# Booster Injection in the Era of PIP-II a Preliminary Assessment

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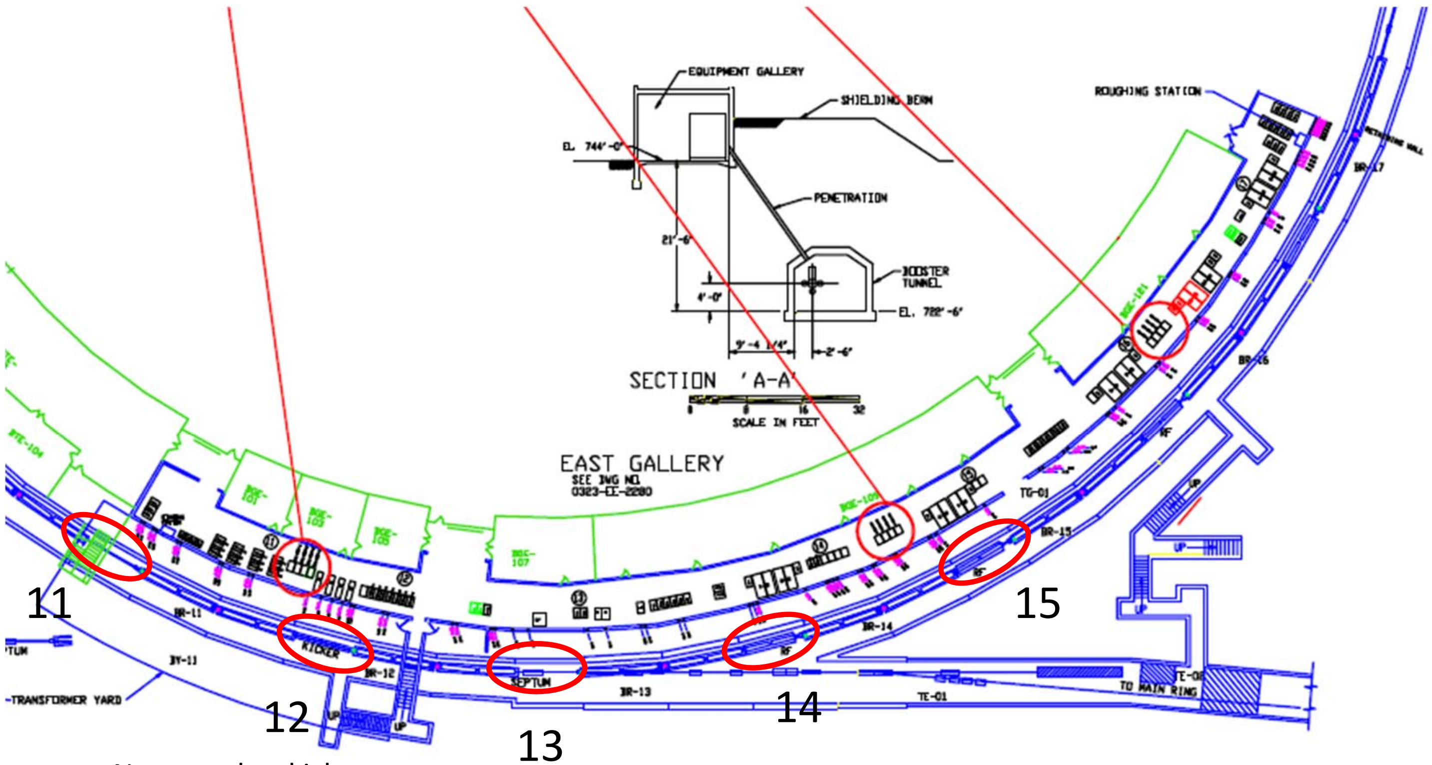
- What is shown is a preliminary assessment of the issues of injection into Booster.
- I'll describe a couple of potential geometries but none of them have been optimized.
- As of current we do not have any task codes associated with Booster modifications for 800 MeV injection.

