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Inclusive Charged Hadron and K^0 Production in Two-Photon Interactions

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The analogous process to quark pair production in $e^+ e^-$ annihilation is the hard-scattering quark exchange process in $\gamma\gamma$ interactions. This hard-scattering process is expected to dominate [1] the cross section at high transverse momenta of the produced quarks. Experimentally, one has looked for this process in two-jet [2] as well as inclusive particle [3] production and has found a relatively low p_T onset of hard scattering in $\gamma\gamma$ interactions. This report examines the issue in more detail (high statistics) for charged particle inclusive production and checks if the heavier flavors display a similar behavior in inclusive K^0 production.

The results are based on an integrated luminosity of 220 pb^{-1} obtained with the Mark II detector at PEP. The major features of the Mark II detector have been described elsewhere[4]. The small angle tagging system measures electrons scattered between 21 and 83 mrads providing some 60,000 tagged events in the Q^2 interval between 0.075 and 1.00 GeV. Since we do not observe the entire final state, the transverse momentum of hadrons, p_T, is calculated in the usual manner, with respect to the $e^+ e^-$ beam axis. To eliminate the large QED background we accept only events with 3 or more charged prongs observed (in addition to the tagging electron). Identified leptons are removed using the Liquid Argon Calorimeter and the muon chambers. To minimize the beam-gas interaction background we also eliminate events with protons or deuterons identified by the time of flight. The background from $e^+ e^- \rightarrow e^+ e^- \tau^+\tau^-$ is subtracted using the Monte Carlo simulation of this process. The residual background from beam-gas interactions is simulated with events produced at larger z. Both these backgrounds vary between 5% and 10% with p_T and are subtracted. Taking advantage of the precision vertex chamber, the VFINDP program is used to find K^0's which decay at least 2.5 mm from the primary vertex. After several track quality cuts and three dimensional swimming of tracks to the secondary vertex,

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K^0's are selected in an interval of $\pm$ 20 MeV around the actual K^0 mass.

A Two-Photon Monte Carlo program[5] is used to simulate the hard scattering quark exchange process $e^+ e^- \rightarrow e^+ e^- q\bar{q}$. It incorporates transverse-transverse as well as transverse-longitudinal luminosity functions [6], a summation over the four quark flavors u,d,s,c, and subsequent fragmentation of the quarks according to the LUND scheme[7]. The quark fragmentation parameters are taken as the set of values which best describe the $e^+ e^-$ annihilation data at 30 GeV, and no attempt has been made to optimize the parameters for low two-photon energies. Since the quark flavors enter with the fourth power of their charges, the most important contributions come from the u and c quarks once the available two-photon energy exceeds the respective quark pair thresholds. These Monte Carlo calculations describe the gross features of the data and are used to obtained the detection efficiencies for the various particle species. The efficiencies rise with p_T and reach about 17% for charged hadrons and 3.3% for K^0's at $p_T = 2$ GeV. A preliminary version of the results [8] was presented at the last two-photon workshop but contained errors in the hadron efficiency calculations, especially in the trigger simulation, and did not take the correct threshold behavior for heavy charm production into account.

In an attempt to resolve the discrepancy between the Born term calculations and the untagged TASSO inclusive particle data[9], Aurenche et al. have performed model calculations to include higher order QCD terms and generalized vector dominance model contributions (motivated by photo-production data). The authors have subsequently expanded their calculations to include charm production and to extrapolate to the Mark II tagging range. We have folded their single charged hadron inclusive spectrum with the p_T resolution expected for the Mark II detector. As seen in Fig. 1 the data points lie systematically higher than the calculation of Aurenche et al. for p_T values larger than 1.5 GeV. However, the single-tag TASSO data [10] (in a similar Q^2 range as Mark II) show an even higher hadronic cross section. The discrepancy between the theoretical calculations and the Mark II data may be partially due to various experimental effects. The tagging efficiency is only taken into account for an average Q^2 whereas there exists a clear Q^2 dependence. The subtraction of τ pairs and of beam gas background may introduce systematic errors. Finally, our efficiency estimates are still limited by Monte Carlo statistics, especially for high p_T . But it is hard to see how all these effects could explain a factor of three discrepancy at high p_T .

For a hard scattering quark exchange process the inclusive particle spectrum is expected to fall off as some power of p_T for high p_T . To look for such an effect we plot the inclusive charged hadron cross section multiplied by $p_T{}^3$ in Fig. 2. The data seem to fall off with a higher power (between 4 and 5) for p_T values just above 2 GeV and the power approaches 3 at higher p_T .

