Recent developments in the strange production via hadron photoproductions
"Progresses on $\Lambda(1520)$ studies"

Nam, Seung-il (남승일,南昇日)

Korea Institute for Advanced Study (KIAS), Republic of Korea

This talk is based on
SiN, A.Hosaka, H.-Ch.Kim, Phys.Rev.D71,114012 (2005)
SiN, Phys.Rev.C81, 015201 (2010)
SiN, C.W.Kao, Phys.Rev.C81,055206 (2010)
SiN, B.G.Yu, Phys.Rev.C84, 025203 (2011)

KIAS
Korea Institute for Advanced Study

What is Λ(1520)?

$\Lambda(1520)\ D_{03}$

$I(J^P) = 0(\frac{3}{2}^-)$ Status: ∗∗∗∗

Λ(1520) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
15.6 ±1.0 OUR ESTIMATE				

Λ(1520) DECAY MODES

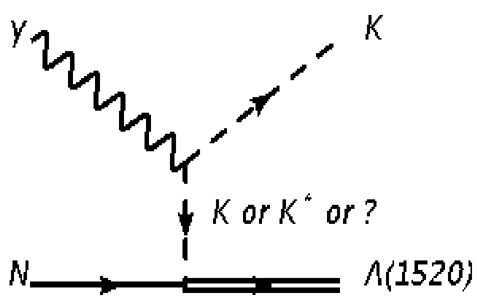
	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\overline{K}$	45 ± 1%
Γ_2	$\Sigma\pi$	42 ± 1%
Γ_3	$\Lambda\pi\pi$	10 ± 1%
Γ_4	$\Sigma(1385)\pi$	
Γ_5	$\Sigma(1385)\pi(\rightarrow \Lambda\pi\pi)$	
Γ_6	$\Lambda(\pi\pi)_{S\text{-wave}}$	
Γ_7	$\Sigma\pi\pi$	0.9 ± 0.1%
Γ_8	$\Lambda\gamma$	0.85 ± 0.15%
Γ_9	$\Sigma^0\gamma$	

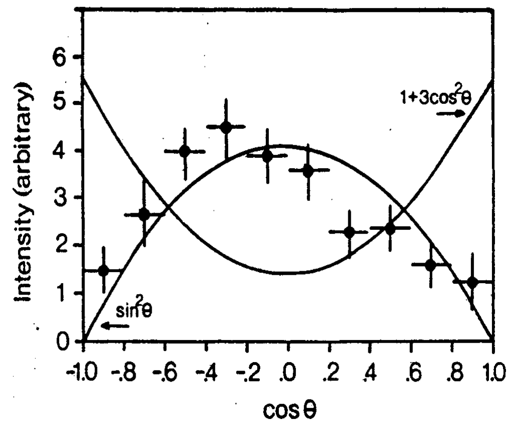
K. Nakamura *et al.* (Particle Data Group), JP G **37**, 075021 (2010)

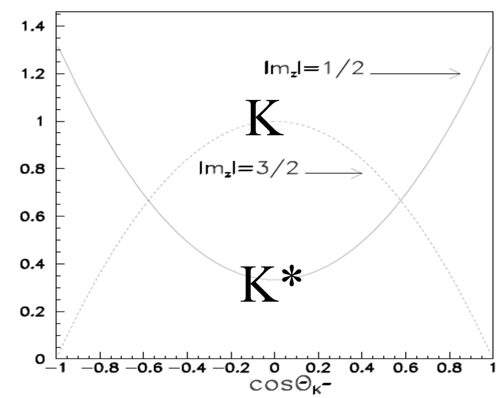
Why is Λ(1520) interesting in physics?

1) Production mechanism in photoproduction

Barrow et al., Phys.Rev.C64:044601,2001
Barber et al, Z.Phys.C7:17,1980







2) Proton-Neutron target asymmetry

There looks strong asymmetry between proton and neutron target data.
- T.Nakano (RCNP)

Phys. Rev. Lett. 103, 012001 (2009) [5 pages]

Near-Threshold Photoproduction of Λ(1520) from Protons and Deuterons

Abstract | References | Citing Articles (6)

Download: PDF (215 kB) Export: BibTeX or EndNote (RIS)

N. Muramatsu *et al.* LEPS Collaboration
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Received 12 April 2009; published 1 July 2009

Photoproduction of Λ(1520) with liquid hydrogen and deuterium targets was examined at photon energies below 2.4 GeV in the SPring-8 LEPS experiment. For the first time, the differential cross sections were measured at low energies and with a deuterium target. A large asymmetry of the production cross sections from protons and neutrons was observed at backward $K^{+/0}$ angles. This suggests the importance of the contact term, which coexists with *t*-channel *K* exchange under gauge invariance. This interpretation was compatible with the differential cross sections, decay asymmetry, and photon beam asymmetry measured in the production from protons at forward K^+ angles.

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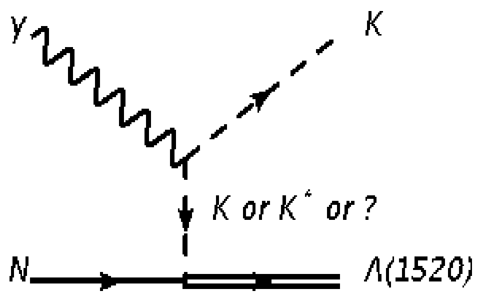

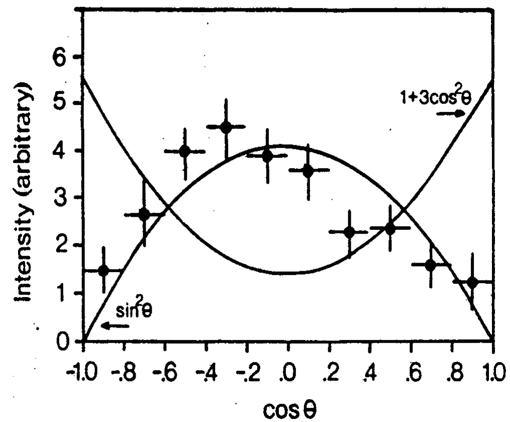

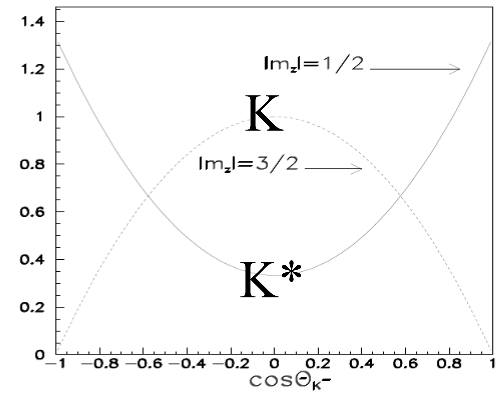

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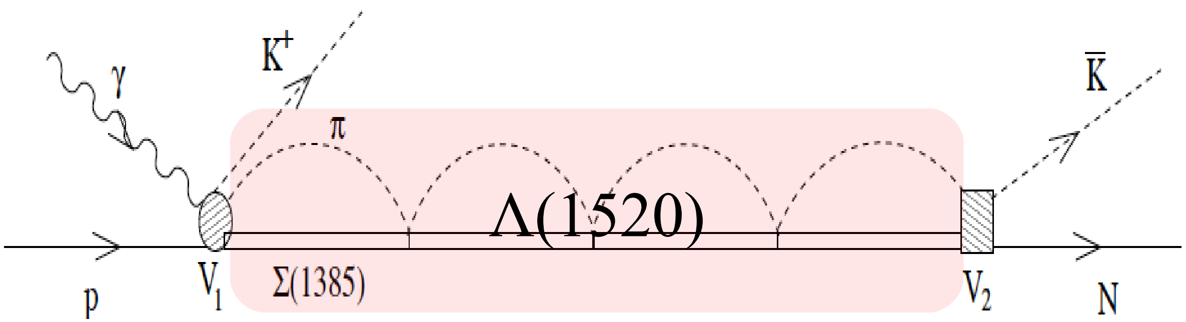
Why is $\Lambda(1520)$ interesting in physics?

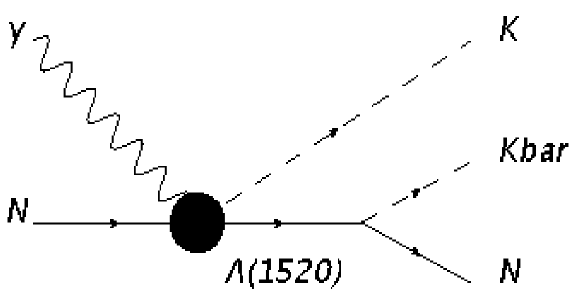
3) Dynamical generation of $\Lambda(1520)$ as a $\pi\Sigma(1385)$ bound state

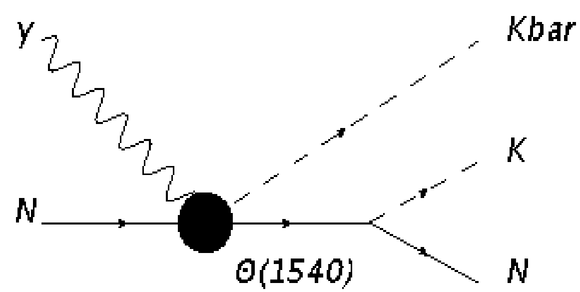


A good method to determine $K^*N\Lambda(1520)$ coupling

Roca et al., nucl-th:0411155
Hyodo et al., Phys.Rev.C73:035209,2006

2) Strong correlation with the exotic pentaquark $\Theta(1540)$

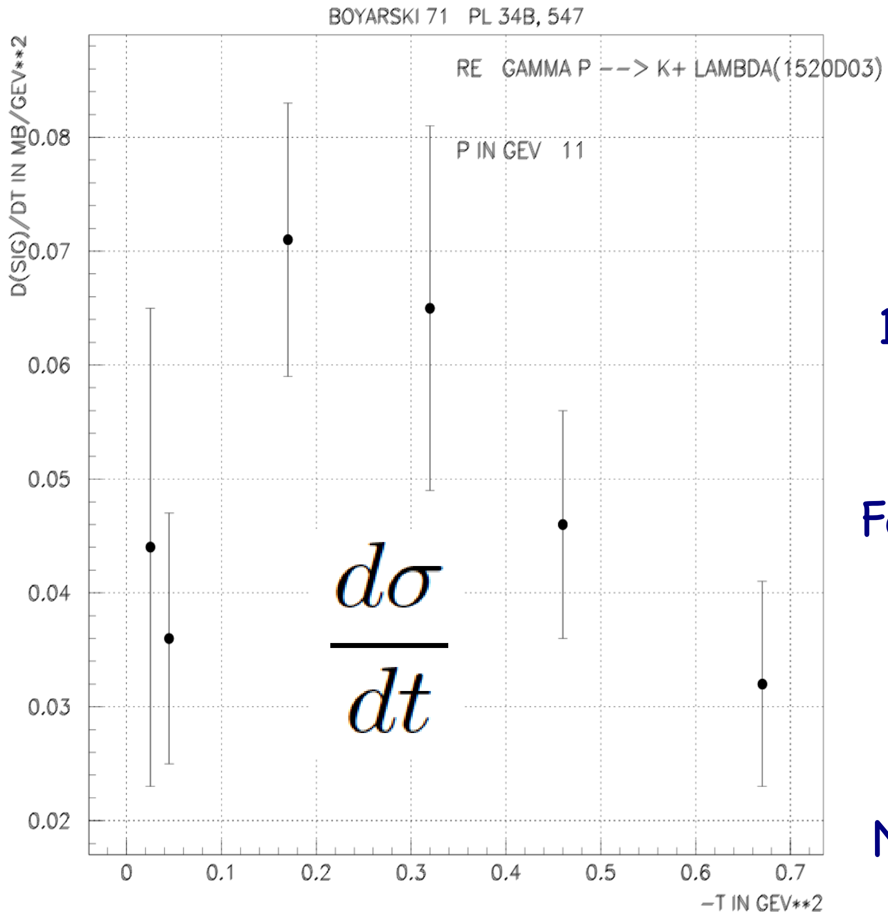




$\Theta(1540)$ production enhanced at which $\Lambda(1520)$ produced by LEPE collaboration

Experimental and theoretical studies on Λ(1520): 1970's

Boyarski et al for SLAC. PL34B, 547 (1971)



$$\gamma p \to K^+ \Lambda(1520)$$

First published paper for Λ(1520)

11 GeV Bremsstralhung beam with SLAC spectrometer

Focussing on various hyperon productions (one for Λ1520)

Large experimental errors

No more experiments for a long time...

