Fermilab

Linac-Booster Beam Interface

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Contents

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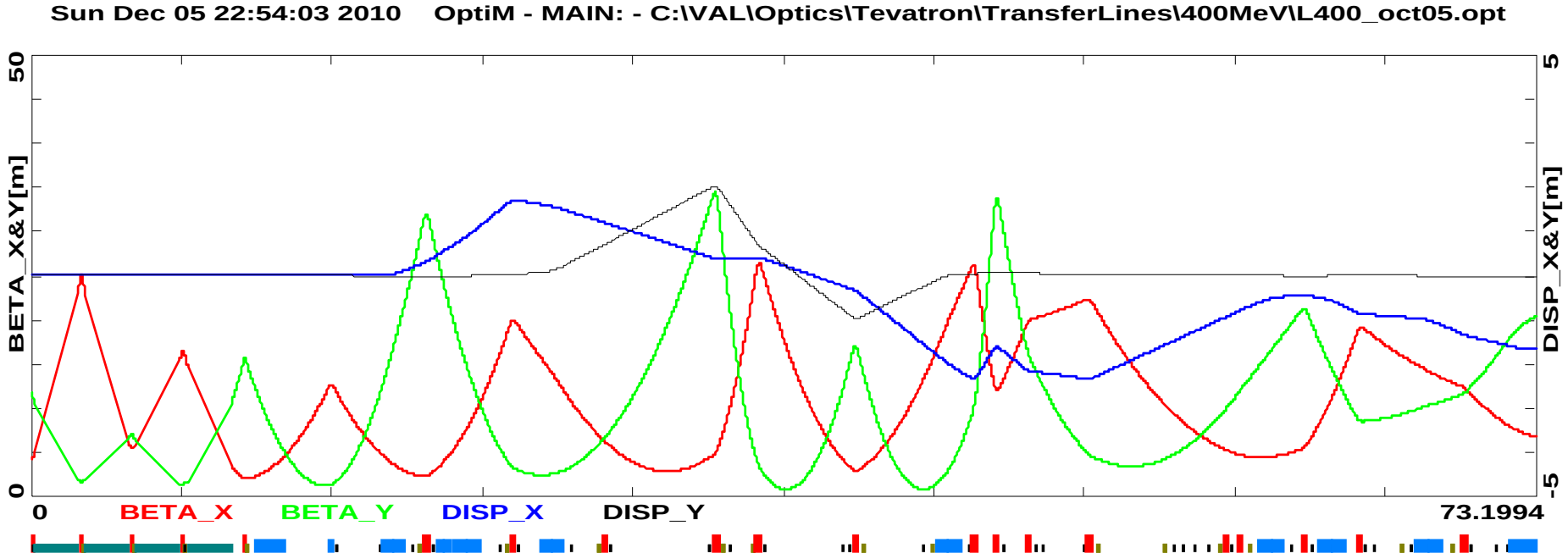
Optics of 400 MeV line

- The line has enough quads to match linac to Booster
- Finding a solution is not straight forward but matching can be done including matching vertical dispersion to zero

