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Nota interna: n° 153
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A. Alberigi-Quaranta(+), M. De Pretis(++), G. Marini(°), A. Odian(°°), G. Stoppini(°) and L. Tau(°):

PHOTOPRODUCTION OF MUON PAIRS IN CARBON.

Evidence for muon pair photoproduction in nuclei was given in a pioneering work by Masek and Panofsky(1), who succeeded in separating one member of the pair from a large background of pions and electrons. We report here on an experiment in which coincidences between the two muons have been detected, at a rate in perfect agreement (within our 5% accuracy) with that deduced from the Bethe Heitler formula(2).

A drawing of the experimental apparatus is shown in fig. 1. The 1000 MeV bremsstrahlung beam of the Frascati Electronsynchrotron was collimated into a 2 cm diameter spot to strike a carbon target of 5 cm in length (8.8 gr/cm^2). Positive muons emitted at 10° in the momentum interval from roughly 300 to 400 MeV/c were deflected by a double focussing magnetic spectrometer(3) to traverse one of the three

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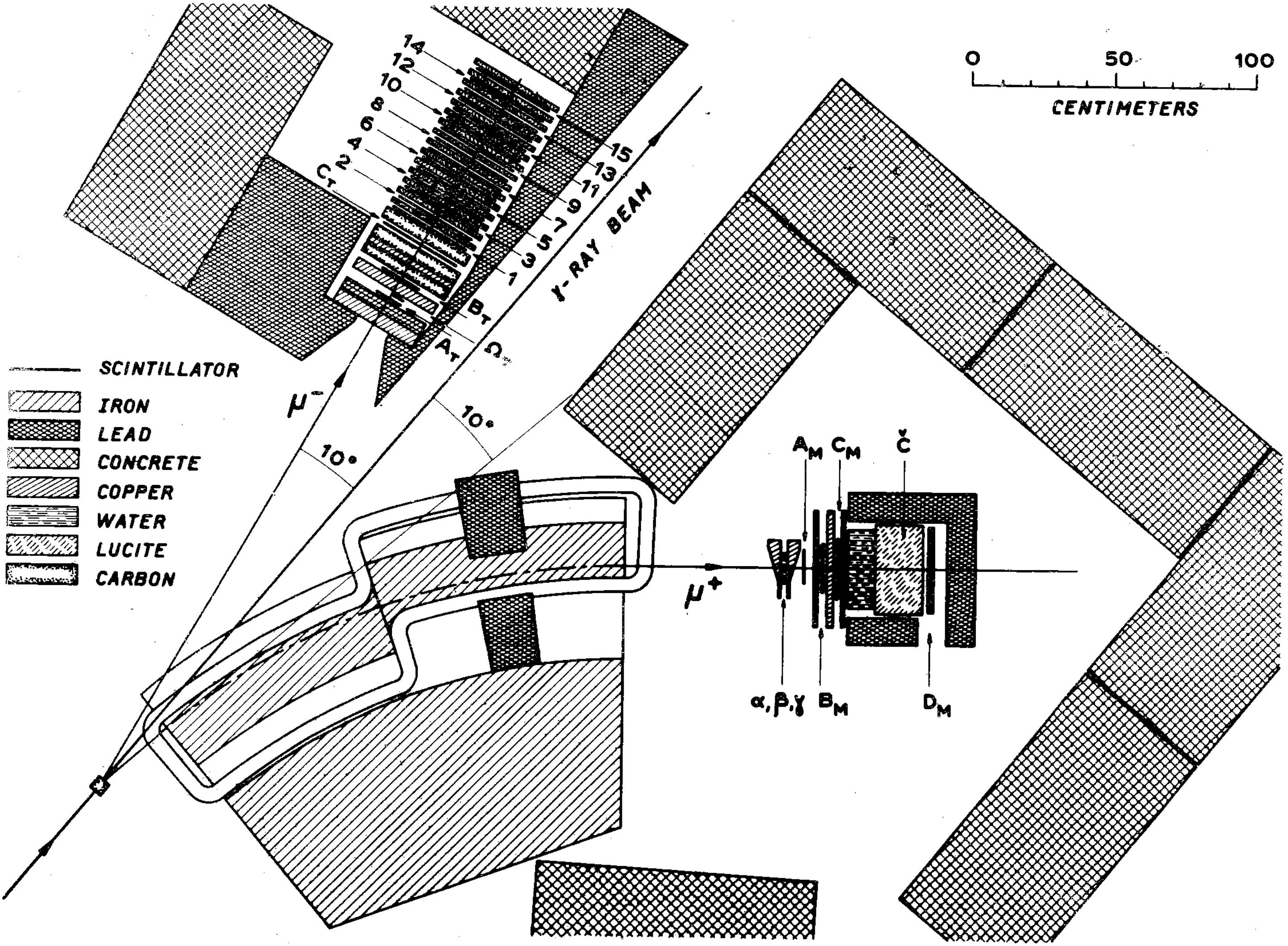
0
50
100
CENTIMETERS
14
12
10
8
6
4
2
C_T
15
13
11
9
7
5
3
1
B_T
A_T
Ω_T
γ-RAY BEAM
μ^-
10°
10°
μ^+
A_M
C_M
Č
α, β, γ
B_M
D_M
SCINTILLATOR
IRON
LEAD
CONCRETE
COPPER
WATER
LUCITE
CARBON

