RECENT PROGRESS IN KAON PHOTOPRODUCTION OFF THE NUCLEON

Terry Mart

Departemen Fisika FMIPA, Universitas Indonesia, Depok 16424, Indonesia
and
Indonesian Academy of Sciences, Jakarta 10110, Indonesia

APCTP Focus Program in Nuclear Physics 2019

Nuclear Many-Body Theories: Beyond the mean field approaches
APCTP Headquarters, Pohang, July 1st - 10th, 2019

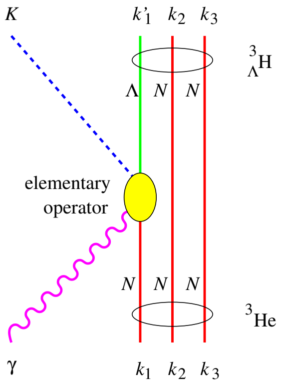
Contents

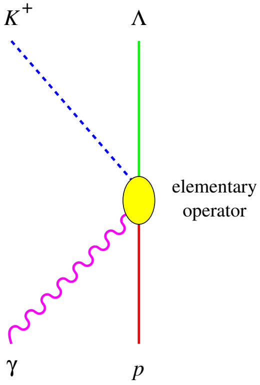
Motivation

$K\Lambda$ Photoproduction $\longrightarrow$ $\gamma + p \rightarrow K^+ + \Lambda$

1. Elementary operator $\rightarrow$ isobar model
2. Study the nucleon, kaon, hyperon resonances
3. Production on deuteron $\rightarrow$ N-N interactions
4. Production of hypernuclei $\rightarrow$ Λ-N interactions
5. Study strong coupling constants, isospin symmetry, strangeness process
6. Gerasimov-Drell-Hearn sum rule
7. etc

Example of the Hypertriton (ΛNN) Photoproduction





$\gamma + {}^3\mathrm{He} \rightarrow K^+ + {}^3_\Lambda\mathrm{H}$

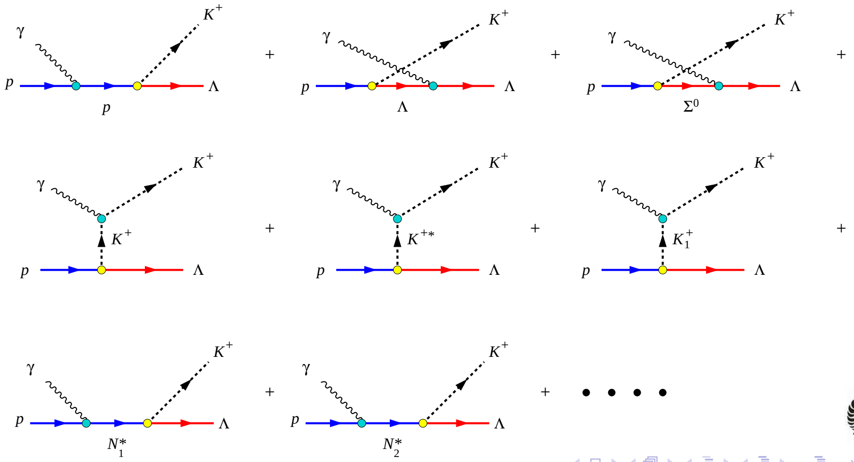
on Helium-3

$\gamma + p \rightarrow K^+ + \Lambda$

elementary operator
(on the nucleon)

The Isobar Model

For the $\gamma p \rightarrow K^+\Lambda$ we can draw the simplest Feynman diagrams for the *s*-, *u*-, and *t*-channel as follows:



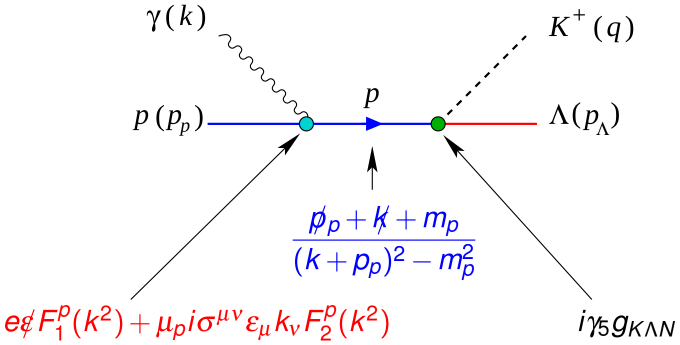
The Isobar Model

In the intermediate states we have:

- p and N^*
- Λ and Σ^0
- K and K^*

Problem: How to translate these diagrams?

Example, s-channel



by collecting all terms we obtain:

$$\mathscr{M}^p = \bar{u}_\Lambda\, i\gamma_5 g_{K\Lambda N} \left\{ \frac{\not{p}_p + \not{k} + m_p}{(k+p_p)^2 - m_p^2} \left(e\not{\epsilon}\, F_1^p + \mu_p i\sigma^{\mu\nu}\varepsilon_\mu k_\nu F_2^p \right) - e\frac{k\cdot\varepsilon}{k^2} F_1^p \right\} u_p$$

...and decompose it to

$$
\begin{aligned}
\mathscr{M}^p = \bar{u}_\Lambda \frac{i\gamma_5 g_{K\Lambda N}}{s-m_p^2} \Bigg[& \tfrac{1}{2}\gamma_5 \left(\not{\epsilon}\not{k} - \not{k}\not{\epsilon}\right)\left(-F_1^p - \kappa_p \frac{m_p - m_\Lambda}{2m_p} F_2^p\right) \\
& + \gamma_5 \left[(2q_K - k)\cdot\epsilon P\cdot k - (2q_K - k)\cdot k P\cdot\epsilon\right] \frac{2F_1^p}{t-m_K^2} \\
& + \gamma_5 \left(q_K\cdot\epsilon k^2 - q_K\cdot k k\cdot\epsilon\right)\left[-2(s-m_p^2)+k^2\right] \frac{F_1^p}{(t-m_K^2)k^2} \\
& + \left\{ i\epsilon_{\mu\nu\rho\sigma}\gamma^\mu q_K^\nu \epsilon^\rho k^\sigma + \gamma_5 \left(q_K\cdot k\not{\epsilon} - q_K\cdot\epsilon\not{k}\right)\right\} \frac{\kappa_p}{2m_p} F_2^p \Bigg] u_p \\
= \bar{u}_\Lambda & \left(\sum_{i=1}^{6} A_i^p \, M_i\right) u_p
\end{aligned}
$$

Calculate also other diagrams to obtain:

$$\mathscr{M}^{\rm tot} = \mathscr{M}^{p} + \mathscr{M}^{\Lambda} + \mathscr{M}^{\Sigma^0} + \mathscr{M}^{K} + \cdots$$
$$= \bar{u}_\Lambda \left[\sum_{i=1}^{6} \left(A_i^p + A_i^\Lambda + A_i^{\Sigma^0} + A_i^K + \cdots \right) M_i \right] u_p$$

so that we obtain

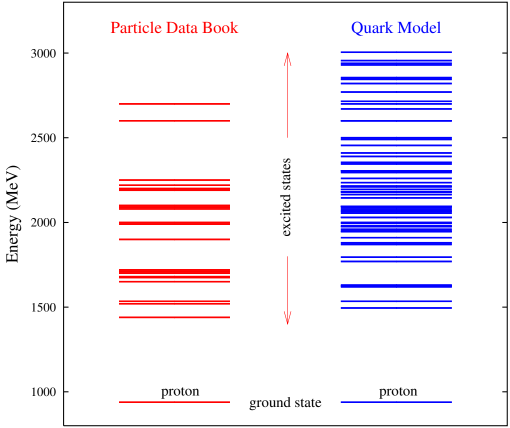
$$A_i^{\rm tot} = A_i^{p} + A_i^{\Lambda} + A_i^{\Sigma^0} + A_i^{K} + \cdots \quad , \quad i = 1, \cdots, 6$$

and we can calculate the cross section (given)

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}\left(A_i^{\rm tot}\right) \quad , \quad i = 1, \cdots, 6$$

and other polarization observables

What is missing resonance?