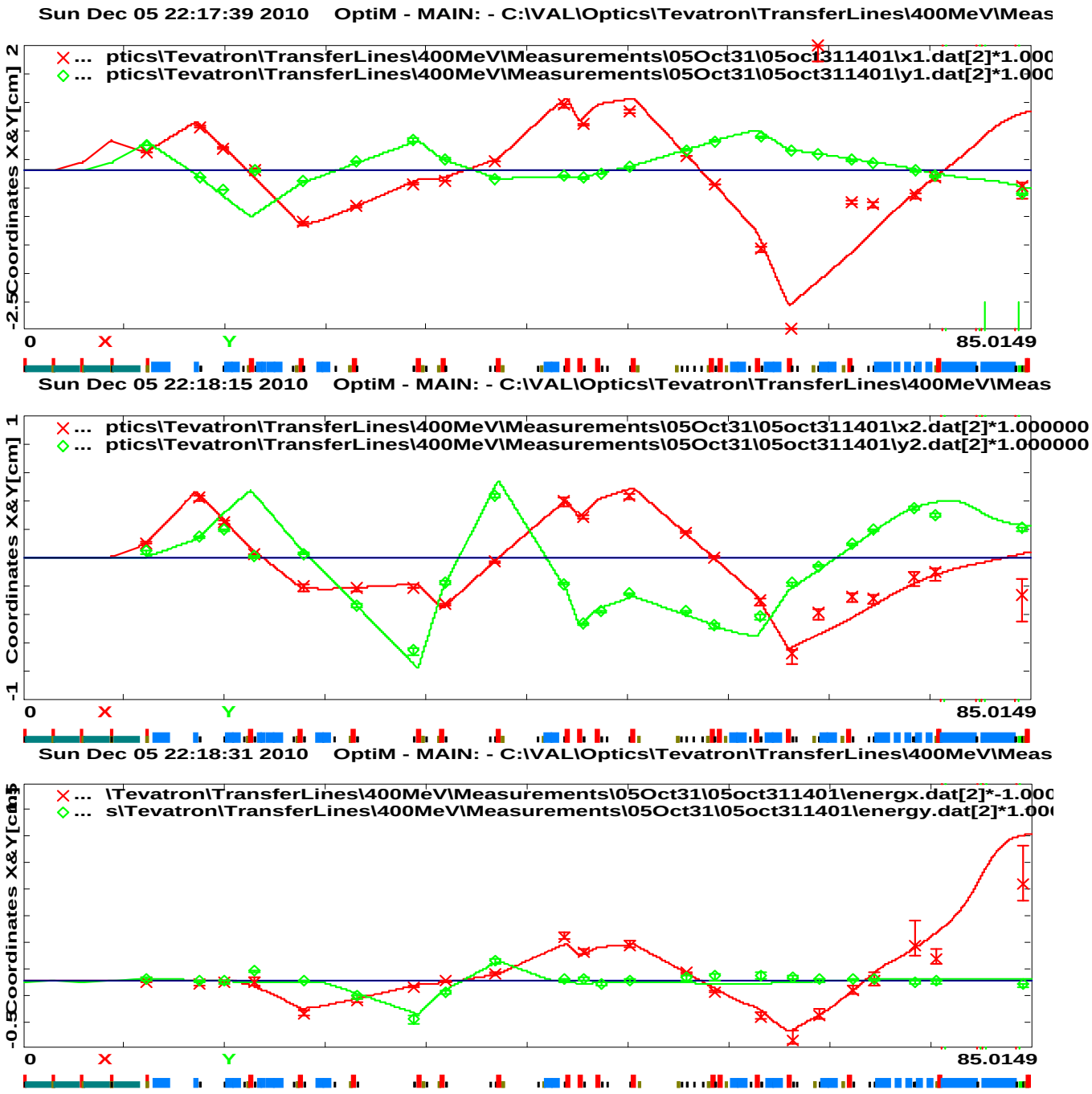


Design Twiss parameters for the line

- Studies in the fall of 2005 yielded some improvements but this work was not finished
  - Did not expect significant improvements of Booster performance
  - Poor knowledge of Booster optics

