IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

The External Proton Beam Lines and the Splitter Systems of the CERN SPS

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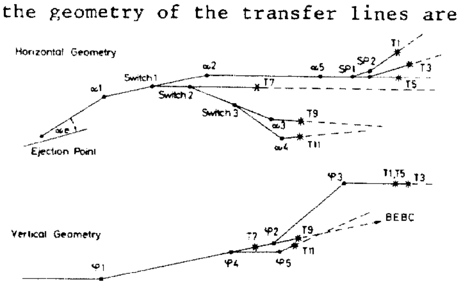
1. Introduction

The exploitation of the CERN Super Proton Synchrotron (SPS) is based on two experimental areas, the West Area and the North Area. The West Area consists of the West Experimental Hall, fed by a slow ejected proton beam of 200 GeV/c maximum momentum and a Neutrino Facility which is fed by protons of 400 GeV/c. Several important detectors are installed in the West Area, the Omega spectrometer, the Big European Bubble Chamber (BEBC) and the heavy liquid bubble chamber Gargamelle. The North Area has been built for physics at 400 GeV/c. At present it consists of two experimental halls, a large multipurpose hall (EHN1) and a smaller hall (EHN1) dedicated to muon physics.

The protons are extracted from the SPS in two of the six long straight sections (LSS) and are transported from the underground machine through a system of tunnels to the external targets. The beam lines have a combined length of approximately 2.7 km. Both the beam lines to the West and North Area contain beam splitting stations which divide the slow extracted proton beam into three branches. The beam line to the West Area also contains a switchyard which can deflect the fast ejected proton beam either onto a target for an r.f. separated beam or into an underground cave where the production targets for the neutrino beams are placed.

2. The West Area Beam Transfer Lines

The altitude difference between the SPS main ring and the West Area is about 46 m. The main features of the geometry of the transfer lines are shown in fig. 1.



Angles	in mrad
αe	9,200
α1	-34,607
α2	-23,467
α3	5,509
α4	27,828
α5	3,503
Switch 1	-23,467
Switch 2	-25,017
Switch 3	-10,710
SP1	7,895
SP2	10,044
φ1	42,486
φ2	42,326
φ3	-84,950
φ4	- 6,414
φ5	17,408

Fig. 1 Geometry of the proton beam lines to the West Area

The proton beam is extracted in LSS6 and immediately after the transfer tunnel has branched off from the main ring tunnel it is bent vertically upwards by an angle ϕ_1 = 42 mrad. Still deep underground the beam arrives at the switchyard which consists of a series of three switches where the beam can be switched onto the target T7 for the r.f. separated beam or towards the Neutrino Cave to feed either target T9 for a wide band neutrino beam or target T11 for a narrow band neutrino beam. Between the targets T9 and T11 and the detectors for the neutrino experiments (BEBC, Gargamelle and a massive counter array) there is a 300m long evacuated decay tunnel followed by a muon shield consisting of 180 m of steel and 180 m of earth.

If neither beam switch is activated the beam will pass straight through the switchyard and after further vertical deflection ϕ_2 = 42 mrad rises steeply to the entrance of the West Hall where it is made horizontal. Immediately downstream of this last vertical bend is situated the West Area beam split station which simultaneously can send protons to the three targets T1, T3 and T5.

The first part of the beam line up to the switchyard, the three switches and the branches to T9 and T11 are built for maximum momenta of 400 GeV/c. The branch to T7 and the beam lines to the splitter and the West Hall targets T1, T3 and T5 are built for 200 GeV/c. During a single machine cycle there can be at present one slow extracted beam at 200 GeV/c, feeding T1, T3, T5, one fast extracted beam at 208 GeV/c for T7, and a fast extracted beam at 400 GeV/c for T9 or T11, (Fig. 2).

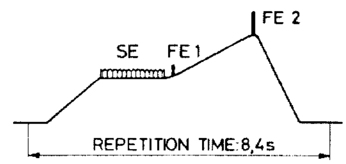
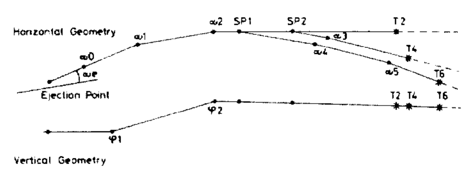


Fig. 2 Typical SPS cycle; SE = slow ejected beam at 200 GeV/c, FE1 and FE2 fast extracted beams at 208 and 400 GeV/c resp.

By pulsing the first part of the beam lines and by suitable timing of the switches all targets can receive protons during the same cycle.

