CORRELATIONS OF HIGH TRANSVERSE MOMENTUM π^0 PAIRS

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PRODUCED AT THE CERN ISR

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ABSTRACT

Correlations of two π^0 mesons with transverse momenta up to 10 GeV/c have been measured utilizing apparatus with large azimuthal acceptance. The data are analysed in the context of constituent scattering models, and also compared with a simple "background" hypothesis.

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1. INTRODUCTION

We report here measurements of the correlations of two high transverse momentum neutral pions, created in proton-proton interactions at the CERN Intersecting Storage Rings (ISR). The emphasis is on the distribution of the relative angle between the two pions in azimuth, measured in a plane perpendicular to the proton directions. A small fraction of these data have been reported in a previous publication [1].

Correlations play a most important part in the current studies of high transverse momentum phenomena. The discovery of single-particle inclusive spectra falling as a power of p_T , instead of exponentially, stimulated a great deal of theoretical work, and by now all theories incorporate the correct inclusive distributions, at least in the range of p_T in which they are well measured. The correlations among high p_T particles may be used to distinguish different theories which have been constructed under the constraint of fitting the inclusive spectra. This point is illustrated by the work of Feynman, Field and Fox [2] who found that such correlation measurements [3] as the average of " p_{out} " allowed them to distinguish between the "black box" and QCD theories, in favour of the latter [4]. This leads us to hope that the present data, with a larger p_T range and more complete azimuthal coverage, will be important in distinguishing QCD and other approaches.

The correlations of two high p_T particles may be presented by several methods. (Figure 1 illustrates the variables used in this paper.) The most direct method utilizes distributions in the azimuthal angle ϕ , for fixed intervals of p_T for the two particles. This is presented in tabular and graphical form in Section 4. For interpretation in terms of constituent scattering models, it is convenient to present the data in terms of other variables, such as distributions in p_{out} and z , the fragmentation or scaling variable. This will be done in Section 5.

All of the above methods of presenting the data are better suited for investigating aspects of the different varieties of constituent scattering models than for determining whether the data indeed suggest that simple scattering of two

constituents is dominant in a certain range of p_T . The constraint of momentum conservation will ensure the presence of the typical collinear peaks in the azimuthal distribution in any theory. In our previous paper [1] we have introduced a technique of analysing the data which reduces this kinematic bias, though it does not eliminate it entirely. This involves classifying the events by E_T , the arithmetic sum of p_T for the different particles. Since we do not measure all particles produced, we use an approximate lower limit for E_T determined from the two detected particles. This analysis is presented in Section 6. It allows us to conclude that the expected constituent scattering effects are prominent in the upper portion of our E_T range, but not in the lower part. The fraction of events lying outside the collinear peaks, in this representation of the data, may reflect processes of greater complexity than elastic scattering of two constituents.

2. EXPERIMENTAL APPARATUS AND TRIGGER

The apparatus, composed of calorimeter modules (octants) is shown in Fig. 2, and has been described elsewhere [5]. We shall omit the description of the proportional wire chambers, scintillator hodoscopes, and transition radiation detectors, that are not used in this analysis, and concentrate on the calorimeter parameters [6] that are especially relevant here.

The liquid-argon calorimeters, with front face 73 cm and 0.16 radiation lengths from the interaction region are more than 17 radiation lengths deep. About 20% of the energy deposit is in the liquid argon. The depth is divided into three sections:

- i) 2.5 radiation lengths of 14 gaps divided into 32 strips, 2 cm wide, measuring essentially the azimuthal coordinate;
- ii) 2.5 radiation lengths of 14 gaps divided into similar strips at $\pm 23^\circ$ to the strips above;
- iii) 12 radiation lengths of 44 gaps of 16 strips, 10 cm wide, measuring essentially the polar angle.

The hardware trigger utilized the division in depth to select events with energy deposits larger than separate thresholds consistent with expected shower

development in each section. The fine strip division inhibited overlaps and yielded azimuthal resolution $\leq \pm 1^\circ$. Energy resolution was found to be $\sigma(E) = \pm 10\%/\sqrt{E} \text{ (GeV)}$.

