Proton Economics and Proton Plan - Update

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Outline

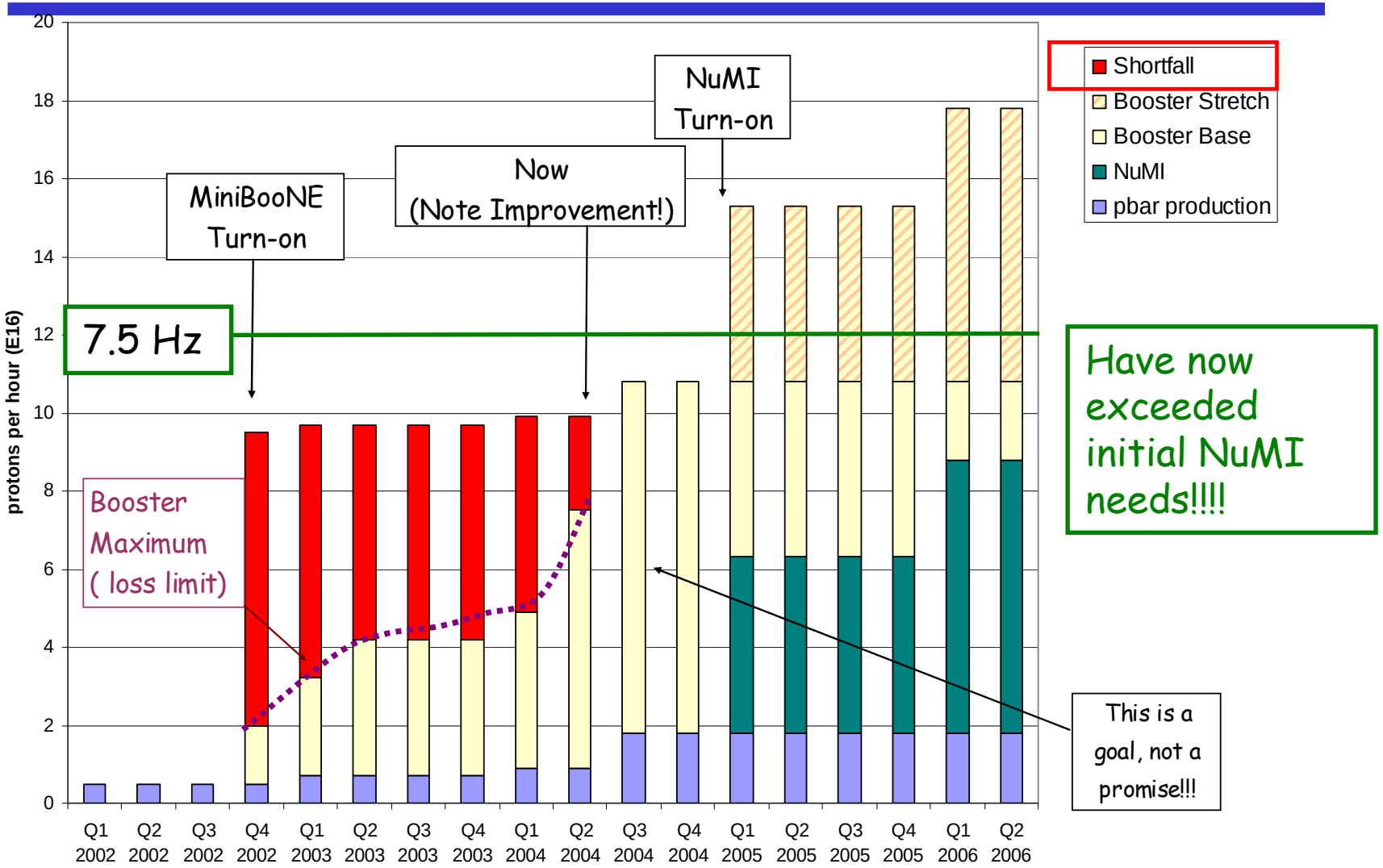
- General Issues
  - Limitations
  - Demands
- Recent Successes
  - The past year
  - Proton intensity
  - Exposure to workers
  - Other topics
- The "Proton Plan"
  - Near future
  - Long term
- Projections

What Limits Total Proton Intensity?

- Maximum number of Protons the Booster can stably accelerate: 5E12
- 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): 1.4s+loading time (at least 1/15s**nbatches*)
- Losses in the Booster:
  - Above ground radiation
  - Damage and/or activation of tunnel components

Our biggest worry at the moment!!!!