momentum defining scintillation counters α/β and γ, and two wedge shaped copper absorbers. After emerging, approximately monocromatic, from the wedges, the muons produced a four-fold coincidence in scintillators A_M B_M C_M and D_M, and gave Cerenkov light in the water+lucite counter C. Pions, on the other hand, were slowed down to about the Cerenkov threshold by copper absorbers. At 10° on the opposite side of the photon beam, negative muons with momentum larger than 446 MeV/c produced the coincidence (A_T,B_T, C_T,1) and then came to rest into a range telescope composed of 14 30x30x1 cm^3 scintillators spaced by a carbon layers of 2.3 cm thickness (4.9 gr/cm^2). A system of 14 double coincidences (obtained by letting each counter in the telescope make a coincidence with the next) was connected to an hodoscope of 14 indicator lights to give the end point of the muon. This same system of double coincidences, connected through a delayed gate to a second 14 light hodoscope, detected the muon decay electron, and will later enable us to verify the spatial correlation of the two events. The presence or absence of a pulse in counter Ω_T indicated which half of the solid angle the negative muon had traversed, thus improving the angular resolution.

A master coincidence between the outputs of (A_M, B_M,C_M,D_M) and (A_T,B_T,C_T,1) triggered the sweep of a four-trace oscilloscope. We displayed pulses from counters α/β and γ on its second trace, pulses from C_T and C_M on the third, and pulses from D_M C and Ω_T on the fourth. On its first trace, a pulse from the electron gave the time interval between the muon arrival and its decay. Finally, the oscilloscope and hodoscope patterns of each event were both recorded on the same photogram.

The information from the two hodoscopes will eventually permit us to discriminate against pion or electron counts in the telescope, and measurements of the pulse height in C and D_M enable us to eliminate the surviving background of pions pairs which succeed, through decay, in sending into the telescope a negative muon. On the other hand, owing to loss of muons through scattering out of the telescope, a complete analysis of our data must include a Montecarlo calculation of our detection efficiency. This is under way, and we present in this note only an alternative analysis in which results from the hodoscopes are not taken into account.