Optics measurements

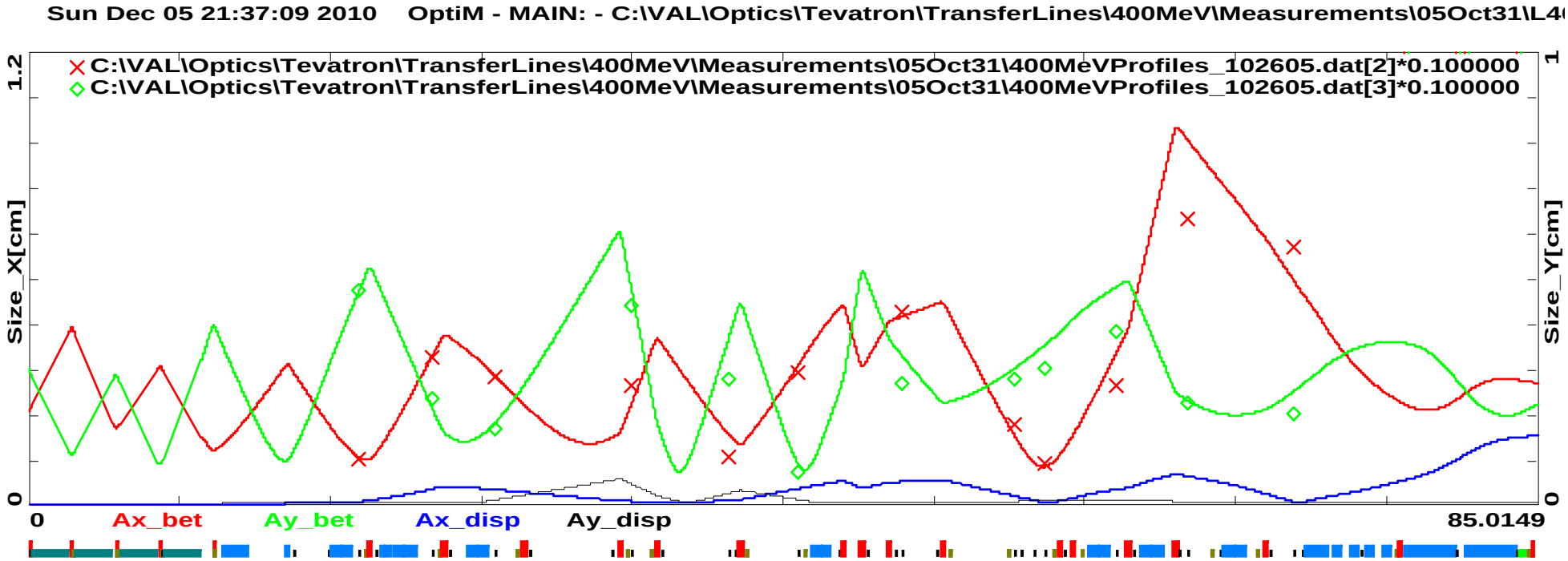
- Differential orbits were used to measure focusing properties of lattice elements
  - Five differential orbits
    - 2 vertical, 2 horizontal and energy kicks
  - Insensitive to the beam space charge
- Beam size measurements to find the emittances and Twiss parameters of beam injected in Booster
  - All profile monitors were used (12 hor. & 12 vert.)
  - For the 400 MeV line the beam sizes are affected by beam space charge
    - It was neglected in 2005



Results of differential optics measurements performed 31 Oct. 2005

- Differential responses of B:HPH23 and B:HPQ17 look incorrect
- B:HPSEPD did not work and was not used in fitting
- Quad fudge factors are up to 15%
- Q13, 14 & 17 very large discrepancy between setting and readbacks

