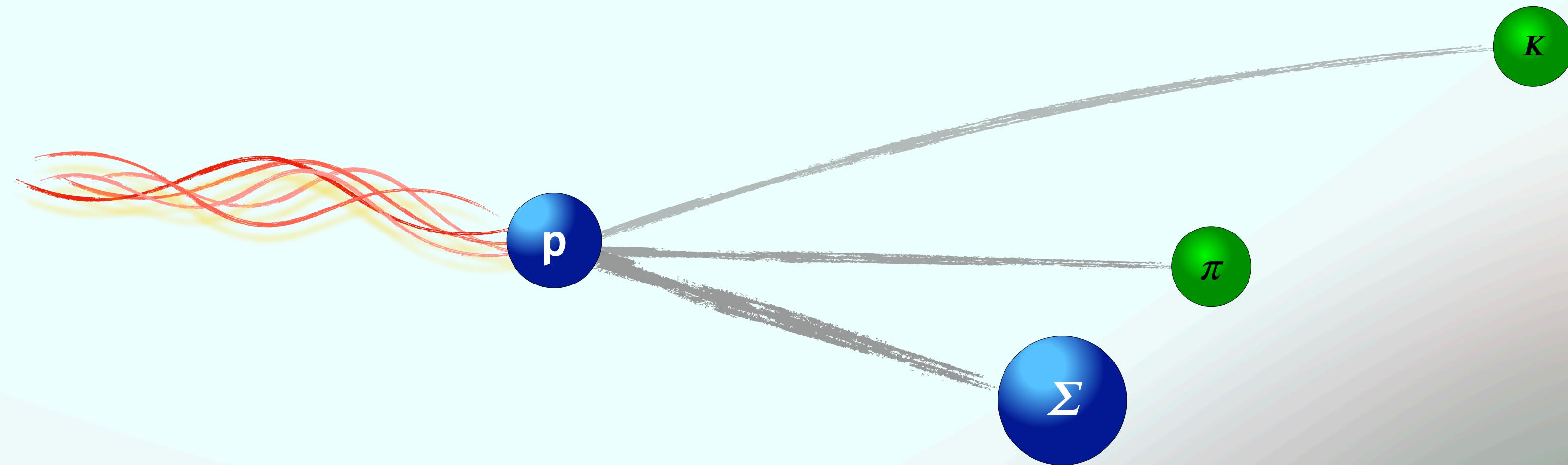


# $\Lambda(1405)$ from $(\pi \Sigma)K$ photoproduction



*Maxim Mai*

*University Bonn*  
*The George Washington University*

# INTRODUCTION



**this talk**

# CURIOSUS CASE: $\Lambda(1405)$

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## Impact

- Test of our understanding of QCD

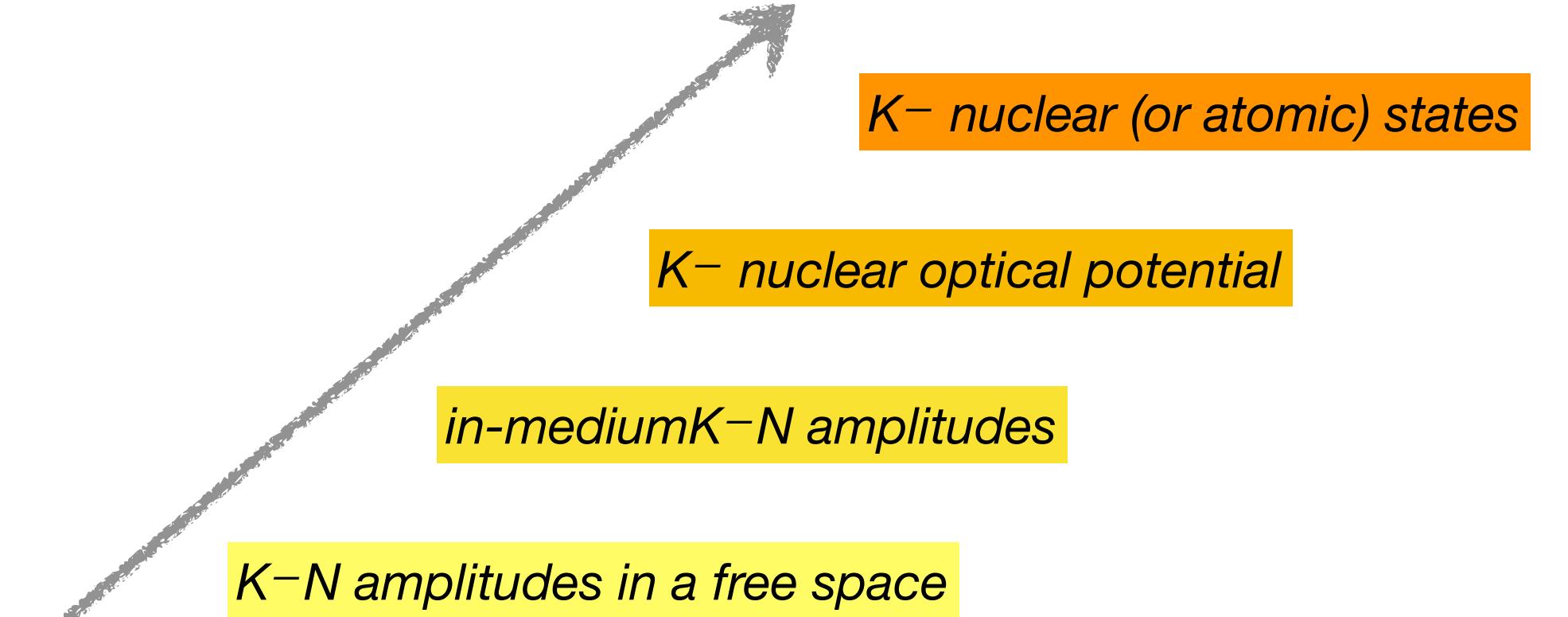
1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**  
2) Cieply et al. (2011); ...

# CURIOSUS CASE: $\Lambda(1405)$



## Impact

- Test of our understanding of QCD
- KbarNN & KbarNNN bound states<sup>1</sup>



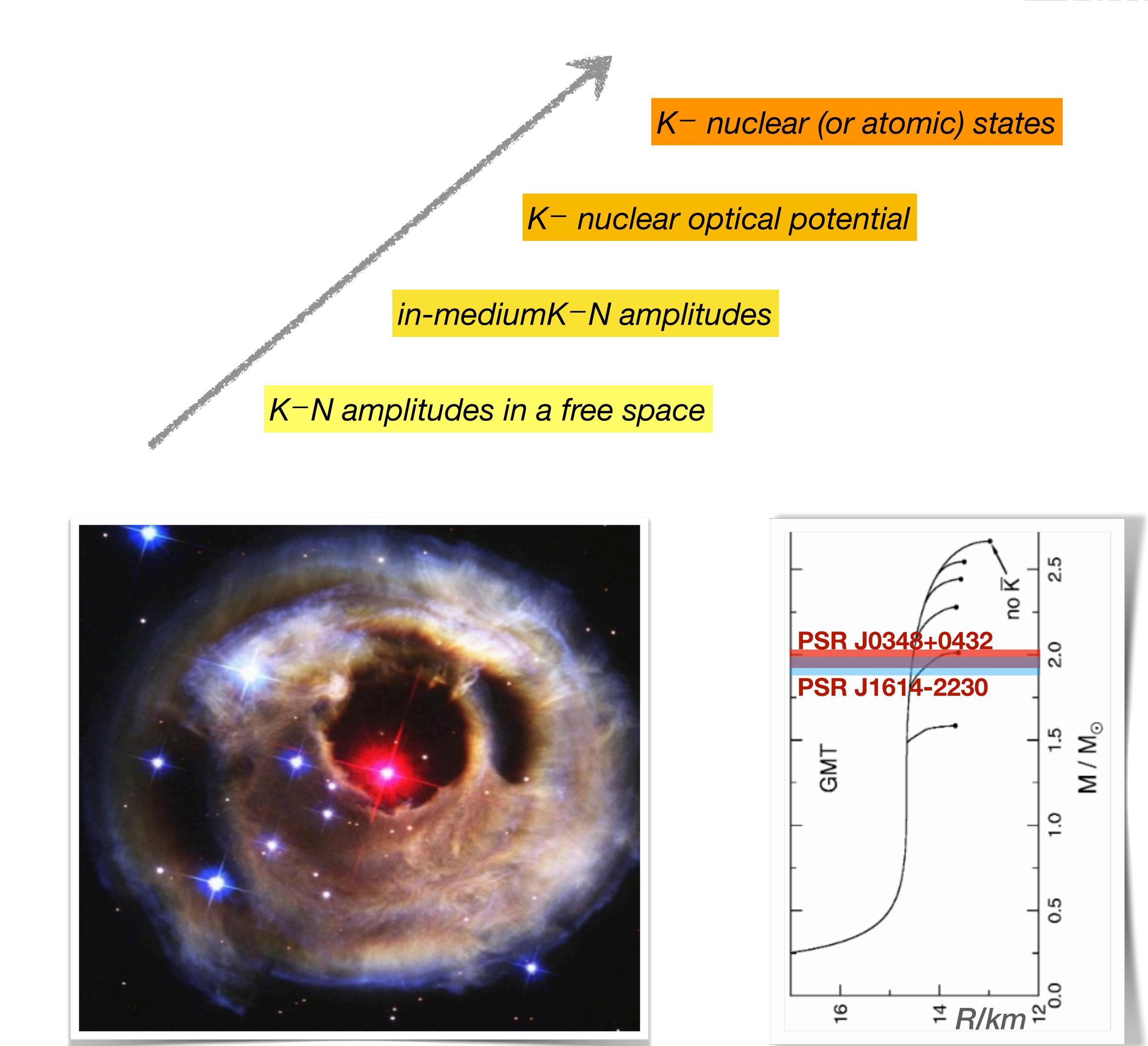
1) Review by Gal/Hungerford/Millener (2016); **TALK: Shevchenko, Sekihara**  
2) Cieply et al. (2011); ...

