PENTAQUARKS: INTRODUCTION AND REVIEW*

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This review and critique of the experimental searches for pentaquarks follows the lectures given at the Zakopane summer school in May 2004. This is a rapidly changing field, and the viewpoint of the present article is according to the state of the results known at the time the lectures were given. A brief review of the theoretical motivation for the recent experimental results is also presented.

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1. Introduction

Pentaquarks are simply defined as particles made from four quarks and one antiquark. Since pentaquarks can decay (or "fall apart") into a three-quark baryon and a quark–antiquark meson, pentaquarks were expected [1] to have wide widths and would be difficult to observe experimentally. However, some theorists [2, 3] suggested that particular quark structures might exist with a narrow width. This led to renewed interest in experimental searches for pentaquarks, some of which are reviewed in this paper.

Why is it important to know whether pentaquarks (with narrow widths) exist? The answer is simple. If they do exist, then we have a new multiquark system which can be used to test the theory of quantum chromodynamics (QCD) in the nonperturbative regime. Until now, most of the effort for calculations of nonperturbative QCD have focused on baryons and mesons. The laws of QCD do not forbid the existence of pentaquarks, and the question of how tightly this multiquark system might be bound, as well as the overlap of its wavefunction with the final decay state, provides a new testbed for QCD. In particular, lattice QCD has recently produced (in the quenched approximation) a spectrum of baryon resonances [4], but detailed studies of pentaquarks in lattice QCD are yet to be done[1].

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[1] Some papers have recently been submitted after these lectures were given.

If pentaquarks with a narrow width exist, which is supported by initial results at a number of experiments around the world, then we will learn more about the effective forces between quarks and whether lattice QCD calculations can reproduce the data. So it is important to do experimental searches for pentaquarks whether or not you believe in any particular theory that predicts a specific multiquark state. However, theoretical predictions can be useful as a guide for what mass and width might be experimentally observable. Since there were many experiments done in previous decades, new searches should have advantages not previously available. For example, new photoproduction facilities are now able to gather data for multiparticle final states at least an order of magnitude better than before [5]. This opens the door to new precision measurements and detection of weakly-produced states not seen before. With theoretical guidance, it is reasonable to again look at new data for evidence of narrow pentaquark states.

There have been many articles describing the discovery of the pentaquark known as the Θ^+at the SPring-8 facility in Japan. For more details about the initial discovery and two confirming experiments, please see Ref. [6].

1.1. General outline

The structure of this paper is as follows. Section 2 has some selected experiments from kaon scattering done in previous decades, with emphasis on possible resonances in the (nK^+) system, where the lightest nontrivial pentaquark would be found. Limits on the pentaquark width near mass 1540 MeV are also discussed. Section 3 gives a simplified explanation of the chiral soliton model prediction of the pentaquark, and a short foray into other recent models of pentaquarks. Section 4 gives a critique of all recent experiments with evidence, both positive and null, for the Θ^+pentaquark. The last section provides a summary.

2. Experimental data before year 2000

There were many searches in the 1960's and 1970's to find baryon resonances in the strangeness $S = +1$ channel. At that time, many $S = -1$ resonances had been found using K^- beams, and it was natural to search for $S = +1$ baryon resonances using K^+ beams as well. A review of the K^+N scattering database is given in 1992 by Ref. [7]. The majority of data is for K^+ scattering on the proton, corresponding to the isospin $I = 1$ channel, since much of the data was taken using liquid hydrogen bubble chambers. In addition, the database is dominated by K^+ beams with momenta above 500 MeV/c. For lower momentum, the kaons decay quickly because the relativistic effect on the lifetime is small.

