MI-Note 0031
Sloping the Main Injector
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The Main Injector could be placed in sloping plane in order to increase the amount of shielding on one side of the ring. This note describes how that might best be accomplished. Placing the ring in a non-level plane does not represent any great hardship for the survey, according to Larry Ketcham.

The first constraint I have imposed is that we want to keep the symmetry of the proton and antiproton transfers to the Tevatron. Thus, the MI-70 straight section should be parallel to the Tevatron, i.e. the Main Injector ring is rotated about MI-70. In other words, MI-70 defines the strike axis. While this may not produce the optimal effect with regard to radiation shielding issues, it is not an unreasonable restriction. For calculations of the effects of introducing a dip angle, I have taken component coordinates from the MI_15 lattice specifications, translated them such that the center of the MI-70 straight becomes the origin, and then rotated them from the laboratory grid system to a system in which the x-axis is parallel to the MI-70 beam line. In this rotated system, all Main Injector elements are located with a y-coordinate which has a negative value. The dip angle is a second rotation which leaves the x-coordinates of elements unchanged, but changes the y and z coordinates. To determine the appropriate dip angle, the useful point to consider is the MI-30 straight section, which is parallel to MI-70 on the far side of the ring. Its coordinates in a level plane are (-45.0778,-928.4445,0.00). A 1 mrad dip angle produces a change in z at MI-30 of 928.4443 mm, or 36.553", i.e. about three feet. A dip angle of 1-2 mrad will produce the desired lowering of the tunnel by 3-6 feet.

The effect of the dip angle on extraction has been examined. There are several ways in which the change in angle can be handled. (i) One way is to change the extraction dogleg which raises the extracted beam above the Main Injector, e.g. by bending less with the Lambertsons or more with the C-magnets. The problem with this is that the then-level extracted beam pipe may interfere with the downstream magnets which are continuing to rise; the last interfering magnet is about 50 m downstream. (ii) The second method that would work is to effectively lower the Main Injector some more (everywhere). The extraction dogleg can then be increased to eliminate any interference; doing so may require a third Lambertson magnet and a third C-magnet, i.e. it costs some money. (iii) The third possibility is to leave the early part of the extraction line alone but incorporate an angle-removing bend at some downstream point. By choosing the appropriate location, it can improve the vertical dispersion mismatch, but only slightly. Appropriate locations are near the QD2 or QF3 beamline quads, and could be accomplished by rolling a horizontal bend by about .5° per mrad dip angle. A corresponding magnet in the Main Ring remnant must also be rolled. (iv) Finally, and the easiest way, the entire extraction line can be dipped along with the Main Injector so that it lies in a parallel plane (after the C-magnets). To keep the extracted beam line the proper height for injection into the Tevatron, the entire ring must be lowered by 10 m times the dip angle. I will assume this is the preferred choice. At some point along the injection line into the Tevatron, within the F-0 straight, there is a "redefinition" of coordinates in which the beam must be effectively rotated by the dip angle. The consequences of this must be further investigated, but I suspect they are small in terms of emittance growth and coupling.

Table 1.
Laboratory Coordinates (x,y,θ) (meters,meters,radians)
Directions relative to proton motion

TeV FO	(30959.7826,29609.8481,-.54517)
MI-70	(30943.9080,29607.7788,-.54517)
MI-60 extraction point	(31126.2421,29462.5007,-.81744)
MI-30	(30423.9244,28837.2877,-3.6867)

Table 2.
Coordinates Relative to MI-70

TeV FO	(12.5003, 10.0013, 0.0000)
MI-70	(0.0000, 0.0000, 0.0000)
MI-60 extraction point	(231.2387, -29.6667,-.27227)
MI-30	(-45.0778, -928.4445,-3.1416)

