Fermilab Future Neutrino Program

Hitoshi Kameika

Meeting at SLAC

February 21, 2008

My “Charge”

E-mail from Bill Marciano, Feb. 6,2008

- Timetable from now through long term vision : MINOS, NOvA, large detector at DUSEL
- Decision points based on results from reactors and T2K
- Funding profile for projects on the timeline
- Physics reach for
  - 100kT LAr
  - Input assumptions

From P. Oddone's remarks to HEPAP, Feb. 14, 2008

Concluding remarks

- We need a base program that
  - provides exciting physics
  - maintains many options for the future
  - is not dependent on huge jumps in funding
  - it can be carried out incrementally in bite si pieces
  - supports a path to gain a large machine at energy frontier

Outline

- Current Program
  - NuMI Beam - MINOS, detector technology tests, MINERvA, NOvA
  - Booster Neutrino Beam (BNB) - MiniBooNE, SciBooNE
- Next generation long baseline experiments
  - Physics goals
  - Beam from Fermilab
  - Detectors
- Getting there - exploiting our existing facility
- Cost & Schedule for planning purposes
- Summary

The Fermilab Neutrino Program

- 8 GeV protons from the Booster
  - Neutrinos from Booster Neutrino Beam (BNB)
    - To MiniBooNE (running)
    - To SciBooNE (running)

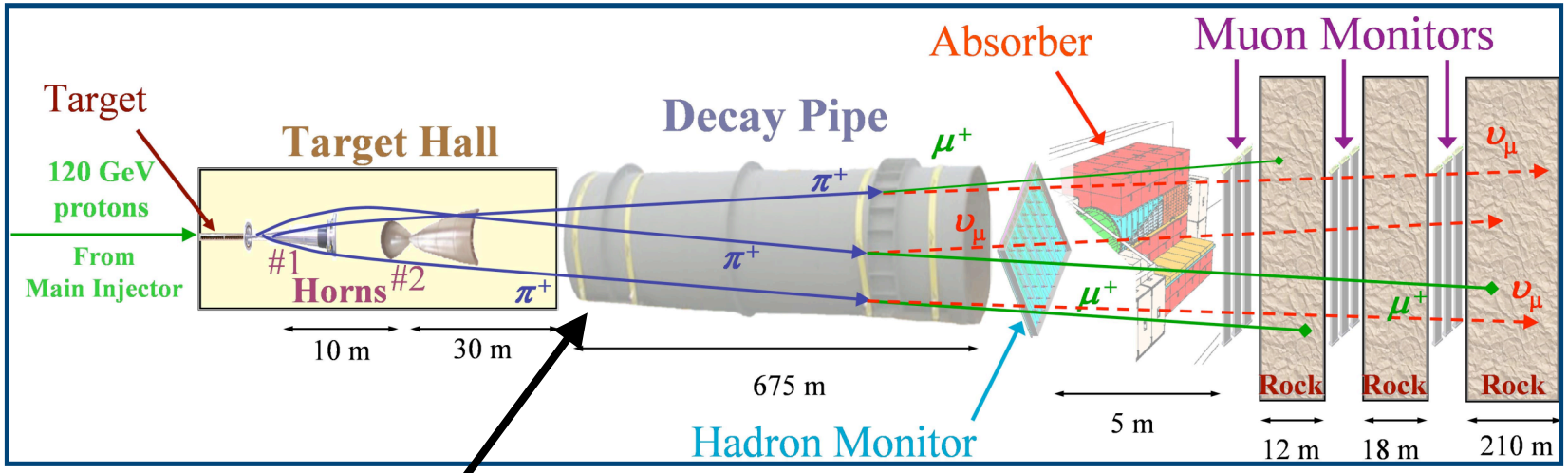
- 120 GeV protons from the Main Injector
  - Neutrinos from NuMI
    - To MINOS (running)
    - To emulsion and liquid argon detector tests (in progress)
    - To MINERvA (design, construction)
    - To NOvA (design, prototyping)

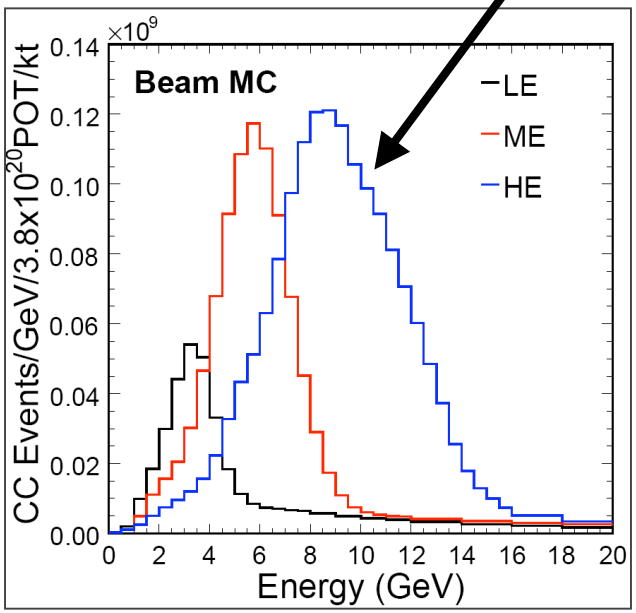
The Fermilab Neutrino Program

- 8 GeV protons from the Booster
  - Neutrinos from Booster Neutrino Beam (BNB)
    - To MiniBooNE (running)
    - To SciBooNE (running)
    - To MicroBooNE (proposed)
- 120 GeV protons from the Main Injector
  - Neutrinos from NuMI
    - To MINOS (running)
    - To emulsion and liquid argon detector tests (in progress)
    - To MINERvA (design, construction)
    - To NOvA (design, prototyping)
    - To LAr5 at SOUDAN (LOI under development)

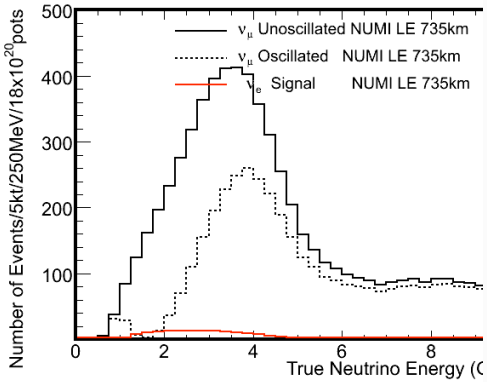
The NuMI Beam

Originally optimized for high energy ($\Delta m^2_{23} > 3e^{-3}$ eV^2)

