800 MeV Injection into Booster in the PIP-II Era

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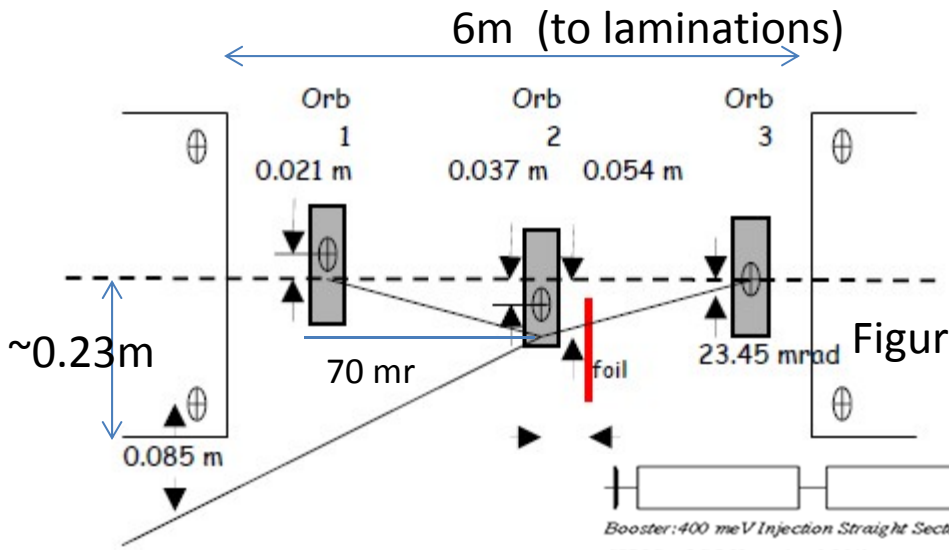
Beams-doc 4683

Parameters

- Existing Booster injection (400 MeV)
  - 5E12 @ 7.5 Hz (soon to be upgraded to 15 Hz for PIP)
  - 2.4 kW beam power at injection
  - Foil thickness 380 $\mu g/cm^2$ should give 99.9% stripping efficiency (2W loss)
    - 20 mr/hr @ 1 ft due to neutrals (downstream loss point on 2nd GM)
  - Assume ½% lost by other means (10W loss)
    - 100 mr/hr @ 1 ft due to H- missing foil (upstream loss point on 2nd GM)
  - Injection time < 35 us (for 16 turns)
- PIP-II Operational Parameters (800 MeV)
  - 6.633E12 @ 20 Hz for ~ 17 kW injected beam power (x7increase)
  - Linac 95% normalized emittance 1.5 π-mm-mr (H&V)
  - Booster final 95% normalized emittance 16 π-mm-mr (H&V)
  - Injection time ~560 us Injection turns ~315
- PIP-II Beam loss at injection assumptions (~360 W loss)
  - H- conversion efficiency 99.9%
    - Foil thickness increase from 380 to 545 $\mu g/cm^2$
    - Implies 17 W to absorber
  - H- missing foil 2%
    - Implies 340 W to absorber