3. The North Area Beam Transfer Lines

The beam lines to the North Area have been designed for 400 GeV/c. The geometry is shown in Figure 3.



Angles	in mrad
α0	- 0,700
α1	- 16,552
α2	- 16,552
SP1	- 8,200
SP2	- 8,200
α3	- 31,800
α4	- 35,176
α5	- 4,824
φ1	109,391
φ2	-109,519

Fig. 3 Geometry of the proton beam lines to the North Area

The beam is extracted from the SPS in LSS2 and is brought through a tunnel which rises with an 11% slope to the level of the target hall situated 40 m above the main ring. After the beam has been made horizontal, two splitter stations which each divide the beam into two parts distribute the beam over three branches which feed the targets T2, T4 and T6.

4. Beam Optics

The beam transfer lines are made using FODO lattices with period length of about 70 m. A set of 4 separately powered quadrupoles at the beginning of the beam lines match the extracted beams to the lattices. The phase advance of the lattices is chosen to minimize the dispersion due to the bending elements. In the target regions the beams are focussed either by doublets or triplets depending on the available space and on target requirements. The spot sizes at the targets are typically between 1 and 3 mm in diameter.

Special beam optics problems arise in the splitter regions. As will be described in the following paragraph, the beam splitter is based on horizontally deflecting steel septum magnets. In order to minimize the losses at the septa of these magnets the beam must strongly be blown up vertically and it must have a narrow waist in the horizontal plane. Moreover, to achieve full flexibility of the splitter systems it is necessary to vary the vertical beam size within wide limits. For example at the West Area splitter the vertical amplitude function beta must be adjustable between 50 m for single target operation up to 60 km for a symmetrical 3-way split, while maintaining always the same horizontal beta of about 6 m. The matching of the beam to these conditions is achieved with 6 independently powered quadrupoles upstream of the splitter stations.

5. Beam splitting

The West Area Beam Split Station

The design of the 200 GeV/c West Area beam split station was governed by very tight space limitation. The space available between the first element of the splitter system and the targets is only 80 m. An additional limitation was the need to deflect the central and densest part of the beam towards target T1 which is the left of the three West Hall targets. As a result of these considerations the final layout was based on two types of horizontally deflecting steel septum magnets (figs. 4 and 5).

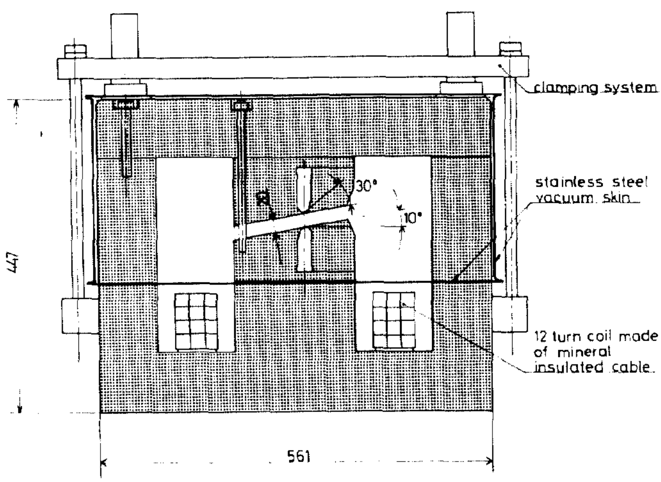


Fig. 4 Cross section of the double septum magnet.

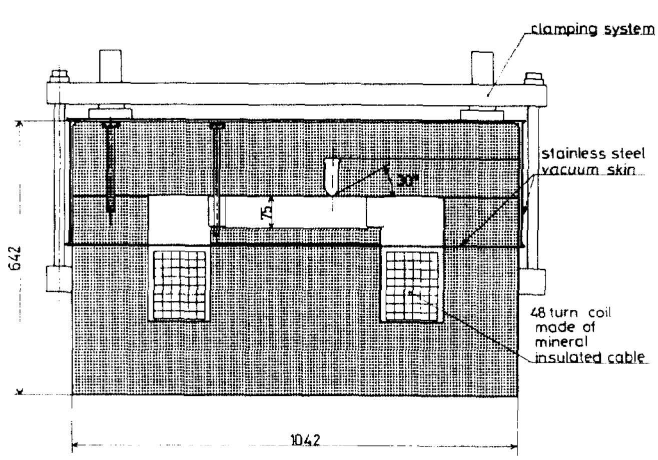


Fig. 5 Cross section of the single septum magnet.

