our numerical calculation.

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[9]Another crucial consequence of locality in L^0-mediated dimuon production is that no parity-nonconserving correlation of the type $\vec{p}_\nu \times \vec{p}_- \cdot \vec{p}_+$ can occur, where $\vec{p}_\nu$ denotes the laboratory momentum of the incoming neutrino, and $\vec{p}_\pm$ the muons' laboratory momenta. Such a transverse asymmetry, τ, can only be induced by higher-order interactions, as in the case of hadron-mediated dimuon production (see Ref. 6), or by violation of time-reversal invariance.

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Search for φ Mesons Produced at High p_t in p-Be Collisions at 300 GeV

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We have searched for production of φ mesons at high transverse momenta. Upper limits with a 95% confidence level on the ratio φ/π^- ranging from 0.055 at $p_t = 2.48$ GeV/c to 0.103 at $p_t = 3.33$ GeV/c are given, ruling out the φ meson as a significant source of the high-p_t leptons observed to be produced directly in hadron collisions.

Following our observations[1,2] of directly produced electrons and muons at high p_t in proton-beryllium interactions at 300 GeV and similar observations by other groups,[3-6] we have endeavored to determine the source of this new and interesting phenomenon. Most or all of the high-p_t "direct" leptons could result from the decay of low-mass vector mesons produced with high p_t. The most likely contributor would be the $\varphi(1019)$ which has a dilepton branching ratio 7 times that of the ρ^0 and which could be responsible for a large part of the direct-lepton signal without violating the constraints of the known high-p_t pion cross sections and K/π ratios. A largely φ-meson origin for the directly produced leptons would require φ-meson production at high p_t to be approximately 3 times larger than the observed pion production. This Letter reports upper limits on φ production which rule out the φ as a significant source of direct leptons at high p_t.

The experiment was performed using 300-GeV protons incident on a beryllium target. The single-arm spectrometer used previously to measure hadron and direct-lepton production[2] was set to 50 mrad in the laboratory (66° c.m. system). This "up" arm, shown in Fig. 1, contained scintillation hodoscopes, lead-glass and steel-scintillator calorimeters, and three scintillation trigger planes. Particles were detected only after magnetic deflection in the vertical plane. The low Q value of the $\varphi \to K^+K^-$ decay mode permits a reasonable acceptance within the 9-mrad $\times$ 9-mrad nominal aperture of this spectrometer and thus a second arm was added to detect the second member of the K^+K^- pair. This new "down" arm is also shown in Fig. 1 and consisted of three scintillation counters for triggering, two counter hodoscopes, and a proportional wire

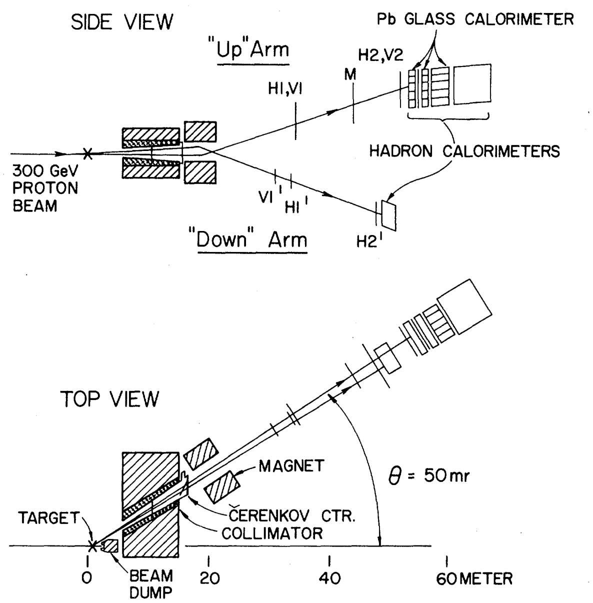

FIG. 1. Schematic drawing of the apparatus.

chamber (H_1') to measure the trajectory of the downward-bending particle and a hadron-shower calorimeter.

In addition, a 3-m-long Cherenkov counter operated with nitrogen between 0.1 and 0.5 atm was installed in the collimator upstream of the bending magnet. The pulse height of this Cherenkov counter was recorded for each event and was used to veto pions off-line.

The apparatus was triggered by a coincidence of the original up arm and the new down arm. Events with single up-arm triggers and down-arm triggers were sampled simultaneously with the two-arm coincidences. The up-arm triggers permitted a direct measurement of the φ-to-hadron ratio with the charged hadrons measured in the up arm as reported in Ref. 2. The down-arm-triggered events allowed a check on the efficiency of that arm by comparison of its hadron rates with those of the more fully instrumented up arm.

