Near threshold $K^0\Lambda$ photoproduction on the neutron studied with an electromagnetic calorimeter FOREST

ELPH

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The $\gamma n \rightarrow K^0 \Lambda$ photoproduction studied with an electromagnetic calorimeter FOREST

Outline

- Motivation and background
- Experiment
  - ELPH accelerator
  - 4π electromagnetic calorimeter FOREST
- Analysis
  - Particle identification
  - Background subtraction
  - Differential cross section
- Summary

Motivation and background

Baryon spectroscopy

One of the useful probes for revealing the QCD in low energy scale

Photoproduction case

$\pi N,\ \eta N$ channels

→ well investigated

KY channel

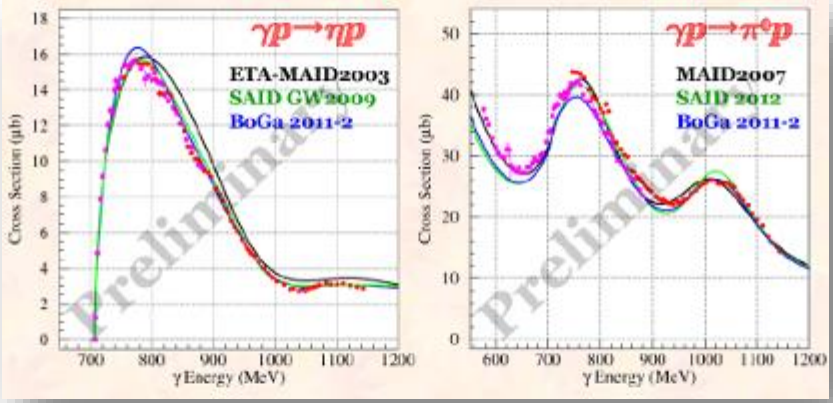
$K^+\Lambda(\Sigma)$:

recently investigated

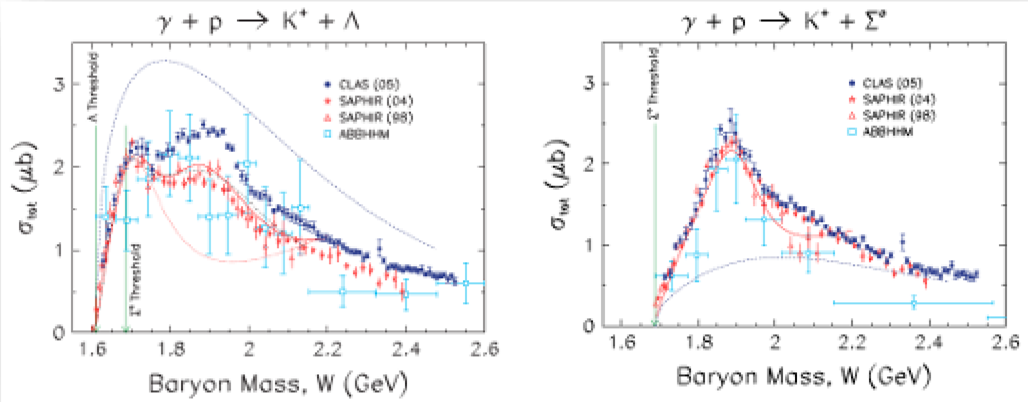
(CLAS, LEPS, MAINZ…)

particularly

charged kaon, Sigma

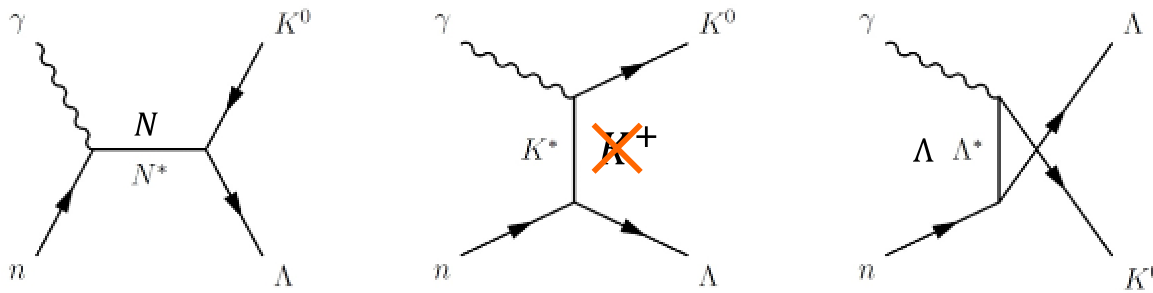


T. Ishikawa "Baryon spectroscopy at ELPH and LEPS2" (Hawaii2014)



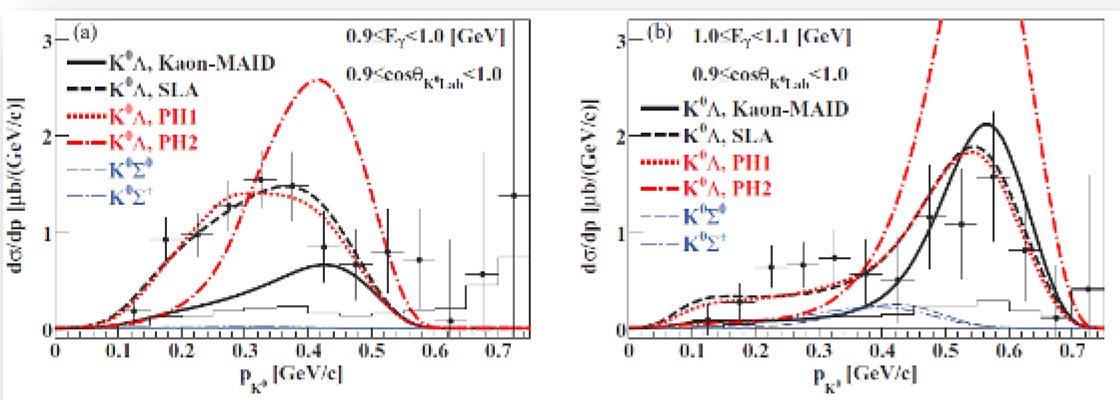
Phys. Rev. C **73**, 035202 (2006)

