Proton Economics and Proton Plan - Update

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Outline

- **General Issues**
  - Limitations
  - Demands

- **Recent Successes**
  - The past year
  - Proton intensity
  - Exposure to workers
  - Other topics

- The “Proton Plan”
  - Near future
  - Long term

- Projections
What Limits Total Proton Intensity?

- Maximum number of Protons the Booster can stably accelerate: $5 \times 10^{12}$
- Maximum average Booster rep. Rate: currently 7.5 Hz, may have to go to 10 Hz for NuMI+ (full) MiniBooNE
- (NUMI only) Maximum number of booster batches the Main Injector can hold: currently 6 in principle, possibly go to 11 with fancy loading schemes in the future
- (NUMI only) Minimum Main Injector ramp cycle time (NUMI only): $1.4 \text{s} + \text{loading time (at least } 1/15 \text{s} \times \text{n batches)}$
- Losses in the Booster:
  - Above ground radiation
  - **Damage and/or activation of tunnel components**

Our biggest worry at the moment!!!!
Proton Demand

- **Shortfall**
- **Booster Stretch**
- **Booster Base**
- **NuMI**
- **pbar production**

**MiniBooNE Turn-on**

**NuMI Turn-on**

7.5 Hz

Now (Note Improvement!)

Have now exceeded initial NuMI needs!!!!

This is a goal, not a promise!!!
Big Improvements in the Last Year

- Primary extraction “dogleg fix”
  - Increase spacing between magnets in chicane system
  - Reduces distortion to injection lattice by ~40%
- Vertical alignment
  - Eliminate ¼” misalignment at collimator region
  - Improve high field orbit
- 400 MeV line work
  - Better understanding
  - Improved stability and repeatability
- Injection bump (ORBUMP) improvements
  - Improved water flow
  - New, lower resistance capacitors
  - Much more reliable
- Collimator installation and commissioning
**Vertical Alignment**

- **Magnet moves**
  - Moved 9 (out of 48) girders and one magnet on a girder

![Graph showing vertical alignment](image)

- Fix high field orbit
- Fix L3 misalignment

**Index:**
- 1=24-3, 2=24-4, 3=1-1, etc

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Effects of Moves on High Field Orbit

Before (blue curve)

After (matches prediction)

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Long 3 Dogleg Work

- Increase spacing between dogleg pairs from 18” to 40” to reduce lattice distortions at injection.

New magnet to match extraction line
Collimator System

Basic Idea...

A scraping foil deflects the orbit of halo particles…

…and they are absorbed by thick collimators in the next periods.

- Should dramatically reduce uncontrolled losses
Collimator Commissioning

- We have begun to use the collimators in normal operation:

![Graph showing losses with and without collimators]

- Losses w/o collimators
- Losses with collimators
Taking advantage of Collimators

- **General principles**
  - Activation was “OK” before collimator implementation.
  - Want to use collimators to increase rate while keeping activation “about the same”.

- Historically, the “watt meter” has been our most reliable indicator of activation, but
  - It works by counting lost protons
  - Can’t distinguish protons absorbed on the collimator

- Now must rely on individual loss monitors
- Tighten up limits based on detailed study of activation versus measured loss
- Do weekly radiation surveys
- Increase rate (watt limit) to keep activation at roughly the level it was before the collimators were implemented.
**Basis of activation assessment - Dose to Workers**

- Administrative limit at 300 mRem/qtr
- This is “ok”, but we don’t want to get any worse

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**PA Shop by Qtr**

- **MiniBooNE**

- Qtr and Year

- mrem

- 0 20 40 60 80 100 120 140 160 180


- O’Connel
- Plant
- Ruffin
- Scala
- Zifko

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Normalized Dose to Workers (as reported to DOE)

Fermilab Total Effective Dose Equivalent Normalized to 8 GeV Proton Intensity

- - - TEDE/Beam

- - - Annual Average TEDE/beam

Date

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Activation History In Booster

- MiniBooNE
  - x2~3 activation
- 16x proton increase

Collimators
Change In Activation Since Collimators

Since Collimators

Collimator region

L3 Extraction

L13 Extraction

RF Region

Location

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Activation in RF Cavities

MiniBooNE

Collimators

Pre-MiniBooNE levels!!
Booster History

MiniBooNE

Power Loss

Total proton rate

Energy loss/proton

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How far have we come?


