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Radiative Charged Current Interactions at HERA

H1 Collaboration

Abstract

A search for processes producing large missing transverse momentum in conjunction with an energetic, isolated photon in e^+p collisions is reported. The data were collected at the HERA collider in the years 1994 to 2000, during which $27.5\,\mathrm{GeV}$ positron beams were in collision with 820 and $920\,\mathrm{GeV}$ proton beams. The data were recorded with the H1 detector, and correspond to an integrated luminosity of $100.9\,\mathrm{pb}^{-1}$. The data are presented, within the context of the Standard Model, as the first measurement of the cross section for radiative charged current interactions.

1 Introduction

Measurements of the inclusive cross sections for neutral current ($e^+p \to e^+X$) and charged current ($e^+p \to \bar{\nu}X$) processes[1] demonstrate sensitivity to the partonic structure of the proton and to the properties of the γ, Z^0 and $W^\pm$ propagators. Charged current interactions with final states containing an isolated, energetic photon in addition to significant missing transverse momentum ("radiative charged current interactions") are sensitive to the size of radiative corrections to the inclusive charged current cross section. In the standard model the rate of such interactions thus receives a contribution from the $WW\gamma$ triple boson vertex. An anomalous rate of such interactions could be related to the "anomalous couplings", $\Delta\kappa$ and λ, related to the magnetic dipole and electric quadrupole moments of the exchange propagators respectively. Non-zero values for $\Delta\kappa$ orλ would be consistent with physics beyond the standard model (BSM). Several putative BSM processes, for example the production and subsequent decay of excited neutrinos, produce "radiative charged current" final states. A failure of the standard model to predict the rate or properties of such interactions would also call into question the validity of the radiative corrections applied in the estimation of the born cross sections for inclusive neutral and charged current interactions.

This paper summarises the differences between this analysis and that of the inclusive cross section measurements, and presents the first cross section measurement for radiative charged current interactions.

2 Definition of the Cross Section

The events considered in this analysis are a subset of those selected for the measurement of the inclusive charged current cross section [1]. An important variable is the transverse momentum P_T^{miss}, defined

$$(P_T^{miss})^2 = \left(\sum_i P_X^i\right)^2 + \left(\sum_i P_Y^i\right)^2 \tag{1}$$

where the sum is over all i final state particles (excluding neutrinos). The $x - y$ plane is perpendicular to the z axis defined by the direction of the proton beam. A large value of P_T^{miss}, indicating a large missing transverse momentum, is characteristic of an energetic final state neutrino or antineutrino. The selection of charged current events in this analysis is identical to that of [1] except that the data are restricted to the range $P_T^{miss} > 25\,\mathrm{GeV}$.

Within this sample a search is performed for events containing one or more isolated photons. Photons are required to have transverse momentum greater than $3\,\mathrm{GeV}$ and $25^\circ < \theta_\gamma < 145^\circ$. An isolation of at least 0.5 units in $\eta-\phi$ between the photon and the nearest jet with $P_T > 5\,\mathrm{GeV}$ is required. Jets are defined according to the inclusive K_T algorithm such that all final state particles are included in a jet. The cross section is fully corrected for all effects arising from finite efficiencies and resolutions such that it corresponds to this kinematic region, summarised in table 1.

3 Experimental Procedure

The e^+p data used in this analysis were collected in the years between 1994 and 2000 and amount to a total integrated luminosity of $100.9\,\mathrm{pb}^{-1}$. Data were collected with proton beams of both $820\,\mathrm{GeV}$ and $920\,\mathrm{GeV}$. The luminosity weighted average centre of mass energy is $\sqrt{s} = 313\,\mathrm{GeV}$.

In addition to the selection requirements applied in the inclusive charged current analysis [1] and the requirement that $P_T^{miss} > 25\,\mathrm{GeV}$, isolated photons are identified using three basic properties. First, they will produce compact clusters in the electromagnetic section of the calorimeter. Second, they will not be associated with a charged track in the tracking chambers. Third, they will be isolated from other activity. The selection for isolated photons requires that all of the following criteria are satisfied.

- $P_T^\gamma > 3\,\mathrm{GeV}$.
  P_T^γ is the transverse momentum of the photon candidate.

- $E^\gamma_{e.m.}/E^\gamma > 0.95$.
  E^γ is the energy of the photon candidate. $E^\gamma_{e.m.}$ is the fraction of this energy in the electromagnetic section of the H1 LAr calorimeter. The calorimeter design is such that electromagnetic particles will usually deposit the majority of their energy in the electromagnetic section, whereas hadronic particles will usually deposit energy in both the electromagnetic and hadronic sections.

