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# Proton Plan

Eric Prebys, FNAL Accelerator Division

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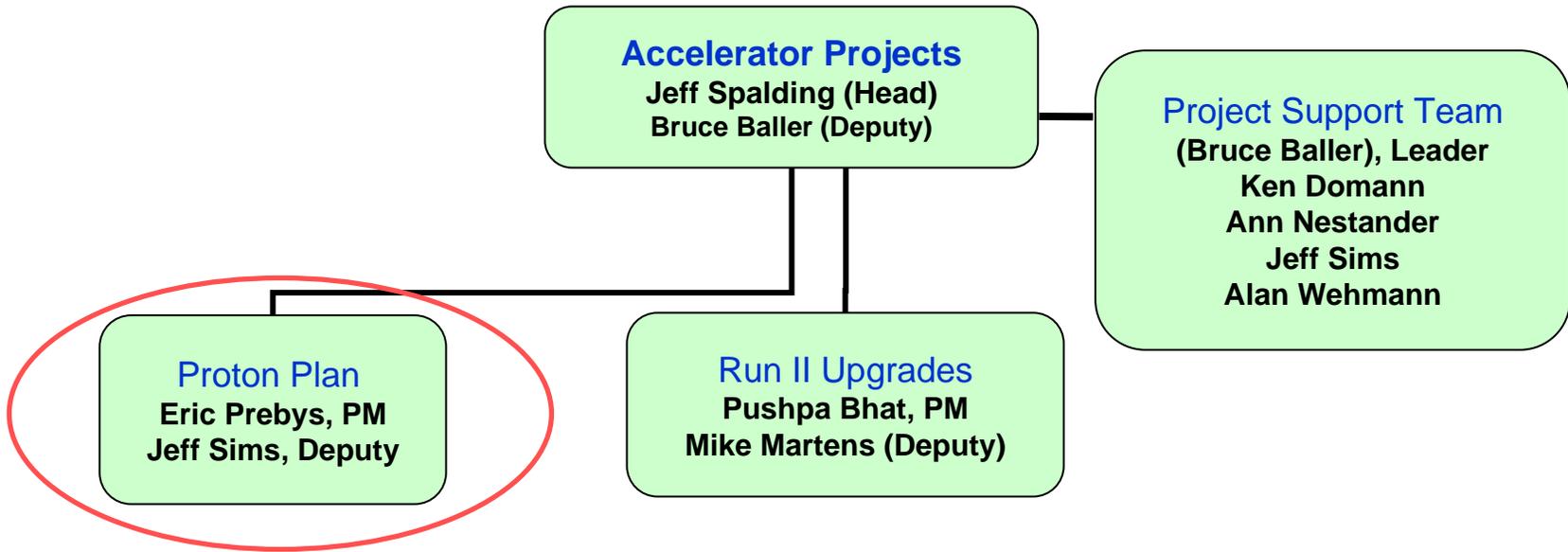
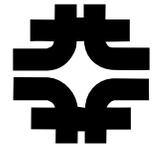
# Proton Plan Charge

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- Develop a plan for a set of upgrades and operational improvements to maximize proton delivery to:
  - NuMI beamline (120 GeV from MI)
  - Booster Neutrino Beam (BNB) (8 GeV from Booster)
- (Original) Goal: complete the upgrades over the next 3 years, and operate through 2015 or beyond
  - This plan precedes the Proton Driver replacement of the existing Proton Source (Linac+Booster).
  - We are currently refining our plans in the wake of the BTeV cancellation.
- Develop the budget and timeline for these improvements
- Estimate projected proton delivery (PoT) to both beam lines

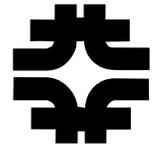
# Management Organization



- Benefit from experiences with the Run II plan
- Project support team:
  - Resource-Loaded Schedule (MS Project) – Domann
  - Accounting - Cobra interface to Lab's system - Nestander
  - Project management support – Sims
  - Web and documentation support - Wehmann

# Context: Staged Approach to Neutrino Program

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- Stage 0 (now):
  - Goal: deliver  $2.5E13$  protons per 2 second MI cycle to NuMI ( $\sim 2E20$  p/yr)
  - Deliver  $1-2E20$  protons per year to Booster Neutrino Beam (currently MiniBooNE)
- Stage 1 ( $\sim 2008$ ):
  - A combination of Main Injector RF improvements and operational loading initiatives will increase the NuMI intensity to  $4-5E13$  protons per 2.2 second cycle ( $\sim 3E20$  p/yr)
  - This will increase by  $\sim 20\%$  as protons currently used for pbar production become available
  - It is hoped we can continue to operate BNB at the  $2E20$  p/yr level during this period.
- Stage 2 (post-collider):
  - Consider (for example) using the Recycler as a preloader to the Main Injector and reducing the Main Injector cycle time
  - The exact scope and potential of these improvements are under study
- Stage 3 (proton driver)
  - Main Injector must accommodate  $1.5E14$  protons every 1.5 seconds
  - NuMI beamline and target must also be compatible with these intensities.

