An 800 MeV/c separated kaon beam at J-PARC

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Abstract

This report gives result for the optics design of a 0.8 GeV/c stopped kaon beam which branches off from an existing optics design for a 1.1 GeV/c kaon beam. The design of the 1.1 GeV/c beam has been left unchanged, except for a useful small modification after the last bend. Both beams share the part up till the first mass slit. After that, the 1.1 GeV/c beam bends 29 degrees counter clockwise, while the 0.8 GeV/c beam bends 50 degrees clockwise. The total acceptance of the 19.06 m long 0.8 GeV/c beam is about 6 msr percent DP/P. The acceptance of the 27.29 m long 1.1 GeV/c beam is about 4 msr percent DP/P. The pion contamination due to higher order aberrations, slit scattering and the pion cloud has been studied for both beams. The conclusion is that the contamination due to all these processes can be reduced sufficiently, so that the final pion contamination is less than half the kaon intensity. An important role is played in this respect by a horizontal focus after the last bending magnet.

Contents

1 Introduction

In the early stage of J-PARC two kaon beams are planned, both taking off from the same production target. A 1.8 GeV/c beam for hypernuclear physics takes off to the left at 6 degrees to the 50 GeV proton beam. A 1.1 GeV/c beam for hypernuclear physics and a 0.8 GeV/c stopped kaon beam for the study of Time Reversal Violation share the first part of a beam which takes off to the right, also at 6 degrees. An optics design exists for the 1.1 GeV/c beam. It is shown in figure 1. The purpose of this report is to describe the optics design of the 0.8 GeV/c beam in figure 2. Both beams have the same layout up to the first mass slit MS1. Then follows a 29 degrees counter clockwise bend for the 1.1 GeV/c beam, or a 50 degrees clockwise bend for the 0.8 GeV/c beam. Figure 3 shows that the beams overlap in that area. Therefore, only one can be used in a given time period. The other beam can be used by installing the other bend system. Figure 4 shows the center lines of both beams on the same scale.

A number of different designs were made with different solid angle acceptance by changing the quadrupole doublet at the front to a triplet, and by using longer separators. However, in the end it was decided to keep the layout of the 1.1 GeV/c beam the same up till the last bend. The last bend was replaced by a 45 degrees wedge bending magnet in order to make a horizontal focus after the bend. This focus helps to remove the pion contamination.

2 Main features of the optics of the 1.1 GeV/c beam

The layout is shown in figure 1 and the beam envelopes in figure 5 for a 43 mr horizontal and 9 mr vertical angle, an initial 0.35 cm horizontal and 0.2 cm vertical spot. All widths are half widths in accordance with TRANSPORT convention. The momentum bite is zero. The characteristics of the beamline elements are listed in tables 1 and 2.

The optics of the existing design has been maintained, except for a modification after the last bend. The beam takes off at 6 degrees to the proton beam. The 20 degrees clockwise bend B1 is followed by a quadrupole doublet that produces a vertical focus at IFY, after the 24 degrees clockwise bend B2. A further doublet makes the beam vertically parallel in the 2 m long crossed field separator. Then the beam is vertically focussed at the first mass slit MS1. Bend B3 bends 29 degrees in the counter clockwise direction. Quadrupole Q7 makes the beam vertically parallel in a second 2 m long crossed field separator, after which the beam is focussed vertically at a second mass slit MS2. Until here the existing design has been maintained. However, the last clockwise bend B4 is changed to a 45 degrees wedge bending magnet, with the beam entering and exiting at right angle to the pole faces. After B4 the beam is fully achromatic in the sense that both position and angle are in first order independent of momentum. This arrangement makes it possible to create a horizontal focus, HFOC, after B4 that will turn out to be very useful for controlling the pion contamination in the beam. The following doublet focusses the beam at the final focus, but in order to reduce the strength of the last quadrupoles the final focus is now placed at a distance of 1.75 m from the last quadrupole, instead of the original 1.00 m.

The momentum dispersion along the beam is plotted in figure 6.

Each of the two separators with 550 kV over a 10 cm vertical gap gives a vertical kick of 0.88 mr to the pion beam.

The beam line is 27.29 m long.

3 Optics of the 0.8 GeV/c beam

The layout is shown in figure 2 and the beam envelopes in figure 7 for a 43 mr horizontal and 9 mr vertical angle, an initial 0.35 cm horizontal and 0.2 cm vertical spot. All widths are half widths in accordance with TRANSPORT convention. The momentum bite is zero. The characteristics of the beamline elements are listed in tables 3 and 4.

The layout is the same as for the 1.1 GeV/c beam up till mass slit MS1, but the tuning is different. The mass slit is followed by a 50 degrees clockwise bend B3, with normal entry and exit to the pole faces. There is a horizontal focus, HFOC, after B3 which is very important for suppressing the pion contamination. A doublet focusses the beam at the final focus, 1.50 m from the last quadrupole. The beam is achromatic in position, but not in angle, at HFOC and at the final focus. This can be seen in figure 6 where the momentum dispersion along the beam is plotted in blue. There is still dispersion after B3 but the focus HFOC is located where the dispersion goes through zero.

The separator with 550 kV over the 10 cm vertical gap kicks the pion beam by 2.20 mr.

The beam line is 19.06 m long.

4 Sources of pion contamination

This report considers the following sources of contamination.

- Higher order aberrations which cause pions directly produced in the production target to pass through mass slits.
- Direct pions which scatter on the top and bottom surfaces of the 30 cm long slits.
- Cloud pions from the decay of neutral kaons near the production target.
- Muons from pion decay in the channel. It turned out that this did not give an important contribution to the contamination. Therefore, it is not discussed in this report.

4.1 Contamination due to higher order aberrations

Direct pions can pass through mass slits due to higher order aberrations. The vertical beam size at mass slits can be expressed in terms of the initial coordinates as

$$\begin{aligned} y = R_{33}y_0 + R_{34}\phi + A_1\phi\theta + A_2\phi\theta^2 \\ +B_1\phi\delta + B_2\phi\delta^2 + \cdots \end{aligned} \tag{1}$$

where y_0 is the initial size and R_{33} is the magnification. The first order matrix element R_{34} is exactly zero at a focus. θ is the initial angle in mr that the projection of a ray on the horizontal plane makes with the beam axis. ϕ is the angle in mr of the projection on the vertical plane with the beam axis. δ is the deviation of the momentum from the central momentum ΔP/P in percent, where P is the central momentum.

The large coefficients A_1 and B_1 can be corrected by two sextupoles located just before and after the separator. The important third order coefficients are A_2 and B_2. A single octupole between Q3 and Q4 can not correct both at the same time, but it is still useful. Its best value was found by trial and error in higher order Monte Carlo calculations with the program ZGOUBI.

4.2 Contamination due to scattering on the 30 cm long slits

In the calculations with ZGOUBI mathematical slits of zero length are used both at IFY and at MS1. However, in reality those slits will have a length of about 30 cm, and they are tapered. Second order Monte Carlo calculations with the TRIUMF program REVMOC, which is similar to second order TURTLE, using such realistic slits, show that many direct pions will pass through IFY and MS1. The focus HFOC will drastically cut down on this type of direct pion contamination.

4.3 Contamination due to cloud pions

The 0.8 GeV/c beam has only one stage of separation. An important cause of the pion contamination in a single stage separated beam is thought to be the presence of a so called cloud of pions near the production target due to the decay of neutral kaons, which presents a large vertical and horizontal source to the beam line. In a two stage separated beam the first mass slit has two functions. It removes most of the pions directly produced by the proton beam, and it defines a small source of cloud pions for the second stage. In a single stage separated beam, the second function can also be performed by creating a vertical focus in the beginning of the beam line before the separation takes place. Since the 1.1 GeV/c beam has such a focus, it can be used by the 0.8 GeV/c beam to help with the removal of the cloud pions. This focus is labelled IFY in the beam line layouts, and in the beam envelopes plots. The horizontal focus HFOC after B3 also strongly reduces the cloud pion contamination by selecting a small horizontal source near the production target in a similar way that the vertical focus IFY selects a small vertical source size.

5 Relative normalization of pion intensity to kaon intensity

Both the 0.8 GeV/c and the 1.1 Gev/c beam are 3.2 to 3.3 kaon decay lengths long, just like beamline LESB3 at Brookhaven. If the separators in LESB3 are turned off then there are 500 times as many pions as kaons. LESB3 takes off at zero degrees to the 24 GeV proton beam and has a horizontal angle acceptance of ± 12 degrees and a vertical acceptance of ± 1.5 degrees. The J-PARC beams take off at 6 degrees to the 30 to 50 GeV proton beam, with a horizontal angle acceptance of less than ± 3 degrees and a vertical angle acceptance of about ± 0.5 degrees. The relative cross sections at J-PARC are unknown, but the situation is similar to the situation at BNL. Therefore, it is assumed in this report that at the end of the 0.8 GeV/c and 1.1 GeV/c beam there will be 500 times as many pions as kaons if the separators are turned off. Therefore, if a fraction of 0.2 percent of the pions passes to the end of the beam when the separators are turned on, then the pion intensity in the kaon beam will be equal to the kaon intensity.

6 Results of higher order Monte Carlo calculations with ZGOUBI for the 0.8 GeV/c beam

The next six figures illustrate the results obtained with ZGOUBI. This program uses extended realistic fringe fields for all magnetic elements, and traces rays stepwise through the beam elements.

Figure 8 shows the vertical and horizontal beam size at the first vertical focus IFY before the first separation state. It was assumed that the source size at the production target was 4 mm full width, populated as a square distribution. The vertical magnification at IFY is 0.38. Therefore, the beam width should be 1.52 mm. The FWHM is 2.0 mm and the FWQ(uarter)M is 2.8 mm. The difference is due to higher order aberrations. If a 2 mm wide source is taken, the width will be a little bit smaller, but not much.

Figure 9 shows the vertical pion and kaon spot at the mass slit MS1. The magnification is 0.45. A 4 mm original source would give a 1.8 mm width. In fact the size is 2.1 mm FWHM and 2.7 mm FWQM. At the bottom the width of the tail is 6 mm. The pion and kaon spots overlap slightly, but since there are 500 times as many pions as kaons when the separators are turned off, this pion tail causes a considerable contamination in the pion beam. When MS1 is closed to 4 mm full width, then the pion contamination will be a fraction of 0.25 of the kaons. This fraction drops to 0.05 if MS1 is closed further to 3 mm, at the expense of 5 percent of the kaon flux. The width of the slit at IFY was 6 or 5 mm full width, but this width does not make much difference to the results. As will be shown later, the main function of IFY is to reduce the cloud pion contamination. The bottom figure shows in more detail the area of the beam between +1 and +3 mm. The pion intensity between +1 mm and +2 mm is much larger than the pion intensity between +1 mm and +1.5 mm. The results for a 2 mm source size will be even better. These results show that the higher order corrections with the two sextupoles and the octupole are succesfull. These corrections were found by trial and error in Monte CARLO calculations with ZGOUBI, starting with the sextupole values of TRANSPORT.

Figure 10 shows the horizontal and vertical kaon beam spot at HFOC at the bottom, and an x-y scatter plot for kaons and pions at the top. IFY had a 6 mm width and MS1 a 4 mm width. It shows beautifully how the horizontal kaon beam is very narrow. A horizontal slit here, will be very useful as will be shown in the next section. The pions which pass through the IFY and MS1 slits are in a small area away from the main kaon beam, and can be removed by some blocking material.

Figure 11 shows the momentum distribution for the kaons. It does not depend much on the slit widths. The FWHM is 4.6 percent DP/P and the FWQM is 7.0 percent DP/P.

Figure 12 shows the final beam spot. The vertical beamspot is 0.52 cm FWHM and 1.04 cm FWQM. The horizontal beam spot has 0.47 cm FWHM and 0.78 cm FWQM. If the horizontal slit at HFOC is closed to 1.2 cm full width, the tails on the final horizontal spot are reduced.

Figure 13 shows the vertical and horizontal angle acceptance at the production target averaged over the accepted momentum distribution. The horizontal acceptance is ± 24 mr FWHM and ± 34 mr FWQM. The vertical acceptance is ± 8.2 mr FWHM and ± 8.9 mr FWQM. The total acceptance is about 6 msr percent DP/P. This number was obtained by multiplying the initial angle and momentum acceptance by the fraction of initial kaons that made it to the final focus. For a comparison, the beam line LESB3 at BNL has a total acceptance of 50 msr percent DP/P.

7 Results of higher order Monte Carlo calculations with ZGOUBI for the 1.1 GeV/c beam

Although the purpose of this study was the design of the 0.8 GeV/c beam, it is still useful to check the performance of the 1.1 GeV/c beam. Figure 14 shows a scatter plot of y at MS2 versus y at MS1. Kaons and pions are not sufficiently separated at MS1, but the separation is good at MS2 except for some overlap near y=-2 mm. Figure 15 gives the projected vertical beam spots at both mass slits. The kaon spot is 1.8 mm FWHM and 2.4 mm FWQM at MS1. The spot is 2.1 mm FWHM and 2.7 mm FWQM at MS2. The magnification is 0.41 at MS1 and 0.43 at MS2. The higher order corrections were done by trial and error with Monte Carlo calculations with ZGOUBI, starting from the sextupole values of the TRANSPORT tune. The green line shows the pion spot multiplied by 500. It can be seen that it makes a large difference to the pion contamination if MS2 is closed to ± 2 mm or ± 1.5 mm. The pion to kaon ratio is 0.38 for a 4 mm wide MS2 and

0.04 for a 3 mm wide MS2. The kaon rate drops only 5 percent going from 4 mm to 3 mm. Even with the 4 mm wide MS1 the ratio is only 0.05, if it is assumed that the vertical source size at the production target is a square distribution with a 2 mm full width.

