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Informal Report

MASTER

CHARACTERISTICS OF MESB DESCRIPTION FOR USERS

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Introduction

The medium energy separated beam (MESB) is a one-stage, DC separated beam from the AGS external proton beam target B, designed to purify K's up to 6.0 GeV/c and $\bar{p}$'s up to 9.4 GeV/c for electronic experiments.

MESB was originally designed by Carroll¹ to separate 5 GeV/c K's and 8 GeV $\bar{p}$'s. Fox² increased the upstream bend angle in order that the beam reach MPS (Multiparticle spectrometer), added a quadrupole to the front-end doublet so as to approximately double the low momentum flux, and arranged a Y branch in the downstream end. This third effort on the beam design has resulted in a full utilization of the variable-focal length properties of the front-end triplet so as to increase the momentum-limit of separability. Bend angles decreased slightly and the beam grew 220" in length; however, the beam uses the same number of power supplies, only one extra quadrupole (active in only one branch of the Y), and about the same power (but at a higher momentum) as the Fox design.

Numerous details are still under study--most notably, the optimum target material and length, the mass slit design, the effect of bending magnet and quadrupole aberrations, collimators and details of how to focus on MPS. Hence both the flux and the remaining contamination are somewhat uncertain: only lower limits can be set on both. What is firm is the position and number of elements in the beam, which have been determined by the sometimes conflicting requirements of momentum recombination and adequate K- π separation in both branches and the several modes of the beam. In addition, the placement of the final two quadrupoles in each branch of the beam is regarded as experiment-dependent and has been studied only for two hypothesized experiments.

The purpose of this note is to familiarize potential users with the certain aspects of the beam and invite participation and assistance in resolution of the uncertain details of the beam. A revised description of the beam will be written when these details are resolved. First, the beam optics are discussed in cursory fashion; then probable fluxes, purity, and spot sizes (or phase spaces) at the final focus of the beam are discussed.

Layout and Optics

The layout of the beam is shown in Fig. 1. At the upstream end, the beam accepts particles at a 6° production angle from a target shared simultaneously with the 0° unseparated beam. At the downstream end, the beam serves experiments non-simultaneously at three places: (a) the East branch, in the region between MPS and the 0° experiments; (b) the West branch, between the last bending magnet (D5) and MPS; (c) MPS. These branches are hereafter abbreviated E, W and MPS.

The variable-focal length triplet, Q1-2-3, allows the K- π separation at the first vertical focus (the mass slit) to be held constant at twice the magnified unaberrated, target height (a condition referred to hereafter as " $\eta = 2$ ") as the momentum is increased, in a continuous manner. As the momentum increases, the vertical focal length (f_v) increases and the vertical acceptance angle (y'_t) decreases, in proportion. However, there are upper and lower limits in this variation. The lower limit, designated as Mode 1 of the beam, occurs when Q3 is horizontally filled to its maximum usable aperture of about $\pm 5.5''$. The optics of this mode are illustrated in Fig. 1 for the first half of the beam. In this mode, $f_v = 250''$, $y'_t = 4$ mrad, and the beam separates with $\eta = 2$ up to 4 GeV/c K's and 6.3 GeV/c $\bar{p}$'s. This mode is a lower limit because lowering the vertical focal length any further leads to greater losses in horizontal acceptance angle than gains in vertical acceptance angle. Hence experiments below 4 GeV/c can do no better than to run in mode 1. The upper limit, designated as Mode 3, has the polarities of Q2 and Q3 reversed from those of mode 1 and is defined as the point at which the vertical focal length is a maximum (850''). The optics are shown in Fig. 3. This mode separates 6 GeV/c K's and 9.4 GeV/c $\bar{p}$'s with $\eta = 2$. The gradients in the triplet Q1,Q2,Q3 as a function of momentum (as the focal length is gradually increased to 850'') are shown in Fig. 4.

Table I lists the properties of the beam for modes 1 and 3 in the East and West branch. Gradients and bending magnet fields are listed in Table II for 5 GeV/c only. For exact information on modes in between 1 and 3, consult the authors. Alternately, the following crude scaling can be applied: the solid angle decreases proportional to p^{-3} ; bending magnet fields and quadrupole gradients (excepting Q1,2,3) increase linearly with

P, except for Q6, which is both mode and branch dependent. In the East branch the Q6 gradient increases as P^2 ; in the West branch, the gradient remains roughly constant.

