# Chiral effective field theory for hadron and nuclear physics

Jose Manuel Alarcón

Helmholtz-Institut für Strahlen- und Kernphysik
University of Bonn

# *Biographical presentation*

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- Born in 1983 in Cartagena in the Region of Murcia (Spain).
- 2001- I started my studies in Physics at the University of Murcia.
- 2005 - I received the 1st prize in the physics contest "Celebrando la Física" organized by the University of Murcia.
- 2006 - I completed my studies with the best grades, receiving a special prize for it (Premio extraordinario fin de carrera).
- 2007 - I finished the "Master of Advanced Physics", with specialization in theoretical physics, at the University of Valencia (maximum grade in Master Thesis).
- 2007 - I started to work on my thesis under the supervision of Prof. Jose Antonio Oller, at the University of Murcia.
- Topic: Relativistic formulations of chiral EFT with baryons and application to $\pi N$ scattering.

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- 2012 - I defended my thesis, entitled "Baryon Chiral Perturbation Theory in its manifestly covariant forms and the study of the **πN** dynamics & On the Y(2175) resonance". (Sobresaliente Cum Laude).
- 2014 - Thesis awarded with the "Premio extraordinario de doctorado", given to the best thesis in physics defended in the period 2012-2013 at the University of Murcia.
- 2015 - Thesis awarded by the Nuclear Physics Division of the European Physical Society with the Dissertation Award (2012-2014)
- July 2012 - I started to work in the group of Prof. Marc Vanderhaeghen at the Johannes Gutenberg University, Mainz.
  - Working with V. Pascalutsa: Nucleon Polarizabilities and **μH** Lamb shift.
- September 2014 - I started to work in Bonn.
  - Application of EFT to *ab initio* many-body nuclear calculations.

# *Research topics*

# πN *scattering*

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    - Important hadronic uncertainty in direct detection of DM *[Bottino, Donato, Fornengo and Scopel, Astropart. Phys. 13, (2000); Astropart. Phys. 18, (2002)] [Ellis, Olive and Savage PRD 77, (2008)]*.
    - Formation of elements needed for life *[Berengut et. al., PRD 87, (2013)].*

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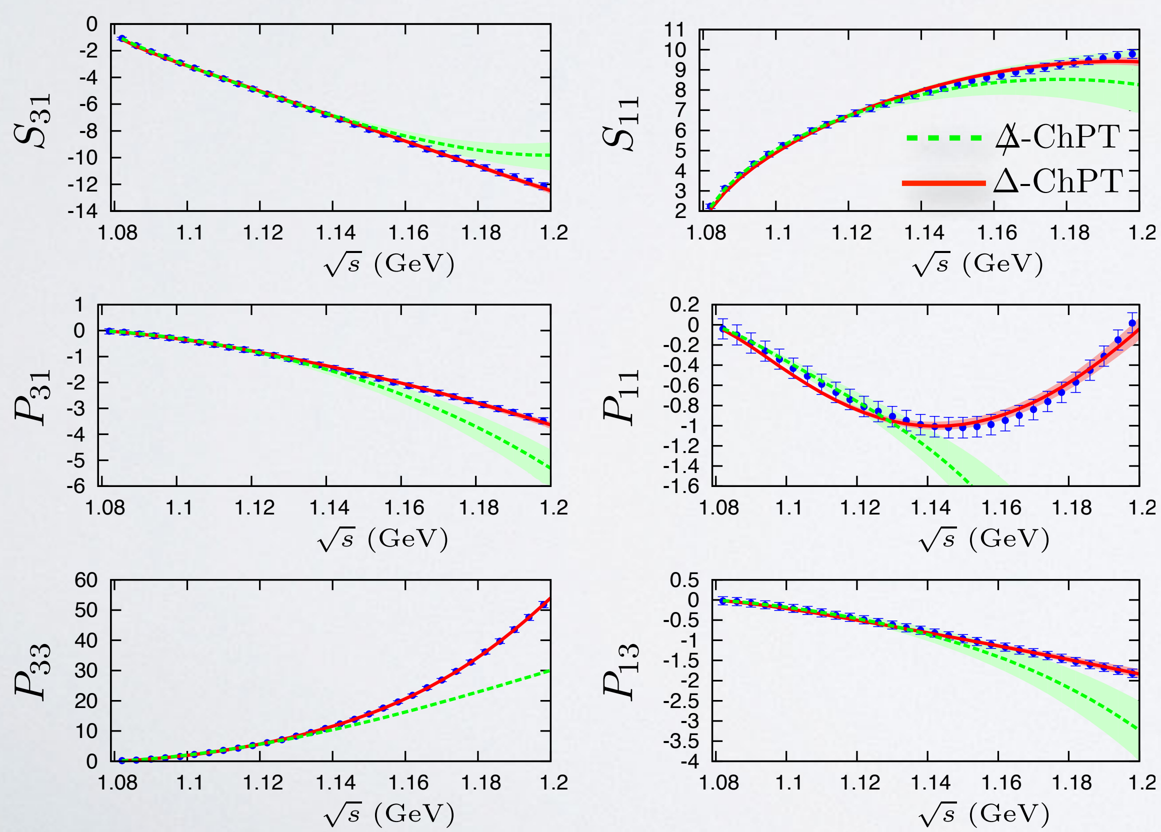

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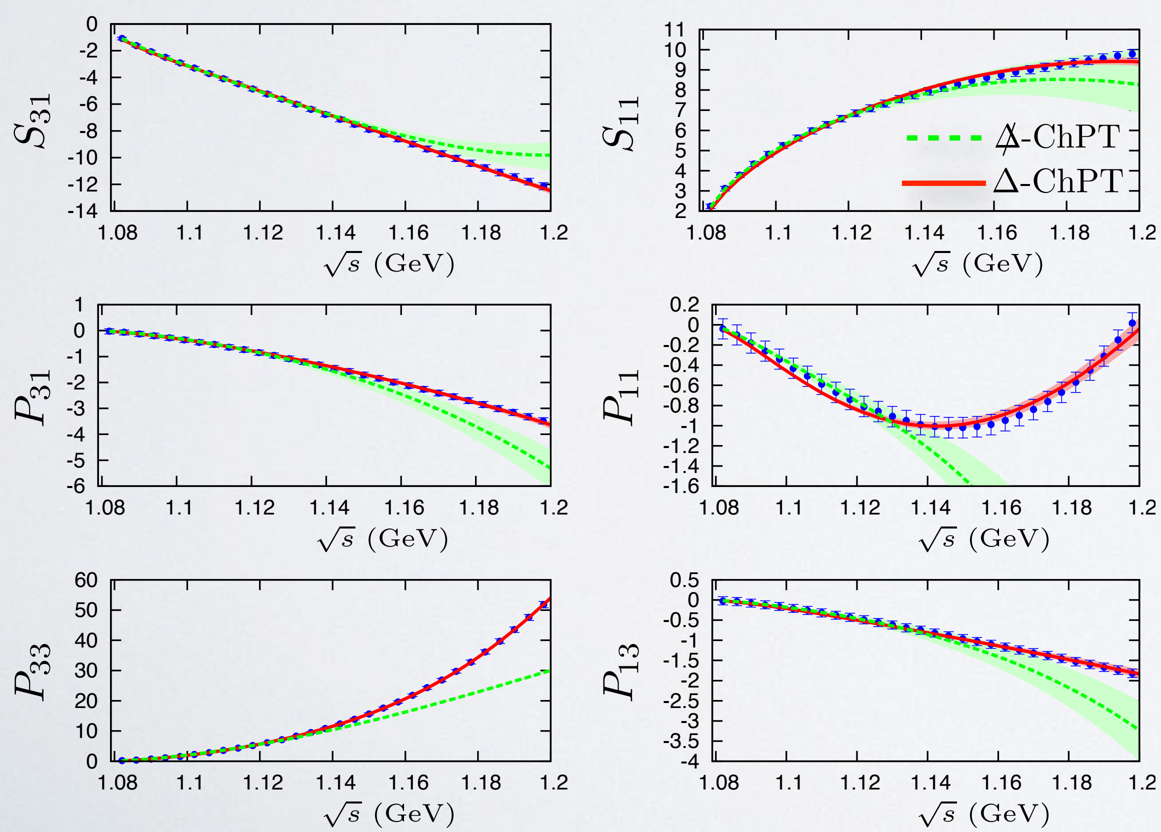


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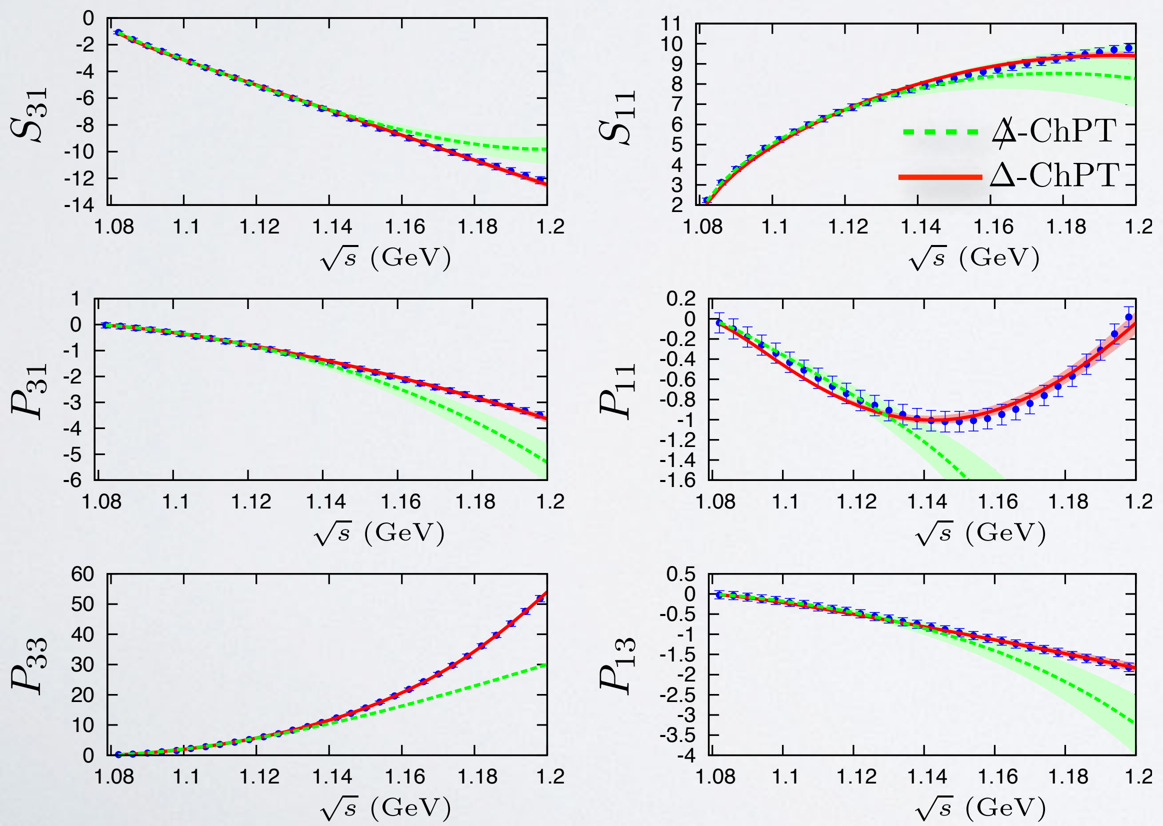