# 800 MeV Booster Injection Issues

- Which straight section to inject?
  - Current concept is on East side of Booster (long 11-15 region)
  - Should miss East side Transformer yard, if possible
- Injection straight geometry and optics (ring modifications)
- Transverse matching and painting
- Foil issues
- Waste beam –> do we need an injection absorber
- Magnet/GMPS/ramp issues
  - Flatten BMIN ? What new magnets needed?
- Longitudinal dynamics --- Not addressed here
  - Adiabatic capture – should look into
  - Micro-bunch to bucket injection – preliminary estimates (C.Y Tan)
- Injection Line properties – not addressed, but should not be a big deal

# Potential locations in Booster for New Injection Insert



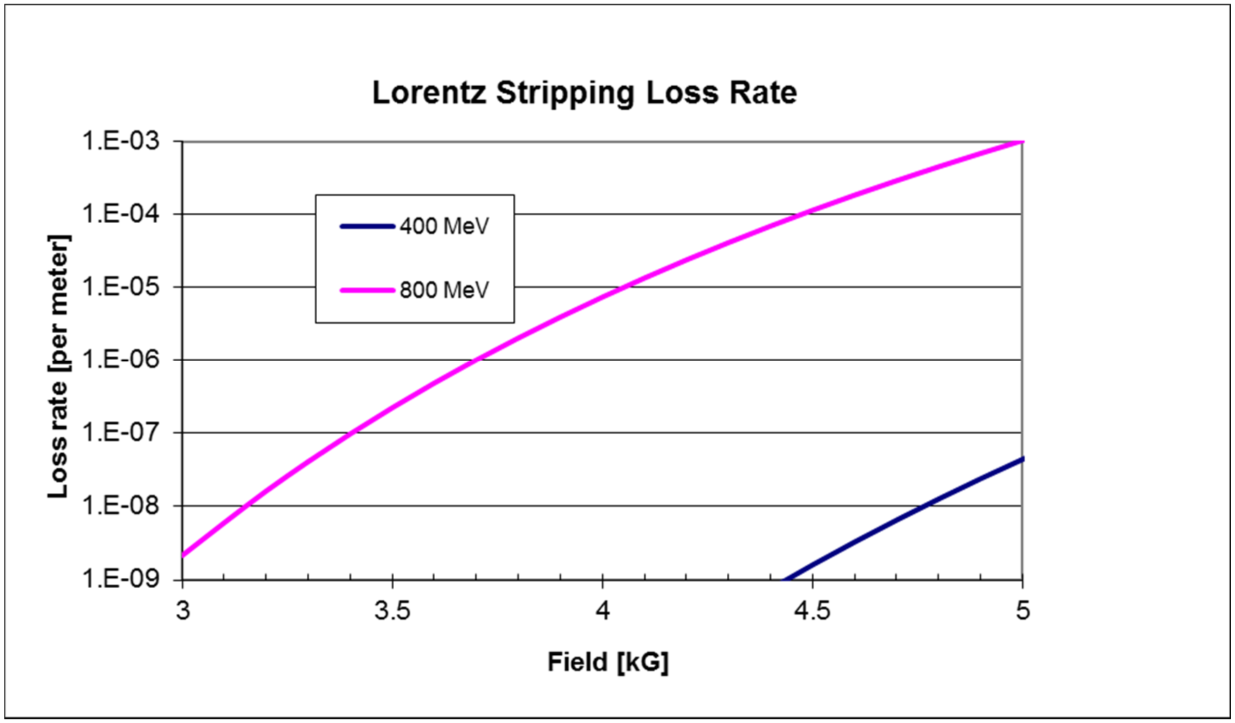

New notcher kickers

New notcher absorber

# Assumed PIP-II Parameters

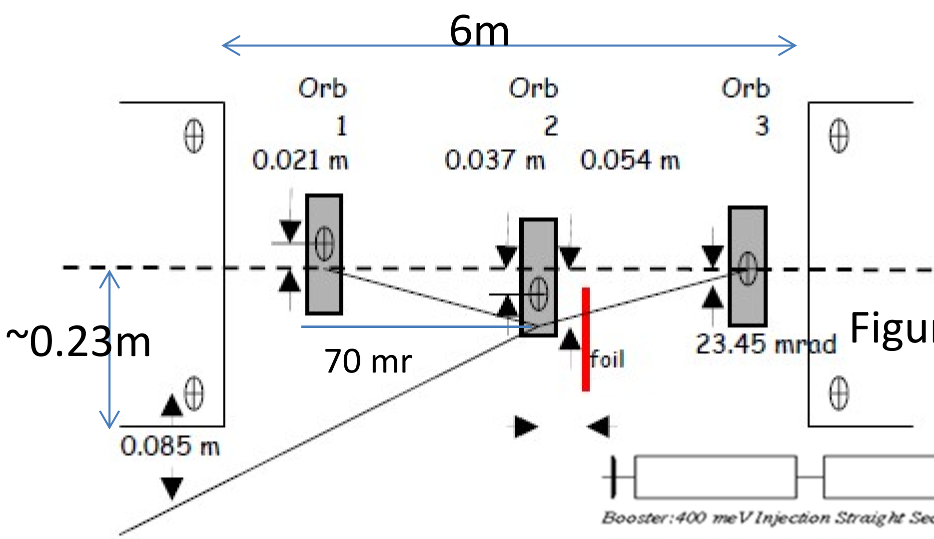
- Linac (pulsed)
  - Kinetic energy 800 MeV
  - Bunch frequency 162.5 MHz
  - Beam pulse length ~ 0.56 ms
  - Transverse emittance <0.3 mm-mr (rms-normalized)
  - Longitudinal emittance <1.1 keV-ns (rms-normalized)
  - Bunch length 4 ps (rms)
  - Energy spread (bunch) ~ 0.275 MeV (rms)
  - Average current 2 mA (averaged over 1 us)
- Booster
  - RF frequency 45.305 MHz
  - Revolution period 1.854 usec
  - Protons/pulse injected 7.0E12
  - Injection time ~0.56 ms
  - Injection turns ~315
  - Rep rate 15 Hz
  - Injected beam power 13.44 kW
  - Transverse emittance 15 $\pi$-mm-mr ($6\sigma$, normalized)

