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PRODUCTION OF KAONS AT ELECTRON ACCELERATORS*

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Introduction

The primary electron beam at SLAC has been variously used to produce secondary beams of both charged and neutral particles.[1] Four general purpose charged particle beams are now in operation, each capable of useful kaon fluxes with the momentum range of several GeV/c. There is also a recently used neutral kaon beam which is now dormant. The measured yields together with the expected yields are reported herein. Empirical formulas have been fitted to the data to permit extrapolation of the measured yields to other electron energies and to other secondary momenta with some confidence.

SLAC Primary Beam

The SLAC primary electron beam is pulsed at rates up to 360 Hz with pulse duration of 1.6 μsec. Useful electron energies of 21.5 GeV at 30 mA peak current (or 20.5 GeV at 50 mA) are readily attainable. With a duty cycle of 0.06%, the average current is limited to ~30 μamp at best. Typical operation in the recent past has been at 180 Hz where the duty cycle is 0.03%.

Secondary beams are run simultaneously and independently, each having a discrete set of pulses and choice of primary beam current. The primary energy may also be independently chosen, depending in some cases upon the requirements of other beams.

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The modulation of the electron beam at 2856 MHz permits the introduction of an rf deflector (RFS) into a secondary charged particle beam.[2] The electron beam has been measured to be present only within $\sim 5^{\circ}$ of rf phase. Thus the beam is delivered in 5 psec bunches separated by 350 psec. This inherent time structure is retained in secondary beams which are produced by impinging the primary beam onto a target. Placement of an RFS at a suitable distance L from the target enables beam constituents of the same momentum but with different velocities (i.e., different masses) to be spatially separated. Given the maximum transverse momentum $P_{\perp}$ imparted to a beam of momentum P, the deflection angle θ is $\theta = \frac{P_{\perp}}{P} \sin\phi$ and the phase angle ϕ is given by

$$\phi = \frac{\pi L}{\lambda}\left[\frac{m_1^2 - m_2^2}{P^2}\right]$$

where λ is the rf wavelength and m_1 and m_2 are the masses of the particles. Unwanted constituents are eliminated by collimation. Studies at SLAC[3] have led to an optimum RFS aperture of 45 mm which constrains the RFS to be located only where the beam is small, i.e., near a focus. Thus the optics of the transport system dominates the choice of L and the subsequent particle bandpasses.

<u>LASS Beam</u>

A specific example of an existing charged particle beam is the secondary beam to the Large-Angle-Solenoid-Spectrometer (LASS). This is a 4-stage beam with an overall length of 149 m. There are two RFS's, one located at 36 m and the second at 79 m. By properly phasing the separators, there is a near continuum of K momenta that can be separated from the other beam constituents (Fig. 1). Typical flux at the LASS experimental area (corrected for decay) is shown in Fig. 2a. The acceptance $\Omega \frac{\Delta p}{p}$ of the beam is 56 μsr-%. The yields at the target are shown in Fig. 3. Backgrounds from π's plus protons after separation are typically 5-10%. Muons from K decays upstream of the final bend are largely lost from the beam aperture; μ's from decay in the last 30 meters of the beam downstream of the final bend are not considered a problem whenever K's are tagged.

Other Charged Particle Beams at SLAC

In addition to the LASS beam, three other beams are capable of separating charged K's. As there is a limited complement of 4 RFS's at SLAC of which 2 are in use in the LASS beam, any 2 of the other 3 beams may then be configured with a single RFS. These three beams are quite similar and typical experimental fluxes are shown in Fig. 2b. Bandpasses for K's are at about 7 and 12 GeV/c in each of these beams.

As the design of secondary beams inevitably involves some compromises, it is reasonable to ask if the fluxes are optimized. There are undoubtedly some changes that could be incorporated in the beam design such as overall length, momentum acceptance, production angle, target length, angular acceptance, etc., but there is probably not more than a factor of 2 or so to be gained above 4 GeV/c. Below 4 GeV/c a substantial redesign has the potential of considerable increase in flux. It should be pointed out that the advantages of using rf separation diminishes as the momentum decreases; the choice defaults to electrostatic separation with all the attendant difficulties at ~2.5 GeV/c. Combined background rates from π's and protons will be much larger than the K flux so that some means of separation is certainly required.