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



- All of the participants are *NEUTRAL*
  - → no charged particle (e.g. K^+) can be exchanged
  - → Born term contribution is smaller than that of $K^+\Lambda$ case
- Previous measurement: one publication for this channel

  for $E_\gamma = [0.9, 1.1)\mathrm{GeV}$ and $\cos\theta_K^{Lab} = [0.9, 1.0)$



The first measurement of $\gamma n \to K^0\Lambda$ photoproduciton by NKS collaboration
K. Tsukada et al.,
Phys. Rev. C **83** 039904

$N(1685)$

- The prominent structure observed in the $\gamma n \rightarrow \eta n$
  - Reported by **LNS, ELPH, GRAAL, MAINZ, CB-ELSA/TAPS**
  - Each results are well agreed with each other:
    - Observed in $n(\gamma,\eta)n$ reaction but no such structure in $p(\gamma,\eta)p$
    - Narrow width (~ 25 MeV) and peak position ~ 1670 MeV

The $\gamma d \rightarrow \eta pn$ photoproduction cross sections

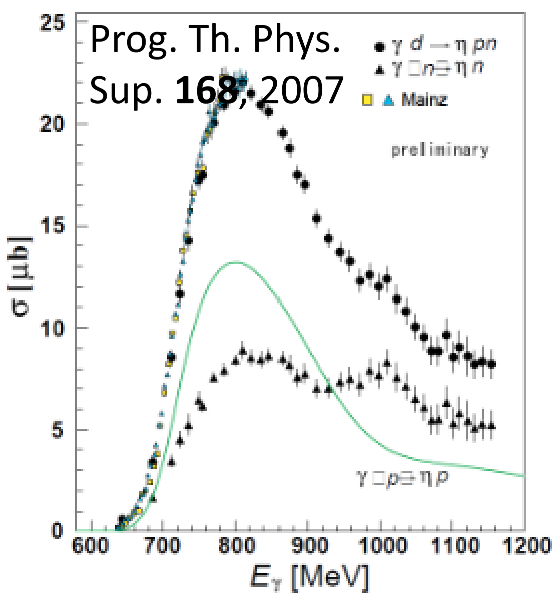
$N(1685)$?$^?$ $\qquad I(J^P) = \frac{1}{2}(?^?)$

OMITTED FROM SUMMARY TABLE

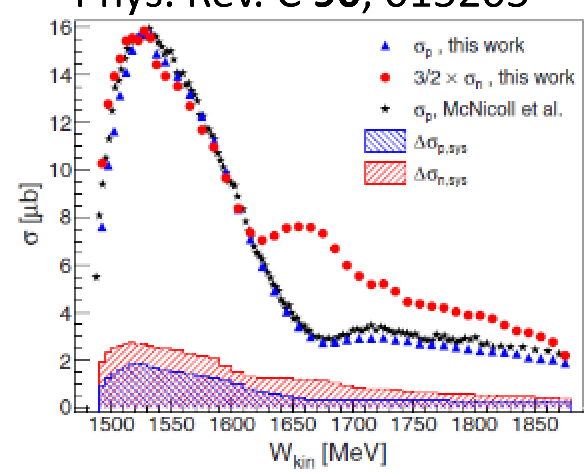
There is a small literature (which we do not try to c
possible narrow state. See KUZNETSOV 11A, MAR
other papers for further references. This state does n
by being a sought-after member of a baryon anti-decu

$N(1685)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, et			
1670±5	WERTHMUEL.13	CRBT	$\gamma d \rightarrow \eta n$
~ 1670	JAEGLE 11	CBTP	$\gamma d \rightarrow \eta n$
~ 1685	KUZNETSOV 11	GRAL	$\gamma d \rightarrow \gamma n$
~ 1680	KUZNETSOV 07	GRAL	$\gamma d \rightarrow \eta n$



Phys. Rev. C **90**, 015205

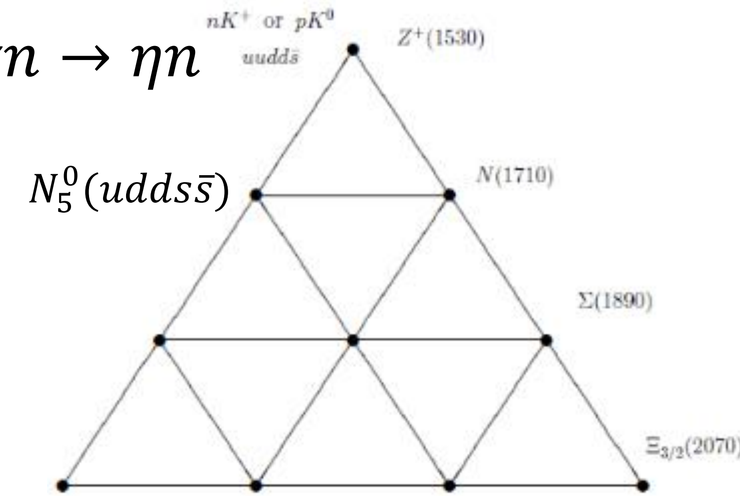


$N(1685)$

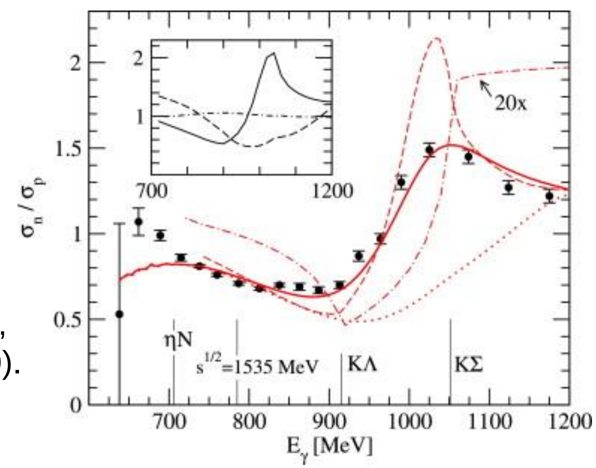
The prominent structure observed in the $\gamma n \to \eta n$

