Photo-induced Strangeness Production off the Nucleon

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☛ Description of Kaon production in coupled-channels framework, (K-martix)

- Channels coupling very important → loop corrections important
- Sensitivity to gauge restoration scheme

☛ Beyond K-Matrix

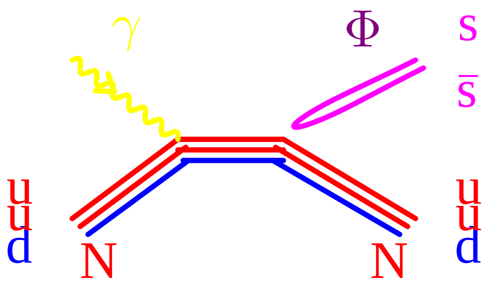
- Restoring causality

Interest

- Structures in spectrum due to resonances or to channel coupling effects?
- Relation to quark model.

quark level: meson level:

Direct:



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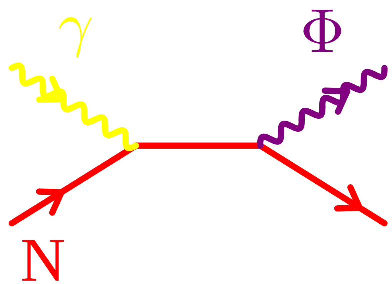
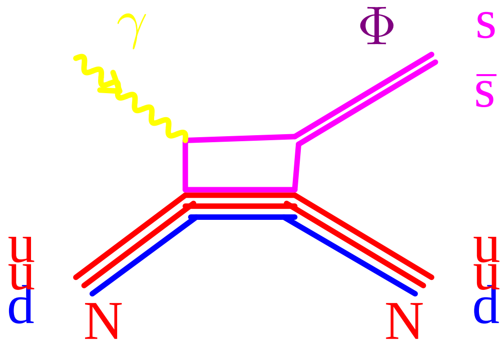


This would measure strangeness content on the nucleon

Or rather??

Loop corrections:



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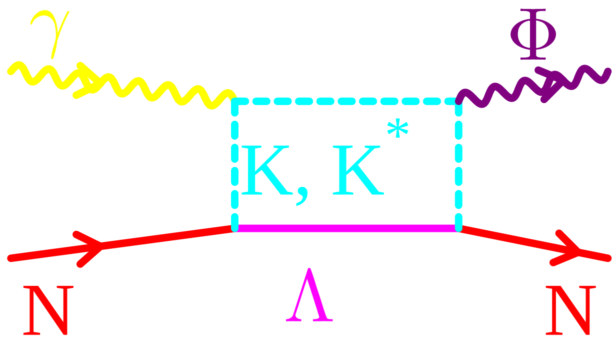


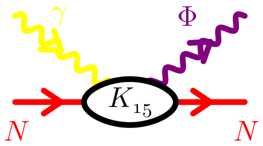
Coupled channels K-matrix

$$S = 1 + 2iT \quad ; \quad T = \frac{K}{1 - iK} = K + iK \times K + \cdots$$

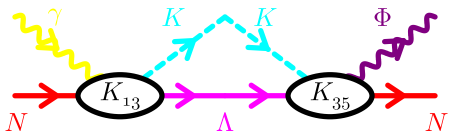
Unitary Algebraic Physics

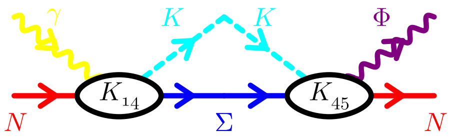
K = sum of tree-level diagrams
Covariant, Gauge invariant
Crossing symmetry

Order K



Some diagrams of order $iK \times K$





Imaginary part of loop integrals via K-matrix $\longrightarrow$ Unitarity

Real part of loop integrals $\longrightarrow$ 'Form Factors' or vertex functions

Consistency among all channels !!!!!

Covariant, Gauge, Unitarity and Crossing symmetry

Kaon production, Model Ingredients

(A. Usov and O.S., Phys. Rev. C **72**, 025205 (2005).)

channel space:
(N+γ), (N+π), (N+η), (N+ρ), (N+Φ), (Λ+K), and (Σ+K)

s- & u-diagrams:
N, Λ, Σ, $S_{11} \times 2$, S_{31}, $P_{11} \times 2$, P_{31}, P_{13}, $P_{33} \times 2$, $D_{13} \times 2$, and D_{33} intermediate states
t-exchange diagrams:
π, η, ρ, ω, σ, K, K^* exchanges

form factors in 3-point vertices

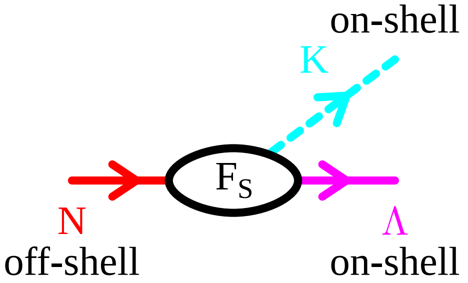
contact terms (=4-point vertices):
gauge restoration

☛ Allows for systematic treatment of gauge-restoration ambiguities
$\approx$ as in chiral-pertubation theory