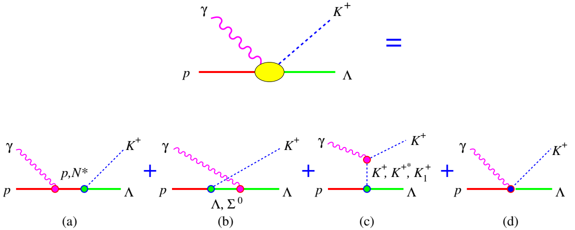


There are a number of nucleon resonances predicted by the Quark Model but are missing from the PDG list

Let's Make a Model

Collect all suitable tree-level Feynman diagrams

Born	Resonance
p K^+, K^{*+}, K^+ Λ, Σ^0	$S_{11}(1650)$ $P_{11}(1710)$ $P_{13}(1720)$ $D_{13}(1895)$



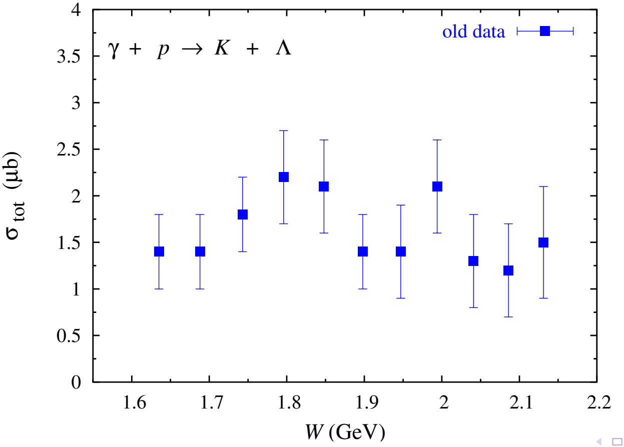
requires some information on

- hadronic coupling constants → fitted to exp. data (except Born's ones)
- number of participating resonances → some constraints
- gauge method (to preserve gauge invariance) → Haberzettl's

Missing resonance?

New 1998 SAPHIR data reveals a missing resonance $D_{13}(1895)$

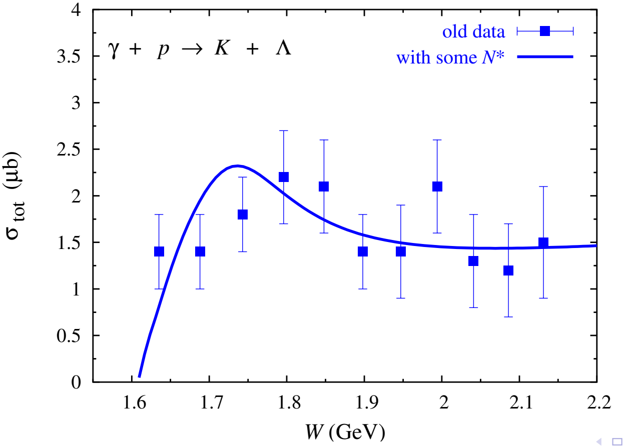
TM and C. Bennhold, Phys. Rev. C **61**, 012201(R) (2000)



Missing resonance?

New 1998 SAPHIR data reveals a missing resonance $D_{13}(1895)$

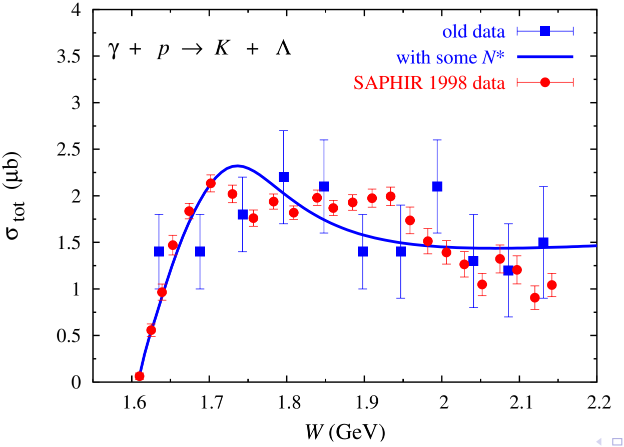
TM and C. Bennhold, Phys. Rev. C **61**, 012201(R) (2000)



Missing resonance?

New 1998 SAPHIR data reveals a missing resonance $D_{13}(1895)$

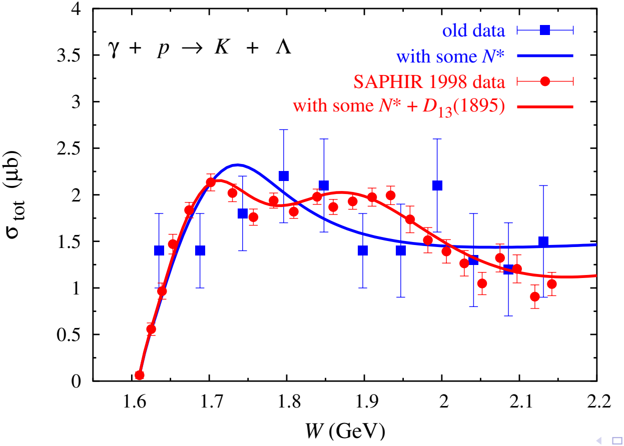
TM and C. Bennhold, Phys. Rev. C **61**, 012201(R) (2000)



Missing resonance?

New 1998 SAPHIR data reveals a missing resonance $D_{13}(1895)$

TM and C. Bennhold, Phys. Rev. C **61**, 012201(R) (2000)



Why we Believe this Missing Resonance?

Comparison between the results from our fit to the Quark Model (QM)

Missing Resonance	Model	m_{N^*} (MeV)	Γ_{N^*} (MeV)	$\sqrt{\Gamma_{N^* N\gamma}\Gamma_{N^* K\Lambda}}/\Gamma_{N^*}$ (10^{-3})
$S_{11}(1945)$	Fit	1847	258	-10.370 ± 0.875
	QM	1945	595	0.298 ± 0.349
$P_{11}(1975)$	Fit	1935	131	9.623 ± 0.789
	QM	1975	45	1.960 ± 0.535
$D_{13}(1960)$	Fit	1895	372	$2.292^{+0.722}_{-0.204}$
	QM	1960	535	-2.722 ± 0.729
$P_{13}(1950)$	Fit	1853	189	$1.097^{+0.011}_{-0.010}$
	QM	1950	140	-0.334 ± 0.070

QM = S. Capstick and W. Roberts, Phys. Rev. D **58**, 074011 (1998).

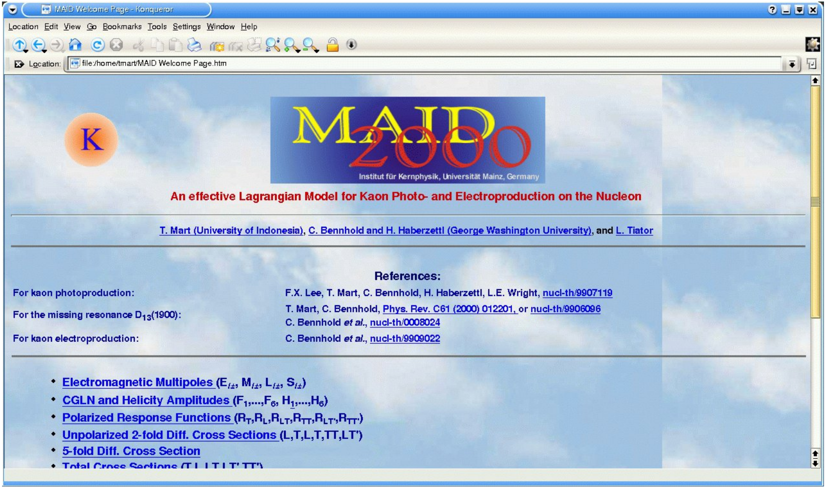
Compared with other calculations

Particle Data Book 2000 - 2012:

$N(2080)$ BREIT-WIGNER MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
≈ 2080 OUR ESTIMATE				
1804 ± 55	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1920	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
1880 ± 100	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$
2060 ± 80	[1] CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1900	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
2081 ± 20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1946 ± 1	PENNER	02C	DPWA	Multichannel
1895	MART	00	DPWA	$\gamma p \to \Lambda K^+$
2003 ± 18	VRANA	00	DPWA	Multichannel
1986 ± 75	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
1880	BAKER	79	DPWA	$\pi^- p \to n\eta$

Elementary Operator Available Online Since 2000



TM, C. Bennhold, H. Haberzettl, and L. Tiator, Kaon Maid, http://www.kph.uni-mainz.de/MAID/kaon/kaonmaid.html

Intrinsic Problems of the Isobar Model

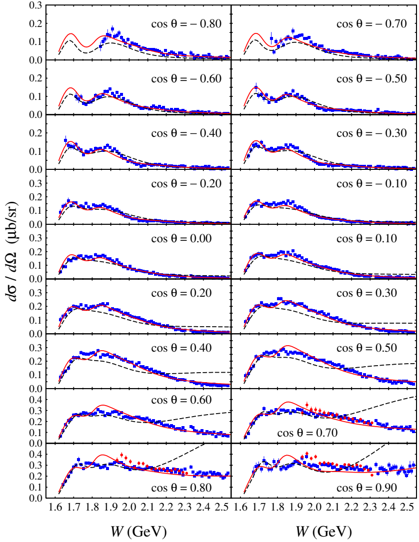
Problems

- Threshold energies are too high
- Too many nucleon, hyperon, and kaon resonances
  $\rightarrow$ complicated models
- Almost all coupling constants are hardly known
- Higher order corrections are not considered
- Strong couplings are not perturbative!
  $\rightarrow$ Bethe-Salpeter or Lippman-Schwinger equation
  $\rightarrow$ much more complicated

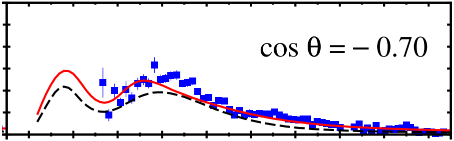
What to do?