# CURIOSUS CASE: $\Lambda(1405)$



## Impact

- Test of our understanding of QCD
  - KbarNN & KbarNNN bound states<sup>1</sup>
  - K- in medium<sup>2</sup>
- K- condensate can change NS EoS  
... many theoretical challenges<sup>3</sup>



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

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

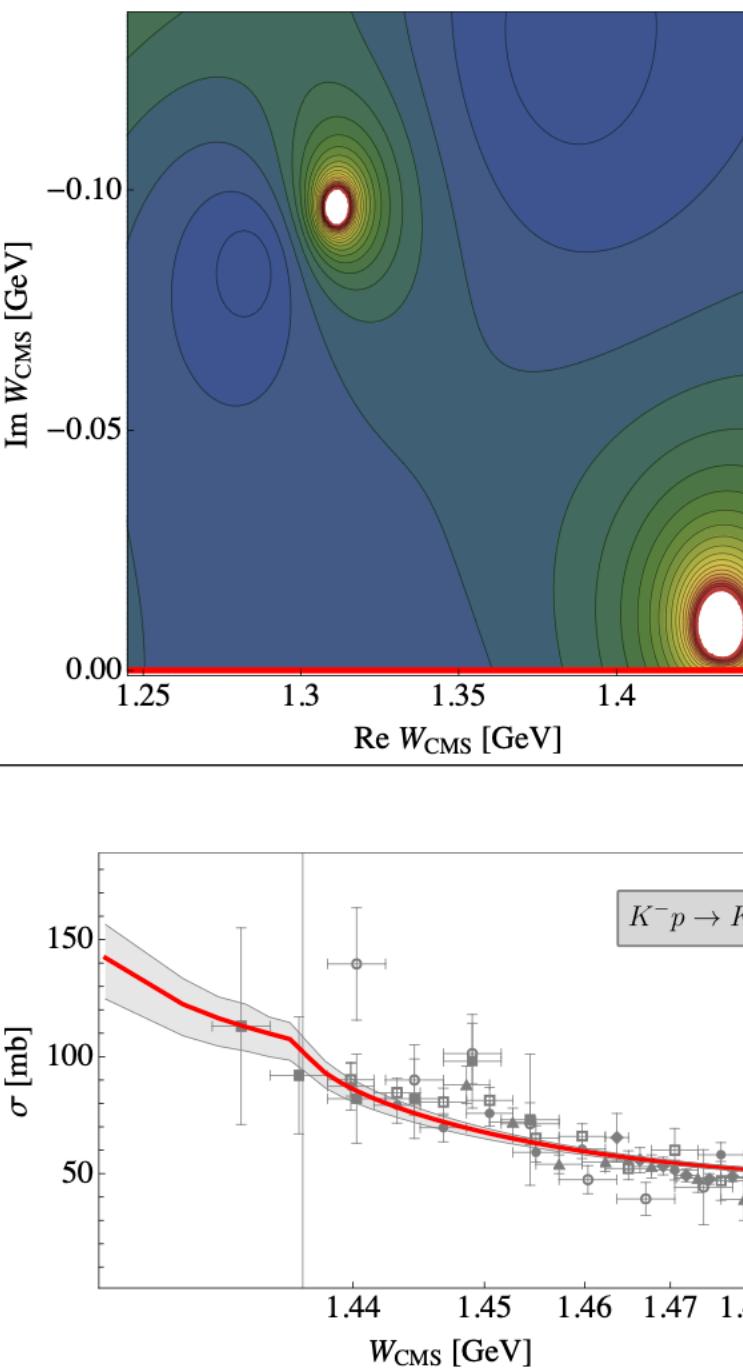
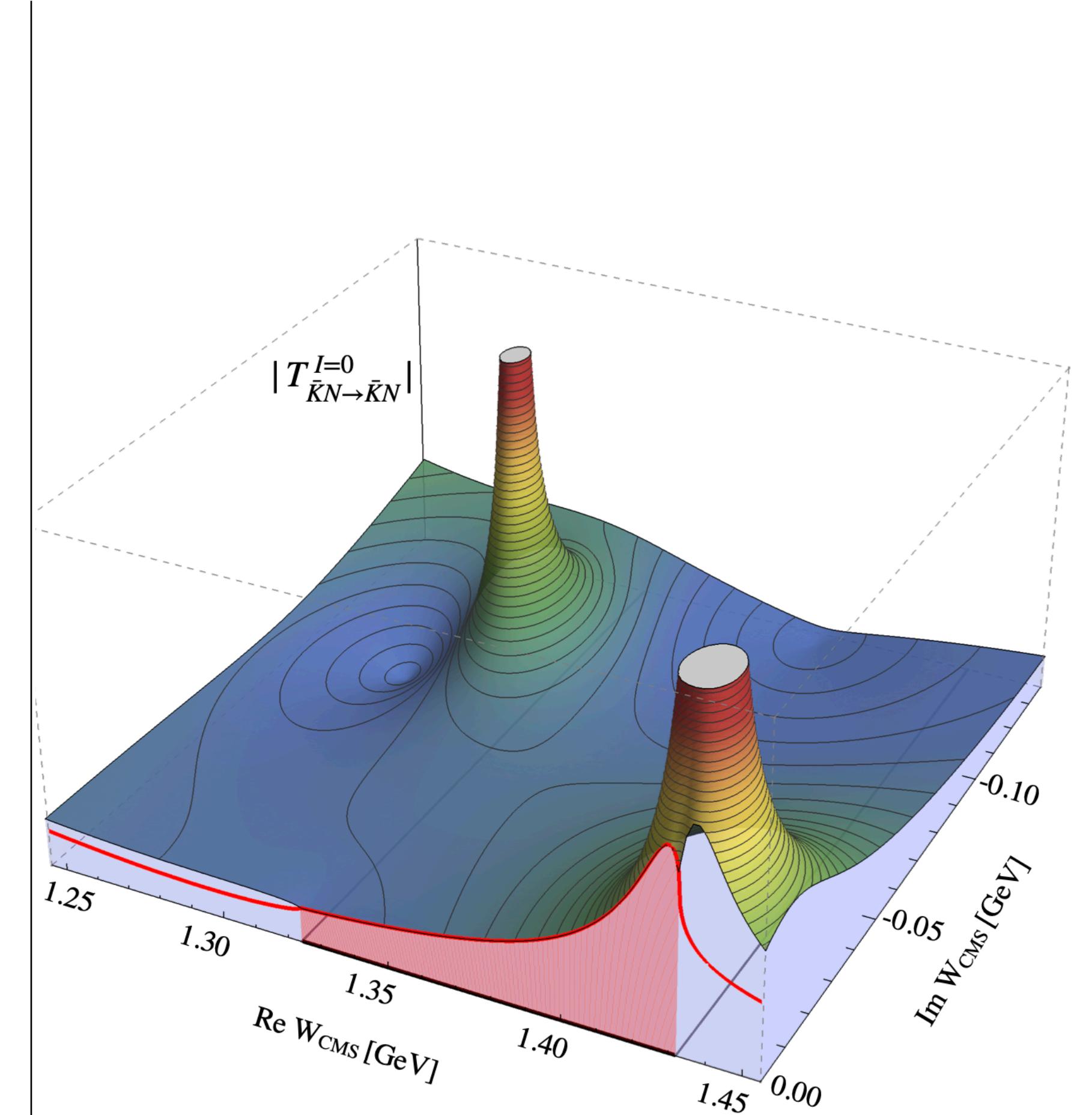
Pal et al. (2000)

# K<sub>BARN</sub> 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**

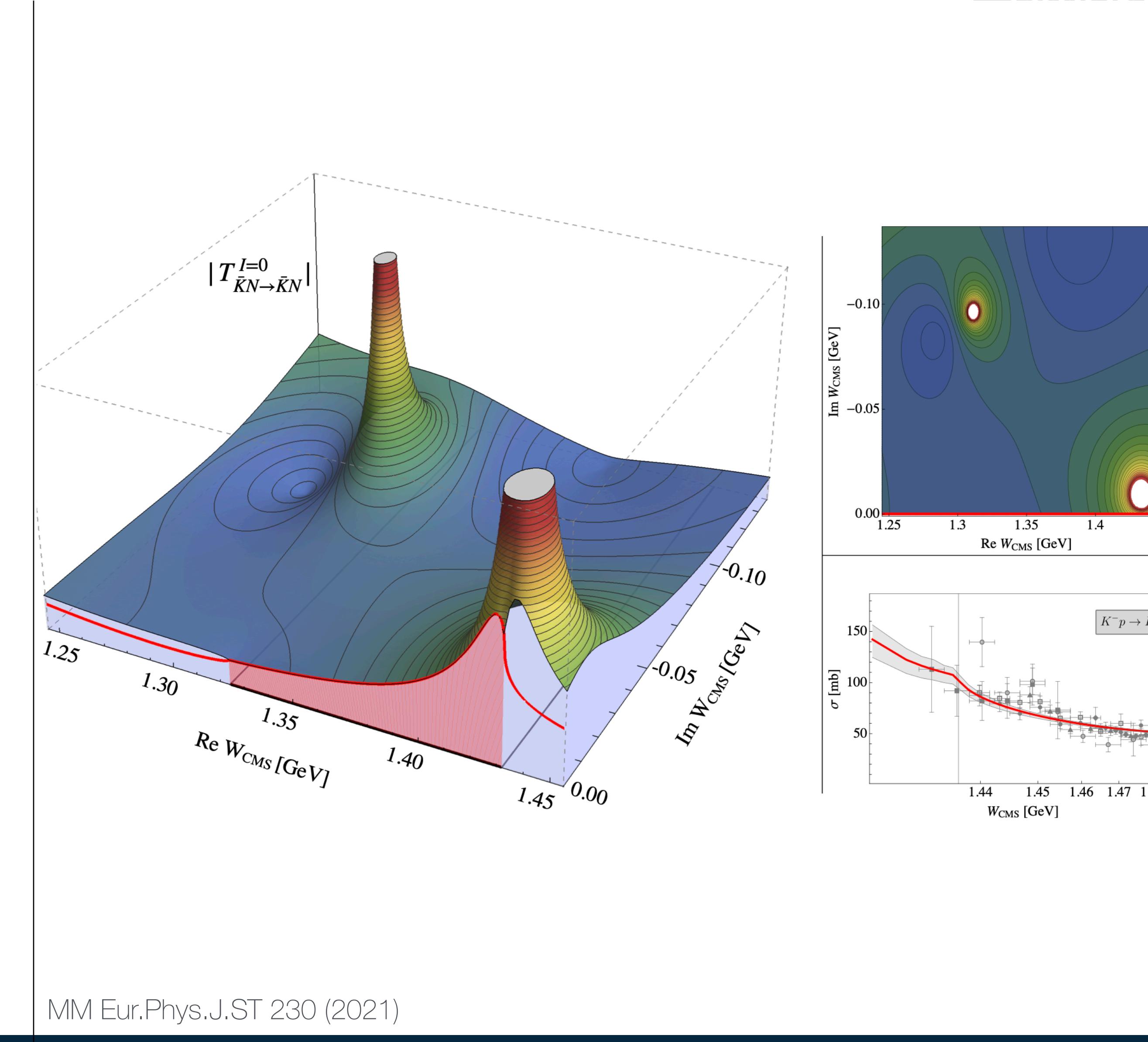
MM Eur.Phys.J.ST 230 (2021)

