Constraints on the chiral unitary $\bar{K}N$ amplitude from $\pi\Sigma K^+$ photoproduction data

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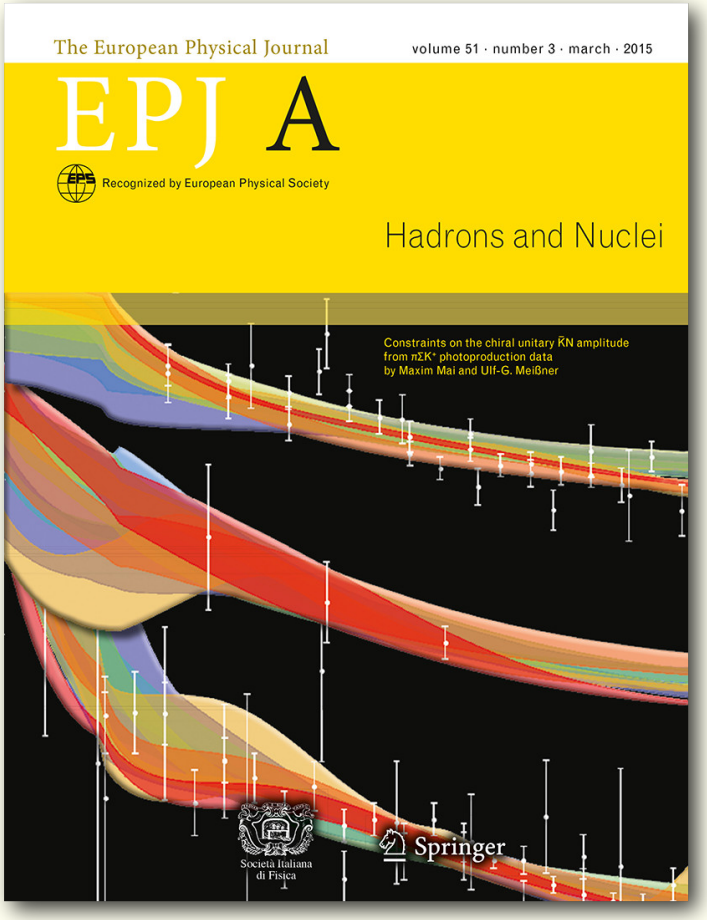
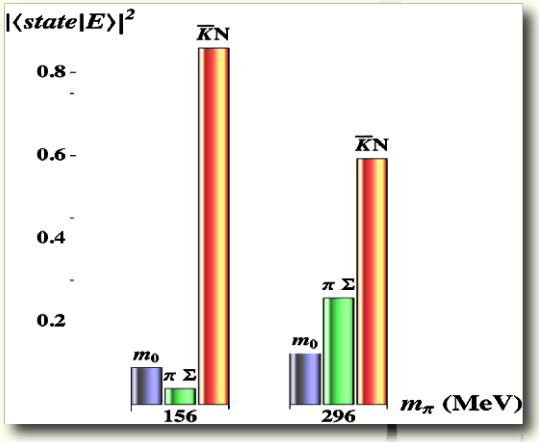


What is $\Lambda(1405)$ made of?

- **Quark model genuine qqq state** Capstick, Isgur (1986)
  - → or even more exotic states: hybrids, active glue, ...
- **Dynamically generated from coupled-channel effects** Dalitz, Tuan (1960!)
  - → unitarized coupled-channel amplitude from ChPT[1]
  - ⇒ two pole solution[2]...***accepted by PDG!***
- **Lattice QCD**
  - → $\Lambda(1405)$ is dominated by a molecular $\bar{K}N$ state[3]



[1] **Kaiser, Siegel, Weise (1995) ...**
[2] **Oller, Meißner (2001) ...**
[3] **Hall et al. (2014)**

Experimental situation

- **Total cross sections on** $K^- p \to K^- p, \bar{K}^0 n, \ldots$ 1960s-1980s
  - → old and not very restrictive[4]
- $\pi\Sigma$ **mass distribution** Hemingway (1985)
  - → multistep production: $K^- p \to (\pi^-)\Sigma^+(1660) \to (\pi^+)\Lambda(1405) \to \Sigma\pi$
  - → low resolution
- **SIDDHARTA experiment** Bazzi (2011)
  - → $\bar{K}H$ strong energy shift and width → $a_{K^- p}$
  - → Plans for an upgrade to $\bar{K}D \to A_{Kd} \Rightarrow$ extract a_1, a_0 directly[5]
- pp **collisions** COSY (2008); HADES (2013)
  - → theoretical analysis very intricate
- $\pi\Sigma$ **mass distribution** CLAS (2012)
  - → electro- and photoproduction: $\gamma p \to (K^+)\Lambda(1405) \to \pi\Sigma$
  - → high statistics and good angular resolution
  - → $J^P = \frac{1}{2}^-$ "confirmed"

[4] **MM, Meißner (2012), Guo, Oller (2013)**

[5] **Kamalov, Oset, Ramos (2001); MM, Baru, ... (2014)**

I. Meson-baryon scattering

Meson-baryon scattering - framework

- **Bethe-Salpeter equation**

$$T(\not{q}_2, \not{q}_1; p) = V(\not{q}_2, \not{q}_1; p) + i \int \frac{d^d l}{(2\pi)^d} \frac{V(\not{q}_2, \not{l}; p) T(\not{l}, \not{q}_1; p)}{((\not{p} - \not{l}) - m + i\epsilon)(l^2 - M^2 + i\epsilon)}$$