2.1. A few samples of K^+d scattering data

If theoretical predictions of a narrow $I = 0$ resonance at 1540 MeV had been available in the 1970's, then more data would likely have been taken using bubble chambers at the relevant energy. The mass of 1540 MeV corresponds to a K^+ beam momentum of about 440 MeV/c, and isospin $I = 0$ requires a deuterium target. As it is, such data are sparse and have gaps in the coverage of the beam momenta. For example, one data set [8] gives cross sections for K^+ momenta of 252, 342, 470 and 587 MeV/c. A narrow resonance at, say, 420 MeV/c could easily have been missed in this study. A more relevant data set is that by Bowen *et al.* [9] which has a cross section for K^+d at 440 MeV/c. Curiously, this cross section is slightly higher than the surrounding data between 366 and 506 MeV/c, a point that will be discussed below. There is an additional complication that these data have been corrected for the Fermi momentum of the nucleons in deuterium, which would spread out the energy dependence of a potentially narrow resonance. It is reasonable to ask how accurately this Fermi momentum correction can be done within the uncertainties of the data and the significant spread of the incident beam momenta. This question has not been examined in sufficient detail at the present time.

2.2. Estimates of the Θ^+ width

Several authors have examined the KN database for possible signs of the Θ^+which could be seen in the cross sections even tens of MeV/c away from the central momentum of 440 MeV/c. The reason, of course, is because all resonances have widths, and the effect due to the tail of the resonance will be seen even if the peak falls between data points. One of the first to do this was Nussinov [10] who suggested that the Θ^+width, based on the KN database, must be less than 6 MeV. This was followed shortly by other papers [11–14] estimating that the Θ^+width must be as narrow as about 1 MeV (or less). If the KN database is correct, it is difficult to see how these estimates could be wrong.

One comparison to the KN database by Gibbs [15] is particularly interesting. This paper is based on a weak scattering approximation and the resulting calculation is compared with the total cross section data of Ref. [9], as shown in Fig. 1. The dotted curve is for non-resonant background, and the other three curves correspond to Θ^+widths of 0.6, 0.9 and 1.2 MeV for a positive parity resonance of mass about 1.56 GeV. This resonance mass was obtained as the best fit to the data. Of course, the uncertainties in the data allow reasonable χ^2 values down to a mass of about 1.545 GeV. Assuming a negative parity resonance gives lower masses, shown by the lower half of the figure. In all cases, the width of the Θ^+must be unusually small, on the order of 1 MeV. If the Θ^+exists with such a small width, then theoretical models of the Θ^+become highly constrained.

