A Muon Storage/Decay Ring at Fermilab,

A Concept

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Abstract

This note describes a concept of muon decay/storage ring on the Fermilab site. Muons are created using 8 GeV proton beam and an existing AP0 target station. The ring is assumed to be racetrack shape oriented in direction of MiniBoon detector. Initially, the Booster proton beam will be used but the concept assumes that in the future 8GeV protons will come from ProjectX. The initial estimate for 8 GeV protons is that ~1e-3 pions of 2GeV can be produced in 0.1 radians in forward direction per one proton. This beam can be captured and stored with not much effort so that just using the Booster beam we can have ~1e+11 muons per second stored.

Introduction

In attempt to create more opportunities for beam based experiments using existing Fermilab infrastructure and in the light of recently expressed interest in short base line neutrino experiments we propose to build racetrack shape muon storage/decay ring. The idea is to use the existing target station and MiniBoon detector to reduce construction time and cost of the project. The long straight of the racetrack is directed toward the MiniBoon detector. The ring is positioned near AP0 target station and pions are injected in the straight section of the racetrack. Pions are produced using 8GeV Booster beam and existing p-bar target station. The proton beam from Booster is injected in the Recycler and Booster batch is broken in four trains ~300ns long using barrier bucket system with ~100ns gap, like for g-2 experiment. Each of four trains is extracted using ~60ns rise time kicker. The racetrack is ~120 meter long and this assumes single turn injection. The layout of the site is shown in Figure 1.

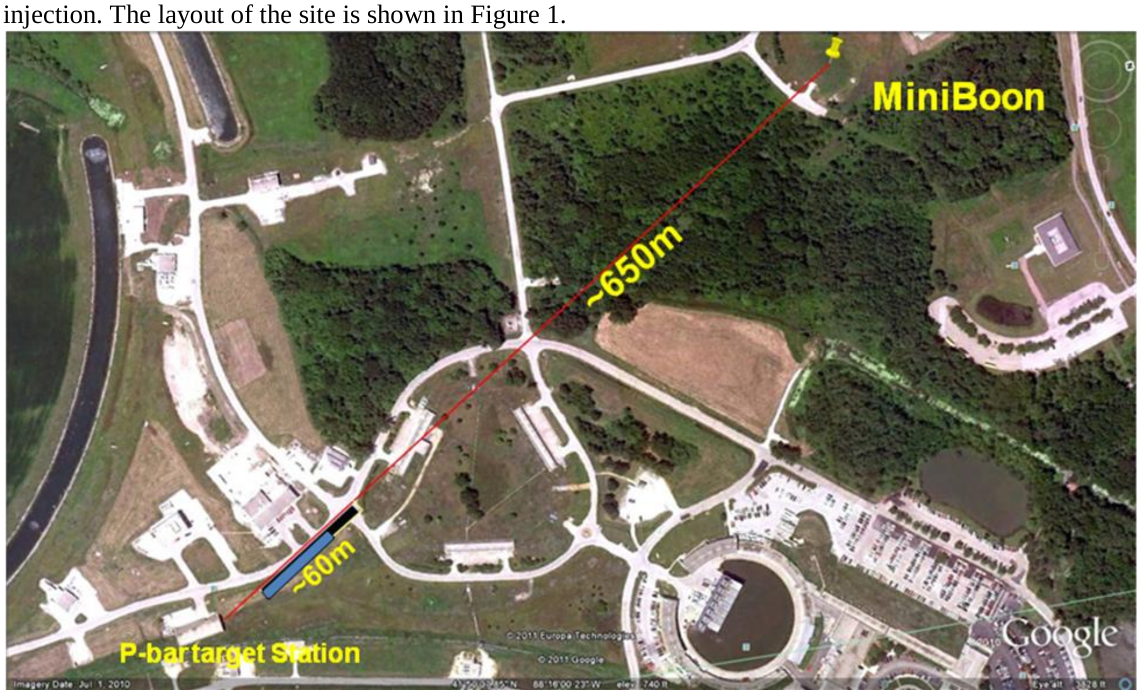


Figure 1: Fermilab, Antiproton Complex, with racetrack storage/decay ring depicted as blue box. The red line indicates direction of neutrino beam that hits MiniBoon detector.

