Neutrino beams at Fermilab

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LAGUNA-LBNE General Meeting

March 3-5, 2011

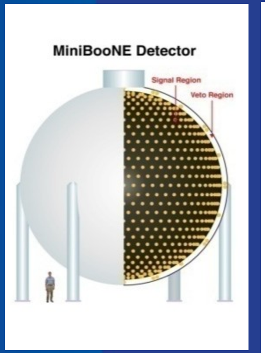
U.S. DEPARTMENT OF ENERGY

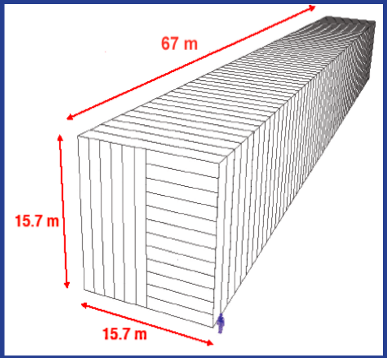
Fermilab

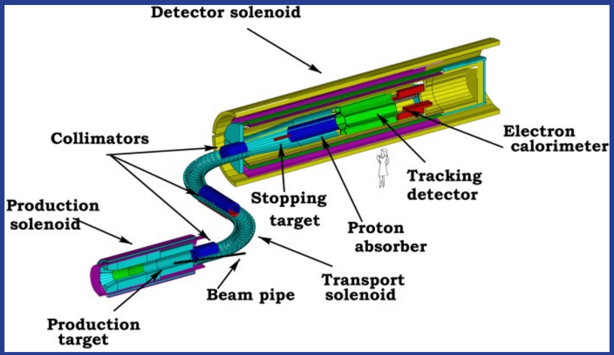
Outline

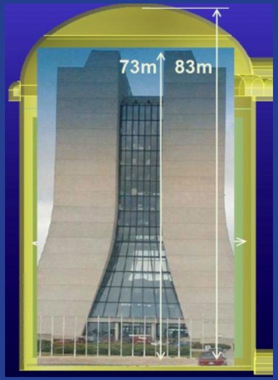
- Neutrino Beams at Fermilab
  - Booster Neutrino Beam (BNB) : MiniBooNE
  - NuMI : MINOS, MINERvA
- Near-term upgrades and operations
  - NuMI for NOvA
  - Proton economics and the BNB : MicroBooNE, future expt.
- Longer-term projects and prospects
  - LBNE
  - Project X

Fermilab Intensity Frontier Experiments



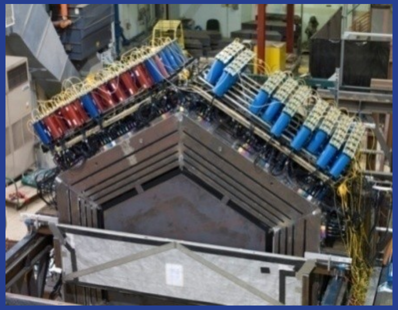


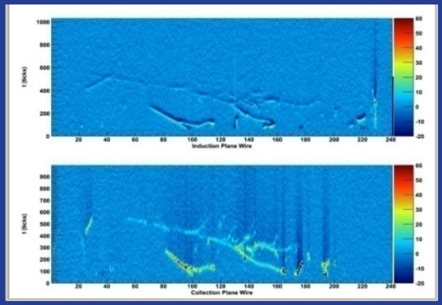


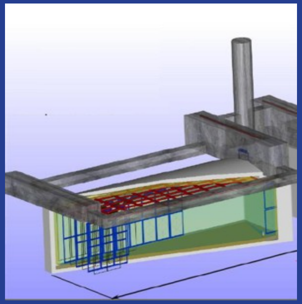


Now – 2013	2013 – 2016	2016 – 2019	2019 – 2022
☆MINOS ☆MiniBooNE ☆MINERvA SeaQuest	☆NOvA ☆MicroBooNE g-2 SeaQuest	☆LBNE Mu2e	Project X+LBNE ☆ mu, K, nuclear, … Factory ??

Now 2013 2016 2019 2022

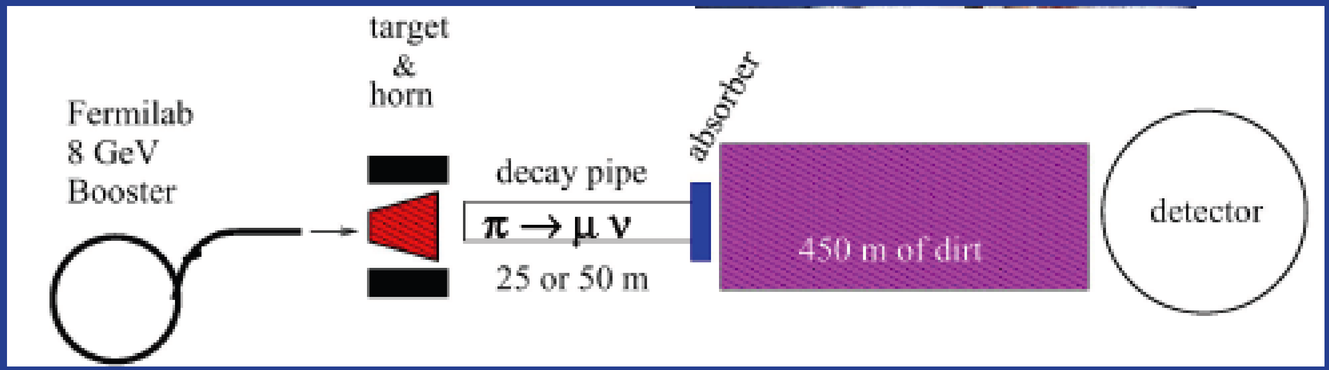


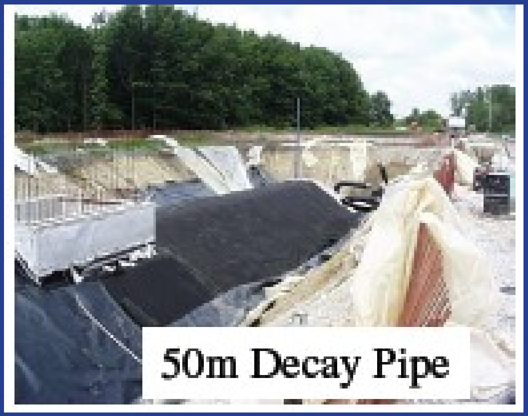




Present and Planned Accelerator Complex

Booster Neutrino Beam (BNB)





Short baseline –
Near surface

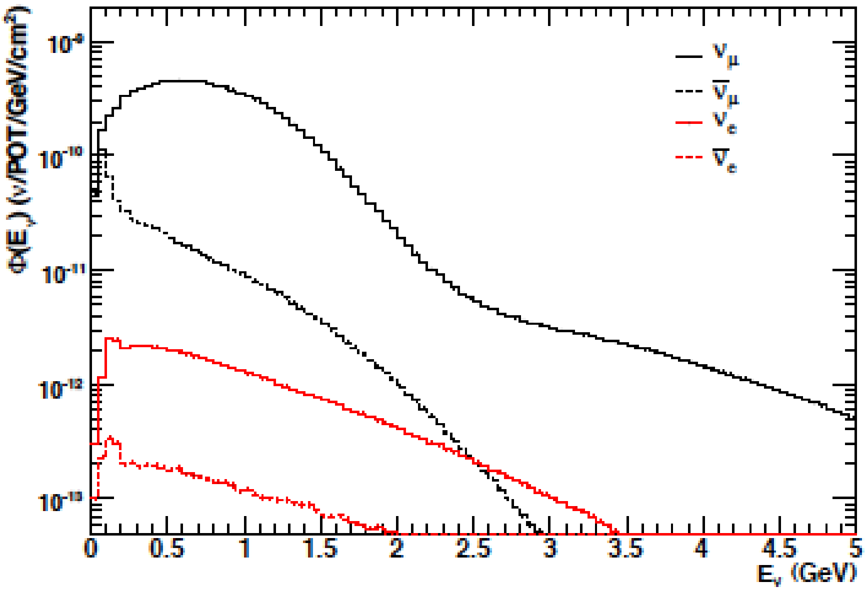


FIG. 27: Total predicted flux at the MiniBooNE detector by r
mode.

