

A STUDY OF PARTICLE CORRELATIONS AND CHARGE RATIOS
IN DIRECT PHOTON EVENTS AT THE CERN INTERSECTING STORAGE RINGS

CERN¹-Columbia²-Oxford³-Rockefeller⁴ (CCOR) Collaboration

A.L.S. Angelis³⁾, H.-J. Besch¹⁾, B.J. Blumenfeld^{2,1*)}, L. Camilleri¹⁾,
T.J. Chapin⁴⁾, R.L. Cool⁴⁾, C. del Papa^{1**)}, L. Di Lella¹⁾,
Z. Dimčovski^{4***)}, R.J. Hollebeek^{2†)}, L.M. Lederman^{2††)},
D.A. Levinthal²⁾, J.T. Linnemann⁴⁾, C.B. Newman^{1†††)}, N. Phinney^{1,3)},
B.G. Pope^{1†††)}, S.H. Pordes^{1,4††)}, A.F. Rothenberg^{4,1)}, R.W. Rusack²⁾,
A.M. Segar³⁾, J. Singh-Sidhu¹⁺⁾, A.M. Smith¹⁾, M.J. Tannenbaum⁴⁺⁺⁺⁾,
R.A. Vidal^{2†)}, J.S. Wallace-Hadrill^{3,1)}, J.M. Yelton³⁾ and K.K. Young¹⁺⁺⁺⁾

- 1) CERN, Geneva, Switzerland
- 2) Columbia University^{x)}, New York, NY, USA
- 3) University of Oxford, Oxford, UK
- 4) The Rockefeller University^{xx)}, New York, NY, USA

(Submitted to Physics Letters)

-
- *) Present address: Physics Dept., Johns Hopkins University, Baltimore, Maryland, USA.
 - **) Present address: Physics Dept., University of Washington, Seattle, Washington, USA.
 - ***) Present address: University of Skopje, Macedonia, Yugoslavia.
 - †) Present address: SLAC, Stanford, California, USA.
 - ††) Present address: FNAL, Batavia, Illinois, USA.
 - †††) Present address: Physics Dept., Princeton University, Princeton, New Jersey, USA.
 - +) Present address: Physics Dept., University of Manchester, Manchester, UK.
 - ++) Present address: Brookhaven National Laboratory, Upton, New York, USA.
 - +++) Permanent address: Physics Dept., University of Washington, Seattle, Washington, USA.
 - x) Research supported in part by the National Science Foundation.
 - xx) Research supported in part by the US Department of Energy.

ABSTRACT

A search for direct photons produced in proton-proton collisions has been performed at two \sqrt{s} values at the CERN Intersecting Storage Rings (ISR). It is found that direct photons are produced preferentially with no accompanying particles on the same side. On the away side, the ratio of positive to negative high- x_E particles is found to be higher for high transverse momentum direct-photon events, than for high transverse momentum neutral-meson events.

In our previous publication [1], a measurement of direct-photon production in p-p collisions at $\sqrt{s} = 62.4$ GeV was described. This letter reports results obtained by analysis of data at $\sqrt{s} = 44$ GeV, and a study of the correlation of charged and neutral particles with the direct photons.

The apparatus [1-5] and method [1] have been discussed elsewhere. The experiment used two lead-glass arrays to trigger on high- p_T single photons and neutral mesons decaying into photons. A statistical separation between these two kinds of particles is achieved by measuring the fraction of particles that did not convert when passing through a 1.0 radiation length converter (the coil of a superconducting solenoid magnet), and contrasting it with the fraction expected if all the particles were neutral mesons, and the fraction expected if all were single photons. The integrated luminosities, energies, and trigger thresholds used are shown in table 1. The results (fig. 1) are expressed in terms of f_γ , which is the ratio of the number of events ascribed to direct photons to the total number of events. The errors shown are statistical only. There is a further $\pm 5\%$ systematic error of which 3% is \sqrt{s} dependent. The data suggest an increase of f_γ as \sqrt{s} decreases. A comparison with the data of ref. 6 at $\sqrt{s} = 63$ GeV was presented in ref. 1. For $\sqrt{s} = 44$ GeV and $5 < p_T < 8$ GeV/c, $f_\gamma = 9.6 \pm 1.5\%$. When the data of ref. 6 are restated in terms of f_γ , their result at the same \sqrt{s} and p_T is $f_\gamma \approx 0.14$.

