Hadron Physics with Photon Beam at LEPS/ LEPS2
Takashi Nakano (RCNP, Osaka Univ.)

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Outline

**LEPS**
- Overview
- Some recent results

**LEPS2**
- Physics Motivation
- Overview
- First experiment

Summary
Laser Electron Photon beamline at SPring-8

Operated since 2000.
Photon tagging and experiment

Timing and position of a scattered electron is measured at a counting rate of ~1 M/sec.

- $E_\gamma \geq 1.5 \text{ GeV}$: about 40% of $(0 < E_\gamma < E_{\text{max}})$ photons
- For incident photon number normalization
- For trigger: rate ~ 100 /sec
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

- 1.5 ~ 2.4 GeV photon beam
  - Collimator

- Only FWD spectrometer ±20° x ±10°
  - Dipole Magnet
  - Start Counter
  - Buffer Collimator
  - TPC
  - Solenoid
  - Up Stream e+e- Veto Counter
  - Aerogel Cherenkov Counter
  - Drift Chambers
  - TOF Counters
Setup of LEPS

1.5 〜 2.4 GeV photon beam

In e storage ring
Tagging counters

Dipole Magnet
Start Counter
Buffer Collimator
Solenoid
TPC
Cherenkov
Drift Chambers

Polarized HD target will be ready soon.
Linearly Polarized Photons

(1) Natural parity

(2) Unnatural parity

Exchanged particle

Vector K*

Decayed Particles
Scalar $\kappa$ exchange in $\Sigma^+$ production

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

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

Dominance of natural-parity exchange is indicated at forward angles. 
⇒ Consistent with \( \kappa(800) \) meson exchange.

Y. Oh and H. Kim, PRC 74, 015208 (2006)

PRL 108, 092001 (2012)
Kaonic nuclei search

Virtual $K, K^*$

$\gamma$

$K/K^*$

$\pi$

Direct $K$-exchange is forbidden in $(\pi^+, K^+)$ reaction.
Physics motivation

• $\bar{K}$-N interaction is strongly attractive ($I=0$).
  weakly attractive ($I=1$).
  $\rightarrow \bar{K}NN$ bound state ($K^{\ -}pp$, $K^{\ -}pn$, $K^{\ -}nn$)
  the strongest bound state

• $K^{\ -}pp$
  • Theory: $B.E. = 20 - 120 \text{ MeV, } \Gamma=60 – 110 \text{ MeV}$
  • Experiment : FINUDA (B.E. =115 MeV, $\Gamma = 67\text{MeV}$)
    DISTO (B.E. =103 MeV, $\Gamma = 118\text{MeV}$)
**$K^-pp$ search via $\gamma + d \rightarrow K^+ + \pi^- + X$**

Search region 2.22 – 2.36 GeV/$c^2$

So far, no peak was observed in inclusive modes. We will try to detect decay products. → Larger acceptance, LEPS2.

Significant peak cannot be observed. → ~10% of Q.F. processes

Upper limit of cross section (95% C.L.)

- $\Gamma = 20$ MeV: 0.17 - 0.55 $\mu$b
- $\Gamma = 60$ MeV: 0.55 - 1.7 $\mu$b
- $\Gamma = 100$ MeV: 1.1 - 2.9 $\mu$b

~10% of Q.F. processes
Prediction of the $\Theta^+$ Baryon

$\Theta^+(1530)$

$M = [1890 - 180 \times Y] \text{ MeV}$


- Exotic: $S=+1$
- Low mass: 1530 MeV
- Narrow width: $< 15 \text{ MeV}$
- $J^P=1/2^+$
Previous result

\[ \gamma \, d \rightarrow K^+ K^- p n \] reaction

- Data taken in 2002-2003.
- \( 2.0 < E_\gamma < 2.4 \text{ GeV} \).
- Significance of 5.1\( \sigma \) from shape analysis.
  \((\Delta(-2\ln L) \text{ with/without signal})\)
- Mass = 1524\( \pm 2 + 3 \text{ MeV/c}^2 \).

If the peak is real,

- It should be reproducible.
- It should appear in \( M(nK^+) \).
- It should not appear in \( M(nK^-) \) nor in \( M(pK^+) \).
Results of Inclusive Analysis

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

\[ \chi^2/\text{ndf}=56.4/66 \]

K.S test 58.8%

Blind analysis: Cuts are pre-determined.

Narrow strong structure is not seen in the signal region.

The significance is \( \sim 2\sigma \) 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
Exclusive Analysis

\[ \Lambda(1520), \phi, \ldots \]

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

\[ \text{Pid} = (\text{Measured energy loss in SC}) - (\text{Expectation of KK}) - (\text{Half of expectation of proton}) \]

- KKp only
- KKn and a part of KKp
- Proton not tagged (Proton rejected)
- Proton tagged (\( \varepsilon \approx 60\% \))

Signal enhancement is seen in proton rejected events.
\( \rightarrow \) should be associated with \( \gamma n \) reaction.

p/n ratio:
- 1.6 before proton rejection
- 0.6 after proton rejection

\[ \text{M}(nK^+) \text{ (GeV/c}^2) \]

Preliminary
Two methods to reduce “leaked” proton BG

1. dE/dx-based exclusive analysis

Proton rejection efficiency becomes 60% → 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 leaked proton contributions are subtracted from full data sample (without z-vertex).
M(nK⁻) distribution

✓ The peak did not appear in M(nK⁻)

n and p(leaked) subtracted

![Graph showing M(nK⁻) distribution with peak not appearing after subtraction.]
M(nK⁺) with two methods

MC-based exclusive events

dE/dX-based exclusive events

Counts/12.5 MeV

Counts/12.5 MeV

M(nK⁺) (GeV/c²)

M(nK⁺) (GeV/c²)
M(nK⁺) with two methods

MC-based exclusive events

\[ \frac{dE}{dX} \]-based exclusive events

Subtract proton contribution.
Overlay with normalization by entry
Large Start Counter to improve proton tag/rejection efficiency.
Proton detection efficiency

We have just finished data taking with the new setup.