Figure 16 shows at the top the momentum distribution if both MS1 and MS2 have a 4 mm width. The width is 4.3 percent DP/P FWHM and 4.7 percent DP/P FWQM. At the bottom are the beam spots at the final focus. Horizontally, the width is 0.38 cm FWHM and 0.61 cm FWQM, but there is a lot of intensity in the tail which stretches to ± 1.5 cm. Vertically, the width is 0.46 cm FWHM and 0.73 cm FWQM with tails stretching to ± 1.0 cm.

Figure 17 shows the accepted angle range, averaged over the accepted momentum distribution. The width is ± 28 mr FWHM and ± 32 mr FWQM. Vertically the width is ± 8.5 mr FWHM and ± 9.0 mr FWQM. The total angle momentum acceptance is about 4 msr percent DP/P.

8 Pion contamination due to slit scattering for the 0.8 GeV/c beam

The vertical slits at IFY and MS1 are 30 cm long, divided in three parts. The middle 10 cm has a flat surface. The first and last 10 cm have tapered surfaces. The taper angle is 20 mr at IFY and 15 mr at MS1. Calculations were done for slit scattering with the TRIUMF program REVMOC. This program treats the optics in the same way as second order TURTLE, but was designed many years ago to incorporate all kinds of interactions in matter. Table 5 shows for a 2 mm full square width vertical source how many pions and kaons arrive at the final focus depending on the slit widths. All calculations were started with the same number of pions and kaons. However, to obtain the pi/K ratio the number of pions has to be multiplied by 500. The top part of the table shows that closing only IFY and MS1 is not sufficient to get the pi/K ratio small. Slit scattering is obviously a major source of pion contamination. Closing MS1 is the most effective. The second part of the table shows a drastic improvement in the pi/K ratio when the horizontal slit at HFOC is closed to a full width of 1.6 cm, at the expense of a minor amount of kaon flux. After that, the width of MS1 is less important for the pi/K ratio, as can be seen in the third part. The ratio is already so small that further closing MS1 does not make much sense. The bottom part of the table shows the effect of varying the width of HFOC. When IFY is 5 mm wide and MS1 is 4 mm wide, it does not make much sense to narrow the width of HFOC even more. If the original source size is 4 mm, see table 6, the results are very similar, but slightly worse. Figure 18 helps to understand the importance of HFOC. It shows the kaon and pion distribution at HFOC, on a logarithmic scale at the top and after renormaliztion on a normal scale at the bottom. The green line is the pion distribution multiplied by 500. It is clear that closing the horizontal slit to ± 0.8 cm gives a huge reduction in the pion contamination.

9 Pion contamination due to slit scattering for the 1.1 GeV/c beam

Slit scattering studies were also done for the 1.1 GeV/c beam. Figure 19 shows the importance of the focus at HFOC. The widths of MS1 and MS2 were both 3.6 mm. In that case the pi/K ratio is 0.7. Closing HFOC to ± 0.8 cm reduces the ratio by more than an order of magnitude.

10 Cloud pion contamination in the 0.8 GeV/c beam

In order to study the cloud pion contamination an area of 4 by 4 cm square at the production target was uniformly populated. The transmission to the end of the beamline was calculated with REVMOC for a variety of slit settings. The area was displaced 1 cm upwards in the vertical plane, so it was between -1 cm and +3 cm. Figure 20 shows the vertical distribution at the production target of pions that make it to the end. The following slit widths were used. MS1 4 mm, IFY 5 mm and HFOC 1.6 cm. The black line shows the distribution with only MS1 closed, the blue line with in addition IFY closed, and the red line with also HFOC closed. The top left figure is on a linear scale. Closing IFY gives such an enormous reduction in the transmission that it is difficult to see. Therefore, the bottom left figure shows the same curves on a logarithmic scale. The top right shows the effect of closing HFOC on a linear scale. It is quite important. This can also be seen in the bottom right plot which gives the ratio of the curves in the top right plot.

Figure 21 shows the results of the same exercise if the width of MS1 is 5 mm and the width of IFY is 6 mm. The reductions are less pronounced. The results are summarized in table 7. For instance, in the case with MS1 4 mm, the number of pions drops from 384,624 to 5,372 if IFY is closed to

5 mm. Then there is again a drop to 972 if HFOC is closed to 1.6 cm.

The conclusion is that sufficient means are available to reduce the cloud pion contamination.

11 Cloud pion contamination in the 1.1 GeV/c beam

Similar calculations were done for the 1.1 GeV/c beam as for the 0.8 GeV/c beam. Some results are given in table 8. If MS1 is closed in addition to MS2 there does not occur a great reduction in the pion intensity that reaches the end of the beam. This is not surprising, because there is only one separator between MS1 and MS2, and that separator gives a kick of only 0.88 mr to the pion beam. However, a much larger reduction occurs if also IFY is closed to 4.8 mm. As in the 0.8 GeV/c case, closing HFOC to 1.4 cm helps even more. The conclusion is that manipulation of the slits makes it possible to sufficiently reduce the cloud pion contamination.

12 Conclusions

An investigation was made of the possibility of a 0.8 GeV/c separated kaon beam branching off from the middle of a existing preliminary design of an 1.1 GeV/c two stage separated kaon beam. It turns out to be possible, due to the fact that the 1.1 GeV/c beam has a vertical focus before the first separation state. A slit at this focus, named IFY, can in principle define an initial source size, and reduce the contamination of cloud pions. However, other sources of contamination also have to be taken into account. Therefore, a horizontal focus HFOC after the last bend is used to help reduce the contamination due to slit scattering. That focus is also useful for a further reduction of the cloud pion contamination. The higher order optics was studied with the ray tracing program ZGOUBI. Although some higher order aberrations cause pions pass to the final focus, a combination of the slits at IFY, MS1 and HFOC, as well as optimization of the two sextupoles and the octupole reduce the pion contamination to an acceptable level, certainly less than the kaon intensity.

For the 0.8 GeV/c design to be feasible, it is important that the existing 1.1 GeV/c design does also work. It was found that the higher order aberrations can be minimized sufficiently. However, slit scattering gave a considerable contamination of pions. Therefore, the existing design was modified by creating an extra horizontal focus after the last bending magnet B4. A slit at this focus also helps with a reduction of the cloud pion contamination. This slightly modified existing design will work, and give a sufficiently small pion contamination.

Table 1: Beamline Elements for 1.1 GeV/c beam

element	length (cm)	pole radius (cm)	design pole field (kG)
Quadrupole			
Q1	40.0	12.5	9.200
Q2	40.0	12.5	-11.388
Q3	40.0	12.5	8.400
Q4	40.0	12.5	-8.926
Q5	40.0	12.5	-8.960
Q6	40.0	15.0	8.353
Q7	40.0	15.0	-6.385
Q8	40.0	12.5	-9.865
Q9	50.0	15.0	9.356
Q10	50.0	10.0	-9.200
Q11	50.0	10.0	11.726
Sextupole			
S1	20.0	15.0	0.719
S2	20.0	15.0	-1.479
S3	20.0	12.5	-1.176
S4	20.0	10.0	0.711
Octupole			
O1	20.0	12.5	NA
O2	20.0	12.5	NA

Table 2: Dipole and separator characteristics for 1.1 GeV/c beam

	entr/exit angle to pole face (deg)	length (cm)	pole gap (cm)	field (kG)	bend angle (deg)
dipole					
B1	0.0/0.0	90.0	10.0	14.230	20.0
B2	12.0/12.0	100.0	15.0	15.375	24.0
B3	0.0/0.0	100.0	15.0	18.572	-29.0
B4	0.0/0.0	160.7	15.0	17.927	45.0
separator	length (m)	plate width (cm)	plate gap (cm)	plate gap voltage (kV)	magnetic field (kG)
SEP1	2.00	40	10.00	550	0.201
SEP2	2.00	40	10.00	550	0.201

Table 3: Beamline Elements for 0.8 GeV/c beam

element	length (cm)	pole radius (cm)	design pole field (kG)
Quadrupole			
Q1	40.0	12.5	6.763
Q2	40.0	12.5	-8.285
Q3	40.0	12.5	6.902
Q4	40.0	12.5	-6.602
Q5	40.0	12.5	-7.209
Q6	40.0	12.5	9.288
Q7	50.0	12.5	-8.677
Q8	50.0	12.5	11.212
Sextupole			
S1	20.0	15.0	-0.783
S2	20.0	15.0	-0.667
Octupole			
O1	20.0	12.5	NA

Table 4: Dipole and separator characteristics for 0.8 GeV/c beam

	entr/exit angle to pole face (deg)	length (cm)	pole gap (cm)	field (kG)	bend angle (deg)
dipole					
B1	0.0/0.0	90.0	10.0	10.349	20.0
B2	12.0/12.0	100.0	15.0	11.182	24.0
B3	0.0/0.0	129.4	15.0	18.000	-29.0
separator	length (m)	plate width (cm)	plate gap (cm)	plate gap voltage (kV)	magnetic field (kG)
SEP1	2.00	40	10.00	550	0.215
SEP2	2.00	40	10.00	550	0.215

Table 5: Kaon acceptance and pion contamination as function of slits for 2 mm vertical source

IFY (mm)	MS1 (mm)	HFOC (cm)	N(kaons)	N(pions)	pi/K	acceptance (msr.percent)
6	5	open	684,868	3,327	2.42	6.8
5	5	open	660,808	2,769	2.10	6.6
5	4	open	651,280	1,526	1.17	6.5
5	3	open	603,136	769	0.64	6.0
6	5	1.6	674,048	415	0.31	6.7
5	5	1.6	647,032	342	0.26	6.5
4	5	1.6	591,380	282	0.24	5.9
3	5	1.6	492,608	186	0.18	4.9
5	4	1.6	639,108	184	0.14	6.4
5	3	1.6	590,980	86	0.07	5.9
5	2	1.6	453,032	32	0.04	4.5
5	4	1.4	623,688	162	0.13	6.2
5	4	1.2	587,536	140	0.12	5.9
5	4	1.0	533,756	119	0.11	5.3

Table 6: Kaon acceptance and pion contamination as function of slits for 4 mm vertical source

IFY (mm)	MS1 (mm)	HFOC (cm)	N(kaons)	N(pions)	pi/K	acceptance (msr.percent)
6	5	open	676,472	3,379	2.50	6.8
5	5	open	644,752	2,925	2.27	6.4
5	4	open	627,076	1,630	1.30	6.3
5	3	open	557,704	783	0.70	5.6
6	5	1.6	667,504	408	0.30	6.7
5	5	1.6	633,028	383	0.30	6.3
4	5	1.6	579,240	282	0.24	5.8
3	5	1.6	473,972	169	0.18	4.7
5	4	1.6	614,264	195	0.16	6.1
5	3	1.6	541,712	76	0.07	5.4
5	5	1.4	614,720	324	0.26	6.1
5	5	1.2	581,580	288	0.25	5.8
5	5	1.0	530,108	231	0.22	5.3

Table 7: Cloud pions as function of slits for the 0.8 GeV/c beam

MS1 (mm)	IFY (mm)	HFOC (cm)	N(pions)
5	open	open	508,525
4	open	open	384,624
5	6	open	32,142
5	5	open	12,090
4	6	open	12,917
4	5	open	5,372
3	5	open	2,450
5	6	1.6	10,870
4	5	1.6	974

Table 8: Cloud pions as function of slits for the 1.1 GeV/c beam

IFY (mm)	MS1 (mm)	MS2 (mm)	HFOC (cm)	N(pions)
open	open	3.6	open	188,431
open	3.6	3.6	open	51,897
4.8	3.6	3.6	open	10,178
4.8	3.6	3.6	1.4	2,996
open	3.6	3.6	1.4	26,945

