MCTF

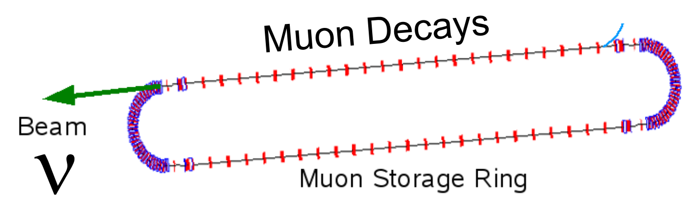
Prospects for Muon Decay Beams at Fermilab

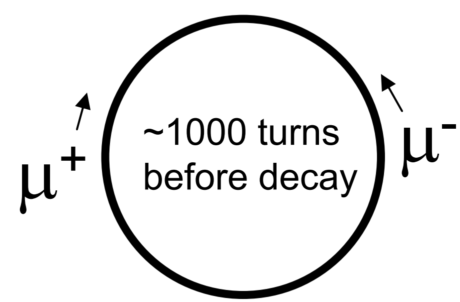
(A muon based vision for Fermilab)

Steve Geer

Introduction

- Over the last decade there has been significant progress in developing the concepts & technologies required to create $O(10^{21})$ 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 → multi-TeV lepton collider.





A Muon-Based Vision

♦ In the U.S. Neutrino Factory R&D is pursued together with Muon Collider R&D … much of the R&D is in common for both types of future facility.

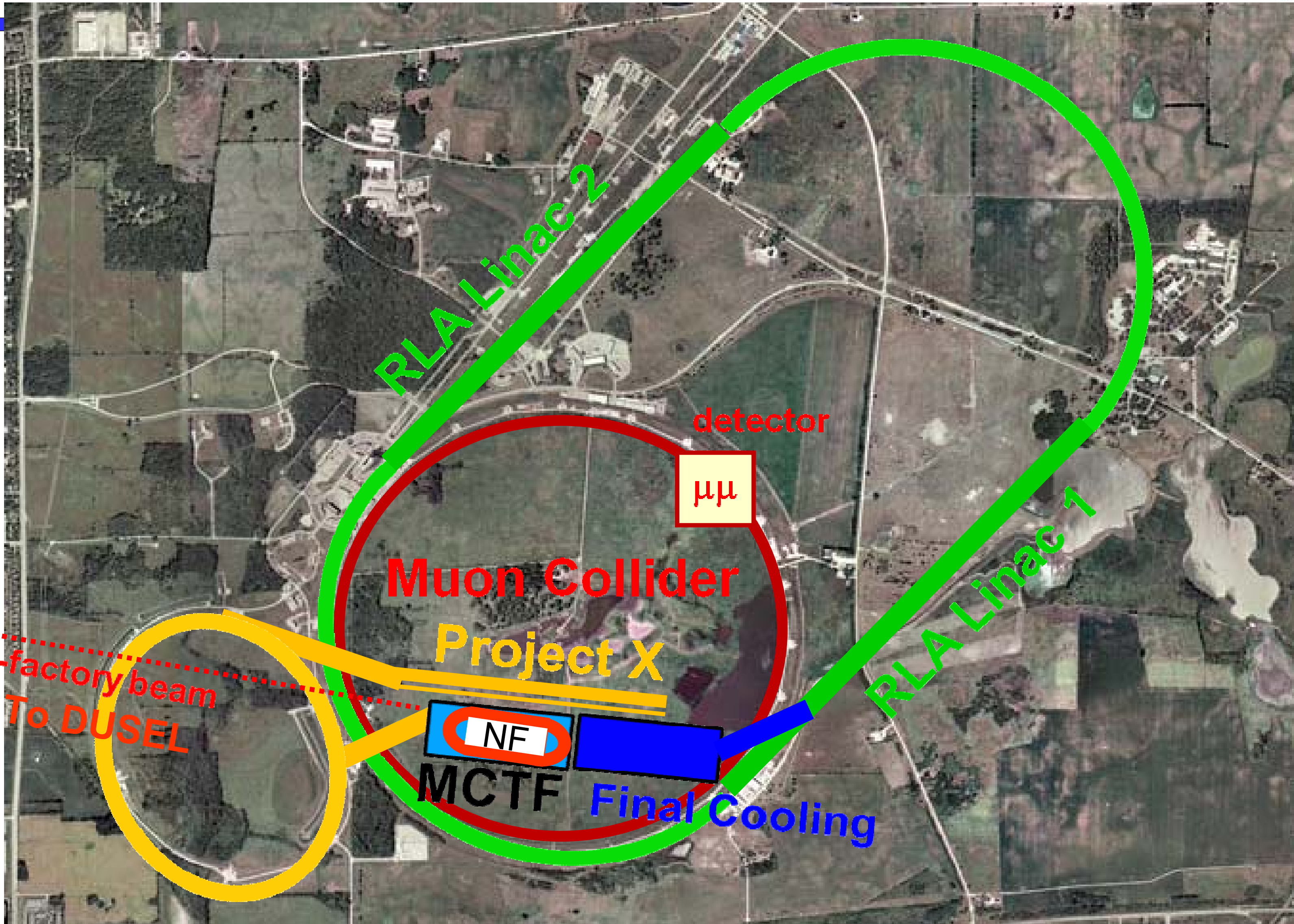
♦ A Neutrino Factory is considered as a possible step towards a Muon Collider, & hence the prospects for Muon Colliders & Neutrino Factories are somehow coupled together.

♦ Hence in the following I will talk about:

- the overall muon-based accelerator vision in the U.S.
- Muon Collider motivation (which underpins U.S muon-based thinking)
- where we would like to be in a few years time with both Neutrino Factory and Muon Collider R&D.

MCTF

An Illustrative Muon Vision at FNAL



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 U.S. EFFORT ~ 47 FTE

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

♦ Neutrino Factory R&D is pursued in the International Context (ISS → IDS)

Organization

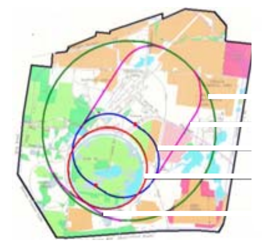
- NFMCC (Neutrino Factory & Muon Collider Collab.)
  - National collaboration funded since 1998.
  - Pursues Neutrino Factory & Muon Collider R&D.
  - NF R&D pursued with international partners
- MCTF (Muon Collider Task Force)
  - Task Force established at Fermilab in 2006
  - Pursues Muon Collider 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.

