MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

CONCLUDING REMARKS

Ben Nefkens[1] *and Aleksandr Starostin*
Department of Physics and Astronomy
University of California, Los Angeles
Los Angeles, CA 90095-1547, USA

Abstract

Hadron Physics is undergoing a renaissance witnessed the extraordinarily large number of participants to this conference, MENU 2007. The physics thrust now is nonperturbative QCD, specifically tackling the problem of the occurrence of exotic hadronic matter and the existence, or not of the missing states, which are ordinary three–quark states predicted to exist by various quark models, but not observed experimentally. Conclusive searches are possible in the framework of the Flavor Symmetry of QCD.

A brief overview is given of new and upgraded accelerators. This is followed by a status report on the existence of various baryon and meson species; a comparison is made with the status at the time of the first MENU Conference in 1983.

Next we outline the Flavor Symmetry of QCD and its origin in the QCD Lagrangian. We illustrate its existence with different experimental tests. Encouraged by its success we use Flavor Symmetry for a successful comparison of charmed Λ_c hyperons with the ordinary, strange, Λ states. Finally we touch on the diverging modern views on the structure of the nucleon.

1 Introduction

The future of hadron physics looks bright seen in the light of new and upgraded facilities. IUPAP has just produced the much anticipated booklet on the properties of all accelerators in the world available for hadron physics. The major new workplace is going to be FAIR (Facility for Antiproton and Ion Research) at GSI in Darmstadt, Germany, featuring an intense 29 GeV proton beam. Especially attractive is the 15 GeV antiproton storage ring with a large 4π–acceptance detector PANDA. It is particularly suited for investigating the light mesons and the lightest baryons: the old, the new, the

[1]E–mail:nefkens@physics.ucla.edu

exotic and the "missing" ones. Unfortunately, at present there are no plans for a secondary meson beam.

The JLab (Newport News, USA) 12 GeV upgrade has just passed some major approval hurdles. An important aim is to find exotic hadrons. They will be searched for with a new detector that has near 4π acceptance and includes a magnetic field. There is plenty of room for baryon physics and other stuff.

Good progress is being made with the construction of J–PARC (Japan Proton Accelerator Research Complex) in Japan. This is a 50 GeV proton accelerator with a few modest, low energy, secondary beams of pions and kaons. It is geared toward hypernucler physics such as searching for double Λ hypernuclei. BESII in Beijing is a e^+e^- collider in the J/Ψ region. It has just undergone an important upgrade in intensity. It produces a large number of charmed baryons and mesons. MAMI in Mainz Germany is an electron accelerator with a high resolution, high intensity photon tagger upgraded to 1.5 GeV. It has a large program for polarized beams and polarized targets. The KLOE group at DAFNE is making a case for a substantial intensity upgrade of the machine and a possible upgrade of the maximum c. m. energy to 2.5 GeV. There are e^- laser backscattering photon beam facilities, SPring–8 in Japan and MAX–Lab in Lund, they are successfully used for nuclear and particle physics experiments. We will miss GRAAL as well as the charming contributions of CESAR and the beautiful work in spectroscopy done at BaBar and Belle.

We like to give a special merit citation to WASA at COSY. It an outstanding example of an international collaboration at the forefront of technology. Especially interesting is the novel pellet target. Our compliments to all who have made its possible.

Key physics to be investigated with the new facilities is QCD in the non–perturbative region. We need to find an appropriate description of the complicated structure of the nucleon. Also important are the searches for exotica and missing states.

For decades the experimentalists have directed much effort toward establishing the extend of isospin symmetry. Now that interest has changed to measuring the magnitude of the breaking of isospin symmetry in different systems. It is a way to experimentally investigating the validity of QCD in the nonperturbative regime.

