BEVATRON EXTERNAL PROTON BEAM*

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EXTRACTION SYSTEM

The achromatic extraction system for the Bevatron employs an energyloss (jump) target and two internal deflecting magnets, each accompanied by a small Panofsky-type quadrupole lens. The beam emerges from the accelerator approximately one betatron wavelength after the target. This kind of system [1] has several advantages over the corresponding single-magnet extraction system [2, 3].

A. Because the vertical and horizontal betatron periods are nearly equal ($\nu_h \approx 0.7$ $\nu_v \approx 0.8$), the internal optics can be adjusted to obtain a triple focus near the exit window. As a consequence:

1. The dispersion produced by the energy

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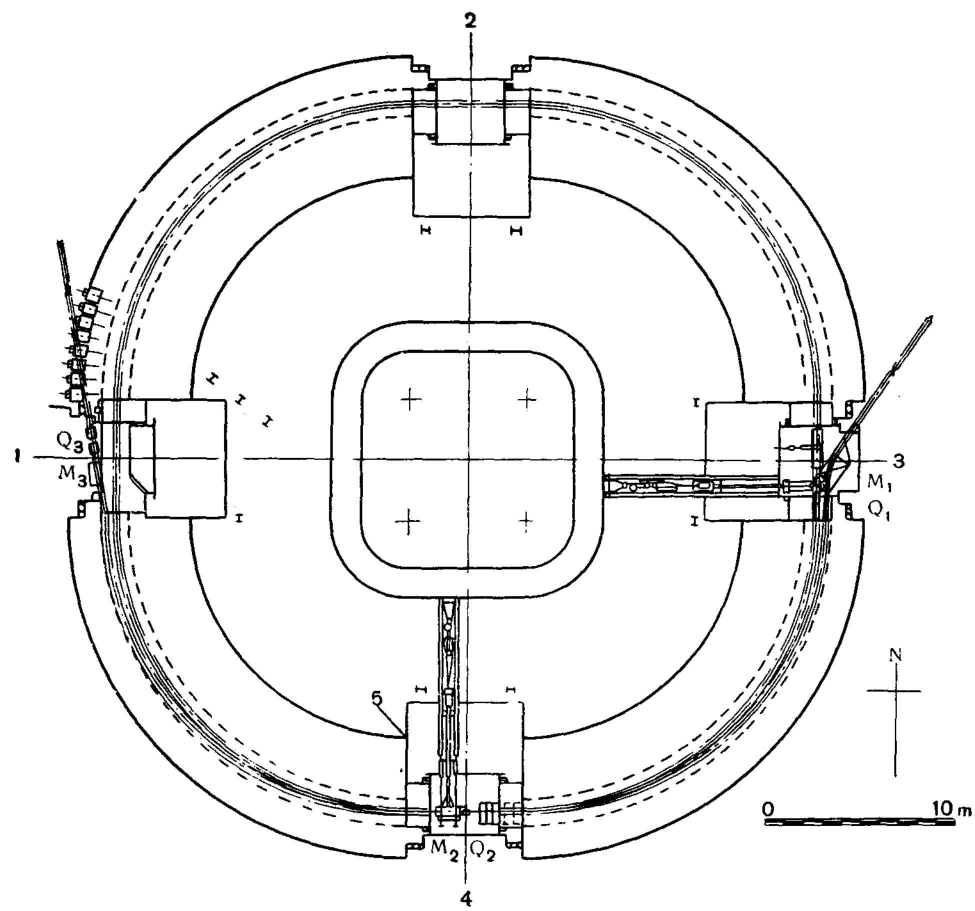

Fig. 1. Layout of the internal deflection system. The circulating beam travels in a clockwise direction:

1 — west straight section; *2* — north straight section; *3* — east straight section; *4* — south straight section; *5* — energy-loss target.

spread in the beam emerging from the target is minimized.

2. There is a reduction in the effect of the fringing field, which not only defocusses strongly horizontally (and focusses vertically), but also is very aberrational.

