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HADRON BEAMS IN THE NEUTRINO AREA

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We describe here the geometrical and optical properties of the two hadron beams in the neutrino area. These beams were designed to service the NAL 15 foot bubble chamber and the ANL 30 inch bubble chamber with up to 500 GeV hadrons.

Geometry

Figure 1 shows the hadron beam lines. Hadrons from the neutrino tunnel are brought through an aperture in the shield wall which is 4 x 2 inches (H x V). This hole is located 14.5 inches from the neutrino beam center line. Hadrons passing through this aperture may be either secondaries produced by interactions in the target box or the proton beam itself which has been imaged onto the shield hole. Shielding in the downstream area has been sized with the expectation that only a small portion of the available proton flux (10^{10} - 10^{11} ppp) would ever be brought through the shield wall.

Beam coming through the shield aperture is transported by the magnets immediately following the shield wall onto a hadron beam production target which will serve as a source of particles for both bubble chamber beams (see Figure 1). The hadron beams view this target at a production angle of

3.0 mr so as to minimize the acceptance of muons produced by decays in the neutrino tunnel. A dipole capable of a 3.0 mr bend will be placed near the target so that the target may be removed and particles from the neutrino decay tunnel may be injected directly into the hadron beam lines.

The beams for the two bubble chambers separate at approximately the first focus. In the initial phase of operation the energizing of a magnet near this focus will deflect the beam from the 15 foot bubble chamber channel into the 30 inch bubble chamber channel. In a later section we discuss how this might evolve into a fast switch which would allow both chambers to operate on the same accelerator cycle.

After the first focus the two beams are completely separate. Tables 1-3 show the positions of the major beam components for the transfer section, the 15 foot bubble chamber beam, and the 30 inch bubble chamber beam respectively. The coordinate system used is the DUSAF system with 100,000 subtracted from the z-component. In this system the neutrino beam center line is at x = -8 inches. The units used in these tables are feet, milliradians, amperes, kilowatts. The magnetic fields are in kilogauss for dipoles and kilogauss per inch for quadrupoles and are given at a beam momentum of 500 GeV/c.

Optics

An optical diagram of the transition section, 15 foot bubble chamber beam, and 30 inch bubble chamber beam is given

in Figures 2-4 respectively. In the bubble chamber beam diagrams we have drawn the limiting rays assuming a target of full width and height of 0.10 x 0.04 inches. It is seen from these diagrams that with such a target size the beam to the 15 foot chamber is capable of momentum resolution of .038% and to the 30 inch chamber of 0.066% (full width). Second order optical effects, magnet allignment errors, etc., have not been included in these estimates. Both bubble chamber beams have a solid angle acceptance at the target of about 0.25 μsr and will be capable of transmitting a momentum bite of up to 1% full width.

Fast Switching

For fast (~ 100 msec) switching of the hadron beam from the 15' bubble chamber to the 30" bubble chamber we can consider changing the field in the bending magnets just before F1. Main ring bending magnets operate with a dB/dt of 5.5 kilogauss/sec. Thus for 500 GeV/c particles a main ring bending magnet can change its bend angle by 0.2 mradian in 100 msec. If we were to use only the last three bending magnets before F1 so as to avoid changing the beam center line through quadrupoles, then we could move the center line of the beam over by 4.7" at the first horizontal focus. We could then insert a septum dipole producing a 1.4 milliradian bend (77 kilogauss ft. at 500 GeV/c). This new beam line would insect the old 30" beam line just inside the muon cut at which point we would require another bending magnet producing 1.0 mrad to make the two lines coincide.

It is often desirable in a bubble chamber beam to be able to count the number of particles entering the bubble chamber and, when the number exceeds a certain level, kick the rest of the particles coming down the beam line out of the beam line onto a slit face.

In the hadron beam to the 15' bubble chamber this can be done by a vertical kicker magnet located at ~ 6650 DUSAF, that is, ~ 120' before the field lens. This has the advantage that the displacement caused by the kicker at the vertical slit at ~ 6910 is increased by ~ 90% by the field lens. To be specific, the kicker can produce a displacement of 8 mm/ .05 mrad of kick. Since the beam at this point is only 4 mm high (including second order effects for a momentum bite of $\pm$ 0.5%) .05 mrad of kick should be sufficient. For 500 GeV/c this requires ~ 2.5 kilogauss ft. -- just 1/10 what the .3 m CERN pulsed magnet described in CERN 64-35 will produce.

Fluxes

Particle yield calculations have been made for incident proton energies of 200 and 500 GeV using the Hagedorn-Ranft model. Figures 5 and 6 show the expected yields of negative pions at the bubble chamber. We choose to plot these yields in terms of the number of interacting protons needed to produce 100 pions at the bubble chamber for a beam with a nominal solid angle acceptance of 1.0 μsr and full momentum bite of 0.1%. Note that the beam described here has a solid angle acceptance of 0.25 μsr. Zero degree production has been

assumed even though the nominal production angle viewed by the beam is 3.0 mr; with the use of a target magnet zero degrees could be reached. Decay losses have been included in all of the flux computations.

We now consider the question of positive pion beams. Here the relevant quantity is the ratio of positive pions to protons as a function of bombarding proton energy and secondary particle momentum. This ratio is plotted in Figures 7 and 8 for 200 and 500 GeV incident protons respectively. For a substantial range of positive pion momenta, beams of considerable pion content can be achieved which with Cerenkov detector tagging could be used in a bubble chamber. It may be practical to produce a positive pion beam with a lower proton contamination if sufficient negative pions from the neutrino decay tunnel could be targetted and used for the production of a positive pion beam.

Figures 9 and 10 show the fraction of the hadron beams which will be composed of $K^{\pm}$ and $\bar{P}$ at 200 and 500 GeV incident protons respectively. Even with mass tagging the study of bubble chamber interactions with these particles would seem very difficult in this beam if this production model is correct.

Transfer Section - Neutrino Target to Hadron Beam Target

		ELEMENT	LENGTH	FIELD	BEND	CURRENT	POWER	Z	X	ANGLE	
1	DRIFT		0.000					3479.0000	-0.6700	-0.900	NEUTRINO TARGET
2	DRIFT		1337.000					4147.4997	-1.2716	-0.900	DECAY TUNNEL
3	DRIFT		0.000					4815.9994	-1.8733	-0.900	END OF SHIELD
4	DRIFT		22.000					4826.9994	-1.8832	-0.900	
5	DRIFT		20.000					4847.9994	-1.9021	-0.900	MUON BEAM DIPOLE
6	DRIFT		1.000					4858.4994	-1.9116	-0.900	
7	QUAD	3Q52	4.330	-4.8100		-3506.97	32.12	4861.1644	-1.9139	-0.900	
8	DRIFT		1.000					4863.8294	-1.9163	-0.900	
9	QUAD	3Q84	7.000	-4.8100		-3506.97	55.37	4867.8294	-1.9199	-0.900	
10	DRIFT		30.000					4886.3294	-1.9366	-0.900	
11	QUAD	3Q84	7.000	4.6100		3361.15	50.86	4904.8294	-1.9532	-0.900	
12	DRIFT		1.000					4908.8294	-1.9568	-0.900	
13	QUAD	3Q84	7.000	4.6100		3361.15	50.86	4912.8294	-1.9604	-0.900	
14	DRIFT		1.000					4916.8295	-1.9640	-0.900	
15	QUAD	3Q84	7.000	4.6100		3361.15	50.86	4920.8295	-1.9676	-0.900	
16	DRIFT		30.000					4939.3294	-1.9843	-0.900	
17	QUAD	3Q84	7.000	-4.8100		-3506.97	55.37	4957.8295	-2.0009	-0.900	
18	DRIFT		1.000					4961.8294	-2.0045	-0.900	
19	QUAD	3Q52	4.330	-4.8100		-3506.97	32.12	4964.4944	-2.0069	-0.900	
20	DRIFT		5.600					4969.4595	-2.0114	-0.900	
21	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	4982.2595	-2.0229	-6.400	
22	DRIFT		35.440					5009.9790	-2.2003	-6.400	
23	DRIFT		0.000					5027.6986	-2.3137	-6.400	HADRON BEAM TARGET