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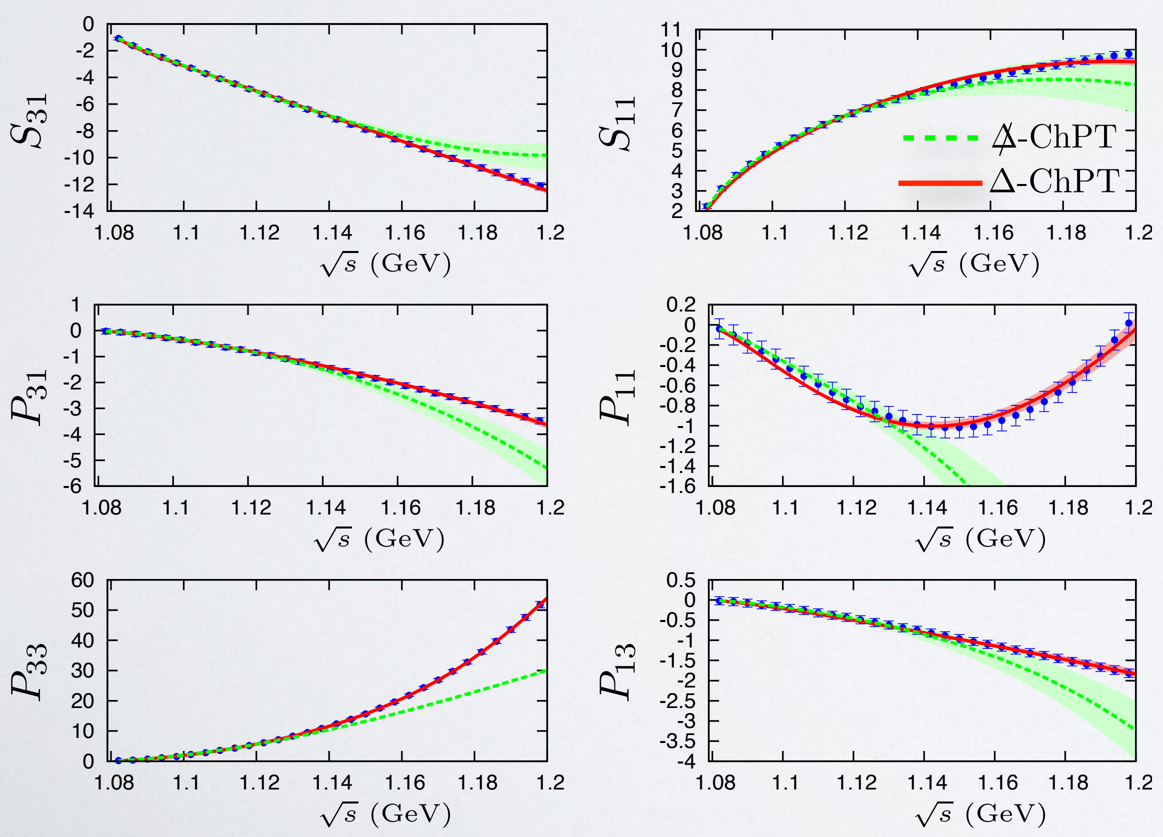


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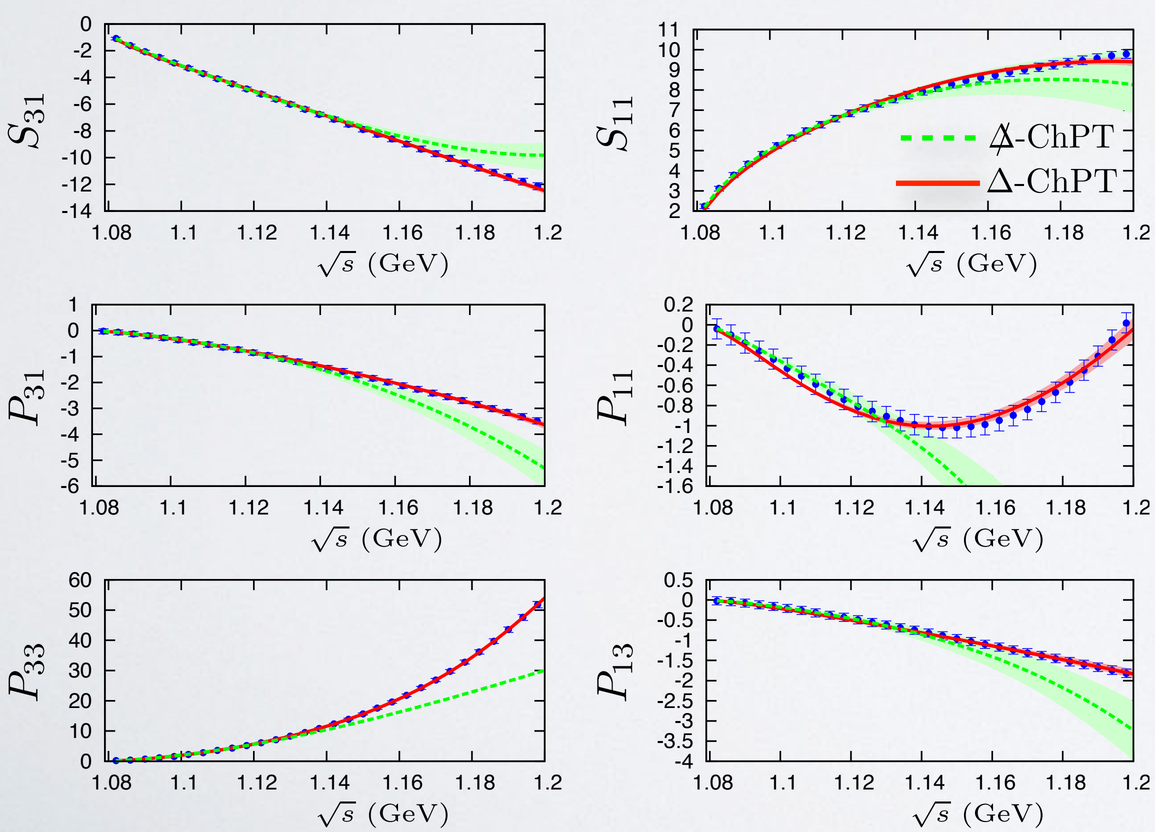


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  - Determination of $\sigma_{\pi N}$ from modern phenomenological information.

$$\sigma_{\pi N} = 59(7)\ \text{MeV}$$

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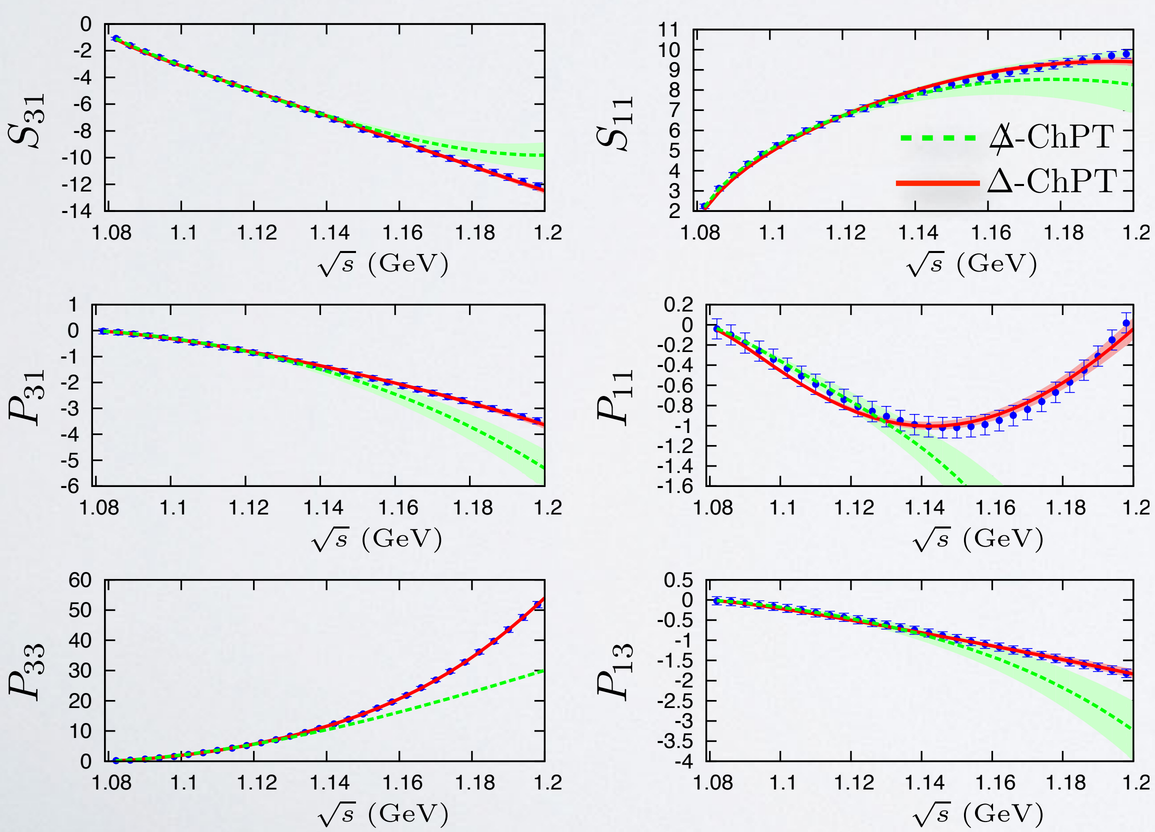


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  - Analysis confirmed point by point by the Roy-Steiner analysis of *[Hoferichter et al., PRL 115 (2015)]*

