The R&D Program For A *Future Muon Collider*

Mark Palmer

for the MAP Collaboration

September 30, 2013

Fermilab

The US Muon Accelerator Program

MAP was formally established in March 2011 with the mission:

… to develop and demonstrate the concepts and critical technologies required to produce, capture, condition, accelerate, and store intense beams of muons for Muon Colliders and Neutrino Factories.

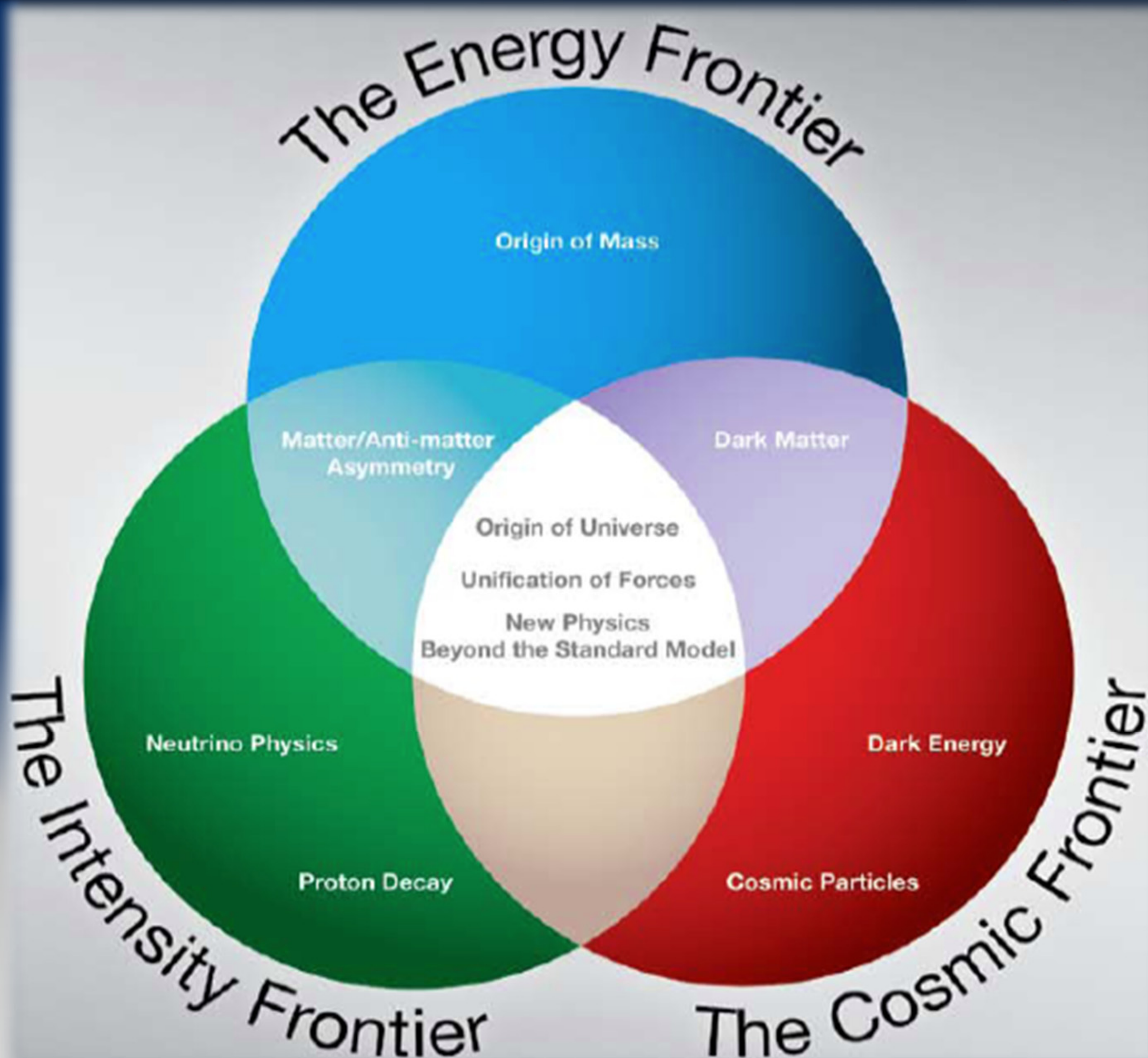
The goal of MAP is to deliver results that will permit the high-energy physics community to make an informed choice of the optimal path to a high-energy lepton collider and/or a next-generation neutrino beam facility.

The Aims of the U.S. Muon Accelerator Program

Muon accelerator R&D is focused on developing a facility that can address critical questions spanning two frontiers…

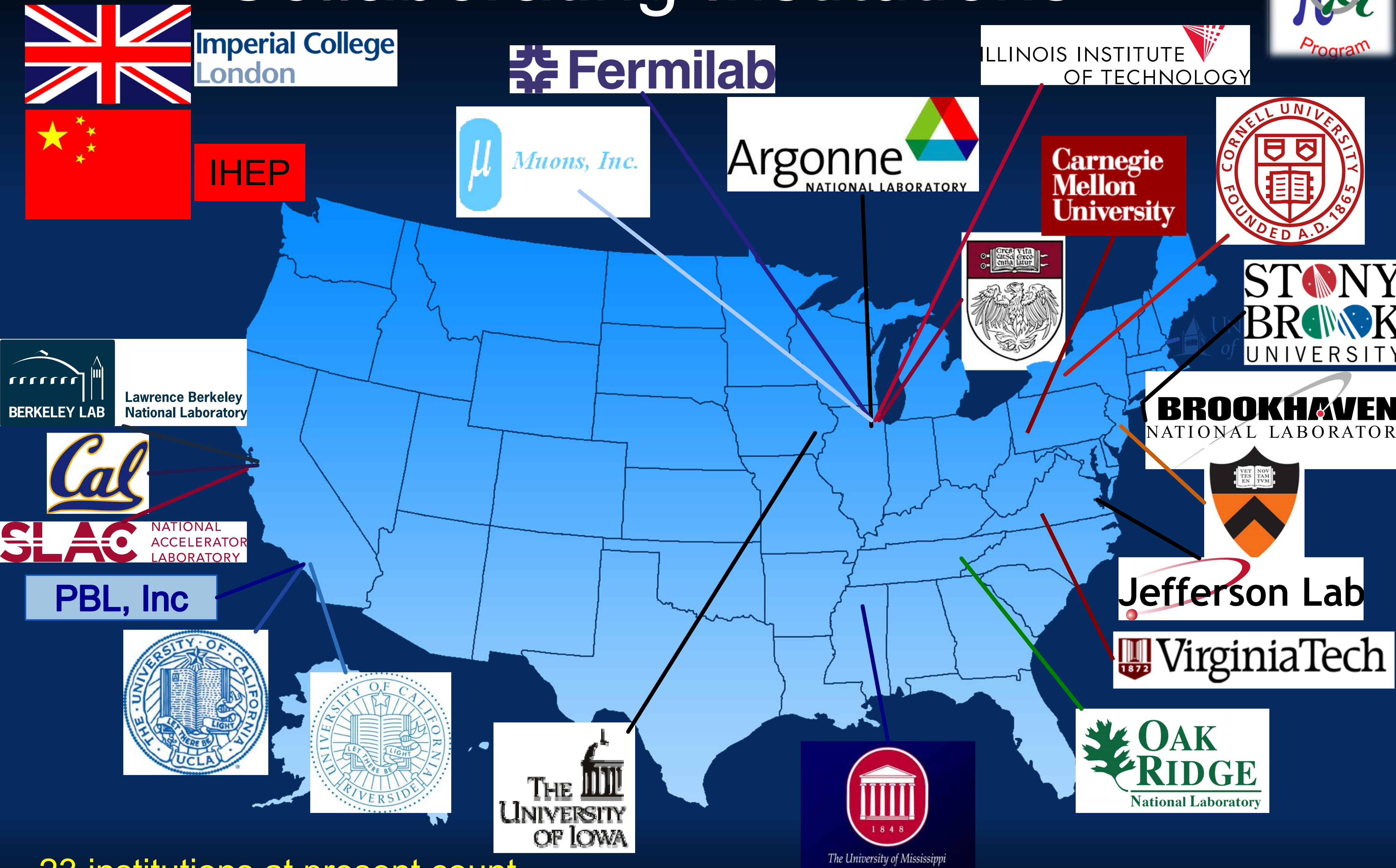
The Intensity Frontier:
with a ***Neutrino Factory*** producing well-characterized ν beams for precise, high sensitivity studies

The Energy Frontier:
with a ***Muon Collider*** capable of reaching multi-TeV CoM energies
and
*a **Higgs Factory** on the border between these Frontiers*



The unique potential of a facility based on muon accelerators is physics reach that SPANS 2 FRONTIERS

Collaborating Institutions



23 institutions at present count

The Remainder of This Talk

- Physics Motivations
- The Muon Collider Concept
- R&D Program Overview
- Neutrino Factory and Muon Collider Synergies
  ⇨ The Potential for a Staged Physics Program
- Conclusion

THE PHYSICS MOTIVATIONS

The Physics Motivations

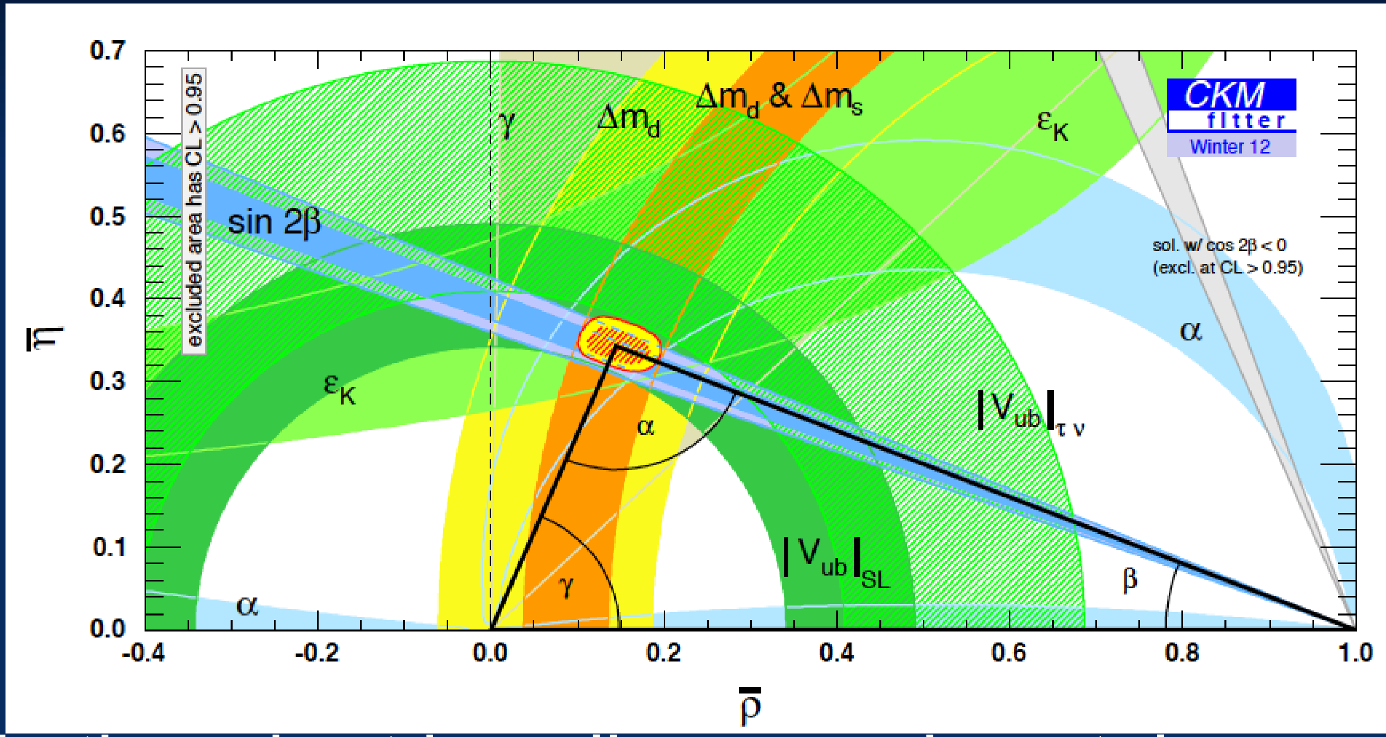
- Physics potential for the HEP community using muon beams
  - Tests of Lepton Flavor Violation
  - Anomalous magnetic moment ⇨ hints of new physics (g-2)
  - Can provide equal fractions of electron and muon neutrinos at high intensity for studies of neutrino oscillations – the Neutrino Factory concept

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$
$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

  - Offers a large coupling to the "Higgs mechanism" $\sim \left(\frac{m_\mu^2}{m_e^2}\right) \cong 4 \times 10^4$
  - As with an e^+e^- collider, a $\mu^+\mu^-$ collider would offer a precision probe of fundamental interactions – in contrast to hadron colliders

The Physics Needs: Neutrinos

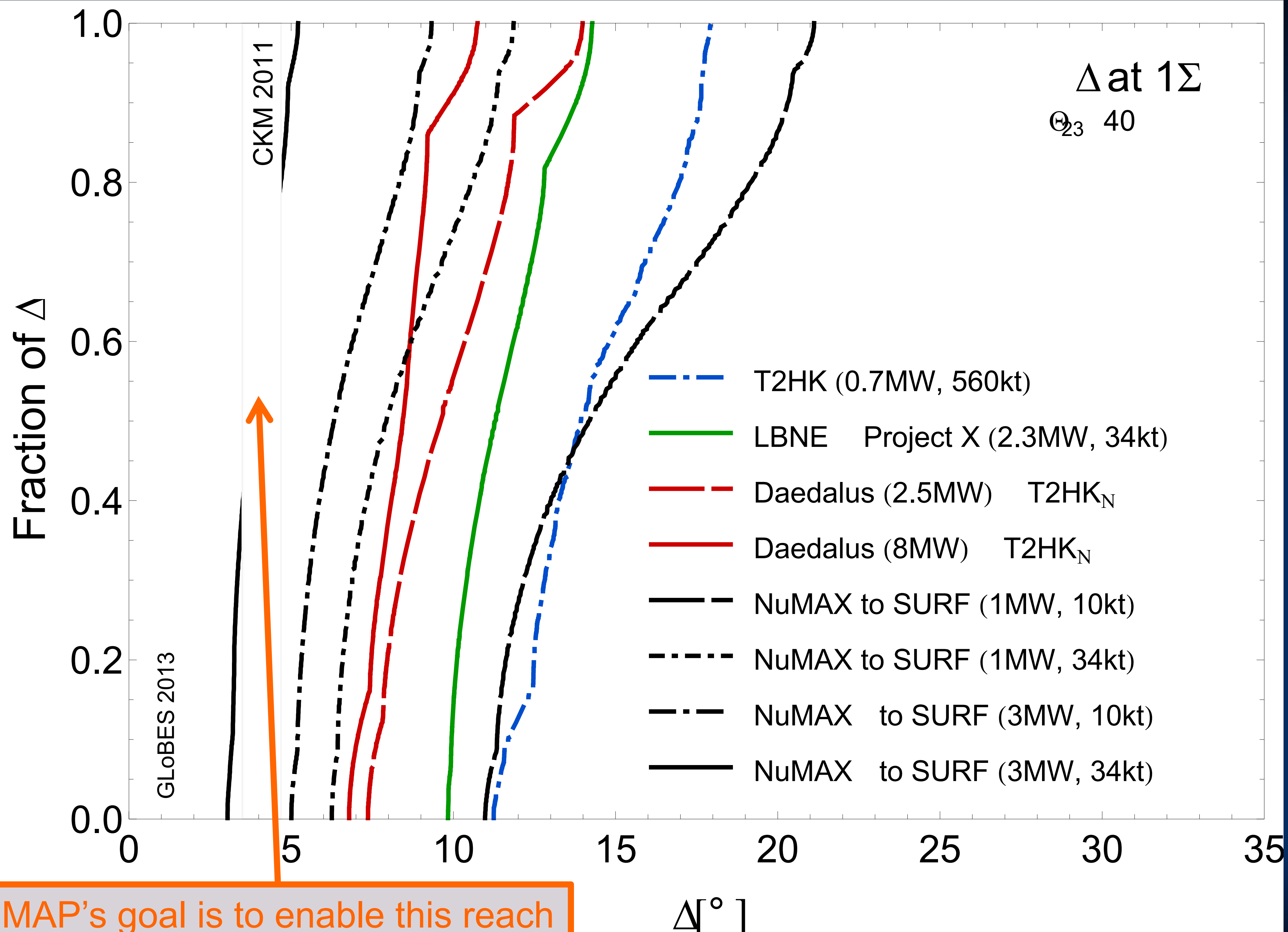
- In the neutrino sector it is critical to understand:
  - δ_{CP}
  - The mass hierarchy
  - $\theta_{23} = \pi/4$, $\theta_{23} < \pi/4$ or $\theta_{23} > \pi/4$



  - Resolve the LSND and other short baseline experimental anomalies [perhaps using beams from a muon storage ring (νSTORM) in a short baseline experiment]
  - And continue to probe for signs new physics

P. Huber

The Potential of a Neutrino Factory



MAP's goal is to enable this reach

A Staged Approach with NuMAX at Fermilab

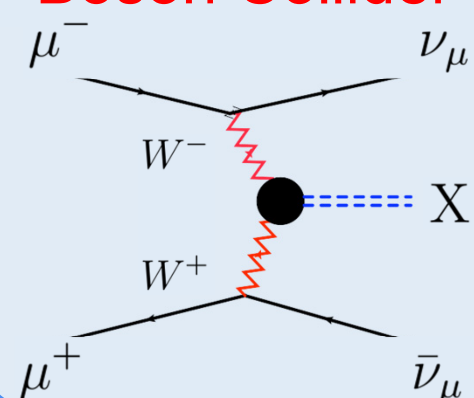
Muon Collider Physics Reach

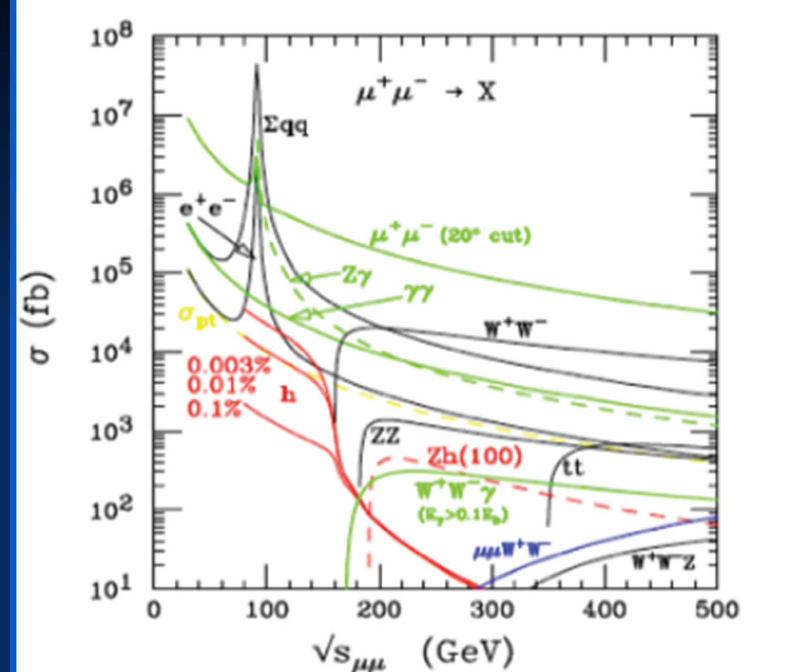
- $\sqrt{s}$ < 500 GeV ⇨ exquisite $\delta E/E$ (few $\cdot 10^{-5}$)
  - SM thresholds: Z^0h, W^+W^-, top pairs
  - Higgs factory ($\sqrt{s} \approx$ 126 GeV)
- $\sqrt{s}$ > 500 GeV
  - Sensitive to possible physics beyond SM
  - Requires high luminosity
    - Cross sections for central ($|\theta| > 10^o$) pair production ~ R × 86.8 fb/s[TeV^2] (R ≈ 1)
    - At $\sqrt{s}$ = 3 TeV for 100 fb^{-1} ~ 1000 events/unit of R
- $\sqrt{s}$ > 1 TeV
  - Fusion processes become dominant in a multi-TeV MC

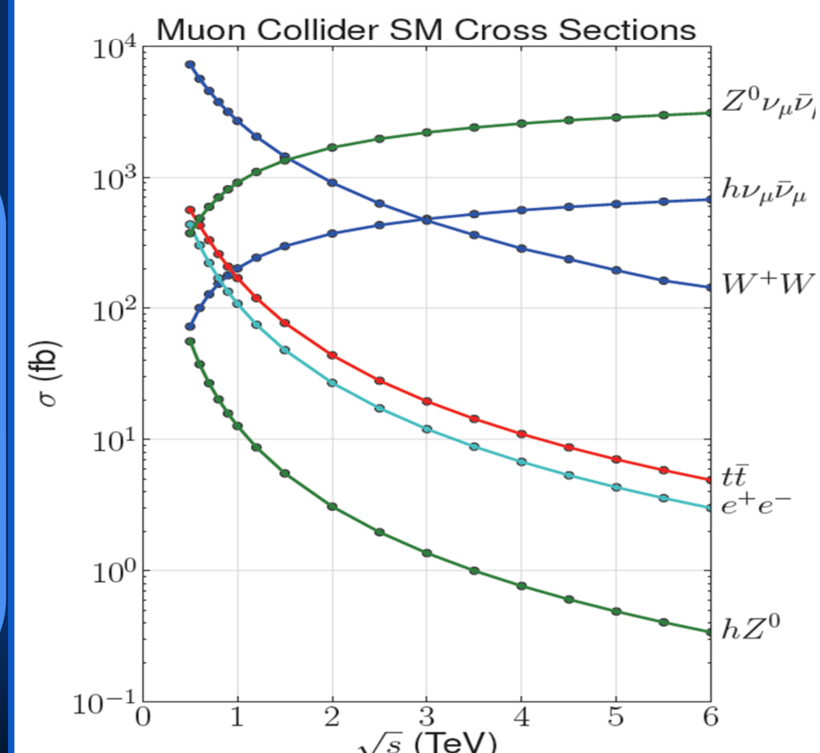
$$\sigma(s) = C \ln\left(\frac{s}{M_X^2}\right) + \ldots$$

