Fermi National Accelerator Laboratory

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Upgrade of the Proton West Secondary Beamline

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Introduction

Beamline elements in the Proton West beamline are grouped into eight distinct interlocked regions. These enclosures are either connected by long vacuum pipes or else are resident within a common structure. Protons from the Switchyard are directed into enclosure P01 where a three-way split is effected by Lambertson magnets. Protons from the "top" portion of the incident beam are deflected westward and form the Proton West beam.

Following the split, the Proton West beam is guided through the subsequent PW enclosures by a series of dipoles (generally deflecting horizontally), collimators, and quadrupoles. At the downstream end of the PW5 enclosure one has the choice of either dumping the beam into a water-cooled beam dump, capable of handling 10^{14} protons per pulse, or actively diverting it through an evacuated beam pipe into the PW6 enclosure.

As originally designed and operated, protons entering PW6 were steered by a series of EPB dipoles into a single interaction length beryllium target, some 43 feet from the enclosure wall. Ensuing secondary beams, either p^+/π^+ or p^-/π^-, were collected by a string of quadrupoles following the target, steered westward, away from the Proton Center line, through PW6 and PW7, and ultimately focussed on experiment production targets located within the large PW8 hall. Around the Spring of 1988 it was decided to upgrade the existing Proton West secondary beamline to allow for transport of a primary proton beam, anticipated to be either 800 or 900 GeV/c, through PW8. This upgrade project, which is now nearing completion, was largely motivated by the then recent approval of E-771[1], a hadronic beauty production experiment located in PW8. E-771 represents the third in a series of experiments for the large-acceptance dimuon spectrometer presently located at the end of the Proton West beamline.

This Technical Memo is a summary of the upgrade - an explanation of the underlying strategy and a documentation of the final locations of the secondary beamline elements. Much of the early conceptually planning for the upgrade was carried out by Brad Cox and Thornton Murphy in the course of the E-771 proposal effort. Bruce Baller, Ray Stefanski, and Alan Wehmann aided in trying to understand the optics for both primary beam transport and for secondary beam transport, 600 GeV/c in particular. The contents of this memo, however, are solely my responsibility.

T-type collimators and delivery of beam to PW6

In order to reduce 10^{11} protons per pulse, which is the minimum number that Switchyard can reliably deliver, down to 4×10^9 or less, two T-type collimators were built and have been installed in enclosures PW2 and PW5. Both collimators are essentially 60 inch blocks of steel with three rectangular passage holes in each along the length of the block. The reduction in beam flux implied by the holes is to good approximation the ratio of the size of the beam at the entrance window to the area of the window. Holes, which are always square in cross-section, have sides of length .05, .10, and .20 inches respectively in PW2TCOL and .08, .18, and .45 inches in PW5TCOL. Remote motor controls allow for both vertical and horizontal positioning of both the upstream and downstream ends of the two T-type devices. Jim Volk oversaw the design and construction of the T-type collimators and details on the two may be found in TM-1553.

Upstream of the new T-type collimator in PW2, the beam optics will be very much the same as it was in previous years; beam coming from P01 will be diverging and should produce a spot size at the front face of the collimator of about a centimeter in radius. More accurately, one predicts, based on previously recorded tunes for the beamline and TURTLE[2] simulations, reduction factors for the three hole sizes in PW2TCOL of approximately 185, 48, and 13 respectively. These numbers follow from the initial state of the Proton beam as delivered by Switchyard and from the recorded currents in quadrupole elements located upstream of P01. The intent is use the larger hole for the initial alignment of the collimator and the mid-sized hole for the normal running mode.

Following the PW2 T-type collimator, the beam will again diverge as it emerges from the pinhole. However, as the divergence is not large enough in order to achieve a comparable 1 cm spot at the PW5TCOL entrance it will be necessary to use the PW2 quadrupoles to defocus the beam somewhat. The holes in PW5TCOL were initially designed to achieve reductions of roughly 125, 25, and 5 respectively. As in the case of the PW2 collimator the true entrance spot sizes and reduction factors will most certainly not be known until they are determined in actual running conditions.

Figures 1a and 1b, which are derived from TURTLE simulations, map the vertical and horizontal sizes of the beam as it enters into P01, goes through the two T-type collimators, and is finally directed onto the target in PW8.

Upgrade strategy

Basically, the upgrade strategy was to preserve the existing bend points in the secondary beamline, which ran previously at up to 300 GeV/c, while increasing the number of benders and power so as to allow for transport of primary protons of up to 925 GeV. The second essential feature of the plan was to allow for the new possibility of 600 GeV secondary beams in addition to maintaining lower energy beams for electron calibration and testing purposes. Since a major revision of the secondary beamline was not a realistic choice, it was decided to leave the existing quadrupole elements in their original locations save for minor translations transverse to the beam path. Other elements of the beamline were to be treated accordingly - little change in location except in those cases where space was required for the additional dipoles. Quadrupoles, collimator, trims, and spoilers downstream of the last bend string were not moved so as to preserve targeting in PW8.

In addition to large and effectively fixed parts of the experiment located in PW8, such as the muon-filter steel, there are two other monuments - massive steel structures - located in PW6 which must be considered as constraints in any reasonable transport plan. First, there is the Target Box, PW6TGT, which consists of a 3" x 1.74" rectangular aperture upstream of the target region followed by a 21.3 foot post-target conical collimator with diameter ranging from 1.125 to 1.770 inches. Second, downstream of the Target Box is the Momentum Slit, PW6MS, the 19.7 foot channel used for selecting the momentum of the secondaries. The jaws of the Momentum Slit open horizontally about the beam axis from a fully closed position to a maximum of about 3 inches. As neither of these devices are easily moved, their survey coordinates were used as constraints in generating the final beamline plan.