# Peak dipole fields for H-




- At 800 MeV
  - dipole field of ~ 4 kG gives loss rate of 7.44E-6 /m
  - dipole field of ~4.8 kG gives loss rate of 4.55E-4/m (~8.7 μs lifetime)
- Field limits depend on dipole length and distance from foil

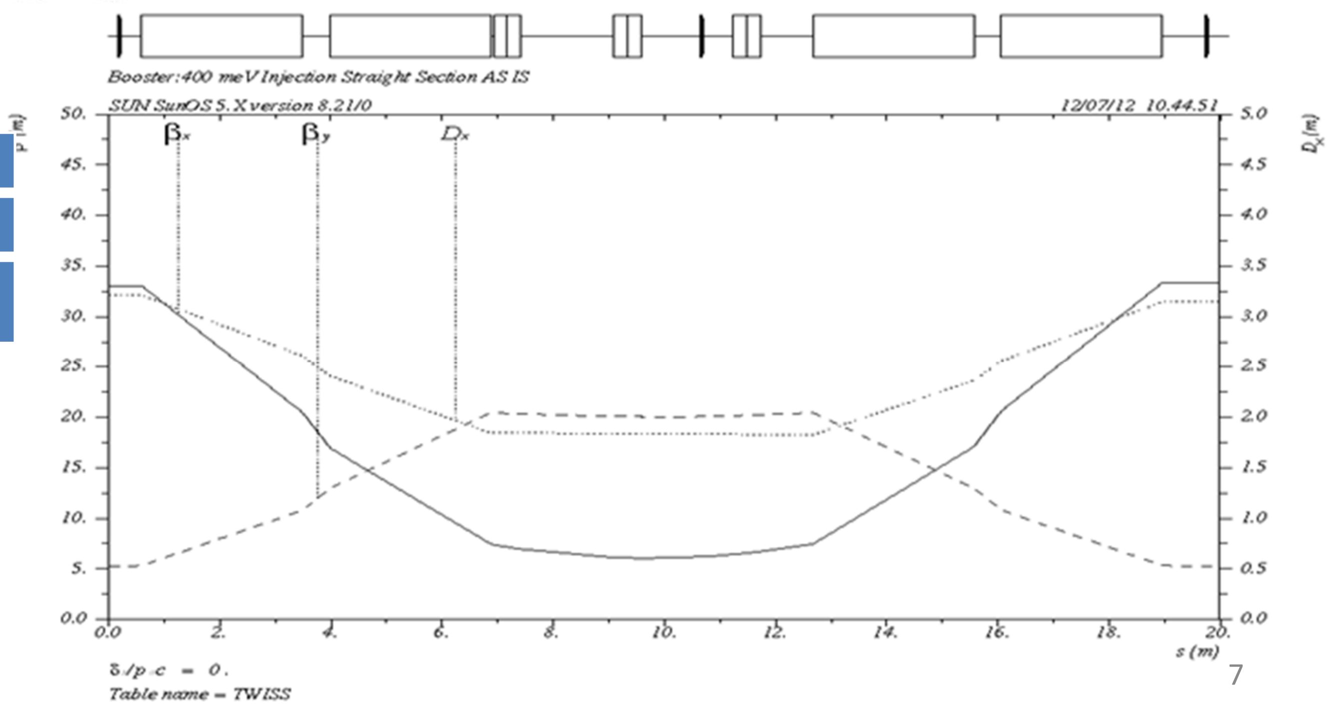
# Existing Booster – Straight Section



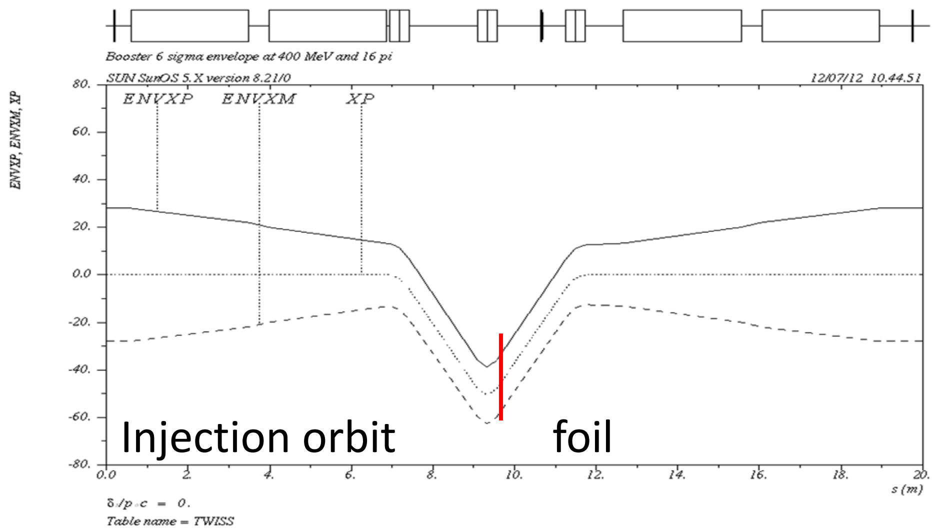

SNS (1 GeV inj) 12.3m