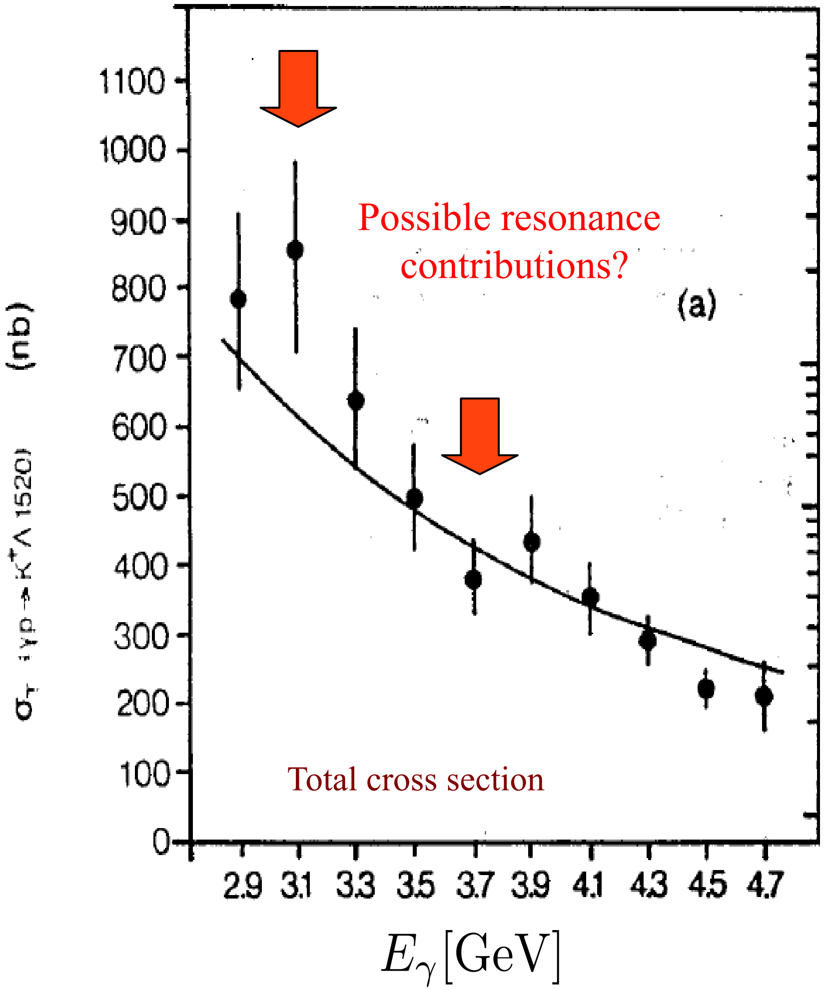
Experimental and theoretical studies on Λ(1520): 1980's

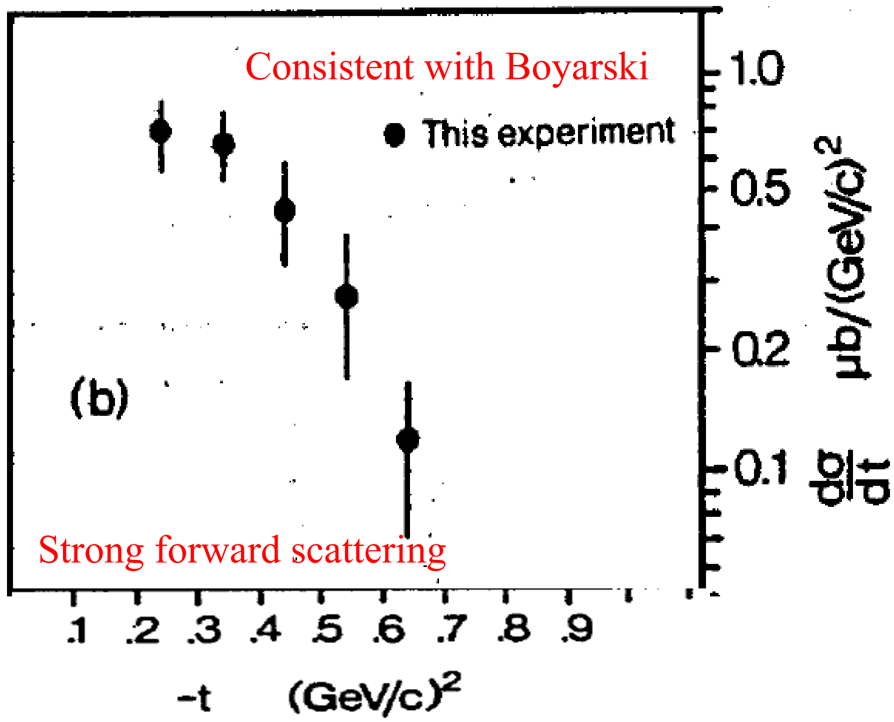
Barber et al for LAMP2 collaboration, ZP C7, 17 (1980)

$$\gamma p \to K^+ \Lambda(1520)$$

Daresbury tagged photon beam

LAMP2 multiparticle spectrometer

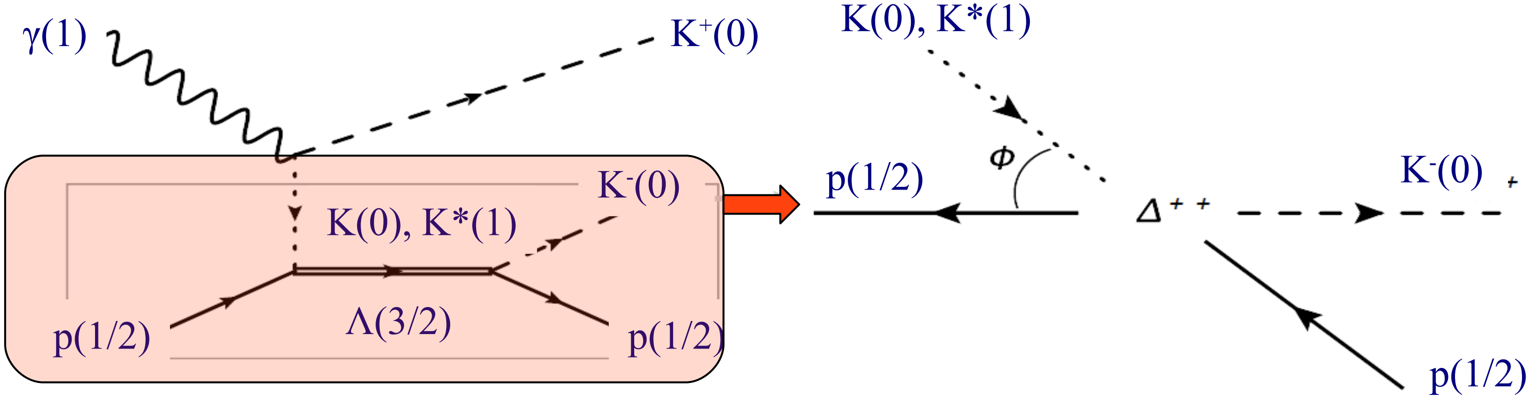




Experimental and theoretical studies on Λ(1520): 1980's

Barber et al for LAMP2 collaboration, ZP C7, 17 (1980)