# Limits to Proton Intensity



- Total proton rate from Proton Source (Linac+Booster):
  - Booster batch size
    - Typical  $\sim 5E12$  protons/batch
  - Booster repetition rate
    - 15 Hz instantaneous
    - Currently 7.5Hz average (limited by injection bump and RF cooling)
  - Beam loss
    - **Damage and/or activation of Booster components**
    - Above ground radiation
- Total protons accelerated in Main Injector:
  - Maximum main injector load
    - Six “slots” for booster batches ( $3E13$ )
    - Up to  $\sim 11$  with slip stacking ( $5.5E13$ )
    - RF stability limitations (currently  $\sim 4E13$ )
  - Cycle time:
    - 1.4s + loading time (1/15s per booster batch)

Operational  
Limit

# Plan Strategy

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See document: BEAMS-DOC-1441 (11/09/04) at  
<http://beamsdocs.fnal.gov/cgi-bin/public/DocDB/DocumentDatabase>

- **Increase the proton delivery from the Booster (to both NuMI and BNB)**
  - Increase acceptance by improving orbit control and beam quality
  - Increase maximum average Booster repetition rate
- **Increase the beam intensity in the Main Injector for NuMI**
  - Main Injector multi-batch operation
  - Slip stacking in Main Injector (probably requires RF upgrade)
- **Improve operational reliability**
  - Alleviate 7835 Problem
  - Linac quad supplies

# Current Budget Guidance

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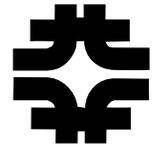


- After the cancellation of BTeV, we have the following budget guidance (M&S+SWF):

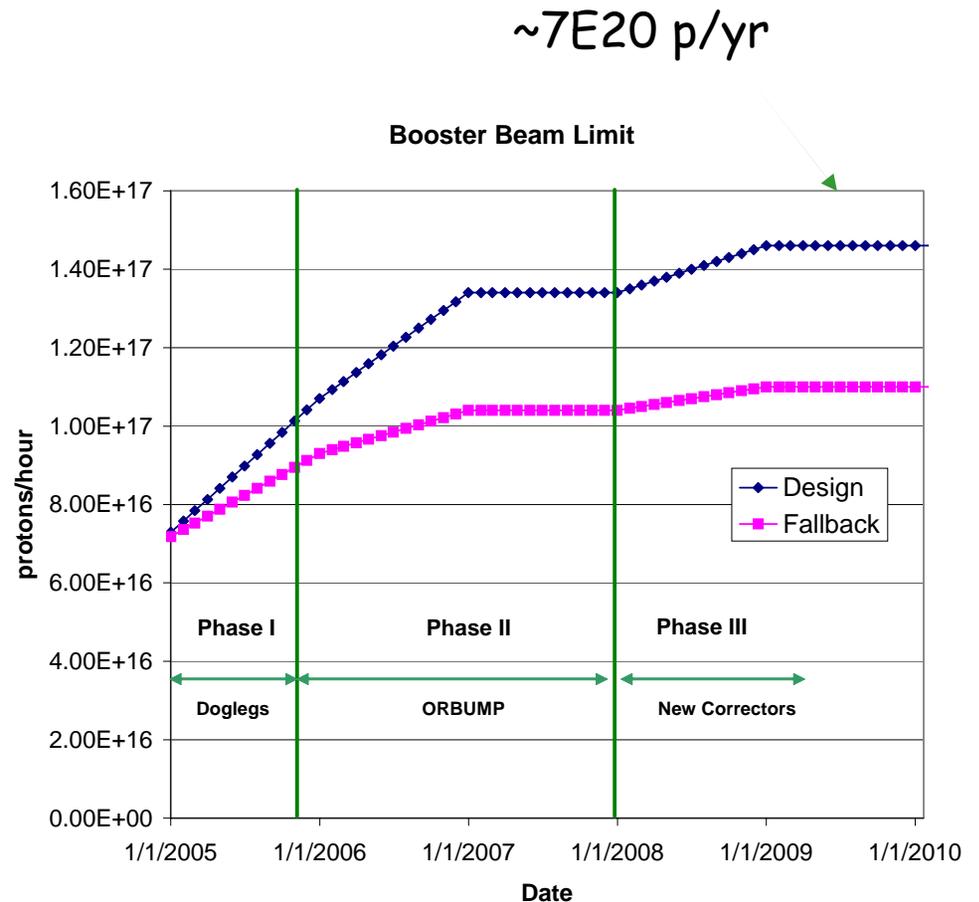
	FY05	FY06	FY07	FY08	Total
<b>Present Guidance</b>	7327	7845	6915	6116	28203

- This results in a scenario very close to the “delayed” scenario in the original document.

# Booster Throughput

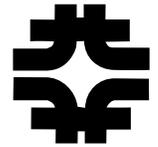


- Major Improvements:
  - New ORBUMP system (2005 shutdown)
  - Relocate L13 dump to MI-8 line (2005 shutdown)
  - New corrector system (2007)
  - 19<sup>th</sup> and 20<sup>th</sup> cavities added
- Performance
  - Rep rate (after 2005)
    - 7.5 Hz -> 8-9 Hz
  - Total protons (by end 2008)
    - 8E16 pph -> 1.45E17 pph
  - Batch size (by end 2008):
    - 5E12 -> 5.5E12



# Main Injector Loading

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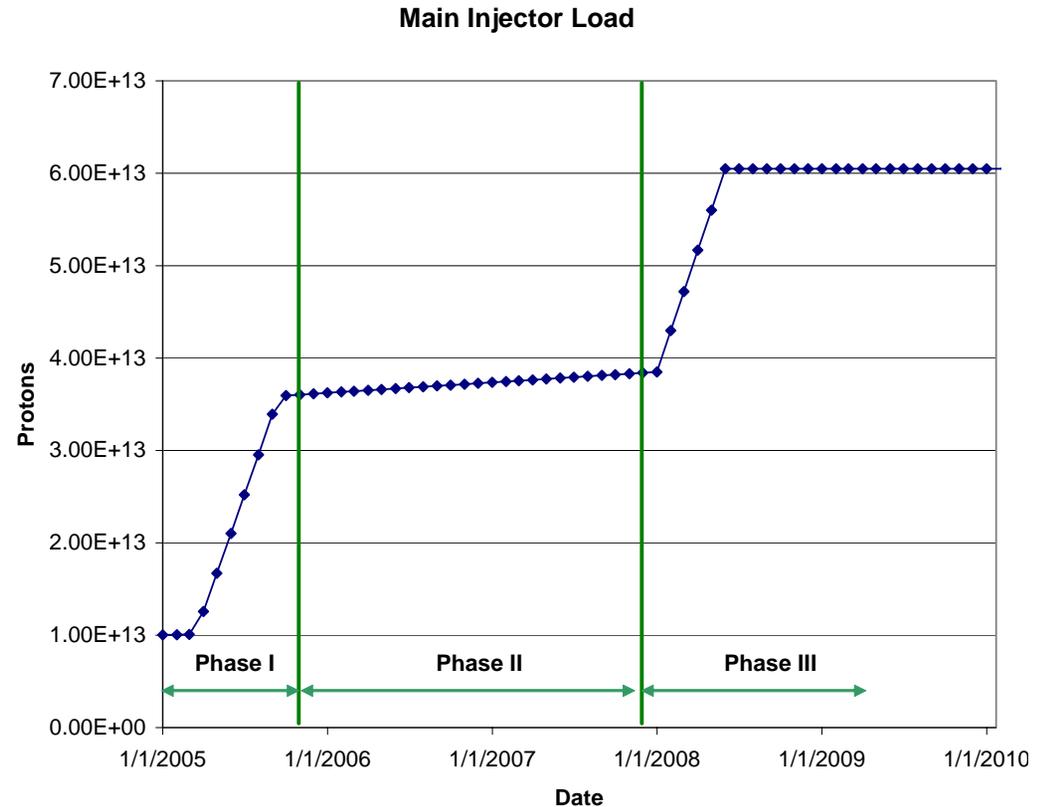


