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PROPOSAL

TO STUDY THE MESONS PRODUCED CENTRALLY IN THE REACTION $pp \to pp + X^0$ AND $\pi^+p \to \pi^+p + X^0$ AT 85 GeV/c

Athens[1]-Bari[2]-Birmingham[3]-CERN[4] Collaboration

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Spokesman : *B.R. French*

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ABSTRACT

We propose an experiment aimed at

a) Studying the properties of the mesons X^0 produced in the central region ($x_F \simeq 0$) of the exclusive reactions $(\pi^+/p)p \to (\pi^+/p)p + X^0$; and

b) A search for mesons having the characteristics of glueball states.

We request a 15 day run with the Ω' spectrometer in the H_1 beam at 85 GeV/c.

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* Will participate in setting up and running only.

1. PHYSICS INTEREST

Many authors have noted that if QCD is the correct theory of strong interactions then it would be surprising if bound states of gluons, the so-called glueballs, do not exist[1]. Their observation would represent a success for QCD, based as it is on quarks and gluons, and it is the role of the experimenter to search for such states. The question arises where should one look in order to have a chance to observe glueballs.

Several places have been suggested:

a) The final state resulting from the γ decay of the ψ is expected to be composed of two gluons which can therefore combine to form a glueball.

b) The products of the fragmentation of gluon jets may contain glueballs. It has therefore been proposed to look at the final states of the Υ decay which is expected to decay into three-gluon jets.

c) One can also look at the products of the gluon jets produced in high p_t collisions such as $q + \bar{q} \to \gamma$ + gluon or q + gluon $\to q$ + gluon (prompt γ or high p_t particle triggers for example).

d) Another place where glueball production can be expected is in the central region of low p_t hadron-hadron collisions[1b,c,m].

In the description of hadron collisions of Pokorski and Van Hove[2] the valence quarks of the original hadrons go right on through after the collision giving rise to the forward and backward fragmentation regions whereas the central particle clusters result mainly from the gluon interactions which can thus act as a source of glueballs. Another possible source of central glueball production which has been suggested is that of Double Pomeron Exchange (PP) [1b,c,i] where the description of the Pomeron in QCD theory is in terms of two or more gluons.

In this experiment we intend to make a detailed study of the meson systems X^0 produced centrally in the *exclusive* reaction $(\pi^+/p)p \to (\pi^+/p)p + X^0$ and in so doing to search for evidence of states which do not fit into the normal $q\bar{q}$ meson spectrum and which might be interpreted in terms of glueballs. No such study with the statistical level and the many exclusive channels proposed here has been previously performed.

Until now a considerable amount of work has been done on inclusive meson production where it is known that the cross-section is at a maximum in the central region. However, several of the known meson resonances have not been observed due most likely to the high background obtained from the large number of possible particle combinations and the difficulties of particle identification at high energies. The combinatorial problem is avoided in the exclusive channel analysis proposed here.

At the ISR, experiments have been performed on the reaction $pp \to pp + X^0$ and on the exclusive reaction $pp \to pp + \pi^+\pi^-$ [3]. These experiments, which have a sensitivity of $\sim$ 100 times smaller than the experiment proposed here, demonstrated that when the system X^0 was restricted to the central region the data had all the characteristics required for a description in terms of Double Pomeron Exchange and that the $pp\pi^+\pi^-$ exclusive channel cross-section is $\sim$ 10 μb. At the lower ISR energies ($\sqrt{s}$ = 23.5), where the error on missing mass to the outgoing protons was smallest, a signal in the centrally produced X^0 mass spectrum (Fig. 1) was seen in the $f^0/A_2^0/D^0$ region[3,4]. This signal was interpreted as due to the A_2^0. However, due to the large error on the missing mass X^0 (σ = ±150 MeV) it was not possible to exclude that the signal was due to the D^0 [5]. The E^0 was not seen. (In the proposed experiment the trigger on a K^+ or K^- should help considerably in searching for the $K^{\pm}K^0\pi^{\mp}$ decay mode of the E^0.) Also present in the X^0 mass spectrum are signals in the ρ^0, ω^0 region which is indicative of the presence of other processes [viz. Regge-Regge (RR), Pomeron-Regge (PR), and Regge-Pomeron (RP) exchanges], as expected, in addition to the Pomeron-Pomeron (PP) contribution.

In order to estimate the contributions of the PP, PR, RP, and RR exchanges in the central region at the energy proposed for this experiment ($\sqrt{s}$ = 12.7, 85 GeV/c), we have used the method described in Ref. 3a for the reaction $pp \to pp + X^0$. Figure 2 shows the percentage contributions of the various exchanges for $|y(X^0)| < 0.6$, i.e. central production, as a function of the mass of X^0. In the region of $m(X^0)$ = 1 GeV the four different processes contribute equally. In Fig. 3 the variation of the PP cross-section versus energy[6] is shown and it is seen that a total PP cross-section of 53 μb is predicted at $\sqrt{s}$ = 12.7 (85 GeV/c).

If glueball states exist, what are the characteristics which may help in their detection? The answer to this question is that there seems to be no single property of a glueball that one can pinpoint as absolutely characteristic. Thus it will probably be an ensemble of observations that will indicate a state as being mainly composed of glue. Amongst these we mention:

a) A width $\Gamma \sim$ 3-30 MeV which is narrower than that of ordinary $q\bar{q}$ mesons ($\Gamma \sim$ 100 MeV) due to Zweig rule violation. This notion comes from the observation that ψ decay to mesons involves two vertices coupled to gluons as shown in Fig. 4 whereas a glueball decay to mesons involves only one such vertex.

b) Since a glueball is an SU(3) colourless unitary singlet with I = B = 0 the study of the relative decay branching ratios contains important information as has been pointed out by Lipkin[7]. For example, in the case of an E^0(1440) glueball one would expect to see pseudoscalar-pseudoscalar decay ($E^0 \rightarrow \delta\pi$) rather than vector pseudoscalar decay ($E^0 \rightarrow K^*K$). Thus in the case that E^0 is a glueball the decay modes $\eta^0\pi^+\pi^-$ and $K_1^0K^\pm\pi^\mp$ should be similar in magnitude.

c) A spin-parity determination of any suspected glueball candidate can provide evidence against it being a $q\bar{q}$ meson. Table 1 shows the J^{PC} states allowed for $q\bar{q}$, gg and ggg coupled mesons where it is seen that some J^{PC} values are not possible for certain $q\bar{q}$ states[1j]. The experiment proposed here is aimed at providing information in each of these areas.

