OBSERVED DIFFERENCE IN THE STRUCTURE OF EVENTS WITH
A HIGH p_T π^0 OR SINGLE PHOTON

C. Kourkouvelis and L.K. Resvanis
Athens University, Athens, Greece

T.A. Filippas and E. Fokitis
National Technical University, Athens, Greece

A.M. Cnops, S. Iwata, R.B. Palmer, D.C. Rahm, P. Rehak and I. Stumer
Brookhaven National Laboratory, Upton, NY, USA¹⁾

C.W. Fabjan, D. Lissauer²⁾, I. Mannelli³⁾,
P. Mouzourakis⁴⁾ and W.J. Willis
CERN, Geneva, Switzerland

ABSTRACT

The rapidity correlation (Δy) and the azimuthal correlation ($\Delta\phi$) between a π^0 or single photon trigger particle and an additional charged particle or π^0 were measured at the CERN Intersecting Storage Rings. It is observed that same-side correlations depend on the nature of the trigger particle, the differences appearing mainly at small Δy and $\Delta\phi$. This effect becomes more pronounced when the p_T of the second π^0 is increased. The results are consistent with the hypothesis that π^0 events have additional associated particles, while single photons have significantly fewer, if any, additional associated particles.

(Submitted to Nuclear Physics B)

-
- 1) Research supported under the auspices of the US Department of Energy.
 - 2) Permanent address: Tel-Aviv University, Israel.
 - 3) On leave of absence from University of Pisa and INFN, Sezione di Pisa, Italy.
 - 4) Present address: LAL Orsay, Université de Paris-Sud, France.

The possibility of using direct photon production to probe the constituent structure of hadrons has been investigated by many authors [1-8]. The recent observations of a direct single photon signal [9-11] and of differences in the event structure of π^0 and single photon events have been reported by this collaboration [12]. According to present theoretical views, direct photons are produced in proton-proton interactions predominantly via the sub-process $qg \rightarrow \gamma q$ with important contributions also coming from the $qq \rightarrow qq\gamma$ process [7,8], where the photon is radiated in a bremsstrahlung process from the scattered quark. In pp collisions the contribution from $q\bar{q}$ annihilation into a photon and a gluon is expected to be small in the high p_T small X_{Feynman} region covered by this experiment. The production of high p_T mesons, on the other hand, is thought to proceed via the hard scattering of the proton constituents (quarks, gluons and antiquarks) and their subsequent fragmentation. The high p_T mesons are expected to be the leading particles of the "jets" produced by the scattered constituents. The different production mechanisms for high p_T mesons and single photons are thus likely to be reflected in the event structure associated with each particle.

In a previous letter [12] we showed that π^0 and single photon event structures differ in the azimuthal correlation of charged tracks with the trigger particle. In that study no measurement of the charged track energy or rapidity was available. In this paper we report on the correlation both in rapidity and azimuth between the trigger particle and an additional neutral pion of known energy and direction as well as charged particles of which the direction, but not the energy, is known. In the present study a different experimental configuration from that of the previous single photon work was used. In particular it is shown that the correlations in the rapidity variable (Δy) and the azimuthal angle ($\Delta\phi$) defined between a π^0 or single photon trigger particle and an additional charged track or π^0 depend on the nature of the trigger particle. For both variables the probability of finding an additional associated π^0 or charged track is significantly larger for π^0 triggered events than for single photon events. The observed differences appearing in the same-side correlations increase with decreasing Δy or $\Delta\phi$. In addition the observed effect is enhanced when the p_T of the second π^0 is increased.

The apparatus (fig. 1) consisted of four identical modules each covering a solid angle of approximately 1 sr, 50° - 130° in polar angle and 40° in azimuth. The energies and positions of the electromagnetic showers were measured in a segmented lead liquid-argon calorimeter. The calorimeters were 17.7 radiation lengths in total thickness. Both longitudinal and radial shower developments were measured, enabling one to separate electromagnetic from hadronic showers. The energy resolution obtained can be parametrized as $\sigma(E)/E = 10\%/\sqrt{E}$, where E is the shower energy in GeV. The spatial position information for charged tracks was obtained from two layers of cylindrical multiwire proportional chambers placed immediately outside the ISR vacuum chamber, a set of two proportional chambers placed immediately outside the ISR vacuum chamber, a set of two proportional Xe-CO₂ wire chambers which followed the lithium radiators (used for electron identification), and the set of scintillation counters each covering 6° in ϕ . Each proportional chamber had two-dimensional read-outs. A charged track was defined by a straight line fit to the points in space given by the chambers and counters. In the absence of a magnetic field, only the direction, but not the sign of the charge or the momentum of the particle, could be measured. A more detailed description of the apparatus is given elsewhere [13].