Existing Booster – Straight Section



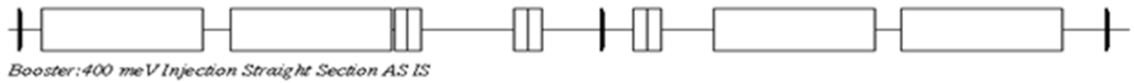
No injection absorber

Waste beam lost in 2nd gradient magnet downstream

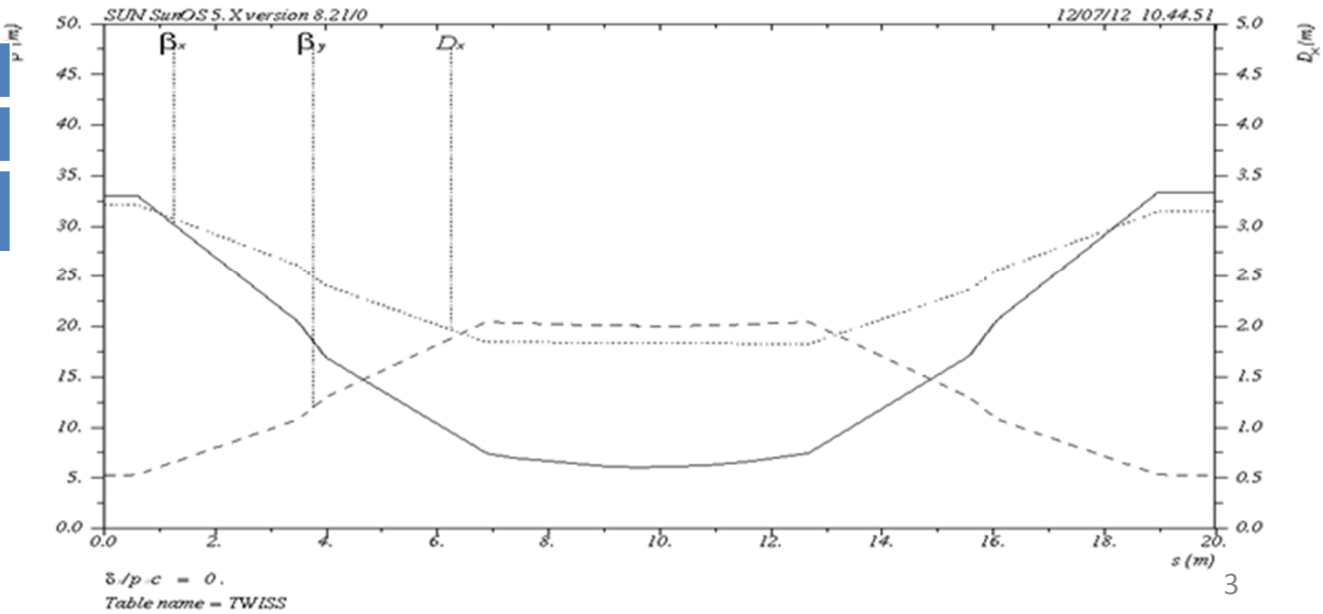
PIP-II power increases X7 -> ~17 kW

Figure from Jim Lackey '07 PAC paper

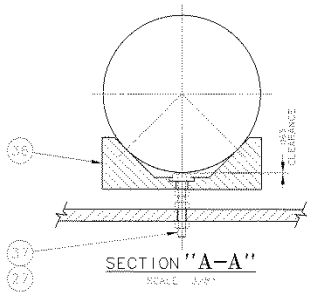
Installed 2006

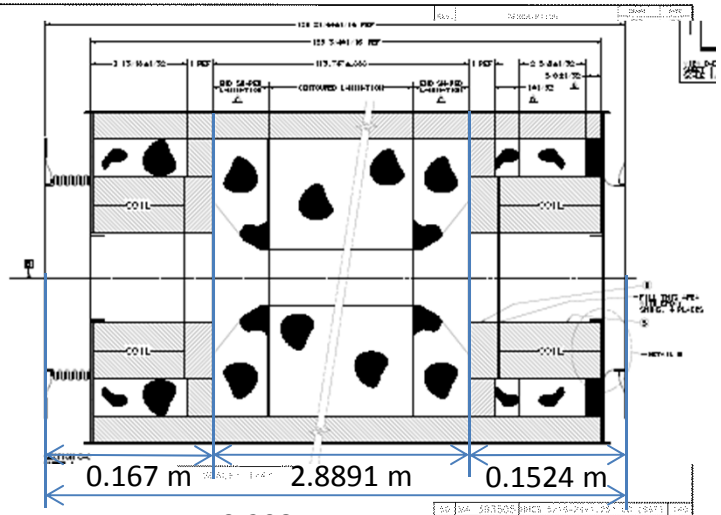


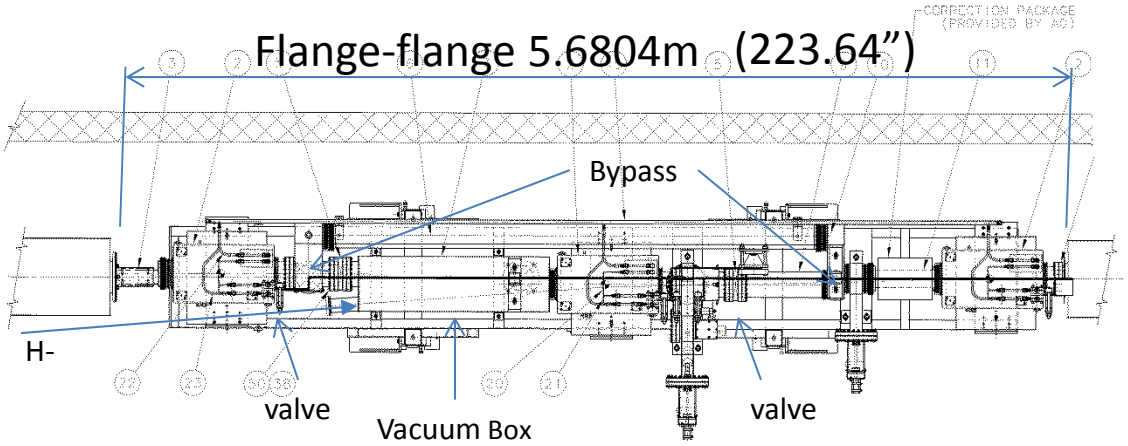
β_x	4.88 m
β_y	18.52 m
D_x	1.73 m

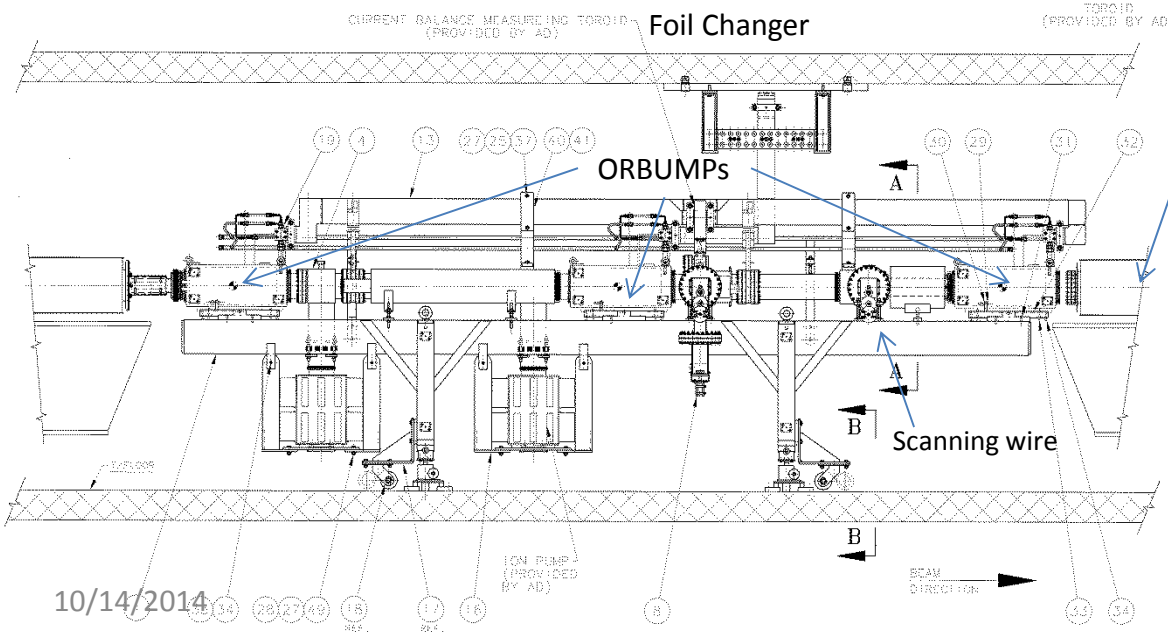


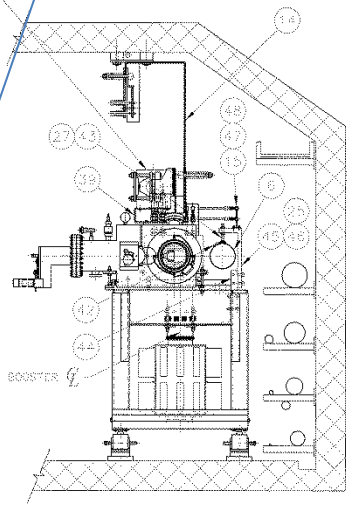
PHYSICAL LAYOUTOF INJECTION GIRDER

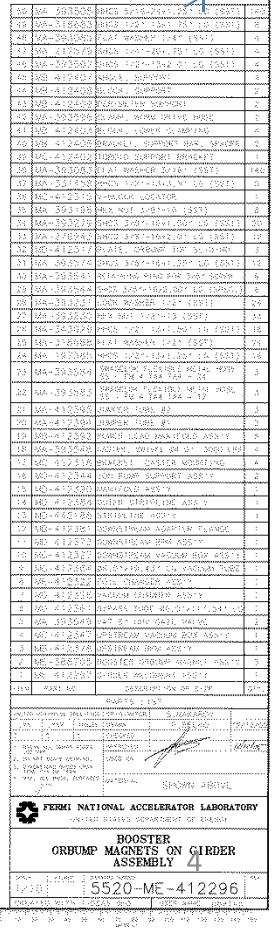












Current Geometry Real Estate

- Existing Equipment fit within 223.64”
  - BPM assembly 12.46”
  - 3 Orbump magnets (28.808”) 86.424”
