Изучение структуры протона на детекторах CLAS/CLAS12

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НИИЯФ МГУ, 25 сентября 2018
Ground nucleon structure from inclusive electron scattering exploring

Three valence current quarks (Q) embedded in a sea of gauge gluons (g) and quark+antiquark pairs

Distribution of the partons of all relevant flavors in the ground state

A. Accardi et al., PRD 93, 114017 (2016)
Kinematic of inclusive electron scattering

\[ q = p'_e - p_e \]  \hspace{1cm} (1)

\[ W = \sqrt{(q + p_p)^2} \]  \hspace{1cm} (2)

\[ Q^2 = -q^2 = 4E_eE'_e \sin^2 \frac{\theta_e}{2} \]  \hspace{1cm} (3)

\[ \nu = \frac{qp_p}{M_N} = \frac{W^2 + Q^2 - M_N^2}{2M_N} = (E_e - E'_e) \text{ in lab frame} \]  \hspace{1cm} (4)

\[ x = \frac{Q^2}{2M_N \nu} \]  \hspace{1cm} (5)
From inclusive electron scattering to parton distribution

\[
\frac{d\sigma}{dE'd\Omega} = \Gamma(\sigma_T + \varepsilon\sigma_L)
\]  

(6)

\[
\Gamma = \frac{\alpha K}{2\pi^2|q^2|} \frac{E_e'}{E_e} \frac{1}{1 - \varepsilon}, \quad K = \frac{W^2 - M^2}{2M}
\]  

(7)

\[
\varepsilon = \left(1 - 2\frac{\nu^2 - q^2}{q^2}\tan^2 \theta_e \frac{\theta_e}{2}\right)^{-1}
\]  

(8)

\[
\sigma_T = \frac{4\pi^2\alpha}{K} W_1(\nu, q^2)
\]  

(9)

\[
\sigma_L = \frac{4\pi^2\alpha}{K} \left[\left(1 - \frac{\nu}{q^2}\right) W_2(\nu, q^2) - W_1(\nu, q^2)\right]
\]  

(10)

\[
\nu W_2(\nu, Q^2) \rightarrow F_2(x) = \sum_i e_i^2 x f_i(x)
\]  

(11)

\[
MW_1(\nu, Q^2) \rightarrow F_1(x) = \frac{1}{2x} F_2(x)
\]  

(12)
CLAS results on inclusive structure function $F_2$

Interpolated results from the CLAS Physics DB, V.Chesnokov

Advances in Exploration of the N*-Spectrum

N*/Δ* Spectrum 2018

Nucleon resonances listed in Particle Data Group (PDG) tables

<table>
<thead>
<tr>
<th>State</th>
<th>N(mass)J^p</th>
<th>PDG pre 2012</th>
<th>PDG 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N(1710)1/2^+</td>
<td>***</td>
<td>****</td>
</tr>
<tr>
<td></td>
<td>N(1880)1/2^+</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N(1895)1/2^-</td>
<td>****</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N(1900)3/2^+</td>
<td>**</td>
<td>****</td>
</tr>
<tr>
<td></td>
<td>N(1875)3/2^-</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N(2100)1/2^+</td>
<td>*</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>N(2120)3/2^-</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N(2000)5/2^+</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>N(2060)5/2^-</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Δ(1600)3/2^+</td>
<td>***</td>
<td>****</td>
</tr>
<tr>
<td></td>
<td>Δ(1900)1/2^-</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Δ(2200)7/2^-</td>
<td>*</td>
<td>***</td>
</tr>
</tbody>
</table>

The results of joint activity between Hall B (Jlab) and OEPVAYa (MSU), V.D.Burkert, B.S. Ishkhanov, V.I.Mokeev

А.А.Голубенко. Изучение структуры протона на детекторе CLAS12, 25 сентября 2018
### Summary of Results on $\gamma pN^*$ Photo-/Electrocouplings from CLAS

<table>
<thead>
<tr>
<th>Exclusive meson electroproduction channels</th>
<th>Excited proton states</th>
<th>$Q^2$-ranges for extracted $\gamma pN^*$ electrocouplings, GeV$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 p$, $\pi^+ n$</td>
<td>$\Delta(1232)3/2^+$, $N(1440)1/2^+$, $N(1520)3/2^+$, $N(1535)1/2^+$</td>
<td>0.16-6.0, 0.30-4.16</td>
</tr>
<tr>
<td>$\pi^+ n$</td>
<td>$N(1675)5/2^+$, $N(1680)5/2^+$, $N(1710)1/2^+$</td>
<td>1.6-4.5</td>
</tr>
<tr>
<td>$\eta p$</td>
<td>$N(1535)1/2^+$</td>
<td>0.2-2.9</td>
</tr>
<tr>
<td>$\pi^+ \pi^- p$</td>
<td>$N(1440)1/2^+$, $N(1520)3/2^+$, $\Delta(1620)1/2^+$, $N(1650)1/2^+$, $N(1680)5/2^+$, $\Delta(1700)3/2^+$, $N(1720)3/2^+$, $N'(1720)3/2^+$, $\Delta(1905)5/2^+$, $\Delta(1950)7/2^+$</td>
<td>0.25-1.50, 0.5-1.5 photoproduction</td>
</tr>
</tbody>
</table>

