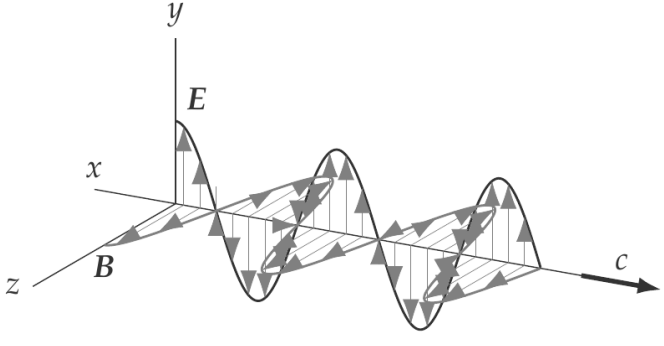
LEPS experiments with polarized photons

Photoproduction of hadrons with Compton backscattered photon facilities, LEPS and LEPS2

Jung Keun Ahn for the LEPS/LEPS2 Collaborations
(Korea University)

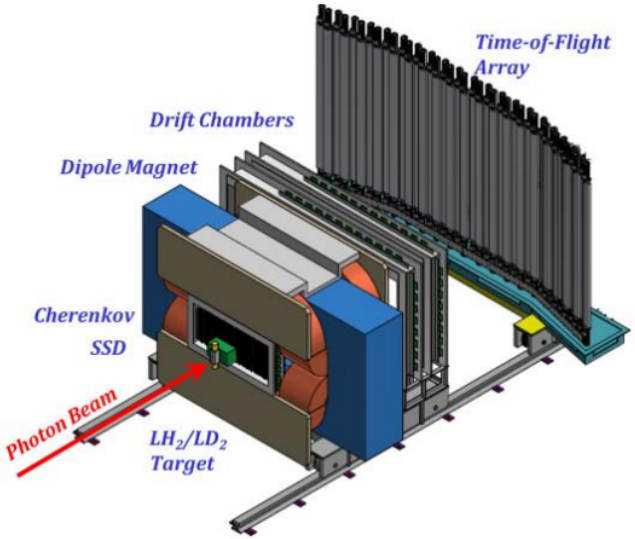
Outline

1. Highlights from the LEPS experiments.
2. Current status of the LEPS2 photoproduction experiments using Compton-backscattered photons from 8-GeV electrons at SPring-8, Japan.
3. Selected physics programs with the LEPS2 detector.

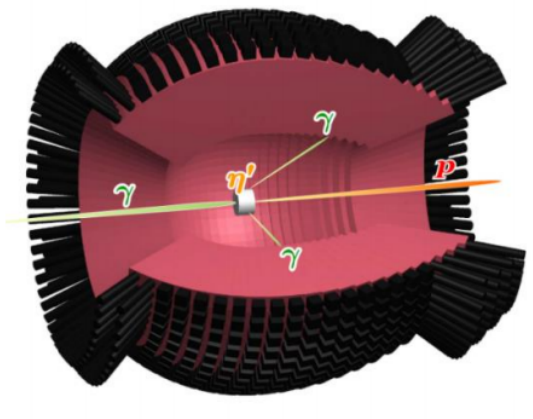


GeV γ

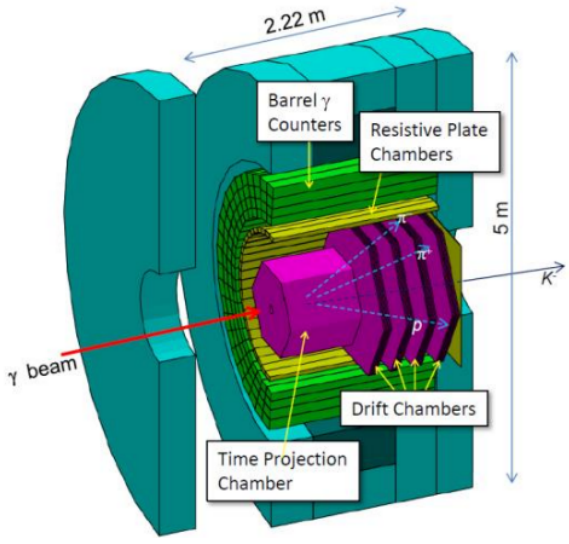
LEPS and LEPS2 at SPring-8



LEPS spectrometer



BGOegg calorimeter

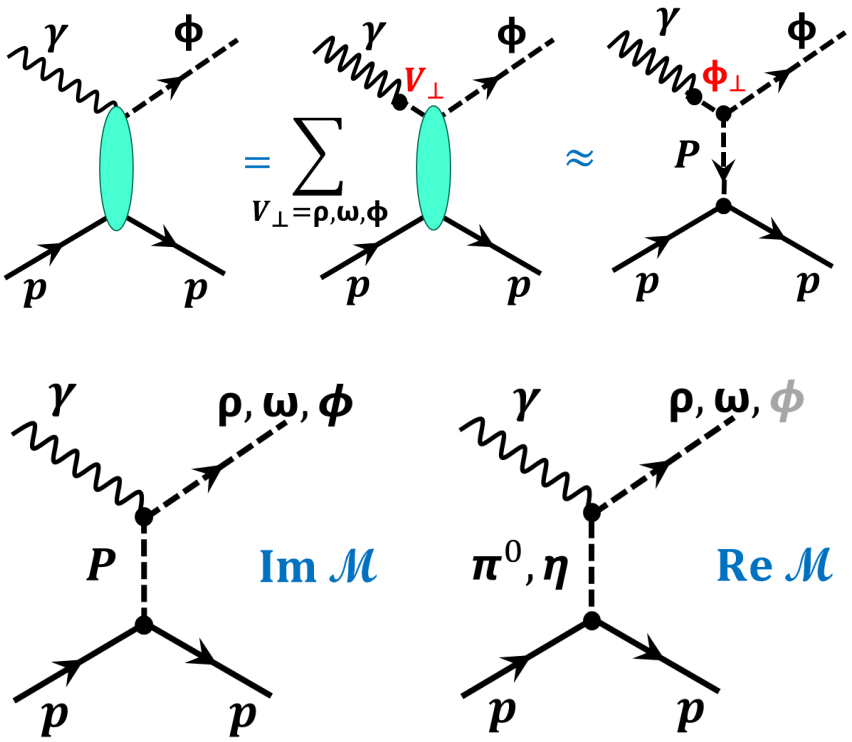


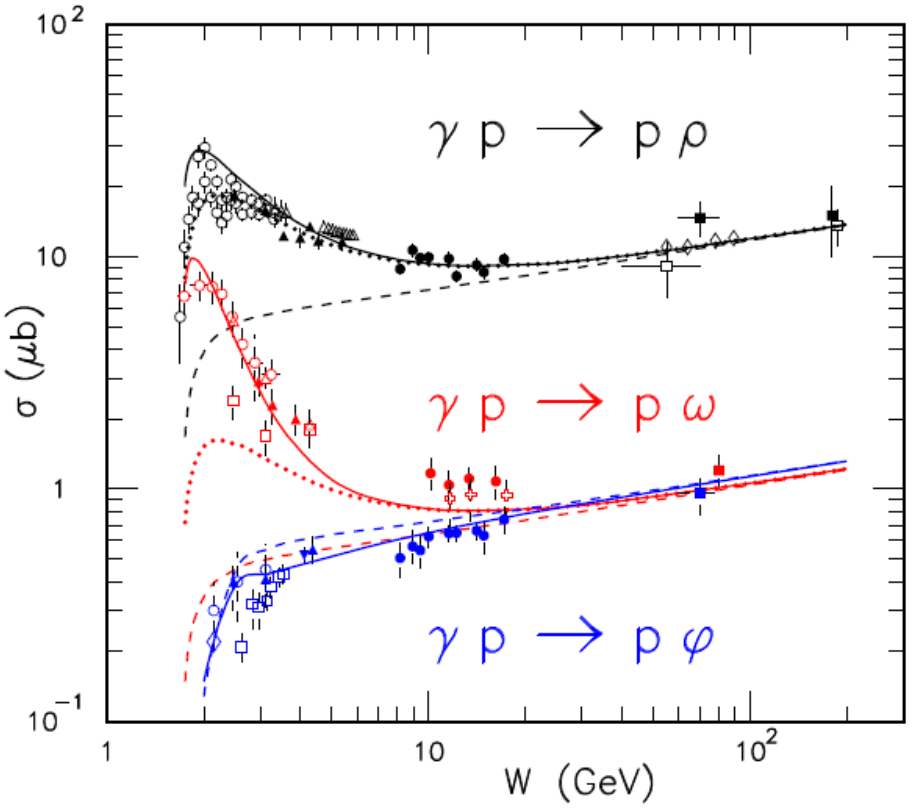
Solenoid spectrometer

	LEPS (2000 – 2020)	LEPS2 (2013 --)	
Tagged γ Energy	$1.5 < E_\gamma < 2.4$ GeV (UV laser) $1.5 < E_\gamma < 2.9$ GeV (DUV laser)	$1.3 < E_\gamma < 2.4$ GeV (UV laser) $1.3 < E_\gamma < 2.9$ GeV (DUV laser)	
Photon Beam Intensity	Two laser injection 2×10^6 cps (UV laser) 2×10^5 cps (UV laser)	Four laser injection $< 10^7$ cps (UV laser) $< 10^6$ cps (DUV laser)	
Detector	Forward Dipole Spectrometer	BGOegg EM Calorimeter	Solenoid Spectrometer

ϕ Photoproduction near Threshold

- In the vector meson dominance (VMD) model for photoproduction, a real photon can fluctuate into a virtual vector meson $V = \{\rho, \omega, \phi\}$, which subsequently scatters off the target proton.
- The ϕ meson production has the unique feature within gluon dynamics of being a result of OZI suppression due to the dominant $\bar{s}s$ structure.