New magnets

In order to make room for the new dipoles it was necessary to remove six elements from the pre-existing beamline: two horizontal trim magnets and four muon spoilers. Eleven dipole magnets were added to the secondary beamline: seven 6-3-120's and four 4-2-240's (B2's). Of the 6-3-120's, five were used to augment the 6W3 string raising the total to seven. The remaining magnets were deployed in PW7 after some rearrangement of the existing dipoles and trims. The resulting new strings - 7W1, 7W2, and 7W3 - form an almost continuous bend with the B2's in the middle, where there is a narrowing of the secondary beam profile. As indicated earlier, the original bend points were approximately preserved. Figure 2 illustrates the upgraded secondary beamline and explicitly indicates the eleven dipoles which are new to the beamline.

One feature of related interest worth noting is the special support jacks on which the new dipoles and some of the old ones sit. Built originally for CERN, these adjusters operate by compressing two polyurethane pads trapped inside the cylindrical body in a fashion similar to that of a hydraulic lift. Small screws on the side of the jacks, easily turned by a hand-held wrench, allow for vertical adjustments (±12.5 mm) as well as ±1 cm in any direction within the horizontal plane. By design, the load range is 1 to 12 metric tons; lighter loads are possible with some loss in vertical range.

Transport

During the Fall of 1988 a complete survey of the as-built PW beamline was made by the Research Division Surveying and Alignment group. Coordinates of elements from enclosures P01 through PW8 were measured within a common, almost-Cartesian coordinate system (elevation readings conform to the Earth's curvature.) In order to tie enclosures together special lenses were constructed so as to sight through vacuum pipes. A listing of elements and coordinates is obtainable through the S & A group (project #5001). Results from this survey formed the basis for the computer simulation of the beamline.

Modeling of the upgraded beamline was done using TRANSPORT[3], a computer program for designing charged particle beam transport systems. By constraint, the simulated beam was obligated to enter PW6 along the path defined by the first bend string, follow the path defined by the collection quadrupoles, hit the center of the upstream end of the Momentum Slit, and hit the center of the experiment target with the correct angles. The final specification of the beamline, as conveyed to the Surveying and Alignment group, was generated by BSHEET[4], a program which mimics TRANSPORT but whose output is both corrected for the Earth's curvature and is in the form required by the S & A group. Both the TRANSPORT and the BSHEET programs were run on the FNAL VAX CLUSTER from the KNE_PRJ project area. Table 1 lists the ideal coordinates of beamline elements from Switchyard through PW8 and, along with a terse description for each element, the B fields in kG where appropriate.

Changes to the old beamline were generally small with the largest deviation, a transverse displacement of about 2 inches away from the east wall, occurring in the vicinity of the 7W2 bend string. In addition to alterations in the original bend points, changes to the beamline also arise from the increased number of bending magnets due to magnet transversal sagitta considerations taken into account by TRANSPORT.

Optics of upgraded beamline

Within the secondary beamline there are three sets of quadrupoles, each set consisting of four 4Q120 quads. The first set, configured as a triplet, follows the target box and is referred to as the Collection set. These are referred to as PW6Q1 and PW6Q2 in figure 2. The Waisting set, consisting of PW6Q3 and PW7Q1, is configured as a doublet and bridges the PW6 and PW7 enclosures. Finally, the Targeting quads or PW7Q2 and PW7Q3, configured as a triplet, are used to focus secondary beams onto the experiment target. For primary beam transport, the Collection and Targeting quads will be normally off and the Waisting quads will be set so as to affect a point-to-parallel transformation. Secondary beamline transport utilizes all three quad strings. For 300 GeV/c secondaries the Collection and Waisting quads are already at maximum strength and will thus limit acceptance for higher momentum secondary beams.

Although the locations of the quadrupoles is pretty much unchanged in the upgrade, there have been changes in the manner in which they are powered. In particular, the Waisting quads, which used to run in series as focusing, defocusing, focusing, defocusing (in the horizontal plane), will now run as two independent sets - focusing, focusing and defocusing, defocusing. Also, the outer elements of Collection string (now PW7Q2) used to be powered separately; now they are powered in series.

Power requirements

Comparing electrical power needs for the established 300 GeV secondary beamline with the upgraded beamline (assuming 925 GeV/c primary momentum) one sees an increase in power from 1210 kW to 1610 kW. This power estimate is based solely on field-current relations and I^2R losses in the elements. A breakdown of the individual power requirements, compared with past usage, may be found in table 2. Note that the increase in bending power is in part offset by diminished power requirements for the quadrupoles during primary transport. There is also a small gain in that muon-spoiling magnetic elements are presumably not needed with the primary proton beam.

At 925 GeV the estimated power requirement for the PS5 sub-station is approaching the station limit[5]. For this reason, 925 GeV has been defined to be the maximum energy transportable by the upgraded beamline and power supplies and power busses have been specified accordingly.

Radiation Considerations

The advent of primary energy protons through PW8 has led to a new running mode - the West Bend Pinhole Mode. With the condition that PW2TCOL is IN (attenuating the primary beam), Proton West is allowed a maximum intensity of 2×10^{11}, 800 GeV protons per pulse. This assumes that the design specification of an attenuation factor of 25 for the PW2 collimator is met or exceeded.

With regards to a single-pulse accident, by suitably shielding the limiting aperture in PW8, the PW8H magnets, the entire beamline will be certified to take an intensity of 2.5×10^{13} protons/pulse as a single-pulse accident[6]. This intensity represents roughly the anticipated full machine intensity. Both the single-pulse limit and the continuous operation limit have been set by Mike Gerardi, who is presently serving as the Radiation Safety Officer for the Proton West beamline.

Instrumentation

As there is little change in the optics of the secondary beamline, Segmented Ionization Chambers, or SWIC's, will, for the most part, remain in their traditional locations. However, in order to better resolve the primary proton beam, the granularity of some of SWIC's downstream of the target box has been increased, in particular going from 3 mm spacing to 2 mm spacing. SWIC locations along the upgraded beamline as well as granularities may be found in table 1.

