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 POSITIVE kaon beam which branches off from a proposed but not yet finalized 1.1 GeV/c kaon beam. The total acceptance of the 20.3 m long beam is about 4.5 msr percent DP/P. The contamination due to higher order aberrations, cloud pions, muons and slit scattering has been studied. 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. A crucial role is played by a horizontal focus after the last bending magnet.

Contents

1 Beam layout and optics

In an earlier report the possibility of a 0.8 GeV/c beam as a branch of the 1.1 GeV/c beam was investigated. Since that report some important changes have occurred to the first stage of the 1.1 GeV/c beam. In particular, the distance from the production target to the first bending magnet was changed from 1.2 m to 2.0 m. Therefore, a new optics design was required for the 0.8 GeV/c beam.

The new layout is given in figure 1. The beam takes off at an angle of 6 degrees to the proton beam from a 5.4 cm long Nickel production target. A 2.5 mm thick Beryllium window is placed 40 cm from the production target. The first bend of 18 degrees starts 2.0 m from the production target. It is followed by a 12.5 cm radius quadrupole doublet Q1-Q2 that focusses the beam at the intermediate vertical focus IFY, 1.0 m downstream of the 26 degrees bending magnet B2. A 50 micron stainless steel window is placed 15 cm downstream of IFY. The 12.5 cm radius doublet Q3-Q4 makes the beam vertically parallel in the separator and contains the beam horizontally. The characteristics for the separator in the 1.1 GeV/c beam have not yet been finalized. Until now, a length of 2.0 m was assumed. However, it was found necessary to increase the length to 2.5 m. This will also be beneficial for the cleanliness of the 1.1 GeV/c beam, when it gets eventually built. It is assumed that an electric gradient of 50 kV/cm is used over an 11 cm vertical gap. This gives a total voltage over the gap of 550 kV. The 12.5 cm radius quadrupole Q5 and the 15 cm radius quadrupole Q6 make a vertical focus at the position MS1, and a horizontal focus at HFOC, after bending magnet B3. At MS1 a vertical slit removes most of the pions which are displaced about 6.5 mm from the horizontal plane. At the horizontal focus HFOC the beam has zero dispersion in position but not in angle. This slit is crucial for the removal of contamination caused by slit scattering and muons. The final 12.5 cm radius doublet Q7-Q8 focusses the beam at the final focus, 1.5 downstream of the exit of Q8.

The beam contains two sextupoles just before and just after the separator. An octupole is placed between Q3 and Q4. The corrections of the vertical aberrations at MS1 are not perfect, but they are sufficient to obtain a clean kaon beam.

The beam line elements are listed in tables 1 and 2. The beam envelopes are given in figure 2 for zero momentum bite and ± 3 percent $\Delta P/P$. The momentum dispersion is about 5.0 cm per percent $\Delta P/P$ close to Q6. The angle used for the envelopes were ± 9 mr vertically and ± 35 mr horizontally.

1.1 Slits

There are three sets of slits. Vertical slits at IFY and at MS1, and horizontal slits at HFOC. The horizontal slits are modeled as zero length apertures. The IFY slits and MS1 slits are made of Tungsten. The IFY slit is 30 cm long. The central 10 cm are flat, the other parts are tapered with an angle of 25 mr. For example, a ± 3 mm aperture in the center goes with a ± 5.5 mm aperture at beginning and end. The MS1 slit is 50 cm long. The central 10 cm is flat. Beginning and end are tapered with an angle of 25 mr. For example, a central aperture of ± 2.5 mm goes with an aperture of ± 6.5 mm at beginning and end.

2 Relative normalization of pion intensity to kaon intensity

The length of the beam is 20.3 m, 0.7 m longer than the length of beamline LESB3 at Brookhaven. If the separators in LESB3 are turned off then there are 500 times as many positive 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 about ± 2 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 slightly longer J-PARC beam there will be 600 times as many pions as kaons if the separators are turned off. Therefore, if a fraction of 0.16 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.

