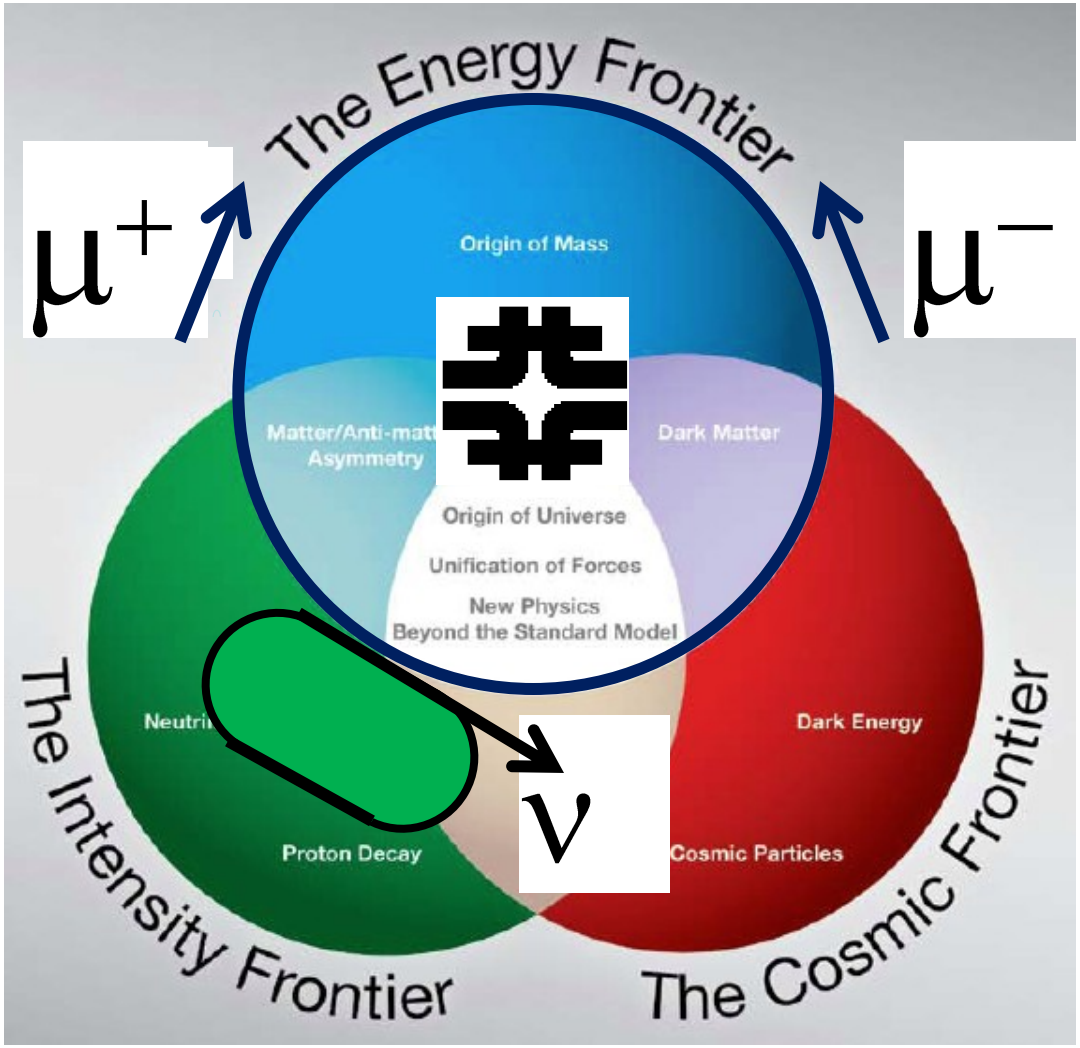
Muon Collider R&D



Muon Accelerator Program (MAP)

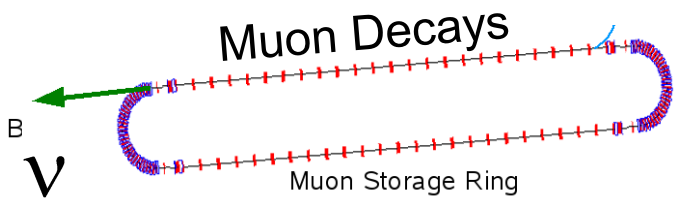
MUON COLLIDER & NEUTRINO FACTORY R&D

Introduction

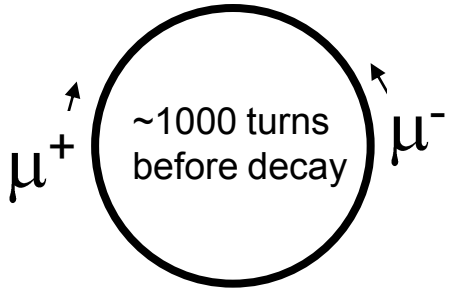
Over the last decade there has been significant progress in developing the concepts & technologies required to create a muon source that would provide $O(10^{21})$ muons per year within a 6D-phase-space that fits within the acceptance of an accelerator.