## *Nucleon Polarizabilities and Lamb shift*

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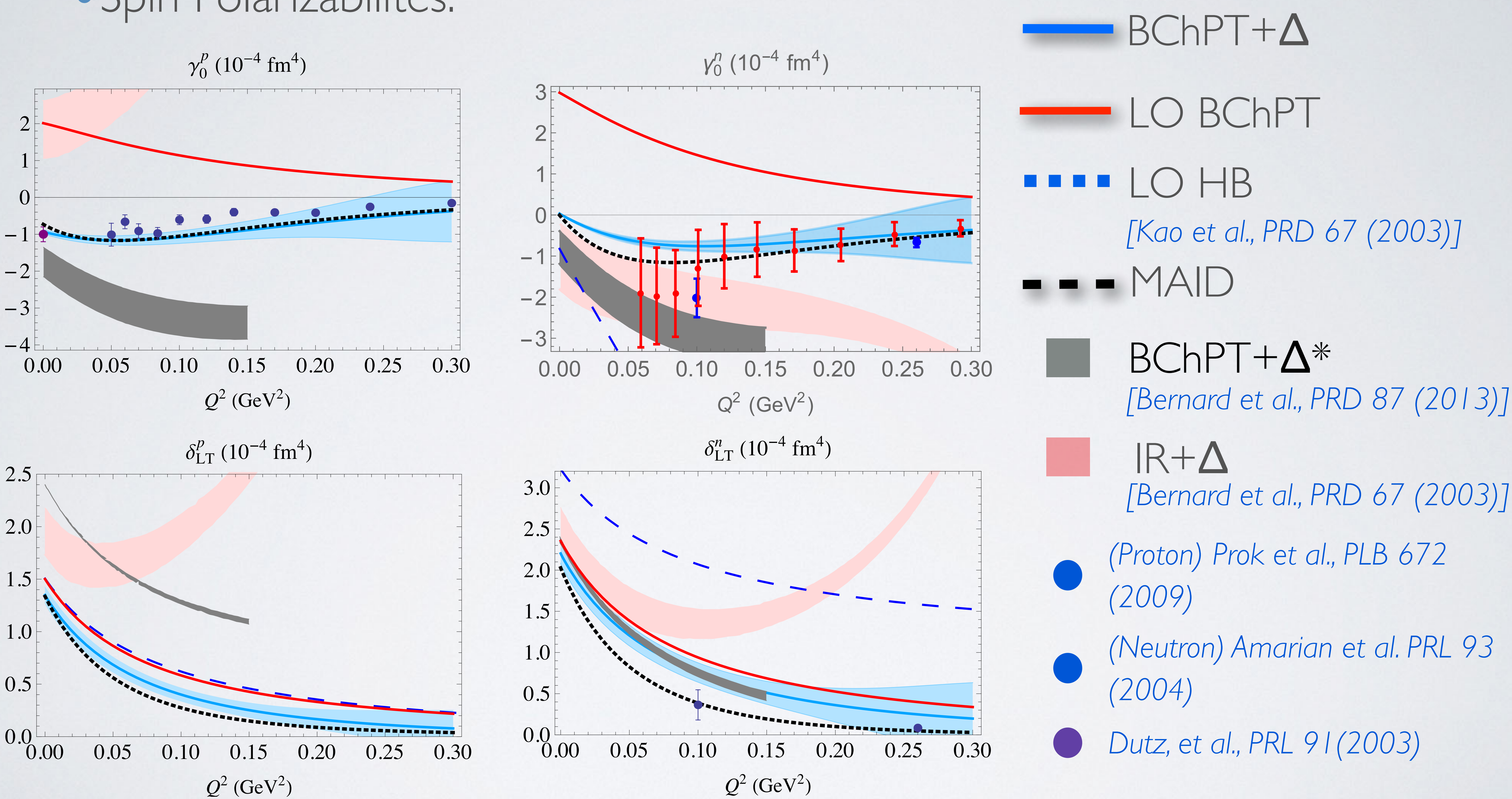
  - Spin Polarizabilites:

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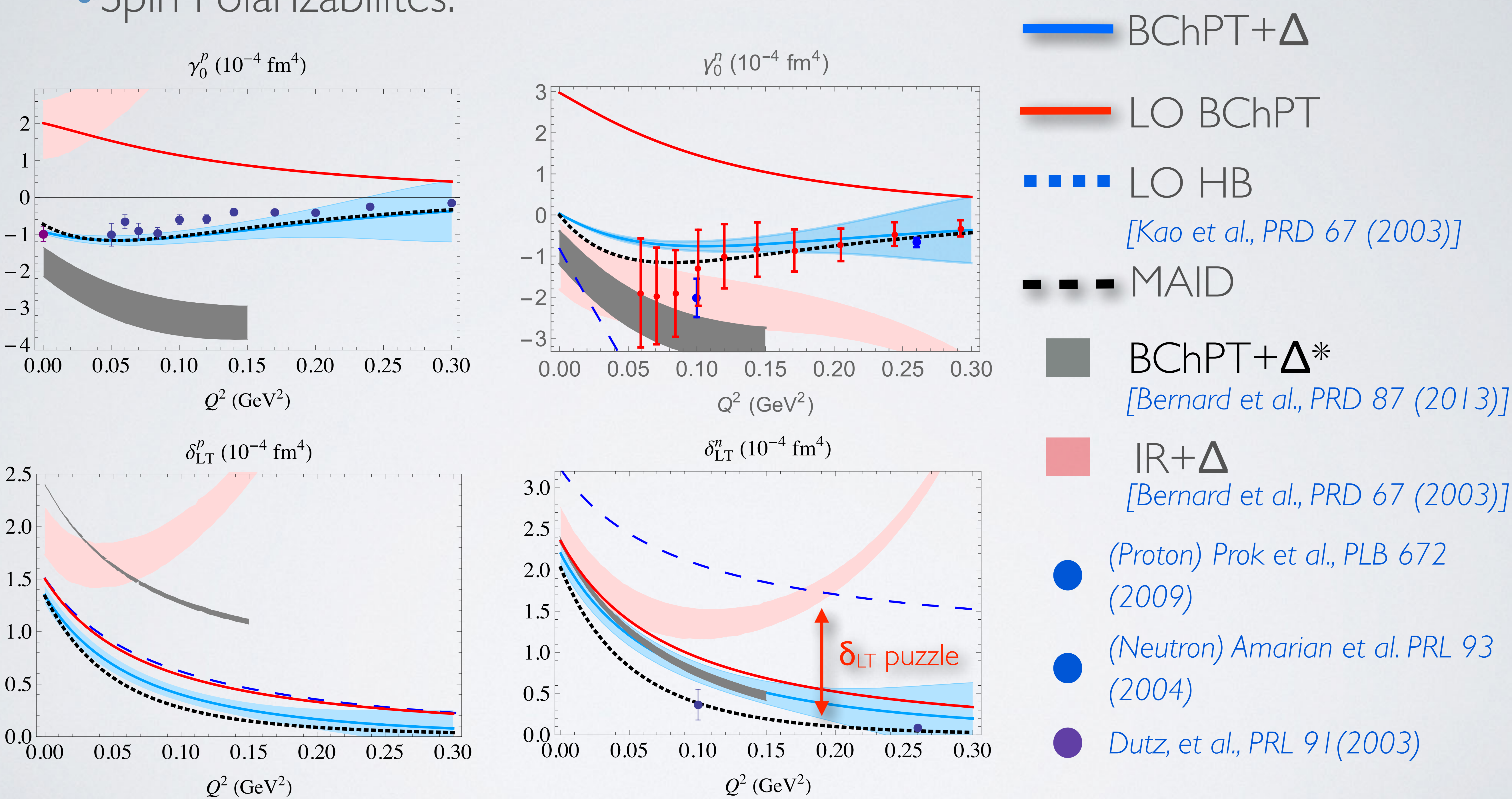


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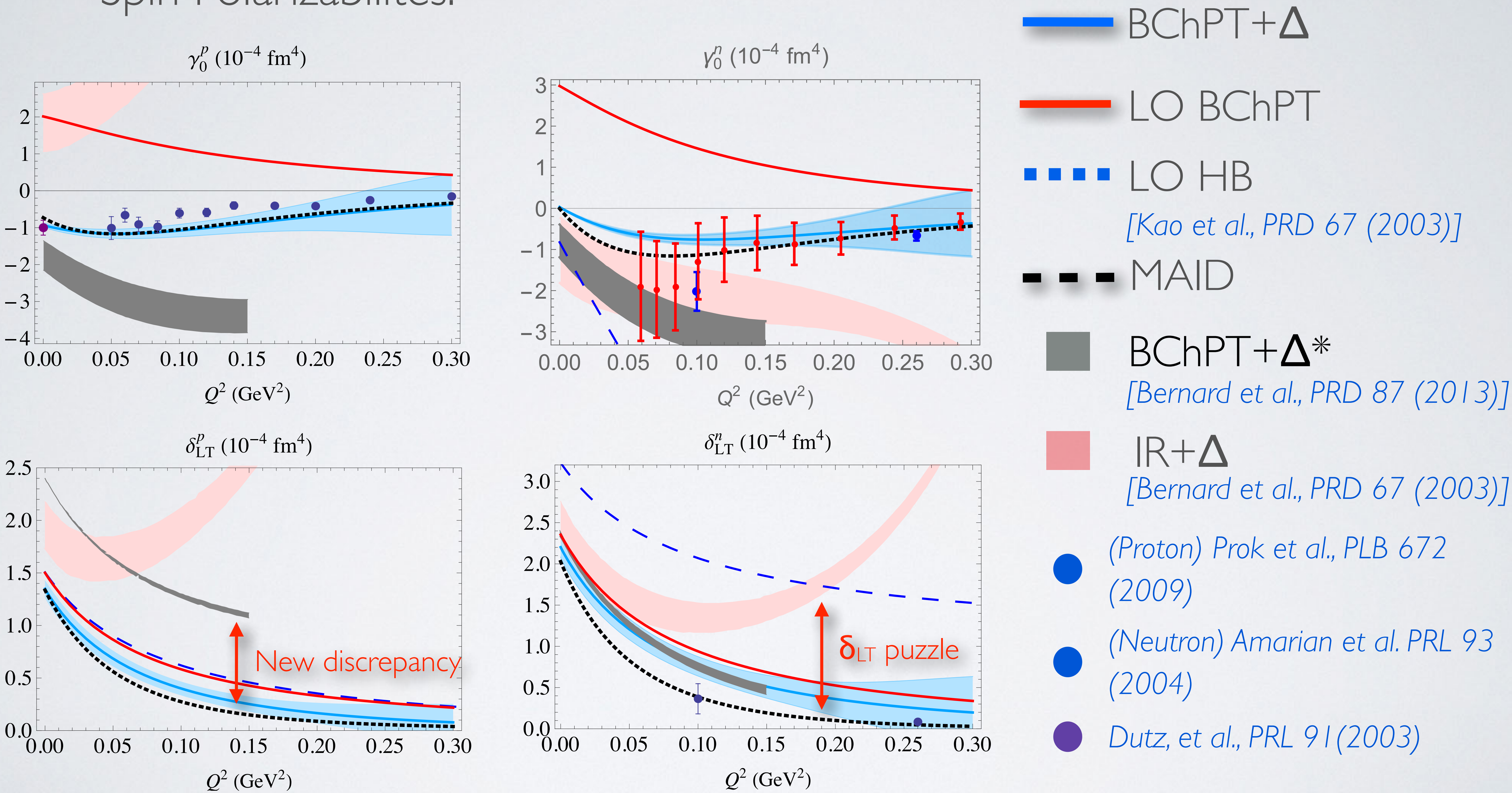