For many years the determination of the $\pi N-$ resonance properties was dominated by three large πN partial wave analyses (PWA), those of Carnegie–Mellon–Lawrence–Berkeley, Karlsruhe–Helsinki and SAID (Blacksburg). These analyses are based mainly on $\pi^{\pm}p$ elastic scattering and pion charge exchange. Promising new efforts on a modern analysis of new scattering data are under-

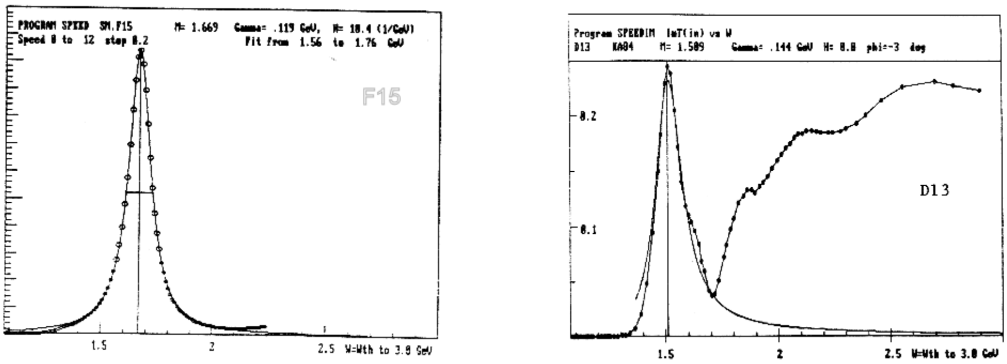

Figure 1: Examples of the speed plots for the F_{15} (left) and D_{13} (right) partial amplitudes from Ref. [2].

way at Mainz, JLab, and ANL. GWU is continuing with the SAID program. Restricted, but important results are coming from Giessen, Bonn–Gatchina and other places. Improvements include the inclusion of major inelastic channels and the use of coupled channel techniques. The latter are effectively promoted by the EBAC Group at JLab [1]. Unfortunately, π and K^- meson beams are no longer available in Europe and the U.S. Badly needed data on πN and KN interactions at intermediate energies are not in the cards in the near future. We are happy to note that extensive work in meson photoproduction is now being carried out at JLab, MAMI and ELSA. There are also important contributions from smaller facilities, which use back scattered laser photons. A complete photoproduction program should include linearly and circularly polarized photons as well as transversely and longitudinally polarized proton and deuteron targets.

2 The Status of Hadron Families

The energy dependence of the πN and KN partial wave amplitudes, $A(W)$, contains the full information on the dynamics of the light–quark resonances. W is the total energy in the c. m. frame. A useful quantity is the speed, SP, of the W–dependence of the scattering amplitudes:

$$SP(W) = |dA/dW| \quad (1)$$

as emphasized long ago by the pioneers of scattering theory [3]. A pronounced maximum in a speed plot corresponds to a maximum in the time

Table 1: Status of baryon spectroscopy. Comparison of the number of three– and four–star states available to the 1st and 11th MENU conferences.

state	number in 1983	number in 2007
N^*	18	14
Δ^*	13	10
Λ^*	15	14
Σ^*	12	9
Ξ^*	4	4
Ω^-	1	2
B_c	1	14
B_b	0	1
Dibaryon	3	0
Total	67	68

delay between the arrival and departure of the incident wave packet. It is a direct indication of the formation of an unstable particle in the intermediate state. It is a valuable alternative to the use of poles in the complex scattering plane. Since the speed plot is not well know to many we present two examples in Fig. 1. The speed plot of an elastic resonance has a smooth peak described by a Breit–Wigner. In most cases, but not always, the peak value agrees well with the pole position.

In the history of hadron physics there was a time around 1970 that it was generally assumed that the strong resonances were broad states like the ρ–meson or the Δ–baryon. There was little incentive to search for the existence of narrow hadrons. That picture changed dramatically with the discovery of the J/Ψ–meson in 1974. It is not expected that history will repeat itself. There is at present no good theoretical reason for expecting the existence of small and narrow nucleon resonances which could lead to a small and narrow peak in a pseudo speed plot for the photoproduction of π^0, η, η', *etc*. But a serious search for this has never been carried out. The necessary experimental tools – a high resolution tagged photon beam and a 4π photon detector – are now available. Making such a search should now be considered.

MENU2007 is the eleventh conference in this series. It started out in 1983. It could be revealing to compare the resonance population then and now. For input we use the Review of Particle Properties then [5] and now [4]. We should limit the comparison to three and four star states as they are considered to be genuine states and not some statistical fluctuation. Listed in Table 1 are the number of the three– and four–star baryon family members then and now. The total number of genuine baryon resonances has barely

Table 2: Spectroscopy of mesonic states. Number of various mesons in 1983 and 2007 Review of Particle Properties. "Bullet" states only are shown.

