Hadron Physics at LEPS and ELPH

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LEPS
Laser Compton Scattering
1.5~3.0 GeV
0.2~2 MHz
Linearly polarized

Beam Generation
Tagged $E_\gamma$ Range
Beam Intensity
Polarization

ELPH (⇔ LNS)
Bremsstrahlung
0.57~1.15 GeV
20 MHz
Un-polarized

LEPS and ELPH are complementary to each other.
Outline

**SPring-8/LEPS**
- Facility
- Evidence for a $\kappa$ meson
- $\Theta^+$ Photoproduction (*New data*)

**Tohoku/ELPH**
- Facility
- $N^*(1670)$ Photoproduction (*$N^*_5 0$ Candidate*)
- $\omega N$ Scattering Length

**New Beamline Project LEPS2**
- Key Concepts & Construction Status
- BGO-EGG
Laser Electron Photon beamline at SPring-8

SPring-8:
8 GeV electron storage ring
100 mA

Operated since 2000.
Linearly Polarized Photons

Exchanged particle

Hyperon

Decayed Particles

(1) Natural parity

(2) Unnatural parity
Backward-Compton Scattered Photon

8 GeV electrons in SPring-8 + 350nm(260nm) laser ➔ maximum 2.4 GeV(2.9 GeV) photon

Laser Power ~6 W ➔ Photon Flux ~1 Mcps

$E_\gamma$ measured by tagging a recoil electron ➔ $E_\gamma > 1.4$ GeV, $\Delta E_\gamma \sim 10$ MeV

Laser linear polarization 95-100% ⇒ Highly polarized $\gamma$ beam
Setup of LEPS

- In e storage ring
- Tagging counters
- Photon beam 1.5 ~ 2.4 GeV

- Only FWD spectrometer ±20° x ±10°
Polarized HD target will be ready soon.
Scalar $K$ exchange in $\Sigma^+$ production

$K$ : Pseudoscalar meson $\rightarrow$ unnatural exchange

$\mid$ : Scalar meson $\rightarrow$ natural exchange
Parity Spin Asymmetry

Dominance of natural-parity exchange is indicated at forward angles.

⇒ Consistent with $\kappa(800)$ meson exchange.
Prediction of the $\Theta^+$ Baryon

$ud \sim s$


- Exotic: $S=+1$
- Low mass: 1530 MeV
- Narrow width: < 15 MeV
- $J^P=1/2^+$

$M = [1890-180*Y] \text{ MeV}$
Previous result

\[ \gamma d \rightarrow K^+K^-pn \text{ reaction} \]

- Data taken in 2002-2003.
- \(2.0 < E_{\gamma} < 2.4\) GeV.
- Significance of 5.1\(\sigma\) from shape analysis.
  \((\Delta(-2\ln L) \text{ with/without signal})\)

If the peak is real,

- It should be reproducible.
- It should appear in \(M(nK^+)\).
- It should not appear in \(M(nK^-)\) nor in \(M(pK^+)\).
- Fermi-motion correction should work.
Search for $\Theta^+$ in Fermi-motion corrected $K^-$ missing mass

$\Upsilon^+ : K^- \text{ missing mass}$
$\Lambda(1520) : K^+ \text{ missing mass}$

For the further improvement

**Inclusive analysis:**
- $p/n \text{ unseparated}$

**Exclusive analysis:**
- $p/n \text{ separated}$

Separation of the two types of $K^+K^-$ events from neutron and proton largely improves the signal sensitivity.

In the previous analysis, only inclusive analysis was carried out.

Minimum Momentum Spectator Approximation (MMSA):
Assume possible minimum momentum configuration for the spectator.

Simple $\text{MMn}(\gamma,K^-)X: 30 \text{ MeV/c}^2$
$\text{M(nK^+)} \text{ by MMSA :11 MeV/c}^2$
($16 \text{ MeV/c}^2 \text{ for } \Lambda(1520)$)
Inclusive Analysis

- **New data** was taken in 2006-2007 with almost the same setup.