The bending magnet D3 disperses the beam in the horizontal plane. Following Q3, four rectangular separators assumed to operate at 225 KV/inch, with a 2" gap separate K's from π 's in the vertical plane. The physical separation is achieved in the mass slit at the first vertical focus. A sextupole placed at the first horizontal focus, between Q4 and Q5, corrects most of the chromatic aberration of the vertical plane. The momentum bite of the beam is defined by remotely variable collimators just upstream and downstream of the sextupole.

As can be seen in Figs. 2 and 3, mode 3 will barely transmit a momentum bite of $\pm 2.5\%$ through Q4, while mode 1 could transmit $\pm 5\%$. However, K- π separation is aberration-limited with a bite of $\pm 3\%$ in mode 1, at least at 4 GeV/c where $\eta = 2$. At lower momenta, it would be possible to separate a bigger momentum bite.

Momentum recombination in both position and angle is achieved at both the East and West final foci by the bending magnets D4 and D5. The optics for the East branch are illustrated in Figs. 2 and 3. Because of the sign change in the field of D5, the optics for the West branch are quite different and are illustrated in Figs. 5 and 6. As a result of the extra horizontal focus necessary for the East branch, this branch has more chromatic aberration in the horizontal plane, enlarging the spot size. In Mode 1W, it is planned to move the mass slit 50" upstream of its usual position in order to rectify a vertical magnification problem at the final focus.

The final quadrupole doublets have been placed so as to satisfy the requirements of two hypothesized experiments. In the East branch, Q9-10 produces a focus with a large horizontal magnification at the rear of the proposed CMU/Pittsburgh Experiment (Exp. #553); thus the horizontal breadth of the beam is 4" or less throughout the apparatus. Fifteen feet of drift length is allowed before and after D5 in order to measure the momentum of each beam particle with wire planes. Other experiments may have different

requirements for the positions and polarities of Q9 and Q10. In the West branch, the beam is brought to a focus very close behind D5 with the doublet Q7,8 which brackets D5. The horizontal magnification is small so that the spot size is small but with larger divergence. This focus is typical of that required by a low momentum K experiment with a small hydrogen target. Further discussion of spot sizes appear below.

With the magnets shown, the beam can transport particles at least to 9.1 GeV/c (given enough power) in both the East and West branches, and perhaps higher, depending on the field which is achievable in D3. This field is uncertain, as it will be shimmed to 3.5" vertical gap, a situation for which there is no data. The rest of the beam will transport to 10 GeV/c, limited by D4.

However, to reach MPS, the bend angle of D5 must be increased by 2° , so that the magnets shown limit MPS to 8 GeV/c. It is planned to add an extra bending magnet after D5 for higher momenta.

Phase II

The layout as shown is called phase I. It is actually not very usable above 7 GeV for $\bar{p}$'s, as the flux at a 6° production angle is falling very fast (see Fig. 9). Hence a phase II of MESB is envisaged in which a septum bending magnet is added in front of Q1 which will bend particles produced at 3° towards the fixed bend point of D3; Q1 and Q2 are moved inward a few inches. The rest of the beam remains intact and then will transport up to 10 GeV/c, limiting entirely by D3. The $\bar{p}$ flux should increase by a factor of 3 at 7 GeV/c and a factor 6 at 10 GeV/c. Phase II also has the fringe benefit of reducing two problems associated with the large apparent width of a 4" long target viewed at 6° . This large apparent width creates a rather large horizontal phase space, so that small spot sizes are difficult to achieve (see below). Secondly, this large width induces large aberrations in the vertical plane in mode 3 at the mass slit, making separation very marginal (see below). In phase I, the only cures available, such as halving the target length, result in a loss of flux. With a 4" target in phase II (3° production), both the vertical plane aberrations and the horizontal spot size are dominated by other effects (largely chromatic aberration).

Target Design

The properties of the beam listed in Table I assumed a target of dimensions (height, width, length) = (0.04", 0.10", 4"). It is hoped that it can be shaped as shown below.

Conservative estimates of fluxes have been made using the data on production in beryllium of Sanford and Wang. Extrapolations to heavier nuclei are uncertain because of reabsorption in the struck nucleus. It is estimated that for K^- perhaps a gain of a factor 2 (per inch of target length) can be achieved using copper instead. The optimization problem has yet to be studied in detail, and is probably experiment dependent. In addition, the target must satisfy the requirements of the 0° beam.

