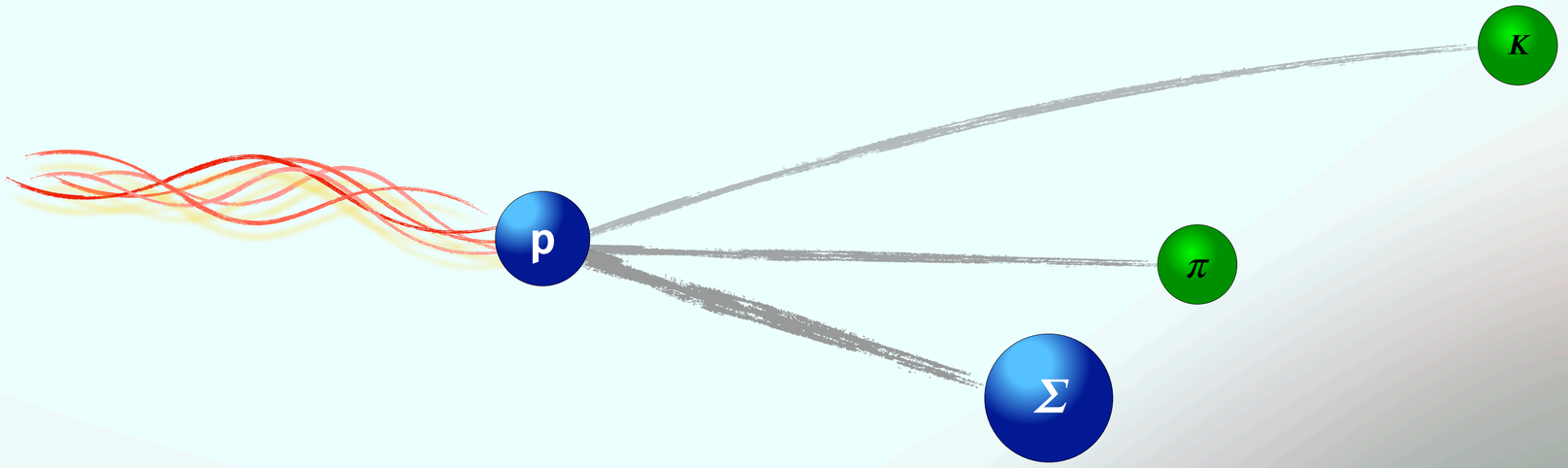
$\Lambda(1405)$ from $(\pi\Sigma)K$ photoproduction



Maxim Mai

University Bonn

The George Washington University

INTRODUCTION

this talk

CURIOUS CASE: $\Lambda(1405)$

Impact

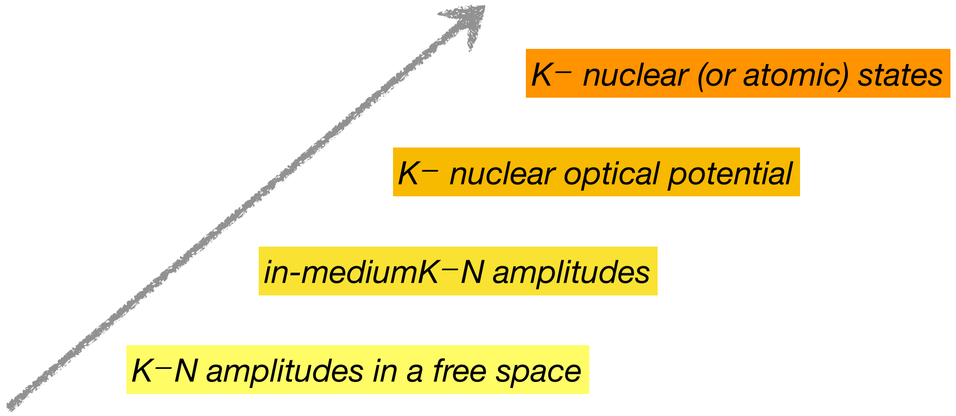
- Test of our understanding of QCD

1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**
2) Cieply et al. (2011); ...

CURIOUS CASE: Λ(1405)

Impact

- Test of our understanding of QCD
- KbarNN & KbarNNN bound states[1]



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2) Cieply et al. (2011); ...

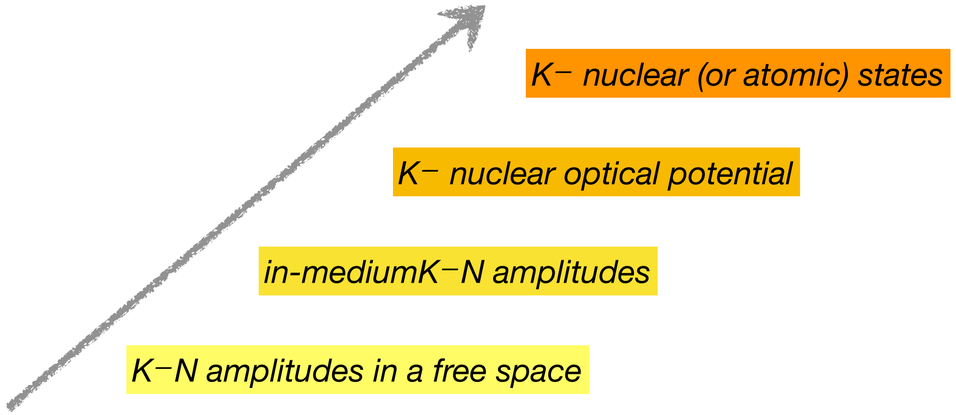
CURIOUS CASE: Λ(1405)

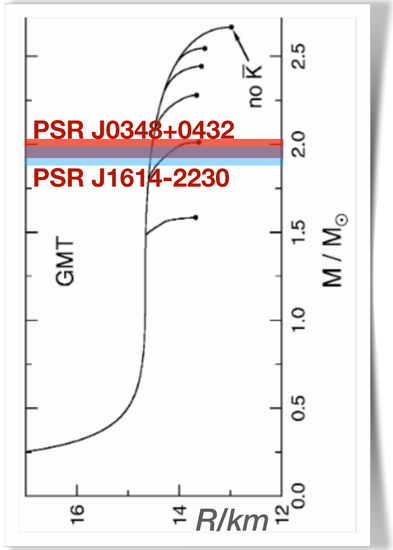
Impact

- Test of our understanding of QCD
- KbarNN & KbarNNN bound states[1]
- K- in medium[2]

  K- condensate can change NS EoS

  ... many theoretical challenges[3]





Pal et al. (2000)

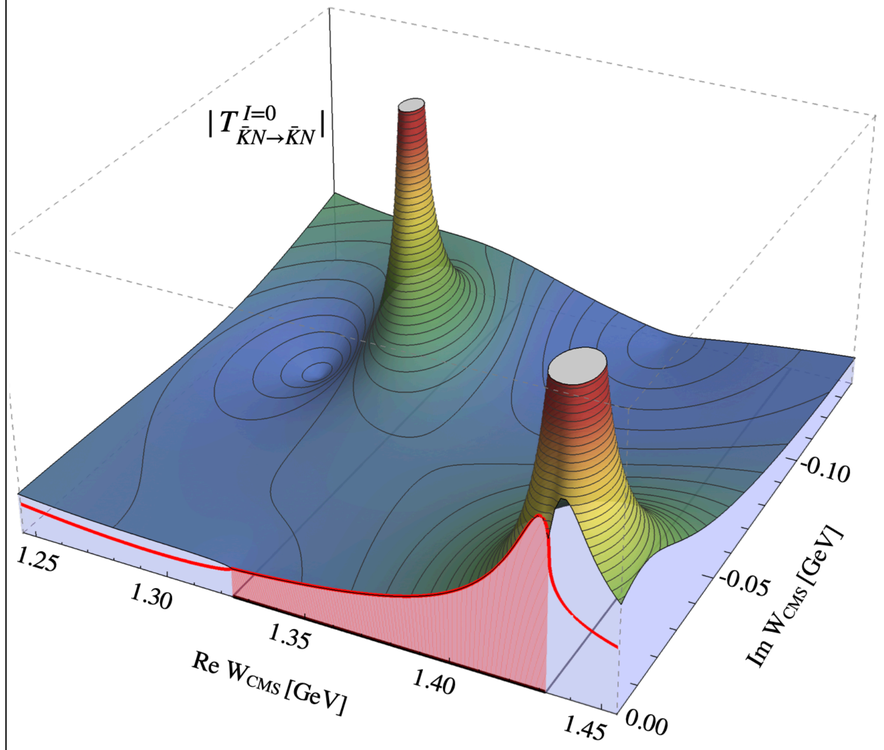
1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**
2) Cieply et al. (2011); ...