4 bump chicane
2nd foil to convert waste to P
External injection absorber

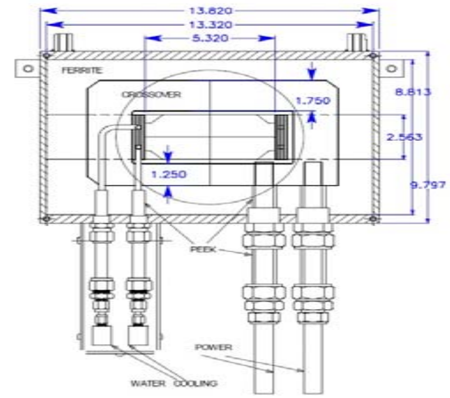
Figure from Jim Lackey

| | |
|---|---|
| $\beta_x$ | 4.88 m |
| $\beta_y$ | 18.52 m |
| $D_x$ | 1.73 m |



# Existing Booster & Orbump



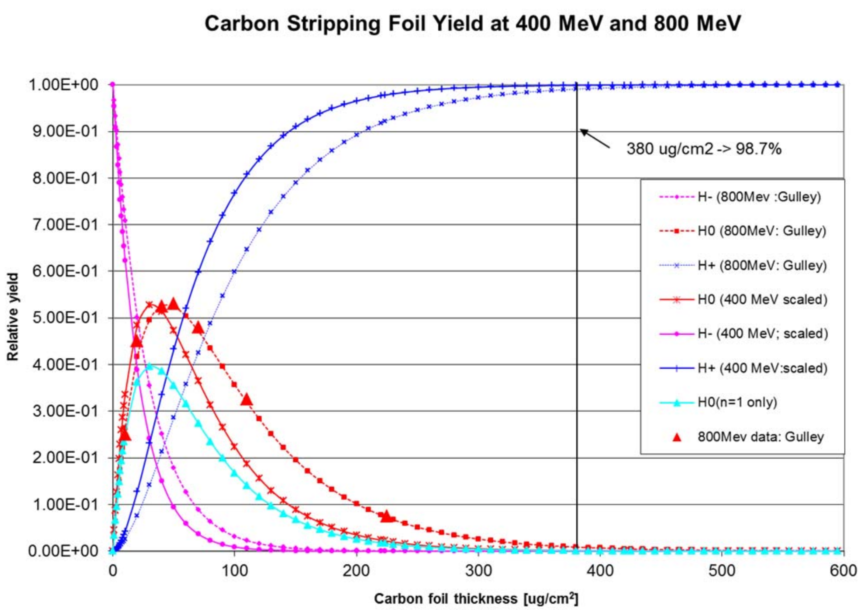




Design peak integrated field 1.676 kG-m
Peak field ~ 3 kG -> Leff= 0.5597 m.