Extrapolation to Other Energies

Although the data is rather sketchy, some measurements of K yields have been made at SLAC electron energies of 13-21.5 GeV and with K momenta from 2.5 to 16 GeV/c. Empirical fits have been made to the data. Several efforts to extrapolate the data simultaneously to K momenta and electron energies outside of the measured data have been made[4] but the results differ widely. Figure 4 is a freehand compromise representation of the several extrapolations for K^+; it is probably correct to within an order of magnitude even for low momenta K's. The K^+/K^- ratio is ~2 to 3.

New Beams

SLAC presently has no plans for development of low momentum K beams but for purposes of illustration, if one of the several beams designed for BNL, LBL and ANL were to be duplicated at SLAC, we could expect an experimental flux of $\sim 10^5$ K^+/pulse (see Table I) at 500 MeV/c, assuming the yield at the target to be 2×10^{-4} K^+/(sr GeV/c electron) and with 50 mA of electron beam on the target. It should be pointed out that this represents an extremely high instantaneous rate ($\sim 10^{10}$ K^+/sec) during the short 1.6 μsec SLAC pulse. The K^- flux will be down by a factor ~2.

TABLE I

	BNL[5]		LBL[6]	ANL[7]	
	LESB I	LESB II	Beam 34	Beam 42	Beam 3
Acceptance msr-% $\frac{\Delta P}{P}$	10.6	77	60	21	90
Length (meters)	15.2	13.7	10	15.8	10.2
Bend Angles	$29^\circ, 36^\circ$	$45^\circ, 45^\circ$	$90^\circ, 90^\circ$	$35^\circ, 36^\circ$	$35^\circ, 30^\circ$
Momentum (MeV/c)	1200	800	500	800	500
Flux (K^+/SLAC pulse)	9×10^3	10^5	2×10^5	1.6×10^4	3×10^5

Neutral Kaon Beams

There have been three K^o beams built at SLAC,[8,9] one of which is presently available. The production of K^o's lies roughly between that of K^+ and K^- and is shown in Fig. 5. The advantage of neutral K beams at SLAC is that neutrons are present at substantially lower levels than is the case at a proton machine. Also, at the sacrifice of yield, one can use a TOF measurement technique to measure the momentum of K^o's. The primary beam is chopped such that electrons are delivered to the target in 5 psec bunches separated by 12.5 nsec. The momentum error is dependent upon the time resolution of the counter system and is given by

$$\frac{\Delta P}{P} = \gamma^2 \frac{\Delta t}{t}$$

where Δt is the resolution time, t is the TOF time and $\gamma = \frac{E}{m}$ (see Fig. 6).

The K^o beam at SLAC utilizes a high Z photon absorber (15 cm Pb) and a neutron moderator (60 cm of paraffin). Collimators define the beam line acceptance of $\sim$50 μsr with a size at the spectrometer of 30 cm (H) by 50 cm (V). Bending magnets are used to sweep out charged particles. By turning off the magnets, one can use the ever present muons in calibrating the TOF system. The TOF signal is initiated by placing a secondary emission foil in the primary beam after it has coursed the target and then comparing the SEM signal to the arrival of the decay products (or muons when calibrating) in counters located at the experiment. Particle flux at the spectrometer is $\sim$150 K_L^o/pulse with the momentum spectrum peaking at $\sim$4 GeV/c. Use of the TOF system would decrease this flux an order of magnitude.

Conclusions

Although the experience with charged K's at SLAC has been in the multi-GeV/c range, it is evident that secondary beams could be designed to produce substantial fluxes of low momentum K's. A major difficulty would be in the handling of the extremely high instantaneous rate that would occur within the SLAC pulse length of 1.6 μsec. Neutral kaon physics at SLAC has the advantages of momentum determination by time-of-flight and substantially reduced backgrounds from neutrons in comparison to proton accelerators.