- Initial NuMI operation (“2+5”):
  - Two batches are slip stacked for antiproton production
  - Five more batches loaded for NuMI
  - All are accelerated together
- Ultimate NuMI operation (“2+9”):
  - Five batches will be loaded into the Main Injector, leaving one empty slot
  - Six more batches will be loaded and slipped with the first to make two for antiproton production and 9 for NuMI
  - This may exceed the capacity of the current RF system

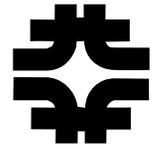
# Main Injector Loading (cont'd)



- Major Improvements:
  - Large Aperture Quads (2005 shutdown)
  - Loss monitoring and collimations system (TBD)
  - Multi-batch operation
  - Dual PA upgrade (??)
- Performance
  - 2 (pbar) + 5 Numi  $5E12$  batches @ 2 sec in 2005
  - 2 (pbar) + 9 NuMI  $5.5E12$
  - Batches @ 2.2 sec in 2008



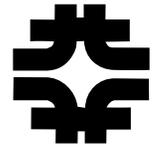
# Proton Plan Schedule - Level 3 Summary



WBS	Name	Start	Finish	2004		2005		2006		2007		2008		2009	
				H2	H1	H2									
<b>1</b>	<b>Proton Plan</b>	<b>Thu 9/30/04</b>	<b>Tue 9/30/08</b>												
<b>1.1</b>	<b>Linac Upgrades</b>	<b>Wed 12/15/04</b>	<b>Tue 1/2/07</b>												
1.1.1	Linac PA Vulnerability	Wed 12/15/04	Mon 3/20/06												
1.1.2	Linac Quad Power Supplies	Mon 1/3/05	Tue 1/2/07												
1.1.3	Linac Instrumentation Upgrade (descoped)	Mon 5/2/05	Fri 9/30/05												
<b>1.2</b>	<b>Booster Upgrades</b>	<b>Thu 9/30/04</b>	<b>Tue 10/16/07</b>												
1.2.1	Determine Rep Rate Limit	Mon 5/2/05	Fri 7/29/05												
1.2.2	OrBump System	Thu 9/30/04	Fri 12/9/05												
1.2.3	Corrector System	Tue 1/4/05	Tue 10/16/07												
1.2.4	30 Hz Harmonic	Mon 1/3/05	Tue 10/3/06												
1.2.5	Gamma-t System	Mon 5/2/05	Fri 9/30/05												
1.2.6	Alignment Improvements	Mon 5/2/05	Fri 9/29/06												
1.2.7	Drift Tube Cooling	Tue 1/4/05	Mon 11/14/05												
1.2.8	Booster RF Cavity #20	Mon 10/3/05	Wed 9/27/06												
1.2.9	Booster Solid State RF Pas (descoped)	Fri 4/1/05	Fri 4/1/05												
1.2.10	Booster Instrumentation Upgrade (descoped)	Mon 5/2/05	Fri 9/28/07												
1.2.11	Booster Dump Relocation	Fri 4/1/05	Mon 11/21/05												
1.2.12	Booster Chopper	Mon 5/2/05	Fri 4/28/06												
<b>1.3</b>	<b>Main Injector Upgrades</b>	<b>Thu 9/30/04</b>	<b>Tue 7/1/08</b>												
1.3.1	Large Aperture Quads	Thu 9/30/04	Thu 12/1/05												
1.3.2	Main Injector Collimation System	Tue 2/1/05	Mon 12/4/06												
1.3.3	NuMI Multibatch Operation	Mon 2/7/05	Tue 1/2/07												
1.3.4	Main Injector RF Upgrade	Tue 3/1/05	Tue 7/1/08												
1.3.5	MI Instrumentation Upgrades (descoped)	Wed 6/1/05	Mon 11/7/05												
<b>1.4</b>	<b>Management</b>	<b>Mon 5/2/05</b>	<b>Tue 9/30/08</b>												
<b>1.5</b>	<b>Proton Study Group</b>	<b>Fri 4/1/05</b>	<b>Fri 3/31/06</b>												

