A Separated Antiproton Beam with Momentum

Tagging up to 2.4 Bev/c*

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Summary

The low energy separated Beam 5B of the A.G.S. at Brookhaven National Laboratory was modified to include a "tilted picket-fence" hodoscope which provides a momentum resolution of better than 0.5% full width.

Beam Description

The beam focusses particles at 10^0 to a target located in the 10th magnet of the G-superperiod in the AGS at Brookhaven National Laboratory. The G-10 target consists of a beryllium-oxide wire 0.040" in diameter and 0.60" long with its axis aligned at 10^0 to the circulating proton beam to present as small an image as possible to the secondary beam. The target is flipped into the circulating proton beam to produce a spill of approximately 500 ms. The beam as first established by Kycia and Barish did not include high resolution tagging and was somewhat shorter to maximize K fluxes. Before describing our modification we briefly describe the original beam.¹

The layout of the beam before modification is shown in Figure 1. The quadrupole triplet Q1, Q2, Q3 was used to produce a nearly parallel beam through the separators. The dipole bending magnet D1 selects both the momentum and bends the beam away from the machine. The maximum momentum particle D1 could bend through the 8^0 bend is 3.5 GeV/c. D1 was followed by two, 15-foot electrostatic separators which provide mass separation in the vertical plane. Immediately after the separators was the quadrupole doublet Q4, Q5 followed by the dipole D2. D2 acted as a switch which bent

1. B. Barish and T. F. Kycia, "A Partially Separated Antiproton and K-Meson Beam of High Intensity." BNL-pre-print (unpublished).

the beam 12° to move the beam from the A ("long") to the B ("short") branch of Beam 5. In the original design of the beam Q4 and Q5 were used to focus the beam horizontally at the sextupole and vertically at the mass slit. The sextupole corrected some of the chromatic aberration in the vertical plane to make the image at the mass slit smaller. Adjustable tungsten momentum stops were placed at the low momentum focus before the sextupole and the high momentum focus after the sextupole. Just after the mass slit a dipole D4 followed by two quadrupoles Q9 and Q10 bent the beam to and focussed it on a secondary target.

Modifications

To use Beam 5B for our experiment (AGS #527) it was necessary to improve the momentum resolution as well as to lengthen the beam considerably in order to place our equipment within crane reach and provided room for the spark chamber optics. As the beam is totally enclosed in vacuum boxes and pipes up to the mass slit there was no way to conveniently place a momentum hodoscope of the type needed for this experiment at the horizontal focus even if the multiple scattering introduced by the counters did not degrade the separation at the mass slit excessively. Previously a hodoscope was located immediately after the mass slit but being far from a horizontal focus the momentum resolution was not good enough for our purposes.

Both problems were solved by redesigning the beam using the computer program BEAM². The present beam layout on the AGS floor is shown in Figure 2 and a description of the elements and their positions in Table 1. While the functions of all the magnets through Q5 are the same, Q4, and Q5 were operated so that the horizontal focus is moved from 200.0" before the mass slit to

2. Our thanks to John Fox, Brookhaven National Lab, who wrote BEAM and helped us use it.

90.0" after the mass slit to allow room for a horizontal hodoscope. To keep the beam from diverging excessively, the polarities of the magnets Q4 and Q5 were reversed. Although the dipole D4 is no longer used it was left in place due to the difficulty of removing it from the shielding wall of which it is a part. In addition, since the horizontal focus is no longer at the sextupole this magnet was not energized. D3, Q6, and Q7 serve the same purposes as the original D4, Q9, and Q10 but their positions are now 337.0 inches farther downstream and D3 bends the beam 16° instead of the 13.5° D4 bent it. The angle was dictated primarily by crane access, available floor space, and maximum momentum. Although a 16° bend is not quite sufficient to remove the horizontal dispersion introduced by D1 and D2, it does allow D3 to bend particles of up to 2.4 GeV/c. Since the beam is not quite recombined at the secondary target, Q6 and Q7 focus the beam beyond the target 123.0" so that the circle-of-least-confusion is at the target. Figures 3 and 4 show a horizontal and a vertical ray trace of the extreme rays for a $\pm 2.5\%$ momentum spread. The horizontal phase space at the target and the vertical phase space at the mass slit is shown in Figure 6.

Momentum Hodoscope

Due to dispersion by the dipoles, the foci of particles of different momenta are distributed across the horizontal plane of the beam and due to chromatic aberration the foci are also distributed along the length of the beam. The twelve, $1/2$ " wide, 3" high, and $1/8$ " thick hodoscope counters are positioned along the line of horizontal foci. They extend 85.0" along the beam and since they are non-overlapping the counters span the 6.0" across the beam. It was estimated using the Monte Carlo facilities in BEAM that each hodoscope counter sees slightly more than a 0.4% (full width) momentum bite. (See Figure 5) Measurements using time-of-flight of tritons at low

momenta indicate that the dispersion across the hodoscope counters and within the individual counters is in good agreement with the design calculation. Tungsten momentum stops are placed at the plus and minus 2.5% momentum foci. Horizontal phase space diagrams of the beam at the high and low momentum stops are shown in Figure 7.

