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Experimental limit on the decay $W^\pm \rightarrow \pi^\pm \gamma$ at the CERN**proton-antiproton collider***UA1 Collaboration, CERN, Geneva, Switzerland*

Aachen¹ - Amsterdam (NIKHEF)² - Annecy (LAPP)³ - Birmingham⁴ - Boston⁵ -
 CERN⁶ - Helsinki⁷ - Kiel⁸ - Imperial College, London⁹ -
 Queen Mary College, London¹⁰ - Madrid (CIEMAT)¹¹ - MIT¹² - Padua¹³ -
 Paris (College de France)¹⁴ - Rome¹⁵ - Rutherford Appleton Lab¹⁶ - Saclay (CEN)¹⁷ -
 UCLA¹⁸ - Vienna¹⁹ Collaboration

C. Albajar⁶, M.G. Albrow¹⁶, O.C. Allkofer^{8*}, B. Andrieu¹⁴, K. Ankoviak¹⁸,
 R. Apsimon¹⁶, B. Aubert³, C. Bacci¹⁵, S. Bartha⁸, G. Bauer⁵, A. Bettini¹³,
 A. Bezaguet⁶, P. Biddulph¹⁰, H. Bohn⁸, A. Böhrer¹, R. Bonino⁶, K. Bos², M. Botlo⁶,
 D. Brockhausen⁸, C. Buchanan¹⁸, B. Buschbeck¹⁹, G. Busetto¹³, A. Caner¹³,
 P. Casoli¹³, M. Castilla¹⁸, F. Cavanna³, P. Cennini⁶, S. Centro¹³, F. Ceradini¹⁵,
 G. Ciapetti¹⁵, S. Cittolin⁶, E. Clayton⁹, D. Cline¹⁸, J. Colas³, R. Conte¹³,
 J.A. Coughlan¹⁶, G. Cox⁴, D. Dau⁸, C. Daum², M. Della Negra⁶, M. Demoulin⁶,
 D. Denegri¹⁷, H. Dibon¹⁹, A. DiCiaccio¹⁵, F.J. Diez Hedo⁶, L. Dobrzynski¹⁴,
 J. Dorenbosch², J. D. Dowell⁴, D. Drijard⁶, K. Eggert⁶, E. Eisenhandler¹⁰, N. Ellis⁴,
 H. Evans¹⁸, H. Faissner¹, M. Felcini⁵, I.F. Fensome⁴, A. Ferrando¹¹, L. Fortson¹⁸,
 T. Fuess¹², J. Garvey⁴, A. Geiser¹, A. Givernaud⁶, A. Gonidec⁶, B. Gonzales^{18*},
 J. M. Gregory⁴, J. Gronberg¹⁸, D.J. Holthuizen², W. Jank⁶, G. Jorat⁶, M.I. Josa¹¹,
 P.I.P. Kalmus¹⁰, V. Karimäki⁷, I. Kenyon⁴, R. Kinnunen⁷, M. Krammer¹⁹,
 D. Kryn¹⁴, F. Lacava¹⁵, S. Lammel¹, M. Landon¹⁰, Y. Lemoigne¹⁷, S. Levegrün⁸,
 D. Linglin³, P. Lipa¹⁹, C. Markou⁹, M. Markytan¹⁹, M.A. Marquina⁶, R. Martinelli¹³,
 G. Maurin⁶, S. McMahon⁹, J.-P. Mendiburu¹⁴, A. Meneguzzo¹³, J. P. Merlo¹⁷,
 T. Meyer⁶, T. Moers¹, M. Mohammadi¹⁸, K. Morgan⁵, A. Morsch⁸, B. Mours³,
 A. Moulin¹, Th. Muller⁶, R. Munoz⁶, L. Naumann⁶, P. Nedelec¹⁴, M. Nikitas⁴,
 A. Nisati¹⁵, A. Norton⁶, V. O'Dell¹⁶, S. Otwinowski⁵, G. Pancheri¹², M. Passaseo¹⁵,
 F. Pauss⁶, E. Petrollo¹⁵, G. Piano Mortari¹⁵, E. Pietarinen⁷, M. Pimiä⁷, A. Placci⁶,
 L. Pontecorvo¹⁵, J.-P. Porte⁶, R. Prosi⁸, E. Radermacher⁶, M. Rauschkolb⁸,
 H. Reithler¹, J.-P. Revol^{6,12}, S. Robins¹⁰, D. Robinson¹⁰, T. Rodrigo⁶, J. Rohlf⁵,
 C. Rubbia⁶, G. Sajot¹⁴, J.M. Salicio¹¹, D. Samyn⁶, D. Schinzel⁶, M. Schröder²,
 C. Seez⁹, T. P. Shah^{6,16}, P. Sphicas⁶, D. Stork¹⁸, C. Stubenrauch⁶, K. Sumorok¹²,
 F. Szoncs¹⁹, A. Taurok¹⁹, L. Taylor⁹, S. Tether¹², G. Thompson¹⁰,
 E. Torrente-Lujan¹¹, H. Tuchscherer¹, J. Tuominiemi⁷, W. van de Guchte²,
 A. van Dijk², M. Vargas¹⁸, S. Veneziano¹⁵, J.P. Vialle³, T.S. Virdee^{6,9},
 W. von Schlippe¹⁰, J. Vrana¹⁴, V. Vuillemin⁶, K. Wacker¹, X. Wu¹², C.-E. Wulz¹⁹,
 M. Yvert³, I. Zacharov⁶, L. Zanello¹⁵, Y. Zolnierowski¹³ and P. Zotto⁶.