# K<sub>BARN</sub> 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<sup>1</sup>
  2. Experiment



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

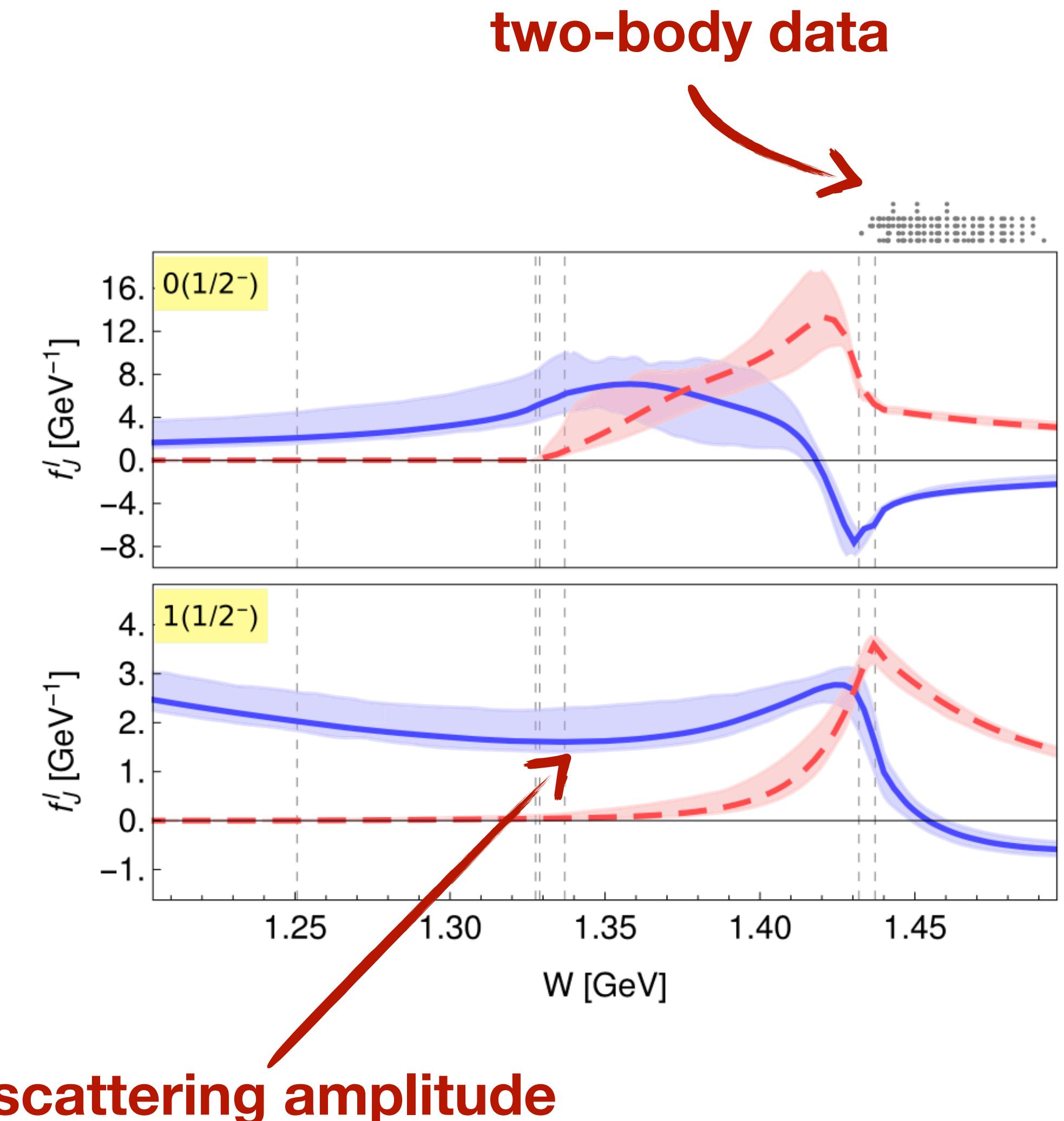
MM Eur.Phys.J.ST 230 (2021)

# K<sub>BARN</sub> SCATTERING



## Challenge

- many data available above/at the KbarN threshold<sup>1</sup>
- going below...  
→ use chiral symmetry / unitarity / ...<sup>2</sup>



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)

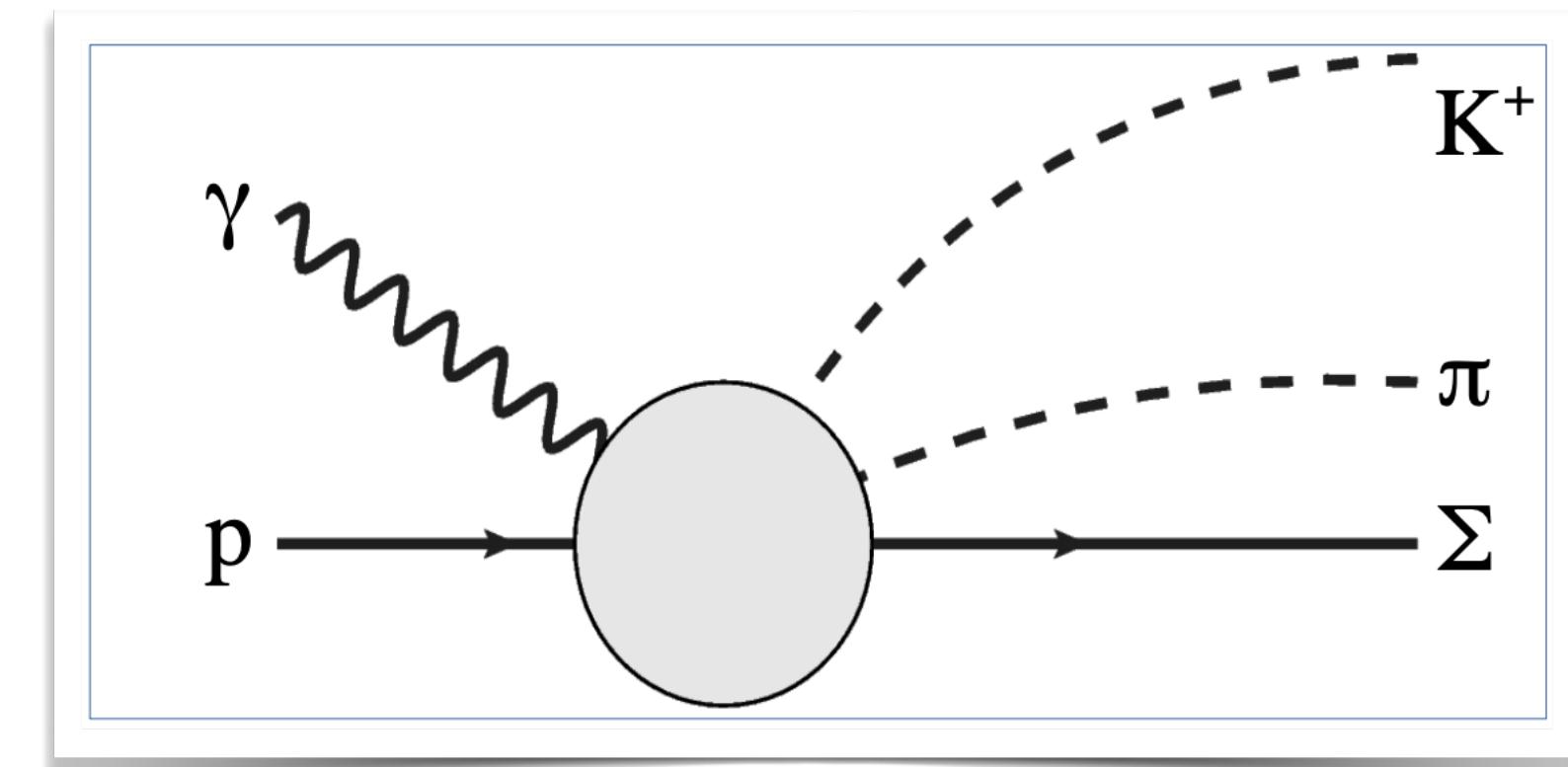
Sadasivan, MM, Döring (2019)

# K<sub>BARN</sub> SCATTERING



## Challenge

- many data available above/at the KbarN threshold<sup>1</sup>
- going below...
  - use chiral symmetry / unitarity / ... <sup>2</sup>
  - experiments with 3-body final states<sup>3</sup>