Decay K^- distribution angle analysis on Gottfried-Jackson frame

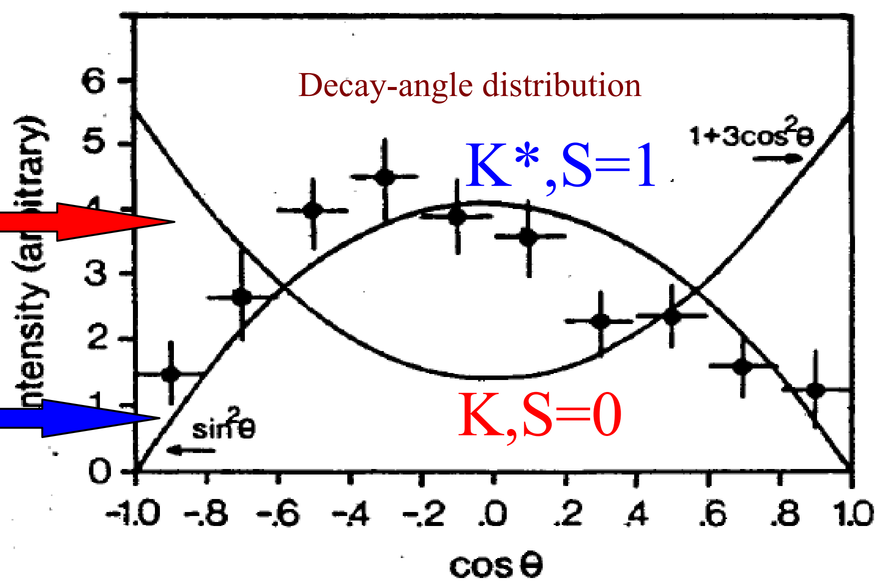


Due to a simple spin statistics,
If Λ(1520) in Sz=1/2 spin states,

$$\frac{1}{3} + \cos^2\theta_{K^-}$$

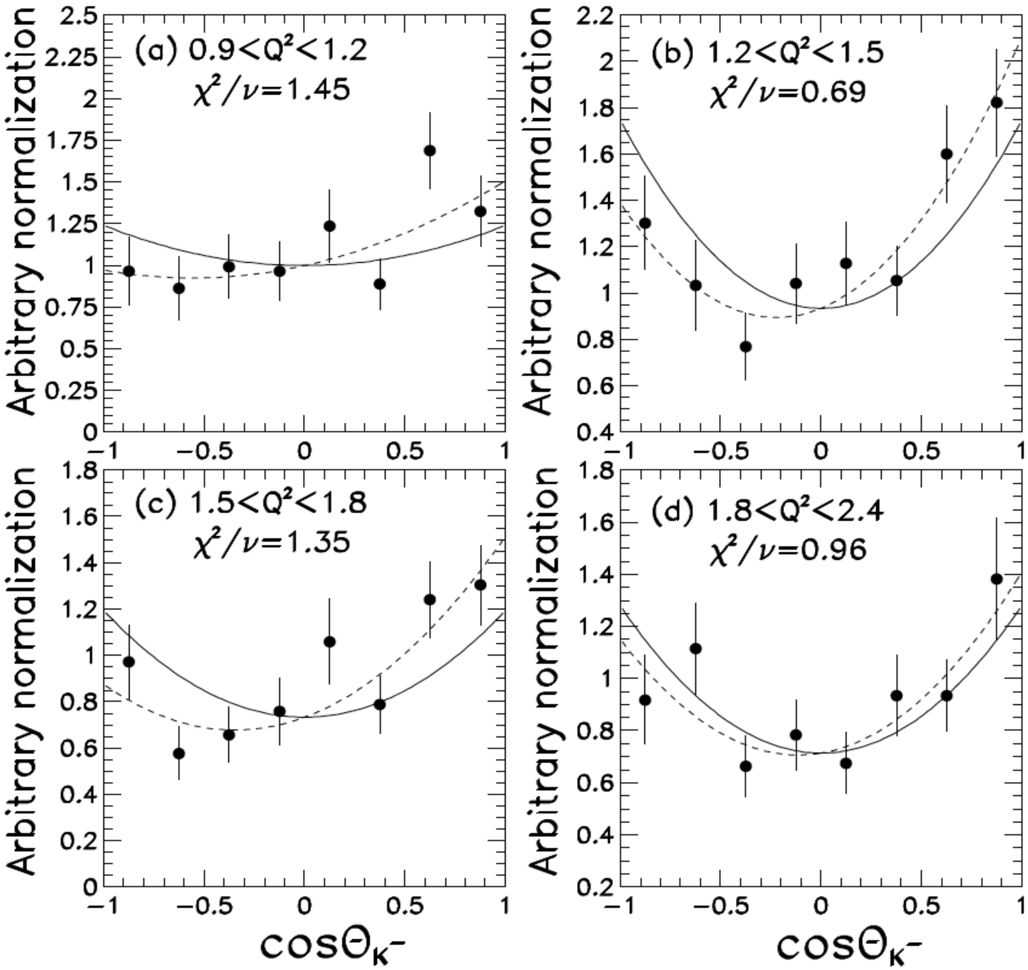
Else if in Sz=3/2 spin states

$$\sin^2\theta_{K^-}$$



Experimental and theoretical studies on Λ(1520): 2001

Barrow et al. For CLAS collaboration, Phys.Rev.C64:044601,2001

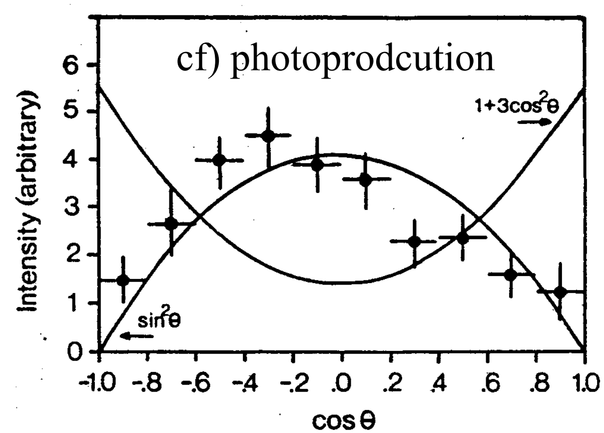


CEBAF detector at Jefferson lab

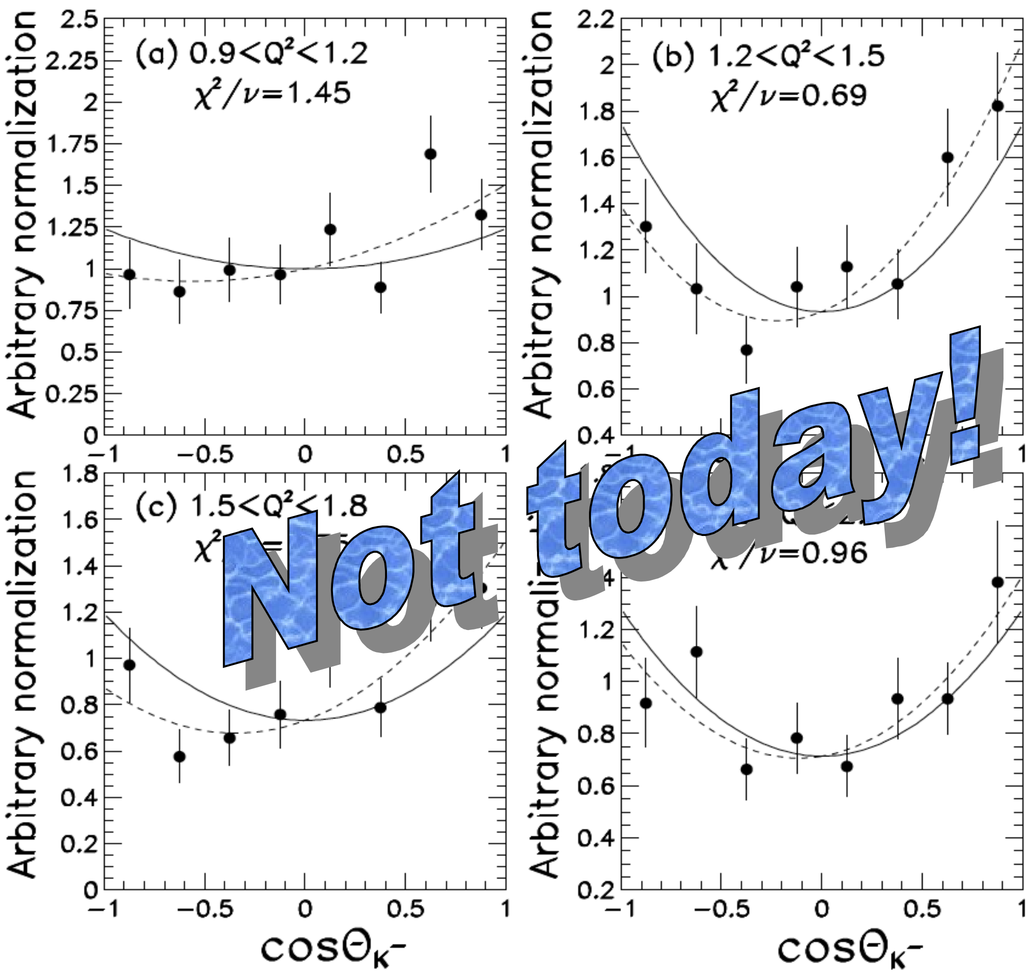
Electroproduction of **Λ**(1520)

$$\gamma^{*} p \to K^{+}\Lambda(1520)$$

K- and K*-exchanges contribute similarly? (K > K*)



Barrow et al. For CLAS collaboration, Phys.Rev.C64:044601,2001



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Electroproduction of **Λ**(1520)

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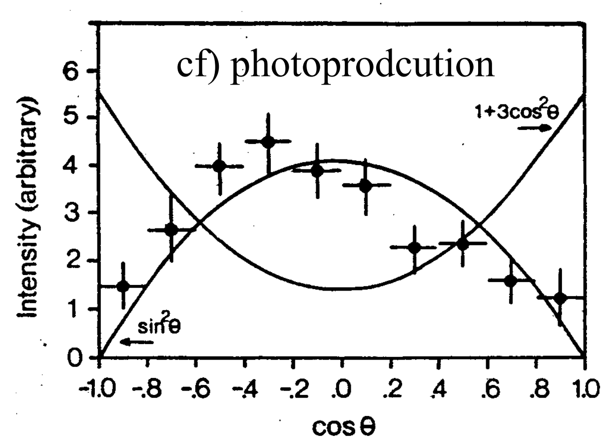
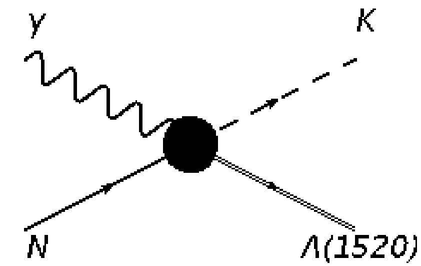


Experimental and theoretical studies on Λ(1520): 2005



Phys. Rev. D 71, 114012 (2005) [11 pages]

$\Lambda(1520,3/2^-)$-photoproduction reaction via $\gamma N \to K\Lambda^*(1520)$

Abstract | References | Citing Articles (18)

Seung-Il Nam*
Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan
Department of Physics and Nuclear Physics & Radiation Technology Institute (NuRI), Pusan National University, Busan 609-735, Republic of Korea

Atsushi Hosaka†
Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan

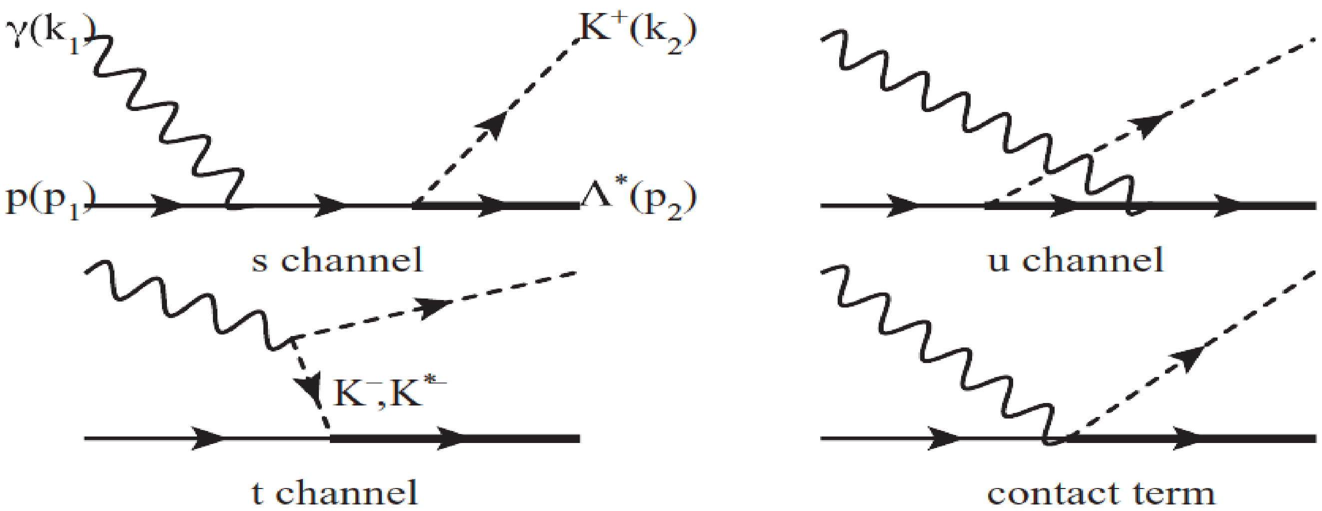
Hyun-Chul Kim‡
Department of Physics and Nuclear Physics & Radiation Technology Institute (NuRI), Pusan National University, Busan 609-735, Republic of Korea

We were motivated by the experiments, which had not been analyzed theoretically: initiative theoretical work for Λ(1520)

What production mechanism governs the reaction process?

