Muonic decay of the Z^0

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Abstract: In an integrated Luminosity of $\int L \cdot dt$ = 378 nb^{-1} we observe 9 events of the type $Z^0 \rightarrow \mu^+ \mu^-$ at the $p\bar{p}$-collider with the UA1-detector. From these events we calculate the Z^0-mass to be 88.8 (+5.5,-4.6) GeV/c^2.

1. INTRODUCTION

In 1984 we reported the decay of the neutral intermediate vector boson Z^0 in 2 muons [1] . In winter 1984 we continued our data taking and accumulated a much higher number of events due to the increased luminosity offered to UA1. Our total integrated luminosity is now 378 nb^{-1}. In this paper we report on 4 new events $Z^0 \rightarrow \mu^+ \mu^-$ which we have found in a first analysis of the new data. The analysis of these data is not yet complete so this paper should be taken as a status report.
We studied also the process $W^{+-} \rightarrow \mu^{+-} \nu$. I will shortly summarize the status in a separate chapter.

2. MUON IDENTIFICATION WITH THE UA1-DETECTOR

2.1 Muon Detection

The UA1 apparatus has already been described. Here we concentrate on those components which are relevant for the detection of muons.
The outer shell of the UA1-detector is build out of 58 drift tube chambers of a size of 4·6 m^2 each [2] . Two chambers form a module in which we detect a charged track in two orthogonal projections by hits in 3 or 4 drift tubes out of 4 tubes per projection.
The muon fast trigger [3] uses the dectectd hit pattern and compares it with a set of allowed patterns which are compatible with the signature of a fast particle coming from the vertex. This fast trigger decision can be done within 2 μs after the $p\bar{p}$ interaction and no deadtime is induced. A typical angular resolution of 300 mrad can be achieved.
A second level trigger based on microprocessors does a more careful check of the hit pattern using the detailed drift time information of each tube. Here a better pointing to the vertex can be demanded which gives us an effective p_t cut of 3 to 5 GeV/c.
A fast muon, emerging from a $p\bar{p}$-interaction will pass in turn through the Central Detector, the electromagnetic calorimeter and the hadron calorimeter, which consists of the instrumented magnet return yoke. Behind the calorimeters there is additional iron shielding to absorb a particle that might have left the hadron calorimeter. There is 60 cm of additional iron in the side walls, 40 cm in the top and bottom region and since the background is highest here up to 1.2 m in the front region. This absorber is partially magnetized and instrumented with Iarocci tubes to get a second independant measurement of the muon track improving so the momentum determination. Totally the muons will have traversed up to 9/sin(Θ) nuclear interaction lengths before they enter the muon chambers.
To identify a muon we demand :

- well reconstructed tracks in the Central Detector and the μ-chambers
- an energy deposit correponding to a minimum ionizing particle in the calorimeters (this is only demanded if we look for isolated muons)
- a good matching between the CD track and the μ-chamber track

2.2 Muon Momentum Determination

There are two independant methods to measure the muon momentum:

- It can be calculated from the curvature of the charged track in the Central Detector.
- The track position and angle measurements in the muon chambers permit a second measurement of the momentum. The statistical and systematic errrors in this second momentum determination were carefully checked with cosmic rays. We found that the measurements in the Central Detector and in the muon chambers are in good agreement.

Both methods can be combined to an overall momentum fit. Because of the long lever arm to the muon chambers, a significant increase in precision is achieved. The errors of the momenta are reduced by typically 20 % (see fig. 1).