[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

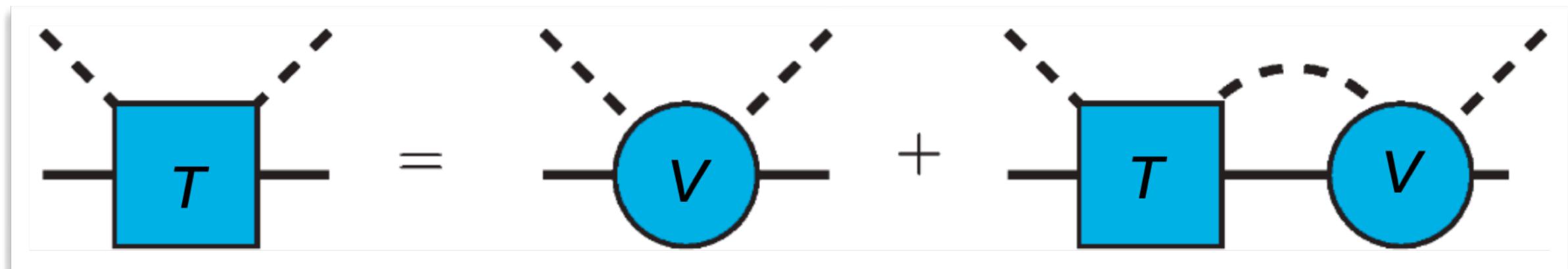
*"can photoproduction data reduce ambiguity on  $K\bar{b}N$  scattering amplitude?"*

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

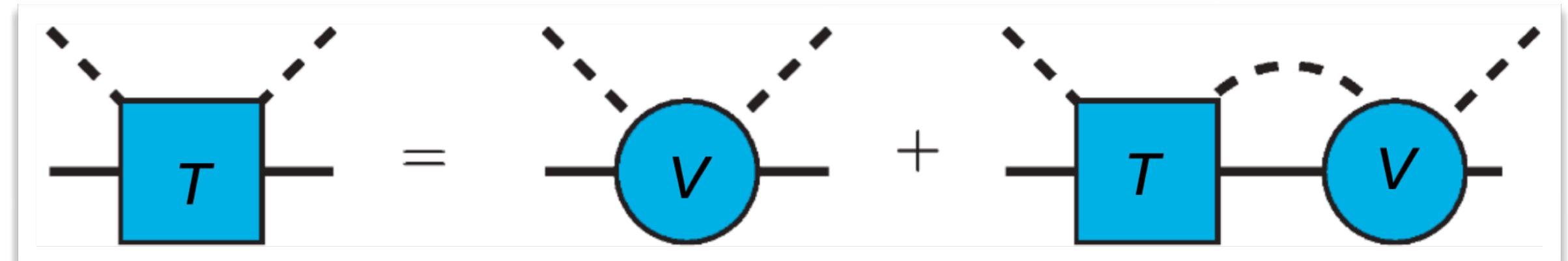


1) Weinberg (1979) Gasser, Leutwyler (1981)

# HADRONIC PART



- Unitarity of the S-matrix:
  - > mathematical foundation of universality of resonance parameters
  - > one implementation: Bethe-Salpeter equation
- ChPT<sup>1</sup>: (Effective field theory of QCD)
  - > incorporates symmetries of QCD
  - > reduces number of degrees of freedom



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

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

# HADRONIC PART

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- Various implementations
  - ➡ many scenarios with NLO kernel<sup>1</sup> tested

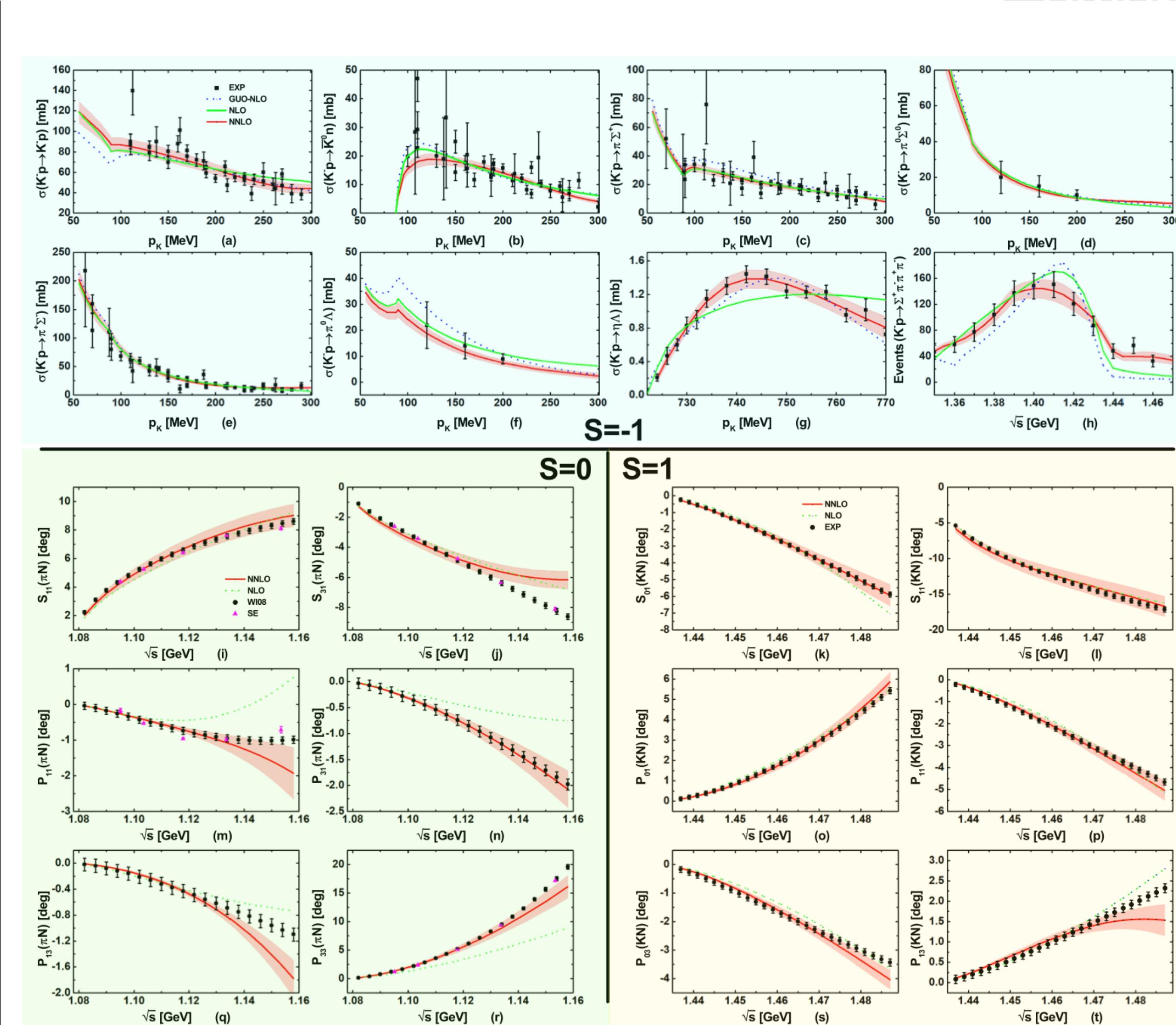
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadasivan et al. (2019)  
2) Lu/Geng/Döring/MM (2022)

# HADRONIC PART



- Various implementations
- many scenarios with NLO kernel<sup>1</sup> tested

→ first NNLO calculation<sup>2</sup> including  $K\bar{N}/\pi N/KN$



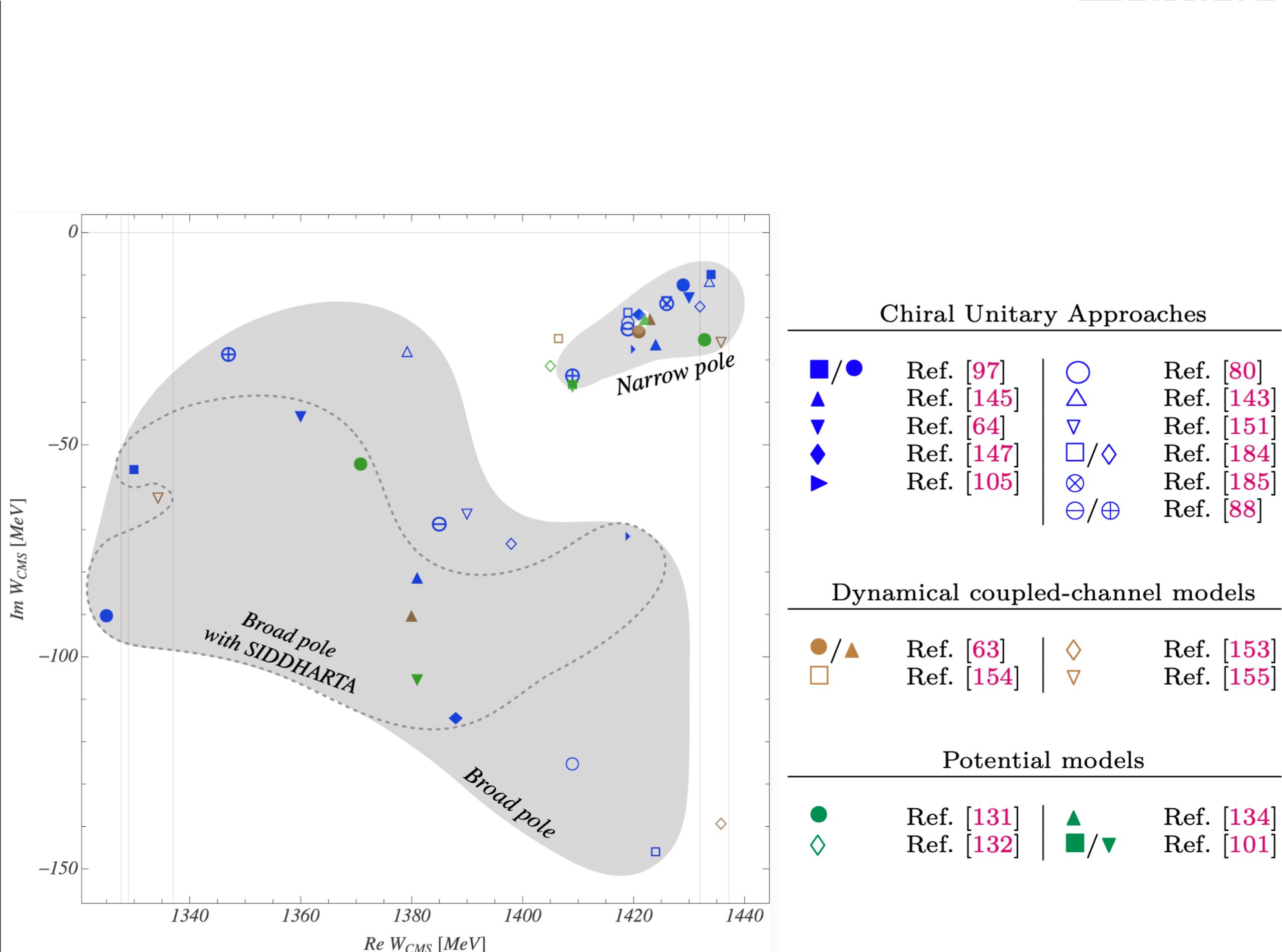
1) Ikeda et al. (2012); Guo/Oller (2013); MM/Meißner (2013,14); Sadashivan et al. (2019)

