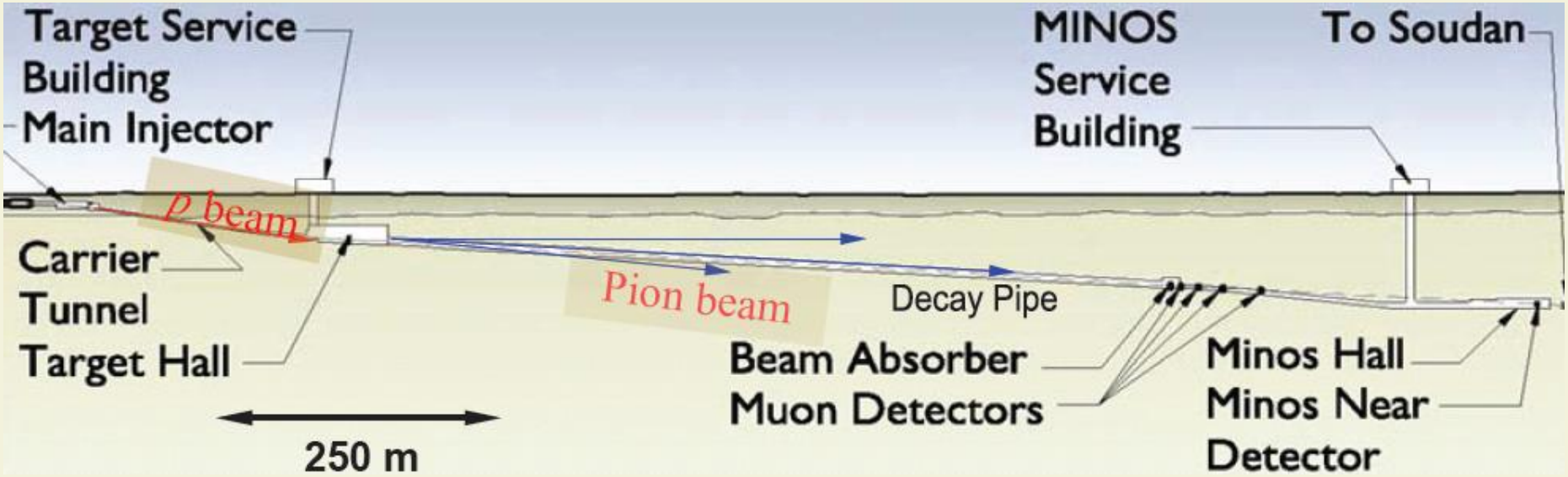
NuMI Operation Summary: 2005-2012

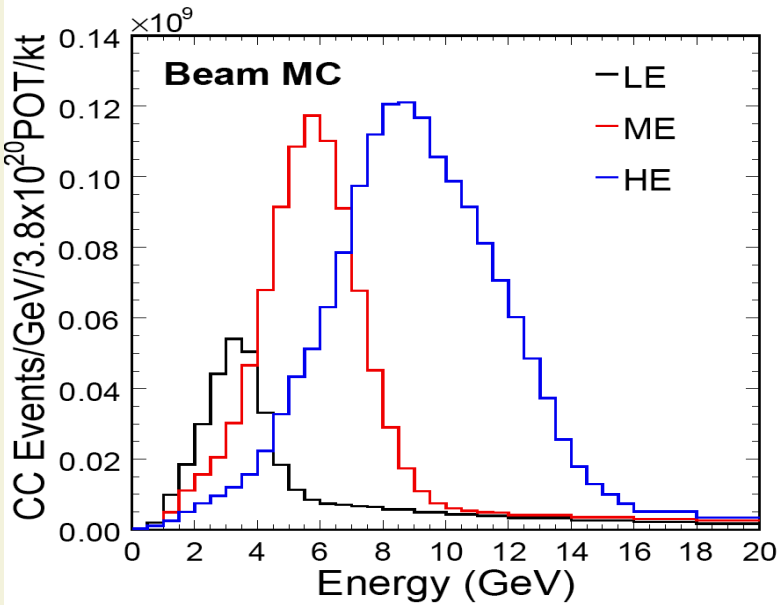
Sam Childress - Fermilab

NuMI Beam Layout:

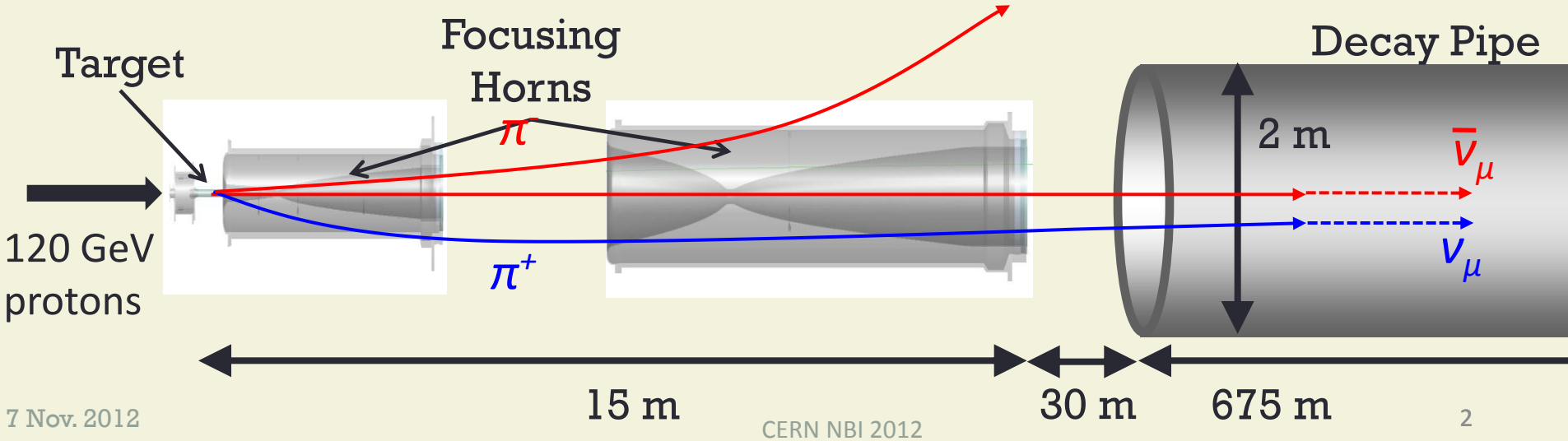


- 735 km baseline to Soudan, MN. far detector -> beam pitch angle = 58 mrad.
- Optimized for medium – high energy neutrino beam and tunability (designed before oscillation parameters were known)

NuMI Neutrino Beam



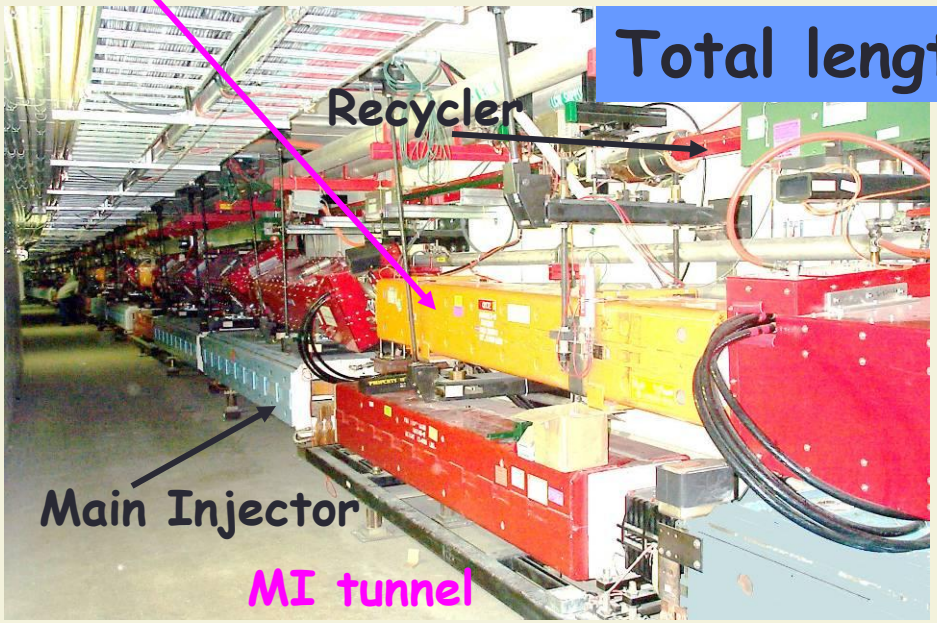
- Neutrino energy tuned by moving target (usually Low Energy)
- Change horn polarity to select ν_μ or $\bar{\nu}_\mu$



