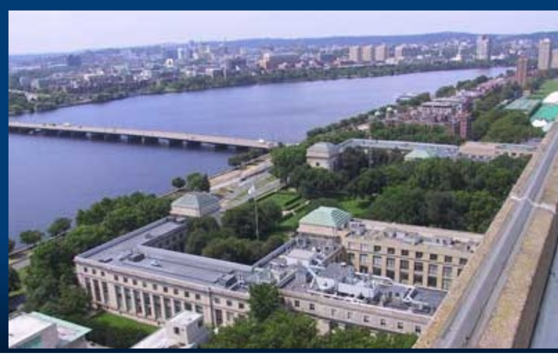
Muon Accelerators for the Next Generation of High Energy Physics Experiments

Mark A. Palmer

Director, U.S. Muon Accelerator Program

September 9, 2013



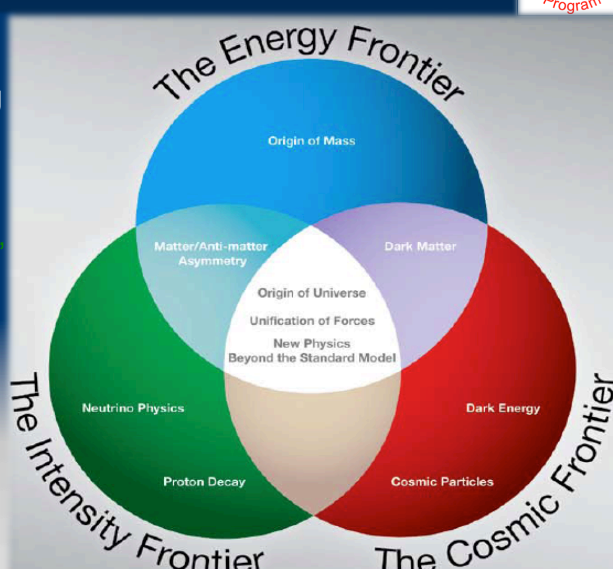
Fermilab

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

Outline

- Physics Motivations – Neutrino Factory and Muon Collider
- Muon Collider and Neutrino Factory Synergies
- R&D Challenges and the MAP Feasibility Assessment
- Concluding Remarks

THE PHYSICS MOTIVATIONS

The Physics Motivations

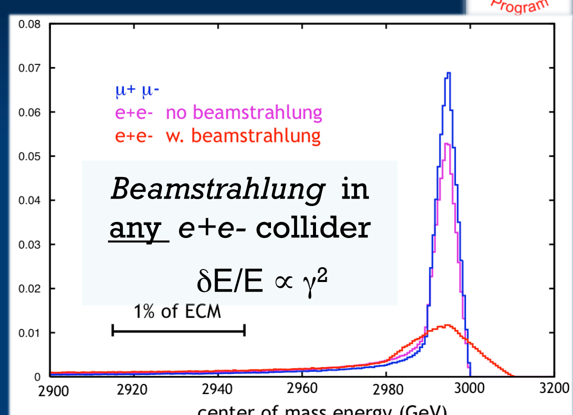
- μ – an elementary charged lepton:
  - 200 times heavier than the electron
  - 2.2 μs lifetime at rest
- Physics potential for the HEP community using muon beams
  - Tests of Lepton Flavor Violation
  - Anomalous magnetic moment ⇨ hints of new physics (g-2)
  - Can provide equal fractions of electron 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

Muon Accelerator Physics

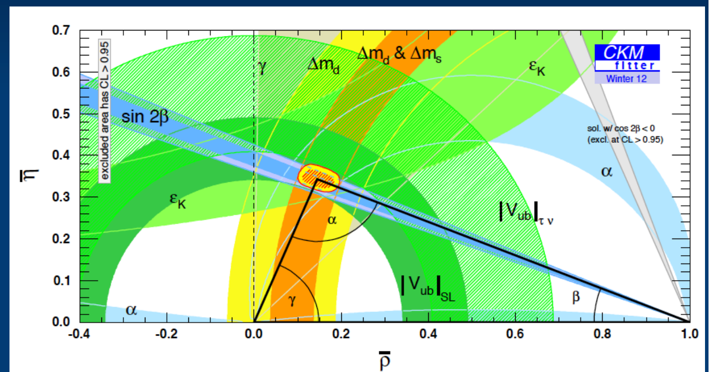
- Large muon mass strongly suppresses synchrotron radiation
  - ⇨ Muons can be accelerated and stored using rings at much higher energy than electrons
  - ⇨ Colliding beams can be of higher quality with reduced beamstrahlung



- Short muon lifetime has impacts as well
  - Acceleration and storage time of a muon beam is limited
  - Collider ⇨ a new class of decay backgrounds must be dealt with
- Precision beam energy measurement by g-2 allows precision Higgs width determination
- Muon beams produced as tertiary beams: $p \rightarrow \pi \rightarrow \mu$
  - Offers key accelerator challenges…

The Physics Needs: Neutrinos (I)

- 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

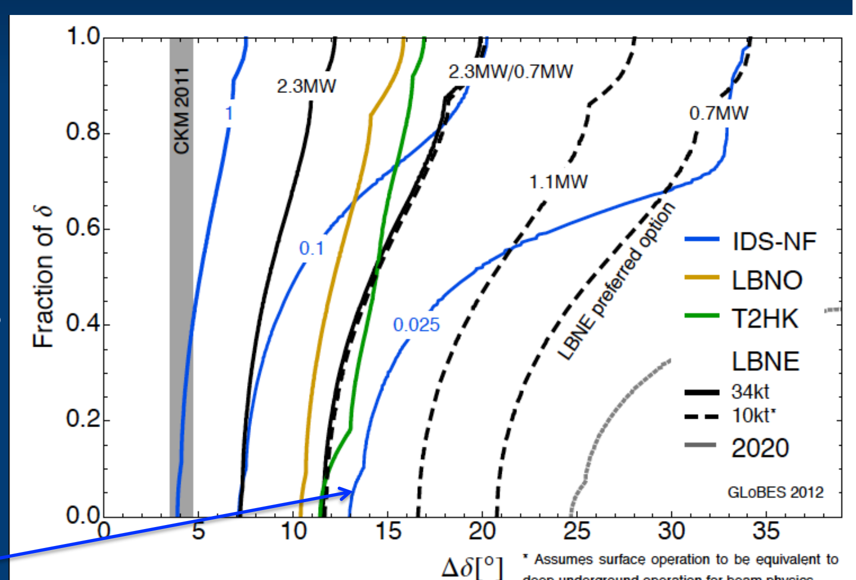


P. Huber

The Physics Needs: Neutrinos (II)

- CP violation physics reach of various facilities

Can we probe the CP violation in the neutrino sector at the same level as in the CKM Matrix?

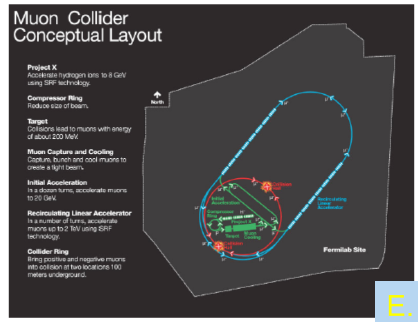


0.025 IDS-NF:
700kW target,
no cooling,
2×10^{8} s running time
10-15 kTon detector

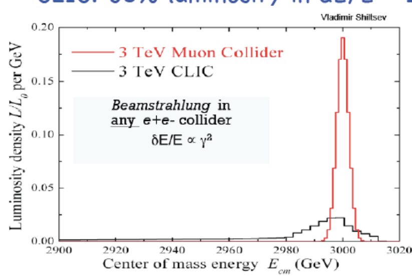
P. Coloma, P. Huber, J. Kopp, W. Winter – article in preparation

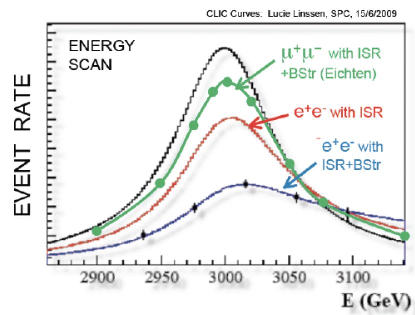
The Physics Needs: Colliders

- $\mu^+\mu^-$ Collider:
  - Center of Mass energy: 1.5 - 6 TeV (3 Tev)
  - Luminosity > 10^{34} cm^{-2} sec^{-1} (350 fb^{-1}/yr)
  - Compact facility
    - 3 TeV - ring circumference 3.8 km
    - 2 Detectors
  - Superb Energy Resolution
    - MC: 95% luminosity in dE/E ~ 0.1%
    - CLIC: 35% luminosity in dE/E ~ 1%



E. Eichten

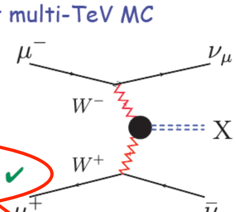




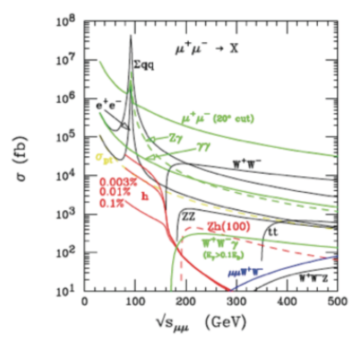
Muon Collider Reach

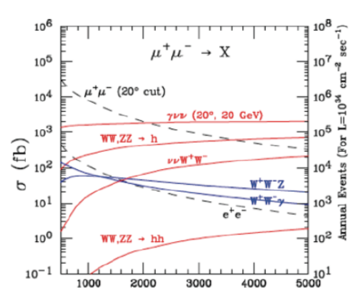
- For $\sqrt{s}$ < 500 GeV
  - SM thresholds: Z^0h, W^+W^-, top pairs
  - Higgs factory ($\sqrt{s}\approx$ 126 GeV) ✔
- For $\sqrt{s}$ > 500 GeV
  - Sensitive to possible Beyond SM physics.
  - High luminosity required. ✔
    - Cross sections for central (| θ | > 10°) pair production ~ R × 86.8 fb/s(in TeV^2) (R ≈ 1)
    - At $\sqrt{s}$ = 3 TeV for 100 fb^{-1} ~ 1000 events/(unit of R)
- For $\sqrt{s}$ > 1 TeV
  - Fusion processes important at multi-TeV MC