Proton Demand

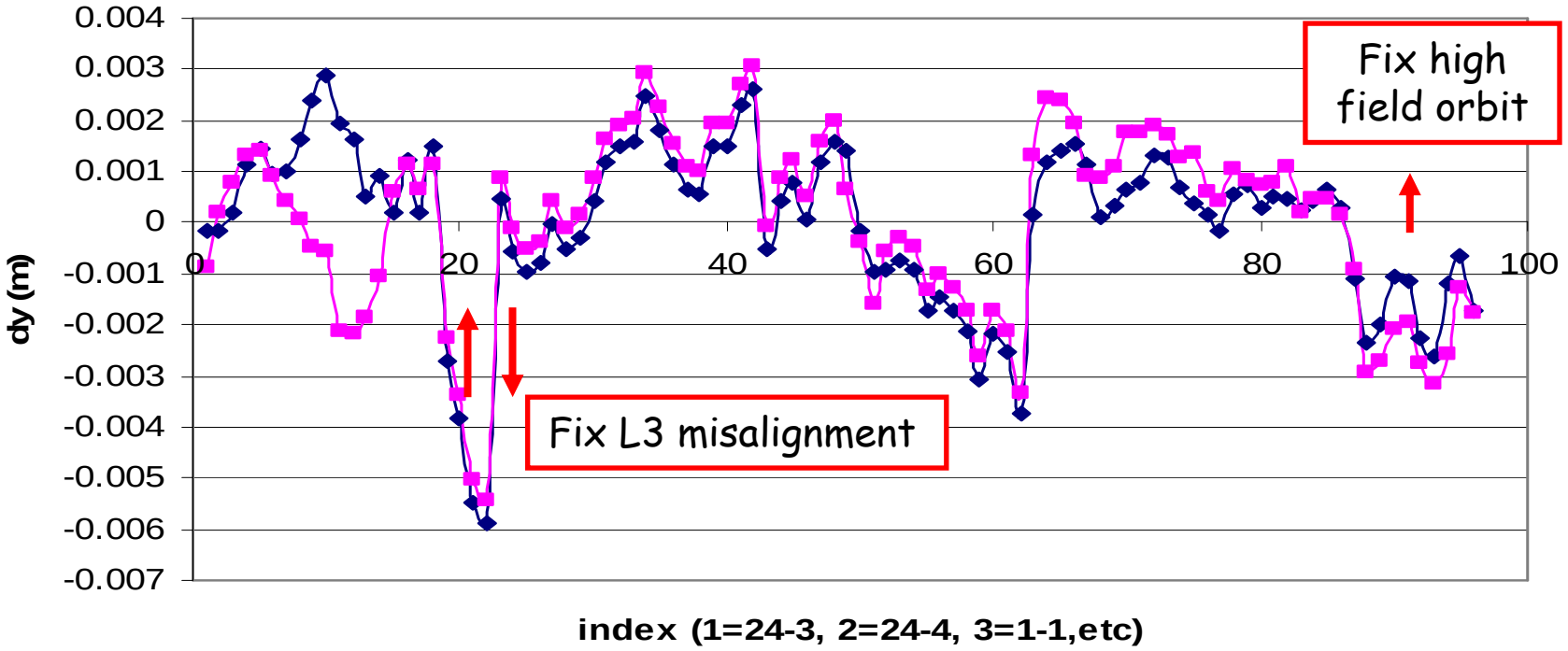


Big Improvements in the Last Year

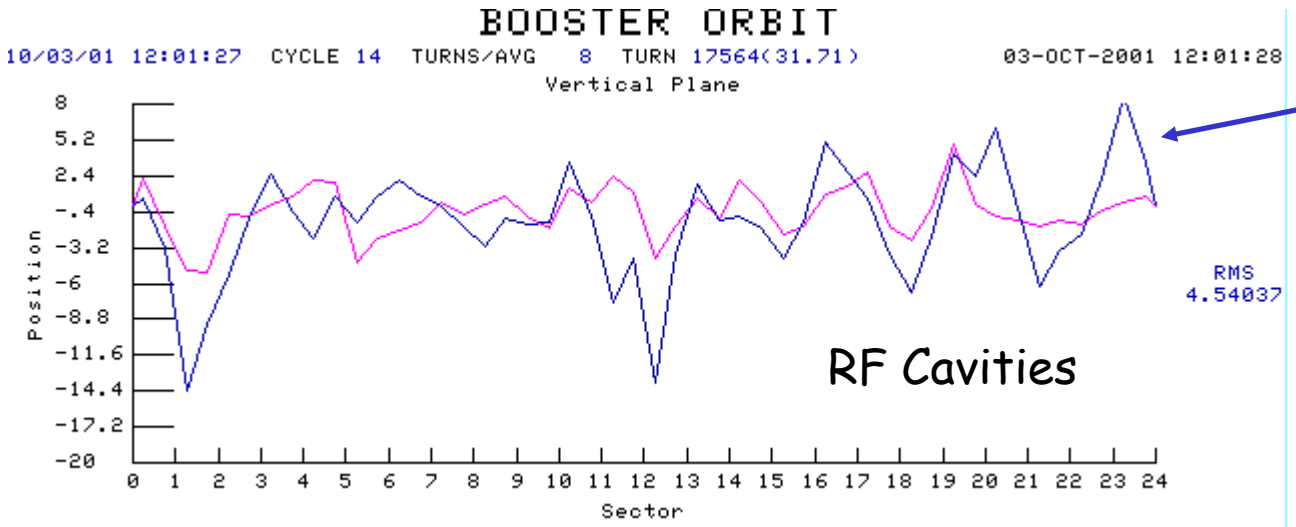
- Primary extraction "dogleg fix"
  - Increase spacing between magnets in chicane system
  - Reduces distortion to injection lattice by ~40%
- Vertical alignment
  - Eliminate $\frac{1}{4}$" misalignment at collimator region
  - Improve high field orbit
- 400 MeV line work
  - Better understanding
  - 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

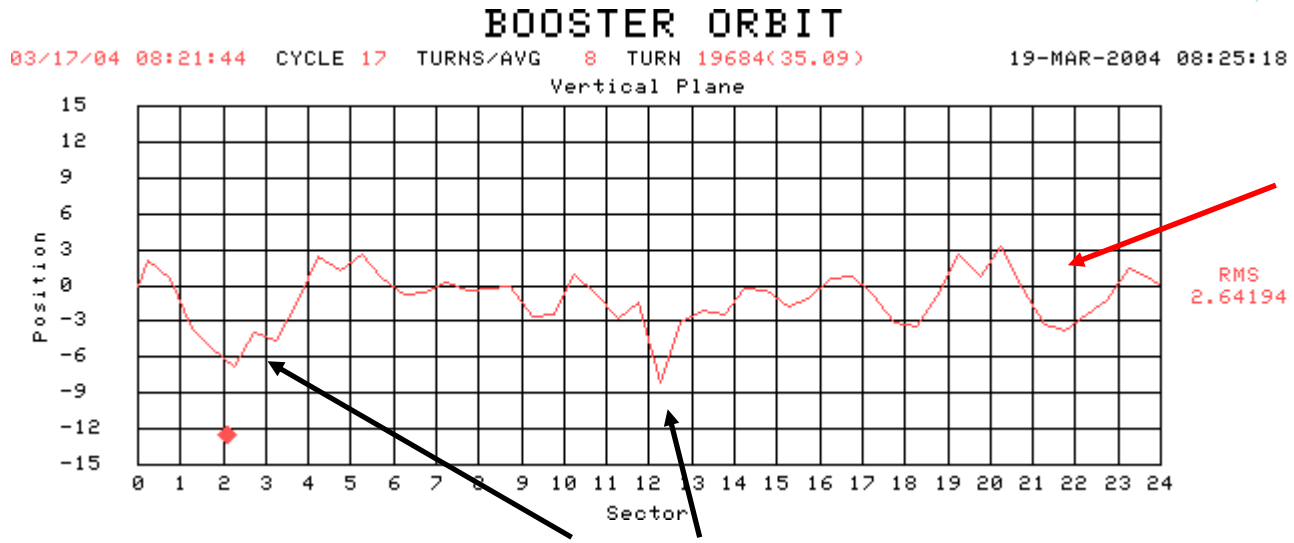


Effects of Moves on High Field Orbit



Before (blue curve)

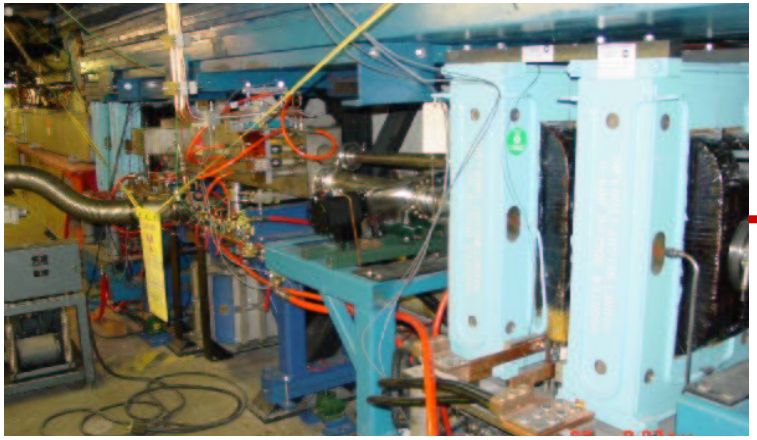
RF Cavities

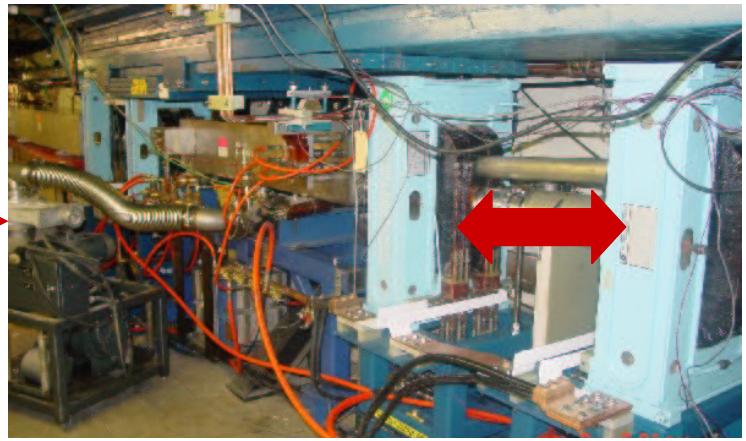


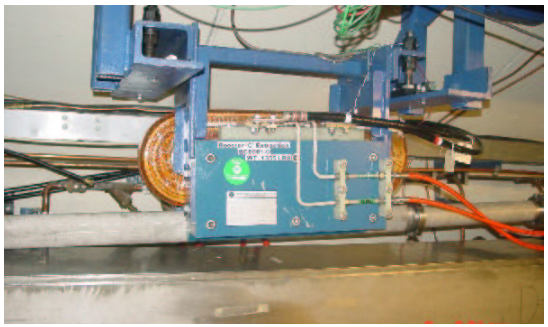
After (matches prediction)