  - Vacuum box to merge inj. Beam 48.538”
  - Vacuum bypass (2) 20.86”
  - Vacuum valves (2) 5.52”
  - Foil changer 12.25”
  - Crawling wire (diagnostics) ~ 6”
  - Correction package ~19.43” (17” steel 5” aperture)
  - **Total real estate used** **211.482”**
  - Drift space/connections/etc. 12.155”

Ideal Design features

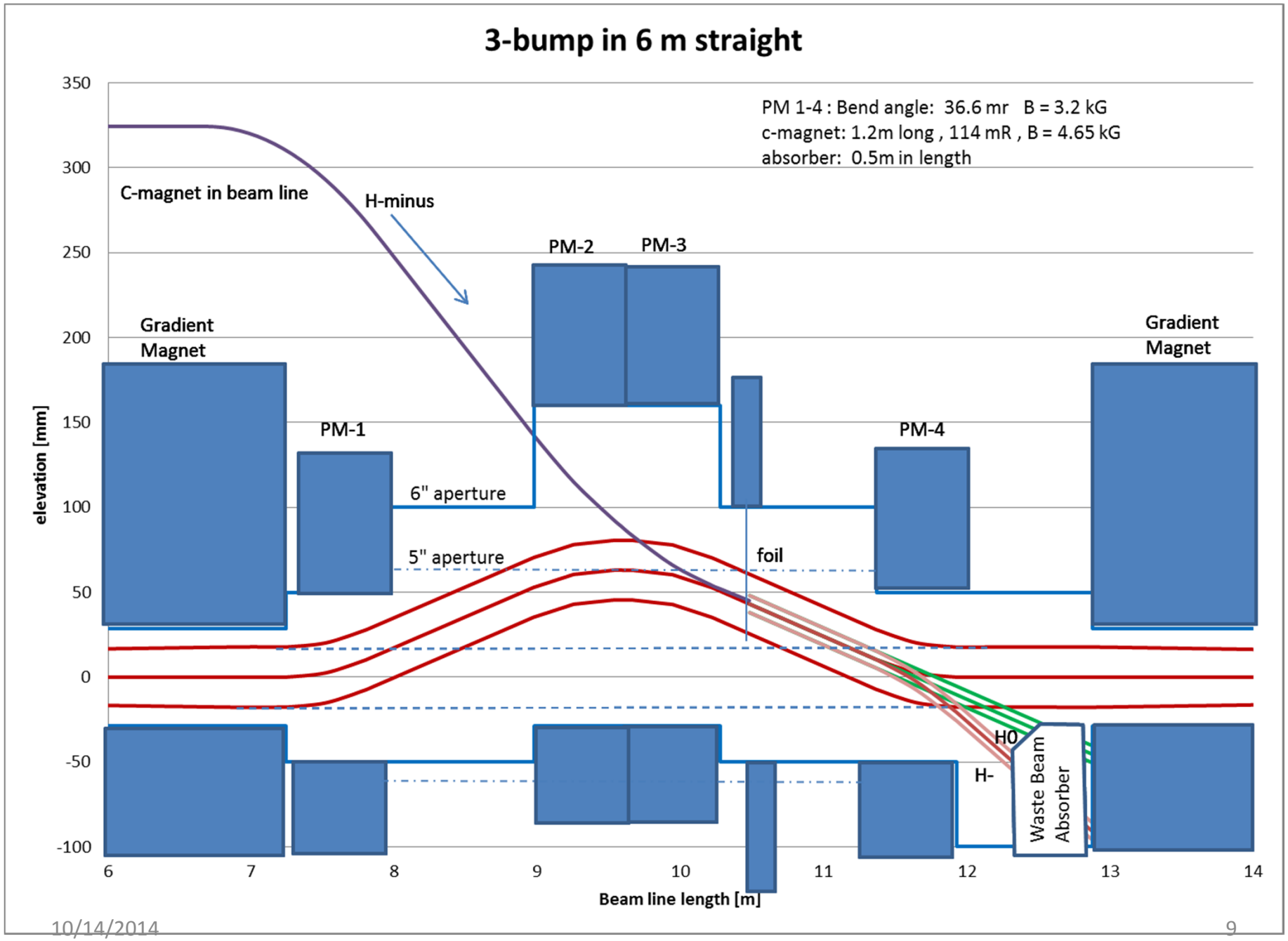
- Separate chicane and painting dipoles
  - Chicane operate on both circ. and injected beam
  - Painting dipoles operate only on circulating beam
- Separate foil from circulating beam
- Well shielded absorber for injected waste beam not to interfere with circulating beam
- Vacuum bypass for foil changer
- Injection diagnostics (bpm & profile monitor for waste beam & circulating beam)

