A Concept: 8GeV Storage Ring

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DRAFT

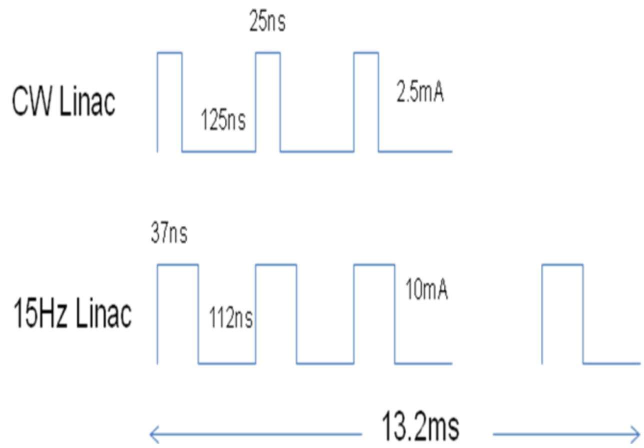
Abstract

This note describes a concept for an 8 GeV accumulation ring for beam provided by a 4 MW CW H- Linac on the Fermilab site. The linac beam is assumed here to have 81 MHz a bunch structure, however the same ring could accommodate either a pulsed or CW linac with 162.5 MHz beam structure.

Introduction

Accumulation of the 4 MW beam is done in 15 pulses per second. The average CW linac current is assumed to be 0.5 mA with a peak of 2.5 mA. The linac beam has an 81 MHz bunch structure with two full buckets followed by ten empty buckets; this pattern is shifted from time to time to ensure injection remains synchronized within the ring RF buckets. Every 66 ms, the beam is extracted to a bunching ring where it longitudinally confined using a ~24 MHz RF system.

Assuming a 15 Hz pulsed linac rather than the CW version just described, a possible scenario is a 10 mA peak current in conjunction with a 3/9 ratio of full to empty buckets. With that scenario, the ring bunches would be longer and injection would last ~13.2 ms; the accumulation ring might also have an additional an RF system to providing more bunching before beam is transfer to the ring.



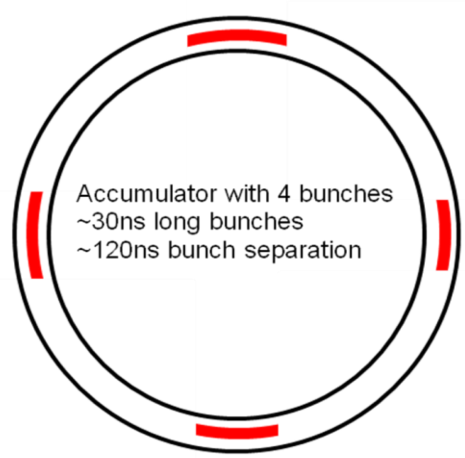


Figure 1 Beam accumulation for Muon Collider

The beam from the CW linac has a 95% normalized transverse emittance of ~1 mm-mrad and a total energy spread of ~5 MeV. It is assumed that during injection, this beam is painted into a beam with transverse emittances of ~200 mm-mrad and four ~30 ns long bunches with an elliptical distribution.

At injection, the main limitations on beam parameters arise from longitudinal instabilities. The maximum allowable beam power per bunch is

$$P_{MAXperBuch} \leq f_{rep} m_o c^2 (\gamma - 1) \frac{\beta^2 \gamma^3 (\frac{\sigma_p}{p_0})^2 L_b \eta_{lattice}}{p_r \ln(\frac{a_{pipe}}{1.5\sigma_{beam}})}$$

For our choice of parameters, this limit is ~2 MW per bunch. As the formula indicates, increasing the bunch length might be helpful; however, final bunching into 3ns long bunches may then become too challenging.

The storage ring

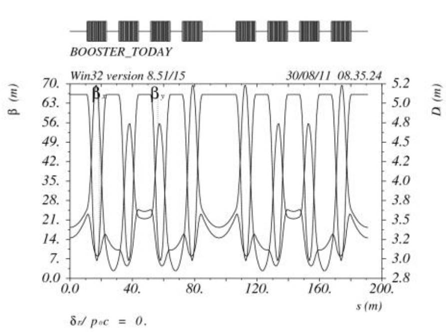
The storage ring is made as short as possible with banding field limited ~1.8T. Dipole magnets are combined function magnets. The distance between magnets is minimized to ~0.2m. There are 32 magnets grouped in eight cells with six 8 meter straights and two 21 meter straights for injection and extraction.

