Chiral dynamics in the $\gamma p \longrightarrow p\pi^0$ reaction at threshold

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May 26, 2015

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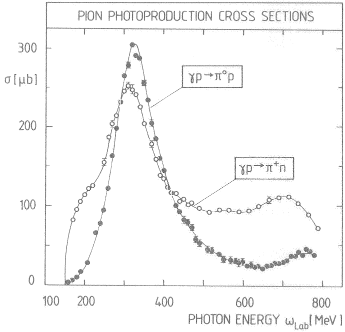
arXiv:1412.4083

Motivation

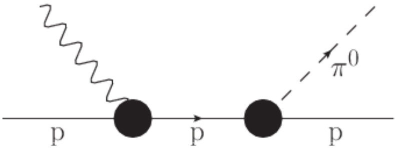
Ericson and Weise (1988) Pions and Nuclei



Reaction	Relative dipole moment
$\gamma p \to \pi^+ n$	1
$\gamma p \to \pi^0 p$	$-\frac{m_\pi}{m_N}$
$\gamma n \to \pi^- p$	$-\left(1+\frac{m_\pi}{m_N}\right)$
$\gamma n \to \pi^0 n$	0

- In the threshold region, the charged channels have much bigger cross sections than the neutral one.
- There are huge cancellations betweens pieces.
- The charged channels are well described in low-order ChPT. The neutral channel is NOT!

Experimental data



- New very precise data from MAMI. Hornidge et al. (2013) PRL
- Can be used to test the convergence of ChPT models.
- Measured polarization observables:

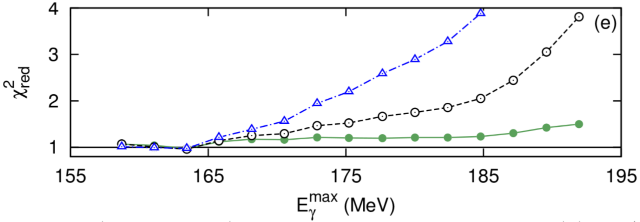
$$\frac{d\sigma}{d\Omega} \quad \text{and} \quad \Sigma = \frac{d\sigma_{\perp} - d\sigma_{\parallel}}{d\sigma_{\perp} + d\sigma_{\parallel}}.$$

Approaching the experimental input

- Photon energies $\approx$ 140 MeV — 210 MeV $\Rightarrow$ Non-perturbative QCD — ChPT.
- New degrees of freedom: quarks, gluons $\Rightarrow$ pions, nucleons,...
- Previous ChPT works have problems when approaching regions $> 20\mathrm{MeV}$ above threshold.

Previous works

$\mathcal{O}(p^4)$ ChPT (terms proportional to M_π^4): **HBChPT** and **covariant.** Hornidge et al. (2013) PRL



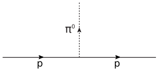
- Empirical fit.
- $\mathcal{O}(p^4)$ HBChPT.
- $\mathcal{O}(p^4)$ relativistic ChPT.

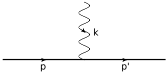
} Starts failing at 20 MeV above threshold.

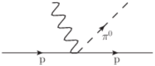
The nucleonic Lagrangian

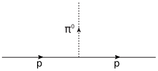
$$\mathcal{L}_N = \bar{\Psi}\left(\mathrm{i}\not{D} - m + \frac{g_A}{2}\not{u}\gamma_5\right)\Psi + \cdots$$

Each chiral order brings new LECs with it. For this channel, one finds the following combinations of LECs:

- $\mathcal{O}(p^1)$ 

g_A
- $\mathcal{O}(p^2)$ 

c_{67}
- $\mathcal{O}(p^3)$ 

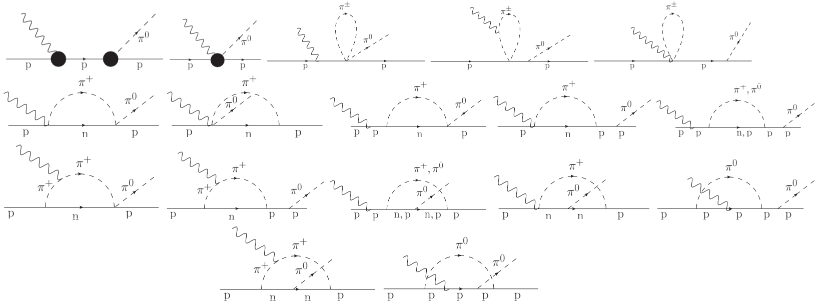
d_{89} 

d_{168}

See arXiv:1412.4083 for LECs definitions.

Putting the pieces together

- With these ingredients we calculate all possible nucleonic diagrams up to $\mathcal{O}(p^3)$. (Crossed diagrams are not depicted.)



- This is the same approach as in previous ChPT works.

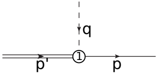
Our strategy

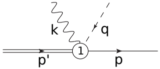
- We stay at $\mathcal{O}(p^3)$ — avoids inclusion of too many LECs.
- The calculation of loop diagrams leads to divergences and power counting breaking terms $\Longrightarrow$ We use the EOMS-renormalization prescription.
  - It absorbs divergent terms of the type $L = \frac{2}{\epsilon} + \log(4\pi) - \gamma_E + 1$.
  - It also easily subtracts terms of lower order than the nominal order of a diagram.