Target Plan View (not to scale)

Fluxes

Fluxes can be calculated with the aid of Figs. 7-11, which give yields at the final foci per 10^{12} interacting proton in beryllium at 6° (phase I) and 3° (phase II). The solid curves show the yields in modes 1 and 3 assuming the full solid angles and momentum bites of Table I; the dashed curves show the yield as one gradually varies the focal length of the front triplet, moving continuously from mode 1 to mode 3. The dotted lines at the end of the solid mode 3 curves suggest that one might exceed the upper limit momenta with a reduction of solid angle acceptance to clean-up the image. The curves include the effect of 70% transmission of the full solid angle and momentum bite through MESB, a figure resulting from Monte Carlo studies.

To obtain the true flux in the beam, one must fold in the number of protons in the external beam (probably 3×10^{12} when the AGS works) and the fraction which interact in the target. If 4" of beryllium is used,

this fraction might be $1/16$, assuming that all protons hit the target. It is hoped that this estimate is conservative.

Purity

The $\pi:K$ and $\pi:\bar{P}$ ratios just before the mass slit are shown in Fig. 12. The Sanford-Wang production formula at 6° in beryllium was assumed; decay loss was folded in. The fraction of the π 's which leak through the mass slit is always difficult to predict. For this beam the problem is complicated by the fact that the aberrations which largely contribute to the leakage are a strong function of the mode, branch, momentum bite and target length.

Lastly, the problem has only begun to be studied: only chromatic aberrations have been investigated. Magnet aberrations and muon flux have not been studied; the mass slit has not been designed.

The problem should be studied for individual experiments, as the general problem involves too many variables. For the moment, one general statement will be made and four examples given of the effects of chromatic aberration on pion contamination. If one operates at $\eta = 2$ (a rather arbitrary criterion), then the pion contamination will be about eight times worse in mode 3E (the worst mode) than in 1W (the cleanest mode), given that all other conditions are the same (target length, momentum bite, solid angle). For absolute numbers, we give four examples based on Monte Carlo studies of particle distributions at the mass slit.

Fig. 13 shows the π and K phase spaces (y vs. $y' = dy/dz$) at the mass slit, assuming a 4" target and $\pm 3\%$ bite, for mode 1W operating at $\eta = 2$ at 4 GeV/c. The phase space includes off-momentum particles and is not uniformly populated. Hence, a histogram has been made of the intensities as a function of y , assuming an 80:1 ratio for $\pi:K$ before the mass slit. If the mass slit is constructed so as to simply remove all particles with $y \geq 0.05''$ (i.e., sloped plates), 80% of the K's are transmitted with about a 1:1 ratio of $\pi:K$. The same exercise is repeated for a $\pm 1\%$ momentum bite in Fig. 14, where the contamination is seen to be much less than 1:1.

Figs. 15 and 16 illustrate the same exercise for mode 3E, operating with $\eta = 2$ at 6 GeV/c with full momentum bite and a 4" target (Fig. 15) and a 2" target (Fig. 16). A mass slit designed to remove all particles

with $y \geq 0.02''$ would leave a 6:1 ratio of π :K (4" target), or 1.2:1 (2" target). However, there are some tricks which can be employed to reduce this contamination in mode 3E, with a small loss of K flux.

Other uncertainties which have not been investigated are pions which traverse insufficient material of the mass slit to be removed from the beam, separator stability and mass slit alignment. The last two are critical, inasmuch as the K- π separation is sometimes only 40 mils (mode 3W) while the beam is 4" broad.

Spot Sizes at Final Focus

The spot size at the final focus is, of course, dependent on the positioning and polarity of the final doublet. The quantity which is approximately conserved as the doublet is changed is the phase space, the product of the horizontal width and the horizontal divergence (see Table I); similarly for the vertical plane.

The phase spaces listed in Table I include the effects of chromatic aberration and include 95% of the particles. The horizontal phase space is very much a function of the momentum bite selected and the target length used. Furthermore, the phase space is not uniformly populated. The three effects are illustrated for mode 1W in Fig. 17 and mode 3E in Fig. 18, which show horizontal profiles at the final focus as a function of momentum bite and target length, with all other conditions fixed, including the positions and gradients of the final quadrupole double. In phase II the septum magnet, by decreasing production angle from 6° to 3° , will reduce horizontal spot sizes by a factor of 2.