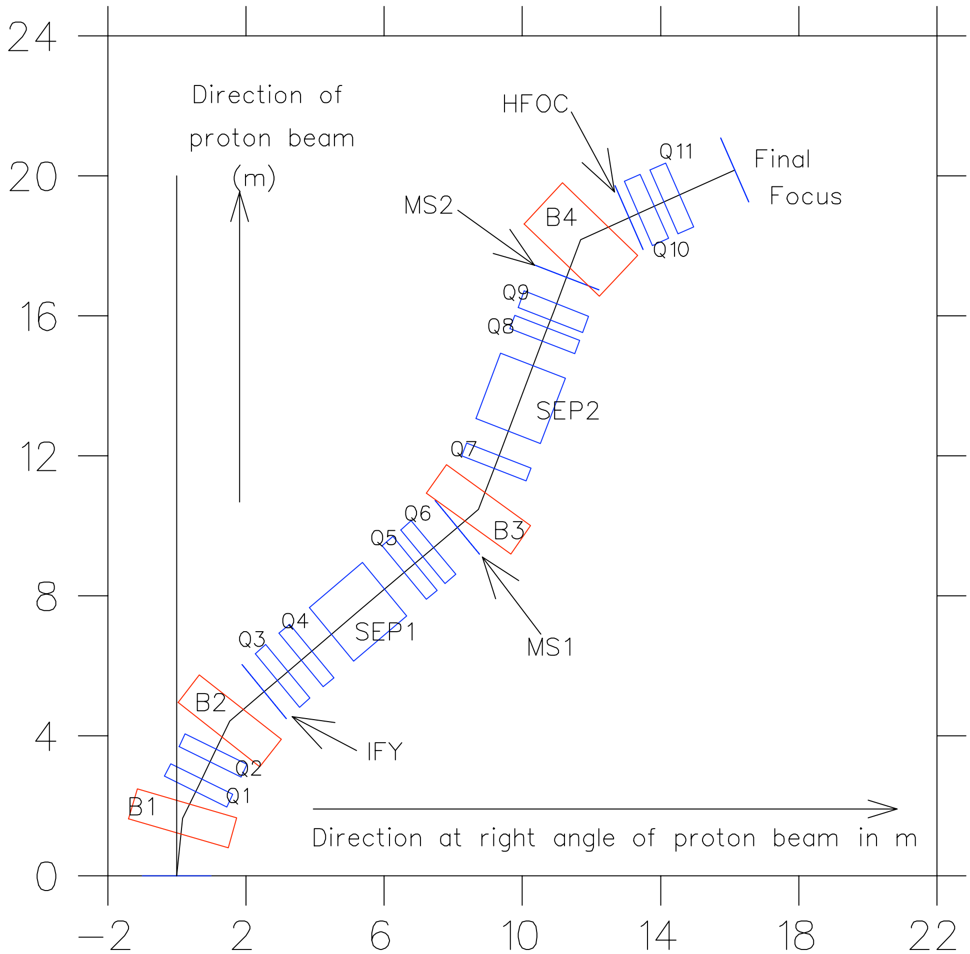


Figure 1: Layout of the 1.1 GeV/c beam.

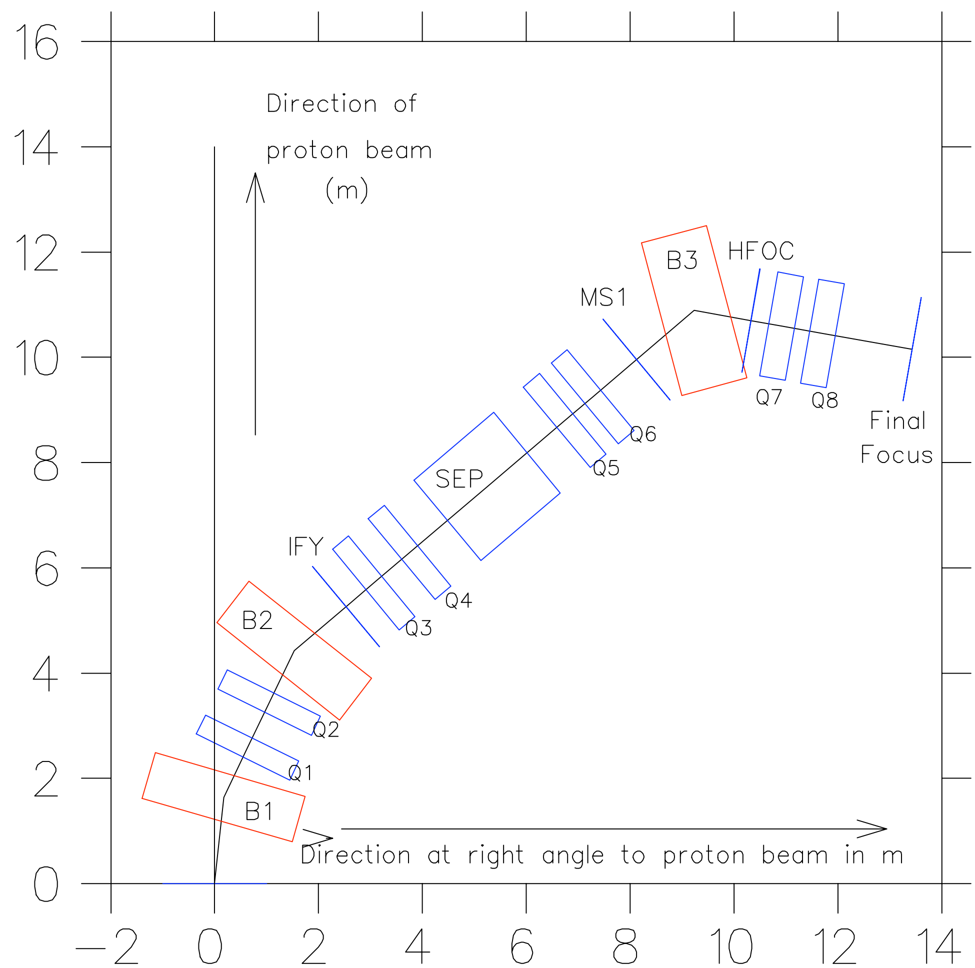


Figure 2: Layout of the 0.8 GeV/c beam.

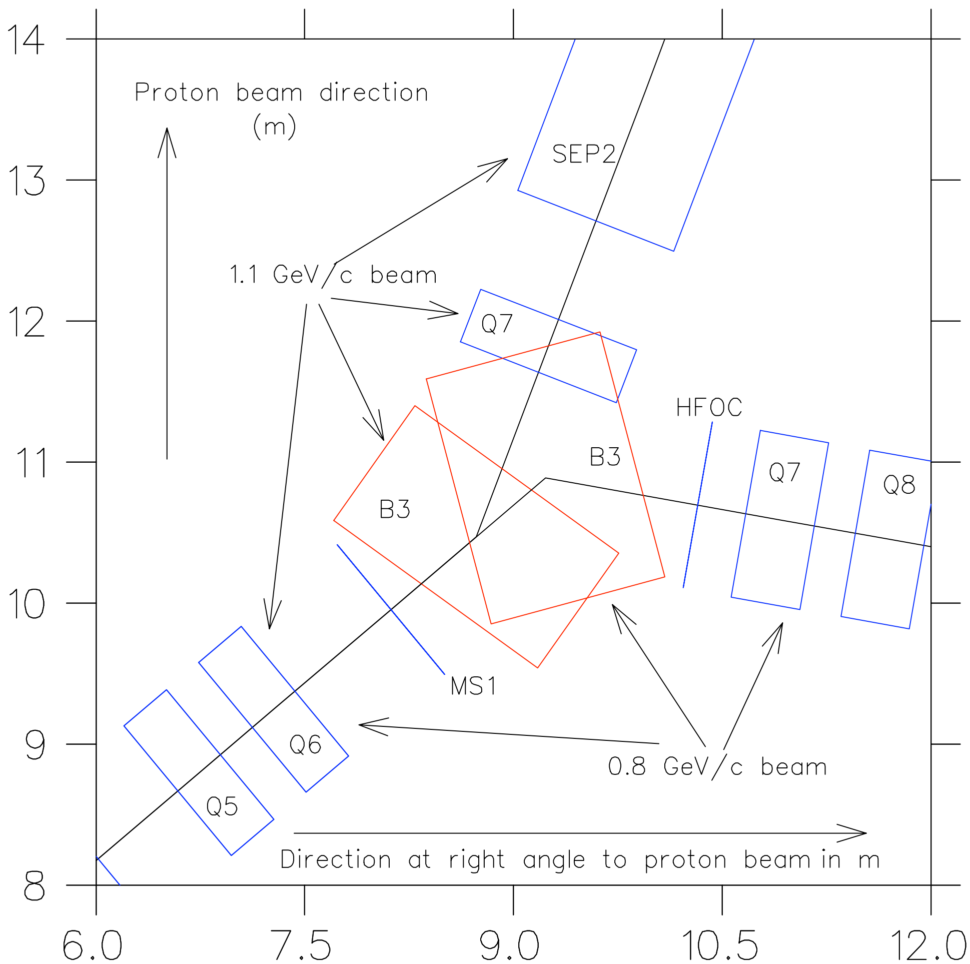


Figure 3: Layout of the area shared by the 0.8 GeV/c beam and the 1.1 GeV/c beam.

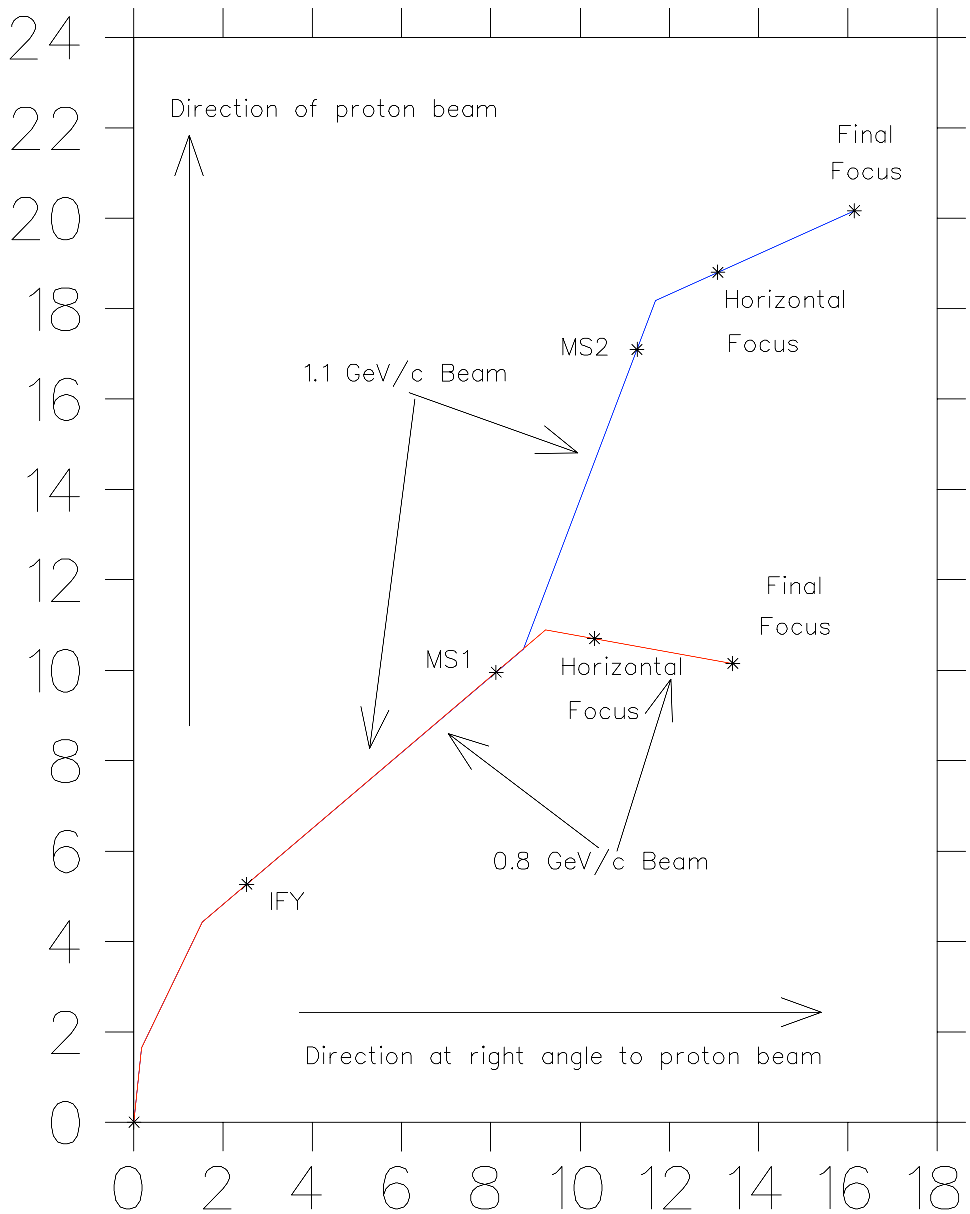


Figure 4: Layout of the center lines of the 0.8 GeV/c beam and the 1.1 GeV/c beam.

