Special Session on Prompt Photon Production and Other Current Topics

T. Ferbel, University of Rochester
Session Organizer

DIRECT PHOTON PRODUCTION AT ISR ENERGIES

P. Mouzourakis
CERN
Geneva, Switzerland

The hadronic production of single photons at large p_T has recently been the object of many theoretical [1] and experimental [2-6] investigations. Such directly produced photons are expected to result from the same mechanism that also gives rise to high p_T hadrons, such as the π^0: that is, the hard scattering of hadronic constituents. Unlike the π^0, however, the photon can also be a participant in the hard scattering subprocess, rather than just a fragment of a scattered constituent. This would make direct photon production a particularly clean way of studying the hard scattering dynamics underlying all large p_T phenomena. Another consequence of this absence of fragmentation for the produced photon is that eventually the γ/π^0 ratio should rise with p_T at fixed $\sqrt{s}$. Thus, a large yield of direct photons is expected at sufficiently high p_T, reflecting the pointlike coupling of the photon to quarks.

This experiment has studied direct photon production in pp collisions at the CERN ISR, for c.m. energies between $\sqrt{s} = 31$ and $\sqrt{s} = 62$ GeV. The apparatus used for the single photon measurement consisted of two lead-liquid argon calorimeters, which are described in more detail elsewhere [7-8]. These were subdivided both longitudinally (in the direction of shower development) for effective hadron-photon discrimination, and laterally. A position resolution of $\sigma_x \sim 5$ mm and the ability to reliably resolve two showers down to a transverse separation of 50 mm resulted from the high degree of lateral segmentation.

Two different detector configurations were used for the single photon study. In configuration A (Fig. 1a) the two calorimeters were placed at a distance of 1.6 m from the beam intersection, each module covering polar angles between 70^0 and 110^0 and an azimuthal range of 20^0 ($\sim 1/4$ of a steradian). With this arrangement of the modules, the two photons from the π^0 decay could be resolved up to a p_T of 7 GeV/c. Preliminary results are also available from configuration B (Fig. 2), where the distance from the ISR interaction diamond was 2.1 m. In that run, the angular coverage of each module was 75^0 to 105^0 in polar angle and 15^0 in azimuth (about 1/8 of a steradian); π^0 decays were resolved up to 10 GeV/c of p_T. A third configuration, the "near" configuration (Fig. 1b), in which four detector modules had been placed at a distance of 0.8 m from the beam intersection, was also used for systematic checks.

An event would trigger the detector if the energy deposited in localized regions in the first two calorimeter sections (~ 3 radiation lengths each), as well as the total energy deposited, determined by summing over all calorimeter sections, exceeded corresponding thresholds. The total energy requirement imposed an effective cut-off for transverse momenta below 3 GeV/c.

The recorded events were then subjected to a set of selection criteria:

i) All showers should lie within a fiducial region chosen to exclude the calorimeter edges, with the remainder of the calorimeter used as a veto region in which no additional showers were allowed.

ii) At least 25% of the energy deposit should be in the third calorimeter section (12 radiation lengths deep). This cut removed most of the background events due to beam-gas collisions.

iii) There should be no "unassigned energy" in the calorimeter. This quantity corresponds to the total of the energy deposits which do not lie close enough to become part of a reconstructed shower. This cut eliminates events with additional showers which failed to be reconstructed. However, it also eliminates those events where a charged track entered the calorimeter, since such tracks will also produce unassigned energy.

Two classes of events are of interest for the purpose of this analysis:

i) Single photon candidates, that is showers that are alone in the calorimeter. These are also required to have a radius of less than 13.5 mm. This cut has been found to be 90% efficient for true single photons but eliminates most of the merged π^0's that would otherwise fake a single shower.

ii) π^0's, that is shower pairs with an invariant mass $90 < M_{\gamma\gamma} < 180$ MeV. These were required to have no additional showers in the calorimeter.

