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Simple beam splitter for the slow extracted beam

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Introduction

A recent proposal[1] has been made for a beam splitter to divide the extracted proton beam of the AGS between target stations B and C in the East Experimental Building Addition. The proposed splitting system consists of three elements: an electrostatic septum, a water-cooled septum and a liquid helium-cooled superconducting beam splitter magnet. The design of this splitter is very compact; the overall length of the system is 652" and the distance between the two front elements and the superconducting magnet is 406". Because of this relatively short distance, the current density needed in the septum of the third magnet is much greater than that obtainable from water-cooled copper; therefore a superconducting magnet is required. Operation of an exotic component in a high radiation area has certain obvious disadvantages. Since there is a lot of space available in the R pipe, it might be better to make a longer splitter system so that the separation between the two beams will permit the use of a water cooled copper magnet. This solution would still require the design and development of a special component since none of the bending magnets presently available at the AGS would be suitable for this job. The purpose of this paper is to explore a third solution: use of two standard 8Q48 magnets, horizontally defocussing, as the final element in the splitter system. With proper beam design these magnets can be used to amplify the split giving an angular divergence equal to that introduced by the superconducting magnet, $\pm$ 19 mrad. A further advantage of the quadrupole technique is that no material is placed in the beam. In event of failure of the front two elements, the beam would pass cleanly through the 8" quadrupoles and could be stopped well downstream. This is a safer way to dispose of the beam than the shield block upstream of the superconducting septum proposed in Reference 1. The use of quadrupole-amplified splitting requires, however, very careful adjustment of the beam transport. It will be the purpose of this paper to investigate the proper optical design of such a beam for the specific case of the split between target stations B and C.

General Requirements for Quadrupole Splitting

The basic idea behind using a combination of a septum and a horizontally defocussing quadrupole to split a beam is illustrated in Figure 1A. The beam is assumed to be parallel in the septum magnet; the beam might also be slightly diverging. Magnet Q1, immediately downstream of the septum, focusses the horizontal rays to the center of Q1; thus magnet Q2, in the thin lens approximation has no effect on the horizontal beam if the splitter is turned off. With the splitter turned on, as shown in Figure 1, magnet Q2 amplifies the split but does not blow up the beam. Since the original split introduced by the septum is assumed to be small, magnet Q2 must be run at a high gradient, and Q1 must have a long focal length.

Figure 1A is an idealized picture with thin lenses and a point source. The real beam has thick lenses and an extended source; the characteristics of the beam in the x,x′ plane can be described by an ellipse

$$(1) \qquad \gamma x^2 + 2\,\alpha\, x\, x' + \beta\, x'^2 = \epsilon$$

The requirement for clean separation is illustrated in Figures 1B and 1C, namely that the separation of the two halves of the ellipse be large compared with the vertical thickness Δx. The amount of separation, S_x', is determined by the available strength of the splitting magnets; for a given S_x' the beam transport must be chosen so that at the entrance to the splitter

$$(2) \qquad \Delta x' = 2\sqrt{\epsilon/\beta} \ll S_x'$$

Since ϵ cannot be altered by beam transport, the requirement of equation (2) is satisfied by making the β large at the entrance to the splitter. The losses on a septum of width δ depend on the ratio δ/x_{max}. The requirement for small losses is that this ratio be $\ll 1$, that is

$$(3) \qquad \delta \ll x_{max} = 2\sqrt{\epsilon\beta}$$

Thus, the requirements of both equations (2) and (3) are satisfied by large β; however in design of the optics the size of the beam, x_{max}, must not be allowed to exceed the size of the available pipe.

Because the splitting quadrupole, Q2 in Figure 1A, is run at much stronger gradient then the rest of the beam, careful consideration has to be given to the shape of the phase ellipse as it enters the splitter quadrupole, Q2, so that the beam will not be blown up by this diverging magnet. The matrix of a diverging quadrupole may be written in the form

$$(4) \qquad \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} \cosh\varphi & \rho\sinh\varphi \\ 1/\rho\sinh\varphi & \cosh\varphi \end{pmatrix}$$

The divergence of the beam emerging from this quadrupole is $\sqrt{\gamma_2\epsilon}$ where γ_2 is obtained from the parameters of the ellipse entering the quadrupole γ_1, β_1 and α_1 by the relation[2]

$$(5) \qquad \gamma_2 = c^2\,\beta_1 - 2cd\,x_1 + d^2\,\gamma_1$$

Substituting 4 into 5 and using the relation $\beta\gamma - \alpha^2 = 1$

$$(6) \qquad \gamma_2 = 1/\gamma_1 \left\{ \frac{\sinh\varphi}{\rho} + \left[\cosh\varphi - \frac{\alpha_1}{\gamma_1}\,\frac{\sinh\varphi}{\rho}\right]^2 \right\}$$

The quantities φ and ρ are determined by the field strength required to split the beam and the effective length of the splitter quadrupole Q2, the quantity γ_1 is determined by the requirement that magnet Q1 have a long enough focal length so that the images are well separated entering Q2. This leaves then α_1 as the adjustable parameter; the proper choice of field strength in Q1 will result in a α_1 such that the term in square brackets is equal to zero. The adjustment in practice is quite sensitive, but with a proper α_1, the beam can go through a very strong diverging magnet without being blown up.

Optical Design

A layout of the proposed splitter system is shown in Figure 2. The beam transport elements are the same, 8Q16 magnets as those presently in use in the R channel, 8Q16s, with the exception of magnets QQ1 and QQ2 which are the splitter quadrupoles. Some views of horizontal phase ellipses are shown in Figures 3A through 3F, for various points in the system. This ellipse is the $1/e^2$ contour (with no target at G10) as measured in 1969[3]. The beam enters the splitter system horizontally diverging as shown in Figure 3A. After passing through the two splitter magnets, Figure 3B, the beam is brought to a horizontal focus by magnet RQ5. Figure 3D shows the two phase ellipses separated by about 2" at the entrance to the splitter quadrupole. The beam is almost, but not quite focussed at this point; the requirements for focus were discussed above. Figure 3E shows the two halves after giving through the first splitter quadrupole; Figure 3F shows the beam after the second quadrupole. Figure 4 shows the same rays but with the splitter turned off. It can be seen that both the horizontal and vertical divergence are reasonable, in fact the beam can drift the rest of the way to the 3Q36 magnets that are used to make the target focus, without any other beam transport elements.

Conclusions

This paper has attempted to show that a split between target station B and C would be possible using 8Q48 magnets in place of a superconducting septum magnet. 8Q48 magnets use power; they are not in plentiful supply; it may be argued that it is going to be necessary to go to superconducting magnets at the AGS sooner or later, and the split between target stations B and C is a reasonable place to start. The author feels, however, that the use of superconducting beam transport elements should be reserved for locations where their unique high current density is essential. One such location, of immediate interest, is the forthcoming split between the R and S lines; here the short distance available precludes the use of a quadrupole splitter. This split is going to be vital to our experimental program at the AGS; therefore it would be desireable to direct our superconducting magnet development program towards filling the needs of this split (a superconducting magnet of approximately twice the bending power of the magnet proposed in Reference 1 is required). But for the split between target stations B and C, it appears that a quadrupole splitter would be the easiest and most reliable solution.

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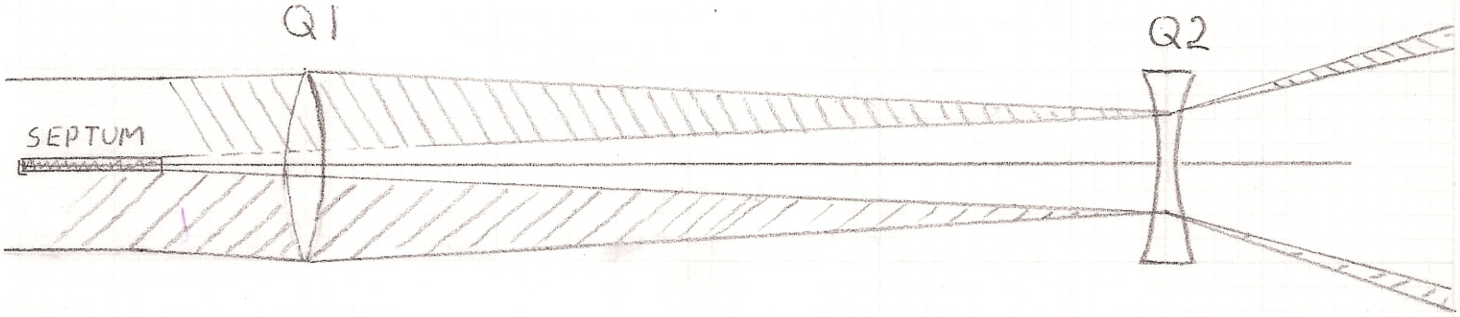
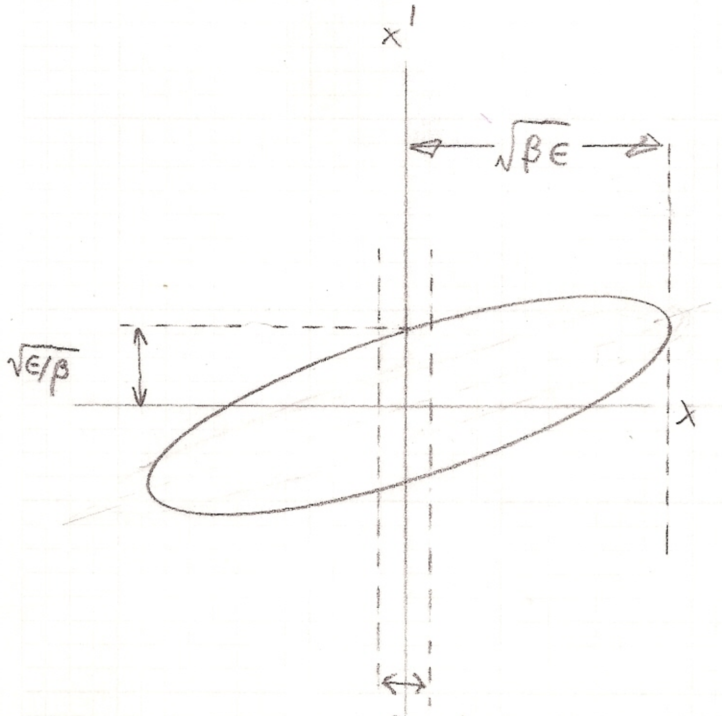
2. K.G. Steffen, H. Haultschig and W. Keon, Proceedings of the Berkeley Conference on Instrumentation of High Energy Physics, pp 302-304. 1960.

3. L.N. Blumberg, et al, Accelerator Department Internal Report AGS Div. 69-12, October 27, 1969.

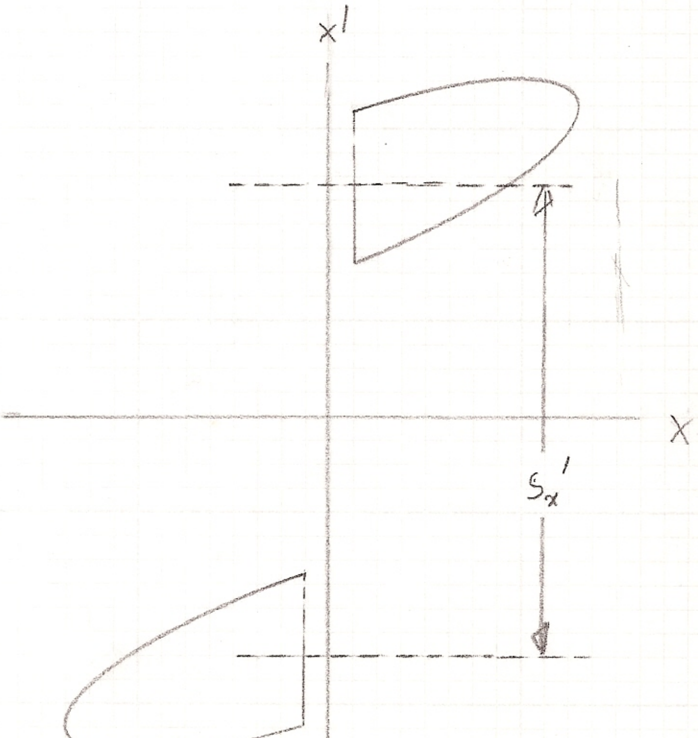
FIGURE 1A AMPLIFICATION OF SPLIT



1B BEFORE SEPTUM



1C AFTER SEPTUM



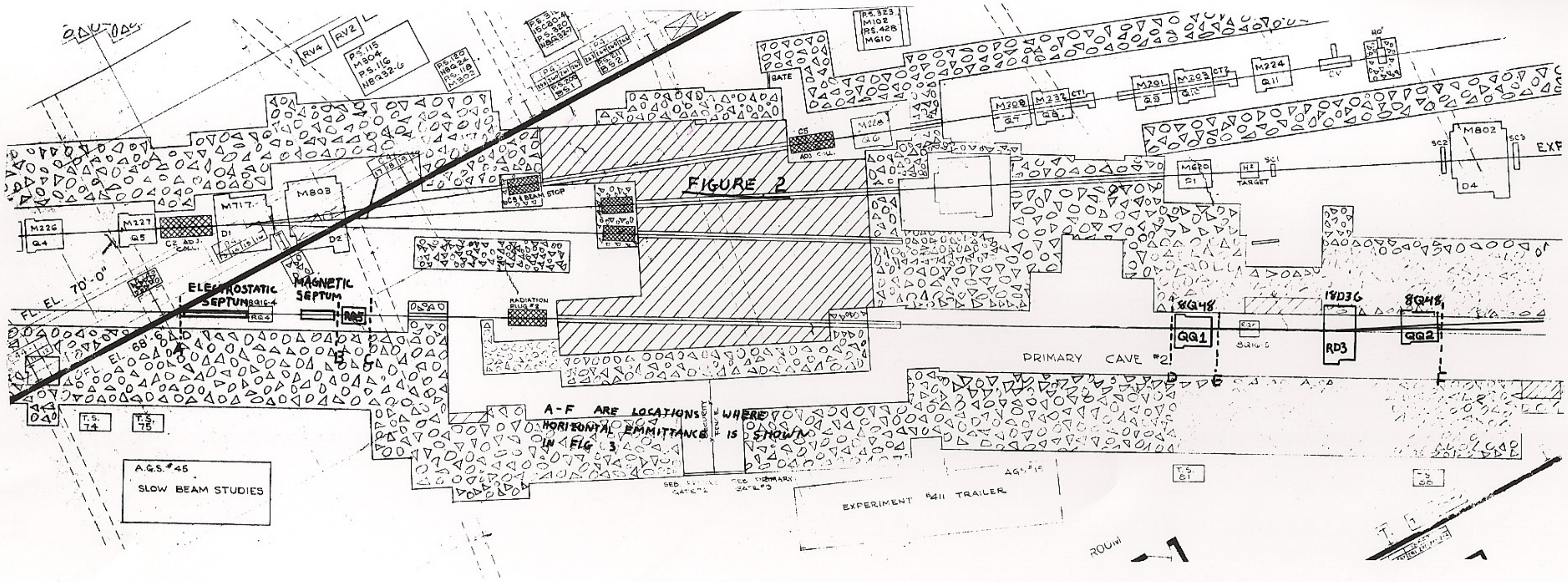

ELECTROSTATIC SEPTUM
MAGNETIC SEPTUM
A-F ARE LOCATIONS WHERE HORIZONTAL EMMITTANCE IS SHOWN IN FIG 3
PRIMARY CAVE #2
8Q48
18D36
8Q48
QQ1
RD3
QQ2
M803
M717
M227
Q5
M226
Q4
M802
D4
D1
D2
TARGET
BEAM STOP
RADIATION PLUG
FL. EL. 70'-0"
FL. EL. 68'-6"
EXPERIMENT #411 TRAILER
A.G.S. #45
SLOW BEAM STUDIES

FIGURE 2

PHASE ELLIPSES IN REGION QQ2 MOMENTUM =29,000

SAMPLE RAYS

FIGURE 4

SYMB	X	DX	Y	DY
A	-,169	-,00100	,184	,00067
B	-,138	-,00091	,160	,00063
C	-,098	-,00076	,125	,00055
D	-,051	-,00055	,081	,00044
E	-,000	-,00031	,032	,00029
F	,050	-,00005	-,020	,00012
G	,097	,00022	-,070	-,00005
H	,138	,00047	-,115	-,00022
I	,169	,00069	-,153	-,00038
J	,188	,00086	-,180	-,00051
K	,195	,00097	-,195	-,00060
L	,188	,00102	-,196	-,00066

XMAX	DXMAX	ALPHX	BETAX	GAMMX
1,000	,00200	-3.12	625	,017185

YMAX	DYMAX	ALPHY	BETAY	GAMMY
1,000	,00200	-3,39	1044	,011963