High-resolution Search for $\Theta^+$ Pentaquark in $\pi^-p\rightarrow K^-X$ Reaction

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Collaboration

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Proposed Exp. – Abstract –

• natural expansion of E522 ($\pi p \rightarrow KX@K2$)
• $\sim 5$ times better resolution: $\sim 2.5$ MeV FWHM with SKS
  – 10 times better S/N
• 100 times larger yield: $1.2 \times 10^4 \Theta^+$ with 20 shifts

• expected sensitivity (lab) $75$ nb/sr $\Gamma < 2$ MeV $\rightarrow \sigma_{tot} \sim 112$ nb
  $150$ nb/sr $\Gamma = 10$ MeV
• momentum dependence of cross section: $p_\pi = (1.87, 1.92, 1.97 \text{GeV/c})$

- Goal -
  confirm $\Theta^+$ existence with high statistics
The $\Theta^+$ baryon

**Theoretical prediction**
- Diakonov et al. ('97)
  - Chiral soliton model
  - Anti-decuplet
  - $M=1530$ MeV, $\Gamma<15$ MeV
- Irreducible 5 quark(uudds) state

**Experiment**
- LEPS at Spring-8 ('03)
  - $\gamma n \rightarrow K^{-}\Theta^+ \rightarrow K^-K^+n$
  - $M=1540\pm10$ MeV
  - $\Gamma<25$ MeV
Controversial status

- Experiments with positive evidence
  - Better statistics is needed (significance $\sim 5\sigma$)
- Experiments with negative results
  - High statistics

Positive results
- BABAR
- SPHINX
- HyperCP
- CLAS-D
- CDF
- BES
- HERA-B
- BELLE

Negative results
- High statistics experiment with hadronic reaction at low energy region
- JLab-p
- HERMES
- p+C
- SVD/IHEP
- CDF
- ZEUS
- ITEP
- SPHINX
- COSY-TOF

JLab-d $pp \rightarrow \Sigma^+\Theta^-$. 

High statistics experiment - hadronic reaction at low energy
Θ⁺ search via hadronic reaction

• multiquark system: to test the QCD in non perturbative regime.
  – how tightly are they bound?
  – qqqqq → qqq + qq: wide width?
• the narrow width (< 1 MeV) is remarkable characteristic.
  – What is the reason of this suppression?
  – ex. diquark model by Jaffe & Wilczek
    • -- exchange of quark combination
    • -- excitation of orbital angular momentum
  – effective forces between quarks

• To show the narrow pentaquark really exist (or not).
• We search for Θ⁺ via hadronic reaction \( \pi^- p \rightarrow K^- \Theta^+ \)
  – high statistics
  – less ambiguity
s-channel via N*

- CLAS observed $\Theta^+$ in $\gamma p \rightarrow \pi^+ K^- K^+ n$ reaction.
- if s-channel is dominant, $\Theta^+$ production is reduced at higher energies.

→ this process possibly exists in $\pi p \rightarrow n \rightarrow K^- \Theta^+$ reaction!

$\gamma p \rightarrow \pi^+ K^- K^+ (n)$

7.8$\sigma$
E522 experiment @ KEK-PS K2

- $\Theta^+$ search via $\pi^- p \rightarrow K^- X$ reaction
- beam momentum: 1.87, 1.92 GeV/c
- target: Polyethylene
- intensity: $3.3 \times 10^5 \pi^- /\text{spill}$
- net beam time: 32 hours for each momentum $\rightarrow \sim 7 \times 10^9 \pi^-$

A bump was observed at $M = 1530.8\,\text{MeV/c}^2$
- at $p_\pi = 1.92\,\text{GeV/c}$
- $\text{S/N} = 2.5\sigma$
- upper limit: $\sigma_{\text{tot}} = 3.9\mu\text{b}$

$p_\pi = 1.92\,\text{GeV/c}$

$\frac{d\sigma}{d\Omega} = 1.9\,\mu\text{b/sr}$
$\rightarrow \sigma_{\text{tot}} = 2.9\,\mu\text{b}$
Experimental Method