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.



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):

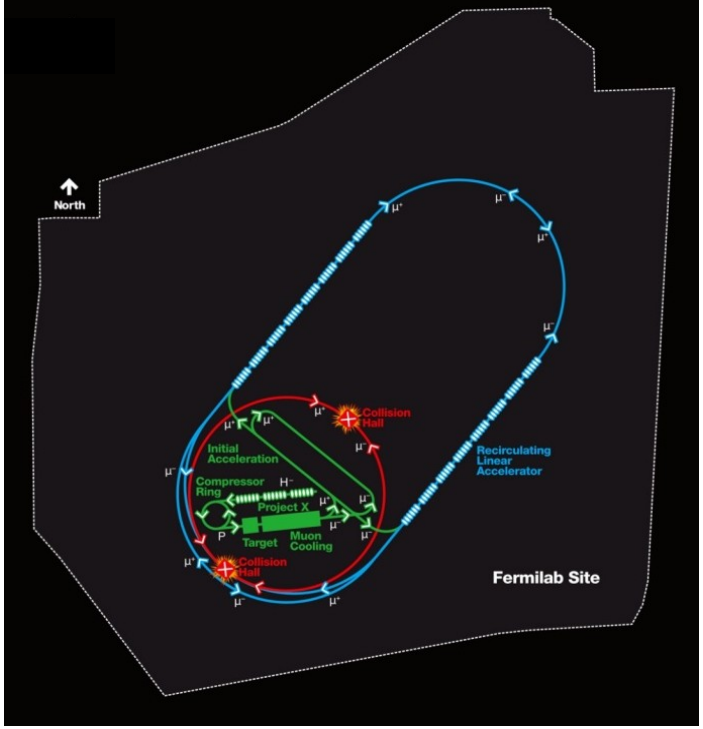
COST

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

PHYSICS

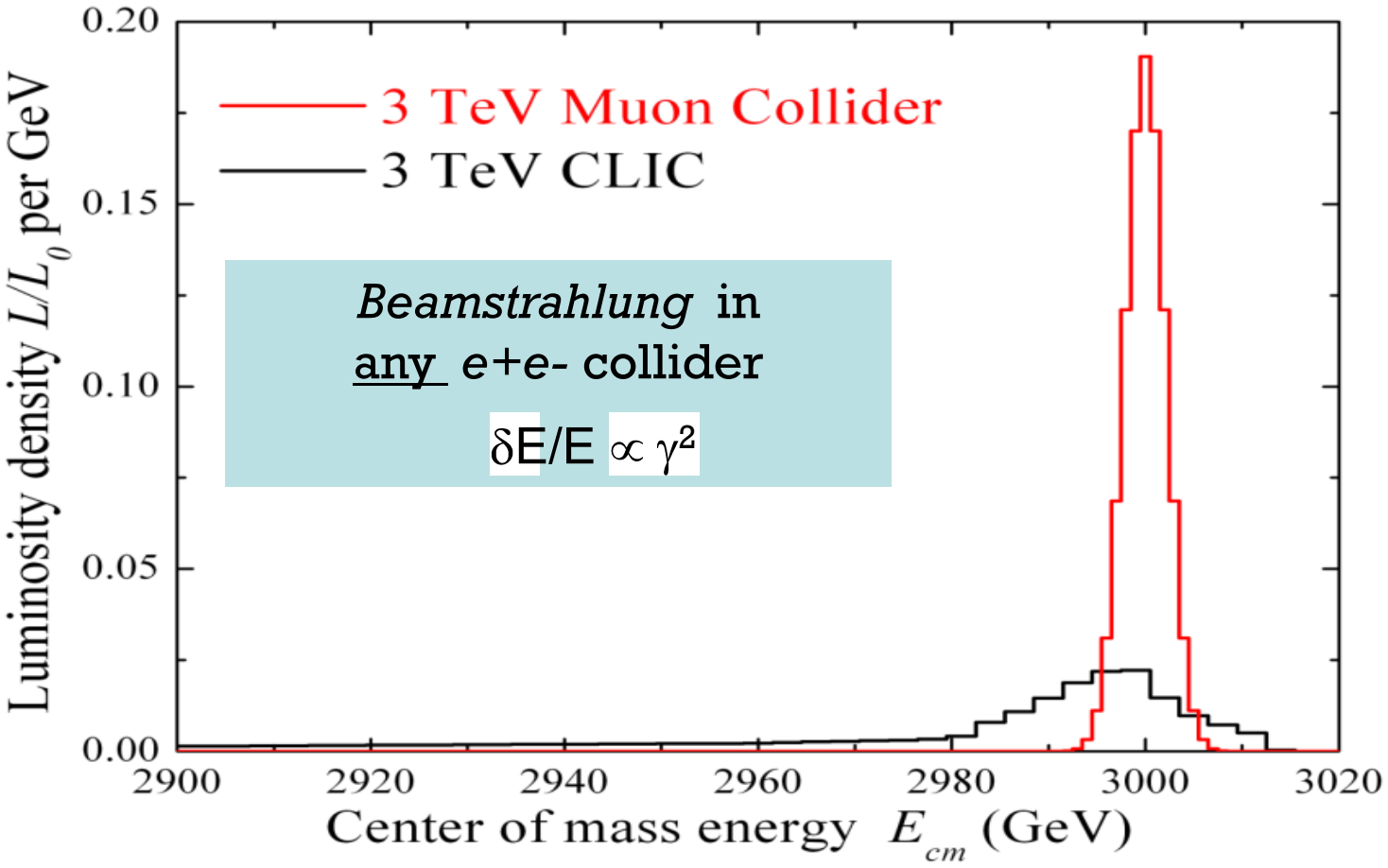
- NARROW ENERGY SPREAD
  Precision scans, kinematic constraints
- TWO DETECTORS (2 IPs)
- ΔT_{bunch} ~ 10 μs … (e.g. 4 TeV collider)
  Lots of time for readout
  Backgrounds don't pile up
- $(m_\mu/m_e)^2$ = ~40000
  Enhanced s-channel rates for Higgs-like particles