The trigger requirement for these data was a large energy deposition in any one of the liquid-argon calorimeters ($E \geq 6$ GeV). The trigger efficiency was calculated and found to be rising rapidly from 5 to 7 GeV/c, where it reached a constant value of more than 95% [13]. Inclusive measurement of high p_T π^0 's using the present set-up have been reported elsewhere [14]. In this configuration the calorimeters were placed at a distance of 86 cm from the intersection point, giving a separation of showers with opening angles of 3° or more. The separation of single photon events from π^0 events is more difficult in this configuration than in the retracted configuration used to measure the γ/π ratio [11]. At this calorimeter position 70% of the π^0 's above 7 GeV/c in p_T are not resolved into two separate showers, but are reconstructed as a single shower. It is, however, still possible to select a sample significantly enhanced in single photon events.

To investigate possible differences between π^0 's and single photon events, the data were separated into samples containing a π^0 or single photon candidate. The trigger particle was required to have a $p_T \geq 6.5$ GeV/c. In order to remove background in the single photon candidate sample from π^0 's and other meson decays where only one shower was reconstructed, a cut was imposed requiring that all the energy deposited in the calorimeter be assigned to the trigger particle [11]. This cut introduced a physics bias in the sample, since it had the effect of vetoing events which have additional particles in the solid angle covered by the calorimeter (≈ 1 sr). By imposing the same requirement on both the π^0 and single photon events one would not create a difference if none actually existed; however, the magnitude of the difference could be affected by this cut. This selection applies only to the trigger octant and is not imposed on the others. To remove π^0 events with overlapping showers which reconstruct as a single shower, we required that the lateral shower size [11] be less than 13.5 mm. From EGS [15] Monte Carlo studies, this cut was found to remove about 75% of all merged π^0 in the interval 7-10 GeV p_T .

To investigate the event structure the following variables were used: for π^0 's where both energy and direction are known the rapidity in the centre of mass defined by

$$y = -0.5 \ln \left(\frac{E - p_L}{E + p_L} \right),$$

while for charged tracks the pseudorapidity in the ISR frame, $y = -\ln (\tan \theta/2)$, is used. In the small y region covered by this experiment the two definitions are essentially the same. The azimuthal angle ϕ is defined in the transverse plane perpendicular to the incident proton beams in the over-all centre of mass.

Figures 2a and 2b show, for π^0 and single photon events, the normalized distribution of the difference in the pseudorapidity variable (Δy) defined between the trigger particle and a second charged track on the same side. The distribution is restricted to particles with azimuthal angular difference $20^\circ < \Delta\phi < 70^\circ$, by the acceptance of our apparatus. The solid line represents the expected Δy

distribution for uncorrelated tracks calculated assuming a flat y distribution for the randomly produced particle and our experimental acceptance of $-0.7 \leq y \leq 0.7$. The curve is normalized to the number of events with $|\Delta y| > 0.6$, where most tracks are expected to be uncorrelated [16], but the results are insensitive to any reasonable choice of the limit of Δy . A clear excess is observed for the π^0 events over that expected from the uncorrelated background in the small Δy region. A much smaller excess is observed for the single photon candidates sample when normalized in a similar way.

The expected level of background in the single photon candidates sample can be obtained by using a Monte Carlo to simulate known sources of background such as merged π^0 , wide angle η decays, etc. This can be normalized to the number of π^0 's to obtain the fraction of single photons in the sample (see ref. 11). The background calculated in the single photon sample is 42%. This background consists mostly of merged π^0 events and is therefore expected to behave like the π^0 events sample. Subtracting the background contribution from the distribution of the single photon candidate sample shown in fig. 2b, we obtain the expected distribution for clean single photon events (fig. 2c). In this Δy distribution no excess over that of the uncorrelated background can be seen.

Figures 2d and e show the rapidity difference between the trigger particle (π^0 or γ) and a π^0 in another module.

Figure 2f shows the distribution for the direct photon sample calculated in a manner analogous to that in fig. 2c. An effect similar to that observed for the charged particles is seen here. In figs. 2g, h and i the same plots are shown with the additional requirement that the second π^0 has a transverse momentum greater than 0.5 GeV/c. The correlation effect is seen to increase with this selection, indicating that a larger fraction of the high p_T tracks are associated with the trigger particles. A lack of correlation with single photon events is also observed here (fig. 2i).

Figure 3 shows the azimuthal difference between the trigger particle and a second π^0 . The regions $0 \leq \Delta\phi \leq 20^\circ$ and $70^\circ \leq \Delta\phi \leq 110^\circ$ were removed because of

the poor acceptance in those regions [17]. In fig. 3a the second shower is restricted to have a p_T less than 0.5 GeV. One observes that on the same side there is a significant difference between the two samples, with the magnitude of the difference increasing with decreasing $\Delta\phi$. On the away side ($\Delta\phi > 90^\circ$) there is no significant difference between events with a π^0 or single photon trigger. In fig. 3b we show the same distribution for events with a second π^0 having $p_T \geq 0.5$ GeV. The fraction of events on the same side relative to the away side has decreased significantly and the away-side distribution is now peaked closer to 180° . The relative difference on the same side between the single photon events and π^0 's has increased, however.

