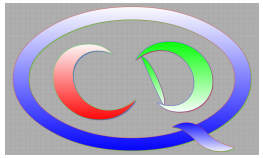
Collaborative Research Center CRC 110
"Symmetries and the emergence of structure in QCD"



Status of project B.11
"Coupled-channel dynamics"

Deborah Rönchen, Bing-Song Zou

CRC 110 General Meeting, Beijing, August 2017

HPC support by Jülich Supercomputing Centre

B11: Coupled-channel dynamics

Goals:

- Extraction of N^*, Δ^* **and** Y^* **resonances** in pion-, kaon-, photon- and electron induced reactions using a **dynamical coupled-channel** (DCC) approach
- Analysis of super-heavy $N^*_{c\bar{c}}$, $\Lambda^*_{c\bar{c}}$ and $N^*_{b\bar{b}}$, $\Lambda^*_{b\bar{b}}$

Staff:

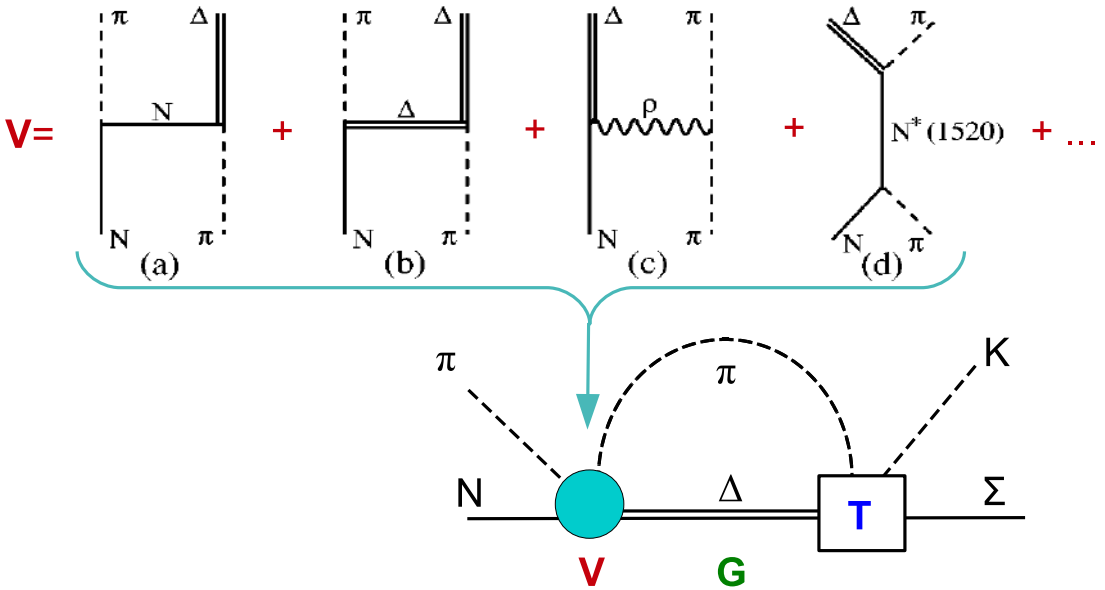
- **PIs:** D. Rönchen (UBO) and B.-S. Zou (ITP)
- **PhD students:** Y.-H. Lin, C.-W. Shen (ITP)
- **Collaborators:** F.-K. Guo, J. Haidenbauer (FZJ), U.-G. Meißner (UBO, FZJ)
- **External collaborators:** M. Döring (GWU), Z.-H. Guo (Hebei Normal University), H. Haberzettl (GWU), F. Huang (UCAS), K. Nakayama (UGA)

Methods: the Jülich-Bonn (JüBo) dynamical coupled-channels (DCC) aproach

Dynamical coupled-channels (DCC): **simultaneous** analysis of different reactions

The scattering equation in partial-wave basis

$$\langle L'S'p'|T^{IJ}_{\mu\nu}|LSp\rangle = \langle L'S'p'|V^{IJ}_{\mu\nu}|LSp\rangle + \sum_{\gamma,L''S''}\int_0^\infty dq\; q^2\; \langle L'S'p'|V^{IJ}_{\mu\gamma}|L''S''q\rangle \frac{1}{E - E_\gamma(q) + i\epsilon} \langle L''S''q|T^{IJ}_{\gamma\nu}|LSp\rangle$$



- theoretical constraints on the $\mathcal{S}$ matrix: **unitarity** and **analyticity**
- resonances = poles on the 2nd Riemann sheet of T
- potentials V constructed from chiral effective $\mathcal{L}$
- s-channel diagrams: T^P genuine resonance states
- t- and u-channel: T^{NP} dynamical generation of poles possible

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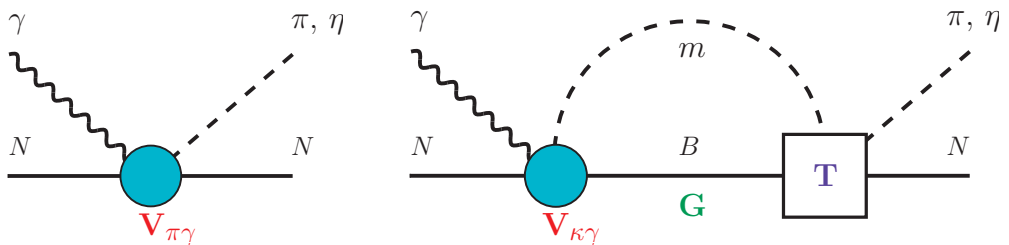

