Required Proton Source Role in Run II Era

• Supply protons for antiproton production
  – 5E12 protons per pulse each 1.47 seconds for antiproton production (1.2E16 protons per hour) required

• Supply protons for Collider filling
  – 5-7 bunches of 5-6E10 protons with 0.1 eV-sec/bunch longitudinal emittance and <15 π mm-mr transverse emittance required

• Supply protons for other Laboratory programs: MiniBooNE currently and SY120, NUMI/MINOS later
  – 5E12 per pulse at 5 Hz (9E16 pph) required by MiniBooNE

• Most demanding requirements: Reliability & Availability
• Most difficult problem: Beam loss with resulting radiation and activation
### Goals and Performance for Collider Run II

#### Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Current Performance</th>
<th>Run II Handbook Goal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 GeV Beam Pulse Intensity for Pbar Stacking</td>
<td>4.7E12/batch*</td>
<td>&gt;5E12/batch</td>
<td>Limited by Booster efficiency and residual radiation concerns</td>
</tr>
<tr>
<td></td>
<td>= 5.9E10/bunch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly 8 GeV Beam for Run II</td>
<td>0.8E16</td>
<td>1.2E16</td>
<td>Limited by cooling time in Pbar Debuncher</td>
</tr>
<tr>
<td>Transverse Emittance</td>
<td>15-17 π mm-mr</td>
<td>&lt;15 π mm-mr</td>
<td>~OK</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>6E10 times 5 not enough to make 270E9 in TeV</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 and improved longitudinal dampers</td>
</tr>
</tbody>
</table>

* One batch ~80 bunches (harmonic 84 with 4 bunch gap)
Emittance vs. 8 GeV Intensity

Data and plot courtesy of Ming-Jen Yang
8 GeV Longitudinal Emittance vs. Intensity

Error bars represent standard deviation of 4 measurements at each intensity
Typical Booster Bunches at 8 GeV

Notice non-uniform bunch spacing

10 nsec/div

50 nsec/div
Proton Source Run II-Specific Projects (1)

- Understanding Booster Performance Limitations
  - Injection and Capture Studies (R. Tomlin et al.)
  - Space Charge Effect Studies (P. Spentzouris)
  - Transition Crossing Studies (W. Pellico)
  - Investigate Need for / Benefit of Transverse Dampers in Booster (R. Tomlin)

- Booster Longitudinal dampers (W. Pellico)
  - Re-design low level electronics system to reduce noise and facilitate maintainability
  - Dedicated damper cavity and power amplifier recently commissioned
Proton Source Run II-Specific Projects (2)

- Phase Lock Improvements (W. Pellico, R. Webber)
  - Phase-locking Booster beam to Main Injector RF before transfer imparts significant perturbation to beam with some increase to longitudinal emittance
  - Devise and implement hardware improvements for more “adiabatic” phase lock
  - Attempt phase lock of beam signal rather than VCO signal to MI RF reference

- Aperture and Orbit Improvements
  - Commission Ramped Correctors (E. Prebys)
  - Magnet Moves (J. Lackey)
• **Booster Beam Collimator System (J. Lackey, E. Prebys)**
  – Collimation system is expected to absorb radiation load from beam losses in a location that can be well shielded
  – This load would otherwise be carried by RF cavities and other critical beamline devices
  – Permits increased proton delivery rate
    • To the benefit of antiproton stacking
    • To reduce Booster tunnel maintenance worker radiation exposure
  – Collimators and absorbers are installed. Shielding must be installed before exposing collimators to high radiation doses.
    • Complete shielding design
    • Procure shielding materials
    • Install shielding
    • Commission collimation system with beam
The Proton Source in Full Context

• Reliable, 24/7, 39 week/year Proton Source operation (on TeV schedule) is crucial to Run II success
• Now less than one in three 8 GeV protons is used by Collider Run II, potentially less than one in ten
• **Total Proton Demand Is A Big Deal to Run II !**
• Increased pulse repetition rate demands on 30 year old equipment will impact machine availability
• Component irradiation and activation, especially in Booster, will potentially cause failures and ALARA steps will require extended repair times
Proton Source Department

