Effective Theories in Hadronic and Nuclear Physics

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Topics: Effective field theory and many body techniques applied to study:

- Properties of light and heavy (with charm and beauty) hadrons
  - spectroscopy; form factors; strong and weak decays
  - exotic hadrons; X, Y, Z states; pentaquarks
- Dynamics of meson-meson and meson-baryon systems; dynamically generated resonances and triangle singularities
- Hadron dynamics at finite volume
- Neutrino interactions with nucleons and nuclei
- Hadron properties in dense matter
- Nuclear matter response
- Nonlinear dynamics and complex systems

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Collaborations: Barcelona, Granada, Madrid, Murcia, Salamanca, 大阪, 北京, 奈良, 兰州市, 郑州市, 广西, 鳥取市, ANL, Aligarh, Bonn, Fermilab, Frankfurt, Geneva, JLab, Jülich, Kokaeli, Lyon, Mainz, Sao Paulo, Wroclaw, York, ...

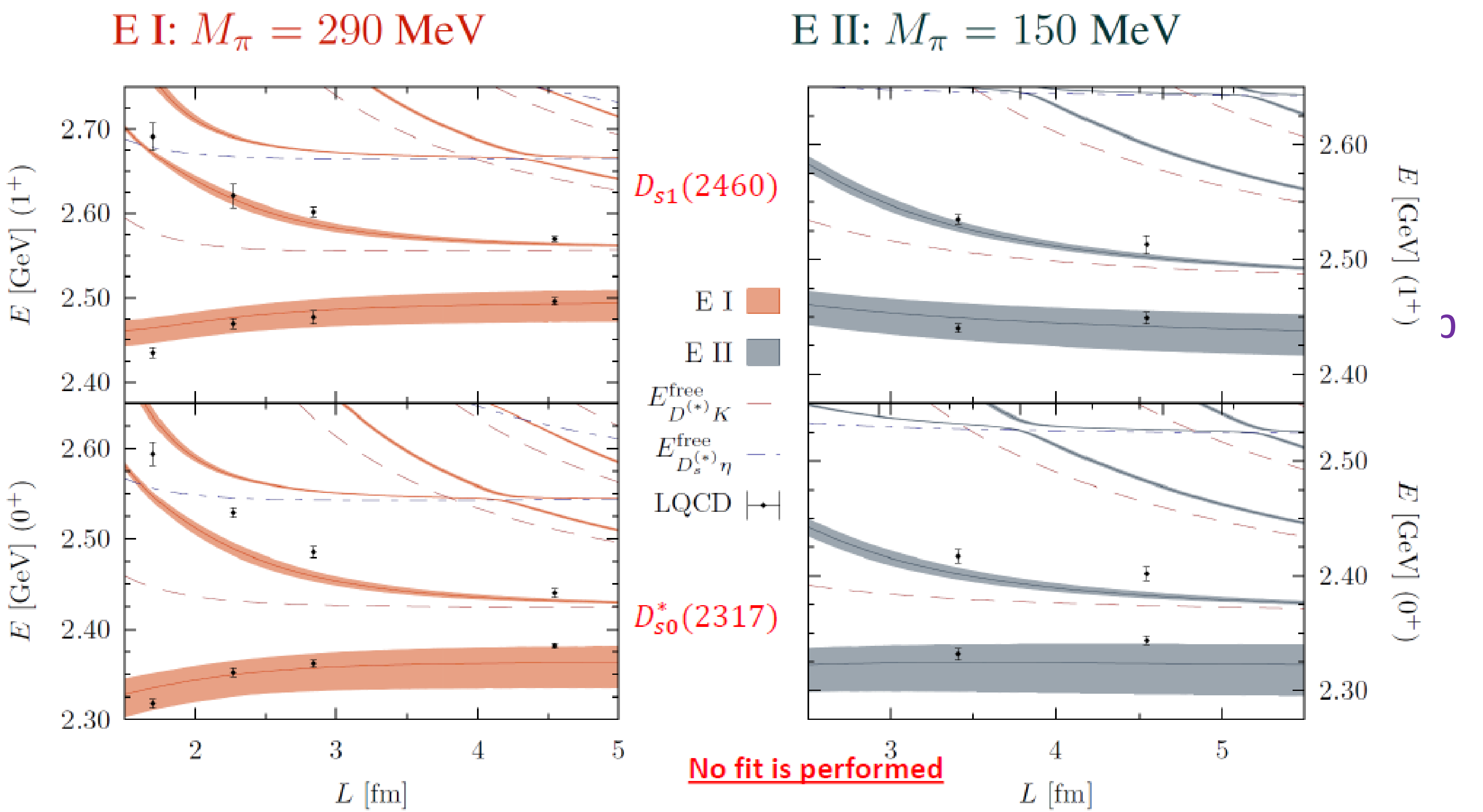
- Members of the EU network "The strong interaction at the frontier of knowledge : Research and Applications" (STRONG-2020)