From the ratio of these two samples, i.e. the apparent γ/π^0 ratio, one must subtract all background contributions. These are computed using the observed spectra of π^0's and η's produced in pp collisions [9]. The small contribution of the $\omega \to \pi^0\gamma$ and $\eta' \to \gamma\gamma$ decays is also taken into account using the preliminary cross sections measured in this experiment [10]; the contribution of all other sources is negligible.

The larger part of the background in the single photon sample comes from π^0 and η decays where one photon misses the calorimeter. An additional contribution arises from very asymmetric decays, where the soft photon is not reconstructed but does not give any unassigned energy and from the small fraction of merged π^0's. This contribution is calculated on the basis of a detailed simulation of shower development in the liquid argon calorimeters using the EGS shower Monte Carlo [11].

When the background subtraction is performed, an excess of single photons is found at all values of the c.m. energy used in this experiment; this excess rises significantly with p_T. Apart from the direct production of single photons, this excess could, in principle, be due to a number of effects:

i) Hadrons interacting in the calorimeter and simulating single showers. Tests of a calorimeter module at the CERN PS have shown that the acceptance of a charged pion relative to that of a photon is about 0.15%. When all other species of hadrons are included, the background to the apparent single shower yield is less than 2%.

ii) Cosmic rays and beam-gas interactions. These sources produce showers that mostly do not point to the interaction diamond and will also tend to have a wider radius than true single photons. Therefore, these sources of background are rejected by the selection cuts, giving an estimated contribution of less than 2%.

iii) A non-linear energy response of the calorimeter, together with the steep p_T spectra of the observed single photons and π^0's could artificially create an excess in the γ/π^0 ratio. The amount of non-linearity required to reproduce the observed excess is, however, large and not consistent with the experimentally obtained limits for such a non-linearity of the liquid argon calorimeters. [12] These limits have been used to estimate the contribution of such a possible non-linearity to the systematic error quoted (Fig. 3a).

iv) The merging of the two showers from high energy π^0's. This effect is taken into account in the EGS simulation and has been checked using the results obtained in the "near" configuration, where the detector modules are only 0.8 m from the beam intersection and thus merging of the π^0 decay photons should set in at only 3.5 GeV/c of p_T. The data clearly indicates that the observed effect cannot be due to merging (Fig. 3b).

The conclusion is that none of these sources can explain the single photon excess, which should therefore be attributed to direct photon production. After correcting for the relative efficiencies for π^0's and γ's, one obtains the γ/π^0 ratio shown in Fig. 4 for configuration A [12]. The signal is seen to rise as a function of p_T for all three c.m. energies, while no significant $\sqrt{s}$ dependence is seen. Preliminary results obtained in configuration B also show the same behaviour (Fig. 5).

It must be emphasized that this ratio is obtained under somewhat restrictive conditions, namely by requiring that the detected π^0 or γ is not accompanied by any additional photons or charged particles within the calorimeter solid angle; this is particularly important when comparing the data to theoretical calculations [13-15]. The above requirement is expected to bias the π^0 sample more than the direct photon one, since theoretical models predict that direct photons are predominantly produced with no accompanying particles. One expects then that the resulting bias will be less the smaller the detector solid angle, which is consistent with the preliminary results from configuration B being systematically somewhat lower than those from configuration A, where the calorimeters subtend a solid angle which is twice as large.

To conclude, we have observed a significant signal due to direct photon production. This signal cannot be produced by the decays of the known sources, nor explained by systematic effects, such as π^0 merging and calorimeter non-linearity, or by hadronic and beam gas backgrounds. [16]