We finally exploit the fact that we generated Monte Carlo events for the quark exchange process. In Fig. 3 we look at the ratio of data to Monte Carlo for inclusive charged hadrons. After being dominated by VDM contributions at low p_T the ratio for charged hadrons levels off above 2 GeV which is characteristic for the hard scattering process. With its ability to identify K^0's over a wide momentum range the Mark II detector can be used to look for a similar behavior in inclusive K^0 production. With the same normalization as for charged hadrons the ratio of K^0 data to Monte Carlo in Fig. 4 also levels off around 2 GeV, thus repeating the characteristic pattern of the charged hadrons.

Finally, the presence of charm production can be tested by the relative abundance of K^0's . In Fig. 5 the K^0 to charged hadron ratio is shown to increase with p_T, in agreement with the Monte Carlo simulation (solid line). If the c quark is not included in the Monte Carlo simulation (dashed line), the K^0 content of the events is expected to be a factor of 2 lower at high p_T . Although the data is statistically limited the comparison with Monte Carlo favors the inclusion of charm.

In summary, we observe, that the relative abundance of K^0's increases to about 30% at the highest p_T, and that K^0's - similar to charged hadrons - approach the point like pattern of the quark exchange process around p_T of 2.GeV. The model calculations of Aurenche et al. fall below the experimental inclusive charged hadron distribution for p_T values above 1.5 GeV.

