Recent results and progress from LEPS and LEPS2 at SPring-8

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on behalf of
the LEPS&LEPS2 collaboration
Outline

• Introduction to the LEPS/LEPS2 experiments
• Recent results from LEPS
  – Search for $K^-pp$ bound state
  – $\Xi^+(1530)$: new data and analysis
• Current status of LEPS2
• Summary
Laser-Electron Photon @ SPring-8

- SPring-8: 8-GeV Synchrotron Radiation facility
  - Electron storage ring dedicated to SR light source.
- 2 beamlines (LEPS & LEPS2) are operated at the same time.

Compton Scattering

$E_\gamma$ Tagging

Backscattered photon $\rightarrow$

UV or DUV Laser
$\lambda = 351$ nm, 257 nm
Properties of LEPS/LEPS2 beam

- 355 nm or 351 nm UV laser $\rightarrow$ 2.4 GeV (max.)
- 266 nm or 257 nm Deep UV laser $\rightarrow$ 2.9 GeV (max.)
- Tagged photon $E_{\gamma} > 1.5$ GeV, $\sim$10 MeV resolution.
- Laser: $\sim$100% polarized $\rightarrow$ Highly polarized $\gamma$ beam.
LEPS Detector Setup

Forward Spectrometer
- TOF : RF signal - TOF wall, $\Delta t = \sim 150$ ps
- Momentum : $\Delta p \sim 6$ MeV/c for 1 GeV/c $K$
- Acceptance : Hori $\pm 20^\circ \times$ Vert $\pm 10^\circ$

TPC
- $20^\circ < \theta < 140^\circ$
- $\Delta P/P \sim 0.2$
- $\Delta \phi \sim 0.04$ rad
Recent results from LEPS

Forward spectrometer

• $\kappa(800)$ exchange in $\gamma p \rightarrow K^*0 \Sigma^+$ reaction. Hwang et al., PRL108, 092001(2012)

• $K^-pp$ bound state search in $\gamma d \rightarrow K^+\pi^-X$ reaction. Tokiyasu et al., PLB728(2014)616

• $\Theta^+(1530)$ photoproduction (new data)

Forward spectrometer + TPC

• $\Lambda(1405)$ photoproduction at $E_\gamma = 3$ GeV

• $\omega$ and $\eta'$ photoproduction at backward angles. arXiv:1306.3031
**$K^{-}pp$ bound state**

- strong $\bar{K}N$ attraction in $I = 0$ channel.
- Existence of **Kaonic Nuclei** is suggested.
- $\bar{K}NN$ is the lightest kaonic nuclei.
- $K^{-}pp$ : strongest binding $\bar{K}NN$ system.
- Investigating sub-threshold $\bar{K}N$ interaction.
- Theoretical prediction, depending on models
  
  Binding Energy = $9 - 95$ MeV, Width = $34 - 110$ MeV
Possible candidates

FINUDA: Stopped $K^-$ on nuclear targets

**PRL 94, 212303 (2005)**

\[ B.E. = 115^{+6}_{-5} \text{(stat)}^{+3}_{-4} \text{(syst)} \]

\[ \Gamma = 67^{+14}_{-11} \text{(stat)}^{+2}_{-3} \text{(syst)} \text{MeV} \]

Peak structure in $\rho\Lambda$ invariant mass
Possible candidates

DISTO: \( pp \rightarrow pK^+\Lambda \) reaction

Peak structure in \( K^+ \) missing mass

\[ B.E. = 103 \pm 3(\text{stat}) \pm 5(\text{syst}) \]
\[ \Gamma = 118 \pm 8(\text{stat}) \pm 10(\text{syst}) \text{MeV} \]
Our search

$$\gamma d \rightarrow K^+ \pi^- X$$ reaction

Tokiyasu et al., PLB 728(2014)616

$$E_\gamma = 1.5 - 2.4 \text{ GeV}$$

Detecting $$K^+$$ and $$\pi^-$$ at forward

$$\rightarrow$$ Low momentum transfer

$$(0.1 - 0.4 \text{ GeV/c})$$

detected

$$K^-pp$$ bound state
Result

\[ \gamma d \rightarrow K^+ \pi^- X \]

missing mass

Log-likelihood test if the fitting improved with \( K^-pp \) bound state signal

No significant peak in \( M = 2.22 - 2.36 \text{ GeV}/c^2 \) (B.E. = 10 – 150 MeV)

\( \gamma n \rightarrow \Lambda K^+ \)
\( \gamma p \rightarrow \Sigma^+ K^- \)
\( \gamma p \rightarrow \Lambda(1520) K^+ \)
\( \gamma n \rightarrow \Lambda \pi^0 K^+ \pi^- \)
\( \gamma n \rightarrow \Sigma^0 \pi^0 K^+ \pi^- \)
\( \gamma n \rightarrow \Sigma^0 (1385) K^- \pi^- \)

Tokiyasu et al., PLB 728(2014)616
Upper limit

Upper Limit of the $K^0 p p$ production

\[ \frac{d^2\sigma}{d\cos\theta_{K^0} d\cos\theta_p} \text{[}\mu b]\] vs Missing Mass [GeV/c^2]

- \( \Gamma = 20 \text{ MeV} \)
- \( \Gamma = 60 \text{ MeV} \)
- \( \Gamma = 100 \text{ MeV} \)

<table>
<thead>
<tr>
<th>( \Gamma ) (MeV)</th>
<th>Upper Limit (( \mu b ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.17 – 0.55</td>
</tr>
<tr>
<td>60</td>
<td>0.55 – 1.7</td>
</tr>
<tr>
<td>100</td>
<td>1.1 – 2.9</td>
</tr>
</tbody>
</table>

at 95% C.L.