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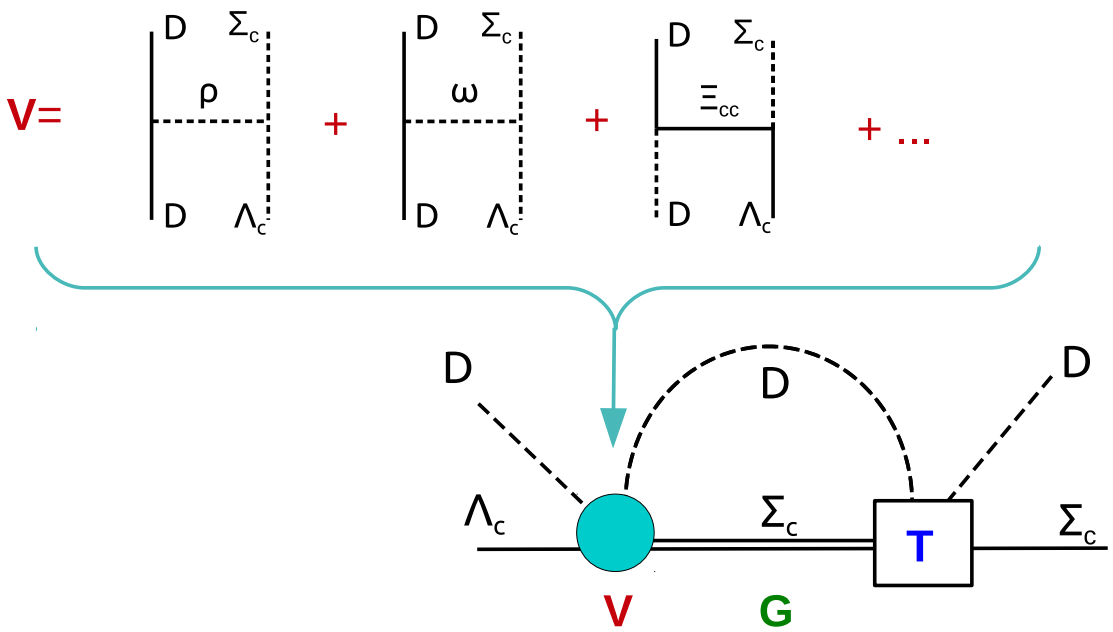

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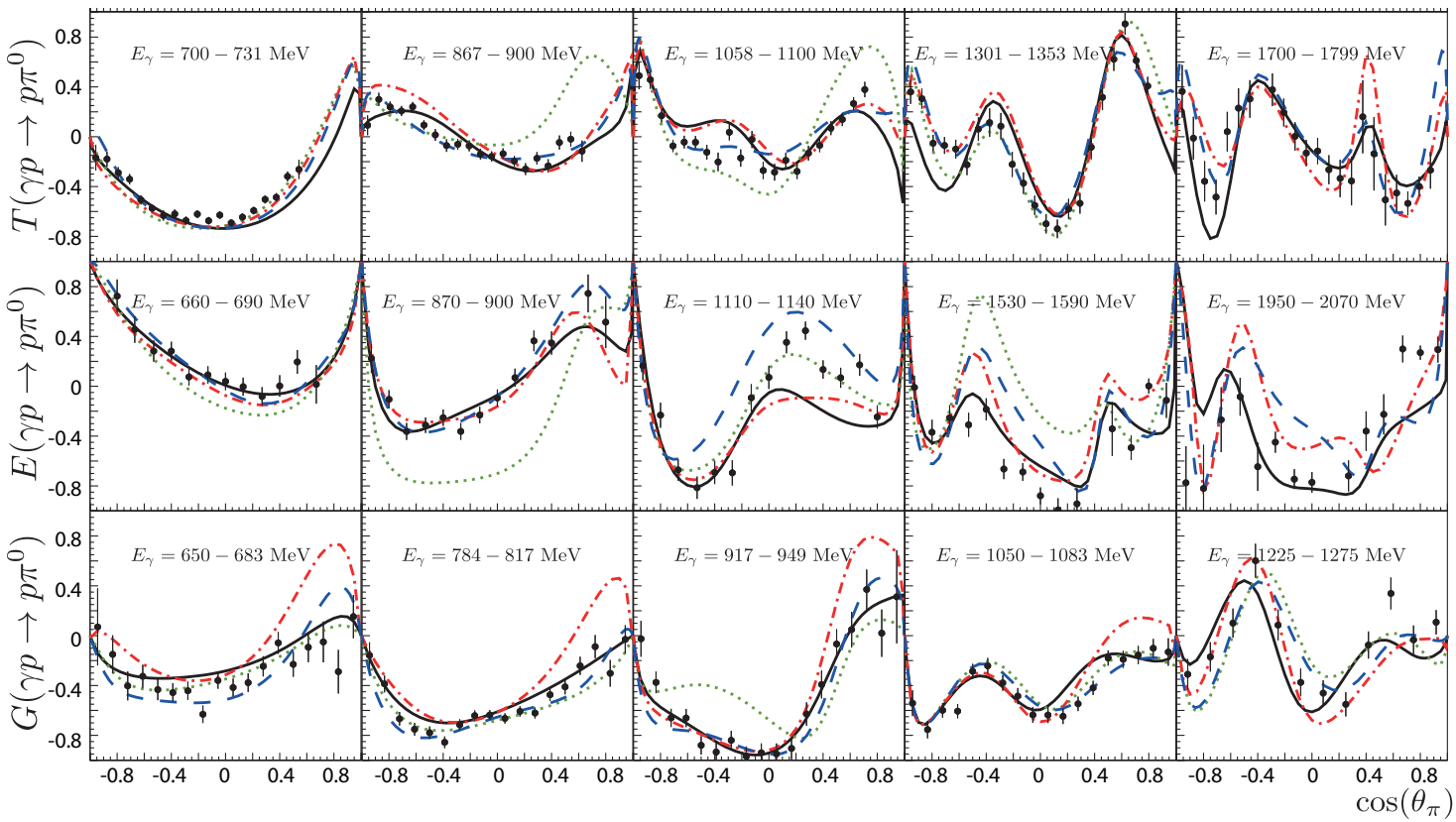
Results I: Impact of new polarization data on $\gamma p \to \pi N$ amplitudes

joint effort of the BnGa, JüBo, and SAID groups EPJ A 52, 284 (2016)

- recent new data in pion photoproduction: E, G, H, P, T (ELSA), Σ (JLab), Σ (MAMI)
  $\Rightarrow$ included in the BnGa, JüBo, SAID fits
  - compare **multipoles** before and after the inclusion of the new data
  - convergence to a common solution?



Data: CBELSA/TAPS Collaboration.