- Limit the energy of interest!

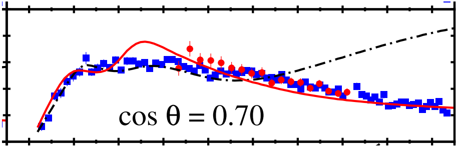
Abundant data available, if the energies were not limited...



zoom at cos $\theta = -0.70$



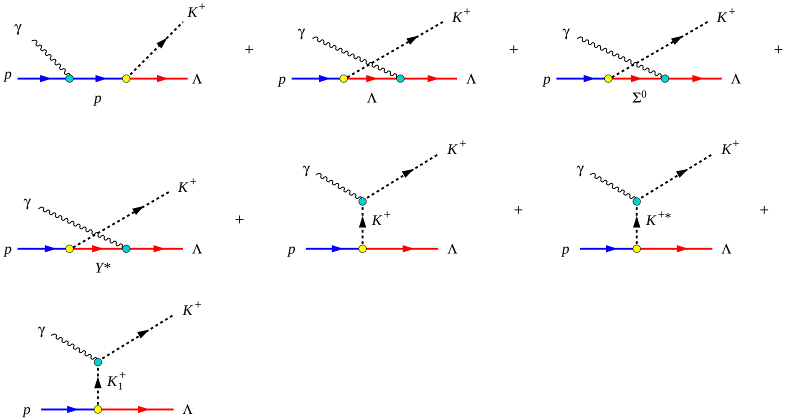
and at cos $\theta = +0.70$



- some structures are overlooked
- artificial structure appears

$K^+\Lambda$ Photoproduction Near Threshold

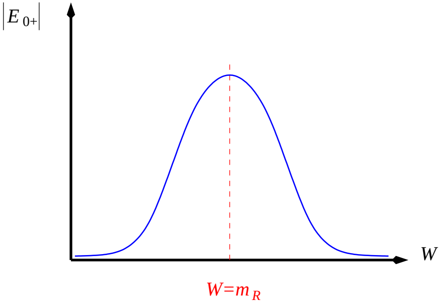
The background (non-resonance) terms are constructed from a series of Feynman diagrams as in the previous isobar model



Resonance Term?

For resonance term $S_{11}(1650)$ use multipoles amplitude (Breit-Wigner form):

$$E_{0+}(W) = \bar{E}_{0+}\, c_{K\Lambda} \frac{f_{\gamma R}(W)\,\Gamma_{\rm tot}(W)\, m_R\, f_{KR}(W)}{m_R^2 - W^2 - i m_R \Gamma_{\rm tot}(W)}\, e^{i\phi}$$

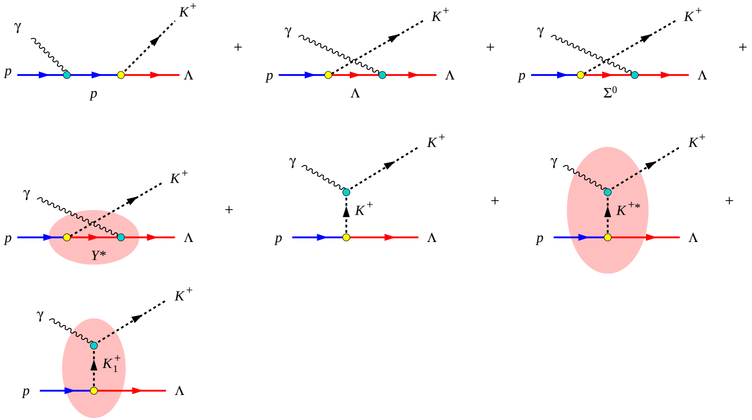


The advantage: Simple and does not generate unnecessary additional background term as in the case of the covariant calculation

see e.g. TM and A. Sulaksono, Phys. Rev. C **74**, 055203 (2006)

Coupling Constants

Except for K^*, K_1, and Y^* resonance, all coupling constants are taken from the SU(3) prediction and Particle data Book



Previous studies of kaon photoproduction at or near threshold

- S. Steininger and U. G. Meissner, Phys. Lett. B **391**, 446 (1997).
- M. K. Cheoun, B. S. Han, I. T. Cheon and B. G. Yu, Phys. Rev. C **54**, 1811 (1996).
- S. S. Hsiao, D. H. Lu, and S. N. Yang Phys. Rev. C **61**, 068201 (2000).

Fit results

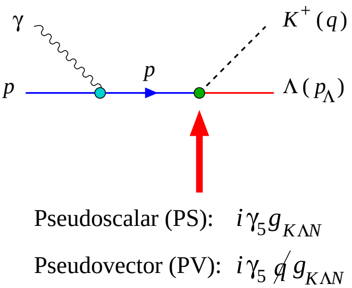
The extracted coupling constants from the present work (PS and PV) compared with those from previous analyses of Adelseck and Saghai (AS1 and AS2), Williams *et al* (WJC), and Cheoun *et al.* (CHYC).

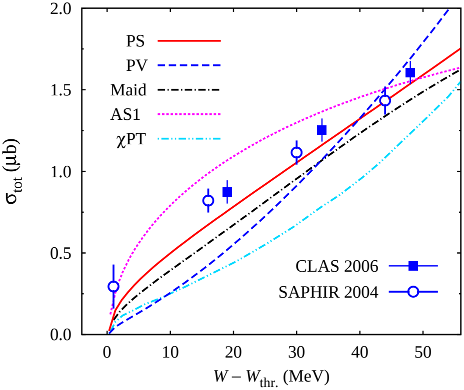
Coupl. Const.	PS	PV	AS1	AS2	WJC	CHYC
$g_{K\Lambda N}/\sqrt{4\pi}$	-3.80	-3.80	-4.17	-4.26	-2.38	varies
$g_{K\Sigma N}/\sqrt{4\pi}$	1.20	1.20	1.18	1.20	0.23	varies
$G^V_{K^*}/4\pi$	-0.65	-0.79	-0.43	-0.38	-0.16	-0.09
$G^T_{K^*}/4\pi$	0.29	-0.04	0.20	0.30	0.08	$-0.17 \sim -0.36$
$G^V_{K_1}/4\pi$	0.42	1.19	-0.10	-0.06	0.02	-0.06
$G^T_{K_1}/4\pi$	-3.17	-0.68	-1.21	-1.35	0.17	$-0.11 \sim -0.23$
$G_{Y^*_1}/\sqrt{4\pi}$	-	-	-	-2.47	-0.10	-
$G_{Y^*_2}/\sqrt{4\pi}$	-	-	-3.17	-	-	-
$G_{Y^*_3}/\sqrt{4\pi}$	-4.93	-10.00	-	-	-	-
ϕ (deg)	218	202	-	-	-	-

Comparison with experimental data

TM, Phys. Rev. C **82**, 025209 (2010)

χPT $\rightarrow$ Steininger and Meissner, Phys. Lett. B **391**, 446 (1997).



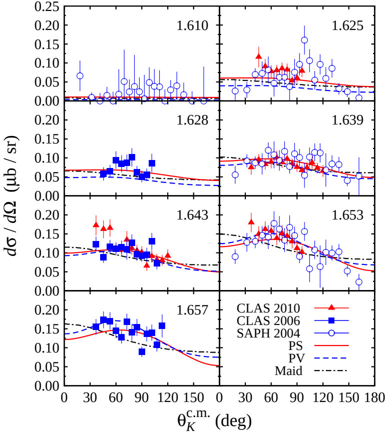


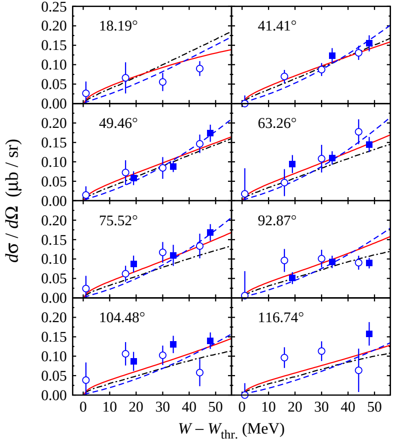
Comparing two theories (PS & PV) with other previous models

PS model can explain better

Comparison with experimental data

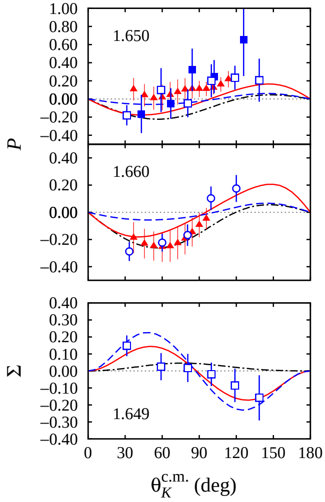
Differential cross section [TM, Phys. Rev. C **82**, 025209 (2010)]



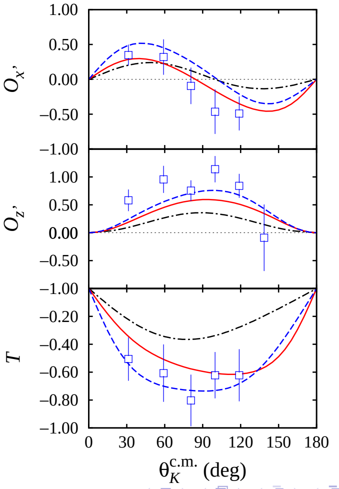


Comparison with experimental data

Polarization observables



Pure prediction!