In the rest of the note we describe each stage of beam delivery/creation in more details.

Proton Beam

In initial stage we assume that the 8 GeV proton beam from Booster will be used. As in the case of g-2 experiment, Booster batch will be stored in Recycler and using a barrier bucket system separated in four trains, each ~300ns long with ~100ns gap for extraction. Each train will be separately extracted and targeted using existing target station in AP0. We have also envisioned that the present design can use ProjectX beam without any modification. The proton beam from ProjectX will be injected in the Recycler with chopped structure so barrier bucket system will not be needed. Assuming that Recycler can store 5.10e+13 protons, it is clear that this part of the complex will not be a restricting element.

Target, Pion Capture

As it was said, our intention is to use existing AP0 target station for pion/muon production. Presently p-bars are produced using 120GeV beam and Lithium lens with an average beam power of ~70kW. Assuming it is a Be target it will be simple to estimate number of pions produced.
Striganov formula
For pions of p=2+/-0.1GeV/c produced in small angle, smaller than 0.1 radian, number of pion per incident proton on Be target is given by

$$N_p = e^{-x/\lambda\_Be} \frac{a}{b}(1-e^{-b\theta^2}) \ ,$$

	a	b
pi+	0.48	22.57
pi-	0.3	18.91

Where x is length of target, λ_Be=0.42m interaction length for Berilium.
The p-bar target vault has limiting space so the Be target and collection system, quadrupole triplet, have to fit in the 2.5 meter space before shielding block. Also beam pipe is limited to the 40mm in the center of the shielding wall.

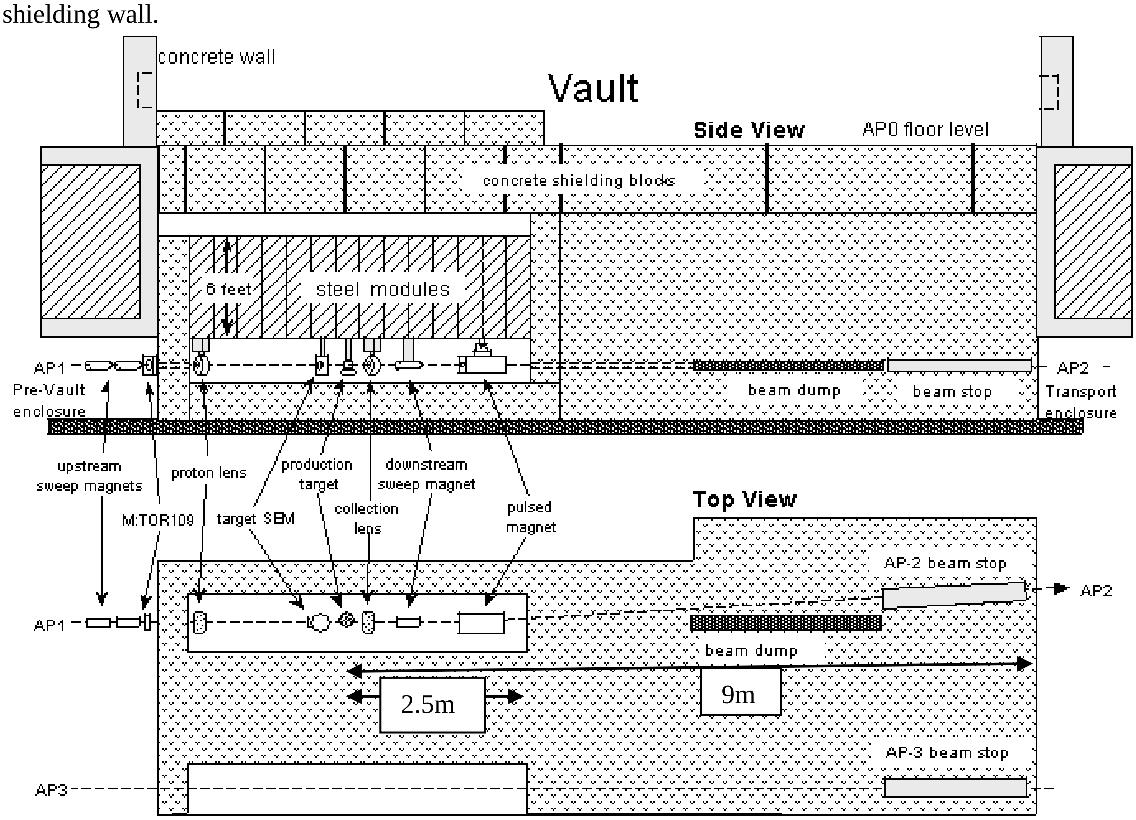


Figure 2: The target and focusing triplet have to fit in 2.5meter long space.

