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An Emittance Exchange Idea Using Transverse Bunch Stacking

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Abstract

A robust emittance exchange system is considered where muons are bunched longitudinally into many bunches and transversely cooled first, then separated into individual time-delay lines where the bunches are synchronized. Finally the bunches are merged by stacking in the transverse momentum space. The longitudinal emittance can be reduced by a maximum factor of N and the transverse emittances can be increased by a minimum factor of $\sqrt{N}$ in each direction. Emittance dilution may increase the transverse emittance by a factor of 2 ~ 3.

1. Introduction

Muon sources under consideration presently has a longitudinal emittance which is about two orders of magnitude larger than what is required for a muon collider. [1] A robust emittance exchange technique is required that converts the beam longitudinal emittance into transverse emittance for the muon collider to be viable. No such method has been proposed so far which is capable to compress all muons to a single bunch.

An emittance exchange system was considered using wedge-shaped absorbers placed in a channel with a finite dispersion. [2] The dispersion can be generated using bent solenoids or wigglers. Particles with a larger momentum would lose more energy by passing through the thicker part of the wedge, thus the longitudinal emittance is decreased while the transverse emittance is increased. However, the necessary re-acceleration of such a large-emittance beam is extremely difficult. This type of emittance exchange system is likely to be useful for a smaller emittance beam later in the cooling channel.

In the present report, we consider an emittance exchange scheme in which a muon beam is bunched longitudinally and pre-cooled, separated and time-delayed individually, and finally merged transversely back into a single bunch. We present some ideas and some zero-th order calculations here and identify possible issues that require further investigations.

A scaled demonstration experiment using electron bunches can also be considered. In such an experiment, emittance dilutions in beam separation and merging operations can be measured and compared with simulations.

2. Bunching and pre-cooling

We assume that initial bunching and pre-cooling can be done in the same way as is being considered recently for the Neutrino Factory. [3] Beam parameters at the end of the cooling channel is summarized in table 1.

Table 1. Beam parameters at the end of the pre-cooling channel

Number of bunches	49
Transverse emittance	1.5 mm radian, rms normalized
Longitudinal Momentum	0.200 GeV/c
Single bunch longitudinal emittance	28 mm, rms normalized

The number of bunches is assumed to be 49 which will reduce the longitudinal emittance by a maximum factor of N and increase the transverse emittances by a minimum factor of $\sqrt{N}$. Transverse emittance dilution during beam separation and beam merging will depend on detailed design of the system and must be investigated carefully.

If the resulting bunch emittance is still too large, one can now use the other emittance exchange and cooling techniques to reduce it further.

3. Bunch Separation and Synchronization

A different amount of time delay for each bunch is necessary to synchronize all the bunches. Bunches need to be separated and passed through separate channels whose length is designed to give the necessary time delays for bunch synchronization.

A transverse beam deflection system can be built in which each bunch is deflected by different amount by rf cavities whose rf frequency is slightly different from the bunch frequency. If there are N number of bunches with bunch frequency of F, the frequency for the deflection system is $F_d = F(1+a/N)$, where $a \sim 0.4$ is a constant such that the phase for the first bunch is $a\pi$ and the last bunch is $-a\pi$.

Required differential transverse momentum between two adjacent bunches is $dP_x = k\,\sigma_{px}$ where $k \sim 2.5$ is a constant. If all bunches are deflected in a square array in x-y space the maximum differential transverse momentum between the inner most and the outer most bunches is $dP_x^{max} = \sqrt{N}\,k\,\sigma_{px} / 2$. If we assume that we extract the bunches at high beta region where $\sigma_{px} \sim 5$ MeV/c. Then, $dP_x^{max} \sim 40$ MeV/c. If we assume a deflection rate of 14 MV/m the total length of deflection system is less than 3 meters in each of the X and Y directions. It appears to be advantageous to have a high beta region at the end of the deflection system. All bunches emerge from the deflector and separated transversely in the x-y space as they drift.

The distance from the first bunch to the last bunch is $dz = \beta c\, N / F < 80$ meters, where βc is the beam velocity. Each bunch can now be directed to individual time-delay channels. The first bunch is made to detour half way to meet the last bunch, etc., as shown in figure 1.

Possible emittance growth and particle losses in such a deflection system need to be investigated through simulations and some scaled experiments.

4. Beam Merging by Stacking In Transverse Space

All bunches are synchronized after proper the time delays, and brought together parallel to each other in a square array . The bunches are then bent in the direction of a common focal spot for beam merging.

Bending magnet of up to 0.5 Tesla and 20 cm long is required to bend up to 100 mrad to a focal disdance of about 2 meters can be considered. To minimize emittance dilution the bunches must be brought as close to each other as possible. The physical locations of the bending magnets can be staggered longitudinally between adjacent bunches to achieve this goal.

Emittance dilution and particle losses during beam merging will depend on the detailed design and also need to be simulated.

5. Recycling the Beam

The merged beam can then be sent back to the phase rotation section and reuse the induction linac, bunching and matching system, and the 130 meter long transverse cooling section.

6. Conclusion

An initial look at the emittance exchange scheme by transverse momentum stacking has not revealed any fatal flaw so far. Emittance dilution during beam separation and merging may give a transverse emittance dilution of a factor of 2 to 3, which can be compensated by subsequent cooling. More work and some simulations may be worth a while. The author appreciate exciting discussions with and constructive criticisms of Yasuo Fukui, Eun San Kim, Gregg Penn, Andy Sessler, and Jonathan Wurtele.

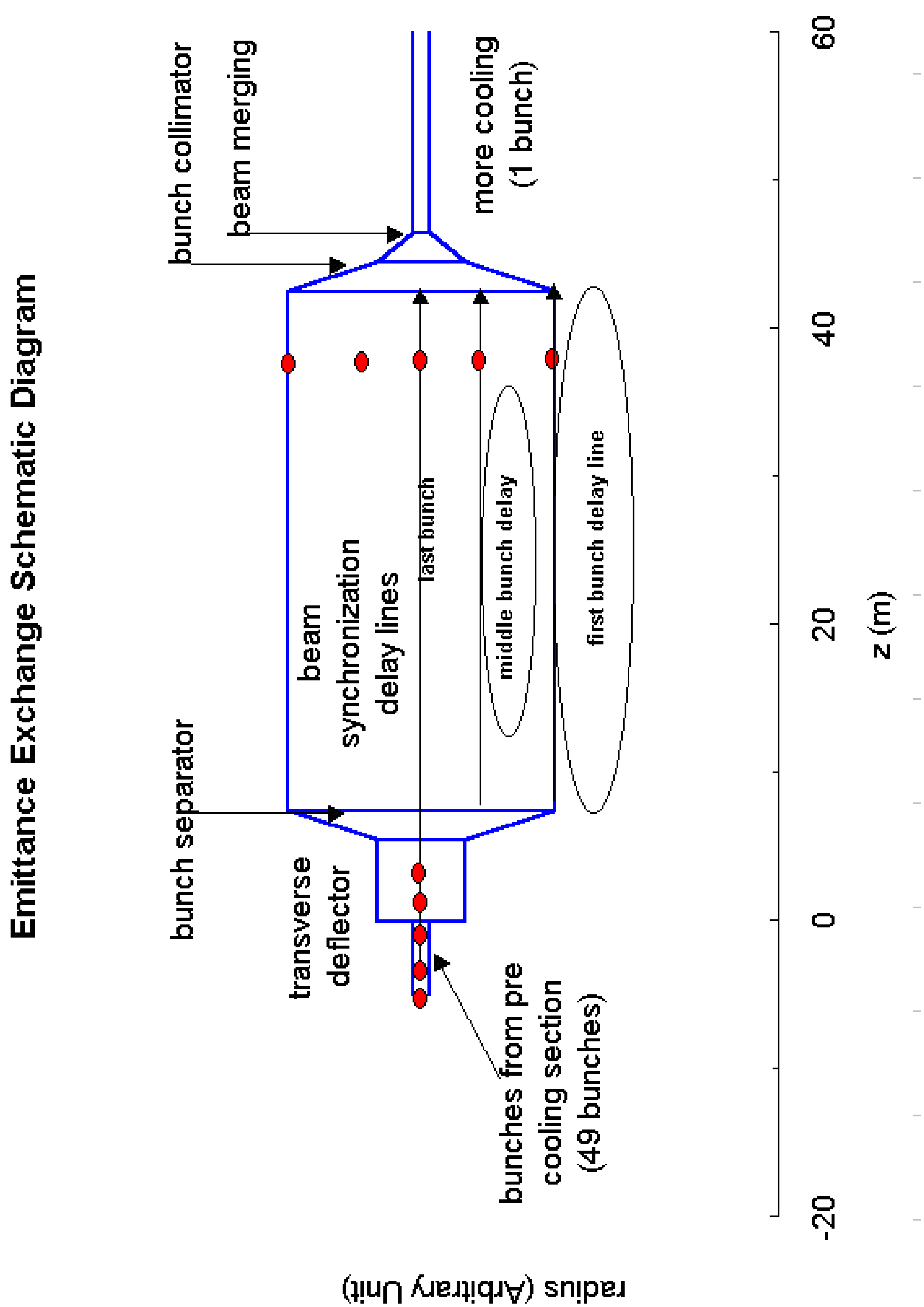
References

1. "Status of Muon Collider Research and Development and Future Plans", BNL-65623, Fermilab-PUB-98/179, LBNL-41935, May 10, 1999
2. "Bent Solenoids as Beam Transport Elements", J. Norem, Muon Collider Notes #14
3. "A Cost-Effective Design for a Neutrino Factory", R.B.Palmer, C.Johnson, and E.Keil, Muon Collider Notes #67

Figure Caption

Figure 1. A schematic diagram of the emittance exchange system. Beam synchronization delay lines are shown only schematically for three typical bunches. An actual delay lines may have the shape of a race track.

Figure 1


Emittance Exchange Schematic Diagram
bunch separator
bunch collimator
beam merging
more cooling
(1 bunch)
transverse
deflector
beam
synchronization
delay lines
last bunch
middle bunch delay
first bunch delay line
bunches from pre
cooling section
(49 bunches)
-20
0
20
40
60
z (m)
radius (Arbitrary Unit)