$(\theta = -.27227 = 15.600° = 13 * 360°/300)$

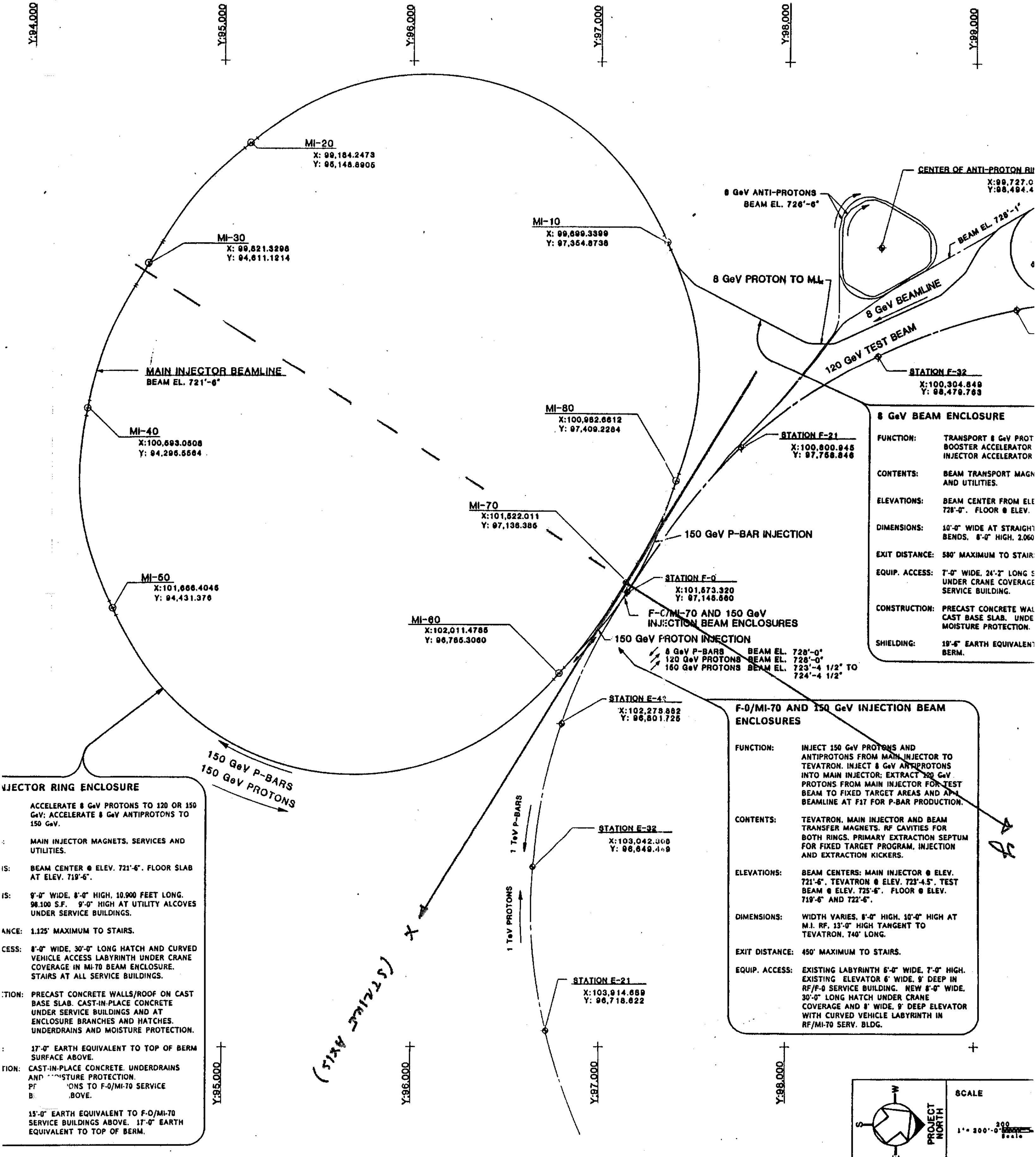
The inclusion of a dip angle to the Main Injector modifies the angles of both the circulating and extracted beam relative to the Tevatron. To describe the effect of a dip on the angle of a line segment, we define the orientation of a line segment by its angle θ in the x-y plane, and its angle ϕ out of the plane. If the angle, relative to the strike axis, of the circulating beam at some point around the level ring is θ, ($\phi = 0$), then the angles in a ring tipped by a dip angle δ are (the "prime" denotes with the dip angle)

$$\theta' = \tan^{-1}(\cos \delta \tan \theta)$$

and

$$\phi' = \tan^{-1}(- \tan \delta \sin \theta').$$

For small δ, the change in θ is less than closed orbit errors; e.g. a 1 mm orbit error corresponds to 29 μrad over a 34 m cell, while a 2 mrad dip angle corresponds to 1 μrad at $\tan \theta = 1$ (and smaller errors at different angles). Also for small δ, ϕ' can be approximated by $\phi' \simeq (-\sin \theta)\, \delta$.



