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Double ϕ-meson production with a tagged 100 GeV/c hadron beam on a Be target

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Abstract: The production of ϕ-meson pairs is studied in the reaction hadron + Be $\rightarrow \phi + \phi$ + anything at 100 GeV/c incident momentum. The ϕ-mesons are identified via their K^+K^--decay channel. The number of $\phi\phi$-events is a factor 6 larger than expected for uncorrelated production of two ϕ-mesons. In the x_F region $0.2 < x_F(\phi\phi) < 0.7$, where $x_F(\phi\phi)$ is the Feynman-x of the $\phi\phi$-system, the ratio

$$\frac{d\sigma}{dx_F}(K^- + Be \rightarrow \phi\phi + X) \Big/ \frac{d\sigma}{dx_F}(\pi^- + Be \rightarrow \phi\phi + X)$$

shows an increase with increasing x_F similar to that observed for single ϕ-production. This suggests an analogous production mechanism for single-ϕ and $\phi\phi$-production.

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1. Introduction

The main interest in the study of $\phi\phi$ states at present comes from the fact that it is a likely decay channel for gluon bound states[1]. So far there is no conclusive evidence for the existence of such "glueball" states. There are several candidates among which two are reported in the $\phi\phi$-decay channel in the exclusive reaction $\pi^- p \rightarrow \phi\phi n$ [2]. Results on the inclusive production of $\phi\phi$-pairs[3] show a strong enhancement of the production cross-section, relative to what would be expected for the uncorrelated production of two ϕ-mesons, suggesting strong correlation effects. In this paper some characteristics of the $\phi\phi$-production are investigated for different incident particles and compared with single ϕ-production, thus allowing some qualitative conclusions concerning the production process.

2. Experiment

The data presented were obtained in experiment NA11 at the CERN-SPS. Two data samples will be used, the first one is obtained from a dedicated $\phi\phi$ run during the autumn of 1981, the second one from an experiment which aimed for the study of inclusive single-ϕ production during the summer of 1982. The analysis of the last experiment is not completed and hence the presented results are preliminary.

The aim of the 1981 experiment was to study low mass $\phi\phi$ pairs at 100 GeV/c incident momentum in the reaction

$$\text{hadron} + \text{Be} \rightarrow \underset{\rightarrow K_1^+ K_1^-}{\phi_1} + \underset{\rightarrow K_2^+ K_2^-}{\phi_2} + \text{anything} \qquad (1)$$

The incident hadrons, π^-, K^-, and $\bar{p}$, were identified with two differential Cerenkov counters (Cedars). The trigger used two Cerenkov hodoscopes (C_2, C_3) and two scintillation hodoscopes (MA, MB). The MA (MB) array was located immediately behind C_2 (C_3). The elements of these arrays matched one for one the dimensions of the Cerenkov mirrors. The π threshold for C_2 and C_3 were 3.7 and 6.5 GeV/c respectively. For a charged kaon the trigger demanded either a signal from an MA element without light in the corresponding C_2 cell, or a signal from an MB element giving no light in its C_3 cell and light in the corresponding C_2 cell. The kaons were identified in the momentum range 3.7-23. GeV/c. The trigger required a minimum of two negative and two positive charged K meson candidates with a topology typical for kaons originating from ϕ-meson decay. The acceptance for ϕ-mesons was limited to the x_F-range of $0.05 < x_F(\phi) < 0.45$.

It should be noted that in the momentum range 3.7-13.2 GeV/c we were not able to distinguish between protons and kaons. Whenever we refer to non-resonant K^+K^- pairs, each kaon can also be a misidentified proton.

The 1982 experiment was set up to study inclusive single ϕ production with various beam energies. The experimental set-up was almost the same as that used for the double ϕ experiment. The trigger required a minimum of two oppositely charged kaon candidates. In this experiment the dead time losses were reduced by introducing a second stage trigger using a micro-processor system (FAMP[4]) to impose more sophisticated trigger conditions. In this study we use the inclusive single-ϕ data taken with a 100 GeV/c negative beam.

3. Results

3.1 Determination of the number of $\phi\phi$-events.

Figure 2 shows the K^+K^- invariant mass spectrum for all events from the 1981 run which contain at least two K^+K^- combinations. A clear ϕ signal (1.0196 GeV/c^2 [5]) is present. The two-dimensional histogram of $(K^+K^-)_1$ versus $(K^+K^-)_2$ for these events is shown in fig. 3. One can observe the two ϕ bands and the enhancement in the $\phi\phi$ overlap region. A fraction of the events in the $\phi\phi$ overlap region is due to ϕK^+K^- or $K^+K^-K^+K^-$ events. The number of $\phi\phi$-events above background in fig. 3 is computed selecting 9 regions corresponding to the 3 mass intervals $M_1(0.996-1.012)$, $M_2(1.012-1.028)$ and $M_3(1.028-1.044)$ GeV/c^2 on each axis. The integrated number of events in these regions is shown in table 1a and table 1b for the 1981 and 1982 data respectively, both for incident π-mesons. We define the following quantities:

A_{ij} = the number of $(K^+K^-K^+K^-)$ events where the two K^+K^- pairs lie in the mass interval M_i and M_j respectively

B_i = the number of ϕK^+K^- events, where the (K^+K^-) invariant mass lies in the interval M_i