Fixed field during injection

- Injection orbit ~45 mm outside at center ORBUMP magnet
- Injection foil edge ~ 32 mm
- Stripped & unstripped ions exit foil on same trajectory toward centerline
- Center ORBUMP Θ~44 mr ( ~1.4 kG-m) → **800 MeV requires peak field of ~3.8 kG**
- Outer magnets Θ~22 mr Doubling the center ORBUMP magnet could allow the use of the existing insert, BUT….
- Injection loss from neutrals and H- on $2^{nd}$ GM downstream
  - With 5E12/cycle & 7.5Hz -> ~ 2.4 kW injected
  - For 0.1% inefficiency -> ~2 W loss -> Rad surveys show "a few R on contact"
  - Since upgrade will yield increase of beam power by factor ~5 to 6, it is prudent to address this waste beam by integrating some type of injection absorber

# Foil Stripping



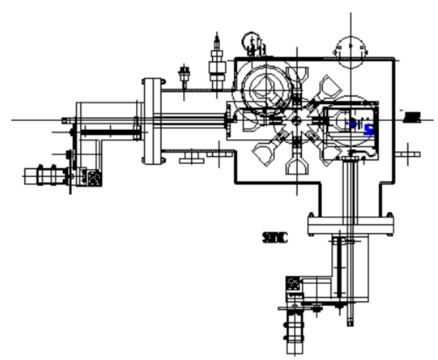

For a std. foil thickness 380 $\mu$g/cm$^2$ (1.15 $\mu$m)

400 MeV -> 99.9% efficiency to protons
800 MeV -> 99.1% efficiency to protons

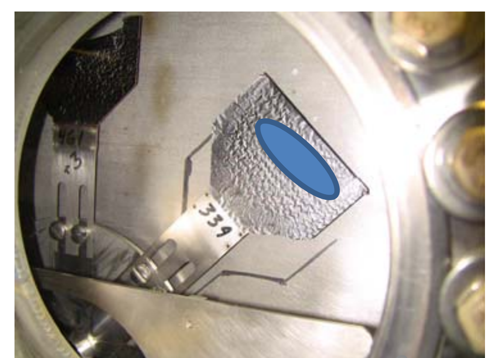
To match 400 MeV efficiency at 800 MeV
foil thickness needs to increase to ~545 $\mu$g/cm$^2$

At 800 MeV with 7E12 injected at 15 Hz
Injection power increases to ~ 13 kW.
For a 0.1% loss -> 13 Watts on d.s. GM.
-> **<u>Need to provide injection absorber</u>**