Predictions: black solid: BnGa, blue dashed: JüBo, red dash-dotted: SAID ,green dotted: MAID

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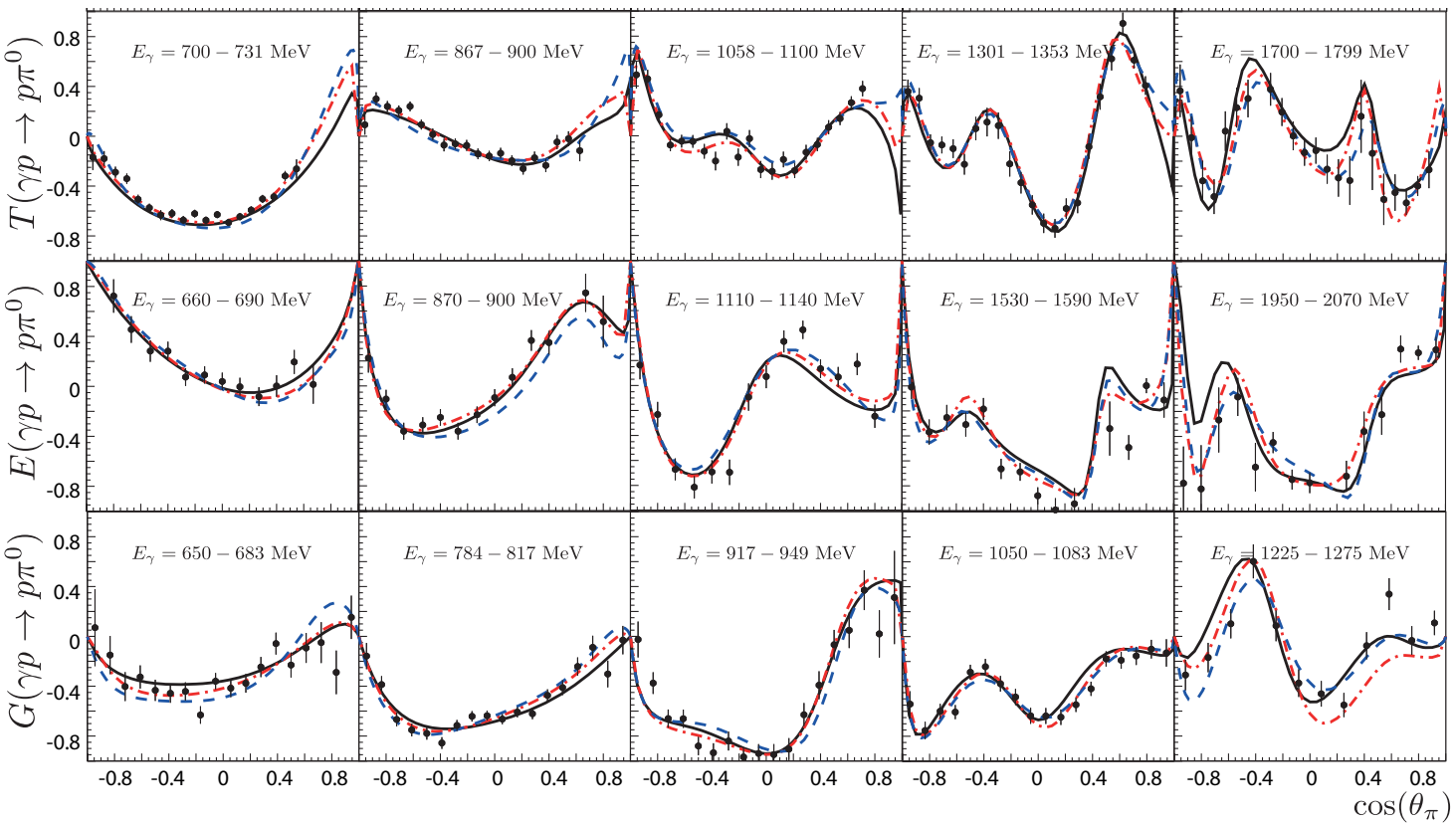

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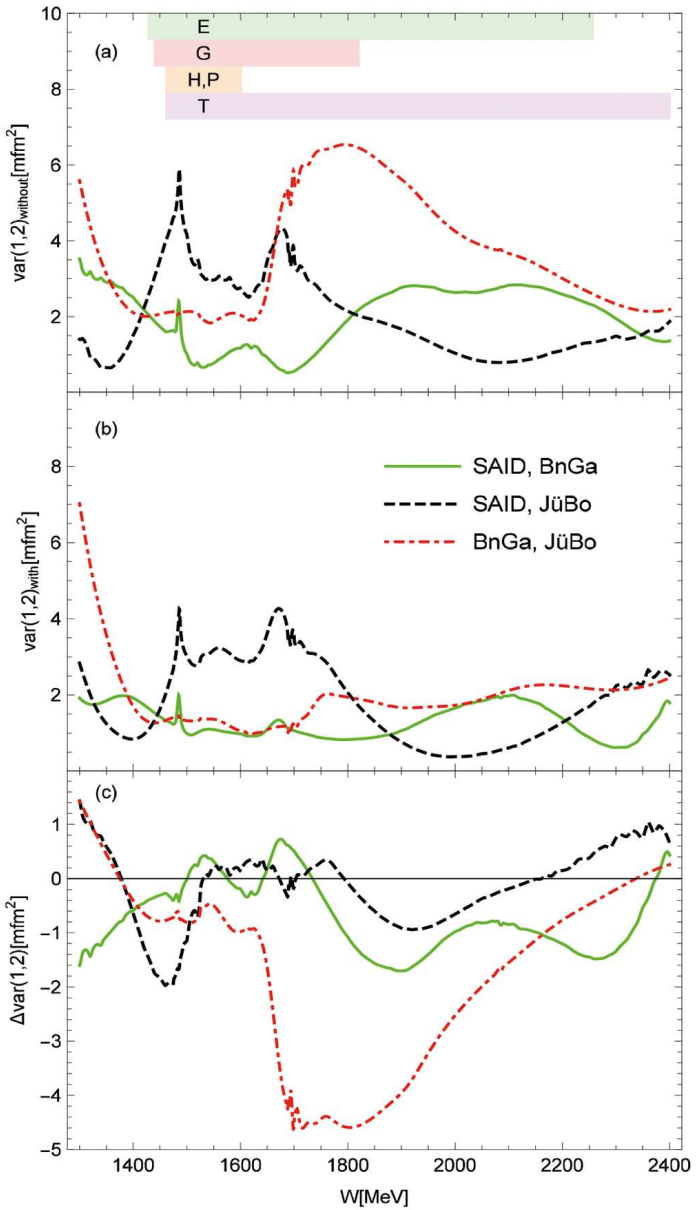


With new, precise data:

$\to$ convergence to a common solution?