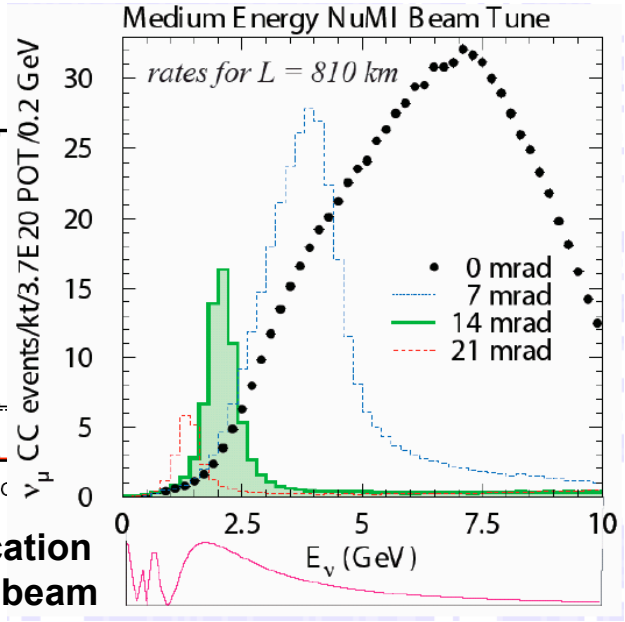




Target - horn separation sets the neutrino energy spectrum.

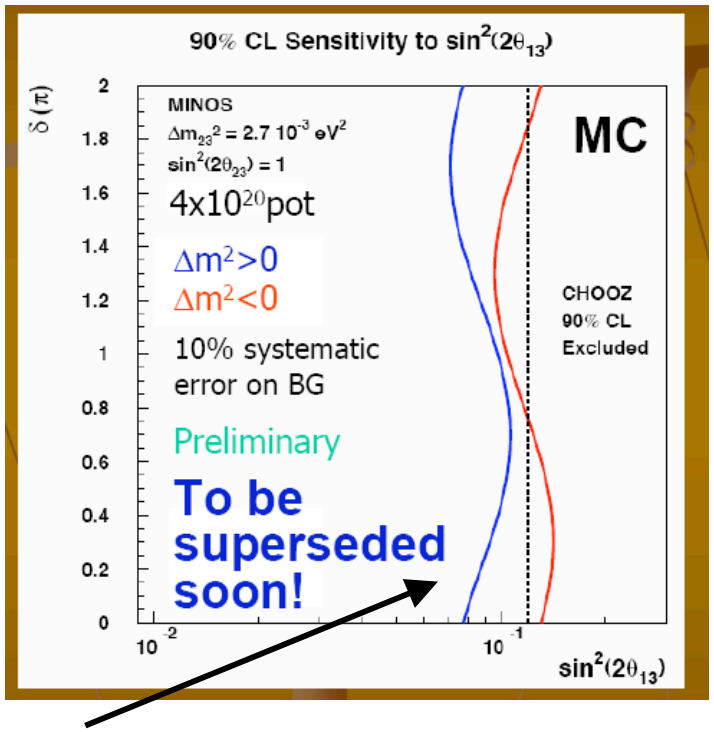


Off-axis detector location sees a narrow band beam



MINOS Expected Sensitivities in $\sin^2 2\theta_{13}$

- MINOS currently running: >4 x 10^{20} protons accumulated.
- Primary goal is measurement of Δm^2_{23} (see hep-ex 07081495)
- Also have some sensitivity to $\sin^2 2\theta_{13}$ via e^- appearance
  - Difficult because of large backgrounds and low statistics
  - Techniques include understanding backgrounds with near detector data and varying beam energies.
  - Shows variation with hierarchy, CP phase δ
- By end of FY 2009 should have explored significant part of region bounding CHOOZ limit from below.



Monte Carlo only study of sensitivity
Use of detector data to constrain sensitivities now in progress

NOνA

- With the current funding profile data taking can begin in 2014
- NOvA is a unique experiment
  - ν's from FNAL to Ash River experience significant matter effects
  - ν and $\bar{\nu}$ rates depend on the mass hierarchy
- As measurements or limits on θ_{13} emerge, a run plan can be optimized to maximize sensitivity
- The physics program can be enhanced with intensity upgrades (Project X) and a complimentary on-axis detector (LAr5 at SOUDAN)