BNB flux

Small intrinsic rate → event ratio ~6×10^{-3}

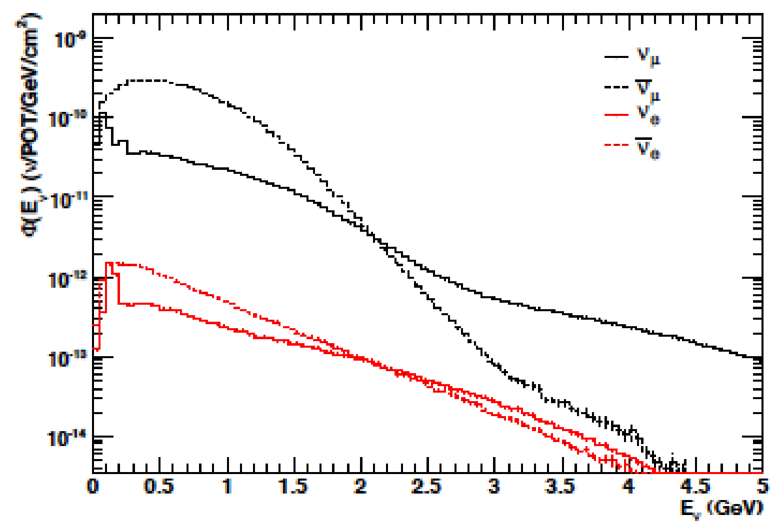
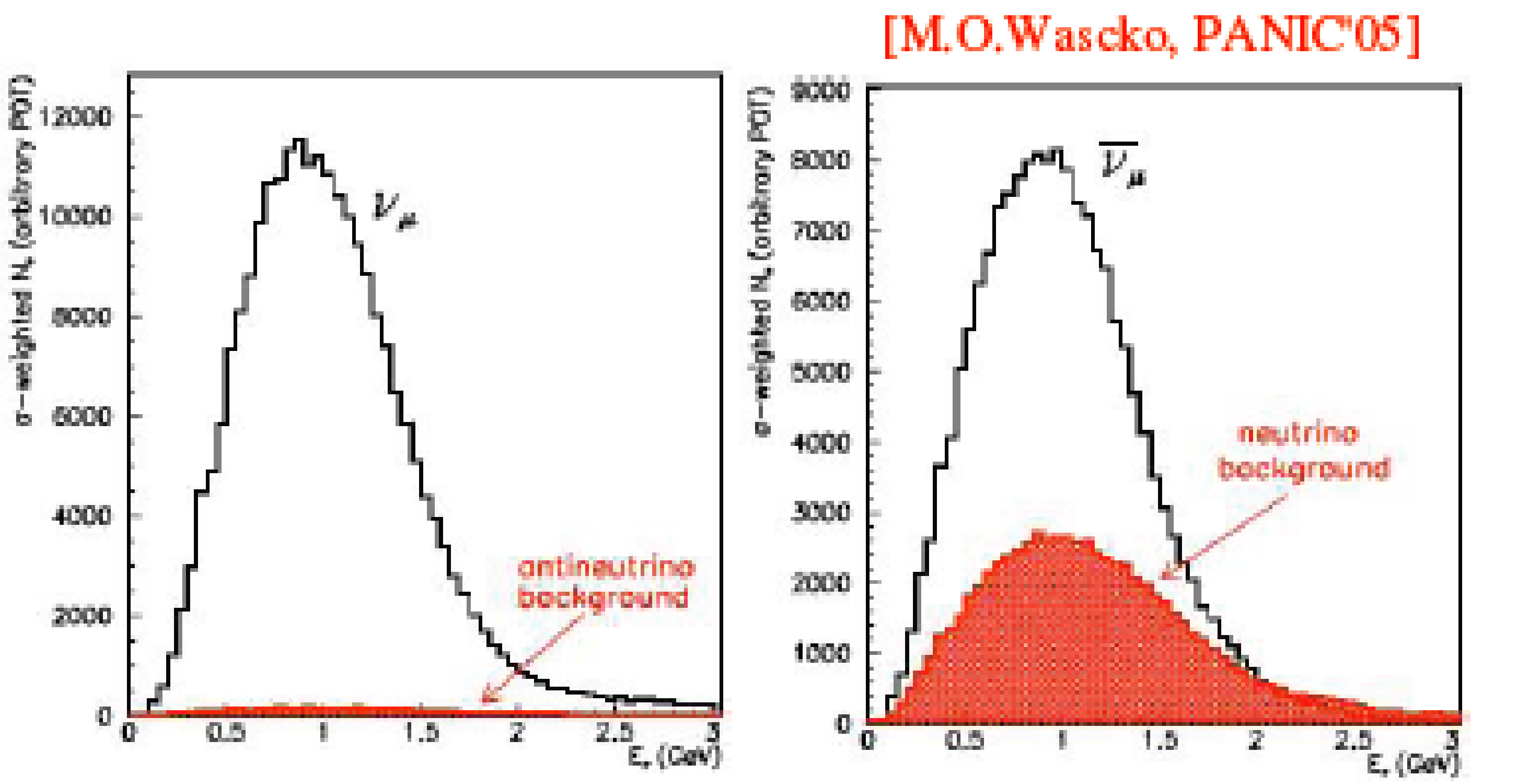


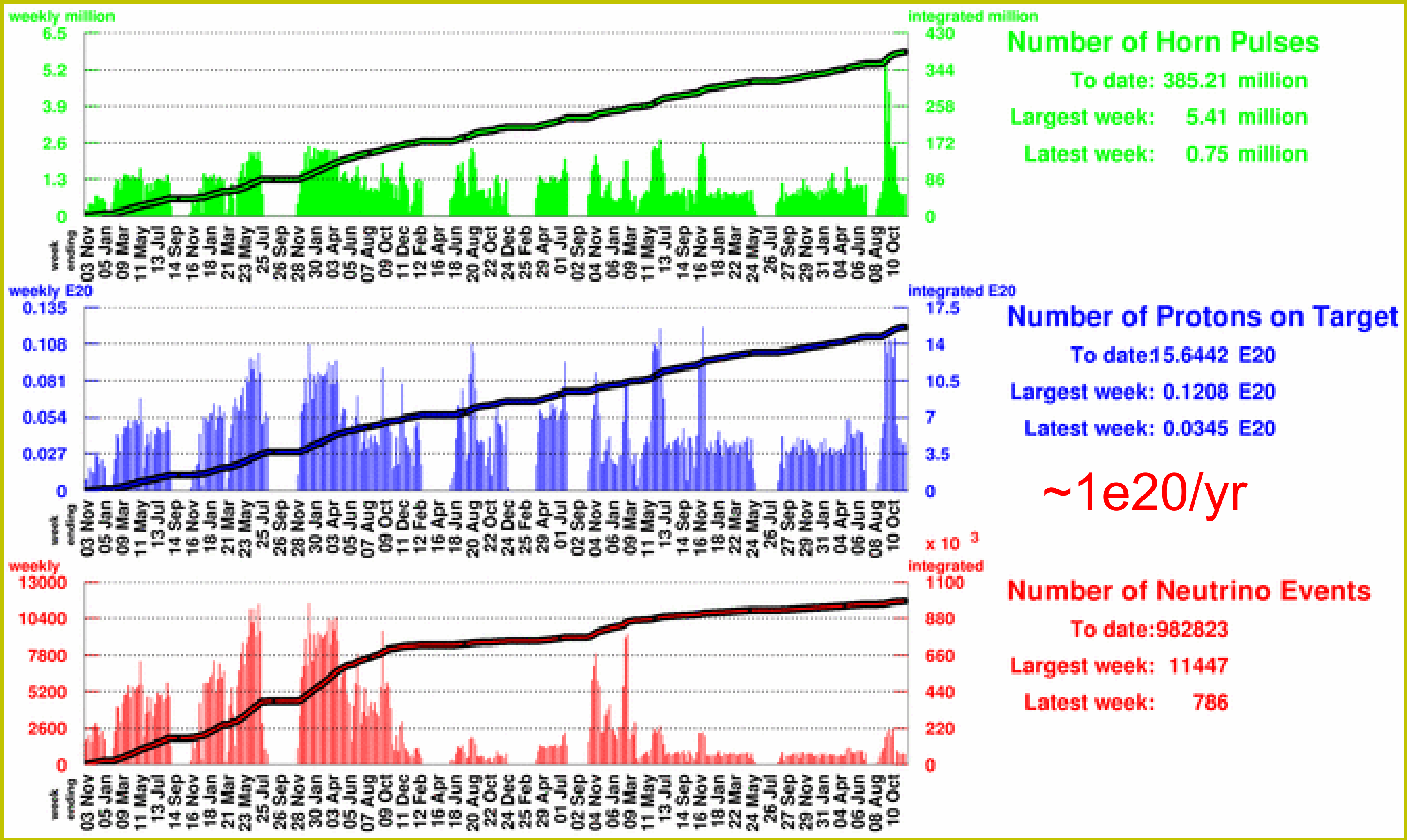
FIG. 28: Total predicted flux at the MiniBooNE detector by neutrino species with horn in anti-neutrino mode.