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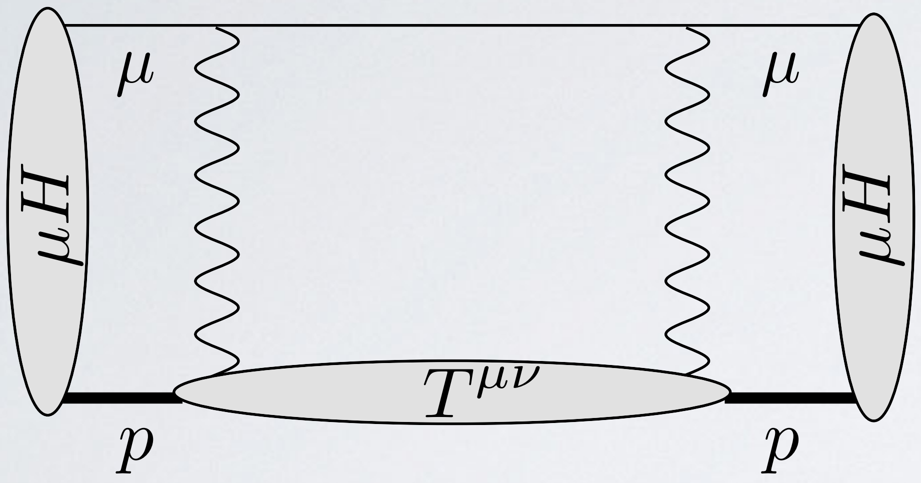

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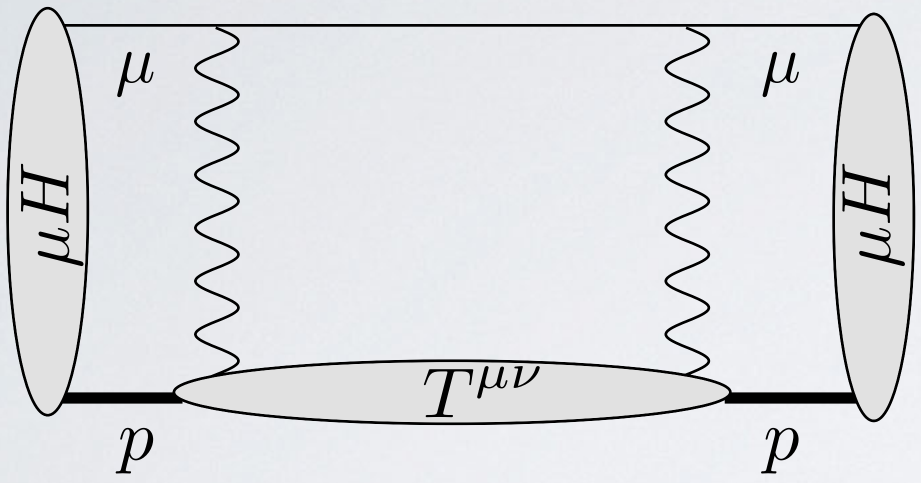


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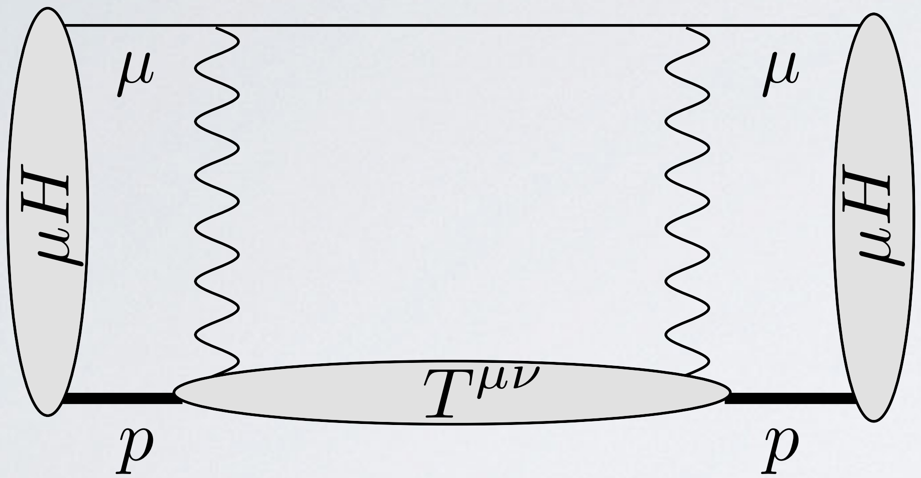


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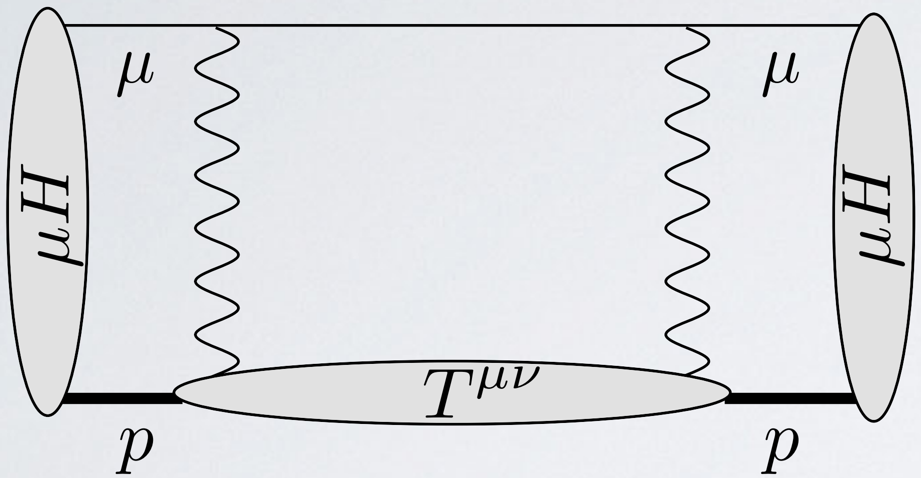


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Chiral EFT calculations (light blue)

Phenomenological determinations (dispersion relations+data) (green)


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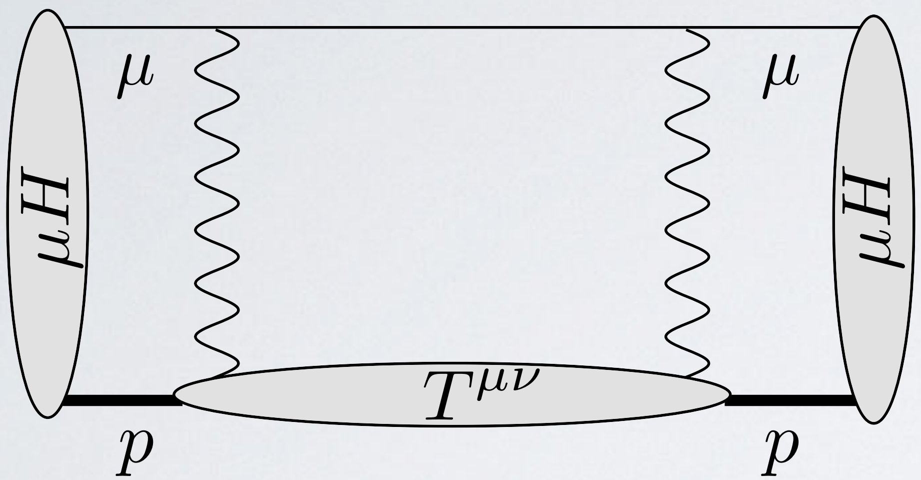


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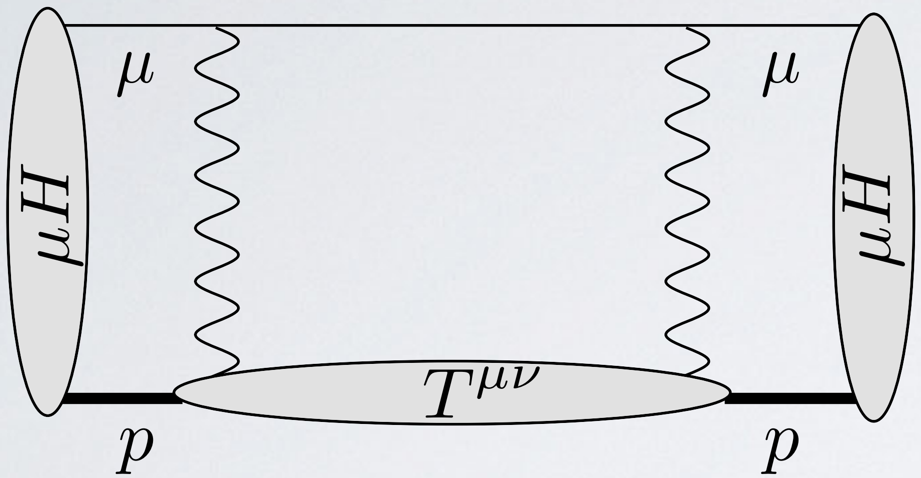


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# *Nuclear Lattice Effective Field Theory*

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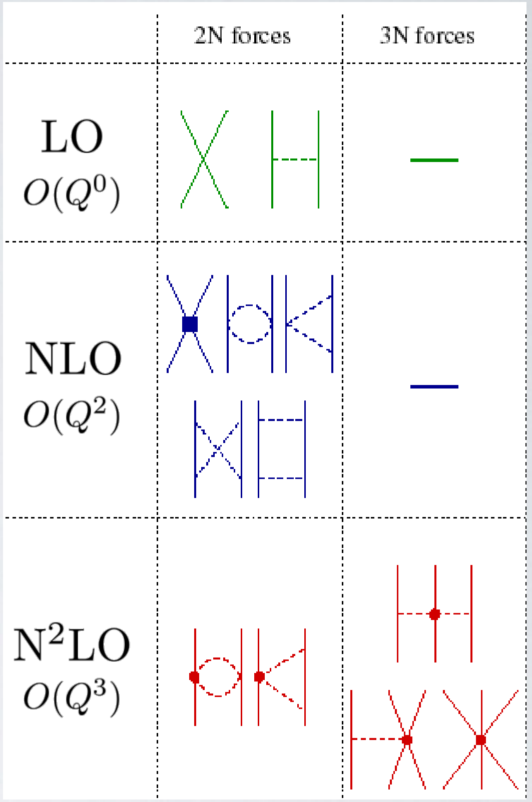


