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GLUON TAGGING IN HARD PROTON-PROTON INTERACTIONS AT THE ISR

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ABSTRACT

Events obtained by triggering on a single particle with high transverse momentum p_T show a four-jet structure. The two transverse jets are due to the fragmentation of point-like scattered partons. Experimental evidence is presented that high p_T K^- mesons and their associated jets are produced by hard scattering and subsequent fragmentation of flavour neutral partons with a rather soft structure function. Hence, gluons are a natural source of high p_T K^- mesons which do not share any valence quark with the incoming protons. The analysis is based upon measurements of short-range quantum number correlations within the trigger jet and of long-range correlations between different jets. The data were obtained at $\sqrt{s}$ = 62 GeV with the Split Field Magnet Detector (SFM) at the CERN ISR.

1. INTRODUCTION

The study of hard proton-proton collisions allows direct access to fundamental strong interactions between quarks and gluons. A typical hard process is shown in fig. 1(a). Large angle scattering of two partons yields two transverse jets (trigger jet and away jet), whereas the non-interacting proton constituents fragment into the longitudinal spectator jets. Triggering on a particle of large transverse momentum p_T separates these reactions from the much more numerous soft hadronic interactions.

It is well known that the events selected in this way show the expected four-jet structure [1]. Moreover it was demonstrated recently [2] that, in hard proton-proton collisions, triggering π^+ and K^+ mesons are dominantly leading particles of u-quark jets, while π^- triggers enhance d-quark jets.

In contrast K^- (= $\bar{u}s$) mesons have no valence quarks in common with the incoming protons. Therefore one expects significant differences between the mechanisms for high p_T K^- and π^+, π^- or K^+ production which will be explored in this paper.

2. METHOD OF ANALYSIS

The type of analysis to be performed here was developped in ref. [2] to determine the dominant sources of high p_T π^+, K^+ and π^- mesons independently of model calculations. The results obtained were mainly based upon the following arguments and experimental observations (see ref. [2] for details):

(a) The ratio of inclusive cross sections for the trigger mesons as function of $x_T = 2p_T/\sqrt{s}$ reflects the relative dependence on Bjorken x of the structure functions of those partons which fragment into the trigger mesons.

(b) The charge structure of the jet accompanying the trigger particle is characteristically correlated with the charge of the scattered parent parton.

(c) The charge composition of the spectator jets reflects the quantum numbers of the proton constituents left behind after a parton has been deflected at large angles. It therefore carries information on the quantum numbers of the scattered partons.

(d) The correlation between the average polar angle of the away jet and its charge composition yields further information on the nature of the scattered partons.

Along these lines it was concluded in ref. [2] that high p_T π^+ and K^+ (and π^-) mesons are leading fragments of scattered u- (and d-) quarks in most cases. This result is intuitively expected and also supported by QCD model calculations [3]. One can therefore hope that a similar way of analyzing the data will help to clarify the more involved case of high p_T K^- mesons, which may be produced (a) as leading fragments of scattered $\bar{u}$ or s quarks from the sea, (b) as higher rank [4] fragments of scattered valence quarks and (c) as leading fragments of scattered gluons as indicated in fig. 1(b). The dominant source of high p_T K^- mesons among the ones mentioned above will be established in the following.

3. EXPERIMENTAL RESULTS

The data were recorded at a centre of mass energy $\sqrt{s}$ = 62 GeV with the Split Field Magnet detector at the CERN ISR. The detector allows the reconstruction of charged particle trajectories over nearly the full solid angle. It was triggered by K^- mesons emitted at $\theta \approx 45°$ with $p_T > 4$ GeV/c. A sample of 10700 events with K^- triggers (having momenta below the kaon threshold of a Cerenkov counter) was reconstructed. The triggering K^- contain about 10% antiprotons [5]. Details of the experimental set-up, of data taking and of analysis are described in ref. [6]. All variables used throughout the paper are given in the pp centre of mass system. Unless stated otherwise, the measurements presented here are not corrected for acceptance. Note that the acceptance is symmetric about rapidity y = 0 and independent of the flavour of the trigger particle.

3.1 Inclusive cross sections

The inclusive ratio $\sigma(K^-)/\sigma(\pi^-)$ for K^- and π^- triggers, displayed in fig. 2 [7], decreases with increasing x_T. In ref. [2] it was shown that π^- triggers originate frequently from d-quark fragmentation. The corresponding ratio for K^+ and π^+ triggers is constant [7] as expected since both mesons are predominantly leading fragments(*) of u-quark jets [2].

In contrast to π^- mesons, K^- mesons do not share valence quarks with protons. Therefore the decrease of $\sigma(K^-)/\sigma(\pi^-)$ with increasing x_T may either reflect a relatively soft structure function of the parton fragmenting into the K^- meson or it may indicate that K^- triggers are not the first rank fragments of valence quarks in most cases.