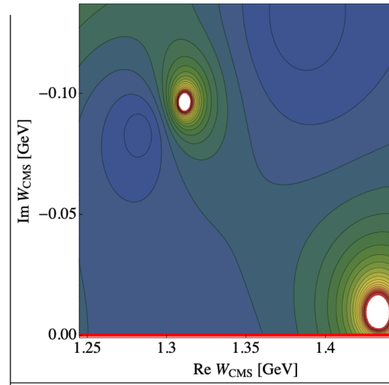
KBARN SCATTERING

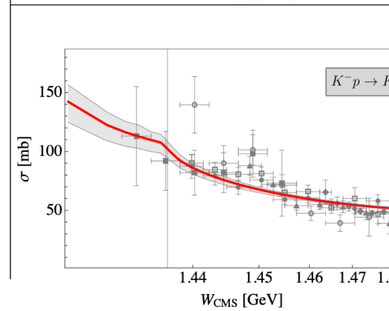
Universal resonance parameters:

- analyticity of the scattering amplitude

  ➟ poles on the 2. Riemann sheet







1) Hall et al. PRL 114(2015); **TALK: A.W.Thomas**

Review: MM Eur.Phys.J.ST 230 (2021)

KBARN SCATTERING

Universal resonance parameters:

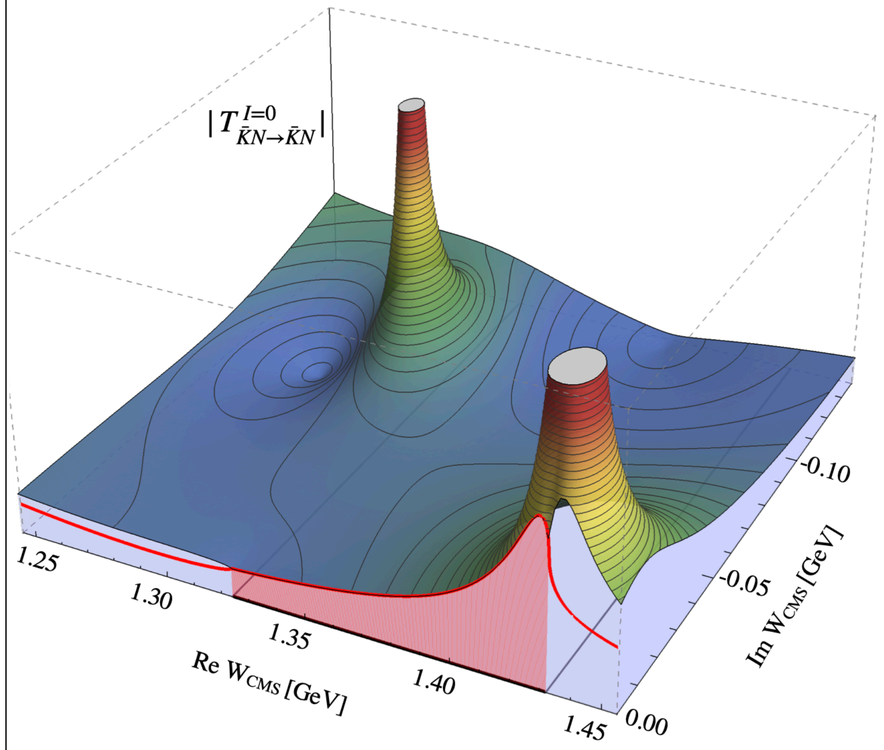
- analyticity of the scattering amplitude

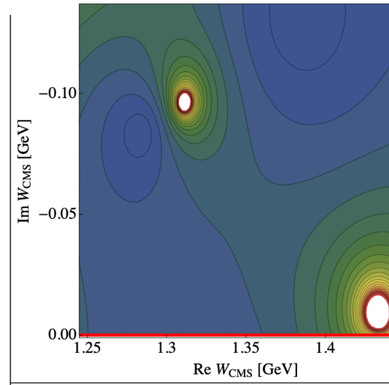
  ➟ poles on the 2. Riemann sheet

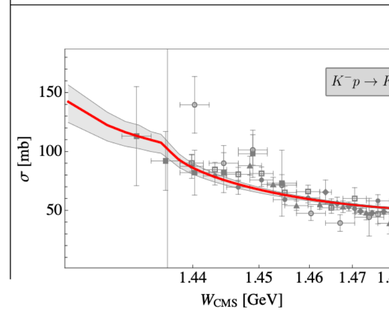
- physical information at $E \in \mathbb{R}$ from:

  1. Theory: Lattice QCD[1]

  2. Experiment







1) Hall et al. PRL 114(2015); **TALK: A.W.Thomas**

Review: MM Eur.Phys.J.ST 230 (2021)

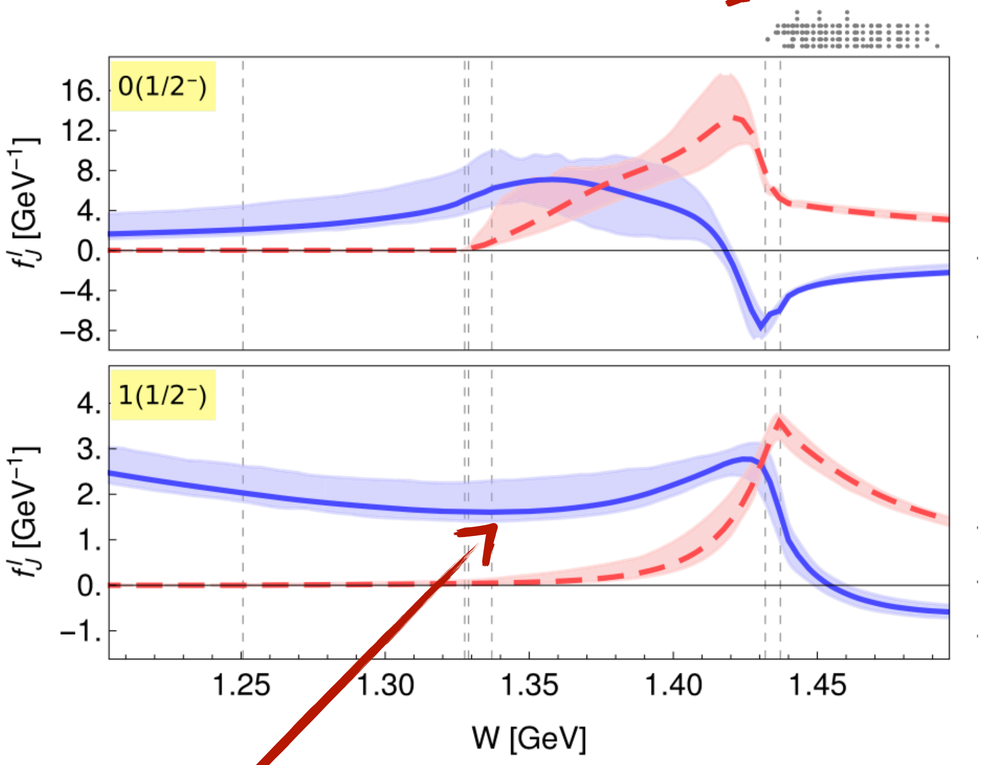
KbarN SCATTERING

Challenge

- many data available above/at the KbarN threshold[1]
- going below...