Beam Profile Measurements and Linac Emittances

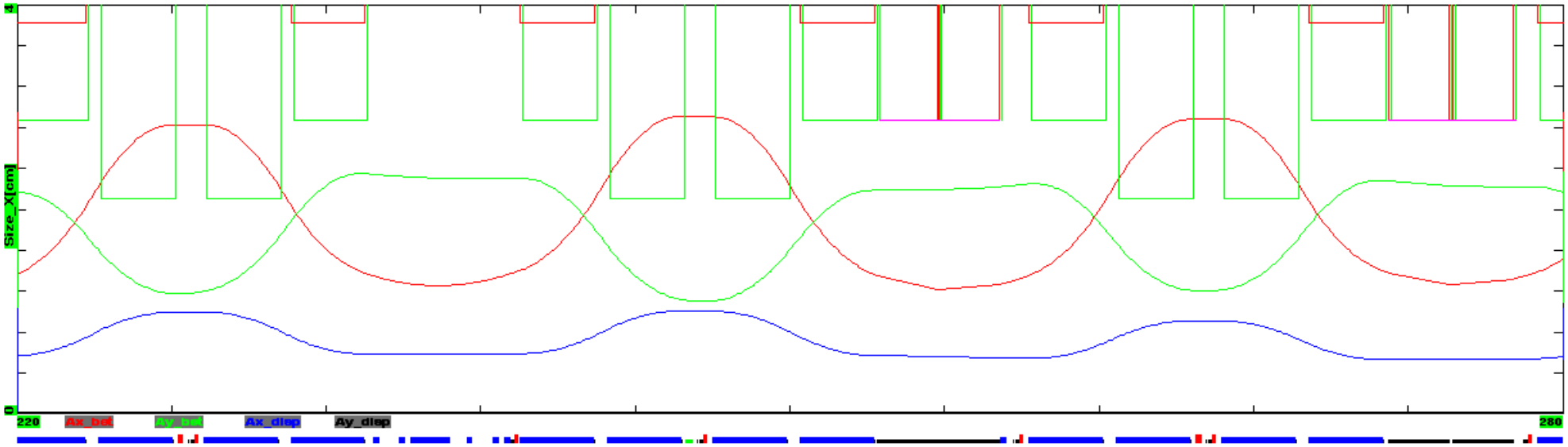


Simulated and measured rms beam envelopes. Measurements of at Oct. 26, 2005. Fitted rms emittances are 2.3 mm mrad

- Normally the rms norm. linac emittance is ~2.5 mm mrad
  - 95% emittance is 15 mm mrad
- The space charge affects the beam envelopes and has to be correctly taken into account in simulations
  - It was not done in 2005

Booster Acceptance

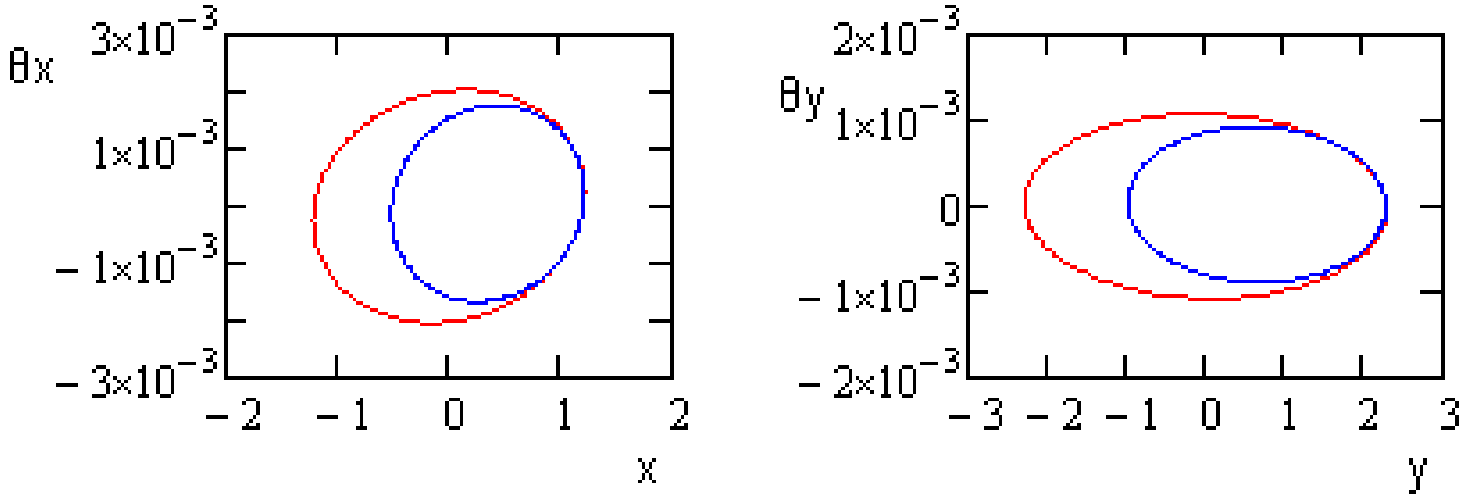
- Vertical acceptance is limited by dipoles to 25 mm mrad (norm.)
  - maximum vertical orbit offset of 5 mm is assumed)
  - ♦ Full acceptance 50 mm mrad (no orbit errors)
- RF cavities are located at minimum of β_x and do not limit both horizontal and vertical acceptances
  - ♦ ±15 mm total horizontal orbit displacement is allowed
    - For 5 mm orbit accuracy the momentum offset can be up to $5 \cdot 10^{-3}$
- Thus, the normalized acceptance of 25 mm mrad should be OK if there is no other aperture limitations
  - ♦ RF bucket size does not exceed $3 \cdot 10^{-3}$ during entire acceleration