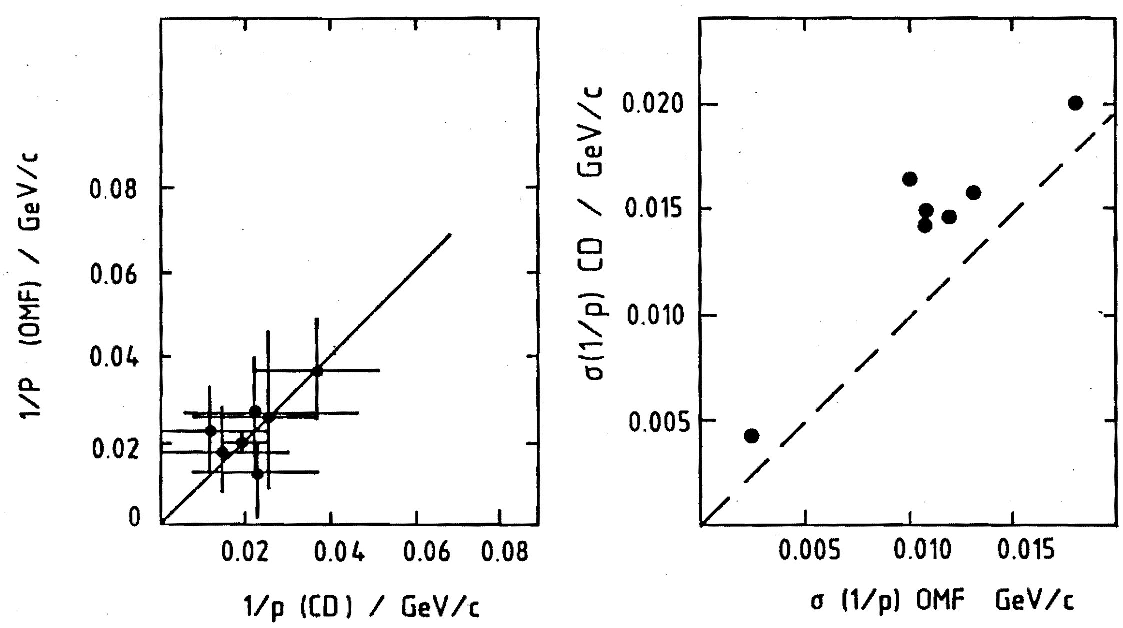

Figure 1: Overall momentum fit : Comparison of measurements in the CD and the μ chambers, a) for the momentum b) for the error in momentum. Only the '84 events are plotted. For one track the algorithm does not converge properly.

3. BACKGROUND

We have considered a number of possible backgrounds to the muon sample. High p_t charged hadrons can fake muons either by penetrating the calorimeters and the additional shielding without interaction, or by leakage of the hadronic shower. These backgrounds have been measured in a test beam and are found to be smaller than 10^{-4} per incident hadron after requiring matching between CD and μ-chamber tracks [4] . The leakage induced background is then negligible. The dominant background process is pion and kaon decay. The probability for a pion (kaon) to decay before reaching the calorimeters is $\approx 0.02/p_t$ ($\approx 0.11/p_t$), where p_t is in GeV/c. This background has been evaluated from events with a single high p_t muon candidate by calculating the probability for decays of other high p_t particles (pion or kaon) in each event. The background is found to be smaller than 10^{-3} events.
The background contribution due to heavy flavour jets, with semileptonic decays has been estimated from events with a large-p_t lepton accompanied by a recoil jet ($<10^{-3}$). The Drell-Yan continuum [5] yields a background of 0.1 events for masses greater than 60 GeV/c^2 . Production of W^+W^- pairs was found to be completely negligible.

4. EVENT SELECTION AND ACCEPTANCE

4.1 Event Selection

During the data-taking periods of 1983 and 1984 about $5 \cdot 10^6$ events were recorded on magnetic tape. The total integrated luminosity is $\int L \cdot dt$ = 378 nb^{-1} and there are about $3 \cdot 10^6$ muon triggers. The events were passed through fast filter programs which select muon candidates with p_t > 3 GeV/c or p > 6 GeV/c. This filter ran offline for the '83 data. In the '84 period a p_t > 3 GeV/c selection was mainly done online with an equivalent algorithm that ran in a set of 168E machines. From the fast filter output all events that contain a muon candidate with p_t > 5 GeV/c were fully reconstructed and then passed through an automatic selection program which applied stricter quality requirements for the track reconstructed in the Central Detector as well as for the track in the muon chambers and the matching of both.
From this inclusive sample we selected all events with 2 muon candidates applying the following cuts:

- $p_t\ (\mu_1) > 3$ GeV/c
- $p_t\ (\mu_2) > 3$ GeV/c
- $|p_t\ (\mu_1)| + |p_t\ (\mu_2)| > 10$ GeV/c