$K^0\Lambda$ Photoproduction Near Threshold

The results obtained in the $K^+\Lambda$ photoproduction can be used to predict the $\gamma + n \rightarrow K^0 + \Lambda$ process

- Use SU(3) symmetry to relate the coupling constants in the two channels

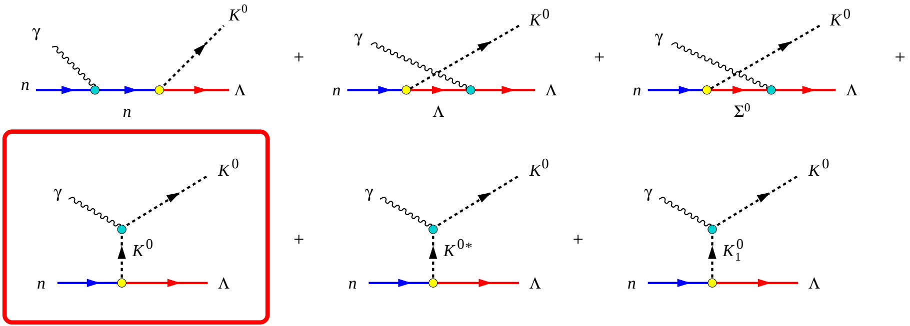
$$g_{K^+\Lambda p} = g_{K^0\Lambda n}, \quad g_{K^+\Sigma^0 p} = -g_{K^0\Sigma^0 n}, \quad g^{V,T}_{K^{*+}\Lambda p} = g^{V,T}_{K^{*0}\Lambda n}$$

- Use information from Particle Data Book and previous works (Kaon-Maid, Pion-Maid, etc)

$$g_{K^{*0}K^0\gamma}/g_{K^{*+}K^+\gamma} = -1.53 \pm 0.20\ , \quad g_{K_1^0 K^0\gamma}/g_{K_1^+ K^+\gamma} = -0.45$$

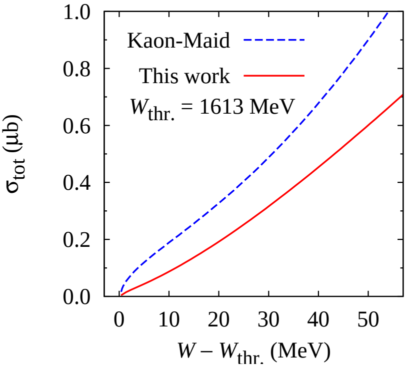
$$A^n_{1/2} = -0.015 \pm 0.021\ \mathrm{GeV}^{-1/2}$$

No t-Channel K^0 Intermediate State in Photoproduction



Not allowed except for virtual photons

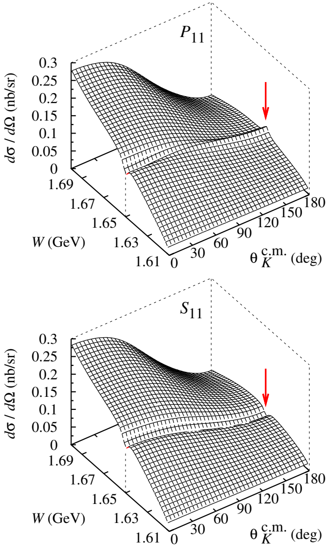
Result, predicted total cross section



- Significantly smaller than Kaon-Maid prediction
- May affect the predictions made based on Kaon-Maid
- Needs experimental confirmation
  - $\gamma + d \to K^0 + \Lambda + p$
  - $\gamma + d \to K^0 + \Sigma^0 + p$

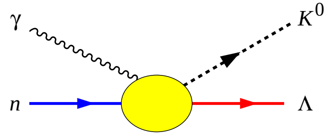
TM, Phys. Rev. C **83**, 048203 (2011)

Result, predicted differential cross section

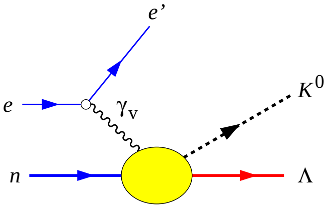


- This work yields smaller cross section
- Forward vs backward peaking behaviors
- Kaon-Maid displays certain structure → effect of the $P_{13}(1720)$ resonance, not available in the present work
- Experimental confirmation required

Extending to Electroproduction



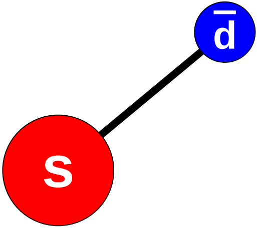
PHOTOPRODUCTION



ELECTROPRODUCTION

- Photon mass squared
  $$Q^2 : \begin{cases} \text{Photoproduction} & = 0 \\ \text{Electroproduction} & \neq 0 \end{cases}$$
- photoproduction: $\sigma_{\rm T}, \sigma_{\rm TT}$
- additional longitudinal terms for electroproduction: $\sigma_{\rm L}, \sigma_{\rm LT}$

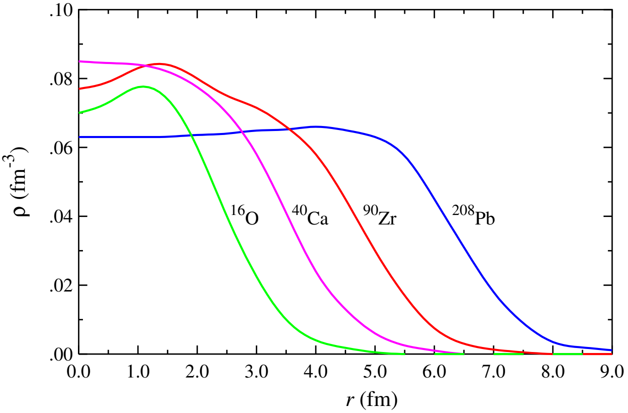
K^0 Form Factor



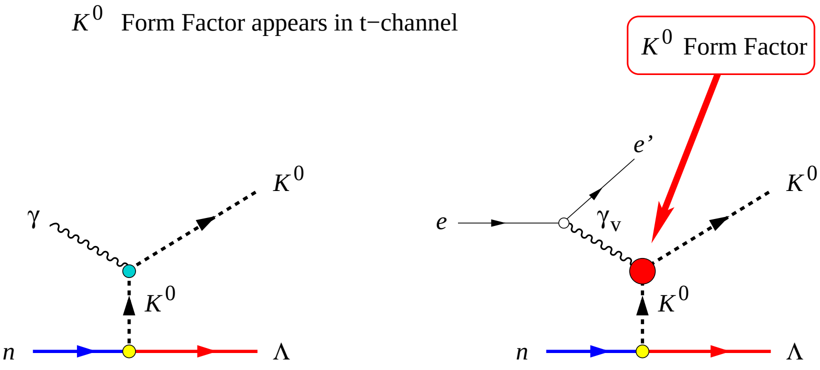
- The difference between strange and non-strange quark masses creates a non-uniform charge distribution in the K^0 $\rightarrow$ electromagnetic/charge form factor
- Different models of the K^0 charge form factor
  - Quark Meson Vertex (QMV)
  - Light Cone Quark (LCQ)
  - Vector Meson Dominance (VMD)
  - Chiral Perturbation Theory
  - etc
- Can we find a sensitive process to this form factor?
  - If yes, what observable and what kinematics?

Form factor corresponds to the density

e.g. Nuclear density



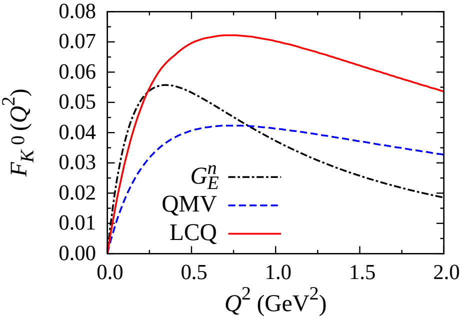
Where does the K^0 Form Factor appears?