Flavor	number in 1983	number in 2007
$s = c = b = 0$	24	44
$s = \pm 1; c = b = 0$	7	12
$b, s, c = \pm 1$	0	14
$c\bar{c}$	10	13
$b\bar{b}$	4	12
$Total$	46	95

changed, only 2%. But we have lost some three–star N^* and Δ^* states. This loss is compensated by the discovery of 13 charmed baryons. These states are quite narrow and are therefore easy to find. However, the direct determination of spin and parity is very challenging and only done indirectly by flavor symmetry of QCD, see Sect. 3.

It should be pointed out that the spin and parity of all N^*, Δ^*, Λ^* and Σ^* follow directly from the fabric of a PWA. For these states the number of stars reflects the quality of various data sets and the fits to the data. This approach does not work for the Ξ and Ω states, which are otherwise readily discovered as a large, genuine peak in the appropriate missing mass or invariant mass distributions. The known Ξ resonances are quite narrow in contrast to the N^*, Δ^*, Λ^* and Σ^* states, which tend to be broad. Spin and parity of new Ξ states can be investigated in a Byers–Fensters analysis, or from selected decays, such as the determination of the spin of the Ω^- from the decay $\Xi_c^0 \to \Omega^- K^+$ by Veronique Ziegler using BaBar data [6].

The star system was not made for cascade hyperons. We recommend to use four stars only if spin and parity have been measured directly, or reliably indirectly. Three stars should be awarded for a peak in excess of 5σ and some kind of spin/parity assessment. Finding a five standard deviation peak only with no information on spin and parity gets only two stars. A 4σ peak is rewarded with only one star.

Table 2 shows the comparison of the meson population in 1983 [5] and now [4]. A comprehensive evaluation of the quality of different meson states is not available. The only selection we can make is to limit the Table to mesons, which have been marked with a bullet in the Review of Particle Properties. The criteria for a bullet are not clear. The table caption in the Review of Particle Properties reads: "A bullet indicates particles that appear in the preceding Meson Summary Table. We do not regard the other entries as being established." We count 95 accepted mesons in 2007 and half in 1983.

The increase is in all families.

One of the mysteries seen in all hadronic states is their relative simplicity: all baryon resonances can be satisfactory described as three quark bound states. There is no indication that we need a gluon degree of freedom. All but a few mesons can be characterized as a quark–antiquark pair, again there is no requirement for gluons in meson spectroscopy. Neither is there at present evidence for color and/or flavor correlations. More spectroscopy data is needed to settle this.

3 The Flavor Symmetry of QCD

The interactions of quarks and gluons with one another are adequately described by the theory of Quantum Chronodynamics, QCD. Its Lagrangian, L_{QCD} has only two components, the chiral part, L_0, and the mass part, L_m. In other words,

$$L_{\mathrm{QCD}} = L_0 + L_m \tag{2}$$

L_0 and L_m are very different. L_0 has chiral symmetry and it depends primarily on the quark fields, ψ_q, and gluon fields A_ν. There is only one coupling constant, g_s, for all interactions, this is the manifestation of the universality of the strong interactions. The detailed expressions for L_{QCD} are given in the Appendix.

The important property of L_0, aside from chiral symmetry, is that of Flavor Symmetry, FS. It means that L_0 is the same for all six quark flavors, d, u, s, c, b and t.

The second component of L_{QCD} is the mass term L_m, it depends only on the quark fields and the quark masses, m_q

$$L_m = -\sum_q \overline{\psi_i} m_q \psi_{qi}. \tag{3}$$

L_m is responsible for Flavor Symmetry Breaking, FSB. Flavor Symmetry, which applies to all quarks, is the generalization of isospin symmetry, which concerns only up and down quarks. In the theoretical limit of massless quarks we have $L_m = 0$ thus $L_{QCD} = L_0$ and L_{QCD} will have FS.

Isospin symmetry leads to many relations of masses, cross sections, polarizations and decay branching ratios. Flavor symmetry features even more such relations. Examples will be discussed in the next section.

Exotica, such as hybrids, meson–baryon bound states, pentaquarks, glueballs and so forth are defined as resonances that do not obey flavor symmetry. Furthermore, they can be searched for by measuring various of flavor–symmetry relations.