In order to measure and monitor the transmission of the two T-type collimators, several new Secondary Emission Monitors, SEM's, and Ionization Chambers, IC's, have been added to the beamline. In particular, a SEM has been installed at the downstream end of PW1, an IC has been added to the existing SEM at the entrance of PW5, an IC and SEM pair has been located between the two quadrupole strings in PW5, and an IC has been added to the existing SEM at the entrance of PW6.

Drawings

An up-to-date set of to-scale drawings for the PW enclosures may be obtained through the Research Division. They are listed as revision A of drawing number(s) 2430-ME-172105-1(-14). Norm Cuny was the draftsman.

Acknowledgements

I am indebted to Ray Stefanski for his guidance in my beamline modeling. Also, I would like to acknowledge the help of Larry Ketchem in leading me through the alignment specification process.

References and footnotes

[1] At this point, the best reference for E-771 is probably the proposal, AN EXPERIMENT TO STUDY BEAUTY PRODUCTION AND OTHER HEAVY QUARK PHYSICS ASSOCIATED WITH DIMUON PRODUCTION IN 800 (925) GEV/C PP INT., on file with FNAL. For a short overview of the issues pertinent to B physics at the Lab, see Beauty Physics at Fermilab Fixed Target Energies, B. Cox, FERMILAB-Conf-88/48.

[2] TURTLE (Trace Unlimited Rays Through Lumped Elements) A Computer Program For Simulating Charged Particle Beam Transport Systems, David C. Carey, NAL-64, May, 1978.

[3] TRANSPORT, A COMPUTER PROGRAM FOR DESIGNING CHARGED PARTICLE BEAM TRANSPORT SYSTEMS, K.L. Brown and F. Rothacker, Stanford Linear Accelerator Center, Stanford, California, USA; D.C. Carey, Fermi National Accelerator Laboratory, Batavia, Illinois, USA; Ch. Iselin, CERN Geneva, Switzerland; Geneva 1980. As mentioned, the actual software used was resident on the VAX CLUSTER.

[4] Written by Dave Carey by modifying the original TRANSPORT "beam sheet". See Beamline Design Aid "Automatic" Earth's Curvature Corrections BSHEET version of TRANSPORT, A. Wehmann, September 25, 1987 (internal memo). Note that TRANSPORT and BSHEET assume the positive "X" axis points to the left of the beam (looking downstream) whereas the S & A considers the "X" axis to be pointing to the right!

[5] Actually, it is the RMS current which is in trouble; at 925 GeV the PS5 RMS current is at 92% of capacity, although this is based on a guess of 200 amps for the building loads and unaccounted trims (private communication from Age Visser.)

[6] SHIELDING EXP. 771 IN PWEST, internal memo written by M. Gerardi, June 1988.