Target Parameters

The Monte Carlo provisions in BEAM were also used to predict the angular, spatial, and momentum distributions of particles at the target shown in Figure 8. For these results particles were thrown isotropically distributed within the acceptance of the beam which is ± 10 mrad (milliradians) vertically and ± 13 mrad horizontally. The initial momenta had a uniform distribution to .33%. No provision was made to include the effects of multiple scattering due to material in the beam.

The image size at the target was roughly measured at 1.5 GeV/c using an arrangement of overlapping counters and sweeping D3. The horizontal fwhm was found to be near 1.8" and the vertical fwhm to be less than 1.5".

Beam Tuning

The beam was tuned by starting with the design magnet settings calculated from the results of BEAM runs. Q3 and the separators were adjusted to bring the beam to a focus at the mass slit. It was necessary to run D3 approximately 10% higher than the design settings to bring the beam to the center of the target due to the truncation of its fringing field by the steel of the quadrupole Q6 only inches away. At the lower energies stepping Q1 and Q2 in 5% steps about the design values while tuning Q3 to maximize the beam resulted in significant intensity gains. Adjusting D1 to maximize the beam and symmetrize the horizontal distribution in the hodoscope also lead to large increases in

intensity. Particularly at the lowest momenta the image size at the mass slit is a function of the voltage on the separators. Consequently the intensity was increased by running with one separator off and the other as low as was consistent with a favorable $\pi/\bar{p}$ ratio. Table II shows the actual magnet settings in mv for a number of momenta and the resulting intensity and $\pi/\bar{p}$ ratio. The intensity is normalized to 10^{12} protons on G10 as indicated by 1430 counts on the 90° G10 monitor.³ The intensities are reasonable per pulse values. The momenta listed are nominal since they are determined only by calculation from the bending magnet settings.

Figure 9 gives a measure of the vertical, spatial distribution at the mass slit. It was obtained by making a sweep of the magnetic field in a separator with all other parameters held fixed.

Time of Flight

Because of a 639 inch flight path it is possible to differentiate pions and $\bar{p}$'s by the difference in their time of flight. A 3.0" x 6.0" x 1/8" counter immediately upstream of the horizontal hodoscope and another 2.5" diameter by 1/8" counter just before the hydrogen target were used for the time of flight coincidence. The photomultiplier signals were fed into EGG TR204S/N discriminators whose outputs, set to minimum width and clipped by 1 ns cables, were fed into a Chronetics 152 coincidence unit. The resulting delay curves at 1.5 GeV/c and at 2.0 GeV/c are shown in Figures 10 and 11. The pion contamination in those particles identified as antiprotons is estimated from these curves to be consistent with 0% at 1.5 GeV/c and around 0.14% at 2.0 BeV/c. The $\pi/\bar{p}$ ratio without time of flight is 0.63 and 0.69 respectively.

3. When only the G10 target was being flipped and the G10 targeting efficiency had been maximized it was found that 10^{12} circulating protons lead to 1430 counts on the G10-90 $^\circ$ monitor. (See AGS Technical Note No. 89) This number on the 90 $^\circ$ monitor we took to mean 10^{12} protons on G10 modulo the uncertainty in targeting efficiency.

TABLE I
BEAM 5B PARAMETERS

<u>Symbol</u>	<u>Element</u>	<u>Effective Length in</u>	<u>Position to magnet center (in)</u>
	(10° Production)		
Q1	N8Q24	28.0	157.
Q2	N8Q32	36.0	201.
Q3	N8Q32	36.0	245.
D1	15C30MkII 5.0" Gap	38.0	288.
	(6° Deflection)		
Q4	12Q30	36.0	855.
Q5	12Q30	36.0	897.0
D2	18D36-8.0" Gap	46.0	954.0
	(12° Deflection)		
	Mass Slit		1258.0
	Low Momentum Stop - 2.5%		1298.0
	High Momentum Stop + 2.5%		1395.0
D3	18D36 - 6.0" Gap	44.0	1631.0
	(16° Deflection)		
Q6	12Q60	66.0	1693.0
Q7	12Q30	36.0	1754.0
	Target		1964
	Final Focus		2087.0

Table II

Magnet settings (in millivolts), intensity, and $\pi/\bar{p}$ ratio for different momenta