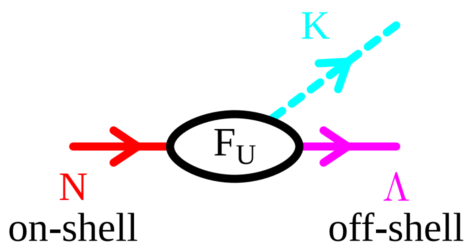
Vertex function

Example $\Gamma_{p\Lambda K}$ in $(p + \gamma \rightarrow \Sigma^+ + K^0)$

s-type



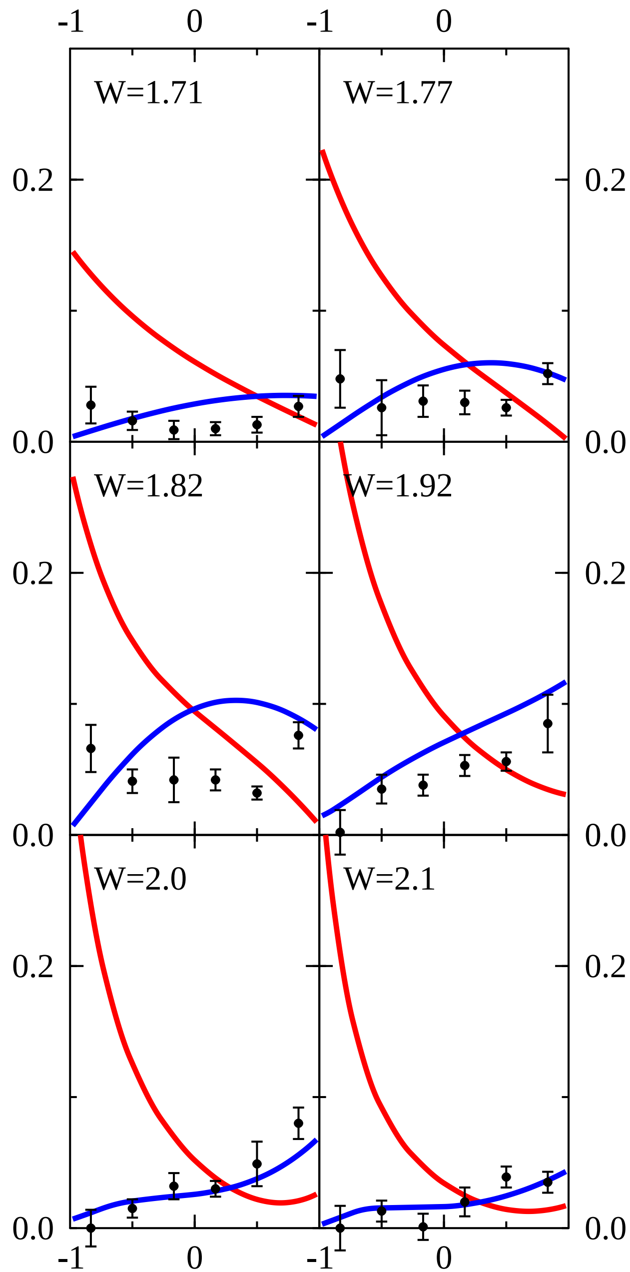
u-type



dipole: $F(s) = \frac{\Lambda^2}{\Lambda^2+(s-m^2)^2}$, ($\Lambda > 1$ GeV^2)

☛ modified: $H(u) = \frac{u}{m^2} F(u)$

$\frac{d\sigma}{d\Omega}(p + \gamma \rightarrow \Sigma^+ + K^0)$ v.s. $\cos(\theta) \Longrightarrow \Longrightarrow$



Gauge Restoration not unique

example: $p+\gamma \rightarrow \Sigma^{+}+K^{0}$ s- & u-diagrams + contact terms

Ohta prescription:

$$\Gamma_{p\Lambda K}=F(p^2)F_{\Sigma}(p'^2)\gamma_5\not{q} \overset{\text{min.}}{\underset{\text{sub.}}{\longmapsto}} \overbrace{(2p+k)^{\mu}\tilde{f}(s)\gamma_5\not{q}+(2p'-k)^{\mu}\tilde{f}_{\Sigma}(u)\gamma_5\not{q}}^{\text{contact terms}}$$

No net suppression of convection current. ; $\tilde{f}(s)=(1-F(s))/(s-m^2)$

Same, reworked:

$$\Gamma_{p\Lambda K}=\gamma_5\Big(\not{p}F(p^2)F_{\Sigma}((p-q)^2)-\not{p}'F_{\Sigma}(p'^2)F((p'+q)^2)\Big) \overset{\text{min.}}{\underset{\text{sub.}}{\longmapsto}}$$

$$\big(F_{\Sigma}(u)-F(s)\big)\gamma_5\gamma^{\mu}+\Big((2p+k)^{\mu}\tilde{f}(s)F_{\Sigma}(u)+(2p'-k)^{\mu}\tilde{f}_{\Sigma}(u)F(s)\Big)\gamma_5(\not{q}-\not{k})$$

Convection current suppressed; Davidson-Workman prescription

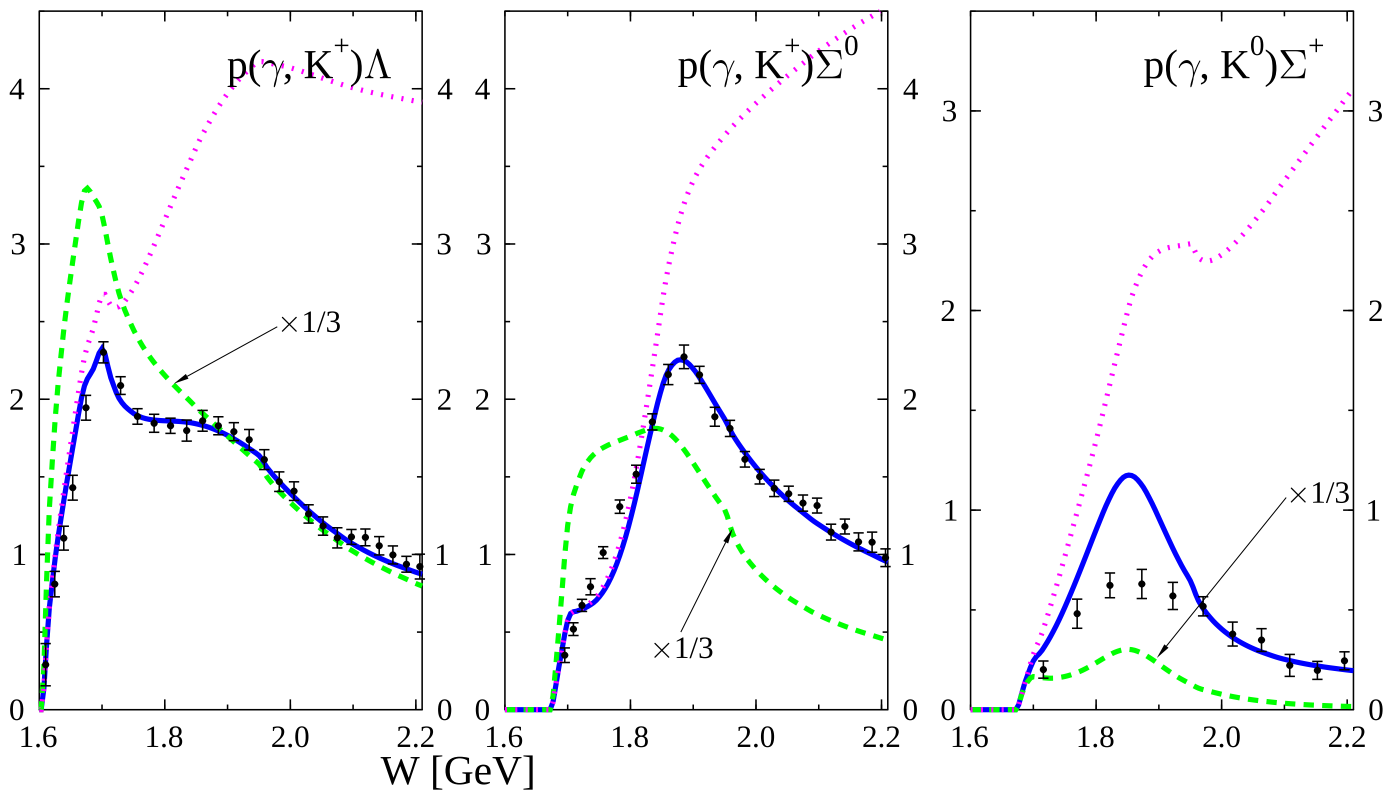
(S. Kondratyuk and O.S., Nucl. Phys. A **677**, 396 (2000).)

