A 1-GeV Accumulator Ring in the Booster Tunnel

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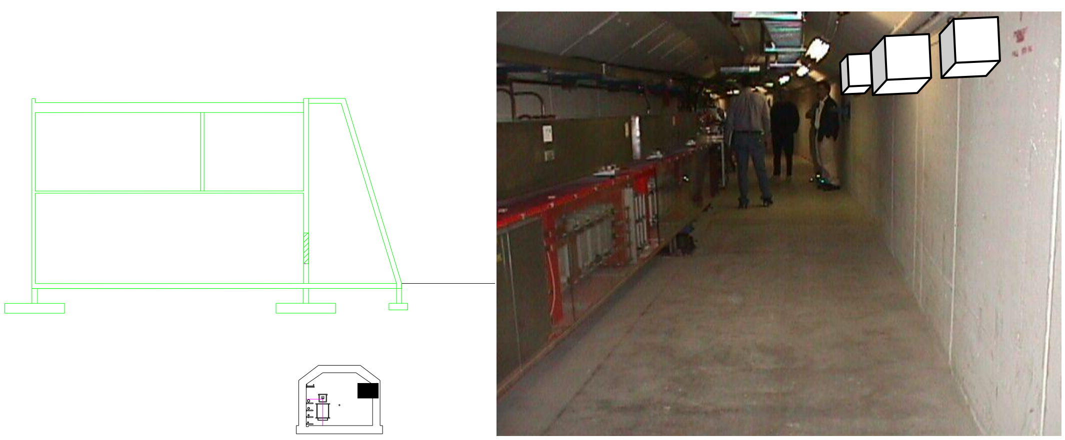
Abstract

This note describes a concept for a storage ring in the Fermilab Booster tunnel to accumulate 1-GeV beam from the Project-X H^- Linac. The ring is made out of permanent magnets, and its primary purpose is to accumulate beam for the Booster. The concept is flexible with regard to linac beam structure. The beam intended for the Booster is accumulated into stationary buckets at ~47 MHz during ~1 msec. (This is much simpler than trying to inject "on the fly" into the ramping Booster.) The beam is then transferred bunch to bucket in a one-turn extraction into the Booster. For the rest of the Booster cycle time of 66.7 msec, the permanent magnet ring can be used to accumulate and store beam for other purposes. The ability to chop bunch-by-bunch in the linac creates many opportunities to package beam for different users in the proposed storage ring. For example, the stored beam can be used for a Pulsed Spallation Source, for a muon-to-electron conversion experiment based on a 100-Hz FFAG ring (Prism/Prime), and/or for a pulsed beam for Short Baseline Neutrino Experiments. These specially packaged beams can be used either directly or after acceleration in the Booster.

Introduction

The beam that is destined for the Booster is accumulated at a rate of 15 pulses per second. The ring can also be used for additional accumulation, depending on the beam structure that users may need. The ring will have harmonic number h = 85 or 86 and will be positioned on the ceiling or outside wall of the Booster tunnel.



Cross section of tunnel and Booster tower. Booster with storage ring magnets indicated as white boxes.

Ring Lattice

The ring lattice is designed to mimic the present Booster lattice. Such lattices might be implemented using combined- or separated-function magnets, whichever is more practical. The ring has 24 periods and 24 long straight sections. To help with H^- injection, the straight section is made about 1.6 meters longer than that of the Booster ring. The dipole field (<0.2 T) and field gradient (< 0.35T/m) are kept in the range achievable using ferrite-based permanent magnets.

