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CORRELATIONS BETWEEN TWO IDENTIFIED CHARGED HADRONS AT THE CERN ISR

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Abstract

We have measured the value of the correlation $R(h_1, h_2)$ between two identified charged hadrons ($h = \pi^{\pm}, K^{\pm}$, p or $\bar{p}$) produced in pp collisions at the CERN ISR. One hadron was produced in the forward direction and the other at a large angle. Quantum number dependent effects have been observed.

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We have performed an experiment at the CERN ISR to study the reaction $pp \rightarrow h_1 h_2 + X$ where h_1 and h_2 are identified charged hadrons ($\pi^\pm$, $K^\pm$, p or $\bar{p}$). In an earlier paper$^{1)}$ we have reported on a search for narrow resonances in this data. Here we report on the values measured for the correlation function between the hadrons h_1 and h_2:

$$R(h_1,h_2)=\sigma_{inel}\bullet\left\{\frac{\dfrac{d^6\sigma}{dy_1\, dp^2_{T_1}\, d\phi_1\, dy_2\, dp^2_{T_2}\, d\phi_2}}{\dfrac{d^3\sigma}{dy_1\, dp^2_{T_1}\, d\phi_1}\bullet\dfrac{d^3\sigma}{dy_2\, dp^2_{T_2}\, d\phi_2}}\right\}-1$$

$R(h_1,h_2)$ is in principle a function of y_1, y_2, $p^2_{T_1}$, $p^2_{T_2}$, ϕ_{12} and s, where y_i is the rapidity and p_{T_i} is the transverse momentum of the particle i, ϕ_{12} is the relative azimuthal angle ($|\phi_1 - \phi_2|$) of the two particles and s is the squared total centre of mass energy of the two incident protons. In this experiment the range of the kinematic variables was limited and the emphasis is on the types of particles h_1 and h_2. All the data were taken with colliding proton beams of 26.6 GeV, i.e. at $s \simeq 2800$ GeV^2.

The two hadrons were detected in two single arm spectrometers$^{2,3)}$, each providing momentum measurement and particle identification using a combination of time-of-flight and threshold gas Cerenkov counters. A top view of the apparatus is shown in Fig. 1. Spectrometer 1 (Small Angle Spectrometer/SAS)$^{2)}$ was positioned at a polar angle $\theta_1 \simeq 50$ mrad above one of the downstream beams ($\phi_1 \simeq 90^0$) and accepted particles of one sign of charge with momenta between 5 and 12 GeV. Spectrometer 2 (Wide Angle Spectrometer/WAS)$^{3)}$ was placed in the plane of the colliding beams ($\phi_2 = 0^0$) at a c.m. polar angle $\theta_2 \simeq 32^0$. The kinematic configuration of the two hadrons is sketched in Fig. 2. Spectrometer 2 had a low momentum cut-off near 0.5 GeV and particles could be identified up to 3.4 GeV, except for a K/p ambiguity in the range $1.4 < p < 1.65$ GeV. The particles in this spectrometer mostly had momenta in the range 0.8 - 2.0 GeV. Thus both hadrons were in the same polar hemisphere, with h_1 characterized by a centre-of-mass rapidity $y \sim 3$, Feynman $x \sim 0.3$ and h_2 by $y \sim 1$, $x \sim 0.03$. Specifically the mean centre-of-mass values and ranges accepted were:

$$\begin{aligned}
y_1 &= 3.73 \pm 0.15 \text{ for } \pi^+, \pi^- \\
&= 3.15 \pm 0.15 \text{ for } K^+, K^- \\
&= 2.65 \pm 0.20 \text{ for } p, \bar{p} \\
p_{T_1} &= 0.40 \pm 0.15 \text{ GeV} \\
y_2 &= 1.25 \pm 0.15 \text{ for } \pi^+, K^+, p \\
&= 1.35 \pm 0.15 \text{ for } \pi^-, K^-, \bar{p} \\
p_{T_2} &= 0.75 \pm 0.35 \text{ GeV} \\
\text{and} \quad \phi_{12} &= 90 \pm 4^0
\end{aligned}$$

The value of R was obtained by comparing the measured rate (per inelastic proton-proton collision) for pair production to the product of the single particle rates measured independently in the two spectrometers. Luminosity monitoring scintillation counter telescopes were used for normalizing the data. To first order the acceptance, including losses through inefficiencies, decays, interactions and multiple scattering, cancels in the measurement of the correlation R. The value used for σ_{inel} was 35.6 mbarn$^{4)}$. Table I and Fig. 3a and b show the measured value of $R(h_1, h_2)$ for the 36 possible pairs. The data of Fig. 3a and Fig. 3b were obtained separately with Spectrometer 1 accepting positive and negative particles respectively. The errors shown are statistical only; the overall systematic error on the measured quantity R + 1 could be as large as $\sim 20\%$, but the relative values are expected to be free of systematic error.