REFERENCES

1. G.R. Farrar and S.C. Frautschi, Phys.Rev.Lett. 36 (1976) 1017.
   C.O. Escobar, Nucl.Phys. B98 (1975) 174.
   E.L. Feinberg, Nuovo Cimento 34A (1976) 391.
   H. Fritzsch and P. Minkowski, Phys.Lett. 69B (1977) 316.
   F. Halzen and D.M. Scott, Phys.Rev.Lett. 40 (1978) 1117.
2. F.W. Büsser et al., Nucl.Phys. B113 (1976) 189.
3. A. Chilingrov et al., Contribution to the XIX International Conference on High Energy Physics, Tokyo (1978).
4. J.H. Cobb et al., Phys.Lett. 78B (1978) 519.
5. E. Amaldi et al., Phys.Lett. 77B (1978) 240; Phys.Lett. 84B (1979) 360.
6. R.M. Baltrusaitis et al., FERMILAB-PUB-79/38 EXP (to appear in Phys.Lett.B).
7. C. Kourkoumelis, CERN Report 77-06 (1977).
   A.J. Lankford, CERN EP Report 78-03 (1978).
8. J.H. Cobb et al., Nucl.Instr. and Meth. 158 (1979) 93.
9. C. Kourkoumelis et al., Phys.Lett. 84B (1979) 271; Phys.Lett. 84B (1979) 277.
10. M. Diaconou et al., Inclusive production of η' and ω mesons at the CERN ISR, in preparation.
11. R.L. Ford and W.R. Nelson, SLAC Report 210 (1978).
12. M. Diaconou et al., Direct production of high p_T single photons in pp collisions at the CERN ISR, to be published in Phys.Letters.
13. R. Rückl, S.J. Brodsky and J.F. Gunion, SLAC-PUB 2115 (1978).
14. A.P. Contogouris, S. Papadopoulos and M. Hongoh, Phys.Rev. D19 (1979) 2607.
15. R.D. Field and R.P. Feynman, Proceedings of the XIX International Conference on High Energy Physics, Tokyo (1978).
16. Members of the Athens/BNL/CERN Collaboration are: M. Diaconou, C. Kourkoumelis, L.K. Resvanis, T.A. Filippas, E. Fokitis, S. Karpathopoulos, C. Trakkas, A.M. Cnops, J.H. Cobb, E.C. Fowler, D.M. Hood, S. Iwata, R.B. Palmer, D.C. Rahm, P. Rehak, I. Stumer, C.W. Fabjan, T. Fields, D. Lissauer, I. Mannelli, W. Molzon, P. Mouzourakis, K. Nakamura, A. Nappi and W.J. Willis.

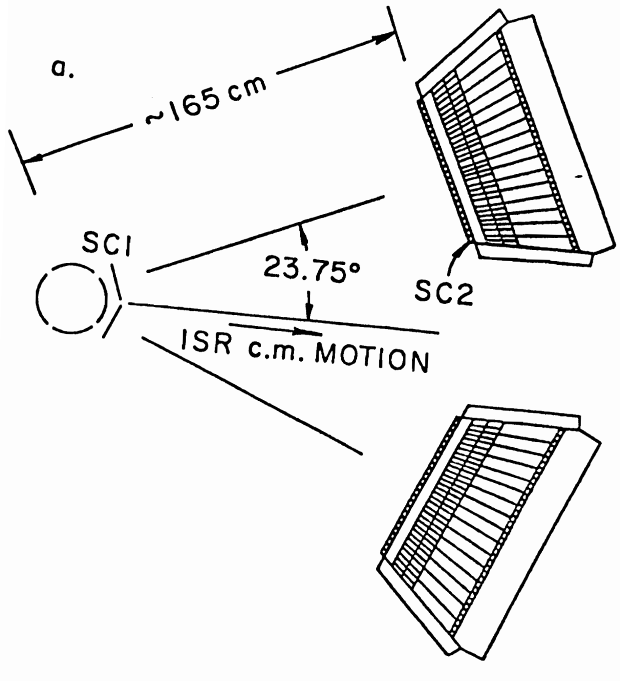

Figure 1a : Arrangement of the liquid argon calorimeters for the single photon search (configuration A).

