THE MUON ACCELERATOR RESEARCH AND DEVELOPMENT PROGRAM

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On Behalf of the Muon Accelerator Program (MAP)

OUTLINE

- Why A Muon Collider?
- Muon Accelerator Program (MAP)
- Muon Collider Facility
  - Proton Driver
  - Target and Capture
  - Phase Rotation
  - Cooling
  - Acceleration
  - Collider Ring
- Critical Issues
- MuCool Test Area
- Summary and Conclusions

WHY A MUON COLLIDER?

- LHC hints need for higher energy (ILC is 0.5 TeV)

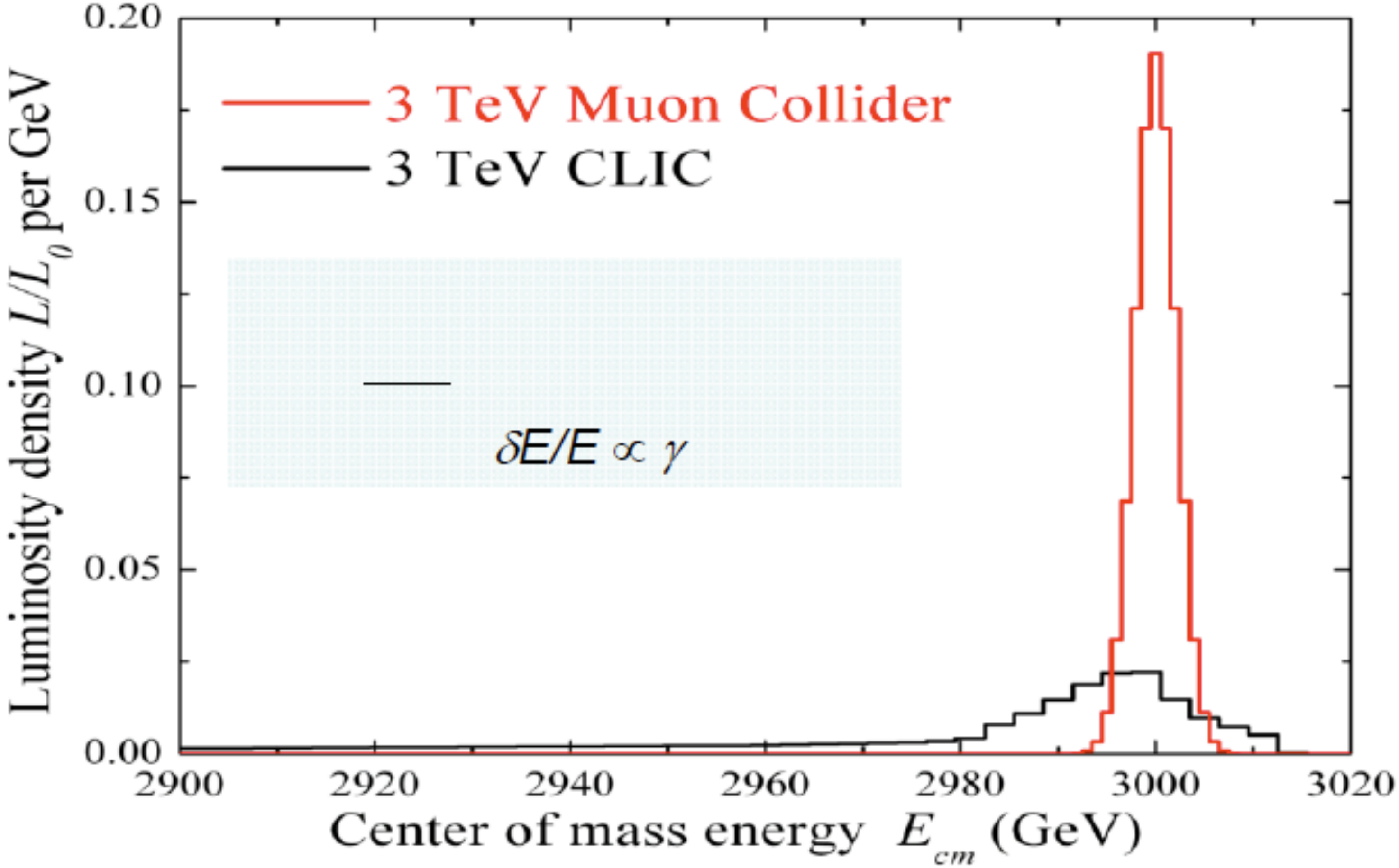
Compare with CLIC

	$\mu^+\mu^-$	$\mu^+\mu^-$		e^+e^-CLIC
C of m Energy	1.5	3	TeV	3
Luminosity	1	4	10^{34} cm^{-2} s^{-1}	$2^{(1)}$
Ring <bending field>	6	8.4	T	-
Accelerator circ./length	6	12	km	48
rms bunch height	6	4	μm	0.001
Proton Driver power	4.	3.2	MW	-
Lepton power	7	11	MW	28
Wall power	$\approx$147	$\approx$159	MW	560

