EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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A STUDY OF TRIMUON EVENTS IN 280 GeV
MUON INTERACTIONS

The European Muon Collaboration

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ABSTRACT

In 280 GeV μ^+ iron interactions the inelastic production of muon pairs has been observed in excess of QED processes. For energies greater than 20 GeV deposited in the target calorimeter the interactions are found to be mainly hadronic. Cross sections are presented for this process in the mass range 1-2.5 GeV/c² and in the kinematic regions covered by the apparatus acceptance. The data are in good agreement with a photon-gluon fusion model for charmed particle production.

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The production of muon pairs in muon-nucleon interactions is dominated by standard Bethe-Heitler QED processes but there are several predictions for additional inelastic production. Contributions are expected from vector meson decays, quark bremsstrahlung and Drell-Yan type production [1,2]. Charm particle pair production is also a source of trimuon events through semi-leptonic decays.

The data presented here were taken concurrently with those used for our dimuon measurements [3] and correspond to the same integrated luminosity of $7 \times 10^{37} \text{cm}^{-2}$. The apparatus and trigger conditions are described in the previous letter [3]. Muons at small angles and high momenta were detected only in the two small proportional chambers P0 in the beam. The energy of such muons was determined assuming energy balance and thus neglecting any missing energy.

A clean sample of trimuon events was selected using the following cuts:

- 1) An upstream 3 meter fiducial cut on the STAC target leaving 60cm of iron in 3 active elements to measure and absorb the outgoing shower.
- 2) A 10 GeV/c minimum momentum cut on each of the outgoing muons to suppress the contribution of events from double pion or kaon decay.

With these cuts a sample of 5260 trimuon events of the type $\mu^+N \rightarrow \mu^+\mu^+\mu^-X$ was obtained. For these events the μ^+ with the higher momentum was taken as the scattered muon unless the other μ^+ momentum was greater than half this value in which case the one with the smaller angle was used. The same criterion was applied in all Monte Carlo comparisons. The distribution of mass ($M_{\mu\mu}$) for the remaining muon pairs produced in events with a STAC shower $< 5 \text{ GeV}$ is shown in fig. 1a). The smooth curve is an absolute calculation [4] of Bethe-Heitler production contributing to this sample in which the apparatus acceptance and bremsstrahlung have been included. For this sample there is good agreement between data and calculations above $1 \text{ GeV}/c^2$ and below the J/ψ peak. Below $1 \text{ GeV}/c^2$ the acceptance is changing rapidly and is therefore more difficult to calculate. For events with a STAC shower greater than 5 GeV , bremsstrahlung of a hard photon in

elastic Bethe-Heitler events is a large contribution. These electromagnetic showers have been suppressed in the data after a study of the shower distributions.

To separate hadronic and electromagnetic showers, samples of each measured concurrently in this apparatus have been studied. The hadronic sample consisted of deep inelastic single muon scattering events and the electromagnetic sample of small angle muon scatters accumulated using a beam transmission trigger. The fraction of the total shower energy deposited in the element containing most energy and the number of elements firing downstream of the maximum were used to characterise the showers. For a perfect calorimeter this fraction should be large for electromagnetic and small for hadronic, and the length should be short for electromagnetic and long for hadronic. Showers of energy less than 20 GeV could not be distinguished and such events were rejected from further analysis. For shower energies between 20 and 80 GeV each event was weighted according to its probability to have a hadronic shower. Above 80 GeV the identification was unique.

The weighted $M_{\mu\mu}$ distribution of trimuon events with shower energy greater than 20 GeV is shown in fig. 1b). There is a clear excess of events above the inelastic QED calculation in the whole mass range. Below 1 GeV/c² there are contributions from inelastic ρ -meson production and results for the J/ψ mass region are presented elsewhere [5]. The mass continuum between 1 and 2.5 GeV/c² has been selected therefore for further study. 122 observed events (75.6 weighted events) remain in this mass range. The z distribution for these weighted events is shown in fig. 2 where z is the fraction of the photon energy transferred to the produced muon pair. There is a large excess of events above the calculated inelastic QED contribution. Events with $z < 0.6$ were selected for further investigation.

Of the resulting sample of 60 events (49.2 weighted), 20 events (18.1 weighted) are fully reconstructed trimuons where the momentum of the fast μ^+ is measured in the spectrometer. For these 20 events the

missing energy

$$E_{\text{MISS}} = E_{\text{Beam}} - E_{\text{STAC}} - E_{3\mu}$$

is shown in fig. 3. For comparison the missing energy is also shown for fully measured trimuons in the other two mass regions. There is a clear signal for large missing energy in the selected events, $\langle E_{\text{MISS}} \rangle = 44 \text{ GeV}$. The remaining 40 events (31.1 weighted) in this sample have no direct momentum measurement for the fast μ^+ and in each case its momentum was determined assuming zero missing energy. Distortions to the results from this assumption have been studied using the fully reconstructed events and found to be small.

