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Abstract

The reaction $\gamma p \rightarrow \pi^+ n$ has been investigated for photon energies between 1.2 and 3 GeV and pion c.m. angles from 2.5° to 15°. The cross section is strongly peaked in the forward direction and shows resonance structure in the region of the $N^*_{3/2}(1920)$ and $N^*_{1/2}(2190)$.

We have measured the photoproduction of single positive pions from hydrogen at angles ranging from 1^o to 6^o in the lab. A modified version of the magnetic spectrometer and scintillation counter hodoscope system described in Ref. 1 was used. In order to reject the large electromagnetic background produced at small angles, the following changes in the apparatus[1] had to be made:

i) The counter hodoscope H1 which previously measured the production angle (θ) of particles passing through the spectrometer was replaced by a collimator of variable width and height at the first angular focus in the horizontal plane (H1). The collimator size was chosen to optimize solid angle acceptance while maintaining an angular resolution $\Delta\theta = \pm 4.5$ mrad at all production angles except for the one-degree measurements, where $\Delta\theta = \pm 2.5$ mrad was chosen to enable a more detailed investigation of the expected rapid variation of the cross section with angle.

ii) Five scintillation counters, S_1 to S_5, were used to define the geometry of the beam. They were all placed behind the magnetic system to limit the highest instantaneous single counting rate to $\lesssim$ 1 Mc/s.

iii) A threshold gas Cerenkov counter[2] (C_e) of 25 cm diameter and 2.40 m radiator length filled with ethylene at 1.2 atm. was placed between S_1 and S_2 to detect positrons passing through the spectrometer. Its efficiency was (99.93 ± 0.03) %.

iv) A second threshold gas Cerenkov counter (C_π) of the same diameter, but 3.40 m long, located between S_2 and S_3 and filled with ethylene at 3.5 atm. detected pions with momentum $p_\pi > 2.1$ GeV/c with an efficiency $\varepsilon_\pi > 99$ %.

v) The time-of-flight of particles was measured between counters S_1 and S_4 (7.7 m distance) with a resolution of 1.3 nsec FWHM, permitting the separation of pions from protons below 2.1 GeV/c where the C_π counter becomes inefficient.

An event was defined as the passage of a charged particle other than a positron through the spectrometer. Its occurrence was indicated by an anti-coincidence ($G\bar{C}_e$) of C_e with $G = (S_1S_2S_3S_4S_5)$, the geometry-defining coincidence between all trigger counters. Among these events pions were distinguished from protons by either a coincidence of $G\bar{C}_e$ with C_π or by using the time-of-flight information, depending on momentum.

The number of positrons not rejected by $G\bar{C}_e$ because of the inefficiency of C_e contributed less than 1 % to the pion rate except at $\theta_\pi^{lab} = 1^\circ$, $E_\gamma = 1.37$ GeV, where it contributed 2 %. Muons from pair production contribute a negligible fraction to the event rate; photoproduced kaons fall outside the momentum acceptance of the spectrometer. The proton contamination of the pion rate is estimated to be less than 1 % at all momenta.

The methods used for determining particle momentum and photon energy, for calculating acceptances and energy resolution, and for recording and storing the data from each event on a PDP-5 computer on-line were essentially the same as in Ref. 1. The total acceptance $A = \int d\Omega\, dp/p$ of the spectrometer was 0.48×10^{-5} sterad except at $\theta_\pi^{c.m.} = 2.5^\circ$, where it was 0.18×10^{-5} sterad.

Differential cross sections were measured at five pion center-of-mass angles ($\theta_\pi^{c.m.} = 2.5^\circ, 5^\circ, 7.5^\circ, 10^\circ, 15^\circ$) and at ten photon energies between 1.2 and 3.0 GeV. In addition, some measurements were made at selected angles and energies to verify structure found in the systematic survey. The data analysis was performed on the IBM 7044 of the DESY computing center and included corrections for empty-target background (4 to 8 %), nuclear absorption (8 %), pion decay in flight (6 to 22 %), ambiguous events (3 %), and the effects of a thick target on the shape of the bremsstrahlung spectrum. The total systematic error is estimated to be less than 10 %.

The differential cross sections $d\sigma/d\Omega^{c.m.}$ are presented in Table I as functions of $\theta_\pi^{c.m.}$ and E_γ. The errors shown are only due to counting statistics and do not include the systematic errors mentioned above. To improve counting statistics, events from all hodoscope counters were averaged over a photon energy interval ($\Delta E_\gamma/E_\gamma$) of typically $\pm$ 2 %.

