The role of Chiral Effective Field Theory in the precision era

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PROGRAMA
Atracción de Talento

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  - Important to disentangle new physics from theoretical or systematic errors.

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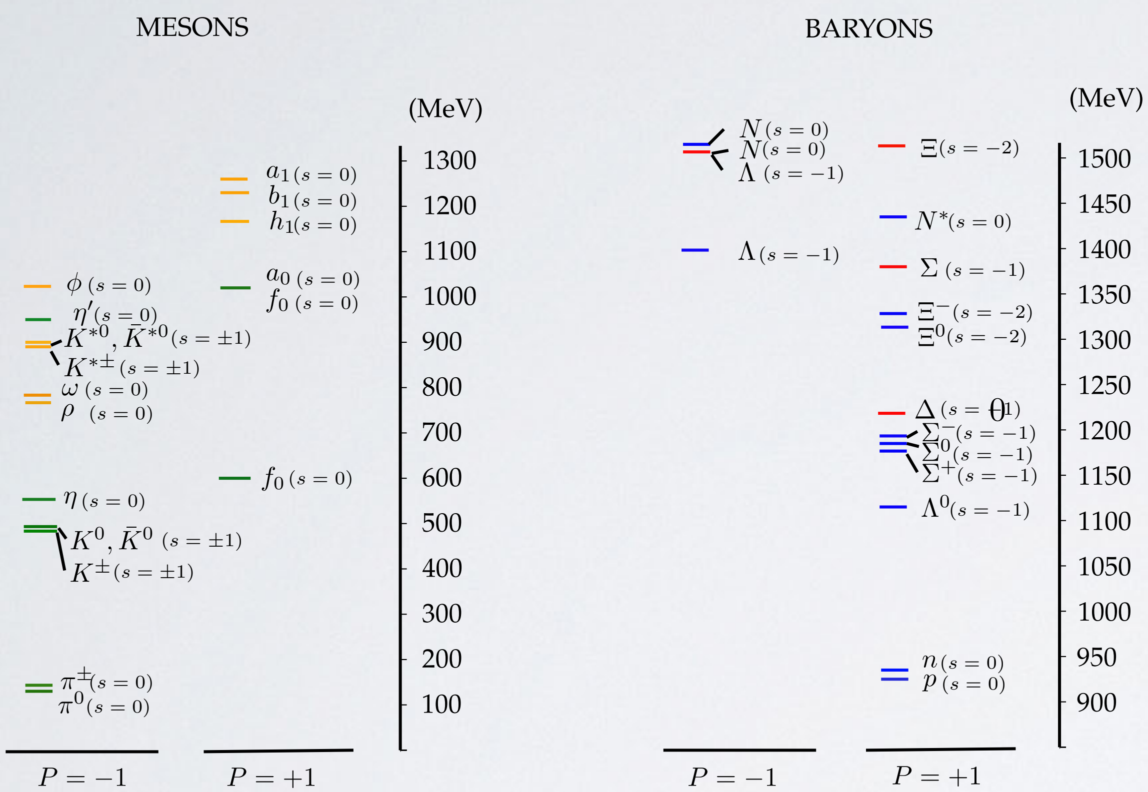

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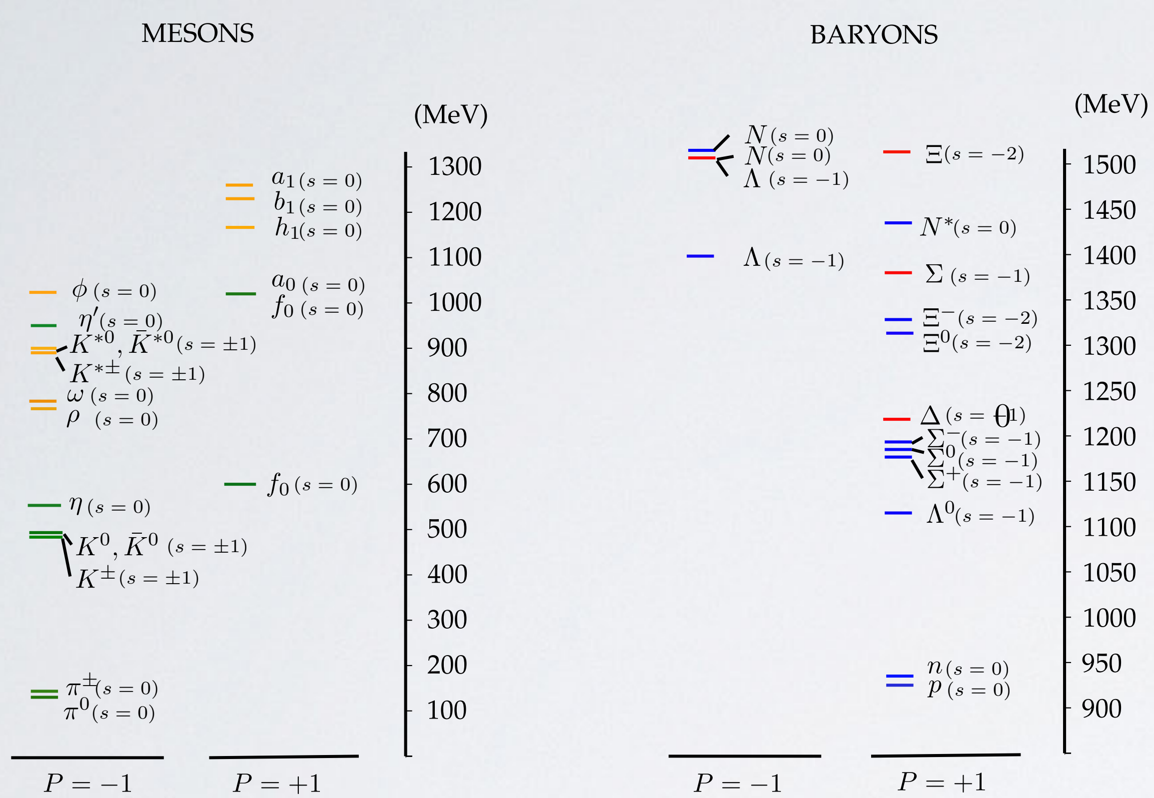

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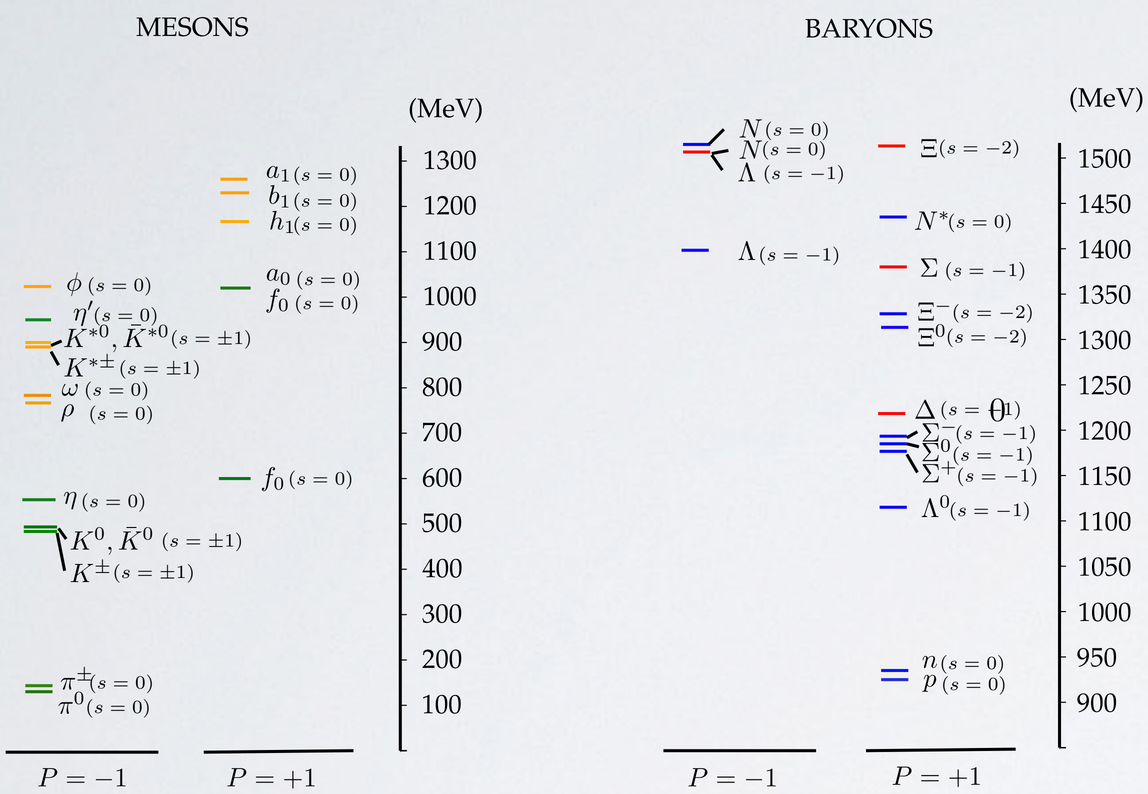

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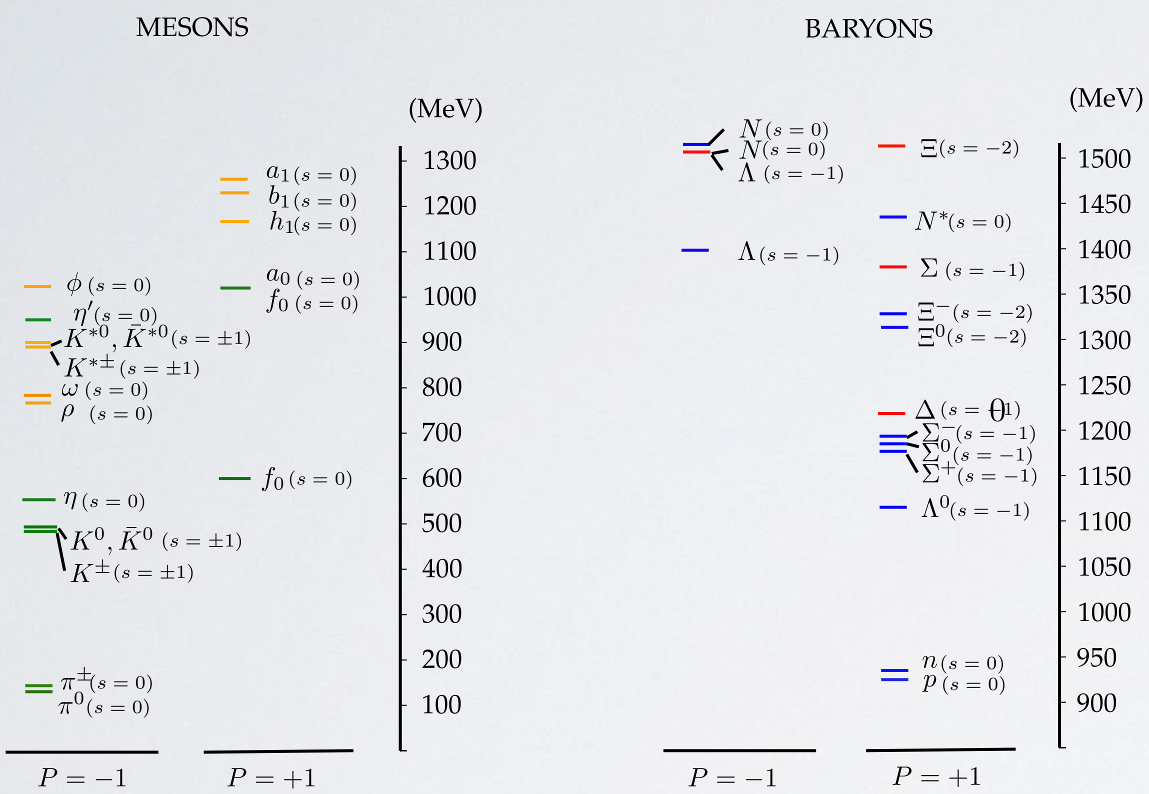

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- Chiral EFT provides a way to incorporate systematically corrections to the low energy theorems.
- Theoretical progress in the recent years opened new possibilities in the field → Provide hadronic ME and nuclear corrections!

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- Heavy Baryon ChPT *[Jenkins and Manohar, PLB 255 (1991)]*
- Infrared Regularization *[Becher and Leutwyler, EPJ C9 (1999)]*
- Extended-On-Mass-Shell *[Fuchs, Gegelia, Japaridze and Scherer, PRD68 (2003)]*

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  ↳ Used to extract valuable phenomenological information

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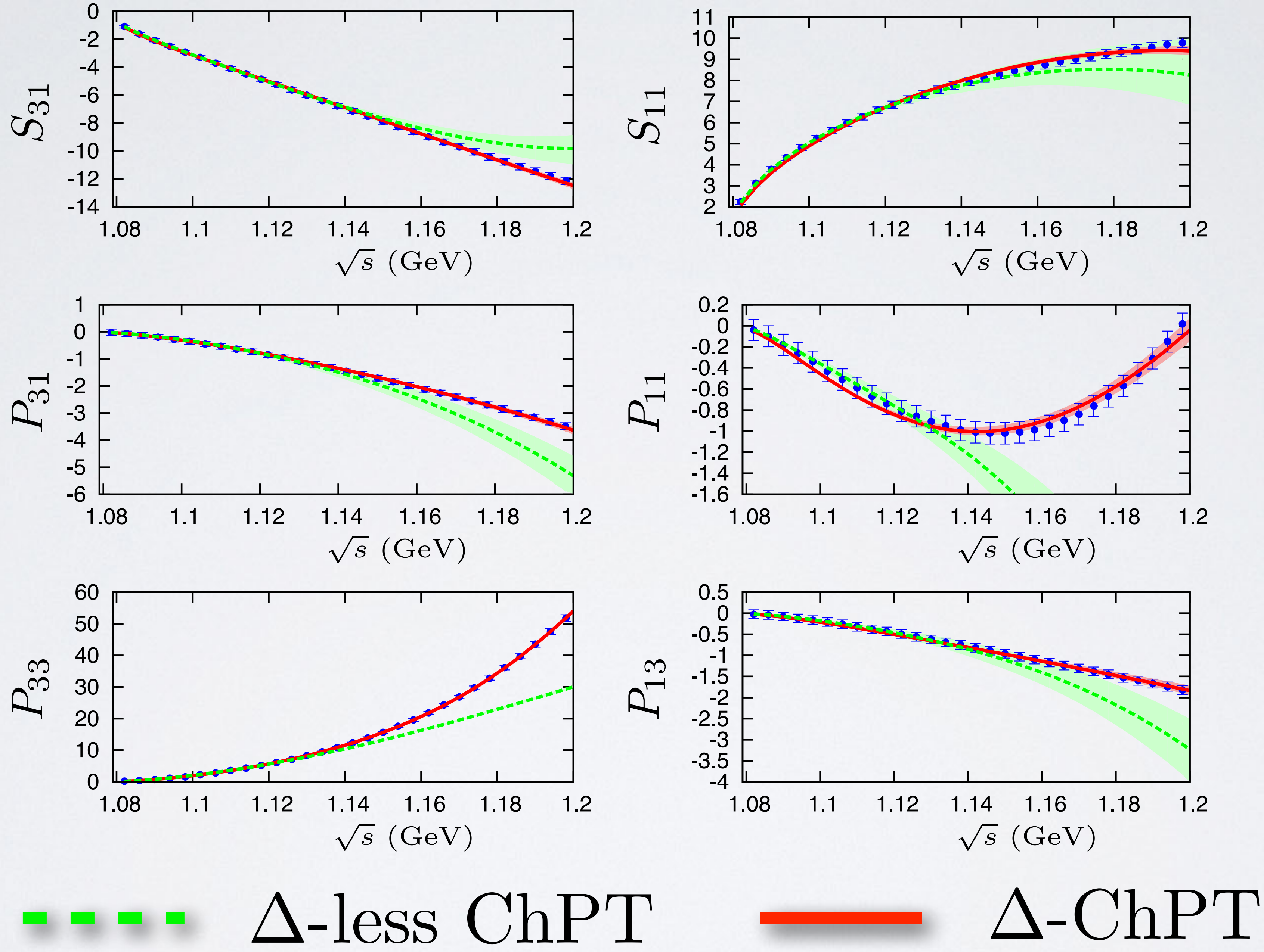
Fits to WI08



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Threshold parameters

Partial Wave	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85	WI08	EM06
a_{0+}^{+}	-1.1(1.0)	-0.12(33)	0.23(20)	-0.8	$-0.10(12)$	0.22(12)
a_{0+}^{-}	8.8(5)	8.33(44)	7.70(8)	9.2	8.83(5)	7.742(61)
$a_{S_{31}}$	-10.0(1.1)	-8.5(6)	-7.47(22)	$-10.0(4)$	-8.4	$-7.52(16)$
$a_{S_{11}}$	16.6(1.5)	16.6(9)	15.63(26)	17.5(3)	17.1	15.71(13)
$a_{P_{31}}$	-4.15(35)	-3.89(35)	-4.10(9)	$-4.4(2)$	-3.8	$-4.176(80)$
$a_{P_{11}}$	-8.4(5)	-7.5(1.0)	-8.43(18)	$-7.8(2)$	-5.8	$-7.99(16)$
$a_{P_{33}}$	22.69(30)	21.4(5)	20.89(9)	21.4(2)	19.4	21.00(20)
$a_{P_{13}}$	-3.00(32)	-2.84(31)	-3.09(8)	$-3.0(2)$	-2.3	$-3.159(67)$

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Pion-nucleon coupling (d_{18})

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Δ_{GT}	5.1(8)%	1.0(2.5)%	2.0(4)%	4.5(7)%	2.1(1)%	0.2(1.0)%
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$\sigma_{\pi N}$ (MeV)	43(5)	59(4)	59(2)	45(8)	64(7)	56(9)

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Agreement with the PWA that provides the input.

Never achieved before in ChEFT !!!

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Subthreshold region

	KA85 $\not\Delta$-ChPT	WI08 $\not\Delta$-ChPT	EM06 $\not\Delta$-ChPT	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85 [50]	WI08 [4]
d^+_{00} (M_π^{-1})	−2.02(41)	−1.65(28)	−1.56(5)	−1.48(15)	−1.20(13)	−0.98(4)	−1.46	−1.30
d^+_{01} (M_π^{-3})	1.73(19)	1.70(18)	1.64(4)	1.21(10)	1.20(9)	1.09(4)	1.14	1.19
d^+_{10} (M_π^{-3})	1.81(16)	1.60(18)	1.532(45)	0.99(14)	0.82(9)	0.631(42)	1.12(2)	–
d^+_{02} (M_π^{-5})	0.021(6)	0.021(6)	0.021(6)	0.004(6)	0.005(6)	0.004(6)	0.036	0.037
b^+_{00} (M_π^{-3})	−6.5(2.4)	−7.4(2.3)	−7.01(1.1)	−5.1(1.7)	−5.1(1.7)	−4.5(9)	−3.54(6)	–
d^-_{00} (M_π^{-2})	1.81(24)	1.68(16)	1.495(28)	1.63(9)	1.53(8)	1.379(8)	1.53(2)	–
d^-_{01} (M_π^{-4})	−0.17(6)	−0.20(5)	−0.199(7)	−0.112(25)	−0.115(24)	−0.0923(11)	−0.134(5)	–
d^-_{10} (M_π^{-4})	−0.35(10)	−0.33(10)	−0.267(14)	−0.18(5)	−0.16(5)	−0.0892(41)	−0.167(5)	–
b^-_{00} (M_π^{-2})	17(7)	17(7)	16.8(7)	9.63(30)	9.755(42)	8.67(8)	10.36(10)	–

[Alarcón, Martin Camalich and Oller, Ann. of Phys. 336 (2013)]

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$a_{S_{11}}$	16.6(1.5)	16.6(9)	15.63(26)	[illegible]	[illegible]	[illegible]
$a_{P_{31}}$	-4.15(35)	-3.89(35)	-4.10(9)	−4.4(2)	−3.8	−4.176(80)
$a_{P_{11}}$	-8.4(5)	-7.5(1.0)	-8.43(18)	−7.8(2)	−5.8	−7.99(16)
$a_{P_{33}}$	22.69(30)	21.4(5)	20.89(9)	21.4(2)	19.4	21.00(20)
$a_{P_{13}}$	-3.00(32)	-2.84(31)	-3.09(8)	−3.0(2)	−2.3	−3.159(67)

Pion-nucleon coupling (d_{18})

	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85	WI08	EM06
Δ_{GT}	[illegible]	[illegible]	[illegible]	[illegible]	2.[illegible](1)%	0.2(1.0)%
$g_{\pi N}$	13.53(10)	13.00(31)	13.13(5)	13.46(9)	13.[illegible]5(1)	12.90(12)

Agreement with the PWA that provides the input.

