The Proton Source (mostly Booster) in the "Collider Era"

Eric Prebys

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Outline:

- General:
  - Current and expected demands on the Booster
  - Limiting factors
  - Proton economics
- Longevity issues
  - non-radiation related
  - radiation related
- Planned and proposed long-term projects.
  - Low energy Linac upgrade?
  - Booster collimation system.
  - New Booster RF system.
  - New Booster kickers.
  - New Booster injection bump (ORBUMP) magnets.
  - Booster cogging system.

The “Run II Era”

- The proton source is very close the the specifications in the Run II Handbook.
- Although it’s the highest priority, support of collider operations is a relatively minor facet of life in the proton source.
- Proton source activities are dominated by the current and projected needs of the neutrino program (MiniBooNE+NuMI+??)
- Whatever a WBS chart may say, there’s not a separate proton source for RunII, MiniBooNE, NuMI, etc.

8 GeV Proton Goals and Performance

Parameter	Typical Current Performance	Run II Handbook Goal	Comments
Pbar Stacking Pulse Intensity	4.7E12/batch* = 5.9E10/bunch	>5E12/batch	Limited by Booster efficiency and residual radiation concerns
Hourly Intensity	0.8E16 Run II	1.2E16	Limited by Pbar cooling cycle time
Transverse Emittance	15-17 π mm-mr	<15 π mm-mr	
Collider filling Intensity	7 bunches @ 5.5 - 5.9E10 / bunch	5-7 bunches @ 6E10 / bunch	
Longitudinal Emittance	0.1 - 0.15 eV-sec / bunch	<0.1 eV-sec / bunch	Better understanding of transition crossing and improved longitudinal dampers

* One batch ~80 bunches (harmonic 84 with 4 bunch gap)

Some Cold Hard Facts about the Proton Source

- Running as we are now, the Booster can deliver a little over 1E20 protons per year – this is about a factor of four over typical stacking operations, and gives MiniBooNE about 20% of their baseline.
- NuMI will come on line in 2005, initially wanting about half of MiniBooNE's rate, but hoping to increase their capacity – through Main Injector Improvements – *until it is equal to MiniBooNE*.
- Whatever the lab's official policy, there will be great pressure (and good physics arguments) for running MiniBooNE and NuMI *at the same time*.
- -> By 2006 or so, the Proton Source will be called upon to deliver 10 times what it is delivering now.
- *At the moment, there is NO PLAN for achieving this, short of a complete replacement*!

Limitations to Total Booster Flux

- Total protons per batch: 4E12 with decent beam loss, 5E12 max.
- Average rep rate of the machine:
  - Injection bump magnets (7.5Hz)
  - RF cavities (7.5Hz, maybe 15 w/cooling)
  - Kickers (15 Hz)
  - Extraction septa (15Hz after Jan. shutdown)
- Beam loss
  - Above ground:
    - Shielding
    - Occupancy class of Booster towers
  - Tunnel losses
    - Component damage
    - Activiation of high maintenance items (particularly RF cavities)

Of particular interest to NUMI

Our biggest concern

Proton Timelines

- Everything measured in 15 Hz “clicks”
- Minimum Main Injector Ramp = 22 clicks = 1.4 s
- MiniBoone batches “sneak in” while the MI is ramping.
- Cycle times of interest
  - Min. Stack cycle: 1 inj + 22 MI ramp = 23 clicks = 1.5 s
  - Min. NuMI cycle: 6 inj + 22 MI ramp = 28 clicks = 1.9 s
  - Full “Slipstack” cycle (total 11 batches):

6 inject
+ 2 capture (6 -> 3)
+ 2 inject
+ 2 capture (2 -> 1)
+ 2 inject
+ 2 capture (2 -> 1)
+ 1 inject
+ 22 M.I. Ramp
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39 clicks = 2.6 s

Summary of Proton Ecomomics

MiniBooNE baseline ≈ 5E20 p/year

Booster Hardware Issues

Radiation Issues

Scenario	Cycle (clicks)	Batches				Rep rate (ave. Hz)	Protons delivered (x E12 pps)*			Total	
		prepulse	Stack	MB	NuMI		Stack	MB	NuMI	E12	/RunII
Stack	23	2	1			2.0	3.3	0.	0.	3.3	1.
Stack/MB	23	2	1	8		7.2	3.3	26.1	0.	29.3	9.0
Stack/NuMI	28	2	1		5	4.3	2.7	0.	13.4	16.1	4.9
Stack/NuMI/MB	28	2	1	10	5	9.6	2.7	28.8	13.4	42.9	13.1
Slipstack/NuMI	39	2	2		9	5.0	3.8	0.	17.3	21.2	6.5
Slipstack/NuMI/MB	39	2	2	13	9	10.0	3.8	25.0	17.3	46.2	14.2

