Formation process of $\ominus^+$n inclusive $\gamma D \to \ominus^+ X$ reactions

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and

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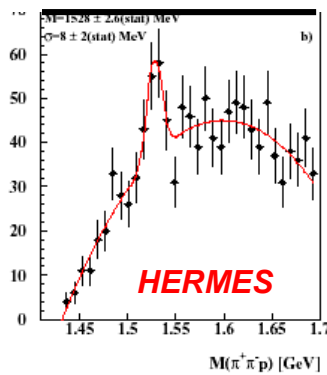with Burkhard Kämpfer, Schin Daté and Yuji Ohashi

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Talk Outline

- **Motivation: is Θ^+ still alive ?**
- **Formation** $K + N \to \Theta^+$ **process**
- **Background processes**
- **Results:**
  - Θ^+ **formation at LEPS conditions**
  - Θ^+ **formation at CLAS conditions**
- **Summary**

Evidence for Penta-Quark States
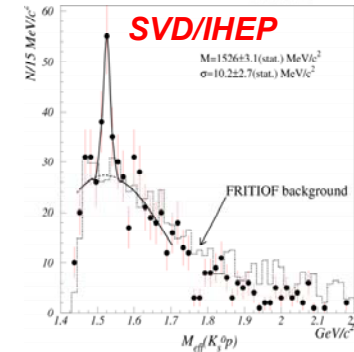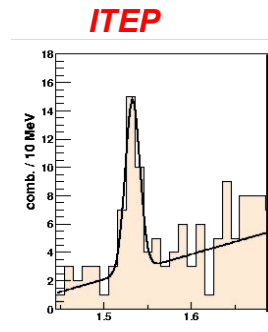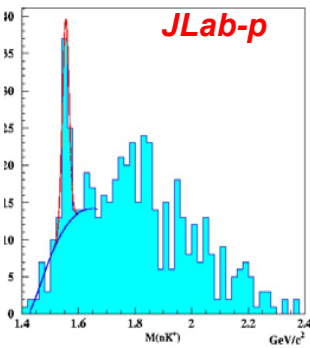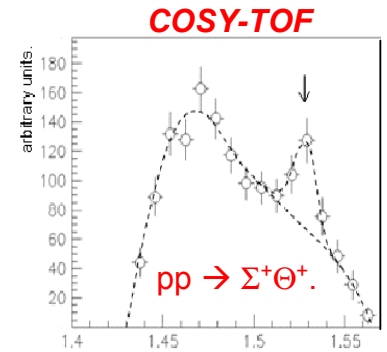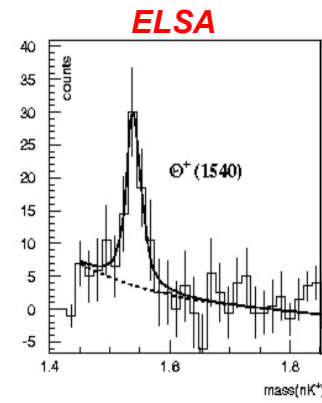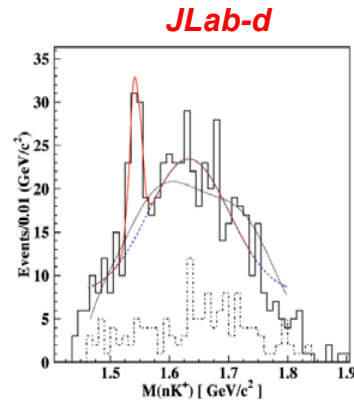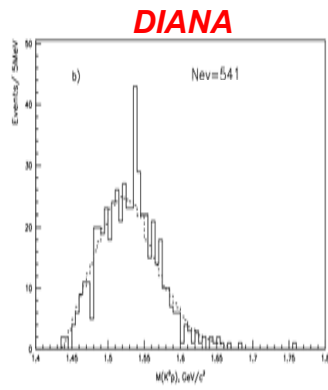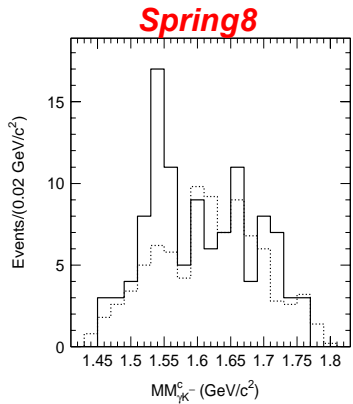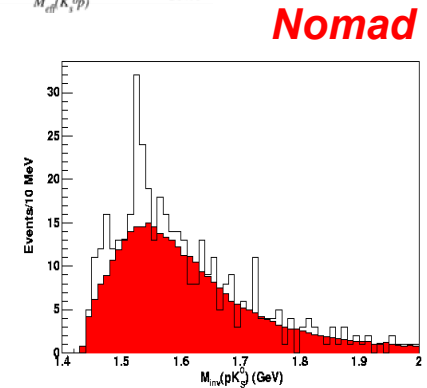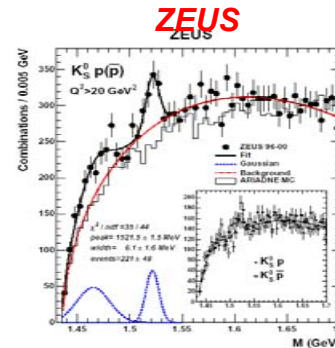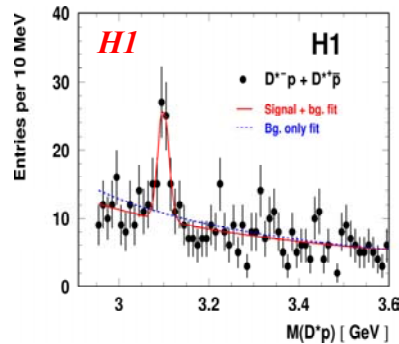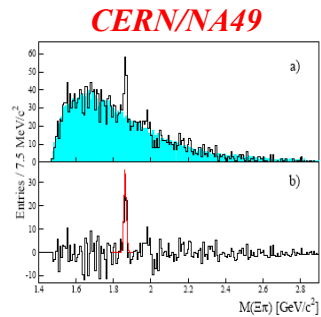

This is a lot of evidence

Experiments on the Θ^+

ï **Similar number of positive and** negative results have been reported.

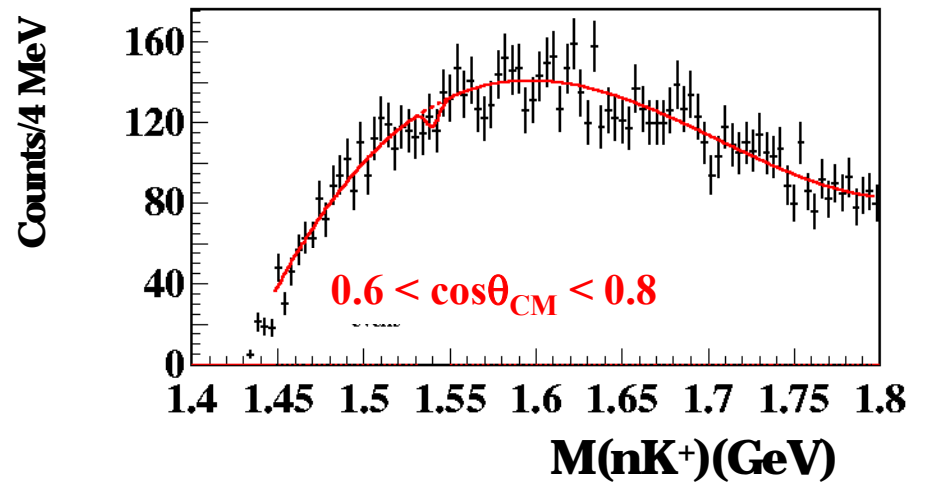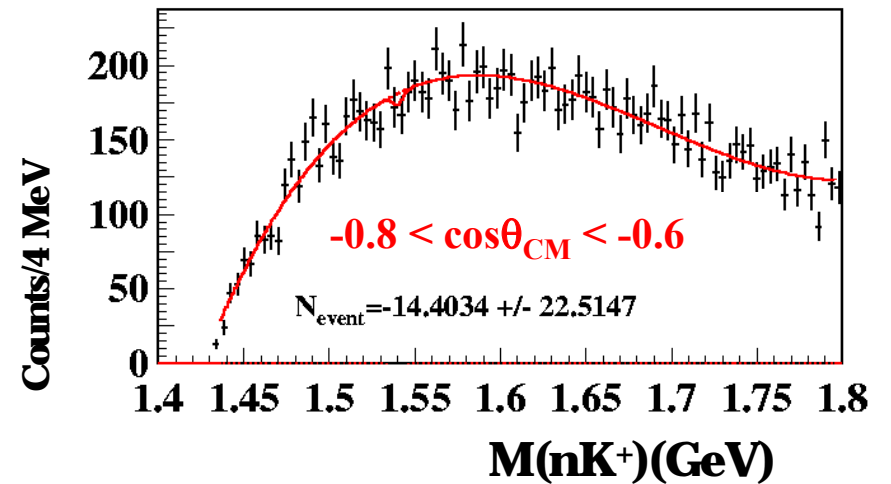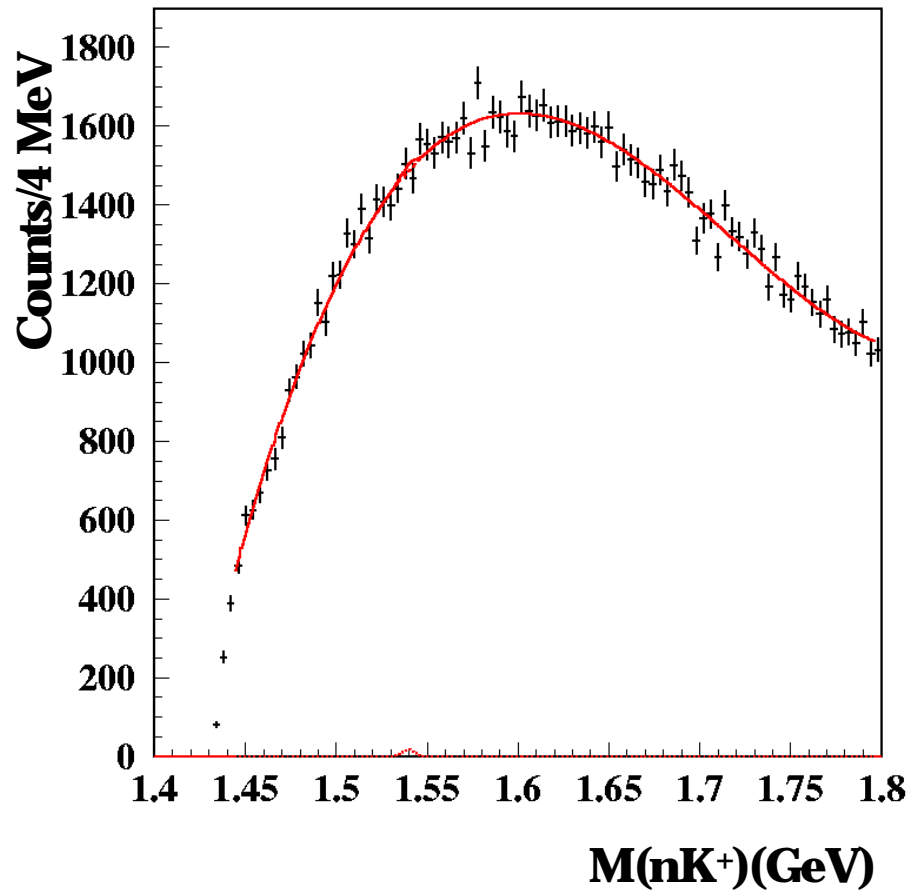## - But most of the recent ones are negative.