(A. Usov and O.S., Phys. Rev. C **72**, 025205 (2005), (nucl-th/0503013).)

Photon coupling at higher energies

Different models available:

- Ohta: simple minimal substitution
  Too large convection current (A_2-term).
- Davidson-Workman: Ohta + contact terms
  Affects A_2-amplitude in Kaon production.
- Janssen-Ryckebusch: WD + contact terms
  Works well in tree-level calculation.



Observation: SAPHIR data

- ☛ gauge-restoration scheme dependence is large
- ☛ affects extracted parameters!

Challenge of Photon coupling at higher energies

Gauge invariance restoration via counter (contact) terms

Choice of contact terms / gauge restauration scheme
an issue if $E_\gamma \geq M_p$

Form factors -or equivalently- contact terms
these model short-range structure & loop corrections

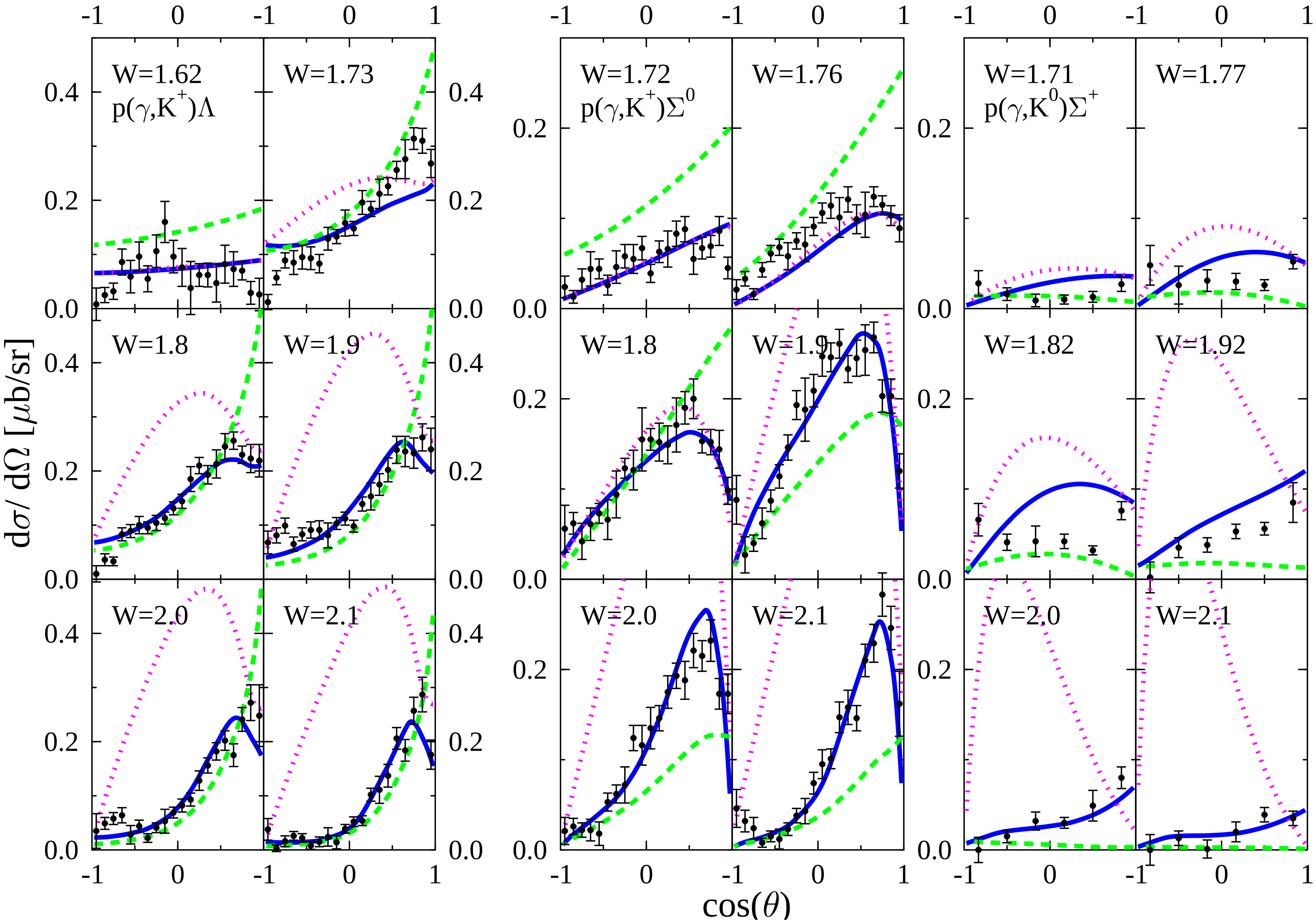
Large number of possibilities,
approach like in χ-perturbation theory difficult