  ➥ use chiral symmetry / unitarity / ... [2]

two-body data



scattering amplitude

Sadasivan, MM, Döring (2019)

1) Bubble chamber experiments; [SIDDHARTA] Bazzi et al. (2009);
2) **Reviews**: Meißner(2020); MM (2021); Hyodo (2021);
3) e.g. [CLAS] Moryia et al. (2015)

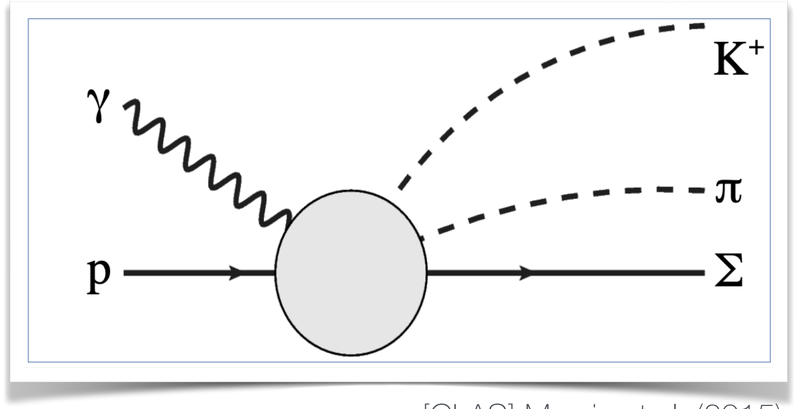
KbarN SCATTERING

Challenge

- many data available above/at the KbarN threshold[1]
- going below...

  ➥ use chiral symmetry / unitarity / ... [2]

  ➥ experiments with 3-body final states[3]



[CLAS] Moryia et al. (2015)

CLAS data on γp → $K^+\pi\Sigma$

- 9 energy bins
- 60 values of M(πΣ)
- 3 channels: $\pi^+\Sigma^-$, $\pi^-\Sigma^+$, $\pi^0\Sigma^0$

➥ $J^P = 1/2^-$ "confirmed" experimentally
➥ high statistics and good angular resolution

➥ requires a photoproduction amplitude

1) Bubble chamber experiments; [SIDDHARTA] Bazzi et al. (2009);
2) **Reviews**: Meißner(2020); MM (2021); Hyodo (2021);
3) e.g. [CLAS] Moryia et al. (2015)

CASE 1

"can photoproduction data reduce ambiguity on KbarN scattering amplitude?"

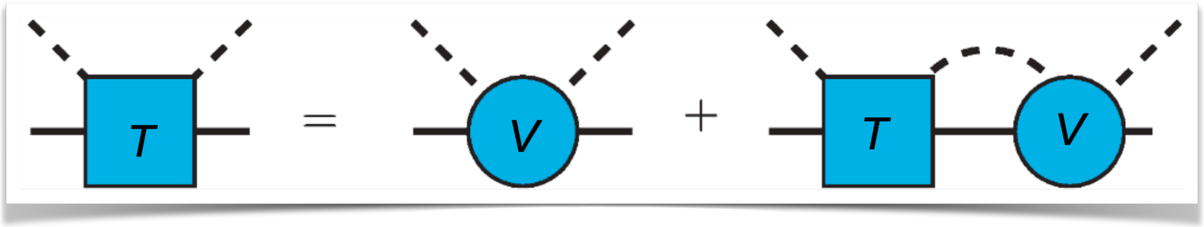
MM, Ulf-G. Meißner *Eur.Phys.J.A* 51 (2015) 3, 30

HADRONIC PART

- Unitarity of the S-matrix:

  > mathematical foundation of universality of resonance parameters

  > one implementation: Bethe-Salpeter equation



HADRONIC PART

- Unitarity of the S-matrix:

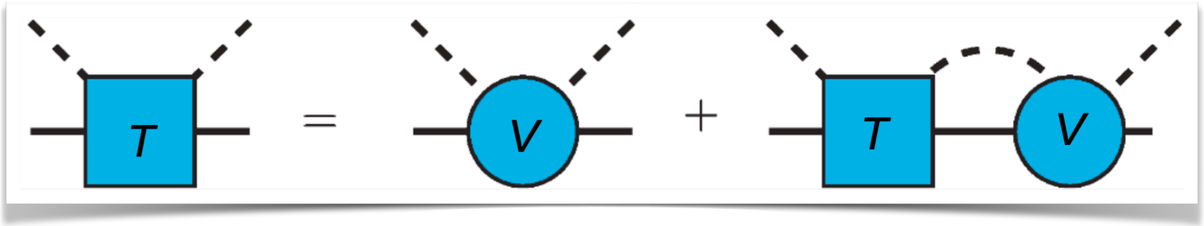
  > mathematical foundation of universality of resonance parameters

  > one implementation: Bethe-Salpeter equation

- ChPT[1]: (Effective field theory of QCD)

  > incorporates symmetries of QCD

  > reduces number of degrees of freedom



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

1) Weinberg (1979) Gasser, Leutwyler (1981)

HADRONIC PART

- Various implementations

➥ many scenarios with NLO kernel[1] tested

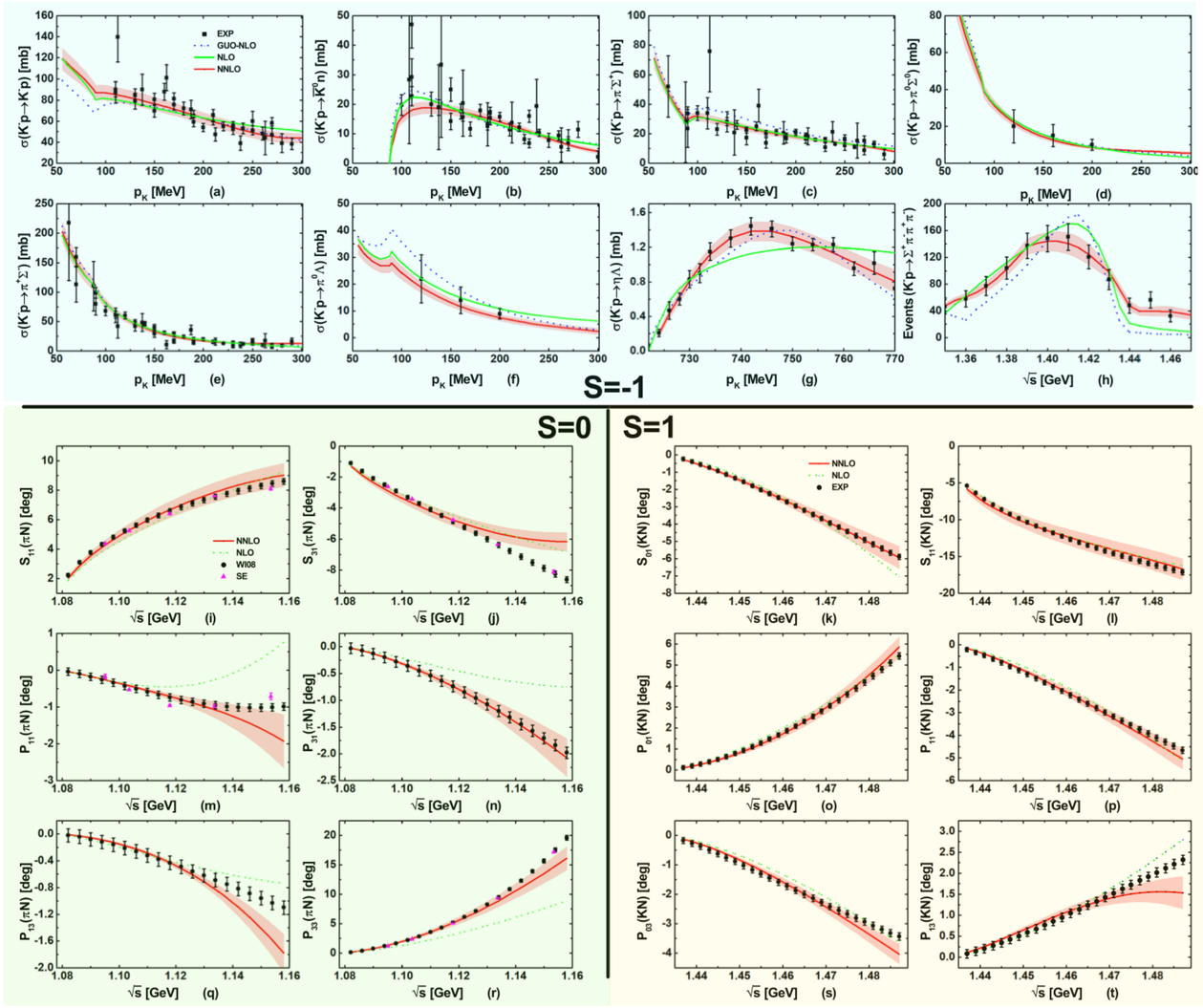
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadasivan et al. (2019)