2. EXPERIMENTAL DESIGN CONSIDERATIONS

2.1 Beam energy and mass range of X^0

If $(1-x_1)p^*$ and $(1-x_2)p^*$ are the longitudinal momenta of the two hadrons after the collision then the mass M of X^0 is given by

$$M^2 \doteq x_1 x_2 s$$

where $\sqrt{s}$ is the c.m.s. energy of the collision.

For the case of 85 GeV/c incident protons, γ_C = 6.7 and $\sqrt{s}$ = 12.7, the region below a mass X^0 of 3.9 GeV can be explored with $x_{1,2}$ values $\leq$ 0.3.

2.2 Trigger and apparatus

The trigger is designed to enhance selection of events with a hadron in the beam region with $x_F > 0.5$, a hadron in the target region with $x_F < -0.5$ and ≥ 2 charged particles with laboratory momenta compatible with having been produced within near $x_F = 0$, i.e. ≥ 1 GeV/c in the laboratory system. The last condition excludes elastic scatters. A trigger in which both hadrons with $|x|_F > 0.5$ are on the same side of the beam allows study of the all neutral X^0 system without including elastic scatters.

Figure 6 shows the required layout of the OMEGA spectrometer. For this experiment the one half of the MWPC "C" modules are rotated 90° so that detection of recoil protons with momentum 0.3 to 1 GeV/c is efficient.

The 60 cm long hydrogen target is surrounded by a four sided scintillator box TS with sides parallel to the beam direction. This will be required to give a pulse on the side of the slow proton counter (SPC) only. In order to reject events in which the slow hadron emits other slow charged particles the C-type MWPC which is adjacent to the side of the box that fired, will be required to have only one particle in it.

The fast proton is triggered on by its passage through counter A placed downstream of C_1. Its dimensions have been optimized to have a good acceptance for $x_F > 0.7$.

In order to trigger on events producing particles in the central region a demand of $\geq$ three charged particles passing through the MWPC A4 will be required. Particles of < 1 GeV/c momentum and $p_t = 0$ do not reach A4.

The fast trigger ($\sim$ 100 ns) will be composed of:

i) a beam signal from the beam telescope;

ii) a signal in TS on the same side as the SPC;

iii) a signal in the SPC;

iv) no signal in beam veto counter A_0;

v) a signal in counter A for the fast particle; and

vi) a multiplicity count of ≥ 3 in the high precision MWPC (HPC) placed just after the target plus the 24 element cylindrical scintillation counter placed around the target.

A second stage trigger ($\sim$ 100 μs) will demand a multiplicity > 2 in MWPC A4 outside the beam region.

In the case of the $K^{\pm}$ trigger the trigger will demand in addition hits in correlated hodoscopes H_1, H_2 with no correlated light in the corresponding Cerenkov cell of C_1. The Cerenkov, filled with Freon 114, gives no light for $K^{\pm}$ with $2.8 < p < 9.8$ GeV/c and protons (antiprotons) with $2.8 < p < 18.8$ GeV/c.

The identification of the beam particle as a π^+ or proton, which are present in the H_1 beam in equal numbers at 85 GeV/c, will be done with threshold and disc Cerenkovs and its momentum measured to 0.2% with the H_1 beam spectrometer.

2.3 Event reconstruction

i) The particles from the central region moving with $\gamma_C = 6.7$ will have mean momenta of $\langle p \rangle = \beta_C \gamma_C E^* = 3$ GeV/c and will be well measured with the MWPCs A and B.

ii) The recoil proton will be well measured with the MWPCs C rotated by 90°.

iii) The fast forward particle will be measured using essentially three points: the 1 mm wire spacing beam chambers, the drift chambers 1 and 2 and the drift chamber 3 placed behind Cerenkov C_1. The drift chambers will be backed up by MWPCs T2 and T3, each consisting of four "C"-type modules. In order to reduce the multiple scattering error below the measurement error a bag filled with He will be placed inside C_1 covering the shadow of the forward counter A.

2.4 Errors

i) Errors on missing mass of the system X^0. This error arises mainly from the measurement error on the fast forward particle. At 85 GeV/c the Δp with the set up proposed will be ±300 MeV/c (including multiple scattering) and translates into an error of $\Delta m_x = 30$ MeV in the central region allowing events with a single π^0 to be isolated.

ii) Error on the effective mass of the system X^0. This will be $\Delta m_{X^0} =$ $= \pm 15$ MeV at the E meson mass.

2.5 Acceptance

i) Slow proton: the acceptance of the slow proton in the slow proton counter as a function of x_F is shown in Fig. 7 and demonstrates how for $x_F > -0.7$ the acceptance rapidly drops to zero.

ii) Fast forward particle: the acceptance of the counter A as a function of x_F is shown in Fig. 8. The acceptance is > 70% in the region $x_F > 0.7$ and drops rapidly for $x_F < 0.5$.

iii) Central system X^0: in order to see if a J^P analysis, based on the Dalitz plot distribution, was possible for the $E^0 \to K^+K_1^0\pi^-$ where the K^+ is triggered on using the Cerenkov C_1 with a π threshold of 2.8 GeV/c, an E^0 of mass 1.42 GeV was generated at different values of x_F. Figure 9 shows how the acceptance varies with x_F. Between $x_F = -0.1$ and $+0.1$ the acceptance rises from 20% to 90% for a magnetic field of 13.5 Kgauss. A study of the Dalitz plot showed that no holes exist in the distribution for $x_F(E^0) \geq 0$. A similar study for the two-body decay of the $f^0(1250) \to$ $\to K^+K^-$ gave the same result namely that no holes exist in the cos θ_{K^+} angular distribution for $x_F(f^0) \geq 0$. In this case the acceptance is 72% at $x_F = -0.05$ rising to 100% at $x_F = +0.05$. Thus after correcting the angular distribution for the Cerenkov acceptance information may be obtained on the J^P content of states with mass < 1.5 GeV.