The website with numerical results and references: userweb.jlab.org/~mokeev/resonance_electrocouplings/

The interpolated/extrapolated CLAS results on $\gamma pN^*$ electrocouplings in the mass range <1.8 GeV and $Q^2$<5.0 GeV$^2$: userweb.jlab.org/~isupov/couplings/
Summary of Results on $\gamma pN^*$ Photo-/Electrocouplings from CLAS

V. D. Burkert, Baryons 2002

V. D. Burkert, Baryons 2016
**$\gamma pN^*$ Electrocouplings from N$\pi$, N$\eta$, and $\pi^+\pi^-p$ Electroproduction**

Consistent values of resonance electrocouplings from N$\pi$, N$\eta$, and $\pi^+\pi^-p$ electroproduction strongly support their reliable extraction.

The structure of all resonances studied with CLAS represents a complex interplay between the inner quark core and external meson-baryon cloud.

CLAS data points from:

LF RQM:

AO CC:
First measurements with CLAS12

Accessible kinematic coverage with CLAS12. Inclusive electron scattering events from the RGA run.
Evaluation of the structure functions and inclusive cross sections

- CLAS data were used for the interpolation of inclusive cross-sections in the kinematic range covered by CLAS
- For the extrapolation of the data we used P. Bosted fit (M.E. Christy and P.E. Bosted, arXiv:0711.0159)
- Combination of these interpolation/extrapolation were fitted by this dependence in spirit of operator product expansion

\[
F_1(W, Q^2) = C_{0,1}(W) + \frac{C_{1,1}(W)}{Q^2} + \frac{C_{2,1}(W)}{Q^4} + \ldots
\]
\[
F_2(W, Q^2) = C_{0,2}(W) + \frac{C_{1,2}(W)}{Q^2} + \frac{C_{2,2}(W)}{Q^4} + \ldots
\]  

(13)
Inclusive virtual photon cross sections from the CLAS/world data

\[ Q^2 = 2 \text{ GeV}^2 \]

\[ Q^2 = 3 \text{ GeV}^2 \]

\[ Q^2 = 4 \text{ GeV}^2 \]

\[ Q^2 = 5 \text{ GeV}^2 \]
Inclusive electron scattering cross sections

\[
\frac{\mathrm{d}^2\sigma_{\text{ep} \rightarrow X}}{\mathrm{d}W\mathrm{d}Q^2} = \Gamma_\nu\sigma_{\text{incl}}
\]

\begin{align*}
Q^2 &= 2 \text{ GeV}^2 \\
Q^2 &= 3 \text{ GeV}^2 \\
Q^2 &= 4 \text{ GeV}^2 \\
Q^2 &= 5 \text{ GeV}^2
\end{align*}
Resonant contributions to inclusive electron scattering cross sections

\[
\sigma_{T,L}^{R}(W, Q^2) = \frac{\pi}{q_{\gamma}^2} \sum_{N^*, \Delta^*} (2J_r + 1) \frac{M_r^2 \Gamma_{tot}(W) \Gamma_{\gamma,T,L}^r(M_r)}{(M_r^2 - W^2)^2 + M_r^2 \Gamma_{tot}(W)} \frac{q_{\gamma}}{K} \tag{15}
\]

where \( q_{\gamma,r} = q_{\gamma} \big|_{W=M_r} \)

\[
\Gamma_{\gamma}^T(M_r, Q^2) = \frac{q_{\gamma,r}^2(Q^2)}{\pi} \frac{2M_N}{(2J_r + 1)M_r} \left( |A_{1/2}(Q^2)|^2 + |A_{3/2}(Q^2)|^2 \right) \tag{14}
\]

\[
\Gamma_{\gamma}^L(M_r, Q^2) = 2 \frac{q_{\gamma,r}^2(Q^2)}{\pi} \frac{2M_N}{(2J_r + 1)M_r} |S_{1/2}(Q^2)|^2
\]

http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi
Resonant contributions to inclusive electron scattering cross sections

\[
Q^2 = 2 \text{ GeV}^2
\]

\[
Q^2 = 3 \text{ GeV}^2
\]

\[
Q^2 = 4 \text{ GeV}^2
\]

\[
Q^2 = 5 \text{ GeV}^2
\]
Resonant contributions to inclusive electron scattering cross sections

\[ N(1535)1/2^+ A_{1/2} \]

\[ N(1520)3/2^+ A_{3/2} \]

\[ N(1675)5/2^+ A_{3/2} \]

\[ \Delta(1232)3/2^{+} \]
Extrapolated inclusive electron scattering cross sections

- Electron beam energy: 10.6 GeV
- Integrated luminosity: 12.8*10^{10} mb^{-1}
- Bin sizes: W = 0.01 GeV and Q^2 = 0.1 GeV^2
- Expected statistical accuracy is in the range from 0.2% to 2.0%

First precise measurements of inclusive cross section evolution with W and Q^2 in the resonance region (smallest bin sizes over W, Q^2 ever achieved) at Q^2 > 5 GeV^2, yield valuable insight into quark hadron duality
Спасибо за внимание!