Not allowed in the case of the real photons (photoproduction)

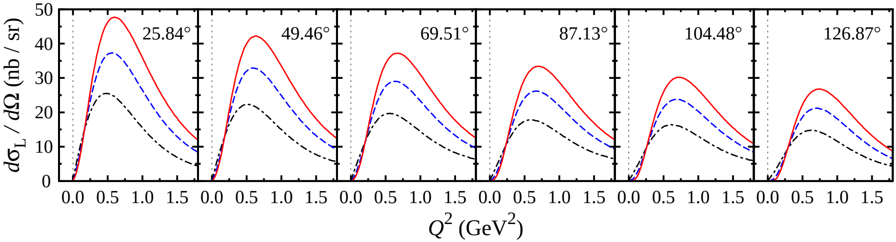
Electroproduction

Comparison between different K^0 form factor models



- QMV & LCQ models compared to the neutron charge form factor $G_E^n(Q^2)$
- the two neutral kaon form factors fall off slower than the neutron one

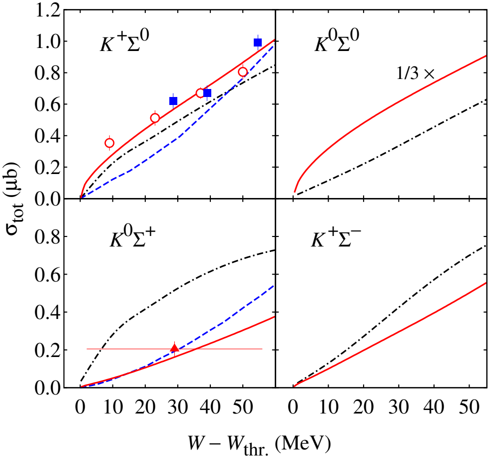
Solid line: LCQ, dashed line: QMV, dash-dotted line: without K^0 pole



- the longitudinal cross section is sensitive to the K^0 charge form factor, in contrast to the transverse one
- at forward angles LCQ form factor raises cross section up to 50%
- Open the possibility of investigating the K^0 form factor experimentally

TM, Phys. Rev. C **83**, 048203 (2011)

$K\Sigma$ channels have been also investigated

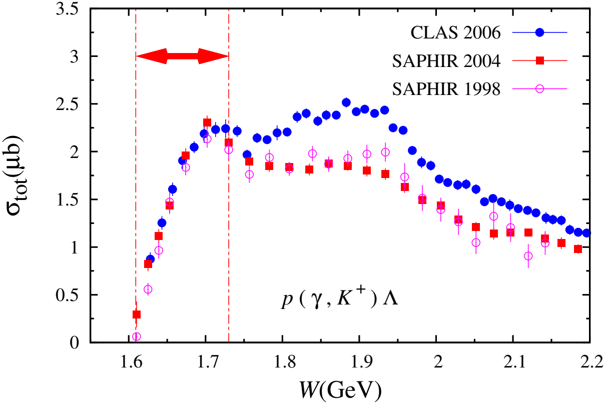


TM, Phys. Rev. C **90**, 065202 (2014)

- Cross section of $K^0\Sigma^0$ channels is 3× larger
- Direct consequence of the isospin symmetry:
  $g_{K^+\Sigma^0 p} = -g_{K^0\Sigma^0 n}$
  $g_{K^+\Sigma^0 p} = g_{K^0\Sigma^+ p}/\sqrt{2}$
  $g_{K^+\Sigma^0 p} = g_{K^+\Sigma^- n}/\sqrt{2}$
- No suppression from nucleon resonances

Extension to $W = 1730$ MeV

Avoid the problem of data discrepancy



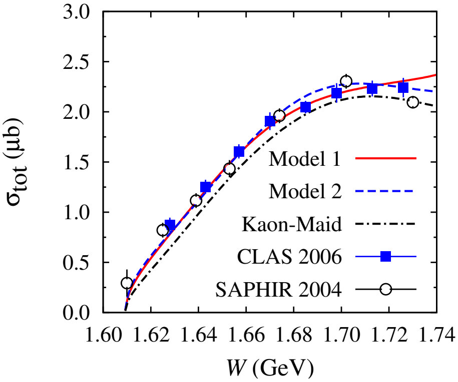
Extension to $W = 1730$ MeV

Focus on the $\gamma + p \to K^+ + \Lambda$ channel
More nucleon resonances

Resonance	M_R (MeV)	Γ_R (MeV)	β_K	$A_{1/2}(p)$	$A_{3/2}(p)$	Overall status
$S_{11}(1650)$	1655^{+15}_{-10}	165 ± 20	0.029 ± 0.004	$+53 \pm 16$	-	****
$D_{15}(1675)$	1675 ± 5	150^{+15}_{-20}	< 0.01	$+19 \pm 8$	$+15 \pm 9$	****
$F_{15}(1680)$	1685 ± 5	130 ± 10	-	-15 ± 6	$+133 \pm 12$	****
$D_{13}(1700)$	1700 ± 50	100 ± 50	< 0.03	-18 ± 13	-2 ± 24	***
$P_{11}(1710)$	1710 ± 30	100^{+150}_{-50}	0.15 ± 0.10	$+9 \pm 22$	-	***
$P_{13}(1720)$	1720^{+30}_{-20}	200^{+100}_{-50}	0.044 ± 0.004	$+18 \pm 30$	-19 ± 20	****
$P_{13}(1900)$						
$F_{17}(1990)$						
...						

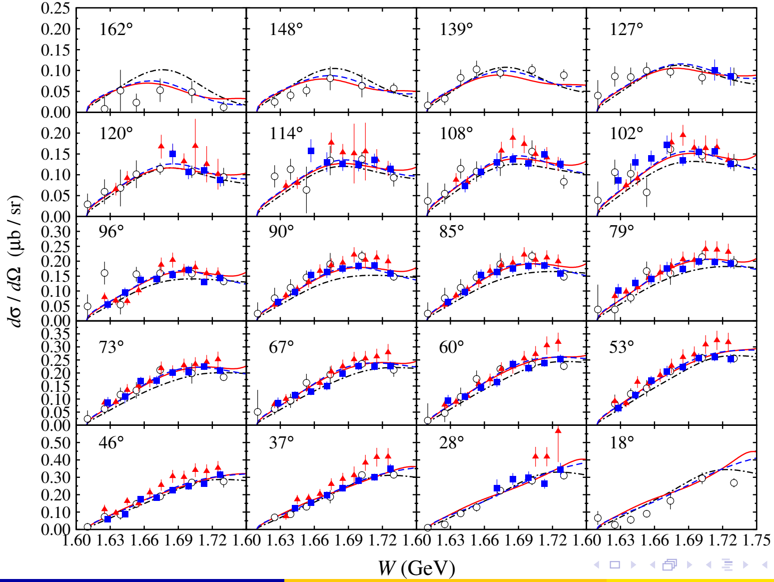
$A_{1/2}$ and $A_{3/2}$ are in $10^{-3}\text{GeV}^{-1/2}$

Extension to $W = 1730$ MeV

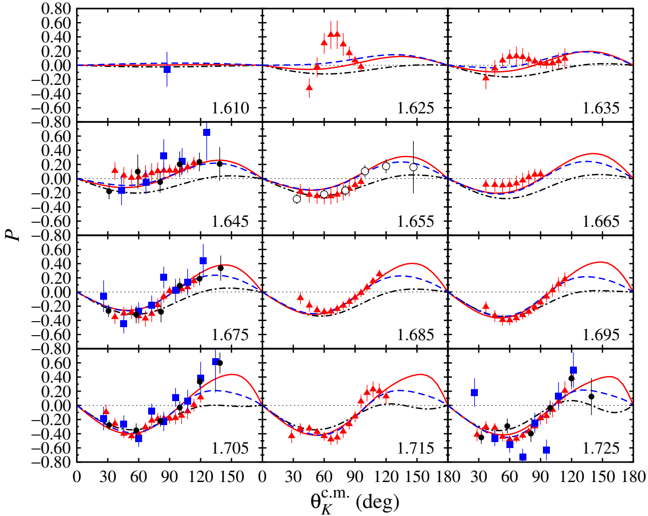


- Models 1 & 2 differ only by the restriction of the resonance parameters in the fits
- Model 2 is less restricted
  $\rightarrow$ smaller χ^2
  $\rightarrow$ better agreement with data

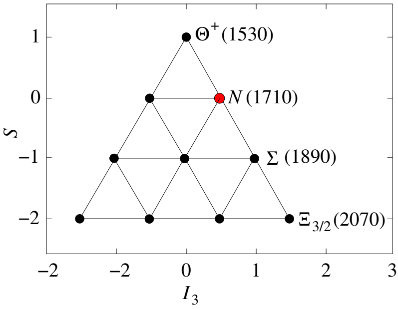
Extension to $W = 1730$ MeV



Extension to $W = 1730$ MeV



Evidence of the $J^p = 1/2^+$ narrow state in kaon photoproduction



Diakonov, Petrov, Polyakov, Z. Phys. A **359**, 305 (1997)