**Charge through Booster cycle**

**Energy Lost**

- **Typical:**
  - $5.5 \times 10^{12}$ protons/batch to stacking (Run II handbook = $5 \times 10^{12}$)
  - $>7 \times 10^6$ pph to MiniBooNE (MiniBooNE goal $9 \times 10^{16}$)

- **Records:**
  - $6 \times 10^{12}$ protons/batch to stacking
  - $8 \times 10^6$ pph to MiniBooNE (current administrative limit)

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Effect of increased intensity (recent running)

- 4E12
- 5E12

Energy Lost per proton

~5% more losses (activation) at 5E12

Protons per pulse

Can really deliver 5E12 efficiently for the first time!!!!!
Progress in Beam Cogging

- Vital to multibatch operation
  - Slipstacked pBar production - after Main Injector beam loading compensation in shutdown
  - Multibatch to NuMI - assume 1/05

- Cogging principle demonstrated
  - Have coggled multi-batch transfers up to 4E12 protons/batch
  - Expect to be fully operational soon
Current Status - Summary

- Exceeding Run II intensity goals
- Can deliver 5E12 protons per batch with good efficiency
- Regularly delivering ~80% of MiniBooNE goal
- Demonstrated NuMI intensities
- Expect increased intensity in the near future, quite possibly to 9E16 pph MiniBooNE goal.
- Cogged multibatch operation demonstrated at 80% of nominal intensity.
  - Expect full intensity test soon.
  - Last Run II milestone for the proton source.
"Proton Plan"

- The details of proton demand and issues can be found in an official report to the director at:
  www.fnal.gov/directorate/program_planning/studies/ProtonReport.pdf

- **Working assumptions:**
  - Existing proton source must last at least another 10 years or so in more or less its current configuration.
  - During that time, a new "proton driver" will be built, which will ultimately replace the existing proton source.
  - Proton source improvements should require no significant downtimes beyond those needed for other reasons.
  - The maximum total funding for proton source improvements will be of the order of $18M over the next few years.
  - Near term projects most important to performance
Scope of Improvements

- The level of funding precludes some things which have been discussed:
  - Replacement or major upgrade of 200 MHz linac
    - Official policy on 7835 PA's: keep fingers crossed.
  - Decrease of Main Injector ramp time
    - Unless it is done as part of Proton Driver
- For this reason, the proton plan focuses primarily on the Booster
  - Decreasing uncontrolled losses.
  - Increasing reliable average repetition rate.
  - Biggest decisions involve plan for RF system.
Booster RF Issues

- The existing RF cavities are an aperture restriction

- They are a high maintenance item (primarily the PA), so their activation is a worry.
- There is a possibility that heating could be a worry beyond 7.5 Hz.
- The RFSUM of the existing 18-cavity system is a limitation to the maximum proton batch size.

Decisions about the RF system are the most significant part of the plan, at least from the finance/resource point of view.
Booster RF Options

- **New, solid state PA’s**
  - Dramatically reduce maintenance
  - Similar to Main Injector design
  - One being used already.
  - Total cost: ~$7M
  - Definitely part of the plan

- **Increase number of RF cavities:**
  - Can use the two large aperture prototypes built with help from MiniBooNE and NuMI/Minos universities
  - Hope to have at least one in by end of Summer shutdown.
  - Second in during 2005.
  - Could potentially increase Booster batch size to 6.5E12 or higher.
RF Cavity Replacement Options

- Control losses with alignment and collimators?
  - Don’t replace
  - Should know by ~8/04

- Move forward with 5” prototype design?
  - Design complete and tested
  - Could begin procurement and construction immediately in FY05.
  - Aggressive schedule could have cavities in place by 2007
  - Cost: ~6M

- Completely new design?
  - Could be designed with higher GE voltage and reduced HOM.
  - Frequency range a challenge
  - Could have design by end of 2005, cavities in place by 2008
  - Plan to decide on preliminary recommendation by 8/04
Corrector Packages

- The Booster contains corrector packages at each of the 48 sub-periods.
  - Horizontal trim
  - Vertical trim
  - Quad
  - Skew quad
- The trims are not powerful enough to control the orbit throughout the cycle
- The quads are not powerful enough to fully control the tune/coupling throughout the cycle
- We would like to replace the corrector system with one with roughly 3-4 times the strength.
- Working with TD on the specifications.
- Could have in place in ~2 years
- Cost ~3M.
By adding a 30 Hz component to the Booster magnetic lattice, we could reduce the maximum $dp/dt$ by $\sim$35%, effectively increasing the RF power.

- Pursue prototype in 2005
- If successful, implement in 2006
- Cost $\sim$1M
Major Linac Projects

- Quad power supplies
  - Very old technology, reliability concern
  - Major source of PCB’s
  - About $1M to replace

- 7835 filament current stability
  - Believed to be a source of linac instability
  - Investigating 480 isolation
  - Plan to implement on all stations ASAP
  - Cost ~100K
Projects - Near term

- Fall Shutdown
  - Modify L13 extraction region
    - Increased aperture
    - A factor of 3 reduction in injection lattice distortion
  - Use prototype RF cavity at 19th cavity and prep for 20th
    - Increase reliability
    - Increase efficiency
    - Allow batch intensities of 6.5E12 or higher
  - Add extra extraction kicker
    - Increase beam aperture near extraction
    - Reduce extraction losses
    - Increase reliability (can run without one kicker)
  - Alignment projects
    - Complete RF cavity and vertical alignment
    - Complete 3D network and as-found
  - (possibly) Add two quads to 400 MeV line
    - Decrease tuning sensitivity of line
Projects - near term (cont'd)

