CORRELATIONS IN HIGH TRANSVERSE MOMENTUM FINAL STATES

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1. INTRODUCTION

A study of particle correlations in high energy collisions leading to high transverse momentum secondaries can provide further insight into the dynamics of these processes. In particular, it is hoped to test the hypothesis [1] that hadron production at high values of the transverse momentum $p_\perp$ result from large angle scattering of elementary constituents within the proton (partons). In this case it is expected to observe "jets" of hadrons, with a total transverse momentum balancing that of the high $p_\perp$ secondary hadron which triggered the apparatus.

All the experimental results on this subject have so far been obtained at the CERN Intersecting Storage Rings (ISR). Most of them are limited by statistics to $p_\perp < 4$ GeV/c.

2. CHARGED PARTICLE MULTIPLICITIES AND ANGULAR DISTRIBUTIONS

The Pisa-Stony Brook (PSB) collaboration [2),3)] have used a system of counter hodoscopes covering a solid angle of almost 4π, triggered by a photon detector (a matrix of lead glass Cerenkov counters) located at 90^o (see Fig. 1). Fig. 2 shows the average charged particle multiplicities at the five standard ISR c.m.s. energies ($\sqrt{s}$=23,31,45,53 and 62 GeV), as a function of the photon transverse momentum $p_\perp$, as measured in the hemisphere opposite to the photon direction. These data have been normalized to the value relative to the lowest $p_\perp$ bin ($p_\perp < 0.5$ GeV/c), in order to divide out most of the experimental errors and to stress the dependence on $p_\perp$. The raw normalizing multiplicities range from 5.1 at $\sqrt{s}$=23 GeV, to 8.2 at 62 GeV. It is seen that the normalized multiplicities increase roughly linearly with $p_\perp$ and display little s-dependence. However, in the hemisphere toward the photon, the data (see Fig. 3) show a strong s dependence: at the lower energies the normalized multiplicities decrease as $p_\perp$ increases, while they become flat or even increase slightly at the higher energies.

The angular distribution of charged particles associated with a high $p_\perp$ photon or π^o, has been measured by the PSB collaboration [2),3)] and by the Aachen-CERN-Heidelberg-Munich(MPI)(ACHM) Collaboration [4)]. The apparatus used in this latter experiment is shown in Fig. 4 : it consists mainly of two streamer chambers surrounding an ISR intersection region, and an array of lead glass Cerenkov counters to detect π^o's emitted at 90^o in the lab system. Fig. 5 shows the difference of the η

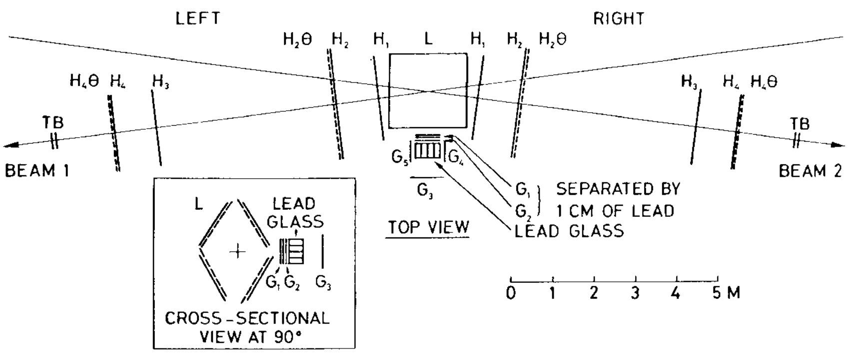

Fig. 1
Plan view of the Pisa-Stony Brook experimental set-up.

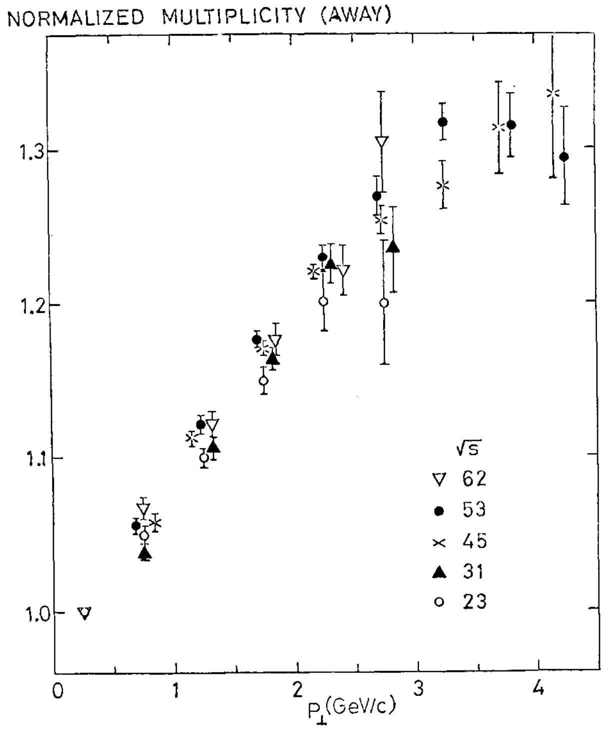

Fig.2 Normalised partial multiplicities as a function of the photon transverse momentum, in the hemisphere away from the detected photon.