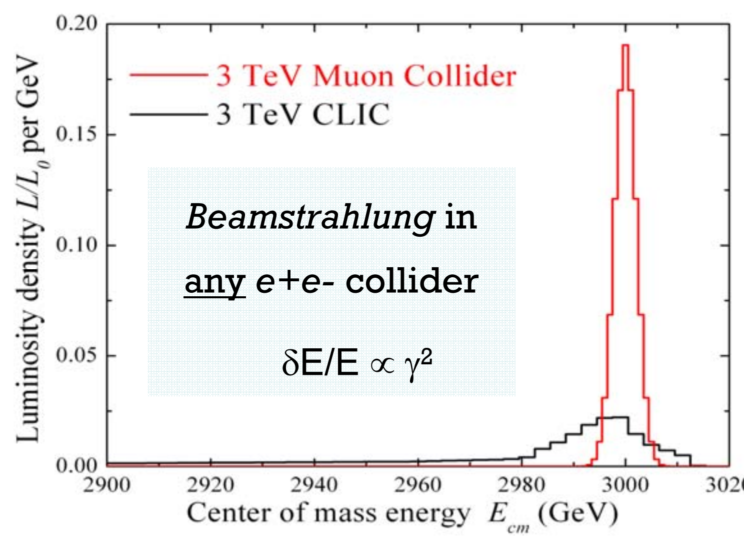
Muon Collider Advantages

- 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

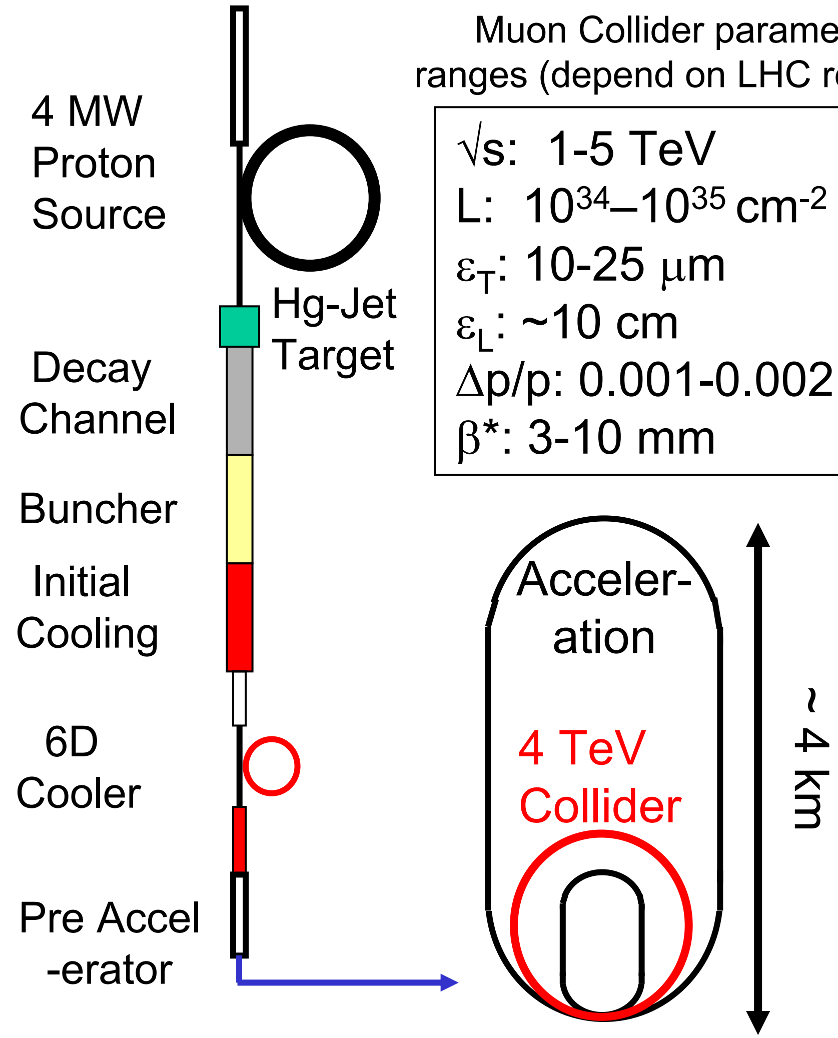
- $(m_\mu/m_e)^2$ = ~40000
  $\rightarrow$ s-channel Higgs Factory
  (requires lower luminosity)



MCTF

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 $\rightarrow$ *O*(1) TeV**
- **Storage Ring**
  - **store for ~1000 turns**

