V AB

BUCHAREST UNIVERSITY

EXPERIMENTAL PARTICLE PHYSICS GROUP

UB Pub – EPPG/Phys .51
July 2001

ELECTROPRODUCTION EXPERIMENTS AT JEFFERSON LABORATORY

TATIANA ANGELESCU , ALEXANDRU MIHUL , LILIANA TEODORESCU

Bucharest University, Romania

-Research report-

Presented at the Annual Scientific Conference of the UB Faculty of Physics
25 May 2001

Abstract. The collaboration of the Experimental Elementary Particle Group (EPPG) of the Bucharest University (UB) with Hampton University and Jefferson Laboratory started in 1995. Results on the following subjects have been obtained: the value of the ratio of longitudinal and transverse cross section and the evaluation of the K^+ formfactor, the induced and transfered value of the polarization of the lambda hyperon, the detection of the bound levels of the hypernucleus $_{\Lambda}^{12}B$. All these results are unique regarding the accuracy and statistics. The paper presents the results and their impact on the future thematics of the laboratory. Proposals of experiments with the participation of the Romanian group have been approved and will run in the following years at Jefferson Laboratory.

Keywords: electroproduction, strange particles, polarization, hypernuclei

#2315170

Aims

The publication of the UBPub. EPPG/Phys series is in the first a mirror of the activities of the Experimental Particle Physics Group (EPPG) of the Bucharest University and of related groups. The publication report on research and progress in the field of Physics and Instrumentation related to the EPPG activities and those of connected groups. Publications of outside groups are strongly encouraged

Publisher

Experimental Particle Physics Group
Faculty of Physics
Bucharest University
Bucharest Magurele POBox

Editor Board

Disclaimer

The material presented for multiplication is usually accepted only after the positive recommendation of at least two independent specialists referees

Dissemination

Reprinting and further dissemination is permitted with proper acknowledgements

ELECTROPRODUCTION EXPERIMENTS AT JEFFERSON LABORATORY

TATIANA ANGELESCU , ALEXANDRU MIHUL , LILIANA TEODORESCU

Bucharest University, Romania

Abstract. The collaboration of the Experimental Elementary Particle Group (EPPG) of the Bucharest University (UB) with Hampton University and Jefferson Laboratory started in 1995. Results on the following subjects have been obtained: the value of the ratio of longitudinal and transverse cross section and the evaluation of the K^- formfactor, the induced and transfered value of the polarization of the lambda hyperon, the detection of the bound levels of the hypernucleus $_\Lambda{}^{12}B$. All these results are unique egarding the accuracy and statistics. The paper presents the results and their impact on the future thematics of the laboratory. Proposals of experiments with the participation of the Romanian group have been approved and will run in the following years at Jefferson Laboratory.

Keywords: electroproduction, strange particles, polarization, hypernuclei

1. INTRODUCTION

The electron beam on fixed target experiments at SLAC and DESY have been abandoned in 1975. he crucial results on proton structure obtained at SLAC in 1970 fully justified the interest of these first xperiments. Unfortunately, the differential cross sections for hadron production obtained at these ccelerators had large statistical errors due to the small beam intensity and, the lack of polarized beam and arget did not permit the study of the hadron polarization. Consequently, new electroproduction experiments vith high precision, high statistics and polarization facilities were necessary in order to test the new heoretical trends in quantum cromodynamics. One of the main goals of a intermediate energy electron acility was the systematical study of nuclear and hypernuclear physics.

The continuous electron beam accelerator produced the first physics results at the beginning of 995. A new upgrade of the accelerator to higher energies (12GeV) was proposed for the following years. is expected that the results of these experiments are likely to significantly change the way we think about uclear physics and the strong unperturbative limit of QCD [7].

We discuss in the following , the results obtained in Hall C at Jefferson Laboratory experiments in hich the Bucharest University has been part of the collaboration.