RF Inception 10/1/05

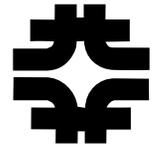
# All Milestones



WBS	Name	Finish	2004		2005		2006		2007		2008		2009
			H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	
1.1.1.1.2	Linac Task Force Phase 1 Report Issued	Mon 2/14/05			2/14								
1.3.4.1.6	Review MI RF Upgrade Prototype Test (Internal)	Thu 5/26/05					5/26						
1.3.2.1.2.2	Review Concept for MI-8 Collimation System	Tue 5/31/05					5/31						
1.5.2	Submit Preliminary Proton Study Group Report	Wed 6/1/05					6/1						
1.1.1.1.4	Linac Task Force Phase 2 Report Issued	Thu 6/30/05					6/30						
1.1.2.1.5	Linac Quad Power Supplies Design & Dwgs Complete	Fri 7/1/05					7/1						
1.2.2.1.2.6	OrBump Magnets Ready for Install on Girder	Fri 7/1/05					7/1						
1.2.2.1.3.4	OrBump Stripline Assy Complete	Mon 8/1/05					8/1						
1.2.2.1.4.5	OrBump Girder Assy Complete	Tue 8/9/05					8/9						
1.2.2.2.10	OrBump Power Supply Ready for Installation	Fri 9/30/05					9/30						
1.2.4.1.1	30 Hz Harmonic Project Decision	Mon 10/31/05					10/31						
1.4.5	Start 2005 Shutdown	Tue 11/1/05					11/1						
1.5.3	Submit Final Proton Study Group Report	Tue 11/1/05					11/1						
1.3.2.1.2.7	MI-8 Collimators Installation Complete	Mon 11/7/05					11/7						
1.3.3.1.3.1.4	Barrier Bucket Cavity Installation Complete	Mon 11/14/05					11/14						
1.2.11.3.10	Booster Dump Relocation Installation Complete	Tue 11/15/05					11/15						
1.3.1.1.7.5	Large Aperture Quad P.S. Installation Complete	Mon 11/21/05					11/21						
1.3.2.1.3.2	Review Concept for MI Collimation System	Mon 11/28/05					11/28						
1.2.3.3.3	Corrector PS Design Complete	Tue 11/29/05					11/29						
1.3.1.1.6.3	Large Aperture Quads Align/Install Complete	Thu 12/1/05					12/1						
1.2.2.1.6.6	OrBump System Installation Complete	Fri 12/9/05					12/9						
1.4.6	Finish 2005 Shutdown	Tue 1/3/06					1/3						
1.3.4.1.5	Review MI RF Upgrade Plan	Thu 2/2/06					2/2						
1.2.3.1.5	Corrector Prototype Magnet Complete	Mon 2/20/06					2/20						
1.1.2.2.2.5	Linac Quad Tank #1 Commissioning Complete	Tue 3/14/06					3/14						
1.1.1.1.6	Linac Task Force Complete	Mon 3/20/06					3/20						
1.2.8.1.3.4	RF Cavity #20 Misc Control Modules Ready for Installation	Fri 5/5/06					5/5						
1.4.7	Start 2006 Shutdown	Mon 8/7/06					8/7						
1.2.8.1.4.5	RF Cavity #20 Solid State Driver Amplifier Ready for Installation	Mon 8/21/06					8/21						
1.2.8.1.1.4	RF Cavity #20 Ferrite Bias Supply Ready for Installation	Wed 9/13/06					9/13						
1.2.8.1.2.5	RF Cavity #20 Misc Control Modules Ready for Installation	Wed 9/13/06					9/13						
1.3.2.1.3.7	MI Collimation System Install/Align Complete	Wed 9/20/06					9/20						
1.2.8.1.7	RF Cavity#20 Installation Complete	Wed 9/27/06					9/27						
1.2.4.2.4	30Hz Installation Complete	Tue 10/3/06					10/3						
1.4.8	Finish 2006 Shutdown	Tue 10/3/06					10/3						
1.3.4.2.7	DOE Approve MIE Line Item Package	Mon 10/30/06					10/30						
1.3.2.1.4	Main Injector Loss Mitigation Complete	Mon 12/4/06					12/4						
1.1.2.2.3.4	Linac Quad Installation Complete	Tue 1/2/07					1/2						
1.2.3.4.5	Corrector PS Fabrication Complete	Tue 1/30/07					1/30						
1.2.3.2.8	Corrector Magnets Ready for Installation	Thu 6/21/07					6/21						
1.4.9	Start 2007 Shutdown	Mon 8/6/07					8/6						

# Main Injector RF (1.03.04)

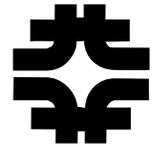
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- The Main Injector Upgrade path remains the single largest uncertainty in the Proton Plan
  - Might be possible to reach intensities of the current Plan without upgrades of any kind.
  - Represents ~half the budget!!!
- Towards a decision
  - Proceed with two/PA prototype
  - Proceed with systematic studies in the Main Injector
  - Organize a workshop this summer
    - Will consider the following
      - Potential of feed forward system
      - Potential and concerns with two PA solution
      - New RF system proposals.
    - Will coordinate needs of current plan, Stage II Plan, and Proton Driver
    - Generate a performance/price table
  - Goal: reach a decision for Stage I by end of FY05

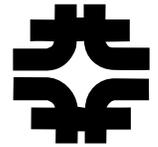
# 200 MHz Power Tube (7835) Situation

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- The 7835's have been a historical weak spot in the complex
  - Original technology
  - Made by one company (Burle) which has had major quality control issues
  - Often been forced to borrow spares from ANL, LANL, and BNL to keep program going.
- The Proton Plan includes a working group to evaluate the 7835 situation
  - Short term
    - Maximize delivery of tubes to provide a two year supply of spares by end of 2006
    - Determined best way was a single, large order
  - Longer term
    - Generate a plan should the supply of 7835's cease
      - Build them ourselves?
      - New tube?
      - Multibeam 200 MHz klystron?
      - New low energy linac?
    - These solutions will be beyond the scope of this plan, but we want to have them in place by 7/1/05