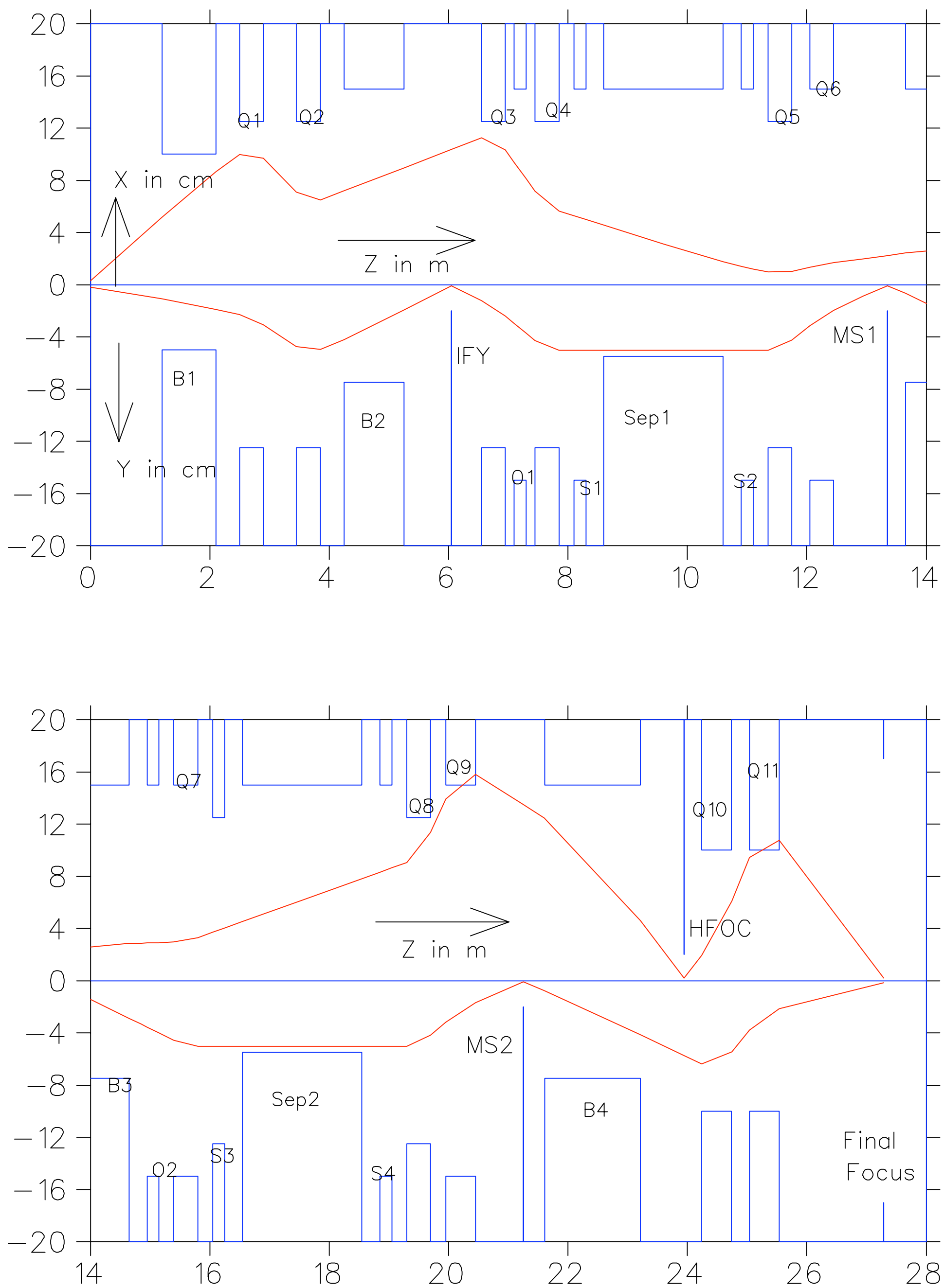


Figure 5: First order beam envelopes for the central momentum of the 1.1 GeV/c beam from TRANSPORT. The initial horizontal angle is 43 mr, the vertical angle is 9 mr. X is 3.5 mm and Y is 2 mm. All numbers indicate half widths.

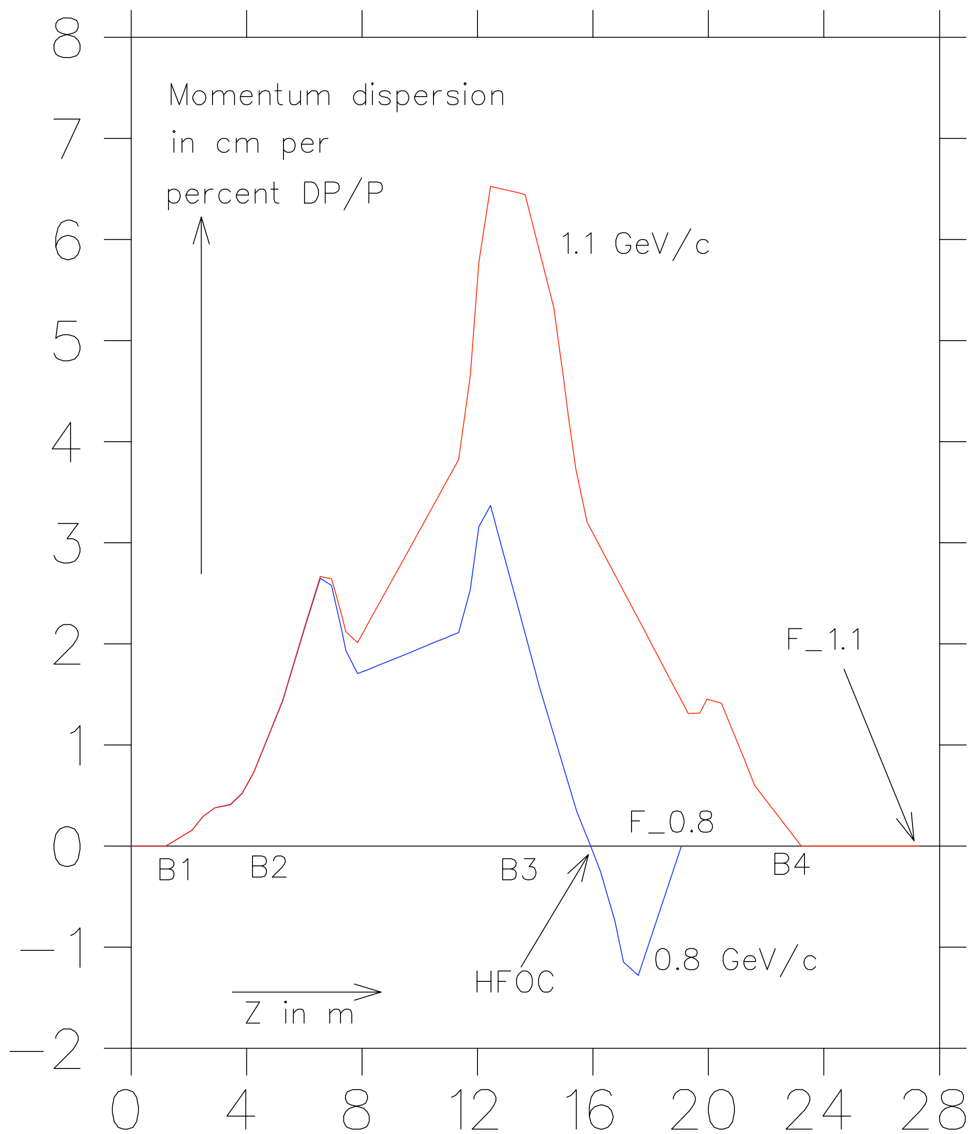


Figure 6: Momentum dispersion for the 0.8 GeV/c and the 1.1 GeV/c beam.

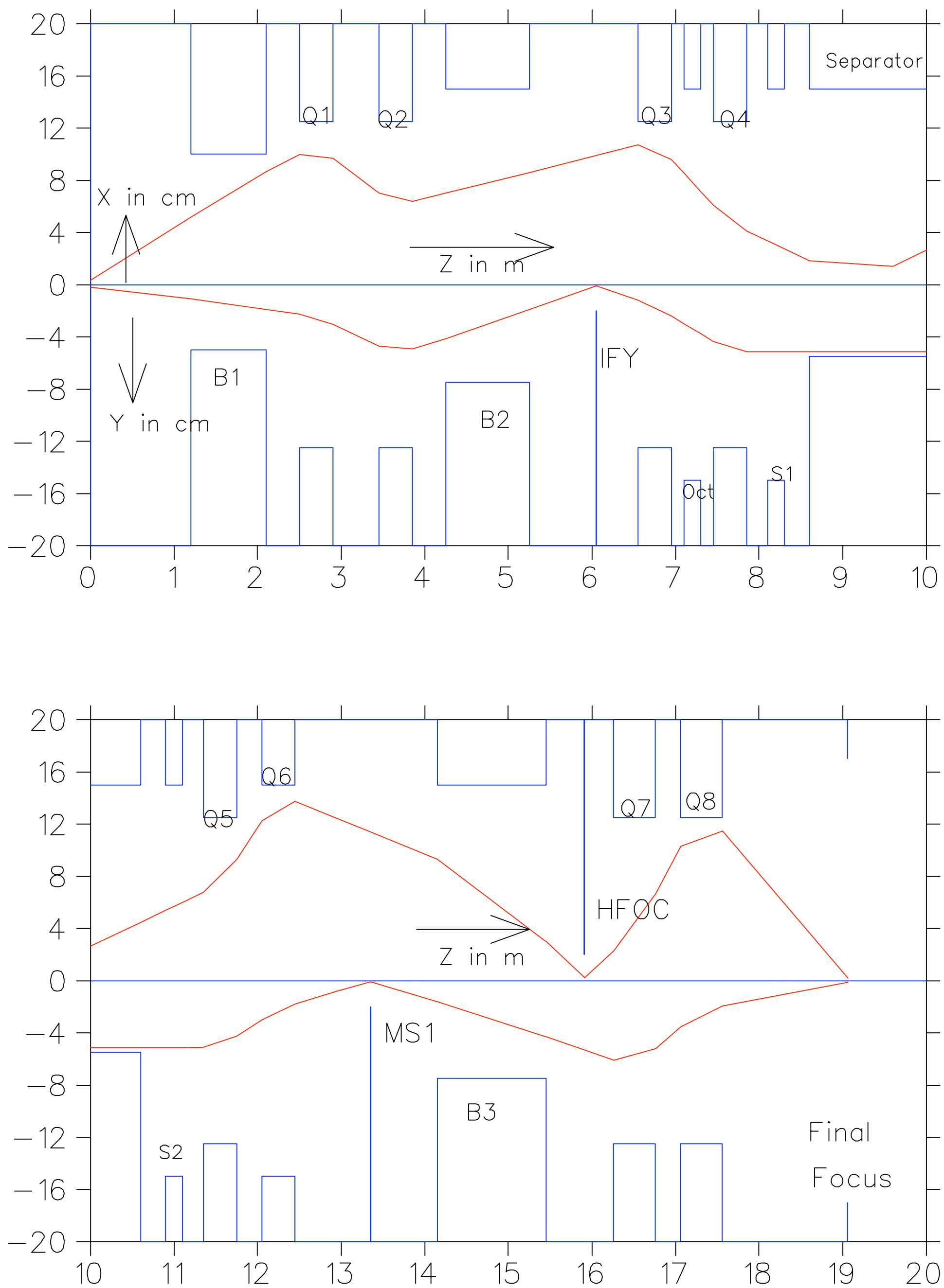


Figure 7: First order beam envelopes for the central momentum of the 0.8 GeV/c beam from TRANSPORT. The initial horizontal angle is 43 mr, the vertical angle is 9 mr. X is 3.5 mm and Y is 2 mm. All numbers indicate half widths.

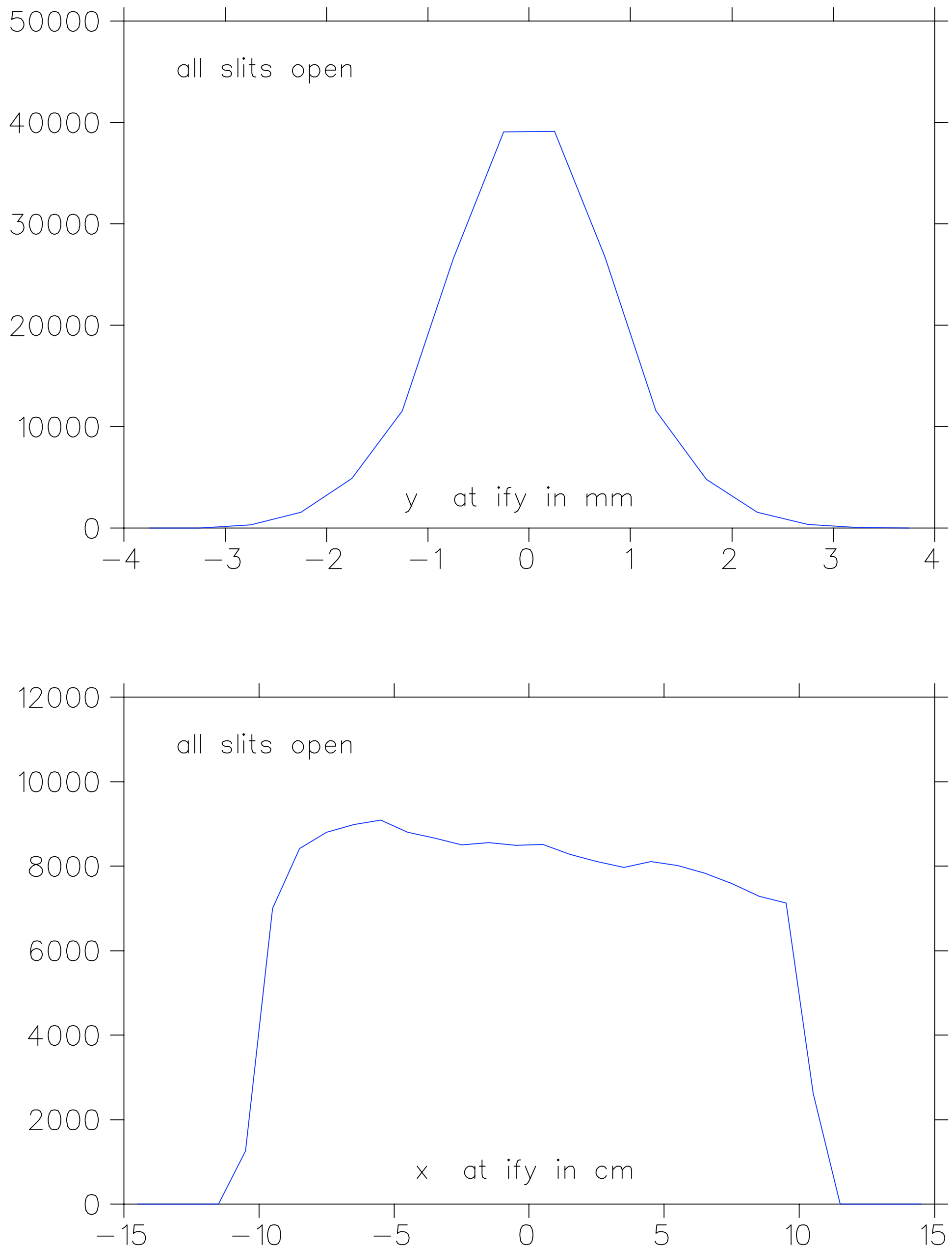


Figure 8: The vertical and horizontal beam spot at IFY for the 0.8 GeV/c beam from the higher order Monte Carlo calculation with ZGOUBI.