C = the number of $\phi\phi$ events

In table 2 the number of events from table 1 are related to the variables defined above. To determine the K^+K^--background under the ϕ we have fitted the K^+K^--invariant mass spectrum (fig. 2) with the sum of a Breit-Wigner, folded with a Gaussian for the experimental resolution, and a second order polynomial P (m), where m is the K^+K^--invariant mass. The mass and decay width of the ϕ were fixed at 1.0196 GeV/c^2 and 4.2 MeV/c^2 respectively. The solid line in fig. 2 shows the fit while the dashed curve represents the background P (m). Defining the integral

$$S_i = \int P(m)\, dm \quad \text{over the mass interval } M_i ,$$

we find the following ratios between the background under the ϕ (i.e. S_2) and the adjacent mass intervals:

$$S_2/S_1 = 1.21 \pm 0.05 ,$$
$$S_2/S_3 = 0.93 \pm 0.03 .$$

From these ratios, and tables 1 and 2 we derive that for the 1981 data out of the 530 events in the $\phi\phi$ overlap region (table 1a): 91±6 events can be attributed to $K^+K^-K^+K^-$ and 158±17 to ϕK^+K^- events. This leaves a total of 281±29 $\phi\phi$ events. For the 1982 data we find that 253±15 $K^+K^-K^+K^-$ events and 460±33 ϕK^+K^- events contribute to the 1246 events in the $\phi\phi$-overlap region (table 1b), leaving 533±51 $\phi\phi$-events. Due to less restrict trigger conditions the background in the 1982 data is slightly larger than the background in the 1981 data.

At this energy (100 GeV/c) the single ϕ differential cross-sections $d\sigma/dx_F$ and $d\sigma/dp_\perp^2$ are well-known[6,7]. These data have been used as an input for a Monte Carlo program to determine the expected number of uncorrelated $\phi\phi$-events. Taking as single-ϕ production cross-section

(180±8) μb [6], and as inelastic cross-section 20 mb, we calculate the uncorrelated $\phi\phi$-production in the 1981 data to be 50±12 events. This leaves an excess of 231±31 events. Fig. 4a shows the $\phi\phi$-invariant mass distribution of the 1981 data. The dashed curve is normalized to the 158 ϕK^+K^- events, the dash-dotted curve is normalized to the 91 $K^+K^-K^+K^-$ events and the dotted curve is normalized to the 50 uncorrelated $\phi\phi$ events. The shape of the ϕK^+K^- and $K^+K^-K^+K^-$ curves has been estimated by combining K^+K^- and ϕ from different events. The shape of the uncorrelated $\phi\phi$ distribution results from the aforementioned Monte Carlo program. Since the normalization of the 1982 cross-section has not yet been evaluated in this stage of the analysis, the number of uncorrelated ϕ-pairs cannot be computed for the 1982 data. However, since the signal over background ratios for the two data samples are quite similar, it is justified to conclude that also in the 1982 data the uncorrelated ϕ-pairs contribute only a small fraction to the number of $\phi\phi$-events observed. Fig. 4b shows the $\phi\phi$-invariant mass distribution of the 1982 data. The full, dash-dotted and dotted curves are the distributions for incident π^-, K^- and $\bar{p}$ respectively.

3.2 Ratios of cross-sections

As mentioned in the previous paragraph the absolute cross-section normalization for the 1982 data is still uncertain. On the other hand, the number of $\phi\phi$-events for incident K^- and $\bar{p}$ in the 1981 data is insufficient to give meaningful differential cross-sections. For these reasons the 1981 and 1982 data on $\phi\phi$-production are combined and the cross-sections are normalized to the cross-section for incident π^--mesons. In table 3 the cross-section ratios $\sigma^K(\phi\phi)/\sigma^\pi(\phi\phi)$ and $\sigma^{\bar{p}}(\phi\phi)/\sigma^\pi(\phi\phi)$ for inclusive $\phi\phi$-production in the x_F-interval $.2 < x_F(\phi\phi) < 0.7$ are given. Here $x_F(\phi\phi)$ is the Feynman-x of the $\phi\phi$-system. We assume that the p_T-distributions (not shown) do not depend on the incident particle.

In table 3 we also give the cross-section ratios for inclusive single-ϕ production in the x_F interval $0.05 < x_F(\phi) < 0.45$; these ratios have been determined from the 1982 data.

In fig. 5 and fig. 6. the ratios are shown for the differential cross-sections $d\sigma^h(\phi\phi)/dx_F$ for the different beam particles. The background from non-$\phi\phi$

events is subtracted. For comparison the cross-section ratios $d\sigma^K(\phi)/d\sigma^\pi(\phi)$ and $d\sigma^{\bar{p}}(\phi)/d\sigma^\pi(\phi)$ are shown in fig. 7 as a function of $x_F(\phi)$. The background has been subtracted using the information from the bins adjacent to the mass interval containing the ϕ-meson peak.

4. Interpretation of the results

The $\phi\phi$ effective mass spectra (fig. 4) do not show any evidence for narrow enhancements. The observed increase of $d\sigma^K(\phi)/d\sigma^\pi(\phi)$ (fig. 7a) with increasing x_F is expected in the quark fusion model as a consequence of the presence of a valence s-quark in the incident K-mesons[6,7]. The $d\sigma^{\bar{p}}(\phi)/d\sigma^\pi(\phi)$ distribution (fig. 7b) shows a slow decrease with increasing x_F, in agreement with this model, indicating that the s-quarks in the sea of the anti-proton are somewhat softer than those in the sea of the π-meson.
In fig. 5a,b and c we show the ratio $d\sigma^K(\phi\phi)/d\sigma^\pi(\phi\phi)$ as a function of the x_F of the $\phi\phi$-system and as a function of the x_F of the ϕ-meson with the larger and with the smaller momentum respectively. In all these distributions an increase is observed with increasing x_F, indicating that the ϕ-mesons remember the presence of a valence s-quark in the initial state. The distributions 5b and 5c are in qualitative agreement with the distribution obtained for single ϕ-production (fig. 7a).