Figure 1a

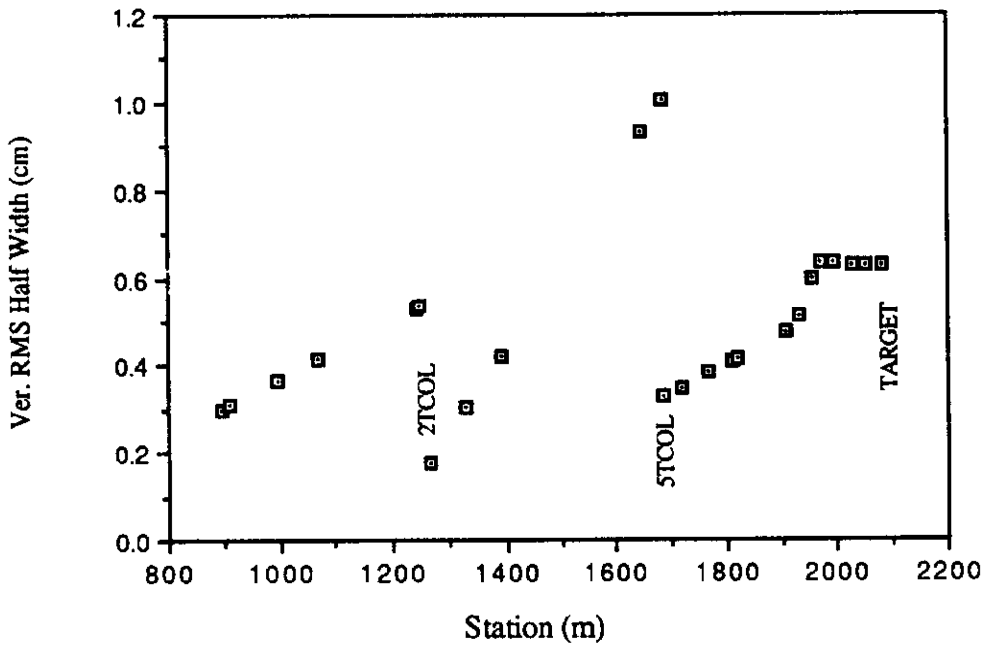

Figure 1b

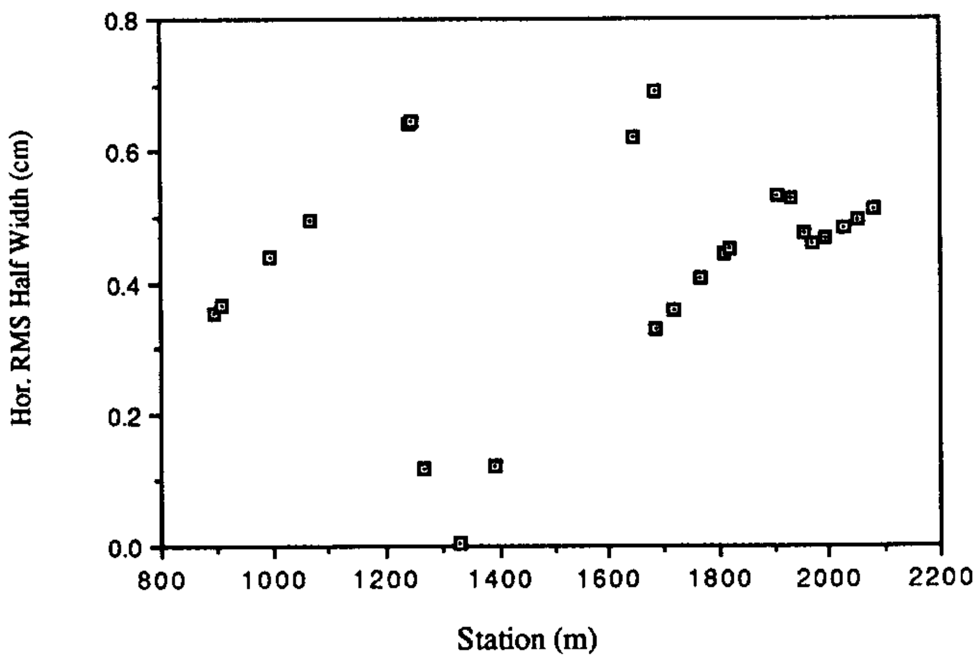

Figure 2 - Proton West Secondary Beamline

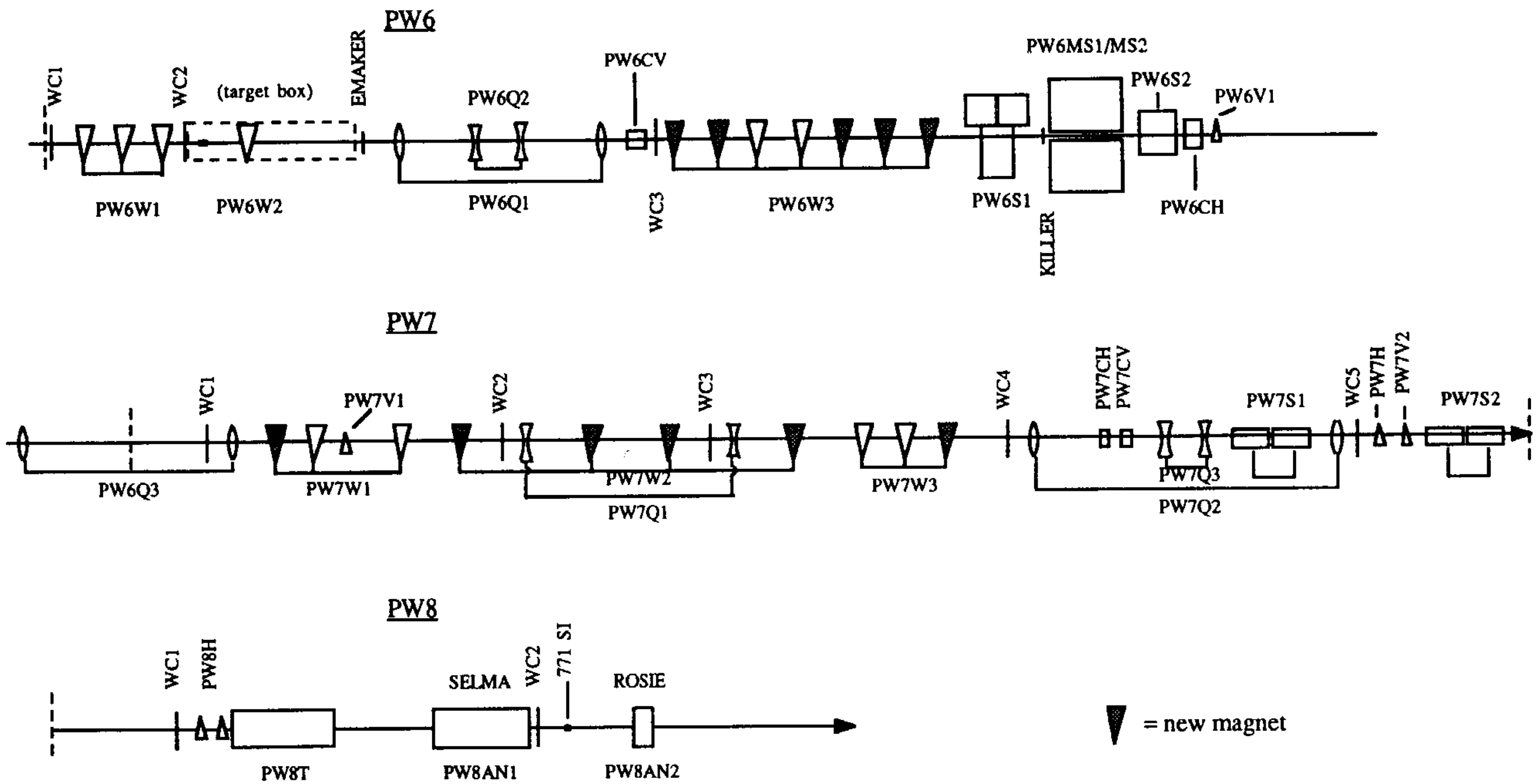

TABLE 1 - PW UPGRADED BEAMLINE SPECIFICATIONS AT 800 GEV/C

Z CENT.	X CENT.	Y CENT.	POSITION CODE	ELEMENT CODE	POWER SUPPLY	B/G(KG) OR (KG/IN)
-76.46	1.72	3.39	PWSYM-1			8.921
-57.38	1.30	3.43	PWSYM-2			8.921
-38.30	0.88	3.50	PWSYM-3			8.921
-19.23	0.46	3.61	PWASYM-1			12.010
-0.15	0.04	3.76	PWASYM-2			12.010
13.92	-0.27	3.90	PWVBPM			
29.30	-0.58	4.05	PWSKDP-1			35.392
50.30	-0.88	4.22	PWSKDP-2			35.392
71.30	-1.02	4.34	PWSKDP-3			35.392
99.08	-1.02	4.43	PWRFMN			
106.02	-1.01	4.46	PWHBPM			
109.30	-1.00	4.47	PWXSEM			
117.29	-0.99	4.49	PWV90			
126.23	-0.98	4.52	PWH90-1			3.240
132.31	-0.98	4.54	PWH90-2			3.240
140.96	-0.96	4.56	PWQ90			-3.297
152.00	-0.94	4.60	PWV91			0.000
158.02	-0.94	4.62	PWVBPM			
159.14	-0.93	4.62	PWSWIC			
168.42	-0.92	4.65	PWPSEP-1			0.147
181.04	-0.90	4.69	PWPSEP-2			0.147
193.67	-0.88	4.73	PWPSEP-3			0.147
206.29	-0.86	4.77	PWPSEP-4			0.147
218.92	-0.84	4.81	PWPSEP-5			0.147
231.54	-0.82	4.85	PWPSEP-6			0.147
244.17	-0.80	4.89	PWPSEP-7			0.147
259.46	-0.78	4.94	PWPV92			0.000
267.16	-0.76	4.97	PWVT92			0.000
303.60	-0.71	5.08	PWVBPM			
307.30	-0.70	5.10	PWHBPM			
309.93	-0.70	5.10	PWSWIC			
316.17	-0.69	5.12	PWVH94-1			10.007
327.17	-0.68	5.15	PWVH94-2			10.007
338.17	-0.67	5.16	PWVH94-3			10.007
347.86	-0.67	5.16	PWCOLL			
355.27	-0.67	5.17	PWVBPM			
358.97	-0.67	5.17	PWHBPM			
363.82	-0.67	5.17	PWLMSH			
373.01	-0.67	5.17	PWH100			0.000
376.12	-0.67	5.17	PWSWIC			
383.00	-0.67	5.17	PWPLAM-1			6.795
394.00	-0.68	5.17	PWPLAM-2			6.795
405.00	-0.70	5.18	PWPLAM-3			6.795
416.00	-0.72	5.18	PWPLAM-4			6.795
427.00	-0.76	5.18	PWPLAM-5			6.795
438.00	-0.80	5.18	PWPLAM-6			6.795
449.00	-0.85	5.18	PWPLAM-7			6.795
527.75	-1.28	5.20	PWBRFM			
541.44	-1.35	5.20	PWSWIC			
553.43	-1.42	5.20	PWV301			6.150
561.23	-1.46	5.20	PWQ300			3.958
580.77	-1.57	5.20	PWHBPM			
584.47	-1.59	5.20	PWVBPM			
590.23	-1.62	5.20	PWTAB			
602.23	-1.71	5.20	PWH301-1			27.489