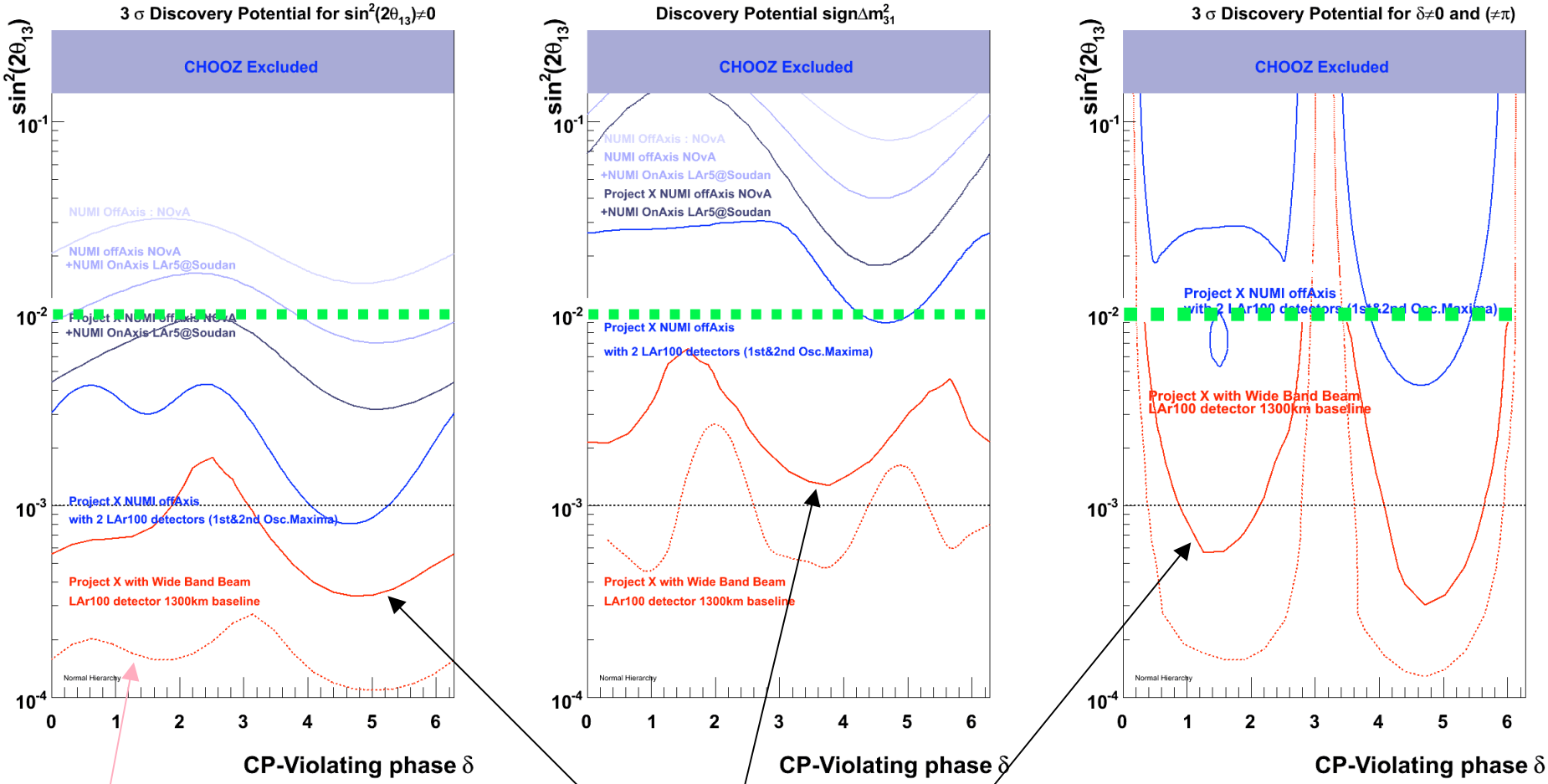
Neutrino Program Evolution

- Numerous studies over the past several years have laid out options for further exploring the neutrino sector
- i.e. BNL-FNAL US long baseline neutrino experiment study (March 2006-June 2007) explored
  - Beam options
    - NuMI , new Wide Band Beam
    - On and off axis detector locations
  - Detector technology options
    - Water cerenkov, liquid argon
- Several independent calculations of sensitivities give consistent results for the level of accuracy that can be expected at this stage

General Conclusions

- Future experiments using conventional neutrino beams can be designed to have sensitivity to measuring CP violation and the neutrino mass hierarchy down to very small values of $\sin^2 2\theta_{13}$, at the 3-5σ discovery level *but* require :
  - **Proton source** at the Megawatt level (or decades of running time → We need Project X!)
  - A **neutrino beam** optimized to the oscillation probability (covering the 1st and 2nd oscillation maximum) if possible
  - The increased matter effects in an **experiment baseline > 1000 km** improves the sensitivity to determine the mass hierarchy
  - **Detector** with effective masses (mass*efficiency) **> 100kT**

Sensitivities at a 1300 km baseline

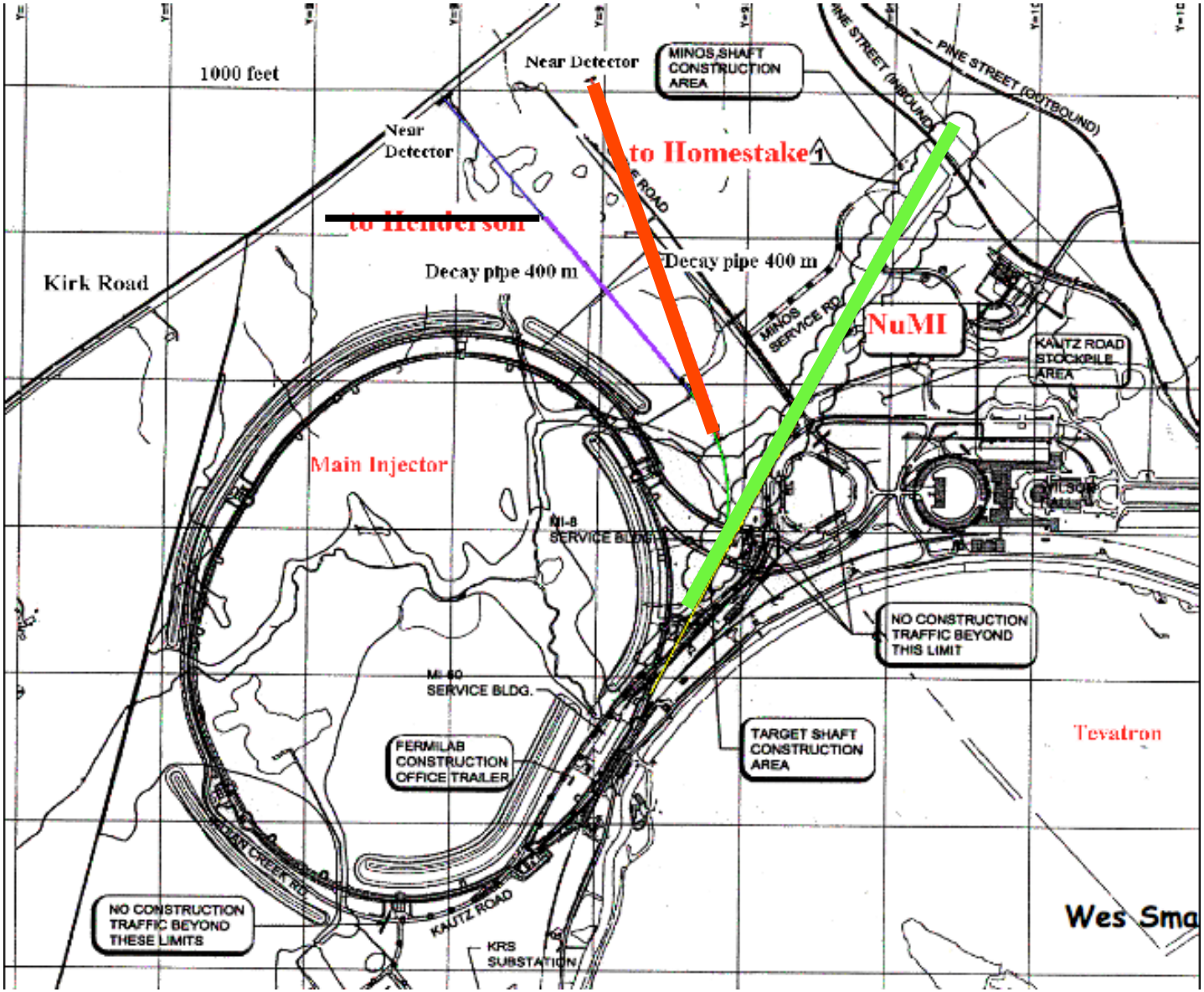


Updated curves

Low statistics
run - lesson learned!