Guidance from microscopic model is necessary

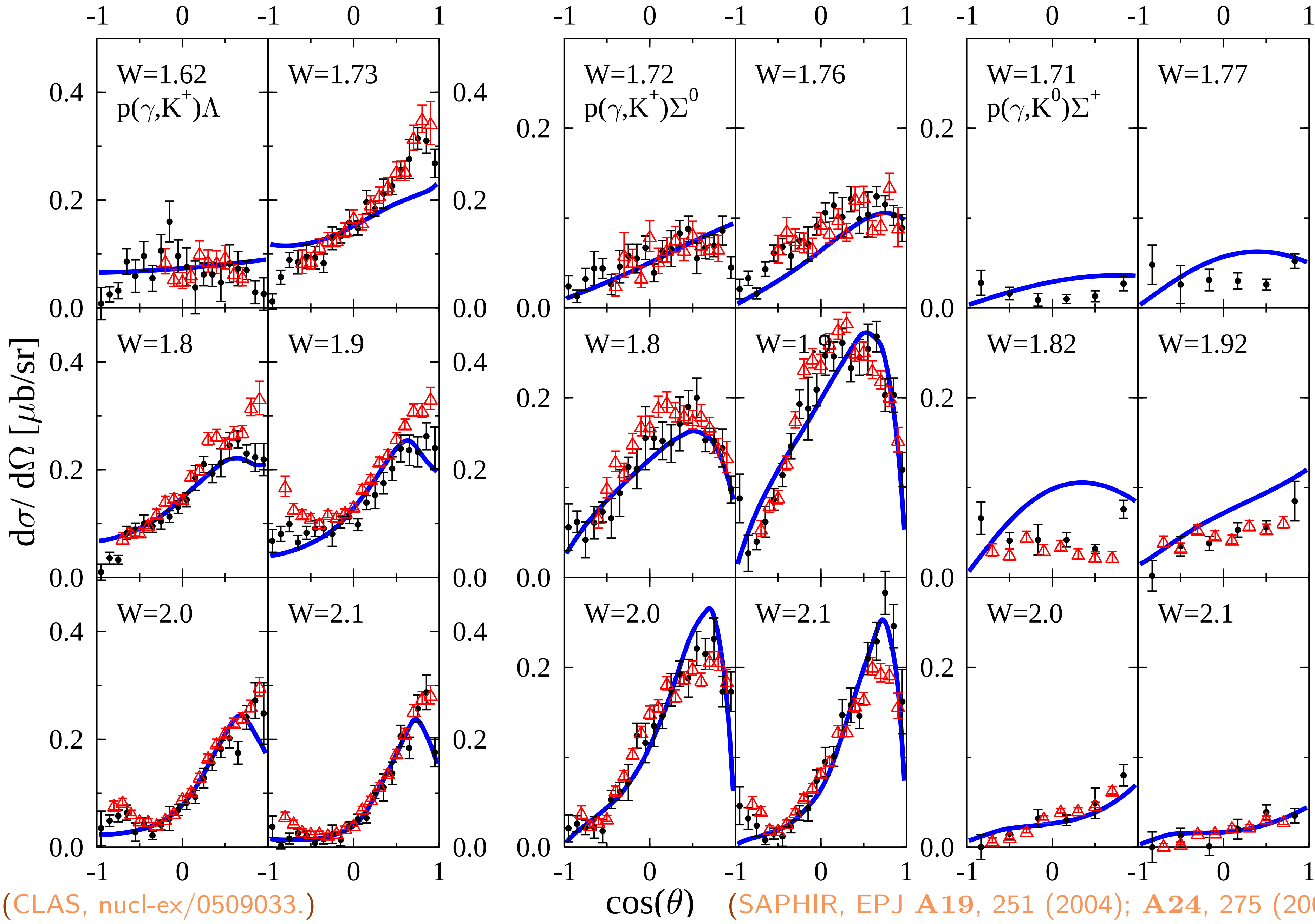
Vertex function == real parts of loop corrections
+ contact terms from short-range physics

Schematic microscopic model (A.Yu. Korchin and O.S., PRC68(2003)045206)

DW **Ohta** **JR ×1/3** **SAPHIR data**



CLAS '05 v.s. SAPHIR data



(CLAS, nucl-ex/0509033.) (SAPHIR, EPJ **A19**, 251 (2004); **A24**, 275 (2005).)

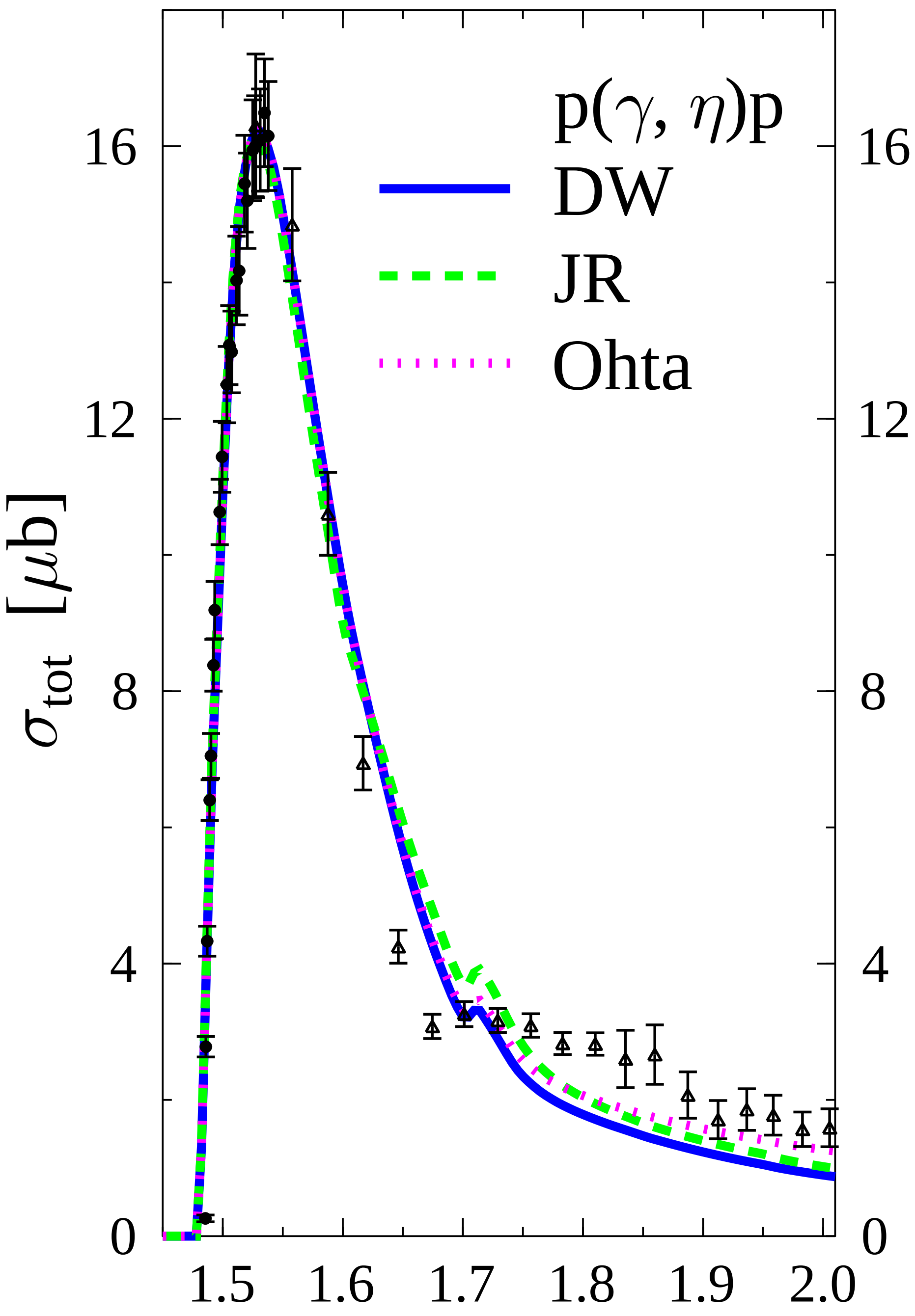
eta production

$(\gamma + p \to \eta + p)$

cross section
v.s.
W [GeV]

data: CB-ELSA Collaboration

cross section is resonance dominated.
Contact terms of little importance.



