A 15-Hz spill cycle scenario for Mu2e

Sergei Nagaitsev and Chandra Bhat (FNAL)

June 29, 2009

Abstract:

The muon-to-electron conversion experiment (Mu2e) [1] is designed to address some fundamental questions in the standard model of elementary particles. The high energy physics accelerator facility at Fermilab can be easily upgraded to conduct this experiment. One of the current operational scenario for the experiment at Fermilab envisions slow extraction of an 8 GeV proton beam in the Debuncher Ring. In this document we describe a plausible and robust technique for preparation of beam bunches for the experiment that can be made integral part of the current plans for NOvA accelerator upgrades and also can be extended for future upgrades with Porject-X.

The beam intensity requirements for the Mu2e [1] experiment calls for slow extraction of 8 GeV proton beam with a pulse length of about 160 nsec with a dead time of about 1.9μsec between pulses. The beam intensity requirement for Mu2e is about $2x10^{17}$ protons/hour. Our preliminary analysis shows that goal can be achieved at Fermilab accelerators with a few upgrades to the existing LINAC, Accumulator and the Debuncher. The modification presented is quite versatile and can be easily extended to much higher intensity beam operation from the future Project-X.

At present, the Fermilab Booster accelerates $4x10^{12}$ protons (4 Tp) per batch. The batch consists of 80 bunches at 53 MHz followed by a four 53 MHz bucket extraction kicker gap. Each bunch has a 95% longitudinal emittance of about 0.1 eV-s. For the Mu2e operating scenario presented here, one needs only about 54 Booster bucket to be populated with proton beam leaving a gap of about 30 buckets before acceleration to 8 GeV and provide beam to the experiment by slow extraction. With NOvA accelerator upgrades, the Booster will be capable of accelerating beam at a 15-Hz rate. In case when the Mu2e experiment is the only user, it would be beneficial to develop a scenario of operating the slow extraction process on a 15-Hz cycle rate. This could be accomplished in the following manner.

Suppose that one can partially fill the Booster circumference, leaving a 30-bucket gap, instead of the present 4-bucket gap. At present this capability exists in a study mode only. Normally at injection the Booster is filled with a dc proton beam at zero rf voltage. The beam is then bunched by increasing the rf voltage adiabatically. The 4-bucket gap is created by a partial-turn (4-bunch) extraction at injection energy into a Booster dump. In study mode 30-bucket gap is produced by extracting beam in them to the existing beam dump at 400 MeV and use only 54 bunches for the experiment. However, the dump is not designed for additional beam power to run the facility at 15 MHz rate.

We propose a plausible way to fix this problem by,

1. Developing a beam chopper system for the LINAC for filling the Booster partially. In this case, fill booster only 65% per Booster turns.
2. Use standard multi-turn filling procedure via H^- stripping to fill Booster so that beam is stacked 10-14 turns one over the other. With <0.25% energy spread [2] (full energy spread of the H- beam at injection to the Booster) the beam will have sheared not more than 40 nsec azimuthally during the injection period of 20-30 μsec.
3. Next, adopt standard 53 MHz capture for next 3-4 msec. This will naturally produce high intensity partial Booster batch. There will be a small amount of beam particles captured in the trailing buckets with very low intensity. Those can be removed adopting standard technique if needed.

Thus, a possibility exists to partially fill the Booster with 50-55 bunches leaving a gap of about 25-30 buckets. The desired intensity per bunch could be about 5-6x10^{10} protons with a total intensity of about 2.5-3 Tp per batch.

At the end of the Booster cycle the batch is transferred to the Accumulator using the Recycler as a transfer line. In the Accumulator these 53 MHz bunches can be recaptured using existing 53-MHz rf system and soon after rotate it in h=1+h=2 rf systems or to expedite the rf manipulation one can directly transfer the Booster beam to the h=1+h=2 rf systems (here the voltage ratio between h=2 and h=1 is about 0.2. The h=2 is added to linearize the rf wave near the center of the bunch train during bunch rotation). Figures 1-3 show the single-particle simulation of bunch capture and its evolution in the Accumulator. This simulation was performed using ESME code [3].

