Muon Accelerator R&D Program
(Muon Colliders & Neutrino Factories)

Steve Geer
(on behalf of the Muon Collider Coordinating Committee)

U.S. Muon Accelerator R&D Community

♦ In the U.S. Muon Collider & Neutrino Factory R&D is pursued by a collaboration of accelerator scientists, particle physicists & engineers from laboratories, universities, and SBIR companies:

- Sponsoring U.S. Labs (~30 FTE)
  - BNL, FNAL, LBNL
- Other U.S. Labs (~2 FTE)
  - ANL, TJNAF, ORNL
- U.S. Universities (~5 FTE)
  - IIT, Mississippi, Princeton, UC-Berkeley, UCLA, UC-Riverside
- SBIR Companies (~10 FTE)
  - Muons Inc., Tech X, PBL

TOTAL EFFORT ~ 47 FTE

♦ Other institutions have made past contributions but are not presently supported: U-Chicago, Cornell, NIU, Northwestern, UIUC

♦ In addition, Neutrino Factory R&D has been "internationalized" (see later)

Organization

- NFMCC (Neutrino Factory & Muon Collider Collab.)
  - National collaboration funded since 1998.
  - Pursues Neutrino Factory & Muon Collider R&D.
  - NF R&D pursued with international partners
- MCTF (Muon Collider Task Force)
  - Task Force established at Fermilab in 2006
  - Pursues Muon Collider R&D, utilizing FNAL assets and extends & complements the NFMCC program
- MCCC (Muon Collider Co-ordinating Committee)
  - Leadership of NFMCC (Bross, Kirk, Zisman) and MCTF (Geer, Shiltsev)
  - Co-ordinates NFMCC & MCTF plans to optimize the overall program … has worked well and resulted in a joint 5 year plan for future activities.
- MUTAC (Muon Technical Advisory Committee)
  - Appointed by the multi-Lab oversight group (MCOG)
  - Reviews NFMCC & MCTF activities jointly

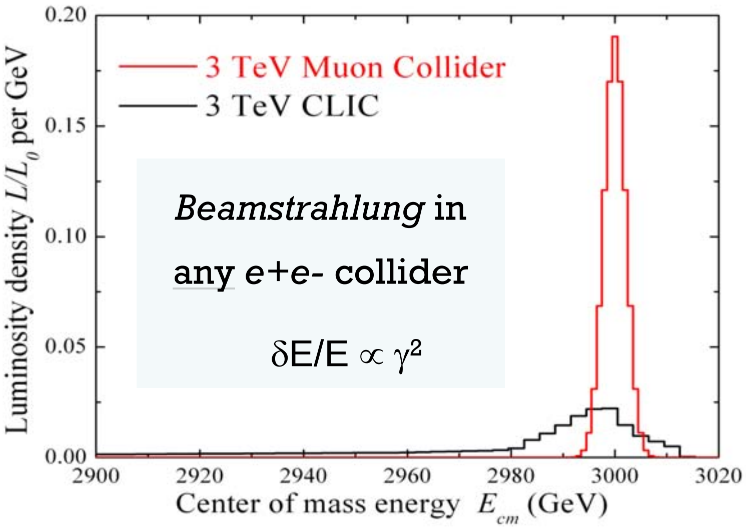
Motivation: Lepton Colliders

- The capabilities of high energy lepton colliders have captured the imagination of the HEP community:
  - elucidate EWK symmetery breaking mechanism
  - search for (discover) supersymmetry
  - search for (discover) extra space-time dimensions & quantum gravity
- Studies have motivated lepton colliders with multi-TeV energies and luminosities of order 10^{34} cm^{-2} s^{-1}.
  - LHC results on a timescale of ~2013 are expected to establish desired lepton collider energy.
  - P5 recommended " … R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established."
- Alternatives for a multi-TeV lepton collider are:
  - Muon Colliders
  - Normal-Conducting RF e+e- linacs (NLC-like, CLIC, …)
  - Plasma wakefield linacs driven by lasers or short e- bunches.

Muon Collider Advantages

- Muon Collider concept is attractive because muons are point-like particles that do not radiate as readily as electrons (m_μ / m_e ~ 207):
  - Circular (compact) multi-TeV lepton collider that would fit on an existing laboratory site.
  - Very small beam energy spread enabling precise scans and width measurements

EXAMPLE
4 TeV Collider
on the FNAL site



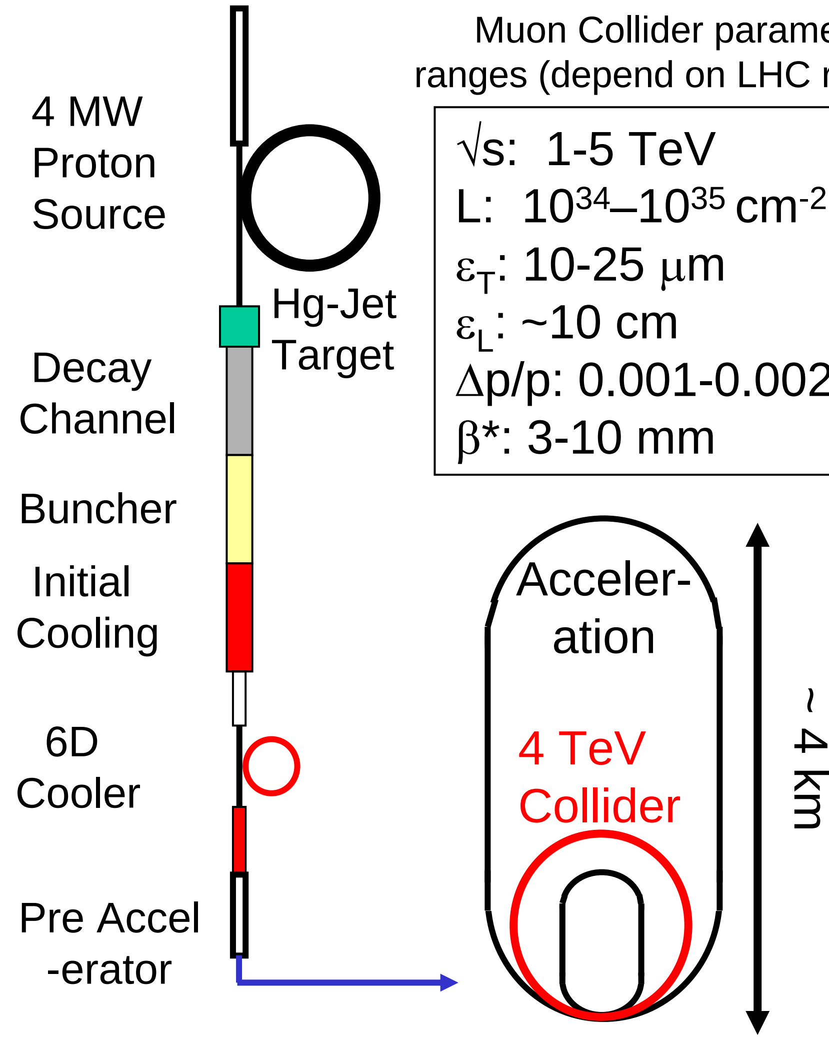
- $(m_\mu/m_e)^2$ = ~40000
  → s-channel Higgs Factory
  (requires lower luminosity)

