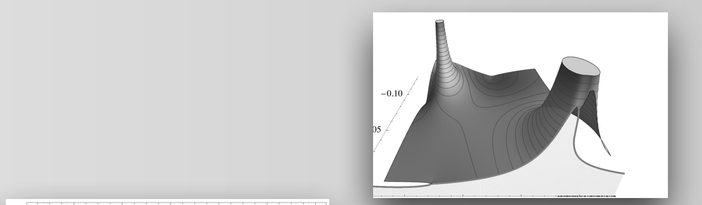
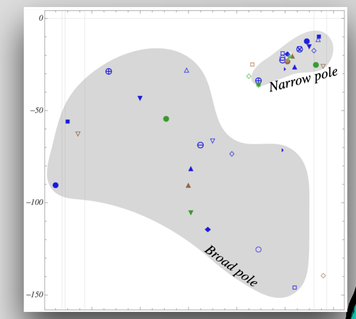
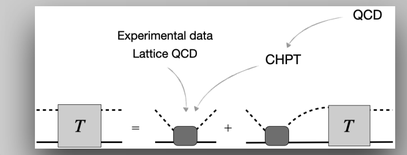
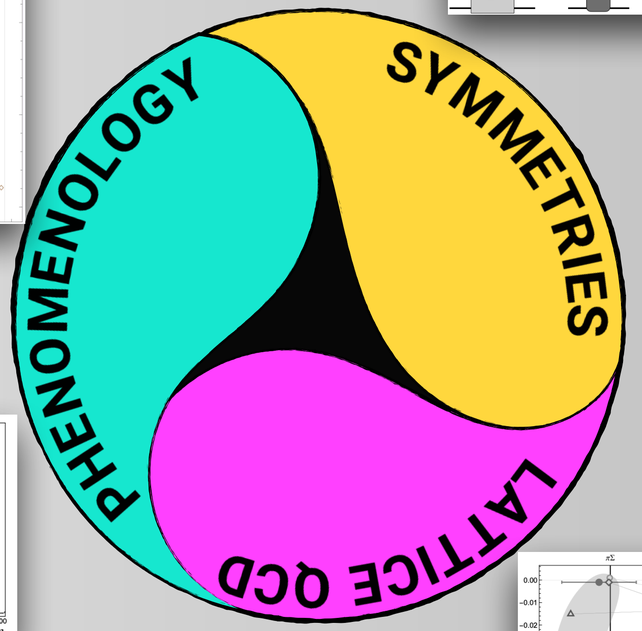
THEORY OF KAON-NUCLEON INTERACTION

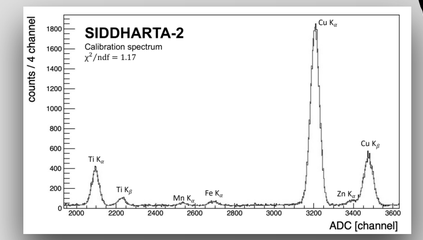
26.-30.08.2024 — EXA/LEAP'24

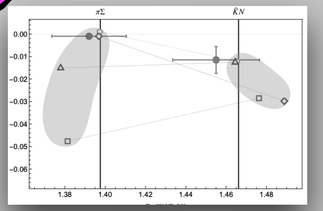


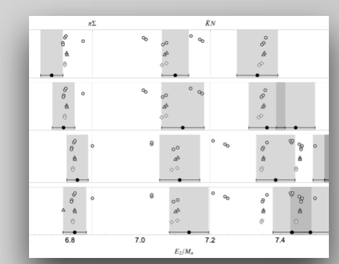












MAXIM MAI

UNIVERSITY OF BERN (MAIN)

THE GEORGE WASHINGTON UNIVERSITY

TRR110: NSFC Grant No. 12070131001, DFG Project-ID 196253076

DOE: DE-SC0016582, DE-AC05-06OR23177, DE-FG02-95ER40907

DFG: Heisenberg Programme (project number: 532635001)

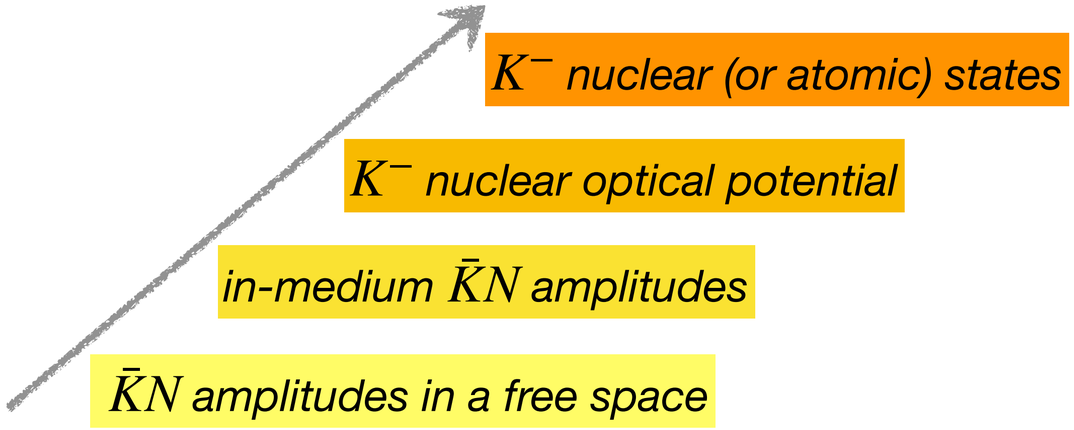
NSF: PHY-2012289

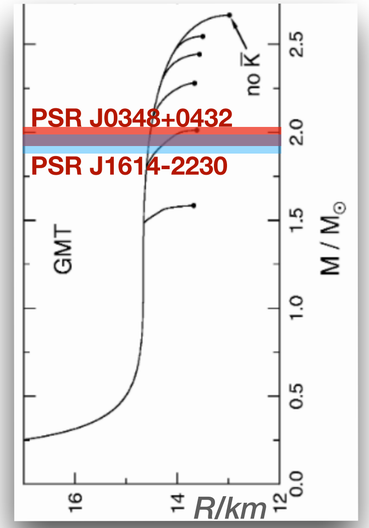
OVERARCHING IMPACT

- Test of our understanding of QCD
- $\bar{K}NN$ & $\bar{K}NNN$ bound states[1]
- K^- in medium[2]

  K^--condensate can change NS EoS

  ... many theoretical challenges[3]





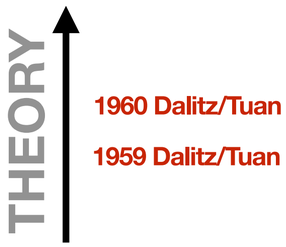
Pal et al., Nucl. Phys. A **674**, 553 (200

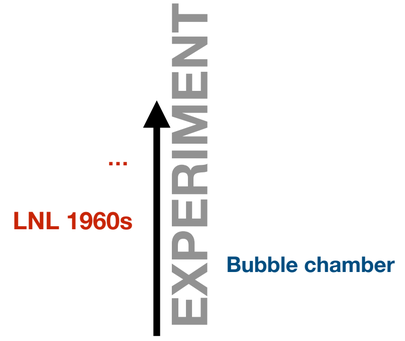
[1] Review by Gal/Hungerford/Millener (2016); **Talk: FRIEDMAN [Tuesday] GAZDA [Friday]**
[2] Mareš et al. Acta Phys. Polon. B 51, 129 (2020); Hrtánkova et al. Phys.Lett. B 785, 90 (2018)
[3] **Talk: JINNO [Thursday]**

STRANGENESS PROGRAM/HISTORY

“There is a large experimental program on production of S particles
… But just between us theoretical physicists:
What do we do with all these data?
We can’t do anything.”

R. P. FEYNMAN





[1] Sakurai Annals Phys. 11, 1 (1960).
[2] MM EPJST 230 (2021) “Review of the Λ(1405) A curious case of a strangeness resonance”;
[3] **TALK: SGARAMELLA[Thursday]**
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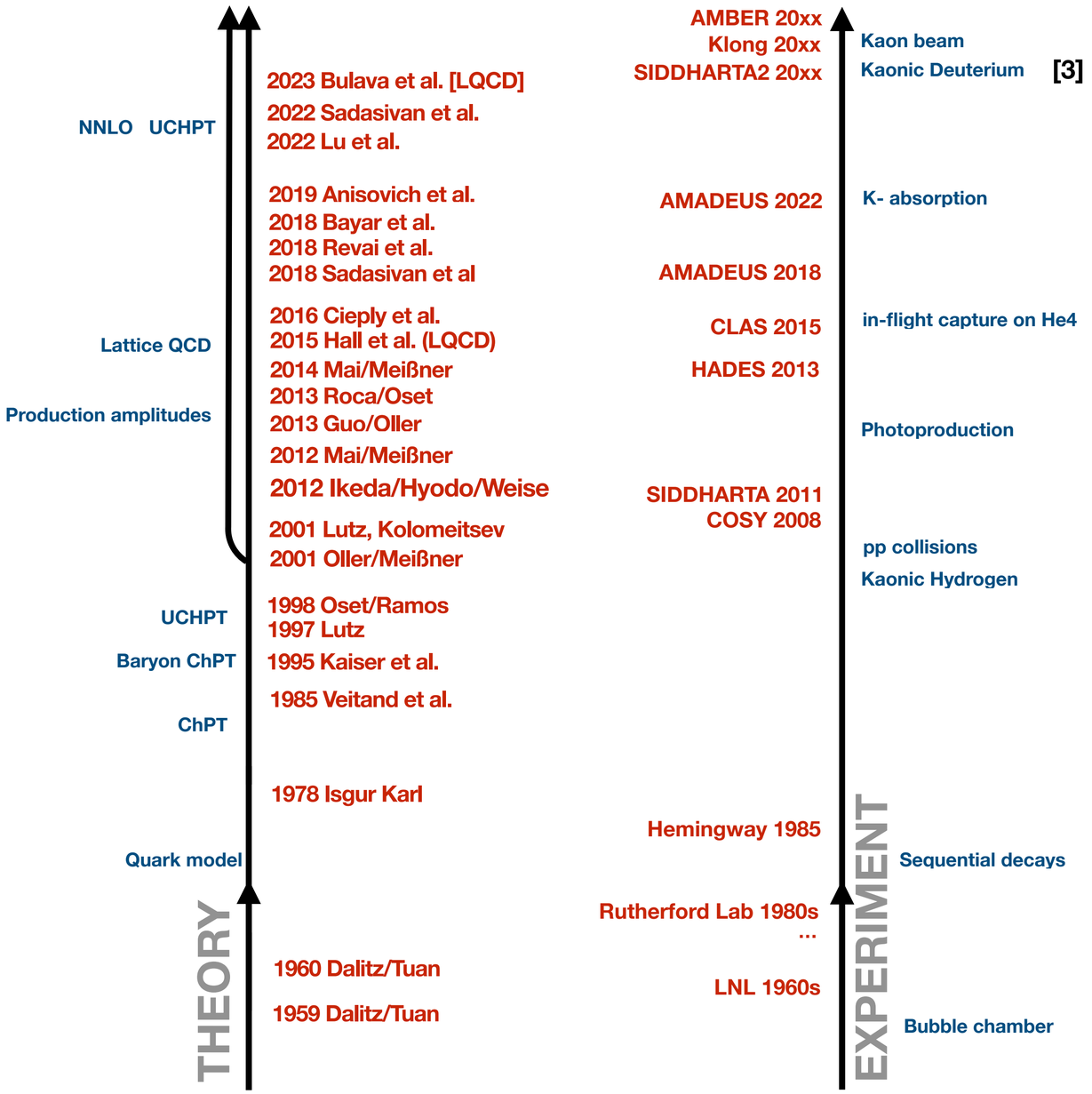

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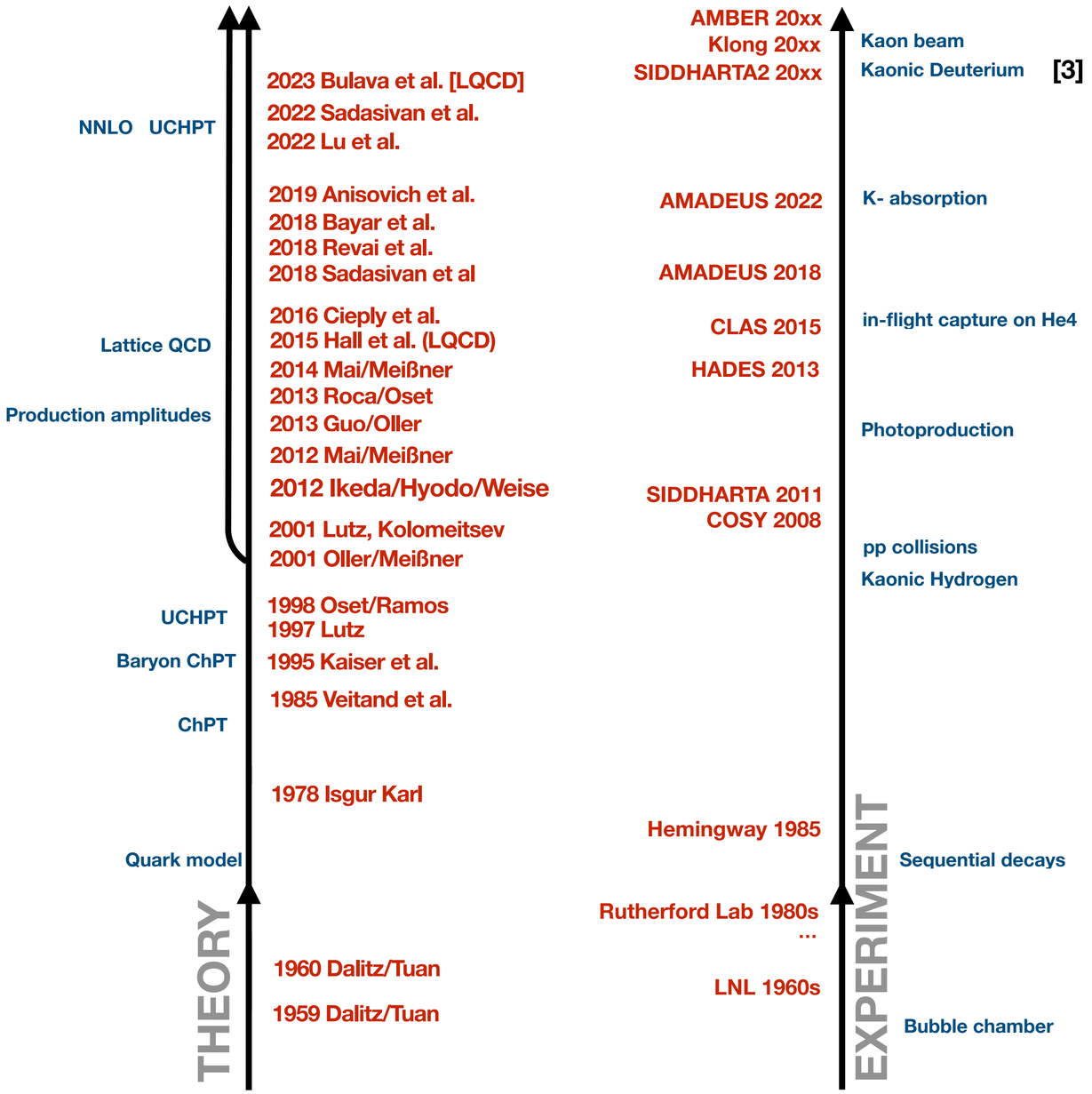
NEW STRANGENESS RESONANCES