The fact that the ratio $d\sigma^K(\phi\phi)/d\sigma^\pi(\phi\phi)$ as a function of the x_F of the lower momentum ϕ-mesons (fig. 5c) also shows an increase indicates strong short-range correlation effects.

The ratio $d\sigma^{\bar{p}}(\phi\phi)/d\sigma^\pi(\phi\phi)$ (fig. 6) shows a rather flat distribution similar to that for single ϕ-production (fig. 7b). The above observations are of course also reflected in the cross-section ratios of table 3.

5. Conclusion

We have observed production of $\phi\phi$ states in 100 GeV/c hadron-Be interactions. Uncorrelated $\phi\phi$ production can account for only 18% of the observed events in the reaction $\pi^- + Be \to \phi + \phi + \text{anything}$. We do not observe any narrow enhancement in the $\phi\phi$-invariant mass spectra. The increase of the ratio $d\sigma^K(\phi\phi)/d\sigma^\pi(\phi\phi)$ with increasing $x_F(\phi\phi)$ reflects the presence of the valence s-quarks in the incident K-mesons.

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TABLE CAPTIONS:

Table 1: Distribution of the invariant mass of $(K^+K^-)_1$ versus $(K^+K^-)_2$ in the $\phi\phi$ mass overlap region for the 1981 data (a) and the 1982 data (b), both for incident π-mesons.

Table 2: Contribution of $K^+K^-K^+K^-$ (A_{ij}) and ϕK^+K^- (B_i) events to the $\phi\phi$ overlap region. The $\phi\phi$ events are represented by $\langle C \rangle$.

Table 3: Cross-section ratios for inclusive $\phi\phi$ and single ϕ production in the x_F range $0.2 < x_F(\phi\phi) < 0.7$ for the incident particles considered.

FIGURE CAPTIONS:

Fig. 1. Schematic plan of the NA11 spectrometer as it was used during the $\phi\phi$ and ϕ run. T is the target; MA and MB are the scintillator hodoscopes; C_1, C_2 and C_3 are the Cerenkov counter hodoscopes; ARM-II and ARM-III a-c are drift chambers.

Fig. 2. K^+K^- invariant mass spectrum for all events that contain 4 charged kaons from the 1981 data set. The solid curve is a fit to the sum of a Breit-Wigner, folded with a Gaussian for the experimental resolution, and a polynomial. The dashed line represents the polynomial.

Fig. 3. The 2-dimensional histogram of the effective mass of $(K^+K^-)_1$ versus $(K^+K^-)_2$ from the 1981 data.

Fig. 4. Distribution of the $\phi\phi$ invariant mass for the 1981 data (a) and the 1982 data (b). The dashed, dash-dotted and dotted curves in fig. 4a represent the contributions of ϕK^+K^-, $K^+K^-K^+K^-$ and uncorrelated $\phi\phi$ respectively. The solid line represents the sum of the background contributions. In fig. 4b the full, dash-dotted and dashed line represent the $\phi\phi$-invariant mass distributions with incident π^-, K^- and $\bar{p}$ respectively.

Fig. 5. $d\sigma^K(\phi\phi)/d\sigma^\pi(\phi\phi)$ as a function of the x_F of the $\phi\phi$-system (a), and as a function of the x_F of the ϕ with the larger (b) and with the smaller (c) momentum.

Fig. 6. $d\sigma^{\bar{P}}(\phi\phi)/d\sigma^\pi(\phi\phi)$ as a function of the x_F of the $\phi\phi$-system (a), and as a function of the x_F of the ϕ with the larger (b) and with the smaller (c) momentum.

Fig. 7. $d\sigma^K(\phi)/d\sigma^\pi(\phi)$ (a) and $d\sigma^{\bar{P}}(\phi)/d\sigma^\pi(\phi)$ (b) for the inclusive single-ϕ events in the 1982 data, as a function of the Feynman-x of the ϕ.

Table 1

a)

100	176	86
141	530	183
62	146	82

$M(K^+K^-)_2$ (GeV/c^2): 0.996 – 1.044

$M(K^+K^-)_1$ (GeV/c^2): 0.996 – 1.044

b)

196	521	268
409	1246	505
197	403	254

$M(K^+K^-)_2$ (GeV/c^2): 0.996 – 1.044

$M(K^+K^-)_1$ (GeV/c^2): 0.996 – 1.044

Table 2

(GeV/c^2)			
1.044	A_{13}	$A_{23}+B_3$	A_{33}
	B_1+A_{12}	$A_{22}+2B_2+C$	B_3+A_{32}
	A_{11}	$A_{21}+B_1$	A_{31}
	0.996		1.044

(GeV/c^2)

Table 3

	Inclusive production of	
	$\phi\phi$	ϕ
$\frac{\sigma(\text{incident } K^-)}{\sigma(\text{incident } \pi^-)}$	3.5 ± .6	2.4 ± .1
$\frac{\sigma(\text{incident } \bar{p})}{\sigma(\text{incident } \pi^-)}$	.8 ± .2	1.0 ± .1