Muon Collider Challenges

- To achieve the required luminosity, we need to produce, collect and accelerate O(10^{21}) muons per year – requires few MW proton source & suitable target technology.
- Muons, produced in pion decay, are born into a large 6D Phase Space – must be cooled by O(10^{6}) to obtain needed luminosity.
- All beam manipulations and acceleration must be done rapidly before the muons decay (τ_0 = 2μs) – requires fast cooling technique (ionization cooling).

Muon Collider Schematic

- **Proton Driver**
  - **primary beam on target**
- **Target, Capture, and Decay**
  - **create π; decay into μ**
- **Bunching & Phase Rotation**
  - **reduce ΔE of bunch**
- **Cooling**
  - **reduce 6D emittance**
- **Acceleration**
  - **130 MeV → *O*(1) TeV**
- **Storage Ring**
  - **store for ~1000 turns**

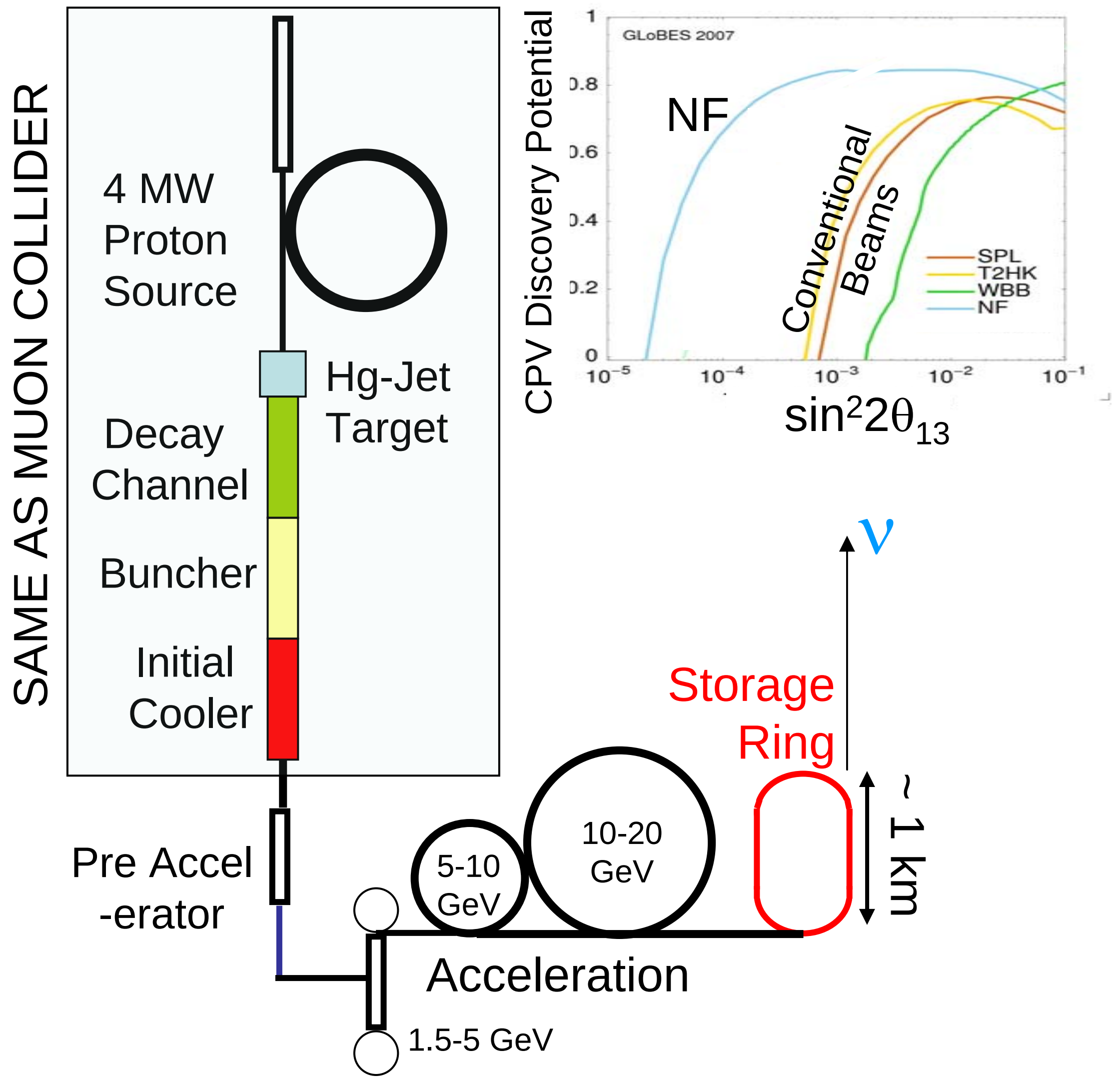


Muon Collider parameter ranges (depend on LHC results)

$\sqrt{s}$: 1-5 TeV
L: 10^{34}–10^{35} cm^{-2} s^{-1}
ε_T: 10-25 μm
ε_L: ~10 cm
Δp/p: 0.001-0.002
β*: 3-10 mm

