Proton Source: Linac and Booster

Elliott McCrory
AAC Review
February 4, 2003
Talk Outline

- Improvements made since last June.
- Current operational performance.
  - Beam parameters.
- Current issues:
  - Operational.
  - Technical.
  - Physics.
  - Administrative.
- Plans and expectations for the next 8 months.
Improvements Since June, 2002

- Linac 201 MHz Modulator “Switch Tube” inventory (61 tubes) tested
  - *One tube rebuilt successfully by Econco.*
- Tevatron Clock: Trailer hitch mode for adding MiniBooNE pulses
  - *Full flexibility in added MiniBooNE pulses to TCLK.*
- Replaced Booster’s MP02 extraction magnet & power supply
  - *No hardware limits for running at 5 Hz*
- Upgrade of Linac water systems (200 MHz)
- Booster tune measurement through cycle 📈
Booster Tunes Through Cycle

Time in Booster cycle, milliseconds
Improvements, Continued

- MiniBooNE: 4E12 protons/pulse at 1 Hz
- Booster vacuum controls upgrade underway
- Longitudinal dampers work ongoing
  - Dedicated cavity commissioned
- Booster Collimators
  - New plan is underway
    - Project Manager: Kasper
  - Expect to install by July shutdown
- 2X improvement in flux?
- Ion Profile Monitor (IPM) operational
- Significant improvements in personnel deficit
Calibrating the Booster Ionization Profile Monitor: Preliminary Summary

J. Amundson, P. Spentzouris

*FNAL*

and

G. Jungman

*LANL*

January 28, 2003

Abstract

We have performed a calibration of the Booster Ionization Profile Monitor (IPM) using a new model of the ion dynamics in the detector and independent measurements of the beam width. We obtain the formula

\[ \sigma_{\text{measured}} = \sigma_{\text{beam}} + C_1 N \sigma^p, \]

where \( N \) is the current in units of \( 10^{12} \), \( C_1 = (1.13 \pm 0.06) \times 10^{-5} \text{m}^{1-p} / 10^{12} \), and \( p = 0.615 \pm 0.013 \).

1 Device Description

The Booster IPM measures beam profiles using ions produced by the beam from the imperfect vacuum of the machine. An applied transverse clearing field causes the ions to drift to a Micro Channel Plate (MCP). The beam direction defines the longitudinal coordinate[1]. The detector is 0.5 m long, with a transverse gap of 12 cm. The MCP plate is \( 8 \times 10 \text{ cm}^2 \) and has strip spacing 1.5 mm. The clearing field is 8 kV.

2 Theoretical Calculation

We start by considering the scattering of particles in a gaussian beam by the beam itself as well as an applied electric field. The total force felt by an ion in the combined field is

\[ \vec{F} = \frac{\alpha}{r} (1 - \exp(-r^2/2\sigma^2)) + b\hat{x} \]
Personnel Changes!!

- **Chuck Ankenbrandt** (1/1/03) has transferred to Booster as “Beam Physics Liaison,” charged with prioritizing studies.
- **Craig Drennan** (1/1/03) has transferred to Booster to assist and to take over engineering duties with/from Bill Pellico (~replaces Bob Webber).
- **Tom Dombeck** (10/1/02) has transferred to Booster to help with physics and administrative duties.
- **Trevor Butler** (6/15/02) has been hired to perform engineering duties for Linac.
- **Yang Xi** (postdoc) will soon join group (2/15/03?), primarily working on non-invasive, laser-based profile measurement. Will work for Chuck and for NICADD (Court Bohn).
- **Xiaobiao Huang** (graduate student) will come up from Indiana to work on precision lattice measurement and study mechanisms of beam loss from space charge. Volunteer
- **Linda Coney** (postdoc) has begun to contribute significant time. Primarily working on beam steering and lattice measurement. Volunteer
- **Larry Bartoszek** has been commissioned, through the efforts of the MiniBooNE collaboration, to assist in designing the collimator shielding.
Current Operational Performance

