1 Introduction

In view of the LHC starting to provide $pp$ collisions at $\sqrt{s} = 14$ TeV in 2007 and a future $e^+e^-$ linear collider in the TeV range, new tools for the Monte Carlo simulation of multi-hadron final states are required. These tools will once be faced with the most precise measurements in high energy particle physics – this aspect dictating their improved physics content. In addition transparency and maintenance of these codes become an issue and therefore the object oriented language C++ was chosen to write them. Beside the rewrites of the well-established tools Pythia 1 and Herwig 2, namely Pythia7 3 and Herwig++ 4, another approach is available with the program Sherpa 5. One of the striking features of Sherpa is the inclusion of the CKKW prescription to combine multi-jet matrix elements with parton showers 6. This method allows a consistent description of multi-jet final states and a combination of such higher order calculations with the non-perturbative regime of hadron production in an universal manner. Even though the public Sherpa version 7 contains an interface to the Pythia string fragmentation, strong efforts have been made to develop a fragmentation model for Sherpa 8 that relies on the cluster fragmentation ansatz used within Herwig 9.

2 The Cluster Model

A typical cluster fragmentation model consists of two parts: first, primary clusters are formed and, following this, such colour neutral states decay into hadrons and/or secondary clusters, which, in turn, decay further.

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In the first step the partons emerging from the parton shower are brought to their constituent masses; this includes a finite gluon mass. The gluon then is forced to split into a light quark-antiquark ($q\bar{q}$) or antidiquark-diquark ($\bar{D}D$) pair. The resulting triplet and antitriplet states are combined to obtain colour-neutral clusters. The model thereby allows for the incorporation of soft colour reconnection effects, which lead to configurations that are beyond the planar structure given by the parton shower evolution. However, these configurations are suppressed by a combined weight of $1/N_C^2$ and a kinematic function. After this first step four different cluster types can arise, mesonic ($q\bar{q}$ and $\bar{D}D$), baryonic ($qD$) and antibaryonic ($\bar{D}q$).

In the second step the primary clusters, continuously distributed in mass with a peak at low cluster masses, have to be transformed into observable hadrons featuring a discrete mass spectrum. This is achieved by binary cluster decays and converting individual clusters into single primary hadrons. The model so far does not incorporate the subsequent decay of unstable hadrons. This task is still handled by the corresponding Pythia routines. Beside the request of locality and low momentum transfer in cluster decays, the model relies on a dynamic separation of clusters and hadrons. This implies that according to the flavour of its constituents a cluster is supposed to be a hadron, if its mass is below a certain threshold. Similar to the case of cluster formation, the model for cluster decays incorporates the possibility for soft colour reconnection. Thereby a quark-antiquark pair or antidiquark-diquark pair produced to disintegrate the cluster can recombine. Again these configurations are suppressed according to $1/N_C^2$ and a kinematic weight.

The model so far is restricted to the fragmentation of light quarks ($uds$) and gluons produced in $e^+e^-$ annihilation. Nevertheless various observables and distributions can be studied in order to validate the model. Figure 1 shows the mass distribution of the primary clusters at $e^+e^-$ collisions for different
energies proving the universality of the approach. Table 1 contains the mean multiplicities of $\pi^\pm$, $K^\pm$ and $p$, $\bar{p}$ in comparison with experimental $uds$ results and Pythia and Herwig. In Figure 2 the charged particle hemisphere multiplicity distribution and the charged particle scaled momentum prediction are compared to OPAL$^{12}$ and SLD$^{11}$ data, respectively, again taking into account $uds$ events only.

3 Conclusion

The cluster-hadronization model developed for Sherpa proved to work successfully for $e^+e^-$ annihilation events into light-quark and gluon jets. First tests show a satisfactory agreement with experimental data. Some cluster model shortcomings, such as the too low charged-particle multiplicities, could be cured; and the spectrum of the scaled momentum could be improved. The model will soon be extended to cover heavy-quark hadronization and the fragmentation of beam remnants in hadron-hadron collisions.

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Primary cluster mass distribution with CRM

![Graph showing primary cluster mass distribution]

**Figure 1:** The primary cluster mass distribution in $e^+e^-$ annihilation events for different centre of mass energies using the colour reconnection model (CRM).

Charged particle hemisphere multiplicity distribution

![Graph showing charged particle hemisphere multiplicity distribution]

Charged particle scaled momentum distribution

![Graph showing charged particle scaled momentum distribution]

**Figure 2:** Predictions for the hemisphere multiplicity distribution (left) and the scaled momentum distribution (right) of charged particles considering the light-quark sector only. Results are compared to OPAL and SLD data, respectively.