Proton Plan for Neutrinos

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DOE Annual Science & Technology Review
July 12-14, 2010

U.S. DEPARTMENT OF ENERGY

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Protons for Neutrino Experiments

- Accelerator Complex provides
  - 8 GeV protons to Booster Neutrino Beam (BNB)
    - MiniBoone
    - MicroBoone (future)
  - 120 GeV protons to NuMI Target
    - MINOS
    - MINERνA
    - NOνA (future)
    - LBNE (future)
  - 8 GeV protons to pbar source
    - g-2, Mu2e (future)

- Series of upgrades to increase proton flux

Proton Plan

- 2004: "A three year plan for increasing the proton intensity delivered to the 120 GeV and 8 GeV neutrino beams, with upgrades to the Linac, Booster, and Main Injector"
  - Beam Quality and Aperture
    - Reducing beam loss to allow more total protons to be accelerated while still maintaining reasonable levels of activation
  - Repetition Rate limitations
    - Making improvements which will physically allow the Booster to operate at a higher average repetition rate (9.5-10 Hz) than the 7.5 Hz it began with.
  - Reliability and Stability
  - Beam intensity in MI for NuMI
    - Multibatch operation and slip stacking, increasing the acceptance, and removing beam halo at injection

Proton Plan

- Goals:
  - Finish by 2008, operate through 2015
  - Maximum Average Repetition Rate: 9 Hz
  - Maximum Hourly Rate: 1.4e17
  - Average Hourly Rate: 9e16
- Completed in 2009 shutdown (installation of corrector packages)

- Linac
  - 7835 Power Amplifiers
  - Quad Power Supplies
  - Instrumentation (descoped)
  - 200 MHz LLRF upgrade
- Booster
  - ORBUMP
  - Corrector Packages
  - Alignment
  - Drift Tube Cooling
  - Limits on Repetition Rate
  - Instrumentation (descoped)
  - 30 Hz Harmonic (descoped)
  - γ_t jump (descoped)
  - Solid State RF (descoped)
- Main Injector
  - Large Aperture Quads
  - Collimators
  - NuMI Slip Stacking
  - RF Upgrade

Proton Plan 2

- Upgrades to Recycler Ring, Main Injector, and NuMI Target hall to support 700 kW (1 MW) 120 GeV protons for NOνA
  - Convert Recycler to proton accumulation ring
  - Shorten MI cycle to 1.33 seconds
  - New target and horn designs
  - Assumed success of Proton Plan, does not address 8 GeV protons
  - Became part of NOνA project December 2006
- Goals:
  - 4.9e13/pulse @ 120 GeV to NuMI Target
  - 1.33 second cycle
  - 95% MI efficiency

