Nucleon sigma terms in chiral effective field theory

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Works done in collaboration with L. S. Geng, J. Martín Camalich and J. A. Oller

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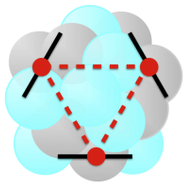

LENPIC

Low Energy Nuclear Physics International Collaboration

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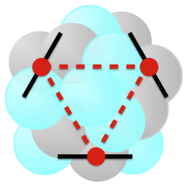

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- … and all starts with a reliable chiral representation of the **πN** amplitude.

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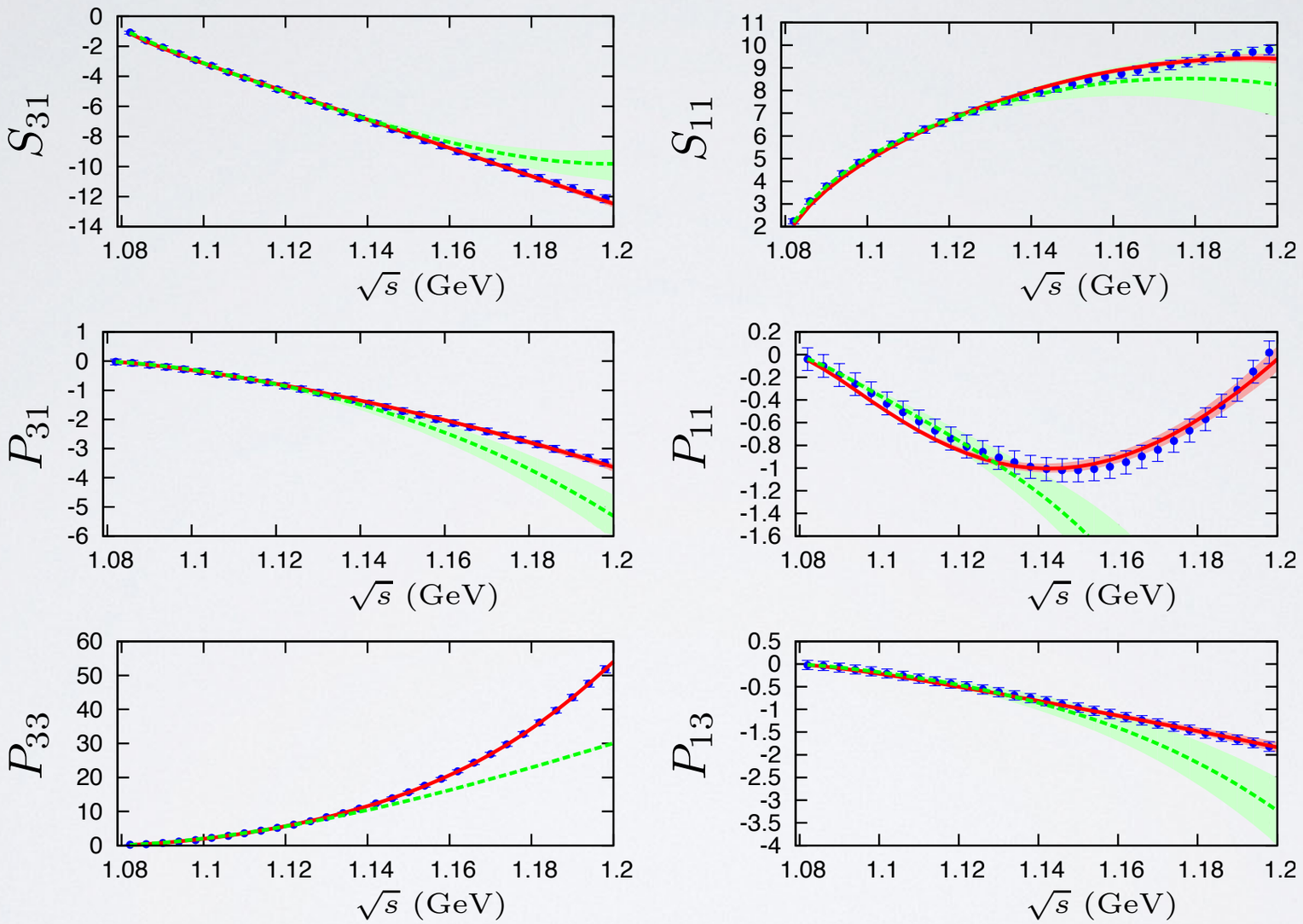
    - George Washington University (WI08) *[Workman, et al. . PRC 86 ,(2012)]*
    - Zürich group (EM06) *[Matsinos, Woolcock, Oades, Rasche and Gashi, NPA 95 (2006)]*

πN scattering with relativistic chiral EFT

Fits to WI08



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

πN scattering with relativistic chiral EFT

- 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	$-3.159(67)$

- Pion-nucleon coupling (d_{18}):

	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85	WI08	EM06
Δ_{GT}	5.1(8)%	1.0(2.5)%	2.0(4)%	4.5(7)%	2.1(1)%	0.2(1.0)%
$g_{\pi N}$	13.53(10)	13.00(31)	13.13(5)	13.46(9)	13.15(1)	12.90(12)

- 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)

Agreement with the PWA that provides the input.

πN scattering with relativistic chiral EFT

- 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	$-3.159(67)$

- Pion-nucleon coupling (d_{18}):

	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85	WI08	EM06
Δ_{GT}	5.1(8)%	1.0(2.5)%	2.0(4)%	4.5(7)%	2.1(1)%	0.2(1.0)%
$g_{\pi N}$	13.53(10)	13.00(31)	13.13(5)	13.46(9)	13.15(1)	12.90(12)

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Never achieved before in ChEFT !!!

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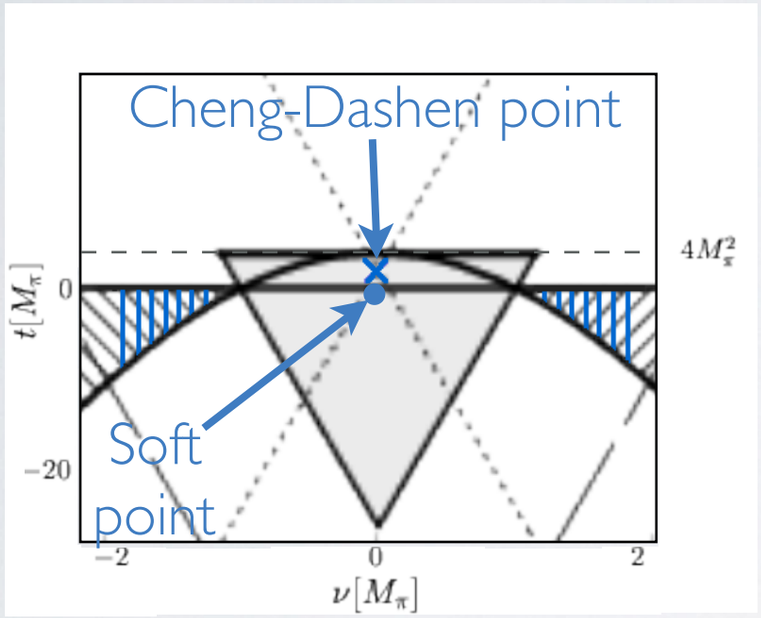

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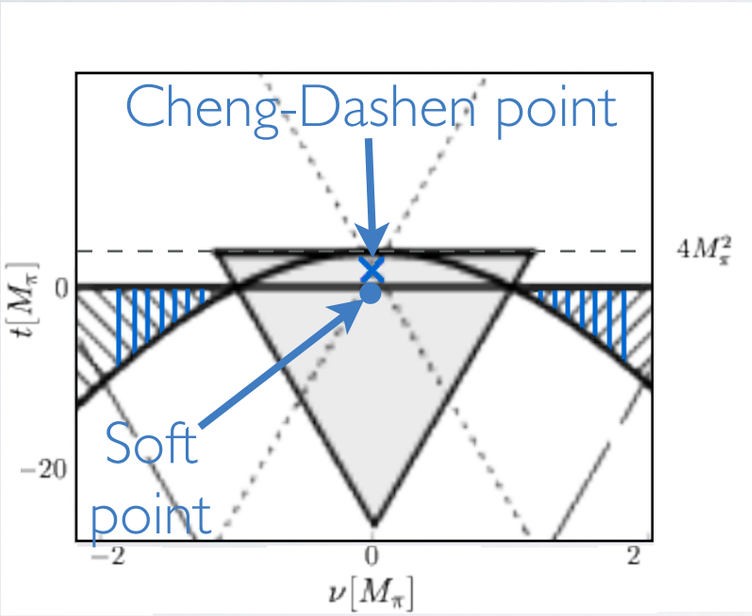

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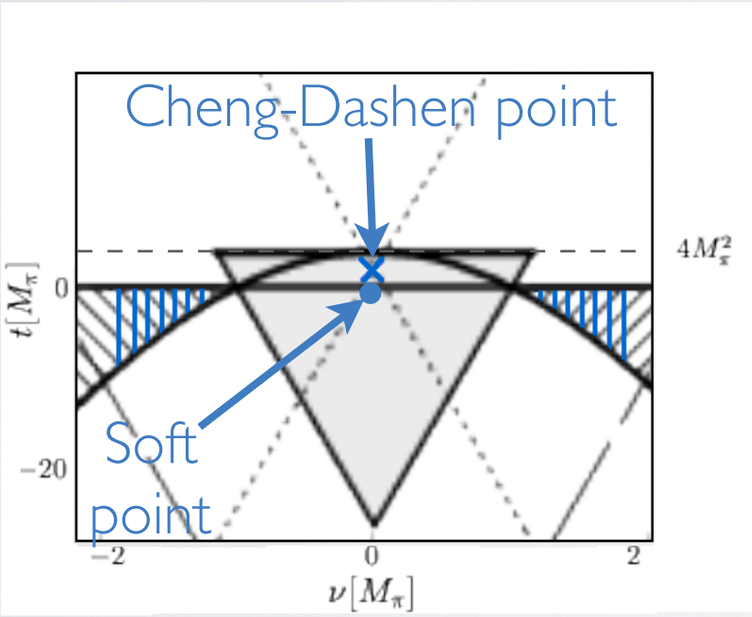