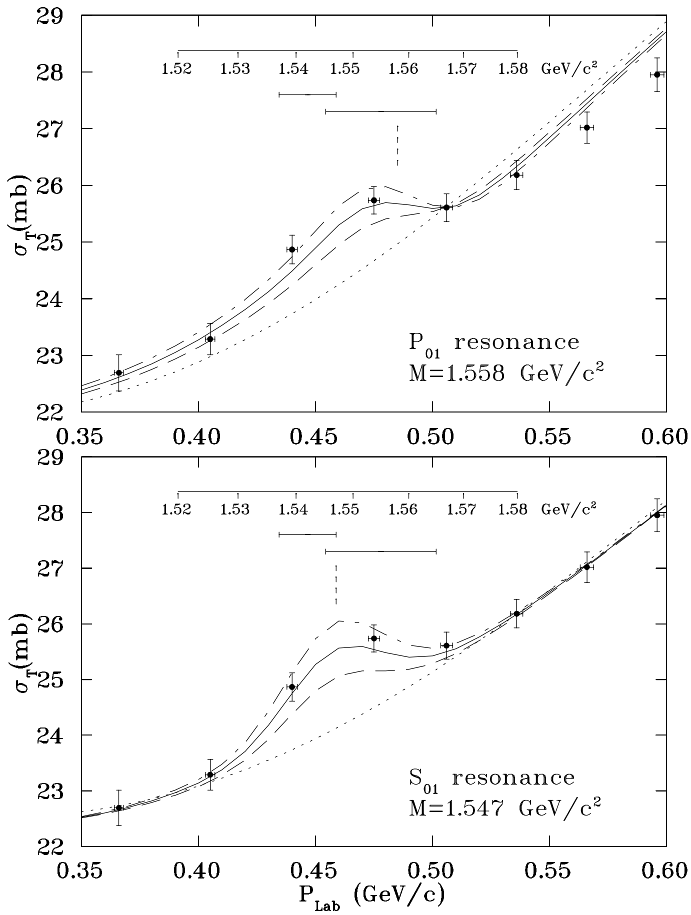

Fig. 1. Fits to the total cross sections of Ref. [9] by Gibbs [15] using a weak-scattering approximation, assuming a positive-parity resonance (top) or a negative-parity resonance (bottom) at the mass and width shown.

One final comment about the KN data is from the paper by Berthon *et al.* [16] for the reaction $K^+p \to pK^0_{\rm s}\pi^+$. This bubble chamber experiment was done at several incident kaon energies, with the highest momentum shown in Fig. 2. This figure shows several combinations of invariant mass of final state particles, for $M(p\pi^+)$, $M(K^0\pi^+)$ and $M(pK^0)$. The first shows a broad peak near the $\Delta(1232)$ mass, the second shows a clear peak at the mass of the $K^*(892)$ vector meson, and the third has a small shoulder at $M^2 = 2.35$ GeV^2 (or $M = 1.54$ GeV). However, further examination of the Dalitz plot for this reaction does not show any resonance structure, and so it is possible that this small shoulder in the mass distribution is just a statistical fluctuation. Better data for this reaction is desired, and an experiment at KEK [17] for the $H(K^+, \pi^+)$ reaction has been approved and is scheduled to run in May 2005.

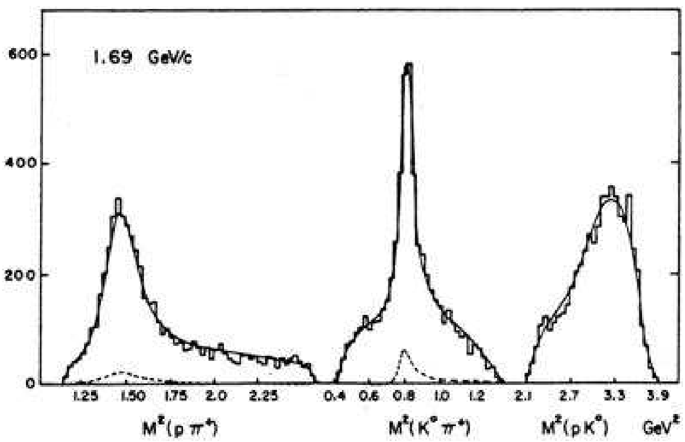

Fig. 2. Data of Berthon *et al.* (Ref. [16]) for the K^+ particles of momentum 1.69 GeV/c incident on a hydrogen bubble chamber. If the pentaquark has mass 1.54 GeV, then it would appear as a peak at $M2 = 2.37$ GeV in the $pK0$ invariant mass spectrum shown on the right.

3. Theoretical models of pentaquarks

The prediction of the Θ^+pentaquark mass and width was given in 1997 by Diakonov, Petrov and Polyakov (DPP) [3]. At that time, the $\Theta^+$was called the Z^+, where the symbol Z was just a placeholder until a resonance was clearly seen. Although there were earlier suggestions that pentaquarks might exist [1, 2, 18, 19] these predictions did not give specific values for the mass or the width. In contrast, DPP made very specific (and hence testable) predictions. One of the DPP authors (Diakonov) encouraged experimentalists to look again for the Θ^+pentaquark in modern experiments, even though the older KN data did not see anything. Below, a simplified explanation of the DPP model is described.

3.1. The chiral soliton model

It has been known for a long time [20, 21] that one solution to the Lagrangian for a pion field (the nonlinear sigma model) is a soliton. The interpretation of this soliton as a baryon is strictly true only in the limit of a fictional world where the number of colors in QCD goes to infinity (the large N_c model [21]). Regardless of the validity of such a model, one can investigate the rotational properties of the soliton based on general rotational dynamics of a Hamiltonian of the so-called hedgehog form (where a space rotation of the field is equivalent to a rotation in isospin). The energy eigenvalues of such a rotation are quantized and the rotational Hamiltonian is described in terms of the generators of the SU(3) group.