2. EXPERIMENTAL SET - UP.

The standard detection system in Hall C at Jefferson Laboratory consists of two highly flexible ectromagnetic spectrometers with medium resolution and relatively large momentum and angular ceptances (fig 1) . The High Momentum Spectrometer(HMS) is capable to analyze high momentum rticles (up to 7. 5 GeV/c). The Short Orbit Spectrometer has a large momentum acceptance but its aximum central moment is around 1. 7 GeV/c.

Momentum resolution is $\delta p/p = 0.04$ % for the HMS and 0. 1 % for SOS. Both spectrometers ve angular resolution of about 2-3 milliradians. Particle identification (ID)is performed by detector ckages which consist of two drift chambers, two sets of x-y scintillators, a gas Cherenkov detector and a ower counter.

The HMS identifies electrons out of π^- at a level of 99. 8 % and SOS separates kaons from otons and pions at a level of 1/800.

These characteristics of the spectrometers combined with the high quality of the electron beam (QF=1) are ideal for the study of differential cross sections in exclusive reactions with strange particle production such as :

$$e + p \rightarrow e' + K^+ + \Lambda^0 (\Sigma^0)$$

Using unpolarized and polarized electron beam we can separate transverse and longitudinal cross sections and induced and transfered polarization of the hyperon and compare these data with different theoretical models or extract the kaon form-factor out of longitudinal cross section.

These results have been obtained for the first time at Jefferson Laboratory with high accuracy.

The large acceptance of the SOS spectrometer was used for detecting in coincidence K^+ and protons from the Λ decay and measure, from proton asymmetries, the hyperon polarization which could not be measured in other experiments.

A modification of the Hall C standard detection system was used to investigate hypernuclear states with high resolution. This method leads to results, which could not be obtained in hadron induced experiments. In order to obtain hypernuclear states, reactions with very small momentum transfer have been used , that is:

$$e + {}^{12}C \rightarrow e' + {}^{12}{}_\Lambda B + K^+$$

in which the scattered electrons are detected at zero degrees with low momenta (300 MeV/c) .
The HMS spectrometer has been replaced by HNSS spectrometer (shown in fig. 2).

A "Split Pole" magnet deviates the electrons and focalizes them in the detector plane. The detector for electrons was in the first version of the experiment E89 -009 a silicon strip detector (SSD) with 100 μm spatial resolution. The trigger is given by a coincidence of a K^+ in SOS arm with an electron in a hodoscope array behind the SSD. With about 100 picoseconds resolution time, one can avoid a lot of background given by bremsstrahlung of scattered electrons.

Due to the still high background, an update of the detection system has been proposed and approved, which would increase 3 times the resolution of the missing mass spectrum and suppress the background up to 10^3 times.

An increase in the SOS spectrometer resolution has been obtained with a HKS (high resolution kaon spectrometer). The missing mass spectrum has about 300 keV resolution, being able to separate the bound states of the hypernuclei of intermediate mass (${}^{28}Si$, ${}^{51}V$, ${}^{89}Y$). The experimental set upgrade is shown in fig. 3. The main improvements are in a higher yields of hypernuclei by using electron detection angle of zero degrees and kaon detection angle close to zero degrees. To avoid the bremsstrahlung and hadron background, the electron momentum should be low (1. 8 GeV/c), the electron detection plane is tilted at 2. 25 degrees and the electron silicon detector is replaced by a drift chamber with very thin walls.

The momentum resolution achieved is about 10^{-4} which gives a binding energy resolution of about 300 keV . The signal to background ratio would be a factor of 10 higher than that obtained in the E89-009 experiment.

3 . PHYSICS BACKGROUND

a. *Why strange particle electroproduction?*

Lepton -nuclei scattering is an important tool for investigating nuclear structure. The leptonic part of the interaction is well known, described by quantum electrodynamics (QED) and very well verified experimentally. Only the lowest order process is taken into consideration (one photon exchange), due to the smallness of the electromagnetic coupling constant ($\alpha = 1/137$). At intermediate energies the weak interaction contribution is to be neglected, the electromagnetic coupling constant being orders of magnitude higher than the weak one.