For the study of correlations, the data from the two \sqrt{s} values are combined in order to improve the statistical accuracy of the subsequent analysis. High- p_T mesons are usually produced as part of a jet, and are observed in conjunction with other particles emitted at similar azimuth and rapidity. On the other hand, in most models [7], direct photons are preferentially produced unaccompanied by such particles. Accordingly, the data have been divided into two classes of events: a) those which have at least one charged or neutral particle, of $p_T > 0.3$ GeV/c, other than the trigger in the trigger hemisphere ($|\Delta\phi| < 90^\circ$ about the trigger direction and pseudorapidity η in the range $-0.7 < \eta < 0.7$), and b) those which do not. The resulting values of f_γ are shown in figs. 2a,b for the

two classes of events. The values of f_γ for the accompanied trigger particles are clearly lower than those for the unaccompanied trigger particles. For trigger transverse momenta $p_{T \text{ trig}}$ in the range 6 to 10 GeV/c, $17.0 \pm 2.0\%$ (statistical) of the unaccompanied sample may be attributed to direct photons, whereas for the accompanied sample the single photon fraction is $0.7 \pm 1.2\%$. For transverse momenta above 10 GeV/c, the single-photon content of the unaccompanied and accompanied samples is $33.0 \pm 6.0\%$ and $16.0 \pm 5.0\%$ respectively. This result suggests that direct photons are due mainly to processes such as $q\bar{q} \rightarrow \gamma q$ and $gq \rightarrow \gamma q$ which result in photons that are unaccompanied by other particles in the trigger hemisphere, rather than processes, for example quark bremsstrahlung, in which the photon would be accompanied by particles resulting from quark fragmentation. This enhancement of direct-photon production in a sample of unaccompanied trigger particles is in qualitative agreement with other ISR results [8].

If the process yielding direct photons is $gq \rightarrow \gamma q$, then it is expected from theory that a u quark will be involved eight times more often than a d quark because of the quark charges and abundances in the proton. This large excess with a positively charged parent quark should be reflected in the charge of the jet opposite to the direct photon [9]. This possibility has been investigated by measuring the charge ratio, $R = \text{positive particles/negative particles}$, in the hemisphere opposite the trigger as a function of $x_E = -\vec{p}_{T \text{ trig}} \cdot \vec{p}_{T \text{ track}} / |p_{T \text{ trig}}|^2$, where $p_{T \text{ track}}$ is the transverse momentum of the charged particle. It should be noted that the ratio R is sensitive to a small difference in the relative p_T scales of positive and negative particles, such as that resulting from a small misalignment of the drift chambers. An estimate of the possible systematic error on the charge ratio introduced by such effects was obtained by measuring the mean momentum of positrons $\langle p_{e^+} \rangle$ and electrons $\langle p_{e^-} \rangle$ from a sample of 70 upsilons obtained in the same apparatus and at the same time as the direct-photon data [2]. The results were $\langle p_{e^+} \rangle = 5.60 \pm 0.30$ GeV/c, $\langle p_{e^-} \rangle = 5.65 \pm 0.37$ GeV/c. Note that these momenta are similar to or higher than the momenta of most charged particles used in the measurement of R . Given the x_E distribution of the charged particles

and the accuracy in the measurement of $\langle p_{e+} \rangle$ and $\langle p_{e-} \rangle$, the effect on R of a possible misalignment of the drift chambers is estimated to be $\Delta R/R < 0.2$. In addition, the charge ratio in the jet recoiling against a sample of triggers consisting mostly of π^0 's is found to be in very good agreement with the charge ratio of Clark et al. [10]: for instance, for $p_{T \text{ trig}} > 5 \text{ GeV/c}$ and $0.3 < x_E < 0.5$, $R = 1.25 \pm 0.08$, to be compared to 1.30 ± 0.09 as measured by ref. 9.