623.23	-1.95	5.20	PWH301-2			27.489

644.23	-2.33	5.20	PWH301-3	27.489
665.22	-2.84	5.20	PWH301-4	27.489
677.22	-3.19	5.20	PWDSA	
689.21	-3.58	5.20	PWH301-5	27.489
710.20	-4.35	5.20	PWH301-6	27.489
731.18	-5.26	5.20	PWH301-7	27.489
743.16	-5.83	5.20	PWMCB	
751.65	-6.25	5.20	PWQ301	-4.139
757.97	-6.57	5.20	PWSWIC	
767.95	-7.06	5.19	PWVBPM	
771.64	-7.25	5.19	PWHBPM	
775.74	-7.45	5.19	PWV302-1	1.223
780.24	-7.67	5.19	PWV302-2	1.223
786.95	-8.01	5.19	PWCOLL	
961.71	-16.68	5.17	PWCNCH	
962.23	-16.70	5.17	PWVBPM	
964.60	-16.82	5.17	PWHBPM	
971.94	-17.18	5.17	PWQ302	1.102
978.21	-17.49	5.17	PWSWIC	
1130.48	-25.05	5.15	PWVBPM	
1134.17	-25.23	5.15	PWHBPM	
1136.79	-25.36	5.15	PWSWIC	
1143.01	-25.67	5.15	PWQ303-1	-2.371
1153.99	-26.22	5.15	PWQ303-2	-2.371
1164.98	-26.76	5.15	PWH302-1	10.806
1175.97	-27.32	5.14	PWH302-2	10.806
1186.95	-27.89	5.14	PWH302-3	10.806
1197.90	-28.48	5.14	PWQ304	2.762
1206.47	-28.93	5.14	PWMCB	
1218.45	-29.59	5.14	PWH303-1	27.489
1239.41	-30.85	5.14	PWH303-2	27.489
1260.36	-32.23	5.13	PWH303-3	27.489
1281.31	-33.74	5.13	PWH303-4	27.489
1293.27	-34.66	5.13	PWDSA	
1305.23	-35.62	5.13	PWH303-5	27.489
1326.16	-37.40	5.13	PWH303-6	27.489
1347.07	-39.31	5.12	PWH303-7	27.489
1359.02	-40.46	5.12	PWMCB	
1372.89	-41.81	5.12	PWVBPM	
1376.57	-42.17	5.12	PWHBPM	
1383.89	-42.89	5.12	PWQ305	2.267
1391.52	-43.63	5.12	PWV305	3.134
1396.04	-44.08	5.12	PWH305	0.000
1445.28	-48.89	5.10	PWSWIC	
1451.53	-49.50	5.10	PWQ306	-0.582
1642.26	-68.14	5.06	PWVBPM	
1645.94	-68.50	5.06	PWHBPM	
1648.59	-68.76	5.06	PWSWIC	
1660.73	-69.94	5.05	PWESEP-1	0.090
1674.12	-71.25	5.05	PWESEP-2	0.090
1687.52	-72.56	5.05	PWESEP-3	0.090
1700.91	-73.87	5.04	PWESEP-4	0.090
1714.31	-75.18	5.04	PWESEP-5	0.090
1730.90	-76.80	5.04	PWESEP-6	0.090
1744.29	-78.11	5.03	PWESEP-7	0.090
1757.68	-79.42	5.03	PWESEP-8	0.090
1771.08	-80.73	5.03	PWESEP-9	0.090
1784.47	-82.04	5.03	PWESEP-10	0.090
1800.51	-83.60	5.02	PWV307	11.546
2049.09	-107.89	4.66	PWVBPM	
2052.77	-108.25	4.66	PWHBPM	
2055.34	-108.51	4.65	PWSWIC	
2063.54	-109.31	4.64	PWV310-1	11.546
2074.49	-110.38	4.64	PWV310-2	11.546