The result of the chiral soliton model is a set of states with masses determined by the given group structure and the splitting of the light-quark and strange-quark masses. For example, the lowest rotational state corresponds to an octet with spin $J = 1/2$. The next highest rotational state is a decuplet with spin $J = 3/2$. These states are identified with the lowest mass baryon octet and decuplet. The next highest rotational state is an antidecuplet (a decuplet with opposite symmetry, written as $\overline{10}$) with spin $J = 1/2$ which does not correspond to known baryons. The unique feature of the $\overline{10}$ is a baryon with strangeness $S = +1$, isospin $I = 0$ and spin $J = 1/2$. The lowest valence quark structure to describe this particle can only be $uudd\bar{s}$, which is the Θ^+pentaquark.

In order to estimate the mass of the Θ^+it is necessary to get numerical values for the parameters of the model. Only 2 parameters are needed to relate the mass splittings of the 3 rotational states, corresponding to the (unknown) moment of inertia I_1 and I_2. Since dynamical models cannot provide reliable estimates of these parameters, one must look to data (the baryon masses) to determine these. In the particle data group (PDG) tables of baryons [22], there are only a few choices for non-strange resonances with spin $J = 1/2$. The Roper resonance is too low in mass (this choice would result in a stable Θ^+which is ruled out by experiment) and the only other choice is an N^* resonance at mass 1710 MeV. Using this choice, the mass scale for the $\overline{10}$ is set.

The next step is to determine the mass splittings within each group. Here, one can use the symmetries of the chiral soliton model to relate the mass splittings of the octet, the decuplet and the antidecuplet all with just 3 parameters. Two of these parameters can be determined using data for the masses of the octet and decuplet, and the third parameter is tied to the nucleon sigma term (corresponding to the effective mass of the light quarks — up and down — when they are bound inside the nucleon). The value of the nucleon sigma term has not been determined precisely by experiment, but values in the range of 45–65 MeV are reasonable. Using the best value available at the time, along with the $N(1710)$ mass, DPP predicted that the Θ^+would have a mass of about 1530 MeV.

Finally, the width of the $\Theta^+$is desired. This can also be predicted using the symmetries of the chiral soliton model, but here there is considerably more uncertainty due to the mixing between the effective coupling constants. Without going into the detail here (note that there is an error in the equations of the DPP paper [23]) the width of the Θ^+turns out to be small, of the order of 15 MeV or less. However, this causes some problem, as the $N(1710)$ resonance should also be fairly narrow (about 40 MeV) whereas the partial wave analyses that identified the $N(1710)$ also had widths that were typically 2 to 5 times larger. The question of the width of the $\Theta^+$and which N^* resonance might fit into the $\overline{10}$ group is now an experimental question, as discussed in the next section.

3.2. Other theoretical models

The consituent quark model cannot easily accommodate pentaquarks with a low mass and a narrow width. If one does a naïve calculation using constituent quarks, the mass of the Θ^+should be roughly 1700 MeV or so. At this mass, there is nothing to prevent the quarks from rearranging themselves into a nucleon and a kaon (or “fall-apart” mode). Since this would take place on the time-scale characteristic of the strong force, the width of the Θ^+would be about 500 MeV or so [24]. Two ways to get around this reasoning are: (1) some symmetry such as isospin that constrains the fall-apart mode [24] or (2) a correlated-quark effective force that only becomes apparent in the multi-quark system. Of course, there could be some other way to get a narrow-width pentaquark in a theoretical quark model, but these two choices are the most obvious.

