Booster injection modifications and emittance reduction plans for Run9 Polarized Protons


12/4/08
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• Why?
• LtB Layout and Instrumentation
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Why? Emittance Improvement for PP

• For FY08 Polarized protons
  Measured LINAC Emittances
  H \( 10 \pi \text{ mm mrad (N, 90 \%)} \)
  V \( 12 \pi \text{ mm mrad (N, 90 \%)} \)

• After MEBT modifications, emittances from LINAC will be reduced by factor of 2.

• Making emittances as small as possible is desired because reduced emittance correlates with higher polarization (and higher luminosity, of course).

• So how do we make them smaller?
Kevin Brown, December 5, 2008

FY09 APEX Planning Workshop

LINAC

Booster

Ixfmr 011

MW035

Q1 Q2 Q3 Q4 Q5

Q7 Q6

200 MeV

Polarimeter

200 MeV
Polarimeter
LtB Optics
$\beta_x = 13.5774 \, \text{m}$

$\alpha_x = -1.56$

$\beta_y = 5.56$

$\alpha_y = 0.78$

$R_{16} = 3.3$

$R_{26} = 0.42$
LTB New Optics

These optics need to be tested and developed in January.
From LtB to Injection Foil

C5 Booster Dipole
Injection through C5 Magnet

The hard edges of the field are shown by the dotted blue curves.

C-A/AP/#192 – C.J. Gardner
Emittance Growth

Emittance growth due to multiple scattering
\[ \Delta \varepsilon \equiv n \beta \theta^2 \]

N=number of traversal: Pulse Length & Rev. Freq.
\( \beta \) = Beta function at foil: ring lattice, (matching etc.)
\( \theta \) = Scattering angle: Material of foil, Thickness (x)

For a thin foil the amount of angular spread introduced into the distribution is

\[ \theta_0 = 14.2 z \frac{\sqrt{x / X_0}}{\beta c p} \left[ 1 + 0.038 \ln \left( x z^2 / X_0 \beta^2 \right) \right] \]

\[ \theta_0 = \theta_{rms \ plane} = \frac{1}{\sqrt{2}} \theta_{rms \ space} \]
Stripping Efficiencies

\[
\theta_0 = \frac{13.6 \text{MeV}}{\beta cp} z \sqrt{\frac{x}{X_0}} \left[ 1 + 0.038 \ln \left( \frac{x}{X_0} \right) \right]
\]

Thin Foil

\[
\theta_0 = 14.2 z \frac{\sqrt{x/ X_0}}{\beta cp} \left[ 1 + 0.038 \ln \left( \frac{xz^2}{X_0 \beta^2} \right) \right]
\]
Reducing Emittance Growth During Booster Injection: New Foils
New Foils

• Main Idea is to
  – Reduce amount of scattering per pass
  – Reduce the number of times the circulating beam hits the foil

• How?
  – Reduce the thickness of the foils
  – Reduce the size of the foils
Booster Foils: 3 September 2003

<table>
<thead>
<tr>
<th>Holder Number</th>
<th>Thickness $\mu g/cm^2$</th>
<th>Edge Inches</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>No foil</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>–0.75</td>
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<tr>
<td>3</td>
<td>100</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>100</td>
<td>–1.00</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>–1.125</td>
</tr>
</tbody>
</table>
100 microgram/cm$^2$ strip foil
Postage Stamp Foil

100 mg/cm² Carbon foil

30 mm x 20 mm carbon foil aligned along top edge of frame centered horizontally

5 mm wide legs coming off each corner

Corners “radiused”

Bottom legs coming off 45° to vertical
Postage Stamp Foil

65 mm
Reducing Emittance Growth During Booster Injection: Small $\beta$-functions on Foil
½ integer stop-band strings

4 Power Supplies; 20 Amp max each (30 V) = 3 A/msec max
Polarities ensure no 10θ, 5θ, 4θ, or 0θ harmonics are produced. Produce 9θ

QVSTR1: +QVA1 +QVA7-QVB1 -QVB7+QVC1 +QVC7-QVD1
-QVD7 +QVE1 +QVE7 -QVF1 -QVF7.

