R&D plan, timeline, FTE and M&S needs.

What has changed since over the last decade?

- Lattice design
  - Developed designs for all MuC subsystems, including a promising solution for a neutrino flux mitigation system
- Targets
  - Significant developments on MW-class target concepts due to the strong demand by many experiments.
- Magnet technology
  - Development of high-field solenoids & dipoles with specs close to the MuC needs
- RF technology
  - Demonstrated high-gradient operation of NC cavities in B-fields (50 MV/m @ 3T)
  - SCRF cavity gradients for a MuC are within reach of current technology
- Ionization cooling concept demonstration
  - Physics of ionization cooling has been demonstrated; many publications

Summary (1)

- MC offers a unique opportunity for energy frontier collider with high luminosity
- Physics & technology landscape has significantly changed recently
  - Explosion of physics interest in muon colliders as indicated by the number of publications, activities in IMCC, Muon Collider Forum, and Snowmass white papers
- No fundamental show-stoppers in physics and technology have been identified
  - Nevertheless, engineering challenges exist in many aspects of the design and targeted R&D is necessary in order to make further engineering and design progress
- It is crucial for the US to engage NOW if we want an MC as a future option!

Summary (2)

- Our ask for P5 townhall is:
  - Recommend establishing a Muon Collider R&D program with the aim for delivering a RDR report for the final facility & TDR report for the demo facility by 2030 AND with an overall goal of having a TDR for the final facility by 2040
  - Recommend that DOE and NSF recognize Muon Collider work within the AF and EF base program proposals
  - Support the formation of a US Muon Collider effort to coordinate US impact while engaging in the international effort
  - Support the national future collider R&D program
  - Enable US to compete for hosting a Muon Collider

Backup