3 Higher order calculations with ZGOUBI

In order to determine the pion contamination due to pions produced in the production target, so called direct pions, it is necessary to take into account the higher order optics, using sextupoles and an octupole. This was done with ZGOUBI. The 5.4 cm length of the production target and the 6 degree take off angle were taken into account. Uniform initial distributions were generated for a horizontal width of the proton beam of 5 mm, a 30 mr wide vertical angle distribution, a 100 mr wide horizontal angle distribution, and a 10 percent ΔP/P wide momentum distribution. For the vertical position distribution of the proton beam on the production target a gaussian distribution was taken with σ=1.3 mm. Table 3 gives the results for various settings of the MS1 slit and the HFOC slit. Here, the slits were modelled as zero length apertures. The IFY slit is open. The slit HFOC has a beneficial effect for the pion contamination. The conclusion is that the pion contamination due to direct pions can be made less than one third of the kaon intensity. The acceptance of the beam is about 4.5 msr.percent.

Figure 4 gives the vertical beam spots for pions and kaons at MS1. The blue curves give the input gaussian with a width of σ=1.3 mm. It's width has been multiplied with the first order magnification of 0.51. The distributions from ZGOUBI are considerably wider than the blue curves. However, about 90 percent of the kaon beam is within $\pm$2 mm. The pions are well separated by 6.4 mm. Without the sextupoles and the octupole there would be considerable tails on the distributions, and the pion contamination would be too large.

Figure 3 gives the vertical distribution at IFY. The blue curve is obtained from the input gaussian distribution, taking into account the magnification of 0.35. The distribution from ZGOUBI is much wider due to uncorrected higher order aberrations.

4 Contamination due to cloud pions

The 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. It was necessary to place a 50 micron stainless steel window in the beam in order to manage the vacuum conditions in the beam line. This can only been done at a vertical focus, because in a more or less vertically parallel beam the scattering in the window would cause a too large beam spot at the mass slit and in this way prevent the removal of a sufficient fraction of the pions. Therefore, the vertical focus IFY was created. The position magnification is about 0.35, and the angle magnification is about 3.0. Therefore, the width of ±9 mr of the initial angle distribution becomes ±27 mr at IFY. The scattering in the window gives a scattering angle distribution with σ=0.83 mr.

Since a slit is placed at IFY, it can be used to limit the cloud pion contamination. For the Monte Carlo calculations of cloud pions with REVMOC(similar to TURTLE) extended slits are used without taking into account the scattering in the slit material. But the scattering in the windows was taken into account. The longitudinal slit profiles are discussed in section 1.1. It turns out that the assumption about the horizontal width of the cloud pion source is of little influence on the results. A large phase space area was assumed, and a large momentum bite. Horizontally I took a source size of 2 cm, Vertically it was 4 cm and displaced by 1 cm from the axis. Table 4 gives the accepted number of pions for several settings of the slits at MS1 and IFY. If MS1 is 5 mm wide, the reduction in the cloud pions is a factor 16 if IFY is closed to 6 mm. If MS1 is 4 mm wide the reduction is a factor 32 if IFY is closed to 6 mm. Since the cloud pion contamination is less than five times the kaon intensity, if only MS1 is closed, the IFY slit brings the cloud pion fraction down to an acceptable level. Tables 5 and 6 show the vertically accepted distributions at the production target for the indicated slit settings. When only the mass slit is closed, the beam line sees a vertical area with a width at FWQ(arter)M level of about 12 mm, centered 13 mm above the axis.

5 Muon contamination

Five million pions were run through the beam line. The decay muons were registered at the final focus. Scattering on windows was included, but not scattering on the slits. Table 7 gives the results for the kaon to muon ratio depending on slit settings. When only MS1 is closed there is a large muon contamination. A large fraction is due to muons decaying before IFY. The contamination decreases by a factor 2.5 or 3 if IFY is closed to a full width of 6 mm, but the muon intensity is still far too large. Closing the horizontal slit at HFOC brings the muon contamination down to acceptable levels.

