YITP workshop
MIN16 - Meson in Nucleus 2016 -

$K^0\Lambda$ photoproduction on the neutron studied with the FOREST detector at ELPH

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for the FOREST collaboration

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Outline

Introduction - Baryon spectroscopy and KY channels

- Narrow peak structures of special interest at W ~ 1.67 and 1.71 GeV

Experiment - ELPH & 4π electromagnetic calorimeter FOREST

Analysis - Particle identification, Kinematic fit

- Yield counting, Background subtraction

Results - Differential and Total cross sections

- Reaction mechanism for the $K^0\Lambda$ photoproduction

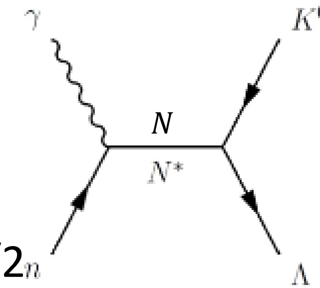
Summary

Baryon spectroscopy via KY *photoproduction*

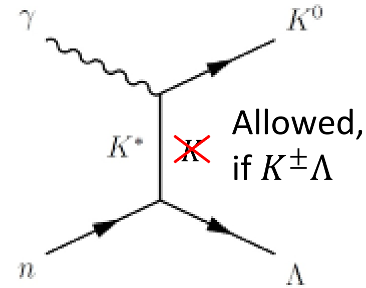
-> accessible highly excited baryons which hardly couple to πN (ηN)

- $K^+\Lambda(\Sigma)$: recently well studied (CLAS, LEPS, SAPHIR, MAINZ,…)
- $K^0\Lambda(\Sigma)$: few reports

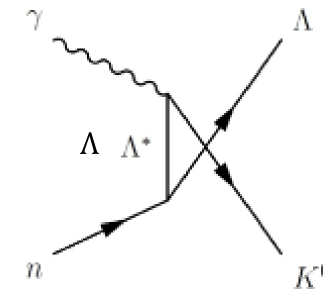
$\gamma n \rightarrow K^0\Lambda$ reaction



s-channel



t-channel



u-channel

Isospin selective -> $K\Lambda$: **1/2**, $K\Sigma$: 3/2

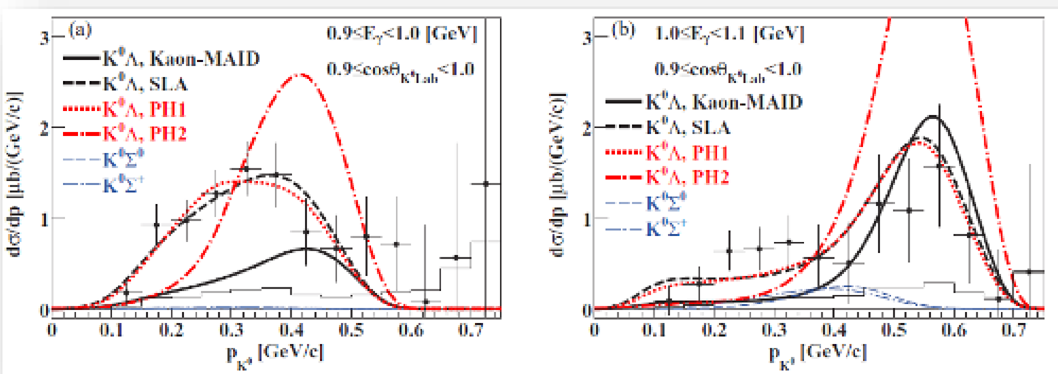
Expected **few t-channel contributions**

All of the participants are *NEUTRAL*

→ no K (not K^*) can be exchanged

→ Born term contributions are expected to be smaller than that of the $K^+\Lambda$ case

K. Tsukada et al. (NKS collaboration), Phys. Rev. C **83** 039904



The previous measurement near the reaction threshold was done for $E_\gamma = [0.9, 1.1)\mathrm{GeV}$ and $\cos\theta_K^{Lab} = [0.9, 1.0)$

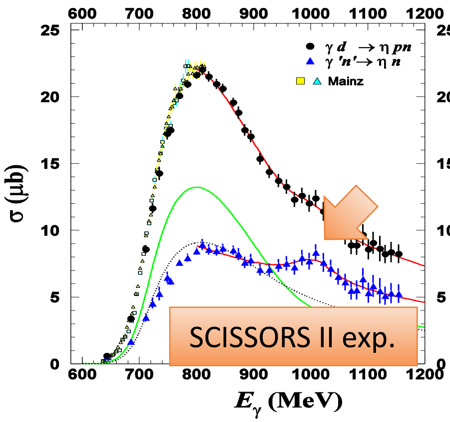
Need the study with entire angle region

$N(1670)$

$\gamma N \to \eta N$

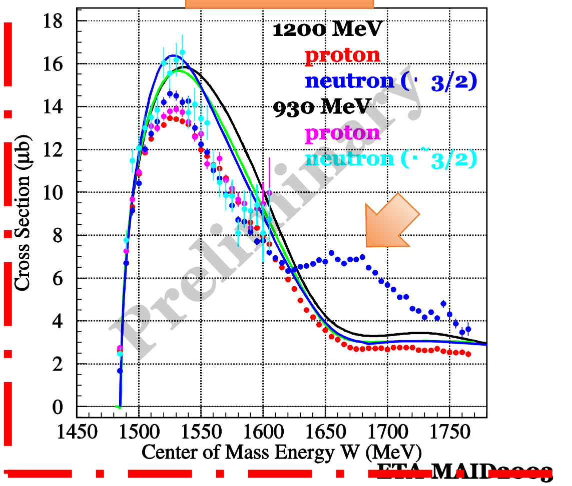
$\gamma n \to \eta n$ -> A narrow resonance-like structure @1670 MeV
$\gamma p \to \eta p$ -> *No* such structure (but a dip?)

LNS (ELPH)



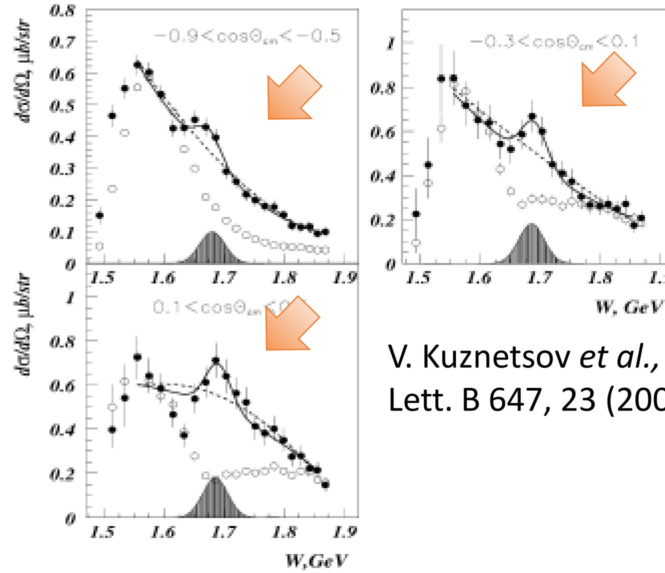
F. Miyahara *et al.*, Prog. Theor. Phys. Suppl. **168,** 90, (2007)

FOREST



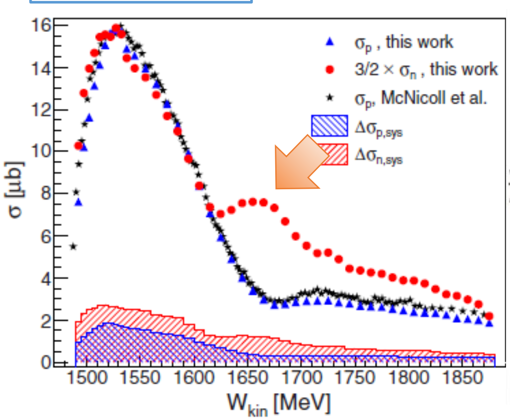
T. Ishikawa *et al.*, PoS (Hadron2013)025

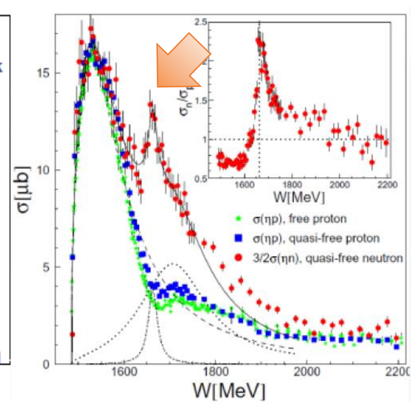
GRAAL



V. Kuznetsov *et al.*, Phys. Lett. B 647, 23 (2007)

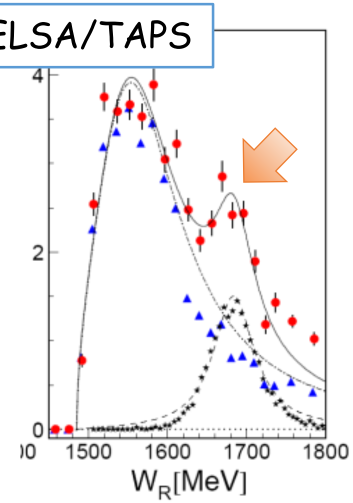
A2@Mainz

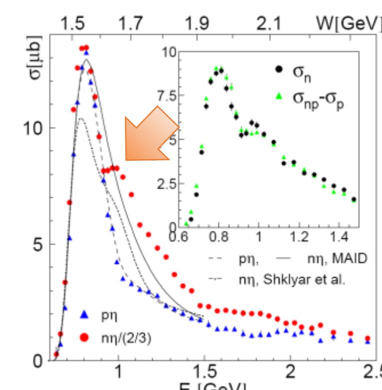




R.Wertmuller *et al.*, PRC 90, 015205 (2014)