Extraction

Long 3 Dogleg Work





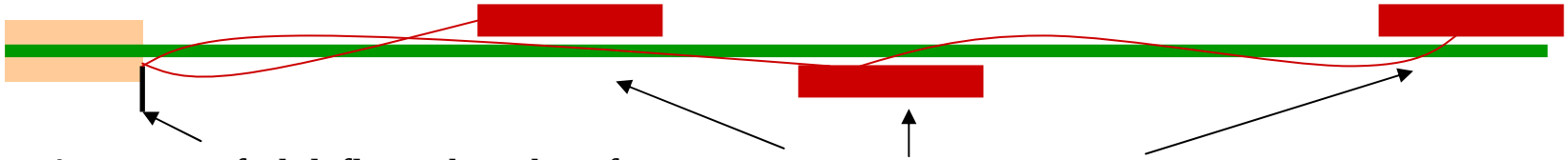


New magnet to match extraction line

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

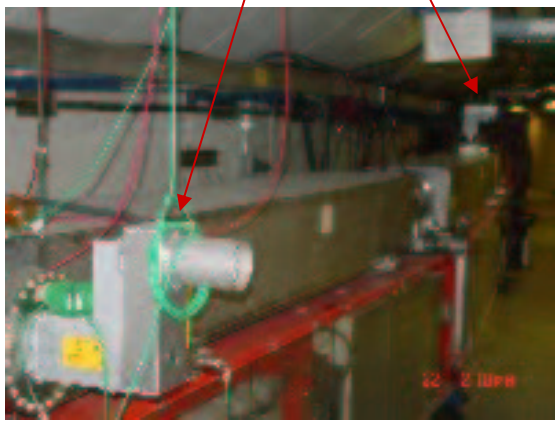
Collimator System

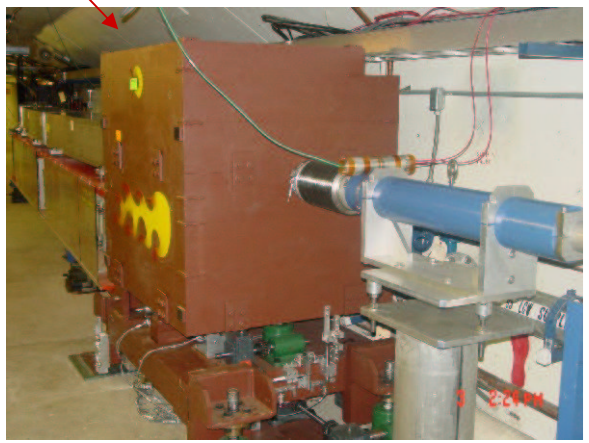
Basic Idea…



A scraping foil deflects the orbit of halo particles…

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

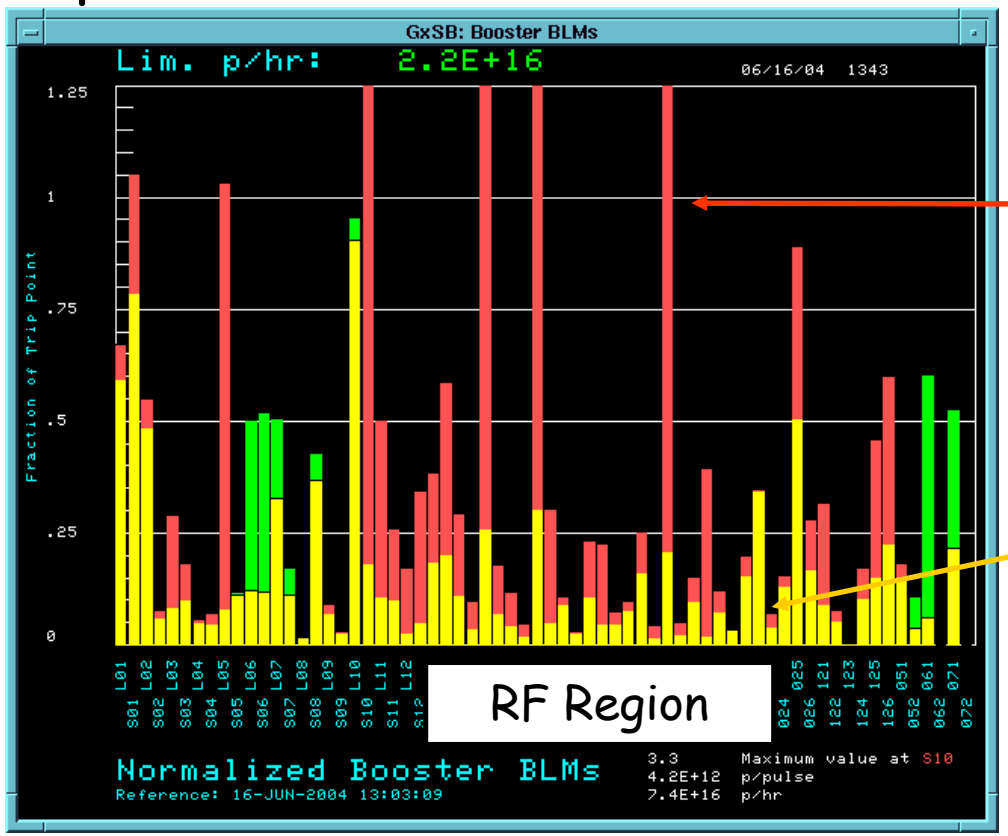




- Should dramatically reduce uncontrolled losses

Collimator Commissioning

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



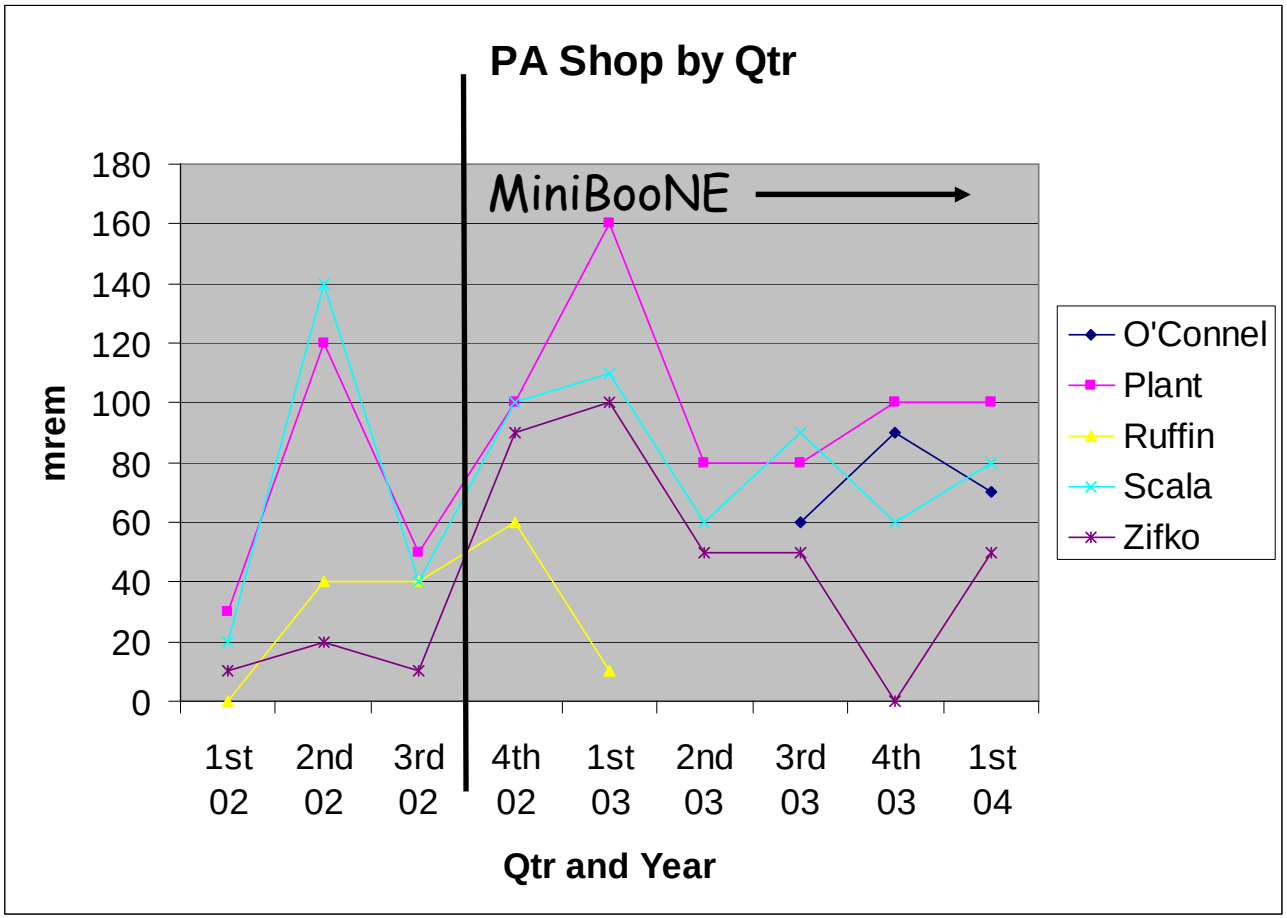