Event spectra (for arbitrary POTs)



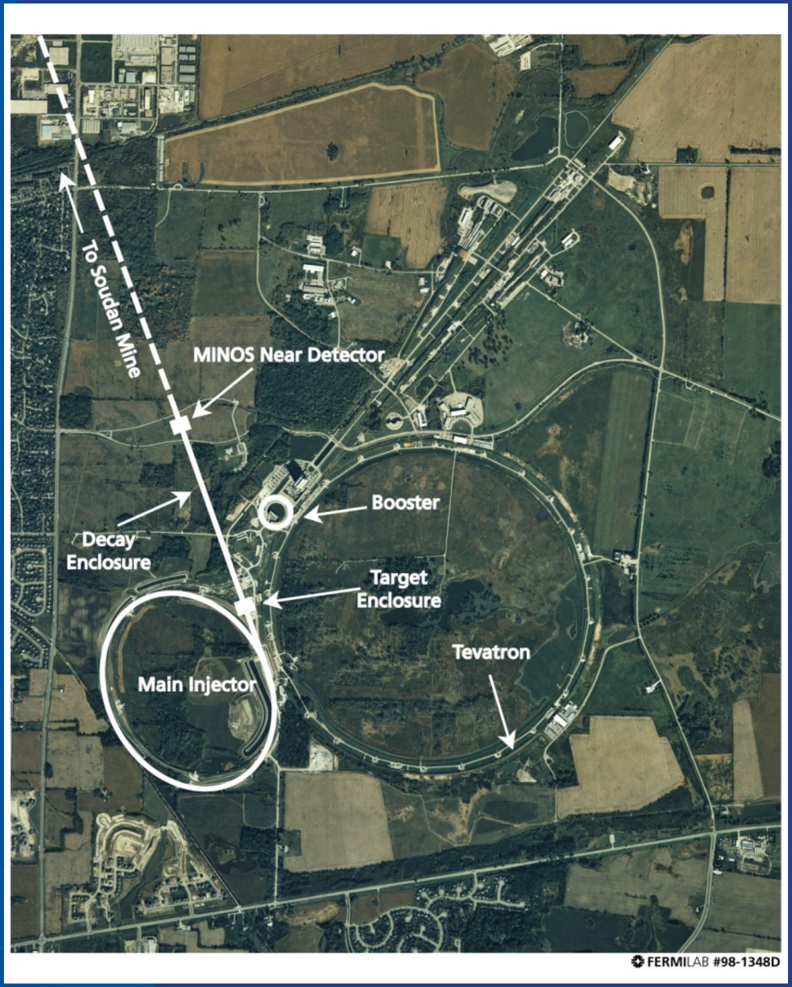
Proton Delivery to BNB

Depends on other demands for the protons

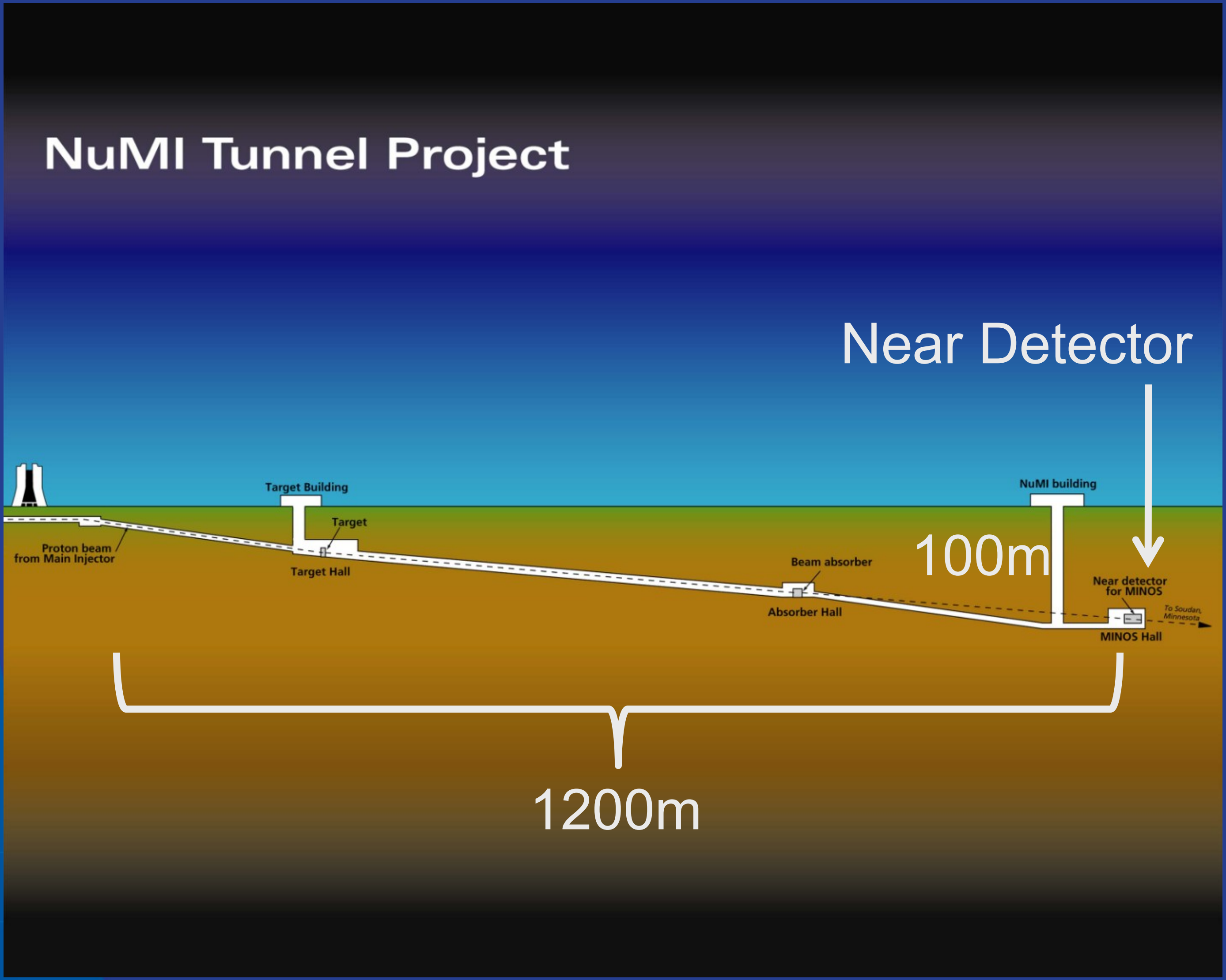


~1e20/yr

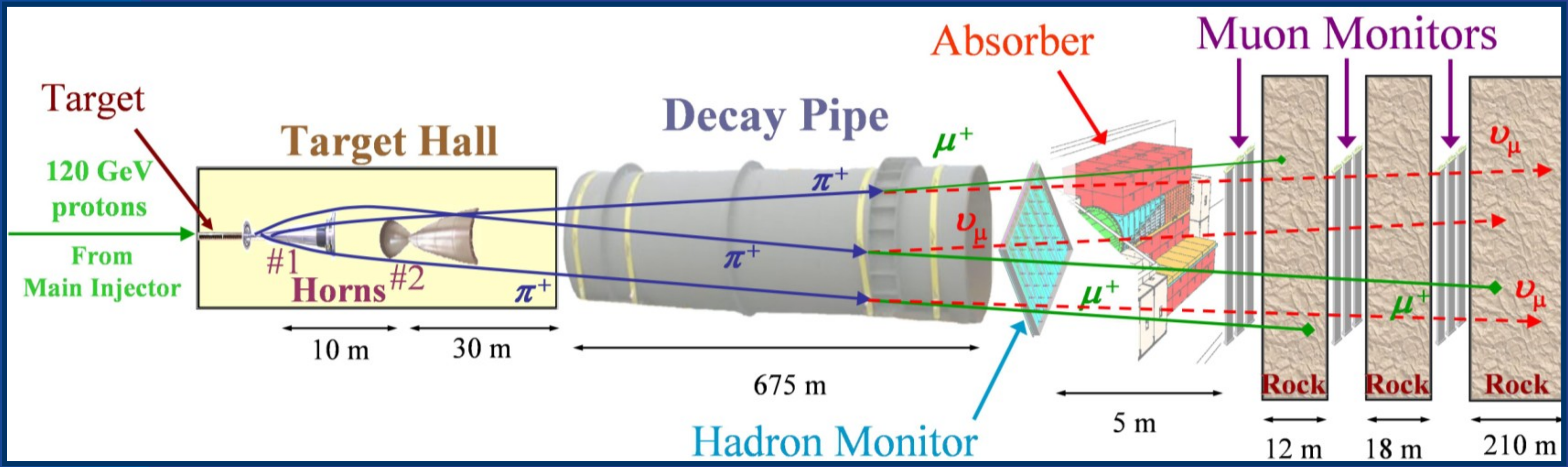
Neutrinos at the Main Injector (NuMI)