Two subsets of the data were used to measure R . Subset a), enriched in single-photon content by requiring the trigger particle not to have converted and to be unaccompanied by another particle in the trigger hemisphere, consisted of 39% single photons and 61% neutral mesons. Subset b), enriched in neutral-meson content by requiring the trigger particle to have converted and to be accompanied by another particle in the trigger hemisphere, consisted of only 4% single photons and 96% neutral mesons. It can be seen (figs. 3a,b) that the direct-photon-enhanced sample has a higher charge ratio than the neutral-meson sample for $x_E > 0.3$ and $p_{T \text{ trig}} > 5 \text{ GeV/c}$. From the values of R shown in fig. 3, the values of f_γ shown in fig. 2, and the non-conversion probabilities for γ 's and other particles, it is then possible to extract R for pure direct-photon events and pure neutral-meson events. The values obtained, shown in fig. 4 as a function of $p_{T \text{ trig}}$ for $x_E > 0.3$, again exhibit the fact that R for single photons is higher than R for neutral mesons. It should be stressed that this difference in R between the two types of events is unaffected by the 20% systematic uncertainty in R described earlier. Note that direct-photon events arising from quark bremsstrahlung are excluded by the nature of the charge ratio analysis.

In conclusion, in this letter we have presented data that show that direct photons are produced predominantly

- with no additional particles in the trigger hemisphere,
- with a higher charge ratio than neutral mesons in the opposite hemisphere.

Both these results favour the process $gq \rightarrow \gamma q$ as the main source of the direct photons.

REFERENCES

- [1] A.L.S. Angelis et al., Phys. Lett 94B (1980) 106.
- [2] A.L.S. Angelis et al., Phys. Lett. 79B (1978) 505.
- [3] A.L.S. Angelis et al., Phys. Lett. 87B (1979) 398.
- [4] L. Camilleri et al., Nucl. Instrum. Methods 156 (1978) 275.
- [5] M. Morpurgo, Cryogenics 17 (1977) 89.
- [6] M. Diakonou et al., Phys. Lett. 91B (1980) 296.
- [7] H. Fritzsche and P. Minkowski, Phys. Lett. 69B (1977) 316.
R. Rückl, S.J. Brodsky and J.F. Gunion, Phys. Rev. D 18 (1978) 2469.
F. Halzen and D.M. Scott, Phys. Rev. D 18 (1978) 3378.
F. Halzen and D.M. Scott, Phys. Rev. Lett. 40 (1978) 1117.
A.P. Contogouris, S. Papadopoulos and M. Hongoh, Phys. Rev. D 19 (1979)
2607.
- [8] M. Diakonou et al., Phys. Lett. 91B (1980) 301.
C. Kourkoumelis et al., CERN-EP/80-136, submitted to Nucl. Phys. B.
- [9] F. Halzen, M. Dechantsreiter and D.M. Scott, Univ. Wisconsin preprint
COO-881-140 (1980).
R. Baier, J. Engels and B. Petterson, University of Bielefeld preprint
BI-TP 80/07 (1980).
- [10] A.G. Clark et al., Nucl. Phys. B160 (1979) 397.

Table 1

Integrated luminosities

Trigger threshold (GeV/c)	$\sqrt{s} = 44.8$ GeV (cm^{-2})	$\sqrt{s} = 62.4$ GeV (cm^{-2})
3.5	5.2×10^{34}	3.7×10^{34}
5	3.0×10^{36}	1.1×10^{36}
7	1.7×10^{37}	2.8×10^{37}
9		2.8×10^{37}

Figure captions

- Fig. 1 : The fraction of events attributed to direct-photon production as a function of p_T , for two \sqrt{s} values. In addition to the errors shown, there is a systematic uncertainty of $\pm 5\%$.
- Fig. 2 : a) The fraction of events attributed to direct-photon production as a function of $p_{T \text{ trig}}$, for those events where the trigger was accompanied by a particle in the trigger hemisphere.
b) The same for those events where the trigger was not accompanied by a particle in the trigger hemisphere.
- Fig. 3 : a) The charge ratio R for particles in the hemisphere opposite to the trigger, as a function of x_E , for those events where the trigger particle did not convert and was not accompanied by a particle in the trigger hemisphere.
b) The same for those events where the trigger particle did convert and was accompanied by a particle in the trigger hemisphere.
- Fig. 4 : The charge ratio R for $x_E > 0.3$ plotted as a function of $p_{T \text{ trig}}$ for direct photons and neutral mesons. In addition to the errors shown, there is an over-all systematic uncertainty of $\pm 20\%$.