Theoretical interpretations

- Intrinsic narrow state
- Pentaquark
- Coupled-channel effect
- Interference effects
- KY threshold effect

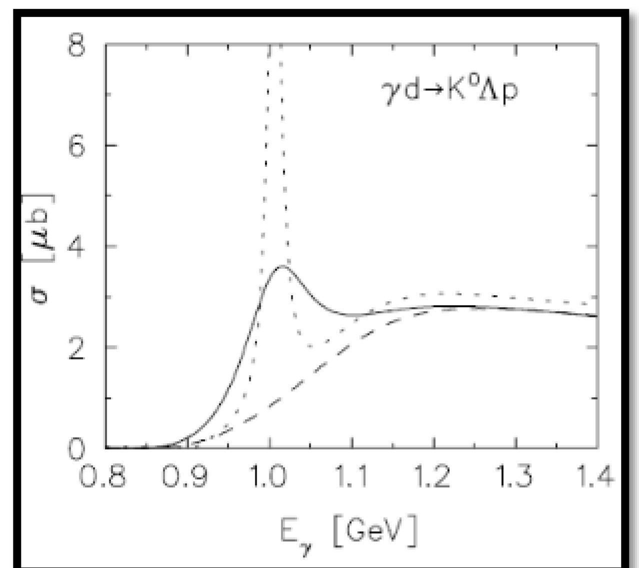


Diakonov et al, Z. Phys. A 359, 305–314 (1997)



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

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



-> How about in the $\gamma n \to K^0 \Lambda$ case?

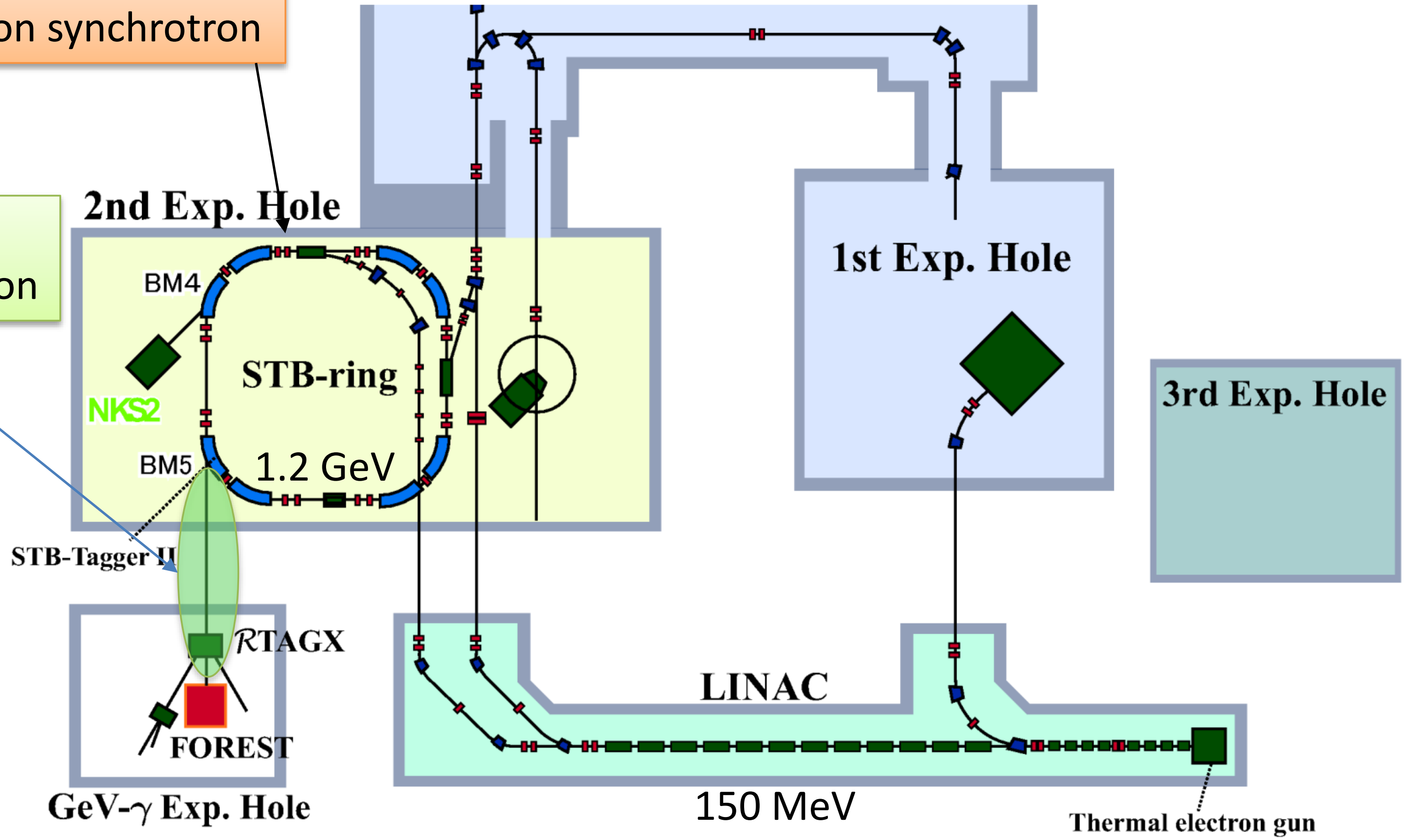
Experiment

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

STretcher-**B**ooster Ring:
1.2 GeV electron synchrotron

GeV-γ Beam line:
0.5-1.2 GeV photon

Layout of ELPH beam lines (~2012)