K*-exchange contribution really dominates the process?

Tree-level Born diagrams for Λ(1520) photoproduction



These four, s,u,t(K),contact, are necessary to satisfy the WT identity

No resonant contributions considered (Y* and N*)

Scattering amplitude evaluated by effective Lagrangian approach

Rarita-Schwinger formalism for spin-3/2 fermion

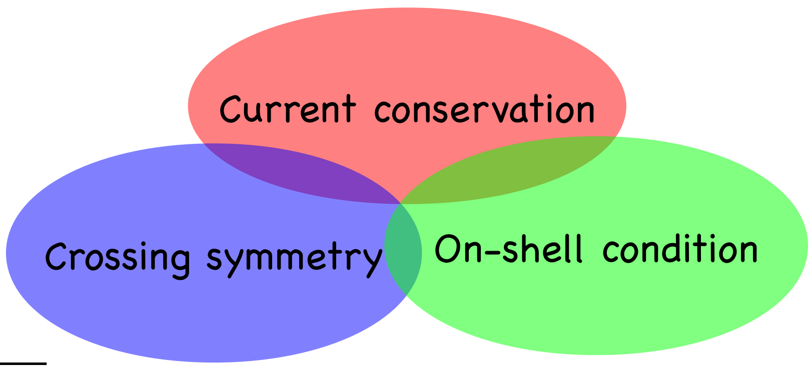
Current-conserving form factor prescription

Hadrons: spatially extended particles → spatial distribution

Photoprodcution of hadrons needs careful treatment of form factors to satisfy the current conservation, i.e. Ward-Takahashi identity

Form factor prescription suggested by Ohta, Workman, Haberzettl et al.

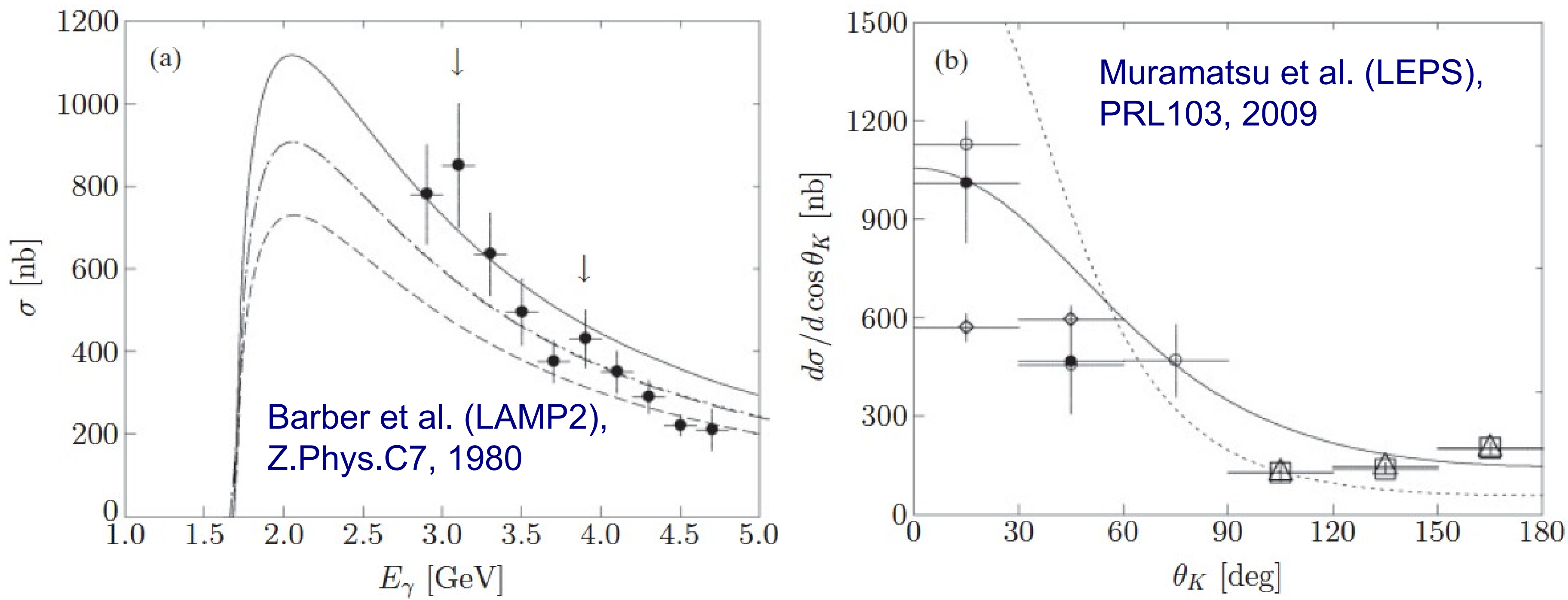
$$i\mathcal{M}_{\rm total} = [i\mathcal{M}_{\rm contact} + i\mathcal{M}_s^E + i\mathcal{M}_t^E + i\mathcal{M}_u^E]F_{\rm common} + i\mathcal{M}_s^M F_s + i\mathcal{M}_u^M F_u + i\mathcal{M}_t^M F_t$$



$$\frac{\Lambda^4}{\Lambda^4 + [(s,t,u) - M^2_{(s,t,u)}]^2}$$

$$F_{\rm common} = 1 - (1 - F_s)(1 - F_t)$$

Unpolarized results for Λ(1520)



Qualitatively well reproduce data

Dominant contact-term contribution ~ 90%

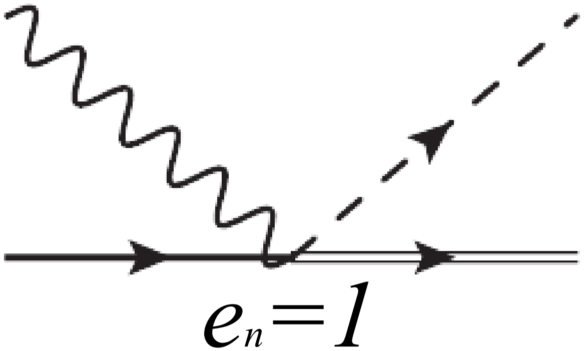
SiN, A.Hosaka,
H.C.Kim, PRD71,2005

Negligible resonant contributions

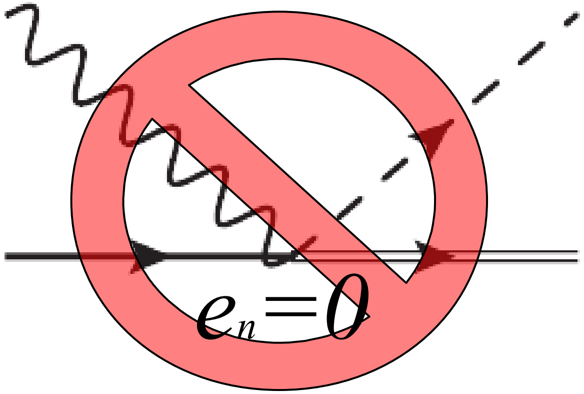
Simple but important consequences of contact-term dominance

Contact-term dominance, caused by current conservation, crossing symmetry and form factor on-shell condition, results in

Proton target



Neutron target

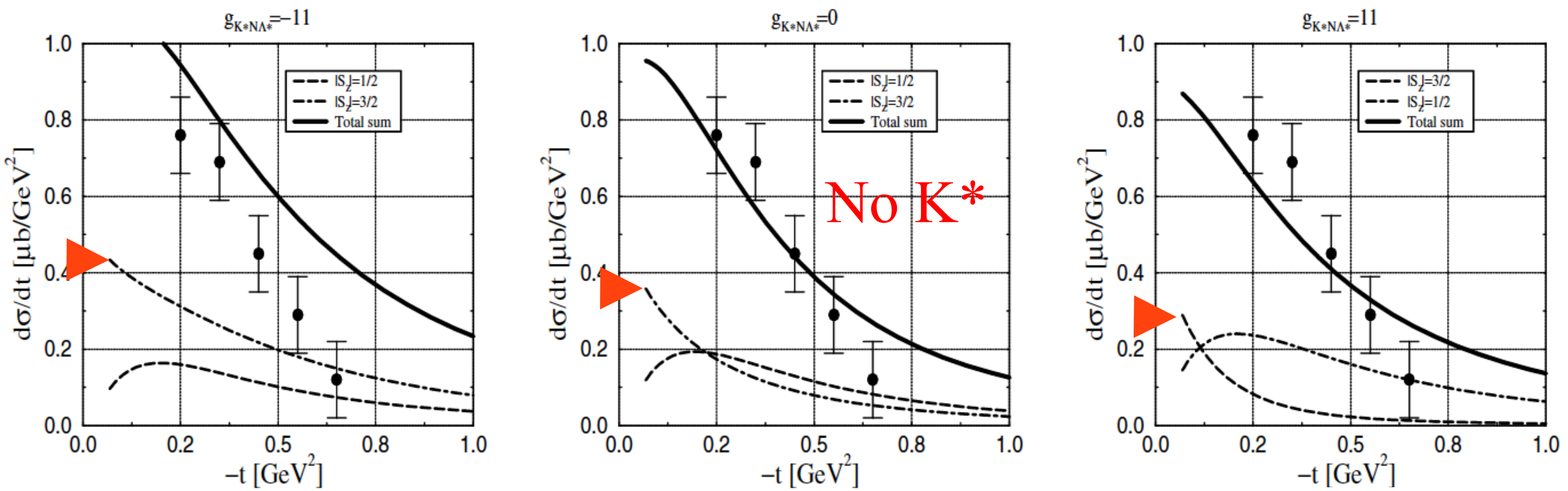


Possible large target asymmetry: $\sigma_{proton} >> \sigma_{neutron}$

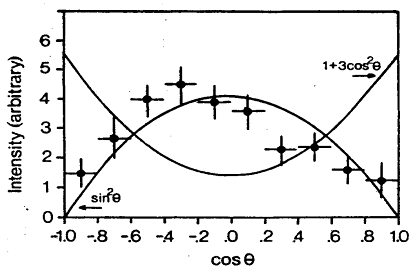
Theoretically, we observe $\sigma_{proton} / \sigma_{neutron} \sim 20$

