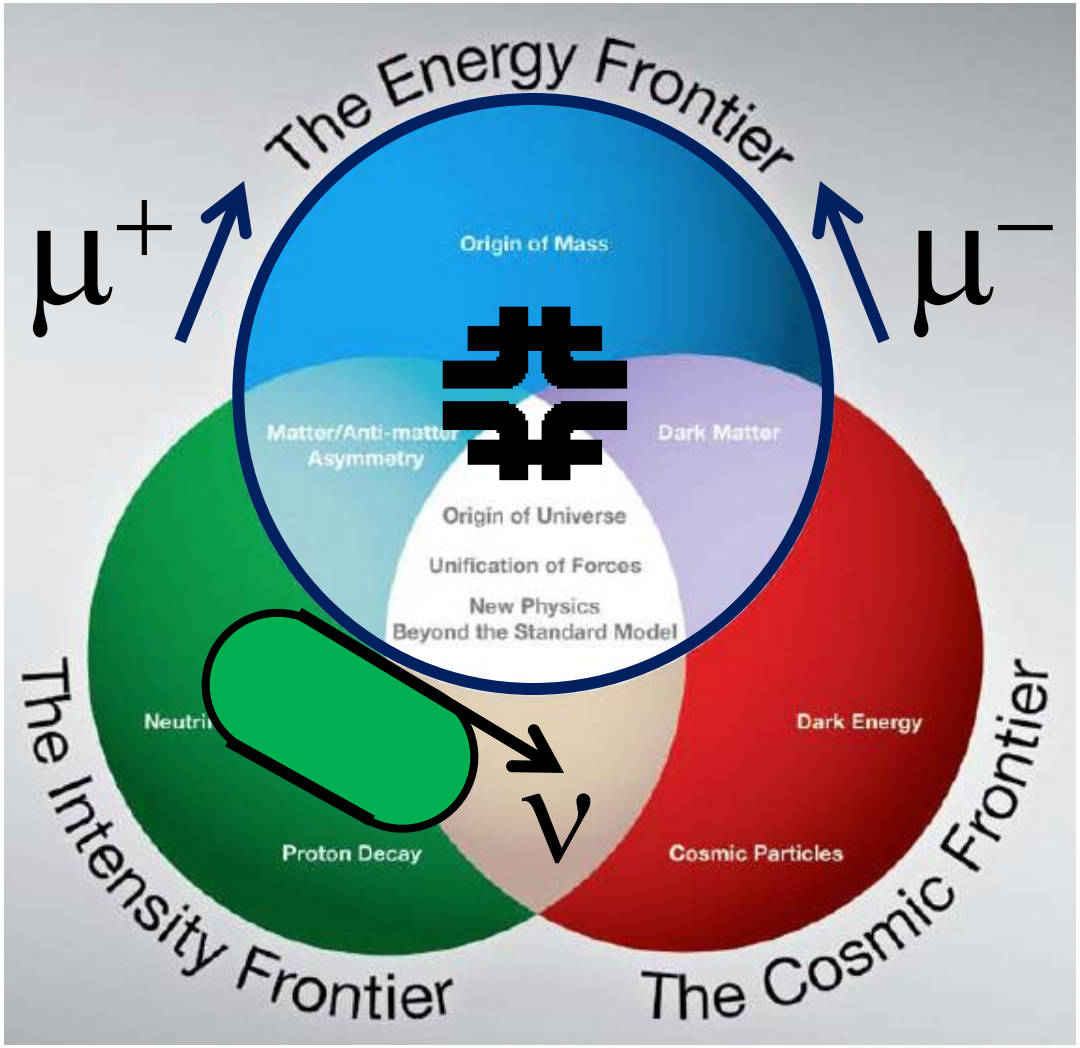
U.S. Muon Accelerator R&D



Muon Accelerator Program (MAP)

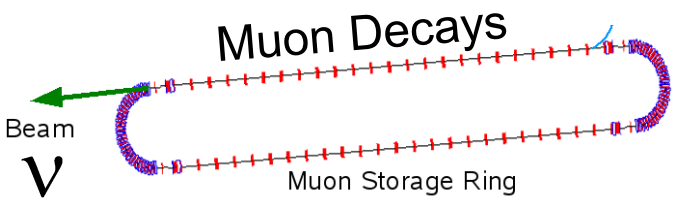
MUON COLLIDER & NEUTRINO FACTORY R&D

Introduction

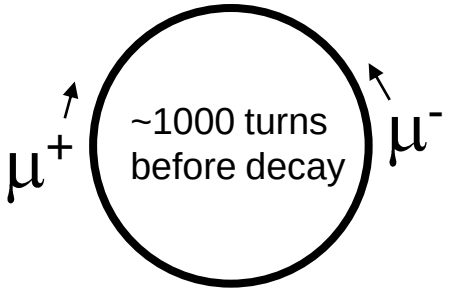
Over the last decade there has been significant progress in developing the concepts & technologies required to create a muon source that would provide $O(10^{21})$ muons per year within a 6D-phase-space that fits within the acceptance of an accelerator.

This enabling R&D opens the way for:

NEUTRINO FACTORIES in which muons decaying in the straight section of a storage ring create a neutrino beam with unique properties for precision neutrino oscillation measurements.



MUON COLLIDERS in which positive & negative muons collide in a storage ring to produce lepton-antilepton collisions up to multi-TeV energies.



NFMCC, MCTF and MAP

Muon Collider (MC) & Neutrino Factory (NF) R&D has been pursued in the U.S. by:

- -Neutrino Factory and Muon Collider Collaboration (NFMCC) since 1996
- -Fermilab Muon Collider Task Force (MCTF) since 2006

The NFMCC & MCTF R&D programs have been coordinated by the "Muon Collider Coordination Committee" comprising the NFMCC+MCTF leadership

The NF part of the R&D has been internationalized, and is being pursued within the context of the International Design Study for a Neutrino Factory (IDS-NF) which aspires to deliver a Reference Design Report by ~2013.

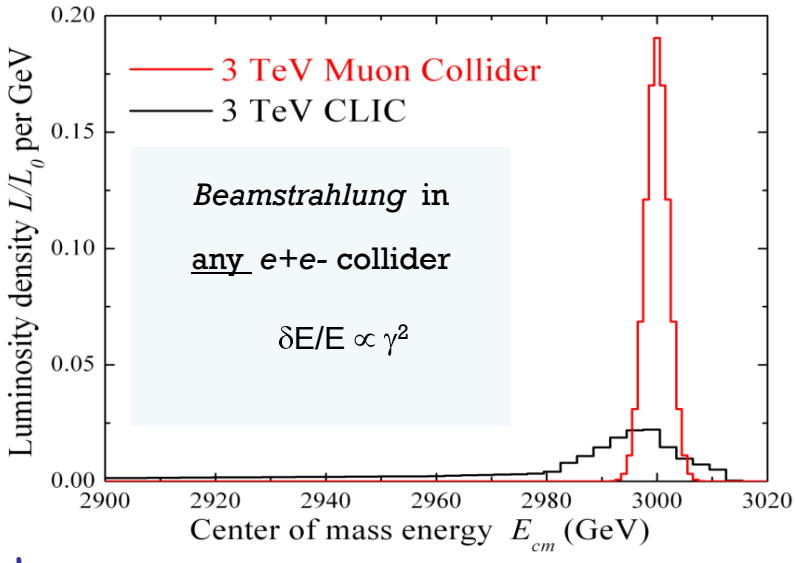
In the U.S. the NFMCC + MCTF activities are being merged into a new national organization (MAP) to pursue MC & NF R&D, hosted at Fermilab.