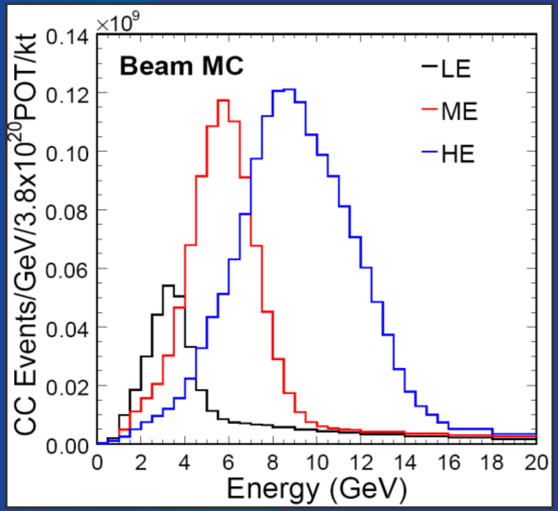


Constructed 2000-2004 to send Neutrinos to Soudan, Minnesota For the MINOS experiment


NuMI Tunnel Project
Near Detector
Target Building
Target
Proton beam from Main Injector
Target Hall
Beam absorber
Absorber Hall
NuMI building
100m
Near detector for MINOS
MINOS Hall
To Soudan, Minnesota
1200m

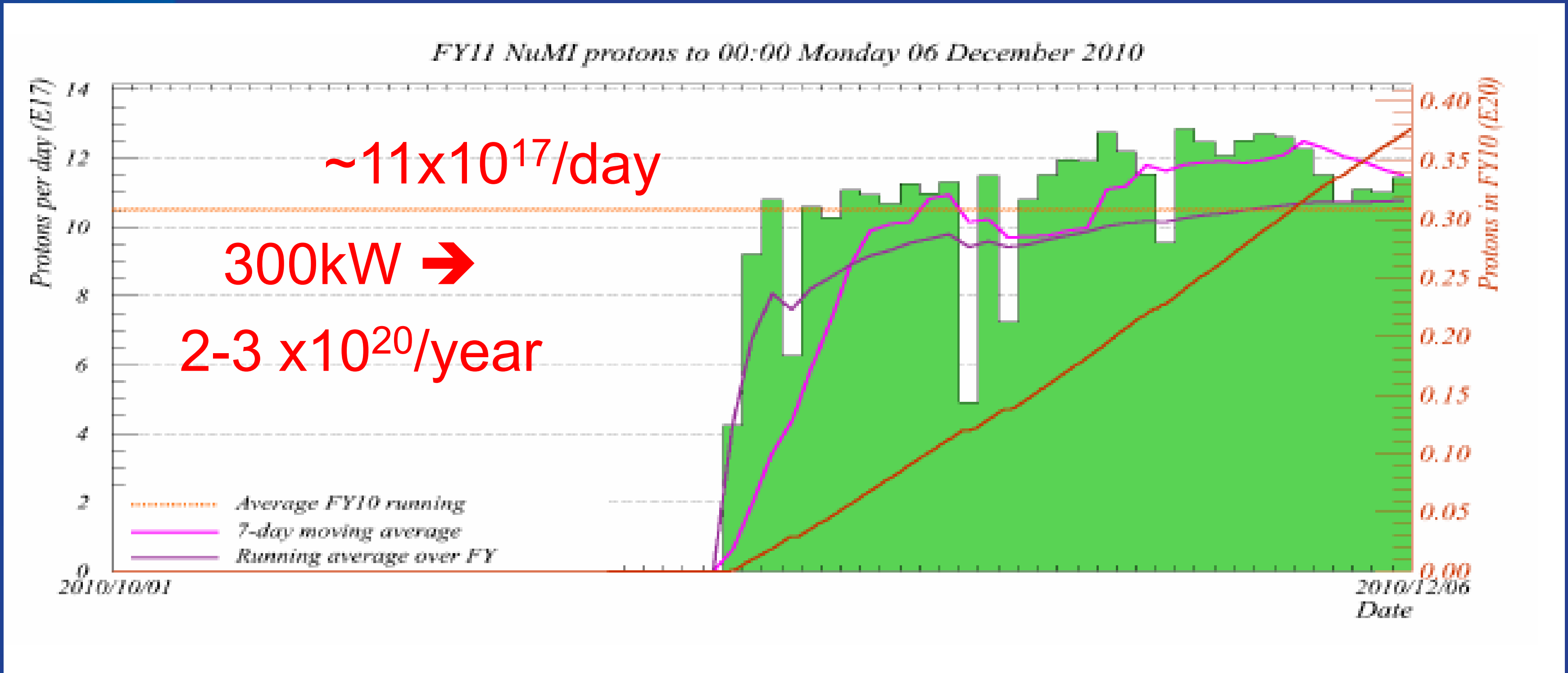
Components of the NuMI Beam





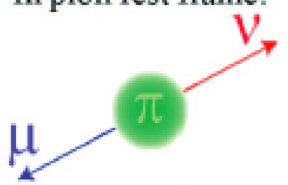
Neutrino beam spectra is tunable by arrangement of target-horn separations

POT delivery to NuMI



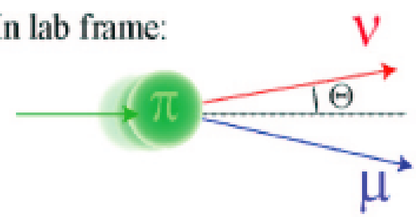
Off-axis Neutrino Beams

In pion rest frame:



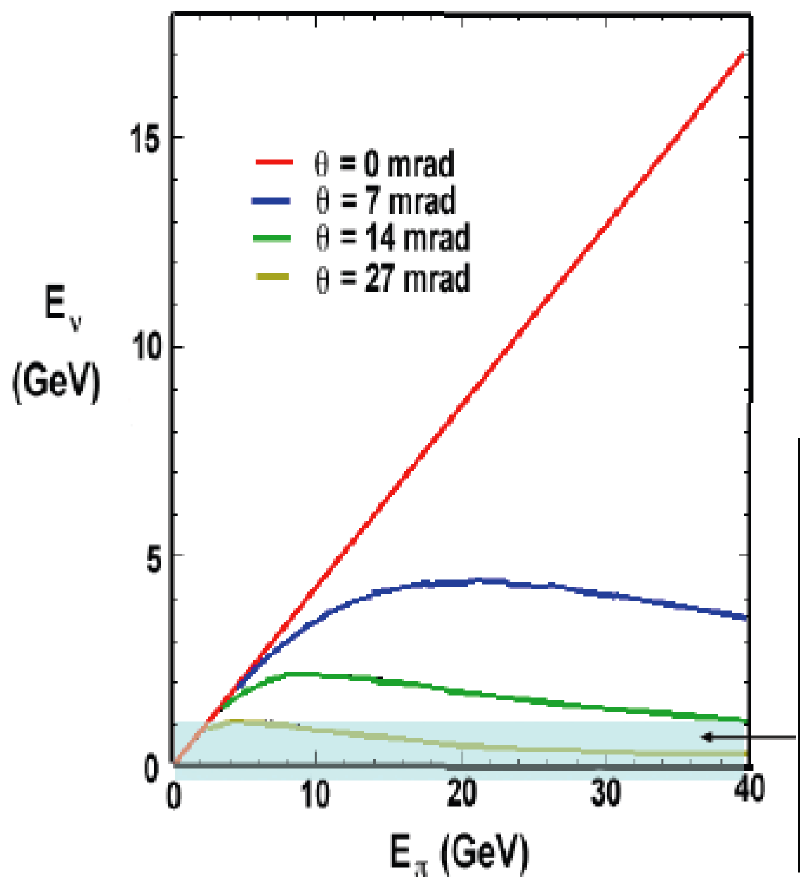
Neutrino and muon energy completely determined

In lab frame:



Neutrino energy depends on boost and angle to boost direction

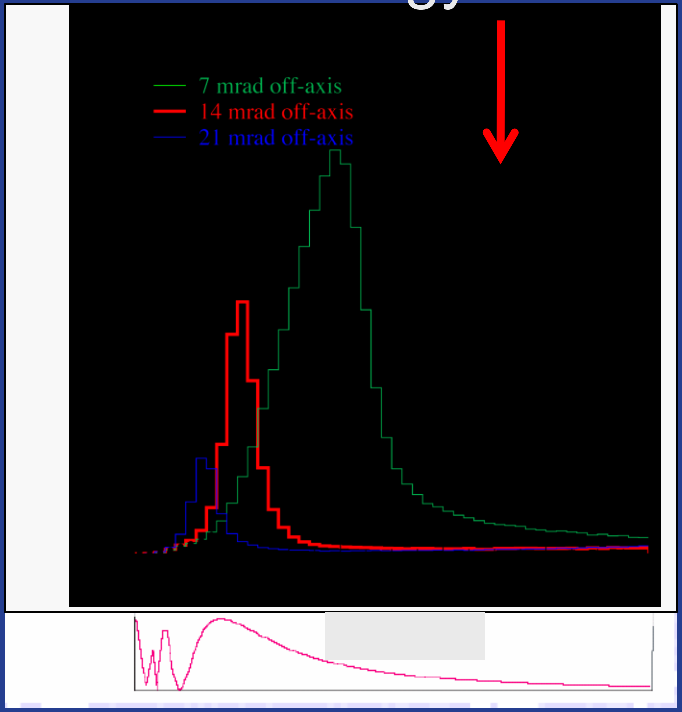
$$E_\nu = \frac{0.43\gamma\, m_\pi}{1+\gamma^2\theta^2}$$