As can be seen from Figure 2. The target and focusing triplet have to fit in the space no longer than 2.5 meters. Also, the beam has to travel about 6.5 meters with a size less then 80mm in the middle of the shielding wall. Figure 3, show trace3D simulation of beam transport, starting from Be target and ending at entrance to the storage ring.

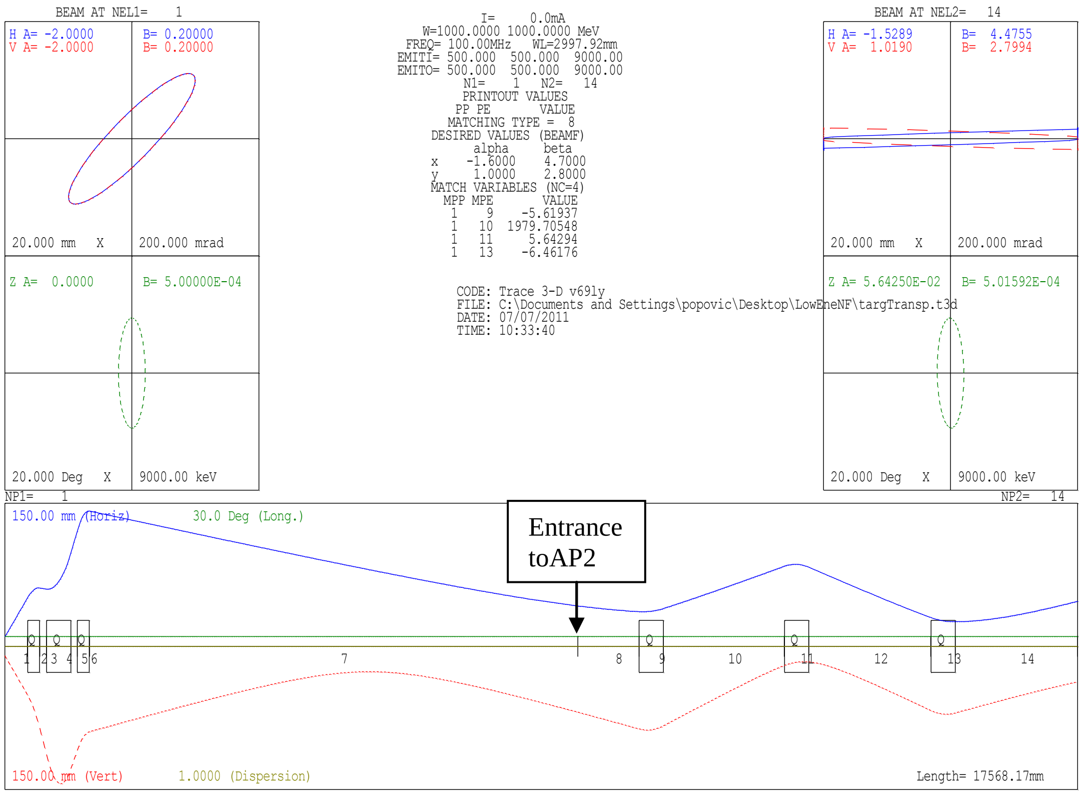


Figure 3.

Pion Transport and Injection

As soon as pions/muons enter AP2 enclosure there will be system of quads to transport and inject these beams in the storage ring. We should allow about eight meters of transport from exit of the target shielding wall and injection to the ring. We assume that last bending magnet in the arc will be used to bend beam in the ring as it is indicated in Figure 4. To match the beam we use three quadrupoles, the same type that will be used in the storage ring.