Momentum Distribution at the Final Focus

These distributions have not yet been studied with the inclusion of the important fact that the low-momentum collimation is done upstream of the sextupole and the high momentum collimator downstream. This placement allows a sharp momentum bite at about $\pm 3/4\%$. In the crude approximation that the momentum slit is a beam stop at the sextupole, the momentum distribution always extends out beyond the desired bite by $\pm 1\%$. This is a good approximation for the large momentum bites.

Momentum Determination

In the East branch, precise momentum tagging of individual beam particles can be made with wire planes sandwiching D5, as described. The method is probably not used in the West branch as shown because of the interference of Q7,8. However, Q7,8 could be moved further downstream for particular experiments.

A picket fence of counters at the first horizontal focus would probably introduce too much multiple scattering in the vertical plane at the mass slit to retain good purity. In any case, the momentum resolution that could be obtained from a picket fence would be poor, e.g. $\Delta p/p = \pm 3/4\%$ for a 4" long target and production angle 6° .

Other Collimators

A remotely variable horizontal collimator is planned to follow Q1. Only a fixed aperture (2") collimator to follow Q3 is planned for the vertical plane to follow Q3.

In mode 3E the mass slit is also the second horizontal focus, so the mass slit should be followed by a horizontal stop which can be crude, as it will be in air. The corresponding horizontal focus in mode 1E is just in front of D5, where it would be desirable to have the possibility of a variable (by hand) horizontal stop.

The square pipe through the steel proton beam shield wall in the middle of the separators is a natural vertical collimator. It would be wise to put a fixed aperture horizontal collimator inside Q4 in order to remove very off-momentum particles from the badfield region of Q4. These off-momentum particles will not necessarily be removed by the momentum collimators between Q4-5.

Acknowledgements

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References

1. A. Carroll, AGS Summer Studies 1970.
2. J.D. Fox, EP&S Division Technical Note No. 38, 1970.
3. J. Sanford and C.L. Wang, AGS Internal Report, 1967.

FIGURE CAPTIONS

1. Beam Layout
2. Optics of mode 1E
3. Optics of mode 3E
4. Gradients of quadrupoles Q1, Q2, Q3 vs. momentum at which $\eta = 2$, for K separation and $\bar{p}$ separation.
5. Optics for mode 1W
6. Optics for mode 3W
- 7-11. Fluxes of particles at the two final foci per 10^{12} interacting protons in a beryllium target. The curves assume the full solid angle and momentum bites of Table I and a 70% transmission through the beam. For genuine numbers of particles at the end of beam, multiply by the number of protons in the external beam and the fraction which interact in the target.
12. $K:\pi$ and $\bar{p}:\pi$ ratio in front of mass slit as function of momentum.
- 13-16. K and π phase spaces at mass slit (upper plot) and histogram of y-distribution of K's and π 's (lower plot) for Mode, $^+\Delta p/p$, and target length as labelled (based on Monte Carlo Studies).
- 17-18. Horizontal distribution of particles at final focus for nine values of $^+\Delta p/p$ and target length W, for modes 1W and 3E.

TABLE I - Properties of MESB Phase I (6^0 Production)

Definitions:

$$n_K \equiv \frac{\text{K-}\pi \text{ separation at mass slit}}{\text{magnified geometrical target height}}$$