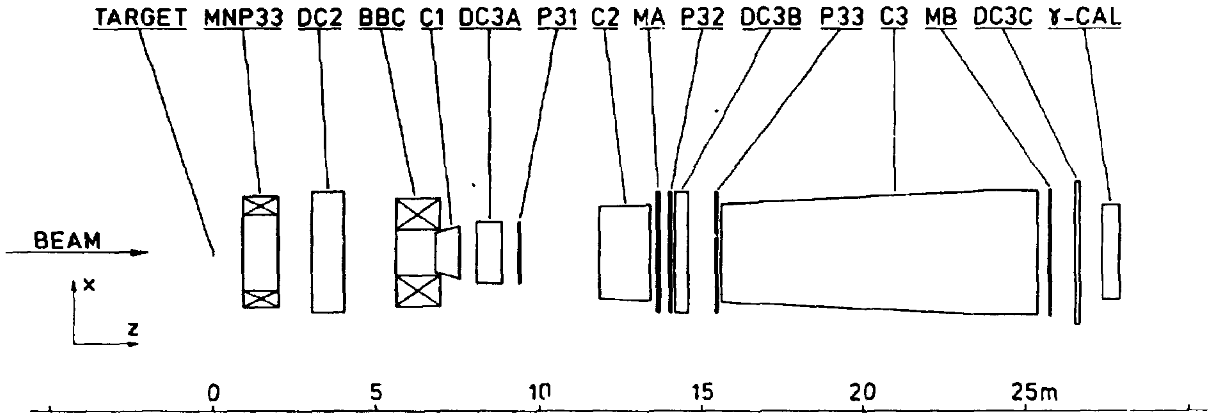

TARGET
MNP33
DC2
BBC
C1
DC3A
P31
C2
MA
P32
DC3B
P33
C3
MB
DC3C
γ-CAL
BEAM
x
z
0
5
10
15
20
25m

Fig. 1

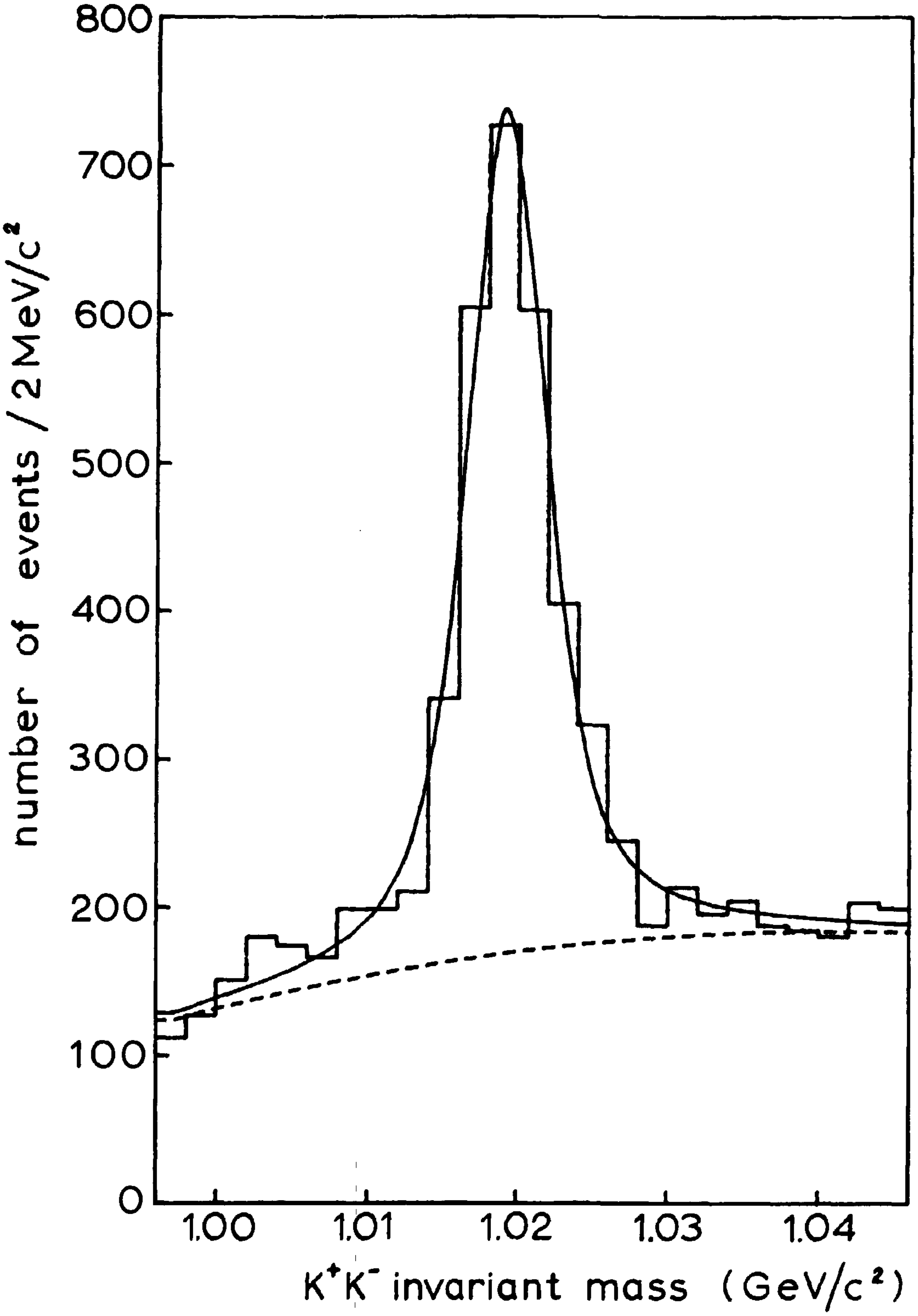
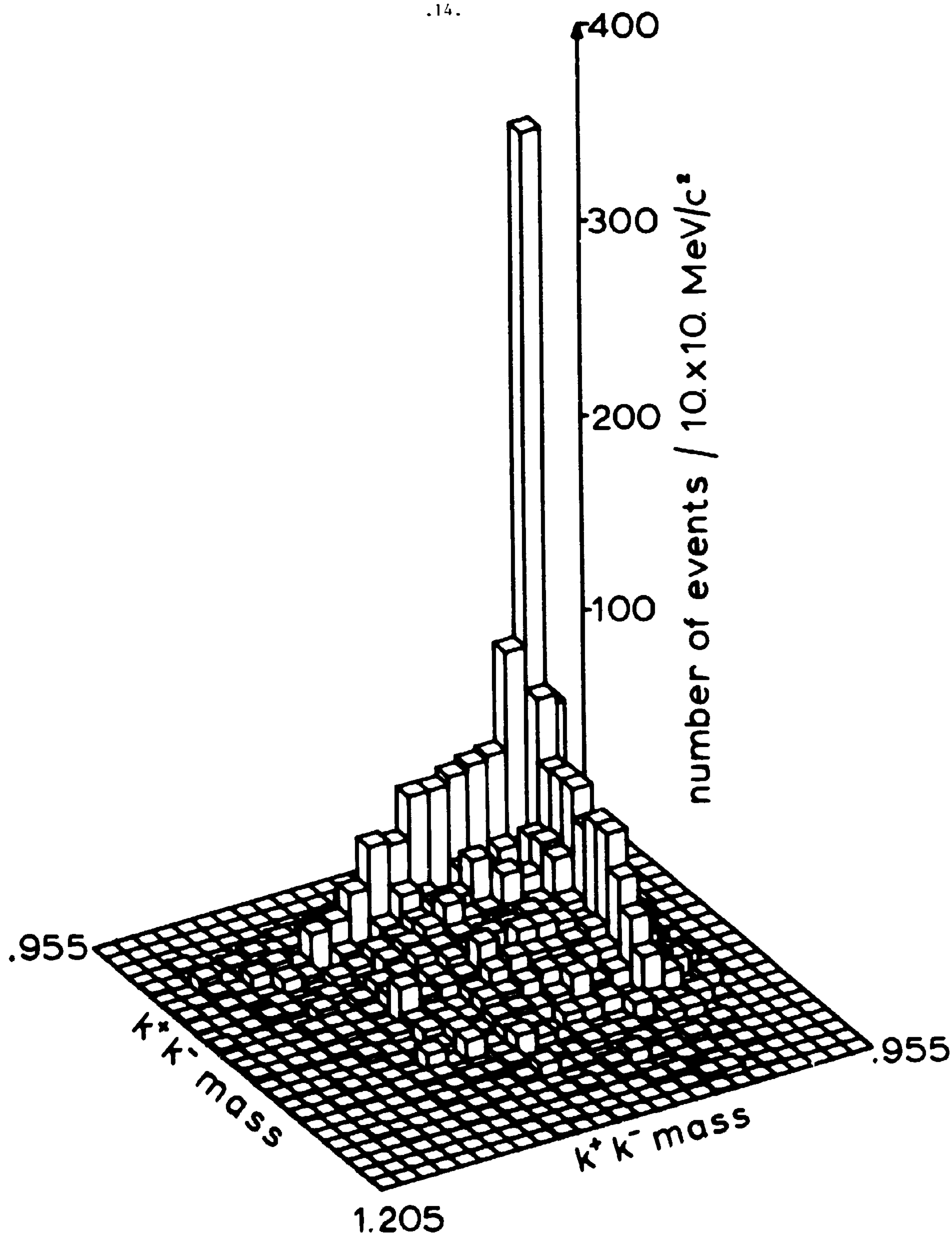

800
700
600
500
400
300
200
100
0
number of events / 2 MeV/c²
1.00
1.01
1.02
1.03
1.04
K⁺K⁻ invariant mass (GeV/c²)

Fig. 2


400
300
200
100
number of events / 10.x10. MeV/c²
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K⁺K⁻ mass
.955
K⁺K⁻ mass
1.205