Typically the values of $R(h_1, h_2)$ indicate a slightly negative correlation between particles produced in these regions of phase-space. A similar negative correlation ($R \sim -0.2$ to -0.4) between π^-, K^- and $\bar{p}$ at $x = 0.4$, $p_T = 0$ and unidentified charged particles (detected in scintillation hodoscopes) at the angle corresponding to our Spectrometer 2 was observed by the CERN-Rome-Pisa-

Stony Brook collaboration$^{5)}$ at $s = 2800$ GeV^2. Earlier the Pisa-Stony Brook$^{6)}$ group measured the correlation between two unidentified charged hadrons at the angles corresponding to our spectrometers ($\eta_1 = 3.7$ and $\eta_2 = 1.25$ where $\eta = -\ln \mathrm{tg}(\theta/2)$) integrated over $0 < \phi_{12} < \pi$, and found $R \simeq -0.2$ at $s = 530$ GeV^2 increasing to $R \simeq +0.05$ at $s = 3850$ GeV^2. These numbers are not necessarily comparable with our results, as no momentum region was selected, but they are nevertheless similar in magnitude.

The general level of R is lower for positive particles in spectrometer 1 (Fig. 3a) than for negative particles (Fig. 3b). This shows that a positive particle detected in spectrometer 1 is accompanied less often by charged particles at large angles in the same polar hemipshere.

The largest correlation we observe is for $\bar{p}_1 p_2$ (subscript 1 refers to the fast forward particle), i.e. the observation of a forward antiproton enhances the probability of observing a proton at large angles. It should be noted that the two particles are observed at $\Delta\phi = 90^0$ where kinematic correlations are expected to be rather weak (no influence of p_T conservation) and for rapidity differences $\Delta y > 1.4$ units. The effective mass of these $\bar{p}p$ pairs is typically 2.5 - 3.5 GeV and no significant dependence of the correlation on the effective mass is observed within this limited range$^{1)}$. Thus, if the positive correlation observed were interpreted as resulting from the production and decay of mesonic clusters, there must exist clusters with masses as high as $\simeq 3.5$ GeV. We note that the reverse correlation $R(p_1, \bar{p}_2)$, where one might also expect baryon number conserving effects, does not deviate from the general level of R. This follows naturally from the notion that most small angle protons are de-energized beam protons which dominate over pair-produced protons.

The next largest correlation is for $K_1^- K_2^+$, showing that the strangeness conserving correlation extends up to $\Delta y \sim 2$. The $K_1^+ K_2^-$ correlation is also significantly above the general level of Fig. 3a. Again no significant dependence of the correlation on the effective mass is observed in the range 2 to 3 GeV$^{1)}$.

It may be noted that rare combinations, e.g. $\bar{p}\bar{p}$ and K^-K^-,do not have especially small values of R. This implies that the production of a pair of baryons or strange particles does not significantly inhibit the production of a further pair.

Some effects of charge conservation can be observed in that the neutral pairs generally (but not always) have a higher value of R than double-charged pairs of otherwise similar nature. This can be seen (table I) in that $R(\pi_1^+\pi_2^-) > R(\pi_1^+\pi_2^+)$ and $R(\pi_1^-\pi_2^+) > R(\pi_1^-\pi_2^-)$.

We find that the value of R for particle pairs with opposite quantum numbers ($\pi^+\pi^-$, K^+K^-, $\bar{p}p$) increases as the production probability decreases.

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TABLE I

Values of the correlation coefficient $R(h_1,h_2)$ as shown in Fig. 3.

