The results of the K^0 photoproduction with NKS in the threshold region

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1. Motivation
2. Setup
3. Analysis
4. Result and discussion
5. Summary

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Motivation

Physics motivations

- Strangeness production by electromagnetic interaction is of interest itself because interaction with photon is considered well-understood.
  → coupling constant, form factor, etc.
- Strangeness photoproduction is also a good probe for hadron physics.
  For example, (e,e'K) hypernuclear spectroscopy (very high resolution)
  Missing resonance search (not found in pN channel)

- High quality data for K^+ photo- or electro-production since 1990s.
  - Bonn-SAPHIR – $p(\gamma,K^+)\Lambda$, $p(\gamma,K^+)\Sigma^0$, $p(\gamma,K^0)\Sigma^+$
  - JLAB – $p(\gamma,K^+)\Lambda$, $p(\gamma,K^+)\Sigma^0$, $p(e,e'K^+)\Lambda$
  - SPring8/LEPS – $p(\gamma,K^+)\Lambda$, $p(\gamma,K^+)\Sigma^0$

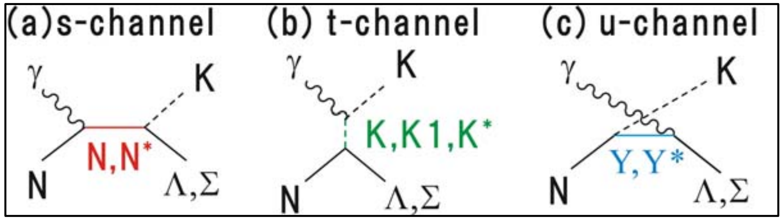
  - Almost no data for K^0 production

- Since any models do not succeed to explain sufficiently KY photoproduction at the present, the further study for individual other isospin channels is desired.

The $n(\gamma,K^0)\Lambda$ reaction is important and we carried out the measurement of the K^0 photoproduction reaction on the deuteron target.

The features of n(γ,K^0)Λ reaction

- Interference among diagrams are quite different from K^+ production
  - no charge in the reaction
    → t-channel Born term does not contribute.



  - Isospin symmetry
    → coupling constant of Σ^0 exchange term in u-channel,

$$g(K^0\Sigma^0 n) = -g(K^+\Sigma^0 p)$$

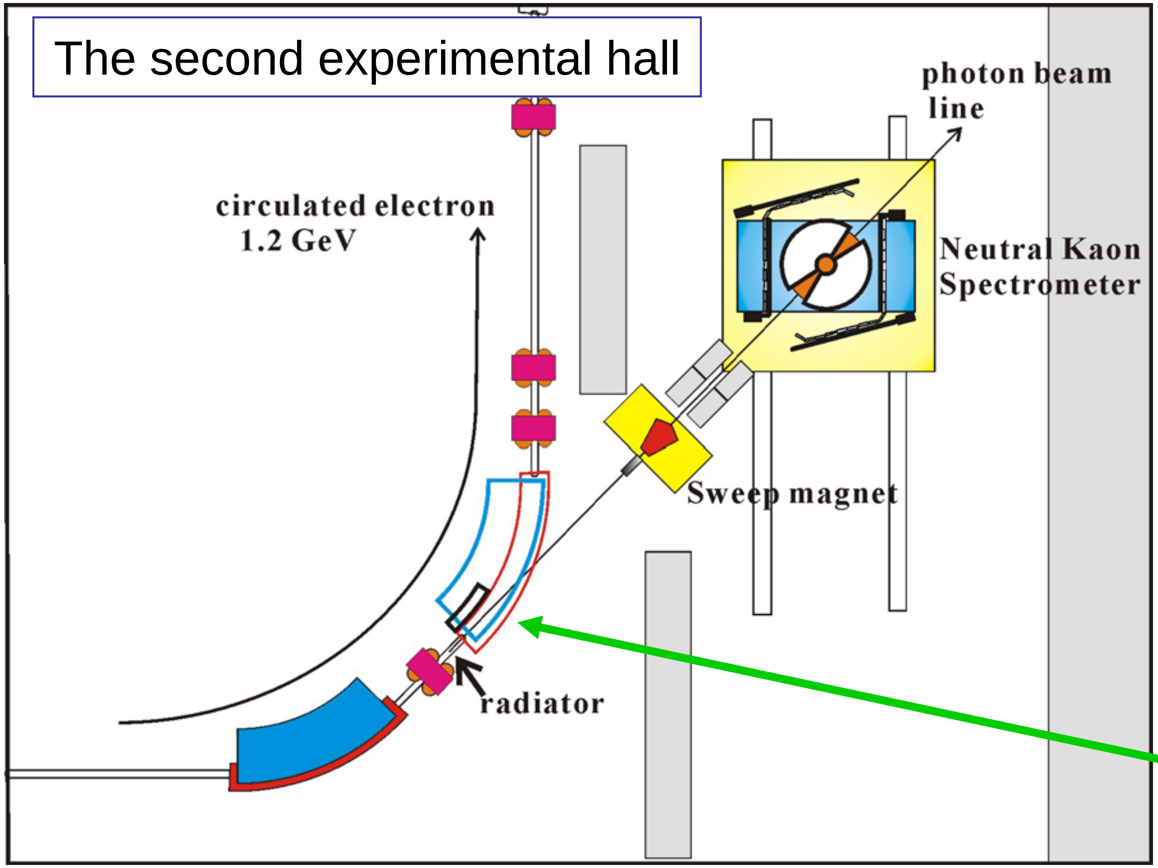
- In the threshold region, the influence from higher resonances is considered small.

Comparing of the K0 production data with the K+ production data plays a unique role for the investigation of the strangeness photoproduction mechanism.

