TUNING MC MODELS TO FIT DIS e\gamma SCATTERING EVENTS

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Monte Carlo models of DIS e\gamma scattering must describe hard emissions as well as the soft and collinear limits. Comparison with the observed experimental hadronic energy flow has shown that various models underestimate the high-\pt contribution, in particular at low \x. We have attempted to tune the HERWIG, PYTHIA and ARIADNE models to improve the agreement with the data, and to understand the physical implications of the changes required. Unless the physics of these processes is understood it will not be possible to unfold the photon structure functions \Fg from the $e^+e^-$ data without large model dependent systematic errors.

1 The Problem

The measurement of \Fg in deep inelastic e\gamma scattering, where only one of the electrons is "tagged" in the detector and the other one escapes unseen, involves the determination of the $\gamma^*\gamma$ invariant mass \Wvis from the hadronic final state. Because of the non-uniform detection efficiency and incomplete angular coverage the correlation between \Wvis and \W critically depends on the modelling of the hadronic final state. It has been shown\textsuperscript{1)} that there exist serious discrepancies in the description of this hadronic final state. Fig. 1 shows the transverse energy out of the plane, defined by the tag and the beam. For \xvis > 0.1 all of the generators are adequate, but for \xvis < 0.1 they are mutually inconsistent, and in disagreement with the data. At high \Et out the data show a clear excess over HERWIG\textsuperscript{2)} and PYTHIA\textsuperscript{3)}, while the pointlike F2GEN\textsuperscript{4)} sample exceeds the data. Similar discrepancies are observed in the hadronic energy flow per event\textsuperscript{1)} where both HERWIG and PYTHIA overestimate the energy in the forward region (|\eta| > 2.5) and underestimate the energy in the central region of the detector.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Transverse energy out of the tag plane.}
\end{figure}
2 The Tools

To study the contributions of the various partons, the Pythia/Ariadne energy flow in the lab frame as a function of pseudorapidity is plotted in Figure 2 for the quark that couples to the off-shell probe photon $\gamma^*$, denoted the probe quark, and for the quark that couples to the quasi-real target photon $\gamma$, denoted the target quark. The total energy flow of all partons after gluon radiation is also shown. The direction of the tagged electron is always at negative $\eta$. It is apparent that the hump at negative $\eta$ stems mostly from the probe quark which is scattered in the hemisphere of the tag, while the hump at positive $\eta$ originates mostly from the target quark in the opposite hemisphere of the struck photon.

From comparisons of the hadronic energy flow of the data with the various models, it became apparent that the energy flow of the probe quark needs to be shifted to lower $\eta$, corresponding to an increased transverse energy. This can be achieved in several ways:

Anomalous events carry more transverse momentum than hadronic events. Figure 3a) shows the partonic energy flow after gluon radiation. Increasing the fraction of anomalous to hadronic or VMD type events would have the desired effect, but the parton density functions (PDF) used (in this case SaS1D in Pythia and GRV in Herwig) does not readily allow changing this ratio.

Another way to increase the transverse energy is to allow for more gluon radiation. This can be achieved by augmenting the inverse transverse size of the remnant, $\mu$, in the Ariadne colour dipole model, shown in Figure 3b). $\mu$ is set proportional to the intrinsic $k_T$ of the struck quark on an event-by-event basis. For VMD events, $k_T$ is gaussian with a width of 0.5 GeV. For anomalous events $k_T$ follows a power law. But even a generous increase of the $\mu$ parameter ($\mu = 10$) has a relatively small effect on the partonic energy flow.

Increasing the intrinsic transverse momentum $k_T$ of the struck photon is another way of directly influencing the angular distribution of the hadronic final state. Figure 3c) shows the energy flow for Pythia events with default settings and enhanced $k_T$. This appears to be the most promising method.
3 The Fix

In PYTHIA the PDF determines whether an event is generated as a VMD or an anomalous event. The intrinsic $k_T$ of the quasi-real photon can be controlled with parameters. Just increasing the width of the gaussian distribution does not produce events that populate the region of high $E_{\text{t, out}}$ at low $x$ observed in the data (Fig. 4). A similar deficiency had been observed in the resolved photoproduction data at Zeus, which lead to the introduction of a power-like $k_T$-distribution of the form $dk_T^2/(k_T^2 + k_0^2)$, improving the distributions of the photon remnant. $k_0$ is a constant, for which 0.66 GeV was used. The PYTHIA parameters only allow adjusting the $k_T$ for VMD type events, figure 6, but not for anomalous ones. To change the intrinsic $k_T$ of anomalous events a gaussian smearing is added in quadrature.

Figure 5 show the $E_{\text{t, out}}$, and figure 7 the hadronic energy flows on detector level of PYTHIA with default parameter settings and with the $dk_T^2/(k_T^2 + k_0^2)$ distribution for VMD plus a gaussian smearing of the anomalous events, compared to the OPAL data taken in 1993–1995 at $\sqrt{s_{ee}} = 91$ GeV. In addition the ARIADNE distributions with enhanced gluon radiation are shown. While the $E_{\text{t, out}}$ spectrum has been improved, it still falls short of the data in the tail of the distribution. The hadronic energy flow generated by the enhanced PYTHIA recreates the peak on the remnant side (positive $\eta$) seen in the data at low $x_{\text{vis}}$, at the expense of a somewhat worse fit on the tag side.

The 2-jet rates, listed in Table 1, found with the cone algorithm, requiring
a minimum $E_{T,\text{jet}} > 3$ GeV in the pseudorapidity range of $|\eta_{\text{jet}}| < 2$ are almost doubled over the default version of Pythia, but are still substantially lower than the data.

HERWIG separates events dynamically into hadronic and anomalous type. A similar $dk_T^2/(k_T^2 + k_0^2)$ distribution of the intrinsic transverse momentum of the photon can be added by hand. The results of this are shown in figures 5 and 6. Both the $E_{\text{out}}$ and the energy flows are greatly improved with the inclusion of the power-like $k_T$ distribution, with the exception of the peak in the energy flow at low $x_{\text{vis}} - \text{high } Q^2$, which still falls short of the data.

The cone algorithm 2-jet rate, listed in Table 2, is more than doubled over the default version of HERWIG and is in agreement with the data.

### 4 Conclusion

The power-like distribution of the intrinsic transverse momentum of the struck photon of the form $dk_T^2/(k_T^2 + k_0^2)$ greatly improves the hadronic final state distributions of both Pythia and HERWIG. This improved description of the data should reduce the model-dependent systematic errors in the unfolded result of the photon structure function $F_2^\gamma$. More fine-tuning is required.
It should be stressed, though, that this is just an *ad hoc* solution which does not explain the origin of the discrepancies. It appears that the photon displays a more pointlike behaviour at low $x$ than predicted. $F_2^\gamma$ and the $\gamma^*\gamma$ fragmentation are not orthogonal. Changing the latter will affect the measurement of the former. A thorough enquiry is urgently needed.

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