2.6 Identification of the slow and fast particles

The slow particle which will have a momentum < 1 GeV/c and therefore a $\beta < 0.7$, if it is a proton, will have its pulse height in the slow proton counter recorded and allow discrimination between a pion with $\beta = 1$.

As regards the fast forward particle (or the slow particle also) the contamination by other particles will be < 2% for $x_F > 0.7$. This can be seen in Fig. 10 where the inclusive distribution of the proton and π^+ are shown[8].

2.7 Trigger rate, data taking and computing

In order to estimate the trigger rates we have used a bubble chamber data summary tape of K^+p interactions at 70 GeV/c where particles < 1 GeV/c have been identified by ionization. We find that 0.2% of the interactions are accepted by the trigger with a 60 cm H_2 target. Thus $\sigma_{trig.} = 80\ \mu b$ and will yield 160 events/burst for 10^6 incident protons. In the case of a $K^{\mp}$ trigger since $\sigma(K^{\mp}) \sim 0.2\ \sigma_{tot}$, $\sigma_{trig.} \sim 16\ \mu b$, and 2.5×10^6 beam will yield 80 events/burst × acceptance of the $K^{\pm}$. A K^+ acceptance of $\sim 50\%$ gives 40 events/burst.

We propose a run of 15 days with a trigger which asks for i) a K^+ or K^- in Cerenkov 1, in order to study the strange particle decays of X^0, and ii) a scaled down trigger (factor 4) in which no kaon is demanded in order to study the non-strange decays of X^0. The total number of triggers will be 8×10^6 assuming 70% efficiency and 20% dead time. With a computation time of 0.2 seconds (CERN IBM 168/event) 450 hours of computer time is necessary to process the events, which will be divided equally amonst the laboratories.

2.8 Estimate of number of events in a given resonance

The cross-section estimated for the peak in the "A_2" region of reference 2a for the rapidity interval $-0.8 < y < 0.8$ is $\sim 30\ \mu b$ after integrating over the t of the slow and fast proton. In this experiment the acceptance of the slow proton for $|t| > 0.1\ GeV^2$ is 10%. The forward proton has an acceptance of 70% and therefore the σ("A_2") observable in the experiment is $\sim 2\ \mu b$. For 0.6×10^5 effective beam on a 60 cm target the beam flux sensitivity is ~ 75 events/nb. Thus 75,000 "A_2^0" should be seen in the missing mass spectrum for an A_2^0 acceptance of 50%.

For a $K^{\mp}K^0\pi^{\pm}$ decay triggered on the kaon the effective beam flux will be 2.5×10^6 which yields a beam flux sensitivity of 300 events/nb. With a mean kaon acceptance of 50%, ⅓ of the K^0 giving a $K_1^0 \to \pi^+\pi^-$ decay and assuming 50% of these K_1^0 are detected, we obtain 2,000 events for a resonance production cross-section × branching ratio of 1 μb in the y interval $-0.8 < y < 0.8$. As regards sensitivity to a resonant signal consider a D^0 type state of $\Gamma = 50$ MeV. A computation shows that for a Y interval of $-0.6 < y < 0.6$ the background cross-section due to PP, RP, PR and RR contribution is $\sim 5\ \mu b$. This would yield a background of $\sim 6{,}000$ events whereas a signal of $\sim 1{,}200$ events is expected for a $\sigma = 1\ \mu b$ cross-section in the region $|\Delta Y| < 0.6$.

3, CONCLUSION

The OMEGA spectrometer is well suited to analyse the multiparticle events coming from the central region of pp or π^+p collisions at 85 GeV/c incident momentum. The proposed experiment takes advantage of this fact and aims at studying an as yet little explored area of physics. The experiment should a) establish the characteristics of the mesons which are produced centrally in the exclusive channels $pp \to pp + X^0$ and $\pi^+p \to \pi^+p + X^0$, and b) allow a search to be made for glueballs in a favourable region of phase space.

The experiment requires 15 days for setting up (of which a large fraction could be in the S_1 beam) and $\sim$ 15 days in the H_1 beam for data taking. The number of triggers will be $\sim 8 \times 10^6$.

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5) It is of interest to note that an experiment at lower energy [$\sqrt{s}$ = = 5.1, R. Thun et al., Phys. Rev. Lett. 28 (1972) 1733] found a peak in the missing mass in the central region with mass and width compatible with that of the D^0 meson and not the A_2^0. It will thus be of considerable interest to see if at higher energies it is mainly D^0 which is produced centrally rather than the A_2^0 or f^0. As Robson[1b)] has pointed out, the D^0 could be a candidate for a glueball state.

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TABLE I

List of states (J^{PC}) for quark model and glueballs. ✓(X) indicates allowed (disallowed). 2g (3g) correspond to glueball states formed from 2 (3) gluons. Solid arrow (→) indicates quark model exotics in 3g states. Dotted arrow (⇢) indicates exotics in 2g states.

State	$q\bar{q}$	2g	3g
0^{++}	✓	✓	✓
$\xrightarrow{3g}$ 0^{+-}	X	X	✓
0^{-+}	✓	✓	✓
$\xrightarrow{3g}$ 0^{--}	X	X	✓
1^{++}	✓	✓	✓
1^{+-}	✓	X	✓
$\xrightarrow{3g}$⇢ 1^{-+}	X	✓	✓
1^{--}	✓	X	✓
2^{++}	✓	✓	✓
$\xrightarrow{3g}$ 2^{+-}	X	X	✓
2^{-+}	✓	✓	✓
2^{--}	✓	X	✓
3^{++}	✓	✓	✓
3^{+-}	✓	X	✓
$\xrightarrow{3g}$⇢ 3^{-+}	X	✓	✓
3^{--}	✓	X	✓

Figure captions

Fig. 1 : X^0 mass distribution from the reaction $pp \rightarrow pp + X^0$ at $\sqrt{s} = 23.5$ [3,4].

Fig. 2 : Variation of the contributions of Regge-Regge (RR), Regge-Pomeron (RP), Pomeron-Regge (PR) and Pomeron-Pomeron (PP) exchanges with mass of X^0 produced in the central region $|y| < 0.6$.

Fig. 3 : Variation of the Double Pomeron Exchange cross-section with p_{lab} [6].