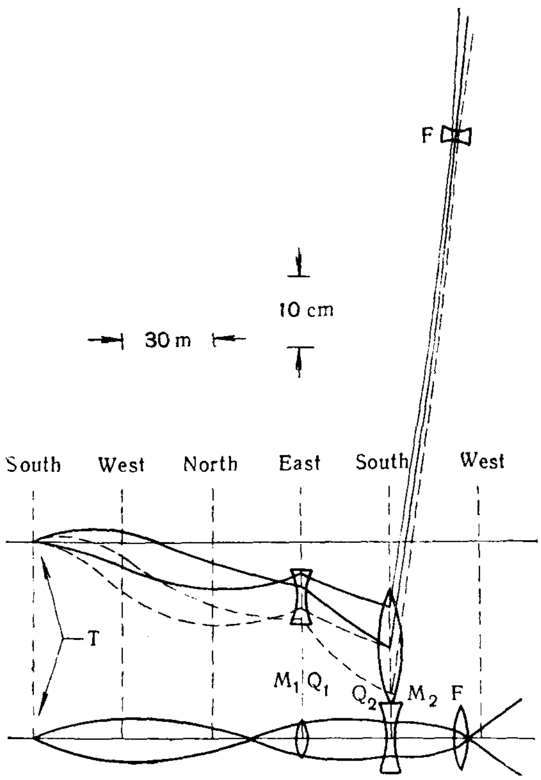

Fig. 2. Optical properties of the internal deflected beam. Here M_1 and M_2 are C magnets, and Q_1 and Q_2 are «Panofsky-type» quadrupoles. F represents the effect of the fringing field which focuses strongly vertically and defocuses horizontally. T is the energy-loss target of beryllium or polyethylene. Note that there is a difference of a factor of 240 between the radial and azimuthal scales.

3. The aperture requirements for the exit channel are reduced.

B. Because only a small deflection is required of the first magnet, a smaller septum, and therefore a smaller target, may be used. This leads to a reduction in beam disorder produced in the targeting process.

The layout of the internal system is shown in Fig. 1. The beryllium target in or near the south straight section is 13 to 40 mm long (depending upon the extraction energy) and $\approx$ 6 mm high. The maximum inward deflection of the beam in terms of the momentum lose ΔP is given by

$$\Delta R_{\max} \approx \frac{2R}{\nu_h^2}\frac{\Delta P}{P}, \qquad (1)$$

where $R = 15.2$ m is the initial radius of the beam. Normally $\Delta R_{\max}$ is $\approx$ 100 mm.

Magnets M_1 and Q_1 are located in the east straight section just over one-half betatron period from the target near the point of maximum inward deflection and maximum dispersion of the deflected beam. Consequently, a major function of Q_1 is to control the spatial recombination of beam particles of different energies. Magnet M_1 deflects the beam inward to M_2 and Q_2 located in the south straight section at a radius smaller than that of the target; M_2 deflects the

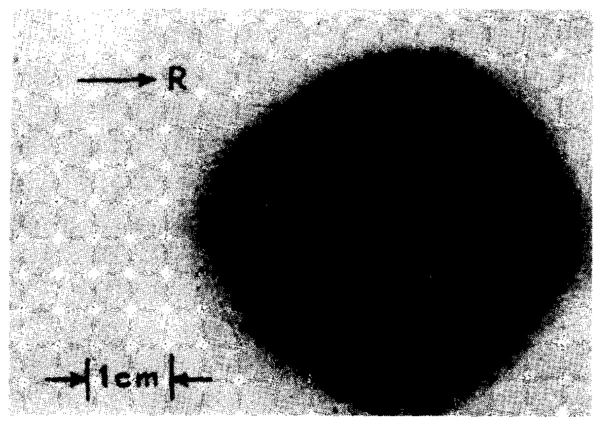

Fig. 3. Pattern of the deflected beam ahead of M_1Q_1, made from exposure of X-ray film to an irradiated sheet of 3-mm polyethylene. Corners of the aperture of M_1 are shown for reference. External proton beam— 6 GeV ahead of M_1.

beam outwards so that it emerges from the Bevatron at the entrance to the west straight section. A schematic of the internal optics is shown in Fig. 2. The alternating-gradient character of Q_1, Q_2, and the fringing field «lens» is required to limit the aperture required for the beam both inside and outside the accelerator. The design of the internal magnets (see Table 1) was guided by the results of an orbit integration program which used the Bevatron field measurements at both 5 and 7 GeV/c. Predictions of this program have been verified by direct measurement of the beam characteristics.

