Fermilab

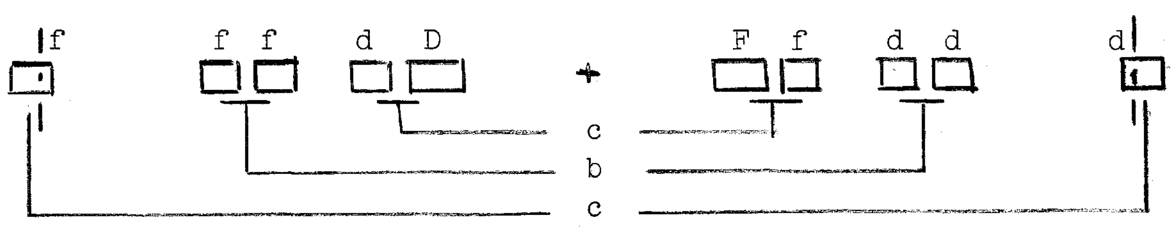
TM-649
0400

EASY LOW-BETA FOR THE MAIN RING

T.L. Collins

March 11, 1976

The present great interest in colliding beam experiments using the main ring as one of the beams would be even greater if one could enhance the luminosity by reducing the main-ring beam size at the center of a long-straight section. For cases where the main-ring energy is less than its maximum, either flat-topped or ramping, one can indeed lower beta without additional quadrupoles by separately powering the present straight-section quads. The simplest arrangement requires three separately programmed power supplies and gives beta as low as $2\frac{1}{2}$ M, in place of the usual 70 m, in both planes. The beam size is reduced by the ratio of the square root of these numbers in each plane, and the beam density increased by the ratio, or 28 times.



A main-ring long-straight section is an anti-symmetric arrangement of quads which gives a vertical beta that is the mirror image of the horizontal beta. In the low-beta reconnection this symmetry is preserved, thus horizontal and vertical betas at the center are automatically equal. We connect in series to power supply a the short quads which join the long-straight section to the regular lattice. This supply will be required to reverse smoothly. To power supplies b and c we connect the outer and inner elements of each doublet as shown. The elements are actually quad pairs, short plus short for the outer, and short plus standard for the inner. For the perfect adiabatic transition from normal to low beta these supplies would also have to reverse smoothly but this can be avoided with a small, tolerable mismatch near normal betas. The currents in these circuits are given as ratios to the normal quad current and are also labelled a, b, and c. In addition we must change the rest of the ring quads to preserve a constant tune and this current ratio is labelled r.

The problem was to find ratios a, b, c and r which produce a specified β^* at the center without changing beta outside the straight section. In addition one required a continuous set of ratios from normal β^* (a=b=c=1) down to the lowest beta so that one could "turn-on" the low beta after beam was injected and accelerated. I have found solutions with three circuits down to β^* slightly less than 2.5 M.

The retuning of the rest of the ring introduces a complication - primarily an arithmetic nuisance. When all quads in the main ring are changed together, beta is slightly modified (mismatched). Because of the six-fold symmetry stop-bands develop at ν=18 and 21 but not at the other half-intergers. So that nearby stop-bands do not develop, the single new straight section must reproduce the slightly mismatched beta for the ring retuned to compensate for the new straight section.

The computations used the original, matched, beta functions and tune (20.28) for the main-ring. The current ratios are given in Table I. The reader may be more interested in Figure 1, which is a plot of Table I.

Some other beam functions are listed in Table II and plotted in Figure 2:

(a) By β^* I mean simply the value at the center where $\beta_H = \beta_V$. Except by chance this is not the minimum β and some care is required in applying luminosity formulas for long interactions. I list the slope parameter $\alpha^* = -\frac{1}{2}\, d\beta/ds$ at the center, then at a point s meters from the center

$$\beta_s = \beta^* - 2\alpha^* s + (1+\alpha^{*2}) s^2/\beta^* \ .$$

Because of the anti-symmetry $\alpha^*_y = -\alpha^*_H$ and minimum for vertical beta is on the opposite side from the horizontal minimum. To a large extent this cancels the effect of α^* on luminosity.

