Possible Main Injector Operating Modes
17 Mar 2003

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I discuss possible Main Injector operating modes in support of the Fermilab Program about tobe reviewed by the P5 committee; e.g. CDF and D0 Run IIb, BTeV and CKM as well as NUMI/MINOS. The assumed boundary conditions on the problem are:

1. The Main Injector is a conventional magnet strong focusing synchrotron with half the circumference of the Tevatron. It can hold 7 batches from the 8 GeV booster with one batch normally left empty as an abort gap. The design intensity of the Main Injector is $3x10^{13}$; 6 booster batches of $5x10^{12}$ each. With slip stacking a single booster batch of $8x10^{12}$ for anti-proton production and 5 batches with $5x10^{12}$ each for NuMI are possible.

2. Anti-proton production for either Run IIb and/or BTeV requires one $8x10^{12}$ proton batch per Main Injector (MI) cycle. The other batches in the MI are $5x10^{12}$ for a total of $3.3x10^{13}$ per MI cycle.

3. CKM requires slow spill, de-bunched 120 GeV proton beam at a rate of $5x10^{12}$/slow-spill-sec. De-bunched operation is required to control accidentals in CKM which must achieve background rejection of 10^{-11} in a 50MHz secondary separated K^+ beam at 22 GeV/c.

4. MINOS can profitable use every proton they can get.

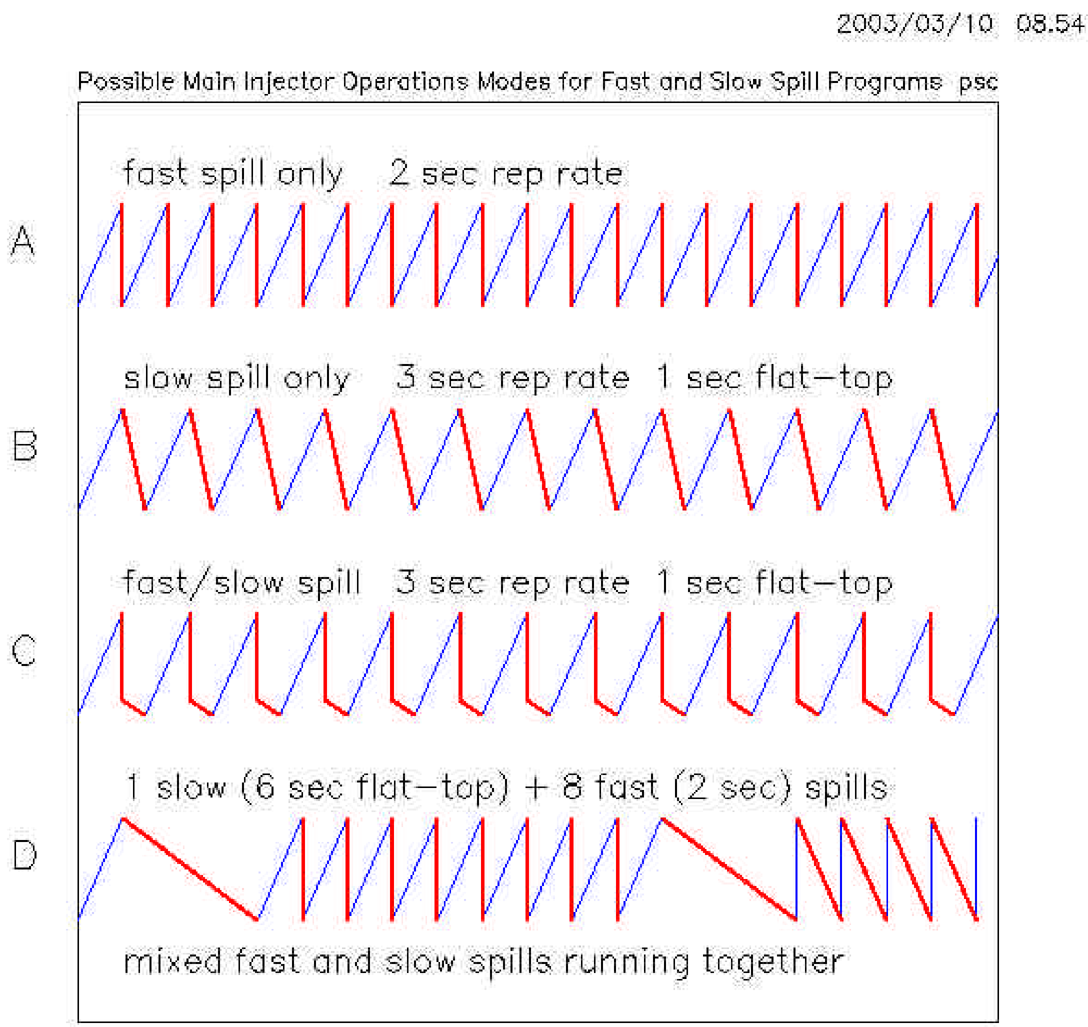
Below I discuss 4 scenarios for operation of the Main Injector, all of which are believed to be technically achievable. These scenarios, labeled A-D, are shown in the attached figure where blue curves are the magnet ramp of the MI and red curves are extracted beam. The scenarios are:

A. Fast spill only. The MI is cycled as rapidly as possible (1.9 sec) with an $8x10^{12}$ batch extracted for anti-proton production and the remaining 5 batches ($25x10^{12}$) fast-extracted for NUMI. This scenario fails to support any slow spill experiments.