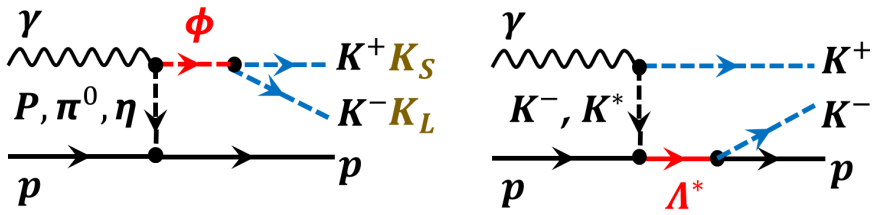


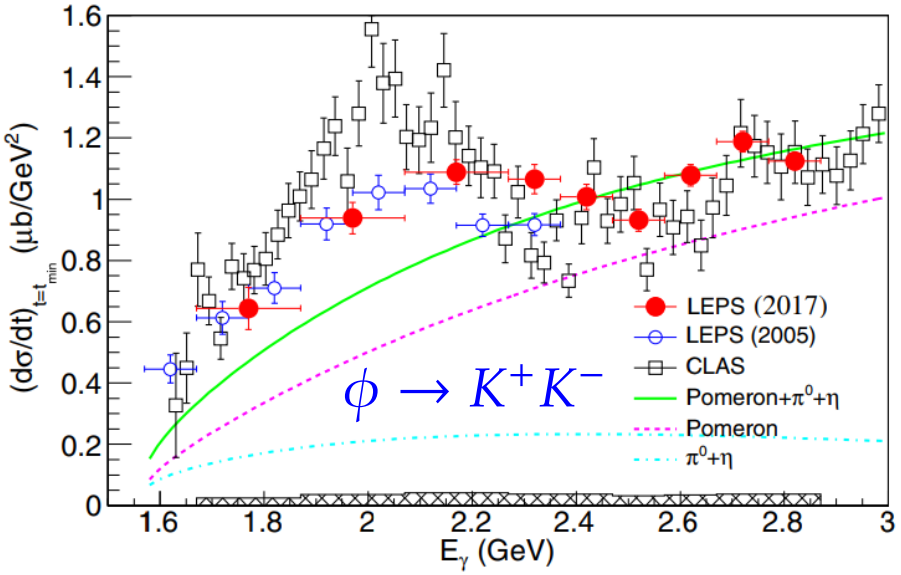


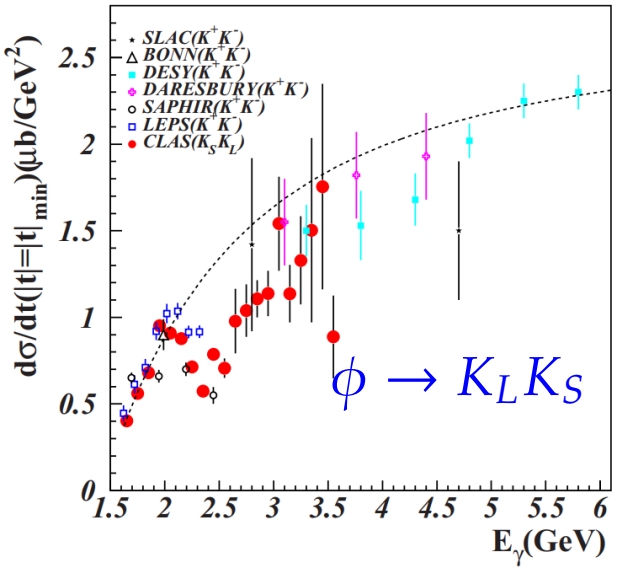
ϕ Photoproduction near Threshold

- For Pomeron exchanges, the photoproduction cross section can be written in the form

$$\frac{d\sigma}{dt}(\gamma p \to \phi p) = \left(\frac{d\sigma}{dt}\right)_{t=t_{\min}} \exp(-b_\phi |t - t_{\min}|)$$







- Differential cross sections for ϕ photoproduction in the reaction $\gamma p \to p\phi$ followed by $\phi \to K^+K^-$ [a] and $K_S K_L$ [b] show some enhancement in the photon beam energy range near 2.1 GeV.

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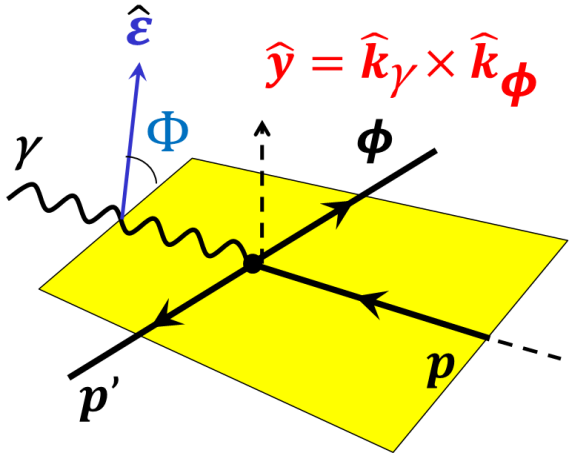
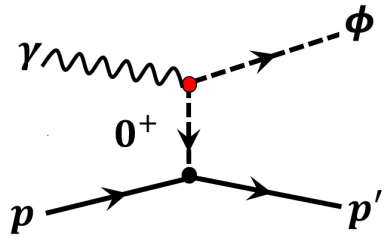
[a] K. Mizutani *et al.* (LEPS Collab), PRC 96, 062201(*R*)(2017); B. Dey *et al.* (CLAS Collab), PRC 89, 055208(2014)

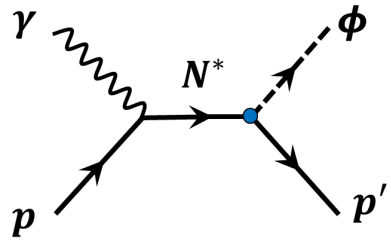
[b] H. Seraydaryan *et al.* (CLAS Collab), PRC 89, 055206(2014).

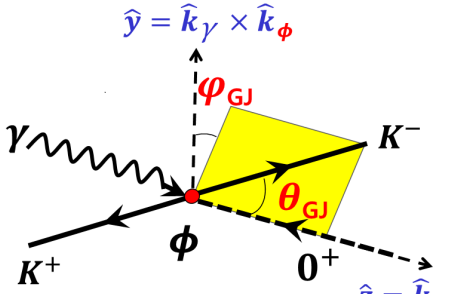
Decay Angular Distribution and SDMEs

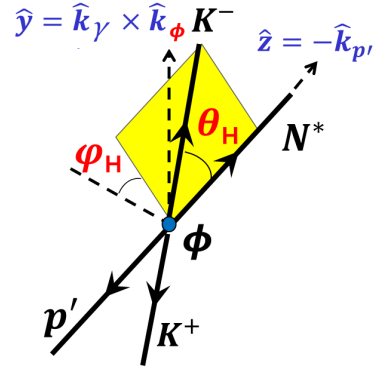
$\gamma p \to \phi p$











$$W(\cos\theta) = \frac{3}{2}\left(\frac{1}{2}(1-\rho^0_{00})\sin^2\theta + \rho^0_{00}\cos^2\theta\right),$$

$$W(\phi) = \frac{1}{2\pi}(1 - 2\rho^0_{1-1}\cos 2\phi),$$

$$W(\phi-\Phi) = \frac{1}{2\pi}\left(1 + P_\gamma(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})\cos 2(\phi-\Phi)\right),$$

$$W(\phi+\Phi) = \frac{1}{2\pi}\left(1 + P_\gamma(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1})\cos 2(\phi+\Phi)\right),$$

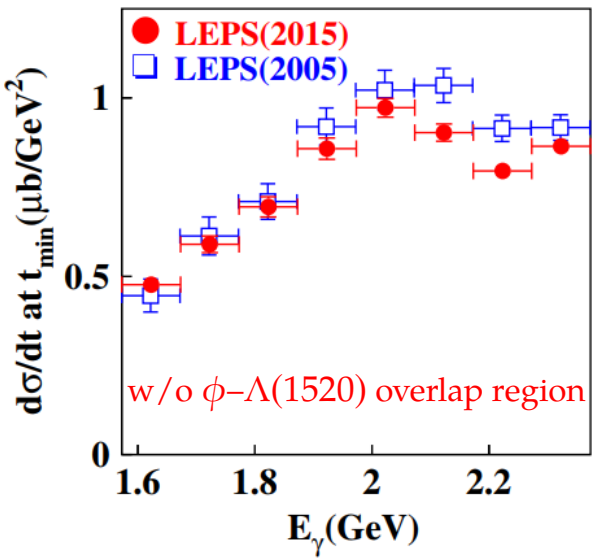
$$W(\Phi) = 1 - P_\gamma(2\rho^1_{11} + \rho^1_{00})\cos 2\Phi$$

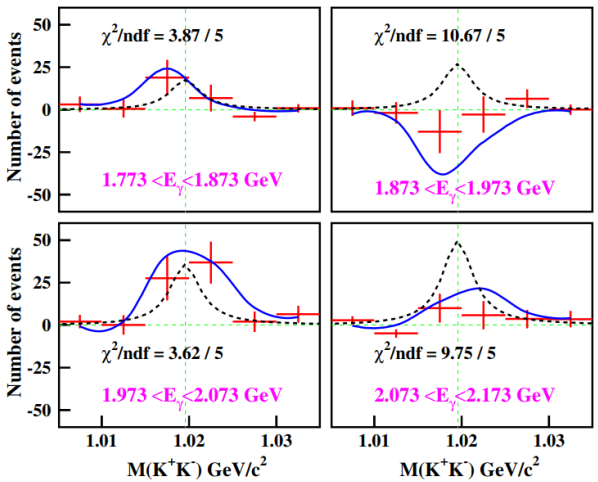
$$P_\sigma = \frac{\sigma^N - \sigma^U}{\sigma^N + \sigma^U} = 2\rho^1_{1-1} - \rho^1_{00}$$

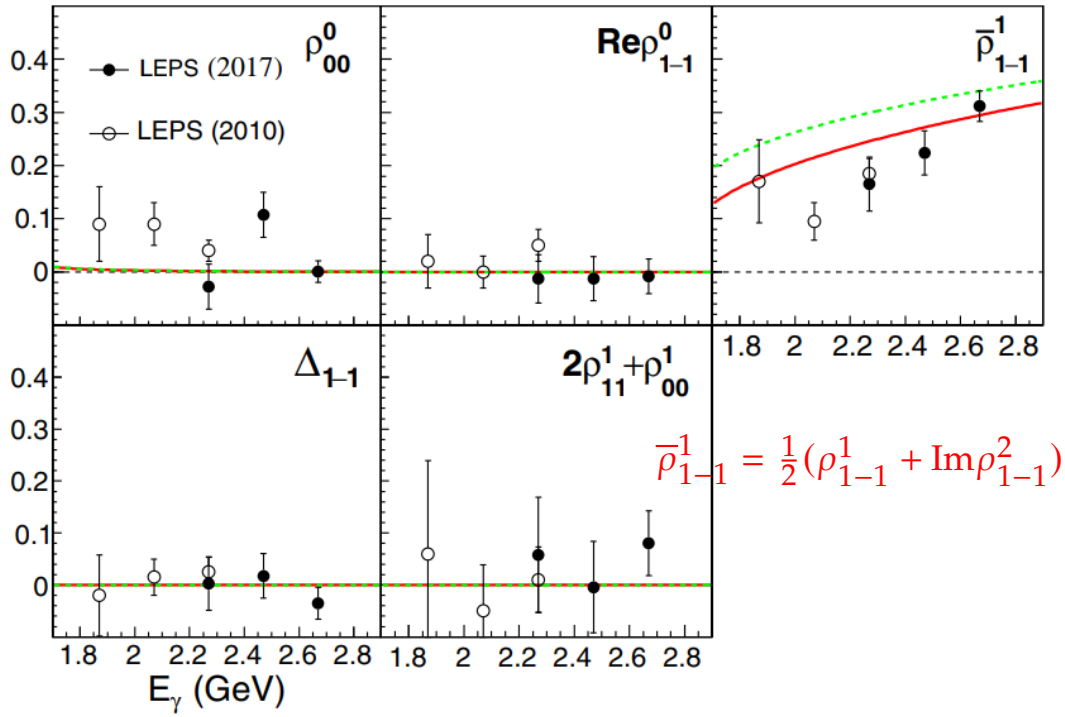
$$\Sigma = \frac{\sigma_\parallel - \sigma_\perp}{\sigma_\parallel + \sigma_\perp} = \frac{\rho^1_{11} + \rho^1_{1-1}}{\rho^0_{11} + \rho^0_{1-1}}$$

For the helicity-conserving exchanges, $\rho^1_{1-1} = -\mathrm{Im}\rho^2_{1-1} = +0.5(N), -0.5(U)$