- The Proton Source does not limit Run II Operations
  - But MiniBooNE demands lead to compromises
- Current Linac performance
  - 43-45 mA at up to 4 Hz
  - NTF operates 3 times/week
  - MuCool Annex construction
## Proton Source Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current Performance</th>
<th>Run II Handbook Goal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pbar Stacking Pulse Intensity</td>
<td>4.5E12/batch</td>
<td>&gt;5E12/batch</td>
<td>Limited by Booster efficiency and residual radiation concerns</td>
</tr>
<tr>
<td></td>
<td>= 5.5E10/bunch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly Intensity</td>
<td>0.8E16 Run II</td>
<td>1.2E16</td>
<td>Limited by Pbar cooling cycle time</td>
</tr>
<tr>
<td>Transverse Emittance</td>
<td>15-17 π mm-mr</td>
<td>&lt;15 π mm-mr</td>
<td></td>
</tr>
<tr>
<td>Collider filling Intensity</td>
<td>7 bunches @ 5.5 - 5.9E10 / bunch</td>
<td>5-7 bunches @ 6E10 / bunch</td>
<td></td>
</tr>
<tr>
<td>Longitudinal Emittance</td>
<td>0.1 - 0.15 eV-sec / bunch</td>
<td>&lt;0.1 eV-sec / bunch</td>
<td>Better understanding of transition crossing &amp; improved long’l dampers</td>
</tr>
<tr>
<td>MiniBooNE Intensity</td>
<td>4.0E12/batch @ 1 Hz = 1.4E16 pph</td>
<td>8E16 pph</td>
<td>Residual radiation issues</td>
</tr>
</tbody>
</table>

4 February 2003
Proton Source--McCrary
Current Booster Performance

Collider: 4.5E12 protons per pulse at (1/2.2) Hz.
  - Approximately satisfying their demands.
  - Can provide 5E12 ppp, but reducing this to accommodate more flux for MiniBooNE.

MiniBooNE: 4.0E12 ppp at 1 Hz (1.4E16 pph)
  - Only 20% of desired 8E16 pph
One Week of Running over 1/1/2003
Operational Limitations

**Linac**
- *Inventory of 200 MHz power amplifiers (Burle “7835”) still an issue*
  - Situation has not affected operations, yet
  - # of spares has not increased
  - Three of last 11 tubes failed prematurely
    - *Expect/need 11,000 hours, got: 2664, 5469 and 6410 hours*

**Booster & Linac: Losses & Activation**
Limitations: Losses/Activation

**Linac**
- Activation is noticeable, but not a limiting factor
- Tunnel shielding a problem at flux $\rightarrow 5X$ higher

**Booster**
- Booster losses increase non-linearly above $\sim 4E12$ ppp
  - Can run $4.8E12$ (and higher), but leads to unacceptable activation
- Activation already limiting maintenance
  - RF15: $>200$ mR/hr at one foot
  - Average activation in Booster tunnel is $\sim 10$ mR/hr
- Component damage
  - Cable failures seen already
  - Extraction kicker failed 1/28/2003, probably from radiation damage

**Activation decays, roughly, as $e^{-\alpha t/[days]}$**
- $0.03 < \alpha < 0.05$
- *Half-life: 15-20 days*
Activation Decay of Linac 400 MeV Lambertson

Slated for replacement in July shutdown

Lambertson Activation (@1 Ft, error bars at 10%)

\[ y = 163.08e^{-0.0442x} \]

Days since beam off

mR/hr at 1 foot
Activation of Booster RF Station 15

An improvement since November

- We reduced beam to MiniBooNE

→ Changed this PA last week

4 February 2003
Proton Source--McCrary
Booster Losses vs. Intensity

Intensity (E12)

Energy Lost (KJ)
Trips Points Added to Contain Losses

- Dozens loss monitors with trip levels set to reduce activation

  - Not completely adequate!