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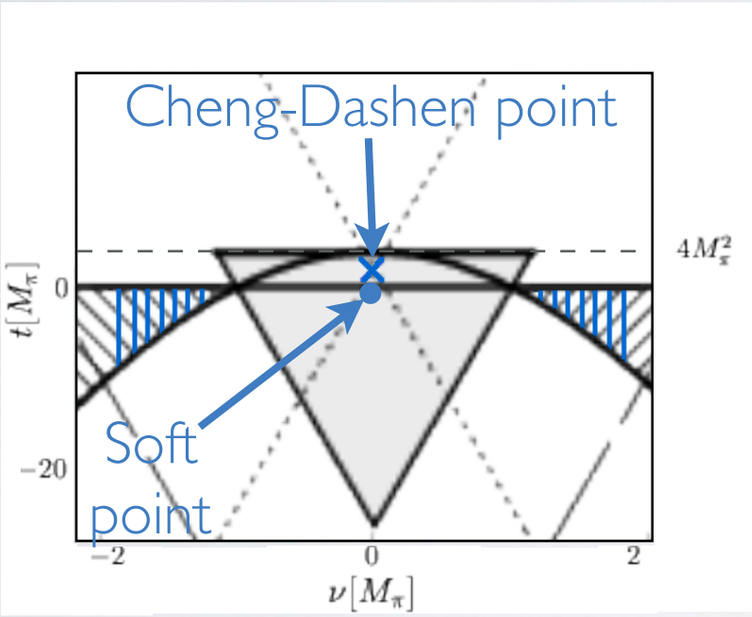

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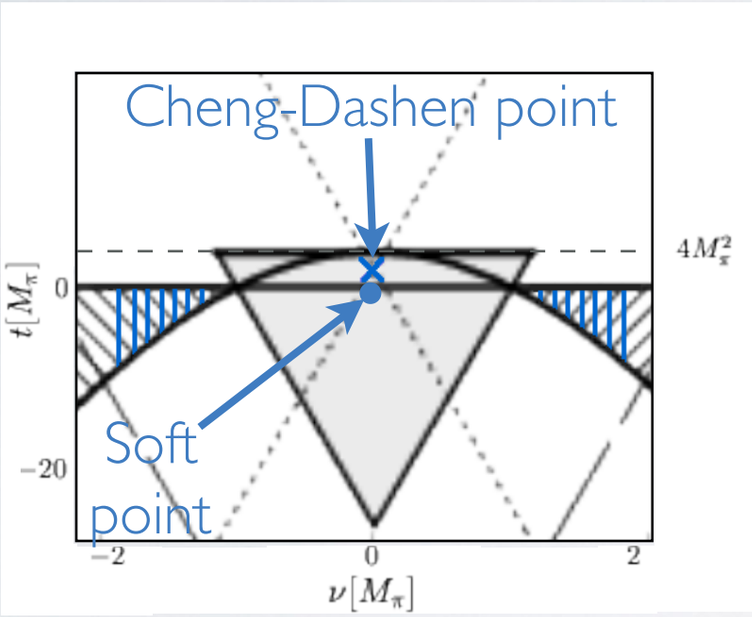

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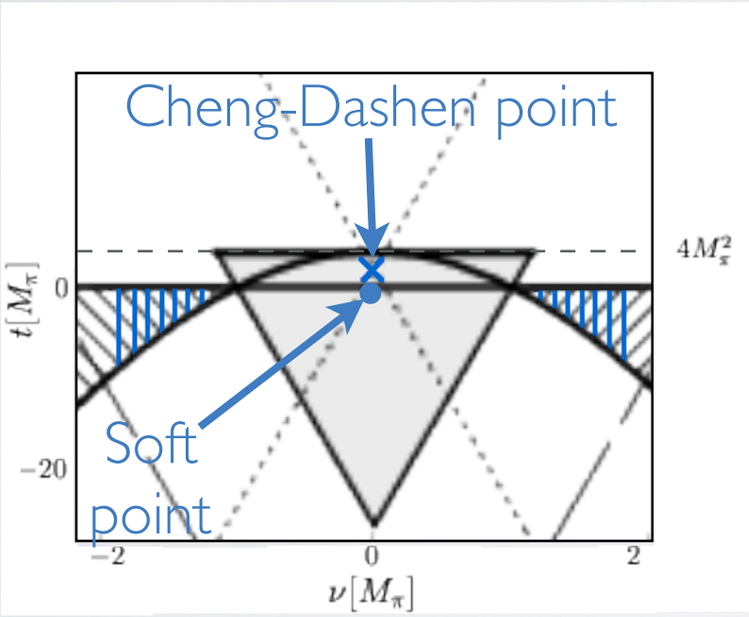

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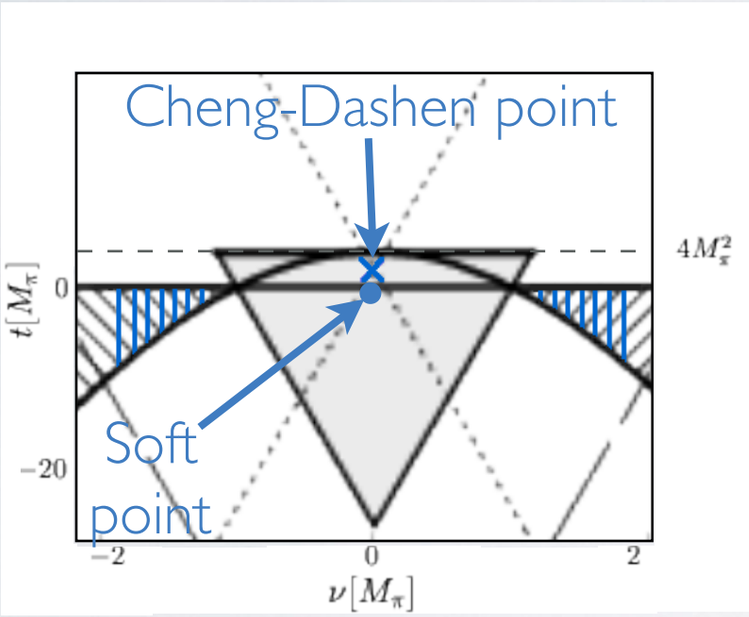

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Underestimated in ~10 MeV

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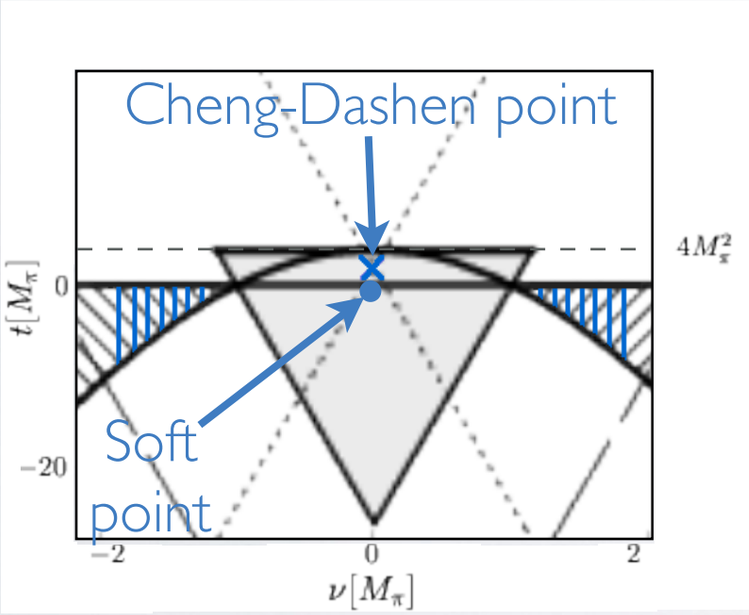

	KA85 $\not\Delta$-ChPT	WI08 $\not\Delta$-ChPT	EM06 $\not\Delta$-ChPT	KA85 Δ-ChPT	WI08 Δ-ChPT	EM06 Δ-ChPT	KA85 [50]	WI08 [4]
d^+_{00} (M_π^{-1})	−2.02(41)	−1.65(28)	−1.56(5)	−1.48(15)	−1.20(13)	−0.98(4)	−1.46	−1.30
d^+_{01} (M_π^{-3})	1.73(19)	1.70(18)	1.64(4)	1.21(10)	1.20(9)	1.09(4)	1.14	1.19
d^+_{10} (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

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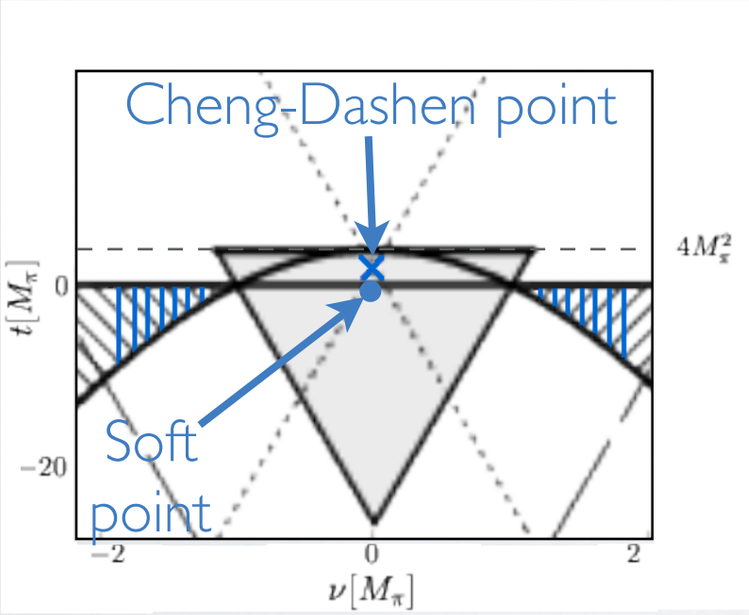