Options for New Design

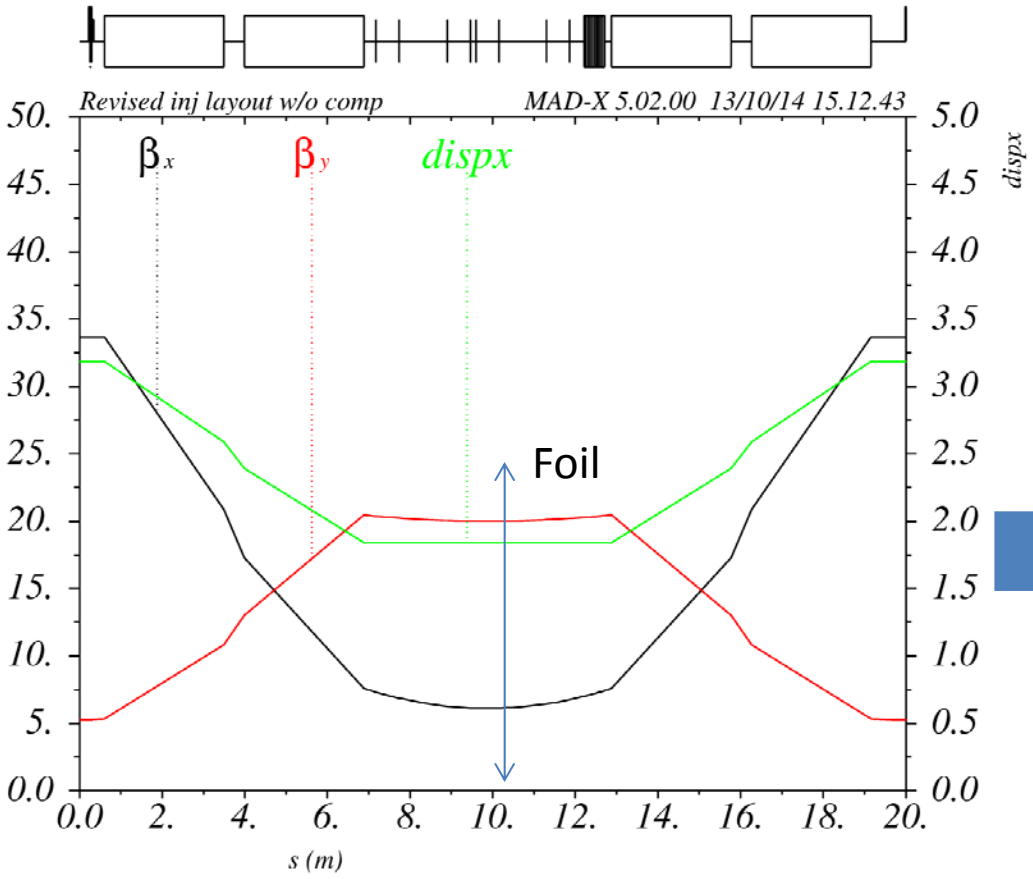
- Chicane Geometry -> Vertical
  - Relative Horizontal & Vertical beam size at foil
  - Limited vertical aperture of surrounding gradient magnets
  - Chicane dipoles double duty as vertical painting magnets
- Horizontal painting magnets outside straight
- Three or four bump design
- Make things fit with existing straight, or
- EXPAND existing straight by shortening defocusing gradient magnets

Initial Conceptual Design

- Length of Booster straight section remains unchanged.
- Three bump design (vertical chicane)
  - Single magnet at each end
  - Two magnets in the middle
- Use chicane dipoles for vertical painting
  - Requires new magnet
  - Requires new 20 Hz power supply
    - ~500 us vs 30 us injection time
    - Flattop waveform changes during injection time for painting (C.O.-> 45mm to 30 mm
- Use horizontal dipoles outside straight for horizontal painting (not included yet in model)
- Injected H- position at foil (~45mm V & ~5mm H)
- H- injection line comes into ORBUMP #2 at an angle of 114 mr
- Separation between ORBUMP 1 & 2 and 3&4 at 1.01 meter


3-bump in 6 m straight
PM 1-4 : Bend angle: 36.6 mr B = 3.2 kG
c-magnet: 1.2m long , 114 mR , B = 4.65 kG
absorber: 0.5m in length
C-magnet in beam line
H-minus
PM-2
PM-3
Gradient Magnet
Gradient Magnet
PM-1
PM-4
6" aperture
5" aperture
foil
H0
H-
Waste Beam Absorber
elevation [mm]
Beam line length [m]
350
300
250
200
150
100
50
0
-50
-100
6
7
8
9
10
11
12
13
14