K1.8 beam line + SKS

2GeV/c $\pi^- + p \rightarrow K^- + \Theta^+$

target : liquid H$_2$, reuse E559’s

K$^-$: scattered angle $\leq 40^\circ$
momentum up to 0.9 GeV/c

SKS: momentum coverage: 0.7-0.95GeV/c
angle coverage $\leq 20^\circ$

$p_{\text{scattered}}$ up to $\sim 1.1$ GeV/c
dp/p $\sim 0.2\%$ @ 1GeV/c
($\sim 10$ times better than KURAMA)
ideal for $\Theta^+$ detection
acceptable beam intensity is limited to rate capability of the beam line chamber

- tracking chambers @PS K6 : 5mm pitch
  - stands up to
    \[4 \times 10^6 \times 1.1 \text{(protons)} / 1.8 \text{sec} = 5 \times 10^6 \pi^- / \text{sec}\]
- new tracking chambers; 1mm pitch MWPC
  - \[5 \times 10^6 / \text{sec} \times 5 / 1 \text{ mm} = 1.3 \times 10^7 / \text{sec}\]
  \[\rightarrow 1.0 \times 10^7 / \text{spill w/ 0.7 sec flat top}\]
  \[\rightarrow 1.5 \times 10^7 / \text{spill w/ 1.4 sec flat top}\]

required number of protons : \[4 \times 10^{12} \text{ pps}\]
\[\sim 1/50 \text{ of DAY-I intensity}\]
Missing Mass Resolution

\[ \Delta M = 1.8 \text{ MeV (FWHM sim.)} \]

\[ \sigma = 0.26^\circ \]

\[ \frac{d \rho}{\rho} / \rho = 0.096 \times \% + 0.092\% \]

\[ \frac{d \rho_{\text{beam}}}{\rho_{\text{beam}}} = 1.4 \times 10^{-4} @ 1 \text{ GeV/c} \]

\[ \Rightarrow \Delta M = 2.5 \text{ MeV (FWHM calc.)} \]
Missing mass simulation

1.9µb/sr

main contributions come from;

\[ \phi : \phi n \rightarrow K^+K^-n \rightarrow 30.0\pm8.0 \mu b \]

\[ \Lambda : \Lambda(1520)K^0 \rightarrow K^-K^0\pi \rightarrow 20.8\pm5.0 \mu b \]

phase space : K^-KN \rightarrow 26 \mu b

significance : 62\sigma

assuming \Gamma < 2MeV

\sigma = 1.9\mu b
Expected Yield & Sensitivity

• yield
  – beam pions: 160 hours beam time $\rightarrow 4.8 \times 10^{11} \pi$ for each $p_\pi$
  – SKS acceptance: 0.1 sr
  – analysis efficiency: 50%
  – K decay: 50% $\leftarrow$ TOF 4.7m
  – $1.9 \mu$b/sr @ $p_\pi=1.92$GeV/c $\leftarrow$ E522
    $\rightarrow 1.2 \times 10^4$ events

• background
  – $0.8 \mu$b/sr/MeV @ 1.530MeV for proton target $\leftarrow$ E522
  – momentum flat
    $\rightarrow 5.0 \times 10^3$ counts/MeV

<table>
<thead>
<tr>
<th>statistics</th>
<th>sensitivity</th>
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<tbody>
<tr>
<td>$62\sigma \quad \Gamma &lt; 2$ MeV</td>
<td>$75$nb/sr $\quad \Gamma &lt; 2$ MeV</td>
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<tr>
<td>$48\sigma \quad \Gamma = 10$ MeV</td>
<td>$150$nb/sr $\quad \Gamma = 10$ MeV</td>
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Summary

- J-PARC K1.8 beam line + SKS is ideal for $\Theta^+$ production
  - at low energy
  - in hadronic reaction $\rightarrow$ high statistics
  - with high mass resolution

- If exist;
  - confirm $\Theta^+$ existence with high-statistics.
  - production mechanism: $\pi^- p \rightarrow K^- \Theta^+$