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AN ATTEMPT TO OBSERVE DIRECTLY BEAUTY PARTICLES IN NUCLEAR EMULSIONS

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ABSTRACT

An attempt at the direct observation of the cascade decay of beauty particles, produced by π^- of 350 GeV/c leading to 3 muons or 4 muons in the final state, has been made in an emulsion/counter hybrid experiment at CERN. Under the assumption that the lifetime of beauty particles is of the order of 10^{-13}s the non-observation of any candidates provides an upper limit for beauty production of $\sim$ 90 nb at the 90% confidence level.

INTRODUCTION

The existence of further quark flavours beyond charm, which was suggested in 1973 by Kobayashi and Maskawa [1], has been indirectly confirmed by the discovery of narrow Τ states in e^+e^- collisions [2] which are interpreted as bound states of b and $\bar{b}$ quarks and by the observation of broader resonances at higher energies. Enhancements in the numbers of leptons and kaons in this region indicate the formation of particles with naked beauty [3]. While some results on the leptonic branching ratios of these states are available [3], only upper limits [4] exist for the lifetime of "beauty" particles and no decays of such particles have been fully reconstructed.

Various estimates have been made of the lifetimes of beauty particles [5], but standard models suggest that they should lie within the range 10^{-14} to 10^{-13}s, which is well suited for direct observation by the emulsion technique. However, the small cross-sections for the associated production of beauty particles by high energy hadrons [6] preclude a feasible emulsion experiment without an external tagging system to select an enriched sample of interactions.

Beauty quarks decay preferentially to charmed quarks [7], which in turn tend to favour decay to strange ones. Each step in this sequence may be semi-leptonic so that the cascade decays of an associated pair of beauty-antibeauty particles could give rise to as many as four muons, all arising within a few millimetres of the original production vertex. With this possibility in mind and with preliminary indications of a significant hadronic beauty production cross-section [8] an emulsion/counter hybrid experiment has been performed at CERN to observe high energy pion interactions with the "prompt" emission of at least three muons.

The main advantage of this experiment compared to previous ones [9] performed to detect beauty, is its capability to observe directly the beauty decays in a visual detector. Furthermore, this paper presents data for pions at a higher energy than previous experiments.

EXPERIMENTAL ARRANGEMENT

The experiment was performed in the 350 GeV/c π^--beam of the H2 beamline in the North Experimental Area of the CERN SPS. A schematic diagram of the set up is shown in Fig. 1. A small volume of emulsion containing the primary interaction of interest is defined by the intersection of the path of the incident particle with those of outgoing particles observed downstream. Hadrons produced in the interaction were effectively absorbed by a dump but muons of momentum greater than 5 GeV/c survive to be detected in the remainder of the apparatus. Incident beam particles, defined by the two scintillators S1 and S2 were considered to interact in the emulsion whenever the pulse height in each of the 4 scintillation counters $S3_{A,B,C,D}$ corresponded to the passage of at least three minimum ionizing particles. A set of 3 X-Y hodoscope planes H1-H3 having a 5 cm pitch downstream of the 1.8 m iron dump enabled muons to be identified on-line. A loose on-line 2 muon trigger required

$$(H1 \geq 2)\cdot(H2 \geq 2)\cdot(H3 \geq 1)$$

A lower multiplicity on the third hodoscope H3 was set to avoid event losses due to the apparatus acceptance. The additional MWPC's (3 chambers WC1-WC3 [10] each consisting of 3 u, v, w planes with a 2 mm pitch and another 6 chambers WC4-WC9 [11] also containing a set of u, v, w planes with an effective pitch of 8 mm) were not used in the on-line decision logic but served only to disentangle ambiguities in track reconstruction and selection of the 3-muon candidates in the off-line analysis.

The trigger was defined by

$$S1\cdot S2\cdot \overline{SH}\cdot(S3\geq 3)\cdot(H1\geq 2)\cdot(H2\geq 2)\cdot(H3\geq 1)$$

($\overline{SH}$ is a veto on beam halo).

The mean trigger rate was of the order of 10^{-4} per particle at an incident particle intensity of 8×10^4 per burst.

The position of an incident particle on entry to an emulsion stack was obtained from the coordinates as measured by the 9 cathode readout centroïd MWPC's. Each chamber measured a single coordinate transverse to the beam with a 70 μm precision [12]. In order to estimate the actual error on the beam position at the emulsion, including errors from surveying, springloading of the emulsion stack within its frame and the subsequent gridding of the pellicles, two tests were performed. Using respectively a thin 600 μm pellicle and a stack of vertical emulsion pellicles as target in a low intensity beam, a comparison of the measurement of the interaction vertex in the emulsion with the predicted coordinates from the centroïd chambers showed that the lateral uncertainty in the position of an individual particle in the emulsion was of the order of 150 μm.

