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BEAMS FOR KAON RESEARCH

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A proposed 1-2 GeV/c kaon beam line for BNL, designed to deliver momentum analyzed negative kaon beams with intensities above 10^6 per spill, is discussed. The beam intensity is expected to be about an order of magnitude greater than presently available and it is expected to be a clean beam with no more than 1:1 $(\pi^-,\mu^-,e^-)/K^-$. The beam line will allow a detailed investigation of strangeness -2 systems as well as continued investigations of strangeness -1 systems.

1. INTRODUCTION

Both Λ and Σ hypernuclei have been studied using negative kaon beam available at BNL, CERN and KEK. However, current hypernuclear physics programs exist only at BNL and KEK. The BNL LESB-I[1] beam line is limited to kaon beams with less than 1 GeV/c momentum and is therefore not suitable for exploring doubly-strange (S=-2) systems. The KEK K2[2] and K3[3] beam lines deliver kaons in the momentum range 1-2 and 0.5 - 1.0 GeV/c respectively. The kaon flux available at KEK is, however, generally about a factor of 10 less than the typical flux available at BNL due to the lower primary proton momentum and a lower proton beam current.

A new beam line has been proposed[4] for the BNL AGS which will deliver kaon beams in the 1-2 GeV/c momentum range and will allow, for the first time, detailed studies of S=-2 hypernuclear systems. The design considerations and expected performance of the beam line are discussed.

2. DESIGN CONSIDERATION

Figure 1a shows the variation of the forward angle cascade (Ξ) production cross section with incident kaon momentum.[5] An ideal beam line for producing Ξ^- particles will be optimized at about a 1.8 GeV/c kaon momentum. Shown in Fig. 1b is the variation in cross section and momentum transfer for S=-1 Λ production as a function of incident kaon momentum. One can see that a 1.8 GeV/c kaon beam is also suitable for producing Λ hypernuclei since a second maximum in the production cross section is found around 1.8 GeV/c and the momentum transfer is still below the typical nuclear Fermi momentum.

The predicted differential cross sections for producing such things as cascade hypernuclei[5] and the S=-2 "H" dibaryon resonance[6] are in the range of 0.1 to 1 μb/sr. A beam line which can adequately explore these physics

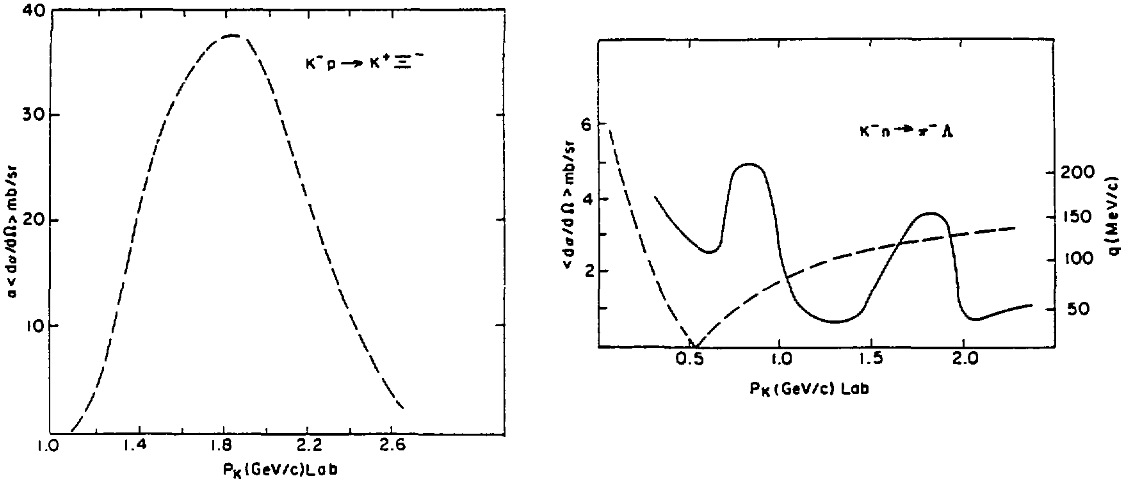

Fig. 1 (a) Forward angle averaged differential cross section for the $K^-p \to K^+\Xi^-$ reaction as a function of kaon momentum
(b) Forward angle differential cross section (solid line) and momentum transfer (dashed line) as a function kaon momentum.

problems must then provide an intense clean beam of momentum analyzed kaons. The following design goals were estblished for such a beam line.

1. The beam line must provide a minimum of 10^6 negative 1.8 GeV/c kaons per AGS beam spill.
2. The kaon beam purity should be about 1:1 unwanted particles to negative kaons.
3. The beam line optics should allow the beam momentum to be determined to better than 0.1% with the use of conventional hodoscopes and drift chambers.

The K2 beam line at KEK is currently the only existing kaon beam line capable of delivering a separated kaon beam with a momentum in the range 1-2 GeV/c. A layout of the K2 beam line is shown in Fig. 2 (from ref. 2) and represents a typical separated beam line design.