- **Blind analysis** was applied to check the previous result. (Selection cut is not changed from previous analysis. calibration fixed before opening the box)
Box open for new data

The significance is less than 2σ if we perform the same shape analysis as the previous analysis.

Λ(1520) cut: M(pK⁻)>1.55 GeV/c²
Exclusive Analysis

Separate

\[ \Lambda(1520), \phi, \ldots \]  
\[ \Theta^+, \phi, \ldots \]
Proton detection by using dE/dx in Start Counter

Proton not tagged (Proton rejected)

KKn and a part of KKp

Proton tagged ($\varepsilon \sim 60\%$)

KKp only

Signal enhancement is seen in proton rejected events. → should be associated with $\gamma n$ reaction.

p/n ratio:
1.6 before proton rejection
0.6 after proton rejection
**M(NK⁺) for exclusive samples**

- Peak is seen in tagged events for the previous data while not seen in the new data.
- An enhancement is seen in proton rejected events in the both data.
Neutron enhanced sample

Proton rejection efficiency becomes $60\% \rightarrow 90\%$ by selecting events from the downstream region of target

$M(nK^+)$

Preliminary
Estimation of the leaked proton contribution

proton “tagged” events

proton “leaked” events

Fit by MC

~60% of KKp events

Estimate with a help of MC

~40% of KKp events
Fitting proton-tagged events

- Extended maximum-likelihood un-binned fit.
- $M(pK^+)$, $M(pK^-)$, $\cos(\theta)$ of $K^+$ are simultaneously fitted.
- Ratio of $\phi$ to non-resonant KK is determined from $M(KK)$.
- $\Lambda(1405)$ to explain threshold enhancement of $M(pK^-)$.
- $\chi^2$/ndf is close to one.
M(nK\(^{-}\)) distribution

✓ The peak did not appear in M(nK\(^{-}\))

n and p(leaked) subtracted
The peak appeared in $M(nK^+)$ after subtracting $n$ and $p$ (leaked) contributions.
Downstream(vtz>-980 mm)

✓ The peak appear in low proton-leakage region.

n and p(leaked)

subtracted
The peak appears in the high proton-leakage region. The number of neutron events is consistent with the acceptance.
The peak appeared in the new data.

n and p(leaked) subtracted
Fermi-motion correction by MMSA

✓ MMSA worked for $\Lambda(1520)$

w/o correction

w/ correction

Preliminary
Fermi-motion correction by MMSA

✓ MMSA worked for $\Theta^+$

w/o correction

w/ correction
New data taking with a large start counter was just started.
ELPH Tohoku University

Electron Beam
LINAC 150 MeV
Booster Ring 1200 MeV (max)

Photon Beam
Bremsstrahlung
Tagged

Typical Tagging Rate
20 MHz (photon: 10 MHz)
Bremsstrahlung Tagged Photon Beam
740~1150 MeV @ 1200 MeV
STB-Tagger II @ ELPH

STB-Tagger II

- 2-operation modes:
  @1200 MeV and 920 MeV
- Bremsstrahlung photon energy
  570 – 1150 MeV
ELPH : FOREST Experiment

- **62 Lead Glasses**
  - $110^\circ$~$170^\circ$
  - $\Delta E/E \sim 5\% @ 1\ GeV$

- **192 CsI crystals**
  - $5^\circ$~$24^\circ$
  - $\Delta E/E \sim 3\% @ 1\ GeV$

- **252 Lead/SciFi modules**
  - $30^\circ$~$100^\circ$
  - $\Delta E/E \sim 7\% @ 1\ GeV$

Diagram:
- Rafflesia II
- LOTUS
- IVY
- LEPS Backward Gamma
- SPIDER
- SCISSORS III
- FOREST

$\gamma$ beam
Study of $N^*(1670)$

$N^*(1670)$ is suggested as a pentaquark candidate from ELPH (LNS), CB-ELSA, and GRAAL data.

Mass order may be important to know internal structure.

- diquark correlation: $M_{\Theta^+} > M_{N^*}$
- chiral soliton model: $M_{\Theta^+} < M_{N^*}$

$\gamma N \rightarrow \eta N$ or $\pi^0 N$ using a $LD_2$ target

- $\eta/\pi^0$ is reconstructed by $M(\gamma\gamma)$.
- A proton is identified by kinetic energy vs. dE/dx.
- A neutron is identified by TOF.
- A kinematical fit is performed.
\[ \eta \text{ & } \pi^0 \text{ photoproduction from the neutron} \]

- Structure around \( W=1670 \text{ MeV} \) is **observed in } \gamma n^* \rightarrow \eta n \), but not in } \gamma n^* \rightarrow \pi^0 n \).

\( N^*(1670) \) couples strongly to a \( s\bar{s} \) content \( (u\bar{d}s\bar{s}\,?) \)

- Bump in \( \gamma p^* \rightarrow \pi^0 p \) corresponds to \( D_{15}(1675) \) as reproduced by SAID/MAID.

- Charged partner of \( N^*(1670) \) is not observed in } \gamma p^* \rightarrow \eta p \).

- **4 times larger sample** will be analyzed after further checks of acceptances.
**ωN Final State Interaction**

A proton identified by dE/dx at scintillating counters & kinetic energy at calorimeter.

\[ \gamma p \rightarrow \omega p \rightarrow \pi^+ \pi^- \pi^0 p \]

\( \pi^0 \) is identified by \( M(\gamma\gamma) \) near the \( \pi^0 \) mass.

\( \omega \) is identified by \( MMp(\gamma,p) \).

2 extra charge are required.

**Fit w/ FSI : \( \chi^2/ndf=1.1 \)**

**Fit w/o FSI : \( \chi^2/ndf=7.9 \)**

Very high statistics data near the threshold is available at ELPH, so that a scattering length can be measured for the first time.
**LEPS2 Facility**

**Backward Compton Scattering**

- 8 GeV electron
- Recoil electron (Tagging)
- Laser
- SR ring

**30m long line**

**Laser room**

**10 times high intensity:**
- Multi laser injection & Laser beam shaping

**LEP (GeV γ-ray)**

**Inside SR bldg**

**Outside SR bldg**

**Large 4π spectrometer** based on BNL-E949 detector system.

**Better resolutions** are expected.

Best emittance ⇒ photon beam does not spread
LEPS2 Detector

B=1 T : $\Delta p/p \sim 1\%$ for $\theta > 7^\circ$

TPC Prototype Residual

RPC ToF time distribution

$\gamma$ counter

RPC

TOP

TPC

DC

$\gamma$

2.22 m

2.96 m

RMS=117 $\mu$m

$\sigma = 49.8 \pm 1.3$ ps

$>3\sigma$ K/$\pi$ separation @1.1 GeV/c$^2$
## Comparison of LEPS and LEPS2

<table>
<thead>
<tr>
<th></th>
<th>LEPS</th>
<th>LEPS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Intensity (~2.4 GeV)</td>
<td>$2 \sim 3 \times 10^6$ (2 lasers)</td>
<td>$&lt;10^7$ (4 high-power lasers)</td>
</tr>
<tr>
<td>Beam Intensity (~2.9 GeV)</td>
<td>$2 \sim 3 \times 10^5$ (2 lasers)</td>
<td>$&lt;10^6$ (4 high-power lasers)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Linear/Circular</td>
<td>Linear/Circular</td>
</tr>
<tr>
<td>Detector Area</td>
<td>$42 \text{m}^2 \times 3\text{m(h)}$</td>
<td>$198 \text{m}^2 \times 10\text{m(h)}$</td>
</tr>
<tr>
<td>Charged Particle Acceptance</td>
<td>0~30 degrees</td>
<td>7~120 degrees</td>
</tr>
<tr>
<td>Momentum Resolution</td>
<td>0.5% (for 1-GeV kaon)</td>
<td>1~1.5% (for 1-GeV kaon)</td>
</tr>
<tr>
<td>Photon Coverage</td>
<td>none</td>
<td>30~110 degrees</td>
</tr>
</tbody>
</table>
Exp. hall was constructed. (2010.Oct-2012Jan)