Fig. 3

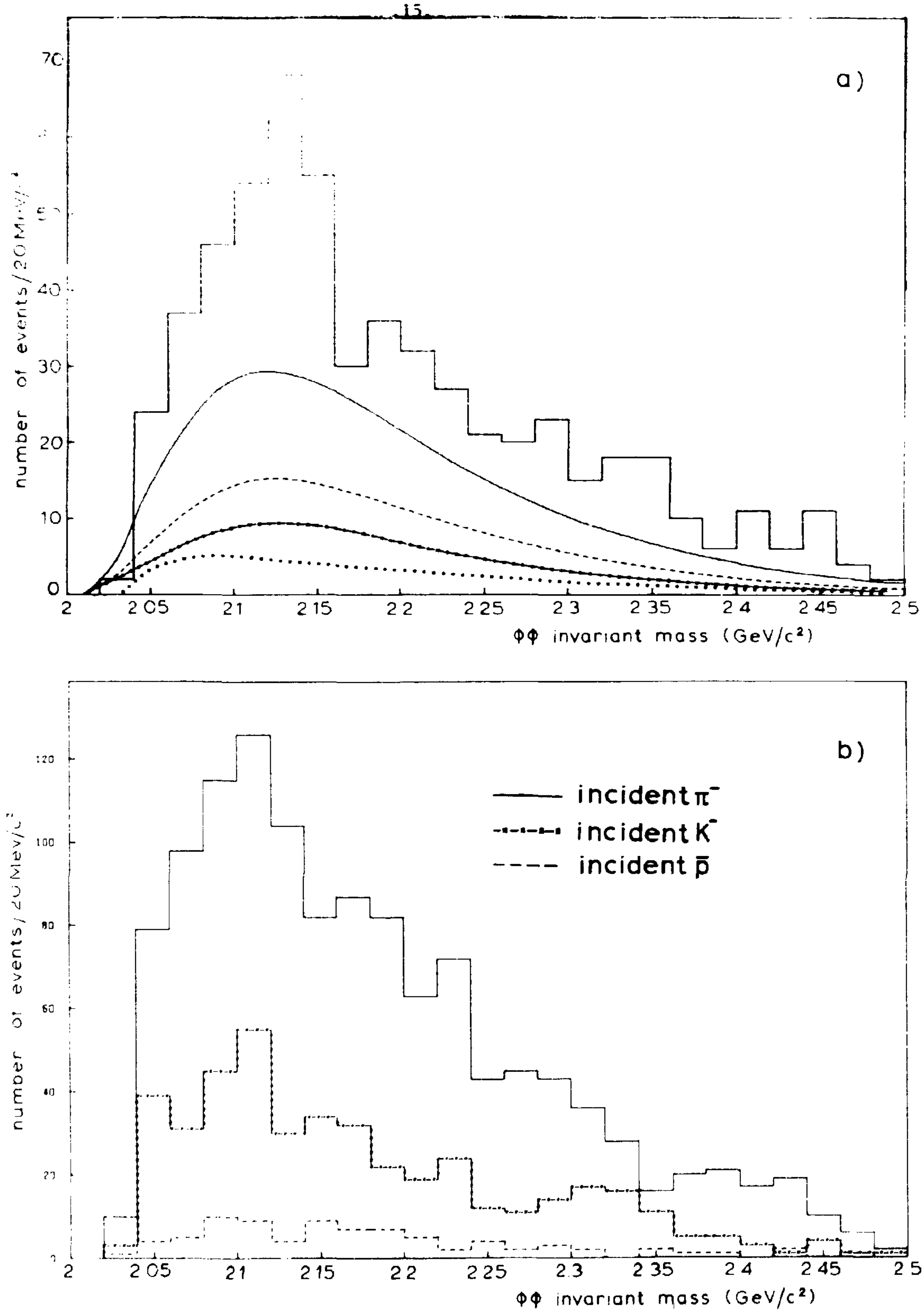

a)
b)
number of events/20 MeV/c²
ΦΦ invariant mass (GeV/c²)
incident π⁻
incident K⁻
incident p̄
2
2.05
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
2.5