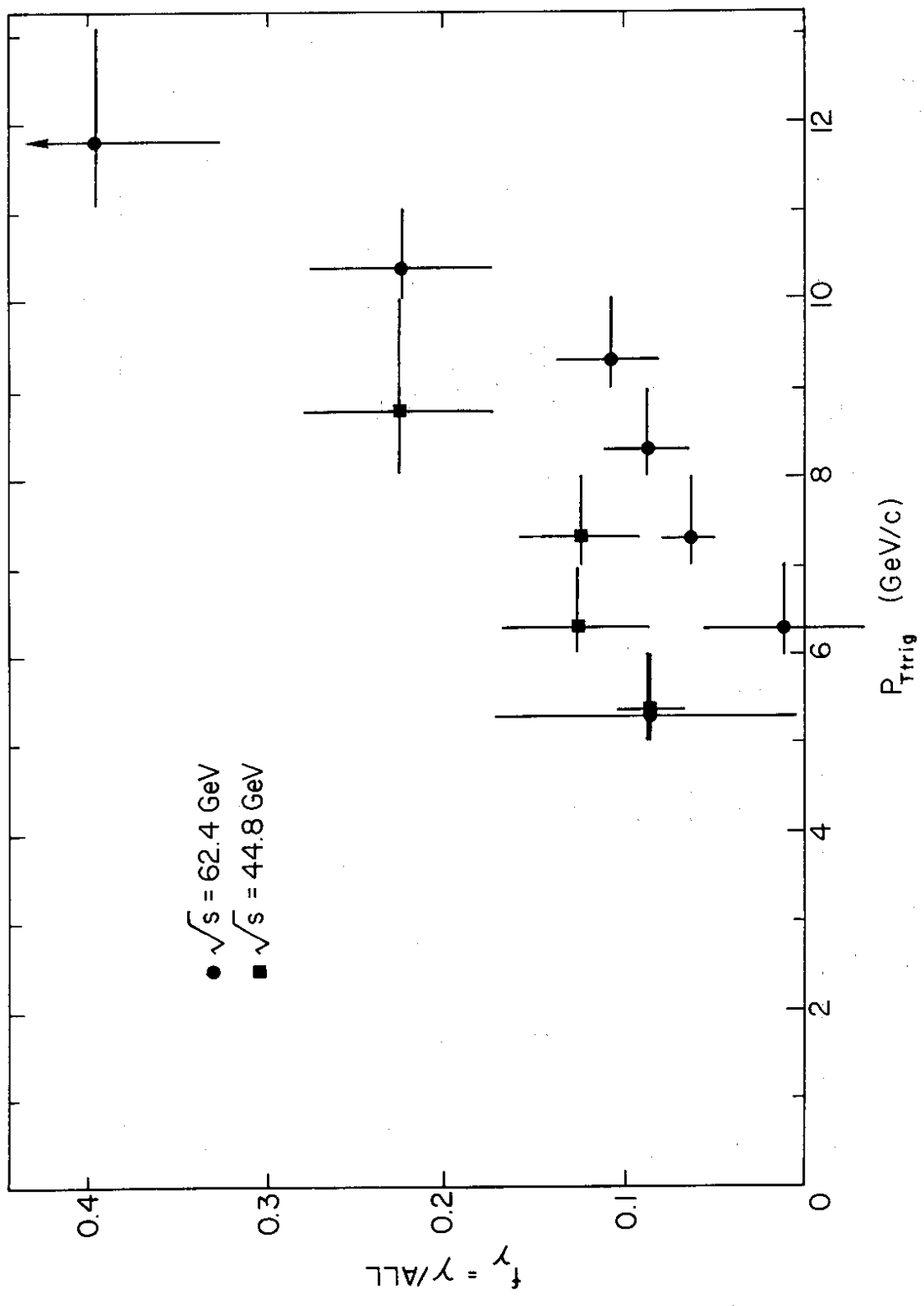


Fig. 1