- Wall power 1/3 of 3 TeV CLIC, 2/3 of 0.5 TeV ILC

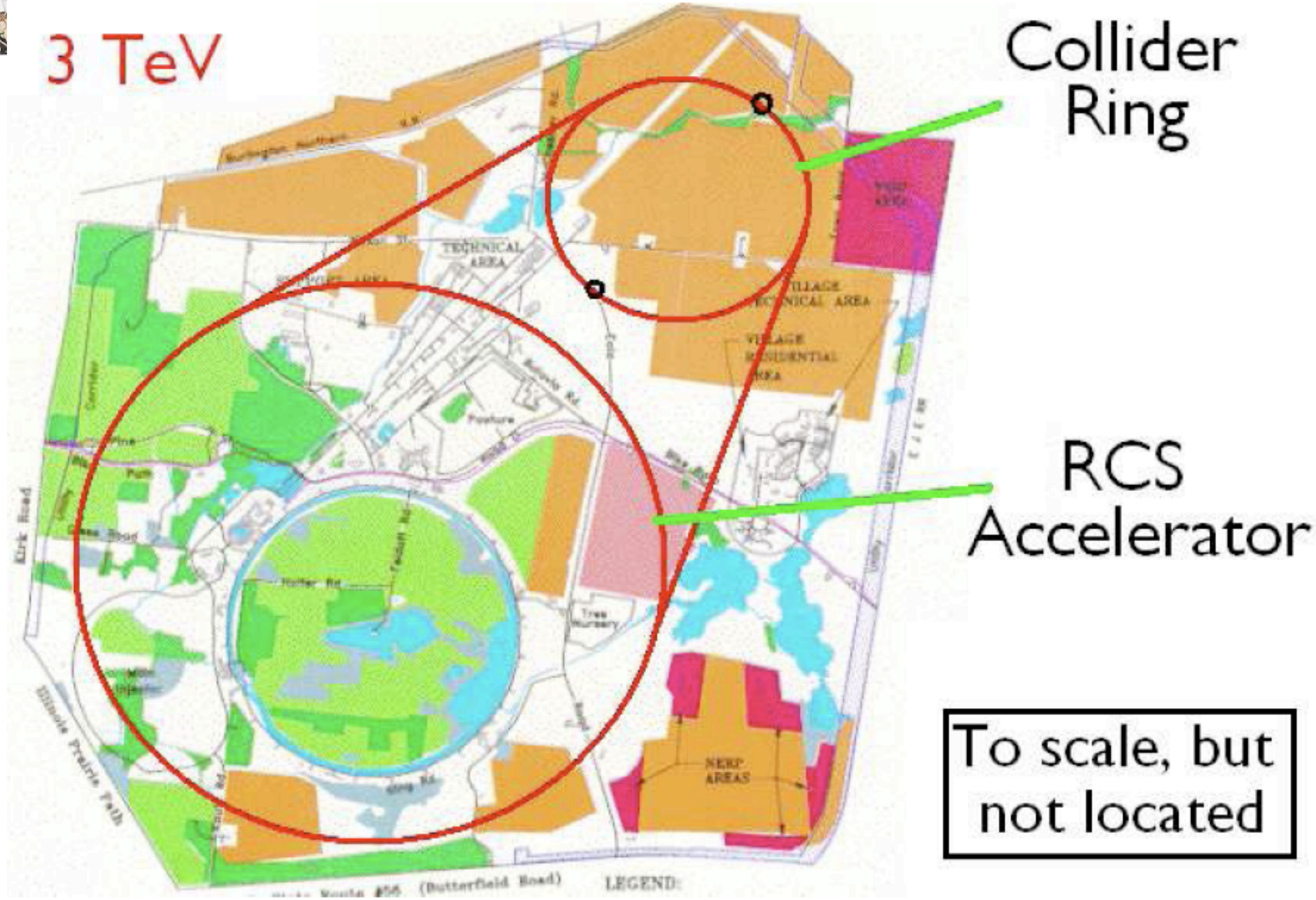
WHY A MUON COLLIDER?

- Large muon mass greatly reduces beamstrahlung



Muon Collider Fits on Fermilab Site

Layout at FNAL



MUON ACCELERATOR PROGRAM (MAP)

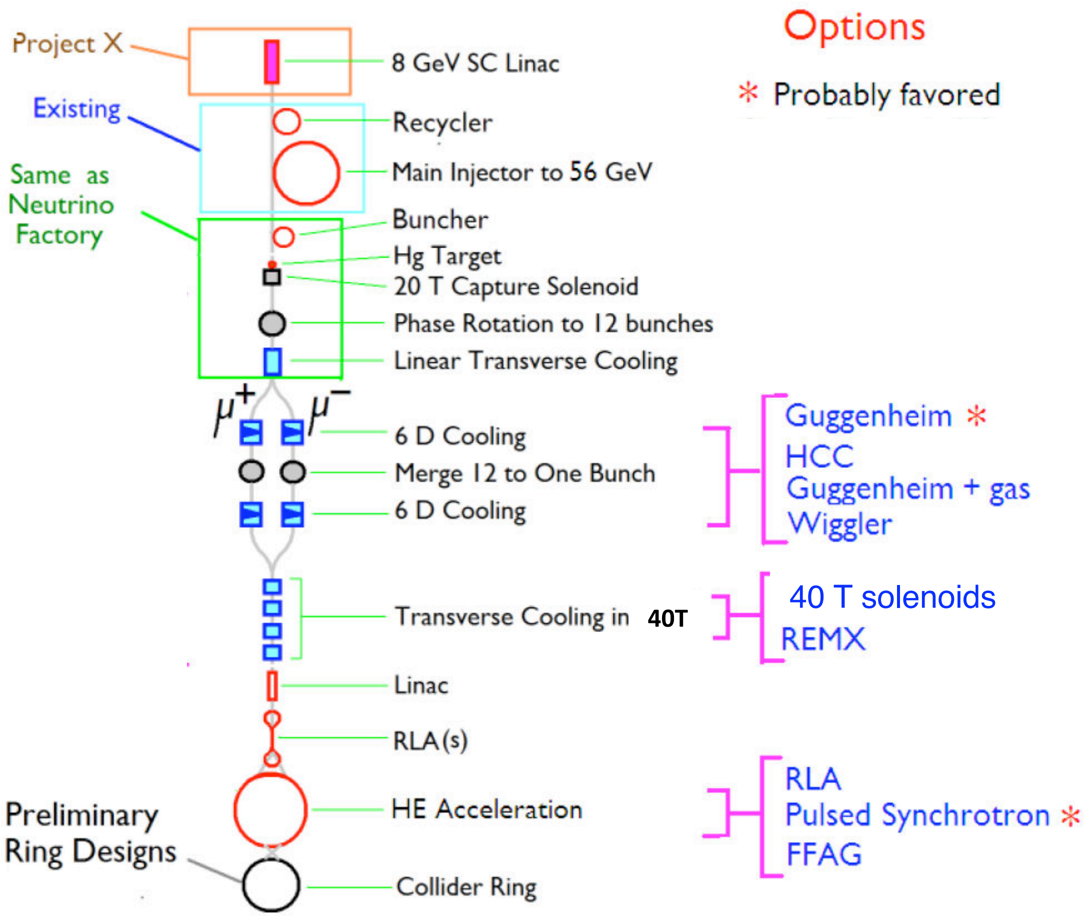
- Of course, much development is still needed.
- The Muon Accelerator Program (MAP), hosted by Fermilab, was formed to coordinate the R&D that had been carried out by the Neutrino Factory and Muon Collider Collaboration (NFMCC) and the Muon Collider Task Force (MCTF) over 10 years.
- A review of the program was held at Fermilab 24-26 August 2010.
- MAP was approved by the U.S. Department of Energy in March 2011.
- Search for a Director is underway.
- URL http://map.fnal.gov/