One of the first models using correlations in a quark model to describe the $\Theta^+$is by Karliner and Lipkin (KL) [25]. In this model, one ud pair is bound together into a diquark with spin-0 and the other three quarks $ud\bar{s}$ bind into a triquark from the color-magnetic interaction. In order to keep these systems separated, they assume one unit of orbital angular momentum (so that the two clusters are spatially separated) which gives the overall system positive parity (since the antiquark has intrinsic negative parity). The binding energy of the diquark–triquark system lowers the overall mass, and reduces the decay width because the overlap with the kaon–nucleon wave function (a different diquark–triquark system) is small. In order to find out if this is the true description of the pentaquark, comparisons with experiment will be necessary. For example, one prediction [26] is that there should be a spin-orbit partner with $J = 3/2$ that should be within 100 MeV of the Θ^+mass.

Another popular quark model paper that was submitted just a few weeks after the KL model is by Jaffe and Wilczek (JW) [27]. The appeal of the JW model is, in part, due to its symmetry with both ud pairs in the Θ^+bound into spin-0 diquarks. These diquarks can be treated as quasiparticles with boson statistics, which requires $L = 1$ orbital angular momentum between them. The $\bar{s}$ quark carries the spin of the $\Theta^+$and is at the “center” with

$L = 0$. It is now straight-forward to calculate (using Clebsch–Gordon coefficients) the overlap of the wavefunctions for decay to a kaon–nucleon final state, which gives a suppression factor of $(2\sqrt{6})^2 = 24$ to the decay width. An additional prediction of the JW model is that the strangeness $S = -2$ state of the $\overline{10}$ would have a much lighter mass (by about 300 MeV) than predicted by the chiral soliton model. Again, it is now up to experiment to test the predictions of these models.

4. The Θ^+ pentaquark

Virtually all experiments are subject to some criticism. It is quite difficult to understand the systematic uncertainties in a measurement, and this is especially true when the statistics are limited. The experiments with evidence for the Θ^+have low statistics, and the background under the peaks may not be completely understood. As a result, the statistical significance of the evidence has been questioned. It makes sense to focus on the most reliable experiments to answer the question of whether the Θ^+exists.

4.1. Experiments with positive evidence for the Θ^+

First results from the LEPS [28], DIANA [29], CLAS [30] and SAPHIR [31] collaborations were ground-breaking, but each experiment has some weakness. The LEPS experiment had only 19 counts in the peak on top of a background that was 17 counts, so detailed studies of the systematics of the background and the Fermi motion correction were difficult. (New data from LEPS with more statistics will be presented below.) The DIANA experiment is hampered by background from kaon charge-exchange reactions, and not enough detail is given in their paper to show how the cuts they employ to reduce this background affect the mass spectrum with the Θ^+peak, which is concentrated into a single bin. The CLAS data was the first exclusive reaction on the Θ^+but requires a complicated mechanism with secondary-scattering to give energy to the proton, which would otherwise be a spectator. As a result, the shape of the background under the Θ^+peak is difficult to estimate and may include kinematic reflections [32]. The SAPHIR collaboration was the first to publish for the $\gamma p \to K^0_{\rm s} K^+ n$ reaction, but the large cross section they estimated from their measurement conflicted with data for the same reaction from CLAS [33]. A re-analysis of the SAPHIR data [34] suggests a smaller cross section but is still under study.

Following the first reports, several experiments measured the invariant mass of the $K^0_{\rm s}$ and a proton, which showed a peak close to the Θ^+mass, from inclusive production. One of these collected data from neutrino experiments (ITEP [35]) and two others used electroproduction (HERMES [36] and ZEUS [37]). Of course, the K^0_s is a mixture of both strangeness +1 and −1, so the invariant mass spectra will include both Σ^{*+} and possible Θ^+peaks. It follows that a peak at a mass where no Σ^{*+} resonance is known could be evidence for the Θ^+or an unknown Σ^{*+} resonance. It is also curious that these three measurements reported a Θ^+mass which is about 10 MeV below that seen by the first experiments (barely compatible within the experimental uncertainties). Furthermore, most of the null evidence for the Θ^+(see below) also measure the pK^0_s invariant mass, but no peak is seen at the Θ^+mass. The inherent weakness in not knowing the strangeness of a particle, coupled with the uncertainty in the background which must include the overlapping Σ^{*+} resonances, makes this evidence less convincing than exclusive measurements.