A 4 TeV Muon Collider would fit on the Fermilab Site



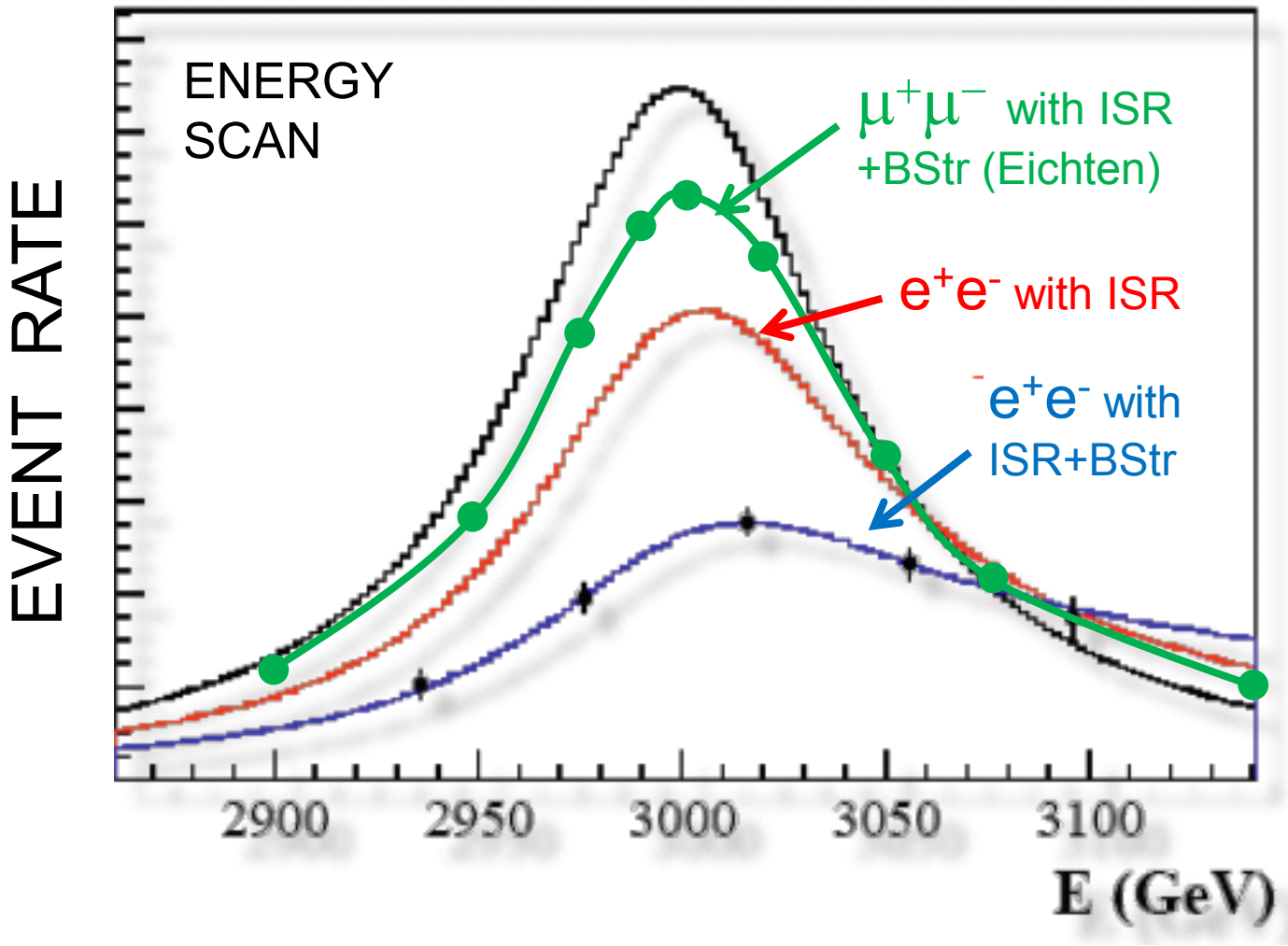
Beam Energy Spread

Vladimir Shiltsev



Energy Scan: $l^+l^- \rightarrow Z' \rightarrow \mu^+\mu^-$

CLIC Curves: Lucie Linssen, SPC, 15/6/2009



Challenges

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

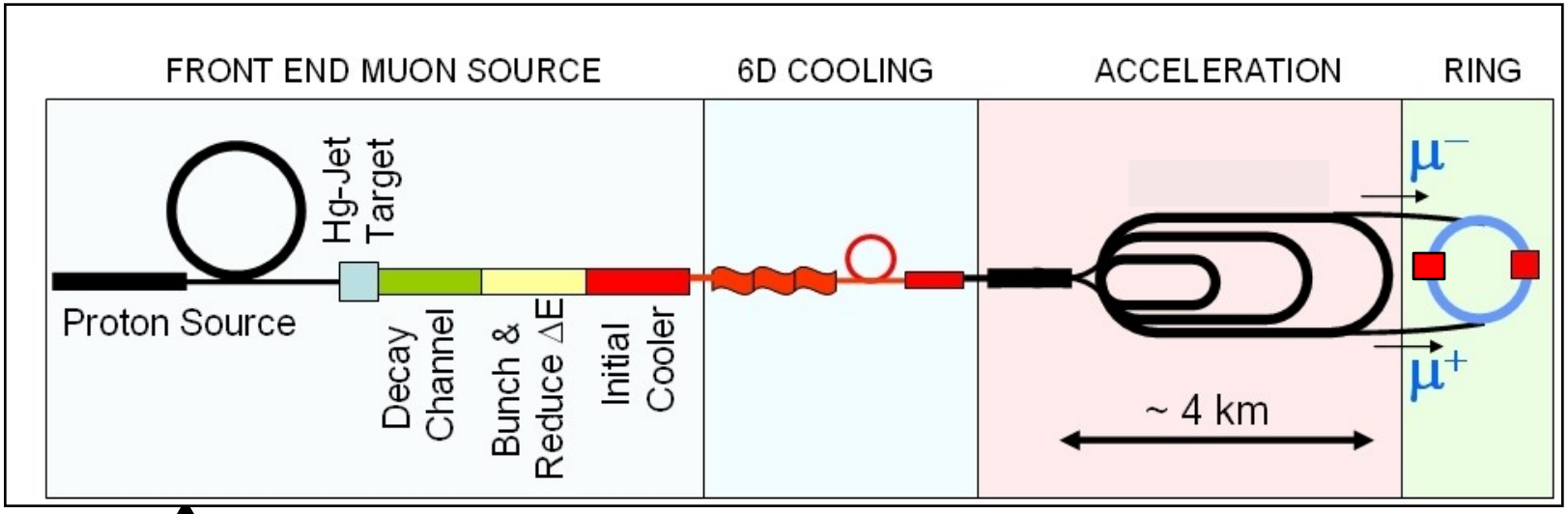
- To obtain luminosities $O(10^{34})$ $cm^{-2}s^{-1}$, need to reduce initial phase space by $O(10^{6})$

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

In present MC baseline design, Front – End is same as for Neutrino Factory

Achievements – Concepts

Front-End concept (up to initial cooling) developed & simulated:
- Delivers ~0.1 muons / 8 GeV proton.
- 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