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 (* deceased)

Abstract.

We present a search for the decay : $W^{\pm} \rightarrow \pi^{\pm}\gamma$, using data taken at the CERN proton-antiproton Collider with the UA1 detector and corresponding to an integrated luminosity of 0.7 pb^{-1} . We do not observe a signal for such a process; hence we obtain an upper limit on the the $\pi^{\pm}\gamma$ decay width of $5.8 \times 10^{-2} \Gamma (W^{\pm} \rightarrow e^{\pm}\nu)$ (95% C. L.).

1. Introduction.

UA1 has observed all three leptonic decay channels of the charged intermediate vector boson: $W^\pm \rightarrow e^\pm \nu$, $W^\pm \rightarrow \mu^\pm \nu$ and $W^\pm \rightarrow \tau^\pm \nu$ [1]. It is natural to search for other decay modes of the $W^\pm$, in particular any decay involving a photon in the final state. Our first study in that direction was the search for $e^\pm \nu \gamma$ and $\mu^\pm \nu \gamma$ decays of the $W^\pm$ [2], which gave negative results. In this analysis we search for the decay $W^\pm \rightarrow \pi^\pm \gamma$.

The decay amplitude of the intermediate vector boson into a pseudoscalar meson and a photon calculated on the basis of the asymptotic behaviour of the meson form factor leads to a very small branching ratio [3]:

$$\Gamma(W^\pm \rightarrow \pi^\pm \gamma) / \Gamma(W^\pm \rightarrow e^\pm \nu) \approx 3 \times 10^{-8}$$

It has been pointed out recently [4] that pion dominance of the divergence of the axial vector current could lead to a much bigger branching ratio of 1.7×10^{-3} for $Z^0 \rightarrow \pi^0 \gamma$ and of 0.1 for $W^\pm \rightarrow \pi^\pm \gamma$.

It was however acknowledged [4] that such $\pi\gamma$ decay amplitudes could not be as large as those obtained from the straightforward application of PCAC, since strong limitations are already obtained from upper limits on the $e^+e^- \rightarrow \pi^0 \gamma$ reaction rate at TRISTAN [5]. This is confirmed by new experimental limits on the $Z^0 \rightarrow \pi^0 \gamma$ decay mode, now available from LEP experiments [6].

This paper describes our search for a $W^\pm \rightarrow \pi^\pm \gamma$ signal using the UA1 detector. We have used our inclusive photon sample, from data taken during the 1983 to 1985 running period at the CERN proton-antiproton Collider.