QHSTR1: +QHA2 +QHA8 -QHB2 -QHB8 +QHC2 +QHC8 -QHD2
-QHD8 +QHE2 +QHE8 -QHF2 -QHF8.

QVSTR2: +QVA3 -QVA5 -QVB3 +QVB5 +QVC3 -QVC5 -QVD3
+QVD5 +QVE3 -QVE5 -QVF3 +QVF5.

QHSTR2: +QHA4 -QHA6 -QHB4 +QHB6 +QHC4 -QHC6 -QHD4
+QHD6 +QHE4 -QHE6 -QHF4 +QHF6.

Distorted $\beta$-function at injection foil using 1/2 integer stop band strings.

- Nominal $\beta_H = 11.07503$ m
- Nominal $\beta_V = 5.337392$ m
- Distorted $\beta_H = 4.671282$ m
- Distorted $\beta_V = 2.629119$ m

$Q_x = Q_y = 4.52$
Distorted $\beta$-function at injection foil using 1/2 integer stop band strings.

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- Distorted $\beta_V = 2.629119$ m
What’s the plan?

• LtB
  – What is emittance from LINAC?
• Study injection into Booster with both tunes near 4.5
  – Can good efficiency be achieved (just normal tune up)?
  – Which foil gives best efficiency?
  – Which foil gives smallest emittance? What is efficiency?
• Develop methods for determining LTB optics match to Booster lattice.
  – How do we know if we have a good match?
• Measure change in emittance using distorted $\beta$ function optics (need LTB match to these optics).
  – What is effect on efficiency and emittance?
What’s needed?

• Power supplies
  – ½ integer Stop band correctors

• Instrumentation
  – LtB Multiwires
  – Booster Current Transformer
  – BtA Multiwires
  – Flag/camera systems at F6 and bta005
  – Booster Tune Meter (new bpm electronics, rev-tick)
Summary

• Reduced emittance correlates with higher polarization.
• Emittance growth in Booster is mainly due foil scattering.
• Reducing foil size will reduce emittance growth.
• Lower beta functions at the foil will reduce emittance growth.
• Goals:
  – $5 \pi \text{ mm mrad, normalized } 90\%$ at end of LINAC after improvements.
  – Assuming matched (we are matched), with present booster lattice.
    • $H$ $12 \pi \text{ mm mrad (N, 90 \%), } \Delta \varepsilon_x=7$
    • $V$ $8 \pi \text{ mm mrad (N, 90 \%), } \Delta \varepsilon_y=3$
  – With low beta lattice at injection (assuming matched).
    • $H$ $8 \pi \text{ mm mrad (N, 90 \%), } \Delta \varepsilon_x=3$
    • $V$ $7 \pi \text{ mm mrad (N, 90 \%), } \Delta \varepsilon_y=2$

Note: To get to these emittances will involve learning curve.
Extra
Beam Studies for model tests

• Push the tunes to 4.52.

• Measure the change in the equilibrium orbit (e.o.) when each of the four stopband strings is powered to +/- 9.5A as well as with the design settings. The reference e.o. is taken with one corrector (e.g. A1 vertical correction dipole) powered as hard as allowed without losing beam.

• Measure coherence amplitude at different turn-by-turn bpm’s when beam is kicked by E3 (Horz. and Vert. kickers) and by F3 (Horz. Only). Compare these to the model predictions.
Equilibrium orbit with $Q_x=Q_y=4.52$ and single corrector at 20 amp

- $QVSTR1=-9.5$ & $DVCA1i = 20$ amp
Equilibrium orbit with $Q_x=Q_y=4.52$ and single corrector at 20 amp

- Red line: $QVSTR1=-9.5$ & $DVCA1i = 20$ amp
- Black line: $QVSTR1=0.0$ & $DVCA1i = 20$ amp
Equilibrium orbit with $Q_x=Q_y=4.52$ and single corrector at 20 amp
E8 pue coherence amplitude
(tune meter coherence fitting),
hori kick at F3,
current in j2, j4 stopband strings varied