Figs. 3,4 and 5 show radiographs made from foils exposed to the deflected beam ahead of M_1 and Q_1, ahead of M_2 and Q_2, and at the west

Table 1

Bevatron external-beam magnets

Magnet			Aperture (mm)		Length, m	Design field, kGs	Field gradient, kGs/cm	Field[a] uniformity, %	Design[b] power, kW	Lamitation thickness, mm	Weight, kGs
name	type	no.	width	height							
M_1	C	1	76	53	0.32	5.5		±0.25	35	6	120
M_2	C	1	152	110	1.22	6.3		±0.1	84	6	2040
M_3	H	1	127	51	1.37	15		±0.05	154	6	1860
M_{3v}	H	1	125	110	0.25	2		±1	5.5	—	45
M_4[c]	H	4	380	110	2.13	14		±0.1	143	13	26400
Q_1	Panofsky Quad.	1	82	82	0.64		0.4	±0.25[d]	47	6	17
Q_2	Panofsky Quad.	1	164	164	0.64		0.2	±0.25[d]	29	6	180
Q_3	Quad.	2	112 (diam)		0.74		2.4	±0.25[d]	155	3	780
Q_4[c]	Quad.	6	209 (diam)		1.22		1.2	±0.25[d]	203	0.8	5630

a) Based on line integral of field.
b) Peak value for pulsed operation or the dc value corresponding to a beam momentum of 7 GeV/c.
c) Magnets designed but not yet constructed.
d) Maximum relative amplitude of sixth and tenth field harmonics at 85% of the pole-tip radius.

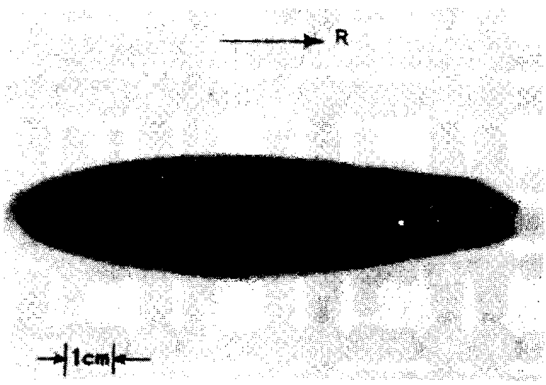

Fig. 4. Pattern of deflected beam ahead of M_2Q_2 made from exposure of X-ray film to an irradiated sheet of 3-mm polyethylene. Corners of the aperture of M_2 are shown for reference. External proton beam—6 GeV ahead of Q_2.

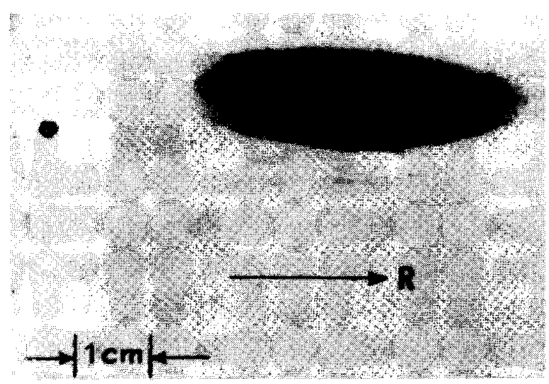

Fig. 5. Pattern of beam emerging at west straight section, made by direct exposure of X-ray film to the 7 GeV/c beam of approximately 10^8 protons. External proton beam —.6 GeV emerging from Bevatron.

straight section, respectively. The limiting apertures of each following deflecting magnet is indicated. Additional tests made by simultaneous activation of aluminum foils at the three positions indicate that, as suggested by Figs. 3 and 4, very little ($\approx 10\%$) of the deflected beam is lost on the internal magnets.