Positive result

Negative result

Group	Reaction	Mass (MeV)
LEPS	$\gamma C \to K^+K^-X$	1540 ± 10
DIANA	$K^+Xe \to K^0pX$	1539 ± 2
CLAS	$\gamma d \to K^+K^-p(n)$	1542 ± 5
SAPHIR	$\gamma d \to K^+K^0(n)$	1540 ± 6
ITEP	$\nu A \to K^0pX$	1533 ± 5
CLAS	$\gamma p \to \pi^+K^+K^-(n)$	1555 ± 10
HERMES	$e^+d \to K^0pX$	1526 ± 3
ZEUS	$e^+p \to e^+K^0pX$	1522 ± 3
COSY-TOF	$pp \to K^0p\Sigma^+$	1530 ± 5
SVD	$pA \to K^0pX$	1526 ± 5

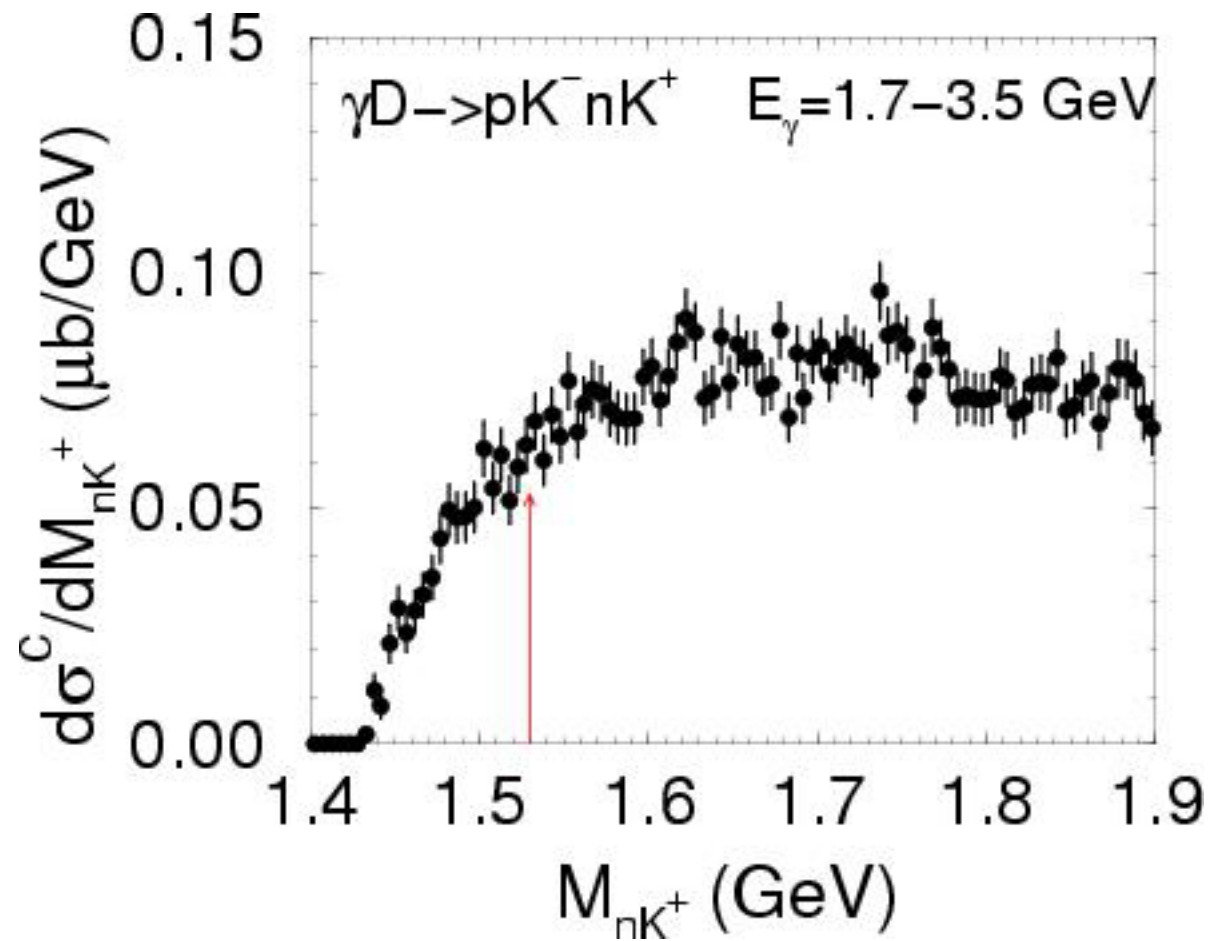| Group	Reaction
BES	$e^+e^- \to J/\Psi \to \Theta\Theta$
BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0X$
Belle	$e^+e^- \to B^0\bar{B}^0 \to p\bar{p}K^0X$
LEP	$e^+e^- \to Z \to pK^0X$
HERA-B	$pA \to K^0pX$
SPHINX	$pC \to K^0\Theta^+X$
HyperCP	$pCu \to K^0pX$
CDF	$p\bar{p} \to K^0pX$
FOCUS	$\gamma BeO \to K^0pX$
Belle	$\pi + Si \to K^0pX$
PHENIX	$Au + Au \to K^-\bar{n}X$

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R. De Vita et al,[The CLAS Coll.]

hep-ex/0606062

CLAS: New high statistics exp.
Search for Θ^+ in $\gamma p \rightarrow \Theta^+ K_s \rightarrow K^+ K_s n$

Counts/4 MeV vs M(nK⁺)(GeV)

$-0.8 < \cos\theta_{CM} < -0.6$

$N_{event} = -14.4034 +/- 22.5147$

Counts/4 MeV vs M(nK⁺)(GeV)

$0.6 < \cos\theta_{CM} < 0.8$
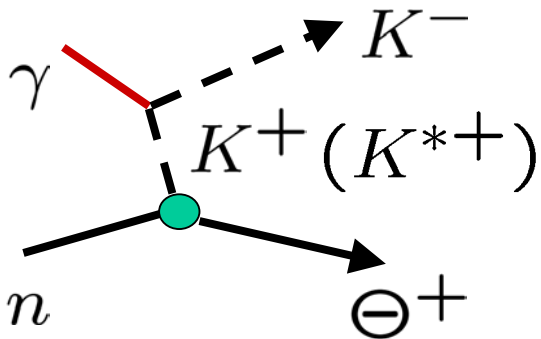
Counts/4 MeV vs M(nK⁺)(GeV)

B. McKinnon et al, [The CLAS collaboration]
Phys. Rev. Lett. 96, 212001 (2006)]

Sense of the CLAS new result

Θ^+ photoproduction in elementary
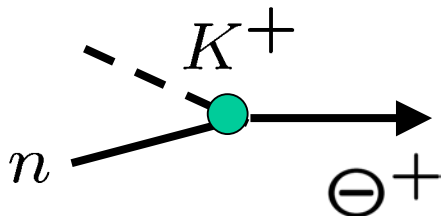$\gamma n \to \Theta^+ K^-$ and $\gamma p \to \Theta^+ \bar{K}^0$ is suppressed

$$T \sim g_{\Theta NK} \times F(p^2_{K+})$$

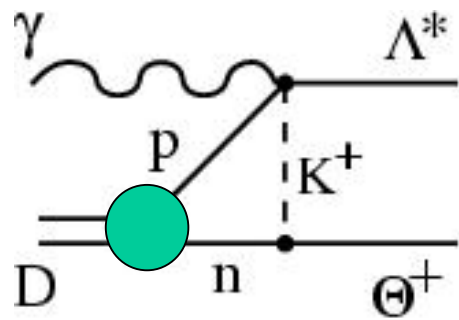$$g_{\Theta NK} = f(\Gamma_\Theta)$$

$$F(p^2) = \frac{\Lambda^4}{\Lambda^4 + (M_K^2 - P^2)^2}$$
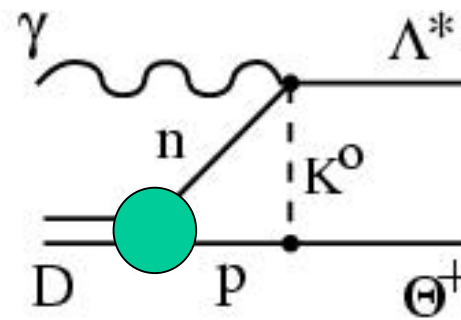
Search for formation process

$$T \sim \sqrt{\Gamma_\Theta}$$
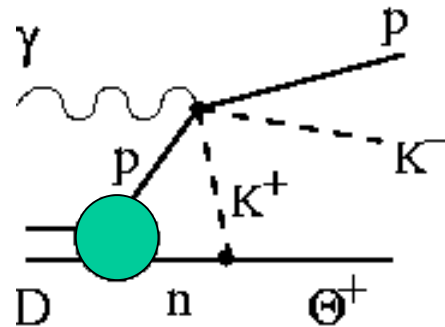
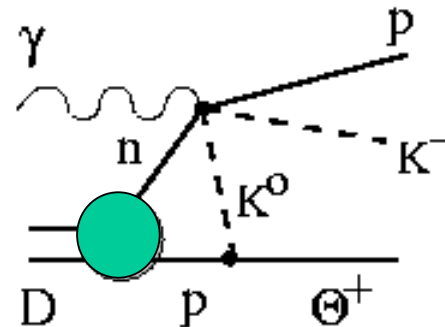# *Associated* $\Theta^+ \Lambda^*$ *photoproduction*
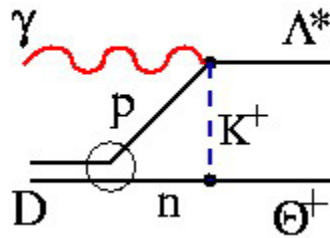

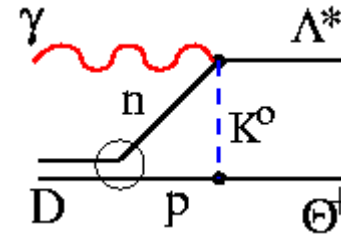# *Associated* $\Theta^+ {}_{p}K^-$ *photoproduction*
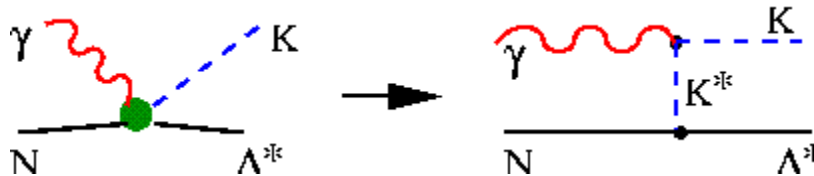

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Two comments

1. *interference between* *and* *is constructive*
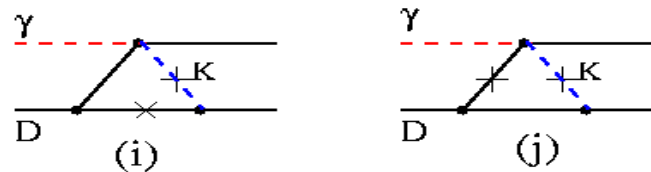
K^* - exchange dominance

$$g_{n\Theta^+K^+} = -g_{p\Theta^+K^o}$$

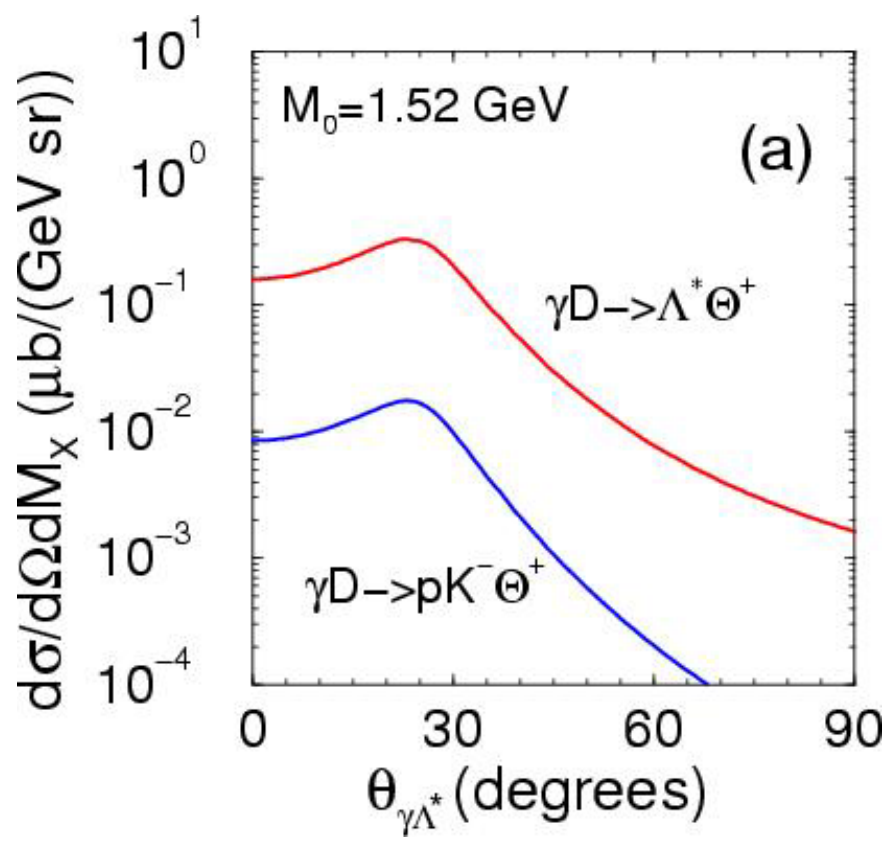$$g_{\gamma K^{o*}K^o} \simeq -\sqrt{2}\,g_{\gamma K^{-*}K^+}$$