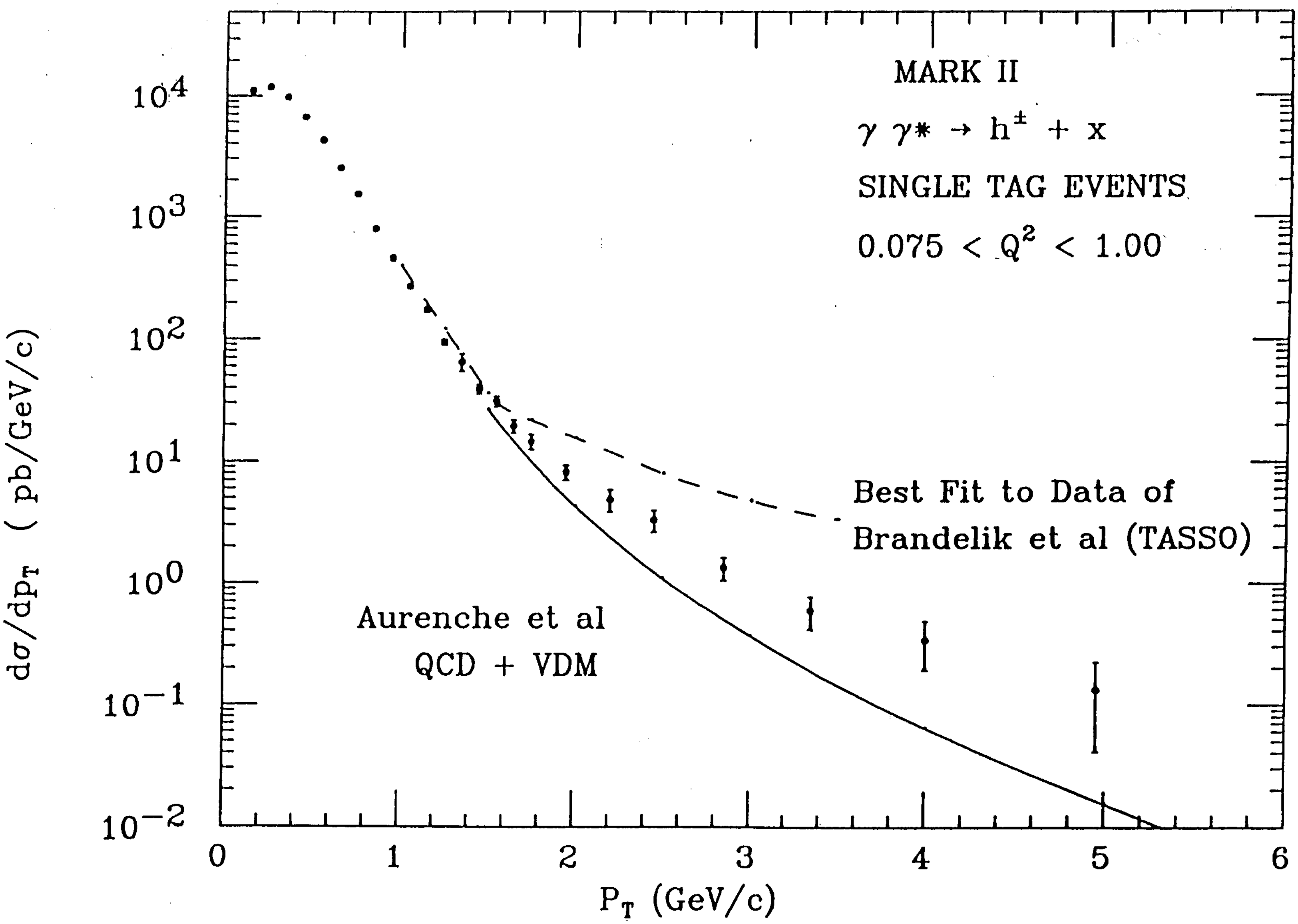

MARK II
γ γ* → h± + x
SINGLE TAG EVENTS
0.075 < Q2 < 1.00
Best Fit to Data of
Brandelik et al (TASSO)
Aurenche et al
QCD + VDM
dσ/dpT (pb/GeV/c)
PT (GeV/c)
10^4
10^3
10^2
10^1
10^0
10^−1
10^−2
0
1
2
3
4
5
6