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Remains small

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

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Sigma-term update ☆

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$\sigma \simeq 45$ MeV , $\Sigma \simeq 60$ MeV

The pion-nucleon Σ term is definitely large: results from a G.W.U. analysis of πN scattering data

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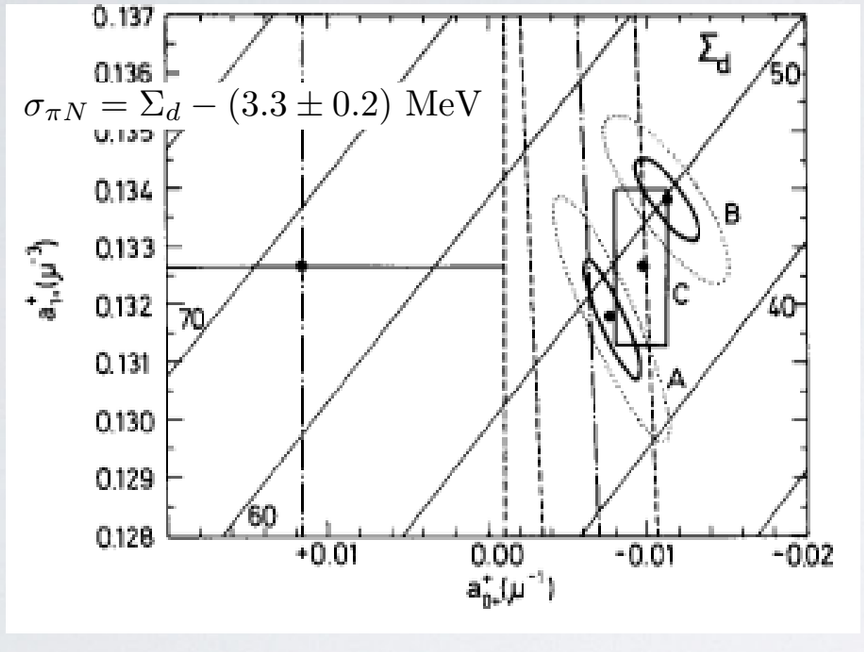

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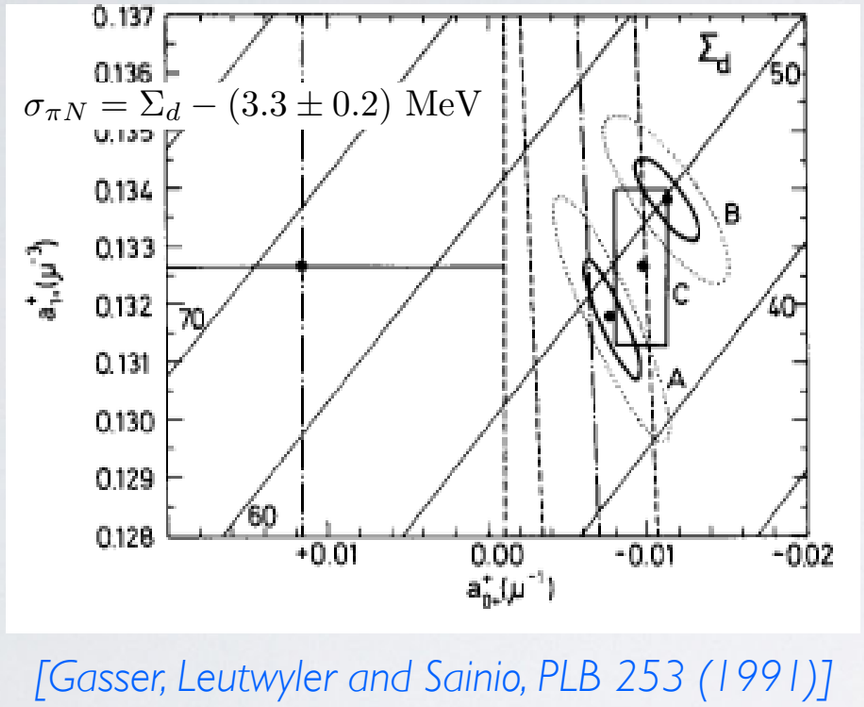

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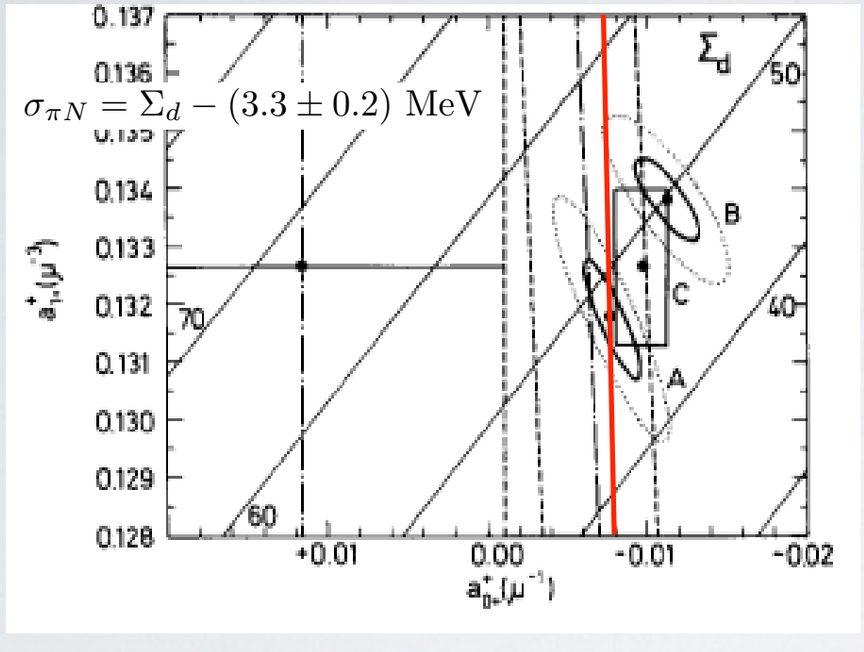

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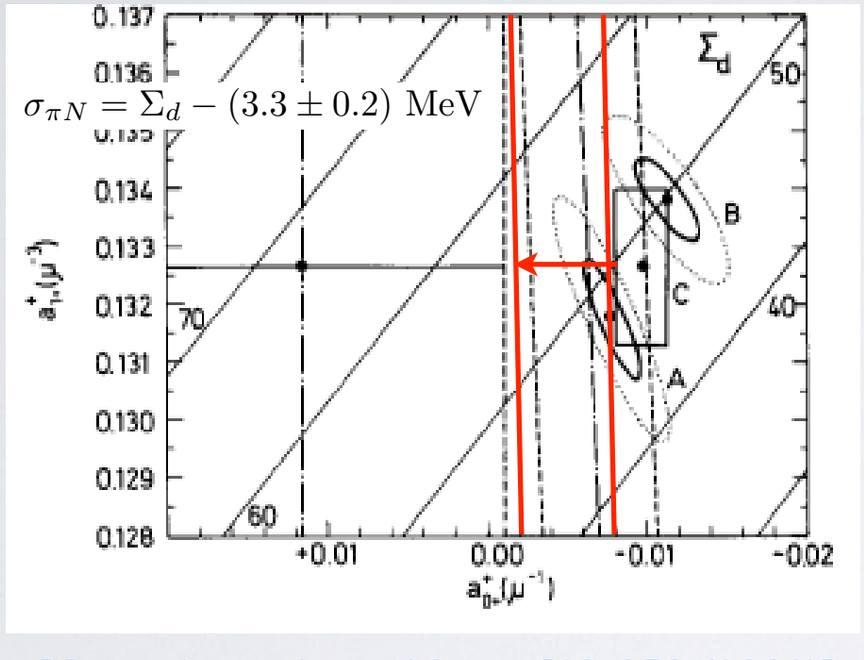

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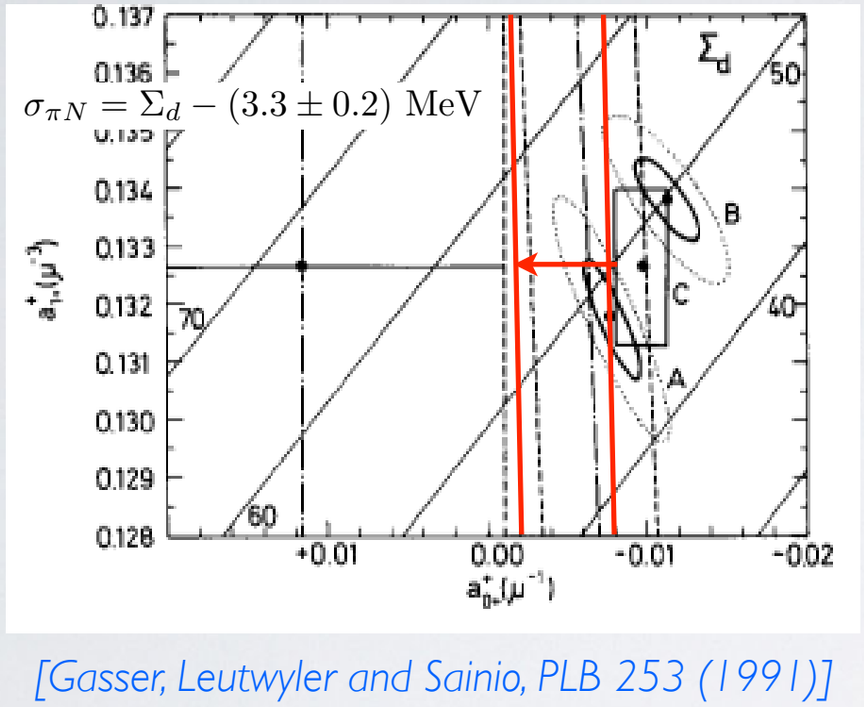

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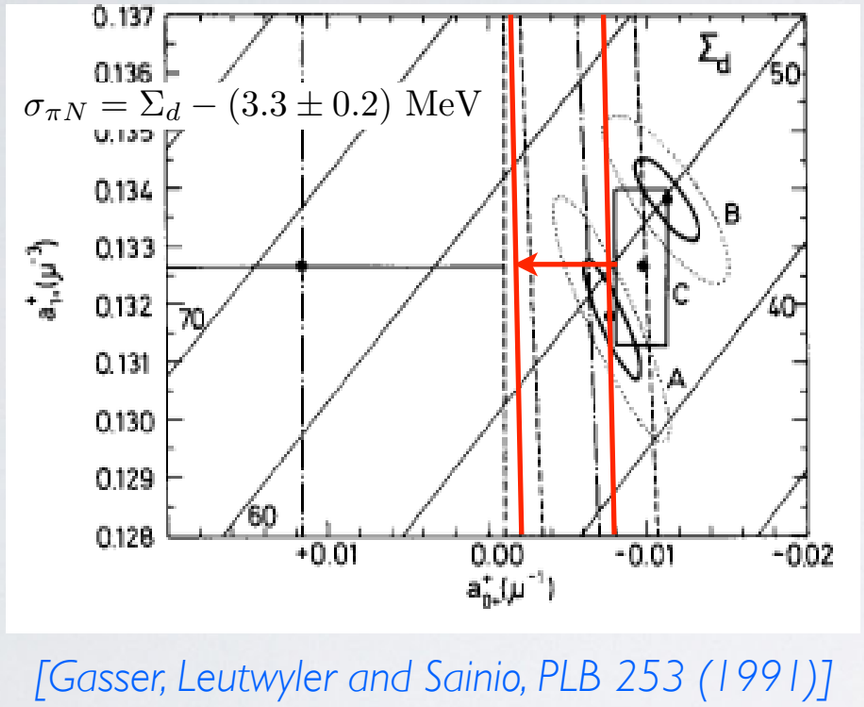

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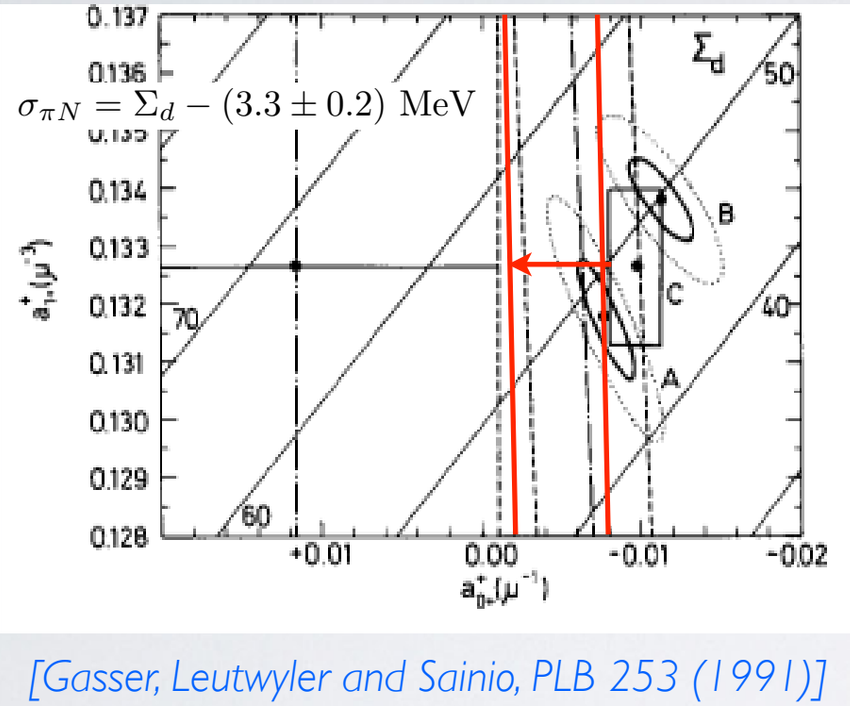

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In order to recover $\sigma_{\pi N} = 45$ MeV one needs $a_{0+}^{+} \sim -9 \times 10^{-3} M_\pi^{-1}$

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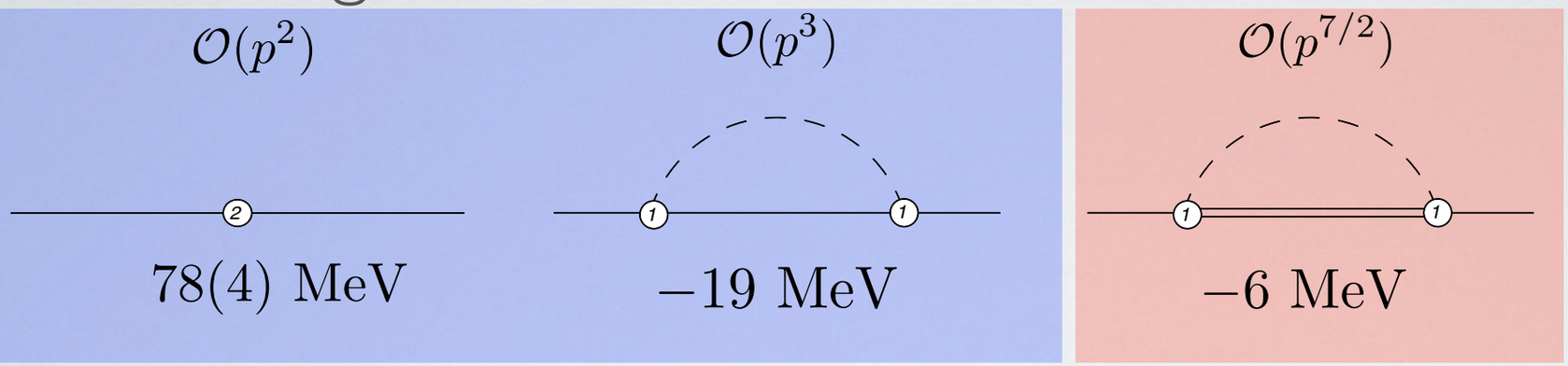

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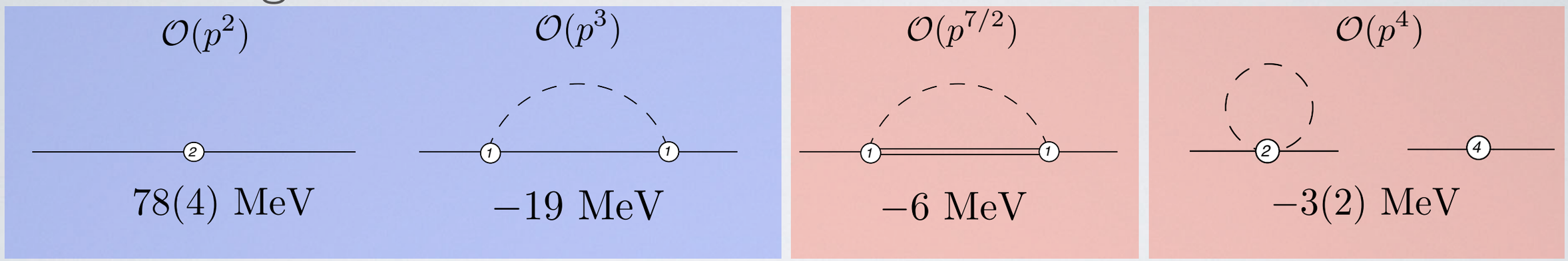

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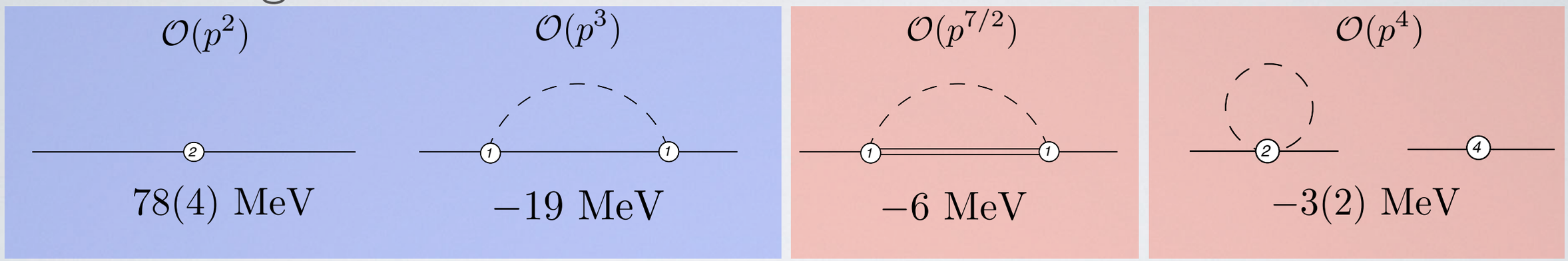

