



An Overview of Recent Results from LEPS

Sun Young Ryu (RCNP, Osaka University)
for the LEPS/LEPS2 Collaboration

Outline

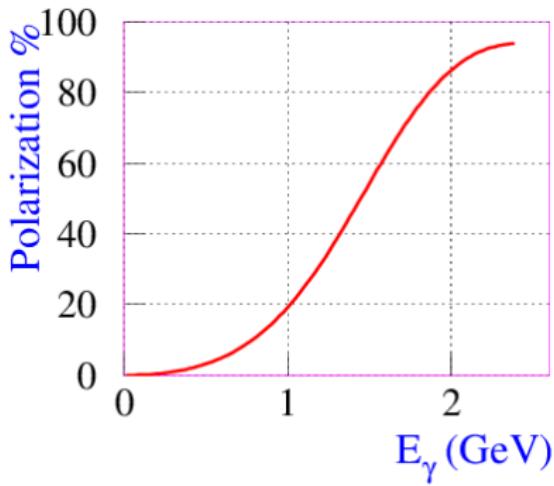
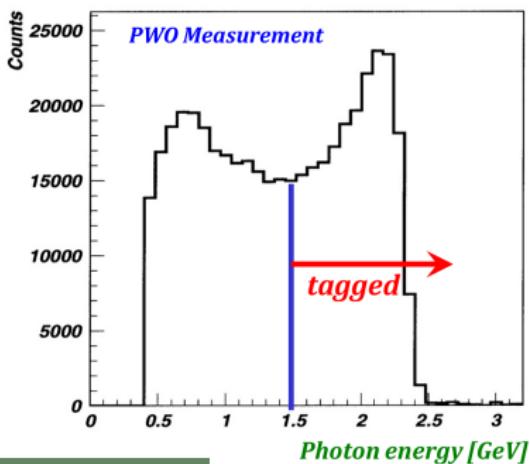
- 1 Interference effect between ϕ and $\Lambda(1520)$ production channels.

Published in *Phys. Rev. Lett.* **116**, 232001 (2016)

- 2 Current Status of the LEPS2 Solenoid Spectrometer
- 3 Photoproduciton of $K^- pp$ from LEPS and LEPS2
- 4 Photoproduction of $\Lambda(1405)K(892)$ from LEPS2
- 5 Search for Θ^+ at LEPS2

Compton Backscattered Photons from SPring-8

- Backward (head-on) Compton Scattering with laser light of 351 nm (3.5 eV) and 266 nm wavelength (4.6 eV) from 8-GeV electrons.
- Tagged photon in the energy region from 1.5 to 2.4 GeV (3.0 GeV) with $\Delta E_\gamma \approx 10$ MeV.



LEPS Spectrometer at SPring-8

- A dipole spectrometer at forward angles.

Dipole magnet : 0.7T

Acceptance

→ Hori. : $\pm 10^\circ$

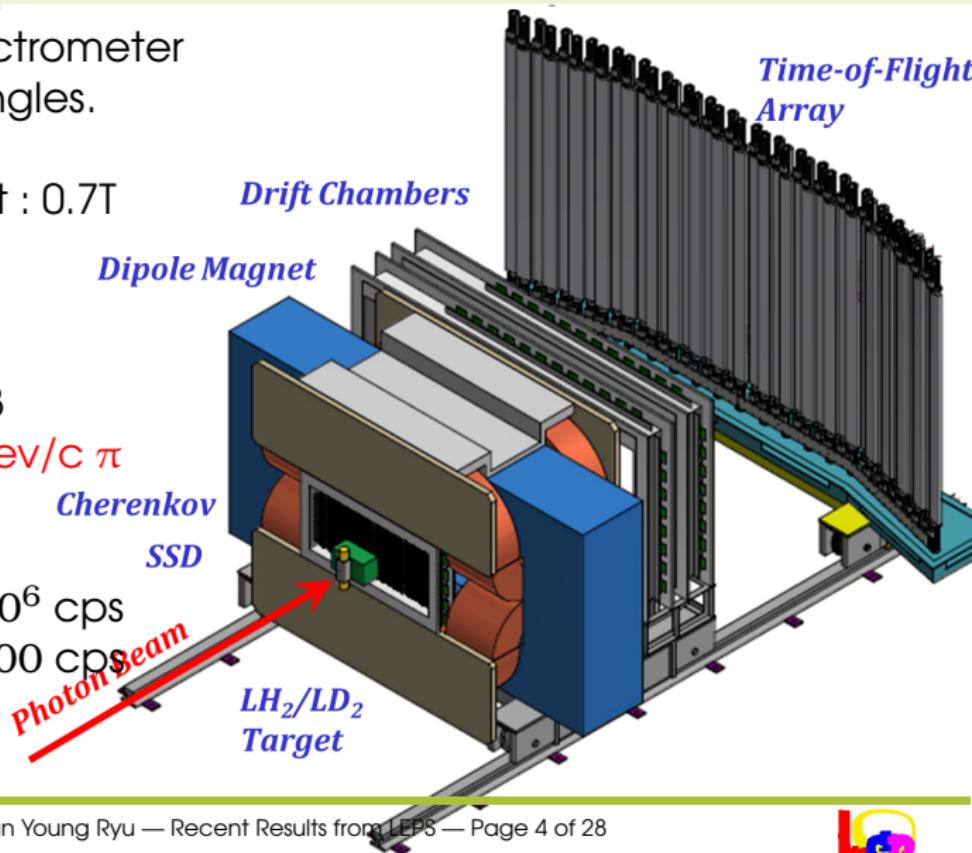
→ Vert. : $\pm 20^\circ$

AC Index : 1.03

→ reject 0.6 Gev/c π

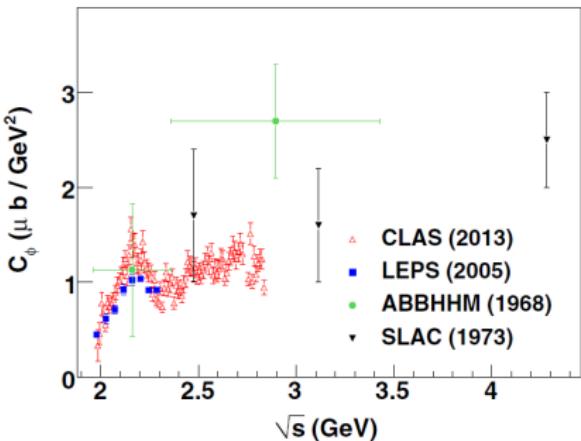
Tagger rate : 10^6 cps

Trigger rate : 100 cps



Bumps in ϕ Meson Photoproduction

- The $\sqrt{s} = 2.1$ GeV bump in ϕ photoproduction has not yet been explained in detail¹.



