LEPS upgrade and LEPS2

- Upgrade works @LEPS in the past few years and near future
- LEPS2 – new project (Maeda-san’s talk in detail)

WS on New Hadrons with Various Flavors @Nagoya 2008/12/06
Why GeV photon beam for study the quark hadron physics?

- Wave length: $\lambda < 1$ fm (typical hadron size)
- Photon interaction is simpler than hadron interactions
- $J^{PC} = 1^{--}$: the same as vector mesons ($\rho$, $\omega$, $\phi$, …)
  - Contain a large fraction of $s\bar{s}$ and
  - the same amount of quark and anti-quark
- Isospin: both $I=0$ and $I=1$ components
- When beam is linearly polarized, it can be used as a parity filter

- Disadvantage: low interaction rates
  $\Delta q = \Delta \omega$ (c.f. $(e,e')$)
Schematic view of the LEPS facility

Collision

8 GeV electron
Recall electron

36m

SSD + Sc phodoscope
ScFi + Sc phodoscope

Backward-Compton scattering

8 GeV electron

a) SPring-8
SR ring

b) Laser hutch

Laser light

Inverse Compton $\gamma$-ray

c) Experimental hutch

Energy spectrum of

BCS photons

Bremsstrahlung
LEPS forward spectrometer

• Target LH$_2$, LD$_2$, etc.
• AC index = 1.03 to reject $e^+e^-$ pairs
• SSD 120μm pitch
• DCs $\sigma \sim 200$ μm
• Magnet 135 x 55 cm$^2$, (35° x 15°)
  $B = 0.7$T
  ($\sim 10^6$/sec, $E_{\text{max}} = 2.4$GeV)

Same acceptance for the $+$ and $-$ charged particles
($\phi \rightarrow K^+K^-$)
Upgrade items @LEPS

- **Beam**
  - Intensity: $1 \times 10^6 / \text{sec} \rightarrow 2 \times 10^6 / \text{sec} \rightarrow$ more
  - Energy: $E_{\text{max}} = 2.4 \text{ GeV} \rightarrow E_{\text{max}} = 3 \text{ GeV}
  - Stability

- **Detector**
  - Acceptance: FWD spectrometer $\rightarrow$ FWD+Side-way
  - DAQ

- **Target**
  - Polarized target: LH$_2$, LD$_2$ $\rightarrow$ polarized HD

*I will Skip the DAQ and polarized HD in my talk. Their developments are going on and recently some progress has been made.*
1st upgrade (2004): Time Projection Chamber (TPC) was introduced for the study of $\Lambda(1405)$

missing mass spectrum can not separate $\Lambda(1405)$ and $\Sigma(1385)$

→ detect decay products and distinguish two resonances

$$\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ \Sigma^{\pm} \pi^{\mp} \rightarrow K^+ n \pi^+ \pi^-$$

$$\gamma p \rightarrow K^+ \Sigma(1385)^0 \rightarrow K^+ \Lambda \pi^0 \rightarrow K^+ p \pi^- \pi^0$$
\( \Lambda(1405) \)

- Long-standing question: 3q state or meson-baryon resonance?
  Large energy difference between \( \Lambda(1520) 3/2^- \) and \( \Lambda(1405) 1/2^- \rightarrow 3q \)
- Line shape is reproduced as the meson-baryon molecule in Chiral Unitary model.
  \( \rightarrow \) predict the medium modification of its width in nucleus.
- 2-poles of \( \pi \Sigma \) and \( \bar{K}N \)? Pole position of \( \bar{K}N \) is especially important for kaonic nuclei (bound \( Kpp \) state) and \( K \)-condensation in neutron star.

\[ \text{Jido et. al NPA725 (2003) Nacher et al., PLB455 (1999)} \]
Time Projection Chamber

3-dimentional position information:
- pad-plane → x-y position
- drift time → z position
- dE/dX, momentum → PID

No thick materials for opposite side of the pad plane, i.e., forward region.
(CDC needs wire support frames)
TPC

Drift field cage

High voltage plane

700mm

Beam

Target holder

Wire & pad plane

E // B

Active volume (cylindrical shape)
700 mm in length
400 mm in diameter

A Solid Target (CH2 or C) is put inside the TPC for detecting Σ decay point, if possible.