Sub-($\bar{K}N$)-threshold $\Lambda(1405)$ resonance

- second state $\Lambda(1380)$ predicted from UCHPT[4]
- confirmed by many critical tests[5] / LQCD



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THEORY

QUANTUM CHROMODYNAMICS

Sub-($\bar{K}N$)-threshold $\Lambda(1405)$ resonance

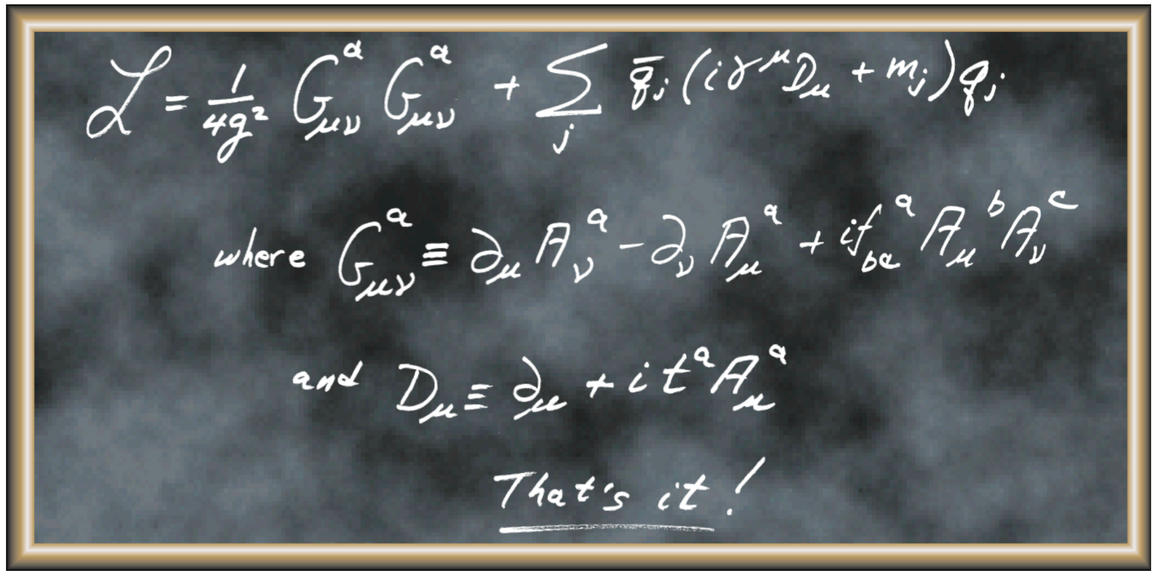
➡ no direct experimental verification

🧐 ***why not directly from QCD?***

➡ non-perturbative energy regime

🧐 ***why not QCD/EFT?***

➡ resonant interaction



http://frankwilczek.com/Wilczek_Easy_Pieces/298_QCD_Made_Simple.pdf

[1] Sakurai Annals Phys. 11, 1 (1960).
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TOOLS

Sub-($\bar{K}N$)-threshold $\Lambda(1405)$ resonance

➡ no direct experimental verification

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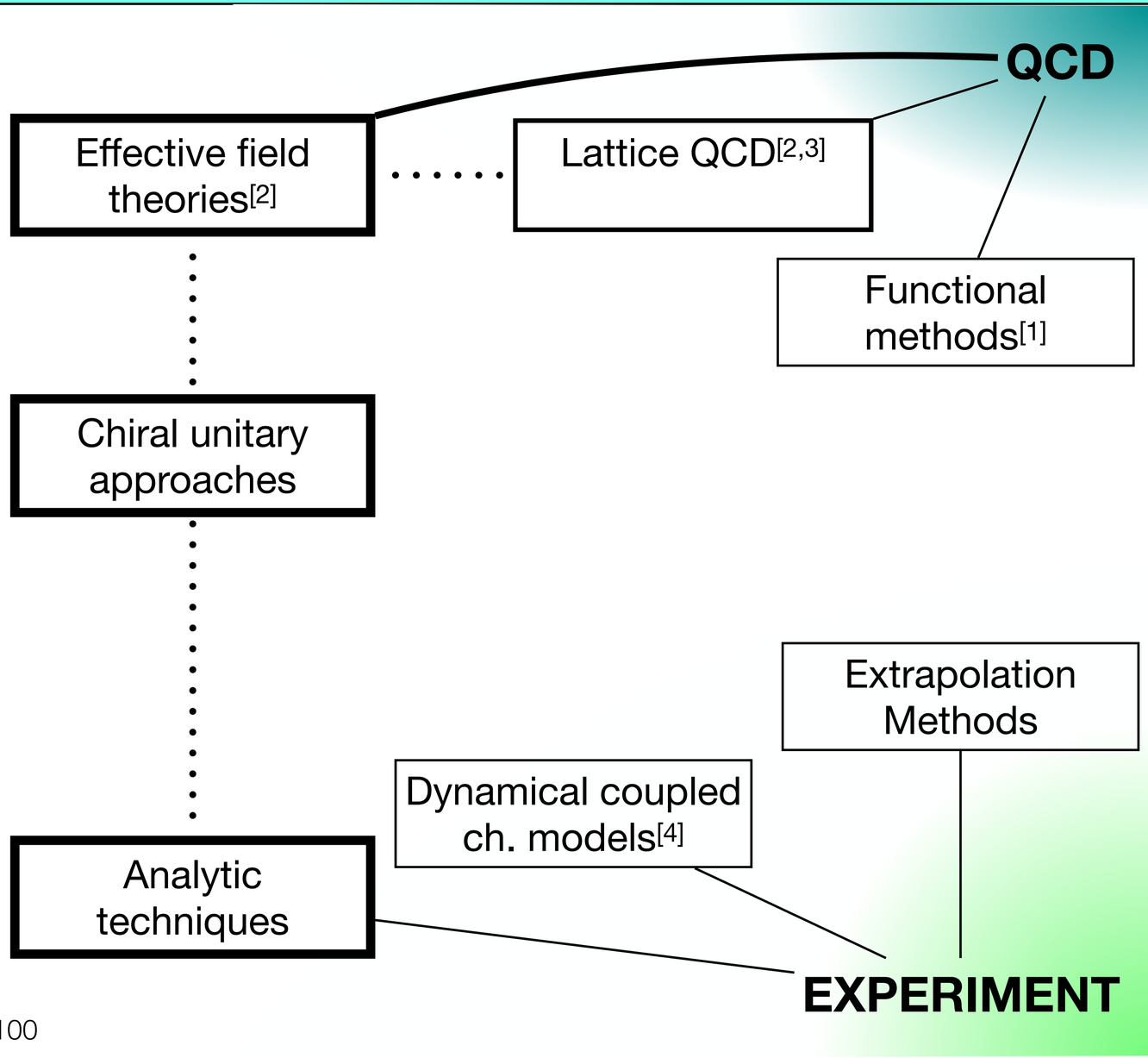


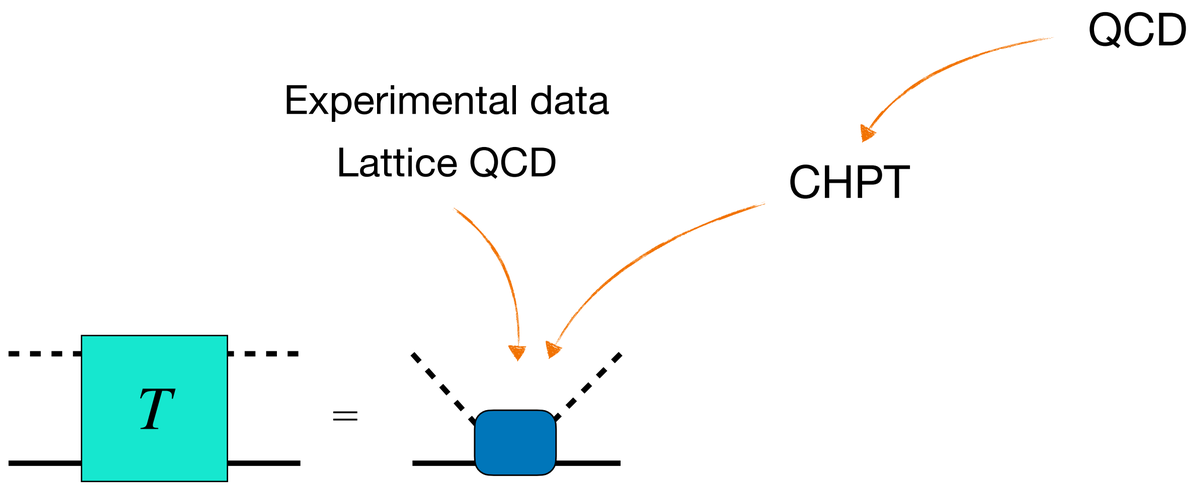
[1] Review: Eichmann/Sanchis-Alepuz/Alkofer/Fischer Prog.Part.Nucl.Phys. 91 (2016) 1-100
[2] Review: Briceño/Dudek/Young Rev.Mod.Phys. 90 (2018)
[3] Review: MM/Meißner/Urbach Phys.Rept. 1001 (2023) 1-6
[4] Review: Döring/Haidenbauer/Sato/MM PPNP in progress

UNIVERSAL PARAMETERS

Transition amplitude — chiral unitary approach[1]

Chiral Perturbation Theory (#QCD#EFT)

form of the interaction at low energies



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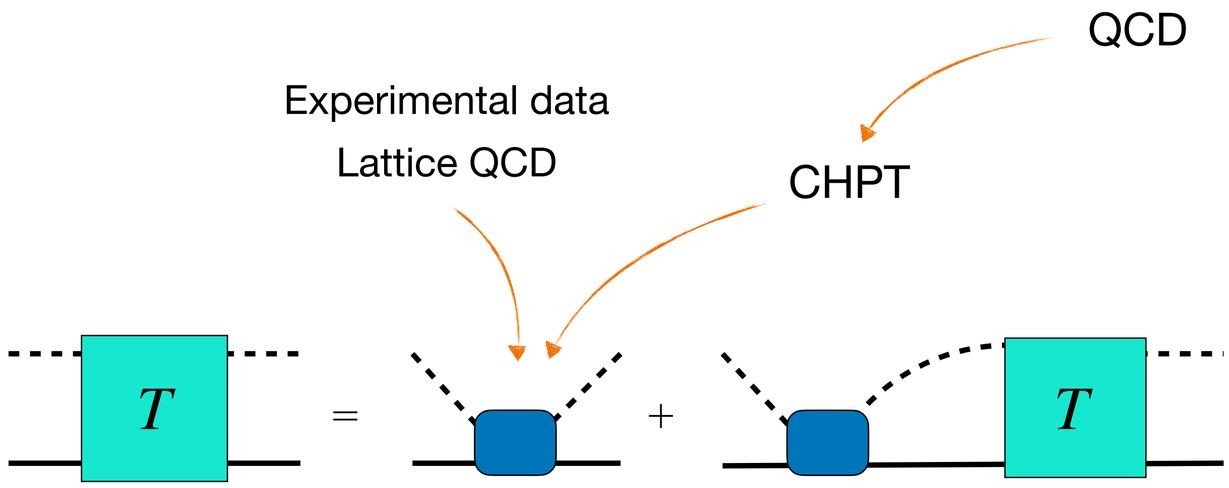

Unitary amplitude from the Bethe-Salpeter equation

(Fit free parameters to experimental data or LQCD)

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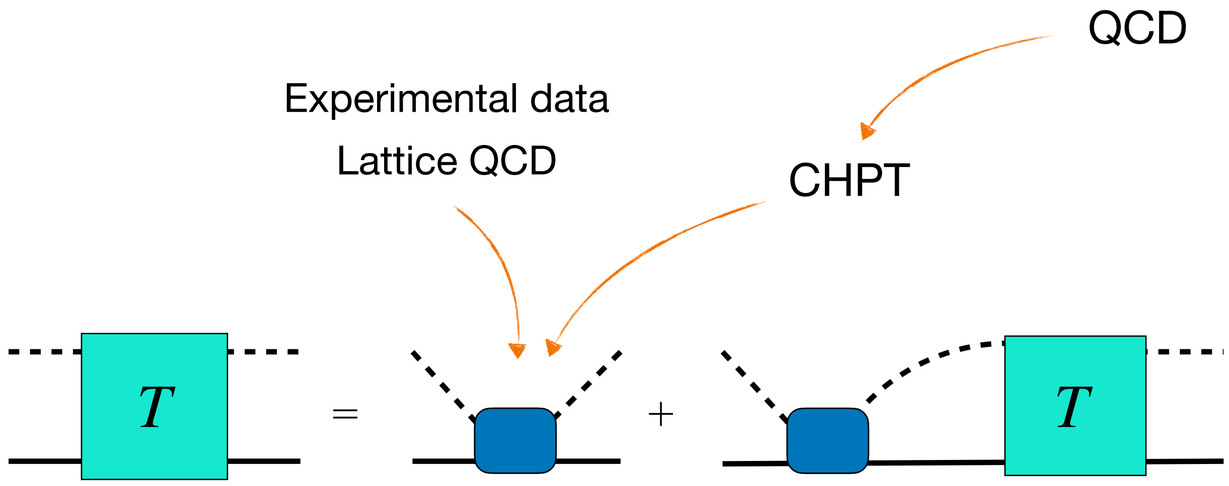