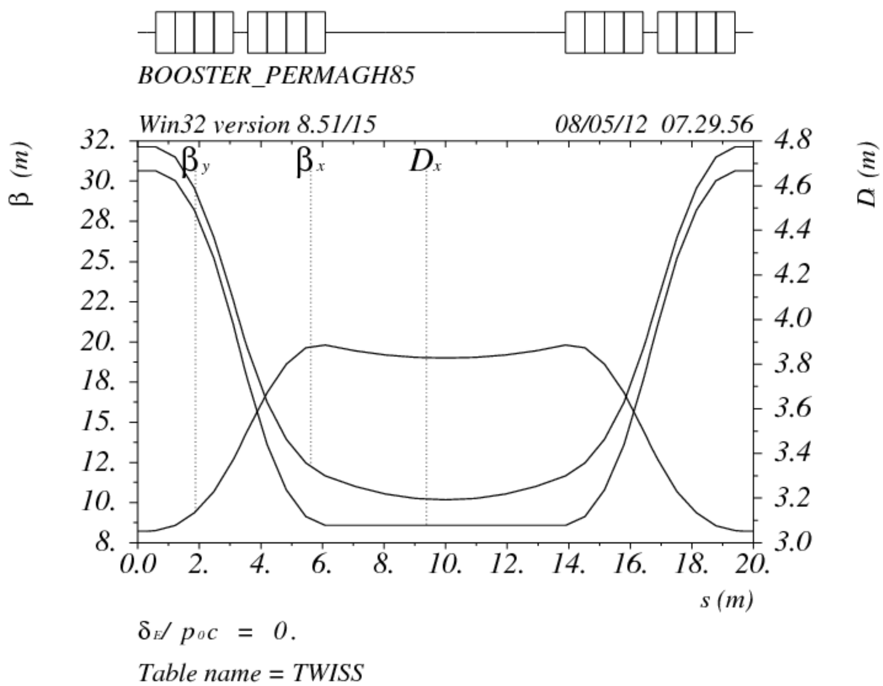
Combined-function based ring

Using combined-function magnets, the following parameters have been chosen in order to preserve similarity with the Booster lattice and to elongate the straight sections for cleaner injection of H^- in the ring:

Length of straight section is 7.81 m (Booster 5.975 m). Both F and D magnets of the storage ring are 0.4 m shorter than Booster magnets.

Magnet	length	Dipole(T)	Grad(T/m)	Sagitta (m)	Width /Gap(m)
D	2.516	0.159	-0.326	0.013	0.155/0.065
F	2.517	0.159	0.301	0.015	0.155/0.065

The figure shows lattice functions for the storage ring. Note that, though the tunes are different from those of the Booster, the beta functions are similar.



Parameter	X	Y	
Total length(m)			24*19.9862=479.6
Tune	24*0.214=5.136	24*0.226=5.437	
BetaMax(m)	32.14	19.8	
DispersionMax(m)	4.66	0	
GamaT			4.419

Booster can accept and accelerate beam with normalized emittances (95%) of 10 pi mm-mrad. To avoid any restriction on the beam, we should have permanent magnets with the same horizontal size as Booster magnet (full width of 0.155 m) and the gap 0.065 m (larger than Booster to allow room for a beam pipe) The space charge tune shift is calculated using the following formulas.

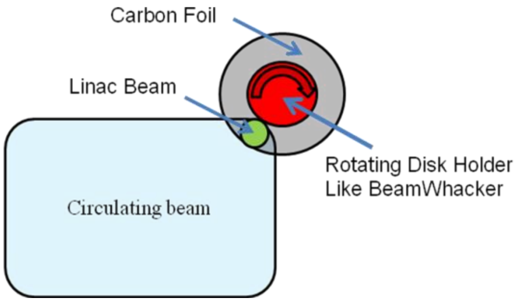
$$B_{fact} = \frac{\sqrt{2\pi}\sigma_s}{2\pi R_{aver}}, \qquad \Delta\nu_{sc} = -N_{ppB}\frac{r_p}{4\pi B_{fact}\beta\gamma^2\varepsilon_{Nrms}}$$

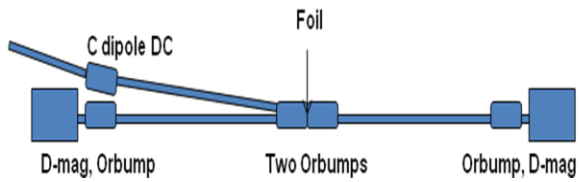
Where σ_s =1 m is bunch rms length, NppB=$8\times10^{12}/84$ is number of protons per bunch, R_{aver}=75 m average ring radius, $r_p=1.5\times10^{-18}$ m classical proton radius, and beta and gamma the usual relativistic parameters at 1 GeV. With the listed parameters, direct space charge tune shift is not an issue in this ring ($\Delta\nu\sim 0.05$).