Muon Collider Motivation

- If we can build a muon collider, it is an attractive multi-TeV lepton collider option because muons don't radiate as readily as electrons (m_μ / m_e ~ 207):

COST

- COMPACT
  Fits on laboratory site
- MULTI-PASS ACCELERATION
  Cost Effective
- MULTIPASS COLLISIONS IN A RING (~1000 turns)
  Relaxed emittance requirements & hence relaxed tolerances



PHYSICS

- NARROW ENERGY SPREAD
  Precision scans, kinematic constraints
- TWO DETECTORS (2 IPs)
- ΔT_{bunch} ~ 10 μs … (e.g. 4 TeV collider)
  Lots of time for readout
  Backgrounds don't pile up
- $(m_\mu/m_e)^2$ = ~40000
  Enhanced s-channel rates for Higgs-like particles

Challenges

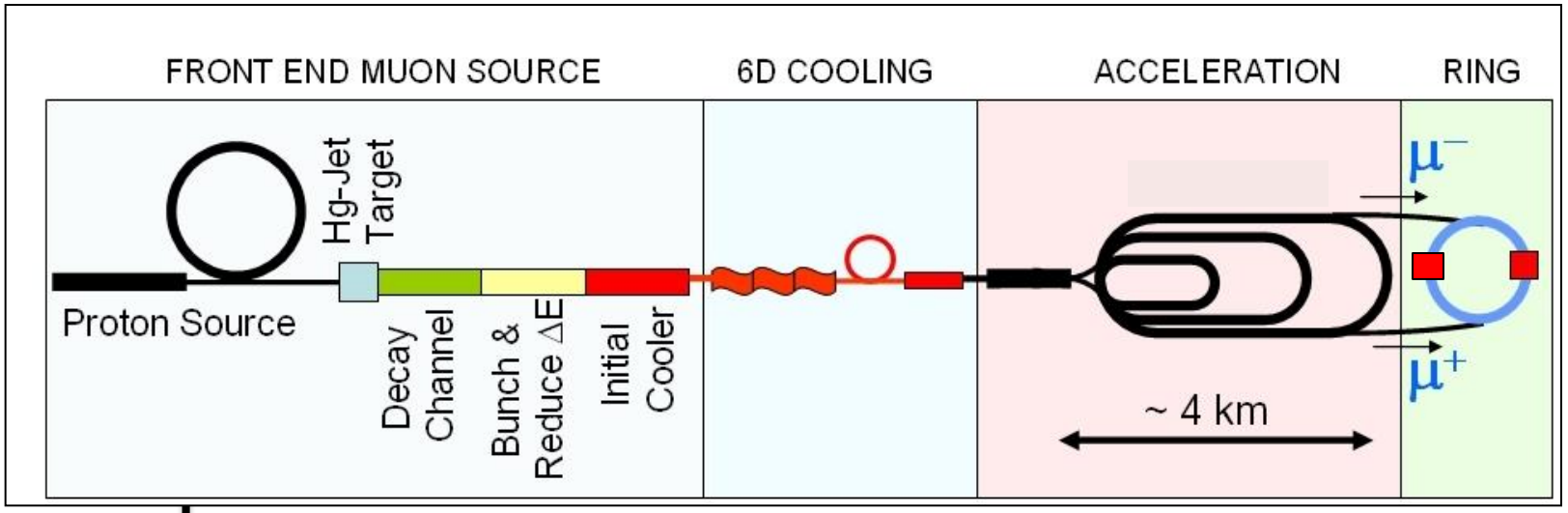
Muons are born ($\pi \rightarrow \mu\nu$) within a large phase space

- To obtain luminosities $O(10^{34})$ $cm^{-2}s^{-1}$, need to reduce initial phase space by $O(10^{6})$

Muons Decay ($\tau_0 = 2\mu s$)

- Everything must be done fast
  - → need ionization cooling
- Must deal with decay electrons
- Above ~3 TeV, must be careful about decay neutrinos !

Muon Collider Schematic

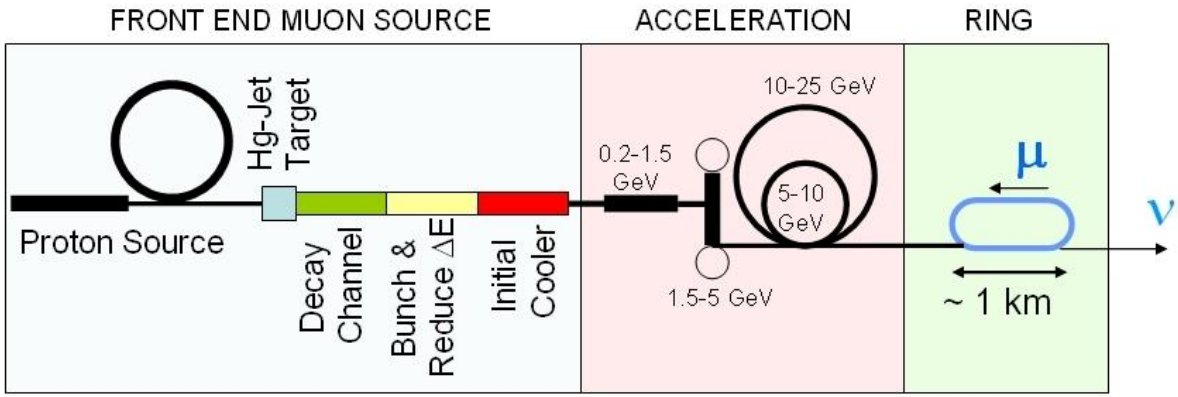


Proton source: Upgraded PROJECT X (4 MW, 2±1 ns long bunches)

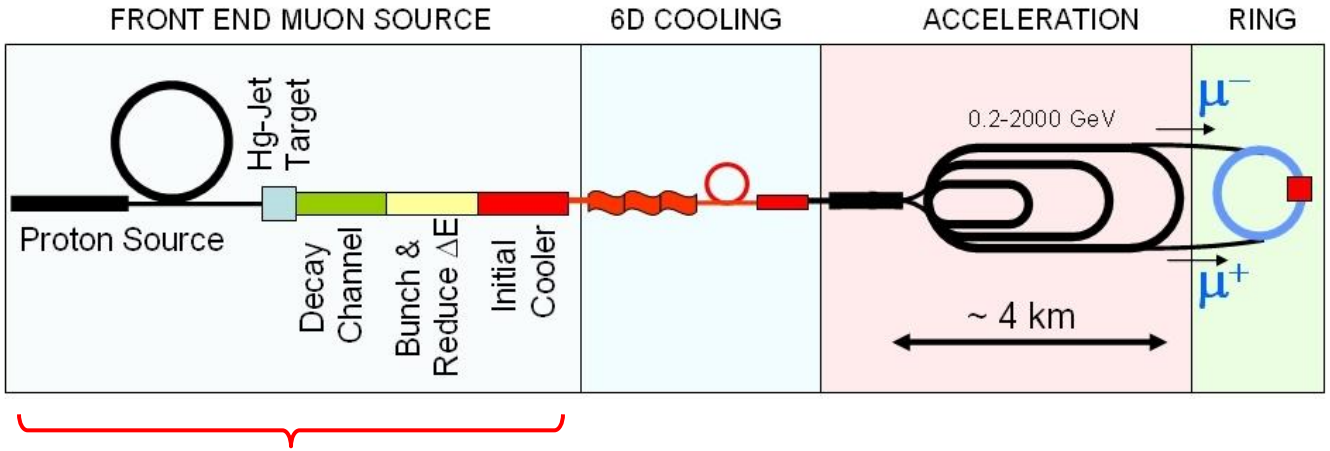
10^{21} muons per year that fit within the acceptance of an accelerator