2. Data Sample and inclusive photon selection.

The UA1 detector and trigger conditions are those used for W/Z studies, and we refer the reader to ref. [1] for more details. The data sample used in this study is the inclusive π^0/γ sample from our previous study [7] of γ 's produced in proton-antiproton collisions. Those data were taken during the 1983 CERN Collider run at $\sqrt{s} = 546$ GeV ($\int L dt = 148$ nb $^{-1}$, corresponding to 59 $W^\pm \rightarrow e^\pm \nu$), and during the 1984 and 1985 runs at $\sqrt{s} = 630$ GeV ($\int L dt = 619$ nb $^{-1}$, corresponding to 240 $W^\pm \rightarrow e^\pm \nu$). Both the central (Gondolas) and the forward (Bouchons) electromagnetic calorimeters were used.

The initial selection for our inclusive photon study requires, in the pseudorapidity range $|\eta| < 3$, an isolated neutral electromagnetic cluster of large transverse energy without significant associated missing transverse energy:

Cluster transverse energy: $E_T^{\text{clus}} > 20$ GeV,

Vertical cuts: Vertical clusters within 15° of the vertical plane are excluded,

Cluster isolation: The additional transverse energy in a cone $\Delta R = 0.7$

[$\Delta R \equiv \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$] around the cluster direction is required to be less than 2 GeV,

Event transverse energy balance: To eliminate cosmic rays, beam halo and instrumental problems, the missing transverse energy is required to be less than 2.5σ , with $\sigma \equiv 0.7 \sqrt{\Sigma E_T}$ [1],

Neutral cluster: The sum of transverse momenta of tracks (ΣP_T) in a cone $\Delta R = 0.7$ around the electromagnetic cluster direction is less than 2 GeV/c.

The data sample at this stage (3684 events) still contains a large background coming from QCD jets, when they fragment mainly into π^0 's. A statistical method based on the difference in size, isolation properties and shower shape between photons and π^0 's from QCD jets was used to enrich further the sample in genuine photons. The detailed description of the method can be found in ref [7], where a photon likelihood variable (L_γ) was defined. The requirement $L_\gamma > 0$ leaves us with 2350 events containing more than about 60% genuine photons.

3. Selection for $W^\pm \rightarrow \pi^\pm \gamma$.

$W^\pm \rightarrow \pi^\pm \gamma$ decays are characterized by the following signature: a high transverse momentum, isolated charged hadron (h) associated with a large hadronic energy deposition in the calorimeter, which balances the transverse momentum of the photon. This clear topology leads to the following selection:

a) A *charged hadron* reconstructed in the Central Detector (CD) with $P_T^h > 5 \text{ GeV}/c$ (824 events selected).

b) A *calorimeter "jet"* with $E_T^{\text{jet}} > 7 \text{ GeV}$ close in space to the charged hadron ($\Delta R(\text{jet}, h) < 0.5$) and far away from the photon ($\Delta R(\text{jet}, \gamma) > 1.0$) (645 events selected).

The properties of the 645 events selected thus far were studied and compared to the expectation from a Monte-Carlo simulation of $W^\pm \rightarrow \pi^\pm \gamma$ using the ISAJET generator [8] and a full simulation of the UA1 detector. The $W^\pm \rightarrow \pi^\pm \gamma$ decay branching ratio used is 0.1. The Monte-Carlo expectation is normalized to the same integrated luminosity as the data .