- **ORBUMP**
  - New magnets, based on ferrites
  - New power supply, based on existing new SCR switch
  - Both ready early to mid-2005
  - -> Full 15 Hz operation
Approximate Timeline

- 2004
  - Collimators commissioned and fully operational
  - L13 Modification
  - Vertical and RF cavity alignment
  - Complete alignment network and as-found
  - 19th RF cavity added to Booster

- 2005
  - New ORBUMP magnets and Power supplies.
  - Horizontal alignment proceeds
  - Procurement for solid state PA’s
  - Either design or procurement of new RF cavities, if recommended
  - Design and procurement for new corrector system
  - New quad supplies in Linac

- 2006
  - Complete installation of solid state PA’s
  - Install new corrector system
  - Continue with RF cavity design/procurement.
  - Install 30 Hz harmonic, if recommended

- 2007
  - Complete installation of 5” RF cavities, if recommended.

- 2008
  - Complete installation of new RF system, if recommended.
Proton Projections - Basic Assumptions

- Based on stated policies of Directorate...
  - Run II (pBar production) will continue to have priority.
  - One NuMI comes on line, it will be given protons up to the lower of:
    - The Main Injector loading/ramp time limit
    - The Booster loss limit
  - IF the Main Injector loading limit is reached with significant Booster loss headroom, we will continue to run the 8 GeV line (MiniBooNE, FiNESSE, etc) up to the Booster loss limit.

- We have demonstrated the ability to deliver the intensities needed by NuMI, with at least some headroom left over for 8 GeV line operation*

- Unfortunately, under this scenario, it is still very difficult to make accurate projections wrt MiniBooNE’s future.

*I could not have made this statement a month ago!!!
Making Projections
Projecting to MiniBooNE

- Rather than use the instantaneous rate, will scale from typical weekly MiniBooNE totals:

![Graph showing weekly data]

- Typically 7.5E18/wk

- Baseline Scenario:
  - Improvements compensate for increased protons to pBar -> Continue to average 7.5E18/wk (have gotten 1E19 in last 7 days!)
  - Get About 1.5E18 after 1/05

- Design Scenario:
  - MBBooNE rate increases more or less linearly to 10E18/wk at 1/05
  - 5.5E18/wk after NuMI turns on.

- Stretch Scenario:
  - MBBooNE rate increases to 10E18 at 1/05
  - 5.5E18 when NuMI turns on
  - Increases to 10E18 over 2005
Protons to MiniBooNE

Date

Total protons on target

- Base
- Design
- Stretch

2004 Shutdown
2005 Shutdown
2006 Shutdown

NuMI

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Summary

- The proton source has made remarkable progress in the two years, and recently in particular.
- We have exceeded our Run II intensity commitments, and when beam cogging is fully operational, we will have met all of our run II specifications.
- We have demonstrated 89% of the MiniBooNE and hope to meet the goal in the near future.
- We have demonstrated NuMI intensity goals.
- We still expect significant improvement in the future.
  - By mid-2005, the Booster should be a full 15Hz machine
  - The improvements in this year’s shutdown should allow us to reach significantly higher proton throughput
- We are working toward a plan which will maximize reliable proton source output over the next 10-15 years.
Acknowledgements (it takes a village)

- I won’t name names, because I’d leave someone out, but realize that these achievements reflect enormous efforts:
  - Within the proton source department
  - Operations!!!
  - All parts of the lab
  - The MiniBooNE and NuMI collaborations
  - Other national labs
Closing Comments: Expectation Management

- What we really think we can achieve:
  - Slipstacking to provide 1E13 protons per pulse for pbar production.
  - 5E20 protons to MiniBooNE by the time NuMI fully comes on in early 2005.
  - 2-2.5E20 p/yr to NuMI in the first year of operation.
  - Increasing that over the next few years, to something over 3E20 p/yr.
  - The ability to run the 8 GeV line at some level at least during early NuMI operation.

- What we might achieve:
  - Continuing to operate the 8 GeV line at some significant level after NuMI comes on, ultimately delivering 1E21 protons to MiniBooNE and possibly supporting other experiments (e.g. FINESSE).
  - Delivering as many as 4E20 p/yr to NuMI, at which point things will be limited by Main Injector aperture and cycle time (with the present source, anyway).
  - Maintaining a total Booster output of as high as 1E21 protons/year.

- It would be unrealistic to believe:
  - We will ever send more than 4E20 p/yr to NuMI without significant (~$100M) investment in the existing complex.
  - That would be direct competition for resources with the current Proton Driver proposal.