Pad design

Cathode pads : 1055
Anode wires : 95

Resolution
Drift direction : 800 μm
Pad plane : 400 μm
Setup of TPC experiment

- In e storage ring
- Tagging counters

1.5 ~ 2.4 GeV

- photon beam
- Collimator
- Buffer Collimator
- TPC
- Solenoid
- Start Counter
- Dipole Magnet
- Only FWD spectrometer
- ~ ± 25°
- TOF Counters
- Drift Chambers
- Up Stream e+e- Veto Counter
- Aerogel Cherenkov Counter

- 0 m
- 1 m
- 2 m
- 3 m
- 4 m
Setup of TPC experiment

Measure both production and decay simultaneously!
Spectrum of $\Sigma(1385)$ in 2 $E_{\gamma}$ bins $[\text{CH}_2-\text{C}]$

$\gamma \, p \rightarrow K^+ \Sigma(1385) \rightarrow K^+ \Lambda \, \pi^0 \rightarrow K^+ p \pi^- \pi^0$

Missing mass

(a) $1.5 < E_{\gamma} < 2.0$

$\Lambda(1116)$

$\Sigma^0(1192)$

$\Sigma(1385)$

(b) $2.0 < E_{\gamma} < 2.4$

$\Lambda(1116)$

$\Sigma^0(1192)$

$\Sigma(1385)$
Spectrum of $\Lambda(1405)$ in 2 $E_\gamma$ bins [CH$_2$-C]

- data
- $\Sigma(1385)$ ($\Lambda\pi^0$ mode)
- $\Sigma\pi$ phase space
- $K^*(892)\Sigma^+$
- theoretical model

$1.5 < E_\gamma < 2.0$ GeV

$\chi^2/\text{ndf} = 43/24$

$182 \pm 26$ events

$2.0 < E_\gamma < 2.4$ GeV

$\chi^2/\text{ndf} = 42/24$

$43 \pm 32$ events

$\Lambda^*/\Sigma^* = 0.54 \pm 0.17$ ($1.5 < E_\gamma < 2.0$)

$0.074 \pm 0.076$ ($2 < E_\gamma < 2.4$)
Absolute value of the differential cross section

Using the ratio of \( \Lambda(1405)/\Sigma(1385) \), the absolute value is obtained using LH2 data.

\[
0.8 < \cos \theta_{kCM} < 1
\]

<table>
<thead>
<tr>
<th>1.5 &lt; ( E_\gamma ) &lt; 2.0 GeV</th>
<th>2.0 &lt; ( E_\gamma ) &lt; 2.4 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d\sigma/d(\cos \theta) ) [( \mu b )]</td>
<td>( d\sigma/d(\cos \theta) ) [( \mu b )]</td>
</tr>
<tr>
<td>( \Lambda^*(1405) )</td>
<td>0.43 ( \pm ) 0.088(^{+0.034}_{-0.14} ) &lt; 0.17 with 95% C.L.</td>
</tr>
<tr>
<td>( \Sigma^*(1385) )</td>
<td>0.80 ( \pm ) 0.092(^{+0.062}<em>{-0.27} ) 0.87 ( \pm ) 0.064(^{+0.13}</em>{-0.067} )</td>
</tr>
</tbody>
</table>

\( t \) : -0.45 < \( t \) < -0.12 GeV\(^2\) \quad -0.37 < \( t \) < -0.08 GeV\(^2\)

The production cross section of \( L(1405) \) decreases in higher photon energy region. It suggests the difference of production mechanism and/or their internal structures.

Niiyama et al. PRC78,035202(2008)

- 351nm Ar laser (6.5W CW) was replaced by 355nm solid-state laser:
  (1) quasi-CW (80 MHz, 8W)  (2) no interference
- 2-laser injection has been installed at BL33LEP ⇒ ~2 Mcps
- But aperture of BL33LEP is narrow. [Only 20 mm / laser is allowed.]
  ⇒ Larger aperture will give more efficient transmission and allow additional laser injections. → LEPS2

Used in 2006-2007 run for the Θ+ study with higher statistics
3rd upgrade: Energy up with deep-UV laser

\( E_{\text{max}} = 2.96 \text{ GeV} @ 257\text{nm Ar laser} \)

2005: test exp. for \( \omega \) mesic nucleus

2006:

\[ \gamma + p \rightarrow K^0 + \Sigma^+ \]

But the intensity is still low \(<1.8 \times 10^5\).