$$\theta_V \equiv \text{vertical plane divergence}$$

$$\theta_H \equiv \text{horizontal plane divergence}$$

<u>Front End</u>	<u>Mode 1</u>	<u>Mode 3</u>		
Max. θ_V	± 4.0 mr	± 1.17 mr		
Max. θ_H	± 20 mr	± 20 mr		
Ω (geometrical solid angle) = $4\theta_V\theta_H$	320 μ st	93 μ st		
Assumed production target (height x width x length)	.04"x.10"x4"	.04"x.10"x4"		
f_V (vertical front focal length)	250"	853"		
momentum at which $n_K = 2$	4.0 GeV/c	6.0 GeV/c		
momentum at which $n_p = 2$	6.3 GeV/c	9.4 GeV/c		
<u>At first horizontal focus (momentum slit)</u>	<u>1W</u>	<u>1E</u>	<u>3W</u>	<u>3E</u>
$\pm \Delta P/P$ (max. momentum bite)	$\pm 3\%^*$	$\pm 3\%^*$	$\pm 2.5\%$	$\pm 2.5\%$
momentum dispersion	0.83"/%	0.75"/%	1.68"/%	1.53"/%
horizontal magnification	3.0	2.7	7.3	6.7
horizontal image full width (on momentum)	1.2"	1.1"	2.9"	2.7"
<u>At mass slit</u>				
distance from target	2017"	2077"	2077"	2077"
vertical magnification	1.58	1.88	0.510	0.715
aberrated vertical image full height(95%†)	.12"	.21"	.058"	.10"
K- π separation at momentum where $\eta = 2$	.126"	.15"	.040"	.057"
max. θ_V (95%†)	± 2.2 mr	± 2.2 mr	± 2.1 mr	± 1.5 mr
horizontal full width	5.2"	4.4"	4.8"	2.4"
<u>At final focus</u>				
horizontal magnification	2.9	7.2	1.6	6.1
vertical magnification	4.3	1.0	2.0	0.41
vertical image full height (95%†)	0.4"	0.2"	0.2"	0.20"
max. θ_V (95%†)	± 1.0 mr	± 4.5 mr	± 1.0 mr	± 4.0 mr
vertical phase space #($2\theta_V$ x height)	0.8mr"	1.8mr"	0.4mr"	1.6mr"
horizontal image full width (95%†)	1.6"	3.3"	0.8"	2.4"
max. θ_H (95%†)	± 8.2 mr	± 5.4 mr	± 13 mr	± 4.7 mr
horizontal phase space#($2\theta_H$ x width)	26mr"	35mr"	21 mr"	22 mr"
distance from target	2680"	3300"	2680"	3300"

* Could transmit $\pm 5\%$, badly aberrated

† Includes chromatic aberrations; "95%" implies that 95% of flux contained within these limits. See histograms in text.

Approximately conserved if final doublet is moved or refocused.

TABLE II

Gradients and Fields in MESB at 5 GeV/c

<u>Magnet</u>	<u>Type</u>	<u>Vert. Gap</u>	<u>Bend Angle</u>	<u>Eff. Length</u>	<u>Mode 1W</u>	<u>Field in kG</u>			
						<u>3W</u>	<u>1E</u>	<u>3E</u>	
D3	18C72	3.5"	8.0°	75.5"	12.10	12.10	12.10	12.10	
D4	18D72	2.5"	8.0°	74.5"	12.25	12.25	12.25	12.25	
D5	18D72	2.5"	8.0°	74.5"	12.25	12.25	12.25	12.25	
		<u>Diameter</u>	<u>Polarity</u>			<u>Gradient in EG/in</u>			
Q1*	N8Q32	8"	HF	36"	+1.55	+0.95	+1.55	+0.95	
Q2*	N8Q32	8"	*	36"	-1.62	+0.58	-1.62	+0.58	
Q3*	12Q30	12"	*	36"	+0.75	-0.66	+0.75	-0.66	
Q4	12Q30	12"	FH	36"	+0.90	+0.89	+1.18	+1.13	
Q5	8Q24	8"	DH	28"	-1.38	-1.30	-1.51	-1.52	
Q6	8Q32	8"	FH	36"	+0.84	+0.51	+1.04	+1.51	
Q7	8Q24	8"	DH	28"	-1.97	-2.40			
Q8	8Q24	8"	FH	28"	+1.55	+1.96			OFF
Q9	12Q30	12"	FH	36"		OFF	+1.34	+1.09	
Q10	12Q30	12"	DF	36"			-1.16	-1.06	
Sext	12S24	12"			-0.55	-0.12	-0.55	-0.15	