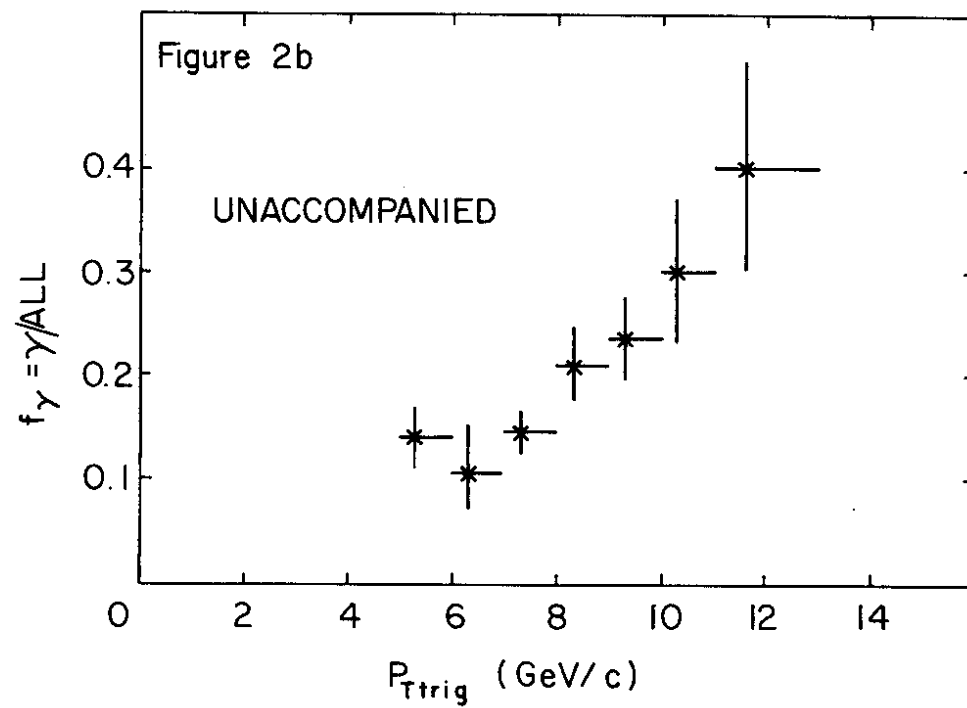
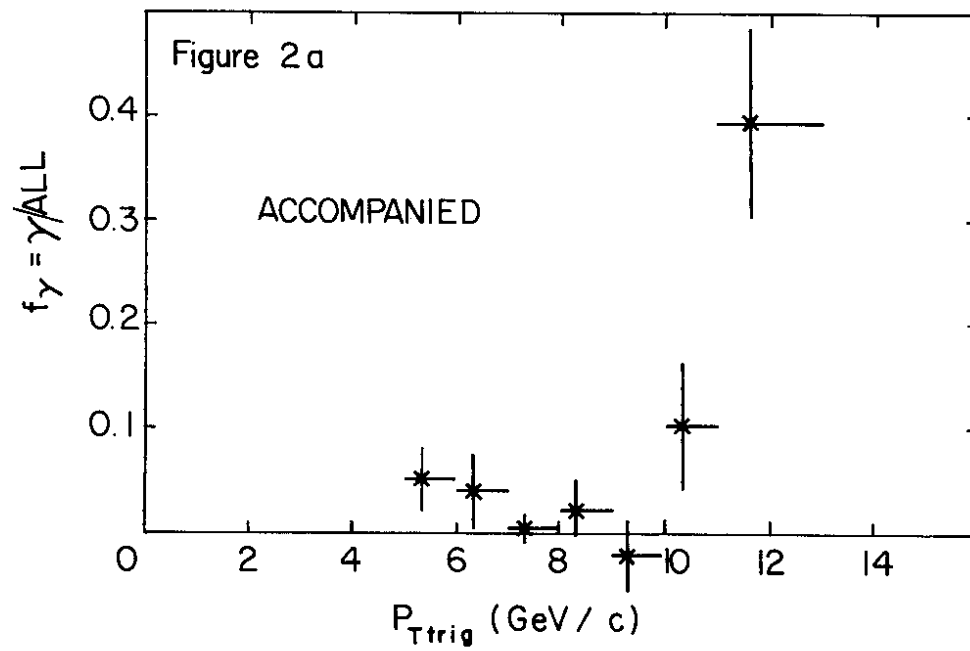


