Recent status and plans at SPring-8 LEPS2 facility

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LEPS and LEPS2 collaborations
Contents

• SPring-8/LEPS2 overview
  – LEPS2 and BGOEGG experiment is just now starting.

• Physics motivations at LEPS2 and BGOEGG
  – \( \eta' \) mesic nuclei, baryon resonance, etc

• Experimental setup for LEPS2 and BGOEGG

• Summary
**SPring-8/LEPS**

- $E_\gamma \sim 2.4 \text{GeV}$
- Polarization $\sim 95\%$
- $\sim 1 \text{ Mcps}$

LEPS spectrometer
- Detect charged particle at Forward angle
- $\theta \sim 20\text{ deg}$
Backward Compton Scattering

8 GeV electron

Recoil electron (Tagging)

SPring-8 SR ring

30m long line (LEPS 7.8m)

Better divergence beam ⇒ collimated photon beam ⇒ better tagger resolution
Different focus points for multi CW laser injection

High intensity:
Multi (ex. 4) laser injection w/ large aperture beam-line & Laser beam shaping
~10^7 photons/s (LEPS ~10^6)

High energy: Re-injection of X-ray from undulator
E_γ < 7.5 GeV (LEPS < 3 GeV)

Laser hutch

Laser or re-injected X-ray

GeV γ-ray

Large acceptance EM calorimeter BGOEGG.

Large 4π spectrometer based on BNL-E949 detector system.
PHYSICS MOTIVATION
$\eta'(958)$ and $U_A(1)$ anomaly

- The experimental mass of $\eta'$ is more than 2 times larger expected value.  
  - $U_A(1)$ anomaly effect.
- Origin of large $\eta'$ mass  
  - Chiral symmetry breaking  
  - $U_A(1)$ anomaly


Poor experimental information for $U_A(1)$ anomaly effect
Mass reduction of $\eta'(958)$

• Prediction from NJL model

$$\mathcal{L} = \bar{q} (i \not\partial - m) q + \frac{g_s}{2} \sum_{a=0}^{g} \left[ (\bar{q} \lambda_a q)^2 + (i \bar{q} \lambda_a \gamma_5 q)^2 \right]$$

$$+ g_D \left[ \det \bar{q}_i (1 - \gamma_5) q_j + h.c. \right]$$

KMT interaction: $U_A(1)$ anomaly

$$g_D = \text{const} \quad g_D = 0 \quad g_D \sim \exp[-(\rho/\rho_0)^2]$$

H. Nagahiro, M Takizawa, S. Hirenzaki
Mass modification in finite density

- Mass of $\eta'$ is possibly modified under the finite density compared with mass in the vacuum
  - $\Delta m_{\eta'} \sim -150\text{MeV} @ \rho_0$
  - $\Delta m_{\eta} \sim +20\text{MeV} @ \rho_0$

- H. Nagahiro, M. Takizawa, S. Hirenzaki
Measurement of $\eta'$ in finite density

- Large mass reduction (150 MeV) of the $\eta'$ meson in the normal nuclear density

- Existence of a bound state with a nucleus ($\eta'$-mesic nuclei)

- If we observe the $\eta'$ bound state, we get the information for UA(1) anomaly effect.
η’-mesic nuclei

- Strong attractive force and small absorption
  - Attractive force
    - $U_A(1)$ anomaly effect
  - Absorption
    - $\text{Re}W_0 \sim 7.5-12.5\text{MeV} \ (\text{CB-ELSA})$
      - M. Nanova et al., PLB 710, 600 (2012)
- Experimental results
  - $\text{Re} a_{\eta'N} < 0.8\text{fm}$
  - $|a_{\eta'N}| < 0.1\text{fm}$
- Optical potential with Chiral unitary model
  - $\text{Re}V \gg \text{Im}V$ (possible)

$\rightarrow$ more detailed experiment!

Search the η’ mesic nuclei using nuclear target.
• Lower Recoil momentum of $\eta'$ than hadron beam

• Experimental parameters
  – $E_\gamma$ 1.6~2.9 GeV
  – Target C
  – Forward proton detection

$\eta'$ mesic nuclei in ($\gamma$,p) reaction

Numerical results: $^{12}$C($\gamma$,p)$^{11}$B$_{\eta',\eta}$

$g_0 = -12.36/\Lambda^5$

$V_0 = -(156\pm29)$ [MeV]

(Klingl et al., NPA650(99)299)

$W_0 = -20$ MeV

Mass reduction due to the medium effect through anomaly term

C($\gamma$, p )X missing mass

Hirenzaki@ELPH 2011
Baryon resonance study with multi-meson production

- The multi-meson photoproduction process provides important information on highly excited baryon states, which usually have a large branching ratio to multi-meson decay channels.

Invariant mass in $\gamma p \rightarrow \pi^0 \eta p$ reaction


Highly exited baryon state contribution
P33(1920), D33(1930)

More detaild study with BGO EGG @LEPS2
LEP2 Project at SPring-8

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LEPS2 laser system

- simultaneous 4-laser injection
- Increase the laser power
  - 8 W → 16 W or 24W
- Smaller beam size
  - Lower $e^-$ divergence
    \[ <\sigma_x> = 58 \, \mu m \rightarrow 14 \, \mu m \]
First beam observation at LEPS2

beam profile is well collimated
consistent with the expectation

Energy spectrum with
large BGO crystal (φ 8 cm x L 30cm)

Photon beam intensity \( \sim 7 \text{ MHz} \) (for \( 0 < E_\gamma < 2.4 \text{ GeV} \))
@ 3-(355nm) laser
LEPS2 tagging system