4 Applications of Flavor Symmetry

The minimum content of any baryon is three quarks. FS implies that there are 27 different three–flavor combinations grouped in four $SU(3)$ multiplets:

$$3 \otimes 3 \otimes 3 = 1_a + 8_m + 8_m + 10_s. \quad (4)$$

Every baryon belongs to a large family that consists of one singlet that is antisymmetric under flavor interchange, two octets with mixed symmetries and one fully symmetric decuplet.

FS implies that there must be a Λ^* octet state, Λ^*_8, with the same spin/parity for every N^* (since all N^* are octet members). The mass of the Λ^*_8 is heavier than the J^P–corresponding N^* by the mass difference between the d and s constituent quarks. For every Λ^*_8 there should be a singlet Λ^*_1. There is an important exception here: when the *color* part of the Λ statefunction is fully antisymmetric than Fermi statistics forbid the existence of a particle with an antisymmetric *flavor* statefunction. Thus FS predicts *absence* of a $\Lambda\frac{1}{2}^+$ singlet, ground state particle.

For the $d - s$ quark mass difference we will use the following

$$m(s) - m(d) = 1/3[m(\Omega) - m(\Delta)] = 147 \text{ MeV}. \quad (5)$$

Shown in Table 3 are the properties of 14 established N^* (three– and four–star) states. They have been arranged in order of increasing mass. The first column gives the name of each resonance as listed in RPP [4]. Followed are $SU(3)$ classification and the experimentally determined J^P. In the right side part we have listed the Λ^* states (three– and four–star only) by name and the measured $SU(3)$ classification and J^P. The next two columns show the prediction of the Λ^* mass as the sum of the mass of the matching N^* state and the quark mass correction, $M_{predicted}(\Lambda^*) = M_{measured}(N^*) + 147$ MeV, followed by the measured Λ^* mass. The good agreement between all predictions based on FS and experiment is stunning.

There are four unseen Λ^* states they could be named the FS based "missing" Λ^* resonances. There are no unmatched Λ^*'s, so no unseen N^*'s. This does not mean that there could not be missing N^*'s at higher mass.

FS relates all $SU(3)$ connected processes. For instance, FS predicts that at the appropriate beam momenta we must have

$$d\sigma(\pi^- p \to \eta n) = \Phi_1 d\sigma(K^- p \to \eta\Lambda), \quad (6)$$

where Φ_1 is a numerical factor that combines the Clebsch–Gordan factor and a correction factor for the different kinematics of the two processes. Relation 6 is very well fulfilled [7].

Table 3: Application of flavor symmetry to N^* and Λ^*

N^*			Λ^*				
name	SU(3)	J^P	name	SU(3)	J^P	mass, (MeV/c^2)	
						predicted	measured
n	8	$\frac{1}{2}^+$	$\Lambda(1116)$	8	$\frac{1}{2}^+$	1086	1115 ± 1
$N(1440)$	8	$\frac{1}{2}^+$	$\Lambda(1600)$	8	$\frac{1}{2}^+$	1587	1600 ± 40
$N(1520)$	8	$\frac{3}{2}^-$	$\Lambda(1690)$	8	$\frac{3}{2}^-$	1667	1690 ± 10
$N(1535)$	8	$\frac{1}{2}^-$	$\Lambda(1670)$	8	$\frac{1}{2}^-$	1682	1670 ± 10
$N(1650)$	8	$\frac{1}{2}^-$	$\Lambda(1800)$	8	$\frac{1}{2}^-$	1797	1800 ± 50
$N(1675)$	8	$\frac{5}{2}^-$	$\Lambda(1830)$	8	$\frac{5}{2}^-$	1822	1830 ± 10
$N(1680)$	8	$\frac{5}{2}^+$	$\Lambda(1820)$	8	$\frac{5}{2}^+$	1817	1820 ± 5
$N(1700)$	8	$\frac{3}{2}^-$	missing	8	$\frac{3}{2}^-$	1847	missing
$N(1710)$	8	$\frac{1}{2}^+$	$\Lambda(1810)$	8	$\frac{1}{2}^+$	1857	1810 ± 40
$N(1720)$	8	$\frac{3}{2}^+$	$\Lambda(1890)$	8	$\frac{3}{2}^+$	1867	1890 ± 20
$N(2190)$	8	$\frac{7}{2}^-$	missing	8	$\frac{7}{2}^-$	2337	missing
$N(2220)$	8	$\frac{9}{2}^+$	$\Lambda(2350)$	8	$\frac{9}{2}^+$	2367	2350 ± 15
$N(2250)$	8	$\frac{9}{2}^-$	missing	8	$\frac{9}{2}^-$	2397	missing
$N(2600)$	8	$\frac{11}{2}^-$	missing	8	$\frac{11}{2}^-$	2747	missing
			$\Lambda(1405)$	1	$\frac{1}{2}^-$	no predic.	1406 ± 4
			$\Lambda(1520)$	1	$\frac{3}{2}^-$	no predic.	1519.5 ± 1.0
			$\Lambda(2100)$	1	$\frac{7}{2}^-$	no predic.	2100 ± 10