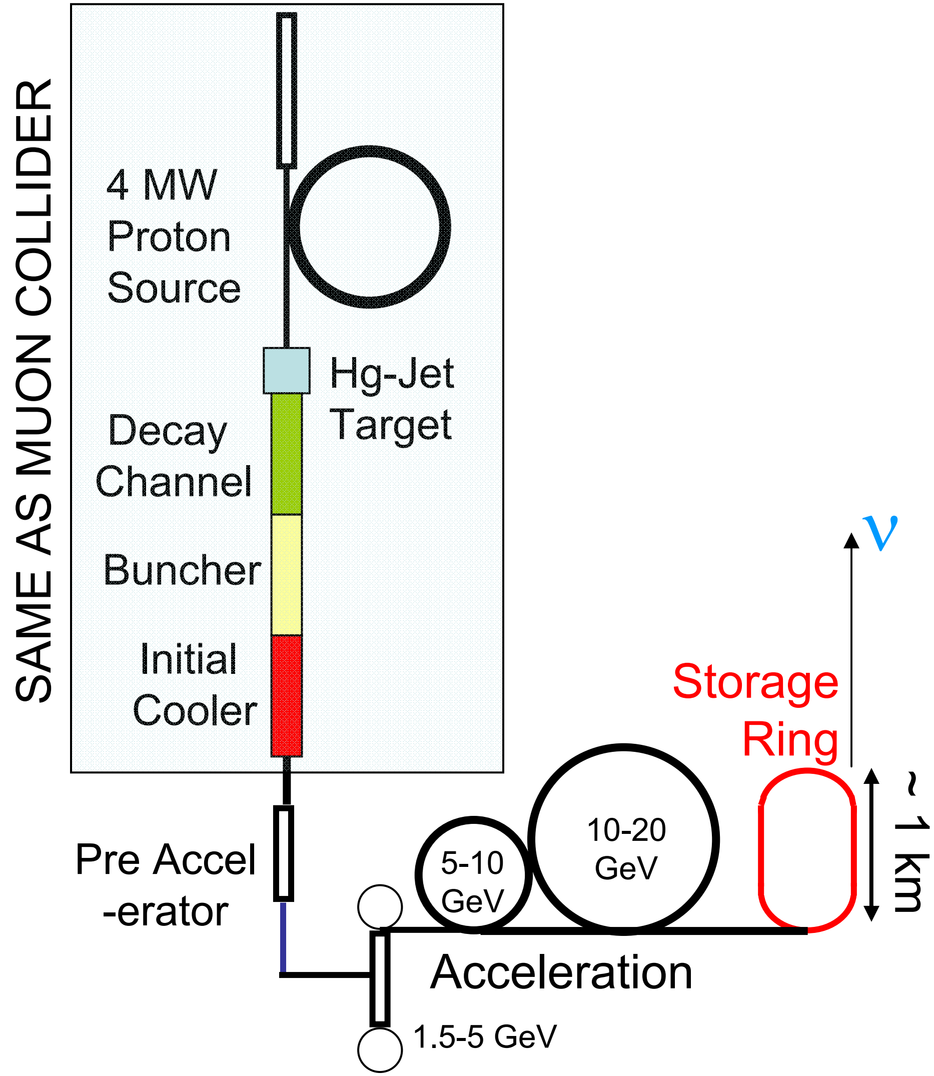


Muon Collider parameter ranges (depend on LHC results)

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

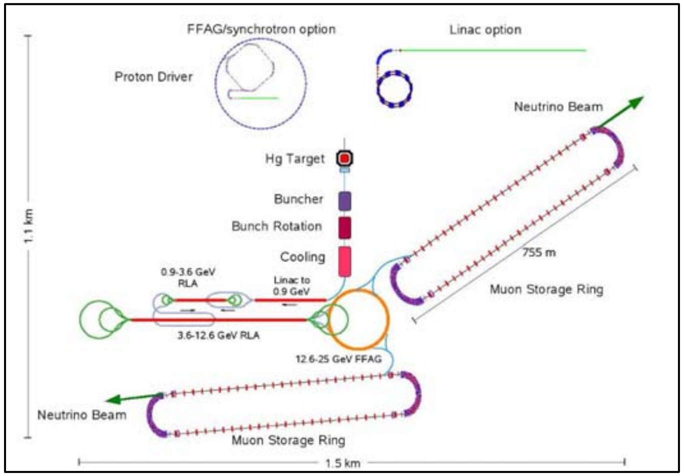
Neutrino Factory

- 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)

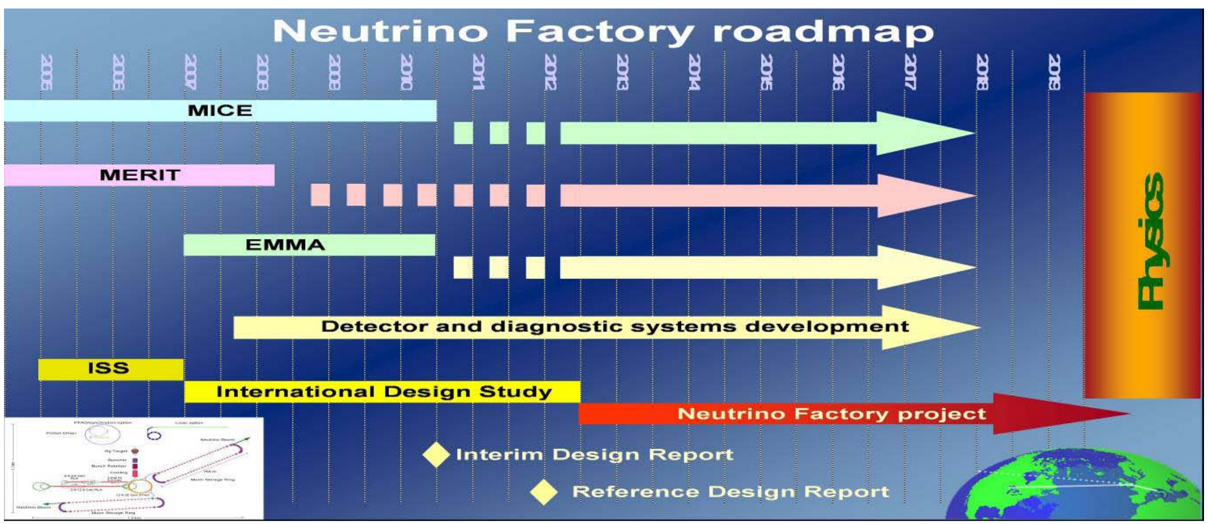


MCTF

Neutrino Factory Vision



Baseline scenario
= 25 GeV NF (ISS)



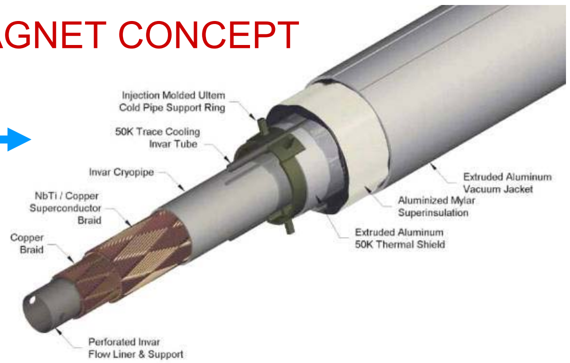
Aspirational
NF timeline
presented
in ISS
report

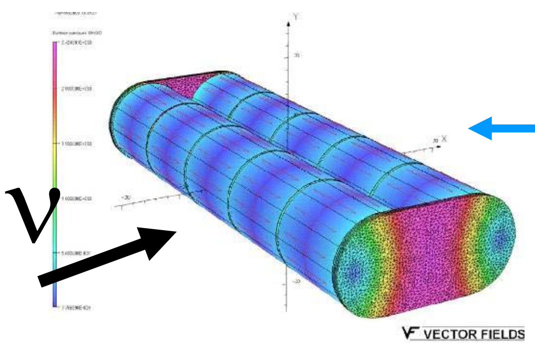
Low Energy NF Introduction

- A new concept has emerged for a detector that can measure the muon charge from low energy neutrino interactions.

Eliminate large (expensive) cryostat & vac loads by using superconducting transmission line concept developed for the VLHC – wrap it into a solenoid !