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

Neutrino Factory c.f. Muon Collider



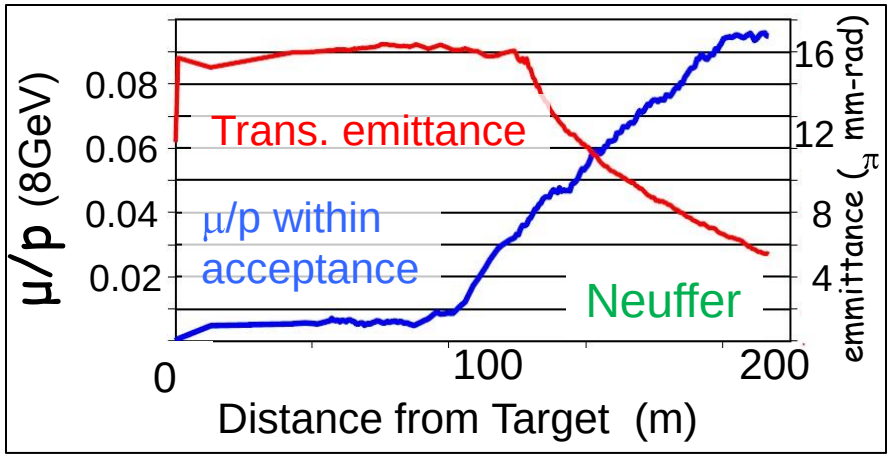
NEUTRINO FACTORY



MUON COLLIDER

In present MC baseline design, Front End is same as for NF

Achievements – Concepts

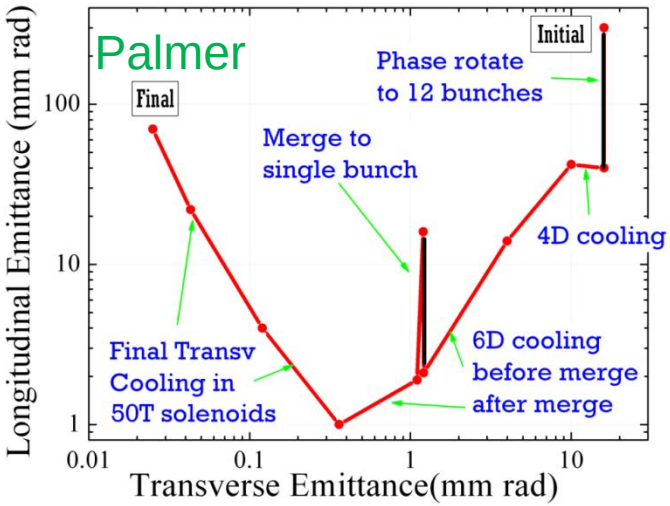


Front-End concept (up to initial cooling) developed & simulated:
- Requires development of RF cavities within few Tesla fields.

Complete self-consistent 6D cooling channel concept exists, with several candidate variants partly simulated:
- Technologies must be developed & performance established

Acceleration (Bogacz)
- Low energy: IDS-NF scheme
-High energy: e.g. rapid cycling syncrotron → magnet R&D (Summers)

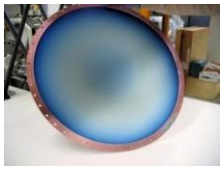
Collider Ring (Alexahin, Gianfelice-Wendt)
- Good progress on 1.5 TeV lattice with 1.2% momentum acceptance, 4.7σ dynamic aperture.



Achievements - Technologies



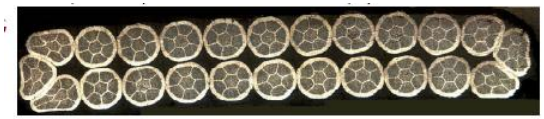
MUCOOL Test Area built at FNAL for ionization cooling component testing:
5T magnet, RF power at 805MHz & 201MHz, LH2 handling capability, 400MeV beam from linac.


42cm ∅ Be RF window (LBNL)


HCC magnet tests (FNAL – TD)

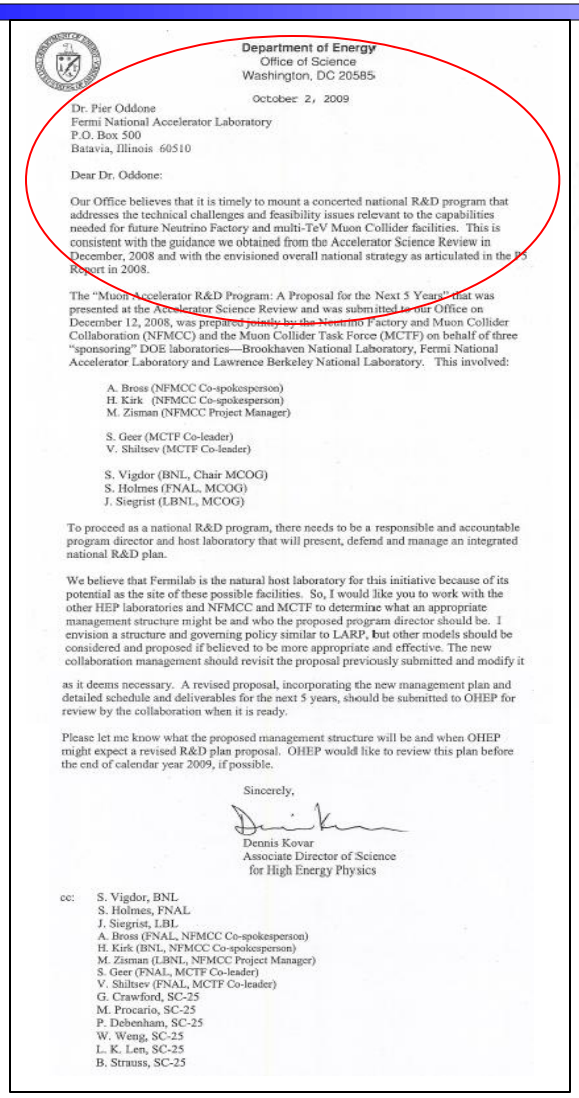


201 MHz RF cavities for MuCool & MICE R&D (LBNL et al.)



HTS cable R&D (FNAL – TD)

MAP Initiative



Department of Energy
Office of Science
Washington, DC 20585

October 2, 2009

Dr. Pier Oddone
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Dear Dr. Oddone:

Our Office believes that it is timely to mount a concerted national R&D program that addresses the technical challenges and feasibility issues relevant to the capabilities needed for future Neutrino Factory and multi-TeV Muon Collider facilities. This is consistent with the guidance we obtained from the Accelerator Science Review in December, 2008 and with the envisioned overall national strategy as articulated in the P5 Report in 2008.

The "Muon Accelerator R&D Program: A Proposal for the Next 5 Years" that was presented at the Accelerator Science Review and was submitted to our Office on December 12, 2008, was prepared jointly by the Neutrino Factory and Muon Collider Collaboration (NFMCC) and the Muon Collider Task Force (MCTF) on behalf of three "sponsoring" DOE laboratories—Brookhaven National Laboratory, Fermi National Accelerator Laboratory and Lawrence Berkeley National Laboratory. This involved:

A. Bross (NFMCC Co-spokesperson)
H. Kirk (NFMCC Co-spokesperson)
M. Zisman (NFMCC Project Manager)

S. Geer (MCTF Co-leader)
V. Shiltsev (MCTF Co-leader)

S. Vigdor (BNL, Chair MCOG)
S. Holmes (FNAL, MCOG)
J. Siegrist (LBNL, MCOG)

To proceed as a national R&D program, there needs to be a responsible and accountable program director and host laboratory that will present, defend and manage an integrated national R&D plan.

We believe that Fermilab is the natural host laboratory for this initiative because of its potential as the site of these possible facilities. So, I would like you to work with the other HEP laboratories and NFMCC and MCTF to determine what an appropriate management structure might be and who the proposed program director should be. I envision a structure and governing policy similar to LARP, but other models should be considered and proposed if believed to be more appropriate and effective. The new collaboration management should revisit the proposal previously submitted and modify it as it deems necessary. A revised proposal, incorporating the new management plan and detailed schedule and deliverables for the next 5 years, should be submitted to OHEP for review by the collaboration when it is ready.