Sensitivity to Coupled Channels

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

left

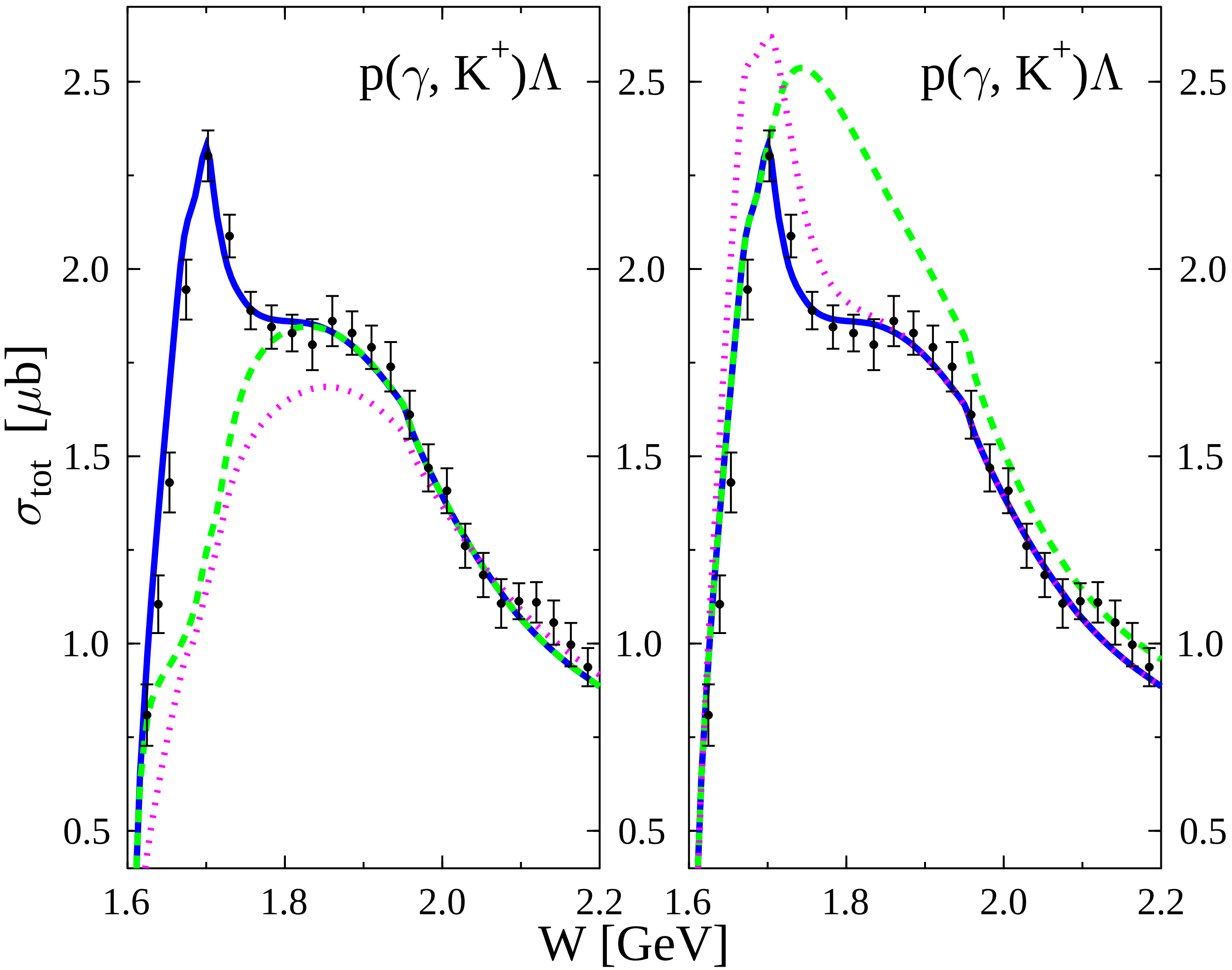
$g_{N\gamma S_{11}}/10$, $g_{K\Lambda S_{11}} \times 10$,
same $(\gamma + p \to K + \Lambda)$

$g_{NK^*\Lambda}$=0,
$(\pi + N \to K + \Lambda) \downarrow$.

right

no ρ final state.

$g_{N\eta S_{11}}$×-1.