Fig. 2

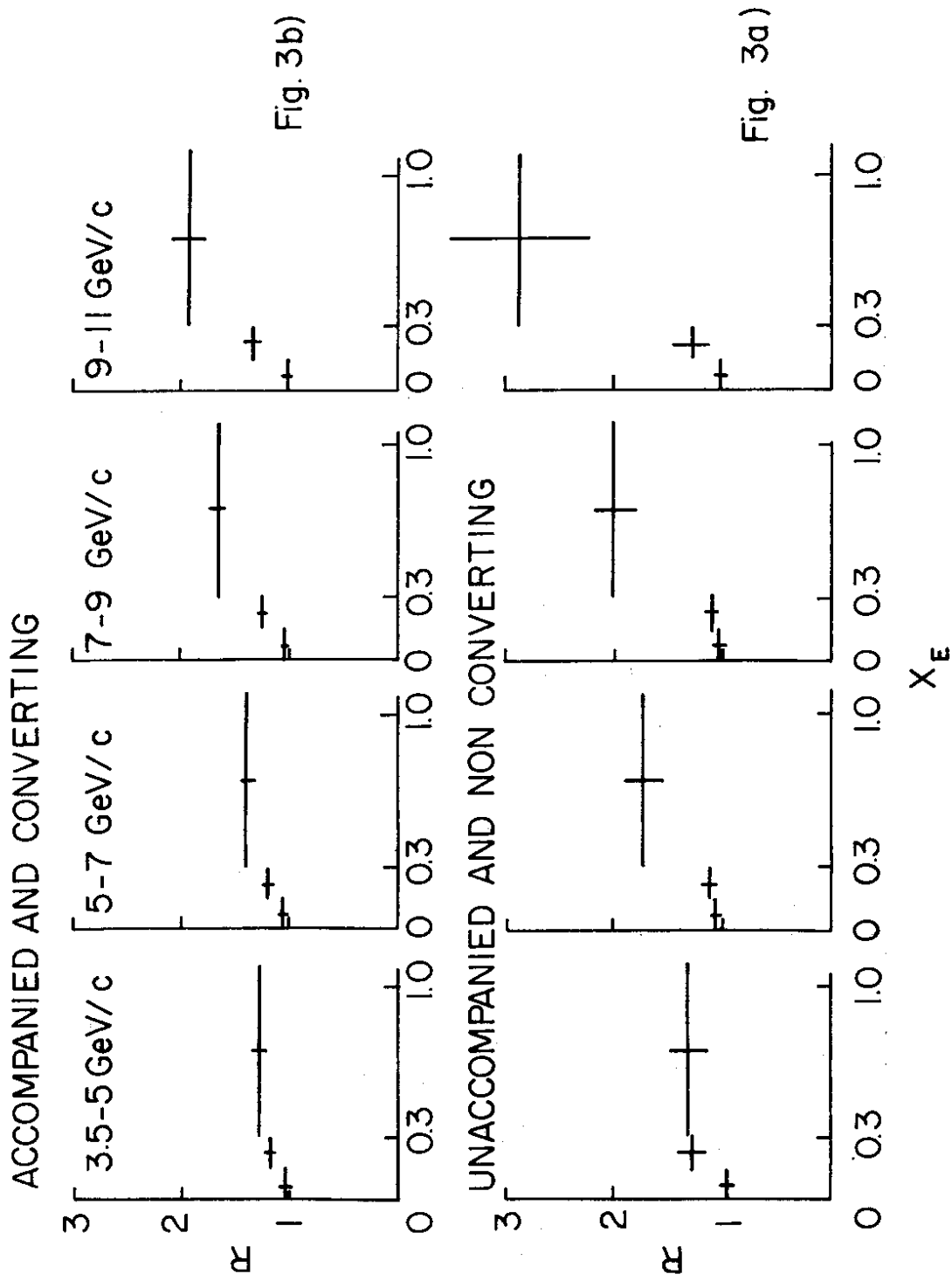