CBELSA/TAPS





J.Jeagle *et al*, PRL **100**, 252002 (2008)

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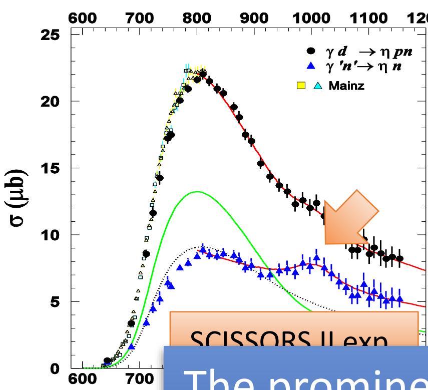
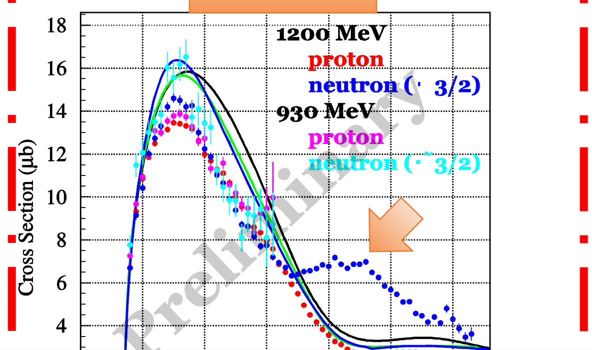
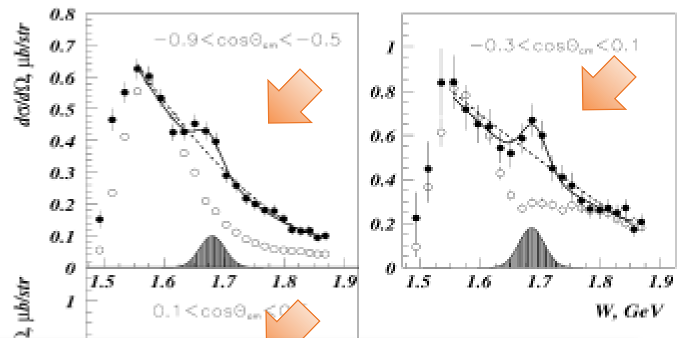


FOREST



GRAAL



F. Miyal...

Phys. Su...

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...007)

The prominent structure observed in the $\gamma n \to \eta n$

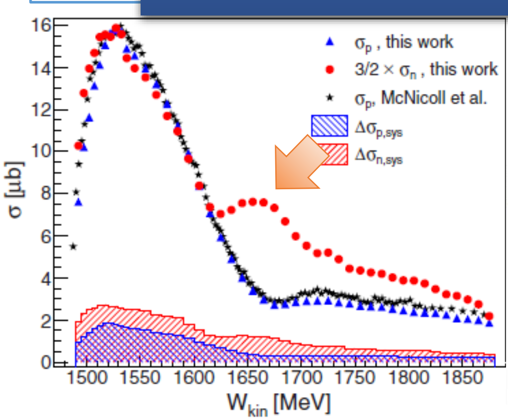
Reported by many exp. groups **LNS (ELPH), GRAAL, MAINZ, CB-ELSA/TAPS**

→ Consistent results:

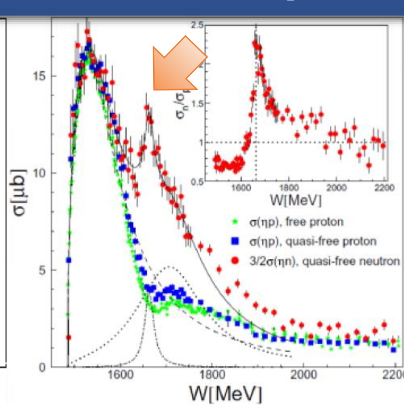
Narrow width ($\sim$ **30 MeV**) and peak position $\sim$ 1670 MeV

Observed in the $\boldsymbol{n(\gamma, \eta)n}$ reaction but ***not* in the** $\boldsymbol{p(\gamma, \eta)p}$ case

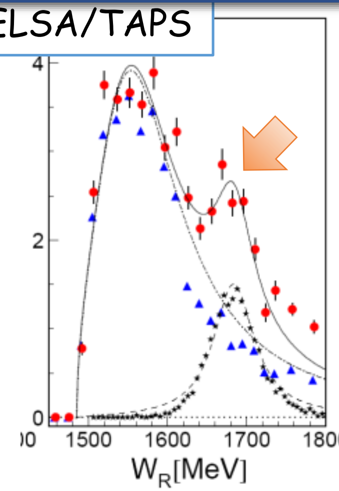
A2@...

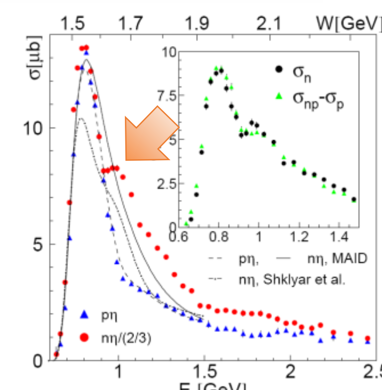


R.Wertmuller *et al.*, PRC 90, 015205 (2014)



CBELSA/TAPS





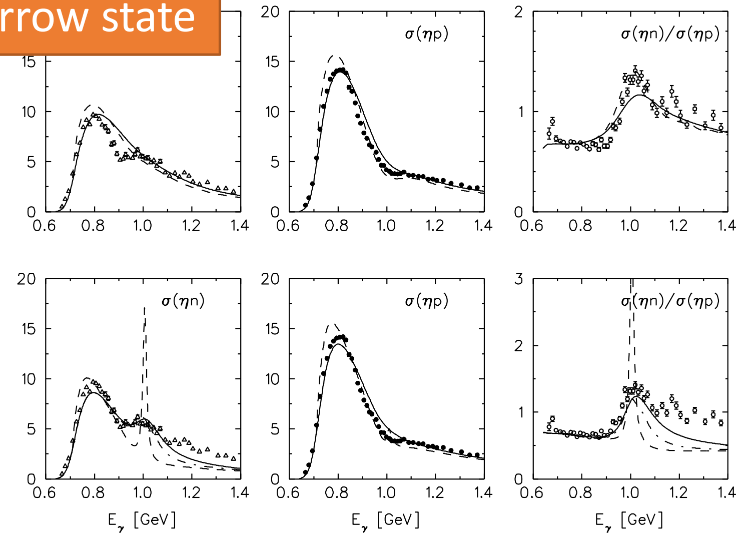
J.Jeagle *et al*, PRL **100**, 252002 (2008)

$N(1670)$

Recent theoretical interpretations

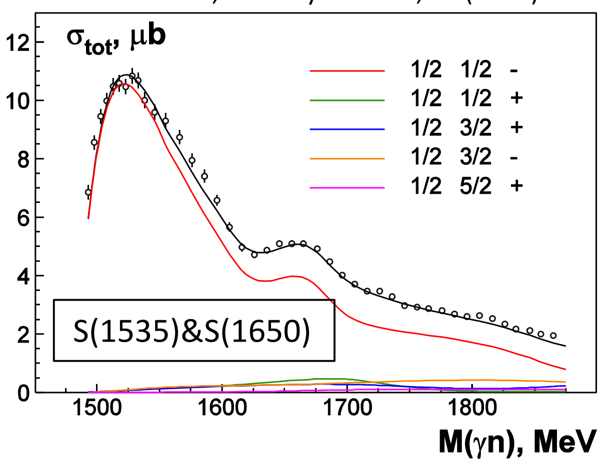
- Intrinsic narrow state
- Coupled-channel effects
- Interference effects
- KY threshold effects
- …

Intrinsic narrow state



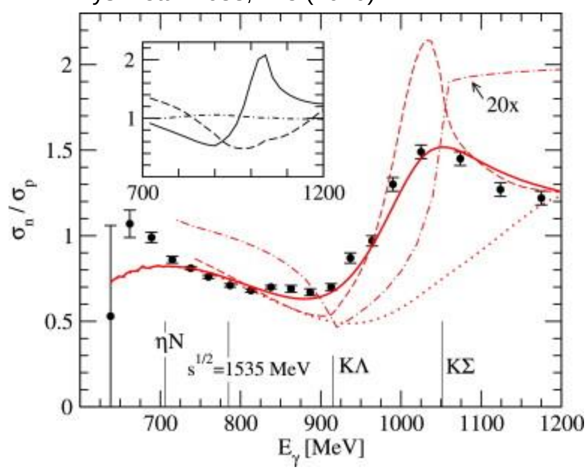
Interference effect

Anisovich et al., Eur. Phys. J. A **51**, 72 (2015)



Threshold effect (KY ch.)

