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SPIN-ORBIT INTERACTION OF LAMBDA PARTICLES IN NUCLEI

(Heidelberg-Saclay-Strasbourg Collaboration)

W. Brückner, M.A. Faessler, T.J. Ketel, K. Kilian,
J. Niewisch, B. Pietrzyk, B. Povh,
H.G. Ritter and M. Uhrmacher

Max-Planck-Institut, Heidelberg

Phys. Institut der Universität, Heidelberg

P. Birien, H. Catz**), A. Chaumeaux*),
J.M. Durand, B. Mayer and J. Thirion,

CEN, Saclay, Gif-sur-Yvette

R. Bertini*) and O. Bing,

CRN, Strasbourg

ABSTRACT

In the strangeness exchange reaction (K^-, π^-) on ^{12}C and ^{16}O the most prominent transitions to hypernuclear states produced in recoilless and quasi-free Λ production have been identified. The analysis of the spectra shows that in the Λ-nucleus interaction the spin-orbit coupling is at least one order of magnitude smaller than for the nucleon-nucleus interaction.

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*) CERN Associate

**) CERN Fellow

The strangeness exchange reaction (K^-, π^-) on nuclear targets has successfully been applied to hypernuclear spectroscopy. Recoilless Λ production was identified [1] in first generation experiments. At kaon momenta below 1 GeV/c and for collinear events in the (K^-, π^-) reaction, the most prominent transitions stem from the recoilless Λ production. Hypernuclear states populated via these transitions have configurations analogous to that of the target nucleus in its ground state. Even for collinear events there will be, in addition to the transitions stemming from the recoilless production, numerous but less prominent transitions characterized as quasi-free Λ production [2, 3]. The most important transitions of this type are those corresponding to the strangeness exchange reaction on one of the outer neutrons accompanied by a jump of the Λ particle to one of the neighbouring shells [4].

It was soon realized [5] that a quantitative understanding of the Λ-nucleus interaction is possible only if in addition to the recoilless Λ production, for which the Λ particle does not change the orbit, the leading quasi-free transitions can be identified. Only if both types of transitions can be experimentally located can one determine the energy separation of the Λ shells and the quasi-particle properties of the Λ particle in the nucleus. Calculations by Bouyssy [4] show that in fact in light nuclei there are only a few important quasifree transitions, each of about an order of magnitude smaller in strength than the recoilless transitions that could show up if collinear or nearly collinear events are selected in experiments.

The experiment described here was designed to investigate the fine structure of the recoilless transitions and to identify single quasi-free transitions. Compared to the previous experiment [1], many improvements were made, the most important one being the increased production of (K^-, π^-) events by almost two orders of magnitude. In the present paper we report first results obtained with strangeness-exchange reactions on ^{12}C and ^{16}O targets, which enabled us to deduce the spin-orbit part of the Λ-nucleus interaction in p-shell hypernuclei. The result is extremely surprising: contrary to the nucleon-nucleus interaction, which is dominated by the strong spin-orbit force, the Λ-nucleus interaction lacks any appreciable spin-orbit contribution.

The (K^-, π^-) reaction on ^{12}C and ^{16}O was studied at a K^- momentum of 715 MeV/c by means of a separated K^- beam at the CERN Proton Synchrotron (PS). The experimental set-up is shown schematically in Fig. 1. Particles produced in the production target are refocused to an achromatic focus in the experimental target. Under normal operation with about 1.3×10^{12} protons on a 3 cm thick tungsten production target 2×10^4 K^- reached the experimental target at the kaon momentum chosen. The π^-/K^- ratio at the target was about 12. The kaons were identified by their time of flight in the second half of the beam, whereas the pions were vetoed by a liquid-hydrogen Čerenkov counter in front of the target. The kaon momentum was determined by measuring the particle trajectories in the second half of the beam with a hodoscope of plastic counters installed directly in the mass and momentum slits and with a set of wire chambers in front of the target. Pions produced in the forward direction were analysed by the specially designed spectrometer SPES II of Saclay, described in detail elsewhere [6]. The angular acceptance of the spectrometer was 20 msr, the accepted momentum bite ±18%. The spectrometer could rotate around the target from $-5°$ to $30°$. Pions in the spectrometer were identified by a liquid-hydrogen Čerenkov counter just behind the target and by the time of flight in the spectrometer. The pion trajectories in the SPES II were determined with one set of wire chambers at the entrance to the spectrometer and a second set at the exit. Final selection of the (K^-, π^-)-reaction events was made by requiring that the kaon trajectories of the beam and the pion trajectories in the spectrometer meet within the target. The momentum resolution of the SPES II was better than 0.5 MeV/c at 715 MeV/c momentum, whereas the momentum determination of the beam particles was about 1.3 MeV/c. However, the over-all resolution in the experiment, of about 2.0 MeV/c, was determined by the energy-loss difference for kaons and pions in the target and by the straggling in the trigger counters.

