Synchrotron Design and Methodical Cell Optics Study

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Motivation for a new RCS

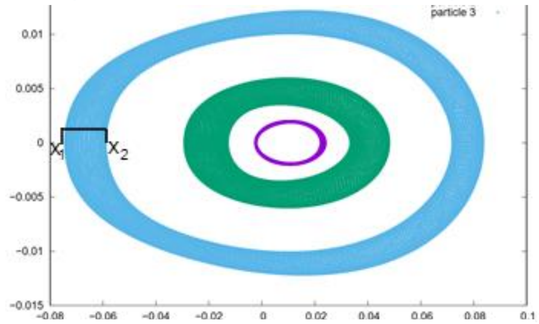
A new Rapid Cycling Synchrotron (RCS) is required to support future experiments, namely LBNF/DUNE. These experiments require 2.4+ MW of beam power to remain top experiments in this field. As PIP-II continues, the Fermilab Booster will become a bottleneck for beam power. This proposed design for a new RCS could replace the Booster and will allow for up to 2.4 MW of beam power through the Main Injector in 5-6 batches. This proposed ring is 563 meters in circumference with an injection of 2 GeV. The injection will be a single turn injection and will inject through a quadrupole in the middle of a long drift. This is uncommon but has been done in other accelerators. A previous multi-turn injection is assumed to be done in a previous accumulator ring.

PUFF Cell Optics Study

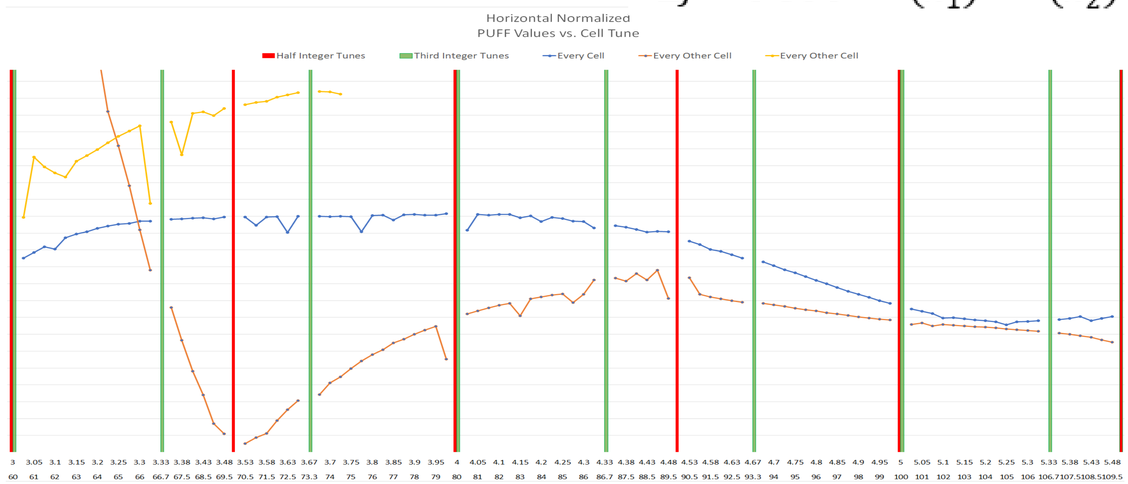
PUFF - Particle Undulation Form Factor

PUFF is a general optics study to measure how stable a lattice is with respect to its sextupole placement. Minimums in PUFF values demonstrate the least undulation, and thus, the best performance.

Visual representation of the derivation of the PUFF equation.



$$\Delta J = PUFF = (x_1)^2 - (x_2)^2$$

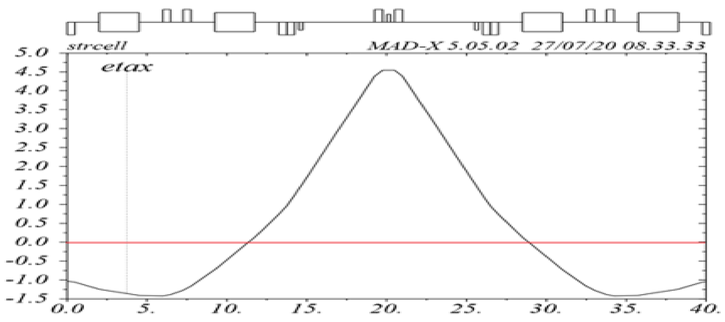


PUFF plotted vs cell phase advance (60°-110°) in generic FODO lattice. Vertical Red and green lines are resonances. Each line is a different placement of sextupoles

Imaginary Transition Lattice

To avoid transition, we created a lattice to create negative dispersion. This creates a negative momentum compaction factor because of the movement of high momentum particles to the inside of the ring. This decreases pathlength yet keeps the increased momentum. The same can be said for low momentum particles except vice versa. This creates an imaginary transition energy.

$$\gamma_t = \frac{1}{\sqrt{\alpha_c}} \qquad \text{where} \qquad \alpha_c = \frac{\Delta L/L}{\delta}$$



where:
δ = dp/p
L = on momentum path length

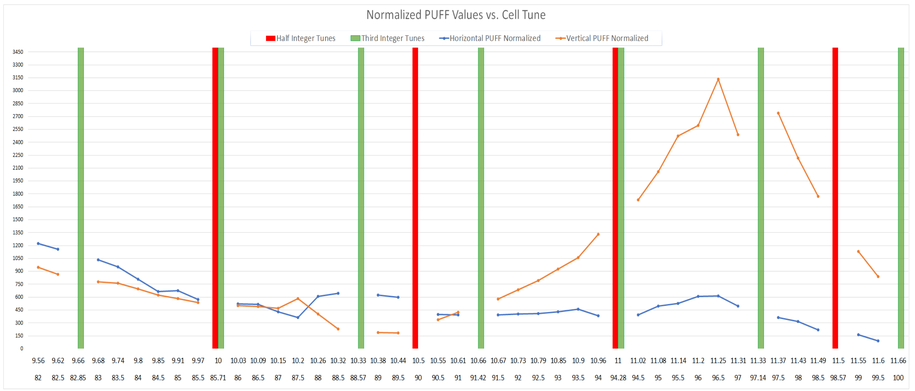
Dispersion plotted vs longitudinal length. Equation for transition energy and how it can be imaginary.

A New RCS Design

The new RCS takes 2-16 GeV protons (based on PIP-II LINAC upgrade). The increase in energy will allow for accommodation of future experiments. The PUFF study applied to this new lattice gives us optimal phase advances at which this lattice performs.

Parameter	Value
Dipole Poletip Field	1.18 T*
Quadrupole Poletip Field	0.63 T
Sextupole Poletip Field	0.12 T
Injection Energy	2 Gev
Injection Type	Single Turn**
Extraction Energy	16 GeV
Circumference	563 m
Straight Length	10 m

Main parameters of new synchrotron



PUFF study applied to new Synchrotron design lattice