- ✓ Excitation of missing nucleon resonances²
- ✓ Hidden-strangeness pentaquark state³
- ✓ Rescattering processes⁴
- ✓ Interference effect between ϕ and $\Lambda(1520)$ production channels

¹T. Mibe *et al.* (LEPS), PRL 95, 182001 (2005); H. Seraydaryan *et al.* (CLAS) PRC 89, 182001 (2005); B. Dey *et al.* (CLAS) PRC 89, 055206 (2014)

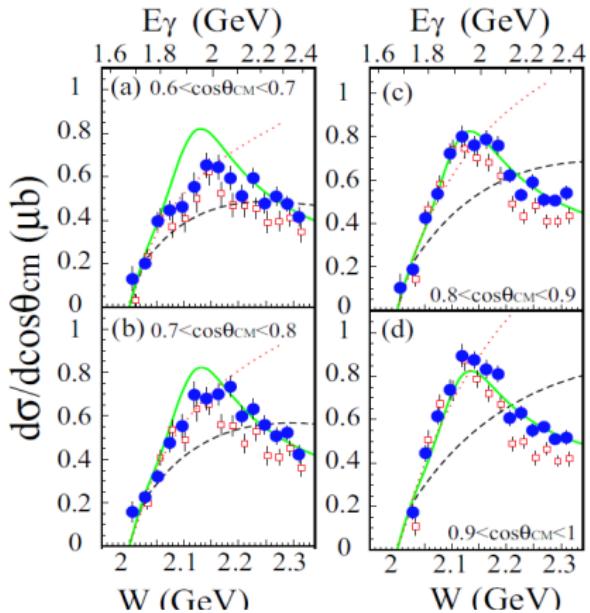
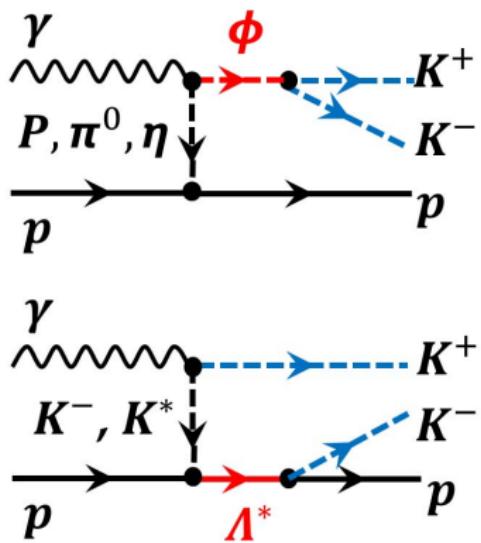
²A. Kiswandhi *et al.*, PLB 691, 214 (2010)

³R. Aaij *et al.* (LHCb), PRL 115, 072001 (2015)

⁴S. Ozaki *et al.*, PRC 80, 035201 (2009); H-Y. Ryu *et al.*, PTEP 2014, 023D03 (2014)

Bumps in ϕ and $\Lambda(1520)$ Photoproduction

- Similar bump in $\Lambda(1520)$ photoproduction⁵.



⁵H. Kohri et al. (LEPS), PRL 108, 092001 (2012)

Differential Cross Sections for $\gamma p \rightarrow K^+K^-p$

$$\begin{aligned}\frac{d^2\sigma}{dm_{K^+K^-} dm_{K^-p}} &\propto |\mathcal{M}_\phi + \mathcal{M}_{\Lambda(1520)} + \mathcal{M}_{nr}|^2 \\ &\approx |\mathcal{M}_\phi + \mathcal{M}_{\Lambda(1520)}|^2 + |\mathcal{M}_{nr}|^2,\end{aligned}$$

where \mathcal{M}_ϕ and $\mathcal{M}_{\Lambda(1520)}$ are the complex amplitudes for ϕ and $\Lambda(1520)$ production processes, respectively. \mathcal{M}_{nr} represents non-resonant K^+K^-p production.

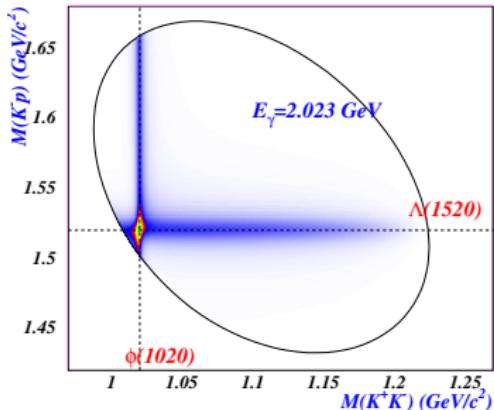
Interference between $\phi(1020)$ and $\Lambda(1520)$

Differential cross sections for the $\gamma p \rightarrow K^+ K^- p$ reaction via the ϕ and $\Lambda(1520)$ resonances:

$$\frac{d^2\sigma}{dm_{K^+K^-} dm_{K^-p}} \Big|_{\phi, \Lambda(1520)} \propto \left| \frac{a e^{i\psi_a}}{\underbrace{m_\phi^2 - m_{K^+K^-}^2 + im_\phi \Gamma_\phi}_{\mathcal{M}_\phi}} + \frac{b e^{i\psi_b}}{\underbrace{m_{\Lambda^*}^2 - m_{K^-p}^2 + im_{\Lambda^*} \Gamma_{\Lambda^*}}_{\mathcal{M}_{\Lambda(1520)}}} \right|^2,$$

where $a = a(E_\gamma)$ and $b = b(E_\gamma)$ denote the magnitudes of the Breit-Wigner amplitudes for ϕ and $\Lambda(1520)$.