In 2018: 34 publications; 15 presentations in Conferences and Workshops

Effective Theories in Hadronic and Nuclear Physics

- Hadron dynamics allows to describe several new states with s,c,b
- Meson-baryon:
  - Ξ_c , Ξ_b observed by BaBar, Belle, LHCb
  - Ξ_{cc} (C=2, S=0, I=1/2) predicted with interactions mediated by the exchange of vector mesons
  - Ω_c following the discovery of Ω_c(3000,3050,3066,3090,3119) by LHCb
  - Ω_b predicted
  - Ω(2020) , observed at Belle, generated by $K\Xi$, $K\Xi^*$, $\eta\Omega$ coupled channels

- Meson-meson:
  - $D_{s0}^*(2317)$, $D_{s1}(2460)$ with masses below the DK, D^*K thresholds
    - contradicts quark models
    - points at large effects from DK, D^*K loops



- at finite volume: excellent agreement with LQCD

M. Albaladejo, **P. Fernandez-Soler**, **J. Nieves**, P. G Ortega, EPJC78 (2018)

Effective Theories in Hadronic and Nuclear Physics

- Weak decays of heavy hadrons:

$$\Lambda_c \to \pi\pi\pi\Sigma$$

$$\Lambda_c \to \bar{K}^0 M B\,,\;\; MB = \pi N\,,\; \eta p\,,\; K\Sigma$$ ← N*(1535,1650)

$$\Omega_b^- \to \pi^- K^- \Xi_c^+$$ ← Ω_c(3050,3090)

$$B_c^- \to \bar{\nu}_l l^- X(3930, 3940, 4160)$$

$$B \to \bar{\nu}_l l^- P\,,\; \bar{\nu}_l l^- V$$ ← V polarization

$$D \to \nu_l l^+ \pi\,,\; \nu_l l^+ \bar{K}$$

$$\bar{B} \to \bar{\nu}_l l^- \pi \quad \bar{B} \to \bar{\nu}_l l^- \pi$$

← studied to extract $|V_{cd,cs,ub}|$ from LQCD + exp.

- τ decays:

$$\tau \to M M \nu_\tau\,,\; MM = PP, PV, VV, PA, PS$$

- These decays involve nontrivial dynamics and enhancements due to triangle singularities