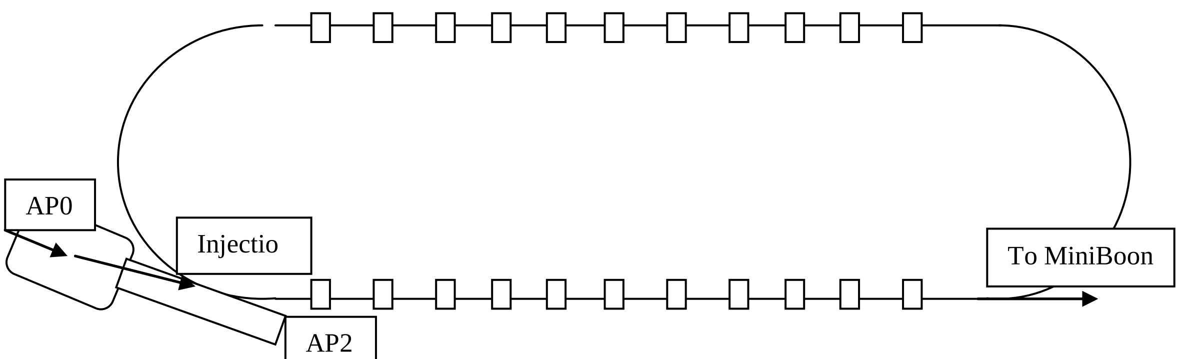


Figure 4.

Racetrack Storage Ring

The racetrack storage ring has two straight sections 50 meters long. The lattice is simple FODO with arcs 10 meters long and dispersion canceled inside the arcs. Figure 5 shows the Trace3D display showing half of the ring, starting from the half of the straight section with one arc and half of the straight section.

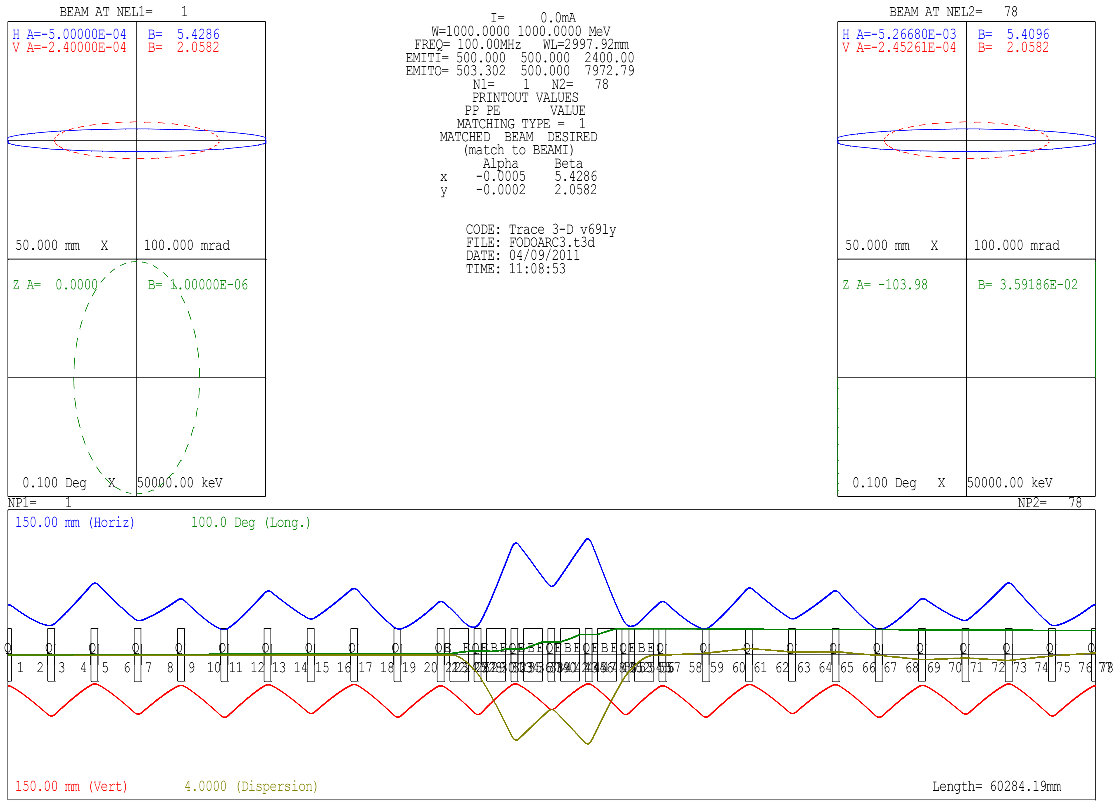


Figure 5. Blue and red are horizontal and vertical envelopes.