data: SAPHIR Collaboration

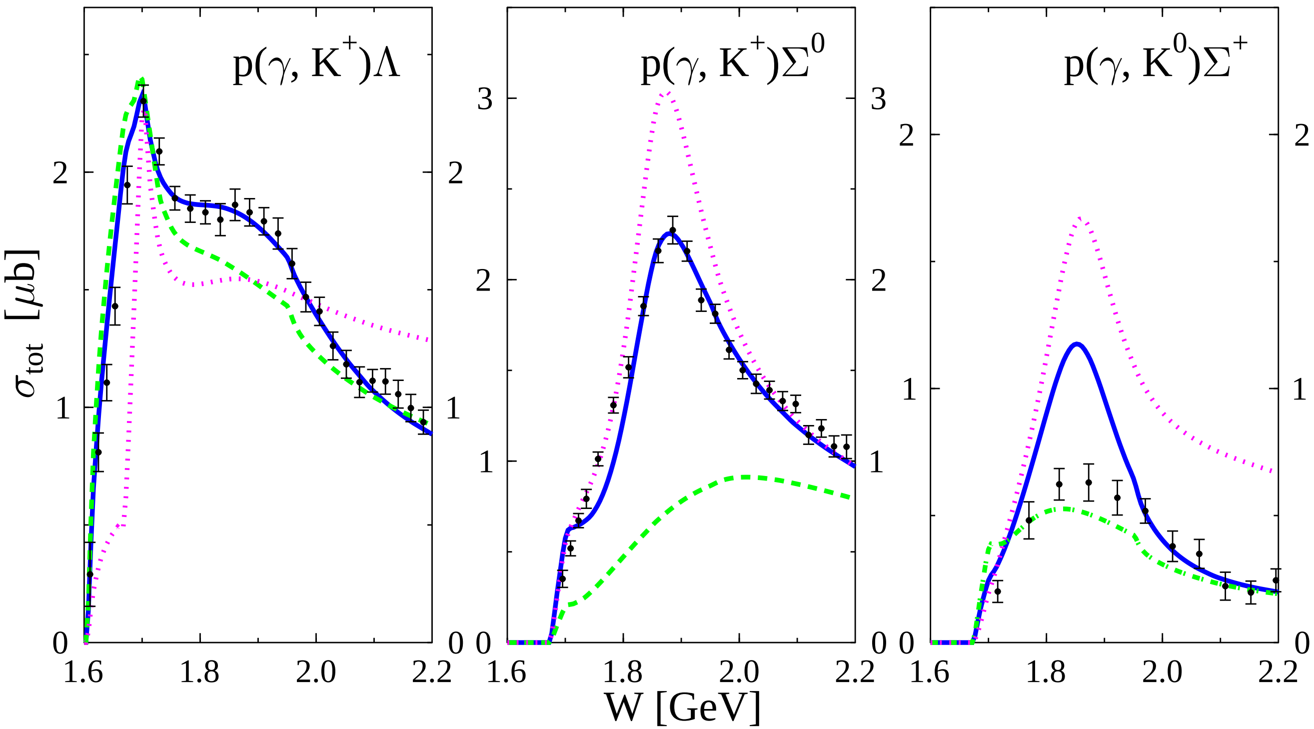
Effects Resonances

$(\gamma + p \rightarrow \Lambda + K)$

Resonances excluded.

No channel coupling.

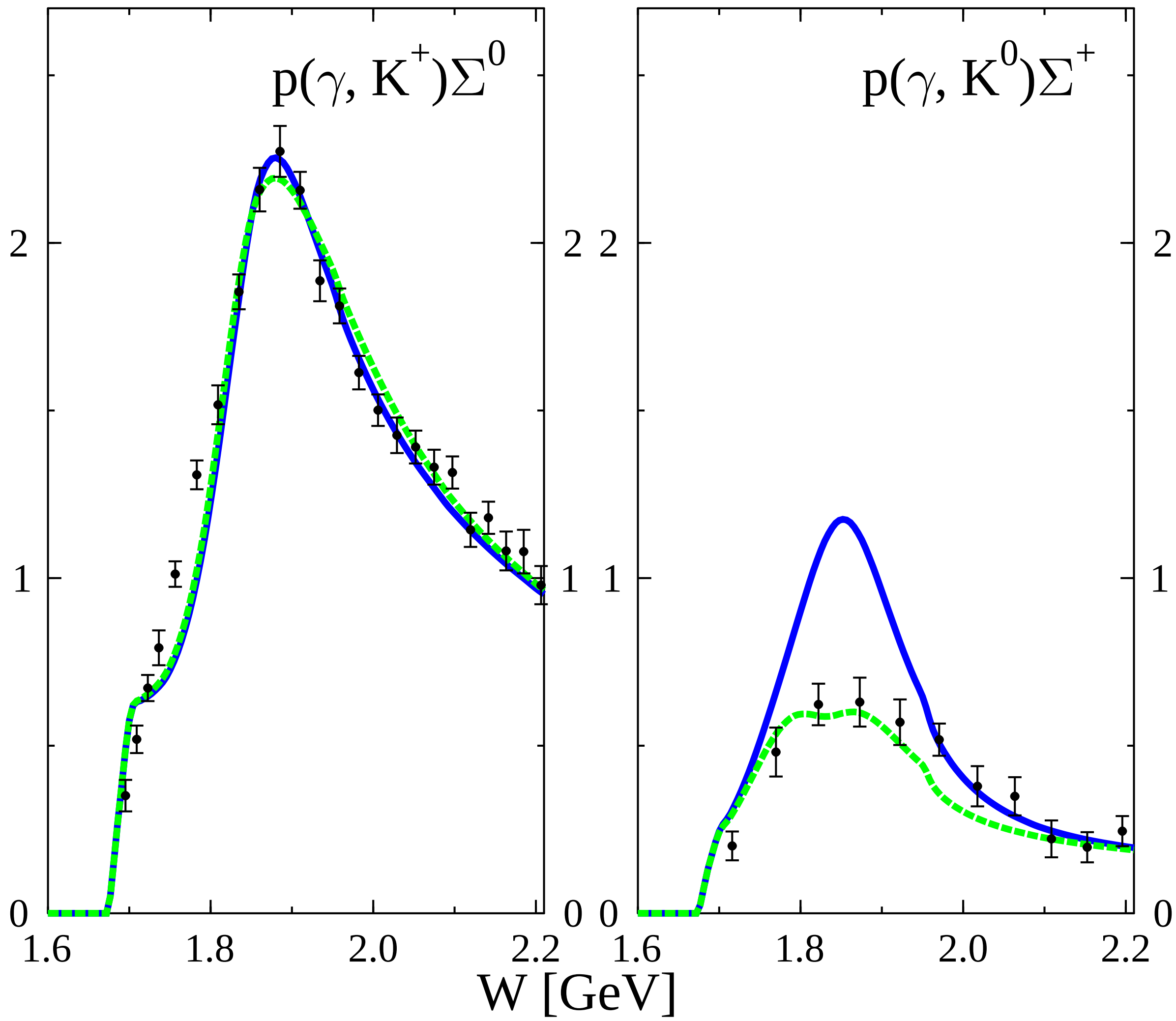
data: SAPHIR Collaboration



$(\gamma + p \rightarrow \Lambda + K)$

Extra P_{13} resonance added.

evidence requires detailed analysis



data: SAPHIR Collaboration

Strength K-matrix approach

Unitarity S

- K-matrix formalism:

$T = \frac{K}{1-i\,K}$

thus: $S = \frac{1+i\,K}{1-i\,K}$ Unitary !

