Hadron Physics at LEPS and LEPS2

Masaru Yosoi
RCNP, Osaka University

• Overview of the LEPS facility
• Recent Results
  \( K^*0\Sigma^+ \) photoproduction with evidence for \( \kappa \) meson exchange
  New result on \( \Theta^+ \)
• LEPS2 project
Characteristics of Laser-Electron Photon (Backward-Compton Scattering)

- rather flat energy distribution with small spreading
  (Unlike the Bremsstrahlung, where low energy photons are dominated, \( \sim 1/E_\gamma \))
- high linear- or circular-polarization
- photon energy can be tagged by recoil electron

\[ E_e = 8 \text{ GeV} \]
\[ \lambda = 351 \text{ nm} \]
Schematic view of the LEPS facility

Collision

8 GeV electron

Recoil electron

Backward-Compton scattering

SSD + Sc phodoscope
ScFi + Sc phodoscope

36m

70m

Energy spectrum of BCS photons

Bremsstrahlung

b) Laser hutch

c) Experimental hutch

a) SPring-8 SR ring

Laser light

Inverse Compton γ-ray
LEPS Detector Setup

Forward Spectrometer

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

TPC

- $20^\circ < \theta < 140^\circ$
- $\Delta p/p \approx 0.2$
- $\Delta \phi \approx 0.04$ rad
Energy Extension of Photon beam

Introduce Deep-UV lasers

Coherent : Innova Savre MOTOFRED
Ar-laser + BBO
CW 1W, $\lambda=257.2$ nm
Power consumption 10 kW

Oxide : Frequad-HP
Diode-laser + LBO+BBO
CW 1W, $\lambda=266$ nm
Power consumption 300 W

• Obtain higher energy beam by decreasing laser wavelength

  UV-laser (355 nm (3.49 eV)) $\rightarrow E_{\gamma}^{\text{max}} = 2.38$ GeV
  Deep UV-laser (257 nm(4.82 eV)) $\rightarrow E_{\gamma}^{\text{max}} = 2.96$ GeV

• Studies of heavier system of photoproduction become possible
$K^*{^0}\Sigma^+$ Photoproduction to investigate κ meson exchange with 3 GeV beam

PRL108, 092001(2012)
Light mesons

- SU(3) nonets of pseudo-scalar mesons ($\pi, K, \eta, \eta'$) and vector mesons ($\rho, K^*, \omega, \phi$) are well established.
- But the identification of scalar mesons and their nature are still in question. (4-quark states ?)

$$\sigma(600): M=400\sim600 \text{ MeV}, \Gamma: 600\sim1000 \text{ MeV}$$

($\pi-\pi$ scattering, D decay.)

$$\kappa(800): M=700\sim900 \text{ MeV}, \Gamma: \sim500 \text{ MeV}$$

($K-\pi$ scattering, D decay, $J/\Psi$ decay)

Their existence has been controversial based on mass shape analysis due to their broad width.
Forward $\gamma p \rightarrow K^{*0} \Sigma^+$ photoproduction

- t-channel exchange is dominant
- There is no Pomeron exchange
- $K^*$ exchange is suppressed
- Only $K$ or $\kappa$ exchange is possible

Identified by $\text{MMp}(\gamma, K^+\pi^-)$

$K^+\pi^-$ Invariant Mass vs $p(\gamma, K^+\pi^-)$ Missing Mass

Detected at forward spectrometer. Identified by $M(K^+\pi^-)$.
Decay polarization observables with linearly polarized photons $\rightarrow$ parity filter

$K^*0 \rightarrow K^+ + \pi^-$

Decay Plane $\parallel \rightarrow $
natural parity exchange $(-1)^J$
(Scalar mesons ($\kappa$))

Decay Plane $\perp \rightarrow $
unnatural parity exchange $(-1)^J$
(Pseudoscalar mesons ($K$))

The decay angular distribution of the vector mesons gives information on the relative contribution of the natural and unnatural parity exchange.
Parity Spin Asymmetry ($P_\sigma$)

Decay angular distribution

\[ P_\sigma \equiv \frac{d\sigma^N - d\sigma^U}{d\sigma^N + d\sigma^U} = 2\rho_{1-1}^1 - \rho_{00}^1 \]

- GJ frame
- helicity frame

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

\[ w/ \ \kappa\text{-exchange} \]

\[ w/o \ \kappa\text{-exchange} \]

Y. Oh and H. Kim
PRC74, 015208(2006)

Acceptance corrected data (red), MC data with fitted spin-density matrix elements (dashed)
Hyperon production contribution (black)
**New Result on Θ^+**

$\gamma d \rightarrow K^+K^-pn$ reaction

High statistics data

Improved analysis

*the previous result*
Search for $\Theta^+$ in Fermi-motion corrected K$^-$ missing mass

$\Theta^+$: K$^-$ missing mass
$\Lambda(1520)$: K$^+$ missing mass

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

Inclusive analysis: p/n unseparated
Exclusive analysis: p/n 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.

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

New data contains 2.6 times more statistics than the previous data.

\[ \chi^2/\text{ndf} = 56.4/66 \]
\[ \text{K.S test} = 58.8\% \]

New data
previous data

Results of Inclusive Analysis

- 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.

- Two data sets are normalized by the entry.
- In total, two data sets are consistent.

Fluctuation? Human bias? Over/under-estimation?