GOALS OF MAP

- Complete Design Feasibility Study (DFS) Report for a multi-TeV muon collider, including cost range
- Contribute to the International Neutrino Factory Design Study (IDS-NF) to produce a Reference Design Report by 2013
- Carry out supporting technology R&D needed to inform the muon collider DFS and enable down-selection
- Participate in system tests of 4D and 6D cooling – Muon Ionization Cooling Experiment (MICE) and 6D "bench test" (no beam)
- Time scale of 6-7 years

MUON COLLIDER FACILITY

Scheme

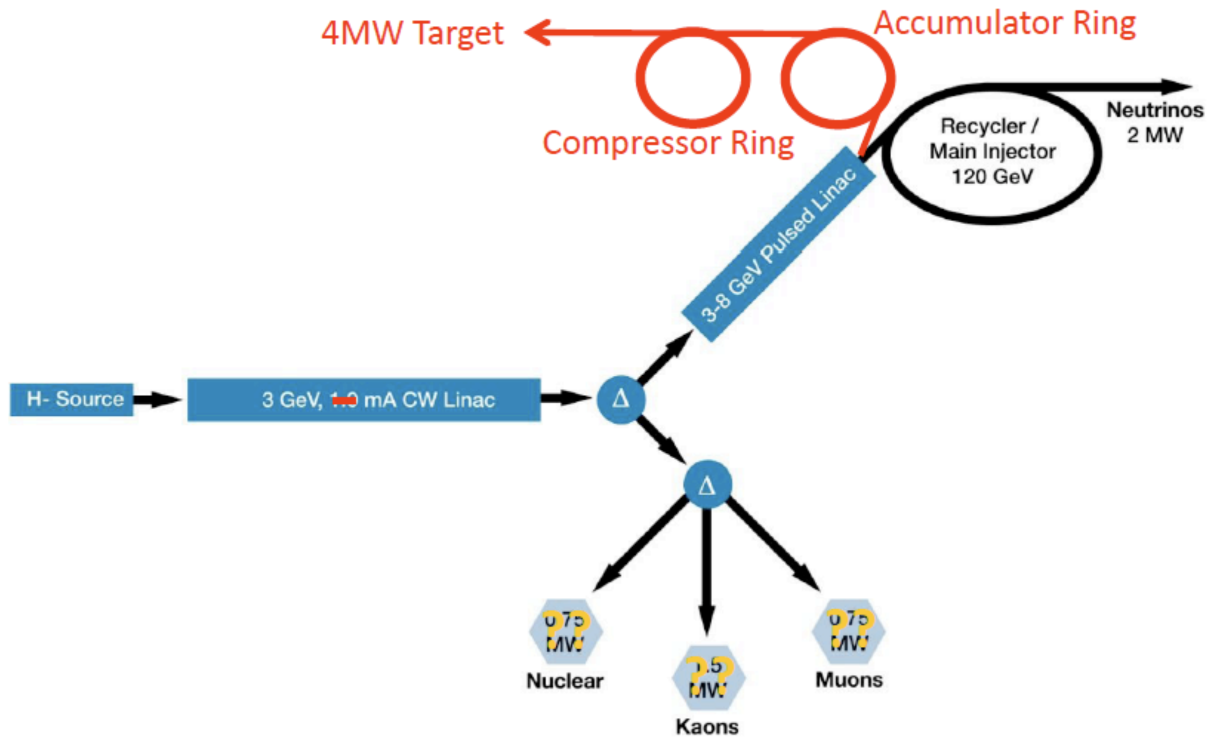


More R&D needed to confirm viability and narrow the options

(Palmer)