(b) Off momentum protons oscillate about displaced equilibrium orbits. The displacement at the center is $\eta^* \Delta p/p$. For these low-beta sections η^* is usually less than $\frac{1}{10}$ of the normal η and momentum spread contributes essentially nothing to the beam width. Outside the section the maximum η is increased from a normal 5M to about 10M at the lower β^*'s. This should not be noticeable.

(c) As shown in Figure 3, beta is increased elsewhere in the straight section when it is decreased at the center. Above β^* = 19M the maximum is found in the normal location in the first downstream element (for horizontal). Below 19M the reduction of focussing at the beginning of the straight section takes over and maximum beta occurs in the focussing element of the upstream doublet.

Figure 4 shows the energy range possible as a function of β^* using the following simple assumptions. The injected beam at 8 GeV (8.89 GeV/c) has successfully negotiated several locations with β_{max} = 123.9. Because of the decrease of beam size with momentum ($\sqrt{p}$), I assume that β_{max} can be increased to keep the same size - proportional to p. Extra alignment care is required but we know exactly which quads are involved. This assumption gives a lower limit to the energy. I also assume that quads can run at their 400-GeV gradient - with more forceful cooling if necessary. The maximum of the current ratios a, b or c then gives an upper limit. The range for $2\frac{1}{2}$M is 82 to 153 GeV.

Table III gives the results of a brief look at the problem of including two low-beta sections in the ring. A comparison is made between one set to 5M with the other normal and both at 5M. Because of the increased detuning (r) required in the second case, the main-ring functions to which we are matching are different requiring slightly different currents a, b and c producing a somewhat increased β_{max}. The momentum parameters depend on the spacing of the pair of low-betas and are not the same for each (except for the symmetric case). Some interaction exists but it does not seem large enough to prohibit this mode of operation.

Finally, if three circuits are so good, how about 4 or 5? Clearly the arithmetic gets much more extensive. I have spent considerable effort readjusting the individual quads of the doublet elements and the next outside regular cell quads keeping β^* = 5M without substantial improvement of the energy range.

Table I. Quad. Current Ratios

β^*	circuit a	circuit b	circuit c	ring r
75	1.845	1.094	1.017	1.0004
70.27	1	1	1	1
65	1.158	.906	.984	.9992
60	1.292	.861	.992	.9980
55	1.403	.953	1.073	.9960
50	1.403	1.277	1.257	.9935
45	1.315	1.497	1.371	.9922
40	1.214	1.635	1.442	.9915
35	1.102	1.737	1.498	.9909
30	.979	1.821	1.548	.9903
28	.925	1.853	1.567	.9901
26	.868	1.883	1.587	.9899
24	.806	1.913	1.608	.9896
22	.740	1.944	1.629	.9894
20	.666	1.975	1.653	.9891
18	.585	2.007	1.679	.9888
16	.491	2.043	1.709	.9884
14	.380	2.083	1.746	.9880
12	.240	2.131	1.752	.9874
10	.046	2.195	1.859	.9865
9	- .092	2.239	1.907	.9858
8	- .283	2.297	1.972	.9848
7	- .552	2.372	2.056	.9833
6	- .874	2.446	2.135	.9814
5	-1.202	2.503	2.184	.9797
4½	-1.369	2.525	2.198	.9790
4	-1.545	2.545	2.208	.9782
3½	-1.739	2.563	2.212	.9775
3	-1.975	2.581	2.212	.9767
2½	-2.393	2.606	2.204	.9757

Table II. Beam Parameters

β^*	α_H^*	η^* meters	β_{max} meters
75	- .58	3.05	117
70.27	- .751	2.858	123.9
65	- .92	2.56	132
60	-1.09	2.17	142
55	-1.33	1.62	158
50	-1.57	1.04	179
45	-1.61	.75	183
40	-1.56	.58	179
35	-1.46	.45	172
30	-1.34	.33	163
28	-1.28	.29	159
26	-1.22	.24	154
24	-1.15	.20	149
22	-1.07	.16	144
20	- .99	.12	139
18	- .90	.08	141
16	- .80	.05	157
14	- .68	.01	177
12	- .54	-.02	204
10	- .37	-.04	246
9	- .26	-.04	278
8	- .13	-.01	326
7	.02	.06	400
6	.13	.17	500
5	.17	.27	614
4½	.17	.30	676
4	.15	.32	760
3½	.10	.31	843
3	.00	.27	950
2½	-.25	.14	1156