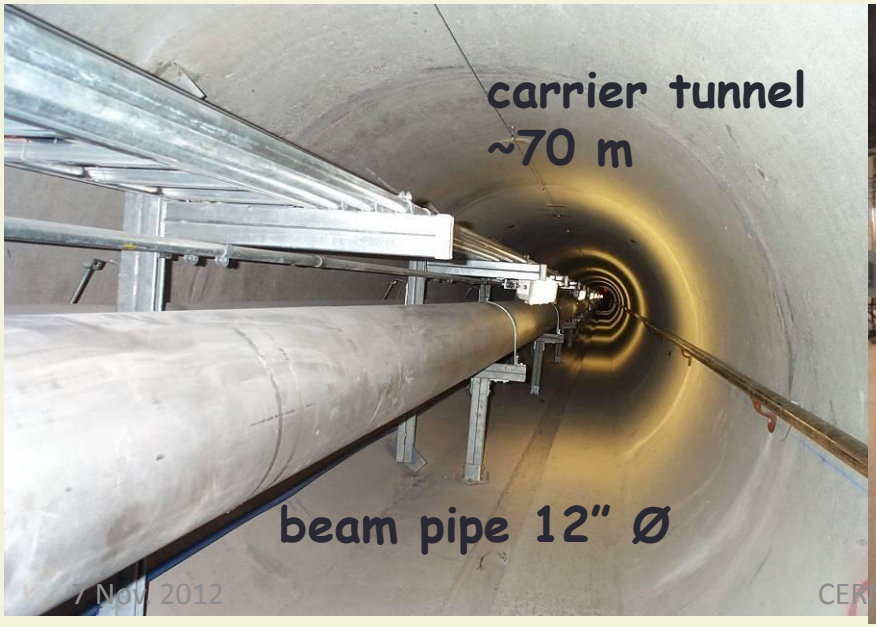
Primary Proton Line

NuMI line

bending down by 156 mrad



Total length ~ 350 m



Graphite Target

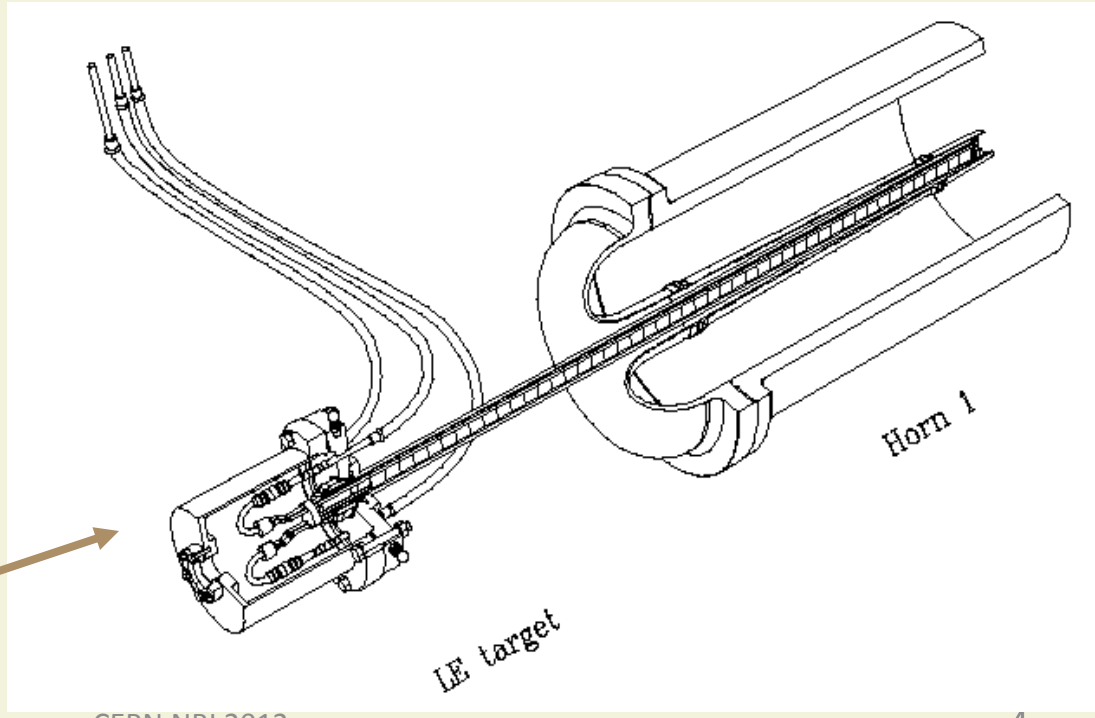
Graphite Fin Core

2 interaction lengths

Water cooling tube

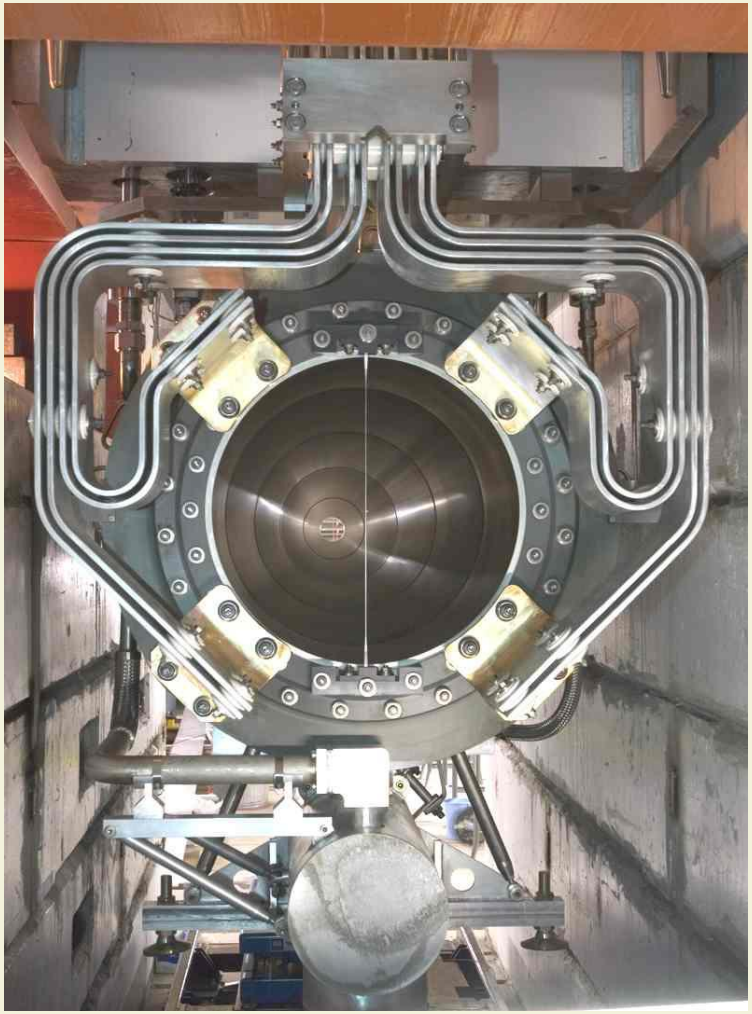
provides mechanical support

Low Energy Target fits in horn without touching



Horn System – 2 Horns

(Shown in work cell, hanging from support module)



Other NBI 2012 Presentations Covering Details of NuMI Beam Operation

- Proton Beam Monitoring & Control - S. Childress
- Secondary Beam Monitoring - L. Loiacono
- Recent Experience with NuMI Targets & Dumps – J. Hylen
- Horn Design - J. Hylen
- NuMI Experience with Tritium - J. Hylen

Here, will provide a brief summary of the 7 years of NuMI beam operation – some challenges & successes, along with key lessons learned. Our beam data is summarized by Fiscal years (Oct – Sept).