Demand for 8 GeV Protons

8 GeV Proton Demand

- MiniBooNE
- NUMI/MINOS

Present Operating Level

Historical High ~3E12 ppp x 13 to Main Ring each 5 sec

Calendar Quarter

Protons per Hour (1E16)
• To meet the increasing demand for protons from a 30 year old machine without destroying it and within the safety regulations of the Fermilab Radiation Control Manual
• Increase pulse intensity 10% and beam pulse repetition rate 5 times above current levels
• This is a challenge relevant to the entire program of this Laboratory. Every proton utilized by any Fermilab HEP experiment (Run II, MiniBooNE, NUMI, SY120) for at least the next 6 years must be accelerated by the present Linac and Booster
Recent 6 Weeks with MiniBooNE Turn-On

- 1.8E16/hr
- 400 Watts
Proton Source Department

Booster Charge and “Beam Energy Lost” Family

4.5E12
580 Joules
Beam Loss Intensity Sensitivity

- **Beam Energy Lost During Acceleration**
  - (Notch off & excluding extraction)

  - Data taken during stacking with notcher on while running at 68 pulses per 220 sec.

- **Chipmunk Radiation vs. Beam Pulse Intensity**
  - (Normalized to 1.2E16/hr)

  - Chipmunk Reading Normalized to Trip

  - Long 4
  - Short 12
Projects to Meet New Demands
(Not Necessarily Run II-Specific)

- New Booster pulsed extraction septum magnets and power supplies to permit higher average pulse rates (J. Lackey, TD, and EE Support)
- New enlarged aperture upstream MI-8 magnets (J. Lackey and TD)
- Redesign Booster Injection Orbit Bump magnet system (T. Dombeck)
- Complete vacuum-proof prototype of enlarged aperture Booster RF cavity (J. Reid and RF Dept)
- Improved applications software to enforce better operational discipline (E. Prebys, P. Kasper [Proton Source] and G. Guglielmo [Computing Division])
Major Systems in Need of Attention to Maintain Traditional Reliability

- Low Energy Linac water systems
- Linac 200MHz RF power systems
- Low Energy Linac pulsed quad power supplies
- 400 MeV Lambertson magnet
- 400 MeV transfer line power supply systems
- Booster Orbit Bump power supply output switch
- Booster vacuum system controls
- Booster High Power RF amplifiers and modulators
- Booster low level RF electronics
- Booster extraction kicker magnets
Booster Residual Radiation Tracking Program

• Establish “fixed” measurement locations around Booster ring
  – Selected easily repeatable measurement locations
  – Some measurements at contact (some on beam pipe some not) and some at 1 foot

• Make measurements most opportunities for access

• Typically 2-8 hours after beam is shut down
  – “fuzzy” number because operation is irregular

• Provide good “baseline” prior to MiniBooNE operation and trending during MiniBooNE
Booster Residual Radiation Data

Normal Locations
Excludes Injection, extraction, and RF

Readings mRem/HR On Contact
Note: Logarithmic Vertical Scale

mRem/hr on contact

October 28-31, 2002
DOE Fermilab Collider Run II Review
Booster Residual Radiation Data

Upstream RF Cavity Locations

Readings mRem/Hr At 1 Foot
Note: Linear Vertical Scale
**Dose Rate Trends**

The doses at each measurement point are normalized to an average of one for measurements before Sep '02 and plotted versus time. The thick black line is the overall average.
Planned Booster Collimator Layout

PHC is in upstream mini-straight section of Period 5
PVC is in downstream mini-straight section of Period 5
SHC1 is 20 cm from upstream end of Long 6 straight section
SVC1 is 300 cm from upstream end of Long 6 straight section
SHC2 and SVC2 are both located 60 cm from downstream end of Long 7 straight section
Proton Source Department

Vertical Primary Collimator Installation

[Images of vertical primary collimator installation equipment]
Booster Secondary Collimator Installation
Conclusions

• **Proton Source is very close to meeting Run II goals and does not presently limit Run II luminosity performance**
  – 10% beam pulse intensity improvement is needed to meet goals
  – Longitudinal emittance improvement may benefit Collider

• **Aging Booster and Low Energy Linac equipment and operation at increased average beam pulse rates threaten continued operation at historical level of reliability**

• **Accelerator component irradiation and activation is the most serious issue facing the Booster**
  – Operational discipline, additional dedicated scientific and technical staff, and automated loss monitoring and data logging are required
  – Administrative operational limits are set to limit machine damage, personnel radiation exposure, and reduced machine availability
  – Entering era of maintenance in elevated radiation environment