The down arm had a total of 53 elements for determining the downward trajectory with an acceptance for single particles of approximately 30 μsr in the laboratory and an average momentum resolution $\Delta p/p$ of 5.3% [full width at half-maximum (FWHM)]. This compares with values for the up arm of 60 μsr and $\Delta p/p$ of 4.0%, respectively, obtained with its 210 hodoscope elements, 45 lead-glass blocks, and a steel-scintillator hadron calorimeter. The two arms in combination had a FWHM mass resolution of 6 MeV at the φ mass. Four different average φ transverse momenta from 2.05 to 3.33 GeV/c were covered by four different settings of the magnet. The acceptance of the two-arm apparatus for φ mesons within the nominal 9-mrad × 9-mrad aperture is shown in Fig. 2 for the two extreme magnet settings. The curves in this figure include the effects of the K^+K^- branching ratio of 0.49 and kaon decays in flight.[7]

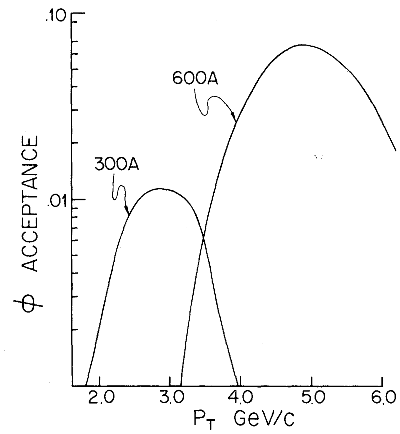

FIG. 2. φ acceptance. Fraction of φ's within the 9-mrad× 9 mrad nominal aperture which are accepted.

Events reconstructed in both arms and satisfying the Cherenkov requirement were assumed to be K^+K^- pairs with the resulting mass spectra shown in Fig. 3. These spectra contain a mixture of real K^+K^- events and misassigned $K^+\bar{p}$, K^-p, and $p\bar{p}$ events as well as random coincidences between these same particle types in the two arms. Significant contamination by pions is also present due to inefficiencies in the Cherenkov veto. We were unable to obtain a satisfactory measurement of the random coincidence rate due to severe intensity variation in the rf bunches of the incident proton beam. A rigorous subtraction of random coincidences was thus not possible. This of course does not prevent a search for narrow structures in the spectra such as the φ meson.

A search for structure in the φ mass region (1.019 GeV) has been carried out using two different methods to describe the shape of the background. First, reconstructed trajectories with up-only triggers and down-only triggers from different events were combined randomly to generate the mass spectra shown as crosses in Fig. 3. This procedure gives the *shape* of the randoms mass spectrum although, for the reasons cited above, the precise normalization is unknown.

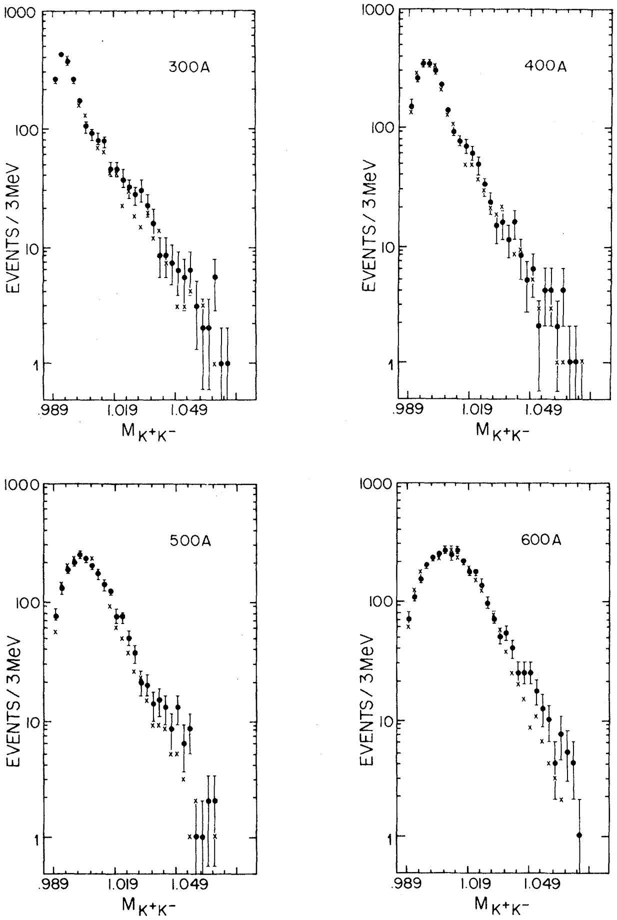

FIG. 3. Observed events versus K^+K^- effective mass. Crosses represent the "randoms" mass spectra normalized to the data.

A fit to the mass spectra in Fig. 3 was performed at each magnet setting to determine the statistical significance of a possible φ resonance contribution. The (up • down) software randoms spectrum was used as the fitting function with its normalization as a free parameter. It was found that all the observed spectra are adequately fitted by a combination of these "randoms" or uncorrelated pairs and a Gaussian representing the φ-meson resonance. Fits were performed both with the φ mass and width fixed at the standard value and expected resolution value, respectively, and with variation permitted. No difference occurred in the results.

The second method consisted of fitting an arbitrary function to each mass spectrum with five bins in the region of the φ mass excluded. The full mass spectra were then fitted by these functions with all parameters fixed with the exception of the overall normalization plus the usual Gaussian to describe the possible φ resonance.