- Pairwise variances between two PWAs:

$$\mathrm{var}(1,2) = \tfrac{1}{2} \sum_{i=1}^{16} \left(\mathcal{M}_1(i) - \mathcal{M}_2(i)\right) \left(\mathcal{M}_1^*(i) - \mathcal{M}_2^*(i)\right)$$

($\mathcal{M}$: $\gamma p \to \pi^0 p$ multipoles up to $L = 4$)

- beyond 1.7 GeV: BnGa, JüBo, SAID multipoles now in closer agreement
- 1.5 to 1.7 GeV:
  - BnGa agrees well with SAID and with JüBo
  - larger discrepancies between SAID and JüBo

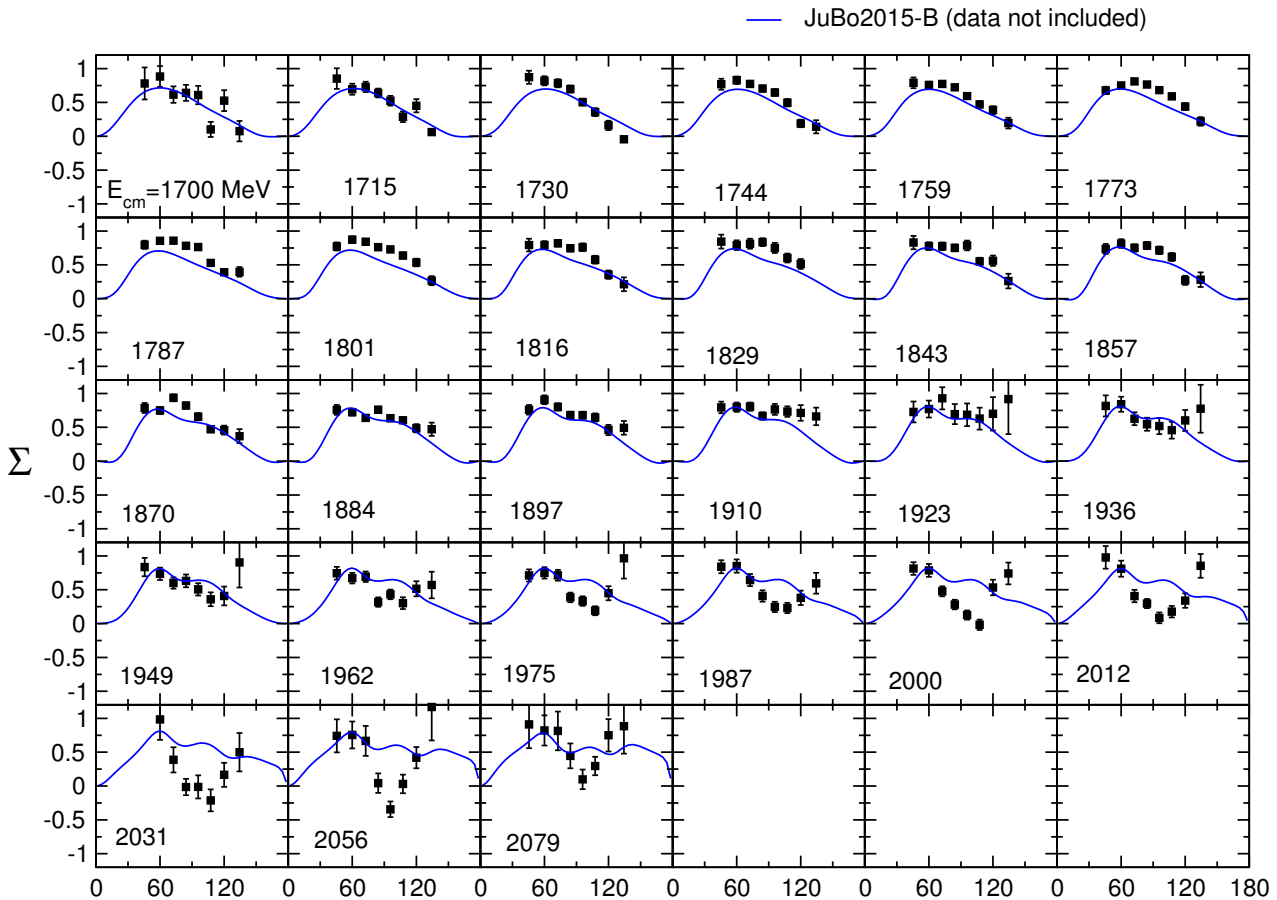
$\Rightarrow$ On a good way: improved agreement of the three solutions

Results II: Analysis of new CLAS data: Σ in $\gamma p \to \eta p$

with the CLAS Collaboration

PLB 771, 213 (2017)

- "Prediction" from JüBo2015-1 solution (earlier Σ data in $\gamma p \to \eta p$ included):