K = Hermitian

Gauge invariance

- Current conservation

$\nabla \vec{J} = \frac{\partial \rho}{\partial t} \Longrightarrow k_\mu J^\mu = 0$

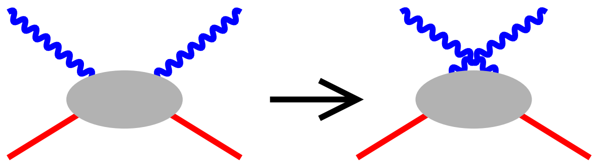
Covariance

- Relativistic kinematics
- 4-vector notation

Vectors transform properly under Lorentz boosts

s-u Crossing Symmetry

- symmetry under



Obeyed in K-matrix formalism

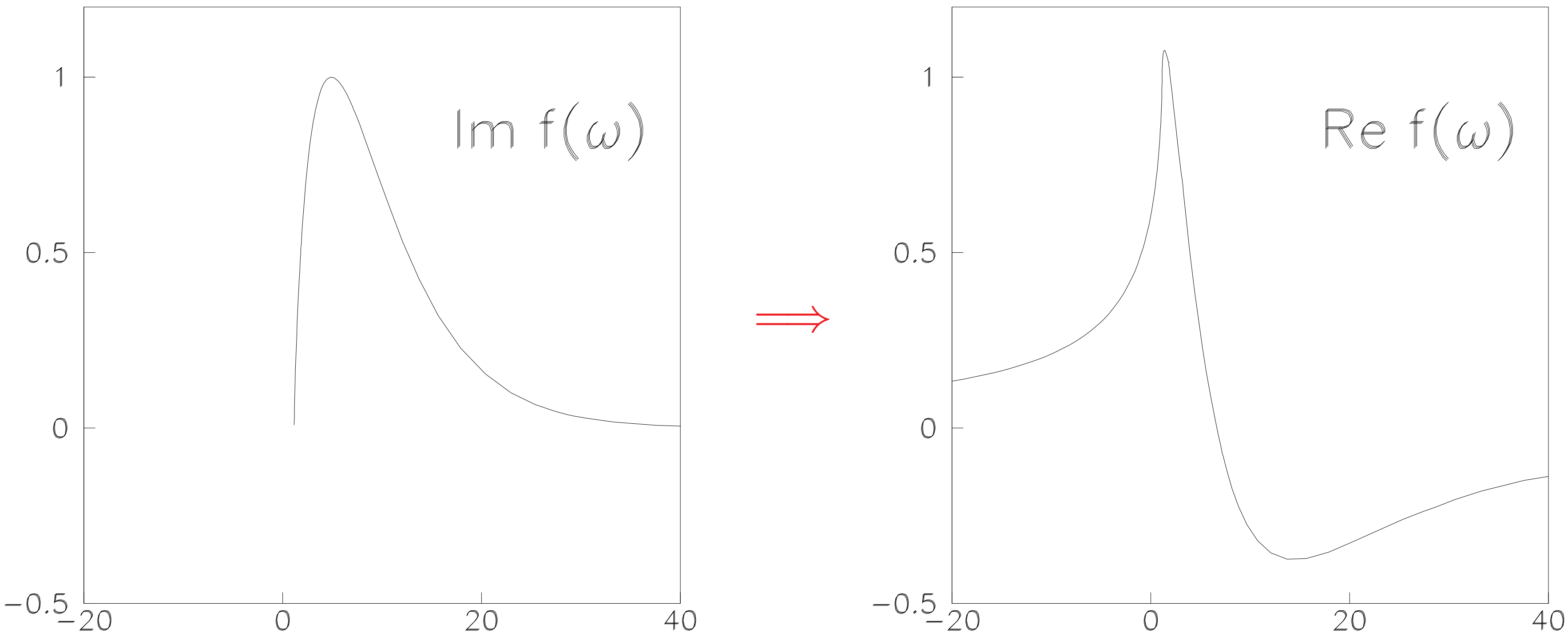
(Provided K is cross. sym.)

Weakness K-matrix approach

Causality ~ Analyticity ~ Dispersion relations

violated

Cauchy theorem $\Rightarrow$ Dispersion relation: $\mathrm{Re} f(\omega) = \frac{\mathcal{P}}{\pi} \int_{-\infty}^{+\infty} d\omega' \frac{\mathrm{Im} f(\omega')}{\omega' - \omega}$



The "Dressed K-matrix" approach

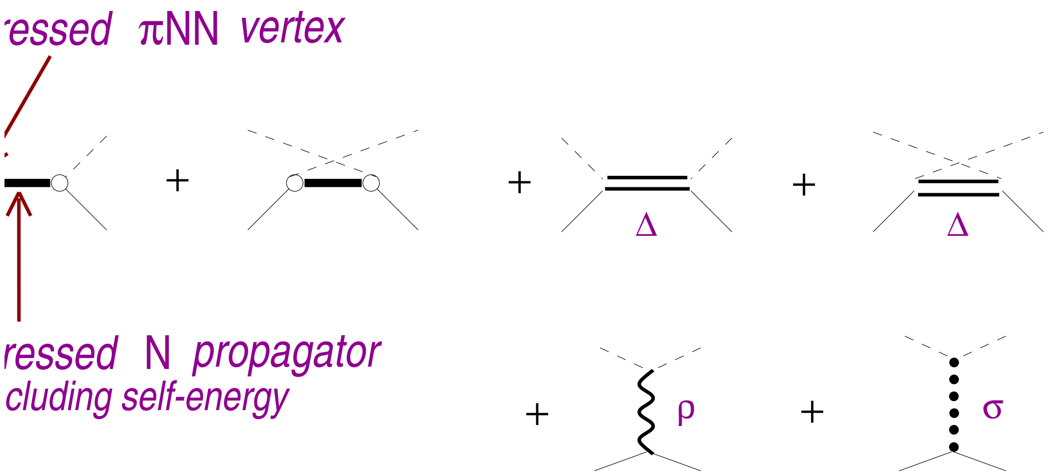
(S. Kondratyuk and O. S., Phys.Rev.C64(2001)024005; Nucl.Phys.A677(2000)396)

Analyticity of amplitude is restored (approximately) by using the 'Dressed K-matrix'