2085.44	-111.45	4.65	PWV310-3			11.546
2096.39	-112.52	4.68	PWV310-4			11.546
2107.33	-113.59	4.72	PWV310-5			11.546
2118.28	-114.66	4.78	PWV310-6			11.546
2129.23	-115.73	4.85	PWV310-7			11.546
2140.18	-116.80	4.94	PWV310-8			11.546
2161.69	-118.89	5.13	PW00LH	LOSS MONITOR	P00LH	
2162.94	-119.01	5.14	PWP00H			0.000
2167.15	-119.42	5.18	PWP00V			1.840
2847.57	-185.70	11.32	PWP01B			
2849.81	-185.92	11.34	PW1LBP	LOSS MONITOR	P01LBP	
2849.81	-185.92	11.34	PW1TLM1	TOTAL LOSS MONITOR	P01TLM	
2849.81	-185.92	11.34	PW0WC1			
2853.39	-186.27	11.37	PW01MV1	VACUUM DEVICE	P01MV1	
2853.39	-186.27	11.37	PW01PG1	VACUUM DEVICE	P01PG1	
2853.39	-186.27	11.37	PW01PG2	VACUUM DEVICE	P01PG2	
2853.39	-186.27	11.37	PW1LD	LOSS MONITOR	P01LD	
2858.37	-186.76	11.41	PW01D-1			13.230
2869.33	-187.82	11.50	PW01D-2			13.230
2880.30	-188.89	11.56	PW01D-3			13.230
2891.27	-189.95	11.61	PW01D-4			13.230
2896.24	-190.44	11.63	PW01RP1	VACUUM DEVICE	P01RP1	
2896.24	-190.44	11.63	PW01MV2	VACUUM DEVICE	P01MV2	
2897.42	-190.55	11.63	PW1WC2	SWIC VACUUM BAYONET F1-G	P01WC2	
2903.25	-191.12	11.65	PW1CF1	LAMBERTSON SHIELD FRD11103		
2907.08	-191.50	11.66	PW1LW	LOSS MONITOR	PW1LW	
2912.40	-192.01	11.68	PW1W-1	DIPOLE 3W LAMBERTSON FRD11104	PW1W	-5.410
2923.34	-193.07	11.71	PW1W-2	DIPOLE 3W LAMBERTSON FRD11105	PW1W	-5.410
2934.32	-194.13	11.74	PW1W-3	DIPOLE 3W LAMBERTSON FRD11106	PW1W	-5.410
2945.28	-195.17	11.77	PW1W-4	DIPOLE 3W LAMBERTSON FRD11107	PW1W	-5.410
2956.24	-196.21	11.81	PW1W-5	DIPOLE 3W LAMBERTSON FRD10392	PW1W	-5.410
2962.04	-196.76	11.82	PW1MV1	VACUUM DEVICE	PW1MV1	
2962.04	-196.76	11.82	PW1WC3	SWIC VACUUM BAYONET F3-G	P01WC3	
2962.04	-196.76	11.82	PW1TLM2	TOTAL LOSS MONITOR	P01TLM	
3153.92	-214.81	12.39	PW1WC0	SWIC AIR D1-G	PW1WC0	
3154.71	-214.88	12.39	PW1LBD	LOSS MONITOR	PW1LBD	
3162.20	-215.58	12.41	PW1BD	FIXED COLLIMATOR		
3182.83	-217.53	12.47	PW1WC1	SWIC VACUUM BAYONET D1-G	PW1WC1	
3182.83	-217.53	12.47	PW1SMVU	VACUUM DEVICE	PW1SMV	
3188.96	-218.10	12.49	PW1LWD1-1	LOSS MONITOR	PW1LWD	
3198.92	-219.02	12.52	PW1WD-1	DIPOLE 2.3-2.3-252S FRD11970	PW1WD-	-22.935
3209.83	-220.01	12.55	PW1LWD1-2	LOSS MONITOR	PW1LWD	
3219.79	-220.87	12.57	PW1WD-2	DIPOLE 2.3-2.3-252S FRD11971	PW1WD-	-22.935
3240.68	-222.62	12.61	PW1WD-3	DIPOLE 2.3-2.3-252S FRD11972	PW1WD-	-22.935
3261.57	-224.26	12.63	PW1WD-4	DIPOLE 2.3-2.3-252S FRD11973	PW1WD-	-22.935
3271.55	-225.00	12.64	PW1LWD2-1	LOSS MONITOR	PW1LWD	
3282.48	-225.78	12.65	PW1WD-5	DIPOLE 2.3-2.3-252S FRD11974	PW1WD-	-22.935
3292.45	-226.48	12.65	PW1LWD2-2	LOSS MONITOR	PW1LWD	
3292.45	-226.48	12.65	PW1SMVD	VACUUM DEVICE	PW1SMV	
3292.45	-226.48	12.65	PW1SEM	SEM	PW1SEM	
3360.07	-231.07	12.66	PW1V-1	DIPOLE 5.125-1.5-40 FRD11955	PW1V	0.000
3363.13	-231.28	12.66	PW1LV	LOSS MONITOR	PW1LV	
3364.79	-231.39	12.66	PW1V-2	DIPOLE 5.125-2-40 FRD11141	PW1V	0.000
3368.40	-231.63	12.66	PW1LBS	LOSS MONITOR	PW1LBS	
3368.40	-231.63	12.66	PW1PG1	VACUUM DEVICE	PW1PG1	
3372.98	-231.94	12.66	PW1BS	VACUUM BEAM STOP	PW1BS	
3379.28	-232.37	12.66	PW1WC2	SWIC VACUUM BAYONET D1-G	PW1WC2	
3411.39	-234.55	12.66	PW1RP1	VACUUM DEVICE	PW1RP1	
3411.39	-234.55	12.66	PW1PV1	VACUUM DEVICE	PW1PV1	
3411.39	-234.55	12.66	PW1LBP	LOSS MONITOR	PW1LBP	
3411.39	-234.55	12.66	PW1******	P01 WALL		
3982.65	-273.31	12.72	PW2******	PW2 WALL		
3982.65	-273.31	12.72	PW2MV1	VACUUM DEVICE	PW2MV1	
3982.65	-273.31	12.72	PW2PG1	VACUUM DEVICE	PW2PG1	