Losses w/o collimators

Losses with collimators

Taking advantage of Collimators

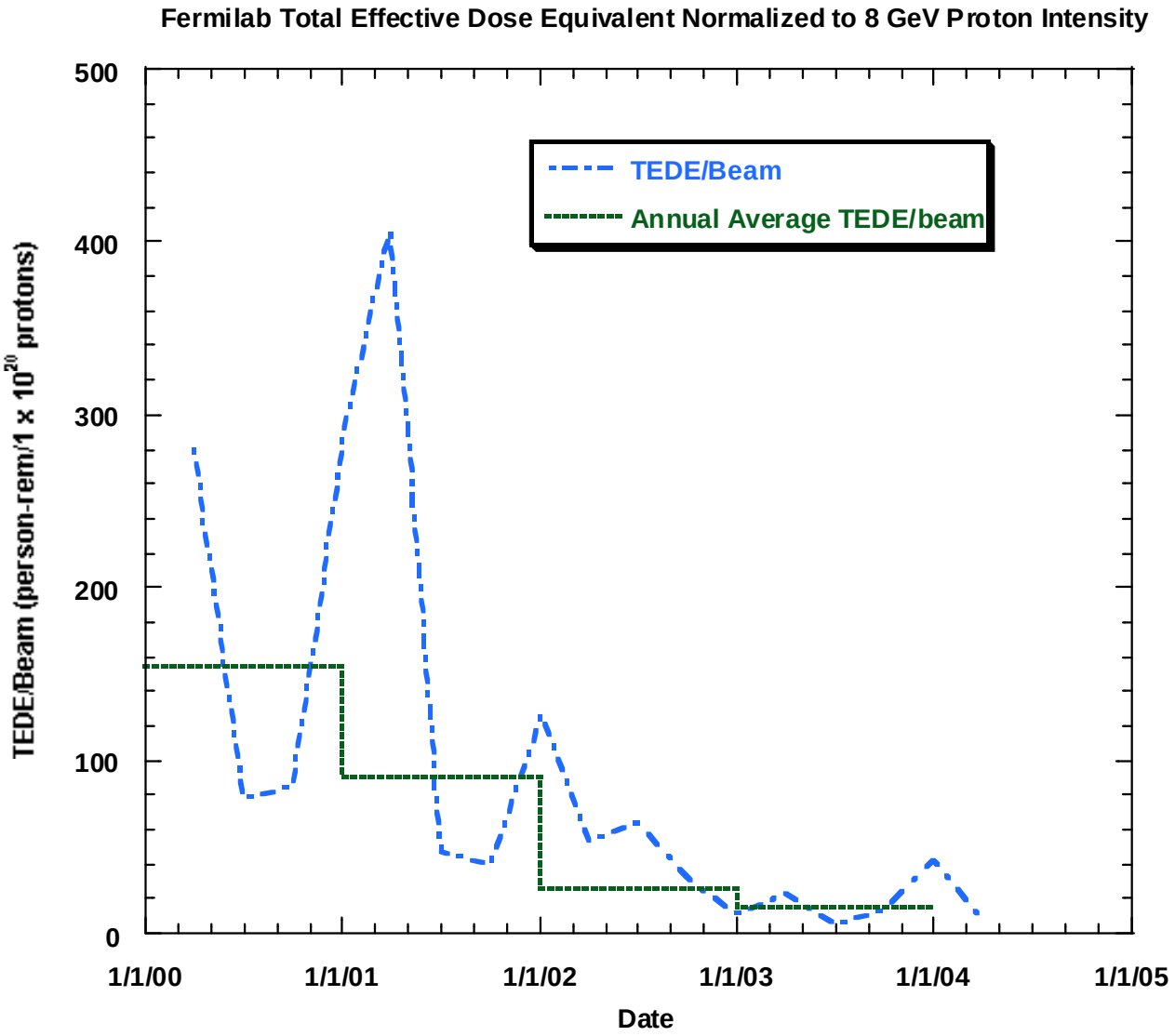
- General principles
  - Activiation was "OK" before collimator implementation.
  - Want to use collimators to increase rate while keeping activation "about the same".
- Historically, the "watt meter" has been our most reliable indicator of activation, but
  - It works by counting lost protons
  - Can't 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

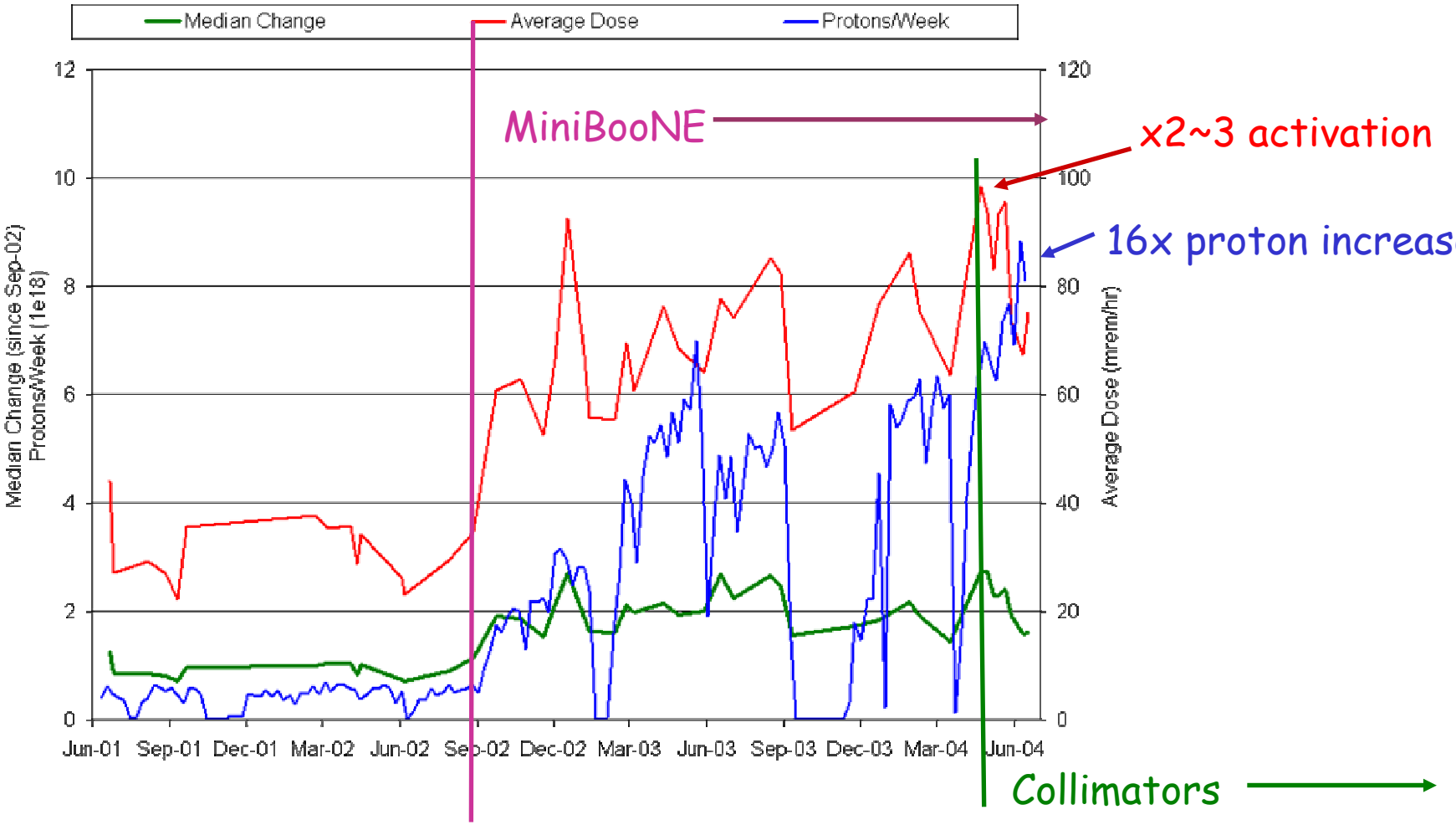


- Administrative limit at 300 mRem/qtr
- This is "ok", but we don't want to get any worse