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



- An Electroweak Boson Collider ✔



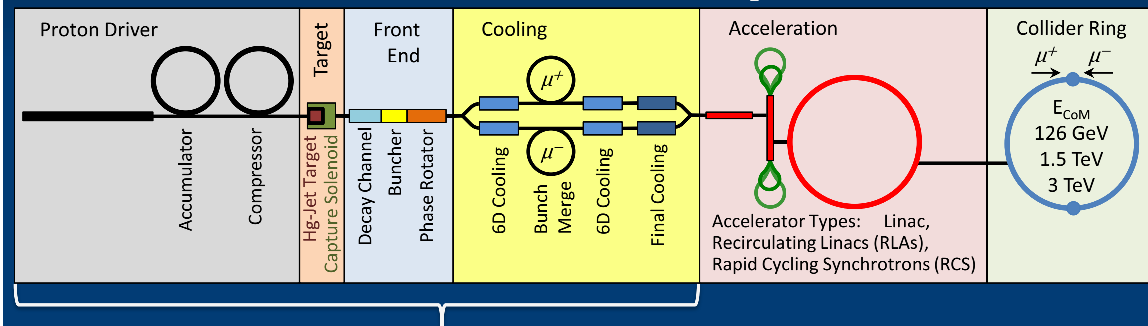


A 10 TeV $\mu^+\mu^-$ collider has similar discovery reach as a 100 TeV pp machine!

E. Eichten

Muon Collider Concept

Muon Collider Block Diagram



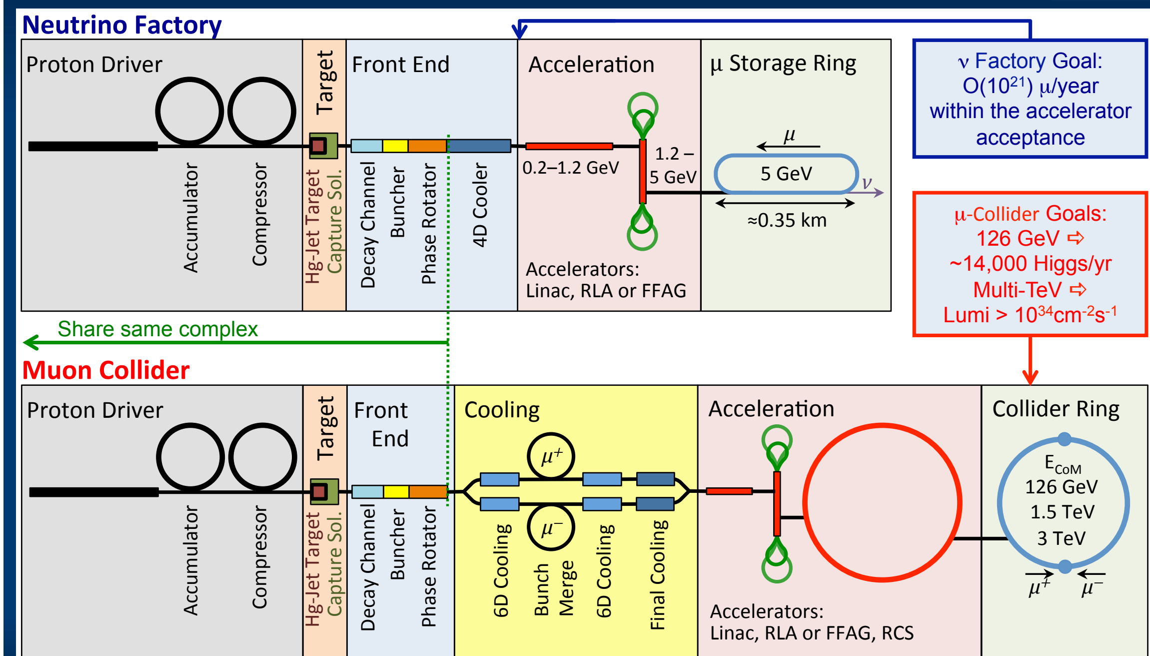
Proton source:
For example PROJECT X at 4 MW, with 2±1 ns long bunches

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

MUON COLLIDER AND NEUTRINO FACTORY SYNERGIES

The U.S. Muon Accelerator Program



Muon Accelerator Staging Study (MASS)

- Two approaches exist:
  - A dedicated "green field" construction project
  - A staged development based on evolving capabilities at an existing facility
    - Desirable if high quality physics can be produced along the way…
    - Can provide clear decision points with well-understood risks for moving forward
    - Incremental deployment of expensive or technically challenging elements
- 2008 P5 Roadmap called for a "world-leading Intensity Frontier program centered at Fermilab"
  - Can a Muon Accelerator effort support this goal as well as provide a path to return to an Energy Frontier facility in the US?
  - Can a staged Muon Accelerator effort provide both physics output and the necessary accelerator R&D along the way?
  - What are the timescales associated with such an effort?

A Staged Muon-Based Neutrino and Collider Physics Program

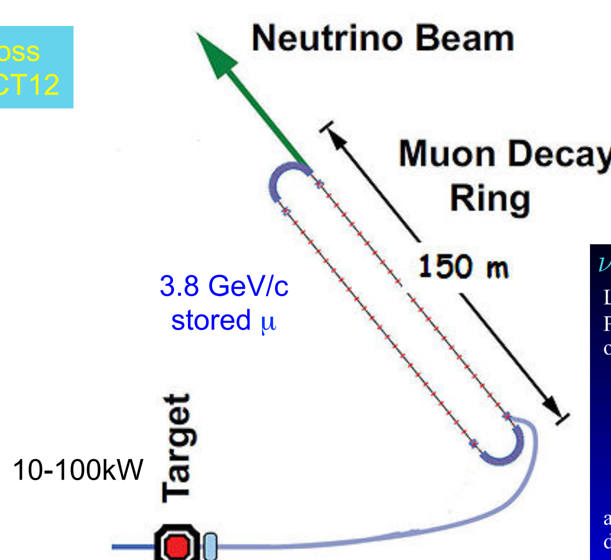
The plan is conceived in four stages, whose exact order remains to be worked out:

- The "entry point" for the plan is the νSTORM facility proposed at Fermilab, which can advance short-baseline physics by making definitive observations or exclusions of sterile neutrinos. Secondly, it can make key measurements to reduce systematic uncertainties in long-baseline neutrino experiments. Finally, it can serve as an R&D platform for demonstration of accelerator capabilities pre-requisite to the later stages.
- A stored-muon-beam Neutrino Factory can take advantage of the large value of θ_{13} recently measured in reactor-antineutrino experiments to make definitive measurements of neutrino oscillations and their possible violation of CP symmetry.
- Thanks to suppression of radiative effects by the muon mass and the m^2_{lepton} proportionality of the s-channel Higgs coupling, a "Higgs Factory" Muon Collider can make uniquely precise measurements of the 126 GeV boson recently discovered at the LHC.
- An energy-frontier Muon Collider can perform unique measurements of Terascale physics, offering both precision and discovery reach.

Neutrinos from Stored Muons

(Fermilab P-1028)

A.Bross NuFACT12



An entry-level NF?

DOES NOT Require the Development of ANY New Technology

νSTORM

Low energy, low luminosity muon storage ring. Provides with 1.7×10^{18} μ^+ stored, the following oscillated event numbers

$\nu_e \to \nu_\mu$ CC	330
$\bar{\nu}_\mu \to \bar{\nu}_\mu$ NC	47000
$\nu_e \to \nu_e$ NC	74000
$\bar{\nu}_\mu \to \bar{\nu}_\mu$ CC	122000
$\nu_e \to \nu_e$ CC	217000

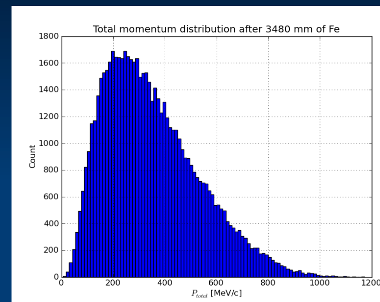
and each of these channels has a more than $10\,\sigma$ difference from no oscillations