3.2 Quantum number correlations in the trigger jet

A measurement of charge and strangeness compensation in the trigger jet is presented in this section. The acceptance corrected densities

$$\rho_t^{\pm Q} = \frac{1}{N_{event}} \cdot \frac{dN_{sec}^{\pm Q}}{dz}$$

of secondaries in the trigger jet with charges equal or opposite to the trigger charge Q were determined as in ref. [2]. For events with a K^- trigger they are shown in fig. 3(a) as function of

$$z_f = \frac{\vec{p}(sec) \cdot \vec{p}(trig)}{|\vec{p}(trig)|^2} ,$$

where $\vec{p}(trig)$ and $\vec{p}(sec)$ are the momenta of the trigger particle and of secondaries in the trigger jet. Equivalent distributions for the combined π^+ and K^+ trigger sample are given in fig. 3(b). In all cases the ratio $R_t(z_f) = \rho_t^{-Q}/\rho_t^{+Q}$ is larger than 1 and increases with z_f. An important quantitative difference exists, however: for the ratios $R_t(z_f > 0.4)$ of particle densities integrated over $z_f > 0.4$ one finds $R_t\ (K^-;\ z_f > 0.4) = 5.36 \pm 0.87$, whereas $R_t(\pi^+ + K^+;\ z_f > 0.4) = 2.00 \pm 0.19$ and $R_t(\pi^-;\ z_f > 0.4) = 3.94 \pm 0.27$. From local charge compensation in trigger jets one expects the same values of $R_t(z_f)$ for the same absolute charge differences between the parent parton and the trigger particle. K^-

(*) In ref. [8] it was shown that all trigger particles in the given kinematical configuration carry on the average more than 70% of the parent parton's momentum.

production by $\bar{u}$ quark fragmentation would therefore yield the relation $R_t(K^-; z_f) = R_t(\pi^+; z_f)$ which is ruled out by the data. Fragmentation into leading K^- mesons of scattered strange quarks should give $R_t(K^-; z_f) = R_t(\pi^-; z_f)$, since π^- mesons were shown to be produced mainly by d quarks [2]. The data are marginally compatible with this hypothesis. Triggering K^- mesons may also be leading fragments of gluons or higher rank fragments of valence quarks. In the latter processes at least one unit of charge must be compensated such that one expects $R_t(K^-; z_f) > R_t(\pi^-; z_f)$. This corresponds to the trend of the data.

The number N_{K^o} of reconstructed K_s^o with $z_f > 0.2$ per trigger jet was found to be a factor of about 2 larger for K^+ triggers than for pion triggers [2]. Since K^+ triggers were shown to be predominantly produced by scattered u quarks, this finding indicates local strangeness compensation in the trigger jet. For K^- and pion triggers one finds $N_{K^o}(K^-)/N_{K^o}(\pi^\pm) = 2.1 \pm 0.33$, which suggests local strangeness compensation also for K^- triggers. Hence one infers that K^- triggers come from non-strange partons. It should be mentioned that a sample of 15943 (53294) events with triggering K^- ($\pi^\pm$) with $p_T > 3$ GeV/c was included for the analysis of K_s^o production.

To summarize, from the measured charge and strangeness correlations $\bar{u}$ scattering is excluded and s quark scattering is disfavoured as the dominant sources of high p_T K^- mesons. On the other hand the hypotheses that most K^- mesons are higher rank fragments of valence quarks (fig. 1(b)) or due to gluon fragmentation are both compatible with the data.

3.3 Correlations between trigger particle and spectator jets

The ratio $R_s^\pm = \rho_s^\pm(\pi^+ + K^+)/\rho_s^\pm(K^-)$ of densities of positive and negative secondaries associated with π^+, K^+ and K^- triggers is shown as function of Feynman x_F in fig. 4. Only secondaries with $p_T(\text{sec}) > 0.3$ GeV/c are considered. Acceptance effects tend to cancel in ratios defined in this way. The contribution from both transverse jets is negligible for $|x_F| > 0.15$ ($x_F(\text{trig}) \approx +0.1$), hence spectator fragments dominate in this range. Whereas the ratios are compatible with 1 for $x_F < 0$, they are significantly different from 1 for $x_F > 0$. This demonstrates that K^- and π^+, K^+ triggers are produced by different mechanisms. Since π^+ and K^+

triggers are known to be mostly produced by u quarks [2], it follows that K^- triggers cannot always be higher rank fragments of scattered u quarks. In protons u quarks are more abundant than d quarks, therefore K^- mesons at high p_T are also not very likely to be higher rank fragments of scattered d quarks.

The measured ratios $R_s^{\pm}$ are, however, qualitatively consistent with neutral partons as the dominant source of high p_T K^- triggers. In this case the three remaining proton valence quarks fragment into spectator jets and may yield more positive hadrons (fig. 4) than the ud spectator system in the case of π^+ triggers [2].