2) Lu/Geng/Döring/MM (2022)

# HADRONIC PART



- Various implementations
  - ↳ many scenarios with NLO kernel<sup>1</sup> tested
  - ↳ first NNLO calculation<sup>2</sup> 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)

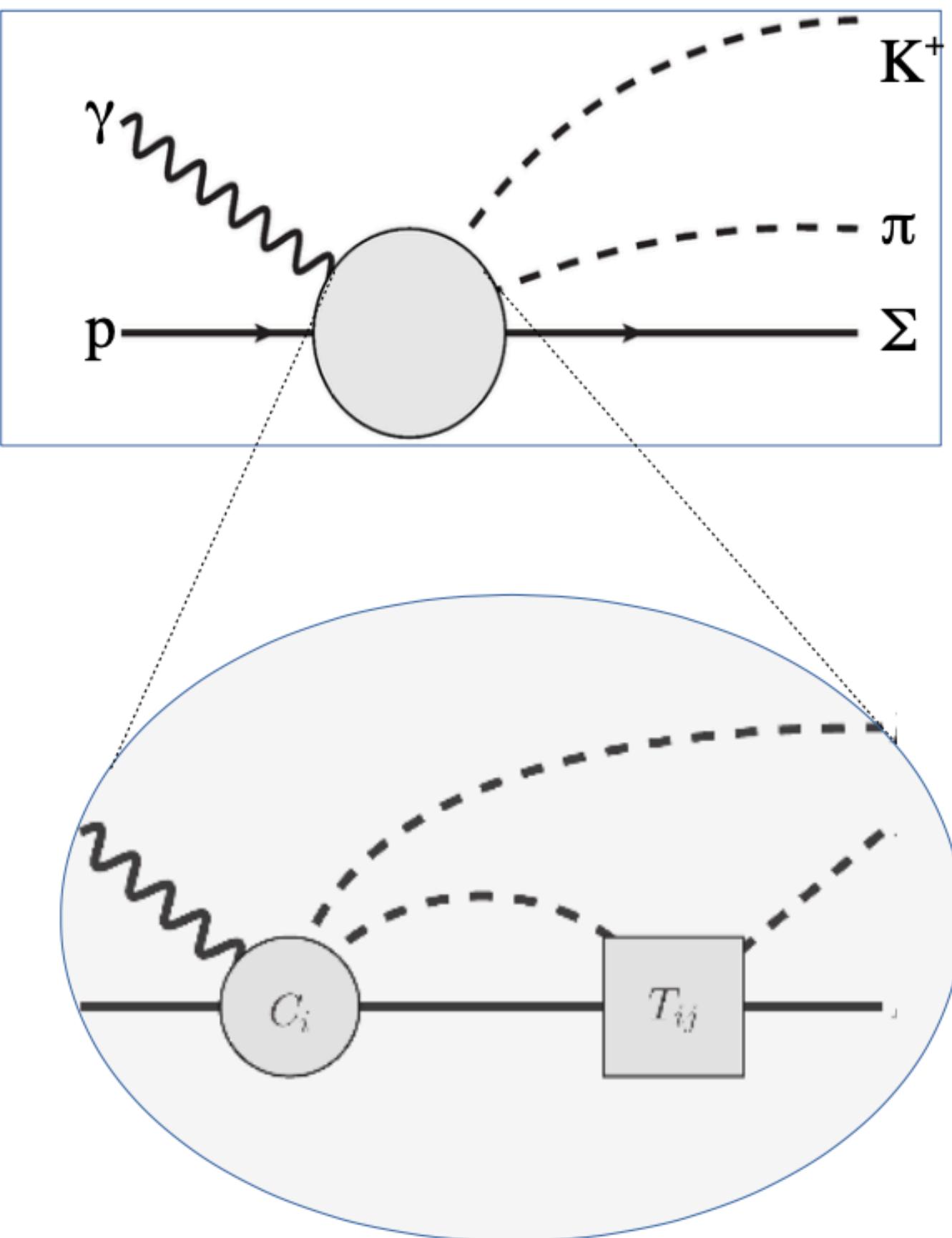
2) Lu/Geng/Döring/MM (2022)

# PHOTOPRODUCTION



## Test model<sup>1,2</sup>

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



1) Oset, Roca (2013)

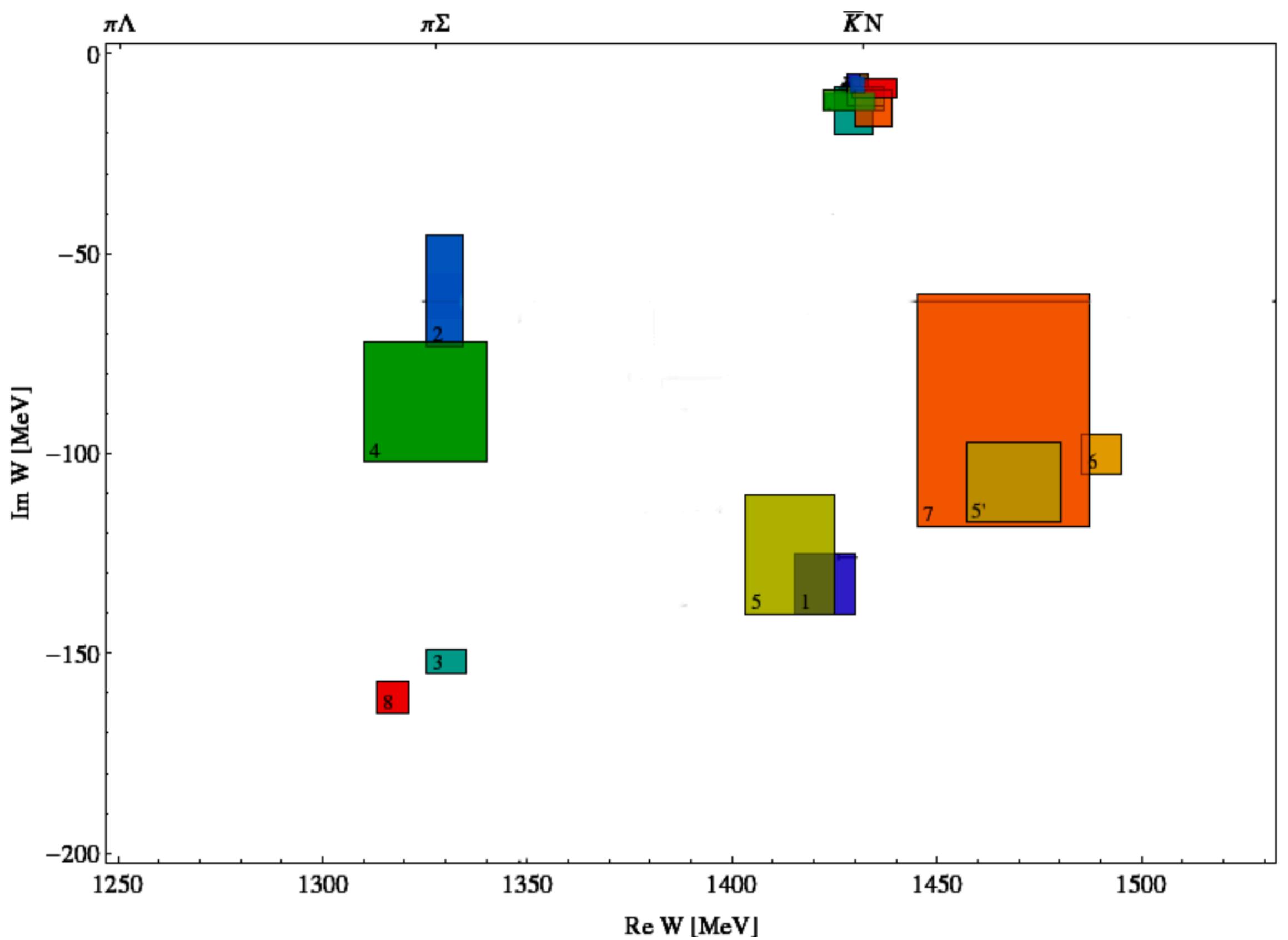
2) MM, Meissner(2015)