Never achieved before in ChEFT !!!

Sigma-term (c_1)

	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85	WI08	EM06
$\sigma_{\pi N}$ (MeV)	43(5)	59(4)	59(2)	45(8)	64(7)	56(9)

Subthreshold region

	KA85 $\not\Delta$-ChPT	WI08 $\not\Delta$-ChPT	EM06 $\not\Delta$-ChPT	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85 [50]	WI08 [4]
d^{+}_{00} (M_π^{-1})	−2.02(41)	−1.65(28)	−1.56(5)	−1.48(15)	−1.20(13)	−0.98(4)	−1.46	−1.30
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.532(45)	[illegible]	[illegible]	[illegible]	1.12(2)	–
d^{+}_{02} (M_π^{-5})	0.021(6)	0.021(6)	0.021(6)	0.004(6)	0.005(6)	0.004(6)	0.036	0.037
b^{+}_{00} (M_π^{-3})	−6.5(2.4)	−7.4(2.3)	−7.01(1.1)	−5.1(1.7)	−5.1(1.7)	−4.5(9)	−3.54(6)	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–
d^{-}_{01} (M_π^{-4})	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–
d^{-}_{10} (M_π^{-4})	−0.35(10)	−0.33(10)	−0.267(14)	−0.18(5)	−0.16(5)	−0.0892(41)	−0.167(5)	–
b^{-}_{00} (M_π^{-2})	17(7)	17(7)	16.8(7)	9.63(30)	9.755(42)	8.67(8)	10.36(10)	–

Agreement with the dispersive results for fist time!

Solves the problem found by Becher and Leutwyler!

[Alarcón, Martin Camalich and Oller, Ann. of Phys. 336 (2013)]

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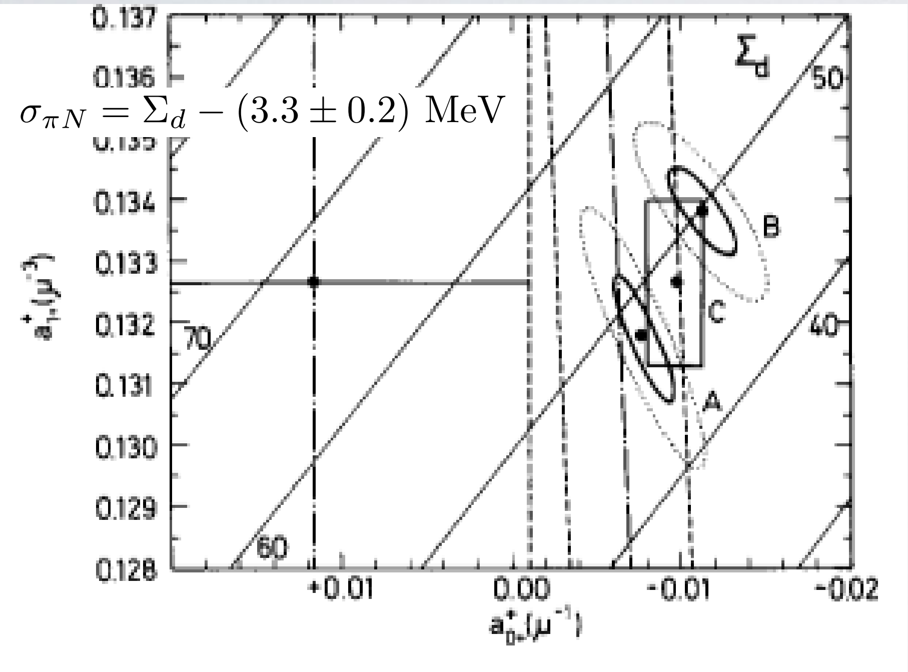

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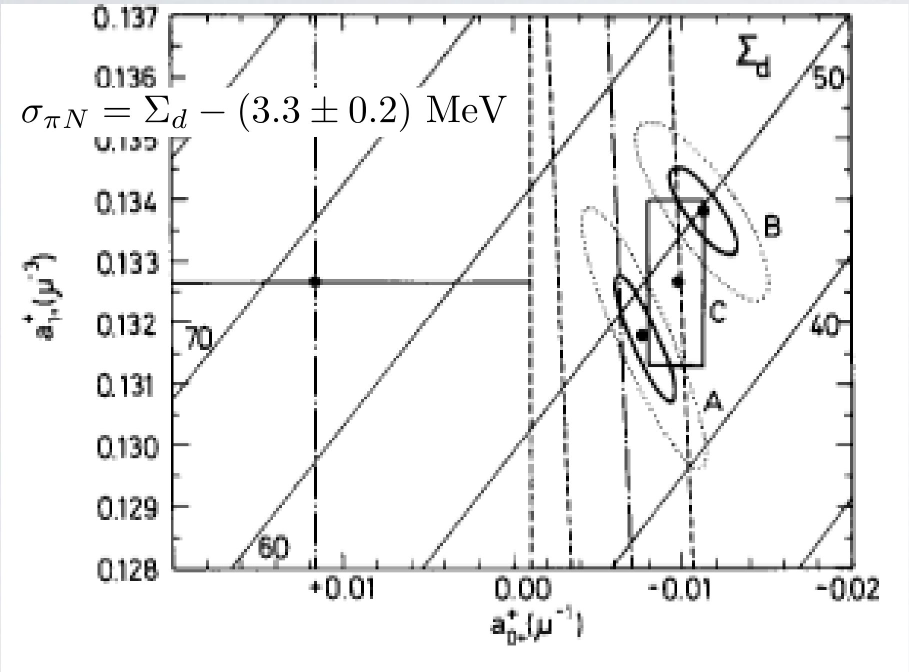

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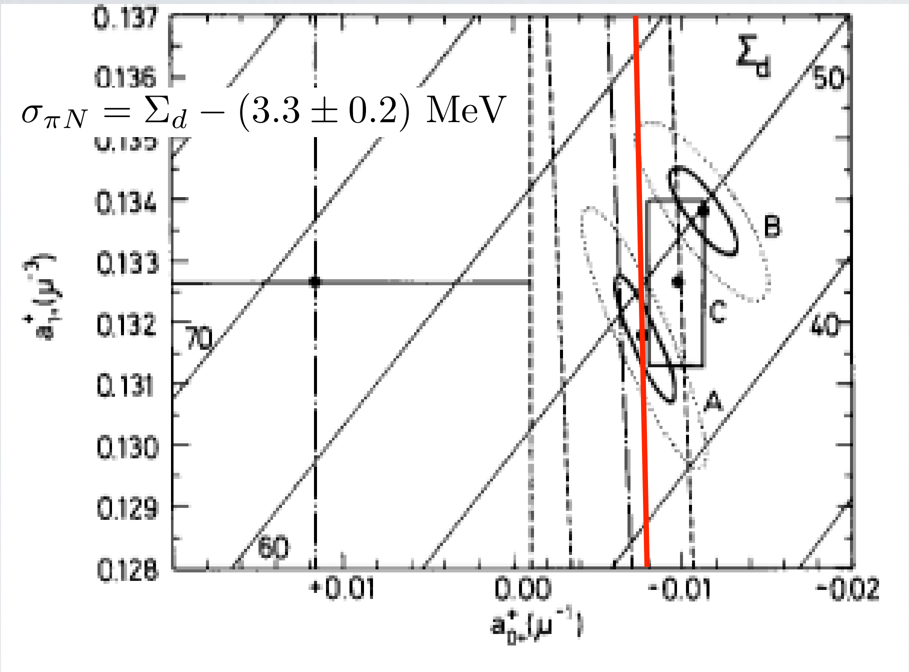

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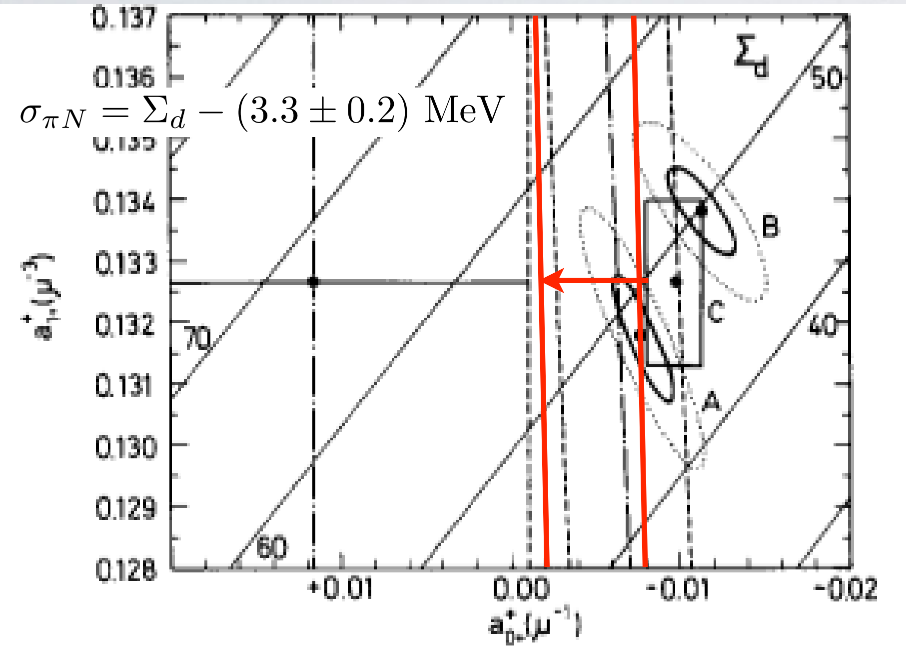

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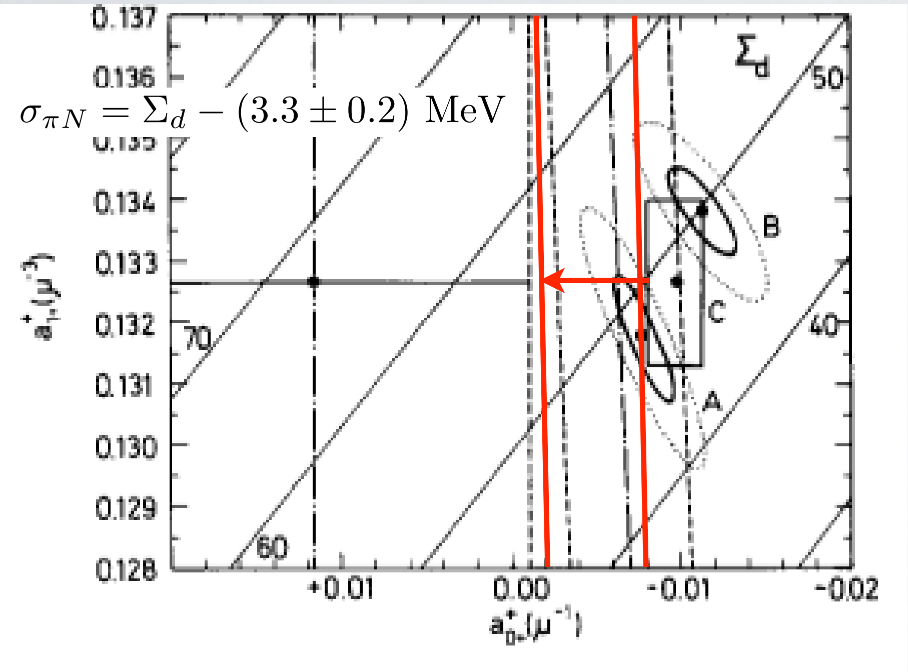

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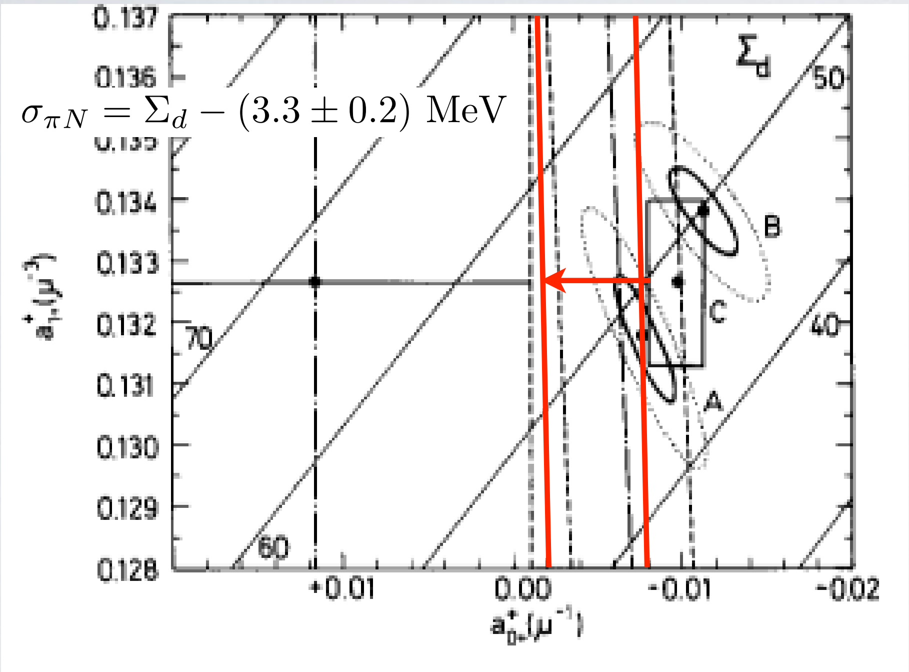

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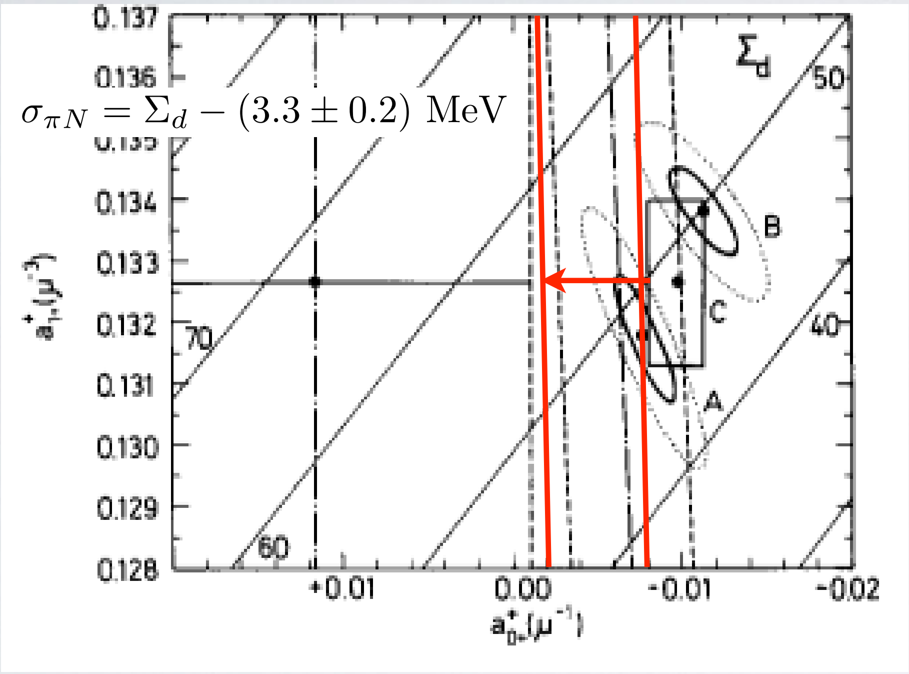

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[Gashi, et al., NPA 778 (2006)]

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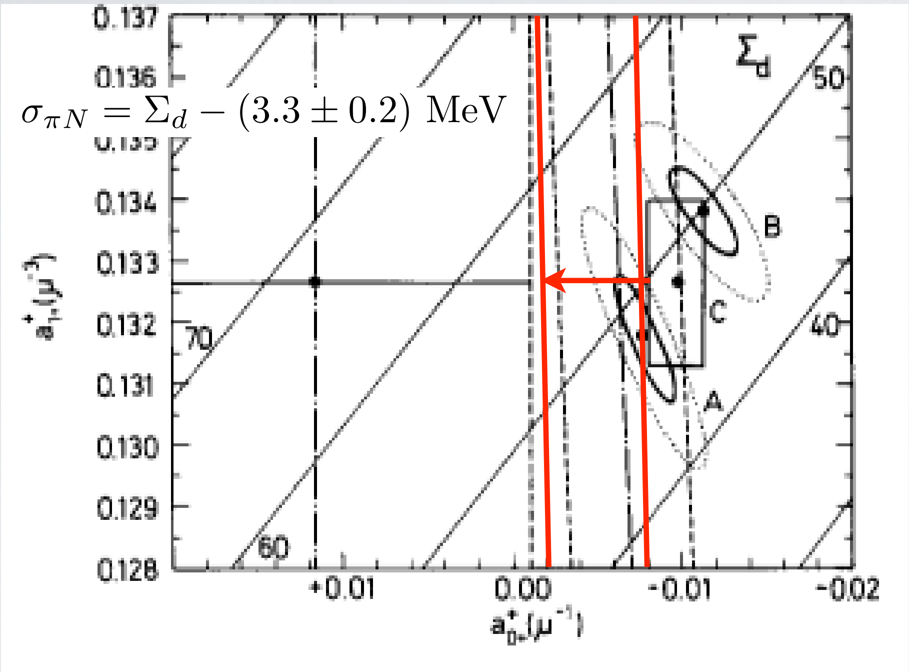

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$$\bar{D}^+(0, 2M_\pi^2) = 14.5 a^+_{0+} - 5.06 (a^{(1/2)}_{0+})^2 - 10.13 (a^{(3/2)}_{0+})^2 - 5.55 C^{(+)} - 0.06 a^+_{1-} + 5.70 a^+_{1+} - (0.08 \pm 0.03)$$

$$a^+_{0+} = 3.5(2.6) \times 10^{-3} M_\pi^{-1}$$

[Gashi, et al., NPA 778 (2006)]

$$\sigma_{\pi N} = 56(9) \text{ MeV}$$

In order to recover $\sigma_{\pi N} = 45$ MeV one needs $a^+_{0+} \sim -9 \times 10^{-3} M_\pi^{-1}$

