ACCELERATOR DEPARTMENT
INTERNAL REPORT

SOME ASPECTS OF TARGETTING SYSTEMS FOR A SLOW EXTRACTED BEAM AT THE
AGS

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I. Introduction

We consider below some possible beam-handling arrangements at targetting stations for the slow extracted beam which is to be developed at the AGS. We discuss in particular some problems, relevant to production of secondary particle beams, which are peculiar to external proton beams, and have thus not been encountered during the use of the F-10 and G-10 internal target areas. The following aspects of the problem would seem to be especially significant:

- A. The phase-space volume occupied by the external proton beam. If (as may frequently be the case) the phase-space at external targets is much larger than for internal targets, then there will be limitations on what types of beam can be obtained at various targetting stations.
- B. The production, frequently at 0° , of intense, high-energy secondary particle beams (especially positive beams) is made difficult by the need to separate the unscattered external beam protons from the desired secondary particles. Some possible arrangements of components are discussed below, for which the residual beam protons either i) are trapped in a beam dump, or ii) are re-focussed at a subsequent targetting station further downstream.
- C. The production of several, simultaneously-usable, secondary particle beams, from one target station (as is done at present at the G-10

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internal target) is quite complicated. Some of the problems involved, and possible solutions, will be discussed in a subsequent report.

- D. Problems associated with high beam intensity, $\sim 10^{13}$ protons per burst at the end of Phase I of the AGS Conversion Program (e.g., radiation damage problems), are obviously very important, but will not be covered here.

II. Properties of the External Proton Beam (EPB) and their Effect on the Use of External Targetting Stations.

Calculations by Barton¹ indicated that the phase-space volume occupied by the EPB would be ~ 0.05 inch-mr (HWxHW) in the horizontal plane, by ~ 0.15 inch-mr (HWxHW) in the vertical plane. Assume that the above estimates turn out to be correct experimentally, let us calculate some beam-sizes at various points. Suppose, for example, that we wish to use a secondary beam production target of very small height (say, 0.050"), with a high interaction efficiency for the EPB. (Such a target might be used for production of a separated secondary beam). The vertical convergence of the beam onto the production target will be $\sim \pm 6$ mr. It follows that the largest reasonable length of the target — in the direction of the EPB — is $\sim \frac{0.050}{12 \times 10^{-3}} \approx 4$ inches, which is about 1/3 of a proton interaction length in beryllium; this gives a reasonably good targetting efficiency. In such a length of Be, the increase in beam divergence due to multiple scattering is negligible compared with the ± 6 mr already present. In the vertical plane, then, the situation seems to be quite promising. However, there is an additional problem, in the horizontal plane, if the production angle of the secondary beam is not 0° , due to the increase in apparent

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target width caused by the finite length of the target. This effect increases with the angle of production, and may in some cases make it desirable to use a short, high-density target, e.g. tungsten. Such a high $-Z$ target would increase considerably the amount of multiple Coulomb scattering of the EPB, and thus its phase-space volume. The consequent "spray" from such a target, even if only a small percentage of the beam is lost in this way, will of course increase the radiation levels downstream of the target, with consequent increases in the shielding needed in this region. It is clear that experimental measurements of the radiation levels present will be required, as targets of various materials and thicknesses are used at a targetting station.

III. Production of Secondary Beams at 0°

To discuss this problem meaningfully, it is convenient to evaluate and criticize a number of specific possible target station layout arrangements. In each case, only one secondary beam produced at the target is considered. (As we have previously noted, the production of many beams at one target station will be discussed in a later report).

A) High-energy 0° - beam; lowest order solution.

A simple scheme for separating a high energy 0° - produced secondary beam from the residual EPB is shown in Fig. I. This is essentially a system in which the EPB is dumped and cannot therefore be transported to a subsequent targetting station. In Fig. I, the EPB is brought to a focus at the secondary beam production target T. A transport system consisting of a quadrupole lens Q (in the simplest likely case, a doublet lens) and deflection magnet(s) M focusses the desired secondary beam, produced at 0° , at the focus F. Depending on the sign and momentum of the secondary beam, the residual EPB proceeds forward somewhere in the shaded region shown in Fig. I, and the EPB is then stopped by the beam dump. This system

depends upon the difference in deflection of the secondary beam and the EPB produced by the bending magnets M. Presumably such a simple scheme as the above could be used in the early stages of the use of the slow EPB. Furthermore, it should be noted that such a system could also be used at the downstream end of a series string of targetting stations. Perhaps the most convenient places to locate the high energy 0° beams will be at the terminal targetting station(s).

B) High-energy 0° beam; residual EPB transported to a subsequent targetting station.