Experiment

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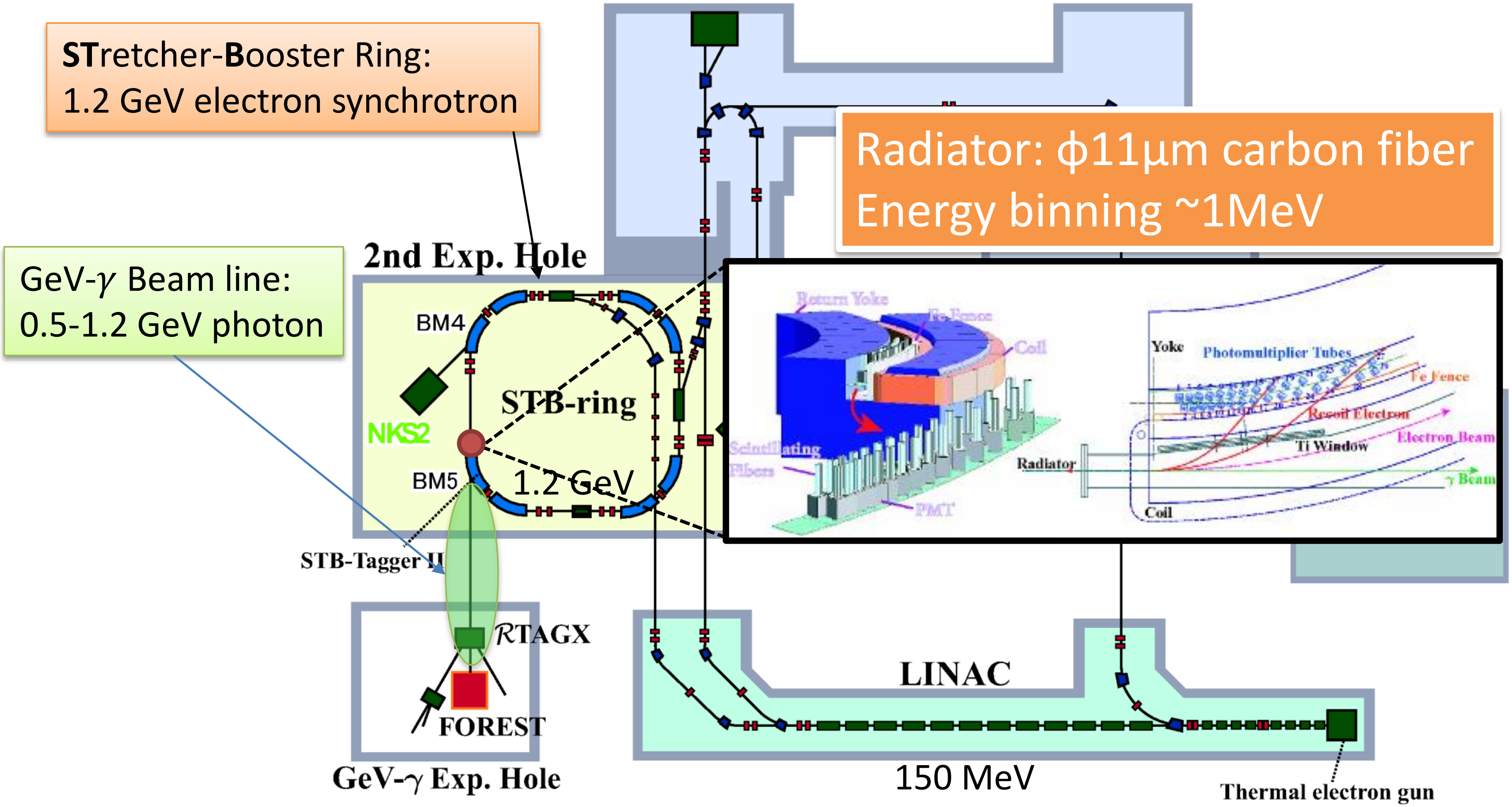
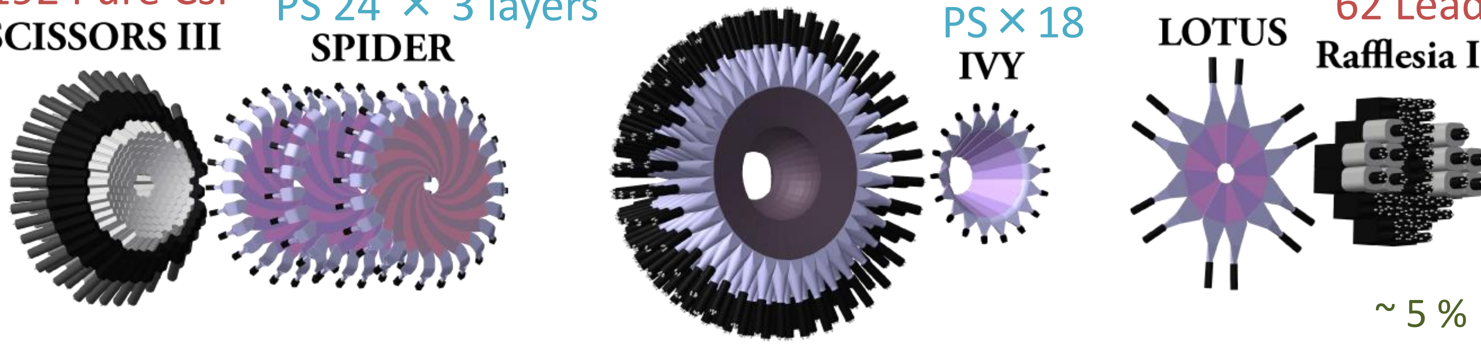
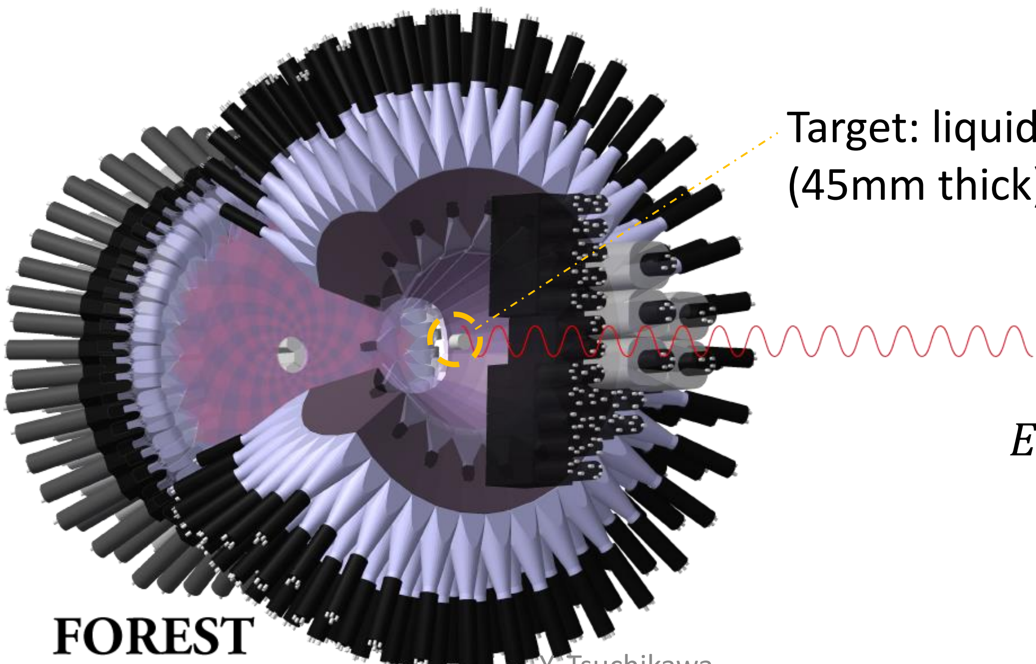