  → Bubble chain in s direction → topologies are missing

  $\Rightarrow$ *scale dependence does* ***not*** *cancel out* $\Rightarrow$ *model parameters*

  → (Off-shell) T can be solved exactly, if $V \subset$ local terms[6]

- **Kernel from NLO chiral potential (contact terms)**

$$V = A_{WT}(\not{q}_1 + \not{q}_2) + A_{14}(q_1 \cdot q_2) + A_{57}[\not{q}_1, \not{q}_2] + A_M + A_{811}\Big(\not{q}_2(q_1 \cdot p) + \not{q}_1(q_2 \cdot p)\Big)$$

  $\Rightarrow$ 14 *low energy constants* $\Rightarrow$ *model parameters*

- **Fit to SIDDHARTA/thr. ratios/tot. cross sections**

  → Off-shell effects are moderate[6]

  onshell approximation → *performance* $\times$ *30*

  → Large scale fitting strategy

  $\sim$ 10 000 *starting values*

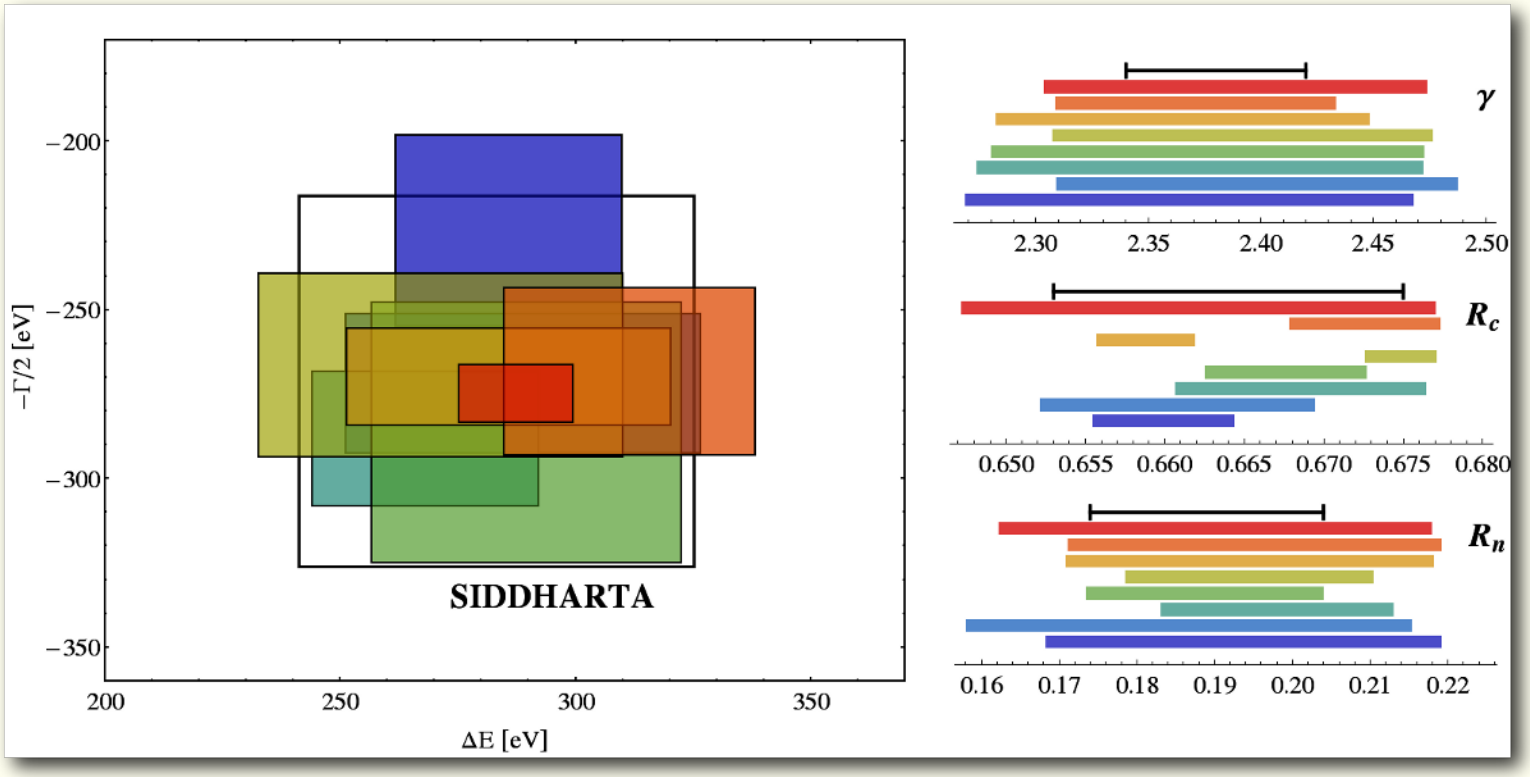
[6] **MM, Meißner (2013)**

Meson-baryon scattering - results

⇒ 8 best fits are obtained:

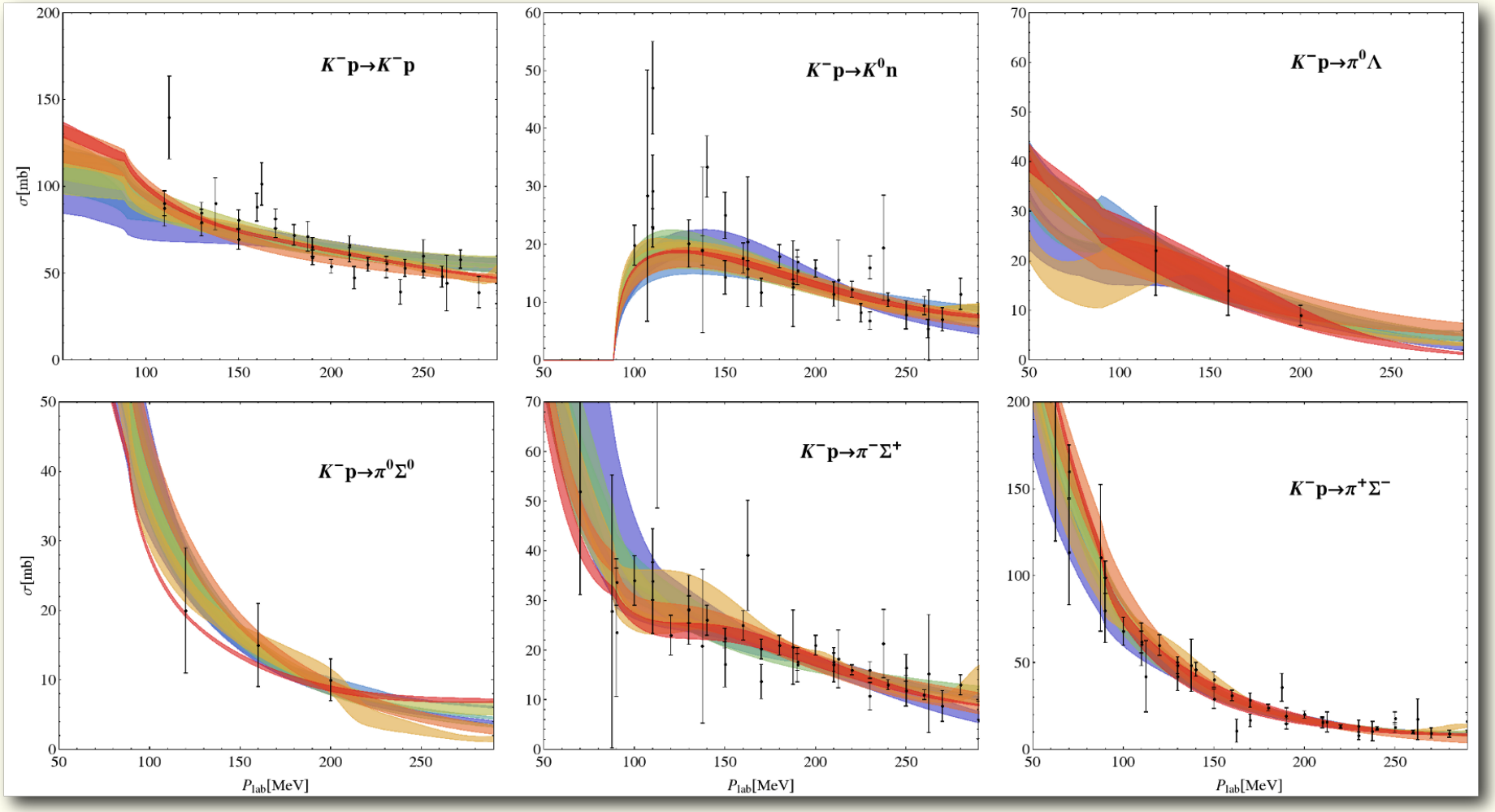
Fit #	1	2	3	4	5	6	7	8
$\chi^2_{\text{d.o.f.}}$	1.35	1.14	0.99	0.96	1.06	1.02	1.15	0.90

... with similar threshold values:



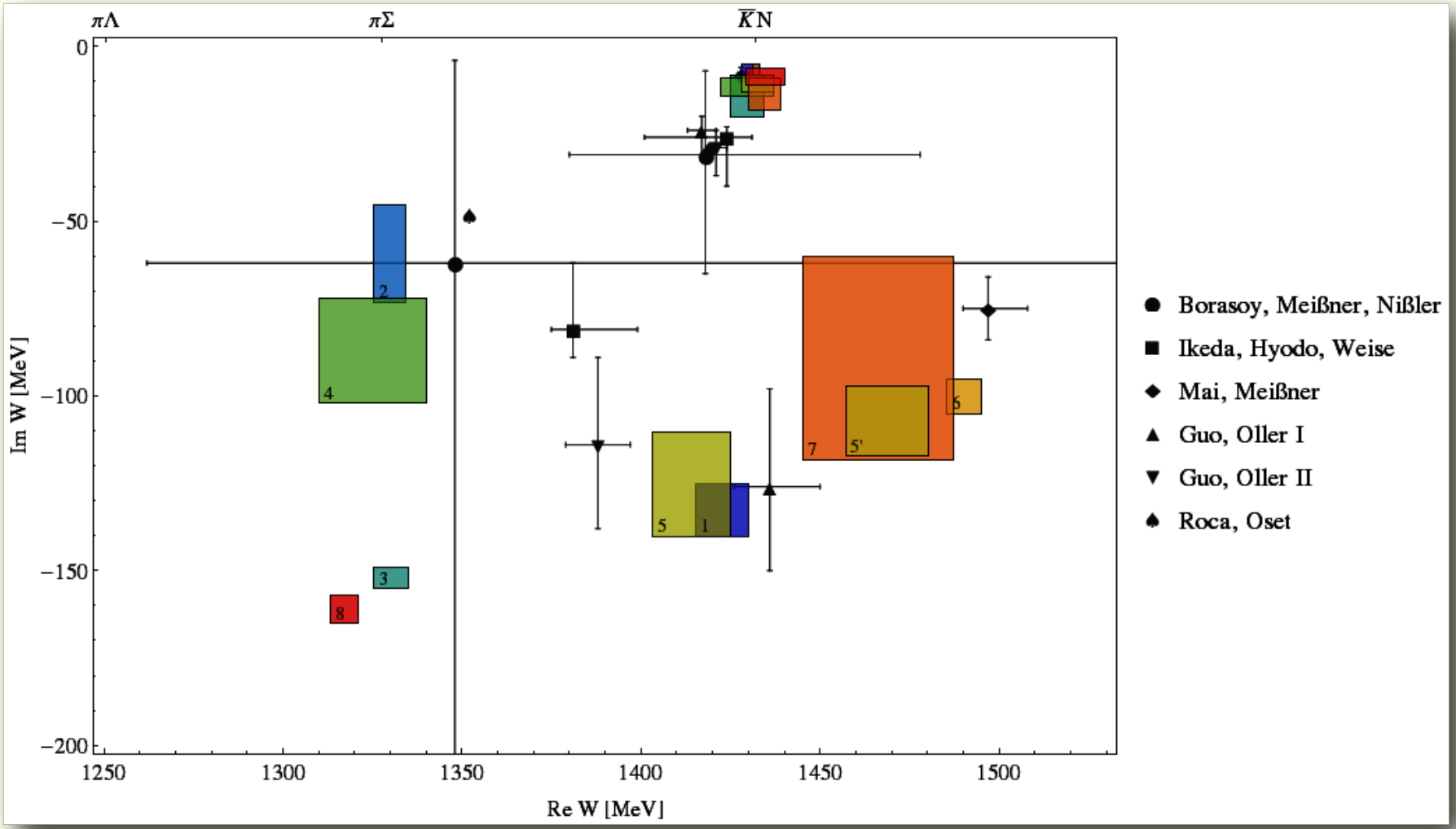
Meson-baryon scattering - results

... with similar cross sections:



Meson-baryon scattering - results

...but different pole positions:



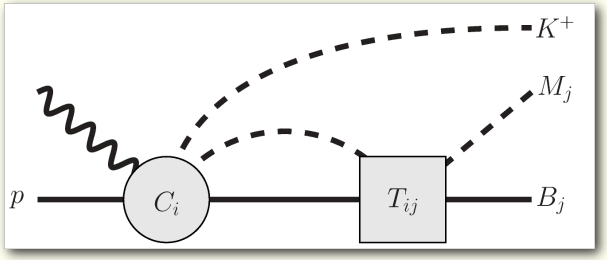
II. CLAS data on $\gamma p \to K^+ \pi \Sigma$

Photoproduction - framework

- **Gauge invariant photoproduction amplitude**
  - LO chiral potential and vector mesons exchange diagrams[6]

    $\Rightarrow$ *good fit with additional parameters: 15 per energy bin !*

- **Simple model**
  - $\mathcal{M}_j(W, M_{\pi\Sigma}) = C_i(W) \cdot G_i(M_{\pi\Sigma}) \cdot T^{on}_{i\to j}(M_{\pi\Sigma})$



  - no gauge invariance, parameters are non-physical

    $\rightarrow$ *global fit is meaningless*

    $\rightarrow$ *microscopic features of the spectrum not accessible*
  - flexible enough for the CLAS data[7]

    $\rightarrow$ *less free parameters (15 $\mapsto$ 10)*

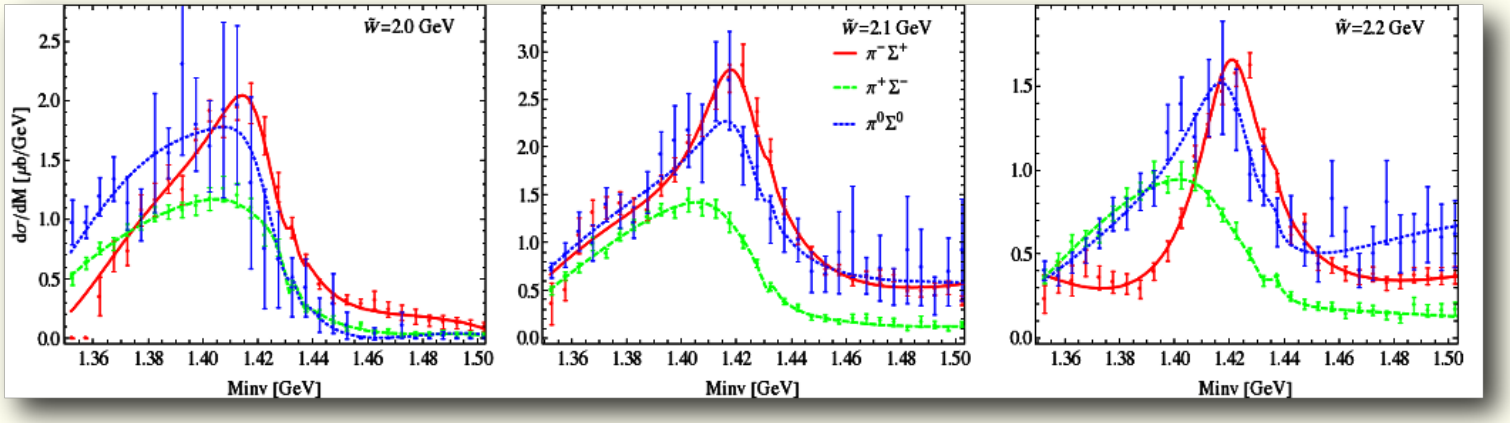
    $\rightarrow$ ***conservative** test for the hadronic solutions*

[6] **Nakamura, Jido (2014)**

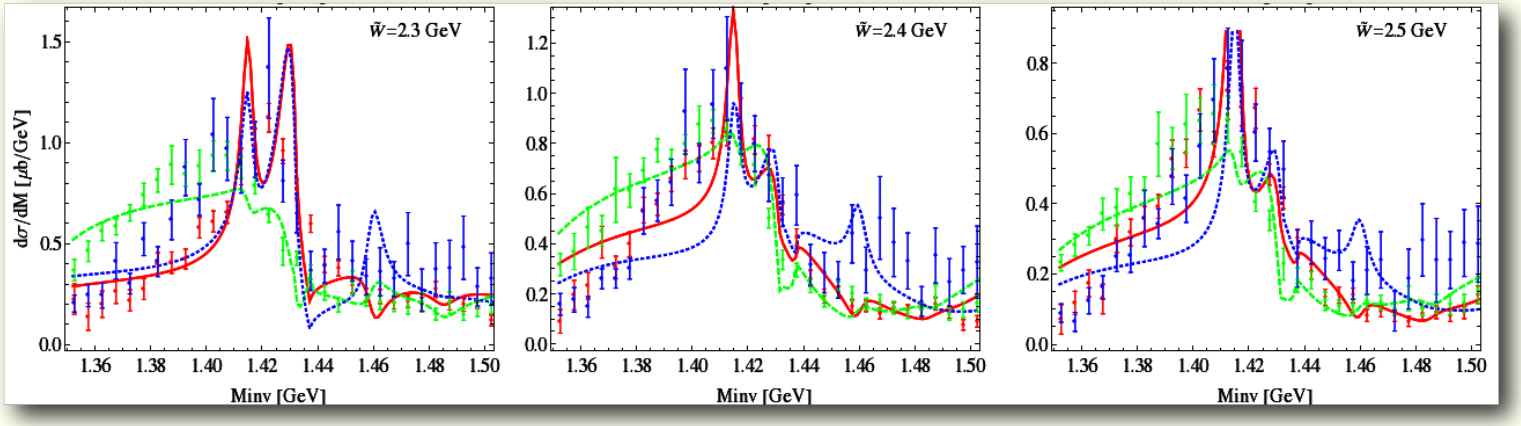
[7] **e.g. Oset, Roca (2013)**

Photoproduction - best fit

- Best fit (sol. #4): $\chi^2_{\text{photo,p.p.}} \approx 1.77$



- But not every solution leads to a good fit, e.g. sol. #6

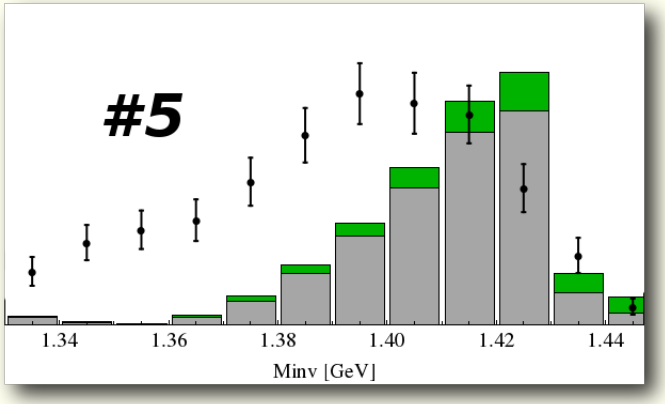


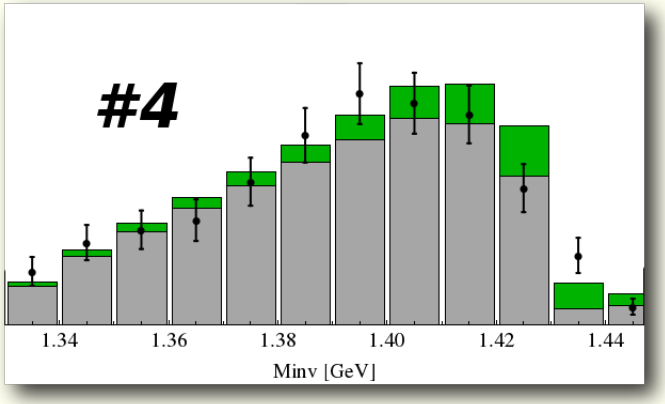
Results - comparison

- Test of hadronic solutions:

Fit #	1	2	3	4	5	6	7	8
$\chi^2_{\text{d.o.f.}}$ (hadr.)	1.35	1.14	0.99	0.96	1.06	1.02	1.15	0.90
$\chi^2_{\text{p.p.}}$ (CLAS)	3.18	1.94	2.56	1.77	1.90	6.11	2.93	3.14

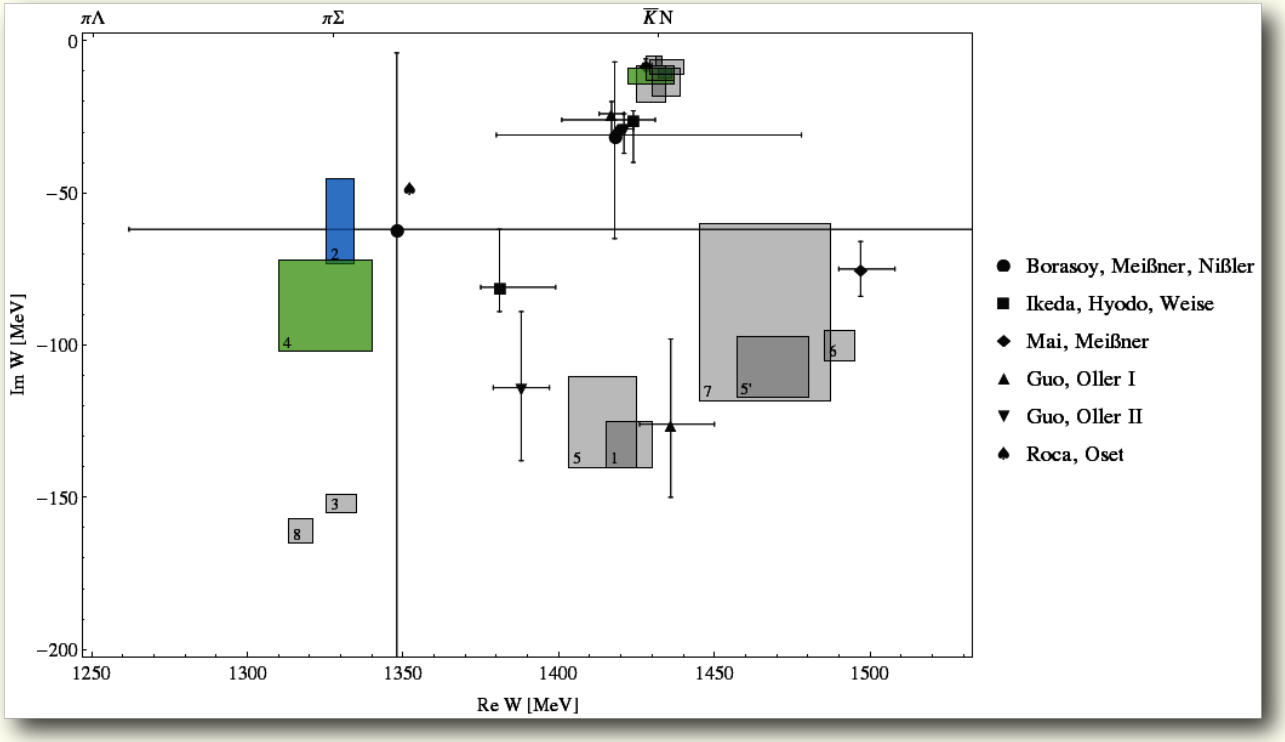
  - #2, #4 and #5 are *good* fits
  - #5 **disagrees** qualitatively with Hemingway ($K^- p \to \Sigma^+ \pi^- \pi^+ \pi^-$):





Results - conclusion

⇒ After comparison with CLAS and Hemingway two solutions remain:



→ Different ansatz for the hadronic part, but similar poles as Oset and Roca

⇒*universal feature, demanded by CLAS data!*

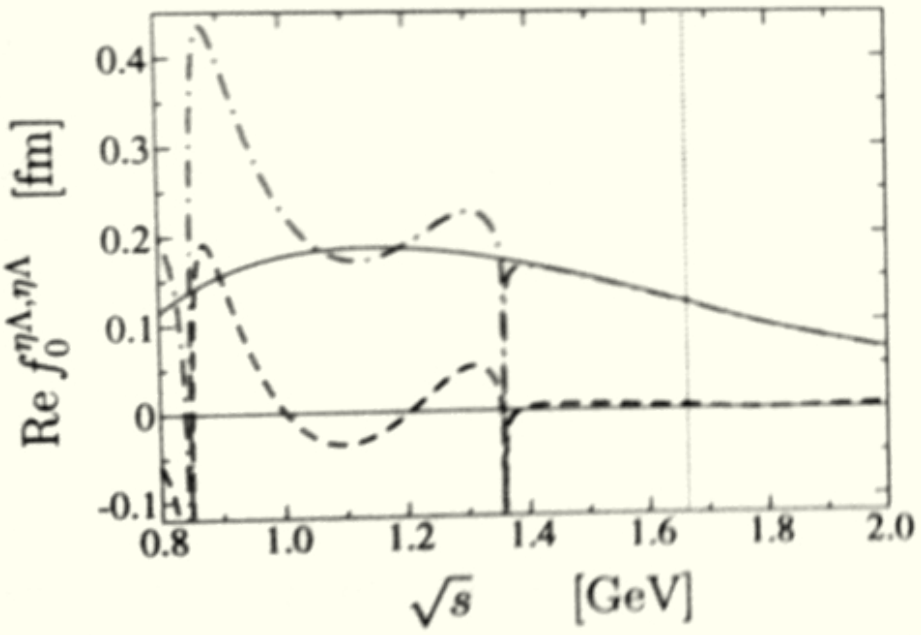
Summary and Outlook

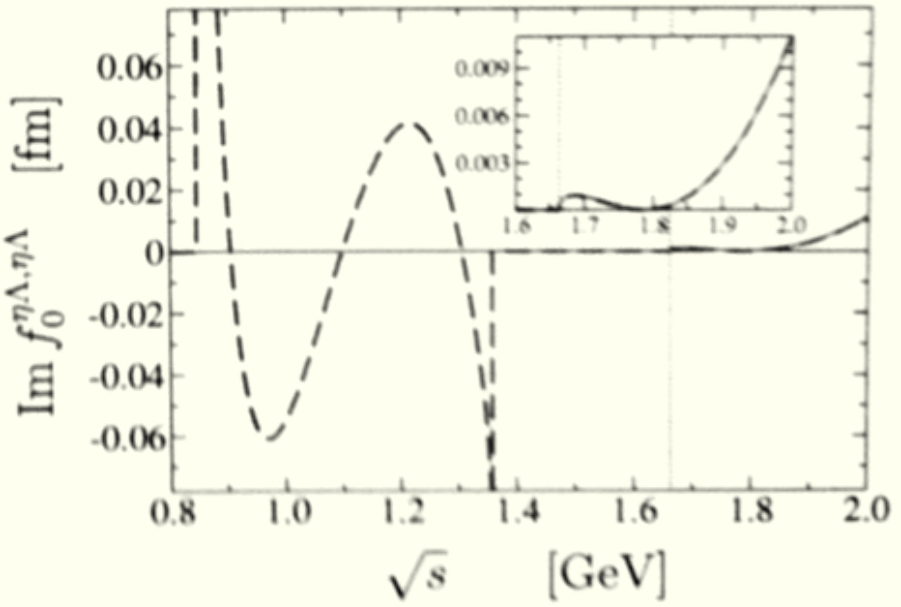
DONE

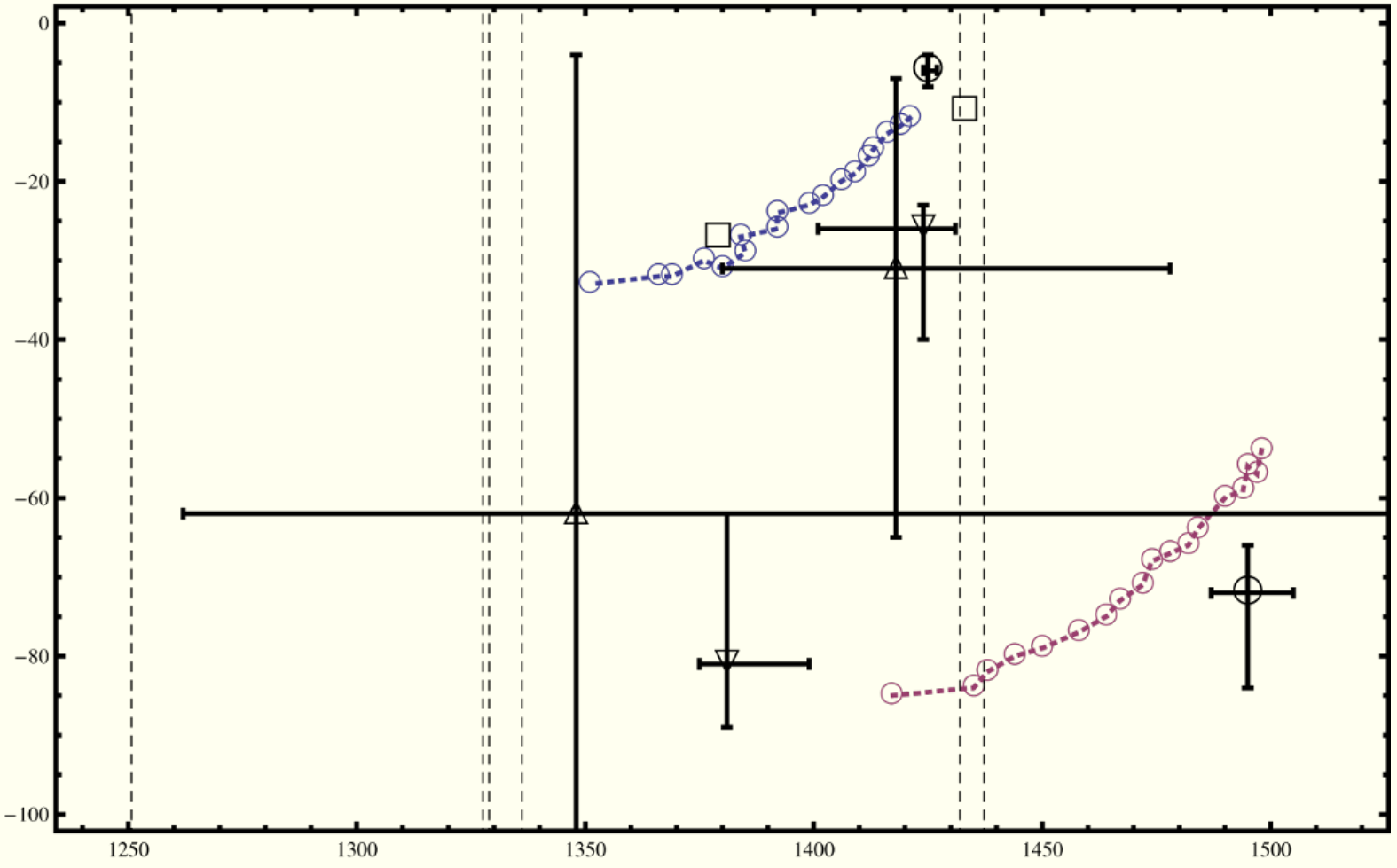
- The NLO chiral unitary $\bar{K}N$ amplitude used to analyze hadronic data
- 8 solutions are found in the onshell approximation:
  $\rightarrow$ *the position of the narrow pole is quite certain*
  $\rightarrow$ *broad pole has large systematic uncertainty*
- Photoproduction amplitude constructed from the hadronic part:
  $\rightarrow$ *very flexible ansatz ...* ***conservative test***
  $\rightarrow$ *5 solutions disagree with the CLAS data, 2 remain after all tests*

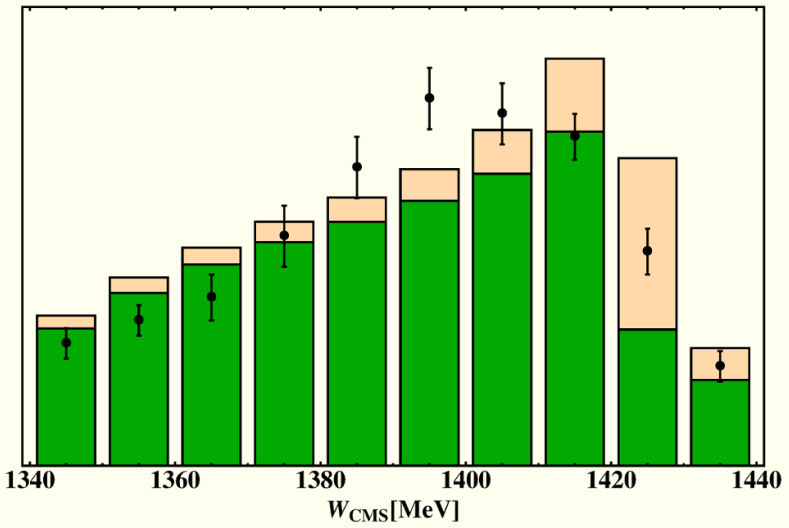
TO DO

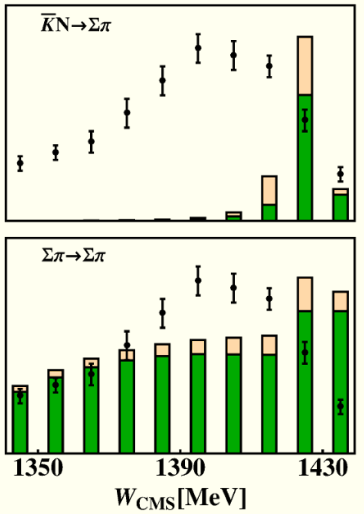
- Better ansatz is required for the photoproduction part
  $\rightarrow$ *physical parameters*
  $\rightarrow$ *microscopic features (electro vs. photoproduction?)*
  $\rightarrow$ *direct extraction of the $\bar{K}N$ amplitude*


Re $f_0^{\eta\Lambda,\eta\Lambda}$ [fm]
0.4
0.3
0.2
0.1
0
-0.1
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\sqrt{s}$ [GeV]


Im $f_0^{\eta\Lambda,\eta\Lambda}$ [fm]
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0.009
0.006
0.003
1.6
1.7
1.8
1.9
2.0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\sqrt{s}$ [GeV]


0
−20
−40
−60
−80
−100
1250
1300
1350
1400
1450
1500


1340
1360
1380
1400
1420
1440
W_{CMS}[MeV]


$\overline{K}N \to \Sigma\pi$
$\Sigma\pi \to \Sigma\pi$
1350
1390
1430
W_{CMS}[MeV]