The measured energy spectra for the (K^-, π^-) reaction on ^{12}C and ^{16}O are shown in figs. 2a and 2c. In order to compare the two spectra, we chose to plot them as a function of the transformation energy $M_{HY} - M_A$, which yields the Q value of the strangeness-exchange reaction in transforming the nuclear ground state with mass M_A into a hypernuclear state with mass M_{HY}. This quantity is measured directly in the experiment because of the relation

$$M_{HY} - M_A = E_K - E_\pi - E_R \ ;$$

here, E_K and E_π represent the energies of incoming kaons and outgoing pions, respectively. In the present experiment the recoil energy E_R of the hypernucleus was always smaller than 0.4 MeV. Owing to the large momentum acceptance of the pion spectrometer, the pions from the strangeness-exchange reaction and the kaons from the beam can be measured simultaneously, and $E_K - E_\pi$ can be determined free of systematic errors. In addition, the B_Λ scale is given for each spectrum, which measures the Λ binding energy on the nuclear core.

The carbon spectrum shows no surprising results. The dominant peak at $B_\Lambda = 0$ belongs to the recoilless Λ production. The angular distributions (Fig. 2b) show that the intensity of the peak drops with increasing momentum transfer as expected for recoilless Λ production [3], i.e. it drops proportionally to exp $[-(qR)^2]$, where R is the nuclear radius. The state was thus assumed to have the $J^\pi = 0^+$ assignment that belongs to the $(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$ configuration, with both the Λ particle and the neutron hole in the $1p_{3/2}$ shell. The state at $B_\Lambda = 11$ MeV was already observed [7] in a previous experiment using stopped K^- for producing hypernuclei. It belongs to the $(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$ configuration and has $J^\pi = 1^-$. The $J^\pi = 2^-$ state of that same configuration cannot be produced in collinear geometry, as in this geometry the spin-flip amplitude necessary to produce this state is zero. We shall not discuss structures at excitations higher than that of the recoilless peak, as we would like to concentrate our discussion on the spin-orbit part of the Λ-nucleus interaction.

It is interesting to compare the oxygen spectrum with that of carbon in the $M_{HY} - M_A$ scale. The transformation energies for the levels corresponding to the $(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$ and $(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$ configurations in carbon coincides well with those of two peaks observed in the oxygen spectrum. Moreover, the relative intensities are equal in both cases. It is rather obvious that in neighbouring nuclei the transformation energy for the nucleons in the same orbit will be the same in the first approximation. We therefore conclude that the two transitions in oxygen at $B_\Lambda = -3.5$ MeV and $B_\Lambda = 7$ MeV belong to the $(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$ and $(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$ configurations, respectively.

In oxygen, two additional transitions are observed. They coincide with the carbon spectrum if shifted to a higher B_Λ by 6 MeV. The angular distributions again reveal that the states at $B_\Lambda = -3.5$ MeV and $B_\Lambda = 2.5$ MeV are produced in recoilless Λ production (Fig. 2d), whereas the states at $B_\Lambda = 7$ MeV and $B_\Lambda = 13$ MeV have a weak angular dependence as expected for quasi-free Λ production. It is therefore obvious to relate the $B_\Lambda = 2.5$ MeV peak to the $J^\pi = 0^+$ state with $(1p_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$, the one at $B_\Lambda = 13$ MeV to the $J^\pi = 1^-$ state with $(1s_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$.

The splitting between the hypernuclear states with the $1p_{3/2}^{-1}$ and $1p_{1/2}^{-1}$ nuclear core is 6 MeV for both the recoilless and the quasi-free produced states. This discloses directly that the spin-orbit interaction of the Λ particle in the p-shell nuclei is small. In fact, the energy difference of 6 MeV between the $(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$ and the $(1p_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$ configurations agrees so well with the 6.1 MeV energy splitting between the $p_{1/2}$ and $p_{3/2}$ hole states in ^{15}O and the 6 MeV difference between the $(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$ and the $(1s_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$ states, that for p-shell hypernuclei we can give an upper limit of 0.3 MeV for the spin-orbit splitting in the Λ-nucleus interaction.