The lattice can be additionally improved if we find that there is no need for such long straight sections.

H^- Injection

The beam is injected vertically in one of the 7.8 meter long straights.





To have full flexibility for painting, the central orbit is moved independently in each plane. Because beam will be large after painting, the central orbit has to be moved by ~5 cm in the horizontal plane and ~ 3 cm in the vertical plane.

Horizontal plane

To move the closed orbit in the horizontal plane up to 5 cm locally and to do this fast (in 1 ms or less), a bump magnet system as shown in the figure below is used:

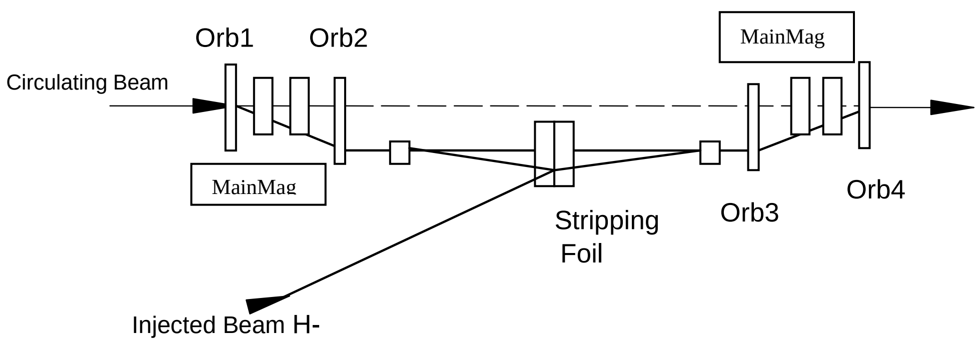
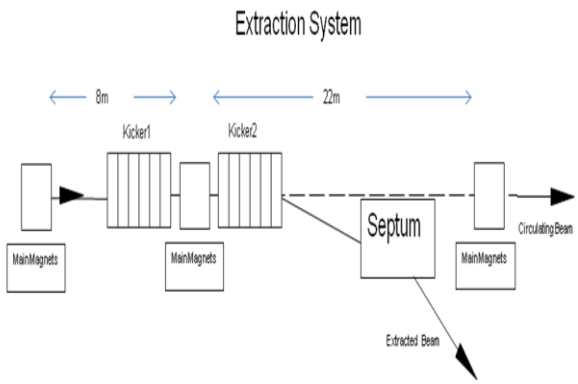


Figure shows horizontal/vertical plane painting as foil injection concept

Extraction

The beam from the permanent magnet ring is extracted horizontally in the long straight section of Period 22 so that injection in the Booster can be as it is now in Period 1. Extraction is accomplished using kickers in the long straight section of Period 21 and a current septum in the extraction region (Period 22).

There are 6 meters for kickers in Period 21. A simple trace3D simulation shows that two Booster type kickers in Period 21 can move the beam ~60 mm horizontally at a position 2.5 meter before the main magnet in the long straight section of Period 22. At this place there is a DC (or perhaps pulsed) septum magnet that bends the beam an additional 5 degrees. Theseptum magnet can be two meters long with a field of ~0.25 Tesla. None of these magnets look demanding.


Extraction System
8m
22m
Kicker1
Kicker2
Septum
MainMagnets
MainMagnets
MainMagnets
CirculatingBeam
Extracted Beam