2. *main contribution comes from the imaginary parts of three-angle diagrams*
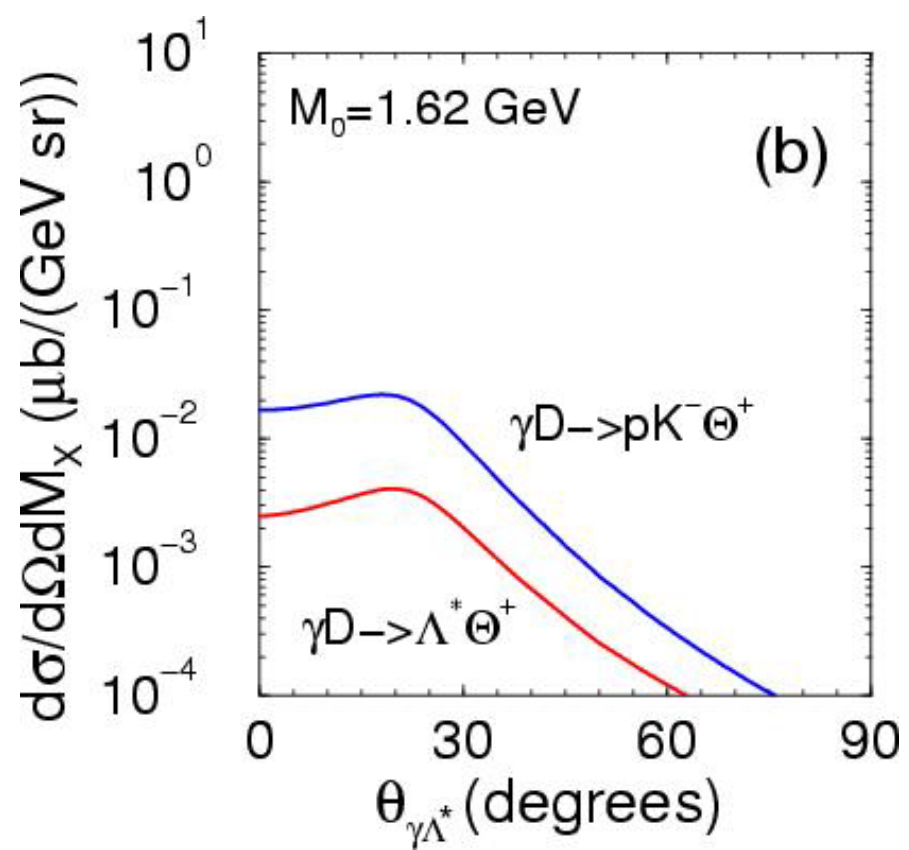

(i)   (j)

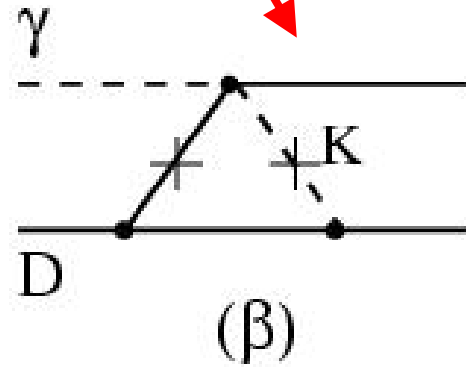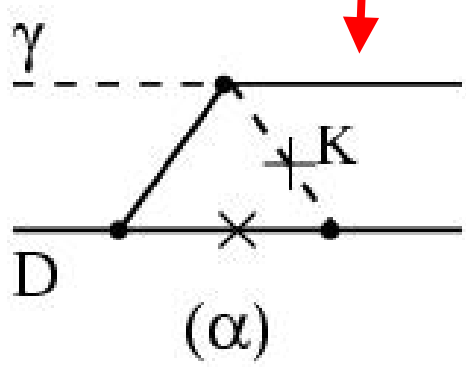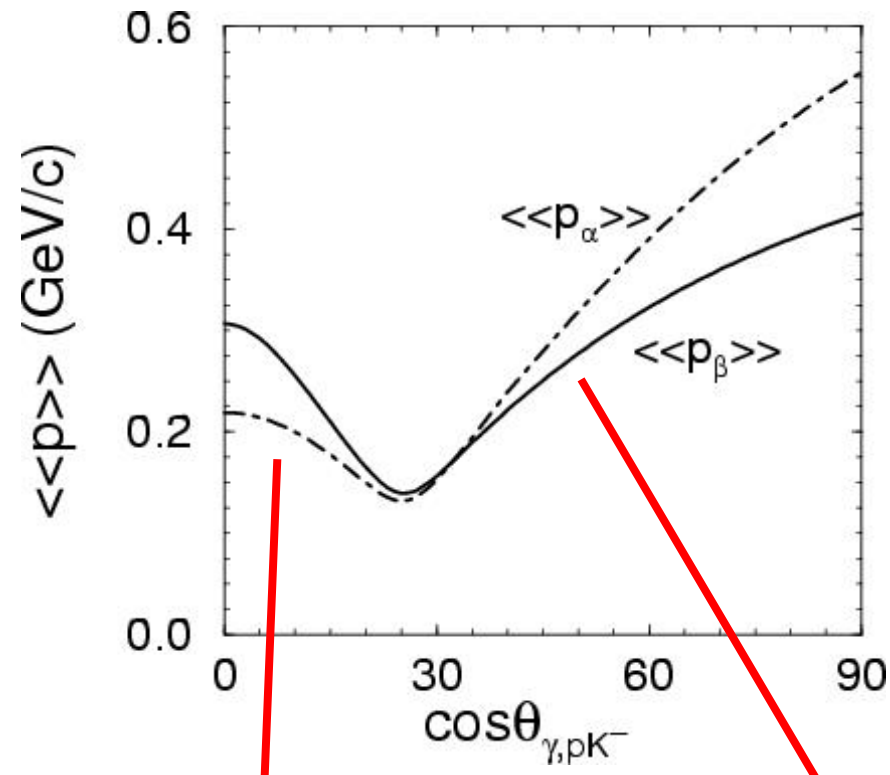$$\frac{1}{q^2 - M_K^2} \rightarrow 2\pi i \delta(q^2 - M_K^2) \ ,$$

$$\frac{\not{p} + M}{p^2 - M^2} \rightarrow 2\pi i \,(\not{p} + M)\,\delta(p^2 - M^2)$$

inside of Λ*
resonance region

outside of Λ*
resonance region

$<<p_\alpha>>$

$<<p_\beta>>$

$<<p>>$ (GeV/c)

$\cos\theta_{\gamma,pK^-}$

γ

K

D

(α)

γ

K

D

(β)

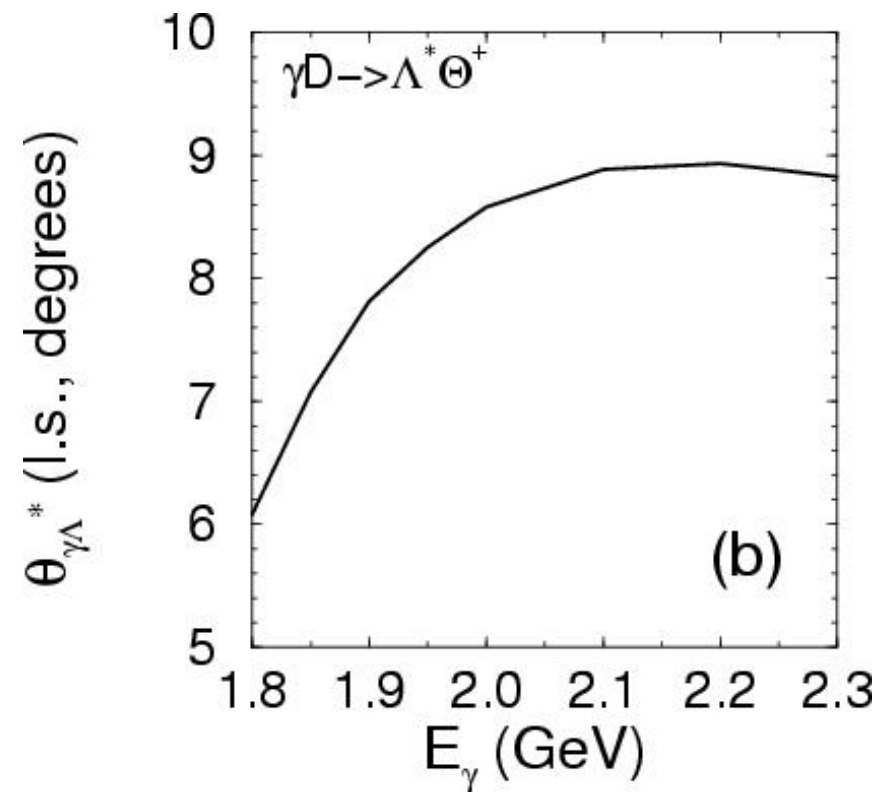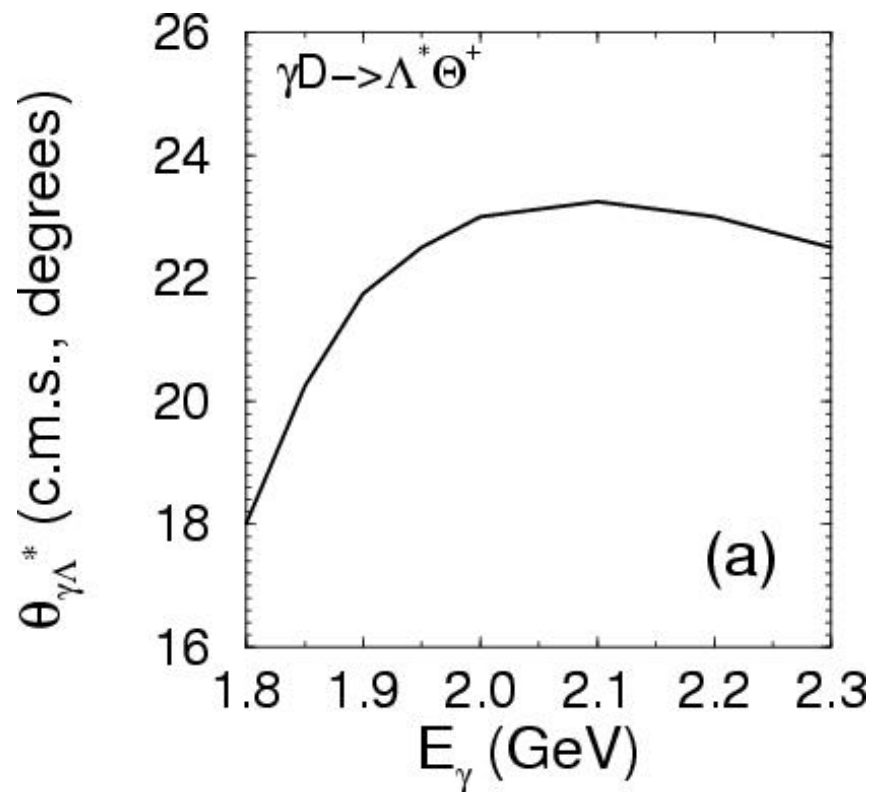# Associated Λ*Θ⁺ photoproduction as a function of Λ* photoproduction angle
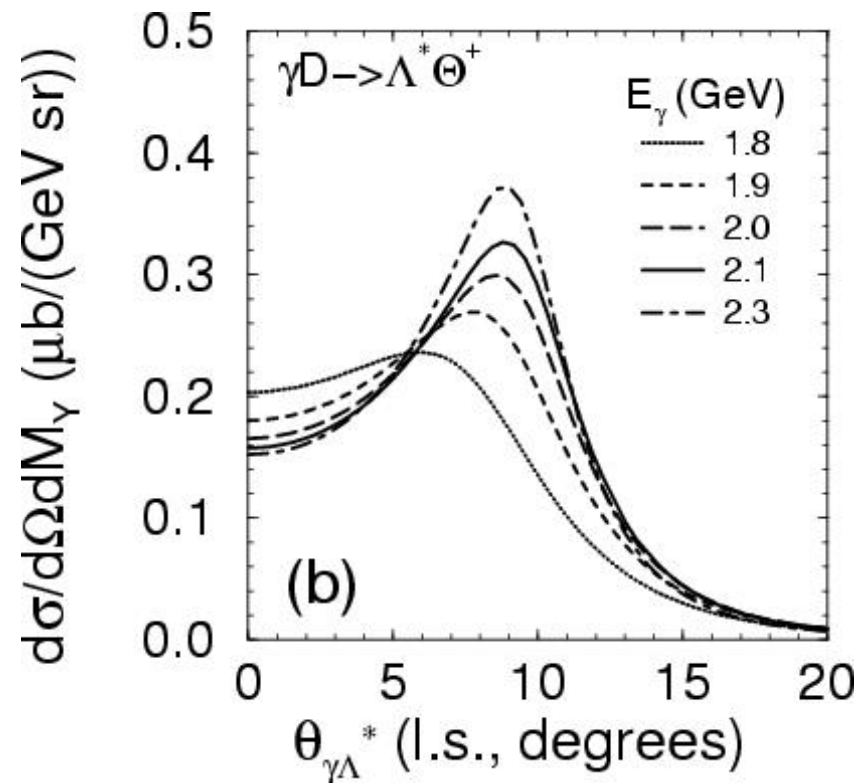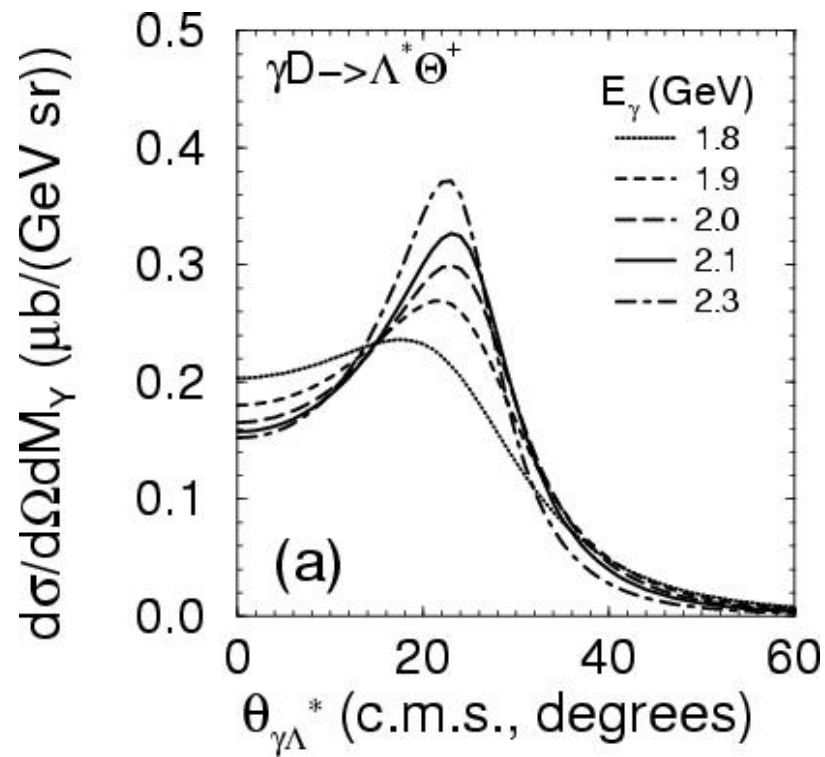
Position of maximun in cross section of the associated $\Lambda^*\Theta^+$ photoproduction as a function of Λ^* photoproduction angle
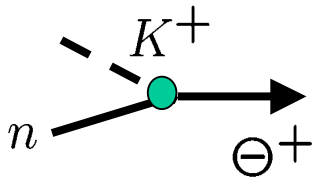
Dependence on Θ^+ spin and parity