The first is a 3.6 m long double septum magnet with a gap of 20 mm and with poles tilted by 10°, the second is a 4.7 m long single septum magnet with a gap of 75mm. The splitter station is composed of two modules of the double septum magnet followed by two modules of the single septum magnet. The principle of the splitting is shown on figure 6.

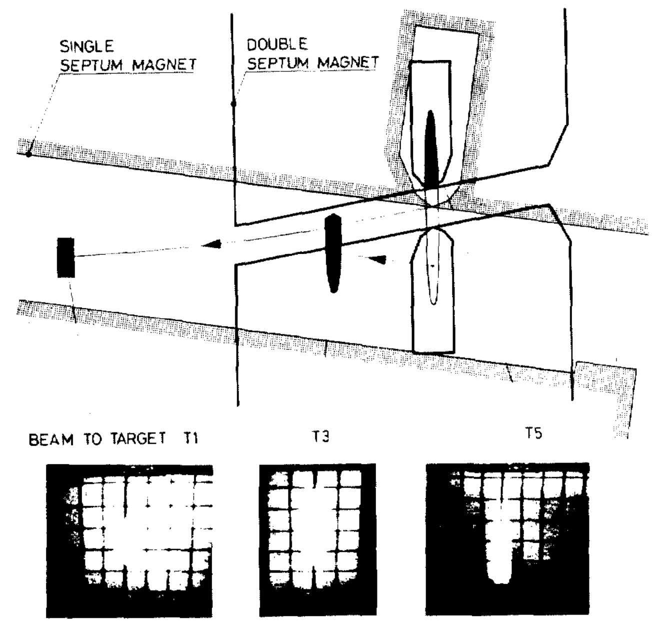


Fig.6 The beam split system for the West Area. Two modules of the double septum magnet are followed by two modules of the single septum magnet. The photographs show the 3 beams on luminescent screens about 20 m downstream of the splitter system.

The beam arrives at the splitter with a large height ($\sim$ 120 mm) and a small width ($\sim$ 5 mm, depending on the horizontal emittance). The double septum magnets deflect the central part of the beam horizontally by 8 mrad and at the same time downward by 1.5 mrad due to the tilted pole pieces. The upper and lower parts of the beam are undeflected by these magnets. These first two magnets are followed by two modules of the single septum type. Due to its downward deflection, the centre part of the beam can now pass between the poles of this magnet and together with the lower part of the beam gets a further deflection of 10 mrad. The upper part of the beam remains undeflected. The downward motion of the central part is corrected by tilting the second pair of magnets in the opposite direction to the first pair. The resulting upward deflection given to the bottom part of the beam is compensated by a dipole further downstream. By adjusting the vertical beam size and position on the double septum magnet a high degree of flexibility in the splitting ratios can be achieved.

Each pair of splitter magnets is protected by a copper collimator with the same profile as the wedge-shaped septa of the magnets. Its purpose is to protect the splitter magnets from damage in the case of operational or hardware errors. In addition, there is some evidence that the permeability of the magnet steel decreases at high radiation levels. This effect is undesirable in the region of the septum tips since it would reduce the field uniformity in the gap and increase the stray field above the septa.

Figure 7a shows the display used at the control console for adjusting the sharing of the beams to the targets. The vertical beam profile is measured upstream of the splitters by a 32 channel secondary emission grid. Figure 7b shows the vertical profiles of the three split beams downstream the splitters, again measured with secondary emission grids. The three cut parts of the roughly gaussian distribution can be clearly seen.

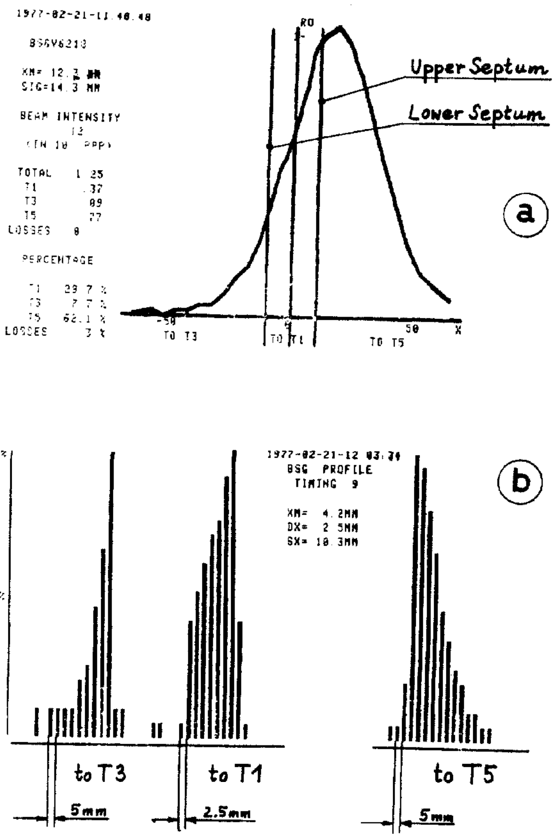


Fig. 7 Control console display showing :