Table III. Interaction of Two Low-Beta Sections

	single	two sections		
β^*	5m	5m each		
a	-1.202	-1.291		
b	2.503	2.517		
c	2.184	2.205		
r	.9797	.9576		
α^*	.17	.26		
β_{max}	614	657		
spacing	-	1/6	1/3	1/2
η_1^*	.27	-.03	-.56	.42
η_2^*		.77	1.36	.42

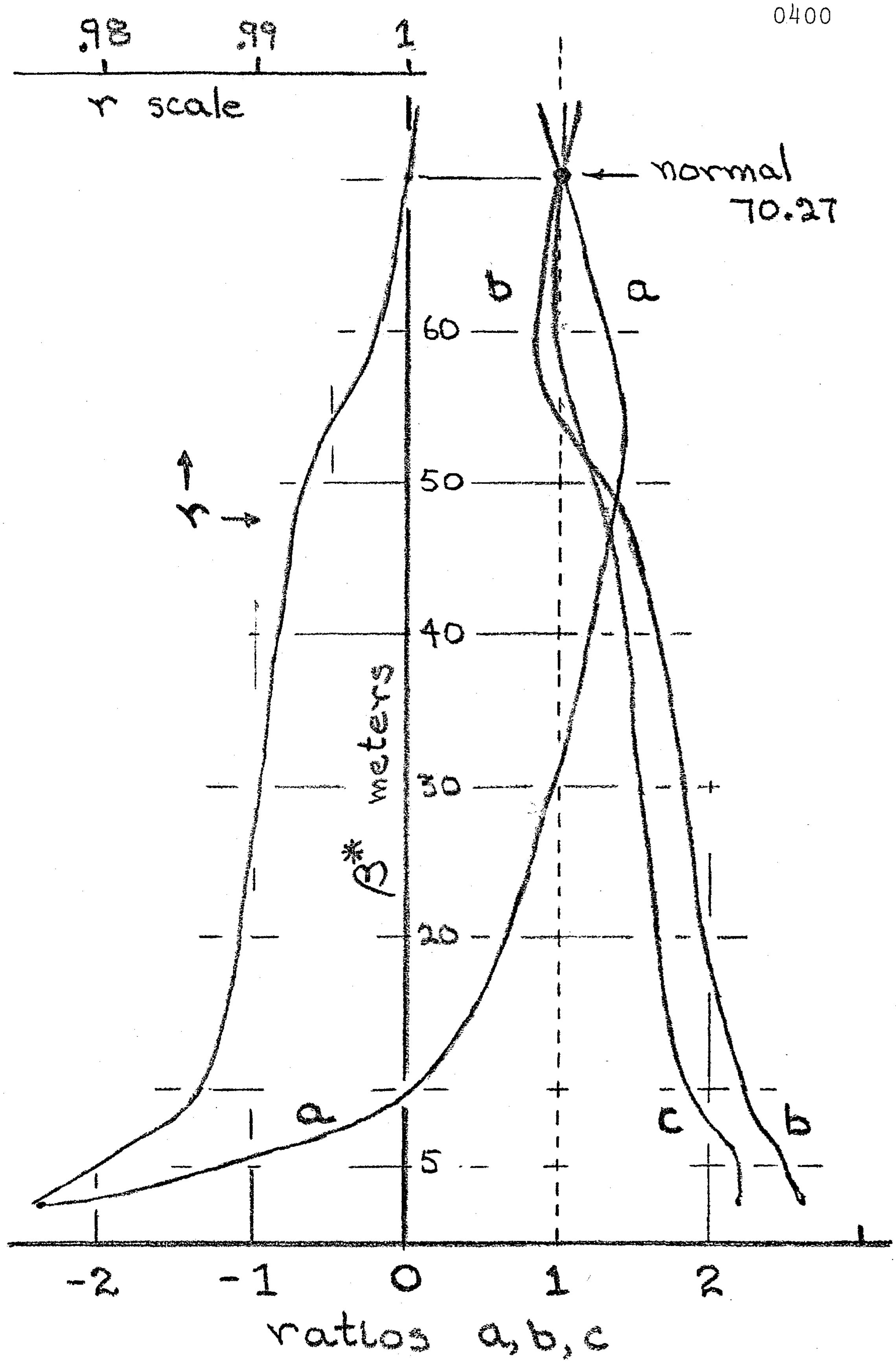


Figure 1. Quad. Current Ratios.