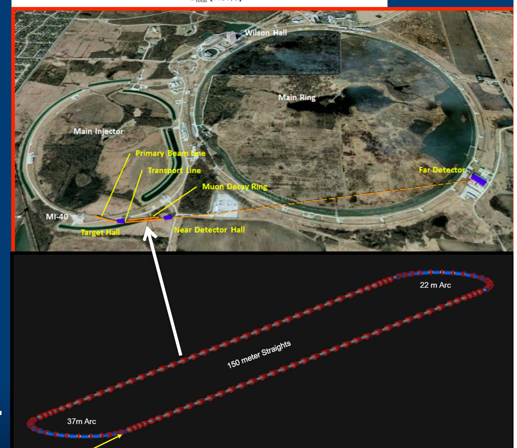
With more than 200 000 ν_e CC events a %-level ν_e cross section measurement should be possible

nuStorm Proposal: http://arxiv.org/abs/1308.6822

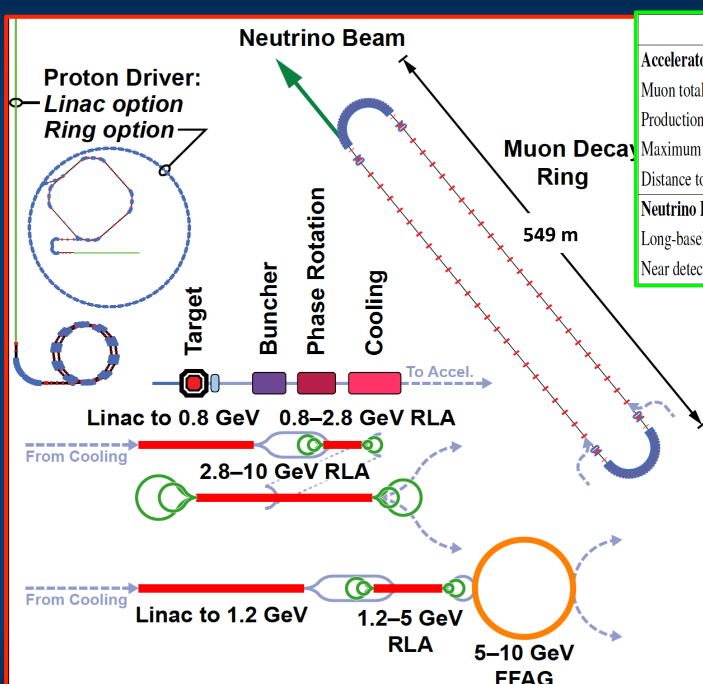
νStorm as an R&D Platform

- A high-intensity pulsed muon source
- $100<p_\mu<300$ MeV/c muons
  - Using extracted beam from ring
  - 10^{10} muons per 1 μsec pulse
- Beam available simultaneously with physics operation
  - Sterile ν search
  - ν cross section measurements needed for ultimate precision in long baseline measurements
- νSTORM also provides the opportunity to design, build and test decay ring instrumentation (BCT, momentum spectrometer, polarimeter) to measure and characterize the circulating muon flux.





IDS-NF baseline Neutrino Factory



	Value
Accelerator facility	
Muon total energy	10 GeV
Production straight muon decays in 10^7 s	10^{21}
Maximum RMS angular divergence of muons in production straight	$0.1/\gamma$
Distance to intermediate baseline detector	1 500–2 500 km
Neutrino Detectors	
Long-baseline Magnetised Iron Detector (MIND)	100 kT
Near detectors, magnetised, high-resolution spectrometers	2

K.Long
NuFACT12

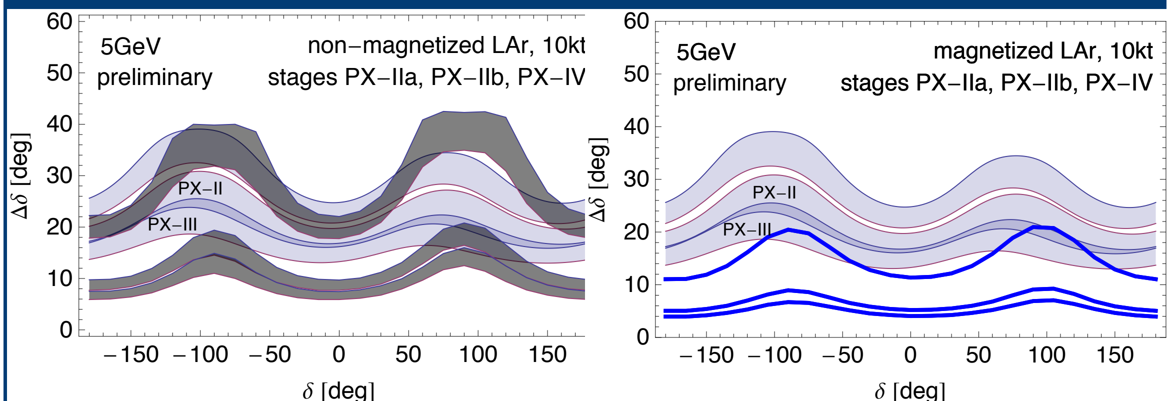
How Could a Staged ν Factory (NuMAX) to SURF Perform?

What if we send beam from a ~5GeV muon storage ring to LBNE?

1 MW, no muon cooling
⇨ 3 MW, w/cooling
⇨ 4 MW, w/cooling

What if we were able to have a magnetized LAr detector?

Or a MIND detector w/3× the mass



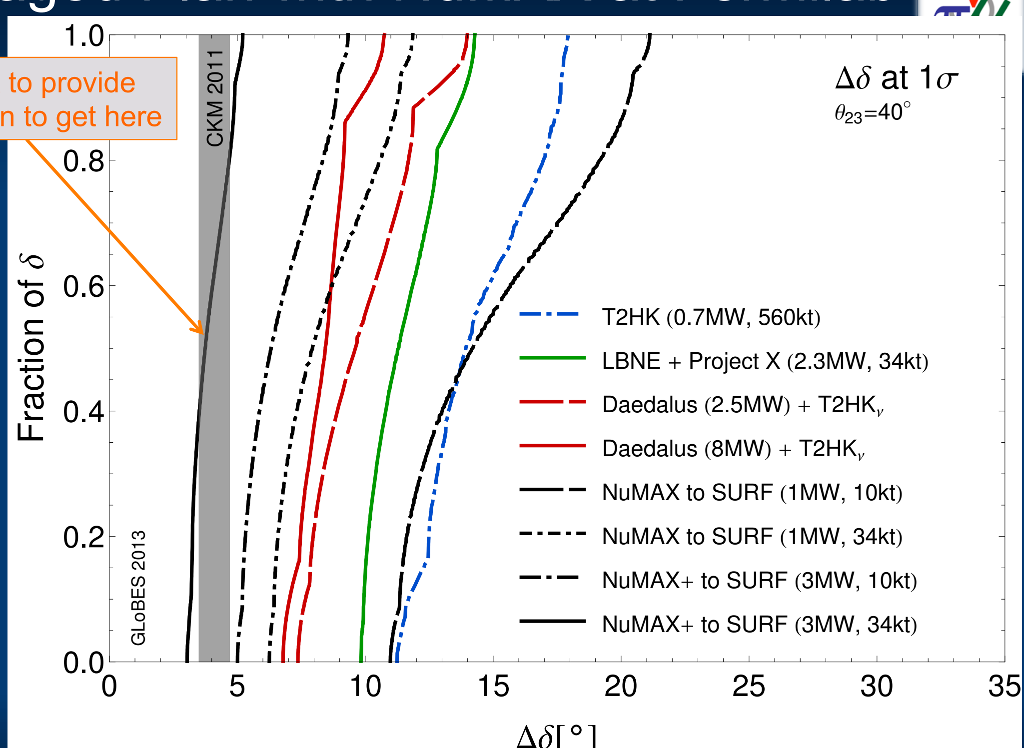
Gray bands represent range of possible detector performance per arXiv:0805.2019

Plots courtesy of P. Huber

Plots assume 100 kt-years

A Staged Plan with NuMAX at Fermilab

We want to provide the option to get here



Neutrino Factory Staging (MASS)

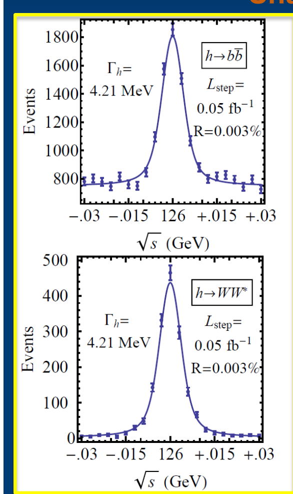
Preliminary Staging Plan Based on **Project X Stage 2**

System	Parameters	Unit	nuSTORM	NuMAX	NuMAX+	IDS-NF
Performance	Stored μ+ or μ-/year		8×10^{17}	2×10^{20}	1.2×10^{21}	1×10^{21}
	ν_e or ν_μ to detectors/yr		3×10^{17}	8×10^{19}	5×10^{20}	5×10^{20}
Detector	*Far Detector:*	Type	SuperBIND	MIND / Mag LAr	MIND / Mag LAr	MIND
	Distance from Ring	km	1.9	1300	1300	2000
	Mass	kT	1.3	30 / 10	100 / 30	100
	Magnetic Field	T	2	0.5-2	0.5-2	1-2
	Near Detector:	Type	SuperBIND	Suite	Suite	Suite
	Distance from Ring	m	50	100	100	100
	Mass	kT	0.1	1	2.7	2.7
	Magnetic Field	T	Yes	Yes	Yes	Yes
Neutrino Ring	Ring Momentum (P_μ)	GeV/c	3.8	5	5	10
	Circumference (C)	m	480	600	600	1190
	Straight section	m	185	235	235	470
	Arc Length	m	50	65	65	125
Acceleration	Initial Momentum	GeV/c	-	0.22	0.22	0.22
	Single-pass Linac	GeV/pass	-	0.95	0.95	0.56
		MHz	-	325	325	201
	4.5-pass RLA — RLA I	GeV/pass	-	0.85	0.85	0.45
		MHz	-	325	325	201
	RLA II	GeV/pass	-	-	-	1.6
		MHz	-	-	-	201
Cooling			No	No	4D	4D
Proton Source	Proton Beam Power	MW	0.2	1	3	4
	Proton Beam Energy	GeV	120	3	3	10
	Protons/year	1×10^{21}	0.1	41	125	25
	Repetition Frequency	Hz	0.75	70	70	50

For reference

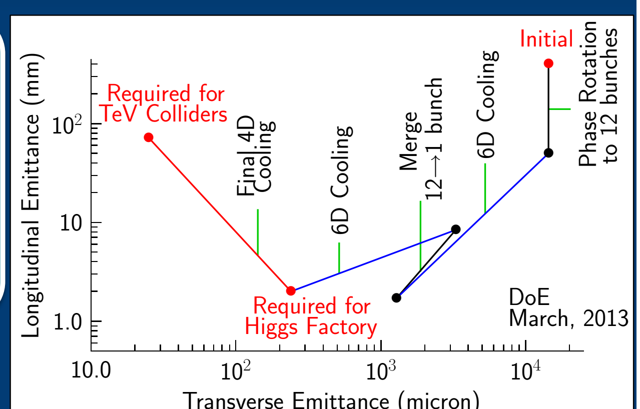
126 GeV Higgs Factory

s-channel coupling of Muons to HIGGS with high cross sections:
Muon Collider of 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