B. Slow spill only. The MI is operated with a 3 second cycle including a 1 second flat top. Resonant slow extraction can provide up to $30x10^{12}$ protons per cycle. CKM cannot use this much beam, requiring only $5x10^{12}$/sec. The intensity would have to be lowered. De-bunching the beam, with a residual ~10% 53MHz modulation for CKM is straight-forward. This scenario fails to support either anti-proton production or MINOS.

C. Combined fast/slow spill operation. The MI is operated with a 3 second cycle including a 1 second flat top. The $8x10^{12}$ batch for anti-proton production is extracted followed by 4 $5x10^{12}$ batches for NUMI/MINOS. The remaining batch in the machine is De-bunched and resonantly extracted in a 1 second slow spill for CKM. This scenario lacks a fast kicker to permit single turn extraction and still leave one batch of protons in the machine for slow spill.

D. Mixed fast and slow spill cycles. A number, n, of Fast spill only (scenario A) cycles are followed by one Slow spill only (scenario B) cycle with a 8 second cycle time and a 6 second flat top. This scenario was originally suggested by Phil Martin. It recognizes that the Main Injector limitation on flat-top time is the cooling of the magnets. The magnet duty factor can not exceed 33%. Whether this is 1sec/3sec or 6sec/18sec is not important. A flat-top of 6 seconds is chosen to allow CKM to completely use all the protons accelerated at the desired rate of $5x10^{12}$/sec.



In the spreadsheet below I calculated the total number of protons per hour to each program for each scenario. Since scenario D is parametric is the number of fast cycles per slow cycle (n) I've done a few representative cases. n<5 violates the 33% MI magnet maximum duty factor.

Spill Mode		Cycle Time [sec]	Flat top [sec]	Protons /Hour [x1E15] Pbar	NuMI	SY120	Total
A	Fast Only	1.9	0	15.2	47.4	-	62.5
B	Slow Only	2.9	1	-	-	41.0	41.0
C	Combined	2.9	1	9.9	24.8	6.2	41.0
D	Mixed Fast Fast cycles / Slow cycle	1.9 / 7.9	0 / 6				
	5	17.4	6	8.3	25.9	6.2	40.3
	6	19.3	6	9.0	28.0	5.6	42.5
	7	21.2	6	9.5	29.7	5.1	44.3
	8	23.1	6	10.0	31.2	4.7	45.8
	9	25	6	10.4	32.4	4.3	47.1
	10	26.9	6	10.7	33.5	4.0	48.2
	11	28.8	6	11.0	34.4	3.8	49.1
	12	30.7	6	11.3	35.2	3.5	50.0

Scenario A and B support only parts of the physics program (fast and slow spill respectively). Either of these requires exclusive operation of the complex and sequential scheduling of fast and slow spill programs.

Scenario C requires both an additional fast kicker and all beam operations to work properly in a non-interfering manner in the same cycle of the Main Injector. It produces less protons per hour than scenario D in most cases.

Scenario D appears to be the most efficient operating mode with a combined fast and slow spill program in terms of total protons accelerated per hour. The ability to tune the number of fast cycles per slow cycle makes the three demand on the Main Injector relatively easy to manage, and the complete separation of fast and slow spill cycles should simplify accelerator tuning and operations. For example, only slow spill cycles need to be de-bunched

These ideas have been discussed with Steve Holmes, John Marriner, Dave Finley, the proton economics committee which Dave Finey chairs, including Shekar Mishra, present head of the Beam Division Main Injector Department, Alberto Marchionni, who is acting for Shekar in his absence from the lab, and other members of the committee. Comments have been received from Phil Martin. As of this writing the only “showstopper” identified was the absent kicker for Scenario C. Discussions continue.

The Main Injector Department has begun to review these issues; in particular, Scenario D. At this time they see no important obstacles to operation with a long flattop beyond the 33% duty factor limitation. Further work and studies will be required to confirm this. There are concerns about slow spill extraction loses and the level of shielding required to contain them. Further calculations and studies will be needed to validate this Main Injector performance goal. Initial MI department internal discussions of de-bunching the beam indicate that the time required for de-bunching is milliseconds. De-bunched beam has never been attempted in the Main Injector. Studies will be required to learn and perfect this technique.

The CKM beam requirement from our proposal was based upon the nominal Main Injector slow spill of 1 sec flattop; 3 sec cycle time. We assumed $5x10^{12}$ de-bunched 120 GeV Main Injector protons per spill in this mode; or $6x10^{15}$protons per beam hour. We assumed 120 beam hours per week, 39 weeks per year and required 2 years to achieve the experiment’s goal of 100 events or $1x10^{-12}$ single event sensitivity. This is 9360 beam hours, for a total of $5.6x10^{19}$ protons.