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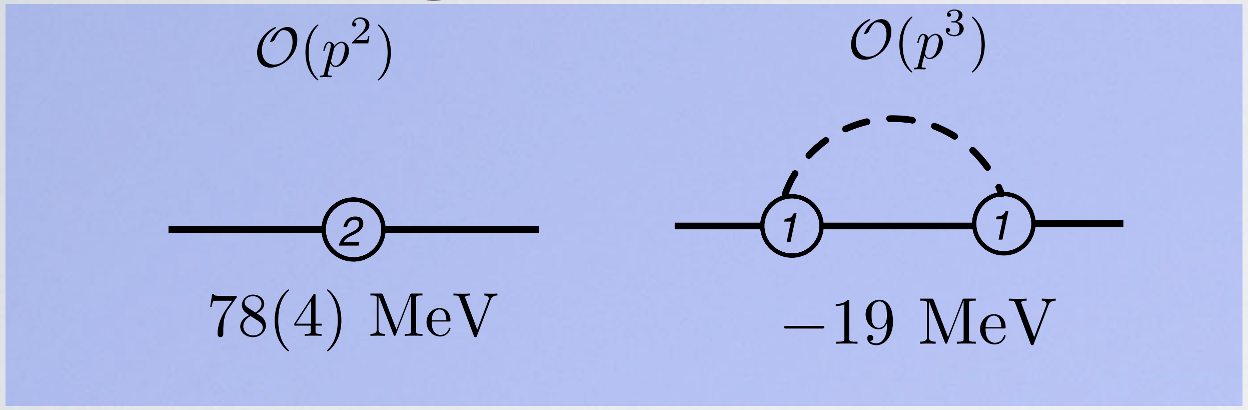

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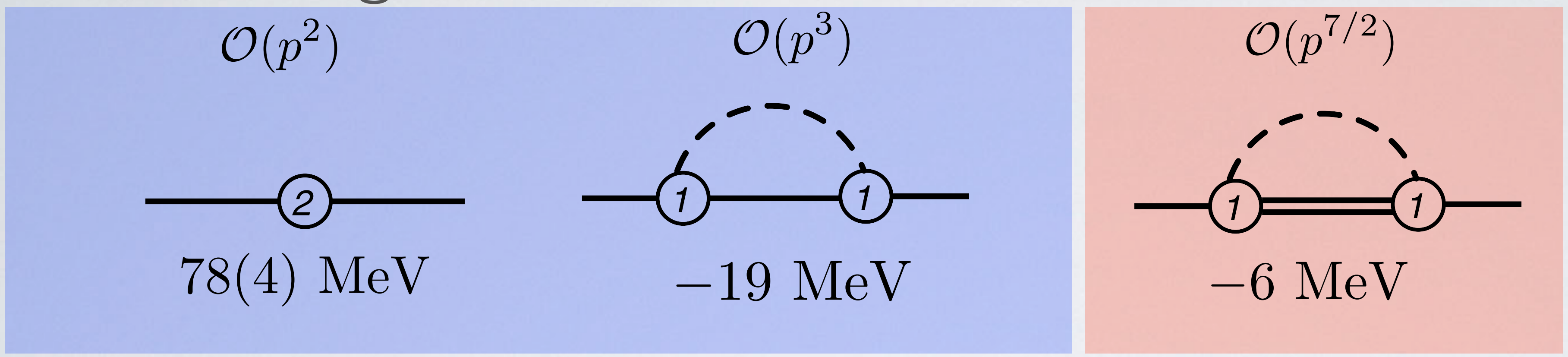

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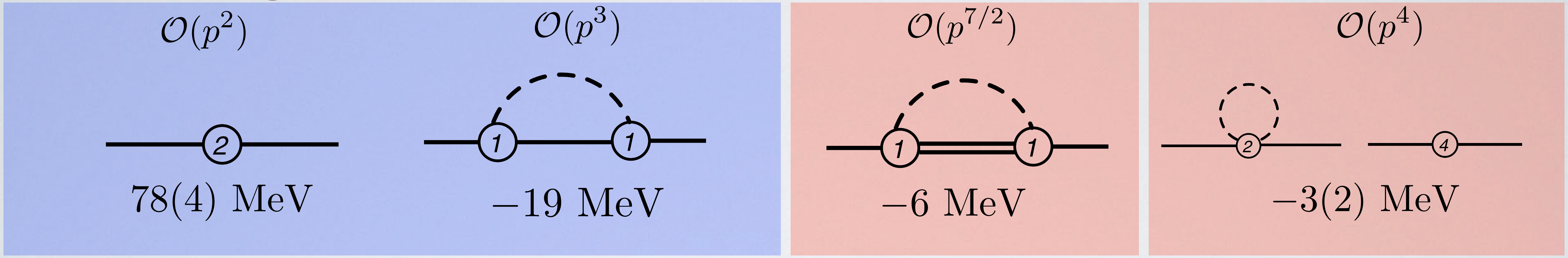

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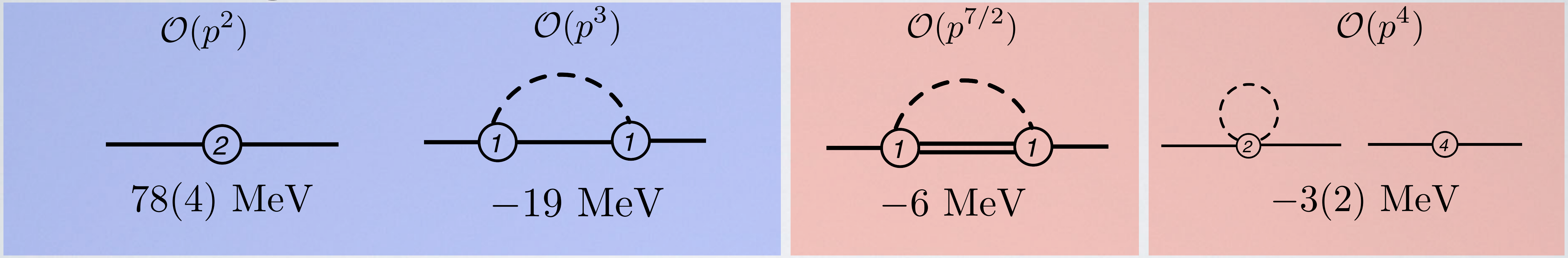

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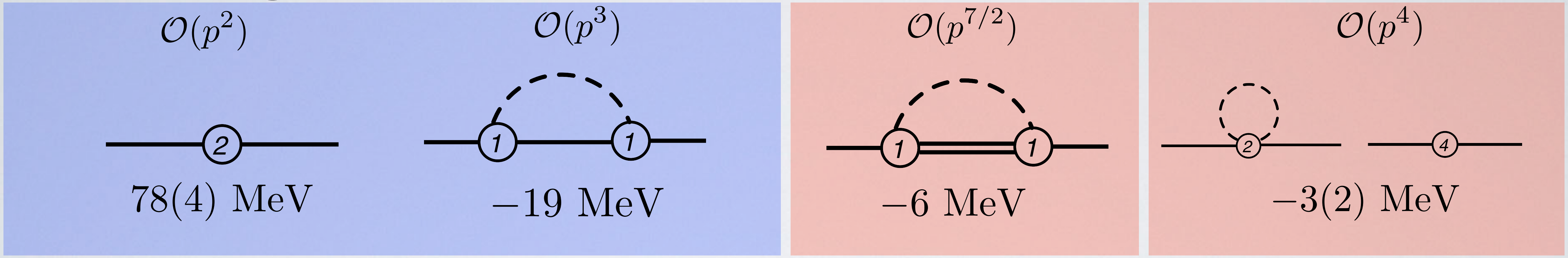

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78(4) MeV	−19 MeV	−6 MeV	−3(2) MeV

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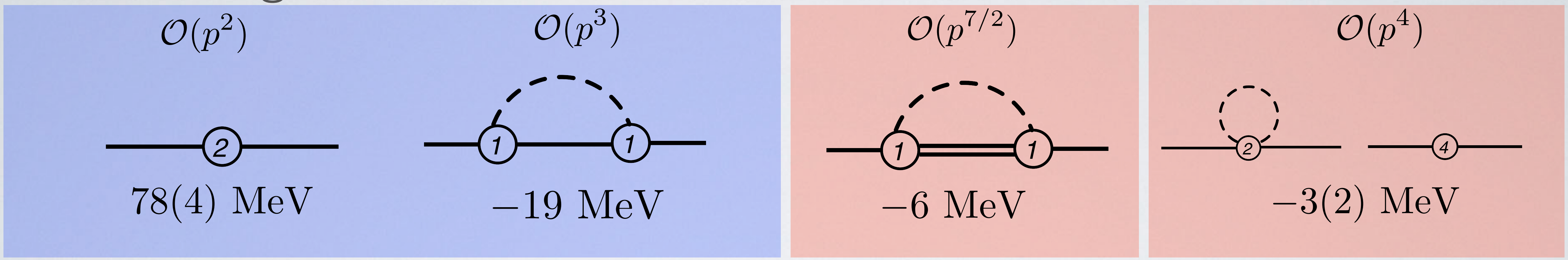

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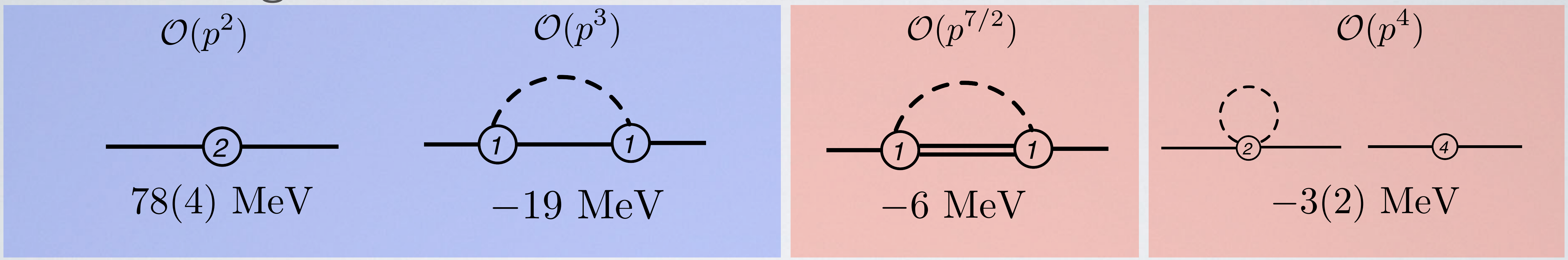

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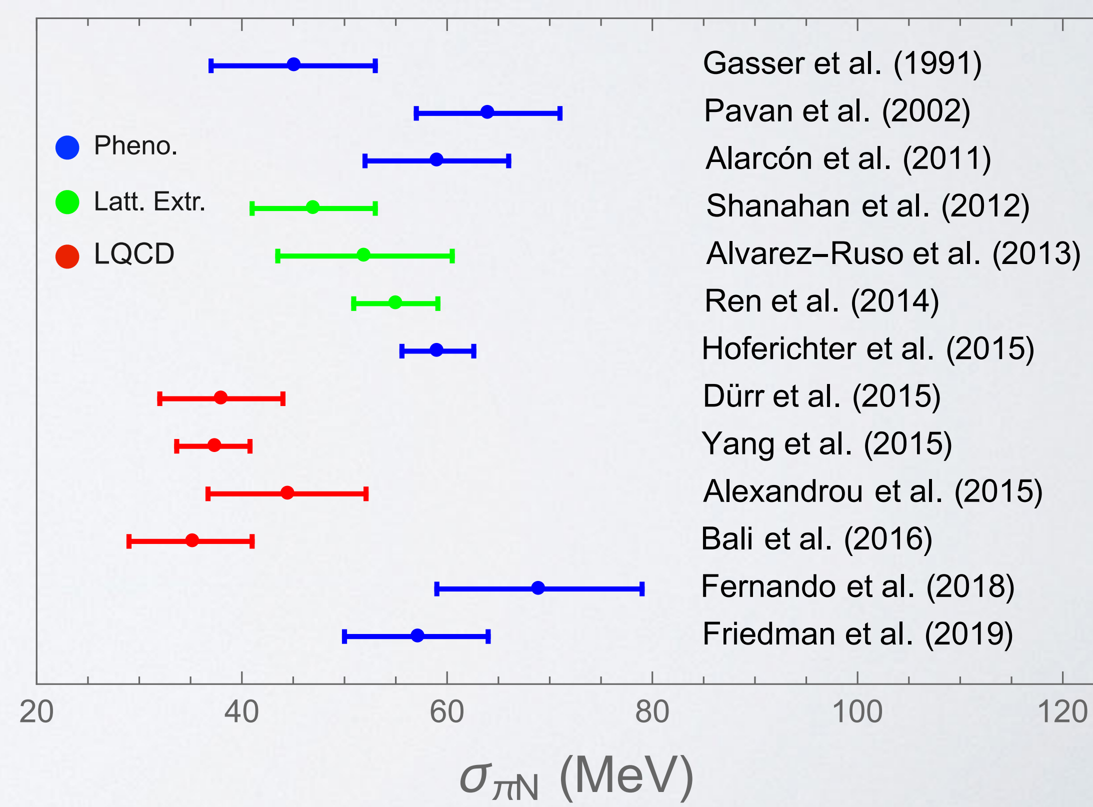

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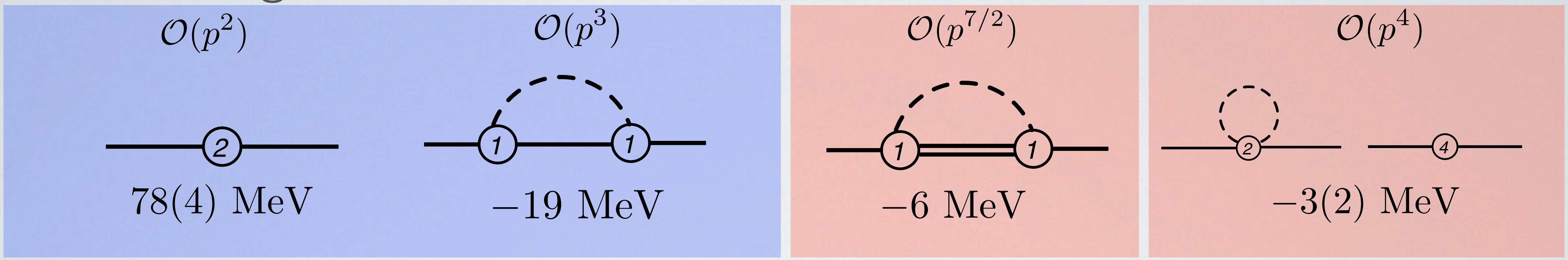

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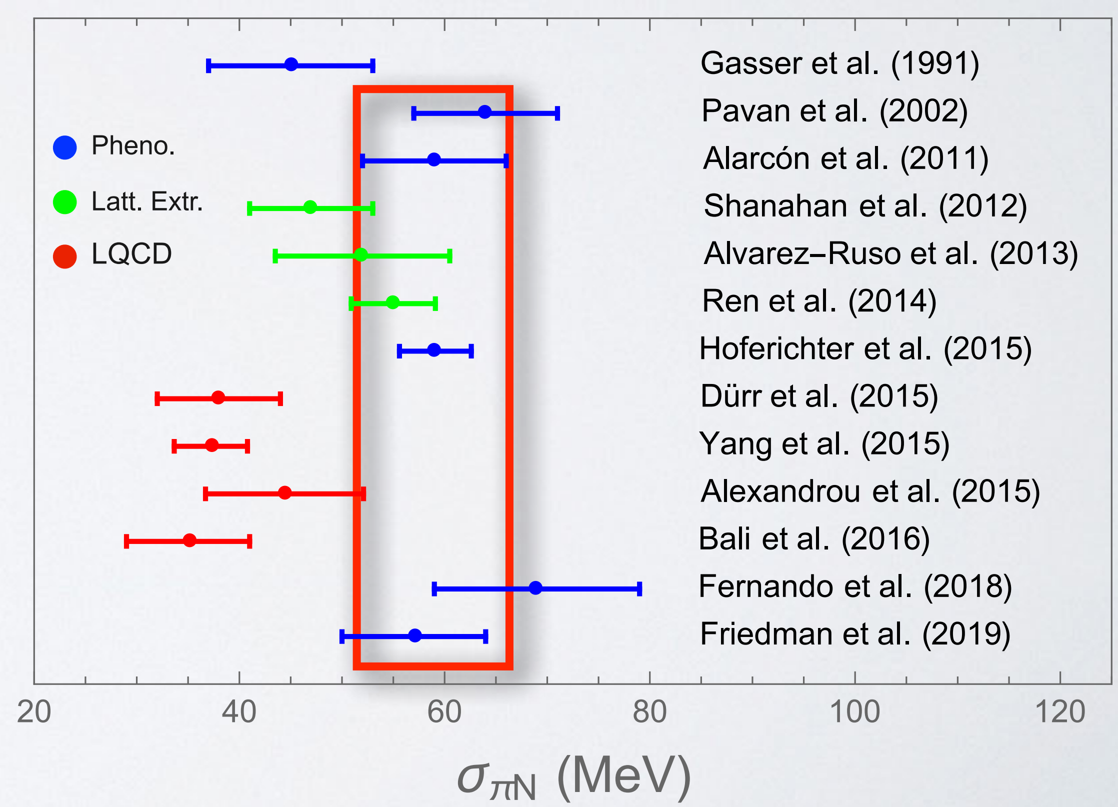

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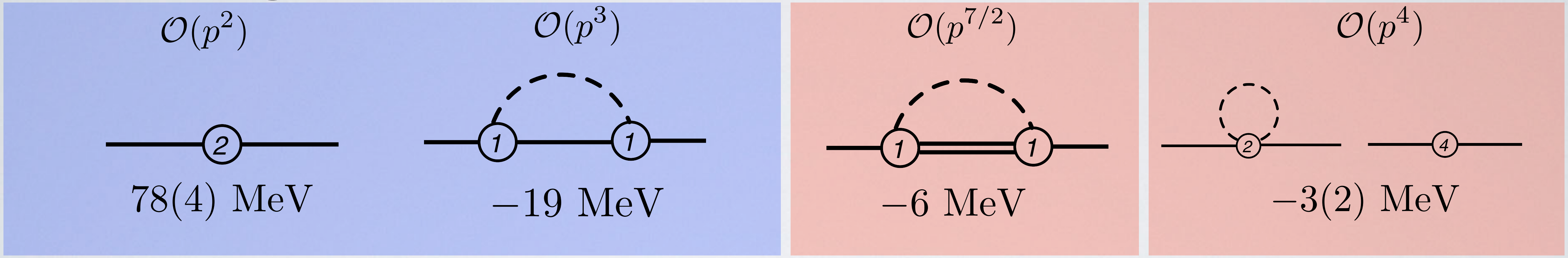