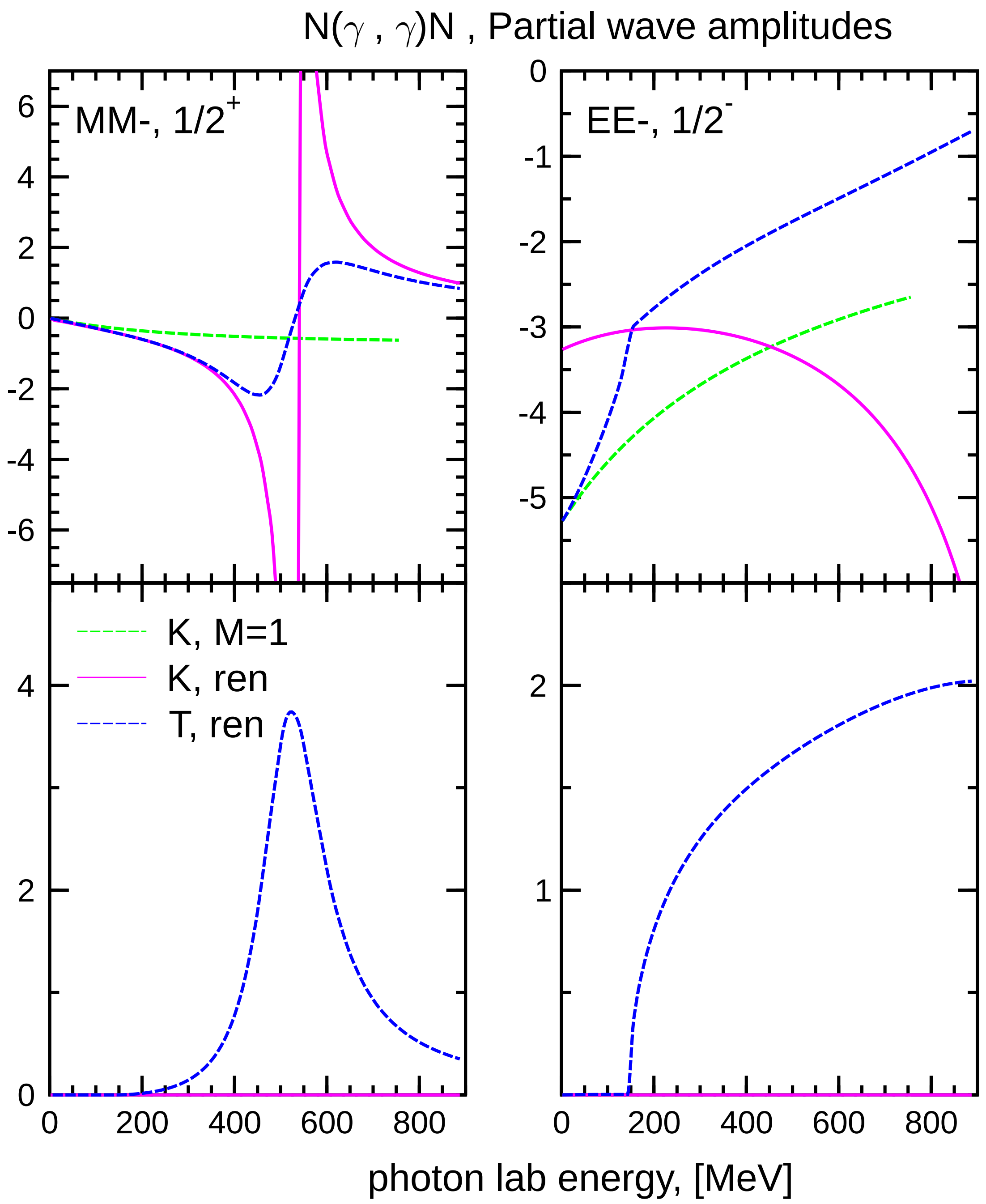
Analyticity important for Amplitude near particle threshold

Basic idea:

Construct real vertex and self-energy functions from Hilbert Transform of cut-loop contributions



The "Imaginary K-matrix" approach



Basic idea:
Analytic continuation below thresholds

Ronormalization needed to obey Low Energy Theorem

- Cusp structure at pion production threshold
- Resonances may develop

Work in progress

(O.S., Setsuo Tamenaga and Hiroshi Toki)

Conclusions

Coupled-channels is important

K-matrix formalism efficient

- ☛ Unitary, Crossing symmetry, gauge invariant, covariant
- ☛ Multi-channel fitting

Implemented in genetic algorithm, in collaboration with Dave Ireland

Phenomenology:

- ☛ Good fit can be obtained of strangeness production
- ☛ Consistency of model for different channels, limiting parameters

To do:

- ☛ Analyticity (while keeping symmetries)
- ☛ Short range correlations

Baryon-meson summary table, defining

$$\Gamma(X) = (\chi X + i\gamma_\mu \partial^\mu X/2M)/(\chi + 1)\gamma_5$$

and

$$\Gamma'(X) = \gamma_\mu X^\mu + \frac{\kappa_X}{2M}(\sigma_{\mu\nu}\partial^\nu X^\mu).$$

	SU(3)	$g_{SU(3)}$	g_{model}
BBP			
$ig_{NN\pi}\bar{N}\Gamma(\vec{\pi}\cdot\vec{\tau})N$	$(D+F)/\sqrt{2}$	13.47	13.47
$ig_{NN\eta}\bar{N}\Gamma(\eta)N$	$(2S+3F-D)/3\sqrt{2}$	5.6	3.0
$ig_{N\Lambda K}\bar{\Lambda}\Gamma(\bar{K})N$	$(D+3F)/\sqrt{6}$	13.3	12
$ig_{N\Sigma K}\bar{\Sigma}_i\Gamma(\bar{K}\tau_i)N$	$(D-F)/\sqrt{2}$	3.9	8.6
BBV			
$-g_{NN\rho}\bar{N}\Gamma'(\vec{\rho}\cdot\vec{\tau})N$	$(D+F)/\sqrt{2}$	2.2	2.2
$-g_{NN\omega}\bar{N}\Gamma'(\omega)N$	$(2S+3F-D)/3\sqrt{2}$	6.6	8
$-g_{NN\phi}\bar{N}\Gamma'(\phi)N$	$(3F-D-S)/3$	0	0
$-g_{N\Lambda K^*}\bar{\Lambda}\Gamma'(\bar{K}^*)N$	$(D+3F)/\sqrt{6}$	3.8	1.7
$-g_{N\Sigma K^*}\bar{\Sigma}_i\Gamma'(\bar{K}^*)\tau_i N$	$(D-F)/\sqrt{2}$	-2.2	0
$-g_{\Sigma\Sigma\rho}\varepsilon_{ijk}\bar{\Sigma}_i\Gamma'(\rho_j)\Sigma_k$	$F\sqrt{2}$	4.4	10
$-g_{\Sigma\Lambda\rho}\bar{\Sigma}_i\Gamma'(\rho_i)\Lambda$	$-D\sqrt{2/3}$	0	-10