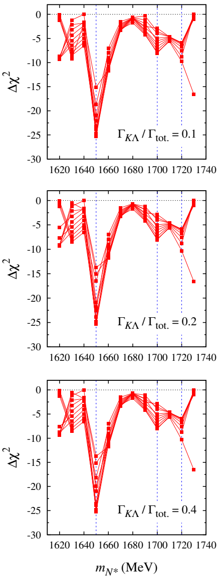
- $\Gamma_{\pi N} \approx 0.13 \rightarrow$ Arndt
- $\Gamma_{\eta N} \approx 0.28 \rightarrow$ Kuznetsov
- $\Gamma_{K\Lambda} \approx 0.13$

Diakonov, Petrov, Phys. Rev. D **69**, 094011 (2004)

- $m_{N^*} =$ 1647 to 1690 MeV

TM, Phys. Rev. D **83**, 094015 (2011); D **88**, 057501 (2013)

Scan the $\Delta\chi^2 = \chi^2_{\rm with} - \chi^2_{\rm without}$ for $m_{N^*} = 1610 - 1730$ MeV



Arndt *et al.*, Phys. Rev. C **69**, 035208 (2004)

Use Model 1

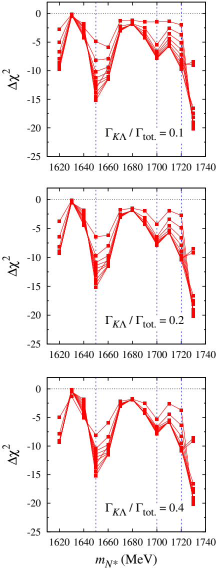
Include a $J^p = 1/2^+$ state with:

- m_{N^*} varies from 1610 to 1730 MeV
- $\Gamma_{\rm tot}$: 1, . . . , 1.0 (step 1 MeV)
- $\Gamma_{K\Lambda}/\Gamma_{\rm tot}$: 0.1, 0.2, 0.4

Result:

- Clear minimum at $m_{N^*} = 1650$ MeV
- Other ”weak” minima at $m_{N^*} = 1700$ and 1720 MeV

Scan the $\Delta\chi^2 = \chi^2_{\rm with} - \chi^2_{\rm without}$ for $m_{N^*} = 1610 - 1730$ MeV



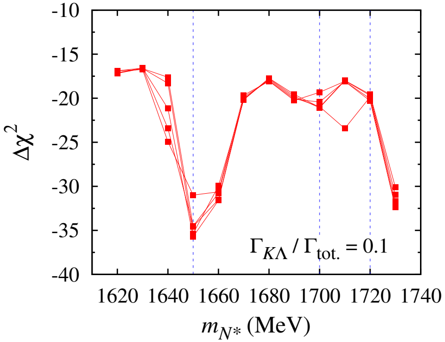
Scan with:

- m_{N^*} varies from 1610 to 1730 MeV
- $\Gamma_{\rm tot}$: 0.1, . . . , 1 (step 0.1 MeV)
- $\Gamma_{K\Lambda}/\Gamma_{\rm tot}$: 0.1, 0.2, 0.4

Result:

- Clear minimum at $m_{N^*} = 1650$ MeV
- Other "weak" minimum at $m_{N^*} = 1700$ MeV

Scan the $\Delta\chi^2$ with Model 2



- Except for $m_{N^*} = 1650$ MeV other minima seem to vanish
- Without narrow resonance Model 2 yields smallest $\chi^2 \rightarrow$ more accurate

Structure at 1650 MeV seems to be almost independent from model, $\Gamma_{\rm tot}$, $\Gamma_{K\Lambda}$

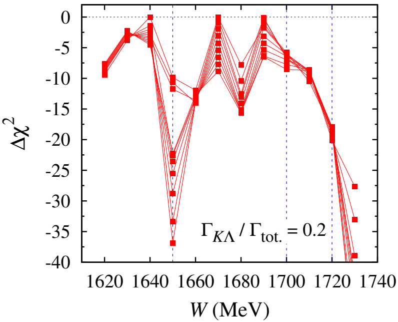
Structures at $W = 1680$ - 1720 MeV difficult to see

Due to opening of many possible channels

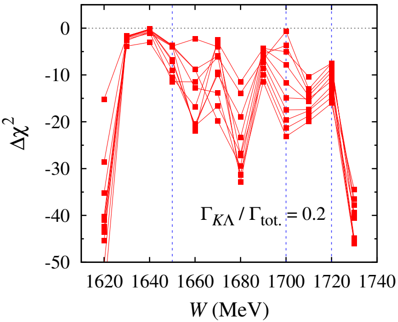
No.	Channel	$E_\gamma^{\rm thr.}$ (MeV)	$W^{\rm thr.}$ (MeV)
1	$\gamma + p \longrightarrow K^+ + \Sigma^0$	1046	1686
2	$\gamma + p \longrightarrow K^0 + \Sigma^+$	1048	1687
3	$\gamma + n \longrightarrow K^+ + \Sigma^-$	1052	1691
4	$\gamma + n \longrightarrow K^0 + \Sigma^0$	1051	1690
5	$\gamma + p \longrightarrow \rho + p$	1096	1714
6	$\gamma + p \longrightarrow \omega + p$	1109	1721

What if the structure is an S_{11} or a P_{13}?

S_{11} $(J^P = 1/2^-)$

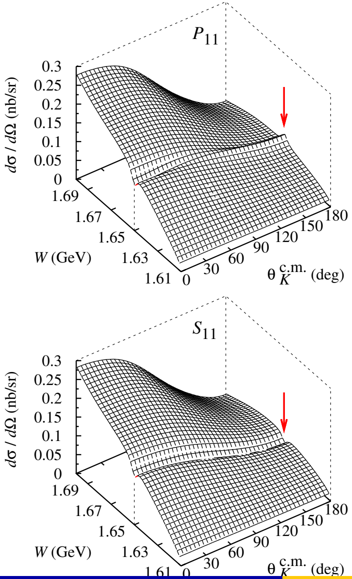


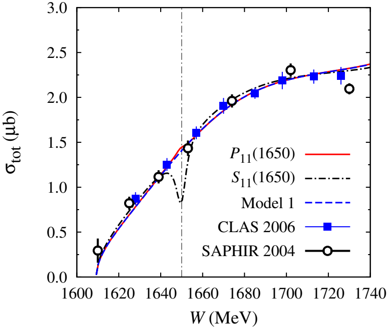
P_{13} $(J^P = 3/2^+)$



- The possibility of P_{13} at 1650 MeV is ruled out
- requires further examination to distinguish the S_{11} from the P_{11} resonance at 1650 MeV

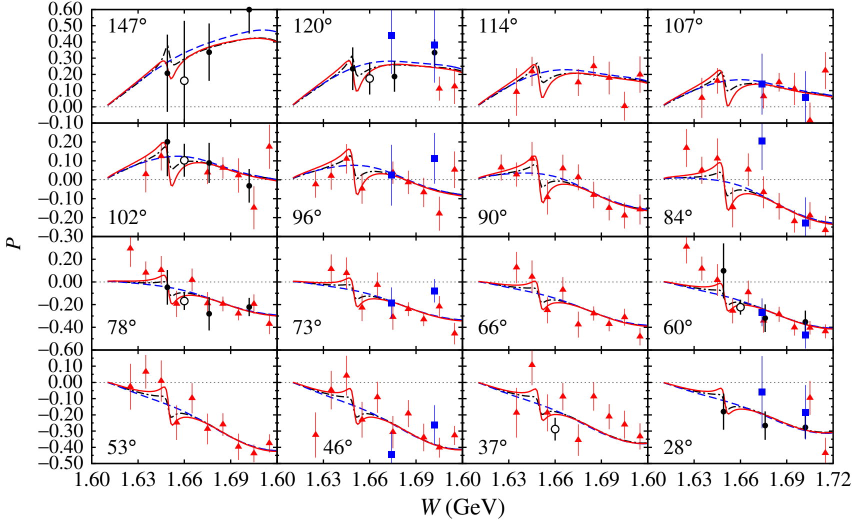
Difference between S_{11} and P_{13}?