From the data presented so far one concludes that valence quarks are not the dominant source of high p_T K^- mesons such that neutral partons are left as the most probable parent partons.

3.4 Correlation between trigger particle and away jets

The differences $\Delta = \rho_a(\pi^+ + K^+) - \rho_a(K^-)$ and $\Delta = \rho_a(\pi^-) - \rho_a(K^-)$ of charged particle densities ρ_a in a region of phase space mainly populated by away jet secondaries, i.e. $p_T(\text{sec}) > 0.8$ GeV/c and azimuthal angle $\phi = 180° \pm 25°$ ($\langle\phi(\text{trig})\rangle = 0°$), are given in fig. 5 as function of y. The data indicate that away jets associated with π^+, K^+ and π^- triggers at fixed $y \approx +0.8$ and $p_T > 4$ GeV/c are more often produced at $y < 0$ (back-to-back) than those from events triggered by K^- mesons and vice versa for $y > 0$ (back-to-antiback)(*). It follows that the average effective energy $\sqrt{\langle\hat{s}\rangle}$ of the trigger jet - away jet system is smaller for K^- triggers; here $\langle\hat{s}\rangle \sim \langle x_1 . x_2\rangle s$, where $x_{1,2}$ are the Bjorken variables of the two scattered partons. Hence one of the two partons producing the sideways jets in the case of K^- triggers has a softer structure function than in the case of π^+, K^+ and π^- triggers.

The significant differences found in fig. 5 show that the parent partons of high p_T K^- mesons cannot be identified with quarks if the couplings in hard interactions are flavour independent.

(*) A detailed study of away jets is presented in ref. [9].

The ratio $R_a = \rho_a^+/\rho_a^-$ of densities of positive and negative fragments in the away jet is shown in fig. 6 as function of the variable $x_E = p_T(\text{sec})/p_T$. In the back-to-back configuration R_a is larger than unity and increases with x_E for all triggers. For $x_E > 0.4$ the ratio reflects the flavour of the parent parton of the away jet. The measured value of about 1.5 is consistent with fragmentation of valence quarks due to the more abundant u quarks. For K^- triggers the charge ratio for the back-to-antiback configuration (fig. 6(b)) is equal to the ratio determined for the back-to-back configuration (fig. 6(a)); it is larger than the corresponding ratio measured for π^+ and K^+ triggers (fig. 6(b)). For K^- triggers this indicates thus that all away jets are dominated by valence quark fragmentation, independently of their kinematical configuration. The observations (a) that $\pi^\pm$ and K^+ triggers are predominantly produced by scattered valence quarks [2], (b) that one of the two scattered partons in the case of high p_T K^- mesons has a softer structure function than any of the scattered partons in the case of $\pi^\pm$ and K^+ triggers and (c) that away jets recoiling against K^- triggers are also produced predominantly by valence quarks suggest that it is the parent partons of K^- triggers which have a rather soft structure function compared to valence quarks.

The data of this section imply that high p_T K^- mesons are produced by fragmentation of partons which are different from quarks and have a softer structure function than valence quarks.

It should be noted in passing that the significant differences of kinematical properties and charge compositions of away jets associated with trigger mesons of different flavours prove, on purely experimental grounds, the claim of ref. [1(c)] that the observed jet structures are not just trivial consequences of conservation laws.

4. CONCLUSIONS

Detailed mesurements of quantum number correlations in trigger jets and of long range correlations between different jets have been presented for events triggered by high p_T K^- mesons. The data were taken with the Split Field Magnet at the ISR. All data are consistently described qualitatively by the existence of flavourless, rather soft partons which produce these K^- mesons by hard scattering and subsequent fragmentation. More conventional interpretations are not favoured by the measurements. The only known partons with the required properties are gluons. Hence one concludes that hard gluon processes in pp collisions can be tagged by triggering on K^- mesons at high transverse momentum. The analysis is independent of numerical model calculations.

Acknowledgements

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TABLE 1

Summary on gluon tagging

Experimental tools:	Incl. ratio	Charge ratio, trigger jet	K^o_s, trigger jet	Correl. with spect. jet	Density away jet	Charge ratio, away jet
Hypotheses for K^- parent partons:						
$\bar{u}$	yes	no	yes	yes	no	no
s	yes	yes	no	yes	no	no
u,d	yes	yes	yes	no	no	no
g	yes	yes	yes	yes	yes	yes

Definition:

no: data qualitatively inconsistent with hypothesis
yes: data qualitatively consistent with hypothesis

FIGURE CAPTIONS

Fig. 1 (a) Pictorial representation of a hard proton-proton interaction.

(b) Various fragmentation schemes yielding leading K^- mesons.