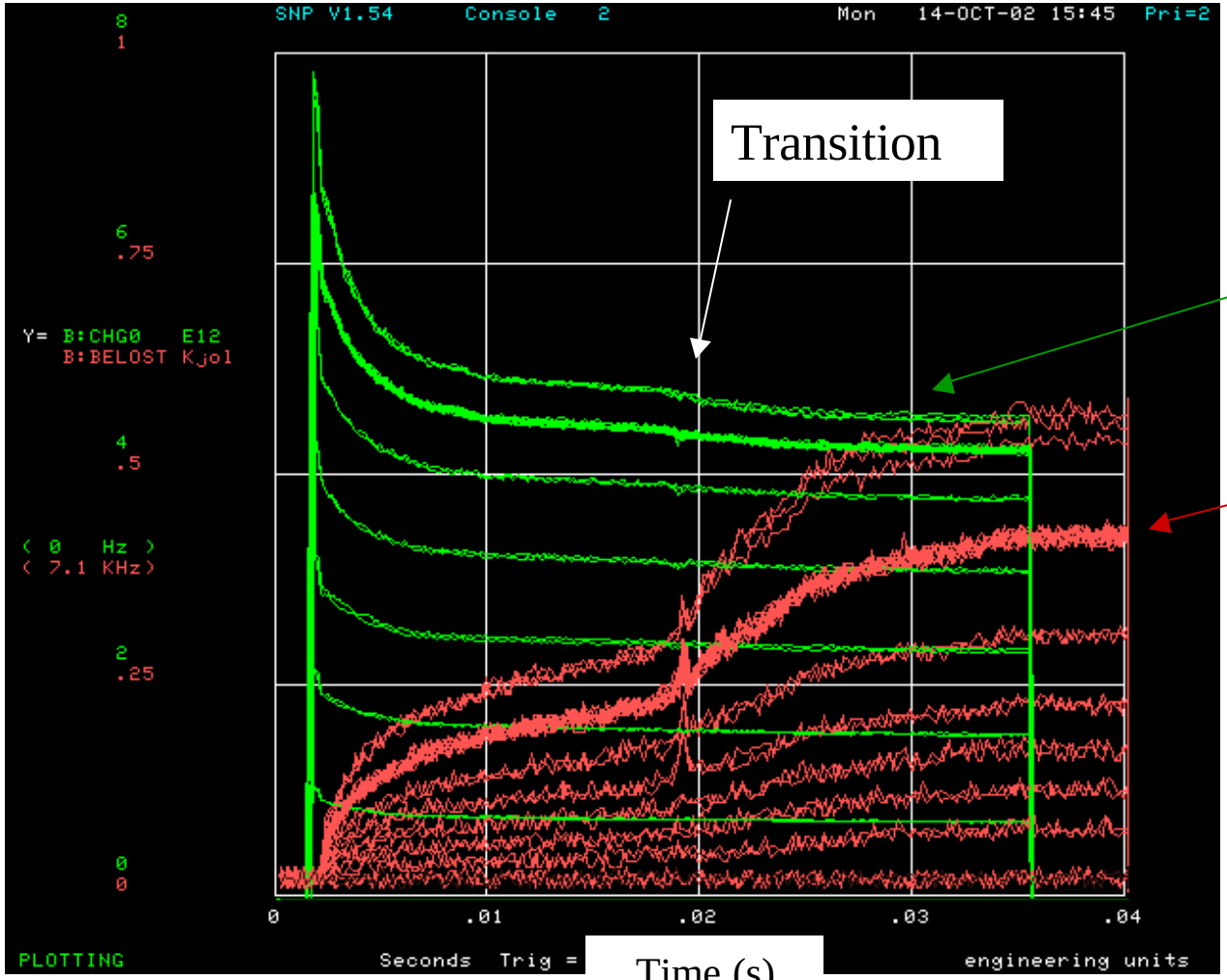
NUMI "baseline" = 13.4E12 pps x 2E7 s/year ≈ 2.7E20 p/year