Each calorimeter covers an azimuthal interval of 45° and the polar angle interval $45^\circ < \theta < 135^\circ$.

The data for this analysis were assembled from the two different configurations shown in Fig. 2. Each configuration also had different requirements on the momentum of the π^0 , owing to different settings of trigger thresholds. We will describe our two set-ups as experiment A, which was run during 1977, and experiment B, in 1978.

The integrated luminosities for experiments A and B are $0.9 \times 10^{37} \text{ cm}^{-2}$ and $1.5 \times 10^{37} \text{ cm}^{-2}$, respectively. The data for experiment A come from runs evenly divided between $\sqrt{s} = 52, 62 \text{ GeV}$, while 90% of experiment B was run at the higher energy.

The trigger of experiment A required that a minimum local energy deposit be exceeded in two different calorimeters. Because of the low trigger efficiency, in the analysis of this experiment we impose a requirement of 1.2 GeV on each calorimeter.

The experiment B trigger was based on a large energy deposit in a single calorimeter. This trigger efficiency was found to be an approximately uniform 95% for the events used, with π^0 momenta greater than 7 GeV/c. In the present analysis the event was required to have a second π^0 with $p_{\pi^0} > 0.5 \text{ GeV/c}$ in a different calorimeter from the one providing the trigger. This ensured adequately low hadron background and high reconstruction efficiency.

In addition to tests in an electron beam at the CERN PS, the installation of both triggers during the running of experiment A allowed us to calibrate one trigger with another. The efficiency for photon showers in experiment A was studied using untriggered calorimeters satisfying experiment B levels in another calorimeter. The average efficiency for showers of a given energy is shown in Fig. 3. The experiment B shower efficiency was established by using events satisfying experiment A thresholds.

3. ACCEPTANCE AND EMPIRICAL VARIABLES

A " π^0 " was defined for these experiments as follows: when the effective mass of two resolved showers was within 2 standard deviations of the π^0 mass, the π^0 direction and momentum were determined from both showers. If only one shower was found, or if the above criterion was not met, each shower was taken as a π^0 . Above $p = 5$ GeV/c essentially all π^0 's appeared as single showers. While the general trends of our data remain invariant to all reasonable variations of this definition, absolute cross-sections vary by $\sim \pm 20\%$.

Ignoring the small required rapidity of the π^0 's, our data may be described by three variables: p_1 , p_2 , the transverse momenta of the π^0 's in an event ($p_1 \geq p_2$), and ϕ , the azimuthal difference between π^0 's.

The azimuthal acceptance of the apparatus in the centre of mass in its two configurations is shown in Fig. 4, after fiducial cuts. The small ϕ region (less than 20° for experiment B, 30° for experiment A) cannot be explored by these experiments, since the triggers and/or software cuts require π^0 's in different octants, and fiducial cuts eliminate events near the edge of the calorimeter. In addition, experiment B has poor acceptance in the region with angles in the range $110^\circ > \phi > 60^\circ$, but instead has larger acceptance by a factor ~ 2.5 at $\phi \approx 180^\circ$.

We have required the rapidity of each π^0 to be $|y| < 0.8$, within which interval acceptance is essentially uniform. Except as noted, all plots shown have been corrected for azimuthal and trigger and software acceptance.

In Table 1 we note, for example, an efficiency of $\sim 2\%$ for $p_1 = 3.0$, $p_2 = 1.2$ GeV/c. This efficiency results from the factors: {geometry $\approx 20\%$ } $\times$ {trigger and software $\approx 10\%$ }. Efficiencies for events with $p_1 > 7$ GeV/c, which come from experiment B, are primarily geometrical in origin.

4. AZIMUTHAL SPECTRA

One method of displaying our data, emphasizing the substantial azimuthal coverage of our apparatus, is to present the distribution in the azimuthal separation ϕ of the two detected π^0 's, for various values of the π^0 momenta. We have segmented the momenta into 1 GeV/c intervals except at the lowest momentum, where

p_2 must be larger than 1.2 GeV/c for experiment A and larger than 0.5 GeV/c for experiment B. In Fig. 5 we show selected distributions corrected for geometrical, trigger, and reconstruction efficiencies, for intervals starting at $p_1 = 4, 6,$ and 8 GeV/c.