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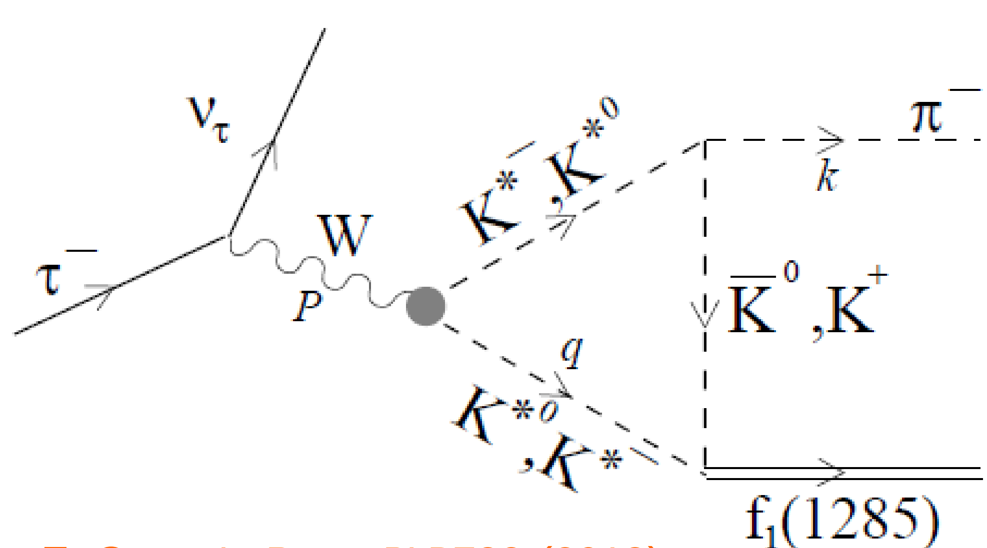
$$B_c^- \to \bar{\nu}_l l^- X(3$$

$$B \to \bar{\nu}_l l^- P \,, \bar{\nu}_l$$

$$D \to \nu_l l^+ \pi \,, \nu_l$$

$$\bar{B} \to \bar{\nu}_l l^- \pi \quad \bar{B}$$



E. Oset, L. Roca, PLB782 (2018)

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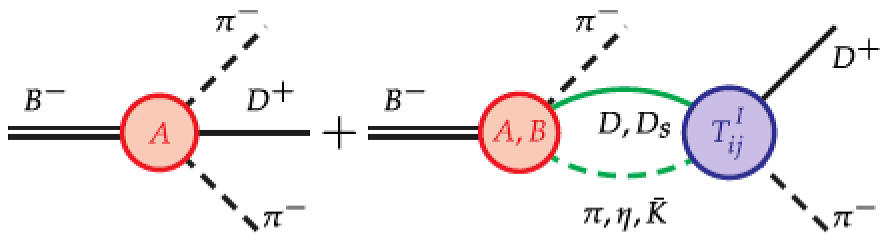
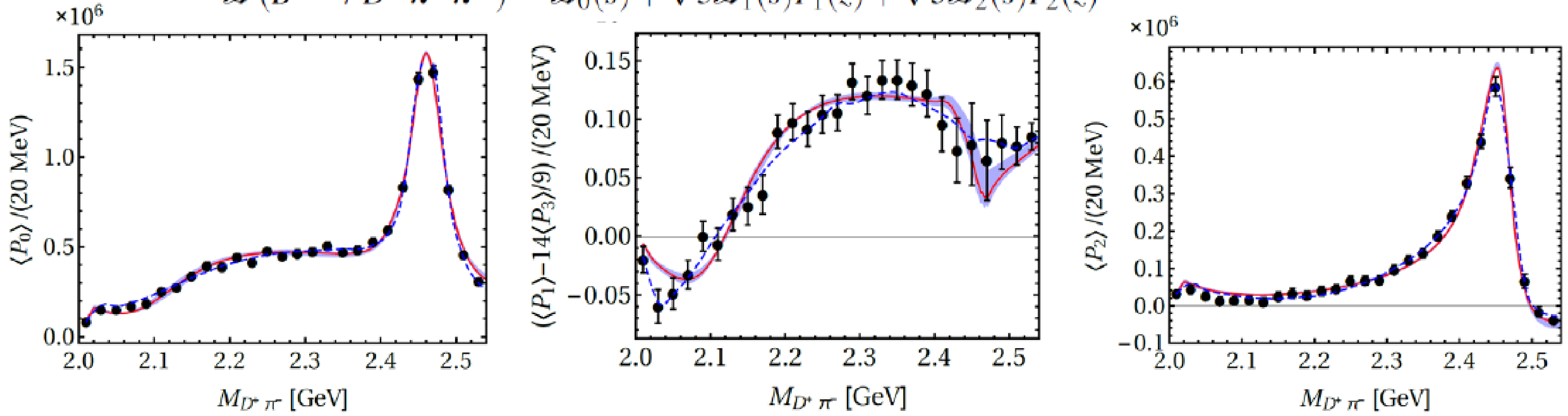
The nature of the $D_0^*(2400)$ unraveled using LHCb data on $B^- \to D^+\pi^-\pi^-$