Three experiments remain that have good evidence for the Θ^+. The first is from CLAS on a proton target [38]. This exclusive reaction, $\gamma p \to \pi^+ K^- K^+ n$ is very clean, and the background comes primarily from meson production reactions. The cuts for this analysis were not chosen arbitrary, as has been suggested by some critics, but are specifically designed to remove the dominant background along with the assumption that the Θ^+can be produced through an s-channel diagram [38]. Furthermore, these data were examined by a partial wave analysis (PWA), where the amplitudes of each partial wave were fit over the full angular coverage of the CLAS detector. Hence, the background under the Θ^+peak (after all cuts are applied) has been fixed by the PWA from the full (uncut) data. The Θ^+peak here has the highest statistical significance yet reported, in excess of 7 σ. Because this is an exclusive measurement from the proton, there is no ambiguity in rescattering from other nucleons, and the strangeness of the final state is clearly identified. On the other hand, the mass of the peak is at 1.55 ± 0.01 GeV, which is about 0.01 GeV higher than the initial Θ^+measurements.

The second experiment with good evidence for the $\Theta^+$is the COSY-TOF result [39] from the exclusive hadronic reaction $pp \to \Sigma^+ K^0_s p$. Here, the strangeness of the pK^0_s invariant mass is tagged by the Σ^+. The particle identification is done entirely by geometric reconstruction which, for this near-threshold reaction, is shown to be very accurate. Some critics have questioned whether this method provides good identification of the final state, but it can be rigorously proven that the kinematics are overconstrained [39]. The result is a very clean final state showing a Θ^+peak at a mass of about 1.53 GeV, which is on the low side of the Θ^+mass measurements.

The third experiment, and perhaps the most convincing one, is the new data from LEPS on a deuterium target [40]. These data are shown in Fig. 3, which uses minimal cuts for the event selection. There are clear peaks for both the $\Lambda(1520)$ and the $\Theta^+$where the same event sample has been used for both plots and the same Fermi motion correction is applied to both. The only difference is that one spectrum uses the K^+ and the other uses the K^-, and the detector acceptance is symmetric for these charged kaons. In addition, the same analysis procedures applied to a mixed-event test do not show any peaks at the location of either the Θ^+or the $\Lambda(1520)$. In the mixed-event test, the K^+ and K^- are taken from different events, but the same analysis cuts (which ensure energy and momentum conservation) are applied. Further confidence is gained by seeing that the peaks cannot be generated from a kinematic reflection of K^+K^- pairs from the ϕ-meson or from tensor meson (a_2 or f_2) production.