An interesting quantity is the ratio R , the probability of finding a second π^0 at a given p_T (PT2) and a given $\Delta\phi$, for the single photon triggered events over the probability for the π^0 triggered events. In fig. 4 the ratio R is shown as a function of PT2 for the following $\Delta\phi$ regions: a) $20-45^\circ$; b) $45-70^\circ$; c) $110-145^\circ$, and d) $145-180^\circ$. The ratio R decreases with increasing PT2 for the same-side $\Delta\phi$ region. No significant difference is observed in the away side. Again, the estimated 35% of π^0 's in the single photon sample could explain all the excess of correlated particles in the small $\Delta\phi$ region, and the same-side high PT2 particles of the single photon candidates sample, as well as the excess of particles with small Δy .

No significant difference in the away-side multiplicity or distribution between the two samples of events can be observed. In a previous study [12], using a much larger rapidity coverage on the away side ($y = \pm 2.25$), a small difference in the away-side multiplicity was observed. Away-side rapidity correlations have been observed to be extended over a Δy of 2 units in rapidity [15]. The difference in rapidity acceptance and selection criteria might explain this difference.

In conclusion, we observe that the single photon events have considerably lower numbers of associated charged tracks as well as π^0 particles on the trigger side. Most of the difference is concentrated in the small $\Delta\phi$ and Δy region, where the accompanying particles of the same "jet" are expected to be found. The relative

magnitude of the effect is increased with increasing transverse momentum of the second particle. These observations are consistent with the hypothesis that high p_T single photons produced in pp collisions are unaccompanied, while high p_T π^0 's are part of a "jet" of particles.

REFERENCES

- [1] G.R. Farrar and S.C. Frautschi, Phys. Rev. Lett. 36 (1976) 1017.
- [2] C.O. Escobar, Nucl. Phys. B98 (1975) 173.
- [3] E.L. Feinberg, Nuovo Cimento 34A (1976) 391.
- [4] H. Fritzsch and P. Minkowski, Phys. Lett. 69B (1977) 316.
- [5] R. Rückl, S.J. Brodsky and J.F. Gunion, Phys. Rev. D18 (1979) 2469.
- [6] R.D. Field, Proc. 19th Int. Conf. on High-Energy Physics, Tokyo, 1978 (Phys. Soc. Japan, Tokyo, 1979), p. 743.
- [7] A.P. Contogouris, S. Papadopoulos and M. Hongoh, Phys. Rev. D19 (1979) 2607.
A.P. Contogouris and J. Kripfganz, McGill University preprint (1979).
- [8] P. Aurenche and J. Lindfors, preprint CERN TH.2768 (1979).
- [9] U. Amaldi et al., Nucl. Phys. B150 (1979) 326.
- [10] R.M. Baltrusaitis et al., Fermilab Pub-79/38-Exp (1979).
- [11] M. Diakonou et al., Phys. Lett. 87B (1979) 292.
M. Diakonou et al., A measurement of direct photon production at large p_T at the CERN ISR, to be published in Physics Letters.
- [12] M. Diakonou et al., The associated charged particle multiplicity of high p_T π^0 and single photon, to be published in Physics Letters.
- [13] J.H. Cobb et al., Nucl. Instrum. Methods 140 (1977) 413.
J.H. Cobb et al., Nucl. Instrum. Methods 159 (1979) 93.
C. Kourkouvelis, CERN 77-06 (1977).
A.J. Lankford, Internal Report CERN-EP/Int. 78-03 (1978).
- [14] C. Kourkouvelis et al., Phys. Lett. 84B (1979) 277.
- [15] R.L. Ford and W.R. Nelson, SLAC Report 210 (1978).
- [16] M.G. Albrow et al., Nucl. Phys. B145 (1978) 305.
- [17] C. Kourkouvelis et al., Phys. Lett. 85B (1979) 147.

Figure captions

- Fig. 1 : Experimental arrangement of the apparatus in the ISR.
- Fig. 2 : The rapidity difference between charged tracks and trigger particles:
a) π^0 ; b) γ -candidate; c) pure γ . The rapidity difference between π^0 and trigger particles: d) π^0 ; e) γ -candidate; f) pure γ . The rapidity difference between π^0 of $p_T > 0.5$ GeV and trigger particle: g) π^0 ; h) γ -candidate; i) pure γ . The curves are the expected distributions assuming uncorrelated particles.
- Fig. 3 : The azimuthal difference between π^0 and single photon candidates with π^0 : a) $p_T \leq 0.5$ GeV; b) $p_T \geq 0.5$ GeV.
- Fig. 4 : The relative probability for the γ -candidate sample and π^0 events to find a second particle of PT2 in the $\Delta\phi$ region: a) $20^\circ \leq \Delta\phi \leq 45^\circ$; b) $45^\circ \leq \Delta\phi \leq 70^\circ$; c) $110^\circ \leq \Delta\phi \leq 145^\circ$; d) $145^\circ \leq \Delta\phi \leq 180^\circ$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4