3982.65	-273.31	12.72	PW2TLM	TOTAL LOSS MONITOR	PW2TLM	
3983.84	-273.40	12.72	PW2WC1	SWIC VACUUM BAYONET D2-G	PW2WC1	
3992.63	-273.99	12.72	PW2CF	VACUUM FIXED APERTURE COLL	PW2CF	
4002.60	-274.67	12.72	PW2LTCOL	LOSS MONITOR	PW2LTC	
4005.10	-274.84	12.72	PW2TCOL	PINHOLE COLLIMATOR	PW2TCO	
4022.56	-276.02	12.72	PW2Q1	QUAD 3Q120 FRD10726	PW2Q1	4.667
4033.96	-276.80	12.72	PW2V	DIPOLE 5.5-2.87-60 FRD11500	PW2V	-6.774
4040.05	-277.21	12.72	PW2H	DIPOLE 5.5-2.87-60 FRD11317	PW2H	-2.900
4049.53	-277.85	12.72	PW2Q2	QUAD 3Q120 FRD11133	PW2Q2	-1.667
4054.52	-278.19	12.71	PW2LBPW	LOSS MONITOR	PW2LBP	
4054.52	-278.19	12.71	PW2LBPE	LOSS MONITOR	PW2LBP	
4057.38	-278.38	12.71	PW2WC2	SWIC VACUUM BAYONET D2-G	PW2WC2	
4058.51	-278.46	12.71	PW2MV2	VACUUM DEVICE	PW2MV2	
4058.51	-278.46	12.71	PW2******	PW2 WALL		
4263.30	-292.32	12.65	PW3******	PW3 WALL		
4263.30	-292.32	12.65	PW3LBPW	LOSS MONITOR	PW3LBP	
4315.18	-295.83	12.64	PW3******	PW3 WALL		
4460.89	-305.70	12.60	PW4******	PW4 WALL		
4460.89	-305.70	12.60	PW4LBPE	LOSS MONITOR	PW4LBP	
4536.72	-310.83	12.57	PW4******	PW4 WALL		
5304.09	-362.77	12.35	PW5******	PW5 WALL		
5304.09	-362.77	12.35	PW5MV1	VACUUM DEVICE	PW5MV1	
5304.09	-362.77	12.35	PW5PG2	VACUUM DEVICE	PW5PG2	
5304.09	-362.77	12.35	PW5WC1	SWIC VACUUM BAYONET D2-G	PW5WC1	
5305.76	-362.89	12.35	PW5IC1	ION CHAMBER	PW5IC1	
5306.67	-362.95	12.35	PW5SEM1	SEM	PW5SEM	
5306.67	-362.95	12.35	PW5TLM1	TOTAL LOSS MONITOR	PW5TLM	
5420.76	-370.67	12.31	PW5LTCOL	LOSS MONITOR	PW5LTC	
5423.25	-370.84	12.31	PW5TCOL	PINHOLE COLLIMATOR	PW5TCO	
5531.02	-378.13	12.28	PW5RP1	VACUUM DEVICE	PW5RP1	
5531.02	-378.13	12.28	PW5PG3	VACUUM DEVICE	PW5PG3	
5532.25	-378.22	12.28	PW5WC2	SWIC VACUUM BAYONET D2-G	PW5WC2	
5535.28	-378.42	12.28	PW5TLM2	TOTAL LOSS MONITOR	PW5TLM	
5540.27	-378.76	12.28	PW5Q1-1	QUAD 3Q120 FRD10731	PW5Q1-	0.000
5551.27	-379.50	12.28	PW5Q1-2	QUAD 3Q120 FRD10730	PW5Q1-	0.000
5562.26	-380.25	12.27	PW5Q1-3	QUAD 3Q120 FRD10727	PW5Q1-	0.000
5574.32	-381.06	12.27	PW5MV2	VACUUM DEVICE	PW5MV2	
5574.32	-381.06	12.27	PW5IC2	ION CHAMBER	PW5IC2	
5575.23	-381.13	12.27	PW5SEM2	SEM	PW5SEM	
5582.22	-381.60	12.27	PW5Q2-1	QUAD 3Q120 FRD10725	PW5Q2-	0.000
5593.19	-382.34	12.26	PW5Q2-2	QUAD 3Q120 FRD11622	PW5Q2-	0.000
5604.17	-383.09	12.26	PW5Q2-3	QUAD 3Q120 FRD10732	PW5Q2-	0.000
5613.18	-383.70	12.26	PW5V	DIPOLE 4-4-30 FRD20760	PW5V	-0.204
5626.22	-384.57	12.25	PW5W1-1	DIPOLE 4-2-240 FRD11304	PW5W1-	-13.622
5647.64	-385.95	12.25	PW5W1-2	DIPOLE 4-2-240 FRD11311	PW5W1-	-13.622
5669.10	-387.27	12.24	PW5W2-1	DIPOLE 4-2-240 FRD11540	PW5W2-	-12.530
5685.49	-388.24	12.24	PW5W2-2	DIPOLE 4-2-120 FRD11639	PW5W2-	-12.530
5693.01	-388.67	12.23	PW5MV3	VACUUM DEVICE	PW5MV3	
5693.01	-388.67	12.23	PW5LCH	LOSS MONITOR	PW5LCH	
5697.00	-388.90	12.23	PW5CH	VAC.COLL. 1-JAW CRITICAL DEVICE	PW5CH	
5701.75	-389.17	12.23	PW5WC3	SWIC AIR MOTORIZED D2-G	PW5WC3	
5703.33	-389.26	12.23	PW5BD	PW5 DUMP, UPSTREAM FACE		
5727.62	-390.65	12.22	PW5******	PW5 WALL		
5832.26	-396.63	12.19	PW6MV1	VACUUM DEVICE	PW6MV1	
5832.26	-396.63	12.19	PW6PG1	VACUUM DEVICE	PW6PG1	
5832.26	-396.63	12.19	PW6RP1	VACUUM DEVICE	PW6RP1	
5832.26	-396.63	12.19	PW6WC1	SWIC AIR D2-G	PW6WC1	
5832.26	-396.63	12.19	PW6SEM	SEM	PW6SEM	
5840.85	-397.12	12.19	PW6W1-1	DIPOLE 5-1.5-120 FRD10394	PW6W1-	-5.811
5846.82	-397.46	12.19	PW6LW1	LOSS MONITOR	PW6LW1	
5851.81	-397.74	12.19	PW6W1-2	DIPOLE 5-1.5-120 FRD10516	PW6W1-	-5.811
5862.78	-398.35	12.18	PW6W1-3	DIPOLE 5-1.5-120 FRD11507	PW6W1-	-5.811
5868.77	-398.68	12.18	PW6WC2	SWIC AIR D1-G	PW6WC2	
5869.77	-398.74	12.18	PW6DUMP	PW6 TARGET DUMP, UPSTREAM FACE		