To limit the actual emulsion volume to be scanned along the beam axis, a vertex detector (VD) was placed close behind the emulsion stack. This detector consisted of four half millimetre spacing MWPC with the wires of all chambers aligned in the same direction. The fourth plane provided an acceptance of ±10° with respect to an interaction point in the emulsion. Track finding problems resulting from the high event multiplicity did not allow a unique topological identification between the vertex detector and the triggering event in the emulsion. Nevertheless, the coordinate of the interaction vertex along the beam could in most cases be determined to within 2 cm. This implies that interactions in the upstream counters could be effectively eliminated.

Sixty-five stacks of Ilford G5 emulsion, each (15 x 10 x 5) cm^3, (50 litres in total), were exposed in sequence, the pellicles being stacked horizontally. Each stack was accurately positioned with its shortest side parallel to the beam and moved through the beam by known amounts using a stepping motor during exposure. After uniformly illuminating one face, each stack was rotated through 180° about the vertical and the exposure was repeated, thus halving, with the same track density, the number of beam particle interactions which had to be carefully studied. The emulsions were exposed to an average intensity of 900 particles/mm^2 in each direction.

A further six litres of Fuji ET7b emulsion, made up into 17 modules was exposed with the pellicles perpendicular to the beam, primarily in order to investigate whether this technique, with its associated automatic analysis method [13] already successfully used in neutrino experiments [14] would be feasible in high intensity hadronic exposures. Tests were carried out at various densities and it was established that track densities up to 2000 mm^{-2} were tolerable.

RESULTS

Altogether the horizontal and vertical emulsions were exposed to a total of 2.26×10^9 350 GeV/c π^- mesons. Of these, approximately 3.2×10^8 interacted.

Some 190,000 triggers with two or more penetrating particles were recorded for off-line analysis and, from these, interaction vertices were reconstructed which were associated with three well identified muon tracks beyond the dump. Further selection criteria, in particular removal of upstream interactions, reduced the number to 171 three muon candidate vertices in the emulsion. These were searched for by recording and analysing all interactions within a volume centred on the vertex prediction and extending to three standard deviations in each direction. The volume scanned for a given prediction usually contains about 25 interactions. In most cases all the interactions had to be analysed because the topological information provided by the vertex detector was not useful. For each interaction all secondary tracks of minimum ionisation were followed for a distance of at least 2 mm for half the sample and at least 1 mm for the remainder to search for evidence of decays. In addition, a search was made for short-lived neutral particles decaying within 200 μm of the primary vertex and inside a 30° forward cone. In forty-six metres of secondary track followed, 93 interactions were found, 6 of which were white stars (interactions without heavily ionising secondaries), indicating a good scanning efficiency for decay-like topologies. White stars and scatters were carefully investigated for evidence of cascade decay sequences.

No candidate for the cascade decays of beauty particles has been seen. In order to evaluate limits on the production cross-sections of beauty by 350 GeV π^-, it is assumed that:

- beauty particles decay to charmed ones in 90% of cases;
- the muonic fraction of beauty decay is 12.5% and that for charm is 8.5%;
- there is a linear A dependence of the beauty production cross section compared to that of $A^{2/3}$ for the total cross section.

The geometrical and muon cut-offs of the apparatus lead to an acceptance of 0.33, the location and scanning efficiencies are together estimated to be 0.5, and the probability of observing a beauty event with decays occuring within the scanning window is $\sim$ 0.8 for beauty lifetimes of 10^{-13}s. This probability drops by less than a factor two in the lifetime range $2 \times 10^{-14}\text{s} < \tau < 10^{-12}\text{s}$.

With the above assumptions the observation of one event would correspond to a beauty production cross-section by 350 GeV/c π^- mesons of 39 nb. The absence of any such candidates, indicates an upper limit for beauty particle production of $\sim$ 90 nb at a 90% confidence level for a lifetime of 10^{-13}s..

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REFERENCES

[1] M. Kobayashi and K. Maskawa, Prog. Theo. Phys. 49, (1973) 652.

[2] S.W. Herb et al., Phys. Rev. Lett. 39, (1977) 252.

[3] D. Andrews et al., Phys. Rev. Lett. 45, (1980) 219;
G. Finocchiaro et al., Phys. Rev. Lett. 45, (1980) 222;
For a recent review see e.g. J. Burger, Proc. of Int. Symp. on Lepton Photon Interactions at high energies - Bonn, p. 2115 amd A. Silverman loc. sit. p. 138.

[4] JADE Collaboration, DESY - 82-014.