HADRONIC PART

- Various implementations

➥ many scenarios with NLO kernel[1] tested

➥ first NNLO calculation[2] including $K_{bar}N/\pi N/KN$

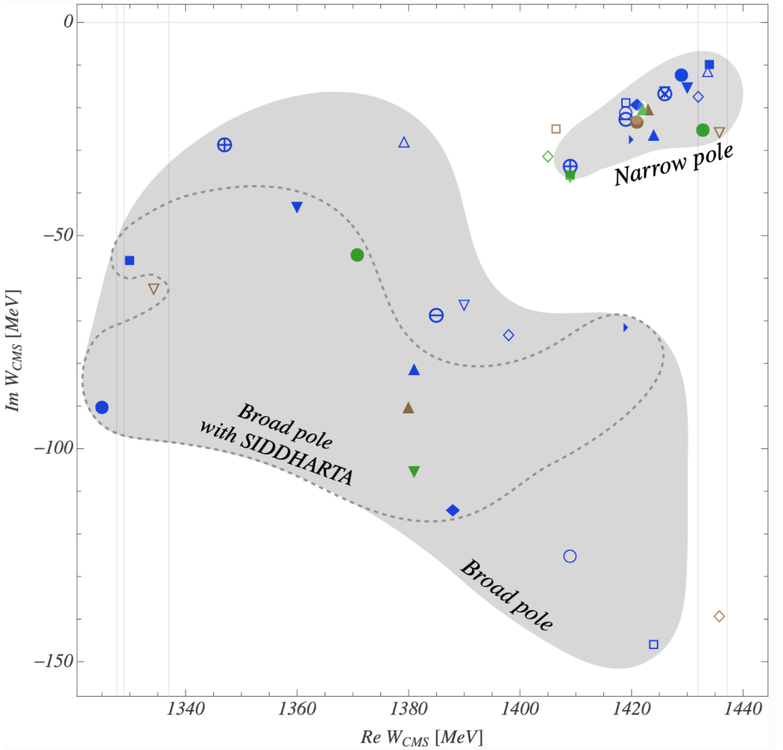


Lu/Geng/Döring/MM (2022)

1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadasivan et al. (2019)
2) Lu/Geng/Döring/MM (2022)

HADRONIC PART

- Various implementations
  - ➥ many scenarios with NLO kernel[1] tested
  - ➥ first NNLO calculation[2] including $K_{bar}N/\pi N/KN$
- Common feature:
  - ➥ good fit to threshold and scattering data
  - ➥ two poles with I=0, S=-1, J=1/2+



Chiral Unitary Approaches

■/●	Ref. [97]	○	Ref. [80]
▲	Ref. [145]	△	Ref. [143]
▼	Ref. [64]	▽	Ref. [151]
◆	Ref. [147]	□/◇	Ref. [184]
▶	Ref. [105]	⊗	Ref. [185]
		⊖/⊕	Ref. [88]

Dynamical coupled-channel models

●/▲	Ref. [63]	◇	Ref. [153]
□	Ref. [154]	▽	Ref. [155]

Potential models

●	Ref. [131]	▲	Ref. [134]
◇	Ref. [132]	■/▼	Ref. [101]

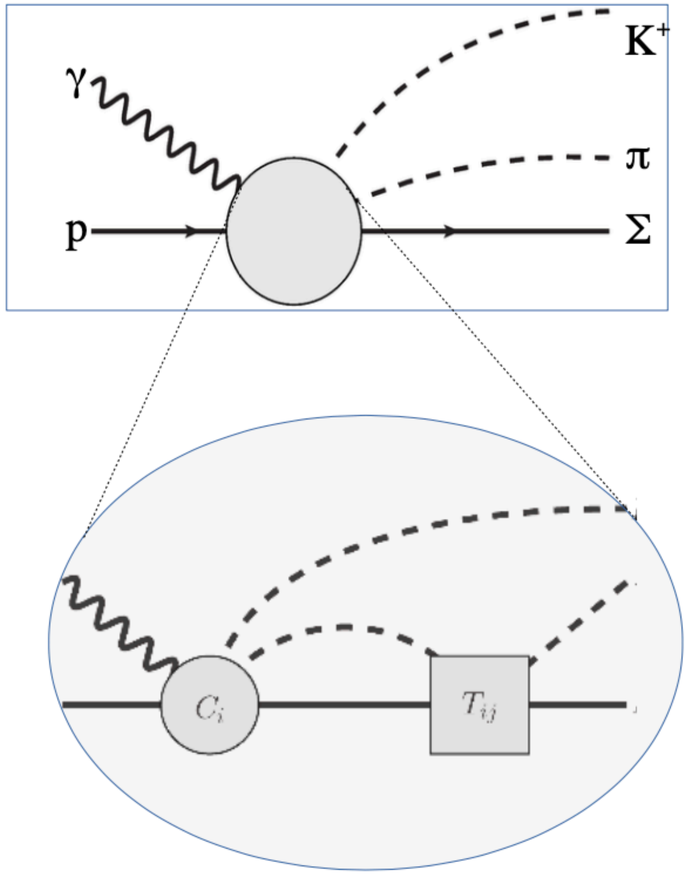
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadasivan et al. (2019)
2) Lu/Geng/Döring/MM (2022)

Review: MM Eur.Phys.J.ST 230 (2021)

PHOTOPRODUCTION

Test model[1,2]

- many new free parameters (*C*)
- no gauge invariance, parameters are not physical
- conservative test of the hadronic solutions

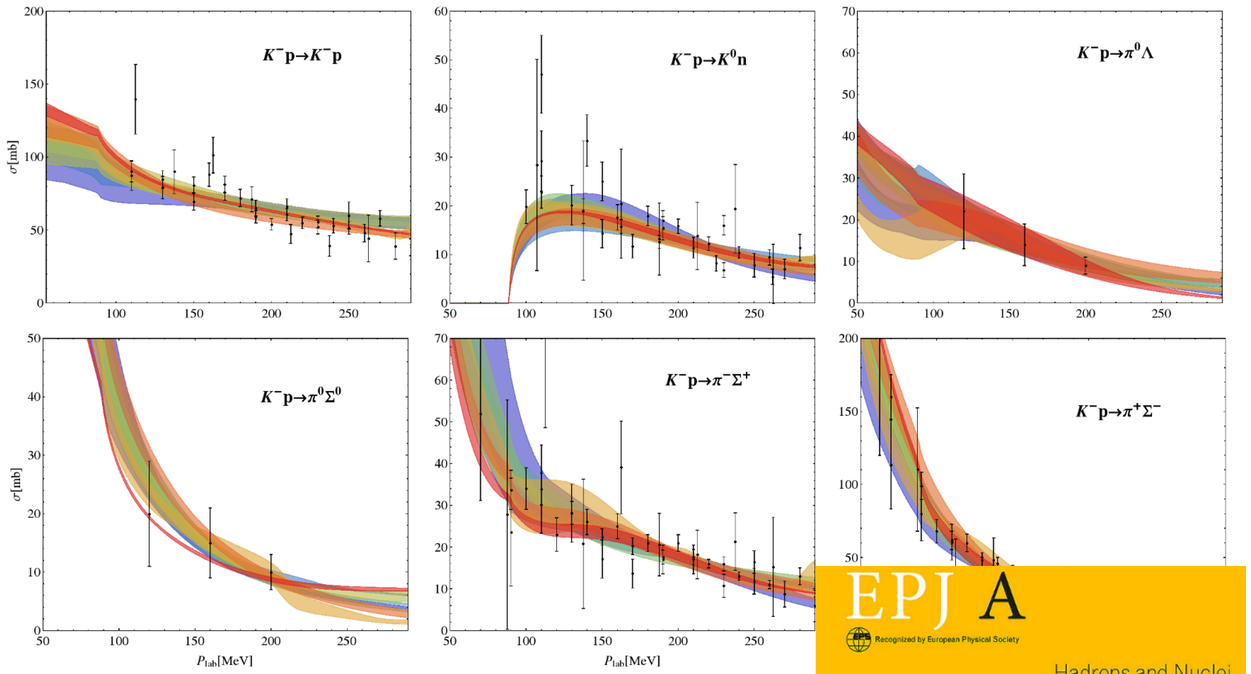


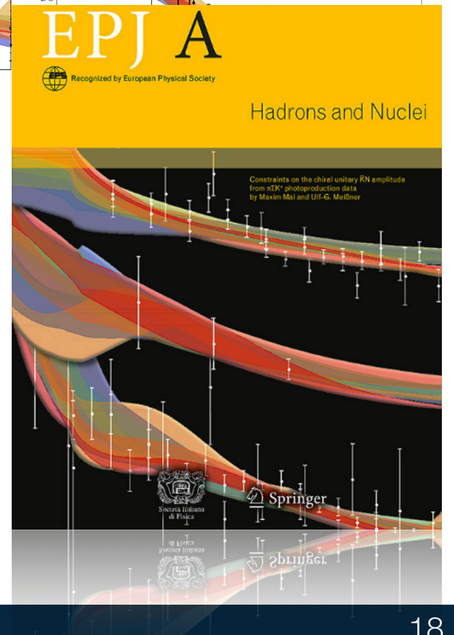
1) Oset, Roca (2013)
2) MM, Meissner(2015)

PHOTOPRODUCTION

Results:

- 8 local minima wrt. two-body data (χ^2~1) each propagates to a two poles on the 2. RS





MM/Meißner *Eur.Phys.J.A* 51 (2015) 3, 30

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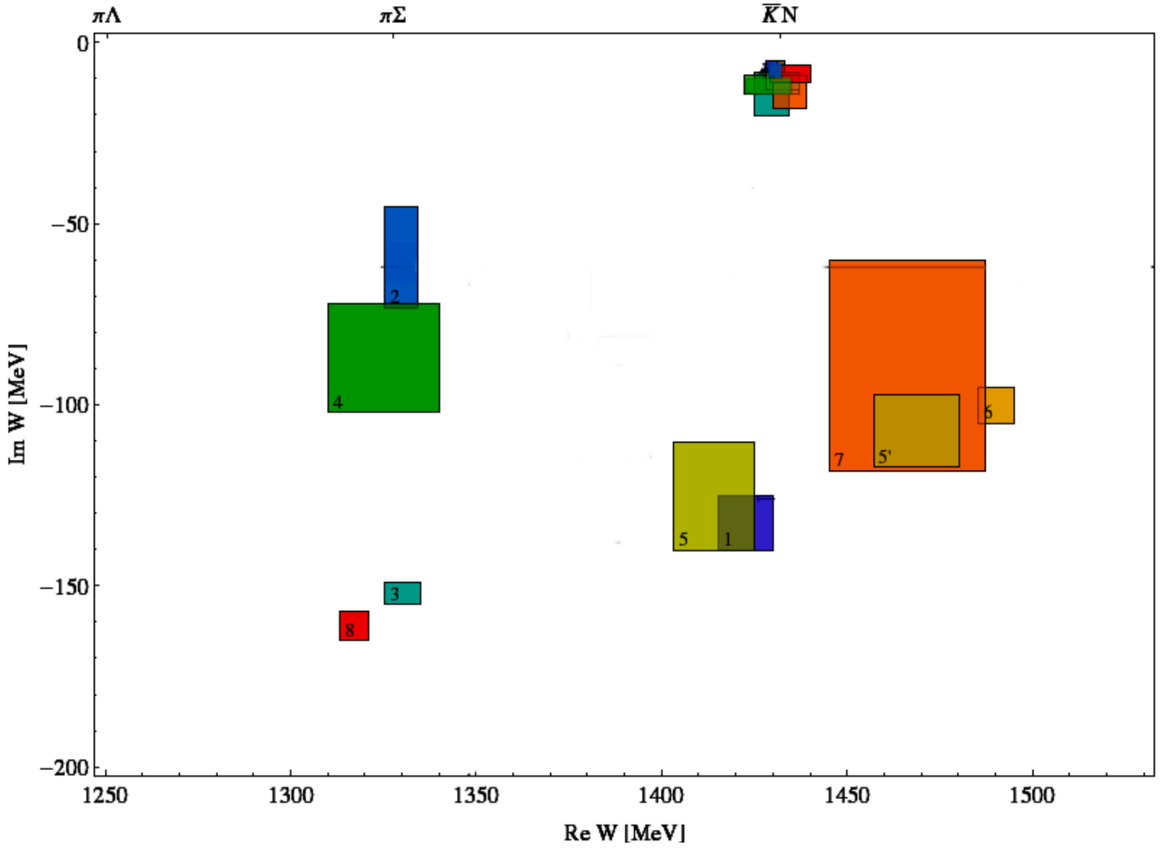
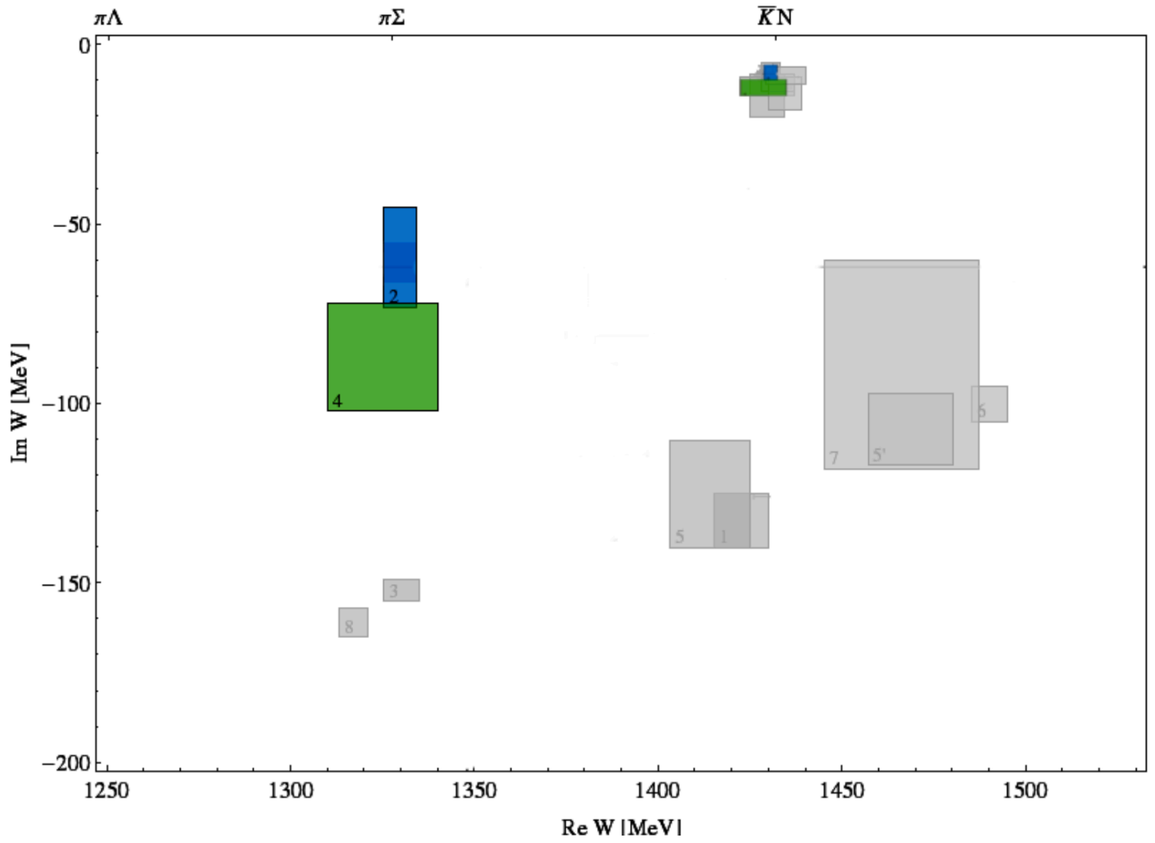


MM/Meißner *Eur.Phys.J.A* 51 (2015) 3, 30

PHOTOPRODUCTION

Results:

- 8 local minima wrt. two-body data (χ^2~1) each propagates to a two poles on the 2. RS
- only 2 solutions survive test wrt photoproduction data



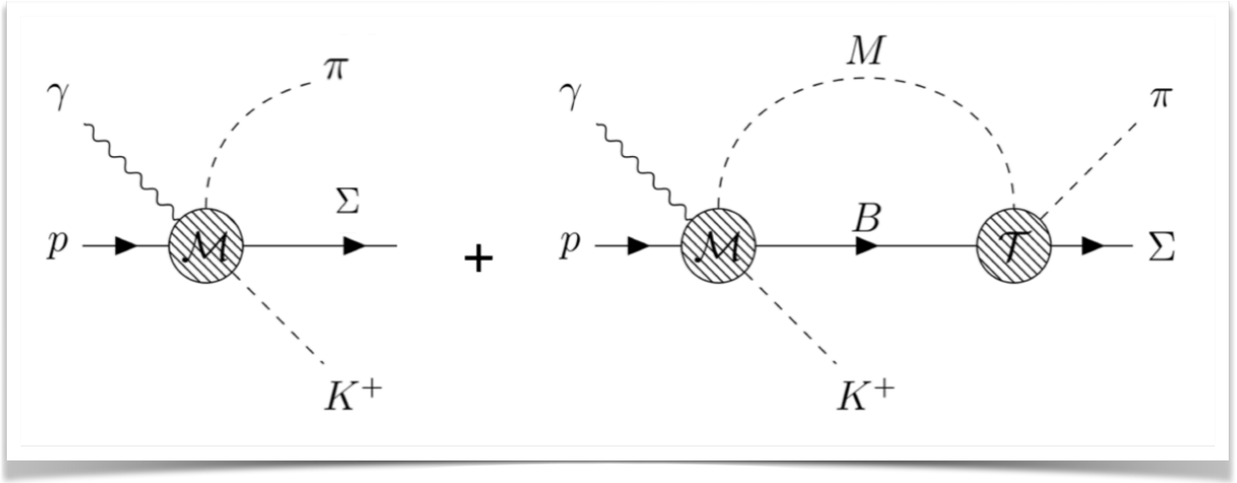
MM/Meißner *Eur.Phys.J.A* 51 (2015) 3, 30

level up the photoproduction model

CASE 2

P.C. Bruns, A. Cieplý, M. Mai 2206.08767 [nucl-th] in print at Phys. Rev. D

MICROSCOPIC MODEL

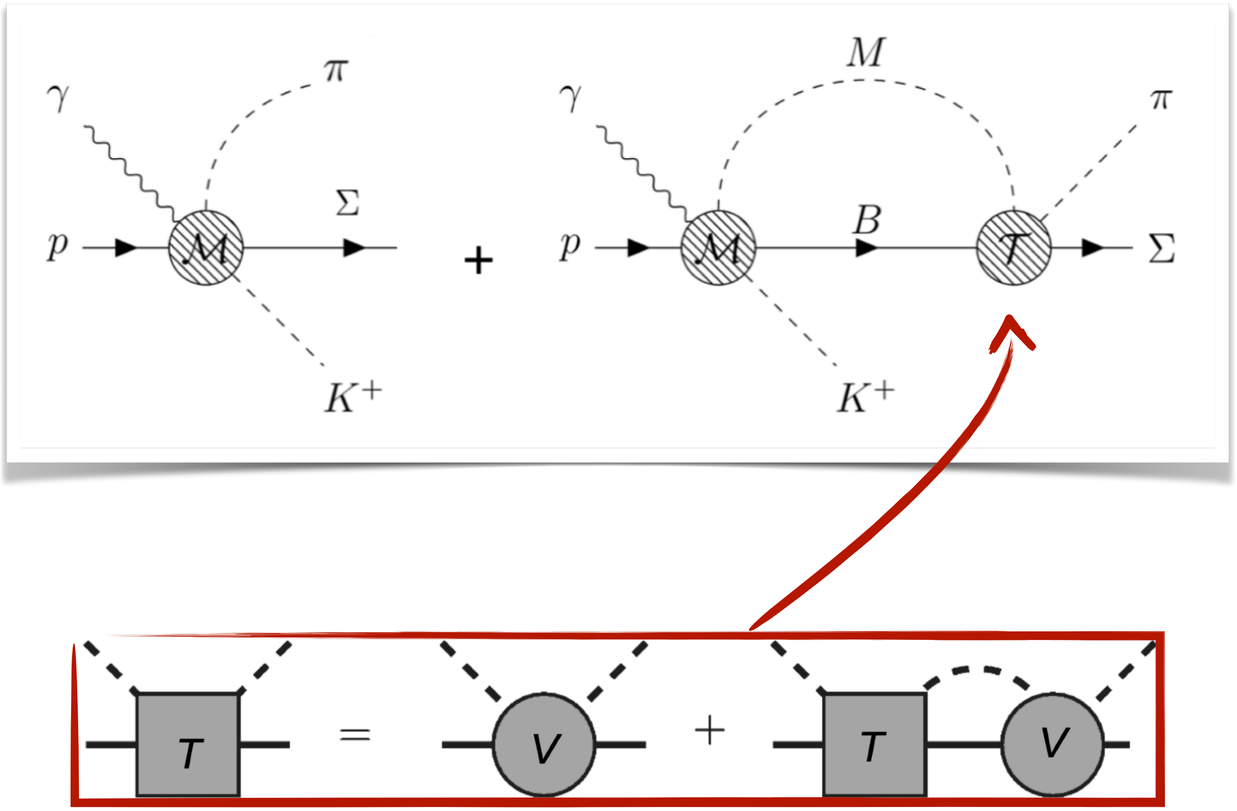


1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)
2) arXiv:2012.11298 [nucl-th].

MICROSCOPIC MODEL

- Theoretical constraints

➥ FSI 2-body unitarity from chiral unitary and potential models[1]



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MICROSCOPIC MODEL

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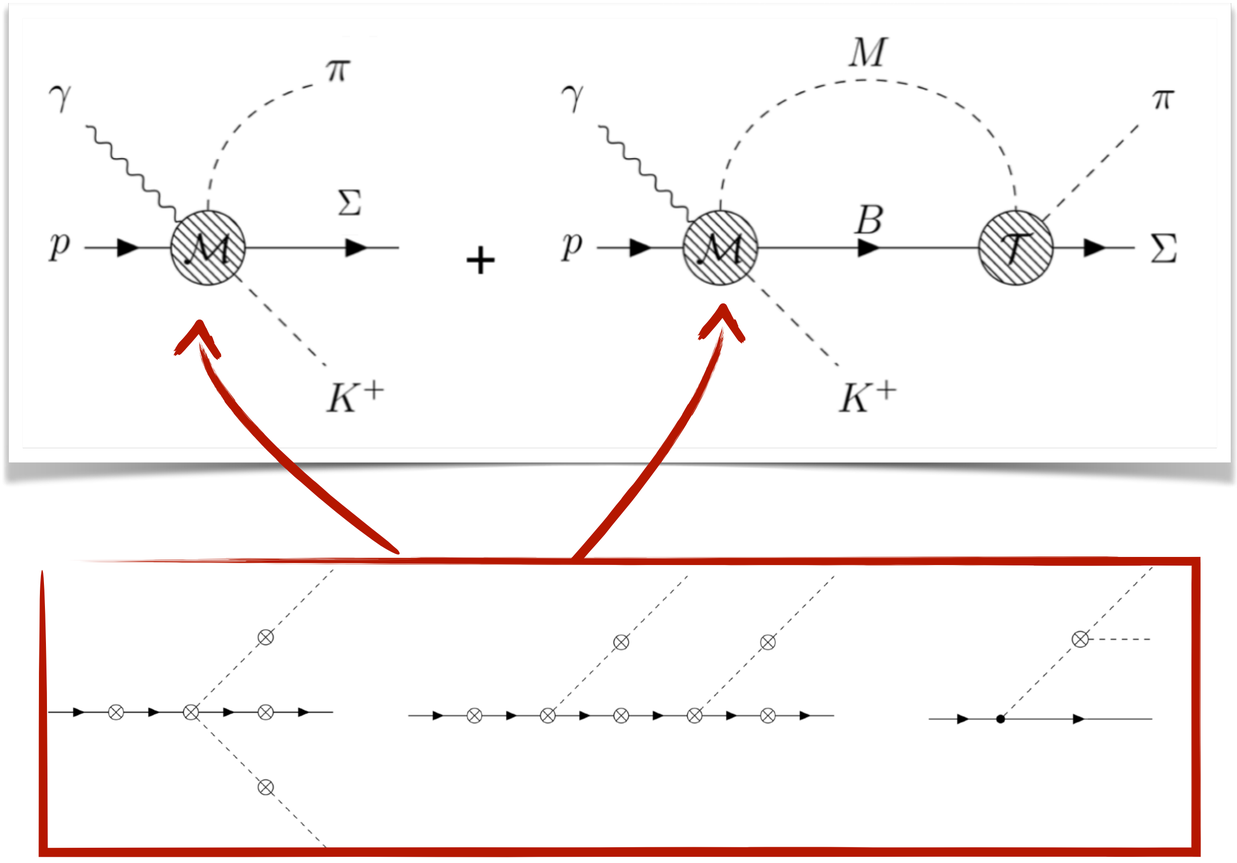
  ➥ chiral symmetry constraints on the production vertex[2]



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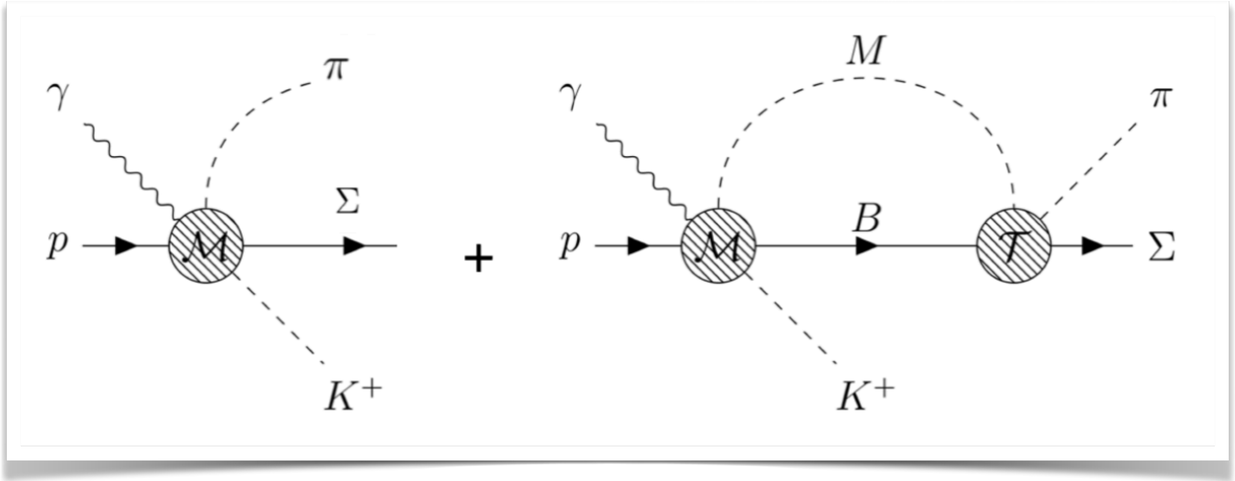
MICROSCOPIC MODEL

- Theoretical constraints

  ➥ FSI 2-body unitarity from chiral unitary and potential models[1]

  ➥ chiral symmetry constraints on the production vertex[2]

  ➥ gauge invariance included by construction



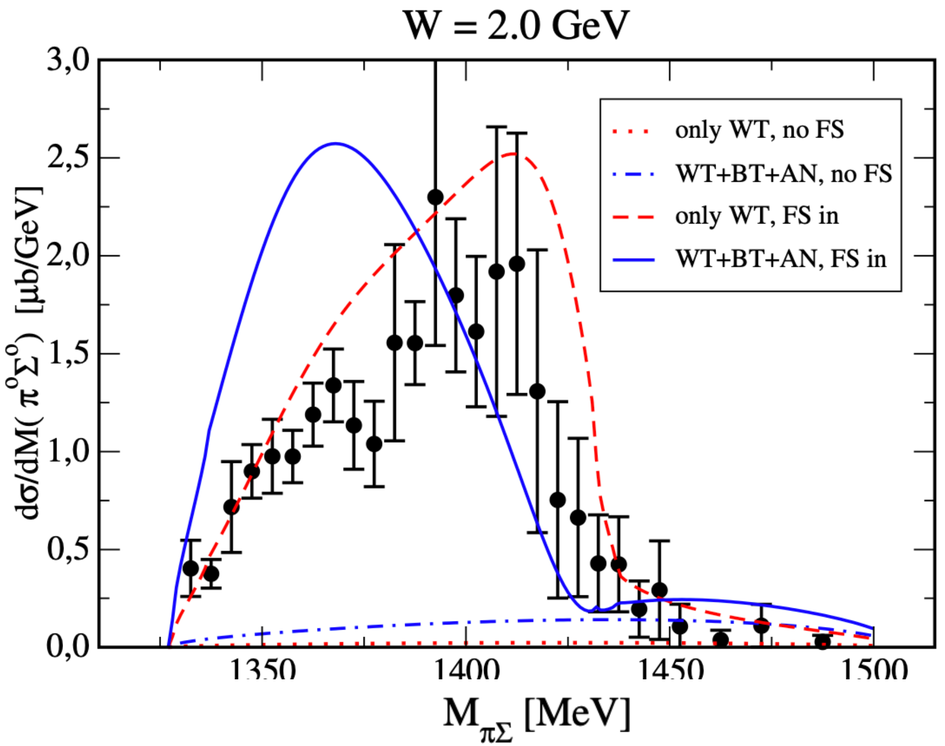
$$(s - m_N^2)\mathcal{M}_2 \stackrel{!}{=} (u_\Sigma - m_\Sigma^2)\mathcal{M}_3 + (t_K - M_K^2)\mathcal{M}_4$$
$$2\mathcal{M}_1 + (s - m_N^2)\mathcal{M}_6 \stackrel{!}{=} (u_\Sigma - m_\Sigma^2)\mathcal{M}_7 + (t_K - M_K^2)\mathcal{M}_8$$

arXiv:2012.11298 [nucl-th].

1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)
2) arXiv:2012.11298 [nucl-th].

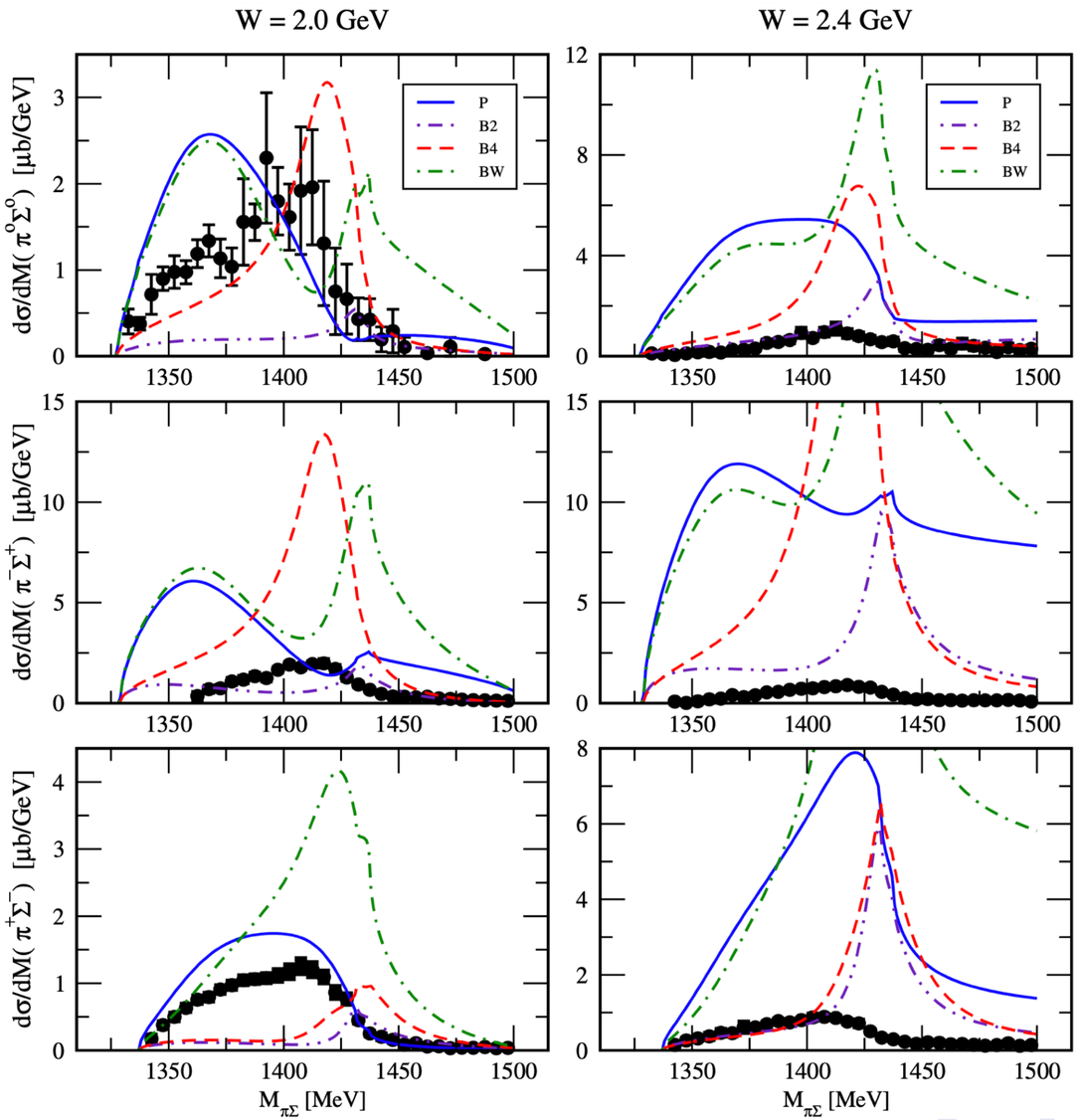
RESULTS

- Final state interaction yields structured line-shape



RESULTS

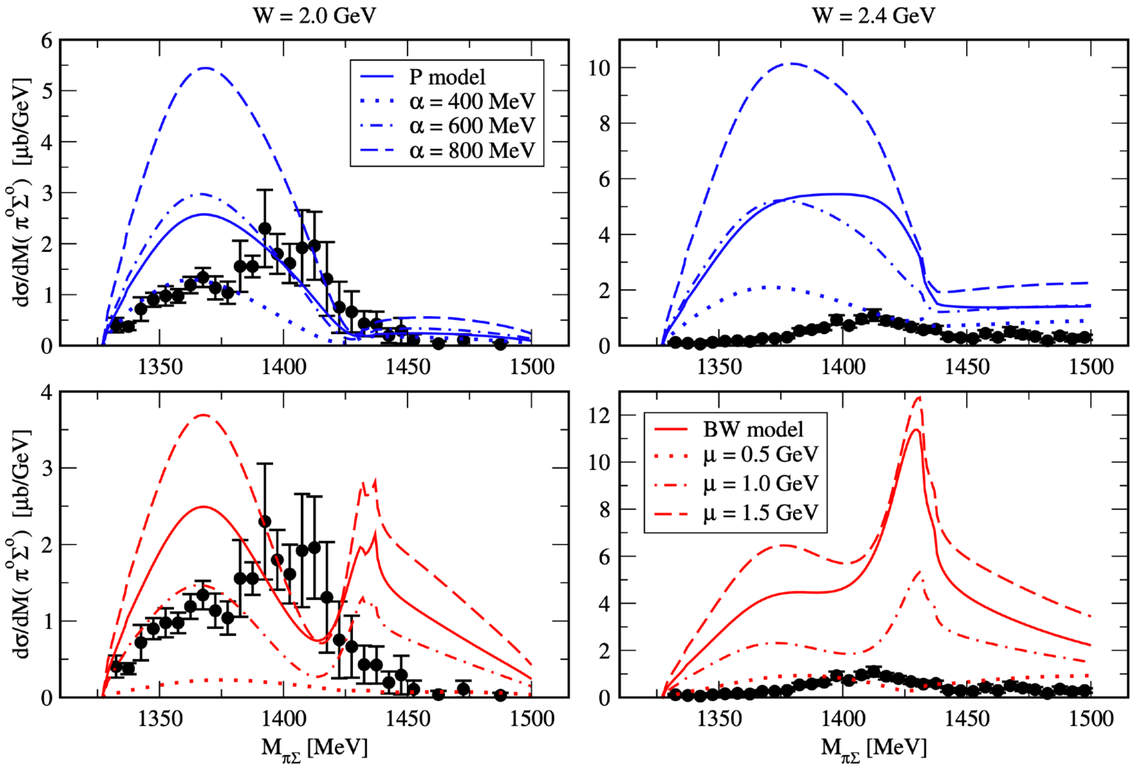
- Final state interaction yields structured line-shape
- Predictions (no free parameters) of line-shapes are vastly different wrt hadronic models



RESULTS

- Final state interaction yields structured line-shape
- Predictions (no free parameters) of line-shapes are vastly different wrt hadronic models
- Slight modification of re-scattering term leads to large changes of the line-shape

  ➥ roadmap to future fits



SUMMARY/OUTLOOK

SUMMARY

"*Photoproduction data starts to play crucial role for the KbarN physics*"

- generic production mechanisms:

  > theoretical ambiguities reduced

- microscopic models come into reach:

  > FSI unitarity, chiral symmetry, gauge invariance

  > line-shapes sensitive to the choice of models

  ... roadmap to future fits