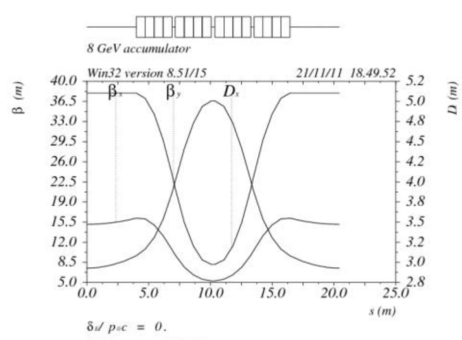
The Table below presents the main lattice parameters.

total length = 191.0363m	Qx = 2.599514	Qy = 2.266236
delta(s) = 0.000000 mm	Qx' = -3.904487	Qy' = 0.345342
alfa = 0.130479	betax(max) = 24.774721	betay(max) = 69.408119
gamma(tr) = 2.768406	Dx(max) = 5.111147	Dy(max) = 0.000000
Dx(r.m.s.) = 4.310250	Dy(r.m.s.) = 0.000000	

Table 1. Lattice parameters (obtained from a MAD run).

The lattice can be improved in the event the long injection and extraction strait section and six 8 meters long straights can be shortened.





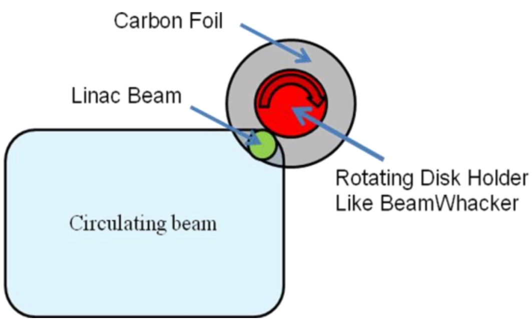
Another limit that related to accumulation and bunching of a very large number of protons is set by the space charge tune shift. To produce very short proton bunches we need to have an accumulation ring of small circumference in conjunction with large transverse beam emittances .

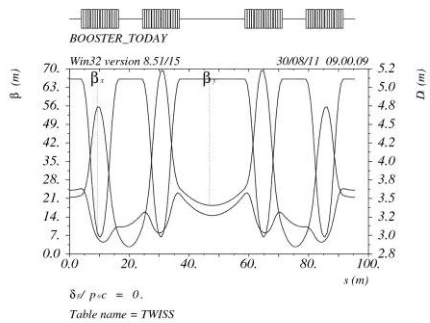
$$B_{fact} = \frac{\sigma_s}{2\pi R_{aver}}\ , \qquad \Delta\nu_{sc} = -N_{ppB}\frac{p_r}{4\pi B_{fact}\beta\gamma^2\varepsilon_{Nrms}}$$

With the parameters listed in Table 1, one gets, $\Delta\nu \sim 0.005$; we conclude that direct space charge tune shift is not an issue.

Injection

The beam is injected in one of two 21 meter long straights





To have full flexibility for painting, the central orbit is moved independently in each plane. Because the beam will be large after painting, the central orbit has to be moved approximately ~10cm in both planes.
Horizontal plane
To move up the closed orbit in the horizontal plane by 10 cm and to do it fast (in 66 ms) and locally, a four-bump magnet system is used: one magnet in the 8 meter straight before the 22 meter long, one magnet at the beginning