current foil holder

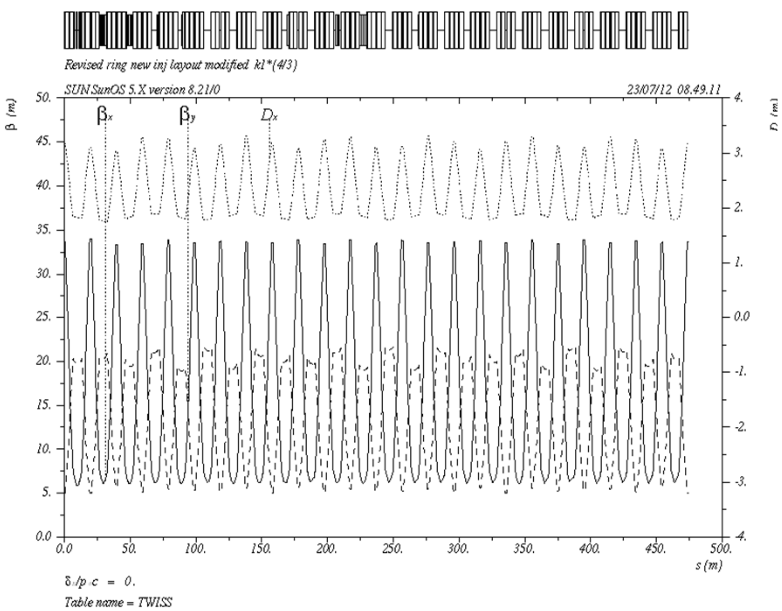


current foil

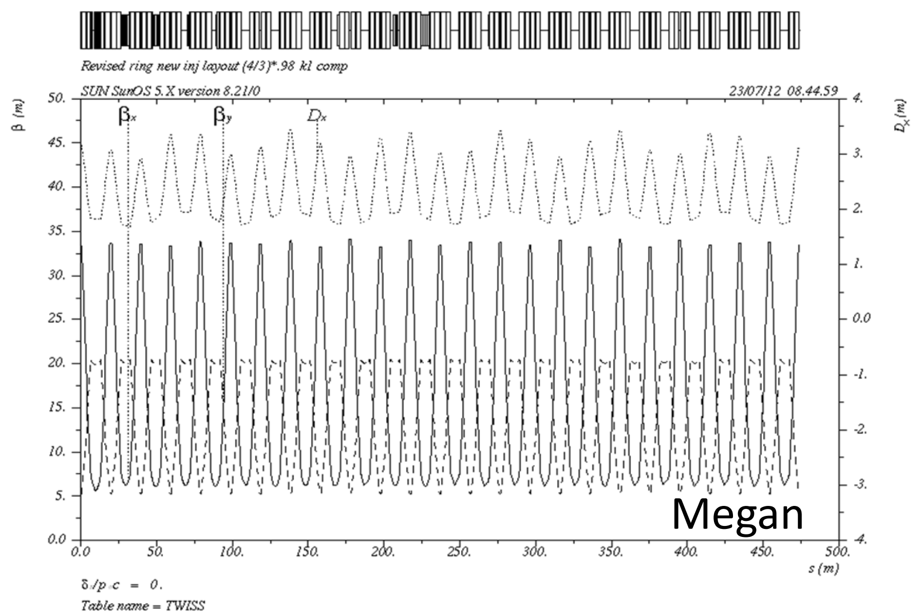


# Increase straight section

- Reduce defocusing gradient magnets on either side of straight section by 25%
  - Scale gradient, dipole field keeping bend center fixed
  - Allows modest increase of 0.72 meters (maybe enough to add in injection absorber)