*[Courtesy of Dean Lee]*

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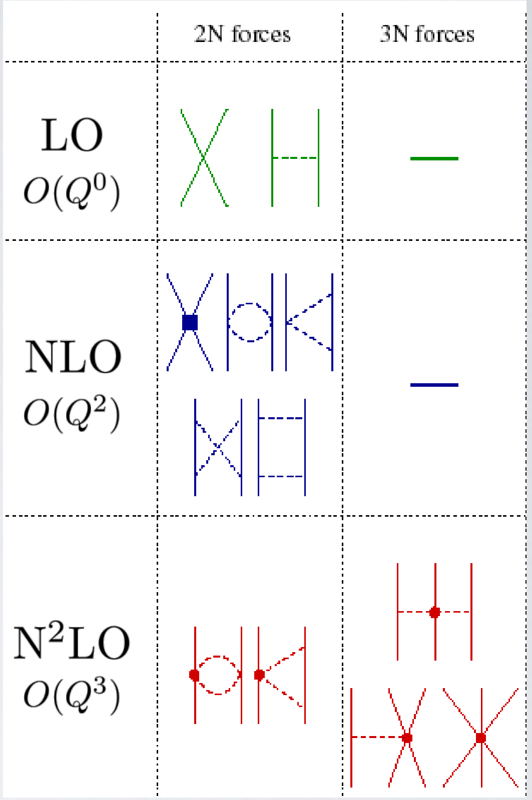


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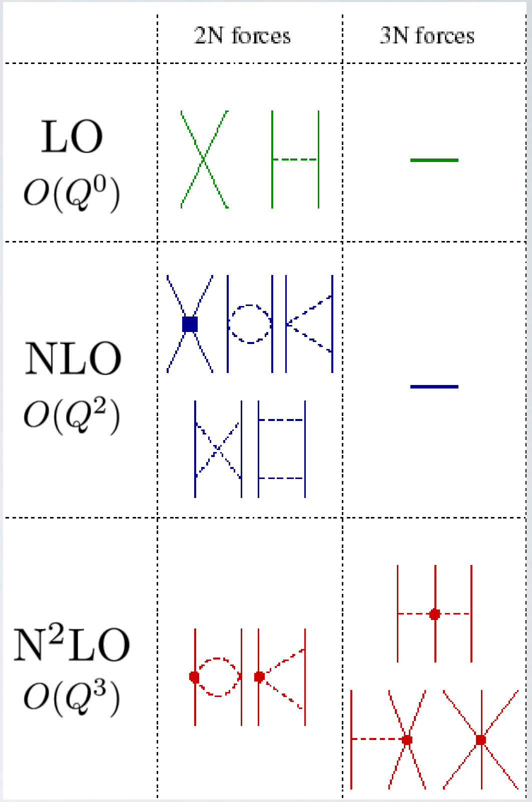


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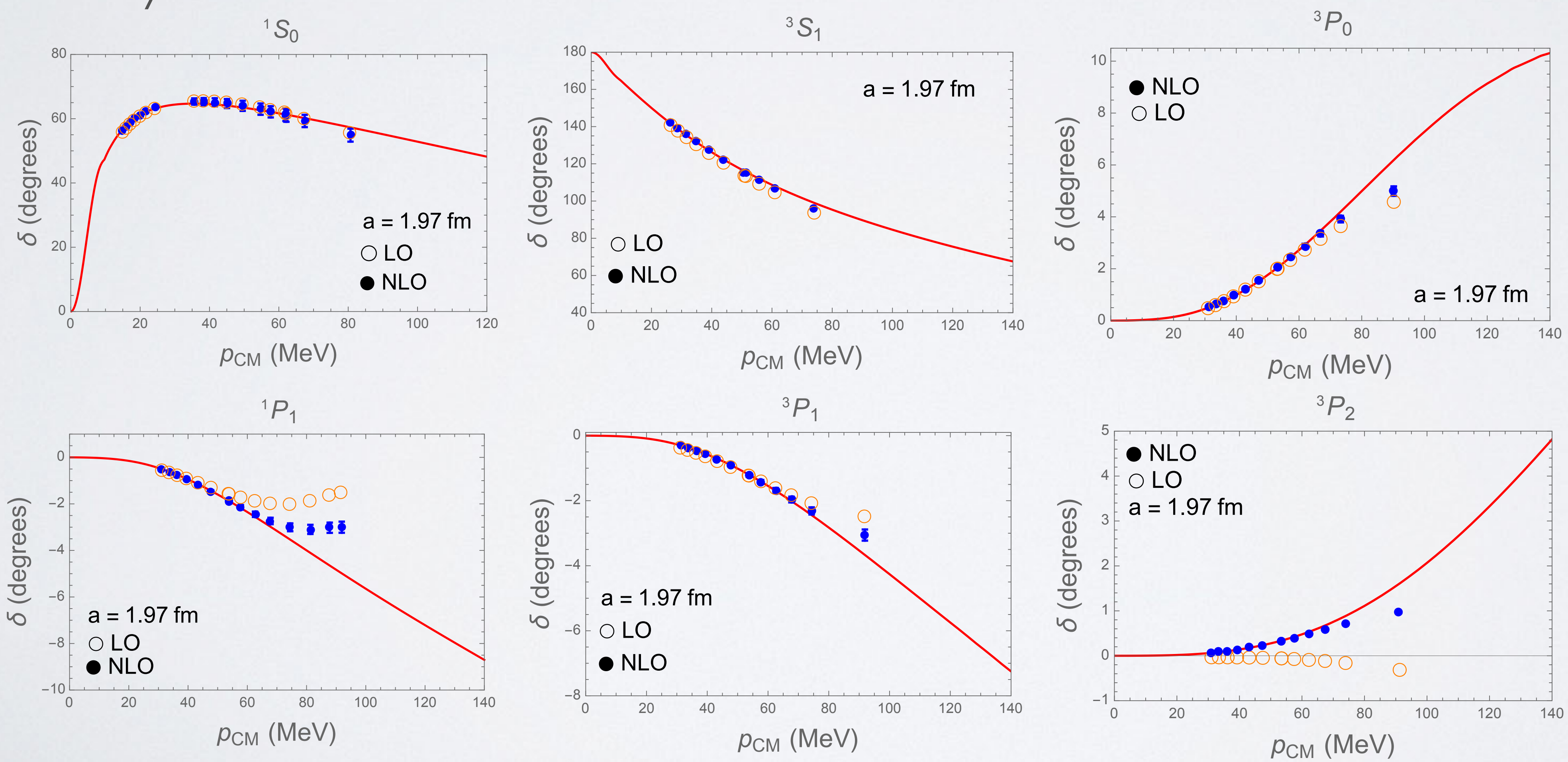
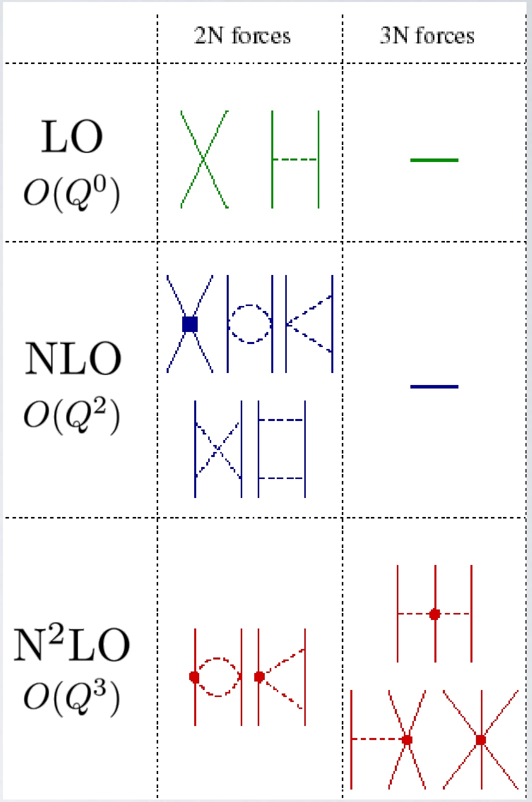



[J. M. Alarcon, Chiral Dynamics Workshop 2015]




[Courtesy of Dean Lee]

# *Future Projects*

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- Provide spatial picture of the charge and magnetic density of the baryon octet and densities of the decuplet.

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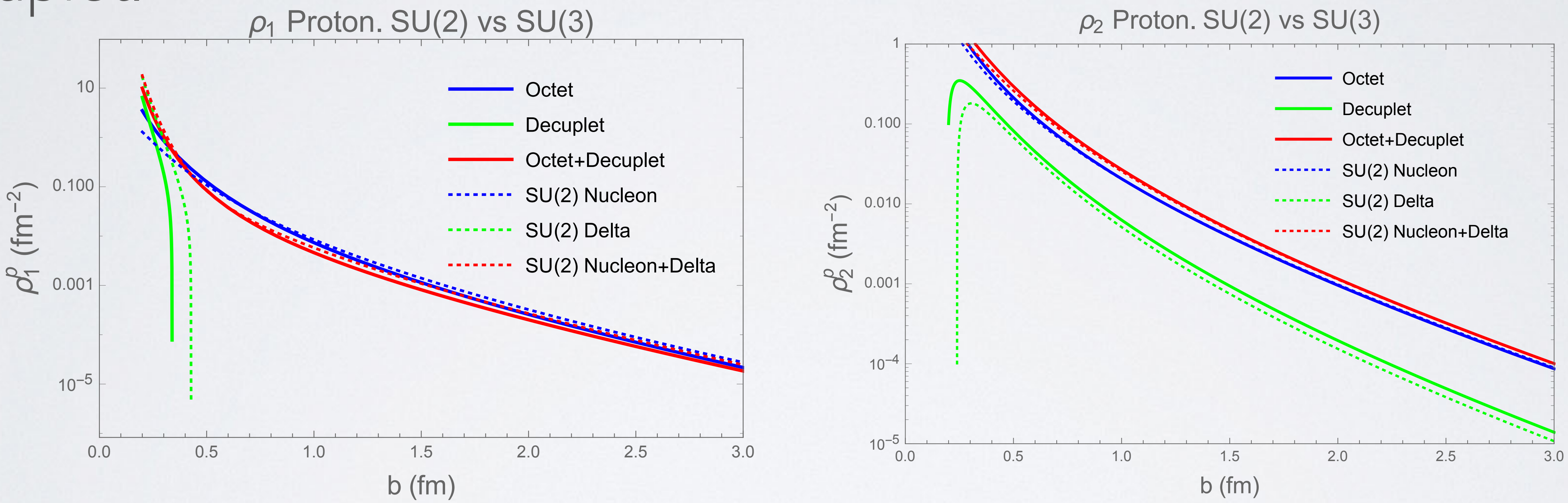