Fig. II illustrates one possible arrangement, proposed by W. Frisken (now of Case Institute of Technology), to preserve the residual EPB following the production of a 0° high energy secondary beam. Such a system would be capable of separating 25-GeV/c 0° produced positive particles from the 31-GeV/c EPB protons. The quadrupole lens combination Q_1 and deflection magnets M_1 produce a focus of the secondary beam at F_1 . The C-magnet sets, C_1 and C_2 , are used to increase the separation between the residual EPB and the secondary beam. For a high-energy positive secondary beam, the separation is not very readily achieved, hence a large number of C-magnets are needed. The quadrupole lens combination Q_2 re-focusses the EPB at F_2 . The bending magnet series C_2 and M_2 are varied in strength, depending on the sign and momentum of the secondary beam, so that the EPB is directed at F_2 , at all times. The magnets M_3 are adjusted so that the EPB can proceed downstream in a fixed direction, independent of the EPB direction between M_2 and M_3 . Note that C_2 , M_2 and Q_2 must be moved laterally, as the secondary beam momentum is varied (especially when its polarity is reversed). Although a system like that shown in Fig. II could be made to operate successfully, there are a number of unpleasant drawbacks:

1. An enormous number of transport magnets is used. Since there is usually a shortage of magnets (and power) for secondary beams and experimental setups, this scheme would appear to be a poor utilization of our limited resources.
2. The magnet moves needed, particularly when changing from positive to negative particles down the secondary beam channel, would certainly be a major operation.
3. A large number of C-magnets, or special septum magnets, are needed in those regions where the high energy positive beam ($\lesssim 20$ GeV/c) and the residual EPB are in close proximity.

C) High-energy 0^0 beam described in B) above - a minor modification.

Using the layout in Fig. II as an example, consider what we could do to simplify the system if we were interested only in producing negative 0^0 - beams. (While it is true that in a large number of experiments it is desirable and sometimes essential to reverse the beam polarity either to make an equipment check or to perform the experiment with both positive and negative beams, nevertheless there are many experiments which require only negative particles). Assuming that a high-energy negative particle beam is a useful possibility, then in such a case none of the C-magnets shown in Fig. II would be needed. Furthermore, the magnets (both bending and focussing) used to direct and focus the residual EPB at the next target station can be placed further upstream, thereby

1. reducing the overall EPB station-to-station length, with consequent savings in shielding and building space, and
2. rendering the movements of the EPB "regathering" magnets either small or unnecessary, as the secondary beam momentum is varied.

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Such a setup, with EPB-preservation possible only for a negative secondary beam, can of course be used for positives by dumping the beam at such times, as in Fig. I — at the temporary expense of having no beam for experiments at downstream target stations.

D) Medium-energy 0° positive beams (≤ 15 GeV/c)

From the foregoing it is clear that a high energy positive beam is difficult to obtain. Let us discuss next a medium energy beam, which does not have the capability of delivering positives above 15 GeV/c (we are ignoring high-energy negatives as a "solved" problem). One possible method for obtaining a medium-energy beam is shown in Fig. III. The following two features of this arrangement should be particularly noted:

1. The residual EPB emerges from the target station at the same position and in the same direction, for various momenta in the secondary beam. These conditions are obtained by setting appropriate fields in the bending magnets M_{1-3} and C_1 .
2. The secondary beam production angle is 0° , for all secondary beam momenta, in order to obtain the maximum beam intensity.

The scheme shown in Fig. III is similar to one of several such beam-handling systems which are discussed in the LRL Design Study document for the 200 GeV accelerator.²

E) Non-zero-degree high energy beams

In this case, the problem of restoration of the EPB can be avoided, at the expense of some secondary particle flux. Whether or not the flux reduction is acceptable clearly depends upon the requirements of a particular experiment and will not be discussed here.

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- I. Scheme for separating a high energy 0^0 -produced secondary beam from the EPB. T is the secondary beam production target, Q is a quadrupole lens combination; M is a deflection magnet; C is a C-type deflection magnet; the first focus of the secondary beam is at F. Depending on the sign and momentum of the secondary beam, the residual EPB proceeds forward somewhere in the shaded region and is then stopped by the beam dump.
- II. Scheme for separating high energy 0^0 -produced secondary beam from the EPB. T is the secondary beam production target; Q_1 and Q_2 are quadrupole lens combinations; M_{1-3} are deflection magnets; C_1 and C_2 are C-type deflection magnets; the first focus of the secondary beam is at f_1 ; the EPB is re-focussed at f_2 . The continuous (dashed) line between M_1 and M_3 indicates the EPB path when the secondary beam is positive (negative).
- III. Scheme for separating a medium energy (≤ 15 GeV/c) 0^0 -produced secondary beam from the EPB. T is the secondary beam production target; Q_1 and Q_2 are quadrupole lens combinations; M_{1-3} are deflection magnets; C_1 is a C-type deflection magnet; the first focus of the secondary beam is at F.

FIG. I

Scheme for separating a high energy O^0 -produced secondary beam from the EPB. T is the secondary beam production target, Q is a quadrupole lens combination; M is a deflection magnet; C is a C-type deflection magnet; the first focus of the secondary beam is at F. Depending on the sign and momentum of the secondary beam, the residual EPB proceeds forward somewhere in the shaded region and is then stopped by the beam dump.

FIG. II

Scheme for separating high energy O^0 -produced secondary beam from the EPB. T is the secondary beam production target; Q and Q are quadrupole lens combinations; M^1 and M^2 are deflection magnets; C^1 and C^2 are C-type deflection magnets; f^1 and f^2 the first focus of the secondary beam is at f^1 ; the EPB is re-focussed at f^2 . The continuous (dashed) line between M^1 and M^2 indicates the EPB path when the secondary beam is positive (negative).

FIG. III

Scheme for separating a medium energy (≤ 15 GeV/c) 0° -produced secondary beam from the EPB. T is the secondary beam production target; Q and Q₂ are quadrupole lens combinations; M₁, M₂ and M₃ are deflection magnets; C₁ is a C-type deflection magnet; the first focus of the secondary beam is at F.