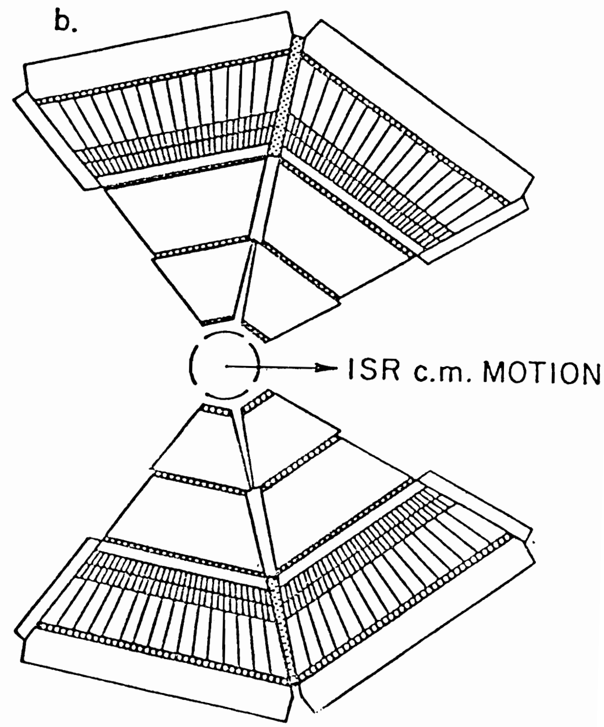

Figure 1b : Detector arrangement for the study of high mass e^+e^- pairs ("near" configuration).

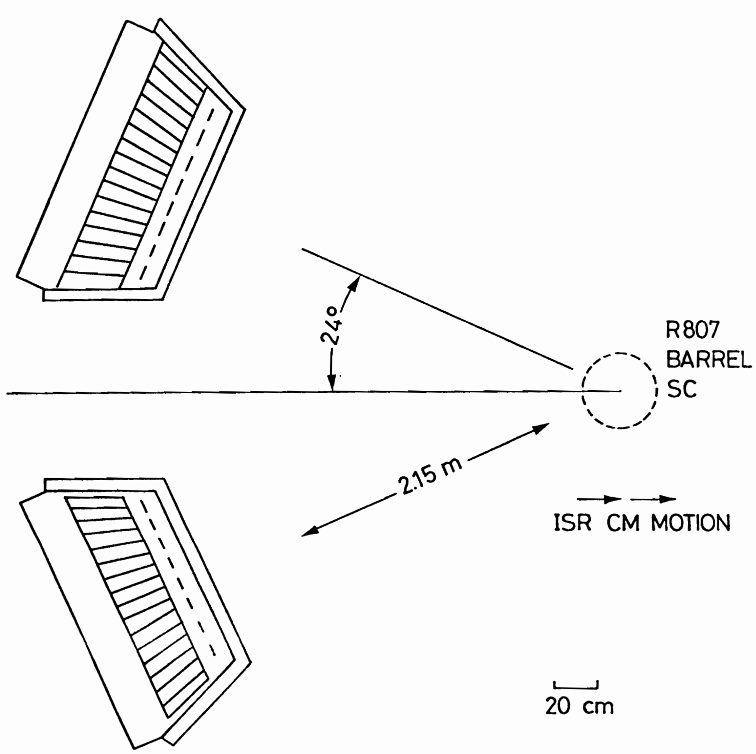

Figure 2 : Arrangement of the calorimeter modules for the study of single photon production at large p_T (configuration B).

