VI. Transport Lines

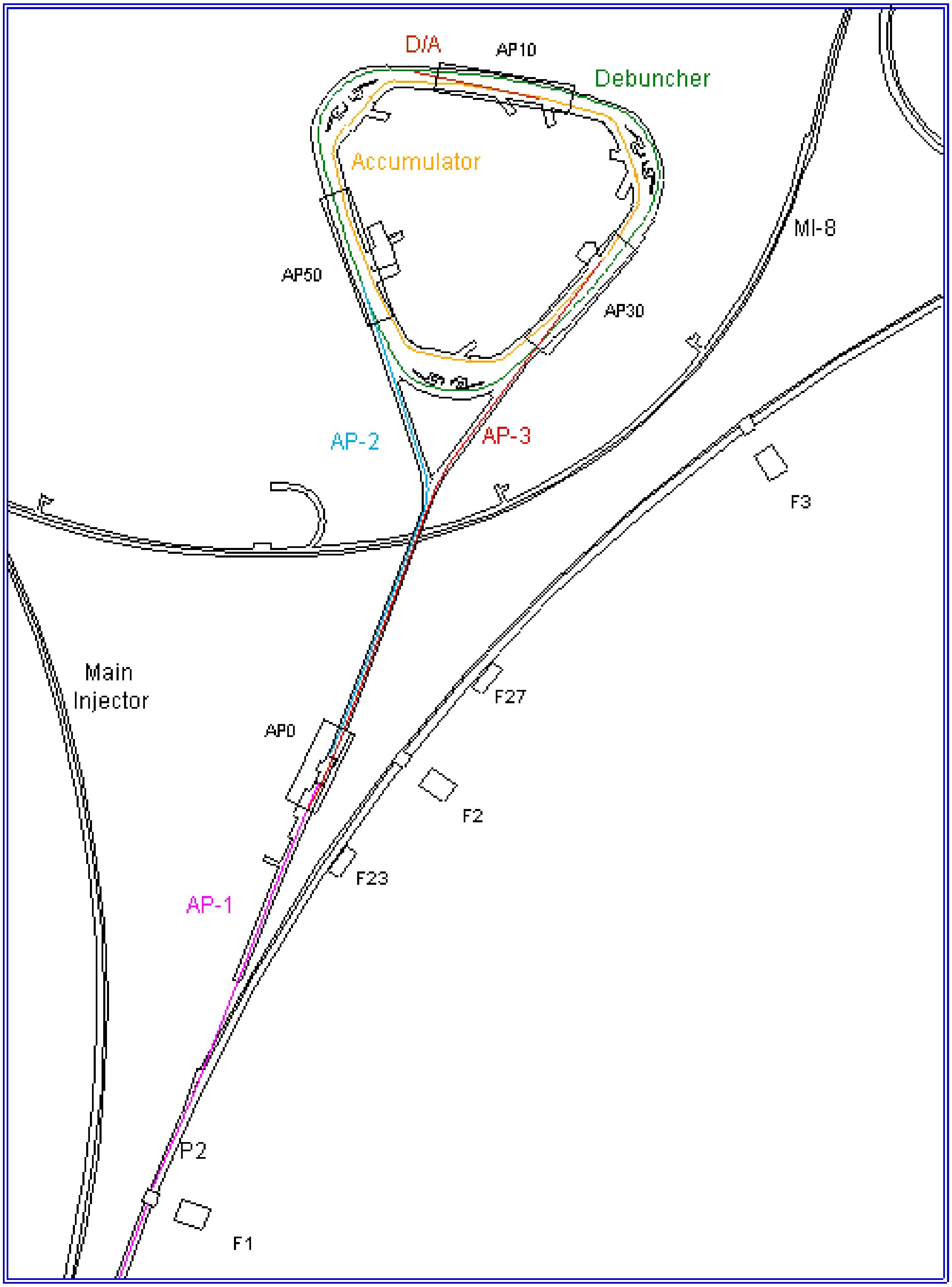

Figure 6.1 Pbar beamlines

A. Introduction

There are six beam transport lines used to connect the Debuncher and Accumulator to the Main Injector, as well as to each other. Figure 6.1 provides an overview map of the beamlines to help visualize their layout.

- The P1, P2 and AP-1 lines transport 120 GeV protons extracted from the Main Injector to the pbar production target. When operating at 8 GeV, the AP-3, AP-1, P2 and P1 lines deliver antiprotons extracted from the Accumulator to the Main Injector. Protons can also be "reverse injected" from the Main Injector to the Accumulator for transfer tune-up or studies.

- AP-2 transports 8 GeV antiprotons from the Target Station to the Debuncher ring. Protons can be reverse injected from the Debuncher into the AP-2 line for studies. On infrequent occasions, magnet polarities are reversed in the AP-2 line and the Target and Lithium Lens removed to allow 8-GeV protons from the Main Injector to be transported to the Debuncher for studies.

- The D to A line transfers antiprotons between the Debuncher and Accumulator. Protons that have been reverse injected into the Accumulator can also be transferred into the Debuncher for studies.

Detailed maps of the beamline magnet locations haven't been included in this chapter, but are available elsewhere. Specifications of electrical, cooling water and vacuum systems are consistent with those found in the Debuncher, details can be found in the Utilities chapter of this book. The Diagnostics chapter contains information about Beam Position Monitors (BPM's), Beam Loss Monitors (BLM's) Secondary Emission Monitors (SEM's) and other diagnostics found in the transport lines.