Fig. 1

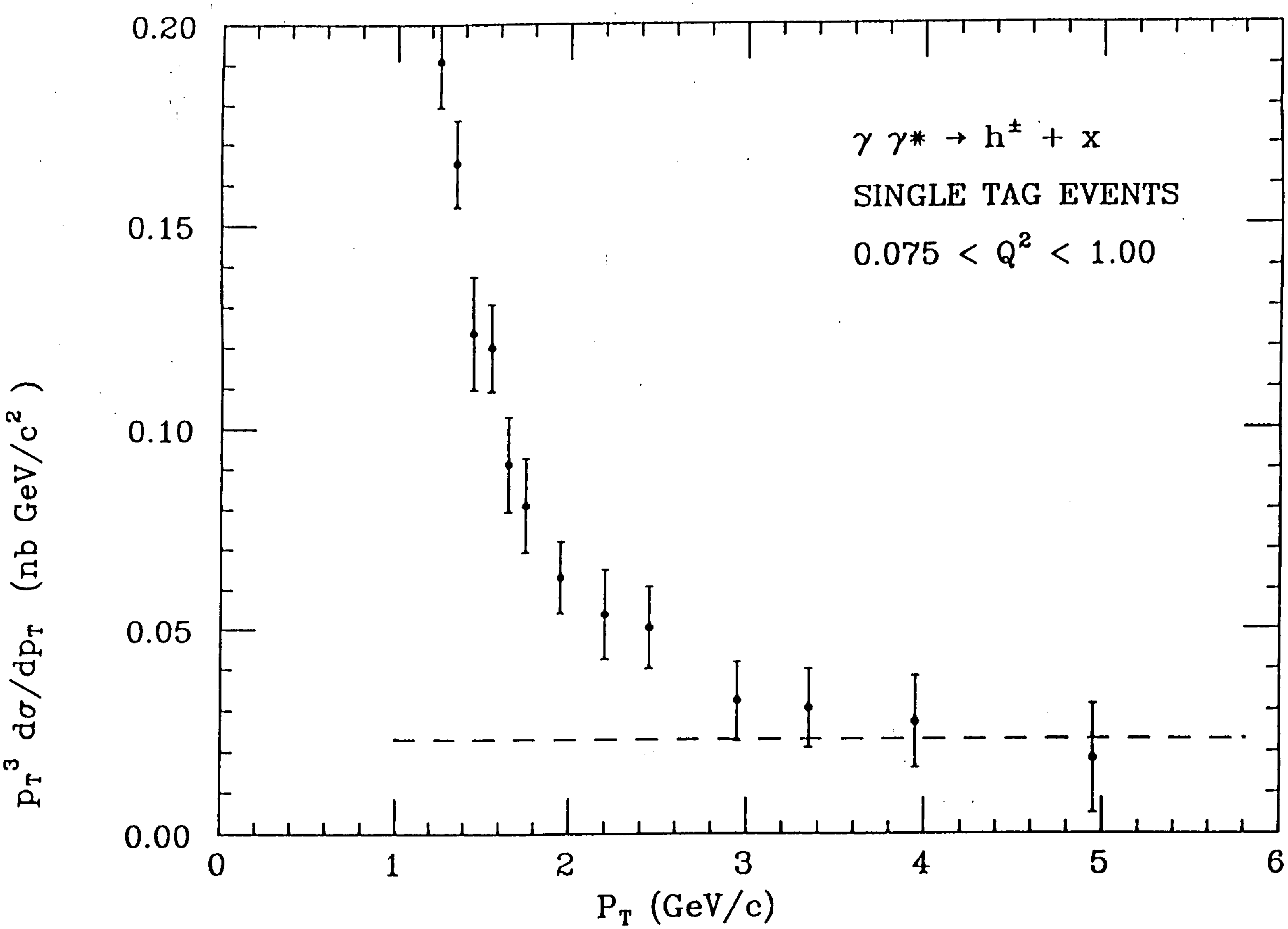