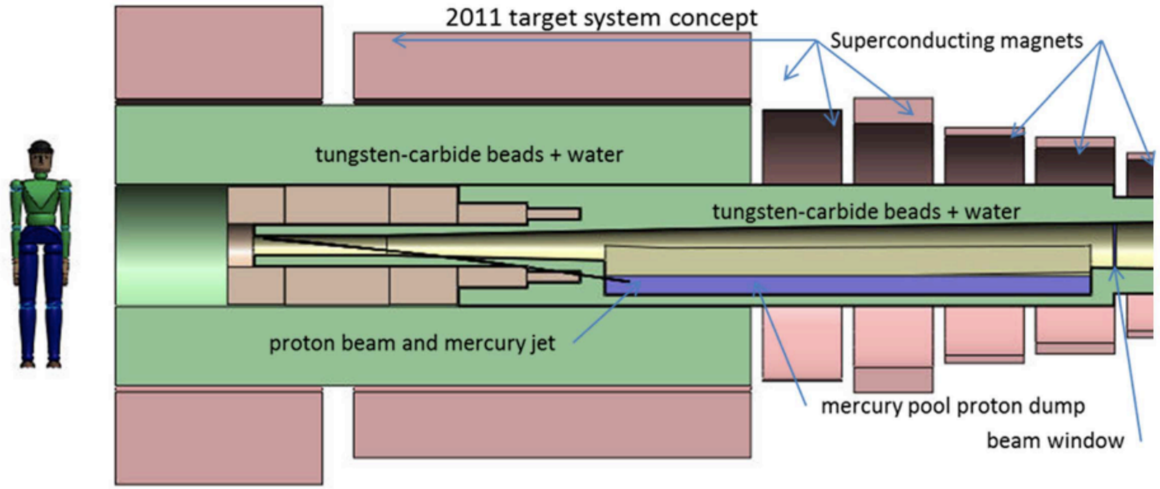
PROTON DRIVER

- Upgrade of Project X – Task Force
- For Muon Collider, want 4 MW at 8 GeV
- CW SC Linac – 1 mA to 3 GeV – increase to 5 mA pulsed Linac 3-8 GeV



TARGET AND CAPTURE

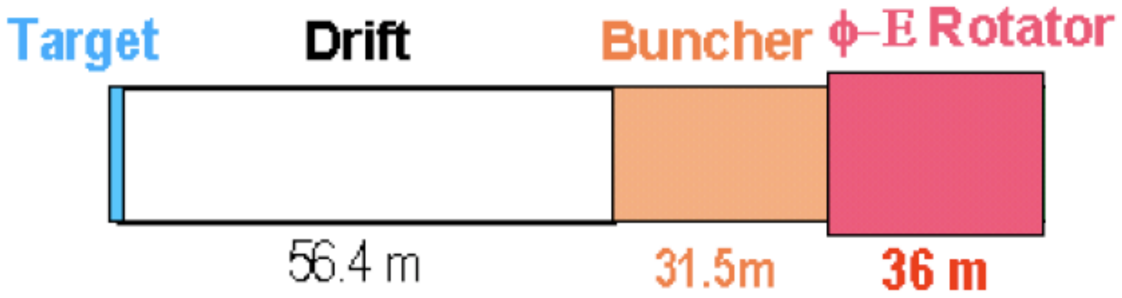
- Target
  - Successful demonstration experiment – MERIT at CERN PS
  - Mercury jet in a 15 T solenoid
- Capture in 20 T solenoid
  - Shielding and radiation issues being studied

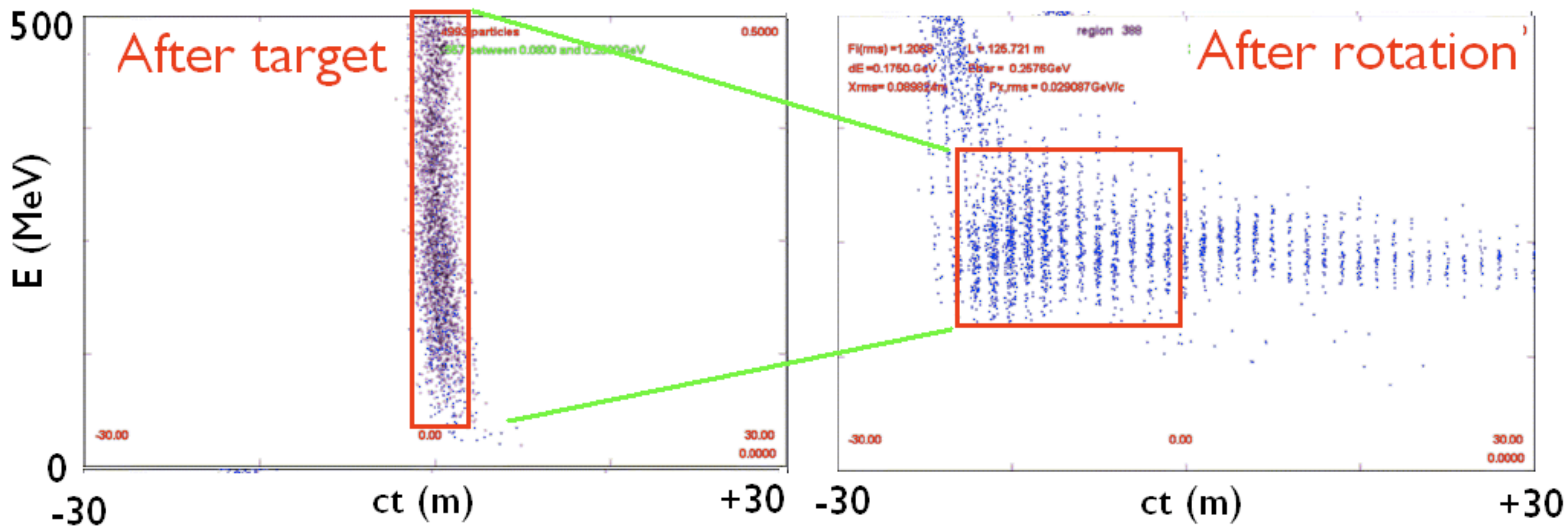


PHASE ROTATION

- Produce, collect, and cool as many muons as possible
- Start with IDS-NF study and reoptimize for collider
  - Shorter bunch train
  - Larger gradients
- Bunch recombiner

