PREPARATIONS FOR MUON EXPERIMENTS AT FERMILAB*

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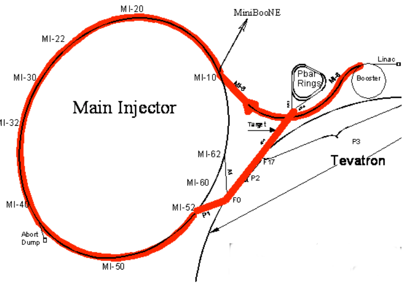
Abstract

The use of existing Fermilab facilities to provide beams for two muon experiments --- the Muon to Electron Conversion Experiment (Mu2e) and the New g-2 Experiment --- is under consideration. Plans are being pursued to perform these experiments following the completion of the Tevatron Collider Run II with no impact to the on-going Main Injector neutrino program by using spare Booster cycles to provide 8.9 GeV/c protons on target. Utilizing the beam lines and storage rings used today for antiproton accumulation, beams can be prepared for these experiments with minimal disruption, reconfiguration or expansion of the Fermilab accelerator infrastructure. Proposed operational scenarios and required alterations to the complex are described.

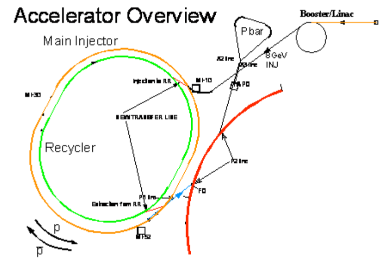
Introduction



Beam transport scheme for Mu2e operation.

Through the NOvA Project [1] plans are made that will allow the Fermilab 120 GeV Main Injector to run with a 1.333 sec cycle time for its neutrino program (NuMI), with twelve batches of beam from the Booster synchrotron being accumulated in the Recycler synchrotron and single-turn injected at the beginning of the MI cycle. Recent upgrades have increased the maximum average Booster repetition rate from roughly 2.5 Hz to 9 Hz. A further upgrade to the Booster RF system to be performed over the next several years will allow the Booster to run at its maximum rate of 15 Hz. At this rate, there remain eight Booster cycles during each MI period that could in principle be used for an 8.9 GeV/c experimental program, with ~4×10^{12} protons (4 Tp) per cycle. Upgrades to the corrector system [2] will allow for the higher flux.

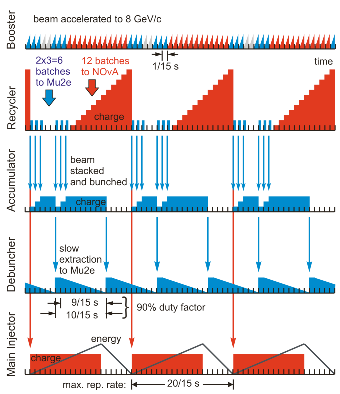
One experiment, the Muon to Electron Conversion Experiment (Mu2e), has been given relatively high priority by HEPAP and would take several years to construct. During the time period between when the Tevatron Run II program is concluded and Mu2e operation begins, much of the same facility components can be used to furnish beam to the other proposed experiment, the New g-2 Experiment (g-2) which would be relocated from Brookhaven National Laboratory.



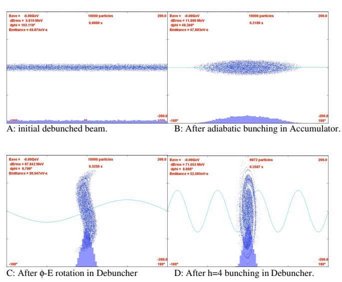
Mu2e

Experimental Requirements

The Mu2e experiment [3] requests a total delivery of 4×10^{20} protons on target (POT) per year for two years. Muons are to be produced and brought onto an aluminum stopping target in narrow (<200 ns) time bursts, separated by intervals of about 1.5 μs, somewhat larger than the lifetime of muonic aluminum. Muon to electron conversion data would be taken between bursts, after waiting a sufficient time (~700 ns) for the prompt background to subside. A suppression (extinction) of the primary proton beam between bursts by a factor of 10^{-9} relative to the burst itself is necessary to control the prompt background.



Bunched beam preparation for the Mu2e experiment. [4]



Extinction

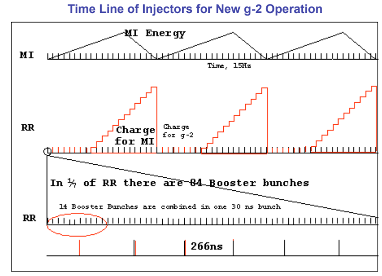
One exceptional feature of the beam line is the extinction insert at its downstream end. This portion of the transport system will utilize a set of rapid cycling dipole magnets (AC dipoles) on either side of a focusing channel the middle of which contains collimators. The dipole magnets cycle at half the burst frequency (~300 kHz) and kick the unwanted beam well into the collimator iron. [5] Various hardware options for these magnets, as well as instrumentation for measuring and monitoring the level of extinction are being explored. [6]

New g-2

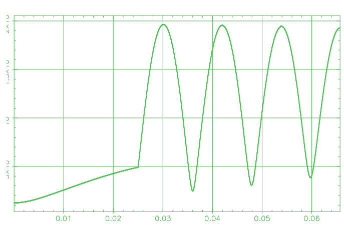
Experimental Requirements

The New g-2 Experiment [7] requires 3.09 GeV/c muons injected into an existing muon storage ring that would be relocated from Brookhaven National Laboratory to Fermilab. The ring is 7 m in radius, giving a revolution time of 147 ns. To account for the injection kicker, the beam pulses need to have lengths of about 100 ns or less and separated by ~10 ms for the muons to decay in the ring and data to be recorded prior to the next injection. To obtain a very pure muon beam, the decay channel should be several times longer than the pion decay length, which is ~170 m at this momentum. The experiment requests a total of 2×10^{20} 8.9 GeV/c POT.

Time Line of Injectors for New g-2 Operation



Bunched beam preparation for the g-2 experiment. [8]



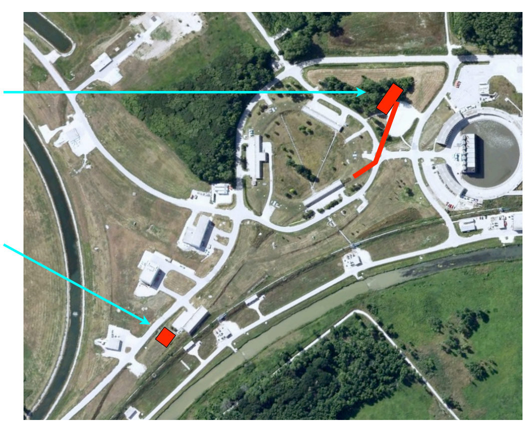
RMS $\frac{\Delta p}{p}$ in the Recycler vs. time [s]

Like for Mu2e, six Booster batches every MI cycle can be sent to the experiment for an average rate of 18 Tp/sec, yielding the required total protons on target in about a single year of running. Each batch would be coalesced into four bunches in ~ 30 ms, and the four bunches would then be delivered to the experiment every 12 ms. Thus, the last bunch is extracted just within the 66.7 ms Booster cycle. One broadband, a 2.5 MHz and a 5 MHz RF system. Upgraded equipment from the present Recycler and Main Injector could be used for this purpose.

Locations and Parameters

The Mu2e experiment will be connected to the Debuncher ring through a new beam transport enclosure as indicated to the right.

The location for the experimental building for the g-2 experiment is being considered near the AP0 target hall. The cryogenic needs of the experiment can be met by the Tevatron accelerator cryogenics system with some modifications and additional transfer line work. Its exact location will be determined by the final design of its connection with the beam transport line.



Baseline Parameters

	g-2	*Mu2e*	
p momentum on target	8.89	8.89	GeV/c
Booster Rep. Rate	15	15	Hz
MI cycle	20	20	1/(15 Hz)
Pulses per MI cycle	6	6	
p per Booster cycle	4	4	Tp (10^{12} particles)
$\langle p/\text{sec}\rangle$ to target	18	18	Tp
$\langle p/10^7\text{sec}\rangle$ to target	1.8	1.8	10^{20}
$\langle\text{pulses/sec}\rangle$ to target	4.5	529,400	Hz
duty factor	30	90	%
Maximum stored in Recycler	4		Tp
Maximum stored in Accum/Deb		12	Tp
Recycler RF			
broadband	4		kV
2.5 MHz	80		kV
5.0 MHz	16		kV
Accumulator RF			
$h = 84$ (53 MHz)		50	kV
$h = 1$ (625 kHz)		4	kV
Debuncher RF			
$h = 1$ (588 kHz)		40	kV
$h = 4$ (2.35 MHz)		250	kV
Beam at Target:			
final bunch length	15	40	nsec, rms
final bunch intensity	1×10^{12}	4.3×10^{7}	
final momentum spread	2	8	10^{-3}, rms
transverse emittance	15	<15	π mm-mrad, norm., 95%

General Remarks

The Booster synchrotron needs to operate at its maximum rate of 15 Hz, and transfers into and out of the Recycler are required for both experiments. The g-2 operation requires kicker magnets as beam will circulate within the Recycler and the same devices could in principle be used for Mu2e as well.

Further refinements to the operational scenarios are being explored. The high space charge in the Mu2e experiment has generated much discussion, and other beam delivery scenarios are being investigated. One example ([9]) uses the same bunch preparation scheme as in g-2, but single-turn transfers the four bunches into the Accumulator and then one-at-a-time delivers a bunch to the Debuncher for slow spill. This reduces the bunch intensities by a factor of 12, and potentially the momentum spread by a factor of 4 as well. It also uses the same bunch formation in the Recycler for the two experiments, which may have some benefits. Attempts will continue to integrate components for the two experimental scenarios where possible.

References

[1] NOvA Collab., NOvA-doc-593 (2006), nova-docdb.fnal.gov.

[2] E.J. Prebys, *et al.*, PAC07, MOPAS016.

[3] Mu2e Collab., MU2E-doc-62 (2008), mu2e-docdb.fnal.gov.

[4] D. Neuffer, Beams-doc-2787 (2007), beamdocs.fnal.gov.

[5] E.J. Prebys, Beams-doc-2925 (2007).

[6] E.J. Prebys, *et al.*, PAC09, TU6RFP033.

[7] Proposal P-989 submitted to Fermilab, 9 Feb. 2009.

[8] C. Bhat, J. MacLachlan, Beams-doc-3192 (2008).

[9] M. Syphers, MU2E-doc-398 (2008).

Acknowledgements

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