F Y 2005: Commissioning & Beginning Operations

- Very successful beam commissioning!
- Photos after day 1, Dec. 2004. Thanks, Malika ! for working with us.

- But… Target after 1 week of beam operation, March 2005

And the serious work of operating a high power neutrino beam begins!

Total POT in FY 2005 = 6.56 x1019**

FY 2006 : Horns, Target & Tritium

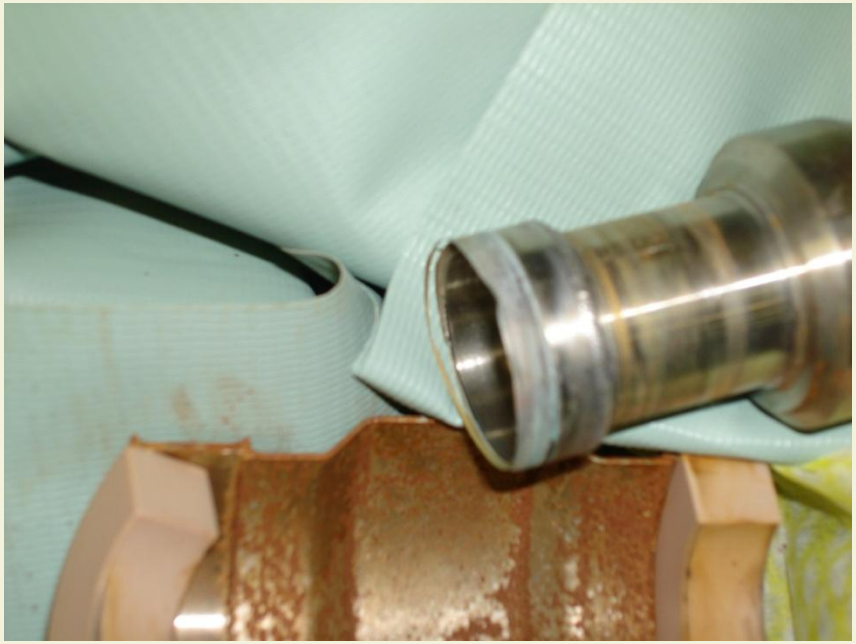
- Oct: Horn 2 ground fault
- Dec: Find Tritium in lab ponds -> from NuMI. Initial mitigation.
- Feb: Tritium analysis in decay tunnel & dehumidification mitigation
- July: Horn 1, DI bottle beads
- Aug: Horn 1 water leak

  Target Z drive stuck; Replace NT01 with NT02

Total POT in FY 2006 =1.02 x1020**

Horn Water Line Ceramic Isolator
Fracture at Geometry Change

-Thin Wall
-Stress Concentration Area
-Shear Failure Appearance



FY 2007 : PB Dipole, Horns & Tritium

- Feb: Primary beam dipole water leak.
- July – Aug: Horn water leak.
- Aug - Sep: Target chase dehumidification for tritium mitigation.

Replacing a primary beam 3 meter dipole. Ceramic isolator water leak.