ϕ Photoproduction near Threshold







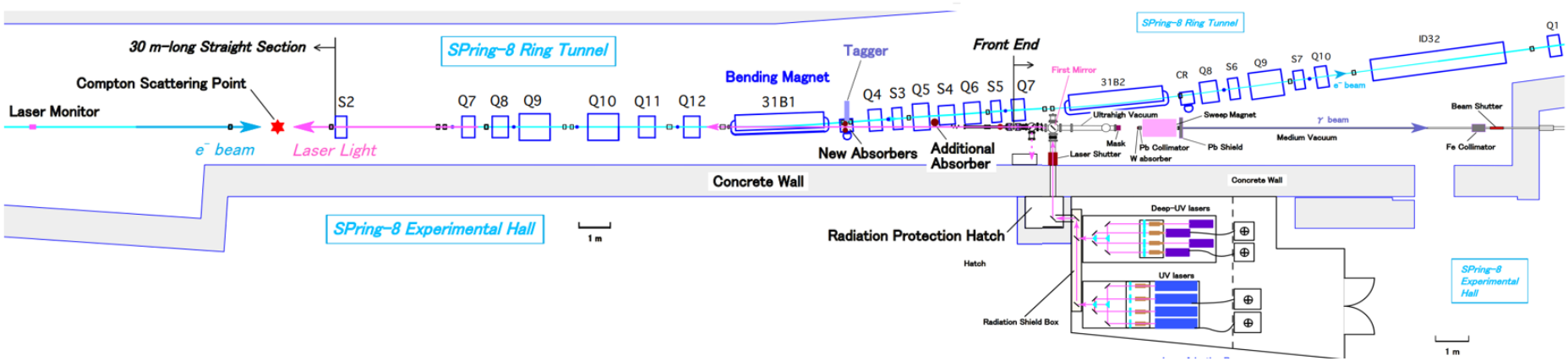
$\overline{\rho}^1_{1-1} = \frac{1}{2}(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1})$

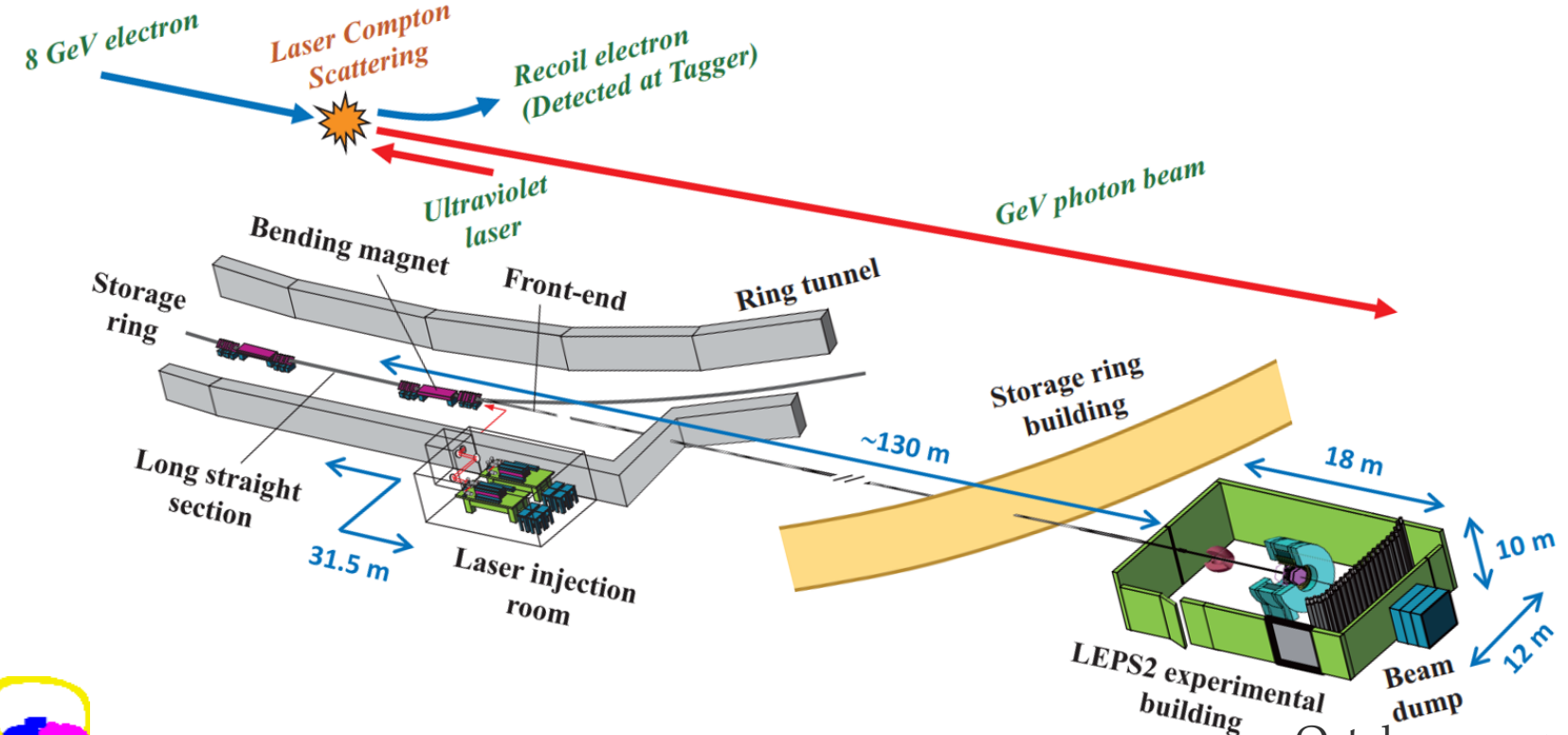
- $\overline{\rho}^1_{1-1}$ deviates largely from the model prediction in $1.97 < E_\gamma < 2.17$ GeV, which reflects the contributions of N^* resonances. [a]
- The $\sqrt{s} = 2.1$ GeV bump structure was reconfirmed without the $\phi - \Lambda(1520)$ interference region. [b]

[a] K. Mizutani *et al.*, PRC 96, 062201(*R*)(2017).

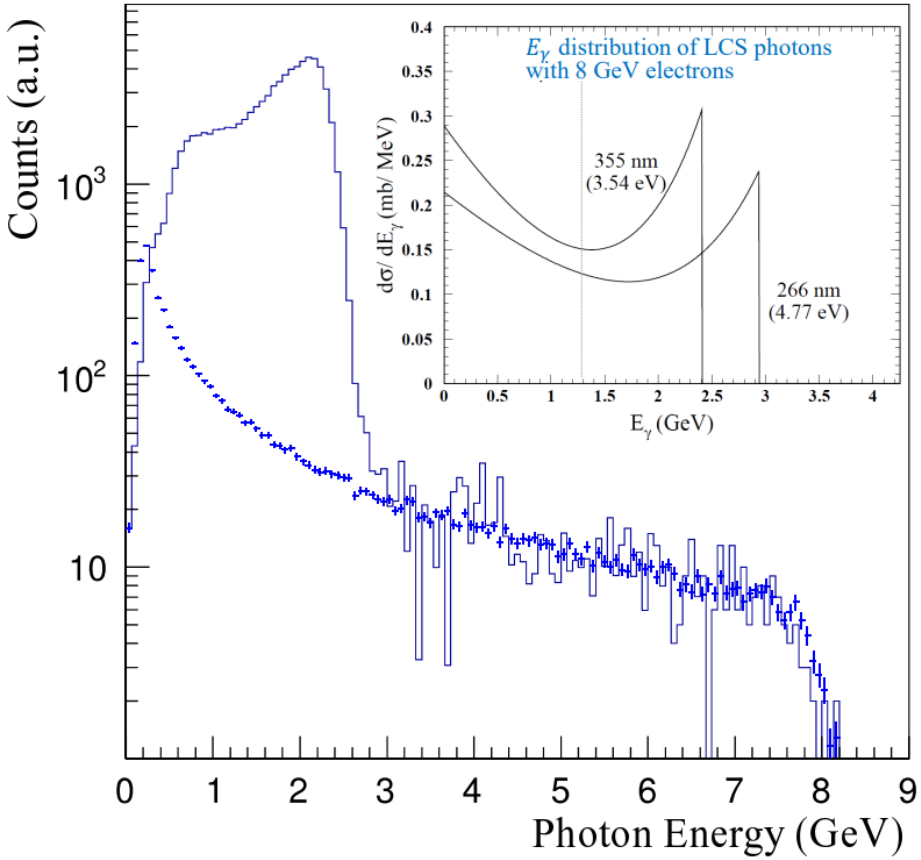
[b] S.Y. Ryu *et al.* (LEPS Collab), PRL 116, 232001(2016).

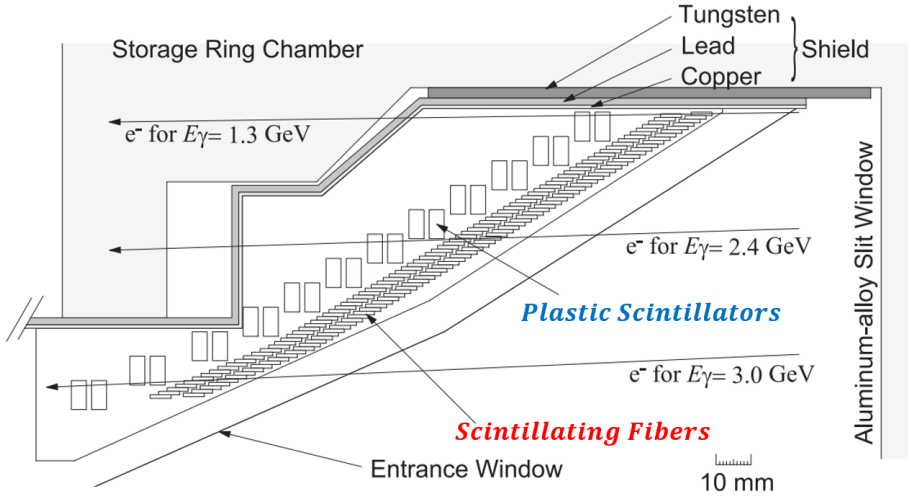
GeV Photon Beam at LEPS2/SPring-8

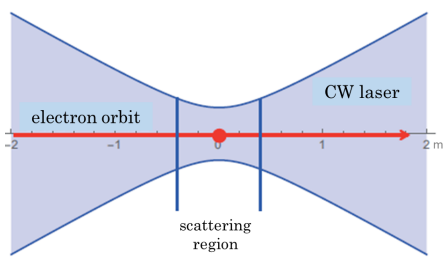




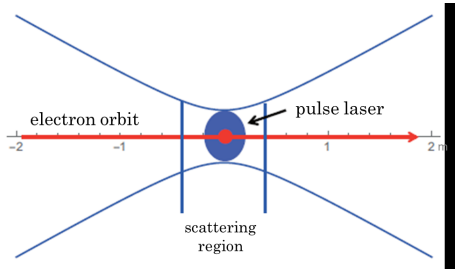
Backward Compton Scattered Photon Beam



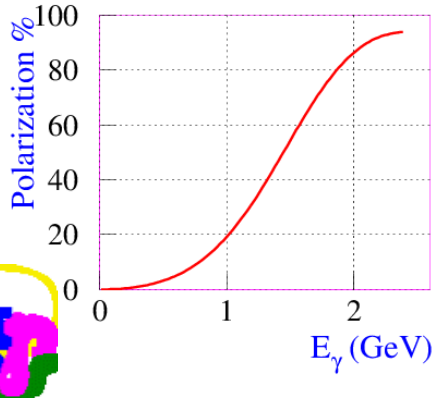




CW laser



Synchronized pulse laser



- The tagged photon energy resolution is 12.3 MeV and the maximum intensity is 2.3×10^6/s in the energy from 1.3 to 2.4 GeV. [a]