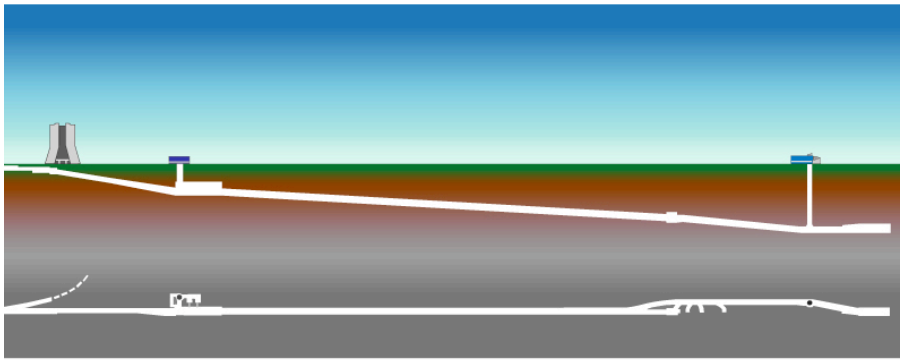
Beam to DUSEL

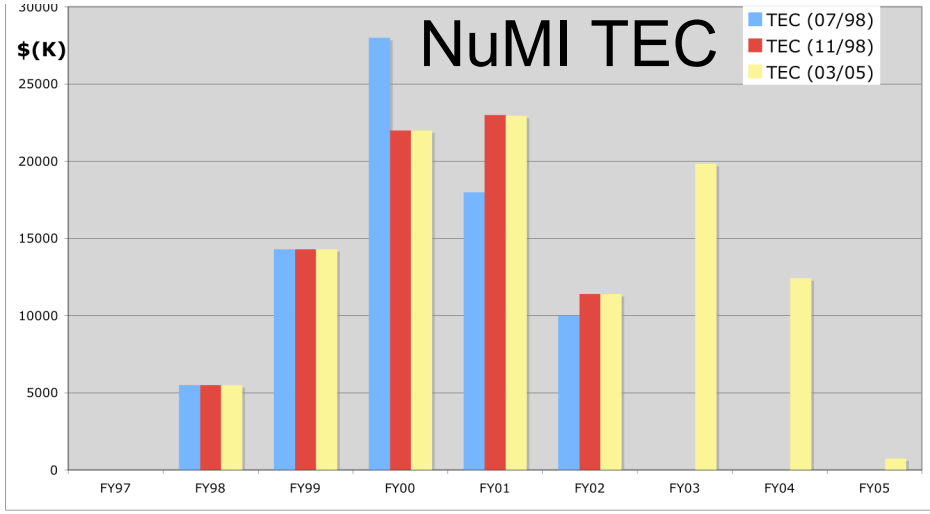
Laid out in Spring 2006



A new beam project ….

Cost and schedule can be based on our Fermilab underground construction **experience**….





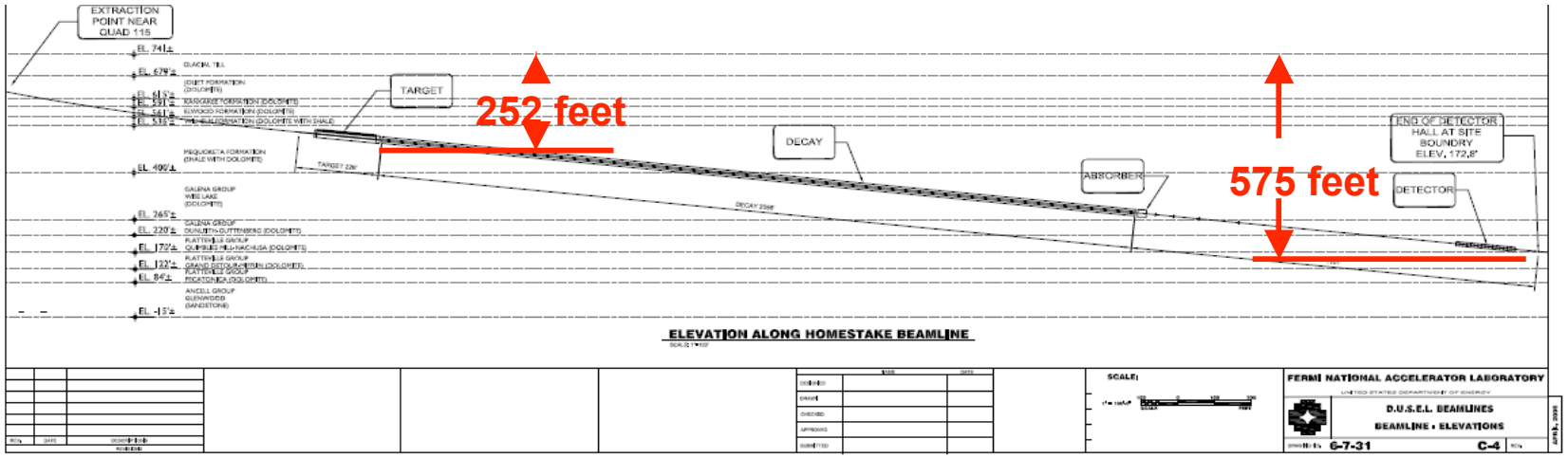
NuMI Civil construction : $75M
NuMI Technical components : $30M
AY$ at project completion 03/05

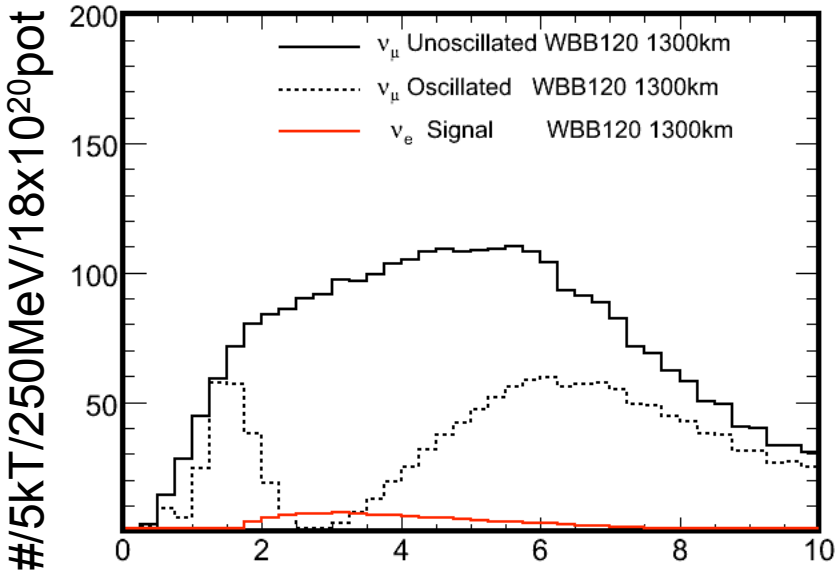
Civil construction included:
2 access shafts
Target & absorber halls
2m diameter x
675m shielded decay tunnel
By-pass tunnel
Near Detector hall

2001 re-baseline added
$33M to the TEC;
More recent projects have been required to incorporate larger initial contingency

Construction projects generally take longer than initially planned, so it's important to start planning early!