M. Döring and K. Nakayama,
Phys. Lett. B 683, 145 (2010).



More experimental information is needed
-> How about the $K^0\Lambda$ case?

Similarities between
ηn & $K^0\Lambda$

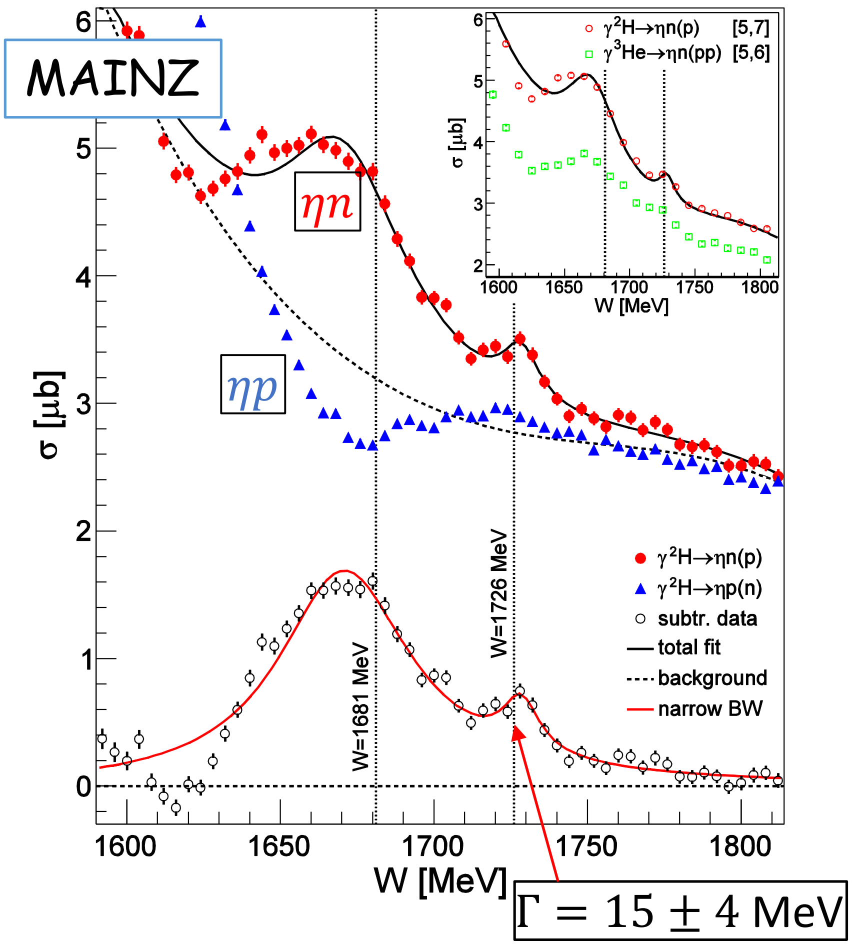
- **Isospin 1/2**
- **γn initial state**
- **$s\bar{s}$ component**

Confirmation of the N(1670) must be a valuable info.

$N(1710)$?

Another narrow, but small, peak structure has been also observed in $\eta(\pi^0)$ photoproduction

Re-analysis of the $\gamma(n, n)\eta$ reaction (re-binned ver.)
Werthmuller et al., arXiv 1511.0829 (very recent!)



Σ asymmetry of the $\gamma(p, p)\pi^0$ reaction
Kuznetsov et al., Phys. Rev. C 91, 042201 (2015)

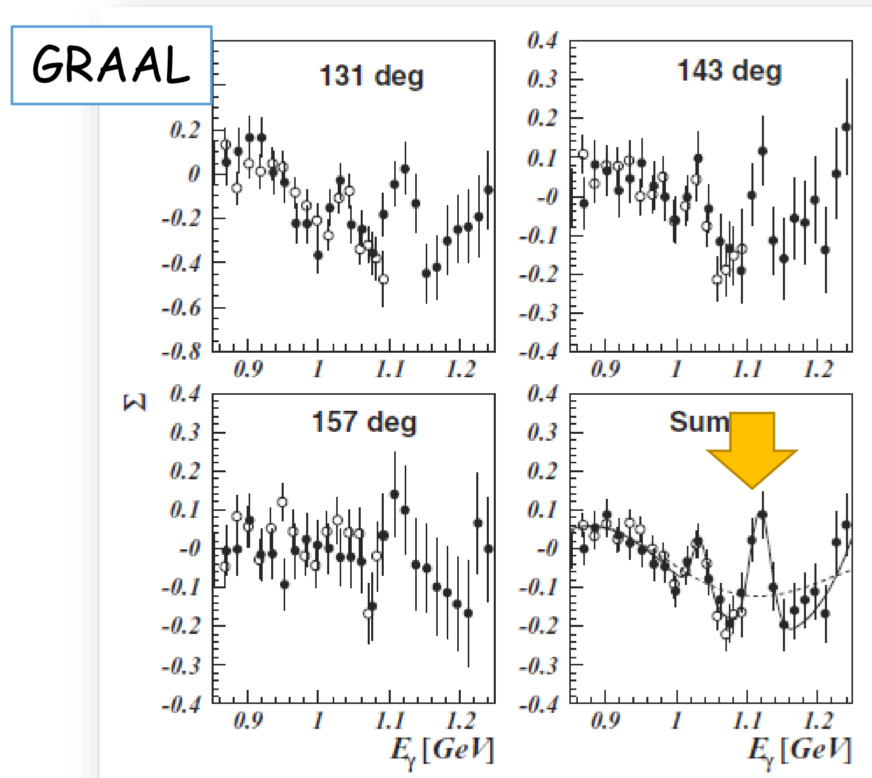
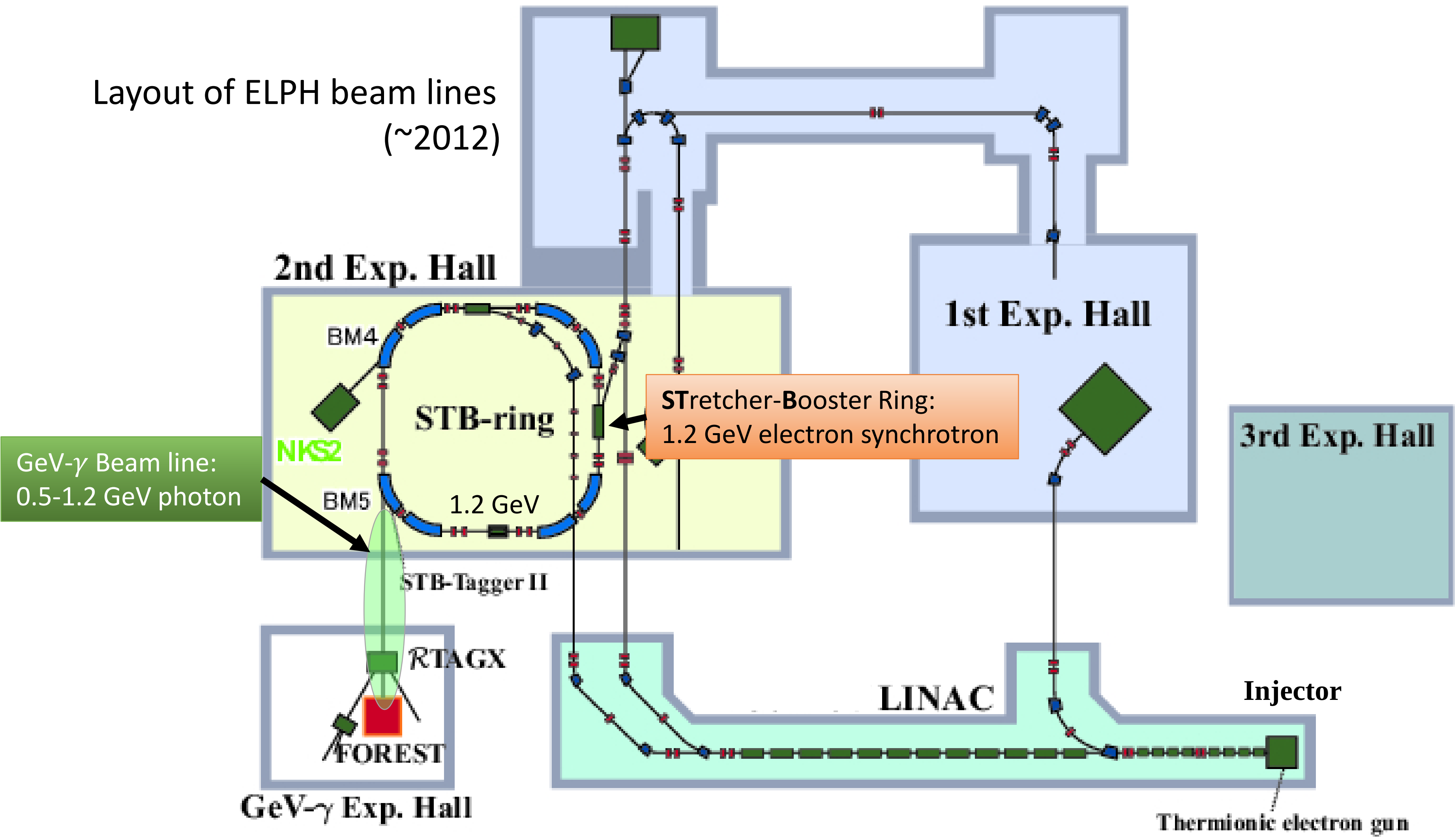