Interference between \mathcal{M}_ϕ and $\mathcal{M}_{\Lambda(1520)}$



Theoretical calculation⁷

The integrated cross sections over the K^-p mass interval in the ϕ - $\Lambda(1520)$ interference region where the two resonances overlap⁶:

$$B(m_{K^+K^-}) = B(m_{K^+K^-}, E_\gamma)$$

$$\frac{d\sigma}{dm_{K^+K^-}} \propto \left| \frac{ae^{i\psi_a}}{m_\phi^2 - m_{K^+K^-}^2 + im_\phi\Gamma_\phi} + B(m_{K^+K^-})e^{i\psi_b} \right|^2$$

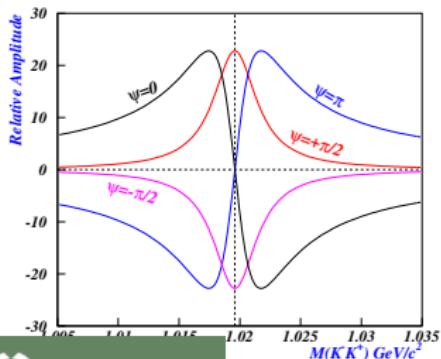
⁶Y. Azimov, J. Phys. G 37, 023001(2010)

⁷S. i. Nam et al. (to be published) for the theoretical calculation approach

Interference between \mathcal{M}_ϕ and $\mathcal{M}_{\Lambda(1520)}$

$$\frac{d^2\sigma}{dm_{K^+K^-}dm_{K^-p}} \propto \frac{|a|^2}{(m_\phi^2 - m^2)^2 + m_\phi^2 \Gamma_\phi^2} + |B(m)|^2 +$$

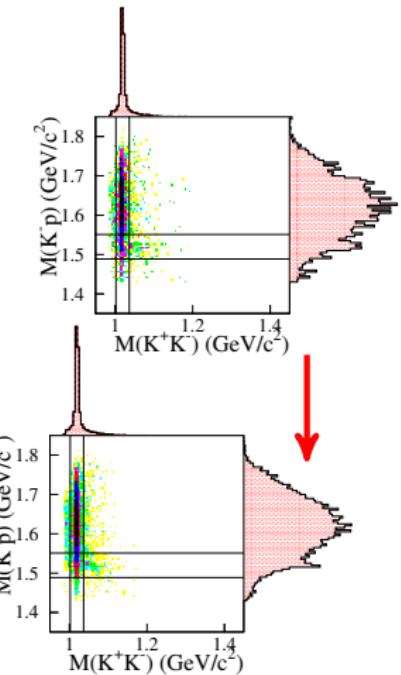
$$\frac{2(m_\phi^2 - m^2)|aB| \cos \psi + 2\Gamma_\phi m_\phi |aB| \sin \psi}{(m_\phi^2 - m^2)^2 + m_\phi^2 \Gamma_\phi^2}$$



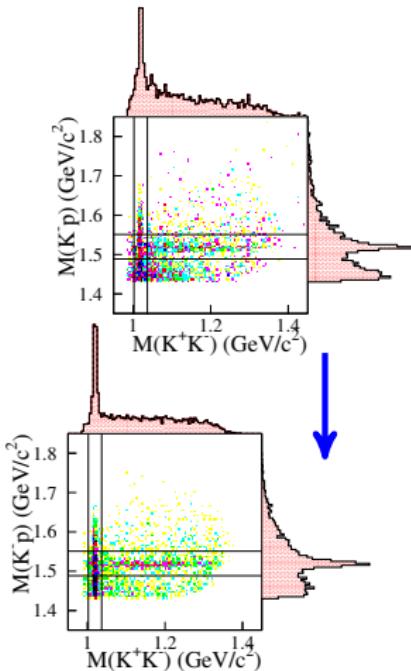
Maximum constructive at $\psi = +\pi/2$
Maximum destructive at $\psi = -\pi/2$.

K^+K^-p Events from Kinematic Fit

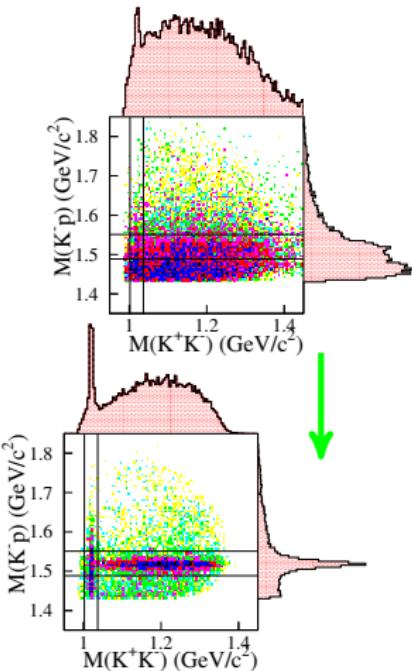
K^+K^- detection



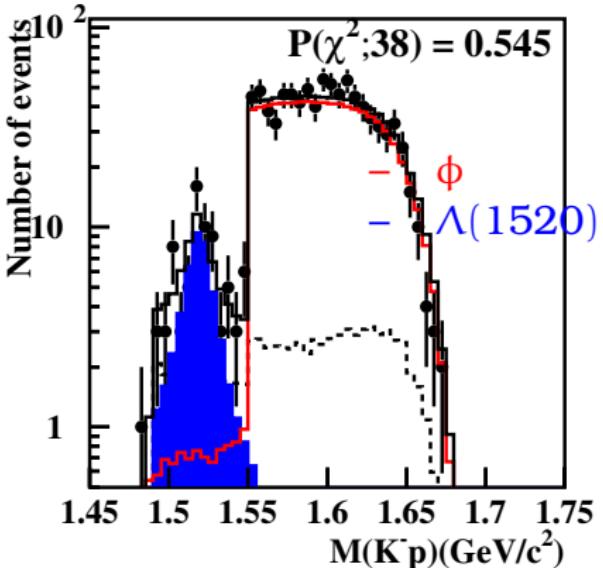
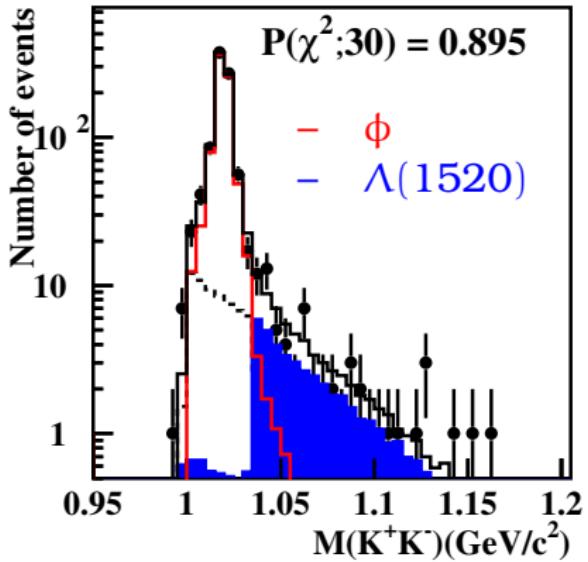
K^-p detection