Very unstable due to the fast deterioration of the optical system.
4\textsuperscript{th} upgrade: new TPC for the cryo-targets (2008~)

Physics motivation

\[ \tilde{\gamma} + p \rightarrow \Theta^+ + \bar{K}^{*0} \quad (K^* \rightarrow K\pi) \]
\[ \tilde{\gamma} + n \rightarrow \Theta^+ + K^{*-} \]
\[ \tilde{\gamma} + p \rightarrow \Theta^+ + K^{*-} + \pi^+(\mp) \]
\[ \tilde{\gamma} + A \rightarrow \text{backward } \phi \text{ production} \]
\[ \tilde{\gamma} + p \rightarrow \Lambda^*(1405) + K^{*+} \]

etc.

Decay asymmetry of $K^*$
\[ \rightarrow \text{sensitive to the parity of exchange particle(s)} \]

new TPC (NTPC) 2.96 GeV $\gamma$
new LH$_2$, LD$_2$ target

\textit{information of both missing masses and invariant masses}
new TPC design

Strong boundary condition: use it with the LEPS solenoid (60 cmφ bore)

- **TPC-I**
  - decay vertex for Σ
    - no inner bore (diameter of target pipe: 25mmφ)
      - Anode wire: one direction, Pad raw: circular, two sizes
    - large position-dependent $\sigma_{xy}$ (300μm to ~800μm)
      - LH₂, LD₂, LHe: impossible

- **new TPC**
  - inner bore size: ~100mmφ for LH₂, LD₂, LHe target
  - hexagonal shape
  - small dead region for the wire-supporting
  - need better $\sigma_{xy}$ for good $\Delta p/p$ ($L_T$ is small!)

$$
\frac{\Delta p_t}{p_t} \approx \frac{\sigma_{xy} p_t}{0.3BL_T^2} \sqrt{\frac{720}{N+4}} \approx 5.4\% \quad @\sigma_{xy} = 200 \mu m, \quad p_t = 0.5 \text{ GeV/c}
$$
New TPC

- LEPS new TPC
  - Inner bore for the cryo-target
  - Determine y-position by using anode wire information

- Add a DC covering the Forward region
New Time Projection Chamber

- Pad size: **5.1mm x 14.5mm**  
  - space: **0.5mm**  
  - 9 layers **225 pads** / sector  
  - (total **1350 pads**)

- Wire anode wire: 27 x 2 (upper half & lower half) = 54 wires  
  - Spacing of anode and potential wires: **2.5mm**  
  - Distance from the pad plane = **4mm**

3-plane structure of gate wires, shield wires, and anode/potential wires
Liquid Cryo-Target System

**target cell**
- Kapton film
- length 150mm
- diameter 40mm\(\phi\)

**CFRP cap**
- (carbon fiber)
**Trigger Counters**

- **inner scintillator**
  - 6 counters (1 for each sector)
  - PMT: one side
  - thickness: 3mm

- **outer scintillator**
  - 12 counters (2 for each sector)
  - PMT: both sides
  - thickness: 5mm
  - time resolution = ~150ps

- **forward scintillator**
  - 4 counters
  - PMT: both sides
  - thickness: 10mm
  - time resolution = ~100ps
Set up

- Before target install
  - Dipole
  - Outer scintillator
  - Solenoid
  - Downstream side
  - Forward scintillator
  - Drift chamber
  - TPC
  - PMT of outer scintillator
  - Liquid target system

- After target install
  - Dipole
  - Inner scintillator
  - PMT & light guide
  - Upstream veto scintillator
  - Solenoid drift chamber
  - PMT of inner scintillator
Summary of LEPS upgrade