Beam line	Dipoles		Quads		Trims	
	Power supplies	Magnets	Power Supplies	Magnets	Power Supplies	Magnets
P1	I:HV7**	HV7**	I:Q7**	Q7**	I:HT7**	HT7**
P2	I:HVF1*	HVF**	I:QF1*	QF1*	I:HTF1*	HTF1*
AP-1	M:H10*	PB*	M:Q10*	PQ*	M:HT10*	PQ*-HT
AP-2	D:H7**	IB*	D:Q7**	IQ**	D:HT7**	IQ**-HT
D to A	D:H8**	TB*	D:Q8**	TQ*	D:HT8**	TQ*-HT
AP-3	D:H9**	EB*	D:Q9**	EQ**	D:HT9**	EQ**-HT

Table 1 Naming conventions

B. Naming Conventions

The naming convention used in the transport lines can be confusing, because there are both magnet names and power supply names. Magnets are generally identified by their installation names since the power supplies are often connected to multiple loads. Table 1 summarizes magnet and power supply names for the beamlines. Note that consecutive magnets at a given location are identified with an additional digit (e.g. HV7071, HV7072) or letter (e.g. PQ9A, PQ9B).

The leading letter in the magnet names for the pbar beamlines represents which beamline it's a part of; for AP-1 magnets the "P" is for "Proton", in AP-2 the "I" is for "Injection", in the D to A line the "T" is for "Transfer" and in AP-3 the "E" is for "Extraction". The second letter is somewhat intuitive, "B" is for "Bend" (dipole), "Q" is for "Quad". Trims are identified with a hyphenated extension, HT (VT) for a horizontal (vertical) trim. Dipoles are assumed to be horizontal unless otherwise indicated, e.g. IB1 is a horizontal dipole while IBV1 is a vertical dipole. In AP-1, bending magnets that have been rolled to bend in both the horizontal and vertical planes include the letter "R" in the magnet name, e.g. PBR2.

Originally, there were separate AP-1 power supplies for 8 GeV and 120 GeV operation. The dual power supply configuration was used to improve power supply regulation at 8 GeV. Although the 8 GeV power supplies still exist (M:H2**, M:Q2**), they are not used operationally. The change from dual power supply operation to ramping AP-1 was driven by the need to reduce the stacking interruption for transfers to the Recycler.

C. Kickers and septa

Beam transfer to and from the Pbar rings is accomplished with kicker and septa pairs. An injection septum bends the beam from a transport line into an accelerator and an injection kicker deflects the beam onto the closed orbit. An extraction kicker deflects beam from the closed orbit of an accelerator into the field region of a septum, which in turn bends the beam into a transport line. There are two styles of kickers in the antiproton source, an Accumulator style and a Debuncher style, that both produce magnetic fields of approximately 500 Gauss. All but one of the septum magnets used in pbar are a single-turn design that are pulsed. The exception is the Accumulator extraction Lambertson (ELAM). Normally ELAM is called the Extraction Lambertson and the name “Septum” refers to a single-turn pulsed septum magnet.

1. Kickers

The Debuncher injection and extraction kickers are ferrite single-turn transmission line pulsed magnets that are similar in design to those found in the Booster, Main Injector and Tevatron. The 200 nanosecond fall time for the injection kicker and rise time for the extraction kicker required some modifications from kickers previously designed.

Debuncher kickers are made up of three separate modules to limit propagation delay. Figure 6.2 is an end view of the Debuncher injection kicker, to use as a reference in the following description. Each module is about a meter long and is made up of a series of 48 sets of 4 ferrite blocks about 1.8 cm thick stacked around a copper conductor. 12 pairs of capacitors are connected on one end to the central copper conductor that carries the current. The other end is connected to the aluminum case, which is grounded. The module case does not contain the beam tube, which is an external elliptical ceramic chamber 5.7 cm. x 4.1 cm. The module has a "c" shape that surrounds the beam tube on three sides, so replacing Debuncher kicker modules doesn't require breaking vacuum. With the central conductor and ferrites providing the inductance and the capacitors providing the capacitance to the circuit, the magnet electrically looks like a 10Ω