MAGNET CONCEPT





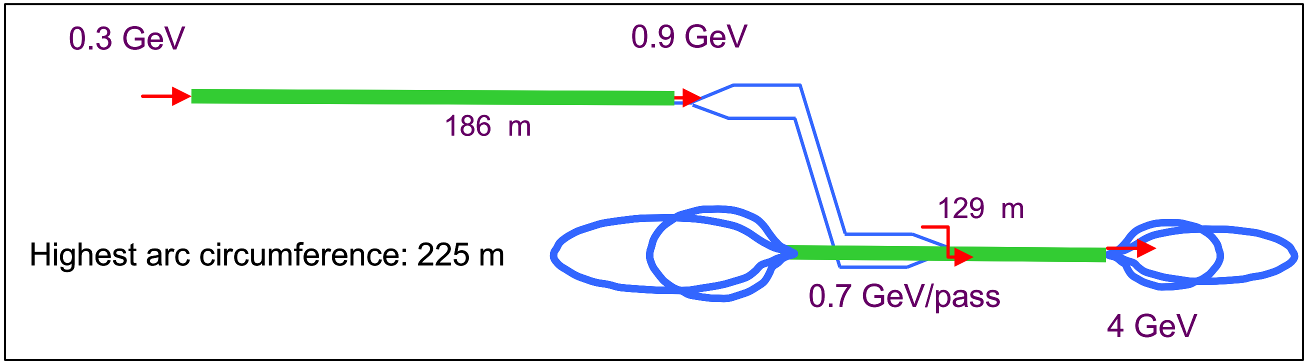
Build a magnetic cavern ($0.5T\times34000\ m^3$). Example: two parallel solenoids with iron end-plates

- E_μ = 4 GeV NF combines strengths of WBB (spanning several oscillations) & NF → good performance for large & small θ_{13}
  - Cheaper (less acceleration) & matched to FNAL-DUSEL baseline
  - Needs R&D to further study detector performance OK

MCTF

Low Energy Neutrino Factory Design

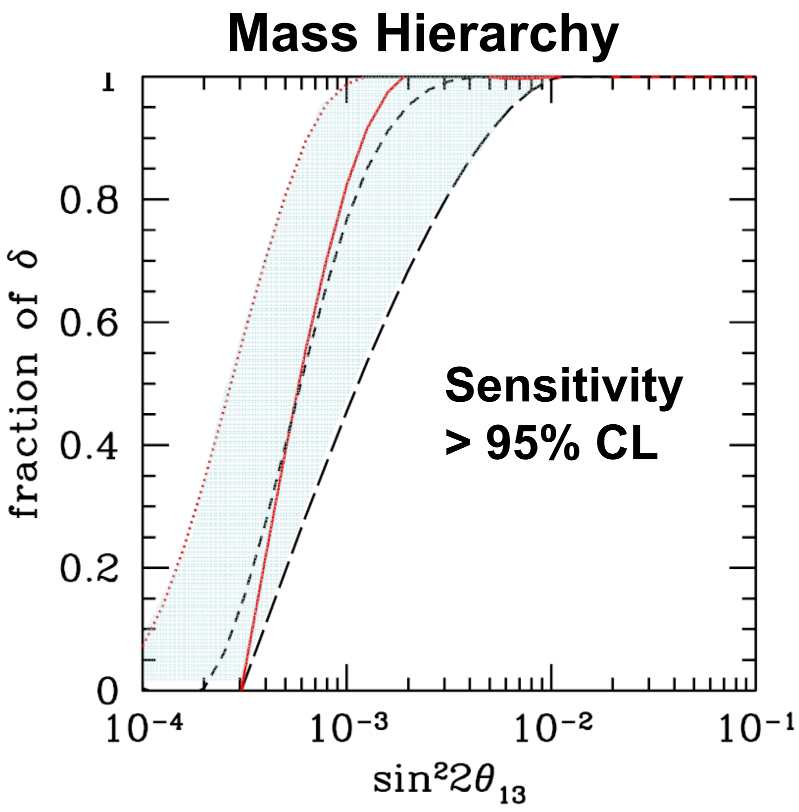
- Paper coming soon (Ankenbrandt, Bogacz, Bross, Geer, Johnstone, Neuffer, Popovic) :
  - –Proton source, target, & decay channel: same as ISS NF
  - –Re-optimized bunching & phase rotation scheme (same performance as ISS but shorter)
  - –Cooling channel same as ISS
  - –New acceleration scheme (lower energy → simpler)
  - –New simpler, smaller, cheaper ring.

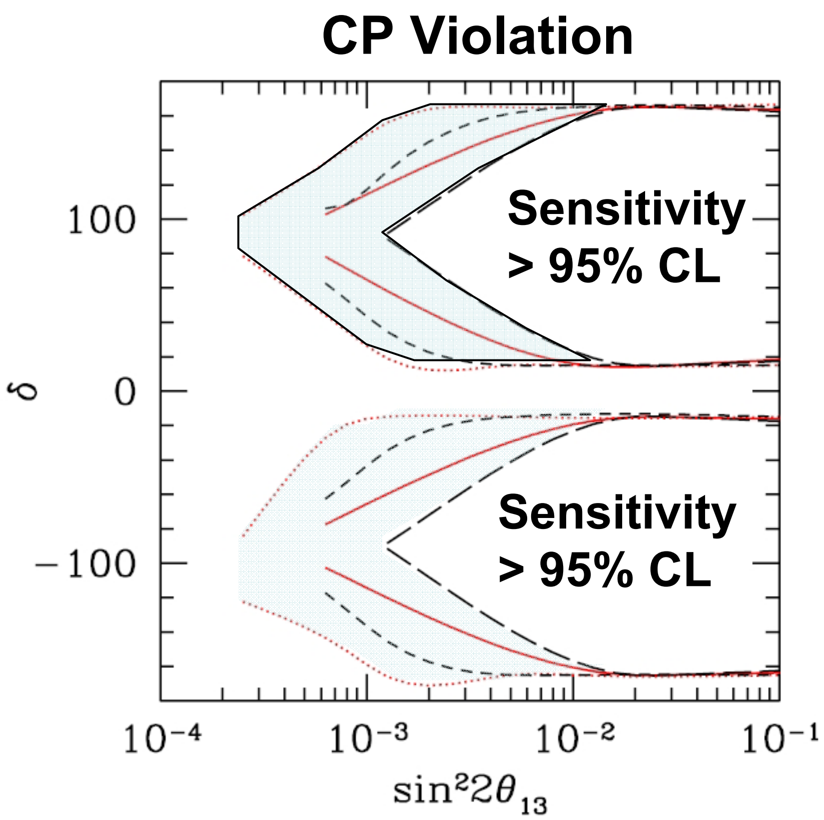


- Design delivers 1.4×10^{21} useful μ^+ decays/year (& same number of useful μ^- decays)

Low Energy NF Physics Reach

Geer, Mena, & Pascoli, Phys. Rev. D75, 093001, (2007); Bross, Ellis, Geer, Mena,& Pascoli, Phys. Rev. D77, 093012 (2008)





- Bands show how 95%CL boundary changes with/without backgrounds, and with running time from 3.3 → 10 years

MCTF

Food for thought: What if θ_{13} = 0 ?