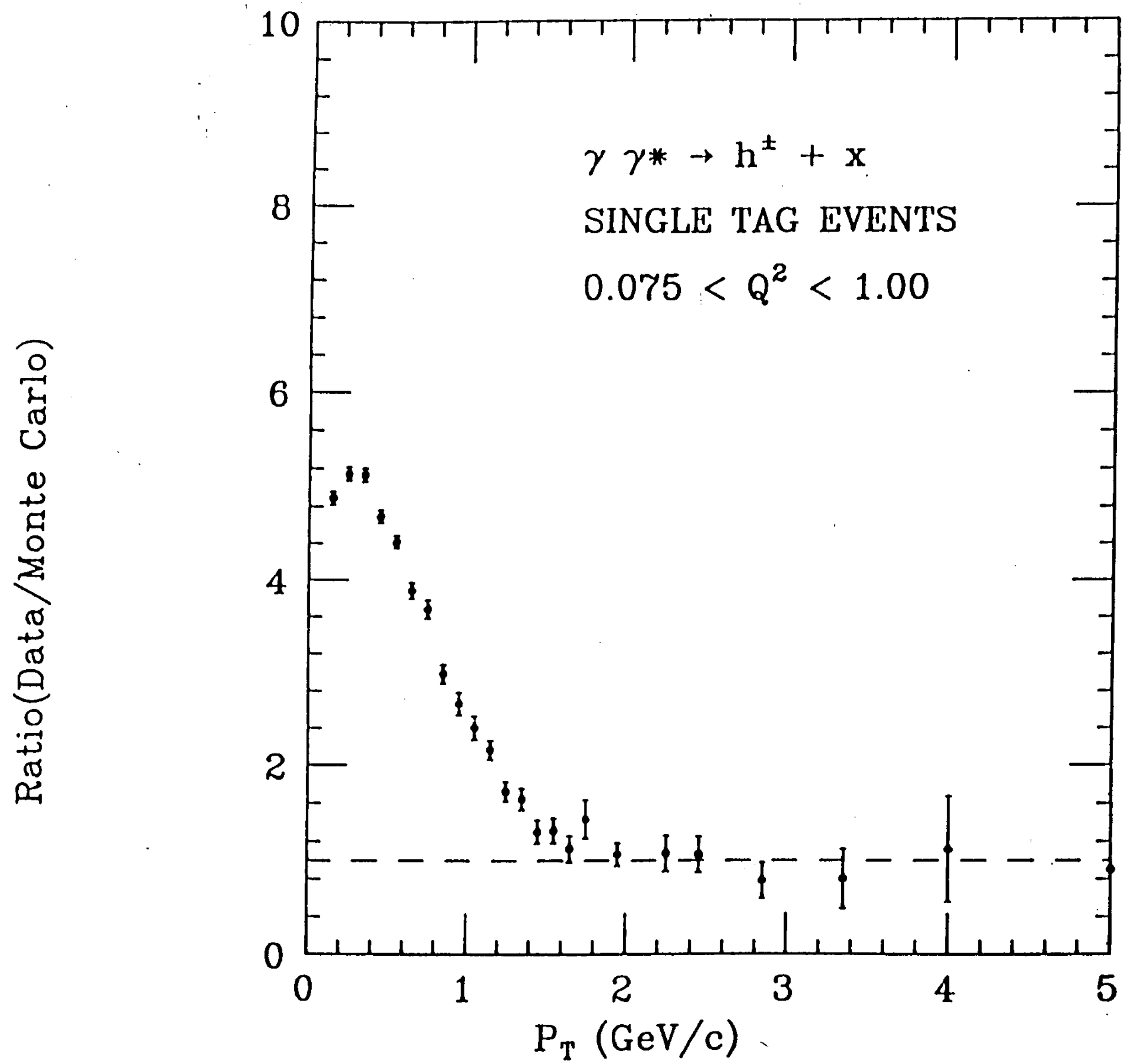
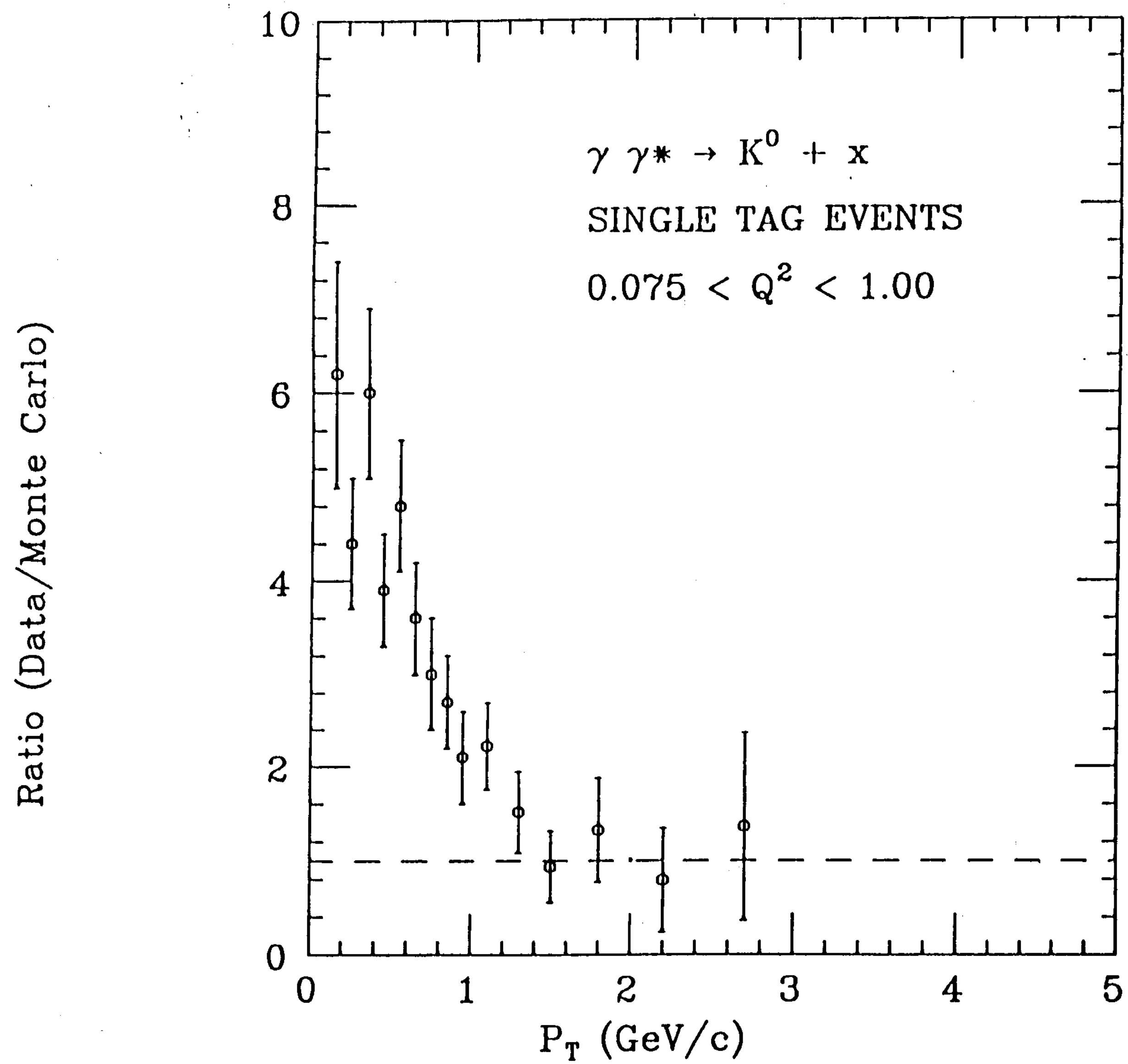