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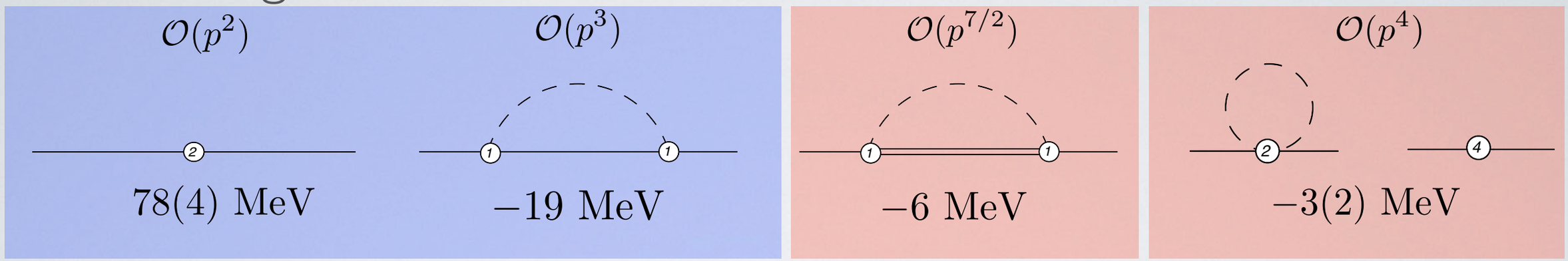

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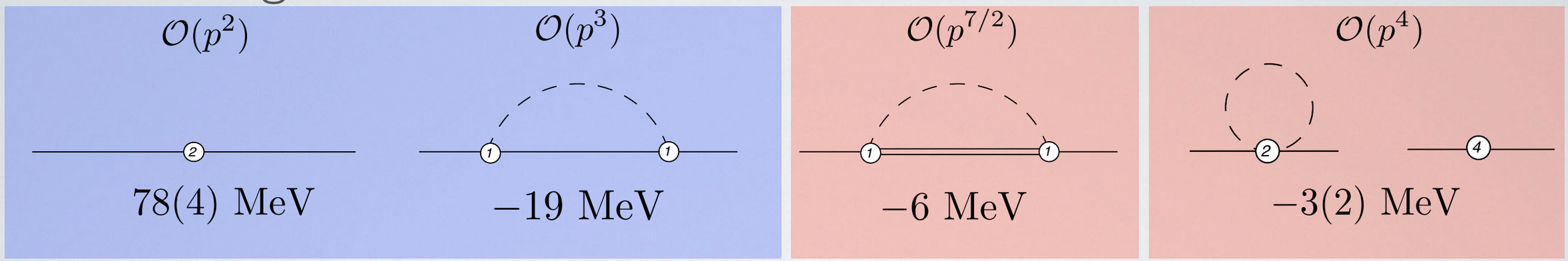

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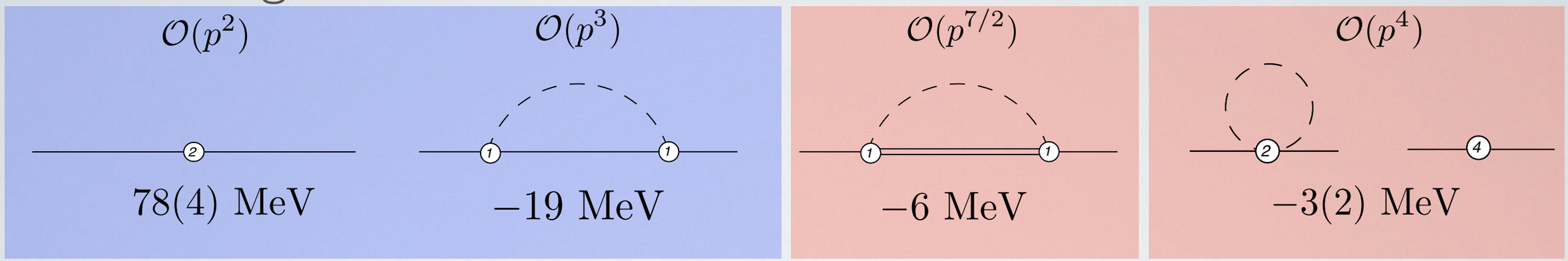

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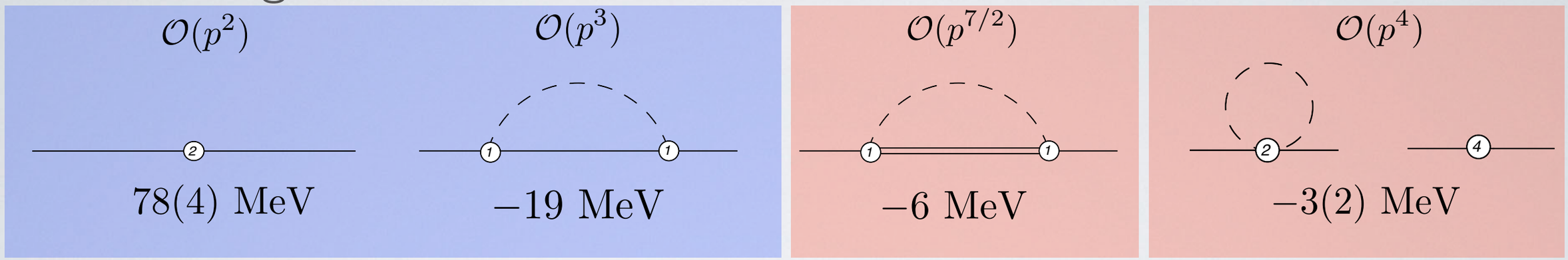

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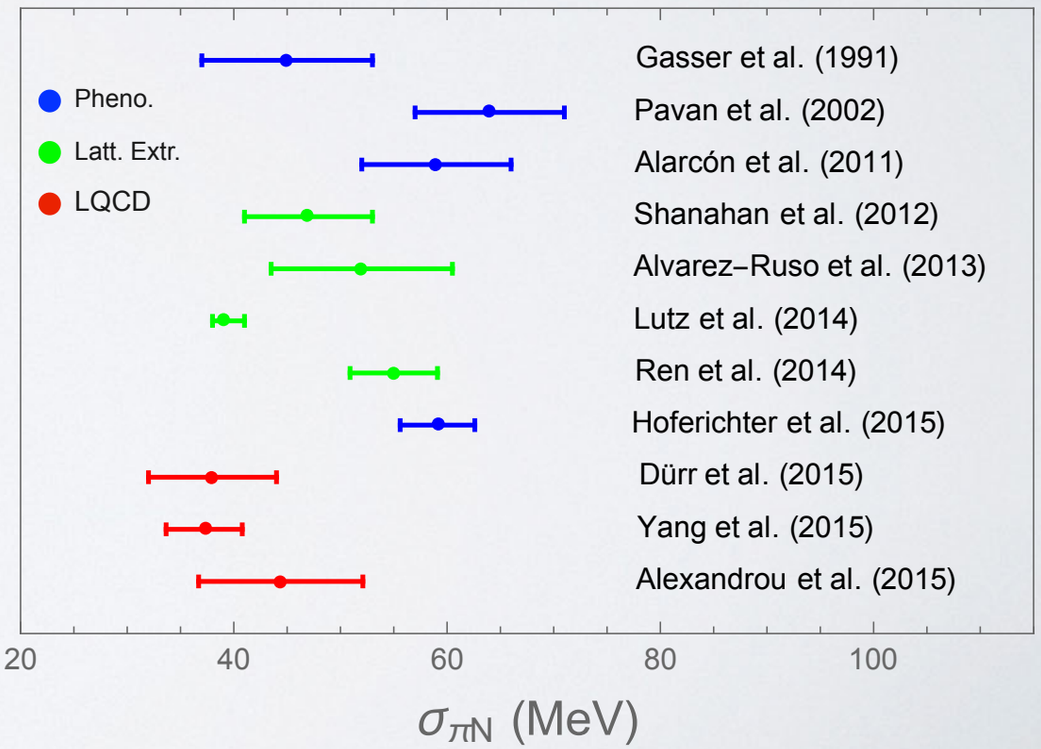

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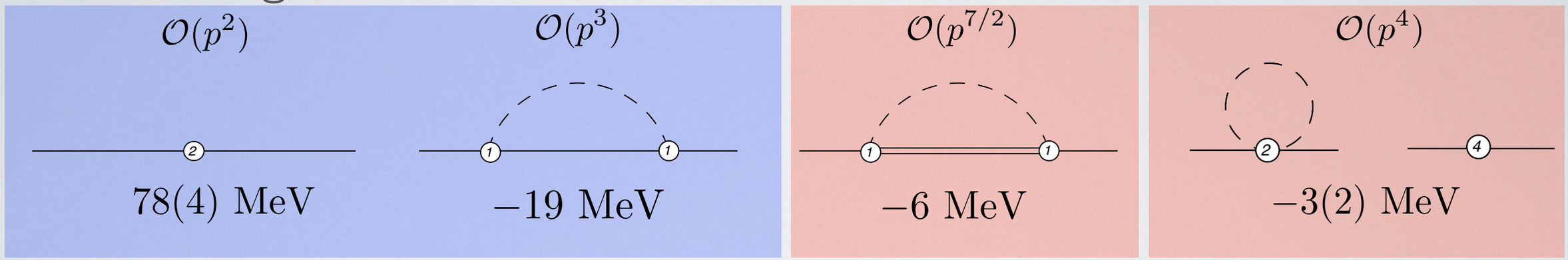