At 14mrad off-axis almost all π produce ν around 2 GeV, i.e. at oscillation maximum

NuMI to NOvA

Medium Energy Tune



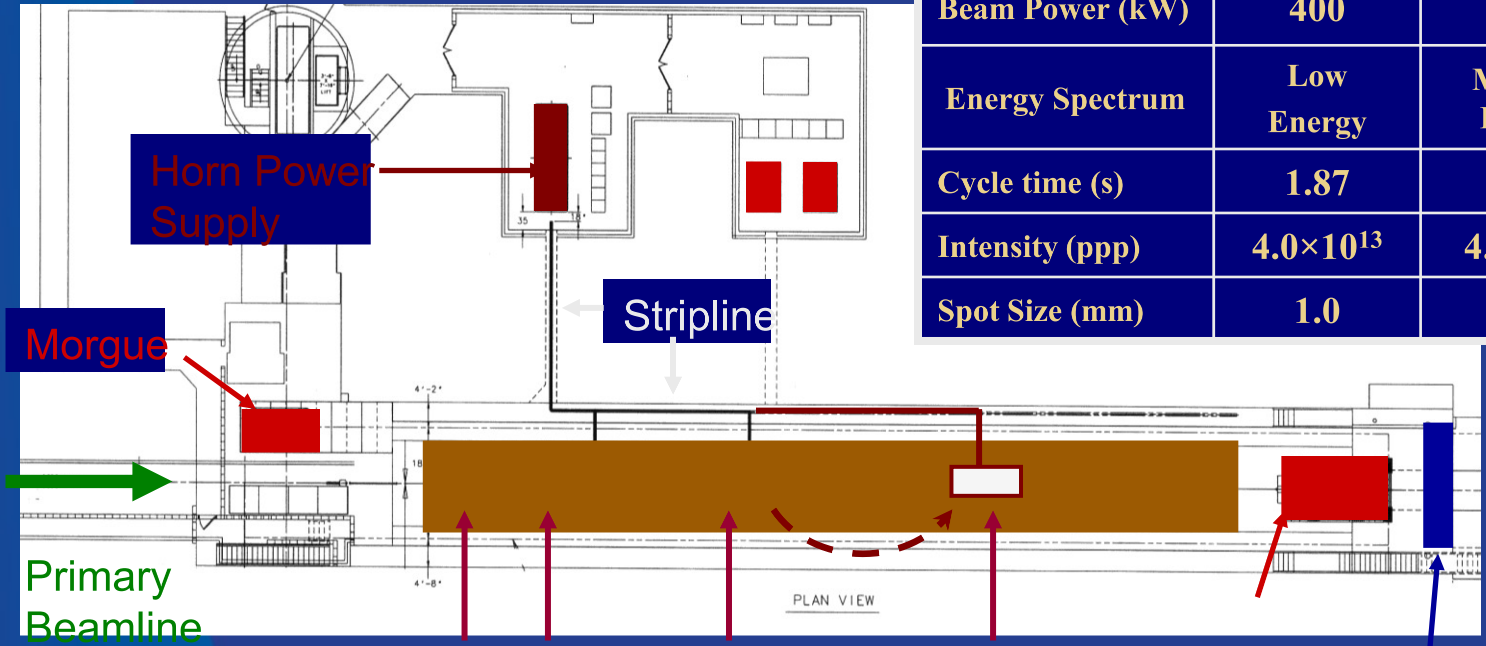
Need to upgrade the proton delivery rate to the NuMI target

Accelerator and NuMI Upgrades (ANU) for NOvA

- Changes to the FNAL Accelerator complex to
  - Turn Recycler from pbar to proton ring
    - Injection and extraction lines
    - Associated kickers and instrumentation
    - 53 MHz RF
    - Decommission/remove pbar devices
  - Shorten MI cycle to 1.33 seconds
    - RF upgrades
    - Power Supply upgrades
    - Decommission/remove pbar devices
  - NuMI target station to 700 kW
    - Target & Horns to handle power
    - Configuration to maximize $\nu\varepsilon\upsilon\tau\rho\iota\nu o$ flux (Medium Energy configuration)

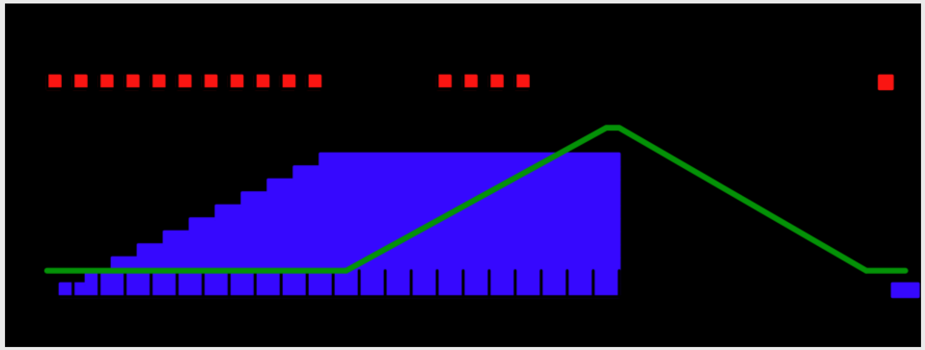
NuMI Configuration for NOvA

	NuMI Design	NOϖA†
Beam Power (kW)	400	700
Energy Spectrum	Low Energy	Medium Energy
Cycle time (s)	1.87	1.33
Intensity (ppp)	4.0×10^{13}	4.9×10^{13}
Spot Size (mm)	1.0	1.3



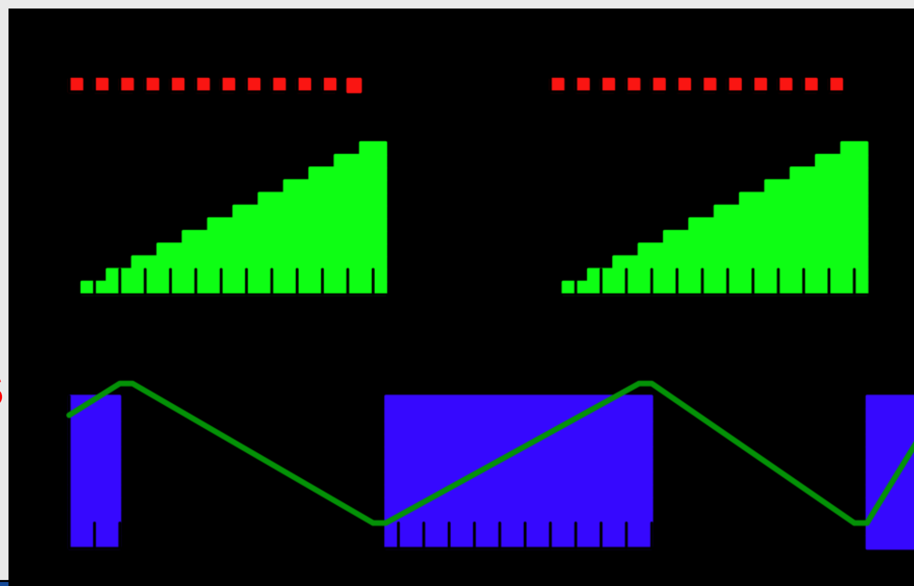
Context of ANU

- Collider Era operation: 11 booster batches (2 to pbar), 3.5e13 on target, 2.2 second cycle



