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ДОКЛАДЫ РАППОРТЕРОВ RAPPORTEURS'·REVIEWS

E-1786

ELECTROMAGNETIC INTERACTIONS
(Experimental)

Rapporteur: Norman Ramsey

Secretaries: P.F.Yermolov
A.S.Belousov
E.M.Leyikin

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Объединенный институт
ядерных исследований
БИБЛИОТЕКА

This publication is of a preliminary character. To facilitate the rapid appearance of Reports, they are printed in the form as presented by Rapporteurs.

Introduction

In 45 minutes I must summarize 45 papers by 175 authors, so I should like to apologize in advance to those authors whose work will be described either inadequately or not at all.

The papers in the sessions on Electromagnetic Interactions fall into four dominant categories and I shall describe the work accordingly:

1. Tests of Electrodynamics
2. Electron Scattering
3. Photoproduction
4. Muons and Mesic Atoms

Tests of Electrodynamics

Several independent experimental confirmations of quantum electrodynamics to distances of about tenth of a fermi were presented. Although none of these tests goes significantly beyond the limit set by the muon g-2, they are of quite different natures and provide additional confirmation.

(a) The Harvard electron scattering group find their results on electron-proton scattering can be consistently described by the Rosenbluth formula up to squared momentum transfers, q^2, of 1 $(\text{Gev/c})^2$.

(b) Experiments by Pipkin and his **group** at Harvard on wide angle pair production by 6 Gev γ-rays on carbon are in agreement with electrodynamic predictions up to a momentum for the virtual electron of 0.3 Gev/c.

(c) Friedman and others at the Cambridge Electron Accelerator have studied wide angle muon pair production by 5 Gev gamma rays on carbon up to a virtual meson momentum of 0.6 Gev/c. The observed agreement with electrodynamic predictions provides a confirmation of electrodynamics down to 0.16 f^{-1}.

(d) Some beautiful new work from Rochester and Brookhaven on muon proton scattering was reported by Tinlot out to a q^2 of 25 f^{-2} or 1 $(Gev/c)^2$. His results are compared in Fig. 1 with the predictions from the electron-proton scattering form factors that we shall discuss subsequently. The excellence of the agreement confirms the electrical nature of both the e-p and μ -p scattering and provides a check of electrodynamics to a distance of 0.07 f.

(f) Although the electric dipole moment of the electron is normally considered to be zero from time reversal invariance, Hofstadter reported an experimental upper limit to its value of the electron charge times 3.5 x 10^{-16} cm.

2. Electron Scattering

At this meeting much important new data were reported on electron proton scattering and there is now quite good agreement between the different laboratories. The results when analyzed in terms of form factors are shown in Fig. 2. Lehmann and Perez Y Jorba reported experiments from Orsay at q^2 below 0.4 $(Gev/c)^2$ and Wilson described the experiments of our group at Harvard at q^2 up to 7 $(Gev/c)^2$. Although the proton electric form factor, G_{Ep}, is necessarily poorly determined it seems to be less than G_{Mp} at all values of q^2 below 4 $(Gev/c)^2$ and all measurements so far are consistent with $G_{Ep} = G_{Mp}/(1+k)$ where 1+k is the magnetic moment of the proton. As a result all data including the latest Stanford results can be plotted on a single curve as in Fig.2. The open circles and triangles are for G_{Ep} and the filled ones are for G_{Mp}.

Although G_{Ep} and $G_{Mp}/(1+k)$ follow the same curve to within experimental error there is no theoretical justification for this and there is even a theoretical difficulty. If the Dirac and Pauli form factors F_1 and F_2 are to remain finite in the time like region at $q^2 = -4\ M^2$, G_E must be equal to G_M there and not to $G_M/(1+k)$. Furthermore, one can approximately fit the form factor curve with a formula showing resonances at the ρ, ω, φ masses. However, additional resonant masses **must** be introduced if the curve is to pass through $G_{Ep} = G_{Mp}$ at $q^2 = -4\ M^2$.

Although G_{Mp} and G_{Ep} have not been separated at $q^2 = 175\ f^{-2} = 7\ (Bev/c)^2$ the indicated value for each is obtained if the other is set equal to zero. If we assume $G_{Ep} = G_{Mp}/(1+k)$, then $G_{Mp} = 0.04 \pm 0.01$. This result is consistent with a $1/q^2$ variation beyond 2.5 $(Bev/c)^2$.