Fig. 4

Fig 5

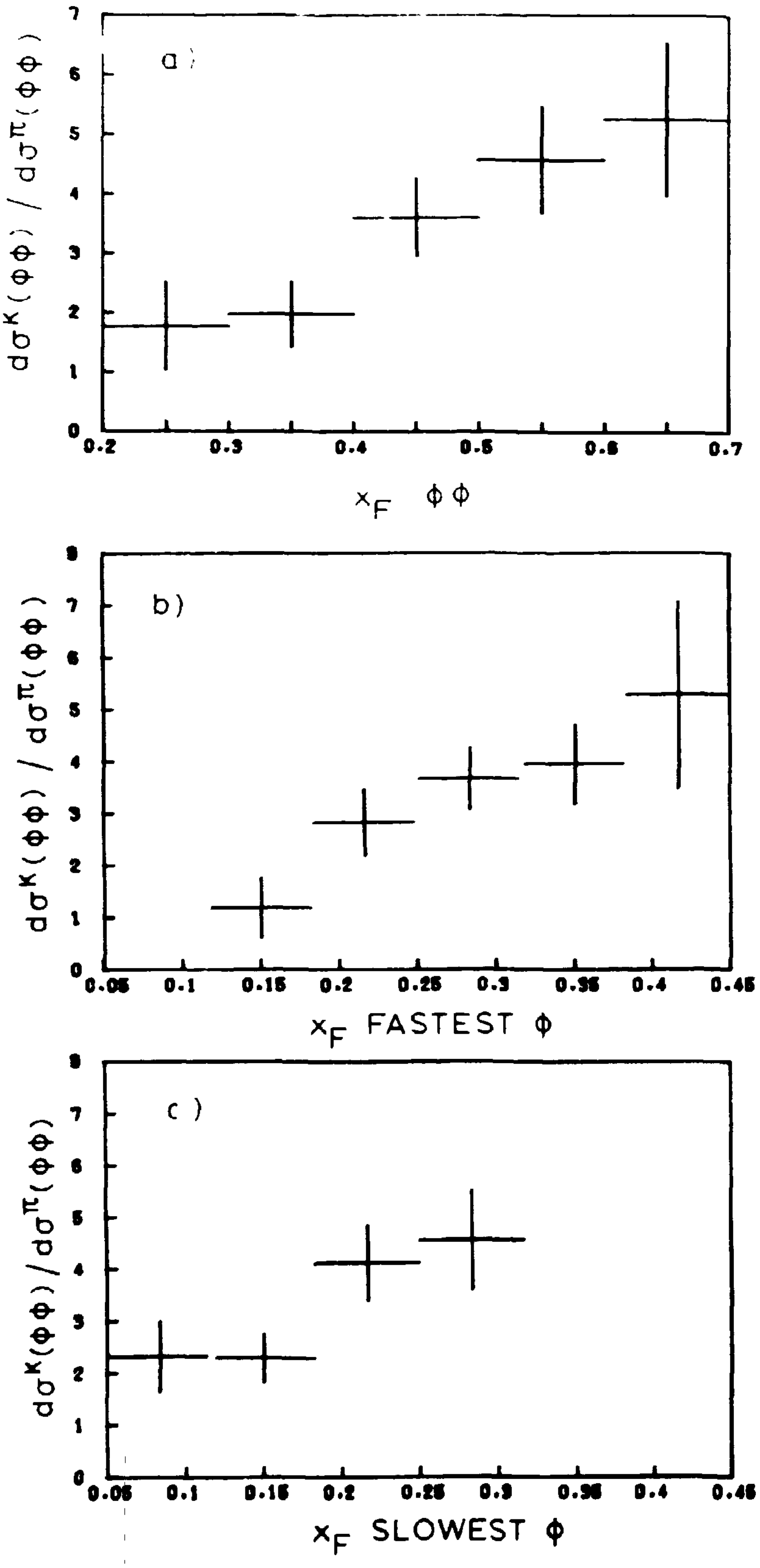

a)
$d\sigma^K(\phi\phi) / d\sigma^\pi(\phi\phi)$
x_F $\phi\phi$
b)
$d\sigma^K(\phi\phi) / d\sigma^\pi(\phi\phi)$
x_F FASTEST ϕ
c)
$d\sigma^K(\phi\phi) / d\sigma^\pi(\phi\phi)$
x_F SLOWEST ϕ