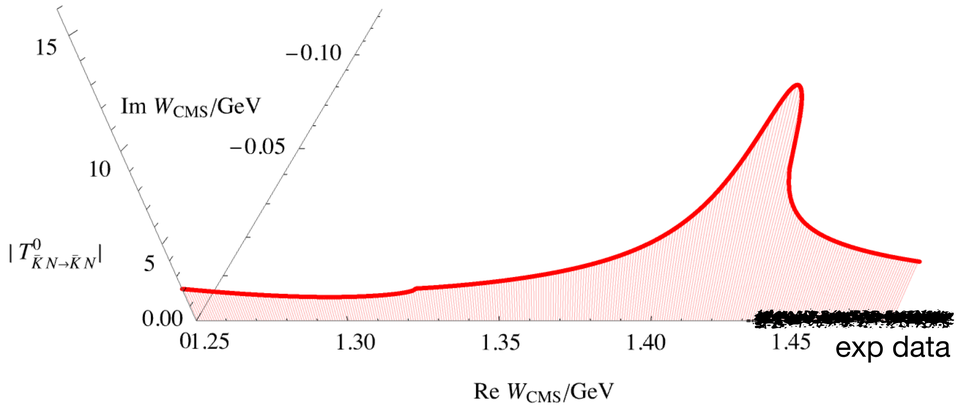

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analyticity, unitarity, Riemann sheets, …

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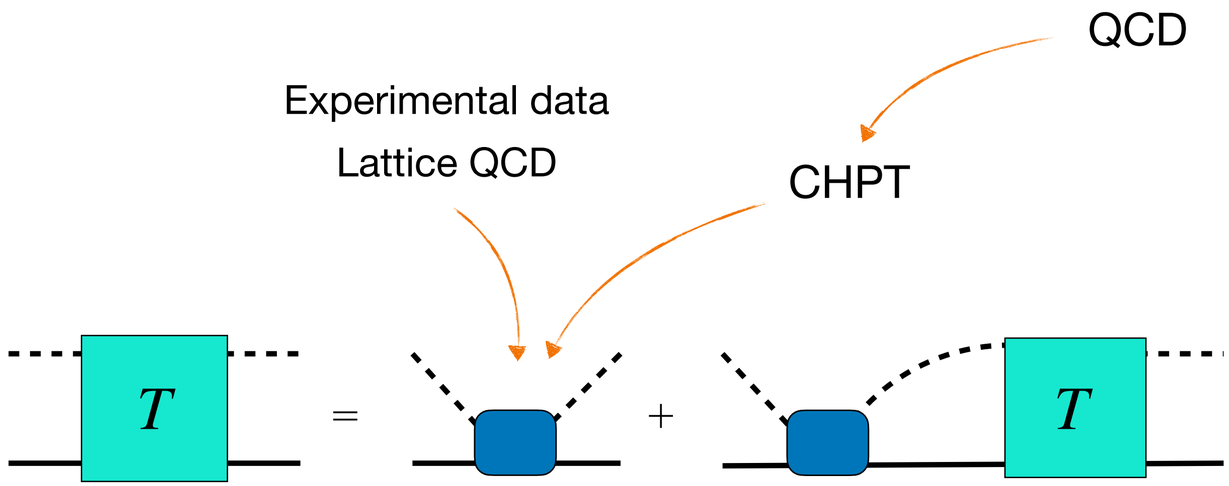
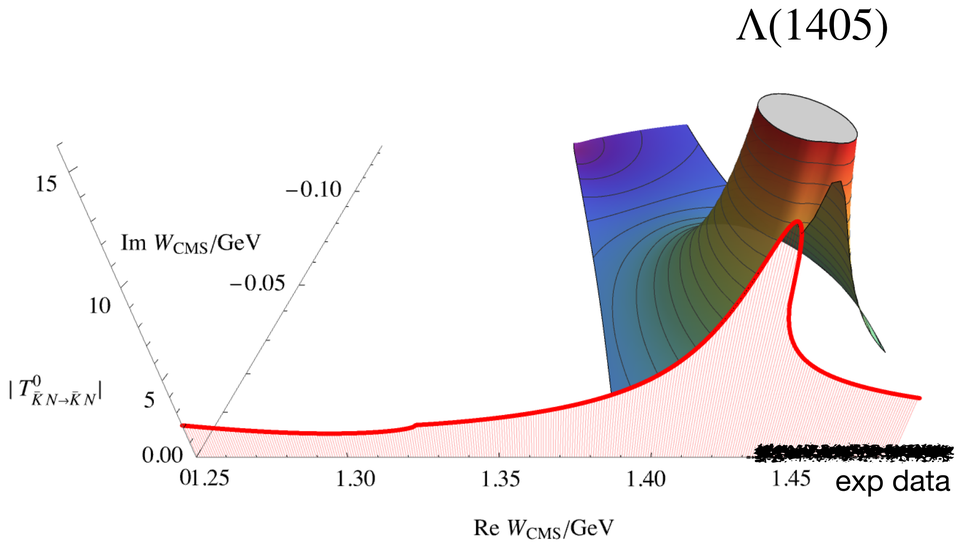
universal
reaction-independent parameters





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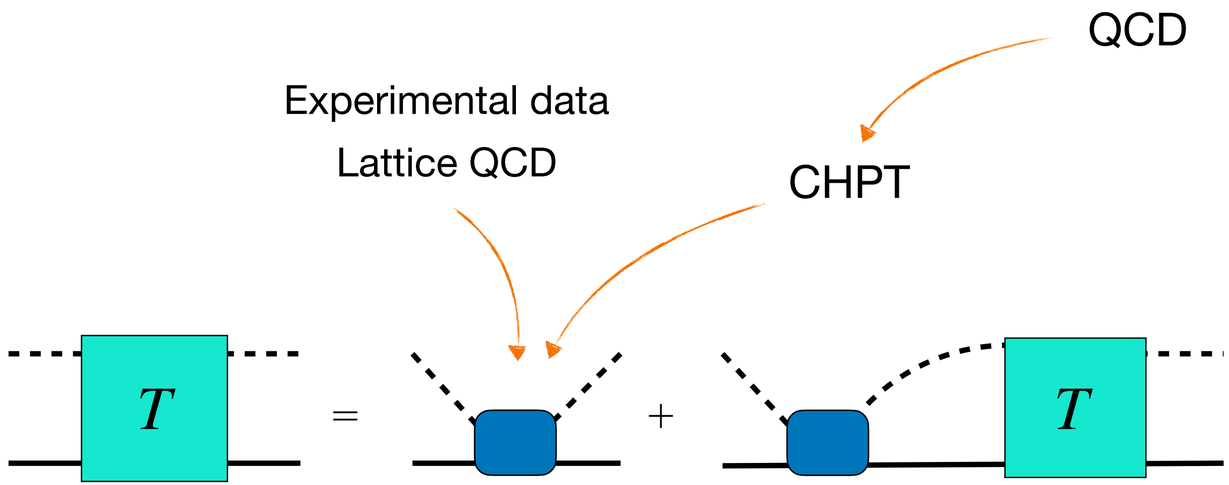

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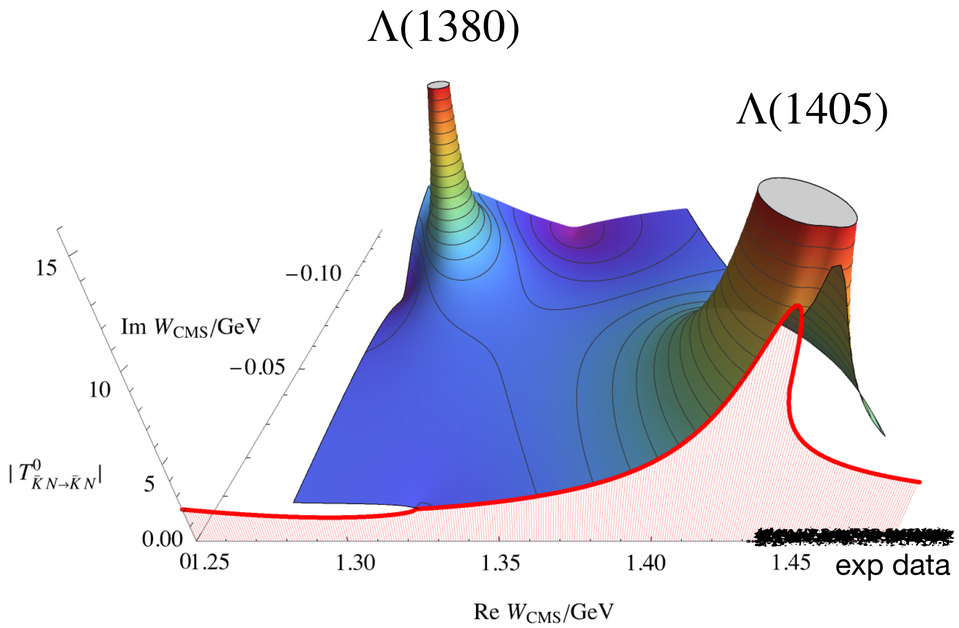

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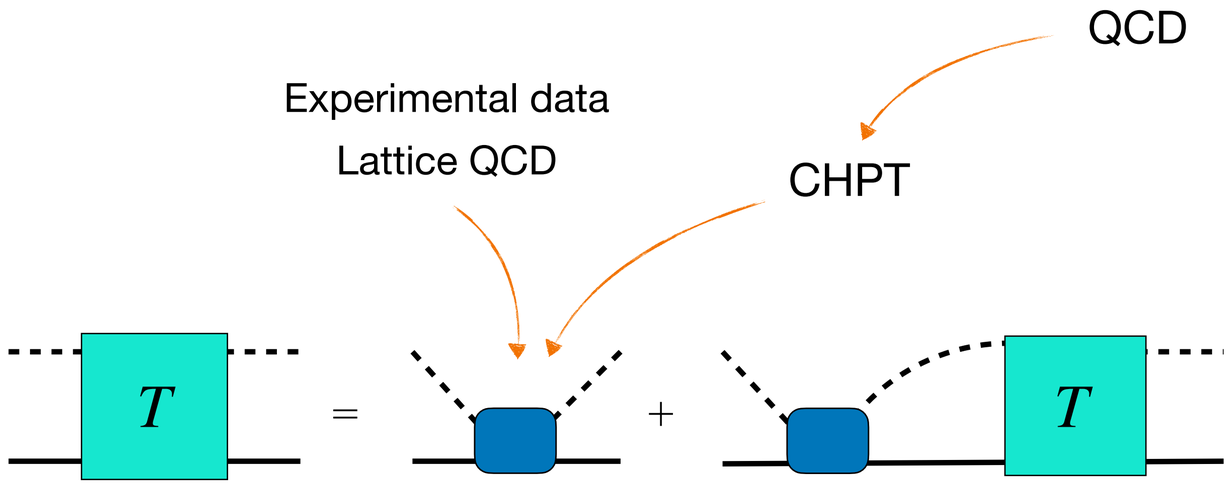

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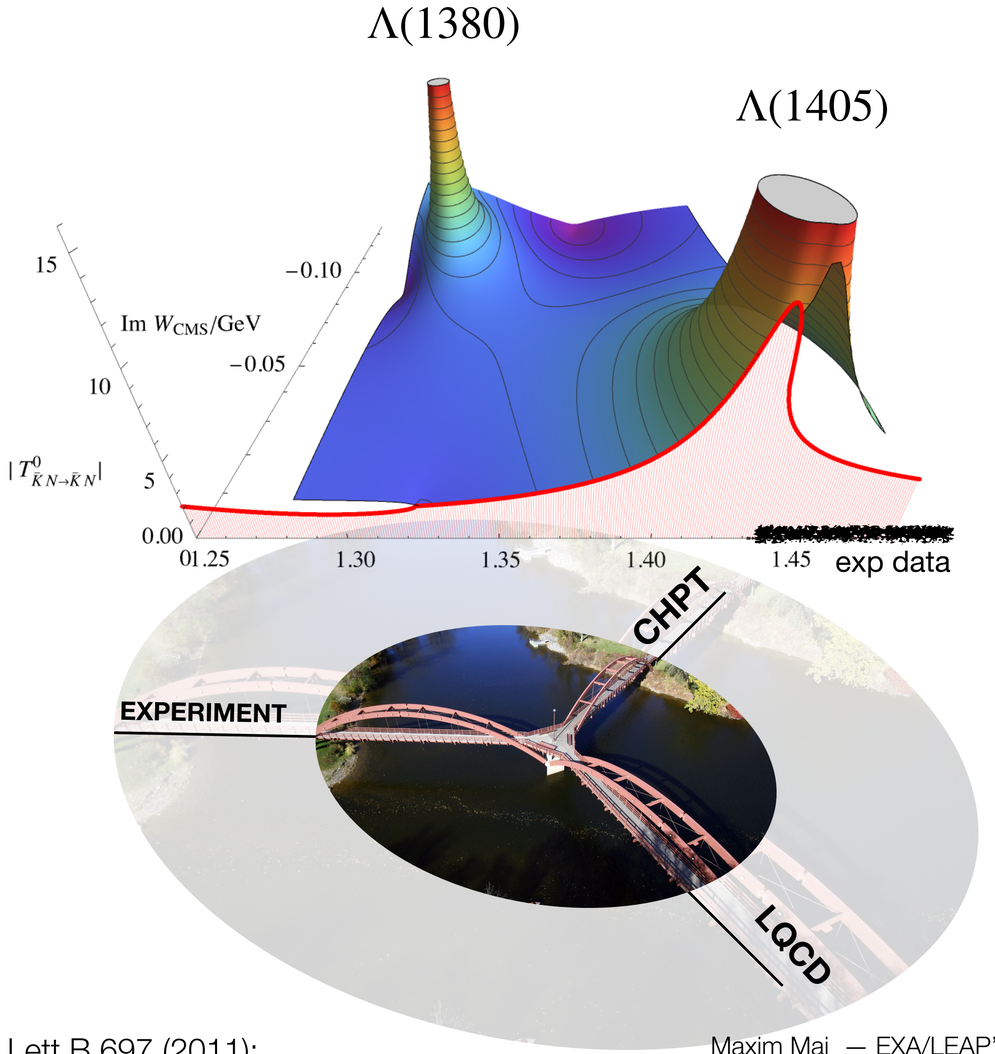