Right now we're at roughly 1/5 of the MiniBooNE baseline

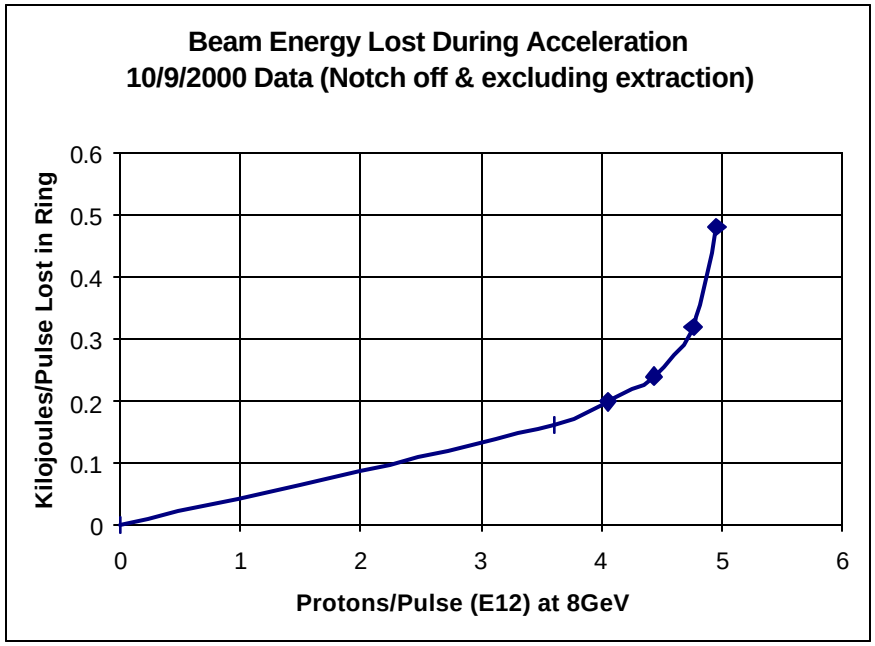
*assuming 5E12 protons per batch

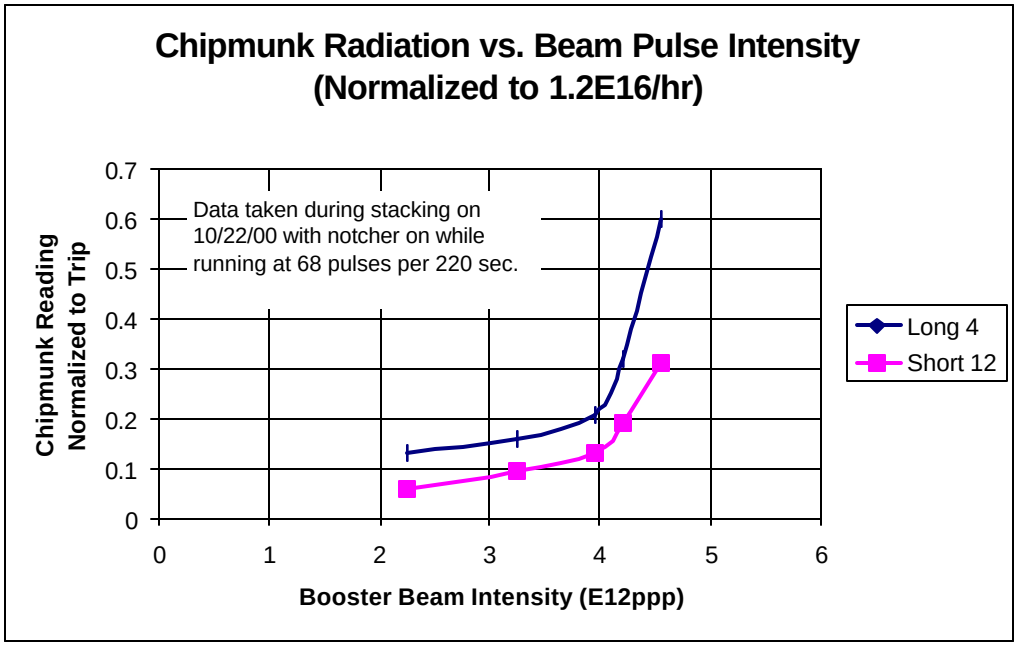
Typical Booster Cycle

Various Injected Intensities

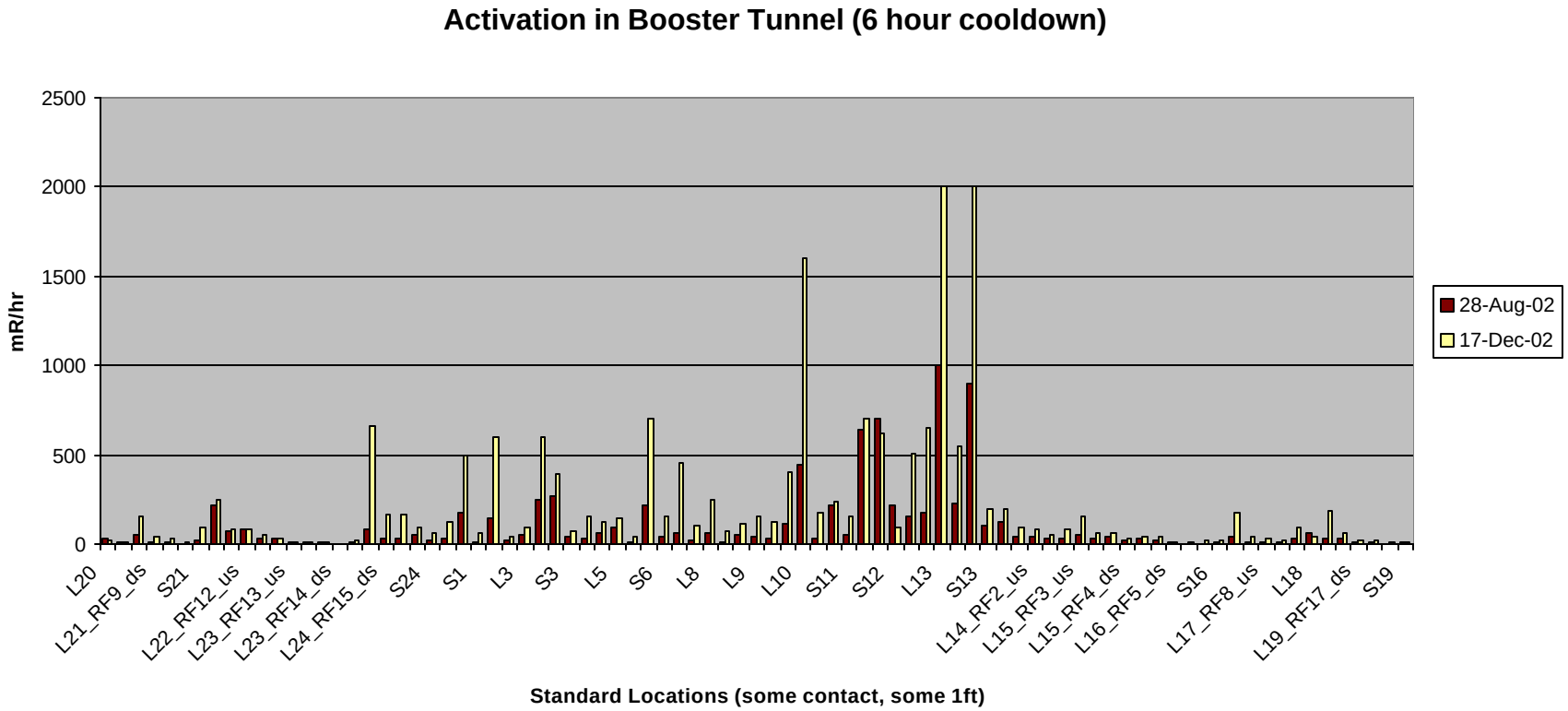


Beam Loss Intensity Sensitivity





Booster Tunnel Radiation Levels



- On a recent access
  - The people doing the radiation survey got about 20 mR.
  - Two technicians received 30 mR doing a minor HV cable repair.
  - We're at (or past??) the absolute limit on our overall activation

Longevity Issues (non-radiation)