- LEPS@Spring-8 has been successfully operated since 2000.Dec for the study of the quark nuclear physics. We have continuously tried to upgrade the LEPS, just after the LEPS experiment was started.
- Beam intensity has been increased \((1 \times 10^6 \rightarrow 2 \times 10^6 / \text{sec})\) by means of two laser injection for the 2.4 GeV beam.
- Beam energy has been upgraded using the 257nm deep-UV laser. But the intensity is still low and unstable.
- Two TPCs have been constructed to enlarge the side-way acceptance. (One is for the inner solid target and the other is for the cryo-liquid target.)

  \[
  \text{Momentum resolution and PI capability are limited by detector size} \\
  \rightarrow \text{LEPS2}
  \]

- The first 10-year contract with Spring-8 has been finished. \(
  \rightarrow \text{extend the LEPS next 6 years.}
\)
- higher intensity \((8W \rightarrow 16W \text{ for } 355\text{nm}, \text{2-laser injection for } 257\text{nm})\), stable operation of 3 GeV beam, speed up of DAQ system, and use of the polarized target.
LEPS new beam line (LEPS2)

• Beam upgrade:
  Intensity  --- High power laser, Multi laser(x4)
  --- Laser elliptic focus
  \[2 \times 10^6 \rightarrow 10^7 /\text{sec} \text{ for } 2.4 \text{ GeV}\]
  \[2 \times 10^5 \rightarrow 10^6 /\text{sec} \text{ for } 3 \text{ GeV}\]
  Energy  --- Laser with short \(\lambda\), re-injected Soft X-ray+BCS (2\text{nd} stage),
  \(\rightarrow\) up to \(~7.5\) GeV

• Detector upgrade: (reaction process & decay process)
  Scale &  --- General-purpose large 4\(\pi\) detector
  Flexibility  Coincidence measurement of charged particles and
  neutral particles (photons) \(\leftarrow\) BNL/E949 detector
  DAQ  --- High speed for the minimum bias trigger

• Physics: Multi-quark (>3)
  Workshop on LEPS2 (2005/7, 2007/1)

Virtual laboratory http://www.hadron.jp
What to measure?

Imai-san’s comment in the workshop

A unique new device can always lead us to a discovery, since the nature is richer than human being can imagine. LEPS new beam line should be such a unique (in the world) device.

- highest intensity and/or highest energy Compton $\gamma$ beam

- High priority
  → Further confirmation of the $\Theta^+$ with high statistics, wide energy range, and large acceptance.
  Determine the spin and parity of $\Theta^+$
Schematic view of the LEPS2 facility

Backward Compton Scattering

a) SPring-8 SR ring

8 GeV electron

30m long line

Recoil electron

(Tagging)

Laser or re-injected X-ray

b) Laser hutch

Inside building

High intensity:
Multi laser injection & Laser beam shaping
~10^7 photons/s

High energy:
Re-injection of X-ray from undulator
E_\gamma < 7.5 GeV

New DAQ system will be adopted

Outside building

Large 4\pi spectrometer based on BNL-E949 detector system. Better resolutions are expected. New DAQ system will be adopted
Divergence of LEP beam

BL31ID $\langle \sigma_x' \rangle = 14 \mu\text{rad.}$

BL33B2 $\langle \sigma_x' \rangle = 58 \mu\text{rad.}$

Better divergence $\rightarrow$ Better tagging resolution
Smaller beam size at the target
Laser hutch for new beam line

BL31 (30m straight section)

Laser hutch will be placed out of the beam line.

→ no radiation shield

→ close to the collision point
High Energy Backward Compton Photons

\[ \frac{d\sigma}{dE_\gamma} \text{ (mb/MeV)} \]

- 350 nm (3.54 eV)
- \( E_x = 100 \text{ eV} \)
- \( E_x = 10 \text{ keV} \)

\[ E_\gamma \text{ (GeV)} \]
Backward Compton Scattering of X-ray for Ultra High Energy LEP
Energy Spectrum of High Energy $\gamma$

$$\frac{d\dot{J}}{dE_\gamma} = \int_{\omega_1}^{\omega_2} d\omega \frac{d\sigma}{dE_\gamma}(\omega) \frac{d\dot{N}_{ph}}{d\omega}$$