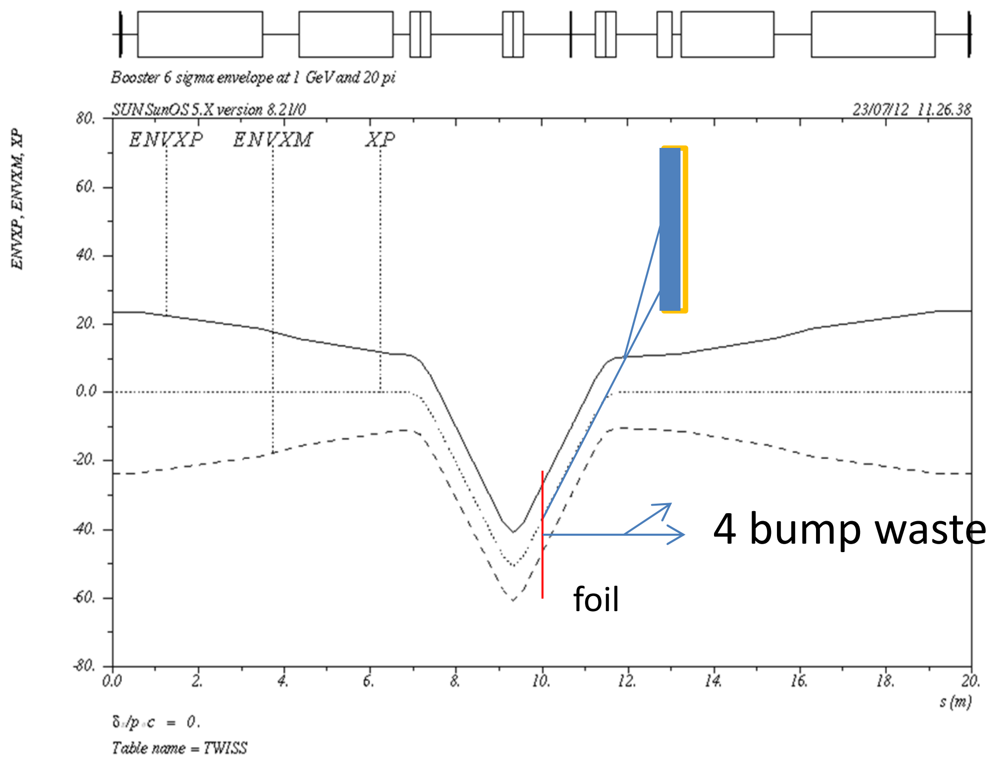



Gradient error due to shortening




Reduce gradient to 98% scaled value

# Horizontal Injection Concept




Outer ORBUMP

~ 22mr -> 1.92 kG

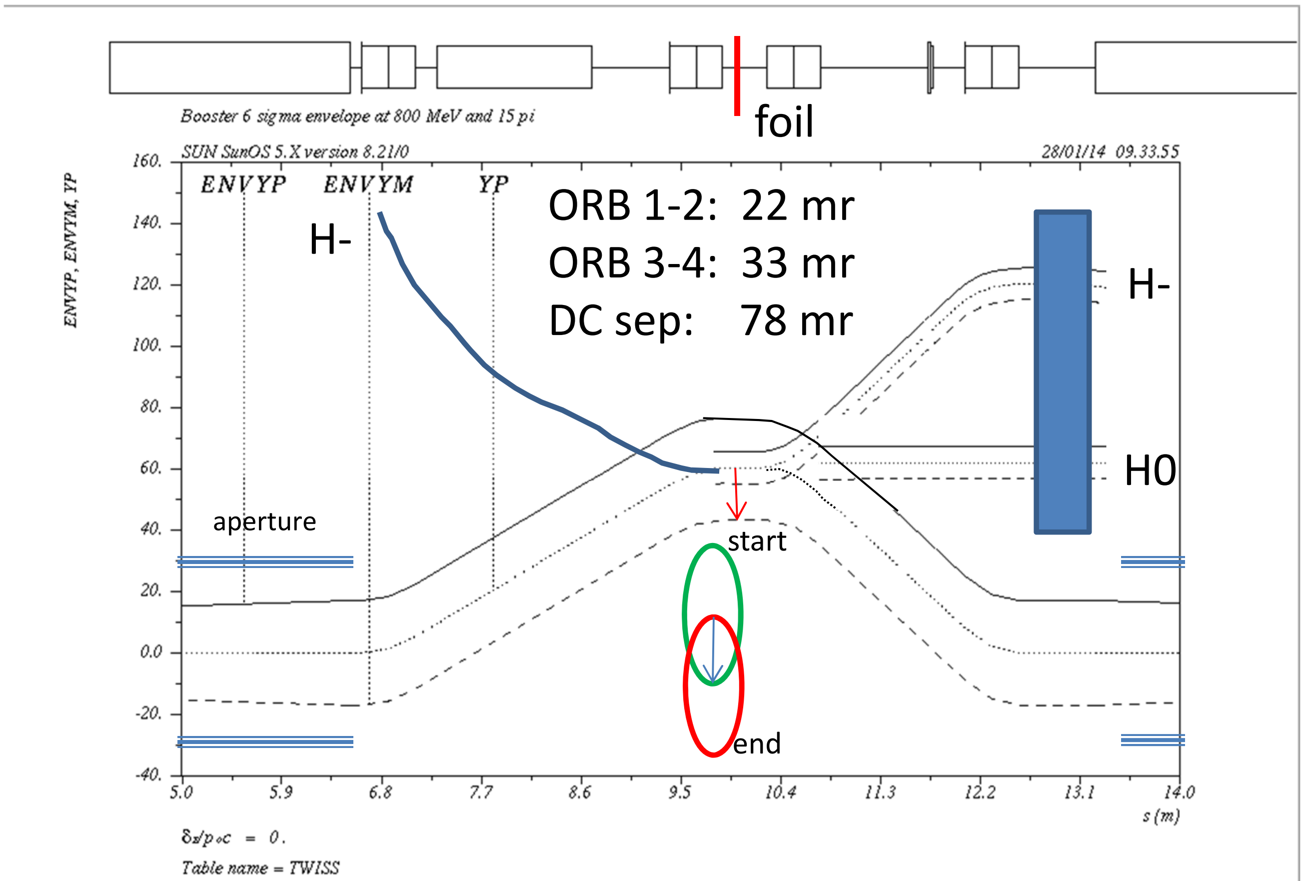
Center ORBUMP

~44 mr -> 3.8 kG

-> use 2 magnets

- Example of Horizontal injection with reduction of GM length to allow for injection absorber. Here the center ORBUMP magnet would need to be replaced with 2 magnets to reduce peak field. The foil is downstream of center bump.
- If the central magnets are separated, the foil could be placed in the center thus the waste beam would not cross the center orbit.