Table 1

15 Foot Bubble Chamber Beam - Hadron Target to 15 Foot Bubble Chamber

	ELEMENT		LENGTH	FIELD	BEND	CURRENT	POWER	Z	X	ANGLE	
1	DRIFT		0.000					5027.6999	-2.3137	-3.400	TARGET
2	DRIFT		300.000					5177.6991	-2.8237	-3.400	
3	QUAD	3Q84	7.000	-6.8500		-4994.33	112.30	5331.1983	-3.3456	-3.400	
4	DRIFT		1.500					5335.4482	-3.3600	-3.400	
5	BEND	4-2-240	20.000	-15.0475	-5.500	-3895.80	108.32	5346.1982	-3.3966	-8.900	
6	DRIFT		1.500					5356.9479	-3.4923	-8.900	
7	BEND	4-2-240	20.000	-15.0475	-5.500	-3895.80	108.32	5367.6975	-3.5879	-14.400	
8	DRIFT		1.500					5378.4464	-3.7427	-14.400	
9	QUAD	3Q84	7.000	6.3300		4615.20	95.89	5382.6959	-3.8039	-14.400	
10	DRIFT		1.500					5386.9455	-3.8651	-14.400	
11	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5397.6943	-4.0199	-19.900	
12	DRIFT		1.500					5408.4422	-4.2338	-19.900	
13	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5419.1902	-4.4478	-25.400	
14	DRIFT		1.500					5429.9367	-4.7208	-25.400	
15	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5440.6834	-4.9938	-30.900	
16	DRIFT		590.000					5745.5377	-14.4168	-30.900	
17	DRIFT		10.000					6045.3945	-23.6853	-30.900	
18	DRIFT		10.000					6055.3898	-23.9942	-30.900	HORIZONTAL SLIT
19	DRIFT		65.000					6092.8719	-25.1528	-30.900	
20	DRIFT		10.000					6130.3540	-26.3113	-30.900	VERTICAL SLIT
21	DRIFT		390.000					6330.2585	-32.4903	-30.900	
22	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	6535.1607	-38.8238	-25.400	
23	DRIFT		1.500					6545.9073	-39.0968	-25.400	
24	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	6556.6540	-39.3698	-19.900	
25	DRIFT		1.500					6567.4019	-39.5638	-19.900	
26	QUAD	3Q84	7.000	6.5500		4775.60	102.67	6571.6510	-39.6633	-19.900	
27	DRIFT		1.500					6575.9001	-39.7529	-19.900	
28	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	6586.6479	-39.9666	-14.400	
29	DRIFT		1.500					6597.3969	-40.1216	-14.400	
30	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	6608.1458	-40.2764	-8.900	
31	DRIFT		1.500					6618.8955	-40.3721	-8.900	
32	BEND	4-2-240	20.000	15.0475	5.500	3895.80	108.32	6629.6450	-40.4677	-3.400	
33	DRIFT		1.500					6640.3950	-40.5043	-3.400	
34	QUAD	3Q52	4.330	-6.5300		-4761.02	59.21	6643.3100	-40.5142	-3.400	
35	DRIFT		1.500					6646.2250	-40.5241	-3.400	
36	QUAD	3Q52	4.330	-6.5300		-4761.02	59.21	6649.1399	-40.5340	-3.400	
37	DRIFT		119.200					6719.9046	-40.7440	-3.400	
38	QUAD	3Q84	7.000	5.7400		4185.03	78.85	6774.0042	-40.9586	-3.400	
39	DRIFT		1.500					6778.2542	-40.9730	-3.400	
40	QUAD	3Q52	4.330	5.7400		4185.03	45.75	6781.1692	-40.9829	-3.400	

Table 2.