A beam to DUSEL : shorter & wider than NuMI

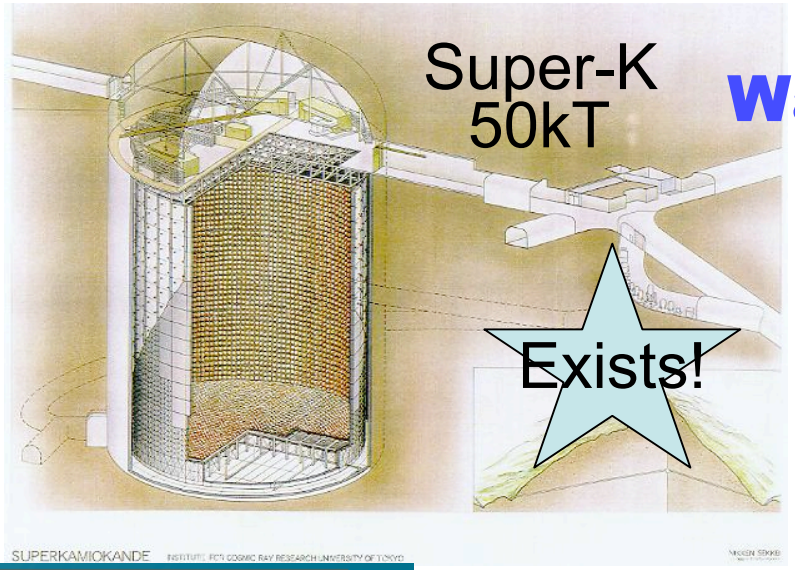




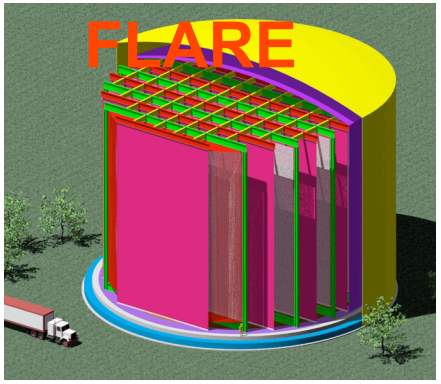
High power issues:
groundwater activation,
radioactive air emissions,
target stress,radiation damage,
decay pipe stress….

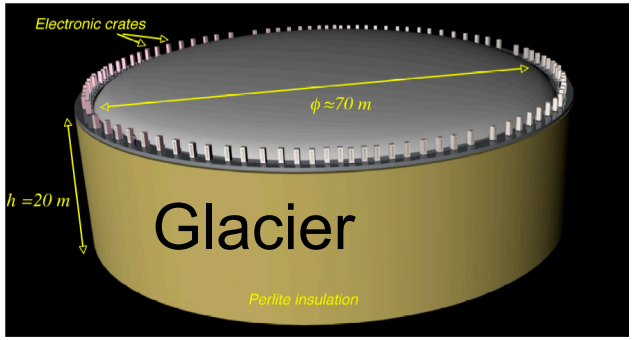
A super beam needs a super detector ….