$$|g_{\Theta NK}^{\frac{1}{2}\pm}|^2 = \frac{4\pi\Gamma_\Theta}{p_F}\frac{M_\Theta^2}{(M_\Theta \mp M_N)^2 - M_K^2},$$

$$|g_{\Theta NK}^{\frac{3}{2}\pm}|^2 = \frac{48\pi\Gamma_\Theta}{p_F}\frac{M_\Theta^6}{\lambda(M_\Theta^2, M_N^2, M_K^2)((M_\Theta \mp M_N)^2 - M_K^2)},$$

$$|g_{\Theta NK}^{\frac{1}{2}-}| : |g_{\Theta NK}^{\frac{1}{2}+}| : |g_{\Theta NK}^{\frac{3}{2}+}| : |g_{\Theta NK}^{\frac{3}{2}-}| = 0.134 : 1 : 1.39 : 10.21 .$$
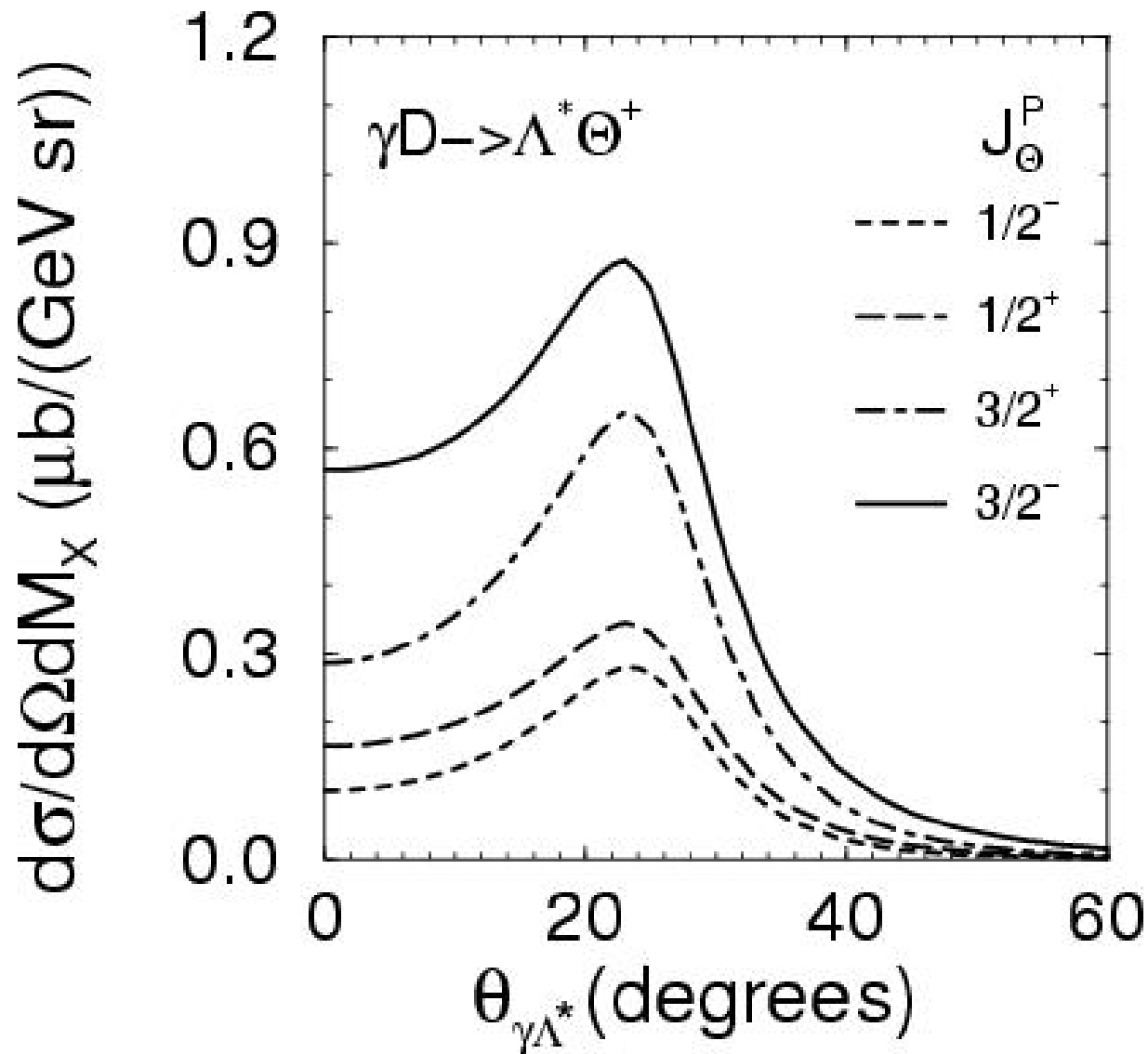
K^+

n

Θ^+

But cross section is proportional to $|A^{J^P}|^2$

$$|A^{\frac{1}{2}\pm}|^2 = 8\pi M_\Theta^2 \frac{\Gamma_\Theta}{p_F}\frac{(M_\Theta \mp \bar{M}_N)^2 - M_K^2}{(M_\Theta \mp M_N)^2 - M_K^2},$$

$$|A^{\frac{3}{2}\pm}|^2 = 16\pi M_\Theta^2 \frac{\Gamma_\Theta}{p_F}\frac{\lambda(M_\Theta^2, \bar{M}_N^2, M_K^2)}{\lambda(M_\Theta^2, M_N^2, M_K^2)}\frac{(M_\Theta \pm \bar{M}_N)^2 - M_K^2}{(M_\Theta \pm M_N)^2 - M_K^2},$$

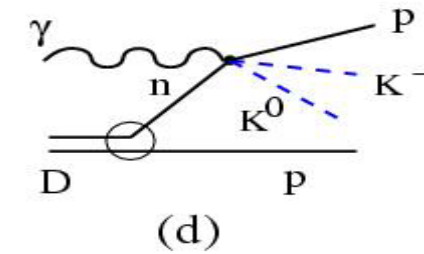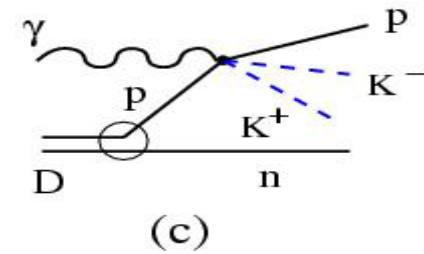$$\frac{1^-}{2} : \frac{1^+}{2} : \frac{3^+}{2} : \frac{3^-}{2} \simeq 0.8 : 1 : 1.9 : 2.5$$

Dependence on Θ⁺ *spin and parity*

Background

Spectator channels
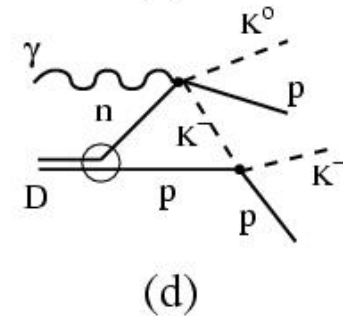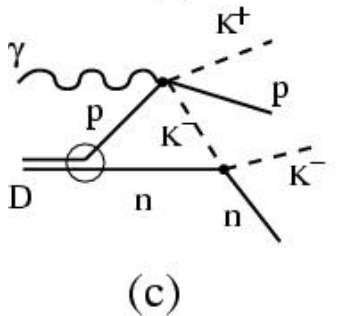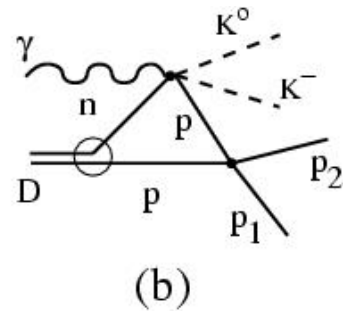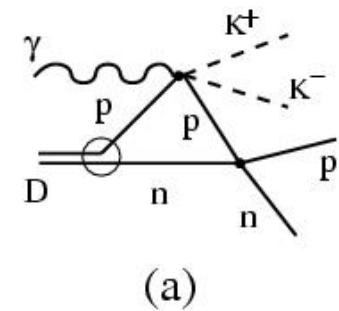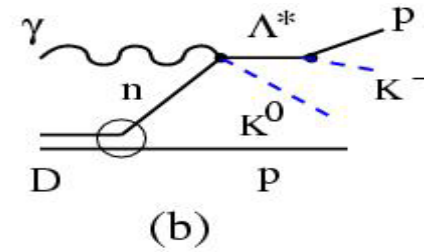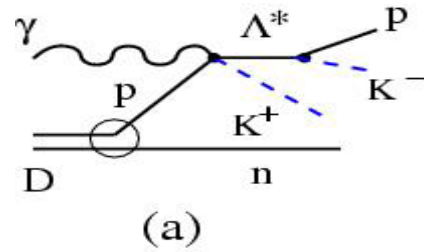
Re-scattering channels