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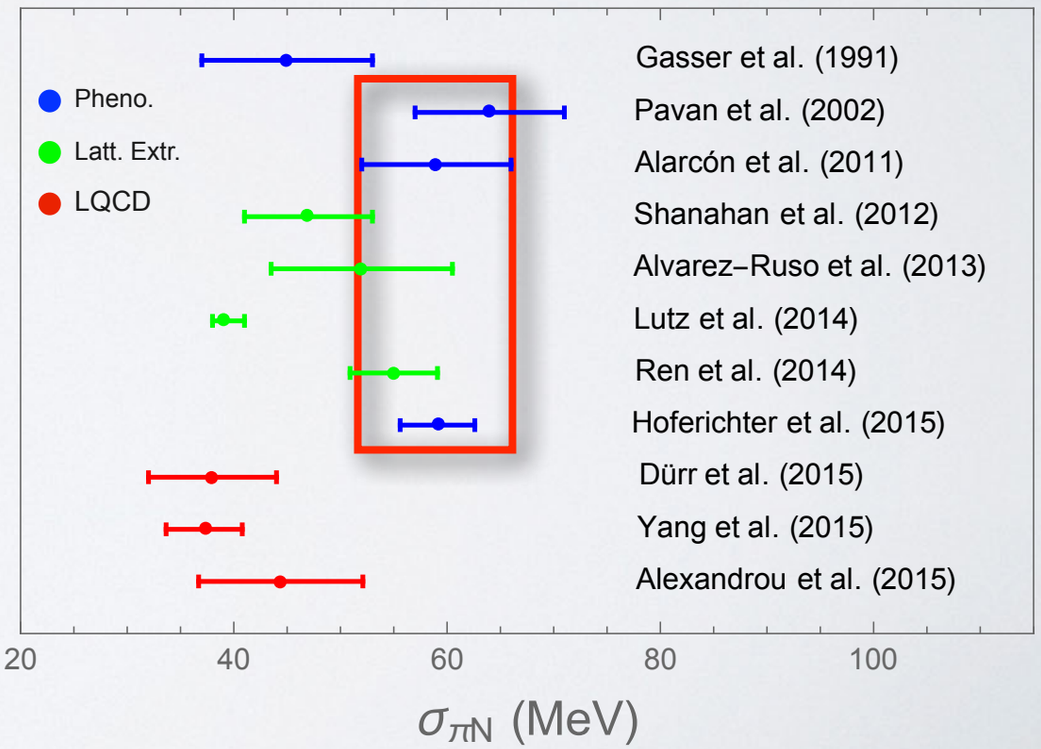

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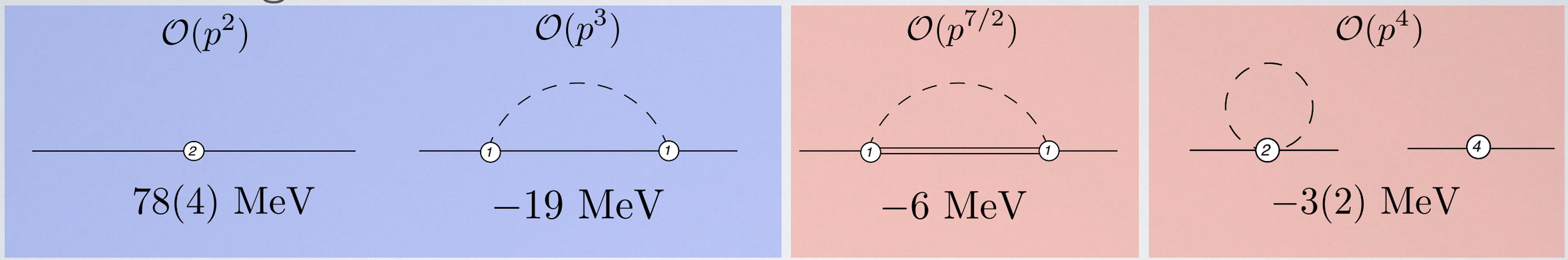

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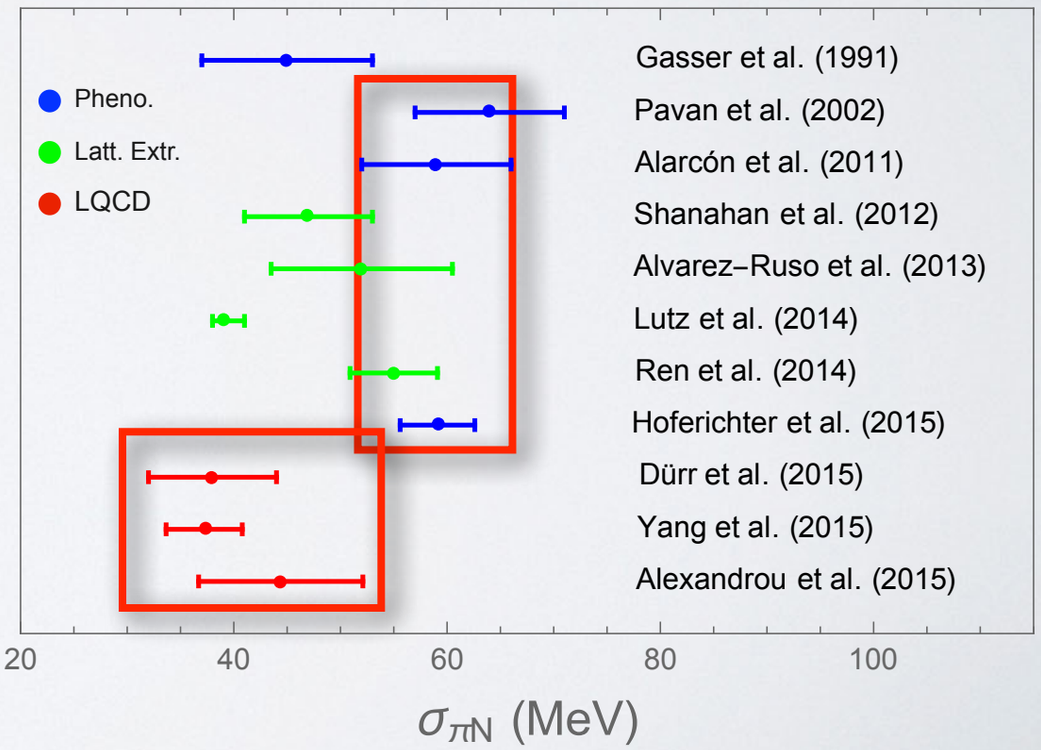

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$\sigma_0 = 35(5)$ MeV *[Gasser, Ann, of Phys. 136, 62 (1981)]*

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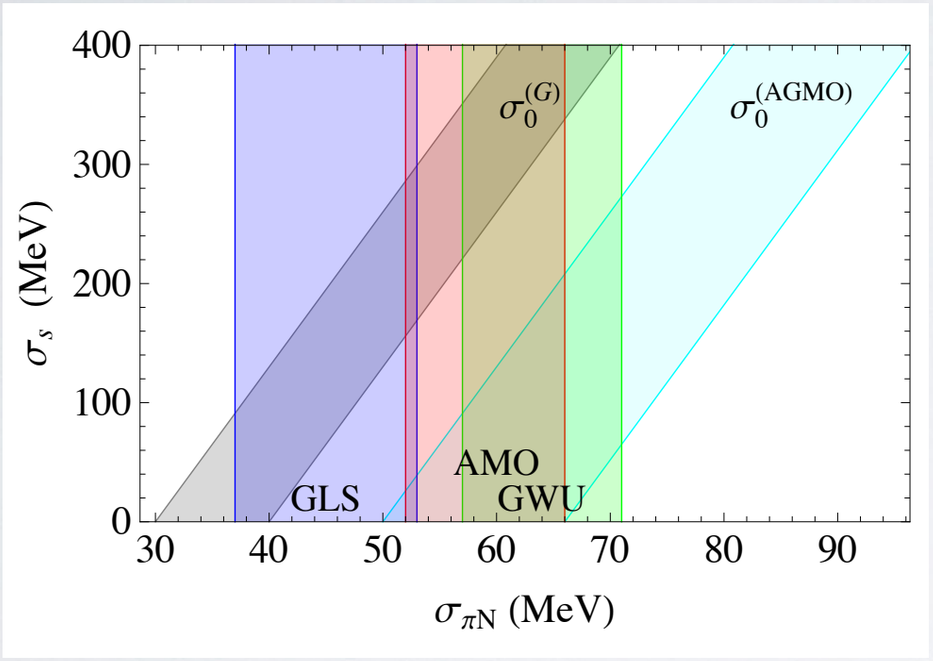

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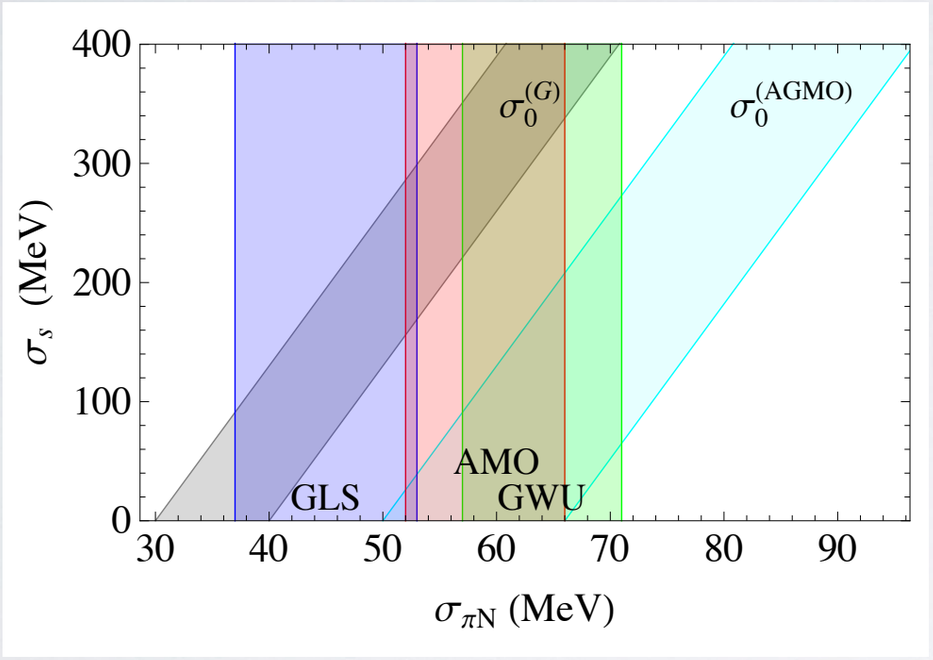

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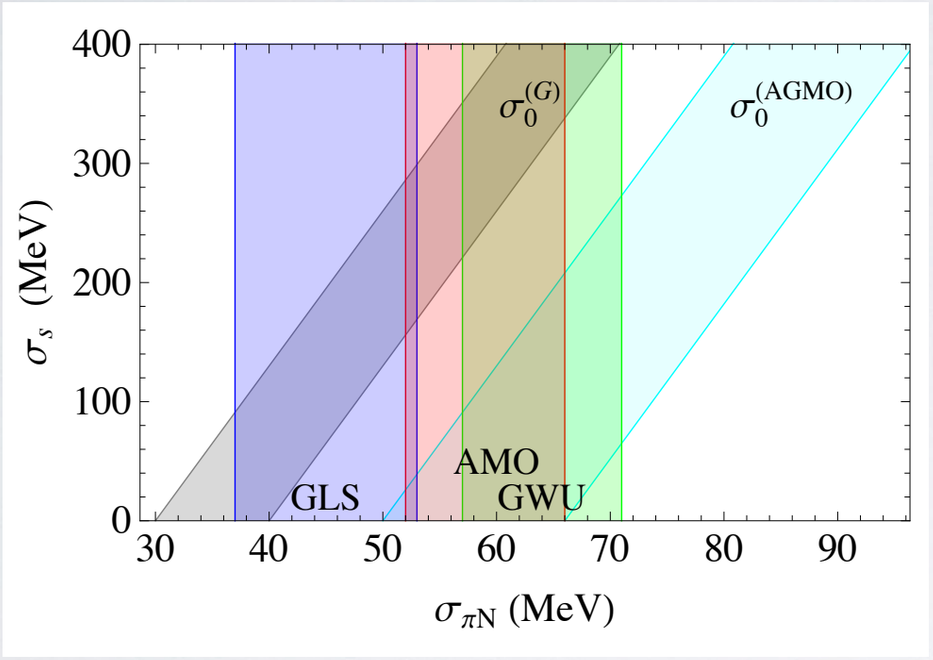

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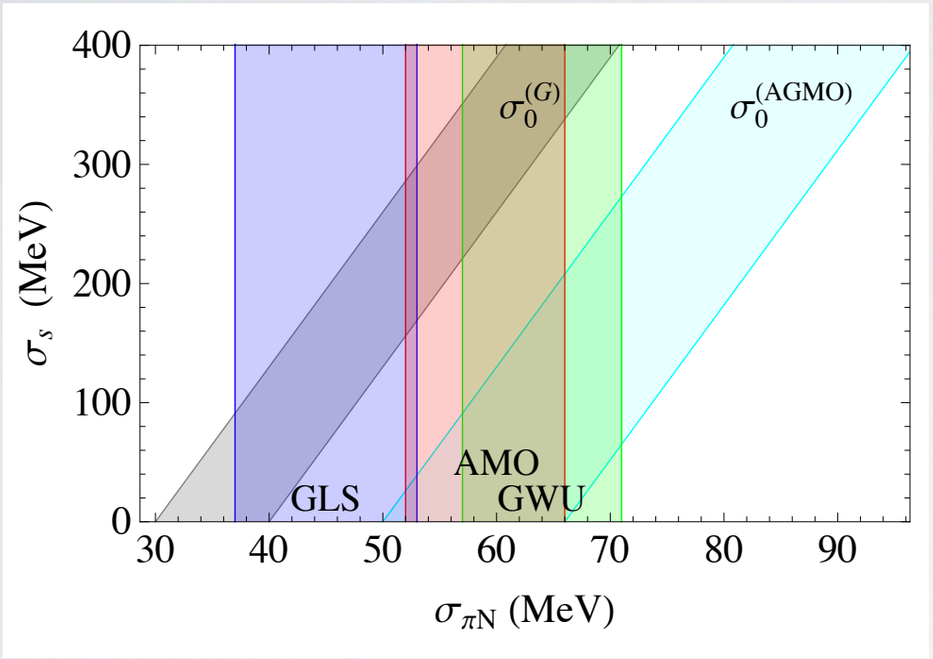

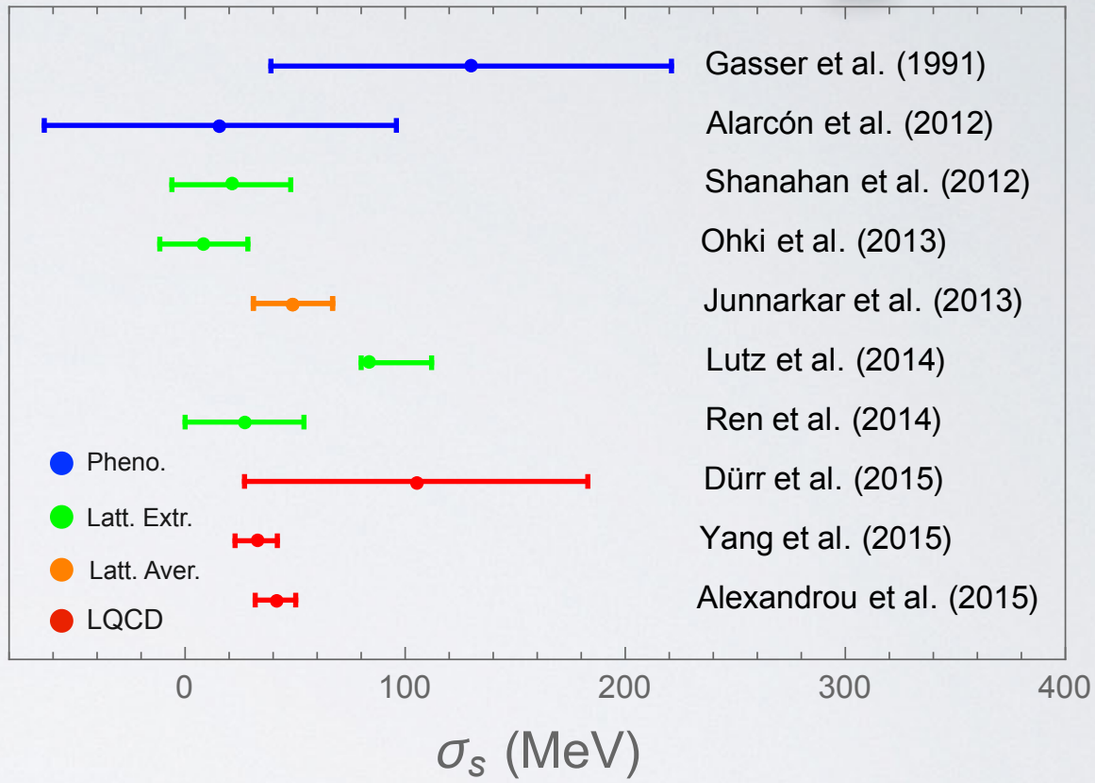

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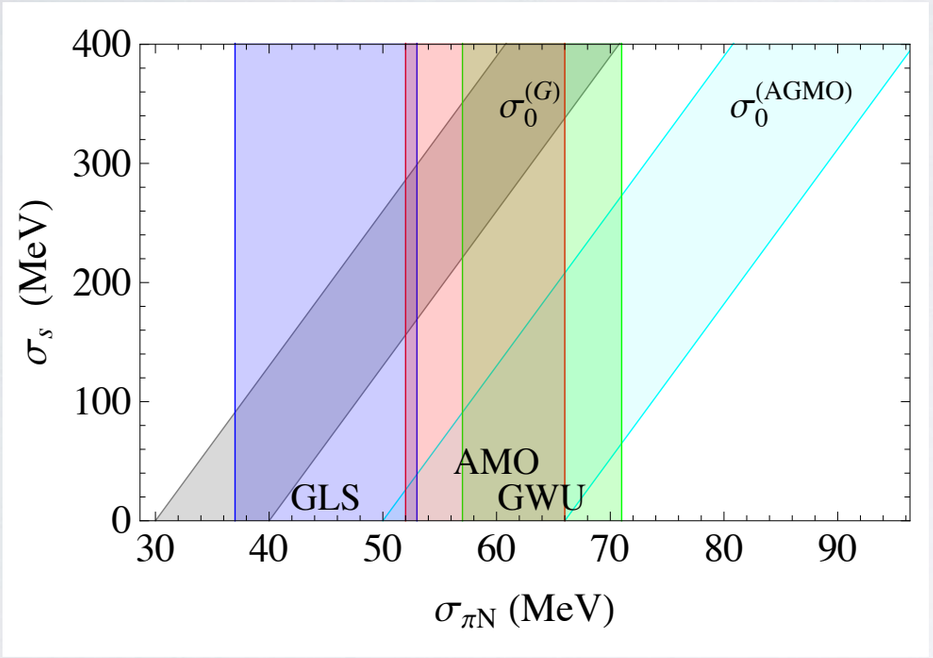