PHASE ROTATION



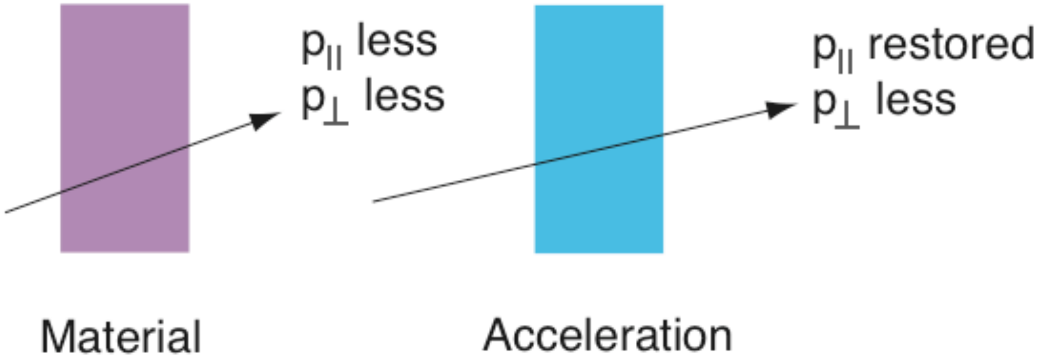


- Large ΔE, small Δt $\rightarrow$ small ΔE, larger Δt
- $\approx$ 48% of longitudinal phase space captured

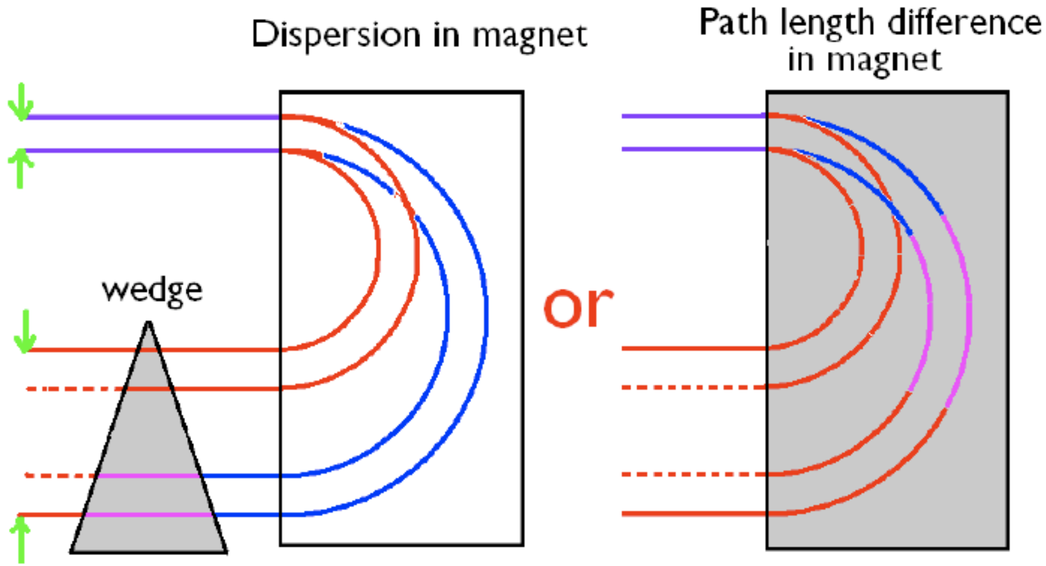
COOLING

- Since muons decay, need ionization cooling

Transverse (4D)