Fig. 4 : a) Graph of ψ decay into mesons via three gluons.
b) Decay of a glueball into mesons via two or three gluons.

Fig. 5 : Graph for the γ decay of the ψ resulting in a two gluon vertex.

Fig. 6 : Layout of the OMEGA apparatus for the proposed experiment.

Fig. 7 : Acceptance of the slow proton counter to slow protons with a t dependence of $d\sigma/dt = A\ e^{-6t}$.

Fig. 8 : Acceptance of the forward counter A to fast particles at a function of x_F. A t dependence of $d\sigma/dt = A\ e^{-6t}$ was assumed.

Fig. 9 : Acceptance for the K^+ in Cerenkov C_1 coming from $E^0 \rightarrow K^{+}\bar{K}_1^0\pi^-$ as a function of Feynman X of E^0.

Fig. 10 : x_F distribution of the proton, positive pion and antiproton for the reaction $p\bar{p} \rightarrow cX$.

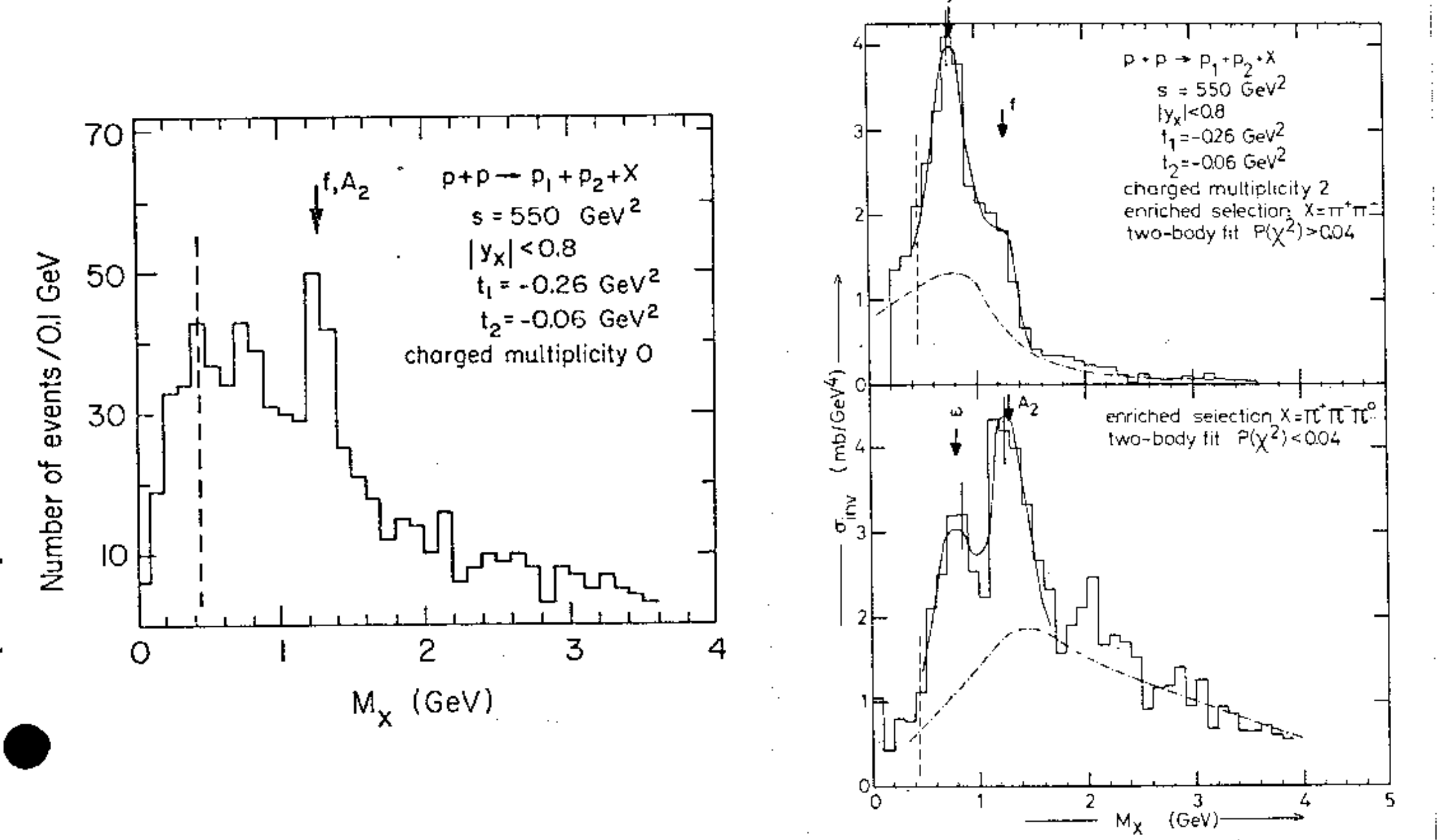

p+p → p1 + p2+X
s = 550 GeV²
|yX| < 0.8
t1 = -0.26 GeV²
t2 = -0.06 GeV²
charged multiplicity 0
f, A2
Number of events /0.1 GeV
MX (GeV)
ρ
f
p + p → p1 + p2 + X
s = 550 GeV²
|yX| < 0.8
t1 = -0.26 GeV²
t2 = -0.06 GeV²
charged multiplicity 2
enriched selection X = π⁺π⁻
two-body fit P(χ²) > 0.04
ω
A2
enriched selection X = π⁺π⁻π⁰
two-body fit P(χ²) < 0.04
σinv (mb/GeV⁴)
MX (GeV)