The table below summarizes parameters of racetrack elements

Element	
Drifts in straits	2m
Dipole radius, gap, field,angle	R=2m, h=0.15m, B=1.85T, ang=30degree
Drift in arcs	0.3m
Quads Length, Aperture, Gradient	L=0.4m, r=0.15m, g=5T/m
Quads total number	50(2x20+2X5)
Dipole total number	12
Total Length=Arcs Length+Straits	120m=(2x10+2x50)m

Cost

Since the suggested facility is simple and based on existing technology makes costing relatively simple. The costing is done based on the cost done for other projects at Fermilab

Civil constructions:

- Two tunnels 3 meters wide each, 30k$*2*65 = ~4M$
- Service building, 2M$

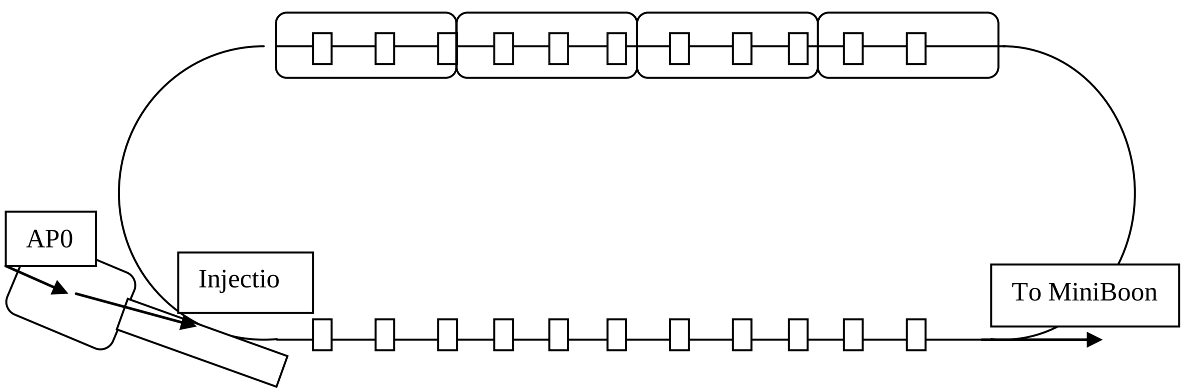
Components:

- There are 12 dipoles plus 2 spares, 60k$ per magnet, =0.84M$
- There are 50 quads in ring plus 10 for transfer line and spares, 40k$ per magnet, = 2.4M$
- Power supplies 70 x 10k$= 0.7M$

All this is summarized in table below.

Item	In M$
Tunnel	4.00
Building	2.00
Dipoles	0.84
Quads	2.40
Power Supplies	0.70
Other, pipe, cables, ???	2.06
Total	12.00
Contingency+???	8.00
Grand Total	**20.00**

Future Improvements- Acceleration



Considering possible future improvements, we can think of accelerating the muon beam to the higher energy than collection energy. One possibility is to use four ProjectX 650MHz 0.9 beta modules and install them in return straight section. The injected pion beam is assumed to be DC, RF is on in the modules, and the path length of the beam is adjusted so that the beam gets bunch in the first few turns. When acceleration is needed, the fast three bump is created so the beam path is elongated. Then the incoming beam in the RF cavities comes with phase of 90 degree, the phase needed for acceleration. With four ProjectX modules muon beam energy can be increased up to 1GeV per single pass.

Conclusions

We believe that muon storage/decay ring can be build quickly, utilizing both the p-bat target station and MiniBoon detector and will cost under 20M$. The building of the facility will have little or no impact on the running of planned experiments. The storage ring can be built to run at ~3GeV muon momentum and can be used for g-2 experiment. This will decouple g-2 from p-bar rings and mu2e experiment, and will allow to run both experiment in parallel.