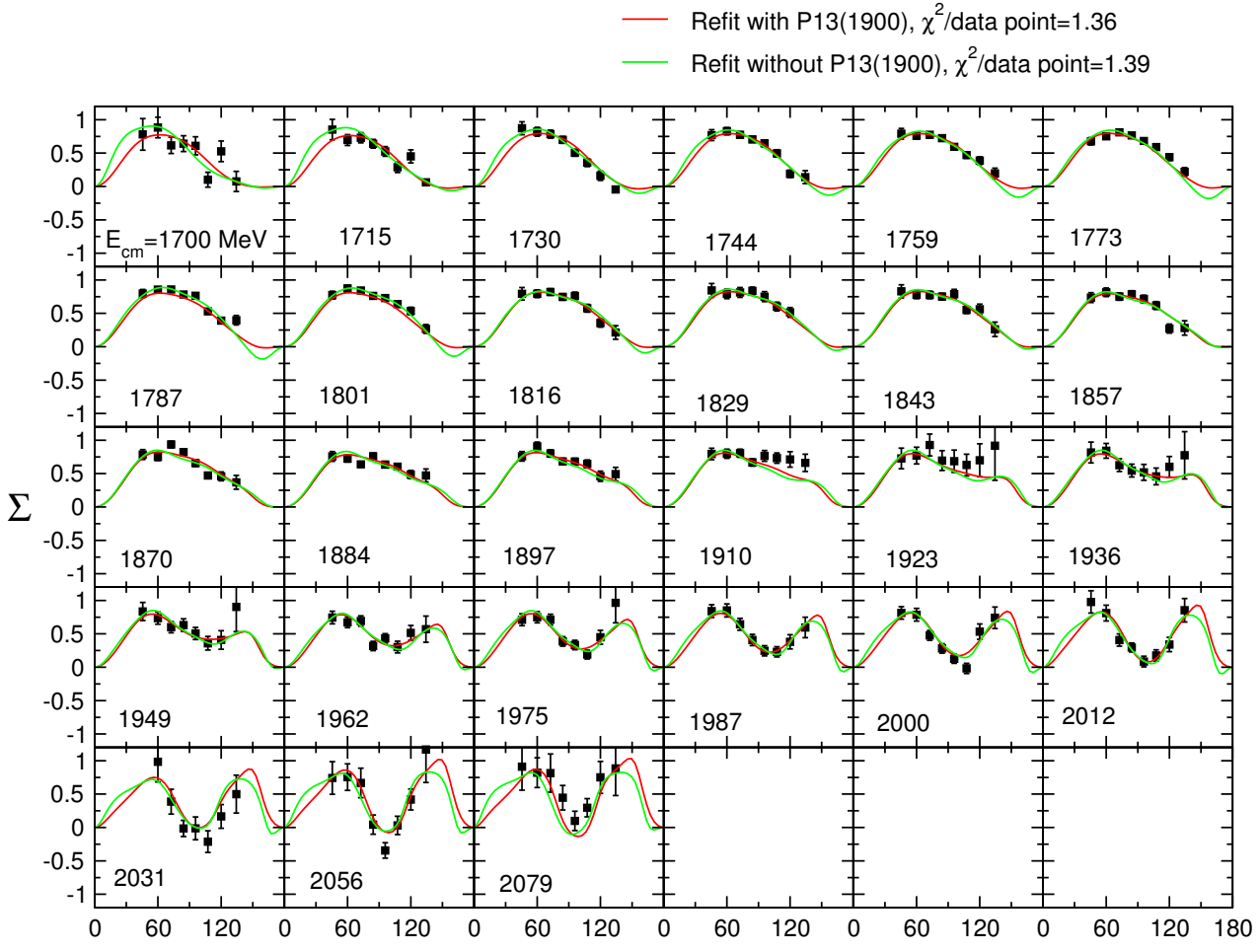


Data: CLAS, P. Collins *et al.* PLB 771, 213 (2017)

Results II: Analysis of new CLAS data: Σ in $\gamma p \to \eta p$

with the CLAS Collaboration PLB 771, 213 (2017)

- Fit to new data:



$\Rightarrow$ $P_{13}(1900)$ not important for this observable in this reaction.

Results III: Extension of the JüBo DCC approach to $\gamma p \to K^+\Lambda$ (preliminary)

- **simultaneous** fit of $\gamma p \to \pi^0 p$, $\pi^+ n$, ηp, $K^+\Lambda$ & $\pi N \to \pi N$, ηN , $K\Lambda$, $K\Sigma$
- $\sim$ 40.000 data points, $\sim$ 500 free parameters
  ↳ fit with JURECA supercomputer: parallelization in energy ($\sim$ 300 - 400 processes)

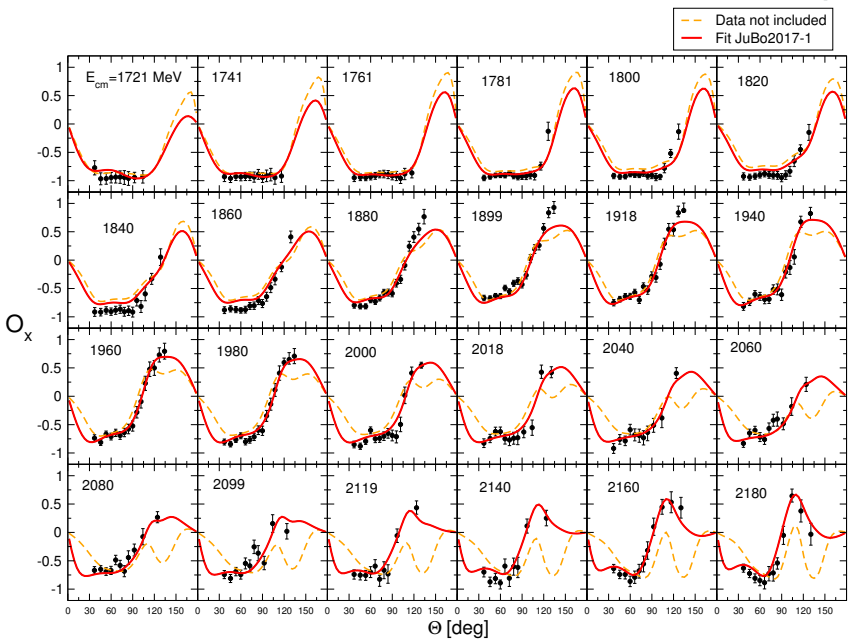
Kaon-photoproduction

Measurement of **recoil polarization** easier due to self-analysing decay of hyperons

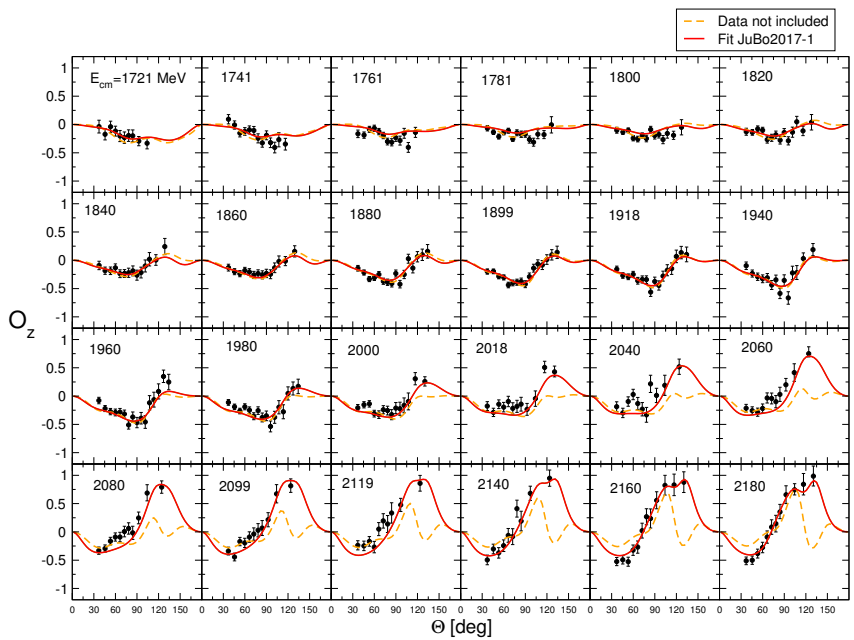
→ more recoil and beam-recoil data available