PROPERTIES OF THE EXTRACTED BEAM

The beam emerges from the west straight section at an average angle to the initial orbit which varies from 3.2 deg at 3 GeV/c to 4.0 deg at 7 GeV/c. The divergence of the beam indicates vertical and horizontal images 1.5 and 6 m, respectively, upstream from the point of initial exit from the Bevatron. At this location the beam is well confined vertically (Fig. 5). About 75% of the emerging beam is contained in a horizontal width of 50 mm. There is evidence that the beam outside this width is of poor optical quality, for reasons that are not completely understood. Collimation inside the Bevatron has improved somewhat

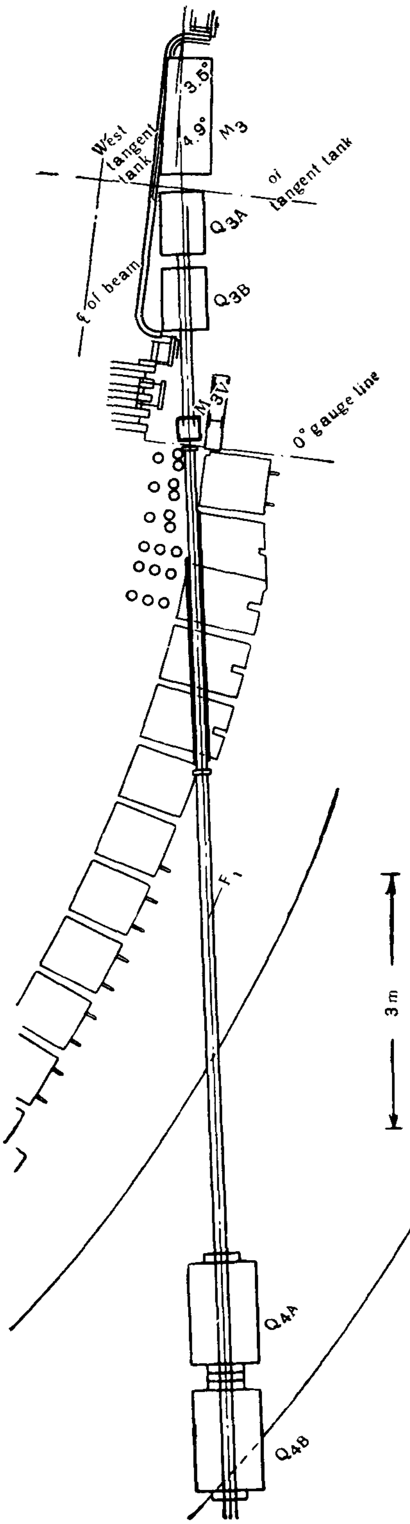

Fig. 6. Initial part of the beam transport system. Magnet M_3 deflects the beam clear of the Bevatron vacuum aperture, and Q_3 produces a third image of the energy-loss target at F_1. Magnet M_{3V} is a small vertical steering magnet. The channel through the return yoke of the Bevatron magnet is doubly shielded magnetically to reduce the energy sensitivity of the external-beam orbits.

the quality of the beam available for experimentation. The extracted beam is monitored with a secondary-emission chamber and an ionization chamber, and by activation methods. The intensity varies from about one-third to one-half the circulating-beam intensity, depending upon the degree of collimation. Because, as was stated above, very little deflected beam is lost on the magnets themselves, it is assumed that the major loss of beam during extraction occurs in targeting.

The emittance of the extracted beam has been measured with the help of the deflecting magnet M_3 and the quadrupole doublet Q_3, which produce a third image of the internal target at F_1 (Figs 6 and 7). At 7 GeV/c the minimum image is 3 mm vertical by 10 mm horizontal (full width at half maximum). The emittance is about 30 mrad·mm vertical and 60 mrad·mm horizontal. These measured values are consistent with the emittances calculated from the initial beam characteristics and the estimated disorder introduced in targeting. The larger horizontal emittance is attributed to the greater horizontal size of the circulating beam, incomplete elimination of the dispersion, and larger magnetic aberrations.

PROPOSED TRANSPORT SYSTEM

The installation of the beam up to the main shielding wall of the Bevatron (Figs. 6 and 7) is now complete, and an experimental program using the beam at F_1 is under way. Fig. 7 shows the proposed transport system through the experimental area to a backstop outside the building. Design of most of the major components for this system is now finished. Completion of the installation is expected by the end of 1963. In addition to the provision for two new experimental areas utilizing possible focal points F_2 and F_3, this system permits the solution of a major shielding problem because the backstop will be displaced beyond the presently most useful experimental areas. It is expected that secondary beams emerging from the backstop will play an important part in the future experimental program. The proposed backstop switching magnet will provide for simultaneous experimental setups in that area.