Neutrino Factory

- A muon source providing $O(10^{21})$ muons/yr would also facilitate a new sort of neutrino source in which muons decaying in a storage ring with long straight sections produce a beam of 50% ν_e (anti- ν_e) & 50% ν_μ (anti- ν_μ)

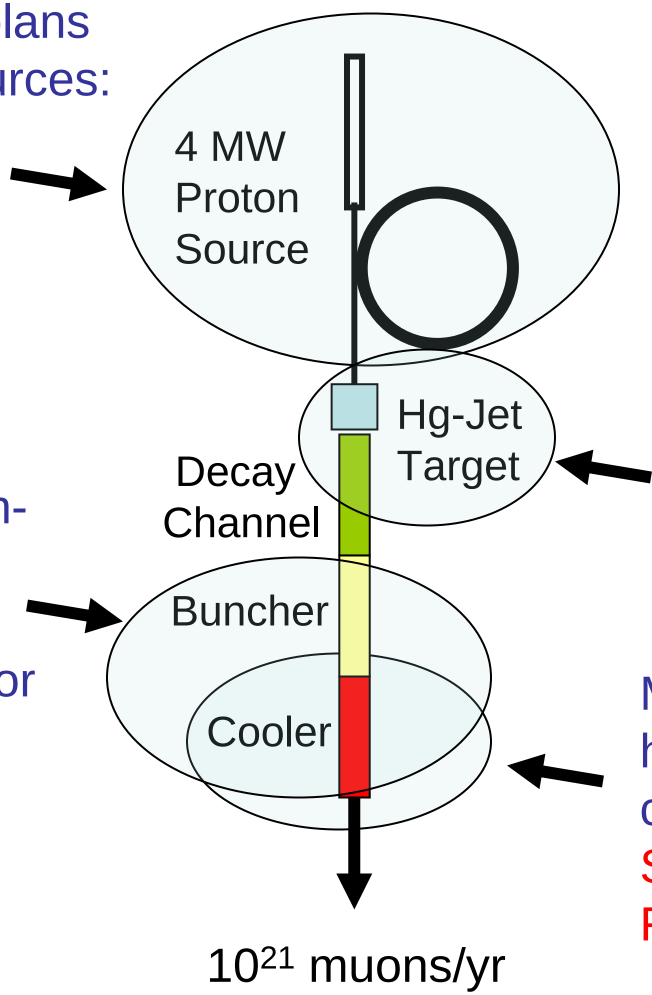


MCTF

Front-End Progress - last 5 years

Rapid development of plans for multi-MW proton sources:
FNAL: Project-X
CERN: Linac 4, SPL …
RAL: ISIS upgrade
EU: ESS

Project-X at FNAL with suitable modifications would be a viable source (see A. Jansson talk in FNAL session)

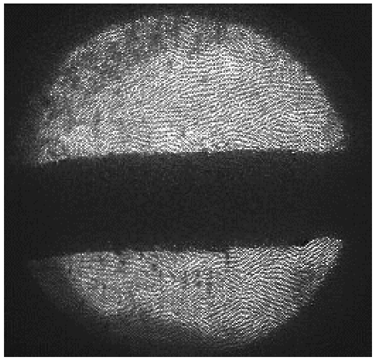


MUCOOL Test area built. Limitations of High-gradient RF in magnetc fields identified. Candidate RF options for RF in ionization cooling channels identified – development in progress. See talks in FNAL & LBNL session.

Successful completion of MERIT proof-of-principle Hg-jet target experiment
See talk in BNL session

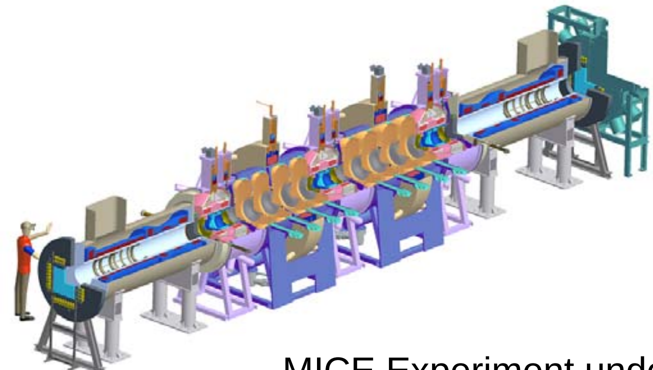
MICE experiment has begun – to be completed 2011-2012
See talks in LBNL & FNAL sessions

Component Development & Experiments



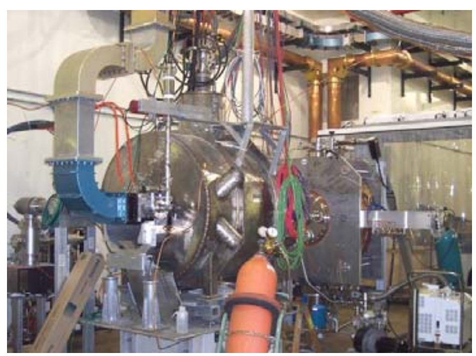
MERIT at CERN: Hg-jet in 15T solenoid, hit by 3×10^{13} 24 GeV protons

MUCOOL Test Area built at FNAL for ionization cooling component testing



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

New beamline built at FNAL to test high-pressure RF concept for muon cooling channels



NFMCC 805 MHz and 201 MHz RF studies in magnetic fields to develop needed capability for muon cooling channels

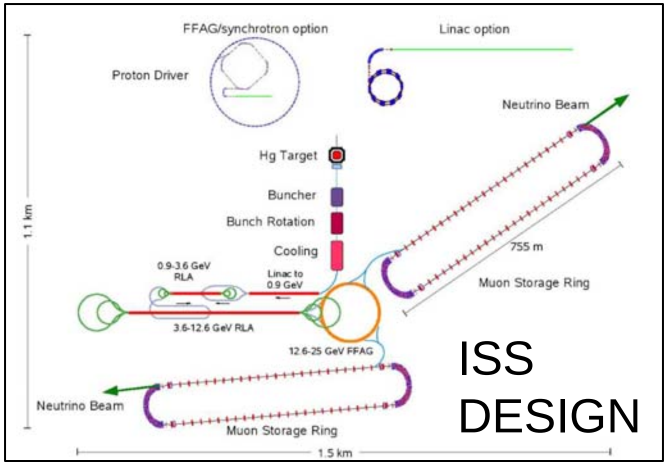
High-field Magnet Studies for muon cooling channels