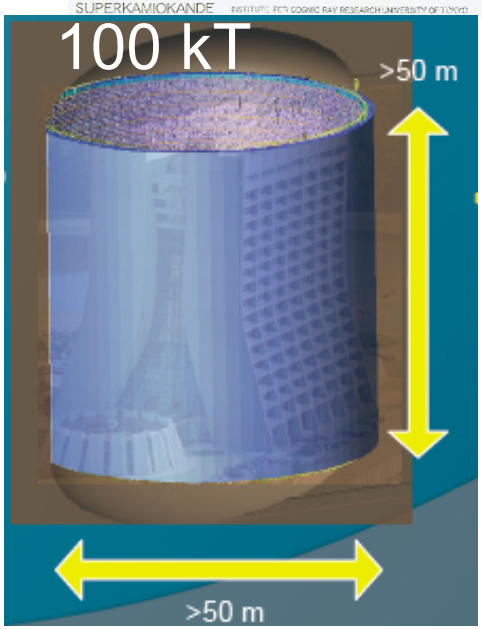
Large Detector Concepts

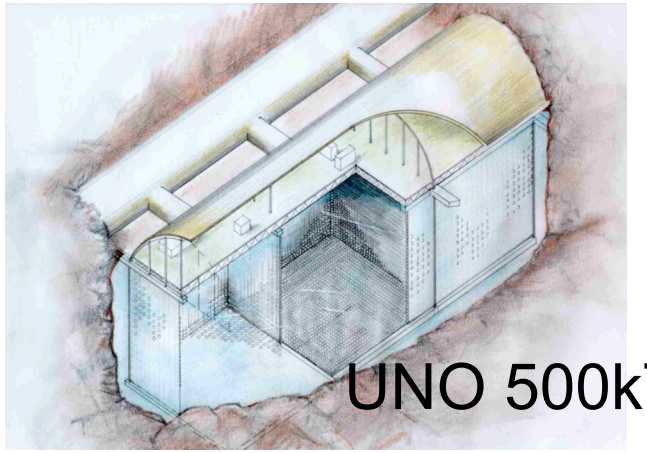


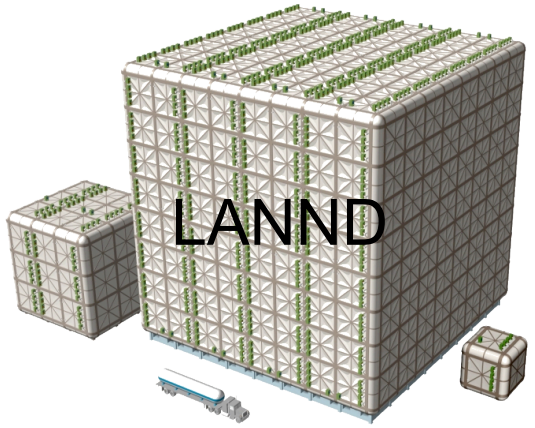
Water Cerenkov And Liquid Argon











Large Detector Issues

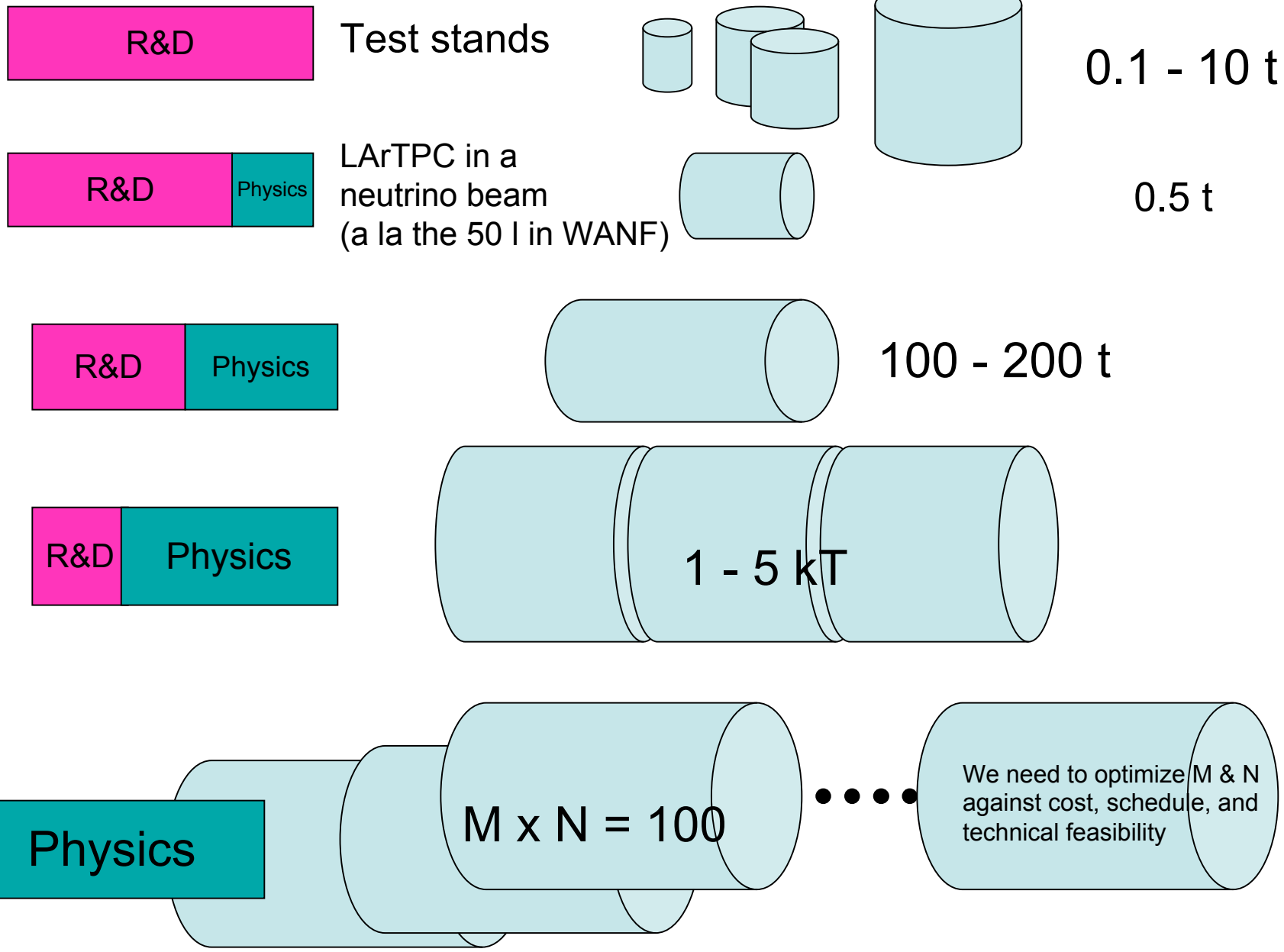
- Independent of technology
  - Cavern excavation costs
- Water Cerenkov
  - Risks associated with cavern size
  - PMT production and delivery schedules
- Liquid Argon
  - Demonstration of performance in a real experiment
  - Cost per unit mass
  - Determine the optimum modular configuration

Development of the LAr technology is well suited to the ***Fermilab accelerator program****…*
Fermilab also has experience and expertise in cavern construction…

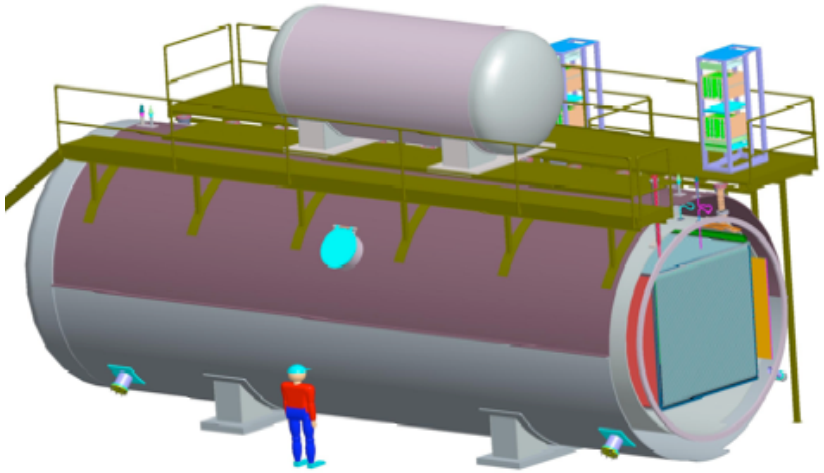
Cavern excavation cost

- MINOS cavern at SOUDAN
  - Rock Excavation only :
    - 1994 Proposal estimate : $3.3M
    - FY2000 actual : $7M for 11,500 m^3
    - Escalate to FY08 → $780/ m^3
- Estimate from Chris Laughton
  - Excavation only :
    - $500 - 1000/$m^3$
    - Range comes from the site specific risk levels
- Excavating caverns for 100kT LAr detector
  - ~80,000 m^3 @$750 / m^3 → $60M
    Discussion of “outfitting” by Bonnie