6521.68	-423.13	11.99	PW7S1	SPOILER FRD11344	PW7S1-	
6533.53	-423.34	11.98	PW7Q2-2	QUAD 4Q120 FRD11529	PW7Q2-	0.000
6539.65	-423.45	11.98	PW7WC6	SWIC AIR F3-G	PW7WC6	
6545.31	-423.55	11.98	PW7H	DIPOLE 4-4-30 FRD11530	PW7H	0.000
6553.16	-423.69	11.98	PW7V2	DIPOLE 'CRYOSTAT MAGNET' FRD11?70	PW7V2	0.000
6564.56	-423.90	11.97	PW7S2	SPOILER FRD11345	PW7S2-	
6575.97	-424.10	11.97	PW7S2	SPOILER FRD11346	PW7S2-	
6580.97	-424.19	11.97	PW7LS2	LOSS MONITOR	PW7LS2	
6587.05	-424.30	11.97	PW8*****	PW7/8 GATE		
6596.93	-424.47	11.96	PW8BD	SHIELD BLOCK DUMP 15" LONG		
6621.42	-424.91	11.96	PW8WC1	SWIC AIR MOTORIZED F3-G	PW8WC1	
6627.09	-425.01	11.95	PW8H1-1	'E95 MAGNET' FRD11708	PW8H1-	0.000
6632.96	-425.11	11.95	PW8H1-2	'E95 MAGNET' FRD11709	PW8H1-	0.000
6639.19	-425.23	11.95	PW8T	TOROID FRD20037	PW8T-1	
6644.89	-425.33	11.95	PW8T	TOROID FRD20038	PW8T-2	
6650.56	-425.43	11.95	PW8T	TOROID FRD20034	PW8T-3	
6656.26	-425.53	11.95	PW8T	TOROID FRD20035	PW8T-4	
6661.97	-425.63	11.94	PW8T	TOROID FRD20036	PW8T-5	
6671.90	-425.81	11.94	PW8BD2	STEEL DUMP 12'9" LONG		
6704.68	-426.39	11.93	PW8AN1	ANALYSIS MAGNET FRD11633 'SELMA'	PW8AN1	
6728.36	-426.82	11.92	PW8WC2	SWIC AIR MOTORIZED D2-G	PW8WC2	
6728.36	-426.82	11.92	PW8E771	E771 TARGET		
6744.46	-427.10	11.92	PW8E705	E705 TARGET LOCATION		

Table 2 - Comparison of E705 and E771 Secondary Beamline Power Needs

300 GeV*			925 GeV		
	amps	kW		amps	kW
PW6W1	250	1	PW6W1	1200	8
PW6W2	1750	9	PW6W2	4158	49
PW6W3	1350	76	PW6W3	1051	194
PW7W1	1720	70	PW7W1	1096	90
PW7W2	1130	86	PW7W2	4480	217
			PW7W3	1096	90
		242			648
PW6Q1	1500	93	PW6Q1	0	0
PW6Q2	1200	42	PW6Q2	0	0
PW6Q4	1200	84	PW6Q3	148	1
			PW7Q1	148	1
PW7Q1	800	9	PW7Q2	0	0
PW7Q2	750	16	PW7Q3	0	0
PW7Q3	900	12			
		256			2
PW7H1	160	12			
PW8T	500	20			
		32			0
PW8AN2	2100	680	PW8AN2	2500	960
		1210			1610

* (charged beam as opposed to higher power-consuming neutral beam)