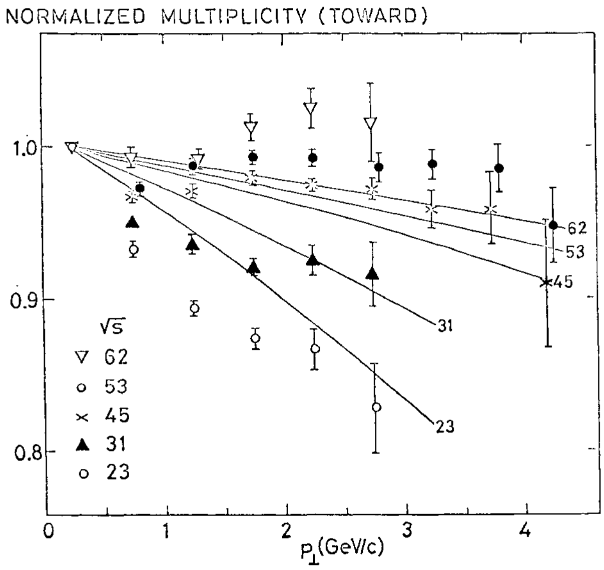

Fig.3 Normalized partial multiplicities as a function of the photon transverse momentum, in the hemisphere toward the detected photon.

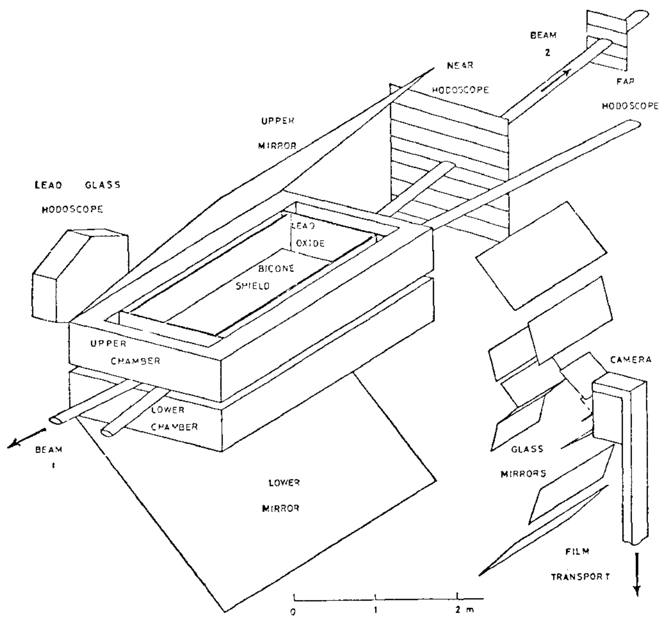

Fig.4 Experimental set-up used by the Aachen-CERN-Heidelberg-Munich (MPI) collaboration.

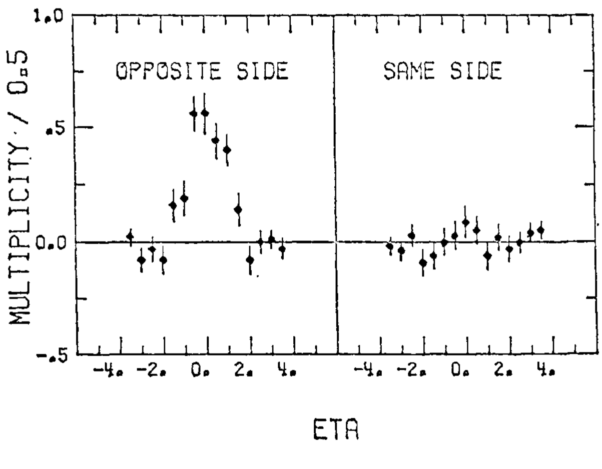

Fig.5 Difference of the η distributions at $p_\perp$ = 3 GeV/c and $p_\perp$ = 1 GeV/c, for the opposite and same hemispheres with respect to the π^o.