Please let me know what the proposed management structure will be and when OHEP might expect a revised R&D plan proposal. OHEP would like to review this plan before the end of calendar year 2009, if possible.

Sincerely,

Dennis Kovar
Associate Director of Science
for High Energy Physics

cc: S. Vigdor, BNL
S. Holmes, FNAL
J. Siegrist, LBL
A. Bross (FNAL, NFMCC Co-spokesperson)
H. Kirk (BNL, NFMCC Co-spokesperson)
M. Zisman (LBNL, NFMCC Project Manager)
S. Geer (FNAL, MCTF Co-leader)
V. Shiltsev (FNAL, MCTF Co-leader)
G. Crawford, SC-25
M. Procario, SC-25
P. Debenham, SC-25
W. Weng, SC-25
L. K. Len, SC-25
B. Strauss, SC-25

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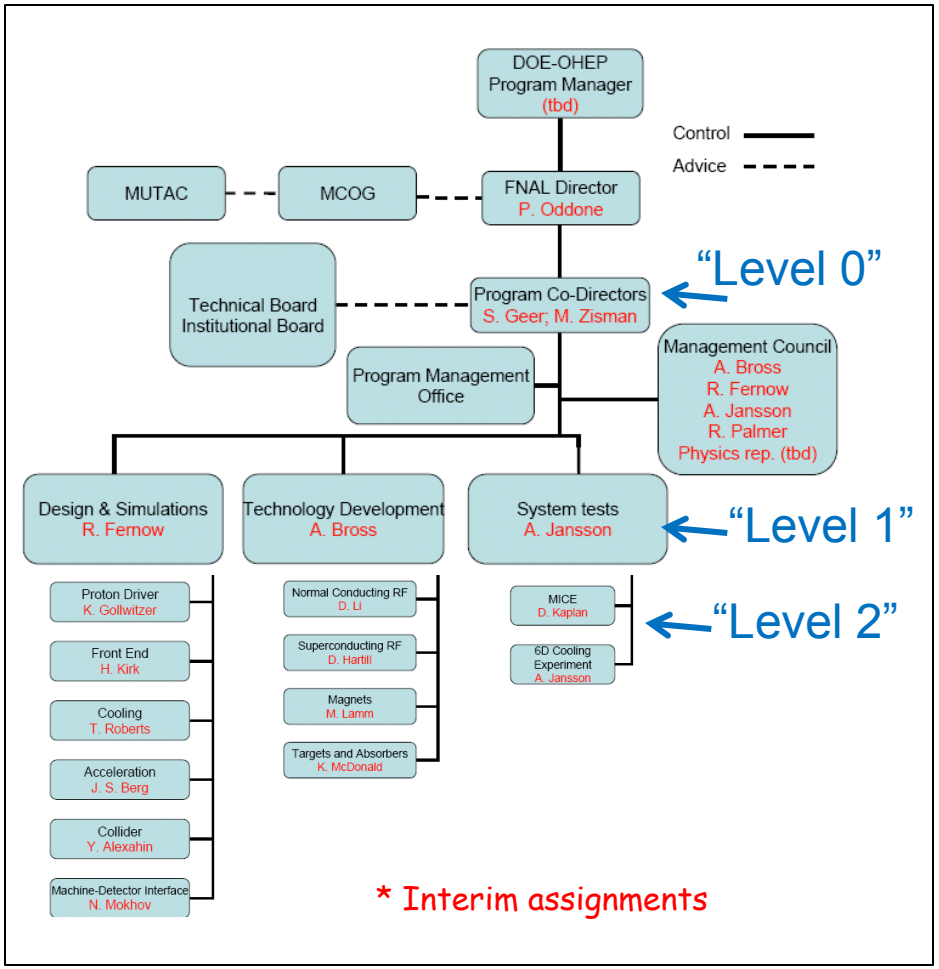
Muon Accelerator Program
MAP

MAP Organization & Proposal



Submitted by Pier Oddone on behalf of the MAP collaboration, 1st March 2010.

214 MAP participants (at birth) from 14 institutions:

ANL, BNL, FNAL, Jlab, LBNL, ORNL, SLAC, Cornell, IIT, Princeton, UCB, UCLA, UCR, U-Miss.

Anticipate a DOE-OHEP review soon.

MAP Goals & Deliverables

Deliverables in 6-7 years:

-Muon Collider Design Feasibility Report (FY16)

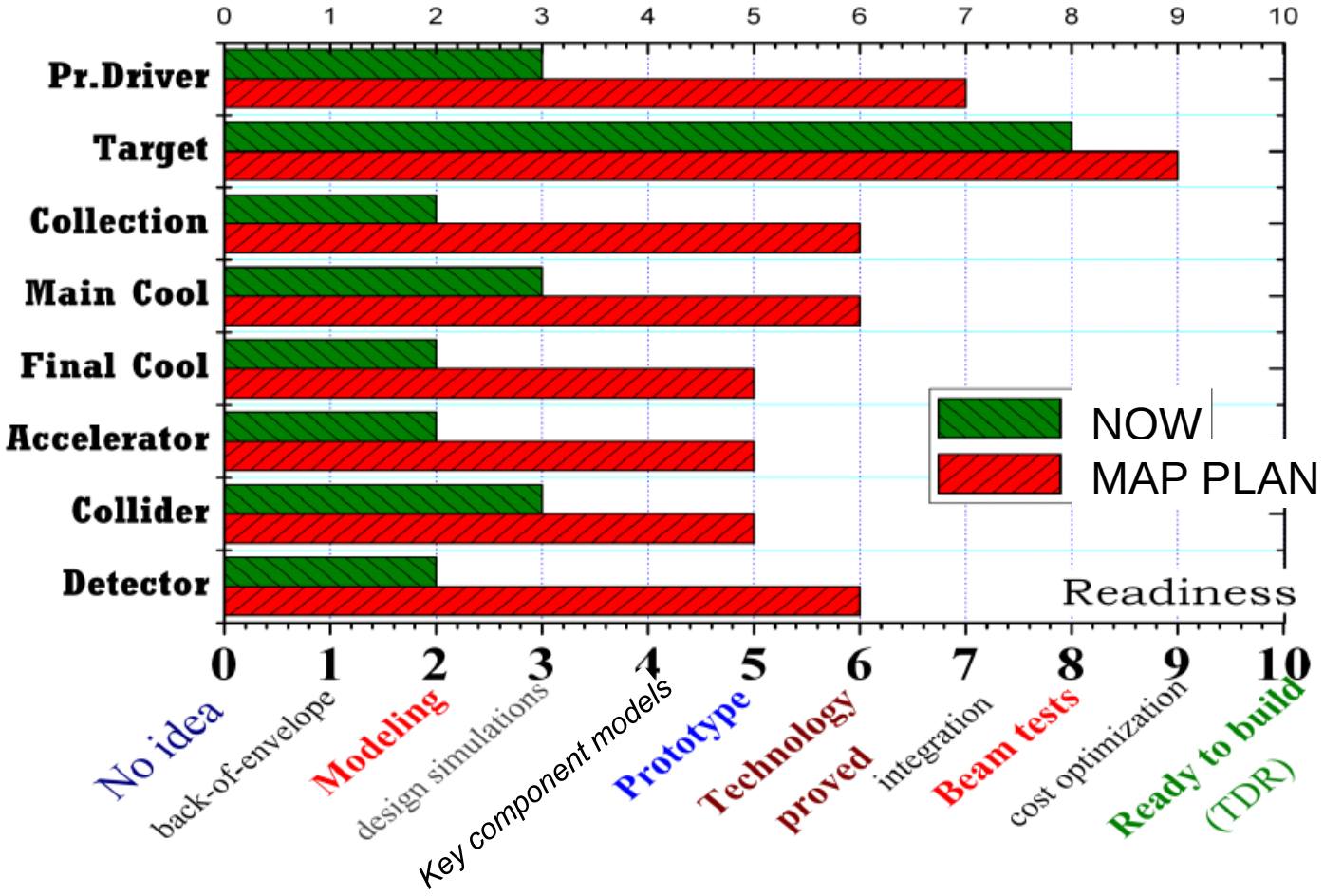
- Hardware R&D results → technology choice
- MC Cost range (FY16)
- Also contributions to the IDS-NF RDR (FY14)