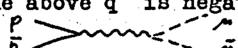
In addition to elastic scattering, the Harvard group at higher energies has observed peaks in the inelastic e-p scattering curves at positions corresponding to the electric excitation of nucleon resonances.

Electron-neutron form factors are shown in Fig.3. Since the electron-neutron form factors have to be extracted from the scattering of electrons by deuterons or heavier nuclei, it is necessary to make some theoretical corrections for the effect of the extra proton. This introduces considerable uncertainty into values of the form factors, especially for the electric form factor at low momentum transfer. This difficulty is experimentally indicated both by some Orsay studies and by some difficulties experienced by Hofstadter in interpreting his low energy electric form factor data; with current theories his G_{En} was a meaningless imaginary number but his result would be consistent with $G_{En} = 0$ if only a 5% shift were made in the theoretical corrections. I therefore urge the theorists here present: if you want a more reliable **neutron form factors** you must provide us with a better means for making theoretical deuteron corrections.

A noteworthy features of the form factor curves is that G_{Mn} falls markedly with q^2. G_{En} on the other hand is much less accurately determined. However almost all of the observations are consistent with $G_{En} = 0$, despite the contrary indication from the slope at $q^2=0$ implied by the slow neutron-electron interaction.

As an indicator of a possible two photon exchange amplitude in the scattering the Orsay group have measured the polarization of the recoil proton in 950 Mev e-p scattering. They find $P = 0.31 \pm 0.026$.

Zichichi from CERN reported preliminary results from a $p+\bar{p}\to\mu+\bar{\mu}$ experiment. This is closely related to the form factor experiments just discussed since it provides information on the electromagnetic structure of the proton in the time like region where the above q^2 is negative, since the diagram is



which is the same as that for μ-p scattering diagram viewed at right angles. At a time like momentum transfer of $q^2=-6.8\ (Gev/c)^2$ they have seen only 30 pair condidates instead of the 200 to be expected if proton were a point so that the form factors retained their $q^2=0$ value. **Since some but not all of the spurious events have been rejected, the experiment so far sets only an upper limit on** $\sigma_{p\bar{p}\to p\bar{p}} \leq 10nb = 10 \times 10^{-33} cm^2$, instead of the 247 nb to be expected if the proton were a point charge.

3. Photoproduction

Adamovich described three different sets of experiments by groups at the Lebedev Institute on the photoproduction of both positively charged and neutral pions at gamma energies up to 230 Mev. Angular distributions of the pions were measured for the purpose of comparing with theory and obtaining information on the $\gamma\pi p$-interaction. Their results were in general agreement and their combined value for the coupling constant $\Lambda_{\gamma\pi p}$ was $\Lambda_{\gamma\pi p}/ef = 0.5 \pm 0.2$.

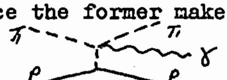
Hitzeroth of Münich has found π^0 angular distributions similar to those found at the Lebedev Institute.

Goldwasser at Illinois described hydrogen and deuterium bubble chamber experiments at 230 Mev in which both positive and negative pions were observed. The results were analyzed in terms of the Chew, Goldberger, Low and Nambu (CGLN) theory and were extrapolated to threshold to give a value for the positive pion-nucleon coupling constant. This gave $f^2 = 0.)79 \pm 0.003$ for the positive pion and $f^2 = 0.073 \pm 0.003$ for the negative while for the a_0's customarily used in such experiments $a_0^- / a_0^+ = 1.23 \pm 0.06$ at threshold. If the small difference between Goldwasser's analysis and the CGLN theory were assumed to be significant and were attributed to $\gamma\pi\rho$ coupling, the coupling constant would be $\Lambda_{\gamma\pi\rho}/ef = 1 \pm 1$.

Freytag at Bonn has studied the photoproduction of positive π's and compared his results with the theory of Hohler based on CGLN, as shown typically in Fig. 4. Althoff and others at the same Institution have studied the polarization of the recoil protons in π^0 photoproduction by measuring the left right asymmetry on scattering in liquid helium. They find that $P \approx +0.1$ at $\theta_{(cm)} = 90^0$ and ≈ -0.15 at 58^0 as is consistent with a negative value for the Re M_{1-} amplitude predicted by dispersion theory and particularly good agreement is found with the Gourdin-Salin version of the isobar model.