distributions (η=-ln tan $\theta/2$) for events with $p_\perp$ = 3 GeV/c and $p_\perp$ = 1 GeV/c, at a c.m.s. energy $\sqrt{s}$ = 53 GeV, for the opposite and same hemispheres with respect to the π^0. It is seen that the $p_\perp$ dependent enhancement in the opposite hemisphere, covers an angular region with a width $\Delta\eta=\pm2$. The difference of the ϕ distributions at $p_\perp$ = 3 GeV/c and $p_\perp$ = 1 GeV/c, for events with $|\eta|\leq2$, is shown in Fig. 6 The enhancement is seen to occur in an azimuth interval $\Delta\phi=\pm60^{\circ}$, centered around a direction opposite to the high $p_\perp$ π^0. Data from the CERN-Columbia-Rockefeller (CCR) collabroation[5)], covering an angular range with $\Delta\phi=\pm23^{\circ}$, $\Delta\eta=\pm0.8$ around 90° (see Fig. 7.), are shown in Fig. 8, for π^0's detected around 90° with $p_\perp$ values as high as 8 GeV/c, at $\sqrt{s}$=53 GeV.

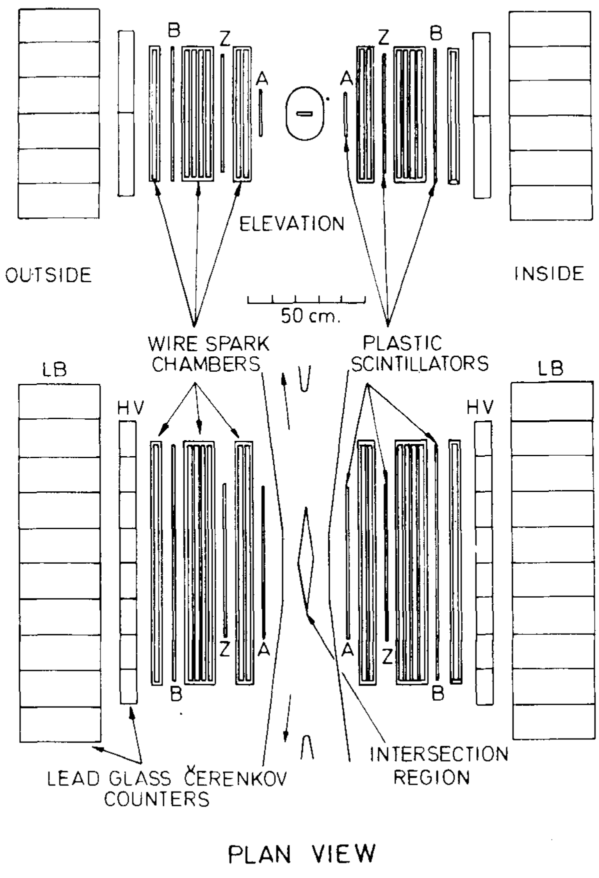

Fig.7 The CERN-Columbia-Rockefeller experimental set-up.

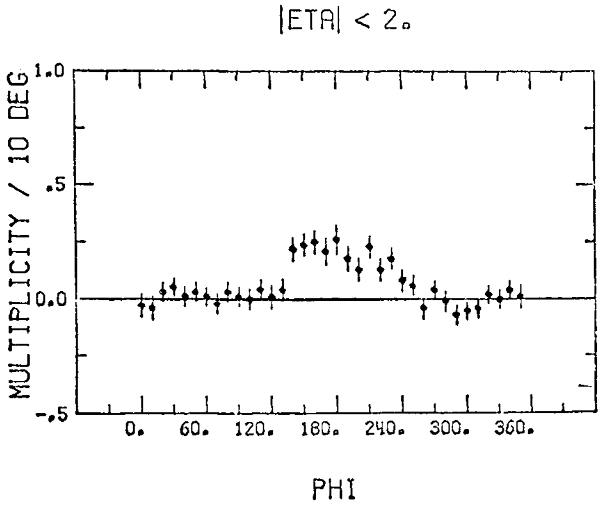

Fig.6 Difference of the ϕ distributions at $p_\perp$ = 3 GeV/c and $p_\perp$ = 1 GeV/c, for all charged particles with $|\eta|\leq 2$.