→ possibility of finding new, so far missing states? (**"missing resonances problem"**)

Recent CLAS data on Σ, T, $\mathbf{O_x}$, $\mathbf{O_z}$ for $\gamma p \to K\Lambda$, $K\Sigma$ (Paterson PRC 93, 065201 (2016)):



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



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

Results III: new states found in the analysis of $\gamma p \to K^+\Lambda$ (preliminary)

simultaneous fit of $\gamma p \to \pi^0 p$, $\pi^+ n$, ηp, $K^+\Lambda$ & $\pi N \to \pi N$, ηN , $K\Lambda$, $K\Sigma$

Previous JüBo analyses of photoproduction:

- resonances included in studies of pion-induced reactions sufficient to describe $\gamma p \to \pi N$, ηN, no additional dynamically generated poles

Inclusion of $\gamma p \to K^+\Lambda$ in JüBo ("JuBo2017-1"): 4 additional states

	z_0 [MeV]	$\frac{\Gamma_{\pi N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{\eta N}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Lambda}}{\Gamma_{\text{tot}}}$	$\frac{\Gamma_{K\Sigma}}{\Gamma_{\text{tot}}}$
N(*1730*)1/2$^-$	$1731 - i\,78.73$	1.86 %	1.30 %	56.43 %	1.11 %
N(1900)3/2$^+$	$1923 - i\,108.4$	1.5 %	0.78 %	2.99 %	69.5 %
N(2060)5/2$^-$	$1924 - i\,100.4$	0.35 %	0.15 %	13.47 %	27.02 %
Δ(*2190*)3/2$^+$	$2191 - i\,103.0$	33.12 %			3.78 %

- N(*1730*)1/2$^-$: dyn. gen., no equivalent PDG state
- N(1900)3/2$^+$: s-channel resonances, seen in many other analyses of kaon photoproduction (e.g. BnGa), 3 stars in PDG
- N(2060)5/2$^-$: dynamically generated, 2 stars in PDG, seen e.g. by BnGa
- Δ(*2190*)3/2$^+$: dyn. gen., no equivalent PDG state

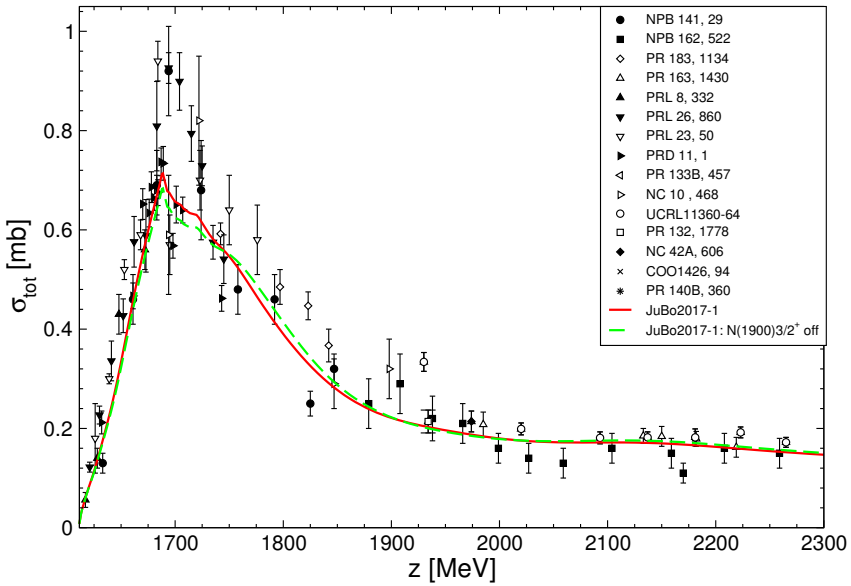
$***$: Existence is very likely but further confirmation of decay modes is required

$**$: Evidence of existence is only fair

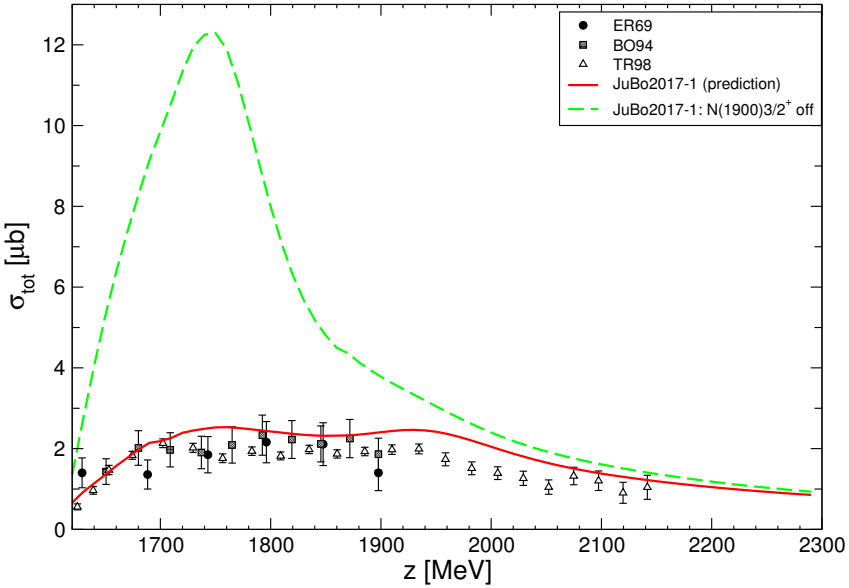
Results III: impact of new states (preliminary)

- N(1900)3/2$^+$:

$\pi^- p \to K^0 \Lambda$



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



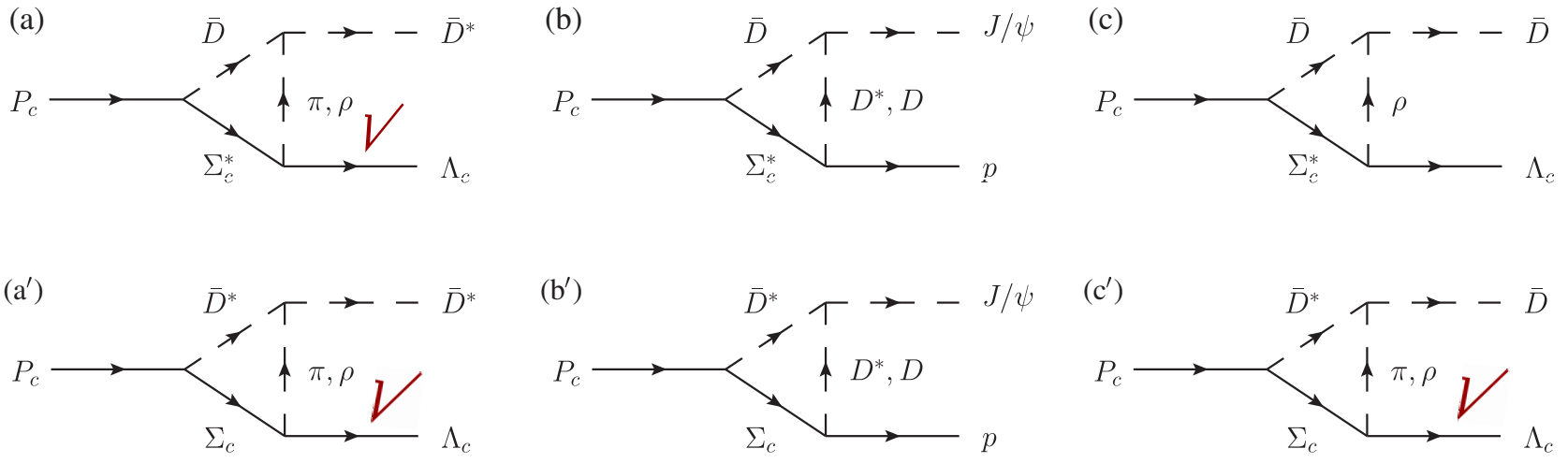
→ not very likely to see the N(1900)3/2$^+$ in $\pi^- p \to K^0 \Lambda$

→ kaon photoproduction important

JuBo2017-1: new DCC fit including $K^+ \Lambda$ photoproduction

Results IV: Disentangling $\bar{D}\Sigma_c^*/\bar{D}^*\Sigma_c$ nature of the P_c^+ states from their decay behaviour

Y.-H. Lin, C.-W. Shen, F.-K. Guo, B.-S. Zou, PRD 95, 114017 (2017)



- It is found that π exchange gives the largest decay modes

$\Rightarrow$ More details: talk by Chao-Wei Shen on Thursday

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Y.-H. Lin, C.-W. Shen, F.-K. Guo, B.-S. Zou, PRD 95, 114017 (2017)

	Widths (MeV)			
	$P_c(4380)$		$P_c(4450)$	
Mode	$\bar{D}\Sigma_c^*(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{3}{2}^-)$	$\bar{D}^*\Sigma_c(\frac{5}{2}^+)$
$\bar{D}^*\Lambda_c$	131.3 ✓	35.3 ✓	72.3 ✓	20.5 ✓
$J/\psi p$	3.8	16.6	16.3	4.0
$\bar{D}\Lambda_c$	1.2	17.0 ✓	41.4 ✓	18.8 ✓
πN	0.06	0.07	0.07	0.2
$\chi_{c0}p$	0.9	0.004	0.02	0.002
$\eta_c p$	0.2	0.09	0.1	0.04
ρN	1.4	0.15	0.14	0.3
ωp	5.3	0.6	0.5	0.3
$\bar{D}\Sigma_c$	0.01	0.1	1.2	0.8
$\bar{D}\Sigma_c^*$	...	...	7.7	1.4
$\bar{D}\Lambda_c\pi$	11.6	...	...	...
Total	144.3	69.9	139.8	46.4

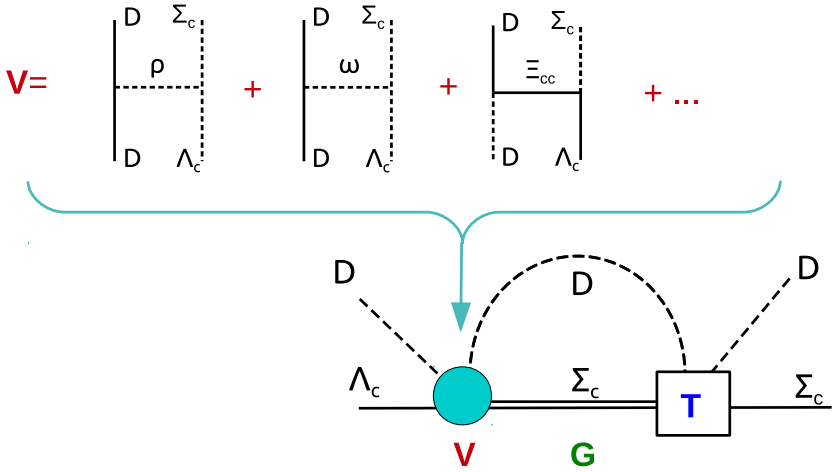
$\Rightarrow$ It is very important to study $P_c \to \bar{D}^*\Lambda_c$ and $\bar{D}\Lambda_c$!