Exclusive analysis
Proton detection by using dE/dx in Start Counter

Proton not tagged
(Proton rejected)

KKn and part of KKp

Proton tagged (ε ~60%)

KKp only

Signal enhancement is seen in proton rejected events.
→ should be associated with γn reaction.

p/n ratio:
1.6 before proton rejection
0.6 after proton rejection
• 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.
Two methods to reduce “leaked” proton BG

1. dE/dx-based exclusive analysis
   - Proton rejection efficiency becomes $60\% \rightarrow 90\%$ by selecting downstream of target

2. MC-based exclusive analysis
   - Proton contribution is estimated by fitting realistic MC distributions to proton-tagged spectra.
   - The estimated proton contributions are subtracted from full data sample (without z-vertex and proton tagging cut).
**M(nK^+)** with two methods

**Subtract proton contribution**

**MC-based exclusive events**

![Graph of MC-based exclusive events]

**dE/dX-based exclusive events**

![Graph of dE/dX-based exclusive events]

Overlay with normalization by entry

- Mass and significance estimation of the enhancement is underway.
- LEPS collaboration plans to perform new experiment with large SC from this October.
Strong polarization dependence of S/N ratio

Horizontal

Vertical

K+ K-

Horizontal

K- → Suggesting non-resonant KK has p-wave component

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.
LEPS2 project
Schematic view of the LEPS2 facility

Backward Compton Scattering

- 8 GeV electron

Recoil electron (Tagging)

Laser

10 times high intensity:
Multi laser injection & Laser beam shaping
(future possibility: Re-injection of X-ray from undulator)

30m long line

SR ring

Inside SR bldg
Outside SR bldg

Laser room

Best emittance (parallel) beam ⇒ photon beam does not spread

LEP (GeV γ-ray)

Large 4π spectrometer based on BNL-E949 detector system.
Better resolutions are expected.
New DAQ system will be adopted

Experimental bldg

Beam dump
How to get the high Intensity Photon Beam

We are aiming to produce one-order higher intensity photon beam:

- LEP intensity $\geq 10^7$ cps for $E_\gamma < 2.4$ GeV beam (355 nm)
- $\geq 10^6$ cps for $E_\gamma < 2.9$ GeV beam (266 nm)

- Simultaneous injection of 4-lasers
- Higher output power and lower power consumption CW lasers.
  - 355 nm (for 2.4 GeV) 8 W $\rightarrow$ 16 W, 266 nm (for 2.9 GeV) 1 W $\rightarrow$ 2 W
- Laser beam shaping with cylindrical expander

- Electron beam is horizontally wide.
  $\Rightarrow$ BCS efficiency will be increased by elliptical laser beam.

Need large aperture of the laser injection $\rightarrow$ reconstruct some BL chambers in SR-ring
LEPS2 Main Detector

**E949 Solenoid Magnet**

- Size: $\Phi 5m \times 3.5m$
- Weight: 400 t
- Field: 1.0 T

**Target and Vertex detector**

- $\Delta P/P \sim 1\%$ for $\theta > 10^\circ$
- $\Delta t$(TOF) $\sim 50$ ps
- Detection of $\gamma$ (Pb/Sci calorimeter)
Large acceptance photon detector (BGO-Egg)

- 1320 BGO crystals
- Covering 24° ~ 144° polar angle
- 1.3% energy resolution for 1 GeV
- Move it to SPring-8 and LEPS2 commissioning will start in the end of this FY with BGO-Egg.
LEPS@SPring-8 has been in operation since 2000 for the study of the hadron structures ($\Theta^+, \Lambda(1405), \ldots$) and hadron interactions ($\phi N, K\Lambda N, \ldots$) using highly polarized photon beam.

In the recent results:

-- Evidence for the $\kappa$ meson through the $\gamma p \rightarrow K^0\Sigma^+$ reaction has been published.

-- High statistics data for $\Theta^+$ has been opened. The significance of peak in the inclusive analysis is reduced. But in the exclusive analysis with proton rejection, the peak structure is enhanced. The S/N ratio strongly depends on beam polarization.

Development of the polarized HD target comes to the final stage. We will start the double-polarization experiment next year at LEPS.

Construction of the LEPS2 facility is in progress. We plan to start a test experiment with BGO-Egg in the end of this FY.

Thank you!
Backup
What can be produced?

Above the threshold of $\phi(s\bar{s})$ meson and hyperon resonances

Key words:
1. Forward angle measurement including 0 deg.
2. Polarization observables
3. Strangeness
Polarization dependence for inclusive samples

Horizontal

Vertical
Recent Results about $\Theta^+$ using CLAS & J-PARC data

M.J. Amaryan et al., PRC85, 035209 (2012)
$\gamma p \rightarrow pK_S K_L$ using CLAS data (not approved by collaboration)
5.3$\sigma$ at 1.543 GeV/c$^2$ ($\sigma$=6 MeV)
A peak appears in a small $t$ region.

K. Shirotori et al., nucl-ex/1203.3604
J-PARC E19
$\pi p \rightarrow K^+ X$ ($2^\circ < \theta_{K^{*0}} < 15^\circ$)
90% CL upper limit 0.26 $\mu$b/sr
Penta-quark $\Theta^+$

Strangeness tagging

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

\[ \rightarrow p \ K^0 \]

\[ \rightarrow \pi^+ \pi^- \]

Invariant Mass measurement

\[ \Delta M(K^0) = 2.4 \text{ MeV/c}^2 \]

\[ \Delta M(\Theta^+) = 3.5 \text{ MeV/c}^2 \]