# Recent Developments with Burle



- **Burle has been sold!!!!**
  - Buyer still confidential, but “foreign”, so must be approved by the government
  - Rumored to “sort of” have “something to do” with “tubes” already
    - might mean test tubes, tube socks, tube tops, etc.
  - Must continue to support coaxitron for the Navy until ~2020
  - In light of that, it is claimed that we are still profitable.
  - We will keep our fingers crossed.
- Present spares: 4 (+1 high hour tube)
- Current delivery schedule (21 total):
  - APR-05: 1
  - MAY-05: 3
  - JUN-05: 3
  - JUL-05: 2
  - AUG-05: 0
  - SEP-05: 2
  - OCT-05: 2
  - NOV-05: 2
  - DEC-05: 2
  - JAN-06: 2
  - FEB-06: 2

Standard order (4 new + 5 rebuilds)

Proton Plan order (all new)

# Major Projects for 2005 Shutdown

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- Linac
  - New pulsed power supplies for one tank
- Booster
  - New injection bump (ORBUMP) system
  - Relocate Long 13 dump to MI-8 line
- Main Injector
  - Install seven large aperture quads



# Proton Projections

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- Phases of Operation
  - Phase I (now)
    - Booster lattice distortions ameliorated
    - Booster limited to 7.5Hz total repetition rate
    - Main Injector limited to  $4E13$  protons (2+5 operation)
  - Phase II (after 2005 shutdown)
    - Injection bump (ORBUMP) replaced
    - Drift tube cooling in Booster RF cooling finished
    - Booster capable of 8-9Hz operation
    - MI still limited to 2+5 operation
  - Phase III (after 2007 shutdown)
    - MI RF upgrade complete
    - 2+9 operation to NuMI

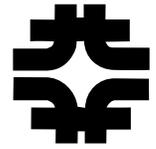
# “Design” PoT from the document



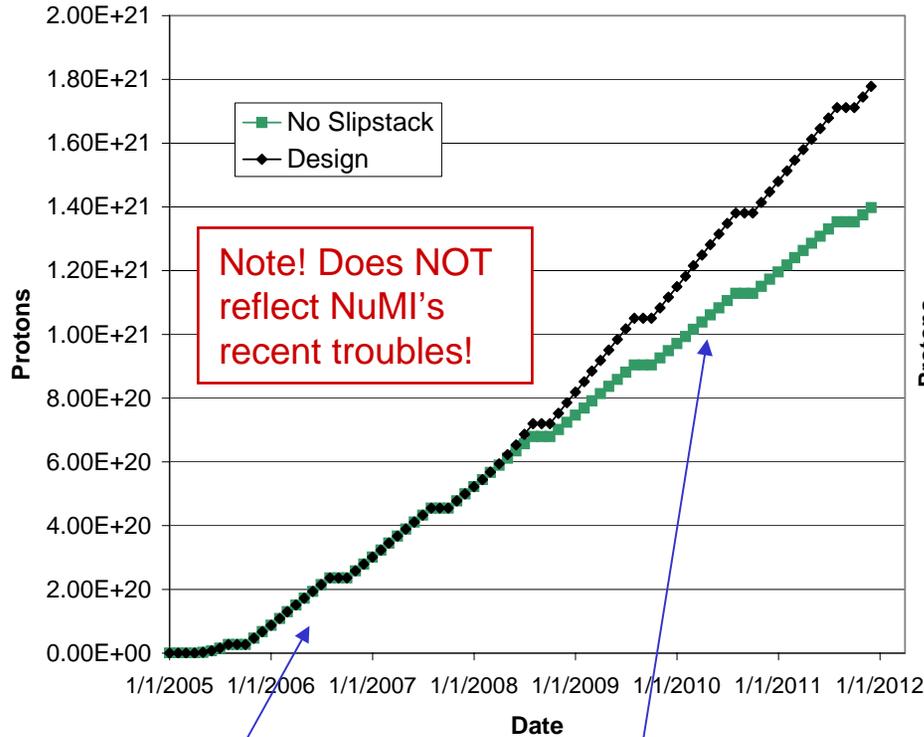
	Booster Batch Size	Main Injector Load	Cycle Time	MI Intensity	Booster Rate*	Total Proton Rate	Annual Rate at end of Phase	
							(AP + NuMI)	(sec)
<b>Actual Operation</b>								
July, 04	5.0E+12	1+0	2.0	0.5E+13	5.1	0.8E+17	0	3.3E+20
<b>Proton Plan</b>								
Phase I	5.10E+12	2+1→2+5	2.0	3.6E+13	6.3	1.0E+17	2.0E+20	1.5E+20
Phase II	5.3E+12	2+5	2.0	3.7E+13	7.5	1.2E+17	2.2E+20	2.8E+20
Phase III	5.50E+12	2+9	2.2	6.0E+13	8.3	1.5E+17	3.4E+20	2.2E+20
<b>Beyond Scope of Present Plan</b>								
11 Hz	5.50E+12	2+9	2.2	6.1E+13	11.0	2.0E+17	3.4E+20	5.0E+20