The design incorporates first a bending magnet D1 used to bend the secondary kaon beam away from the primary protons, then Q1 and Q2 quadrupole focusing to prepare the beam for the electrostatic separator. Quadrupoles Q3 and Q4 then focus the beam onto the mass slit which has an opening that allows kaons to pass. The sextupole element SX before Q3 is used to correct the second order chromatic vertical focusing aberration $(y/\phi\delta)$.

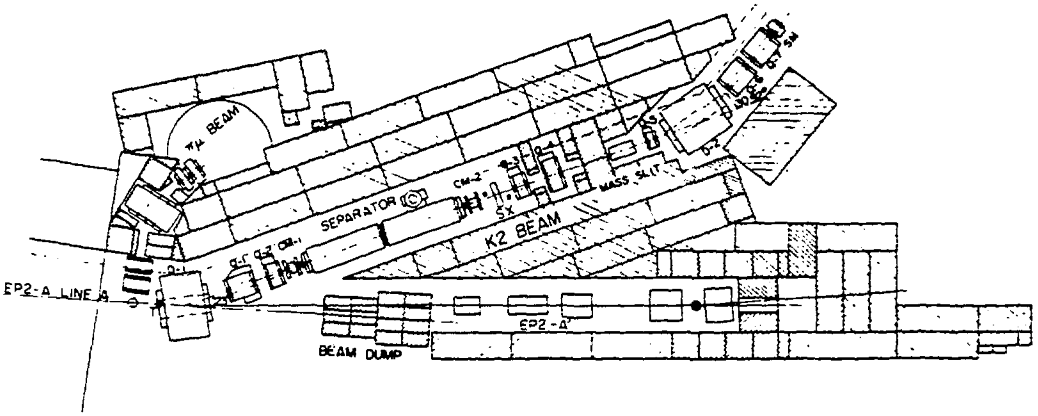

Fig. 2 KEK K2 beam line layout

The remaining quadrupoles Q5-Q7 and dipole D2 then deliver a separated kaon beam to the experimental target.

One crucial feature in the operation of the K2 line is the use of a unique separator design due to Yamamoto, Maki, and Kusumegi.[7] Unlike conventional separators, the KEK design has high voltge supplies mounted directly within the separator chamber. Thus the capacitively stored energy present in the cables and feed throughs is avoided, and damage due to occasional sparking is minimized. Operational voltages between the plates of the separator of greater than 750 kV across a 10 cm gap have been achieved. At these high fields, the magnetic field must be separated from the same spatial region of the electric field; the magnetic field induces a greater probabiity of discharge due to the Penning effect. The KEK design then uses correction magnets CM-1 and CM-2 before and after the separator.

If the K2 beam line were constructeed at the AGS one would expect the kaon flux to increase by a factor of about 3.2 due to the higher primary proton momentum (28 GeV/c vs. 12 GeV/c) and a factor of 4 due to the higher average proton intensity available on the kaon production target. The expected 2 GeV/c flux would then be about 1.4×10^{6}, K^-/AGS beam spill. So the first goal would be met. However, the measured beam purity at KEK for the K2 beam line is about 5:1 $(\pi^-, \mu^-, e^-)/K^-$ at 1.6 GeV/c.[2] At BNL the number of unwanted particles at the end of the beam line would then approach 10^{7}/beam spill. Design goal number 2 is then not met and the intense background of unwanted particles would make design goal 3 difficult to achieve due to detector rate

Figure 3(a) (extracted from reference 2) and 3(b) illustrate two of the problems associated with the K2 and LESB-I beam lines respectively. The figures show the relative rates of unwanted particles and kaons available at the experimental target location as a function of the vertical position of the beam on the mass slit.

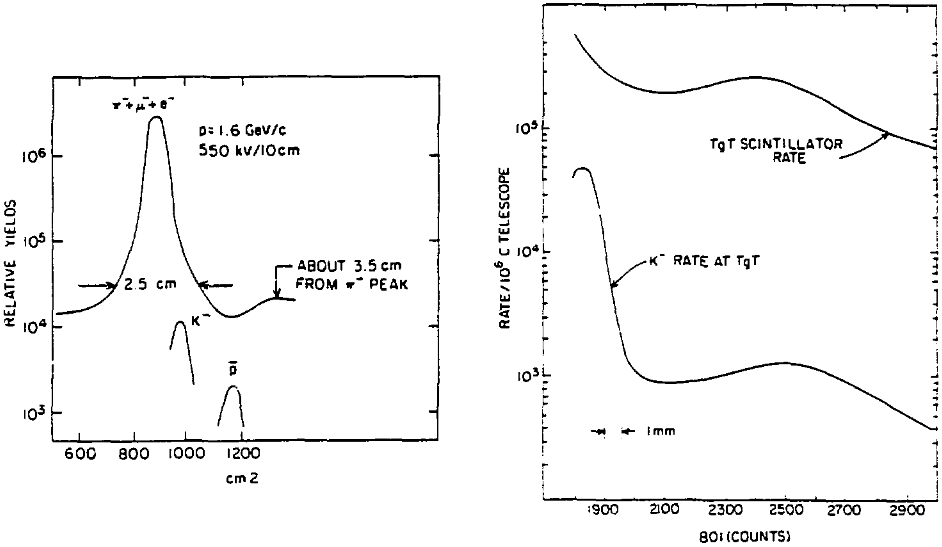

Fig. 3 (a) K2 vertical sweep of particles on the mass slit.
(b) LESB-I vertical sweep of particles on the mass slit at a 0.87 GeV/c momentum.