Simple but important consequences of contact-term dominance

Each contribution from Λ(1520) in |Sz|=3/2 and |Sz|=1/2



▶ for |Sz|=3/2 contribution from K* and/or contact term



Even without K*, contact term reproduces the data

Experimental evidence "|Sz|=3/2" dominance may not support K* dominance

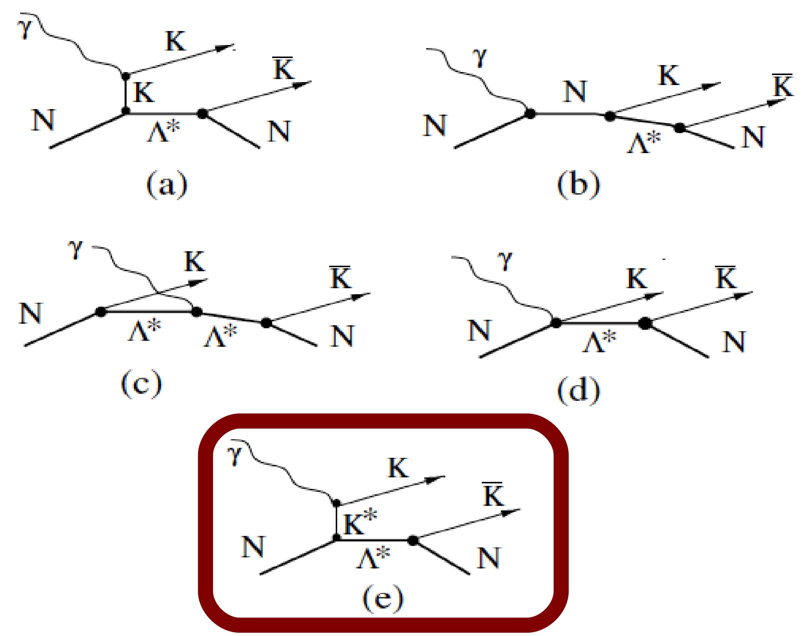
A "contradictory" theoretical work after ours (2005)

Phys. Rev. C 72, 035206 (2005) [16 pages]

Coherent Θ^+ and Λ(1520) photoproduction off the deuteron

Abstract | References | Citing Articles (12)

A. I. Titov[1,2,*], B. Kämpfer[1,3], S. Daté[4], and Y. Ohashi[4]
[1]Forschungszentrum Rossendorf, D-01314 Dresden, Germany
[2]Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna R-141980, Russia
[3]Institut für Theoretische Physik, TU Dresden, D-01062 Dresden, Germany
[4]Japan Synchrotron Radiation Research Institute, SPring-8, 1-1-1 Kouto Mikazuki-cho Sayo-gun Hyog



It was suggested that K*-exchange dominates the process

This theoretical suggest leads to
i) No (negligible) target asymmetry
ii) Large K*NΛ coupling

Experimental and theoretical studies on Λ(1520): 2006

It was rather (un)officially said by LEPS collaboration (Japan) from 2006:

"Neutron target data looks much smaller than proton (preliminary)"

A theoretical estimation for $K^*N\Lambda$ coupling using a chiral unitary model

Phys. Rev. C 73, 035209 (2006) [8 pages]

Coupling of $\bar{K}^*N$ to the Λ(1520)

Abstract | References | Citing Articles (10)

Download: PDF (174 kB) Export: BibTeX or EndNote (RIS)

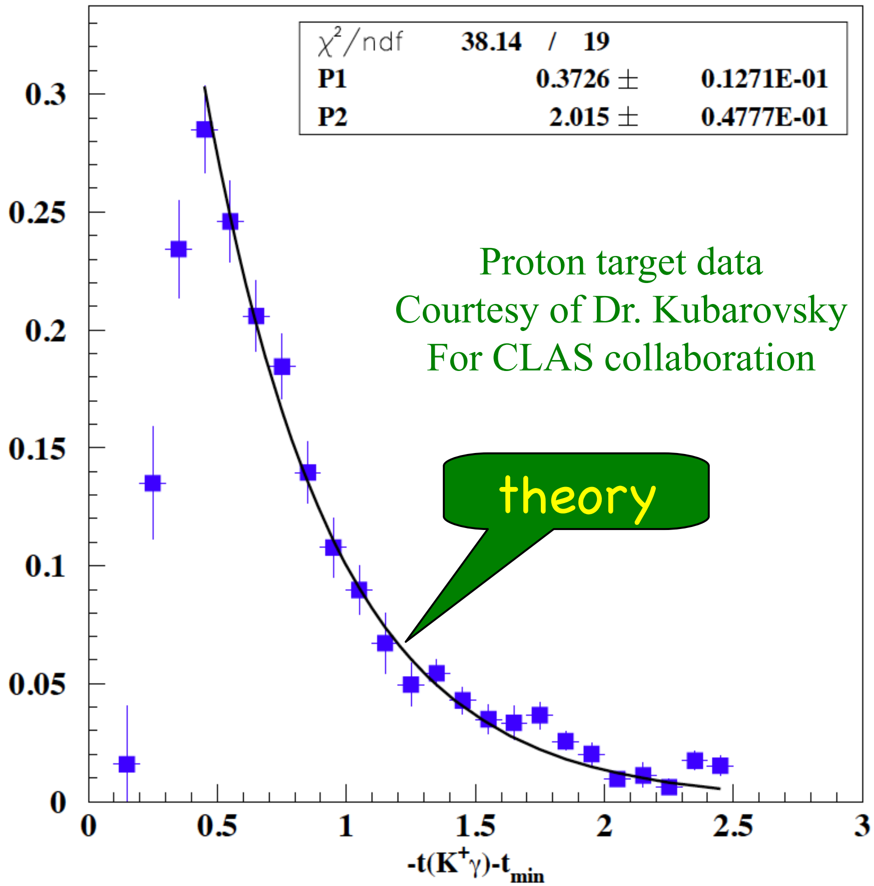
T. Hyodo[1,*], Sourav Sarkar[2,†], A. Hosaka[1], and E. Oset[2]
[1]Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan
[2]Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain

$$\left|g_{\Lambda^* \bar{K}^* N}\right| \sim 1.5$$

which is ~ 10 times smaller than $KN\Lambda$: No significance of K^*-exchange

Experimental and theoretical studies on Λ(1520): 2007~2008

Several private communications for 2007-2008 with
LEPS at SPring-8 (Japan) and CLAS at Jefferson laboratory (USA)



Contact-term dominance prevails?

Needs more exp. Data: Neutron!

Neutron (deuteron) data under analysis by LEPS collaboration (2008 ~ 2009)

Experimental and theoretical studies on Λ(1520): 2008

A new theoretical work vindicates the contact-term dominance

Phys. Rev. D 77, 034001 (2008) [12 pages]

Photon induced Λ(1520) production and the role of the K^* exchange

Abstract | References | Citing Articles (18)

Download: PDF (445 kB) Export: BibTeX or EndNote (RIS)

Hiroshi Toki[1,2], Carmen García-Recio[1], and Juan Nieves[1]
[1]*Departamento de Física Atómica, Molecular y Nuclear, Universidad de Granada, E-18071, Spain*
[2]*Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*

Using the quark-gluon string model employed for $K^*N\Lambda$ coupling

Again, it was observed that $K^*N\Lambda / KN\Lambda \sim 0.1$

Experimental data for neutron (deuteron) target becomes more urgent!!!!

Experimental and theoretical studies on Λ(1520): 2009

Finally, we have the experimental data in 2009, and it reveals...

Phys. Rev. Lett. 103, 012001 (2009) [5 pages]

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Received 12 April 2009; published 1 July 2009

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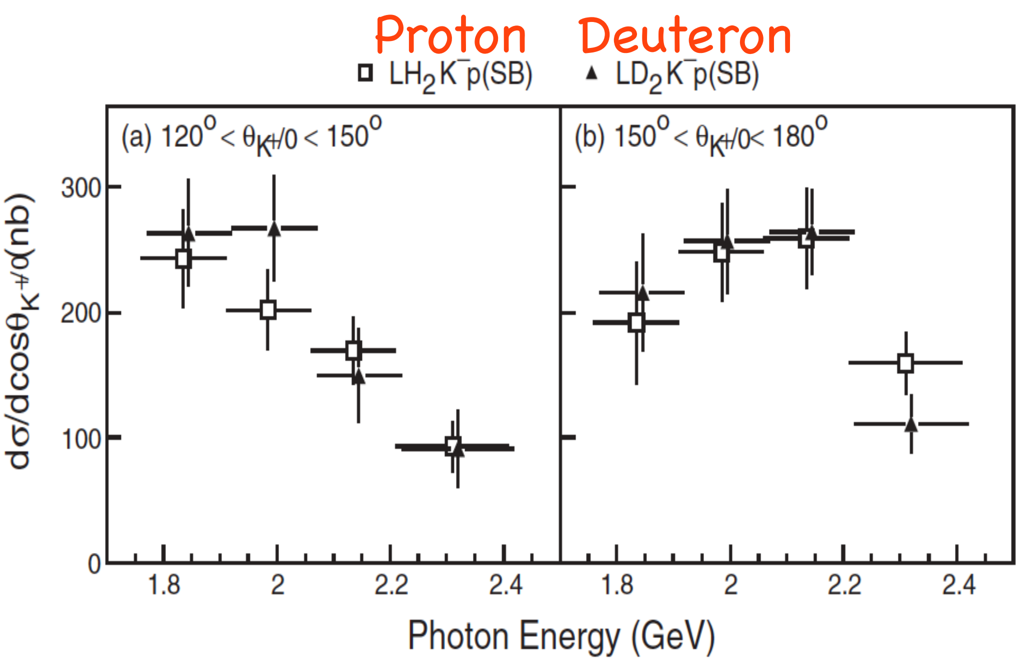


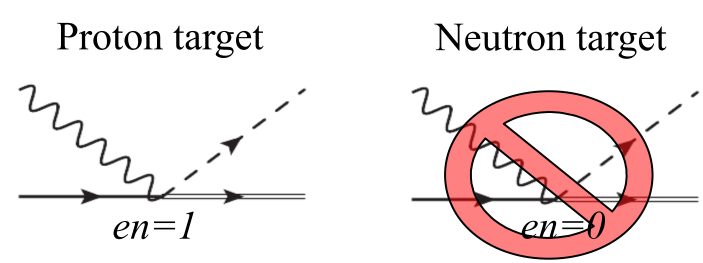
By a simple (flavor symmetric) Consideration: $\sigma_p + \sigma_n \sim \sigma_d$,

But data shows $\sigma_p \sim \sigma_d$!!!

Hence, we conclude $\sigma_p >> \sigma_n$

Experimental evidence for the proton-neutron target asymmetry!!

Experimental support for contact-term dominance



Present status and Next step

Successful theoretical studies for the hadron photoproductions for low E

In collaboration with B.G.Yu, C.W.Kao, A.Hosaka, and H.-Ch.Kim.

Experimental supports for our theoretical framework

Experimental upgrades (LEPS2 & CLAS12) call for modification of theory

Motivations

High E photoproduction needs inclusion of Regge trajectory (well studied)

T. Regge, Nuovo Cim. **14**, 951 (1959).
M. Vanderhaeghen, M. Guidal and J. M. Laget, Phys. Rev. C **57**, 1454 (1998)

Low-E and high-E physics must be continuous!!

