EXPERIMENTAL AREA BEAMS FROM THE ANL 12.5 BEV PROTON SYNCHROTRON

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Abstract

The "picture frame" magnet design, the double vacuum system and the use of tuning magnets at injection have elicited some unique features in the production of beams for the experimental areas of the ZGS.

For the external proton beam, the basic method of extraction is similar to other proton synchrotrons in that an energy-loss target is used to displace the circulating beam. However, the design of the ZGS is such that the necessity for plunging extraction magnets into the aperture has been eliminated. Further, the design of these nonplunging magnets is such that they are operable at a fixed field and thus eliminate the need for complicated pulsing and timing systems. Measurements using various techniques, including scintillators and TV storage systems, poloroid film, secondary emission detectors, and radioactive foil analyses have been made.

For beams from internal targets, it is desirable to produce beams with various production angles, as well as being able to achieve zero degree production. It was found possible to establish three secondary beam channels looking at a common target point near the end of an octant. This point is in a nearly field-free region so that the channel angle becomes the production angle for both positive and negative particles. It is of interest that the construction of the ZGS is such that there is practically no fringe field beyond the octant edges. Furthermore, it was found possible to run targets into the octant along the inner vacuum chamber sidewalls without interfering with the injected beam. Orbits to the field-free point have been calculated such that a range of momenta and production angles is transmitted through the three secondary beam channels.

Work performed under the auspices of the U.S. Atomic Energy Commission.

Extracted Proton Beam

Extraction System

We will first consider the external proton beam from the ZGS. The machine was designed with the anticipation of such a beam, and the special features which make extraction possible without the need for plunging magnets into the aperture is shown in Fig. 1. This shows schematically the displacement of the injected orbits which is produced by the use of tuning magnets in each of the four short straight sections. These magnets also correct for octant field errors at injection and for tuning the betatron oscillation frequencies, thus eliminating the need for pole-face windings.

As one can see, the high energy orbits are radially tilted compared to the more strongly bent low energy orbits. This allows the placement of a permanently positioned extraction magnet to bend the protons out of the machine without using up any injection aperture. The space available is, however, not large and special care has to be exercised in the extraction magnet design. The magnet must provide sufficient field strength to bend the beam out of the machine, but must not interfere with the circulating beam. An idea of the problem faced can be seen in Fig. 2 which shows the orbit positions and the space available for this magnet. There is available radially about 4 in. between these orbits. Since the beam occupies a finite radial space, there is in fact not very much space that can be occupied by the magnet radially out from the machine center. In addition, it must be contained in a 40 in. azimuthal length. To bend the 12.5 BeV beam sufficiently in this distance requires a field of the order of 22 kilogauss. We must, therefore, also terminate this field radially in order for fringing fields not to interfere with the circulating beam. The solution to this problem was a septum magnet as shown in Fig. 3.

This magnet is 30 in. long and can generate a field of 22 kG and a 2° bending angle for 12.5 BeV protons. There is a 1-3/16 in. iron septum and a 1 x 2 in. front coil and a 4 x 2 in. back coil. The leakage field at operating current is about 30 gauss. The addition of correction windings on the radially out face of the magnet reduced this to 3 gauss. This is sufficiently low so that there is no interference with the circulating beam even at injection. The magnets can thus be operated continuously and need not be pulsed. They must, of course, be readjusted for extraction at other energies. The small cross-section coil operates at a current density of 60,000 A/sq. in. They are water-cooled and use a fast acting resistance bridge which balances the two halves of the coils against each other to detect thermal overloads. The circuits are sensitive enough to detect a partial water stoppage in any one of the 64 turns. Such a fast circuit is necessary since the temperature rise on water stoppage is 43°C per second.

The extraction process itself is conventional. We use a beryllium target with a thin lip placed approximately 1/2 of a betatron wavelength upstream from the extraction magnet. The circulating beam can be moved slowly onto the lip by field adjustment on flat-top or can be brought on fast during the rising field by turning RF off or programming the beam in with the RF. Fast spills of the order of 1/2 to 2 msec are easily achievable. Long spills depend on the duration of flat-top which is at present longer than 100 msec. The target lip which is 0.054 in. thick and has a radial length of 0.32 in. will reduce the betatron oscillation amplitudes by about a factor of 10. The beam then enters the 2.5 in. thick portion of the target and loses sufficient energy so that a half wavelength later, it has jumped radially across the septum of the extraction magnet and can be bent out.