To obtain best agreement with the previous data [1] on the (K^-, π^-) reaction on nuclei, Bouyssy [4] in his calculations assumed the spin-orbit force in the Λ-nucleon interaction to be zero. These calculations were carried out before the splitting of the recoilless transitions in the p-shell hypernuclei was determined experimentally beyond any doubt. His calculations reproduce excellently the energy as well as the intensities of the transitions observed in the present experiment.

The spin-orbit force plays a very important role in nuclear physics. It was introduced phenomenologically to explain many prominent nuclear properties. Its origin as well as its strength are still not fully explained. And yet the strength of the Λ-nucleus spin-orbit force, being at least an order of magnitude smaller than that of the nucleon-nucleus one, is puzzling. Using a boson-exchange model for calculating the baryon-baryon interaction, however, Brockmann and Weise [8] have come to the conclusion that the spin-orbit force should be essentially weaker in the Λ-nucleus interaction than in the nucleon-nucleus interaction. It is hoped that with the present results, which supply an additional constraint on the choice of the baryon-nucleus interaction, the understanding of the spin-orbit force in nuclei can be improved.

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REFERENCES

[1] W. Brückner, B. Granz, D. Ingham, K. Kilian, U. Lynen, J. Niewisch, B. Pietrzyk, B. Povh, H.G. Ritter and H. Schröder, Phys. Letters 62B (1976) 481.

[2] R.H. Dalitz and A. Gal, Phys. Letters 64B (1976) 154.

[3] B. Povh, Z. Phys. A279 (1976) 159.

[4] A. Bouyssy, Nuclear Phys. A290 (1977) 324.

[5] B. Povh, in Proc. Internat. Conf. on Nuclear Structure, Tokyo, 1977 [J. Phys. Soc. Japan 44 (1978) Suppl., p. 775].

[6] E. Aslanides, R. Bertini, O. Bing, P. Birien, B. Bricaud, F. Brochard, H. Catz, J.M. Durand, J.C. Faivre, D. Garreta, Ph. Gorodetzky, F. Hibou, J. Pain, J. Thirion, *in* Abstracts of papers submitted to the 7th Internat. Conf. on High-Energy Physics and Nuclear Structure, Zürich, 1977 (SIN, Villigen, 1977), p. 376.

[7] M.A. Faessler, G. Heinzelmann, K. Kilian, U. Lynen, H. Piekarz, J. Piekarz, B. Pietrzyk, B. Povh, H.G. Ritter, B. Schürlein, H.W. Siebert, V. Soergel, A. Wagner and A. Walenta, Phys. Letters 46B (1973) 468.

[8] R. Brockmann and W. Weise, Phys. Letters 69B (1977) 167.

Figure captions

Fig. 1 : Experimental set-up. Kaon and pion momenta are analysed by means of a magnetic system. The particle trajectories are determined by the hodoscopes H1 and H2 and the wire chambers W_1-W_8. Kaons and pions are identified by the liquid-hydrogen Čerenkov counters C1 and C2 at the target position and by the time-of-flight measurements.

Fig. 2 : Spectra obtained from the (K^-,π^-) reaction on a) ^{12}C and c) ^{16}O at a kaon momentum of 715 MeV/c plotted as a function of the transformation energy $M_{HY} - M_A$ in the strangeness-exchange reaction. The Λ-neutron mass difference $M_\Lambda - M_n$ is also indicated. In addition, the Λ binding energy B_Λ is plotted for each spectrum. The angular distribution for (K^-, π^-) on b) ^{12}C and d) ^{16}O shows an intensity dependence $I = \exp\left[-(qR)^2\right]$ on the transfer momentum q for the recoilless Λ production, and a weak q-dependence for quasi-free production. The 0° production corresponds to $q \approx 40$ MeV/c for the incoming 715 MeV/c kaon momentum.