Idea: smooth interpolation of the energy regions with and without Regge

Low-E	High-E

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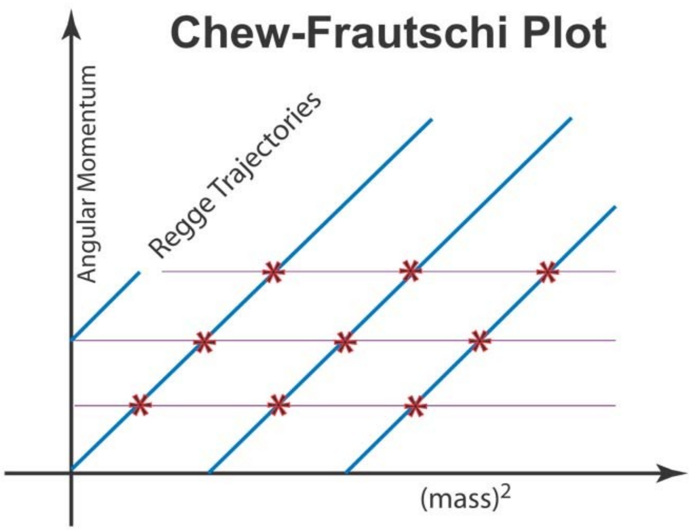
Mesonic Regge trajectories



Mesons, exchanged in t-channel, in terms of M^2 and J

Phenomenological treatment of Meson exchanges at high energy

$s \to \infty$ and $(|t|, u) \to 0$

t-channel Feynman propagators, replaced by Regge ones

Smooth interpolation of Feynman and Regge at some energy point?

$$\frac{1}{t - M_K^2} \to \mathcal{D}_K = \left(\frac{s}{s_0}\right)^{\alpha_K} \frac{\pi \alpha'_K}{\Gamma(1 + \alpha_K)\sin(\pi\alpha_K)},$$

$$\frac{1}{t - M_{K^*}^2} \to \mathcal{D}_{K^*} = \left(\frac{s}{s_0}\right)^{\alpha_{K^*} - 1} \frac{\pi \alpha'_K}{\Gamma(\alpha_K)\sin(\pi\alpha_K)}.$$

$$\alpha_K = 0.70\,\mathrm{GeV}^{-2}(t - M_K^2),$$

$$\alpha_{K^*} = 1 + 0.85\,\mathrm{GeV}^{-2}(t - M_{K^*}^2).$$

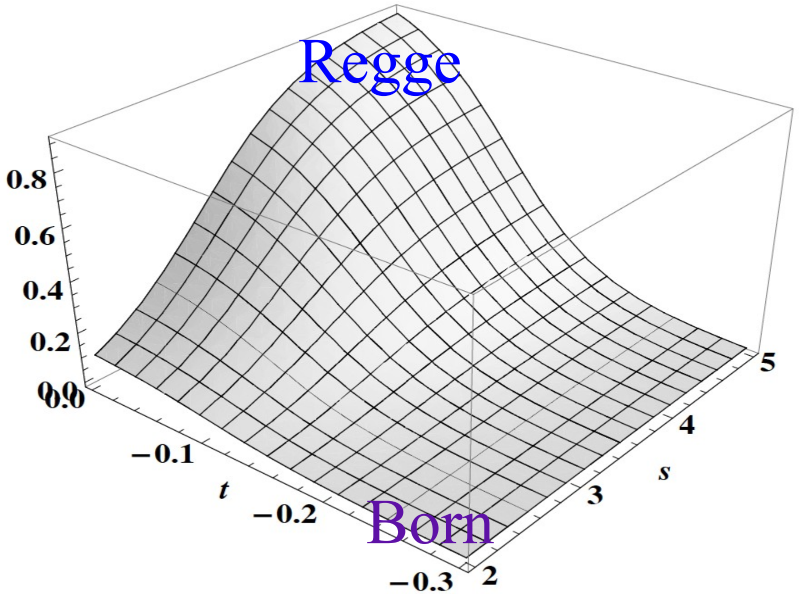
Interpolation of Regge and Feynman propagators

Phenomenological interpolation ansatz introduced

$$F_{c,v} \to \bar{F}_{c,v} \equiv \left[(t - M^2_{K,K^*})\mathcal{D}_{K,K^*}\right]\mathcal{R} + F_{c,v}(1-\mathcal{R}), \quad \mathcal{R} = \mathcal{R}_s\mathcal{R}_t,$$

High-E : Regge propagator   Low-E : Regge propagator

$$\mathcal{R}_s = \frac{1}{2}\left[1+\tanh\left(\frac{s-s_{\mathrm{Regge}}}{s_0}\right)\right], \quad \mathcal{R}_t = 1-\frac{1}{2}\left[1+\tanh\left(\frac{|t|-t_{\mathrm{Regge}}}{t_0}\right)\right]$$



s → ∞ and (|t|,u) → 0

Relevant parameters are determined by matching with data

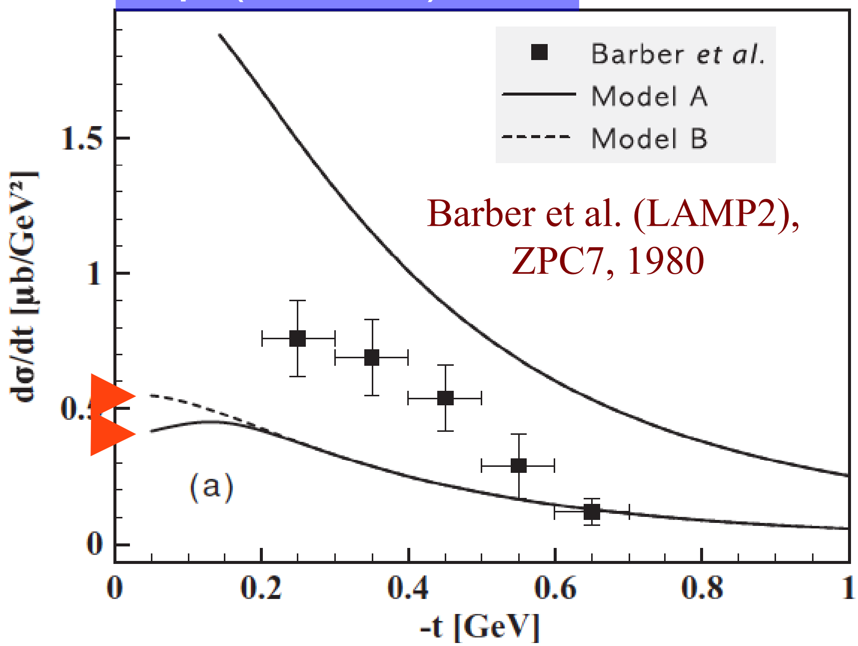
Caution: No firm theoretical ground for the ansatz structure!!

Experimental and theoretical studies on Λ(1520): 2010

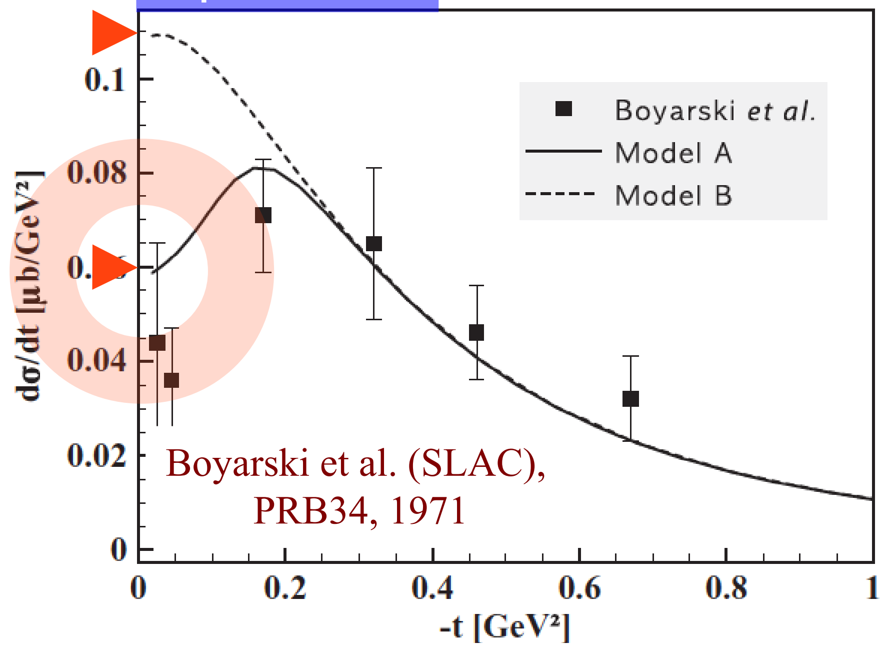
Unpolarized results for Λ(1520)

SiN, C.W.Kao, PRC81,2010

Eγ=(2.4~4.8)GeV



Eγ=11GeV



Model A with Born-Regge interpolation and Model B with simple Born

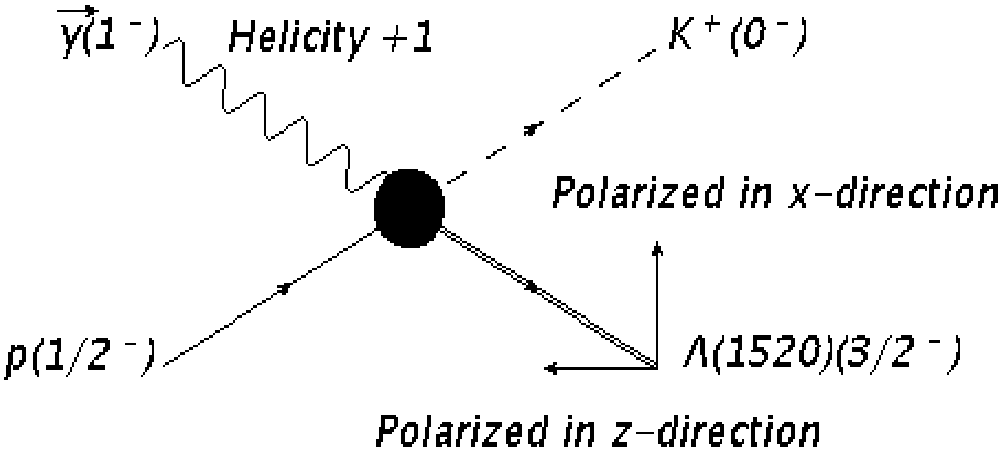
Interpolation becomes effective for higher E: Regge prevails

Double polarization for Λ(1520)

SiN, C.W.Kao, PRC81,2010

$$C_{x',|S_{x'}|} = \frac{\frac{d\sigma}{d\Omega}_{r,0,+S_{x'}} - \frac{d\sigma}{d\Omega}_{r,0,-S_{x'}}}{\frac{d\sigma}{d\Omega}_{r,0,+S_{x'}} + \frac{d\sigma}{d\Omega}_{r,0,-S_{x'}}},$$

$$C_{z',|S_{z'}|} = \frac{\frac{d\sigma}{d\Omega}_{r,0,+S_{z'}} - \frac{d\sigma}{d\Omega}_{r,0,-S_{z'}}}{\frac{d\sigma}{d\Omega}_{r,0,+S_{z'}} + \frac{d\sigma}{d\Omega}_{r,0,-S_{z'}}},$$