References

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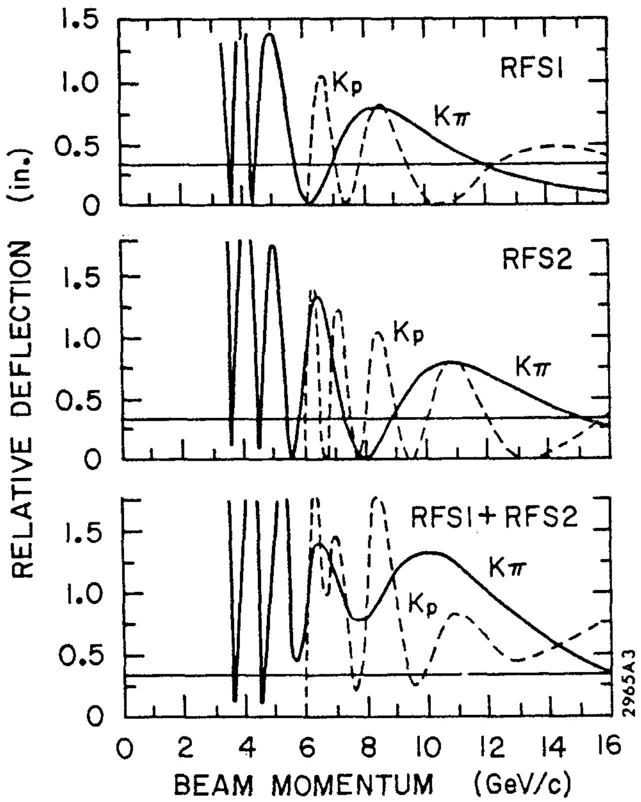

FIG. 1--Deflections of π's and protons relative to K's at the defining collimator in the LASS beam. Deflections ≥ 0.3 inches permit total separation. With the use of two rf separators, K's will be separated over a large range of momentum.