Fig. 1

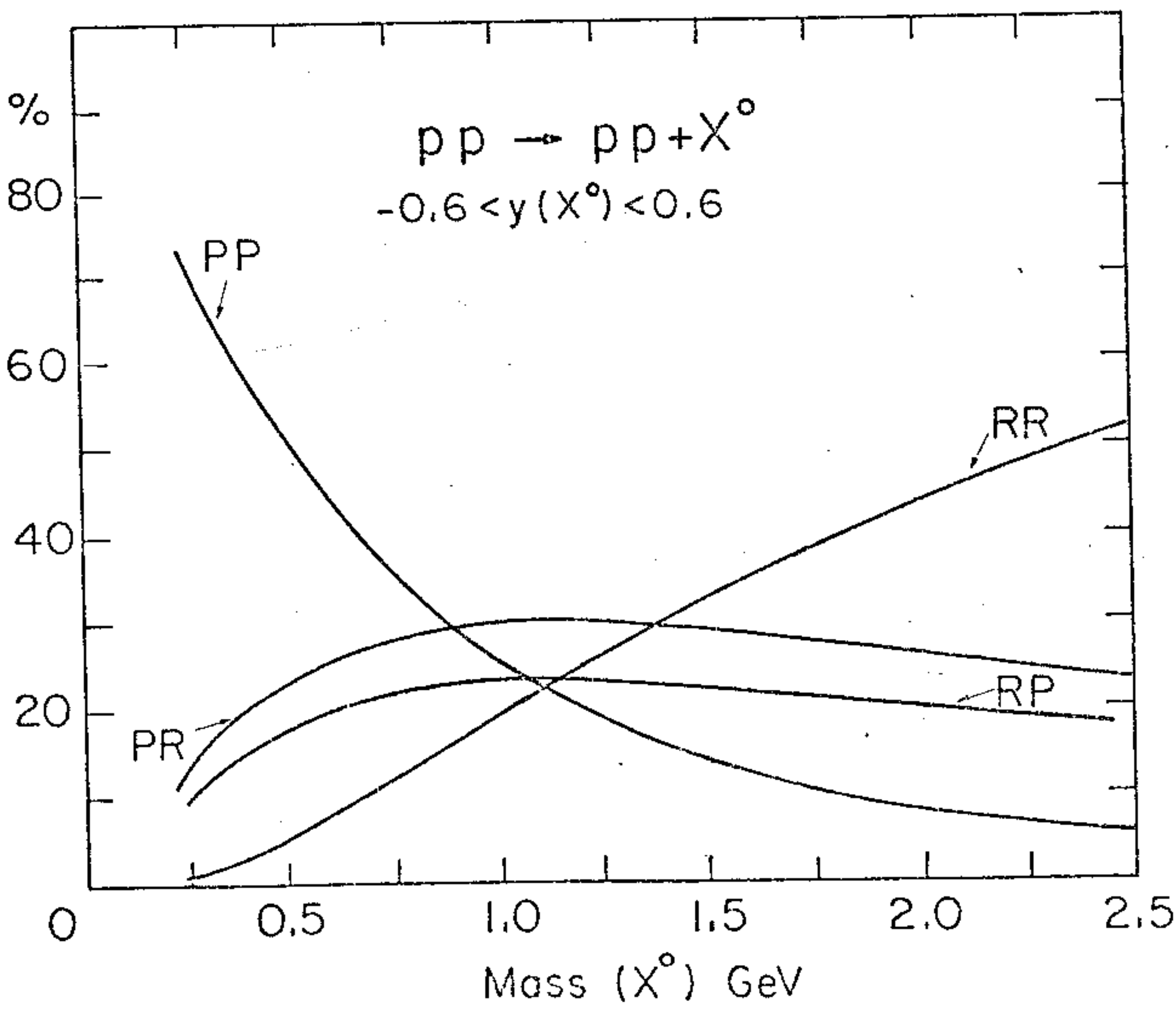

%
pp → pp+X°
-0.6 < y(X°) < 0.6
PP
RR
RP
PR
Mass (X°) GeV

Fig. 2

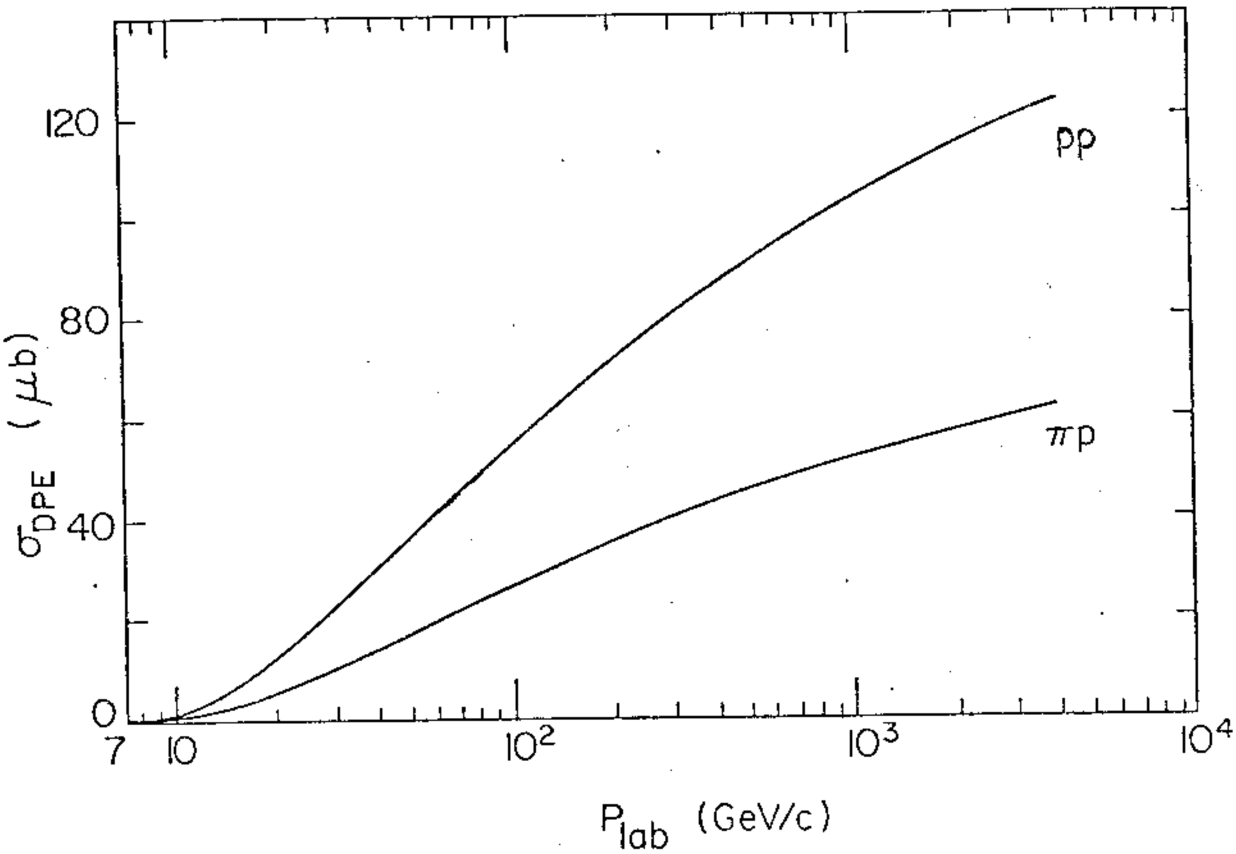


Fig. 3

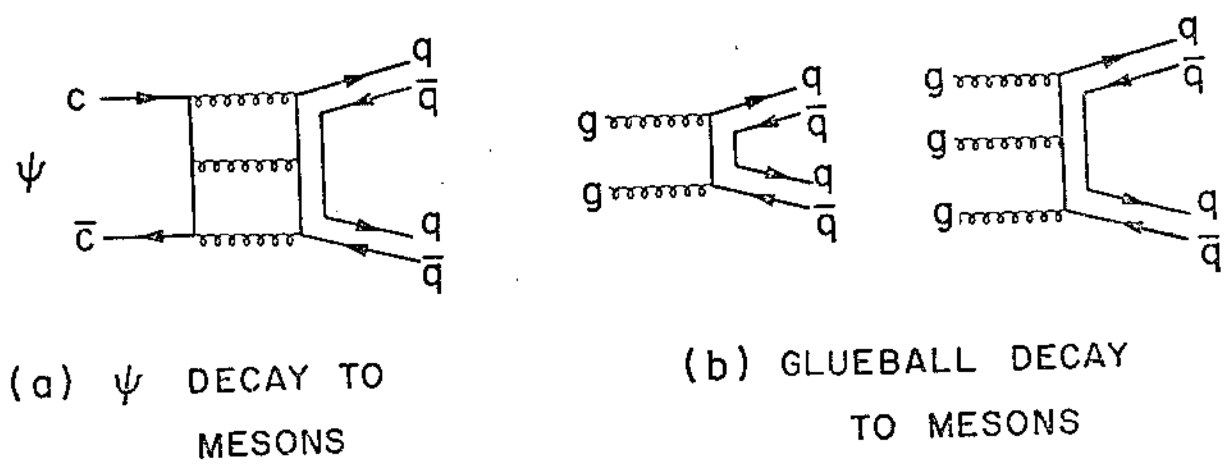


Fig. 4