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APPLICATIONS

MESON-BARYON SCATTERING

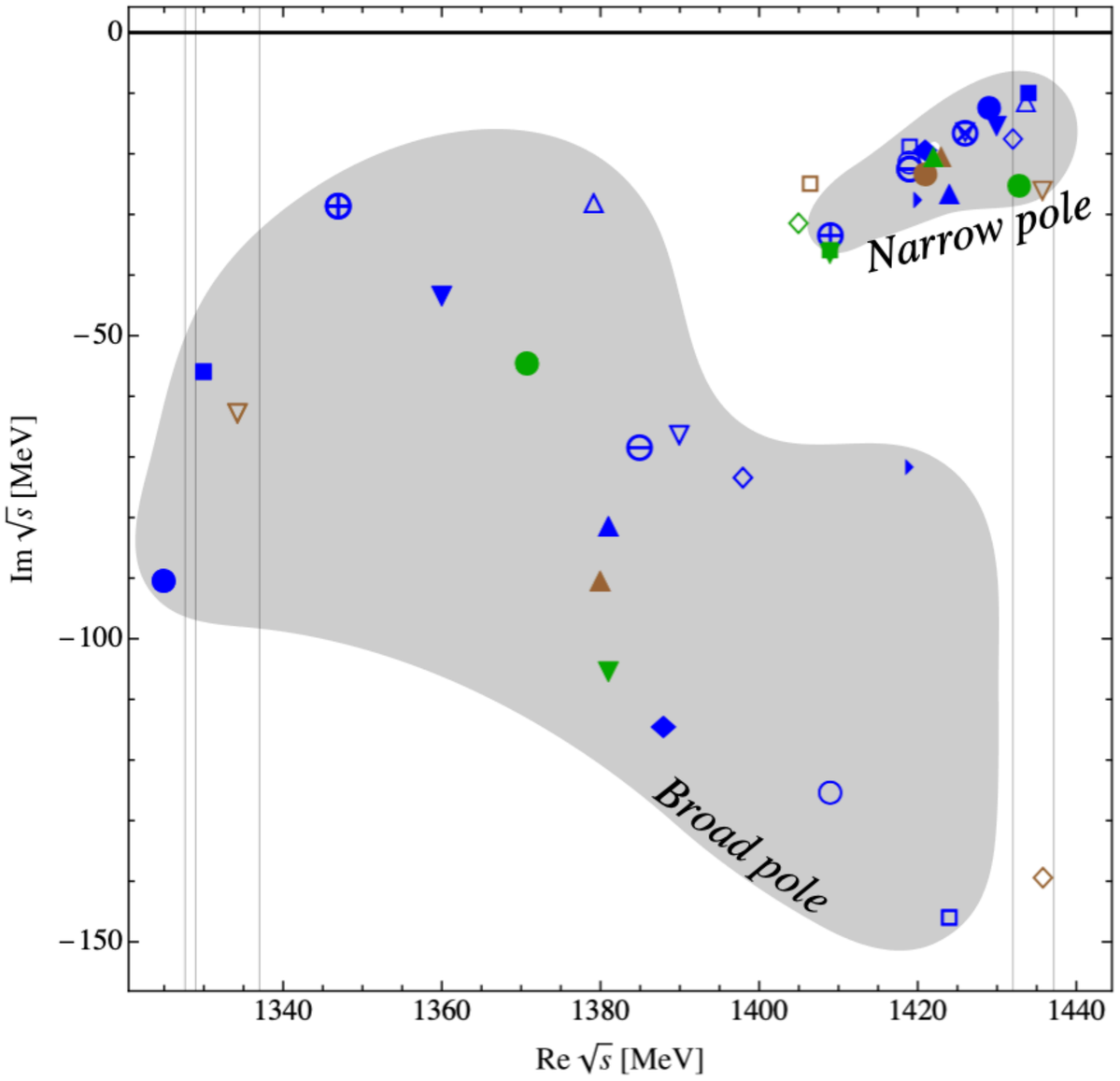
Review: MM Eur.Phys.J.ST 230 (2021)

Various implementations

- many scenarios with NLO kernel[1]
- NNLO calculation[2] including $\bar{K}N/\pi N/KN$

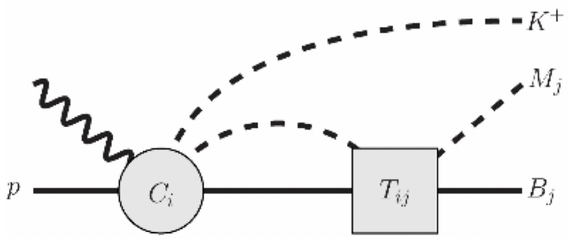
Common feature

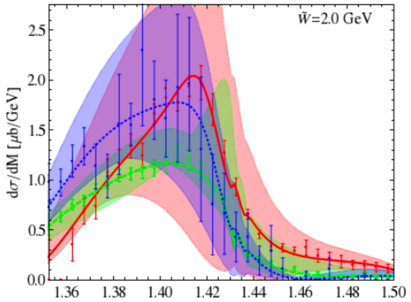
- fit to threshold and scattering data
- two poles persist



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

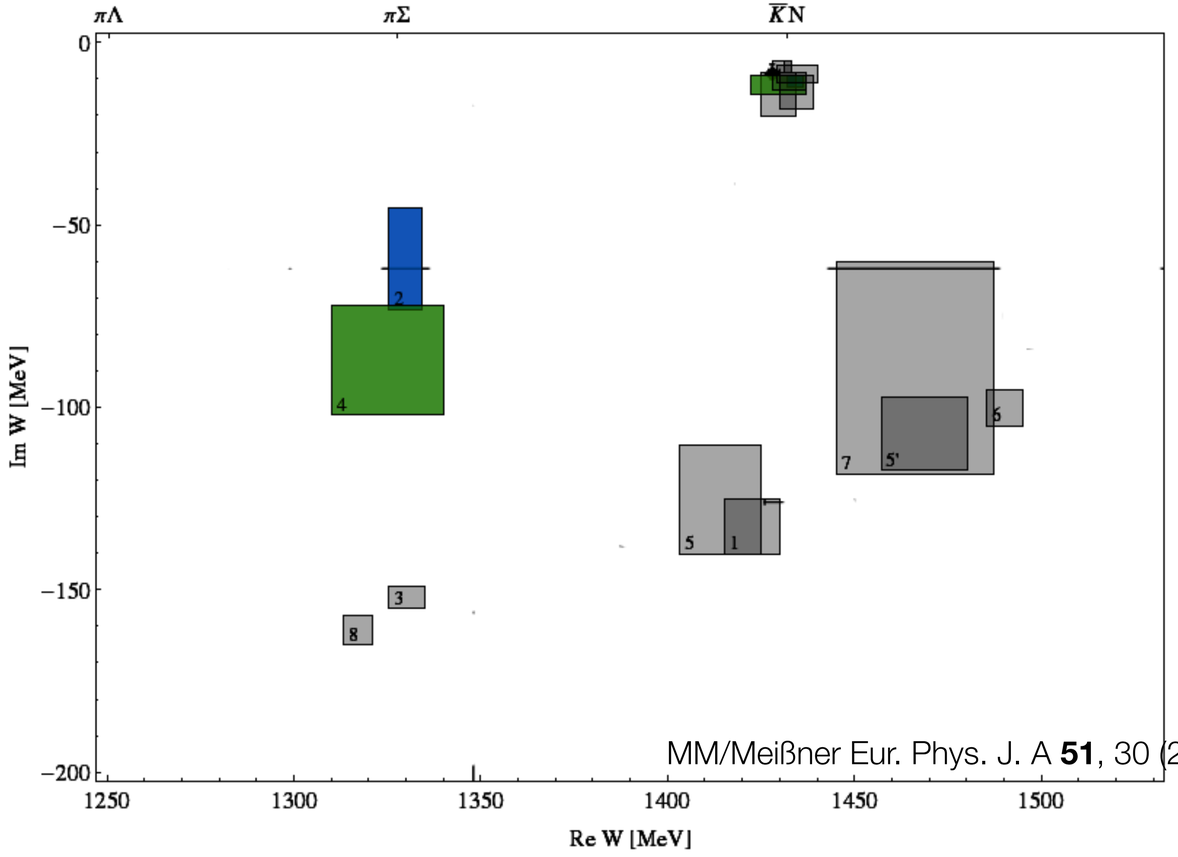
PHOTON INDUCED REACTIONS





High precision $\gamma p \to K^+\pi\Sigma$ data from CLAS@JLAB[1]

- data driven two-meson photo-production mechanism[2]
- reduced systematic uncertainty (various model solutions)



MM/Meißner Eur. Phys. J. A **51**, 30 (2

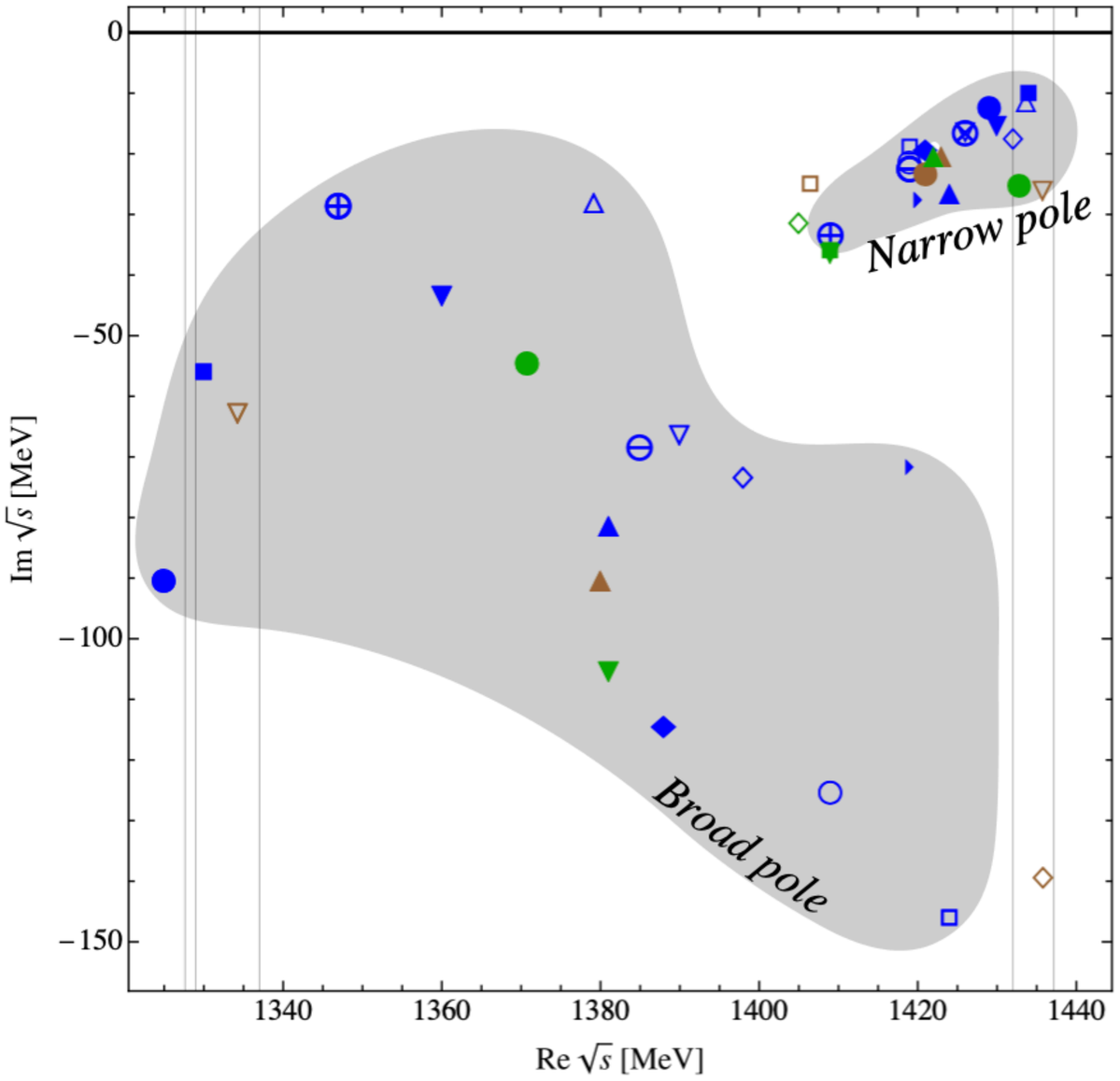
[1] Moryia et al (CLAS coll] 2012, upcoming new data from GlueX
[2] Roca/Oset Phys. Rev. C **87**, 055201 (2013); MM/Meißner Eur. Phys. J. A **51**, 30 (2015)

SIDDHARTA 1 & 2

Kaonic hydrogen[1]

- crucial constraint on $a_{K^-p}(a_0, a_1)$

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



[1] Bazzi et al. SIDDHARTA collaboration (2009)
[2] **TALK: SGARAMELLA[Thursday]**
[3] Shevchenko Phys.Rev.C 85 (2012) 034001; MM/Epelbaum/Baru/Rusetsky *Phys.Rev.D* 91 (2015) 5; Gal Int.J.Mod.Phys.A 22 (2007) 226-233;