MCTF

Neutrino Factory Design Studies

- Over the last decade a series of design studies have developed the NF concept:
  - First Generation - "Feasibility":
    - Feasibility Study 1 (FNAL 2000)
    - Japanese Study 1 (2001)
    - CERN Study (2004)
  - Second Generation – performance & cost-reduction:
    - Study 2 (BNL 2001): performance
    - Studies 2a (2004): cost
  - Third Generation – International:
    - International Scoping Study (RAL 2006):

RAL-TR-2007-019: Physics Group Report
RAL-TR-2007-023: Accelerator Group Report
RAL-TR-2007-024: Detector Group Report

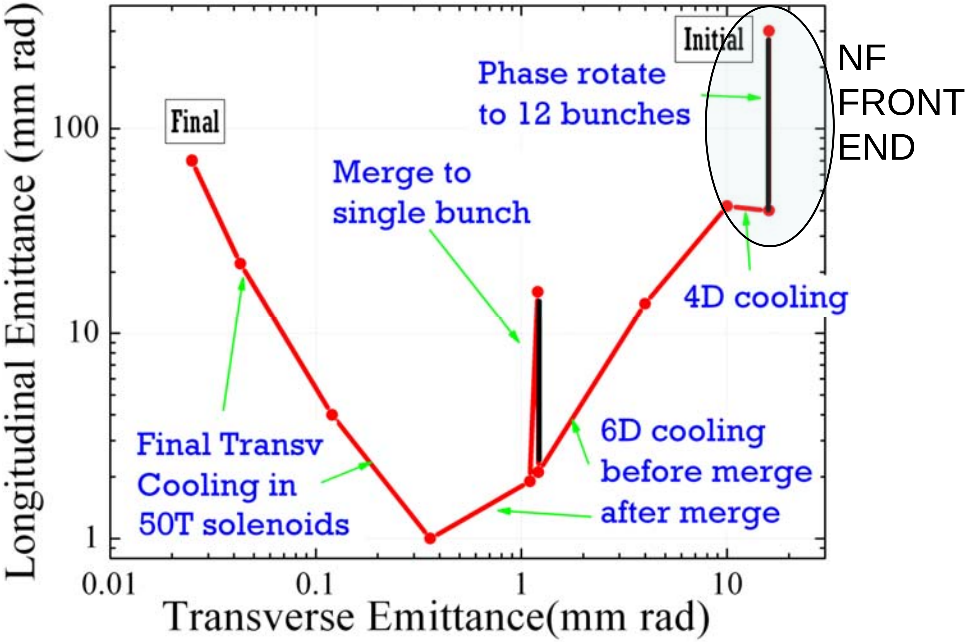


International Design Study (IDS)

- Neutrino Factory R&D is ready for the next step.
- The IDS aspires to deliver a Neutrino Factory RDR by 2012.
  - Steering Group: Blondel, Kuno, Zisman, Long
  - Accelerator Leaders: Berg, Mori, Prior
  - Detector Leaders: Bross, Soler, Mondal, Cervera
  - Physics Leaders: Donini, Huber, Pascoli, Winter, Yasuda
- Support from Europe:
  - U.K.-NF: £15.5M
  - EUROν (NF part): 4.5M Eu

  FY09-12
- Want a significant U.S. involvement
  - Important element of our 5 year plan (see later)
  - Establish a post-Project X NF option for FNAL

Muon Collider Design Progress



- Muon Collider designs start with a NF front-end, but require a much more ambitious cooling channel (6D cooling ~ $\mathcal{O}(10^6)$ c.f. 4D cooling ~ $\mathcal{O}(10)$).
- In the last 5 years concepts for a complete end-to-end self con-sistent cooling scheme have been developed
  - Requires beyond state-of-art components: need to be developed
  - Hardware development and further simulations need to proceed together to inform choices between alternative technologies
- Also progress on acceleration scheme & Collider ring design, but the cooling channel presently provides the main Muon Collider challenge