15 Foot Bubble Chamber Beam - Hadron Target to 15 Foot Bubble Chamber

continued

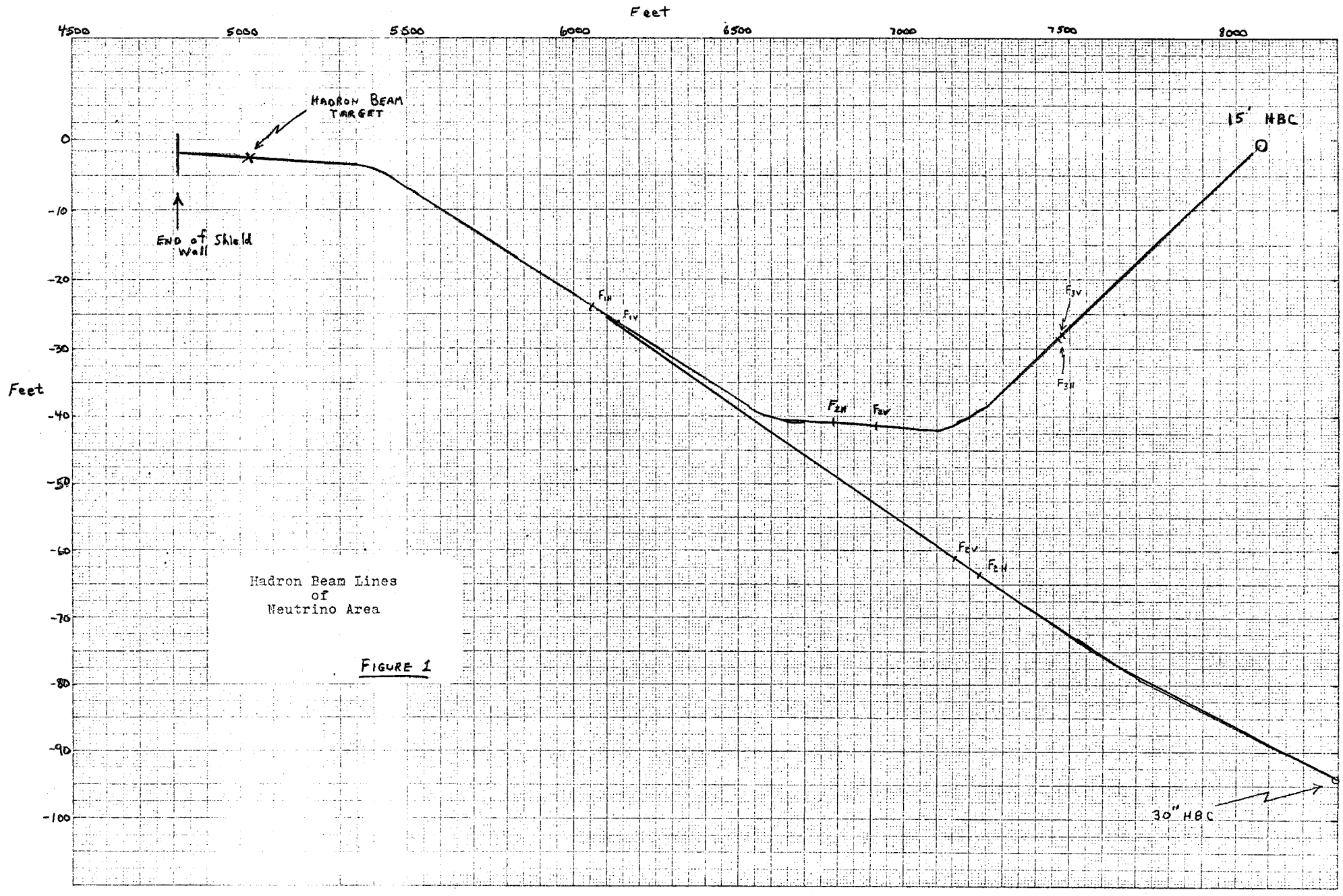
	ELEMENT		LENGTH	FIELD	BEND	CURRENT	POWER	Z	X	ANGLE	
41	DRIFT		10.000					6788.3341	-41.0073	-3.400	HORIZONTAL SLIT
42	DRIFT		120.000					6853.3337	-41.2283	-3.400	
43	DRIFT		10.000					6918.3334	-41.4493	-3.400	VERTICAL SLIT
44	DRIFT		147.300					6996.9829	-41.7167	-3.400	
45	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7080.6324	-42.0011	2.100	
46	DRIFT		1.500					7091.3824	-41.9785	2.100	
47	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7102.1324	-41.9560	7.600	
48	DRIFT		1.500					7112.8821	-41.8743	7.600	
49	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7123.6319	-41.7926	13.100	
50	DRIFT		1.500					7134.3810	-41.6517	13.100	
51	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7145.1302	-41.5109	18.600	
52	DRIFT		1.500					7155.8784	-41.3110	18.600	
53	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7166.6265	-41.1110	24.100	
54	DRIFT		1.500					7177.3735	-40.8520	24.100	
55	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7188.1204	-40.5929	29.600	
56	DRIFT		1.500					7198.8657	-40.2748	29.600	
57	QUAD	3Q84	7.000	6.6200		4826.64	104.88	7203.1139	-40.1490	29.600	
58	DRIFT		1.500					7207.3621	-40.0232	29.600	
59	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7218.1074	-39.7351	35.100	
60	DRIFT		1.500					7228.8507	-39.3278	35.100	
61	BEND	4-2-240	20.000	15.0475	5.500	3895.80	108.32	7239.5942	-38.9526	40.600	
62	DRIFT		1.500					7250.3354	-38.5142	40.600	
63	BEND	4-2-240	20.000	15.0475	5.500	3895.80	108.32	7261.0766	-38.0779	46.100	
64	DRIFT		1.500					7271.8152	-37.5825	46.100	
65	QUAD	3Q52	4.330	-6.4100		-4673.53	57.05	7274.7272	-37.4482	46.100	
66	DRIFT		1.500					7277.6391	-37.3138	46.100	
67	QUAD	3Q52	4.330	-6.4100		-4673.53	57.05	7280.5510	-37.1795	46.100	
68	DRIFT		170.000					7357.6233	-33.1626	46.100	
69	DRIFT		10.000					7457.5277	-29.0151	46.100	
70	DRIFT		10.000					7467.5171	-28.5543	46.100	HORIZONTAL SLIT
71	DRIFT		10.000					7477.5065	-28.0935	46.100	VERTICAL SLIT
72	DRIFT		23.000					7493.9889	-27.3351	46.100	
73	DRIFT		190.000					7600.3758	-22.4252	46.100	
74	QUAD	3Q52	4.330	-5.2400		-3820.48	38.13	7697.4376	-17.9475	46.100	
75	DRIFT		1.500					7700.3495	-17.8132	46.100	
76	QUAD	3Q52	4.330	-5.2400		-3820.48	38.13	7703.2614	-17.6788	46.100	
77	DRIFT		50.000					7730.3976	-16.4270	46.100	
78	QUAD	3Q84	7.000	5.1200		3732.99	62.74	7758.8673	-15.1136	46.100	
79	DRIFT		50.000					7787.3370	-13.8002	46.100	DISC FITS IN HERE
80	QUAD	3Q52	4.330	6.8000		4957.88	64.20	7814.4732	-12.5464	46.100	
81	DRIFT		1.500					7817.3850	-12.4140	46.100	
82	QUAD	3Q52	4.330	6.8000		4957.88	64.20	7820.2970	-12.2797	46.100	
83	DRIFT		1.500					7823.2089	-12.1454	46.100	
84	QUAD	3Q84	7.000	6.8000		4957.88	110.66	7827.4543	-11.9495	46.100	
85	DRIFT		50.000					7855.9240	-10.6361	46.100	
86	QUAD	3Q52	4.330	-5.8500		-4265.23	47.52	7883.0602	-9.3843	46.100	
87	DRIFT		1.500					7885.9720	-9.2499	46.100	
88	QUAD	3Q52	4.330	-5.8500		-4265.23	47.52	7888.8840	-9.1156	46.100	
89	DRIFT		1.500					7891.7959	-8.9813	46.100	
90	QUAD	3Q52	4.330	-5.8500		-4265.23	47.52	7894.7078	-8.8469	46.100	
91	DRIFT		175.000					7984.2775	-4.7148	46.100	
92	DRIFT		0.000					8071.6845	-0.6825	46.100	15 FT BUBBLE CHAMBER

Table 2. cont.

30" Bubble Chamber Beam - Hadron Target to 30" Bubble Chamber

	ELEMENT		LENGTH	FIELD	BEND	CURRENT	POWER	Z	X	ANGLE	
1	DRIFT		0.000					5027.6999	-2.3137	-3.400	TARGET
2	DRIFT		300.000					5177.6991	-2.8237	-3.400	
3	QUAD	3Q84	7.000	-6.8500		-4994.33	112.30	5331.1983	-3.3456	-3.400	
4	DRIFT		1.500					5335.4482	-3.3600	-3.400	
5	BEND	4-2-240	20.000	-15.0475	-5.500	-3895.80	108.32	5346.1982	-3.3966	-8.900	
6	DRIFT		1.500					5356.9479	-3.4923	-8.900	
7	BEND	4-2-240	20.000	-15.0475	-5.500	-3895.80	108.32	5367.6975	-3.5879	-14.400	
8	DRIFT		1.500					5378.4464	-3.7427	-14.400	
9	QUAD	3Q84	7.000	6.3300		4615.20	95.89	5382.6959	-3.8739	-14.400	
10	DRIFT		1.500					5386.9455	-3.8651	-14.400	
11	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5397.6943	-4.0199	-19.900	
12	DRIFT		1.500					5408.4422	-4.2338	-19.900	
13	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5419.1902	-4.4478	-25.400	
14	DRIFT		1.500					5429.9367	-4.7208	-25.400	
15	BEND	5-1.5-240	20.000	-15.0475	-5.500	-3895.80	89.91	5440.6834	-4.9938	-30.900	
16	DRIFT		600.000					5750.5354	-14.5712	-30.900	
17	DRIFT		10.000					6755.3897	-23.9942	-30.900	HORIZONTAL SLIT
18	BEND	5-1.5-240	20.000	-8.2078	-3.000	-2124.99	26.75	6070.3826	-24.4576	-33.900	
19	DRIFT		45.000					6102.8639	-25.5592	-33.900	
20	DRIFT		10.000					6130.3481	-26.4912	-33.900	VERTICAL SLIT
21	DRIFT		375.000					6322.7375	-33.0157	-33.900	
22	DRIFT		25.000					6522.6226	-39.7944	-33.900	
23	DRIFT		25.000					6547.6082	-40.6417	-33.900	
24	DRIFT		25.000					6572.5939	-41.4891	-33.900	
25	DRIFT		10.000					6590.0838	-42.0822	-33.900	
26	DRIFT		0.000					6595.0810	-42.2517	-33.900	
27	QUAD	3Q84	7.000	5.7700		4206.91	79.68	6598.5790	-42.3703	-33.900	
28	DRIFT		45.000					6624.5640	-43.2515	-33.900	
29	QUAD	3Q84	7.000	-5.9300		-4323.56	84.16	6650.5491	-44.1328	-33.900	
30	DRIFT		500.000					6903.9035	-52.7247	-33.900	
31	DRIFT		10.000					7158.7569	-61.3675	-33.900	VERTICAL SLIT
32	DRIFT		1.500					7164.5036	-61.5624	-33.900	
33	QUAD	3Q52	4.330	6.0000		4374.60	49.99	7167.4169	-61.6612	-33.900	
34	DRIFT		54.200					7196.6651	-62.6531	-33.900	
35	DRIFT		10.000					7228.7467	-63.7411	-33.900	HORIZONTAL SLIT
36	DRIFT		278.500					7372.9139	-68.6302	-33.900	
37	BEND	5-1.5-240	20.000	9.3021	3.400	2408.32	34.36	7522.0781	-73.6888	-30.500	
38	DRIFT		1.500					7532.8231	-74.0166	-30.500	
39	QUAD	3Q84	7.000	-6.0000		-4374.60	86.16	7537.0711	-74.1462	-30.500	
40	DRIFT		75.000					7578.0521	-75.3965	-30.500	
41	DRIFT		75.000					7653.0172	-77.6837	-30.500	
42	QUAD	3Q84	7.000	3.8600		2814.33	35.66	7693.9981	-78.9340	-30.500	
43	DRIFT		1.500					7698.2462	-79.0636	-30.500	
44	BEND	5-1.5-240	20.000	15.0475	5.500	3895.80	89.91	7708.9912	-79.3914	-25.000	
45	DRIFT		576.200					8006.9980	-86.8431	-25.000	
46	DRIFT		0.000					8295.0080	-94.0448	-25.000	30 INCH HBC