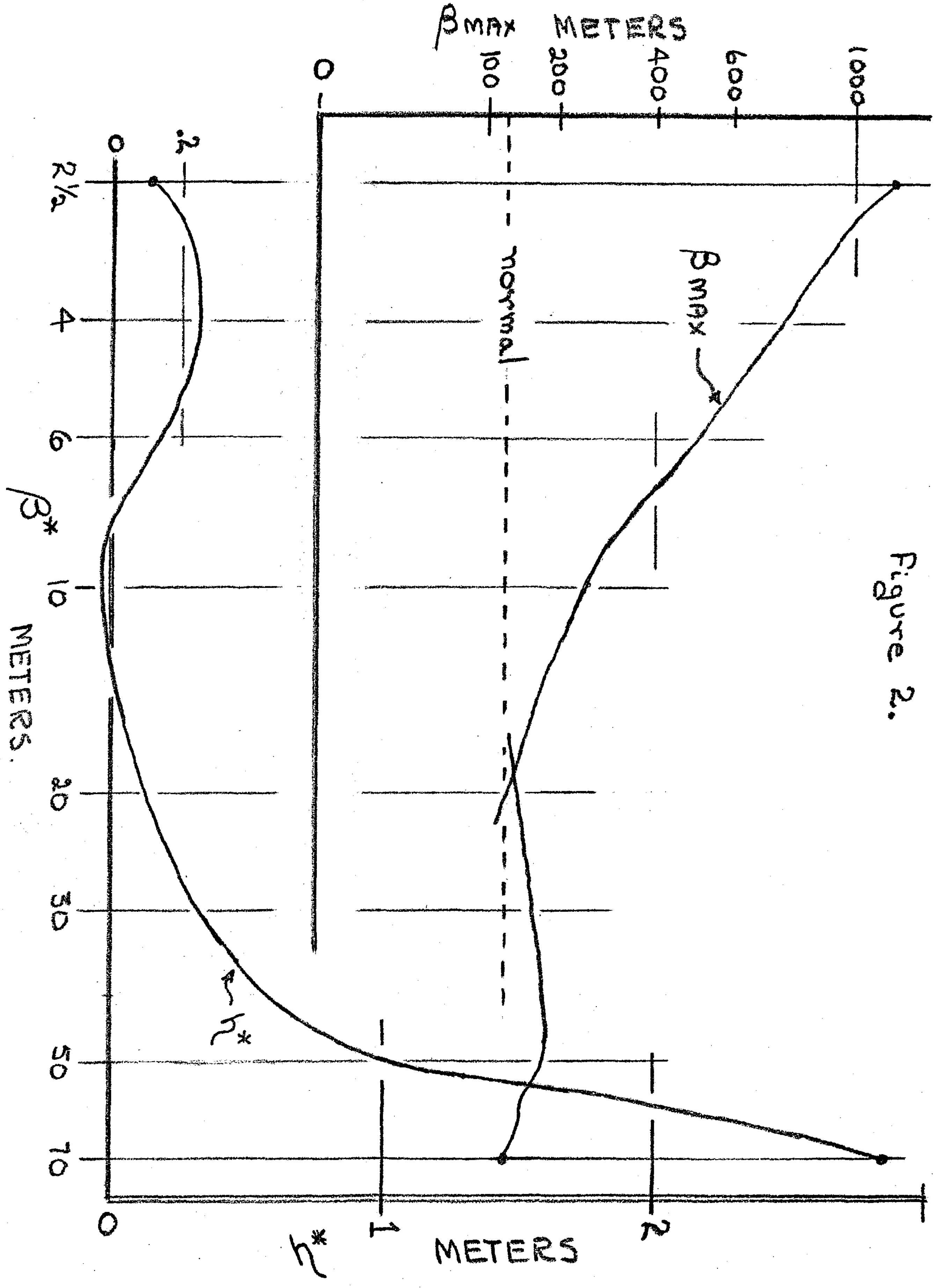

βMAX METERS
0
100
200
400
600
1000
normal
βMAX
.2
0
2½
4
6
β*
10
METERS.
20
30
50
70
h*
0
1
2
h* METERS

Figure 2.