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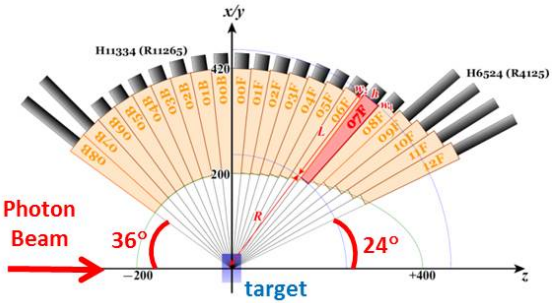
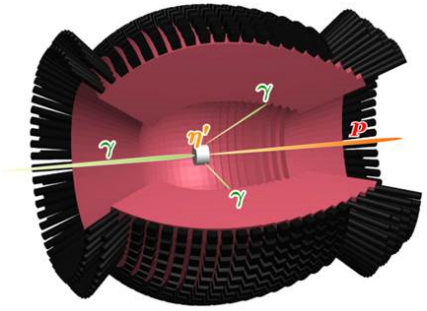
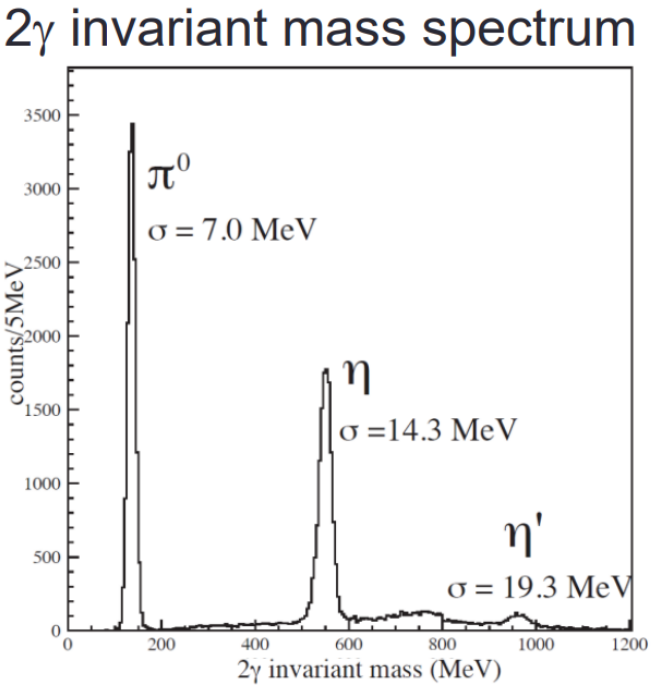
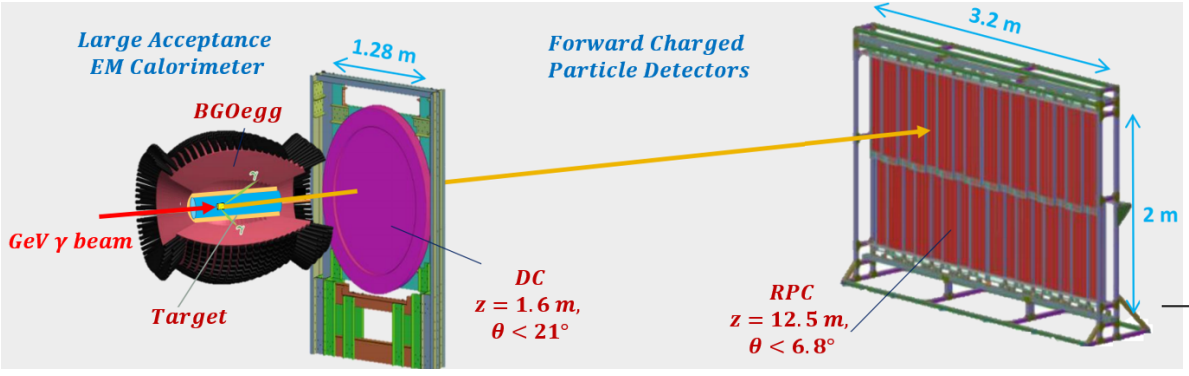
[a] N. Muramatsu *et al.*, submitted in NIMA (2021).

LEPS2 BGOegg Detector





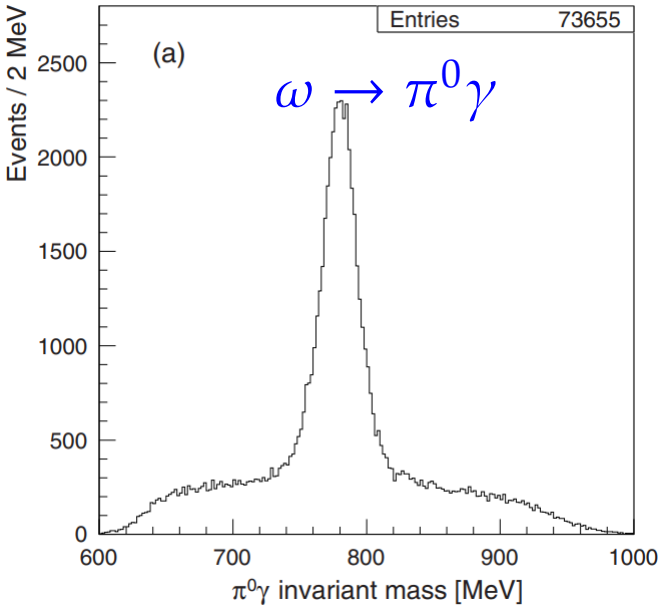




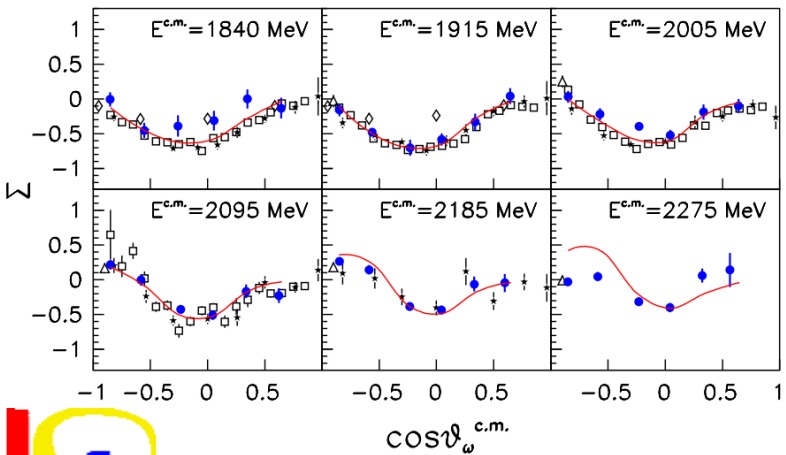
- BGOegg consisting of 1320 BGO crystals (20 X_0) views a target in $\theta = 24° - 144°$ with the world's best energy resolution (1.3% at 1 GeV).[a]

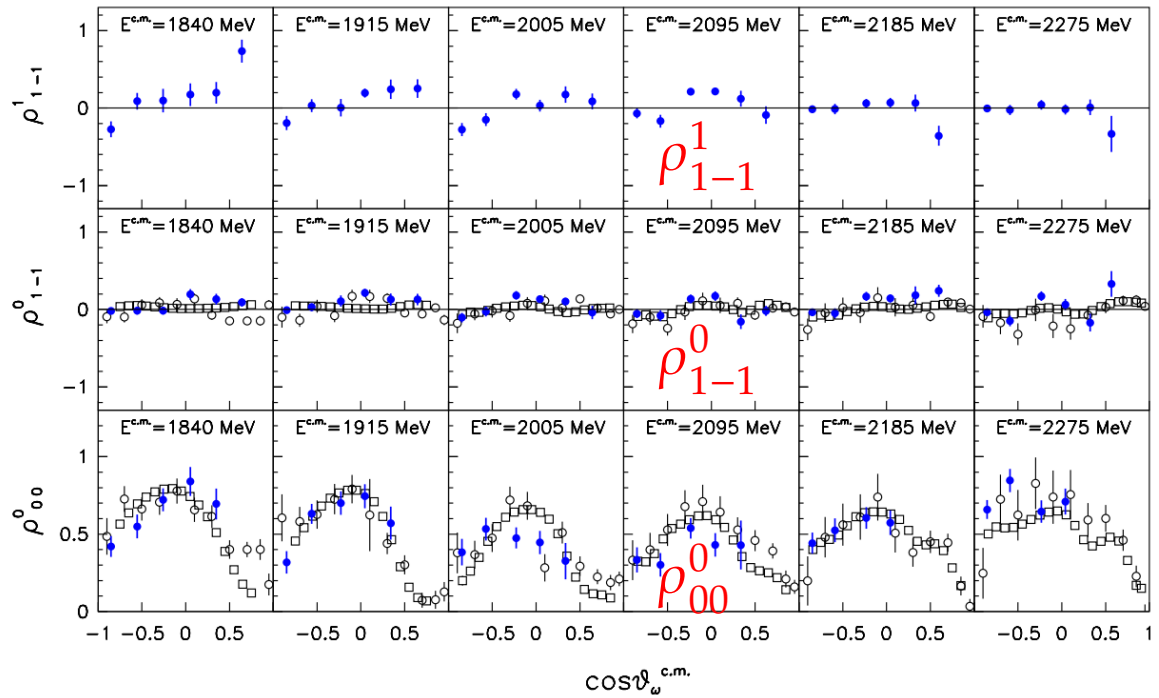
[a] T. Ishikawa *et al.*, NIMA 837, 109(2016).