M.-L. Du, M. Albaladejo, **P. Fernandez-Soler**, F.-K. Guo, C. Hanhart, U.-G. Meissner, **J. Nieves** and **D.-L. Yao**, PRD98 (2018)



$$\mathscr{A}(B^- \to D^+\pi^-\pi^-) = \mathscr{A}_0(s) + \sqrt{3}\mathscr{A}_1(s)P_1(z) + \sqrt{5}\mathscr{A}_2(s)P_2(z)$$



The $D_0^*(2400)$ structure arises from the nontrivial interplay of two states in the presence of interference, coupled-channel and threshold effects.

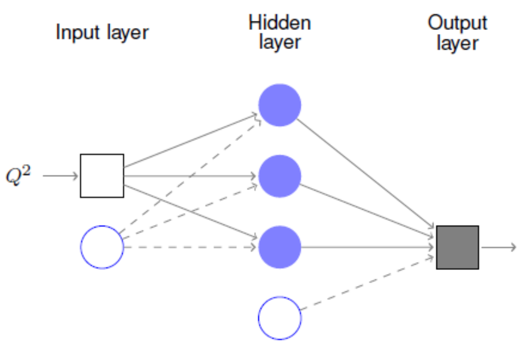
Effective Theories in Hadronic and Nuclear Physics

- Neutrino interactions with nucleons and nuclei
  - crucial for oscillation experiments
- Represented in:
  - International Advisory Committee of the Neutrino Physics Center at Fermilab
  - CERN Neutrino Platform: CENF-ND-Wg2 Cross sections, theory and generators
  - Neutrino Scattering Theory Experiment Collaboration (NuSTEC)
- Collaborate with GENIE, NEUT in the implementation of better cross section models
- Quasielastic scattering on nucleons and the axial form factor
- Weak pion production on nucleons with Baryon Chiral Perturbation Theory and a phenomenological extension
- Scaling properties of nuclear electromagnetic response functions

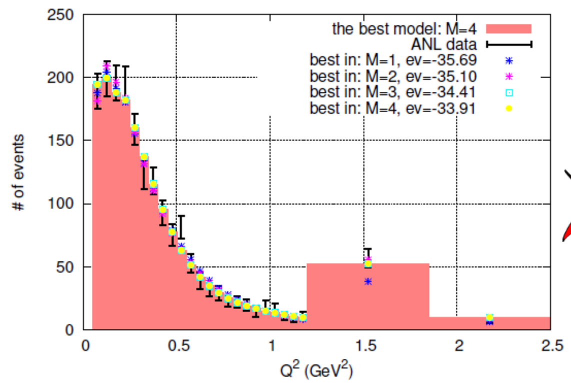
Effective Theories in Hadronic and Nuclear Physics

- The nucleon axial form factor has been extracted from neutrino scattering data using neural networks and Bayesian inference

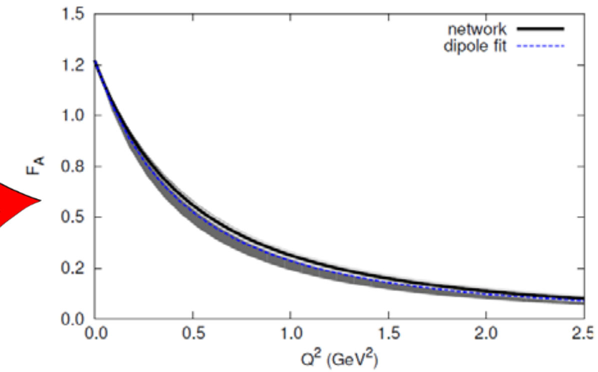
L. Alvarez-Ruso, K. Graczyk, **E. Saúl-Sala**, arXiv:1805.00905