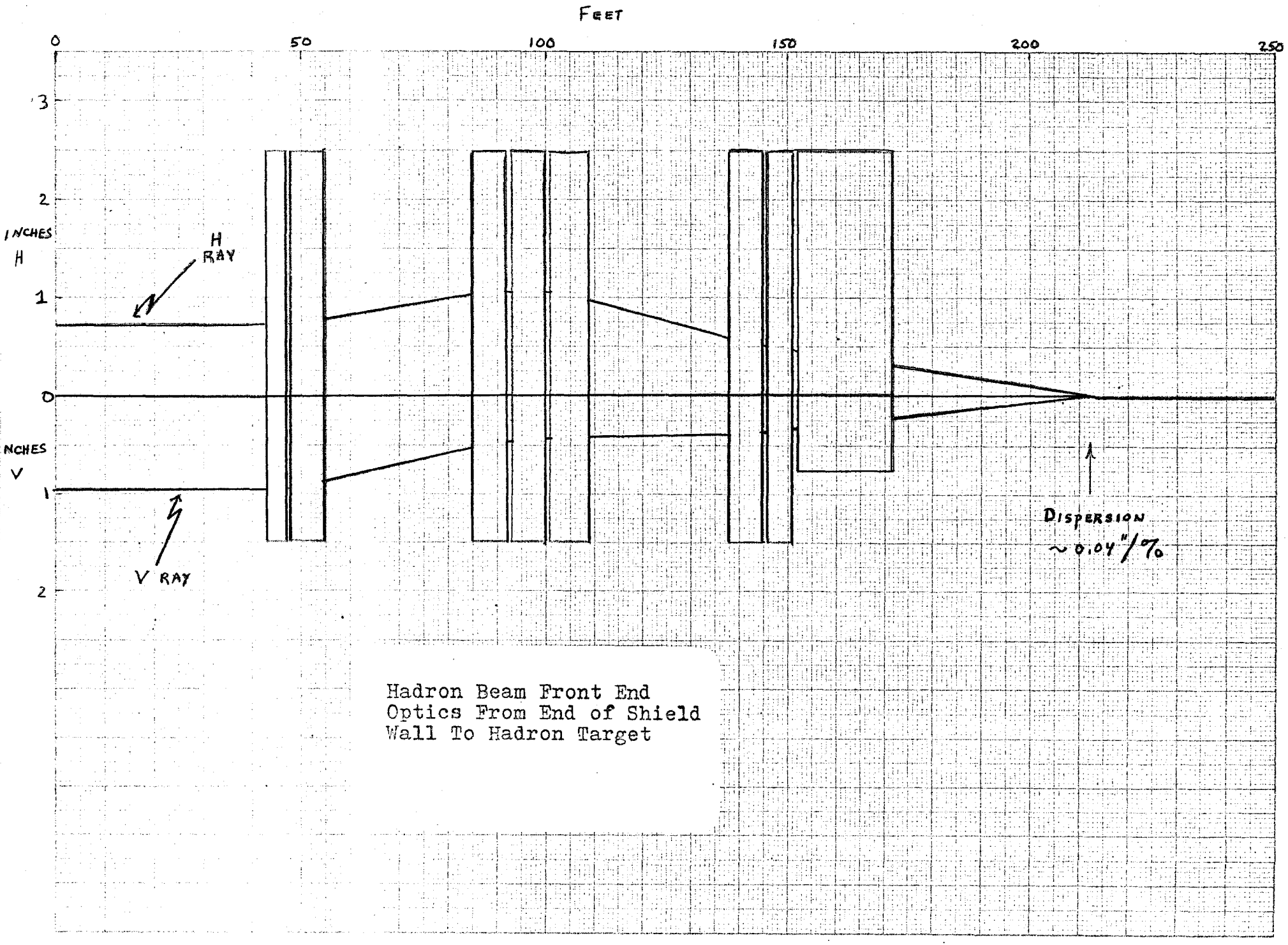
Table 3.



