# $\rho$ PRODUCTION FROM HYDROGEN BY 16 GEV BREMSSTRAHLUNG* 

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[^0]We wish to report on part of the results obtained in the first run of an experiment to study multibody photoproduction with the SLAC 2.2 meter streamer chamber. ${ }^{1}$

A collimated bremsstrahlung beam of 16 GeV peak energy and 3 mm diameter was incident on a 1 cm diameter, 3 atmosphere hydrogen gas target extending through the streamer chamber. The beam of low intensity $\sim 120$ equivalent quanta per $1.5 \mu \mathrm{sec}$ pulse ( $180 \mathrm{pulses} / \mathrm{sec}$ ) was measured by a quantameter. ${ }^{2}$

The chamber was mounted in a large electromagnet producing at this time 8 kG and was viewed by 3 cameras in $18^{\circ}$ stereo through the open upper pole of the magnet.

The streamer chamber was fired and pictures taken everytime a charged particle triggered a 4-fold coincidence array covering approximately $\pm 15^{\circ}$ around the beam direction. The large scintillator counters were split ( $\pm 2^{\circ}$ ) in the horizontal plane containing the target and perpendicular to the magnetic field in order to reduce the number of triggers from electromagnetic background events.

The interaction vertices located inside the hydrogen gas target were invisible.
Of the 87,000 pictures taken and scanned, 7,055 were strong-interaction events; among these were found 3,1823 -prongs. These events have been analyzed using the computer programs SYBIL and TEUTA; ${ }^{3} 851$ events satisfied the following 3 criteria: a 3-constraint kinematical fit of the type $\gamma \mathrm{p} \rightarrow \pi^{+} \pi^{-} \mathrm{p}$, consistency with ionization and apparent photon mass-squared $\left|\mathrm{m}_{\gamma}^{2}\right|<0.1 \mathrm{GeV}^{2}$.

Corrections concerning the inefficiencies of the streamer chamber for steep tracks and the fimte solid angle of the counters were calculated by 2 independent methods: firstly the observed events were rotated around the direction of the incident beam to obtain a geometrical weight; secondly a Monte-Carlo calculation was used to study the effect of inefficiencies on the $\pi \pi$ mass spectrum and angular distributions. Both
results are consistent within the errors: the average efficiency between 3 and 16 GeV was found rather constant $\sim 50$ percent. Each event was individually weighted using the first method.

Figure 1 shows the $\pi^{+} \pi^{-}$invariant mass distributions. The main feature is the strong production of $\rho^{0}$ mesons; it is interesting to observe that at energies above 6 GeV the $\mathrm{p} \pi^{+} \pi^{-}$final state is completely dominated by $\mathrm{p} \rho^{\circ}$. Above 8 GeV other $\pi^{+} \pi^{-}$resonant states of higher mass are absent on the level of $0.2 \mu \mathrm{~b} /$ event. The solid curve in Fig. 1 represents a fit to the data using an incoherent superposition of phase-space, $\Delta^{++}$(1238) and $\rho$ production, the latter being described by a Breit-Wigner distribution of the following form ${ }^{4}$ (fit A)

$$
\begin{aligned}
\mathrm{BW}(\mathrm{~m})= & \mathrm{C} \frac{\mathrm{~m}}{\mathrm{q}} \frac{\Gamma(\mathrm{~m})}{\left(\mathrm{m}^{2}-\mathrm{m}_{\rho}^{2}\right)^{2}+\mathrm{m}_{\rho}^{2} \Gamma^{2}(\mathrm{~m})} \\
& \Gamma(\mathrm{m})=\Gamma_{\rho}\left(\frac{\mathrm{q}}{\mathrm{q}_{\rho}}\right)^{3} \frac{1+\left(\mathrm{q}_{\rho} \mathrm{R}\right)^{2}}{1+(\mathrm{qR})^{2}}
\end{aligned}
$$

where $m$ is the $\pi^{+} \pi^{-}$invariant mass, $q$ and $q_{\rho}$ respectively the center-ofmass $\pi$ momentum corresponding to a center-of-mass energy $m$ and $m_{\cdot \rho}$, R a constant $=3.58(\mathrm{GeV} / \mathrm{c})^{-1}$.