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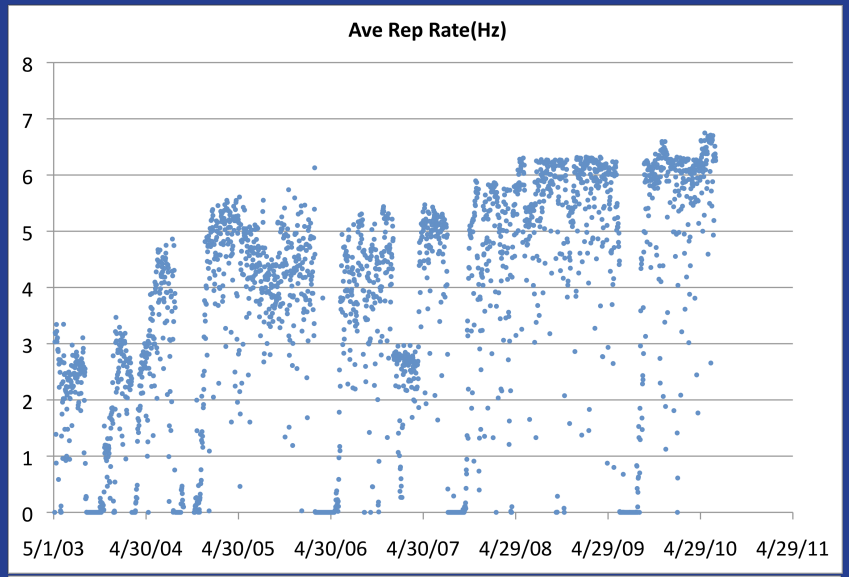
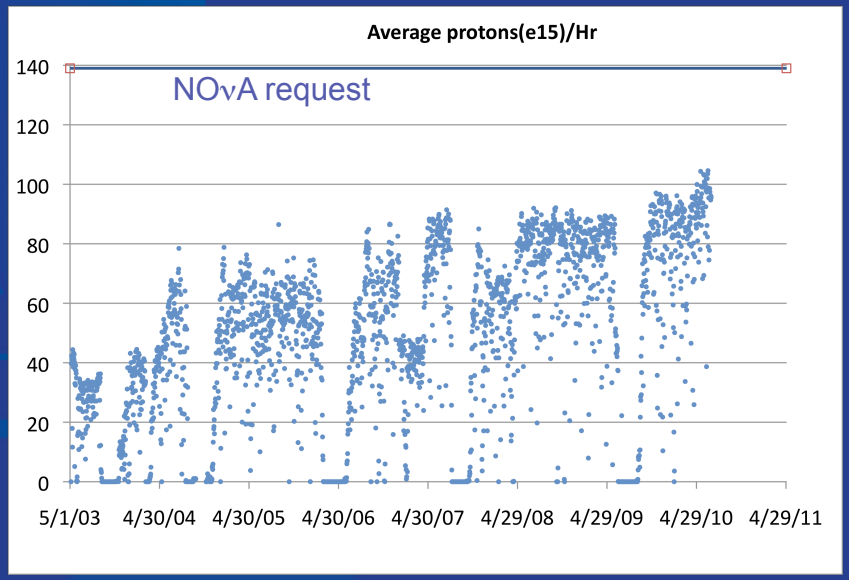
Proton Economics

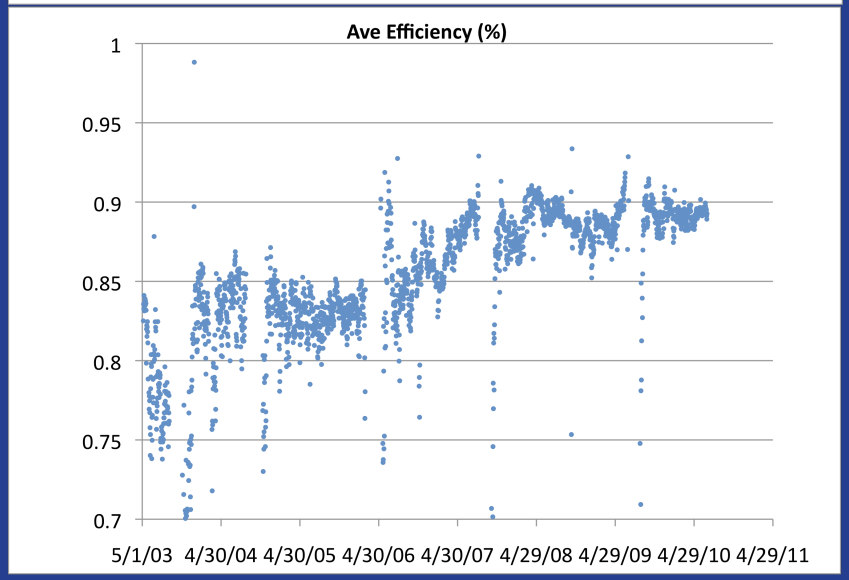
- Dominated by requests at 8 GeV
  - NOνA: 9 Hz, 4.3e12/pulse ⇒ 1.39e17/hour
    - 700 kW at 120 GeV, 1.33 sec MI Cycle
  - MicroBoone: 3 Hz, 4e12/pulse ⇒ 0.43e17/hour
  - Mu2e: 4.5 Hz, 4e12/pulse ⇒ 0.65e17/hour
    - 6 pulses per 1.33 sec MI Cycle
    - Needs to fit around NOνA pulses as uses Recycler to send protons to Accumulator
- SY120 Program (SeaQuest, Test Beam) does impact NOνA Main Injector cycles