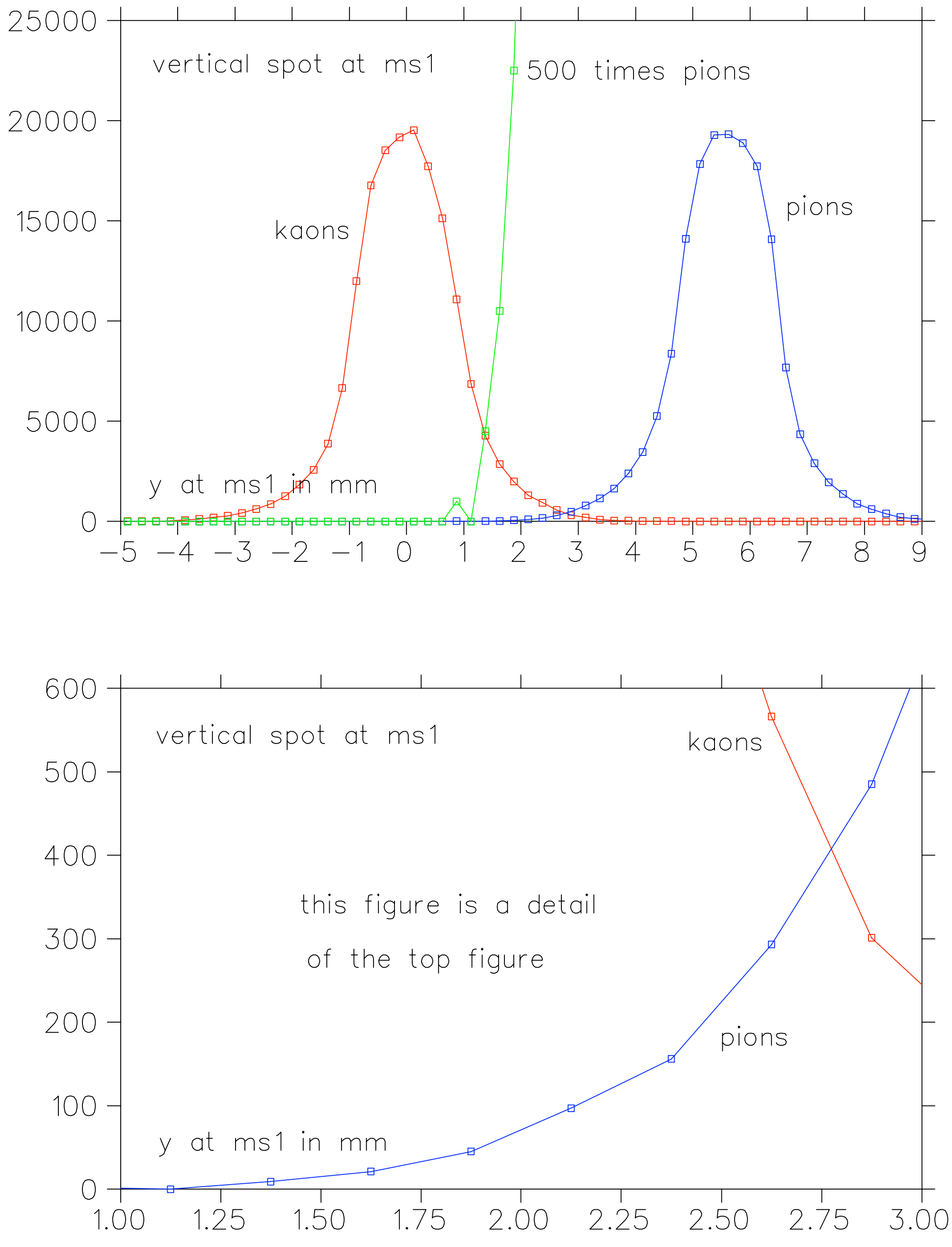


Figure 9: ZGOUBI result for the 0.8 GeV/c beam. The vertical beam spot at MS1 for kaons and pions. The green line shows the pion distribution multiplied by 500.

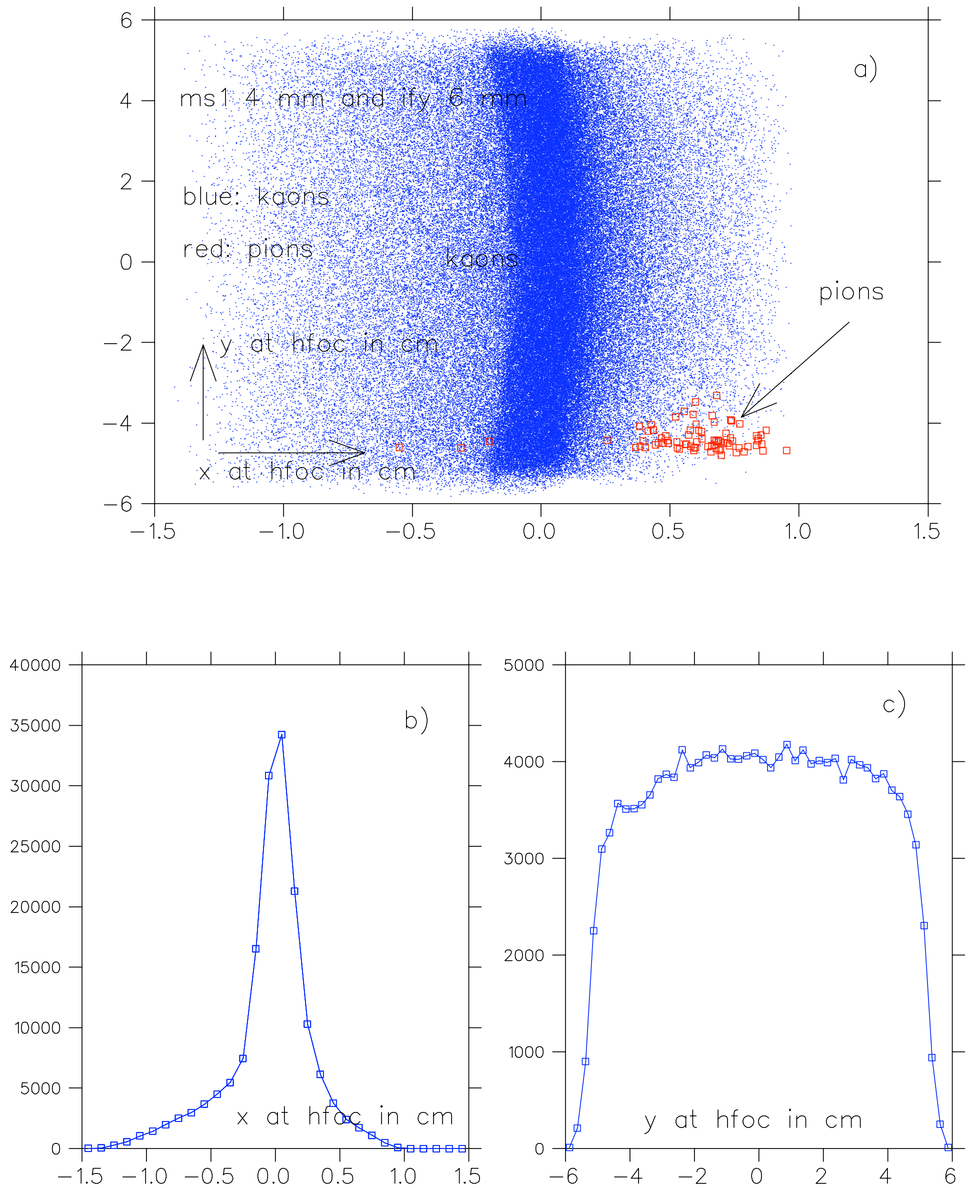


Figure 10: ZGOUBI result for the 0.8 GeV/c beam. Top figure gives a x-y scatter plot a HFOC for kaons and pions when MS1 has a 4 mm full width and IFY 6 mm. The bottom figures give the projected distributions for kaons.

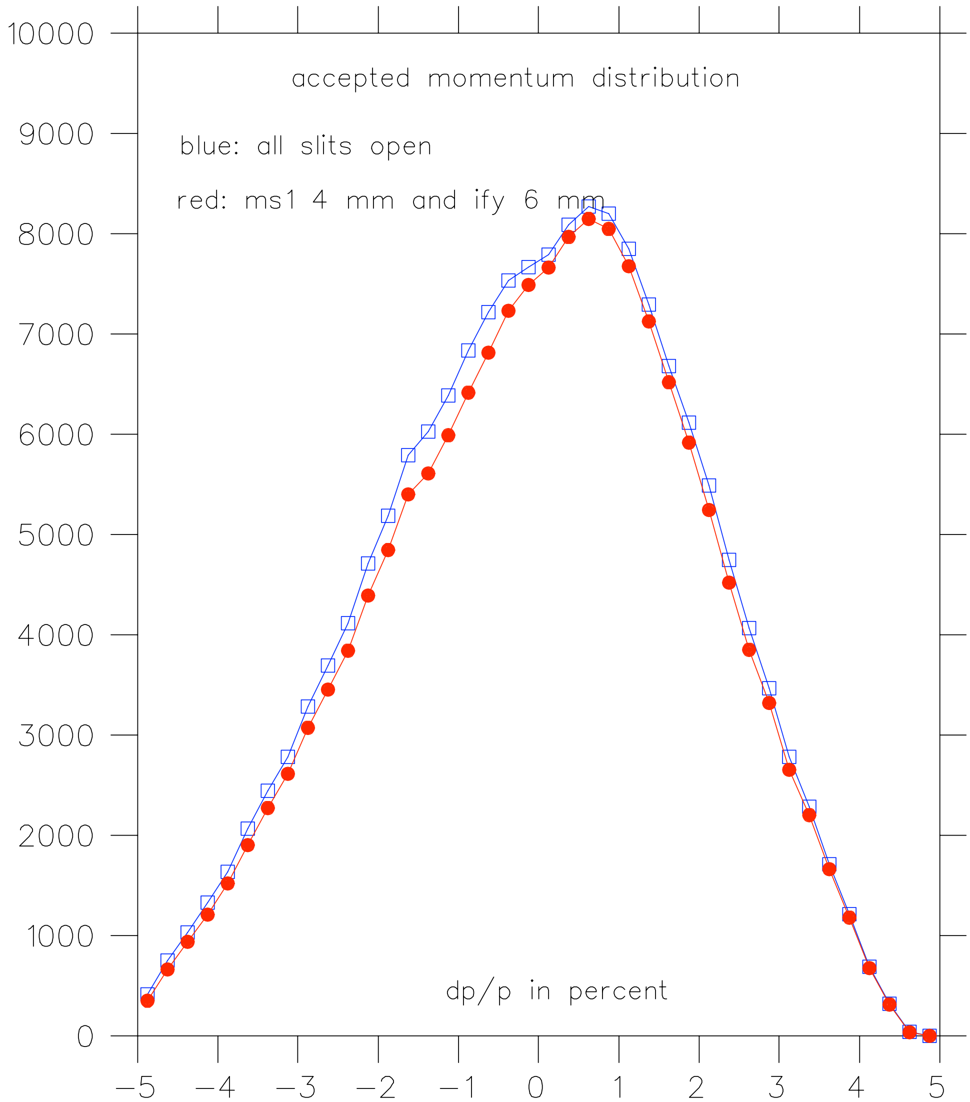


Figure 11: ZGOUBI result for the 0.8 GeV/c beam. The accepted momentum distribution