The width $\Gamma_{\rho}$ was kept constant and equal to 150 MeV . It seems that the fitted shape is not in good agreement with the experimental distribution. In order to understand this difference an attempt was made to fit the $\rho$ region between 500 and 950 MeV using a Breit-Wigner form with a phenomenological background (fit C): a linear expression was used and a change in sign observed under the $\rho$ peak which suggests the presence of an interfering background. ${ }^{5}$ In addition the data have been fitted by multiplying the Breit-Wigner distribution by $\left(\frac{m_{\rho}}{m}\right)^{4}$ as suggested by
M. Ross and L. Stodolsky, ${ }^{6}$ although we are aware of some difficulties inherent to that model (fit. B).

In Table I are listed the $\rho$ parameters obtained by the 3 different procedures; it should be emphasized that the number of $\rho^{\prime}$ s found using these 3 methods is not changed within our statistics.

The values for the cross sections are presented in Table II. The photon flux was measured with a quantameter and was consistent with the number of observed electron pairs while the spectrum was in agreement with the theoretical bremsstrahlung calculation. The number of weighted events was corrected for the following losses: statistically evaluated scanning inefficiency (1 percent), systematic scanning loss (energy dependent 0 to 15 percent), ambiguous and rejected events ( 22 percent) due to the fact that the interaction is obscured by discharges in the chamber and confusion with electron pairs, missing neutrals events contamination (5 percent), counter inefficiencies (8 percent).

At lower energies the cross section agrees well with earlier bubble chamber experiments. ${ }^{7}$ Above 6 GeV the cross section for $\rho$ production is consistent with a diffraction behavior as already observed below 6 GeV . ${ }^{7}$

The momentum-transfer distributions are shown in Fig. 2; the solid line represents a fit to the data of the form:

$$
\begin{aligned}
\frac{\mathrm{d} \sigma}{\mathrm{dt} t^{\prime}}= & A \cdot e^{-B\left|t^{\prime}\right|} \\
& t^{\prime}=t-t_{\min }
\end{aligned}
$$

where $t$ is the squared 4 -momentum transfer to the proton; the events below 0.05 $(\mathrm{GeV} / \mathrm{c})^{2}$ were not included in this fit because of biases on low-momentum protons; however for the cross sections a correction was made assuming the straight-line fit.

We have studied the $\rho$ decay angular distributions in terms of spin density matrix elements in the Jackson, helicity and Adair frames. The Jackson $\cos \theta$ distributions show no appreciable deviation from uniformity which indicated that the process is not dominated by a reasonable one-particle-exchange mechanism. On the other hand the helicity frame distributions shown in Fig. 3 are consistent with $\sin ^{2} \theta$ in agreement with the predictions of the strong-absorption model. ${ }^{8}$ No significant difference between the helicity and Adair distributions is seen within the statistics. The curves in Fig. 3 are the results of a likelihood fit to the data using the $\rho \rightarrow 2 \pi$ decay intensity distribution. ${ }^{4}$

This has been the first experimental use of this large streamer chamber. The success of this project was due to the work in design, construction, operation and analysis of a large group of people in addition to those mentioned on the title pagc. Among those whose help has been of great value are the following:

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## References

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8. Y. Eisenberg et al., Physics Letters 22, 217 (1966).

## Figure Captions

1. $\pi^{+} \pi^{-}$invariant mass distributions and likelihood fits to phase-space, $\Delta^{++}$(1238) and $\rho$ productions; $\Gamma_{\rho}$ is fixed to 150 MeV , the $\rho$ mass and fractions are fitted (see Table I).
a) $2-4 \mathrm{GeV}$
b) 4-8 GeV
c) $8-16 \mathrm{GeV}$
(It should be noted that the number of events in each energy bin do not refer to the same fiducial volume.)
2. Squared-momentum transfer distributions and fits to an exponential curve (the first bin is not included in the fit).
a) 2-4 GeV
b) $4-8 \mathrm{GeV}$
c) $8-16 \mathrm{GeV}$
3. $\rho$ decay angular distributions in the helicity system (all distributions are integrated in $\phi$ ) and likelihood fits to the function $\mathrm{W}(\cos \theta)=\mathrm{A}+\mathrm{B} \cos ^{2} \theta$
a) $2-4 \mathrm{GeV} ; \quad|\mathrm{t}|<0.1(\mathrm{GeV} / \mathrm{c})^{2}$
b) 4-8 GeV; all $t$
c) 8-16 GeV; all t

## Table Captions

I. $\rho$ fitted parameters. Fit A refers to the likelihood method explained in the text where $m \rho$ is fitted; Fit $B$ is a similar fit but using the factor $\left(\frac{m_{\rho}}{m}\right)^{4}$; Fit $C$ is a least-squares fit to the $\rho$ peak only ( 500 to 950 MeV ) with a phenomenological background: $\Gamma_{\rho}$ and $\mathrm{m}_{\rho}$ are fitted.
II. Measured cross sections for $\gamma \mathrm{p} \rightarrow \pi^{+} \pi^{-} \mathrm{p}, \quad \gamma \mathrm{p} \rightarrow \rho^{\circ} \mathrm{p}, \quad \gamma \mathrm{p} \rightarrow \Delta^{++} \pi^{-}$. The quoted errors are both statistical and systematical.

Table I

| Photon Energy <br> (GeV) | Fit A <br> $\mathrm{m} \rho(\mathrm{MeV})$ | Fit B <br> $\mathrm{m} \rho(\mathrm{MeV})$ | $\mathrm{m}_{\rho}(\mathrm{MeV})$ |  |
| :---: | :---: | :---: | :---: | :---: |
| $2-4$ | $725 \pm 13$ | $758 \pm 4$ | $747 \pm 6$ | $80 \pm 23$ |
| $4-8$ | $711 \pm 24$ | $766 \pm 11$ | $754 \pm 9$ | $111 \pm 41$ |
| $8-16$ | $710 \pm 21$ | $770 \pm 23$ | $737 \pm 27$ | $164 \pm 110$ |

Table II

| Photon Energy (GeV) | Number of non-corrected events | $\sigma\left(\underset{(\mu \mathrm{b})}{\sigma\left(\pi_{\rightarrow}^{+} \pi^{-}\right)}\right.$ | $\sigma\left(\underset{(\mu \mathrm{b})}{\left(\gamma \mathrm{p} \rightarrow \rho^{\mathrm{o}} \mathrm{p}\right)}\right.$ | $\sigma \underset{(\mu \mathrm{b})}{\sigma\left(\gamma \mathrm{p} \rightarrow \mathrm{~A}^{++} \pi^{-}\right)}$ |
| :---: | :---: | :---: | :---: | :---: |
| $1-1.5$ | 145 | $63.5 \pm 7.0$ |  |  |
| 1.5-2 | 128 | $41.0 \pm 4.8$ |  |  |
| $2-3$ | 173 | $32.7 \pm 3.2$ | $\} 20.1 \pm 2.3$ | $3.5 \pm 1.2$ |
| $3-4$ | 104 | $27.0 \pm 3.1$ | $\int 20.1 \pm 2.3$ |  |
| $4-6$ | 121 | $22.9 \pm 3.1$ | $\} 18.9 \pm 2.4$ | $0.8 \pm 0.4$ |
| $6-8$ | 49 | $20.0 \pm 3.7$ |  |  |
| $8-12$ | 35 | $15.5 \pm 3.3$ | $\} 13.8 \pm 2.9$ | $<0.3$ |
| $12-16$ | 11 | $12.8 \pm 5.2$ |  |  |



Fig. 1


Fig. 2


Fig. 3


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