A 10 TeV $\mu^+\mu$□ collider ⇨ comparable EW discovery potential to a 70 TeV pp collider

An Electroweak Boson Collider

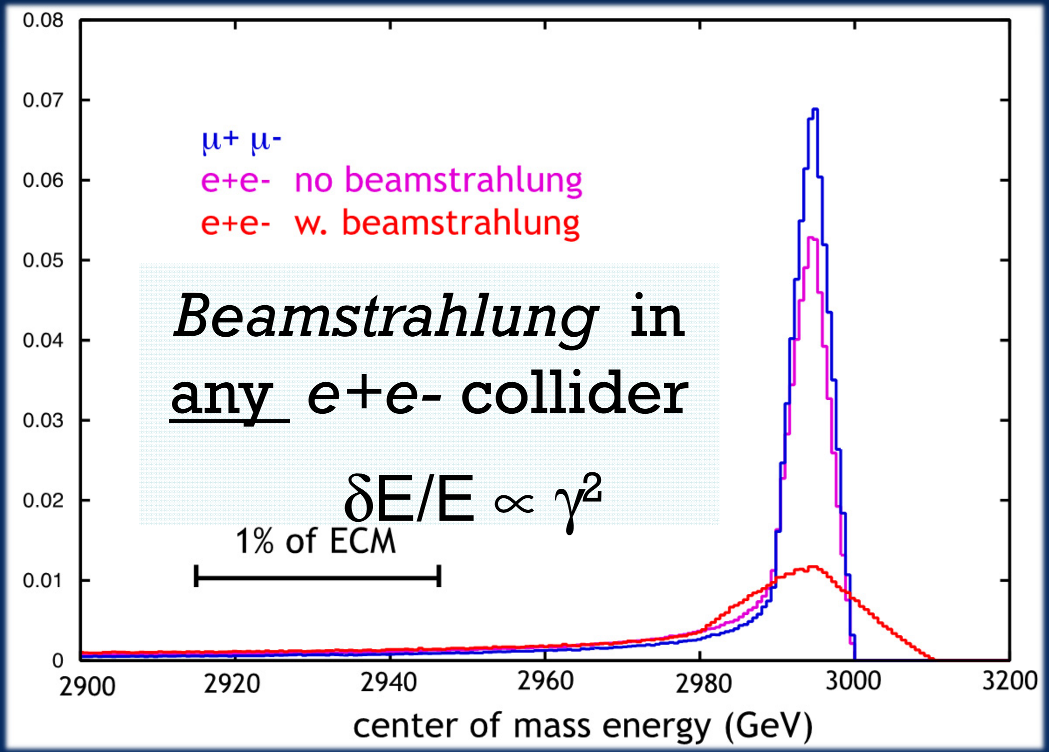






Muon Colliders

- The designs that we are working towards offer:
  - Center of Mass Energies from 125 GeV to ~10 TeV (no SR)
  - Luminosities in excess of $10^{34} cm^{-2} s^{-1}$ at TeV energies
  - Negligible beamstrahlung effects
  - Exquisite energy resolution
    - $\delta E/E \sim 3\text{-}4 \cdot 10^{-5}$ @ E_{beam} = 63 GeV
    - $\delta E/E \sim 1 \cdot 10^{-3}$ @ $E_{beam} \geq$ 1 TeV
    - Measure with g-2 technique
  - Compact footprint with the possibility for multiple IRs
    - Higgs Factory Circumference: ~300m
    - 6 TeV Collider Circumference: ~6km

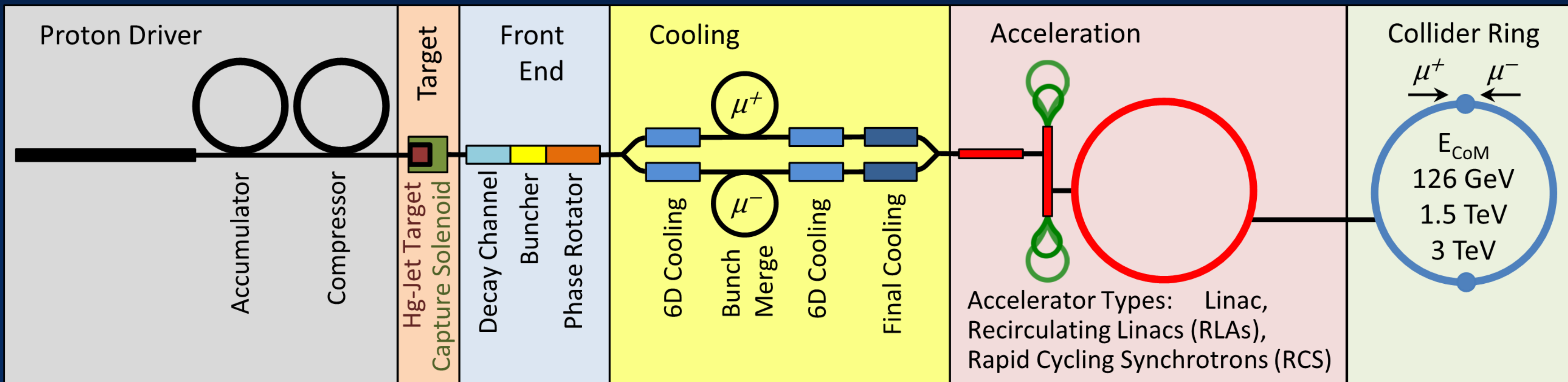


- But…
  - High intensity beams require tertiary production: $p \rightarrow \pi \rightarrow \mu$
  - Muons decay
    - Beams must be manipulated rapidly
    - Decay backgrounds in a collider impact both ring and detector design
  - Large initial emittance ⇨ cooling *(only ionization cooling is fast enough)*

THE MUON COLLIDER CONCEPT

Muon Collider Concept

Muon Collider Block Diagram



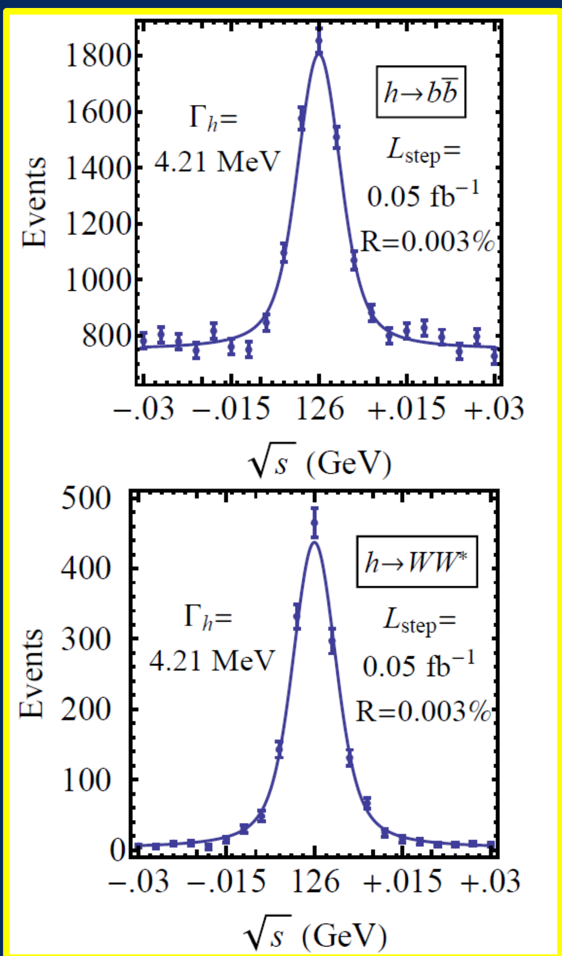
Proton source:
For example PROJECT X at 4 MW, with 2±1 ns long bunches

Goal:
Produce a high intensity μ beam whose 6D phase space is reduced by a factor of ~10^6 from its value at the production target

Collider: $\sqrt{s}$ = 3 TeV
Circumference 4.5km
$L = 3\times10^{34}$ cm^{-2}s^{-1}
μ/bunch = 2×10^{12}
$\sigma(p)/p$ = 0.1%
$\varepsilon_{\perp N}$ = 25 μm, $\varepsilon_{//N}$=72 mm
β^* = 5mm
Rep. Rate = 12 Hz

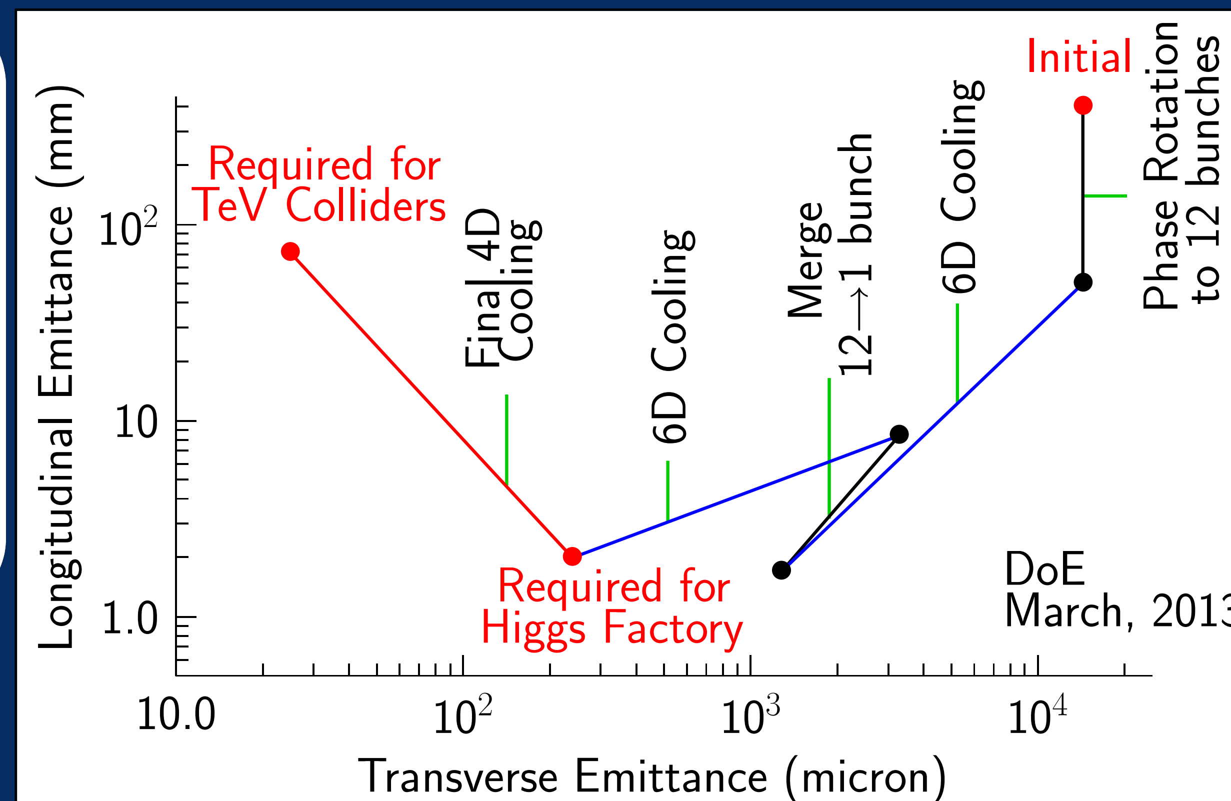
126 GeV Higgs Factory

s-channel coupling of Muons to HIGGS with high cross sections:
Muon Collider with L = 10^{32} cm^{-2}s^{-1} @ 63 GeV/beam (>15,000 Higgs/year)
Competitive with e+/e- Linear Collider with L = 2 × 10^{34} cm^{-2}s^{-1} @ 126 GeV/beam
Sharp resonance: momentum spread of a few × 10^{-5}



Precision energy measurement provided by g-2 effect and residual polarization in muon beams

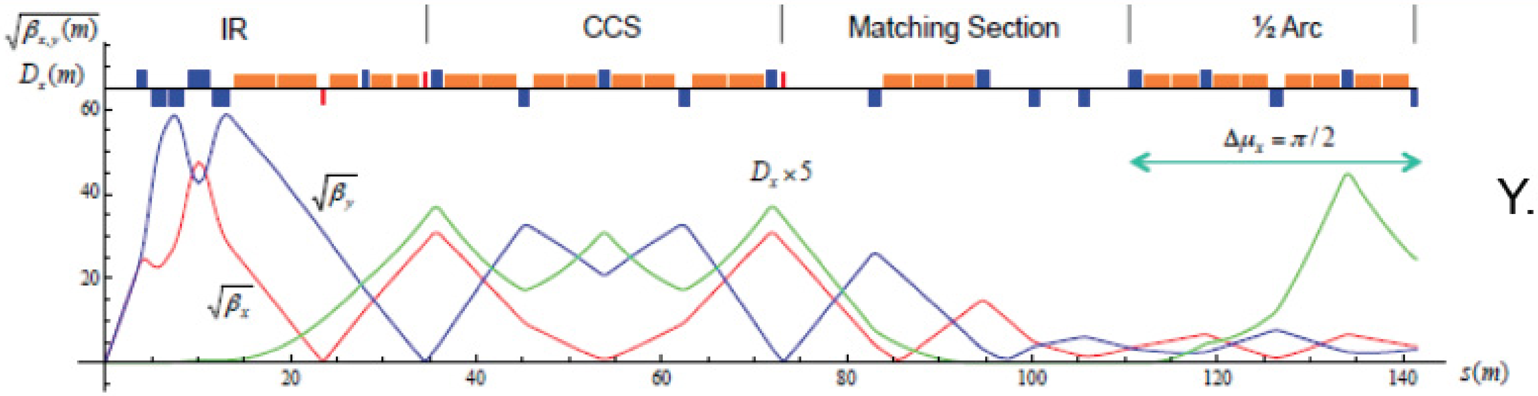
Han and Liu
hep-ph 1210.7803



Reduced cooling:
$\varepsilon_{\perp N}$ =0.3π·mm·rad,
$\varepsilon_{||N}$ =1π·mm·rad

Major advantage for Physics of a $\mu^+\mu^-$ Higgs Factory: possibility of direct measurement of the Higgs boson width (Γ~4MeV FWHM expected)

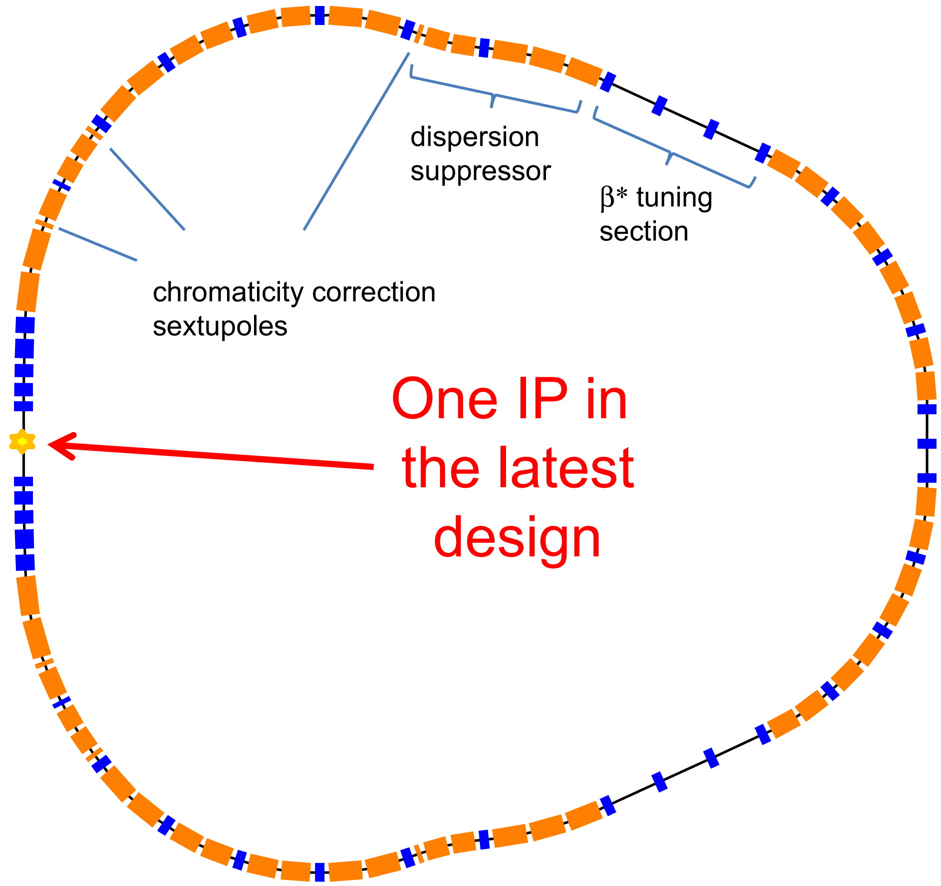
Updated 63 x 63 GeV Lattice



Y. Alexahin

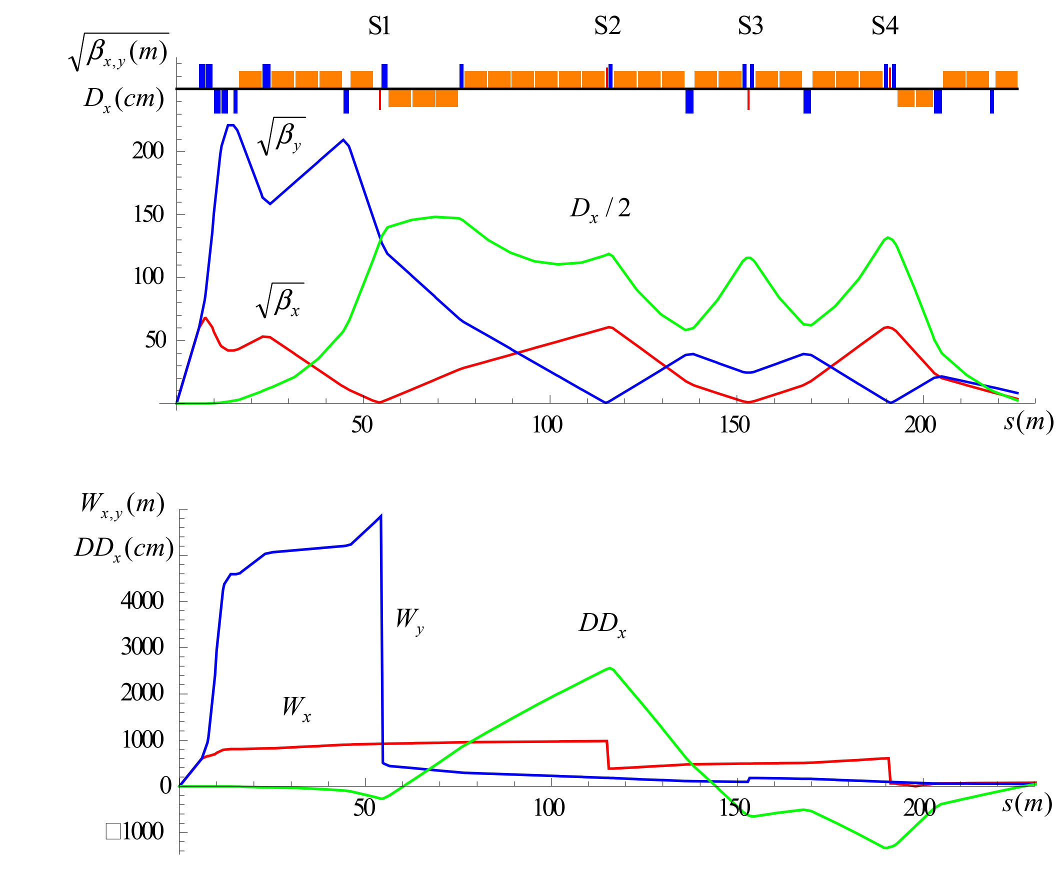
Optics functions in half ring for β*=2.5cm

Parameter			
Beam energy	GeV	63	63
Average luminosity	10^{31}/cm²/s	1.7	8.0
Collision energy spread	MeV	3	4
Circumference, C	m	300	300
Number of IPs	-	1	1
β*	cm	3.3	1.7
Number of muons / bunch	10^{12}	2	4
Number of bunches / beam	-	1	1
Beam energy spread	%	0.003	0.004
Normalized emittance, $\varepsilon_{\perp N}$	π·mm·rad	0.4	0.2
Longitudinal emittance, $\varepsilon_{\parallel N}$	π·mm	1.0	1.5
Bunch length, σ_s	cm	5.6	6.3
Beam size at IP, r.m.s.	mm	0.15	0.075
Beam size in IR quads, r.m.s.	cm	4	4
Beam-beam parameter	-	0.005	0.02
Repetition rate	Hz	30	15
Proton driver power	MW	4	4