K^+p detection



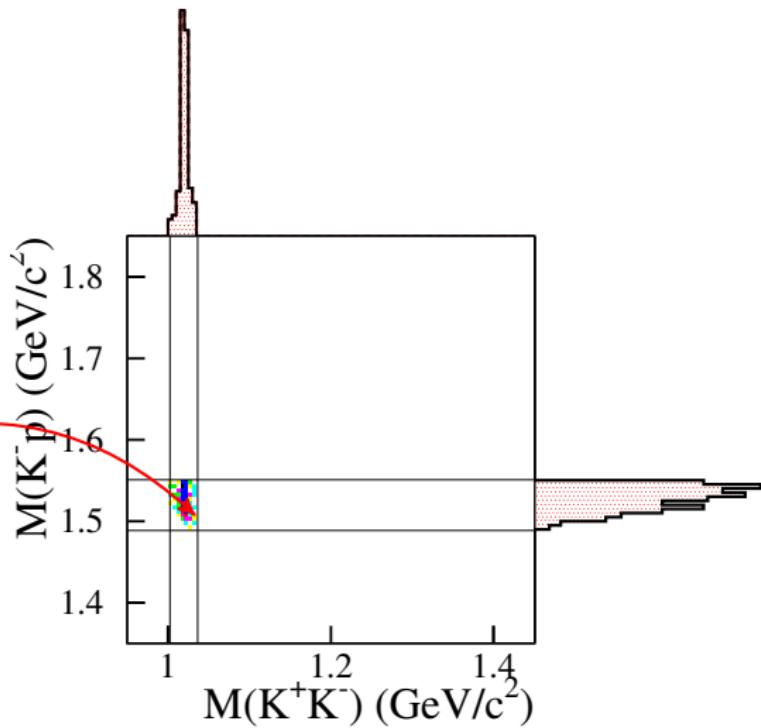
2-D Fit with MC Templates for $\gamma p \rightarrow K^-K^+(p)$



- : The invariant mass spectra for K^+K^- (left) and K^-p (right) system
- - - : MC data for non-resonant K^+K^-p production

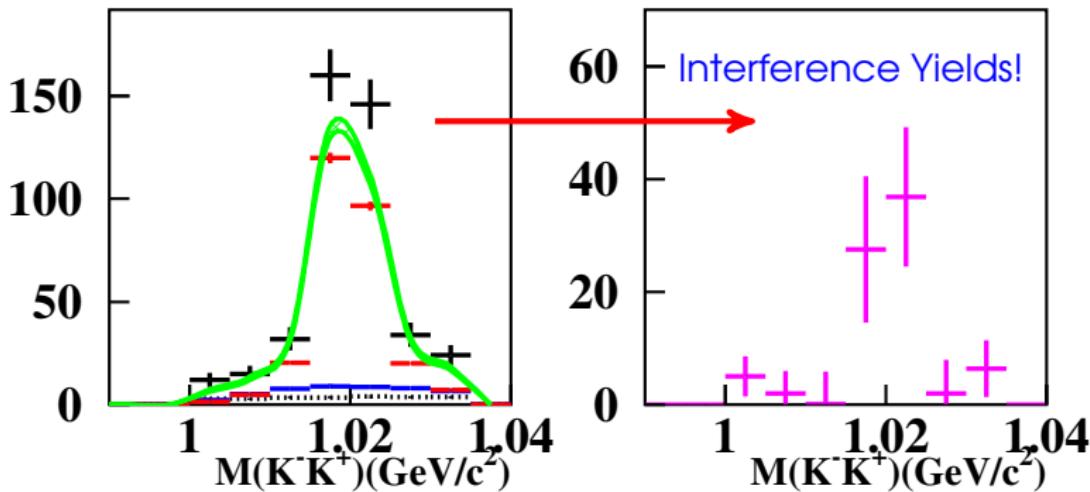
Interference Region $K^+K^-(p)$

Utilizing the MC
linshapes in
Interference Region



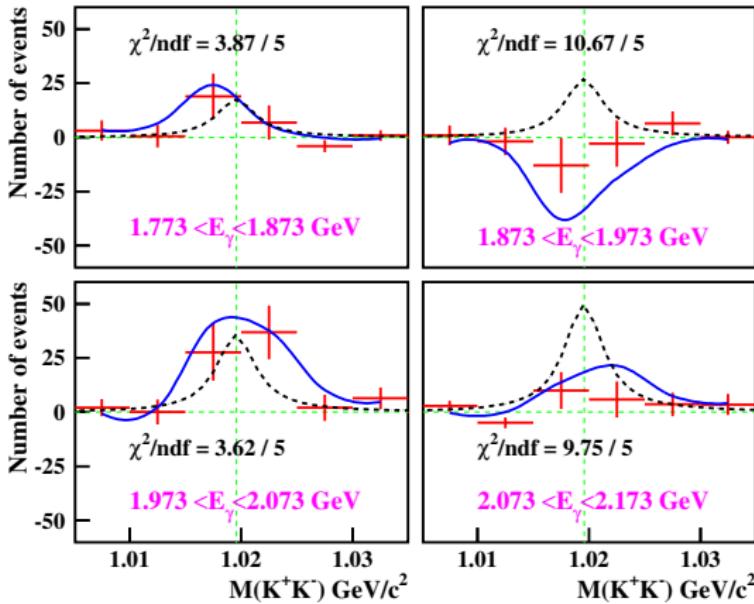
Interference Yields (K^+K^-)

$$1.973 < E_\gamma < 2.073$$



$+ : |\mathcal{M}_\phi + \mathcal{M}_{\Lambda(1520)}|^2 + |\mathcal{M}_{\text{nr}}|^2$, $- : |\mathcal{M}_\phi|^2 + |\mathcal{M}_{\Lambda(1520)}|^2 + |\mathcal{M}_{\text{nr}}|^2$