Fig. 3

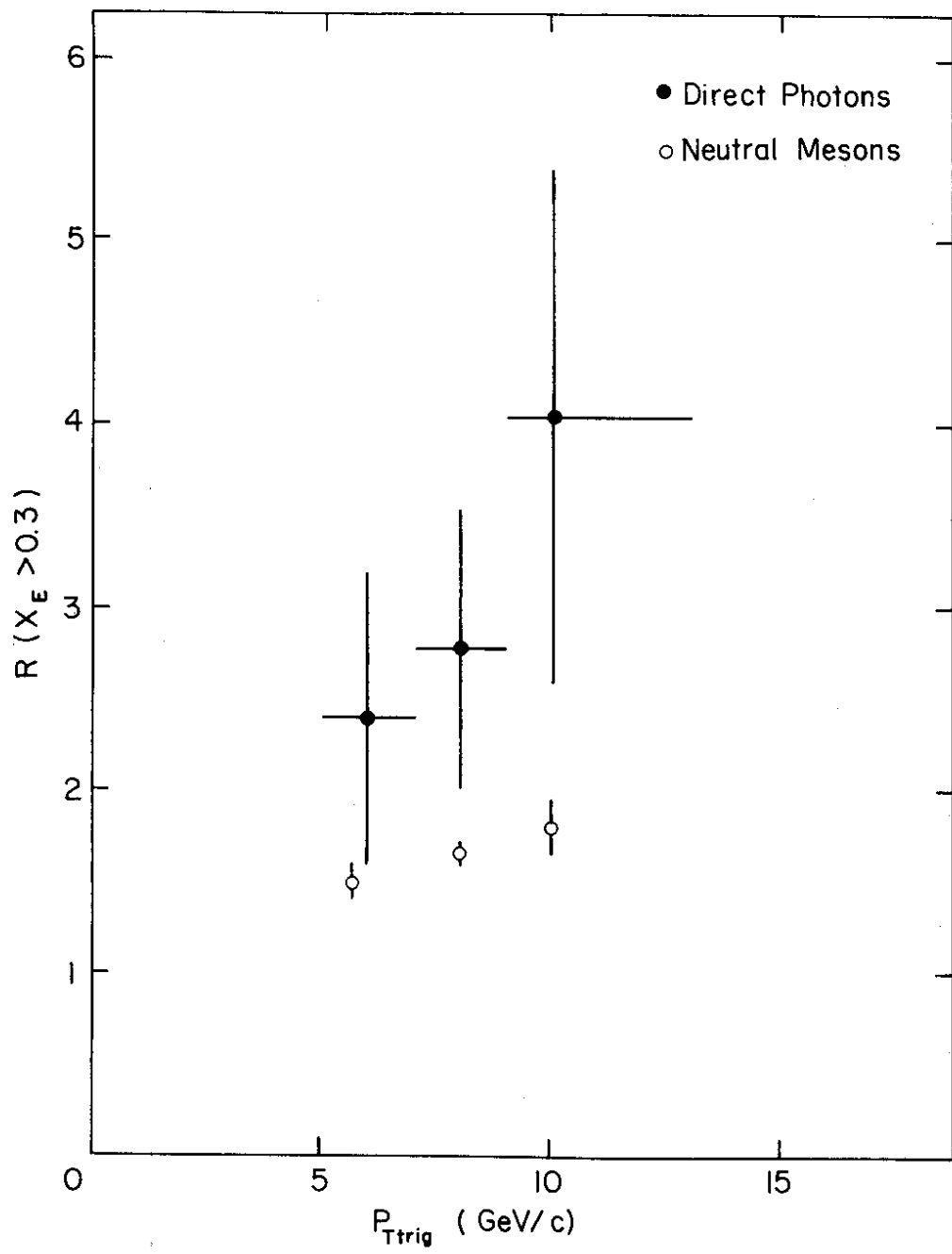


Fig. 4