Proton Economics in the Project X Era

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Abstract

This note summarizes basic proton economics in the Project X era under the base line specifications. The average power and total protons available to the high energy and 8 GeV programs are presented as a function of the energy chosen for the high energy beam.

1 Introduction

There are two very attractive features of the Project X proposal:

- Significant excess 8 GeV proton capacity, which will be naturally stripped and potentially manipulated for end-use in the Recycler.
- The high energy beam has a maximum beam power of 2.3 MW at 120 GeV, but can maintain a major fraction of this down to beam energies of about 50 GeV.

However, there are trade-offs between between the 8 GeV and high energy programs that, while straightforward, are often overlooked.

2 Proton Economics

We assume that the Fermilab High Intensity Proton Source conforms to the requirements outlined in the Project X Requirement Table[1], the most important of which are summarized in Table 1. In addition, we assume an approximate relationship between maximum proton energy and Main Injector cycle time of[2]

$$T = .44 \text{ s} + (.89 \text{ s}) \times \frac{K}{120 \text{ GeV}}$$

up to a maximum of 120 GeV (1.33 s). The constant term in this equation is primarily to allow for the regulation time at the maximum and minimum of the Main Injector acceleration ramp, and this constant term prevents the total power from being completely independent of the beam energy.

There is some possibility that it could be reduced, depending on the exact regulation needs at high energy[3], but we will assume the conservative case here.

Maximum power at high energy is achieved by reducing the Main Injector cycle time and loading more protons, leaving less protons *and* reducing the duty factor for the 8 GeV program. The relationship is summarized in Table 2. The average power and total protrons to both programs are shown in Figure 1 and Figure 2, respectively.

References

[1] http://projectx.fnal.gov/RnDplan/ProjectXRnDReq.xls

[2] R. Zwaska, FNAL-BEAMDOC-2393-v1 (2006)

[3] Dan Wolff,*private communication*

Parameter	**Value**
Linac	
Kinetic Energy	8 GeV
Current	9 mA
Pulse Length	1 ms
Charge per pulse ("blast")	9×10^{-6} C = 5.6×10^{13} protons
Repetition Rate	5 Hz
Average 8 GeV power	360 kW
Main Injector	
Maximum proton load	3 linac pulses = 1.7×10^{14} protons
Maximum kinetic energy	120 GeV
Cycle time for maximum energy	1.4 s = 7 linac pulses
Average 120 GeV power	2.3 MW

Table 1: Table of Project X specifications whith are relevant to proton economics.

Cycle Time		High Energy Program				8 GeV Program			
Ticks	Sec.	Energy (GeV)	Pulses	Power (MW)	Annual Prot. ($\times 10^{20}$)	Pulses	Avg. Power (kW)	Duty Factor	Annual Prot. ($\times 10^{20}$)
3	0.6	22	3	1.0	56	0	0	0	0
4	0.8	49	3	1.6	42	1	90	25%	14
5	1.0	76	3	2.0	34	2	144	40%	23
6	1.2	102	3	2.3	28	3	180	50%	28
7	1.4	120	3	2.3	24	4	206	57%	32

Table 2: Trade off between high energy program and 8 GeV program. The duty factor is calculated by assuming that the 8 GeV beam from each linac pulse is distributed over the full 200 ms available. It will be reduced further by any required beam conditioning, such as rebunching.

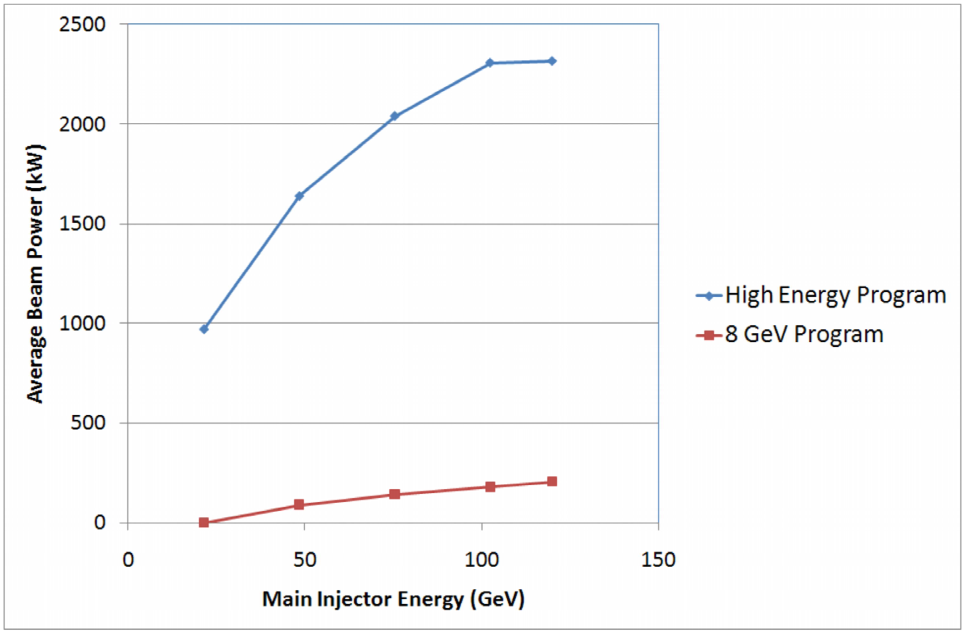

Figure 1: Average power to the high energy and 8 GeV programs as a function of Main Injector energy.

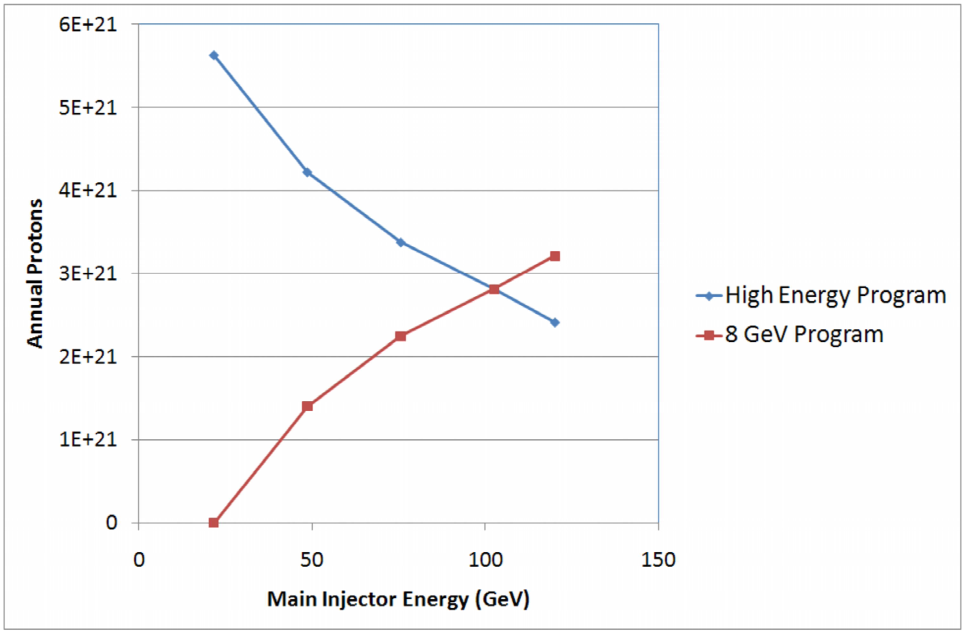

Figure 2: Total number of protons per 2×10^7 s year to the high energy and 8 GeV programs, as a function of Main Injector energy.