Fig 6

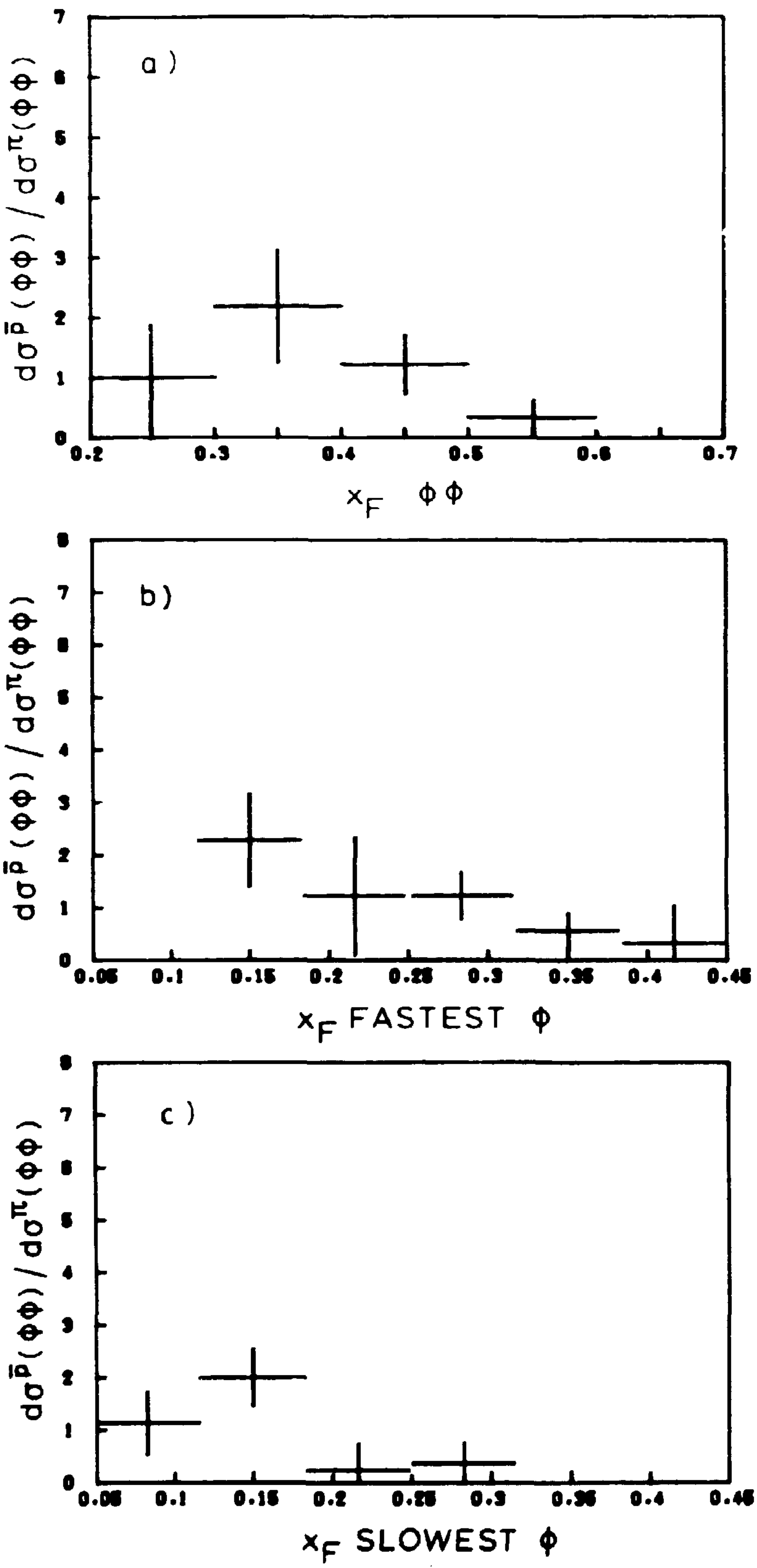
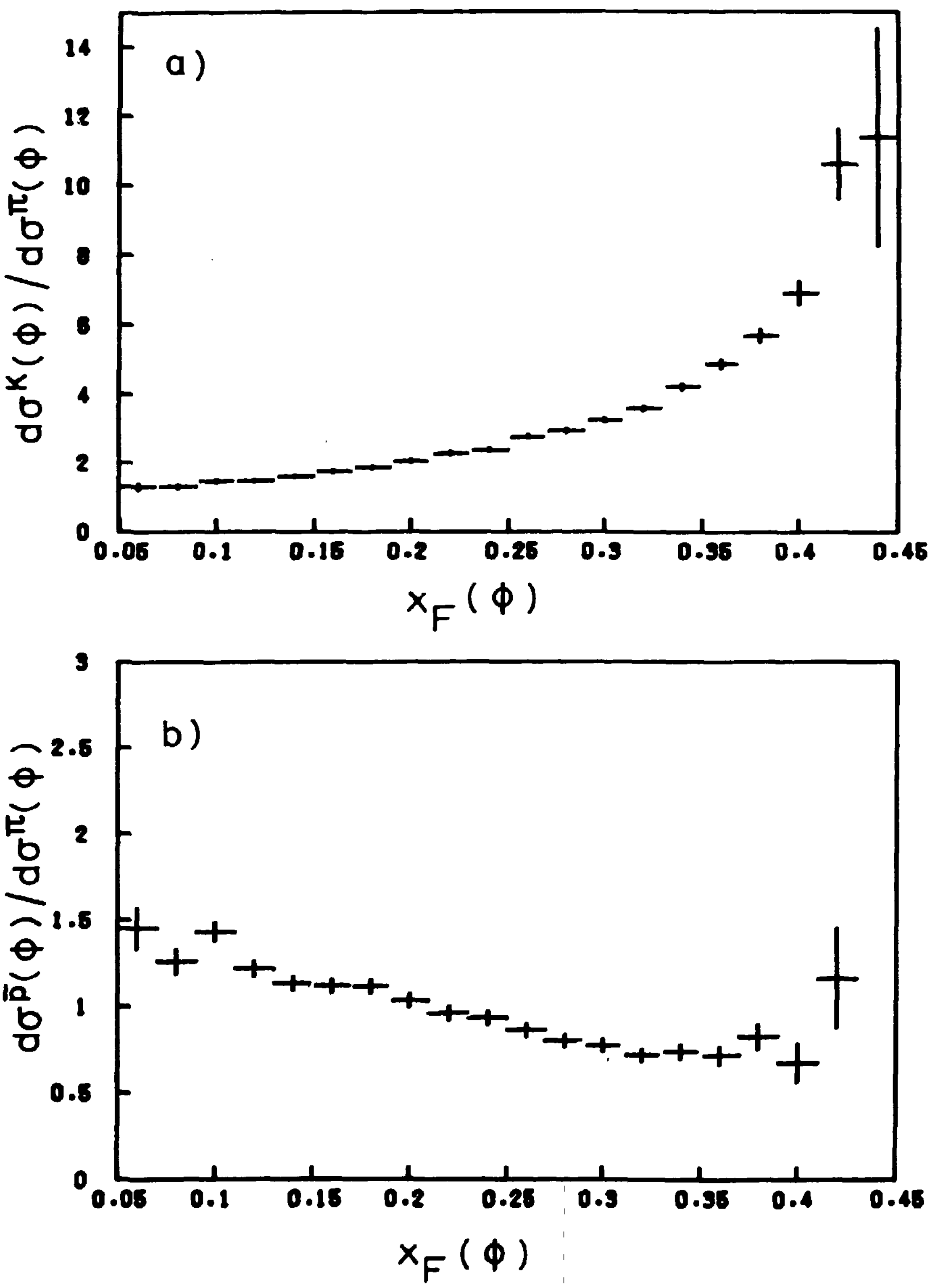

a)
b)
c)
$d\sigma^{\bar{p}}(\phi\phi) / d\sigma^{\pi}(\phi\phi)$
x_F $\phi\phi$
x_F FASTEST ϕ
x_F SLOWEST ϕ

Fig. 7


a)
$d\sigma^{K}(\phi)/d\sigma^{\pi}(\phi)$
0
2
4
6
8
10
12
14
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
$x_F(\phi)$
b)
$d\sigma^{\bar{p}}(\phi)/d\sigma^{\pi}(\phi)$
0
0.5
1
1.5
2
2.5
3
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
$x_F(\phi)$