Additionally, there is a fast bumper magnet which bumps the beam onto a target in times as fast as 10 μsec. This target is so placed that the beam also passes through the same extraction chain. From the extraction magnet, the beam passes through the next octant and arrives at a long straight section as shown in Fig. 4. It must then be bent another 8°, and this is done by three additional magnets similar to the extraction magnet. The beam passes then through a hole in the yoke of the downstream octant and is transported to an experimental setup. There are two quadrupoles for focussing the beam and a switching magnet which can be used to either send the beam into a target to produce neutrinos or to bend the beam away through a tunnel into the external proton area. This figure shows the setup for the neutrino experiment and shows the beam line through the pion focussing "Horn of Plenty." Figure 5 shows the first arrangement of beams in the external area. There are two experiments set up. The beam is first brought to a focus on a thin target (H_2) for a charge-exchange experiment and is then used up in a thick target station for a stopping K experiment. The protons not interacting in these targets then go into a steel-lined concrete mound just outside the Proton Building.

Beam Measurements

We have made several measurements on beam intensity and size. The calculated phase space area of the beam after the beryllium target for $\frac{\Delta P}{P} = 0$ is

$$Q_x = \pi \times x' = 0.434 \text{ mr in.}$$

$$Q_y = \pi \times y' = 0.171 \text{ mr in.}$$

The calculated momentum spread $\frac{\Delta P}{P} = {+1.6\times10^{-4} \atop -2.5\times10^{-4}}$ This asymetric distribution is used to take full advantage of the Landau distribution in the energy loss process. When we include the momentum distribution, the radial phase space area out of the machine becomes about $\frac{\pi}{2}$ mr in. Foil measurements agree within about a factor of 2 or 3 with the calculated areas. For the neutrino experiment, the predicted spot size of 0.37 in. horizontally and 0.65 in. vertically agrees very well with the observed 1/2 in. diameter spot size. In the external proton beam this could be reduced by about a factor of five.

For observing the beam in the ZGS, 1/4 in. thick scintillators were put on the extracted beam orbits. These are viewed by TV cameras and are stored on our TV monitor screens. This gives a very good idea of the size and position of the beam. There are three such stations: one after the first extraction magnet, one after the second magnet, and the last just outside the ring. The use of these three stations makes it very easy to line up the extracted beam by adjusting the extraction magnets. There are several beam counting devices external to the ring. These consist of beam induction monitors, current transformers, and a secondary emission detector. All of these are calibrated by exposing a foil in the external beam and counting the induced activity. Additional foils can be placed at the positions of the scintillator screens and on the targets to determine extraction efficiencies. These measurements have shown that the transport system from the target out of the ring is 45% efficient. The major loss of 47% is from the beryllium target to a point just downstream of the first extraction magnet.

Secondary Beams

For beams from internal targets it was deemed desirable to set up semi-permanent beam channels, through which it would be possible to transmit secondary particles produced at various angles and to provide as complete a momentum spectrum as possible. Considering the size of the straight section and the size of the beam transport elements, it was found possible to establish three secondary beam channels looking at a common target near the end of an octant as shown in Fig.6. This point is in an almost field-free region and for a target at this point, these channel angles of 7-3/4°, 17-3/4°, and 31° are the production angles for both negative and positive secondaries. The construction of the ZGS magnets with their window frame aperture and with an iron plate field-guard covering the coils at the ends, cut the fringe field to an almost negligible value. In the approximately twenty foot path from this point out, the field averages about 20 gauss. There is, therefore, practically no fringe focussing or momentum dispersion from this point out. To provide a complete spectrum, we are able to plunge targets into the octants and make use of the 21.5 kG field of the ZGS as a momentum analyzer. The window frame design with magnet steel covers top, bottom and sides of aperture and forms a rough vacuum chamber. There is then a thin-walled inner high vacuum chamber. A target system was designed to enter the inner chamber from the straight section box and to ride along rails attached to the walls of the inner vacuum chamber. The targets are folded back along the outwardly flared wall during acceleration and are swung into the aperture at appropriate times. There is then no decrease in useful aperture for injection. With this system we can reach 60 in. into the octant and cover the useful radial aperture.