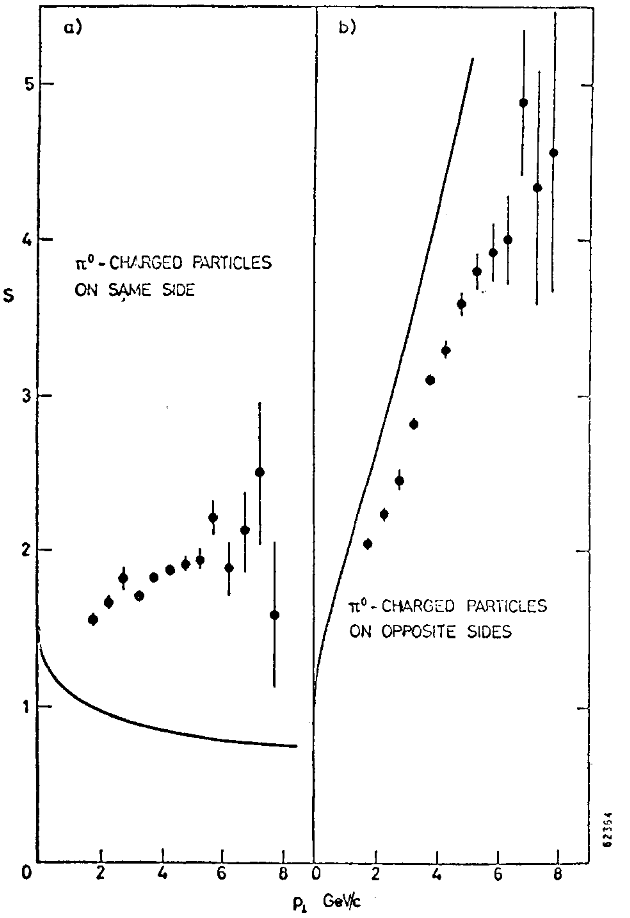

Fig.8 The ratio of the number of charged particles associated with a π^0 meson of transverse momentum $p_\perp$ to the number of charged particles observed in a typical inelastic interaction.

These data are normalized to the average multiplicities, as measured for a typical inelastic interaction. The multiplicity in a direction opposite to the π^o is seen to increase roughly linearly with $p_\perp$ up to $p_\perp$ = 8 GeV/c, while on the same side as the π^o, it is approximately constant with $p_\perp$. In a direction opposite to the π^o, most of the enhancement can be explained by the Uncorrelated Jet Model [6] (see the full curves of Fig. 8), which uses only energy-momentum conservation and the limitation of transverse momentum. However, the data disagree with this model on the same side as the π^o.

In conclusion, one observes an enhancement of the charged particle multiplicity around a direction opposite to that of a high $p_\perp$ π^o emitted at 90^o. This enhancement has the following features:

a) it covers an angular region with width $\Delta\eta=\pm 2$, $\Delta\phi=\pm 60^o$.

b) the multiplicity increases roughly linearly with $p_\perp$ up to at least $p_\perp \approx$ 8 GeV/c.

c) the rate of growth is 0.8 particles/GeV/c.

d) approximately 3.5 extra charged particles are produced when $p_\perp$ = 4 GeV/c.

Similar results have been obtained by the CERN-Daresbury-Rutherford-Liverpool collaboration [7], who detect high $p_\perp$ charged hadrons with a magnetic spectrometer at 60^o and 90^o, and study associated particle multiplicity by means of a barrel shaped counter matrix surrounding an ISR intersection region.

The PSB [8] and ACHM [4] collaboration have also measured the position of the multiplicity enhancement when the high $p_\perp$ π^o is detected at an angle different from 90^o. In the PSB experiment [8], the lead glass detector is moved to 17.5^o ($\eta_\gamma \simeq 1.9$). In the ACHM experiment [4], the π^o detector position is left unchanged, and data are taken with 11.8 GeV protons in one ring and 31.4 GeV protons in the other. These conditions give $\sqrt{s}$ = 38.2 GeV, $\eta_{\pi^o} = -0.5$.

In both cases the enhancement is seen to be centered at values of η which are not equal and opposite to those of the high $p_\perp$ photon or π^o. In the PSB experiment, the centre of the enhancement is at $\eta \approx -0.7$; in the ACHM experiment it is found between η=0 and $\eta=-\eta_{\pi^o}$. It is certainly difficult to explain these results in terms of kinematic effects only.

The ACHM collaboration [4] have also studied the angular correlation between two charged particles in the enhancement, in order to see if there is any evidence for jet structure. A normalised correlation function is defined as

$$R(\Delta\eta,\Delta\phi) = \frac{\sigma' \int \frac{d^4\sigma}{d\eta_1 d\eta_2 d\phi_1 d\phi_2}\, \delta(\phi_2-\phi_1-\Delta\phi)\delta(\eta_2-\eta_1-\Delta\eta)d\eta_1 d\eta_2 d\phi_1 d\phi_2}{\int \frac{d^2\sigma}{d\eta_1 d\phi_1}\frac{d^2\sigma}{d\eta_2 d\phi_2}\, \delta(\phi_2-\phi_1-\Delta\phi)\delta(\eta_2-\eta_1-\Delta\eta)d\eta_1 d\eta_2 d\phi_1 d\phi_2} - 1 \qquad (1)$$