These cuts gave us 251 dimuon candidates which were now scanned on a graphic display facility. From the scan the sample breaks down in the following way:

- dimuon from a cosmic ray	: 91 events
- dimuon from a π,K-decay (kink)	: 7 events

- a muon is in fact leakage through a calorimeter crack : 74 events
- a muon with a matching ambiguity (μ-ch. - CD) : 3 events
- remaining candidates : 76 events

In the 76 events one finds 67 events which contain either a likesign or an opposite sign muon pair with a dimuon mass smaller than 70 GeV/c². These intermediate mass dimuons are the topic of another paper in these proceedings [6] presented by H.G. Moser .
Since we are looking for a heavy neutral object which decays into 2 muons we are only interested in the 24 unlikesign dimuons and in addition the muons have to be isolated. We call a muon isolated if the sum of p_t of all tracks inside a certain cone around the muon is smaller than 2 GeV/c and the sum of E_t in that cone is smaller than 3 GeV. The size of the cone is defined as:
$\Delta R = \sqrt{(\Delta\eta^2) + (\Delta\phi^2)} < 0.7$ [η: pseudo rapidity, φ: azimuth]
The mass distribution of all opposite sign isolated dimuons is shown in Fig. 2 . There is a clear separation between the low mass events and the Z⁰ events. The low mass events are interpreted as coming mainly from Drell-Yan processes. The event with a mass of 147 GeV/c² has very large errors due to an uncertainty in the momentum determination of the muons (see also Fig. 4 and Table 1).