FOREST: 4 π electromagnetic calorimeter complex

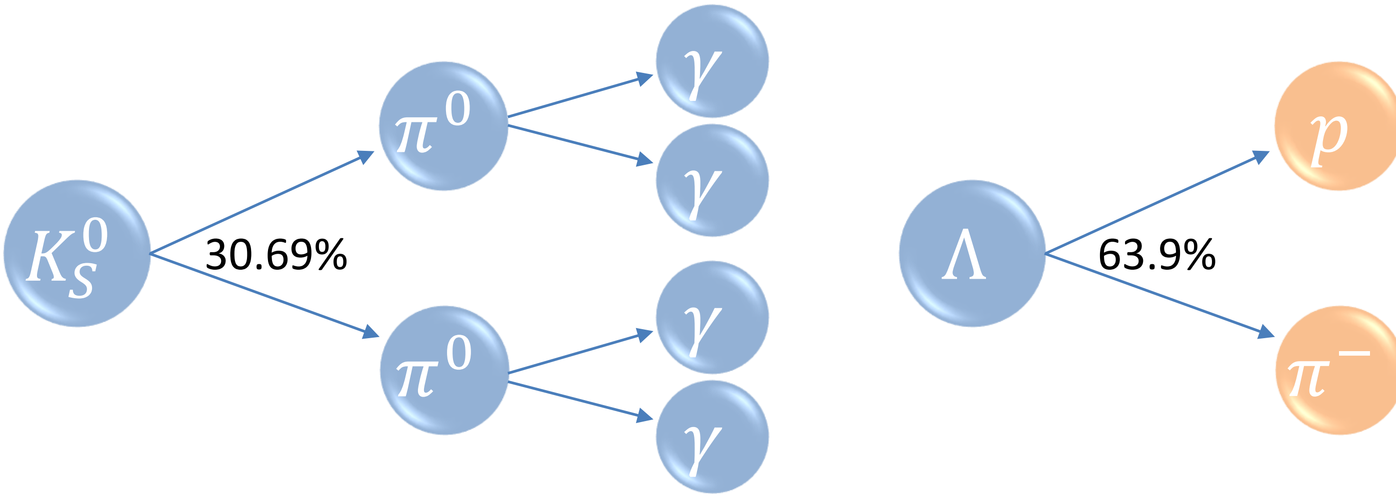




$E_\gamma = 750 - 1150$ MeV

Analysis – particle identification

Focusing on the following decay chains:



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

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

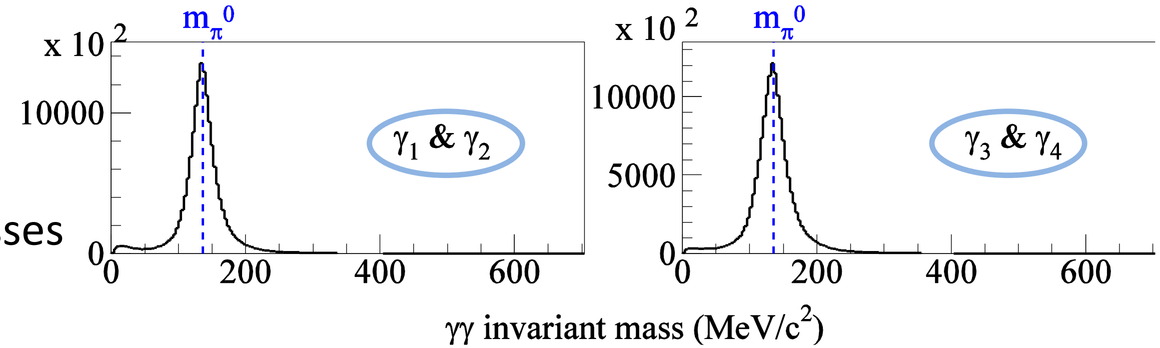
Proton in the deuteron is assumed as a spectator