Current Booster Performance

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







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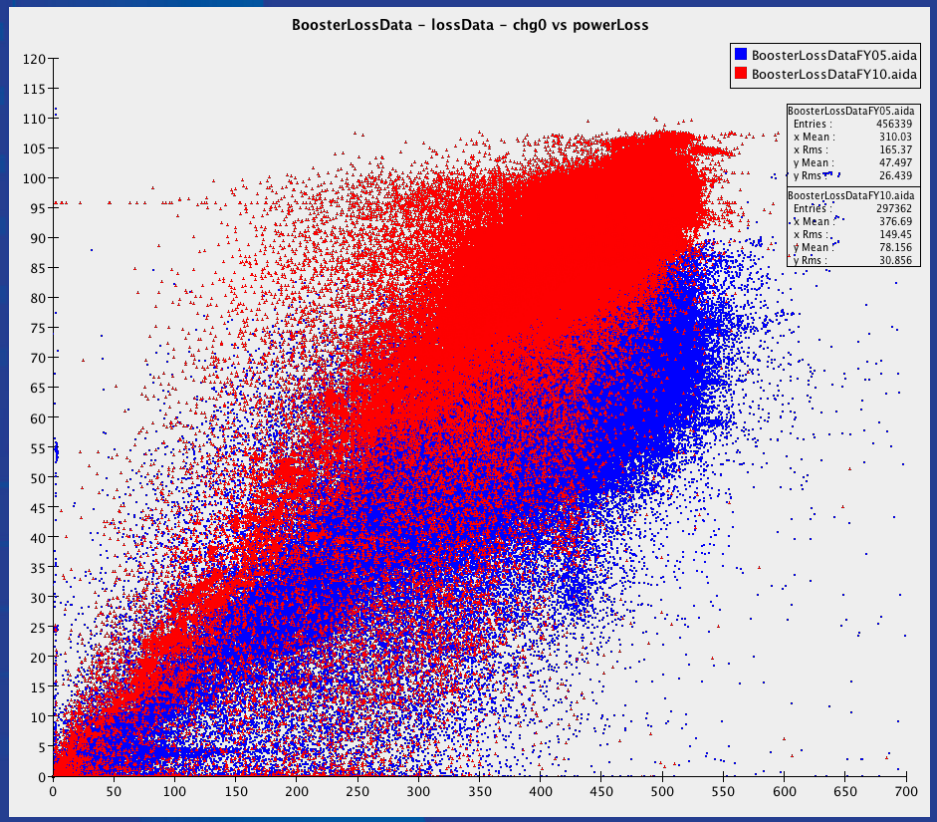
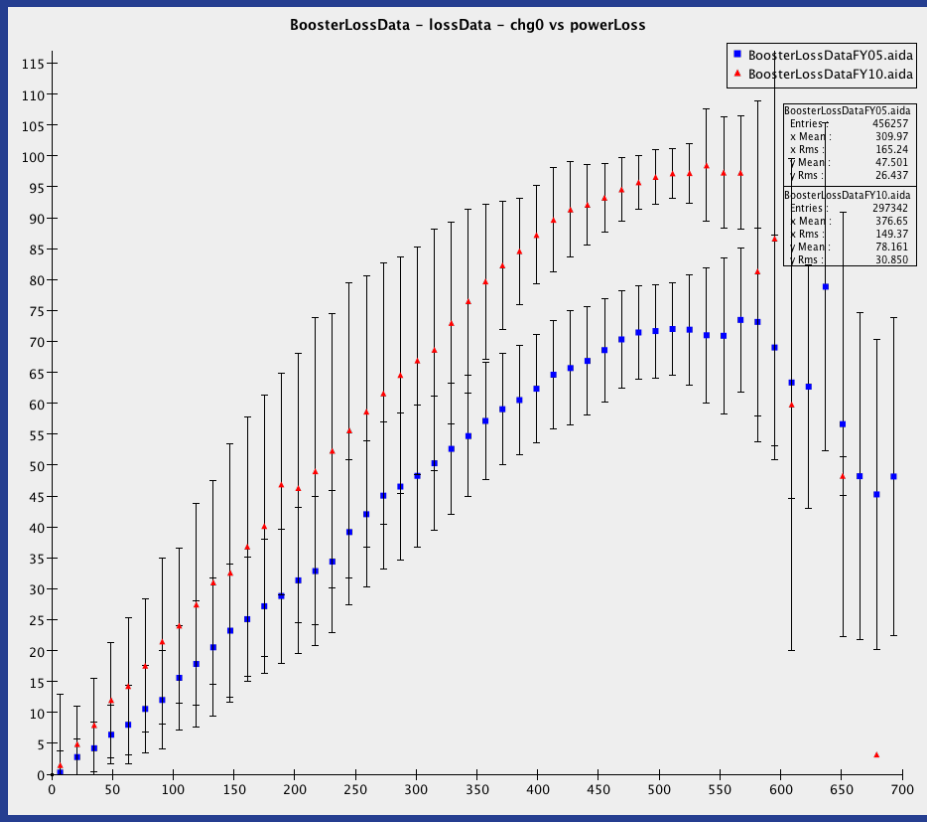
Proton Plan

