An Exploratory Study of the Possible Existence of a New Light Baryon of Mass $M_p < M < M_p + M_\pi$ in the ^{1}H(e,e$'$p)X and ^{1}H(e,e$'\pi^+$)X Reactions

Abstract

It is proposed to search for the possible existence of a light baryon lighter than $M_p + M_\pi$. Such baryons, if they exist, are expected to be narrow and thus enhance detection sensitivity. We will look for these baryons
a) in the ^{1}H(e,e$'$p)X process where X is identified with one or more photons from the decay, vis. $M \rightarrow$ p $+\, n$ photons, and
b) by detecting the decay π^+ of the Δ resonance populated in the electroexcitation studied by means of the ^{1}H(e,e$'\pi^+$)X reaction. The remaining system X is then either a neutron or possibly an excited state.

We request for 100 hours of running time with an electron energy E_0 = 855 MeV and beam currents of 20 μA.

1 Introduction

An important subject in modern hadron spectroscopy is the search for exotic hadrons hitherto unknown. One may cite many motivations, but the main interest is to examine the limits of validity of Quantum Chromodynamics and the inspired models (Chiral perturbation etc.). The activity is mainly centered around exotic mesons heavier than 1 (GeV/c)^2 and exotic baryons heavier than the deuteron [1].
Though not warranted by theory, there are speculations and even a few searches for baryons with masses below pion thresholds. These baryons, if they exist, have far reaching consequences. It is possible that in ordinary matter, particularly for heavy nuclei, one might have to redefine the isospin quantum numbers, as the baryon quantum number may not be what one estimates in neutrons and protons only approximation. This feature will have implications not only to nuclear and hadronic physics but also to astrophysics and cosmology. It is therefore important to examine these possibilities, however speculative they might sound to be.

2 Physics Motivation

So far, to our knowledge, there have been two experiments which searched for an exotic baryon (X) of mass $M_p < M < M_p + M_\pi$.

The first paper was by Ram *et al.* [2] who searched for a doubly charged baryon X in the reaction p(p,X^{++})n using the 460 MeV proton beam at TRIUMF, Canada. This baryon, if it exists, corresponds to isospin $I = 3/2$. Its decay to the ground state (proton) can only proceed through weak interaction, such as $X^{++} \rightarrow p + e + \nu_e$. The search by Ram *et al.* at $E_p = 460$ MeV and $\theta_p = 15^\circ$ puts an upper limit of $\sigma < 75$ pb/sr. They concluded that they have not found a new $I = 3/2$ baryon, but they could not establish that such baryons would not exist. They call for more experiments with beams of protons, electrons, pions, photons etc. to look for both $I = 3/2$ and $I = 1/2$ light baryons.

More recently, Tatischeff *et al.* [3] claimed the existence of a few resonances in the ^{1}H(p,p$'\pi^+$)X reaction at missing masses $M = 1004, 1044$ and 1094 MeV/c^2. The exotic states, if they exist, are neutral baryon excitations of most likely $I = 1/2$. It is to be remarked that this experiment, carried for two incident beam energies and at forward detection angles, is an elaborate measurement and they claim the existence of baryons with excitation energies of 66 and 106 MeV ($M = 1004$ and 1044 MeV/c^2). In a simple minded model of colored quark clusters at the end of a stretched bag, they parametrize the baryon spectrum and they predict several states, as both bound and unbound excitations.
If this result is correct, one would interpret these resonances as the $I = 1/2, I_3 = -1/2$ excited states of the neutron.

However, we should add that a more elaborate chiral constituent quark model calculation, in the frame work of clustering approach, does not yield any new states, as it is applied to the dibaryon problem [4]. One would suspect that the similar results (no bound excited states of the nucleon) obtains. Nevertheless, an interesting observation is that colored clusters tend to bring the levels down compared to those of colorless 3-quark or quark-antiquark clusters.

From charge symmetry reasoning, one would expect levels at the same excitation energy in the proton also with $I = 1/2$ and $I_3 = 1/2$. The photonuclear processes, both production and Compton scattering have been extensively carried out at MAMI [5, 6] and they fail to reveal any anomalous structures. One can then conclude that these levels, if they exist, are not accessible to real photon excitation. It is then unlikely that these excitations are of dipole type. It still leaves open the possibility (assuming that they are of the same parity as the proton ground state) that they can be excited by virtual photons of multipolarities $E0$ or $E2$.

First we consider the ^{1}H(e,e$'$p)X reaction. For reasons of orthogonality, the form factor for $E0$ excitation peaks at the same momentum transfer as the $E2$ transition. Thus the same set of momentum transfers optimizes both multipolarities simultaneously. However, since the real photon $E0$ decays are non-existant, such an excitation will decay by emitting at least two photons or e^+e^- pairs. The resulting missing mass distribution will exhibit a spread in the missing mass spectrum, while the $E2$ deexcitation by a single photon will have a delta function distribution peaking at missing mass zero.

It is also possible that the level may be a higher angular momentum state requiring multipole excitations higher than quadrupole transitions. It would then be almost impossible to excite it by electron scattering with beams of less than 1 GeV energy. The findings of Tatischeff *et al.*, if correct, do allow for higher angular momentum transfers also, since the p-p processes can accommodate for many partial waves.

We can extend the utility of the electron probe, by not limiting ourselves to examine the ^{1}H(e,e$'$p)X reaction in the excitation spectrum only. Additionally, it is proposed to examine the missing mass spectrum of the ^{1}H(e,e$'\pi^+$)X reaction, where the Δ–resonance is excited and the subsequent decay pion is detected in coincidence. The final state X is then expected to be either a neutron or a possibly existing excited state populated by the decay of the Δ resonance. This second alternative is the electron scattering analogon to the reported experiment by Tatischeff *et al.* [3].

In both cases it is searched for narrow structures in the respective spectra, once in the excitation, and once in the decay, respectively.

3 Experimental Method

The experiment will be carried out at the 3–spectrometer arrangement of the A1 collaboration.

The scattered electrons will be detected by spectrometer B, protons and pions, respectively, in spectrometer A. Spectrometer C will additionally be used as a luminosity monitor.

4 Beamtime Request

A running time of about 100 hours is necessary to explore if the bound nucleon excited states are populated by the electron probe. If a signal or some indication for the occurence of such levels is found, we will embark on further detailed studies. At that stage, we will submit another proposal detailing the followup experiments.

The philosophy of this proposal is not that the bound excited states of nucleons necessarily exist. But, if they exist, these measurements at A1 collaboration have the best chance of detecting them. We thus request for the beam time.

References

[1] see e.g. *Review of Particle Physics*, C. Caso *et al.*,
The European Physical Journal **C3** (1998) 1

[2] S. Ram *et al.*, Phys. Rev. **D49** (1994) 3120

[3] B. Tatischeff *et al.*, Phys. Rev. Lett. **79** (1997) 601

[4] A. J. Buchmann, G. Wagner and A. Fäßler, Phys. Rev. **C57** (1998) 3340

[5] M . Fuchs *et al.*, Phys. Lett. **B368** (1996) 20

[6] C. Molinari *et al.*, Phys. Lett. **B371** (1996) 181