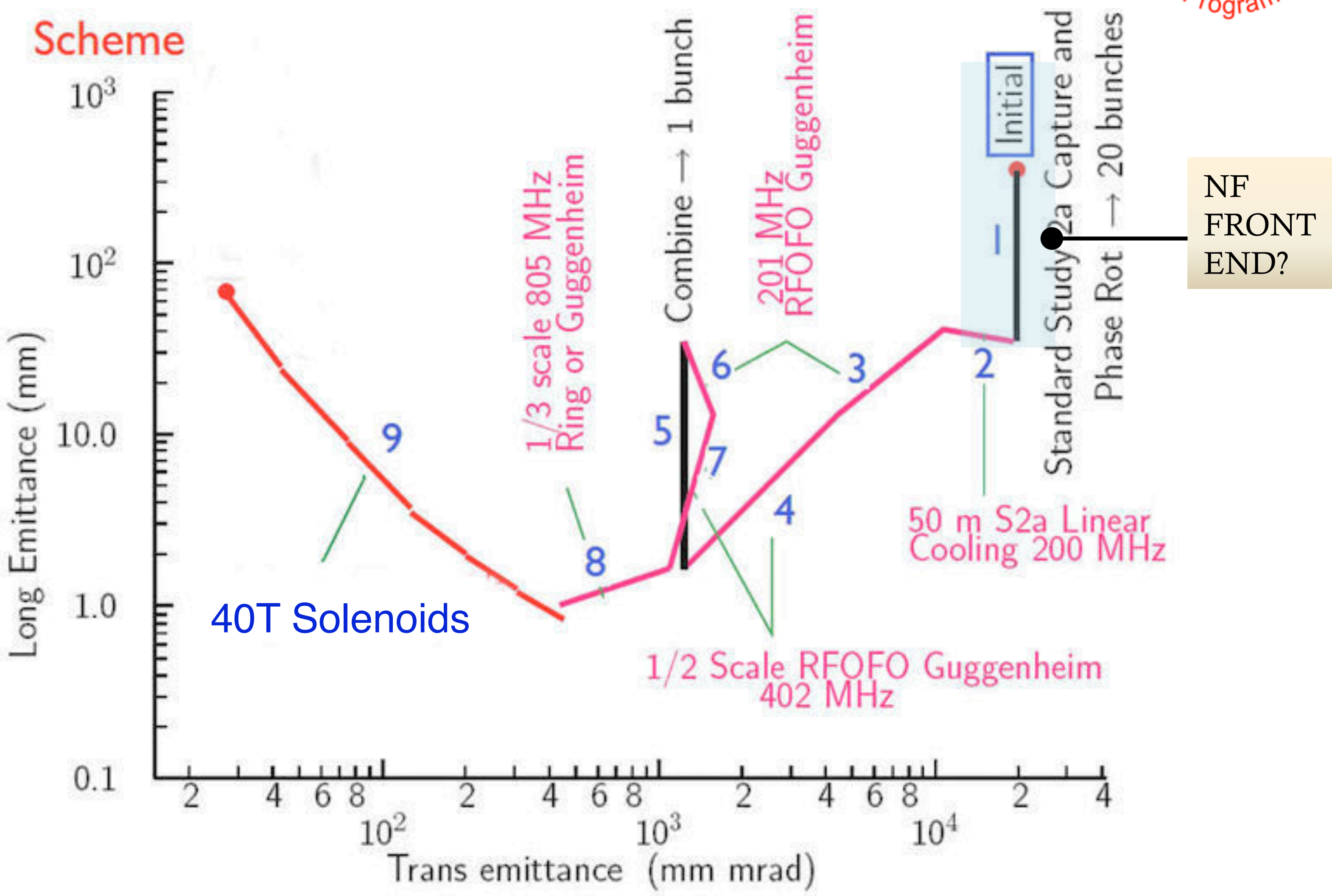


Longitudinal (6D)



COOLING

Scheme

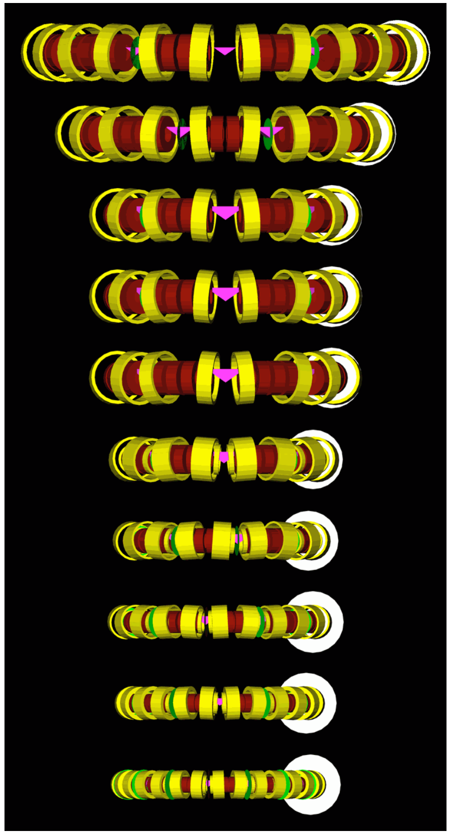


COOLING

- 4D Initial Cooling
  - Based on Neutrino Factory Feasibility Study 2a
  - Vacuum RF (gradients to 18 MV/m)
  - SC solenoids (2 T)
  - LiH absorbers
  - 0.15 μ/p (each sign)

COOLING

- 6-Dimensional Cooling
  - ✧ Tapered Guggenheim (helical RFOFO)
    - Simulated in approximation
    - RF gradient 16 MV/m
    - Maximum magnetic field on axis 2.3 T to 10.6 T
    - Wedge absorbers
  - ✧ Other options: Helical FOFO Snake, Helical Cooling Channel

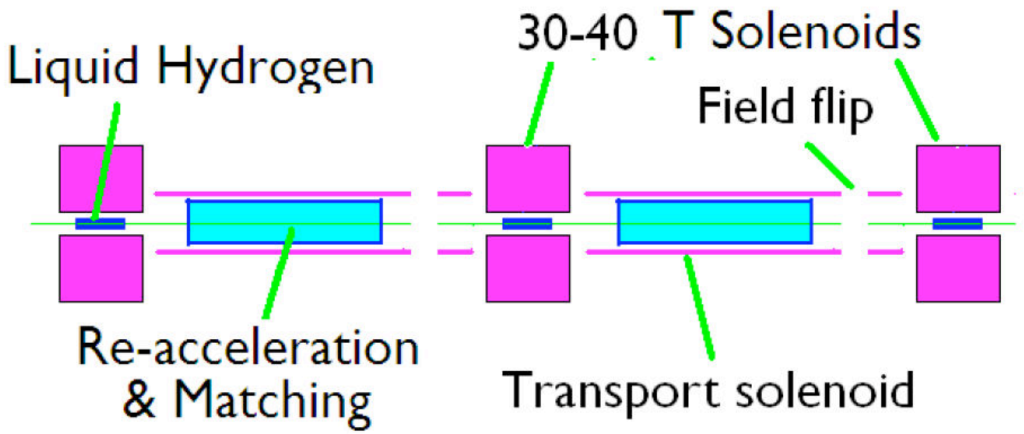


201 MHz

805 MHz

COOLING

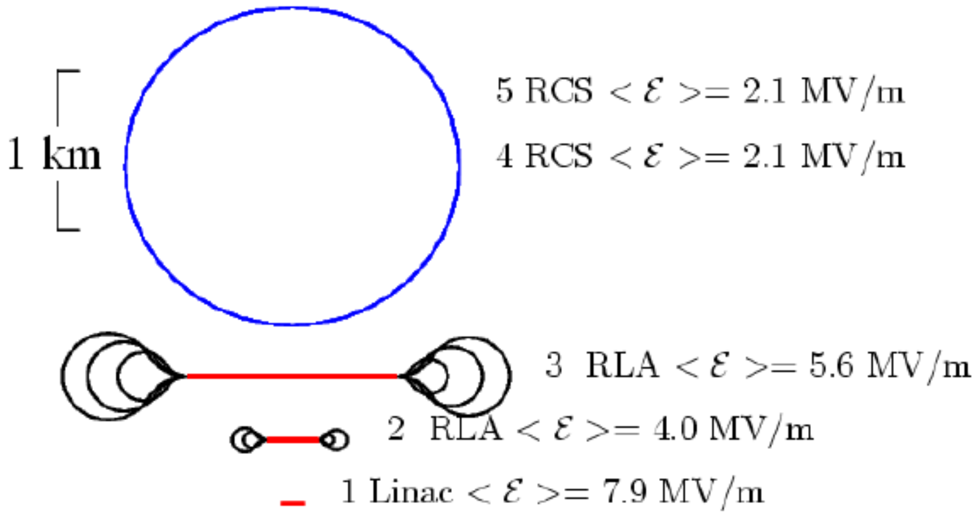
- 4D Final Cooling



  - 30-40T HTS magnets operating at 4K
  - RF cavities and Induction linacs
  - LH_2 forced-flow absorbers
  - Only option that can achieve $\varepsilon_\perp < 25$ μm in simulation