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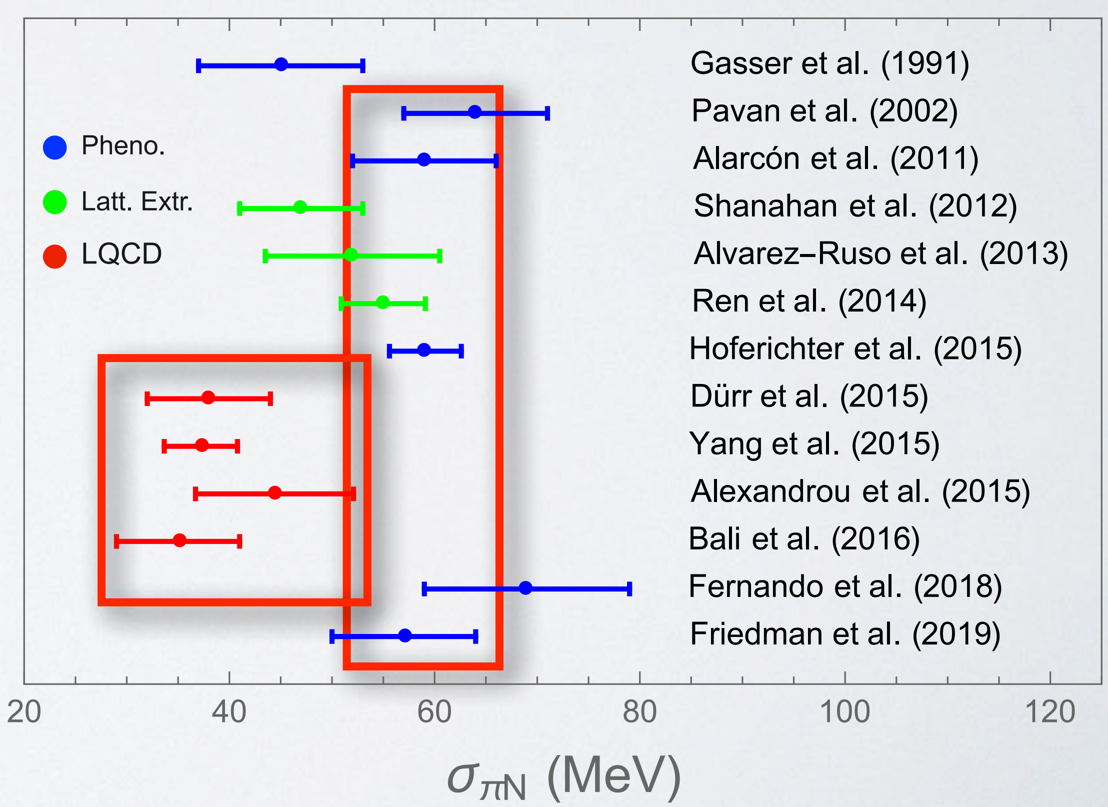

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- Compatible with modern experimental information.
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Nucleon Polarizabilities & Lamb shift

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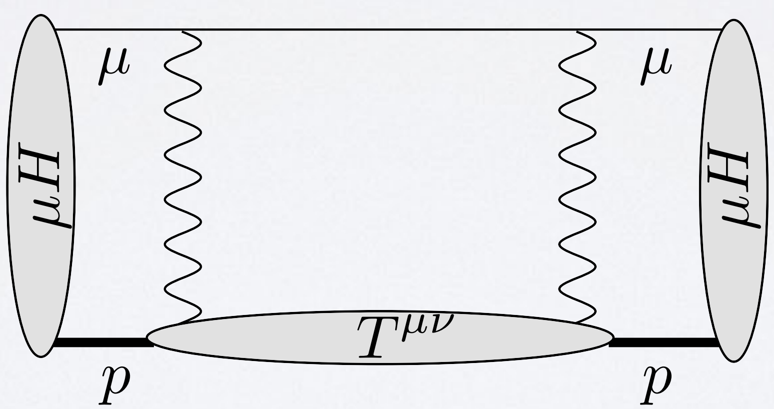

$$T^{\mu\nu}(P,q) = -\left(g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) T_1(\nu^2, Q^2) + \frac{1}{M_p^2}\left(P^\mu - \frac{P\cdot q}{q^2}q^\mu\right)\left(P^\nu - \frac{P\cdot q}{q^2}q^\nu\right) T_2(\nu^2, Q^2)$$

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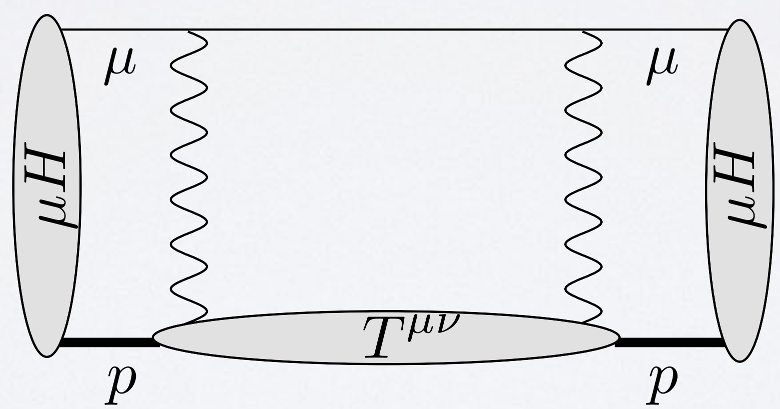
$$\Delta E^{exp}_{2P-2S} - \Delta E^{th}_{2P-2S}(r_E^{\mathrm{CODATA}}) = 0.31 \text{ meV} = 310\ \mu\text{eV}$$

- The polarizability contributions starts with the 2γ exchange.



$$T^{\mu\nu}(P,q) = -\left(g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) T_1(\nu^2,Q^2) + \frac{1}{M_p^2}\left(P^\mu - \frac{P\cdot q}{q^2}q^\mu\right)\left(P^\nu - \frac{P\cdot q}{q^2}q^\nu\right) T_2(\nu^2,Q^2)$$

$$\Delta E_{2S}^{(pol)} \approx \frac{\alpha_{em}}{\pi}\phi^2_{n=2}\int_0^\infty \frac{dQ}{Q^2} w(\tau_\ell)\left[T_1^{(NB)}(0,Q^2) - T_2^{(NB)}(0,Q^2)\right]$$

$$T_1^{(NB)} = 4\pi Q^2 \beta_{M1}(Q^2) + \ldots$$
$$T_2^{(NB)} = 4\pi Q^2 [\alpha_{E1}(Q^2) + \beta_{M1}(Q^2)] + \ldots$$

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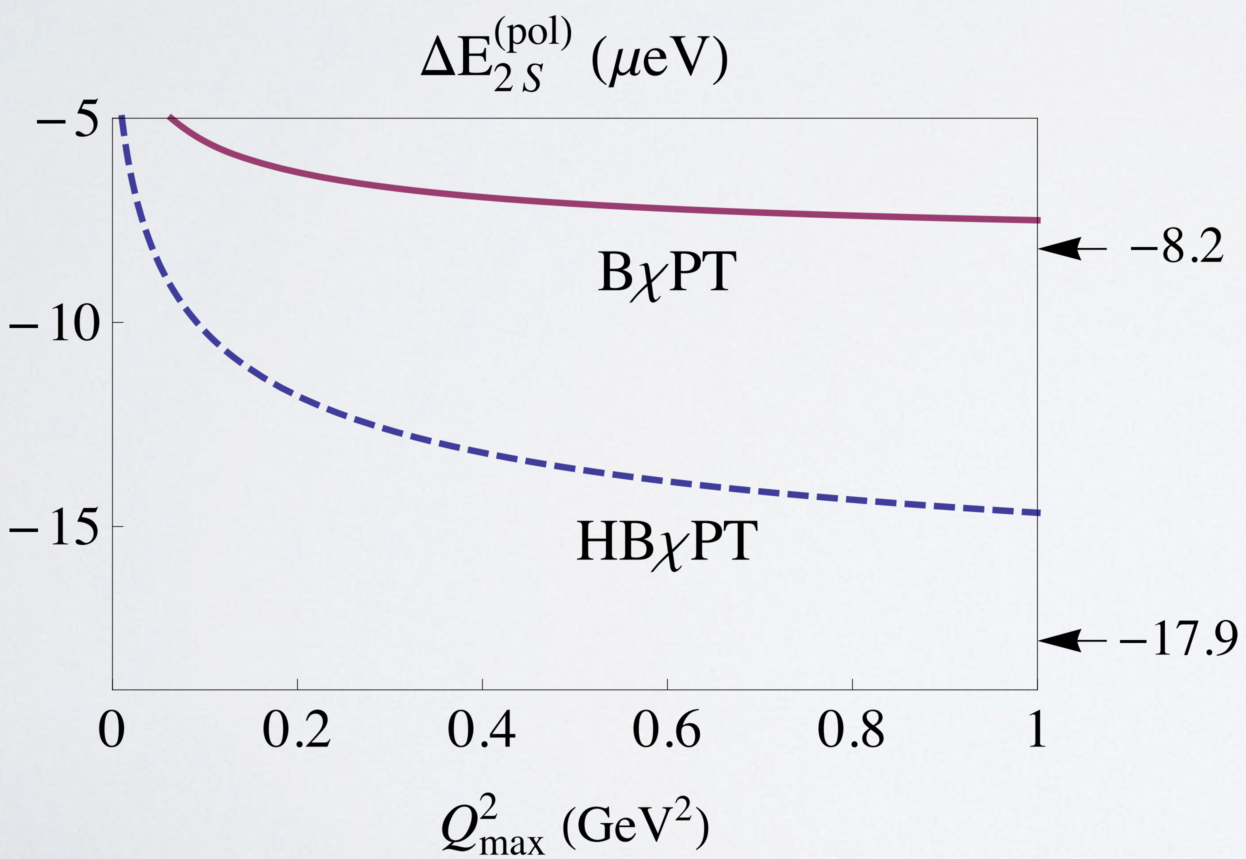
$$\Delta E_{2S}^{(pol)} \approx \frac{\alpha_{em}}{\pi}\phi^2_{n=2}\int_0^{Q_{max}} \frac{dQ}{Q^2} w(\tau_\ell)\left[T_1^{(NB)}(0,Q^2) - T_2^{(NB)}(0,Q^2)\right]$$

$$w(\tau_\ell) = \sqrt{1+\tau_\ell} - \sqrt{\tau_\ell}$$

$$\tau_\ell = \frac{Q^2}{4m_\ell^2}$$



} ~10% → Within the uncertainty of the calculation

} >20% → Too large contribution from $Q^2 > \Lambda^2_{\chi SB}$

[Alarcón, Lensky, Pascalutsa, EPJ C 74 (2014).]

Lamb shift

- The relativistic structure is important to agree with phenomenological determinations of $\Delta E_{2S}^{(\mathrm{pol})}$.

(μeV)	Pachucki [1]	Martynenko [2]	Nevado & Pineda [3]	Carlson & Vanderhaeghen [4]	Birse & McGovern [5]	Gorchtein Llanes-Estrada & Szczepaniak [6]	Alarcón, Lensky & Pascalutsa [7]	Peset & Pineda [8]
$\Delta E_{2S}^{(\mathrm{pol})}$	-12(2)	-11.5	-18.5	-7.4(2.4)	-8.5(1.1)	-15.3(5.6)	$-8.2^{+2.0}_{-2.5}$	-26.5

Chiral EFT calculations (blue: Nevado & Pineda, Alarcón, Lensky & Pascalutsa, Peset & Pineda)

Phenomenological determinations (dispersion relations+data) (green: Pachucki, Martynenko, Carlson & Vanderhaeghen, Birse & McGovern, Gorchtein Llanes-Estrada & Szczepaniak)

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- Electromagetic FF:
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  - Important to understand and solve the "Proton Radius Puzzle".

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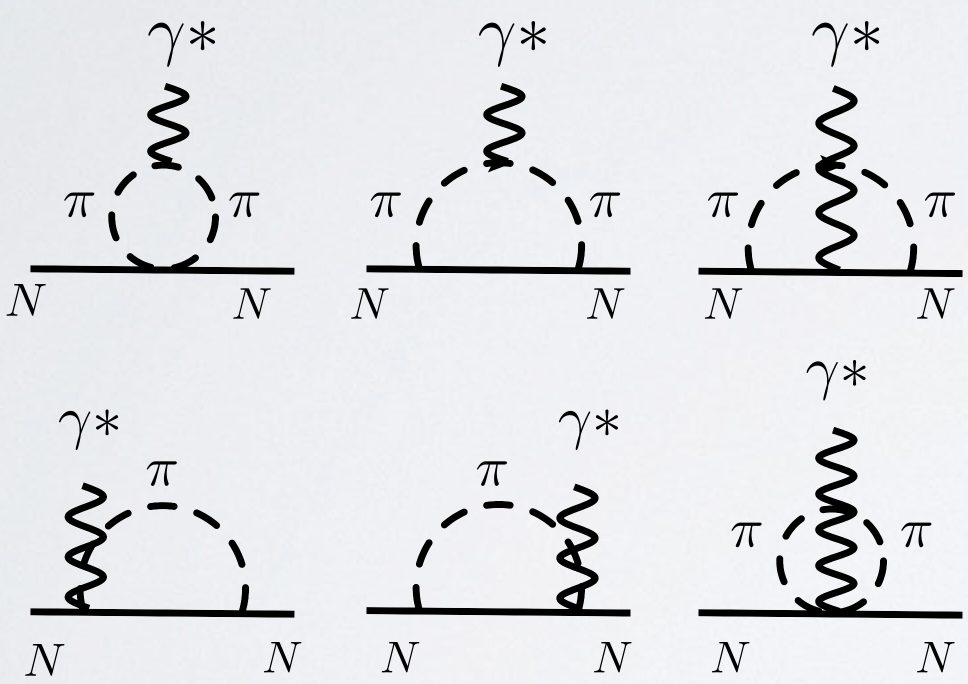

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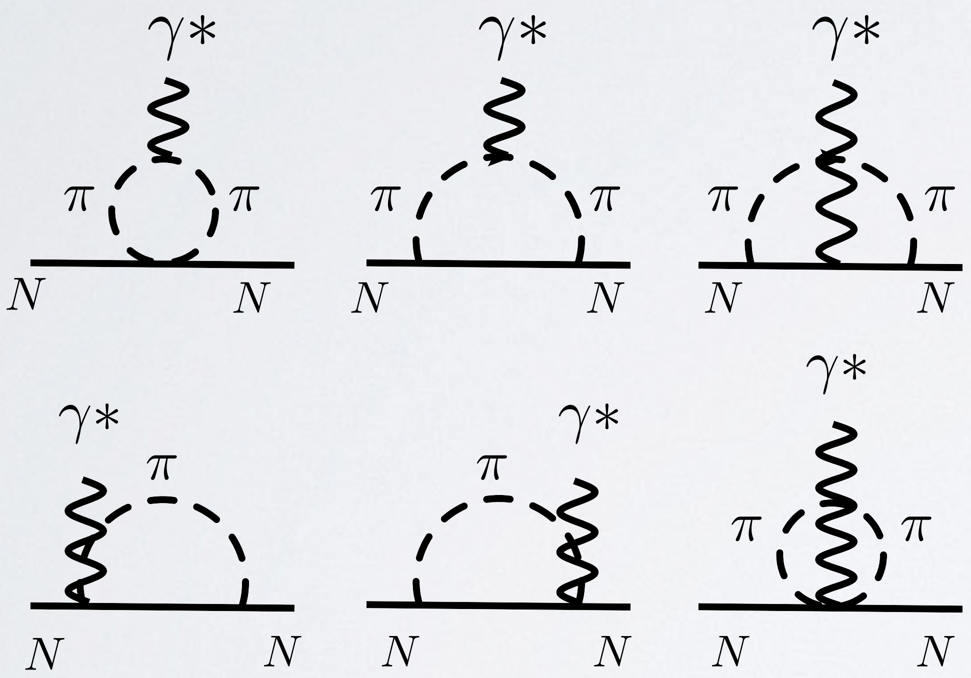

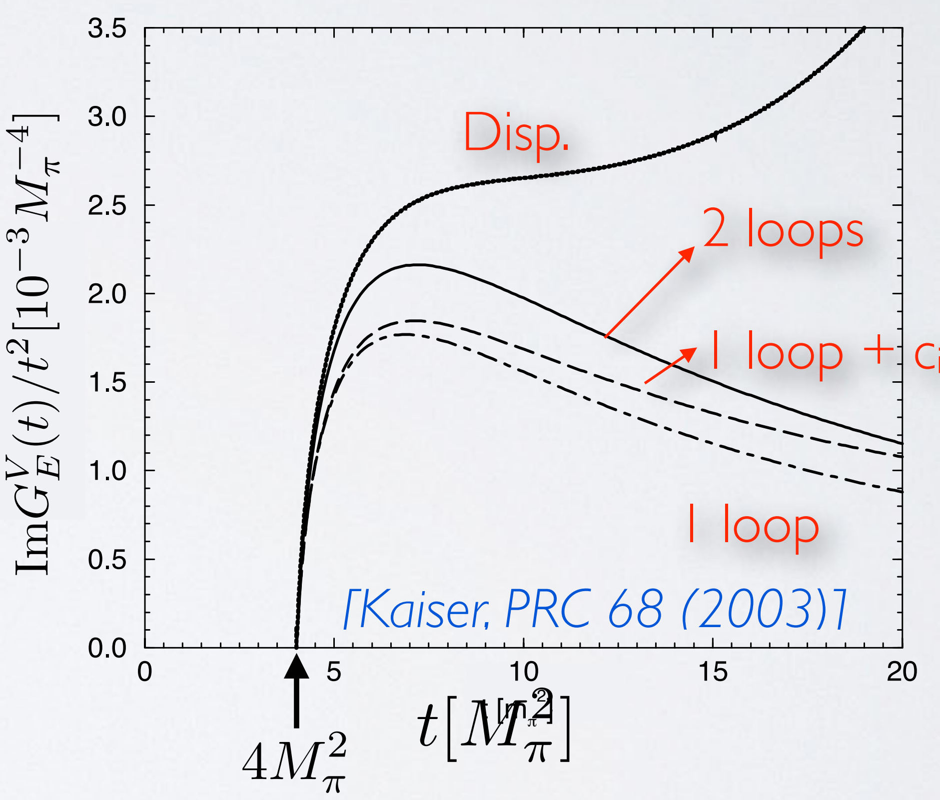

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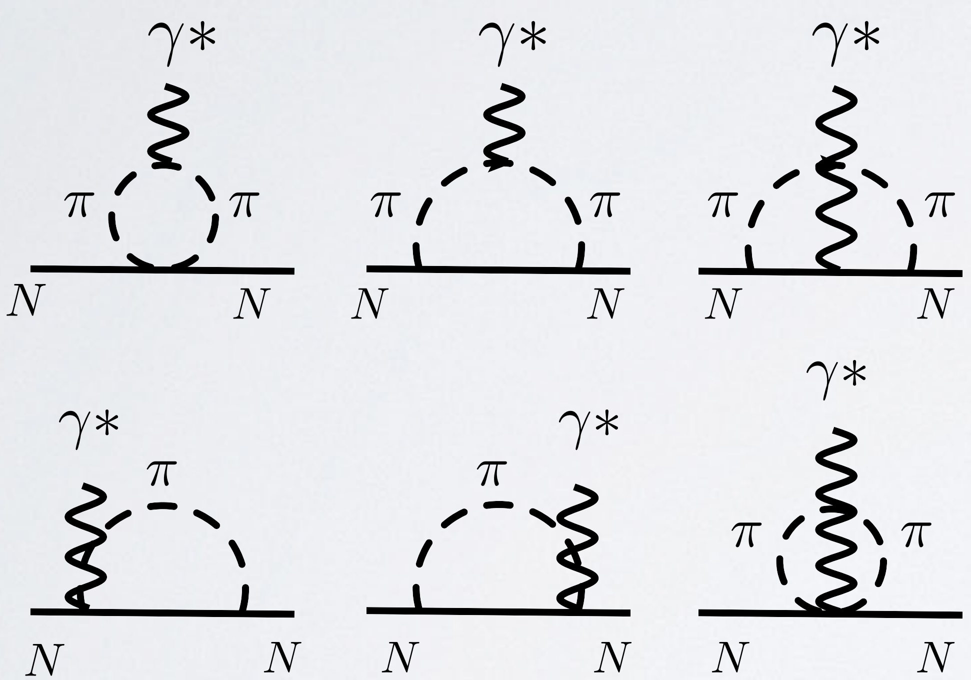