Multi-TeV Collider – 1.5 TeV Baseline

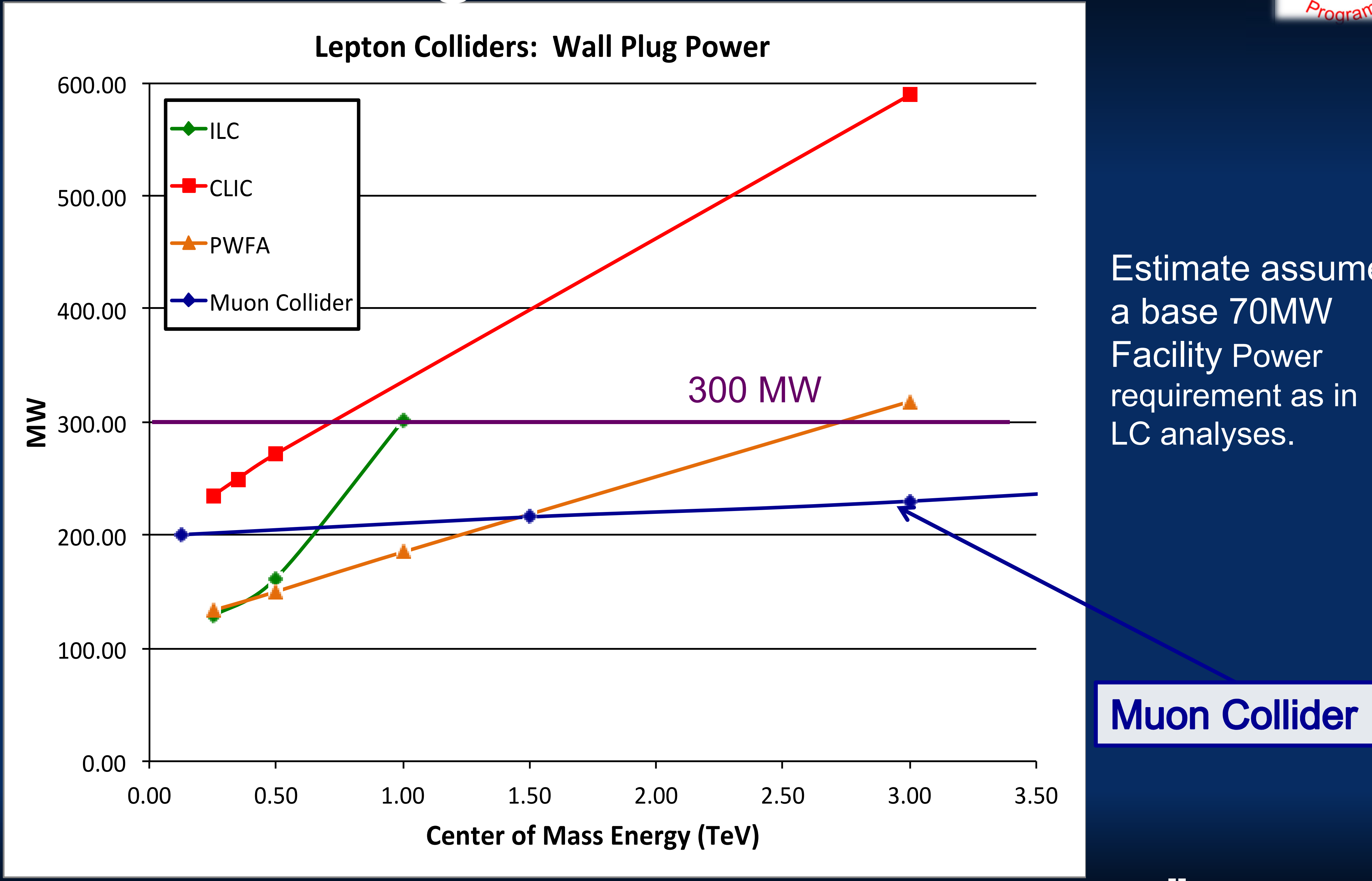
Y. Alexahin



Larger chromatic function (Wy) is corrected first with a single sextupole S1, Wx is corrected with two sextupoles S2, S4 separated by 180° phase advance.

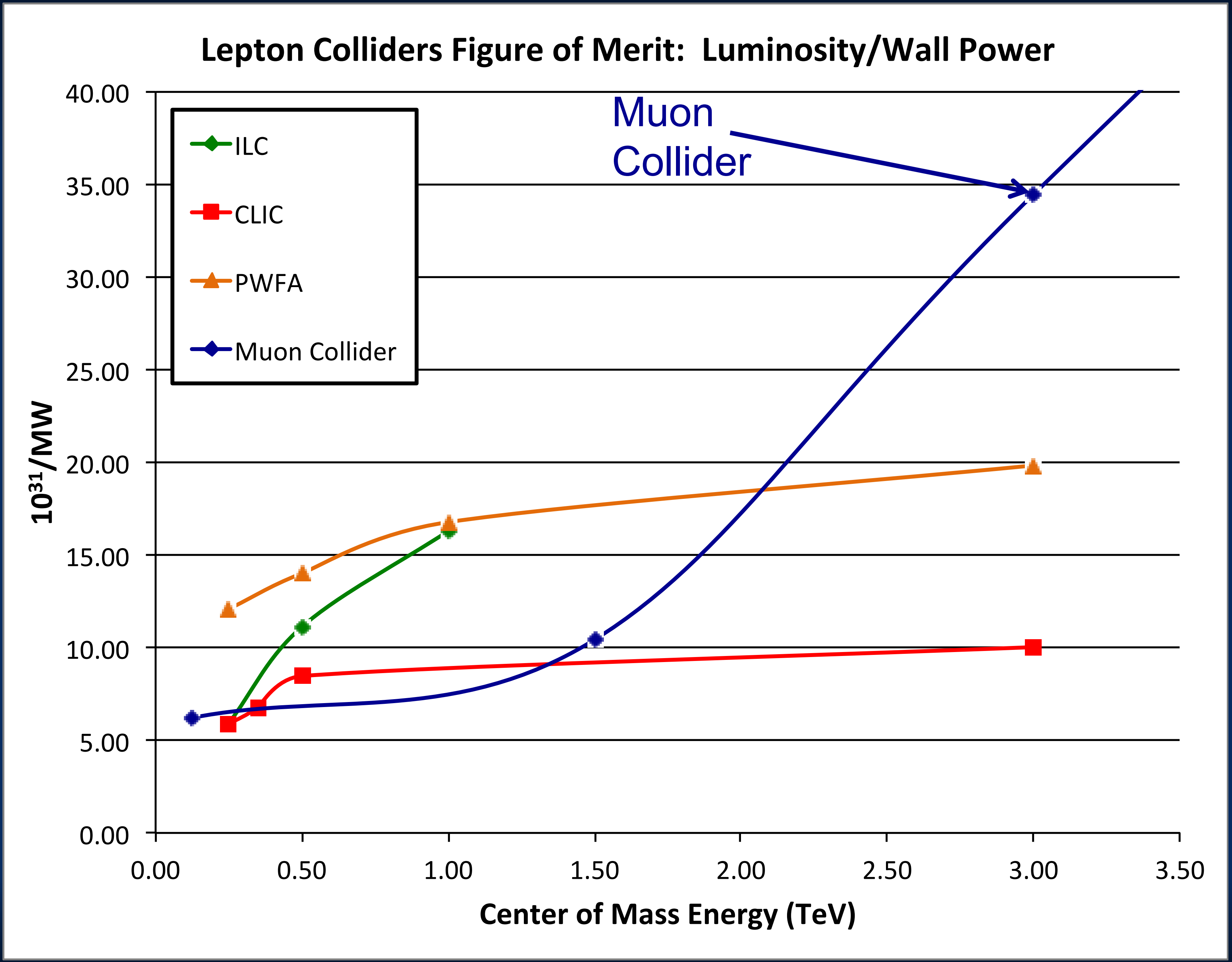
Parameter	Unit	Value
Beam energy	TeV	0.75
Repetition rate	Hz	15
Average luminosity / IP	10^{34}/cm^2/s	1.1
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.73
β^*	cm	1 (0.5-2)
Momentum compaction, α_p	10^{-5}	-1.3
Normalized r.m.s. emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread, σ_p/p	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Number of bunches / beam	-	1
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16

Wall Plug Power Estimates



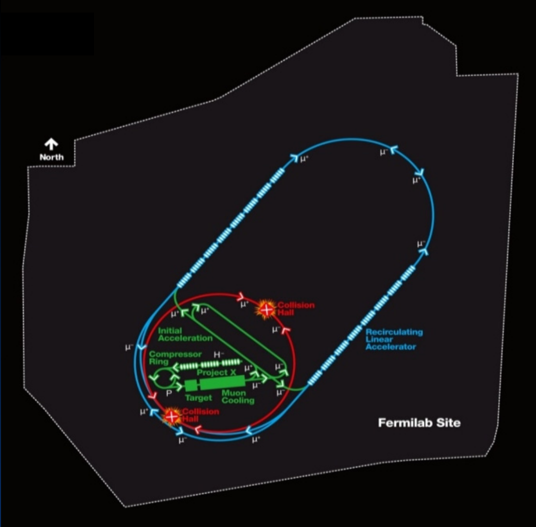
Estimate assumes a base 70MW Facility Power requirement as in LC analyses.

Luminosity Production Metric



Luminosity Metric:

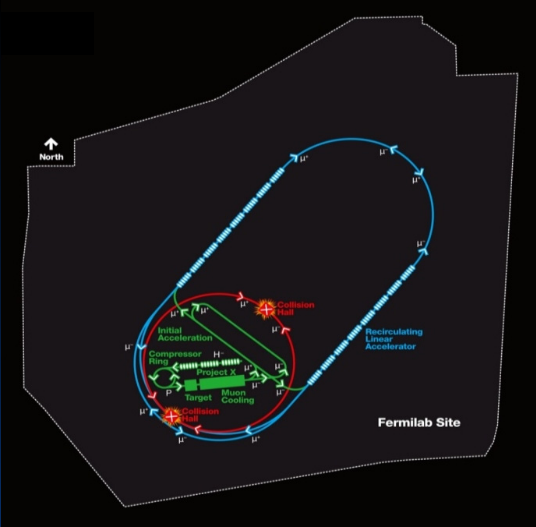
$N_{det} \times L_{avg} / P_{tot}$



Muon Collider Parameters

Muon Collider Parameters								
		Higgs Factory		**Top Threshold Options**		**Multi-TeV Baselines**		
Parameter	***Units***	*Startup Operation*	*Production Operation*	*High Resolution*	*High Luminosity*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	0.126	0.126	0.35	0.35	1.5	3.0	6.0
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	0.0017	0.008	0.07	0.6	1.25	4.4	12
Beam Energy Spread	%	0.003	0.004	0.01	0.1	0.1	0.1	0.1
Higgs* or Top^{+} Production/10^{7}sec		3,500*	13,500*	7,000^{+}	60,000^{+}	37,500*	200,000*	820,000*
Circumference	km	0.3	0.3	0.7	0.7	2.5	4.5	6
No. of IPs		1	1	1	1	2	2	2
Repetition Rate	Hz	30	15	15	15	15	12	6
β*	cm	3.3	1.7	1.5	0.5	1 (0.5-2)	0.5 (0.3-3)	2.5
No. muons/bunch	10^{12}	2	4	4	3	2	2	2
No. bunches/beam		1	1	1	1	1	1	1
Norm. Trans. Emittance, ε_{TN}	π mm-rad	0.4	0.2	0.2	0.05	0.025	0.025	0.025
Norm. Long. Emittance, ε_{LN}	π mm-rad	1	1.5	1.5	10	70	70	70
Bunch Length, σ_s	cm	5.6	6.3	0.9	0.5	1	0.5	2
Proton Driver Power	MW	4$^{\#}$	4	4	4	4	4	1.6

Could begin operation with Project X Stage II beam



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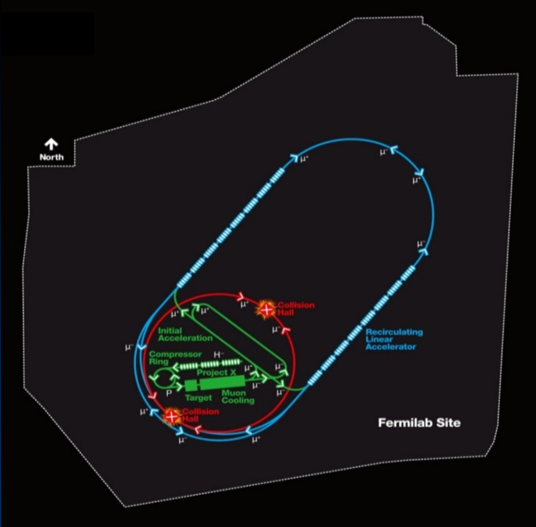
Could begin operation with Project X Stage II beam

Exquisite Energy Resolution Allows Direct Measurement of Higgs Width



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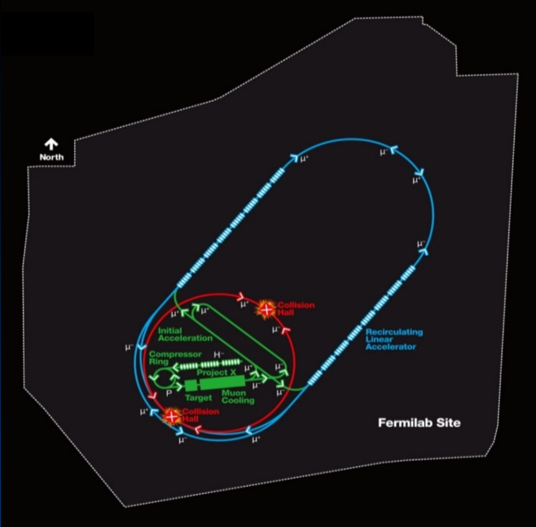

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Could begin operation with Project X Stage II beam

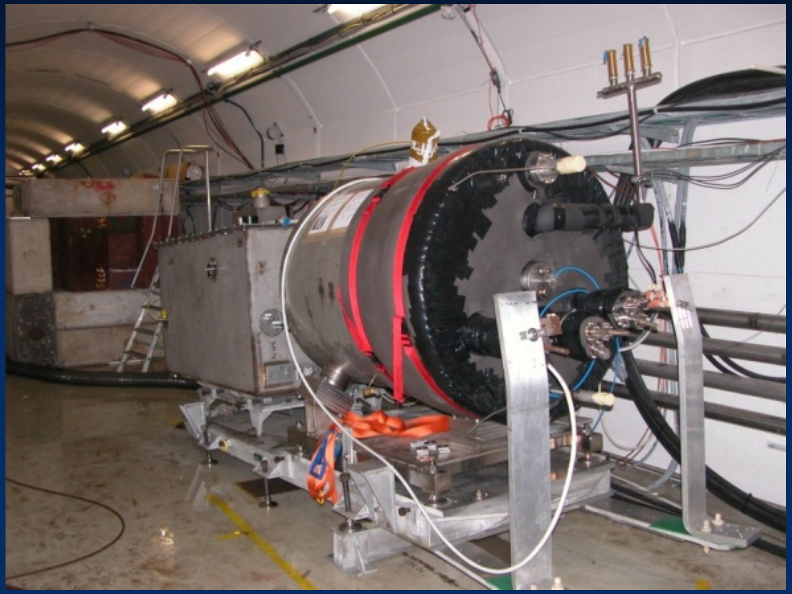
Success of advanced cooling concepts ⇨ several ⇙ 10^{32}

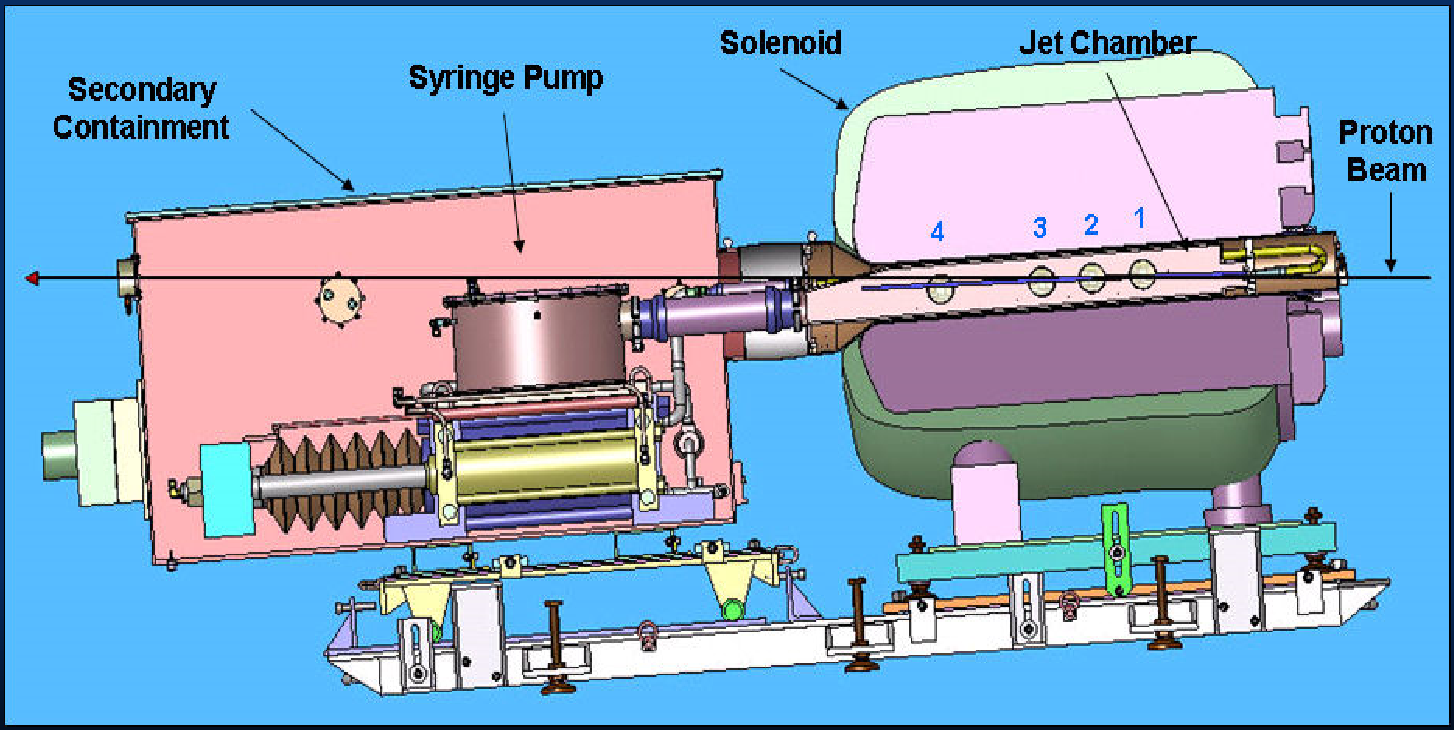
Site Radiation mitigation with depth and lattice design: ≤ 10 TeV

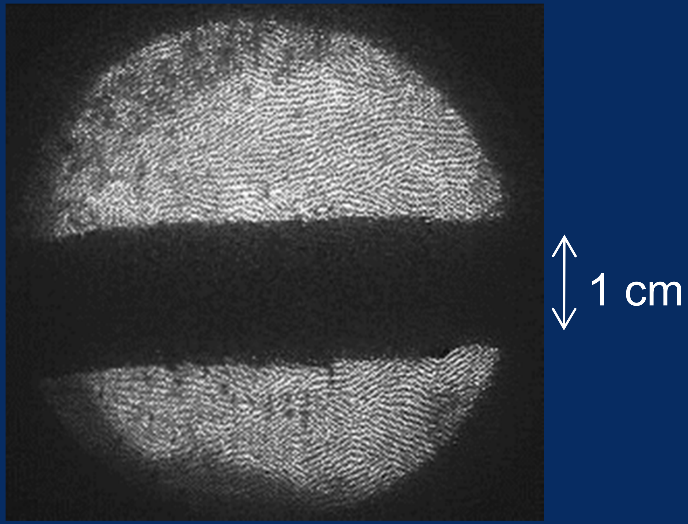
THE R&D CHALLENGES AND THE MAP FEASIBILITY ASSESSMENT

Key Technologies - Target

- The MERIT Experiment at the CERN PS
  - Demonstrated a 20m/s liquid Hg jet injected into a 15 T solenoid and hit with a 115 KJ/pulse beam!
    - ⇨ Jets could operate with beam powers up to **8 MW** with a repetition rate of 70 Hz
- MAP staging aimed at initial 1 MW target