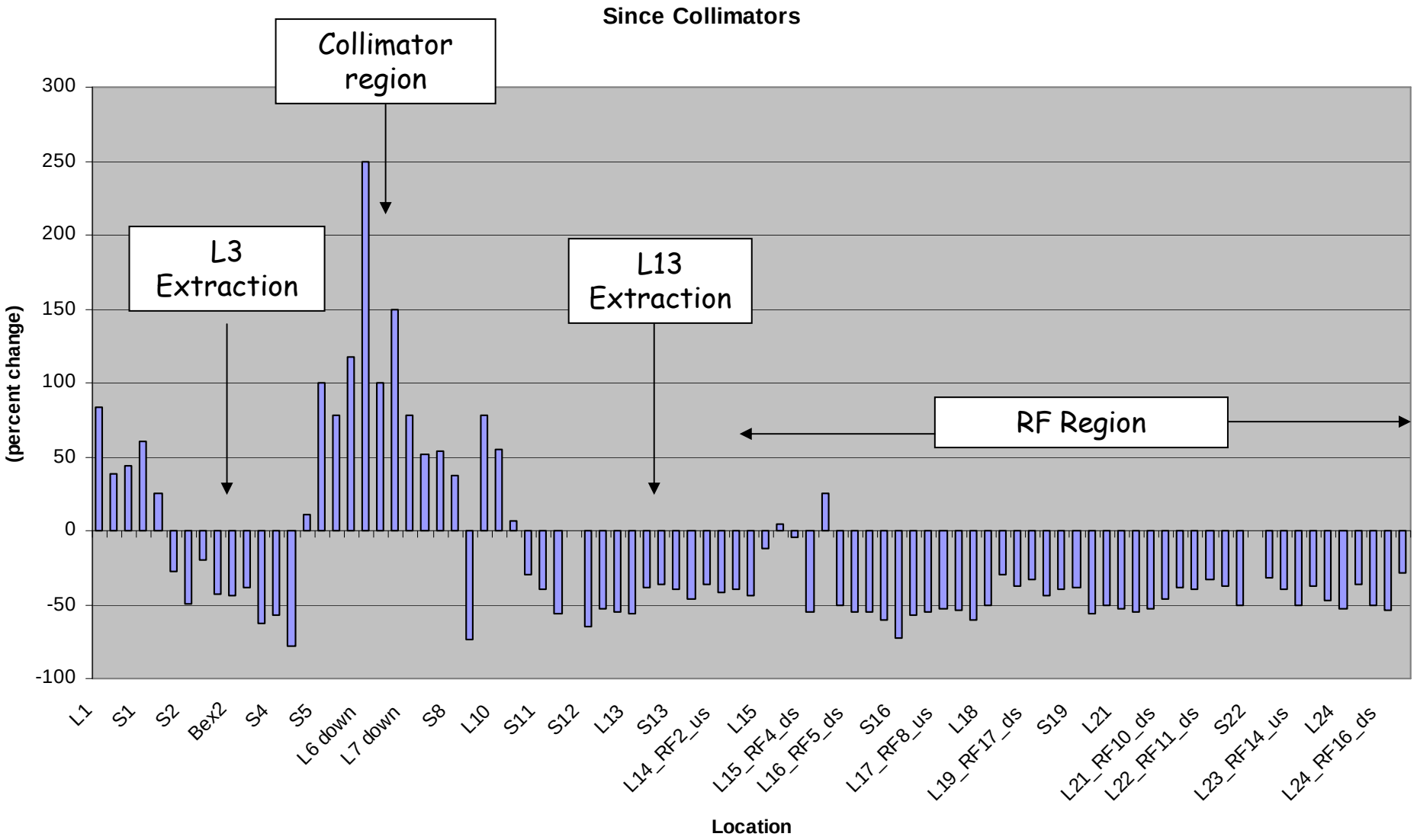
Normalized Dose to Workers (as reported to DOE)