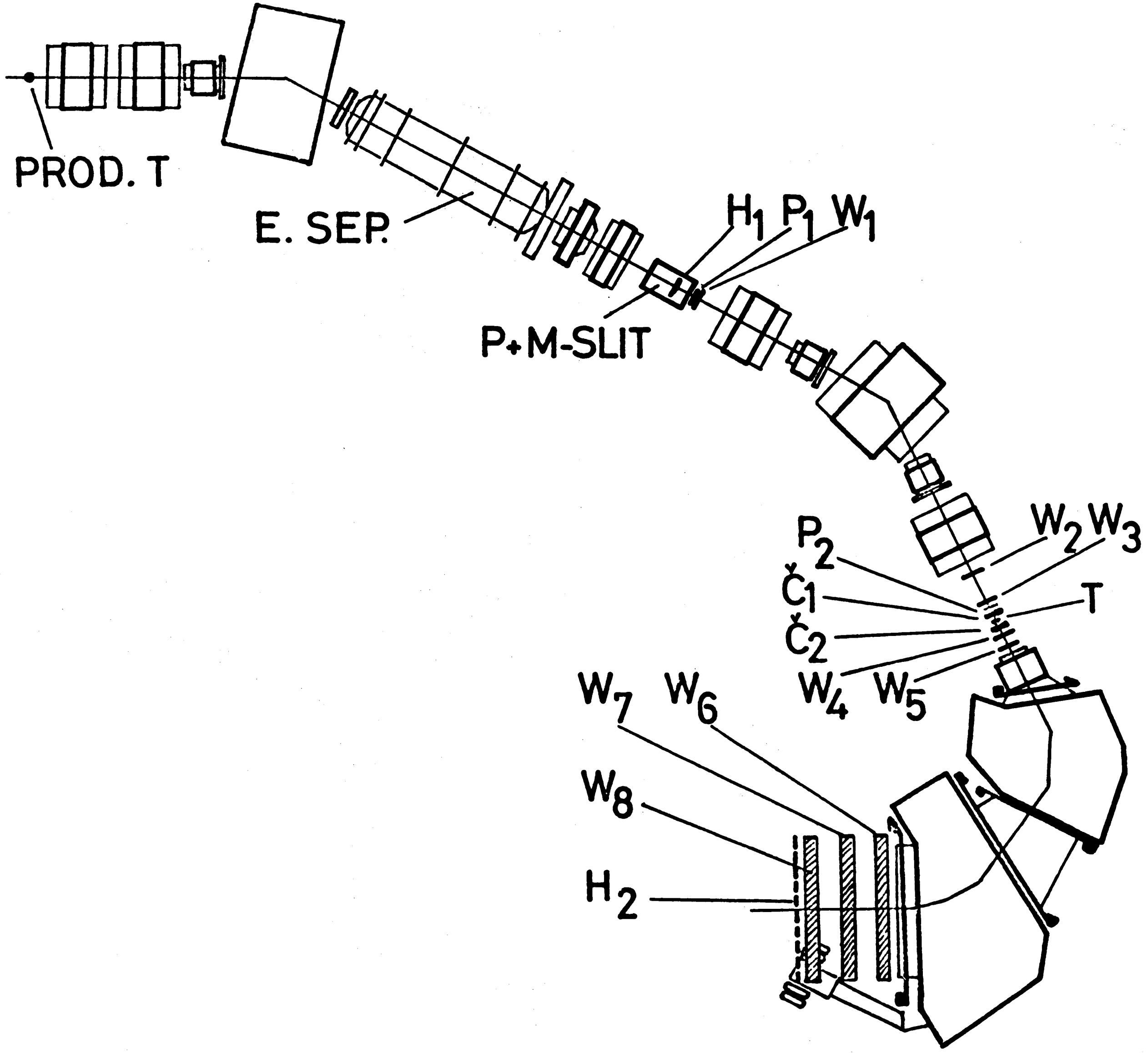
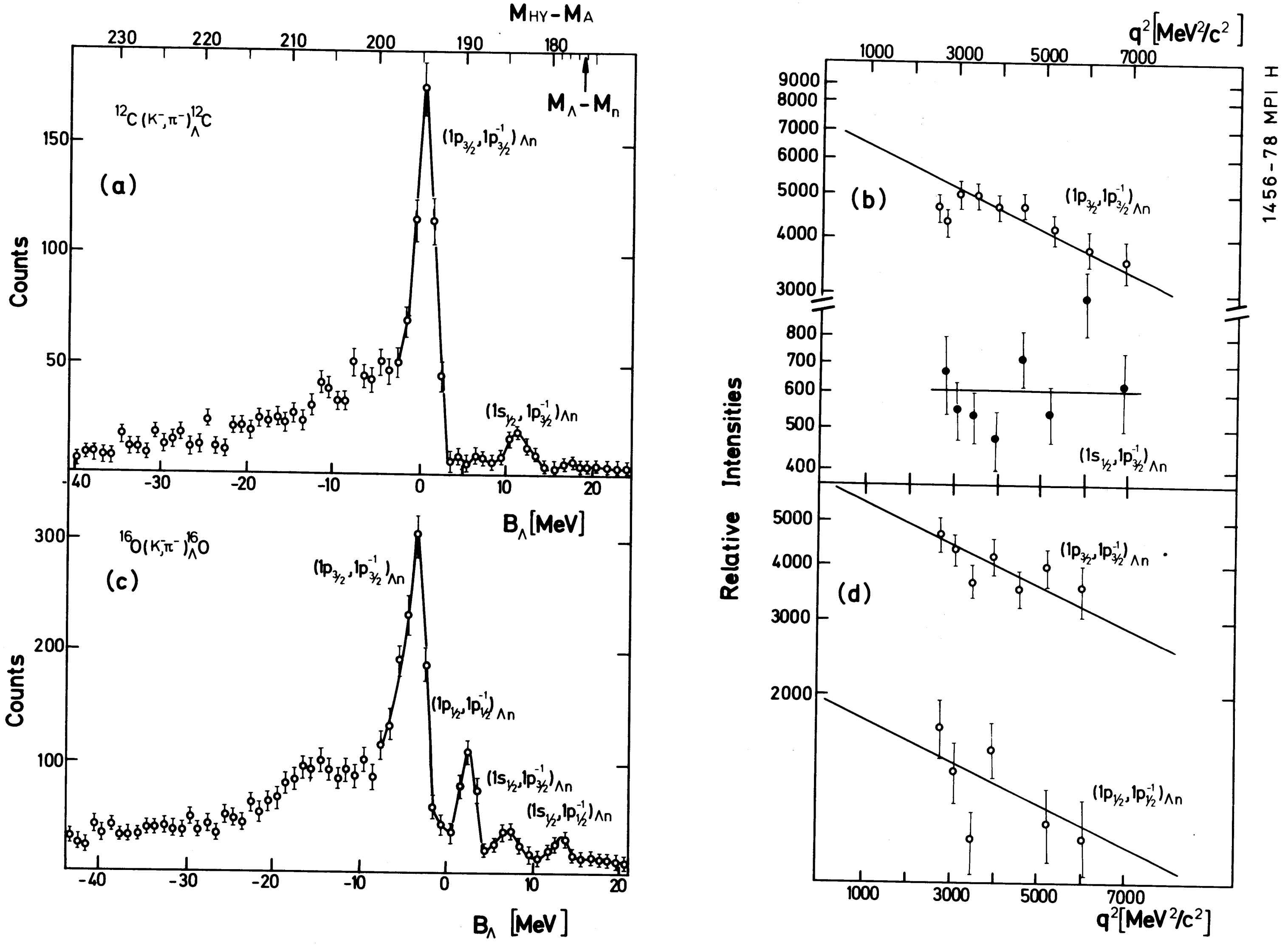