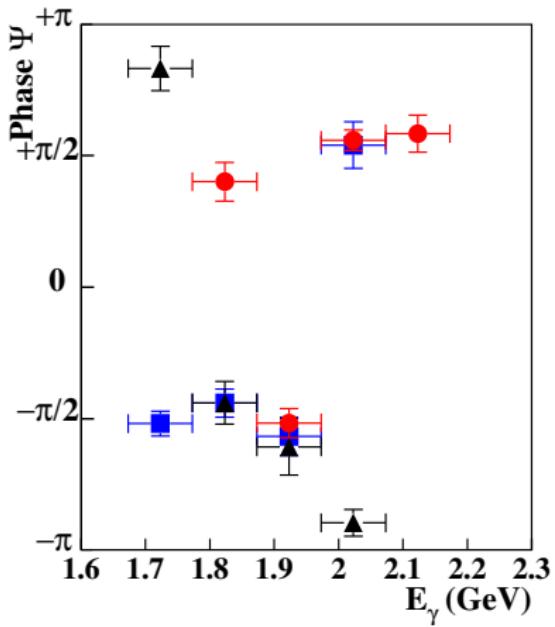
Fit results for the relative phase (K^+K^-)



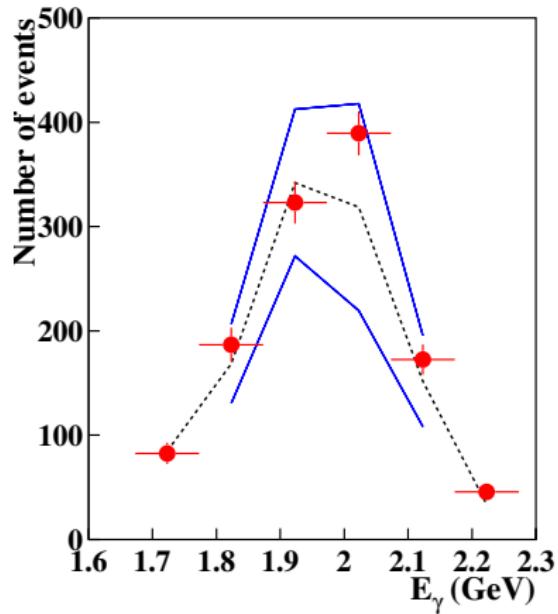
ψ	$P(\chi^2, 5; \psi)$
$69^\circ \pm 13^\circ$	56.8%
$-86^\circ \pm 9^\circ$	5.8%
$98^\circ \pm 7^\circ$	60.5%
$141^\circ \pm 10^\circ$	8.3%

Dashed lines are from theoretical estimates with $\psi = \pi/2$ (S. i. Nam *et al.*)

Integrated Yields and Phases (K^+K^-)

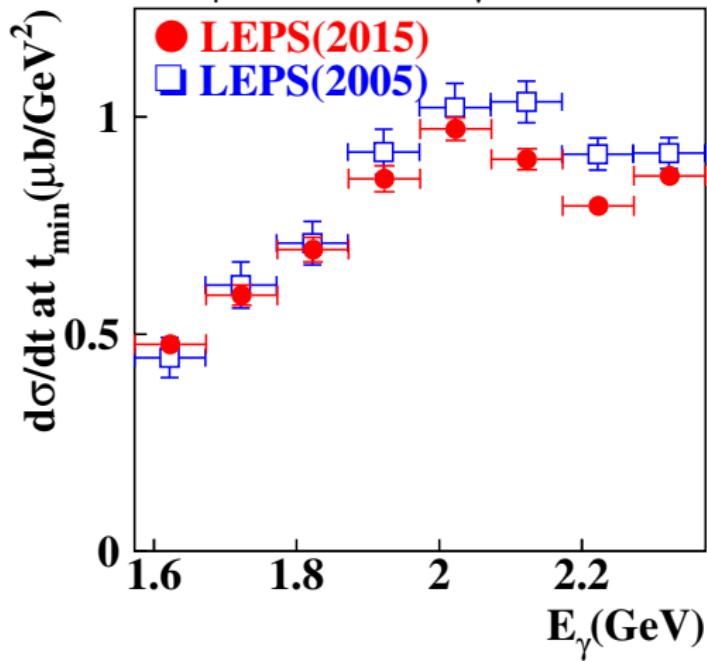


● K^+K^- mode ■ K^-p mode ▲ K^+p mode



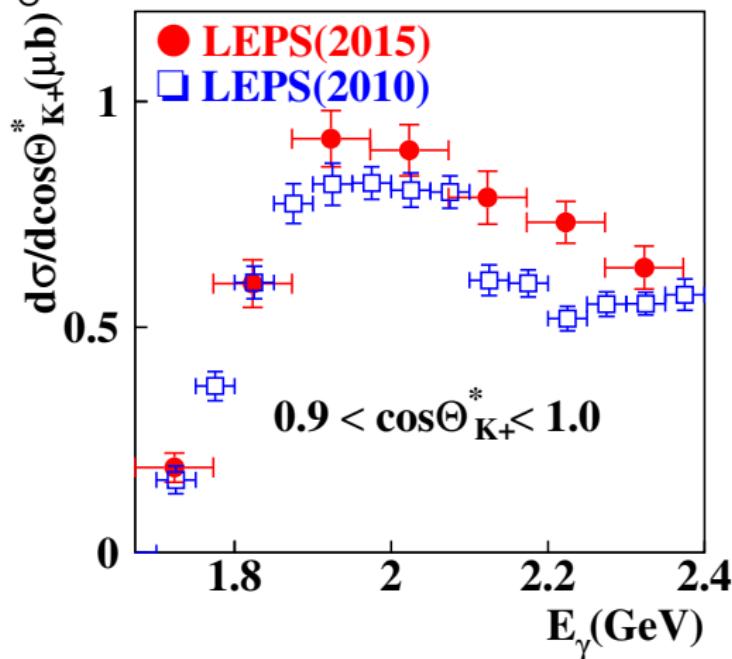
Forward Differential Cross section for $\gamma p \rightarrow \phi p$

- We reconfirm the bump structure at $\sqrt{s} = 2.1$ GeV.