Commission multi-batch slip-stacking in Main Injector! K. Seiya

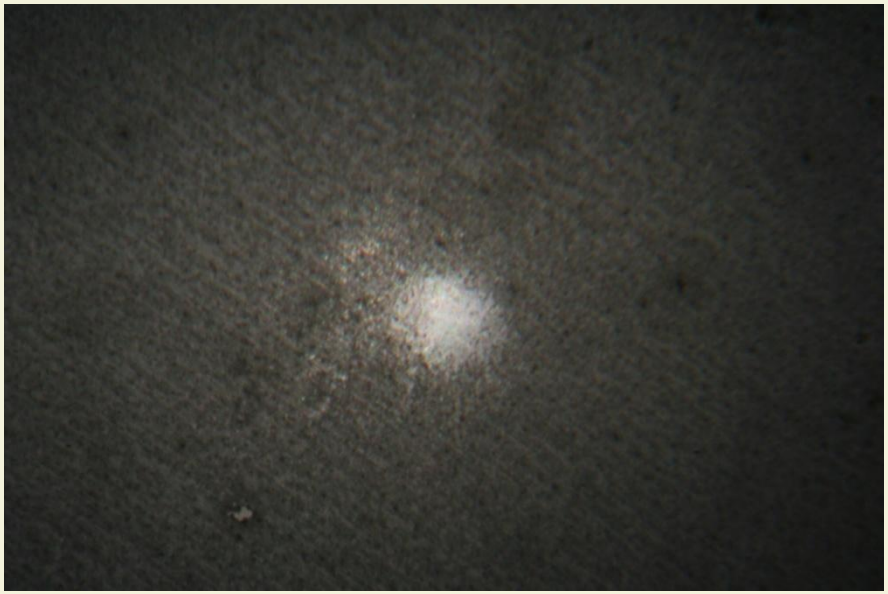
Total POT in FY 2007 =1.91 x1020**

FY 2008 : Horns, Decay Window & PB Quad.
Implement Multi-batch Slip-stacking

- Nov: Horn 2 water leak.
- Oct – Nov: Change from vacuum to He in decay pipe.
- Jan – Implement multi-batch slip-stacking. Increase from 5 to 9 Booster batch normal operation.
- Feb – Mar: Horn 2 water leak. Replace ceramic isolators with new design.
- Mar: PB Quad failure.
- June – July: Horn 1 water leak; replace Horn 1.

Total POT in FY 2008 =1.99 x1020**

Decay window inspection shows oxidation beam profile. Change from vacuum to He in decay to mitigate pressure on window.



FY 2009 : Horn Stripline, Target & Tritium

- Nov – Dec: Replace Horn 2; strip-line failure
- May – PB tunnel flood due to blockage under target hall.
- June – Change target NT02 to NT03. Graphite “depletion”
- June – Add dehumidification to Beam Dump region.

Water backup in PB Pretarget tunnel.

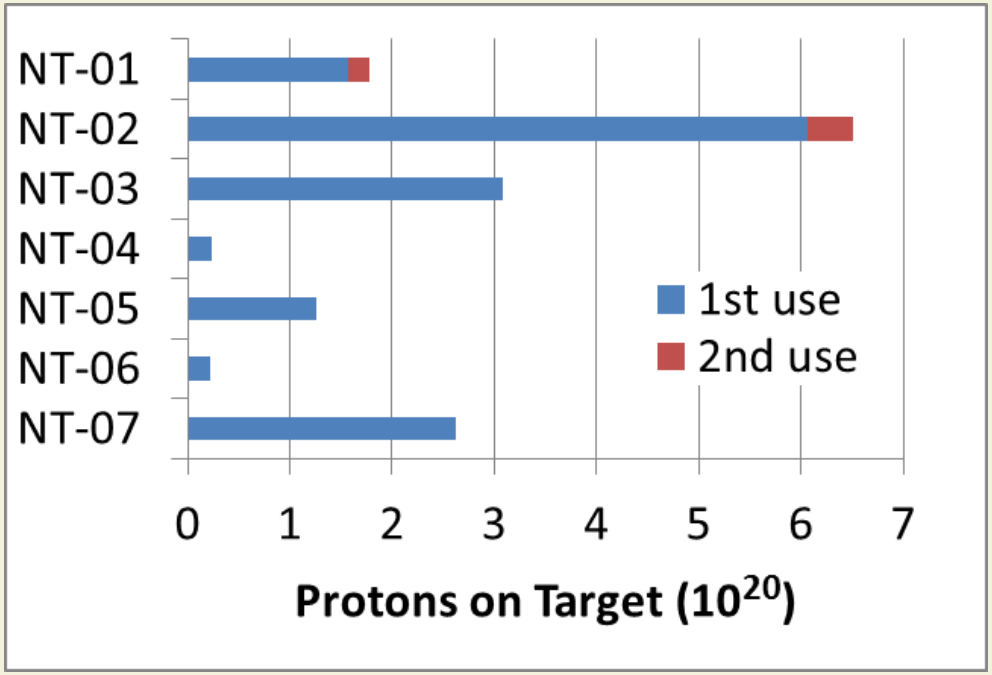
Total POT in FY 2009 =2.18 x1020**

FY 2010 : Tritium Mitigation & Great Uptime

Total POT in FY 2010 = 3.19 x1020**

FY 2011 : Year of the Targets (Five) & PB Cables

- Oct: NT04 -> NT05
- Mar: NT05 -> NT06
- May: NT06 -> NT01
- July: NT01 -> NT02
- July: PB Dipole cables ground fault; Sump pump & alarm failure.
- Sep: NT02 -> NT07