Hg jet in a 15 T solenoid with measured disruption length ~ 28 cm

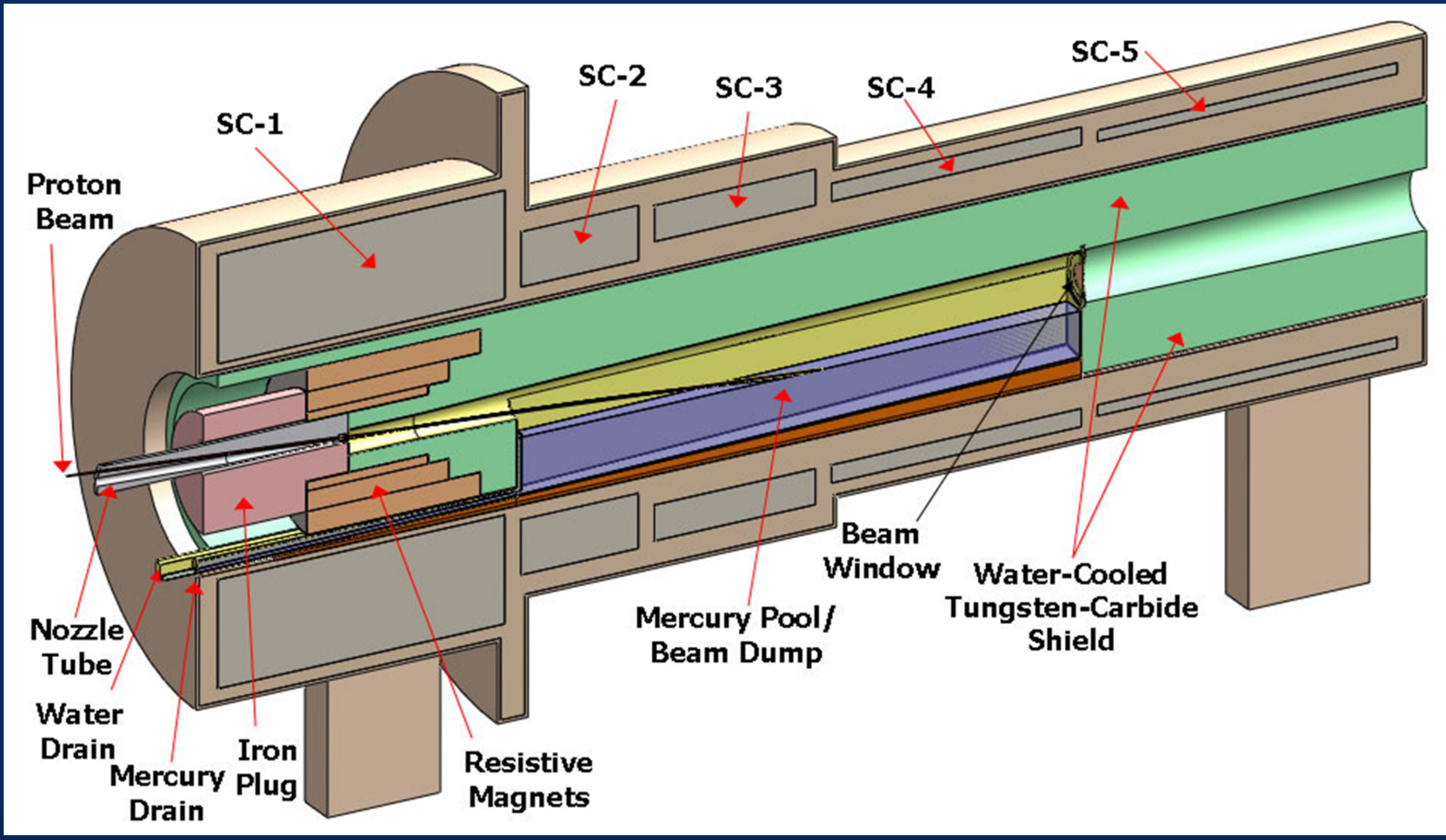
Technology Challenges – Capture Solenoid

- A Neutrino Factory and/or Muon Collider Facility requires challenging magnet design in several areas:
  – Target Capture Solenoid (15-20T with large aperture)

E_{stored} ~ 3 GJ

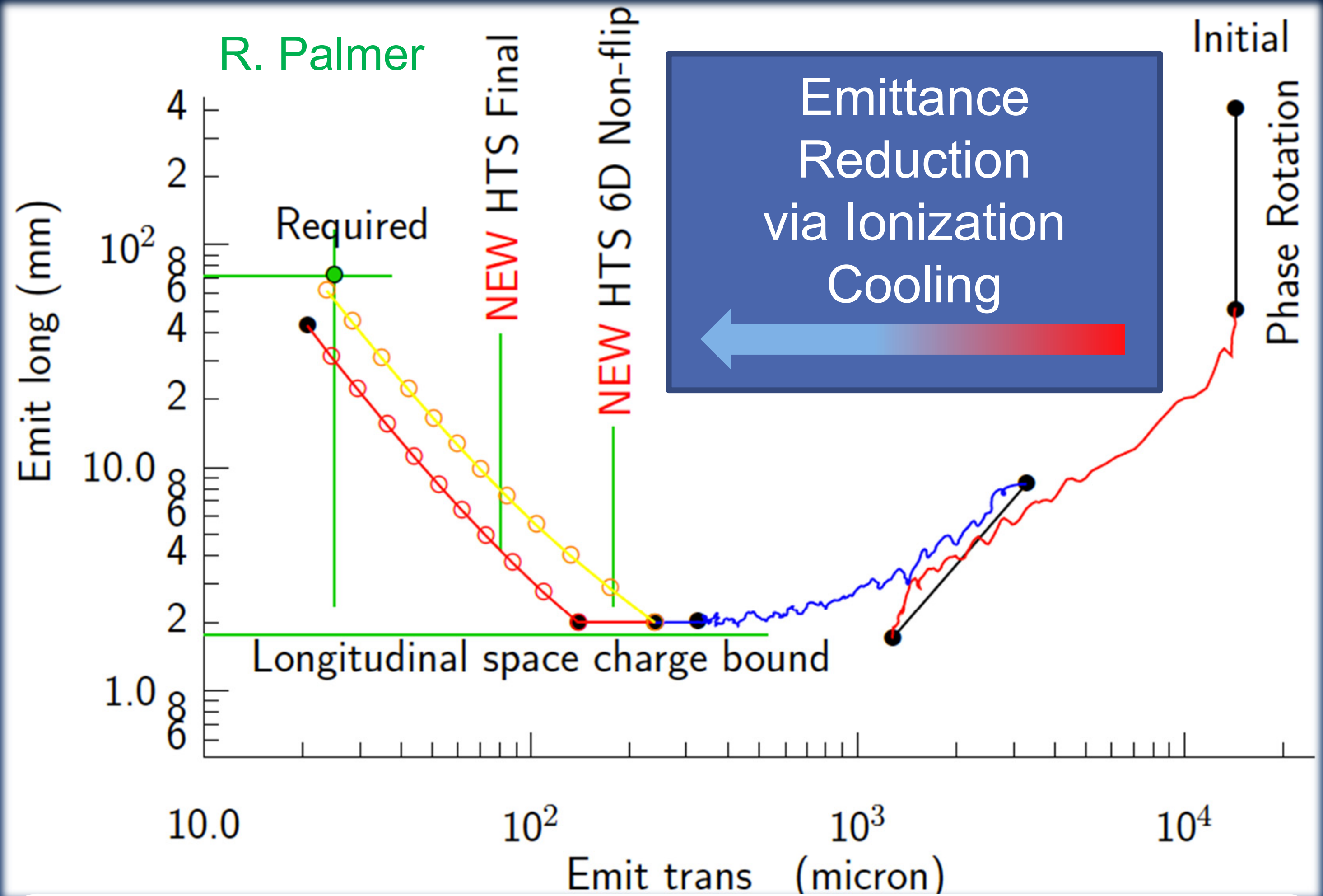
O(10MW) resistive coil in high radiation environment

Possible application for High Temperature Superconducting magnet technology



Technology Challenges - Cooling

Development of a cooling channel design to reduce the 6D phase space by a factor of O(10^6) → MC luminosity of O(10^{34}) cm^{-2} s^{-1}

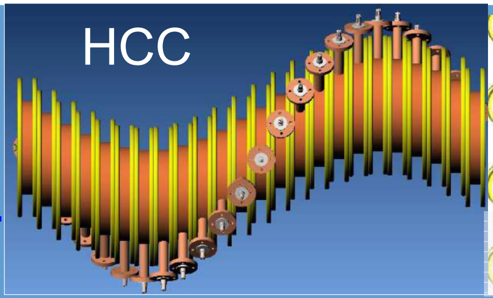


- Some components beyond state-of-art:
  - Very high field HTS solenoids (≥30 T)
  - High gradient RF cavities operating in multi-Tesla fields

The program targets critical magnet and cooling cell technology demonstrations within its feasibility phase.

Cooling Channel Concepts:

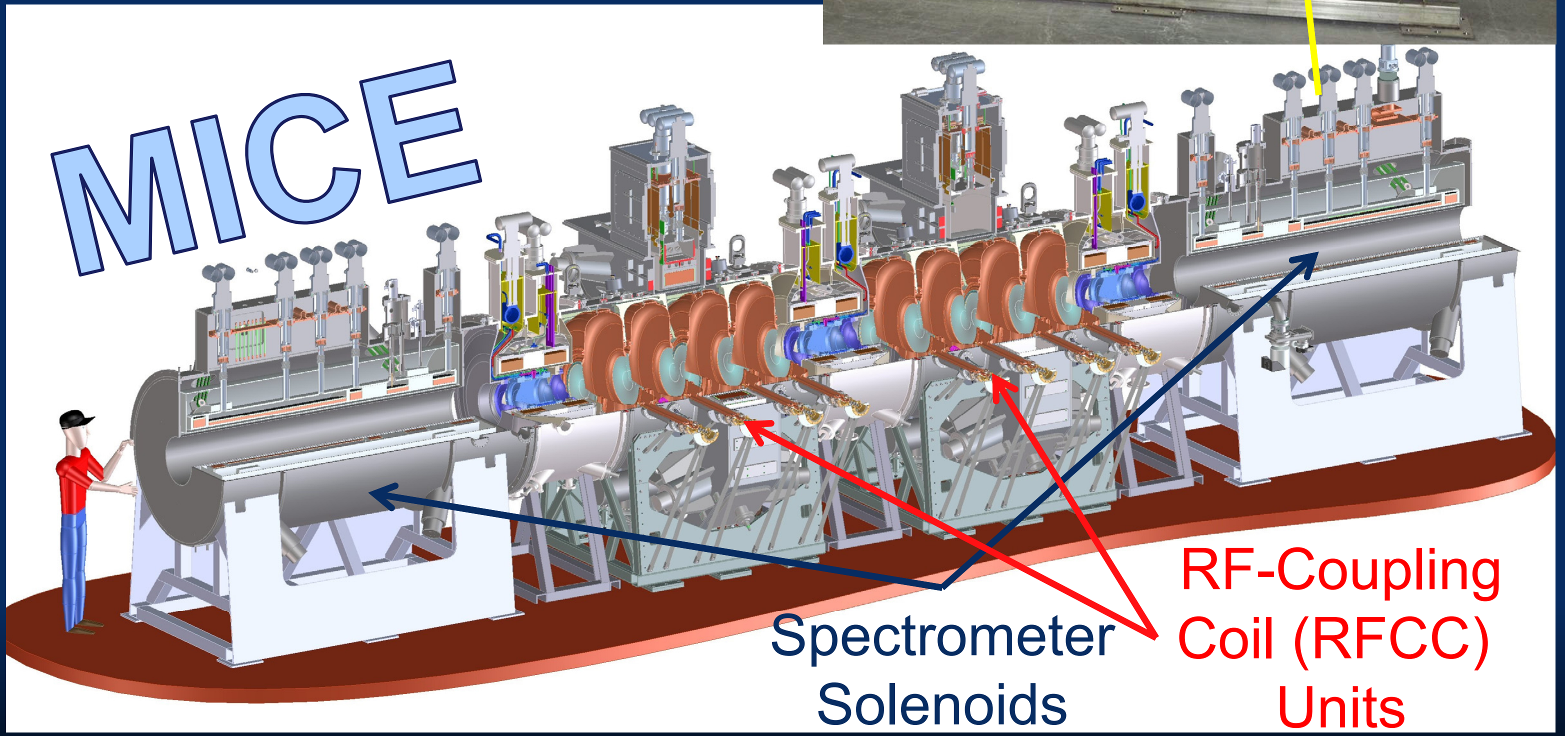
HPRF & Vacuum RF



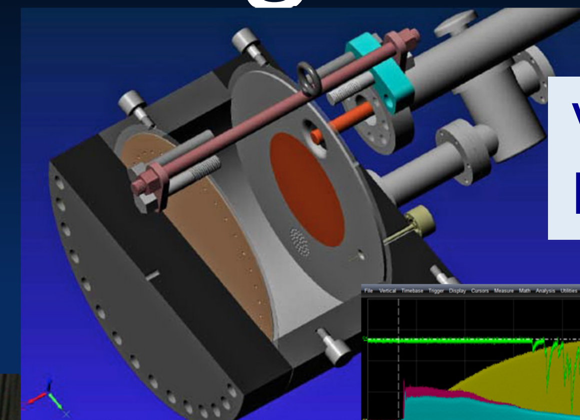
Technology Challenges - Cooling

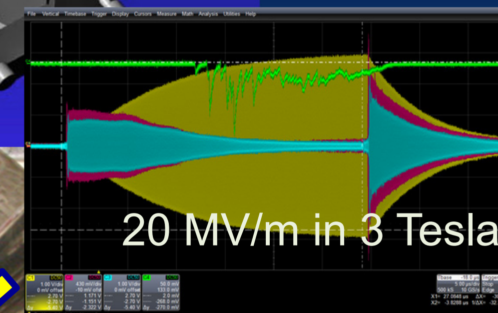
- Tertiary production of muon beams
  - Initial beam emittance intrinsically large
  - Cooling mechanism required, but no radiation damping
- Muon Cooling ⇨ Ionization Cooling
  - dE/dx energy loss in materials
  - RF to replace p_{long}

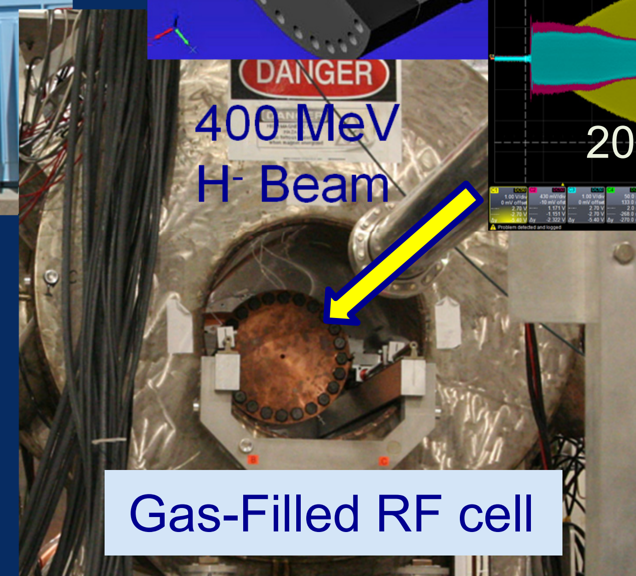
The Muon Ionization Cooling Experiment: Demonstrate the method and validate our simulations

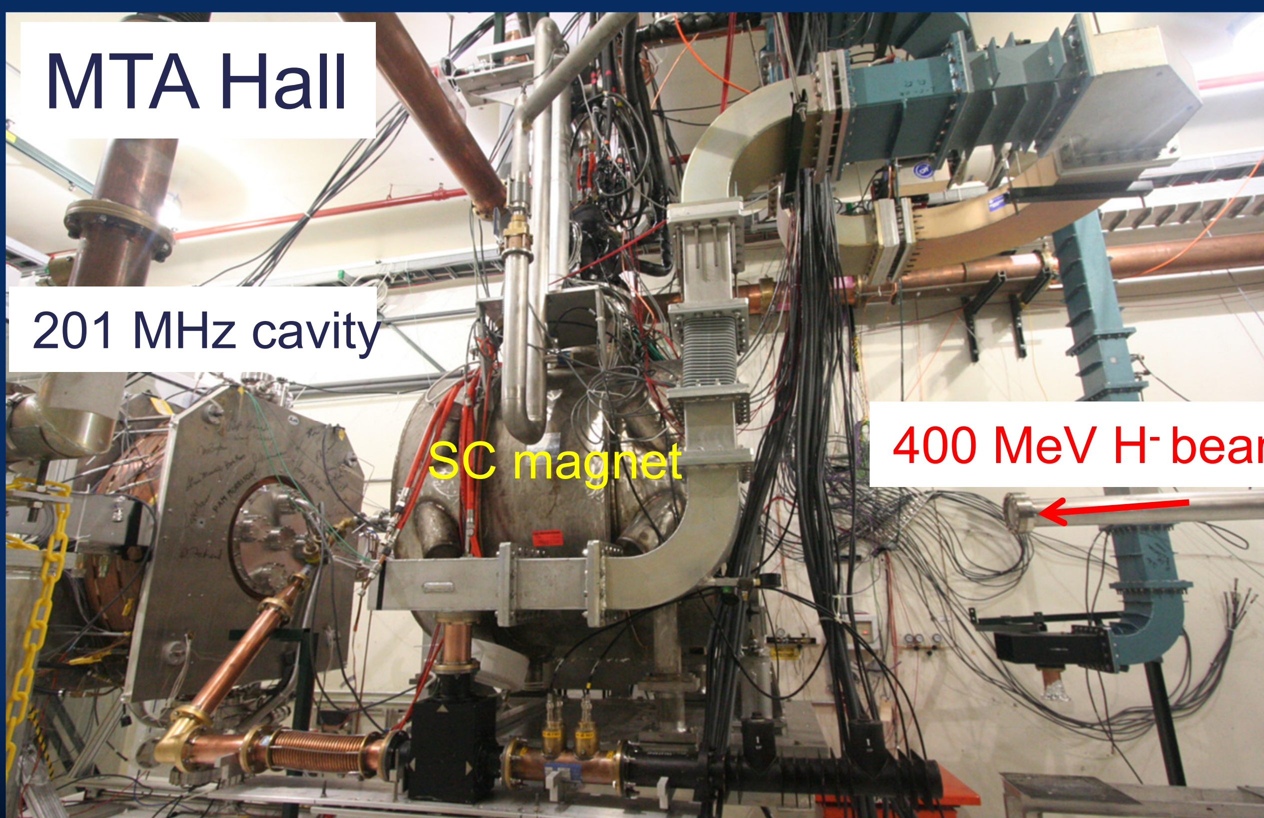


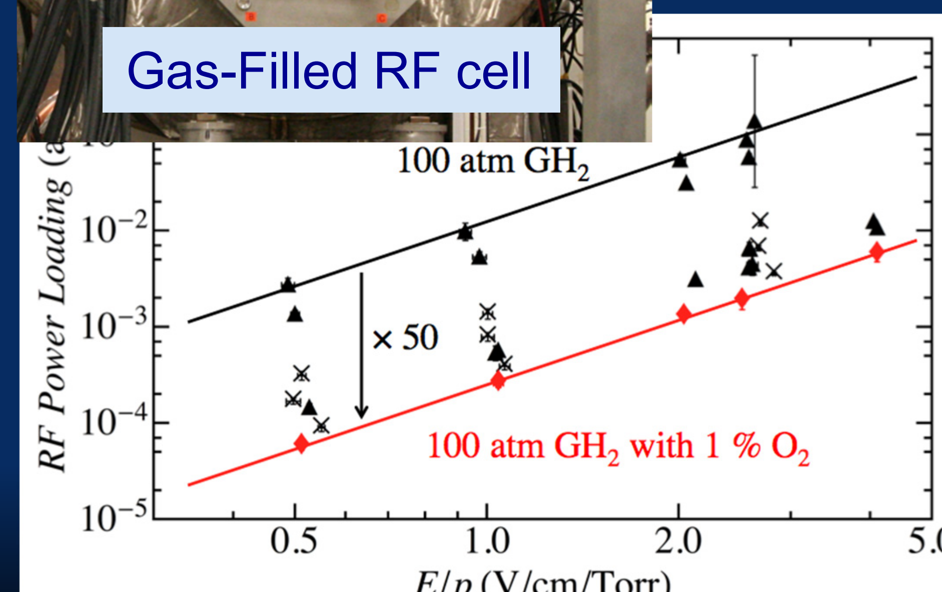
Elements of the R&D Program



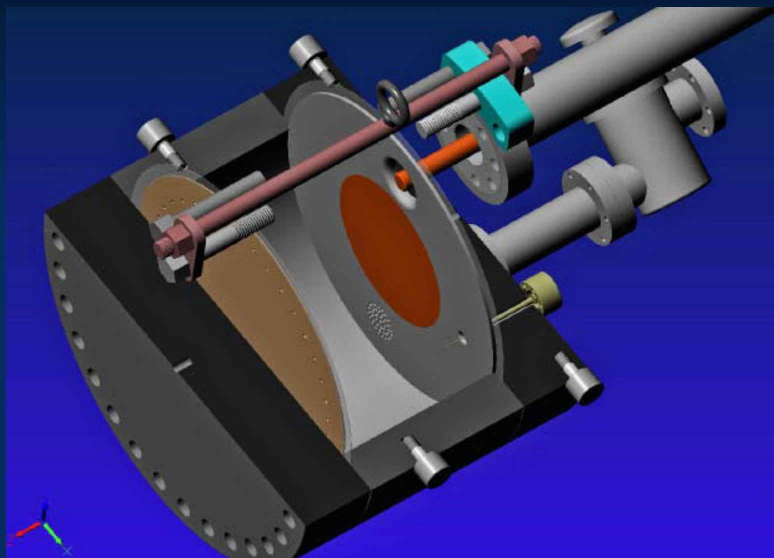






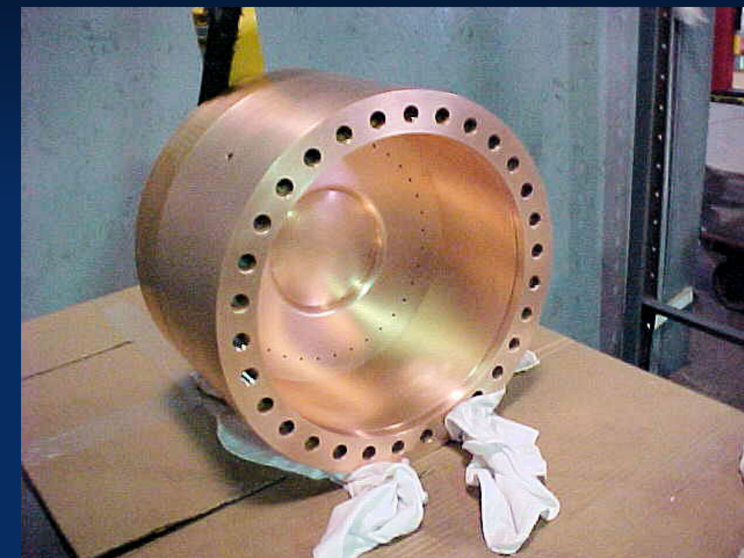


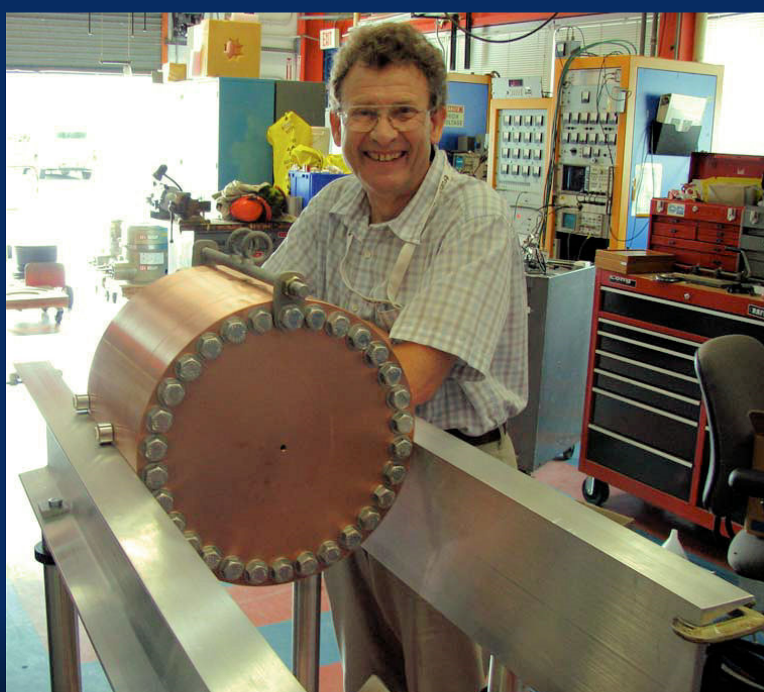
Recent Progress – Vacuum RF



All-Seasons Cavity

(designed for both vacuum and high pressure operation)