where σ' is the partial cross section for the inelastic collisions being studied . The data are then compared with the predictions of two models: the first one, in which the extra particles produced in association with a high $p_\perp$ π^o are distributed at random within the angular band of the enhancement and the second, in which they are distributed in a way corresponding to a jet structure. As it can be seen from Fig. 9, the behaviour of R vs. $\Delta\eta$, as shown by the high $p_\perp$ data, does not agree with that obtained by a random distribution, and exhibits a clear short-range correlation in $\Delta\eta$. However, the same behaviour is found in the experimental data when lower transverse momentum π^o's are selected. This correlation in $\Delta\eta$ is also present in a direction normal to the plane containing the π^o and the beam momenta. It seems that the data can only be interpreted as giving evidence for a short-range rapidity correlation, but the mechanism responsible for this phenomenon is unknown at present.

3. MOMENTUM CORRELATIONS

The CCR collaboration [5] have studied events at $\sqrt{s}$=53 GeV, where two high $p_\perp$ π^0's are produced on either the same side or on opposite sides of an ISR intersection region (see the apparatus shown in Fig. 7). Fig. 10 displays the correlation function

$$R(x_{1\perp},x_{2\perp}) = \frac{\sigma_{INEL} \dfrac{d^6\sigma}{dp_1^3 dp_2^3}}{\dfrac{d^3\sigma}{dp_1^3} \cdot \dfrac{d^3\sigma}{dp_2^3}} \qquad (2)$$

where $x_\perp = 2p_\perp/\sqrt{s}$, for the case of opposite side π^0's. The correlation is seen to increase with increasing $x_\perp$ of either π^0, and R is as high as $\sim 10^4$ for $x_{1\perp} = x_{2\perp} = 0.2$. This behaviour might be largely a consequence of momentum conservation, as shown by the solid curves of Fig. 10, which represent predictions based on UJM [6].

However, the correlation function R for same-side π^0's (see Fig. 11) is also positive and large ($R \sim 10$ at $x_{1\perp}=x_{2\perp}=0.1$), an effect which cannot be explained

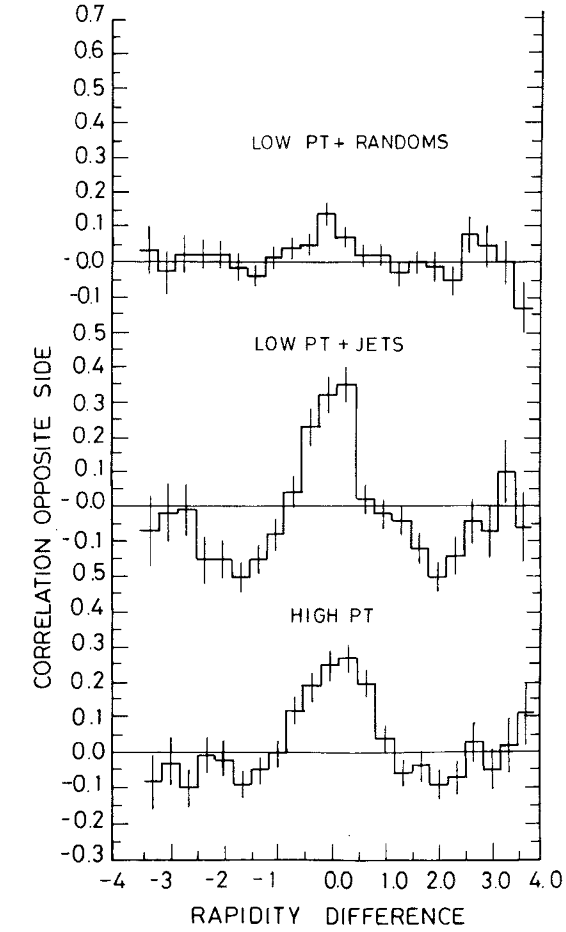

Fig.9 Δη correlations of charged particles opposite to the π^0. Comparison of the data at $p_\perp$ = 3 GeV/c with the jet model and the random distribution model as described in the text.