Nuclear target contribution is expressed in nuclear response functions. In one hadron electroproduction with polarized beam the differential cross section is written as:

$$\frac{d^3\sigma}{dE_e' d\Omega_e d\Omega_K^*} = \sigma_{unpol} + h\sigma_{pol} \qquad (1)$$

vhere h is the electron helicity in the ultrarelativistic limit for a longitudinally polarized beam.
σ_{unpol} is independent on the electron polarization. σ_{pol} can be obtained in a separated form by using cross ection difference for h= + / - 1.

In one virtual photon approximation the virtual photoproduction differential cross section can be eparated:

$$\frac{d^3\sigma}{dE_e' d\Omega_e d\Omega_K^*} = \Gamma \frac{d\sigma_\gamma}{d\Omega_K^*} \qquad (2)$$

here:

$$\Gamma = \frac{\alpha}{2\pi^2} \cdot \frac{E_e'}{E_e} \cdot \frac{W^2 - Mp^2}{2Mp} \cdot \frac{1}{Q^2} \cdot \frac{1}{1-\varepsilon} \qquad (3)$$

the virtual photon flux, E_e , E_e' are the incident and scattered electron energies, W is the invariant mass f the hadronic system , M_p is the target mass and Q^2 is the squared four momentum transfer to the electron. is the transverse polarization of the virtual photon:

$$\varepsilon^{-1} = 1 + \frac{2|\bar{q}|^2}{q^2} \tan\frac{\theta_e}{2} \qquad (4)$$

$^2 = -Q^2$. $\bar{q}$ is the three momentum vector of the virtual photon. θ_e is the electron scattering angle in e laboratory system .

$\frac{\sigma_\gamma}{\Omega_k^*}$ is now expressed as a sum of response functions which depend on the angles θ_k and ϕ_k of the tected kaon and the hadron polarization.

A complete experiment (beam and target polarized) can determine 36 response functions (see [3] d reference [1] therein).

In order to avoid a very complicated separation we used some features of the experiment to extract rt of the response functions.

1. In the first experiment with unpolarized beam and no hyperon polarization detected , the ferential cross section has only four terms:

$$\frac{d\sigma}{d\Omega_K^*} = \sigma_t + \varepsilon\sigma_l + \varepsilon\cos(2\phi)\sigma_{TT} + \left[\frac{\varepsilon(\varepsilon+1)}{2}\right]^{1/2} \cos\phi\,\sigma_{LT} \qquad (5)$$

is the transverse part of virtual photon-proton interaction

σ_L is the longitudinal part
σ_{TT} is the transverse-transverse interference term
σ_{LT} is the longitudinal -transverse interference term.

The σ_T , σ_L separation is possible using the Rosenbluth separation technique. Integrating over ϕ between 0 and 2 π in relation (5) we separate the first two terms. σ_T and σ_L are functions on the invariants Q^2 , W and t = (q-K)^2 (q , K are the four vectors of the virtual photon and kaon). The integration has been allowed by the uniform experimental coverage in ϕ on a small region in t at a given Q^2 and W .

In order to perform the σ_L / σ_T separation, plots of $\sigma_T + \varepsilon\,\sigma_L$ as a function of virtual photon polarization, ε , have been fitted with straight lines [5] (fig. 4). The ratio R= σ_L / σ_T obtained for different Q^2 values is compared with previous data and two theoretical models in fig. 5.

The R value falling down for high Q^2 is confirmed with much smaller errors in disagreement with the predictions of the Saghai model. Both models are strongly dependent on coupling constants and formfactors obtained by phenomenological fits of the previous world data (which are scarce).

Having σ_L as a function of t we can try a Chew Low extrapolation technique for the extraction of the kaon formfactor . In fact the success of such an extrapolation depends on a large number of data at small t values , the m_K^2 pole being far from the physical region. Our data are for t between - 0. 4 and - 0. 2 (GeV/c)^2 and the Q^2 values in a small range (Q^2 · 0. 75 - 1. (GeV/c)^2) fact which makes difficult the extraction of the cutoff parameter in the formfactor formula :

$$F_k^2(Q^2) = \frac{1}{\left(1 + \frac{Q^2}{\Lambda_{K^+}^2}\right)} \qquad (6)$$

The error in Λ_{K^+} is about 20 % or more.