Most striking in these distributions is the tendency for the two π^0 's to emerge nearly collinear in azimuth. This tendency, which is much less striking in the polar angle, is enhanced as the momenta increase. It is expected in a general way by all constituent scattering models with an underlying two-body interaction and fragmentation.

We define the angle α as the deviation from azimuthal collinearity, $\alpha = 180^\circ - \phi$. In Table 1 and Fig. 6 we give the r.m.s. deviation $\sqrt{\langle \alpha^2 \rangle}$ for events with $\phi > 110^\circ$, where both experiments A and B have good acceptance. With the exception of the lowest momenta, $\sqrt{\langle \alpha^2 \rangle}$ is always less than 25° , and it seems to converge to a fixed value of $\sim 13^\circ$ contrary to earlier suppositions based on constituent scattering models that it would continue to decrease. It is noteworthy that $\sqrt{\langle \alpha^2 \rangle}$ has reached its limiting value when p_2 is only about one-half of p_1 , allowing one to suppose that the effect is not due to kinematic constraints at the "boundary" configuration $p_1 = p_2$ (see discussion of Section 5).

The quantity r_T (ratio of the corrected number of events in the interval $70^\circ < \phi < 110^\circ$ to events with $\phi > 110^\circ$) provides an estimate of the fraction of these events uniformly distributed in azimuth. It has already been pointed out that there is a kinematic bias against these events in this parametrization of the data, owing to momentum conservation. In any case these data (Table 2) should provide important tests for QCD and three-jet models [7]. The distribution of Fig. 7 shows that for a given p_1 , r_T falls as $p^{- (2.7 \pm 0.15)}$, showing that the contribution of the uniform part of the distribution decreases for high momentum trigger particles. (See, however, the discussion in Section 6).

5. ANALYSIS WITH THE CONSTITUENT SCATTERING MODEL

The high transverse momentum particles are assumed to arise from the hard scattering of the constituents of the proton, quarks, and gluons. We consider

the underlying interaction to be two-body constituent scattering at polar angles near 90° , and take the highest momentum π^0 to be an estimator of the direction of one of the scattered constituents, with its momentum p_1 estimating the momentum of both constituents. This would not be a satisfactory approximation for the general case of constituent fragmentation, but it is reasonable in this case because our trigger on the high momentum π^0 produces a "trigger bias" [8] selection of those fragmentations with a single leading π^0 . The second π^0 could be a fragment of either of the constituents participating in a two-body scattering, and is expected to be found in configurations "towards" ($\phi \approx 0$) or "away from" the first π^0 . A configuration at $\phi \approx 90^\circ$ may signal the importance of higher order effects, such as the emission of more than two constituents.

We define the variable $p_{out} = p_2 \sin \phi$ and the fragmentation function $z = (p_2/p_1) \cos \phi$. In this model p_{out} is the component of hadron momentum perpendicular to the scattering plane, and z (sometimes denoted by x_E in the literature) is the fractional longitudinal component of the hadron momentum with respect to the constituent momentum. The distribution of p_{out} provides information on the transverse momentum of the incoming constituents, presumably due to their confinement, and the mechanism of fragmentation of the outgoing constituents. According to recent ideas in QCD, it will be greatly affected by the radiation of gluons. Scaling in the z variable reflects the idea that the fragmentation should be independent of the momentum of the outgoing constituent.