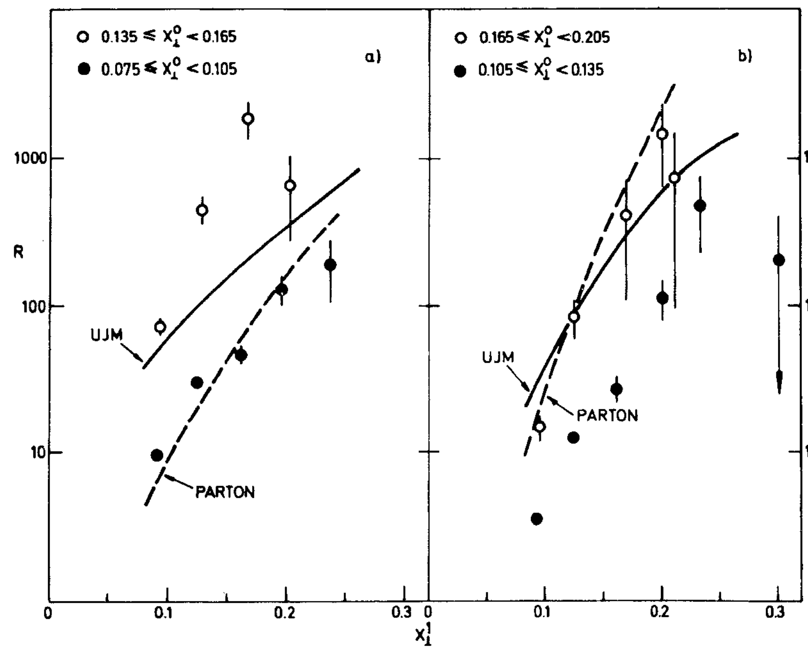

Fig.10 The correlation coefficient R for two π^0's with azimuthal separation $\sim 180^0$.

in terms of kinematics. An obvious possibility here is resonance decay, but the invariant mass distribution for the two π^o's (Fig. 12), does not show any evidence for resonances.

Preliminary data on momentum correlations between two high $p_\perp$ hadrons have been reported by the CERN-Columbia-Rockefeller-Saclay (CCRS) collaboration [9]. The experimental apparatus, shown in Fig. 13, consists of two magnetic spectrometers, each subtending an angular acceptance $\Delta\phi=\pm7^o$ and $\Delta\Theta=\pm12^o$ around 90^o. A π^o detector, consisting of a matrix of lead glass Cerenkov counters, is located at the end of one of the two spectrometers. The results for charged hadrons with an azimuthal separation of approximately 180^o are shown in Fig. 14, where the correlation function R, as defined in (2), is displayed as a function of the two momenta p_1 and p_2. These results are consistent with those obtained by the CCR collaboration on opposite side π^o's and discussed above.

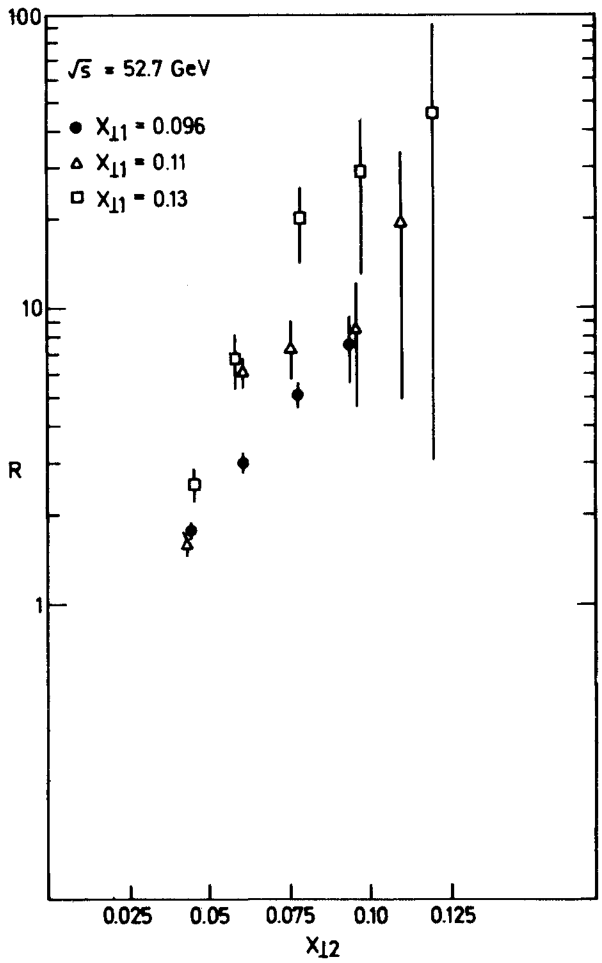

Fig.11 The correlation coefficient R for two π^o's with azimuthal separation $\sim 0^o$.

The momentum distribution of charged hadrons produced along a direction opposite to that of a π^o with $p_\perp > 3$ GeV/c, is shown in Fig. 15, normalized to the total number of events in which a π^o with $p_\perp > 3$ GeV/c is observed. The comparison with the inclusive momentum distribution for charged hadrons (also shown in Fig. 15) is another way to show the existence of a positive and large momentum correlation.

While this correlation might largely result from kinematic effects, the same side effects, shown in Fig. 16, need something more than this, since a positive and large momentum correlation is present here too.