FIG. 3. Beam asymmetry Σ for Compton scattering on the proton. Dark (open) circles are the results obtained with UV (green) laser.

Experiment @ ELPH, Tohoku University, Sendai

1.2 GeV Electron Synchrotron and photon beam line
@ Research Center for Electron Photon Science (ELPH)

Layout of ELPH beam lines
(~2012)



4 π electromagnetic calorimeter complex **FOREST**

192 Pure CsI
SCISSORS III

24 PS × 3 layers
SPIDER

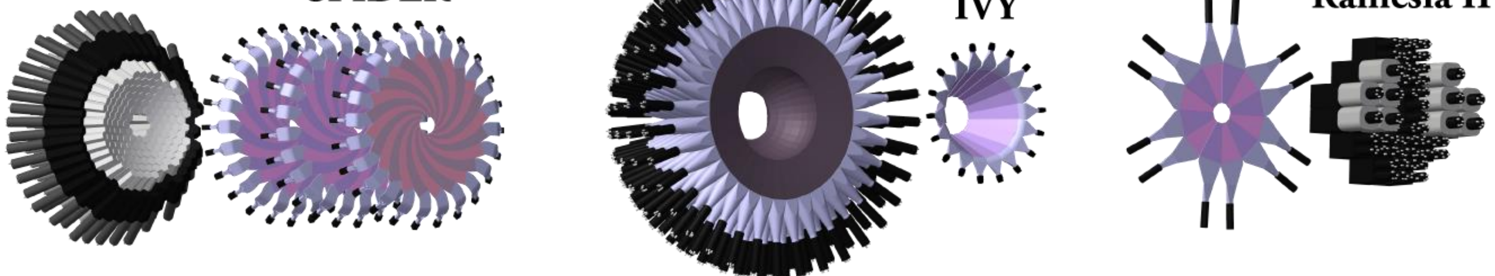
252 Lead/SciFi mod.s
LEPS Backward Gamma

PS × 18
IVY

PS × 12
LOTUS

62 Lead/Glass
Rafflesia II

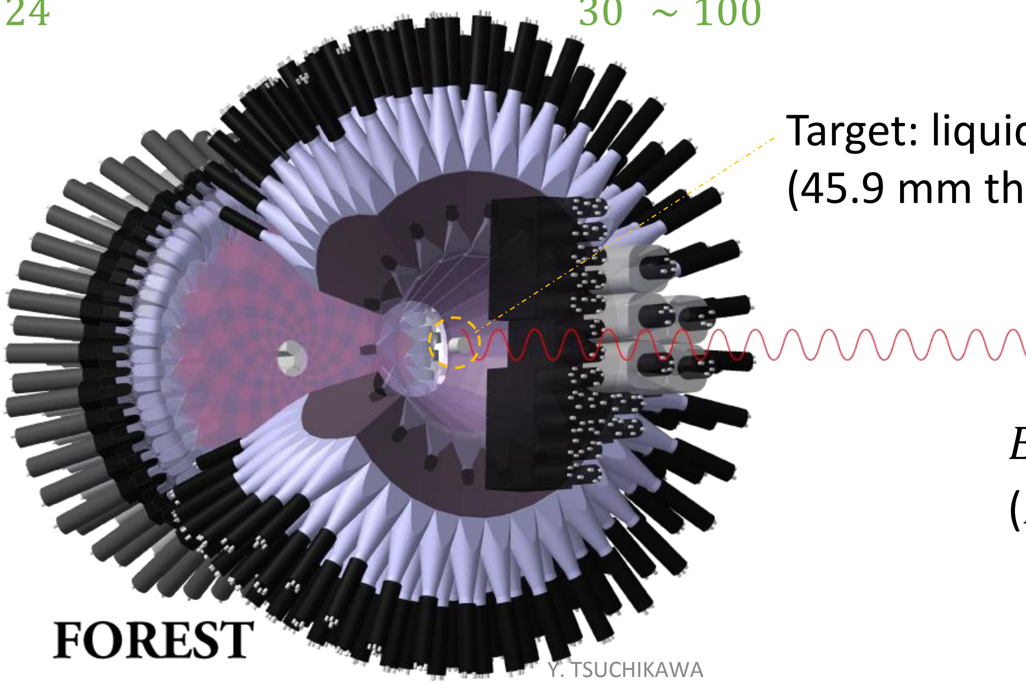
(Forward)



(Backward)

σ_E/E (1 GeV γ) ~3 % ~ 7 % ~ 5 %

Coverage θ $5^\circ \sim 24^\circ$ $30^\circ \sim 100^\circ$ $110^\circ \sim 170^\circ$



FOREST

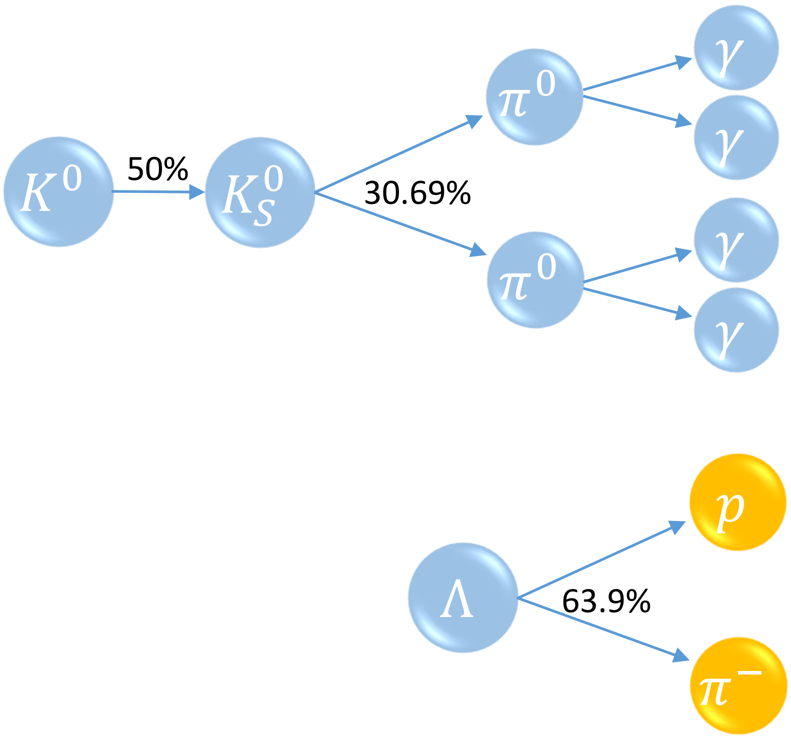
Target: liquid H2/D2 target
(45.9 mm thick)

γ

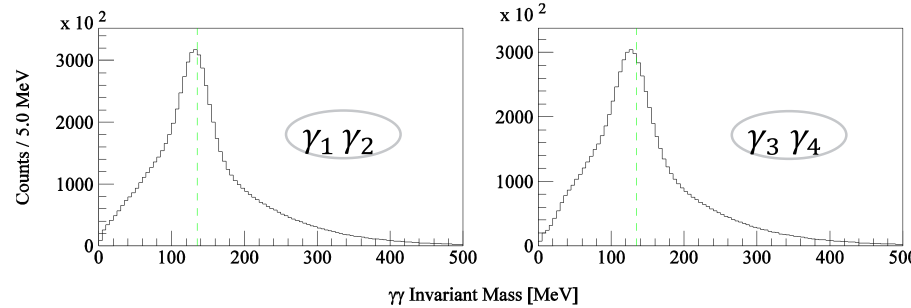
$E_\gamma = 750 - 1150$ MeV
$(E_\gamma^{thr}(K^0\Lambda) = 915$ MeV)