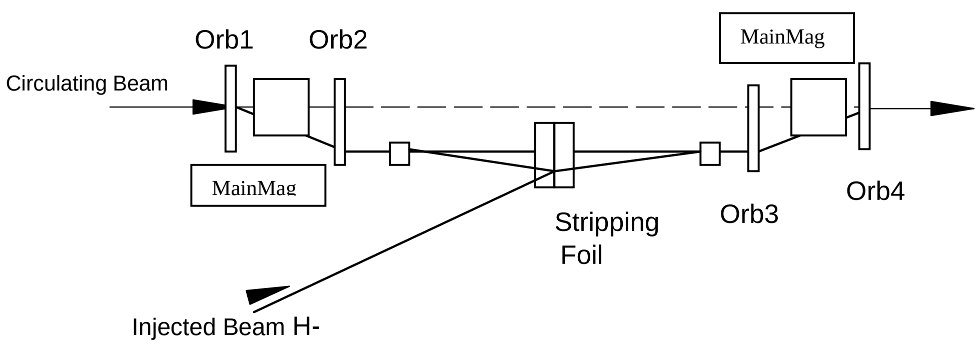
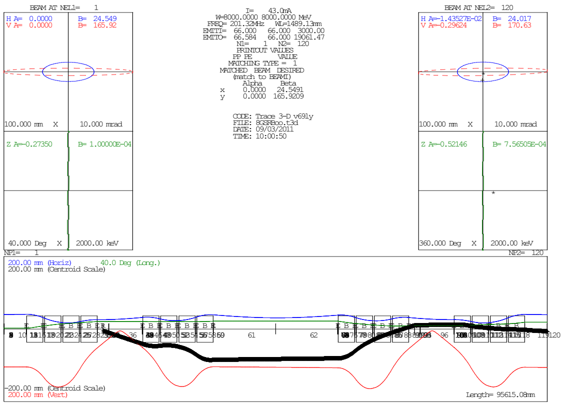
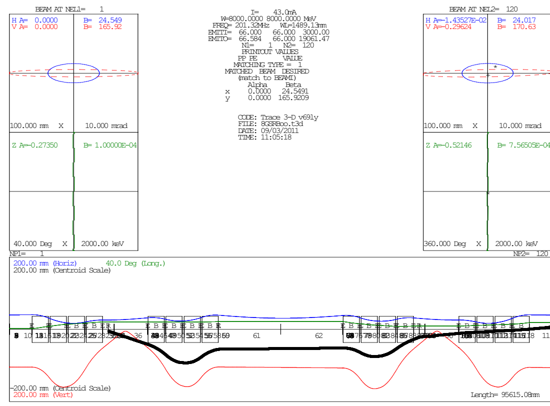


Figure shows vertical plane painting as foil injection concept

and at the end of the long and one magnet in the straight section located downstream of the injection straight. These magnets provide ~0.3 degree bends; they are similar to the Orbump magnets recently installed in the Booster but longer. An 8 GeV storage ring would need 1.5 meter long magnets.

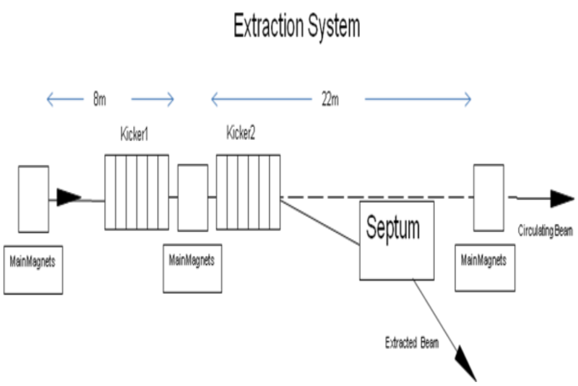



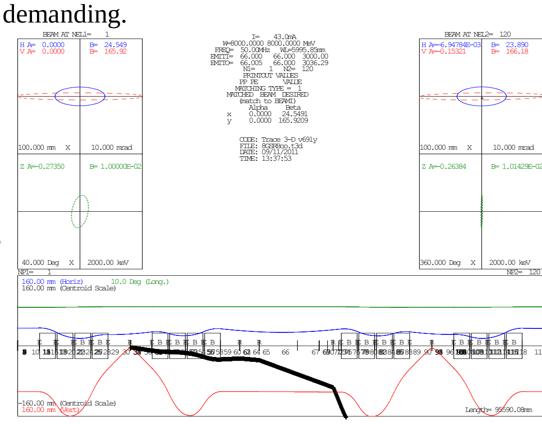
Horizontal bump for painting   Vertical bump for painting

Blue trace: horizontal beam envelope, red trace: vertical beam envelope; black traces: central orbit displacements at the start of injection.

Extraction

The beam is extracted horizontally in the long straight opposite to the injection straight. Extraction is accomplished using kickers located in the straights upstream of the extraction region as well as within the extraction region. There are 8 meters available for kickers in the “short straight” and 21 meters in the long straight. Trace3D simulations show that a total kick of 0.1 degree in the short straight combined with a 0.3 degree kick in the long straight moves the beam closed orbit by ~100 mm horizontally 2.5 meter upstream of the main magnet in the long straight section. At this location, there is DC septum which bends the beam by an additional 1.5 degree. The bending angles can be achieved using Booster style kickers. These kickers are one meter long and bends a 8GeV beam by 5.27urad/(kV-meter) at 8 GeV. The typical voltage across the kicker plates is 50-60kV with a rise time of 40ns. The DC septum magnet can be two meters long with a field of ~0.4 Tesla. None of these magnets look too demanding.