Will address key R&D issues, including

- Maximum RF gradients in magnetic field
- Magnet designs for cooling, acceltn, collider
- 6D cooling section prototype & bench test
- Full start-to-end simulations based on technologies in hand, or achievable with a specified R&D program

Impact of the MAP Plan

Muon Collider Development



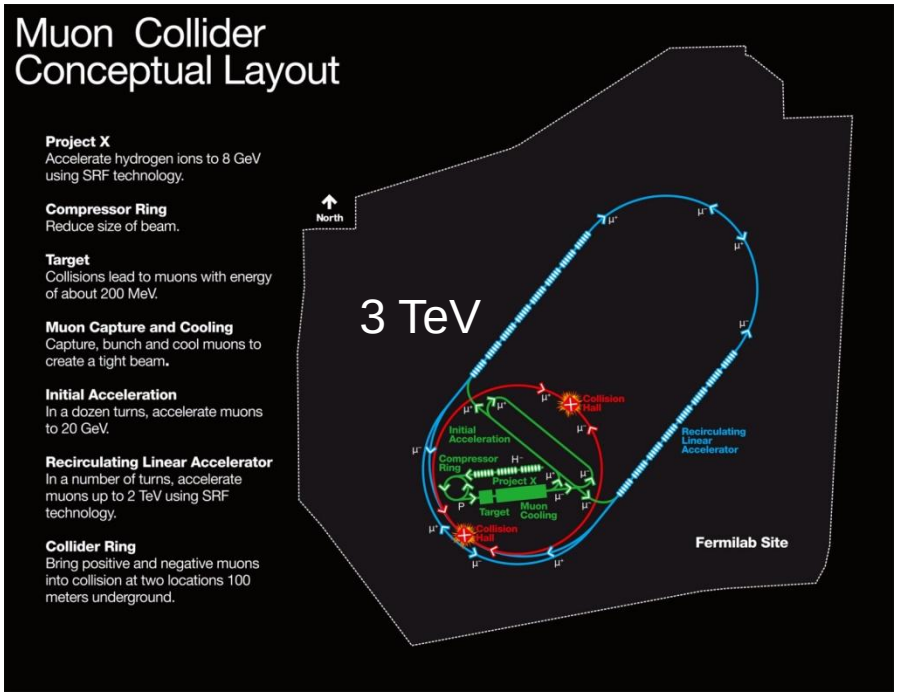
+ NF RDR

Finally …

There is a muon-based vision for Fermilab's future that leads back to the energy frontier.

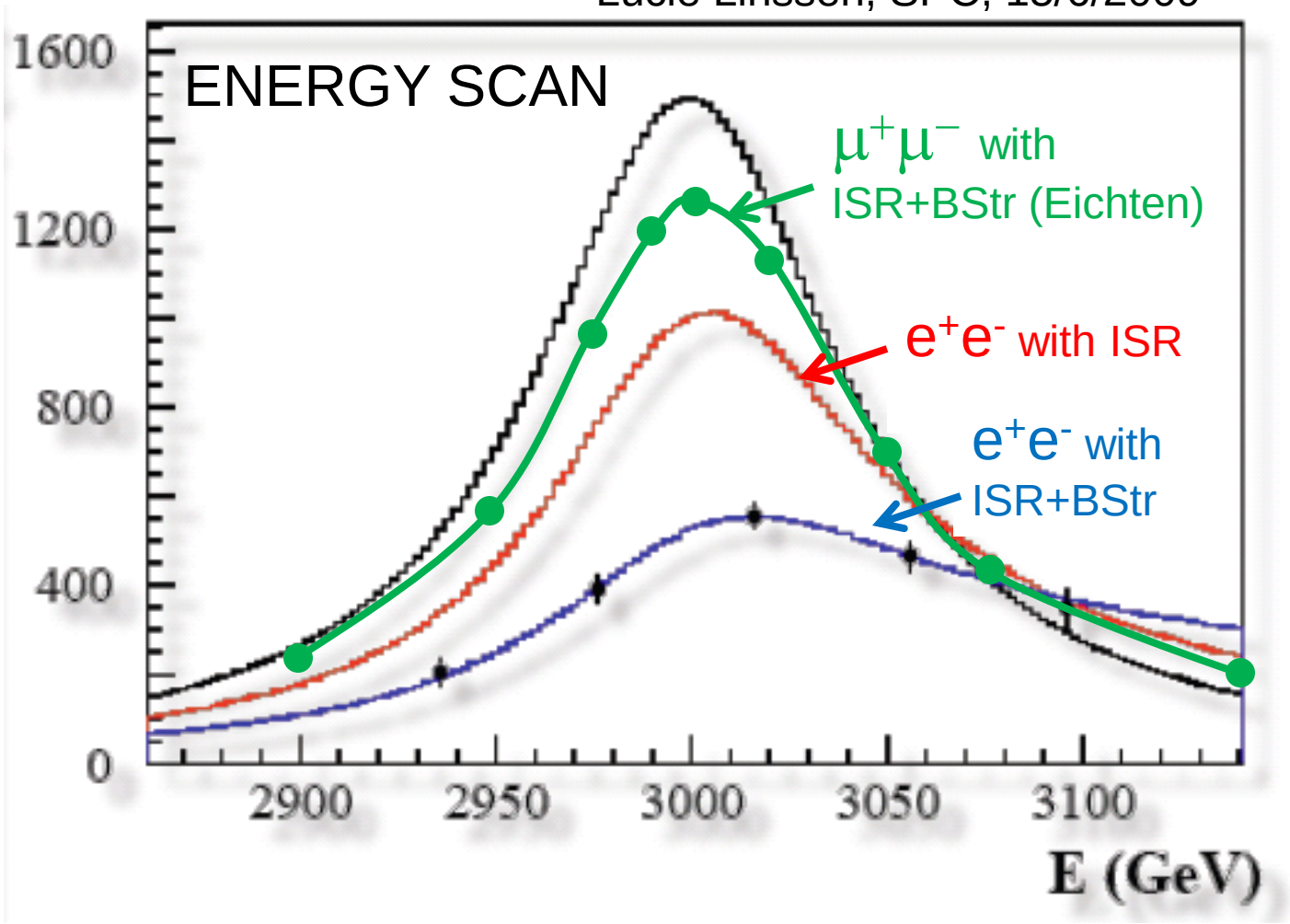
Within the next 6-7 years we propose to find out whether a Muon Collider is feasible, and roughly what it would cost (cost range), and contribute to the IDS-NF work (→ NF RDR).

There is a new U.S. organization (MAP). The MAP proposal builds on past achievements, & is designed to do what is necessary to give Fermilab an attractive option if LHC results motivate a multi-TeV lepton collider.