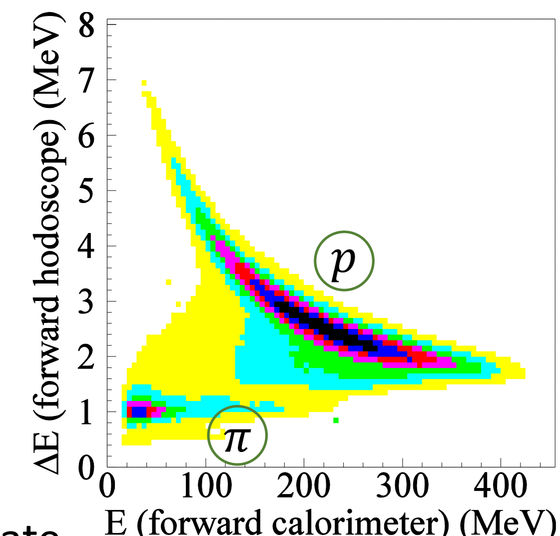
Particle identification

Focusing decay chains:



$\gamma\gamma$ invariant masses





4 photons and **2 charged** particles in the final state

$$\gamma d \rightarrow K^0\Lambda p \rightarrow K_S^0\Lambda p \rightarrow (\pi^0\pi^0)(p\pi^-)p \rightarrow (4\gamma)(p\pi^-)p$$

Proton in the deuteron is assumed as a spectator

Kinematic fit with 4 constraints

16 variables:
γ_i momentum, polar, and azimuthal angles: E_i, θ_i, ϕ_i $(i = 1, \dots, 4)$, same for proton: P_p, θ_p, ϕ_p,
and Photon beam energy: E_γ

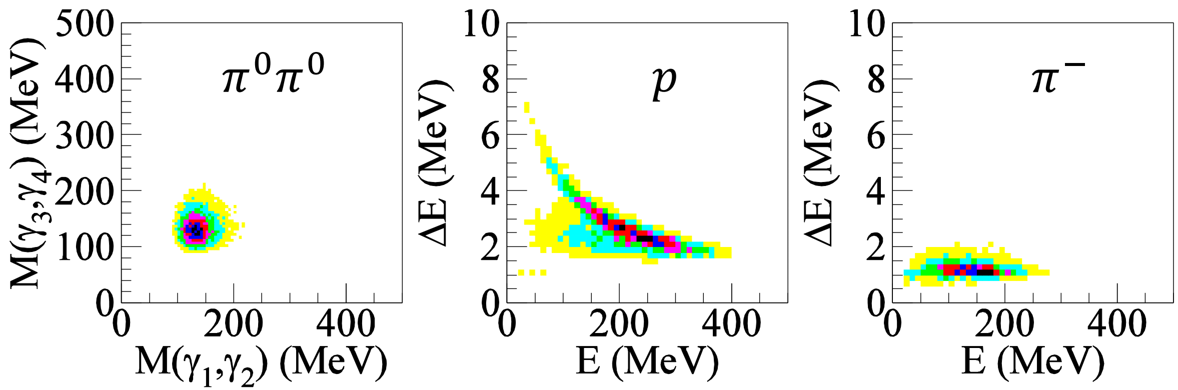
"$\gamma\gamma$ invariant mass = m_{π^0}" x2

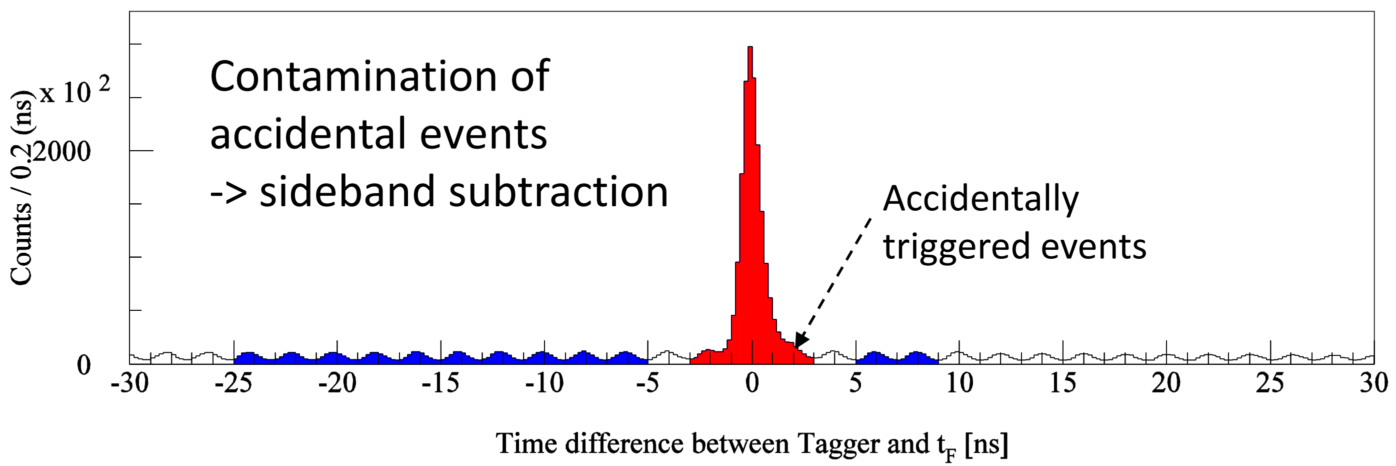
1. $M^2(\gamma_1, \gamma_2) \equiv 2E_1E_2(1 - \sin\theta_1 \sin\theta_2 \cos(\phi_1 - \phi_2) - \cos\theta_1 \cos\theta_2) = m_{\pi^0}^2$
2. $M^2(\gamma_3, \gamma_4) \equiv 2E_3E_4(1 - \sin\theta_3 \sin\theta_4 \cos(\phi_3 - \phi_4) - \cos\theta_3 \cos\theta_4) = m_{\pi^0}^2$

"4γ missing mass = m_Λ" : 3. $M_X^2(\gamma_1, \gamma_2, \gamma_3, \gamma_4) \equiv E_X^2 - P_X^2 = \left(E_\gamma + m_n - \sum_{i=1}^{4} E_i\right)^2 - P_X^2(E_i, \theta_i, \phi_i, E_\gamma) = m_\Lambda^2$

"$4\gamma p$ missing mass = m_{π^-}": 4. $M_X^2(\gamma_1, \gamma_2, \gamma_3, \gamma_4, p) = m_{\pi^-}^2$