The kaon peak lies well within the tail of the pion peak. More separation would move the kaons further from the pion tail but eventually the kaons would encounter secondary sources. Both the secondary maximum shown in Fig. 3(a) and (b) occur at a location that can be associated with pole tip scattering of the particles from the first dipole in the respective beam lines. The pole tip scattering peak is sitting on top of a general background of particles which arise from scattering off other pole tips and from short-lived hyperons which decay in the vicinity of the target, as well as the decay of the kaons and pions in the beam. Clearly, more separation would improve the kaon beam purity but at the expense of beam intensity. The kaon decay rate is about 8% per meter at 1.8 GeV/c.

In order to minimize the effect of the background sources discussed in the preceding paragraph, the magnet aberrations must be controlled or corrected sufficiently so that the full width of the pion distribution at the mass slit is reasonably close to the nominal mass slit opening (2 mm). Note that the base width of the pion peak shown in Fig. 3(a) is 2.5 cm. Furthermore the beam line should incorporate some means of re-imaging the target on a clean-up slit in order to minimize the effect of spurious sources.

The planned improvements over conventional beam line designs are then:

1. In order to minimize the vertical image size of the particles on the mass slit, and therefore improve the separation quality, the vertical aberrations will be corrected to third order.
2. In order to help eliminate secondary sources the separation stage will be divided into two sections, each with a mass slit. The effect of the two stage separation is shown schematically in Fig. 4. This scheme has the additional advantage of allowing most of the primary pions to be stopped in a mass slit located well away from the target area.

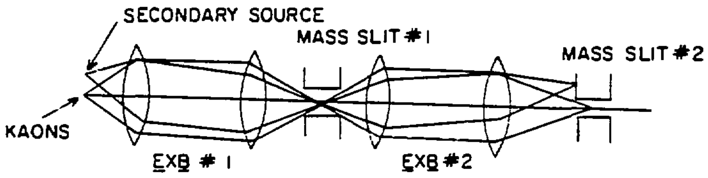

Fig. 4 Schematic of the double separator techniques.

3. In order to get the most separation for a given length, KEK style separators should be used.

3. THE PROPOSED BEAM LINE

Based on the foregoing design criteria a beam line design has been formulated. A layout of the proposed beam line is shown in Fig. 5.

The basic system is approximately symmetric about mass slit 1 (MS1) because for such a system many aberration coefficients are automatically zero. The two dipoles each deflect the beam 30 degrees in the same direction. The total effective length of the velocity filters is 9 m. The basic system is approximately symmetric about (MS1) and is based on the design of Enge.[8,9] Some of the parameters of the beam lines are given in Table 1.

The second half of the beam line can be used as a kaon spectrometer. A first order momentum resolution of about 0.05% is predicted using a hodoscope (H1) with 2 mm wide elements after MS1 in combination with a drift chamber (D1) after MS2. The 5 degree kaon production angle was chosen based on Sanford-Wang flux predictions.[10] Figure 6 shows how the 2.0 GeV/c K^- and π^- rate is predicted to change with production angle. The production peak

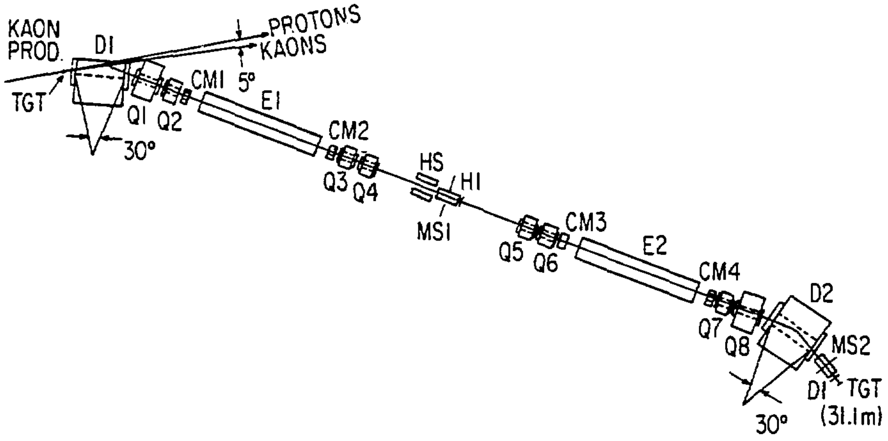

Fig. 5 A floor layout of the proposed 1-2 GeV/c beam line. The design is based on modified, but otherwise standard, magnets in use at the AGS. The separators E1 and E2 are based on KEK designs.