Results V: Extension of the JüBo DCC approach to hidden charm & beauty

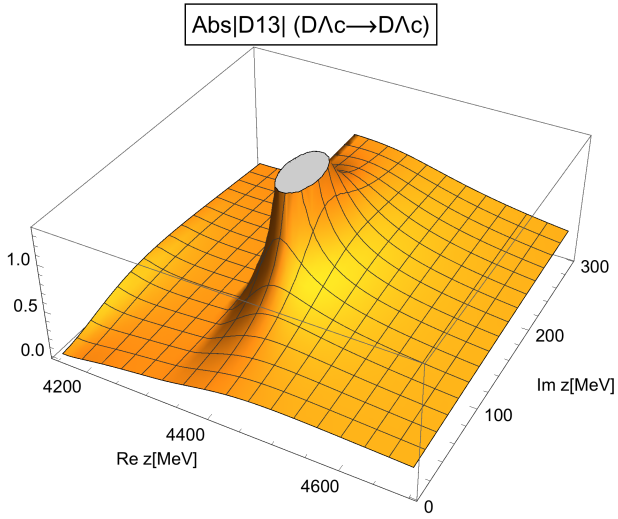
(preliminary)

⇒ Analysis of super-heavy $N^*_{c\bar{c}}$ and $N^*_{b\bar{b}}$

- Starting point: extension of the JüBo DCC approach to hidden charm
- $\bar{D}\Lambda_c \to \bar{D}\Lambda_c$, $\bar{D}\Sigma_c$ and $\bar{D}\Sigma_c \to \bar{D}\Sigma_c$
- predictions of cross sections and amplitudes
- search for dynamically generated poles in the complex energy plane of T



Selected results:



- pole in the D_{13} $(3/2^-)$ wave with z_0 and J^P in agreement with LCHb $P_c(4380)^+$
- pole in F_{15} $(5/2^+)$ wave: much broader than $P_c(4450)^+$

⇒ More details: talk by Chao-Wei Shen on Thursday

Summary

Milestones:

- DCC analysis of $\gamma p \to K^+\Lambda$: publication in preparation
- DCC analysis of $\gamma p \to K^+\Sigma^0$, $K^0\Sigma^+$: fit in progress
- reactions with hidden charm and hidden beauty: proof of concept calculations, preliminary results for super-heavy N^*

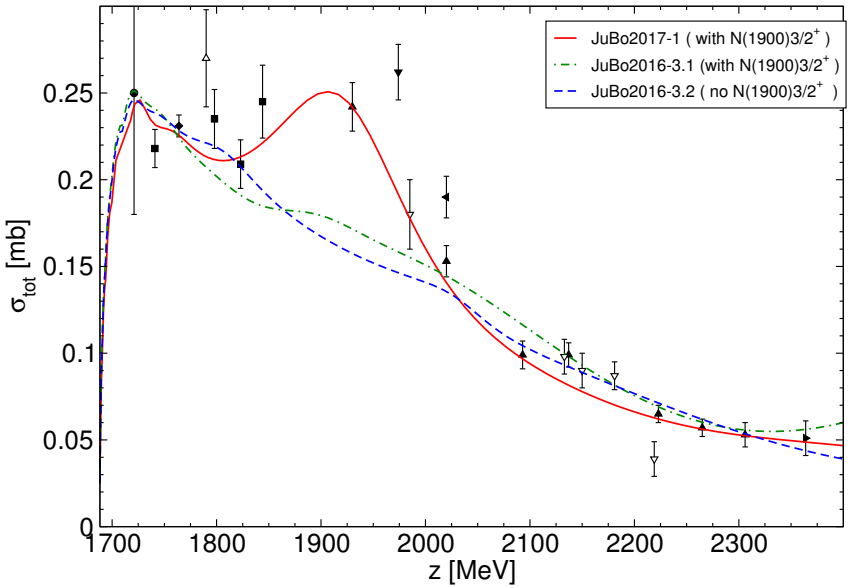
Publications:

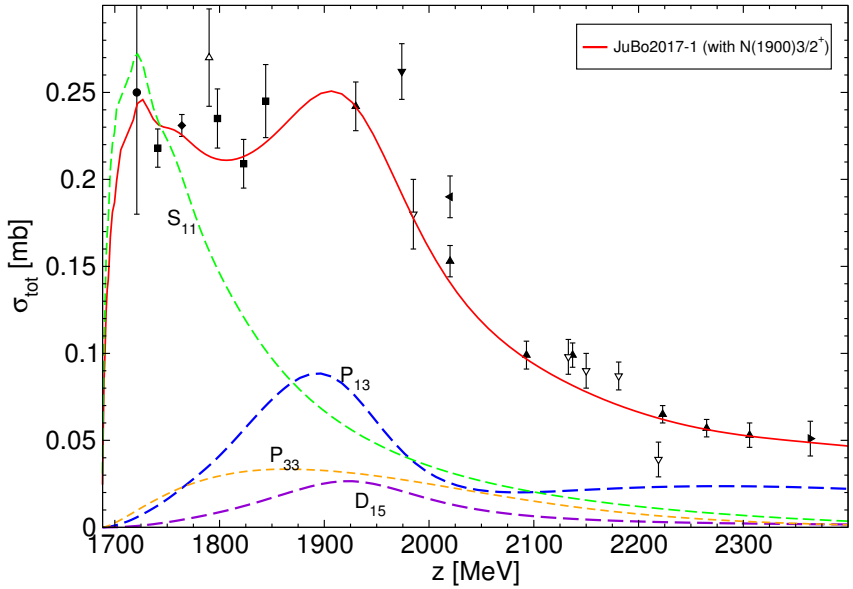
- A. V. Anisovich, *et al.*, "The impact of new polarization data from Bonn, Mainz and Jefferson Laboratory on $\gamma p \to \pi N$ multipoles," Eur. Phys. J. A **52**, 284 (2016) [arXiv:1604.05704 [nucl-th]]
- C. W. Shen, F. K. Guo, J. J. Xie and B. S. Zou, "Disentangling the hadronic molecule nature of the $P_c(4380)$ pentaquark-like structure," Nucl. Phys. A **954**, 393 (2016) [arXiv:1603.04672 [hep-ph]].
- P. Collins *et al.*, "Photon beam asymmetry Σ for η and η' photoproduction from the proton," Phys. Lett. B **771**, 213 (2017) [arXiv:1703.00433 [nucl-ex]]
- Y. H. Lin, C. W. Shen, F. K. Guo and B. S. Zou, "Decay behaviors of the P_c hadronic molecules," Phys. Rev. D **95**, 114017 (2017) [arXiv:1703.01045 [hep-ph]].

Appendix

Results III: impact of new states (preliminary)

- N(1900)3/2$^+$, N(2060)5/2$^-$ in σ_{tot} in $\pi^- p \to K^+ \Sigma^-$:





JuBo2017-1: new DCC fit including $K^+\Lambda$ photoproduction
JuBo2016-3.1 and 3.2: analysis of new CLAS data: Σ in $\gamma p \to \eta p$ (PLB 771, 213 (2017)),
kaon photo data not included

- $\Delta(2190)3/2^+$ in πN PW: