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THE ρ RADIATIVE DECAY WIDTH: A MEASUREMENT AT 200 GeV

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ABSTRACT

The ρ^- radiative decay width has been measured by studying the production of ρ^- via Primakoff effect by 200 GeV incident π^- on Cu and Pb targets.

This width was obtained by fitting the measured $d\sigma/dt$ for ρ production with the theoretical coherent differential cross section including both the electromagnetic and strong contributions.

The measured radiative width value is $81 \pm 4 \pm 4$ KeV: it is consistent with the ratio $\Gamma(\rho \rightarrow \pi\gamma)/\Gamma(\omega \rightarrow \pi\gamma) \sim 1/9$ as expected from the Vector Dominance and the quark model.

1 - INTRODUCTION

The decay of a vector meson (V) into a pseudoscalar meson (P) and a photon is described by a coupling constant $g_{VP\gamma}$, such that:

$$\Gamma(V \rightarrow P\gamma) \approx g_{VP\gamma}^2 k^3 \alpha/3 \quad (1)$$

where $\alpha \approx 1/137$ and $k = (M_V^2 - M_P^2)/2M_V$ is the P meson momentum in the V rest frame.

Various theoretical descriptions of $g_{VP\gamma}$ exist, based on a number of current ideas on light quark bound state dynamics which can accordingly be tested in precise measurements of such decays.

In the nonrelativistic quark model $V \rightarrow P\gamma$ is a magnetic dipole (M1) transition, so that $g_{VP\gamma}$ can be directly related to the magnetic moments of the constituent quarks. Using ideal vector meson mixing one would find in particular for $\rho \rightarrow \pi\gamma$ and $\omega \rightarrow \pi\gamma$ (1)

$$g_{\rho\pi\gamma} = 2\mu_p/3 \quad ; \quad g_{\omega\pi\gamma} = 2\mu_p \quad (2)$$

where $\mu_p = 2.79/2M_p$ is the proton magnetic moment.

Quantitative width calculations are affected by uncertainties, due to the assumptions made in the treatment of the non relativistic limit of the bound quark wavefunctions and eventually of SU(3) breaking.

Thus quark model predictions for $\Gamma(\rho \rightarrow \pi\gamma)$, presented in the literature, range from ~120 KeV implied by eq.(2) to ~57 KeV obtained with broken SU(3) and non relativistic phase space (2).

For the $\rho \rightarrow \pi\gamma$ and $\omega \rightarrow \pi\gamma$ transitions eq.(1) becomes:

$$\begin{aligned}\Gamma_{\omega\pi\gamma} &\approx \frac{\alpha}{3} \cdot g_{\omega\pi\gamma}^2 \cdot k_{\pi(\omega)}^3 \\ \Gamma_{\rho\pi\gamma} &\approx \frac{\alpha}{3} \cdot g_{\rho\pi\gamma}^2 \cdot k_{\pi(\rho)}^3\end{aligned}\quad (3)$$

where $k_{\pi(\omega)}$ and $k_{\pi(\rho)}$ are the CMS momenta of the pion produced in the ω and ρ decays, respectively.

From eqs. (3) and (2), the ratio

$$\frac{\Gamma(\rho \rightarrow \pi\gamma)}{\Gamma(\omega \rightarrow \pi\gamma)} = \frac{1}{9} \cdot 0.96 \quad (4)$$

is predicted, where the factor 0.96 is due to the ratio $k_{\pi(\omega)}^3/k_{\pi(\rho)}^3$. This ratio (4) is expected to be free from the ambiguities due to the uncertainties which affect the width calculations of the quark model and therefore should stand on a much firmer theoretical basis.

In the simplest version of the Vector Dominance Model⁽³⁾ $g_{\rho\pi\gamma}$ and $g_{\omega\pi\gamma}$ can be expressed, assuming ideal mixing again, as

$$g_{\rho\pi\gamma} \approx (1/2\gamma_\omega)g_{\omega\rho\pi} \quad (5)$$

$$g_{\omega\pi\gamma} \approx (1/2\gamma_\rho)g_{\omega\rho\pi}$$

where γ_ρ , γ_ω represent the leptonic transition amplitudes for $\rho \rightarrow e^+e^-$ and $\omega \rightarrow e^+e^-$ measured in e^+e^- annihilation, and $g_{\omega\rho\pi}$ is accessible independently from the strong transition $\omega \rightarrow \rho\pi \rightarrow 3\pi$.