Bross, Ellis, Geer, Mena,& Pascoli, Phys. Rev. D77, 093012 (2008)

- Method relies on exploiting effects of solar Δm^2 on ν_μ disappearance:

$$P(\nu_\mu \to \nu_\mu) = 1 - 4|U_{\mu 1}|^2|U_{\mu 2}|^2 \sin^2 \frac{\Delta m^2_{12} L}{4E} - 4|U_{\mu 1}|^2|U_{\mu 3}|^2 \sin^2 \frac{\Delta m^2_{13} L}{4E} - 4|U_{\mu 2}|^2|U_{\mu 3}|^2 \sin^2 \frac{\Delta m^2_{23} L}{4E}$$

- Depends on both $|\Delta m^2_{13}|$ and $|\Delta m^2_{23}|$ $\to$ can determine who is larger than who … but need $\sigma(\Delta m_{13}{}^2)$ ~ 1-2% … which is within the realm of the potential precision of a low energy NF.

- In our low energy NF scenario (10 yrs running) with θ_{13}=0, if systematic uncertainties are assumed 0 (2%) we find the hierarchy can be resolved at the 95% (90%) CL

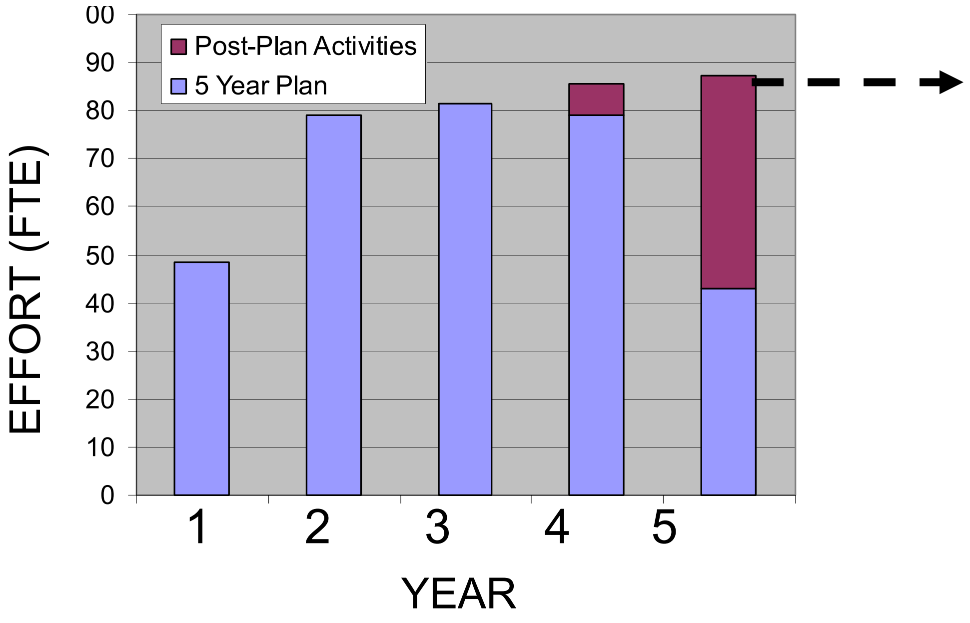
Not a proof that it can be done, but an illustration of the power of precision measurements & an encouragement to work hard on the systematics and strive towards O(1%) measurements

Next Steps: U.S. Muon 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 Way Forward

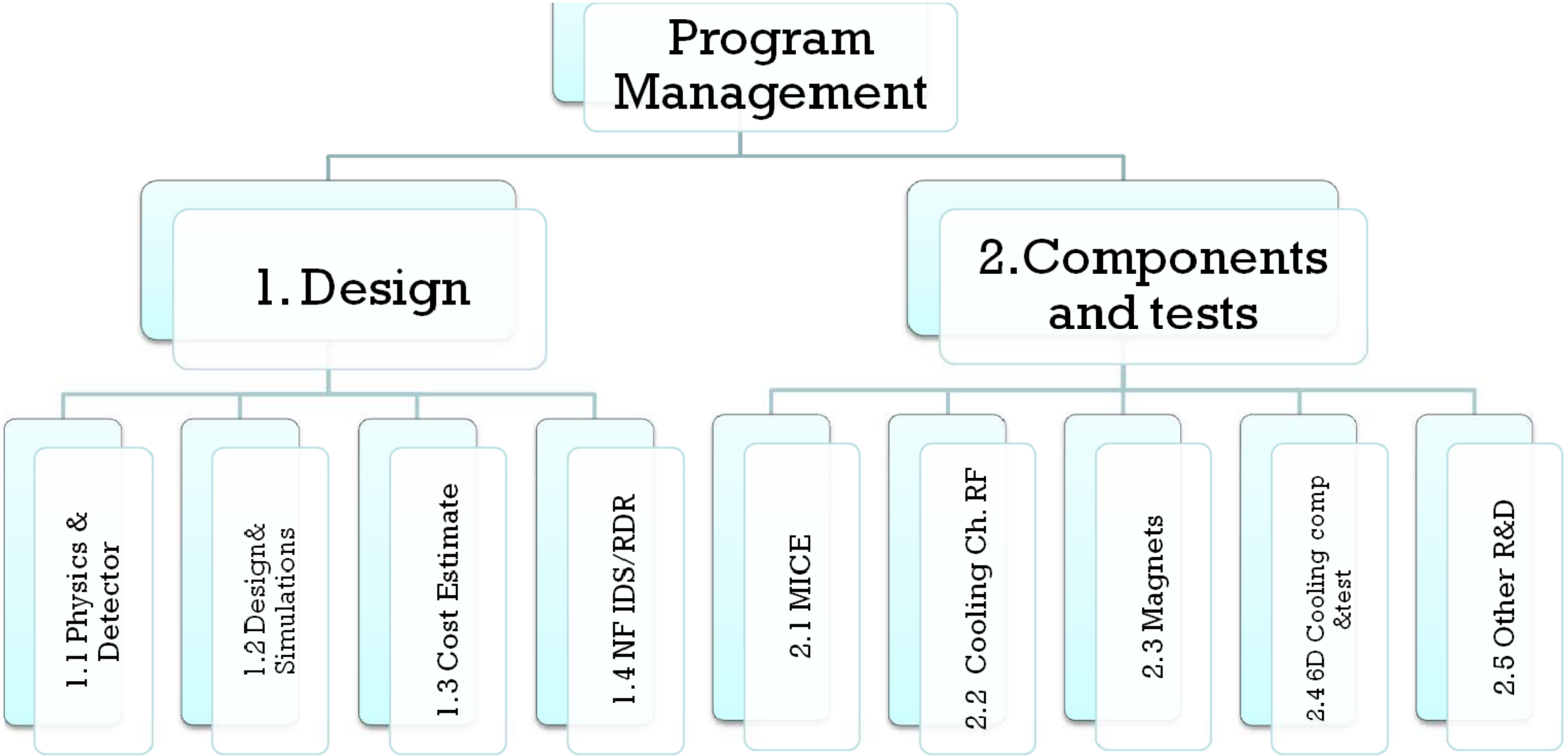
- The U.S. NFMCC & MCTF have created a proposal for muon accelerator R&D for the period FY09-FY13
- The proposal is intended to be aligned with P5 recommendations, & is being presented to the DOE for the first time (right now).