The energy and angular dependence of the differential cross sections $d\sigma/d\Omega^{c.m.}$ is shown in Figures 1 and 2, respectively. We note the following points:

(1) The peak observed in the cross section as a function of energy becomes more pronounced at small angles (compare also Fig. 2 of Ref. 1) and shifts to smaller energies with decreasing center-of-mass angle; at $\theta_{c.m.} = 2.5^{o}$ it is found close to the position expected for the $N^{*}_{3/2}(1920)$ nucleon isobar.

(2) The angular dependence shows a strong peaking in the forward direction at all photon energies. At 1.2 and 1.37 GeV we observe a dip in the cross section near angles corresponding to $|t| = m_{\pi}^{2}$ which may be attributed to the interference between one pion exchange and nucleon pole diagrams. This dip is less prominent at 1.5 GeV and completely disappears at higher energies. It is interesting to note that this change in the angular behaviour occurs in the energy region where the cross section rises to a peak as a function of energy, suggesting that the same mechanism may be responsible for the changes observed in both energy and angular distributions.

At 1.20 and 1.37 GeV we have made a Moravcsik fit[3] to the combined data of this and our previous experiment as well as the large angle data of Kilner[4]. From the pole extrapolation of a fifth order fit we obtain values for the pion-nucleon coupling constant f^2 of 0.101 ± 0.007 from the 1.20 GeV fit and 0.094 ± 0.007 from the 1.37 GeV fit[5]. These are to be compared with the value obtained from pion nucleon scattering of 0.0822 ± 0.0018[6].

The observed forward peaking of $d\sigma/d\Omega^{c.m.}$ vs. $\theta_{\pi}^{c.m.}$ is in contradiction with simple peripheral models (OPE)[7] and their Reggeized versions[8]. Models which take into account the interference of pole-diagrams in the t- and s-channel and also final-state absorption[9] are in qualitative agreement with our data only at small angles and low energies. A recent $U(6)_W \times O(2)_W$ symmetry model[10] agrees with our previous data[1] at 1.5 GeV. At small angles, however, the agreement is poor.

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† NATO Postdoctoral Fellow, on leave from University of California Lawrence Radiation Laboratory.

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Table I: $d\sigma/d\Omega^{c.m.}$ (μb/sterad) as a function of pion center-of-mass angle $\theta_{\pi}^{c.m.}$ and incident laboratory photon energy E_{γ}.

