An interesting observations using exclusive meson electroproduction ratios from CLAS experiment

Phys(za)ics Seminar
Dec, 18, 2013

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Motivation
Phenomenology
Methods
Experiment
Analysis
Results
“Quark confinement”

Quark cannot be observed individually (charge current within nucleon which couple to virtual photon)
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"An infinitely strong the force field" that bind quarks inside of nucleon
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"A string-like flux-tube" that "breaks" with the q̅q̅
The tail of two models

1. Quark-pair creation: “kernel” of exclusive production
2. What field couples to the q-q current?

\[ \text{ss produced} \]

\[ \text{From flux-tube} \]

\[ \begin{align*}
\text{ud} & \quad \Lambda \\
\bar{s} & \quad \bar{s} \\
\text{From photon} & \\
\text{K}^+ & \\
\text{\textbf{Color flux-tube model}} & \\
\text{\textbf{\textsuperscript{3}P}_0 \text{ state}} & \\
\end{align*} \]
L. Micu (1969)  

Introduction

R. Carlitz/M. Kislinger (1970)  
- q\bar{q} vacuum pair creation

Concept

A. Le Yaouanc (1972)  
- Approximation as tunneling from harmonic OSC potential

Dynamics

A. Casher/H. Neuberger/S. Nussinov (1979)  
- Description of color flow between quarks

A guide note

- A successful phenomenology developing  
- Now they are well known authors of the high energy program PYTHIA

LUND model
**Color flux-tube**

- stretched between the outgoing quark and the remainder quarks from the hadronic target, breaks first at a space point located approximately \( \sim 1 \, \text{fm} \) behind the leading quark with the production of a \( qq \) followed by a second break \( \sim 1 \, \text{fm} \) or so behind the new leading quark and so on...

**Probability**
- Calculated by assuming the quarks are bound in a square-well potential with depth proportional to the Constituent Quark (CQ) mass

- The CQ mass is an effective degree-of-freedom

\[
(M)^2 = e^{-\pi (m^2 + pt^2)/\kappa}
\]
A quark pair creation

"The essence of many theories to describe a hadronic decays!"
Assumption: $^3P_0$ state

Reasons:

- It is natural way because it is the simple wave function: + parity / no net $\mathcal{L}_p^{\ell}$, the $\mathcal{Q}_n$ of the vacuum
- Matrix element is simple
  no exchange of $\mathcal{L}_p^{\ell}$, and $\mathcal{Q}_n$
- Pair creation takes place in the middle of a color field
A limited experimental info of angular momentum state:

- A decay of $\eta$-meson proceed via two amplitudes (by $d$-wave and $s$-wave analyzed)
  
  Result: the $s$-wave dominated the $d$-wave by a factor of 4
  
  $\rightarrow$ consistent with a $^3P_0$ wave function (not a $^3S_1$)
  
  $\rightarrow$ $^3S_1$ wave function: a single vector gluon field produced the $q\bar{q}$

- CLAS "exclusive $K^+\Lambda$ electroproduction" the first measurement of large transferred polarization from a polarized electron beam by assuming that $q\bar{q}$ was produced in a spin state $s=0$.

  D. S. Carman et al.,
  PRL90 131804 (2003)

  P. Geiger, E. Swanson,
  PRD50 6855 (1994)
An idea to approach the puzzle ...
Distinguish Models

- Measure ratios: $K^+\Lambda : \pi^+n : \pi^0p$

**Ratio**: exponential in quark mass

0.2 : 1 : 1
Distinguish Models

- Measure ratios: $K^+\Lambda : \pi^+n : \pi^0p$

Ratio: proportional to charge square
How to obtain ...

Experiment and analysis
- Apr. 04 ~ Jul. 26, 2003
- $E_0 = 5.499\text{GeV}$ (pol. e), LH2 target
- Length = 5cm, $\Phi = 6\text{mm}$
- $I_b = 2250\text{A}$
- Trigger = $E_{\text{in}} \times E_{\text{tot}} \times CC$
- Luminosity $\sim 20\text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Quantity</th>
<th>No. Bins</th>
<th>Bin Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W$</td>
<td>6</td>
<td>1.65, 1.75, 1.85, 1.95, 2.05, 2.25, 2.55</td>
</tr>
<tr>
<td>$\cos \theta^*$</td>
<td>5</td>
<td>-1.0, -0.6, -0.2, 0.2, 0.6, 1.0</td>
</tr>
<tr>
<td>$\phi^*$</td>
<td>12</td>
<td>-180., -150., ..., 150., 180.</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>2</td>
<td>1.6, 2.6, 4.6</td>
</tr>
</tbody>
</table>
**Single meson electroproduction**

*Unpol. cross-section w/ one-photon exchange approx.*

\[
\frac{d^2 \sigma}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*} \left[ \sigma_0 + h \sqrt{2 \varepsilon_L (1 - \varepsilon)} \sigma_{LT'} \sin \theta_\pi^* \sin \phi_\pi^* \right]
\]

\[
\sigma_0 = \sigma_T + \varepsilon \sigma_L + \delta \sigma_{TT'} \sin^2 \theta_\pi^* \cos 2\phi_\pi^* + \sqrt{2 \varepsilon_L (1 + \varepsilon)} \sigma_{LT'} \sin \theta_\pi^* \cos \phi_\pi^* 
\]

Incident electron energy \( e \)

Scattered electron energy \( e' \)

Electron energy loss \( \nu = e - e' \)

Invariant momentum transfer \( Q^2 = 2e e' (1 - \cos \theta_e) \)