Beam envelopes for 2 Booster periods for norm. beam acceptance of 25 mm mrad and $\Delta p/p=3 \cdot 10^{-3}$.

Linac to Booster Match

- If matched the linac rms size is only 1.3 times smaller than the rms size for Gaussian beam



Phase space boundaries of 95% emittances for Booster (red) and Linac (blue)

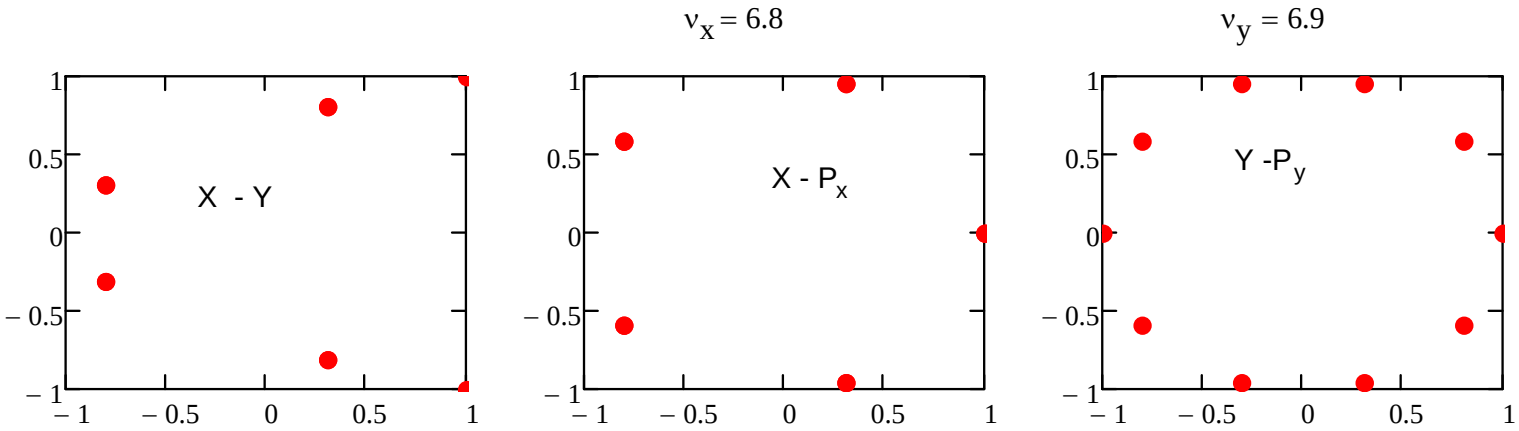
- Operation without painting requires some mismatch so that the arriving beam would take maximum aperture to minimize the space charge effects (present operation)
- Painting can be implemented if
  - Linac rms beam emittance is reduced to ~1 mm mrad
    - foil scattering: $\delta\varepsilon_{nx/ny\_rms}$= 0.17/0.6 mm mrad (600 μg/cm^2, 30 turns)
  - Or present beam is scraped to ~1.5σ; corresponding loss ~50%?