Evolution of a Liquid Argon Physics Program



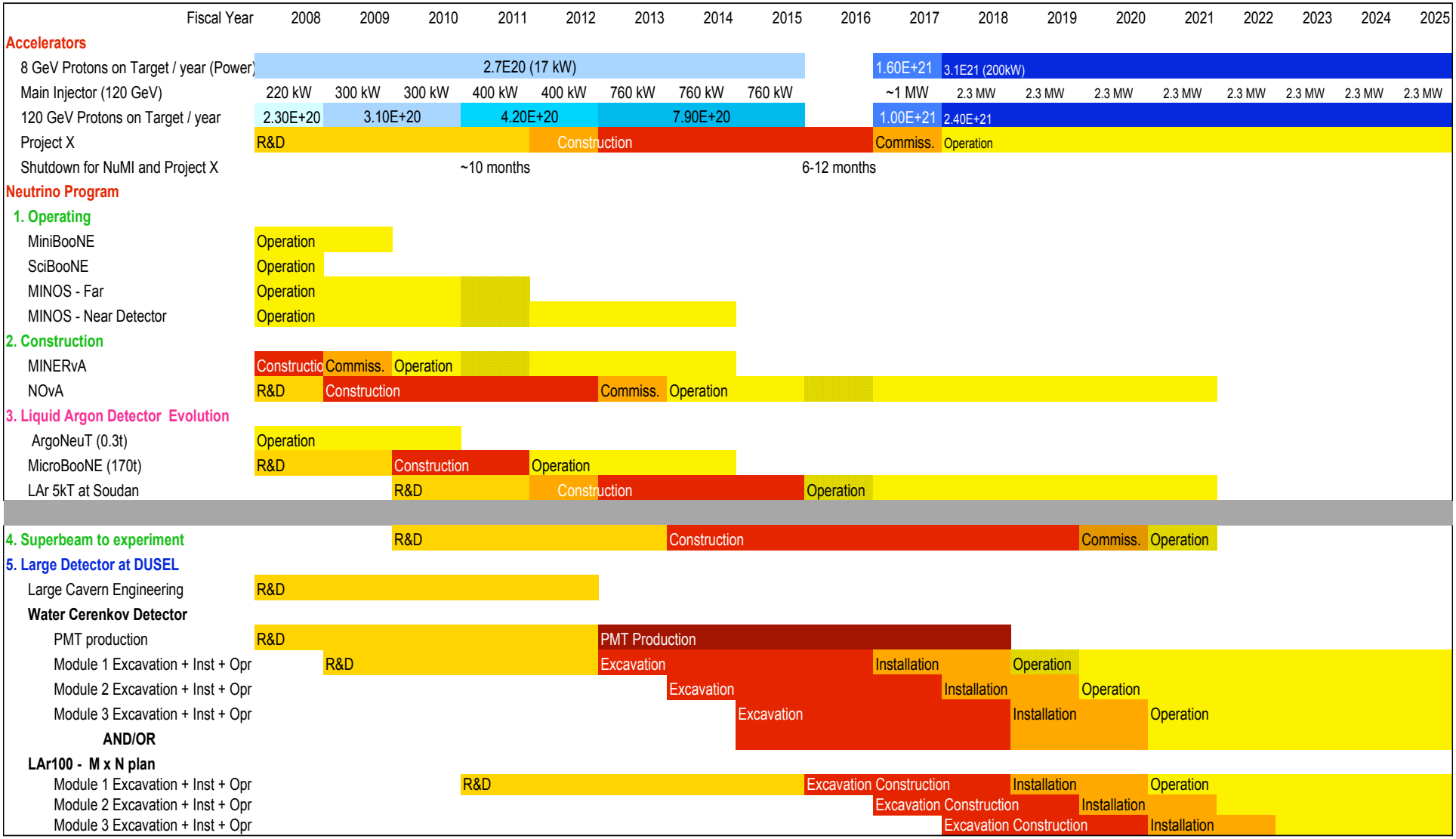
MicroBooNE and LAr5



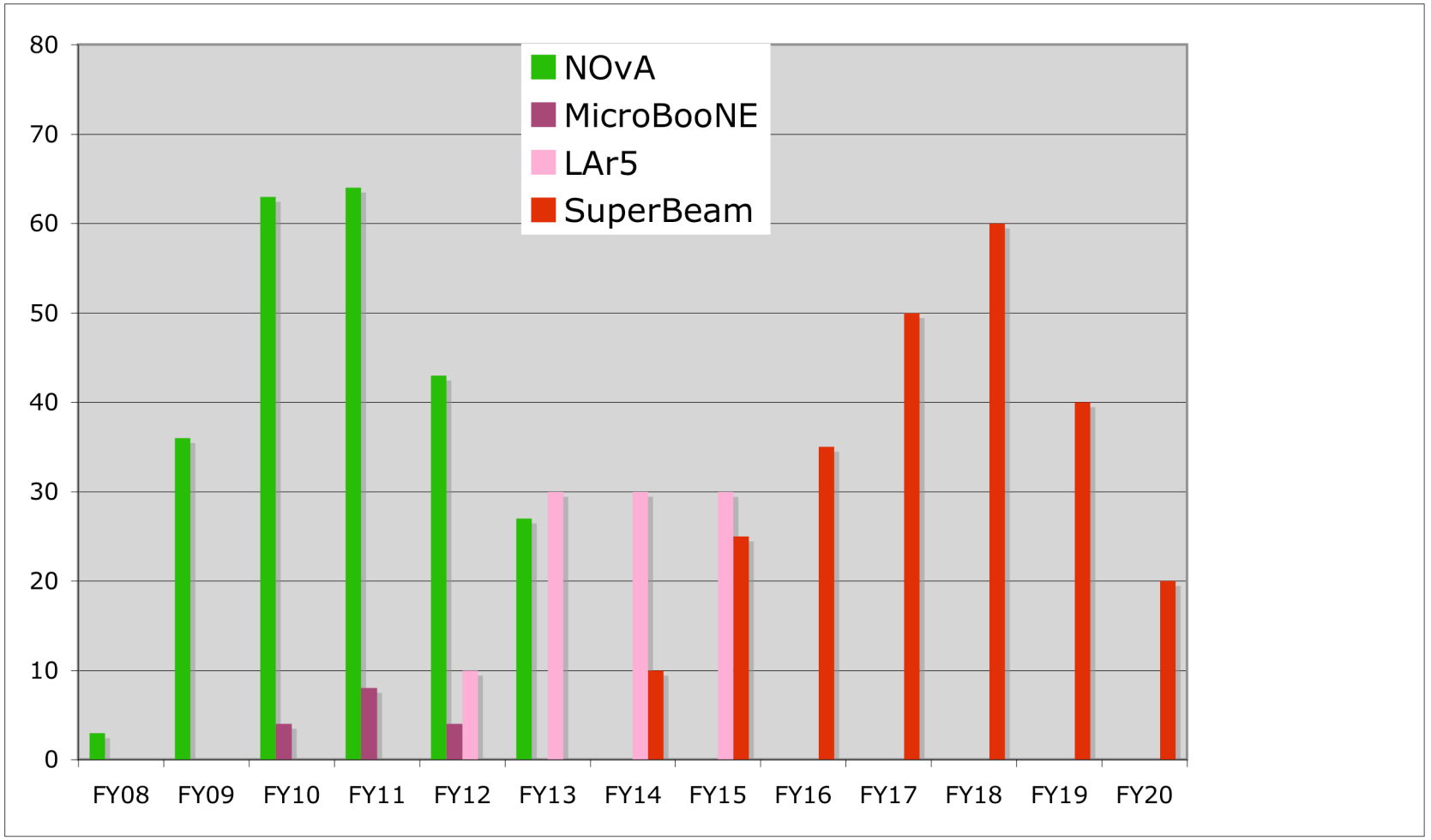
- Exploitation of BNB
- R&D towards LAr5
- Physics opportunity
  - e/π/γ separation
  - MiniBooNE low E excess
  - Neutrino cross sections