Nominal Momentum (GeV/c)		0.750	0.800	0.900	1.00	1.200	1.249	1.300	1.353	1.408	1.465	1.525	1.587	1.652
Element	Shunt Value (amps/mv)													
Q1	25	19.00	20.27	21.70	24.11	28.93	30.11	31.33	32.61	33.94	35.33	36.77	38.30	39.83
Q2	25	20.00	21.33	23.49	26.10	31.32	32.59	33.92	35.30	36.74	38.24	39.80	41.44	43.11
Q3	25	8.30	8.70	10.05	11.20	13.35	13.69	14.24	14.60	15.25	15.90	16.45	17.20	18.00
D1	25	21.95	23.40	25.80	28.65	34.70	35.70	36.95	37.90	39.40	41.40	42.70	44.50	46.10
BS1	8	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	31.70	32.02	36.11	35.70	35.37
Voltage (kv)										300	300	350	350	350
BS2	8	7.95	7.65	7.85	7.55	17.75	20.35	23.80	27.30	30.45	29.90	34.25	33.71	33.70
Voltage (kv)		100	100	100	100	250k	300	350	400	400	400	450	450	450
Q4	25	10.76	11.48	12.92	14.35	17.22	17.92	18.65	19.41	20.20	21.03	21.89	22.80	23.70
Q5	25	11.86	12.65	14.23	15.81	18.97	19.74	20.55	21.38	22.25	23.17	24.12	25.11	26.12
D2	25	27.14	28.93	32.54	36.16	43.49	45.30	47.21	49.18	51.20	53.40	55.17	58.11	60.59
D3	25	29.25	31.00	34.50	38.10	45.80	47.20	49.15	50.8	53.05	55.55	57.20	60.04	62.70
Q6	15	14.00	14.50	18.36	20.40	24.48	25.58	26.51	27.59	28.72	29.89	31.11	32.40	33.69
Q7	25	18.20	19.4	20.63	22.63	27.50	28.62	29.78	31.00	32.28	33.53	34.96	36.40	37.87
Intensity ($P/10^{12}$ on G10)		250	430	940	2.0K	5.1K	6.0K	7.3K	8.2K	8.1K	9.7K	10.5K	12.9K	
Ratio of $\pi/\bar{p}$		13.4	11.2	8.2	5.9	2.1	1.8	1.3	1.4	0.75	0.70	0.59	0.54

Figure 1
Original Layout of Beam 5B.

Figure 3

Figure 4 - Vertical Ray Trace Diagram

Figure 5

Monte Carlo Simulation of Momentum Distribution in the Central Hodoscope Counters

NRAYS	JPRINT	XMAX	DXMAX	YMAX	DYMAX	K1	K2	K3	K4	X1	DX1	Y1	
1000	42 42	5.000	.010	1.000	.010	1	5	3	4	.030	.01300	.010	,
0	0	0	0	0	0	0	56	0	0	0	0	0	56 1.10
0	0	0	0	0	0	14	30	0	0	0	0	0	44
0	0	0	0	0	0	56	1	0	0	0	0	0	57 1.08
0	0	0	0	0	0	46	0	0	0	0	0	0	46
0	0	0	0	0	0	43	0	0	0	0	0	0	43 1.06
0	0	0	0	0	0	11	44	0	0	0	0	0	55
0	0	0	0	0	0	44	0	0	0	0	0	0	44 1.04
0	0	0	0	0	0	57	0	0	0	0	0	0	57
0	0	0	0	0	0	51	0	0	0	0	0	0	51 1.02
0	0	0	0	0	0	3	35	0	0	0	0	0	38
0	0	0	0	0	0	49	10	0	0	0	0	0	59 1.00
0	0	0	0	0	0	57	0	0	0	0	0	0	57
0	0	0	0	0	0	56	0	0	0	0	0	0	56 0.98
0	0	0	0	0	0	51	0	0	0	0	0	0	51
0	0	0	0	0	0	36	13	0	0	0	0	0	49 0.96
0	0	0	0	0	0	51	0	0	0	0	0	0	51
0	0	0	0	0	0	48	0	0	0	0	0	0	48 0.94
0	0	0	0	0	0	42	0	0	0	0	0	0	42
0	0	0	0	0	0	29	20	0	0	0	0	0	49 0.92
0	0	0	0	0	0	47	0	0	0	0	0	0	47 0.90
0	0	0	0	0	0	76	197	229	208	203	87	0	0

Momentum
GeV/c

H4 H5 H6 H7 H8 H9 .5"

1.5 1.0 -0.5 0 +0.5 1.0 1.5

X Displacement across beam

The figure above shows the momentum distribution in the hodoscope counters H5-H8. Each bin on the vertical axis corresponds to 0.1% in momentum while each bin on the horizontal axis corresponds to 0.5" on the horizontal axis of the beam. (The width of a hodoscope counter). Each hodoscope counter has a different position along the length of the beam. Although the counter spacing is not uniform, it is about 8 inches. The momentum overlap for two adjacent counters is about 0.05%.

FIGURE 6

SQUARE 10 X 10 TO THE HALF INCH AS-0013-01

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FIGURE 7

Figure 8 BEAM 5B-TARGET PARAMETERS from Monte Carlo Run
 (1964.0 inches long w momtnum focus 90.0" beyond mass slit, beam focus 123.0" beyond target)

Figure 9

Number of Antiprotons
10 X 10 TO THE HALF INCH
SQUARE AS-0013-01

30k
20k
10k

32.00

33.00

34.00

BS2 MAGNETIC SHUNT READING IN MILLIVOLTS

Number of Antiprotons

30k
20k
10k

37.00

38.00

39.00

BS1 MAGNETIC SHUNT READING IN MILLIVOLTS

Sweep of the magnetic fields of each beam separator in turn
all other parameters held constant.

Figure 10
Time of Flight Delay Curve at 1.5 GeV/c

Figure 11
Time of Flight Delay Curve at 2.0 GeV/c

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