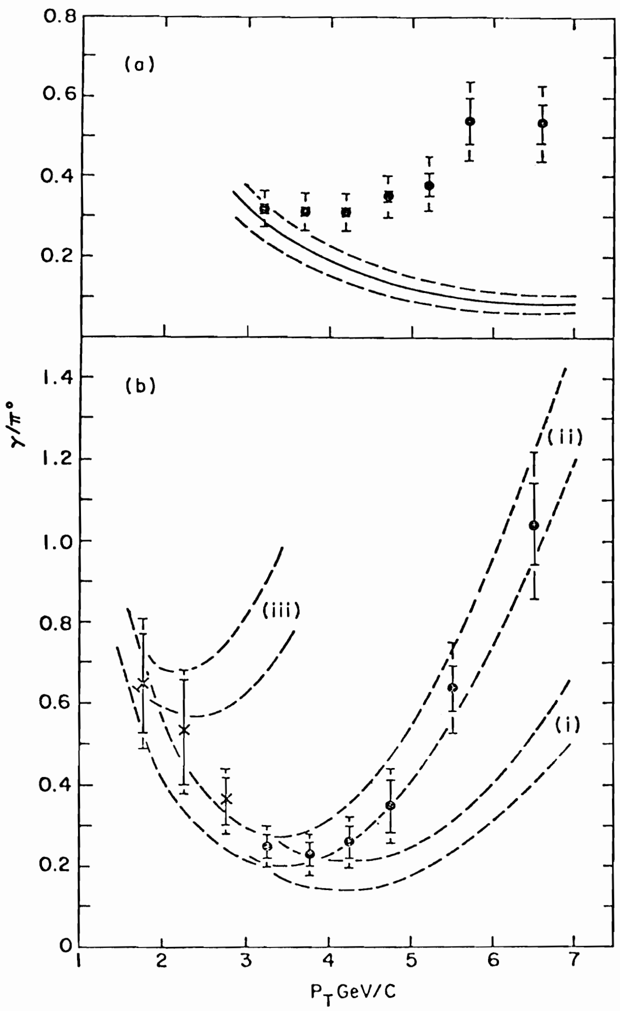

Figure 3a : Observed ratio of γ to π^0 for data from all energies for configuration A. The inner error bars indicate statistical errors. The outer bars indicate possible systematic effects due to calorimeter non-linearity. The smooth line indicates the Monte Carlo prediction for the ratio assuming no direct γ production. The dashed lines indicate the one standard deviation systematic errors on the Monte Carlo calculation.

Figure 3b : Observed ratio of γ to π^0 versus c.m. transverse momentum obtained with the "near" configuration. The dots are from data requiring a trigger, the crosses for untriggered data. Band (i) is based on the Monte Carlo simulation with the assumption that there are no direct photons. The positions of the other two bands have been calculated from the data of 3(a) with different assumptions: (ii) the observed excess is due to direct photon production or (iii) the observed excess is due to merged showers from π^0 decays.

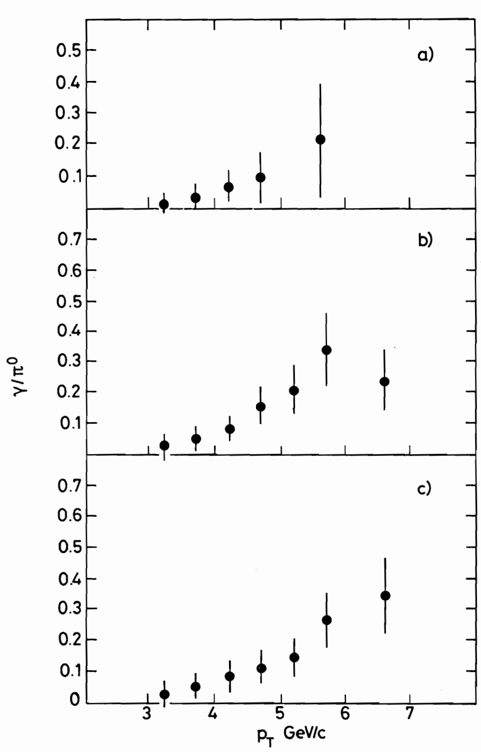

Figure 4 : Final results for the γ/π^0 ratio from configuration A. The contribution of π^0 and η decays has been subtracted and a correction applied for reconstruction efficiency. The errors include all systematics: (a) for $\sqrt{s}$ = 31, (b) for $\sqrt{s}$ = 53, and (c) for $\sqrt{s}$ = 62 GeV.