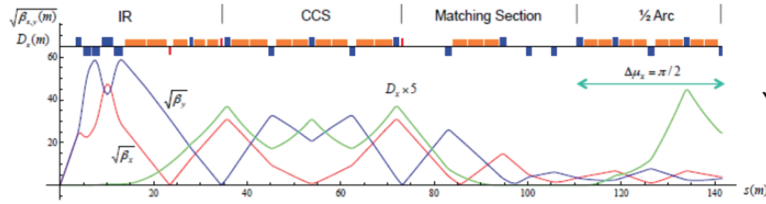
Han and Liu
hep-ph 1210.7803



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)

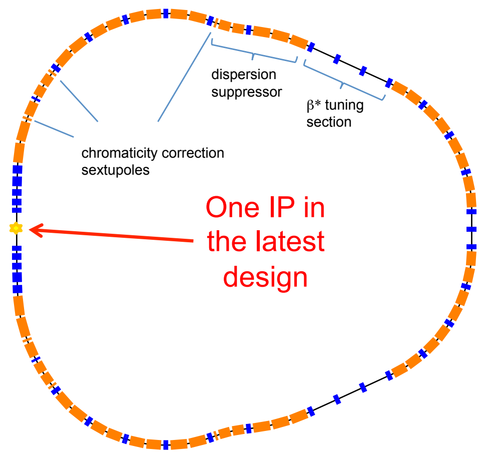
Updated 63 x 63 GeV Lattice



Optics functions in half ring for β*=2.5cm

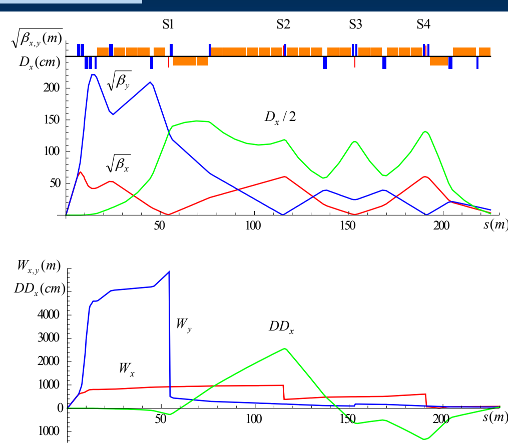
Y. Alexahin

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

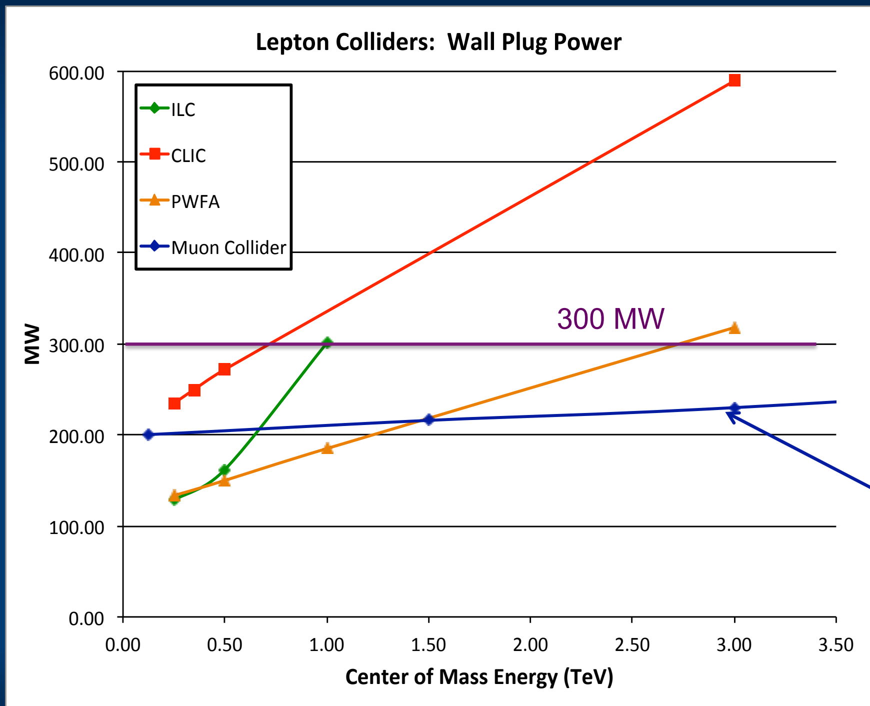
Y. Alexahin



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}/cm²/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

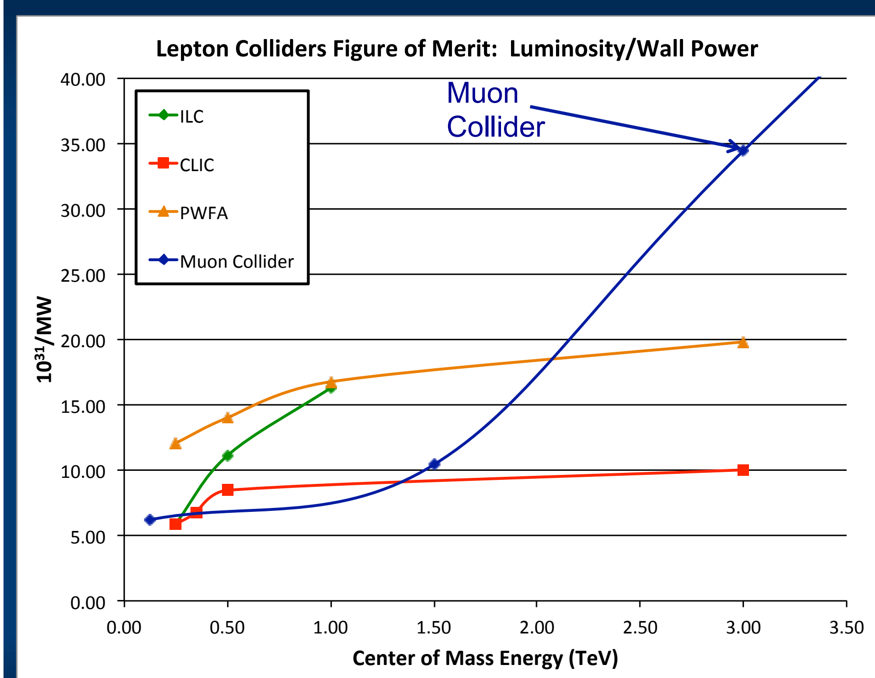
Wall Plug Power Estimates



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

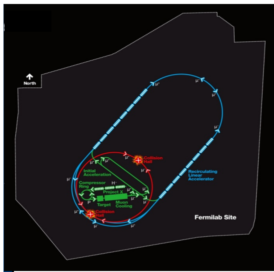
Muon Collider

Luminosity Production Metric



Luminosity Metric:

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



Muon Collider Parameters

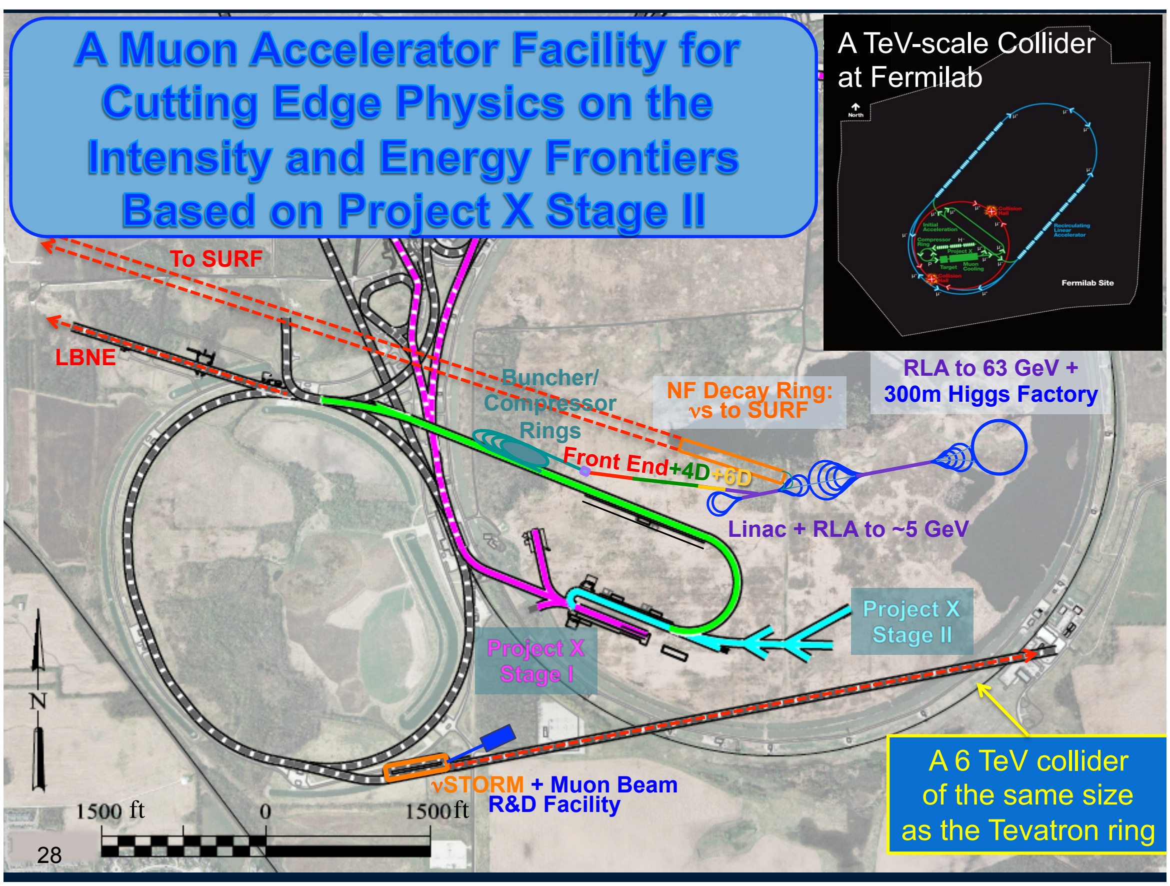
Muon Collider Parameters								
		Higgs Factory		Top Threshold Options		Multi-TeV Baselines		
Parameter	*Units*	*Startup Operation*	*Production Operation*	*High Resolution*	*High Luminosity*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	0.126	0.126	0.35	0.35	1.5	3.0	6.0
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	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/10^7sec		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