- Significant reductions in losses
  - Aperture, orbit, intensity/pulse





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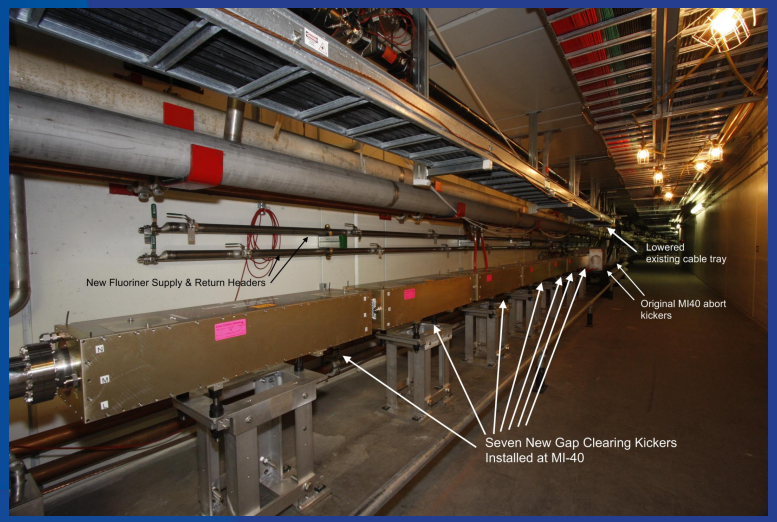
Main Injector Losses

- Important loss:
  - unbunched beam in injection gap caused by slipstacking process
  - Goes in 3 quads downstream of injection kicker
- Installed Gap Clearing Kicker magnets
  - Shutdown 2009
  - Service Building (MI39) in same shutdown
  - Connected 2010 shutdown



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The Plan

- To support operation through 2020-2025(?)
  - NOνA: 700 kW at 120 GeV on NuMI target
    - Combined two shutdowns into one
    - Moved resources into support of accelerator work
    - On schedule for 11 month shutdown starting in Mar 2012 with 3 months of float
  - 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

Task Force within the Accelerator Division

- To identify
  - The known knowns: we know we need to do and know how (have an engineered solution)
    - e.g., Solid State RF
  - The known unknowns: we know we need to do but don't know how (don't have an engineered solution)
    - e.g., ferrite tuner cooling, Anode power supply
  - The unknown unknowns:
    - e.g., reliability questions at 15 Hz operation

- How to meet the program requests and operate for a period of 10-15 years (both reliably and efficiently)