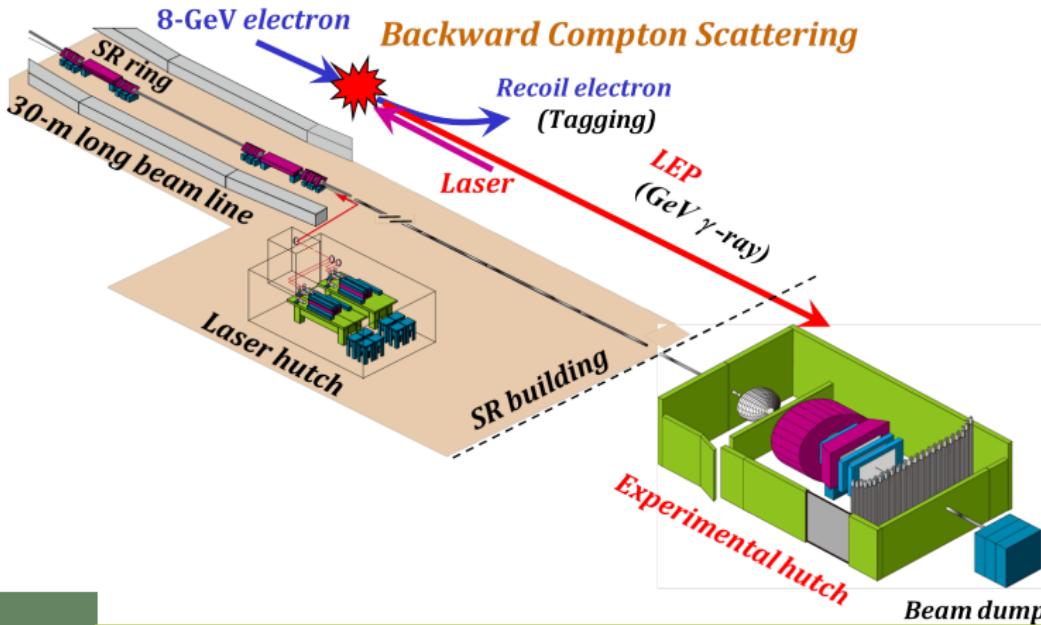
Differential Cross Sections for $\gamma p \rightarrow K^+ \Lambda(1520)$

- We also reconfirm the bump structure for $\gamma p \rightarrow K^+ \Lambda(1520)$ at forward angles.

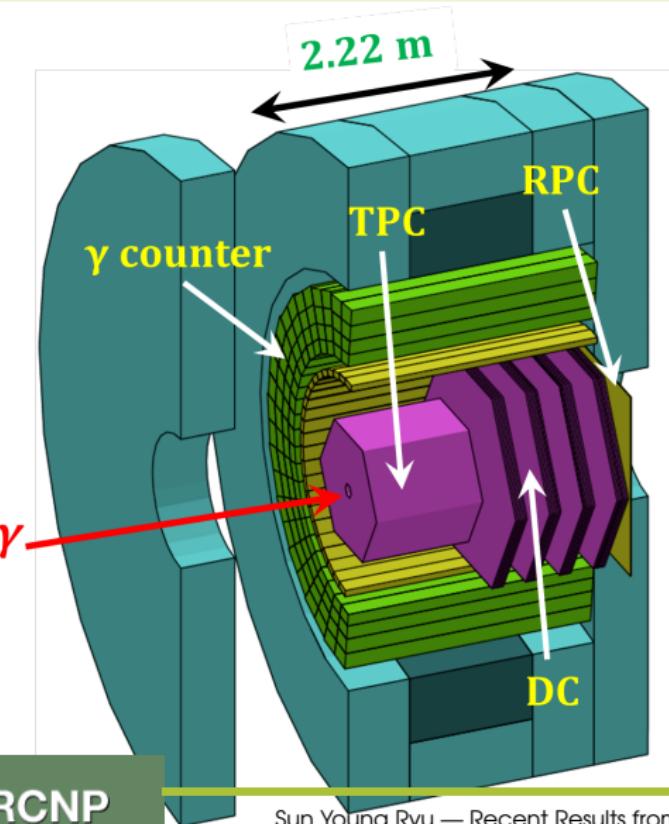


LEPS2 Spectrometer at SPring-8

- High-intensity pencil photon beam with multi-laser injection and a long straight section.
- A large-acceptance solenoid spectrometer



LEPS Solenoid Spectrometer



- Time Projection Chamber (TPC)
- Forward Drift Chambers (DC)
- Resistive Plate Chamber (RPC) for Time-of-Flight Measurement
- Aerogel Cherenkov Counters
- Barrel Pb/Scint Calorimeter ($14.3 X_0$)

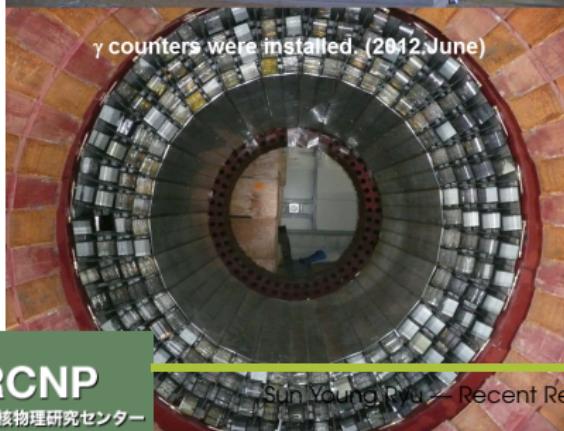
Overview of the LEPS2 Facility



Exp. hall was constructed. (2010.Oct-2012Jan)



Installation of the E949 magnet (2011.Nov-Dec)