6 Pion contamination due to slit scattering

Scattering on the slits and windows was studied with REVMOC. The proton spot on the 5.4 cm long production target was 4 mm horizontally by 3 mm vertically, both uniform distributions. Results are given in table 8 for various slit apertures. It turns out that scattering on the windows gives a very minor contribution. Take the case that the aperture of the flat center of the mass slit is 5 mm. The π/K ratio is 1.23, almost all due to scattering on the mass slit. When now IFY is also closed to 6 mm, the π/K ratio becomes drastically worse to 3.18. Then the horizontal slit comes to the rescue. An aperture of 1.6 cm reduces the ratio to 0.40, and an aperture of 1.2 cm gives 0.28. An even further reduction is possible by lowering a vertical slit to 5 cm above the axis, while the bottom of the slit stays fully open. Now the ratio drops to 0.13. The same trend can be seen for a 4 mm mass slit aperture, but the results are better. This table shows the crucial role of the slit at HFOC. Without this slit the beam line would not work.

7 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 necessary to reduce the contamination caused by slit scattering, and caused by muons from pion decay in the channel. 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.

Table 1: Beamline Elements

element	length (cm)	pole radius (cm)	design pole field (kG)
Quadrupole			
Q1	40.0	12.5	6.502
Q2	40.0	12.5	-8.049
Q3	40.0	12.5	6.983
Q4	40.0	12.5	-7.198
Q5	40.0	12.5	-6.967
Q6	40.0	15.0	8.921
Q7	50.0	12.5	-9.007
Q8	50.0	12.5	11.569
Sextupole			
S1	20.0	15.0	-1.000
S2	20.0	15.0	-0.500
Octupole			
O1	20.0	12.5	-1.000

Table 2: Dipole and separator characteristics

	entr/exit angle to pole face (deg)	length (cm)	pole gap (cm)	field (kG)	bend angle (deg)
dipole					
B1	0.0/0.0	80.0	10.0	10.477	18.0
B2	13.0/13.0	100.8	20.0	12.005	26.0
B3	0.0/0.0	129.4	20.0	18.000	50.0
separator	length (m)	plate width (cm)	plate gap (cm)	plate gap voltage (kV)	magnetic field (kG)
SEP1	2.50	40	11.00	550	0.196

Table 3: Kaon acceptance and pion contamination as function of slits for a gaussian vertical source with σ=1.3 mm. All widths are full width.

MS1 (mm)	HFOC (cm)	N(kaons)	N(pions)	pi/K	acceptance (msr.percent)
5	open	52,348	40	0.46	4.7
5	1.2	46,107	26	0.33	4.1
4.5	open	51,263	24	0.28	4.6
4.5	1.4	46,862	19	0.24	4.2
4	open	49,631	15	0.18	4.5
4	1.2	43,688	8	0.11	3.9

Table 4: Cloud pions as function of slit apertures

MS1 (mm)	IFY (mm)	N(pions)
5	open	14,994
5	6	902
4	open	11,563
4	6	364

Table 5: Vertical distribution at production target of accepted cloud pions. The width of the mass slit is 4 mm.

MS1	4 mm	4 mm
IFY	open	6 mm
Y (mm)		
1	0	0
3	2	0
5	39	11
7	271	82
9	1433	107
11	2527	81
13	3069	42
15	2488	24
17	1196	13
19	263	4
21	41	0
23	4	0
25	0	0
27	0	0

Table 6: Vertical distribution at production target of accepted cloud pions. The width of the mass slit is 5 mm.

MS1	5 mm	5 mm
IFY	open	6 mm
Y (mm)		
1	0	0
3	11	3
5	110	50
7	785	295
9	2229	295
11	3049	140
13	3226	73
15	2991	31
17	1858	12
19	587	3
21	122	0
23	24	0
25	2	0
27	0	0

Table 7: Muon contamination as function of slit apertures.

IFY (mm)	MS1 (mm)	HFOC (cm)	N(pions)	K/Mu
open	5	open	1970	2.33
open	5	1.2	684	0.81
6	5	open	695	0.82
6	5	1.2	190	0.22
open	4	open	1477	1.75
open	4	1.2	588	0.70
6	4	open	544	0.64
6	4	1.2	145	0.17

Table 8: Contamination due to scattering as function of slit apertures.