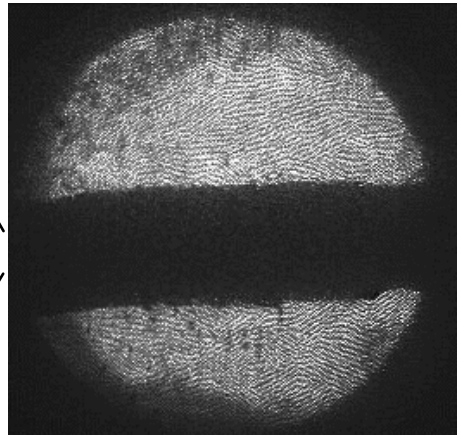
Low energy acceleration (Linac followed by 2 RLAs & FFAG):
- Developed for Neutrino Factory (International Design Study)

High energy acceleration:
- Could use RLAs, but believe rapid cycling synchrotrons likely to be more cost effective.
- R&D on rapid cycling magnets (grain oriented Si Steel) ongoing

Collider Ring:
- Old studies produced initial lattice for 4 TeV collider
- New studies have focused on 1.5 TeV collider. Good recent progress resulting in better lattice with 1.2% momentum acceptance & 4.7σ dynamic aperture (errors yet to be included).

Achievements - Technologies

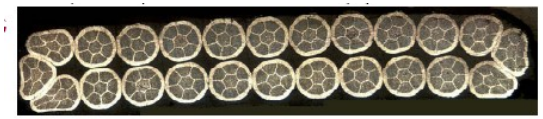
MERIT EXPT at CERN PS



Hg jet in a 15T solenoid
Measured disruption
length = 28 cm

Liq. H2 absorber
(KEK)

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

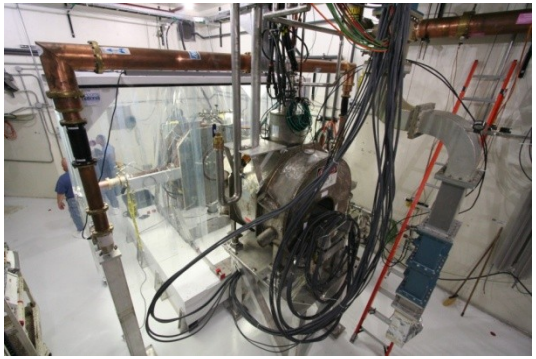


HTS cable R&D
(FNAL – TD)

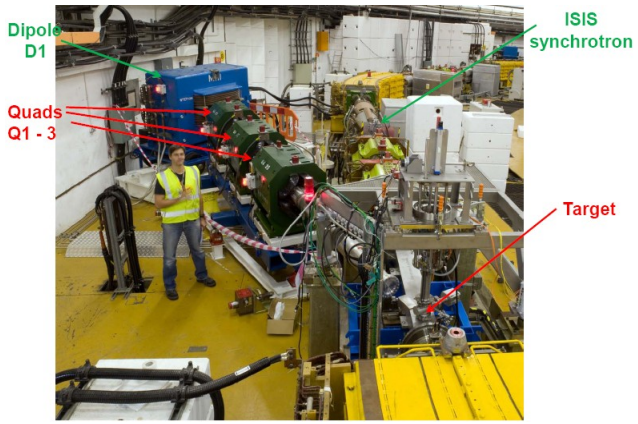
HCC magnet tests
(FNAL – TD)

42cm ∅ Be RF window
(LBNL)

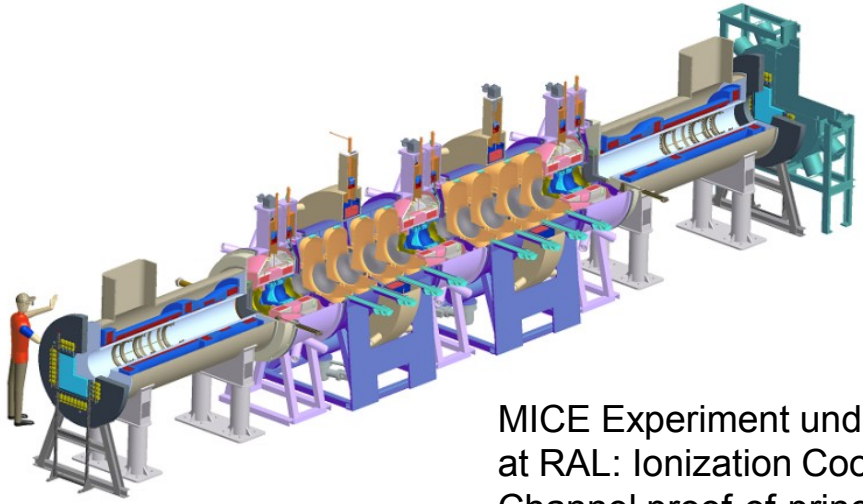
Achievements – Test Facilities


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.