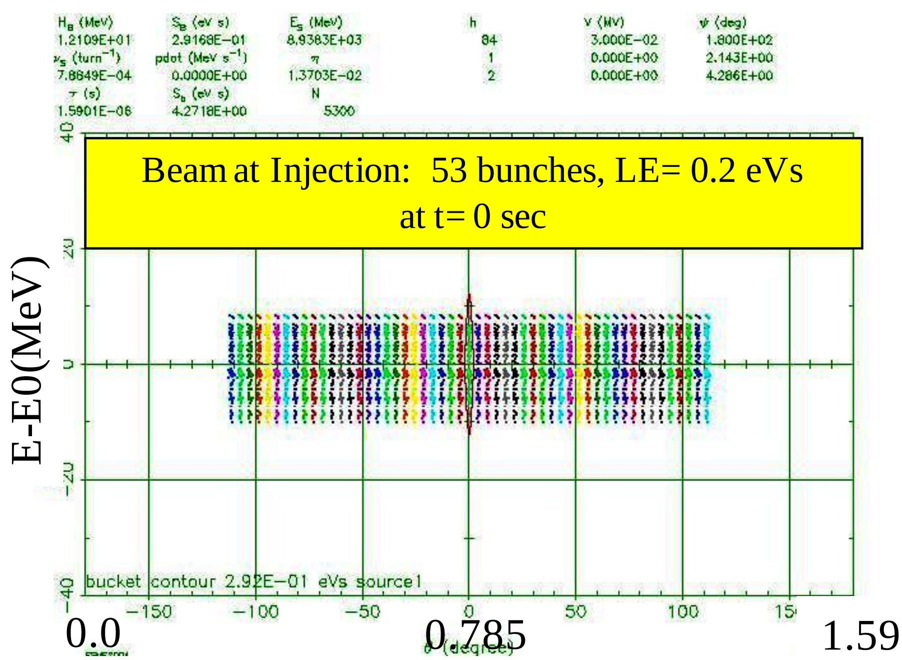

Figure 1: Beam at injection in the Accumulator. Time (hor. axis) is in microseconds.

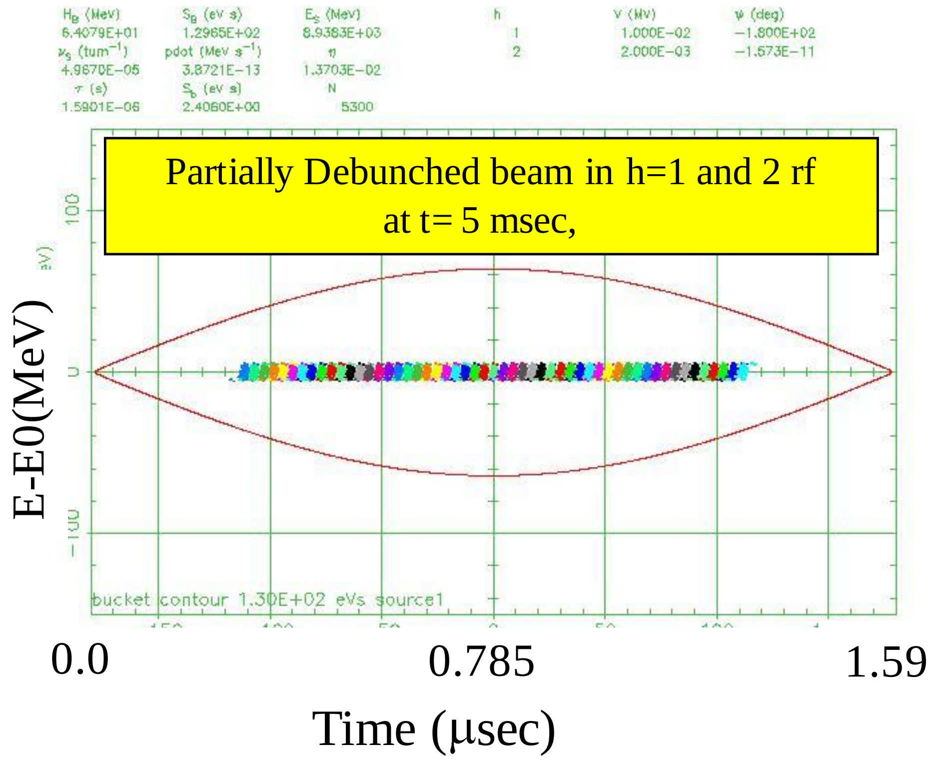

Figure 2: Beam in the Accumulator at 5 ms after injection.

After 15-20 ms in the Accumulator a single bunch 160 nsec long is formed by bunch rotation. At this point it is ready to be transferred to the Debuncher for slow extraction.

