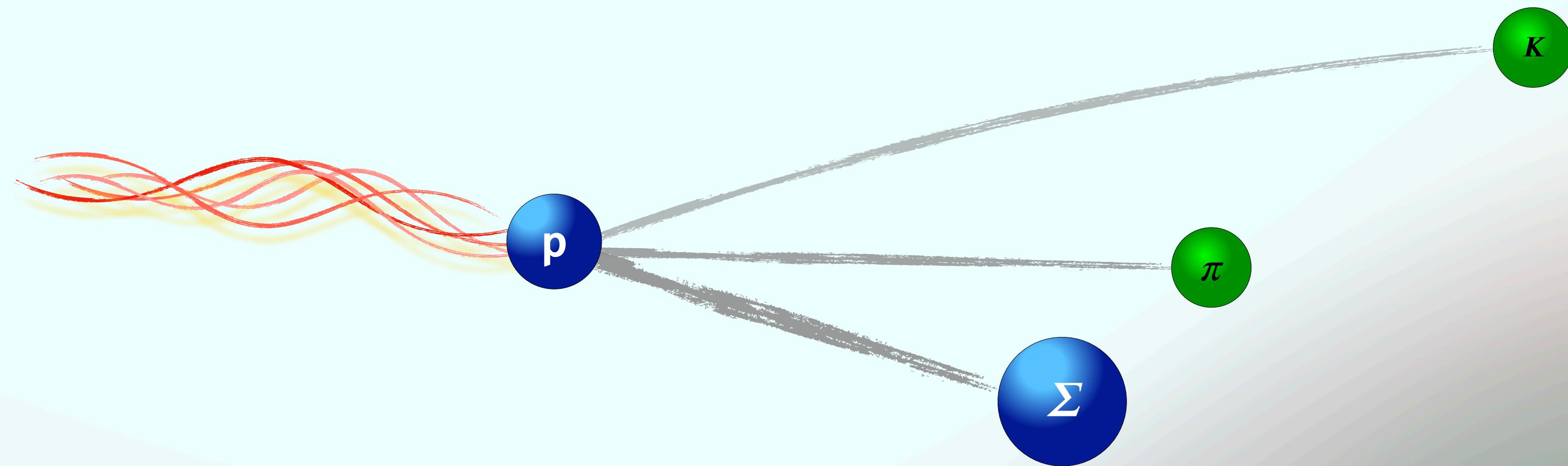


$\Lambda(1405)$ from $(\pi \Sigma)K$ photoproduction



Maxim Mai

University Bonn
The George Washington University

INTRODUCTION



this talk

CURIOSUS CASE: $\Lambda(1405)$



Impact

- Test of our understanding of QCD

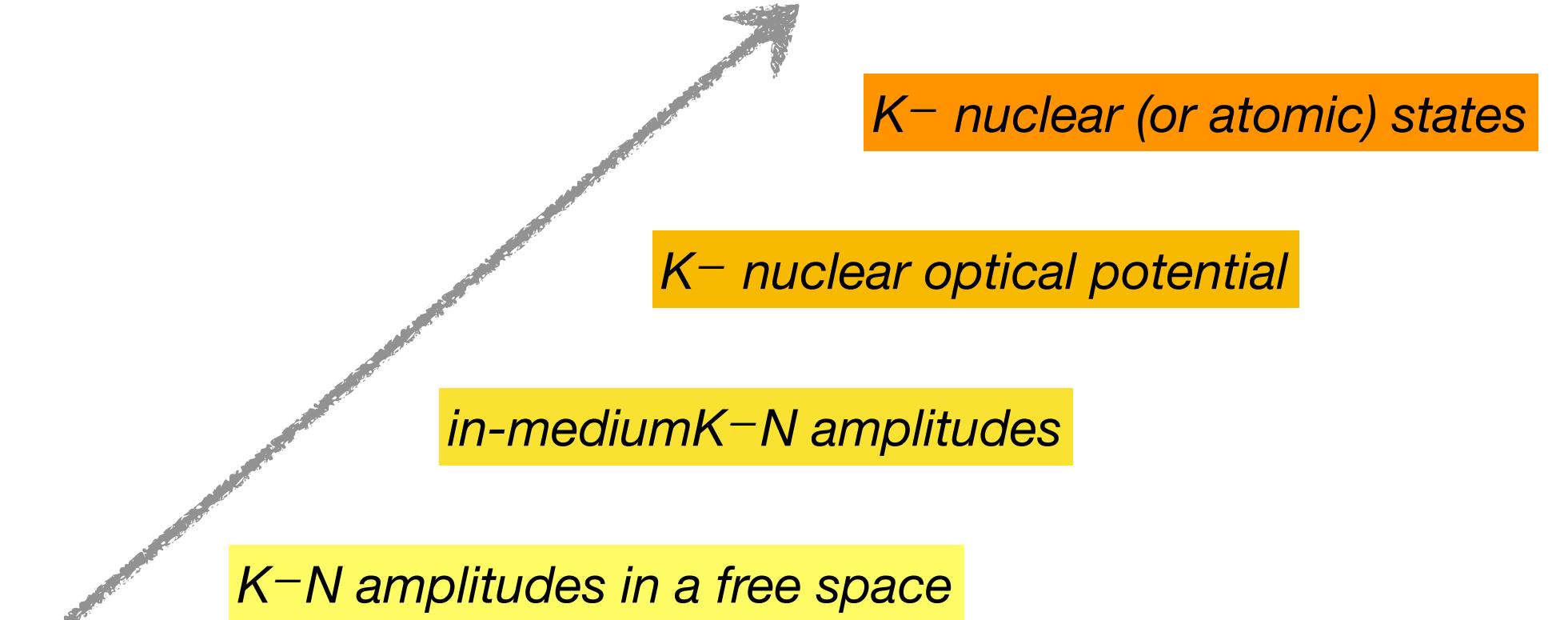
1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**
2) Cieply et al. (2011); ...

CURIOSUS CASE: $\Lambda(1405)$



Impact

- Test of our understanding of QCD
- KbarNN & KbarNNN bound states¹



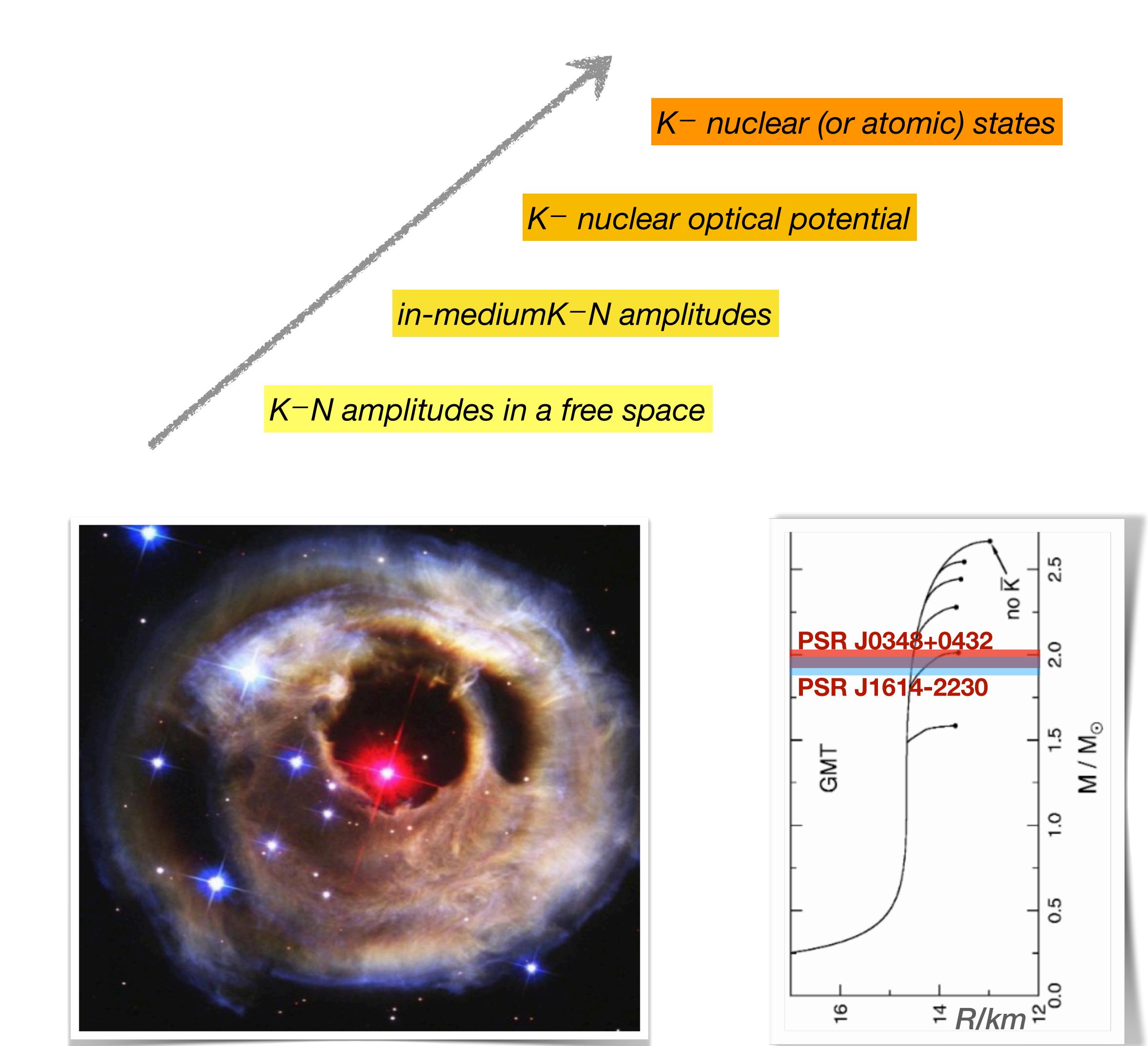
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2) Cieply et al. (2011); ...

CURIOSUS CASE: $\Lambda(1405)$



Impact

- Test of our understanding of QCD
 - KbarNN & KbarNNN bound states¹
 - K- in medium²
- K- condensate can change NS EoS
... many theoretical challenges³



1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**

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

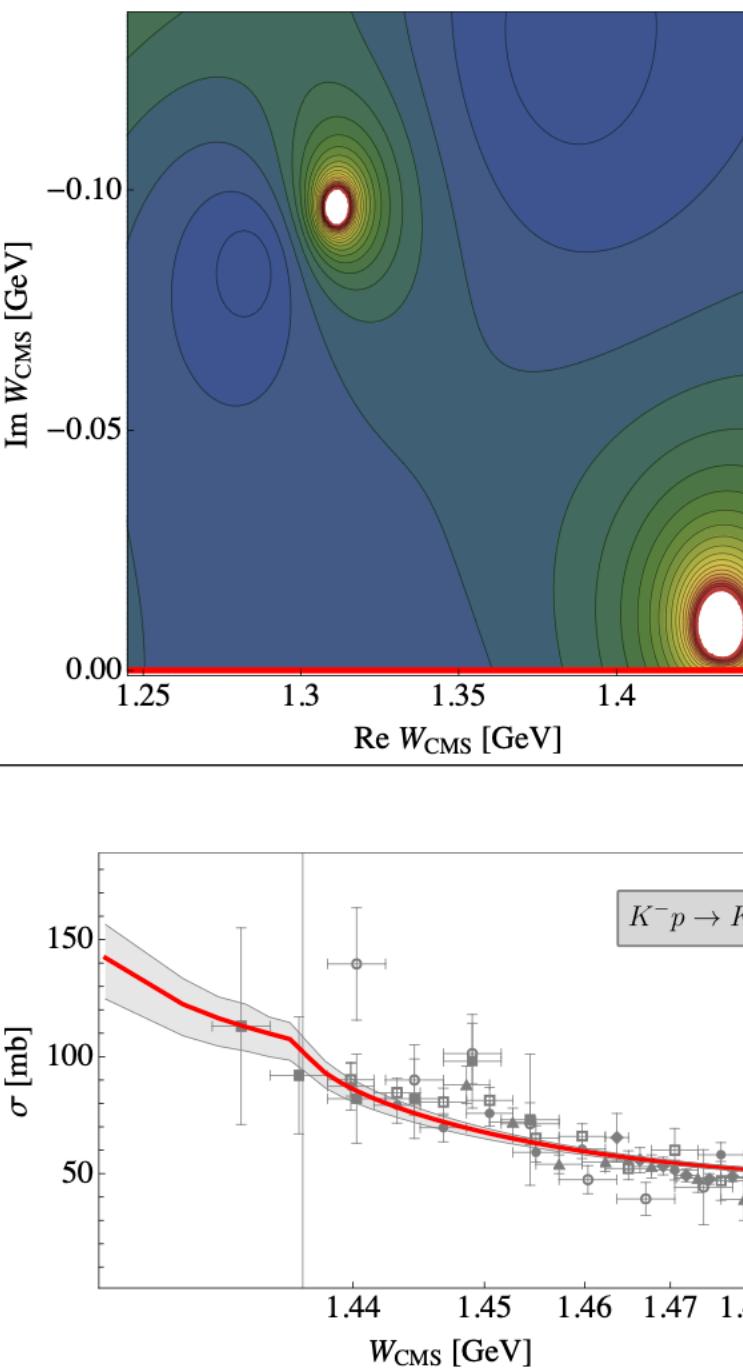
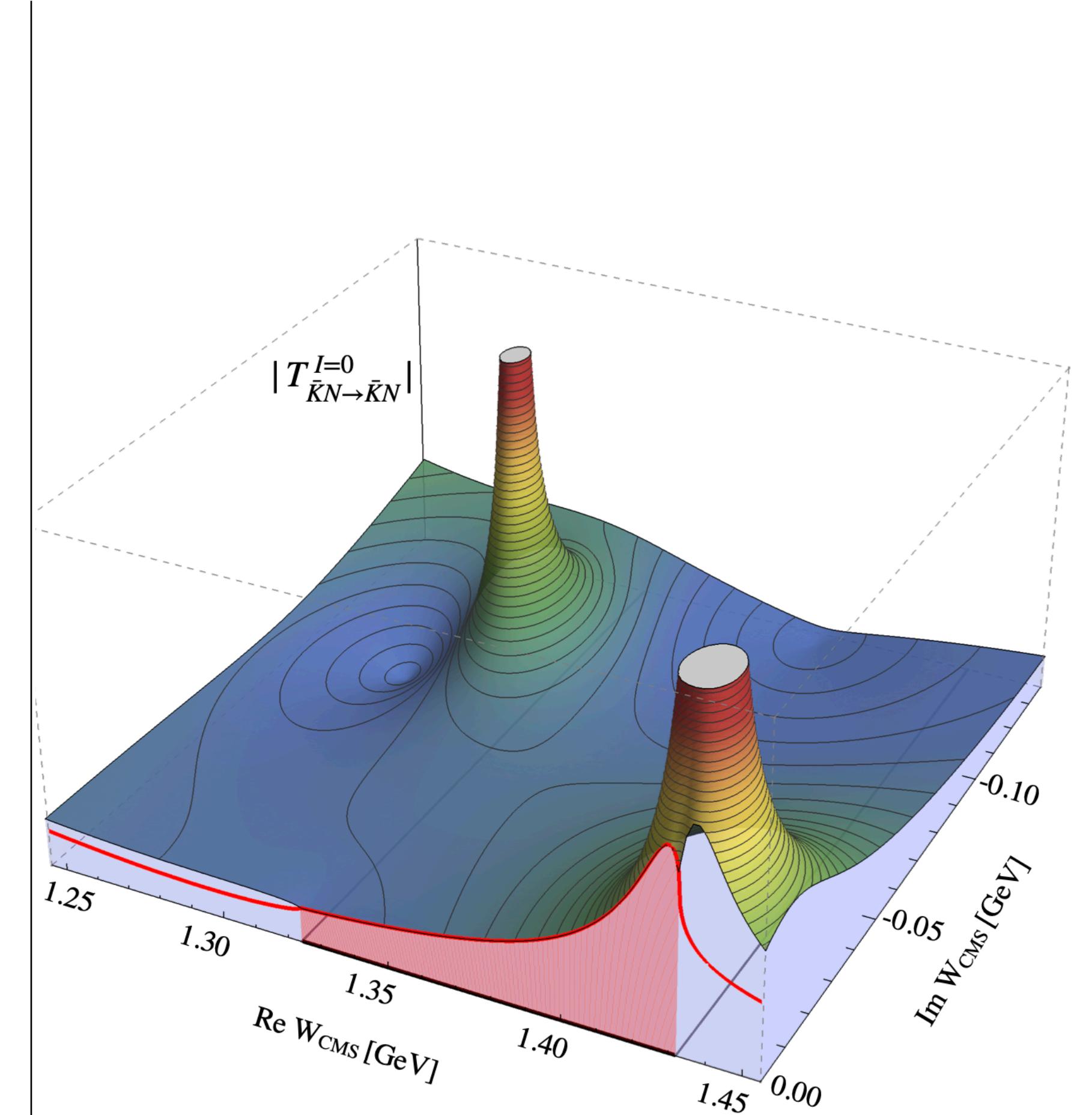
Pal et al. (2000)

K_{BARN} 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**

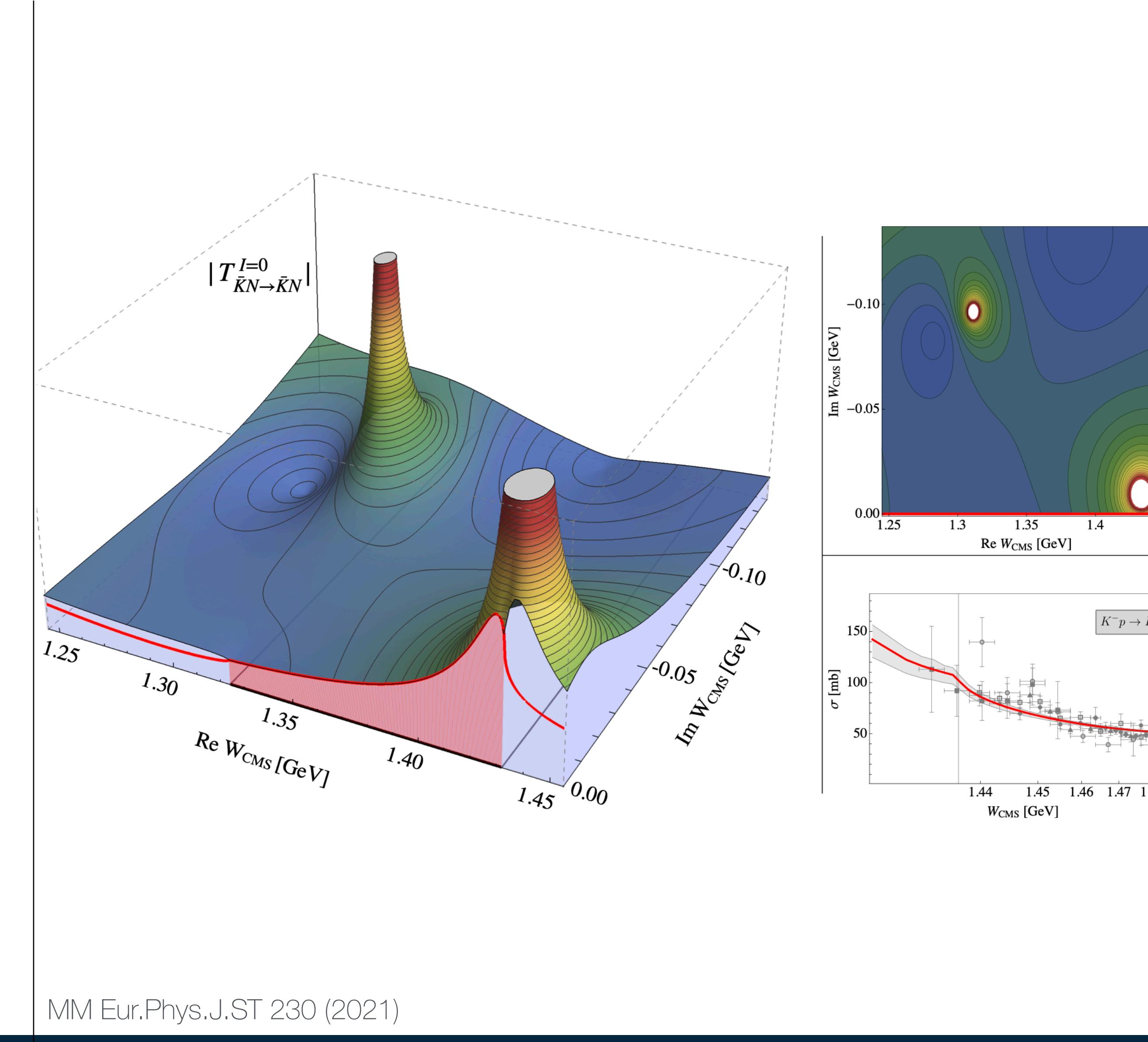
MM Eur.Phys.J.ST 230 (2021)

K_{BARN} 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 QCD¹
 2. Experiment



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

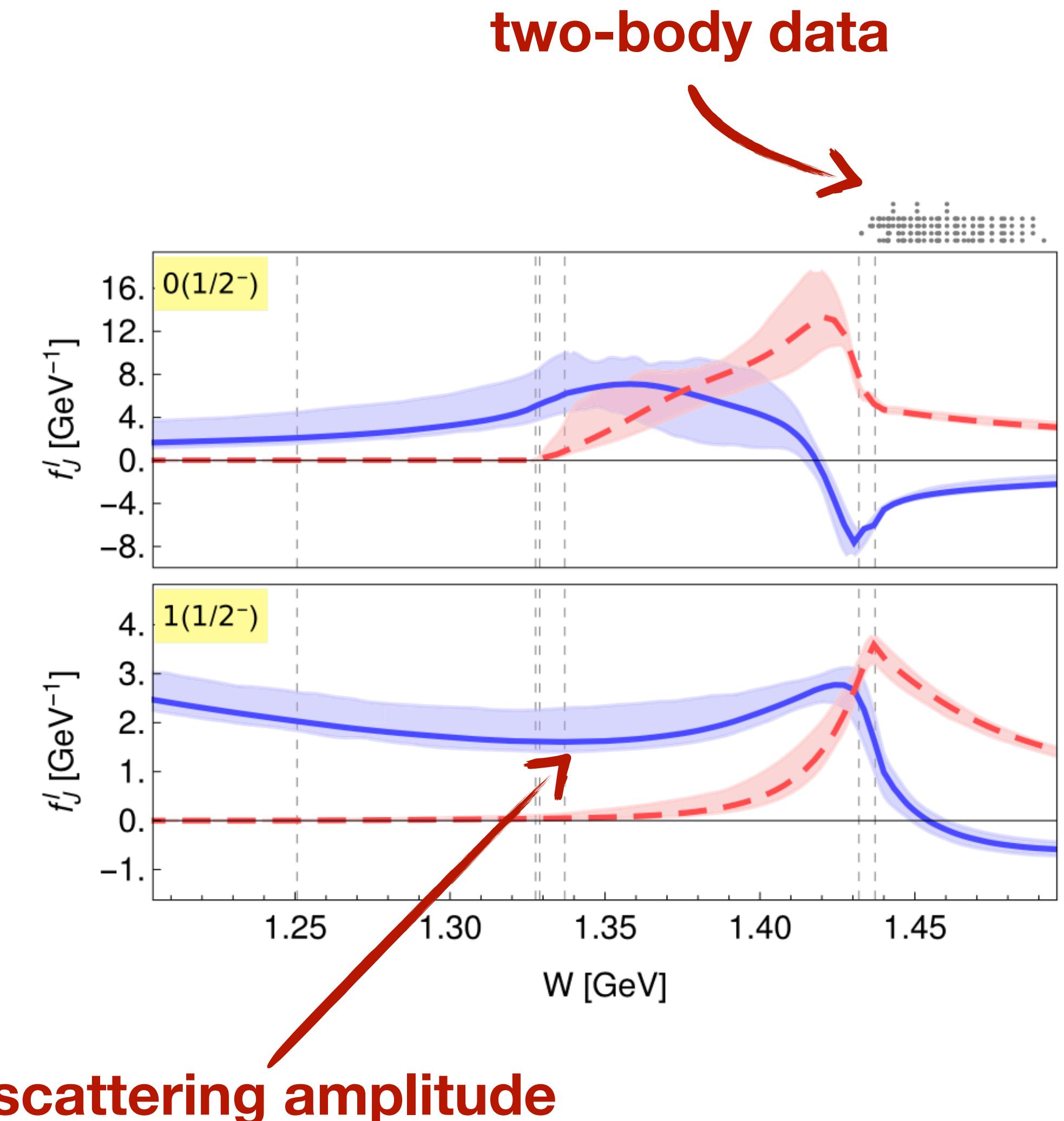
MM Eur.Phys.J.ST 230 (2021)

K_{BARN} SCATTERING



Challenge

- many data available above/at the KbarN threshold¹
- going below...
→ use chiral symmetry / unitarity / ...²



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)

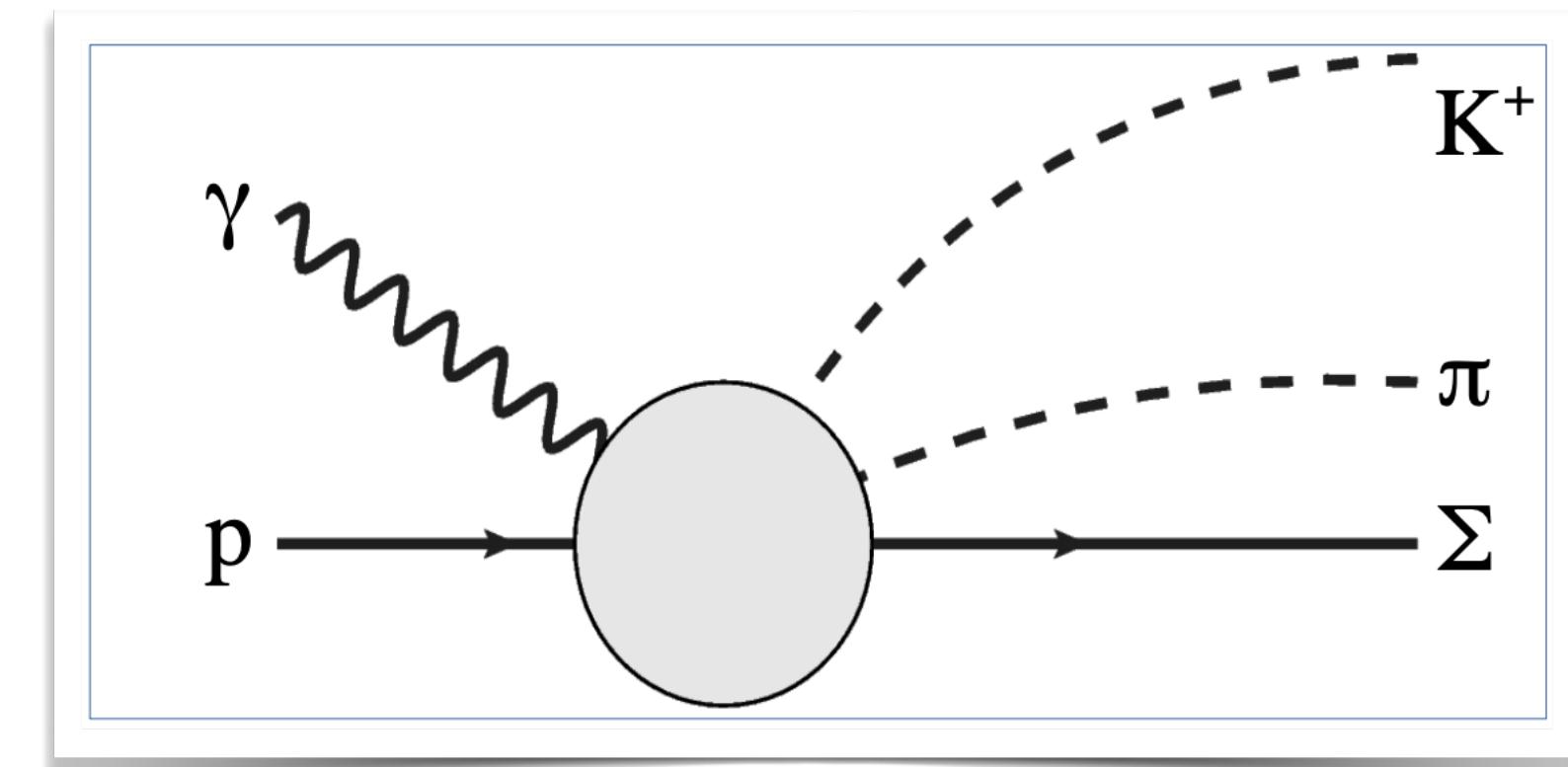
Sadasivan, MM, Döring (2019)

K_{BARN} SCATTERING



Challenge

- many data available above/at the KbarN threshold¹
- going below...
 - use chiral symmetry / unitarity / ... ²
 - experiments with 3-body final states³



[CLAS] Moryia et al. (2015)

CLAS data on $\gamma p \rightarrow K^+ \pi \Sigma$

- 9 energy bins
- 60 values of $M(\pi\Sigma)$
- 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

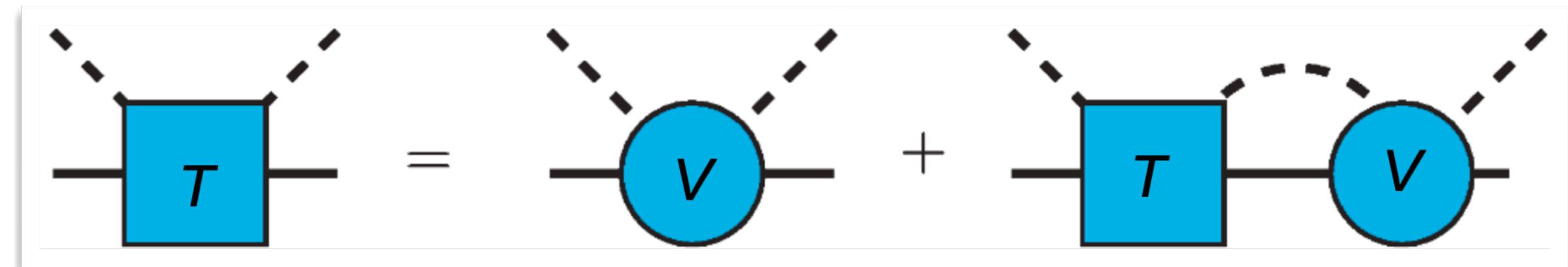
"can photoproduction data reduce ambiguity on $K\bar{b}N$ scattering amplitude?"

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

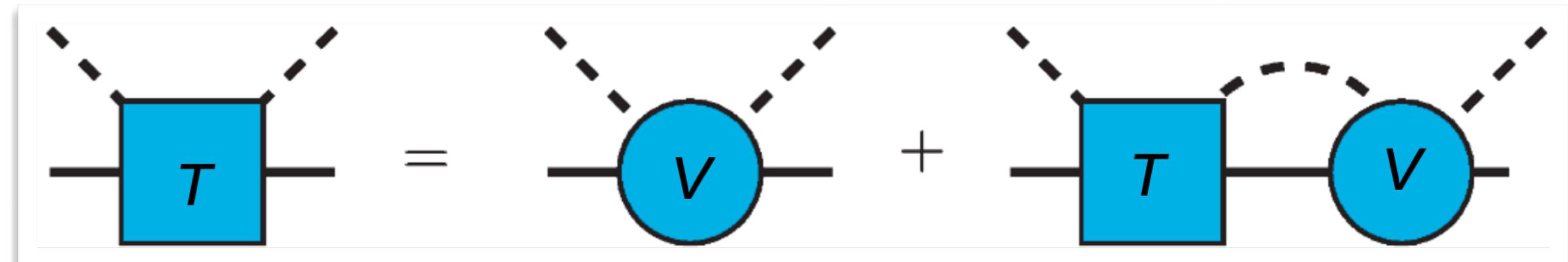


1) Weinberg (1979) Gasser, Leutwyler (1981)

HADRONIC PART



- Unitarity of the S-matrix:
 - > mathematical foundation of universality of resonance parameters
 - > one implementation: Bethe-Salpeter equation
- ChPT¹: (Effective field theory of QCD)
 - > incorporates symmetries of QCD
 - > reduces number of degrees of freedom



$$\begin{aligned} V(q_2, q_1; p) = & \ A_{WT}(q_1 + q_2) + \text{Born}(s) + \text{Born}(u) \\ & + \boxed{A_{14}}(q_1 \cdot q_2) + \boxed{A_{57}}[q_1, q_2] + \boxed{A_M} + \boxed{A_{811}}(q_2(q_1 \cdot p) + q_1(q_2 \cdot p)) \end{aligned}$$

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

HADRONIC PART



- Various implementations
 - ➡ many scenarios with NLO kernel¹ tested

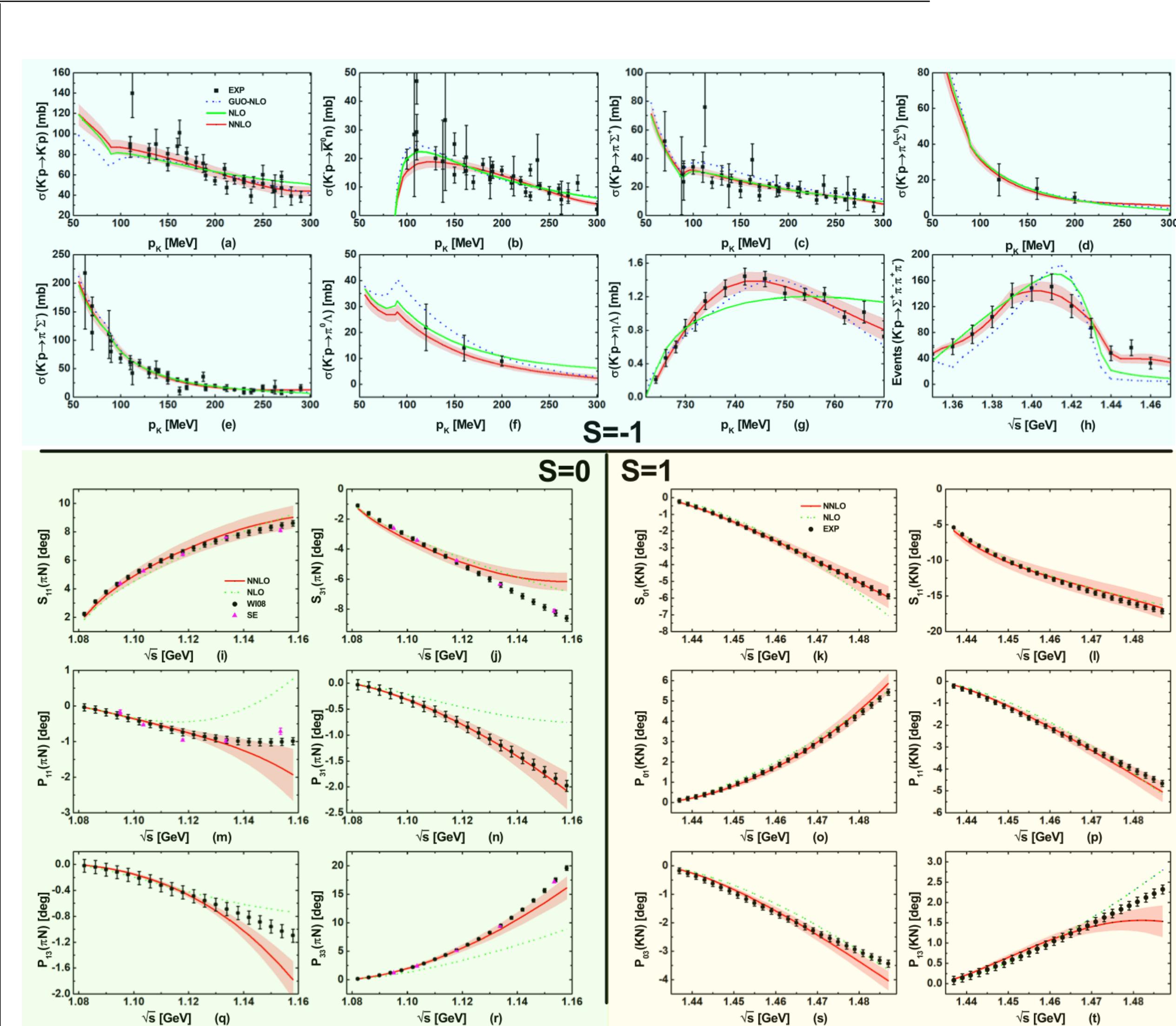
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadasivan et al. (2019)
2) Lu/Geng/Döring/MM (2022)

HADRONIC PART



- Various implementations
- many scenarios with NLO kernel¹ tested

→ first NNLO calculation² including $K\bar{N}/\pi N/KN$



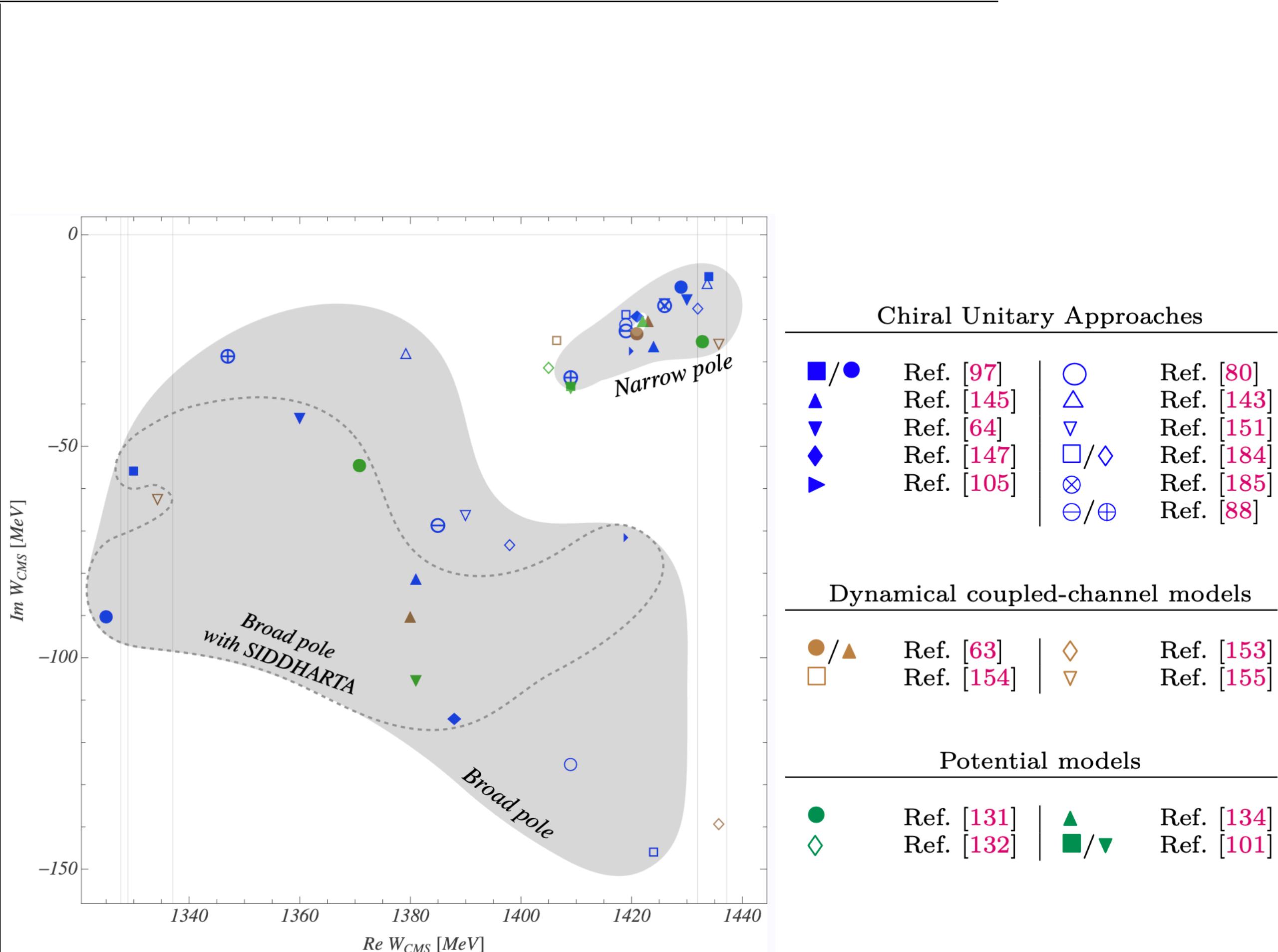
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadashivan et al. (2019)

2) Lu/Geng/Döring/MM (2022)

HADRONIC PART



- Various implementations
 - ↳ many scenarios with NLO kernel¹ tested
 - ↳ first NNLO calculation² including $K_{\bar{N}N}/\pi N/KN$
- Common feature:
 - ↳ good fit to threshold and scattering data
 - ↳ two poles with $I=0, S=-1, J=1/2^+$



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

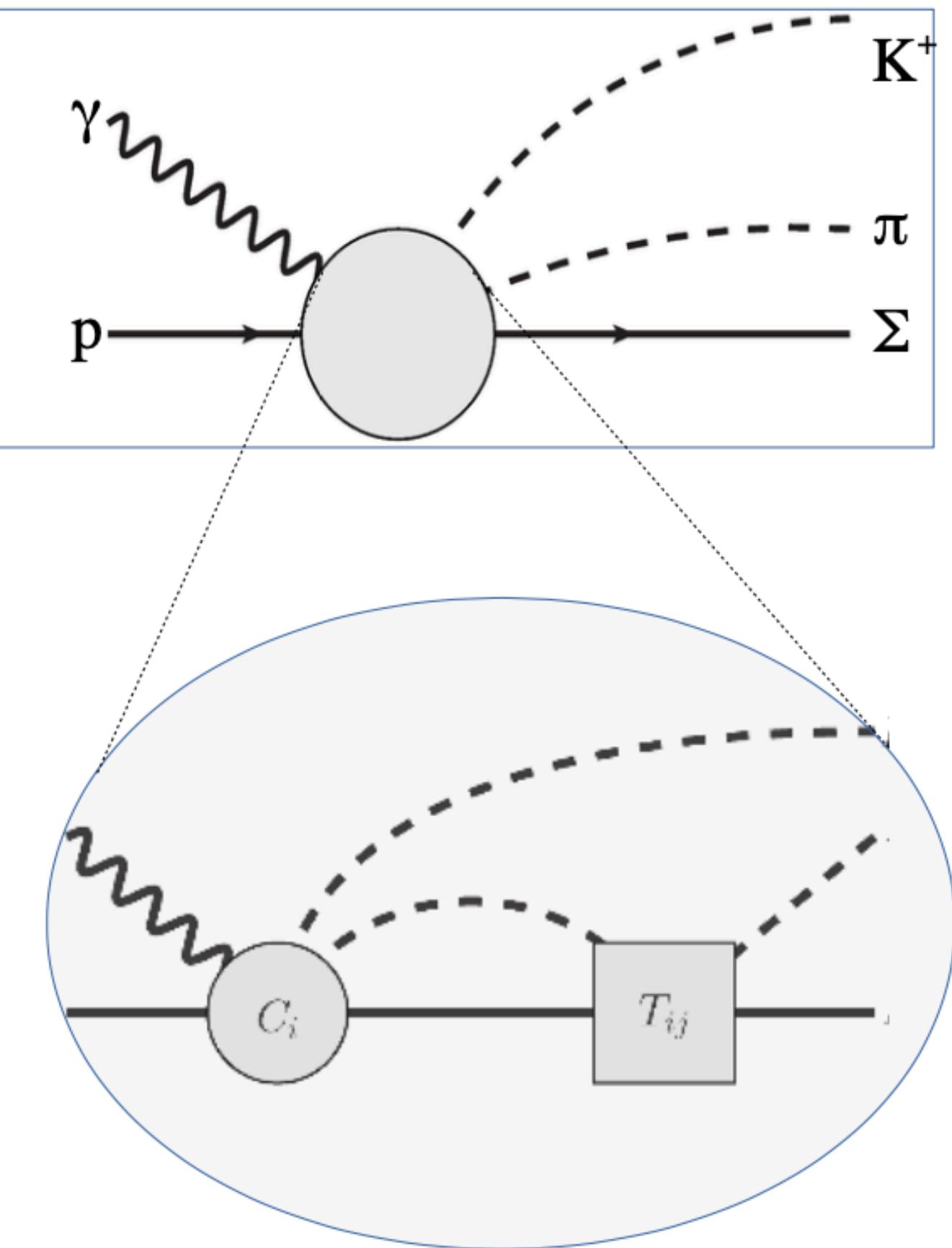
2) Lu/Geng/Döring/MM (2022)

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)

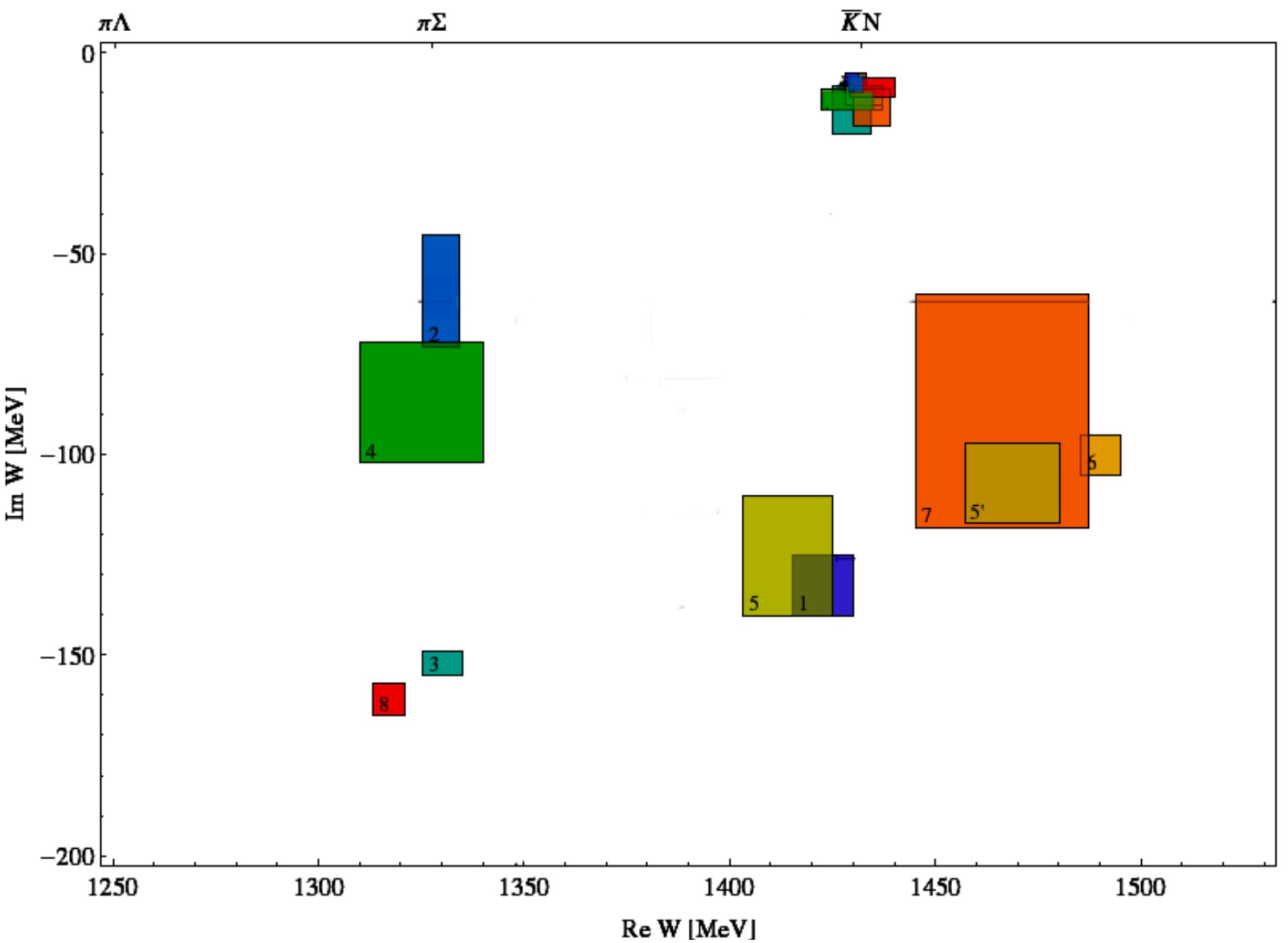
2) MM, Meissner(2015)

PHOTOPRODUCTION



Results:

- 8 local minima wrt. two-body data ($\chi^2 \sim 1$)
each propagates to a two poles on the 2. RS



1) Oset, Roca (2013)

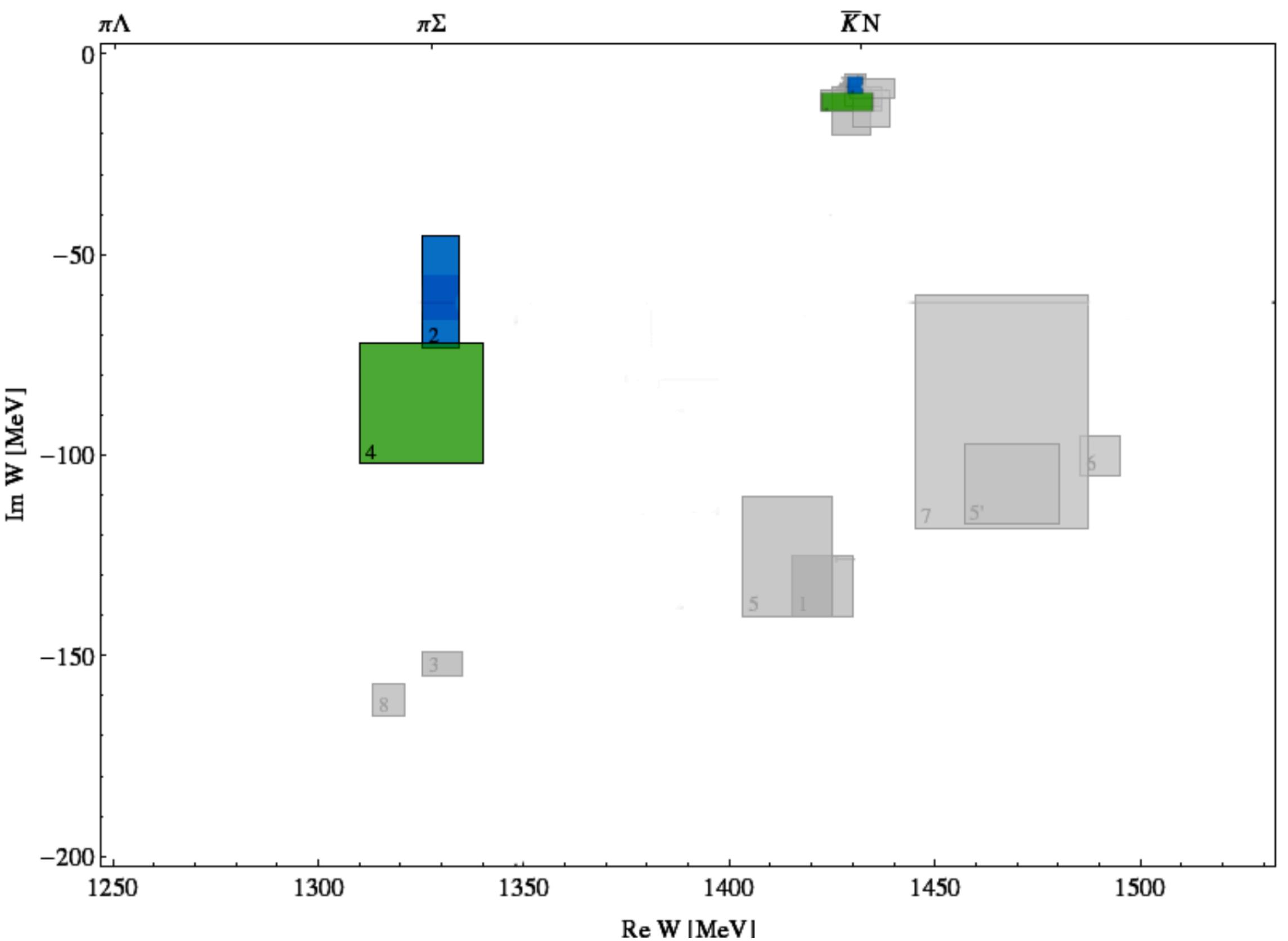
2) MM, Meissner(2015)

PHOTOPRODUCTION



Results:

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



1) Oset, Roca (2013)

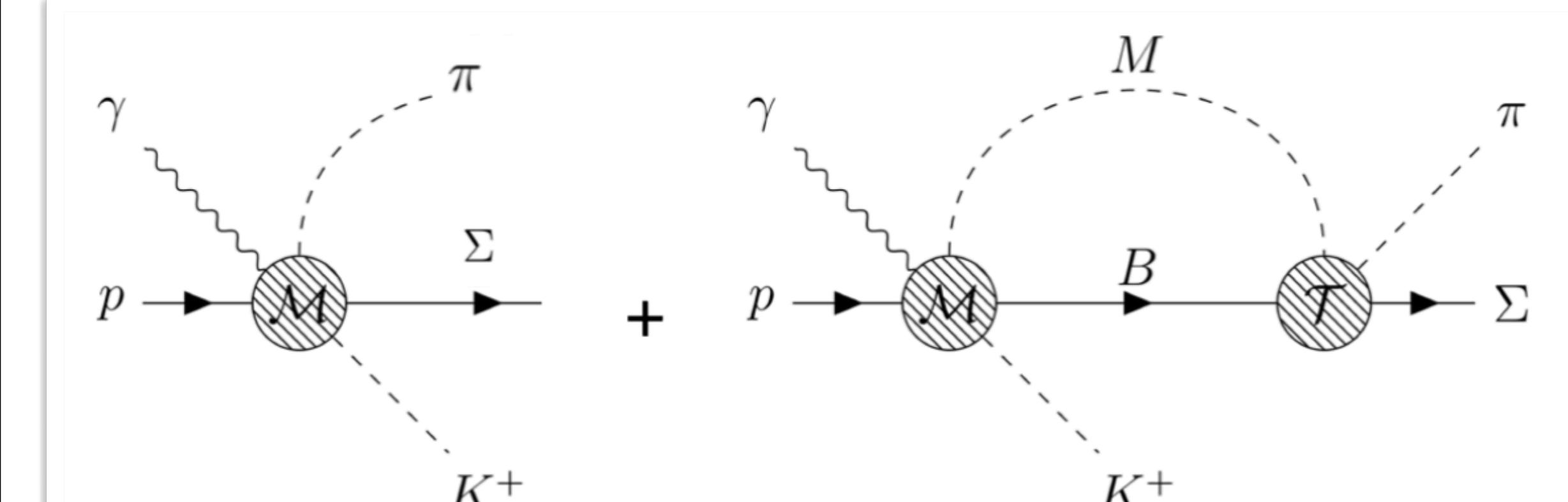
2) MM, Meissner(2015)

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

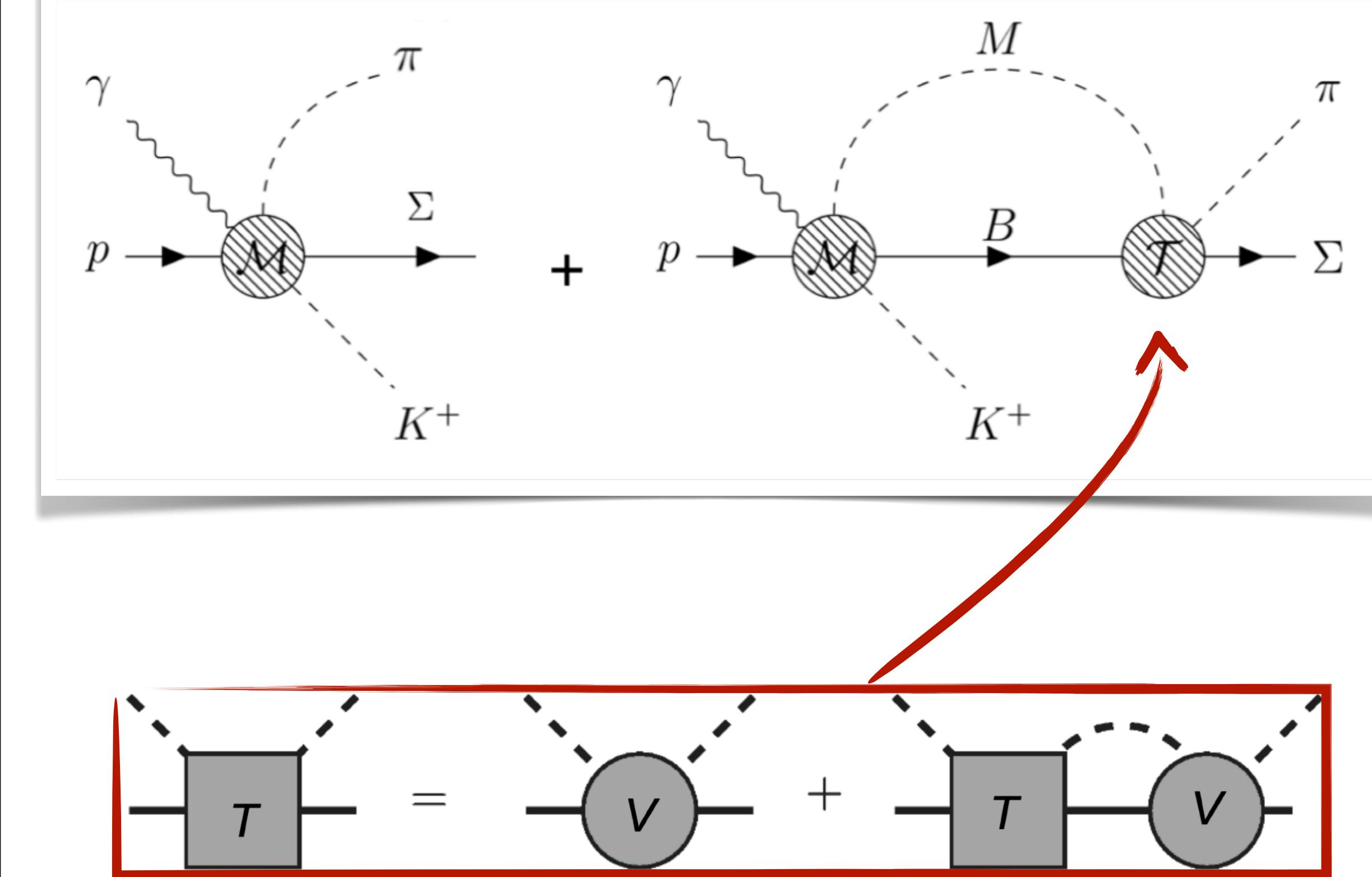


- 1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)
- 2) arXiv:2012.11298 [nucl-th].

MICROSCOPIC MODEL



- Theoretical constraints
- FSI 2-body unitarity from chiral unitary and potential models¹



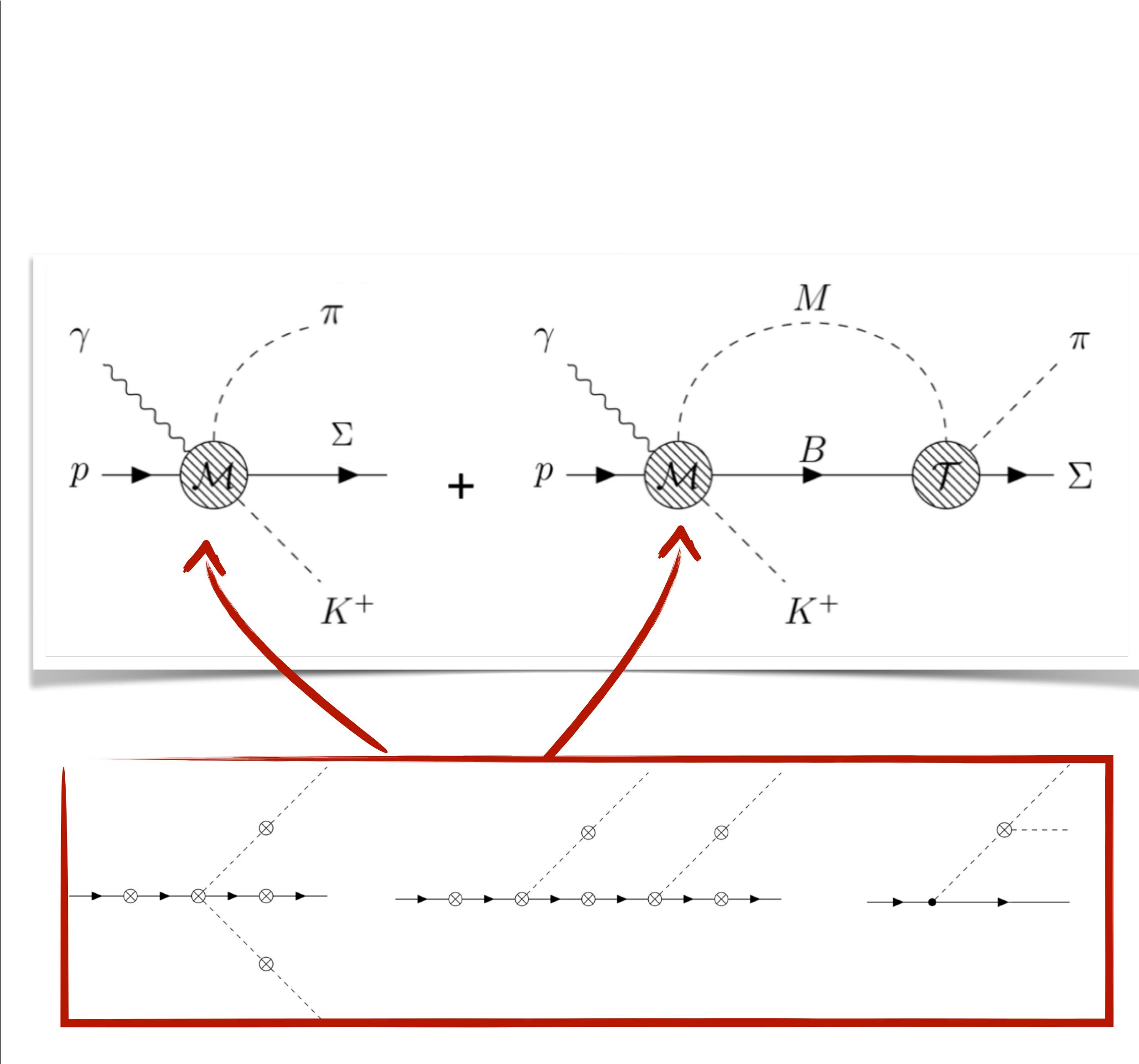
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MICROSCOPIC MODEL



- Theoretical constraints
 - FSI 2-body unitarity from chiral unitary and potential models¹
 - chiral symmetry constraints on the production vertex²



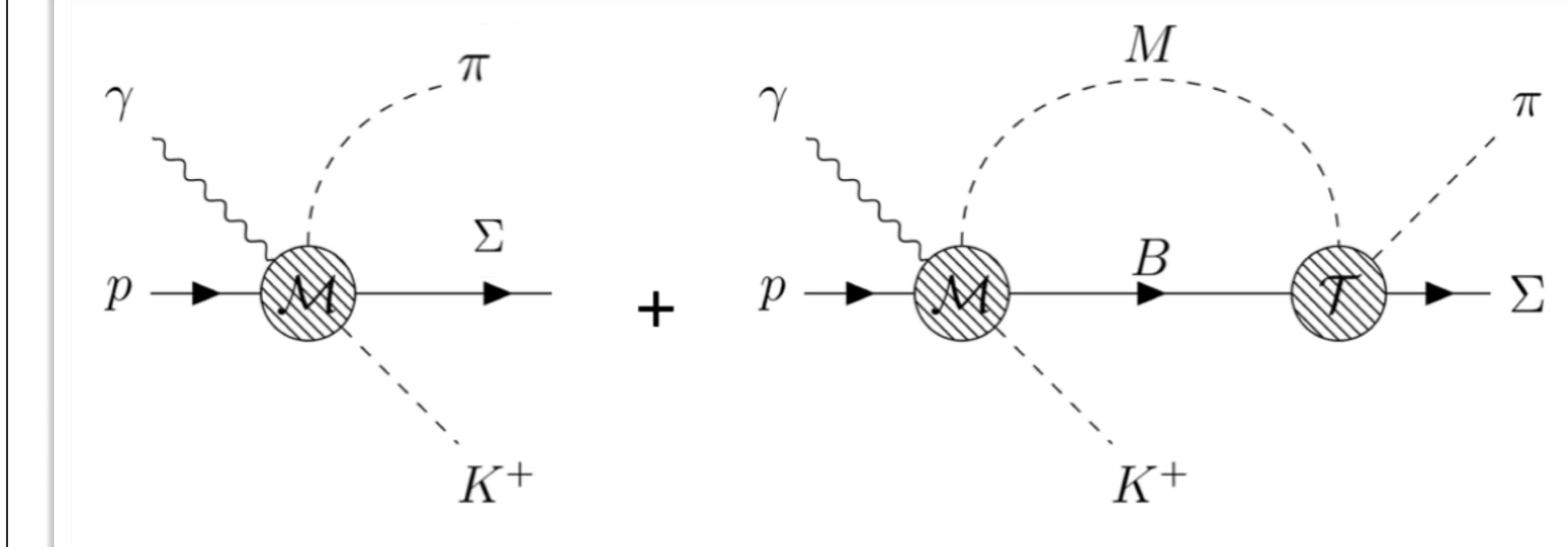
1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)

2) arXiv:2012.11298 [nucl-th].

MICROSCOPIC MODEL



- Theoretical constraints
 - ↳ FSI 2-body unitarity from chiral unitary and potential models¹
 - ↳ chiral symmetry constraints on the production vertex²
 - ↳ gauge invariance included by construction



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



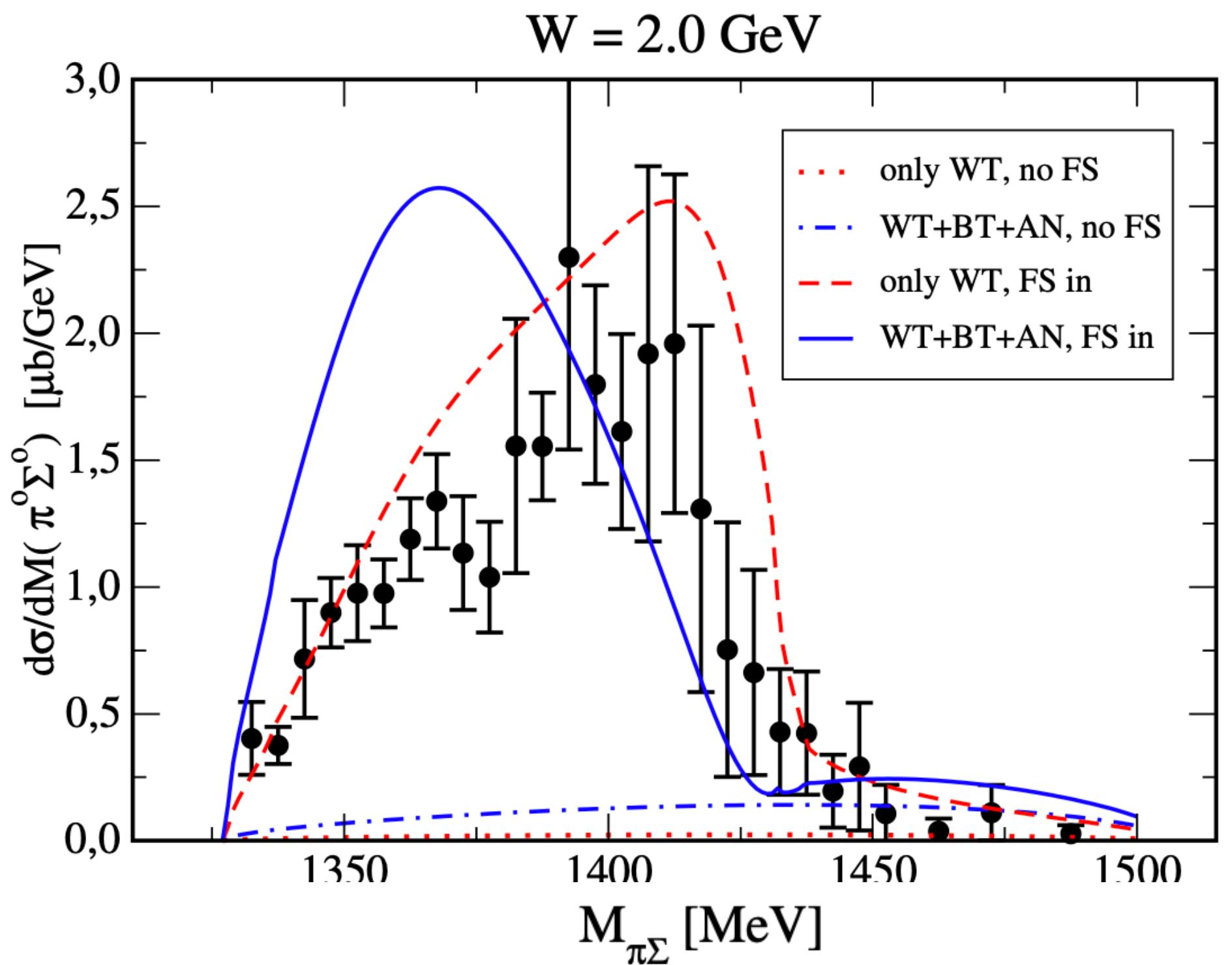
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2) arXiv:2012.11298 [nucl-th].

RESULTS



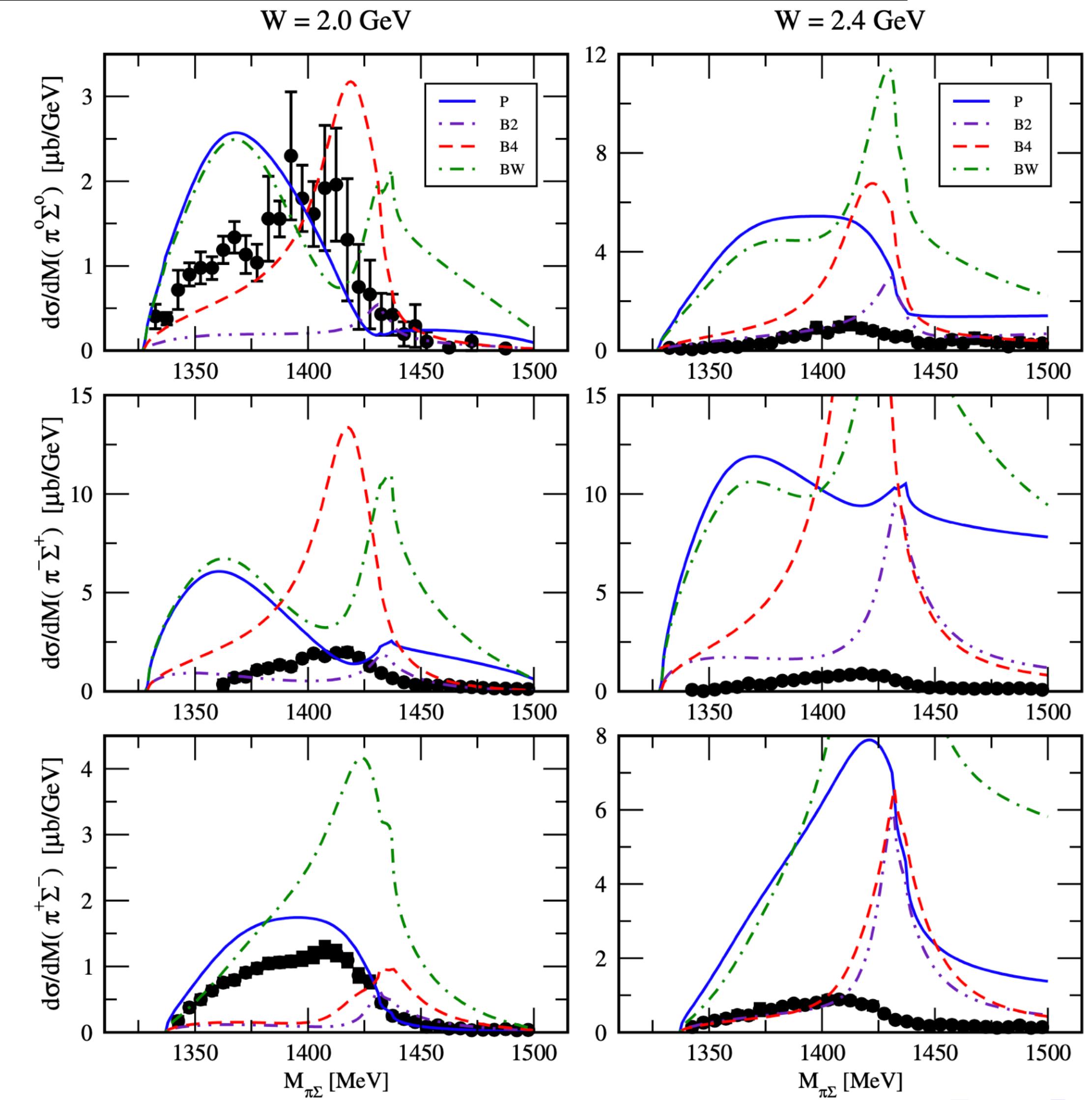
- Final state interaction yields structured line-shape



RESULTS



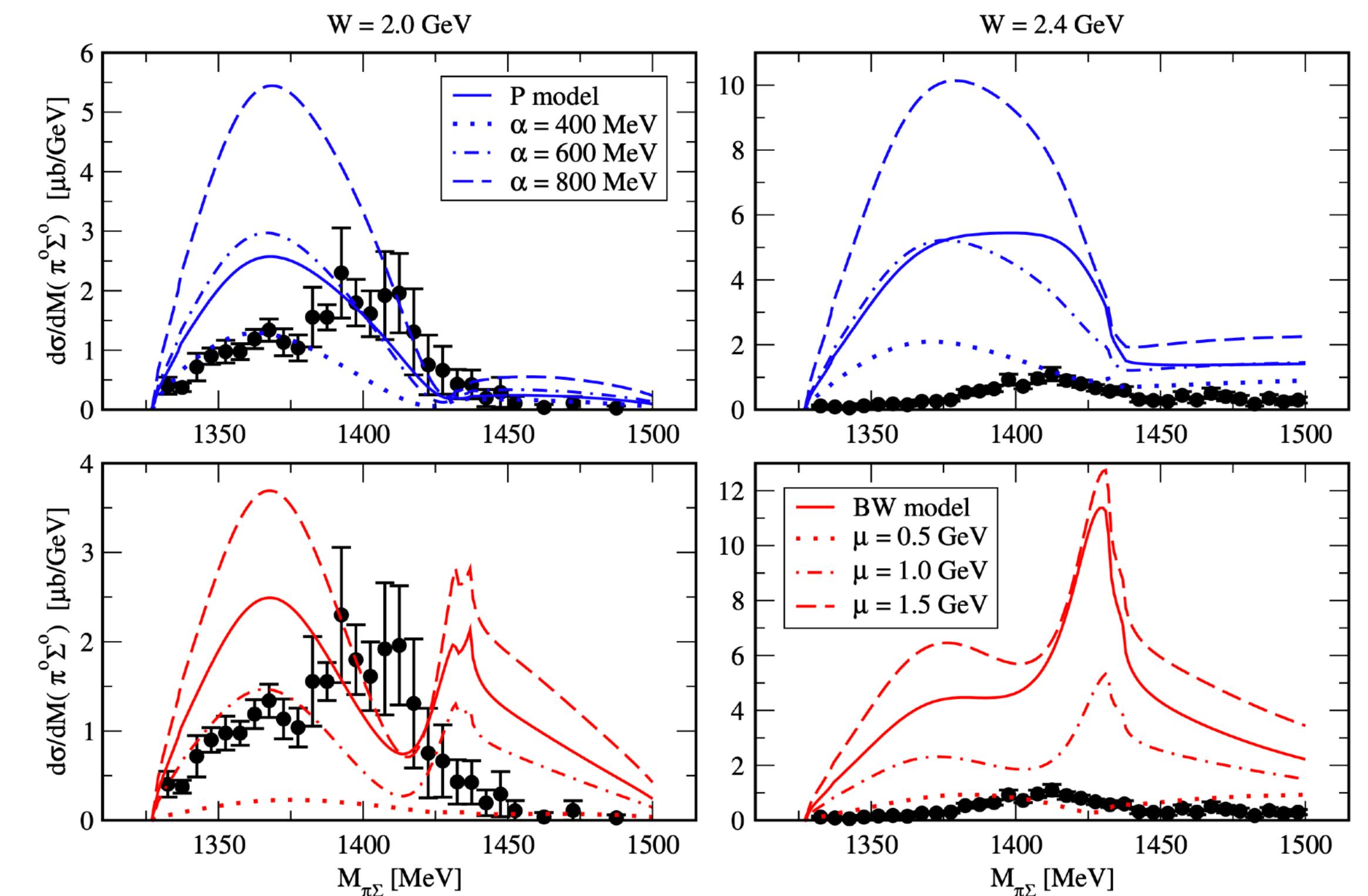
- Final state interaction yields structured line-shape
- Predictions (no free parameters) of line-shapes are vastly different wrt hadronic models



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**