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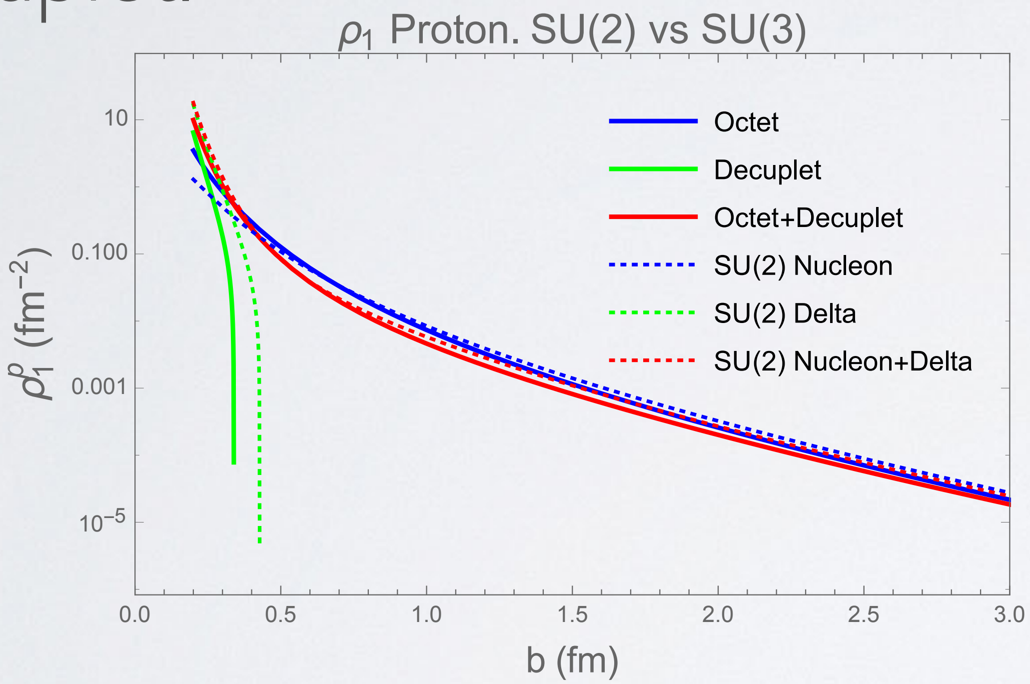


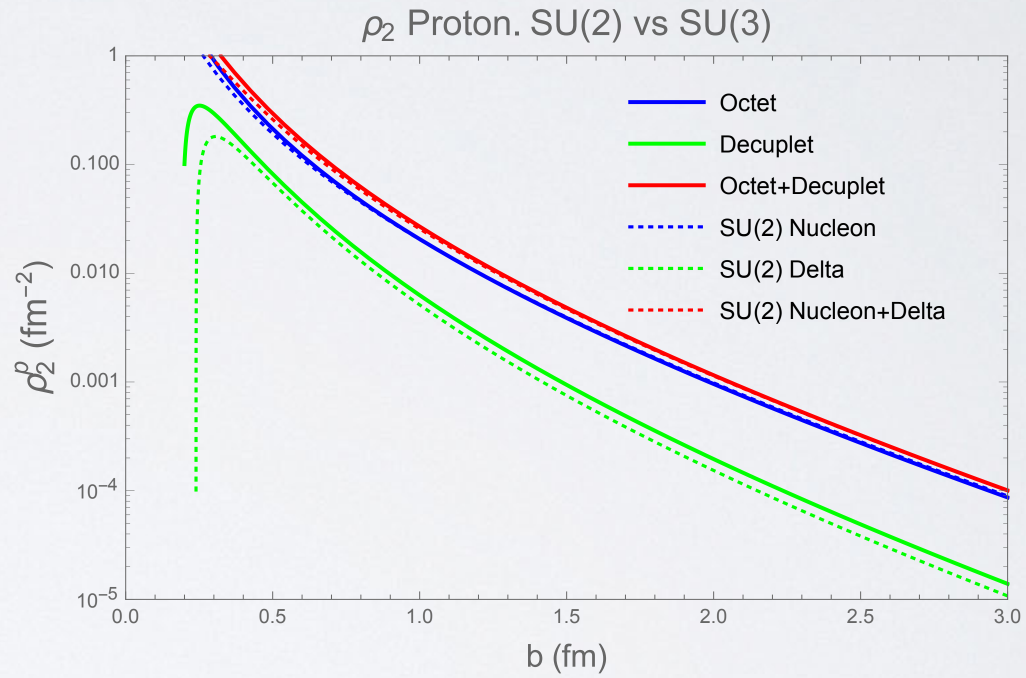


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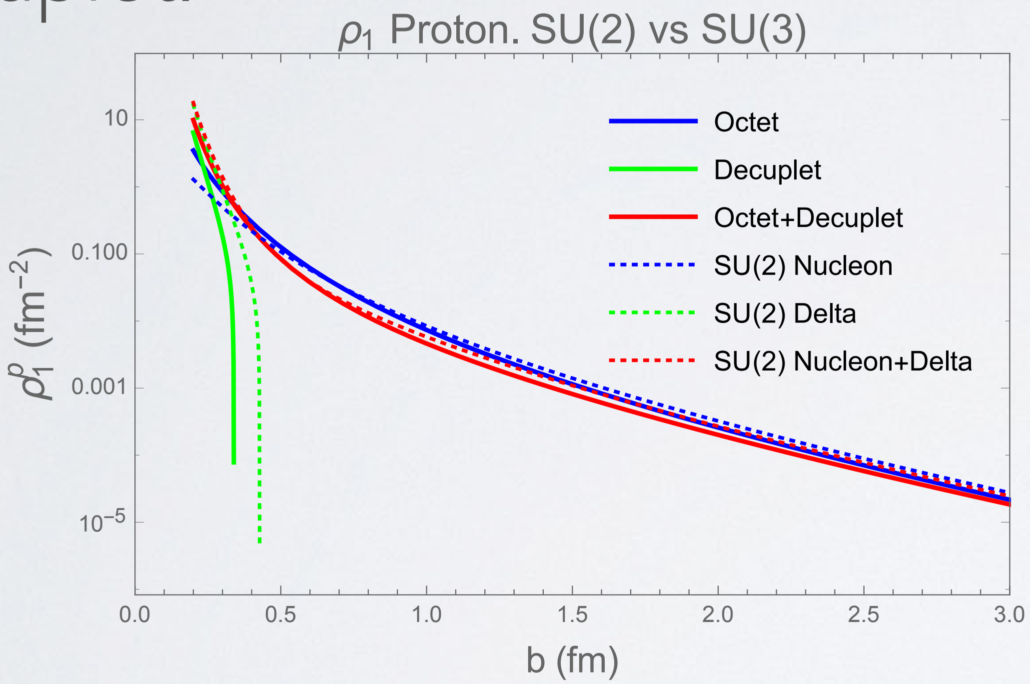


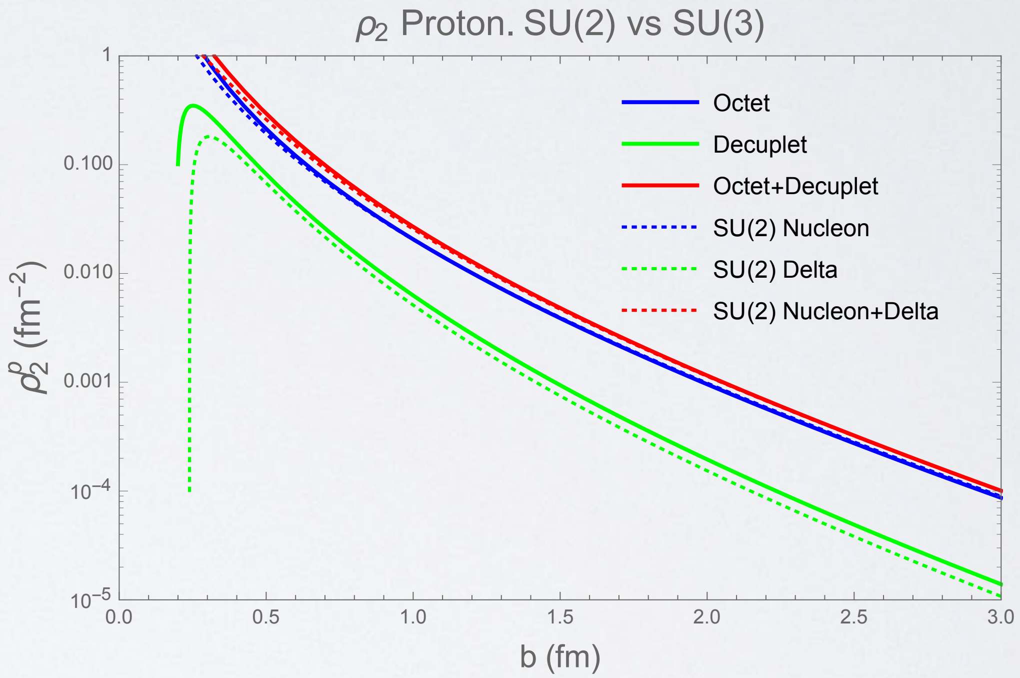


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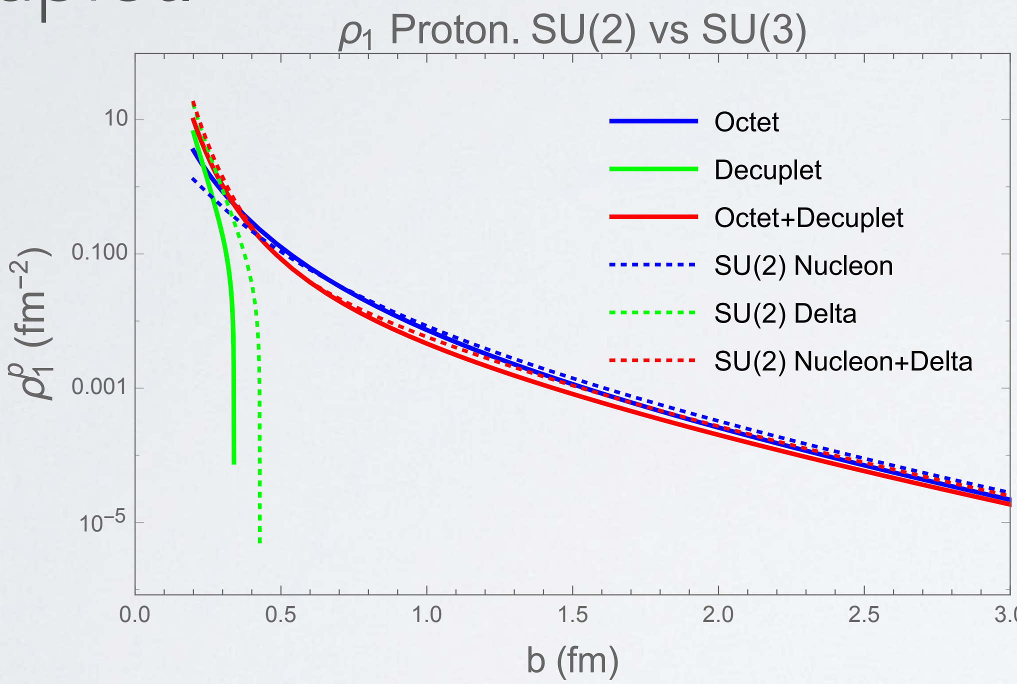