The acceptance for the final sample of 60 events (49.2 weighted) has been calculated assuming that the cross-section is a function of only four variables Q^2 , ν , z and p_T^2 of the produced muon pair to the virtual photon. The Monte Carlo generation was adjusted until the accepted distributions agreed with the data. To avoid extrapolation into insensitive regions of the apparatus cross-sections are presented only in the following kinematic region:

- 1) $1.0 < M_{\mu\mu} < 2.5 \text{ in GeV}/c^2$.
- 2) $z < 0.6$.
- 3) $x_F > 0.0$ (Feynman x of the muon pair)
- 4) $P_{\mu_i} > 10 \text{ GeV}/c$, $i = 1, 2, 3$.

The resulting differential cross-sections are shown in figs. 4a-d). The dashed curves are the result of a calculation of the contribution to the sample from double pion (kaon) decay in the shower of deep inelastic events. The source is $<10\%$ in all kinematic regions and predicts a mean missing energy of 12 GeV. Other processes contributing to the signal have been estimated and upper limits are given below.

- 1) Production of high mass vector mesons ($<4\%$).
- 2) Tails of low mass vector mesons ($<5\%$).
- 3) Residual inelastic Bethe-Heitler events ($<5\%$).
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This last contribution has been estimated using ρ -meson dominance of the virtual photon and low mass data on $\pi N \rightarrow \mu^+ \mu^- X$ [6]. A recent discussion of this process can be found in Ref. [7]. The contribution may be as high as 10-20% in this mass range and it could dominate the low mass region.

The processes described above predict zero or small missing energy. The missing energy observed in the sample of fully reconstructed events is suggestive of charmed particle production where both charmed particles decay semi-leptonically. Therefore the results have been compared to the same photon-gluon fusion model of $c\bar{c}$ quark production [8] used in the previous letter [3]. To compare to the present data both c and $\bar{c}$ are assumed to fragment into a D and $\bar{D}$ meson with constant fragmentation function (i.e. flat in z) which decay with a branching ratio of 10% to muons. A fixed value of the strong coupling constant

$$\alpha_s = \frac{12\pi}{(33-2n_f) \ln(M_c^2/\Lambda^2)}$$

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was used to allow comparison to the lower Q^2 data presented here. The full curves in figs. 4 are the results of the model calculation for trimuon production in the same kinematic region as the data. The agreement is good and the predicted average missing energy is 42 GeV.

The z and p_T^2 dependences of the μ^- alone are shown in fig. 5. These are similar to those observed in the dimuon data. In the photon-gluon model the produced c and $\bar{c}$ are expected to balance their p_T^2 and to share the virtual photon energy. These characteristics may be reflected in the decay muon spectra. There is some hint of this in the data since if there was no correlation between the two decay muons the p_T^2 distribution for the muon pair would be flatter than that for the μ^- alone.

To summarise, inelastic trimuon production has been isolated from QED processes. The large missing energy in a sample of the events is attributed to charm particle production. The observed rate and the kinematic distributions are in agreement with a photon-gluon fusion model for $c\bar{c}$ production. Trimuon events within our acceptance do not arise

naturally in the picture of direct interactions with a single charmed quark in the sea of $q\bar{q}$ pairs. Both the dimuon and trimuon data indicate that the production of $c\bar{c}$ quarks is well described by the photon-gluon fusion model. Thus one may picture the charmed content of the sea as arising from virtual $c\bar{c}$ pairs produced by gluons. The model can be used to predict the contribution to νW_2 [8,9] in deep inelastic scattering and in this way a large fraction of the rise ($\sim 20\%$) seen at small x can be accounted for.

We should like to thank all our colleagues at our home institutions and at CERN who have helped in the performance of this work.

REFERENCES

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Figure Captions

Fig. 1 : Muon pair mass distribution for:

- a) Events with $E_{\text{STAC}} < 5 \text{ GeV}$
- b) Events with $E_{\text{STAC}} > 20 \text{ GeV}$ weighted to suppress electromagnetic showers. The curves are predicted contributions from Bethe-Heitler production.

Fig. 2 : The weighted z distribution for muon pairs in the $M_{\mu\mu}$ range 1-2.5 GeV/c^2 and having $E_{\text{STAC}} > 20 \text{ GeV}$.

Fig. 3 : The missing energy distribution for fully reconstructed events:

- a) $1.0 < M_{\mu\mu} < 2.5 \text{ GeV}/c^2$ and $z < 0.6$.
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Fig. 4 : Differential cross-sections for trimuons inside the kinematic cuts and for $E_{\text{STAC}} > 20 \text{ GeV}$ and $1.0 < M_{\mu\mu} < 2.5 \text{ GeV}/c^2$. The solid curves are the calculated absolute values from the photon-gluon fusion model [8]. The dashed curves are the calculated background from double π , K decays. z and p_T^2 refer to the $\mu^+\mu^-$ pair.

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FIG. 1

FIG. 2

FIG. 4

FIG. 5

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Revised Version

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