Longitudinal Dynamics, Bunch Shortening

The ESME code was used to simulate beam accumulation and longitudinal dynamics. The 4MW beam is split in 15Hz. Accumulation is simulated as 13.3ms long injection. The beam is form in four bunches and injected in ring with h=8. The ring contains 12.4MHz RF system. With cavities distributed in empty 8 meters long straits. At injection RF voltage is 5kV and beam is injected in readily form buckets. During 13.3 ms injection RF voltage is ramped from 5kV to 50kV. The bunches are kept 37ns long with energy spread of +/-5MeV.

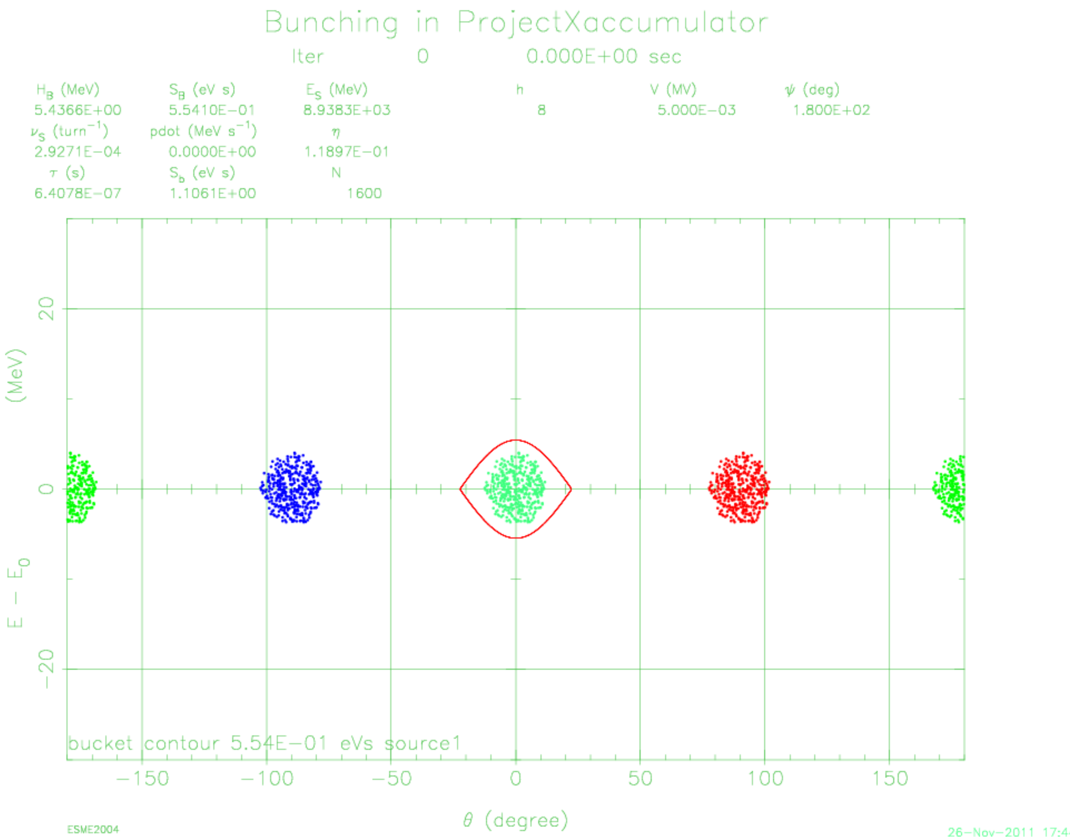
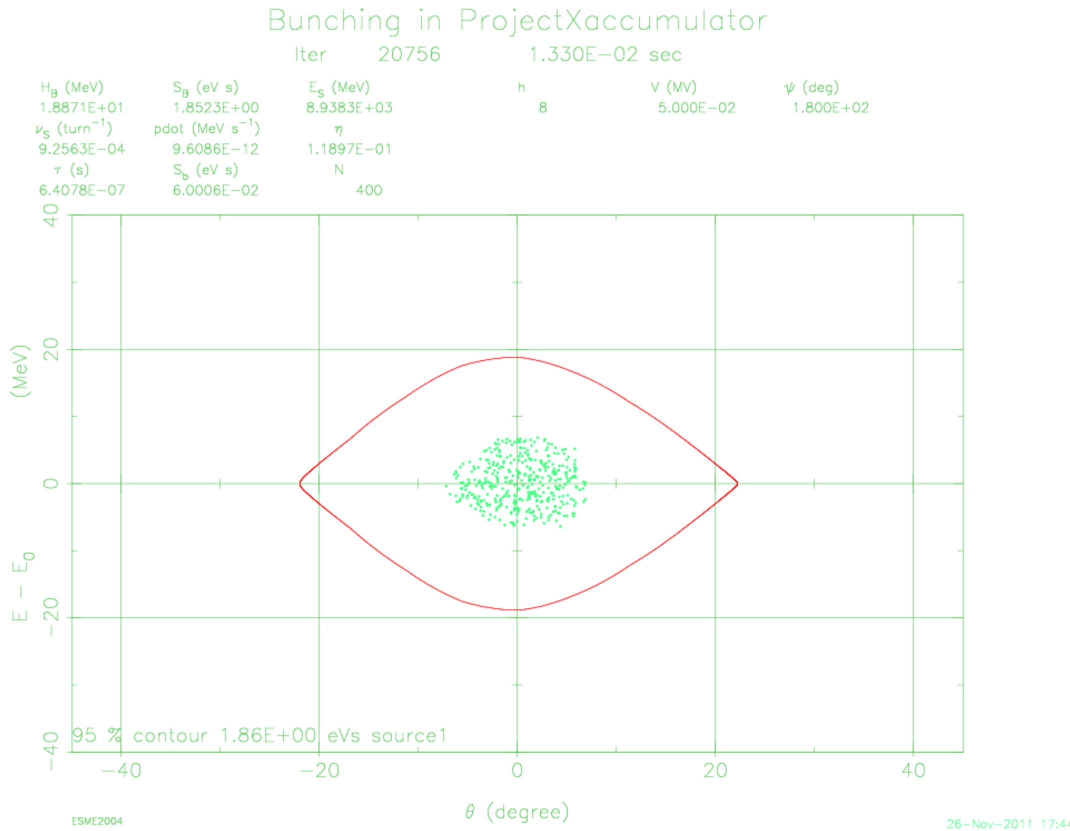
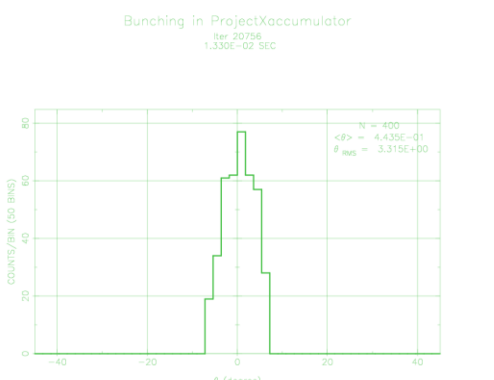
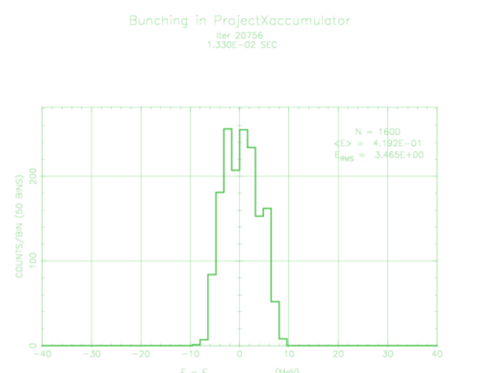