# 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)

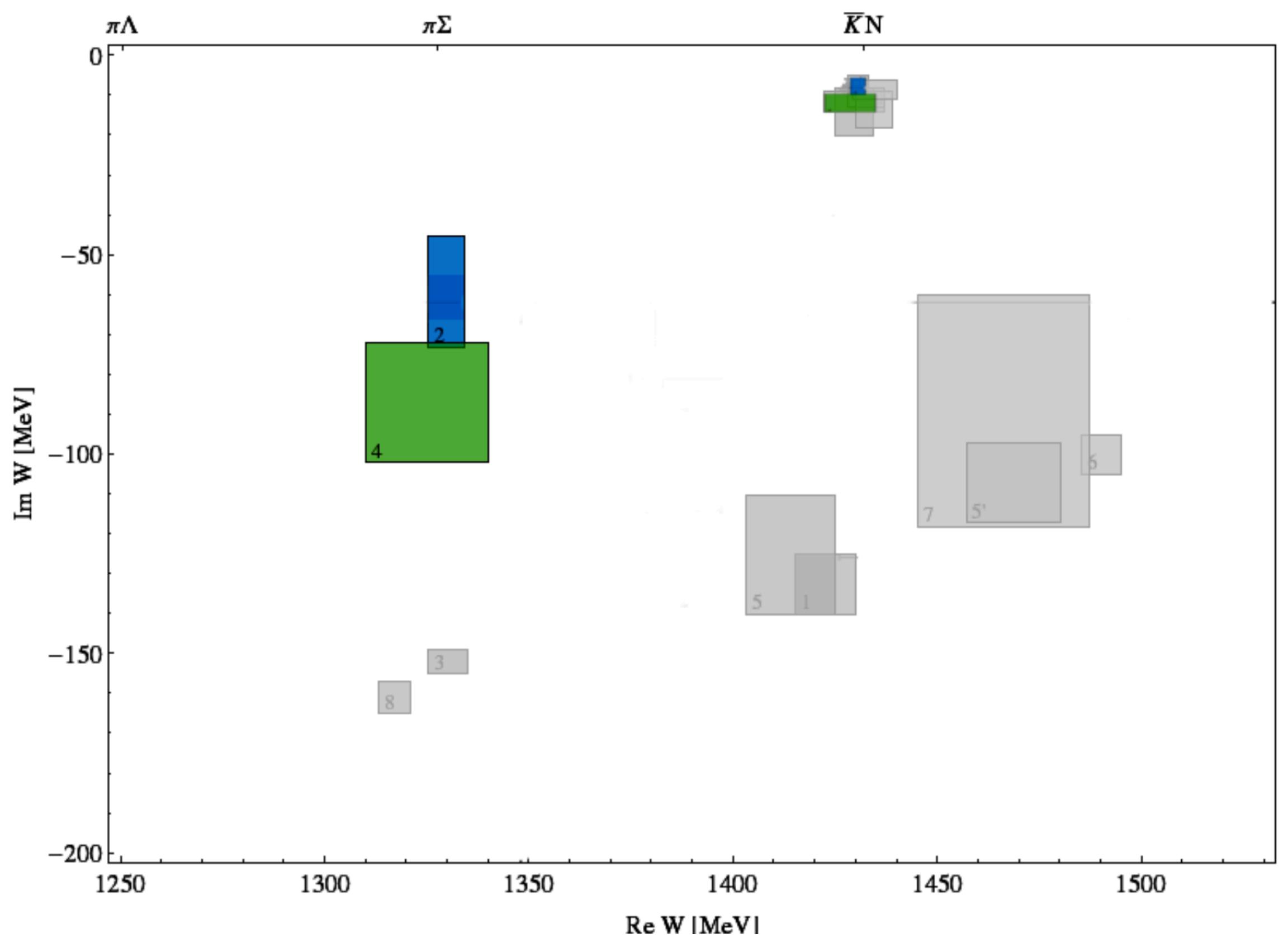
2) MM, Meissner(2015)

# 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)

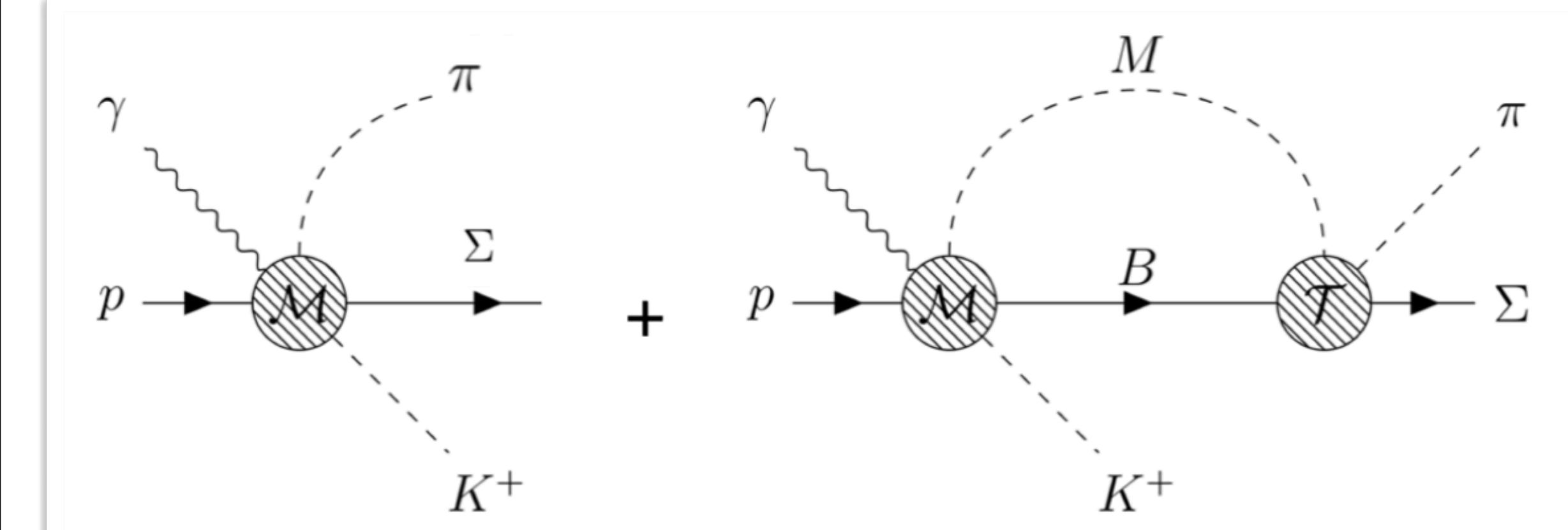
2) MM, Meissner(2015)

*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

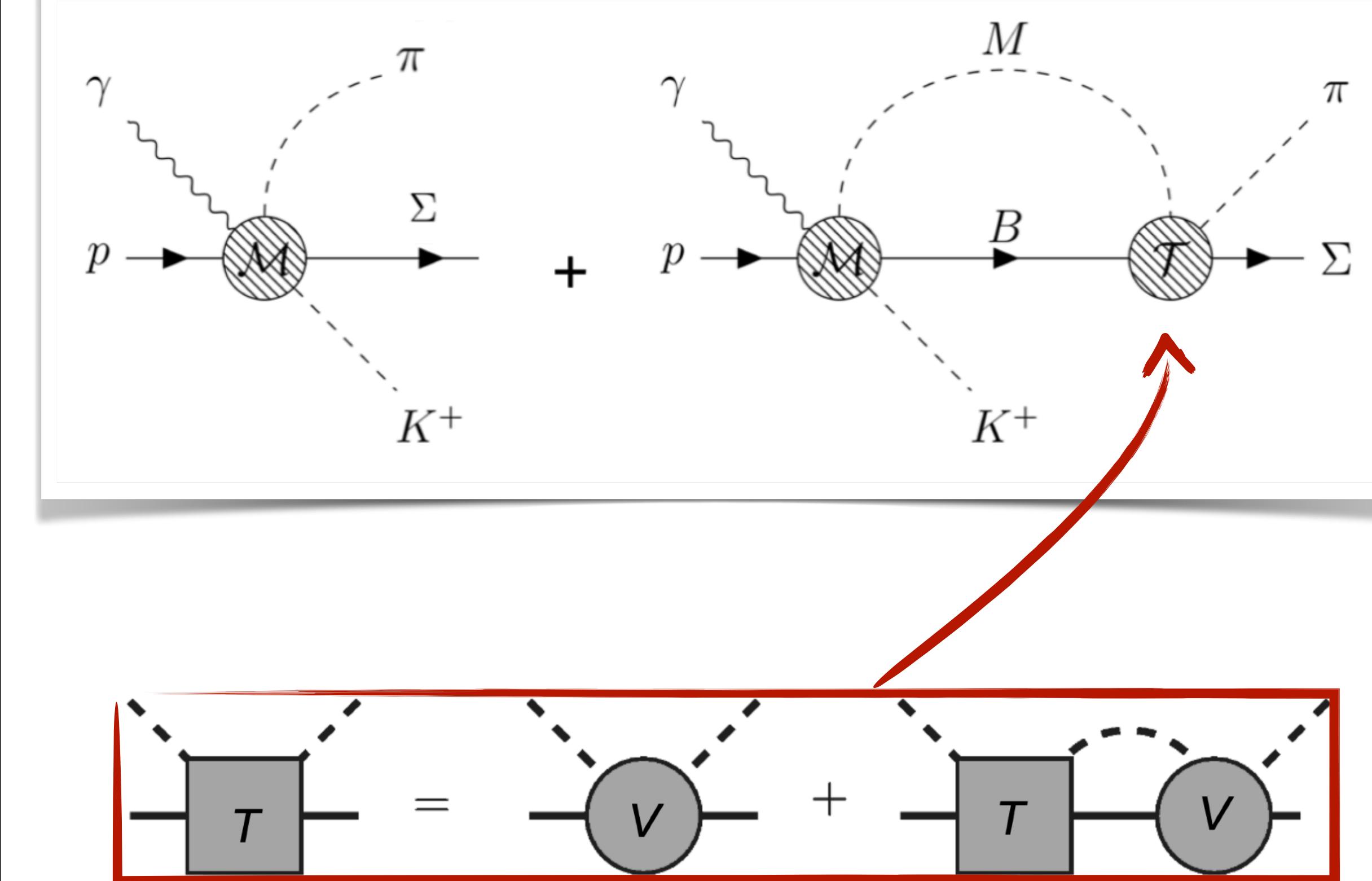


- 1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)
- 2) arXiv:2012.11298 [nucl-th].