- Linac
  - 7835 Power Amlifiers: will supply meet demand? Will supply dry up?
  - Modulator switch tubes: have all we're ever going to have. Is it enough?
- Booster
  - GMPS (upgraded, OK)
  - Transformers (serviced, OK)
  - Vacuum system (being update, finished 2003)
  - MP02 extraction septum and power supply (new, OK)
  - MP01 extraction septum and power supply
    - Will be replaced with duplicates of MP02.
  - Injection bump (ORBUMP): discussed shortly
  - Kicker PS charging cables
    - Run three times over spec
    - Fail at a rate of about 1/month, sometimes repairable.
    - Ordering spare cable.
    - Evaluating improved design (better cable, LCW-filled heliac, etc)

Longevity Issues (non-radiation, cont'd)

- Low voltage power supplies, in particular Power 10 Series:
  - Unreliable, some no longer serviced.
  - Starting search for new supplier and evaluate system to minimize number of different types.
  - Probably a few $100K to upgrade system.
- RF Hardware
  - (original) Copper tuner cooling lines are beginning to spring leaks. Difficult to repair because they're hot.
- High Level RF
  - More or less original.
  - Our highest maintenance item.
  - Will probably last, BUT expensive to maintain.
  - John Reid and Ralph Pasquinelli feel a new solid state system would pay for itself ($5.5M) in about four years.
- Low Level RF
  - Many old modules, some without spares, some without drawings.
  - An upgrade plan in place.
  - Not expensive, but NEED people.

Longevity Issues (radiation related)

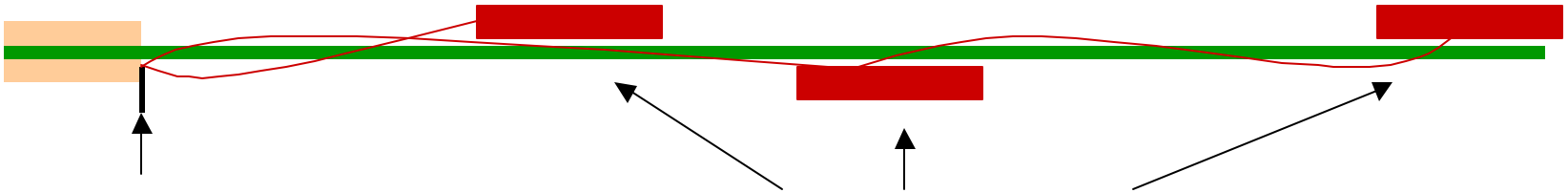
- We've seen failures in ion pump HV lines -> planning to replace.
- Hoses on beam valves will be replaced with copper or stainless.
- Looking at other miscellaneous cabling and hoses.
- Recent kicker magnet failure appeared to be related to radiation damage.
- Main magnet insulation?
  - Haven't had a failure in 30 years, but…
  - Have placed "dose tabs" around the ring to get an idea of the real radiation dose to evaluate danger.

Upgraded Low Energy Linac??

- Most of the Linac longevity issues center around the 200 MHz RF hardware.
- Possible to replace Preacc with a series of RFQ's which would directly feed a 400 MHz klystron-driven low energy linac (a la SNS).
- This is a big ticket item, but could be a step to a new proton driver.