Figure 1 shows that a clear signal would be expected in the distribution of the invariant mass of the photon and pion candidates, if the W contribution were as high as predicted. Figure 2 shows the distribution of the scalar sum of the transverse momenta of charged particles measured in the Central Detector, ΣP_T , in a cone $\Delta R < 0.7$ around the hadron direction. Pions from $W^\pm \rightarrow \pi^\pm \gamma$ are very isolated, while the charged hadrons in the data are not. Figure 3 shows the distribution of the ratio of the pion P_T as measured in the Central Detector to the transverse energy of the associated jet measured in the calorimeter. This ratio is expected to approach unity for isolated hadrons as the jet energy should come entirely from the charged pion shower. Figure 4 shows the ratio, in a narrow cone $\Delta R = 0.2$ around the jet axis, of the calorimeter transverse energy to the jet transverse energy. As the jet is expected to be narrow for a single pion, one sees that indeed this distribution is peaked near 1 for the Monte-Carlo simulation of $W^\pm \rightarrow \pi^\pm \gamma$. As suggested by the distributions shown in Figures 2, 3 and 4, one can improve the selection of charged pion decays of the W by applying the following additional cuts:

c) *Charged hadron isolation in the Central Detector* : $\Sigma P_T < 2 \text{ GeV}/c$ for all charged tracks around the charged hadron, inside a cone $\Delta R=0.7$ (83 events selected).

d) *Narrow jet in the calorimeter*: $(\Sigma E_T) / E_T^{\text{jet}} > 0.5$, where the sum extends to all calorimeter cells within a cone $\Delta R=0.2$ from the jet axis, with the additional requirement that most of the jet energy comes from the charged hadron: $P_T^h / E_T^{\text{jet}} > 0.5$ (11 events selected).

Figure 5 shows the transverse energy of the photons (E_T^γ) versus the transverse momentum of the charged pion (P_T^h) for the 11 events selected. Most of them cluster at small P_T^h and small E_T^γ , suggesting that they are background γ + jet events from QCD processes.

In the region $P_T^h > 20$ GeV/c, $E_T^\gamma > 20$ GeV, where the W signal is expected (Region (I), Fig.5), two events are observed. Their properties are summarized in Table 1. In event 1 the photon candidate is in the horizontal plane ($\Phi\gamma = 181.2$ degree), outside the sensitive volume of the Central Detector, and is therefore likely to be a misidentified electron. On the other hand, the charged isolated track is consistent with an electron : $P_T^h = E_T^{\text{elm}}$ within errors and E_T^{had} is small. This event fulfills all the characteristics of a $Z^0 \rightarrow e^+e^-$ event and can be discarded as such. Event 2 is well reconstructed, the shower associated with the charged track has the signature of an hadronic shower: $E_T^{\text{had}} = 30.9$ GeV and the effective mass of the $\pi\gamma$ system is 67.7 ± 14 GeV. Event 2 is consistent with a $W^\pm \rightarrow \pi^\pm\gamma$ candidate.

4. Limit on $W^\pm \rightarrow \pi^\pm\gamma$.

We retain one event in the signal region. The most probable interpretation of this event is background from the tail of the γ + jet events observed in Region (II) of Fig. 5, in which the recoiling jet fragments into a single charged leading hadron. However, we can obtain an upper limit on the $W^\pm \rightarrow \pi^\pm\gamma$ branching ratio, assuming that we observe one $W^\pm \rightarrow \pi^\pm\gamma$ event with no background.

A Monte-Carlo sample of 2533 events was used to calculate the efficiency, $\epsilon(\pi^\pm\gamma)$, for selecting $W^\pm \rightarrow \pi^\pm\gamma$ events in the signal region (Region (I), Fig.5). Table 2 shows the details of the efficiency of each cut. The overall efficiency for the selection defining the signal region is:

$$\epsilon(\pi^\pm\gamma) = 0.195 \pm 0.009 \pm 0.023.$$

The first error is statistical and the second is an estimate of the total systematic error obtained by combining systematic errors of 8% on the photon selection and 10% on the pion selection.