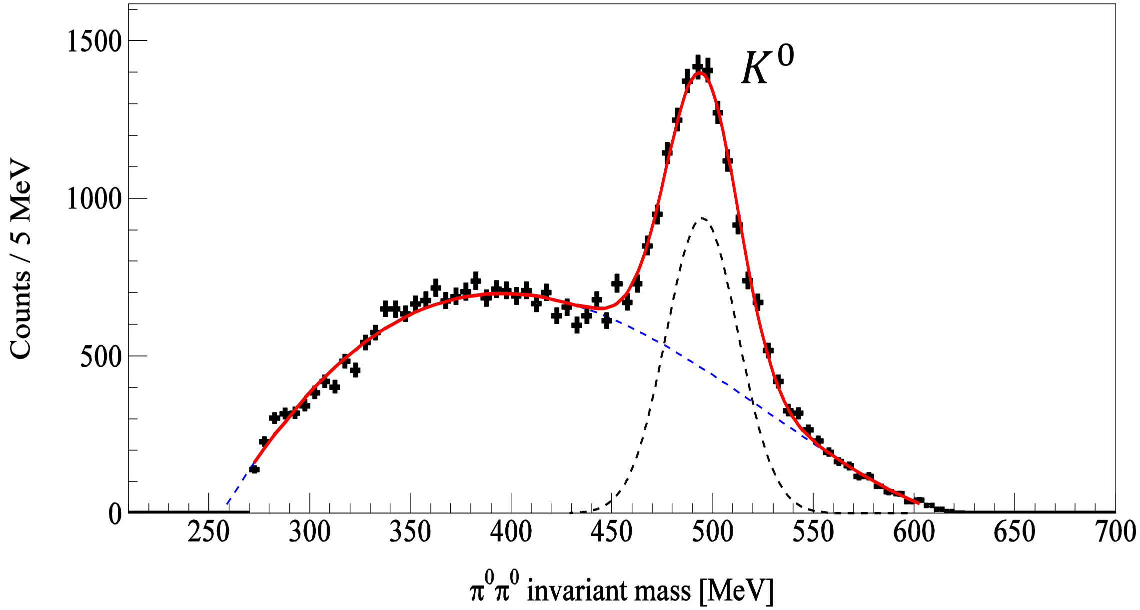
Selected events with detected values





K^0 signal

Clear peak but S/N ~50%

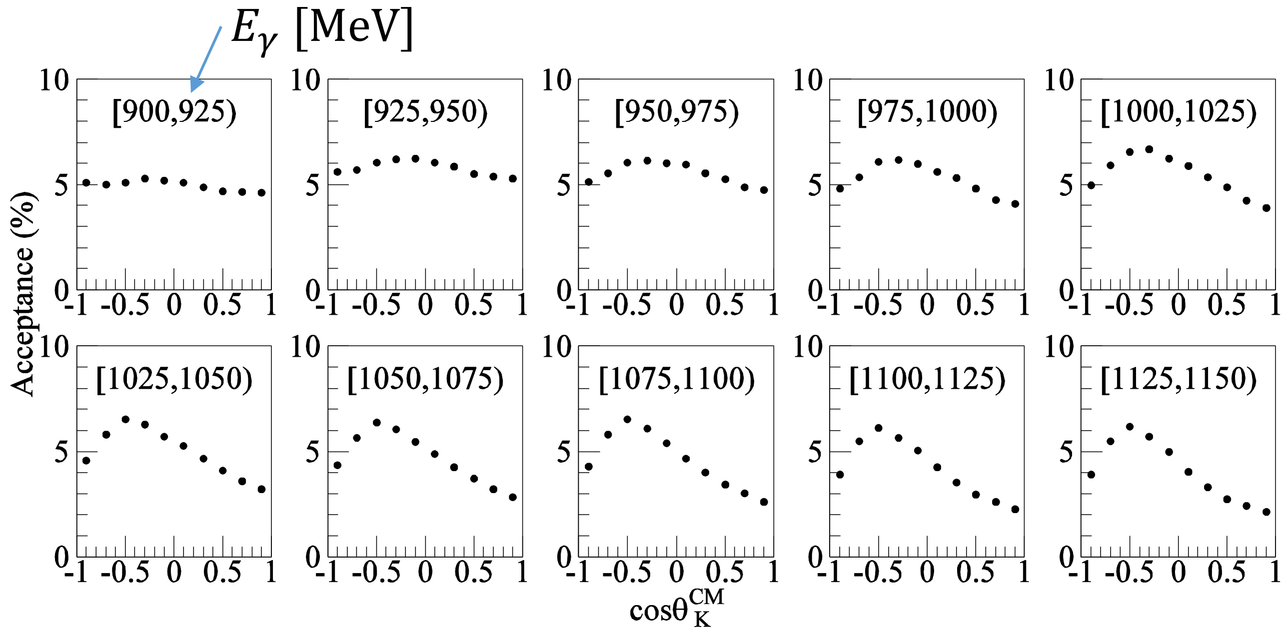


Clear peak but S/N ~50%

$\mu = 494.9(3)$ MeV
$\sigma = 17.9(3)$ MeV
About 8,400 K^0 signals

Acceptance

Full coverage for $\cos\theta_K^{CM}$ to the whole range of E_γ

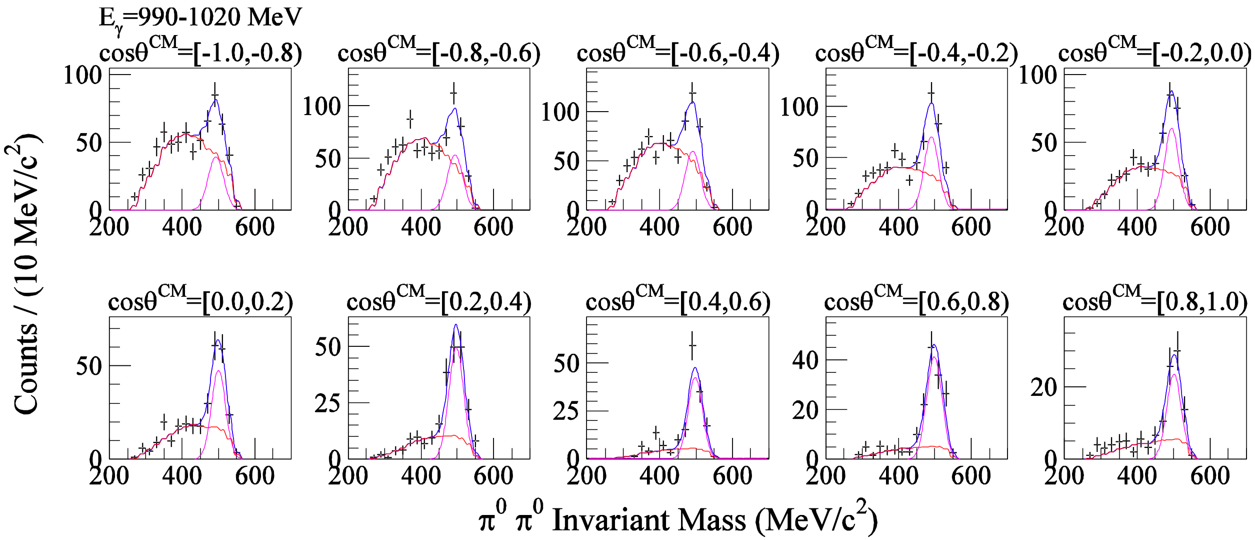


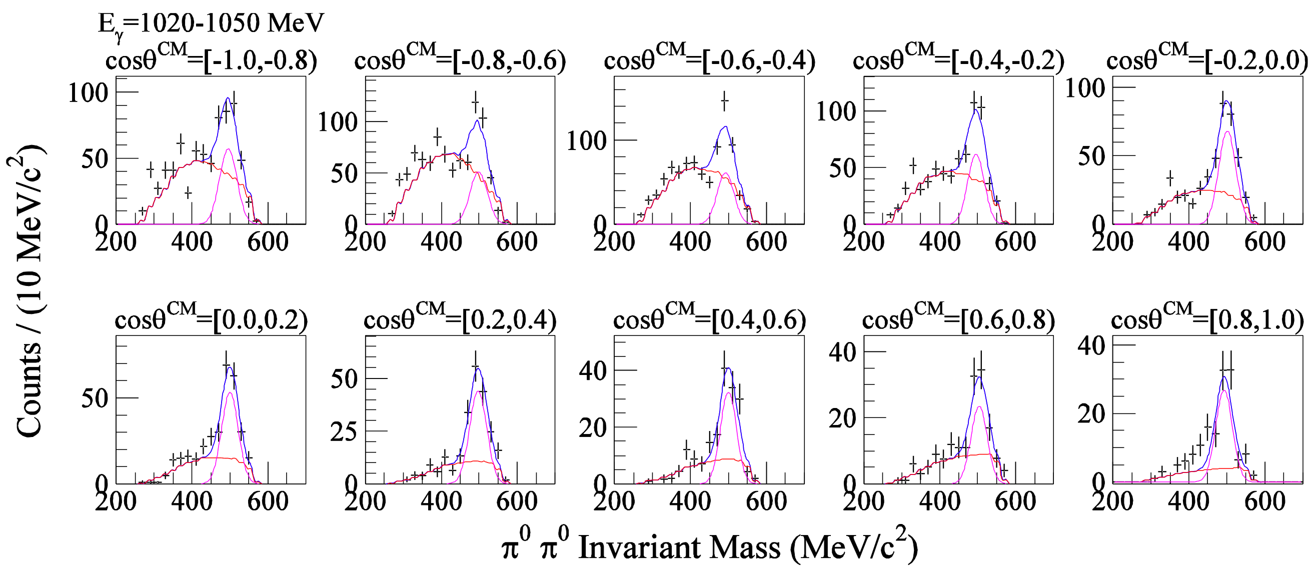
Yield counting

The simulated distributions ($\gamma n \to \pi^0\pi^0\pi^- p$) well reproduce the BG distributions

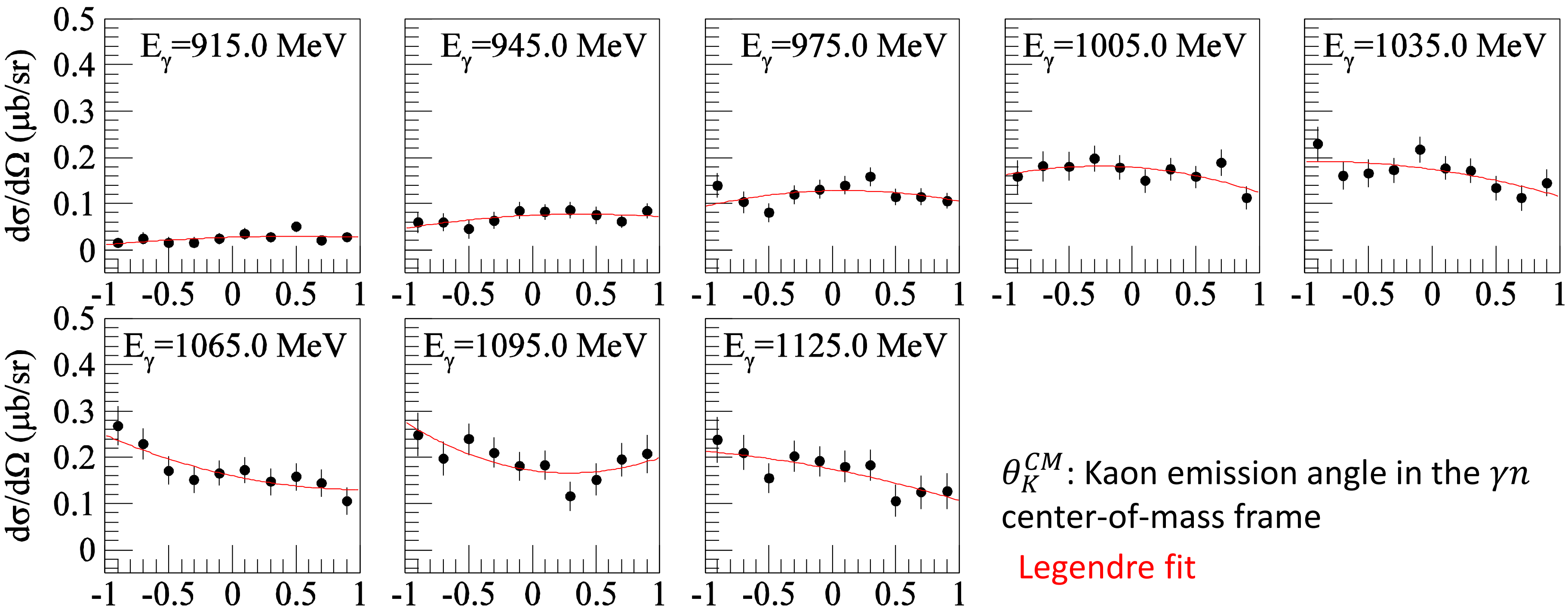
Fit for yield counting:
Total (blue) =
Gaussian (magenta)
+ BG dist. (red)

Examples of the fit results



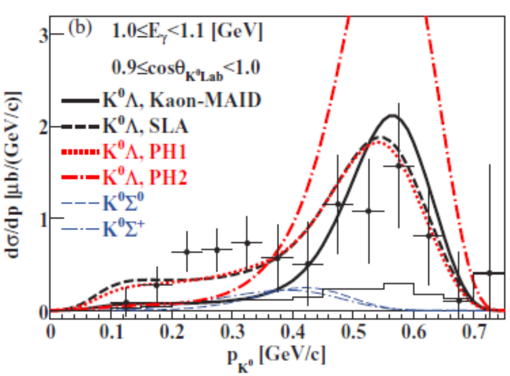


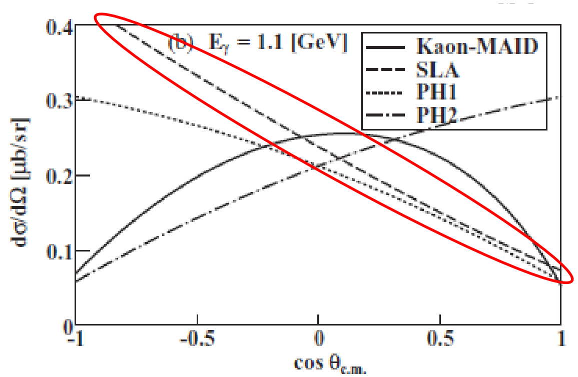
Differential Cross Sections



θ_K^{CM}: Kaon emission angle in the γn center-of-mass frame

Legendre fit



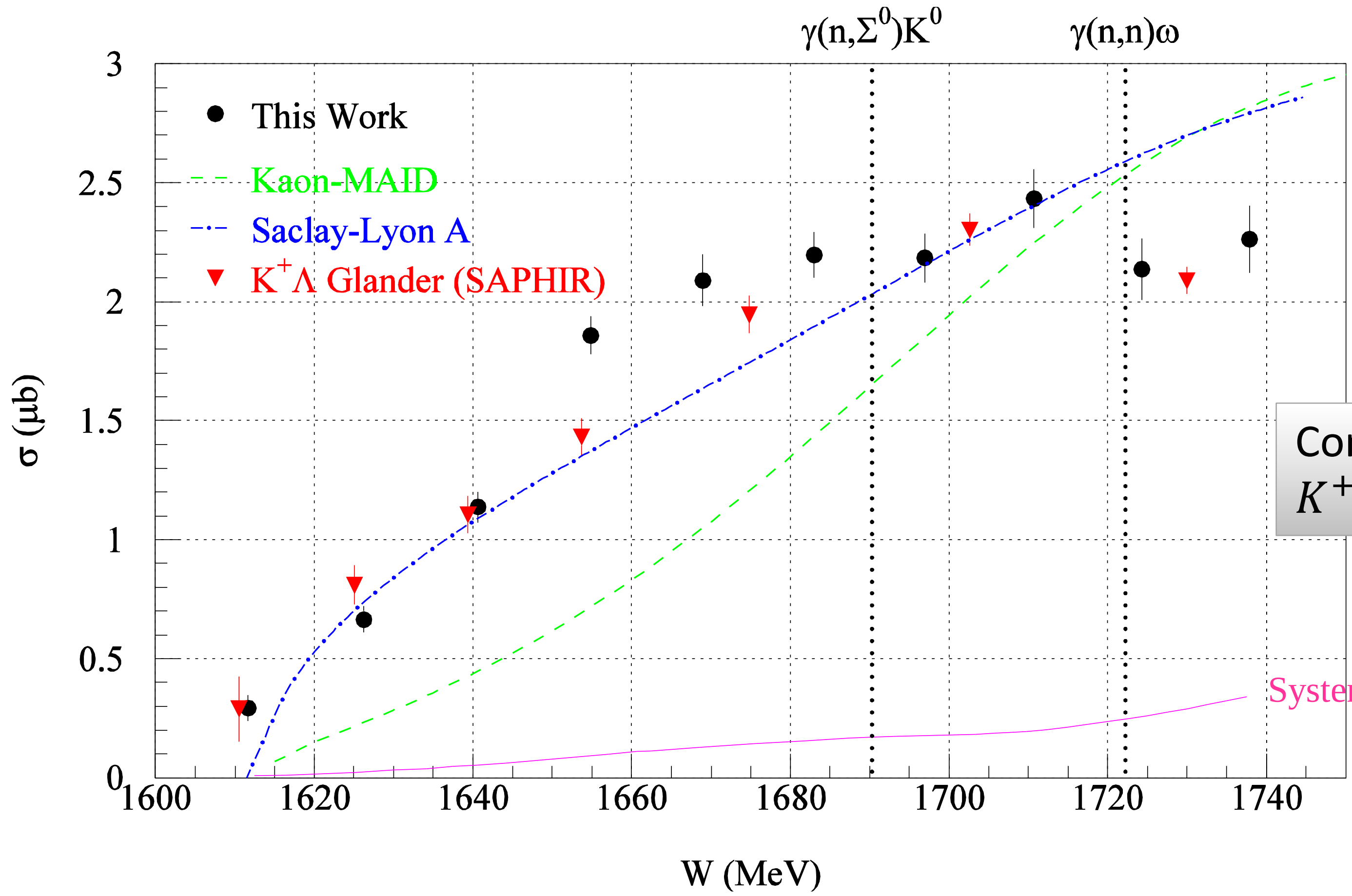


K. Tsukada et al., Phys. Rev. C **83** 039904

Angular distribution:
Flat -> **Backward enhancement**

This result supports the experimental remark in the previous measurement for the $\gamma n \rightarrow K^0\Lambda$ reaction reported by K. Tsukada et al.