γ counters were installed. (2012.June)

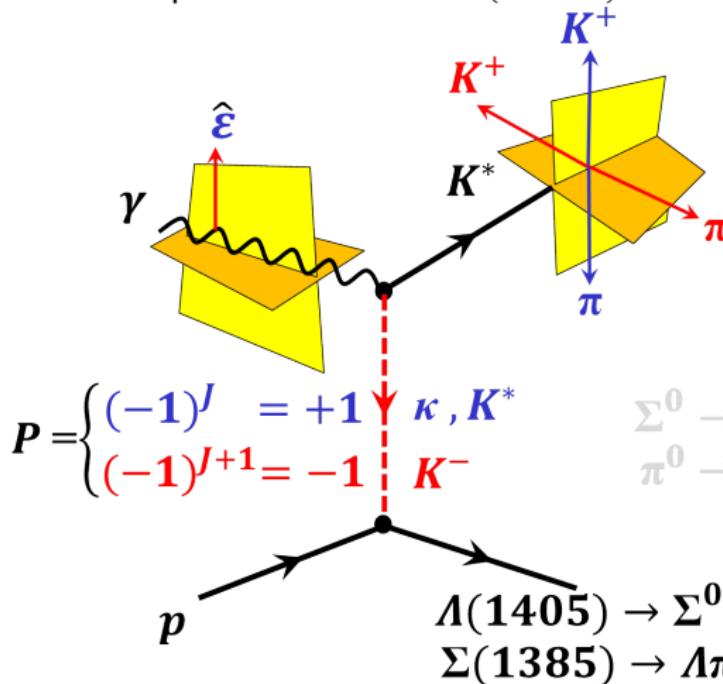


Sun Young Ryu — Recent Results from LEPS — Page 21 of 23 Beam pipe (2012.May)



Unveiling the Two-Pole Structure of $\Lambda(1405)$

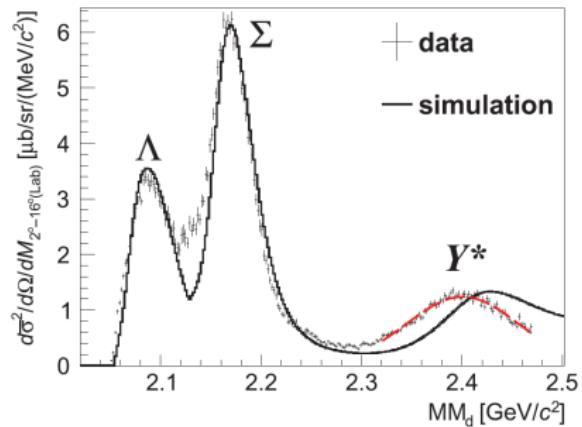
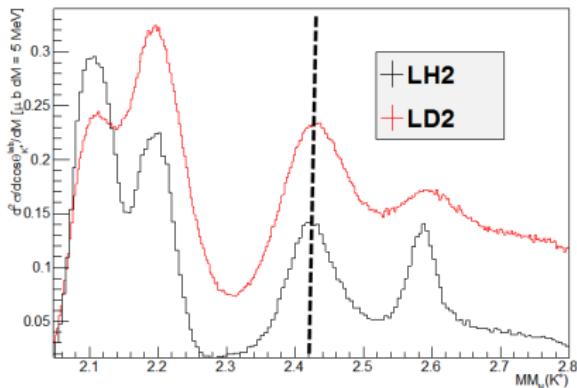
Photoproduction of $\Lambda(1405)$ and $\Sigma(1385)$ with $K(892)^+$



- $K\pi$ decay plane \perp (||) the photon beam polarization ($\hat{\varepsilon}$) for unnatural-parity exchange (natural-parity exchange).
- $I = 0$ channel $\Lambda \rightarrow \Sigma^0 \pi^0$ detection.

The Lightest Kaonic Nucleus $K^- pp$ at LEPS

- If $\Lambda(1405)$ is a $\bar{K}N$ molecule, $K^- pp$ can be tightly bound.
- $K^- pp$ search in $\gamma d \rightarrow K^+ \pi^- X^2$ and $\pi^+ d \rightarrow K^+ X^3$.

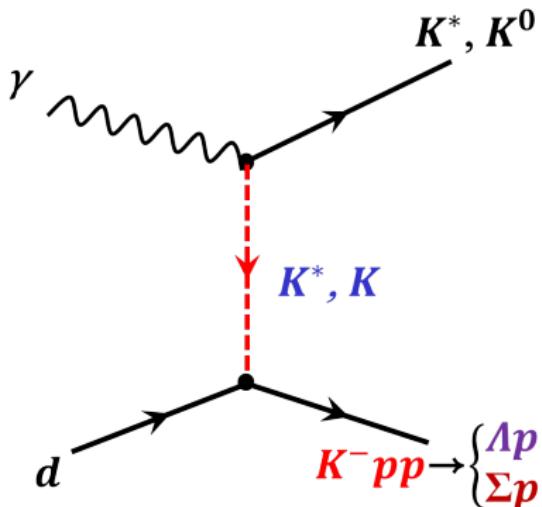


- 30 MeV shift in Y^* appeared only from E27.

²A.O. Tokiyasu *et al.* (LEPS), MENU Conf. (2016)

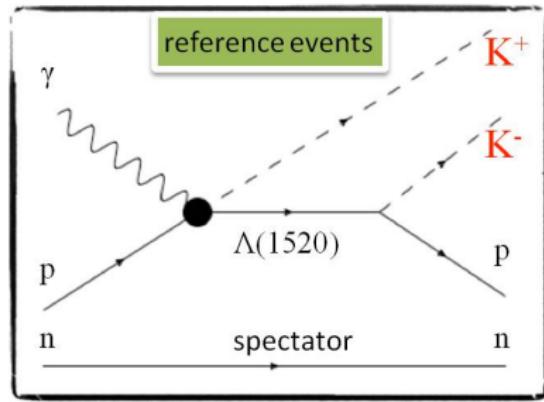
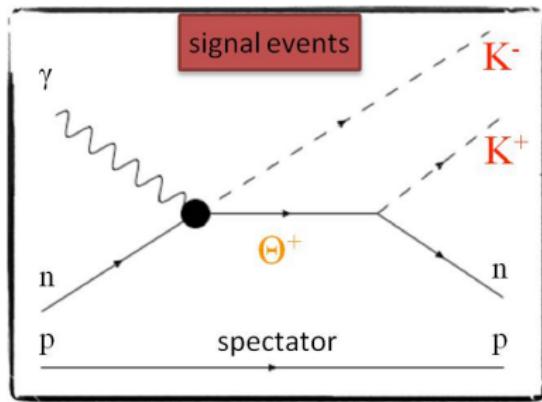
³A. Ichikawa *et al.* (E27), Prog. Theo. Exp. Phys. (2014) 101D03

Search for K^-pp nuclei at LEPS2



- K^-pp search in $\gamma d \rightarrow K^+ \pi^- X, K_S^0 X$, and $K^{*0} X$ at LEPS2
- Complete kinematics with detection of K/K^* and decay products from K^-pp .

