

A LOW MOMENTUM SEPARATED ANTI-PROTON BEAM

A possible beam layout in the South Experimental Hall for anti-protons with momenta between 0.5 GeV/c and 1 GeV/c is given in Fig. 1. The anti-protons are produced by the circulating PS proton beam from an internal target located in the straight section No. 1. The separated anti-proton beam crosses the South Hall and is supposed to be used for a hydrogen bubble chamber experiment. The anti-protons should come to rest inside the chamber to study the annihilation processes. The chamber is at a distance of about 103 metres from the target, its position in the South Hall is indicated in the figure. The anti-protons are separated from the π^- , μ^- mesons with an electrostatic separator of the Berkeley type. This separator consists of two tanks 3 m long having crossed electric and magnetic fields. It was supposed to have inside the separator's useful region an electric field equal to 30 KV/cm; the plates distance was supposed to be equal to 10 cm.

The studied beam presents the following features :

- 1) The acceptance of particles, as determined by the target and the first quadrupole doublet, is maintained through the whole system. The purpose of this is to get the highest possible anti-proton intensity.
- 2) The chromatic dispersion at the bubble chamber position is kept small.
- 3) A momentum band up to $\Delta p/p = \pm 2\%$ is accepted.
- 4) It is carefully avoided that beam particles (π^- and p^-) touch the separator plates, to reduce the background.
- 5) A relatively small number of quadrupole lenses and bending magnets has been employed.
- 6) The beam makes use of the existing holes in the main shielding wall.

To determine particle trajectories, beam envelopes, chromatic dispersion, aberrations and separator action on unwanted particles, a "PACE" analogue computer at DESY, Hamburg, was used. The general formulae solved by the computer are :

for trajectories

$$\frac{d^2 x}{ds^2} + K(s) \cdot x = \frac{1}{\rho(s)} \cdot \frac{\Delta p}{p_0}$$

$$\frac{d^2 z}{ds^2} - \left(K - \frac{1}{\rho^2} \right) z = \frac{1}{R} \cdot \left(\frac{1}{\beta_1} - \frac{1}{\beta_0} \right)$$

and for envelopes

$$\frac{d^2 \tilde{x}}{ds^2} + K \tilde{x} - \frac{1}{\tilde{x}^3} = 0$$

$$\frac{d^2 \tilde{z}}{ds^2} - \left(K - \frac{1}{\rho^2} \right) \tilde{z} - \frac{1}{\tilde{z}^3} = 0$$

where :

s is the co-ordinate along the optical axis.

x is the co-ordinate from the optical axis in the horizontal plane.

z is the co-ordinate from the optical axis in the vertical plane.

\tilde{x}, \tilde{z} are the co-ordinates for envelopes.

$K = \frac{eg}{p}$ multiplied by the co-ordinates x or z represents the action of a lens with a field gradient g on a particle having p momentum.

$\frac{1}{\rho} = \frac{eB}{p}$ and $\frac{1}{\rho^2}$ are the factors taking into account the action of bending magnets having magnetic induction B.

$\frac{1}{R} = \frac{eE}{pc}$ is the factor which represents the action of a separator with electric field E on particles having velocity β and momentum p.

The formulae are valid in the frame of linear theory. Only bending magnets with parallel edges have been considered. Furthermore the focusing action in the vertical plane of these bending magnets is supposed to be distributed along their entire length.

The complete transport system from the target to the bubble chamber consists of the following elements :

<u>Type</u>	<u>Number</u>
1 mt quadrupole lenses	10
1 mt bending magnets	2
3 mt separators	2
momentum slit	1
mass slits	2

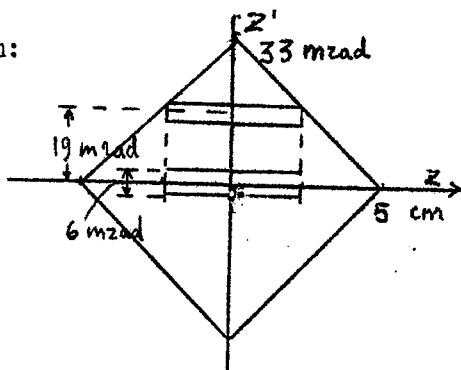
In table I, the locations of all the elements along the optical axis are given.

In table II, the field gradient is given for all the quadrupole lenses in case of 0.5 GeV/c momentum particles.

In Fig. 2, the envelopes in the horizontal and vertical planes are given for the monochromatic beam. The target is supposed to have a cross-section perpendicular to the optical axis equal to $1 \times 1 \text{ cm}^2$. With such a target, the acceptance of the beam in the horizontal plane is 14 mrad.cm; in the vertical plane the acceptance is 34 mrad.cm. The total acceptance is therefore $4.8 \cdot 10^{-4} \text{ sterad.cm}^2$.

In the first section of the beam, that is between the target and the main shielding wall, the momentum selection is obtained by means of the first bending magnet (deflection angle equal to about 5°) and a mass slit 1 cm wide, located at the image of the target (in the horizontal plane) following the bending magnet. The magnification of this image is 0.75. At the same position the chromatic dispersion for $\frac{\Delta p}{p} = 2\%$ particles amounts to 1 cm (see Fig. 3).

The first separator tank is also mounted in this section of the beam. The beam envelope inside the separator is kept smaller than 12 cm in the horizontal plane and 4 cm in the vertical plane; at 0.5 GeV/c the angular separation between π mesons and \bar{p} amounts to about 19 mrad; no particles can therefore touch the separator plates as clearly indicated in the phase space diagram:



Immediately after the shielding wall (about 39 metres from the target), we have the 1st mass slit; at this position the separation between π^- and \bar{p} of 0.5 GeV/c momentum is 11 cm; the vertical magnification at this point is about 3.5. Of course, at this energy, as shown in Fig. 3, most of the π mesons would be stopped between the two lenses (Q_3 and Q_2) in front of the shielding wall.

After the shielding wall the lenses are no more used in doublets; they are placed at about equal distances; this disposition reduces the number of elements as well as the excitation power needed and, what is more important in the present case, the chromatic aberrations are kept very small. The first lens after the shielding wall and the following bending magnet are placed so as to compensate the dispersion of the first bending magnet, as it appears in Fig. 3 where the trajectory of an axial particle having $\frac{\Delta p}{p} = +2\%$ is given in the horizontal plane (2).

The "second mass slit" corresponding to the second separator is located about 1 m in front of the last quadrupole. The separation between $0.5 \text{ GeV}/c \pi^-$ and \bar{p} is 12 cm. Finally, at about 103 m from the target the beam enters the bubble chamber having a profile of 4 cm horizontally and 7 cm vertically. As it can be seen from the x diagram in Fig. 3, the dispersion of the anti-protons with 2% higher momenta is zero inside the chamber.

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Table I. Distances from the target of all the elements of the beam transport along the optical axis of the system.

Element	Q ₁	Q ₂	BM1	Momentum slit	S ₁	Q ₃	Q ₄
Distance from target (m)	6.56	8.68	12.65	18.5	21.09	24.10	25.74
Element	Mass slit 1	Q ₅	BM2	Q ₆	Q ₇	S ₂	
Distance from target (m)	39.00	43.30	48.62	51.52	61.85	70.00	
Element	Q ₈	Q ₉	Mass slit 2	Q ₁₀			
Distance from target (m)	75.12	84.00	92.00	94.35			

Table II. Field gradient in the quadrupole lenses of the system for 0.5 GeV/c momentum particles. The effective length of the lenses is supposed to be 1.12 mt. The positive gradient lenses are focusing in the vertical plane.

Lens	Q ₁	Q ₂	Q ₃	Q ₄	Q ₅	Q ₆	Q ₇	Q ₈	Q ₉	Q ₁₀
Gradient (gauss/cm)	+69.5	-60.5	-60.2	+47.2	-27.4	+25.7	-12.1	-9.7	+24.2	-19.0