In Table 3 we have tabulated the r.m.s. value $\sqrt{\langle p_{out}^2 \rangle}$ for intervals in p_1 and z , while Fig. 8 illustrates the p_{out} distributions for selected momenta. We note that these distributions will be influenced by kinematic constraints near $z = 1$ by our definition of these variables, since $p_{out} = \sqrt{p_2^2 - z^2 p_1^2} < p_1 \sqrt{1 - z^2}$. For this reason, the Gaussian fits to these distributions, shown in Fig. 8, utilize data not near this boundary. The r.m.s. average of p_{out} , $\sqrt{\langle p_{out}^2 \rangle}$, has been computed for different intervals in z and p_1 . These are plotted in Fig. 9, for a selected set of points to avoid confusion. As noted in other experiments involving charged-particle data [9], for large p_1 , $\sqrt{\langle p_{out}^2 \rangle}$ grows with z . This is

related to the approach of $\sqrt{\langle \alpha^2 \rangle}$ to a constant value, as seen in Fig. 6. Note that the $\sqrt{\langle p_{out}^2 \rangle}$ for large z includes values affected by the kinematic condition mentioned above, requiring $p_{out} \approx 0$ at $z = 1$. This leads to the peculiar behaviour of the points in Fig. 9 for large z . For this reason, the presentation of the data in terms of the angle average $\sqrt{\langle \alpha^2 \rangle}$ seems to be more useful.

We have studied the z -scaling distributions for the two π^0 's in the range $4 < p_1 < 10$ GeV/c. Since experiment A requires $p_2 > 1.2$ GeV/c we have a complete sample of such events only for $z > 0.3$. We have therefore normalized the number of events in the various z intervals by the number with $z > 0.3$. The data are displayed in Fig. 10 and it is clear that the scaling hypothesis is well satisfied, except perhaps for some p_T dependence in the largest z interval. Experiments at considerably lower transverse momentum [10] have already indicated that the distribution in fractional momentum z is independent of p_1 except for low z , but in this experiment the larger range of transverse momentum allows a much better test of the scaling hypothesis.

If we consider experiment B only, we can study z distributions for the less restrictive interval $z > 0.1$. Figure 11 displays these data for $p_1 > 7$ GeV/c.

At lower momenta, a roughly exponential fall off has been observed. Here there is a pronounced tendency to flatten at large z , and for the largest p_1 a peak may even develop at $z = 1$. The observed distributions in z result from a convolution of the true fragmentation function from the events where the quark momentum is larger than p_1 . This effect has been shown [11] to produce a flattening of the observed distribution. The possible peak at $z = 1$ could signal the presence of the process where both jets fragment into single π^0 's.

6. TRANSVERSE ENERGY ANALYSIS

In the introduction we have warned that the azimuthal correlations are powerfully affected by kinematic constraints. Once the first π^0 has been selected with a large p_T , there must exist other particles with net transverse momentum opposite to the first. If the second π^0 we observe is at a wide angle to these, it represents an "extra" production of transverse momentum which seems likely to

make the event less probable. Thus it is hardly surprising that azimuthal distributions peak at $\phi \approx 180^\circ$ and that the quantity r_T , measuring the production of wide angle π^0 's, falls rapidly with increasing p_T .

In an attempt to separate what one expects from constituent scattering models and what is expected by kinematical considerations alone, we have constructed [1] a simple kinematical three-body model. We introduce the total transverse energy in the system, approximated by $E_T = p_1 + p_2 + |\vec{p}_1 + \vec{p}_2|$, the energy of the two π^0 's and of a third, momentum balancing, unseen particle. Masses are neglected. For simplicity, we assume that the relative probability that the three particles appear in a particular configuration (then specified completely by the two transverse momenta and E_T) is governed by the invariant three-body density of states factor, yielding a uniform population on a "Dalitz plot" in the variables p_1 and p_2 .

It is clear that a uniform distribution on such a plot, combined with a cross-section falling with transverse energy, implies a tendency toward the back-to-back configurations we have seen in Fig. 5. Consider the case $p_1 = p_2 = 4$ GeV at $\phi = 180^\circ$. These events have $E_T = 8$ GeV since $\vec{p}_1 + \vec{p}_2 = 0$, but at $\phi = 120^\circ$ they will have $E_T = 12$ GeV (see Fig. 12). Then, as cross-sections decrease rapidly with E_T , the number of events at 120° decreases compared with those at 180° . Our three-body model thus can imitate to some degree the observed azimuthal spectra, and so must be examined in more detail.