It is intended that the transport system remain reasonably flexible under experimental demands. The arrangement shown in Fig. 7 is achromatic between F_1 and F_3. The performance of this system is illustrated schematically in

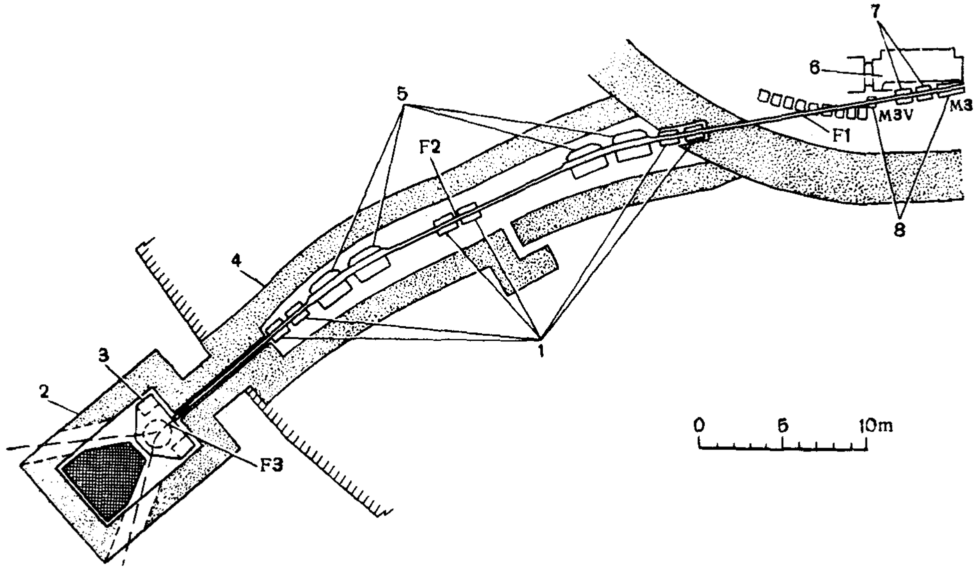

Fig. 7. The entire external system is shown without detail. Here F_1, F_2 and F_3 are possible target locations for secondary beams. The system is now completed as far as the Bevatron main shielding wall; the remainder is under construction:

1 — quadrupoles Q_4; *2* — back stop; *3* — switching magnet M_5; *4* — shielding; *5* — bending magnets M_4; *6* — west straight section; *7* — quadrupoles Q_3; *8* — bending magnets.

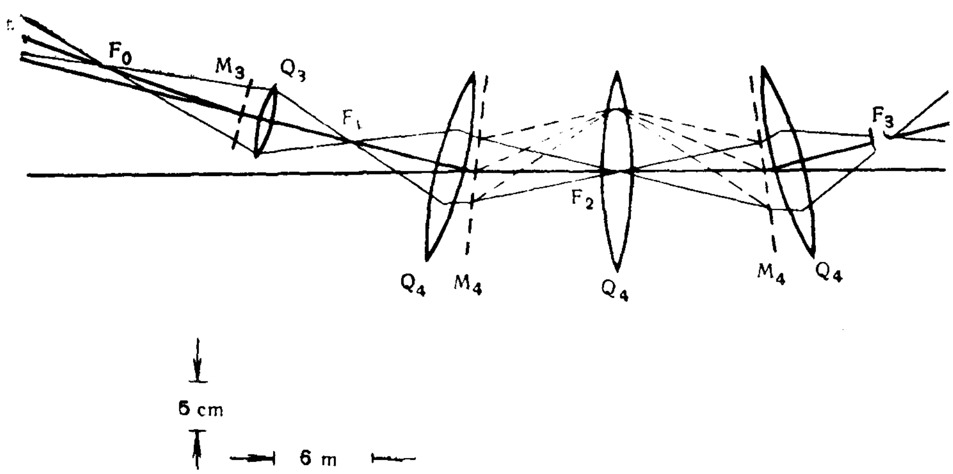

Fig. 8. Optical properties of the transport system. Here F_0 is the second image of the energy-loss target which occurs inside the Bevatron. This arrangement of the deflecting and focussing magnets leads to a system which is achromatic between F_1 and F_3. The dashed rays are for a momentum slightly below that for which the system is tuned.