Barbiellini and others have used the linearly polarized coherent bremstrahlung beam produced by using a crystal diamond radiator in the 1 Gev Frascatti electron beam to study the difference in the differential cross sections with reaction planes respectively perpendicular and parallel to the polarization. They find $(d\sigma_{\perp} - d\sigma_{\parallel}) / (d\sigma_{\perp} + d\sigma_{\parallel}) = 0.51 \pm 0.01$ at a photon energy of 325 Mev and 0.25 ± 0.06 at 228 Mev.

An experiment to obtain information on the $\gamma\pi\rho$ interaction in a completely different fashion was described by Nemenov of Dubna. The Dubna scientists obtained information on the amplitude constant C of pion photoproduction in $\gamma + \pi \rightarrow \pi + \pi$ by studying the reaction $\pi^- + p \rightarrow \pi^- + \gamma + p$ since the former makes up part of the latter in the diagram:



They find $C^2 = 0.9 \pm 0.5$. This result can provide information on $\Lambda_{\gamma\pi\rho}$ but at the present time the theorists are not agreed as to the correct relation. I believe this subject will be discussed further in the theoretical session tomorrow.

Belousov described studies at the Lebedev Institute of the photoproduction of η-mesons from the isotopic spin zero carbon at a mean energy of 608 Mev to obtain information about the isoscalar amplitude of the photoproduction of η-mesons by nucleons. The η was detected by the 30% of decays by $\eta \rightarrow \gamma + \gamma$. After an analysis of 17 observed cases, the Lebedev scientists found for the isoscalar spin independent part of the η-meson photoproduction from the free nucleon, $(\frac{d\sigma}{d\Omega}) = (0.53 \pm 0.29) \times 10^{-30}$ cm^2/steradian.

Silverman described experiments at Cornell which showed that the ρ^o contributed significantly to π-pair production at 1.2 Bev and that the photoproduction is largest at a ρ^o CM angle of 60^o.

Eisenberg described new photoproduction results by the Cambridge hydrogen bubble chamber group at γ energies up to 4.8 Gev from an analysis of 10% of the 1.5 million pictures taken. They find that the total cross section for multiple pion production rises sharply above threshold and is approximately constant at 100 μb from 1 to 4 Gev; in contrast the two pion production drops markedly after reaching a peak at 1 Gev. The 2,3,4 and 5 pion and the strange particle cross sections are all of comparable magnitude beyond 2 Gev. Below 1.2 Gev the main feature of the two charged pion production is the 1238 Mev pion-nucleon isobar with a cross section that agrees with a peripheral one-pion exchange calculation. At γ energies above 1.1 Gev the ρ^o dominates the charged π pair production with a ρ^o production cross section of 21.1 μb.

They observed that the cross section for ρ^0 production is consistent with a one pseudoscalar pion exchange model (OPE) but present statistics can not exclude the exchange of a light scalar meson. Assuming OPE is valid in the momentum region concerned comparison between theoretical and experimental absolute differential cross sections **gives** $\Gamma(\rho^0 \rightarrow \pi + \gamma)$ = 1.35 $\pm$ 0.20 MeV. Approximately 50 events involving K's, Λ's, Σ's or Ξ's have been observed, but no evidence has so far been seen for K^* or φ production. **Most** events could correspond to Y^* with cross sections for the 1385 and 1520 Y^* of about 6 μb.

4. Muons and Mesic Atoms

Harutyunian reported the observation of 77 events of coherent electromagnetic radiation produced when cosmic ray muons at a few thousand GeV pass through 300 sheets of paper spaced 1 cm apart.

So many **interesting** papers were presented on meson **capture** processes and mesic atoms that the regular electromagnetic sessions were extended into a special session that lasted all **Saturday-morning**. Contributions on the subject were presented by Mukhin, Prokoshkin, Yermolov of Dubna, Zeldovich of Lebedev Institute, Bobrov from Moscow, Anderson and Telegdi from Chicago and Zichichi from CERN. Unfortunately my time does not allow me even briefly to discribe more **than three.Dzhelepov,** Yermolov and their associates at Dubna have measured elastic scattering cross sections of μ-mesic atoms by hydrogen or deuterium in a high pressure diffusion cloud chamber. They have also studied inelastic processes and the previously **unobserved** production of He^3 by muon catalysis of the d-d reaction. Telegdi has observed dynamic nuclear quadrupole effects in the μ mesic spectra of heavy elements. Anderson described the use of a lithium drifted germanium diode spectrometer to obtain a vastly increased resolution in mesic X-ray measurements.