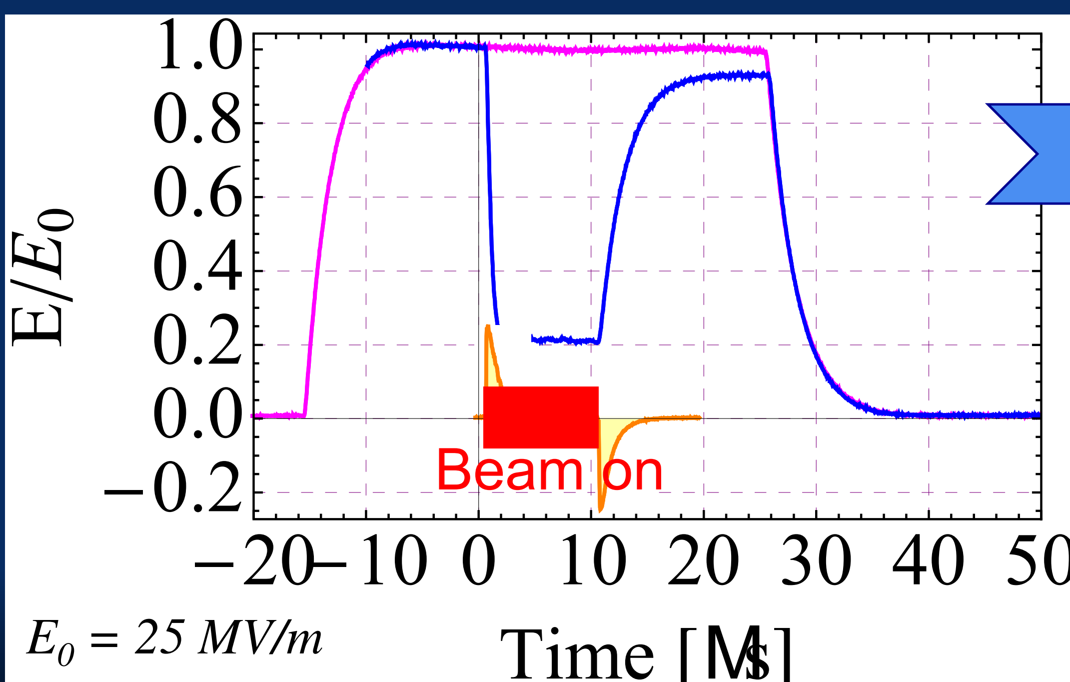




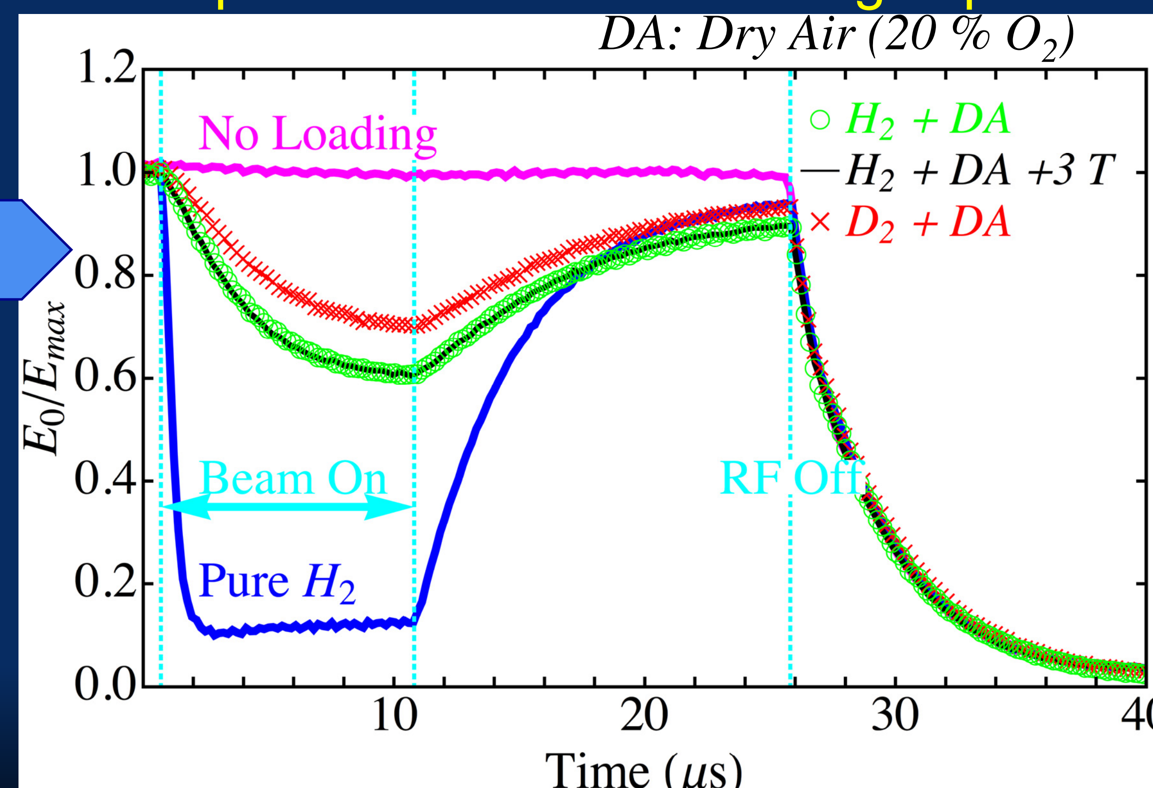
- Vacuum Tests at B = 0 T & B = 3 T in excess of 20 MV/m
- Initial studies demonstrated possibility of successful operation of vacuum cavities in magnetic fields with careful design
- *Also progress on alternative cavity materials*
- *NEXT: A new vacuum cavity design (optimized to reduce surface fields and multipacting in cavity and coupler) will be tested in 2014*

Recent Progress - High Pressure RF

- Gas-filled cavity
  - Can moderate dark current and breakdown currents in magnetic fields
  - Can contribute to cooling
  - Is loaded, however, by beam-induced plasma
- Electronegative Species
  - Dope primary gas
  - Can moderate the loading effects of beam-induced plasma by scavenging the relatively mobile electrons

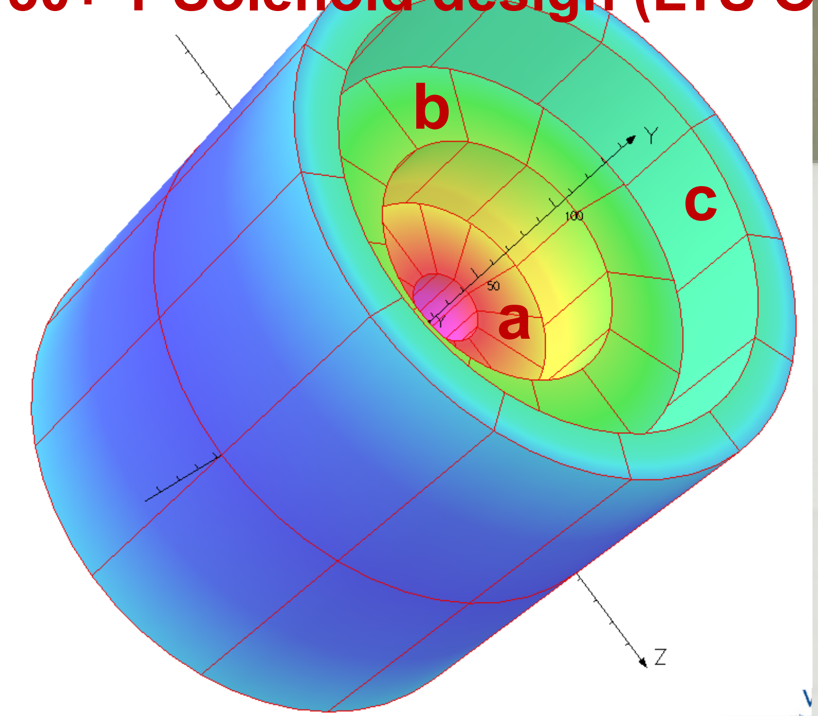


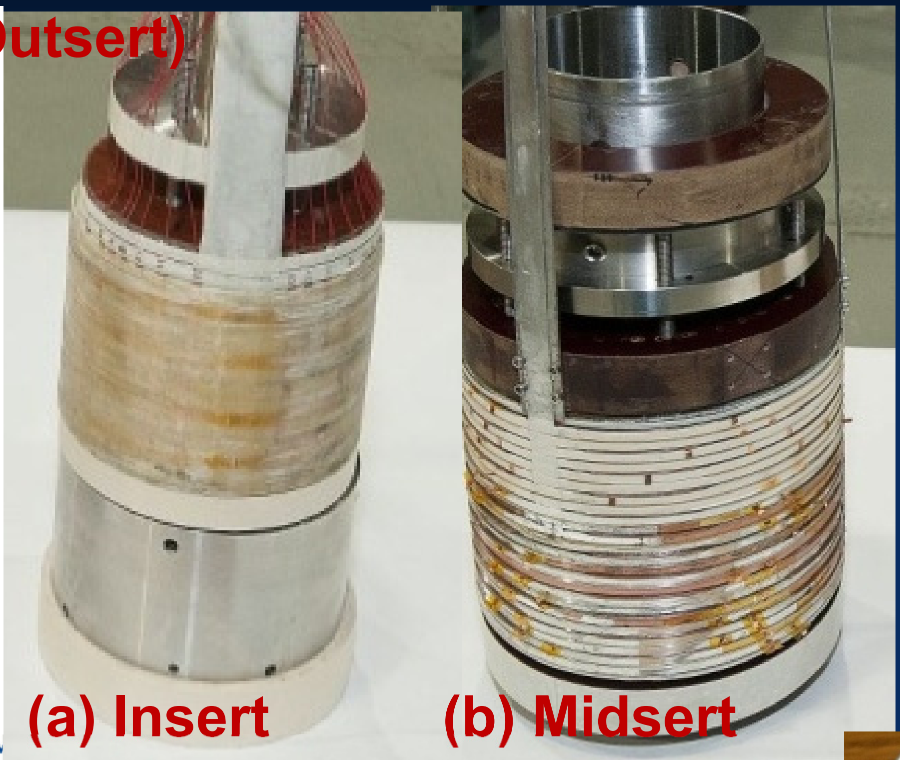
RF amplitude w/ beam-induced gas plasma



High Field Magnet R&D

30+ T Solenoid design (LTS Outsert)





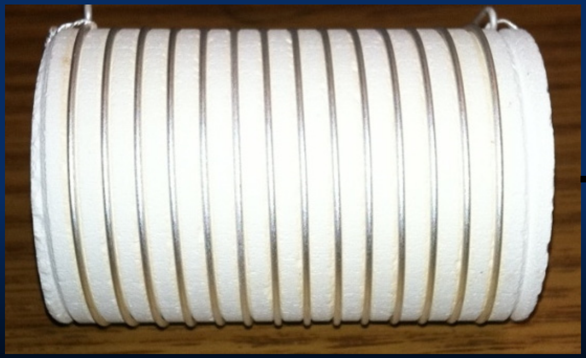
Final Stage Cooling Solenoid

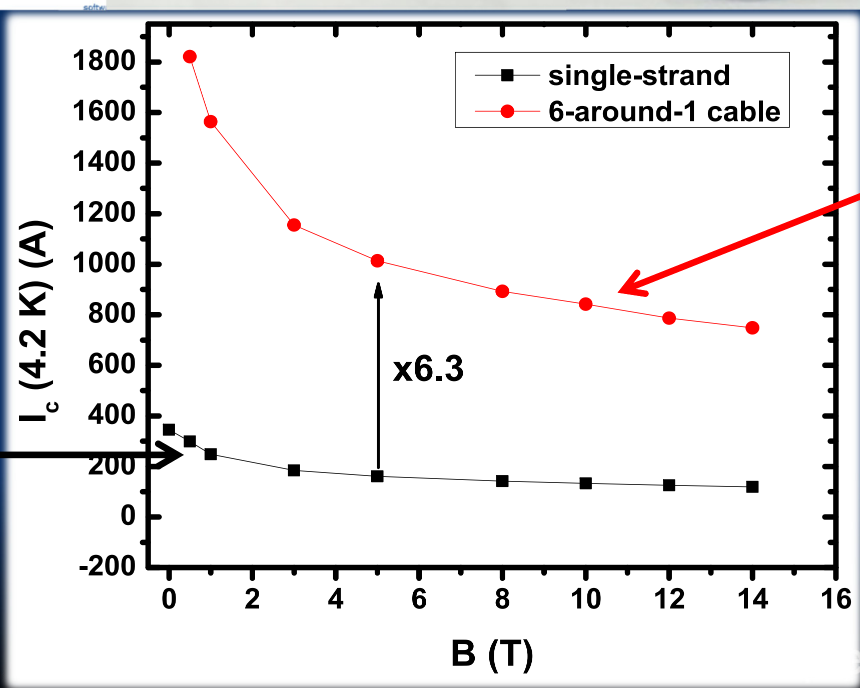
Demonstrated 15+ T (16+ T on coil)

- ~25 mm insert HTS solenoid
- BNL/PBL YBCO Design
- Highest field ever in HTS-only solenoid (by a factor of ~1.5)

BSCCO-2212 -

- New cable fabrication methods with demonstrated J_E
- Hyperbaric processing to avoid strand damage

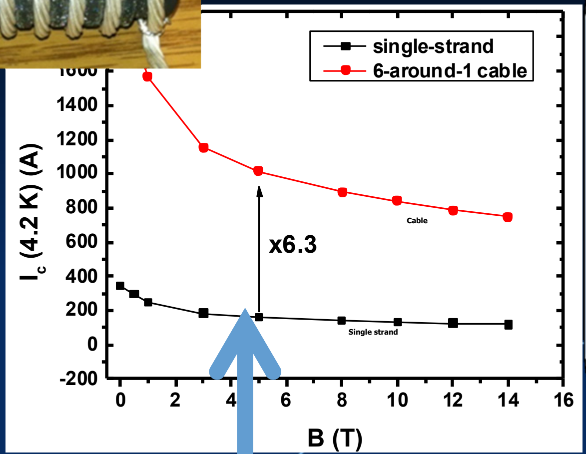




Multi-strand cable utilizing chemically compatible alloy and oxide layer to minimize cracks

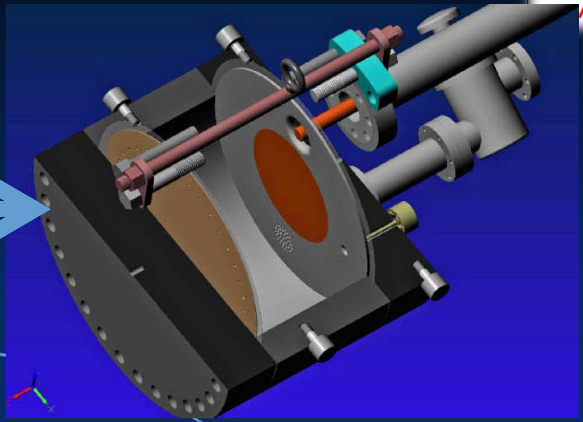
Fermilab

Cooling Channel R&D Effort



Successful Operation of 805 MHz "All Seasons" Cavity in 3T Magnetic Field under Vacuum

MuCool Test Area/Muons Inc



Breakthrough in HTS Cable Performance with Cables Matching Strand Performance

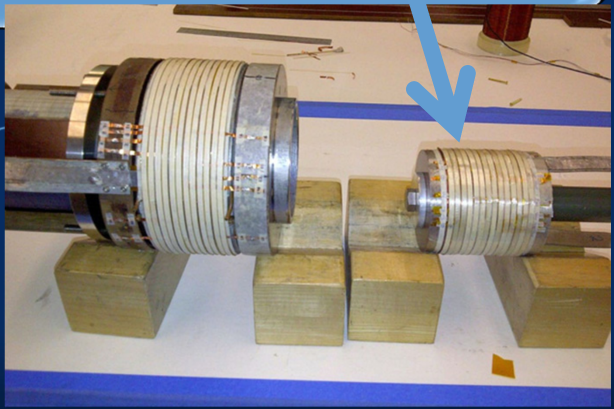
FNAL-Tech Div
T. Shen-Early Career Award

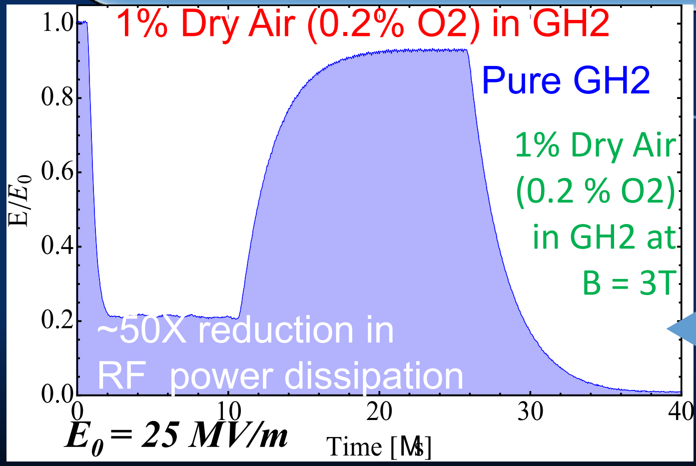
The Path to a Viable Muon Ionization Cooling Channel

World Record HTS-only Coil

15T on-axis field
16T on coil

PBL/BNL





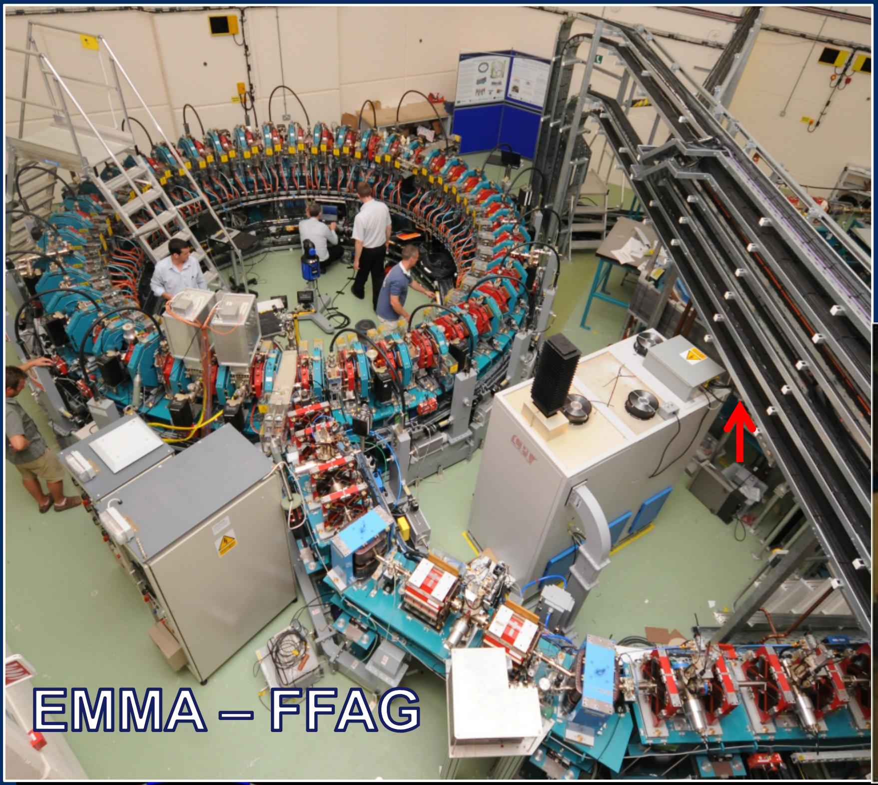
Demonstration of High Pressure RF Cavity in 3T Magnetic Field with Beam