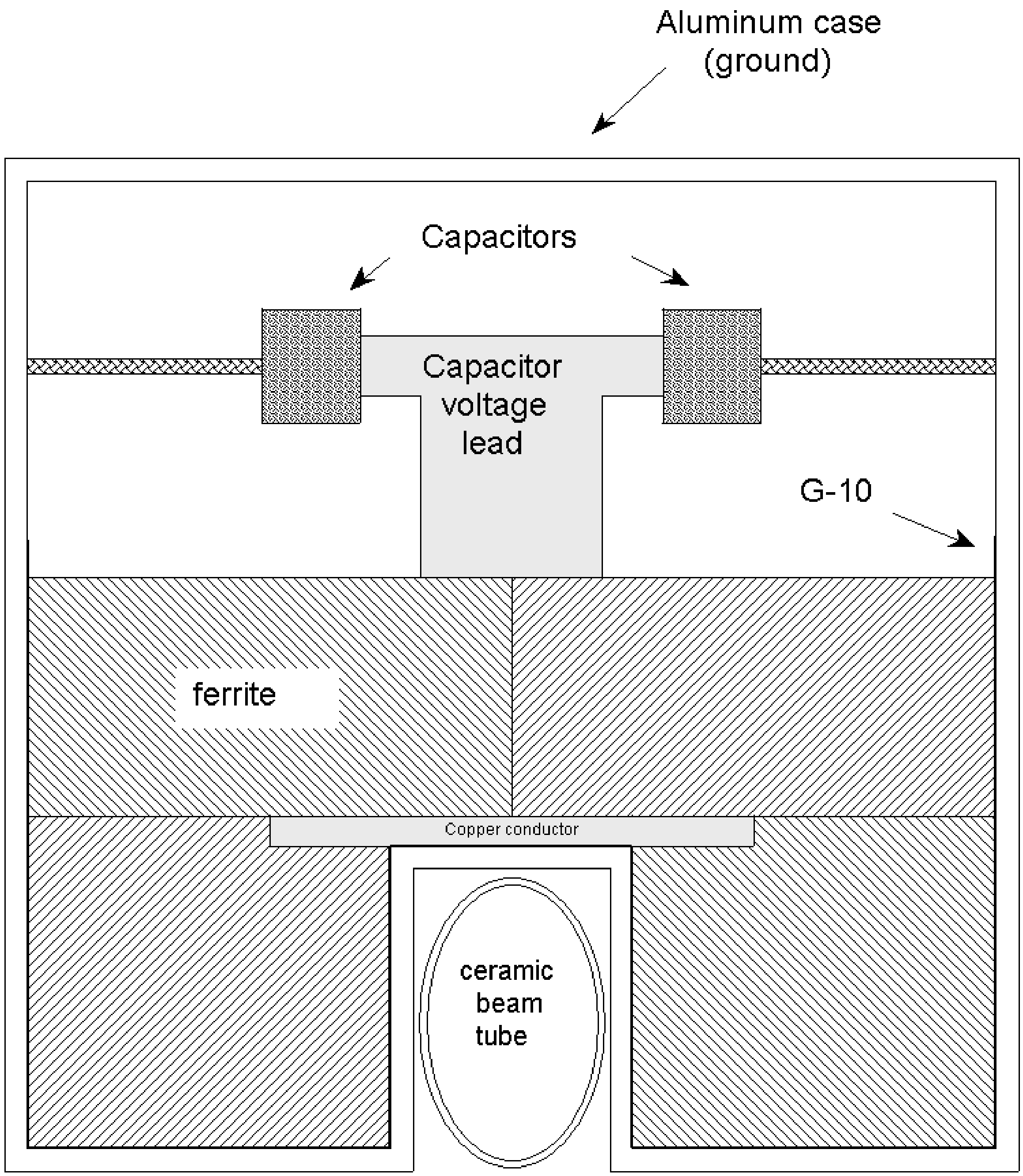

Figure 6.2 Debuncher injection kicker

transmission line. The ferrites, which are at high voltage like the conductor, are insulated from the outer case with G-10. The capacitors and their power leads are potted with an insulating rubber compound.

The Accumulator kickers bear little physical resemblance to those in the Debuncher, although they are similar electrically. Many of the design considerations were driven by the need for excellent vacuum and a cycling shutter to shield the antiproton core from the kicker pulse. The shutter is a plate of aluminum 5 mm thick and 3 m long. Three titanium arms "rock" the shutter in to and out of place and are driven through linkage by a DC stepping motor. Since the stray fields from the kickers are not as strong as originally anticipated, the shutters are usually only used during reverse-proton operation to keep wayward protons from mingling with pbars.

The Accumulator kickers have a cylindrical conductor surrounded by "c" shaped ferrites. The ferrites are specially prepared and handled to minimize outgassing. Capacitance in the kicker circuit is provided by distributing parallel plate capacitors along the length of the magnet. High voltage plates are attached to the center conductor and ground plates are located between the high voltage plates. The capacitors make use of an alumina ceramic as a dielectric as well as for various insulating components.

The A20 straight section contains both Accumulator kickers. The kickers are housed in tanks that are similar in appearance to stochastic cooling tanks. Large high voltage cables feeding into the kicker tanks distinguishes them from their stochastic cooling counterparts. Due to the ultra high

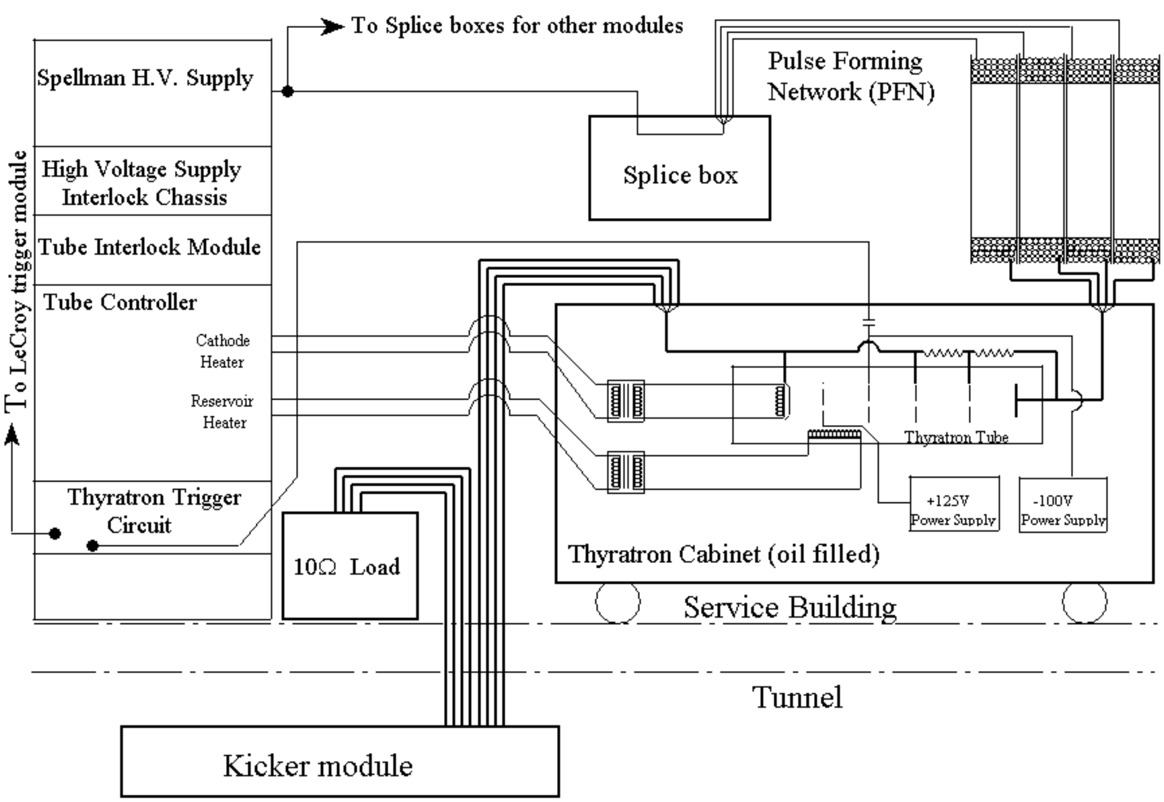

Figure 6.3 Kicker power supply diagram

vacuum requirements of the Accumulator, the magnets and tanks are baked out along with other components after vacuum work.