Small angle particle (h_1)

Large angle particle (h_2)	π^+	K^-	p	π^-	K^-	$\bar{p}$
π^+	−0.39 ± 0.01	−0.27 ± 0.03	−0.24 ± 0.01	−0.13 ± 0.01	−0.11 ± 0.05	−0.22 ± 0.01
π^-	−0.32 ± 0.01	−0.23 ± 0.03	−0.20 ± 0.01	−0.20 ± 0.01	−0.16 ± 0.04	−0.28 ± 0.05
K^+	−0.36 ± 0.04	−0.28 ± 0.09	−0.25 ± 0.04	−0.18 ± 0.06	+0.50 ± 0.17	−0.21 ± 0.14
K^-	−0.38 ± 0.05	+0.12 ± 0.14	−0.21 ± 0.06	−0.23 ± 0.07	+0.01 ± 0.17	−0.25 ± 0.17
p	−0.30 ± 0.03	−0.17 ± 0.07	−0.37 ± 0.03	0.00 ± 0.05	+0.02 ± 0.10	+0.89 ± 0.18
$\bar{p}$	−0.46 ± 0.05	−0.36 ± 0.10	−0.15 ± 0.07	0.00 ± 0.10	+0.22 ± 0.21	−0.10 ± 0.05

Figure captions

Fig. 1. Sketch of the apparatus (top view) showing Spectrometer 1 (SAS) positioned above the downstream arm of one of the beams, and Spectrometer 2 (WAS) positioned in the plane defined by the two proton beams. S2, BM1, BM2, BM3, and BM_W indicate magnets; C1, C2, C3, $C1_W$ and $C2_W$ indicate gas Cerenkov counters.

Fig. 2. Perspective sketch of the kinematical configuration of the particles h_1 and h_2.

Fig. 3. The value of the correlation coefficient $R(h_1, h_2)$ for the kinematical configuration described in the text. Errors are statistical only. (The first named particle is at small angle, the second at large angle).

a) Positive particles in Spectrometer 1

b) Negative particles in Spectrometer 1.