Booster Straight Section Lattice



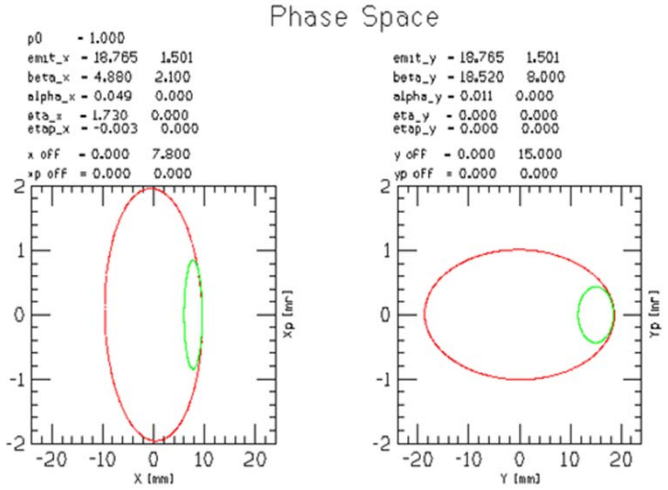
β_y	18.52 m

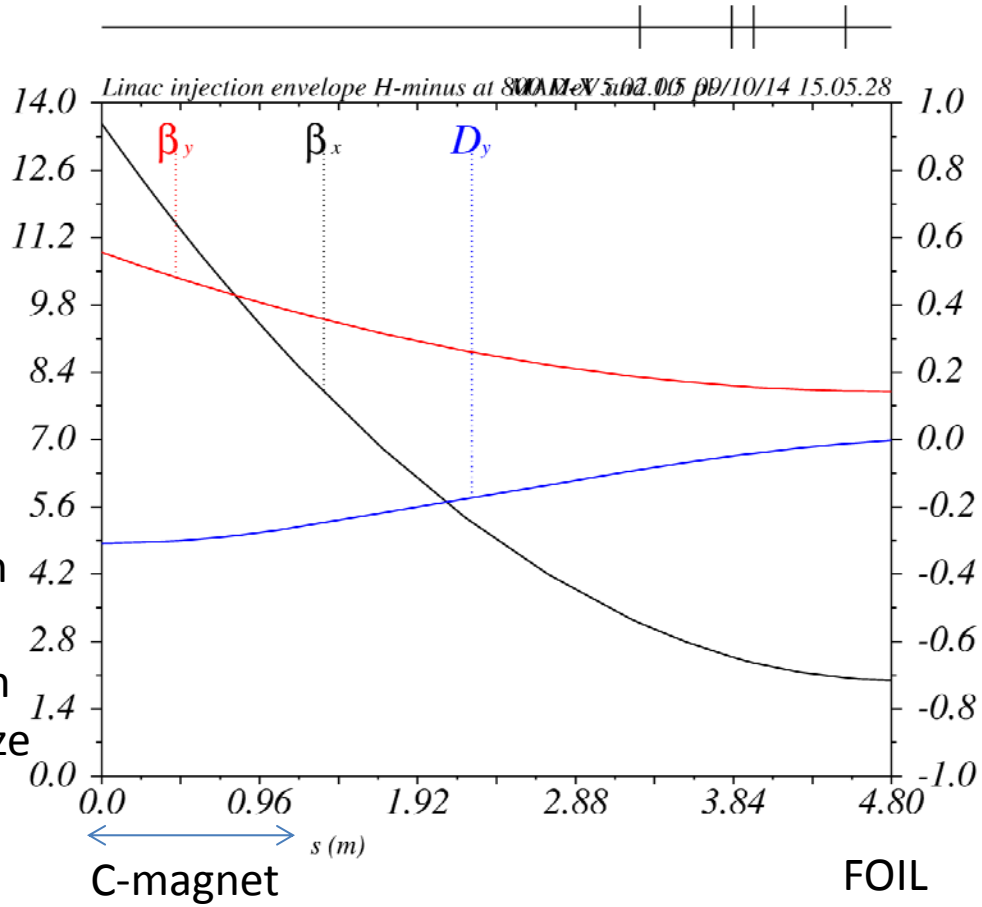
β_x	4.88 m

D_x	1.73 m

Injection Beam Line Lattice

Red- circulating lattice
Green – injection lattice





- Circulating beam closed orbit motion
  - start centered on green ellipse
  - move to zero dx=7.5 mm dy=15 mm
- Lattice function mismatch to minimize foil hits from circulating beam
  - betax 4.88 ring vs 2.1 beam line
  - betay 18.52 ring vs 8.0 beam line
  - alfa x&y = 0 for upright ellipse

- Beam line must match (or miss-match) all 8 lattice parameters

What is included

– **GM and 1st ORB**	**0.2409* m (eff. 0.08 m)**
– **ORB #1**	**0.6917 m**
– **Between 1st & 2nd ORB**	**1.01 m**
– **ORB #2a**	**0.6917 m**
– **Between 2nd & 3rd ORB**	**0.0 m**
– **ORB #2b**	**0.6917 m**
– **Between 3rd PM and Foil**	**0.1012 m**
– **Foil Changer**	**0.3048 m**
– **Between foil and 4th ORB**	**0.605 m**
– **ORB #3**	**0.6917 m**
– **Between 4th ORB and Absorber**	**0.30 m**
– **Absorber**	**0.5 m**
– **Between absorber and GM**	**0.171* m (eff. 0.01 m)**

Available space to install equipment

* About 0.16 of this distance is for gradient magnet flange .