Total Cross Section



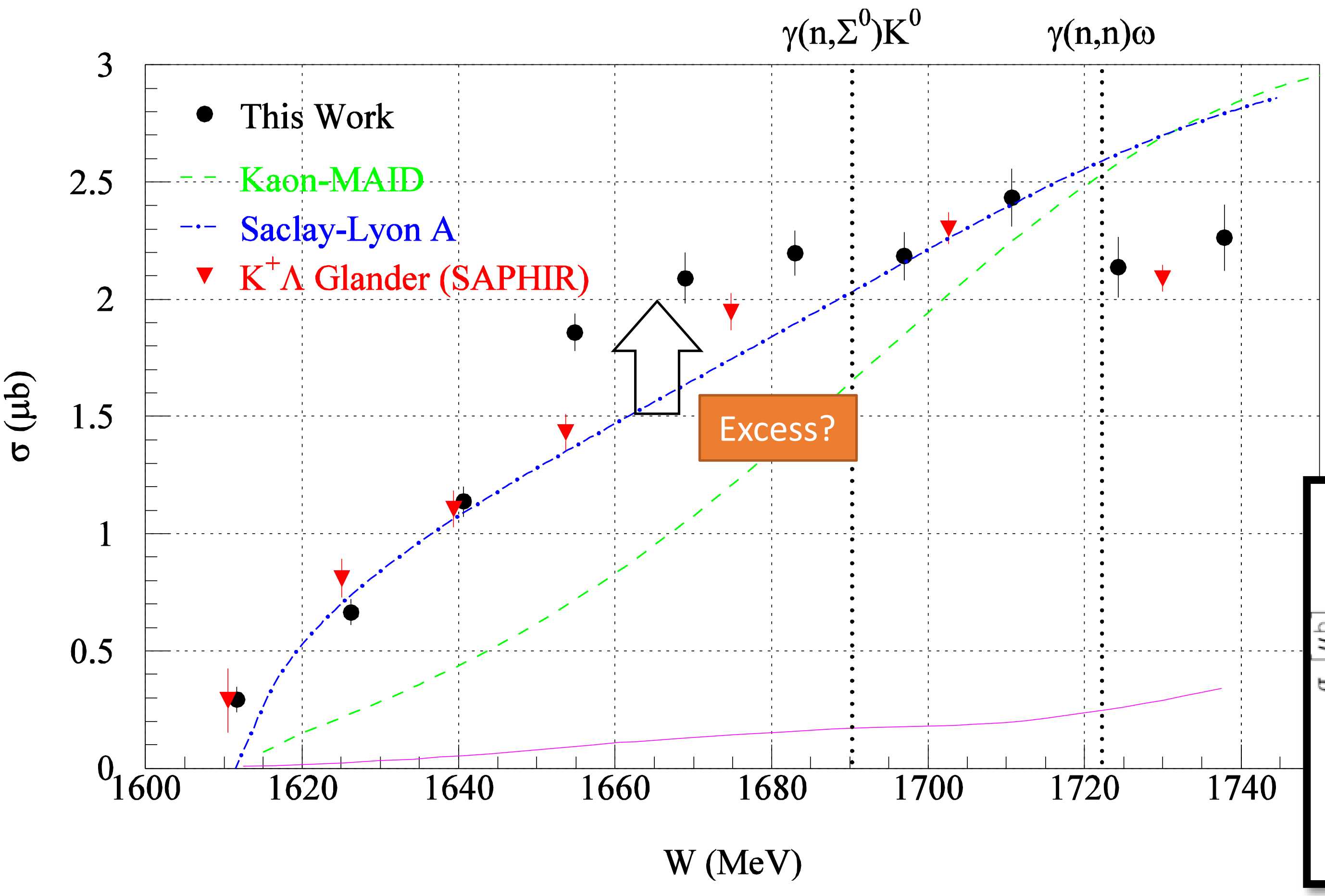
Comparable to the $K^+\Lambda$ channel

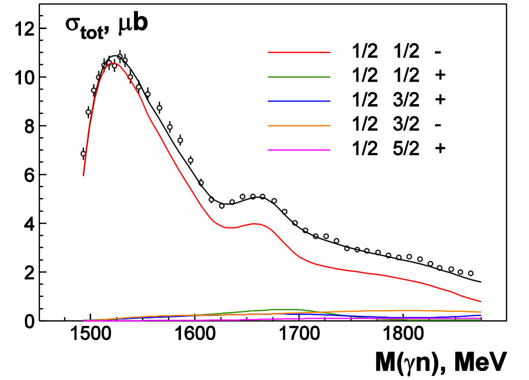
Systematic error (preliminary)

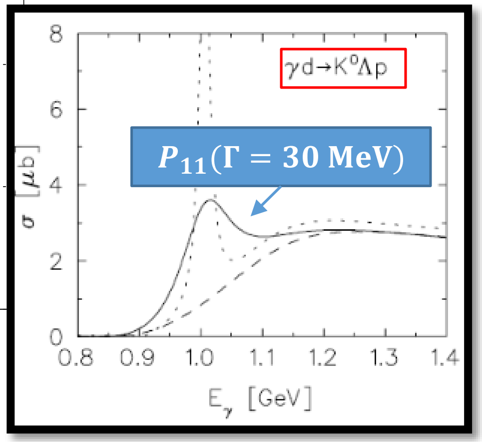
Acceptance
Geometry in the MC sim.
Threshold energies
for TDC
for Trigger cond.
Number of incident photon
Number of target

The target neutron is assumed at rest.

Total Cross Sections

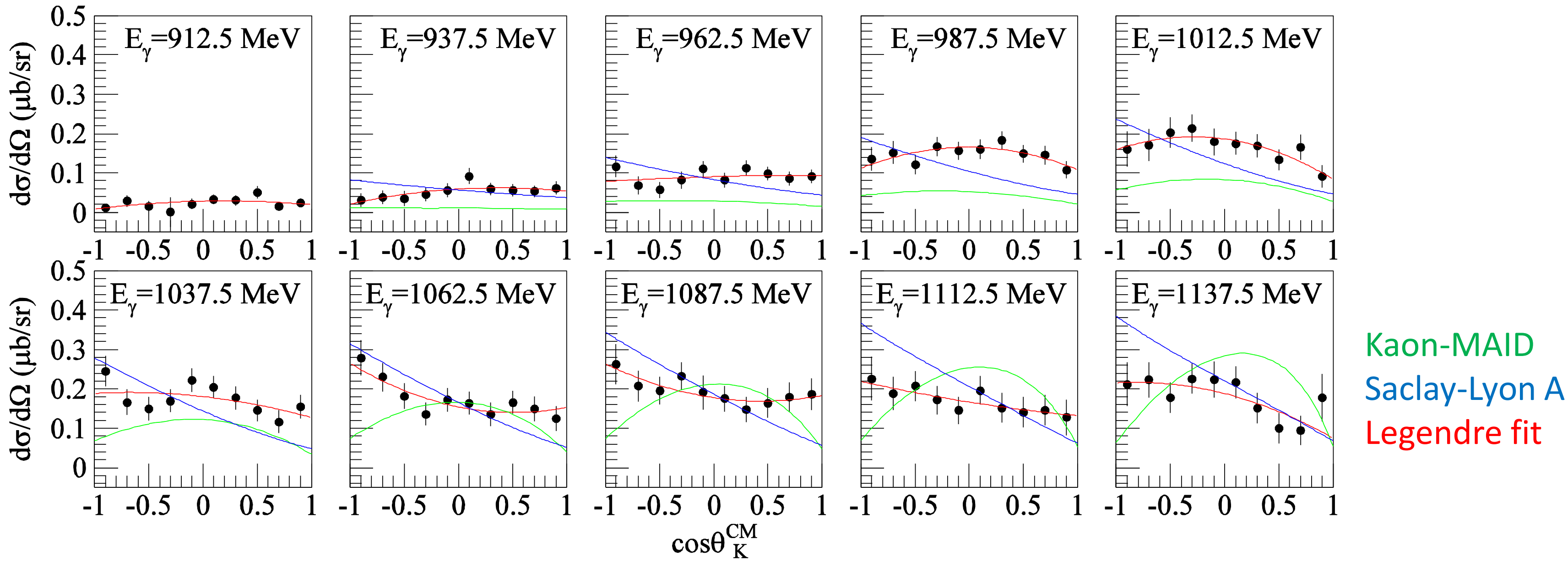






A. Fix et al., Eur. Phys. J. A 32, 311–319 (2007).

Differential Cross Sections and theoretical curves



Resonance term	Kaon-MAID	Saclay-Lyon A
s-channel	$S_{11}(1650)$	$P_{13}(1720)$
	$P_{11}(1710)$	
	$P_{13}(1720)$	
	$D_{13}(1895)$	
t-channel	$K^*(892)$	$K^*(892)$
	$K_1(1270)$	$K_1(1270)$
u-channel		$S_{01}(1407)$
		$S_{01}(1670)$
		$P_{01}(1810)$
		$P_{11}(1660)$

Compared to two theoretical curves:
Kaon-MAID and Saclay-Lyon A

Present results favor the SLA model
→ **u-channel Y* contribution**
may play an important role
in the $\gamma n \rightarrow K^0\Lambda$ reaction

Summary

- The $\gamma d \to K^0 \Lambda p$ photoproduction reaction is studied with electromagnetic calorimeter complex FOREST at ELPH, Sendai
- K^0 signals are well confirmed by $\gamma d \to K_S^0 \Lambda p \to (\pi^0\pi^0)(p\pi^-)p \to (4\gamma)(p\pi^-)p$ reaction chains with an exclusive analysis
- Shape of the background shown in the $\pi^0\pi^0$ invariant mass distribution can be well reproduced by the simulated distribution of $\gamma n \to \pi^0\pi^0\pi^- p$ non-resonant reaction
- Differential cross sections show backward enhancement as E_γ increases

  (This result supports the remark of the previous measurement)
- Comparison with the theoretical calculations may indicate that the hyperon resonance plays an important role in this reaction at higher energies
- The total cross section shows comparable order of magnitude to the $K^+\Lambda$ photoproduction cross section
- An excess-like structure was observed in the vicinity of 1670 MeV it may be related to the prominent structure observed in the $\gamma n \to \eta n$ reaction
- The first measurement for the $K^0\Lambda$ photoproduction proposes new constraints for the theoretical interpretations on the mysterious $N(1670)$ peak structure