Table 1 Proposed AGS Beam line Design Parameters

Momentum Range	1-2 GeV/c	
Target	6 cm platinum	
Central Production Angle	5°	
Beam Length	31.1 m	
Horizontal Acceptance	±50 mr	
Vertical Acceptance	±8 mr	
Momentum Acceptance	±3%	
Solid Angle Momentum Acceptance	8 msr %	
Particle Yields		
4×10^{12}, 30 GeV/c protons		
Sanford-Wang est.	4×10^{6} K^-	at 2 GeV/c
Scaling from K2	1.4×10^{6} K^-	

occurs at about 5 degrees. Shown also is a plot of the π/K ratio at each mass slit as a function of production angle. The difference in the π/K ratio at the two mass slits is due to the kaon decay factor. The π/K ratios at the K2 and LFSE-I mass slits are also shown in the figure for 2 GeV/c and 0.8 GeV/c kaons respectively. Notice that the π/K ratio ($\sim$ 200) at the second slit with mass slit 1 open is about the same as that found at present single stage

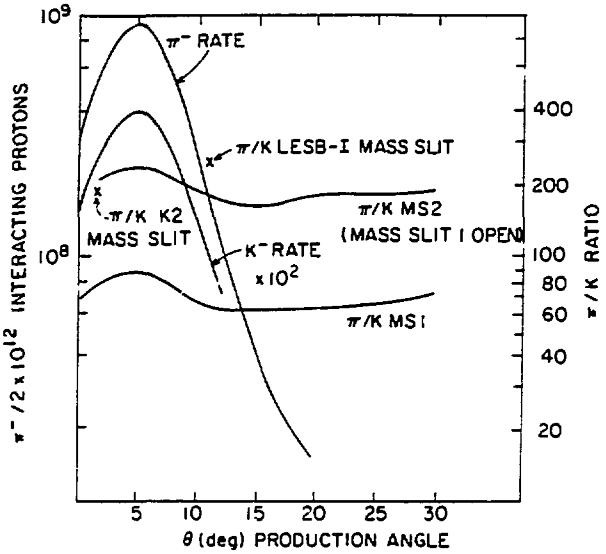

Fig. 6 Plots of predicted fluxes of K and π and the π/K ratio as a function of production angle.

separation beams. The π/K ratio at the second mass slit with the first mass slit closed to 2 mm should then be more than an order of magnitude better - providing the beam line optical aberrations are controlled well enough.

The calculated first order horizontal and vertical envelopes and dispersion are shown in Fig. 7 as a function of position along the beam line. The dispersion at the first mass slit is 4.3 cm/%, therefore the horizontal slits (HS) can be used to make a crude momentum selection. The dispersion at the target is 0.4 cm/% and is not zero because of the asymmetry in the position of the kaon production target and the experimental target relative to D1 and D2 respectively.

Table 2 shows the most important characteristics of the beam elements. The maximum distortion of any quadrupole amounts to about 5 percent of the quadrupole field. These perturbations can easily be introduced by displacing the pole pieces slightly.

Figure 8 illustrates how much the pole tip of a typical BNL quadrupole must be displaced so that the pole tip profile approximates the equipotential of the multipole field.

The third order optimization of the beam line was done with the use of the computer program RAYTRACE[11] which calculates particle trajectories, correct to all orders. Figures 9(a) and 9(b) show the effects of introducing second and third order corrections in selected quadrupoles on the vertical image size at the two mass slits. As can be seen, although the introduction of sextupoles

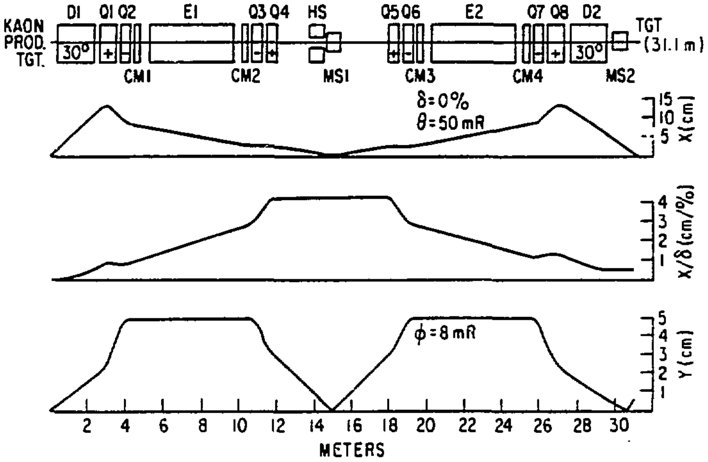

Fig. 7 Some first order properties of the beam line.