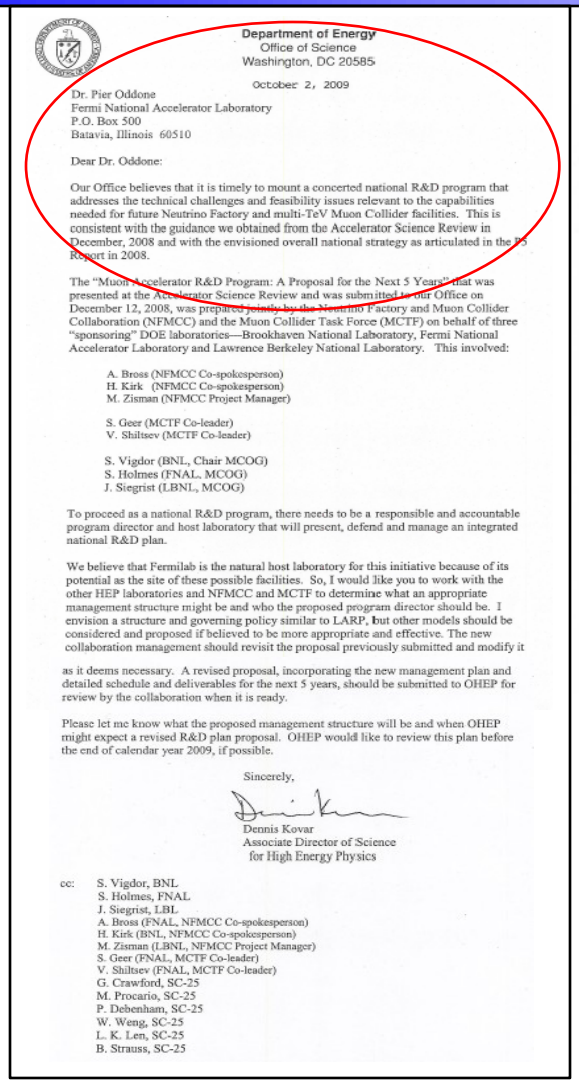


MICE – upstream beamline



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

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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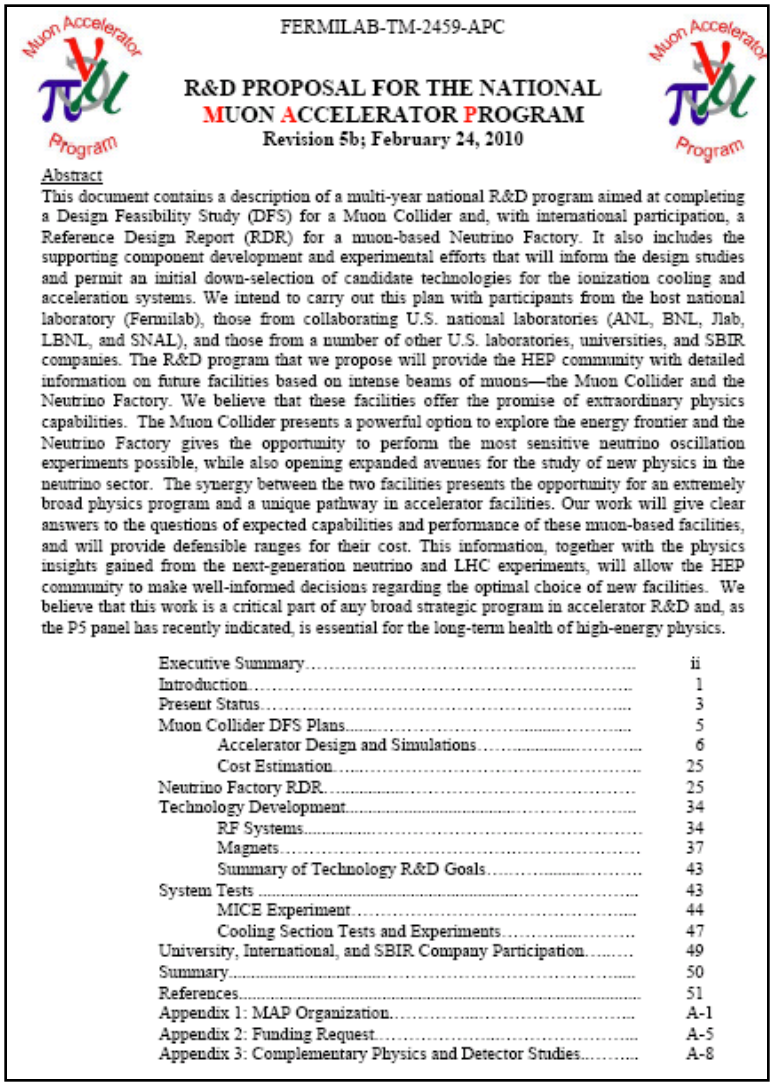
Muon Accelerator Program
MAP

MAP Status



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.

