PION PHOTOPRODUCTION

in a gauge-invariant chiral unitary framework

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BARYON RESONANCES

- A huge effort is made to unravel the spectrum and properties of baryons at ELSA, CEBAF and MAMI in photoproduction experiments
- Theoretically interesting:
  - some low-lying resonances like $N^\star(1440)1/2^+$, $N^\star(1535)1/2^-$ or $\Lambda(1405)1/2^-$ do not fit into simple quark constituent model
  - can be generated via strong coupled-channel dynamics:

    - K-matrix (SAID, Bonn-Gatchina)
    - dynamical models (Jülich model)
    - ...
    - **chiral unitary approach**

CHIRAL UNITARY APPROACH

- ChPT - model independent framework to analyse hadronic processes at low energies

  Gasser, Leutwyler (1984)

  - LO+NLO chiral potential (local terms):

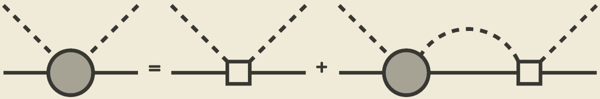
$$V(\phi(q_1)B(p_1) \to \phi(q_2)B(p_2)) = A_{WT}(\not{q}_1 + \not{q}_2) + A_M + A_{14}(q_1 \cdot q_2) + A_{57}[\not{q}_1, \not{q}_2] + A_{811}\big(\not{q}_2(q_1 \cdot p) + \not{q}_1(q_2 \cdot p)\big)$$

  - strictly perturbative calculation yields a decent description in the (sub)threshold region
  - in vicinity of resonances **resummation** is required

CHIRAL UNITARY APPROACH

- Bethe–Salpeter equation:

$$\color{red}{T}(\not{q}_2, \not{q}_1; p) = V(\not{q}_2, \not{q}_1; p) + \int \frac{d^d k}{(2\pi)^d} V(\not{q}_2, \not{k}; p) \frac{1}{k^2 - M^2 + i\epsilon} \frac{i}{\not{p} - \not{k} - m + i\epsilon} \color{red}{T}(\not{k}, \not{q}_1; p)$$

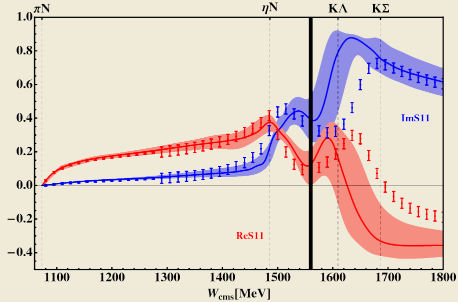


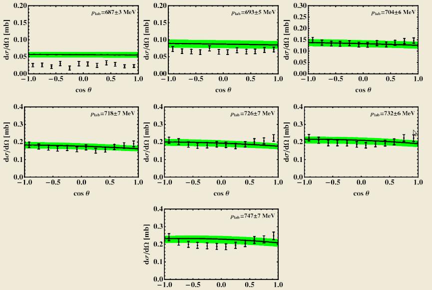
  - dim. regularized one-loop diagrams
  - scale dependence remains

free parameters: $\begin{cases} \textbf{3} \text{ subtraction constants: } \log(\mu_{KN}), \log(\mu_{\pi\Sigma}), \log(\mu_{\pi\Lambda}) \\ \textbf{14} \text{ low-energy constants: } b_0, b_D, b_F, b_1, ..., b_{11} \end{cases}$

EXPERIMENTAL INPUT

- πN scattering via PWA by SAID — Workman et al. (2012)
  - $\Re(S_{11})$ and $\Im(S_{11})$ for $W_{\text{cms}} < 1560$ MeV
  - $\Re(S_{31})$ and $\Im(S_{31})$ for $W_{\text{cms}} < 1560$ MeV
- differential cross section of $\pi^- p \to \eta n$ — Prakhov et al. (2005)





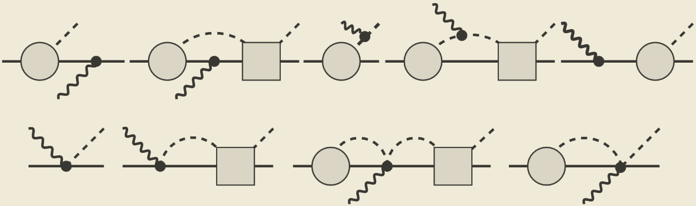
PHOTON COUPLING

- Dynamically generated $N^\star(1535)$ and $N^\star(1650)$
- Natural way to construct a photoproduction amplitude incorporating **gauge invariance**:

Antwerpen, Afnan (1995) Borasoy et al. (2005)

i) hadronic skeleton

ii) photon coupling



PHOTON COUPLING

- Unitarity (subspace of meson-baryon states) and gauge invariance fulfilled automatically
- Two new parameters, i.e. b_{12} and b_{13}
  $\Rightarrow \chi$PT calculation on magnetic moments (p, n):

$$b_{12} = 0.095 \pm 0.015,\ b_{13} = 0.32 \pm 0.06\ \mathrm{GeV}^{-1}$$

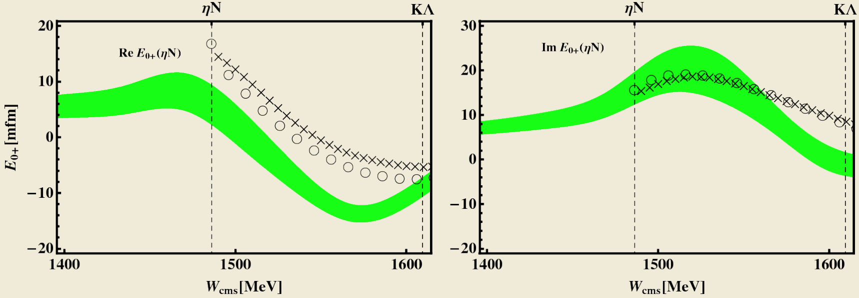
Kubis, Meißner (2001)