γ counters were installed. (2012.June)

Beam pipe (2012.May)
BGO-EGG goes to LEPS2

- ‘Egg’-shape assembly of 1320 Bi$_4$Ge$_3$O$_{12}$ crystals (L=220mm : 20X$_0$)
- Covering 24°~144° in polar angle.
- 1.3% energy resolution @ 1GeV
- 3.1 mm position resolution @ 1GeV
- BGO-EGG will be moved to from ELPH to LEPS2 in December, 2012.
Summary

- SPring-8/LEPS & Tohoku/ELPH are complementary in terms of $E_\gamma$, photon intensity, beam polarization, and $\gamma$ detector setup.
- Currently, studies on hadron structure ($\Omega^+$, $N^*(1670)$) and hadron interaction are in progress.
- LEPS & ELPH are collaborating toward next generation experiments at SPring-8 with RIKEN and KEK.
- We plan to start a test experiment with BGO-EGG at the new LEPS2 facility in the end of this FY.

Thank you for your attention!
Backup
Comparison of data and MC with loose $\phi$ cut

- $\phi$ events are excluded by $M(KK)>1.03$ GeV/$c^2$
- $z$-vertex, proton tagging cut is applied
- Good consistency between data and MC
dE/dX based and MC based $M(nK^+)$ with constant $\phi$ cut

$M(KK) > 1.03$ GeV/c$^2$

$M(KK) > 1.04$ GeV/c$^2$

$M(KK) > 1.05$ GeV/c$^2$
M(nK⁺) with two methods

MC-based exclusive events

Overlay with normalization by entry

Subtract leaked proton contribution

dE/dX-based exclusive events
The large polarization dependence of the S/N ratio was seen.
The spectrometer acceptance has approximately rectangular shape.

If $K^+$ and $K^-$ prefer to fly parallel to the polarization, the acceptance difference cause the difference of the strength.

→ Suggesting non-resonant KK has p-wave component
Year Mixed Spectra

$2.67nK^-(02-03)+pK^-(06-0.7)$

$2.67pK^-(02-03)+nK^+(06-0.7)$

Counts/12.5 MeV

M(NK$^+$) (GeV/c$^2$)

Preliminary
High-p Line for 2ndary Beam

- To be constructed for a 30 GeV primary beam line (by FY2015)
- High-intensity secondary beam (unseparated) can be delivered.
  - 2 msr% $\Rightarrow$ $>1.0 \times 10^7$ Hz @ 15 GeV $\pi$
- High-resolution beam: $\Delta p/p \sim 0.1\%$
  - Momentum dispersion and eliminate 2nd order aberrations
Experiment

* Missing mass spectroscopy
  • Mass and Width measurement for higher excited states
    - Missing mass resolution: Comparable with narrow width ⇒ 5–6 MeV
  • Production cross section

Experiment: \( \pi^- + p \rightarrow \Lambda_c^* + D^{*-} \) reaction @ 15 GeV/c

1) Missing mass spectroscopy
   - High intensity \( \pi^- \) beam measurement: More than \( 10^7 \) Hz
   - Measurement of forward scattered particles
     ○ Decay particles from \( D^*(D) \) meson

2) Invariant mass spectroscopy
   - Decay particles from \( \Lambda_c^* \)
   ⇒ Possible for forward scattering particles
     ○ \( \Lambda_c^* \rightarrow \Lambda_c + \pi + \pi, \Lambda_c^* \rightarrow \Lambda_c + \pi, \Lambda_c^* \rightarrow p + D \)
     ○ Help to identify states
A spectrometer

Concept design

FM cyclotron magnet
J-PARC E16
⇒ 2.3 Tm, 1 m gap

- High rate detectors
- Large detectors
- Internal detectors
- PID: RICH
  - HERMES RICH

Multi-particle spectrometer: It can be used for many experiments.

K. Shirotori  New Hadron WS at Busan  2012/11/21