ω Photoproduction with LEPS2 BGOegg Detector



$\gamma p \to \omega p$

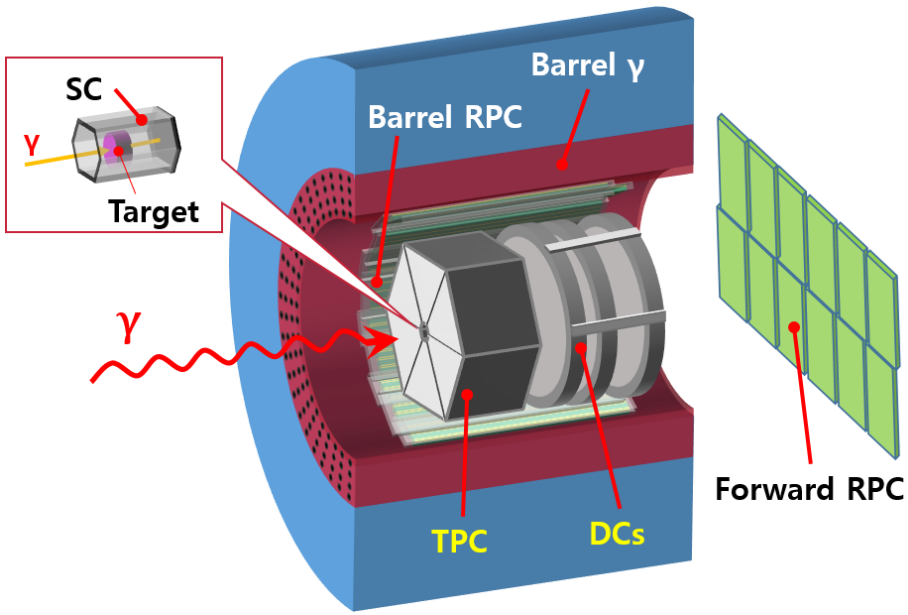


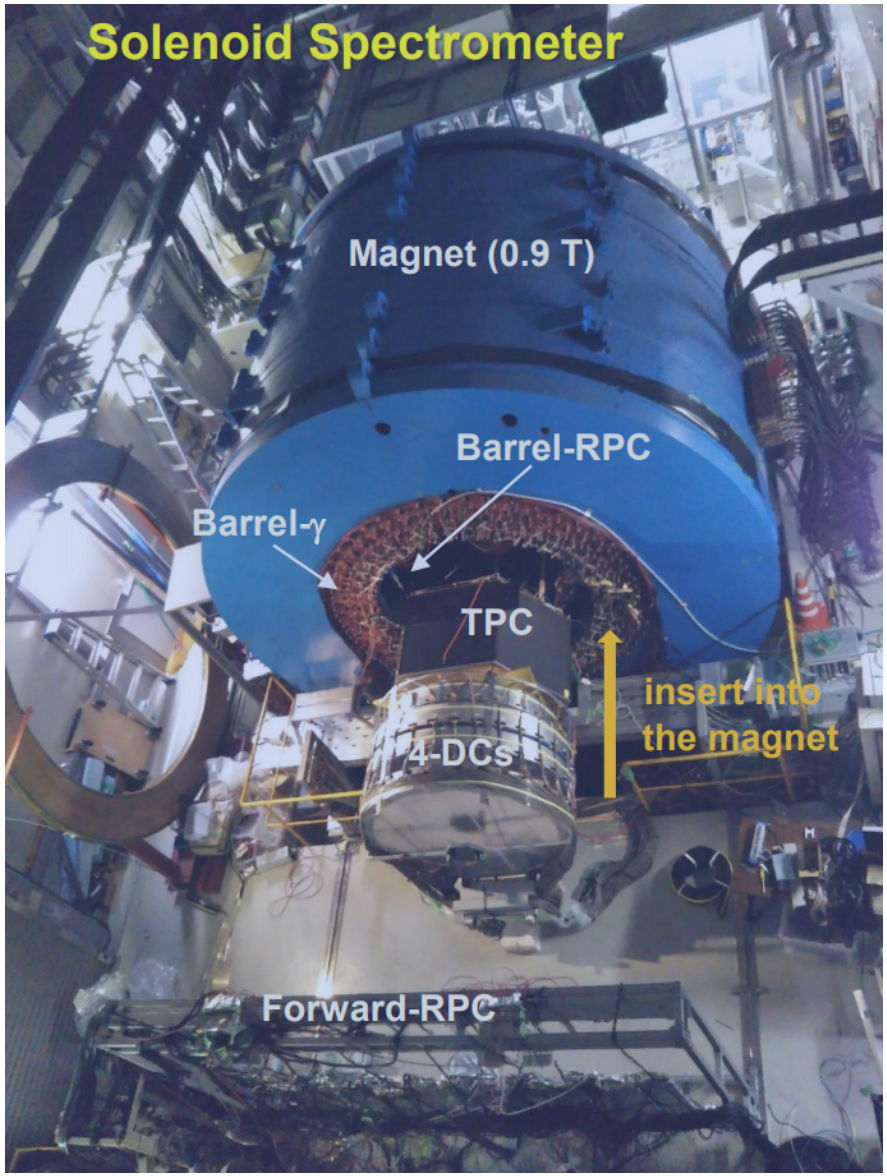


- The measured ρ^1_{1-1} is close to zero for all kinematical bins.
- The observed behaviors of the helicity-flip amplitudes surely reflects the contributions of N^* resonances. [a]

[a] N. Muramatsu *et al.* (LEPS2 Collab), PRC 102, 025201(2020).

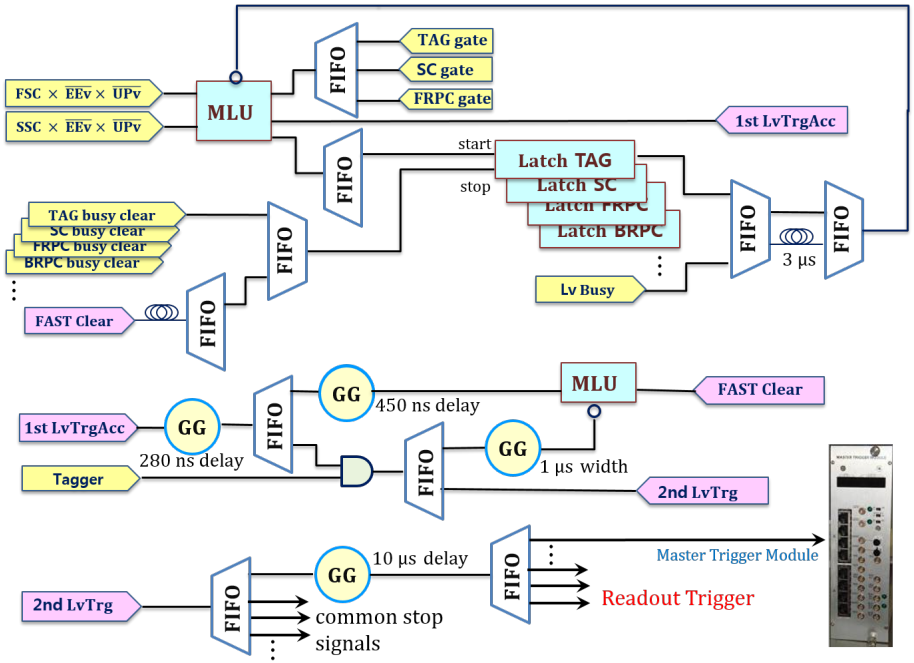
LEPS2 Solenoid Spectrometer

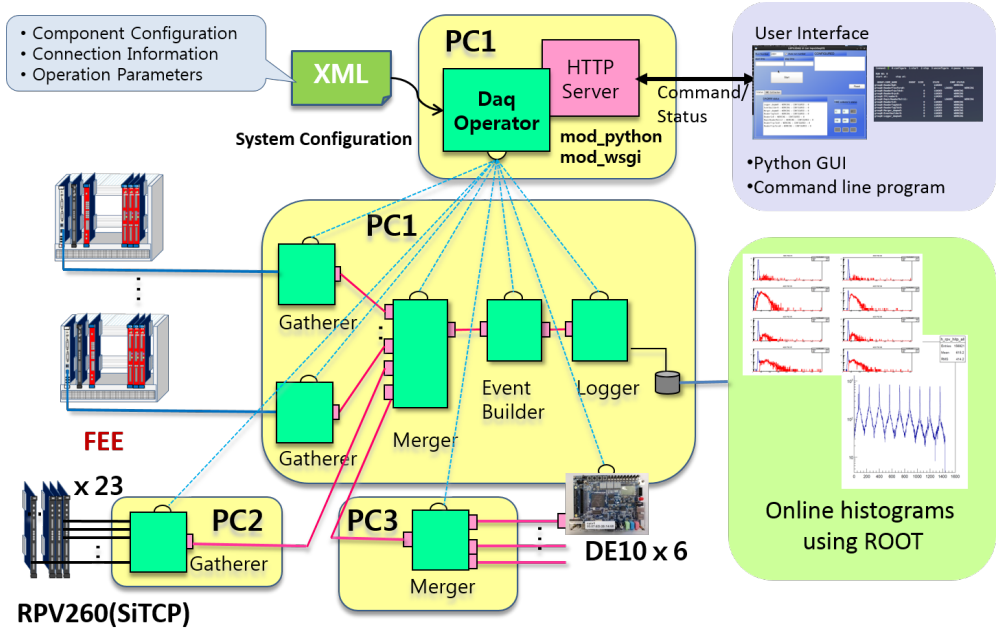


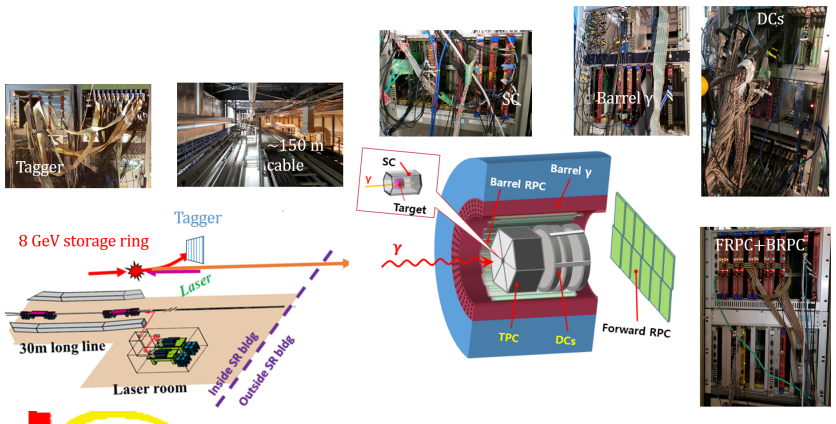


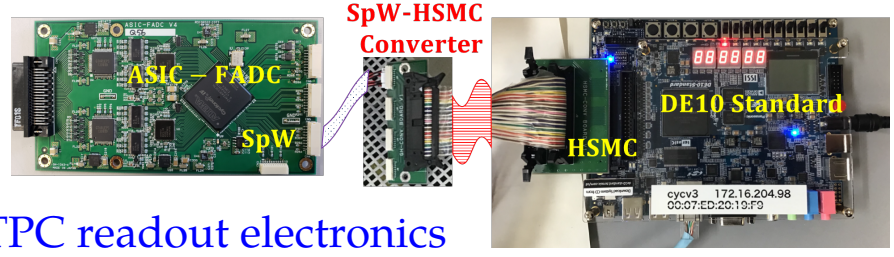
- The LEPS2 solenoid spectrometer consists of TPC, SC, DCs, Forward and barrel RPCs, and Barrel Pb/Scint calorimeter (14.3 X_0) as well as a photon tagger placed approximately 100 m upstream from the detector.