To compare the data more closely with the model, we have grouped our data in transverse energy and constructed "Dalitz plots". Such plots are shown in Fig. 13 in terms of the normalized variable $u_{1,2} = 2p_{1,2}/E_T$, where we compare our 130 events sample in the highest E_T range (16-18 GeV) with partial samples consisting of the same number of events at E_T very close to 6 and 10 GeV. The events in these plots are not corrected for acceptance, but the acceptance is indicated by contour curves. The trends are strikingly clear*). At low transverse energy, compared to the model, π^0 's prefer to emerge at small ϕ , with an additional, approximately uniform

*) If we accept only events in which the missing transverse momentum is in the same rapidity range as the detected π^0 's (80% of our original sample), the features of the Dalitz plots and their projections are not significantly altered.

background. However, at the highest E_T , the π^0 's are almost totally aligned. We suppose that this technique reveals the assumed underlying hard scattering structure emerging from a more complex background as E_T is raised.

To further illustrate the importance of choice of variable in understanding the data, we show in Fig. 14 acceptance-corrected azimuthal distributions corresponding to the above plots, and in Fig. 15 the previously defined quantity r_T , now as a function of E_T . Viewed in this way, the data indicate the clear emergence of underlying two-body structures over background only for $E_T \gtrsim 10$ GeV ($p_T \gtrsim 5$ GeV/c).

7. CONCLUSIONS

The high centre-of-mass energy of the ISR, the high luminosity, and the good duty factor, have allowed us to measure the two π^0 correlations over a very wide range of transverse momenta, with an apparatus which spanned essentially the full range of azimuthal angles. This allowed us to see several features of the underlying hard-scattering processes in a more convincing manner than has been possible before.

- i) Back-to-back peaks are seen in the azimuthal correlations for all transverse momenta. The widths of these peaks do not continue to fall as p_T increases, but rather approach a constant, with a concomitant rise in $\sqrt{\langle p_{out}^2 \rangle}$. This is in qualitative accordance with the QCD picture, where radiated gluons maintain the angular width of the peak.
- ii) The scaling property of the fragmentation distribution in z has been investigated over a much wider range than in previous experiments, and the scaling concept appears valid to $\sim 20\%$ over many orders of magnitude in cross-section.
- iii) By selecting events on the basis of total transverse energy as given by a simple approximation, it seems possible to see the hard-scattering process emerging from the background as E_T is raised.

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Table 1

Tabulation of the number of $2\pi^0$ events found within the p_1, p_2 intervals specified for $\alpha < 70^\circ$, including the number corrected for geometrical and trigger efficiencies. Events below (above) $p_1 = 7$ GeV/c are derived from experiment A (B). Also listed for each momentum is the r.m.s. deviation from coplanarity $\sqrt{\langle \alpha^2 \rangle}$. Intervals containing fewer than 20 events are omitted.