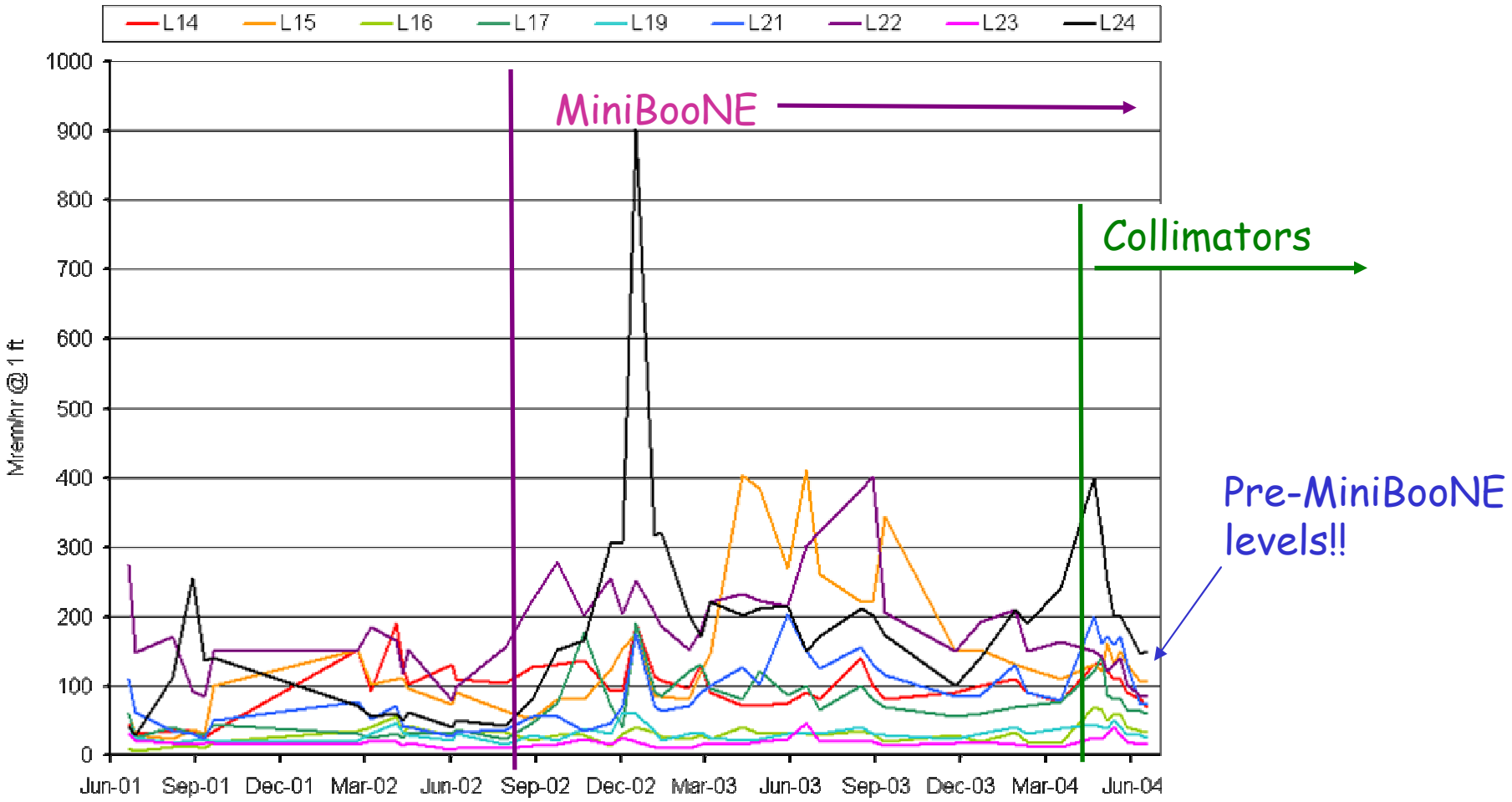
Activation History In Booster



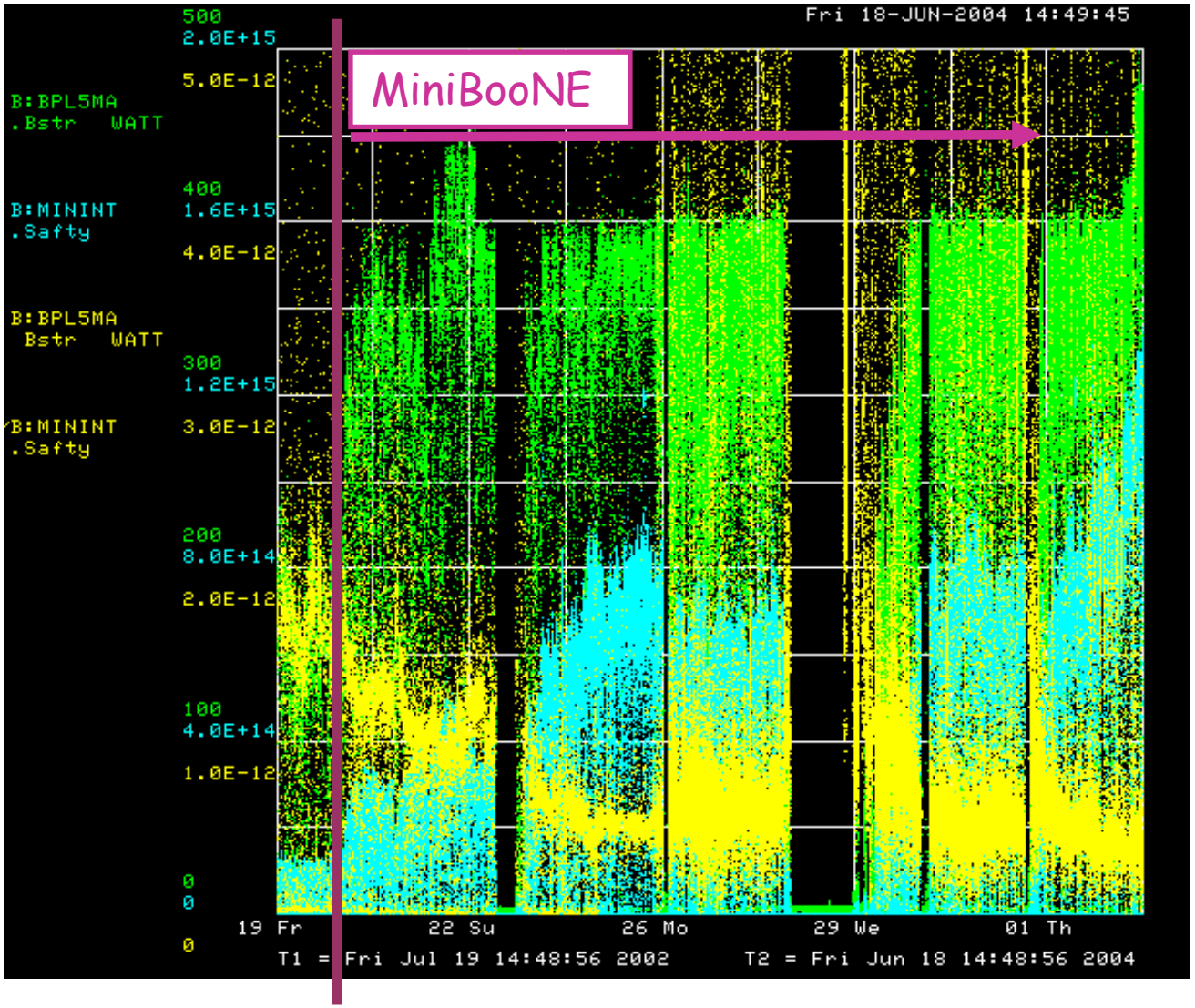
Change In Activation Since Collimators



Activation in RF Cavities



Booster History



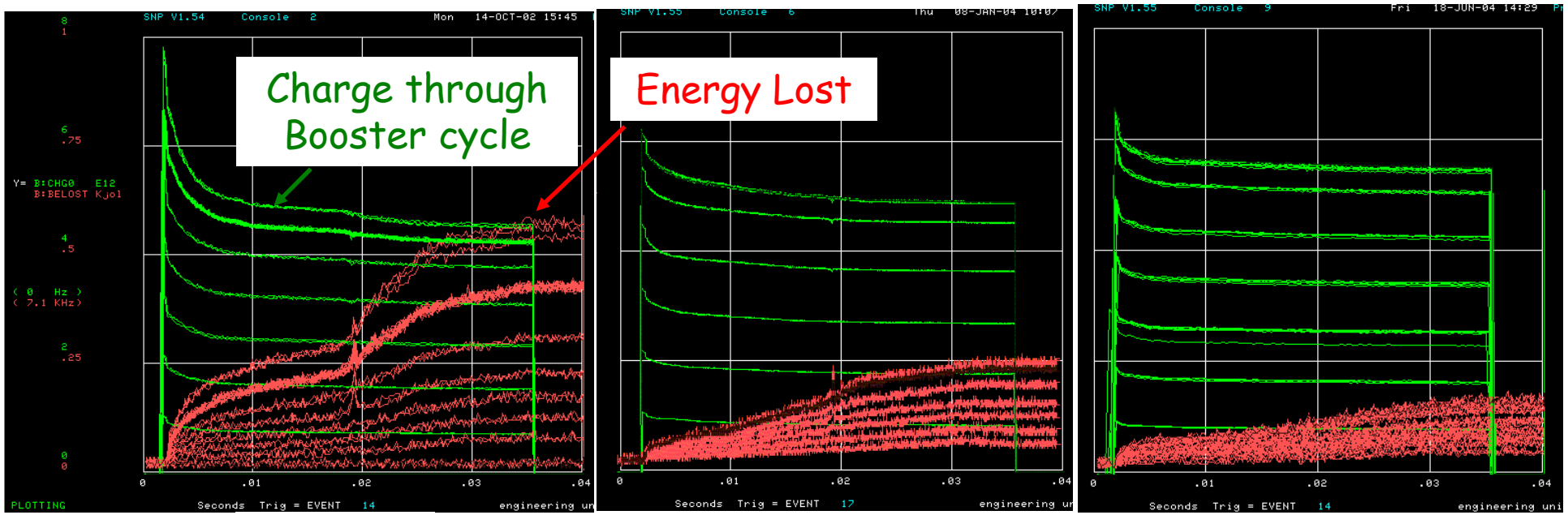
Power Loss

Total proton rate

Energy loss/proton

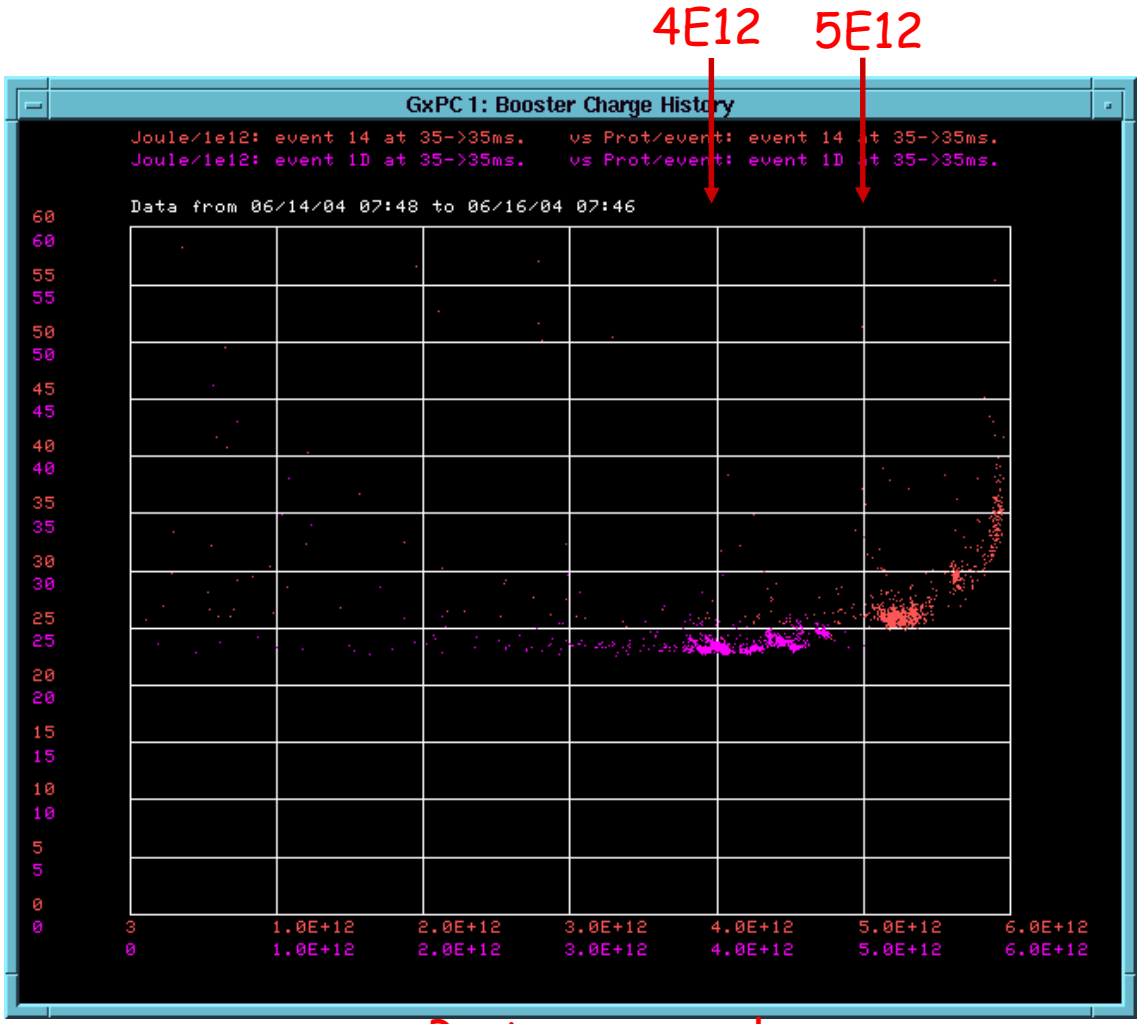
How far have we come?