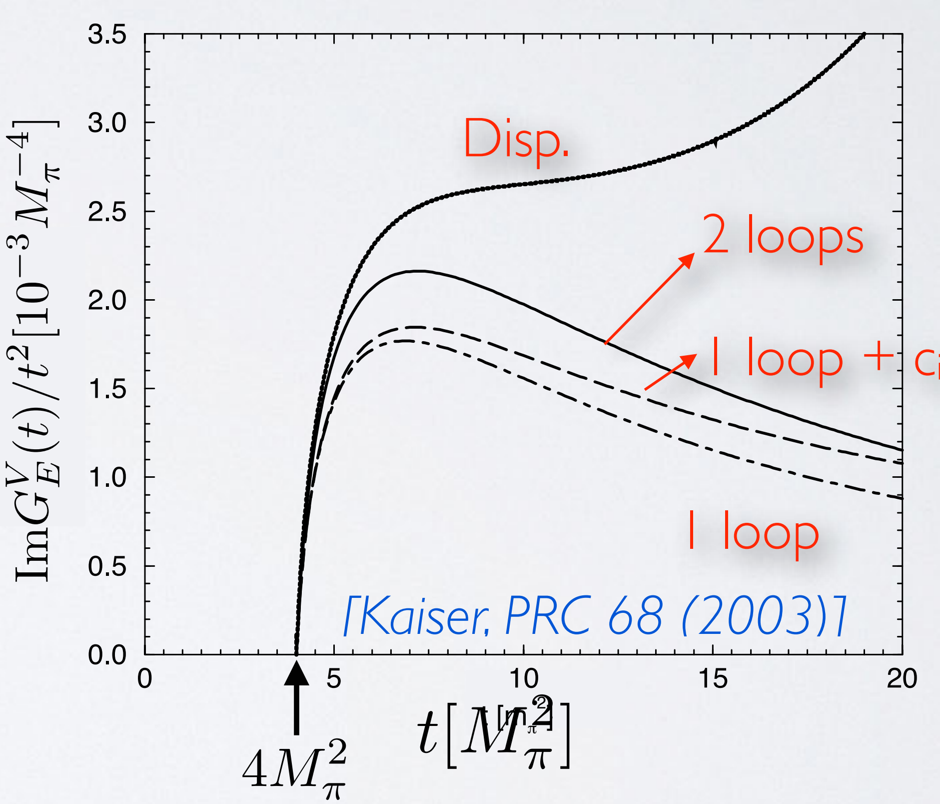

- Higher order calculations become necessary → Unpractical

Form factors and their analytic structure

$$\langle N(p',s')|J_\mu(0)|N(p,s)\rangle = \bar{u}(p',s')\Big[\gamma_\mu F_1(t) + \frac{i\sigma_{\mu\nu}q^\nu}{2m_N}F_2(t)\Big]u(p,s) \qquad J_\mu(x) \equiv \sum_{q=u,d,\ldots} e_q \bar{q}(x)\gamma_\mu q(x)$$

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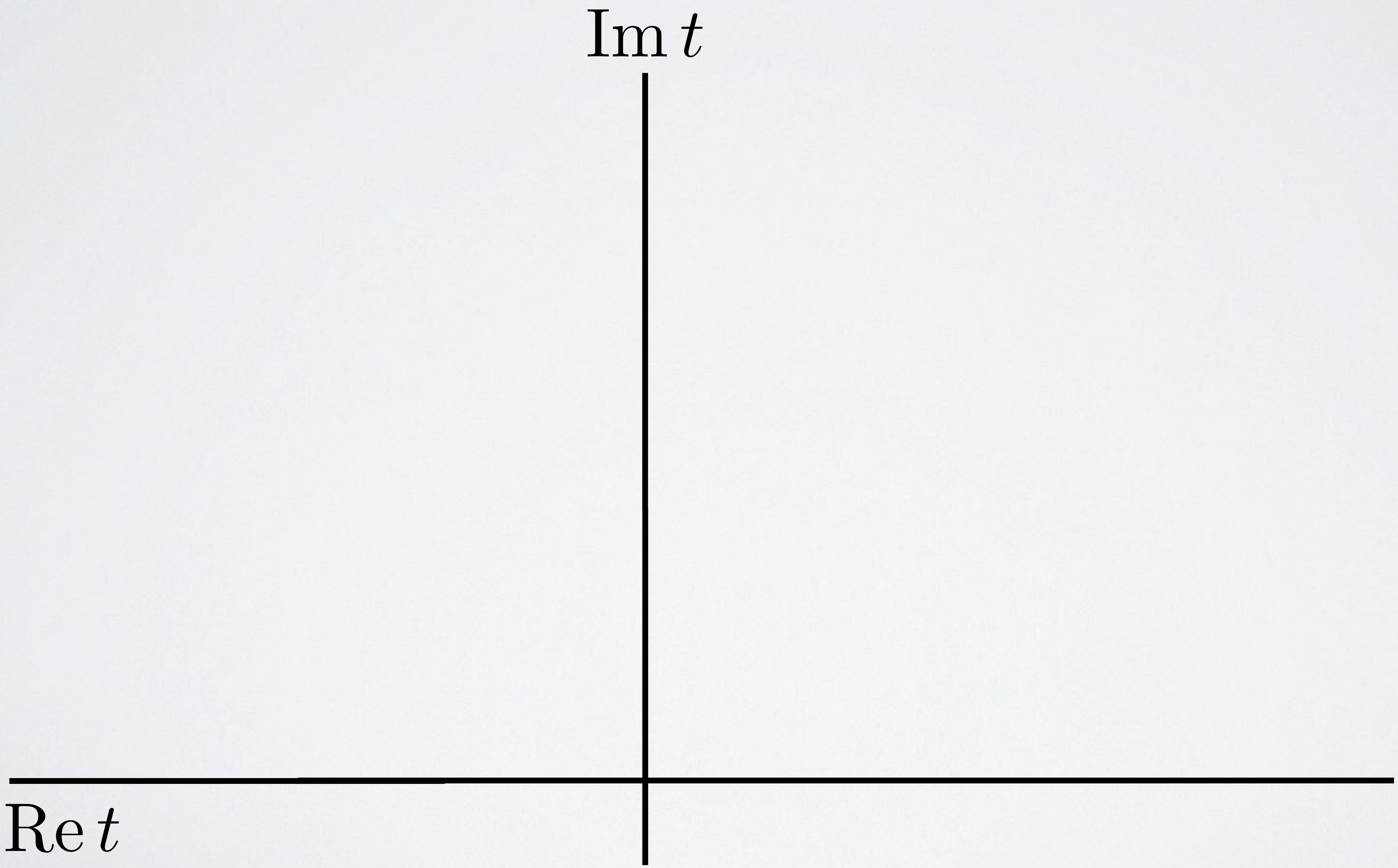

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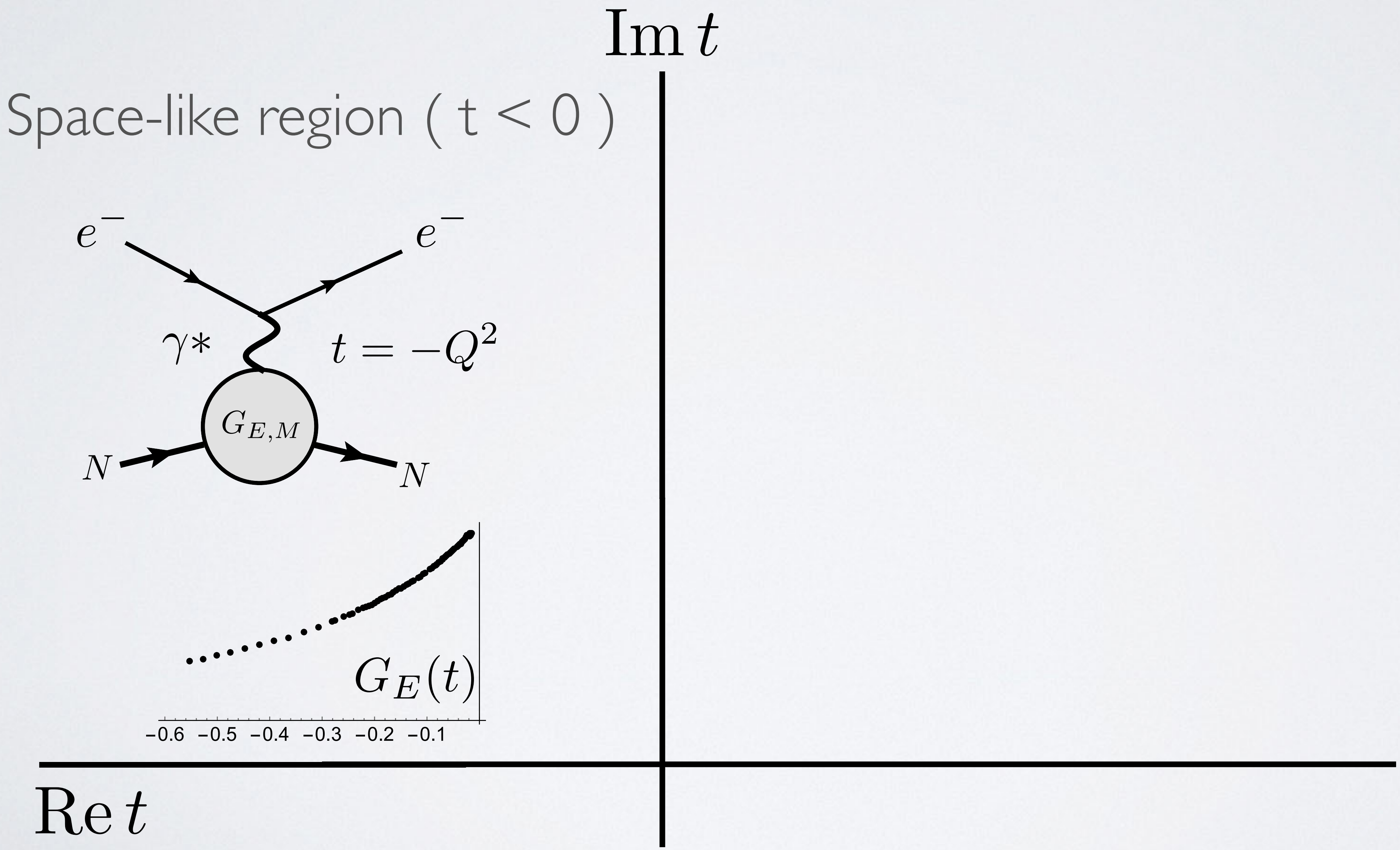

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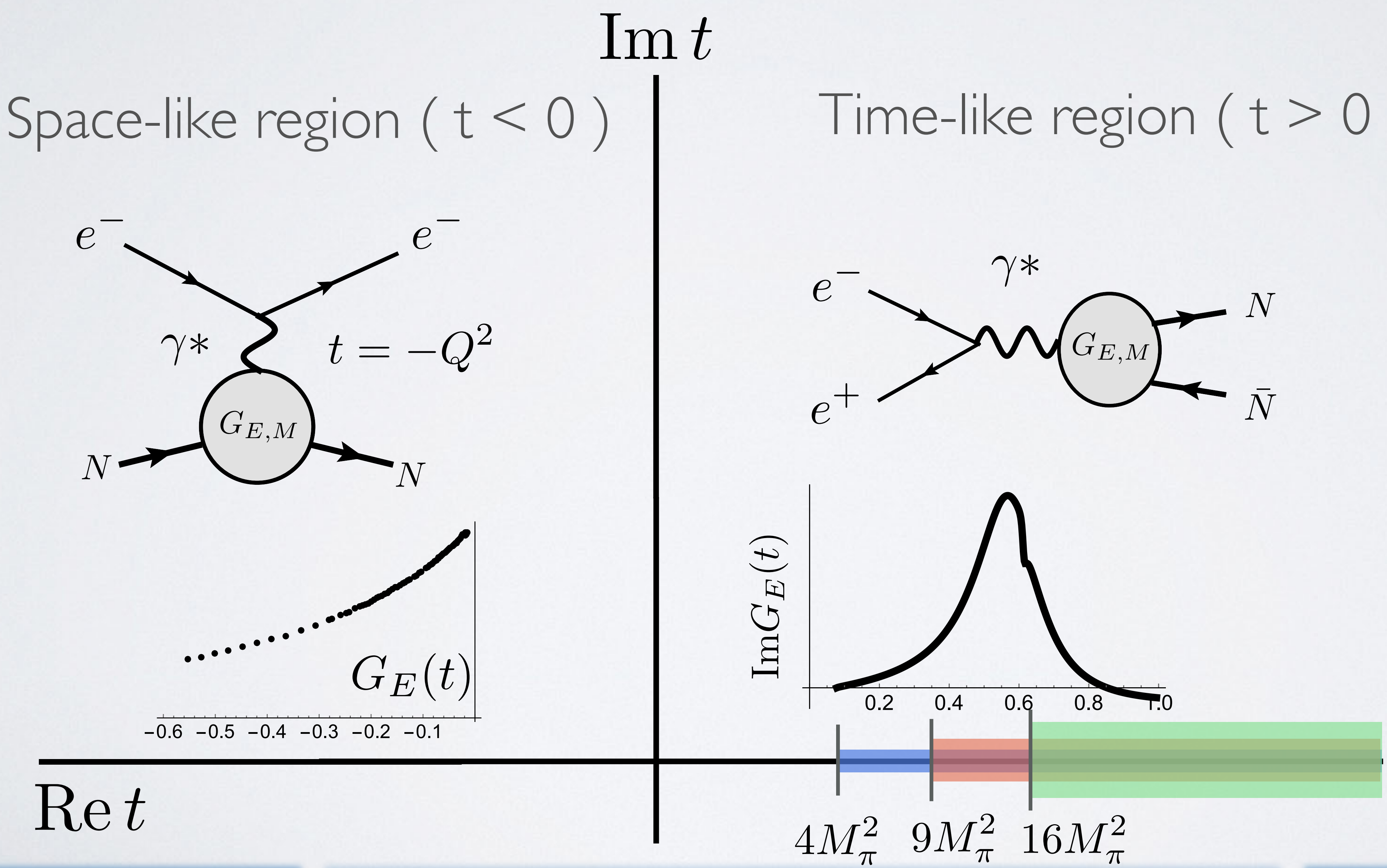

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- From unitarity + analyticity

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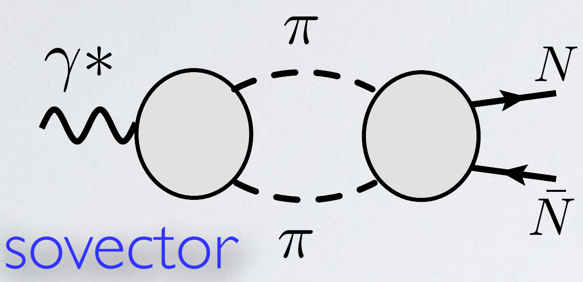

Isovector

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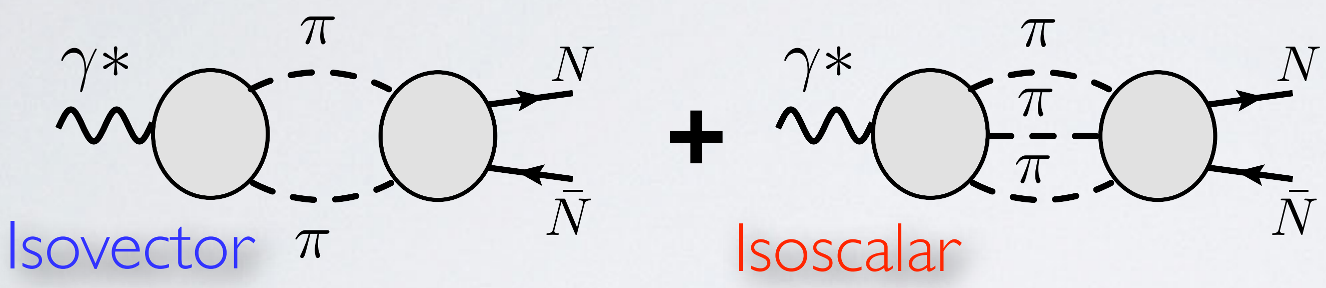

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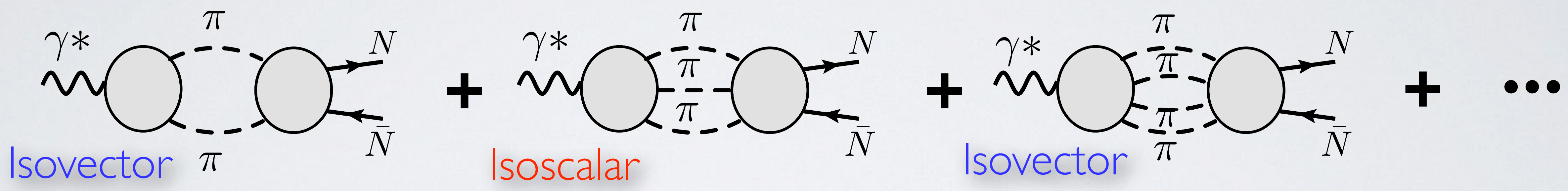

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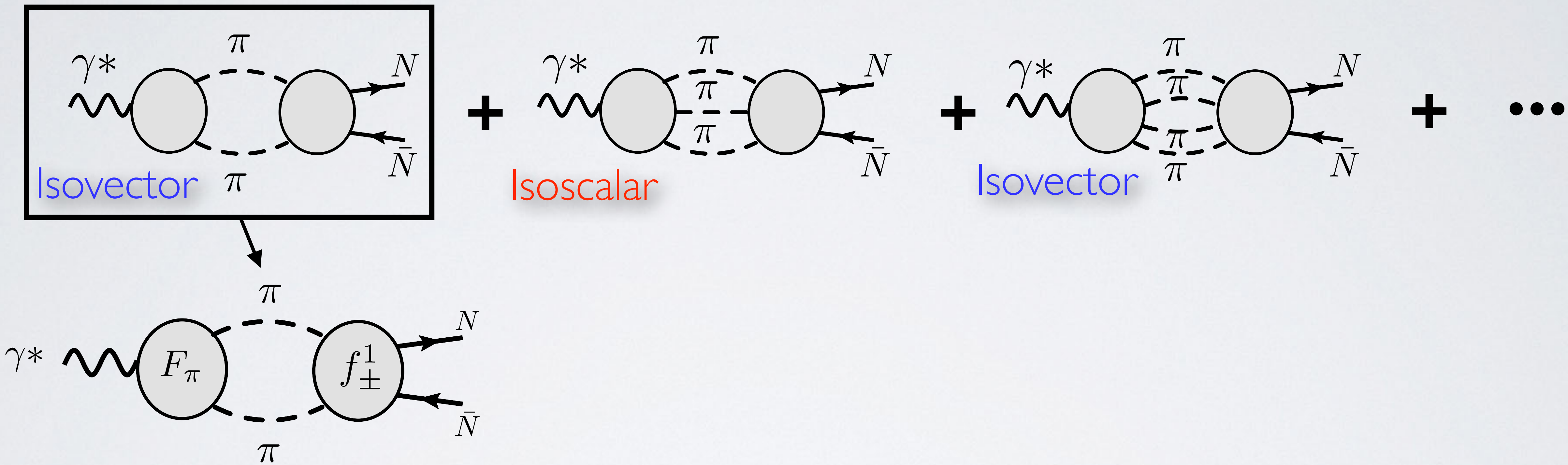