Analysis – particle identification

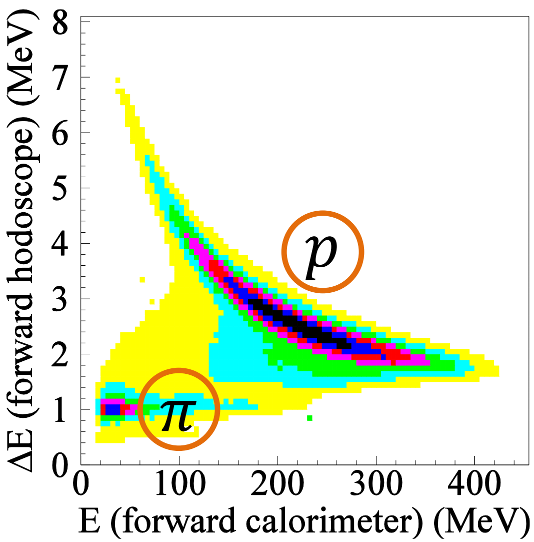
$$\gamma d \rightarrow K_S^0 \Lambda p \rightarrow (\pi^0\pi^0)(p\pi^-)p \rightarrow (4\gamma)(p\pi^-)p$$

$2\pi^0$

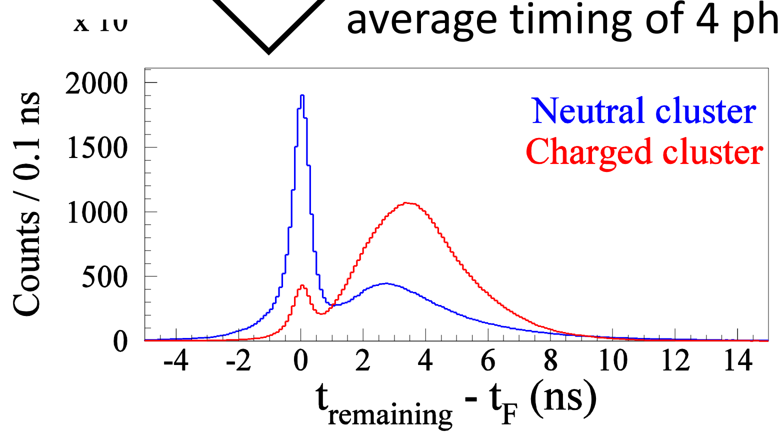
4 photon search
(neutral cluster)
-> Then check the
$\gamma\gamma$ invariant masses



p, π^-



The event timing criterion:
average timing of 4 photons



No other neutral particles but more 2 charged particles are required both of hodoscope and calorimeter

Kinematic fit with 3 constraints

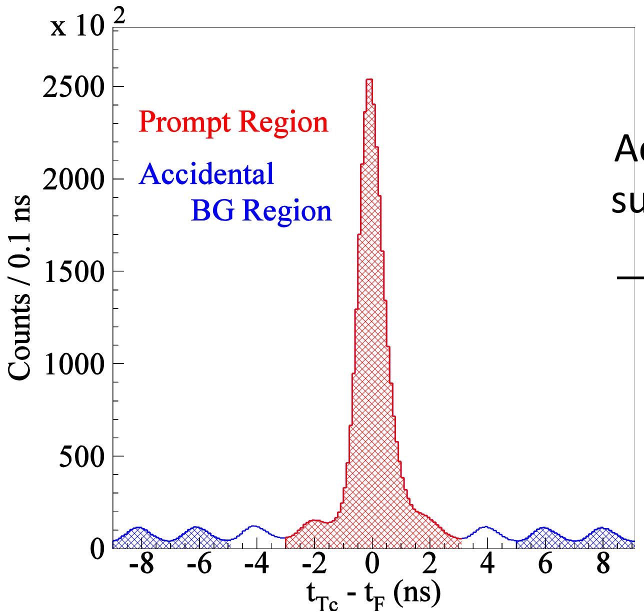
13 variables:
γ_i energy, polar, and azimuthal angles: E_i, θ_i, ϕ_i $(i = 1, \dots, 4)$ and Photon beam energy: E_γ

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

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. $M^2(\gamma_3,\gamma_4) \equiv 2E_3E_4(1 - \sin\theta_3 \sin\theta_4 \cos(\phi_3 - \phi_4) - \cos\theta_3 \cos\theta_4) = m_{\pi^0}^2$

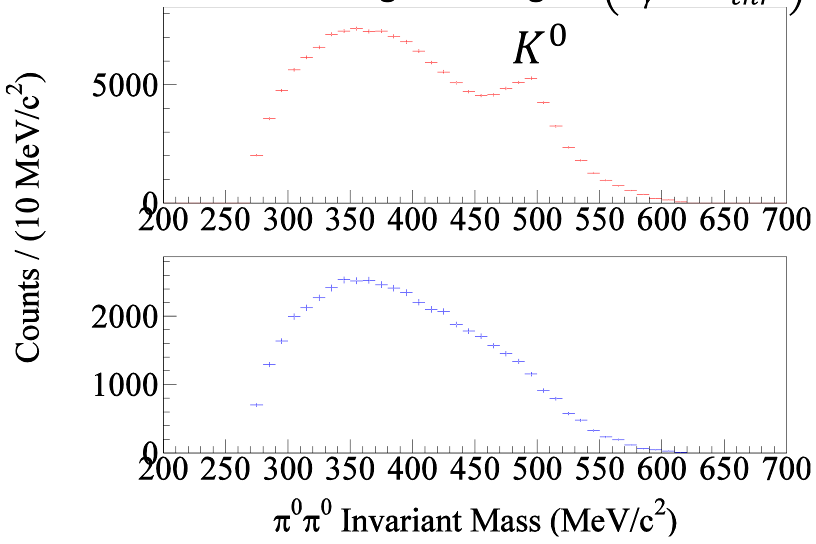
"4γ missing mass $= m_\Lambda$"

