A Global Study of Photon-Induced Jet Production

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We present results of a global tuning of general purpose Monte Carlo models to published measurements of $\gamma p \rightarrow \text{jets}$ at HERA and $\gamma \gamma \rightarrow \text{jets}$ at LEP and TRISTAN. The principle free parameters in the tuning are the simulation of the underlying event and the choice of photon structure. Several combinations of models are ruled out by the data. Some consequences of the tuned models at a future linear collider are discussed.

1. INTRODUCTION

A systematic examination of the manner in which data is described by Monte Carlo models can give valuable insight into the underlying physics involved. However, many such comparisons are to a single result, limiting the extent to which physics conclusions can be drawn and raising the possibility that agreement is achieved in one cross section at the expense of another. The aim of this study is to tune, for the first time, general purpose Monte Carlo models to the existing and expanding set of jet photoproduction data. To that end, we have compared model predictions to published inclusive jet, di-jet and 3-jet data from the ZEUS [1–7] and H1 [8,9] experiments at HERA, the OPAL [10,11] experiment at LEP, and the TOPAZ [12] and AMY [13] experiments at TRISTAN. The inclusion of both $\gamma p$ and $\gamma \gamma$ data (see figure 1) is particularly significant for constraining the tuning.

Our tuning currently focuses on the role of the so-called “underlying event” in hadronic jet production and the extent to which this can be described by perturbative QCD inspired models. We constrain the multiparton interaction (mini-jet) models contained within the Monte Carlos described below, and use these tunings to estimate backgrounds at future colliders.

Such a tuning can also lead to a number of practical benefits. The method employed allows us to check the consistency of the data contained in the various publications, which ranges across different colliders, experiments, years, energies, kinematic regions etc. A better description of the data by the models can be expected to lead to a reduction in the systematic errors due to detector corrections in future measurements.

2. THE MODELS

The models tuned were HERWIG 5.9 [14], interfaced to the JIMMY [15] eikonal model for
multiparton interactions, and PYTHIA 6.125 \cite{1}, which contains a new (since version 5.7) mode aiming to simulate the virtuality of the bremsstrahlung photons \cite{17}. For HERWIG, a previous tuning to DIS data (CLMAX=5.5, PSPLIT=0.65) \cite{13} was used. In addition to the default mode, preliminary investigations were carried out on a modification to HERWIG, whereby the intrinsic transverse momentum distribution of the partons in the photon takes the form of a power law rather than a gaussian. This modified version, referred to as HERWIG+$k_T$, was motivated by studies at HERA \cite{19} and at LEP \cite{20} which indicate that it can lead to a better description of the data.

The main free parameters investigated in the tuning are the description of the “underlying event” and the choice of photon structure. Multiple hard scatters, illustrated in figure 2, can be enabled or not, and it is expected that some of the distributions studied will exhibit great sensitivity to this phenomenon. The other facet of the underlying event is the minimum transverse momentum of the hard scatter(s), hereafter referred to as $\hat{p}_T^{\text{min}}$. Sensitivity to this parameter is greatly increased when multiple interactions are turned on. As one goes to lower $\hat{p}_T$, higher parton densities are being probed, leading to an enhanced probability that more than one hard scatter will occur. It should also be noted at this point that, whilst HERWIG employs a cluster fragmentation scheme, PYTHIA uses string hadronization.

A number of different parameterisations of the photon structure function were investigated. Only leading order sets were used since the matrix elements in the Monte Carlo models are leading order. The sets used were GRV 92 \cite{21}, WHIT2 \cite{22}, SaS1d and SaS2d \cite{23}, and LAC1 \cite{24}. Throughout this work the GRV 94 LO \cite{25} proton pdf was used in the simulation of HERA data.

Finally, the overall normalisation of the Monte Carlo was treated as a tunable parameter. This is justified within a range of about a factor of two or less because of the uncertainty in the scale of $\alpha_s$.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure2.png}
\caption{An example of a multiple scattering.}
\end{figure}

3. FITTING METHOD

This work was carried out within the framework of a package developed by the HERA community to permit easy comparison of data to Monte Carlo \cite{26}. Extensions were made to facilitate the inclusion of the $\gamma\gamma$ data.

The procedure for finding the best fit, for a given set of parameters, of the Monte Carlo to the data was as follows. An overall $\chi^2$ per degree of freedom across all the distributions (some 50 in all) was defined as:

$$
\chi^2 = \frac{1}{n-1} \sum_{i=1}^{n} \frac{(\text{MC}(i) - \text{Data}(i))^2}{\sigma_{\text{MC}(i)}^2 + \sigma_{\text{Data}(i)}^2}
$$

where Data(i) and MC(i) are the values of the distribution in a given bin $i$ for the data and Monte Carlo respectively. The sum runs over the total number of bins $n$ in all the distributions.

The aim was to minimise this $\chi^2$, and a good fit is when it is approximately one or less. The normalisation of the Monte Carlo was varied to find the best fit (The sum in equation (1) is divided by $n - 1$ rather than $n$ to take into account the resulting loss of a degree of freedom). For the HERA distributions, each data plot was allowed to float within the quoted correlated error (typically of 15-20%) and the number of plots was then subtracted from $n$ as well. Otherwise, all
systematic and statistical errors were treated as uncorrelated and added in quadrature.

The distributions from TRISTAN were not included in the fitting procedure. There appears to be a discrepancy between the TOPAZ and AMY results. Indeed, this has been observed in a previous study \[27\].