Each phase evaluated ~one year after associated improvements complete

# Long Term Projections



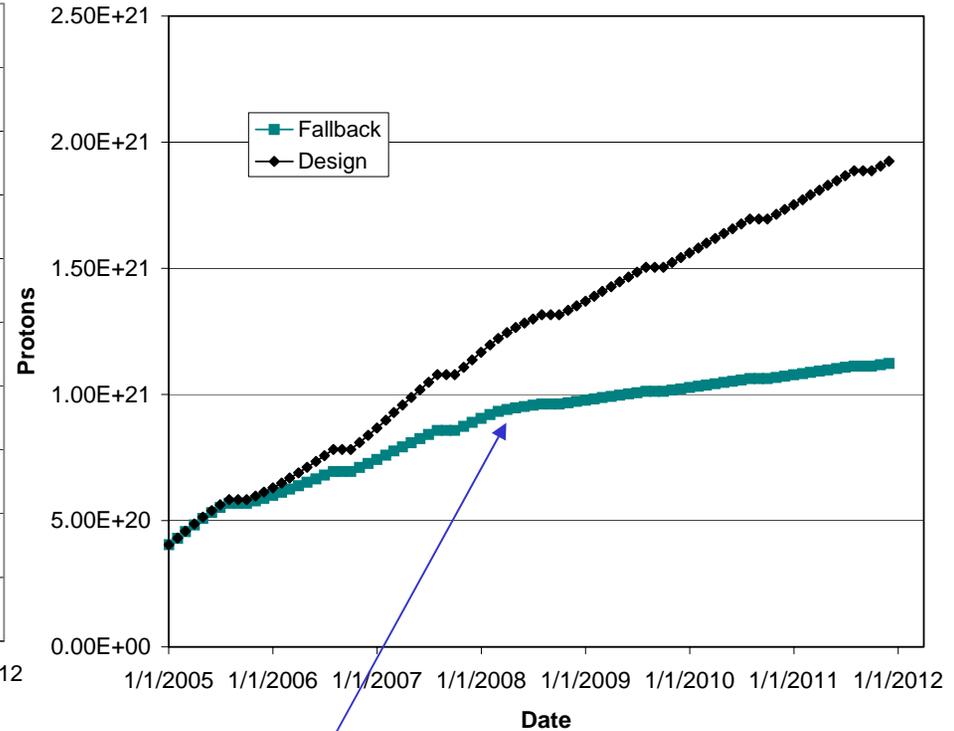
NuMI Totals



This turn-on is slower than in document

NuMI fallback = slip-stacking fails

Protons to BNB



BNB fallback = poor performance of Booster aperture upgrades

BNB only runs during shot setup

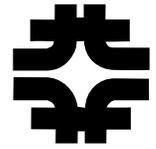
# How are we doing so far?

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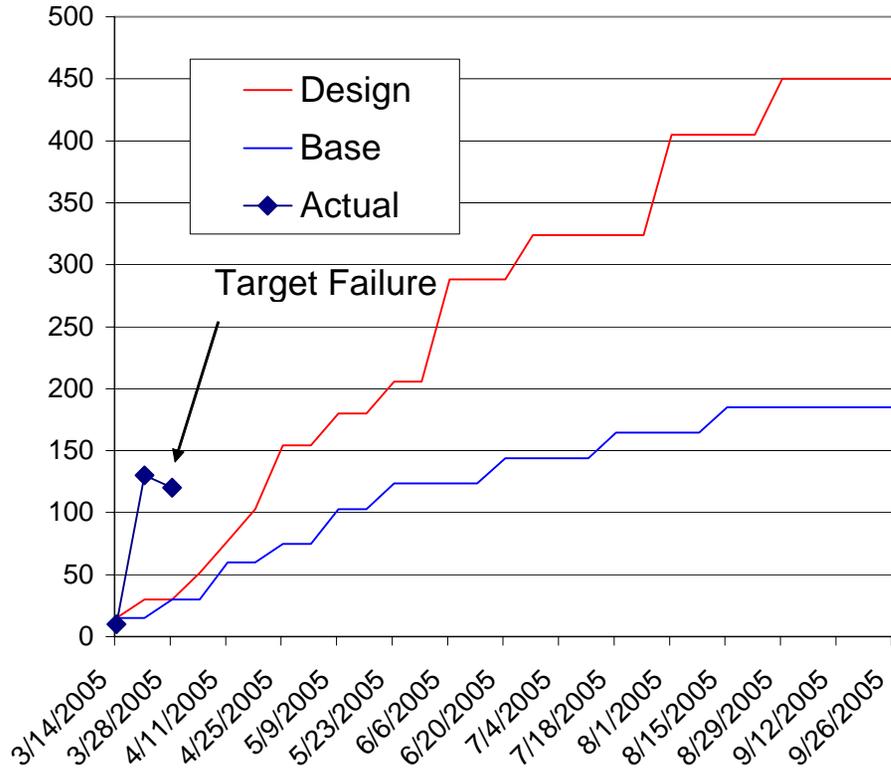


- In light of the NuMI target failure, it's not meaningful to analyze separate NuMI and BNB progress separately.
- After summarizing initial NuMI performance, we will concentrate on total proton delivery:
  - Hourly rates: compare actual total rate to  $pbar+BNB+NuMI$  projections.
  - Integrated total: compare MiniBooNE actual to  $BNB+NuMI$  projections.
- Except for shutdown dates, these have not changed for 2005 since the November document.