Oct. 2002 (MB turn-on) Jan. 2004 Now



- Typical:
  - 5.5E12 protons/batch to stacking (Run II handbook = 5E12)
  - >7E16 pph to MiniBooNE (MiniBooNE goal 9E16)
- Records:
  - 6E12 protons/batch to stacking
  - 8E16 pph to MiniBooNE (current administrative limit)

Effect of increased intensity (recent running)



Energy Lost per proton

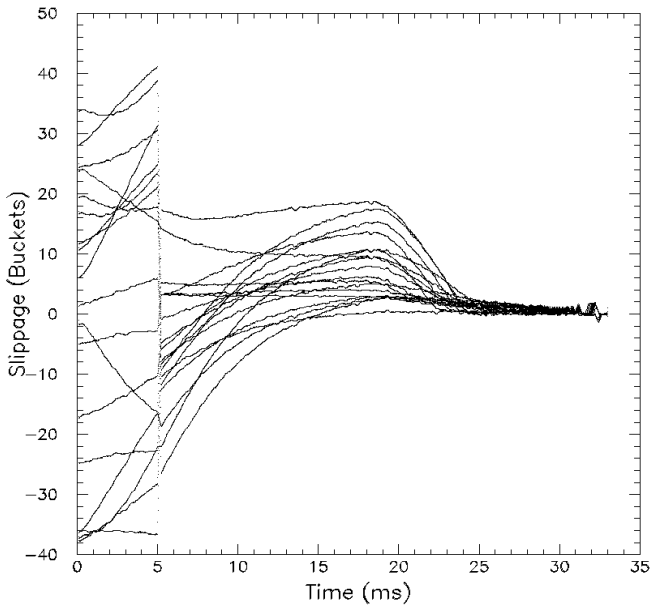
~5% more losses (activation) at 5E12

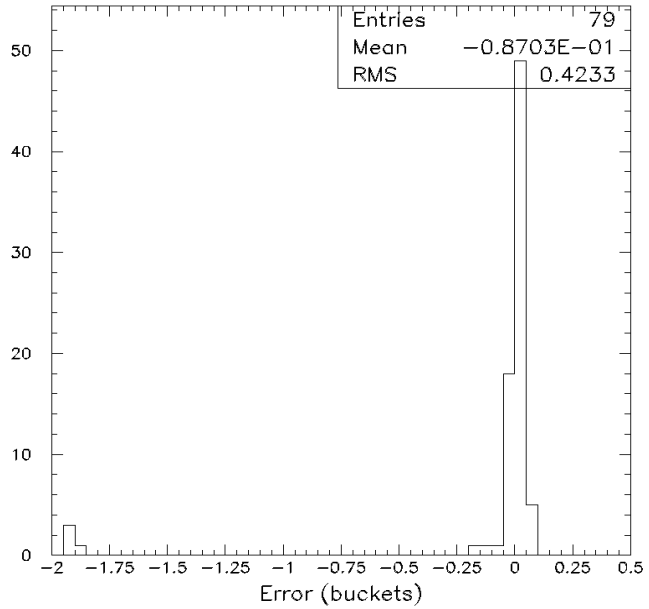
Protons per pulse

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 cogged 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

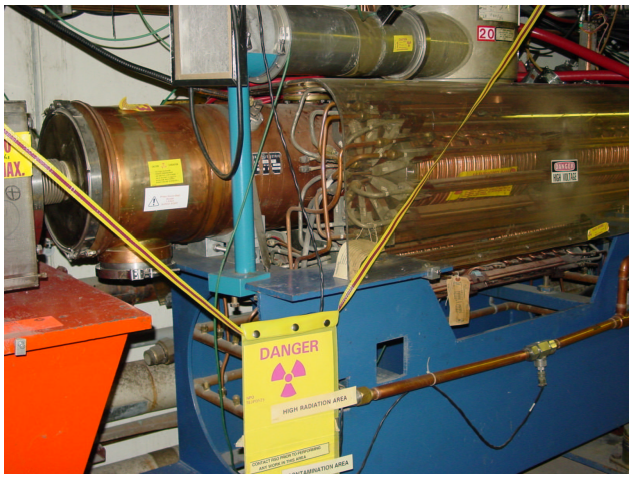
- Working assumptions:
  - Existing proton source must last at least another 10 years or so in more or less it's current configuration.
  - During that time, a new "proton driver" will be built, which will ultimately replace the existing proton source.
  - Proton source improvements should require no 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

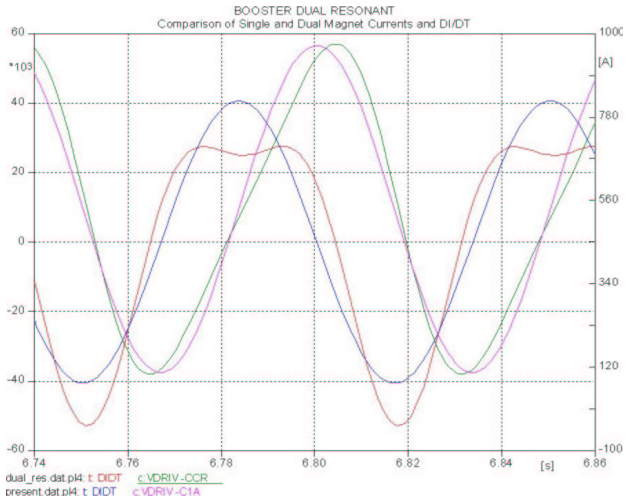
- Control losses with alignment and collimators?
  - Don't replace
  - Should know by ~8/04
- Move forward with 5" prototype design?
  - Design complete and tested
  - Could begin procurement and construction immediately in FY05.
  - Aggressive schedule could have cavities in place by 2007
  - Cost: ~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 strenght.
- Working with TD on the specifications.
- Could have in place in ~2 years
- Cost ~3M.

Higher Harmonic Operation

- By adding a 30 Hz compononent to the Booster magnetic lattice, we could reduce the maximum dp/dt by ~35%, effectively increasing the RF power.



- Pursue prototype in 2005
- If successful, implement in 2006
- Cost ~$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