4. RESULTS AND DISCUSSION

Table 1
HERWIG results (multiparton interactions on, \textbf{not} $k_t$ version). The $\chi^2$ per degree of freedom for a particular parameter set is given first for the combined fits (see text), and then for the separate HERA and LEP fits.

| p.d.f. | $\hat{p}_{T\min}$ | $\chi^2$/D.o.F. | HERA  | LEP  |
|--------|-------------------|-----------------|-------|------|
| WHIT 2 | 1.6               | 3.29            | 4.24  | 1.06 |
|        | 1.8               | 1.89            | 2.27  | 0.99 |
|        | 2.0               | 1.08            | 1.11  | 0.99 |
|        | 2.2               | 1.08            | 1.07  | 1.08 |
|        | 2.4               | 1.47            | 1.60  | 1.14 |
| GRV 92 | 1.6               | 1.03            |       |      |
|        | 1.8               | 1.47            | 1.71  | 0.89 |
|        | 2.0               | 1.35            | 1.46  | 1.09 |
|        | 2.2               |                 |       |      |
| SaS 1d | 1.4               | 2.01            | 2.30  | 1.31 |
|        | 1.6               |                 |       | 1.65 |
|        | 1.8               | 1.37            | 1.16  | 1.81 |
| SaS 2d | 1.6               | 1.57            | 1.81  | 0.98 |
|        | 1.8               | 1.28            | 1.40  | 0.97 |
|        | 2.0               |                 |       | 1.31 |
|        | 2.2               | 1.27            | 1.25  | 1.31 |
| LAC 1  | 2.2               | 8.70            | 10.54 | 4.35 |
|        | 2.6               |                 |       | 2.14 |

The results of the fits using HERWIG (\textbf{not} the $k_t$ version) are shown in table 1, and those for PYTHIA in table 2. Full details of all the fits, including the individual plots, can be found at [http://www.hep.ucl.ac.uk/~jmb/HZTOOL/](http://www.hep.ucl.ac.uk/~jmb/HZTOOL/). Figure 3 shows a summary of the results in graphical form. In most cases there is a clear, favoured value of $\hat{p}_{T\min}$, and overall - at least where reasonable fits are found - there appears to be a favoured range of $\sim 1.6 - 2.2$ GeV. Note that although we do not constrain the $\hat{p}_{T\min}$ to have the same value for both LEP and HERA fits, when we combine to give an overall $\chi^2$ we have taken those runs with the same $\hat{p}_{T\min}$. This is motivated by the idea that, as one moves toward low transverse momentum, two effects can render perturbative QCD inapplicable. Not only does $\alpha_s$ become large, but $x$ becomes small, potentially leading to large $\ln(x)$ corrections. Our conjecture is that if $\alpha_s$ effects are independent of the centre of mass energy, then $\hat{p}_{T\min}$ can be considered to be a universal parameter. The low $x$ effects are modelled by multiple interactions, and so the minijet model is “universal”, but different effects are seen depending on the cms energy and beam particle type. All the results shown have multiple interactions enabled. The agreement without multiple interactions is very poor. A particularly striking example of this is shown in figure 4, and it is low $E_T^{jet}$ measurements such as this which are especially valuable for constraining multiple interaction models.
The scaling of the overall normalisation generally agrees between LEP and HERA for the good fits, and is in the range $1.2 - 1.3$. In addition, there is general consistency between different datasets for both LEP and HERA. With regard to pdf sets, WHIT and GRV lead to better fits for HERWIG, whereas for PYTHIA there are no good fits to LEP data for sets other than the SaS sets. In no circumstances does it appear possible to obtain anything close to a good description of the data with LAC1.

The DIS tuned parameters for HERWIG do help, if only marginally, but there is no firm evidence yet that the HERWIG+$k_t$ modification improves matters.

5. LINEAR COLLIDER

The results of the tuning can be used to estimate photon-induced minijet backgrounds at future colliders. The best fits found using HERWIG have been extrapolated to linear collider energies ($\sqrt{s} = 500$ GeV), with the TESLA beamstrahlung and bremsstrahlung spectra included. The parameters thus used were the WHIT 2 photon pdf and a $\hat{p}_T^{\text{min}}$ of 2.0 GeV with multiple interactions enabled. The overall normalisation was scaled by a factor of 1.4. The estimate for the minijet transverse momentum cross-section is shown in figure 5.

The results are consistent at the 50% level with independent studies using PYTHIA and the DELPHI Monte Carlo. They indicate that the backgrounds will not be a concern for detector occupancy and dosage, but that minijets potentially present a very significant background to physics owing to the high $\hat{p}_T$ tail.
Figure 5. Jet transverse energy differential cross section in the barrel (top) and endcap (lower) calorimeters of the TESLA conceptual design report detector [30], for the high luminosity TESLA option.

6. CONCLUSIONS

The general purpose Monte Carlo models HERWIG and PYTHIA have been tuned to jet photoproduction data from LEP and HERA. An optimal range of hard scales appears to emerge, and some level of multiparton interactions is found to be necessary in these models in order that an adequate description of the data be achieved. Favoured sets of parton distribution functions are established for each generator but currently no generator independent conclusion on photon structure is drawn. The HERWIG tuned parameters are used to estimate photon-induced backgrounds at the linear collider. This work is ongoing and up-to-date results can be found on our web page http://www.hep.ucl.ac.uk/~jmb/HZTOOL/.

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