Total POT in FY 2011 = 2.21 x1020**

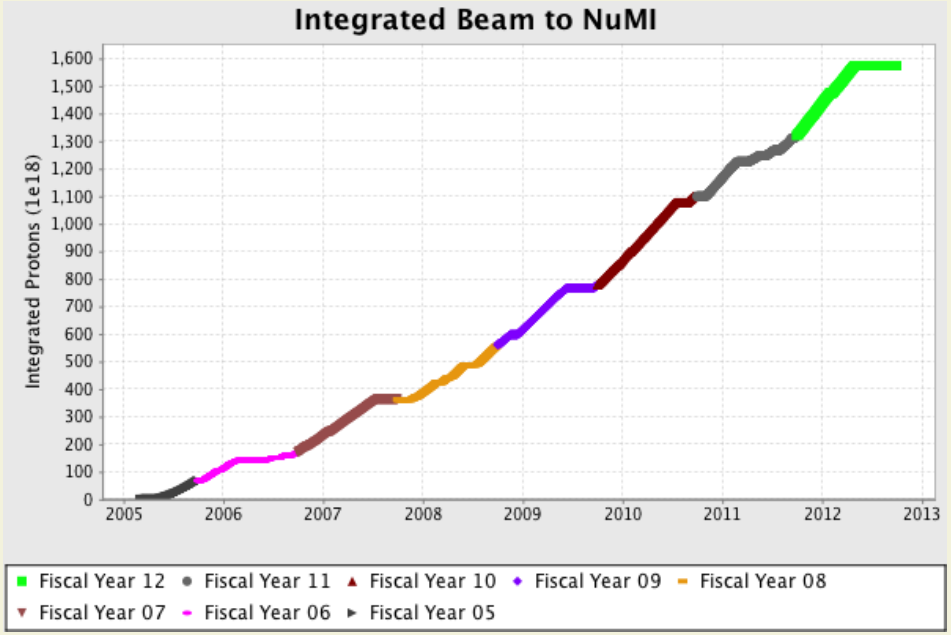
FY 12: Great Uptime. Seven Month Operation before NOvA Shutdown 30 Aoril.

Total POT in FY 2012 = 2.55 x1020**

NuMI Downtime Summary

- Primary Beam ~ 1%
- Neutrino beam ~ 13%
- Accelerator (including scheduled M&D) ~ 13%