The Debuncher needs a h=4 rf system with a minimum rf voltage of 50 kV. This rf system is turned on all the time to accommodate beam injection at 15 Hz rate. Figures 4-5 show the single-particle simulation results for the beam in the Debuncher during the slow extraction process.

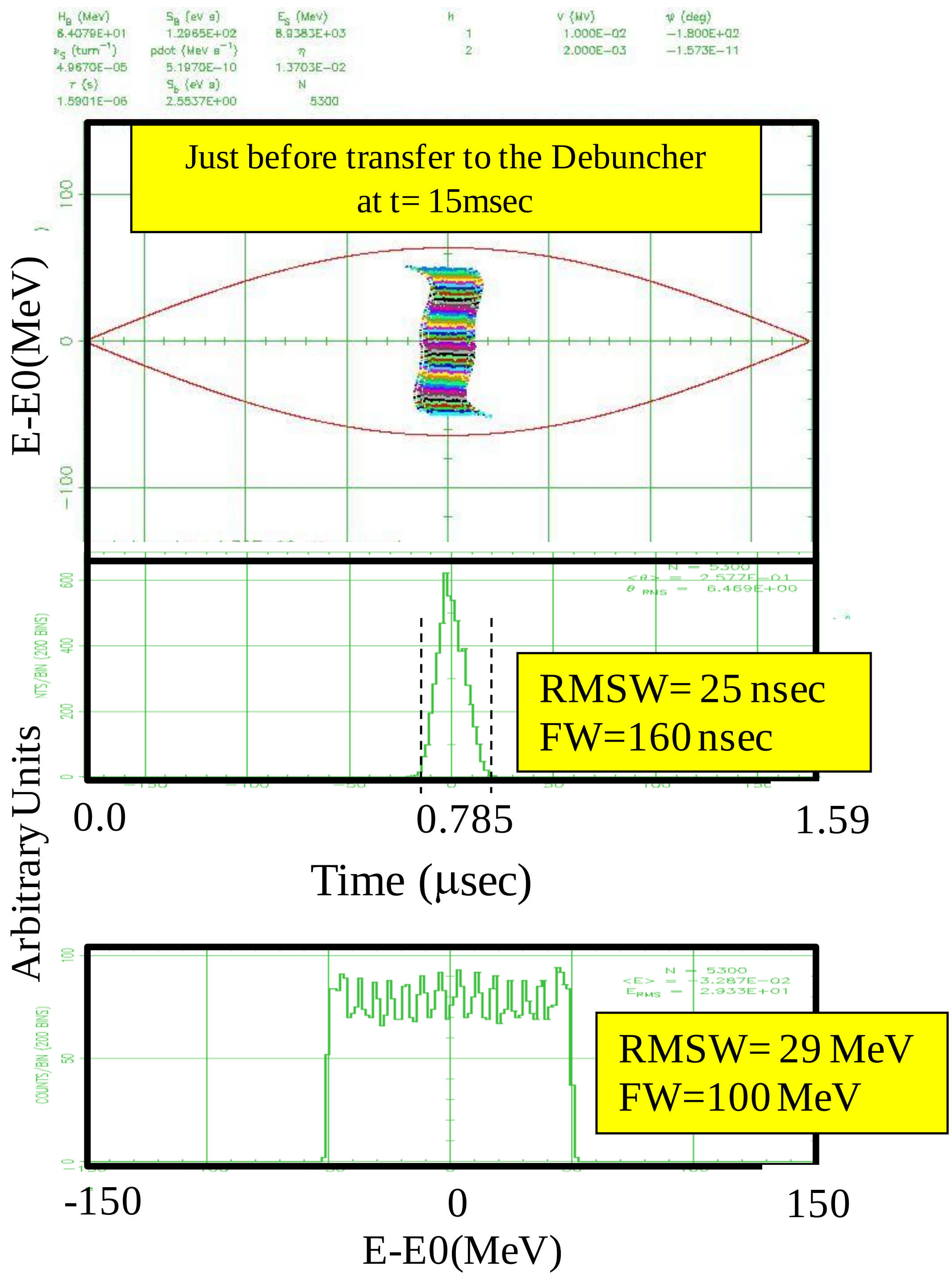

Figure 3: Beam in the Accumulator at 15 ms after injection.