Power supplies are virtually the same for both Accumulator and Debuncher kickers. Figure 6.3 diagrams a typical kicker power supply and associated components. A hydrogen thyratron tube is used as a high voltage switch to allow the electrical current to pulse through the kicker. High voltage cable is coiled on large aluminum frames to provide a Pulse Forming Network (PFN) that helps define the shape and duration of the kicker pulse. During a typical stacking cycle, the PFN's are charged up over about 0.5 sec to approximately 60 kV by a Spellman high voltage power supply. A CAMAC 379 module provides a trigger pulse to a LeCroy 4222 timing module, which in turn provides synchronized pulses to kicker trigger modules at the appropriate time to "fire" the thyratron tubes. This closes the circuit and allows a current pulse to pass through the kicker magnet to a 10Ω load. The thyratron tube is housed in an oil-filled cabinet located in the service building. The 10Ω load and PFN's are located near the thyratron cabinets.

2. Septa

There are five septa magnets found in the pbar rings, four of them are of a single turn design. Debuncher injection and extraction as well as Accumulator injection (two septa are used here) utilize the single turn pulsed septum. Each septum is 2 meters long and is made by stacking "c" shaped steel laminations in a fixture with a slight (50 m radius) curvature for improved aperture. The vacuum enclosure doubles as a stacking fixture for the magnet. Figure 6.4 provides a cross section of a septum magnet. The septum itself is about 1.3 cm thick (the entire septum magnet assembly has a diameter of about 25 cm) and is made up of four parts. A copper conductor is bonded to a stainless steel plate and both carry the current pulse (the steel plate provides support). A sheet of kapton insulates the conductors from a low carbon steel plate used to magnetically shield the circulating beam adjacent to the septum magnet. The conductor carries up to 25,000 Amps to produce a field of 7,000 Gauss (as compared to 500 Gauss for the kickers). The Debuncher injection septum is built with an integrated beam pipe for circulating Debuncher beam. This special septum was built as a Run II upgrade to improve aperture by eliminating the space normally taken up by the upper wall of the vacuum chamber.

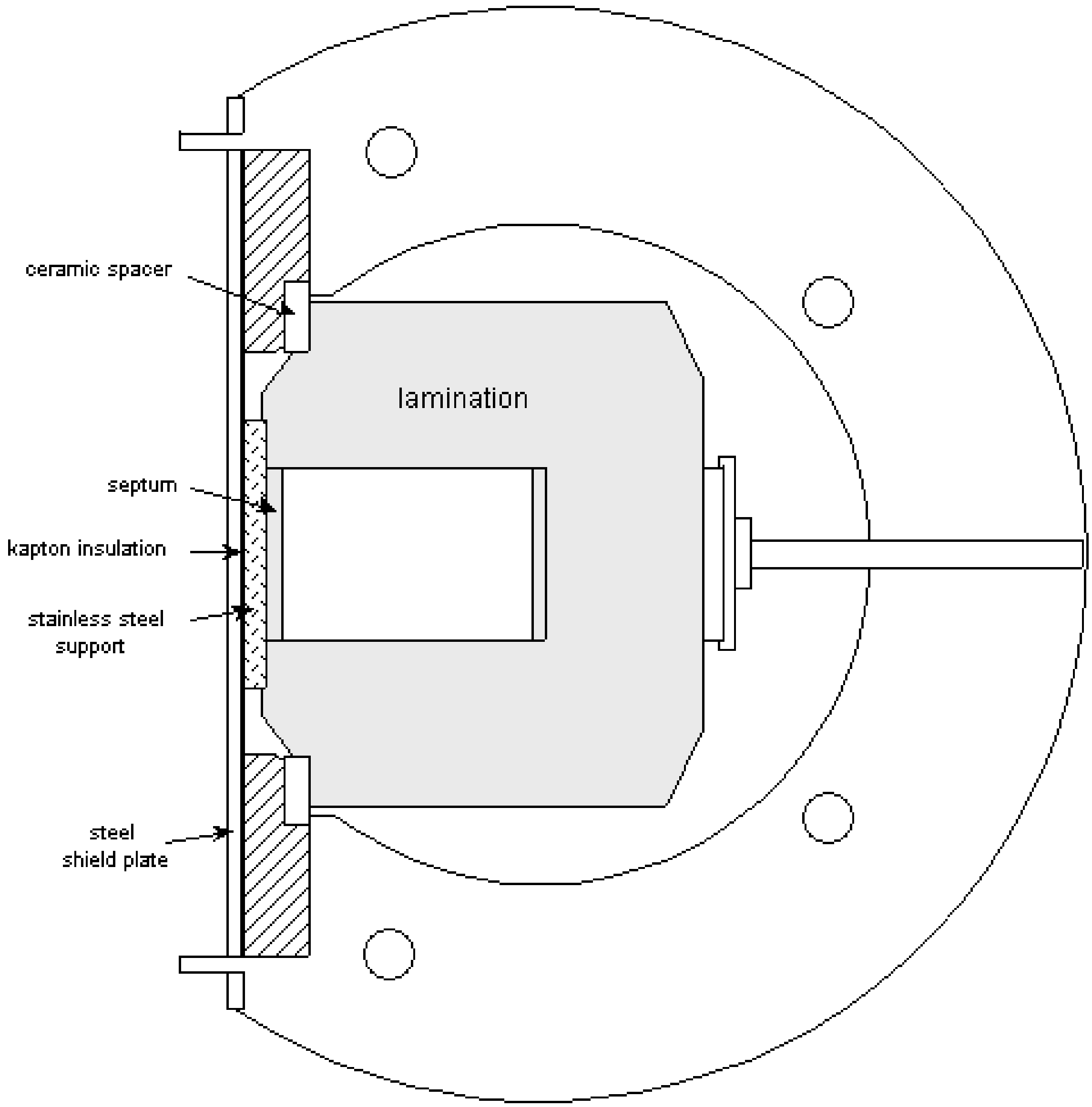

Figure 6.4 Debuncher extraction septum cross section

The Accumulator extraction septum is a Lambertson style magnet made up of a field free region for circulating beam and a field region for extracted beam. A small “C” Magnet is located in the AP-3 line just downstream of ELAM and is powered in series with the Lambertson by the D:ELAM power supply. The Lambertson is normally powered at all times to prevent tune and orbit shifts that would accompany the power supply being turned off and on. Stray fields in the "field free" region of the Lambertson are small enough to compensate for.