The Proposed 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

Elements of the MC R&D Plan



Elements of the Plan - 2

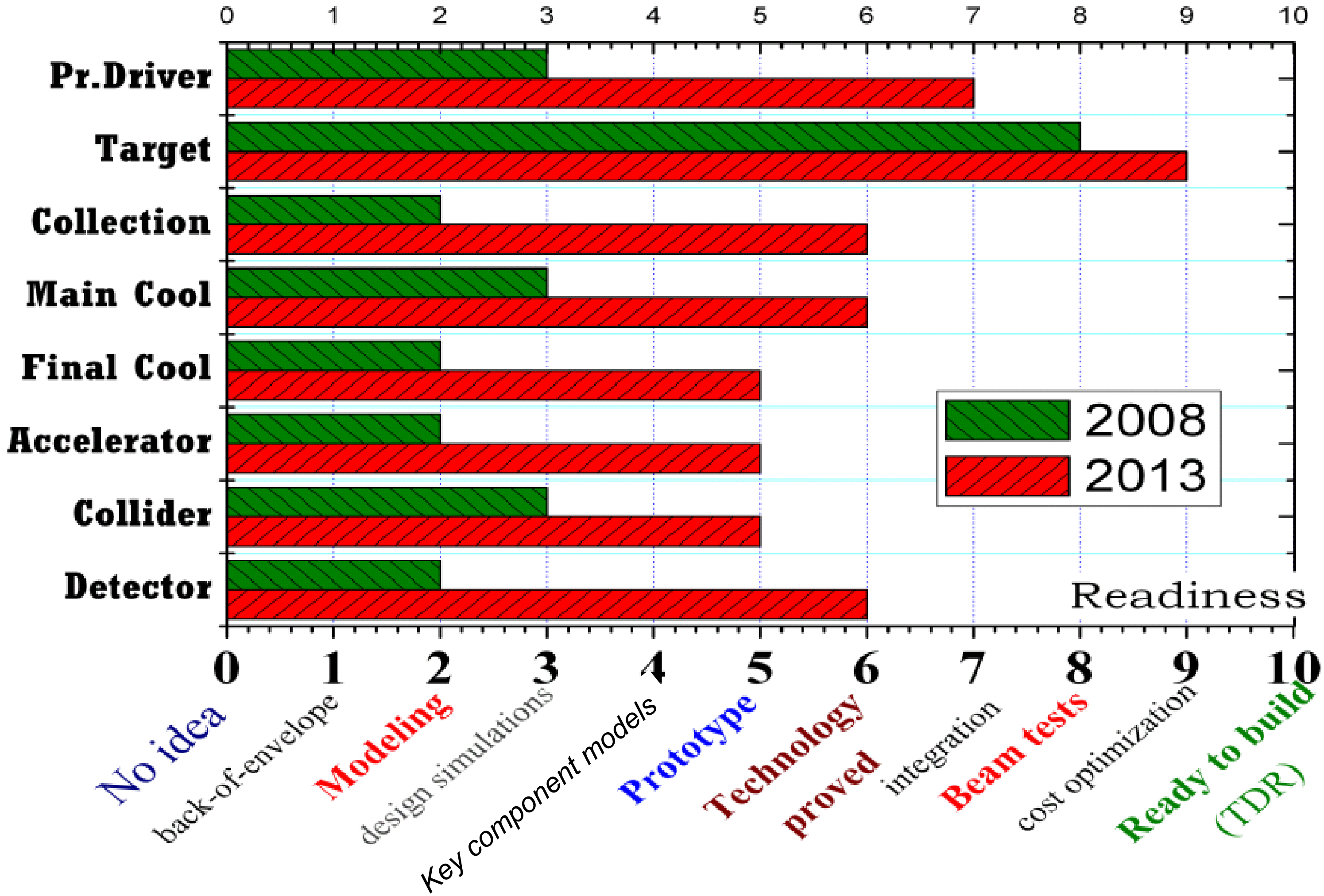
- Design and Simulations
  - MC DFS
    - Physics and Detector Study (Demarteau and Eichten)
    - Accelerator Design & Simulation Study (Ankenbrandt & Fernow)
    - Cost Estimation Study (Zisman)
  - NF RDR (Bross) (under IDS-NF auspices)
    - overall system design and staging scenarios
    - siting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