MAP organization in place and functioning

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

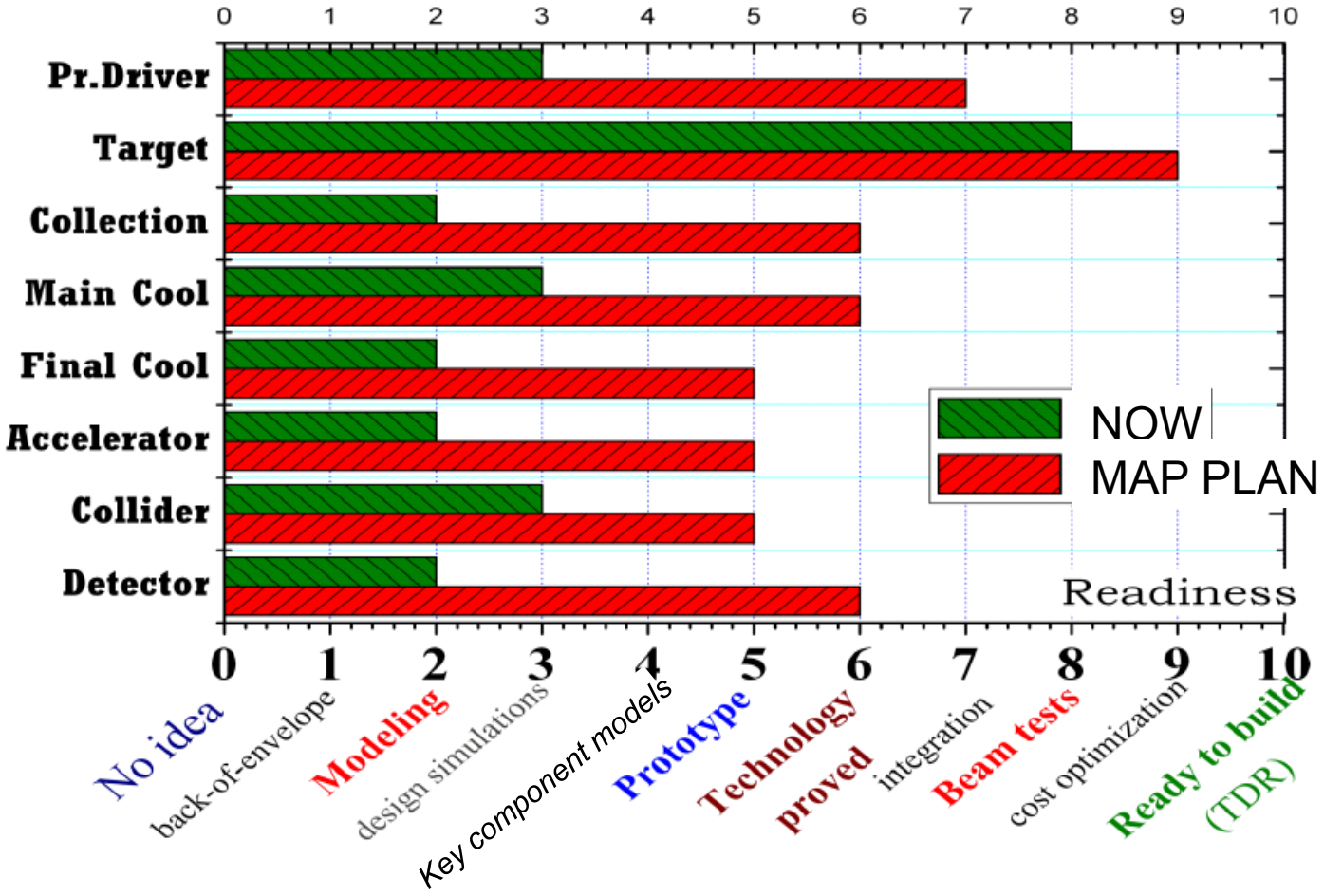
- 6-7 years long program (depending on funding level)
- Aims to establish feasibility and estimate cost range

214 MAP participants (at birth) from 14 institutions:

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

Impact of the MAP R&D Plan

Muon Collider Development



+ NF RDR

Physics, Detector & Background Studies

(Estia Eichten, Marcel Demarteau, Nikolai Mokhov)

Coordinated effort begun on physics & detector studies:

-Machine-Detector Interface group within MAP will generate machine background files for physics-detector activity.