- NOϖA Era operation: 12 booster batches, 4.9e13 on target, 1.33 second

No cycles to the BNB in this plan

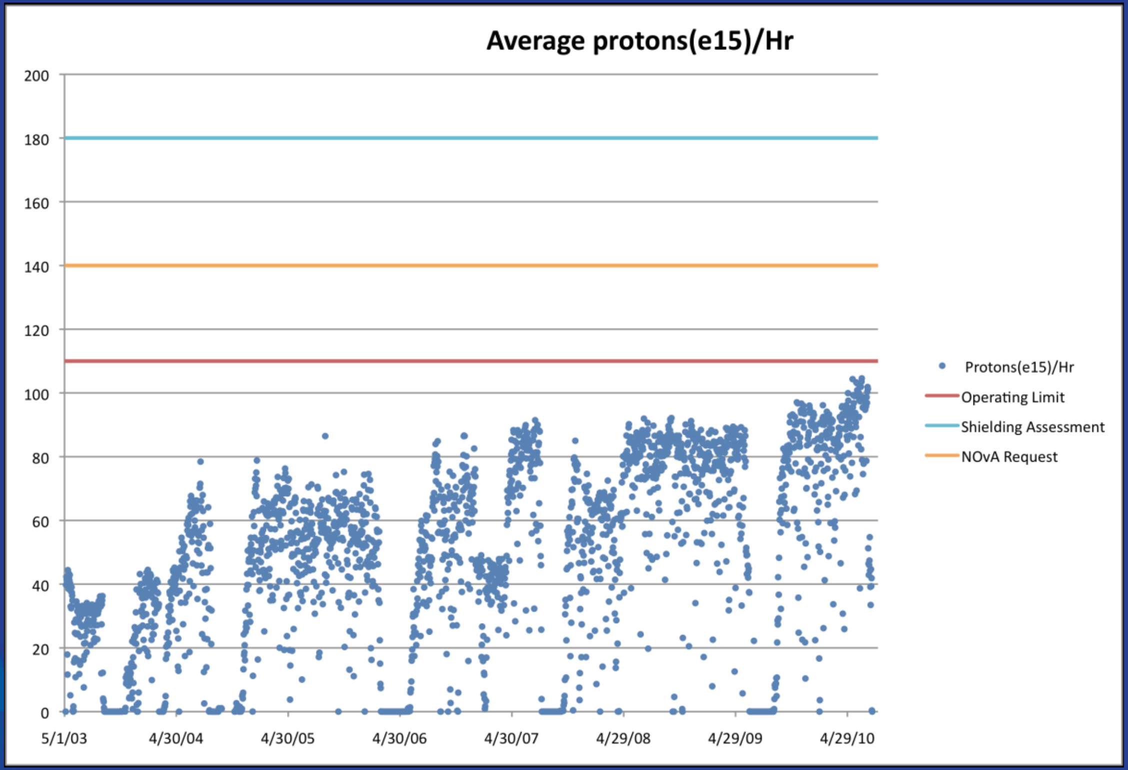


NOvA Numbers

- "700 kW" peak
  - 4.3e12 protons/batch from Booster
  - 12 spills every 4/3 second = 9 Hz
  - 13.9e16 p/hr.
    - 95% efficiency in MI
    - Comes out to 707 kW
    - Booster has never provided this much
- 6e20 Protons per year
  - 44 weeks of running
  - 61% total efficiency
    - Downtimes (accelerator and NuMI)
    - Average vs peak
- Getting NOvA protons means that both the peak proton power and the efficiency need to be maximized

Current Booster Performance

- ~7.5 Hz (6.7 Hz w/ beam)
  Hardware capable of ~9 Hz
- 1e17/hour (pushing administrative operational limits): aperture improvements and loss reduction
- 89% efficiency



Outlook for Booster Performance

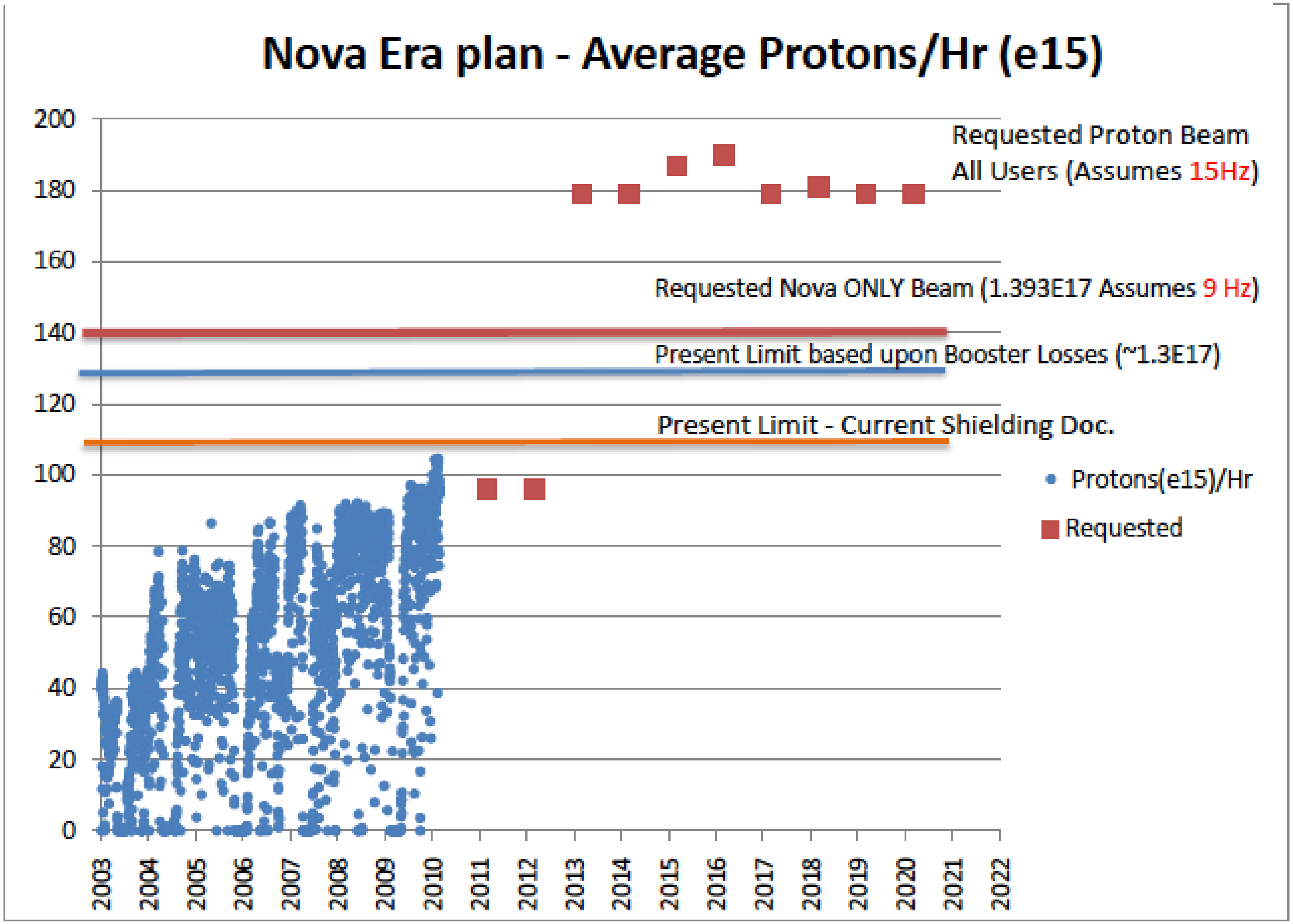
- The Booster appears presently able to produce about 13e16 protons/hr at peak power
  - Within ~10% of NOvA peak demand
  - Recent Record week: 1.62e19 protons (9.6e16 p/hr)
    - Good operational efficiency
    - Limited by beam budget
  - Reliability becomes an increasing issue as rep rate increases
    - Not only a radiation problem
    - Magnitude of this effect is not understood
- Another looming issue is additional users
  - mu2e @ 4.5 Hz (same or higher batch intensity)
  - MicroBooNE at up to 5 Hz
  - g-2 at up to 4 Hz
- These can add up to easily 22e16 if Booster runs at 15 Hz
  - Not enough cycles to service all experiments simultaneously
  - Booster reliability is an issue