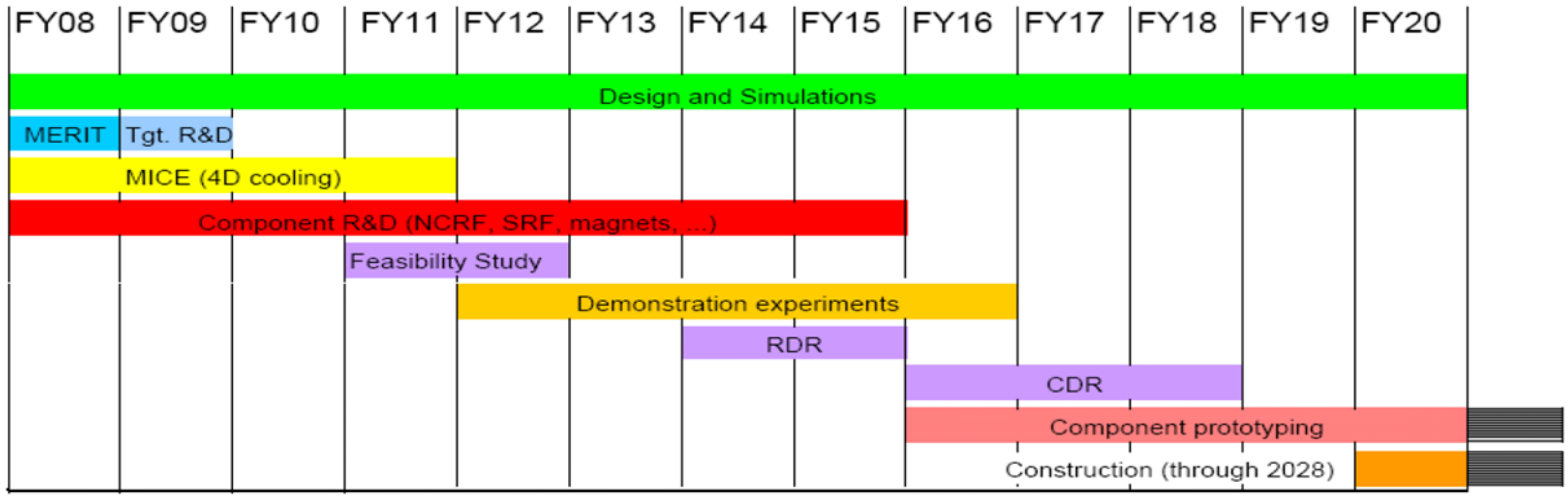
MCTF

Expected MC Status after Plan



Timelines - MC

Illustrative MC timeline presented to P5 (Palmer)