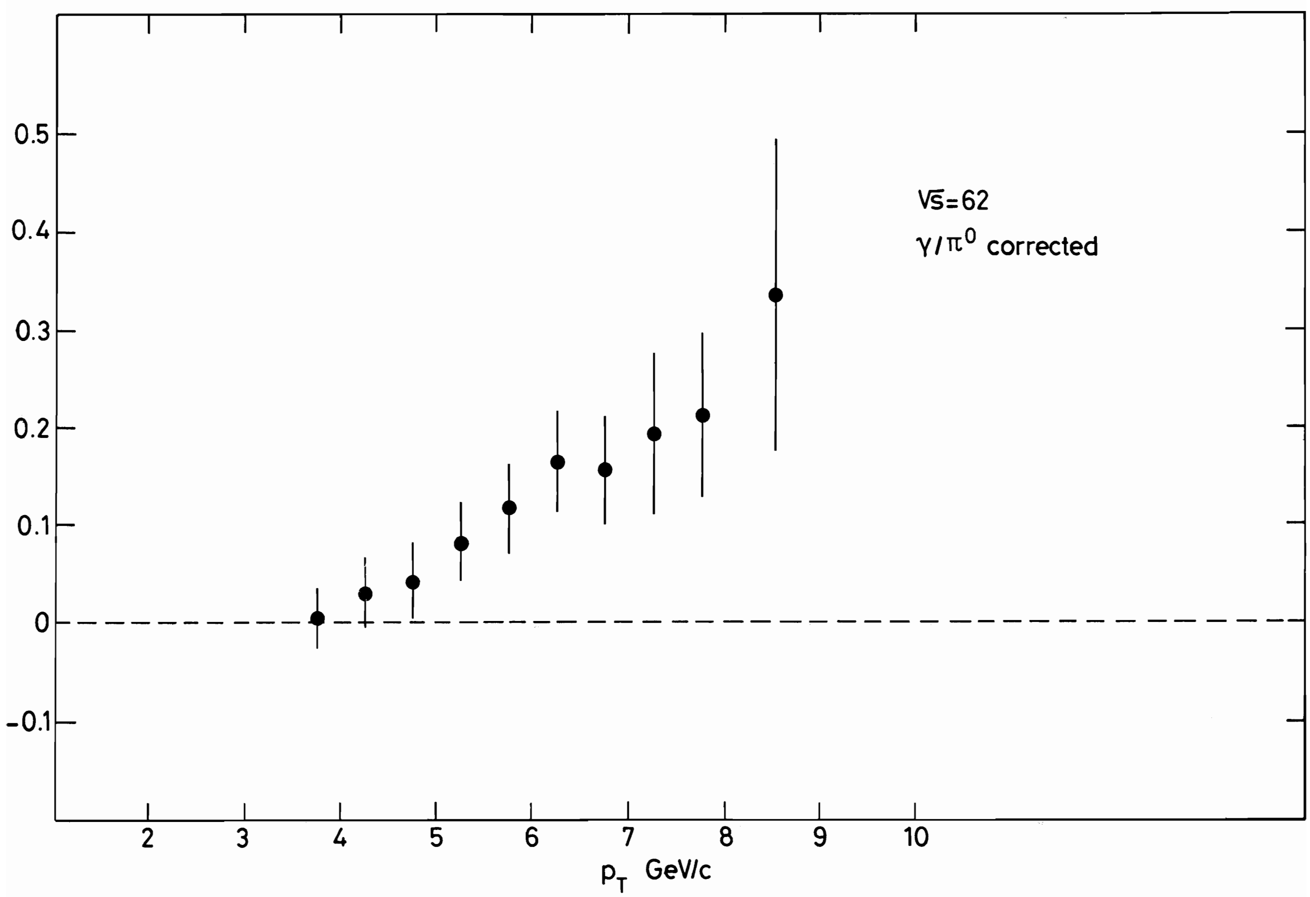

Figure 5 : Preliminary results from configuration B for the γ/π^0 ratio at $\sqrt{s}$ = 62 GeV.