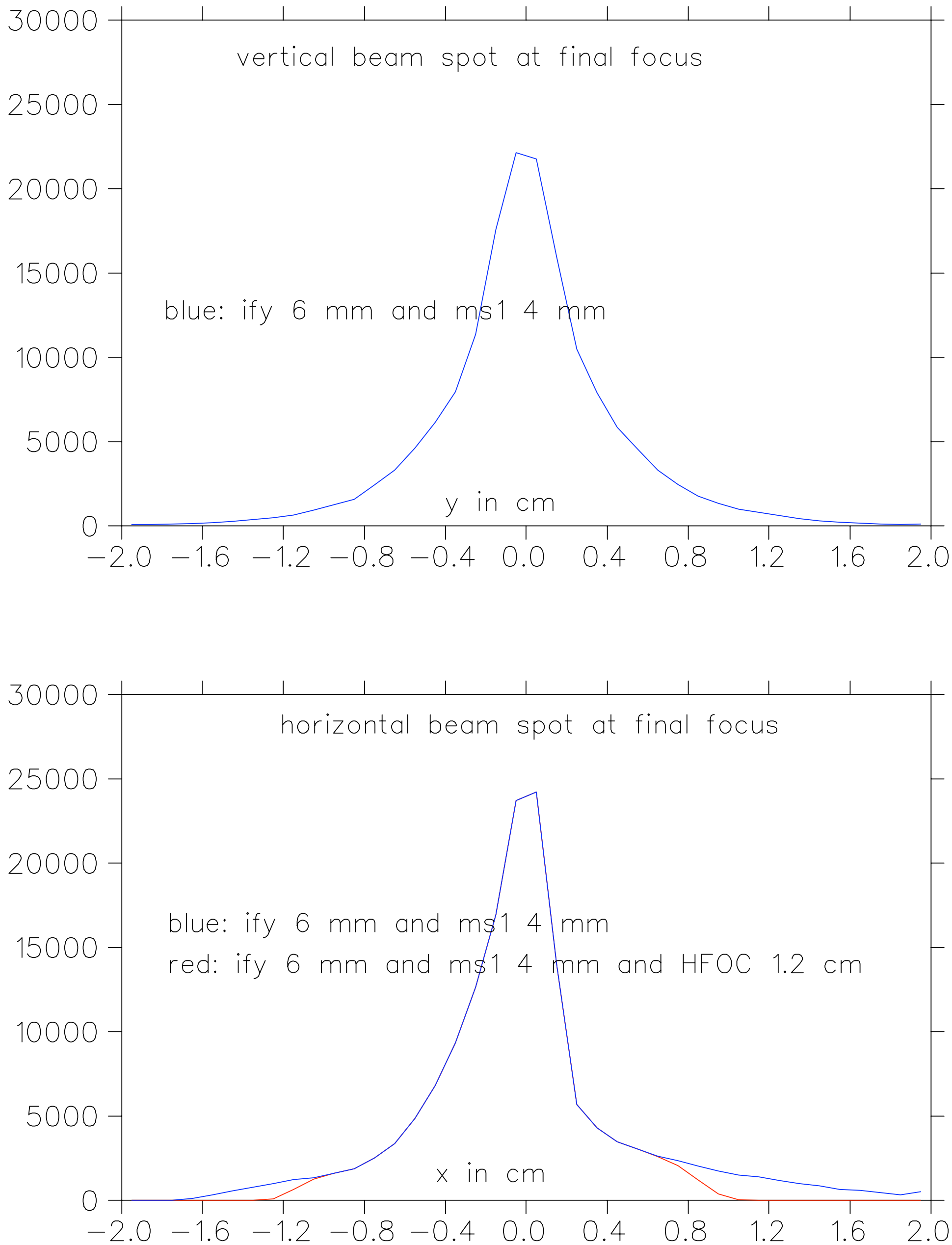


Figure 12: ZGOUBI result for the 0.8 GeV/c beam. Vertical and horizontal beam spots at the final focus.

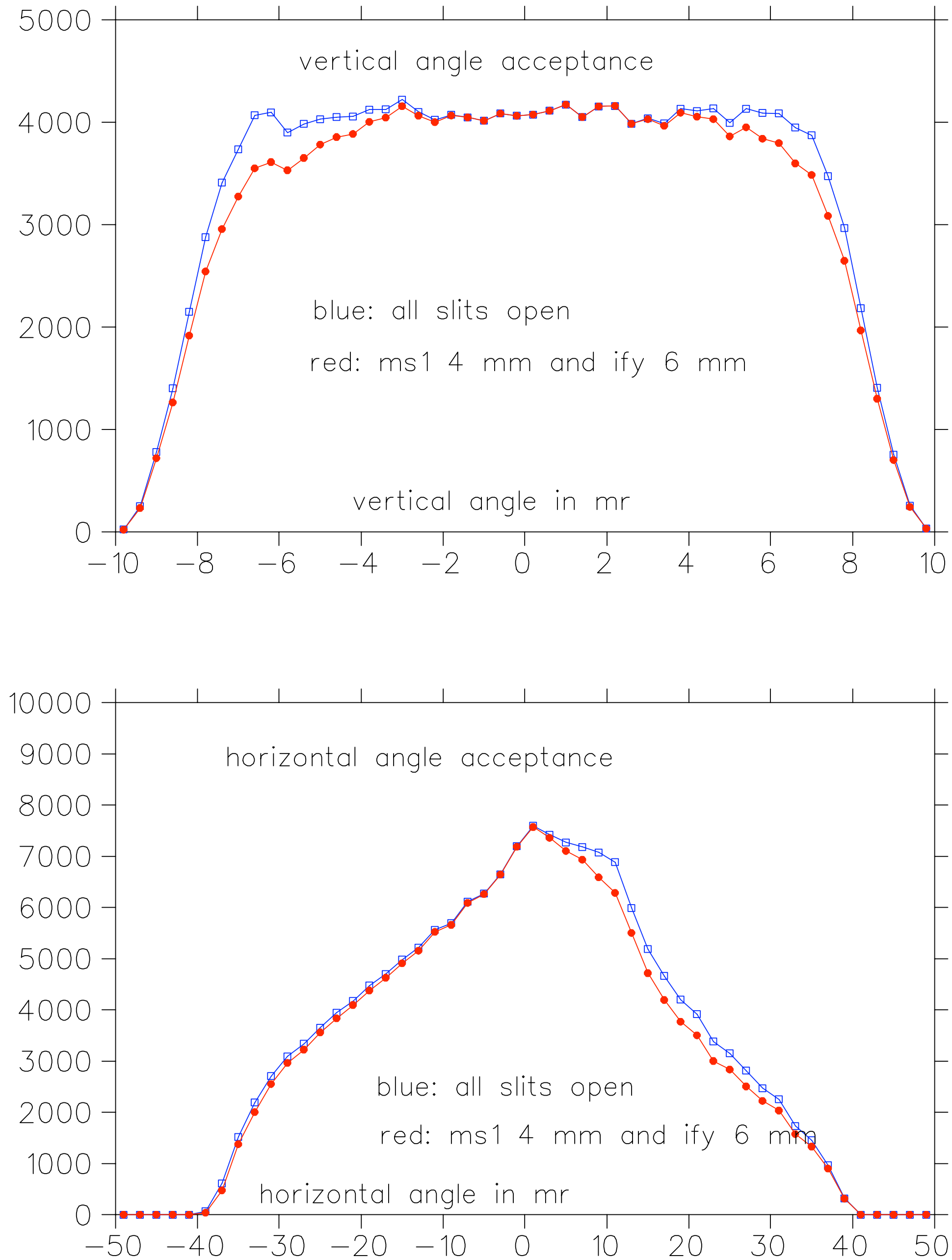


Figure 13: ZGOUBI result for the 0.8 GeV/c beam. Vertical and horizontal angle acceptance averaged over the accepted momentum distribution.

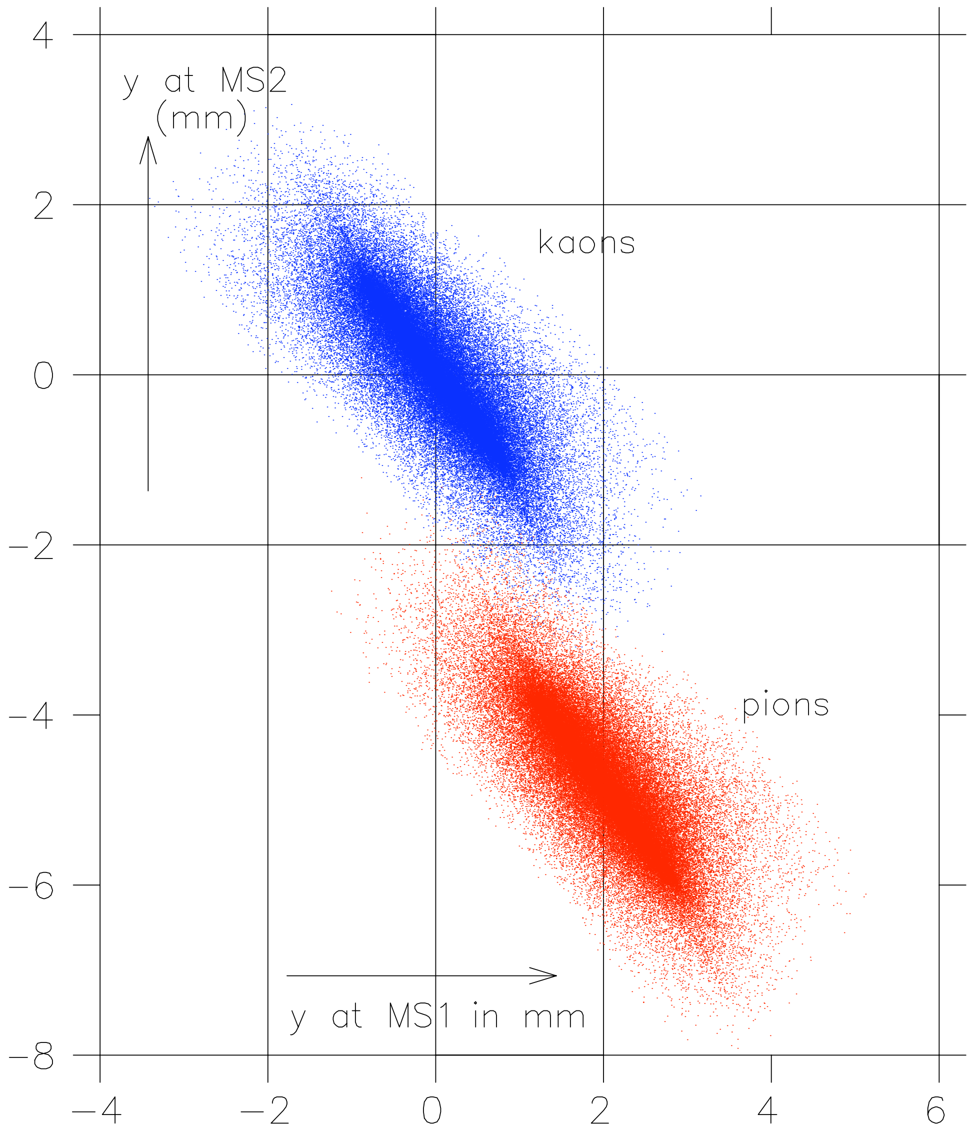


Figure 14: ZGOUBI results for the 1.1 GeV/c beam. Scatter plots of y at MS2 versus y at MS1 for kaons and pions. The tail of the pions extends to within 2 mm of the axis at MS2.