#What's not: ion pumps, vacuum valves, vacuum bypass, corrector package, diagnostics

Active Elements

- Vertical Chicane (c.f. ORBUMP)
- Injection magnet from beam line (c.f. c-magnet)
- Horizontal painting magnets in ring (NOT specified or included yet)
- Foil changer
- Absorber
- Diagnostics

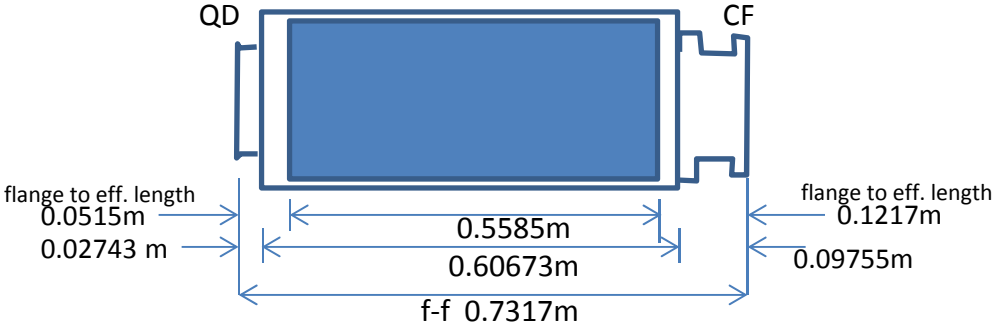
Vertical Chicane

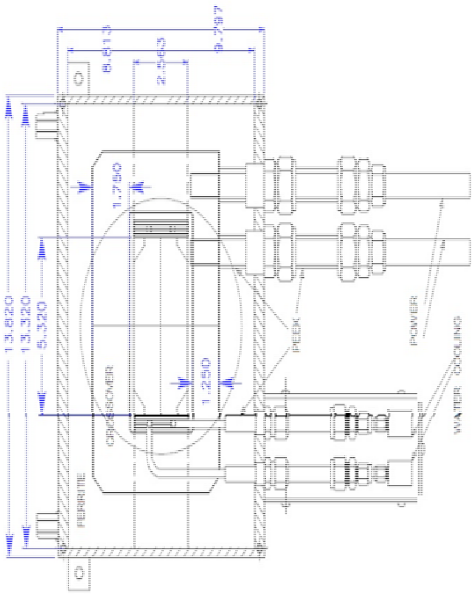
	Current	Opt 1	Opt 2
– Angle * [mr]	22	40	35.7
– Offset @ foil [mm]	45	45	40
– Offset @ center magnet [mm]		68.6	61
– Integrated field [kG-m]	1.676	1.952	1.743
– Field [kG]	3.0	3.496	3.121
– Effective length	0.5585 m (same as existing ORBUMP)		
– Flange-flange length	0.6917 (reduction of 40 mm)		
– Gap	65.1 mm (un-changed)		
– Aperture	100mm for first & last		
	190-200 for center magnet		

*Assume ~ 1 meter separation between chicane dipoles .

At 40 mr, H0 hits top of absorber about 0.15m downstream of face @ 2.3^{o}
At 35.7 mr, H0 hit top of absorber about 0.25m downstream of face @ 2^{o}

Existing ORBUMP





Aperture: H 65.1 mm V 135.1 mm

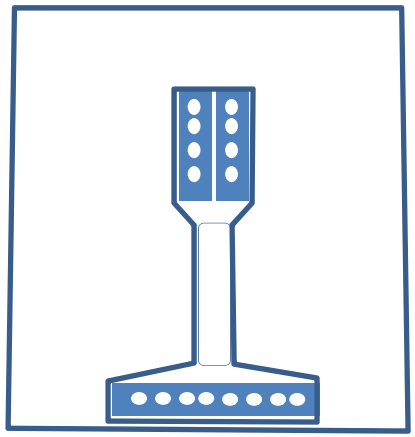
Half-height 175.5 mm

Comments from V. Kashikhin

- Design: Single turn window frame magnet with most current concentrated in 1 mm area close to magnet aperture.
- Used best CMD10 ferrite with Bs=0.46 T.
- How to get higher field:
  - increase field by increasing current and/or reduce the gap
    - ferrite saturation
    - Field homogeneity in the gap
  - Increase effective length
    - Increases stored energy, hence inductance
    - No room in straight section
  - Use a material like Finemet with Bs= 1T
    - Thin laminations - Indutctive (transverse impedance issues?)
    - Very expensive