...JECTOR RING ENCLOSURE

	ACCELERATE 8 GeV PROTONS TO 120 OR 150 GeV; ACCELERATE 8 GeV ANTIPROTONS TO 150 GeV.
:	MAIN INJECTOR MAGNETS, SERVICES AND UTILITIES.
...IS:	BEAM CENTER @ ELEV. 721'-6". FLOOR SLAB AT ELEV. 719'-6".
...IS:	9'-0" WIDE, 8'-0" HIGH, 10,900 FEET LONG. 98,100 S.F. 9'-0" HIGH AT UTILITY ALCOVES UNDER SERVICE BUILDINGS.
...ANCE:	1,125' MAXIMUM TO STAIRS.
...CESS:	8'-0" WIDE, 30'-0" LONG HATCH AND CURVED VEHICLE ACCESS LABYRINTH UNDER CRANE COVERAGE IN MI-70 BEAM ENCLOSURE. STAIRS AT ALL SERVICE BUILDINGS.
...TION:	PRECAST CONCRETE WALLS/ROOF ON CAST BASE SLAB. CAST-IN-PLACE CONCRETE UNDER SERVICE BUILDINGS AND AT ENCLOSURE BRANCHES AND HATCHES. UNDERDRAINS AND MOISTURE PROTECTION.
:	17'-0" EARTH EQUIVALENT TO TOP OF BERM SURFACE ABOVE.
...TION:	CAST-IN-PLACE CONCRETE. UNDERDRAINS AND ...ISTURE PROTECTION. PF... 'ONS TO F-0/MI-70 SERVICE B... BOVE.
	15'-0" EARTH EQUIVALENT TO F-0/MI-70 SERVICE BUILDINGS ABOVE. 17'-0" EARTH EQUIVALENT TO TOP OF BERM.

8 GeV BEAM ENCLOSURE

FUNCTION:	TRANSPORT 8 GeV PROT... BOOSTER ACCELERATOR ... INJECTOR ACCELERATOR ...
CONTENTS:	BEAM TRANSPORT MAGN... AND UTILITIES.
ELEVATIONS:	BEAM CENTER FROM ELE... 728'-0". FLOOR @ ELEV. ...
DIMENSIONS:	10'-0" WIDE AT STRAIGHT... BENDS, 8'-0" HIGH, 2,060 ...
EXIT DISTANCE:	580' MAXIMUM TO STAIR...
EQUIP. ACCESS:	7'-0" WIDE, 24'-2" LONG S... UNDER CRANE COVERAGE ... SERVICE BUILDING.
CONSTRUCTION:	PRECAST CONCRETE WAL... CAST BASE SLAB. UNDE... MOISTURE PROTECTION.
SHIELDING:	19'-6" EARTH EQUIVALEN... BERM.

F-0/MI-70 AND 150 GeV INJECTION BEAM ENCLOSURES

FUNCTION:	INJECT 150 GeV PROTONS AND ANTIPROTONS FROM MAIN INJECTOR TO TEVATRON. INJECT 8 GeV ANTIPROTONS INTO MAIN INJECTOR; EXTRACT 120 GeV PROTONS FROM MAIN INJECTOR FOR TEST BEAM TO FIXED TARGET AREAS AND AP-1 BEAMLINE AT F17 FOR P-BAR PRODUCTION.
CONTENTS:	TEVATRON, MAIN INJECTOR AND BEAM TRANSFER MAGNETS. RF CAVITIES FOR BOTH RINGS. PRIMARY EXTRACTION SEPTUM FOR FIXED TARGET PROGRAM. INJECTION AND EXTRACTION KICKERS.
ELEVATIONS:	BEAM CENTERS: MAIN INJECTOR @ ELEV. 721'-6". TEVATRON @ ELEV. 723'-4.5". TEST BEAM @ ELEV. 725'-6". FLOOR @ ELEV. 719'-6" AND 722'-6".
DIMENSIONS:	WIDTH VARIES, 8'-0" HIGH, 10'-0" HIGH AT M.I. RF, 13'-0" HIGH TANGENT TO TEVATRON, 740' LONG.
EXIT DISTANCE:	450' MAXIMUM TO STAIRS.
EQUIP. ACCESS:	EXISTING LABYRINTH 6'-0" WIDE, 7'-0" HIGH. EXISTING ELEVATOR 6' WIDE, 9' DEEP IN RF/F-0 SERVICE BUILDING. NEW 8'-0" WIDE, 30'-0" LONG HATCH UNDER CRANE COVERAGE AND 8' WIDE, 9' DEEP ELEVATOR WITH CURVED VEHICLE LABYRINTH IN RF/MI-70 SERV. BLDG.