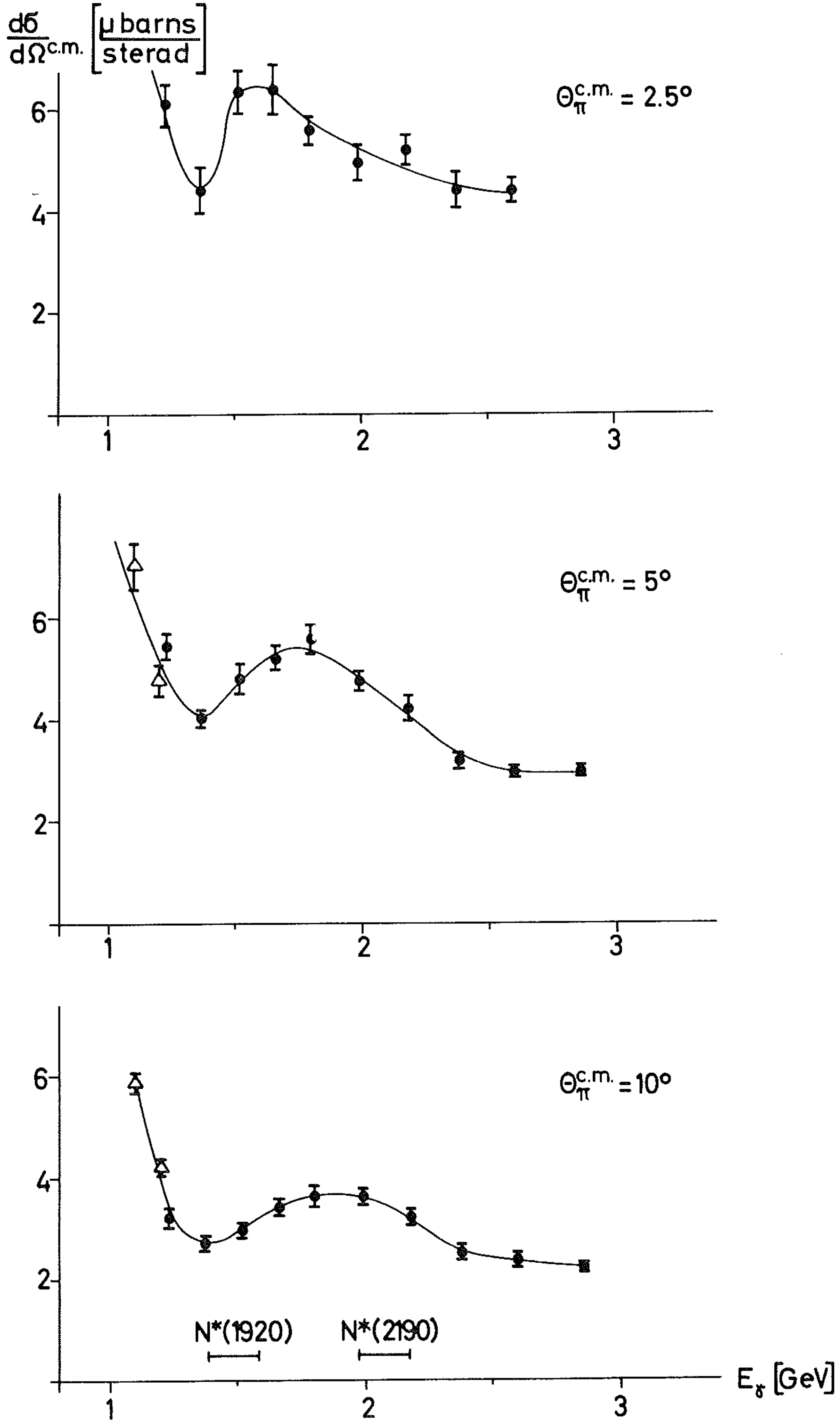
E_{γ}(GeV)	pion c.m. angle $\theta_{\pi}^{c.m.}$: 2.5°	5°	7.5°	10°	15°
1.23	6.09 ± 0.41	5.45 ± 0.25	4.04 ± 0.22[a)]		3.21 ± 0.20[b)]
1.37	4.41 ± 0.44	4.01 ± 0.18		2.71 ± 0.16	
1.52	6.34 ± 0.43	4.81 ± 0.29	4.09 ± 0.21	2.94 ± 0.14	2.71 ± 0.19[c)]
1.66	6.40 ± 0.50	5.21 ± 0.23	4.28 ± 0.22	3.41 ± 0.17	
1.80	5.58 ± 0.28	5.58 ± 0.28	4.25 ± 0.19	3.62 ± 0.19	3.34 ± 0.16[d)]
1.99	4.94 ± 0.36	4.77 ± 0.19		3.61 ± 0.16	3.30 ± 0.15[e)]
2.18	5.20 ± 0.29	4.20 ± 0.23		3.18 ± 0.16	2.60 ± 0.13
2.38	4.39 ± 0.35	3.17 ± 0.16		2.49 ± 0.13	2.28 ± 0.10
2.60	4.38 ± 0.25	2.96 ± 0.10		2.34 ± 0.12	2.24 ± 0.09
2.86		2.96 ± 0.12		2.19 ± 0.09	2.17 ± 0.11

a) $\theta_{\pi}^{c.m.} = 7.8°$, b) $\theta_{\pi}^{c.m.} = 11.5°$, c) $\theta_{\pi}^{c.m.} = 12.4°$, d) $\theta_{\pi}^{c.m.} = 13.2°$, e) $\theta_{\pi}^{c.m.} = 13.8°$