Background: Reaction $\gamma N \to N \bar{K} K$

total cross section

inside of Λ* resonance region

outside of Λ* resonance region

(a) $M_{pK^-}=1.50-1.54$ GeV

(b) $M_{pK^-}=1.60-1.64$ GeV

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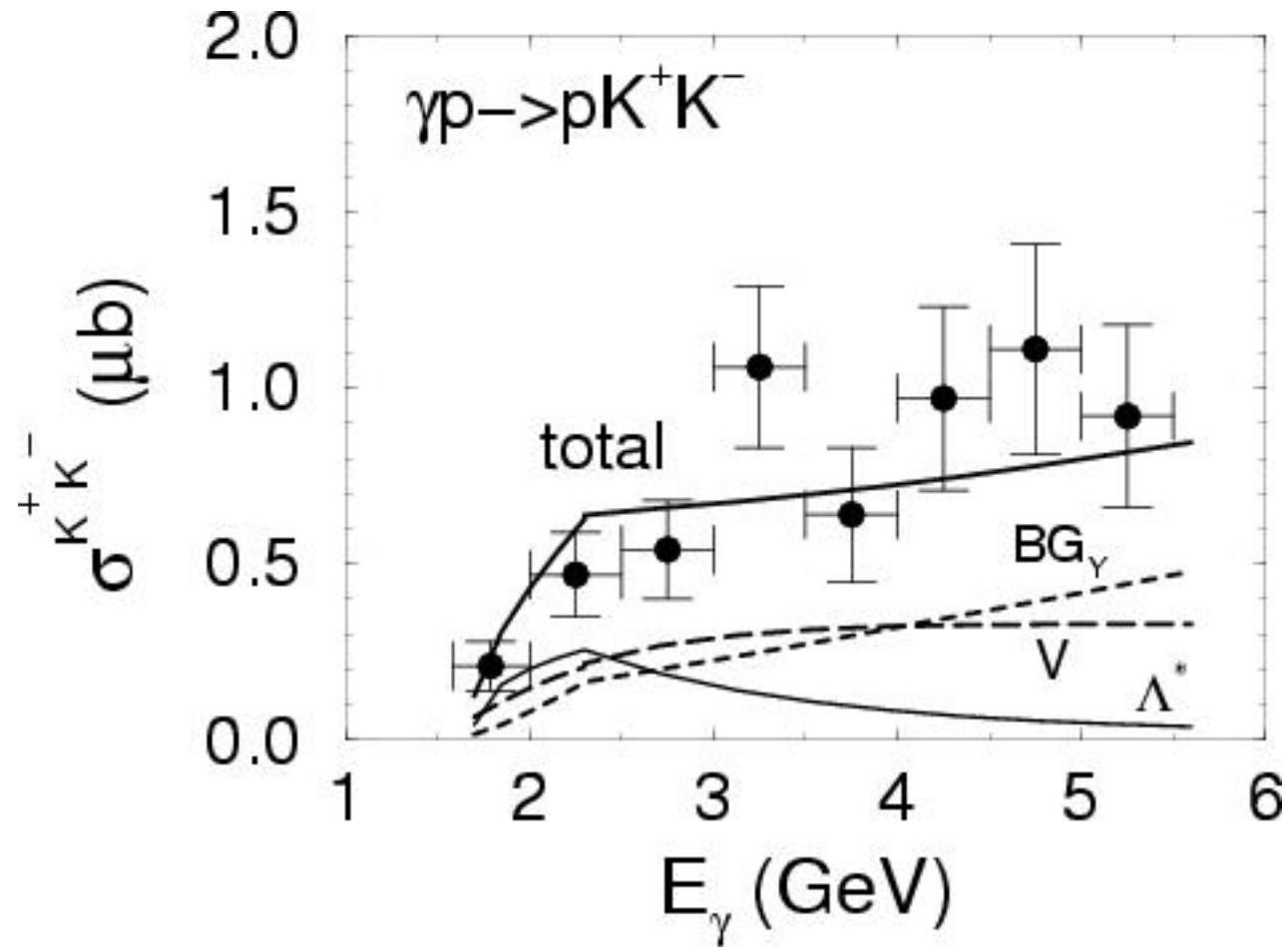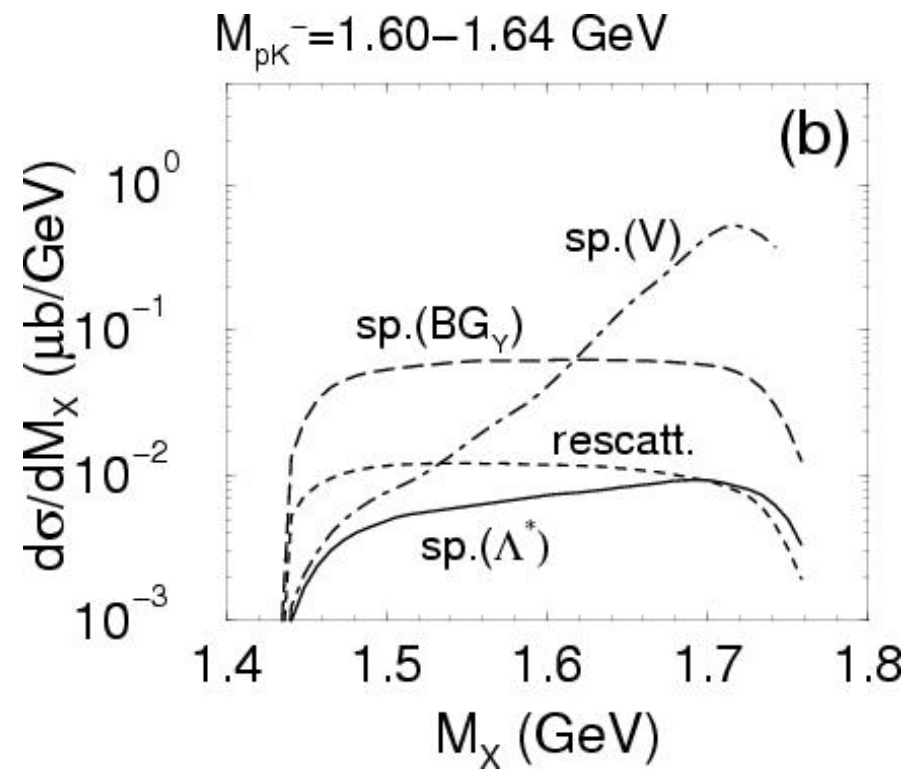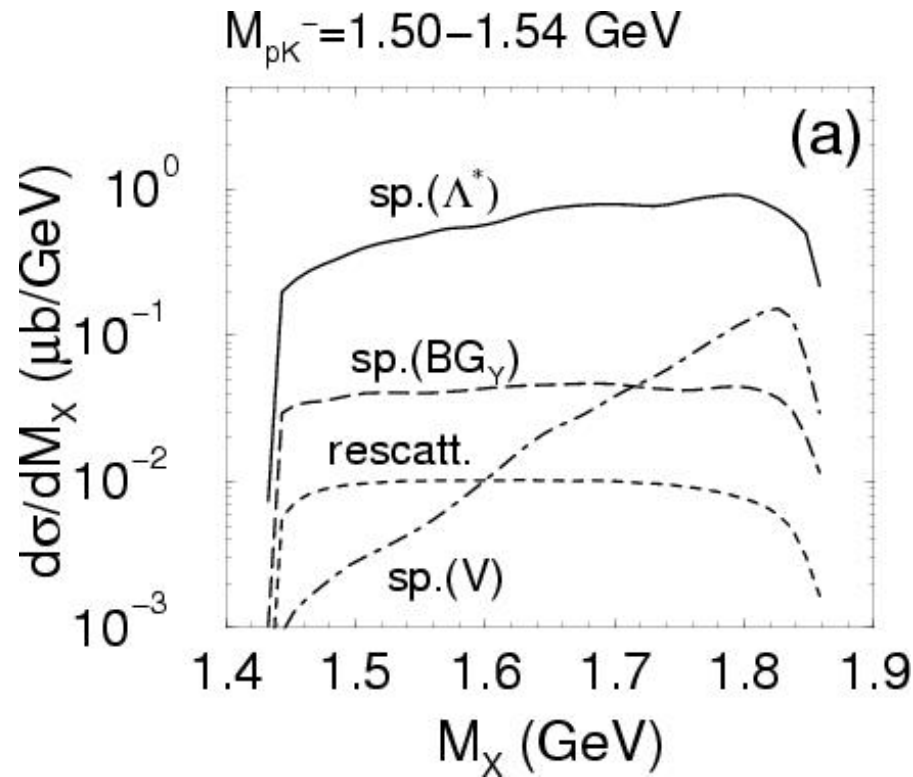
Angular dependence of signal and noise
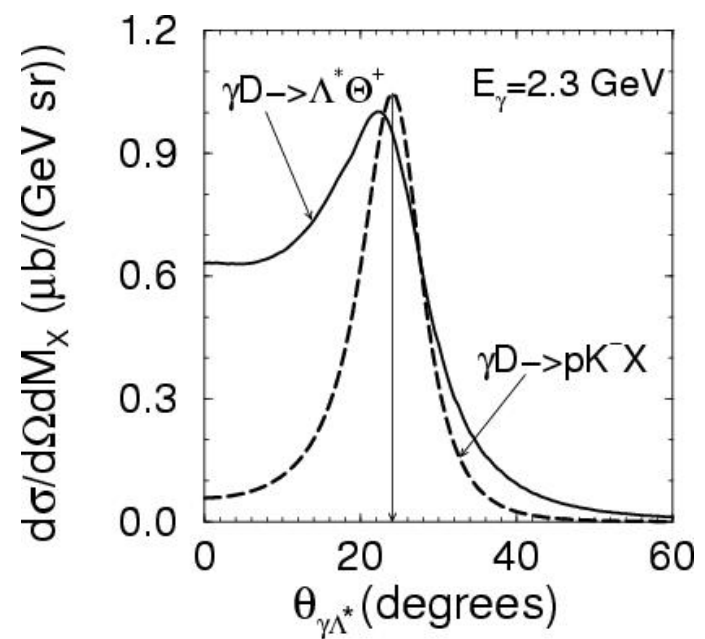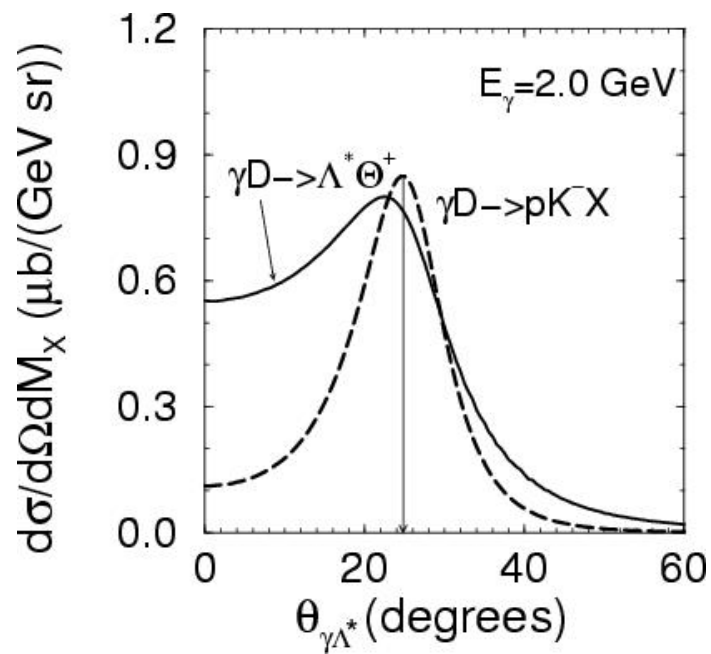
Results for $E_\gamma = 1.7 - 2.3$ GeV (LEPS)