Table 2 Beam Elements for 1.8 GeV/c

Dipoles:		BNL Desig.	R(cm)	ϕ(deg)	α=β(deg)	Gap (cm)	Width (cm)	B(kG)
	D1	18C72	368	30	15	7.6	45.7	16.3
	D2	18D72	368	30	15	7.6	45.7	16.3

Quadrupoles:		BNL Desig.	L_{eff}(cm)	R(cm)	BQ(kG)	BH(G)	BO(G)
	Q1	12Q30	89.4	15.24	9.60	0	-70
	Q2	12Q16	53.8	15.24	-11.31	76	300
	Q3	12Q16	53.8	15.24	-8.64	-482	100
	Q4	12Q16	53.8	15.24	7.60	284	0
	Q5	12Q16	53.8	15.24	7.43	277	135
	Q6	12Q16	53.8	15.24	-8.56	-464	0
	Q7	12Q16	53.8	15.24	-9.93	84	0
	Q8	12Q30	89.4	15.24	7.73	0	0

Separators:		L(m)	Gap(cm)	Width(cm)	V(kV)
	E1 & E2	4.5	10	40	750

Correction dipoles		L_{eff}(cm)	Gap(cm)	Width(cm)	B(kG)
	CM1-4	30	20	20	1.95

Slits: HS = Horizontal slits - 80 cm thick, heavy metal.
MS1,2 = Vertical slits - 80 cm thick, heavy metal.

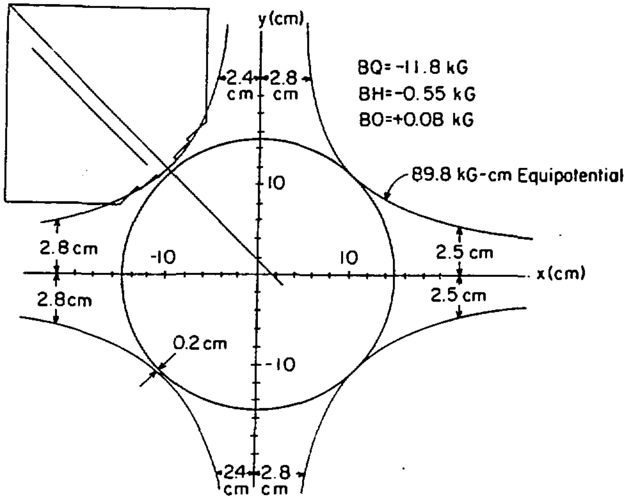

Fig. 8 Equipotential lines at a 15 cm radius for a typical multipole element. A BNL 12Q16 quadrupole pole tip is shown and has ben shifted off-center so that the pole tip profile matches the equipotential surface.

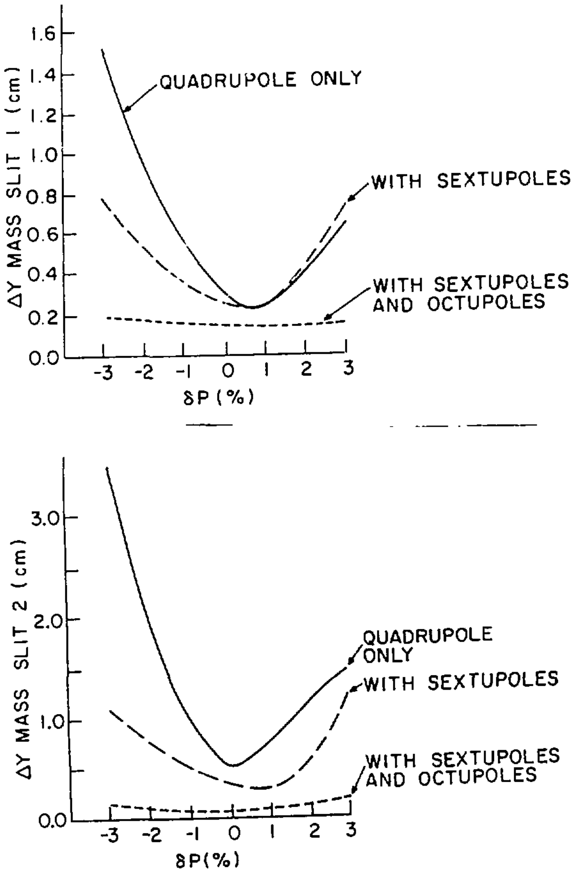

Fig. 9 (a), (b) Effects of sextupole and octupole corrections of the vertical image size (full width) at the two mass slits. The RAYTRACE input phase space was contained within $\Delta\theta = \pm 50$ mr, $\Delta\phi = \pm 8$ mr, with a point source.

has a significant effect on reducing the image size, the octupole corrections are necessary if a vertical image size on the order of 2 mm is desired.

A side view of the first mass slit is shown in Fig. 10. The mass slit profile follows the envelope of the kaon trajectories. The pion profile is also shown and, as can be seen, on the average a pion will pass through about one half of the 80 cm thick mass slit or a little more than 4 interaction lengths. One to two percent of the pions will then exit the mass slit and contribute about 10^7/beam spill of background. These off-momentum pions, however, will not be transported to the second mass slit.