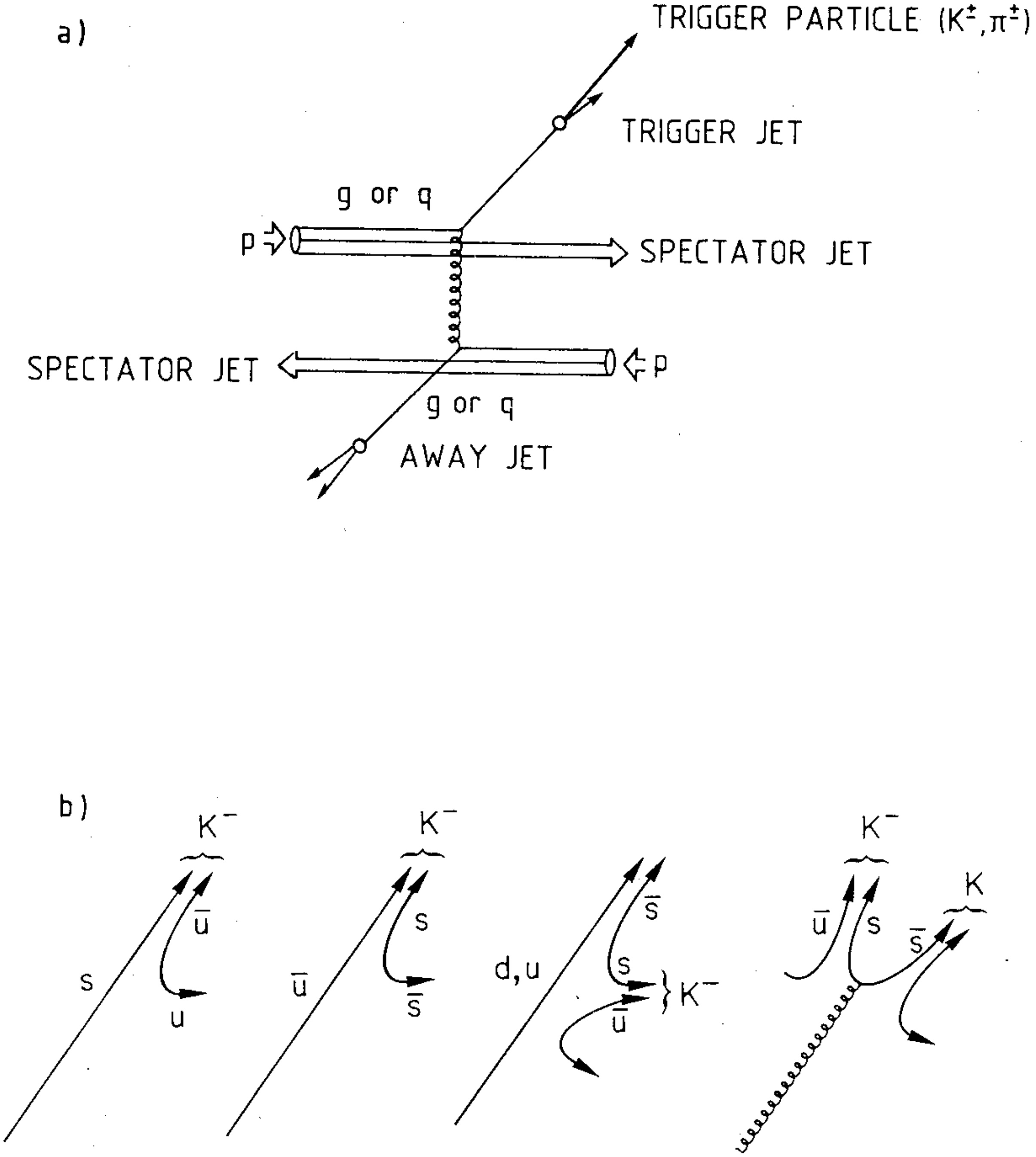
Fig. 2 Ratio of the inclusive cross sections $\sigma(K^{\pm})/\sigma(\pi^{\pm})$ versus x_T at $\sqrt{s}$ = 45 and 62 GeV.

Fig. 3 Particle density in the trigger jet versus z_f for particles with charges equal (crosses) or opposite (dots) to the charge of the trigger ((a): K^-; (b): $\pi^+ + K^+$).

Fig. 4 Density of positive (dots) and negative (crosses) particles versus x_F in events with K^- triggers relative to that for $\pi^+ + K^+$ triggers.

Fig. 5 Differences Δ of particle densities in the away jet region versus y for various trigger particles.