[5] M.K. Gaillard, B.W. Lee and J.L. Rosner, Rev. Mod. Phys. 47, (1975) 277;
J. Ellis, M.K. Gaillard, D.V.Nanopoulos, R. Rudaz, Nucl. Phys. B131, (1977) 285.
M.K. Gaillard and L. Maiani; LAPP TH 09 (1979).

[6] F.Halzen, Proceedings XXI Intern. Conference of High Energy Physics, Paris 1982 (to be published).

[7] CLEO Collaboration - CLNS 81/513, preprint.

[8] H. Fritzsch and K.H. Streng, Phys. Lett. 78B, (1978) 447;
H. Fritzsch, Phys. Lett. 86B, (1979) 164;
D. Treille, Proceedings of the International Conference on High Energy Physics, E.P.S. (1979).

[9] J. Badier et al., XV Rencontre de Moriond, Les Arcs (1980);
A. Diamant-Berger et al., Phys. Rev. Lett. 44, (1980) 507;
F.N. Coleman et al., COO-3072-105 preprint.

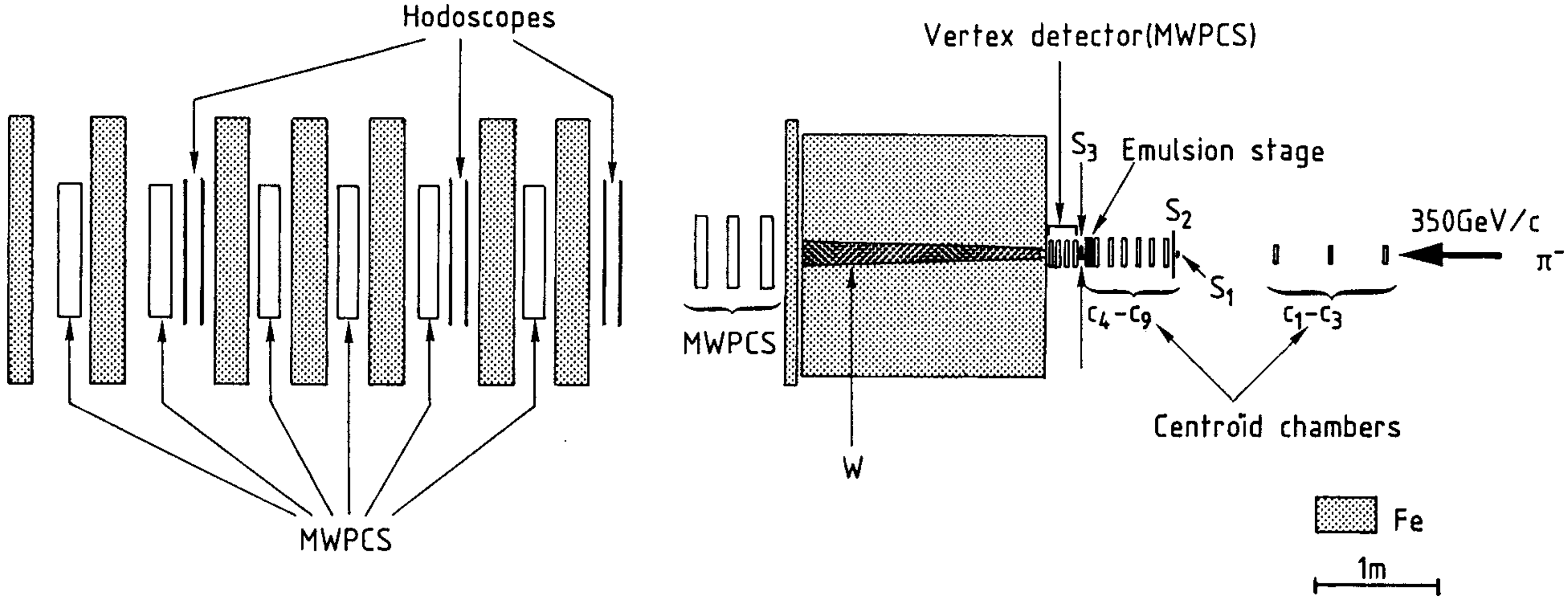
[10] Anelli et al., Rev. Sc. Instr. 49 (8), August 1978.

[11] C. Brand et al., CERN/EF 77-3 (1977).

[12] F. Piuz et al., Nucl. Instr. and Methods 196, (1982) 451.

[13] K. Niu, Proceedings of the 20th Intern. High Energy Physics Conference, Madison (1980), p. 352. American Institute of Physics, ed. L. Durand and L.G. Pondrom.

[14] N. Ushida et al., Phys. Rev. Lett. 45, (1980) 1049 and 45, (1980) 1053.



SCHEMATIC DRAWING OF THE EXPERIMENT