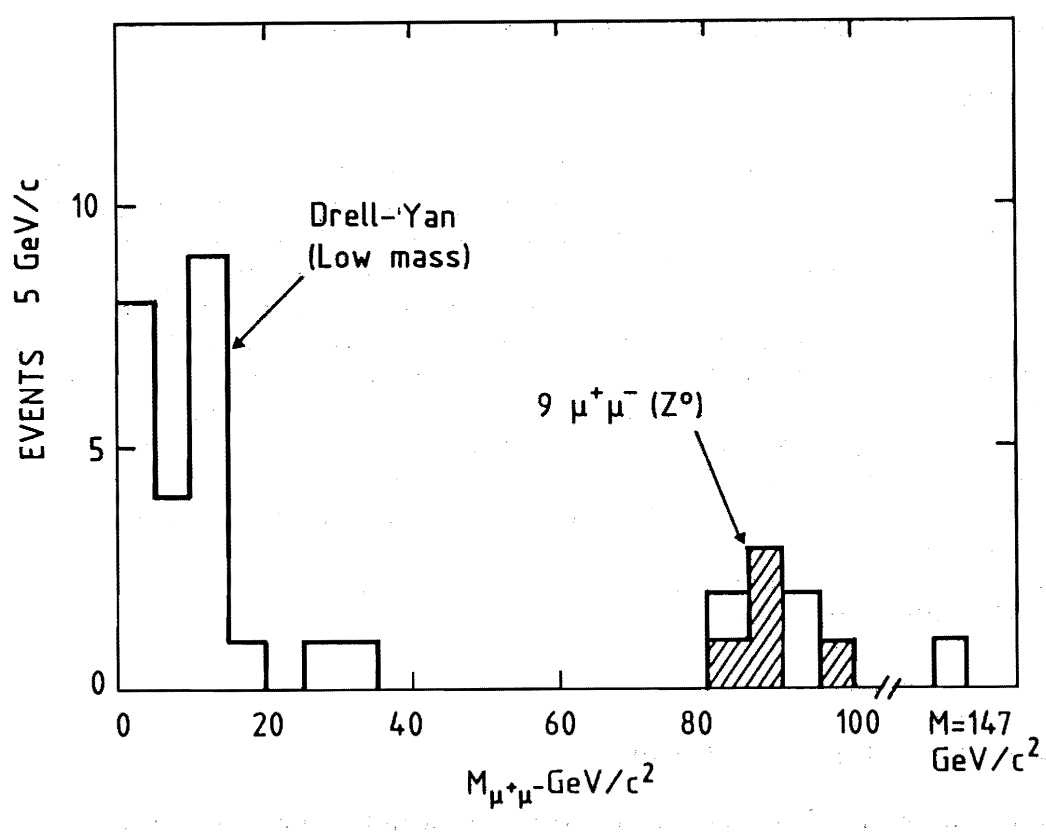

Figure 2: Mass spectrum of isloated unlike sign dimuons

4.2 Acceptance For Dimuon Pairs

We have estimated the acceptance for detecting dimuons from Drell-Yan and Z^0 decays by Monte-Carlo calculation [5] . Both muons are required to have p_t > 5 GeV/c and to hit the sensitive area of the muon chambers ($|\eta|<2$), and at least one muon is required to hit the area that was active in the muon trigger ($|\eta|<1.3$). Due to the 5 GeV/c p_t cut-off, the acceptance for Drell-Yan pairs is small for masses below 10 GeV/c² and rises to 32 % at 25 GeV/c². It then continues to rise slowly, mainly due to the increasing central production of high-mass pairs. At the Z^0-mass the acceptance reaches 44 %, determined by the limited rapidity range of the muon trigger and the azimuth coverage. This acceptance is reduced to 37 % when we require a CD track length of at least 40 cm in the bending plane.

5. THE EVENT SAMPLE OF $Z^0 \rightarrow \mu^+ \mu^-$ EVENTS

The 4 events recorded in 1984 are now discussed . A summary of all events of the muonic decay is given in Tab. 1 . A typical event is shown in Fig.3 .
As for the '83 data the method of transverse energy balance was applied. Since the uncertainties in the momenta of the muons are rather large, the transverse energy flow calculated including the identified muons is normally unequal to the E_t flux calculated with the calorimeters alone. The corresponding difference could then be interpreted as unseen neutrinos. But for the $Z^0 \rightarrow \mu^+\mu^-$ events, where no neutrino is emitted, the transverse momentum of the hadronic debris must be equal to the transverse momentum of the ($\mu^+\mu^-$) system. So the muon momenta can be constrained by relying on the overall momentum conservation.
The muon momenta and the transverse energy flow are therefore adjusted in a fit to obtain an over-all balanced event. After applying this method the errors in the muon momenta are still rather large and therefore the uncertainies in the calculated Z^0-mass are also high (s. Fig.4). In the case of event 937 the positive error is even infinite. Final calibration and alignement with cosmic rays is in progress and will reduce this error.
The jet activity in the '84 sample is conciderably lower than in the '83 data. Two events have no jet with an E_t larger than 10 GeV and the other two have only one jet which is balancing the p_t of the Z^0 within the energy uncertainty of the jets. The jet activity of all Z and W events are fully described in another talk of S. Geer [7] at this conference.
It should be noted that we do not observe any radiative Z^0 decays like event C in the '83 sample which was described in [1] in detail.