- Average power lost: B : BPL 5MA

  - Equals: $<[d/dt (I_{Booster}(t))]*E(t)>_{(5 \text{ minutes})}$
  
  - Limit: 400 Watts
  
  - Also not completely adequate!
Loss Monitor Trip Points

BRF11: 200 mR/hr @ 1ft

BRF15: 300 mR/hr @ 1ft
Power Lost in Booster

Beam extracted per minute, E14

Beam power lost, watts

PPP, E12

1 Sept 2002

4 February 2003 Proton Source--McCrory

13 Jan 2003
Current Issues: Technical (1/3)

- **Goal:** Reduction of losses at higher ppp levels
- **Longitudinal dampers**
  - Work is ongoing, *Pellico*
- **Transition jump system**
  - Tried ~1.5 years ago, but failed due to longitudinal instabilities and misaligned quads
  - Re-commissioning now
Booster Longitudinal Dampers

- **No Dampers**
- **Dampers Working**

4 February 2003

Proton Source--McCrary
Technical Issues, Continued (2/3)

- Ramp monitor program
  - Under development, in Java, Guglielmo (CD)
- Aperture and Orbit Improvements
  - Ramped correctors, Prebys
- RF cavity upgrade
  - Increase aperture from 2¼” to 5”
  - Entire project is very expensive
  - Universities will machine parts for two prototype cavities of new design
  - Project manager assigned: Padilla
    - First assignment: Can prototypes be installed in August?
Ramp Monitor Program

Latest Measurement

1 sigma envelope
Technical Issues, Continued (3/3)

- LLRF improvements
- Longitudinal dampers improvements
- Phase lock improvements to MI
  - Attempt phase lock of beam signal rather than VCO signal to MI RF reference
- Injection overhaul
- Maintaining traditional reliability
- NUMI turn-on is coming …
Current Issues: Physics

- Space-charge study group requesting studies
  - Many participants: BD/Physics (Chou, Spetzouris, Ostiguy), NICADD (Bohn + students & post-docs), NUMI/MINOS (various), MiniBooNE (various)

- Ion Profile Monitors
  - Spetzouris, Amundsun, Jungman, Tomlin, Prebys, etc.
  - Understanding the calibration

- Lattice calculations
  - Drozhdin, et al.
  - Dispersion problems at injection
    - Caused by injection “OrBump” and the “dog legs” around extraction septum
    - Verified by studies last week

- Minimum configuration for Collimator Shielding
  - Kasper, Prebys, Mohkov, Bartoszek, Chen, etc.
Edge Effects of Dog Legs on Dispersion: Predicted

3.2 m

No dog legs

1.8 m

Dog legs on

0 m
Edge Effects from Dog Legs

H Dispersion Difference: Dog Legs at 100% and 60%

Data
Tune Shift from Dog Leg Change

- Dog Legs Nominal
- Dog Legs down 40%
MARS Estimates of Collimator Shielding Activation

Residual Dose, mSv/hr (100 mR/hr)

Edge of Shielding

Relative Location in Shielding, vertical (cm)

After: 30 days beam on, 1 day cooldown

4 February
Mechanical Design for Collimator Shielding

Design from Larry Bartoszek

4 February 2003

Proton Source--McCroy
Current Issues: Administrative

Staffing.

- **Short-term staffing problem: How to use our new workers!**
- **Further needs:**
  - Another technician in Booster to support new engineer.
  - Backup for Lackey already approved, but individual not identified.
  - Coordination of offers of help from MiniBooNE and NUMI.
  - More needs will be determined as new workers gain perspective.

Complete and cogent plan for studies.

- **Coordination and direction of all Booster studies (Ankebrandt, Prebys).**
  - Weekly meetings.
- **Understanding space-charge forces on the beam (Chou).**
  - Weekly meetings.
Plans for the Next 8 Months.

- New Linac power amplifiers
  - 8 scheduled for delivery between now and August
- Improvements in the longitudinal dampers system
- Implementation of transition jump
- Gradual replacement of aged 400 MeV line power supplies
- Installation and commissioning of collimator shielding
  - Want to install before July shutdown
Plans for July Shutdown

- Install & commission new 400 MeV Lambertson magnet
- Installation and commissioning of new 8 GeV EDWA magnets
- Work on RF cavity upgrade: prototypes installed? 
  - Now, possibly install during July shutdown
Summary: Proton Source

- Steady operation for Collider
- Operating for MiniBooNE
  - But they want 5X increase in flux
- Extensive, dynamic and growing team: investigating Booster issues

Worries:
- Linac power amplifiers
- Booster activation
  - Component damage?
  - NUMI turn on before MiniBooNE is finished?!
- 32 year old machines
  - And some workers nearing retirement