Search for Θ^+ at LEPS

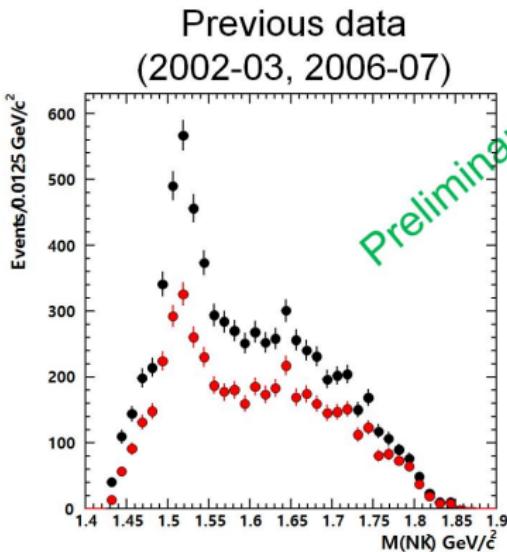


$$\gamma n \rightarrow K^- K^+ n$$

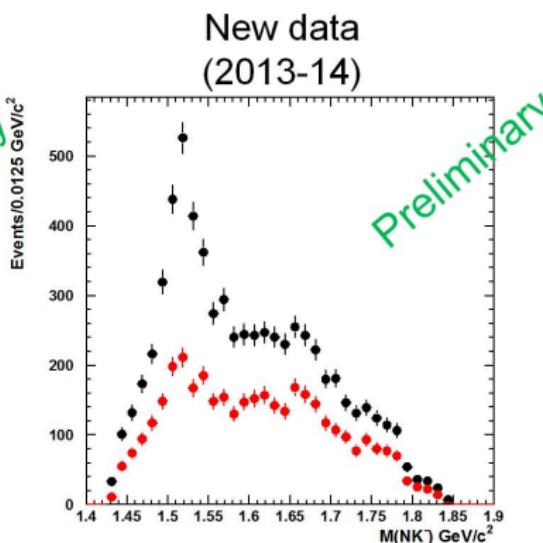
$$\gamma p \rightarrow K^+ K^- p$$

- Spectator can not escape from the target.
- Better n/p separation is possible by improving the proton detection efficiency with a larger proton counter.

Search for Θ^+ at LEPS



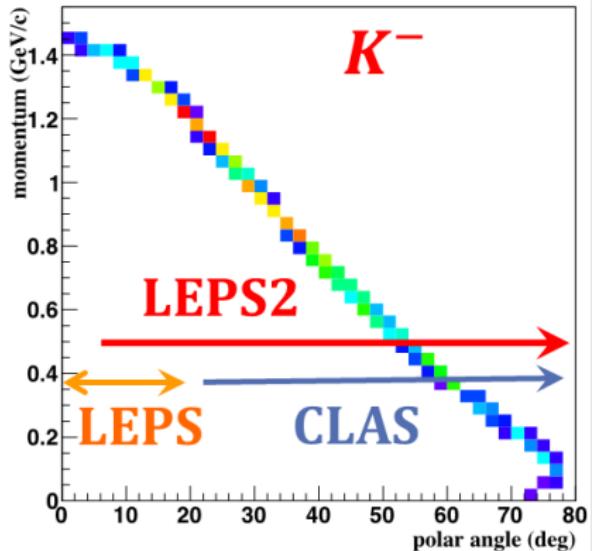
Proton detection efficiency: 59%



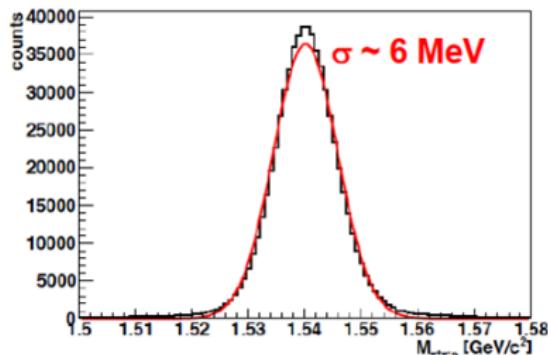
Proton detection efficiency: 84%

- Select K^-n out of $K^-N(K^-p + K^-n)$ with p rejection.

Search for Θ^+ at LEPS2



- $\gamma n \rightarrow K^- \Theta^+$
($\Theta^+ \rightarrow K_S^0 p$; $K_S^0 \rightarrow \pi^+ \pi^-$)
- $\gamma p \rightarrow \bar{K}^{*0} \Theta^+$ ($\bar{K}^{*0} \rightarrow K^- \pi^+$)



- Large acceptance and good particle identification.
- Search for Θ^+ in the $S = +1$ $K^0 p$ system.

Summary

- We **reconfirmed the bump structure** in the analysis without the $\phi\text{-}\Lambda(1520)$ interference region. The interference effect is not large enough to account for the bump structure.
- The relative phases suggest **strong constructive interference for K^+K^- pairs** observed at forward angles.
- The nature of the bump structure could originate from interesting exotic structures such as a hidden-strangeness pentaquark state, a new Pomeron exchange or rescattering processes via other hyperon states.
- The LEPS2 solenoid spectrometer is now prepared for engineering runs in December, 2016. A new DAQ system including **DAQ middleware** will be tested in the beginning of the engineering runs.