Figs 8 and 9. A small momentum error, scattering in a target at F_1, or a deflection following F_1, do not necessarily degrade the image at F_3 [4]. Because of the conservatively designed aperture (200 mm in diameter), a momentum error of several percent does not lose the beam. For this reason it is believed that shielding along the transport system need not be extensive. The proposed 1.5-m-thick concrete shielding wall is formed almost entirely from old blocks replaced during the reconversion of the Bevatron. The backstop itself will contain, in addition to the switching magnet, an iron core surrounded by concrete blocks in modules that facilitate experimental setup.

OPERATIONAL USE OF THE EXTERNAL PROTON BEAM

Maximum intensity for the extracted beam requires that the internal magnets be plunged into the aperture after injection. This is done by two hydraulic plunging mechanisms which accurately position M_1Q_1 and M_2Q_2 in 0.7 s with strokes of 0.7 m. Hence full intensity in the extracted beam can be obtained for proton momenta down to 3 GeV/c. Th beam has been extracted for momenta as low as 2 GeV/c with some loss of intensity because of the aperture restriction. A small fraction of the beam can be injected and accelerated with the internal magnets fixed in their final positions. To provide for extraction of the beam over a range of energies during a given Bevatron pulse, the radial position of M_1Q_1 can be programmed mechanically to compensate for the change in the «jump» distance with energy.

The current in each magnet is pulsed. To a first approximation, the slope follows that of the magnetic field of the Bevatron, but small corrections to this program are available if needed. In this way the extraction system remains «tuned» over a range of momenta. Each magnet is powered with a solid-state power supply, regulated with either silicon-controlled rectifiers or a magnetic-amplifier regulator supplemented with a fast transistor loop. Reproducibility in the current on a pulse-to-pulse basis is at least as good as one part in 10^3 for each magnet.

Targeting is expected to be the same for the external beam as for secondary beams, in the sense that the circulating beam can be divided among several targets during a given pulse. Operation with flattop and with either a long or short beam spill is feasible. Because of the orbit distortions caused by the field of the rapid beam deflector, the extraction efficiency for the fast spill is reduced (by a factor of order 2) with the present system.

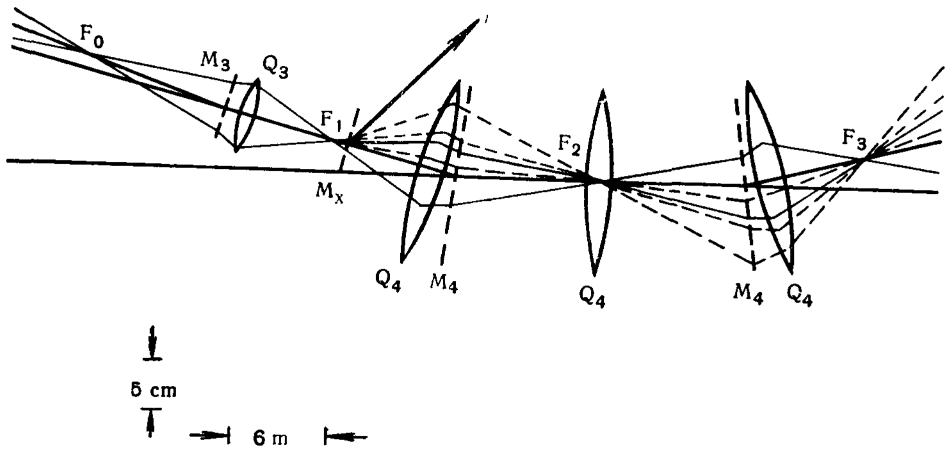

Fig. 9. Optical properties of the transport system. Scattering at F_1 (or deflection by a small magnet M_x near F_1) does not destroy the image at F_2 and F_3. The angular error at F_2 and F_3 can be corrected, if desired, with another magnet like M_x located just ahead of F_2:
1 — secondary beam.

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DISCUSSION

M. G. Meshcheryakov

What is the pulse repetition rate for the current of the accelerated protons in the bevatron in your latest experiments?

W. A. Wenzel

1. Eleven pulses per minute.
2. A telegram has come with new information from Berkeley. The Bevatron circulating beam intensity has been raised from 2.3×10^{12} protons per pulse as reported by Lambertson on tuesday to 3.0×10^{12} protons per pulse. The significant fact is that this happened as a consequence of some alterations in the radio frequency programming at injection.