EUROJET, A MONTE CARLO PROGRAM FOR JET SIMULATIONS

B. van Eijk

NIKHEF, Amsterdam, Netherlands

ABSTRACT

Recent observations at the $p\bar{p}$ Collider raised the question whether one could compute prompt lepton and associated jet activities by relatively simple Monte Carlo calculations. It turns out that lowest order and leading logarithm approximations do not fit the experimental data in detail (for example, jet activity in $W^\pm$ and $Z^0$ events).

Here the first results are reported of a Monte Carlo program which contains higher order corrections based on perturbative QCD. A comparison is made with available dimuon data of the UA1 Collaboration at CERN.

Presented at the 5th Topical Workshop on
Proton-Antiproton Collider Physics
Saint-Vincent, 25 February - 1 March 1985

*) This program was written in collaboration with A. Ali and E. Pietarinen.
**) Visitor at CERN, Geneva, Switzerland.
1. INTRODUCTION

A well accepted method to describe strong interactions, in regions where one is dealing with high-momentum particles, is perturbative quantum chromodynamics (QCD). This theory gives a framework to calculate cross-sections for parton-parton interactions. We have made a first attempt to explain prompt lepton production at the p̅p Collider. In p̅p interactions, leptons are produced via the Drell-Yan mechanism, Intermediate Vector Bosons (IVBs), as well as diffractive processes.

The main source, however, seems to be the semi-leptonic decay of heavy flavours which are contained in jets. We will therefore concentrate on the production of heavy flavours.

In perturbation theory, the lowest order ($\alpha_s^2$) and next to lowest order ($\alpha_s^3$) contributions can be expressed in terms of the Feynman diagrams in Figs 1a and 1b. A closer look at these tree-level diagrams reveals that the first three diagrams in Fig. 1b can be interpreted as the radiative (bremsstrahlung) corrections to the lowest order graphs. The fourth graph in Fig. 1b (quark-gluon scattering) forms an independent contribution and hence cannot be marked as a radiative correction to the lowest order process. The dots in Fig. 1b express the contribution of similar graphs where a permutation between the legs is made. The mass of the heavy quarks ($Q, \bar{Q}$) forms an important part of the calculation. The mass regulates the behaviour of the matrix element both at lowest order$^1$ and next to lowest order$^2$. However, the massless gluon gives rise to divergences in the matrix element. These divergences can be removed by taking into account the virtual corrections. These calculations are not yet available. Nevertheless, by imposing a cut on the transverse momentum of the gluon, one is able to remove the divergences. The importance of the $O(\alpha_s^3)$ contributions depends strongly on the experimental trigger conditions. A detailed discussion is presented elsewhere$^3,4$)
Besides the amplitudes for the various processes there are several other ingredients for a model that can predict distributions and cross-sections. The parton model cross-section can be written in the following form:

$$\sigma(p_k) = \sum_{i,j} \int dx_1 \, dx_2 \, f_i(x_1, Q^2) f_j(x_2, Q^2) \, \sigma_{i,j}(x_k)$$

where $f_i$ are the parton distributions and $i, j$ run over the parton species. So first of all one needs to specify the distribution of quarks, antiquarks, and gluons inside the colliding hadrons. These distributions are obtained mainly from neutrino and fixed-target experiments. Extrapolation to $x$ and $Q^2$ values required at collider energies is performed using the Altarelli-Parisi equations\(^\text{5}\). For an
evaluation of parametrizations found in the literature, see, for instance, the paper by Ellis\textsuperscript{6}).

In order to get detailed lepton distributions, the Monte Carlo program includes several steps. After the generation of the heavy quarks (t, b, c), each quark is fragmented using a longitudinal fragmentation model\textsuperscript{7}). This results in the following average energy fractions ($\langle z \rangle$) carried by the meson (baryon):

\begin{align*}
\text{charm} & : \langle z_c \rangle = 0.6 \\
\text{bottom} & : \langle z_b \rangle = 0.8 \\
\text{top} & : \langle z_t \rangle = 0.95
\end{align*}

During the fragmentation process, the hadron is given a relative transverse momentum with respect to the original quark direction ($\langle p_T \rangle = 0.4 \text{ GeV/c}$). As a next step the heavy quark contained in the hadron will decay. For this the full V-A matrix elements have been included\textsuperscript{8}). Using this scheme, consequently a top quark will fragment and follow the cascade down to the level of (pseudo-) stable particles (t + b + c + s).

