MONTE CARLO STUDY OF CONTAMINATION IN THE LESBI LOW MOMENTUM
KAON BEAM LINE AT BROOKHAVEN

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INTRODUCTION

Present low momentum (< 1 GeV/c) kaon beams have 5-10 times as many other particles as kaons. Although present rates are already quite high, it is still possible to discriminate against contaminating particles by placing counters in the beam. At a kaon factory rates are too high. Purer beams are required. However, the necessary additional optics will lengthen the beam, resulting in a loss of intensity through decay. Although this is unacceptable at present accelerators, new experiments nevertheless demand better purity. It becomes then very important to understand the reasons for the contamination and find less drastic ways of reducing it.

In this paper we present as an example results of a preliminary study with our Monte Carlo program REVMOG of the contamination in LESBI. The conclusion is that the calculated contamination agrees reasonably well with measurements. We mention tentatively a few possible improvements.

BEAM LINE LESBI (Fig. 1)

The beam line takes off at an angle of 10° to the production target. The first magnet bends over 11.5° . Two quads and a 29.4° bend follow. The beam is vertically parallel in the separator. A doublet gives a horizontal and a vertical focus in the centre of the mass slit which is tilted at a variable angle to the beam (here 15°) to minimize chromatic aberrations in the vertical plane. The beam is nearly achromatic after the last bend of 36.8° . The beam line is 14.2 m long. The solid angle is 2 mrad. The momentum acceptance is 5% . The production target is 10 cm long and 3 mm high. In the calculations the mass

Fig. 1. The LESBI beam line at Brookhaven.

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Fig. 2. Vertical positions of π , K and p peaks at mass slit.

slit aperture is 5 mm. All other slits are fully open. Calculations were performed for a 750 MeV/c K^+ beam. A very interesting result was also obtained for a 750 MeV/c $\bar{p}$ beam. For an unseparated beam we would expect the following relative intensities: $1000 \pi^+$, $2.5 K^+$, $800 \pi^-$, $1.4 K^-$, $0.12 \bar{p}$.

SOURCES OF CONTAMINATION

- 1) a) Imperfect second-order optics
- b) Insufficient peak-to-peak separation at mass slit
- 2) Imperfections in magnets
- 3) Halo of proton beam on production target
- 4) Two-body decays
 - a) $\pi + \mu^+ \nu$ before mass slit
 - b) $K_0 \rightarrow \pi^+ \pi^-$ near production target
 - c) other two-body decays
- 5) Scattering on beam line elements
 - a) vacuum boxes
 - b) collimators
 - c) windows
- 6) Three-body decays
- 7) Other

Detailed calculations have been performed for points 4a, 4b, 5a and 5c. We discuss these results after some brief remarks on the other points.

LESBI has no sextupoles; second-order aberrations are minimized by tilting the mass slit. The separator has a gradient of 50 kV/cm. Figure 2 gives the nominal separation at the mass slit for π , K and p. The π -K separation is only 7.3 mm at 750 MeV/c. A small broadening of the pion peak would cause a substantial contamination. A 0.12 trans- mission of $\pi^+ / K^+ = 0.4$.

Unfortunately, it is not possible to calculate the effect of magnet field imperfections in our program. Proton beam halo is not important because the production target is only 3 mm high. Although it is possible to calculate the effect of any two-body decay in our program, we have restricted ourselves to only two types of decay. In other cases there might be a problem with production cross sections. We cannot calculate three-body decays. In our scattering calculations we have restricted ourselves to scattering on the vacuum box in B1 and to scattering in the window at the entrance of the beam line.

Point 4a, Muon contamination from π decay before the mass slit

At 750 MeV/c we obtain $\mu^+/K^+ = 0.55$. Almost all decays come from forward decay. Backward decay of high momentum pions gives a negligible contribution. For an antiproton beam the result is $\mu^-/\bar{p} = 3.2$. At 600 MeV/c the separation at the mass slit is much better than at 750 MeV/c, namely 13.5 mm. However, the π/K ratio at the production target and kaon decay are worse. The result is $\mu^+/K^+ = 1.0$.

A preliminary calculation for LESB2 suggests that $\mu^+/K^+ = 1.5$ at 750 MeV/c, three times as bad as for LESB1.

Point 4b, Pion contamination from K_0 -decay

We assume that the K_0 production cross section is equal to the K^+ production cross section. Momenta between 0.7 and 8 GeV/c contribute to the π contamination. Although the dependence of the K_0 production cross section on the production angle has to be taken into account properly, we have only been able to do that in a very approximate way. We obtain $\pi^+/K^+ = 2.0 \pm 0.5$ at 750 MeV/c.

A preliminary calculation for LESB2 suggests $\pi^+/K^+ = 2$ at 750 MeV/c, the same as for LESB1.

Point 5c, Pion scattering on windows

There is a 0.2 mm thick Al window close to the production target. This gives $\pi^+/K^+ = 0.25$ at most. The effect of a window after the separator has not yet been calculated.