ACCELERATION

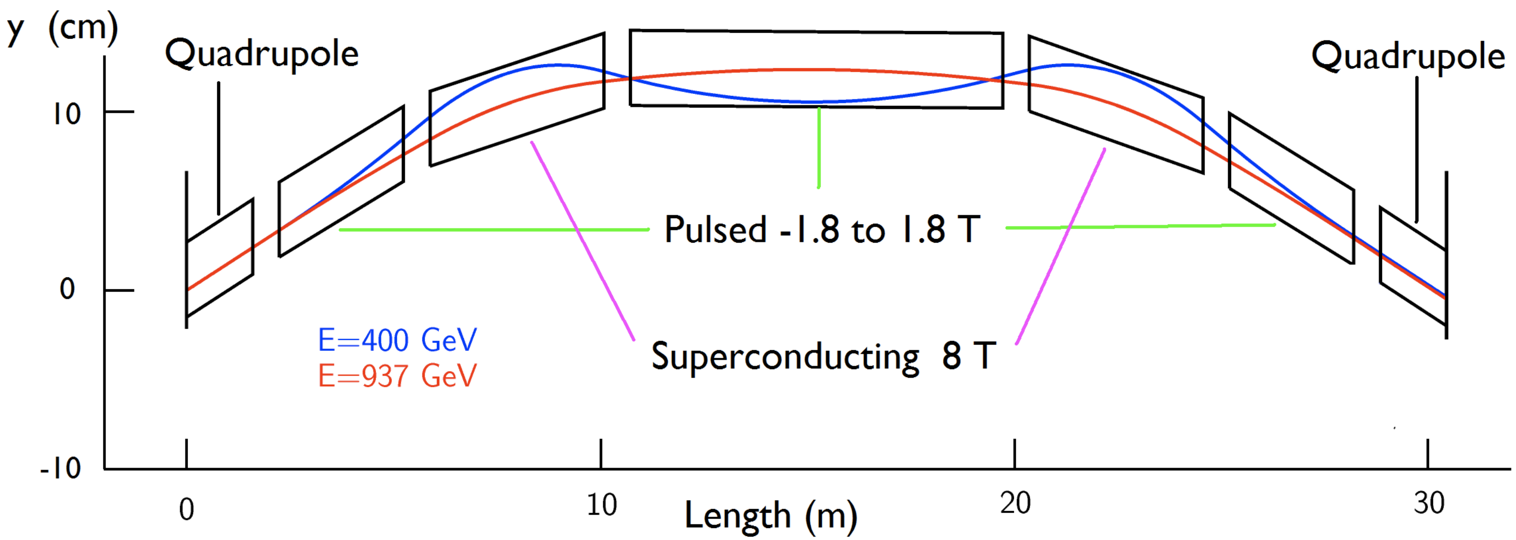
	E_f GeV	n	f_{RF} MHz	V_{avg} MV/m	Decay %	P_{pk} MW	P_{wall} MW
Linac	1.5	1.0	201	7.9	2.4	46	3.4
RLA	12.5	4.5	201	4.0	7.6	105	7.8
RLA	100.0	6.5	402	5.6	5.4	469	11.7
RCS	400.0	23.0	805	2.1	10.2	396	4.7
RCS	750.0	27.0	805	2.1	4.8	393	7.2
					27.1		34.8



- Low-energy Acceleration
  - Re-optimize IDS-NF design
  - LINAC and Two RLA's
  - Exploring dog-bone RLA's – less costly

ACCELERATION

- Acceleration to High Energy
  - Fast-ramping synchrotron – synchrotrons less expensive than racetracks
  - High average bend field (8 T)
  - Magnets ramped extremely fast -1.8 T to 1.8 T at 400 Hz



COLLIDER RING

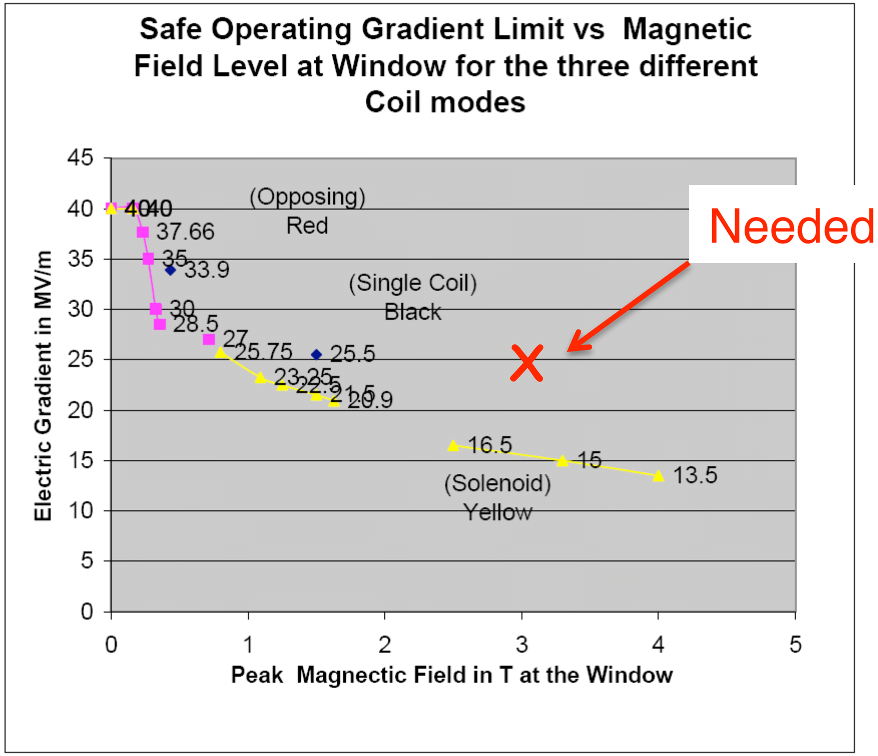
- Challenging design criteria (compared with existing colliders):
  - Much larger momentum acceptance with much smaller β^*
  - As large Dynamic Aperture with much stronger beam-beam effect
  - Very small momentum compaction factor
- Design taking IR's into account
- Large heat load into magnets in plane of ring due to μ decays.