- Exploitation of NuMI and existing facility
- R&D towards LAr100
- Physics opportunity
  - θ_{13} and mass hierarchy
  - LOI and proposal under development

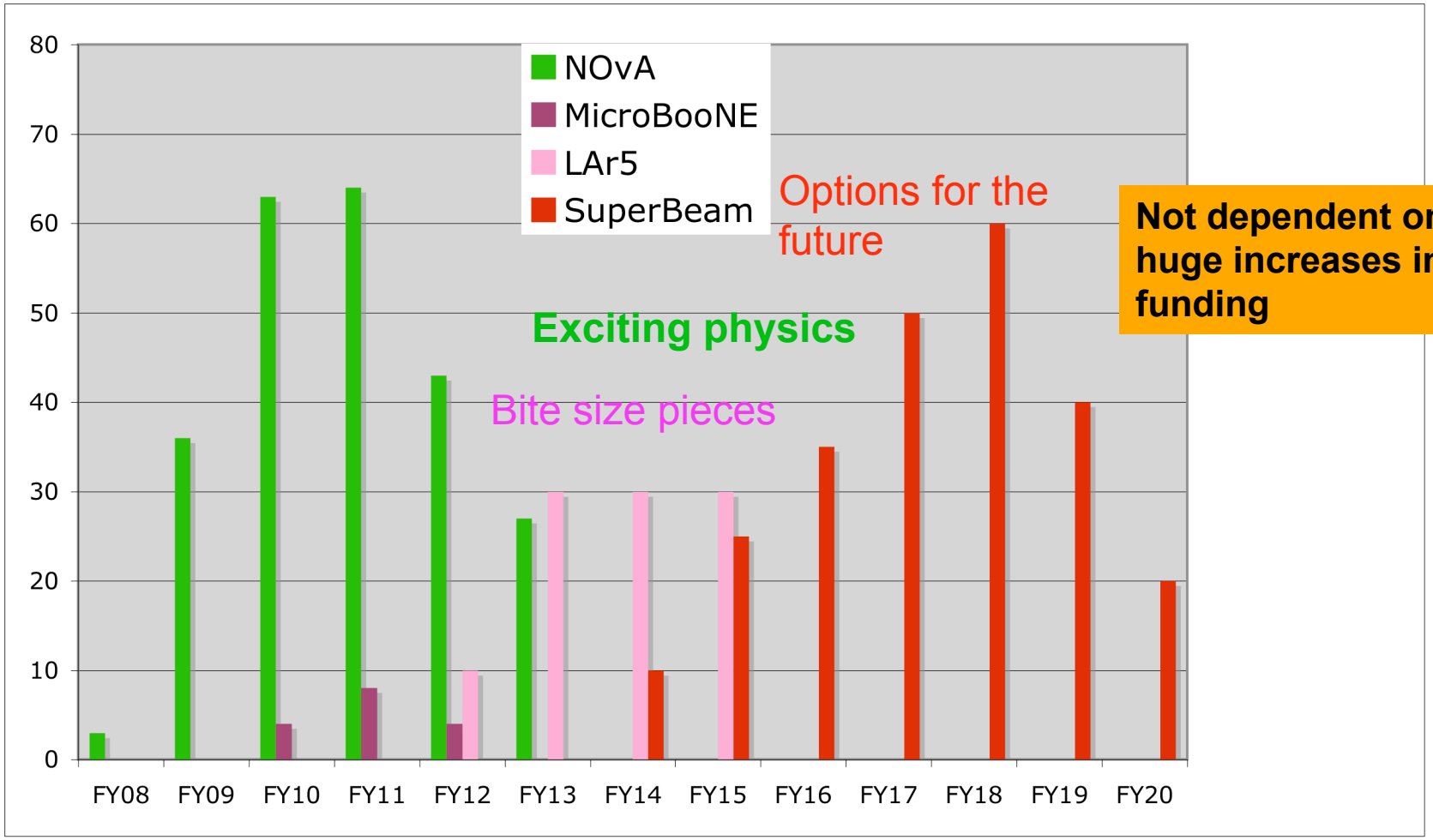
Program Evolution



Neutrinos in the base program



Neutrinos in the base program



Not dependent on huge increases in funding

Issues to address in short and long term planning

- **NuMI Program**
  - When to switch to anti-neutrinos? *(decision point <u>could</u> be based on results from reactors and T2K)*
  - Is LAr5 in SOUDAN feasible and cost effective ?
  - Will increased intensity come from Project X ?
  - Should the SNuMI alternative (1.2MW) be pursued?
- Future Longer Baseline Experiment Configuration decisions depend on :
  - Status of DUSEL
  - Cavern costs and constructability issues
  - Optimization of a new beam design
    - Spectrum matched to oscillation
    - Minimization of background
  - WC performance in multi-GeV region

  } related
  - Demonstration of LAr capability (depth, modularity,cost)

Conclusions

- The existing Fermilab neutrino beams are unique in the world
  - We should continue to fully exploit them by aggressively completing our approved projects and initiating new ones that are directly applicable to a long term vision which includes a new super beam and super detectors
- Aggressive support is needed for the R&D issues related to the super beam and super detectors
- This program meets the criteria of :
  - Exciting physics
  - Maintains options for the future
  - Is not dependent on huge jumps in funding
  - It can be carried out incrementally in bite size pieces
  - It supports a path to gain a large machine at the energy frontier : Neutrinos support Project X!