A view of the first mass slit as seen by kaons and pions is shown in Figs. 11(a) and (b). The RAYTRACE calculation included sufficient rays to flood

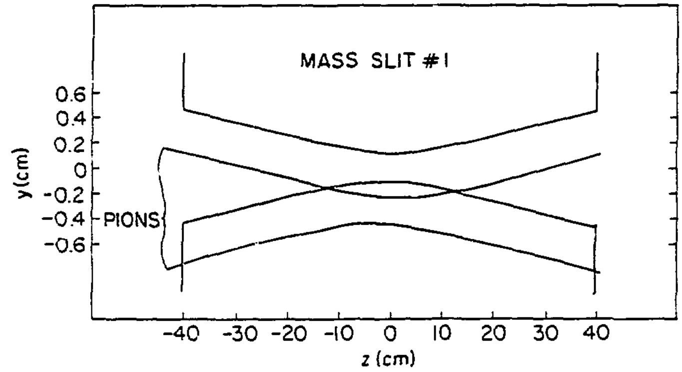

Fig. 10 Side of the first mass slit showing pion envelope. The separator is at 75 kV/cm and is set to transmit kaons through the mass slit.

the beam line acceptance and magnet apertures were included. The high momentum side of the beam has uncorrected chromatic aberrations and are due to the fact that the momentum acceptance of the beam line is not well defined on the high momentum side. The result of a RAYTRACE calculation giving the momentum acceptance at MS1 is shown in Fig. 12. Some of the high momentum tail can be removed, at the expense of kaon flux, by making use of the horizontal slits before the first mass slit.

4. CURRENT STATUS

The beam line design as presented in the previous section will not fit on the AGS experimental floor without extensive (and expensive) modifications to the beam line area. Two changes which modestly affect the symmetry properties

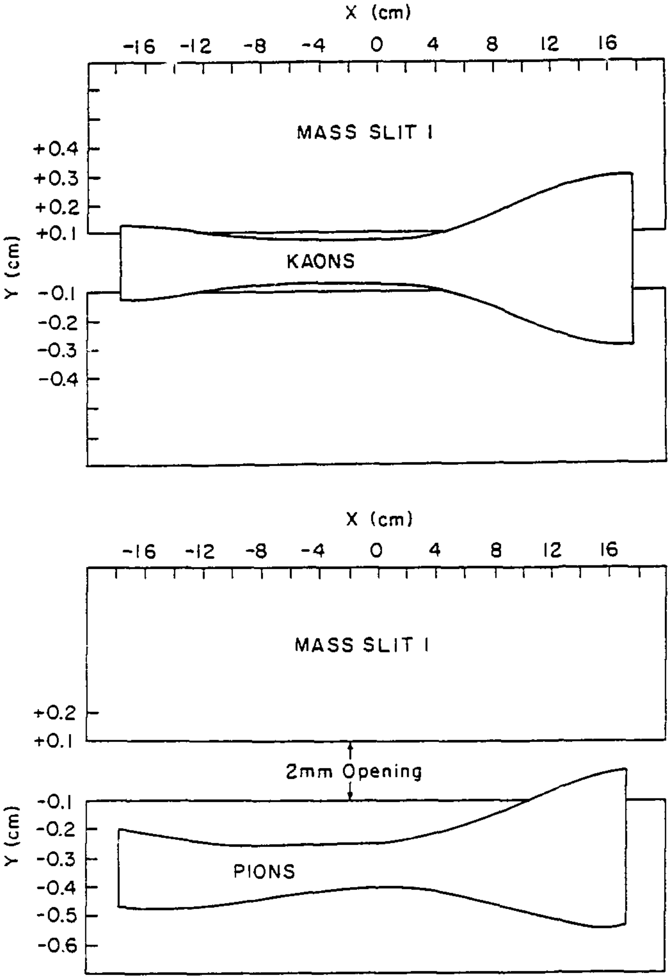

Fig. 11 (a) Kaon envelope at MS1 looking in the direction of the beam.
(b) Pion envelope on MS1 with the separator on at 75 kV/cm and set to transmit kaons through the mass slit.

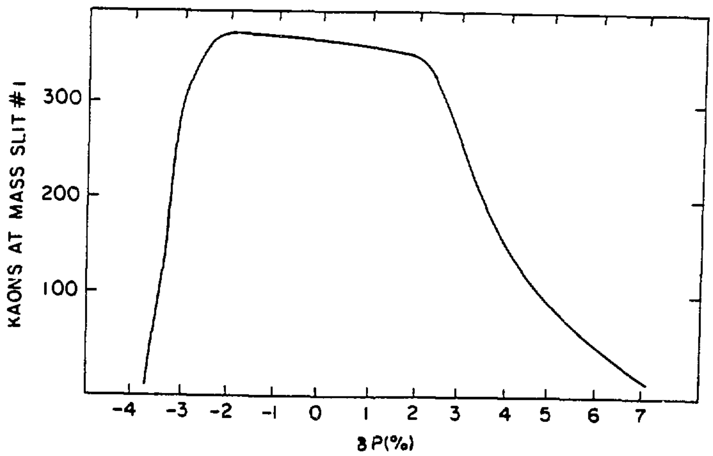

Fig. 12 The momentum acceptance of the beam line to mass slit 1 as predicted by a RAYTRACE calculation.

of the beam line were found to be necessary in order to fit the beam line into the space available at the AGS:

1. the D1 dipole bend angle must be reduced from 30° to 25.5° and
2. a dipole must be inserted after MS1 with a 15° bend angle.