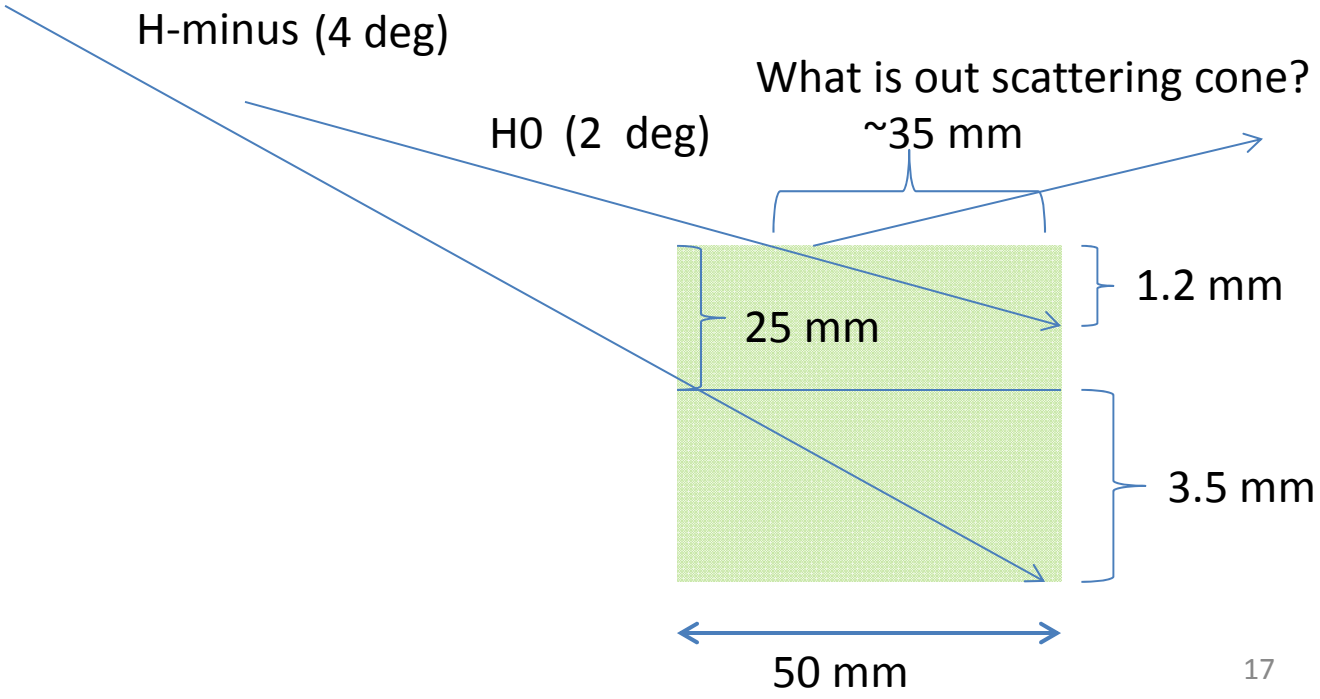
Injection C-magnet

- For the 45 mm foil offset
  - Entrance into c-magnet 278 mm & 0 mr
  - Exit of c-magnet v210 mm & -114 mr
  - Entrance into the upstream flange of the 2nd ORBUMP at 152 mm & -114 mr
  - Vertical sigma of injected beam ~1.15 mm
  - Beam pipe/gap > 10σ -> estimate 1 inch
  - Could have 8 turn magnet with 1200A
  - Can be DC.
  - Length 1.2 m (not in Booster straight)
  - Angle 114 mr -> 5.564 kG-m -> 4.64 kG
    - Lab frame lifetime 20 us loss rate ~2e-04/m
  - Similar in design to ICA



Absorber

- Should handle 375 watts routine running
  - 0.2% Neutrals & 2% H-minus (optimistic)
- Design for factor 2 larger (?)
- Loss protection for X % linac pulse full intensity
- Should provide at least 3 nuclear interaction lengths. 10 cm in W and 17 cm Fe)
  - 30cm W and 51 cm Fe
- Absorber material Tungsten alloy
- Need to define shielding around absorber (how much, what type)

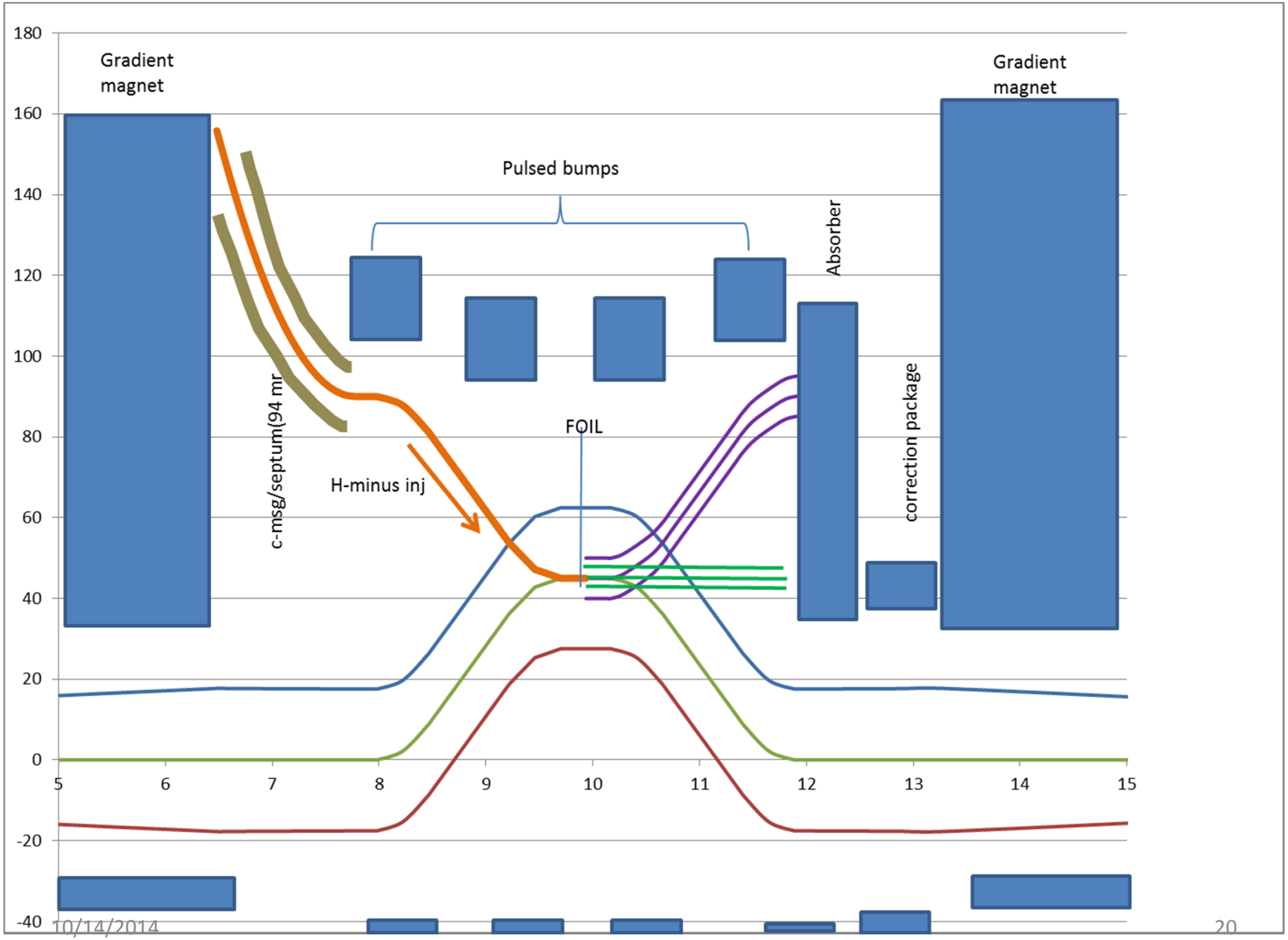


Issues

- We need to make space for
  - Ion pumps
  - Vacuum valves
  - Vacuum bypass
  - Correction element package (5” aperture)
    - Don’t currently see where this can go
  - Diagnostics (for injection, circ. Beam, waste beam)
- Aperture in center PM
  - increase 40% over existing ORBUMP
- Absorber geometry