4. CONCLUSION

Most of the effects observed in opposite direction with respect to that of a high $p_\perp$ hadron, can be largely explained in terms of kinematic effects. These effects have made any search for jets of hadrons opposite to a high $p_\perp$ hadron inconclusive – on the other hand, the positive momentum correlations observed between two high $p_\perp$ hadrons in the same azimuthal region, are certainly of dynamical origin and must be studied further.

It should also be very useful to measure the momenta of all the extra particles produced in a direction opposite to high $p_\perp$ hadron, as well as do special experiments in which not only single high $p_\perp$ hadrons are selected, but clusters of hadrons with a high value of the total transverse momentum.

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4) Paper 1037.

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6) L Caneschi,VII Rencontres de Moriond(1973);
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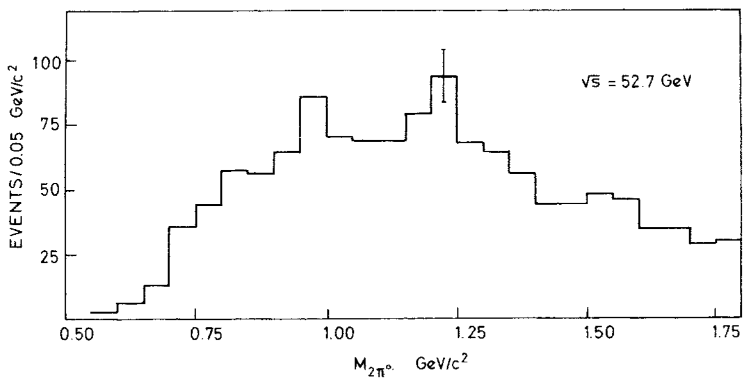

Fig.12 The distribution in invariant mass, $M_{2\pi^0}$ for two π^0's with azimuthal separation $\sim 0^0$.

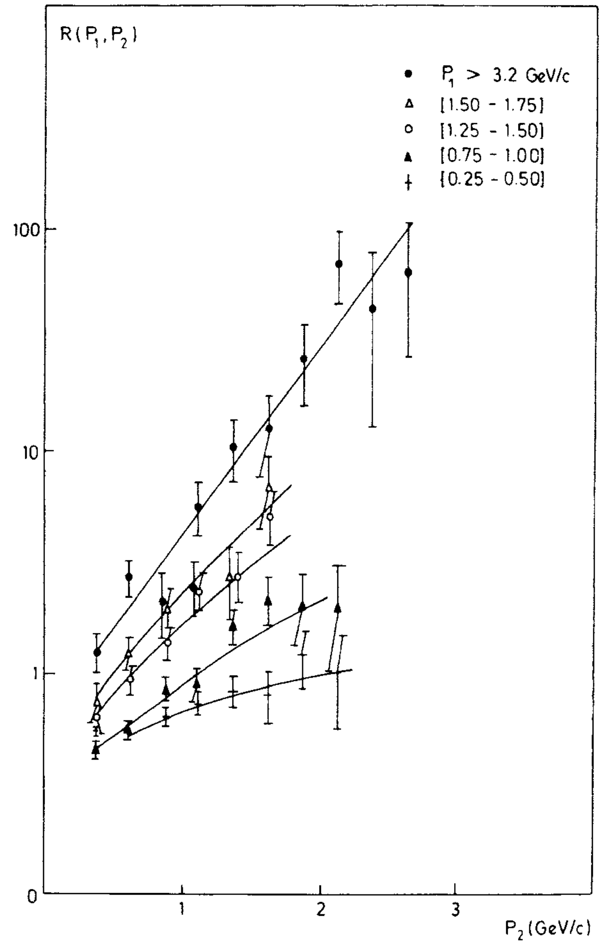

Fig.14 The correlation coefficient R for two charged hadrons with azimuthal separation $\sim 180^0$.