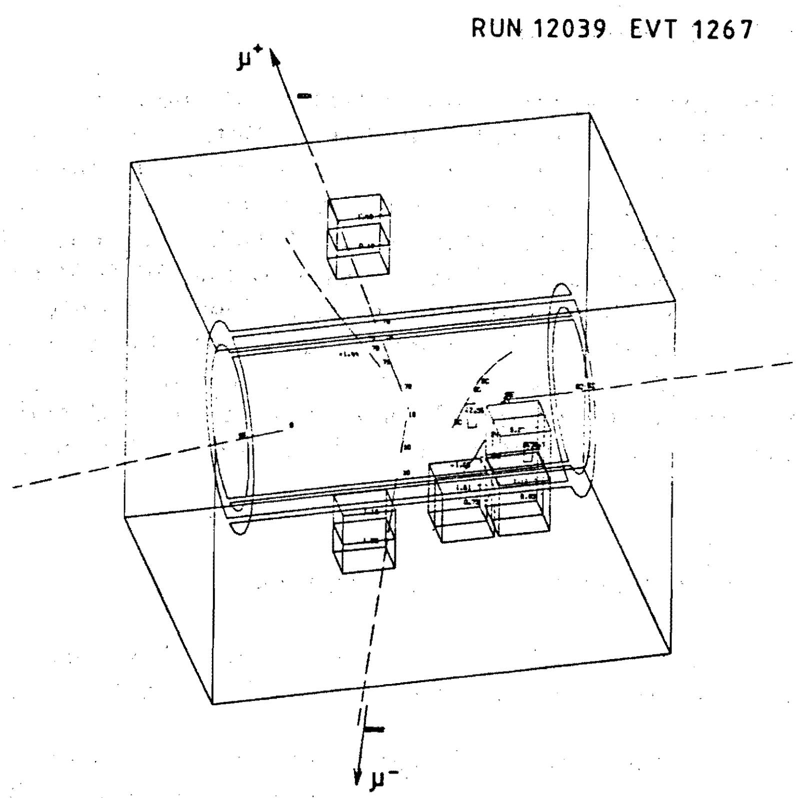

Figure 3: A typical $Z^0 \rightarrow \mu^+ \mu^-$ event

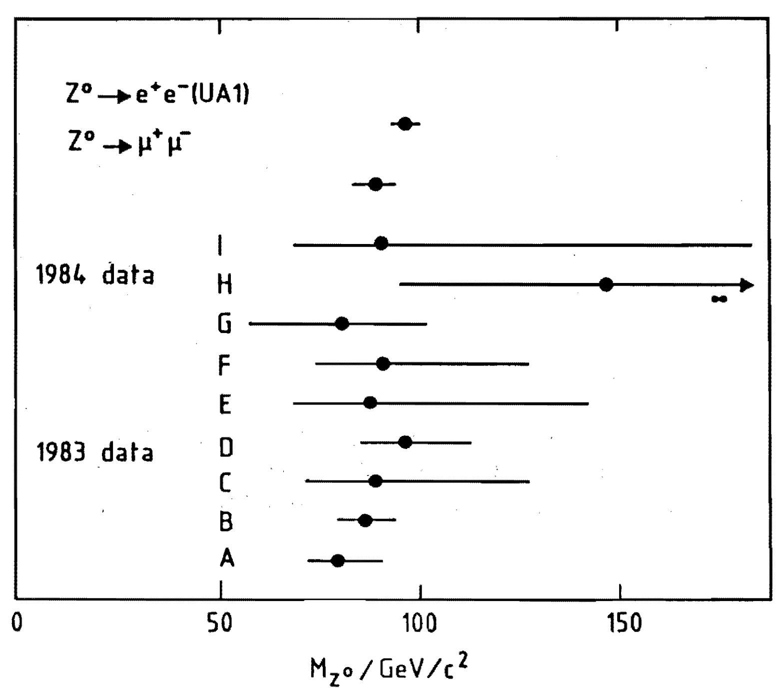

Figure 4: Z^0-mass

Table 1: Event properties

Run Event	Q	p(μ) / GeV/c	M(μμ)/ GeV/c²	p_t/ GeV/c	Nr of jets E_t>10GeV
6219	+	34^{+6}_{-5}	80^{+11}_{-8}	11 ± 4	4
947	-	48^{+10}_{-7}			
6600	+	56^{+7}_{-6}	87^{+8}_{-6}	17 ± 3	3
222	-	40^{+5}_{-4}			
6636	+	51^{+6}_{-5}	88^{+39}_{-17}	6 ± 2	γ event
509	-	43^{+44}_{-15}			
8523	+	62^{+16}_{-11}	96^{+18}_{-11}	$1.3^{+2.6}_{-1.3}$	0
831	-	46^{+12}_{-8}			
7428	+	41^{+36}_{-13}	88^{+55}_{-19}	6 ± 3	0
1110	-	48^{+33}_{-14}			
10605	+	44^{+40}_{-14}	91^{+37}_{-17}	10 ± 4	0
890	-	50^{+7}_{-5}			
12039	+	27^{+13}_{-77}	81^{+21}_{-24}	20 ± 4	1
1267	-	37^{+77}_{-15}			
12530	+	76^{+380}_{-35}	$147^{+\infty}_{-51}$	11 ± 4	0
937	-	$77^{+\infty}_{-40}$			
9323	+	57^{+75}_{-21}	91^{+93}_{-22}	12 ± 3	1
93	-	38^{+37}_{-13}			