IFY (mm)	MS1 (mm)	HFOC (cm)	Y at HFOC (cm)	N(K))	N(PI)	Accep tance	K/Pi
open	4	open	open	86536	178	5.2	1.23
6	4	open	open	80866	262	4.9	1.94
6	4	1.6	open	79630	38	4.8	0.29
6	4	1.2	open	76407	26	4.6	0.20
6	4	1.2	+5,-15	74342	9	4.5	0.07
open	5	open	open	91557	316	5.5	2.07
6	5	open	open	85043	451	5.1	3.18
6	5	1.6	open	83978	56	5.0	0.40
6	5	1.2	open	80034	38	4.8	0.28
6	5	1.2	+5,-15	77557	17	4.7	0.13

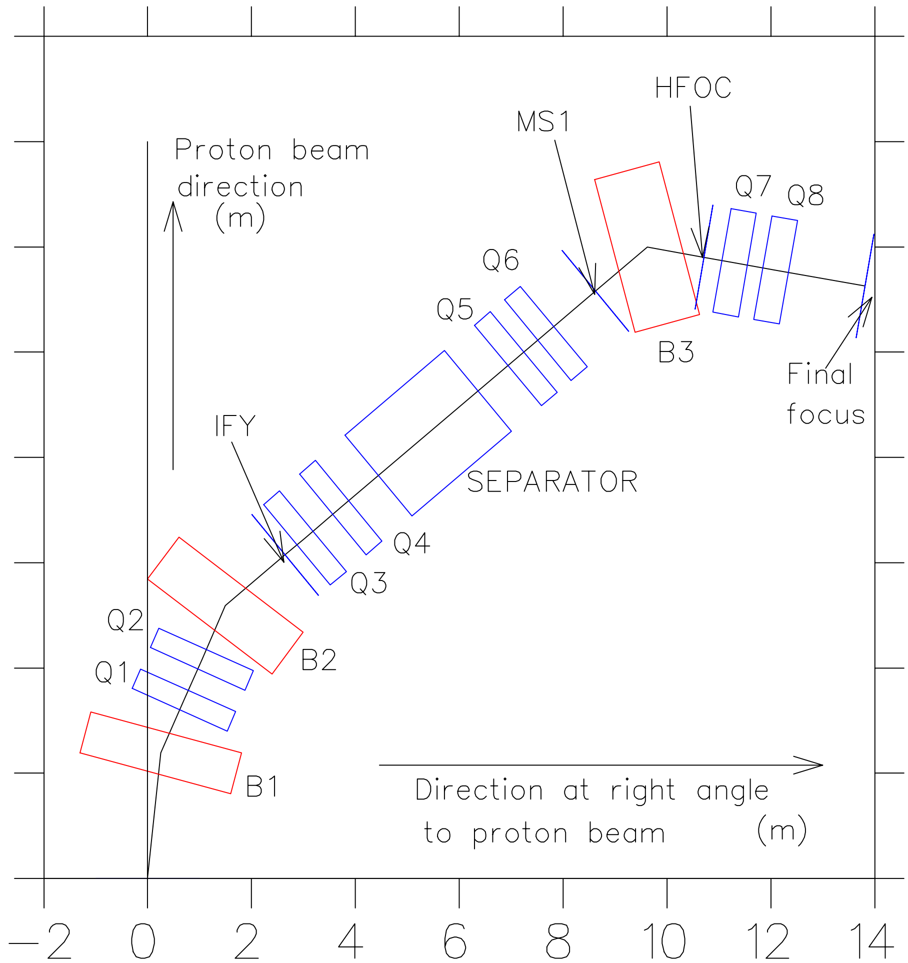

Figure 1: Layout of the 0.8 GeV/c beam.