PL counter: 4mm-thick x 8mm-wide x 10-mm high
SciFi : 1mm x 6mm thick
Large acceptance EM calorimeter

BGO EGG

- Egg like shape
- Total volume 264L
- Total weight 1.9t (crystal only)
- Two type photomultipliers
  - H11334 (metal package type)
  - H6524 (head on type)
- Very few dead-region
  - Without housing material
  - Only with 3M-Vikuity ESR film reflector.
Overview of BGOEGG

- Forward (24° - 90°)
  - 13 layers (153L)
- Backward (90° - 144°)
  - 9 layers (112L)
- 1320 BGO Crystal with 220mm(20X₀) length
- Each crystal is pyramidal shape with isosceles trapezoid face.
- 60 BGO crystals per layer
Performance of BGOEGG

- We test the 5x5 proto-type BGO detector at ELPH
- Positron beam (100-800MeV)
  - Energy resolution
  - Position resolution
- Reflector
  - ESR film
- PMT H11334
- Gate width is 2µs
  - LeCroy2249w
- SciFi phodoscope (3mm fiber, 16x16) position detector
Performance of BGO EGG

**Energy resolution**

- 1.3% energy resolution @ 1GeV
- 3.1 mm for central modules
- 3.7 mm for peripheral modules @1GeV
Simulation result of BGO EGG

- Geant4 simulation
  - 44.3% $\eta' \rightarrow \pi^+\pi^-\eta$
  - 29.5% $\eta' \rightarrow \rho\gamma$
  - 20.9% $\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$
  - 2.1% $\eta' \rightarrow \gamma\gamma$
    @ proton target (40mm)

- $\eta'$ mass resolution
  ~2.8 %

- 1,0000 $\eta'$ event @ LEPS2 per 1 month

* BGO EGGで$\gamma\gamma$の2クラスターのみ検出
BGOEGG test with LEPS2 beam

Test experiment at Jan 2013

Only 300 channel is activated (forward 5 layer)

\[ \gamma\gamma \text{ invariant mass / 6hour} \]

Resolution is worse because of incomplete calibration
Peripheral detectors

- Time of flight counter
  - RPC
- Charge identification detector
- Charged particle tracker chambers
  - CDC, DC
Resistive Plate Chamber (RPC)

- Focus on mesic nuclei search
  - 12 MeV forward proton momentum resolution
  - $\geq 50$ psec time resolution at 12 m flight length

[Graph showing resolution vs proton momentum]

- 3m and 2m dimensions
- 32 modules in wall
Resistive Plate Chamber (RPC)

- Glass resistive plate with Freon and SF$_6$ gas
- Narrow gap → good time resolution
- Multilayer → high efficiency, resolution
Performance of RPC

- Test experiment for RPC at SPring-8/LEPS
- Electron from converter and Dipole magnet
- Estimated resolution: $\sigma \sim 50$ ps!

SPring-8 /LEPS

$e^- \rightarrow e^+ e^- e^-\rightarrow e^-$

Finger scintillator

1 cm*2 cm

$e^+$

RPC

Backward Compton $\gamma$

1.5 ~ 2.4 GeV

$e^-$

$e^+$

$e^-$

$\bigotimes B$

counts

-50 ± 2 ps

RPC-RF
Charge identification detector

- Place at inside of BGOEGG
- 30 scintillators with overlap.
- Scintillator size
  - 5 x 26 x 413
  - -> covering the inner face of BGOEGG
- Multi Pixel Photon Counter (MPPC) readout
  - Effective area 3mm × 3mm
  - Pixel size 50um × 50um
Charge identification detector

Scintillator with 5-connected MPPC
Charged particle tracker chambers

- Inner vertex chamber
- Inside of charge identification detector
- 4 layer (U, U’, V, V’)
- 550mm length
Charged particle tracker chambers

- Charged particle Positions/angles at forward angle ($\theta < 24^\circ$)
- 6 planes (XX’UU’VV’)
- 80 sense wires / plane
- Effective area: $\phi 1280 \text{ mm}$
- 16 mm square cell
  - $\sigma = 130 \mu\text{m}$
Yield estimation $\eta'$ mesic nuclei by $\eta$ tagging at BGOEGG

E. Oset and A. Ramos, PLB704 (2011) 334

- Dominant conversion from $\eta'$
  $\sim \eta'p \rightarrow \eta p$
  - $\eta \rightarrow \gamma \gamma$ (39.3%)
  - $\eta \rightarrow \pi^0 \pi^0 \pi^0 \rightarrow 6\gamma$ (33%)

Multi meson production background
Will be suppressed by $\eta$ tag at BGOEGG!

**Expected yield**

- $d^2\sigma/dE\,d\Omega \sim 2\text{nb/sr/MeV}$
- Target $\sim$ Carbon 20mm
- Beam intensity $\sim 2\text{Mcps}$ (Tag. Eff$\sim$50%)
- Forward proton with RPC(2x4m)
  - $\rightarrow 70000\text{ event / month}$
- With $\eta$ tag at BGOEGG
  - $\rightarrow 2\sim3000\text{ event / month}$
  (\eta'N$\rightarrow\eta N$ : 50% from bound state)
Summary

• SPring-8 LEPS2 facility just started
• LEPS2 has one order of magnitude higher intensity beam and large acceptance coverage.
  – BGOEGG, E949 based detectors.
• BGOEGG calorimeter experiments will start in this autumn.
  – $\eta'$ mesic nuclei, baryon resonance, etc
• Thanks!
This week photos

BGOEGG with all PMTs

RPC support frame

DAQ system