In conclusion, at the request of Hughes at Yale, who was unable to attend this conference, I should like to report what will probably be the lowest energy but highest precision experiment discussed here. Hughes has measured the **hyperfine** structure of muonium (μ^+e^-) with increased accuracy and found for the hyperfine interval $\Delta\nu_\mu = 4463.15 \pm 0.06$ Mc/s. If he assumes the theoretical expression for this to be correct and evaluates the fine structure constant α from it, $\alpha^{-1} = 137.0388$ (± 9 ppm) which is exactly the same number (and even the same error) obtained from Lamb's completely independent direct measurement of the fine structure separation in atomic hydrogen. But the theorists should not be too cheered by this results; it also confirms the genuiness of a (45 ± 17) part per million disagreement between theory and experiment on the hyperfine structure of atomic hydrogen-probably due to inaccuracies in the evaluation of the theoretical corrections for proton structure and recoil.

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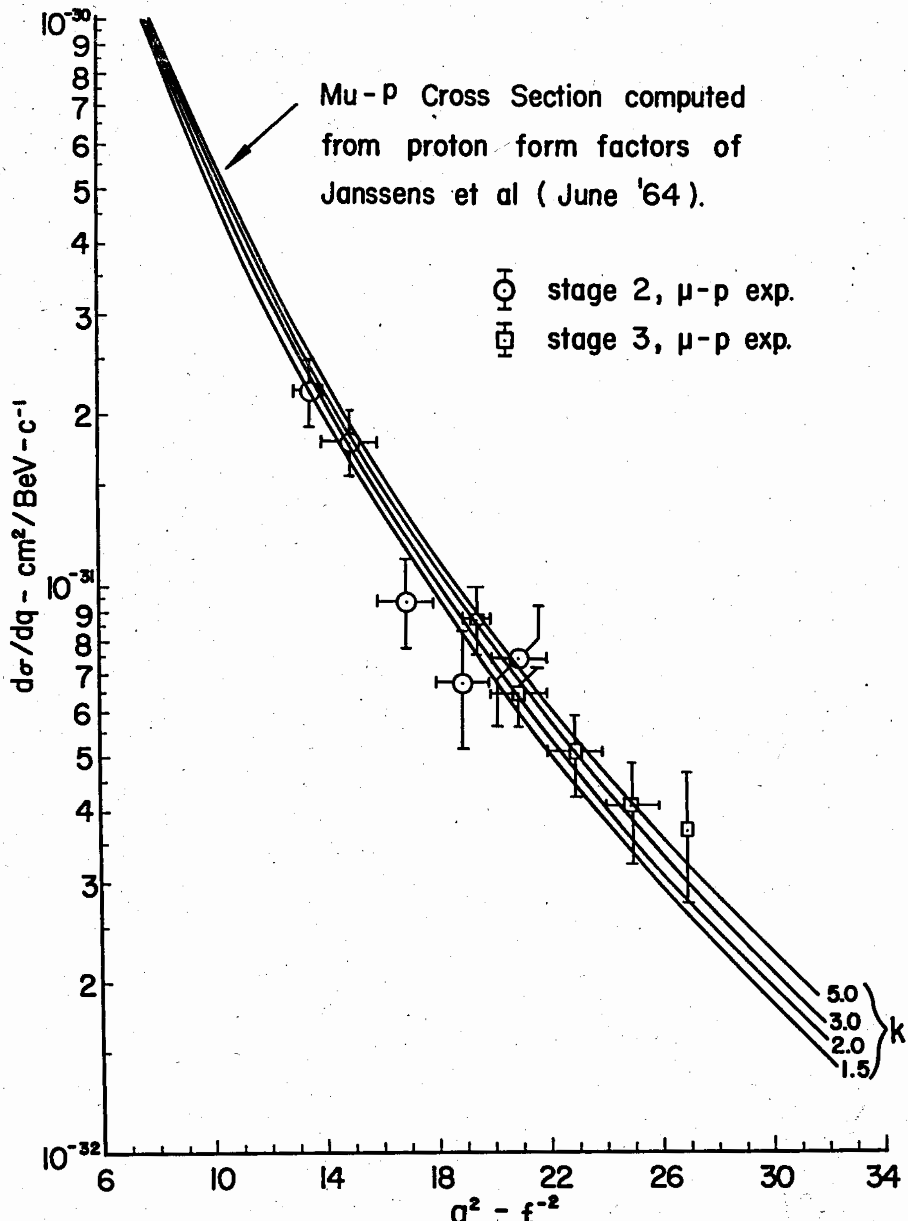