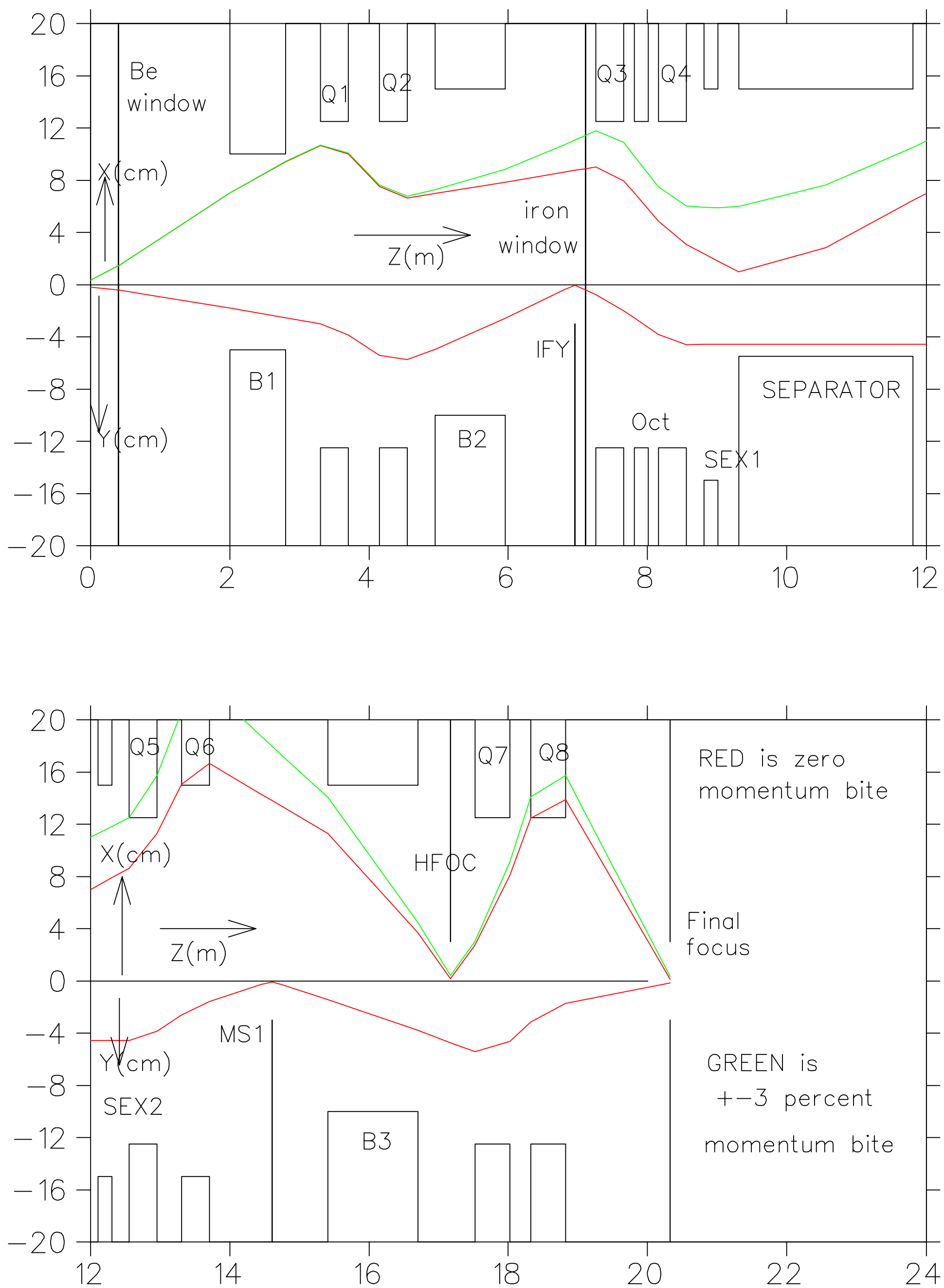

Figure 2: First order beam envelopes from TRANSPORT. The initial horizontal angle is 35 mr, the vertical angle is 9 mr. X is 3.5 mm and Y is 2 mm. All numbers indicate half widths. Red is for the cental momentum. Green is for 3 percent ΔP/P