- Fraction up since May 2005 ~ 73%



Some NuMI Lessons Learned – Primary Beam

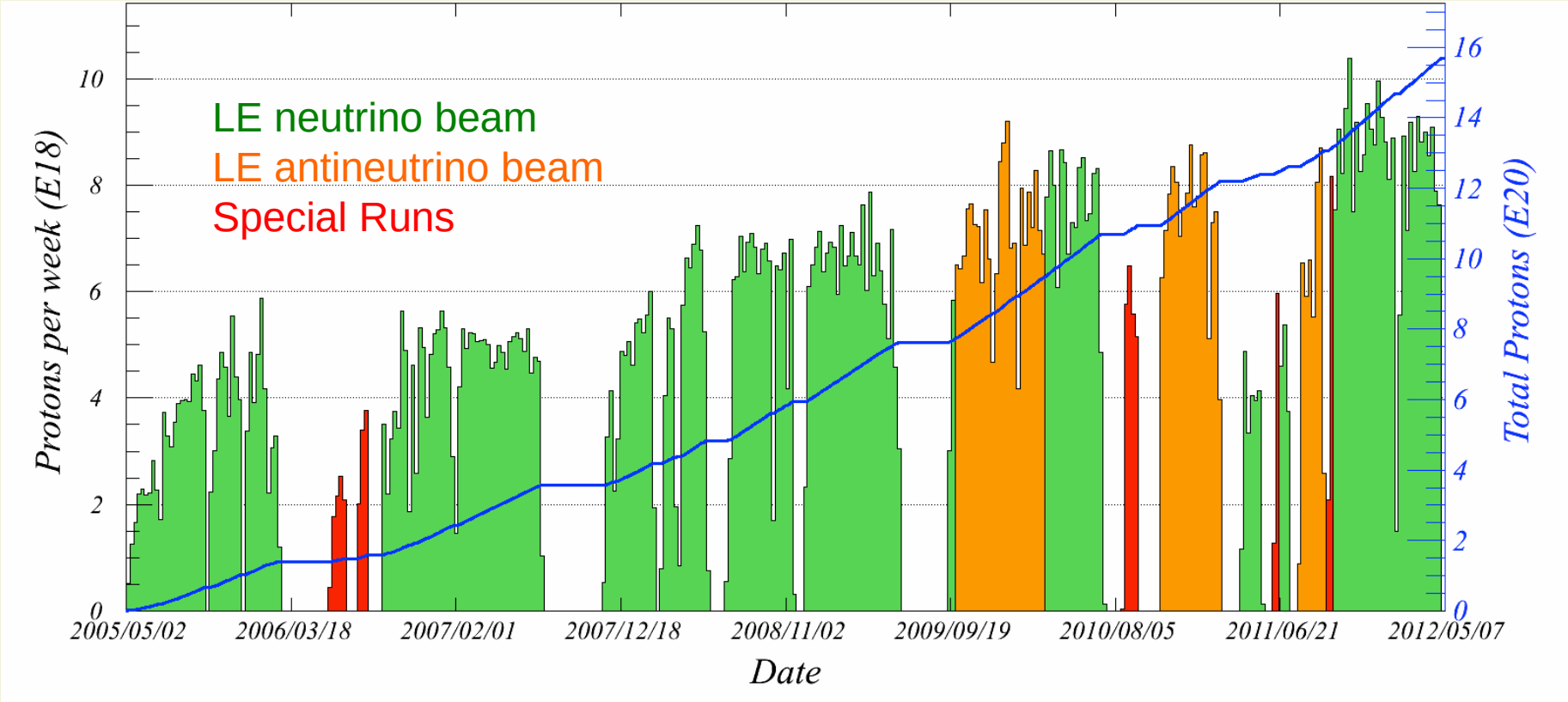
- We refurbished existing dipoles and quads (30-40 years old magnets) for NuMI to save $$.
  - Worked okay -> 99% uptime for PB. But, probably fortunate for quads. We lost many during refurbishment, and had few spares. For NOvA shorter cycle time, have replaced highest current quads with new design.
- Did not skimp on instrumentation, and greatly enhanced beam control.
  - Great payoff here. Prior to operation, control of primary beam losses to avoid ground water activation as unshielded intense beam passes through a protected aquifer region was a great concern.
  - This worked extremely well. **> 60 million** targeted beam pulses, and **ZERO** with large beam loss.
  - Many side benefits also, with no activation issues for PB components, and consistently robust targeting precision.

Some NuMI Lessons Learned – Neutrino Beam

Jim Hylen probably has many more.

- Tritium is **VERY** mobile in moist air
  - Our major problem is transfer of tritium produced in target hall chase [smaller effect from absorber] to wet decay tunnel walkway which then transferred to large volume of "clean" water designed to come in to NuMI tunnel from regions external to system shield. Produces effective shield short circuit
- Began operations with no spares for target or horns, with first spares many months away
  - Not the best approach!
  - **BUT**, our people learned by necessity to repair highly activated components efficiently and safely.
  - **Still, would have been much better to begin beam operation with spares**.
- Need good control over critical component production.
  - 1st targets produced by IHEP worked well. Major quality control problems with later ones.
- Hydrogen embrittlement of high strength steel in high radiation field is **VERY REAL**.
  - Horn 2 Strip-line failure.

NuMI 2005 - 2012



Shutdown begins 30 April 2012 for 700 kW NOvA Upgrade

and 1.57 Sextillion

$(1.57 \quad 10^{21})$

Protons on Target for NuMI