6. THE DECAY $Z^0 \rightarrow \tau^+\tau^-$

Since we have observed the decays of the neutral vectorboson into muon- and electron-pairs it is natural to look for the third decay channel of the Z^0 into tau-pairs. So far we found 1 candidate for this decay mode in the '84 data. The event is shown in Fig.5 . It has the following topology :
Two leptons are observed which are both isolated. The μ^+ has a p_t of 25 GeV/c . Although it misses the muon chambers it is clearly identified as a muon by its energy deposition in the calorimeters. The other lepton is a well identified electron with a p_t of 13 GeV/c. The mass of the μ^+e^- pair is 42 ± 6 GeV/c². The event can clearly be interpretated as a Z^0 decay into $\tau^+\tau^-$ where the neutrinos coming from the τ decays into a muon and an electron are unobserved. Since the branching ratio for τ to μ or e is 20 % we expect ca. 1 event in our data sample . The background is small because we demand that both observed leptons should be isolated and should have a high transverse momentum.

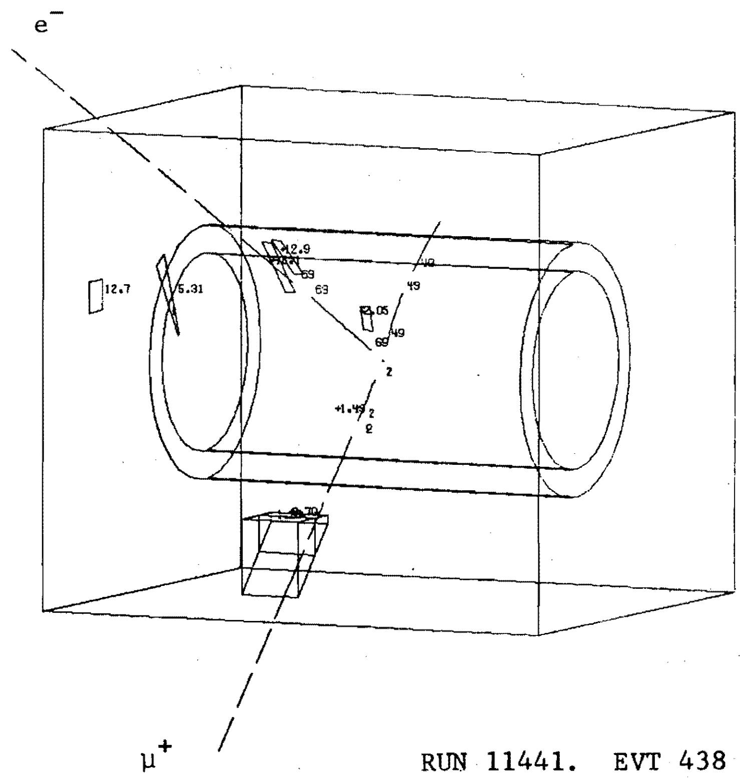

Figure 5: candidate for $Z^0 \rightarrow \tau^+\tau^- \rightarrow \mu^+ \; \nu \; \nu \; + \; e^- \; \nu \; \nu$

7. STATUS OF THE SEARCH FOR $W^{+-} \rightarrow \mu^{+-} \; \nu$ EVENTS

In the data sample of 1983 we found 14 W-decays into a muon and the corresponding neutrino. The properties of these events were published already [8] . The analysis of the 1984 data of an integrated luminosity of 270 nb^{-1} is still in progress. The events were selected in the following way:

- From the inclusive sample of muons with p_t > 5 GeV/c 329 muon candidates with $p_t(\mu)$ > 15 GeV/c were selected.
- These events were validated in a visual scan and quality cuts were applied to the muon track to get rid of badly measured events.
- An additional selection imposed further requirements on the event topology in order to reject events with muons in jets or back-to- back with jets. We demanded that in a cone of ΔR < 0.4 the Σp_t should be smaller than 1 GeV/c and the ΣE_t should be smaller than 2 GeV . This reduced the sample to 47 events.
- We asked that there is no jet with E_t > 10 GeV back-to-back to the muon within ± 30° in the plane perpendicular to the beam and got 35 events.
- A further cut on the p_t of the neutrino reduced the sample finally to 30 events.