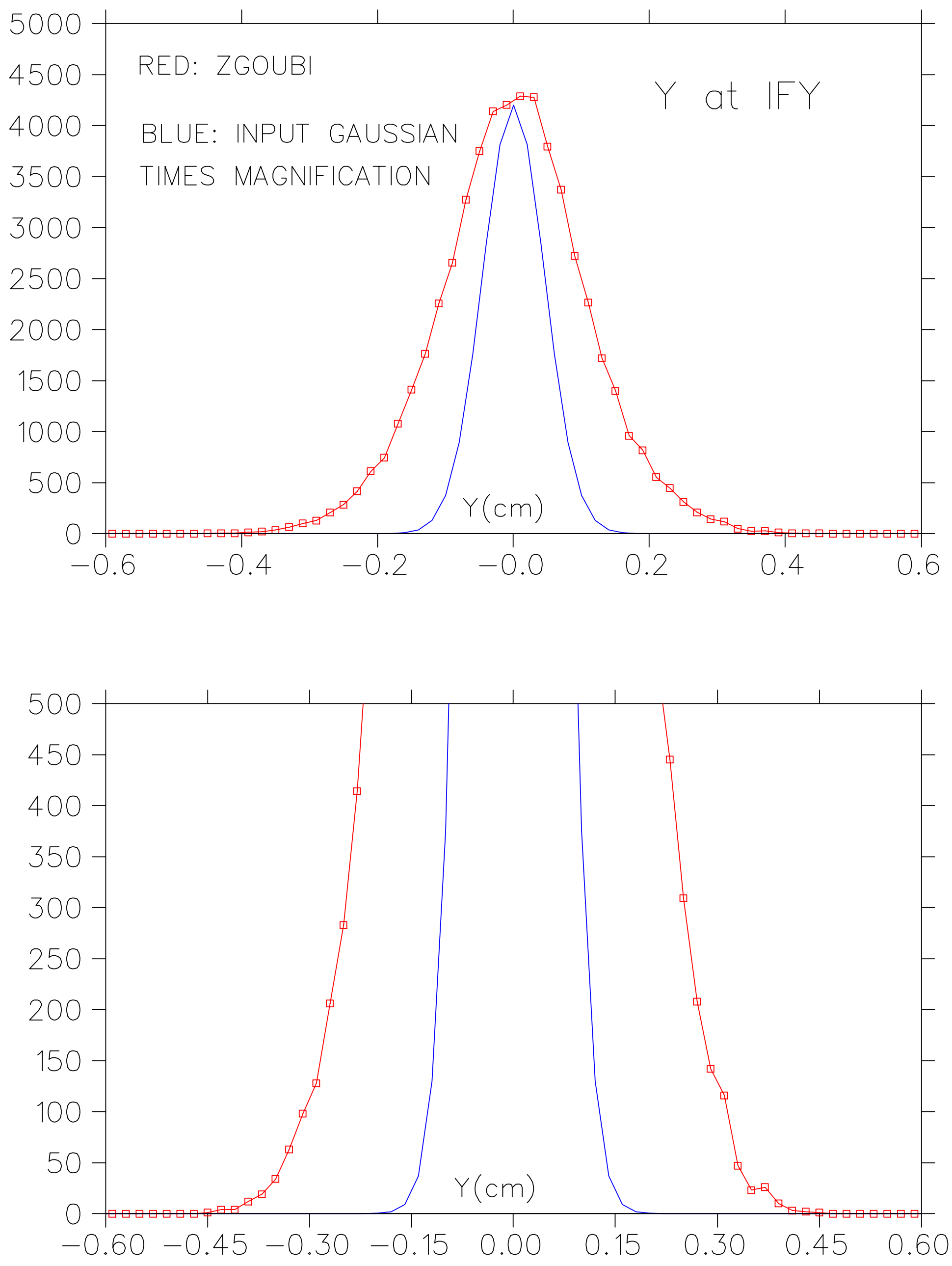

Figure 3: The vertical beam spot at IFY for the 0.8 GeV/c beam from the higher order Monte Carlo calculation with ZGOUBI. The blue curve is the input gaussian with σ of 1.3 mm times the magnification of 0.35