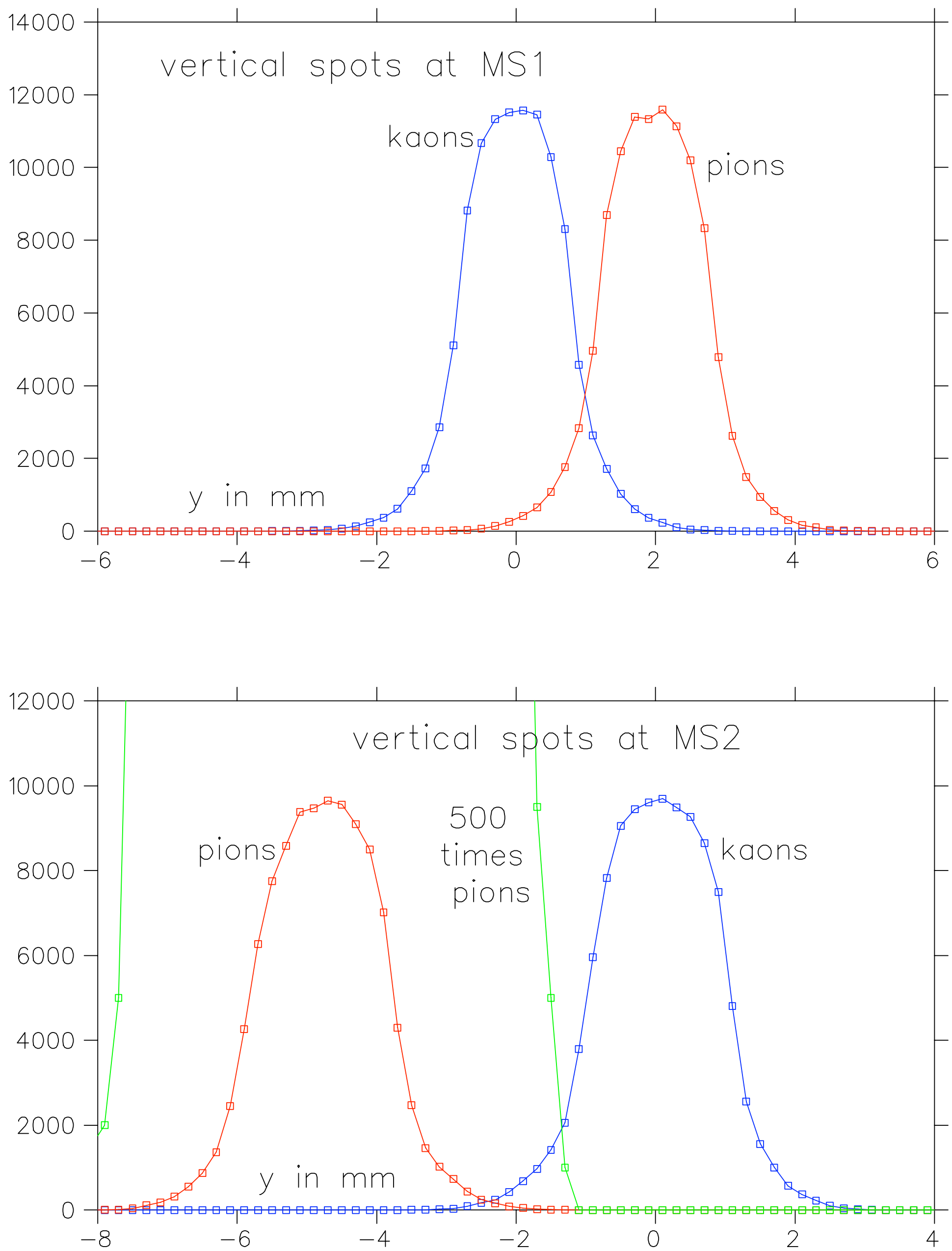


Figure 15: ZGOUBI results for the 1.1 GeV/c beam. The projected distributions of figure 14. The green line indicates the pion distribution multiplied by 500.

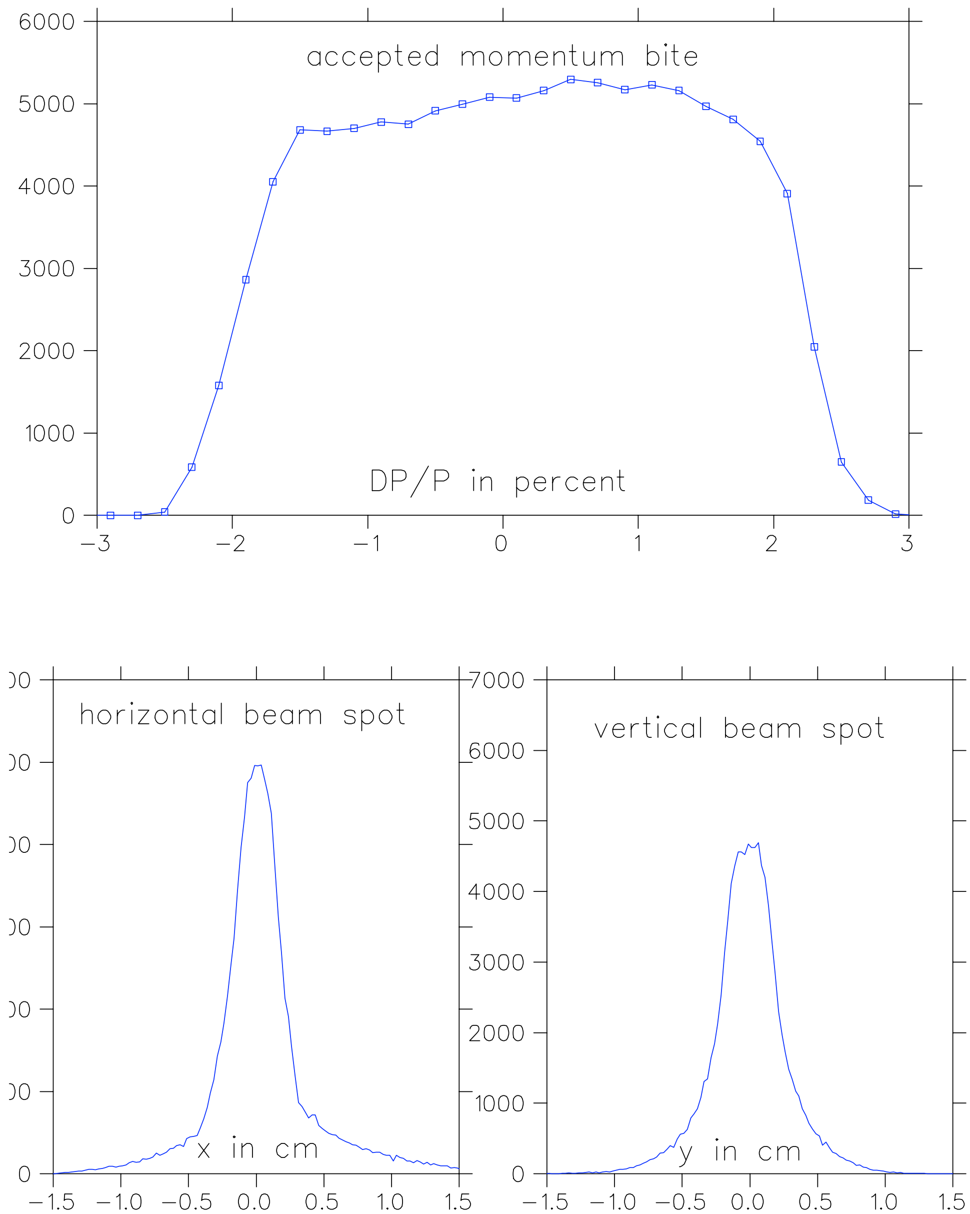


Figure 16: ZGOUBI results for the 1.1 GeV/c beam. The accepted momentum distribution, and the horizontal and vertical beam spots at the final focus.

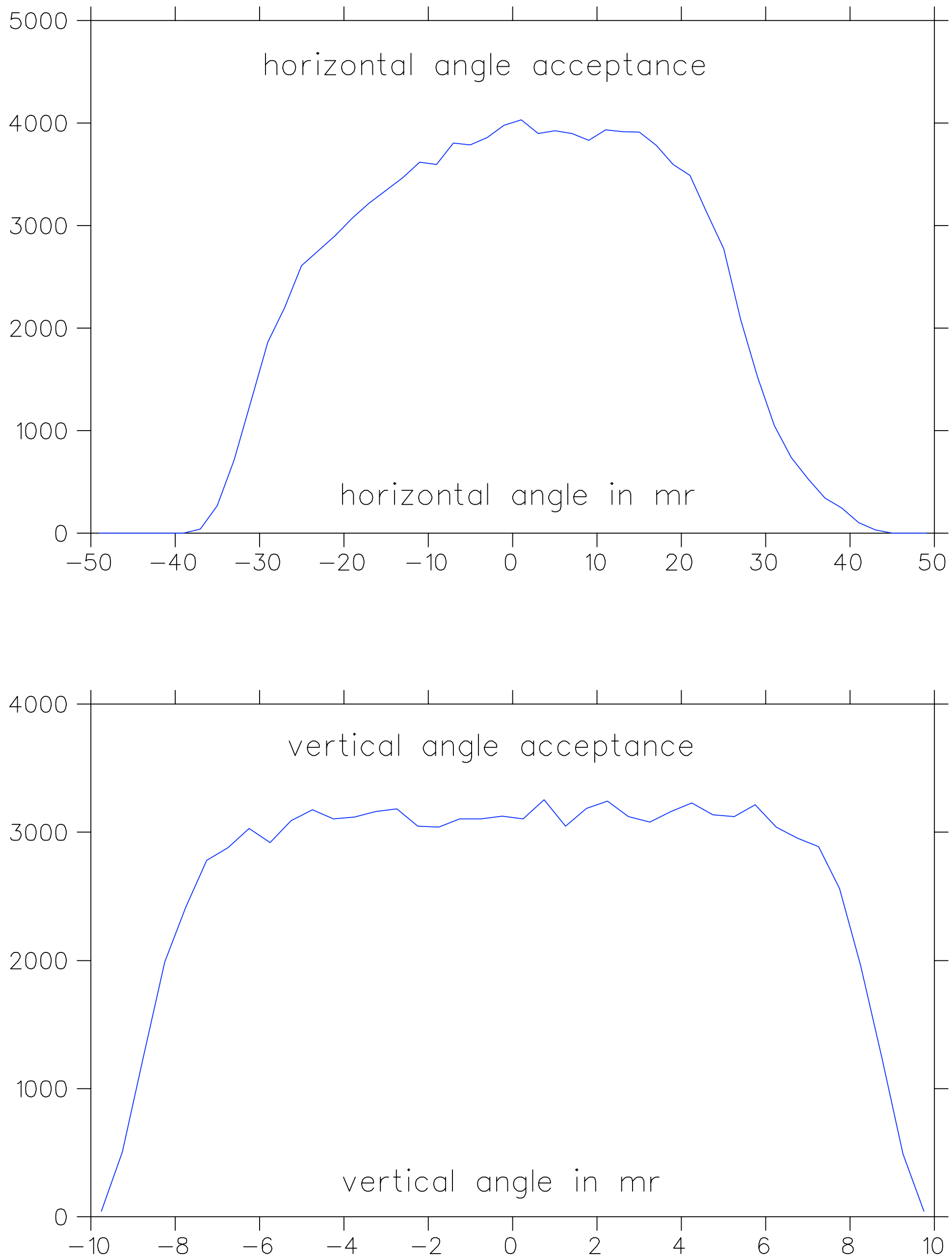


Figure 17: ZGOUBI results for the 1.1 GeV/c beam. The horizontal and vertical angle acceptance, averaged over the accepted momentum bite.

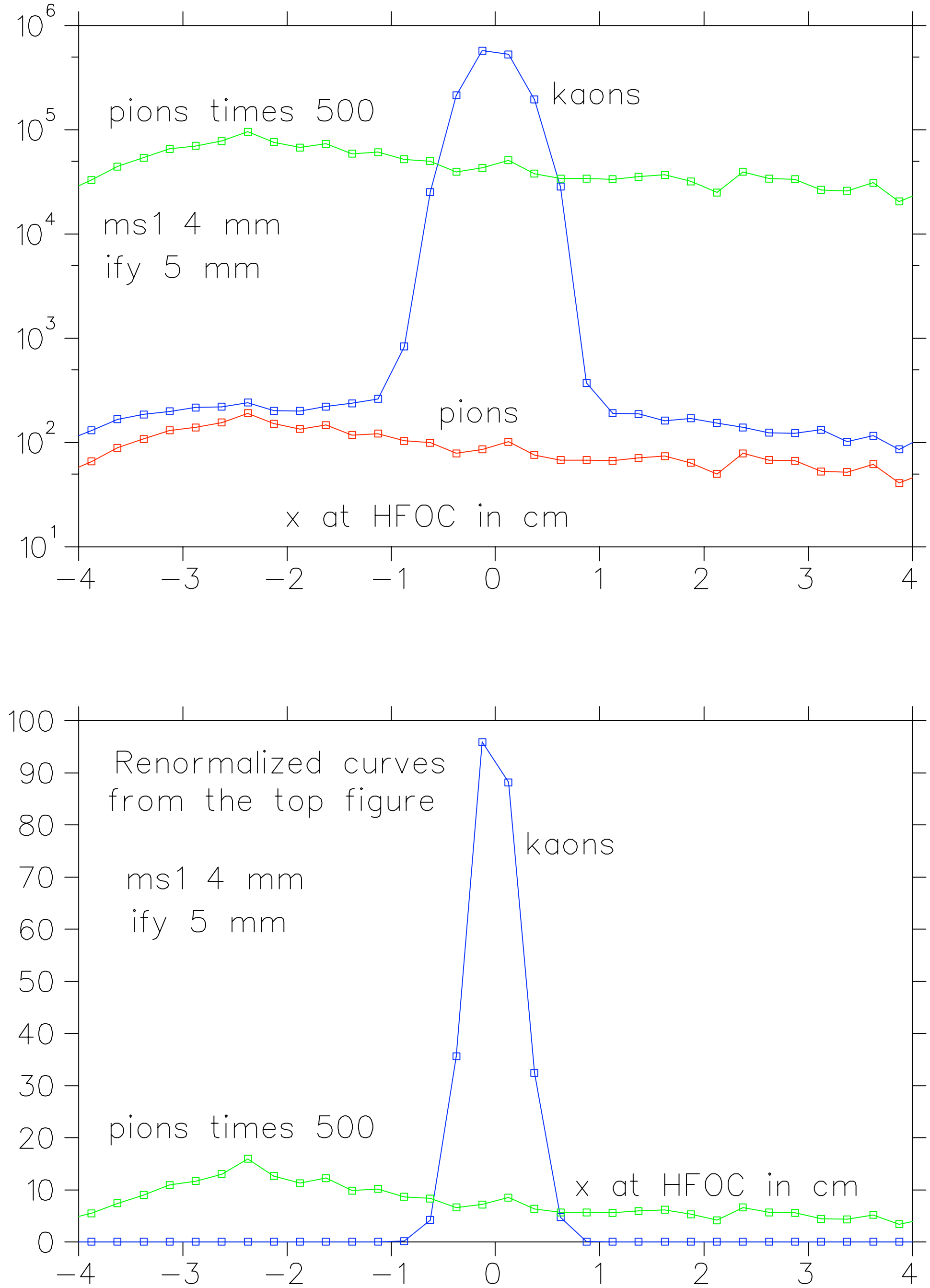
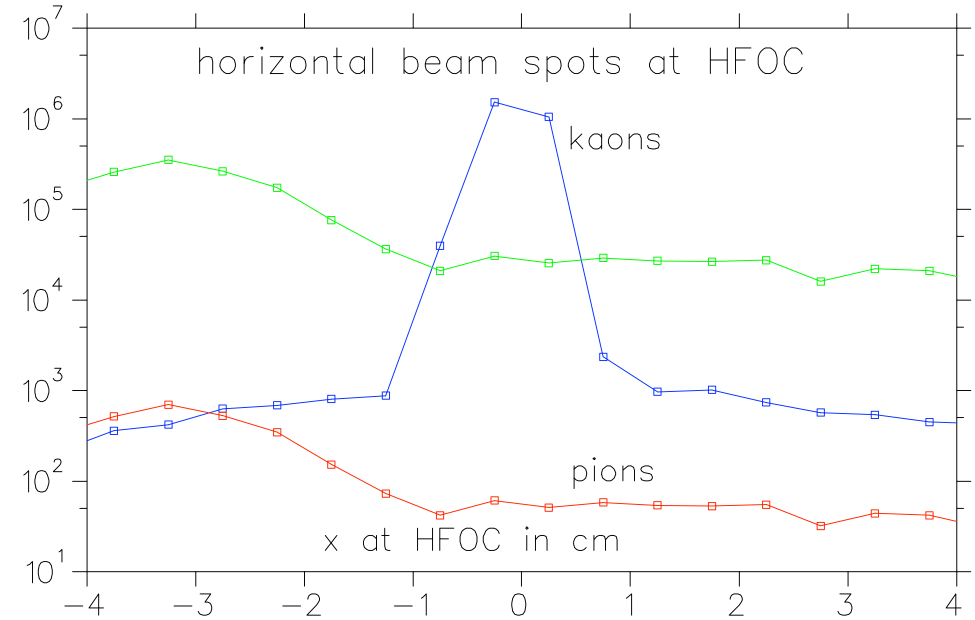