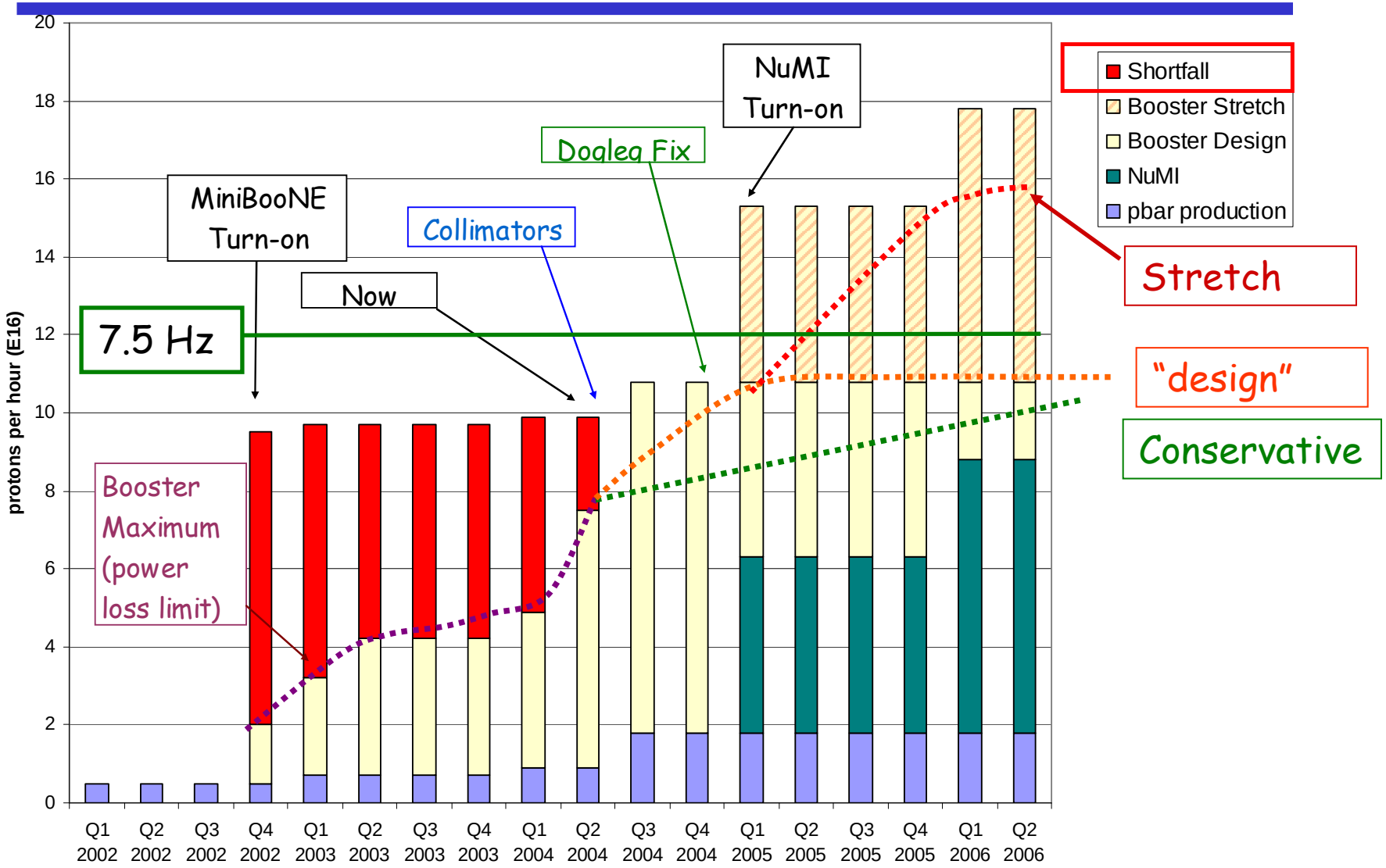
- 2004
  - Collimators commissioned and fully operational
  - L13 Modification
  - Vertical and RF cavity alignment
  - Complete alignment network and as-found
  - 19th RF cavity added to Booster
- 2005
  - New ORBUMP magnets and Power supplies.
  - Horizontal alignment proceeds
  - Procurement for solid 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.

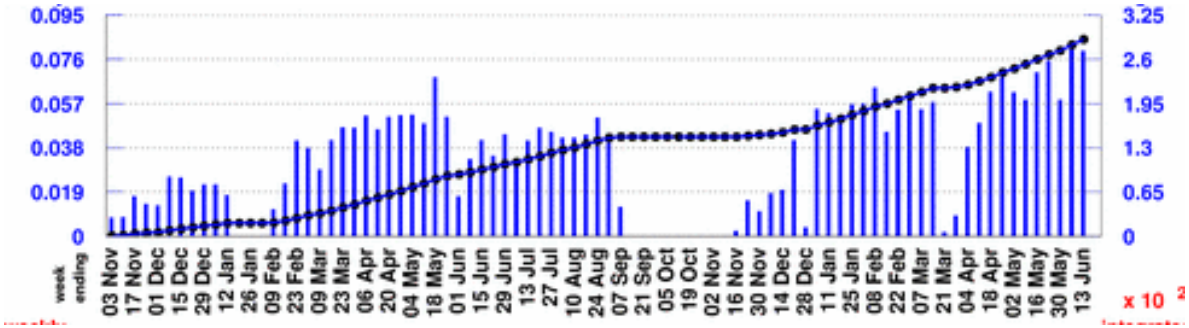
*I could not have made this statement a month ago!!!

Making Projections



Projecting to MiniBooNE

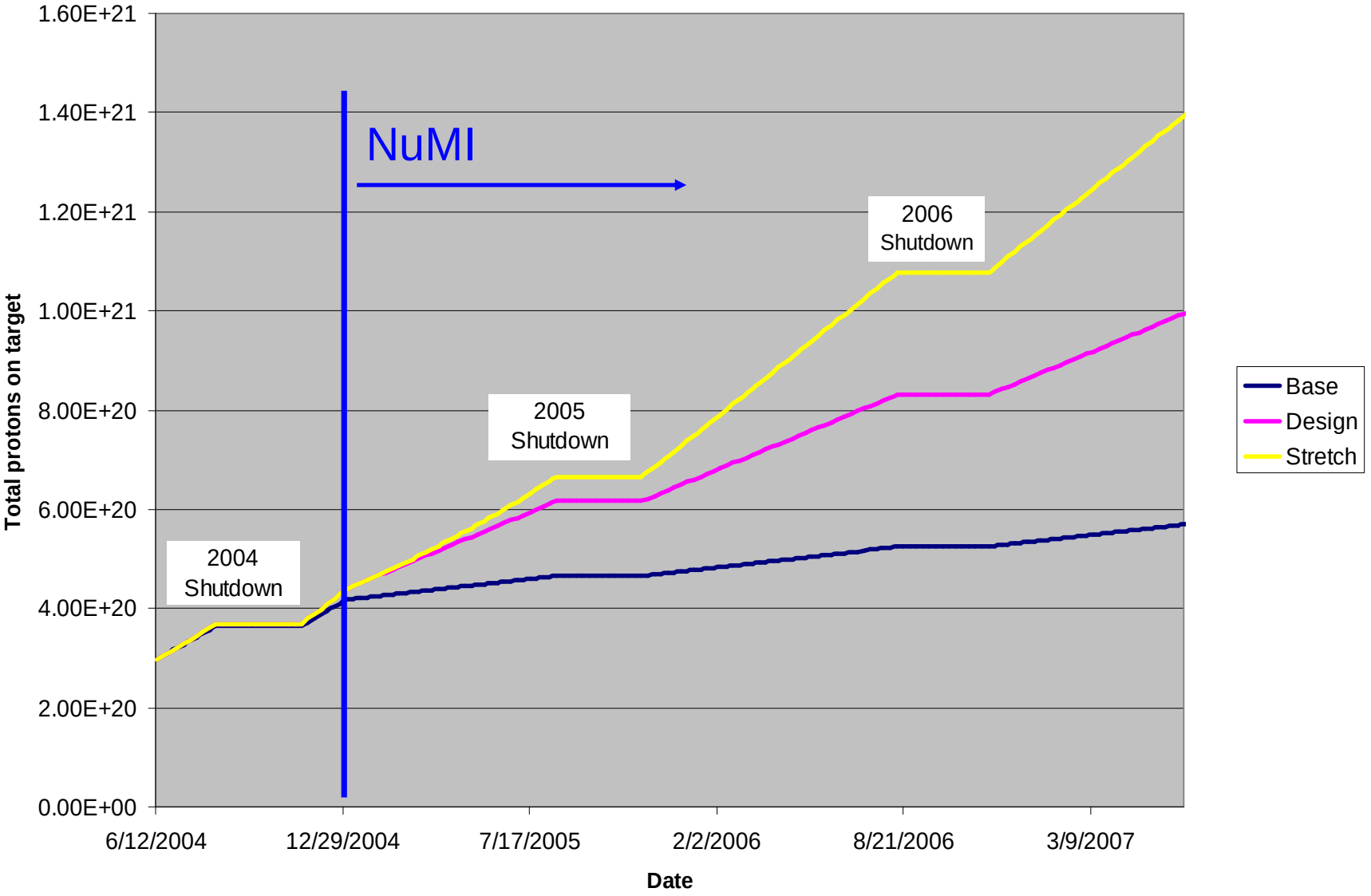
- Rather than use the instantaneous rate, will scale from typical weekly MiniBooNE totals:



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:
  - MBooNE rate increases more or less linearly to 10E18/wk at 1/05
  - 5.5E18/wk after NuMI turns on.
- Stretch Scenario:
  - MBooNE rate increases to 10E18 at 1/05
  - 5.5E18 when NuMI turns on
  - Increases to 10E18 over 2005

Protons to MiniBooNE



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).
  - Maintining 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.