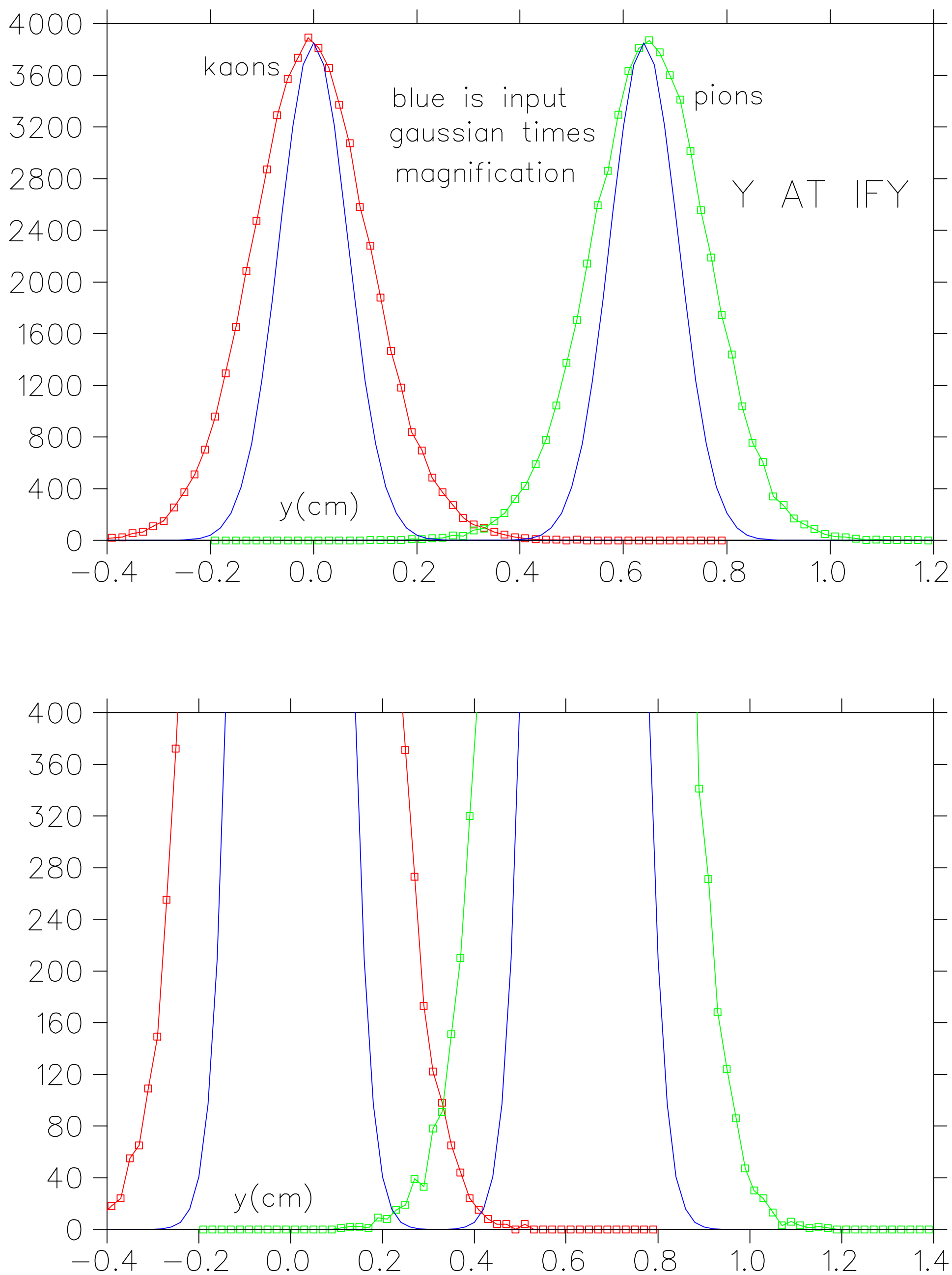

Figure 4: ZGOUBI result. The vertical beam spot at MS1 for kaons and pions. The blue line gives the input gaussian with σ of 1.3 mm times the magnification of 0.51