Fig. 1. Comparison of observed μ-p cross section with predictions from e-p form factors. (Tinlot)

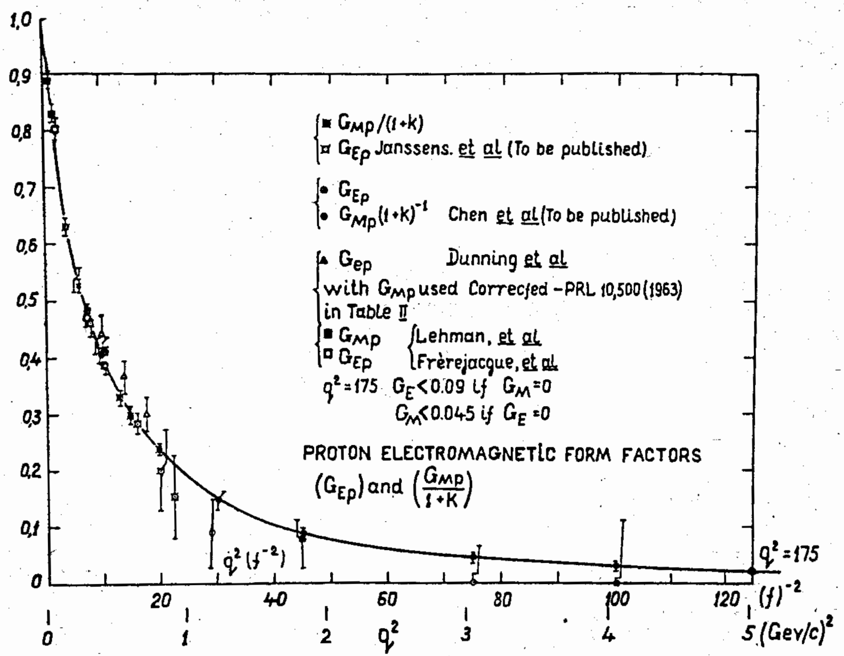

Fig. 2. Electron-proton form factors.