Proton Source Task Force Report

Fermi National Accelerator Laboratory

August 17, 2010

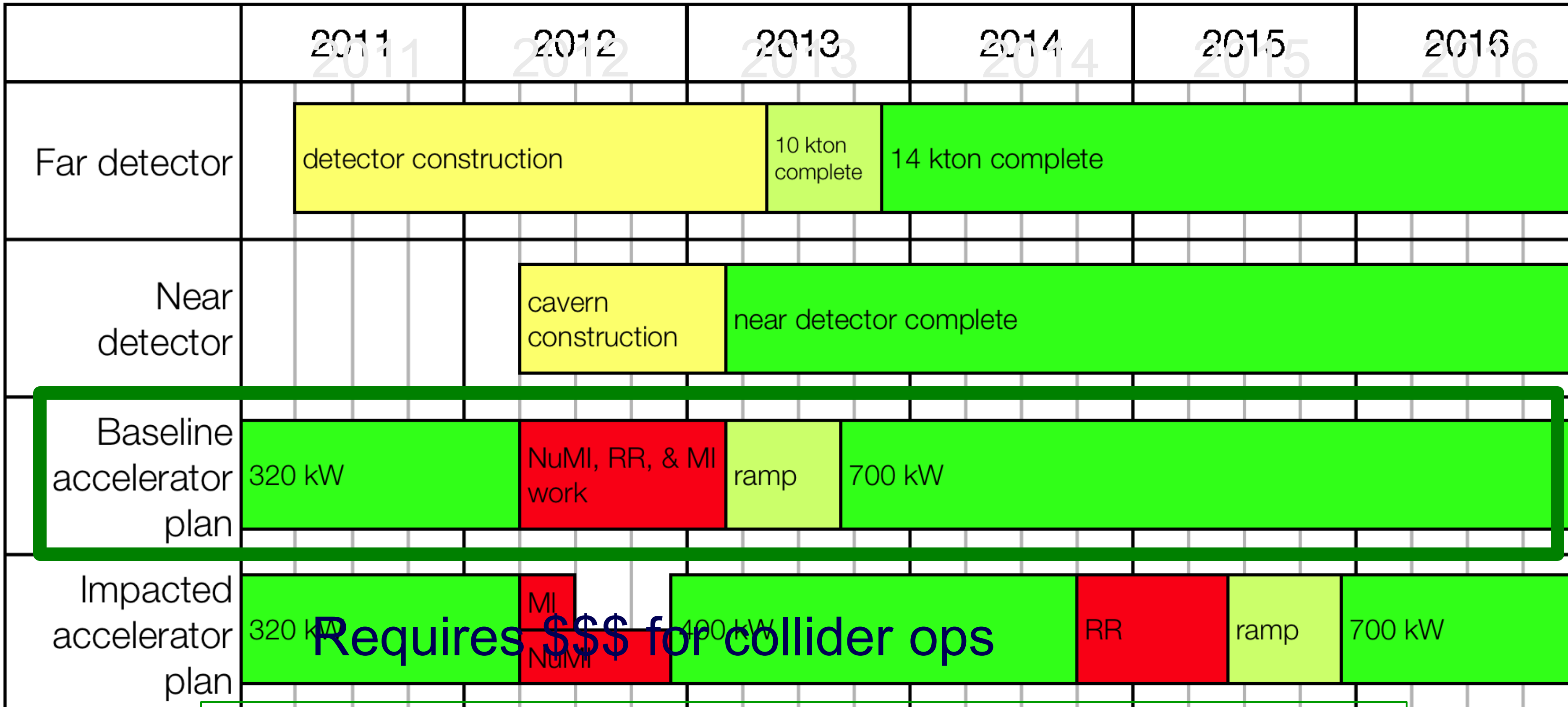
Figure 1.3 Protons Per Hour Past and Requested



The Plan

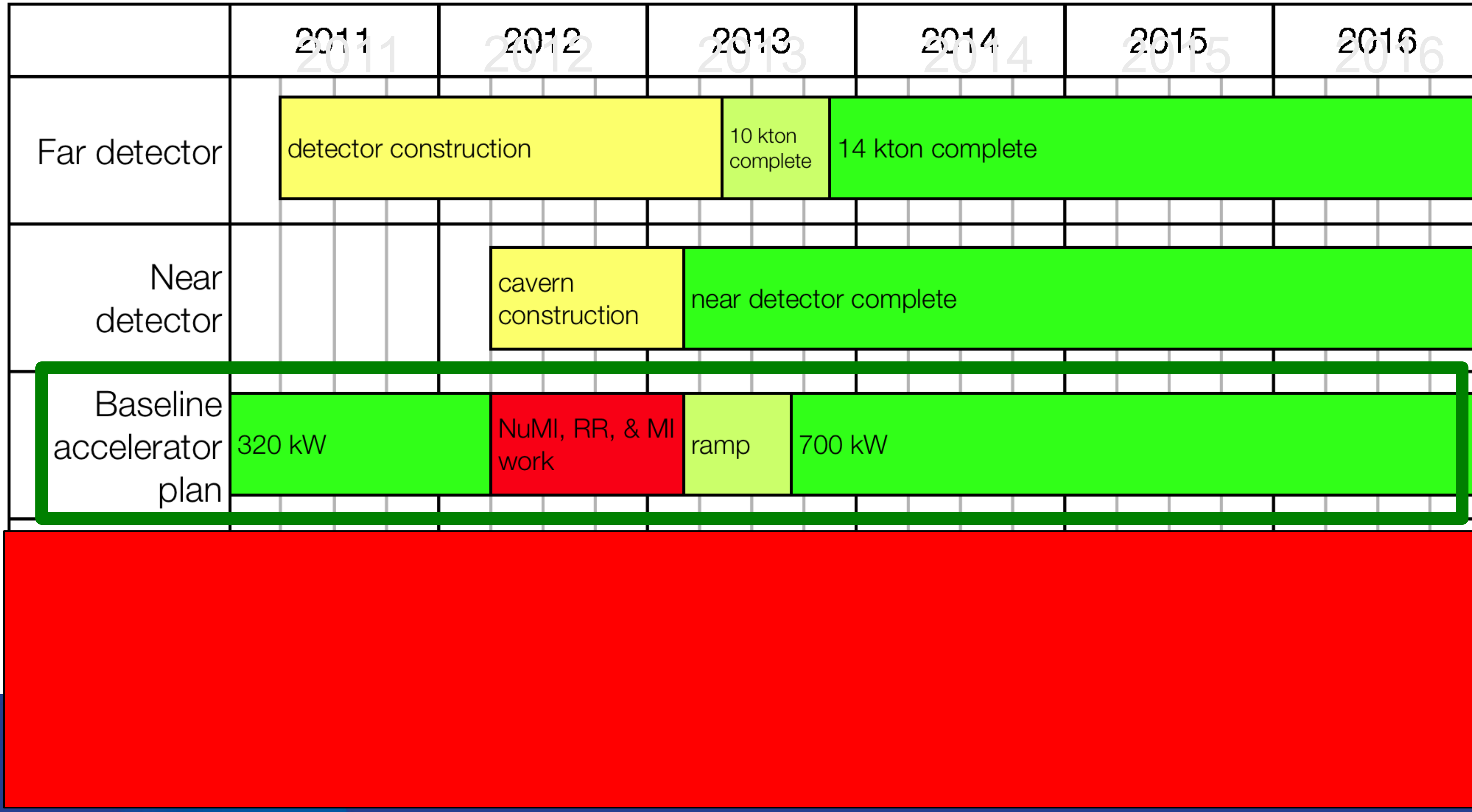
- To support program operation through 2025
  - Both the 8 GeV and the 120 GeV programs do need additional improvements
    - Booster Solid State Upgrade
      - Improved reliability of RF Power Amplifiers
    - Increase repetition rate to 15 Hz
      - Improved electrical infrastructure
      - Improved cooling for RF cavities
      - Requires solid state upgrade
    - New shielding assessment and associated shielding improvements
      - Operational limits
      - Additional shielding in tunnel
      - Office occupancy

NOvA Timeline



When 700kW operation begins depends on if the Tevatron collider runs past 2011

NOvA Timeline



BNB/MicroBooNE Timeline

	2011				2012				2013				2014				2015			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Plan S											DATA									
NuMI	3e20/yr								6e20/yr											
BNB	1-2e20 pot/yr								TBD											
Plan X											DATA									
NuMI	3 - 4 e20/yr																			
BNB	1-2e20 pot/yr																			

Proton Intensity and running time depend on Collider schedule and NOvA readiness and run plan

BNB/MicroBooNE Timeline

	2011				2012				2013				2014				2015			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Plan S											DATA									
NuMI	3e20/yr								6e20/yr											
BNB	1-2e20 pot/yr													TBD						

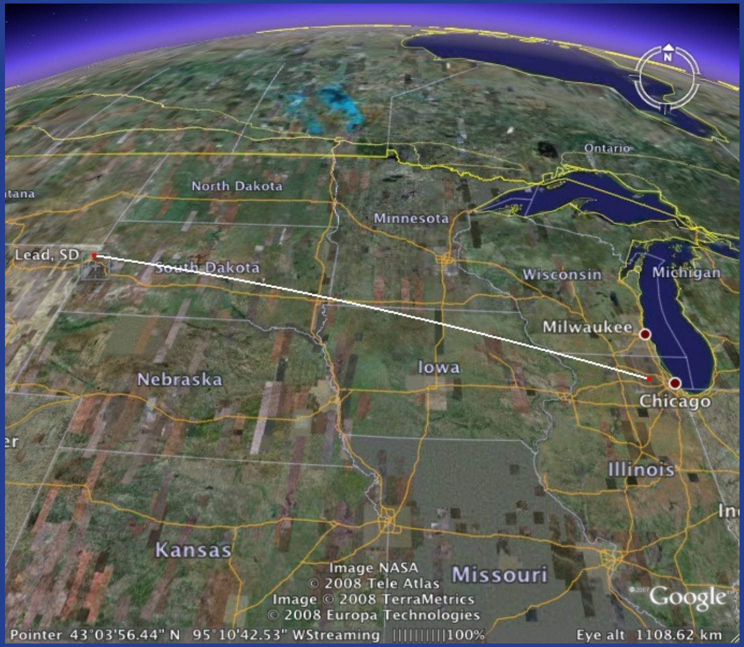
Take Away

- Intensity frontier neutrino program for the next decade puts demands on the accelerator complex
  - Improvements in both hardware and operational efficiency of the Booster complex will be required if the currently approved physics program is to be successful