Also, for a savings of about 0.5 million dollars, the KEK style separators will be replaced with BNL style separators which are currently being used at another AGS separated beam line (MESB). The BNL separators can hold only 550 kV across a 10 cm gap as opposed to 750 kV for the KEK separators. However, the MESB separators will fit into the same space as was allocated for the KEK style separators and are 5.1 meter long compared to 4.5 meters for the KEK style separator. The added length is made possible because the BNL separators do not require correction dipoles before and after the electric field section. The net loss in separation at MS1 is then about 17% or 0.6 mm at 1.8 GeV/c.

The beam line layout with the above changes is shown in Fig. 13. Two experimental setups are shown at the end of the beam line. Exp. 813 is an approved experiment[12] designed to search for a strangeness-2 dibaryon. The present "Moby Dick" hypernuclear spectrometer (modified to allow operation at 1.4 GeV/c) is shown on the beam left side. The spectrometer is a suitable instrument for the study of cascade and lambda hypernuclei.

The beam line is shown sharing the AGS "A" target which currently provides a source of pions for the high energy unseparated beam line (HEUB). The production target area is shown schematically in Fig. 14. Correction magnet C1-C3 have been added in order to bring the primary proton beam back on line. The correction magnet fields will cause the average pion production angle ($\theta\pi$) to deviate from the optimum zero degree angle. With the proposed beam line set for 2 GeV/c negative kaons, the production angle for HEUB pions at the target moves from 4° (for 5 GeV/c) to 1° (for 24 GeV/c). Because the production cross section peaks near 0° for high momentum pions, the HEUB pion rate will be decreased by a factors of about 4.5 at 24 GeV/c to 2.2 at 10 GeV/c. Furthermore, the 6 cm platinum target contemplated for the 2 GeV/c kaon beam is not optimum for pion production at HEUB. Therefore, experiments which require the highest intensity of high momentum pions in the HEUB will not be compatible with the kaon line, and they cannot run simultaneously.

5. CONCLUSION

The design presented for a new 1-2 GeV/c Kaon beam line for BNL is expected to deliver beams of over 10^6 negative kaons per AGS beam spill with a beam purity approaching 1:1. The beam line will allow, for the first time, a detailed search for strangeness-2 dibaryon states, the study of cascade hypernuclei and possibly the study of Ξ nucleon and Λ nucleon scattering.