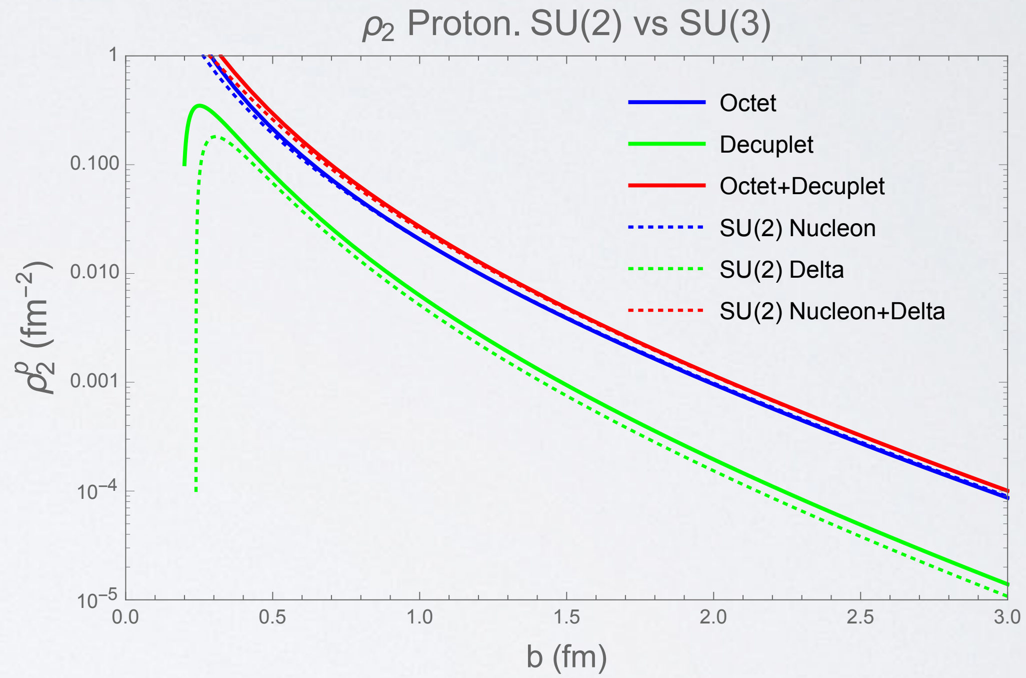


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    → They do not modify the correct Nc scaling.

# *Summary and Conclusions*

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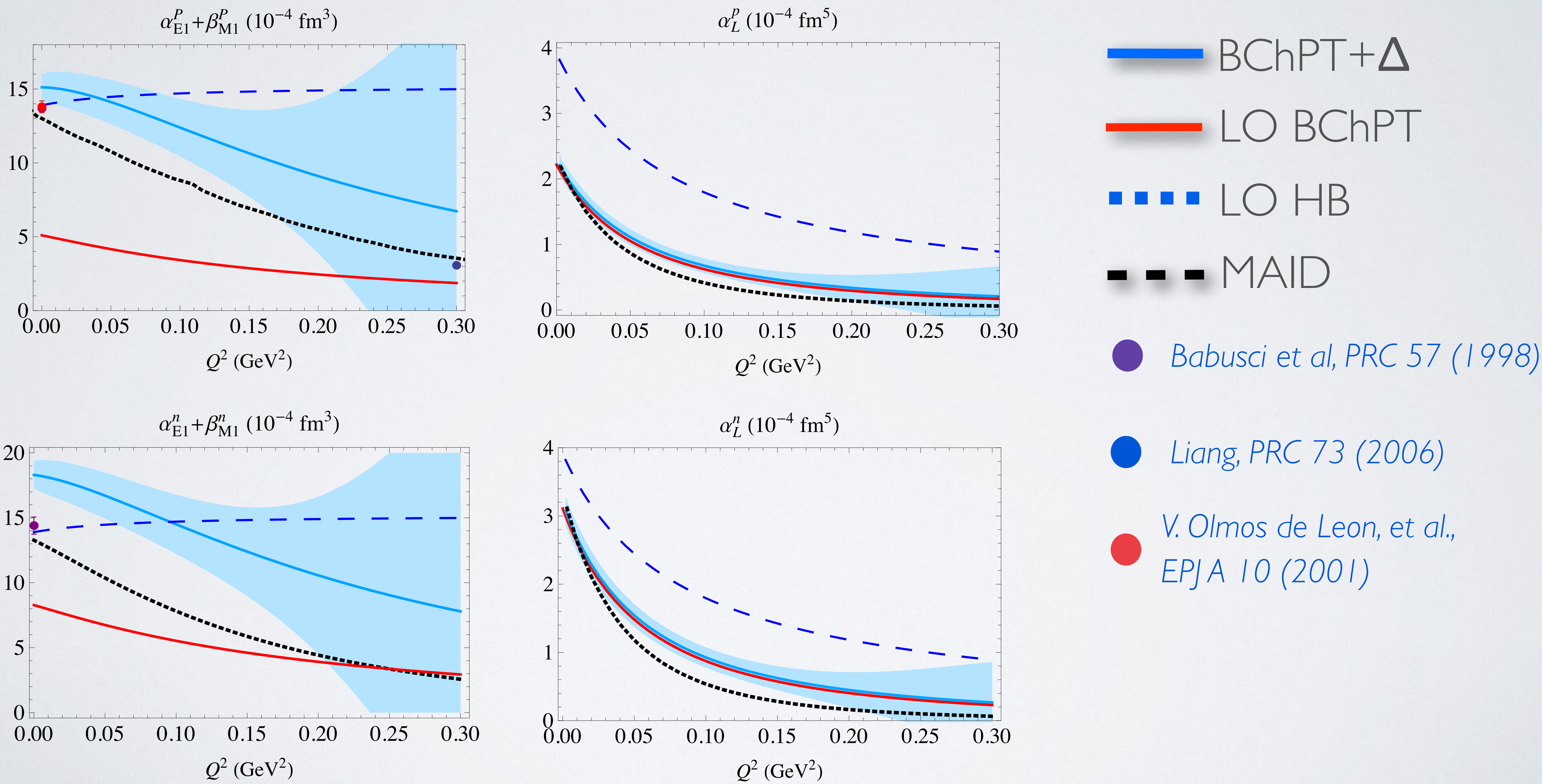
- Chiral EFT with baryons is an excellent tool to investigate fundamental hadronic interactions involving nucleons on QCD grounds.
- $\pi$N
  - Good description of modern scattering data below the $\Delta$ peak.
  - Agreement with dispersive extractions.
  - Extraction of important quantities from phenomenology ( $\sigma_{\pi N}$ )
- Forward doubly virtual Compton scattering
  - Prediction of polarizabilities in agreement with MAID model and experimental data → Improves previous ChPT predictions.
- Nuclear Lattice EFT
  - Fundamental piece in *ab initio* many-body nuclear calculations.
- Further improvements possible including spin-flavor symmetry.

FIN

# *Spares*

# *Polarizabilities*

- Relativistic baryon chiral EFT with electromagnetic probes:
  - Scalar and spin VVCS Polarizabilities.
- Scalar Polarizabilites:

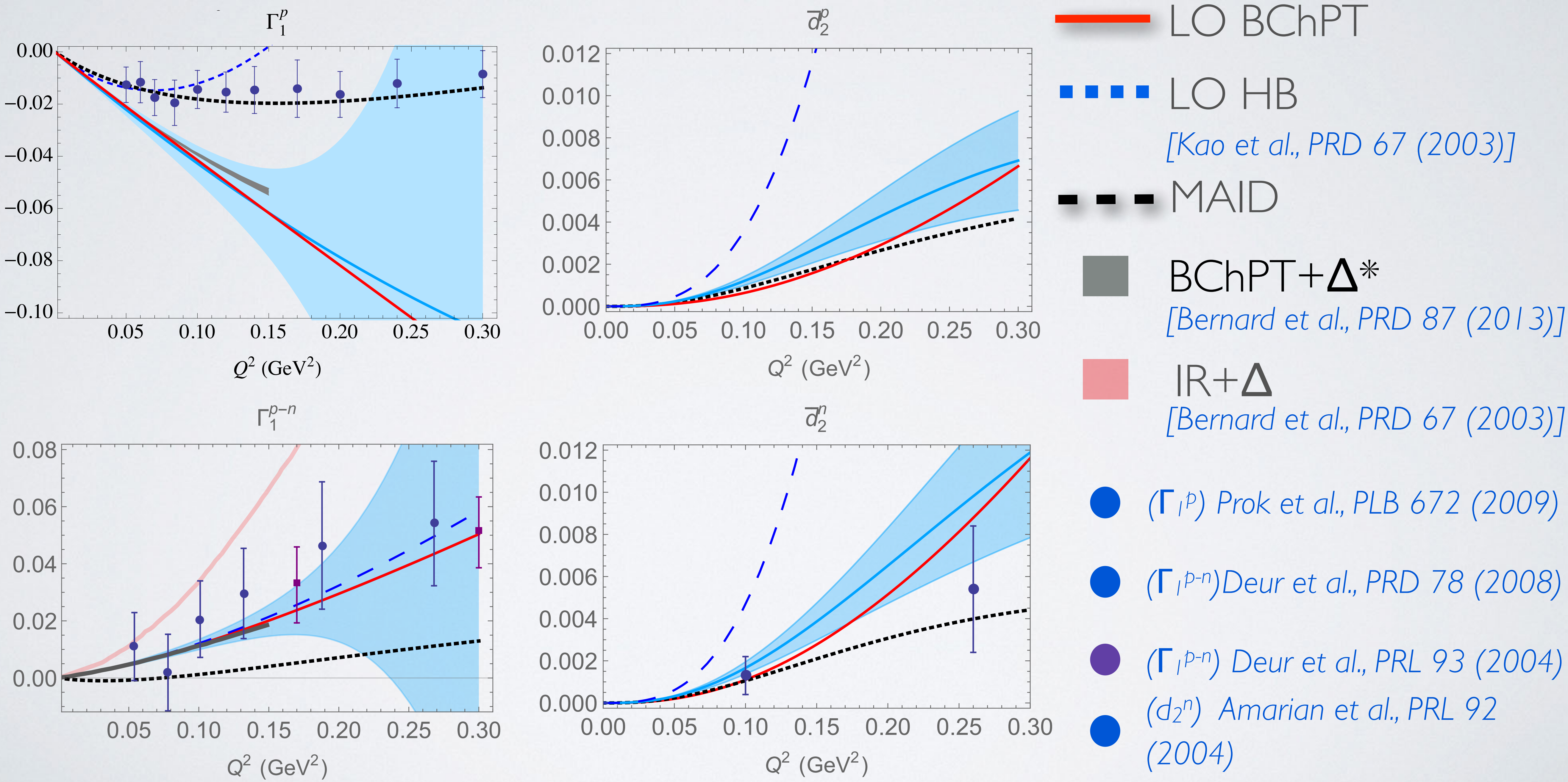


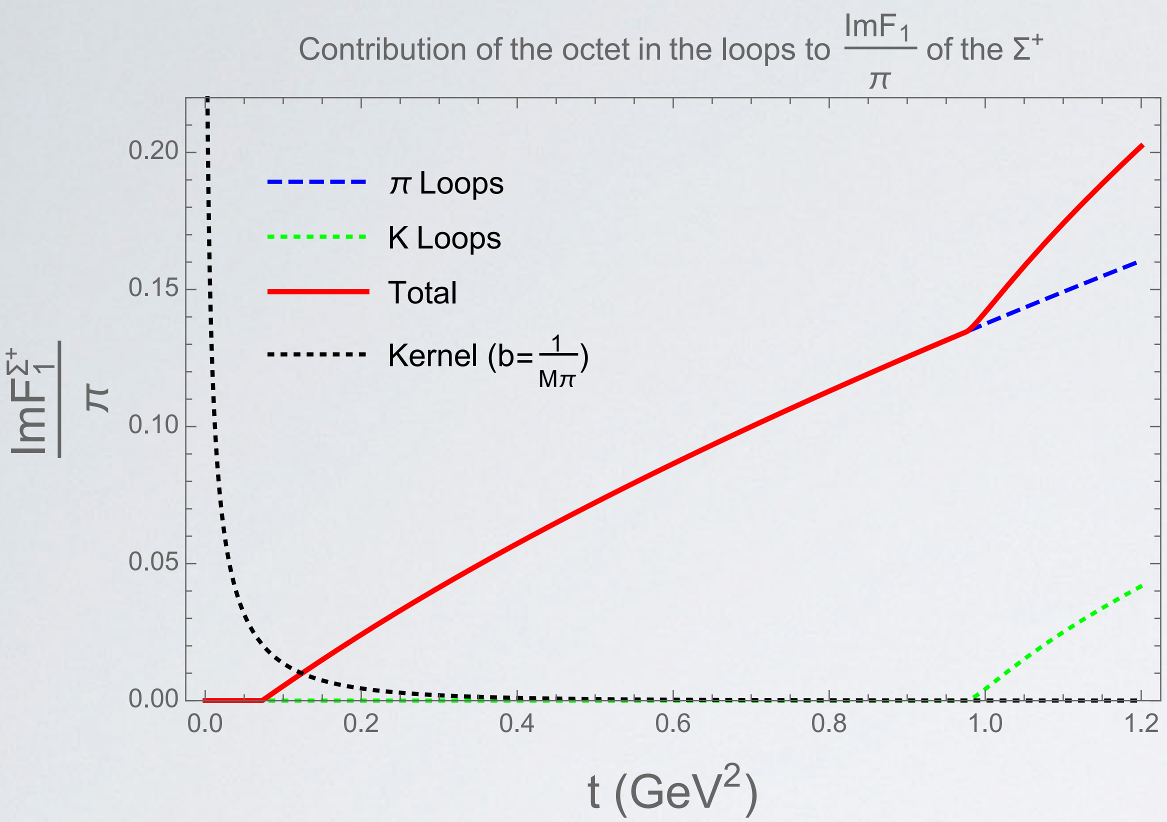
# *Polarizabilities*

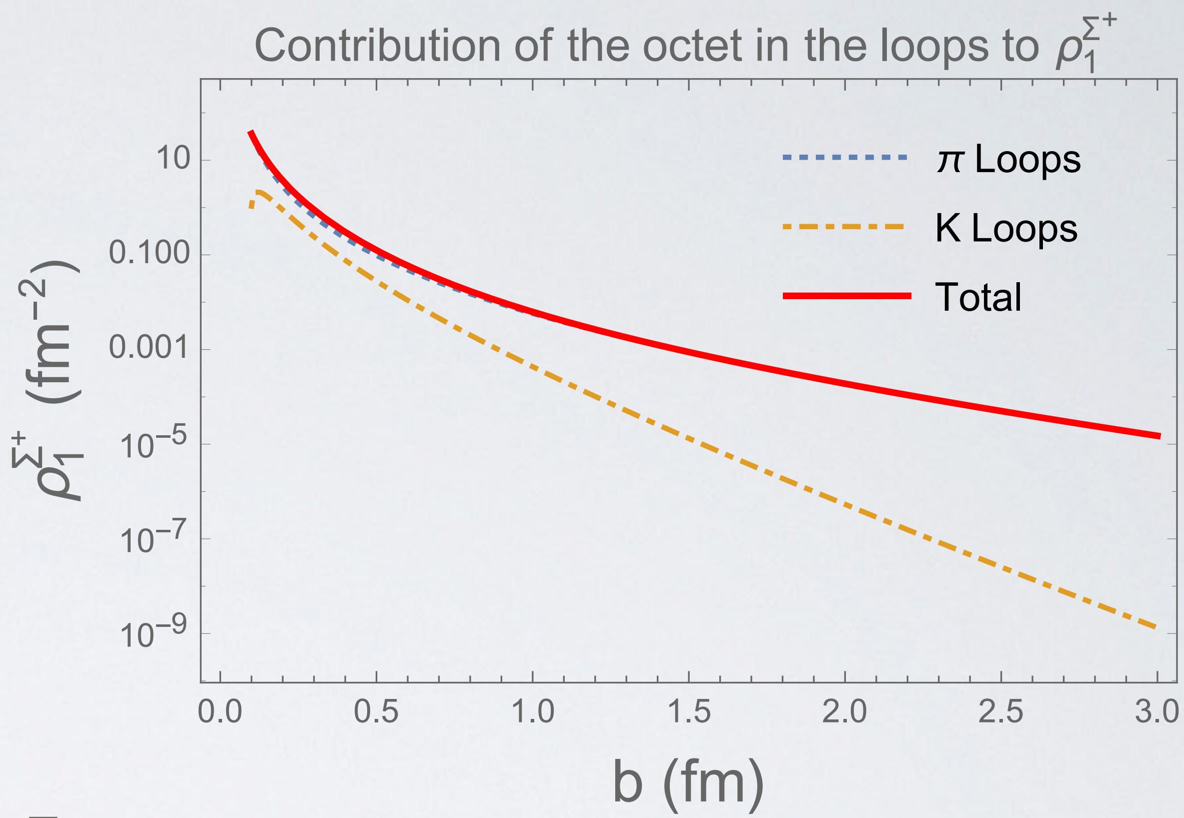
- Some interesting moments:

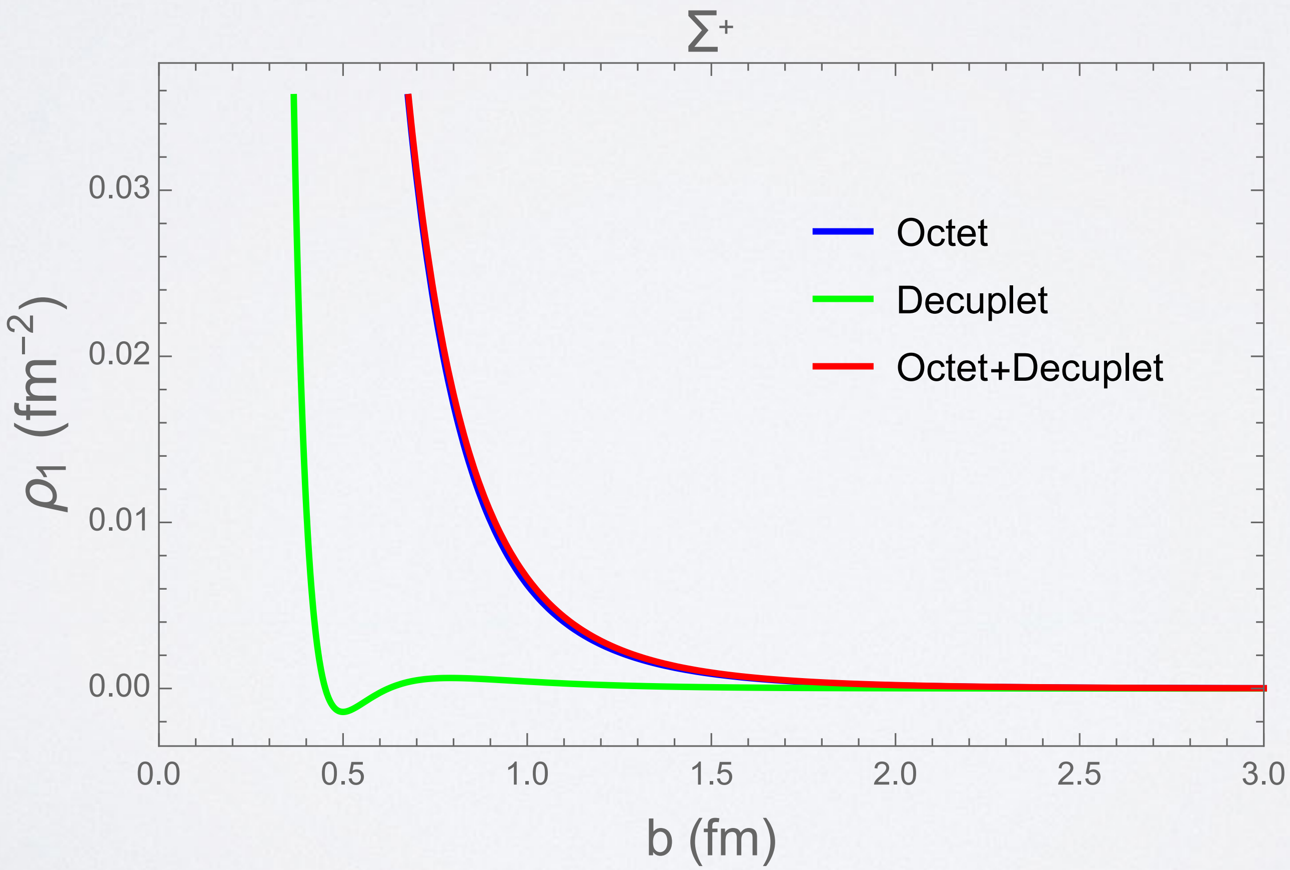
$$\Gamma_1(Q^2) = \int_0^{x_0} dx\; g_1(x,Q^2)$$

$$\bar{d}_2(Q^2) = \int_0^{x_0} dx\, x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]$$




Contribution of the octet in the loops to ImF1/π of the Σ+
ImF1Σ+/π
π Loops
K Loops
Total
Kernel (b=1/Mπ)
t (GeV2)


Contribution of the octet in the loops to ρ1Σ+
ρ1Σ+ (fm−2)
π Loops
K Loops
Total
b (fm)


Σ+
ρ1 (fm−2)
Octet
Decuplet
Octet+Decuplet
b (fm)