D. P1 and P2

The P1 and P2 lines were built as part of the Main Injector project to connect the Main Injector with the AP-1 line. A detailed description of both lines can be found in the Main Injector Rookie Book. The AP-1 line originally attached to the old Main Ring at the F-17 location before it was replaced by the Main Injector. Although the F-17 Lambertson magnets were replaced by a B3 style dipole to improve aperture, the original C-magnets were retained to accommodate the P3 line to Switchyard. With the addition of the P1 and P2 lines, the transfer lines to and from pbar were extended by 430 meters.

D. AP-1

AP-1 is approximately 172 meters long from F17 in the Tevatron enclosure to its terminus at the production target in the Vault. Vertically the line increases elevation 2.1 meters between the P2 line and the production target. The AP-1 line's design was predominately driven by the need to efficiently transport 120 GeV protons from the old Main Ring to the Target Vault. An additional requirement was that the proton beam had to be focused to a small spot size on the production target. With these considerations in mind, the optics of the AP-1 line can be broken down into three sections.

The first section runs from the extraction channel at F17 through PB5 (M:HV102) and was designed to cancel horizontal dispersion from the Main Ring. Although beam no longer comes from the Main Ring, the P2 line was designed so that the lattice functions closely matched those in the old Main Ring. A B3 style magnet replaced the original two extraction Lambertsons at F17 to improve aperture. However, two 118.4 inch C-magnets from the original extraction channel remain and are powered in series with the B3 magnet (I:F17B3). The B3 magnet and C-magnets bend beam from the P2 line upwards by 32.6 mrad. To provide clearance for the AP-1 line, the P3 line has a double strength dipole in place of the normal B-2 dipoles at F17-4 and F17-5.

Downstream of the extraction channel, beam continues upward and to the outside (from the perspective of the P2 line and tunnel). Horizontal trim P0-HT (M:HT100) follows, which was originally intended to compensate for the residual angle at F17 of beam extracted from the Main Ring. A four-dipole string, composed of PB1&2 and PBR1&2 (M:HV100), is next. The second pair of dipoles in this string is rolled 41° to provide both vertical and horizontal bending (the "R" in the magnet name stands for "rolled"). Quadrupole PQ1 (M:Q101) and trim PQ1-VTA (M:VT101A) follows and then AP-1 passes through a 'sewer pipe' of about 23.2 meters and on to the Pre-Target enclosure. The first element in this enclosure is trim PQ1-VT (M:VT101) and is closely followed by PQ2 (M:Q102). A series of four dipoles, the first of which is rolled 45°, PBR3 and PB3-5 (M:HV102), follow.

The second section acts to cancel vertical dispersion. It includes PQ3 (M:Q103), PQ4 (M:Q104), and PQ5A&B (M:Q105I&V). PQ5A&B have two power supplies because it was expected that they would run at a higher current than a single supply can deliver. A horizontal trim dipole, PQ5-HT (M:HT105), is next and is followed by two vertical dipoles, PBV1&2 (M:V105), which straighten out the upward climb of the beam towards the target. The remainder of the AP-1 line is level between PBV1&2 and the production target.

The final section is composed of eight quadrupoles in four circuits, PQ6A&B (M:Q106), PQ7A&B (M:Q107), PQ8A&B (M:Q108), and PQ9A&B (M:Q109). These elements provide the final focus for the proton beam to minimize the spot size on the target (leading to maximized antiproton yield). A horizontal trim, PQ7-HT (M:HT107), is located just upstream of the final quad doublet and a vertical trim, PQ8-VT (M:VT108), just downstream. These trims are used to finely tune the beam's position on the target to about ± 0.2 mm. This third section is coincidentally housed totally within the Pre-Vault enclosure. Table 2 lists all AP-1 magnetic elements.

Since AP-1 operates at two significantly different energies, 8 and 120 GeV, the magnetic elements are ramped. In the original design, Separate low current power supplies were used for 8 GeV operation to improve regulation. In practice, it was found that ramping the 120 GeV power supplies provided adequate regulation and reduced the time required to switch between stacking and pbar transfers.

AP-1 line power supplies, with the exception the supply powering the F17 B3 magnet and C-magnets (M:F17B3 is located at F2), are found in the F23 service building.

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
B3 Magnet	I:F17B3	F-17 Vertical dipole	critical device rolled 6°
C-magnet #1	I:F17B3	F17 Vertical dipole	critical device
C-magnet #2	I:F17B3	F17 Vertical dipole	critical device
P0-HT	M:HT100	20" bump	
PB1	M:HV100	EPB dipole	critical device
PB2	M:HV100	EPB dipole	critical device
PBR1	M:HV100	EPB dipole	critical device, rolled 41°
PBR2	M:HV100	EPB dipole	critical device, rolled 41°
PQ1	M:Q101	3Q120 quad	
PQ1-VTA	M:VT101A	20" bump	before sewer pipe
PQ1-VT	M:VT101	35" bump	after sewer pipe
PQ2	M:Q102	3Q120 quad	
PBR3	M:HV102	AIRCO dipole	rolled 45°
PB3	M:HV102	AIRCO dipole	
PB4	M:HV102	AIRCO dipole	
PB5	M:HV102	AIRCO dipole	
PQ3	M:Q103	3Q120 quad	
PQ4	M:Q104	3Q120 quad	
PQ5A	M:Q105I, M:Q105V	3Q120 quad	
PQ5B	M:Q105I, M:Q105V	3Q120 quad	
PQ5-HT	M:HT105	35" bump	
PBV1	M:V105	AIRCO dipole	
PBV2	M:V105	AIRCO dipole	
PQ6A	M:Q106	3Q120 quad	
PQ6B	M:Q106	3Q120 quad	
PQ7A	M:Q107	3Q120 quad	
PQ7B	M:Q107	3Q120 quad	
EB6		SDD dipole	OFF for stacking, critical device
PQ7-HT	M:HT107	35" bump	
PQ8A	M:Q108	3Q120 quad	
PQ8B	M:Q108	3Q120 quad	
PQ8-VT	M:VT108	40" bump	
PQ9A	M:Q109	3Q120 quad	
PQ9B	M:Q109	3Q120 quad	
Sweeper A	M:USWA	Sweep magnet	special magnet
Sweeper B	M:USWB	Sweep magnet	special magnet