Hadron Beam Lines
of
Neutrino Area

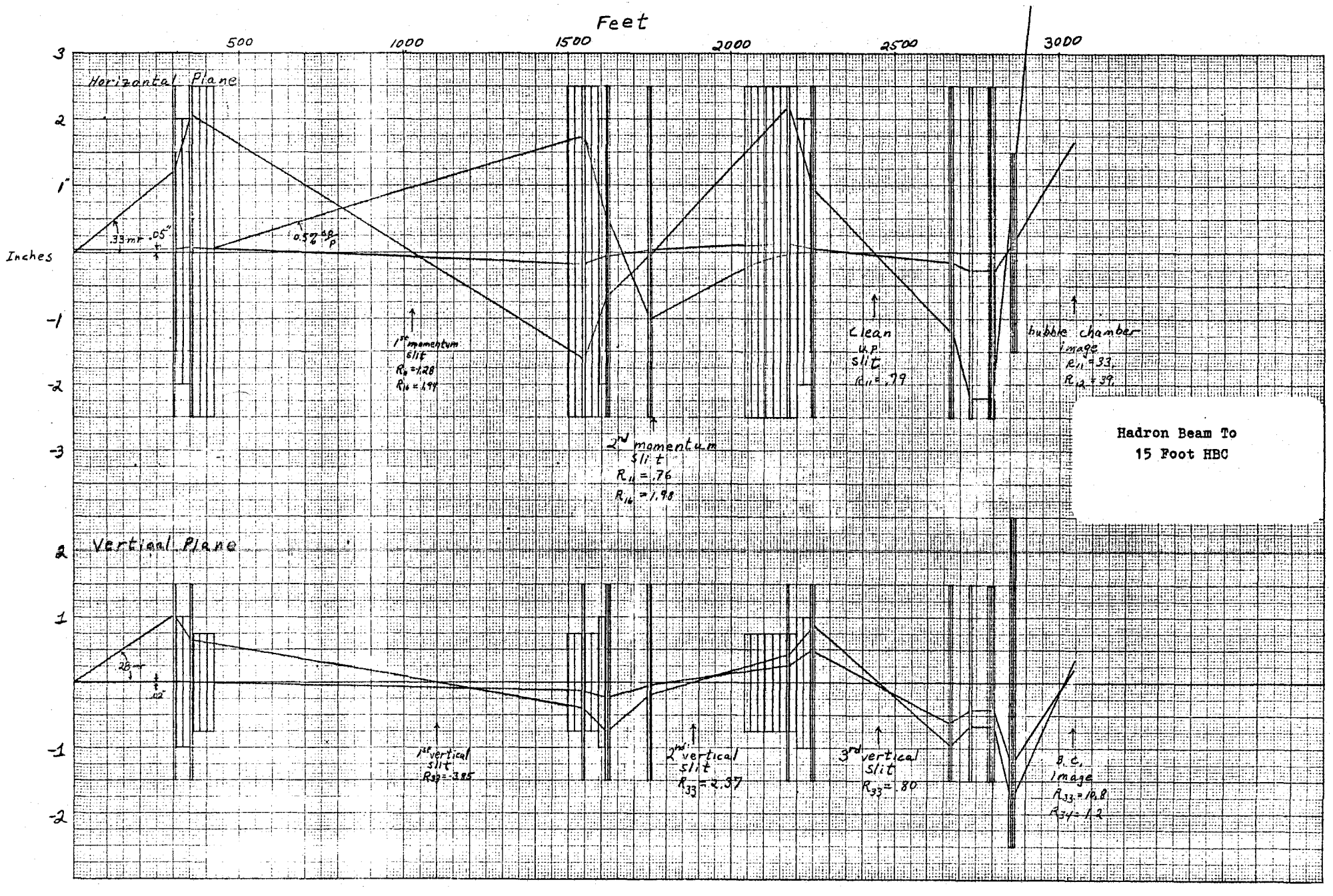
FIGURE 1

Figure 1



Hadron Beam Front End
Optics From End of Shield
Wall To Hadron Target

Figure 2



Hadron Beam To
15 Foot HBC

Figure 3

Figure 4

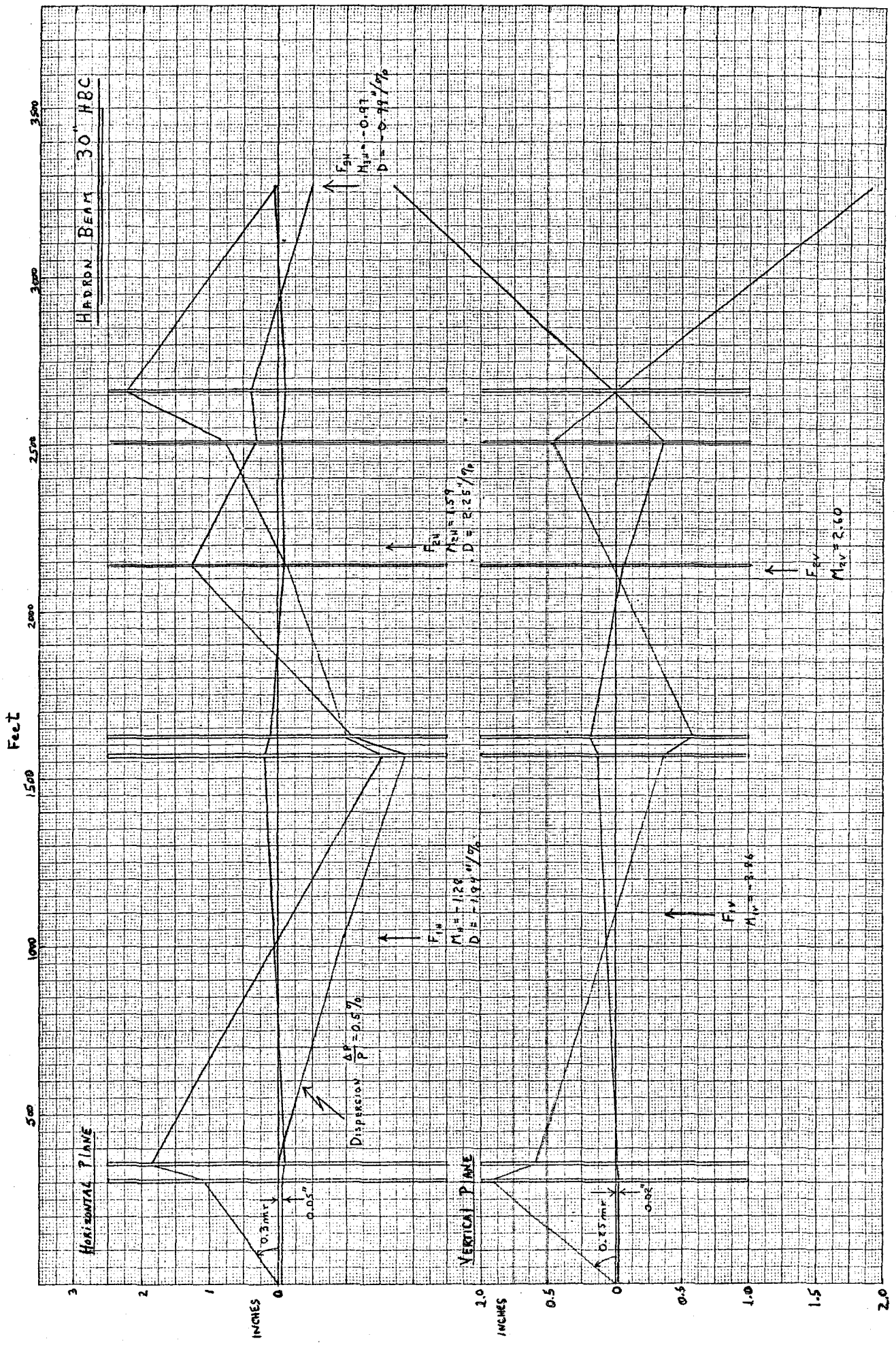

HADRON BEAM 30" HBC
HORIZONTAL PLANE
VERTICAL PLANE
Feet
500
1000
1500
2000
2500
3000
3500
INCHES
3
2
1
0
1.0
0.5
0
0.5
1.0
1.5
2.0
0.3mr
0.05"
0.25mr
0.02"
DISPERSION ΔP/P = 0.5%
F1H
M1H = -1.28
D = -1.94 "/%
F2H
M2H = 1.59
D = 2.25 "/%
F3H
M3H = -0.97
D = -0.99 "/%
F1V
M1V = -3.86
F2V
M2V = 2.60