Estimated LEP Intensity

$$\dot{N}_\gamma = 2 \times 10^5 / s$$

Need R&D study for the mirror, especially its radiation hardness.
Experimental building for LEPS2
Detector Setup

Target cell

CFRP

SSD

Range and TOF

Barrel γ

Barrel Tracker

TPC or CDC

MWDC

Target and Vertex detector

3 m
\[ \gamma d \rightarrow \Lambda(1520) \Theta^+ \]

\[ \gamma d \rightarrow \Lambda(1520) \Theta^+ \xrightarrow{K^- p} \]

\[ \Delta M(\Theta^+) = 17 \text{ MeV/c}^2 \]

\[ \gamma d \rightarrow \Lambda(1520) \Theta^+ \xrightarrow{K^- p K^+ n} \]

\[ \Delta M(\Theta^+) = 10 \text{ MeV/c}^2 \]

\[ \gamma d \rightarrow \Lambda(1520) \Theta^+ \xrightarrow{K^- p K_s p} \]

\[ \Delta M(\Theta^+) = 3 \text{ MeV/c}^2 \]
Status of the LEPS2 project

- 2005.6: Discussion for the LEPS2 beamline was started.
- 2005.7: First workshop was held at RCNP → Both physics and technical issues.
- 2005.12: Basic agreement for the movement of the E949 detector was made with BNL and associated laboratories.
- Numerical consideration for getting the high energy γ beam by re-injection of X-ray has been performed. → Need R&D for the mirror.
- Test of the LRNB method for the high intensity LEP → The same intensity as the normal Gauss beam
- 2006.4: Test of the two laser injection → succeed!
- Disassembling work for E949 detector
- Discuss detector design, modification of beamline etc.
- 2007.1: Second workshop @RCNP
- 2008.1: Change the plan of the laser hutch place.
- 2008.11: Loan agreement for the E949 detector

- LOI to Spring-8: 2006.12 Hearing → Approved. BL31 was assigned.
- Budget request: 2007FY, 2008FY from RCNP → X
Backup
Differential cross section of $\Lambda(1405)$ production

Interesting idea by Jido and En’yo:
KKN bound state. (PRC78,035203(2008))

$M \sim$ below KKN threshold (1930 MeV)
$\Gamma \sim 90$ MeV

Need more statistics experimentally!
Laser Beam shaping

- Electron beam is horizontally wide.  
  ⇒ BCS efficiency will be increased by elliptical laser beam.

  • Both methods are technically available, but option (1) will be easier. (ITOCHU Aero-Tech)

  Beam Spot at focus point:
  Horizontal size = electron beam
  Vertical size = 1/2 x horizontal size.
  ⇒ Energy density becomes twice.
LEPS2 LOI was approved: BL31 was assigned for LEPS2.
Collaboration

- Core institutes
  - RCNP
  - LNS Tohoku U.
  - SPring-8/JASRI Accelerator group
  - RIKEN Radiation Laboratory (new !)

- Other LEPS members
  - Kyoto U., Osaka U., Konan U., Chiba U., Yamagata U., Miyazaki U., Pusan U.(Korea), Seoul U.(Korea), Academia Sinica (Republic of China),
  - Ohio U. (USA), Saskatchewan U. (Canada) etc.

- New members
  - National Defense Academy, …
  - some members from the BNL-E949 experiment
    (domestic and foreign institutes (BNL, TRIUMF,…))

Try to strengthen the collaboration group
Particle Identification

de/dx vs Momentum and/or TOF vs Momentum

(PI is difficult for higher momentum due to small inner diameter of the solenoid!)

$\pi K$ $2\sigma$ separation at 0.5 GeV/c $\rightarrow$ $\sigma$(TOF) = 150 ps or $\sigma$(de/dx)/(dEdx) = 16%
Particle Identification

PID by TPC

Graphical representation of particle identification using $dE/dx$ (arbitrary unit) vs. momentum/charge (GeV/c) for $\pi^+$, $K^+$, and $p$.

- $K^+$ track
- $\pi^+$ track
- $p$ track
- $D$ track