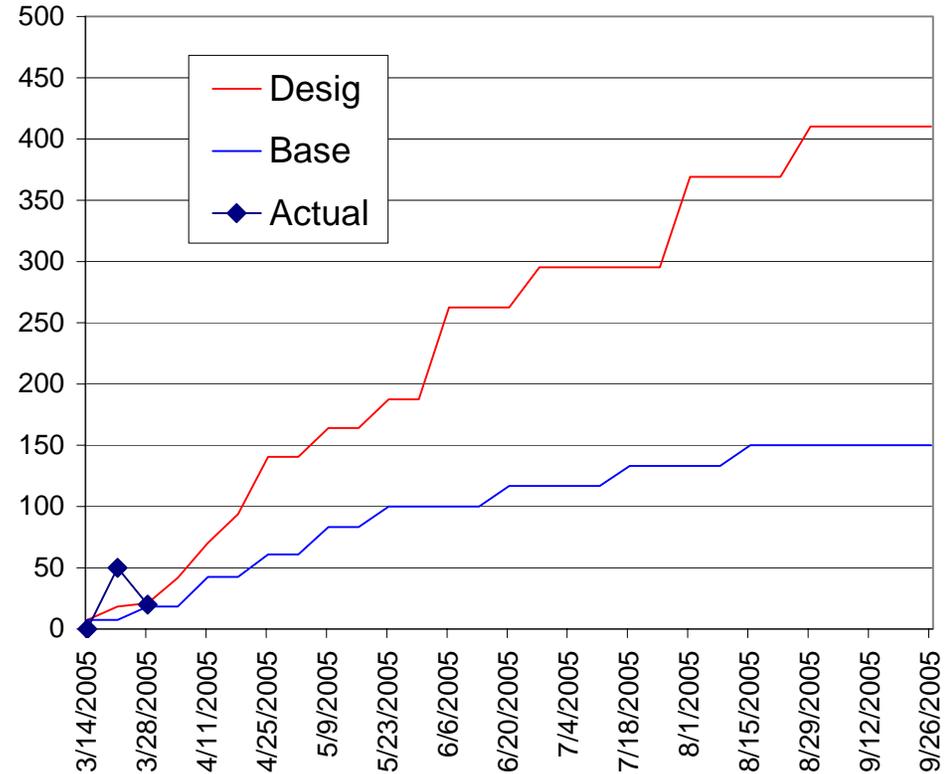
# Initial NuMI Progress



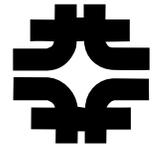
NuMI PoT per Hour (E14)



PoT per Week (E16)

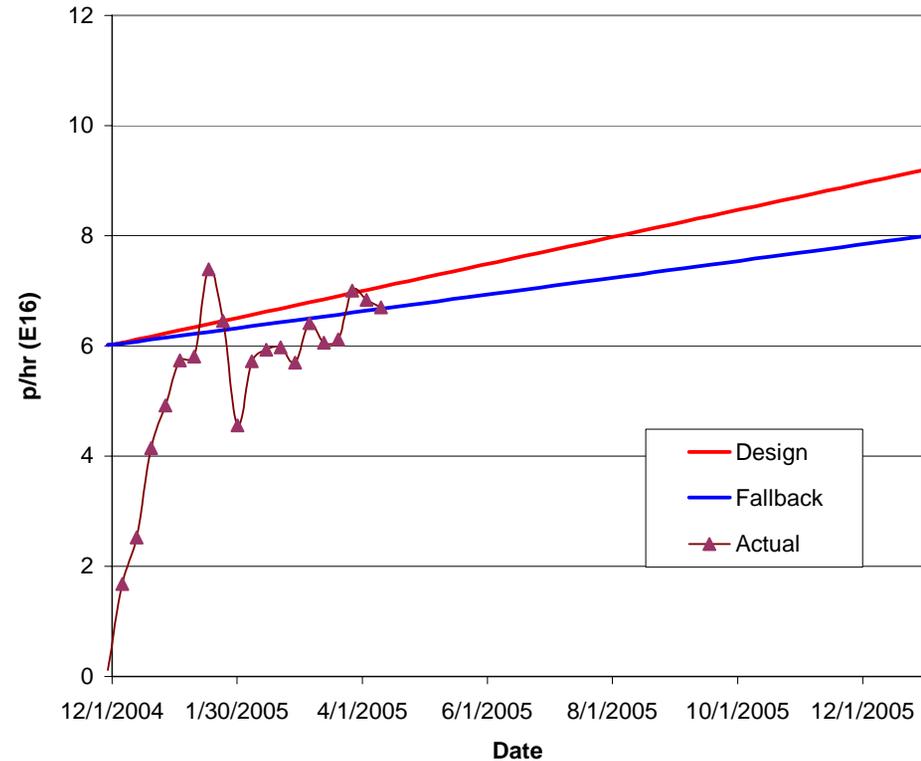
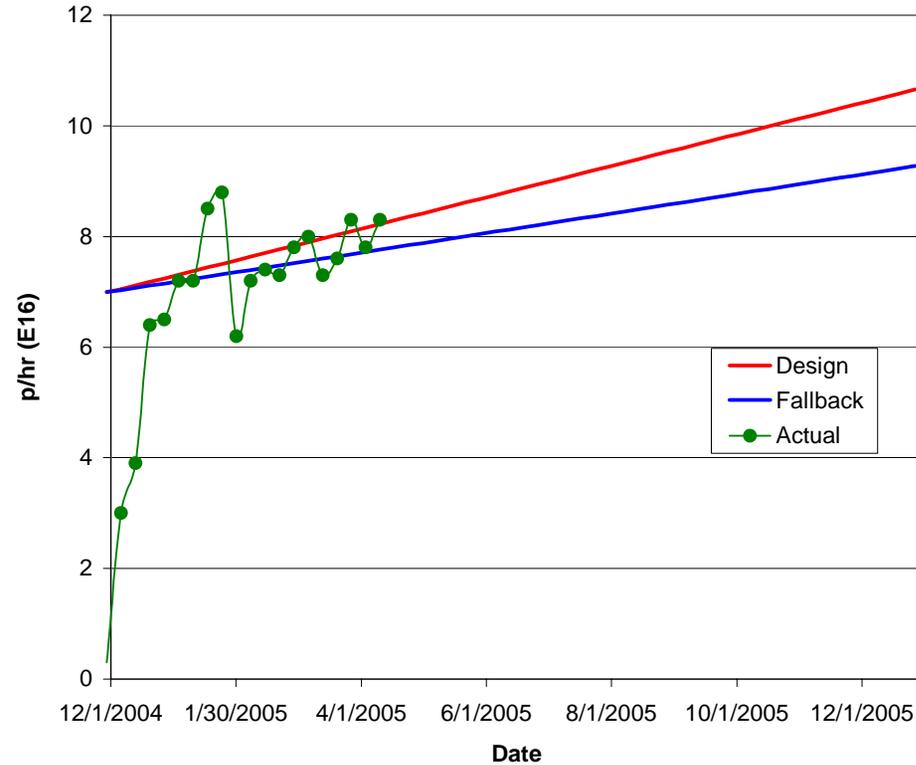


# Hourly Proton Rate

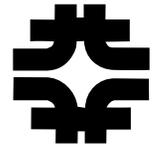


Total Peak Hourly Rate (BNB+NuMI+pbar)