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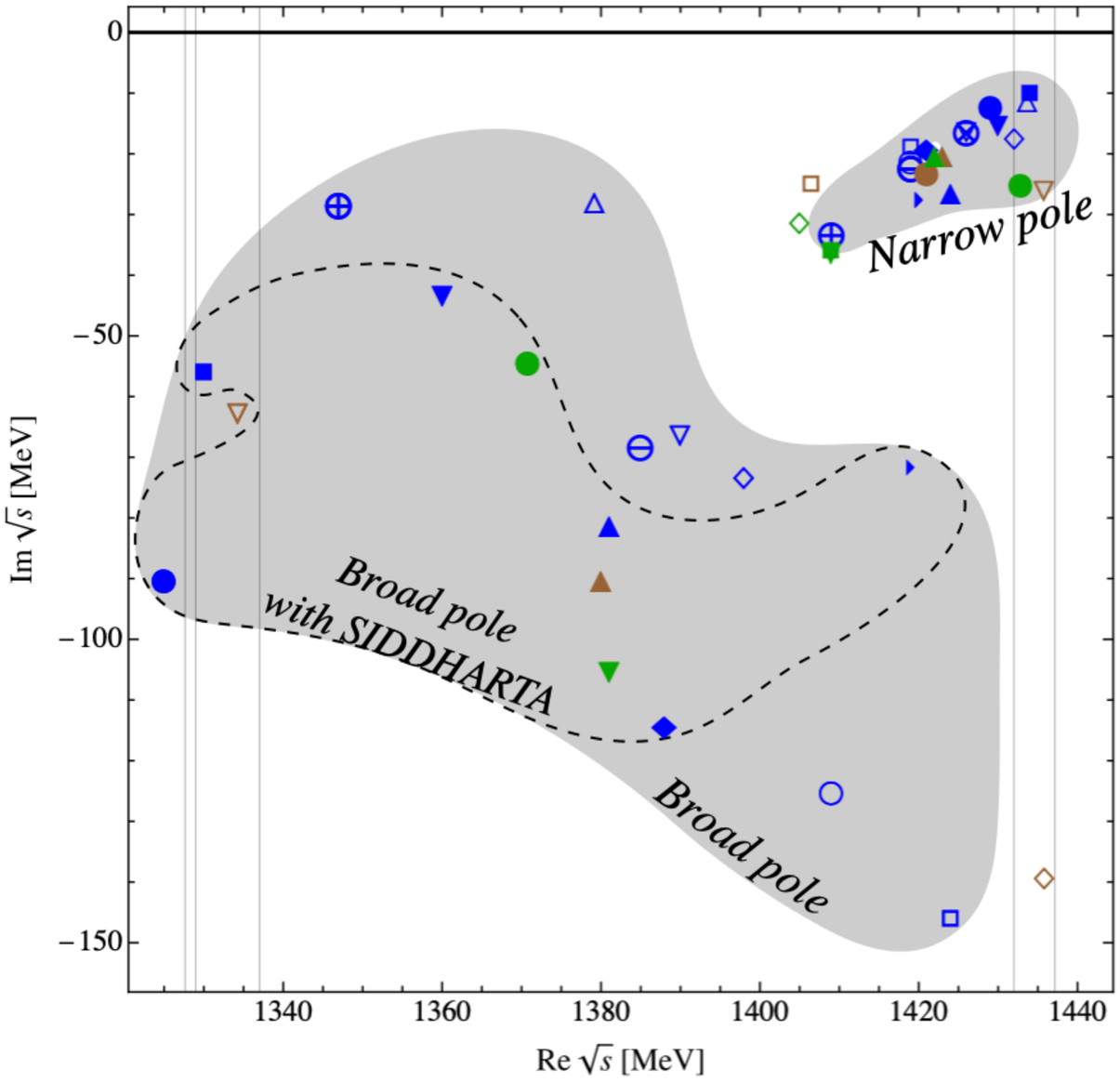

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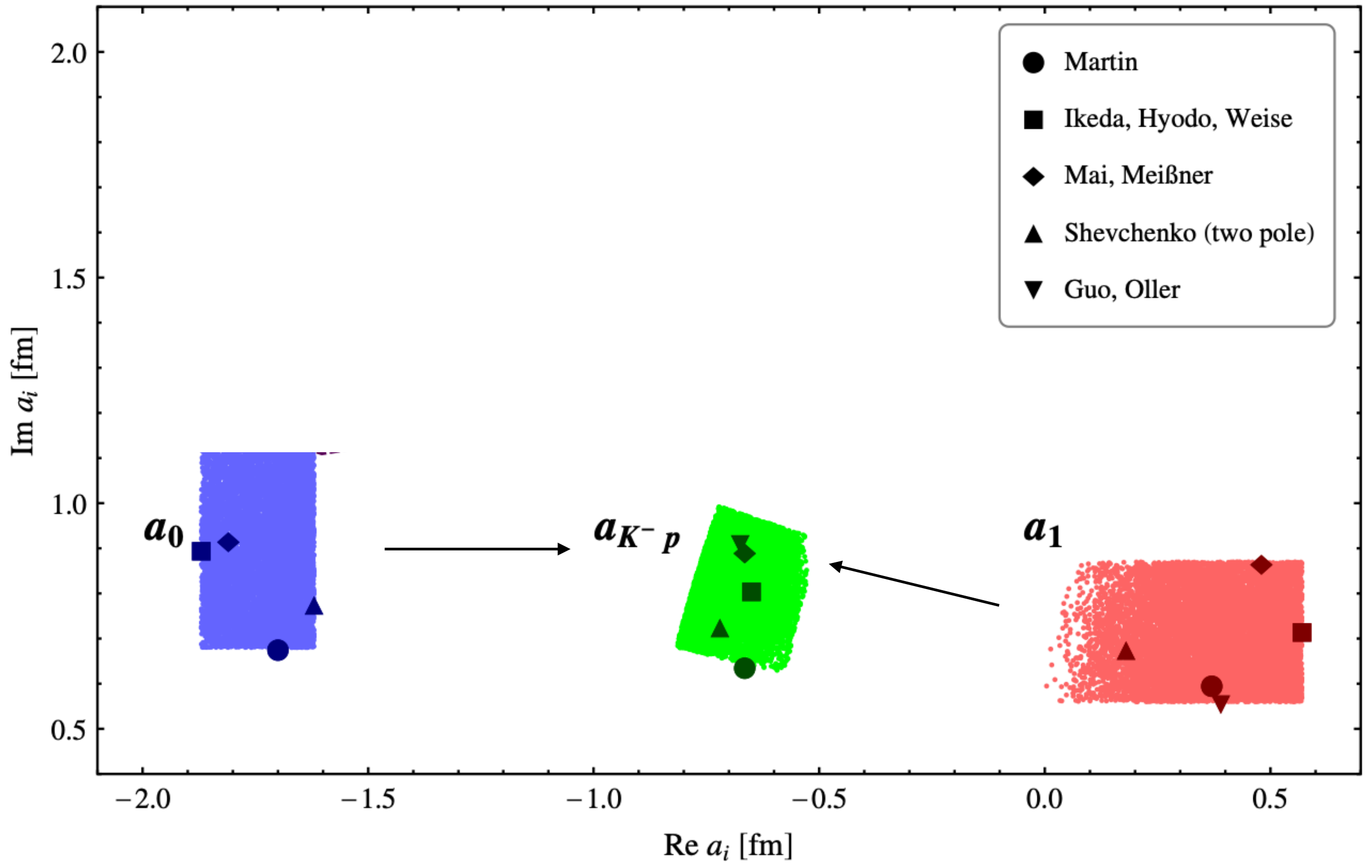

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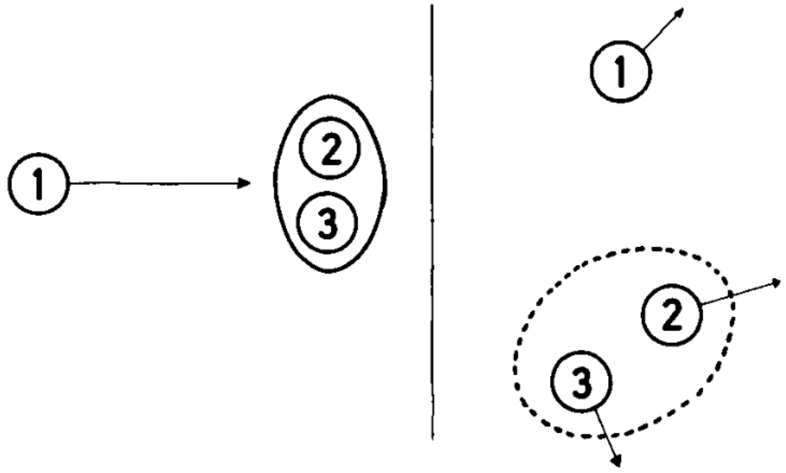
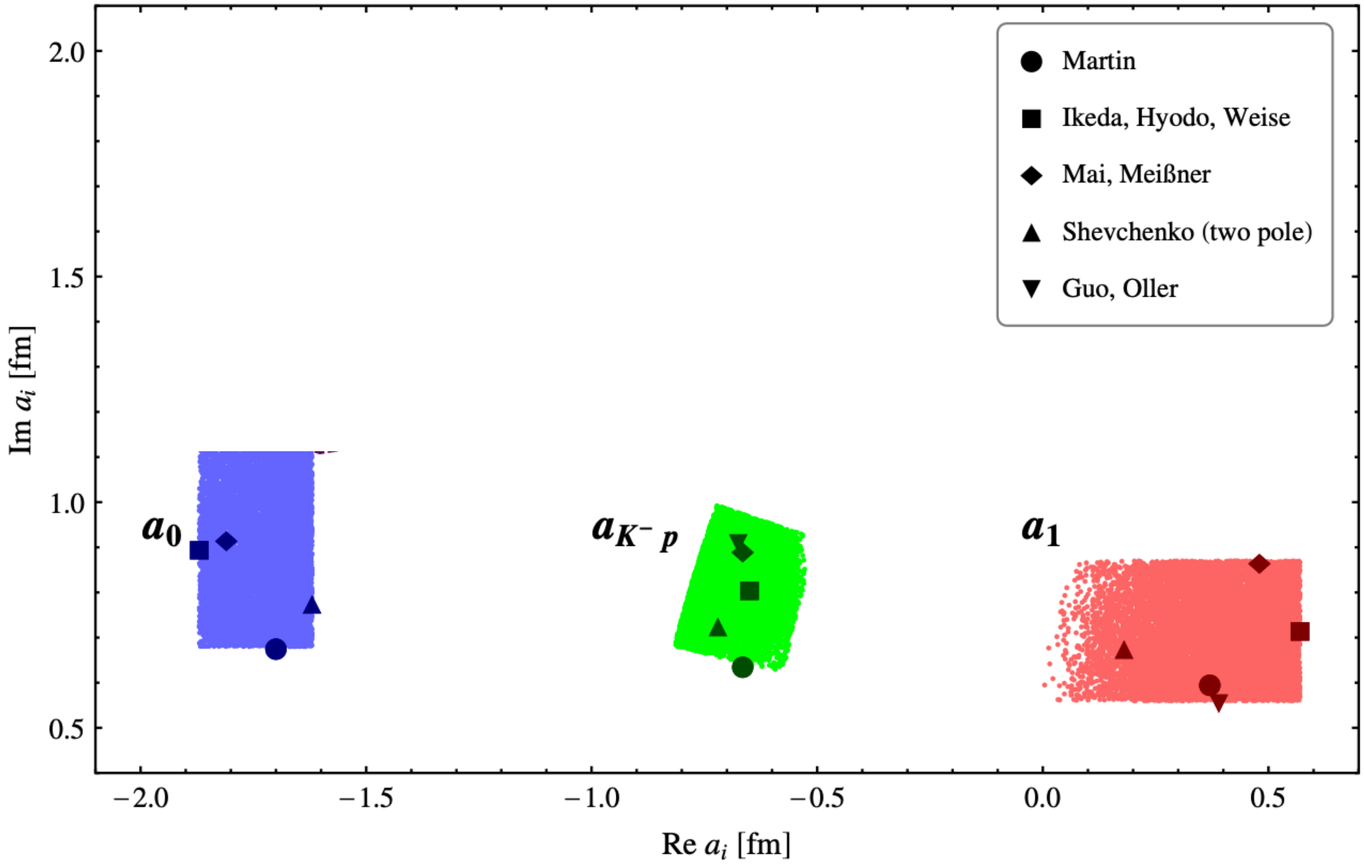
SIDDHARTA 1 & 2

Kaonic deuterium[2]

- another datum needed to constrain
  $\{a_{K^-p}, A_{\bar{K}d}\} \longleftrightarrow \{a_0, a_1\}$
- three-body scattering intricate[3]



MM/Epelbaum/Baru/Rusetsky *Phys.Rev.D* 91 (2015)



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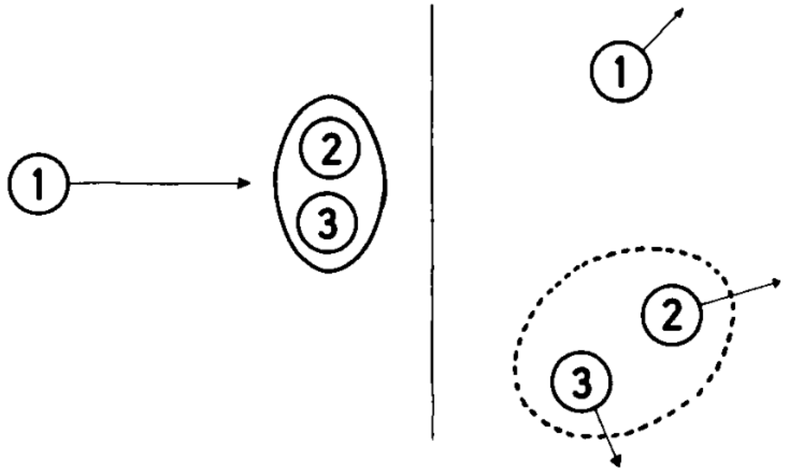