2. The large acceptance of the SOS spectrometer gave us the possibility to detect simultaneously (30 ns coincidence time) the K^+ and the decay proton out of the Λ - hyperon decay. On the other side by combining the time of flight with Cherenkov informations, a very good p - K^+ discrimination was achieved.

A Monte Carlo simulation program [3] showed that decay protons are registered with kaons in the same solid angle at a rate of about 0. 01 s^{-1} , while the kaon rate is about 0. 3 s^{-1} . The selection of a very small coincidence window which is necessary to eliminate part of the background makes the experiment tedious, especially for low values of the Λ polarization.

A test on the Λ induced polarization in an unpolarized beam experiment has been performed [2].

Fig. 6 shows the first result of the Λ induced polarization and some theoretical predictions. Even with such big statistical errors , the result eliminates the first vector resonance model of Williams et al (WJC1). Much bigger statistics at higher K^+ angles are required in order to decide about polarization model predictions.

Another experiment with electron polarized beam has been approved at Jefferson Laboratory to measure the transfered Λ hyperon polarization using the same method. By measuring the cross section averaged on ϕ for electron helicities + / - 1, we can obtain the polarization part , σ_{pol} .

A hyperon polarization has three components (fig. 7): longitudinal, transverse and normal , along **l**, **t**, **n** vectors. For about 1000 - 3000 events, the simulation program computed an error in asymmetry of 0. 03 to 0. 018. Therefore, we have the possibility to measure polarizations between 0. 3 and 0. 5 .

b. *What can we learn from hypernuclear electroproduction?*

Hypernuclei structure and Λ -nucleon interaction can be studied in (π^+ , K^+) and (e , e' K^+) reactions. The last reaction has the advantage of a very good resolution which permits the separation of the uclear shells beyond the p shell from light to intermediate hypernuclei as well as spin -orbit splittings of he Λ shells.

The spectra of Λ hypernuclei studied for intermediate nuclei in (π^+ , K^+) reactions were nterpreted in terms of a Λ bound in a Woods-Saxon density- dependent potential but the poor quality of the pectra (resolution of 15 to 4 MeV) could not emphasize the core excited states or spin -dependent Λ N nteraction.

Hypernuclear spectroscopy coupled with gamma ray spectroscopy can give much more nformation about the interaction potential but until now the hypernuclear spectroscopy could not attain in he (π^+ , K^+) reactions a better resolution.

The first experiment of the collaboration measured the Λ binding energy spectrum with a esolution of 800 keV. A preliminary result is given in fig. 8. A bound state of nucleus $_{\Lambda}{}^{12}B$ at -11 MeV s seen, other peaks are buried in the background fluctuations.

4. CONCLUSIONS.

Electroproduction of strangeness from protons and nuclei can provide many interesting results bout the strange components of protons, strange particle formfactors, hyperon - nucleon interactions inside e nuclei. The first results obtained at Jefferson Laboratory revealed many interesting features of the teractions which promoted new theoretical models. It seems that the nuclear physics at intermediate - high nergy would be one of the most productive in the direct exploration of the quark gluon structure of hadrons nd nuclei.

REFERENCES

T. Angelescu, Al. Mihul , L. Teodorescu et al *Kaon electroproduction at CEBAF (Virginia. SUA)*
om. Rep. Phys. **Vol 48** , 1996 , p 347 - 357
L. Teodorescu, P. Gueye , T. Angelescu et al *Λ Polarization in associated K⁺ - Λ electroproduction*
ucl. Phys. **Vol A 658** , 1999 , p 362 -371
T. Angelescu , O. K. Baker, P. Gueye , L. Teodorescu *Monte Carlo simulation of polarization*
easurements in kaon electroproduction
zika **Vol B9** , 2000, p 83 -96
T. Angelescu, Al. Mihul, L. Teodorescu et al *Polarization measurements in kaon electroproduction*
om. Rep. Phys. **Vol 50** , 1998 , p497 -506
T. Angelescu , Al. Mihul , L. Teodorescu and E93 -018 coll. *Longitudinal and Transverse Cross*
ctions in the ^1H (e, e'K⁺) Λ Reaction
ys. Rev. Lett. **Vol 81** , 1998 p 1805 - 1809
T. Angelescu , Al. Mihul, L. Teodorescu and E93 -018 Coll. *Associated Lambda production at*
fferson Laboratory
ucl. Phys. **Vol A 639** , 1998 , p 189 -196
T. Angelescu , Al. Mihul , L. Teodorescu and CEBAF Hall C Coll. *The Science Driving the 12 GeV*
ograde of CEBAF
EBAF , 2001
T. Angelescu and E97 -008 Coll. *Spectroscopic study of Lambda Hypernuclei up to the medium -heavy*
ass region using the (e , e' K⁺) Reaction
oposal approved PAC 19 , 2000

FIGURE CAPTIONS

. 1. The Standard Spectrometric System in Hall C: HMS and SOS
. 2. HNSS Spectrometer for E89 -009 experiment

Fig. 3. HKS high resolution kaon spectrometer for hypernuclear studies
Fig. 4. $\sigma_T + \varepsilon\,\sigma_L$ versus ε for different values of Q^2
Fig. 5. $R = \sigma_L / \sigma_T$ versus Q^2 compared with previous experimental data and two theoretical models
Fig. 6. The measured and predicted Λ induced polarization as a function of γ -K four momentum transfer , t.
Fig. 7. The coordinate systems for the polarization vectors.
Fig . 8. Binding energy spectrum of the $_{\Lambda}{}^{12}B$ nucleus. Preliminary results.