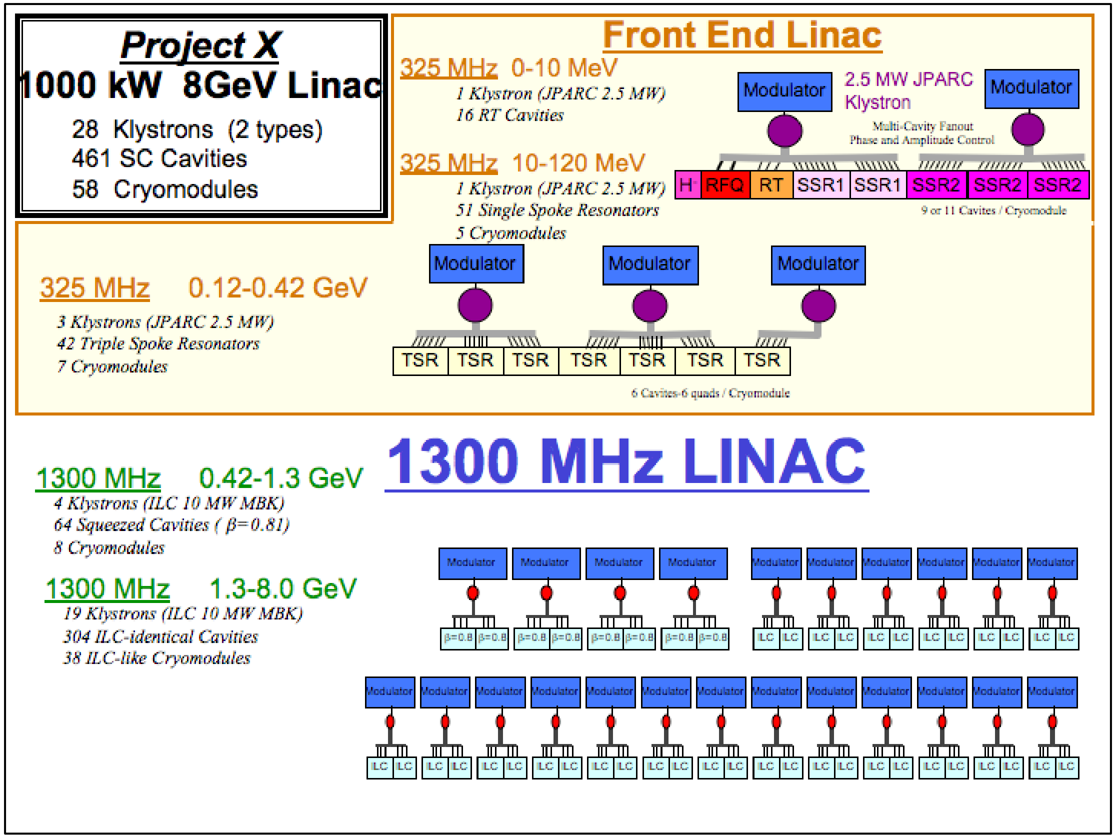
First Step: Project X

- Details still being defined, but presently envisioned as a 1 MW 8 GeV linac

  - Upgrade path to ~4MW by

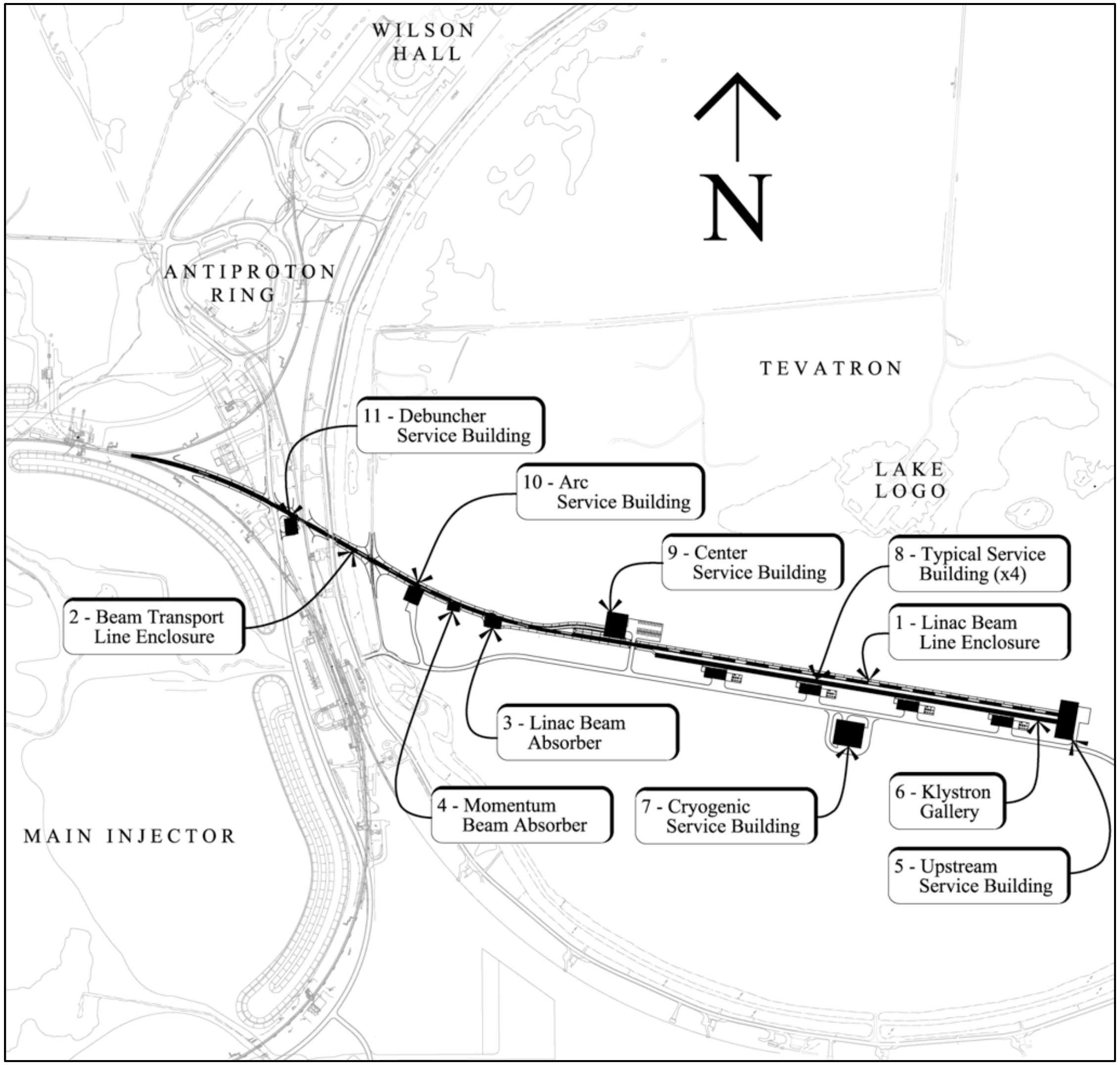
    x2 rep rate (5Hz→10Hz)

    x2 pulse length
  - (1.25ms → 2.5ms)



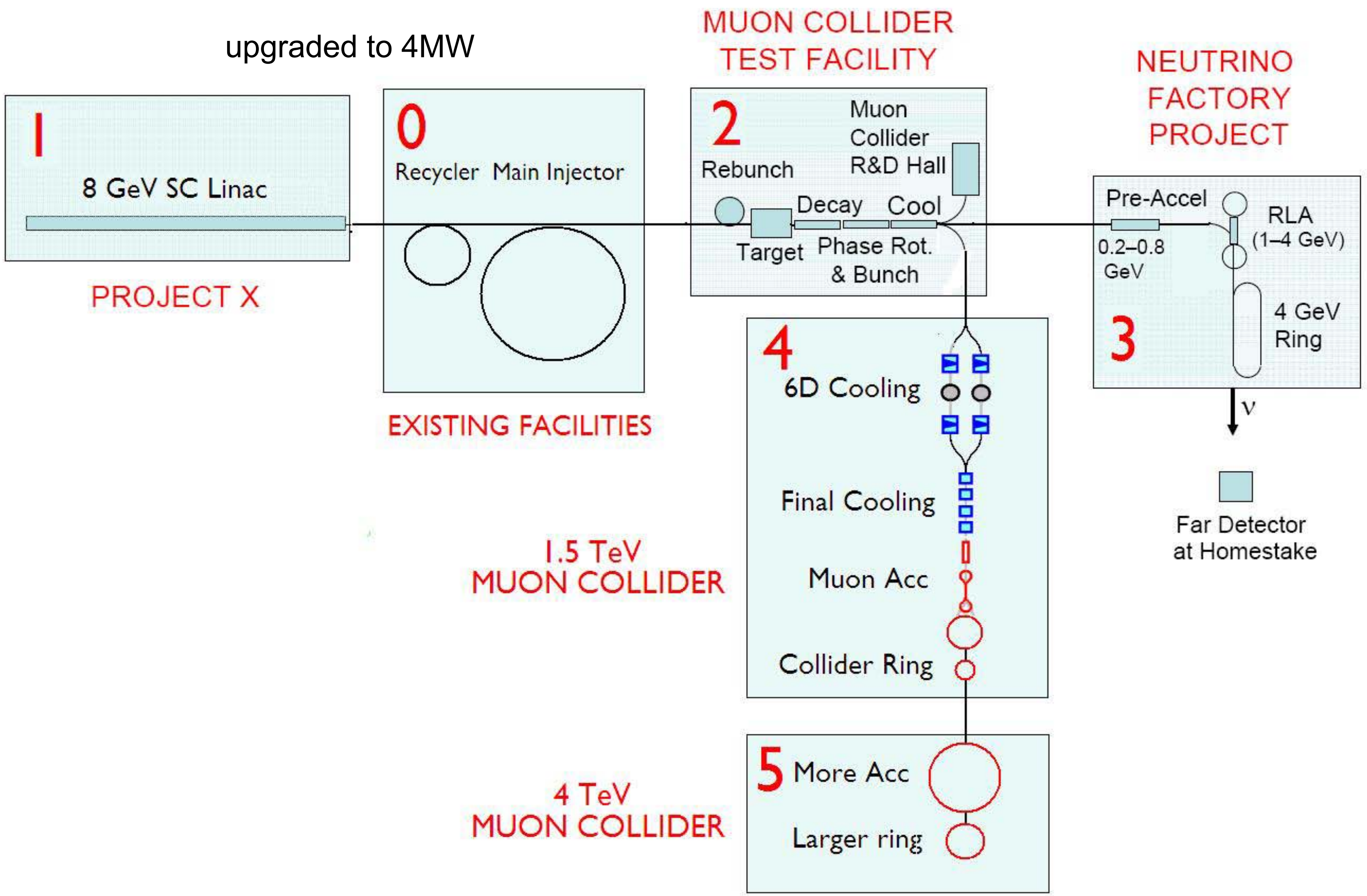
MCTF

Project X - continued



- Possible construction start ~2013
- Would support 2MW MI beam at 120 GeV plus an additional high intensity program at 8GeV
- With suitable modifications, would be able to support a Neutrino Factory &/or Muon Collider in the longer term

Illustrative Staging Scenario



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 U.S. goals are to develop options– a NF construction-start by the late 2010s and an energy frontier MC construction-start by the early-mid 2020s