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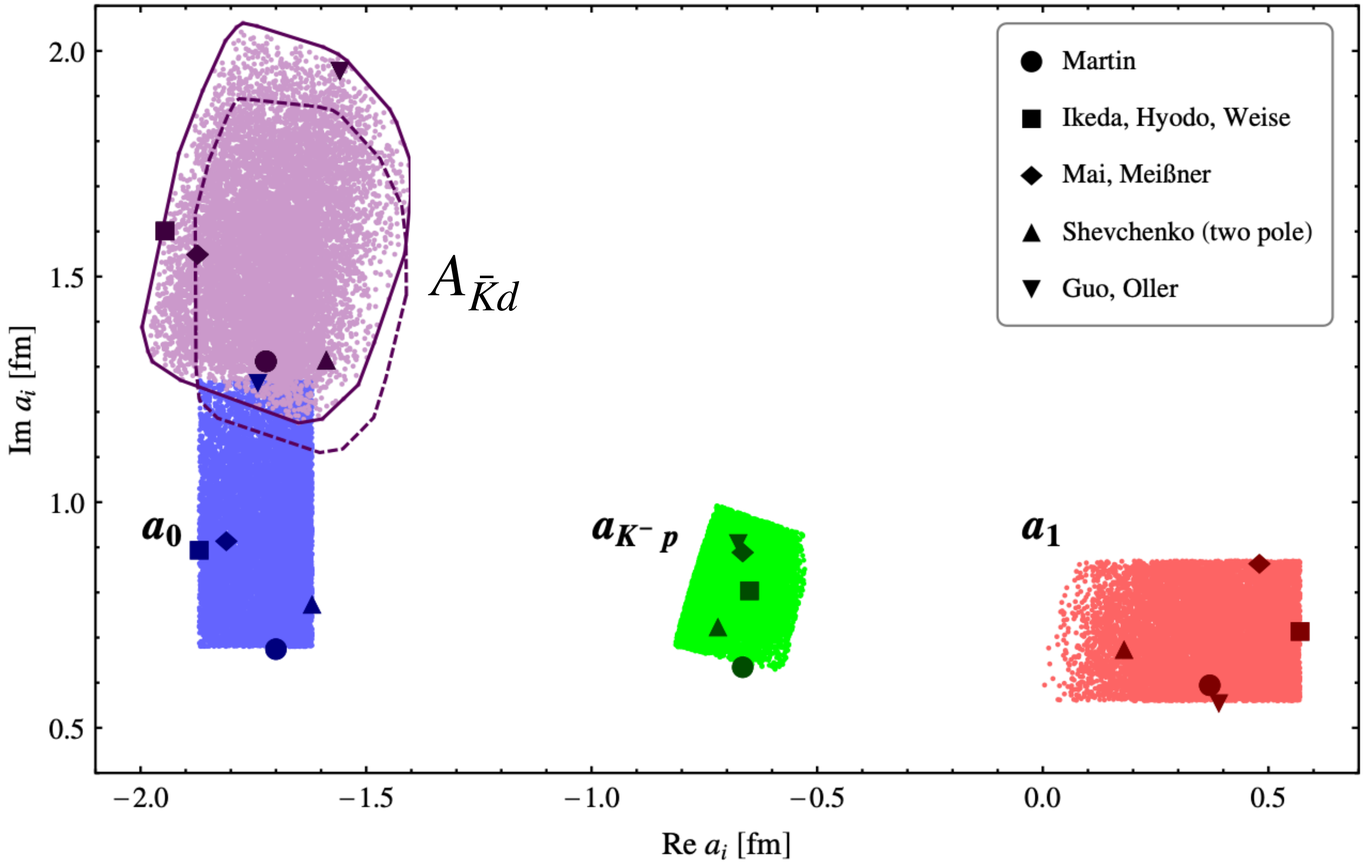
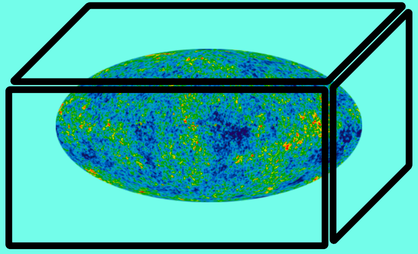


[1] Bazzi et al. SIDDHARTA collaboration (2009)
[2] **TALK: SGARAMELLA[Thursday]**
[3] Shevchenko Phys.Rev.C 85 (2012) 034001; MM/Epelbaum/Baru/Rusetsky *Phys.Rev.D* 91 (2015) 5; Gal Int.J.Mod.Phys.A 22 (2007) 226-233;

LATTICE QCD

Heavy Universe in a box



LATTICE QCD

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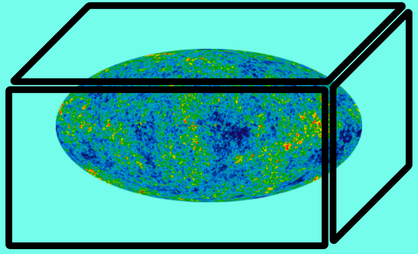
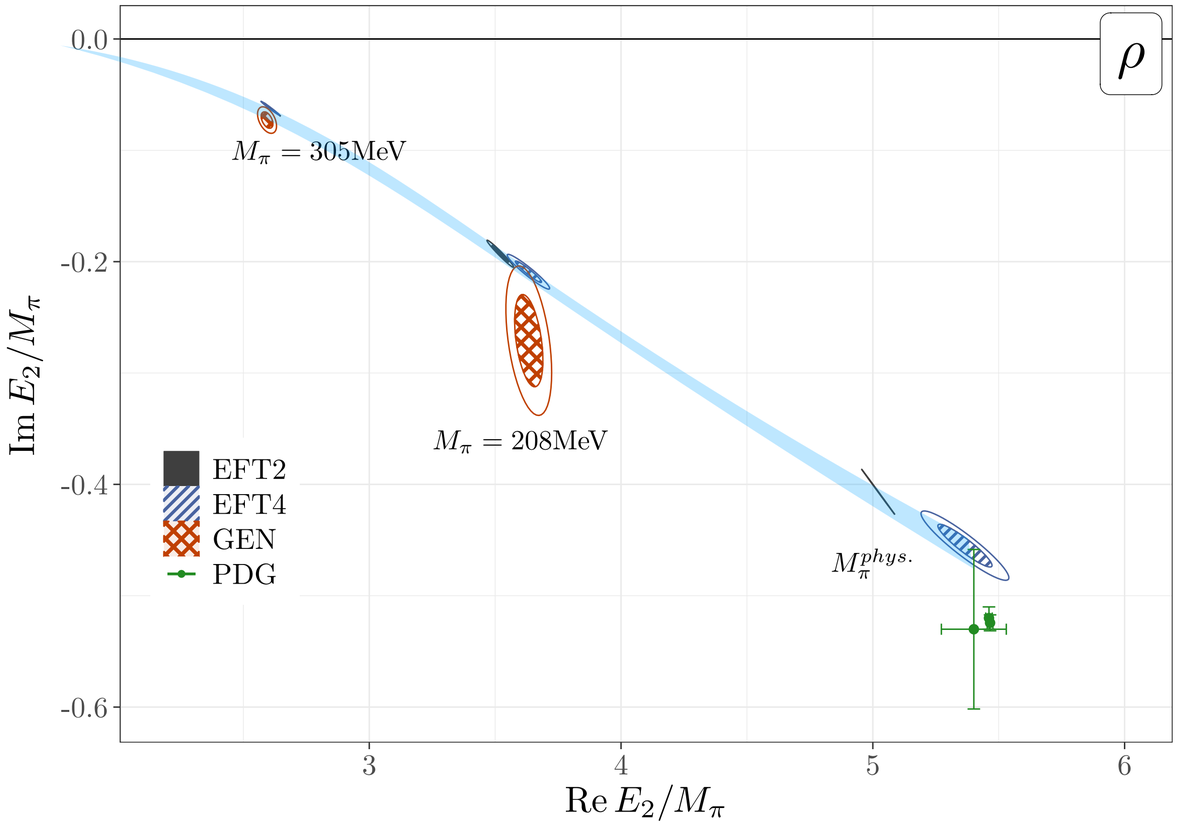
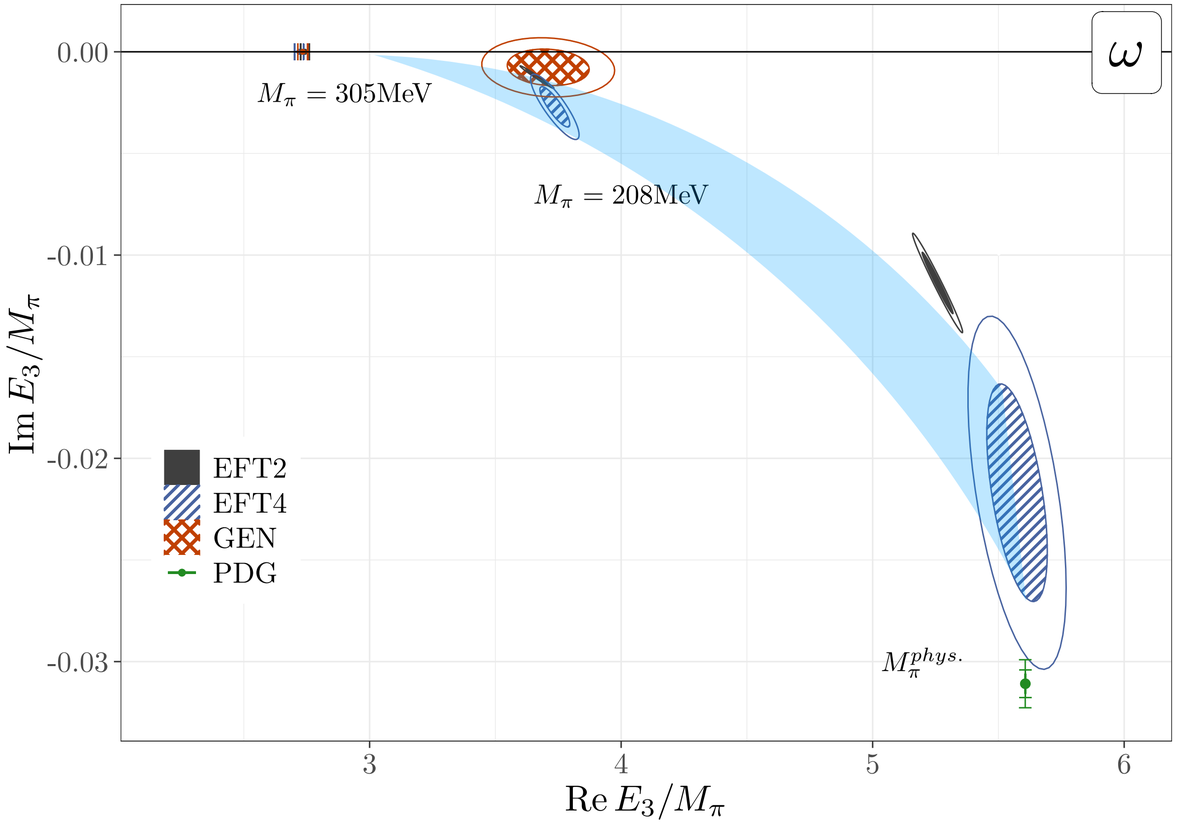


current frontier: 2- & 3-body resonances





ArXive: 2407.16659

LATTICE QCD

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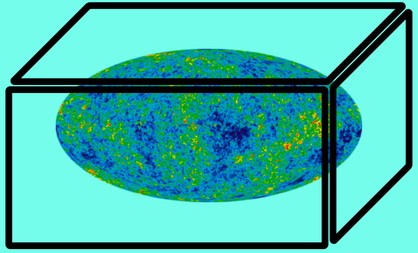
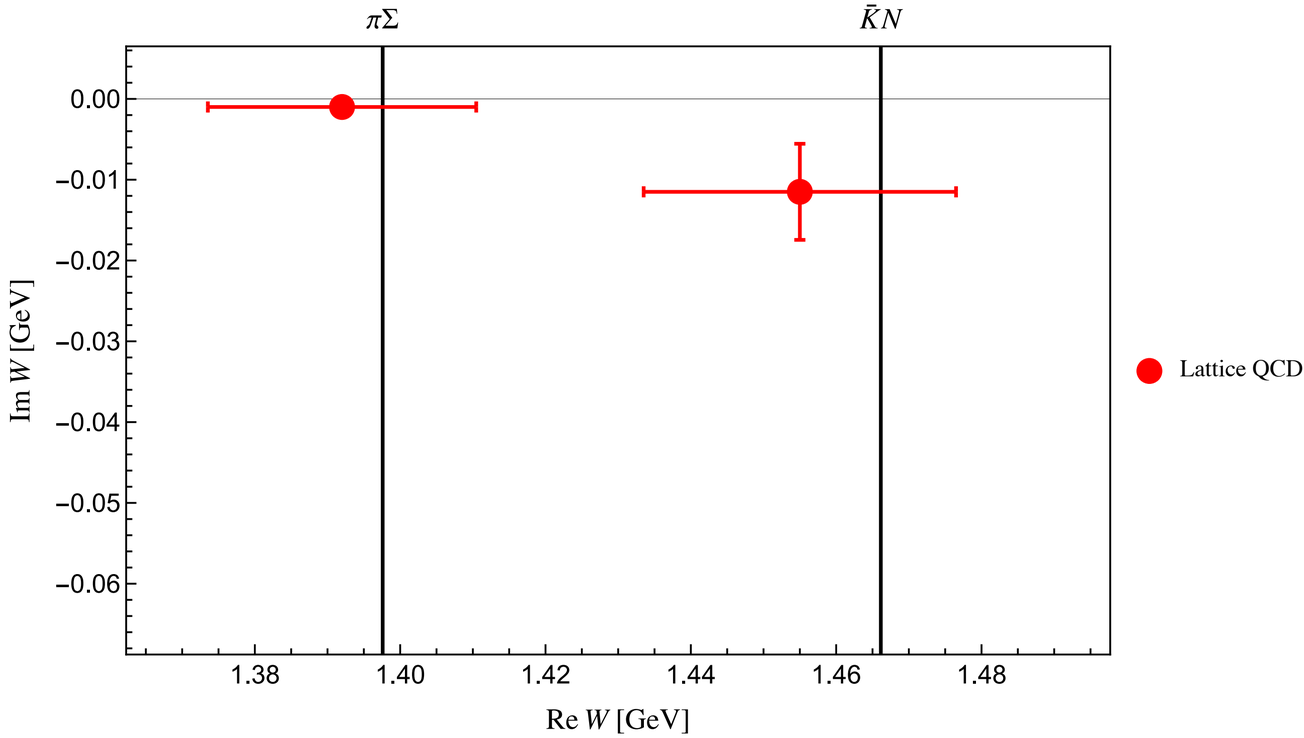


Available Lattice spectrum — BaSc setup[1]

- $M_\pi \approx 200\,\mathrm{MeV}$ $M_K \approx 487\,\mathrm{MeV}$
- two poles! (K-matrix)



[1] [BaSc] Bulava et al. Phys.Rev.Lett. 132 (2024) 5; 2307.13471
[2] Guo/Kamyia/MM/Meißner Phys.Lett.B 846 (2023)
[3] Pittler/MM in preparation