A physical quantity which can be measured without the detailed momentum information of the muon and neutrino respectively is the transverse momentum of the W. Since the neutrino does not deposit any energy in the calorimeters and the energy deposited by the muon is small and can be well measured the p_t of the W is simply given by the missing transvers energy in the event. The W p_t distribution is shown in Fig.6 . The highest p_t is 36 GeV/c. The shape can be compared with a theoretical calculation of Altarelli et al. [9] . It is in reasonable agreement with the theory.

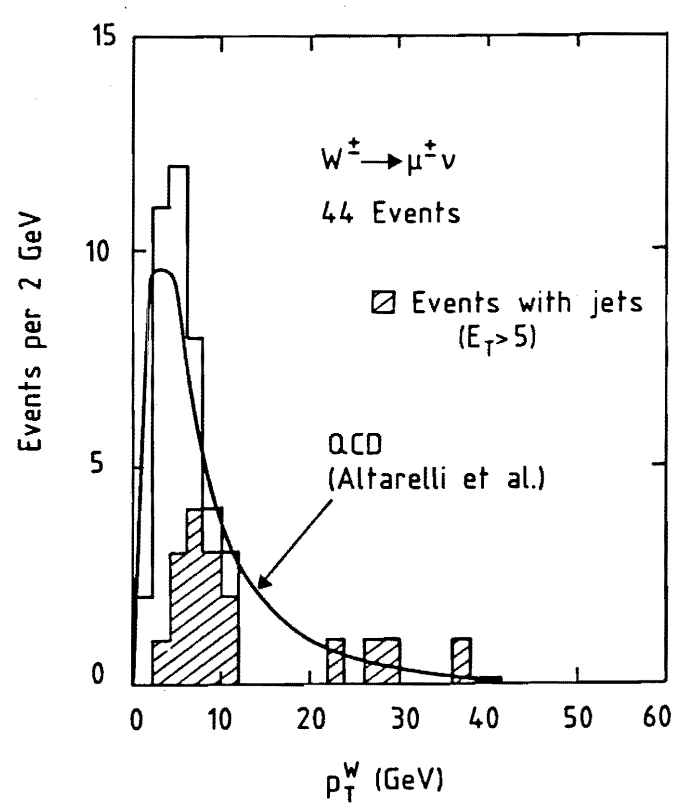

Figure 6: p_t distribution of the W and theoretical calculation of Altarelli

8. CONCLUSIONS

We have observed 9 events of the type $Z^0 \rightarrow \mu^+ \mu^-$ in a total integrated Luminosity of 378 nb^{-1}. We calculate $(\sigma \cdot B) = 64 \pm 21 \pm 10$ pb (statistical and systematic error). The systematic error is due to the uncertainty in luminosity . This value agrees within errors with the value obtained from measurements in the electronic channel by UA1 [10] and UA2 [11] The high jet multiplicity of the '83 events is not observed in '84. There is no additional radiative Z^0 decay in the '84 data.
We also observe a possible candidate for the decay $Z^0 \rightarrow \tau^+\tau^-$.

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References

[1] UA1 Collab.,G.Arnison et al., Phys. Lett. 147B(1984)241
[2] K.Eggert et al.,Nucl.Instrum.Methods 176(1980)217
[3] G. Hilgers et al.,UA1 TN-81/19, TN-81/21
[4] R.Leuchs, Dipl-Arbeit, unpublished
[5] ISAJET program, F.E. Paige, S.D. Protopopescu, BNL 29777 (1981)
[6] H.G. Moser, proceedings of this conference
[7] S. Geer, proceedings of this conference
[8] UA1 Collab.,G.Arnison et al., Phys. Lett. 134B(1984)469
[9] Altarelli et al., CERN Preprint TH 4015/84 (1984)
[10] J. Sass, proceedings of this conference
[11] K. Borer, proceedings of this conference