Next Steps: Strategy

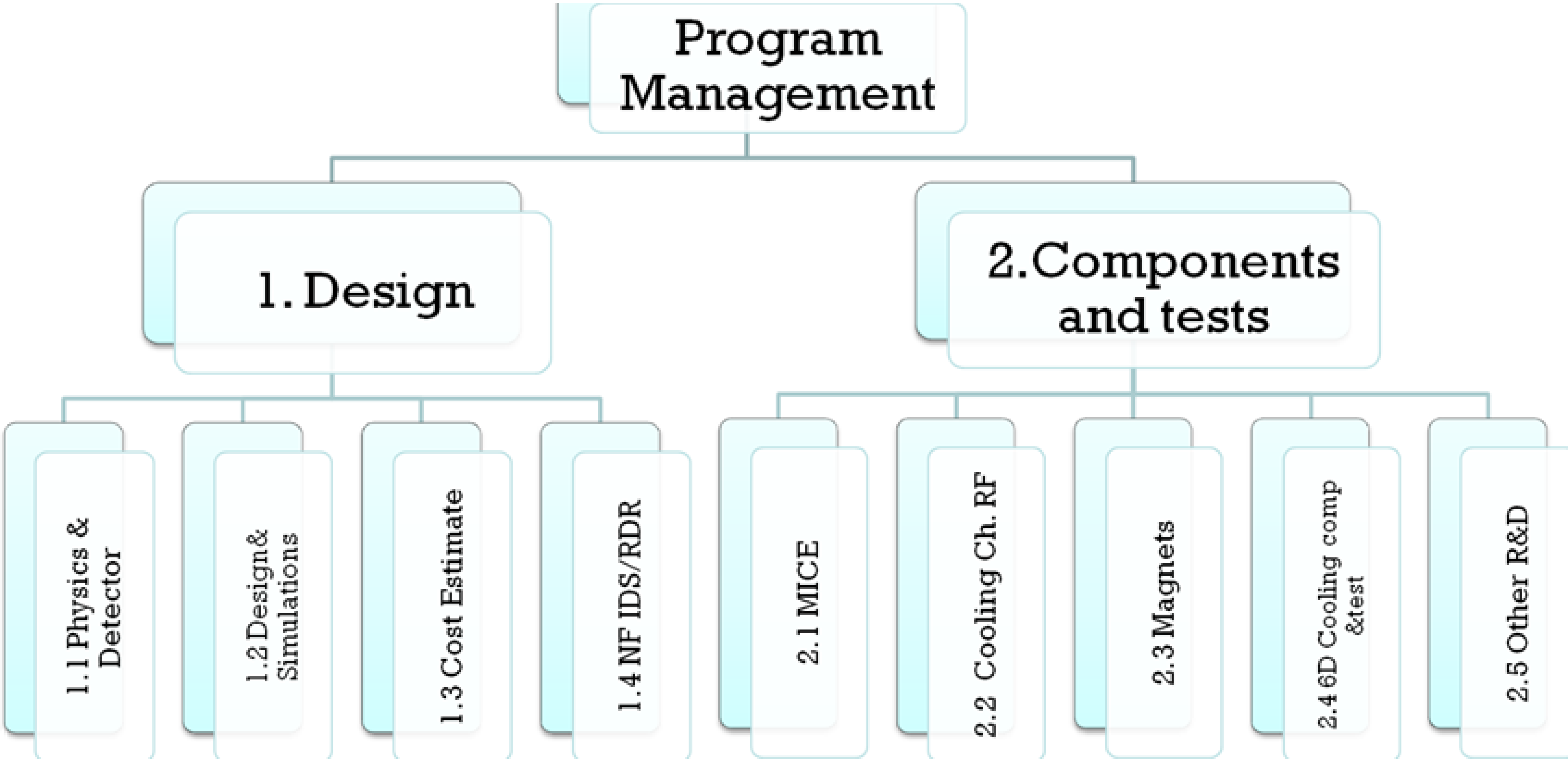
- MC strategy presented to P5 to bring the high energy frontier back to the U.S.
  - study to demonstrate MC feasibility by 2013
  - post-study experiments and component test for 7-10 years
  - Start MC construction early to mid 2020's
- In parallel with MC R&D, the medium term NF development plan presented to P5:
  - Complete MICE experiment & participate in IDS to deliver a NF-RDR by 2012
  - If community wishes to proceed, preconstruction R&D for a few years beyond 2012, with an option to start construction in the late 2010's
- MCOG and MUTAC have encouraged the NFMCC & MCTF leadership to develop a joint 5 year plan that proposes the way forward for the period FY09-13

The 5 Year Plan

- A joint NFMCC-MCTF Plan
  - A measured program based on the solid muon accelerator R&D achievements of the last decade
  - Sufficiently ambitious to make substantial progress before the next round of long-term decisions by the particle physics community
  - Includes accelerator, physics & detector studies (only accelerator part in this talk – we also have plans & estimates for physics & detector studies)
- Meets our existing commitments (NF-RDR, MICE) and in addition will deliver:
  - MC performance requirements based on physics
  - A first end-to-end MC simulation
  - Critical component development & testing
  - A first MC cost estimate

MCTF

Elements of the MC R&D Plan



- 1.1: Not part of this review
- 1.2: BNL, FNAL, LBNL
- 1.3: LBNL
- 1.4: BNL, LBNL, FNAL
- 2.1: LBNL, FNAL
- 2.2: BNL, LBNL, FNAL
- 2.3: BNL, LBNL, FNAL
- 2.4: FNAL
- 2.5: BNL (Targetry)