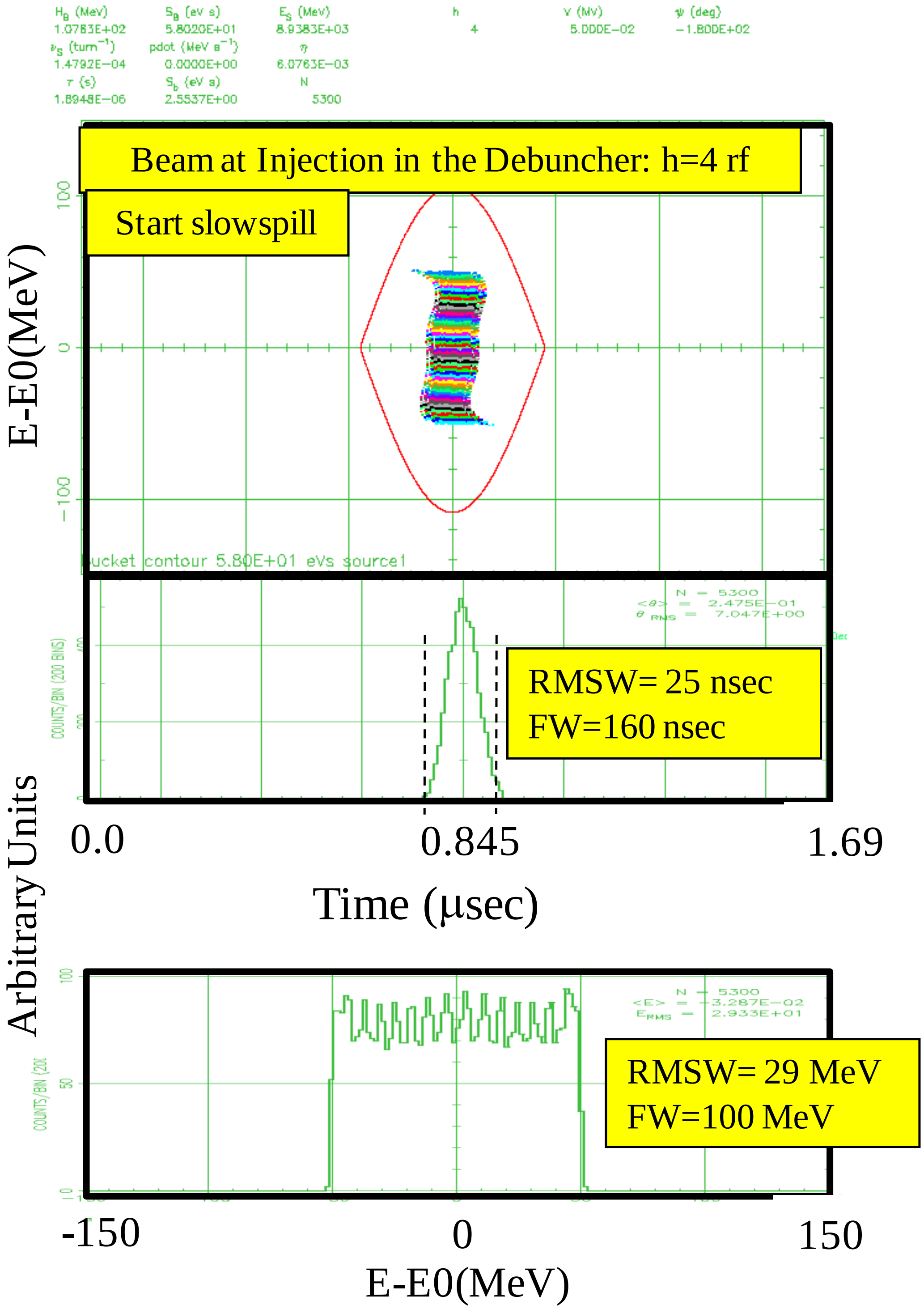

Figure 4: Beam in the Debuncher at injection.