Additional Requirements for transverse painting

- Good betatron match of the linac beam to Booster
- Painting with beam motion looks unrealistic for 10 turn injection
  - Beam offsets in X and Y planes is the only choice
- Painting should not generate coherent beam motion after it is finished

  $\Rightarrow \nu = n / N_{turnInj}$

  $\Rightarrow$ For 10 turn injection: $\nu = n / 10 \Rightarrow (\nu_x = 6.8, \nu_y = 6.9)$
- Tune difference should be 0.05 or 0.01 to achieve good beam mixing between x and y planes after 10 turns
  - Injection simulations with space charge can make a small correction for required tunes



Conclusions

- Injection significantly longer than 10 turns will result in too large emittance growth and single scattering beam loss
  - Present foil scattering (600 $\mu g/cm^2$, 30 turns) yields
    - $\Rightarrow$ $\delta\varepsilon_x$=1 mm mrad, $\delta\varepsilon_y$=3.6 mm mrad (norm., 95%)
    - $\Rightarrow$ Beam loss ~0.5%
- Improvements of Linac-to-Booster matching without reduction of linac emittance and painting does not look promising
  - Already good enough
- Reduction of beam emittance with installation of RFQ allows one an implementation of beam painting and, potentially, reduction of beam loss during acceleration
  - Rms linac emittance of ~1 mm mrad is required

Backup viewgraphs

Fudge factors used for linac optics corrections

Name	%	comments
$FQ74	12	
$FQ2	7	
$FQ3	1.5	
$FQ4	-9.5	
$FQ5	0	
$FQ6	-3.4	
$FQ7	1	
$FQ8	-6.3	
$FQ9	-7	
$FQ10	3.3	
$FQ11	-15	
$FQ12	-5	
$FQ13	425	set by readback
$FQ14	-23	set by readback
$FQ15	9	
$FQ16	0	
$FQ17	-75	set by readback

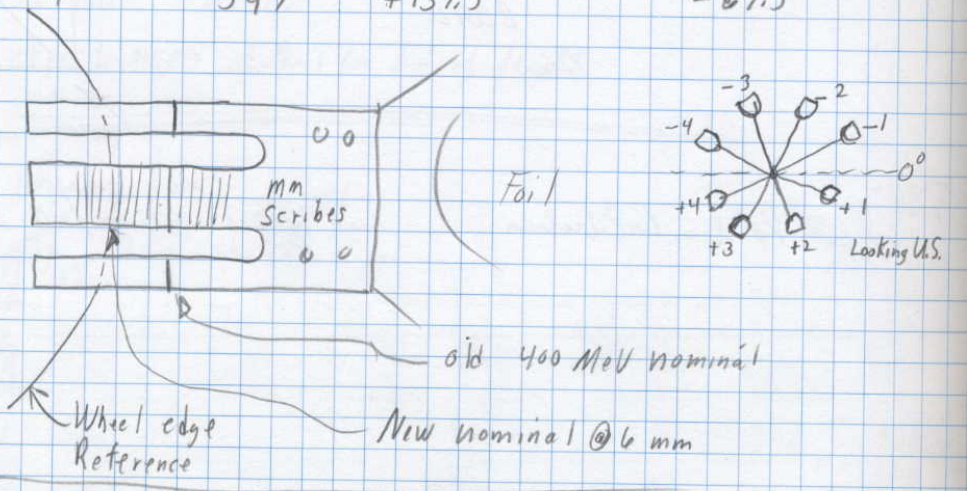
Booster aperture limitations used for optics analysis

Name	Ax[cm]	Ay[cm]	Shape
hRF	2.85	2.85	round
hmagF	5.46	2.08	rectangular
hmagD	3.81	2.85	rectangular

Used foil thickness

110 5/9/06 Foil Installation JRL

Foil Position Number	Installed Foil Density	Stripping Position Command	View Position Command
-4	306	-157.5	-22.5
-3	335	-112.5	+22.5
-2	369	-67.5	+67.5 ←
-1	409	-22.5	+112.5
1	411	+22.5	+157.5
2	339	+67.5	-157.5
3	461	+112.5	-112.5
4	547	+157.5	-67.5



Foil changer Command Volts to Read Volts

$y = 9e{-}4\,x^2 + 98.72e{-}2\,x - 7.92e{-}2$ R^2 0.9996

Scaling for Read back voltage is 15.75 °/volt

fit of actual Position (degrees) to Readback voltage is

$y(\text{deg}) = -12.3\times10^{-3}x^2 + 15.983x + 1.2365$ x in volts

This is the computer Transform