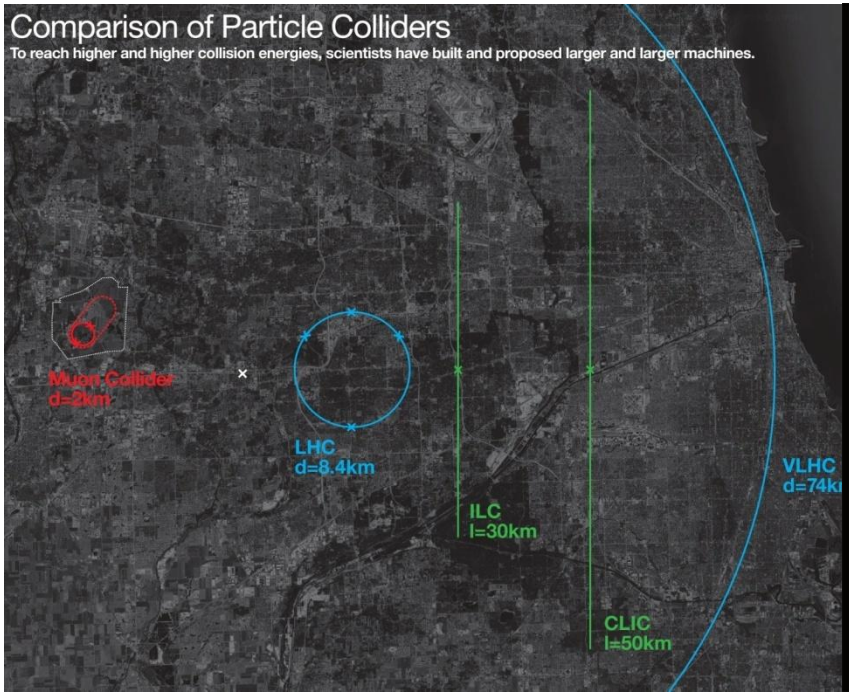
$l^+l^- \rightarrow Z' \rightarrow \mu^+\mu^-$

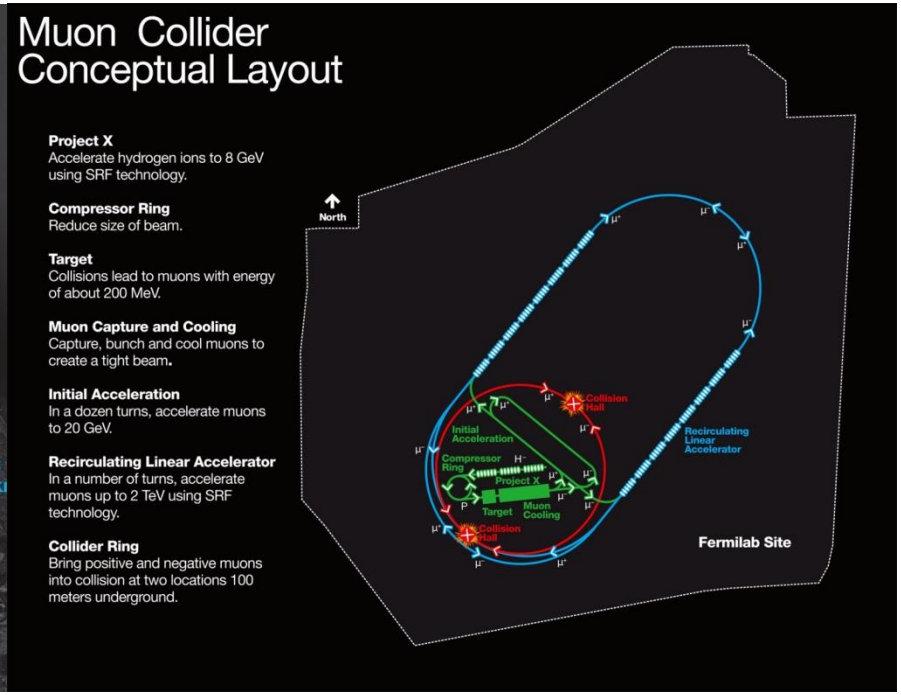
Lucie Linssen, SPC, 15/6/2009



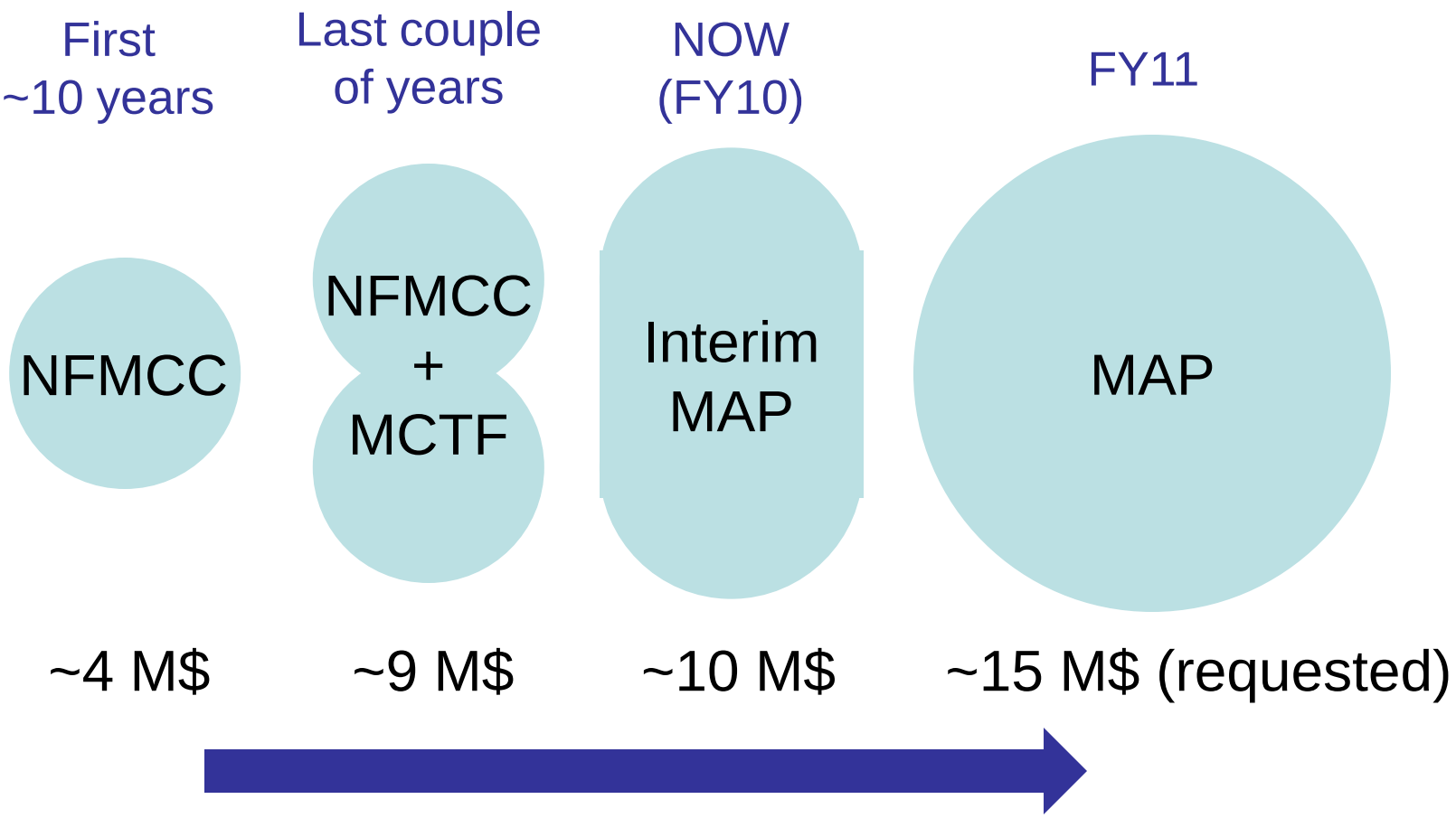
Muon Colliders are Compact

A 4 TeV muon collider would fit on the Fermilab site:





From NFMCC to MAP



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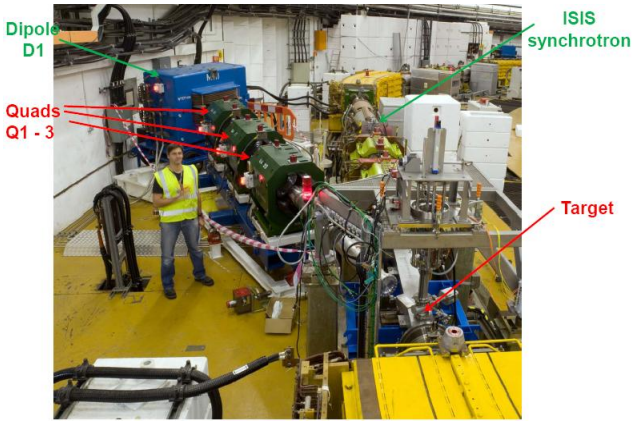
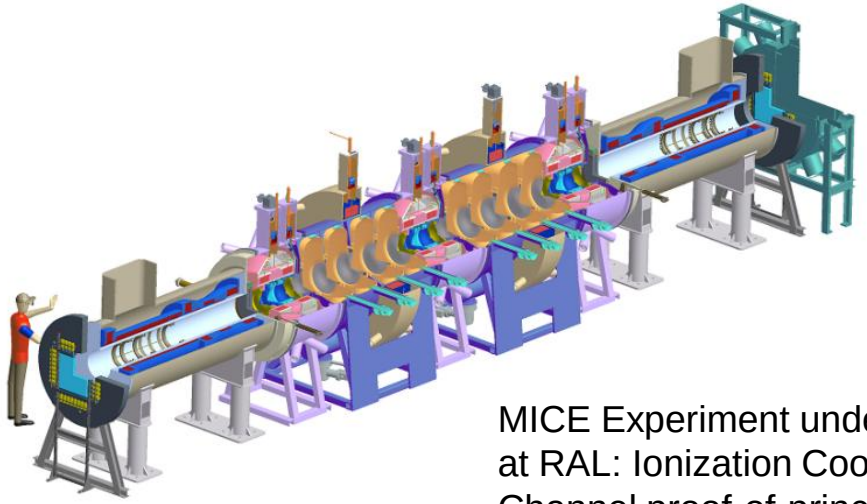
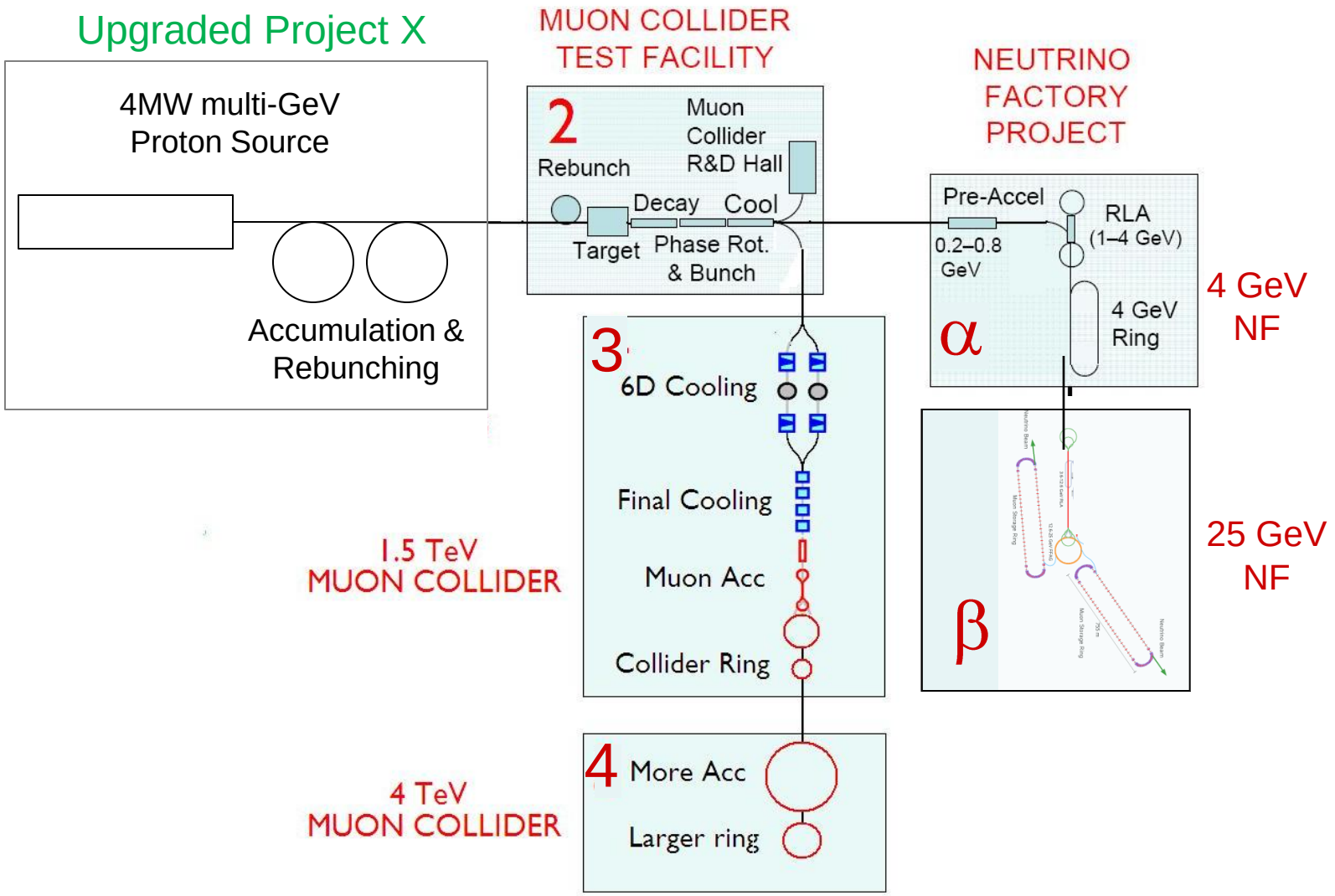


MICE – upstream beamline

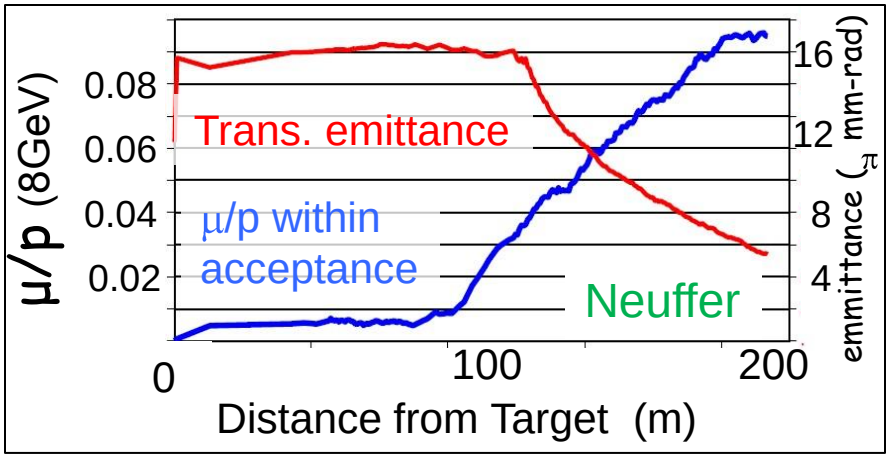


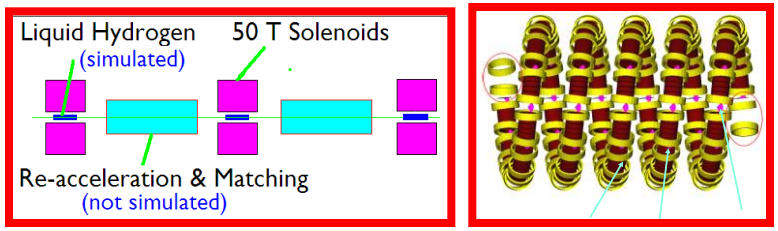
MICE Experiment under way at RAL: Ionization Cooling Channel proof-of-principle

