Photoproduction of $\pi^-\Delta^{++}$ and $\pi^+\Delta^0$ on the proton for the comparison of $\bar{u}u$ and $\bar{d}d$ productions

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Super Photon ring - 8 GeV

Electron storage ring

- 8 GeV electron beam
- Diameter $\approx 457$ m
- RF 508 MHz
- 1-bunch spread is within $\sigma = 12$ psec.
- Beam Current = 100 mA

120 km distant from Osaka
SPring-8 beamline map

BL31LEP Laser-Electron Photon II (Research Center for Nuclear Physics, Osaka University)

BL33LEP Laser-Electron Photon (Research Center for Nuclear Physics, Osaka University)
LEPS facility
LEPS experiment started in 2000

Collision

8 GeV electron

Recoil electron

Tagging counter

SSD + Sc hodoscope

ScFi + Sc hodoscope

Beam intensity
< 2.5 x 10^6 for E_\gamma = 1.5-2.4 GeV
(355 nm laser)

< 3.0 x 10^5 for E_\gamma = 1.5-3.0 GeV
(257 nm laser)

Laser light

36m

70m

Energy spectrum of BCS photons

Bremsstrahlung

a) SPring-8 SR ring

b) Laser hutch

c) Experimental hutch

Backward-Compton scattering
LEPS detector setup

LEPS detector was optimized to detect $\phi$ meson decaying to $K^+K^-$ at forward angles for removing $e^+e^-$ BG. Also removed pions.

- **Aerogel Cerenkov** ($n=1.03$) for removing $e^+e^-$ BG and also removed pions.
- **Dipole Magnet** (0.7 T)
- **Start counter**
- **Target**
- **TOF wall**
- **MWDC 1**, **MWDC 2**, **MWDC 3**
- **Silicon Vertex Detector**

Start counter
New experimental setup for high momentum $\pi$

Plastic counter for vetoing $e^+e^-$ was used

LEPS experiments are complementary to JLAB/CLAS experiments. Data in the LEPS kinematical region are missing in the world data set.
High momentum $\pi$ data

Momentum (GeV/c)

Counts

Mass / Charge (GeV/c²)

Momentum range of previous experiments
Missing mass of $p(\gamma, \pi^+)X$

$p(\gamma, \pi^-)X \quad 0.7 < \cos \theta_{\pi} < 1$

$E_\gamma = 1.5 - 3.0 \text{ GeV}$

$p(\gamma, \pi^+)X \quad 0.7 < \cos \theta_{\pi} < 1$

$E_\gamma = 1.5 - 3.0 \text{ GeV}$
ūu and ũd productions

ūu production is precisely compared with ũd production by the γp → π− Δ++ and π+Δ0 reactions

Simultaneous measurements

Same proton target

Same acceptance

I expect this comparison would give important information to understand how hadrons are produced.
SAPHIR data published in 2005

Physics motivation of $\pi\Delta$ reactions at $E_\gamma$=1.5-3.0 GeV

Low energy \(\sim E_\gamma=1.5\) GeV
Missing resonance search \(s\)-channel

High energy \(\sim E_\gamma=3.0\) GeV
Study other mechanisms than $\pi, \rho$ -exchange in \(t\)-channel

\[\gamma \rightarrow pN^* \rightarrow \pi \Delta\]
\[\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++}) = 1/3\]
Isospin=1

\[\gamma \rightarrow p\Delta^* \rightarrow \pi \Delta\]
\[\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++}) = 4/3\]
Isospin=2

\[\gamma \rightarrow p\Delta \rightarrow \pi \Delta\]
\[\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++}) = 1/3\]
Missing mass \( p(\gamma, \pi)X \)

Missing mass spectrum is fitted with relativistic Breit-Wigner shape for \( \Delta \), \( 2\pi/\rho \), \( 3\pi \), and \( e^- \) or \( e^+ \) curves.

\[
p(\gamma, \pi^-)X \quad \text{0.7}<\cos\theta_{\pi}<1 \quad \text{\( E_\gamma=1.5-3.0 \) GeV}
\]

\[
p(\gamma, \pi^+)X \quad \text{0.7}<\cos\theta_{\pi}<1 \quad \text{\( E_\gamma=1.5-3.0 \) GeV}
\]
Differential cross sections for $\pi^-\Delta^{++}$ and $\pi^+\Delta^0$

\[
p(\gamma, \pi^-)\Delta^{++} \quad \text{and} \quad p(\gamma, \pi^+)\Delta^0
\]

\[
\begin{align*}
    d\sigma / d\cos\theta & \quad (\mu b) \\
    0.7 < \cos\theta < 0.8 & \quad 0.8 < \cos\theta < 0.9 \\
    0.9 < \cos\theta < 0.93 & \quad 0.93 < \cos\theta < 0.97 \\
    0.97 < \cos\theta < 1 & \quad 0.97 < \cos\theta < 1
\end{align*}
\]
Ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ 

$\frac{\bar{d}d\text{ production}}{\bar{u}u\text{ production}}$ is enhanced or $\bar{u}u\text{ production}$ is suppressed.

$\frac{1}{3}$ is expected from isospin=1 exchange in the t-channel.
If interference between $\pi$ and $\rho$ exists, the ratio may be changed from $1/3$.