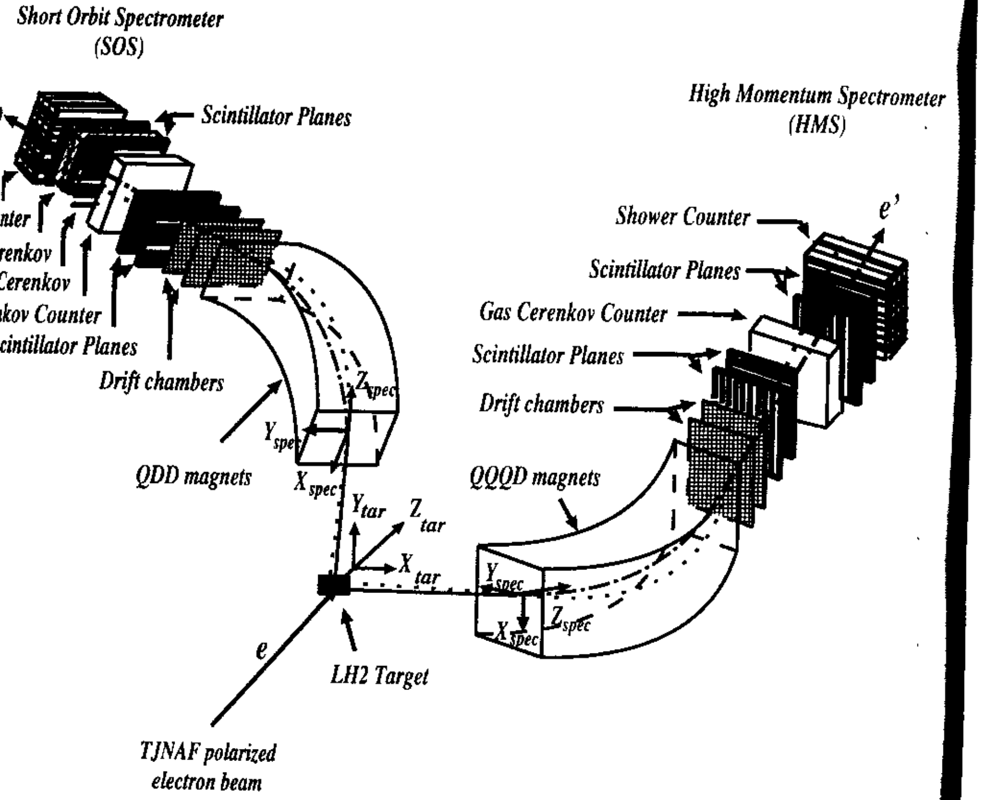


Fig. 1. The Standard Spectrometric System in Hall C: HMS and SOS

TOP VIEW OF EXP89-009 APPARATUS

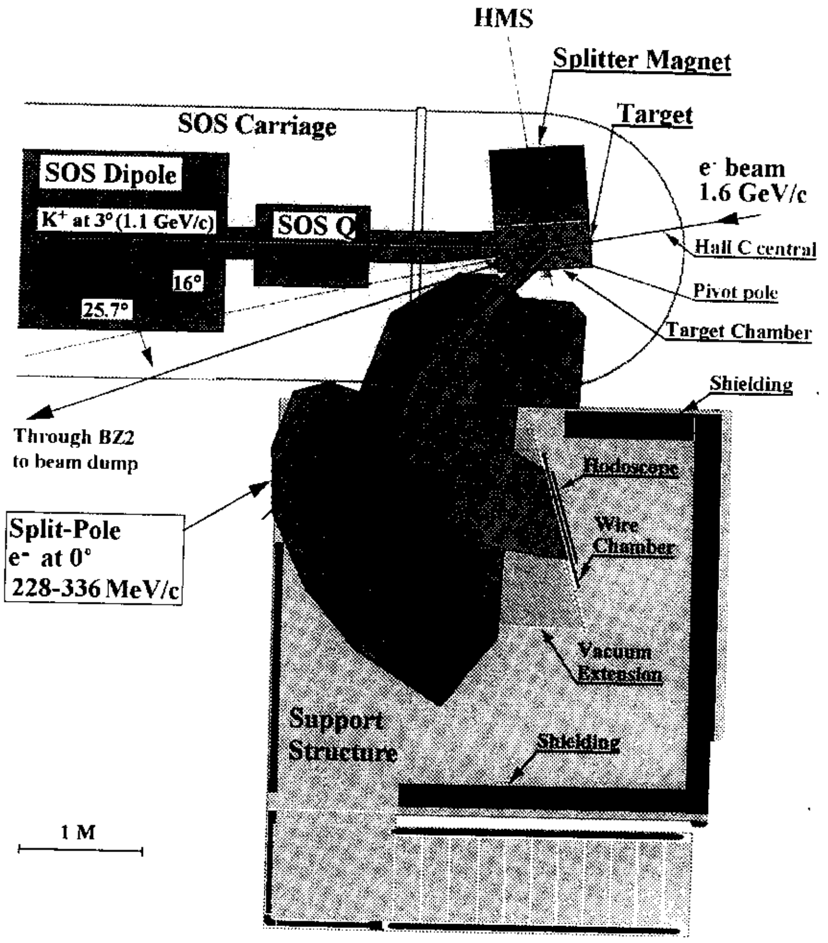
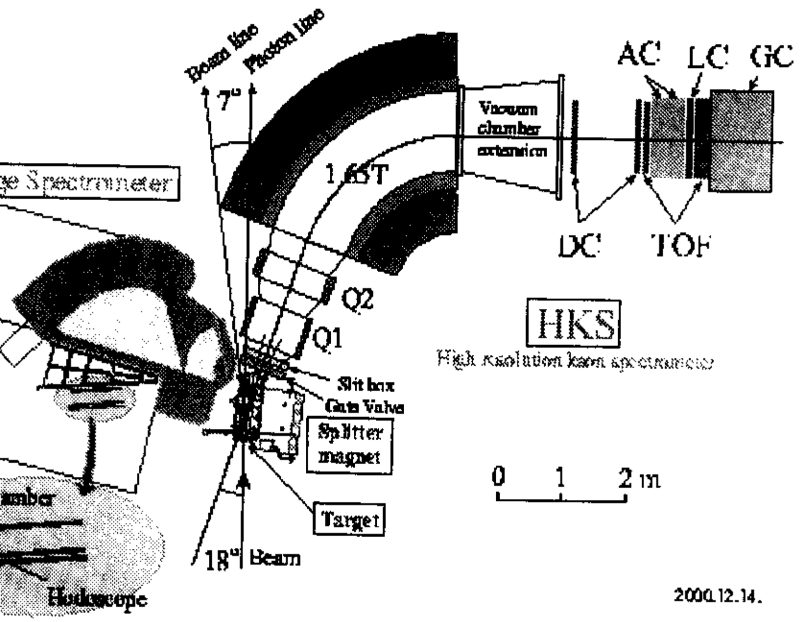