Booster Collimator System

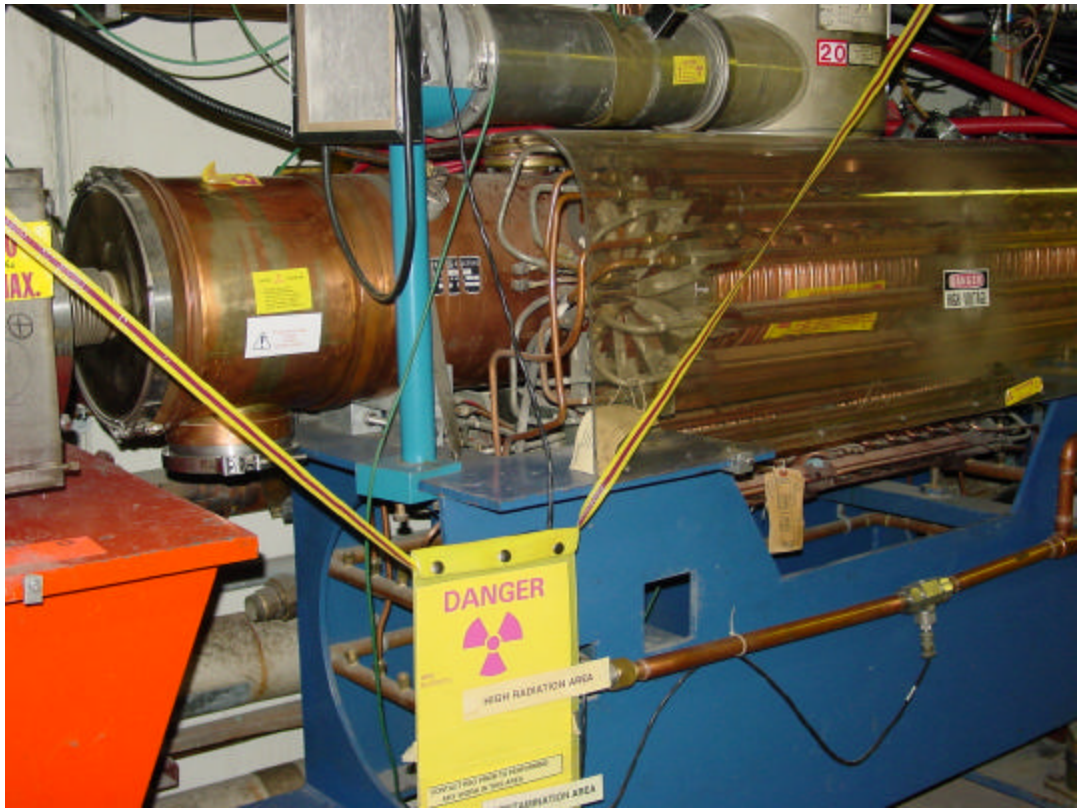
Basic Idea…



- Unshielded copper secondary collimators were installed in summer 2002, with a plan to shield them later.
- Due the the unexpected extent of the shielding and the difficulty of working in the area, the design was ultimately abandoned as unacceptable.
- Collimators were removed during the January shutdown.
- A new collimator system is being designed with steel secondary jaws fixed within a movable shielding body.
- Hope to have then ready in ~3 months.

New RF System?

- The existing RF cavities form the primary aperture restriction (2 ¼” vs. 3 ¼”).



- They are high maintenance, so their activation is a worry.

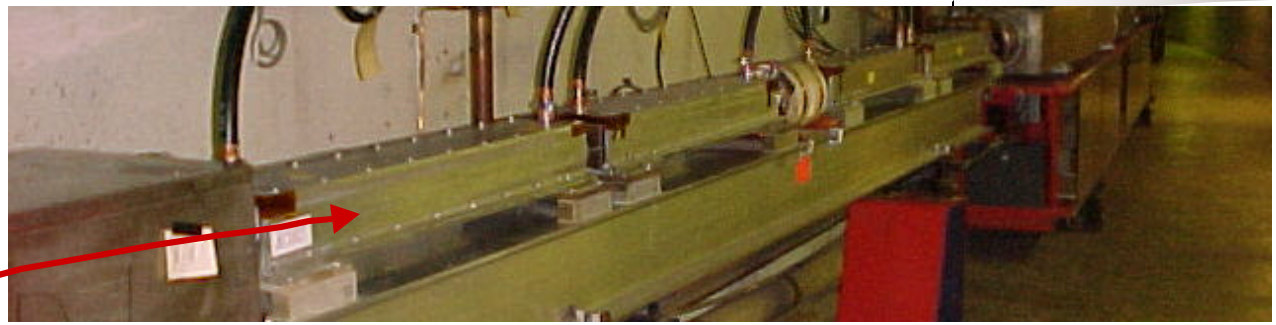
New RF System (cont'd)

- There is a plan for a new RF system with 5" cavities:
  - Powered prototype built
  - Build *two* vacuum prototypes by the summer shutdown with substantial machining done at universities.
  - Evaluate these and procede (hopefully?) with full system.
- Total cost: $5.5M cavities + $5.5M power supplies (power supplies would pay for themselves in a few years)
- Is it worth it? On of the questions for the study group is how much improvement we might expect.