LEPS2 Trigger and DAQ System







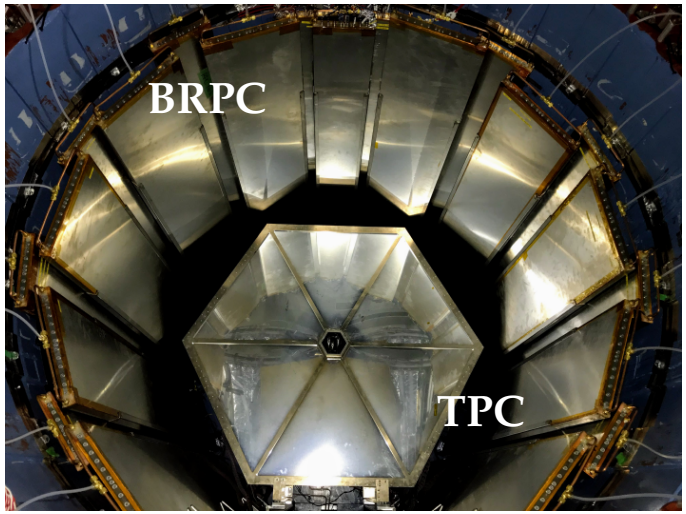


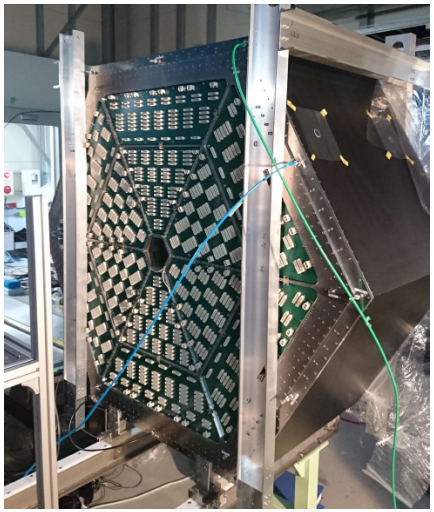
TPC readout electronics

- We have developed a new, network-distributed data acquisition system based on DAQ-middleware framework.[a]

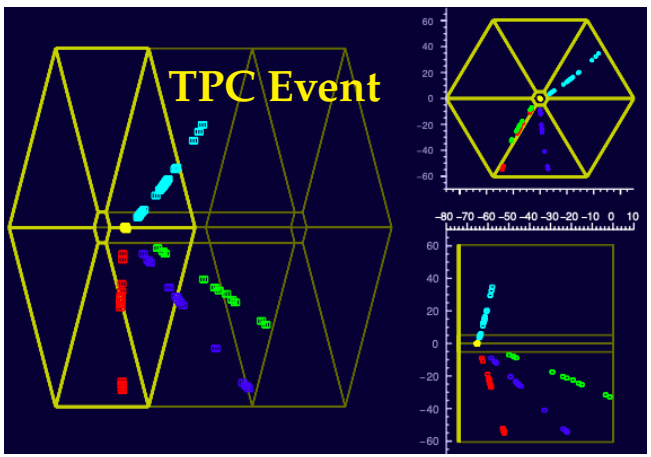
[a] S. Y. Ryu for LEPS2 Collab., AIP Conf. Proc. 2249, 030024 (2020).

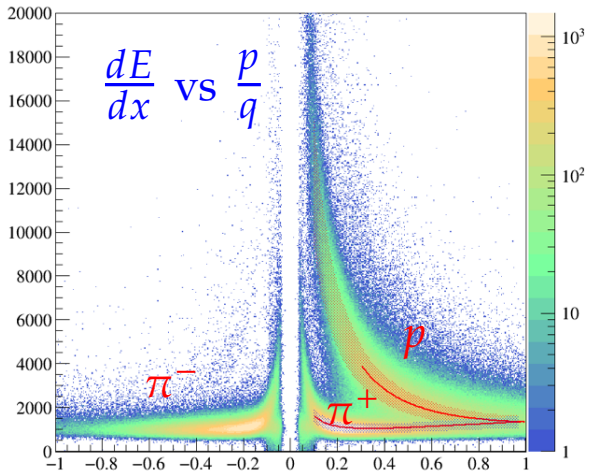
Time Projection Chamber

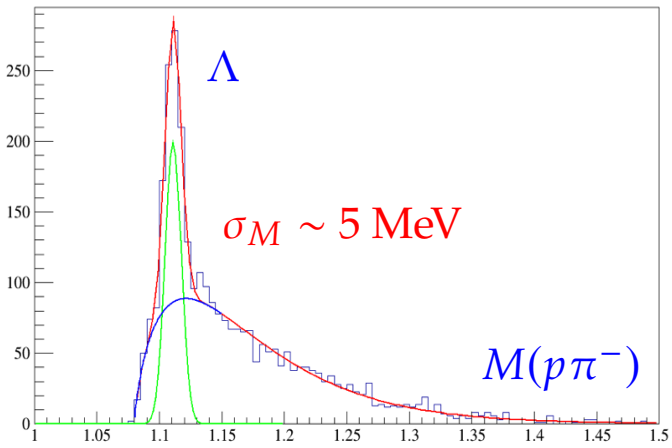




- Hexagonal prism-shaped drift volume : 112 cm (corner-to-corner) $\times$ 71 cm (length).
- 24 straight pad layers grouped into 6 sections forming a hexagonal web-like structure.
- 10, 830 pads with single pad size of 4.6×10 mm^2.

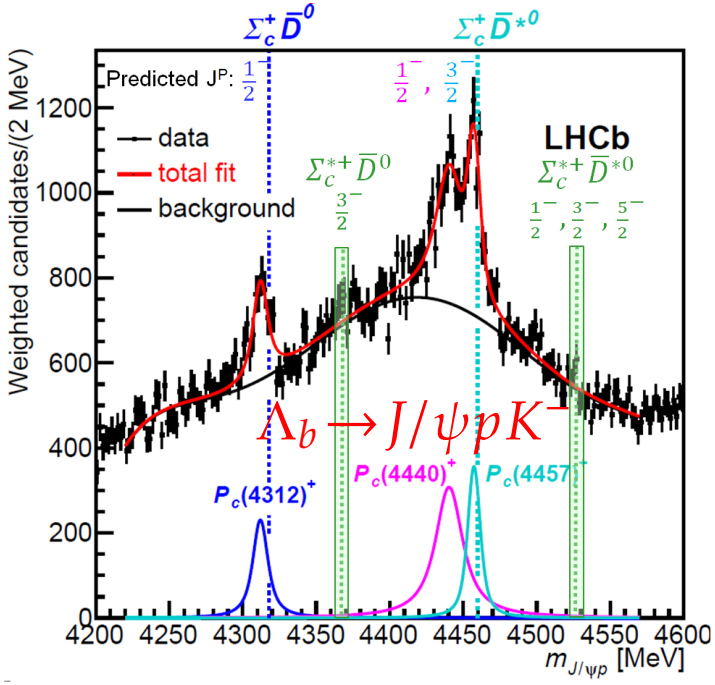




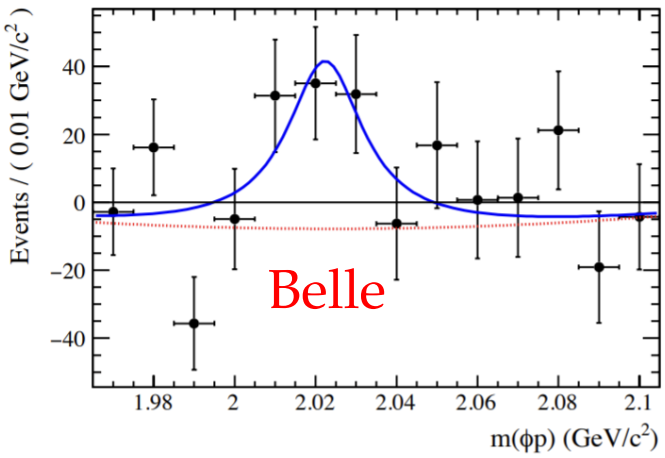


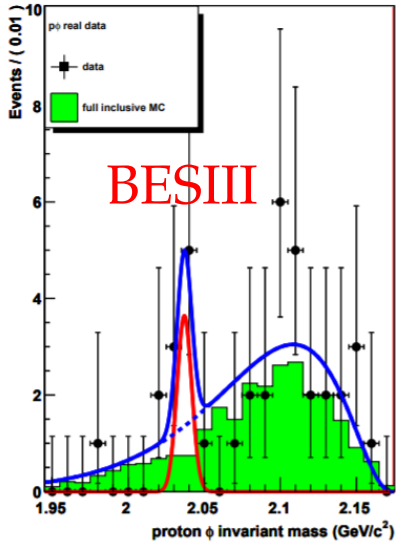
- Λ decays are successfully reconstructed with p and π^- tracks in the first beam commissioning dataset.[a]

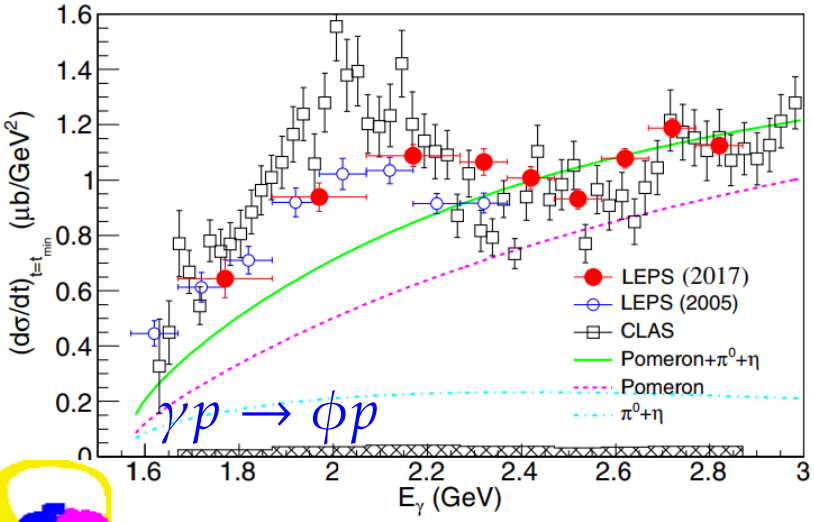
Strange Partner P_s of P_c Pentaquark States



$\Lambda_c^+ \to \phi p \pi^0$







- A strange partner $P_s(uuds\bar{s})$ was searched for in the Cabbibo-suppressed $\Lambda_c^+ \to \phi p \pi^0$ decay at Belle[a] and BESIII.[b]
  ($\mathcal{B}(\Lambda_c^+ \to P_s \pi^0) \cdot \mathcal{B}(P_s \to \phi p) < 8.3 \times 10^{-5}$ at 90% CL)

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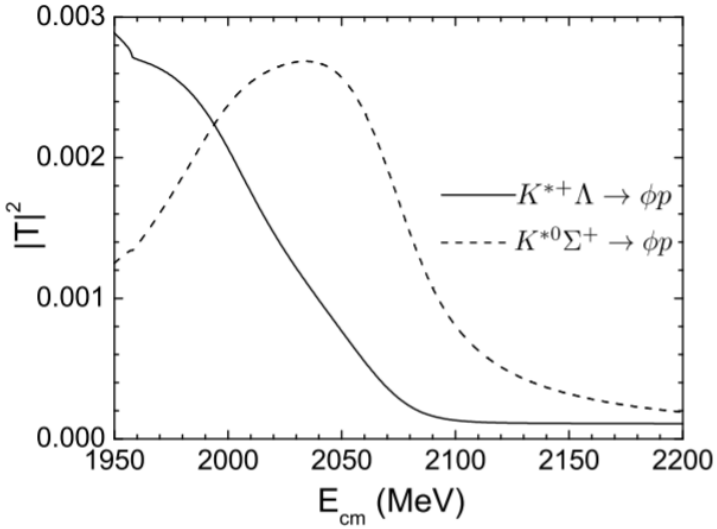
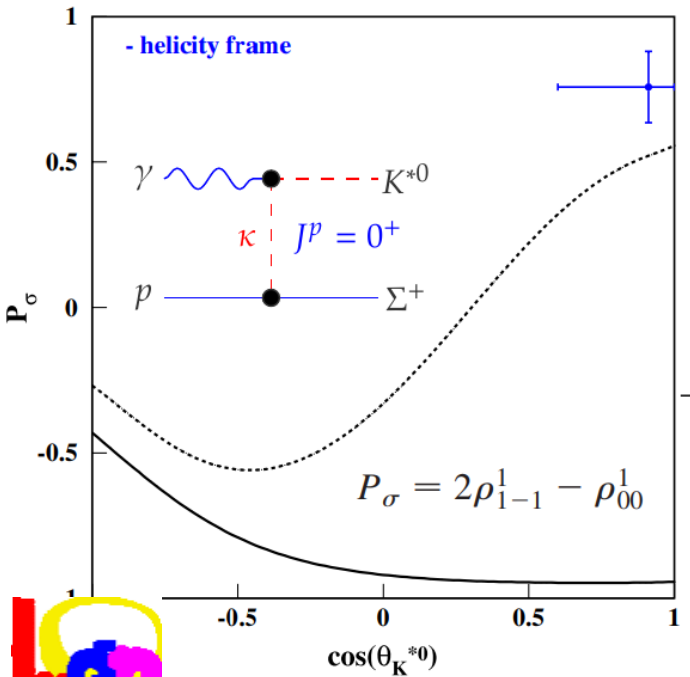
[a] B. Pal *et al.* (Belle Collab), PRD 96, 051102 (2017).