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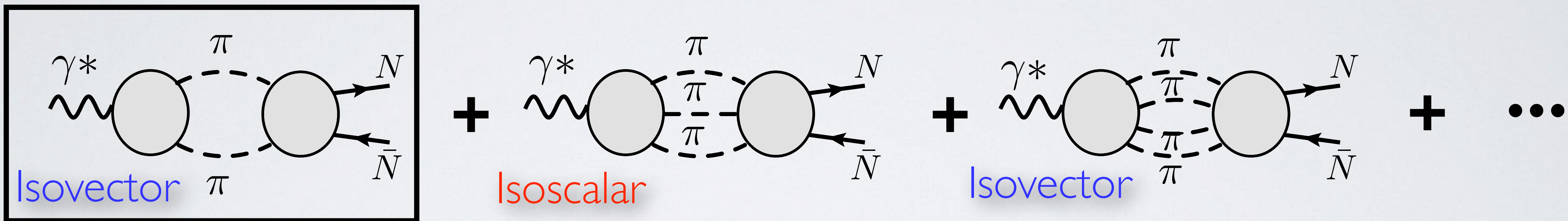

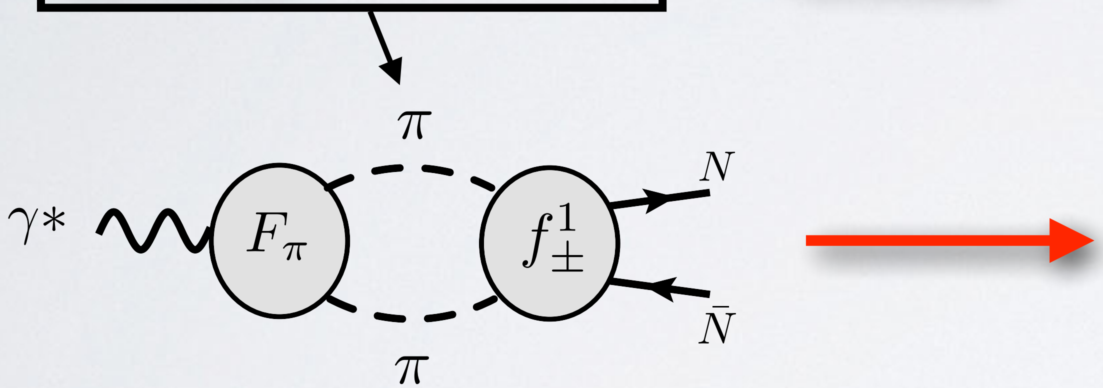

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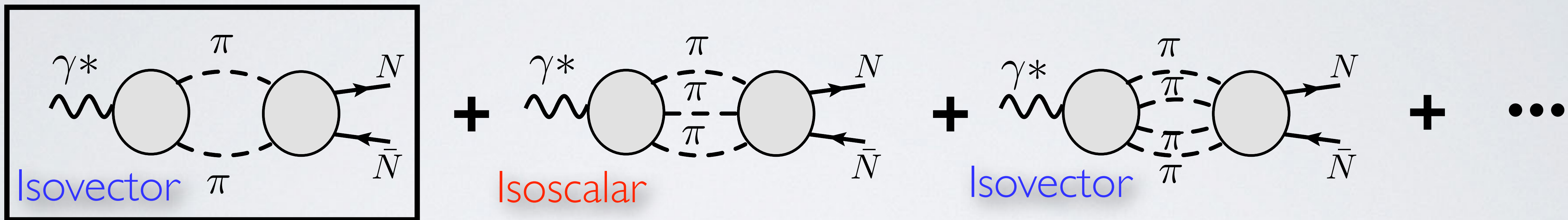

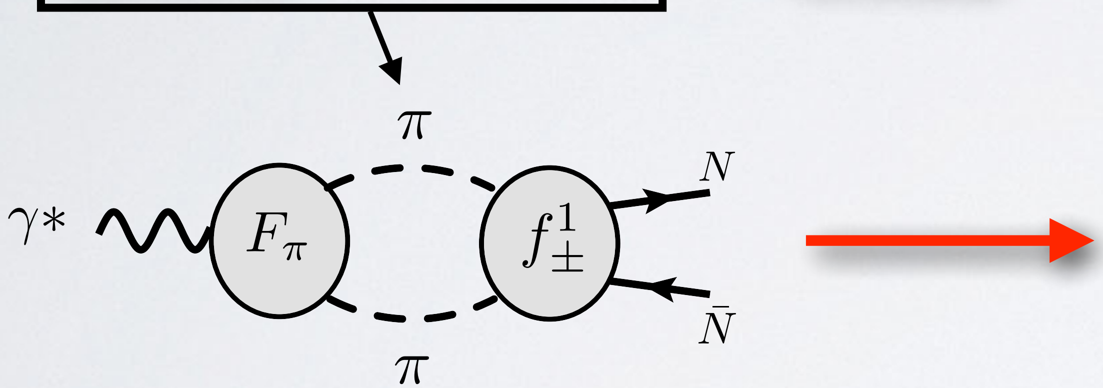

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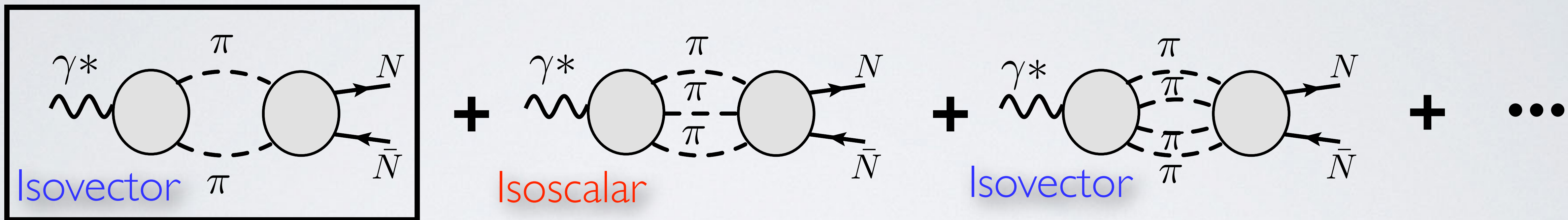

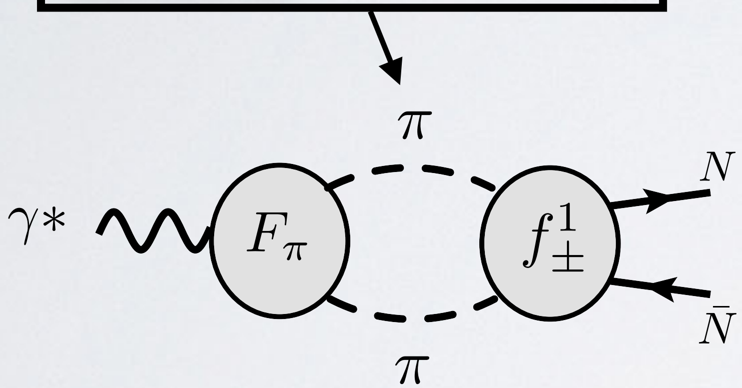

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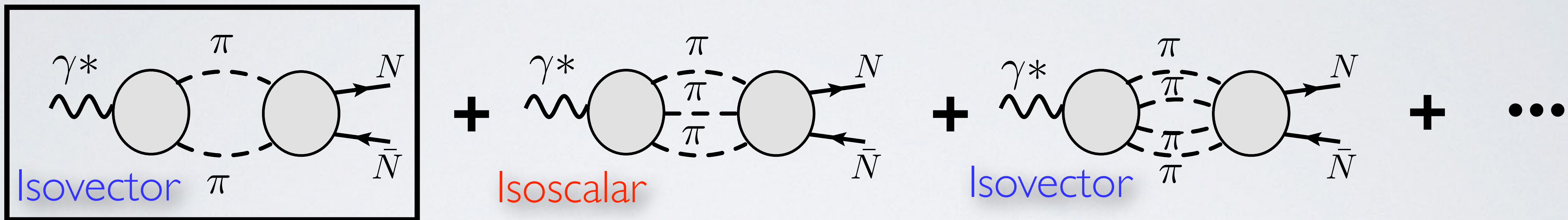

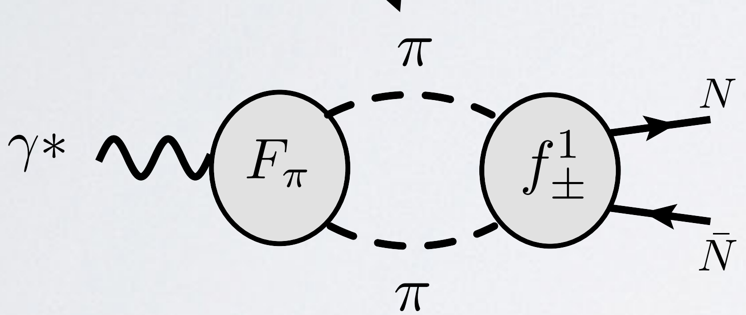

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[Frazer and Fulco, Phys. Rev. 117, 1609 (1960)]

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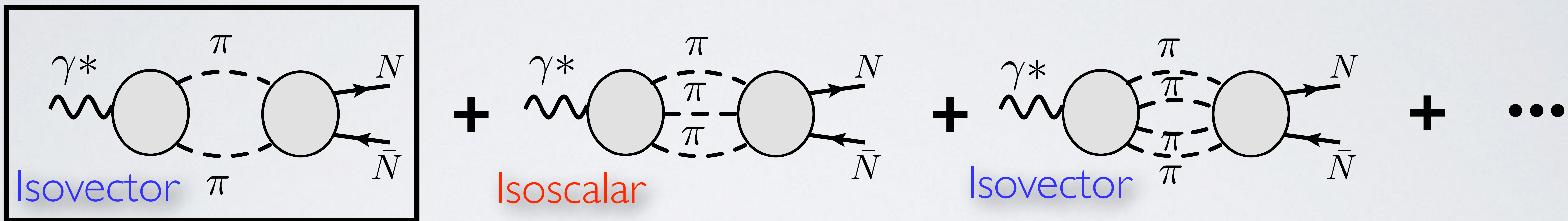

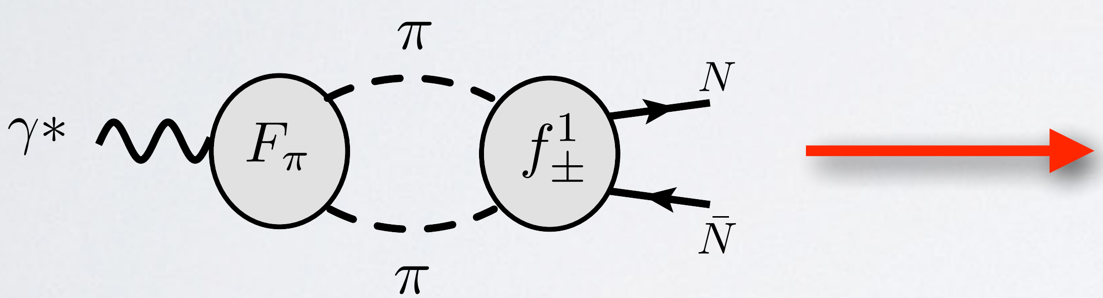

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[Frazer and Fulco, Phys. Rev. 117, 1609 (1960)]

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Non-Perturbative

Form factors and their analytic structure

- From unitarity + analyticity

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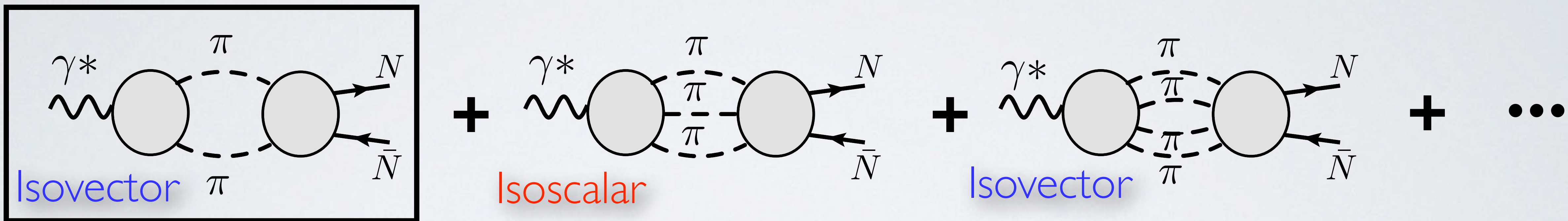

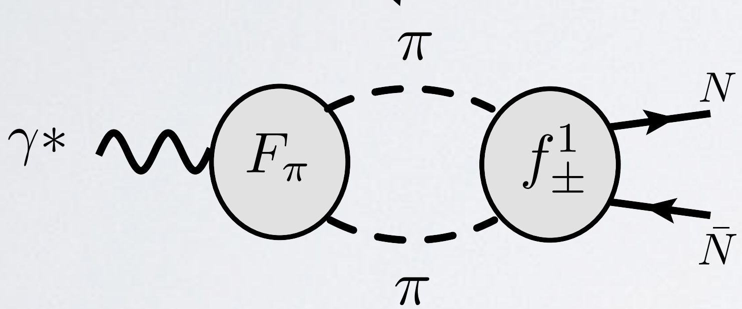

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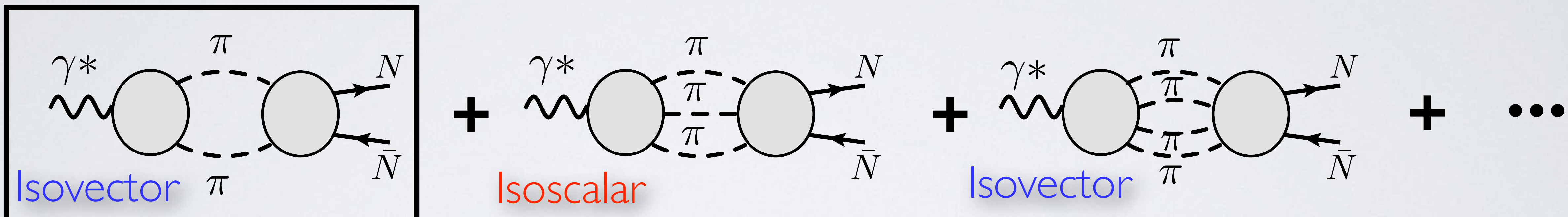

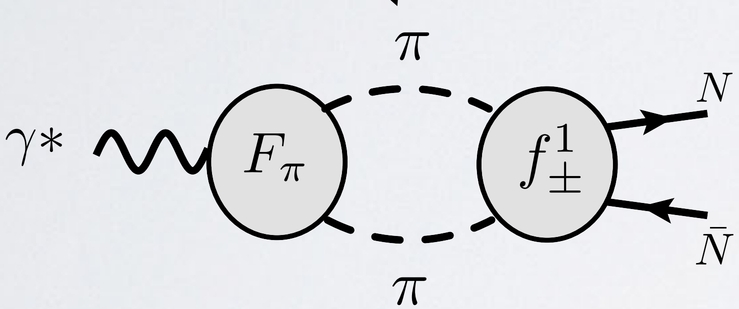

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$F_\pi^*(t)$, $f_\pm^1(t)$: Non-Perturbative

$|F_\pi(t)|^2$: Non-Perturbative

$\frac{f_\pm^1(t)}{F_\pi(t)}$: Perturbative

DIχEFT

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ChEFT

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ChEFT

DIχEFT

Experiment

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ChEFT

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ChEFT

DIχEFT

Experiment / ChEFT

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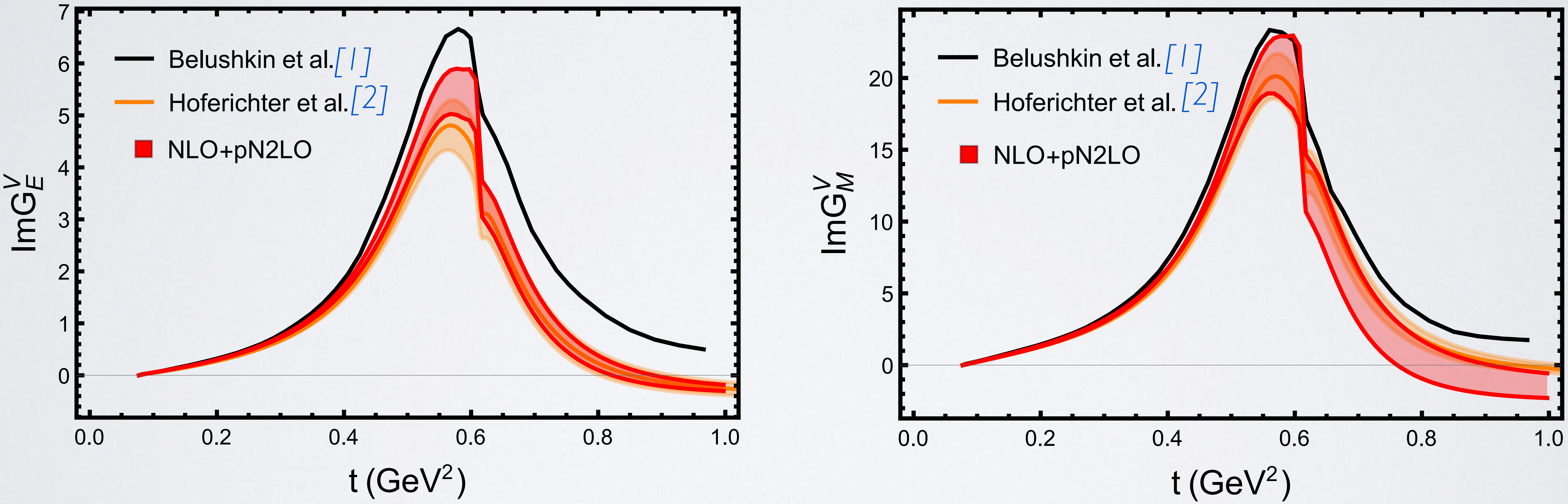
[J. M. Alarcón, C. Weiss, PLB 784 (2018)]



[1] Belushkin, Hammer and Meißner, PRC 75 (2007) [2] Hoferichter, Kubis, Ruiz de Elvira, Hammer, Meißner EPJA 52 (2016)

$DI\chi EFT$

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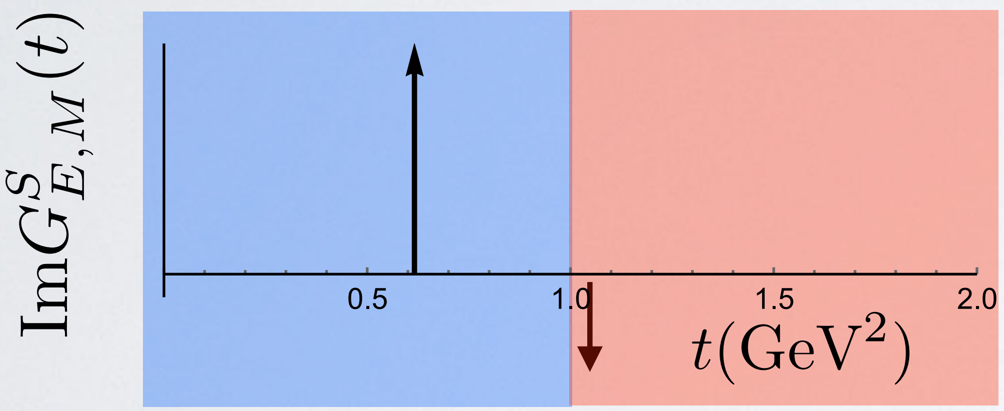