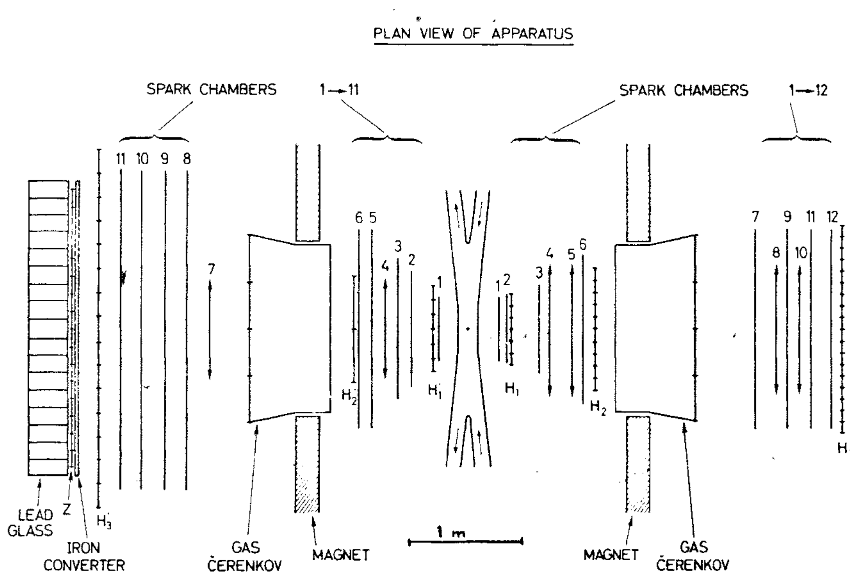

Fig.13

Experimental set-up used by the CERN-Columbia- Rockefeller-Saclay collaboration.

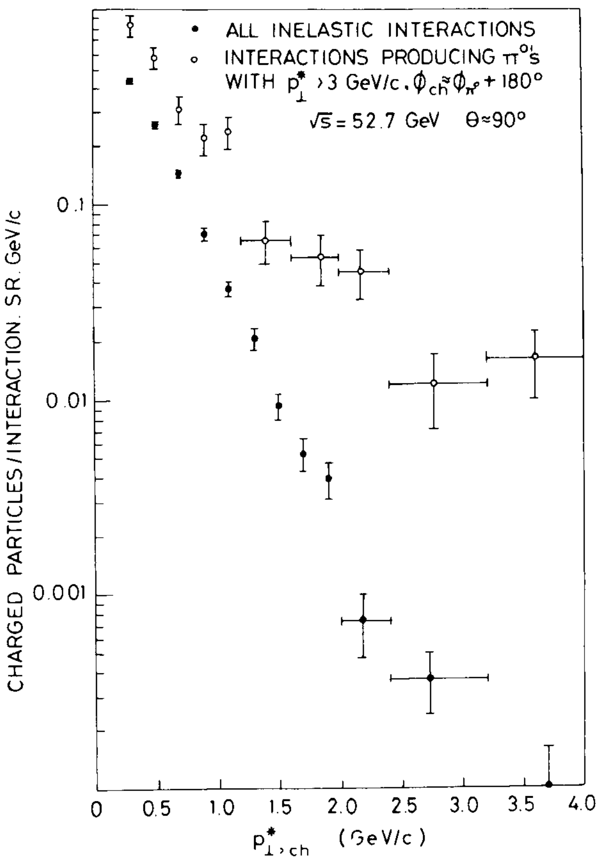

Fig.15 Momentum distributions of charged hadrons at 90°:
a) inclusive (full circles); b) produced together with a π^0 with $p_\perp$ > 3 GeV/c, with an azimuthal separation of ∿ 180° (open circles).

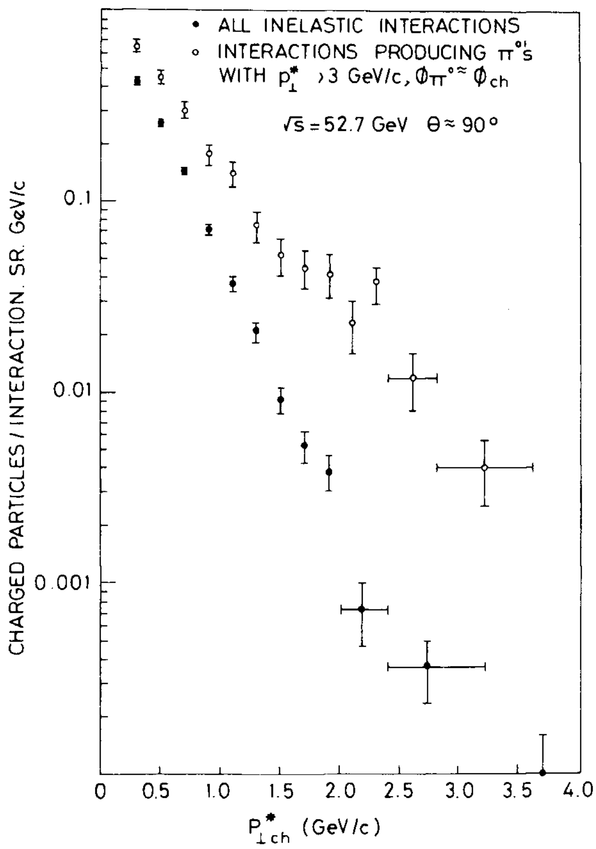

Fig.16 Momentum distributions of charged hadrons at 90°: a) inclusive (full circles);
b) produced together with a π^0 with $p_\perp$ > 3 GeV/c, with an azimuthal separation of ∿ 0° (open circles).