# Vertical Injection Concept

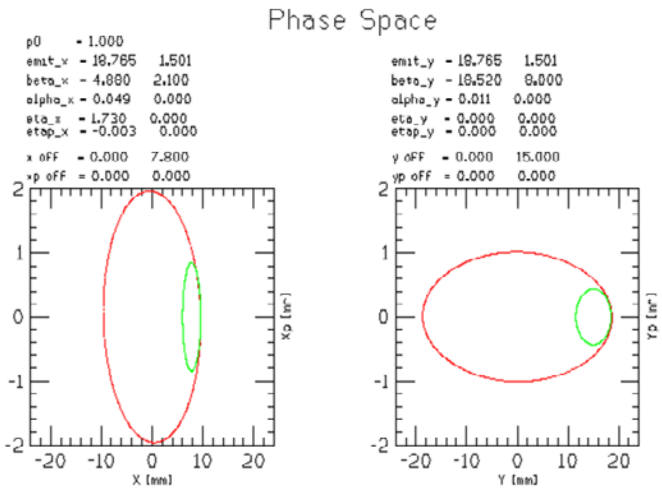


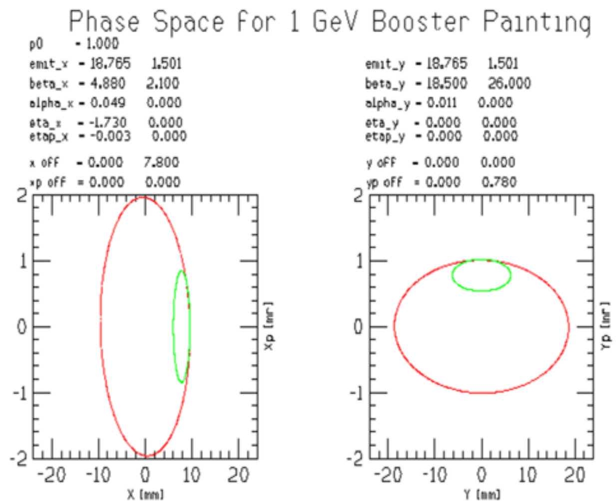

These two examples indicate dedicated absorbers. Another option could be an internal absorber in the downstream gradient magnets.

# Injection Painting

- Painting Schemes
  - Paint in the ring in both dimensions (SNS)
  - Paint in ring/steer beam line (angle @foil) JPARC
  - Correlated or anti-correlated
  - Functional form - exponential, square root, sin/cos
- Use ORBUMP magnets for painting?
- Where to install painting magnets (H and/or V)
- Status/Plans
  - Only concepts at this point
  - Focus in on a geometry, then
  - Initiate painting simulations using STRUCT
    - Final phase space distribution
    - Number of parasitic hits & distribution
    - Parasitic hit density used to determine the foil equilibrium temperature

# Matching Beam Line to Ring




Red ellipse ring final phase space    Green ellipse injected beam from Linac.

- Beam line matching conditions for two painting scenarios. Left paint in both planes in the ring (SNS) and right paint horizontal in ring and steer (angle mismatch) from beam line (JPARC).
- Painting in both planes in the ring increases apertures in the injection insert to accommodate orbit excursions in both planes.

# Painting Schemes

| Type | Advantage | Disadvantage |
|---|---|---|
| Correlated | Paint over halo<br>Square profile | Singular density<br>Coupling emittance growth |
| Anti-Correlated | Immune to coupling<br>Circular Profile | Halo Growth due to space charge<br>Extra 50% aperture |
| H-V Coupled | Paint over halo<br>Diamond Profile | Extra Aperture |
| Paint (H)/ Steer(V) | Similar to anti-correlated<br>Fewer Kicker | Foil Support Difficult<br>Susceptible operation error |
| Paint V/ Steer H | Similar to Anti-correlated.<br>Fewer Kicker | Vertical injection<br>Susceptible to operation error |
| Oscil. Bump | Paint over halo<br>Circular profile | Fast PS Switch<br>Extra 50% Aperture |

# Foil Issues

- Some of the issues that need to be addressed relating to stripping foil
  - Stripping efficiencies
  - Multiple Coulomb scattering
  - Large angle and Nuclear scattering
  - Energy straggling
  - Heating
  - Stress and buckling
  - Lifetime
  - Radiation
  - Stripped Electron
  - Emittance Growth

Comparison:

| **SNS** - | **Booster** – |
| --- | --- |
| 1 GeV | 800 MeV |
| 1 MW injection power | 13 kW injection power |
| 60 Hz rep rate | 15 Hz rep rate |
| 1 ms injection | 0.6 ms injection |
| $1.5\times10^{14}$/cycle | $7\times10^{12}$/cycle |
| ~1100 turns | ~320 turns |

Minimum number of parasitic hits/particle estimated from D. Raparia

$$h_{min} = \frac{1}{4} N_t \left(\frac{\varepsilon}{\mathrm{A}}\right)^{\frac{4}{3}}$$

where for Booster $\varepsilon$/A ~ 0.1
for SNS $\varepsilon$/A ~0.01

# Summary

- Preliminary investigations indicate:
  - We can inject into Booster at 800 MeV.
  - Prudent to include injection absorber into design
  - No show stoppers identified.
- No serious effort has been made on 800 MeV injection into Booster for PIP-II
- NO Task codes to support such an effort, yet.
  - Will probably come after P5 endorses PIP-II