Point 5a, Pion scattering on B1 vacuum box: Effect on K^+ beam.

Extensive calculations have been performed for π scattering on the vacuum box in B1. The present Monte-Carlo program does not allow scattering inside magnets. For the small 10° bend of B1 we can obtain fairly reliable results by replacing the magnet by five very short 2° bending magnets with collimators between them.

A consideration of transport matrix elements between B1 and the mass slit leads to the conclusion that only a small contribution to the total π^+/K^+ ratio can be expected from this effect at 750 MeV/c. A particle emerging from the side of the vacuum box (6 cm from axis) with exactly the central beam momentum will end up at the mass slit about 30 cm from beam axis and will therefore be rejected. Only particles which differ more than 10% from the central momentum will get through the horizontal aperture at the mass slit but they will not be accepted by the last part of the beam line.

The top of the vacuum box (2.5 cm from axis) has an image at the mass slit about 1.5 cm below beam axis. When the separator is tuned

for kaons this image will move closer to axis but not sufficiently to give a worth-while transmission of pions which have scattered from the top of the B1 vacuum box. Our Monte Carlo calculations give $\pi^+/K^+ = 1.0$ at 750 MeV/c for all scattering combined. At 600 MeV/c the image moves close to the mass slit aperture. Many pions are transmitted and we obtain $\pi^+/K^+ = 3.4$.

Point 5a, Pion scattering on B1 vacuum box: Effect on antiproton beam
When the separator is tuned for antiprotons the image at the mass slit of the top of the B1 vacuum box coincides with the centre of the mass slit at 750 MeV/c. We obtained $\pi^-/\bar{p} = 60$ from this effect alone. This is approximately in agreement with measurements made in 1972 under somewhat different conditions.² At that time a collimator was placed before B1. When that collimator was open the ratio $\pi^-/\bar{p}$ was 100. When the collimator was closed to 1 cm the full antiproton beam still went through but scattering on the top of the B1 vacuum box was no longer possible. The ratio $\pi^-/\bar{p}$ was 15. The reason for this contamination is not yet clear. Maybe scattering on the collimator itself gives a contribution. The ratio $\mu^-/\bar{p}$ from pion decay was calculated as 3.0. This is too small.

We also performed some calculations for a 600 MeV/c antiproton beam. In that case scattering from the top of the B1 vacuum box gives no contribution at all since the image at the mass slit moves from below axis to above axis when the separator is tuned for antiprotons. Does this mean that the antiproton beam is cleaner at 600 MeV/c than at 750 MeV/c?

CONCLUSIONS

The purpose of our investigation is to understand the contamination of kaon beams and suggest ways to minimize it. Here we have given some preliminary results of Monte Carlo calculations for LESB1 and LESB2. The results are summarized in Table I. The total ratio $(\mu^+ + \pi^+)/K^+ = 3.9$ at 750 MeV/c, in fair agreement with the measured ratio of 4.5.³ A few ball park calculations not reported here suggest that the π^+/K^+ ratio can be improved substantially if a better separation (10 mm instead of 6.5 mm) can be achieved at the mass slit. Furthermore, a collimator before B1 can reduce the π contamination from K_0 decay by a factor 2. Other preliminary calculations suggest that scattering on a steel vacuum box gives only half as much contamination as for an aluminum (present) vacuum box. It is not unreasonable to expect that with various improvements we can obtain $(\mu^+ + \pi^+)/K^+ = 1.5$.

We also found a reasonable agreement with measurements for the π contamination in a $\bar{p}$ beam at 750 MeV.

In general we can say that the relative importance of different contaminating processes changes with changing momentum and depends also on the beam optics and the specific construction features of beam line elements. This can, for example, be seen from our results for pion scattering on the top of the B1 vacuum box. At 750 MeV/c this process accounts for most of the pion contamination in the $\bar{p}$ beam whereas at 600 MeV/c its contribution is negligible. For the K^+ beam

Table I. Summary of results obtained so far. A case for which no number is given has not yet been calculated.

Contribution from	LESB1		LESB2	
	$(\pi^+\mu^+)/K^+$ 750 MeV/c	$(\pi^+\mu^-)/\bar{p}$ 600 MeV/c	$(\pi^+\mu^+)/K^+$ 750 MeV/c	$(\pi^+\mu^-)/\bar{p}$ 600 MeV/c
$\pi + \mu^+\nu$	0.55	1.0	3.2	-
$K_0 + \pi^+\pi^-$	2.0	-	-	2.0
π -scattering in B1	1.0	3.4	60.0	1.0
π -scattering in window	0.25	-	-	-
Calculated total	3.90	-	-	-
Measured total	4.50	-	100.0	-
				8.07

this process is not important at 750 MeV/c whereas it accounts for $\pi^+/K^+ = 3.4$ at 600 MeV/c. If the vertical gap in B1 were twice as large we would obtain completely different results.

REFERENCES

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