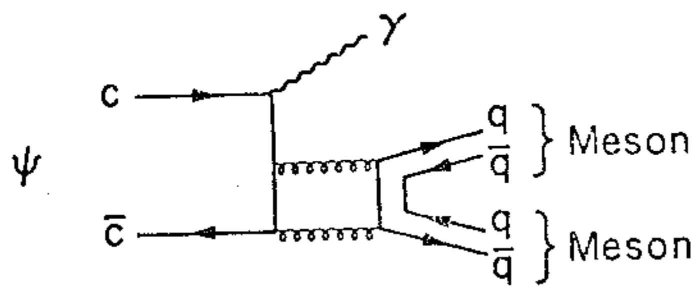


Fig.5

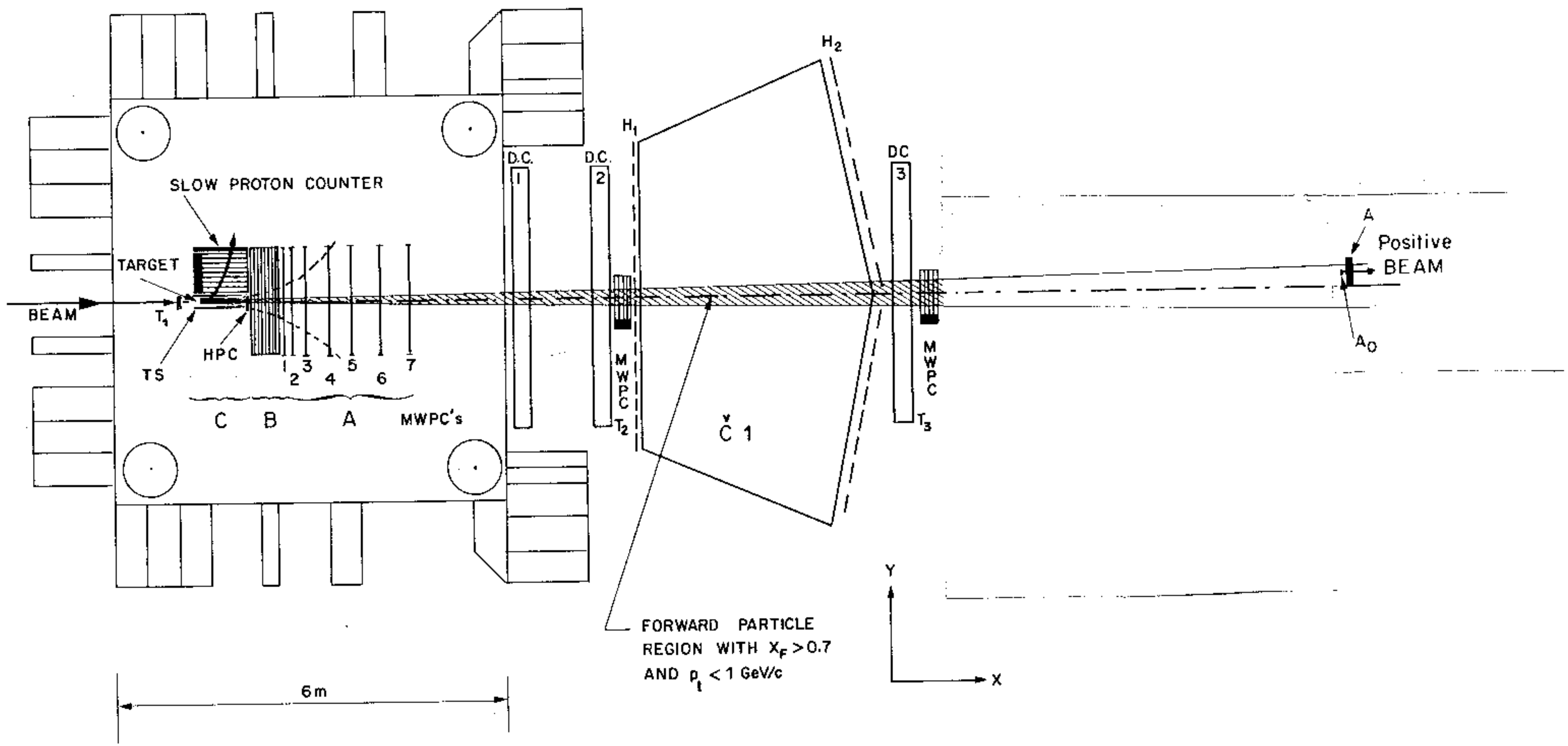

SLOW PROTON COUNTER
TARGET
BEAM
T_1
TS
HPC
1 2 3 4 5 6 7
C B A MWPC's
D.C. 1
D.C. 2
MWPC T_2
H_1
H_2
Č 1
DC 3
MWPC T_3
A