Table 2 AP-1 Magnetic Elements

1. 120 GeV

120 GeV protons from the Main Injector are extracted in a single turn initiated by a kicker located at MI-52. A series of Lambertson magnets downstream of the kicker bends beam vertically into the P1 line. Beam is directed down the P1 line, then passes into the P2 line at F0 in the Tevatron enclosure. A Lambertson magnet at F0 bends beam downward into the Tevatron when it is powered, so it's left off when beam is desired in the P2 line. The P2 line, sometimes referred to as the "Main Ring remnant", transports the beam between F0 and F17 where the AP-1 and P3 lines begin. Beam to pbar is bent upwards by a B3 type dipole and two C-magnets, powered by the I:F17B3 power supply. I:F17B3 was formally a Main Ring bend power supply and has been specially modified for its current use. If beam is destined for the P3 line (for SY120 operation), I:F17B3 is not powered.

2. 8 GeV

When AP-1 is used for pbar transfers into the Main Injector, the first four quadrupoles, PQ7A&B (M:Q107) and PQ6A&B (M:Q106), encountered by the antiproton beam are used to match the optics of AP-1 and AP-3. As with the AP-1 power supplies, the D:H926 supply is ramped so that the EB6 magnet (which bends beam from AP-3 into AP-1) is not powered during stacking and is at the proper field for 8 GeV operation. After entering AP-1, pbars continue through the P2 and P1 lines en route to the Main Injector. Note that PQ8A&B (M:Q108) and PQ9A&B (M:Q109) are bypassed by the AP-3 line, they only run at 8 GeV current on the infrequent study periods when 8 GeV protons are transferred to the Debuncher via AP-2. Protons can also be "reverse injected" from the Main Injector to the Accumulator via AP-1 and AP-3 for tune-up or studies.

E. AP-2

Following the Lithium Lens (D:LNV) in the Target Vault, a pulsed 3 degree horizontal dipole known as the Pulsed Magnet (D:PMAGV) is used to momentum select negatively charged 8 GeV secondary particles into the AP-2 line. The AP-2 line then transports the selected particles towards the Debuncher. Most of the secondaries other than antiprotons have a short lifetime and decay during the journey down this beamline. Whatever is left, mostly pions and electrons, does not survive the first several turns in the Debuncher. AP-2 was designed to transport an 8 GeV beam with 20π mm-mrad (190π mm-mrad normalized) transverse emittance and a momentum spread of 4%. The transverse acceptance has been improved to about 30π mm-mrad through various improvements. Table 3 lists the magnetic elements making up the AP-2 line. Note that there are numerous quadrupole shunts to allow flexibility in changing the optics of the beamline.

According to the *Tevatron I Design Report*, the AP-2 line can be broken into five parts. The first section, beginning with the Pulsed Magnet, is described as the "clean-up" section. After exiting the Target Vault, the AP-2 line passes through two pairs of quadrupoles and vertical trim IQ2-VT (D:VT702) which is located between IQ2 and IQ3. Another 3° bend to the left by IB1 completes this portion of the line. There is also a pair of trims, IQ4-HT (D:HT704) and IQ4-VT (D:VT704) located between IQ4 and IB1. Quadrupoles in this section are powered by the D:Q701 and D:Q702 power supplies.

A transport section follows, which consists of a FODO lattice of quadrupole cells. These periodic cells have a length of 27 meters. D:Q707 powers all of the magnets in this section, IQ7 – IQ14. Pairs of horizontal collimators are located immediately downstream of IQ7 and IQ9. Similarly, pairs of vertical collimators are positioned downstream of IQ8 and IQ10. Three vertical and a horizontal trim dipole are contained in this section to fine tune beam position: IQ6-VT (D:VT706), IQ11-HT (D:HT711), IQ11-VT (D:VT711) and IQ14-VT (D:VT714).

Next is a left bend made up of six bending elements, IB2-7 (D:H717), which deflects the beam by a total of 36.53°. Each bending magnet has a shunt for fine orbit control (e.g. D:HS7172) There is also a vertical trim, IQ16-VT (D:VT716) located at the upstream end of the bending string. Four quadrupoles are interspersed amongst these bending magnets, powered by D:Q718 and D:Q719. The large horizontal dispersion in the left bend section results in a wide horizontal beam, particularly in the center of the bends. For this reason, momentum selection can be done in the middle of the section at the IQ19 location with a set of horizontal collimators.

Another long transport section follows, similar to the first transport, made up of repeating FODO cells. However, the magnets are powered by several different power supplies (D:Q716, D:Q719, D:Q724, D:Q725 and D:Q729).

Three vertical trims and two horizontal trims dipole are in this section, IQ23-VT (D:VT723), IQ25-HT (D:HT725), IQ25-VT (D:VT725), IQ26-VT (D:VT726), and IQ27-HT (D:HT727).