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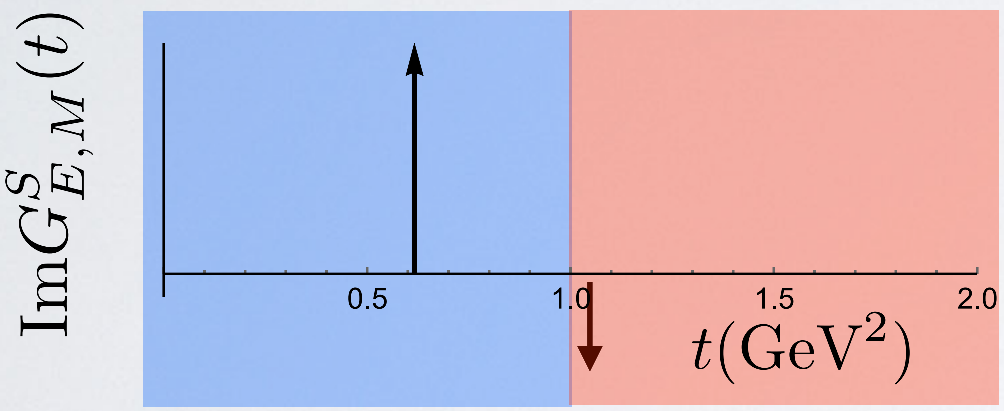


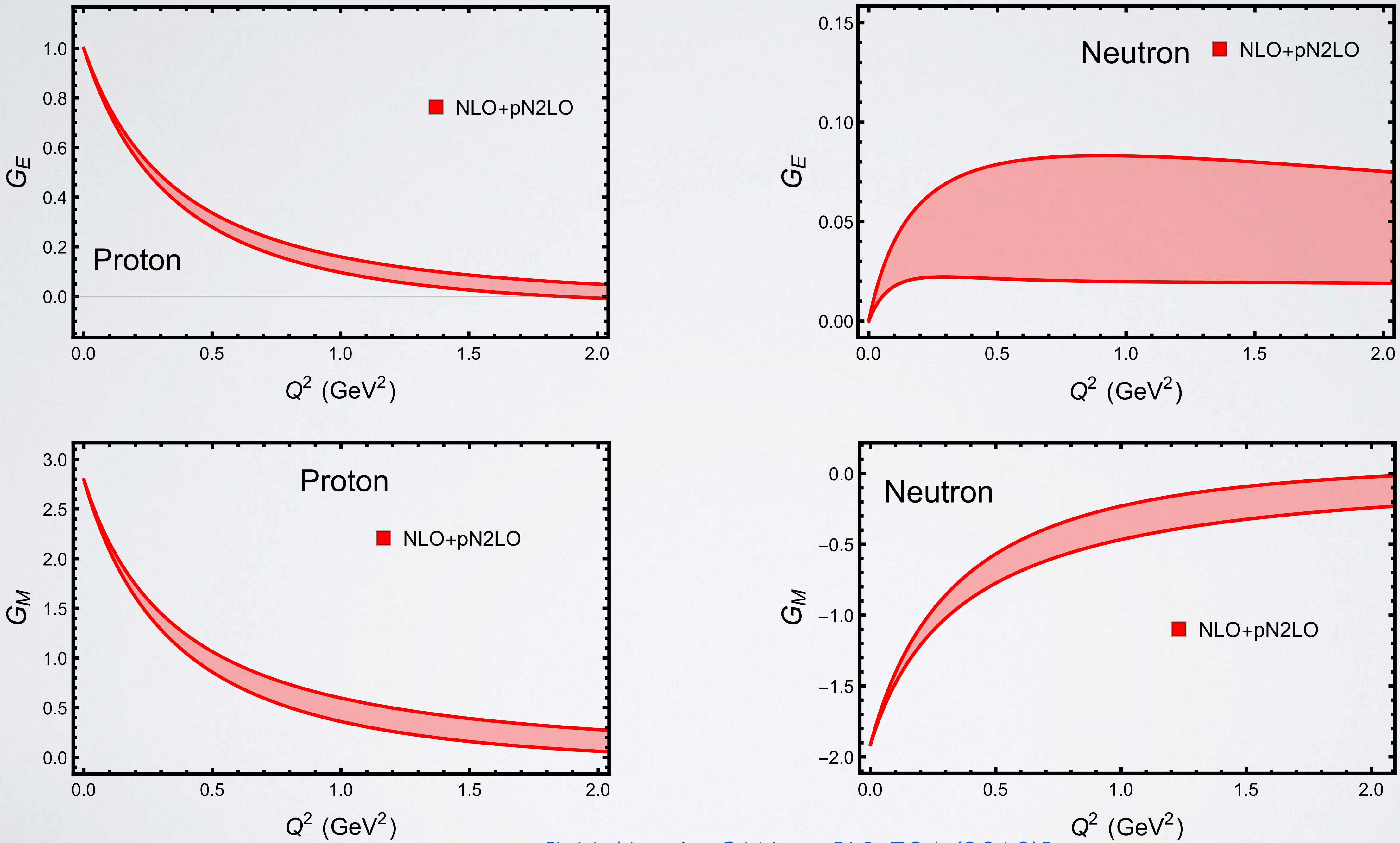
$$\mathrm{Im}G^S_{E,M} = -\pi \sum_{V=\omega,P_S} a_i^{E,M}\delta(t - M_i^2)$$

- We fix the couplings by imposing the charge and radii sum rules:

$$G^S_{E,M}(0) = \frac{1}{\pi}\int_{4M_\pi^2}^{\infty} dt' \frac{\mathrm{Im}G^S_i(t')}{t'} \qquad \langle r^2_{E,M}\rangle^S = \frac{6}{\pi}\int_{4M_\pi^2}^{\infty} dt' \frac{\mathrm{Im}G^S_{E,M}(t')}{t'^2}$$

DIχEFT

- Reconstructing the form factors with $G^{p,n}_{E,M}(t) = \frac{1}{\pi}\int_{4M_\pi^2}^{\infty} dt' \frac{\mathrm{Im}G^{p,n}_{E,M}(t')}{t'-t-i0^+}$



[J. M. Alarcón, C. Weiss, PLB 784 (2018)]

DIχEFT

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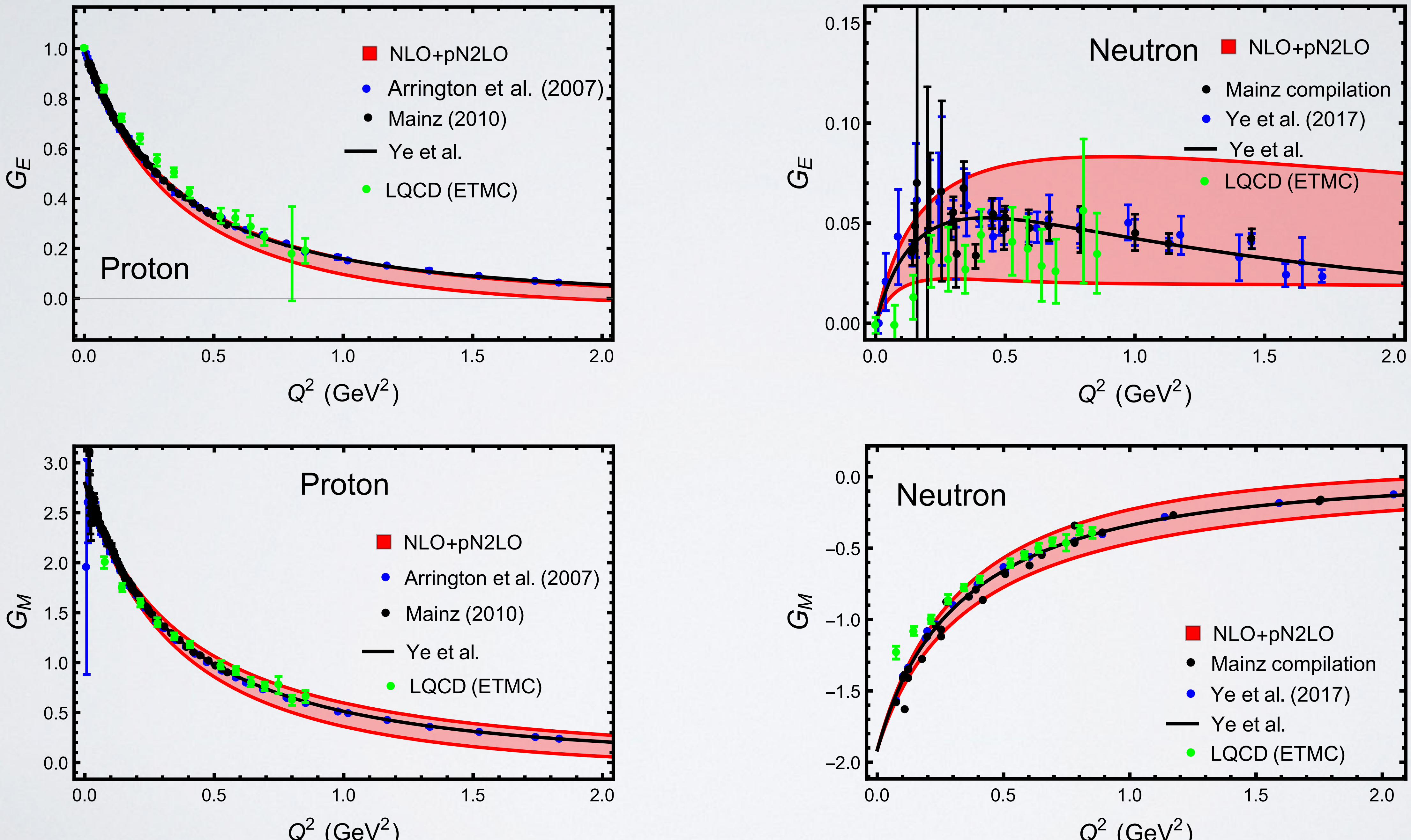
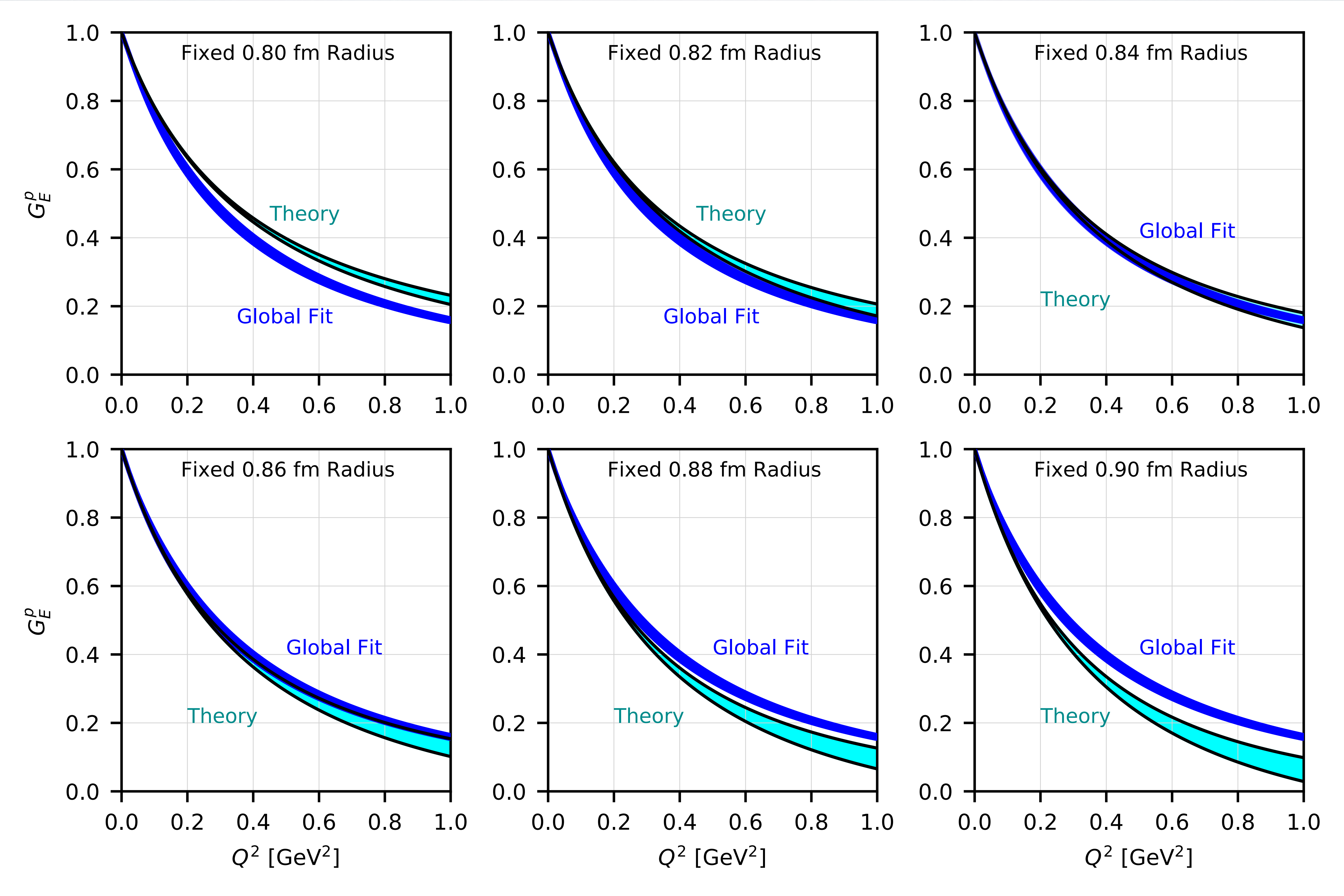


[J. M. Alarcón, C. Weiss, PLB 784 (2018)]

DIχEFT

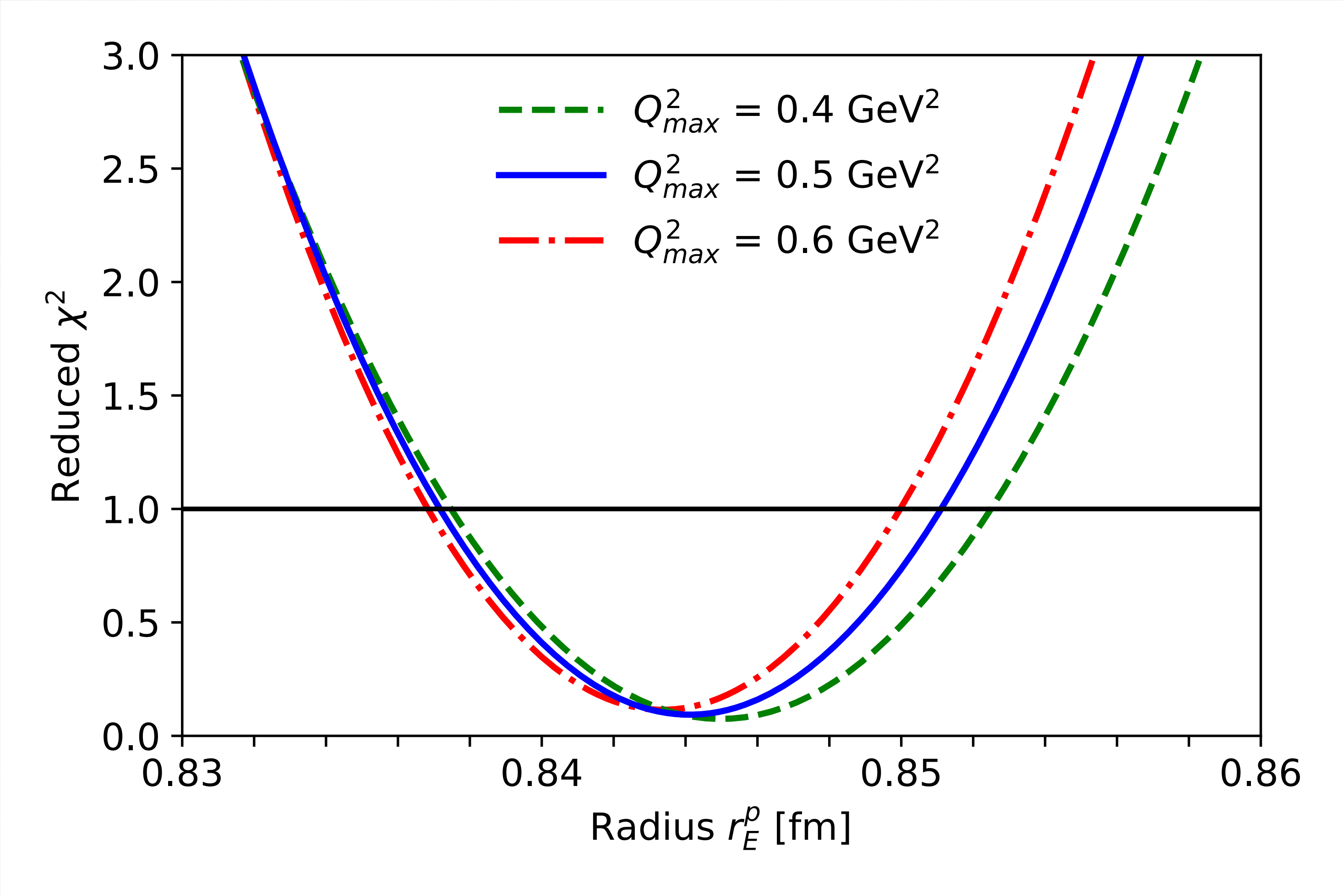


[J. M. Alarcón, D. W. Higinbotham, C. Weiss and Z. Ye, Phys.Rev. C99 (2019)]

DIχEFT

$$\chi^2(r_E^p) \equiv N^{-1} \sum_{\text{bins } i} \frac{(\text{thy}_i - \text{fit}_i)^2}{(\Delta\text{thy}_i)^2 + (\Delta\text{fit}_i)^2}$$

$$\{\text{thy}_i \equiv G_E^p(Q_i^2)\ [\text{DI}\chi\text{EFT, given } r_E^p],\quad \text{fit}_i \equiv G_E^p(Q_i^2)\ [\text{global fit, given } r_E^p]\}$$



$$r_E^p = 0.844(7)\ \text{fm}$$

[J. M. Alarcón, D. W. Higinbotham, C. Weiss and Z. Ye, Phys.Rev. C99 (2019)]

Summary and Conclusions

Summary and Conclusions

- Chiral EFT is a useful tool to investigate hadronic processes at low energies from first principles.
- It provided important hadronic input for searches of physics beyond the standard model:
  - Dark Matter searches: $\sigma_{\pi N}$, t-dependence of the scalar FF (*DIχEFT*).
  - Proton Radius Puzzle: ΔE_{2P-2S}, moments of the EM FF (*DIχEFT*),

  Proton radius from $e^- p$ agrees with μH → $r_E^p = 0.844(7)$ fm
- Insights into the origin of mass:

	$\frac{1}{2m_N}\langle N\vert\hat{m}(\bar{u}u+\bar{d}d)\vert N\rangle$	$\frac{1}{2m_N}\langle N\vert m_s\bar{s}s\vert N\rangle$	$\frac{1}{2m_N}\langle N\vert\frac{\beta}{2g}G_a^{\mu\nu}G^a_{\mu\nu}+\ldots\vert N\rangle$
m_p	59(7) MeV	16(80) MeV	864(87) MeV
%	6.3(7)%	1.7(8.5)%	92.0(9.3)%

- Prominent role in the solution of current and future challenges in hadron and nuclear physics.