2. THEORETICAL DISTRIBUTIONS

We calculated the inclusive quark, muon, and dimuon transverse momentum distributions for the order $\alpha_s^2$ and $\alpha_s^3$ processes at $\sqrt{s} = 540 \text{ GeV}$. We used the Glück et al.\textsuperscript{9}) structure functions with the QCD scale $\Lambda = 0.3 \text{ GeV}$. Although $\Lambda$ enters into the strong coupling constant, differences with other parametrizations stay roughly within 20%. Masses for the quarks were fixed at $m_c = 1.87 \text{ GeV/c}^2$, $m_b = 5.2 \text{ GeV/c}^2$ and $m_t = 40 \text{ GeV/c}^2$. To regulate the $O(\alpha_s^3)$ cross-section we made an arbitrary thrust cut-off:

- 3 -
Thrust = \frac{2 \times \max[E_t^i]}{\sum_i E_t^i} < 0.9, \; i = 1, 2, 3

where \( E_t^i \) is the transverse energy of the i-th jet (this implies a \( p_T \) cut on the heavy quark jets!) Figure 2 shows the inclusive \( p_T \) distribution for charm (dashed line), bottom (dash-dotted line) and top (dotted line) quarks, while the sum is represented by the drawn curve. The quarks had to satisfy a pseudorapidity cut of \( |\eta| < 2.0 \). The dashed lines in Fig. 3 show the individual \( \alpha_s^2 \) and \( \alpha_s^3 \) contributions to the bottom quark cross-section. The lowest order process dominates as a result of the thrust cut on the \( \alpha_s \) processes.)
In order to obtain the inclusive muon and dimuon distributions we applied the 1983 UA1 muon trigger cuts: at least one muon within $|\eta| < 1.3$ and other muons within $|\eta| < 2.0$, all having a $p_T > 3.0$ GeV/c. The results are presented in Figs. 4 and 5 for the inclusive muon and dimuon $p_T$ spectra, respectively. Using the same convention as in Fig. 2, the individual contributions from charm (dashed line), bottom (dash-dotted line), and top (dotted line) are indicated. The drawn curves represent the sum of the individual contributions. The dominance of the lowest order process is indicated in Fig. 2 in the bottom quark case: inclusive muon $p_T$ spectrum (dash-dotted lines) and inclusive dimuon $p_T$ spectrum (dotted lines).

Fig. 4

Fig. 5
3. COMPARISON WITH UA1 DIMUON DATA

The UA1 dimuon data are presented in two separate contributions to this workshop\(^9,10\). We will make a comparison with the data recorded in 1983 and 1984 and restrict ourselves to the intermediate mass dimuon events. For an integrated luminosity of 378 nb\(^{-1}\), 67 dimuon events have been observed requiring \(p_T > 3\) GeV/c for each muon and \(p_T(\mu_1) + p_T(\mu_2) > 10\) GeV/c.

The sample contains 34 events with at least one muon not isolated*); the muon is accompanied by hadronic activity. These events are classified as originating from heavy-flavour decays. (QCD heavy-flavour production or \(Z^0 \rightarrow Q\bar{Q}\).) The contribution from IVB decays into heavy flavours is expected to be small and difficult to disentangle from the QCD processes at the same \(Q^2\) scale.

For comparison with the Monte Carlo program we will neglect the \(Z^0\) contribution. Applying the same cuts as on the data, the spectrum of the individual muons from the Monte Carlo shows excellent agreement with the experimental data (Fig. 6). The theoretical curve has been normalized to the 34 heavy-flavour candidates.

---

\[^*\)A muon is called isolated when the sum of the transverse energy in a cone of \(\Delta R = 0.7\) around the muon is less than 4 GeV\(^2\).]
The invariant mass of the dimuon system is shown in Fig. 7. Events with masses below 5 GeV/c² are originating from decays within the same jet. The theoretical curve in this mass region shows the prediction for the number of cascade decays one would expect. A similar effect is shown in the $p_T$ spectrum of the dimuon system (Fig. 8). The dimuons contained in one jet (or associated with one jet) will have a tendency to higher $p_T$.

The bump around 10 GeV/c is mainly a result of the cut on the sum of the $p_T$'s of both muons. Finally Fig. 9 shows the angular separation of the muons in the plane perpendicular to the beam compared with the Monte Carlo prediction. Further comparisons are shown elsewhere.¹⁰
4. CONCLUSIONS

I have presented the first results on a Monte Carlo program containing higher order QCD corrections. Although a comparison with experimental data has been made without using a full detector simulation, the results seem promising.

We are preparing a detailed analysis using the full UA1 detector simulation. In order to test our model in more detail we expect a significantly enlarged data sample by removing the cut on the sum of the muon $p_T$'s.

Finally, I would like to mention the development of a model containing fragmentations and decays within jets in order to describe jet properties in detail. This will be one of the keys to studying the isolation of the leptons.
ACKNOWLEDGEMENTS

I would like to thank my colleagues in the UA1 Collaboration for many useful discussions, particularly G. Bauer, R. Edgecock, K. Eggert, N. Ellis, H.G. Moser for his help in preparing the plots, and C. Rubbia.

Furthermore, I would like to acknowledge the stimulating collaboration with A. Ali and E. Pietarinen.

REFERENCES


3) Ali, A., this workshop.


10) Ellis, N., this workshop.

11) Leuchs, R., this workshop.