Feed-forward neural network



ANL CCQE data

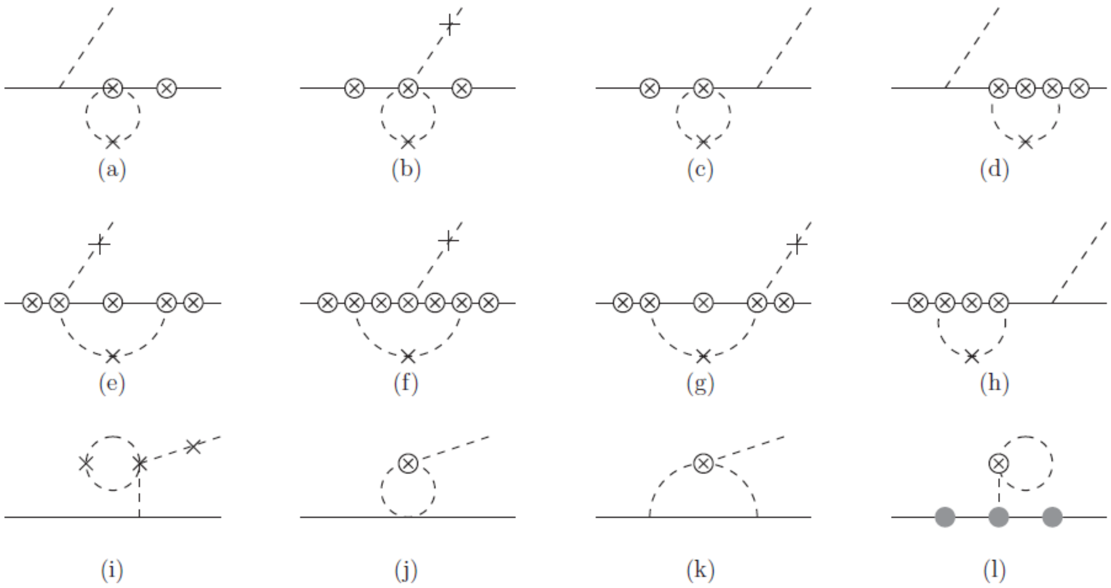


Axial form factor

- Different methods obtain similar $F_A(Q2)$ ... but with different errors
- New input from LQCD and/or experiment is desirable

Effective Theories in Hadronic and Nuclear Physics

- First study in ChPT:
  D. L. Yao, **L. Alvarez-Ruso**, A. N. Hiller Blin, **M. J. Vicente Vacas**, PRD 98 (2018)
- Part of a comprehensive study of
  $\pi N \to N\pi$, $\gamma^* N \to N \pi$, $W^*, Z^* N \to N \pi$, ...
- $O(p^3)$ in EOMS regularization scheme
- Explicit $\Delta(1232)$, in the δ-counting: $\delta = m_\Delta - m_N \sim O(p^{1/2})$



