Status of PIP-II transfer line design from SC linac to Booster

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Site Map and Abs. coordinates
CONTRAINTES

Geometrical

- Initial point: $X=30492.421$ m, $Y=30535.510$ m, $Z=221.431$ m, $\Theta=276.979$ deg (subject to change)

- Final point: $X=30271.288$ m ($30263.786$) $y=30462.831$ m ($30459.105$) $Z=221.756$ m ($221.736$) $\Theta=61.114$ deg. ($58.327$) -- Total rotation angle: -215.865 deg.

- Max B field in bends for stripping probability $1e-8$ m$^{-1}$ at 1 GeV: 2.770 kG, $R = 20.431$m; keeping same $R$ for 800 MeV we have $B_{max}=2.390$ kG. With 3 m bends we get $\Theta_{max} = 8.44$ deg. per bend, 26 bending magnets total.

- First arch necessary to get away from linac dump and enclosure. Second arch to complete rotation. Straight transport between arches to cover the distance between Linac and Booster. Vertical injection.
Optical considerations

- Using FODO lattice with 60 or 90 deg phase advance per cell and same cell length for all the sections and 6 or 4 cells in first arch, we get achromatic sections and no match needed. With 2 bends per cell we have 12 bends in first arch for 60 deg. and 8 bends for 90 deg. \(Q_{60} = 101\) deg, \(Q_{90} = 67.5\) deg.

- Second arch can be realized with 10-12 cells, straight transport with 2-4.

- Need of an injection line with vertical dogleg for vertical injection (c-magnet length =1.2m, \(\Theta = 114\) mrad).

- With 2, 3m bends per cell, assuming 60% packing factor we have 10 m FODO cell length. Quadrupole strength adjusted for 90 deg. phase advance. From thin lens approximation we get quadrupole strength \(K_{90} = 0.71\) m\(^{-2}\) (for 40 cm quadrupole length). Limit on quad strength is given by \(B_{max}\) at bore = 5 kG. Assuming a vacuum chamber radius of 19 mm (1.5” diameter) and using a quadrupole radius of ~2 cm we get a gradient of 25 T/m corresponding to a strength \(K = 5.12\) m\(^{-2}\) > \(K_{90}\).

- \(\beta_{max}\) for 10 m long 90 deg. FODO cell is 17 m. From linac simulations \(\varepsilon \approx 0.154\) \(\mu\)m implying \(\sigma_{x,y} = 1.6\) mm and acceptance (radius vacuum chamber = 17 mm) of 10.6 \(\sigma\).
Transfer line survey (3D)

Applying geometrical constraints:

1. (4-12) $\Theta_{Arch 1} = 48.0847$ deg, $\Theta_{Arch 2} = 167.7803$ deg, FODO cell length $\sim 10$ m transfer line length $\sim 225$ m
2. (4-12) $\Theta_{Arch 1} = 40.6$ deg, $\Theta_{Arch 2} = 178.0$ deg, FODO cell length $\sim 11.7$ m transfer line length $\sim 267$ m
3. (2-12) $\Theta_{Arch 1} = 33.3$ deg, $\Theta_{Arch 2} = 185.3$ deg, FODO cell length $\sim 13.4$ m transfer line length $\sim 268$ m
4. (4-10) $\Theta_{Arch 1} = 50.3$ deg, $\Theta_{Arch 2} = 168.4$ deg, FODO cell length $\sim 11.6$ m transfer line length $\sim 236$ m
5. (2-10) $\Theta_{Arch 1} = 41.0$ deg, $\Theta_{Arch 2} = 177.7$ deg, FODO cell length $\sim 14.5$ m transfer line length $\sim 259$ m
Matching section and Arch 1

Total length ~ 13 m. N. quads = 4. Quad. Length = 40 cm. Quad strength = -0.76 – 0.83 m⁻². Space available for instrumentation, correctors, pumps, etc.

Total length ~ 40 m. N. bends = 8. Bends length = 3 m. Bend angle = 6 deg. Magnetic field = 1.703 kG. Quad. Length = 40 cm. Quad strength = ~ ±0.73 m⁻². Each cell equipped with H and V correctors, BPM, space for pump.
Lattice composed of 4 FODO cells (90 deg.) identical to Arch 1 but without bending magnet. Total length ~40 m.

Total length ~ 120 m. N. bends = 24. Bends length = 3 m. Bend angle ~ 7 deg. Magnetic field = 1.980 kG Quad. Length = 40 cm. Quad strength = -0.73 – 0.80 m\(^2\) Each cell equipped with H and V correctors, BPM, space for pump.
Booster Injection

N. Bends = 3
N. Quadrupoles = 6

Dog-leg bends
Length = 3 m
Magnetic Field ~ 1.85 kG

Treaty point: entrance of c-magnet
Length = 1.2 m
Magnetic field ~ 4.363 kG
Vertical half-size < 160 mm

Lattice functions at treaty point:
(matching not yet optimized)
Betax 13.5652
Alphax 2.4047
Betay 10.8913
Alphay 0.6012
Dx 1.544
Dpx 1.828
Dy -0.26019
Dpy -0.37088
All sections are automatically matched to each other. Quadrupole strength in last 4 cells of Arch 2 has been modified to get non zero horizontal dispersion in injection line.

Max horizontal dispersion in Arch 2 = ~4 m.
From linac simulations $\delta_E = 4e-4$. $\sigma_{\Delta x} = 1.6$ mm.
This will reduce the aperture available to 12 mm $\sim 7.5 \sigma$. 
Outlook

- Update geometric constraints and design (injection magnets, linac elevation, etc.)
- Optimize matching for booster injection.
- Reduce number of quadrupole families (8-6).
- Tracking simulations with space charge (TraceWin).
- Refine technical details.