The final portion of the AP-2 line is an achromatic vertical translation into the Debuncher called the "injector" section. The section ends at the downstream end of the 2 meter magnetic septum magnet. Beam is deflected downward in this portion of the line with a 3.7° bending magnet, IBV1 (D:V730), and is translated 1.3 meters to be at the same elevation as the Debuncher. Three quadrupoles, IQ31-33 (D:Q731), are located in the injector section as well as a vertical trim IQ30-VT (D:VT730) and a pair of horizontal trims, IQ30-HT (D:HT730) and IQ31-HT (D:HT731). A large quadrupole in the Debuncher, D4Q5, has a large aperture to accommodate both the circulating and injected beam. This large quad is of the same design as those found in the Accumulator high dispersion areas. D4Q5 is powered by both D:IB and D:QT405 for a total current of more than 1,500 A. The large quads have fewer windings and more distance between the pole faces as compared with the small quadrupoles found at the other DxQ5 locations. Therefore, they require considerably more current to produce the same field strength. Because the AP-2 beampipe is offset from the center of this magnet, a strong vertical bend is imparted on the injected beam, bending pbars upward like the injection septum. A pulsed magnetic septum, ISEP (D:ISEPV), and 3-module kicker magnet, IKIK (D:IKIKV), complete the injection process. Two large quadrupoles are located in the Debuncher at the D4Q4 location, just downstream of ISEP, to improve aperture in the injection region. The large quadrupole pair replaced a single small quadrupole that was originally there. The D4Q4A&B pair are powered by a single power supply (D:Q404). Injected beam passes through Debuncher quadrupoles D4Q4A&B and D4Q3 before reaching the injection kickers, located between D4Q3 and D4Q2 in the 50 straight section. Power supplies for AP-2 line magnets in the upstream part of the line are located in AP0, those located in the middle of the line can be found at F27, and downstream supplies reside in AP50. Table 3 lists all of the AP-2 magnets and power supplies.

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
IQ1	D:Q701, D:QS701	SQC	
IQ2	D:Q702, D:QS702	SQC	
IQ2-VT	D:VT702	NDB	
IQ3	D:Q702, D:QS703	SQC	
IQ4	D:Q701, D:QS704	SQC	
IQ4-HT	D:HT704	NDB	
IQ4-VT	D:VT704	NDB	
IB1	D:H704	modified B1 wide gap	Critical device
IQ5	D:Q701, D:QS705	SQC	
IQ6	D:Q701, D:QS706	SQC	
IQ6-VT	D:VT706	NDB	
IQ7	D:Q707	SQC	
IQ8	D:Q707	SQC	
IQ9	D:Q707	SQC	
IQ10	D:Q707	SQC	
IQ11	D:Q707	SQC	
IQ11-HT	D:HT711	NDB	
IQ11-VT	D:VT711	NDB	
IQ12	D:Q707	SQC	
IQ13	D:Q707	SQC	
IQ14-VT	D:VT714	NDB	
IQ14	D:Q707	SQC	
IQ15	D:Q715	SQA	
IQ16-VT	D:VT716	NDB	
IQ16	D:Q716, D:QS716	SQB	
IQ17	D:Q716, D:QS717	SQD	
IB2	D:H717, D:HS7172	6-4-120 wide gap	Critical device
IQ18	D:Q718	SQB	
IB3	D:H717, D:HS7173	6-4-120 wide gap	Critical device
IB4	D:H717, D:HS7174	SDE wide gap	Critical device
IQ19	D:Q719, D:QS719	SQB	
IQ20	D:Q719, D:QS720	SQB	
IB5	D:H717, D:HS7175	SDE wide gap	Critical device
IB6	D:H717, D:HS7176	6-4-120 wide gap	Critical device
IQ21	D:Q718	SQB	
IB7	D:H717, D:HS7177	6-4-120 wide gap	Critical device
IQ22	D:Q716, D:QS722	SQD	
IQ23	D:Q716, D:QS723	SQD	
IQ23-VT	D:VT723	NDB	
IQ24	D:Q724	SQA	
IQ25	D:Q725	SQD	
IQ25-HT	D:HT725	NDB	
IQ25-VT	D:VT725	NDB	
IQ26	D:Q719, D:QS726	SQA	
IQ26-VT	D:VT726	NDB	
IQ27	D:Q719	SQA	
IQ27-HT	D:HT727	NDB	
IQ28	D:Q719, D:QS728	SQA	
IQ29	D:Q729, D:QS729	SQD	
IQ30	D:Q729, D:QS730	SQD	
IBV1	D:V730	modified B1 wide gap	Critical device
IQ30-HT	D:HT730	vernier trim	
IQ30-VT	D:VT730	NDB	
IQ31	D:Q731, D:QS731	SQE	
IQ31-HT	D:HT731	vernier trim	
IQ32	D:Q731, D:QS732	SQE	
IQ33	D:Q731, D:QS733	SQE	
D4Q5	D:QT405, D:IB	LQE	
ISEP	D:ISEPV	pulsed septum	
IKIK	D:IKIK	3-module kicker	

Table 3 AP-2 Magnetic Elements

F. Debuncher to Accumulator (D to A)

Beam is transferred horizontally from the Debuncher into the Accumulator in the 10 straight section. Extraction from the Debuncher is accomplished with a 3-module kicker, EKIK (D:EKIKV), and septum, ESEP (D:ESEPV) combination. A 3-bump called "Dex Bump" (Debuncher extraction bump) is ramped shortly before beam transfer to position beam closer to ESEP. Dex Bump was implemented to improve aperture at ESEP, allowing circulating pbars to be further from ESEP when they have a larger emittance (before they are cooled). The quadrupole in the Debuncher just downstream of the septum, D6Q6, is a large style quadrupole used in much the same way as D4Q5 is at the end of the AP-2 line. In this case, beam passes horizontally off-center through D6Q6 providing a greater bend towards the Accumulator. The D to A line has a vertical trim (TQ1-VT) between the first two quadrupoles, and a horizontal trim between the second and third quadrupoles (the horizontal trim retains its old name, TQ4-HT, after being moved upstream at the beginning of Run II). Another vertical trim (TQ6-VT) as well as a major bend, TB1&2 (D:H807A&B), are found between the sixth and seventh quadrupoles. The vertical trims can be used together to control the vertical position and angle at injection into the Accumulator. The horizontal trim and dipoles provide some control of the horizontal position and angle at the Accumulator injection septa. Beam passes through a septa