Table 4: Application of flavor symmetry to Λ^* and Λ_c^*. Note that $\Lambda_c(2765)^+$ can be in fact $\Sigma_c(2765)$, $\Lambda_c(2880)^+$ also can be a Σ_c^* state [4].

Λ^*			Λ_c^*				
name	SU(3)	J^P	name	SU(3)	J^P	mass, (MeV/c^2)	
						predicted	measured
$\Lambda(1116)$	8	$\frac{1}{2}^+$	Λ_c^+	?	$\frac{1}{2}^+$	input	2284.46 ± 0.14
$\Lambda(1405)$	1	$\frac{1}{2}^-$	$\Lambda_c(2593)^+$	?	$\frac{1}{2}^-$	2575	2595.4 ± 0.6
$\Lambda(1520)$	1	$\frac{3}{2}^-$	$\Lambda_c(2625)^+$	?	$\frac{3}{2}^-$	2690	2628.1 ± 0.6
$\Lambda(1600)$	8	$\frac{1}{2}^+$	$\Lambda_c(2765)^+$	?	$\frac{1}{2}^+$	2770	2766.6 ± 2.4
$\Lambda(1690)$	8	$\frac{3}{2}^-$	$\Lambda_c(2880)^+$	?	$\frac{3}{2}^-$	2840	2882.5 ± 2.2
$\Lambda(1670)$	8	$\frac{1}{2}^-$	missing	?	$\frac{1}{2}^-$	2860	missing

One of the remarkable predictions of FS is the relation

$$d^5\sigma(\pi^- p \to \pi^0\pi^0 n) = \Phi_2 d^5\sigma(K^- p \to \pi^0\pi^0\Lambda) \neq \Phi_3 d^5\sigma(K^- p \to \pi^0\pi^0\Sigma). \quad (7)$$

This has been verified as well [8–10].

Among the static relations following from FS are the Gell–Mann and Gell–Mann–Okuba mass relations.

5 Flavor Symmetry and the Spin/Parity of Charmed Baryons

Buoyed by the success of FS shown in Table 3 we like to make a straight forward application of FS to charmed baryons. FS implies that for every Λ–hyperon there should exist a charmed Λ called Λ_c^+ with the same spin parity and $SU(3)$ classification, but more massive due to the large charm–strange quark mass difference. Taking $m_c - m_s$ to be the mass difference of the ground states, $\Lambda_c(2285)^+ - \Lambda(1116)^0 = 1169$ MeV, the predicted masses of the known Λ_c^+ states are listed in column seven of Table 4. The measured Λ_c^+ masses are given in the last column of Table 4. Included are $\Lambda_c(2266)^+$ and $\Lambda_c(2882)^+$ whose isospin have not yet been determined. The agreement is excellent. Apparently, the huge mass correction resulting from the 1169 MeV mass difference of the c and s quarks has little effect on the dynamics, which is driven by the L_0 component of L_{QCD}. Table 4 can be used to justify assigning the spin/parity of the Λ_c^* states to those of the corresponding Λ^* states. This practice is employed by the Review of Particle Properties [4]. Note in Table 4 that the $\Lambda_c(2595)^+$ and $\Lambda_c(2628)^+$ are $SU(3)$ singlet states.

This is easier to verify than the spin/parity of the Λ_c^* states. That task still needs to be done by a direct spin/parity determination.

Applying a similar treatment to other charmed hyperons, the Σ_c^*, Ξ_c^* and Ω_c^*, has several pitfalls such as the fact that the Ξ and Ω have more then one s quark, only one of which is changed to a c quark when making a Ξ_c or Ω_c. Thus the Ξ_c and Ω_c spectra do not have a one to one correspondence to those of the Ξ and Ω.