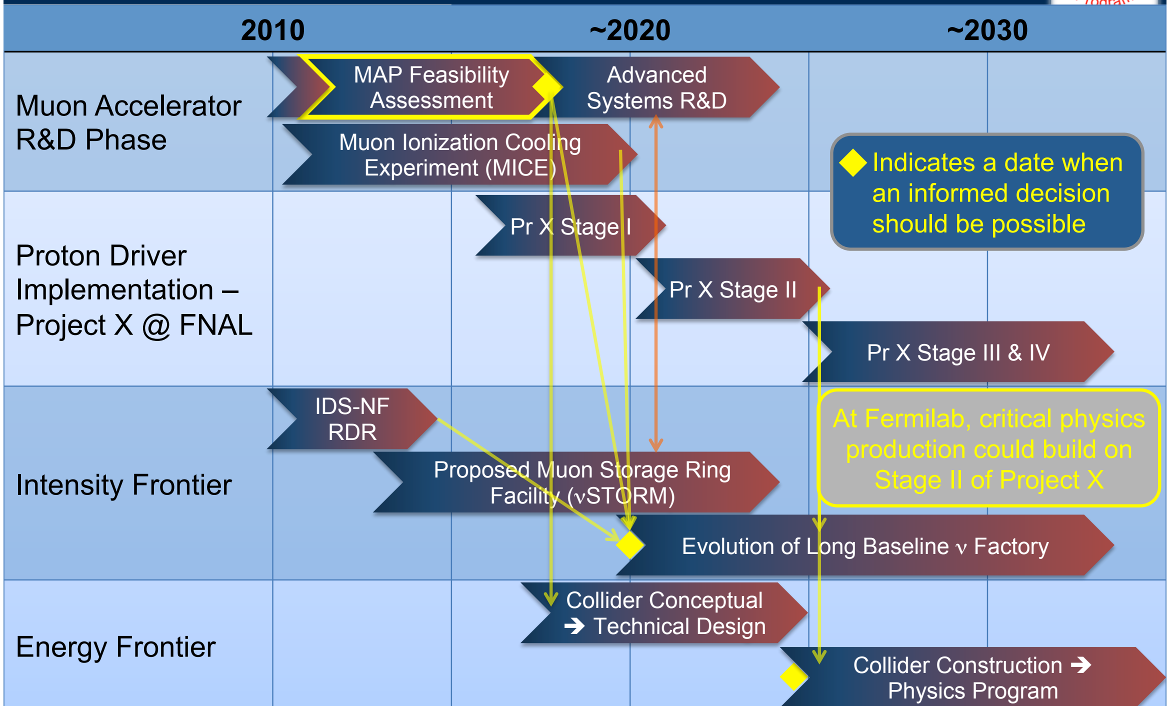
Exquisite Energy Resolution Allows Direct Measurement of Higgs Width

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

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

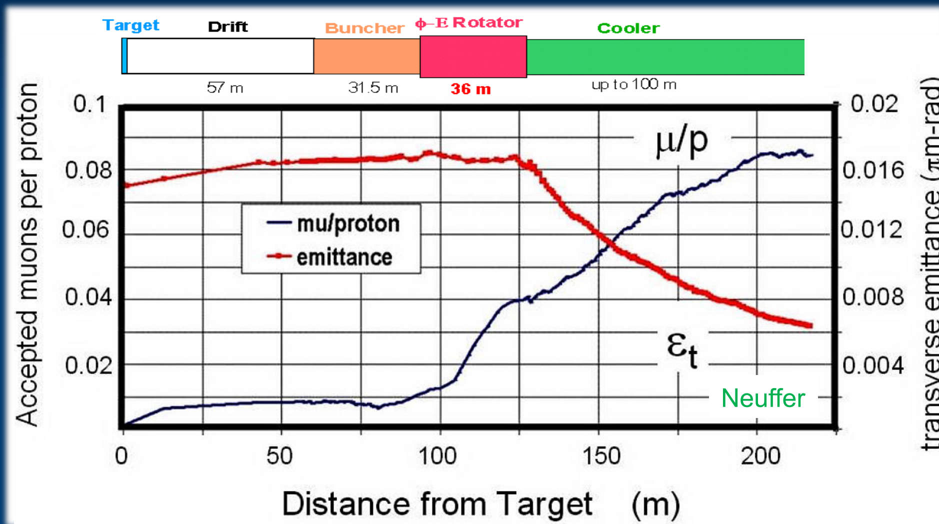


MAP Timeline ⇨ Provide Informed Decision Points



THE R&D CHALLENGES AND THE MAP FEASIBILITY ASSESSMENT

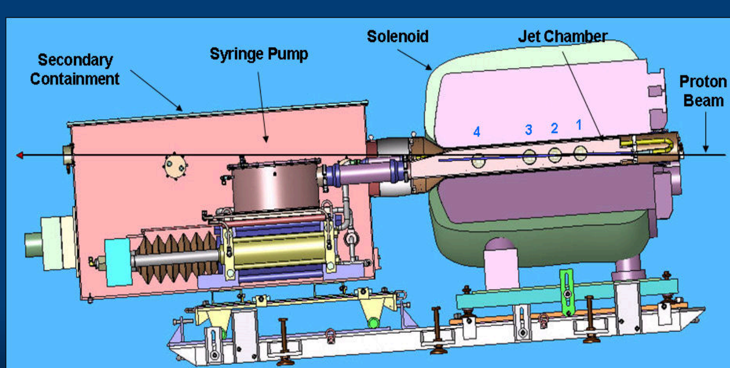
Technology Challenges – Tertiary Production

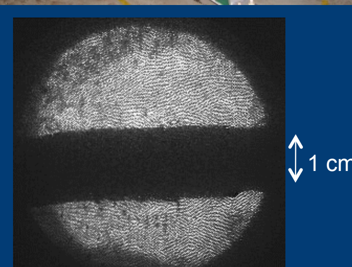


- A multi-MW proton source, *e.g.*, Project X, will enable O(10^{21}) muons/year to be produced, bunched and cooled to fit within the acceptance of an accelerator.

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

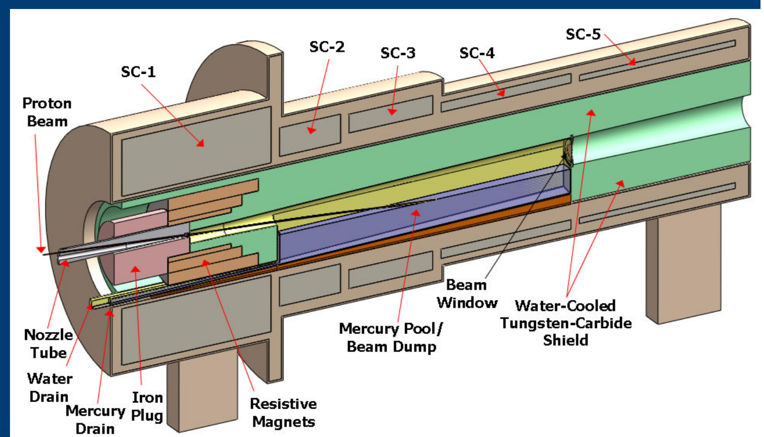
Technology Challenges – Capture Solenoid

- 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

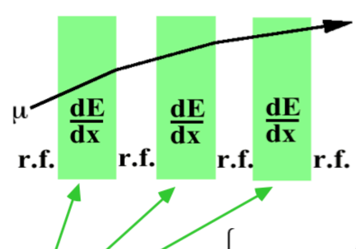
O(10MW) resistive coil in high radiation environment

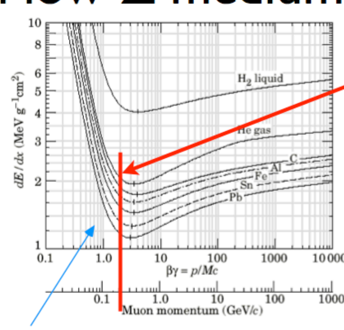
Possible application for High Temperature Superconducting magnet technology



Ionization Cooling

- Muons cool via dE/dx in low-Z medium





- ionization minimum is ≈ optimal working point:
  - longitudinal +ive feedback at lower *p*
  - straggling & expense of reacceleration at higher *p*

– Absorbers:

$$\begin{cases} E \to E - \left\langle \frac{dE}{dx} \right\rangle \Delta s \\ \theta \to \theta + \theta_{space}^{rms} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