Task Force Charge

- The charge to the Proton Source Task Force is:
  - Determine the vulnerabilities of each major subsystem in the Proton Source system including
    - The H- sources and pre-accelerators
    - The low energy drift tube Linac
    - The RF System for the low energy Linac including power amplifier tubes and other associated tubes
    - The 8-GeV Booster magnet systems
    - The 8-GeV vacuum system
    - The 8-GeV RF cavities and modulators
    - The controls and interlocks of all Proton Source systems
  - Review the planned upgrades of the H- sources, the Booster RF system, and the 15Hz upgrade.
    - Identify weaknesses
  - Develop a cost estimate

The Plan

- Plan in support of NOνA
  - Well defined in RR, MI, and NuMI target hall
  - Does assume 9 Hz, 1.4e17/hour capability from Booster
- Address vulnerabilities in Linac, Booster, & MI
  - Specific upgrades known
  - Scale: up to $70 M (not in a resource loaded schedule)
  - *Opportunity for use of NOνA contingency $? (John Cooper in Detector Parallel session)*
- Task Force created to address questions and develop plans
  - Report by end of summer
  - *Best time scale: overlap with 2012 shutdown*

Backup slides

Vulnerabilities

- Pre-accelerators (Source + Cockroft-Walton)
- Low energy Linac
  - Power Amplifiers
  - Modulator Electronics
- 8 GeV Booster Reliability
  - Main Booster Combined Function Magnets
  - Booster RF System
    - Power amplifiers
    - Cavities
  - Booster beam losses
  - Booster shielding
  - Old water and power systems

Task Force Leaders for Subsystems

- Modulators
  - Howie Pfeffer
- Low Energy Linac
  - Paul Czarapata
- High Energy Linac Reliability
  - Peter Prieto
- Linac Controls
  - Mike Kucera
- Linac Power Distribution
  - Steve Hays
- Linac LCW Systems
  - Bob Slazyk

Task Force Leaders (Con't.)

- Linac and Booster Vacuum
  - Dave Augustine
- Linac and Booster Pulsed Systems
  - George Krafczyk
- High Level RF (includes Booster Cavities)
  - John Reid
- Low Level RF
  - Craig Drennan
- Booster Magnets
  - Jim Lackey
- Booster Controls
  - Sharon Lackey

Task Force Leaders (Con't.)

- Pre-acclerator Upgrades
  - Bob Webber, Jim Steimel, Chuck Schmidt
- Booster Shielding Assessments
  - John Anderson
  - Peter Kasper

Proton Economics

- g-2: 4.5 Hz, 4e12/pulse ⇒ 0.65e17/hour
  - 6 pulses per 1.33 sec MI Cycle
  - Needs to fit around NOνA pulses as uses Recycler to send protons to Accumulator
- SY120 takes 120 GeV MI cycles away from neutrinos
  - 5-10% power reduction to 120 GeV target
  - Not a significant demand at 8 GeV

July 2009 IPR Recommendations

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2.1.3 Recommendations

OFFICE OF SCIENCE

1. **Determine the resources required to complete the work and obtain a commitment from the laboratory management to supply the necessary resources. Update the resource loaded schedule to reflect the updated planned commitment.**
2. **Identify a shutdown coordinator to work on detailed organization of the complex shutdown activities**

ANU Replan

- My interpretation: assign by name, the resources associated with tasks
  - Engineers and Scientists
  - 681 in progress or future tasks, 572 with these resources
- Collected from L3 and L4 managers, appropriate Departments
  - Assignments
    - Electrical/Mechanical/RF/Process Engineers (AD & TD)
    - Scientists (AD & TD)
  - Availabilities based on these priorities (in this order)
    - Operations (Collider and NuMI)
    - NOνA
    - Other Work:
      - Operational: BNB, MTA, SY120, …
      - LBNE, Mu2e, PX, HINS, SCRF, MuCool, …