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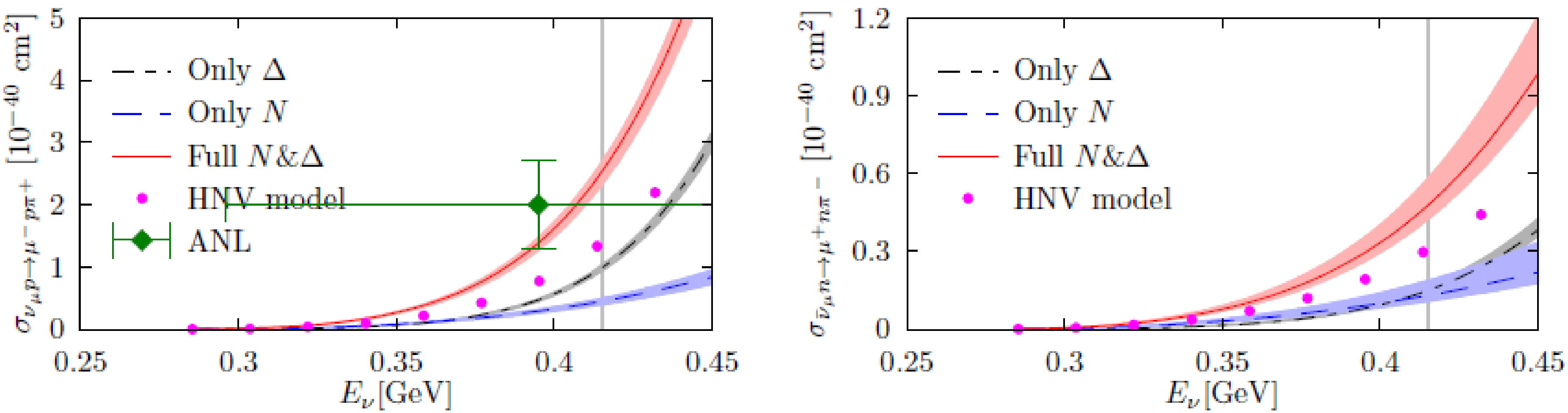


- Valid only close to threshold
- Benchmark for phenomenological models

Effective Theories in Hadronic and Nuclear Physics

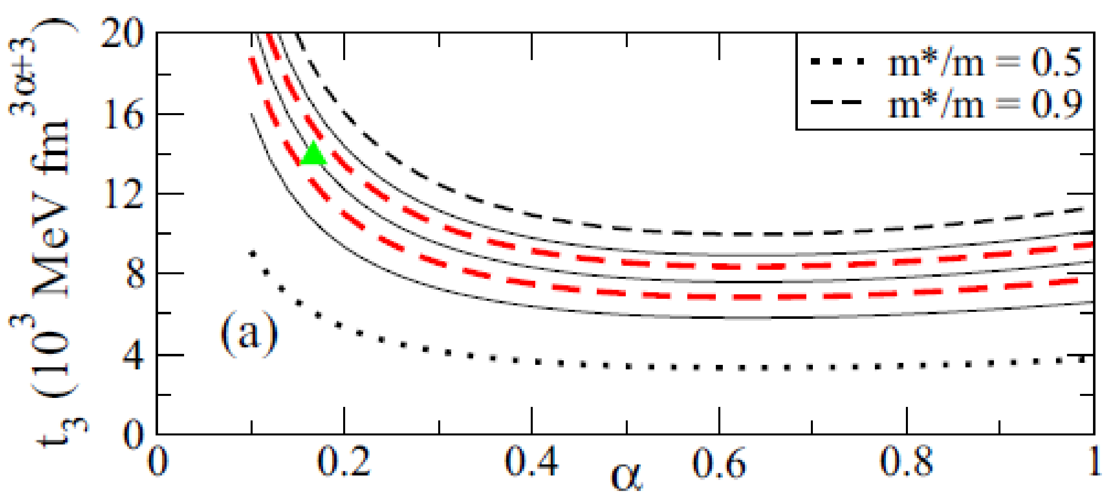
- Two- body contribution to the effective mass in nuclear effective interactions: D. Davesne, **J. Navarro**, J. Meyer, K. Bennaceur, A. Pastore, PRC97 (2018)

$$\frac{m}{m^*} = \frac{11}{8} + \frac{5}{72}\frac{K_\infty - 21\mathcal{E}_0}{\varepsilon_F} + \Delta_{\rm FR}$$

$$-\frac{5}{384}\alpha(10+3\alpha)\frac{t_3\rho_0^{\alpha+1}}{\varepsilon_F}.$$

The two-body contribution is enough to explain nuclear saturation

Density-dependent term required to describe the effective mass



There is a strong correlation between the intensity of the density dependent interaction t_3 and the exponent of the density α