Fermilab to Homestake Mine – 1300km

Project X Mission

- A neutrino beam for long baseline neutrino oscillation experiments
  - **2 MW proton source at 60-120 GeV**
- High intensity, low energy protons for kaon and muon based precision experiments
  - Operations simultaneous with the neutrino program
- A path toward a muon source for possible future Neutrino Factory and/or a Muon Collider
  - Requires ~4 MW at ~5-15 GeV .
- Possible missions beyond P5
  - Standard Model Tests with nuclei and energy applications



Fermilab

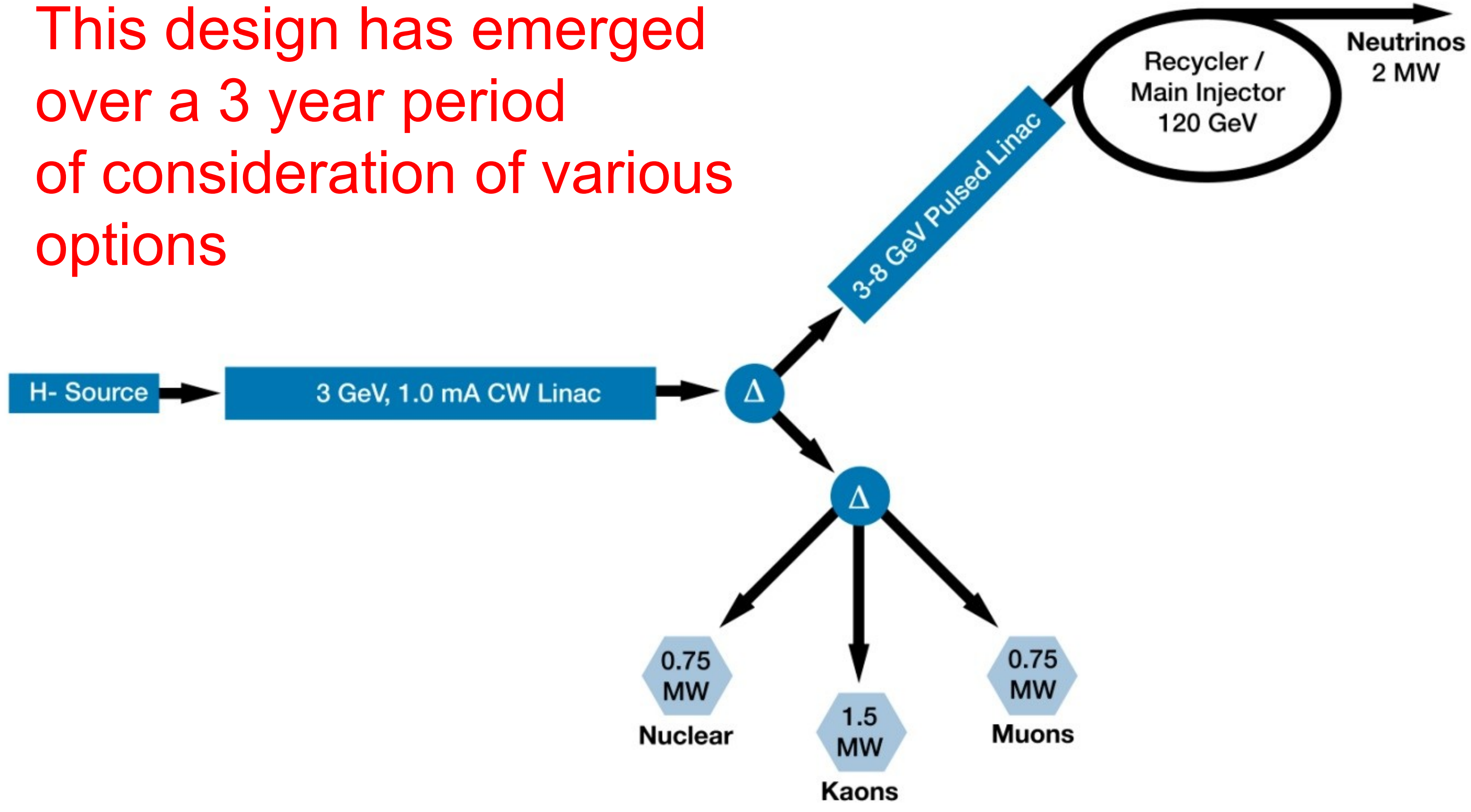
Project X Scope

- 3 GeV CW superconducting H- linac, capable of delivering 1 mA average beam current.
  - Flexible provision for variable beam structures to multiple users
  - Starts at ion source; ends at 3-way split (with stubs)
  - Supports rare processes programs
  - Provision for 1 GeV extraction for nuclear energy program
- 3-8 GeV pulsed linac capable of delivering 300 kW at 8 GeV
  - Supports the neutrino program
  - Establishes a path toward a muon based facility
- Upgrades to the Recycler and Main Injector to provide

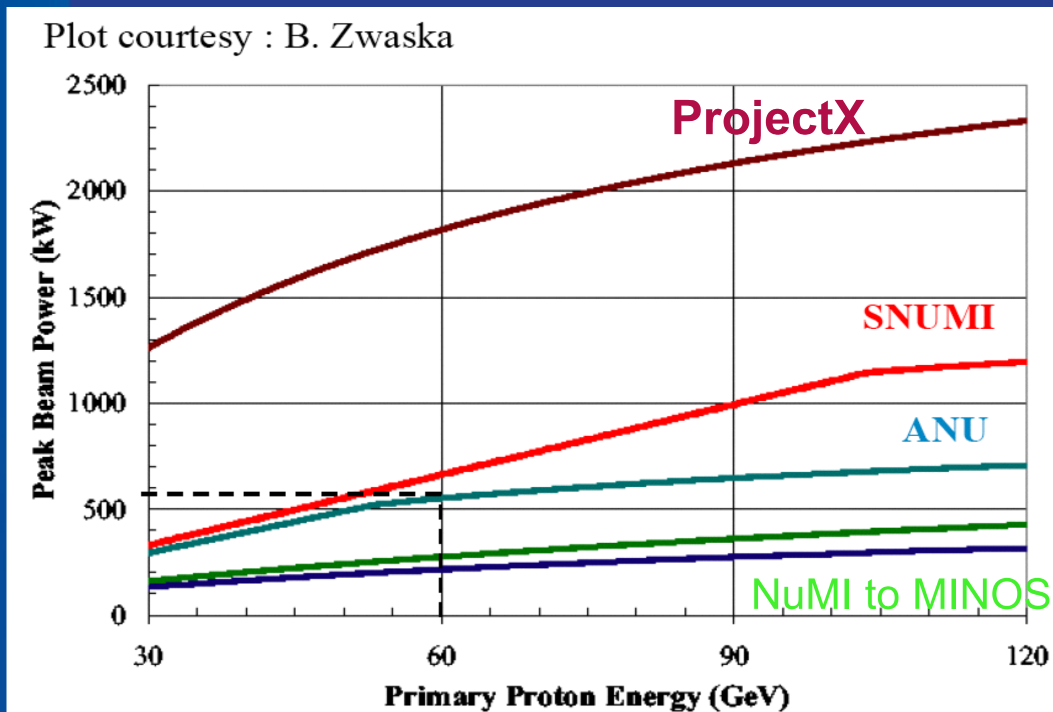
  ≥ 2 MW to the neutrino production target at 60-120 GeV.
  - Ends at MI extraction kicker
  - Supports the long baseline neutrino program
- All interconnecting beamlines

Project X Reference Design

This design has emerged over a 3 year period of consideration of various options



Evolution of the Intensity Frontier : it's all about the protons



20×10^{20} POT/yr

10×10^{20} POT/yr : not current plan

$6 - 7 \times 10^{20}$ POT/yr

3×10^{20} POT/yr

$$POT(10^{20}) = \frac{1000 \times BeamPower(MW) \times T(10^{7}s)}{1.602 \times E_p(GeV)}$$

A Plan for Delivery of 8-GeV Protons through 2025 at Fermilab

R. Webber, W. Pellico, V. Lebedev, and D. McGinnis --- February 18, 2011

Executive Summary

Every proton for the domestic United States High Energy Physics experimental program will be accelerated by the existing, now 40-year-old, Fermilab Linac and Booster until new machines are operational to replace them. Completion of the proposed Fermilab Project X accelerator is anticipated no sooner than 2020 for beams up to 3 GeV and well into that decade for beams at higher energy. The domestic High Energy Physics program for the next 15 years relies on the viability and vitality of the Fermilab Linac and Booster.

Near Term Plan : Begin to acquire the financial and manpower resources to carry out the proposed booster upgrades to reach 15hz operation in the next several years

Conclusion

- For the next decade Fermilab has two proton sources, Booster and MI, that potentially can provide provide significant protons for creation of neutrinos.
- We have two neutrino beams, NuMI and BNB that may be exploited to carry out experimental programs but there are constraints
- Construction of new facilities (beamlines or detector halls) are possible, but challenging due to other projects (geographical) and limited funding in general