p_1 (GeV/c)	p_2 (GeV/c)	No. of events in sample	Corrected No. of events	$\sqrt{\langle \alpha^2 \rangle}$
3-4	1.2-2.0	18,000	940,000	34.0 ± 0.2
	2.0-3.0	12,900	390,000	30.0 ± 0.2
4-5	1.2-2.0	4,460	210,000	30.0 ± 0.3
	2.0-3.0	3,380	90,000	26.0 ± 0.3
	3.0-4.0	1,140	21,400	19.0 ± 0.4
5-6	1.2-2.0	1,220	48,000	26.0 ± 0.5
	2.0-3.0	961	21,600	22.0 ± 0.5
	3.0-4.0	378	5,880	18.0 ± 0.5
	4.0-5.0	140	1,800	17.0 ± 1.0
6-7	1.2-2.0	325	12,500	28.0 ± 1.1
	2.0-3.0	291	5,940	23.0 ± 1.0
	3.0-4.0	109	1,600	16.0 ± 1.1
	4.0-5.0	48	570	14.0 ± 1.4
	5.0-6.0	28	290	14.0 ± 1.9
7-8	0.5-1.0	2,780	12,240	31.0 ± 0.4
	1.0-2.0	1,850	7,420	24.0 ± 0.4
	2.0-3.0	474	1,810	21.0 ± 0.7
	3.0-4.0	186	680	17.0 ± 0.9
	4.0-5.0	89	320	14.0 ± 1.0
	5.0-6.0	18	64	12.0 ± 2.0
	6.0-7.0	21	75	15.0 ± 2.3
8-9	0.5-1.0	824	3,630	30.0 ± 0.7
	1.0-2.0	539	2,150	23.0 ± 0.7
	2.0-3.0	187	700	17.0 ± 0.9
	3.0-4.0	52	190	14.0 ± 1.4
	4.0-5.0	26	94	13.0 ± 1.8
9-10	0.5-1.0	267	1,110	26.0 ± 1.1
	1.0-2.0	183	720	24.0 ± 1.2
	2.0-3.0	65	240	17.0 ± 1.5
10-11	0.5-1.0	104	420	29.0 ± 2.0
	1.0-2.0	42	170	33.0 ± 3.6
11-12	0.5-1.0	39	160	26.0 ± 3.6

Table 2

The ratio of r_T of $2\pi^0$ events where $70^\circ < \alpha < 110^\circ$ to events where $\alpha < 70^\circ$ in the p_1, p_2 intervals specified. Only intervals where the numerator is non-zero are listed.

p_2 (GeV/c)	p_1 (GeV/c)	r_T
1.2-2	3-4	0.255 ± 0.005
	4-5	0.120 ± 0.010
	5-6	0.080 ± 0.011
	6-7	0.041 ± 0.015
2-3	3-4	0.105 ± 0.005
	4-5	0.054 ± 0.006
	5-6	0.027 ± 0.008
	6-7	0.023 ± 0.014
3-4	4-5	0.007 ± 0.004
	5-6	0.004 ± 0.003

Table 3

Tabulation of the numbers of events in the momentum and z intervals listed where $z = p_2 \cos \alpha / p_1$ and $\alpha < 70^\circ$. Also noted for each interval are values of $\sqrt{\langle p_{out}^2 \rangle}$ where $p_{out} = p_2 \sin \alpha$. Only intervals with 20 events or more are listed.

P_1 (GeV/c)	Corrected No. of events for $z > 0.3$	z interval	No. of events in sample	Corrected No. of events	$\sqrt{\langle p_{out}^2 \rangle}$ (GeV/c)
3-4	-	0.4-0.6	13,730	560,000	0.836 ± 0.001
		0.6-0.8	7,220	214,000	0.874 ± 0.007
		0.8-1.0	2,810	71,000	0.781 ± 0.010
4-5	226,000	0.4-0.6	3,200	93,000	0.790 ± 0.010
		0.6-0.8	1,360	26,000	0.890 ± 0.017
		0.8-1.0	444	7,400	0.816 ± 0.027
5-6	43,900	0.4-0.6	783	16,000	0.768 ± 0.019
		0.6-0.8	273	4,020	0.870 ± 0.037
		0.8-1.0	80	940	0.948 ± 0.075
6-7	7,750	0.2-0.4	465	13,200	0.661 ± 0.022
		0.4-0.6	163	2,720	0.738 ± 0.041
		0.6-0.8	55	670	0.986 ± 0.092
		0.8-1.0	26	270	1.125 ± 0.156
7-8	2,150	0.2-0.4	987	3,410	0.693 ± 0.0155
		0.4-0.6	216	780	0.882 ± 0.0424
		0.6-0.8	59	210	1.119 ± 0.1030
		0.8-1.0	25	85	1.190 ± 0.168
8-9	540	0.2-0.4	284	1,040	0.603 ± 0.025
		0.4-0.6	53	190	1.036 ± 0.101
9-10	170	0.2-0.4	81	290	0.634 ± 0.050
		0.4-0.6	20	70	0.915 ± 0.0145
10-11	-	0.2-0.4	25	90	0.590 ± 0.084

