Muon colliders have been promised for many years but muon cooling still has not delivered more than 10% phase space reduction. A muon collider needs phase space reduction by $10^6$.

What is the path to get there?

Mark Palmer
August 2, 2013
The U.S. Muon Accelerator Program

**Neutrino Factory**

- Proton Driver
- Target
- Front End
- Acceleration
- \( \mu \) Storage Ring

Share same complex

**Muon Collider**

- Proton Driver
- Target
- Front End
- Cooling
- Acceleration
- Collider Ring

ν Factory Goal: \( \mathcal{O}(10^{21}) \) \( \mu \)/year within the accelerator acceptance

\( \mu \)-Collider Goals:
- ~14,000 Higgs/yr
- Multi-TeV
- Lumi > 10^{34} cm^{-2}s^{-1}

Accelerators: Linac, RLA or FFAG

Accelerators: Linac, RLA or FFAG, RCS
Elements of the R&D Program

MuCool Test Area

Compressor + refrigerator room

Entrance of MTA exp. hall

201 MHz cavity

SC magnet

MTA exp. hall

MICE

RF-Coupling Coil (RFCC) Units

Spectrometer Solenoids
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

~50X reduction in RF power dissipation

\[ E_0 = 25 \text{ MV/m} \]

Time [μs]

E/E_0
The $\nu$ Sector

We want to provide the option to get here
## Muon Collider Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Higgs Factory</th>
<th>Top Threshold Options</th>
<th>Multi-TeV Baselines</th>
<th>Accounts for Site Radiation Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoM Energy</td>
<td>TeV</td>
<td>0.126</td>
<td>0.35</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Avg. Luminosity</td>
<td>$10^{34}$ cm$^{-2}$s$^{-1}$</td>
<td>0.0017</td>
<td>0.07</td>
<td>1.25</td>
<td>12</td>
</tr>
<tr>
<td>Beam Energy Spread</td>
<td>%</td>
<td>0.003</td>
<td>0.01</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Higgs* or Top* Production/10$^7$ sec</td>
<td></td>
<td>3,500*</td>
<td>7,000*</td>
<td>37,500*</td>
<td>820,000*</td>
</tr>
<tr>
<td>Circumference</td>
<td>km</td>
<td>0.3</td>
<td>0.7</td>
<td>2.5</td>
<td>6</td>
</tr>
<tr>
<td>No. of IPs</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>Hz</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>12</td>
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<tr>
<td>$\beta^*$</td>
<td>cm</td>
<td>3.3</td>
<td>1.5</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>No. muons/bunch</td>
<td>10$^2$</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>No. bunches/beam</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Norm. Trans. Emittance, $\varepsilon_{TN}$</td>
<td>mm-rad</td>
<td>0.4</td>
<td>0.2</td>
<td>0.05</td>
<td>0.025</td>
</tr>
<tr>
<td>Norm. Long. Emittance, $\varepsilon_{LN}$</td>
<td>mm-rad</td>
<td>1</td>
<td>1.5</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>Bunch Length, $\sigma_z$</td>
<td>cm</td>
<td>5.6</td>
<td>0.9</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Proton Driver Power</td>
<td>MW</td>
<td>4$^#$</td>
<td>4</td>
<td>4</td>
<td>1.6</td>
</tr>
</tbody>
</table>

* Could begin operation with Project X Stage II beam

- Exquisite Energy Resolution Allows Direct Measurement of Higgs Width
- Success of advanced cooling concepts $\Rightarrow$ several $\times 10^{32}$
- Site Radiation mitigation with depth and lattice design: $\leq 10$ TeV
### MAP Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Muon Accelerator R&amp;D Phase</td>
</tr>
<tr>
<td></td>
<td>MAP Feasibility Assessment</td>
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<tr>
<td></td>
<td>Advanced Systems R&amp;D</td>
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<tr>
<td></td>
<td>Muon Ionization Cooling Experiment (MICE)</td>
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<tr>
<td>2020</td>
<td>Proton Driver Implementation – Project X @ FNAL</td>
</tr>
<tr>
<td></td>
<td>Pr X Stage I</td>
</tr>
<tr>
<td></td>
<td>Pr X Stage II</td>
</tr>
<tr>
<td></td>
<td>Pr X Stage III &amp; IV</td>
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<tr>
<td></td>
<td>Evolution of Long Baseline ν Factory</td>
</tr>
<tr>
<td>2030</td>
<td>At Fermilab, critical physics production could build on Stage II of Project X</td>
</tr>
</tbody>
</table>

#### Notes:
- Indicates a date when an informed decision should be possible.
A Muon Accelerator Facility for Cutting Edge Physics on the Intensity and Energy Frontiers Based on Project X Stage II

A TeV-scale Collider at Fermilab

A 1.5 TeV collider would fit within the Tevatron ring
The Aims of the 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*