Our strategy to improve the approach

- To reproduce the measured observables: Inclusion of the $\Delta(1232)$ isospin-3/2 resonance.
- More relevant the closer we are to its mass.
- Particularly important for neutral channel, as the lower orders have very small contributions. Hemmert et al. (1997) PLB

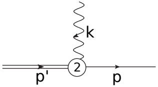
- $\mathcal{O}(p^1)$





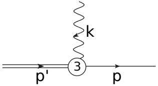
h_A

- $\mathcal{O}(p^2)$



g_M

- $\mathcal{O}(p^3)$



g_E

The propagator is now a Rarita-Schwinger propagator:

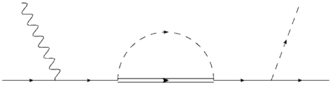
$$\frac{\not p + M_\Delta}{p^2 - M_\Delta^2 + i\varepsilon}\left[-g^{\alpha\beta} + \frac{1}{D-1}\gamma^\alpha\gamma^\beta + \frac{1}{(D-1)M_\Delta}(\gamma^\alpha p^\beta - \gamma^\beta p^\alpha) + \frac{D-2}{(D-1)M_\Delta^2}p^\alpha p^\beta\right]$$

Power counting and divergences

- Followed counting scheme (valid only for energies close to threshold and far from the $\Delta(1232)$ mass):

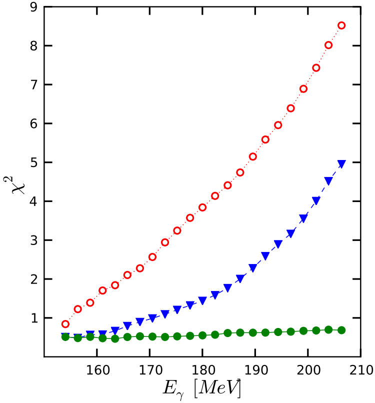
  Lensky and Pascalutsa (2010) EPJ

$$D = 4L + \sum kV_k - 2N_\pi - N_N - \frac{1}{2}N_\Delta .$$



- Δ loop diagrams start only at $\mathcal{O}(p^{7/2})$ — thus at first only tree-level Δ diagrams are included.
- No new fitting LECs.

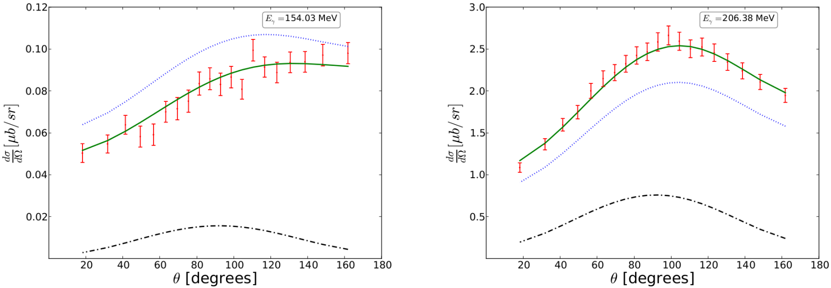
Fitting low-energy constants



- Nucleonic tree level.
- Full nucleonic model up to $\mathcal{O}(p^3)$.
- Inclusion of $\Delta(1232)$ at tree level — no new fitting constants!

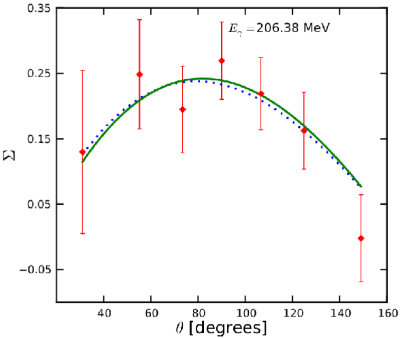
	g_A	$\tilde{c}_{67}$	$\tilde{d}_{89}$ [GeV^{-2}]	$\tilde{d}_{168}$ [GeV^{-2}]	χ^2/d.o.f.
No Δ	1.46	2.86	4.20	-15.1	4.96
Full Model	**1.27**	2.33	1.46	-12.1	0.69
Full Model	1.24	2.36	1.46	-11.1	0.68

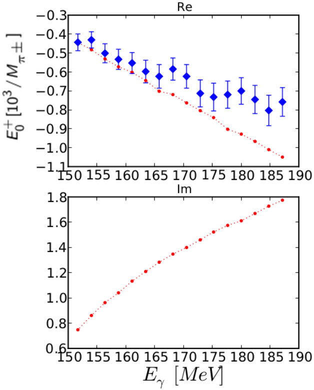
Comparing theoretical curves with data



- Pion photoproduction data from MAMI Hornidge et al. (2013) PRL
- Full nucleonic model up to $\mathcal{O}(p^3)$ Unable to reproduce the energy dependence
- Full nucleonic model and $\Delta(1232)$ at tree level (no new LECs)
- $\Delta(1232)$ degrees of freedom only

Other observables





Summary and outlook

- New pion photoproduction data shows that purely nucleonic ChPT models converge too slowly — even close to threshold.
- Including the $\Delta(1232)$ resonance strongly improves the accordance between data and ChPT models, even without bringing in new fitting constants.
- The extension to higher orders (the inclusion of Δ loop diagrams) is being finished.
- To have more information about the LECs, it would be necessary to extend these calculations to other channels.

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ありがとう　ございます!