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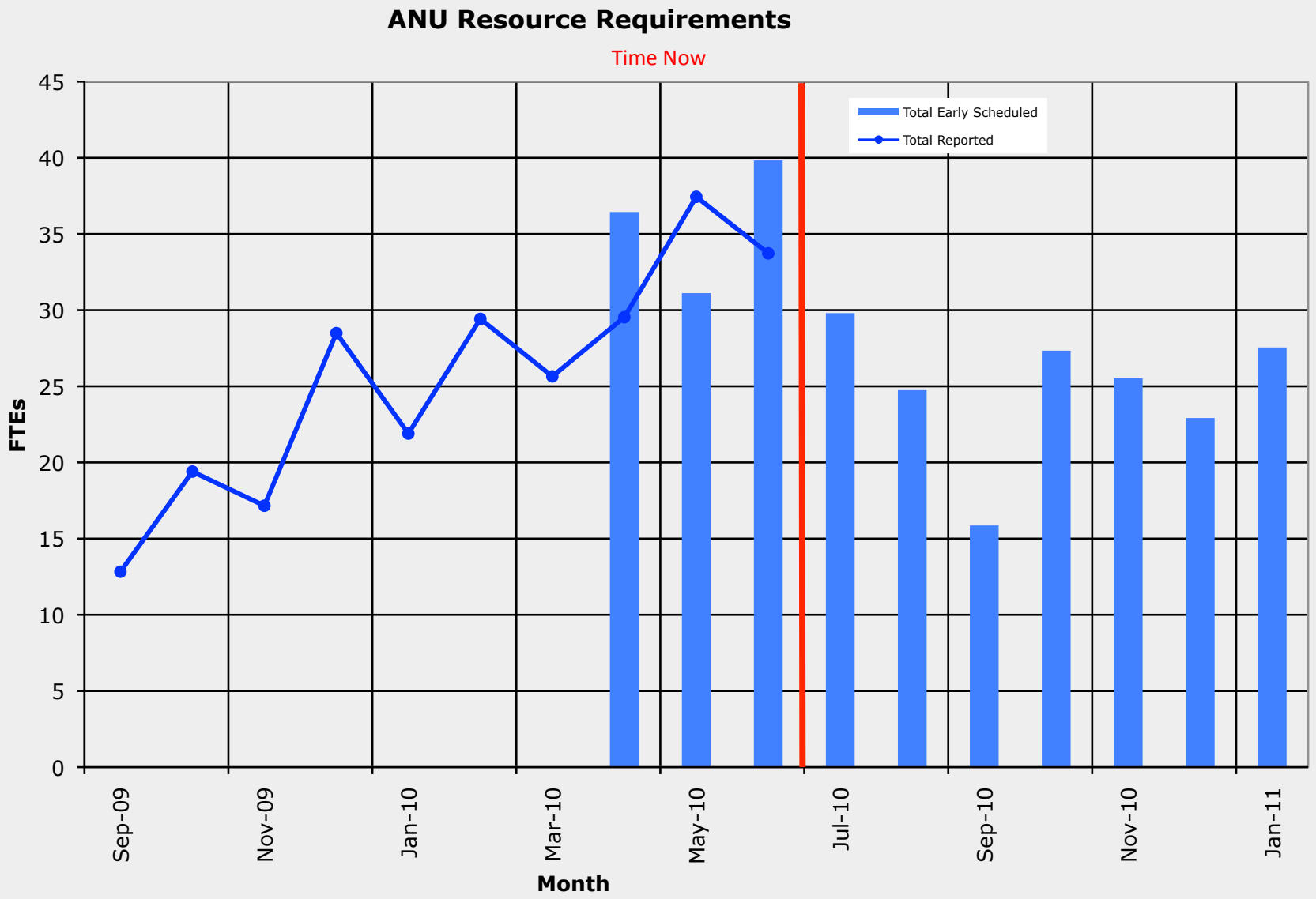
ANU Replan

- Keep a controlled spreadsheet with the assigned resources, allows us to adjust to changes in schedule/ assignment/people
  - Scientist (AD & TD)
  - AD EE, AD ME, RF Eng
  - TD EE, TD ME, TD PRCS

WBS	Activity Description	Start	Finish	% Complete	AD Scientis	Name	AD EE	Name	AD ME	Name	RF Eng	Name	TD EE	Name	TD ME	Name	TD PRCS	Name	TD Sci	Name
2.0.1.2.1.2	**Assembly & Testing of RR Injection Production Kicker**	**23-Jul-10**	**9-May-11**	**0**																
2.0.1.2.1.2.1	RR Inj Weld Bellows & Vacuum Flanges on 8 Ceramic Beam Tube Ends	12-Nov-10	6-Jan-11	0	No		No		No		No		No		Yes	Robotham	No		No	
2.0.1.2.1.2.2	Assemble 1 Pre-production Magnet & Load	23-Jul-10	17-Sep-10	0	No		Yes	Jensen;S Wa	Yes	R. Reilly	No		Yes	Elementi	Yes	Robotham	No		Yes	Velev
2.0.1.2.1.2.3	RR Injection Kicker Low Voltage Testing 1 Pre-production Magnet	20-Sep-10	15-Oct-10	0	No		Yes	Jensen;S Wa	No		No		Yes	Elementi	No		No		Yes	Velev
2.0.1.2.1.2.4	RR Inject Kicker HV Testing 1 Pre-production Magnet	18-Oct-10	12-Nov-10	0	No		Yes	Jensen;S Wa	No		No		Yes	Elementi	No		No		No	
2.0.1.2.1.2.5	RR Inject Kicker Life Testing 1 Pre-production Magnet	15-Nov-10	14-Feb-11	0	No		Yes	Jensen;S Wa	No		No		Yes	Elementi	No		No		No	
2.0.1.2.1.2.6	Assemble 5 RR Injection Kicker Magnets	15-Feb-11	11-Apr-11	0	No		No		No		No		Yes	Elementi	Yes	Robotham	No		Yes	Velev
2.0.1.2.1.2.7	Low voltage testing 5 magnets	18-Jan-11	9-May-11	0	No		Yes	Jensen;S Wa	No		No		Yes	Elementi	No		No		Yes	Velev
2.0.1.2.1.2.9	Apply Resistive Coating Inside Ceramic Beam Tubes	7-Jan-11	12-Jan-11	0	No		No		No		No		Yes	Elementi	No		No		No	
2.0.1.2.2	**RR Injection Production Kicker Power Supply**	**28-Dec-07**	**16-Jul-12**	**0**																
2.0.1.2.2.1	**Procurement of RR Injection Production Kicker Power Supply**	**28-Dec-07**	**11-Apr-11**	**0**																
2.0.1.2.2.1.1	RR Inj Prep Req & Award PO for Parts for 6 Power Supply Controls	15-Nov-10	14-Jan-11	0	No		Yes	J Biggs	No		No		No		No		No		No	
2.0.1.2.2.1.2	RR Inj Receive Parts for 6 Power Supply Controls	14-Mar-11	11-Apr-11	0	No		Yes	J Biggs	No		No		No		No		No		No	

Approach and Goals

- Goals of replan
  - Target Changeover overlaps with Accelerator Changeover
    - Medium energy target configuration after shutdown
      - this impacts the other experiments which run in the NuMI beamline, specifically Minerva, because it changes the neutrino energy spectrum
    - Mar 2012 – Feb 2013 was my first guess to overlap shutdowns
    - Length ~11 months vs 10+3 months
  - Start Accelerator Shutdown Mar 2012 with 3 months of float (Dec 2011 as target)
- Assumed work progressed from October 1st based on July status



FTE = 147.3 hours/month (1768 hours/12)

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FTE Definitions

- FNAL: 85% good representation of available hours (holidays/vacation/ sick leave)
  - For one year: 1 FTE = 52 weeks * 40 hours/week * 0.85 = 1768 hours
  - For one month: 1 FTE = 1768 hours/12 = 147.3 hours
  - For one week: 1 FTE = 40 hours * 0.85 = 34 hours
  - Assumes vacation and holidays spread evenly through year
- FNAL effort reports: Month covers 3rd Sunday – 3rd Sunday
  - Offset with respect to calendar months
    - 8 cover 4 week period, 4 cover 5 week periods
  - Monthly employees report weekly (through Fermi Time & Labor), available weekly
  - Weekly employees report weekly (through paper), available monthly
    - Changed as of June 21 2010