(a) the vertical beam profile at the splitter system measured with a secondary emission grid and showing also the percentage of beam sent to each of the 3 targets;

(b) vertical profiles of the 3 split parts measured with secondary emission grids downstream of the splitter system

The North Area Beam Split Station

The North Area beam split station is designed to operate at 400 GeV/c. It is also based on the use of steel septum magnets. However, the space limitations are less severe so that the split can be made in a simpler way, using only the single septum magnets and making two times a 2-way split.

6. Design of the Steel Septum Magnets

The useful bending field B that can be obtained is governed by the degree of saturation tolerated in the tips of the septa. If B_s is the field in the steel near the tip then B is approximately B_s* sin θ, where θ is the septum wedge angle. For $B_s \sim 1.6$ T and for the chosen wedge angle $\theta = 30^o$ the useful bending field is ~ 0.8T.

* Manufactured by Pyrotenax of Canada Ltd., Trenton, Ontario, Canada.

The cross section of the two types of magnets is shown in figs. 4 and 5. The various parts which form the magnet core are machined from solid steel. Very tight machining tolerances were required for the pole pieces which contain the wedge shaped septa.

In order to avoid building large vacuum tanks to enclose the whole magnet, a stainless steel skin is welded around the upper half of the magnet core which contains the gap and the septa, leaving outside the vacuum the lower half core with the coils and the connections. The unavoidable beam losses require a radiation hard construction of the excitation coils, which have therefore been wound from hollow water-cooled mineral insulated cable of square cross section *. Extensive measurements of the field uniformity in the gap and the stray field in the hole above the septa have been made. The leakage field in front of the holes at the extremities of the magnets has been reduced by making the upper pole plate of the single magnet which contains the septa longer than the lower pole plate. For the double septum magnets magnetic mirror plates have been mounted at 20mm from the end face of the magnet core.

7. Beam Transport Magnets

The beam lines contain a large number of different types of bending and focusing elements. The main deflections are made with the same 6.2 m long dipoles as used for the SPS main ring. Some modifications to these magnets were necessary in order to use them for vertical deflections or for tilted bends. The switches are made with 3 m long C-type bending magnets which can be used at fields up to 1.8 Tesla. An H-type dipole has been built for smaller deflections and for beam steering. It exists in two different lengths (0.7 and 1.4m) with two different gap heights (70 and 90 mm) and for either horizontal or vertical deflection.

For the focusing along the beam lines and onto the targets a special beam transport quadrupole has been built. It is a narrow "figure of 8" quadrupole and is built in two different lengths (1.5 and 3.0 m). The bore diameter for the large series is 80 mm but for a smaller number the pole has been modified to give a bore diameter of 100 or 52 mm. A cross section of this quadrupole together with the measured gradient distribution for the 80 mm bore version is shown in fig. 8.

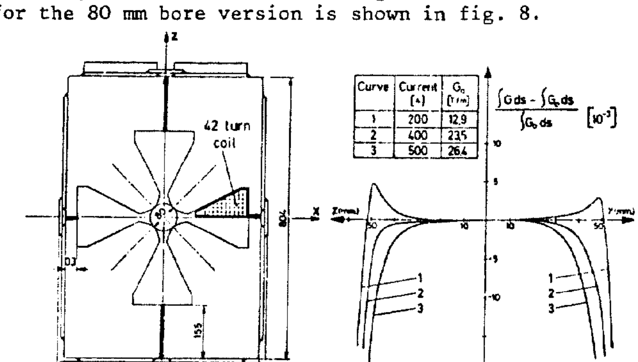


Fig.8. Cross-section and gradient distribution of the beam transfer quadrupole

8. Conclusions

The external proton beam lines to the West Area were commissioned during the last months of 1976 and are now supplying protons for physics on a routine basis with a composite machine cycle as shown in figure 2. The West beam split station performs well and reliably and shows the expected flexibility in providing a wide range of sharing ratios between the three targets.

The beam lines to the North Area are in the stage of installation and are due to be commissioned at the beginning of 1978.