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



Accidental events were subtracted by means of sideband

$\pi^0\pi^0$ invariant masses of prompt and accidental background region $\left(E_\gamma > E_{thr}^{K^0\Lambda}\right)$



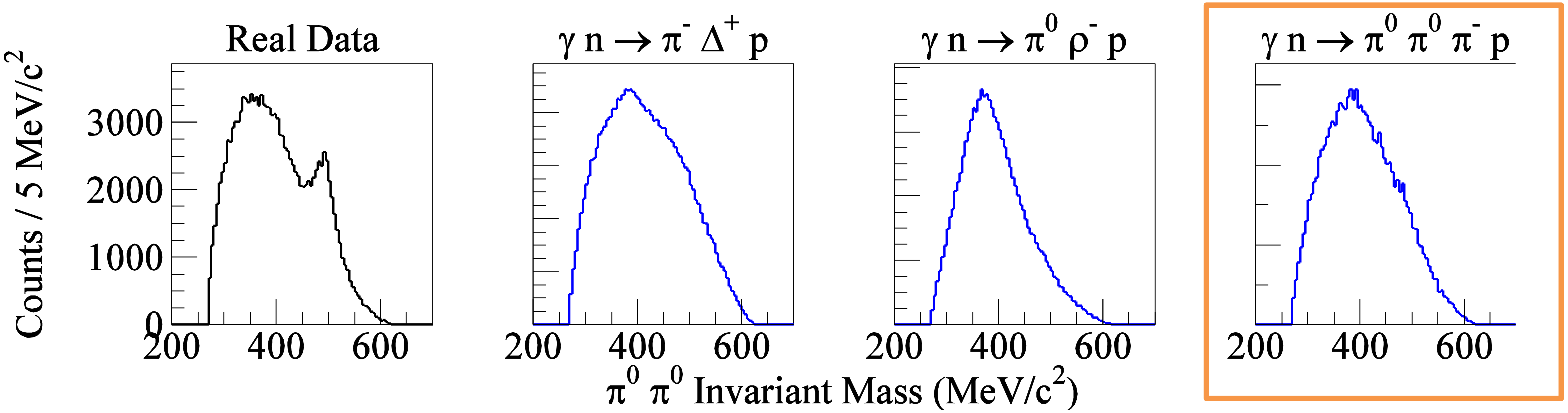
Background subtraction

- Candidates of background events in the $M(\pi^0\pi^0)$ distribution

Candidate reactions for $\pi^0\pi^0\pi^-p$ final state

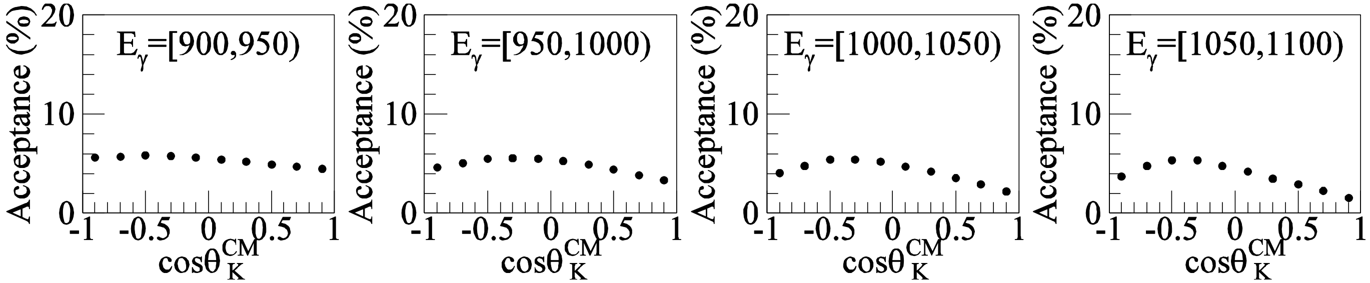
$$\gamma n \to \pi X(\Delta, N^*, \rho N) \to \pi^-\pi^0\pi^0 p,$$ Now checking