- $-225\mathrm{cm} < z_{impact} < 150\mathrm{cm}$.
  z_{impact} is the z coordinate, defined with respect to the nominal interaction point, of the photon candidate cluster centre of gravity. The event by event variation in the interaction vertex makes a cut on z_{impact} preferable to a cut on θ. This z range corresponds approximately to the range $25° < \theta_\gamma < 145°$ for which the cross section is calculated.

- $R_{\gamma-clus} > 0.5$ **if** $P_T^{clus} > 0.5\,\mathrm{GeV}$
  $R_{\gamma-clus}$ is the separation in the $\eta - \phi$ plane between the photon candidate and the nearest cluster with transverse momentum P_T^{clus} above $0.5\,\mathrm{GeV}$.

- $R_{\gamma-jet} > 0.5$
  $R_{\gamma-jet}$ is the separation in the $\eta-\phi$ plane between the photon candidate and the nearest jet, defined according to the inclusive K_T algorithm. This cut and the previous cut distinguish between genuine isolated electromagnetic particles from spurious candidates formed by an electromagnetic component of a hadronic shower or jet.

- $R_{\gamma-track} > 0.5$ **if** $P_T^{track} > 0.8\,\mathrm{GeV}$ **and** $r_{CJC} > 44\mathrm{cm}$**.**
  This cut rejects electromagnetic clusters associated with a charged track. Only tracks with starting radii within the inner most central drift chamber are considered as there is a significant probability that photons will convert into e^+e^- pairs in the material between the inner and outer drift chambers.

The efficiency of this isolated photon selection is studied with the aid of a Monte Carlo simulation of neutral and charged current events produced by the DJANGO program in conjunction with the H1 simulation and reconstruction software [1]. The efficiency is found to be between 70% and 90% with no strong variation as a function of the position or transverse momentum of the photon candidate. The fraction of events passing these cuts which do not contain an isolated photon is estimated to be less than 1%. This background is found to be dominated by neutral current events in which the scattered lepton is misidentified as a photon.

4 Results

A total of 17 events with missing transverse momentum and one or more isolated photons are observed in the entire data sample, compared to SM prediction of $16.14{\pm}0.27$, including an estimated background of 0.16 ± 0.03 events. The properties of these events are summarised in the distributions shown in figure 1. The data are everywhere in good agreement with the SM prediction. The cross section for $e^+p \to \nu\gamma X$ for $P_T^{miss} > 25\,\mathrm{GeV}$, $P_T^{\gamma} > 3\,\mathrm{GeV}$, $25^\circ < \theta^\gamma < 145^\circ$ and $R_{\gamma-jet} > 0.5$ is $\sigma_{data} = 0.208 \pm 0.066(stat) \pm 0.062(syst)\mathrm{pb}$ for an average $\sqrt{s} = 313\,\mathrm{GeV}$. The systematic error includes all of the sources of uncertainty considered in the inclusive charged current analysis and additional uncertainties associated with the isolated photon selection procedure. The SM cross section is estimated to be $\sigma_{django} = 0.192 \pm 0.032\mathrm{pb}$ with the DJANGO Monte Carlo, in good agreement with the measurement. These results are summarised in table 1. Further details of the analysis are described in [2].

5 Conclusions

The first measurement of the cross section for the production of events with large missing transverse momentum and an isolated photon is presented. The cross section for $e^+p \to \nu\gamma X$ for $P_T^{miss} > 25\,\mathrm{GeV}$, $P_T^{\gamma} > 3\,\mathrm{GeV}$, $25^\circ < \theta^\gamma < 145^\circ$ and $R_{\gamma-jet} > 0.5$ is found to be $\sigma_{data} = 0.208 \pm 0.066(stat) \pm 0.062(syst)\mathrm{pb}$, in good agreement with the expectation of the standard model.

References

[1] H1 Collab., C. Adloff et al., Eur. Phys. J. C19 (2001) 269-288 , 12/00.

[2] A. Burrage, PhD Thesis, University of Liverpool, 2000.

Cross Section for Radiative Charged Current
p_t^{miss} >25 GeV $p_t^\gamma > 3\,\mathrm{GeV}$ $2\ 5^o < \theta^\gamma < 145^o$
$R_{jet-\gamma} > 0.5$ for $p_t^{jet} > 5\,\mathrm{GeV}$
e^+p at $\sqrt{s} = 313\,\mathrm{GeV}$ H1 preliminary
σ_{data} = 0.208 ± 0.066 ± 0.048 pb
σ_{django} = 0.192 ± 0.004 pb

Table 1: Definition of the kinematic range for the cross section measurement of radiative charge current events. The combined cross section for the entire data sample is shown, together with the prediction from the DJANGO Monte Carlo (see text). The uncertainties quoted for the data are statistical and systematic in origin respectively. The uncertainty on the Monte Carlo prediction is purely statistical.

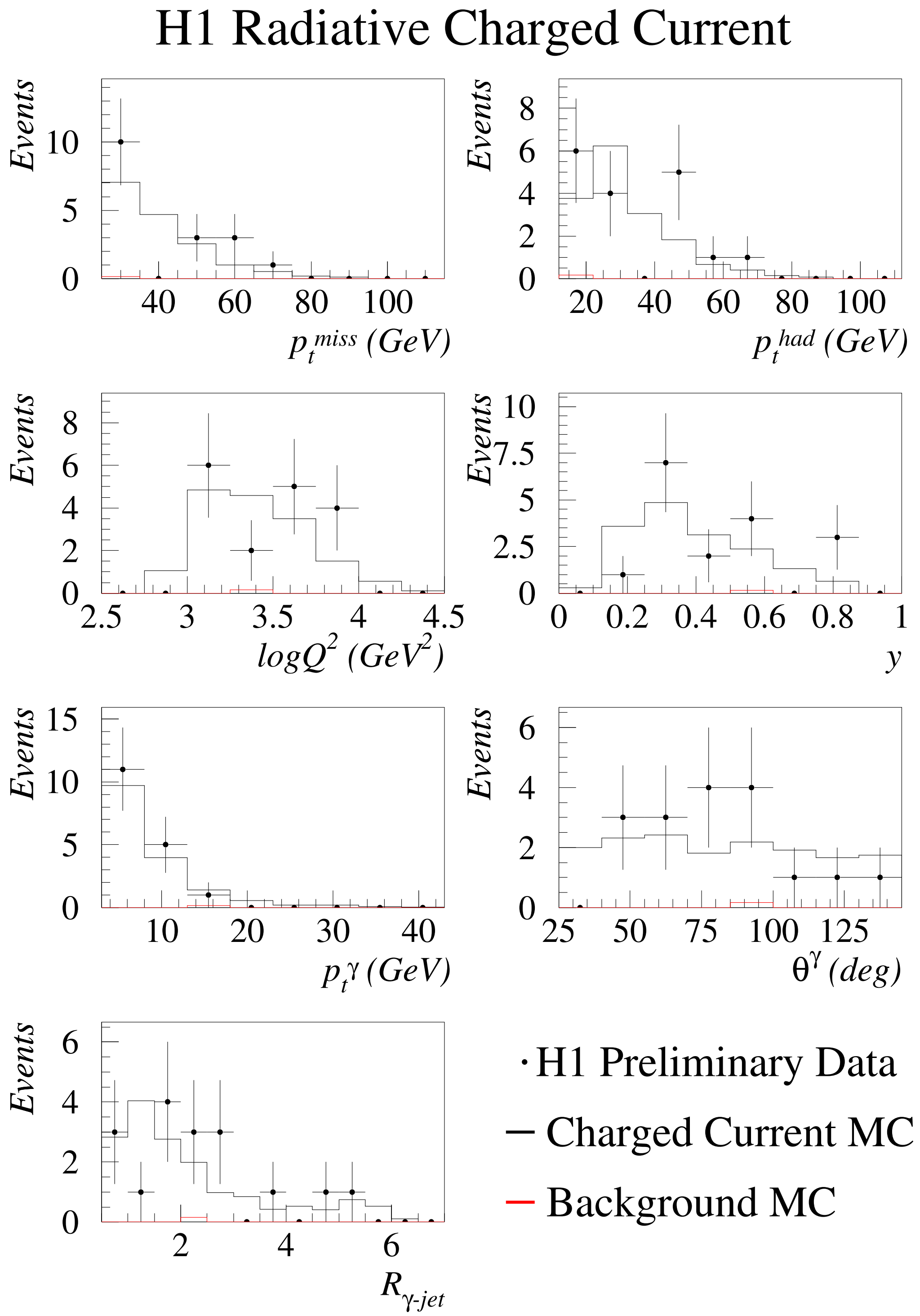

Figure 1: Distributions illustrating the properties (see text) of events with missing transverse momentum and one or more isolated photons. The points are the data and the solid black line the standard model prediction. The solid red line is the estimated background from events which do not contain an isolated photon, which is dominated by neutral current processes in which the scattered lepton is misidentified as a photon.