Figure 5

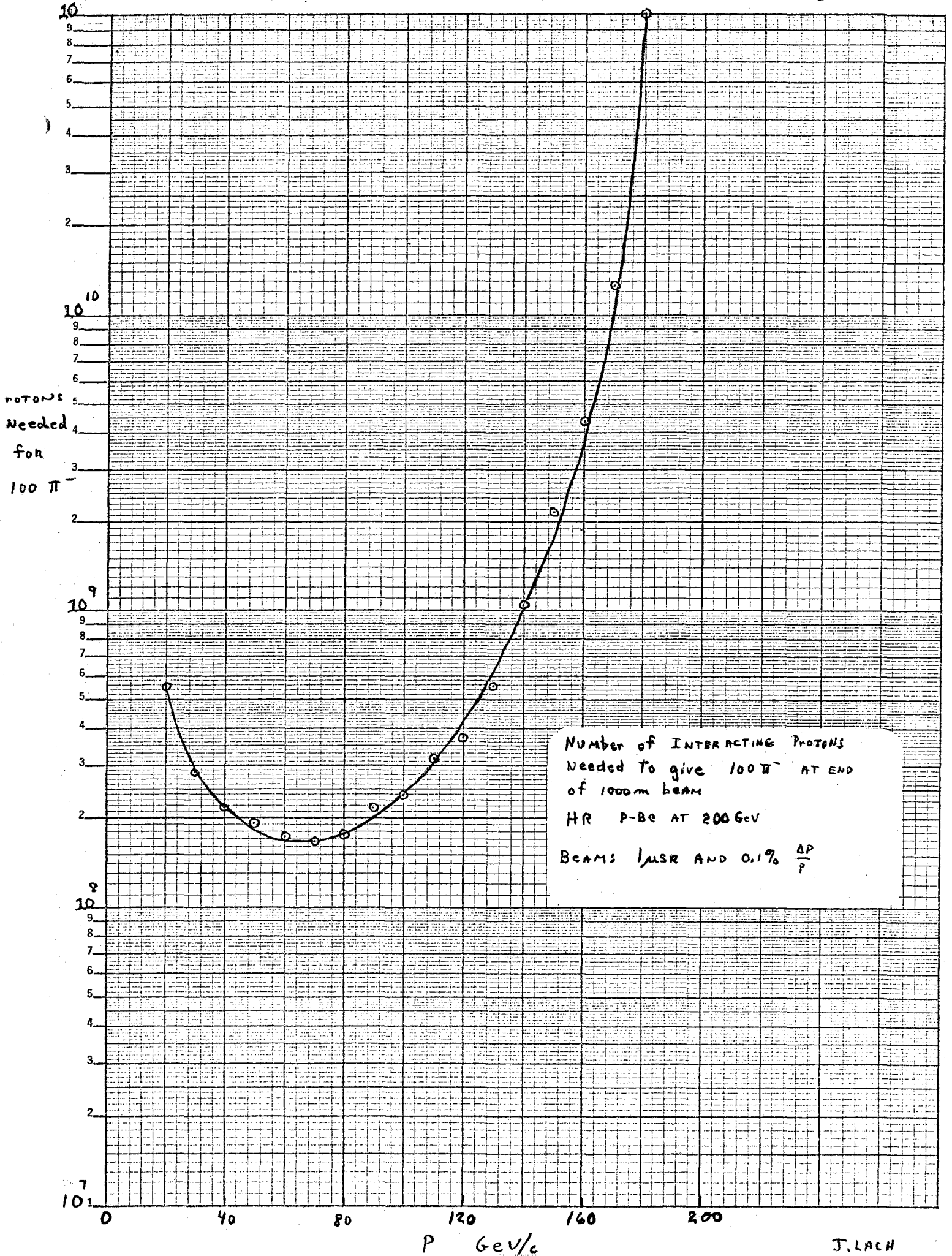

Number of Interacting Protons Needed to give 100 π⁻ at end of 1000m beam
HR p-Be at 200 GeV
Beams: 1μsr and 0.1% Δp/p
Protons Needed for 100 π⁻
P GeV/c
0
40
80
120
160
200
10^11
10^10
10^9
10^8
10^7
J. LACH