Both the randoms and the arbitrary-function forms described above gave consistent results with no statistically significant φ signal observed at any of the 4 magnet settings. These results are combined and summarized in Table I where the 95%-confidence-level upper limits are given for the raw φ signal obtained in the fitting. The upper limit of the directly measured ratio of the φ cross section to that of the negative charged hadrons observed simultaneously in the up arm is also given. These up-arm hadrons are in a narrow (0.2 GeV/c) transverse-momentum bin at the center of the single-arm acceptance. This bin is at a lower p_t than that of the φ. The upper limit on the φ/π^- ratio at the φ mean transverse momentum is obtained from the directly measured ratio to hadrons by using the previously measured high-p_t particle composition and pion transverse-momentum dependence.[8]

Included in all the cross-section ratios presented in Table I are Monte Carlo acceptance calculations[7] which take into account the geometry and the effects of particle decays in flight. Because

TABLE I. Summary of results of φ search.

Magnet setting (A)	φ mean p_t (GeV/c) $[p_t^{\varphi}]$	Hadron p_t (GeV/c) $[p_t^H]$	Raw φ signal (events)	No. φ events	95% confidence level upper limits: φ to negative hadron ratio $\frac{d\sigma_{\varphi}(p_t^{\varphi})}{d\sigma_H(p_t^H)}$	95% confidence level upper limits: φ/π^- ratio $\frac{d\sigma_{\varphi}(p_t^{\varphi})}{d\sigma_{\pi}(p_t^{\varphi})}$ (same p_t)
300	2.05	1.08	20 ± 14	50	5.86×10^{-4}	0.082
400	2.48	1.30	40 ± 17	75	2.90×10^{-4}	0.055
500	2.91	1.69	10 ± 17	44	2.90×10^{-4}	0.069
600	3.33	1.89	34 ± 24	82	2.44×10^{-4}	0.103

the φ is measured relative to up-arm hadrons, the results need be corrected only for the total efficiency of the down arm. These calculations and the operation of the individual spectrometer arms are all extensively checked by the absolute determination of the hadron cross sections in each of the two arms. Absolute hadron cross sections measured in the up arm are consistent to ± 20% with those measured previously.[2,8] This is well within our absolute normalization uncertainty of ± 40% (which does not enter into the results of Table I). From a comparison of the hadrons observed in the down arm, corrected for acceptance and muon contamination, to those in the up arm at the same p_t, relative down-arm efficiency was 0.71 including reconstruction efficiency, trigger efficiency, and losses through nuclear interactions.

The Cherenkov counter efficiency for pions was determined to be approximately 80% by using the known particle ratios.[8] This also does not enter into the φ/π^- ratios except for the effect of greater background introduced by any inefficiency.

In conclusion, the φ/π^- ratio at high p_t has been measured to be less than 0.055 at $p_t = 2.48$ GeV/c and 0.103 at $p_t = 3.33$ GeV/c at the 95% confidence level.[9] This implies that the production of "direct" leptons coming from the φ meson at high p_t in ratio to pions is less than 1.7×10^{-6} and 3.0×10^{-6} at the same p_t values. A φ-meson origin for the high-p_t direct-lepton signal observed at $\sim10^{-4}$ of the pions is therefore clearly ruled out.

We are aware of at least one recent measurement in our kinematic region of an upper limit on the φ/π ratio. Büsser *et al.*[5] have given $\varphi/\pi \leq 0.4$ at the 90% confidence level for $p_t > 1.6$ at the CERN intersecting storage ring energies which is approximately an order of magnitude less stringent than the limits presented here.

We would like to acknowledge the efforts of the Fermilab staff and, in particular, of the Proton Department to facilitate this experiment. We are also grateful to Mr. F. H. Pearsall, Mr. S. J. Upton, and Mr. P. Bury and to the staff of Nevis Laboratories for their help in the design and implementation of the apparatus and also to Dr. M. Atac and Dr. J. Lach for the loan of the proportional wire chamber adapted for use in this experiment.

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[5]F. W. Büsser *et al.*, Phys. Lett. 53B, 212 (1974).

[6]D. Bintinger *et al.*, Phys. Rev. Lett. 34, 982 (1975).

[7]For the limits given in this Letter, the p_t distribution of the φ is assumed to have the same shape as that of the pion. Also, an isotropic $\varphi \to K^+K^-$ decay distribution is assumed. The limits would be decreased at the 500-A setting, for example, by 6% with either a $\cos^2\theta_H$ decay assumption of a 10%-flatter p_t distribution.

[8]The measurements of J. W. Cronin *et al.* [Phys. Rev. D (to be published)] for 300-GeV protons incident on beryllium at 77 mrad were used. We neglect angular dependence in the particle composition and the shape of the p_t distribution between 50 and 77 mrad as is consistent with the p-p measurements of B. Alper *et al.*, Nucl. Phys. B87, 19 (1975).

[9]We have also plotted the observed events versus the effective mass of all other possible pair combinations of π, K, and p with the appropriate Cherenkov requirement. No significant structure was observed. Thus the *order of magnitude* of the limits quoted in this Letter apply to any very low Q (~ 30 MeV), narrow, two-body resonance; e.g., $K^+\bar{p}$, etc.