- The difference is experimentally trackable

Polarization observable → P



RECENT UPDATES

Covariant isobar model updated

PHYSICAL REVIEW D **92,** 094019 (2015)

Nucleon resonances with spin 3/2 and 5/2 in the isobar model for kaon photoproduction

T. Mart, S. Clymton, and A. J. Arifi

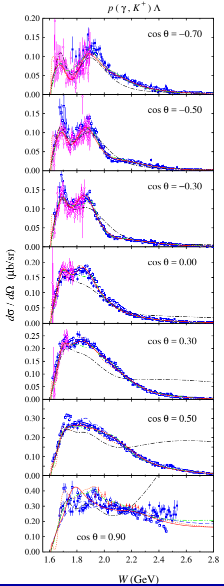
Departemen Fisika, FMIPA, Universitas Indonesia, Depok 16424, Indonesia
(Received 10 April 2015; published 18 November 2015)

We compare two different propagator and vertex factor formulations of spin-3/2 and $-5/2$ nucleon resonances by using isobar models for kaon photoproduction on the proton $\gamma + p \rightarrow K^+ + \Lambda$. All nucleon resonances listed in the Particle Data Group listing with spin up to 5/2 and with at least a two-star rating are included in the model. The unknown coupling constants are extracted from fitting to around 7400 data points. It is found that the gauge-invariant formulation of the spin-3/2 and $-5/2$ interactions leads to a better agreement with experimental data. An extensive comparison of model calculation with experimental data and comparison with the previous analyses are presented. A short discussion on the cross section near the production threshold is also provided.

DOI: 10.1103/PhysRevD.92.094019 PACS numbers: 13.60.Le, 14.20.Gk, 25.20.Lj

- Compares 2 models of propagators and interactions
- Using 17 nucleon resonances with spins up to 5/2
- Using nearly 7400 experimental data points

Covariant isobar model updated



Parameters	A	B	C	D
$g_{K\Lambda N}/\sqrt{4\pi}$	−3.37	−3.00	−3.00	−3.00
$g_{K\Sigma N}/\sqrt{4\pi}$	0.90	0.90	1.30	1.27
$G^V_{K^*}/4\pi$	−0.25	0.12	−0.37	0.15
$G^T_{K^*}/4\pi$	0.17	−0.08	0.72	0.26
$G^V_{K_1}/4\pi$	0.42	0.43	0.23	1.46
$G^T_{K_1}/4\pi$	−0.72	−0.08	−0.91	0.07
$G_{\Lambda(1600)}/4\pi$	−6.30	−9.00	5.12	8.41
$G_{\Lambda(1810)}/4\pi$	10.00	10.00	−4.48	−9.61
Λ_B (GeV)	0.72	0.89	0.70	0.70
Λ_R (GeV)	2.00	2.0	2.00	1.31
θ_{had} (deg)	180	122	56	130
ϕ_{had} (deg)	72	180	180	177
χ^2	15736	13192	14679	11724
N_{par}	74	86	84	96
χ^2/N	2.14	1.77	1.97	1.58

Covariant isobar model updated

PHYSICAL REVIEW D **96,** 054004 (2017)

Isobar model for kaon photoproduction with spin-7/2 and -9/2 nucleon resonances

S. Clymton and T. Mart*

Departemen Fisika, FMIPA, Universitas Indonesia, Depok 16424, Indonesia

(Received 16 August 2016; revised manuscript received 28 February 2017; published 5 September 2017)

We have investigated the effects of spin-7/2 and -9/2 nucleon resonances in the kaon photoproduction process $\gamma p \to K^+\Lambda$. To this end, the corresponding propagators were derived from the generalized spin projection operators. To remove the lower spin backgrounds in the scattering amplitude, we used the vertex factors obtained from the consistent interaction Lagrangians inspired by Pascalutsa and Vrancx *et al.* The scattering amplitude was included in our previous isobar model, and the effects of four nucleon resonances with spins 7/2 and 9/2 listed by the Particle Data Group were investigated by making use of all available kaon photoproduction data. A significant improvement to our previous model has been observed in all observables, especially in the beam-recoil double-polarization observables C_x, C_z, $O_{x'}$, and $O_{z'}$.

DOI: 10.1103/PhysRevD.96.054004

- Added spin-7/2 and -9/2 nucleon resonances
- Using 18 nucleon resonances with spins up to 9/2
- Using nearly 7400 experimental data points

Covariant isobar model updated

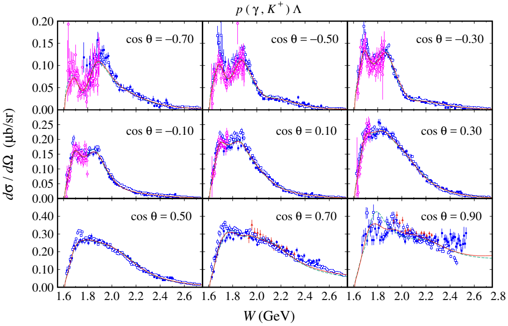


TABLE I. The status, mass, and width of nucleon resonances with spins 7/2 and 9/2 used in our calculation [2].

Resonance	$L_{2I\cdot 2J}$	J^P	Status	Mass (MeV)	Width (MeV)
$N(1990)$	F_{17}	$7/2^+$	**	1990 ± 120	240 ± 50
$N(2190)$	G_{17}	$7/2^-$	****	2190^{+10}_{-90}	500 ± 200
$N(2220)$	H_{19}	$9/2^+$	****	2250 ± 50	400^{+100}_{-50}
$N(2250)$	G_{19}	$9/2^-$	****	2275 ± 75	500^{+300}_{-270}

Parameters	Present work	Previous work [1]
$g_{K\Lambda N}/\sqrt{4\pi}$	−3.00	−3.00
$g_{K\Sigma N}/\sqrt{4\pi}$	0.90	1.27
$G^V_{K^*}/4\pi$	−0.18	0.15
$G^T_{K^*}/4\pi$	0.72	0.26
$G^V_{K_1}/4\pi$	−0.63	1.46
$G^T_{K_1}/4\pi$	−2.94	0.07
$G_{\Lambda(1600)}/4\pi$	−7.19	8.41
$G_{\Lambda(1810)}/4\pi$	10.0	−9.61
Λ_B (GeV)	0.70	0.70
Λ_R (GeV)	1.18	1.31
θ_{had} (deg)	90.0	130
ϕ_{had} (deg)	0.01	177
χ^2/N	1.25	1.58

Multipoles model revisited 2017

PHYSICAL REVIEW C **95**, 045205 (2017)

Multipoles model for $K^+\Lambda$ photoproduction on the nucleon reexamined

T. Mart* and S. Sakinah

Departemen Fisika, FMIPA, Universitas Indonesia, Depok 16424, Indonesia

(Received 2 February 2017; published 25 April 2017)

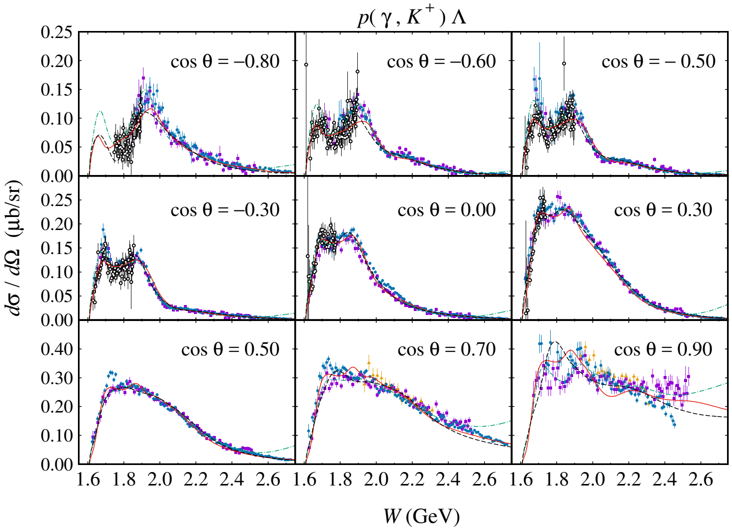
We have updated our previous multipoles model for the kaon photoproduction process $\gamma p \to K^+\Lambda$ by using the recently available experimental data, including the new CLAS 2016 data, and up-to-date information on the nucleon resonance properties provided by the Particle Data Group (PDG). The background and resonance parameters are extracted by fitting the calculated observables to nearly 7400 experimental data points and constraining the resonance parameters within the PDG error bars. The model can nicely reproduce the experimental data with $\chi^2/N_{\rm dof} = 1.63$. Different from the previous result, the present analysis finds the $N(1650)S_{11}$, $N(1720)P_{13}$, and $N(1900)P_{13}$ states to be the most important resonances in the process. Excluding these states in the model increases the value of χ^2 tremendously. As in our previous model, however, the contribution of the $N(1710)P_{11}$ state in minimizing χ^2 is found to be less significant. By including the new CLAS 2016 data in the fitting database and refitting the calculated observables to nearly 9000 data points, the $\chi^2/N_{\rm dof}$ increases to 2.88. In spite of the increase of χ^2, the agreement of model calculations with the new data is improved and the conclusion on the most important resonances in the process remains the same. An extensive comparison between the result of model calculations and experimental data on differential cross section, single polarization observables P, T, and Σ, as well as double polarization observables C_x, C_z, $O_{x'}$, $O_{z'}$, O_x, and O_z, is presented in this paper.