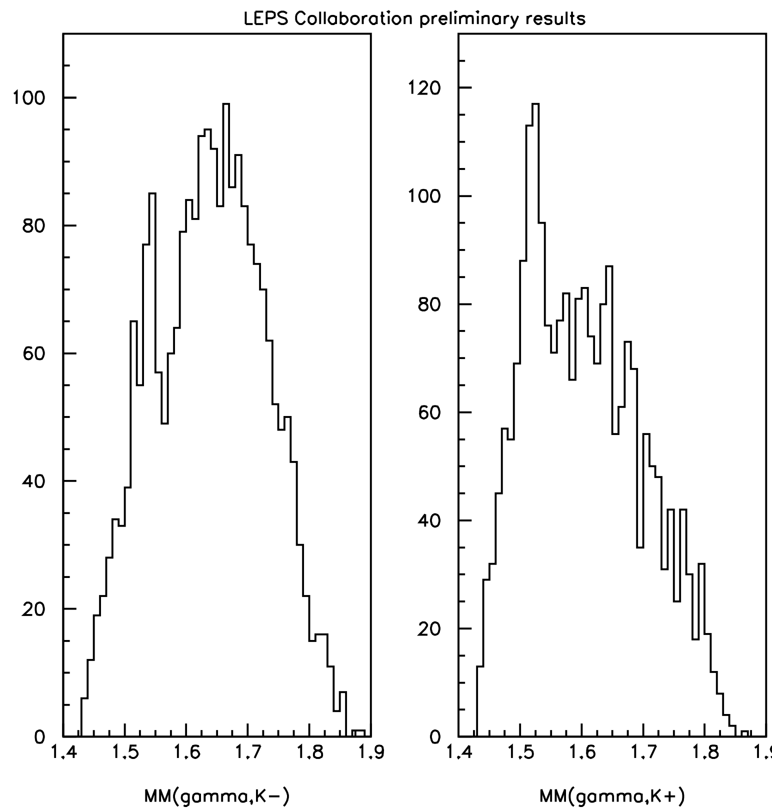

Fig. 3. *Preliminary* missing mass spectra for the $\gamma d \rightarrow K^+K^-X$ reaction measured with the LEPS detector at SPring-8. The event selection requires: (1) particle ID for each kaon; (2) the missing mass of the KK system is within 5 MeV of the nucleon mass; (3) a cut on the KK invariant mass to remove the ϕ-meson resonance; (4) the photon energy is less than 2.35 GeV. The Θ^+peak is seen at about 1.53 GeV on the left and the $\Lambda(1520)$ peak is seen at 1.52 GeV on the right.

4.2. Experiments with non-observation of the Θ^+

Having taken a critical look at the evidence in favor of the Θ^+we now turn to the null results. These have all come from either high-energy reactions using a hadron beam (such as HERA-B [41] and CDF [42]) or from electron-positron colliders (Belle [43], BaBar [44], BES [45]). Because of the difficulty in detecting neutrons in these detectors, typically these experiments look at the pK^0_s invariant mass, like in the HERMES and ZEUS experiments. Unlike the medium-energy electroproduction reactions, the high-energy hadron beam experiments typically have much higher statistics yet see no Θ^+peak. Naively, one might expect that if the Θ^+exists, it should be produced in both high-energy electroproduction and high-energy hadron collisions, perhaps through fragmentation processes as the flux tube breaks when the struck quark exits the nucleon. This reasoning suggests that the Θ^+does not exist. On the other hand, for the electron-positron collisions, it is not clear how an appreciable number of Θ–$\bar{\Theta}$ pairs are produced by a mechanism where 5 quarks and 5 antiquarks must be produced from, say, decay of a $q\bar{q}$ meson.

Since the hadron beam experiments pose a more serious challenge to the existence of the Θ^+we should examine these experiments with some care. In the interest of fairness, the same criticism directed at the HERMES and ZEUS experiments should also be applied to the high-energy hadron experiments. Perhaps the most severe criticism is that the pK^0_s spectra should show evidence for known Σ^{*+} resonances, even if these resonances are broad, yet these spectra are featureless even with high statistics. Clearly, more effort needs to be put toward understanding the background in these measurements.

The production mechanism of the Θ^+(if it exists) or even the Λ^* and Σ^* resonances from fragmentation processes is not well known. Hence the high-energy experiments can only put an upper limit on the ratio of production of, say, the pair of Σ^* resonances at 1660–1670 MeV to $\Lambda(1520)$, or $\Theta^+$to $\Lambda(1520)$. Non-observation of the Σ^* resonances, which might be difficult to detect because of their broad width, does not mean that the Σ^* does not exist. Similar reasoning applies to the non-observation of a Θ^+peak, although the limits will be more stringent because of its narrow width. When examining the results from high-energy hadron beams, it is important to report not just the upper limit on Θ^+but also the upper limits on other known hadron resonance production. These upper limits should then be confronted quantitatively with calculations based on models of flux-tube fragmentation.