- 2 competing effects ⇒ ∃ equilibrium emittance

– RF cavities between absorbers replace ΔE

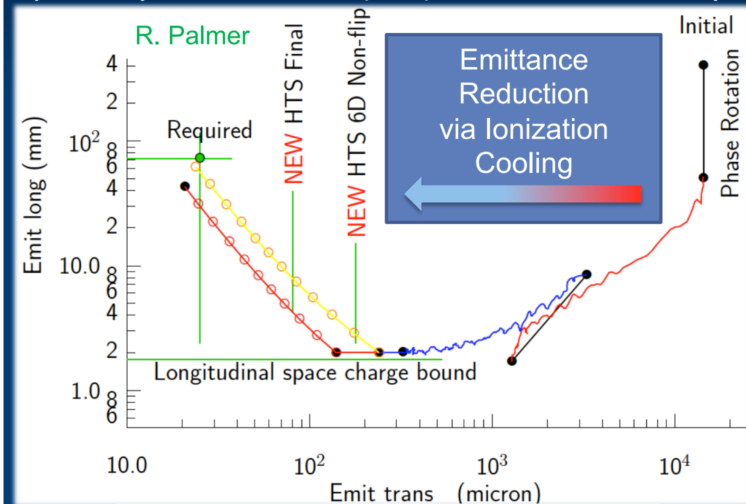
– Net effect: reduction in $p_\perp$ at constant $p_\parallel$, i.e., transverse cooling

$$\frac{d\epsilon_N}{ds} \approx -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \text{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

(emittance change per unit length)

Technology Challenges - Cooling

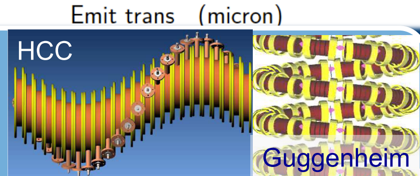
Development of a cooling channel design to reduce the 6D phase space by a factor of O(10^6) ⟶ MC luminosity of O(10^{34}) cm^{-2} s^{-1}



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

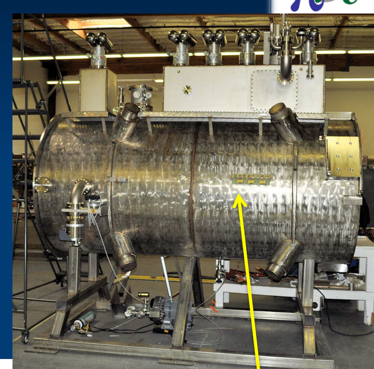
The program targets critical magnet and cooling cell technology demonstrations within its feasibility phase.

Cooling Channel Concepts

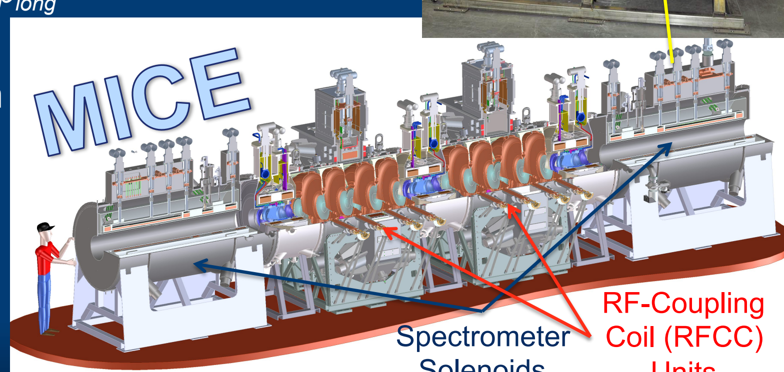


Technology Challenges - Cooling

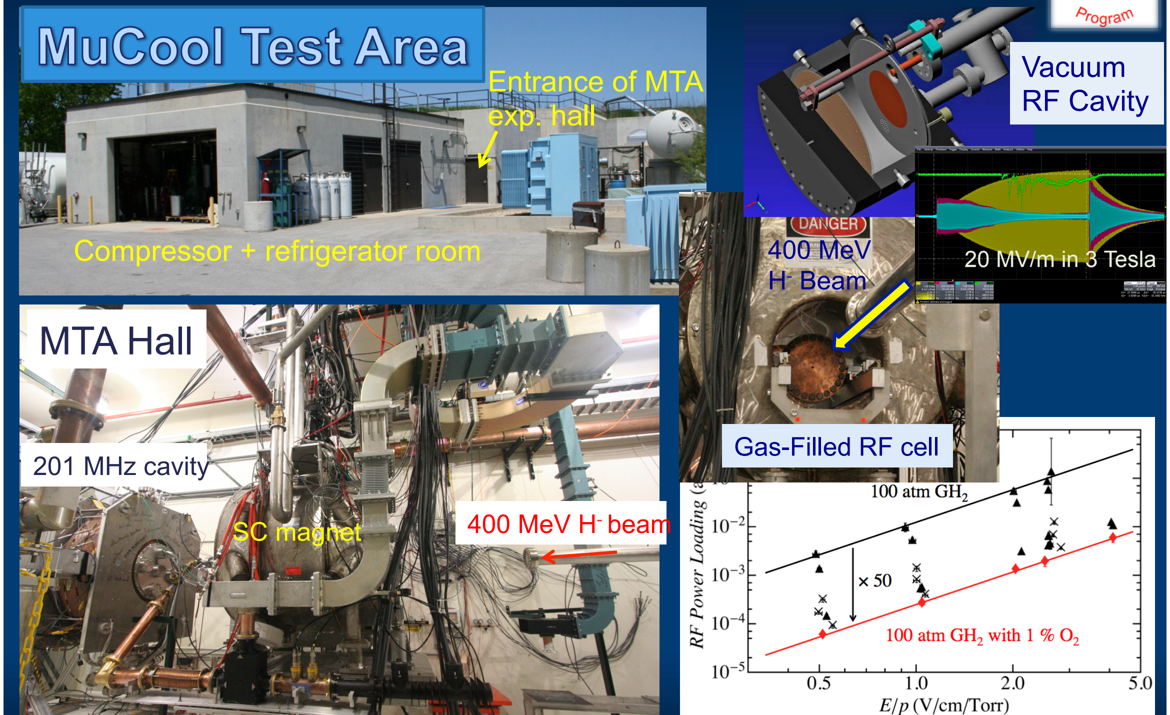
- Tertiary production of muon beams
  - Initial beam emittance intrinsically large
  - Cooling mechanism required, but no radiation damping
- Muon Cooling ⇨ Ionization Cooling
  - dE/dx energy loss in materials
  - RF to replace p_{long}



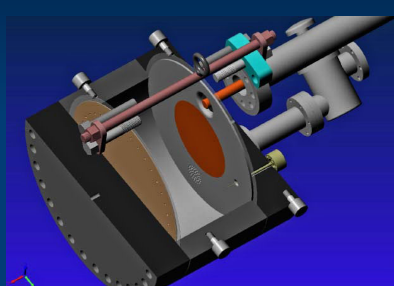
The Muon Ionization Cooling Experiment: Demonstrate the method and validate our simulations



Elements of the R&D Program



Recent Progress – Vacuum RF



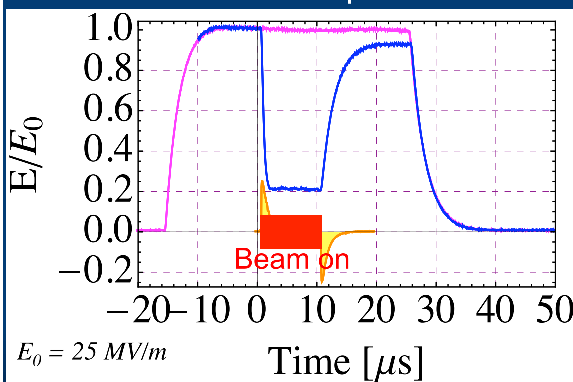
All-Seasons Cavity

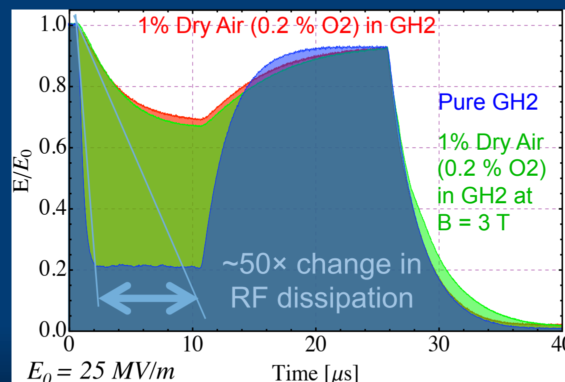
(designed for both vacuum and high pressure operation)

- Vacuum Tests at B = 0 T & B = 3 T
  - Two cycles: B_0 ⇨ B_3 ⇨ B_0 ⇨ B_3
- No difference in maximum stable operating gradient
  - Gradient ≈ 25 MV/m
- Demonstrates possibility of successful operation of vacuum cavities in magnetic fields with careful design
- *Also progress on alternative cavity materials*

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



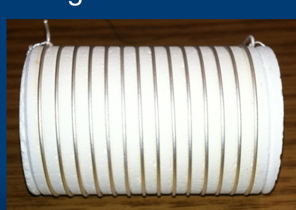


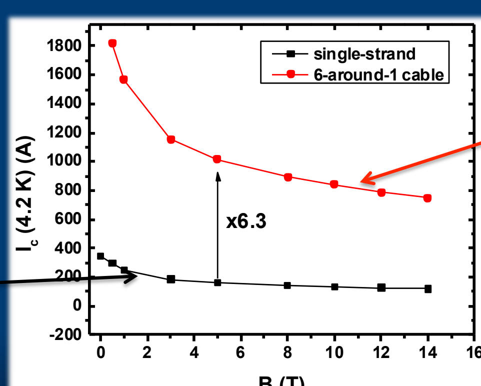
Recent Progress - High Field Magnets

Progress towards a demonstration of a final stage cooling solenoid:

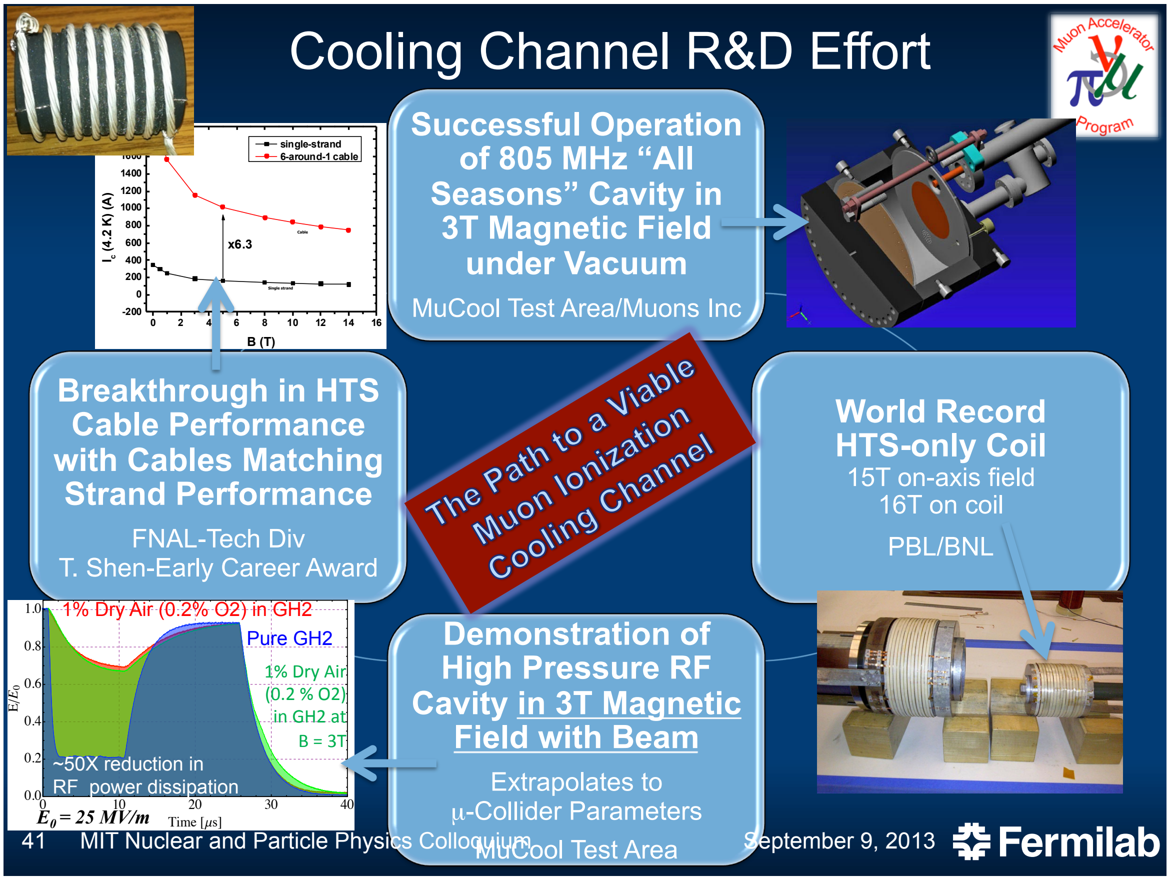
- Demonstrated 15+ T (16+ T on coil)
  - ~25 mm insert HTS solenoid
  - BNL/PBL YBCO Design
  - Highest field ever in HTS-only solenoid (by a factor of ~1.5)
- Developing a test program for operating HTS insert + mid-sert in an external solenoid ➩ >30 T

BSCCO-2212 Cable - Transport measurements show that FNAL cable attains 105% J_c of that of the single-strand

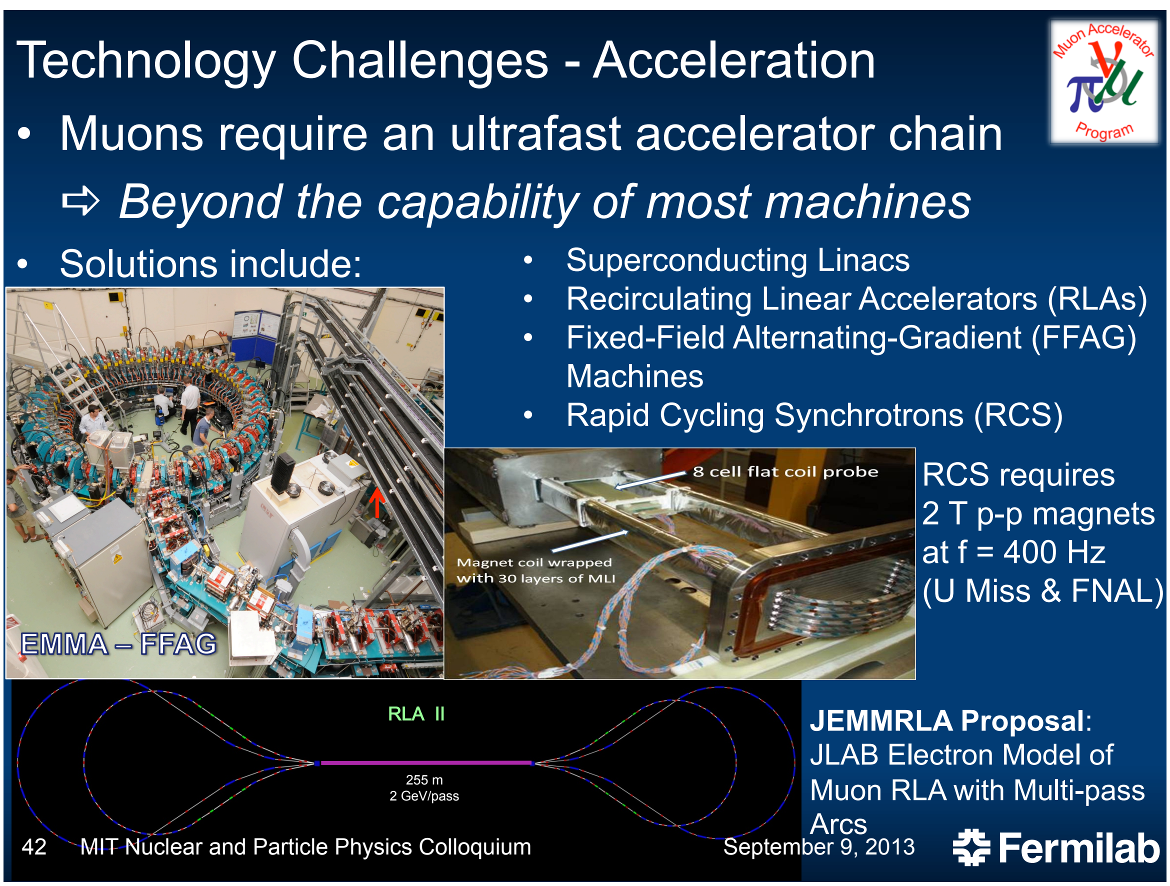




Multi-strand cable utilizing chemically compatible alloy and oxide layer to minimize cracks



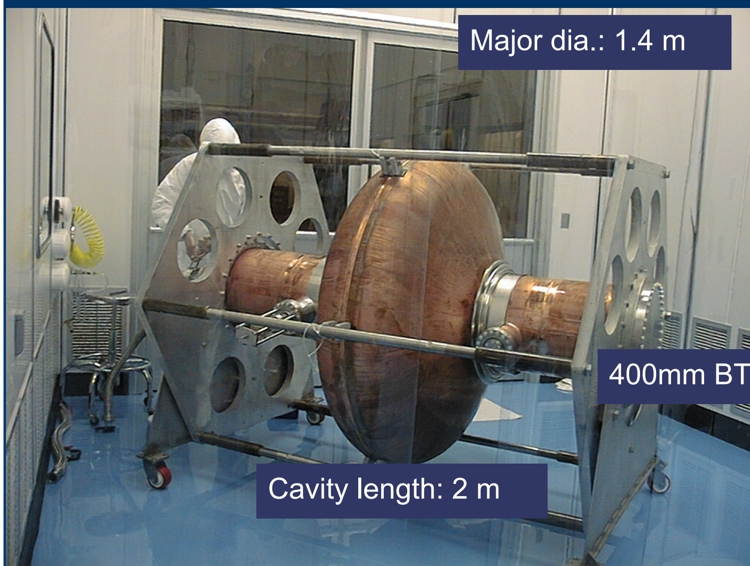
Cooling Channel R&D Effort
Muon Accelerator Program
Successful Operation of 805 MHz "All Seasons" Cavity in 3T Magnetic Field under Vacuum
MuCool Test Area/Muons Inc
single-strand
6-around-1 cable
I_c (4.2 K) (A)
B (T)
x6.3
Breakthrough in HTS Cable Performance with Cables Matching Strand Performance
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
1% Dry Air (0.2% O2) in GH2
Pure GH2
1% Dry Air (0.2 % O2) in GH2 at B = 3T
~50X reduction in RF power dissipation
E/E_0
$E_0 = 25$ MV/m
Time [μs]
Demonstration of High Pressure RF Cavity in 3T Magnetic Field with Beam
Extrapolates to μ-Collider Parameters
MuCool Test Area
41 MIT Nuclear and Particle Physics Colloquium
September 9, 2013
Fermilab

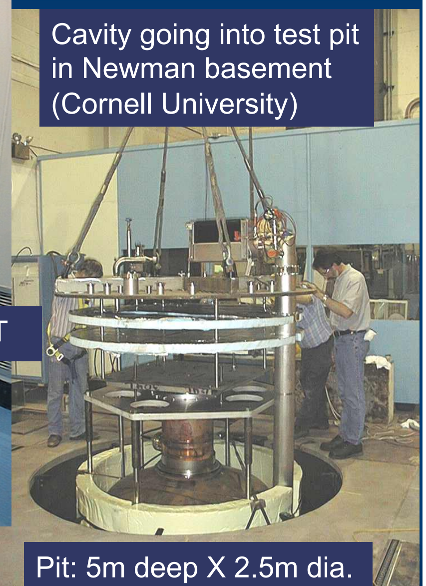


Technology Challenges - Acceleration
Muon Accelerator Program
• Muons require an ultrafast accelerator chain
⇨ Beyond the capability of most machines
• Solutions include:
• Superconducting Linacs
• Recirculating Linear Accelerators (RLAs)
• Fixed-Field Alternating-Gradient (FFAG) Machines
• Rapid Cycling Synchrotrons (RCS)
EMMA – FFAG
8 cell flat coil probe
Magnet coil wrapped with 30 layers of MLI
RCS requires 2 T p-p magnets at f = 400 Hz (U Miss & FNAL)
RLA II
255 m
2 GeV/pass
JEMMRLA Proposal: JLAB Electron Model of Muon RLA with Multi-pass Arcs
42 MIT Nuclear and Particle Physics Colloquium
September 9, 2013
Fermilab