Injection Dogleg (ORBUMP)

- The current injection bump dogleg (ORBUMP) magnets can ramp at 7.5 Hz, with a substantial temperature rise.
- Need to go to 12 to support MiniBooNE and NuMI.
- 2 spares for the 4 (identical) magnets. Most likely failure mode probably repairable.
- New design underway, but needs much more attention.
- Can new design incorporate injection improvements??
- Some power supply issues as well:
  - One full set of replacement SCR's for the switch network.
  - New switchbox being designed, but needs attention (or order more spare SCR's).
  - No spare for charge recovery choke.

Extraction Kickers



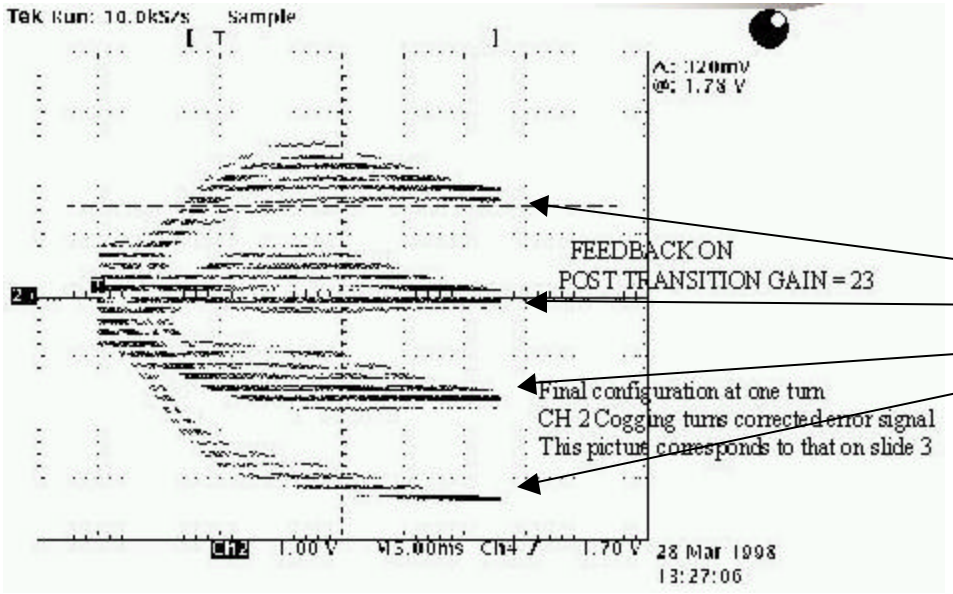
- Each extraction region requires four extraction kickers in the long straight section prior to extraction.
- After these RF cavities, these are the next aperture restriction (2.5” ID).
- Recently, a kicker failed with signs of radiation damage, and we were forced to swap in our only spare (really our tune measurement pinger).
- Plan:
  - Use spare and recovered ferrites to build two spares on a very short timescale.
  - Order ferrites to build at least two additional spares.
  - Investigate a new, larger aperture design.

Multibatch Timing

- In order to Reduce radiation, a “notch” is made in the beam early in the booster cycle.
- Currently, the extraction time is based on the counted number of revolutions (RF buckets) of the Booster. This ensures that the notch is in the right place.
- The actual time can vary by > 5 usec!
- This is not a problem if booster sets the timing, but it’s incompatible with multi-bunch running.
- We must be able to fix this total time so we can synchronize to the M.I. orbit.
- This is called “beam cogging”.

Active cogging

- Detect slippage of notch relative to nominal and adjust radius of beam to compensate.



Allow to slip by integer turns, maintaining the same total time.

- Does not currently work at high intensities.
- Still do not really understand the problem.
- Needs to be solved by the time NuMI runs.

Simulation/Studies

- Historically, the booster has lacked a fundamental understanding of beam loss mechanisms.
- If (!!!) it is possible at all to go the the required beam flux, it will require some mitigation of beam loss.
- Recently, there has been an great increase in the involvement of the Beam Physics department in the Booster:
  - Space charge group (W. Chou, et al) has begun to focus on the Booster again.
  - Chuck Ankenbrandt has moved into Booster group as “Beam Physics Liaison” to help coordinate studies.
  - Starting to make quantitative comparisons between predictions and measurement.
- This is an ongoing effort, which will require at least some dedicated beam study time.

Conclusions

- We are at or near the present limit of the Proton Source output.
- This is a factor of five to ten away from what is needed.
- Current plans (collimators, orbit control, …) might realistically increase things by a factor of two or three, tops.
- Getting further will be hard!!!
- It will not happen parasitically.