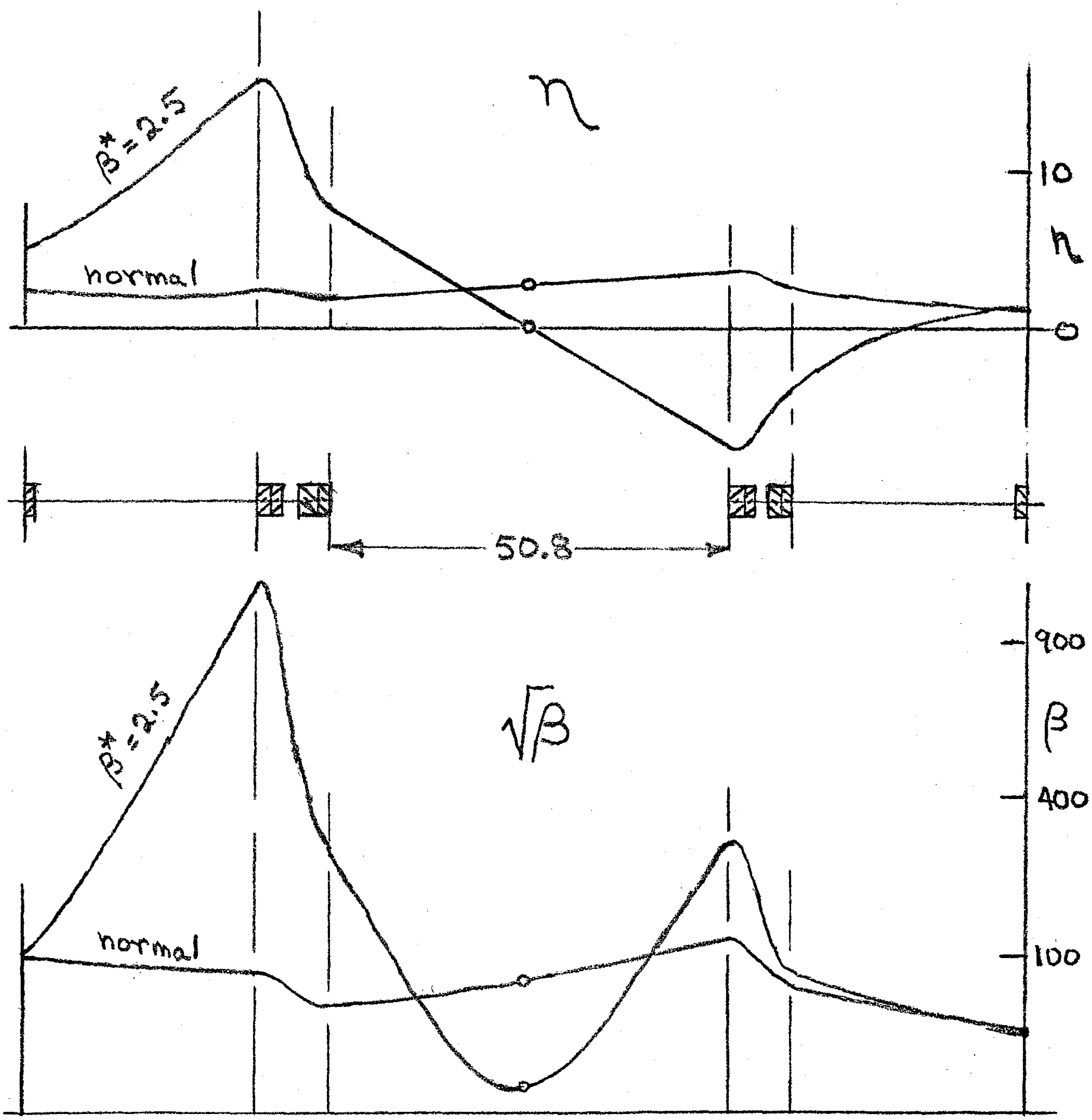


Figure 3. Beam size functions across st. sect.