Finally, the facts should be clearly stated when drawing conclusions from both positive and null evidence. The kinematics in experiments with upper limits on Θ^+production are different from those experiments reporting positive evidence. In other words, the null results do not prove that the positive results are wrong. There may be some interesting physics to be learned, assuming the experiments are correct, as to why exclusive measurements at medium energy show a potential Θ^+peak whereas this signal seems to be obscured in high-energy inclusive measurements. Regardless of the explanation, the facts (and assumptions) should be made clear when drawing conclusions about the existence of the Θ^+pentaquark.

4.3. Experimental outlook

Two measurements expected to produce about a ten-fold increase in statistics, one using a deuterium target and the other using a hydrogen target, are currently being analyzed from CLAS. However results are not expected to be ready until late 2004. In addition, another experiment to get more statistics from the COSY-TOF detector is planned within the year. High statistics will be a crucial test of whether the Θ^+exists or not.

Analysis of the new deuterium data from CLAS is in progress. The missing mass spectrum for the $\gamma p \to K^+K^-pn$ reaction, where only the charged particles are detected, shows a clean neutron peak with very little background. The photon beam had a maximum energy of 3.6 GeV, compared with the published data [30] which was taken at two photon beams with 2.3 and 3.0 GeV maximum energy. The higher beam energy and the lower magnetic field of the new measurement provide different kinematics than before. (Note that one can match the kinematics of the earlier CLAS data by limiting the photon energy and making angular cuts in the data analysis.) Because of the importance of "getting it right the first time", the CLAS collaboration has chosen not to release this mass spectrum for the nK^+ system (where the Θ^+peak would be expected) until the analysis results on the *full data set* are final.

Similar comments apply to the new proton data from CLAS. However, in this case the photon beam energy is lower than the published result [38], which had the majority of the data taken at a maximum photon energy of 5.4 GeV. The new data are focused on a measurement of the reaction $\gamma p \to K^0K^+n$, similar to that reported by the SAPHIR collaboration [31]. The new data will provide at least a ten-fold increase in statistics in the desired photon energy range.

At COSY-TOF, they will take data with improved detector resolution within the next year, and may also increase the statistics of the previously reported results by as much as a factor of five. In addition, the new data are planned at a slightly higher beam energy so that the detector acceptance is more uniform in the region above the Θ^+peak. Again, this measurement could be definitive if the reported results are reproduced with higher statistics. On the other hand, if the peak is not reproduced then it will be important to find an explanation of the previous COSY-TOF Θ^+peak.

5. Summary

At the time these lectures were presented, the experimental question of whether the Θ^+exists was still being debated. It was expected that if the Θ^+exists, it should be seen in a variety of experiments, including high-energy experiments. In addition, the evidence from medium-energy experiments was limited by statistics, and it is possible to find some criticisms of these experiments with positive results that cast some doubt on whether the peaks are real or just statistical fluctuations (or kinematic reflections). Similarly, all the non-observations come from high-energy experiments where the production mechanisms are unknown and the backgrounds are higher than for the exclusive reactions at the medium-energy experiments. It is reasonable to ask if the production mechanism favors the near-threshold production? If true, is this so strange?

One thing is certain. If the Θ^+exists, then it is an exotic baryon with an exotic production mechanism. It may be wrong to extrapolate from our experience with standard baryon resonances to predict what mechanisms are dominant in producing the Θ^+resonance. Whatever mechanism exists must include a small coupling to the KN decay channel (unless the sparse KN scattering data is wrong). The small decay width is perhaps surprising, because the naïve (constituent) quark model predicts a large width from "fall-apart" mode. So if the Θ^+pentaquark exists, it will require us to find a theoretical explanation that goes beyond the traditional quark models. In this sense, the stakes are high and the verification of the Θ^+at high statistics (or killing the evidence with a clearly null result) is an important task for the hadron physics community. Only time will tell, so we must be patient and cautious as we allow science to take its course.

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