CRITICAL ISSUES

1. Operation of high-gradient NCRF in high magnetic fields

- Needed in capture, bunching, phase rotation, and cooling

805 MHz studies: Maximum stable gradient degrades quickly with magnetic field



CRITICAL ISSUES

- Pursuing multiple studies at Fermilab MuCool Test Area:
  - ✧ Reduce/eliminate field emission
    - → Process cavities using SCRF techniques
    - → Surface coatings – Atomic Layer Deposition
  - ✧ Material studies
    - → Non-Cu bodies (Al, Be)
  - ✧ RF cavities filled with high-pressure gas (H_2)
    - → Use Paschen effect to stop breakdown
    - → Test underway at Fermilab MuCool Test Area
  - ✧ Magnetic insulation
    - → Eliminate magnetic focusing

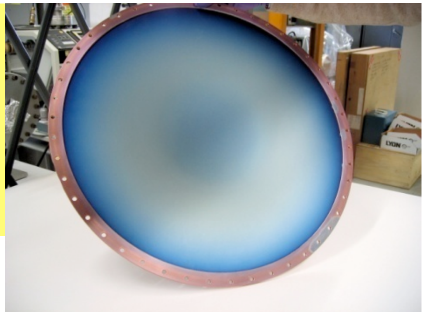
CRITICAL ISSUES

2. Neutrino radiation
   - To stay below Federal limits at 3 TeV need to be well underground – in-depth study needed
   - Incorporate mitigation into ring design
3. R&D on very high field and fast-ramping magnets
4. End-to-end simulation of complete Muon Collider
5. Space charge and wake field questions
6. Successful completion of the Muon Ionization Cooling Experiment (MICE)

MUCOOL TEST AREA AT FERMILAB

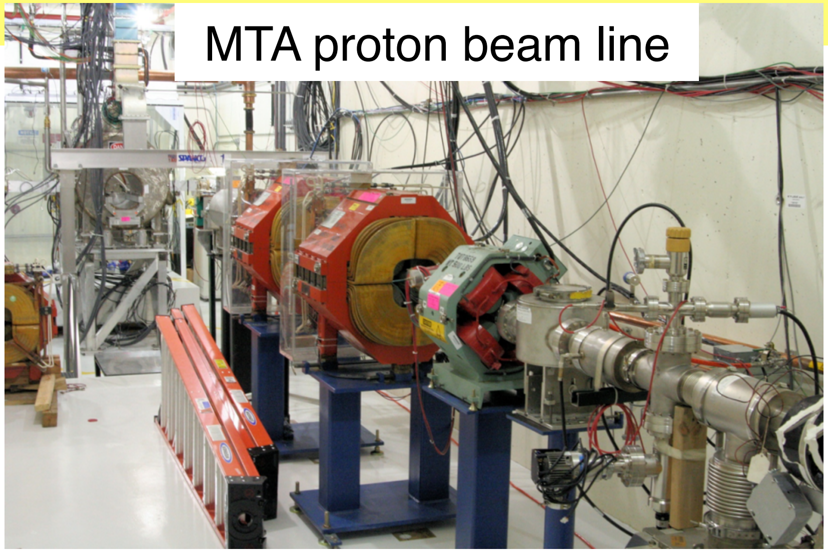
- Component testing: RF, Absorbers, Solenoids with High-Intensity Proton Beam – now taking data!
- Uses MuCool Test Area (MTA) at Fermilab
- Supports Muon Ionization Cooling Experiment (MICE)

50 cm ∅ Be RF window

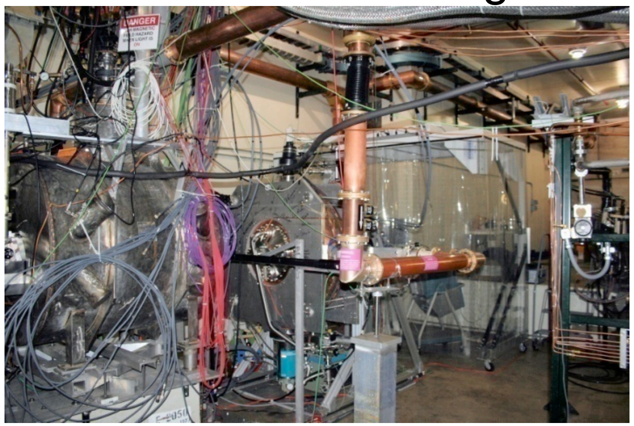


<u>Most Important</u>: Studying the limits on accelerating gradient in NCRF cavities in high magnetic field

MTA proton beam line



201 MHz RF testing



LH_2 Absorber Body

SUMMARY AND CONCLUSIONS

- Muon Acceleration Program (MAP) approved by U.S. Department of Energy
- The Neutrino Factory Design Study (IDS-NF) Reference Design Report will be completed
- Within 5-6 years we will have a Design Feasibility Study and cost range for a multi-TeV muon collider
- Considerable progress on Muon Collider R&D but many challenges remain!
- Decision on energy for next lepton collider depending on LHC results