Invariant mass of final state \( W = -Q^2 + m_p^2 + 2m_p \nu \)

Virtual photon 3-momentum \( |q| = (Q^2 + \nu^2)^{1/2} \)
• **Applying tools**
  - Phase space correction
  - Background subtraction
  - Acceptance correction using same PYTHIA/JETSET (fitting and MC generator)
  - Same kinematic bin size & range
  - Misc. corrections/cuts
    - Momentum correction
    - Electron energy (Hall-A)
    - Vertex correction and cut
    - Fiducial volume cut, missing mass cut (3\(\sigma\))
All consistent hypotheses for PID, a single positive track might pass the K+, \(\pi^+\), proton in \(\beta\)-momentum cuts if at high momentum. However, statistically, only the **correct hypothesis** will produce a **peak signal**. The alternate hypothesis simply forms a **smooth background** under the MMx. **No double-counting**
Correction done by Bethe-Heitler events method

Ratio = $\Delta p_e / p_e = [(p_{e,\text{calc.}} - p_{e,\text{meas.}}) / p_e \sim 0.$

- Both “elastic-event” and “Bethe-Heitler event” methods give same quality of correction. – FIU vs. INFN
... too much detail ...

pizzafiducial cut ...
moredchees...zZ...e
Analysis;
Overview of the missing mass spectrums

\[ \text{ep} \rightarrow e'K^+ X \]

- Fit $\Lambda = 1.114\text{GeV} \pm 19\text{MeV}$
- Fit $\Sigma = 1.186\text{GeV} \pm 35\text{MeV}$

\[ \text{ep} \rightarrow e'\pi^+ X \]

- Fit $n = 0.940\text{GeV} \pm 26\text{MeV}$

\[ \text{ep} \rightarrow e'p X \]

- Fit $\omega = 776.1\text{MeV} \pm 53\text{MeV}$
- Fit $\eta = 546.9\text{MeV} \pm 50\text{MeV}$
- Fit $\pi^0 = 155.9\text{MeV} \pm 68\text{MeV}$
Analysis; $K^+\Lambda$

Example of fit = signal + background
Analysis; $n\pi^+$
Example of fit = signal + background

- $N$, $\chi^2=45.2$
  - $x=0.949$
  - $\sigma=0.021$
- $BG$, $\chi^2=2.2$
  - $x=-4.539$
  - $\sigma=10.287$

- $N$, $\chi^2=53.1$
  - $x=0.951$
  - $\sigma=0.022$
- $BG$, $\chi^2=4.3$
  - $x=-4.298$
  - $\sigma=9.514$

- $N$, $\chi^2=55.5$
  - $x=0.949$
  - $\sigma=9.195$
- $BG$, $\chi^2=3.8$
  - $x=-2.756$
  - $\sigma=0.022$

- $N$, $\chi^2=45.4$
  - $x=0.947$
  - $\sigma=0.022$
- $BG$, $\chi^2=2.2$
  - $x=-3.022$
  - $\sigma=8.724$

-$\phi^*=105$
-$\phi^*=135$
-$\phi^*=195$
-$\phi^*=225$
Analysis; pπ⁰
Example of fit = signal + background

\[ \pi^0, \chi^2=1.5 \, \text{BG}, \, \chi^2=4.8 \]
\[ x=0.175 \, \quad x=0.439 \]
\[ \sigma=0.063 \, \quad \sigma=0.1 \]
Analysis: MC (FSGEN)

**Event Generator:** $n\pi^+, p\pi^0, \Delta K^+$:

- All three reactions are same simulation package
- FSGEN for electro-production
  - modification of FSGEN input parameters
- Approx. $5 \times 10^6$ event in each reaction

**Kinematic range:**

- electron beam energy = 5.499 GeV.
- $W = 0.9 - 3.2$ GeV
- $Q^2 = 1.0 - 4.0$ GeV$^2$
- target = 2212 (proton)
- target position (Z[cm])
  
  $$ (z_{min}, z_{max}, radius) = (-27.5, -22.5, 0.2) $$

**Distribution parameters:**

- $Q^2$ power ($nq^2$) = 2.0
  
  $$ F(Q^2) = 1/x**nq^2 : \text{experimental fitting} $$
- t slope = 0.3
  
  $$ F(t) = \exp(-x*abs(t_{slop})) : \text{experimental fitting} $$
Analysis; Phase-space correction

$$\Delta \rho_2 = \frac{k}{W}$$

Results (samples) \( K^+ \Lambda \) & \( n\pi^+ \) & \( p\pi^0 \)

Acceptance/PS/Background-subtracted yields – \( \phi^* \) distribution and fit

\[
A + B \cos \phi + C \cos^2 \phi
\]
Phenomenological conclusion from the observation

1. $\gamma^*$ couple to quark in proton
2. Significant $\phi^*$-dependence
3. Constant term [$\sim \sigma_U (K^+\Lambda:n\pi^+:p\pi^0)$] ratio from $\phi^*$- fit
4. $K/\pi$ ratio falls off slowly as $\cos\theta^*$
5. $K^+/\pi^+ \sim 0.17 \pm 0.01 \pm 0.02$, $\pi^0/\pi^+ \sim 0.49 \pm 0.02 \pm 0.09$
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Probability given by the strangeness suppression factor

$$\lambda = \frac{2<\text{nss}>}{<\text{nuu}> + <\text{ndd}>} \sim 0.27$$
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Thank you for your attention

Questions/comments ?