Data with new setup  $\equiv$  Data with old setup
Recoil electron (Tagging)

LEPS2 Facility

Backward Compton Scattering

8 GeV electron

Recoil electron (Tagging)

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

LEP (GeV γ-ray)

30m long line

SR ring

Best emittance ⇒ photon beam does not spread

Large 4π spectrometer based on BNL-E949 detector system. Better resolutions are expected.
Divergence of LEP beam

**LEPS2**
- BL31
  - \( <\sigma_x'> \geq 14 \, \mu\text{rad.} \)

**LEPS**
- BL33
  - \( <\sigma_x'> \geq 58 \, \mu\text{rad.} \)

**Better divergence → Better tagging resolution**

- Smaller beam size at long distance

**Reaction region**
- (30m)

**Tagging point**
- (7.8m)
**θ⁺ Search at LEPS2**

No Fermi motion correction.
No φ background.

To measure angular dependence of production rate in large angle region, up to CLAS acceptance.

A large acceptance and better resolution detector is necessary.
Two pole structure of $\Lambda(1405)$

$|T_{\pi \Sigma \rightarrow \pi \Sigma}|^2 q_\pi$

$|T_{\bar{K}N \rightarrow \pi \Sigma}|^2 q_\pi$

D. Jido, et al.
NPA725(2003)

V.K. Magas, E. Oset and A. Ramos, PRL 95

$E_{\text{cm}}$ [MeV]

$M_{l'}$ [GeV]

$\frac{d\sigma}{dM_{l'}}$ [arb. units]
$K^*(890) \Lambda(1405)$ photoproduction with linearly polarized photon
$K^*(890) \Lambda(1405)$ photoproduction with linearly polarized photon

$\gamma \rightarrow K^- \Lambda(1405) \Sigma(1385) \rho$

T. Hyodo et al, PLB593
LEPS2 Detector

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

TPC Prototype Residual

RPC ToF time distribution

$>3\sigma$ $K/\pi$ separation @1.1 GeV/$c^2$
Transport each disk

Open the roof of LEPS2 building
Insert each disk using 360t crane
Installation was finished after painting
Exp. hall was constructed. (2010.Oct-2012Jan)


γ counters were installed. (2012.June)

Beam pipe (2012.May)
Comparison of LEPS and LEPS2

<table>
<thead>
<tr>
<th></th>
<th>LEPS</th>
<th>LEPS2</th>
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</thead>
<tbody>
<tr>
<td>Beam Intensity (~2.4 GeV)</td>
<td>2~3x10^6 (2 lasers)</td>
<td>&lt;10^7 (4 high-power lasers)</td>
</tr>
<tr>
<td>Beam Intensity (~2.9 GeV)</td>
<td>2~3x10^5 (2 lasers)</td>
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</tr>
<tr>
<td>Polarization</td>
<td>Linear/Circular</td>
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</tr>
<tr>
<td>Detector Area</td>
<td>42m^2 x 3m(h)</td>
<td>198m^2 x 10m(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>
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BGO-Egg: constructed @ ELPH, Tohoku U.

Large acceptance photon detector (BGO-Egg)

- 1320 BGO crystals
- Covering $24^\circ \sim 144^\circ$ polar angle
- 1.3% energy resolution for 1 GeV
Obtained mass resolutions are consistent with MC simulation results.

Timing resolution was measured to be 340 ps by checking $\pi^0 \to 2\gamma$. 
Experimental setup

\[ \gamma + {}^{12}\text{C} \rightarrow \eta' \otimes {}^{11}\text{B} + \text{p} \]
Experimental method

\[ \gamma + ^{12}\text{C} \rightarrow \eta' \otimes ^{11}\text{B} + p \]

Identify \( \eta' \) production by \( \eta \) tag

Search for a bound state

BGO egg calorimeter

Forward TOF

12.5m from the target

Vert: \( \pm 7^\circ \)

Hori: \( \pm 4^\circ \)

\( 3 \pi^0 \rightarrow 6 \gamma (33\%) \)

\( 2 \gamma (39\%) \)
Expected energy spectrum

2.4 GeV $\gamma$ $\eta$ tag (6$\gamma$)

No shift

$\Delta E = 28$ MeV

bound

Secondary $\eta$ multi $\pi$

150 MeV shift

$\Delta E = 28$ MeV

bound

Small background

See signals in bound region

NJL model calculation

$E_{\text{ex}} - E_0$ (MeV)

$E_{\gamma} - 2.4$ GeV

H. Nagahiro
Summary

- LEPS
  - Kaonic nuclei search, updates on $\Theta^+$.  
- LEPS2
  - x10 luminosity. $\sim$10Mcps.
  - Two different experimental setups.
    - Solenoid spectrometer
    - $\Theta^+$, $\Lambda(1405)$
    - BGO EGG + TOF
  - Backward meson production from proton and nuclei
- BGO EGG experiment was started last year!