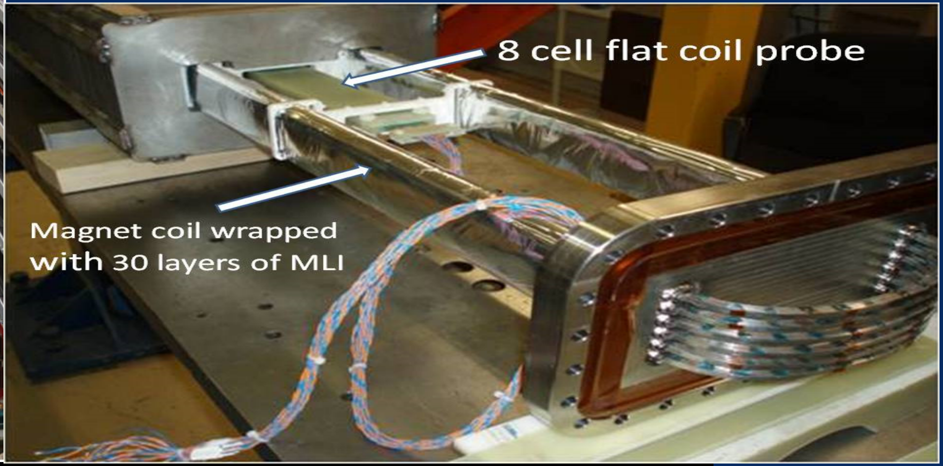
Extrapolates to μ-Collider Parameters

MuCool Test Area

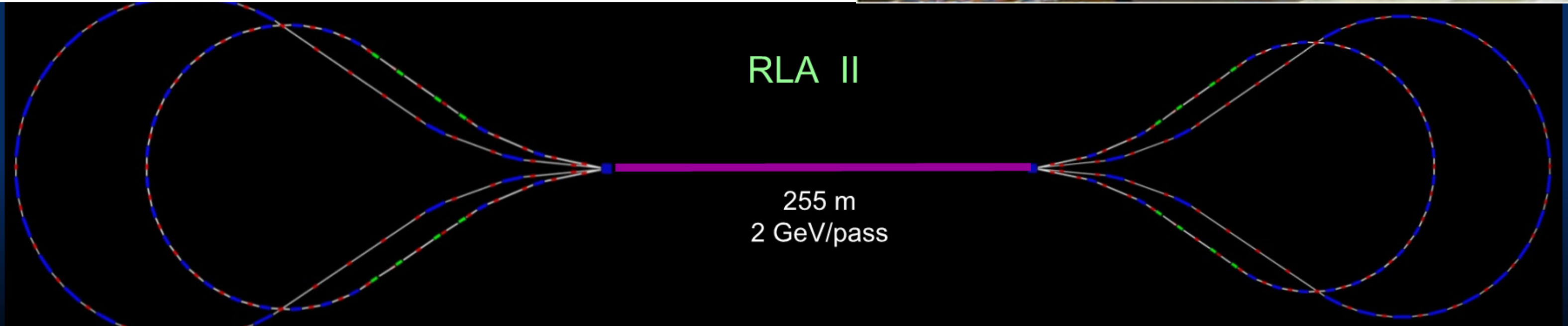
Technology Challenges - Acceleration

- Muons require an ultrafast accelerator chain
  - ⇨ *Beyond the capability of most machines*
- Solutions include:
  - Superconducting Linacs
  - Recirculating Linear Accelerators (RLAs)
  - Fixed-Field Alternating-Gradient (FFAG) Machines
  - Rapid Cycling Synchrotrons (RCS)





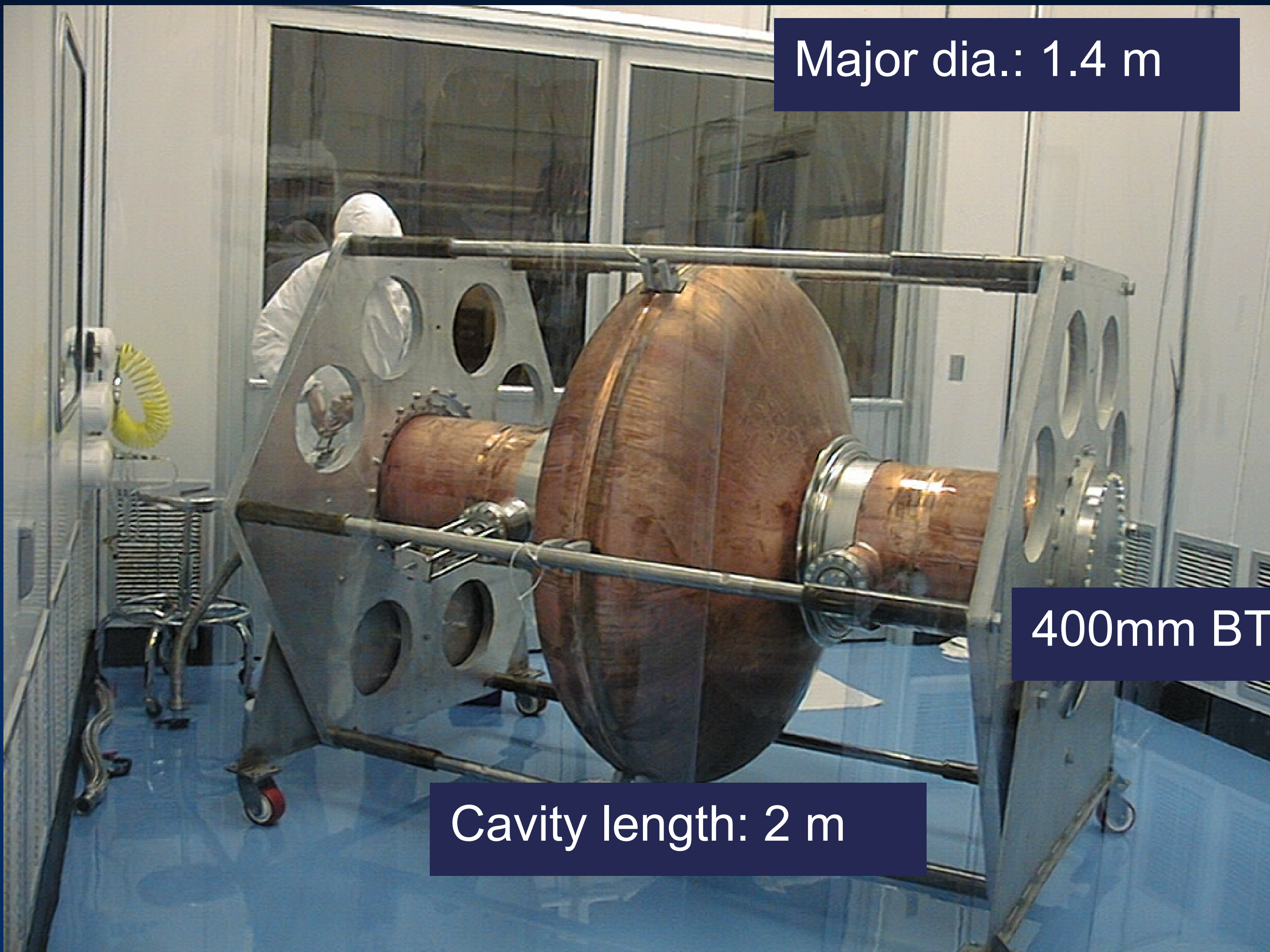
RCS requires 2 T p-p magnets at f = 400 Hz (U Miss & FNAL)

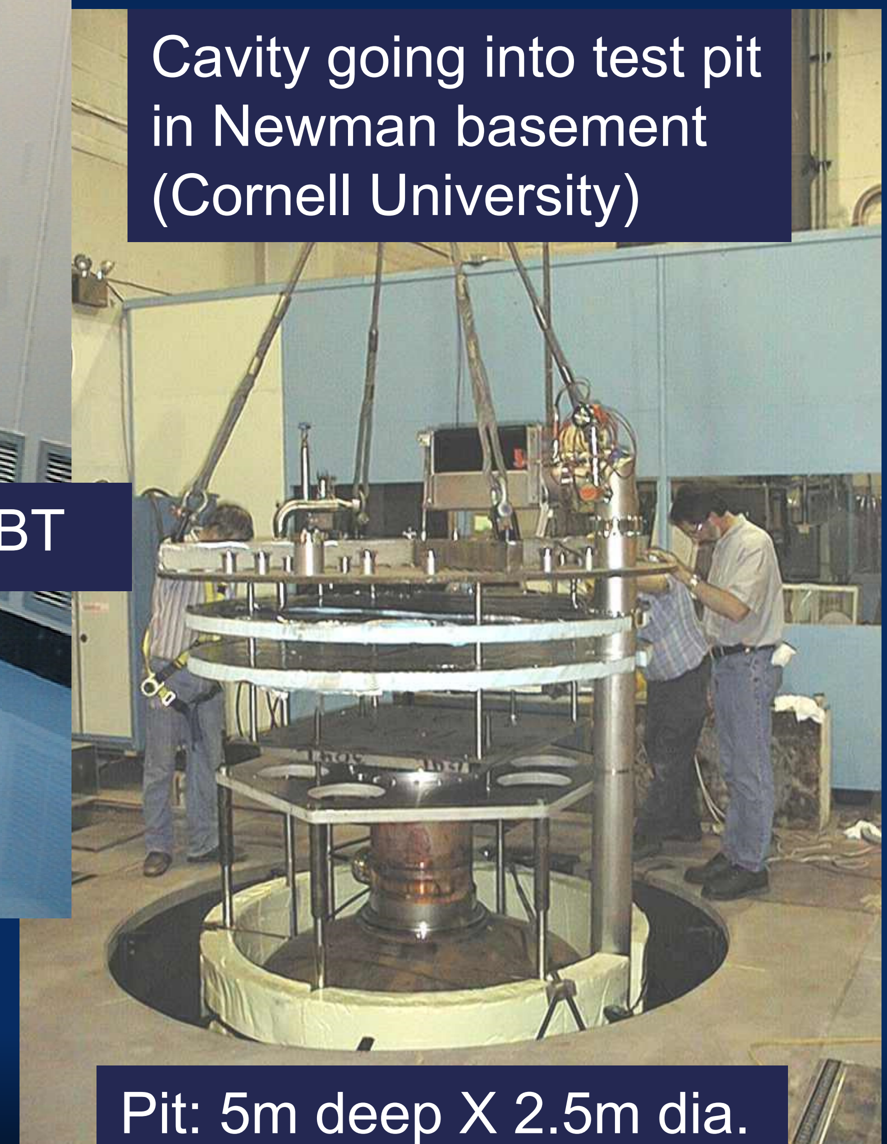


JEMMRLA Proposal: JLAB Electron Model of Muon RLA with Multi-pass Arcs

Superconducting RF Development

201 MHz SCRF R&D



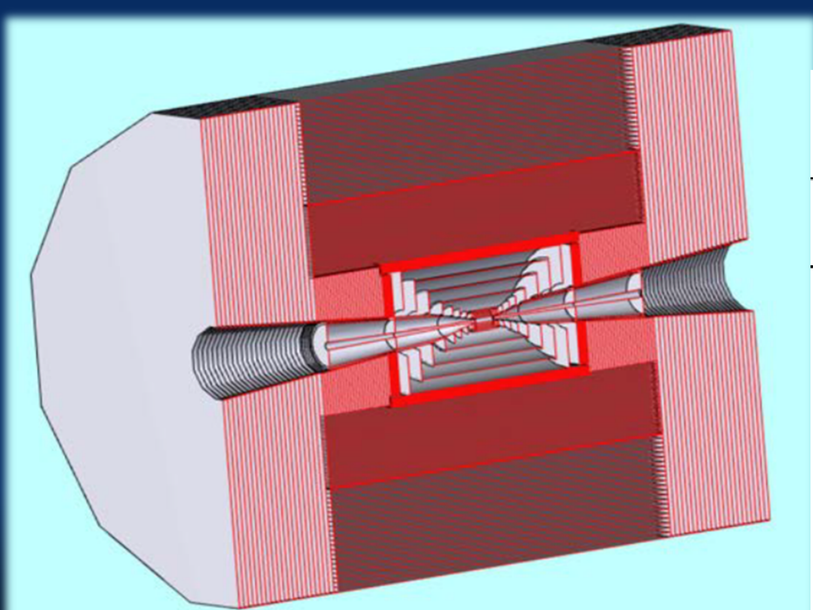


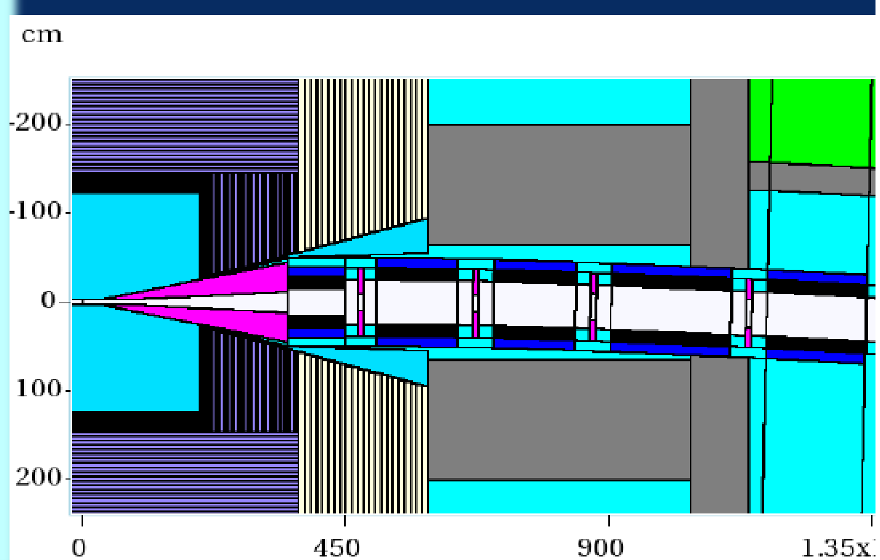
Current focus is on outfitting and testing new explosion-bonded Nb on Cu cavities

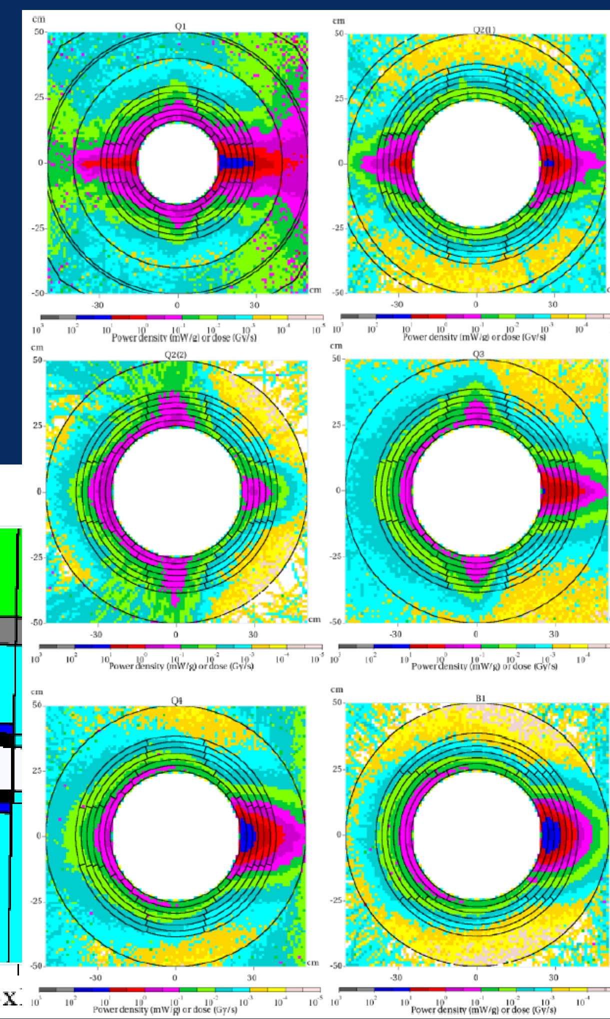
Backgrounds in the Collider Ring

- Emittances are relatively large, but muons circulate for ~1000 turns before decaying
  - Lattice studies have focused on 126 GeV, 1.5 and 3 TeV
- High field dipoles and quadrupoles must operate in high-rate muon decay backgrounds
- IR optimization in progress

Higgs Factory Detector and IR Magnet concepts with MARS15 simulation of energy deposition in the magnets





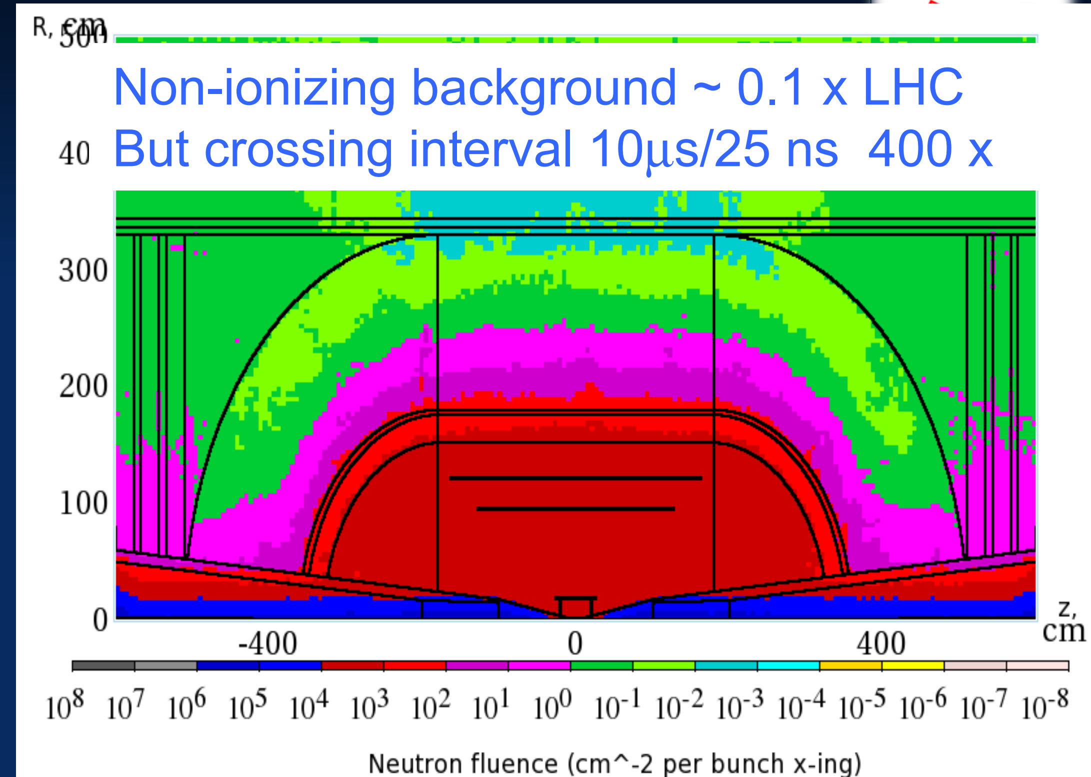


Backgrounds and Detector

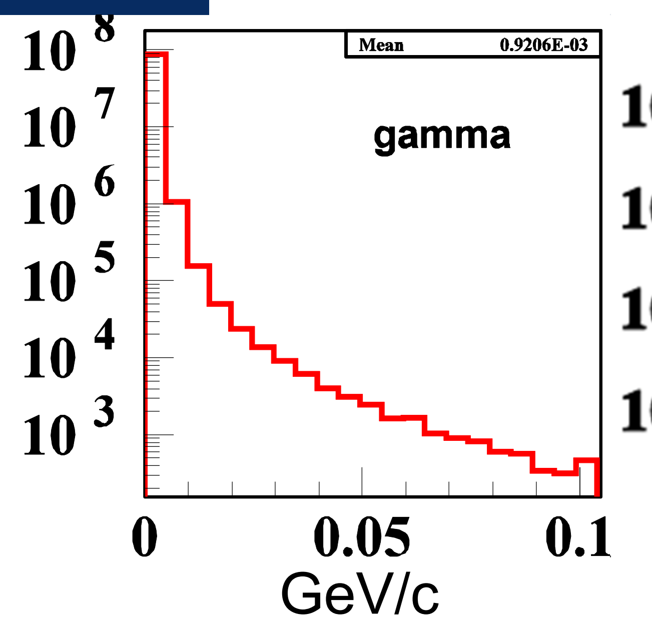
Much of the background is soft and out of time

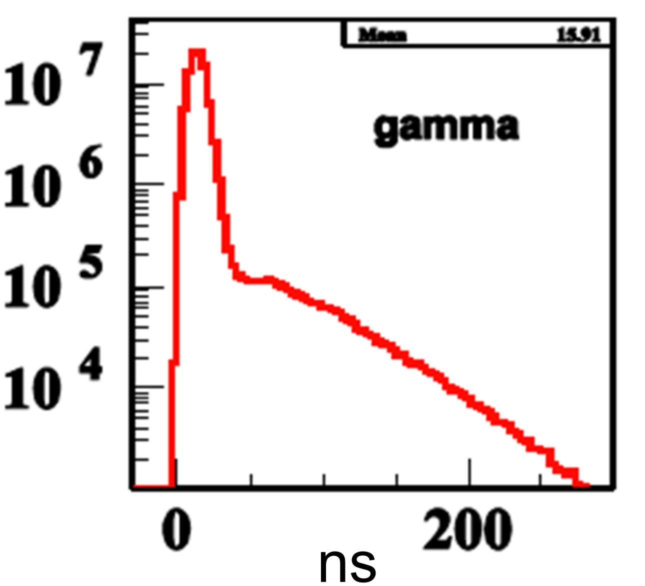
- Nanosecond time resolution can reduce backgrounds by three orders of magnitude

Requires a fast, pixelated tracker and calorimeter.