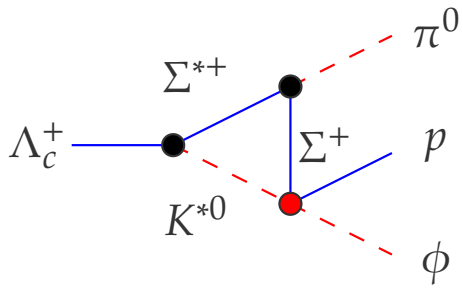
[b] G. Mezzadri, Ph.D thesis, Ferrada U (2018).

Strange Partner of P_c Pentaquark States





- The bump structure observed in ϕ photoproduction could be regarded as a ΣK^* molecular state ($J = 3/2^-$). [a]
- Triangular singularity could also explain the bump structure with $\Sigma K^* \to \phi p$. [b]



- The measured parity spin asymmetry shows that natural-parity exchange is dominant in $\gamma p \to K^{*0}\Sigma^+$ reaction, which clearly indicates the need for t-channel exchange of the κ scalar meson. [c]

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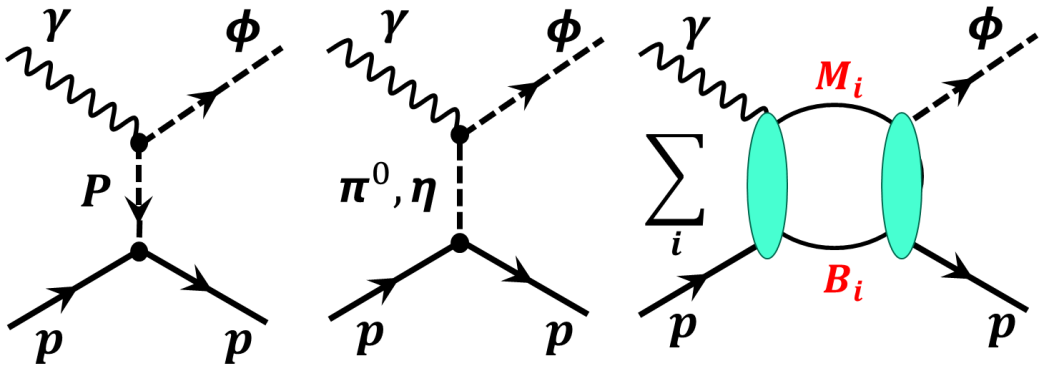
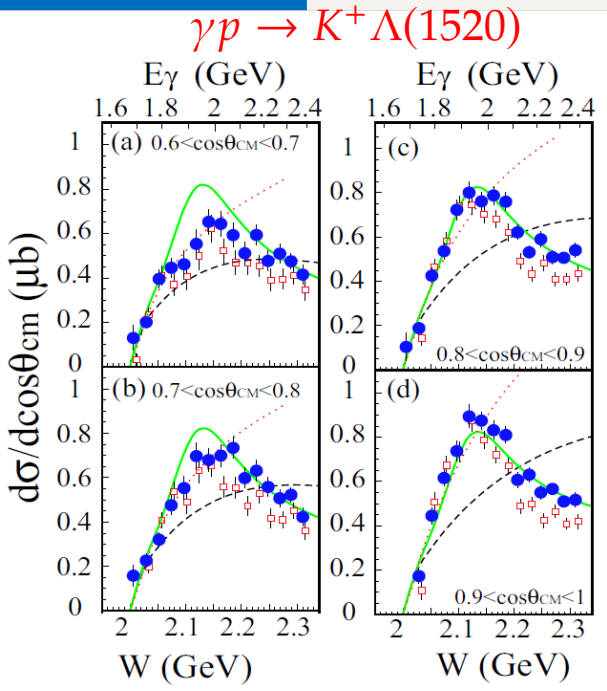
[a] J. He, PRD 95, 074031(2017).

[b] J-J. Xie and F-K Guo, PLB 774, 108 (2017).

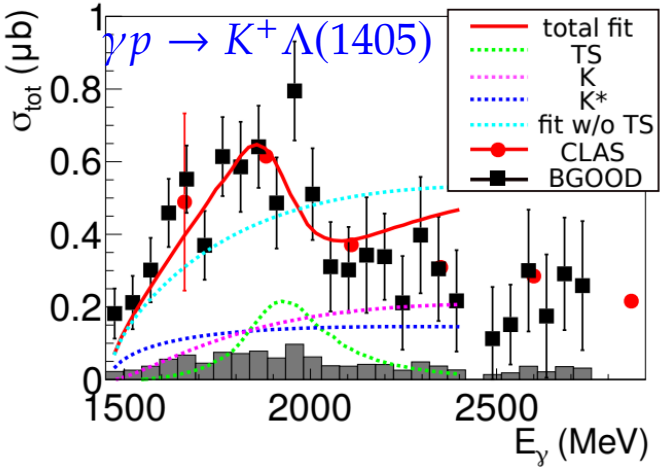
[c] S.H. Hwang *et al.* (LEPS Collab.), PRL 108, 092001(2012).

ϕ Photoproduction near Threshold





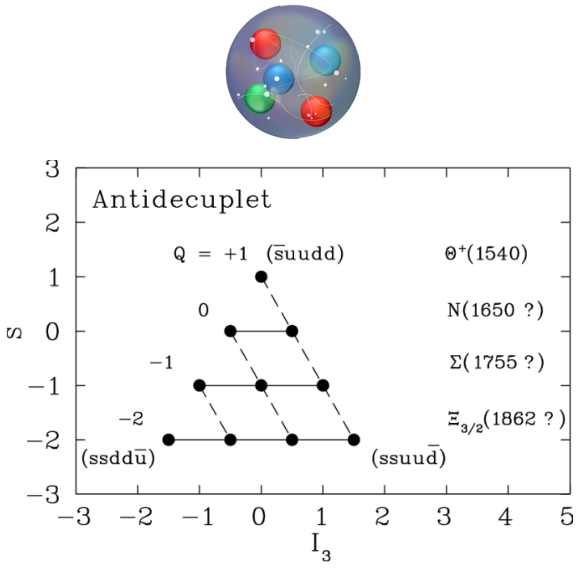
- Meson-baryon rescattering processes via N^* resonance(s) could account for the bump structure observed in ϕ photoproduction at $\sqrt{s}$ = 2.1 GeV.

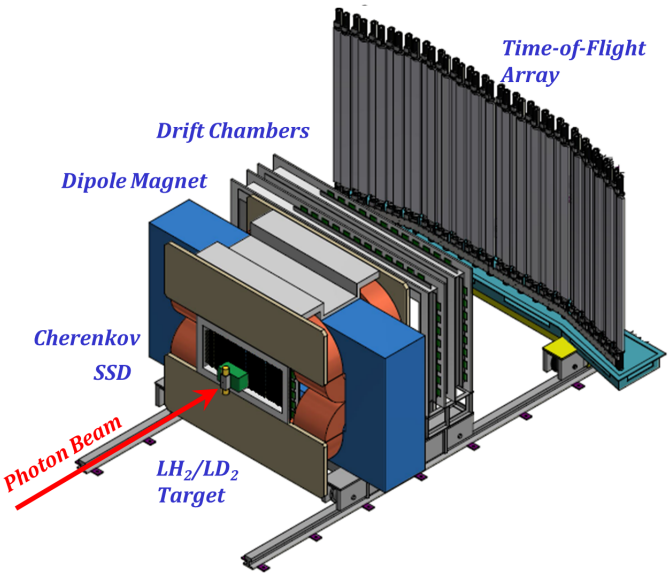


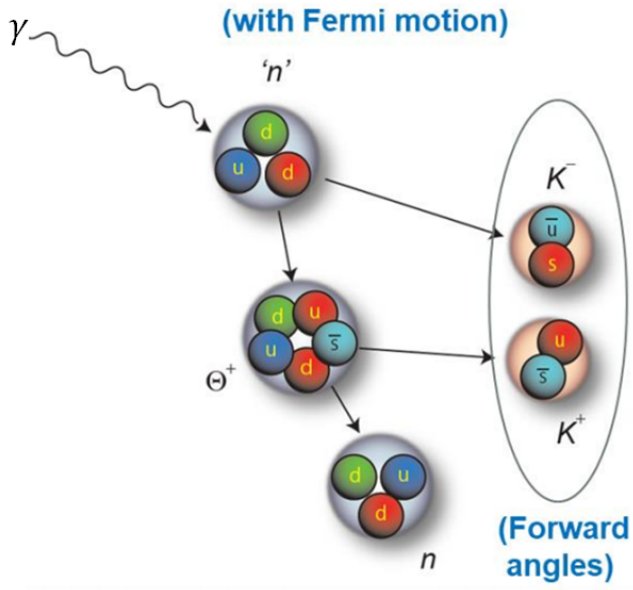
- The nature of the bump structure should be further investigated using circularly polarized photon beam and a polarized (HD) target. This populates selectively a contribution of either $J = 1/2$ or $J = 3/2$ N^* resonance.

Scheluchin *et al.* (BGOOD Collab), arXiv:2108.12235 (2021); H. Kohri *et al.* (LEPS Collab), PRL 104, 172001(2010).

Θ^+ Search at LEPS

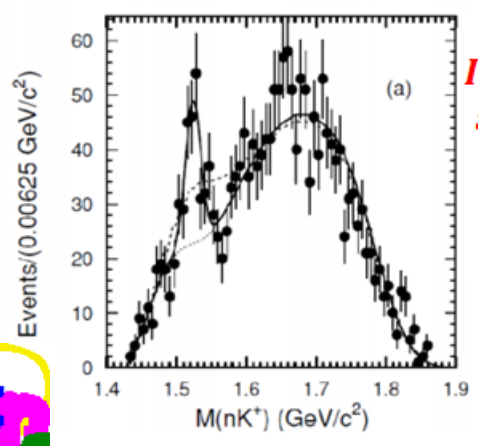






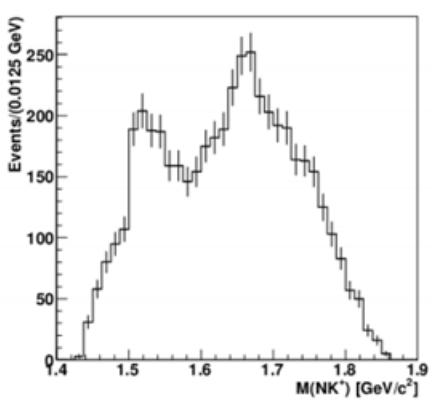
- Θ^+ was searched for in $\gamma n(p) \rightarrow K^+K^-n(p)$ reaction with a LD_2 target. We have collected data in three phase LD_2 runs.