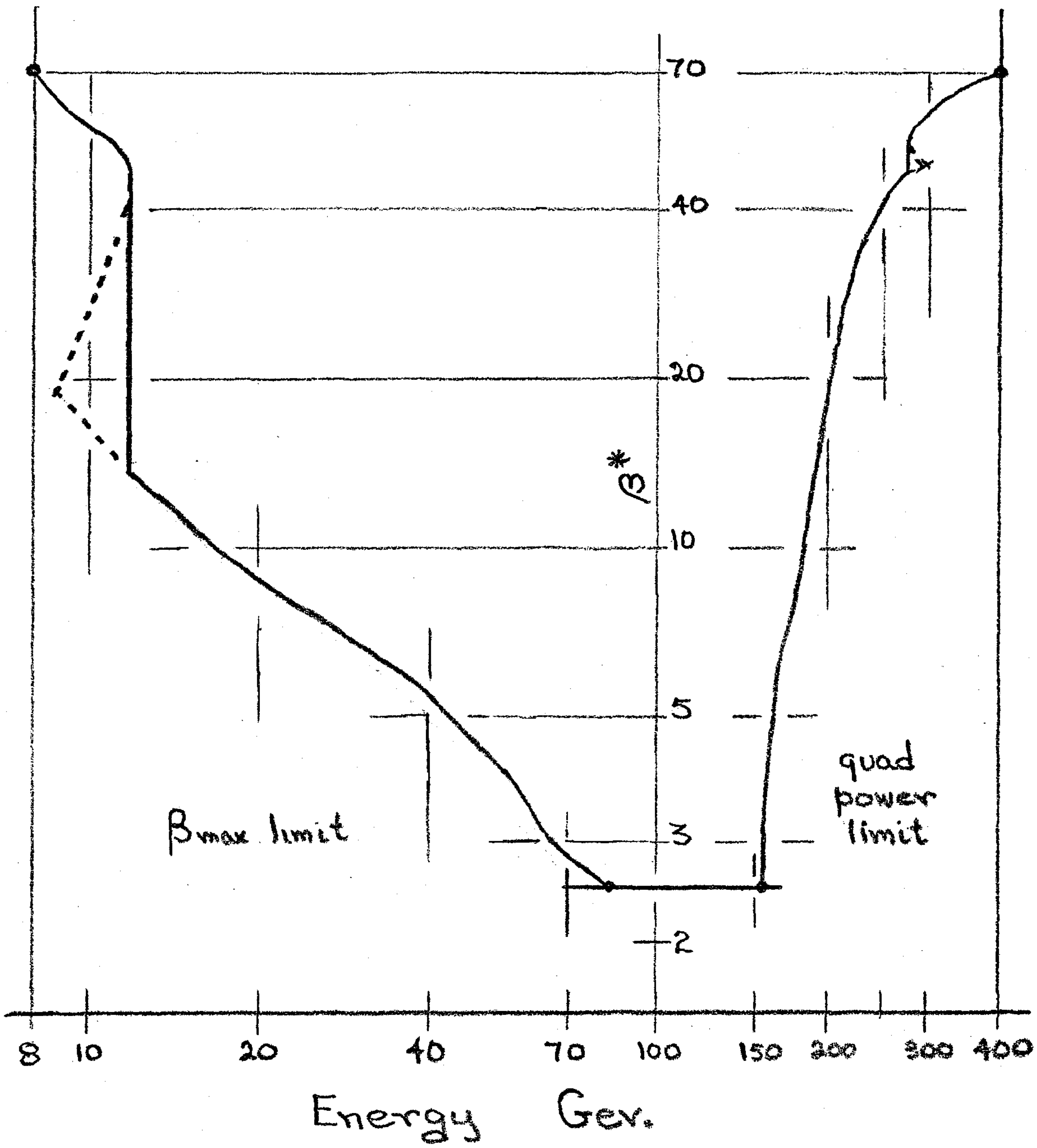


Figure 4. Minimum β* vs. energy.