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
EKIK	D:EKIK	3-module kicker	
ESEP	D:ESEPV	pulsed septum	
D6Q6	D:QT606, D:IB	LQE	
TQ1	D:Q801, D:QS801	SQE	
TQ1-VT	D:VT801	NDB	
TQ2	D:Q801, D:QS802	SQD	
TQ4-HT	D:HT804	NDB	
TQ3	D:Q801	SQD	
TQ4	D:Q804, D:QS804	SQC	
TQ5	D:Q804	SQD	
TQ6	D:Q804, D:QS806	SQD	
TQ6-VT	D:VT806	NDB	
TB1	D:H807A	modified B1	
TB2	D:H807B	modified B1	
TQ7	D:Q807	SQA	
ISEP2	A:ISEP2V	pulsed septum	
ISEP1	A:ISEP1V	pulsed septum	
IKIK	A:IKIKV	shuttered kicker	

Table 4 D to A line Magnetic Elements

pair, ISEP2 (A:ISEP2V) and ISEP1 (A:ISEP1V) into Accumulator quadrupole A1Q4, which has a special extended lobe on the vacuum “star” chamber. The beam travels 51 meters and passes through 270° of phase advance in the Accumulator (and another quadrupole with a special star chamber at A1Q8) and then is kicked onto the Accumulator injection orbit with a shuttered kicker, IKIK (A:IKIKV), in the A20 high dispersion straight section. All D to A line power supplies are located in the AP10 service building except A:IKIKV, which is located at AP30.

G. AP-3

This transport line can be separated into five sections: extraction, a long transport, a left bend, another long transport and a target bypass. When beam is extracted from the Accumulator, a shuttered kicker, EKIK (A:EKIKV) in the A20 high dispersion straight section kicks beam horizontally towards the inside of the Accumulator. The kicked beam goes through 270° of phase advance so that when it reaches straight section 30, it passes through the field region of a Lambertson magnet, ELAM (D:ELAM), on the radial outside of the Accumulator. ELAM bends beam upwards and out of the Accumulator and a 'C' magnet just downstream of the Lambertson supplies an additional upward bend. These devices, both powered by the D:ELAM power supply, raise the extracted beam to a level 1.2 meters above the Accumulator. Two separate downward bends, EBV1&2, of 50 mrad each level the extracted beam at the same height as the AP-1 and AP-2 lines. In the extraction channel there are also five quadrupoles, EQ1, EQ2, EQ3A&B, and EQ4, and a horizontal trim, EQ1-HT. EBV1&2 have shunts that serve the purpose of vertical trims, necessitated by the limited available space in this part of the beamline.

After the down/leveling bends, beam passes through the first long transport consisting of ten quadrupoles, EQ5-14. This has a repeating FODO lattice similar to the long transport sections of the AP-2 line, although the cell length is longer. A cluster of three trims, EQ6-HTA, EQ6-VT, EQ6-HTB, is located at the upstream (in the pbar direction) end of this section.

A bend to the left, EB1-3, follows. There are two quadrupoles, EQ15 and 16, located in the bend section. Beam then is directed through a second long transport, which is similar to the previous one. This long transport runs parallel to the first long transport in the AP-2 line. This section includes nine quadrupoles, EQ17-25, and vertical trims, EQ17-VT & EQ25-VT, at each end.

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
EKIK	A:EKIK	shuttered kicker	
ELAM	D:ELAM	80" Lambertson	
C-magnet	D:ELAM	30" 'C' magnet	
EQ1	D:Q901	SQC	
EBV1	D:V901, D:VS901	modified B1	Critical device
EQ1-HT	D:HT901	NDB	
EQ2	D:Q901	SQD	
EQ3A	D:Q903	SQD	
EQ3B	D:Q903	SQD	
EQ4	D:Q901	SQB	
EBV2	D:V901, D:VS904	modified B1	Critical device
EQ5	D:Q901	SQC	
EQ6	D:Q901	SQD	
EQ6-HTA	D:HT906A	40" bump	
EQ6-VT	D:VT906	NDB	
EQ6-HTB	D:HT906B	NDB	
EQ7	D:Q907	SQE	
EQ8	D:Q907	SQA	
EQ9	D:Q909	SQA	
EQ10	D:Q909	SQA	
EQ10-HT	D:HT910	NDB	
EQ11	D:Q909	SQA	
EQ12	D:Q909	SQA	
EQ13	D:Q913	SQA	
EQ14	D:Q914	SQA	
EB1	D:H914	SDE	Critical device
EQ15	D:Q913, D:QS915	SQC	
EB2	D:H914	SDE	Critical device
EQ16	D:Q916	SQC	
EB3	D:H914	SDE	Critical device
EQ17	D:Q917, D:QS917	SQA	
EQ17-VT	D:VT917	NDB	
EQ18	D:Q917	SQA	
EQ19	D:Q919, D:QS919	SQB	
EQ20	D:Q919	SQA	
EQ21	D:Q919	SQA	
EQ22	D:Q919	SQA	
EQ23	D:Q919	SQA	
EQ24	D:Q924	SQA	
EQ25	D:Q924, D:QS925	SQA	
EQ25-VT	D:VT925	NDB	
EB4	D:H914, D:HS925	SDE	Critical device
Target bypass			
EQ26	D:Q926, D:QS926	SQB	
EB5	D:H926	SDD	
EQ27	D:Q926	SQC	
EQ28	D:Q926, D:QS928	SQD	
EB6	D:H926	SDD	

Table 5 AP-3 Magnetic Elements

The AP-3 line then bypasses the target by means of an achromatic transport using three dipoles and three quadrupoles, EQ26-28. The first of the three dipoles, EB4, is electrically connected with EB1-3, which makes up the left bend. Following EB4, AP-3 exits the Transport enclosure and bypasses the Target Vault. After the target bypass, AP-3 enters the Pre-Vault enclosure and encounters two bends, EB5&6, which direct beam into the AP-1 line. The final dipole of the target bypass, EB6, is actually in the AP-1 line between PQ7B and PQ8A. Since it is physically in the AP-1 line, its power supply (D:H926) must be ramped down during 120 GeV stacking cycles.

Three service buildings house AP-3 line power supplies: AP30 for the upstream end, F27 for the majority of the supplies, and AP0 for the downstream portion.