Positive BEAM
A_0
FORWARD PARTICLE REGION WITH $X_F > 0.7$ AND $p_t < 1$ GeV/c
Y
X
6m

Fig. 6

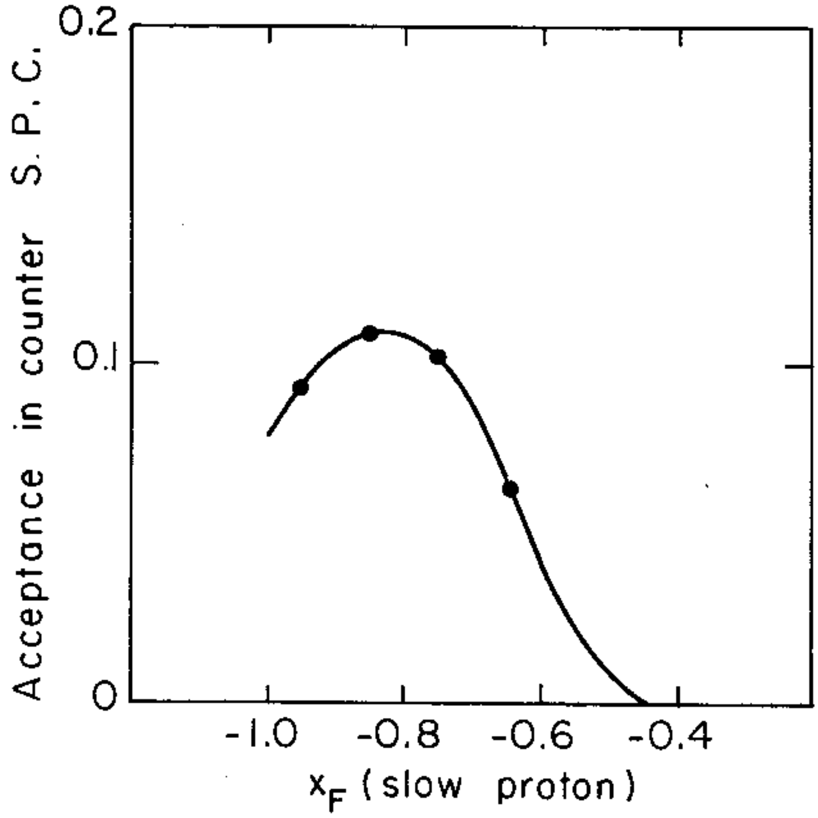

0.2
0.1
0
Acceptance in counter S. P. C.
-1.0
-0.8
-0.6
-0.4
x_F (slow proton)

Fig. 7

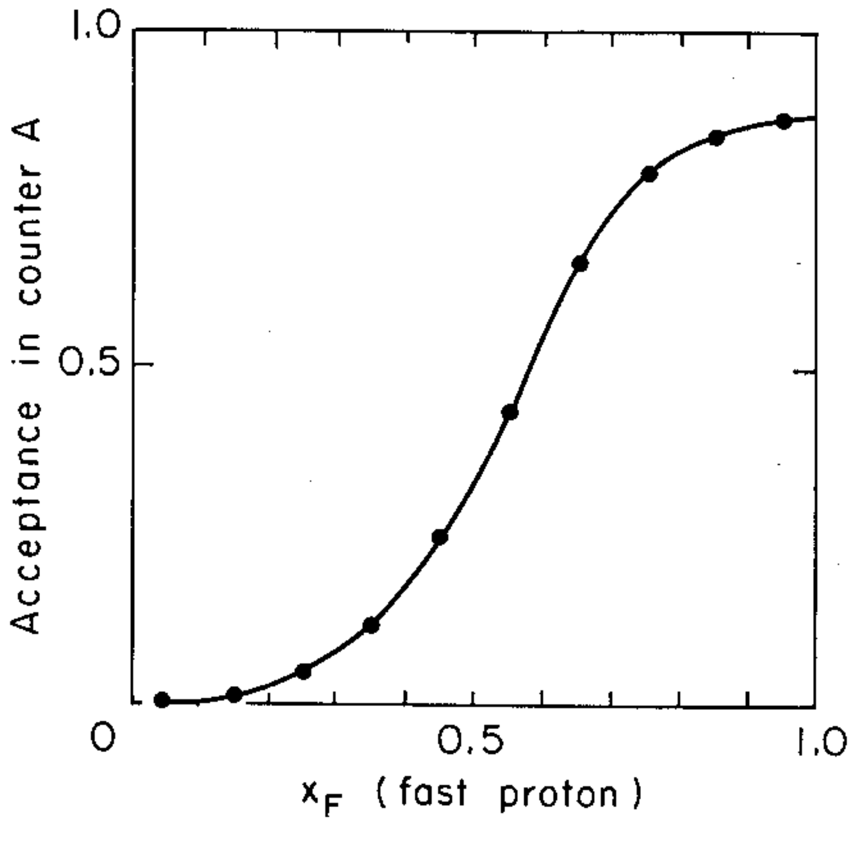
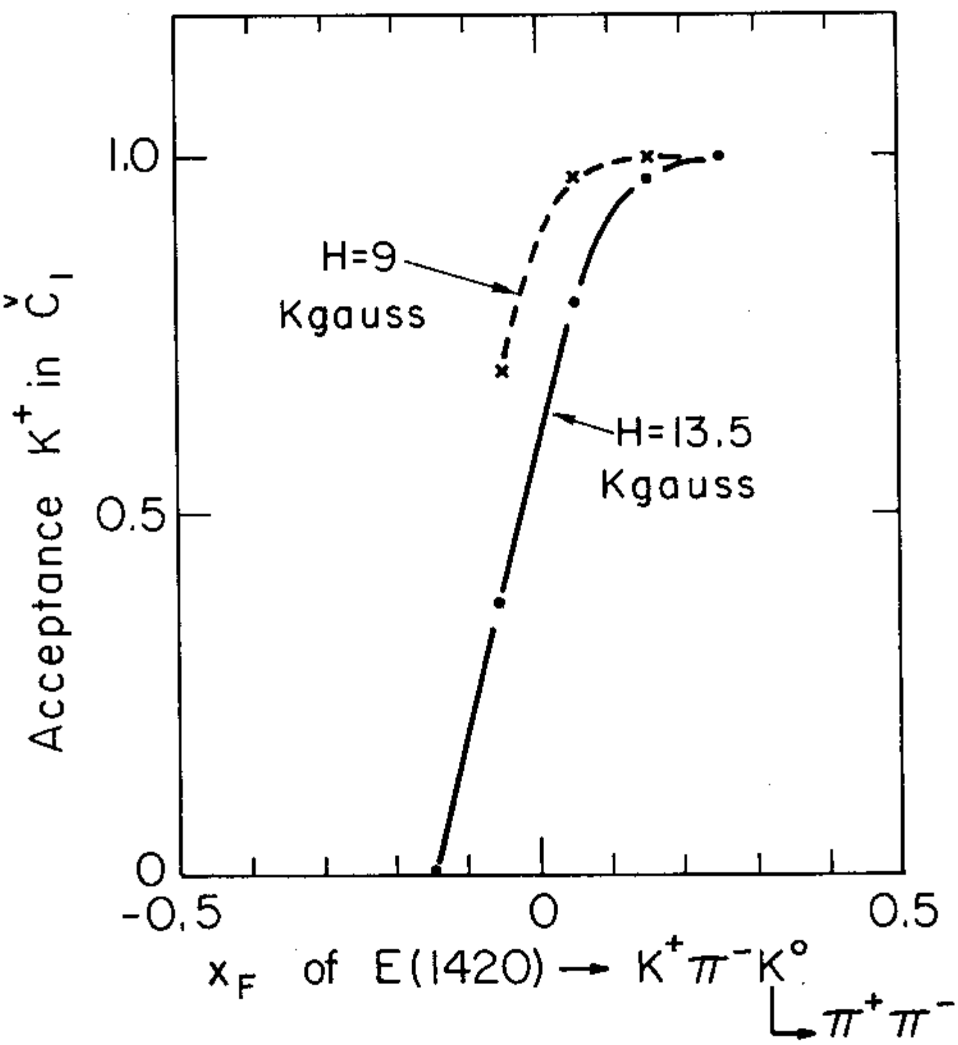

1.0
0.5
0
Acceptance in counter A
0.5
1.0
x_F (fast proton)

Fig. 8



1.0
0.5
0
-0.5
0
0.5
H=9
Kgauss
H=13.5
Kgauss
Acceptance K^+ in $\check{C}_1$
x_F of $E(1420) \rightarrow K^+\pi^-K^0$
$\hookrightarrow \pi^+\pi^-$

Fig. 9

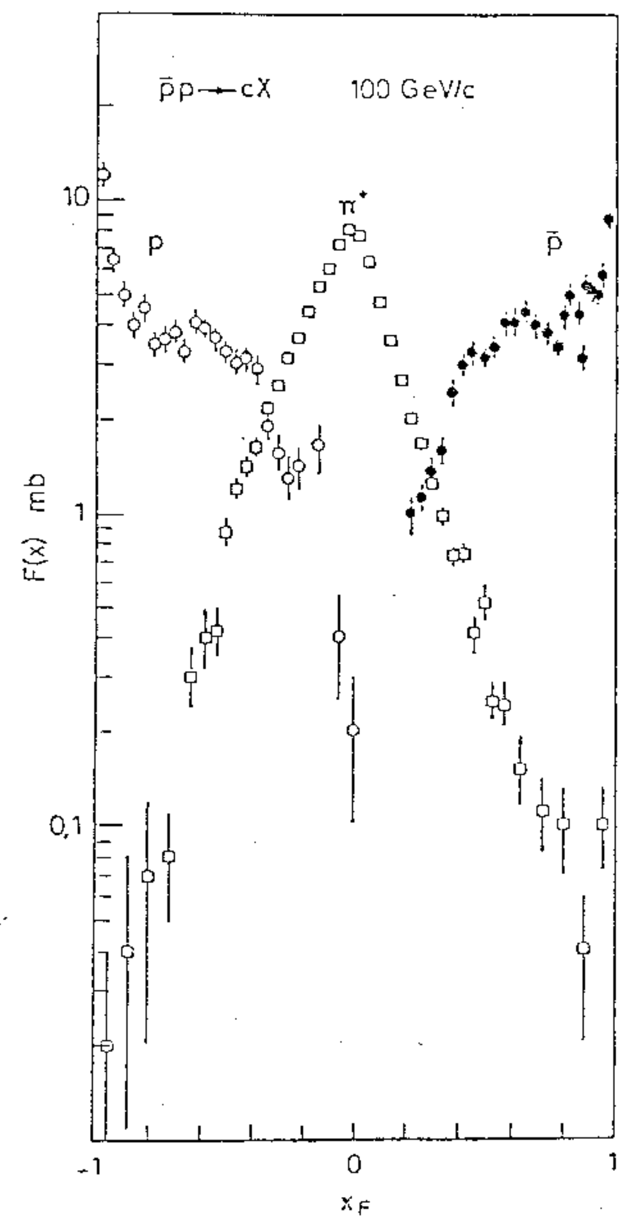


Fig. 10