Figure shows four bunches at start of injection. To simulate effect of space charge total charge in the ring is ramped linearly from zero to $2x10^{14}$ during accumulation.



At the end of accumulation bunch rms length is 5.9ns and energy spread (95%) around 7MeV. Figure bellow show energy and angular spread of the bunch.





This result shows that with DE/E~10^{-3} even with dispersion of ~5m beam horizontally looks like has reasonable size and maybe we may not need Compression Ring to achieve ~3ns long bunches on the target.

Bunching and timing for NF

A Neutrino factory needs beam with 50Hz repetition rate with three bunches 240us apart every 20ms. This beam structure can be created in a CW linac with the following a time structure: the beam is on for 30 ns and off for 270ns. This corresponds to three bunches followed by 20 empty buckets at 81MHz. The peak proton beam current is 5mA. This beam is accumulated for 20ms as three 30 ns long proton bunches, separated by 270 ns. After 20ms of accumulation, the beam is transferred in one shot. The required kicker does not appear too challenging: the rise time should under 200ns with a pulse length of ~600ns. The beam is the transferred to a compressor ring were bunch shortening from 30ns to 3ns is done in 20ms.

Finally, the beam is extracted one bunch at a time every 120 us.
The kicker magnet is identical as the one used in the Accumulation ring, but requires a PFN system. A typical kicker system with PFN and firing switch is show in Figure 10

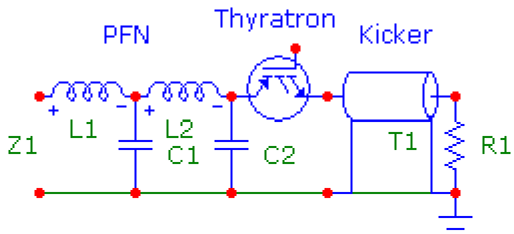


Figure 10.

If we add two more systems such as the system shown in Figure 11 in series with system in Figure 10

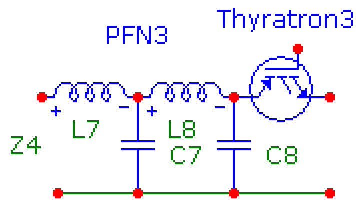
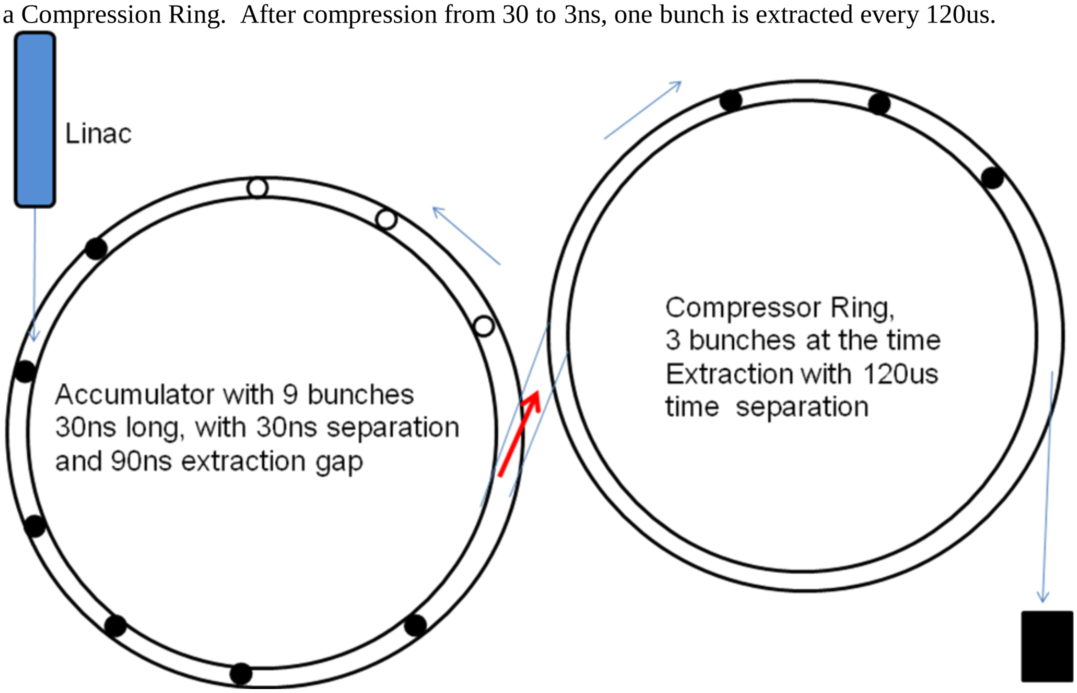


Figure 11

the three systems can be fired in series with a 40us delay allowing sequential bunch extraction. For this application PFN has to produce a pulse with ~20ns rise time and 150 ns fall time.

With a pulsed linac, the assumption is that linac runs at a 20Hz rep rate, with 10ms beam on and 40ms beam off. During the 10ms on, the beam has the following microstructure: 30 ns on followed by 30 ns off or nine trains; then beam is off for an additional 60ns. The beam peak current in linac is 5 mA. This beam is injected in an accumulation ring and nine bunches are formed. These bunches are 30ns long, separated with 30ns gaps except the first and last bunch, where separation is 90ns. In other words, the ring has h=10 with one empty bucket. Once accumulation is over, three bunches at a time are extracted and transferred to a Compression Ring. After compression from 30 to 3ns, one bunch is extracted every 120us.



--The End - That’s all folks ---