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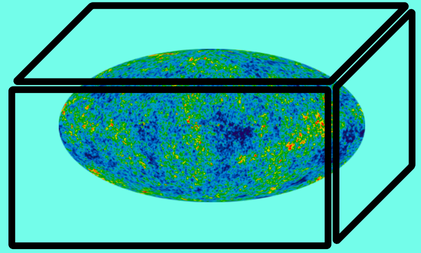
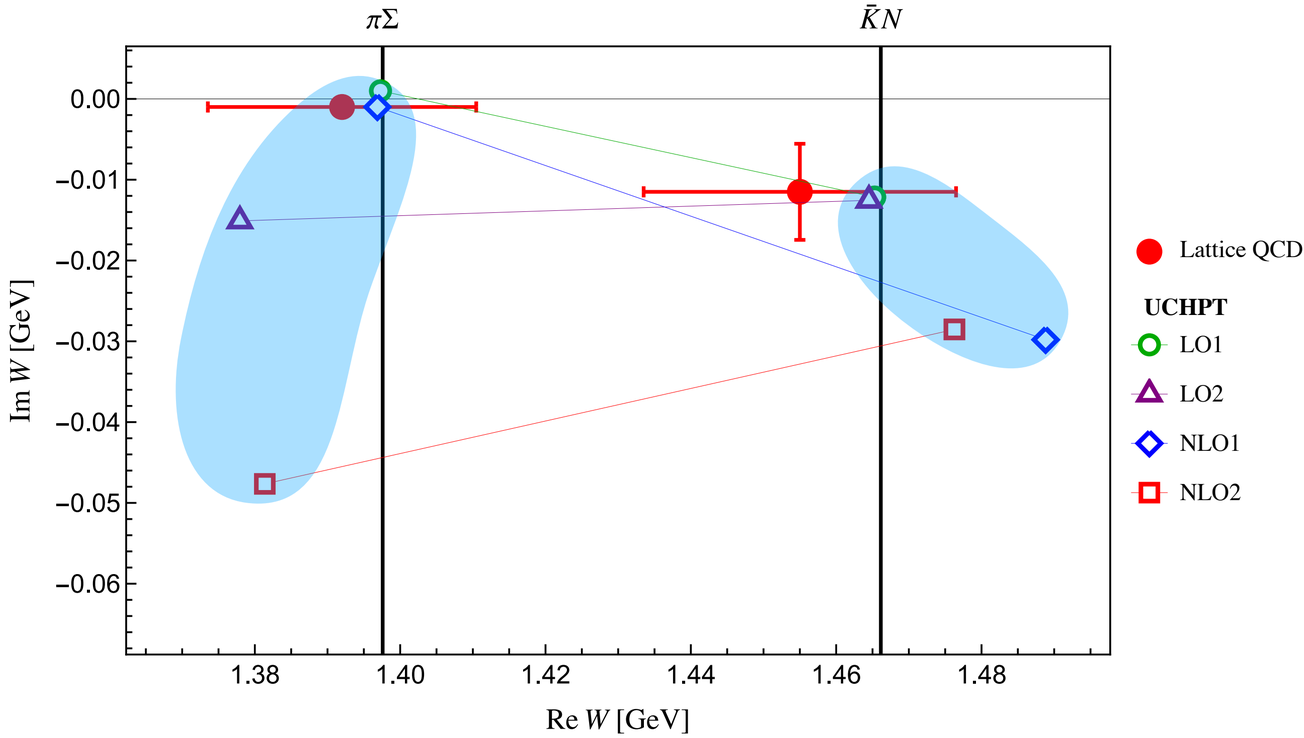


Unified (LQCD+UCHPT+Exp) analysis[2,3]

- two poles
- positions: mostly ok[2], but not always[3]…



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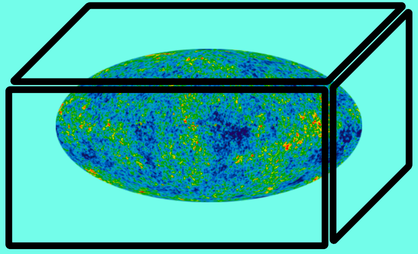

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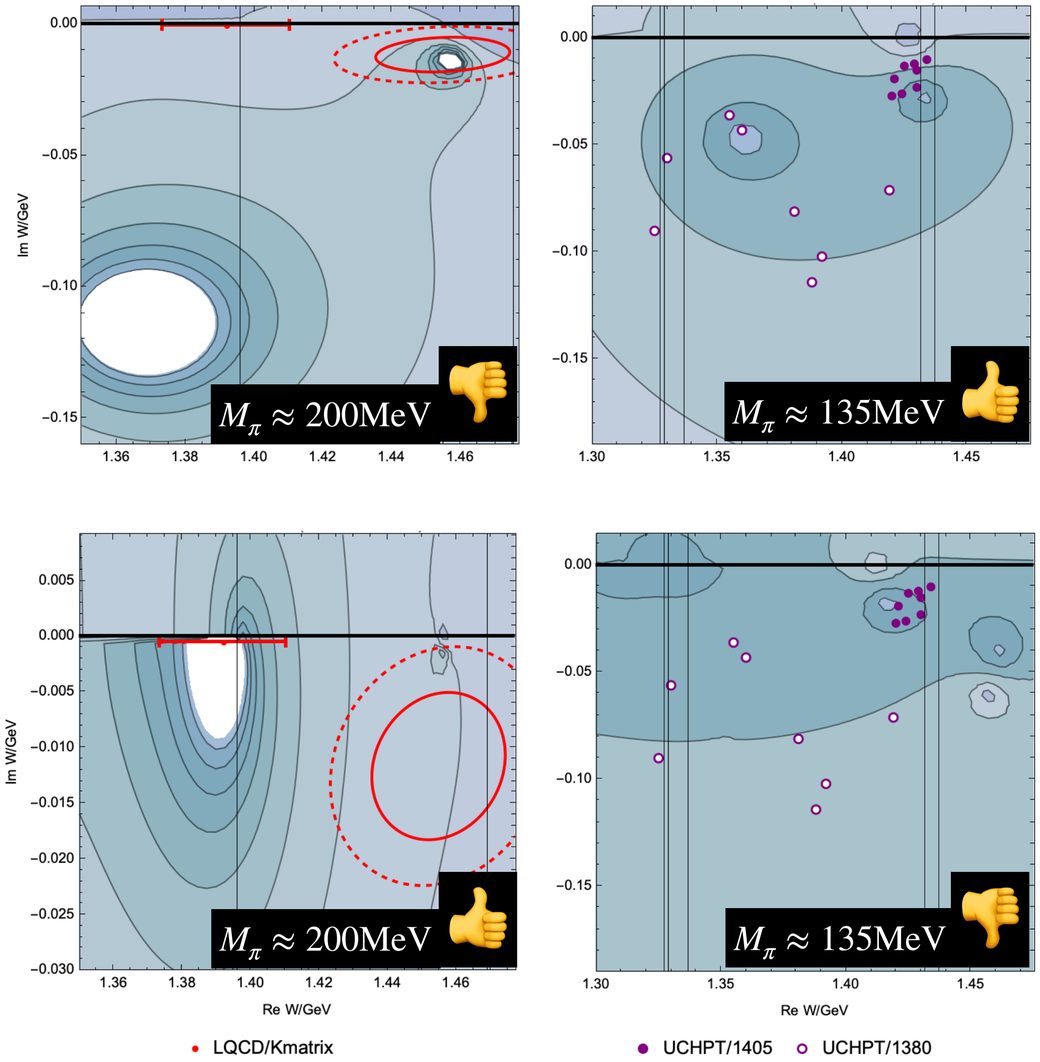

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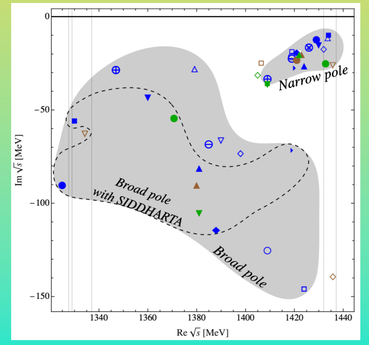
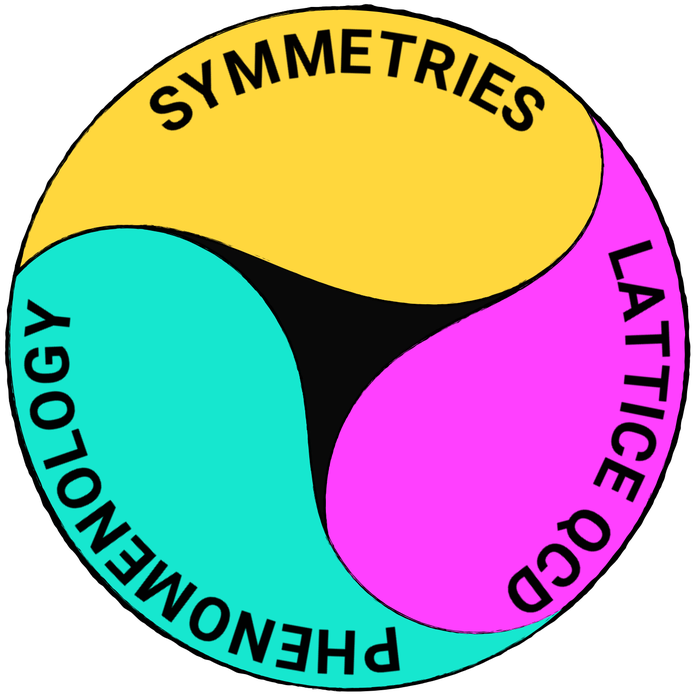
SUMMARY/OUTLOOK

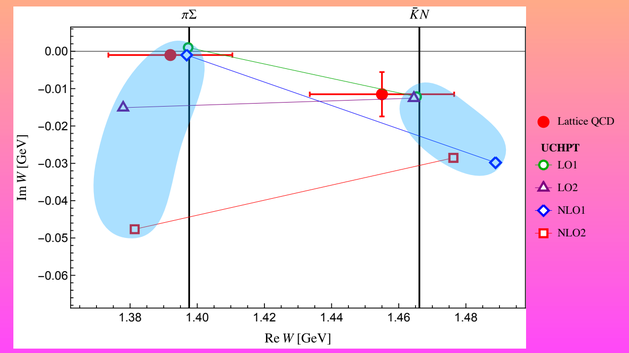
“Kaon-nucleon interaction probes the limits of our understanding of QCD”

- **S-Matrix & QCD symmetries**
- **Two-pole picture**

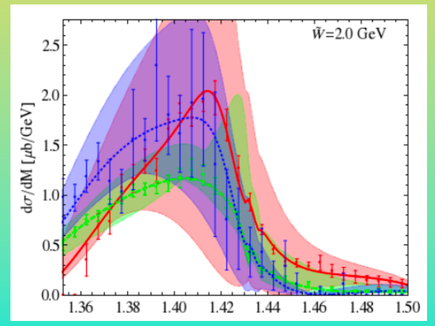




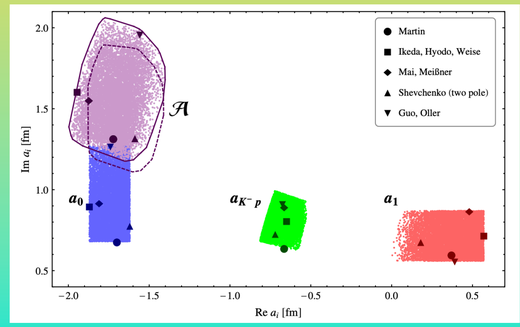
- **Two-pole picture persists**
- **Chiral extrapolations under way**