	Cut	Rejection
Tracker hits	1 ns, dedx	9×10^{-4}
Calorimeter neutrons	2 ns	2.4×10^{-3}
Calorimeter photons	2 ns	2.2×10^{-3}





The Feasibility Assessment

Feasibility Assessment: Phase I

Next 3 years:

- Identify ***baseline*** design concepts and high leverage ***alternatives***
- Develop engineering concepts:
  - RF
  - High Field Magnets
  - 6D Cooling Cell
- Major systems tests
  - MICE Step IV
  - MICE RFCC construction & testing

Feasibility Assessment: Phase II

Following 3 years:

- Technical demonstration of critical ***baseline*** concepts
  - eg, 6D Cooling cell
- Pursue high leverage ***alternative*** concepts
- Major systems tests
  - MICE Step V/VI
  - 6DICE planning
- Feasibility Report

Beyond the Feasibility Assessment

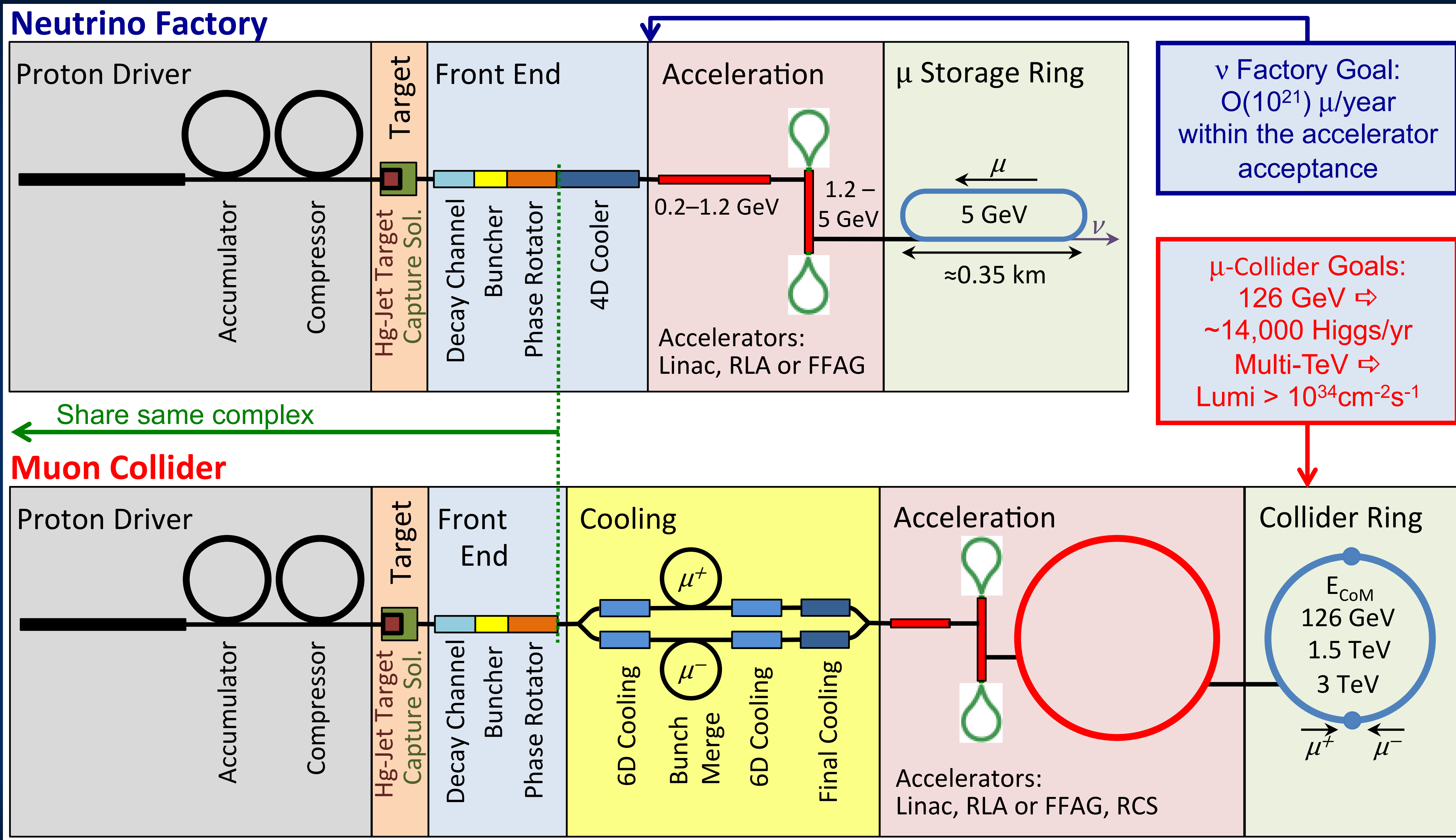
End of decade →

- Decision point provided by the feasibility assessment!
- Design effort towards a staged NF/MC facility
- Advanced systems tests

MUON COLLIDER AND NEUTRINO FACTORY SYNERGIES

⇨ Potential For A Staged Facility Approach

The U.S. Muon Accelerator Program



A Staged Approach

- Muon Accelerator Staging Study (MASS)
  - http://arxiv.org/pdf/1308.0494

Muon Storage Ring – nuSTORM, a short baseline NF

10σ sterile ν search w/$8{\cdot}10^{17}$ stored μs/yr

Precision ν_e cross section measurements

R&D platform for 6D cooling system demonstrations

Provides entry point for high intensity muon accelerator capabilities

NO new technologies needed

Long Baseline NF to SURF - NuMAX

Could begin with a ~1MW proton driver at 3-6 GeV

Initially (w/ no cooling) could provide $2{\cdot}10^{20}$ stored μ^+ & μ^-/yr

Upgradeable (cooling+proton power) to $\geq 1.2{\cdot}10^{21}$ stored μ^+ & μ^-/yr

1st MC – a Higgs Factory?

Add 6D cooling, acceleration, and collider ring

Key technologies could be validated at full beam intensity during NuMAX operations

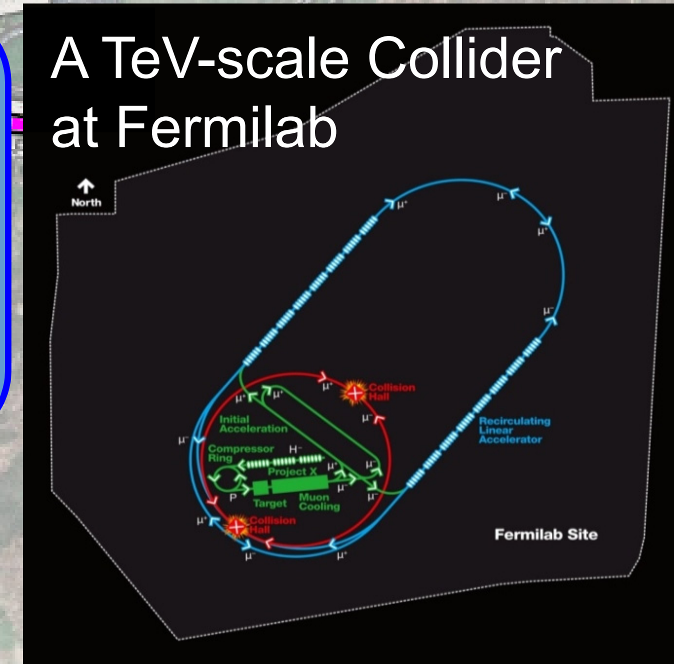
Cooling upgrades beneficial to continued NuMAX operations

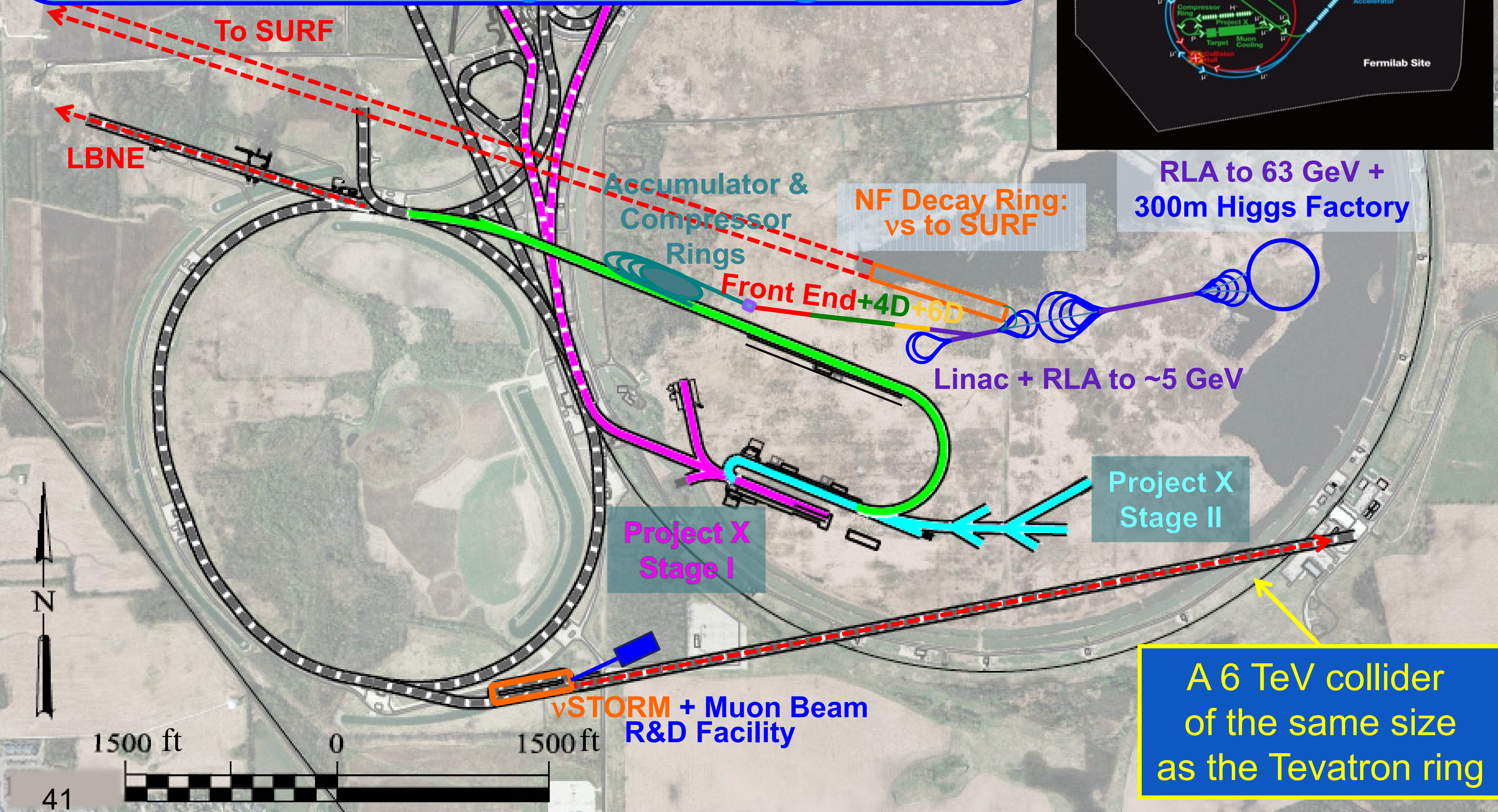
Multi-TeV MC

Add final cooling and acceleration.

Offers both precision measurement capability and discovery potential at the Terascale

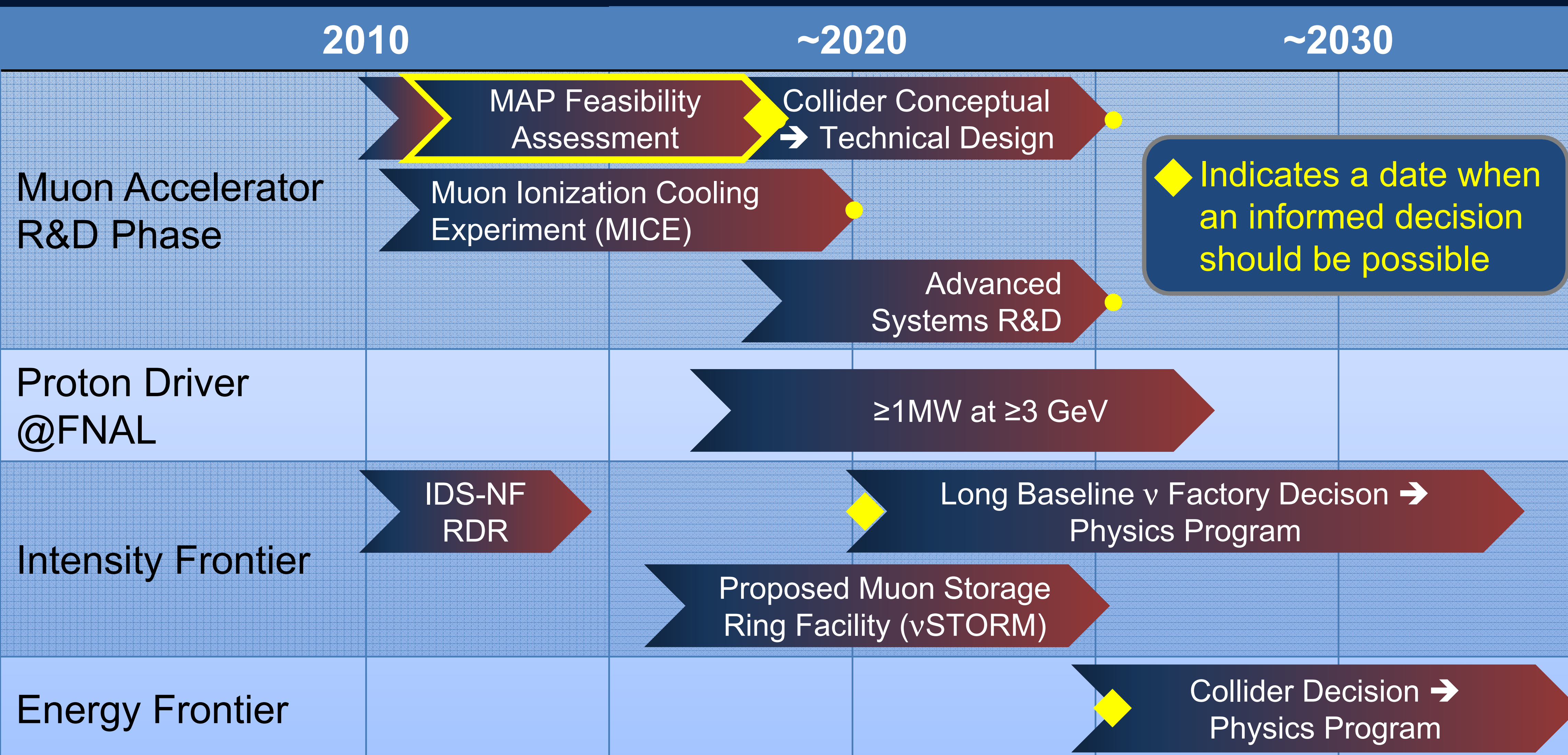
A Muon Accelerator Facility for Cutting Edge Physics on the Intensity and Energy Frontiers Based on Project X Stage II