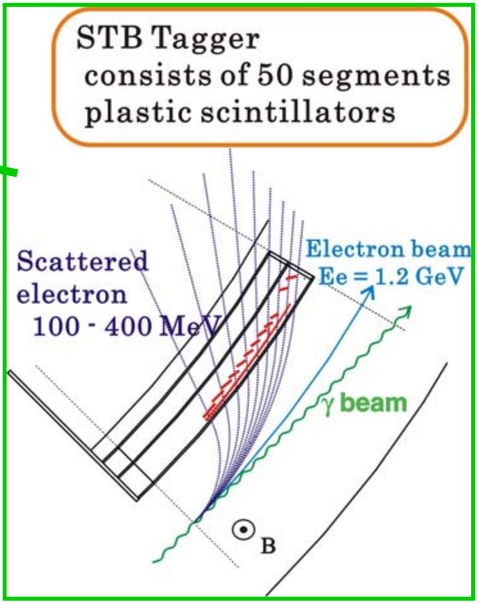
Setup

- Experimental hall
- Spectrometer

Laboratory of Nuclear Science (LNS), Tohoku University



The photon is generated via bremsstrahlung at an internal target (11μmϕ carbon string radiator) and the scattered electron is tagged by STB-Tagger.

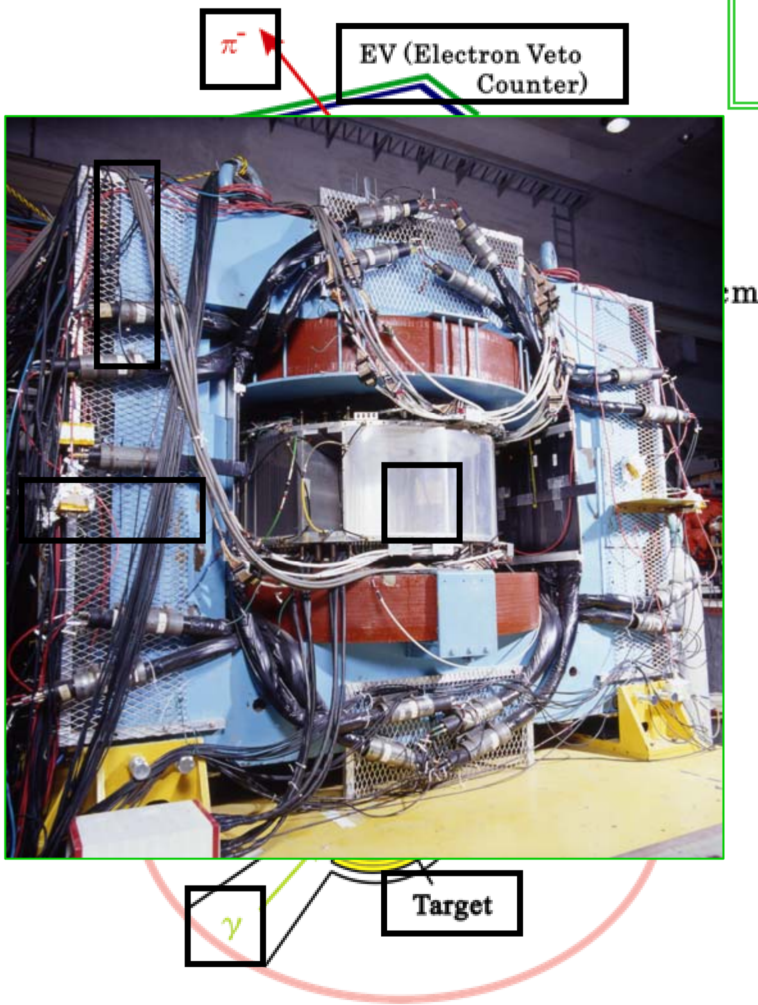


Beam conditions at this experiment

- Eγ : 0.8 ~ 1.1 GeV (Eth=0.91 GeV)
- Duty factor : ~ 60 %
- Beam current : ~ 2 mA
- Photon intensity : ~ 2 MHz

Neutral Kaon Spectrometer - NKS

K^0 was detected via $K^0_S \rightarrow \pi^+\pi^-$ decay channel.
fraction ~ 68.6 %
$c\tau$ ~ 2.67 cm



Solid angle : π sr

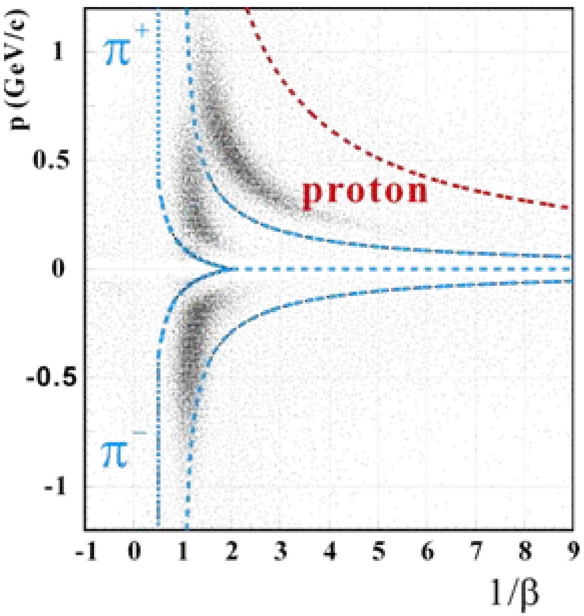
- **TAGX magnet**
  - **Dipole magnet with 0.5 T**
- **CDC (cylindrical drift chamber) and SDC (straw drift chamber)**
  - **Momentum**
  - **Decay vertex**
- **IH (inner hodoscope) and OH (outer hodoscope)**
  - **Trigger counter**
  - **Time of flight measurement**
- **EV (electron veto counter)**
  - **e^+e^- background suppression**
- **target : liquid deuterium**

- Period: Sep 2003 - May 2004, totally about 1000 hours

Analysis

- Event selection
- Background estimation
- Acceptance

Event selection

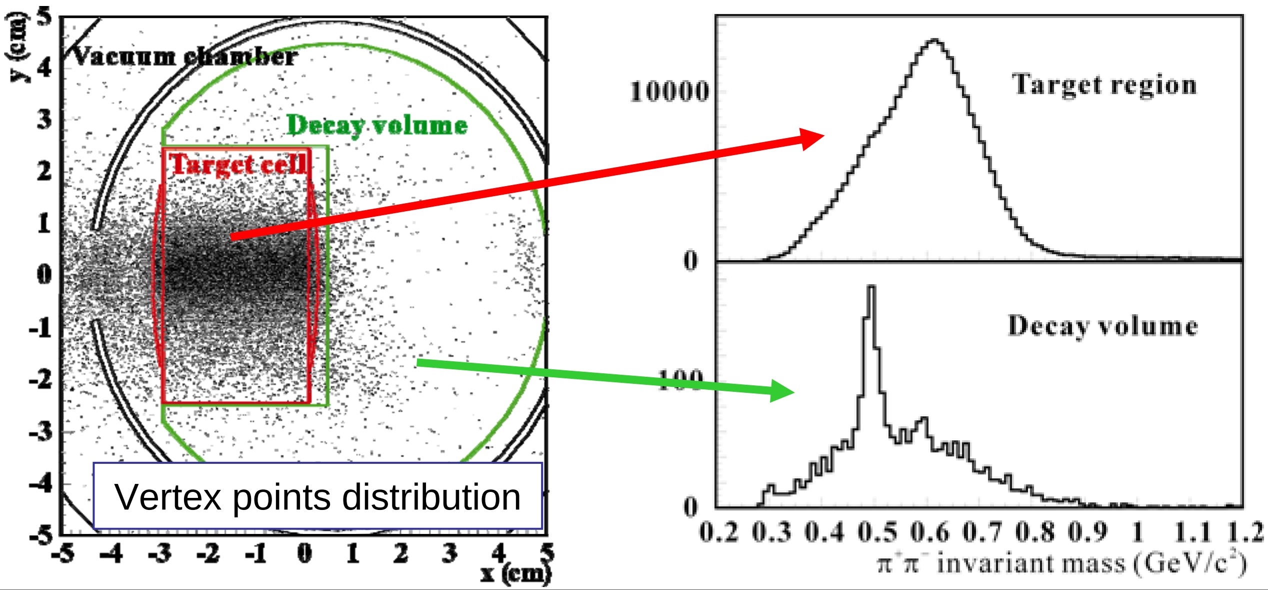


Upper figure

- Separation between proton and pion is good.

Lower figures

- In the target region (red square), huge background of non-strangeness processes, e.g. the production of ρ, nucleon resonances and multi-pions, etc. exist.
- Out of the target (green line), a peak of K^0 is clearly seen in the $\pi^+\pi^-$ invariant mass spectrum because of the relatively long life time of K^0, $c\tau \sim 2.68$ cm.

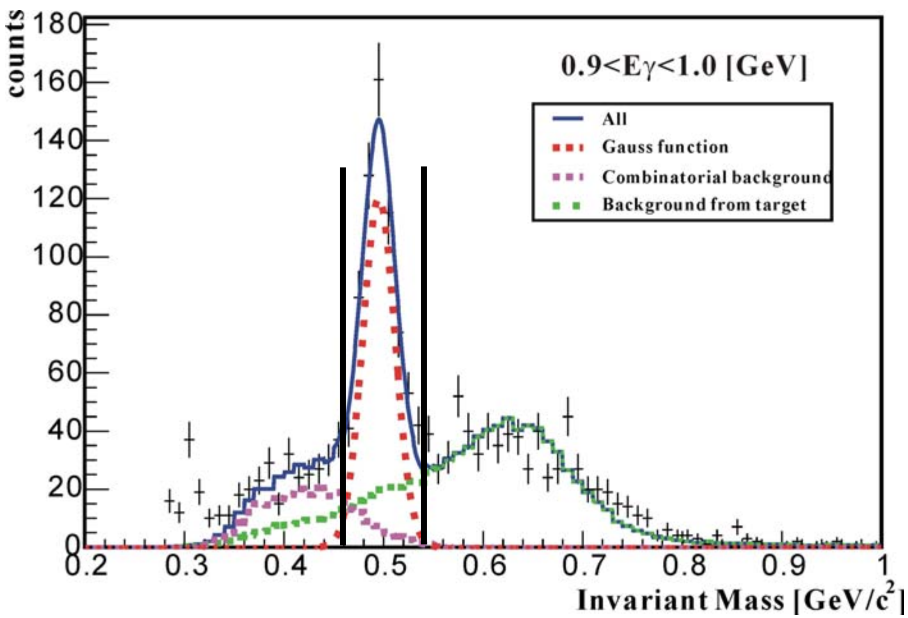


Background estimation

Background source:

Case 1 : leakage from target region due to finite position resolution
→ estimated by the data in the target region

Case 2 : combinatorial background between pions from K^0 and from Λ
→ estimated by a GEANT simulation



black : decay volume
(A peak around 0.3 GeV/c2 is e^+e^- Background)

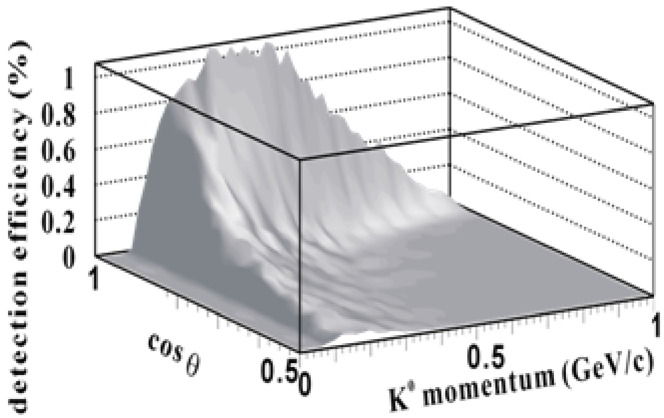
green : case 1
- leak from target region

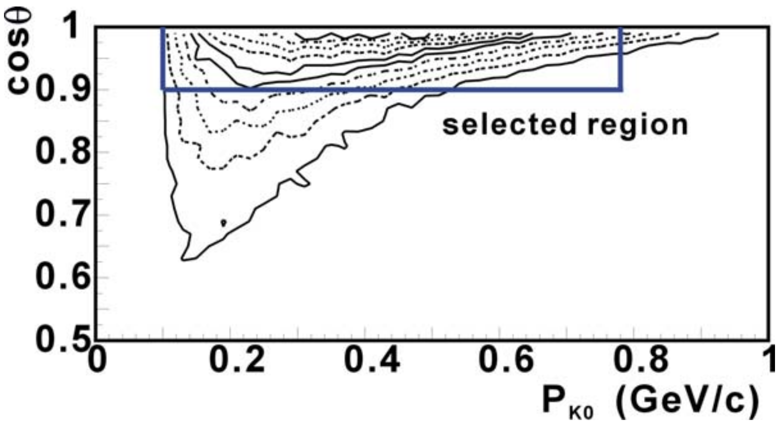
purple : case 2
- π^+ from K^0 and π^- from Λ

The measured invariant mass spectra are fitted using a gaussian for the peak of K^0 and the shapes of two backgrounds which are only scaled in every photon energy regions, that is $0.9 \leq E\gamma < 1.0$ and $1.0 \leq E\gamma \leq 1.1$ GeV.

Acceptance of NKS

- Acceptance of NKS was estimated by GEANT simulation
  - Generate K^0 isotropically in Lab frame.
    $0 < \text{momentum} < 1.0$ GeV, $0.5 < \cos\theta_{K0,Lab} < 1.0$
  - Use the same analyzer for the experimental data.
    → Analysis efficiencies are included.





Left figure shows the acceptance of NKS.
When the momentum spectra are derived, the effective region, that is $0.9 \leq \cos\theta_{Lab} \leq 1.0$ and $0.1 \leq P_K \leq 0.75$ GeV/c is selected to avoid the low efficiency area.
The effective region is overdrawn in right figure.

Results and discussions

- Calculation of $K^0\Lambda$ production for deuteron target
- Elementary amplitudes
- Comparison of data and calculations

Calculation of $K^0\Lambda$ production for deuteron target

- The spectator model

  [P.Bydzovsly, M.Sotona, O.Hashimotoand T.Takahashi (2004), nucl-th/0412035]

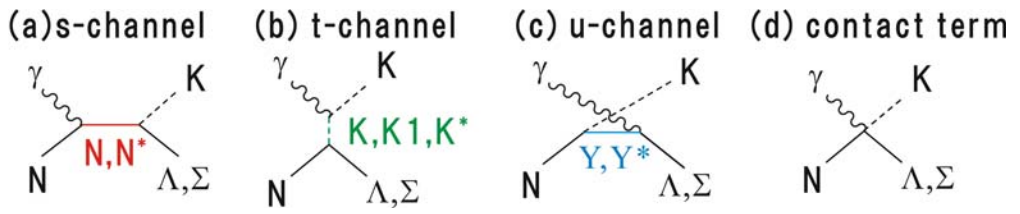
  – Plane wave impulse approximation
  – A proton in the deuteron regarded as a spectator.
  – Off-shell effect
  – OBEPQ (one boson exchange potential in q-space) as the deuteron wave function. [R.Machleidt, K.Holinde and C.Elster, Phys.Rept. 149, 1 (1987)]

Largest uncertainty in this model comes from ambiguity of the elementary amplitude.

Elementary amplitudes

- The isobar model.
  - Kaon-MAID [T.Mart, C.Bennhold, Phys. Rev. C61 (2000) 012201(R)]
    - Resonancs : S_{11}(1650), P_{11}(1710), P_{13}(1720), D_{13}(1895), K*(892), K_1(1270)
    - Hadronic form factor , contact term
    - Reaction of input data : $K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^+$
  - Saclay-Lyon A [T.Mizutani et.al., Phys. Rev. C58 (1998) 75]
    - Resonances : P_{13}(1720), K*(892), K_1(1270), L(1405), L(1670), L(1810), S(1660)
    - No hadronic form factor
    - Reaction of input data : $K^+\Lambda$

!!SLA has a free parameter for $K^0\Lambda$ production.



- Simple formula giving only the angular and energy dependence.

$$\frac{d\sigma}{d\Omega} = \sqrt{(s-s_0)}\left[1+e_0(s-s_0)\right]\left(a_0P_0(x)+a_1P_1(x)+a_2P_2(x)\right)$$

s : *total energy*, $s_0 = 2.603\,GeV$

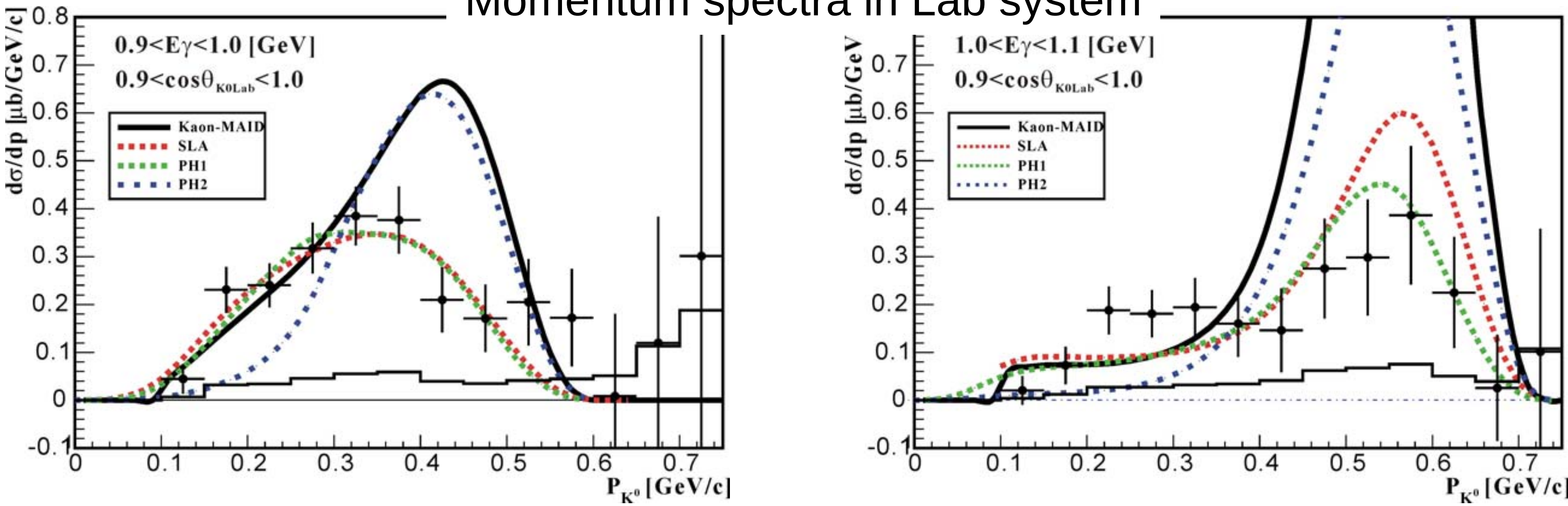
$P_i(x)$: *Legendre polynomials*

x : $\cos\theta$ *in CM*

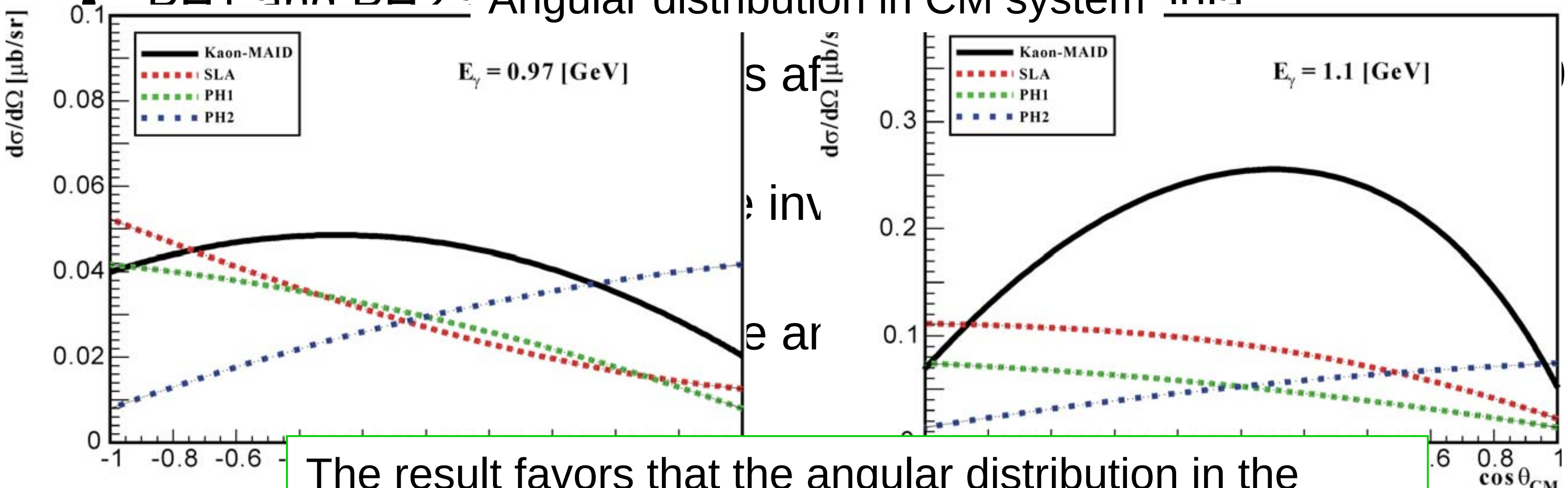
a_i : *fitting parameters*

Momentum spectra in Lab system and Angular distribution in CM system.

Momentum spectra in Lab system



Angular distribution in CM system



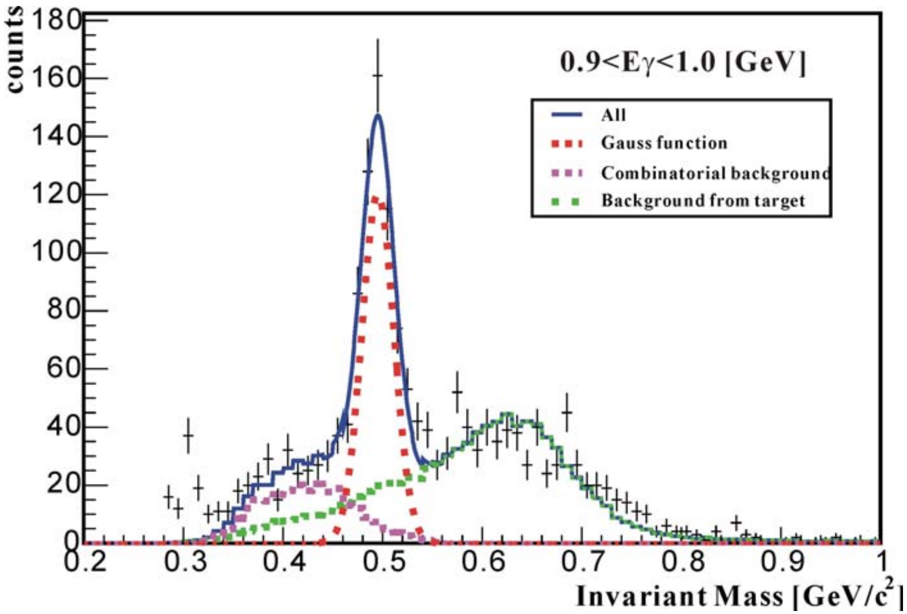
The result favors that the angular distribution in the center of mass system is backward peak.

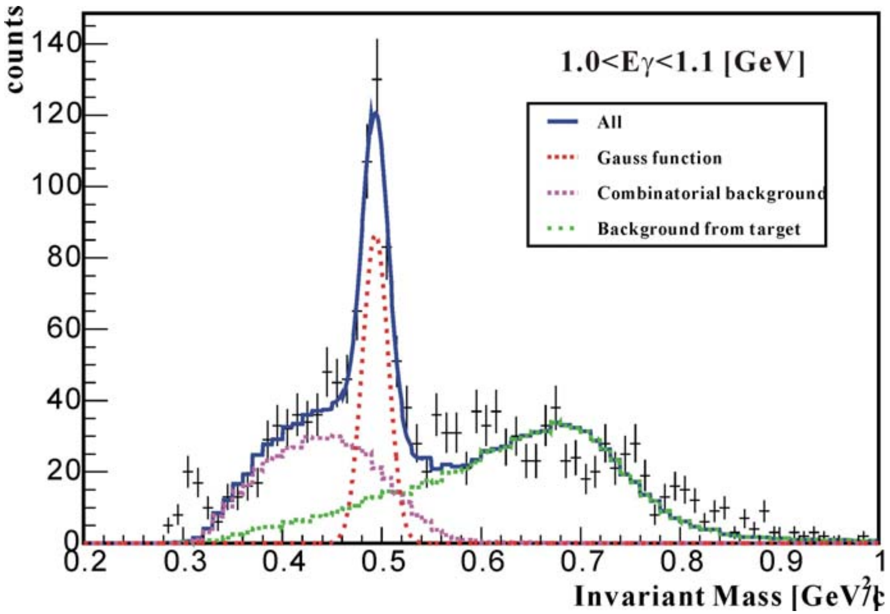
Summary and present status of out experiment

- The $\gamma n \rightarrow K^0\Lambda$ process plays a unique role in the investigation of strangeness photoproduction mechanism.
- We measured the cross section of K^0 photoproduction on deuteron target in the threshold region for the first time.
- Results are presented and compared with some calculations.
- From the spectrum shapes, the backward peak for K^0 photoproduction is suggested.

- Now, we measure the K^0 photoproduction with NKS2
- NKS2 is designed to overcome some weak points of NKS.
- It will be presented in INPC.

Fitting the invariant mass spectra





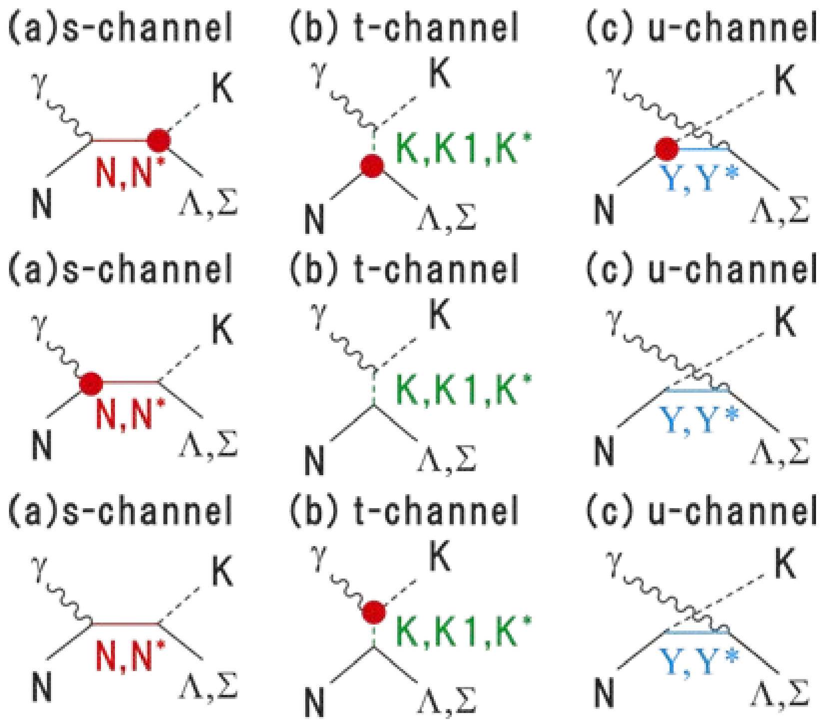
Calculation of n(γ, K^0)Λ reaction by Isobar models

To calculate the elementary cross section of the $K^0\Lambda$ channel, some relations are assumed between p(γ, K^+)Λ reaction and n(γ, K^0)Λ reaction.

1. Hadronic coupling
   - Isospin symmetry is assumed.

     $g_{K^+\Lambda p} = g_{K^0\Lambda n}$

     $g_{K^+\Sigma^0 p} = -g_{K^0\Sigma^0 n} = g_{K^0\Sigma^+ p}/\sqrt{2} = g_{K^+\Sigma^- n}/\sqrt{2}$
2. Electromagnetic coupling
   - Helicity amplitude : photo-coupling of charged and neutral nucleon resonances.
   - Decay width : photo-coupling of charged and neutral kaon resonances. However , the decay width of K1 resonance is not known. Only Kaon-MAID can fix this value by fitting the KΣ channel.

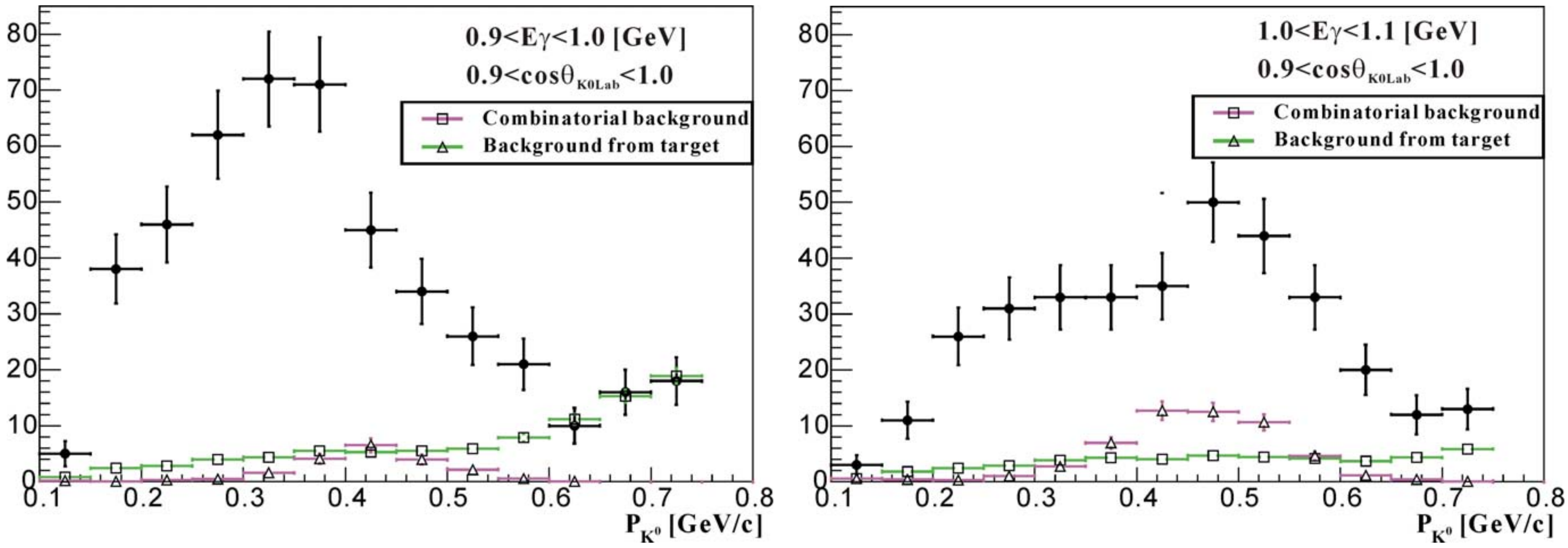


$$r(K^*K\gamma) = \frac{g(K^{*0}K^0\gamma)}{g(K^{*+}K^+\gamma)} = -1.53$$

$r(K_1K\gamma)$: -0.45 for Kaon-MAID from $K^0\Sigma^+$ reaction

Free parameter for SLA

Momentum distributions



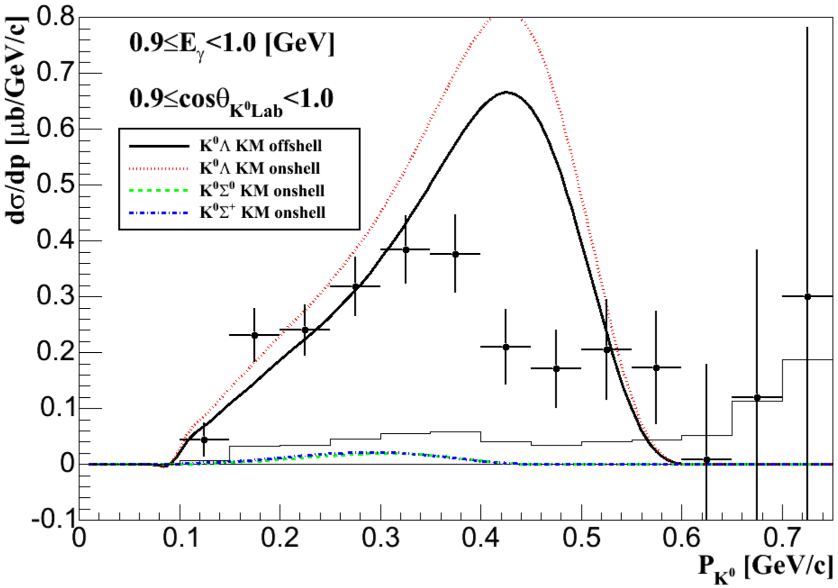
black : decay volume

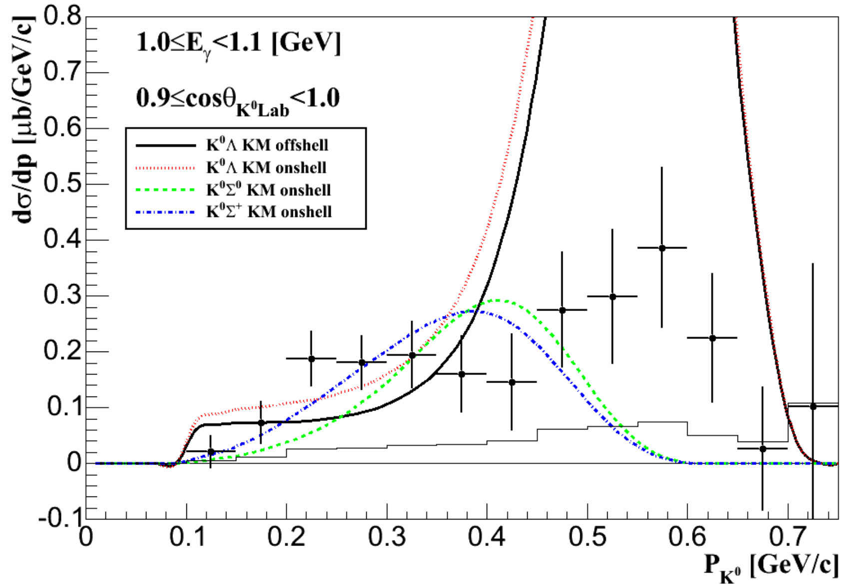
green : case 1 (leak from target region)

blue : case 2 (π^+ from K^0 and π^- from Λ)

The error is statistic only.

The contribution of Σ production

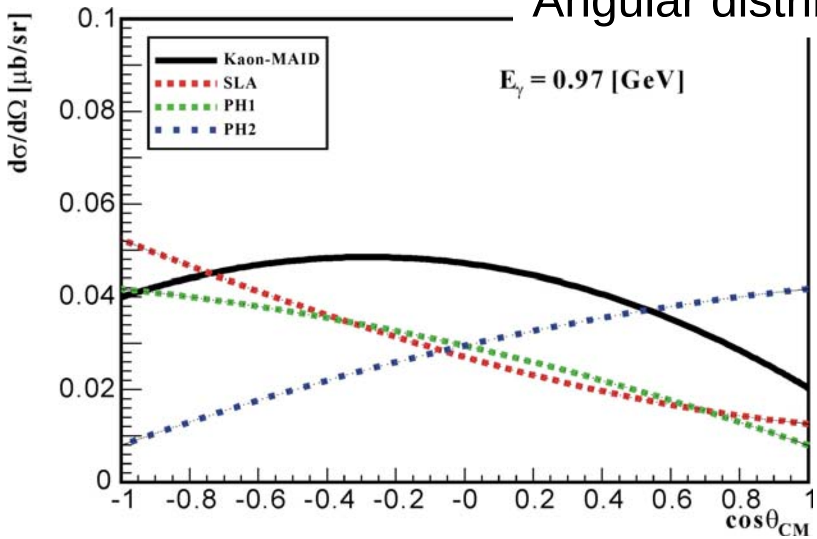


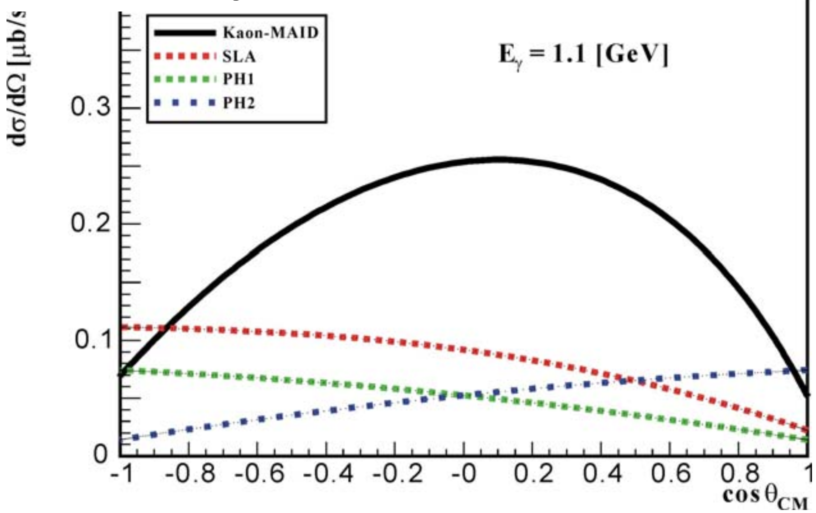


- In these figures, the cross sections are calculated by Kaon-MAID model with the assumption of the on-shell system.
- In lower energy region, the contribution of Σ production is negligible.
- In higher energy region, the contribution of Σ production is large.

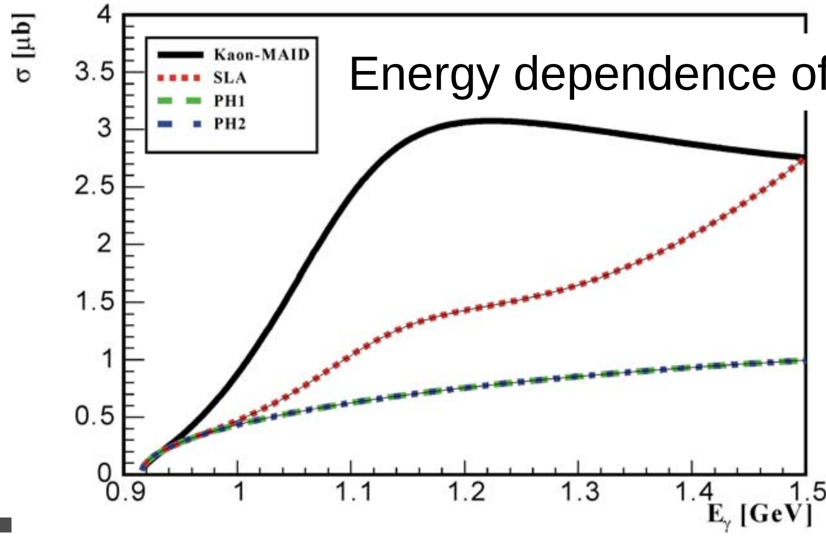
Elementary cross sections

Angular distribution in CM system





Energy dependence of the total cross section



Total cross sections of K^0 and K^+ on carbon target