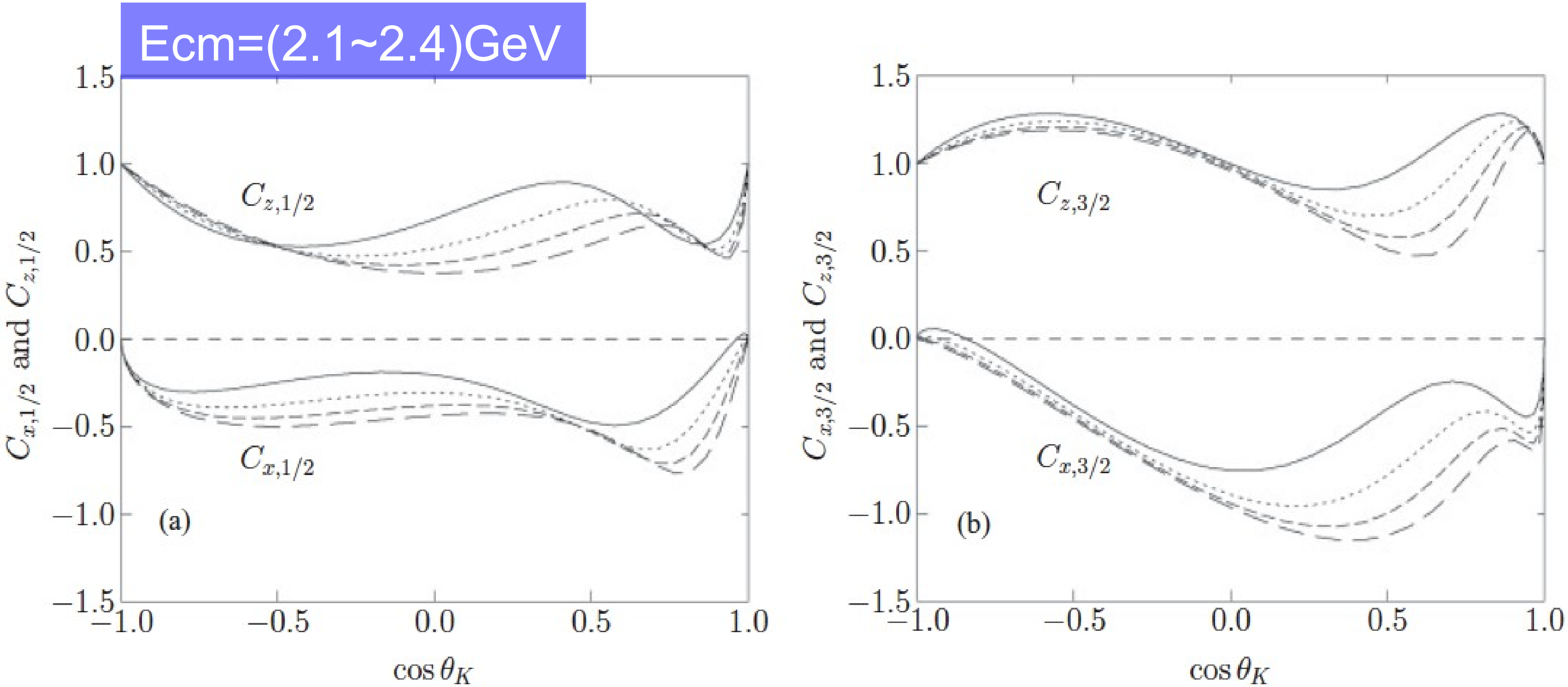


Polarization-transfer coefficients, Cx and Cz

Photon helicity transferred into possible Lambda(1520) spin states

Polarized results for Λ(1520)

SiN, C.W.Kao, PRC81,2010

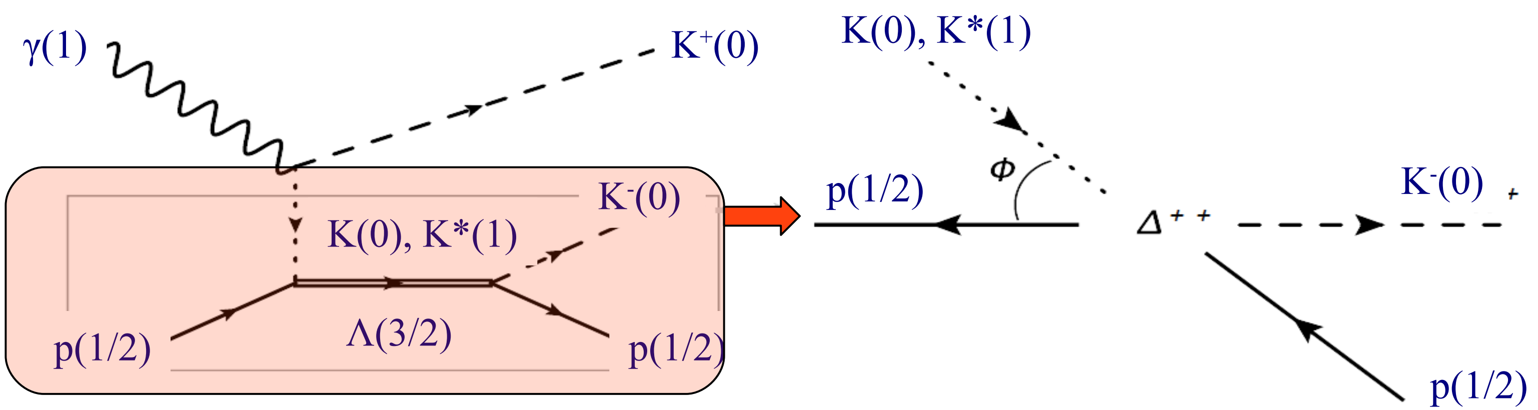


Satisfying the collinear conditions

CLAS and LEPS will do this?: looks difficult (K.Hicks for CLAS)

Deeply related to the K^--decay angle distribution: spin states of Λ(1520)

K⁻ decay-angle distribution for Λ(1520)



$$\mathcal{F}_{K^-} = A\sin^2\theta_{K^-} + B\left(\tfrac{1}{3} + \cos^2\theta_{K^-}\right)$$ Muramatsu et al. (LEPS), PRL103, 2009

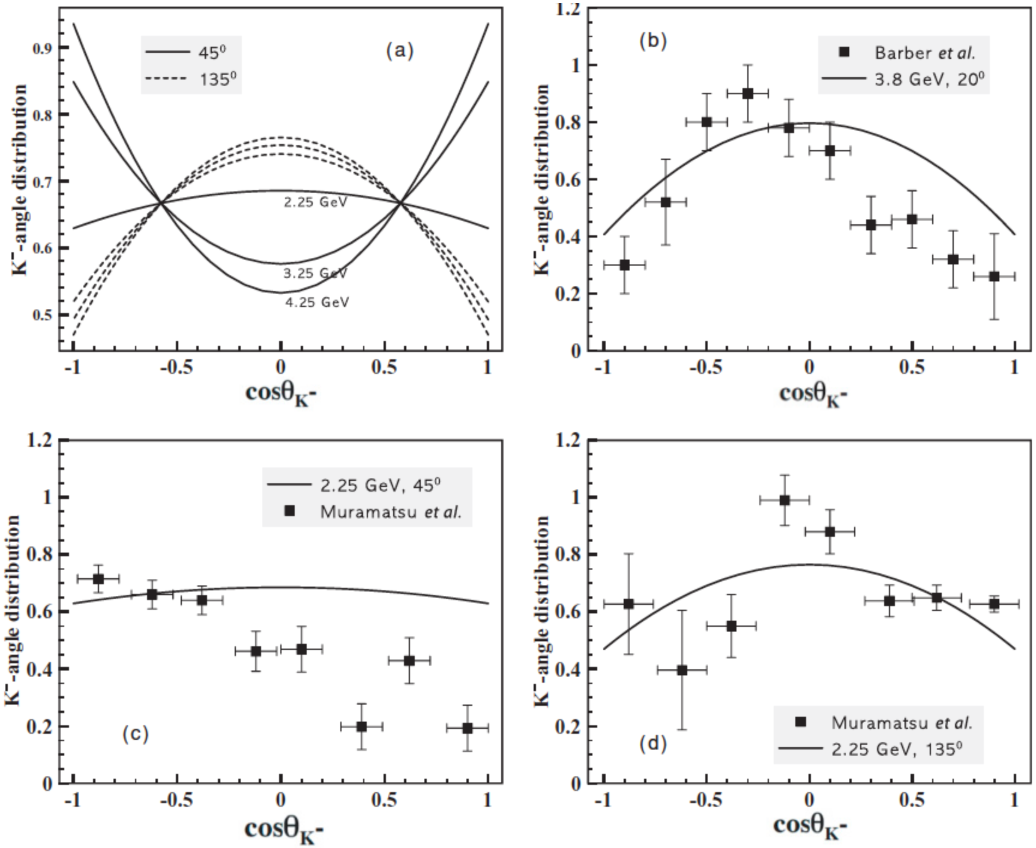
If Lambda in 3/2, (A,B)=(1,0). Otherwise, (A,B)=(0,1): Spin statistics

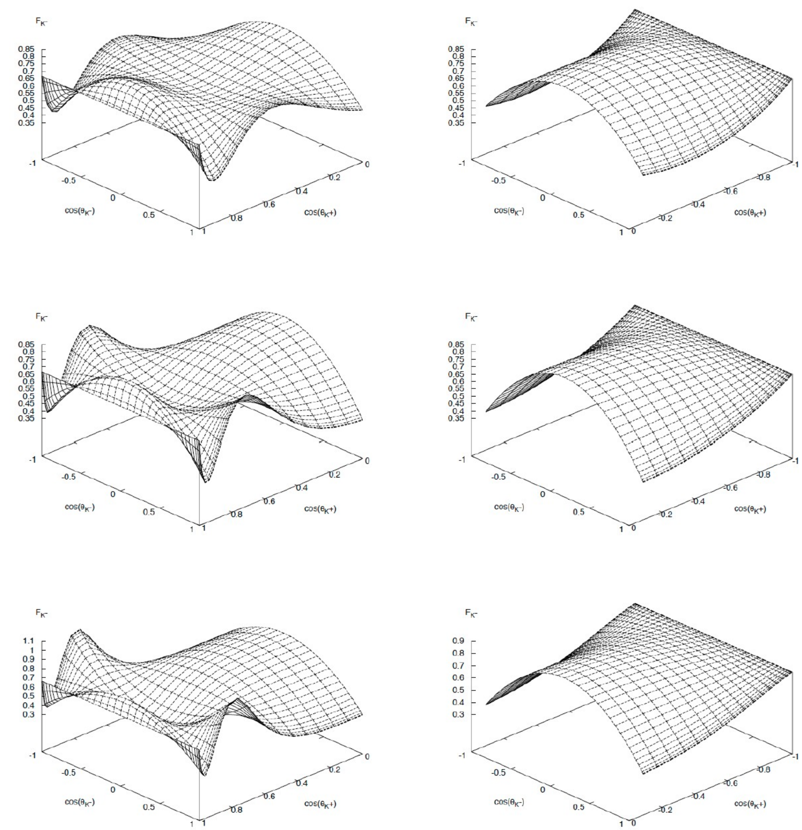
Idea: $$A = \frac{C_{z,3/2}}{C_{z,1/2}+C_{z,3/2}}, \quad B = \frac{C_{z,1/2}}{C_{z,1/2}+C_{z,3/2}}$$ SiN, C.W.Kao, PRC81,2010