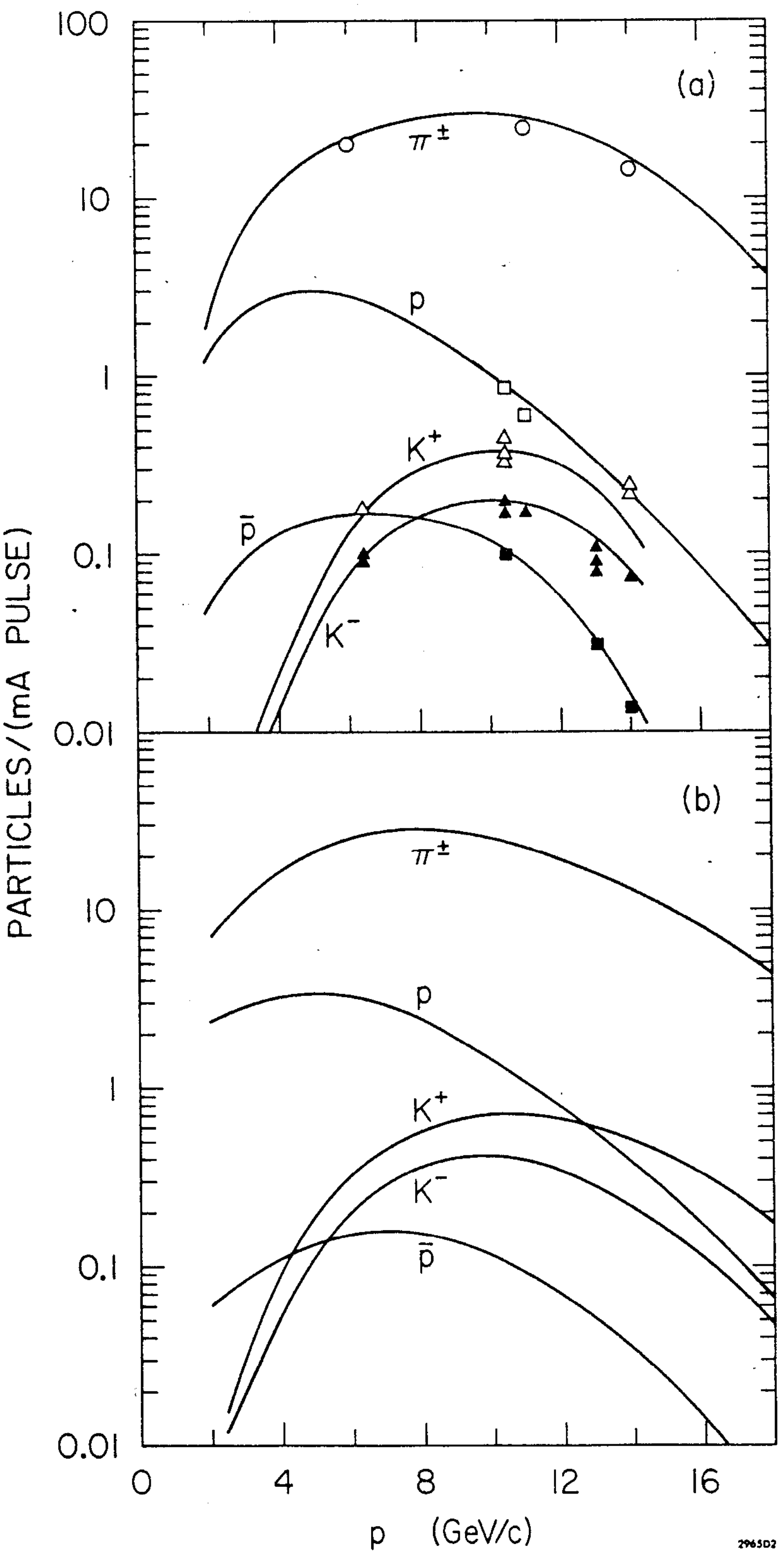

FIG. 2--(a) Measured and calculated fluxes at LASS.
(b) Calculated fluxes at the 40-inch hydrogen bubble chamber.