sponsoring laboratory participation

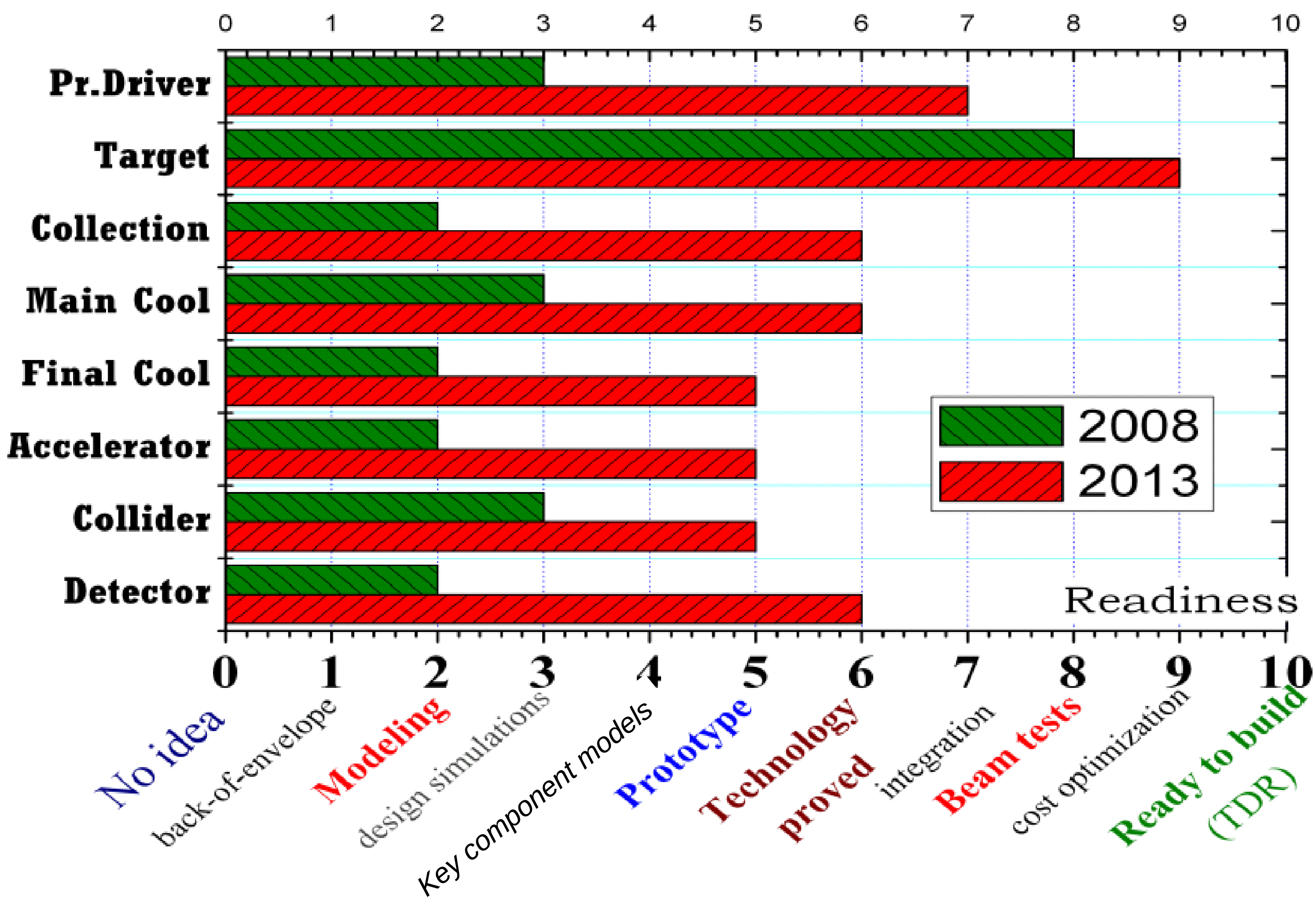
Elements of the Plan - 2

- Design and Simulations
  - MC DFS
    - Physics and Detector Study (Demarteau and Eichten)
    - Accelerator Design & Simulation Study (Ankenbrandt & Fernow)
    - Cost Estimation Study (Zisman)
  - NF RDR (Bross) (under IDS-NF auspices)
    - overall system design and staging scenarios
    - siting issues
    - participation in cost estimation activity

Elements of the Plan - 3

- Component Development and Experiments
  - carry out hardware development & perform tests to "inform" MC DFS & NF RDR (Jansson)
    - facilitate down-selection of MC cooling channel options
    - complete MICE
  - includes ongoing work
    - RF testing, magnet development, absorbers, target
      - understand performance limits, engineering issues, costs
  - hardware R&D has been carefully selected
    - plan only includes activities needed to assess feasibility & make 1st defensible cost estimate.
  - defines subsequent experimental program (extends beyond 5-yr plan)

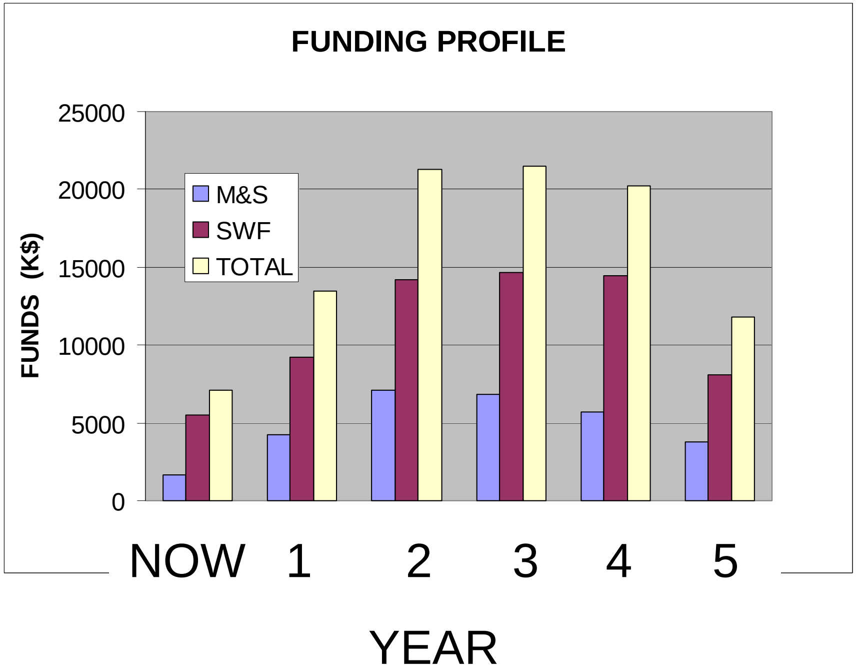
Expected MC Status after Plan

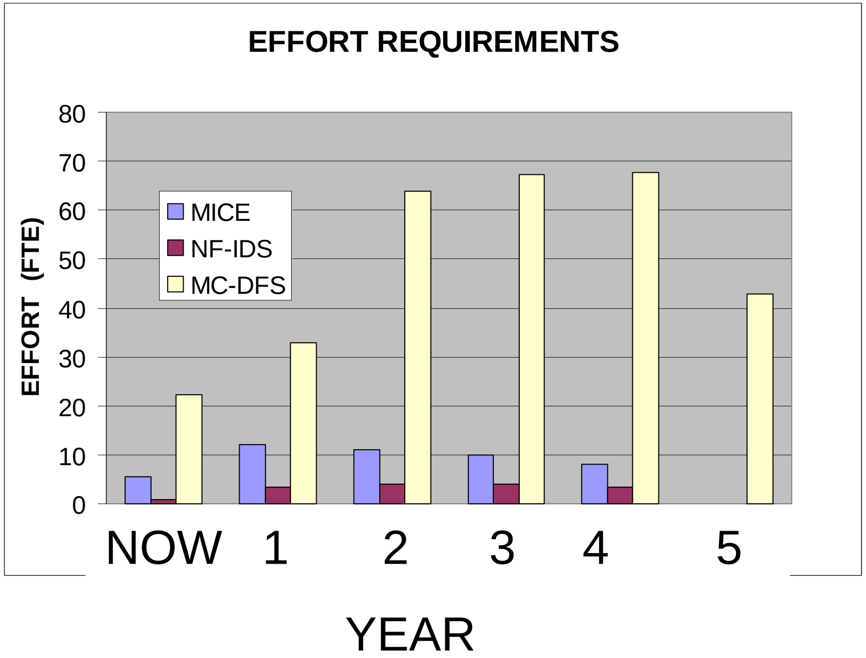


MCTF

Resources

Resources needed to execute the 5 year plan





NOTE: Roll-over in years 4-5 provides an opportunity to initiate post-DFS activities, should the community wish us to proceed to the next step

MCTF

Contributions (FTE)

• Proposed effort profile (FTEs) for muon accelerator R&D:

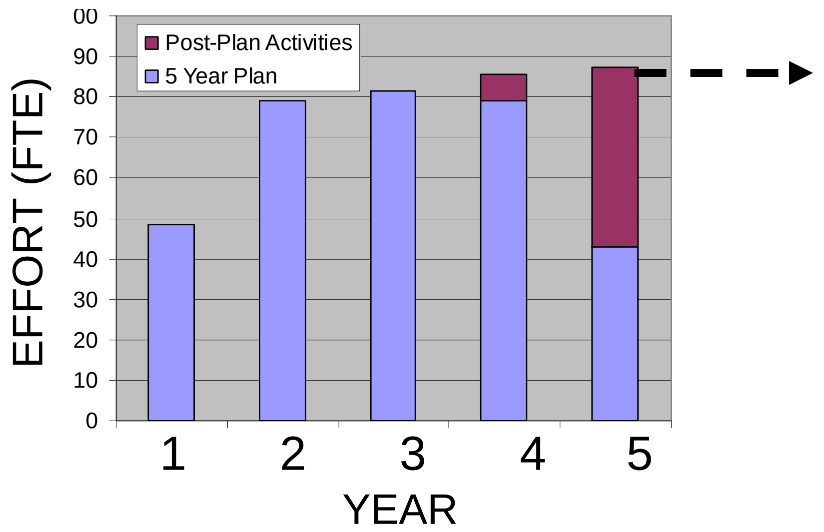
	Now	Year 1	Year 2	Year 3	Year 4	Year 5
BNL	6.5	7	8	11	11	11
FNAL	20.8	23	28	30	33	33
LBNL	2.5	5	8	9	11	13
Other	7 [a)]	13 [b)]	35 [b)]	31 [b)]	31 [b)]	31 [b)]
TOTAL	36.8	48	79	81	86 [c)]	88 [c)]

See present-ations in BNL, FNAL & LBNL sessions

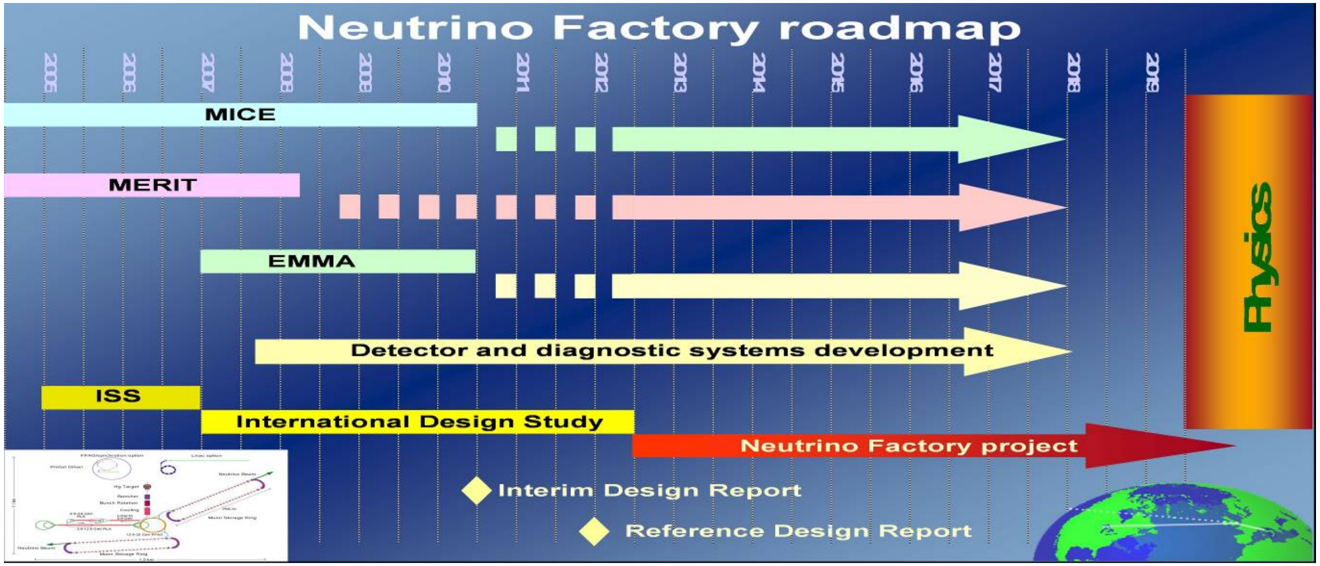
a) Universities ~ 5FTE, Other Labs ~ 2FTE. NOTE: In addition there are ~ 10FTE SBIR.
b) Includes SBIR, Universities, Other Labs, & additional engineering effort from BNL+FNAL+LBNL or external contracts (with M&S vs SWF adjustment)
c) Includes post-5-year plan activities

• Utilization of Effort

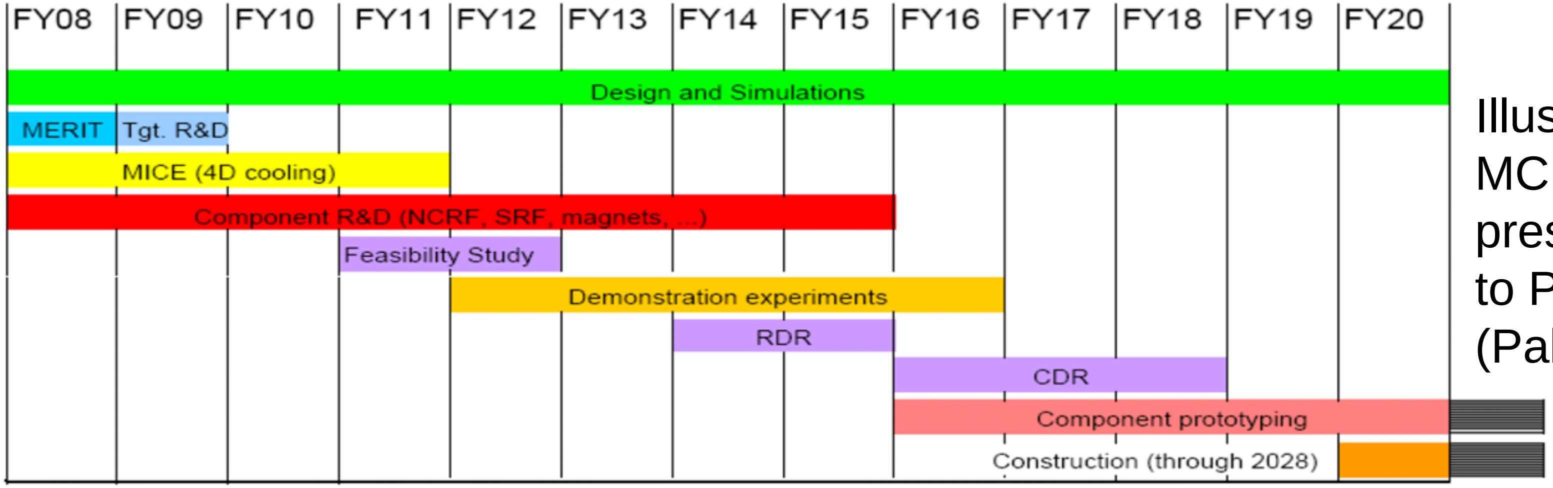
- 5-year plan activities dominate years 1-4
- Start post-plan R&D in years 4-5 if community wishes to proceed to next step



Timelines - NF



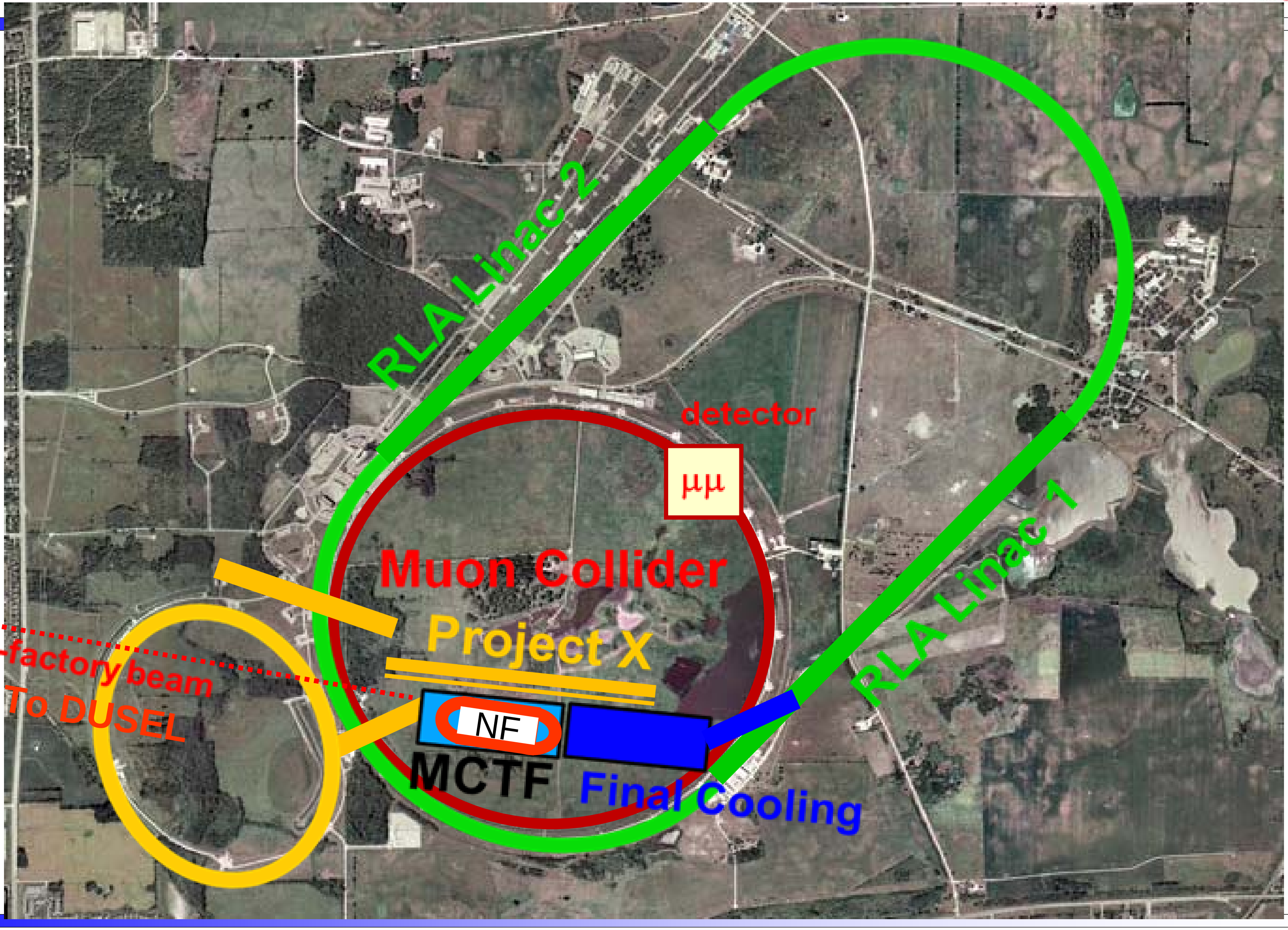
Aspirational NF timeline presented in ISS report



Illustrative MC timeline presented to P5 (Palmer)

MCTF

A Muon-Based Vision



Summary

- In the last 5 years there has been significant progress towards developing a Neutrino Factory and Muon Collider
- The U.S. muon accelerator R&D community (NFMCC+MCTF) has developed a proposal for the next 5 years
  - Contribute to IDS: NF RDR in 2012
  - Deliver a MC-DFS report in 2013
- The aspirational goals are to develop options for the U.S. – a NF construction-start by the late 2010s and an energy frontier MC construction-start by the early-mid 2020s

Lab Talks

- LBNL
  - LBNL Activities in Support on Muon-related R&D M. Zisman
  - Proposed CBP Contributions to Muon-related R&D J. Corlett
- FNAL
  - Muon Accelerator R&D Achievements at FNAL A. Bross
  - Proposed FNAL Contributions to Muon Accelerator R&D A. Jansson
- BNL
  - BNL Contributions to national Neutrino Facility/Muon Collider Effort H. Kirk
- ANL
  - Muon Collider R&D J. Norem