6 The Structure of the Nucleon

When Otto Stern measured the magnetic dipole moment of the proton to be +2.79 Bohr magnetons back in 1932 it implied that the proton is not a point–like particle that obeys the Dirac equation as many famous theorists were hoping. Instead the proton is a particle that has a physical size and structure. After 75 years the structure is still not know and probing it is high an the priority list of nuclear physics. There are two points of view:

(a) The high energy perspective in which a proton consists of partons, which are a mixture of three colored "valence" quarks and many colored gluons, which can turn into a quark–antiquark pair. The probes are high energy polarized muons, electrons, neutrinos and polarized protons. The ease in which energy can turn into $(q\bar{q})$'s has brought P.A.M. Dirac to question the meaning of an elementary particle in this case in the following quote: "The notion of an elementary particle has become more vague. One may at any time create a particle and an antiparticle, ..., and you can no longer say that they were present in the original matter. You can no longer describe in any simple way what are the ultimate constituents of matter" [11]. Note that lepton probes have no strong interactions, they are colorless. Lepton scattering is thus not sensitive to correlations of color.

(b) The spectroscopist's view: all baryons consists of three valence quarks that have "absorbed" the gluon degrees of freedom. Mesons are simple quark–antiquark pairs of color–anticolor.

7 Epilogue

As evidenced by the record–breaking large number of registered participants (351) MENU 2007 has been a roaring success. The singularly large participation is an obvious testimony to the great interest of the physics community in non–perturbative QCD and in particular in baryon spectroscopy. But the main reason for the success lies in the effective and creative organization by the Organizing Committee. It was expertly run under the guidance of the two co–chairmen Sigi Krewald and Hartmut Machner together with Conference Secretary Su Schadmand who dedicated great efforts to the well–being and happiness of all participants. Thanks on behalf of the participants for all the work of the entire Organizing Committee and the efforts of dedicated secretaries.

MENU 2007 will go in history and be remembered for its excellent physics, stimulating presentations, happy reunion with old friends and colleagues, in other words for being a very successful conference.

8 Appendix: Specifics of the QCD Lagrangian

$$L_{QCD} = L_0 + L_m \tag{8}$$

$$L_0 = -\frac{1}{4} F^{(a)}_{\mu\nu} \cdot F^{(a)\mu\nu} + i \sum_q \overline{\psi^i_q} \gamma^\mu (D_\mu)_{ij} \psi^j_q \tag{9}$$

$$L_m = -\sum_q \overline{\psi_i} m_q \psi_{qi} \tag{10}$$

$$F^{(a)}_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - g_s f_{abc} A^b_\mu A^c_\nu \tag{11}$$

$$(D_\mu)_{ij} = \delta_{ij} \partial_\mu + i g_s \sum_a \frac{\lambda^a_{i,j}}{2} A^a_\mu \tag{12}$$

f_{abc} are the SU(3) structure constants.
A_ν = gluon field
ψ = quark field
g_s = strong coupling constant

Note that L_0 depends only on the quark and gluon fields. It is the same for of all massless quarks. This is the famous flavor symmetry of QCD. This symmetry is broken by L_m which depends only on the quark field and the quark mass.

References

[1] A. Matsuyama, T. Sato and T.-S.H. Lee, Phys. Rept. 439 (2007) 193.

[2] G. Höhler and A. Schulte, πN Newsletter Rept. No. 7 (1992) 94.

[3] E.P. Wigner, Phys. Rev. **98** (1955) 145.

[4] W-M Yoa *et al.*, J. Phys. G **33** (2006) 1.

[5] M. Roos. *et al.*, Phys. Lett. 111B (1982) 1.

[6] V. Ziegler, presentation at this conference.

[7] A. Starostin *et al.* Phys. Rev. C **64** (2001) 55205.

[8] S. Prakhov *et al.* Phys. Rev. C **69** (2004) 045202.

[9] S. Prakhov *et al.* Phys. Rev. C **69** (2004) 042202.

[10] S. Prakhov *et al.* Phys. Rev. C **70** (2004) 034605.

[11] P.A.M. Dirac, Crane Lecture, University of Michigan, April 1978.