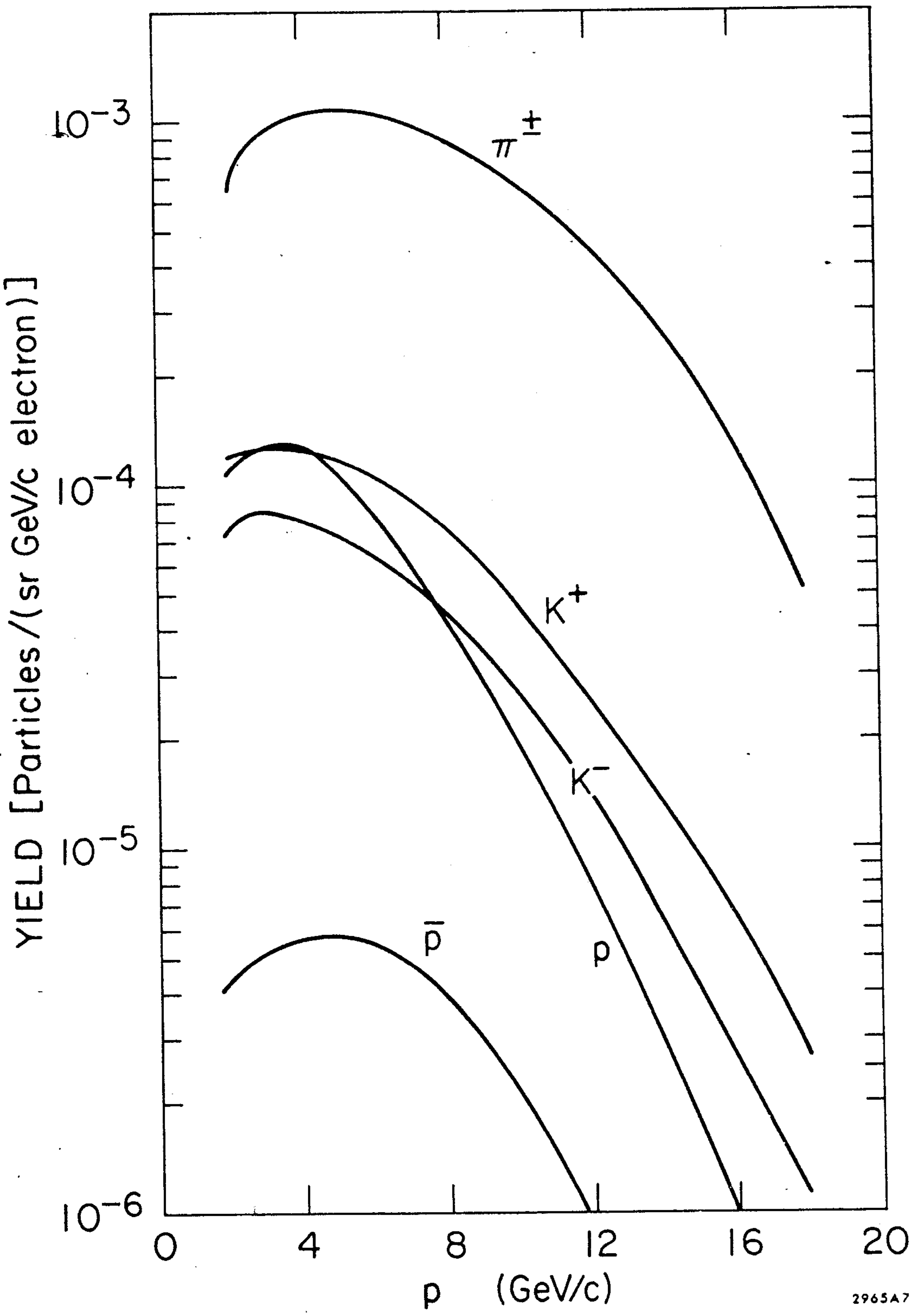

FIG. 3--K^+ yields from a 1.1 X_0 beryllium target.