Figure 6

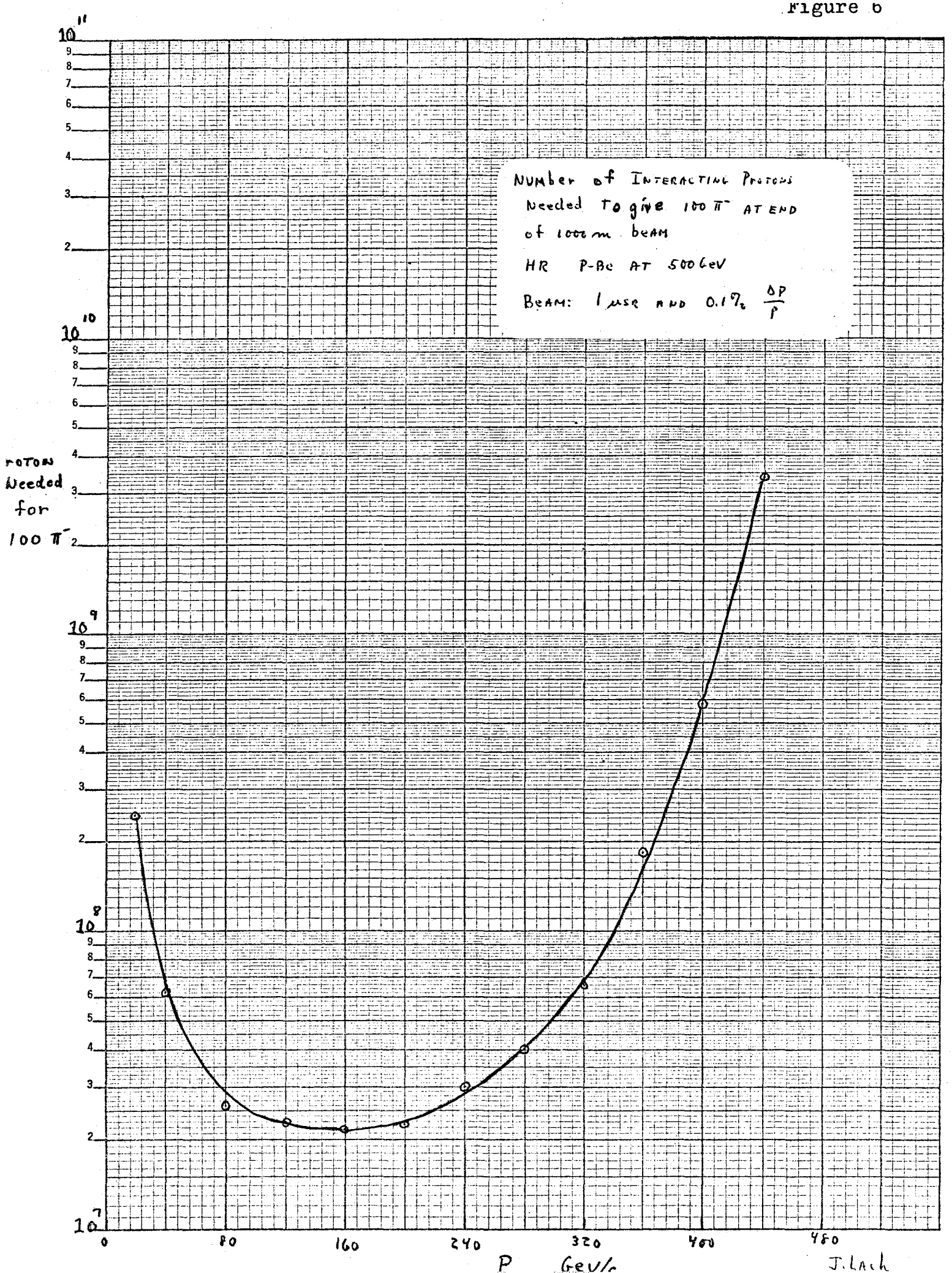
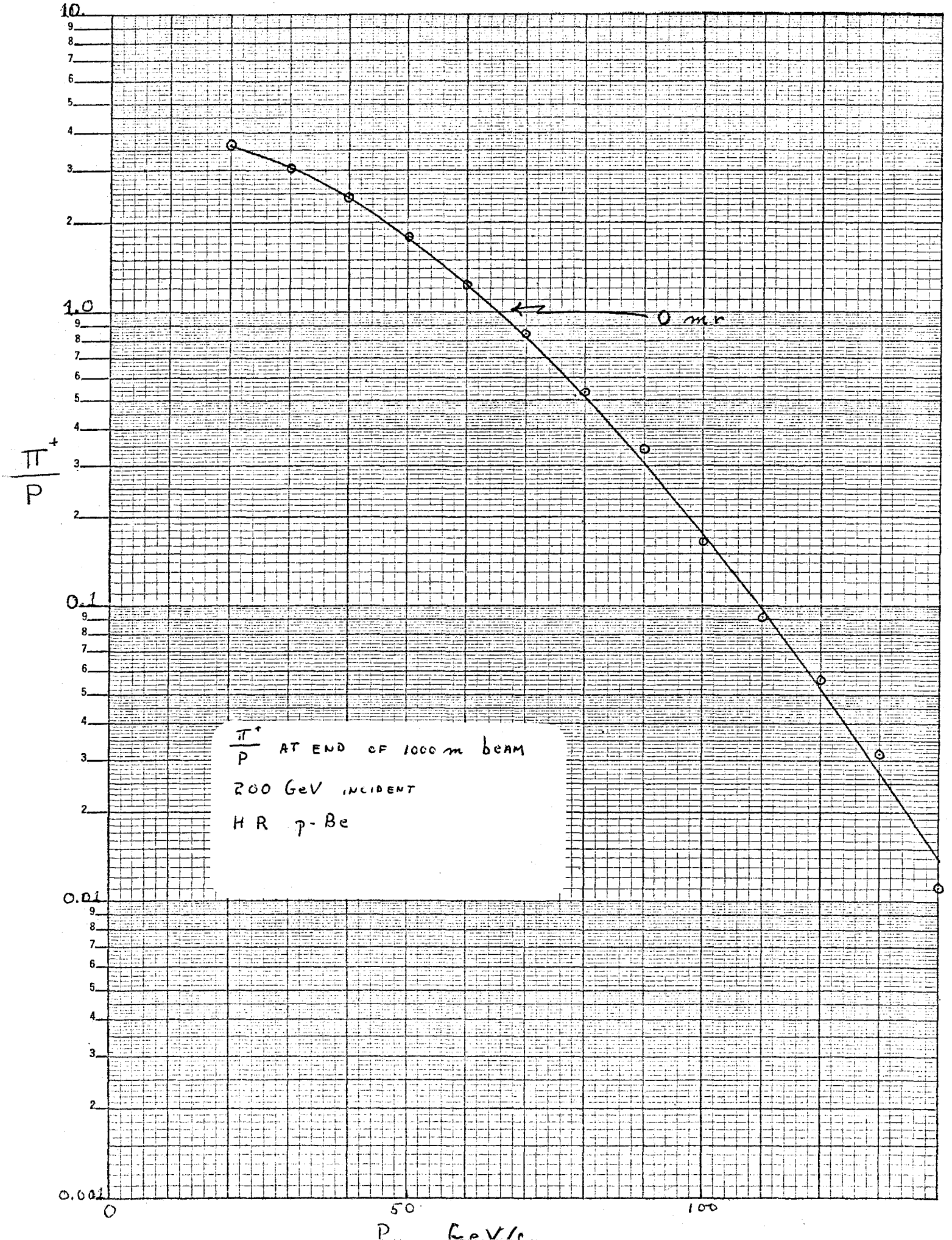
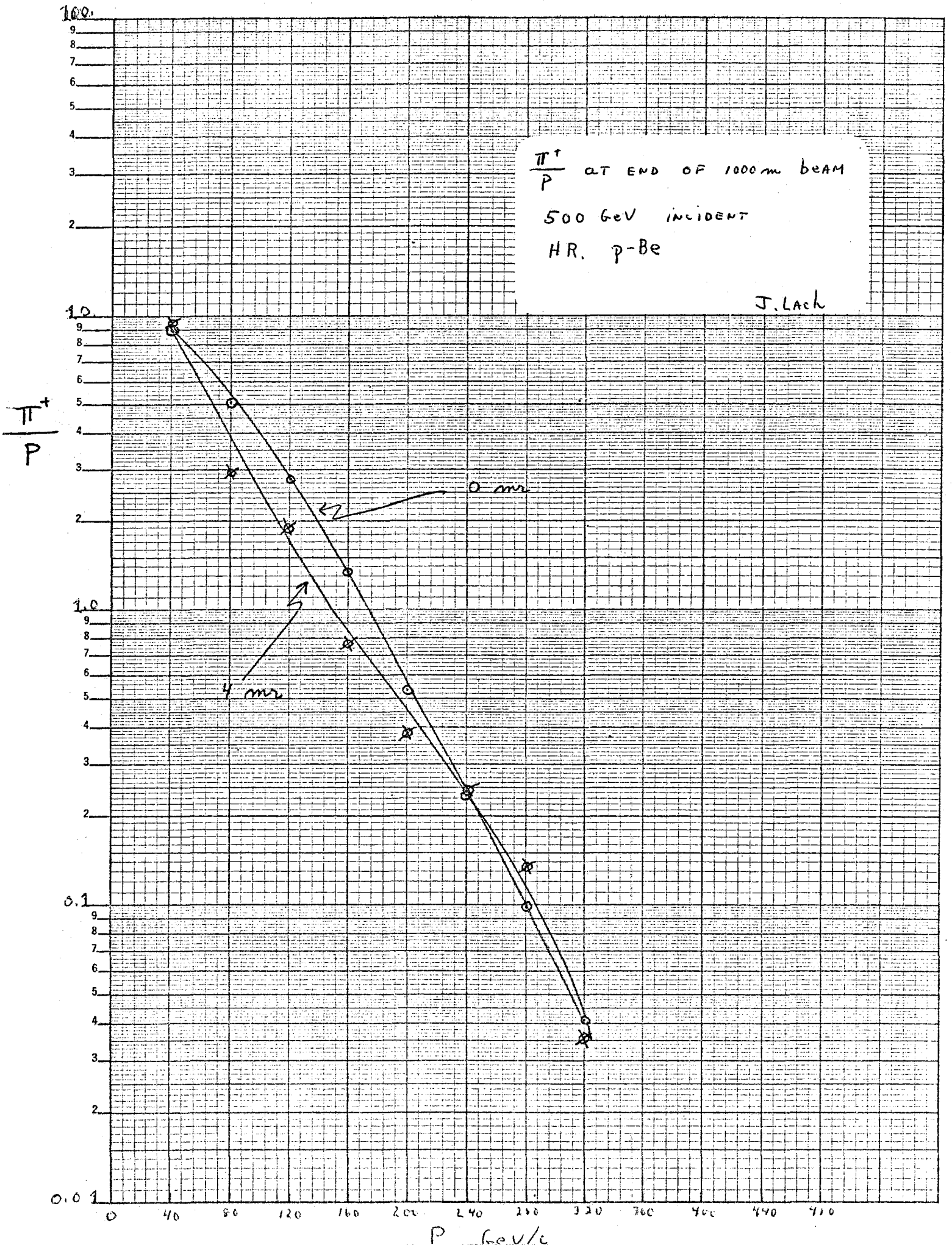
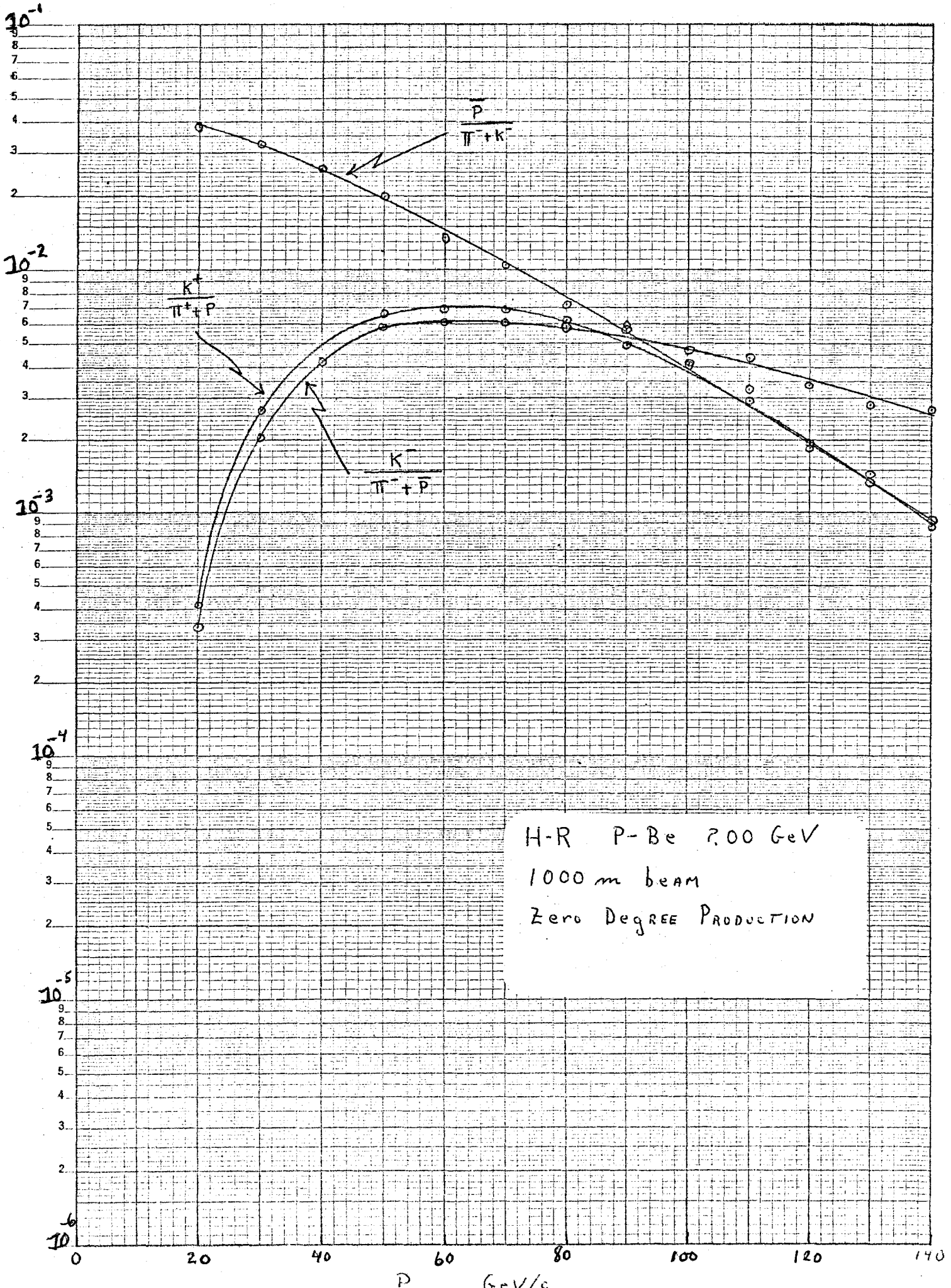
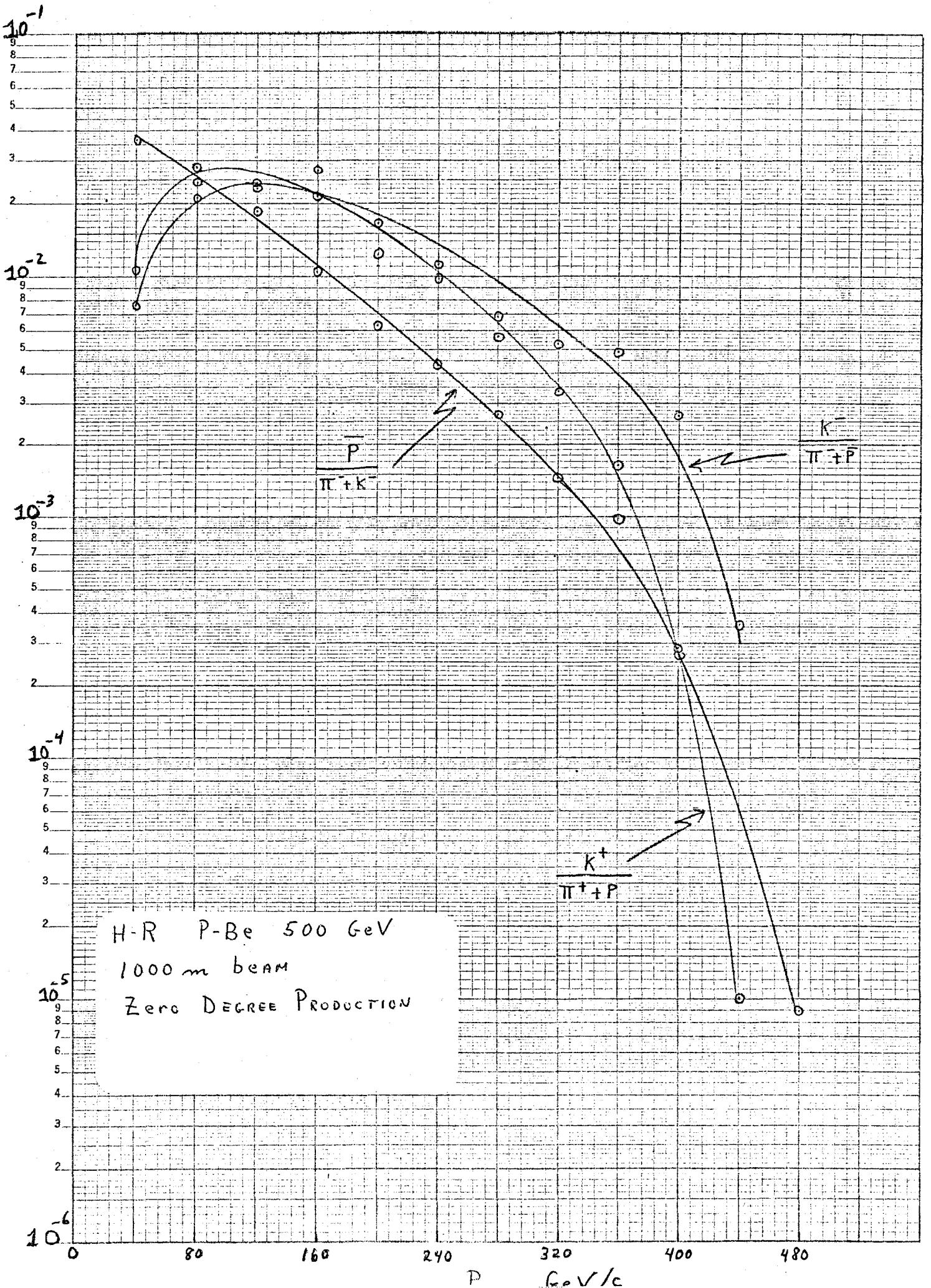