Superconducting RF Development

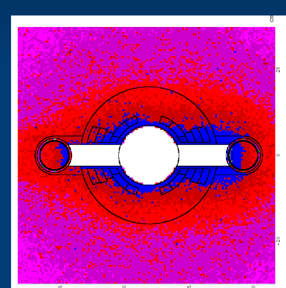
201 MHz SCRF R&D



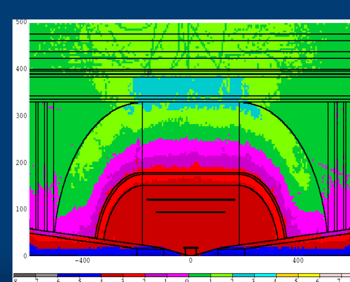


Technology & Design Challenges – Ring, Magnets, Detector

- Emittances are relatively large, but muons circulate for ~1000 turns before decaying
  - Lattice studies for 126 GeV, 1.5 & 3 TeV CoM
- High field dipoles and quadrupoles must operate in high-rate muon decay backgrounds
  - Magnet designs under study
- Detector shielding & performance
  - Initial studies for 1.5 TeV, then 3 TeV and 126 GeV
  - Shielding configuration
  - MARS background simulations

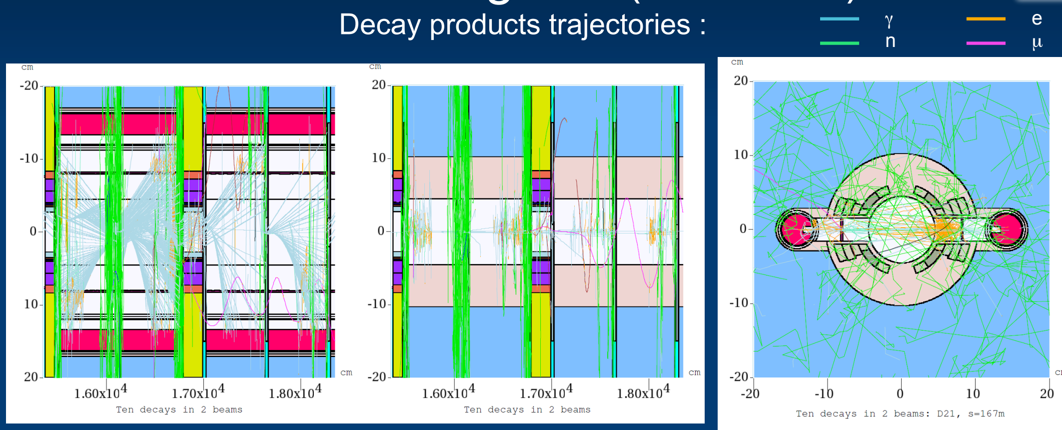


MARS energy deposition map for 1.5 TeV collider dipole



Technology Challenges:
Heat Load in Arc Magnets (N.Mokhov)

Decay products trajectories :



Horizontal view | Vertical view | Cross-section view

Energy deposition: in the ring dipole cold mass @LHe temp 25 W/m - a factor of ~5 too high!
W rods 80 W/m
in the quadrupole cold mass @LHe temp 38 W/m
in masks between magnets 1.5-3 kW/m

Solutions:

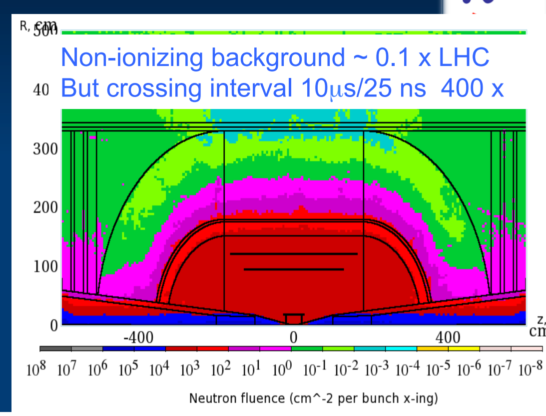
- abandon the open-midplane design, put W absorber inside the dipole bore
- sweep away the decay electrons before they obtain considerable vertical displacement: use combined-function magnets

Backgrounds and Detector

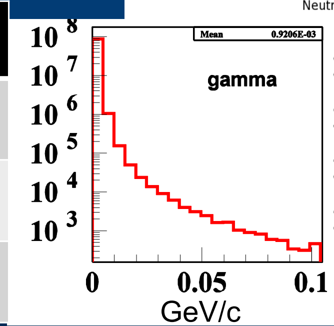
Much of the background is soft and out of time

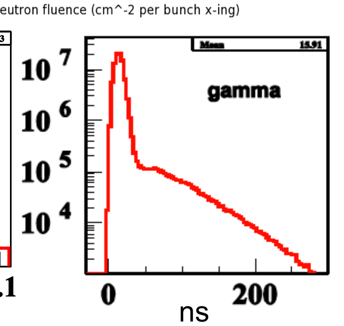
- Nanosecond time resolution can reduce backgrounds by three orders of magnitude

Requires a fast, pixelated tracker and calorimeter.



	Cut	Rejection
Tracker hits	1 ns, dedx	$9x10^{-4}$
Calorimeter neutrons	2 ns	$2.4x10^{-3}$
Calorimeter photons	2 ns	$2.2x10^{-3}$





The Feasibility Assessment I

- MAP was originally proposed as an ~7 year effort to evaluate the feasibility of Neutrino Factory and Muon Collider Technologies
  - Feasibility Assessment Phase in 2 parts
    - Phase I: FY13-15
    - Phase II: FY16-18
  - Approach
    - Establish baseline concepts for each segment of the complex
      - Prepare baseline design specifications that can be employed in the MAP Technical Demonstrations
      - Evaluate realistic performance parameters from those baselines
      - ***Verify feasibility***
    - Continue to pursue alternative options
      - In particular, there exist alternative designs that hold the promise of significantly enhanced performance
      - However, the capability (and funds) to implement demonstrations may well be beyond the reach of the feasibility assessment phase of the program

The Feasibility Assessment II

Feasibility Assessment: Phase I

FY13 – FY15:
- Identify ***baseline*** design concepts
- Identify high leverage ***alternative*** concepts
- Identify key engineering paths to pursue:
  - RF
  - High Field Magnets
- Develop critical engineering concepts (eg, 6D Cooling Cell)
- Support major systems tests
  - MICE Step IV
  - MICE RFCC construction & testing

Feasibility Assessment: Phase II

FY16 – FY18:
- Technical demonstration of critical ***baseline*** concepts
  - eg, 6D Cooling cell
- Pursue high leverage ***alternative*** concepts
- Assess technical and cost feasibility of ***baseline*** concepts
- Support major systems tests
  - MICE Step V/VI
  - 6DICE planning

Beyond the Feasibility Assessment

FY19 →
- Plan contingent on the feasibility assessment!
- Can we launch the design effort towards a staged implementation of a NF & MC?
- Advanced systems tests
  - 6DICE?
  - Support physics?

CONCLUDING REMARKS

Some Thoughts…

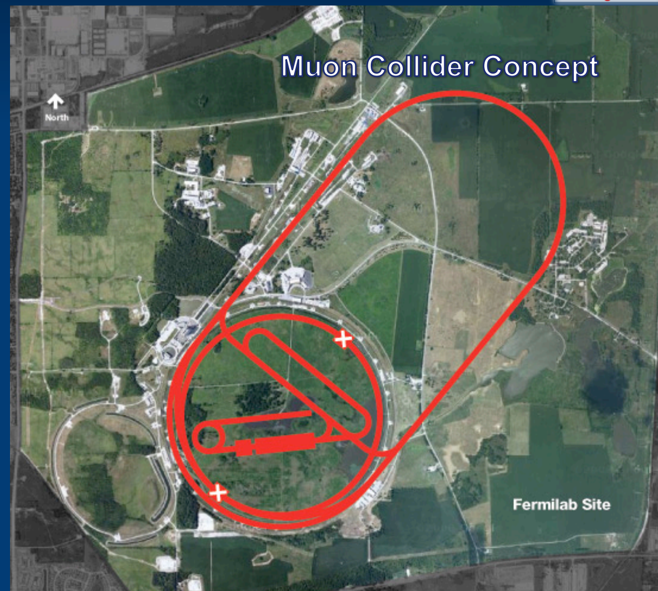
- The unique feature of muon accelerators is the ability to provide cutting edge performance on both the Intensity and Energy Frontiers
  - This is well-matched to the direction specified by the P5 panel for Fermilab
  - The possibilities for a staged approach make this particularly appealing in a time 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!

Muon Accelerator Program Contacts

- MAP Web-Site: http://map.fnal.gov/
- MAP Management Team:

  Mark Palmer, Director: mapalmer@fnal.gov

  Robert Ryne, L1 Manager for Design and Simulation: rdryne@lbl.gov

  Alan Bross, L1 Manager for Technology Development: bross@fnal.gov

  Daniel Kaplan, L1 Manager for Systems Demonstrations: kaplan@iit.edu

  Ron Lipton, L1 Manager for Detectors and Physics: lipton@fnal.gov
- US HEP Community Planning Effort

  Jean-Pierre Delahaye, Muon Accelerator Staging Study jpd@slac.stanford.edu

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 a year ago

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