Figure 7 shows the layout of beam transport in three channels. The 7-3/4° channel provides a momentum spectrum from 10.5 BeV/c down. It also provides for negative secondary particles at 0° production angles up to about 6 BeV/c. The 17-3/4° channel provides secondaries from about 7 BeV/c down and the 31° channel from 4 BeV/c down. Orbits from the internal target position have been calculated so that this complete spectrum of secondaries emerges from the machine with the proper angles at this field-free point and goes down the appropriate beam channel.

The actual targetry system which has been developed will be discussed in a subsequent paper.

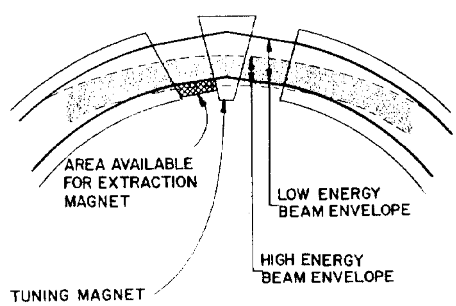

Fig. 1. Injection and high energy orbits.

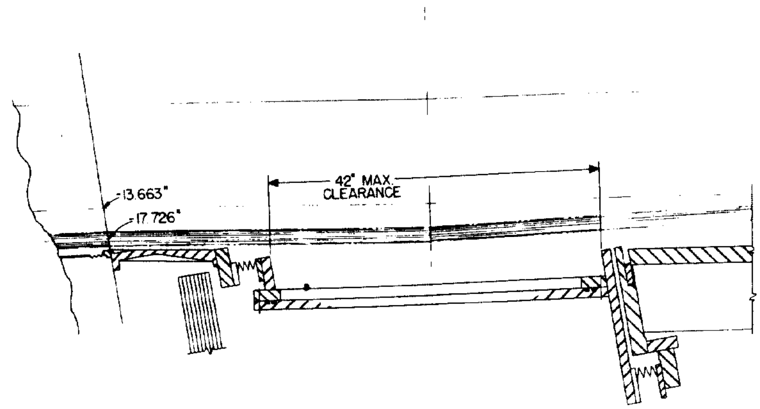

Fig. 2. Clearances for extraction magnet.

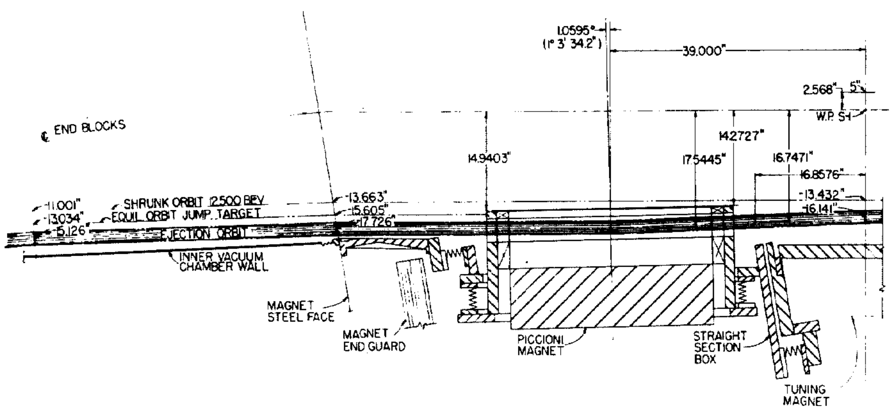

Fig. 4. External beam for Neutrino experiment,

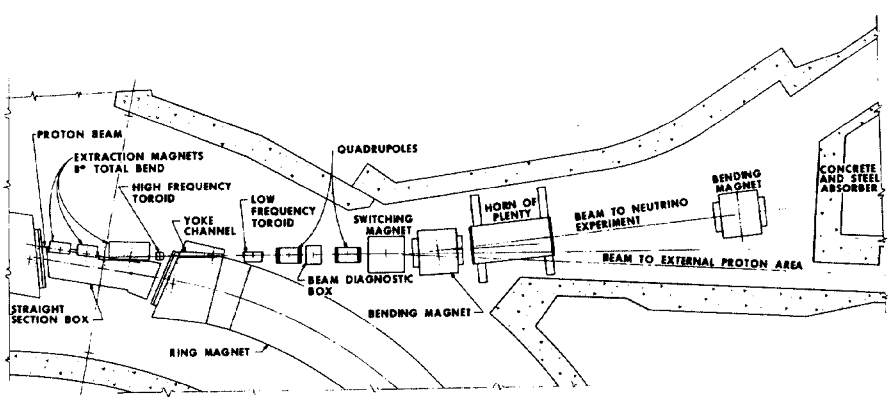

Fig. 3. Extraction magnet and extracted beam orbits.