*See Fig. 4 for scaling

TABLE II

Gradients and Fields in MESB at 5 GeV/c

Type	Vert. Gap	Bend Angle	Eff. Length	Mode 1W	Field in kG		
					3W	1E	3E
Q72	3.5"	8.0°	75.5"	12.10	12.10	12.10	12.10
D72	2.5"	8.0°	74.5"	12.25	12.25	12.25	12.25
D72	2.5"	8.0°	74.5"	12.25	12.25	12.25	12.25
	Diameter	Polarity			Gradient in EG/in		
Q32	8"	HF	36"	+1.55	+0.95	+1.55	+0.95
Q32	8"	*	36"	-1.62	+0.58	-1.62	+0.58
Q30	12"	*	36"	+0.75	-0.66	+0.75	-0.66
Q30	12"	FH	36"	+0.90	+0.89	+1.18	+1.13
24	8"	DH	28"	-1.38	-1.30	-1.51	-1.52
32	8"	FH	36"	+0.84	+0.51	+1.04	+1.51
24	8"	DH	28"	-1.97	-2.40	OFF	
24	8"	FH	28"	+1.55	+1.96		
Q30	12"	FH	36"	OFF		+1.34	+1.09
Q30	12"	DF	36"			-1.16	-1.06
24	12"			-0.55	-0.12	-0.55	-0.15

for scaling

FIG. 1

Fig. 2 - Optics of Mode 1E

Fig. 3 - Optics of Mode 3E

Fig. 4

Fig. 5 - Optics of Mode IW

Fig. 6 - Optics of Mode 3W

East Leg - 3300"

Fig. 7

MESB yields

no. K^+ / 10^{12} interacting protons

in Be (Sanford-Wang)

$$\frac{\Delta P}{P} = \pm 3\% \rightarrow 2\frac{1}{2}\%$$

$$22 \rightarrow 320 \text{ jst} \rightarrow 93 \text{ jst}$$

model $\rightarrow$ mode 3

70% transmission in 14ESB

K^+ - East

East leg - 3300"

Fig. 8

MESB yields

no. $K^-/10^{12}$ interacting protons

in Be (Sanford-Wang)

K^- - East

$\frac{\Delta P}{P} = \pm 3\% \rightarrow \pm 2\frac{1}{2}\%$
 $\sigma = 320 \mu\text{st} \rightarrow 93 \mu\text{st}$
 mode 1 $\rightarrow$ mode 3
 70% transmission in MESB

Fig. 9

MESR YIELDS no. $\bar{p} / 10^{12}$ INTERACTING PROTON
IN BERYLLIUM

(Sanford-Wright)

East or West

$$\frac{\Delta P}{P} = \pm 3\% \rightarrow \pm 2\frac{1}{2}\%$$

$$\Omega = 320 \text{ mst} \rightarrow 93 \text{ mst}$$

mode $\rightarrow$ mode 3
70% transmission in MESR

West leg - 2700"

Fig. 10

MESB YIELDS NO. $K^-/10^{12}$ INTERACTING PROTONS

IN BERYLLIUM

(Sanford-Wang)

K^- -West

$\frac{\Delta P}{P} = \pm 3\% \rightarrow \pm 2\frac{1}{2}\%$
 $\tau = 320 \mu\text{st} \rightarrow 93 \mu\text{st}$
 Model $\rightarrow$ Model 3
 70% transmission in MESB

INTERACTIONS ON TARGET

KE SEMI-LOGARITHMIC 46 6090
 4 CYCLES X 84 DIVISIONS
 KUPFER & ESSER CO. INC.
 MADE IN U.S.A.
 PARTICLES 10^6

P GeV/c

West Leg - 2700"

Fig. 11

MESB

YIELDS

no. $K^+ / 10^{12}$ INTERACTING PROTONS

in Be (Sanford-Wang)

$$\frac{\Delta P}{P} = 3\% \rightarrow 2\frac{1}{2}\%$$

$$\sigma = 320 \mu\text{st} \rightarrow 93 \mu\text{st}$$

70% transmission in MESB

K^+ - West

varying mode
 $n=2$

Fig. 12

Mode 1W $\Delta P/p = \pm 3\%$ 4" target

Fig. 13

Mode 1W $\pm 1\% = \frac{4P}{P}$ 4" target

π and K vertical phase space and y distribution at mass slit

Fig. 14

Mode 3E $\Delta P/p = \pm 2.5\%$ 4" target

Fig. 15

Mode 3E $\Delta P/p = \pm 2.5\%$ 2" target

π and K vertical phase space and y distribution at mass slit

Fig. 16

Horizontal distribution of Particles at Final Focus

Fig. 17

Mode 1W

Horizontal distribution of Particles at final focus

FIG. 18 Mode 3E