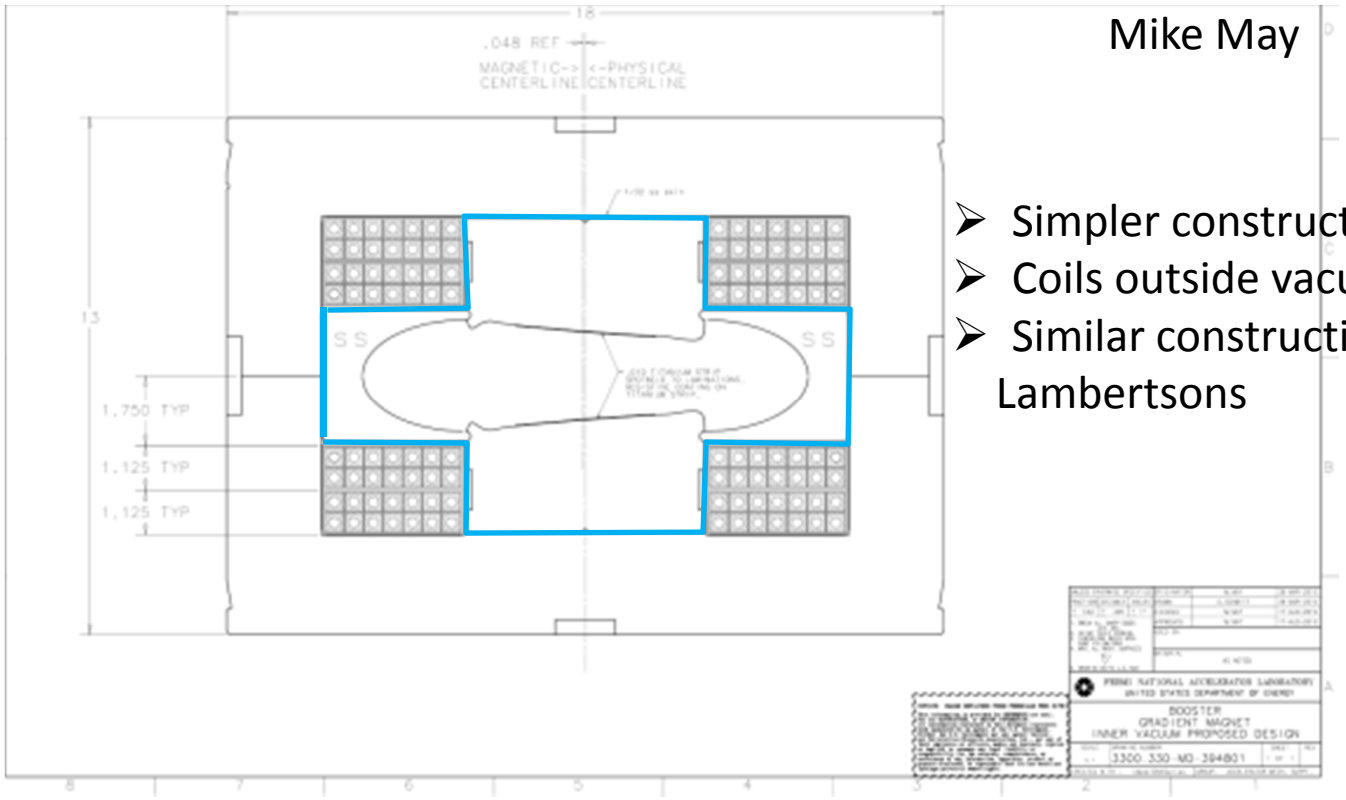
Alternative

- It's clear the existing straight is marginal at best
- Look at a design which increases straight section length
  - Means making 2 new Booster "D" Gradient magnets
    - Magnet construction
    - Power supply tuning of lumped inductance
    - Added expense
- Look at a 4 bump design
  - Smaller chicane dipole apertures
  - Better impact parameters for absorber
  - Room for correction element package
- Use same foil offset as 3 bump (45 mm)
- Includes existing vacuum valve& bypass
- Includes room for correction element package
- Diagnostics could be included in face of absorber
- Still tight (have not included or specified horizontal painting magnets
  - May need to investigate paint (V) steer from beam line (H)


Gradient magnet
Gradient magnet
Pulsed bumps
Absorber
correction package
c-msg/septum(94 mr
H-minus inj
FOIL
180
160
140
120
100
80
60
40
20
0
-20
-40
5
6
7
8
9
10
11
12
13
14
15

Booster Gradient Magnet Proposal

Mike May



- Simpler construction
- Coils outside vacuum
- Similar construction to Lambertsons

- Want to match bend angle (BL) vs current to existing magnets over full ramp
- Gradient should be ~98% nominal to compensate mismatch
- Change in effective length vs excitation should match existing magnets
- Length reduces by ~30% Increases straight section by ~0.87 m.
- Number turns increase from 28 to 40

Current Plans

- Investigate options for vertical chicane
  - Magnet design (what are the limitations)
  - Power supply design (20Hz resonant vs ramped)
  - Field requirements for 3 bump (Opt. 2) & 4 bump similar i.e ~3.2 kG
- Determine what's required to fit the correction element package into the current 3 bump design or the impact of breaking symmetry
- Determine where the horizontal painting magnets can be installed and their magnet parameters
- Start simulations for absorber (Igor R will return first part of November) to determine a preliminary design (starting with 3 bump configuration)
- Start looking at potential painting algorithms (compatible with chicane magnet & p.s. design)
- Specify Booster gradient magnet properties, look at preliminary magnetic design, and the impact on the power supply.