PROD. T
E. SEP.
H_1 P_1 W_1
P+M-SLIT
W_2 W_3
P_2
$\check{C}_1$
T
$\check{C}_2$
W_4 W_5
W_7 W_6
W_8
H_2

Fig. 1



$M_{HY} - M_A$
230
220
210
200
190
180
$M_\Lambda - M_n$
$^{12}C(K^-,\pi^-)^{12}_\Lambda C$
(a)
Counts
150
100
50
$(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$
$(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$
-40
-30
-20
-10
0
10
20
B_Λ [MeV]
$^{16}O(K^-,\pi^-)^{16}_\Lambda O$
(c)
300
200
100
$(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$
$(1p_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$
$(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$
$(1s_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$
B_Λ [MeV]
q^2 [MeV^2/c^2]
1000
3000
5000
7000
Relative Intensities
9000
8000
7000
6000
5000
4000
3000
800
700
600
500
400
(b)
$(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$
$(1s_{1/2}, 1p_{3/2}^{-1})_{\Lambda n}$
5000
4000
3000
2000
(d)
$(1p_{3/2}, 1p_{3/2}^{-1})_{\Lambda n}$
$(1p_{1/2}, 1p_{1/2}^{-1})_{\Lambda n}$
q^2 [MeV^2/c^2]
1456-78 MPI H

Fig. 2