Fig. 6 Ratio of particle densities for positive and negative away jet secondaries versus x_E for (a): back-to-back and (b): back-to-antiback configurations.



a)
TRIGGER PARTICLE (K±,π±)
TRIGGER JET
g or q
p
SPECTATOR JET
SPECTATOR JET
p
g or q
AWAY JET
b)
K⁻
ū
s
u
K⁻
s
ū
s̄
s̄
d,u
s
ū
K⁻
K⁻
ū
s
s̄
K

Fig. 1

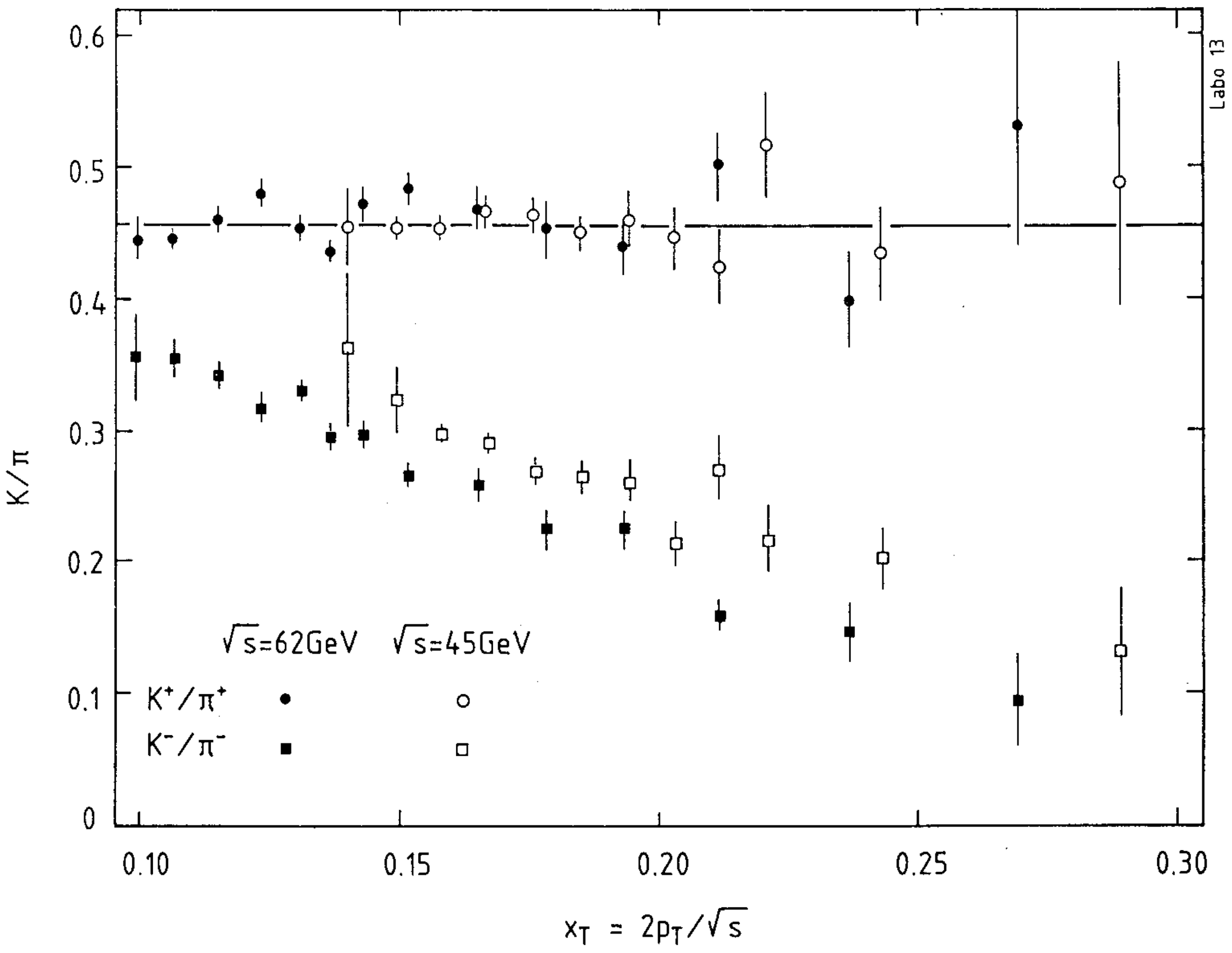
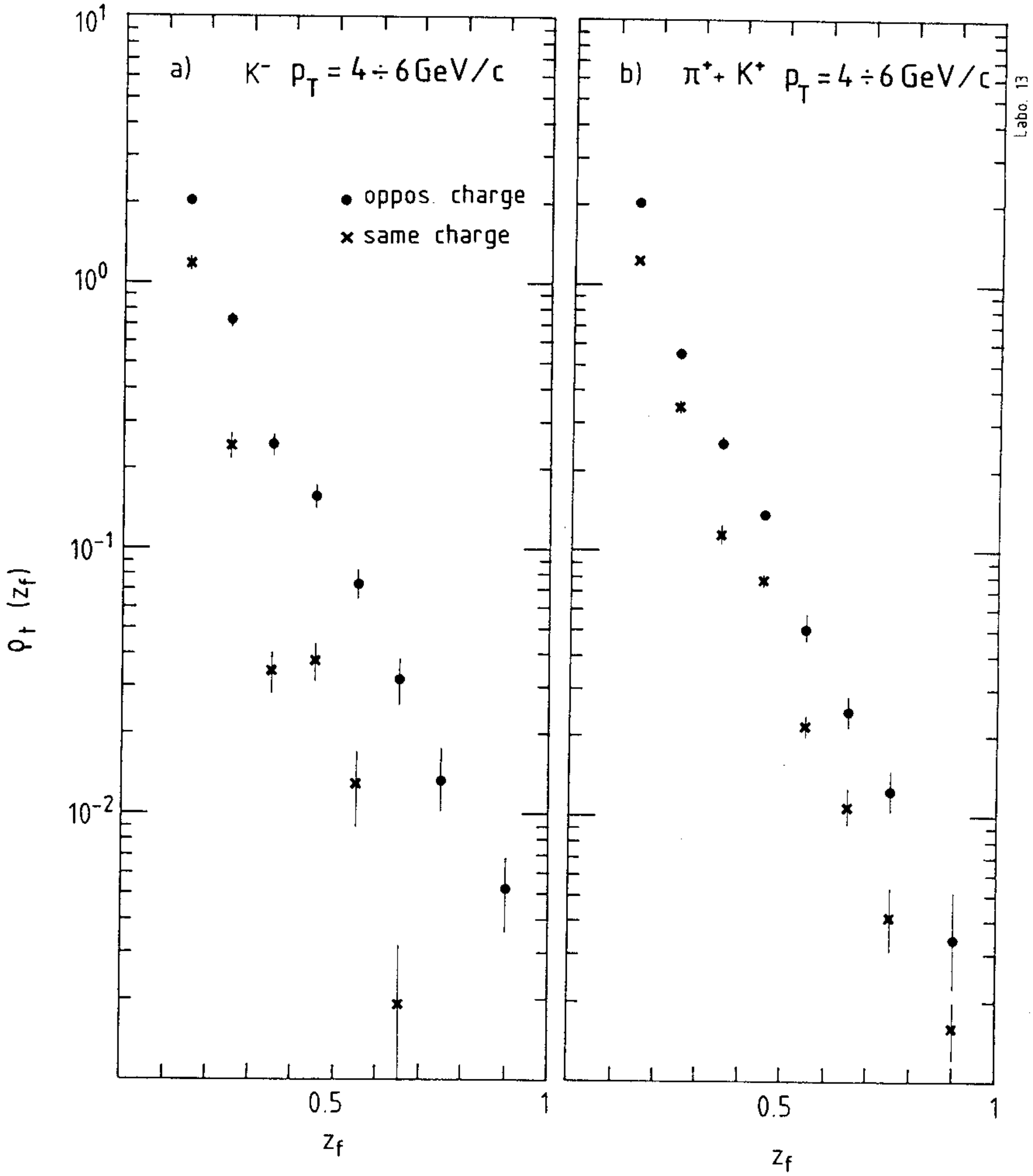
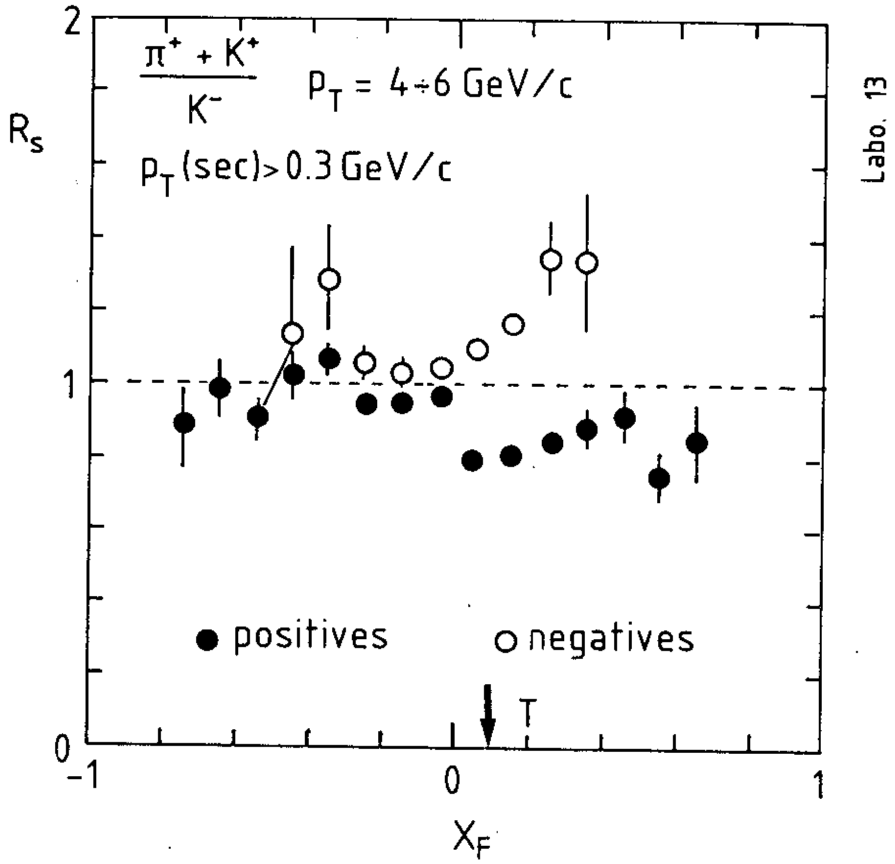