Figure 2: Top view of E89-009 appratus.



g.3 HKS high resolution kaon spectrometer
r hypernuclear studies.

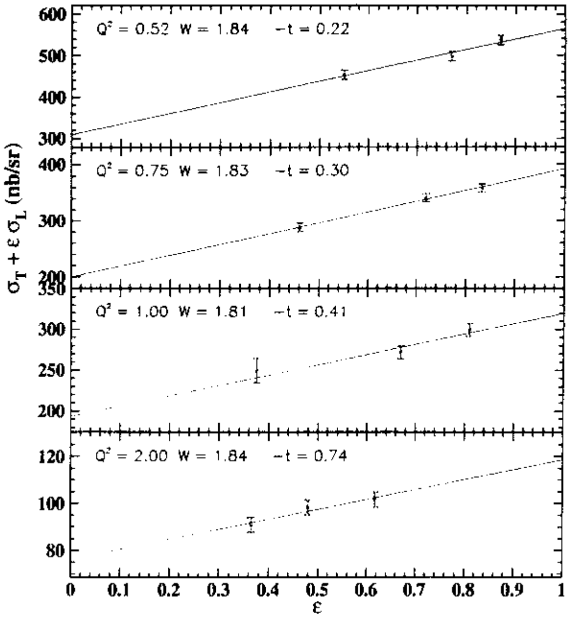
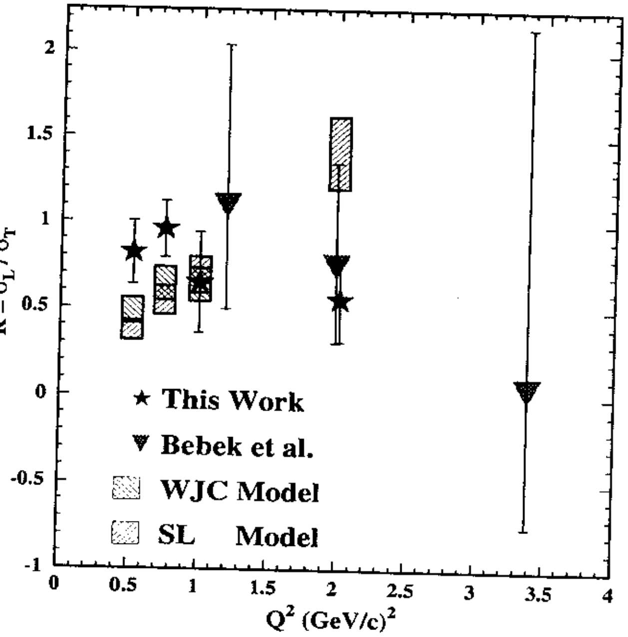


Fig. 4 $\sigma_T + \varepsilon\,\sigma_L$ versus epsilon for different values of Q^2.



$R = \sigma_L / \sigma_T$ versus Q^2 compared with previous imental data and two theoretical models.