with angle cut
$\theta_{\gamma,pK^-} < 22^0$

no angle cut

Reason of the spectrum shape modification

outside of Λ* resonance region

$E_\gamma = 1.7\text{--}2.3$ GeV $M_0 = 1.62$ GeV

$\gamma D \to pK^- X$

S/N=1.2

$\Theta^+(3/2^-)$

spectator

rescatt.
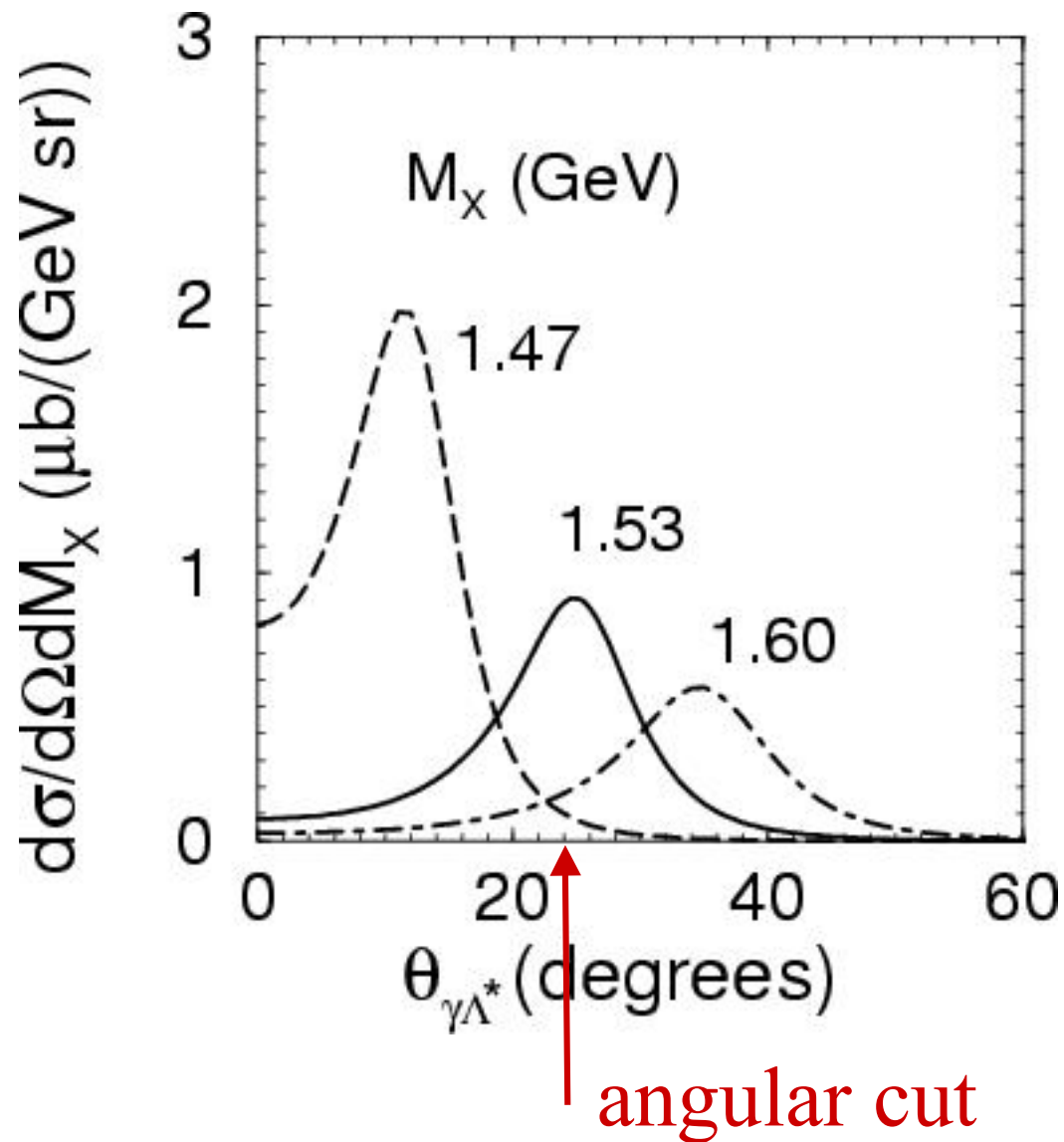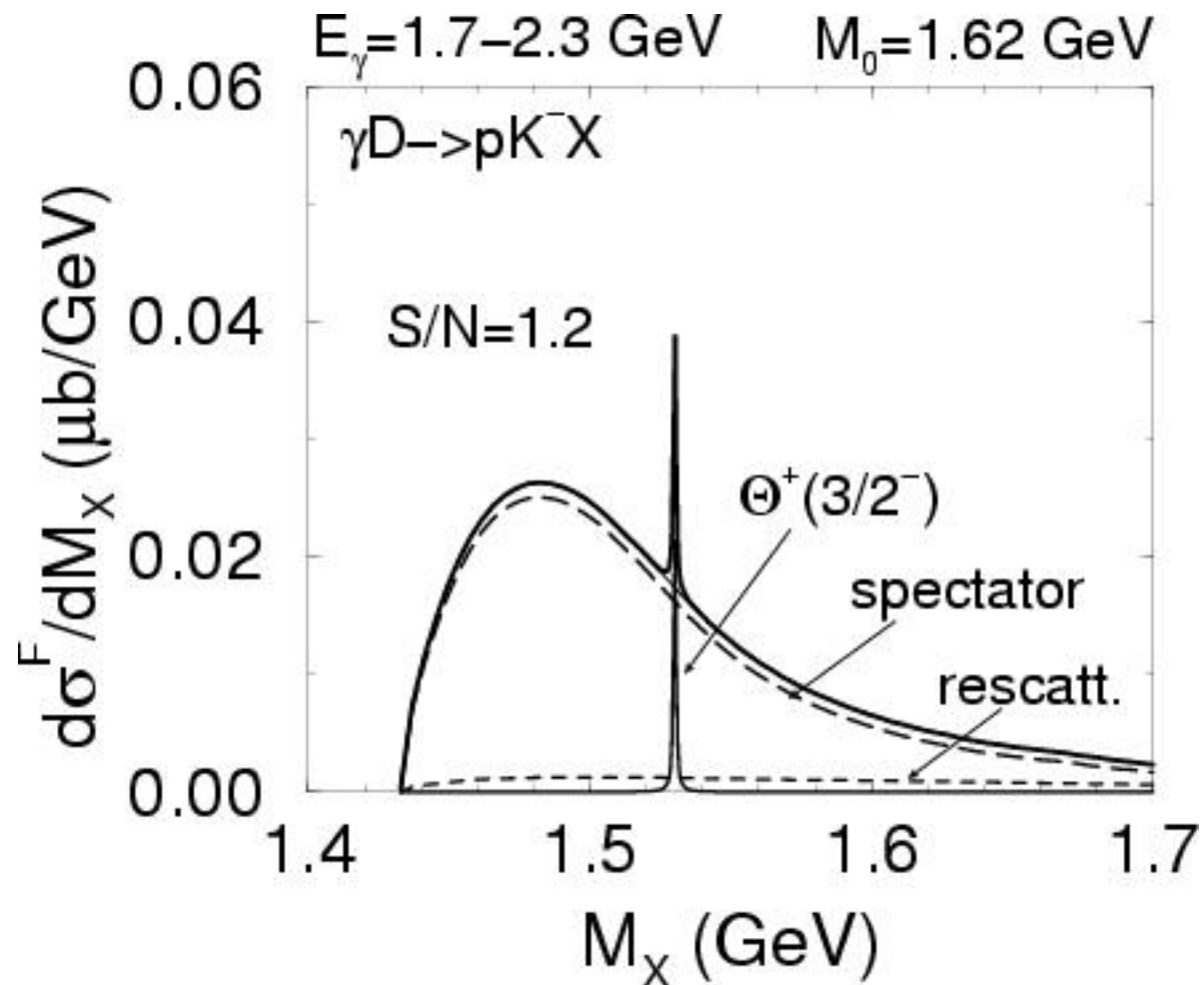
Θ^+ Spin and Parity
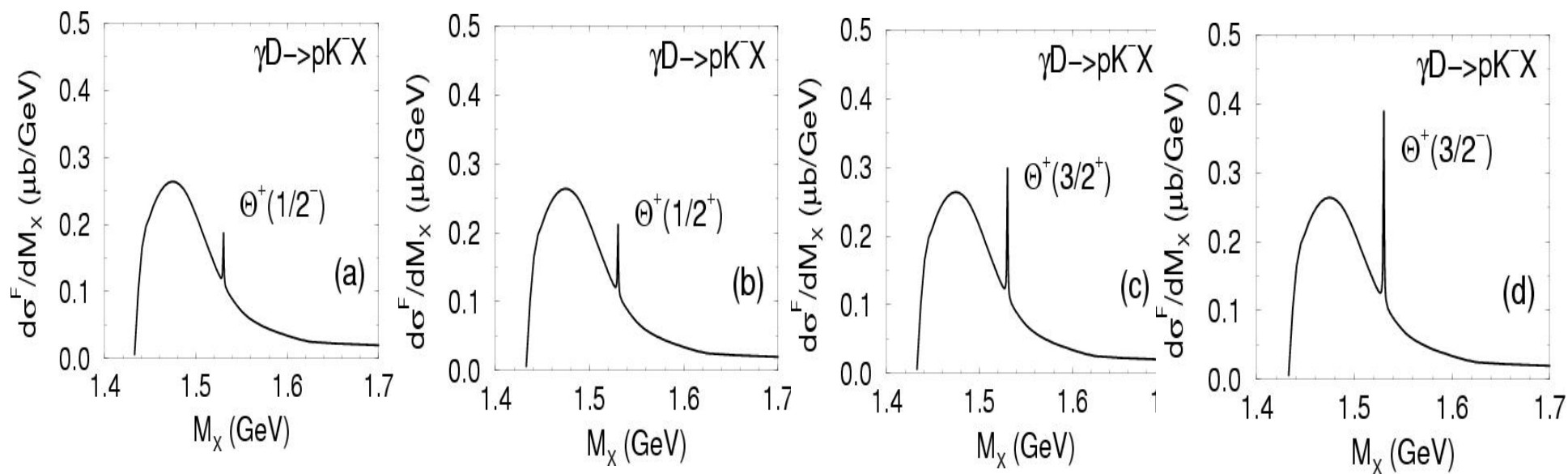
Total cross section
of Θ^+ photoproduction
at LEPS conditions
in $\gamma D \to \Theta^+ X$ reactions

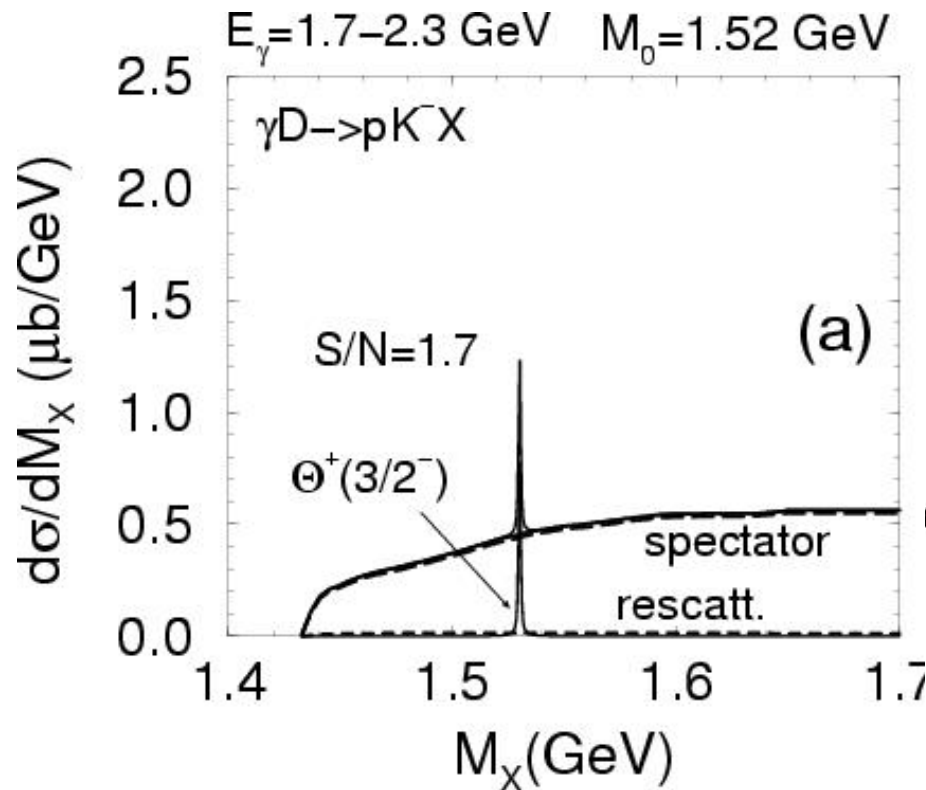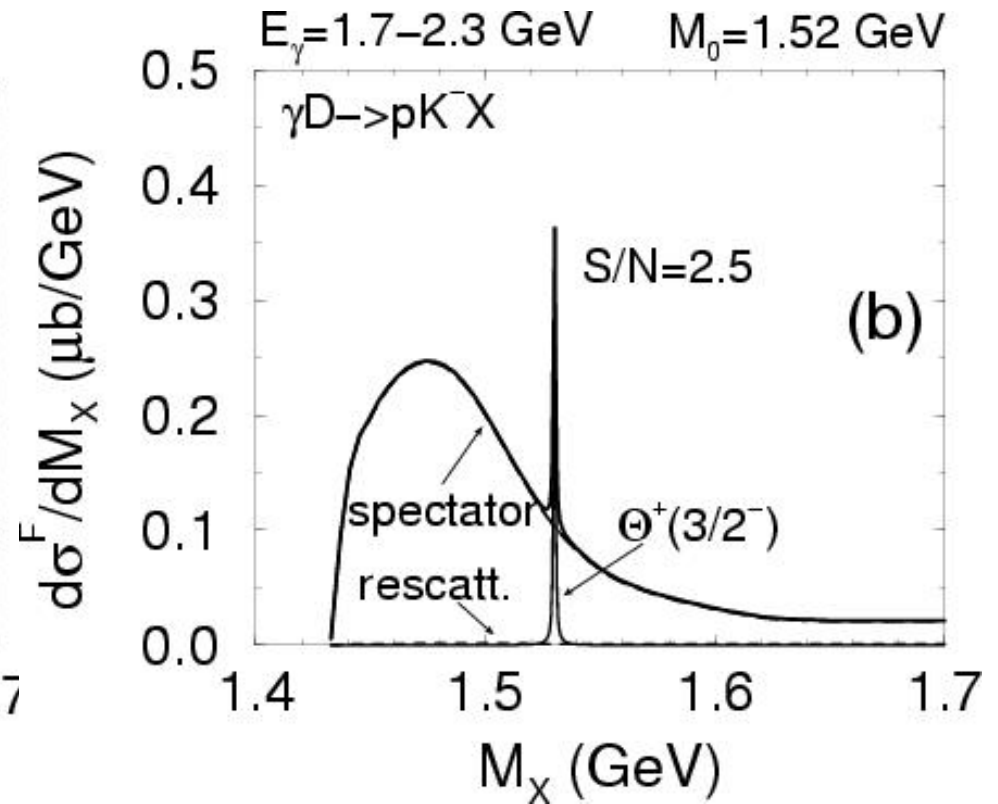$$\frac{d\sigma^{\Theta^+ F}}{dM}\bigg|_{\max} \simeq 0.26 \frac{\mu b}{GeV} \; ,$$

$$\sigma_{tot}^{\Theta^+ F} \simeq \frac{\pi}{2} \times \Gamma_\Theta \times \frac{d\sigma^{\Theta^+ F}}{dM}\bigg|_{\max} \simeq 0.41 \text{ nb}$$
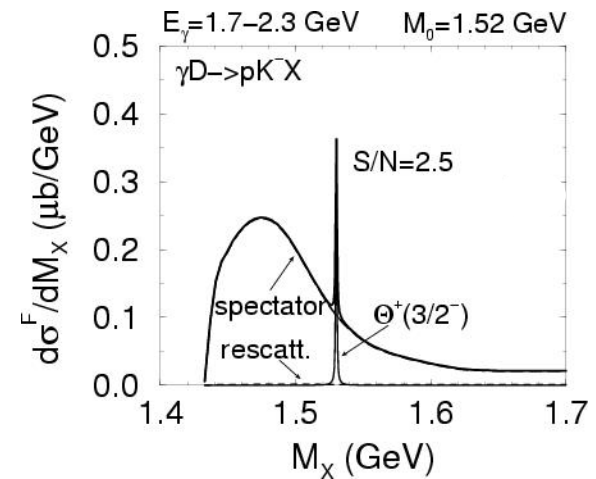
Total cross section
of Θ^+ photoproduction
in $\gamma D \to \Theta^+ X$ reactions

$$\sigma_{tot}^{\Theta^+} \simeq 1.0 \text{ nb}$$

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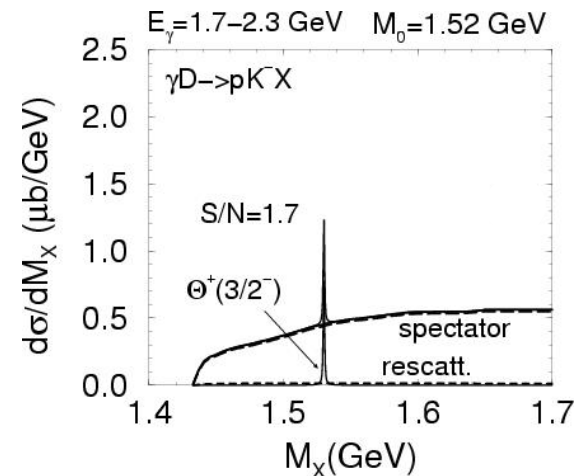
CLAS acceptance and conditions of data analysis

Acceptance:

(i) $p_p > 0.35$ GeV/c, $p_K > 0.25$ GeV/c

(ii) $\theta_+ > 9^0$, $\theta_- > 15^0$

Conditions are related to purpose:
look for $\gamma n \to \Theta^+ K^-$ reaction

(iii) ϕ meson cut $M_{K^+ K^-} > 1.06$ GeV

(iv) Λ^* cut $|M_{pK^-} - M_{\Lambda^*}| > 25$ MeV

(v) neutron momentum cut $p_n > 0.2$ GeV/c

CLAS conditions and Θ^+ signal
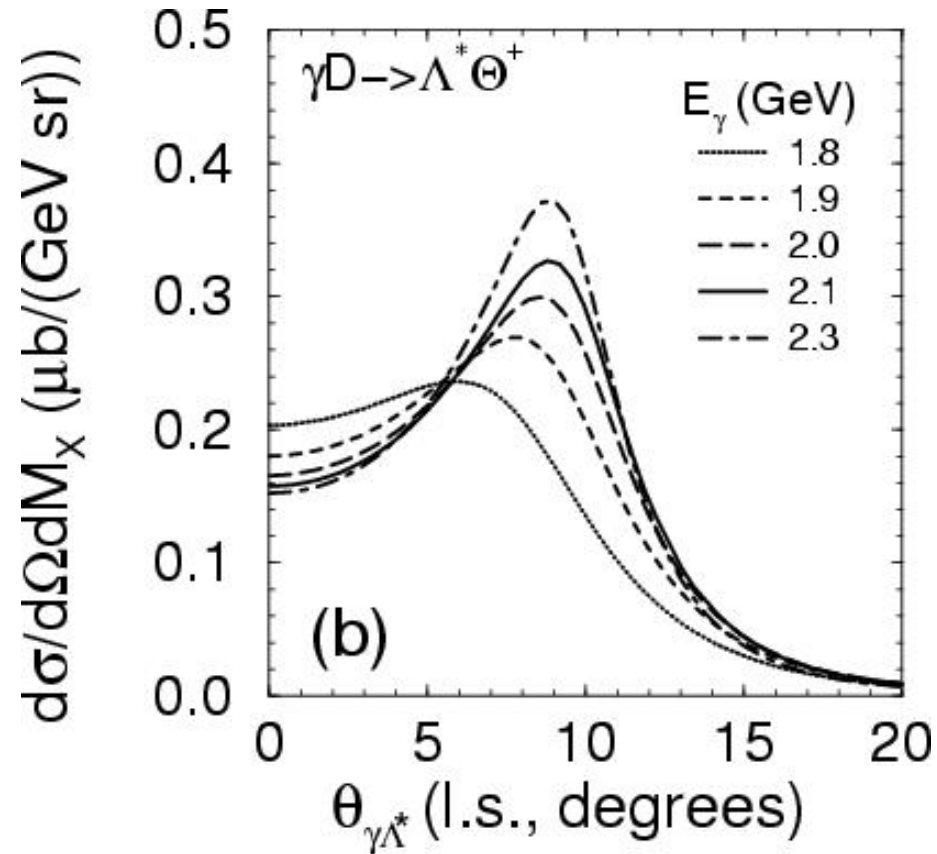
$$\theta_+ > 9^0, \; \theta_- > 15^0 \longrightarrow \textit{Suppress the signal}$$

CLAS conditions and background
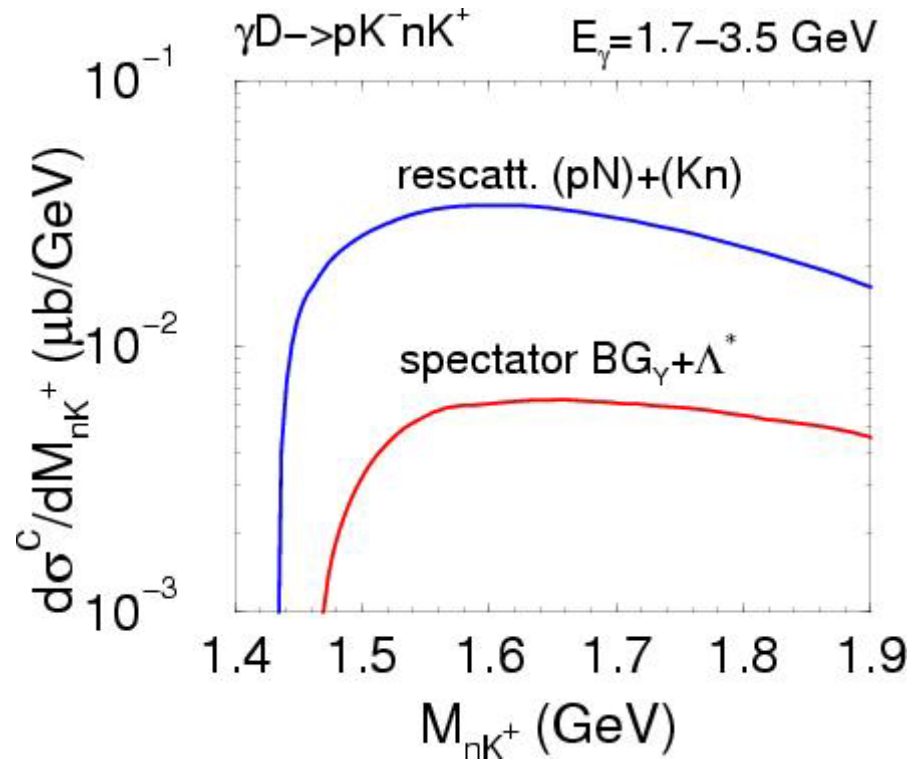
Λ^* cut $|M_{pK^-} - M_{\Lambda^*}| > 25$ MeV
neutron momentum cut $p_n > 0.2$ GeV/c

LEPS conditions   CLAS conditions
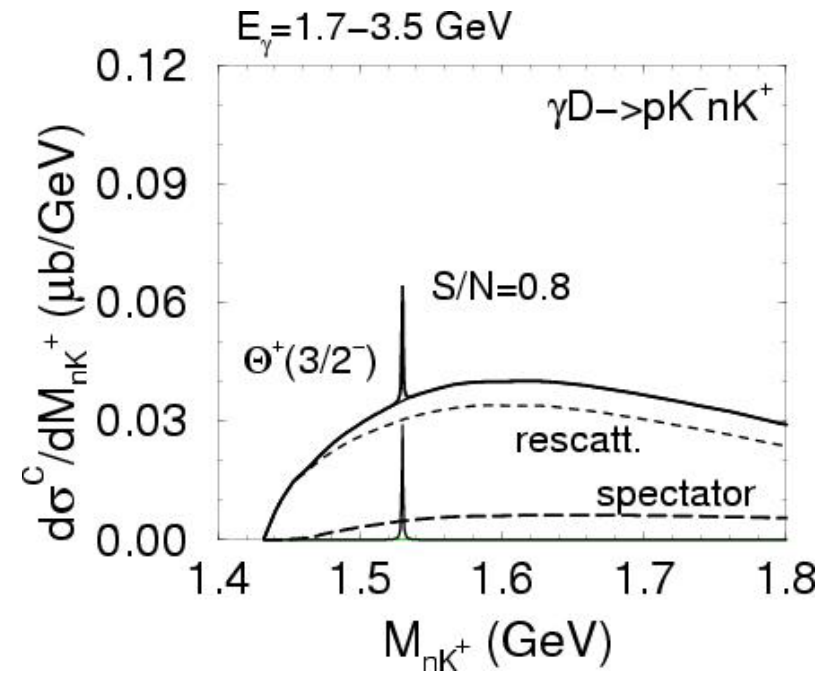
Total cross section
of Θ^+ photoproduction
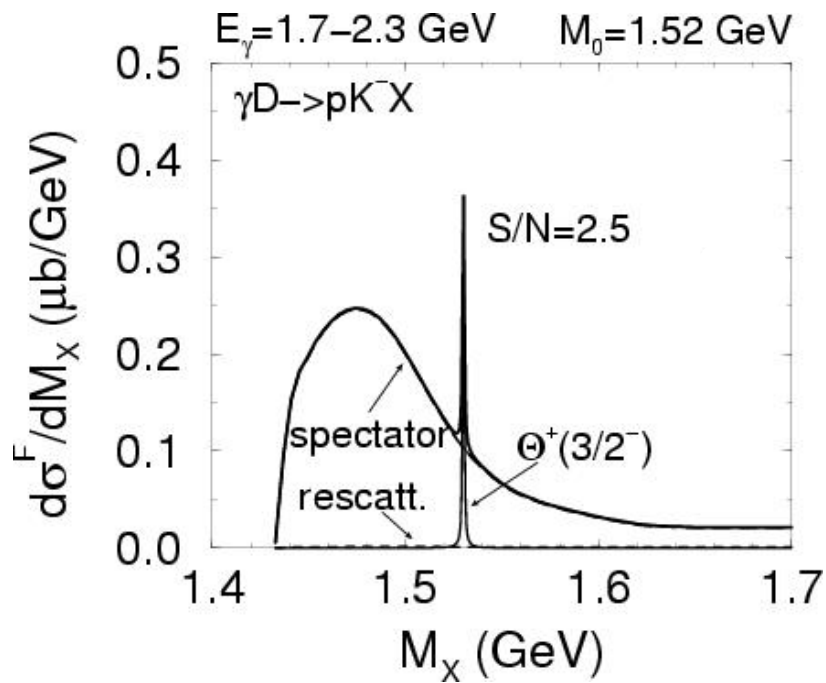at CLAS conditions
in $\gamma D \to \Theta^+ X$ reactions

$$\frac{d\sigma^{\Theta^+ C}}{dM}\bigg|_{\text{max}} \simeq 42 \; \frac{\text{nb}}{\text{GeV}} \; ,$$

$$\sigma_{\text{tot}}^{\Theta^+ C} \simeq 2 \times \frac{\pi}{2} \times \Gamma_\Theta \times \frac{d\sigma^{\Theta^+ F}}{dM}\bigg|_{\text{max}} \simeq 0.13 \; \text{nb}$$
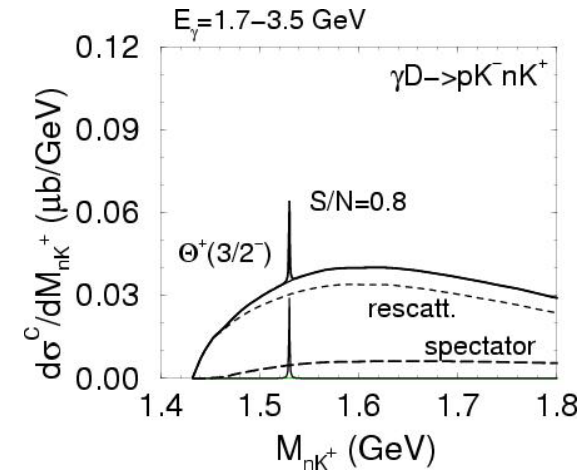
LEPS conditions   CLAS conditions

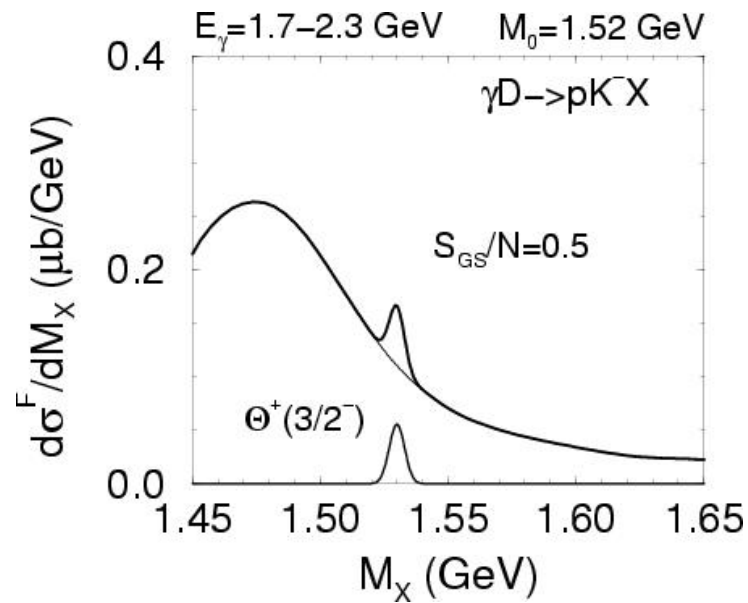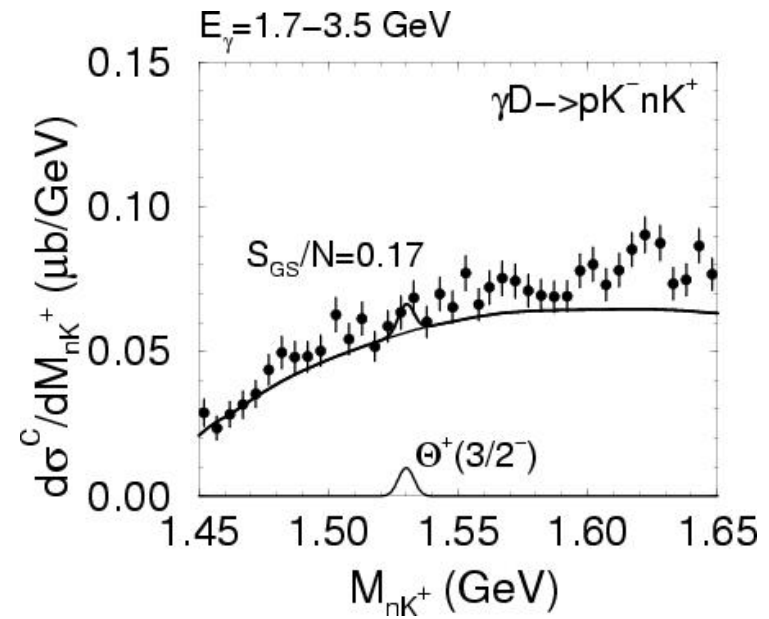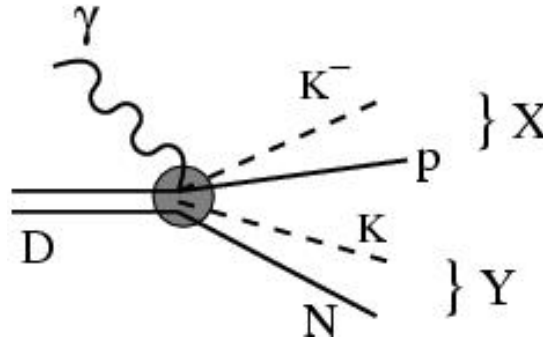# Acceptance correction

$$\frac{d\sigma}{dM_Y} = 2\pi \int \frac{d\sigma}{d[...]} dM_X \, d\cos_X$$

$$\times \frac{1}{64\pi^2 s_D} \frac{p_f}{p_i} \frac{1}{6} \sum_{[fi]} |T_{fi}|^2 \frac{\bar{q}' \, d\Omega_{\bar{q}'}}{16\pi^3} \frac{q' \, d\Omega_{q'}}{16\pi^3} \qquad 6 \; \textit{dimentional integral}$$

$$dM_X \, d\cos\theta \, d\Omega_X \, d\Omega_Y \; \rightarrow \; dM_X \, dp_n \, dp_{K^+} \, d\cos\theta_{K^+} d\cos\theta_{K^-} d\cos\theta_p$$

$$\boxed{\frac{V}{V_{\text{cut}}} \simeq \frac{1^6}{(1-0.05)^6} \simeq 1.4}$$

Acceptance correction
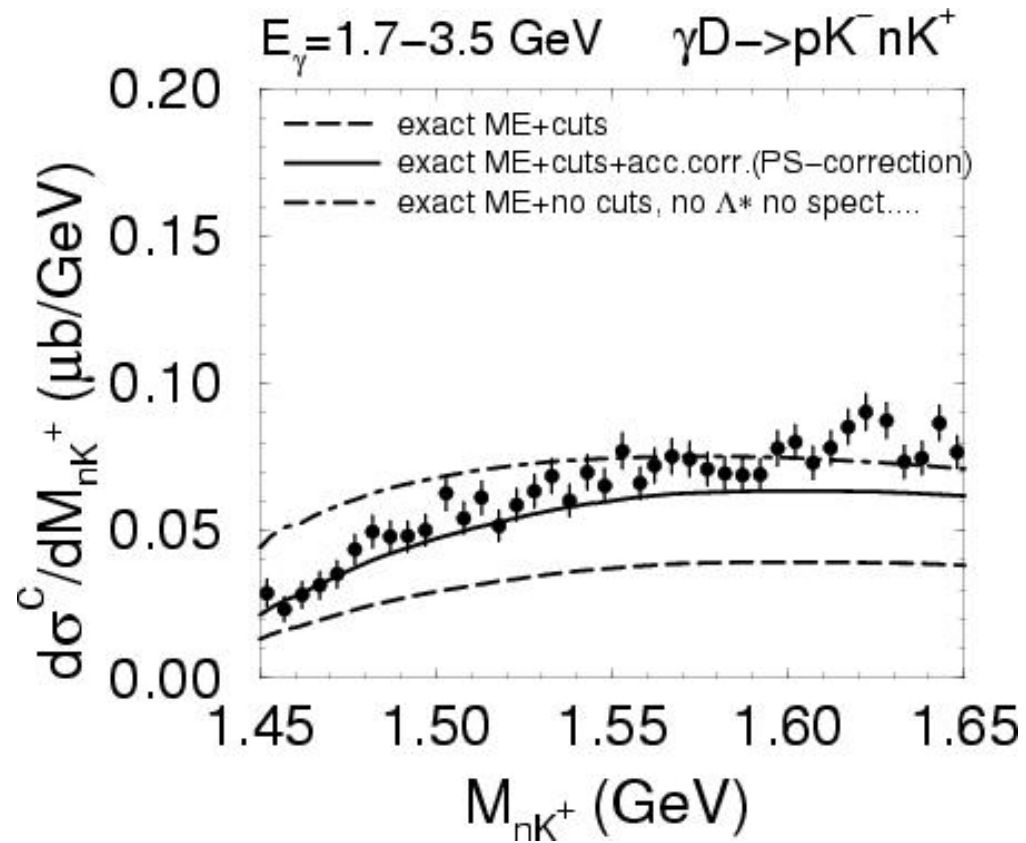
Summary

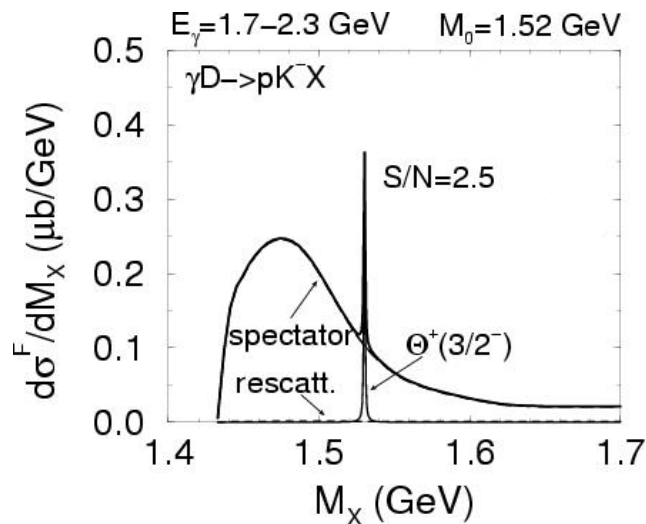*Preferable conditions for Θ^+ formation process*

1. Reaction $\gamma D \to p K^- X$

2. pK^- pair is detected at forward direction with $\theta_{\gamma, pK^-\,\text{lab.}} \leq 9 - 10^0$

3. Mass of pK^- pair is close to M_{Λ^*}

4. Photon energy $E_\gamma \sim 2.0 - 2.2$ GeV

$E_\gamma = 1.7 - 2.3$ GeV $M_0 = 1.52$ GeV

$\gamma D \to p K^- X$

S/N=2.5

spectator rescatt. $\Theta^+(3/2^-)$

$\downarrow$ **LD$_2$ data (preliminary)**
$1.50 < M(pK^-) < 1.54$ GeV/c^2

MMd(γ,pK$^-$) GeV/c^2