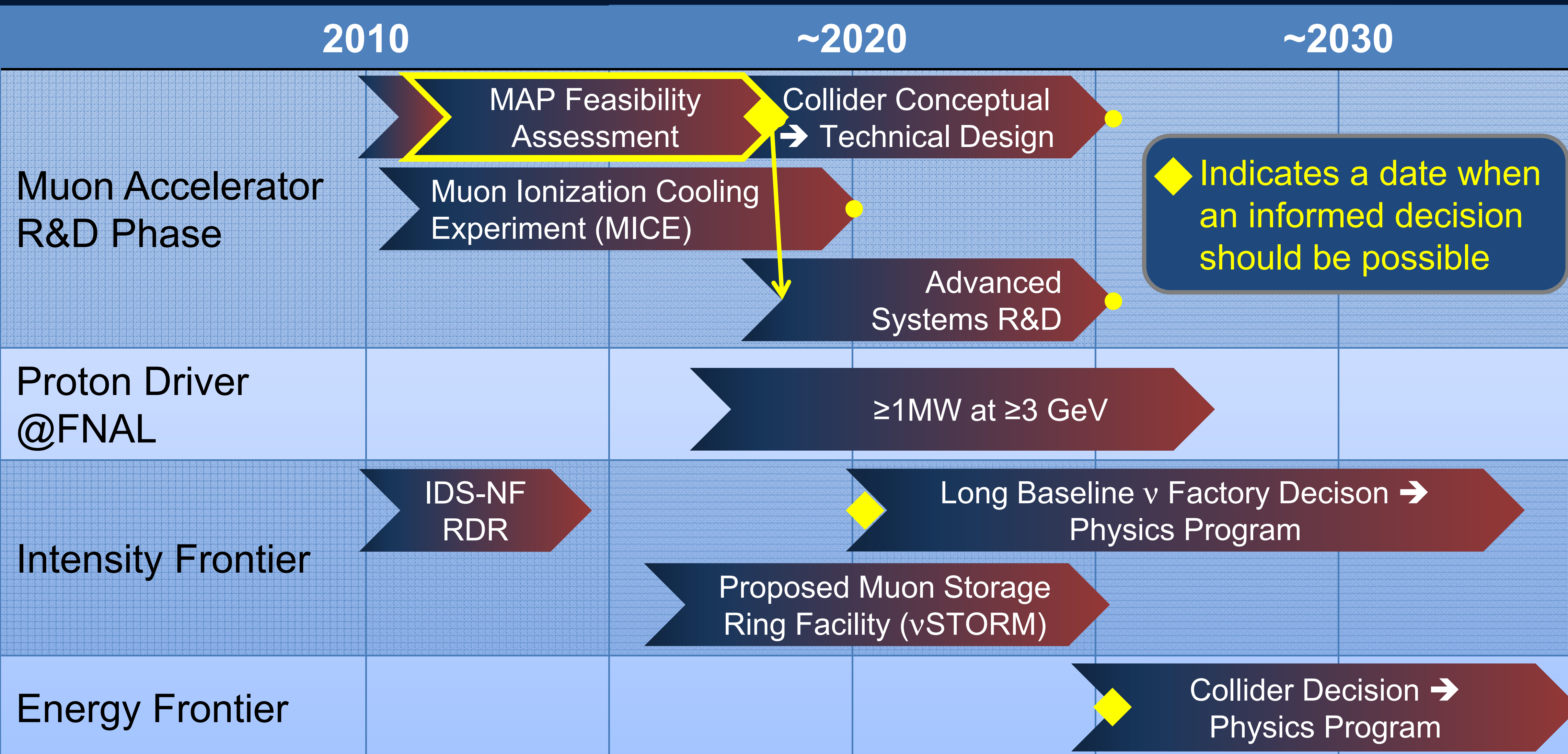


MAP Technical Timeline

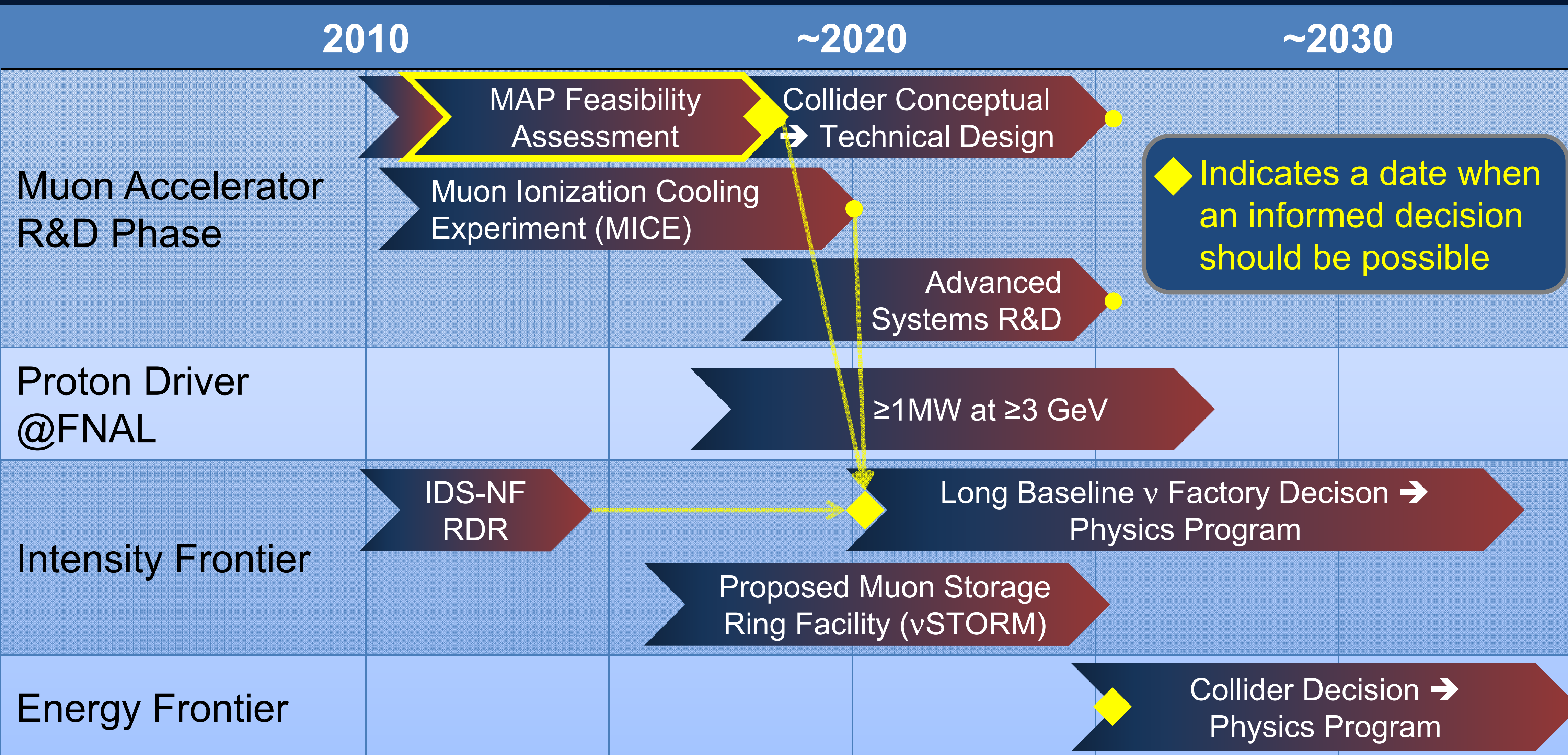
⇨ Provide Informed Decision Points



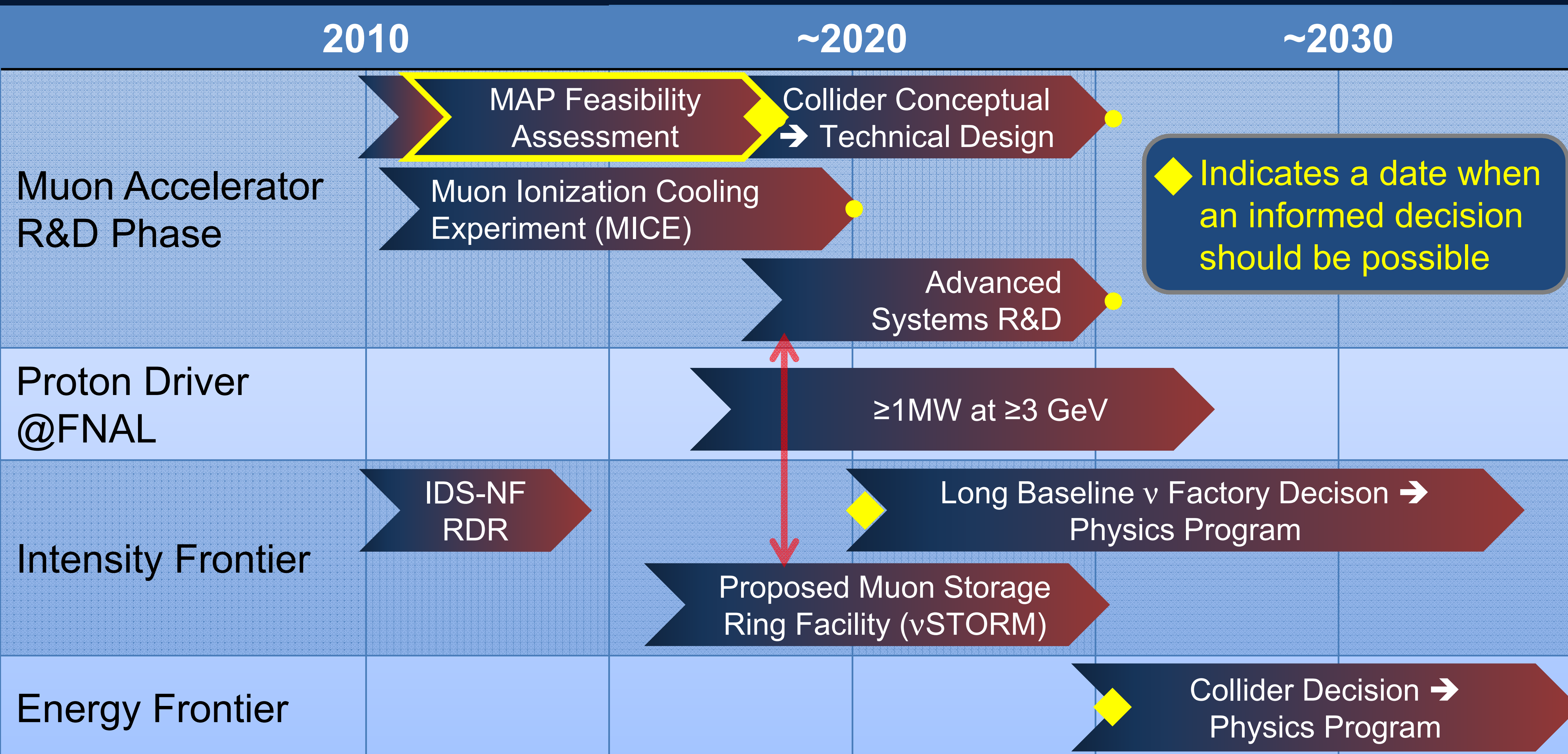
MAP Technical Timeline
⇨ Provide Informed Decision Points



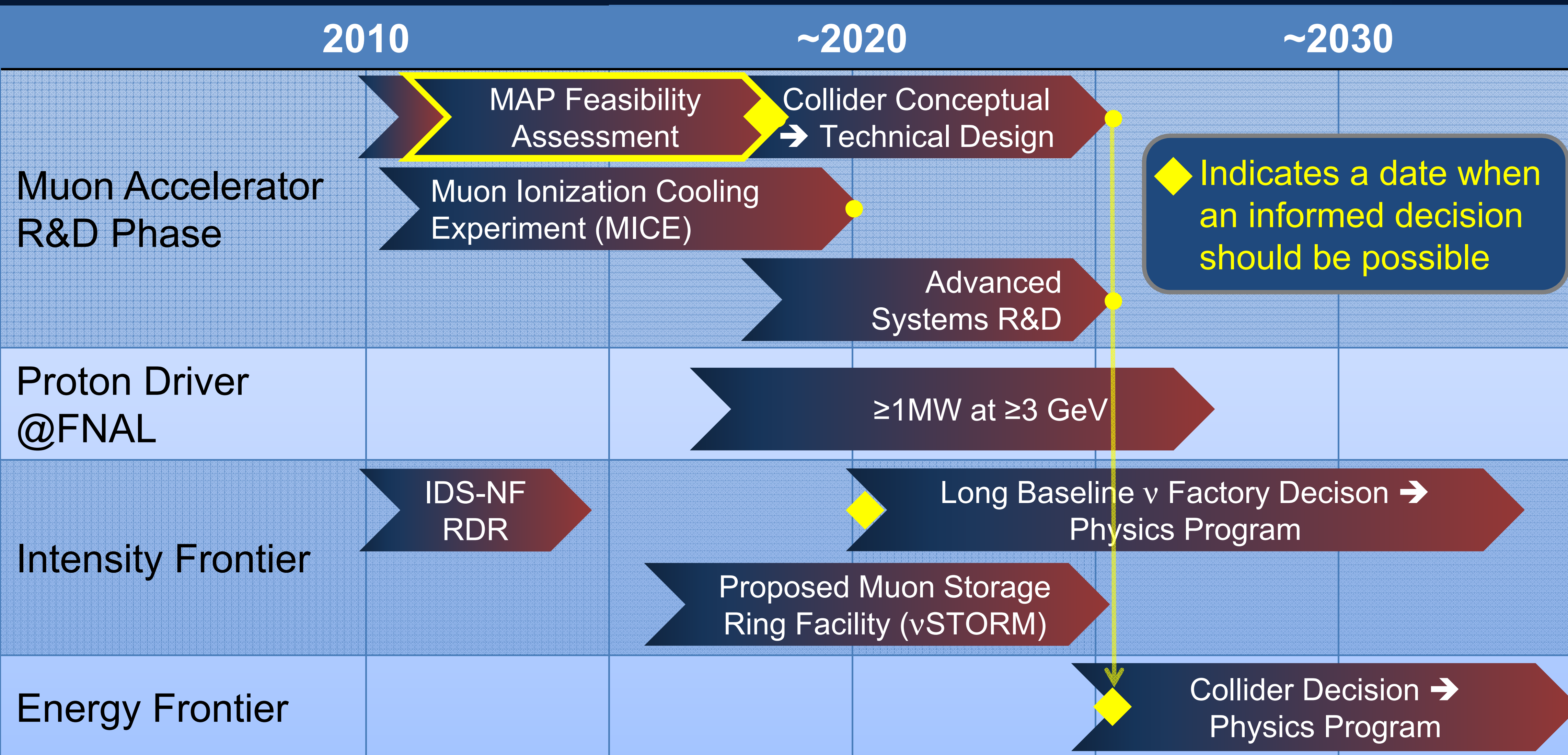
MAP Technical Timeline
⇨ Provide Informed Decision Points



MAP Technical Timeline
⇨ Provide Informed Decision Points

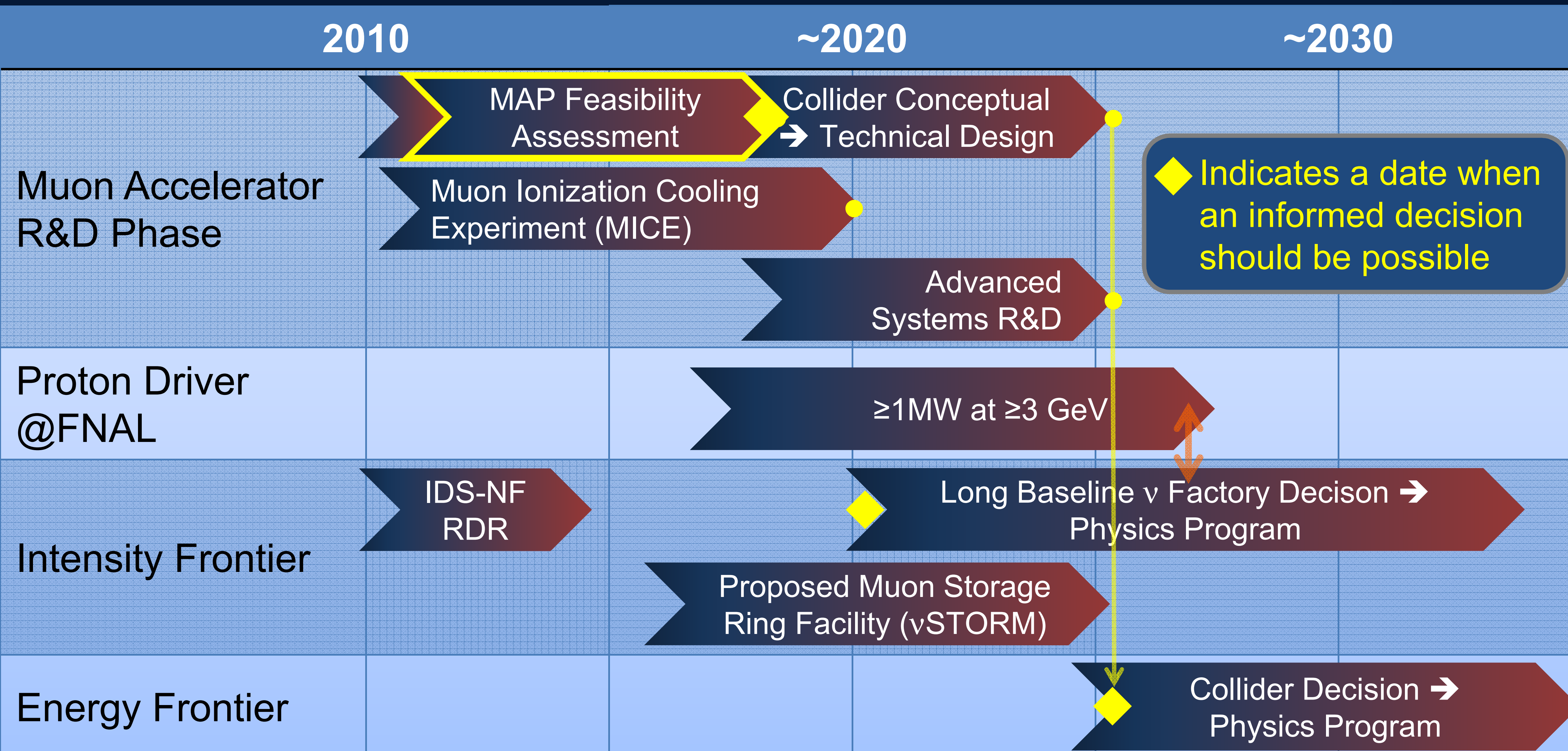


MAP Technical Timeline
⇨ Provide Informed Decision Points



At Fermilab, the νSTORM facility could support a program of advanced 6D cooling system tests

MAP Technical Timeline
⇨ Provide Informed Decision Points



At Fermilab, the νSTORM facility could support a program of advanced 6D cooling system tests

At Fermilab, a Muon Accelerator-based Neutrino Physics program could begin with a 1MW Proton Driver beam at ~3-6 GeV

CONCLUDING REMARKS

Relevant NAPAC`13 Presentations I

6D Cooling Channel Design & Tools

MOPBA09: Advanced Modeling Tools for Muon-Based Accelerators
MOPBA10: Progress of the Matter-dominated Muon Accelerator Lattice Simulation Tools Development for COSY Infinity
MOPBA11: Space Charge Simulation in COSY Using Fast Multipole Method
THPBA27: Simulation Workstation
THPBA22: Helical Muon Beam Cooling Channel Engineering Design
THPBA26: Elliptical Muon Helical Cooling Channel Coils
THPHO04: Linear Analysis for Several 6-D Ionization Cooling Lattices
THPHO05: A Planar Snake Muon Ionization Cooling Lattice
THPHO12: A high-performance rectilinear FOFO channel for muon cooling
THPHO13: Limitations Imposed by Space Charge on the Final Stages of a Muon Collider Ionization Cooling Channel
THPHO19: A Charge Separation Study to Enable the Design of a Complete Muon Cooling Channel
THPHO20: Optimization and Aberration Correction of the Twin Helix Parametric Ionization Cooling Channel for Muon Beams

6D Cooling Technology R&D

MOPBA06: Algorithms and Self-consistent Simulation of Beam-induced Plasma in Muon Cooling Devices
MOPBA18: Multipacting Simulation of Accelerator Cavities using ACE3P
TUODA1: High Pressure Gas-Filled RF Cavities for Use in a Muon Cooling Channel
WEPMA12: Investigation of Breakdown Induced Surface Damage on 805 MHz Pill Box Cavity Interior Surfaces
WEPMA16: Assembly and Testing of the First 201-MHz MICE Cavity at Fermilab
WEPMA17: Extended RF Testing of the 805-MHz Pillbox "All-Season" Cavity for Muon Cooling
THPBA16: A New Facility for Testing Superconducting Solenoid Magnets with Large Fringe Fields at Fermilab

Relevant NAPAC`13 Presentations II

Proton Driver, Target & Front End

TUPBA09: Simulation of High Power Mercury Jet Targets for Neutrino Factory and Muon Collider
TUPBA10: Impact of the Initial Proton Bunch Length on the Performance of the Muon Front End
TUPBA11: Towards a Global Optimization of the Muon Accelerator Front End
TUYAA2: High Power (MW-class) Targets for Particle Beams
THPHO02: Design of the Final Focus of the Proton Beam for a Neutrino Factory
THPHO11: Optimization of the Capture Section of a Staged Neutrino Factory
THPMA10: Energy Deposition in Magnets and Shielding of the Target System of a Staged Neutrino Factory
THPMA11: Optimization of Particle Production for a Staged Neutrino Factory

Collider

THPBA19: Storage Ring and Interaction Region Magnets for a μ+μ- Higgs Factory

Muon Decay Ring/Neutrino Factory

TUODB4: nuSTORM: Neutrinos from STORed Muons

Muon Accelerator Staging Study (MASS)

TUPBA20: A Staged Muon-based Facility to enable Intensity and Energy Frontier Science in the US

Muon Ionization Cooling Experiment (MICE)

WEPMA26: Multipacting Study for the RF Test of the MICE 201 MHz RF Cavity at MTA
THPBA08: Partial Return Yoke for MICE - Engineering Design
THPBA09: Partial Return Yoke for MICE - General Concept and Performance
THPHO15: Analysis of MICE Spectrometer Solenoid Magnetic Field Measurements
THPHO18: Status of the Muon Ionization Cooling Experiment (MICE)

Some Thoughts…

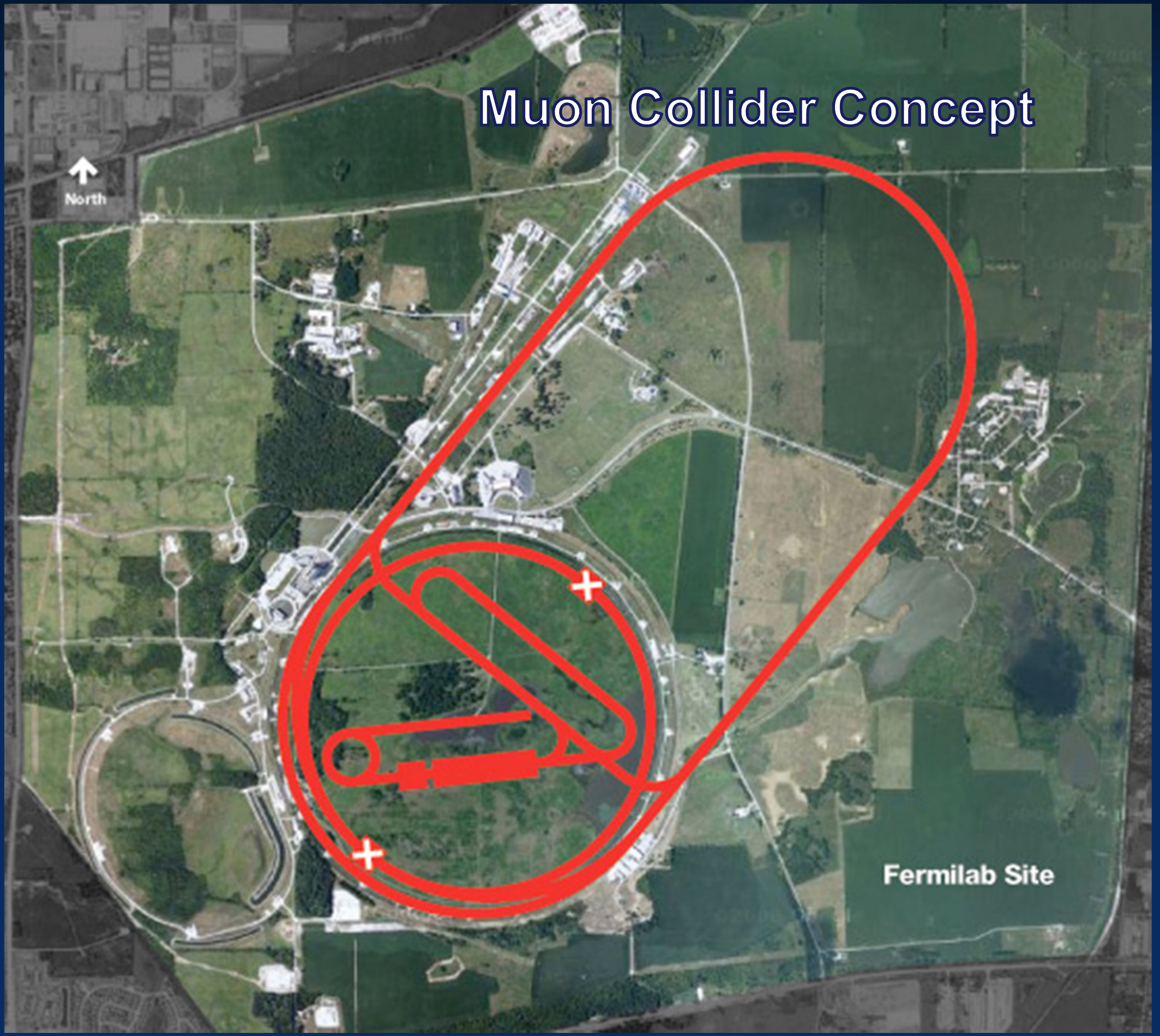
- The unique feature of muon accelerators is the ability to provide cutting edge performance on both the Intensity and Energy Frontiers
  - The possibilities for a staged approach make this particularly appealing in a time of constrained budgets
  - νSTORM would represent a critical first step in providing a muon-based accelerator complex
- World leading Intensity Frontier performance could be provided with a Neutrino Factory based on Project X Phase II
  - This would also provide the necessary foundation for a return to the Energy Frontier with a muon collider on U.S. soil
- A Muon Collider Higgs Factory
  - Would provide exquisite energy resolution to directly measure the width of the Higgs. This capability would be of crucial importance in the MSSM doublet scenario.

The first collider on the path to a multi-TeV Energy Frontier machine?

Conclusion

- Through the end of this decade, the primary goal of MAP is demonstrating the feasibility of key concepts needed for a neutrino factory and muon collider

⇨ Thus enabling an informed decision on the path forward for the HEP community



A challenging, but promising, R&D program is underway!

Acknowledgments

I would personally like to thank Steve Geer, Mike Zisman, Bob Palmer as well as the MAP L1 & L2 managers for their help in familiarizing me with the program since I took over as director last year

The MAP Effort -

- Labs: ANL, BNL, FNAL, JLAB, LBNL, ORNL, SLAC, IHEP-Beijing
- Universities: CMU, Chicago, Cornell, ICL, IIT, Princeton, SUNY-Stony Brook, UC-Berkeley, UCLA, UC-Riverside, UMiss, VT
- Companies: Muons, Inc; Particle Beam Lasers