Hyperon production

\( \sim 11 \mu b \)

Tokiyasu et al., PLB 728(2014)616
Quasi-free Background

Missing mass spectra for $\gamma N \rightarrow K^+\pi^-X$ and $\gamma N \rightarrow K^+X$ were fitted simultaneously.

Tokiyasu et al., PLB 728(2014)616
\[ \Theta^+(1530) \]

- \( S = +1, \ Q = +1 \) Baryon minimal content: \( \text{(uudds)} \) → Pentaquark
  - Light and narrow (chiral quark soliton model)

- Width estimation by \( K^+ n \rightarrow \Theta^+ \) reaction
  - \( 0.36 \pm 0.11 \text{ MeV/c}^2 \) (DIANA)
  - \(< 0.64 \text{ MeV/c}^2\), upper limit (Belle)

Its existence is still controversial.
Evidence with $5.1\sigma$ statistical significance was reported as PRC79, 025210(2009)

$\rightarrow$ New data with higher statistics, same detector setup
Results of inclusive analysis

New data
2.6 times more statistics than the previous data.

- Blind analysis: Cuts are pre-determined.
- Narrow strong structure is not seen in the signal region.
- The significance is less than $2\sigma$, if we perform the same shape analysis as the previous analysis.
Results of inclusive analysis

New data v.s.

previous data

Normalized by entry

- In total, two data sets are consistent.
- $\chi^2/\text{ndf}=56.4/66$
  KS-test 58.8%

Fluctuation?
Human bias?
Over/under-estimation?
→ Exclusive analysis
Exclusive analysis

**SIGNAL**

\[
\gamma p \rightarrow K^-\Theta^+
\]

\[
\gamma n \rightarrow \phi n \rightarrow K^+K^-n
\]

... 

**Background**

\[
\gamma p \rightarrow K^+\Lambda(1520)
\]

\[
\gamma p \rightarrow \phi p \rightarrow K^+K^-p
\]

... 

(0.3 – 0.8 GeV/c)
Detection of recoil proton from BG

Using $dE/dx$ information in start counter

$QF \gamma n$ event + $QF \gamma p$ event $p$: out of acceptance

$QF \gamma p$ event $p$: tagged

Efficiency $\approx 60\%$
Detection of recoil proton from BG

Using $dE/dx$ information in start counter

QF $\gamma n$ event + QF $\gamma p$ event

$p$: out of acceptance

Efficiency $= \sim 60\%$

Signal enhancement is seen.

QF $\gamma p$ event $p$: tagged

Preliminary
Subtraction of proton BG

2 methods for BG estimation

- **Red**: dE/dx method
  - Strict cut for vertex position to improve the rejection efficiency.
  - # of event reduced (normalized in histogram)

- **Black**: Monte-Carlo based estimation
  - MC fit for proton tagged sample → BG estimation for full data sample.

We are now taking data with improved recoil $p$ acceptance
Setup of the current run

Large Start Counter to improve proton tagging/rejection efficiency.
LEPS2 experiments

- 2nd LEPS beamline at SPring-8
  - Can be operated with LEPS at the same time.

- Aiming to obtain $10^7$/sec photon beam with improved laser injection system.

- Large acceptance detector in larger experimental hall
Current Status of LEPS2

Oct. 2013: Tagged photon beam became available.

2 experimental setups:

• **BGOegg**: egg-shaped BGO detector array.

• **Solenoidal spectrometer** (magnet from BNL-E949)
  – Magnet is ready.
  – Construction and development of the detectors are underway.
BGOegg detector

- 1320 BGO crystals covers 22 – 144 deg.
- 1.3% energy resolution, 3.1mm position resolution for 1 GeV photon.
- Used with cylindrical drift chamber inside.
- TOF detector at forward angles.
Physics programs with BGOegg

• Search for $\eta'(958)$ mesic nucleus
  – $U_A(1)$ anomaly effect in medium.

Nagahiro, Hirezaki, PRL94, 232503 (2005)
(Discussed in this session)

• $\gamma N \rightarrow \eta'(958)N$ elementary process with $H_2/D_2$ target
  – Cross section, beam asymmetry...etc.
LEPS2 solenoidal spectrometer

Detector construction is underway.

Magnet from BNL-E949
\( \Theta^+(1530) \) search at LEPS2

\[ pK_S \text{ invariant mass} \quad \overline{K^{*0}} \text{ missing mass} \]

- Without Fermi-motion correction, \( \phi \) background.
- Overwrap with CLAS acceptance
Summary

• **LEPS** and **LEPS2** are now in operation at SPring-8.
• Recent results for $K^-pp$ bound state and $\Theta^+$ pentaquark have been presented.
• BGOegg experiment at **LEPS2** has been started.
• Construction of **LEPS2** solenoidal spectrometer is underway.
LEPS & LEPS2 collaboration

• Japan
  – RCNP, RIKEN, Kyoto, ELPH/Tohoku, KEK, Gifu, Tokyo, Chiba, Nagoya,…

• Taiwan
  – Academia Sinica

• Korea
  – Korea U., Seoul U.

• USA
  – Ohio U.

• Canada
  – U. Saskatchewan

• Russia
  – JINR Dubna

International Collaboration, but not a Huge group
LEPS & LEPS2 collaboration

• Japan
  – RCNP, RIKEN, Kyoto, ELPH/Tohoku, KEK, Gifu, Tokyo, Chiba, Nagoya,…

• Taiwan

• Korea
  – Korea U., Seoul U.

• USA

We welcome your participation in LEPS/LEPS2 !!

• Canada
  – U. Saskatchewan

• Russia
  – JINR Dubna