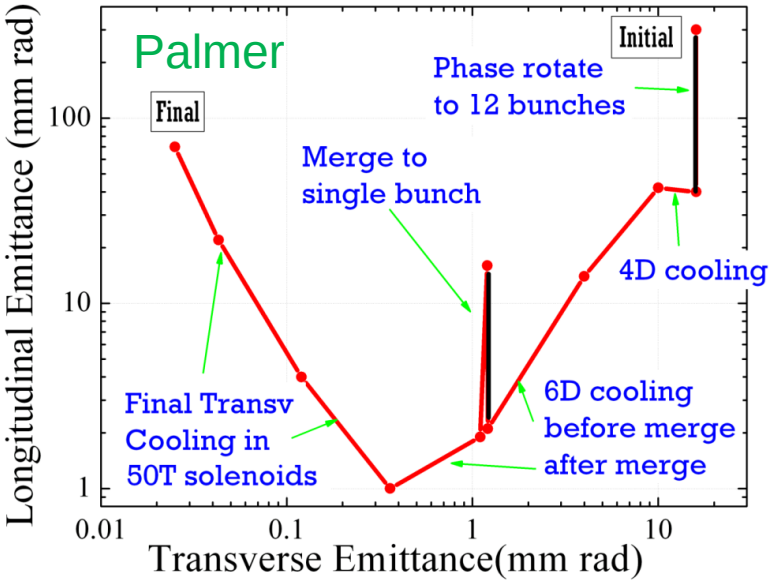
Staging Options



Achievements – Concepts (1)



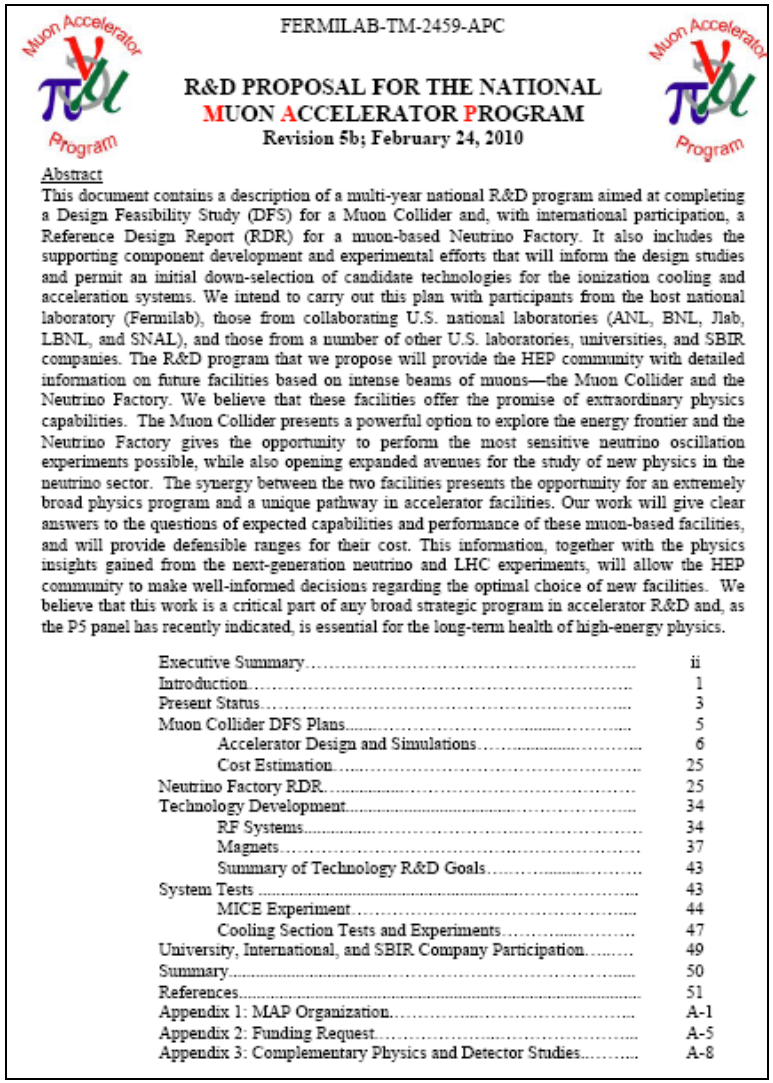




Front-End concept (up to initial cooling) developed & simulated:
- Requires development of RF cavities within few Tesla fields.

Complete self-consistent 6D cooling channel concept exists, with several candidate variants partly simulated:
- Technologies must be developed & performance established

MAP Proposal



FERMILAB-TM-2459-APC

R&D PROPOSAL FOR THE NATIONAL MUON ACCELERATOR PROGRAM

Revision 5b; February 24, 2010

Abstract

This document contains a description of a multi-year national R&D program aimed at completing a Design Feasibility Study (DFS) for a Muon Collider and, with international participation, a Reference Design Report (RDR) for a muon-based Neutrino Factory. It also includes the supporting component development and experimental efforts that will inform the design studies and permit an initial down-selection of candidate technologies for the ionization cooling and acceleration systems. We intend to carry out this plan with participants from the host national laboratory (Fermilab), those from collaborating U.S. national laboratories (ANL, BNL, Jlab, LBNL, and SNAL), and those from a number of other U.S. laboratories, universities, and SBIR companies. The R&D program that we propose will provide the HEP community with detailed information on future facilities based on intense beams of muons—the Muon Collider and the Neutrino Factory. We believe that these facilities offer the promise of extraordinary physics capabilities. The Muon Collider presents a powerful option to explore the energy frontier and the Neutrino Factory gives the opportunity to perform the most sensitive neutrino oscillation experiments possible, while also opening expanded avenues for the study of new physics in the neutrino sector. The synergy between the two facilities presents the opportunity for an extremely broad physics program and a unique pathway in accelerator facilities. Our work will give clear answers to the questions of expected capabilities and performance of these muon-based facilities, and will provide defensible ranges for their cost. This information, together with the physics insights gained from the next-generation neutrino and LHC experiments, will allow the HEP community to make well-informed decisions regarding the optimal choice of new facilities. We believe that this work is a critical part of any broad strategic program in accelerator R&D and, as the P5 panel has recently indicated, is essential for the long-term health of high-energy physics.

Submitted by Pier Oddone on behalf of the MAP collaboration, 1st March 2010.

214 MAP participants (at birth) from 14 institutions:

ANL, BNL, FNAL, Jlab, LBNL, ORNL, SLAC, Cornell, IIT, Princeton, UCB, UCLA, UCR, U-Miss.

Anticipate a DOE-OHEP review soon.

Physics, Detector & Background Studies

In addition to MC accelerator R&D, a parallel but coordinated effort is foreseen on physics & detector studies:

-Machine-Detector Interface group within MAP will generate machine background files for, and "interface" with the physics-detector activity.

- Physics-detector studies leader will participate in MAP "management council".

Detailed detector & Background studies from ~10yrs ago gave encouraging results. A lot has happened since:

- New MC lattice design
- A decade of detector development
-Greater community expectations for detector performance

New physics, detector, background studies begun:

- Kick-off workshop at FNAL November 2009.
- Rapid progress since then on shielding design (shielding cone angle reduced from 20deg to 10deg).
-Active detector simulation group now being created.
-Working towards an initial report ~mid-2011.