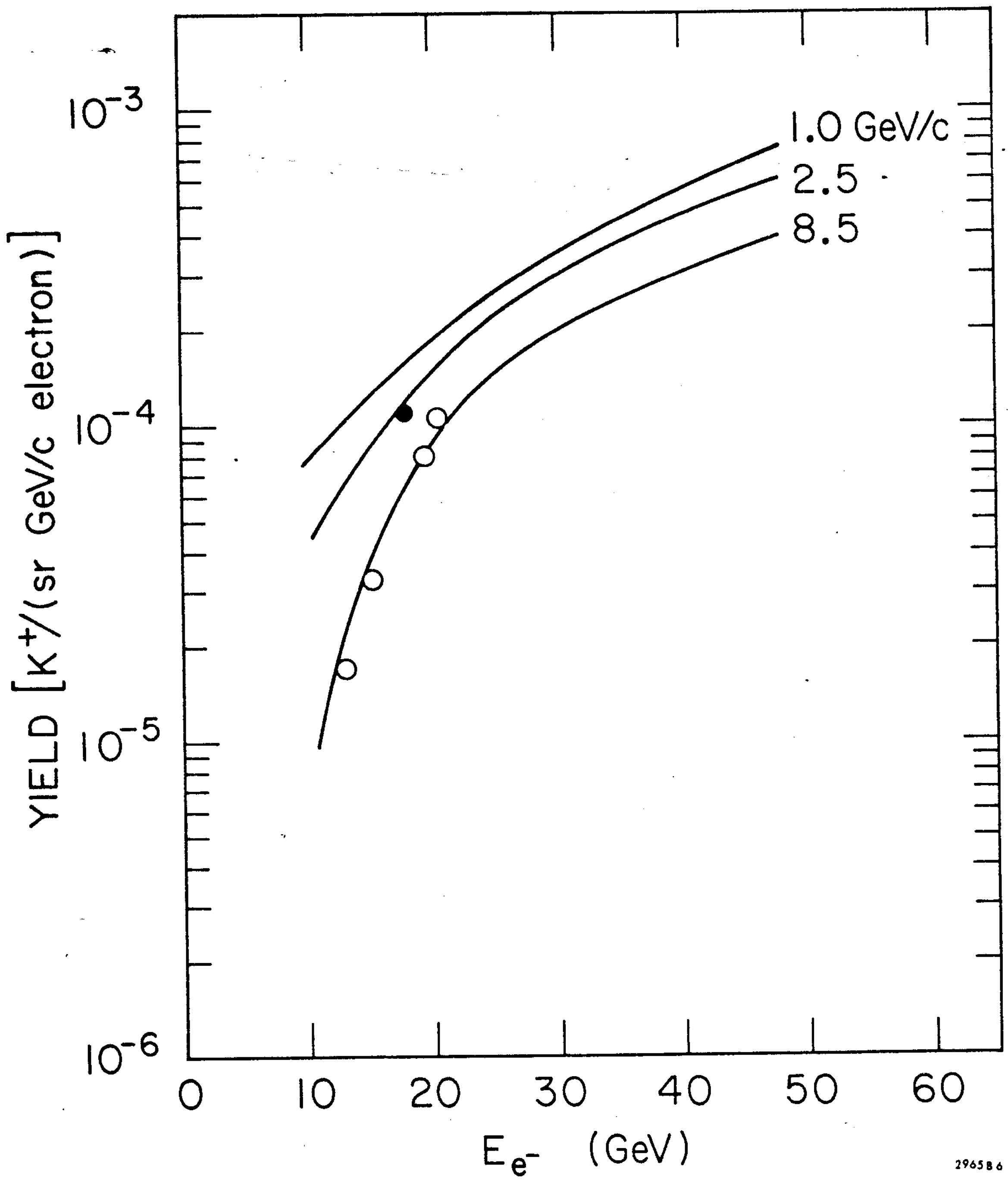

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FIG. 4--Extrapolated yields of $K^+ \cdot \frac{K^+}{K^-} \sim 2$ to 3.