Fig. 2 shows the distribution of the time separating the pulses C_T and C_M. Its sharp peak, due to pairs of particles produced in a single elementary act, rises above a background of accidentals showing the expected effect of bunching produced by the synchrotron radio-frequency. After subtracting this background, we must correct our data for pairs of pions (plus their decay muons) and for pairs of electrons. To this end, we compared the combined C and D_M pulse height distribution for our events with the corresponding distributions for electrons and pions. The distribution for the latter was taken with the magnet located at 30°, where counts from electrons or electromagnetic muons are neglegible, and the distribution for electrons was taken at 10° with a lead converter increasing the number of electrons in the primary beam. Roughly speaking, pions plus their decay muons give a broad spectrum in C, while electrons give a broad spectrum in D_M; on the

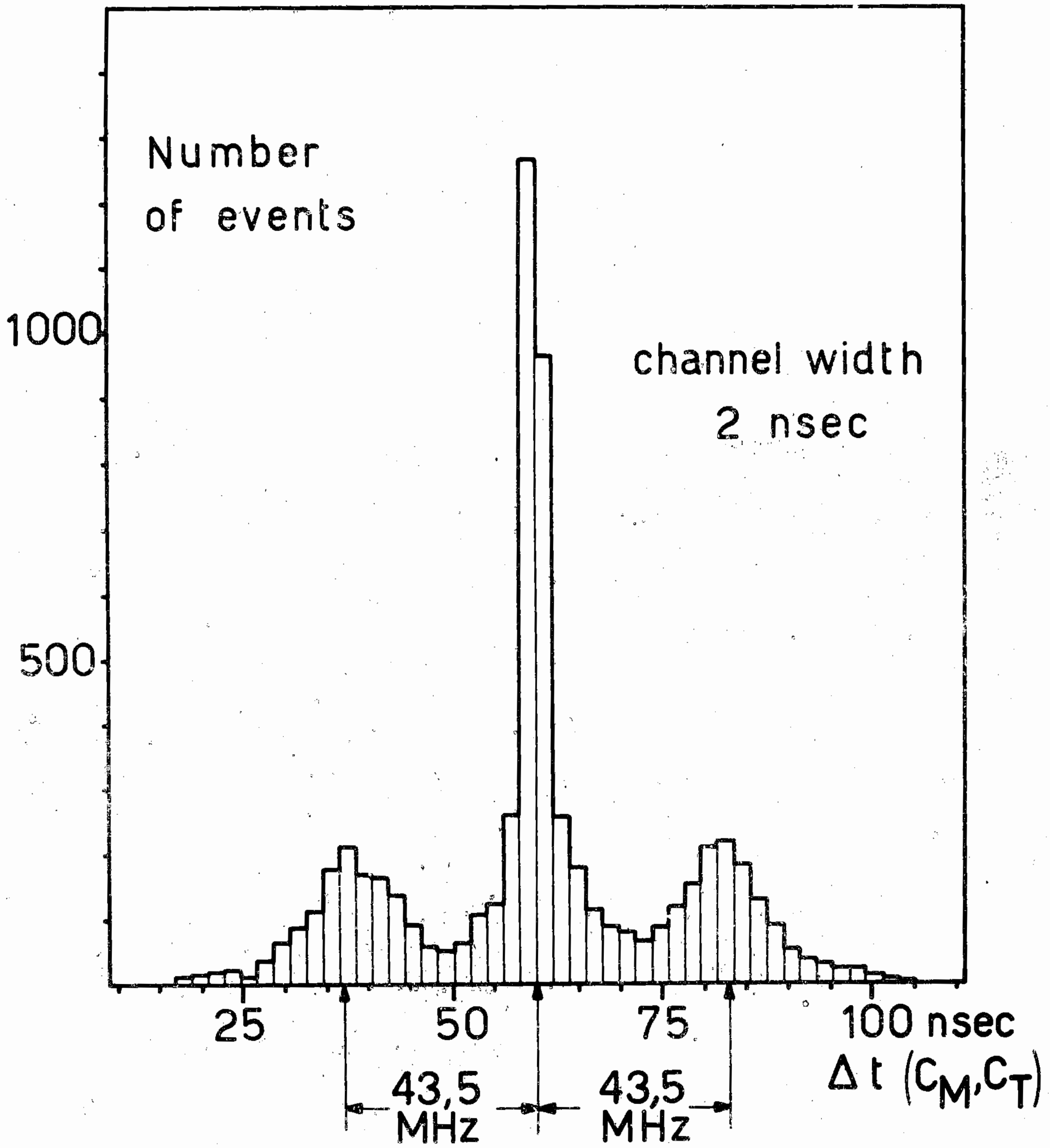
Number
of events
1000
500
channel width
2 nsec
25
50
75
100 nsec
Δ t (C_M, C_T)
43,5
MHz
43,5
MHz

fig. 2

contrary, the distribution for electromagnetic muons, obtained at 30° by simulating them with pions of appropriate momentum, shows well defined peaks in both these counters (see fig. 3). More precisely, we divided our events into three groups: (1) events with D_M pulse height smaller than 4 mm, (2) events with D_M at least 4 mm but C smaller than 4 mm, and (3) events with both D_M and C at least 4 mm, and could show that 98.4% of the electromagnetic muons are in this last group. In it we had 1695 events - collected at a rate of about one every six minutes - and we learned from the other two groups that 42 of these events were electrons and 252 were pions and decay muons.

The table shows our results, in the form of ratios of the absolute experimental cross sections to the theoretical. To obtain the latter, the Bethe-Heitler proton cross sections were first corrected for the carbon form factor(4) and for inelastic processes according to the formula(x) $\sigma_C = \sigma_{BH}\left[Z^2F^2+Z(1-F^2)\right]$. They were then integrated over the μ^+ and μ^- solid angles and over the bremsstrahlung spectrum. Folded into the integrals were the resolution curves of the spectrometer, as obtained by extrapolating alpha-particle calibration measurements(3) to our well below saturation field setting. Not included in the calculation were radiative corrections (estimated by Bjorken et al.(5) to be less than 1,5%), Coulomb interaction corrections of the final states, and nuclear recoil effects. The errors quoted in the table are statistical: we

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(x) - Inelastic corrections, given by the second term, are of the order of 3%.

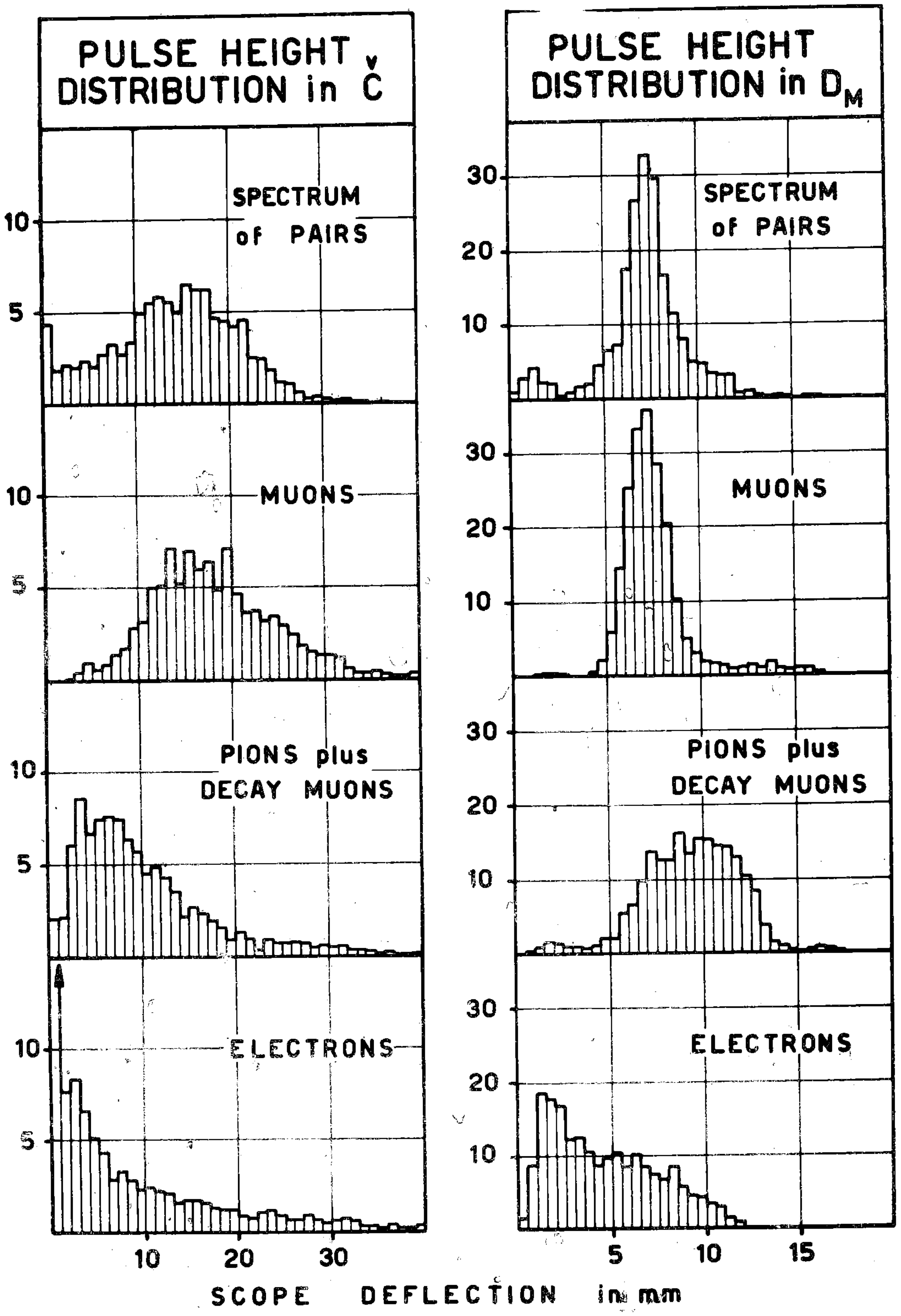
PULSE HEIGHT DISTRIBUTION in Č
PULSE HEIGHT DISTRIBUTION in D_M
SPECTRUM of PAIRS
MUONS
PIONS plus DECAY MUONS
ELECTRONS
5
10
20
30
15
SCOPE DEFLECTION in mm

fig. 3

estimate other uncertainties in the experimental cross sections (coming mainly from beam calibration and the bremsstrahlung spectrum) to be less than 2%.

Differences from unity in the six ratios shown are hardly significant: the overall average gives 1.00 ± 0.05. Assuming this error, and taking into account the range of variation of the four-momentum transfer q to the virtual muon (135-185 MeV/c), we conclude that no anomalous behaviour is observed, within 5% accuracy, down to a distance $h/q = 1.2 \times 10^{-13}$ cm. For those who believe in cutoff theories, we may, of course, push this value further, and set, with 95% confidence, a limit of 2×10^{-14} cm for a cutoff in the virtual muon propagator$^{(6)}$. Accordingly, we confirm the well known result that a group at CERN has recently obtained by means of a highly accurate measurement of the muon magnetic moment. Finally, the total energy of the two muons in their center of mass ranged from 240 to 290 MeV, and we exclude from this interval muon-muon interaction effects larger than 5%. Effects due to possible leptonic decays of the ω^0 and η^0 particles$^{(8)}$, or to the σ^0 meson conjectured by Schwinger$^{(9)}$, may be observed at higher energies. We are planning an experiment to explore these higher masses, and ranges of higher momentum transfers.

We would like to thank Prof. C. Bernardini for his collaboration in the early stages of this work, and to Mr. G. Ubaldini for having carried out much of the technical work with great skill and stamina.

TABLE I

Ratios of the experimental to the theoretical cross sections for the three momentum channels of the μ^+ and for the two angular channels of the μ^- .

	329	360	393 MeV/c
9.3°	0.88 ± 0.13	0.90 ± 0.09	1.04 ± 0.10
10.7°	0.99 ± 0.15	1.15 ± 0.10	1.11 ± 0.10

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