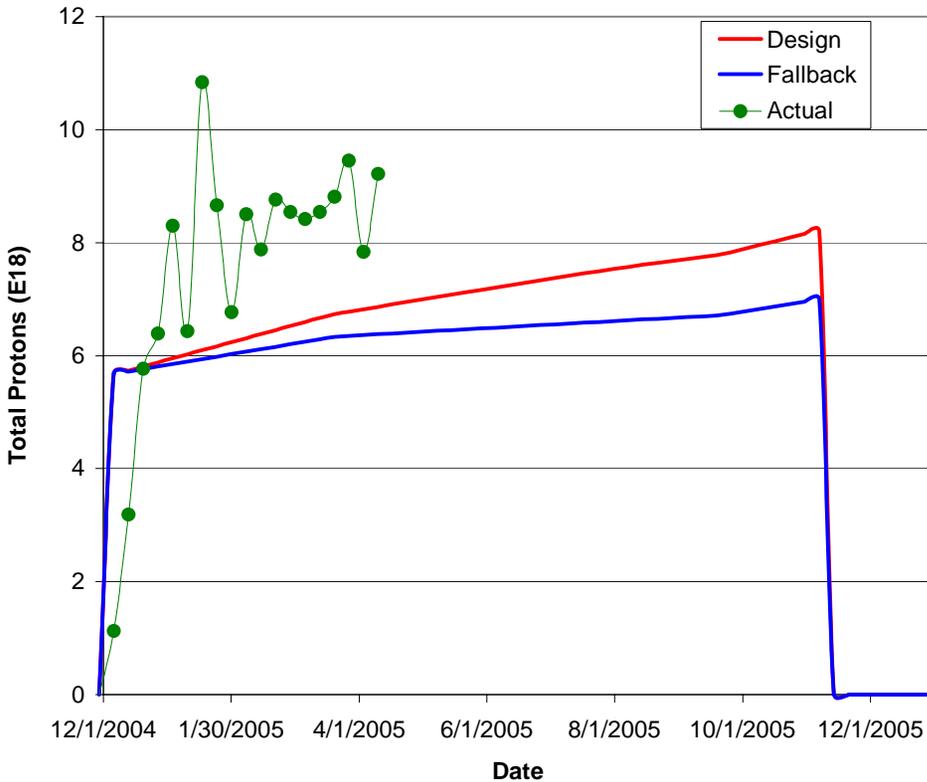
Average Hourly Rate (BNB+NuMI+pbar, while up)



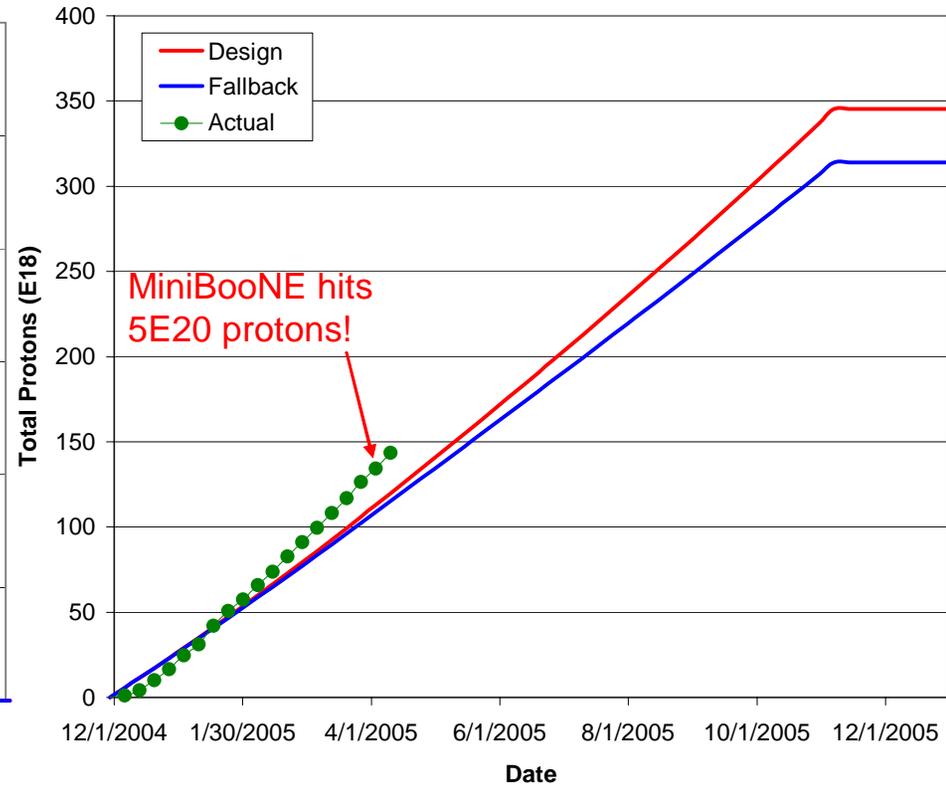
# Integrated Delivery (BNB)



### Weekly Proton Totals (BNB+NuMI)



### Cumulative Proton Totals (BNB+NuMI)



# After the Collider

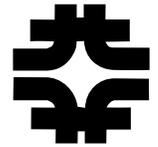
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- A number of suggestions have been made for ways to maximize proton output after Tevatron operation ceases:
  - Stage II in my earlier slide
- While these are beyond the scope of the present plan, we have begun a working group (WBS 1.5) to investigate them and present a report to the Division Head on June 1.

# Summary

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- The Proton Plan encompasses accelerator improvements to maximize protons to NuMI and the 8 GeV line over the next 10 years
- The implementation of the Plan will provide
  - $\sim 7E16$  p/hr to NuMI ( $\sim 3E20$  p/yr)
  - Up to  $\sim 4E16$  p/hr ( $1-2E20$  p/yr) for the 8 GeV line
- We are studying concepts for further improvements in the post collider era (for example using the Recycler as a preloader)
- We are working diligently toward a properly baselined, resource loaded project and schedule.