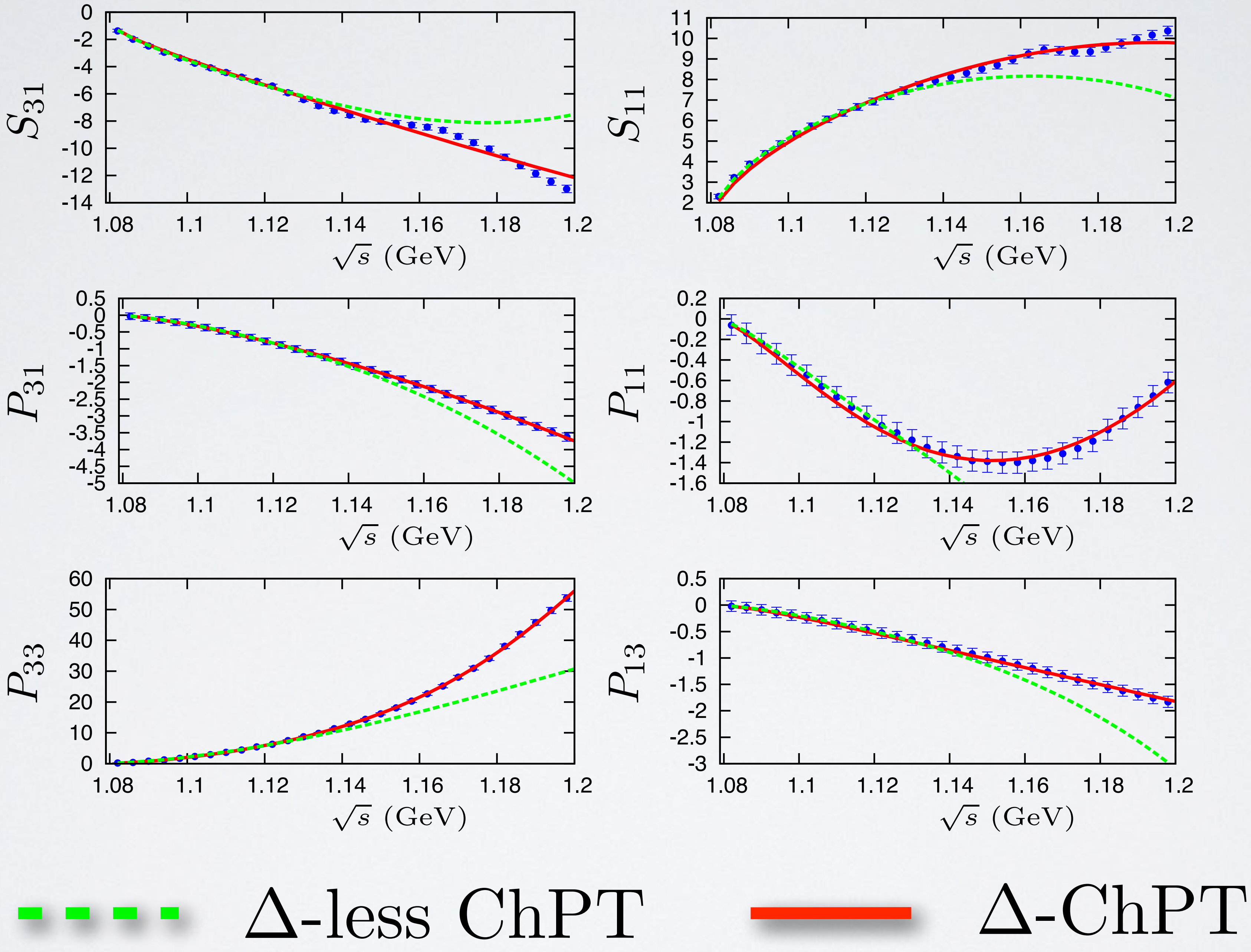
FIN

Spares

Fits to PWAs

Fits to PWAs

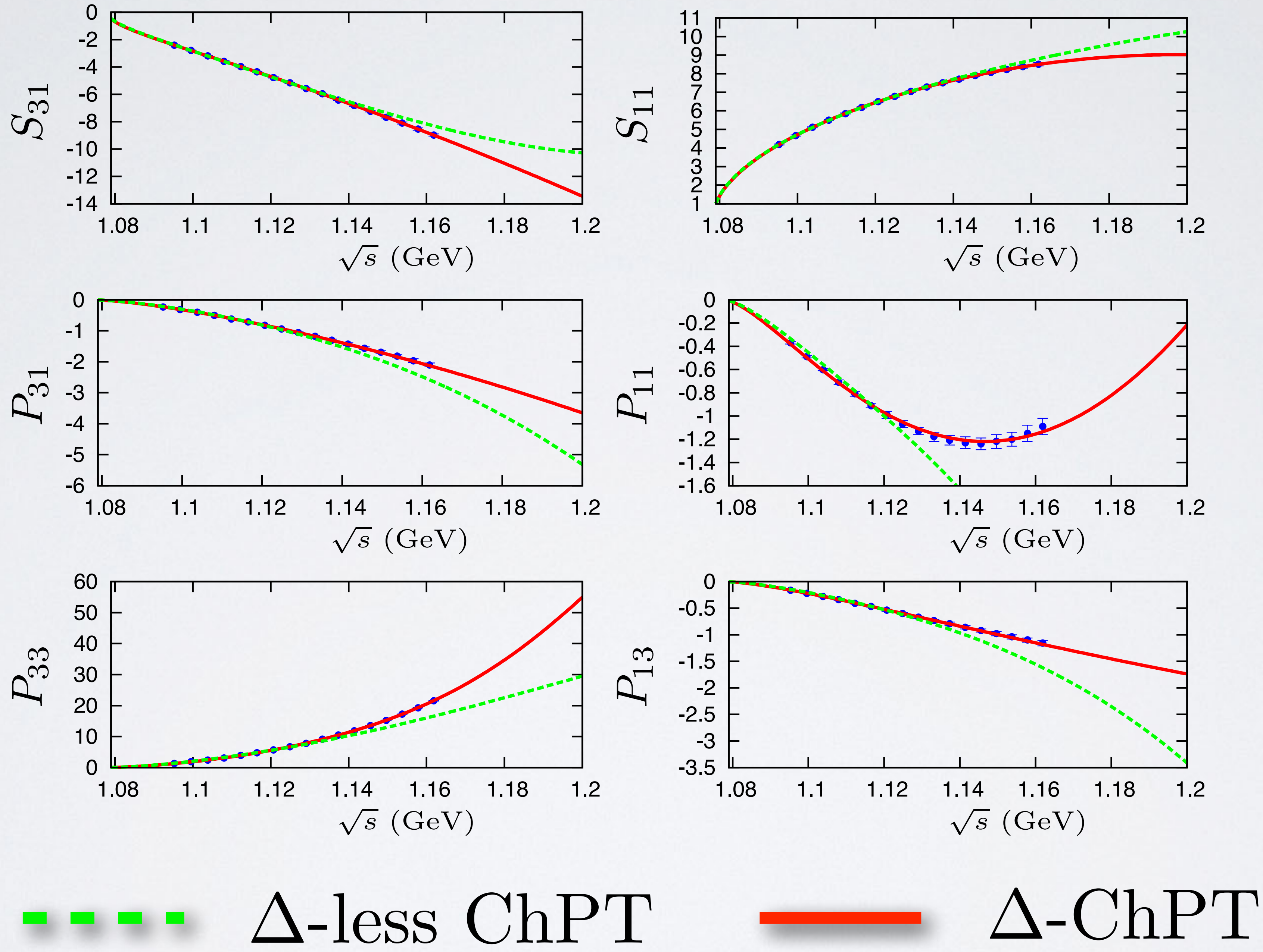
Fits to KA85



[Alarcón, Martin Camalich and Oller, Ann. of Phys. 336 (2013)]

Fits to PWAs

Fits to EM06



[Alarcón, Martin Camalich and Oller, Ann. of Phys. 336 (2013)]

Consecuences of $\sigma_{\pi N}$ *for nuclear matter*

Consecuences of $\sigma_{\pi N}$ for nuclear matter

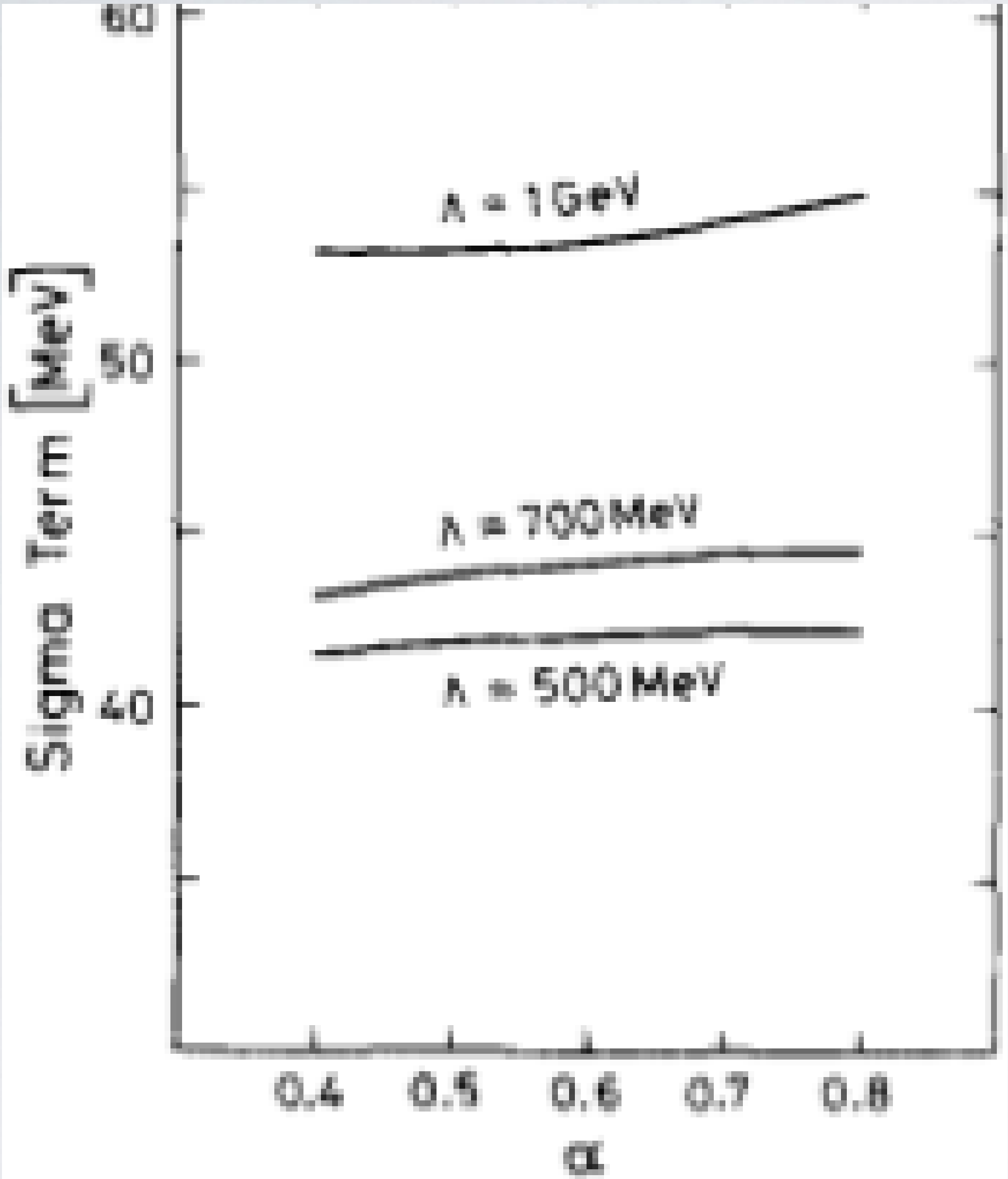
$$\langle\Omega|\bar{q}q|\Omega\rangle = \langle 0|\bar{q}q|0\rangle \left(1 - \frac{\sigma_{\pi N}}{M_\pi^2 f_\pi^2}\rho + \ldots\right)$$

- Restoration of chiral symmetry requires a zero temporal component of f

$$f_t = f_\pi \left\{1 + \frac{2\rho}{f^2}\left(c_2 + c_3 - \frac{g_A^2}{8m_N}\right)\right\}$$

σ_0

σ_0



[Gasser, Annals of Phys. 136, 62 (1981)]

- This plot is for $m_0 = 750$ MeV, which is equivalent to fix b_0.
- Gasser points out that the natural choice is $\Lambda = 1$ GeV because corresponds to the axial vector form factor fit given by Sehgal *[Sehgal, "Proceedings of the International Conference on High Energy Physics"]*.
- He finally takes $\Lambda = 700$ MeV because for $\Lambda = 1$ GeV the mass shift of the nucleon due to massless pions is -200 MeV while for $\Lambda = 700$ MeV is -90 MeV.

Comparison with HB

	Octet $\mathcal{O}(p^3)$		Octet+Decuplet $\mathcal{O}(p^3)$	
	HB	Cov.	HB	Cov.
σ_0 (MeV)	58(23)	46(8)	89(23)	58(8)

Subthreshold region

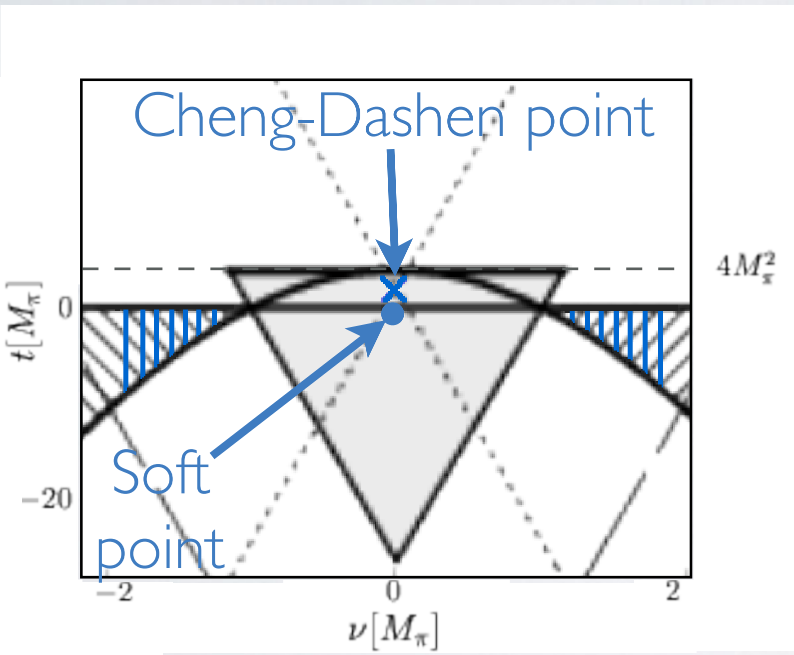
Subthreshold region

- The disagreement found in *[Becher and Leutwyler, JHEP (2001)]* is related to the disagreement in the subthreshold expansion.

$$T(\nu,t) = \bar{u}\left(D(\nu,t) - \frac{1}{4m_N}B(\nu,t)[\not{q},\not{q}']\right)u$$

$$\bar{D}^+(\nu,t) = d^+_{00} + d^+_{01}t + d^+_{10}\nu^2 + d^+_{02}t^2 + \dots \qquad \bar{B}^+(\nu,t) = b^+_{00}\nu + \dots$$

$$\bar{D}^-(\nu,t) = d^-_{00}\nu + d^-_{01}\nu t + d^-_{10}\nu^3 + \dots \qquad \bar{B}^-(\nu,t) = b^-_{00} + \dots$$



	KA85 $\not\Delta$-ChPT	WI08 $\not\Delta$-ChPT	EM06 $\not\Delta$-ChPT	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85 [50]	WI08 [4]
d^+_{00} (M_π^{-1})	−2.02(41)	−1.65(28)	−1.56(5)	−1.48(15)	−1.20(13)	−0.98(4)	−1.46	−1.30
d^+_{01} (M_π^{-3})	1.73(19)	1.70(18)	1.64(4)	1.21(10)	1.20(9)	1.09(4)	1.14	1.19
d^+_{10} (M_π^{-3})	1.81(16)	1.60(18)	1.532(45)	0.99(14)	0.82(9)	0.631(42)	1.12(2)	–
d^+_{02} (M_π^{-5})	0.021(6)	0.021(6)	0.021(6)	0.004(6)	0.005(6)	0.004(6)	0.036	0.037
b^+_{00} (M_π^{-3})	−6.5(2.4)	−7.4(2.3)	−7.01(1.1)	−5.1(1.7)	−5.1(1.7)	−4.5(9)	−3.54(6)	–
d^-_{00} (M_π^{-2})	1.81(24)	1.68(16)	1.495(28)	1.63(9)	1.53(8)	1.379(8)	1.53(2)	–
d^-_{01} (M_π^{-4})	−0.17(6)	−0.20(5)	−0.199(7)	−0.112(25)	−0.115(24)	−0.0923(11)	−0.134(5)	–
d^-_{10} (M_π^{-4})	−0.35(10)	−0.33(10)	−0.267(14)	−0.18(5)	−0.16(5)	−0.0892(41)	−0.167(5)	–
b^-_{00} (M_π^{-2})	17(7)	17(7)	16.8(7)	9.63(30)	9.755(42)	8.67(8)	10.36(10)	–

[Alarcón, Martin Camalich and Oller, Ann. of Phys. 336 (2013)]

Agreement with the dispersive results!

- CD theorem: $\Sigma \equiv f_\pi^2 \bar{D}^+(0, 2M_\pi^2) = \sigma(t = 2M_\pi^2) + \Delta_R = \sigma_{\pi N} + \Delta_\sigma + \Delta_R$

Underestimated in ~10 MeV

$$\Sigma = \underbrace{f_\pi^2(d^+_{00} + 2M_\pi^2 d^+_{01})}_{\Sigma_d} + \underbrace{f_\pi^2(4M_\pi^4 d^+_{02} + \dots)}_{\Delta_D} \qquad \sigma_{\pi N} = \Sigma_d + \Delta_D - \Delta_\sigma - \Delta_R$$

Δ_D Underestimated in ~10 MeV as well!

Remains small

$\Delta_D - \Delta_\sigma = -3.3(2)$ MeV (disp.) ⟷ $\Delta_D^{(3)} - \Delta_\sigma^{(3)} = -3.5(2.0)$ MeV (O(p³) ChEFT)

The sigma-term puzzle

The sigma-term puzzle

- Phenomenological extractions rely on two different sources:

πN-scattering data

- Inconsistent data base ($\pi^{\pm}N \to \pi^{\pm}N$ vs CEX reactions)
- Coulomb *[Tromborg, Waldenstrom and Overbo, PRD 15 (1977)]*.

π-atom spectroscopy

- Experimental uncertainties negligible compared to theoretical error relating (ϵ, Γ) to $a^{\pm}$.
- πD scattering, isospin violation, Coulomb…

What can be done?

- Analysis of the **πN** world data base.
- Reanalysis of Coulomb corrections.
- Reanalysis of extraction of SL through ϵ and Γ.