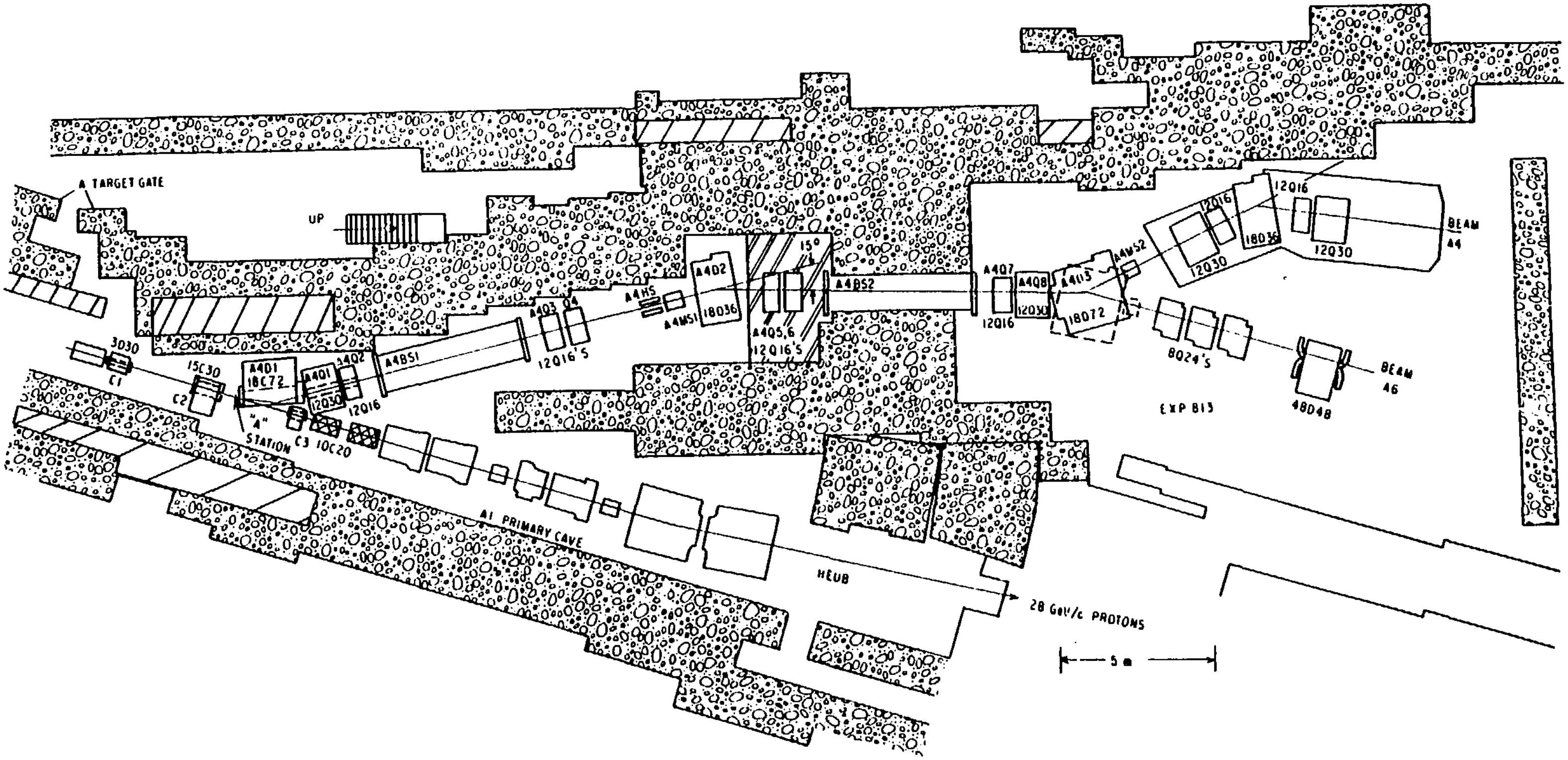

Fig. 13 Proposed beam line shown located at the "A" target station at the AGS. Two experimental setups are shown at the end of the beam line. Exp. 813 is an approved experiment designed to search for the S=-2 dibaryon and on the beam left side is shown a spectrometer suitable for cascade hypernuclear studies.

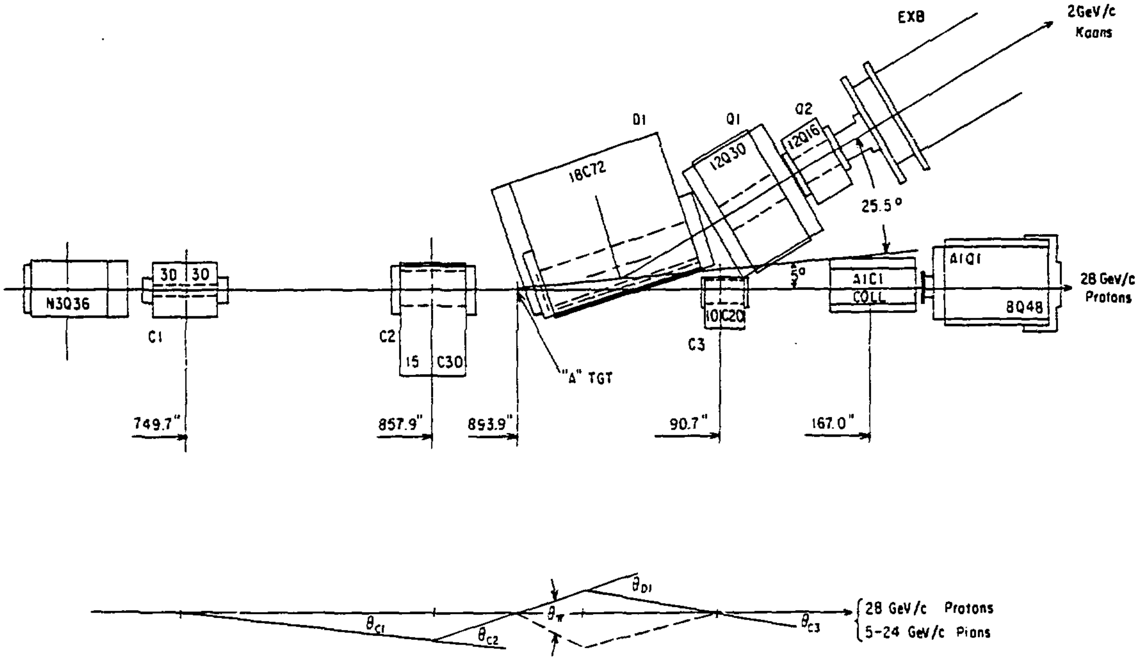

Fig. 14 A layout of the "A" target area and a schematic (not to scale) of the primary proton (solid line) and secondary HEUB negative pions (dashed line) deflections in the correction magnets and D1.

Furthermore, the beam will allow further Λ hypernuclear studies with both the (K^-,π^-) and (π^+,K^+) reactions. Clean antiproton beams will also be available with intensities approaching 10^6 per AGS beam spill at a 2 GeV/c momentum. The construction of this beam line is considered essential in order that the vitality of the hypernuclear physics field be maintained until such time as a kaon factory becomes a reality.

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