CBETA Multipass Lattice Design
FFAG Arc Cell (5 deg)

$Q_x \equiv 0.368$ at 42 MeV

$Q_y \equiv 0.042$ at 150 MeV
Cell designed with fieldmaps
Cell modeled with Bmad_standard
Fields seen: bmad_standard
Offsets, angles scaled by factor:

\[ f(x) = 1 - x + \left(\frac{1}{2} - x\right)x(1 - x)[1.788 + 3.954x(1 - x) + 6.58x^2(1 - x)^2] \]
Full FFAG Arc
• Receive beams on-axis from the linac
• Match each energy beam onto its stable orbit in the FFAG arg
• Match optics for each energy beam into the FFAG arc
• Momentum compaction (r56) adjustment
• Path lengths: \((S1 + FA \text{ pass 1}) = (S2 + FA \text{ pass 2}) = (S3 + FA \text{ pass 3})\)
• Allow path length adjustment by sliding joints, \(\pm 10\) deg rf phase adjustment
• Dipole fields < 0.6 T
• Quad fields < 4 T/m
• Realistic transverse element sizes
Path length: 1-pass ERL

Harmonic:

\[ T_1 \cdot f_{\text{rf}} = 343 - 0.5 \]
Path length: 2-pass ERL

Harmonics:

\[ T_2 \cdot f_{rf} = 343 - 0.5 \]

\[ T_1 \cdot f_{rf} = 343 \]
Path length: 3-pass ERL

Harmonics:

\[ T_3 \cdot f_{rf} = 343 - 0.5 \]
\[ T_2 \cdot f_{rf} = 343 \]
\[ T_1 \cdot f_{rf} = 343 \]
Path length: 4-pass ERL

Harmonics:

\[ T_4 \cdot f_{rf} = 343 + 1.5 \]
\[ T_3 \cdot f_{rf} = 343 \]
\[ T_2 \cdot f_{rf} = 343 \]
\[ T_1 \cdot f_{rf} = 343 \]
Pass 1 length adjustment

Linear sliding joints
Pass 1 length adjustment

Linear sliding joints
Pass 1 length adjustment

Linear sliding joints
Splitter entrance and exit detail

Linac

(Dump)

Common

Septum

Normal-conducting Quadrupole

FFAG Arc

Gate Valve

Half QD

QF

BD

Christopher Mayes – September 9, 2017
S1 optics (42 MeV)
S2 optics (78 MeV)
S3 optics (114 MeV)
SX optics for each pass

<table>
<thead>
<tr>
<th>FFAG pass 1</th>
<th>FFAG pass 2</th>
<th>FFAG pass 3</th>
<th>FFAG pass 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 MeV</td>
<td>78 MeV</td>
<td>114 MeV</td>
<td>150 MeV</td>
</tr>
</tbody>
</table>

6 MeV +36 MeV

S1 +36 MeV S2 +36 MeV S3 +36 MeV S4 150 MeV
RX optics for each pass

FFAG pass 1
42 MeV

FFAG pass 2
78 MeV

FFAG pass 3
114 MeV

FFAG pass 4
150 MeV

6 MeV

+36 MeV

R1

+36 MeV

R2

+36 MeV

R3

+36 MeV

R4

-36 MeV

150 MeV
4-pass Optics Design

Design

Match into Energy 3 (114 MeV) line
Start-to-End tracking

100 pC bunch calculated from GPT with space charge

...spliced into Bmad 4-pass model
Start-to-End tracking

\[ \text{Beam } \sigma_h \text{ (mm-mrad)} \]

\[ \sigma_h^2 \]

\[ \pm 1.2\% \]

6 MeV

\[ \pm 1.2\% \]
Start-to-End tracking envelopes
Start-to-End tracking

![Graph showing particle trajectories and distributions over a distance of 600 meters. The plots display different parameters such as bunch length and time-of-flight.](image-url)
Summary

• CBETA Lattice is finalized

• FFAG designed with fieldmaps, well-modeled in Bmad for fast tracking.

• Splitters designed for:
  • possible 1,2,3,4-pass ERL configuration
  • Match orbit and linear optics into FFAG arc for each beam
  • ±10º RF phase shift adjustment via linear sliding joints.

• 4-pass start-to-end ERL tracking:
  • Negligible emittance growth
  • Well-controlled RMS and full (100%) beam envelope (both transverse and longitudinal)
  • Excellent energy at the dump ±1%
Orbit correction simulation

200 um offset errors in all quads

Simultaneously corrected: h corrector in QF, v corrector in QD
Corrector strength scaling for offsets

Table 2.13.1: Orbit correction analysis procedure. Typically this procedure is iterated for \( N = 100 \) times.

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initialize design lattice</td>
</tr>
<tr>
<td>2</td>
<td>Calculate orbit and dispersion response matrices</td>
</tr>
<tr>
<td>3</td>
<td>Perturb the lattice with random set of errors</td>
</tr>
<tr>
<td>4</td>
<td>Apply the SVD orbit correction algorithm</td>
</tr>
<tr>
<td>5</td>
<td>Save this perturbed lattice</td>
</tr>
<tr>
<td>6</td>
<td>Track particles through, and save statistics</td>
</tr>
<tr>
<td>7</td>
<td>Reset the lattice</td>
</tr>
<tr>
<td>8</td>
<td>Repeat steps 3-7 ( N ) times</td>
</tr>
</tbody>
</table>

![Graphs showing the relationship between quad offset and correction needed.](image1)

- **max correction X**: slope = 2.2 G*cm/µm
- **average correction X**: slope = 2.1 G*cm/µm

![Graphs showing the relationship between quad_y offset and correction needed.](image2)

- **max correction Y**: slope = 2.5 G*cm/µm
- **average correction Y**: slope = 2.1 G*cm/µm