DOI: 10.1103/PhysRevC.95.045205

Multipoles model revisited 2017, number of data

Collaboration	Observable	Symbol	N	Previous	Present	
				Fit 2	Fit 1	Fit 2
CLAS 2006	Differential cross section	$d\sigma/d\Omega$	1377	✓	✓	✓
	Recoil polarization	P	233	✓	✓	✓
CLAS 2010	Differential cross section	$d\sigma/d\Omega$	2066	⋯	✓	✓
	Recoil polarization	P	1707	⋯	✓	✓
Crystal Ball 2014	Differential cross section	$d\sigma/d\Omega$	1301	⋯	✓	✓
LEPS 2006	Differential cross section	$d\sigma/d\Omega$	54	✓	✓	✓
	Photon asymmetry	Σ	30	✓	✓	✓
GRAAL 2007	Recoil polarization	P	66	⋯	✓	✓
	Photon asymmetry	Σ	66	⋯	✓	✓
LEPS 2007	Differential cross section	$d\sigma/d\Omega$	12	⋯	✓	✓
CLAS 2007	Beam-Recoil polarization	C_x	159	⋯	✓	✓
	Beam-Recoil polarization	C_z	160	⋯	✓	✓
GRAAL 2009	Target asymmetry	Σ	66	⋯	✓	✓
	Beam-Recoil polarization	$O_{x'}$	66	⋯	✓	✓
	Beam-Recoil polarization	$O_{z'}$	66	⋯	✓	✓
CLAS 2016	Recoil polarization	P	314	⋯	⋯	✓
	Photon asymmetry	Σ	314	⋯	⋯	✓
	Target asymmetry	T	314	⋯	⋯	✓
	Beam-Recoil polarization	O_x	314	⋯	⋯	✓
	Beam-Recoil polarization	O_z	314	⋯	⋯	✓
Total				1694	7433	9003
$\chi^2/N_{\rm dof}$				0.98	1.63	2.88

Multipoles model revisited 2017, sample of results



TM and Sakinah, Phys. Rev. C **95**, 045205 (2017)

Towards higher spin formalism without background problems

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **96**, 052201(R) (2017)

Pure spin-3/2 propagator for use in particle and nuclear physics

J. Kristiano, S. Clymton, and T. Mart*

Departemen Fisika, FMIPA, Universitas Indonesia, Depok 16424, Indonesia

(Received 14 July 2017; revised manuscript received 3 October 2017; published 7 November 2017)

We propose the use of a pure spin-3/2 propagator in the $(3/2,0) \oplus (0,3/2)$ representation in particle and nuclear physics. To formulate the propagator in a covariant form we use the antisymmetric tensor spinor representation and we consider the Δ resonance contribution to the elastic πN scattering as an example. We find that the use of a conventional gauge-invariant interaction Lagrangian leads to a problem: the obtained scattering amplitude does not exhibit the resonance behavior. To overcome this problem we modify the interaction by adding a momentum dependence. As in the case of the Rarita-Schwinger formalism, we find that a perfect resonance description could be obtained in the pure spin-3/2 formulation only if hadronic form factors were considered in the interactions.

DOI: 10.1103/PhysRevC.96.052201

The pure spin $\frac{3}{2}$ field:

$$\left[\left(\tfrac{3}{2},0\right)\oplus\left(0,\tfrac{3}{2}\right)\right].$$

The conventional spin $\frac{3}{2}$ field:

For decades $\rightarrow$ Rarita-Schwinger $\rightarrow$ problem of lower spin background

$$\left(\tfrac{1}{2},\tfrac{1}{2}\right)\otimes\left[\left(\tfrac{1}{2},0\right)\oplus\left(0,\tfrac{1}{2}\right)\right]=\left[\left(1,\tfrac{1}{2}\right)\oplus\left(\tfrac{1}{2},1\right)\right]\oplus\left[\left(\tfrac{1}{2},0\right)\oplus\left(0,\tfrac{1}{2}\right)\right],$$

RS field consists of two fields: the $\left[\left(1,\frac{1}{2}\right)\oplus\left(\frac{1}{2},1\right)\right]$ and the Dirac field (eliminated by using orthogonality relation), however, still not free from the Dirac background $\rightarrow$ problem of lower spin background

ATS formalism for spin 3/2

Antisymmetric Tensor Spinor:[†]

$$[(1,0)\oplus(0,1)]\otimes\left[\left(\tfrac{1}{2},0\right)\oplus\left(0,\tfrac{1}{2}\right)\right]$$
$$=\left[\left(\tfrac{3}{2},0\right)\oplus\left(0,\tfrac{3}{2}\right)\right]\oplus\left[\left(1,\tfrac{1}{2}\right)\oplus\left(\tfrac{1}{2},1\right)\right]\oplus\left[\left(\tfrac{1}{2},0\right)\oplus\left(0,\tfrac{1}{2}\right)\right].$$

The propagator reads:

$$S_{\alpha\beta\gamma\delta}(p)=\frac{1}{p^2-m^2+i\varepsilon}\left[\left(\frac{p^2}{m^2}\right)\mathscr{P}_{\alpha\beta\gamma\delta}-\left(\frac{p^2-m^2}{m^2}\right)1_{\alpha\beta\gamma\delta}\right],$$

where

$$\mathscr{P}_{\alpha\beta\gamma\delta}=\frac{1}{8}\left(\sigma_{\alpha\beta}\sigma_{\gamma\delta}+\sigma_{\gamma\delta}\sigma_{\alpha\beta}\right)-\frac{1}{12}\sigma_{\alpha\beta}\sigma_{\gamma\delta},$$

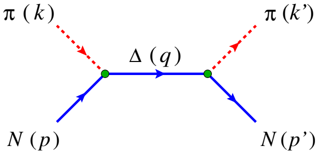
with $\sigma_{\alpha\beta}=\frac{i}{2}\left[\gamma_\alpha,\gamma_\beta\right]$ and

$$1_{\alpha\beta\gamma\delta}=\frac{1}{2}\left(g_{\alpha\gamma}g_{\beta\delta}-g_{\alpha\delta}g_{\beta\gamma}\right)\ .$$

[†] E.G.D Acosta, V.M.B. Guzmán and M. Kirchbach, Eur. Phys. J. A **51**, 35 (2015)

ATS formalism for spin 3/2

But not all interactions can produce resonance properties. For instance: consider the πN scattering with



$$\mathscr{L}_{\pi N\Delta} = g_{\pi N\Delta}\bar{N}\gamma_5\gamma_\mu\tilde{\Psi}^{\mu\nu}\partial_\nu\pi + \text{H.c.},$$

The scattering amplitude reads:

$$\mathscr{M} = \Gamma_{\mu\nu}(k')\tilde{S}^{\mu\nu\rho\sigma}(q)\Gamma_{\rho\sigma}(k) = \frac{g^2_{\pi N\Delta}\left(q^2 - m^2_\Delta\right)}{m^2_\Delta(q^2 - m^2_\Delta + i\varepsilon)}\left(g^{\nu\sigma} + \tfrac{1}{2}\gamma^\nu\gamma^\sigma\right)k'_\nu k_\sigma\,,$$

for which $\mathscr{M} = 0$ for $q^2 = m^2_\Delta$,

not maximum $\rightarrow$ not a resonance.

J. Kristiano, S. Clymton, and TM, Phys. Rev. C **96**, 052201(R) (2017).

Requires a consistent interaction

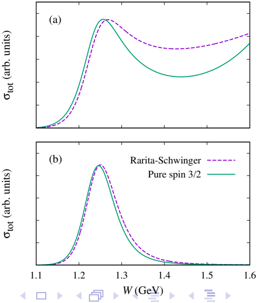
By using

$$\mathscr{L}_{\pi N\Delta} = \left(\frac{g_{\pi N\Delta}}{m_\Delta}\right) \bar{N}\gamma_5 \partial^\mu \Psi_{\mu\nu} \partial^\nu \pi + \mathrm{H.c.}$$

we obtain

$$\mathscr{M} = \frac{g_{\pi N\Delta}^2 k'^\nu k^\sigma}{m_\Delta^2 (q^2 - m_\Delta^2 + i\varepsilon)} \left[\frac{q^4}{4m_\Delta^4} P^{(3/2)}_{\nu\sigma}(q) - \left(\frac{q^2 - m_\Delta^2}{2m_\Delta^4}\right) \left(q^2 g_{\nu\sigma} - q^\nu q^\sigma\right)\right],$$

which is maximum for $q^2 = m_\Delta^2 \rightarrow$ resonance behavior.
Important to use a consistent interaction
TM, J. Kristiano, and S. Clymton, submitted (2019).



Conclusion

- New analysis of kaon photo- and electroproduction near threshold
- Probe the K^0 charge form factor using K^0 electroproduction
- Extend the model up to $W = 1730$ MeV
- Observe an evidence for the $J^p = 1/2^+$ narrow resonance in the $K^+\Lambda$ photoproduction with $m_{N^*} = 1650$ MeV
- Updates the models

Thank you for your patience!