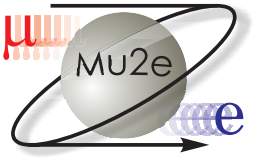

Mu2e Proton Beam Requirements

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Change Log

Revision Number	**Pages Affected**	**Effective Date**
1.0	all, minor; adding change log to existing document	28 July 2011
1.1	all, changing protons on target, other	20 March 2012
1.2	all, updated to more recent references and minor editing	25 November 2013
1.3	all, addressed comments, minor editing	12 December 2013
2.0	all, updated beam spot size and divergence requirements	6 June 2014

The basic requirements of the Mu2e experiment that need to be met by the accelerator complex include

- having pulses of protons reach the production target at a repeat period longer than the lifetime of muons in aluminum, which is approximately 864 ns.
- having the time distribution of particles reaching the target within a window of length less than approximately 250 ns, with essentially no particles outside of this window (for extinction level requirements, see Ref. [1]).
- delivering approximately 3.6×10^{20} protons on target (POT) over approximately 3 years of running.
- optimizing detector performance by having as high a duty factor as possible and as low an instantaneous rate as practical.

To meet these basic requirements, the Mu2e experiment utilizes the 1695 ns revolution period of the 8.9 GeV/c Delivery Ring synchrotron to provide pulses of protons with this time interval to the production target. The Fermilab Booster synchrotron can readily produce 4×10^{12} (4 Tp) protons per cycle, and during the operation of the Main Injector (MI) for the NOνA experiment, 8 Booster cycles can be made available every MI cycle (1.333 s). Mu2e will use two Booster cycles out of the available eight, or $2 \times 4 \times 10^{12}/1.33 = 6 \times 10^{12}$ protons/sec. This is consistent with the planned 3.6×10^{20} POT in a 3–4 year experiment.

To optimize detector performance the experiment desires the beam to arrive with a high duty factor. Each pulse will have a total intensity of approximately 31 Mp, consistent with the anticipated capabilities of the present detector design. This level of proton intensity can also be monitored and controlled; the experiment would prefer a lower intensity and the beam structure is a compromise among the various needs. Furthermore, the high spikes in the instantaneous rate endemic to the extraction process can degrade detector performance. Therefore, the cycle-to-cycle and pulse-to-pulse variations should be maintained to $\sim$50% of the time-average values.

The transverse beam size (assumed round) on target must be less than about 1.5 mm (rms) to hit the 3 mm radius target, but more than 0.5 mm (rms) to spread out the energy deposition in the target (see Refs. [2], [3]). The design value chosen is 1 mm (rms). A beam divergence less than about 4 mr (rms) is also required to be consistent with a target length of about 16 cm (see Ref. [4]). The centers of the beam pulses arriving on the target should be spaced by the revolution period of the Delivery ring with a pulse-to-pulse variation that has a maximum deviation of no more than 10 ns.

Beam outside of a "transmission window" of $\approx \pm 125$ ns centered on the beam pulse should be suppressed (the "extinction" requirement) as described in Ref. [1].

The pulses of beam reaching the target should have a total bunch length less than the transmission window. The proposed design value is $\approx$ 250 nsec total bunch length, with an rms bunch length of approximately 38–40 ns.

The beam line design will need to incorporate trajectory compensation to be able to fine tune the beam position and angle onto the target. It will also need to be able to run at reduced intensity for commissioning and special calibration runs.

Table 1 lists the important parameters for the Mu2e beam, their design values and limiting values.

References

[1] Extinction Requirements Document, Mu2e-docdb 1175.

[2] Production Target Requirements Document, Mu2e-doc-887.

[3] K. Lynch, How can we reliably reduce our stopped particle rates? Mu2e-doc-3991.

[4] K. Lynch, The effect of beam divergence on stopped muon yield, Mu2e-doc-4130.

Table 1: Mu2e Beam Parameters

Parameter	**Design**	**Limit**	**Unit**	**Notes**
Booster synchrotron repetition rate	15	> 10.5	Hz	
Time between beam pulses	1695	> 864	ns	Delivery Ring revolution period
Length of slow spill period	54	> 20	ms	
Beam Line Transmission Window (centered on beam pulse center)	230	250	ns	relevant for AC dipole specs
Transmission Window jitter (rms)	5	< 10	ns	
Extinction Level	10^{-10}	$\leq 10^{-10}$		see Ref. [1]
Average intensity per pulse on target	≈ 31	< 50	Mp	
Maximum spread of pulse intensity on target	$< 50\%$	50%		
Time Average dN/dt on target (averaged over many beam cycles)	6	< 18	Tp/s	
Target rms transverse spot size	1.0	< 1.5	mm	
(assumed "round")		> 0.5	mm	
Target rms transverse beam divergence (assumed "round")	0.5	< 4.0	mr	
Beam pulse total length	250	< 250	ns	
Beam pulse rms time width	38	< 50	ns	