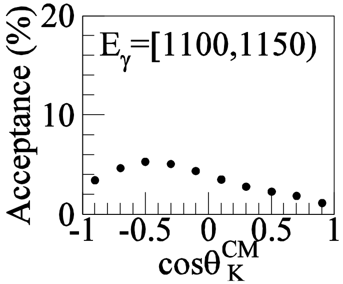
$$\gamma n \to \pi^0\pi^0\pi^- p.$$



Only this is used for yield extraction in this time

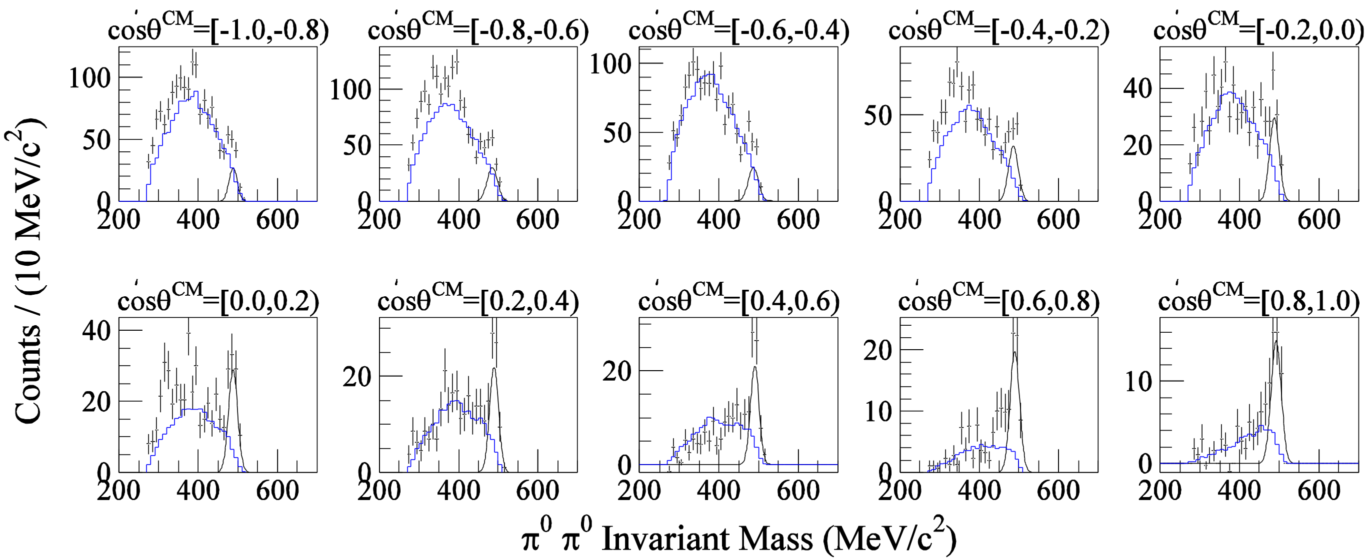
Acceptance and Yields





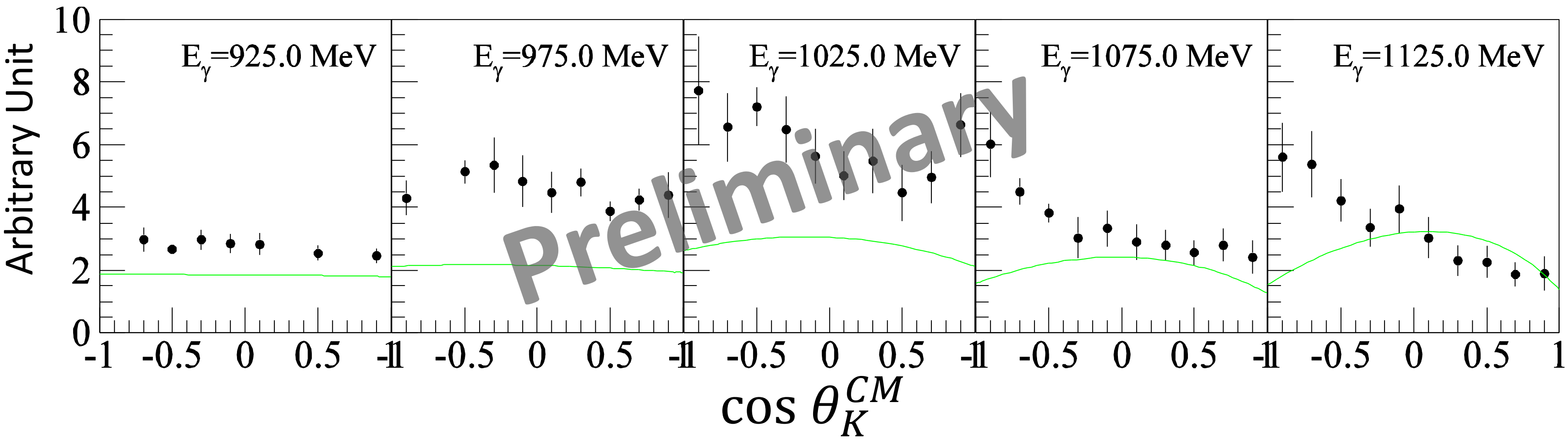
FOREST covers all of the $\cos\theta_K^{CM}$

Examples of the fit for yield counting



Differential Cross Sections

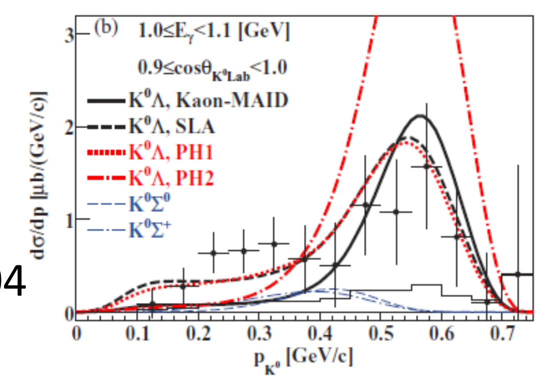
$$\sigma \propto \frac{Yield\ (E_\gamma, \cos\theta_K^{CM})}{N_{targ} N_\gamma \eta_{acc} BRs}$$

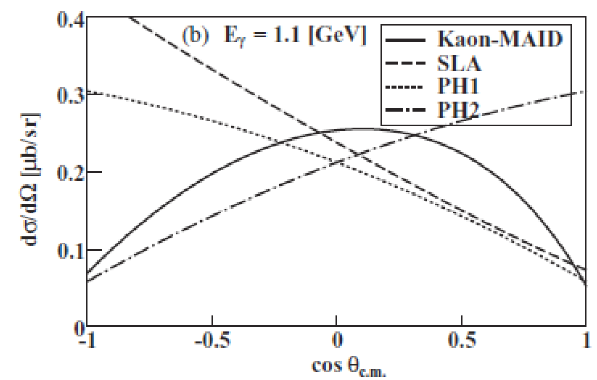


Theoretical curve: Kaon-MAID

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.

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





Summary

- The $\gamma d \to K^0 \Lambda p$ photoproduction reaction is studied with an electromagnetic calorimeter complex FOREST at ELPH, Sendai
- K^0 signals are well confirmed in the $\gamma d \to K_S^0 \Lambda p \to (\pi^0 \pi^0)(p\pi^-)p \to (4\gamma)(p\pi^-)p$ reaction with an exclusive analysis
- Shape of the background in the $\pi^0\pi^0$ invariant mass distribution is enoughlly reproduced by the $\gamma n \to \pi^0\pi^0\pi^- p$ non-resonant reaction
- Differential cross sections showed backward enhanced structures in high E_γ regions
- The results supports the remark of the previous measurement