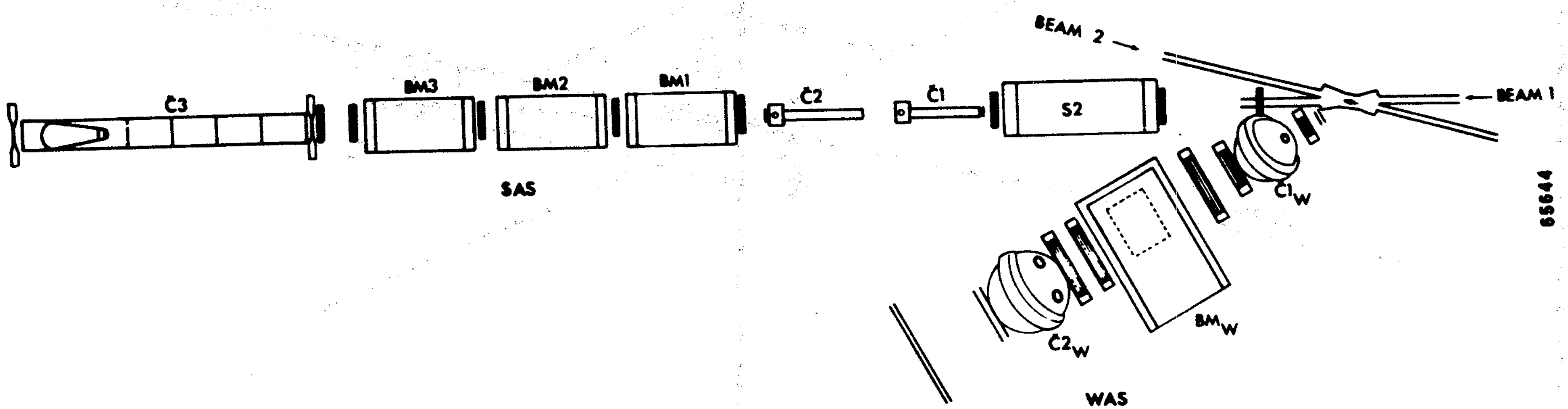

Fig.1

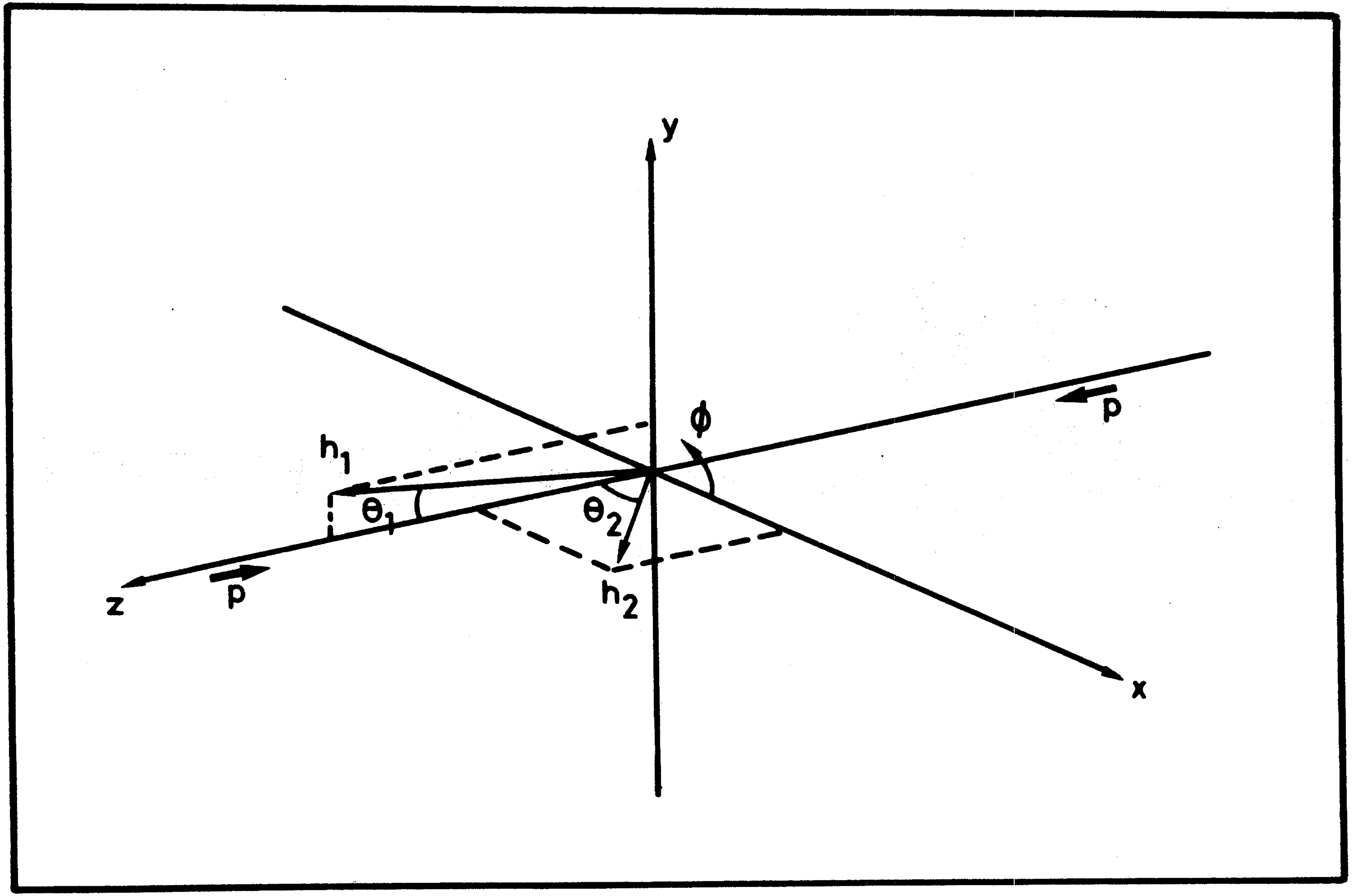

Fig.2

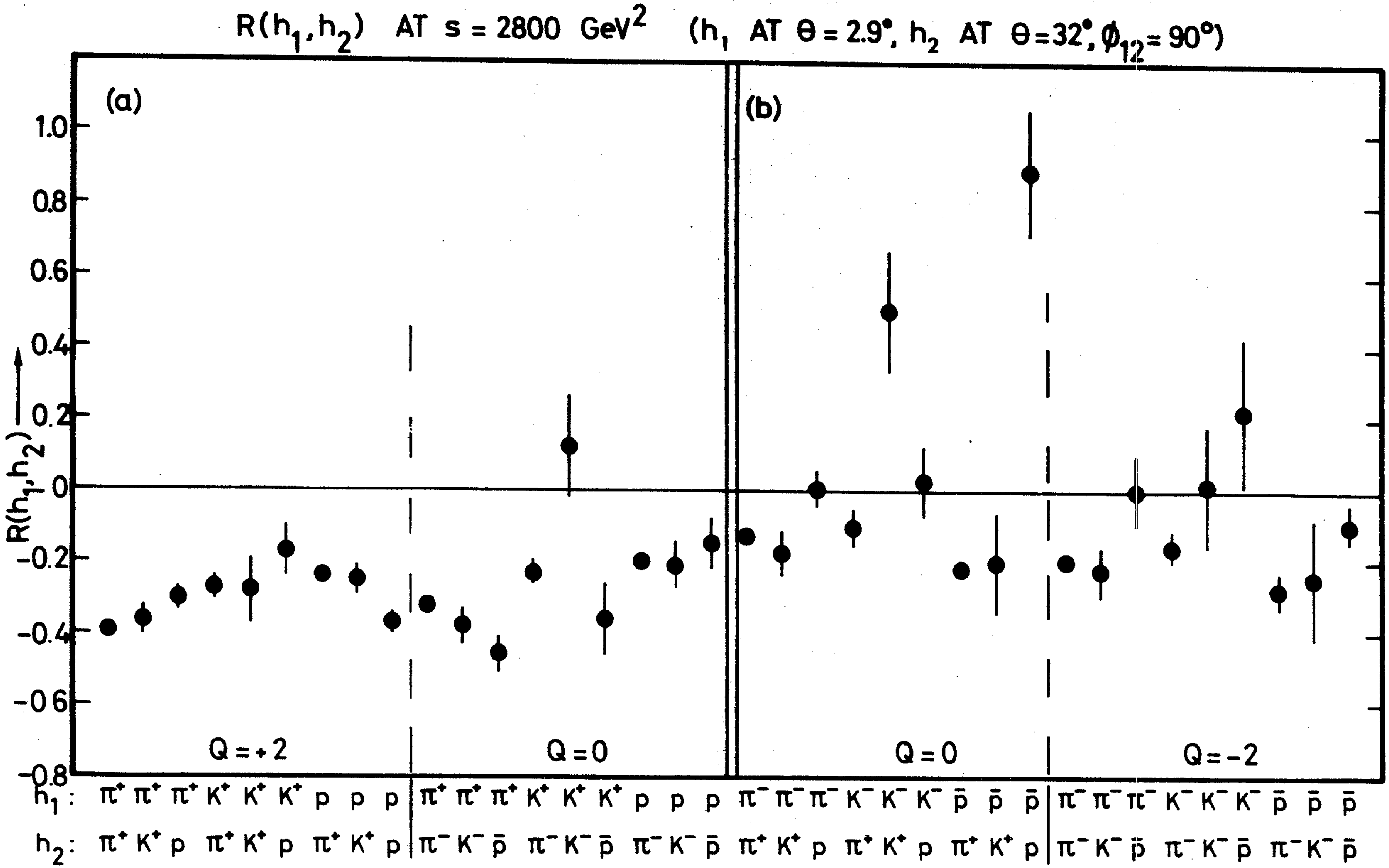
R(h₁,h₂) AT s = 2800 GeV² (h₁ AT θ = 2.9°, h₂ AT θ = 32°, φ₁₂ = 90°)
(a)
(b)
R(h₁,h₂)
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Q = +2
Q = 0
Q = 0
Q = −2
h₁ : π⁺ π⁺ π⁺ K⁺ K⁺ K⁺ p p p | π⁺ π⁺ π⁺ K⁺ K⁺ K⁺ p p p | π⁻ π⁻ π⁻ K⁻ K⁻ K⁻ p̄ p̄ p̄ | π⁻ π⁻ π⁻ K⁻ K⁻ K⁻ p̄ p̄ p̄
h₂ : π⁺ K⁺ p π⁺ K⁺ p π⁺ K⁺ p | π⁻ K⁻ p̄ π⁻ K⁻ p̄ π⁻ K⁻ p̄ | π⁺ K⁺ p π⁺ K⁺ p π⁺ K⁺ p | π⁻ K⁻ p̄ π⁻ K⁻ p̄ π⁻ K⁻ p̄

Fig.3