$\gamma\ \gamma^* \rightarrow h^{\pm} + x$
SINGLE TAG EVENTS
$0.075 < Q^2 < 1.00$
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
$p_T^3\ d\sigma/dp_T$ (nb GeV/c^2)
P_T (GeV/c)

Fig. 2



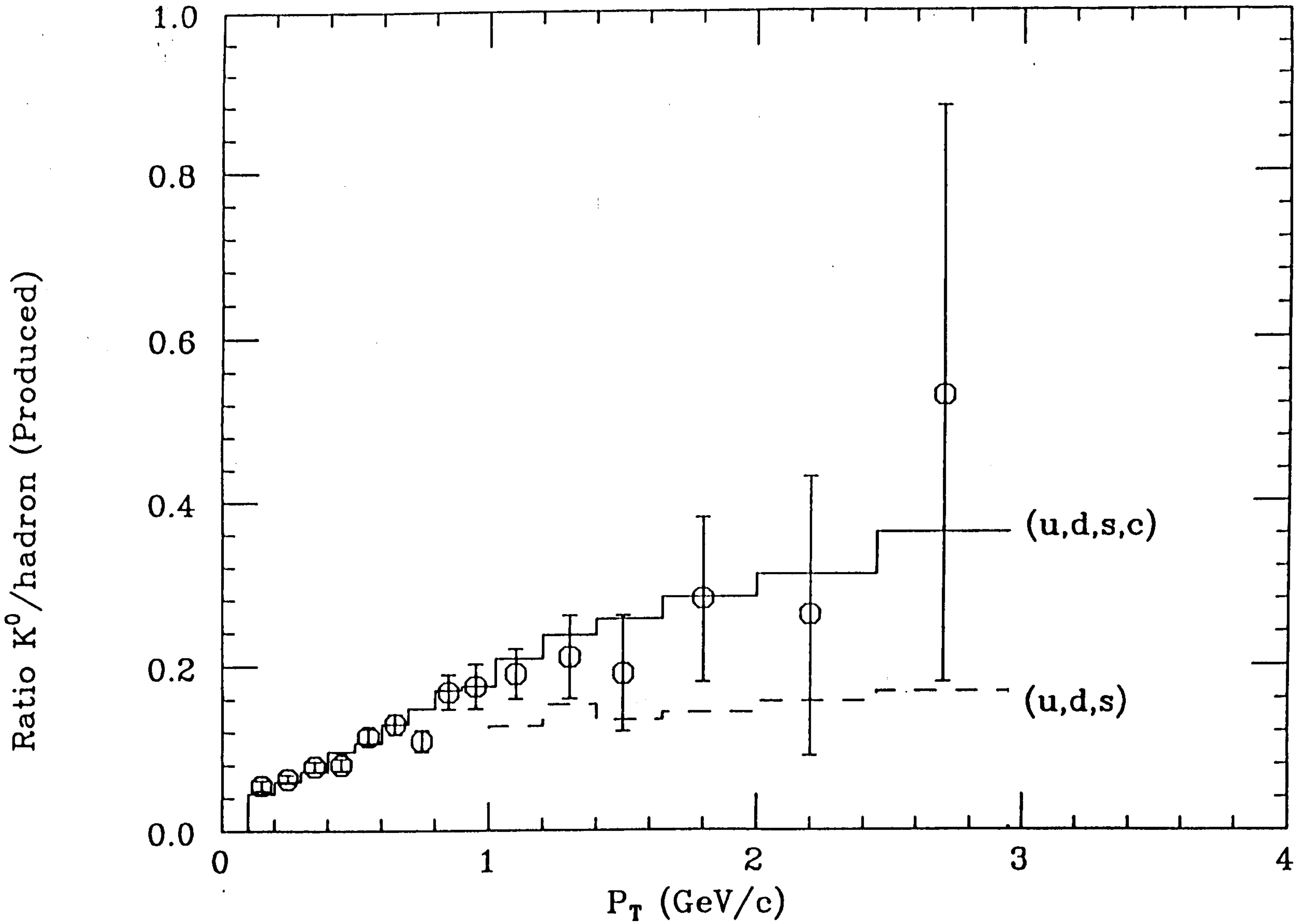
$\gamma\ \gamma^* \rightarrow h^\pm + x$
SINGLE TAG EVENTS
$0.075 < Q^2 < 1.00$
Ratio(Data/Monte Carlo)
P_T (GeV/c)
0
2
4
6
8
10
0
1
2
3
4
5

Fig. 3



γ γ* → K⁰ + x
SINGLE TAG EVENTS
0.075 < Q² < 1.00
Ratio (Data/Monte Carlo)
P_T (GeV/c)
0
1
2
3
4
5
10
8
6
4
2
0

Fig 7



1.0
0.8
0.6
0.4
0.2
0.0
Ratio K0/hadron (Produced)
0
1
2
3
4
P_T (GeV/c)
(u,d,s,c)
(u,d,s)