Labo 13
0.6
0.5
0.4
0.3
0.2
0.1
0
K/π
$\sqrt{s}$=62GeV
$\sqrt{s}$=45GeV
K^+/π^+
K^-/π^-
0.10
0.15
0.20
0.25
0.30
$x_T = 2p_T/\sqrt{s}$

Fig. 2



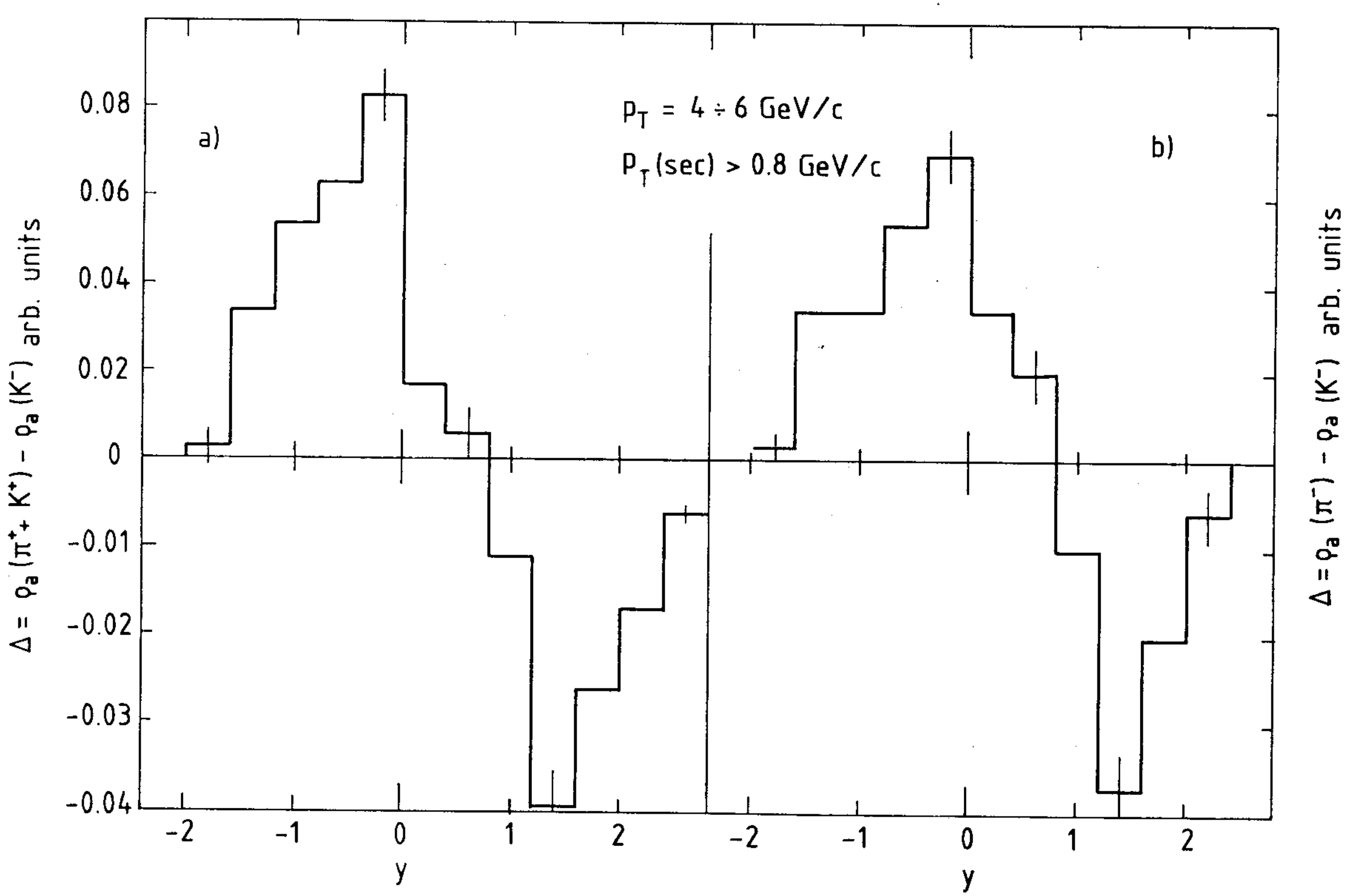
a) K⁻ p_T = 4÷6 GeV/c
b) π⁺+ K⁺ p_T = 4÷6 GeV/c
● oppos. charge
× same charge
10^1
10^0
10^-1
10^-2
ρ_t (z_f)
0.5
1
z_f
Labo. 13