# MICROSCOPIC MODEL



- Theoretical constraints
- FSI 2-body unitarity from chiral unitary and potential models<sup>1</sup>



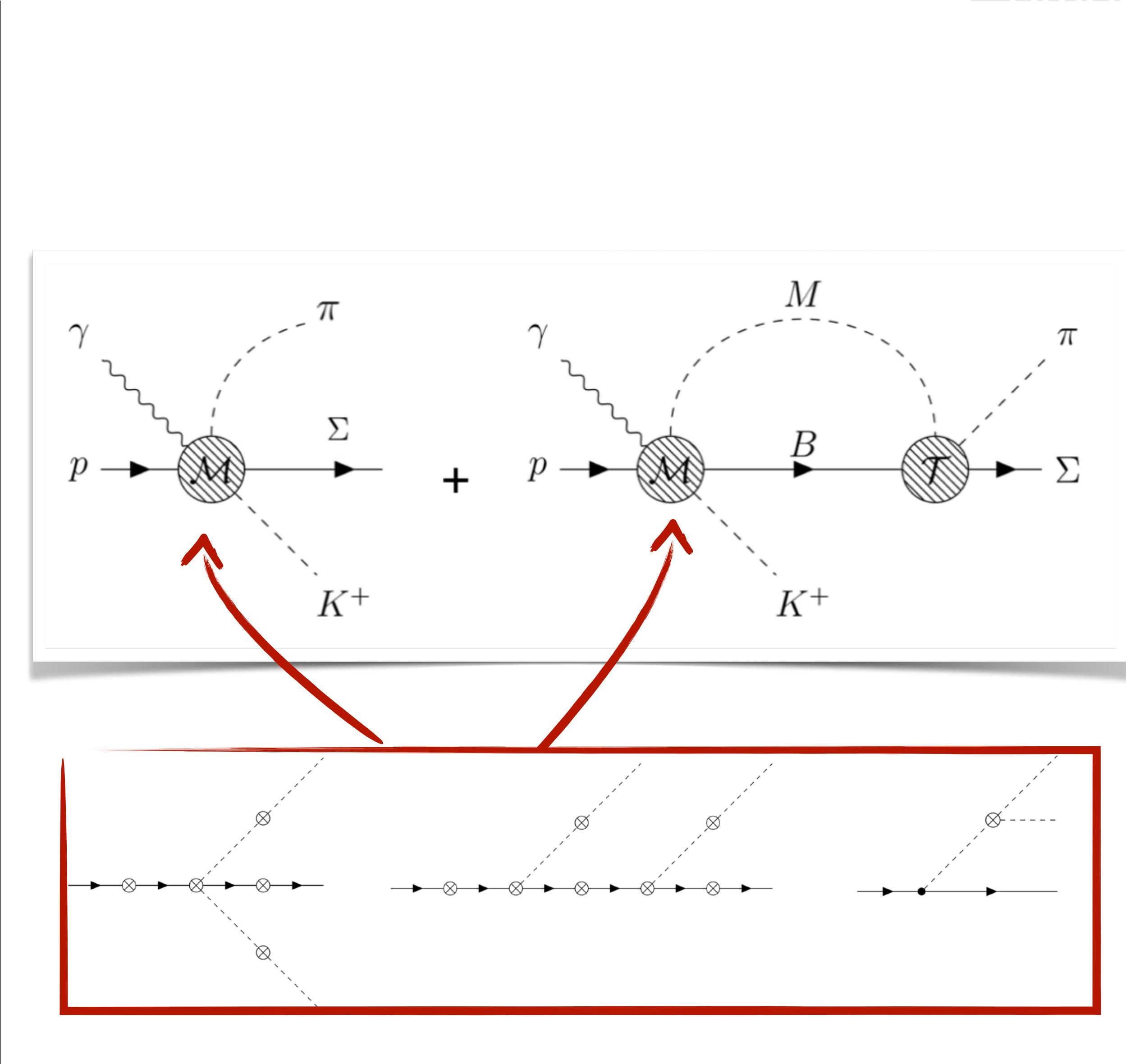
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# MICROSCOPIC MODEL



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  - chiral symmetry constraints on the production vertex<sup>2</sup>



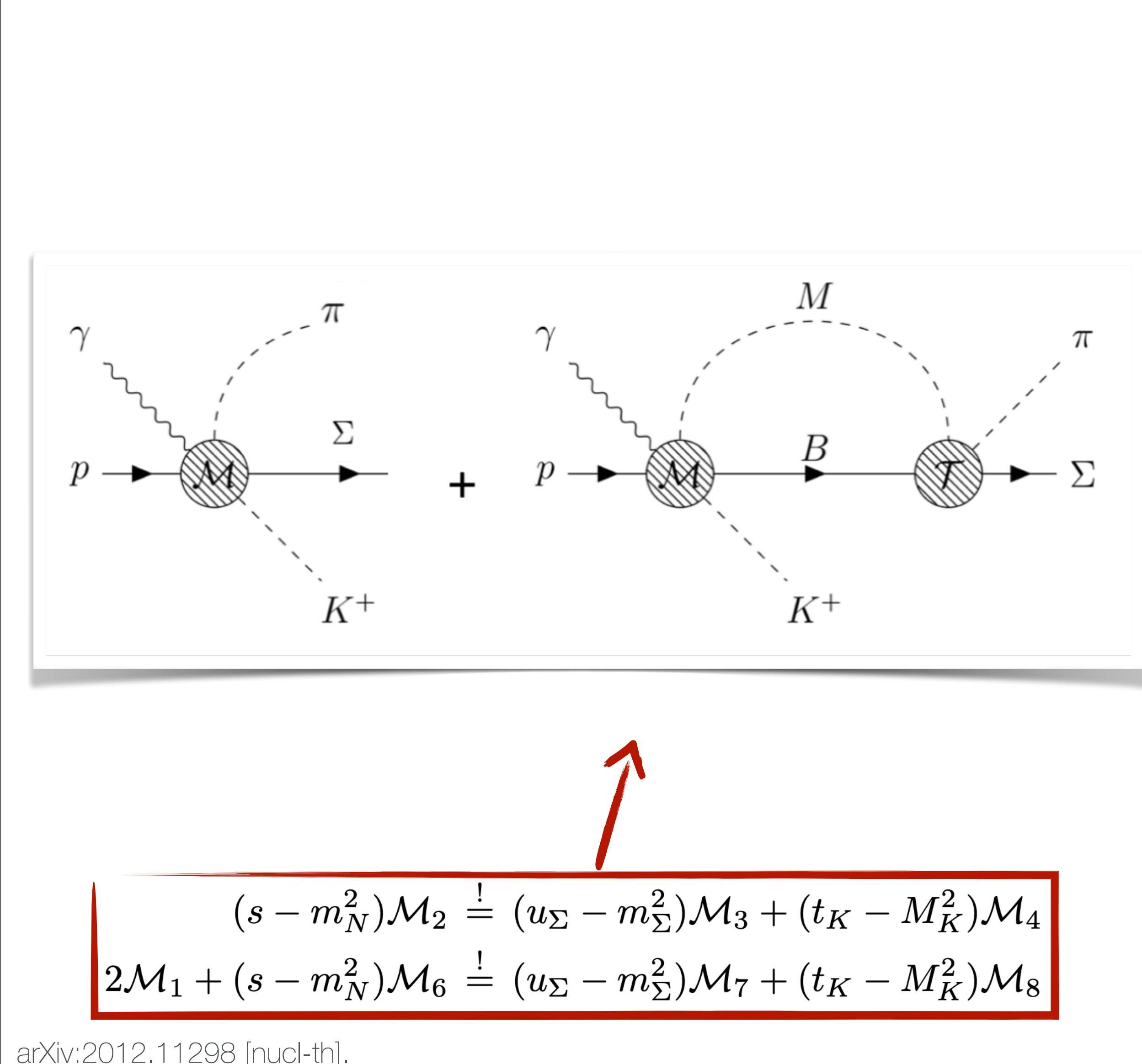
1) Bruns/Cieply (2022); MM/Meißner (2015); Sadasivan et al. (2019)

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# MICROSCOPIC MODEL



- Theoretical constraints
  - ↳ FSI 2-body unitarity from chiral unitary and potential models<sup>1</sup>
  - ↳ chiral symmetry constraints on the production vertex<sup>2</sup>
  - ↳ gauge invariance included by construction