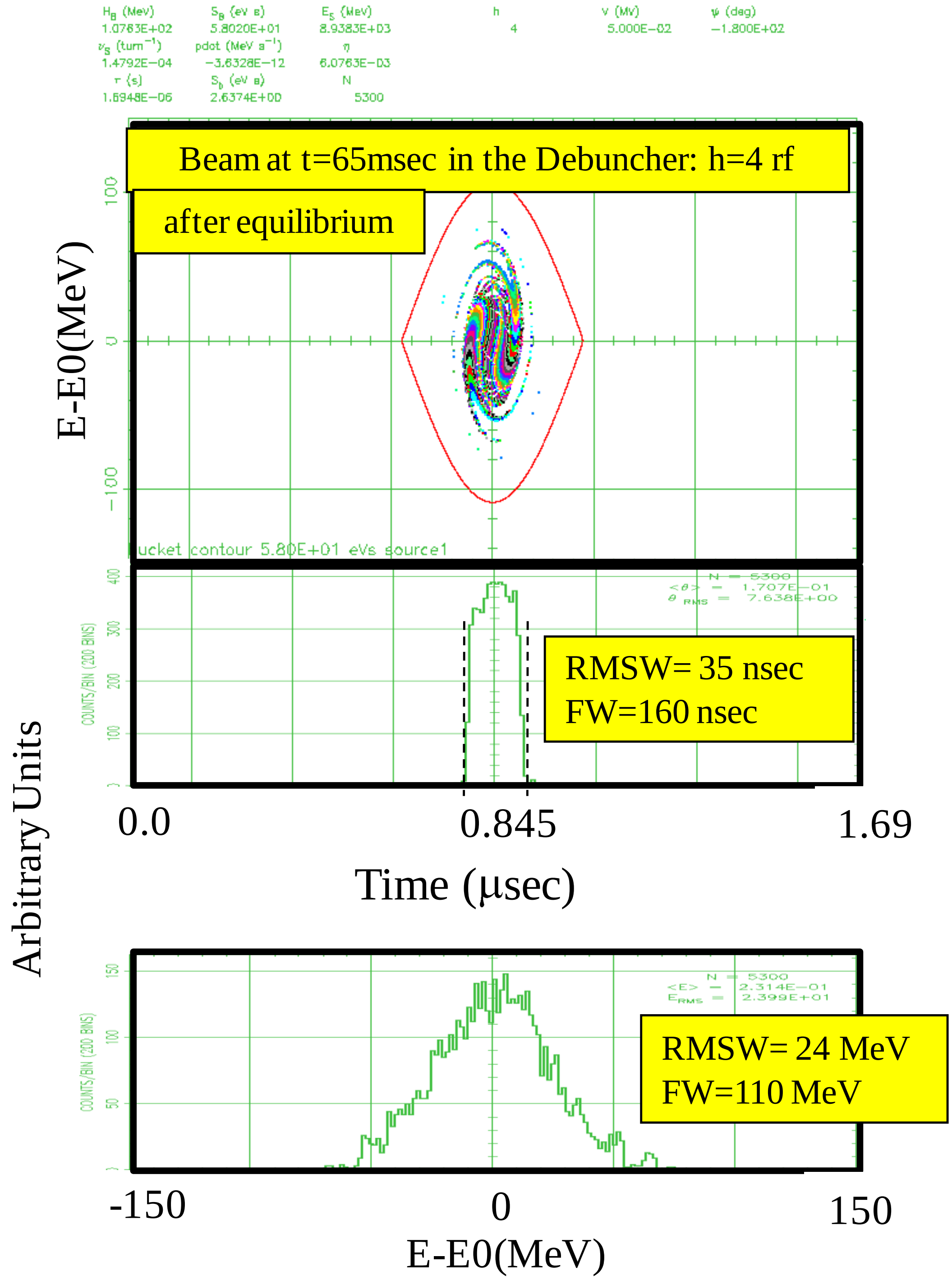

Figure 5: Beam in the Debuncher at the end of the 15-Hz cycle.

Summary

A train of 50-55 Booster bunches can be rotated in the Accumulator to form a 160-ns (FW) bunch for the Mu2e slow extraction with an acceptable momentum spread (1.2% FW) in about 20 ms. We have assumed a conservative 0.2 eV-s longitudinal emittance (95%) per bunch. In this scenario the extraction rate from the Debuncher could be 2.5-3 Tp at 15-Hz. The rf requirements in the Accumulator and Debuncher for this scenario are as follows:

Debuncher

RF System	Frf (MHz)	Vrf(Minimum)	Comments
h=4	2.36	50kV	

Accumulator

RF System	Frf (MHz)	Vrf(Minimum)	Comments
h=84	53	30kV	
h=1	0.6289	10kV	
h=2	1.257	2kV	

References:

1. Mu2e collaboration, http://mu2e.fnal.gov/public/hep/index.shtml.
2. Ray Tomlin (Private communications, June 2009); Booster Elog, 8/22/2001, 11:02 am
3. J. A. MacLachlan, HEACC'98, XVII International Conference on High Energy Accelerators, Dubna, 184, (1998); The latest version of the code is available at http://www-ap.fnal.gov/ESME/.