PRC 79, 025210 (2009)



Increased statistics

Few Body Syst. 54, 1245 (2013)



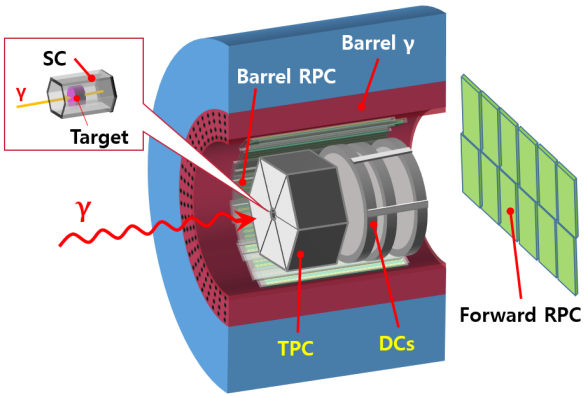
Increased statistics

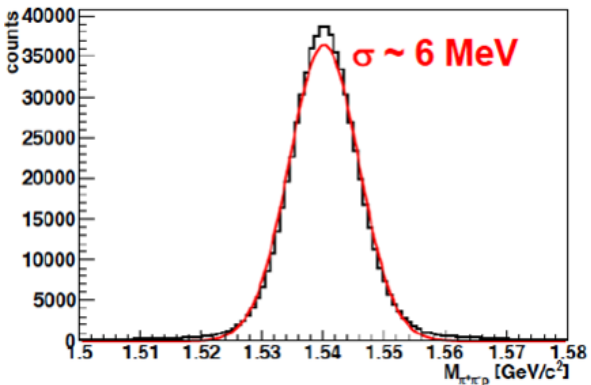
Reduced BG from spectator protons

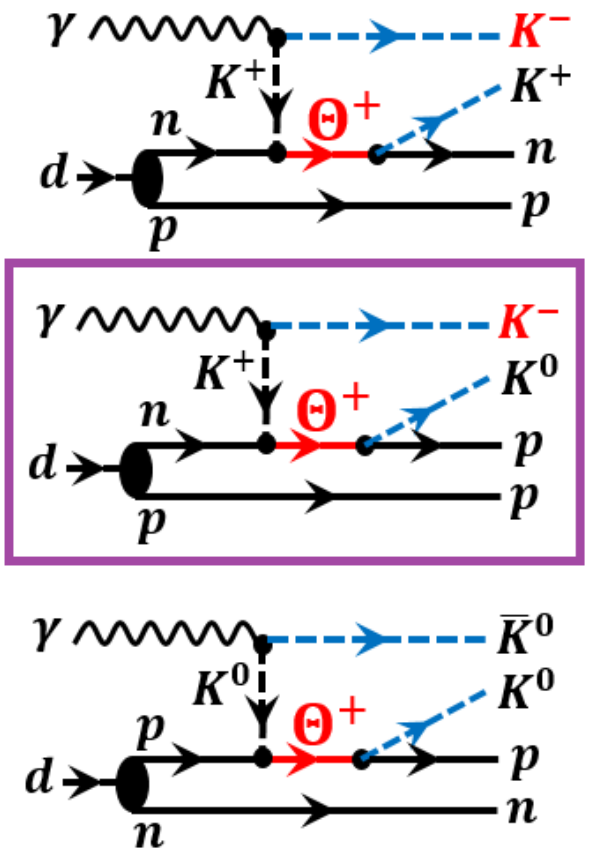
The new results will soon be open

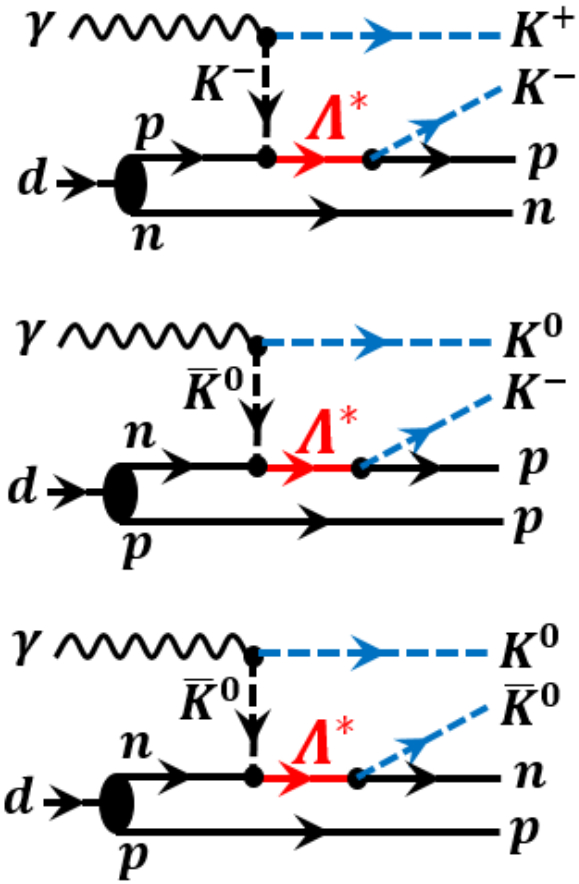
Θ^+ Search at LEPS2

- $\Theta^+(S = +1, uudd\bar{s})$ could be searched for via $\gamma d \to K^- K^0 pp\ (\Theta^+ \to K^0 p;\ K^0(K_S) \to \pi^+\pi^-)$ by complete kinematics.
- All final state particles can be reconstructed with the large-acceptance LEPS2 detector.

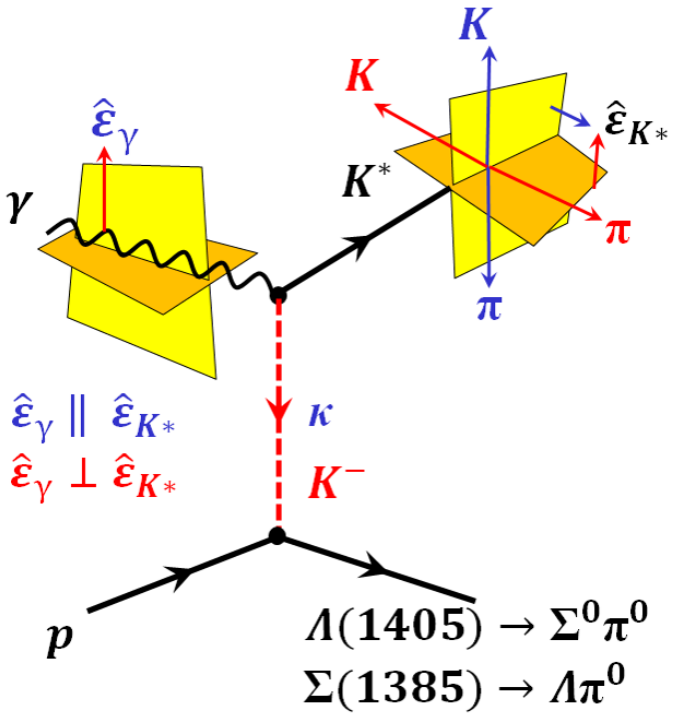


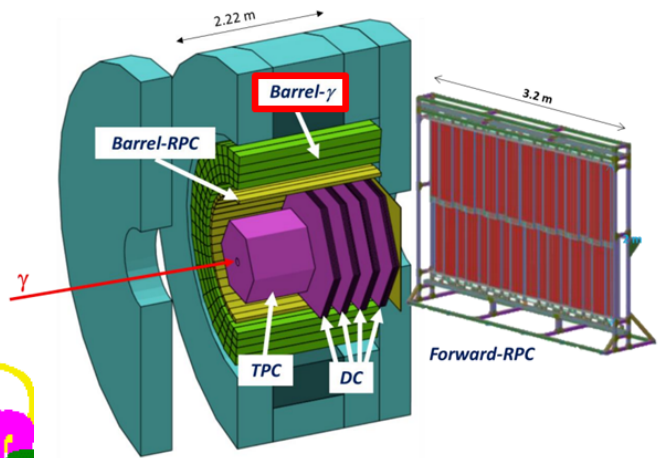




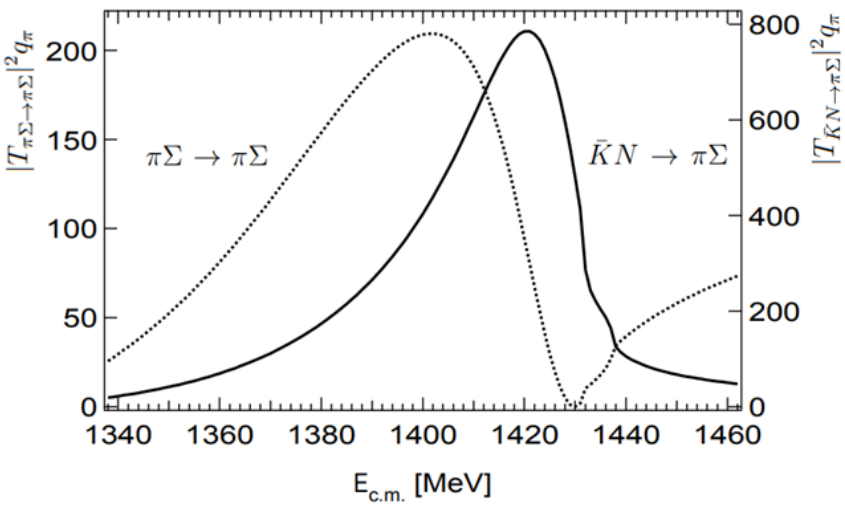


Photoproduction of $\Lambda(1405)$ with K^{*+}





- $K^{*+}(\to \pi^+ K^0_S)$ decay plane $\perp(\parallel)$ the photon beam polarization ($\hat{\varepsilon}$) for unnatural-parity exchange (natural-parity exchange)
- Unnatual-parity K^- exchange selects $\Lambda(1405)$ strongly coupled to a $K^- p$ pole .[a]
- $I = 0$ channel $\Lambda(1405) \to \Sigma^0\pi^0$ can be reconstructed using Barrel-γ detector.



[a] Jido *et al.*, NPA 725, 181(2003); T. Hyodo *et al.*, PLB 593, 75(2004).

Summary

- A new LEPS2 facility with BGOegg and Solenoid detectors has started its full operation for studying hadron spectroscopy from photoproduction using high-intensity Compton backscattered photons at SPring-8.
- Linearly polarized photon beams are very powerful to unveil the nature of hadrons from photoproduction; ϕ, K^*, $\Lambda(1405)$, $K^- pp$, Θ^+ and so on.
- The LEPS2 solenoid detector, consisting of a large solenoid magnet and a time projection chamber, has recently completed its first phase of beam commissioning and physics running. Analysis effort of the first dataset is now underway.