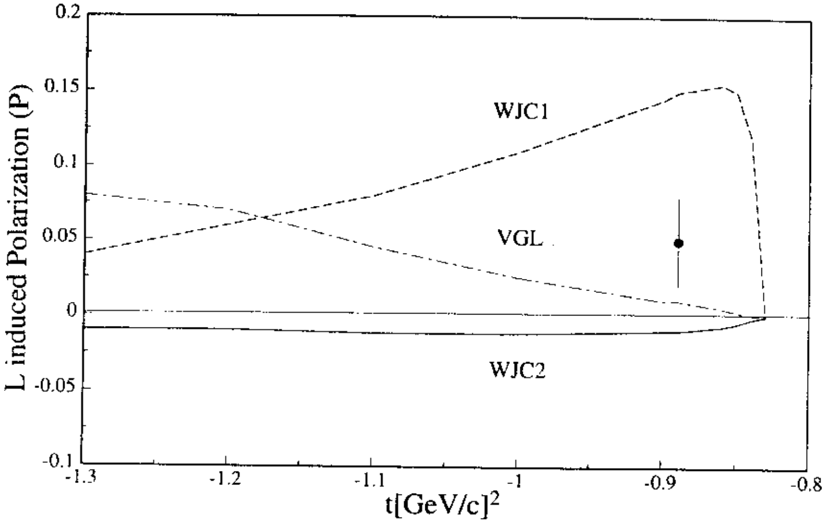


Fig. 6. The measured and predicted Λ-induced polarization as a function of γ-K four-momentum transfer, t

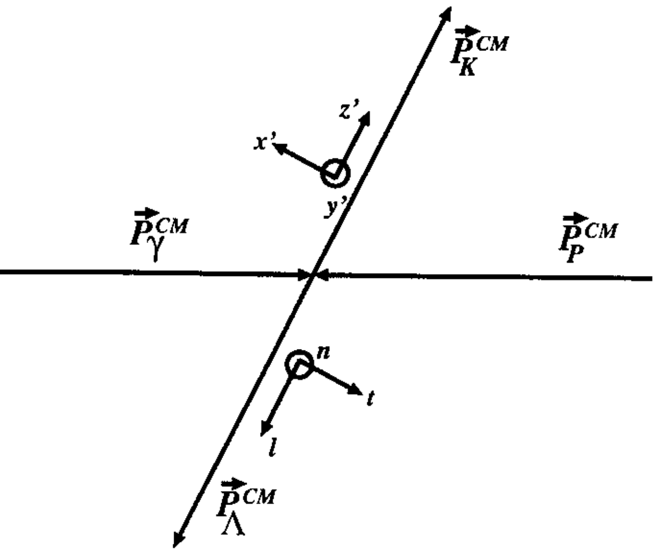


Fig. 7. The coordinate systems for the polarization vectors

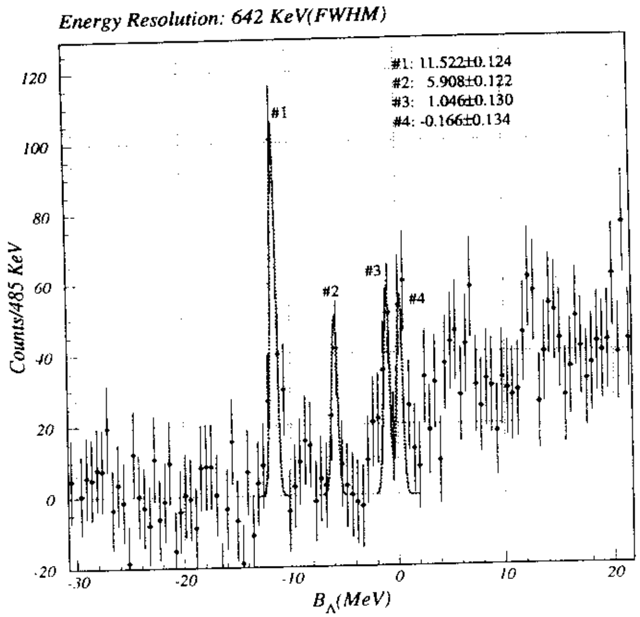


Fig.8 Binding energy spectrum of the Λ-B12. Preliminary results.