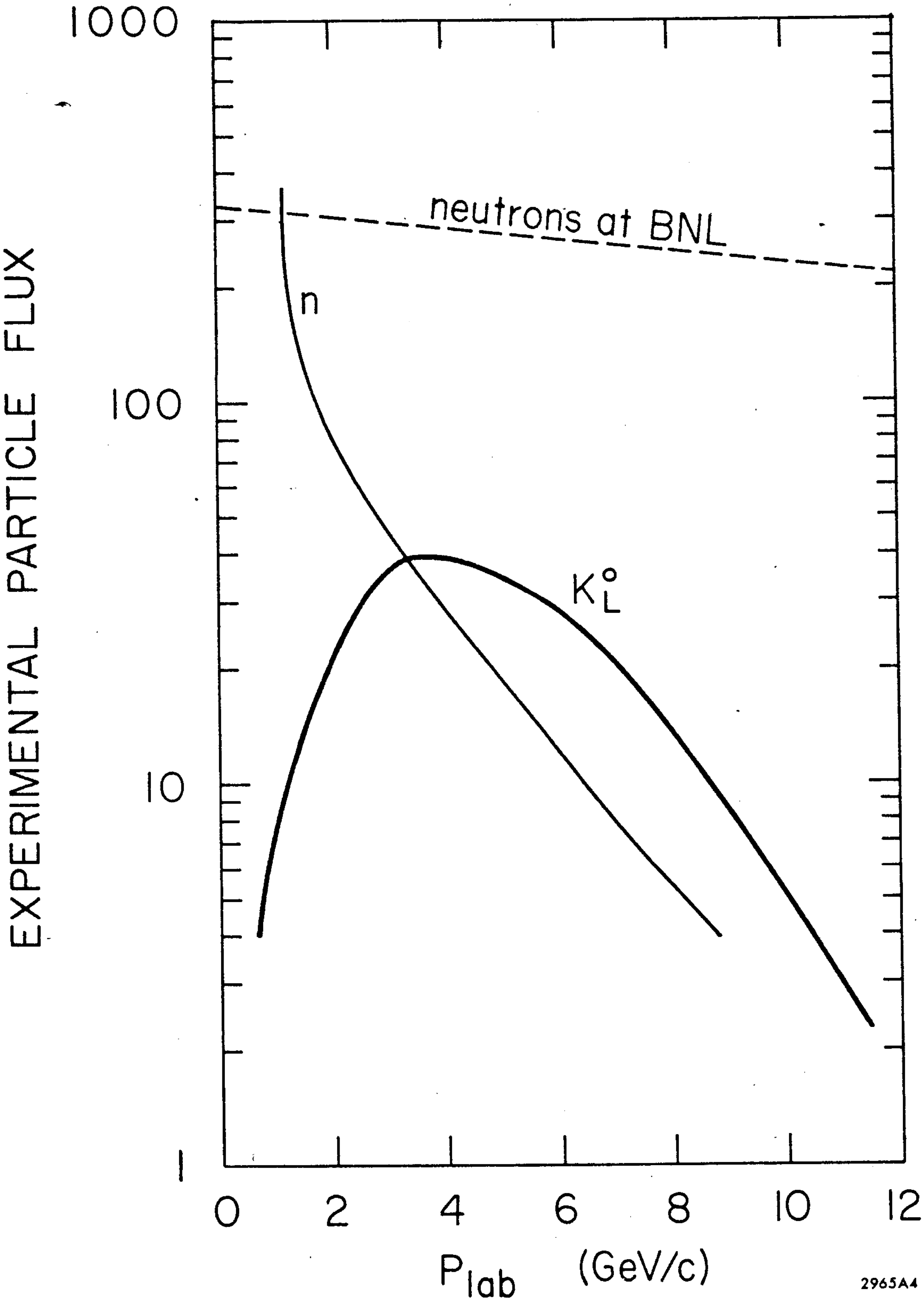

FIG. 5--Experimental K_L^o and neutron fluxes at SLAC. Corresponding neutron flux at BNL[5] is shown for reference.

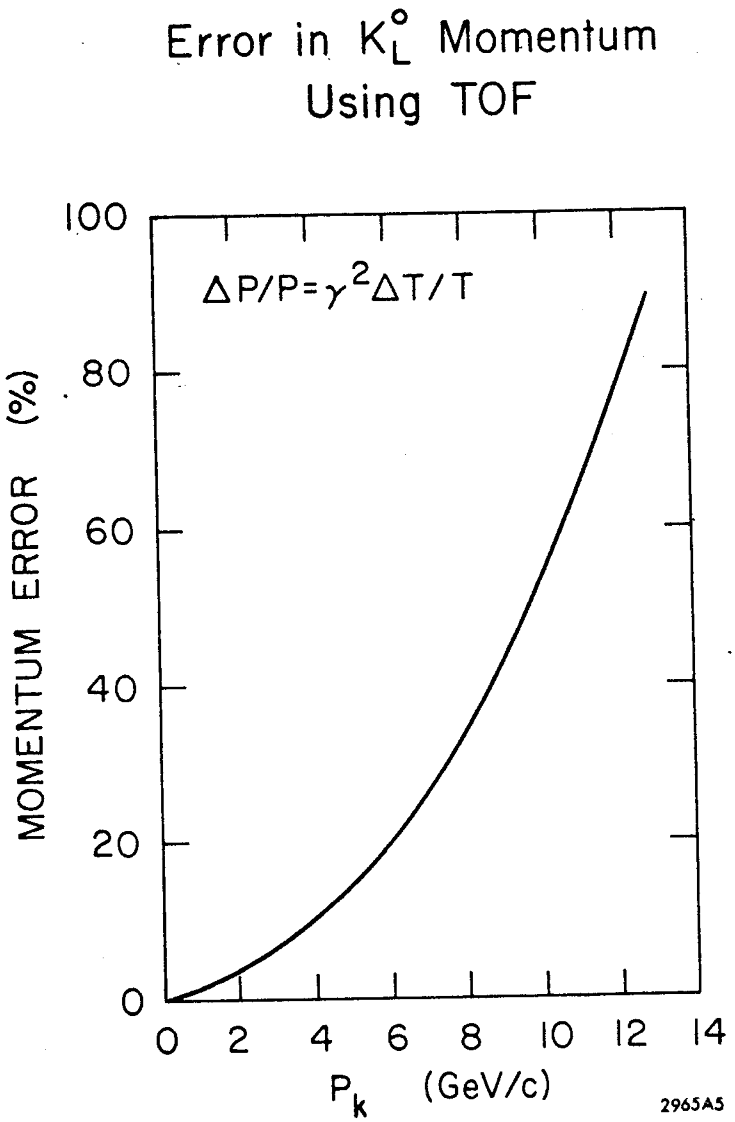

FIG. 6--Error in determination of K_L^0 momentum using time-of-flight technique.