By seeing this, one can tell which contribution is important

Experimental and theoretical studies on Λ(1520): 2010

Decay-angle distribution without K*





Forward

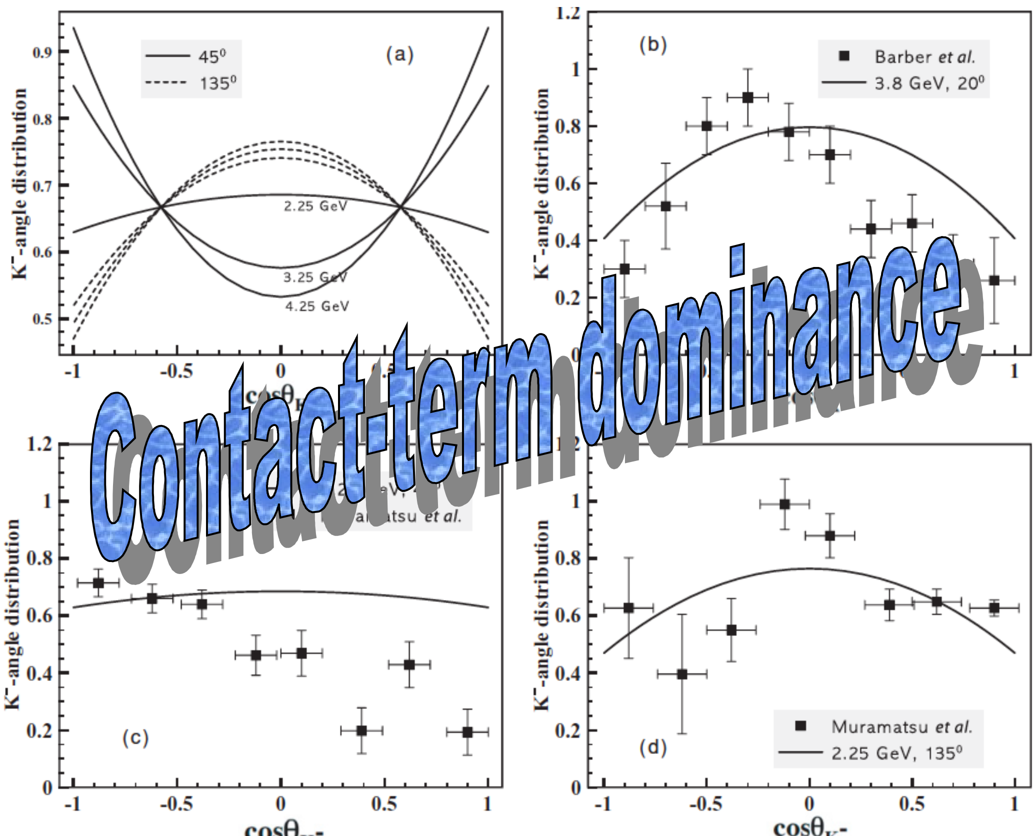
Backward

Experimental data reproduced qualitatively well

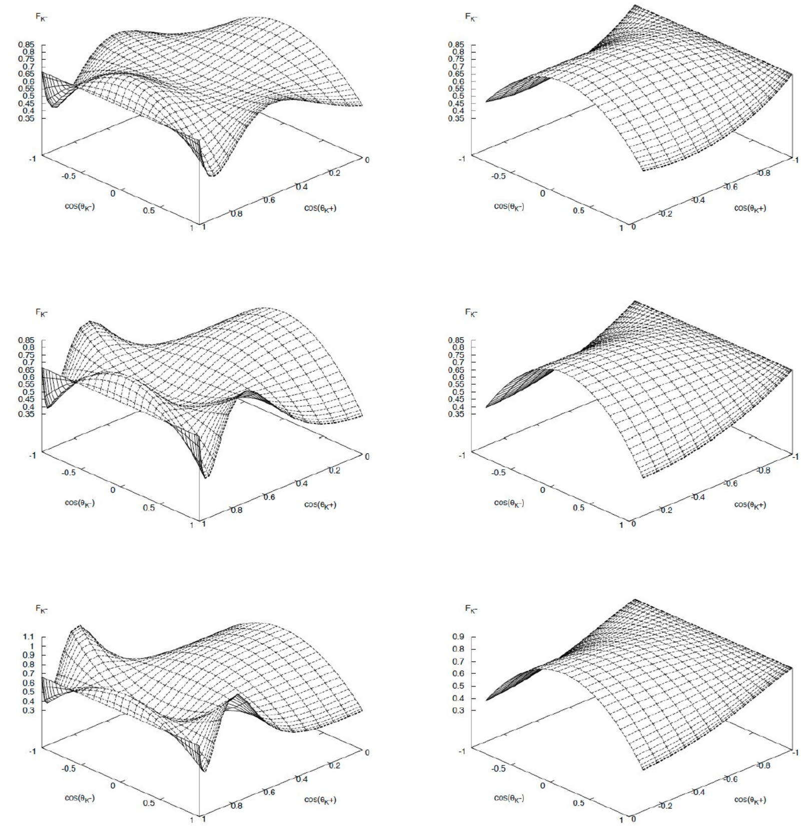
New CLAS data in progress (in private communication with Dr. Z.W.Zhao for CLAS)

Experimental and theoretical studies on Λ(1520): 2010

Decay-angle distribution without K*



Contact-term dominance



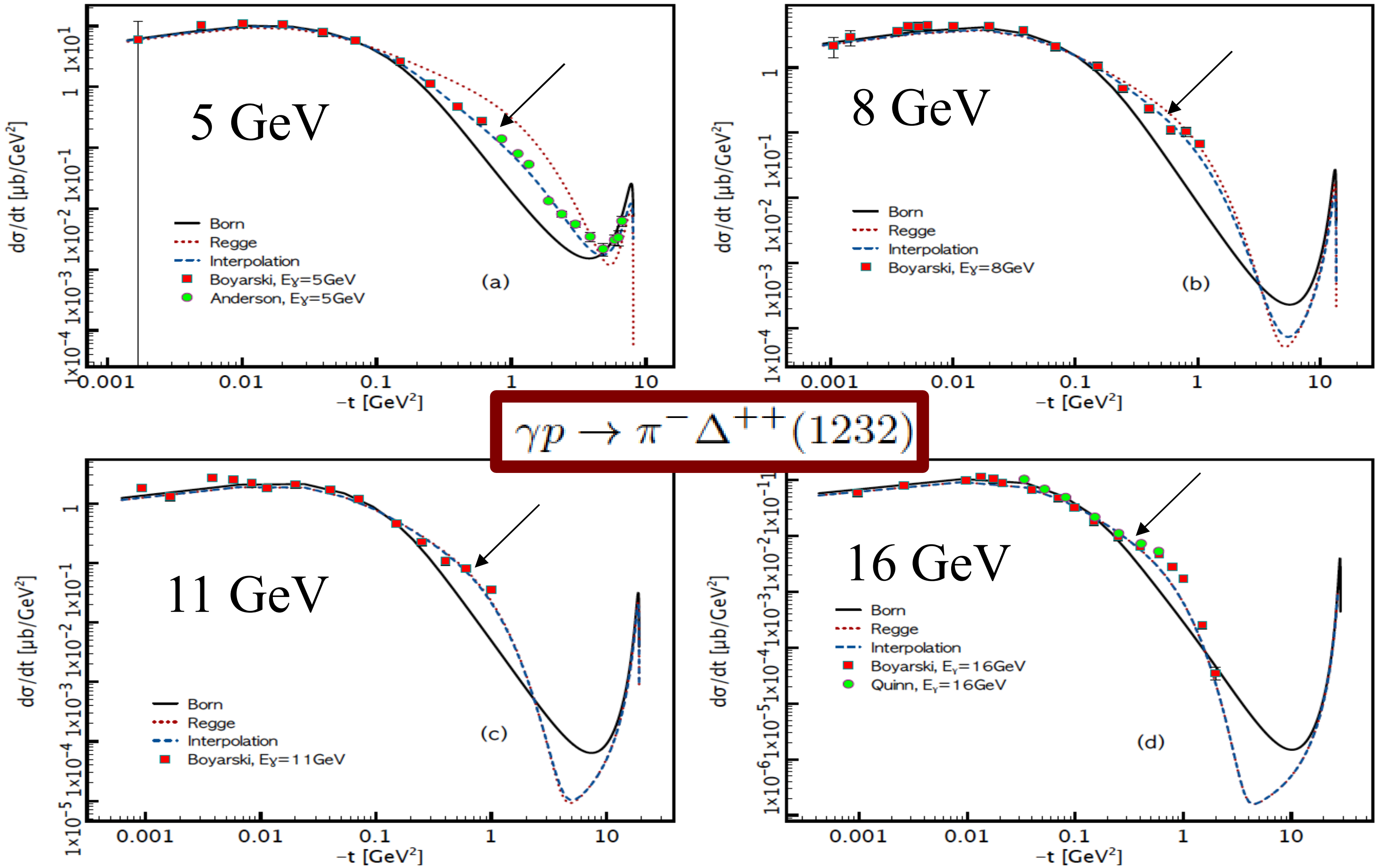
Forward Backward

Experimental data reproduced qualitatively well

New CLAS data in progress (in private communication with Dr. Z.W.Zhao for CLAS)

Same Regge-Born interpolation prescription for Δ photoproduction

SiN, B.G.Yu, PRC84, 025203 (2011)



Summary and Conclusion

Λ(1520) photoproduction investigated via effective Lagrangian method

Contact-term dominance was proposed due to current conservation

Resulting in target asymmetry: $\sigma_{proton} \gg \sigma_{neutron}$

Experimental and theoretical results support contact-term dominance

Based on this, we suggested Regge-Born interpolation prescription

This approach enables us to study low and high E regions simultaneously

K^- decay angle distribution estimated by polarization transfer coefficients reveals again the contact-term dominance (K^*=0)

Problems and Future perspectives

Problems

Present theoretical framework needs more contributions:
nucleon and hyperon resonances, final-state interaction, higher orders, etc

Backward scattering analyses are not enough

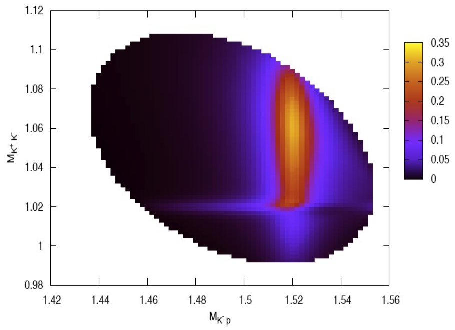
No firm theoretical ground for the Regge-Born interpolating prescription

Future perspectives

Photoproduction with three-body final state, simulating experiments

$\Lambda(1520)$ electroproduction: under progress

Theoretical investigation for Regge-Born interpolation



Finally...