- **photo-production data**
- **new narrow constraints**



- **Kaonic hydrogen**
- **Kaonic deuterium >> NEXT TALK**

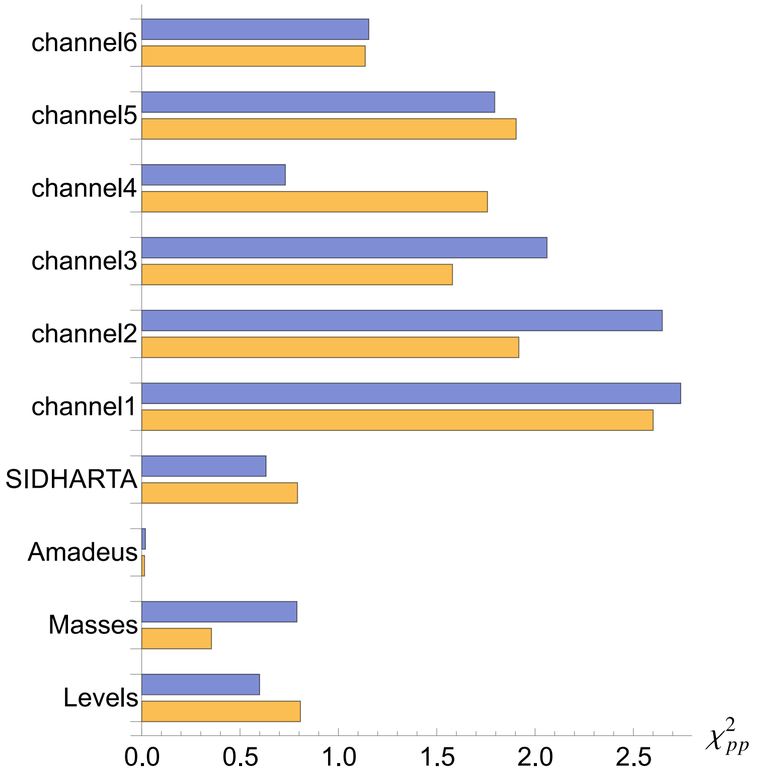


$M_\pi \approx 200\,\text{MeV}$

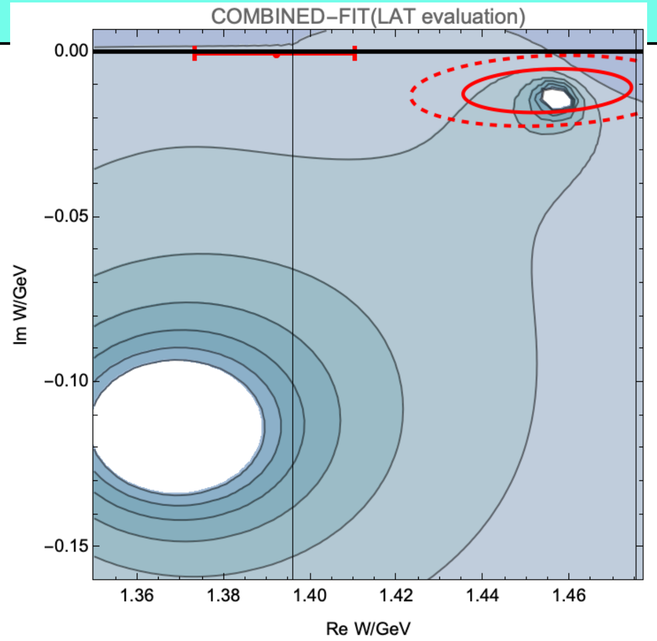
$M_\pi \approx 135\,\text{MeV}$

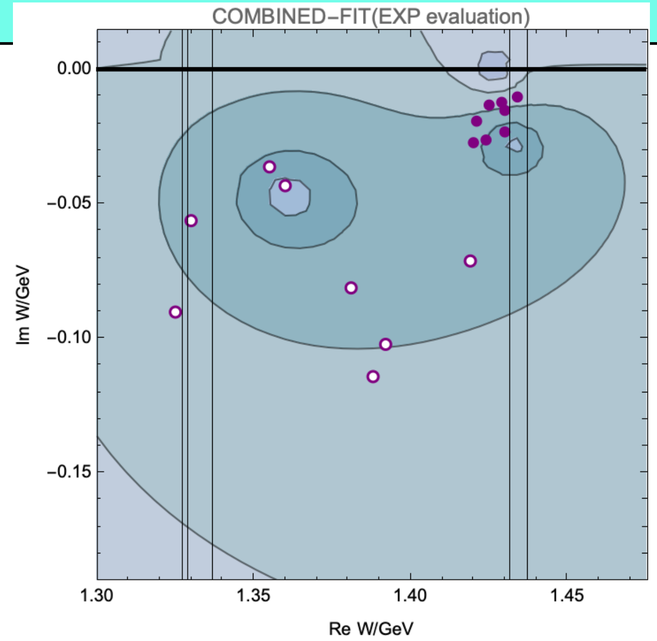
FIT A

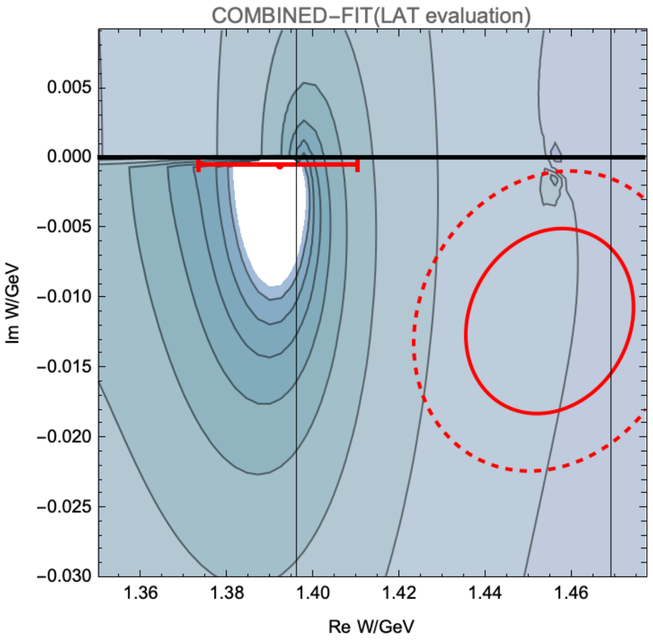
FIT B

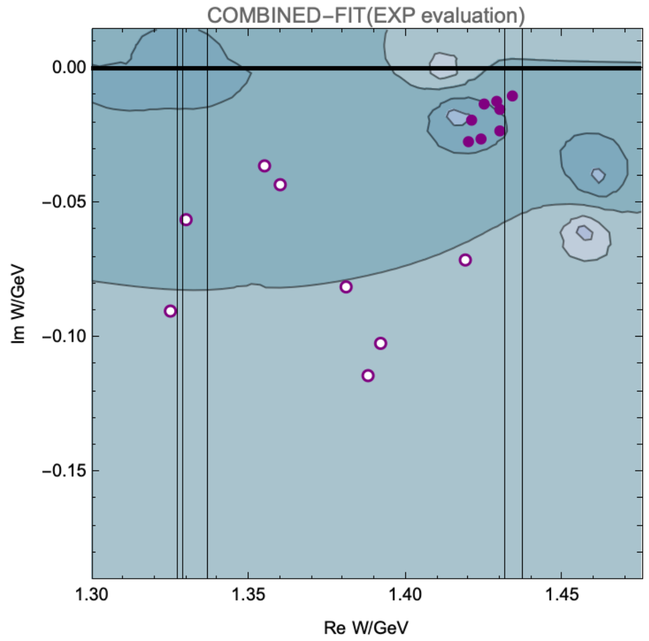


PRELIMINARY
Pittler/MM in preparation









● LQCD/Kmatrix

● UCHPT/1405 ○ UCHPT/1380

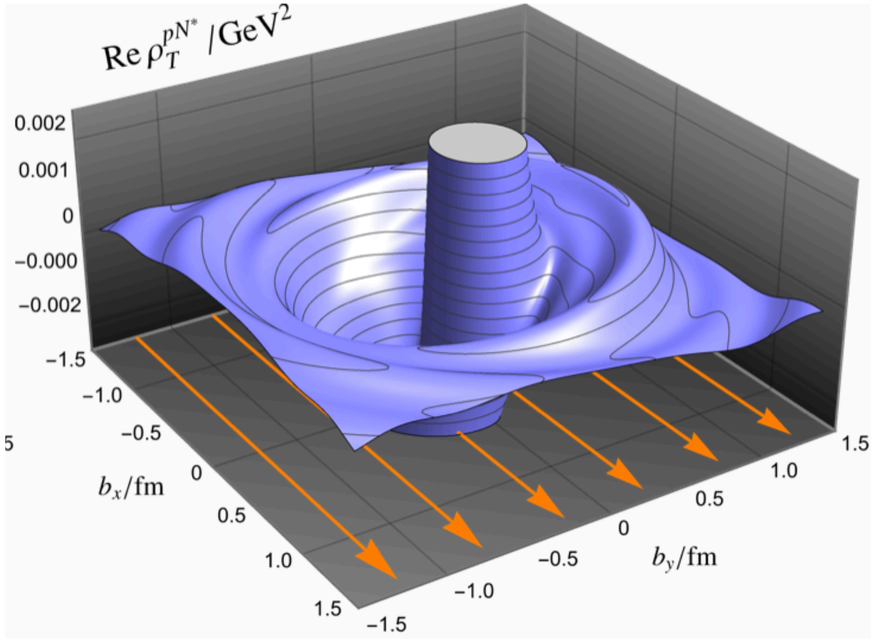
PHOTON INDUCED REACTIONS

Upcoming data from CLAS@JLAB

- New data upcoming in $-3 < S < +3$ Hyperons…[1]

Virtual photons?

- Hadron structure probe[2]
- Charge distribution in the excited states[3]



LF CHARGE DISTRIBUTION OF ROPER N(1440)
[JBW] Wang et al. in print at PRL e-Print: 2404.17444

[1] Garcia-Recio/Lutz/Nieves *Phys.Lett.B* 582 (2004) 49-54; … **Vonk/MM in preparation**
[2] Aznauryan/Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012); Ramalho/ Peña, Prog. Part. Nucl. Phys. 136, 104097 (2024) Tiator et al. CPC(HEP & NP), 2009, 33(X)

LATTICE QCD

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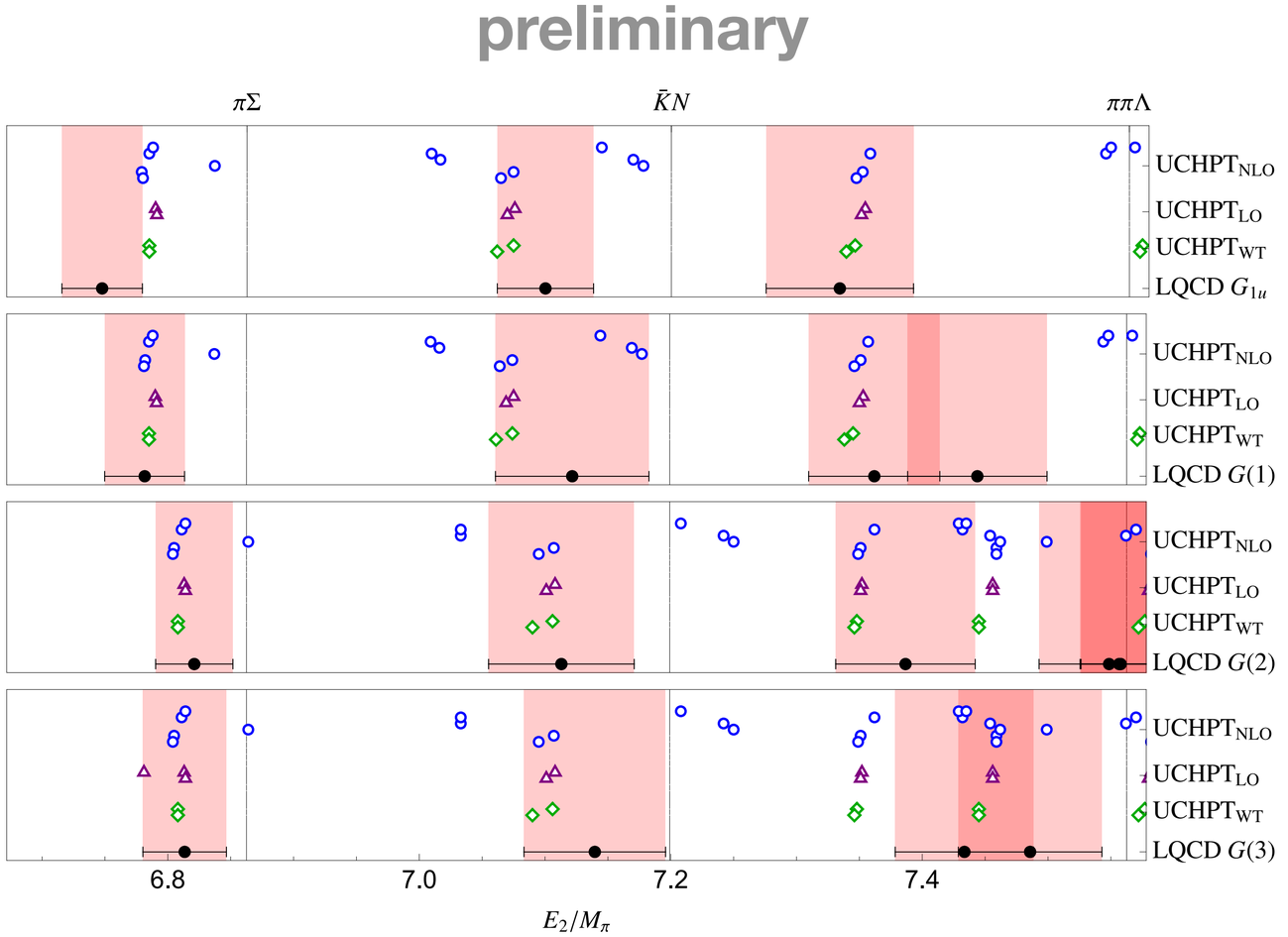
Unified analysis[2] LQCD+UCHPT+Experiment

… mostly ok, but not always



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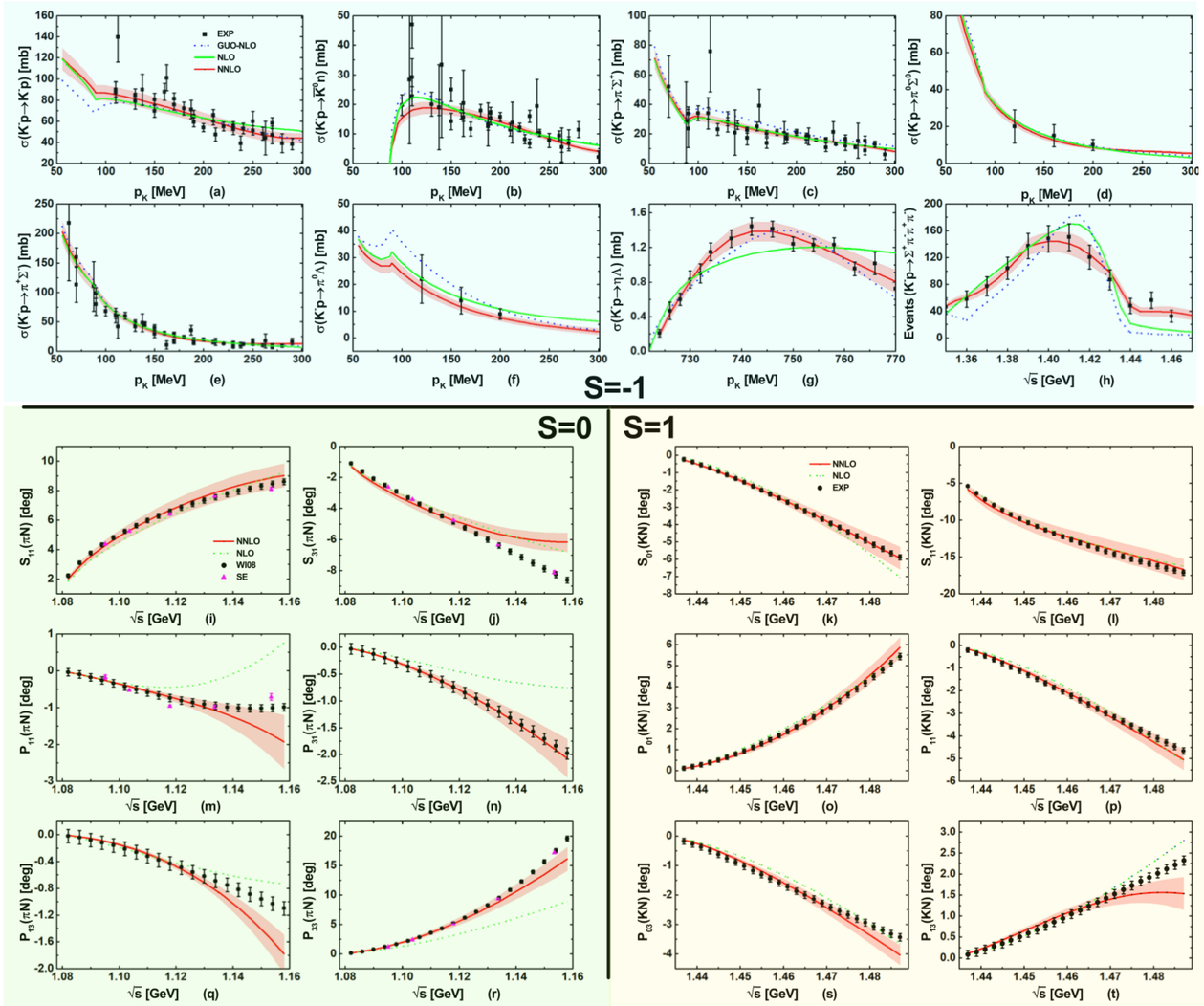
[2] Pittler/MM in preparation

MESON-BARYON SCATTERING

- 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)