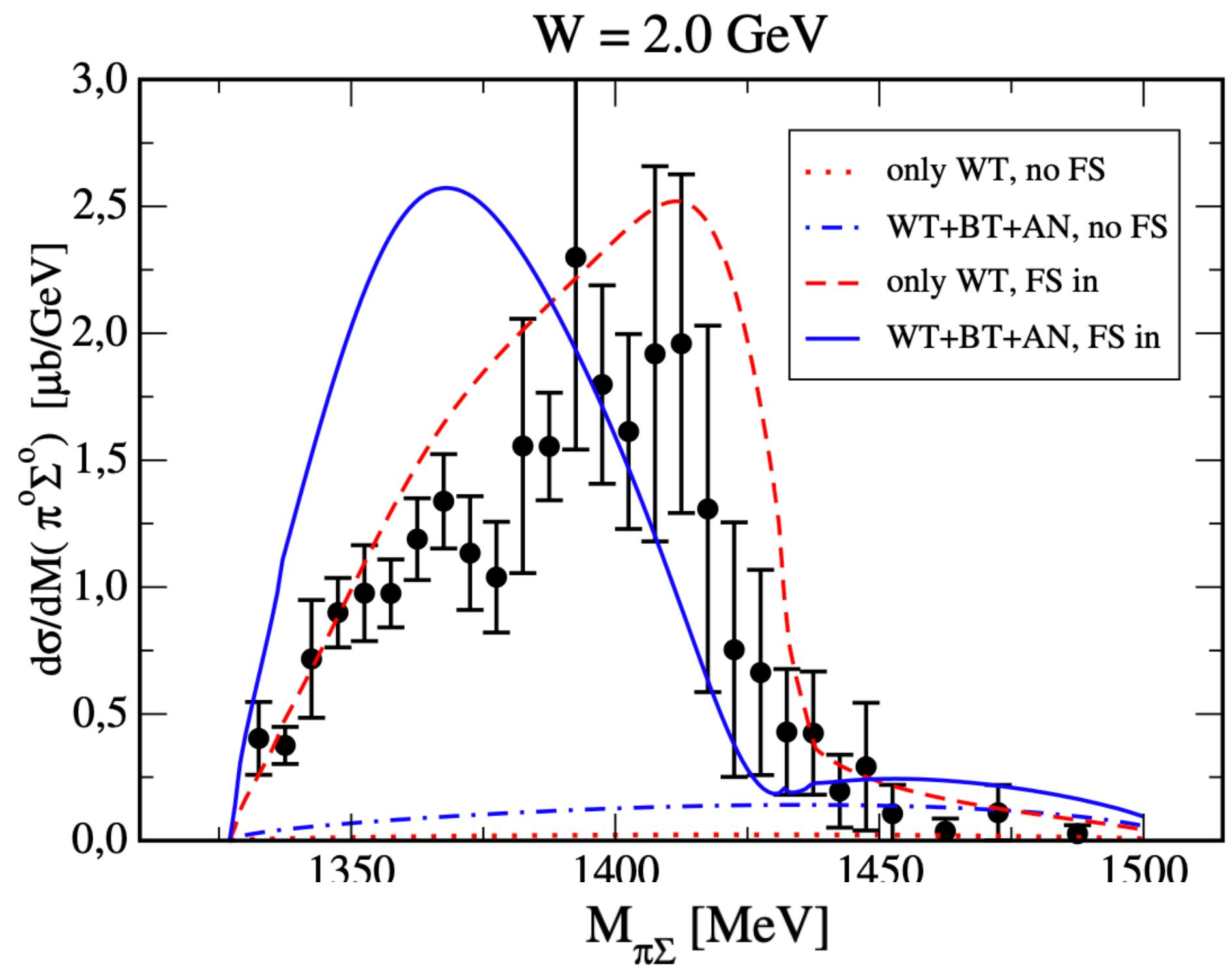
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2) arXiv:2012.11298 [nucl-th].

# RESULTS



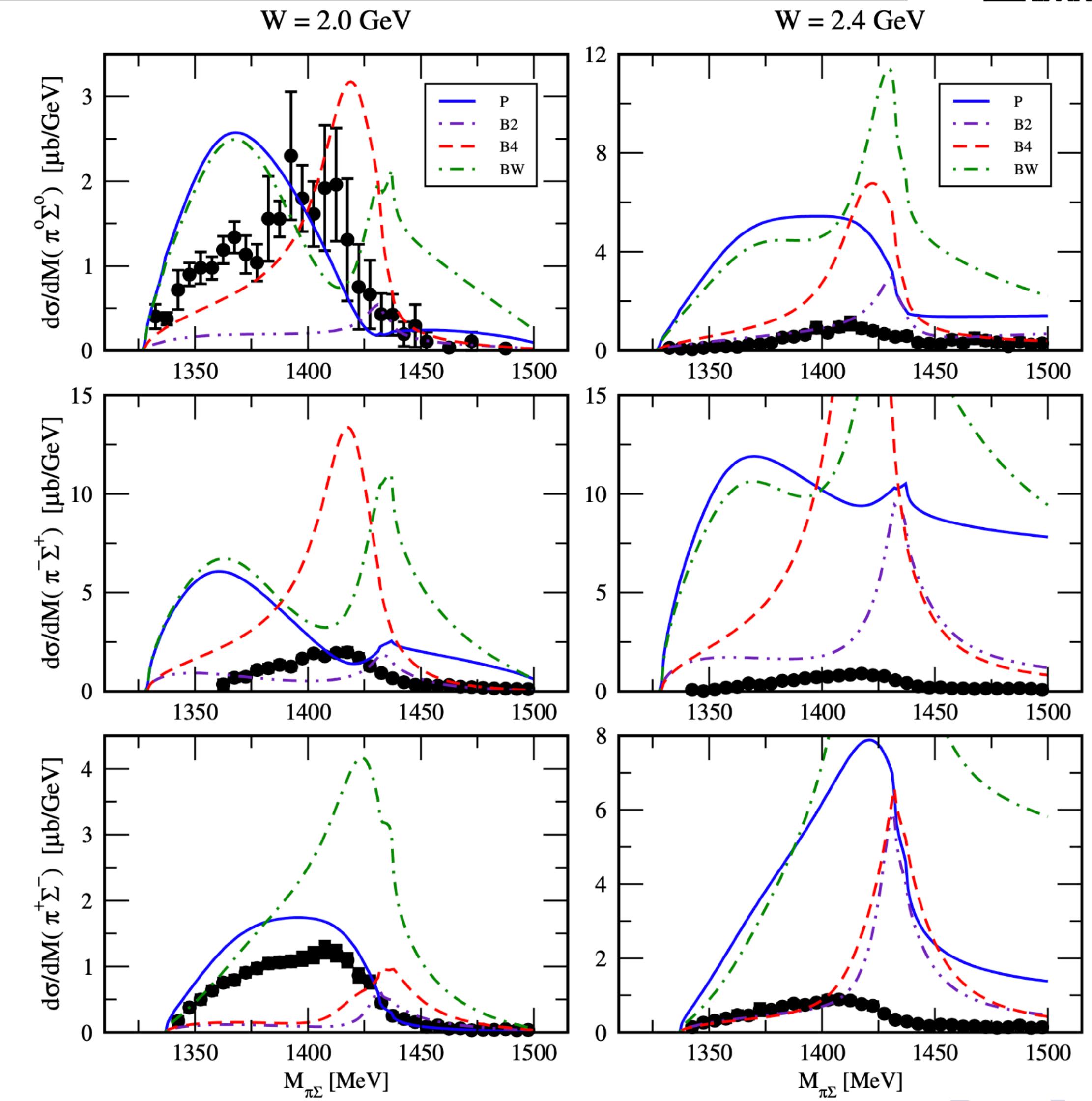
- Final state interaction yields structured line-shape



# RESULTS



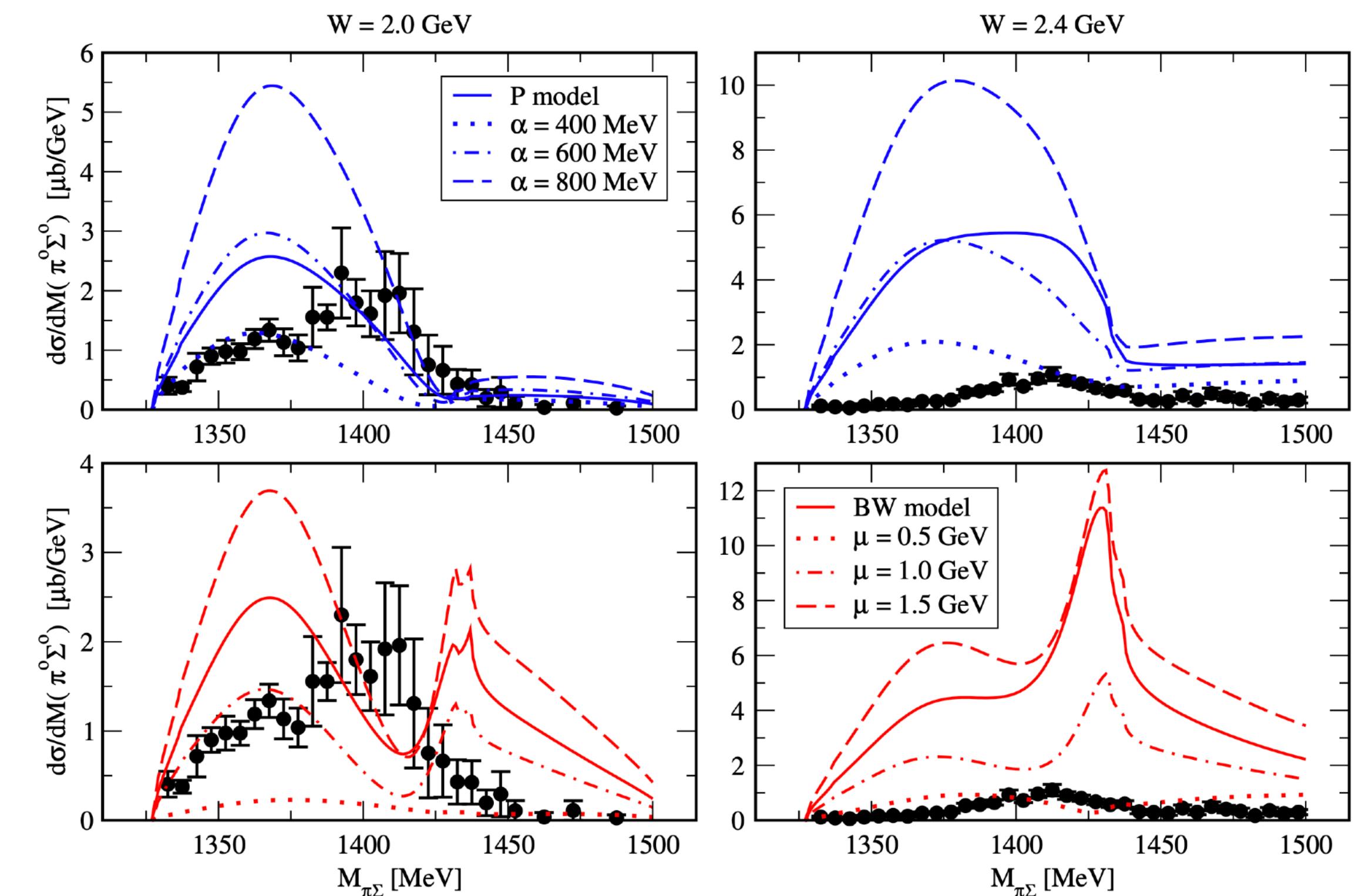
- Final state interaction yields structured line-shape
- Predictions (no free parameters) of line-shapes are vastly different wrt hadronic models



# 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**