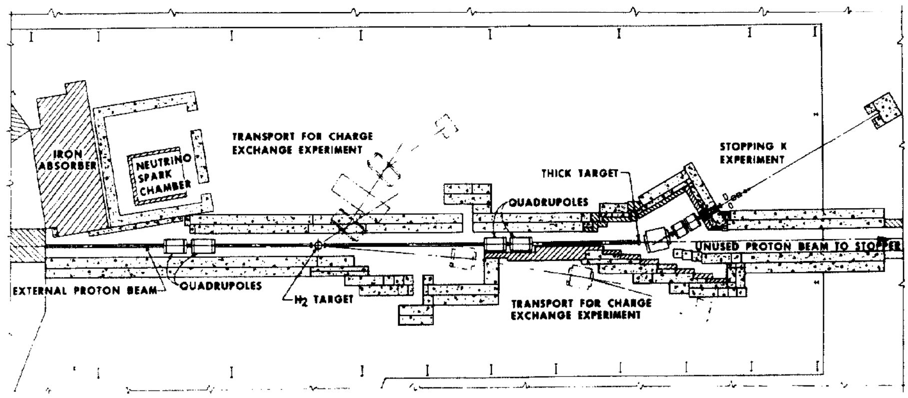

Fig. 5. Beam setups in proton experimental area.

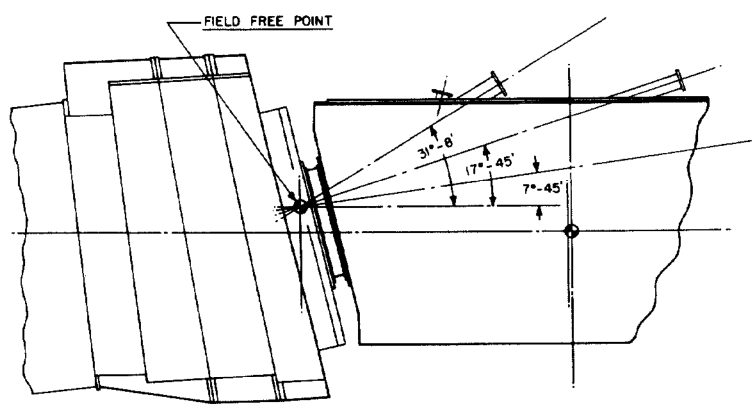

Fig. 6. Origin of secondary beam channels.

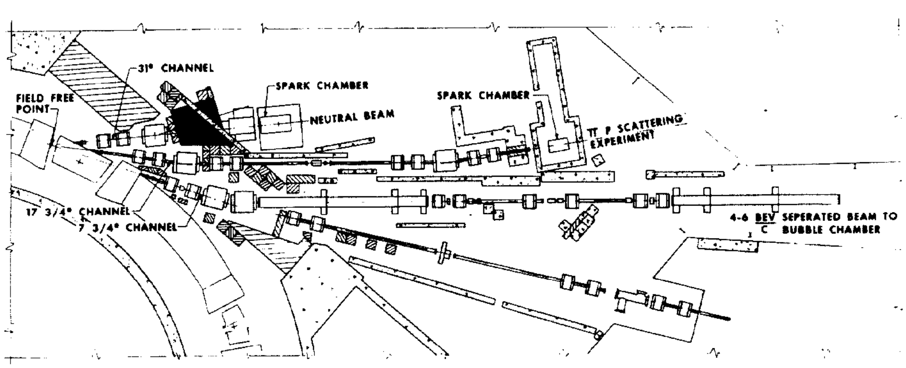

Fig. 7. Beam setup in Meson experimental area.