The interference between $\pi$ and $\rho$ exchanges may change the ratio of $1/3$. 

$t$-channel
Isospin=2 exotic meson exchange in the t-channel may increase the ratio if it exists.
Another explanation

Proton charge distribution

Pion cloud model

\[
|p\rangle = \sqrt{\frac{Z}{p_0}} |p_0\rangle + a_{N\pi/p} \left[ -\sqrt{\frac{1}{3}} |p_0\pi^0\rangle + \sqrt{\frac{2}{3}} |n_0\pi^+\rangle \right]
\]

\(\pi^+ (u\bar{d})\) may enhance \(\pi^+\Delta^0\) production (\(\bar{d}d\) production)

\[\rightarrow \text{ Larger } \sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++}) \quad (\bar{d}d / \bar{u}u)\]
Possible explanations of the ratio $\frac{\sigma(\pi^+\Delta^0)}{\sigma(\pi^-\Delta^{++})}$

(1) Interference between $\pi$ and $\rho$ exchanges.

(2) $I = 2$ exotic meson exchange (ratio = 3)

(3) Pion cloud

(4) $N^*$ (ratio = 1/3) and $\Delta^*$ (ratio = 4/3)

I am going to have discussions with theorists to obtain the best explanation.
Photon beam asymmetry using linearly polarized γ beams

\[ 0.7 < \cos \theta < 0.8 \]

\[ 0.8 < \cos \theta < 0.9 \]

\[ 0.9 < \cos \theta < 1 \]

\[ E_\gamma = 2.8-3.0 \text{ GeV} \]

\[ E_\gamma = 2.9-3.0 \text{ GeV} \]
Photon beam asymmetry for $\gamma p \rightarrow \pi^-\Delta^{++}$ and $\gamma p \rightarrow \pi^+\Delta^0$ reactions

Reaction mechanisms are different at large angles.

Both asymmetries are close to each other at small angles.
Before finalizing the $\pi\Delta$ analysis, the $\pi^+n$ results should be checked.

**Paper**

Differential cross section and photon beam asymmetry for the $\gamma p \rightarrow \pi^+ n$ reaction at forward $\pi^+$ angles at $E_\gamma=1.5-2.95$ GeV

H. Kohri et al. (LEPS collaboration)


arXiv: 1708.09574
Differential cross sections $\gamma p \rightarrow \pi^+ n$

**LEPS data agree with DESY and CLAS data.**

SAID reproduces LEPS data well.

Bonn-Gatchina calculations reproduce LEPS data well at $\cos \theta < 0.8$.

Differences become large at $0.8 < \cos \theta$ because of pure predictions.

Energy dependence is different at small $\pi^+$ angles.

$N^*$ or $\Delta^*$ effects?
Comparison of differential cross sections between $\pi^+n$ and $\pi^+\Delta^0$

Differential cross sections are similar to each other except for $E_\gamma \sim 1.5$ GeV.

$p(\gamma, \pi^+)n$  
$p(\gamma, \pi^+)\Delta^0$

d$\sigma$/d$\cos\theta$ (µb)

$0.7 < \cos\theta < 0.8$

$0.9 < \cos\theta < 0.93$

$0.97 < \cos\theta < 1$

$0.8 < \cos\theta < 0.9$

$0.9 < \cos\theta < 0.93$

$0.97 < \cos\theta < 1$

$E_\gamma$ (GeV)
Ratio \( \frac{N_v - N_h}{N_v + N_h} \) for \( \pi^+ n \) reaction

\( \pi^+ \) favors to scatter at \( \phi \) perpendicular to the polarization plane.

\( \rightarrow \) Asymmetries(\( \Sigma \)) are positive.

\[ P_\gamma \Sigma \cos 2\phi_\pi = \frac{N_v - N_H}{N_v + N_H} \]

\( P_\gamma \): Polarization of photon beam

\( \Sigma \): Asymmetry
Photon beam asymmetry for $\gamma p \rightarrow \pi^-\Delta^{++}, \pi^+\Delta^0, \pi^+n$ reactions

$0.7 < \cos \theta < 0.8$

$0.8 < \cos \theta < 0.9$

$0.9 < \cos \theta < 1$
Summary

* We newly took high momentum $\pi$ data at $E_\gamma=1.5$-2.95 GeV.

* Precise comparison between $\bar{u}u$ and $\bar{d}d$ productions is possible in $\gamma p \rightarrow \pi^- \Delta^{++}$ and $\pi^+ \Delta^0$.
Cross section ratio $\sigma(\pi^+ \Delta^0)/\sigma(\pi^- \Delta^{++})$ is found to be close to 1/3 at small angles and larger than 1/3 at large angles. $\bar{d}d$ production is enhanced or $\bar{u}u$ production is suppressed. Photon beam asymmetry is typically found to be negative for $\pi^- \Delta^{++}$ and positive for $\pi^+ \Delta^0$.

* Differential cross sections for $\gamma p \rightarrow \pi^+ n$ are close to those for $\pi^+ \Delta^0$.
Asymmetries for $\pi^+ n$ are large positive values. Cross sections and asymmetries agree with previous data.
LEPS/LEPS2 collaboration

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Thank you