- **Parameter-free prediction** of photo multipoles (s-wave)

PREDICTION I

- $E_{0+}^{\eta N}$ compared to ETAMAID and Bonn-Gatchina

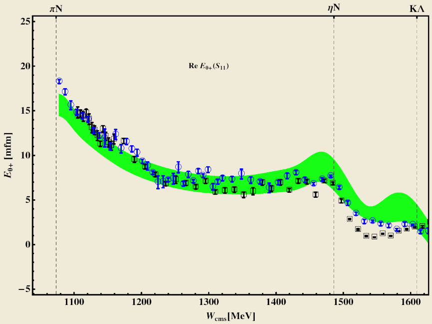
Chiang et al. (2002) Anisovich et al. (2010)

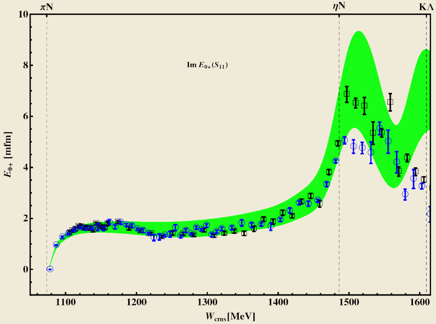


PREDICTION II

- $E_{0+}^{\pi N}(S_{11})$ compared to SAID and MAID2007

Workman et al. (2012) Drechsel et al. (2007)





SUMMARY

DONE

- Solution of (full off-shell) BSE with NLO chiral potential is constructed
- ... and fitted to experimental (phenomenological) data
  ⇒ *dynamically generated states:* $N^{\star}(1535)$ *and* $N^{\star}(1650)$
- A (naturally) gauge-invariant photoproduction amplitude is constructed
  ⇒ *predicted* $E_{0+}^{\pi N}(S_{11})$ *agrees nicely with phenomenology*

TO DO

- Redo the analysis for the eta photoproduction off neutron
- Inclusion of Born graphs into hadronic part

SPARES (renormalization)

- Loop integration $\longrightarrow$ **UV**-divergencies:
  - strict chiral expansion - counterterm renormalization
  - iterated bubble sum - ∞ many counterterms
  - shift loop divergencies into the kernel:

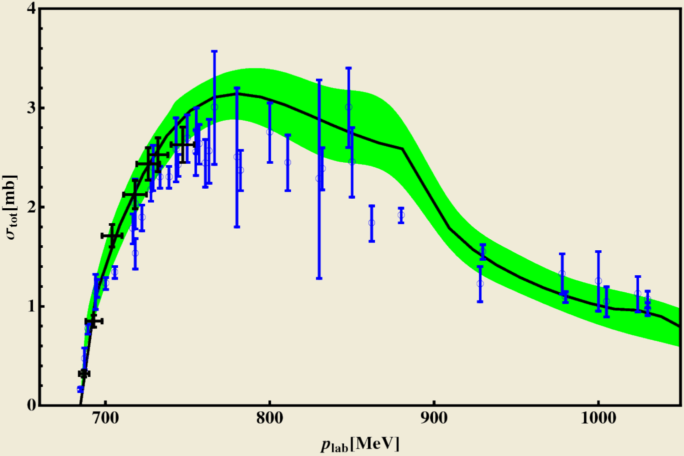
$$T \hat{\sim} \frac{1}{V^{-1} - G} \quad \xrightarrow{\text{loop modification}} \quad T_\delta \hat{\sim} \frac{1}{V_\delta^{-1} - G_\delta}$$

Borasoy et al. (2007)

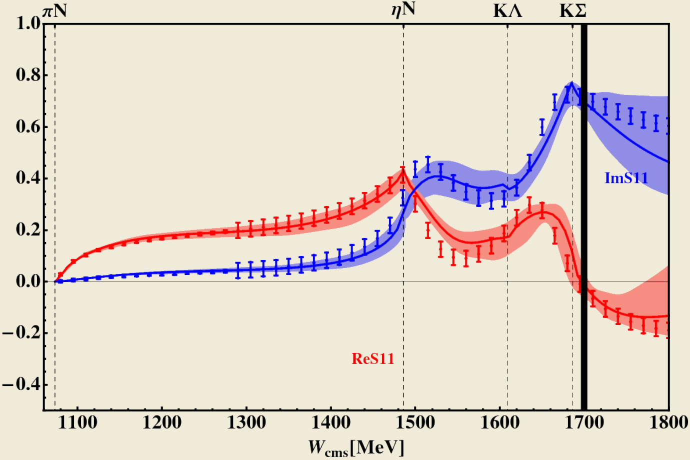
  - technically:

    i) dim-reg. one-loop diagrams
    ii) omit loop divergencies
    iii) scale dependence remains

SPARES ($\sigma_{\eta N}$)



SPARES (NEW FIT)



SPARES (HIGHER ENERGIES)