FIGURE CAPTIONS

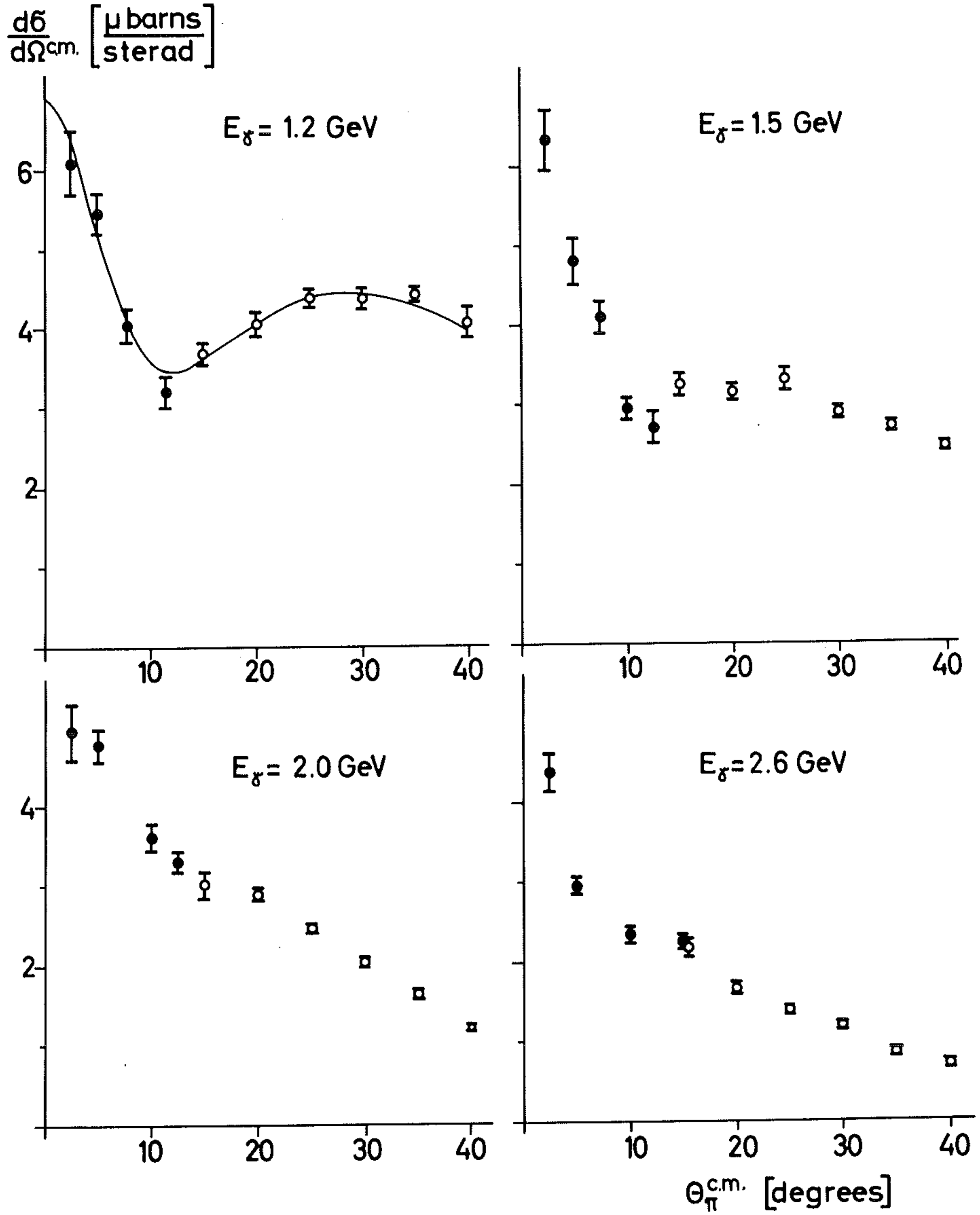
Fig. 1 Center-of-mass differential cross sections as a function of incident photon energy E_γ for different pion c.m. angles $\theta_\pi^{c.m.}$. ● - this experiment, △ - Reference 4. Smooth curves were drawn through the data points to guide the reader.

Fig. 2 Center-of-mass differential cross sections as a function of pion c.m. angle $\theta_\pi^{c.m.}$ for different incident photon energies E_γ. ● - this experiment, ○ - Reference 1. For E_γ = 1.2 GeV a fifth order Moravcsik fit is given (solid line).



dσ/dΩ^c.m. [μ barns / sterad]
Θ_π^c.m. = 2.5°
Θ_π^c.m. = 5°
Θ_π^c.m. = 10°
N*(1920)
N*(2190)
E_γ [GeV]
6
4
2
1
2
3

Fig.1



dσ/dΩ^c.m. [μ barns/sterad]
Eγ = 1.2 GeV
Eγ = 1.5 GeV
Eγ = 2.0 GeV
Eγ = 2.6 GeV
2
4
6
10
20
30
40
Θπ^c.m. [degrees]

Fig. 2