Figure captions

- Fig. 1 : Illustration of the definition of the quantities p_1 , p_2 , ϕ , p_{out} , z .
- Fig. 2 : Vertical section of the apparatus transverse to the proton beam with the four "octants": a) in the configuration of experiment A; b) in the configuration of experiment B. See text for full description of each experiment.
- Fig. 3 : Single-shower trigger efficiency for experiment A averaged over incident angles as a function of shower energy.
- Fig. 4 : Geometrical efficiency of the apparatus as a function of azimuthal separation ϕ between the two π^0 's for: a) experiment A; b) experiment B. In weighting the events a smoothed distribution was used. Only π^0 's with rapidities $|y| < 0.8$ are accepted.
- Fig. 5 : Corrected distributions of the azimuthal difference between the $2\pi^0$'s for selected intervals of momenta p_1 and p_2 . Shaded regions are excluded.
- Fig. 6 : The r.m.s. deviation from coplanarity $\sqrt{\langle \alpha^2 \rangle}$ as a function of p_2 for selected intervals of p_1 .
- Fig. 7 : The ratio r_T (No. of events with $70^\circ < \phi < 110^\circ$ to events with $\phi > 110^\circ$) versus p_1 , for selected intervals of p_2 .
- Fig. 8 : The distribution of events in the quantity p_{out} for selected p_1 and z intervals. Gaussian fits to the data in regions removed from the $p_{out} - z$ boundary are indicated. They correspond to the following values of the r.m.s. widths:
$3 < p_1 < 4$, $0.4 < z < 0.6$:	$\sigma = 816 \pm 4 \text{ MeV/c}$;
$0.6 < z < 0.8$:	$\sigma = 922 \pm 7 \text{ MeV/c}$;
$5 < p_1 < 6$, $0.4 < z < 0.6$:	$\sigma = 716 \pm 17 \text{ MeV/c}$;
$0.6 < z < 0.8$:	$\sigma = 827 \pm 36 \text{ MeV/c}$;
$7 < p_1 < 8$, $0.2 < z < 0.4$:	$\sigma = 562 \pm 12 \text{ MeV/c}$;
$0.4 < z < 0.6$:	$\sigma = 798 \pm 39 \text{ MeV/c}$;
$0.6 < z < 0.8$:	$\sigma = 988 \pm 125 \text{ MeV/c}$.

- Fig. 9 : The r.m.s. value $\sqrt{\langle p_{\text{out}}^2 \rangle}$ as a function of p_1 and z for selected momenta. Curves are only given to guide the eye.
- Fig. 10 : Normalized number of events in a z interval specified as a function of p_1 , illustrating z scaling.
- Fig. 11 : Distribution in z of events with selected values of p_1 .
- Fig. 12 : Illustrating definition of transverse energy E_T for two events with $p_1 = p_2 = 4$ GeV/c, but a) $\phi = 180^\circ$, b) $\phi = 120^\circ$.
- Fig. 13 : Normalized, symmetrized diplots with horizontal and vertical coordinates $u_i = 2p_i/E_T$ for each π^0 . The events are not weighted for acceptance, but isoacceptance curves are shown. The striped regions indicate excluded regions with $p_T < 1.2$ GeV/c. Also excluded (by the requirement $\phi > 30^\circ$) is a small region close to the diagonal boundary. The plots include 130 events: a) at E_T near 6 GeV; b) the same number for 10 GeV; c) those in the range $16 < E_T < 18$ GeV.
- Fig. 14 : Distributions in azimuthal difference ϕ of two π^0 's with selected transverse energies.
- Fig. 15 : The ratio r_T (see Fig. 7) as a function of E_T .

PLANE PERPENDICULAR TO P-P COLLISION

$$z = P_2 \cos \alpha / P_1$$

fig. 1

1978 CONFIGURATION "B"

1977 CONFIGURATION "A"

fig.2

fig. 3

fig. 4

fig. 5

fig. 6

fig.7

fig. 8

fig. 9

fig.10

fig. 11

fig. 12

fig.13a

fig.13b

fig.13c

fig. 14

fig.15