Within the uncertainties associated with the extraction of $g_{\omega\rho\pi}$ from $\omega \rightarrow 3\pi$, the Vector Dominance Model gives similar results to quark models for $\Gamma(\rho \rightarrow \pi\gamma)$ and $\Gamma(\omega \rightarrow \pi\gamma)$. Moreover in the SU(3) limit $\gamma_\omega = 3\gamma_\rho$ (which is confirmed by experimental data); so that the ratio in eq.(4) is also implicit in eqs. (5).

In contrast to $\omega \rightarrow \pi\gamma$, the transition $\rho \rightarrow \pi\gamma$ has a very small branching ratio ($\leq 10^{-3}$); therefore it cannot be measured directly, since it would be overwhelmed by the $\rho \rightarrow \pi\pi^0$ background.

Consequently in order to measure $g_{\rho\pi\gamma}$ it is necessary to study the inverse transition $\gamma\pi\rightarrow\rho$, as in the production of ρ via the Primakoff effect by incident pions (see Fig.1).

Two measurements of the ρ^- radiative decay width have been obtained so far: 35 ± 10 KeV at 22 GeV⁽⁴⁾ and 71 ± 7 KeV at 156-260 GeV;⁽⁵⁾ for the ρ^+ the only measurements gives 60 ± 4 KeV at 200 GeV/c⁽⁶⁾.

These values should be compared with the indirect determination of $\Gamma(\rho\rightarrow\pi\gamma)$ obtainable from eq.(4) and the experimental width $\Gamma(\omega\rightarrow\pi\gamma)=860\pm 60$ KeV, reported by the Particle Data Group Tables⁽⁷⁾, which would indicate $\Gamma(\rho\rightarrow\pi\gamma)\approx 92\pm 7$ KeV.

Given the large discrepancy between the existing measurements, and the model dependence of the theoretical predictions, it seems important to attempt at a clarification of the present situation by a new, high statistics measurement of $\Gamma(\rho\rightarrow\pi\gamma)$.

In this paper we report on the results of an experiment carried out at CERN SPS with a 200 GeV π^- beam. The production:

$$\pi^- A \rightarrow \rho^- A \rightarrow \pi^- \pi^0 A \quad (6)$$

via the Primakoff effect is studied using lead and copper targets.

2 - BASIC PROCEDURE

The coherent production of a state V of mass M induced by an incident meson P , in the nuclear Coulomb field, is given by the following cross section⁽⁸⁾:

$$\frac{d\sigma_c}{dt dM^2} = \frac{Z^2 \alpha}{\pi} \frac{\sigma(\gamma P \rightarrow V)}{M^2 - m_P^2} \frac{t - t_{\min}}{t^2} |F_c(t)|^2 \quad (7)$$

$$t_{\min} \approx q_1^2(M) \approx (M^2 - m_P^2)^2 / 4p_P^2 \quad (p_P = \text{incident momentum})$$

where $F_c(t)$ is the electromagnetic form factor of the nucleus.

For the production of a broad resonance such as the ρ (9), with a central mass value m_ρ :

$$\sigma(\gamma\pi \rightarrow \rho) = \frac{8\pi M^2}{(M^2 - m_\pi^2)^2} \frac{2J_\rho + 1}{2J_\pi + 1} \frac{m_\rho^2 \Gamma(\rho \rightarrow \pi\gamma) \Gamma(\rho \rightarrow \pi\pi)}{(M^2 - m_\rho^2)^2 + m_\rho^2 \Gamma^2(\rho \rightarrow \text{all})} \quad (8)$$

A competitive process is the strong coherent production in the nuclear field, which in the case of ρ occurs mainly via ω exchange; its t distribution is described by:

$$\frac{d\sigma_s}{dt} = C_s A^2 (t - t_{\min}) |F_s(t)|^2 \quad (9)$$

where $F_s(t)$ is the nuclear form factor including the reabsorption and C_s is the normalization factor for strong production on a single nucleon.

The strong coherent process is depressed by a factor proportional to $(E \cdot \log E)^{-1}$ with respect to the electromagnetic production.

Because of the interference between the two processes (Coulomb and strong), the ρ^- radiative decay width is measured by fitting the differential cross section as a function of t with:

$$\frac{d\sigma}{dt} = |\Gamma_\gamma^{1/2} f_c(t) + e^{i\phi} C_s^{1/2} f_s(t)|^2 \quad (10)$$

where f_c and f_s are the Coulomb and the strong production amplitudes, respectively; Γ_γ is the ρ^- radiative decay width and ϕ is an unknown phase between the two amplitudes.

From (7) and (8) the amplitude for the nuclear Coulomb production of the ρ resonance is given by the following relation:

$$|f_c(t)|^2 = 24\pi\alpha Z^2 C_M \frac{t - t_{\min}}{t^2} |F_c(t)|^2, \quad (11)$$

where

$$C_M = \frac{1}{\pi} \int dM^2 \frac{M^2}{(M^2 - m_\pi^2)^3} \frac{m_\rho^2 \Gamma(\rho \rightarrow \pi\pi)}{(M^2 - m_\rho^2)^2 + m_\rho^2 \Gamma^2(\rho \rightarrow \text{all})}$$

The widths are taken to depend on the $\pi\pi$ invariant mass M in the following way⁽⁹⁾:

$$\Gamma(M^2) = \Gamma_0 \left(\frac{q}{q_0} \right)^{2l+1} \frac{g(M^2)}{g(m_\rho^2)} \quad (12)$$

where q and l are the 3-momentum in the $\pi\pi(\pi\gamma)$ rest frame and the relative angular momentum of the $\pi(\gamma)$ (in the diffractive processes $q^2 \approx t$); Γ_0 is the width at $M^2 = m_\rho^2$ and $g(M^2)$ is a relatively slowly varying factor, which in our analysis has been taken as $g = \frac{1}{q^2 + q_0^2}$ (q_0 is q at the resonance).

The electromagnetic form factor is given by:

$$F_C(t) = \frac{1}{4\pi i} \int d^3 r \quad \psi_f^* e^{i\vec{q} \cdot \vec{r}} \hat{q}_t \cdot \vec{E}(\vec{r}) \psi_i \quad (13)$$

$\vec{E}(\vec{r})$ is the electric field; ψ_i and ψ_f are the incident and outgoing waves, modified by the rescattering inside the nucleus.

$F_C(t)$ can be split into three parts; one inside the nucleus and two outside⁽¹⁰⁾

$$F_C = F_C^{\text{int}} + F_C^{\text{ext1}} + F_C^{\text{ext2}} \quad (14)$$

F_C^{int} covers the space occupied by the nucleus; F_C^{ext2} refers to the space outside the nucleus, but inside a flux tube following the beam direction and having the dimension of the nucleus; F_C^{ext1} refers to the space outside this flux tube. They can be written in the following form:

$$\begin{aligned}
F_c^{\text{int}} &= \frac{q^2}{q_1 q_t R^3} \int_0^R db \cdot b^2 e^{-\frac{1}{2}\sigma' T(b)} e^{i\chi_c(b)} J_1(q_t \cdot b) \sin(q_1 \sqrt{R^2 - b^2}) \\
F_c^{\text{ext1}} &= \frac{q^2 q_1}{q_t} \int_R^\infty db \cdot b \cdot K_1(q_1 \cdot b) J_1(q_t \cdot b) e^{i\chi_c(b)} \\
F_c^{\text{ext2}} &= \frac{q^2}{q_t} \int_0^R db \cdot b^2 e^{-\frac{1}{2}\sigma' T(b)} J_1(q_t \cdot b) e^{i\chi_c(b)} \int_{\sqrt{R^2 - b^2}}^\infty dz \frac{\cos(q_1 \cdot z)}{(z^2 + b^2)^{3/2}}
\end{aligned} \tag{15}$$

where b is the impact parameter; χ_c is the Coulomb phase; q_t and q_1 are the trasverse and longitudinal components of the momentum transfer q , respectively; R is the nuclear radius, $T(b)$ is the nuclear "thickness" function:

$$\sigma' T(b) = A(\sigma'_\pi \int_{-\infty}^z \rho(b, z') dz' + \sigma'_\rho \int_z^\infty \rho(b, z') dz') \tag{16}$$

$\rho(b, z)$ is the nuclear density distribution; $\sigma' = (1 - i\alpha)\sigma$ where α is the ratio of the real to imaginary part of the forward scattering amplitude for π (or ρ) on nucleons and σ is the π (or ρ)-nucleon total cross section. In these calculations we have assumed:

$$\alpha_\pi = \alpha_\rho = 0.06^{(11)} \quad \text{and} \quad \sigma_\pi = \sigma_\rho = 24.5 \text{ mb}$$

$\chi_c(b)$ depends on the nuclear density; assuming the Wood-Saxon distribution, the following formula is used⁽¹²⁾:

$$\chi_c(b) = 2Z\alpha \left\{ \ln(Kb) + 4\pi \int_b^\infty dr \cdot r^2 \cdot \rho(r) \left[-\sqrt{1 - \frac{b^2}{r^2}} + \ln\left(\frac{r}{b} + \sqrt{\frac{r^2}{b^2} - 1}\right) \right] \right\} \tag{17}$$

The nuclear coherent amplitude is treated by using the classical Glauber approach⁽¹³⁾. It can be written as:

$$f_s(t) = 4\pi A \int_0^\infty dz \cos(q_1 \cdot z) \int_0^\infty db \cdot b^2 \cdot J_1(q_t \cdot b) e^{-\sigma' T(b)/2} \cdot e^{i\chi_c(b)} \frac{\partial \rho(b, z)}{\partial b} \quad (18)$$

Fig.2 shows the general shape of the Coulomb and nuclear coherent production cross section for a ρ state and for a lead target. The area below the nuclear curve is only a small fraction of the Coulomb production in the t range below $0.01(\text{GeV}/c)^2$ for heavy nuclei.

3 - EXPERIMENTAL APPARATUS

The kinematics and the topology of the reaction (6) require an apparatus with a good acceptance at low t , beam particle identification, photon energy measurements and charged particle momentum analysis.

After minor changes, the forward spectrometer FRAMM and the vertex detector of the CERN NA7 experiment⁽¹⁴⁾ satisfied the above requirements.

A schematic view of the experimental apparatus is presented in Fig.3.

3.1 - THE BEAM

The experiment was performed at the CERN SPS in the H4 beam-line. The composition of the beam at 200 GeV/c and 10^6 ppb was: 95.% π^- and 4.5% K^- ⁽¹⁵⁾.

An upstream differential high pressure gas Cerenkov counter (CEDAR) flagged the incoming particles, discriminating between pions and kaons.

The beam was focused 9.7m downstream of the target, where a small scintillation counter (1.cm x 1.cm) (BK) was used to veto non-interacting particles.

3.2 - THE VERTEX REGION AND THE TARGET

The beam trajectory was defined by 2 blocks of multiwire

chambers, with 1 mm wire spacing. Each block consisted of 8 planes measuring the horizontal (3 planes), the vertical (3 planes) and diagonal (2 planes) coordinates. Downstream of the target two similar blocks of MWPC were used to measure the trajectories of the secondary particles.

The planes measuring the same coordinate were staggered by 1/3 mm, providing a track coordinate determination to better than 0.2 mm, giving an angular resolution of 0.1 mrad.

Along the beam line one set of veto counters, two hodoscopes and a time reference counter were installed; they consisted of the following scintillation counters:

- a) anticoincidence counters V_1 and H to veto the beam-halo, V_3 - V_5 to reject decays or interactions upstream of the target and events with particles at large angles;
- b) a crossed pair of hodoscopes SH, with 5 mm wide counters, to define particle positions within the beam profile and to reject events with more than one incoming particle;
- c) a thin circular counter C (1 mm thick), put in front of the target, to define the beam in the trigger and provide a precise time reference;
- d) a crossed pair of hodoscopes LH, 10 m downstream of the target, to select events with only one charged particle; each hodoscope had 20 counters, 25 cm long, and width varying from 4 cm at wide angles to 5 mm in the beam region.

Two different targets (Pb and Cu) have been used. Their thickness (≈ 0.18 radiation length) was chosen to limit photon conversion and multiple Coulomb scattering: the effect of the latter on the measurements of the charged particle trajectory was within the detector resolution. The position of the target was $z = -10$ cm.

3.3 - THE SPECTROMETER

Downstream of the vertex detector, the FRAMM magnetic spectrometer measured the momenta of the secondary charged particles. It consisted of four magnets ($B_1 \cdot dl_1 = 0.67$ Tm, $B_2 \cdot dl_2 = 1.38$ Tm, $B_3 \cdot dl_3 = 3.02$ Tm, $B_4 \cdot dl_4 = 5.84$ Tm), interspaced with

stacks of drift chambers and electromagnetic shower detectors.

Each drift chamber stack consisted of three pairs of planes, each of them having the sense wires perpendicular to each other. The precision in the measurement of the track coordinate was 0.2mm, using the sense wire information, and 2 mm using delay lines parallel to the sense wires. The first two shower detectors (FS, SD1) were 20 radiation lengths, lead/scintillator sandwiches; the second two (SD2, SD4) were lead glass arrays: their elements of the front parts (4 r.l.) were 7 cm x 21 cm, and the rear part (20 r.l.) elements were 3.5 cm x 35 cm. This longitudinal structure was used to discriminate between electromagnetic and hadronic showers.

A scintillation counter (FA) (positioned in front of FS), defined the acceptance cone of the spectrometer (± 9 mrad), while scintillation counters (T), placed in front of the other shower detectors, helped in discriminating between neutral and charged particles.

The energy resolution of the glass counters was measured (in test conditions) to be $\frac{\Delta E}{E} = \left[1 + \frac{14}{\sqrt{E}(\text{GeV})} \right] \%$, and the space resolution to be ± 2.5 mm, although these values were not achieved for the entire detector.

3.4 - THE TRIGGER

The trigger was set up to select events with only one charged track and with at least one photon signal.

First of all the beam trigger was defined by:

$$\text{BEAM} = C \cdot \text{SH (only 1 particle)} \cdot \overline{\text{V1}} \cdot \overline{\text{H}}$$

where the C counter selected only single particles, within a time window of ± 40 nsec.

A pretrigger (PT) was generated for the fast MWPC readout:

$$\text{PT} = C \cdot \overline{\text{BK}}$$

it inhibited the C signal. The C signal was re-enabled either on

rejection of the event by a later trigger level or upon completion of data acquisition.

A vertex trigger (VTX) selected events with only one secondary track produced inside the acceptance angle of the spectrometer:

$$\text{VTX} = \text{BEAM} \cdot \text{PT} \cdot \text{LH (only one particle)} \cdot \bar{V}_3 \cdot \bar{V}_4 \cdot \bar{V}_5$$

The final trigger was:

$$\text{FINAL} = \text{VTX} \cdot \bar{\text{FA}} \cdot \text{MULTIANTI} \cdot \text{PHOTON}$$

PHOTON required an energy release in SD2 or in SD4 compatible with at least one photon converted. MULTIANTI rejected events with more than 2 secondary charged particles only when they were produced downstream of the vertex region: its logic made use of the T counter signals.

With this trigger, 10^6 incident particles/burst hitting the target produced ~ 70 events/burst, which were recorded on tape.

4 - DATA ANALYSIS

The cross section for the reaction (6) has been calculated by normalizing the ρ^- yield to the $\pi^-\pi^0$ decays of the K^- present in the beam.

The contamination of K^- in the beam was such that we were able to measure a sample of K^- decays comparable to the ρ^- yield. This procedure has the advantage that, because of the similar kinematics of $\rho^- \rightarrow \pi^-\pi^0$ and $K^- \rightarrow \pi^-\pi^0$, any inefficiencies of the detectors and off-line programs, cancelled to the first order, are automatically taken into account.

4.1 - MONTECARLO SIMULATIONS

A detailed Montecarlo program has been developed to measure the different geometrical acceptances, efficiencies of the off-line programs and the effect of the various cuts introduced in the analysis for the two processes and relative background channels.

The ρ^- production via the Primakoff effect has been

simulated by generating the kinematic variables of the ρ^- according to the expected mass and four-momentum transfer distribution as in equation (7). Its decay in the $\pi^-\pi^0$ channel was generated in the Gottfried-Jackson frame using a $\sin^2\theta \sin^2\phi$ angular distribution⁽¹⁶⁾.

The main source of background comes from the $\pi^-A \rightarrow \pi^-\pi^0\pi^0A$ coherent production when one π^0 escapes. This reaction has been simulated using the experimental data on $\pi^-A \rightarrow \pi^-\pi^-\pi^+A$ reported in ref. 17; the $\pi^-\pi^0\pi^0$ cross section, calculated from these data using the Clebsch-Gordan coefficients, is $\sim 1.1\text{mb}$ on a Cu target and $\sim 1.9\text{mb}$ on a Pb target. This background in the ρ^- sample is very small due both to the large photon detector acceptance and to the various cuts introduced in the analysis (see par. 4.2).

The $K^- \rightarrow \pi^-\pi^0$ decays have been simulated with an isotropic angular distribution of the pions in the K^- centre of mass system and decay vertices distributed between $z=-1500$ cm and $z=920$ cm along the beam axis.

Background for this decay can arise from the $K^- \rightarrow 3$ body channels:

$$K^- \rightarrow e^- \nu_e \pi^0$$

$$K^- \rightarrow \mu^- \nu_\mu \pi^0$$

$$K^- \rightarrow \pi^-\pi^0\pi^0$$

when in the first two processes the charged lepton is misinterpreted and in the third one a π^0 is undetected. The particles from these decays have been generated in accordance to the phase space distributions. This background turns out to be negligible due to the branching ratios and the kinematics cuts in the analysis.

The beam was simulated using the characteristics of the real one, as measured by the vertex MWPC's.

The particles produced were then tracked through the apparatus. The events were rejected either when particles are

produced outside the geometrical acceptance or do not satisfy the trigger requirements or when photons are converted in the target or in the scintillation counters.

For the accepted events, charged particles were converted to hits in the chambers, and photons to pulse heights in the photon detectors, according to the measured efficiencies.

The Montecarlo events were then processed by the reconstruction, selection and kinematics fit programs in exactly the same way as the data.

4.2 - ρ^- AND K^- SELECTION

The data sample collected in this experiment consisted of ~ 200.000 triggers taken with the Pb target and of ~ 600.000 triggers with the Cu target.

Data were also taken to measure the magnetic field and the chamber alignments and to calibrate the shower detectors.

Special runs were made with no target to measure the background. Others were also made with trigger requirements removed in turn (but tagged) to study the efficiency of the various vetoes.

The analysis of the events has been organized in successive steps:

- 1) First of all the vertices are found by combining the beam tracks and the downstream tracks when intersecting between MPWC2 ($z=-227.1$ cm) and MWPC3 ($z=181.9$ cm). The vertex region for ρ^- production is defined in the range of z from -20 to $+10$ cm. The asymmetry of the cut was due to avoid the background arising from the counter C, placed at $z = -30$ cm. The vertex region for the K^- decays was defined well outside the target, in the intervals: z from -130 to -50 cm and from $+20$ to $+100$ cm. The longitudinal vertex coordinate is reconstructed with a $\sigma = 6.8$ cm for tracks with angles > 1 mrad.

The agreement between our data and the Montecarlo is shown

in Fig.4a and 4b, where the arrows indicate the vertex fiducial cuts.

- 2) Events with one charged track and two electromagnetic showers in the photon detectors are retained.
- 3) The $\gamma\gamma$ invariant mass is reconstructed. The distribution, presented in Fig.5, is well centered at the π^0 mass and shows a resolution corresponding to $\sigma=20 \text{ MeV}/c^2$. The interval from 80 to $190 \text{ MeV}/c^2$, which was adopted to define the π^0 , includes in practice the full distribution.
- 4) The events are subjected to a two constraint kinematics fit with a fixed π^0 mass. 97% of the ρ and 93% of the K events, which show a convergent fit, are accepted with any χ^2 . The background due to different channels in the ρ^- and K^- samples is largely depressed by this fit.
- 5) The total energy of the secondary particles $E_{\pi^-\pi^0}=E_{\pi^-}+E_{\pi^0}$ as measured by the spectrometer is shown in Fig.6 for events surviving after step 4) and it is compared with the M.C. simulations. The agreement between the two distributions is excellent. The range $150 < E_{\pi^-\pi^0} < 250 \text{ GeV}$ is an appropriate cut for this distribution.

The $\pi^-\pi^0$ invariant mass distributions, as obtained by the kinematics fit are presented in Figs. 7a and 7b for the events which satisfied all the steps described above and for $t < 0.01(\text{GeV}/c)^2$: they are compared with the M.C. predictions.

To define the ρ^- and the K^- events, cuts from 600 to 950 and from 450 to 550 MeV/c^2 , respectively, are introduced in the $\pi^-\pi^0$ mass spectra. No ρ^- signal is visible in the data having the vertex in the K^- region while a K^- signal is present in the ρ^- acceptance interval. As a further check, we have tested cuts different from those adopted for every step and verified that the Montecarlo corrections result in the same numbers of corrected events.

The acceptance of our apparatus for the K decays is shown in Fig.8.

5 - RESULTS AND DISCUSSION

The cross section for ρ^- production is calculated by normalizing the ρ^- yield to the $K^- \rightarrow \pi^- \pi^0$ decays, present in the beam.

For this purpose the following relation is used:

$$\frac{d\sigma}{dt} = \frac{A}{\rho \cdot d \cdot N} \cdot T \cdot \frac{X_K D_K}{X_\pi D_\pi} \cdot \frac{\varepsilon_K}{n_K} \cdot \frac{1}{\varepsilon_\rho} \cdot \frac{dn_\rho}{dt} \quad (19)$$

$A/\rho \cdot d \cdot N$ depends on the target characteristics ($d=1\text{mm}$ and 2.5mm for the lead and copper targets respectively); dn_ρ/dt and n_K are the number of produced ρ^- and K^- , respectively, decaying into the $\pi^- \pi^0$ channel; ε_ρ and ε_K are the efficiencies for ρ^- and K^- detection and reconstruction (including the subtraction of contributions from background channels); X_π and X_K are the fraction of π^- and K^- in the beam at the primary target; D_K is the probability that a beam K^- decays into $\pi^- \pi^0$ in the region chosen for the K decays and D_π is the probability that the incident π survives up to the target; finally T is a correction factor, which takes into account the different inefficiency of the trigger for $\rho^- \rightarrow \pi^- \pi^0$ production with respect to the $K^- \rightarrow \pi^- \pi^0$ decays: it was evaluated by analyzing the data collected with the special runs mentioned in 4.2.

The various cuts and their effects, evaluated with the Montecarlo, are summarized in Table I. The efficiencies are $\varepsilon_\rho \approx 0.35$ for Cu and ≈ 0.34 for Pb; $\varepsilon_K \approx 0.40$. The background subtractions are listed in Table II; the final number of ρ^- and K^- are: 2935 and 4590 for copper and 967 and 1863 for lead, respectively. The factor T turns out to be 0.98.

In Figs. 9a, 9b the distributions of the $\pi^- \pi^0$ invariant mass are shown for the selected events produced on Cu and Pb targets; they are corrected for the geometrical acceptance. The spectra are fitted by the equation (7) written for a broad resonance (eq. 8), integrated in t up to $0.01 (\text{GeV}/c)^2$. The mass resolution, obtained by the K invariant mass spectrum of Fig.7b

is $\sigma \approx 13 \text{ MeV}/c^2$ and does not affect the ρ invariant mass distribution.

The best fit values of the ρ mass and width are presented in Table III: they are in very good agreement with the values reported by the Particles Data Group Tables⁽⁷⁾.

The reliability of the selection of the ρ^- states coherently produced on nucleus is supported by the ϕ and $\cos\theta$ distributions of the pions in the Gottfried-Jackson frame (Figs. 10a, 10b). No cuts in t are applied because at very small four-momentum transfer the definition of the Gottfried-Jackson plane is strongly affected by the resolution. The agreement of the distributions between experimental data and M.C. events generated with a $\sin^2\phi \sin^2\theta$ shape is good.

The measured unphysical four-momentum transfers to $\pi^-\pi^0$ produced by K^- decays, are plotted in Fig. 11. This distribution, which theoretically would be a δ function at $t=0$, provides the q_x and q_y resolutions, of the experiment. These are folded into the equation (10) to fit the differential cross section for the ρ^- production (Fig.12) on copper and lead.

The results of the fits are summarized in Table IV. The best fit values obtained for the radiative width are: $81 \pm 5 \pm 4 \text{ KeV}$ from copper target and $82 \pm 8 \pm 9 \text{ KeV}$ from lead. The first quoted error is the statistical one, while the second takes into account all the uncertainties of the corrections performed in the analysis.

The two values are almost the same, their weighted average is $\Gamma_\gamma = 81 \pm 4 \pm 4 \text{ KeV}$. A global fit of the two differential cross sections on copper and lead, by stating that Γ_γ , C_s and ϕ be the same for the two nuclei, gives a value of $\Gamma_\gamma = 83 \pm 4 \pm 4$.

Although not inconsistent with the previous measurement⁽⁵⁾ $\Gamma_\gamma = 71 \pm 7 \text{ KeV}$, carried out at 156-260 GeV, it confirms the ratio $\Gamma(\rho \rightarrow \pi\gamma)/\Gamma(\omega \rightarrow \pi\gamma) \approx 1/9$ which gives $\Gamma(\rho \rightarrow \pi\gamma) = 92 \pm 7 \text{ KeV}$ using the experimental value $\Gamma(\omega \rightarrow \pi\gamma) = 860 \pm 60 \text{ KeV}$, as quoted in the Particle Data Group Tables⁽⁷⁾. As already pointed out in the introduction this ratio is expected from the quark model and from the Vector Dominance Model in the SU(3) limit.

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FIGURE CAPTIONS

Fig. 1 - Schematic diagram of the ρ production via Primakoff effect.

Fig. 2 - $d\sigma/dt$ distribution for Coulomb and strong coherent production on a Pb target, as obtained from the theoretical formula (7), written for ρ production, and formula (9). The relative weights of the electromagnetic and strong processes are the same as found in the present data.

Fig. 3 - Schematic view of the experimental apparatus.

Fig. 4 - Reconstructed vertex distributions (z coordinate):
 a) interaction vertices for the $\pi^-\pi^0$ production by incident π^- ;
 b) decay vertices of the $K^- \rightarrow \pi^-\pi^0$ present in the beam (the target region is excluded).

Fig. 5 - Invariant mass distribution of two photons. The arrows define the interval used for the π^0 .

Fig. 6 - Total energy of the secondary particles ($E_{\pi^-} + E_{\pi^0}$) as obtained by the spectrometer measurements: in the plot only the events surviving, after the cut on the vertex and π^0 mass and the kinematics fit, are included. The full line represents the Montecarlo simulations and the two arrows, the acceptance range chosen in the analysis.

Fig. 7 - $\pi^-\pi^0$ invariant mass distributions as obtained by the kinematics fit. The events plotted here survived after the cuts on the π^0 mass and total energy, the kinematics fit and the cut at $t < 0.01 \text{ (GeV/c)}^2$. The full line is the Montecarlo prevision.
 a) π interactions
 b) K decays

Fig. 8 - $\cos\theta$ of the secondary π produced in the K decay with respect to the beam in the K rest frame.

Fig. 9 - $\pi^-\pi^0$ invariant mass distributions for the events selected by our analysis for the π interactions: the full line represents the Breit-Wigner formula written for a broad resonance and fitted on the experimental distribution.

Fig.10 - ϕ and $\cos\theta$ distributions of the π 's produced by the ρ^- decay, in the Gottfried-Jackson frame. The full line is the Montecarlo simulation.

Fig.11 - Distributions of the unphysical four-momentum transfer to $\pi^-\pi^0$ produced by K^- decays.

Fig.12 - Differential cross sections $d\sigma/dt$ for the ρ^- production on copper and lead. The full line is the theoretical formula (10) with the resolution folded in, fitted on the experimental data.

TABLE I

Surviving fraction of the Montecarlo generated samples

CUTS	$\pi^- \text{Cu} \rightarrow \text{Cu} \pi^- \pi^0$	$\pi^- \text{Pb} \rightarrow \text{Pb} \pi^- \pi^0$	$K^- (*)$
Geometrical acceptance + rejection of the events with photon converted in the target + trigger	.49	.48	.49
Reconstructed Charged particle angle $> 1.$ mrad + vertex between: -20. $\rightarrow$ 10.cm for ρ^- -130. $\rightarrow$ -50.cm; 20. $\rightarrow$ 100.cm for K^-	.45	.44	.47
$E_{\pi^- \pi^0}$ (150. $\rightarrow$ 250. GeV)	.40	.39	.42
kinematics Fit	.40	.39	.41
$M_{\pi^- \pi^0}$ ρ^- (600. $\rightarrow$ 950. MeV/c^2) K^- (450. $\rightarrow$ 550. MeV/c^2)	.36	.35	.40
$t' < 0.01$ $(\text{GeV}/c)^2$	.35	.34	.40

(*) These fractions are normalized to the generated kaons with the decay vertex within the accepted intervals.

TABLE II

Background Subtractions

	$\pi^- \text{Cu} \rightarrow \text{Cu} \pi^- \pi^0$	$\pi^- \text{Pb} \rightarrow \text{Pb} \pi^- \pi^0$	K^-
empty target events	1.4 %	1.8 %	–
$\pi^- \pi^0 \pi^0$ channel	3.8 %	1.3 %	–
$\text{K} \rightarrow 3$ bodies channels	–	–	0

TABLE III

Fit of the $\pi^- \pi^0$ invariant mass spectrum with the equation (7).

$\pi^- A \rightarrow A \pi^- \pi^0$	m_ρ (MeV/c ²)	$\Gamma(\rho \rightarrow \text{all})$ (MeV/c ²)	χ^2/DF
A = Cu	767.±2.	155.±7.	24/20
A = Pb	761.±3.	154.±9.	43/33

TABLE IV

Fit up to $t=0.01(\text{GeV}/c)^2$ of the t distribution with the equation (10)

$\pi^- A \rightarrow A \pi^- \pi^0$	Γ_γ KeV	C_s mb/GeV ⁴	ϕ rad.	χ^2/DF	$\sigma_c(\text{mb})$ $t < 0.005(\text{GeV}/c)^2$	$\sigma_s(\text{mb})$ $t < 0.005(\text{GeV}/c)^2$
A=Cu	81. $\pm$ 5. $\pm$ 4.	2.7 $\pm$.4 $\pm$.4	4.9 $\pm$.3 $\pm$.2	32/21	.155 $\pm$.01	.030 $\pm$.004
A=Pb	82. $\pm$ 8. $\pm$ 9.	4.1 $\pm$.9 $\pm$ 1.4	4.8 $\pm$.4 $\pm$.5	25/26	1.16 $\pm$.11	.17 $\pm$.04
global	83. $\pm$ 4. $\pm$ 4.	2.9 $\pm$.3 $\pm$.4	4.8 $\pm$.2 $\pm$.2	62/47		

The first error is the statistical one; the second error takes into account the uncertainties due to the corrections performed in the analysis.

Fig. 1

Fig. 2

Fig. 3

Fig. 4a

Fig. 4b

Fig. 5

Fig. 6

Fig. 7a

Fig. 7b

Fig. 8

Fig. 9a

Fig. 9b

Fig. 10a

Fig. 10b

Fig. 11

Fig. 12