Number of Interacting Protons
Needed to give 100 π⁻ at end
of 1000 m beam
HR P-Be at 500 GeV
Beam: 1 μsr and 0.1% Δp/p
Proton Needed for 100 π⁻
10^11
10^10
10^9
10^8
10^7
0
80
160
240
320
400
480
P GeV/c
J. Lach

Figure 1


10.
1.0
0.1
0.01
0.001
π+/P
0 mr
π+/P AT END OF 1000 m beam
200 GeV INCIDENT
H R p-Be
0
50
100
P GeV/c


π+/P AT END OF 1000 m BEAM
500 GeV INCIDENT
HR. p-Be
J. LACK
0 mr
4 mr
π+/P
P GeV/c
100.
10.
1.0
0.1
0.01
0
40
80
120
160
200
240
280
320
360
400
440
480


10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$\frac{\bar{P}}{\pi^- + K^-}$
$\frac{K^+}{\pi^+ + P}$
$\frac{K^-}{\pi^- + \bar{P}}$
H-R P-Be 200 GeV
1000 m beam
Zero Degree Production
0
20
40
60
80
100
120
140
P GeV/c


10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$\frac{\bar{P}}{\pi^- + K^-}$
$\frac{K^-}{\pi^- + \bar{P}}$
$\frac{K^+}{\pi^+ + P}$
H-R P-Be 500 GeV
1000 m beam
Zero Degree Production
0
80
160
240
320
400
480
P GeV/c