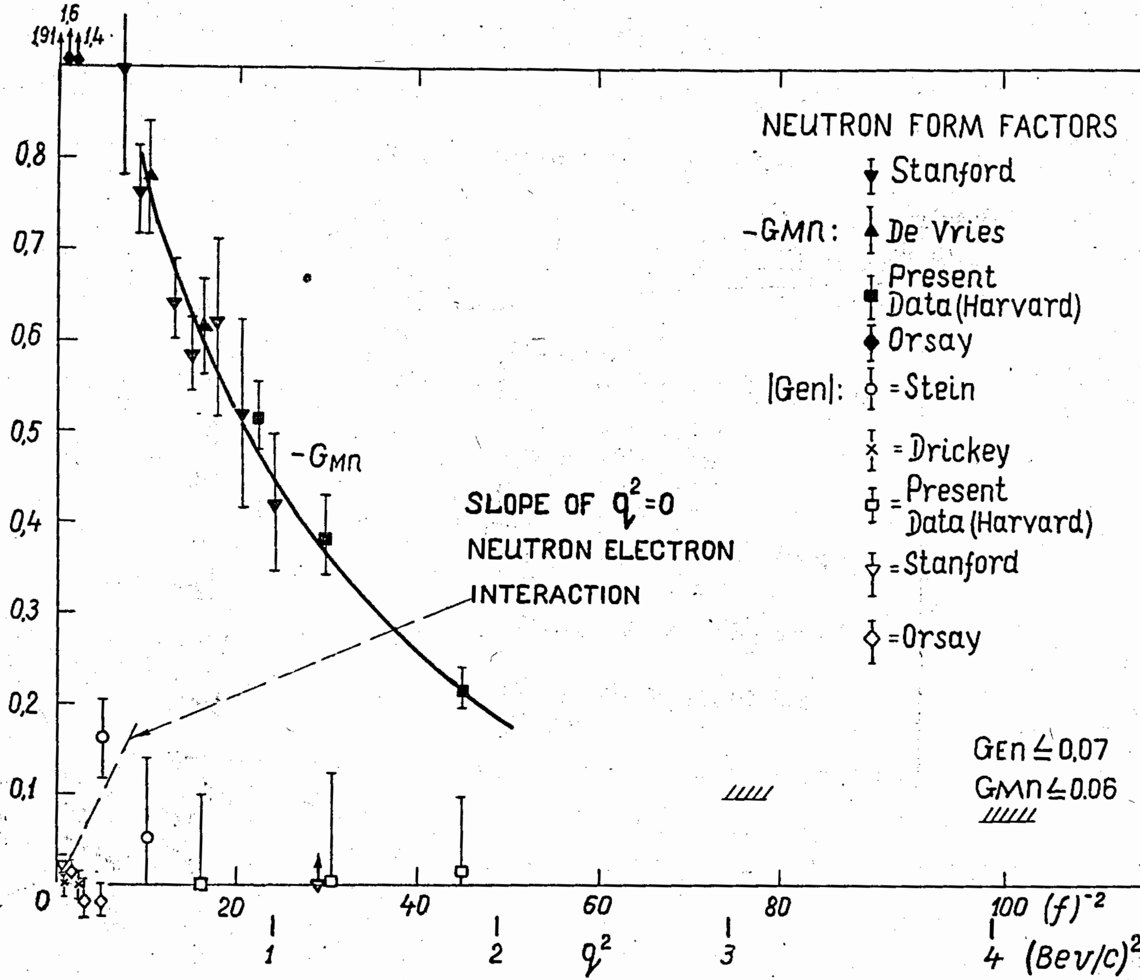

Fig. 3. Electron neutron form factors.

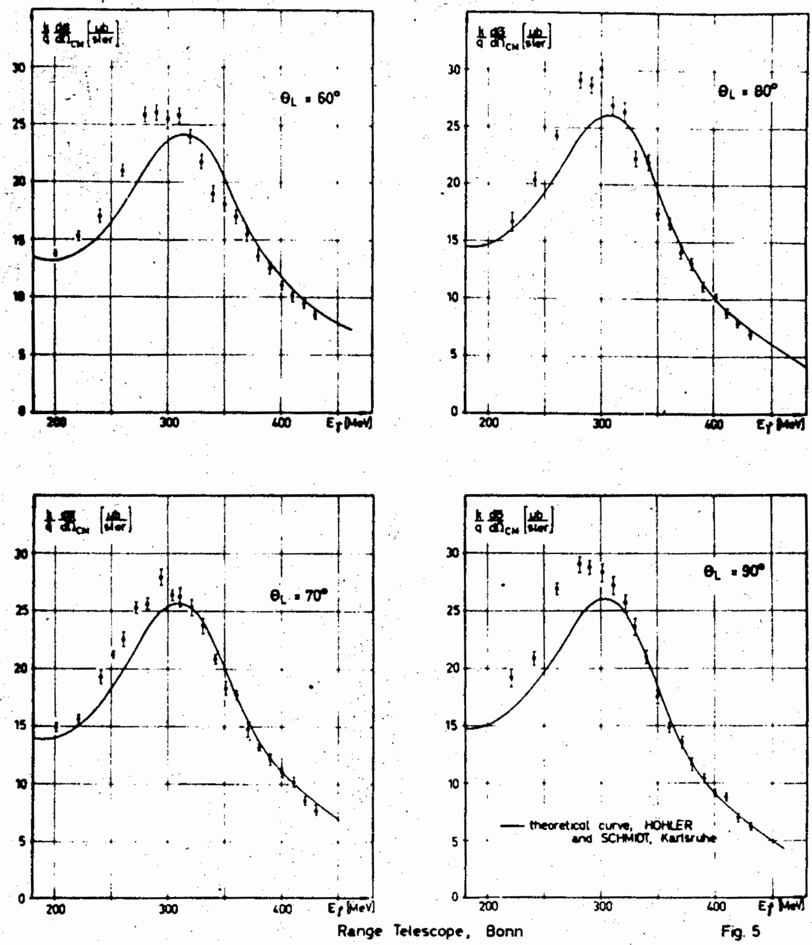

Fig. 4. Comparison of π^+ production with the theory of Hohler. (Freytag)