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

Detailed detector & Muon Decay Background studies from ~10yrs ago gave encouraging results, but since then:

- 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.
- Help welcome !

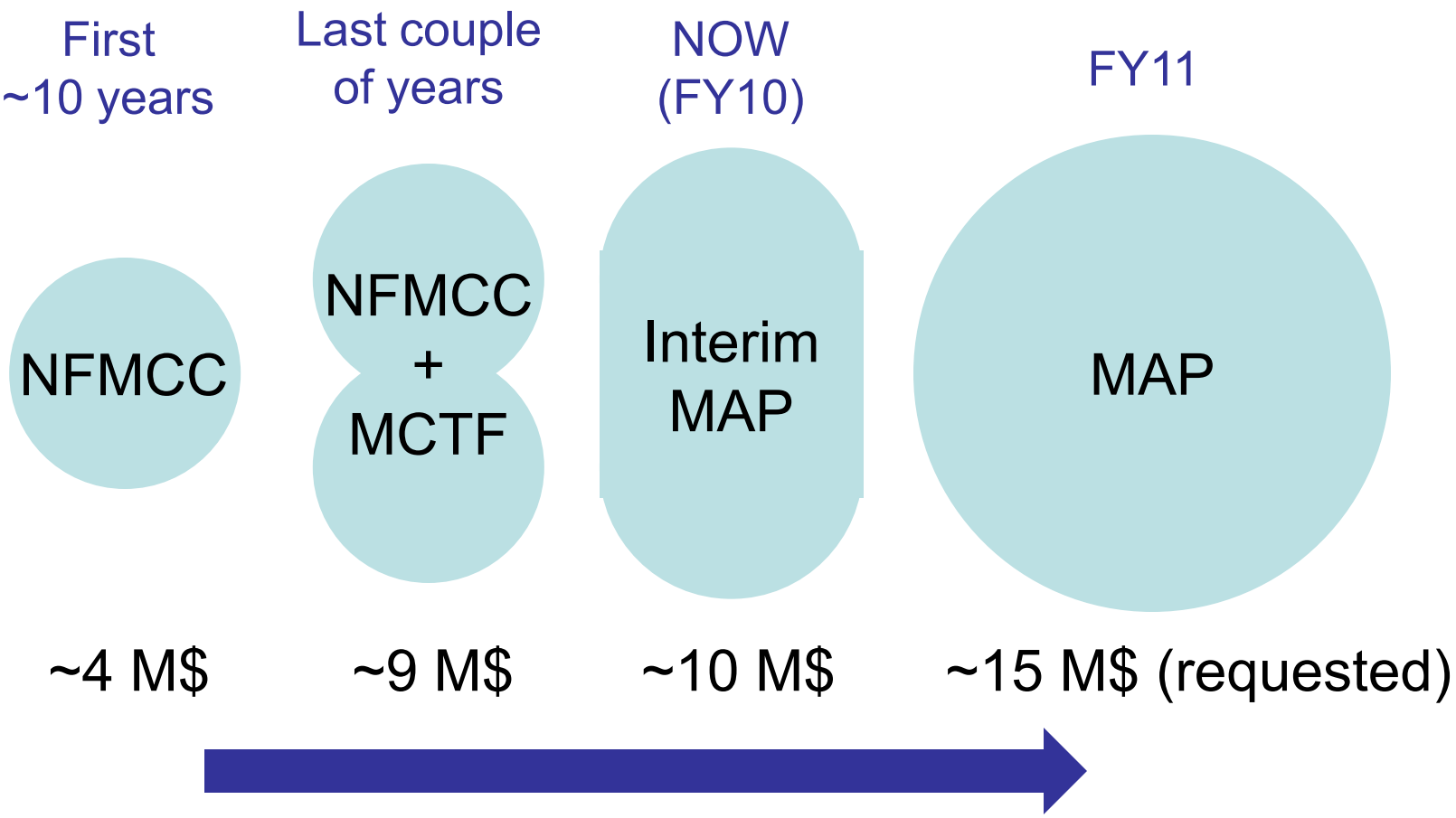
Summary

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, and is designed to do what is necessary to give Fermilab an attractive option if LHC results motivate the community to chose a multi-TeV lepton collider as the next energy frontier machine.

From NFMCC to MAP



Staging Options