Fig. 3



2
1
0
-1
0
1
R_s
$\frac{\pi^+ + K^+}{K^-}$
$p_T = 4 \div 6$ GeV/c
p_T(sec)>0.3 GeV/c
● positives
○ negatives
T
X_F
Labo. 13

Fig. 4



a)
b)
p_T = 4 ÷ 6 GeV/c
p_T(sec) > 0.8 GeV/c
Δ = $\rho_a(\pi^+ + K^+) - \rho_a(K^-)$ arb. units
Δ = $\rho_a(\pi^-) - \rho_a(K^-)$ arb. units
0.08
0.06
0.04
0.02
0
-0.01
-0.02
-0.03
-0.04
-2
-1
0
1
2
y

Fig. 5

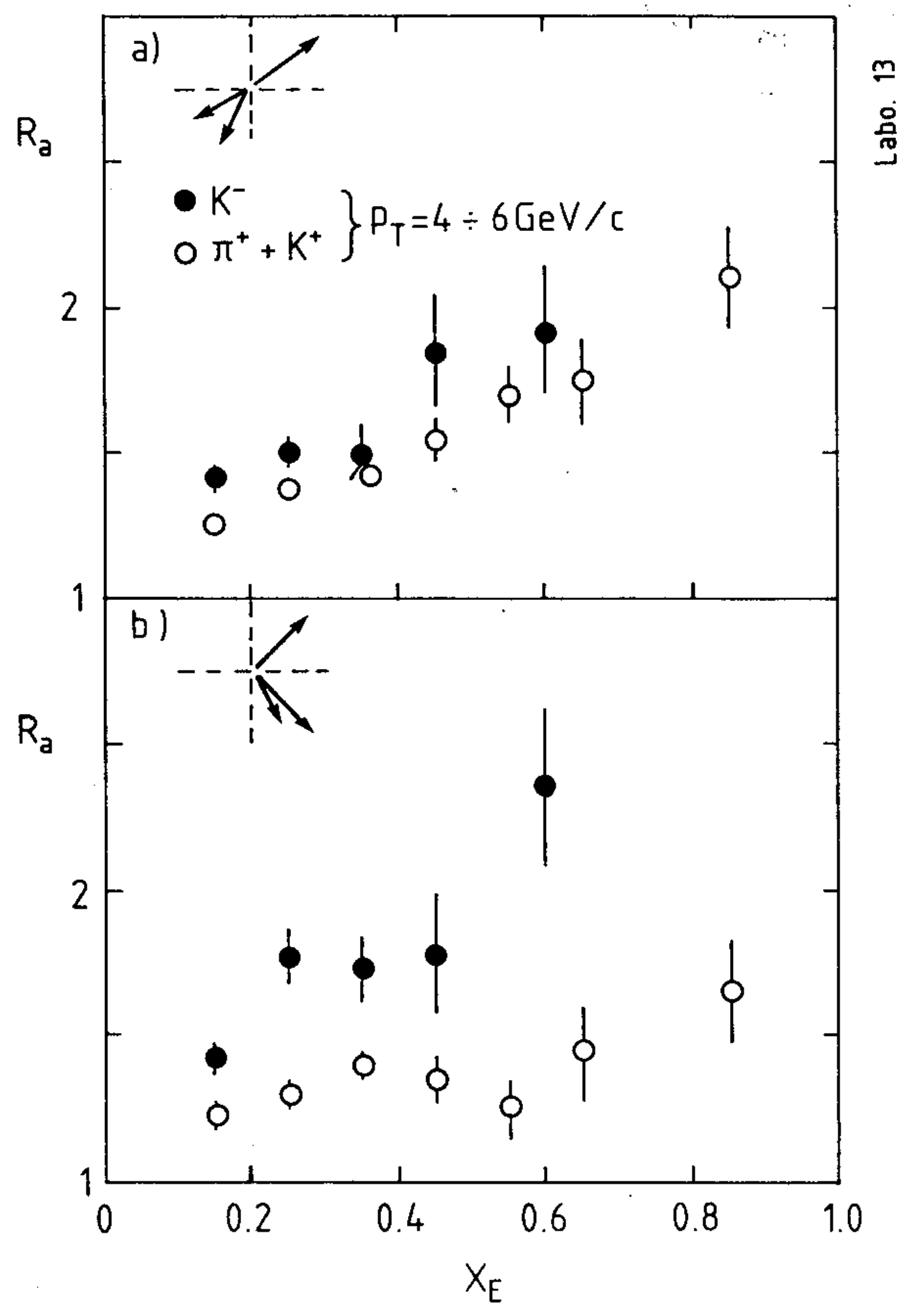


Fig. 6