Figure 18: REVMOC result for the 0.8 GeV/c beam. Horizontal beam spots at HFOC for kaons and pions, logarithmic scale at the top and renormalized scale at the bottom. The pion distribution is wide due to scattering in the 30 cm long slits at IFY and MS1.



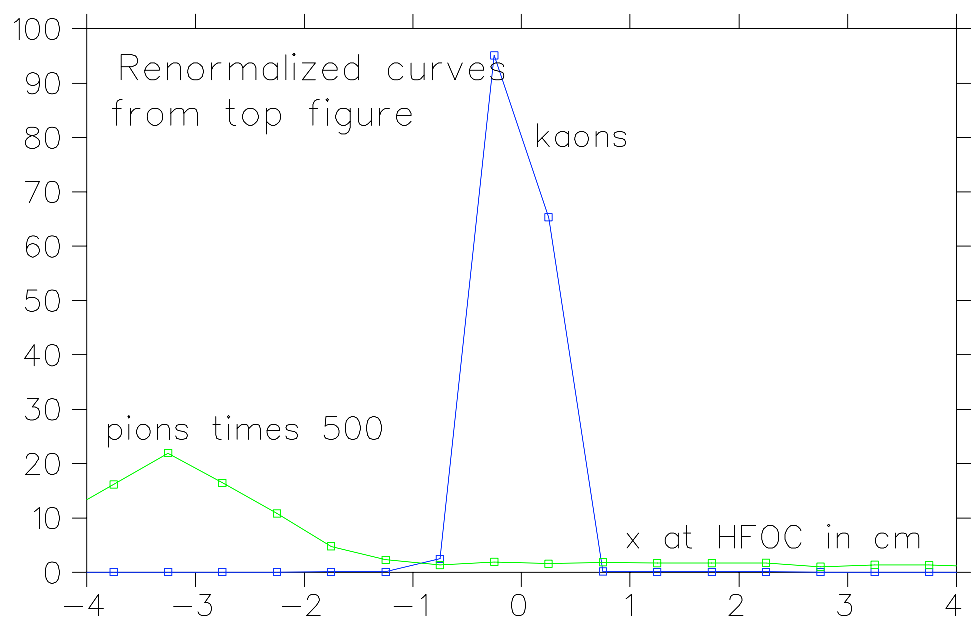


Figure 19: REVMOC results for the 1.1 GeV/c beam. The horizontal beam spots at HFOC for kaons and pions. IFY is open. MS1 and MS2 are both closed to a 3.6 mm full width aperture. The pion distribution is wide due to scattering in the 30 cm long slits at MS1 and MS2. The kaon distribution also has a tail due to scattering. The green line gives the pion distribution multiplied by 500.

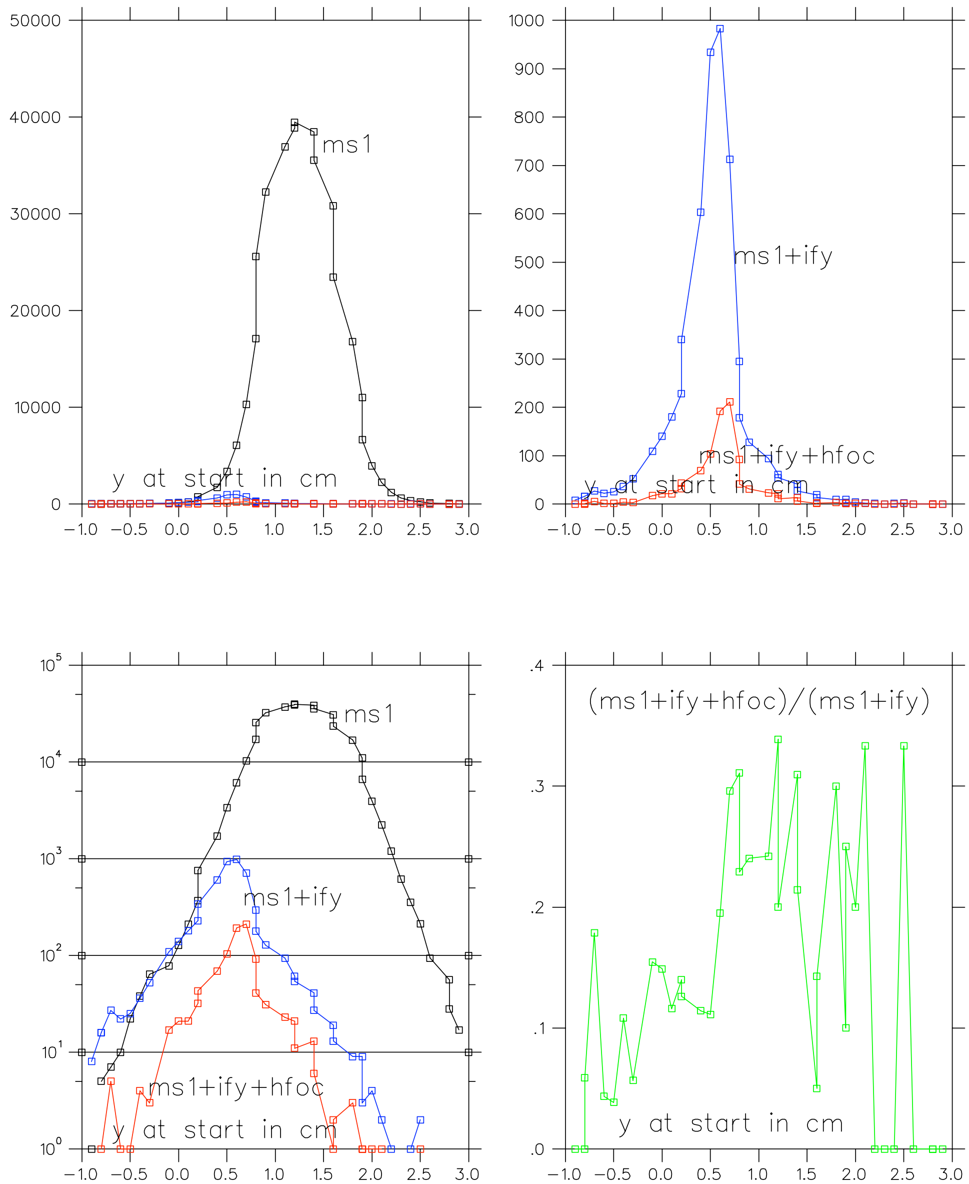


Figure 20: REVMOC results for cloud pions for the 0.8 GeV/c beam. Accepted vertical area at the production target for various slit settings. The slits that are closed are indicated. MS1 is 4 mm full aperture. IFY is 5 mm full aperture and HFOC is 1.6 cm full aperture. All slits are 30 cm long with tapered surfaces.

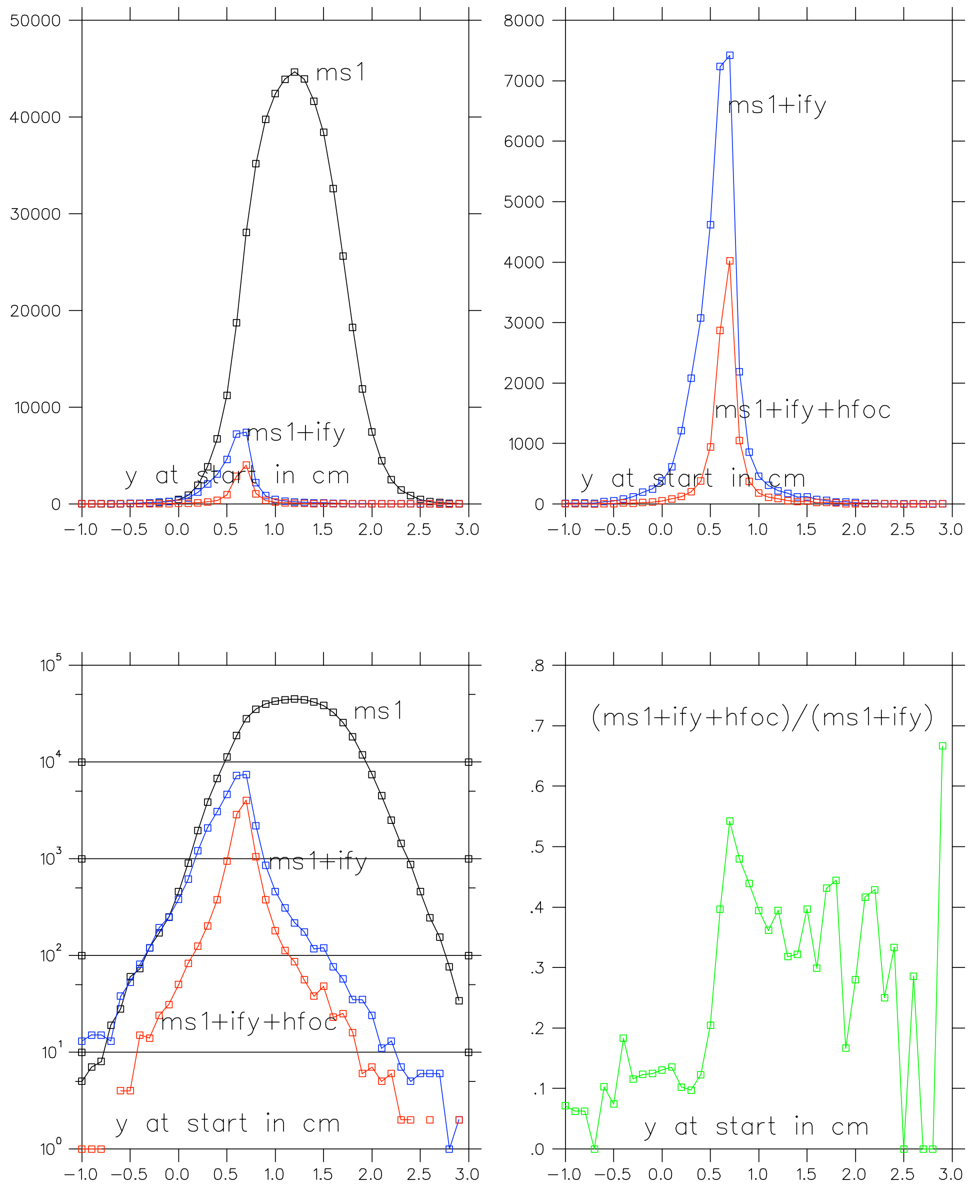


Figure 21: REVMOC results for cloud pions for the 0.8 GeV/c beam. Accepted vertical area at the production target for various slit settings. The slits that are closed are indicated. MS1 is 5 mm full aperture. IFY is 6 mm full aperture and HFOC is 1.6 cm full aperture. All slits are 30 cm long with tapered surfaces.