The total number of $W^\pm \rightarrow e^\pm\nu$ produced, $N(e^\pm\nu)$, is estimated from the number of observed semileptonic decays $W^\pm \rightarrow e^\pm\nu$ and the detection efficiency [1]: $N(e^\pm\nu) = 437 \pm 43$. Consequently, the number of events expected from $W^\pm \rightarrow \pi^\pm\gamma$ can be expressed as:

$$N(\pi^\pm\gamma) = [\Gamma(W^\pm \rightarrow \pi^\pm\gamma) / \Gamma(W^\pm \rightarrow e^\pm\nu)] \alpha,$$

with $\alpha = \epsilon(\pi^\pm\gamma) N(e^\pm\nu)$. Using the values quoted above for $\epsilon(\pi^\pm\gamma)$ and $N(e^\pm\nu)$ we obtain $\alpha = 85.3 \pm 14.4$. The 17% error on α is obtained by combining in quadrature the statistical and systematic errors on $\epsilon(\pi^\pm\gamma)$ and on $N(e^\pm\nu)$. Taking into account the Poisson statistics on one observed event and a 17% gaussian error on α , we get an upper limit on the $\pi^\pm\gamma$ decay width :

$$\Gamma(W^\pm \rightarrow \pi^\pm\gamma) / \Gamma(W^\pm \rightarrow e^\pm\nu) < 5.8 \times 10^{-2} \text{ (95\% C.L.)},$$

$$\Gamma(W^\pm \rightarrow \pi^\pm\gamma) / \Gamma(W^\pm \rightarrow e^\pm\nu) < 4.8 \times 10^{-2} \text{ (90\% C.L.)}.$$

5. Conclusion.

Our data show no evidence for the decay $W^\pm \rightarrow \pi^\pm \gamma$, and our conclusion is that the $\pi^\pm \gamma$ decay width is smaller than $5.8 \times 10^{-2} \Gamma (W^\pm \rightarrow e^\pm \nu)$ (95% C. L.). This result shows that the "straight forward " generalization of the π^0 decay amplitude calculation using PCAC [4] does not hold. Our limit is however still 6 orders of magnitude larger than previous theoretical estimates[3].

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Table 1**"Photon" properties of events 1 and 2**

	P_T^γ [GeV]	η^γ	Φ^γ [degree]	E_{had} [GeV]
Event 1	36.8	0.37	181.2	0
Event 2	23.2	2.3	126.4	0

"Isolated hadron" properties of events 1 and 2

	P_T^h [GeV]	η^h	Φ^h [degree]	E_T^{elm} [GeV]	E_T^{had} [GeV]
Event 1	77.7^{+700}_{-70}	-0.66	-21.7	29.1	1.4
Event 2	23.5 ± 7	0.42	-36.3	3.0	30.9

Table 2**Efficiency of the selection for $W^\pm \rightarrow \pi^\pm \gamma$**

Selection	Number of events	Efficiency (%)
all $W^\pm \rightarrow \pi^\pm \gamma$	2533	100
$p_T^\pi > 20$ GeV/c	1535	60.6
Cut b	1526	9.4
Cut c	1430	93.7
Cut d	1186	83.0
$p_T^\gamma > 20$ GeV & Vert. Cuts	910	76.7
$L_\gamma > 0.$	493	54.2
Global efficiency		19.5

Figure Captions.

- Figure 1.** Distribution of the invariant mass of the photon and the charged hadron candidates for the data and for an absolute prediction from $W^{\pm} \rightarrow \pi^{\pm}\gamma$.
- Figure 2.** Sum of transverse momenta of CD tracks in a cone $\Delta R = 0.7$ around the charged hadron direction for the data and for an absolute prediction from $W^{\pm} \rightarrow \pi^{\pm}\gamma$.
- Figure 3.** Ratio of the transverse momentum of the charged hadron measured in the CD to the jet transverse energy measured in the calorimeter for the data and for an absolute prediction from $W^{\pm} \rightarrow \pi^{\pm}\gamma$.
- Figure 4.** Ratio of the sum of transverse energies from calorimeter cells in a cone $\Delta R = 0.2$ around the jet axis to the jet transverse energy for the data and for an absolute prediction from $W^{\pm} \rightarrow \pi^{\pm}\gamma$.
- Figure 5.** Transverse momentum of the charged hadron versus transverse energy of the photon for the data events passing the selection described in section 4.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5