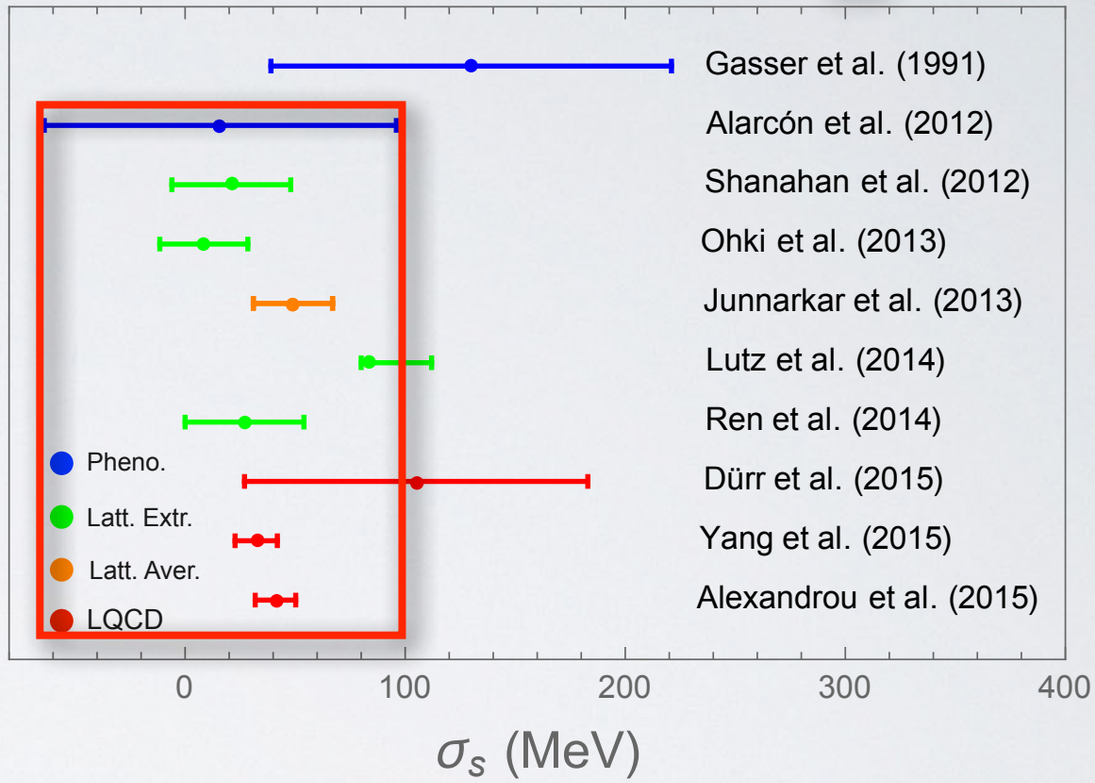

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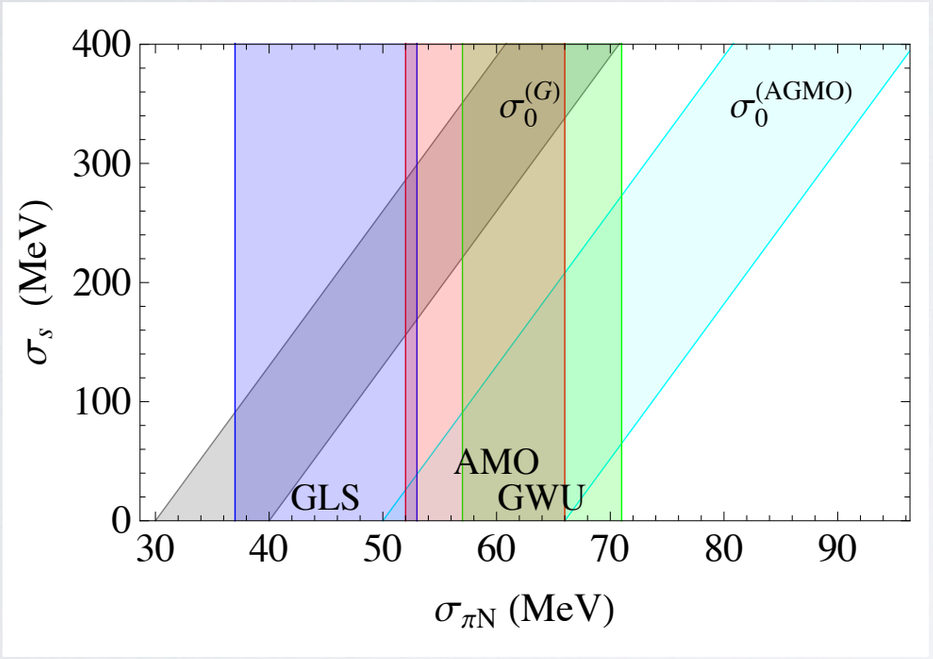

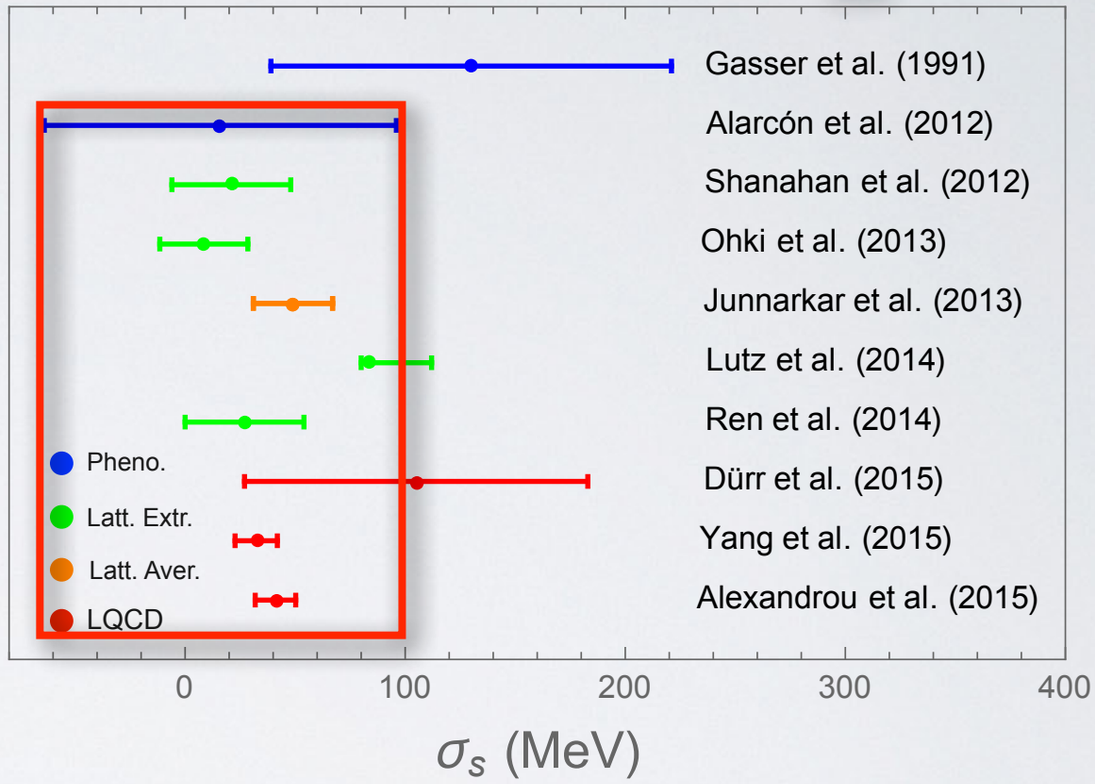

- A new scenario emerges:

	$\sigma_{\pi N}$	σ_0	σ_s	y
Old scenario	45(8)	35(5)	130(91)	0.23
New scenario	59(7)	58(8)	16(80)	0.02(13)

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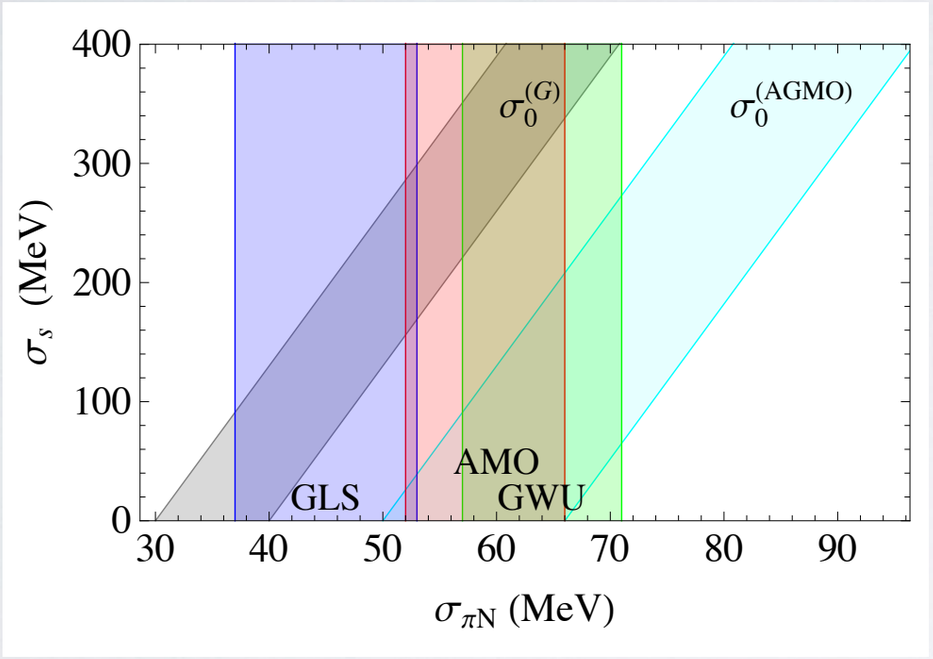

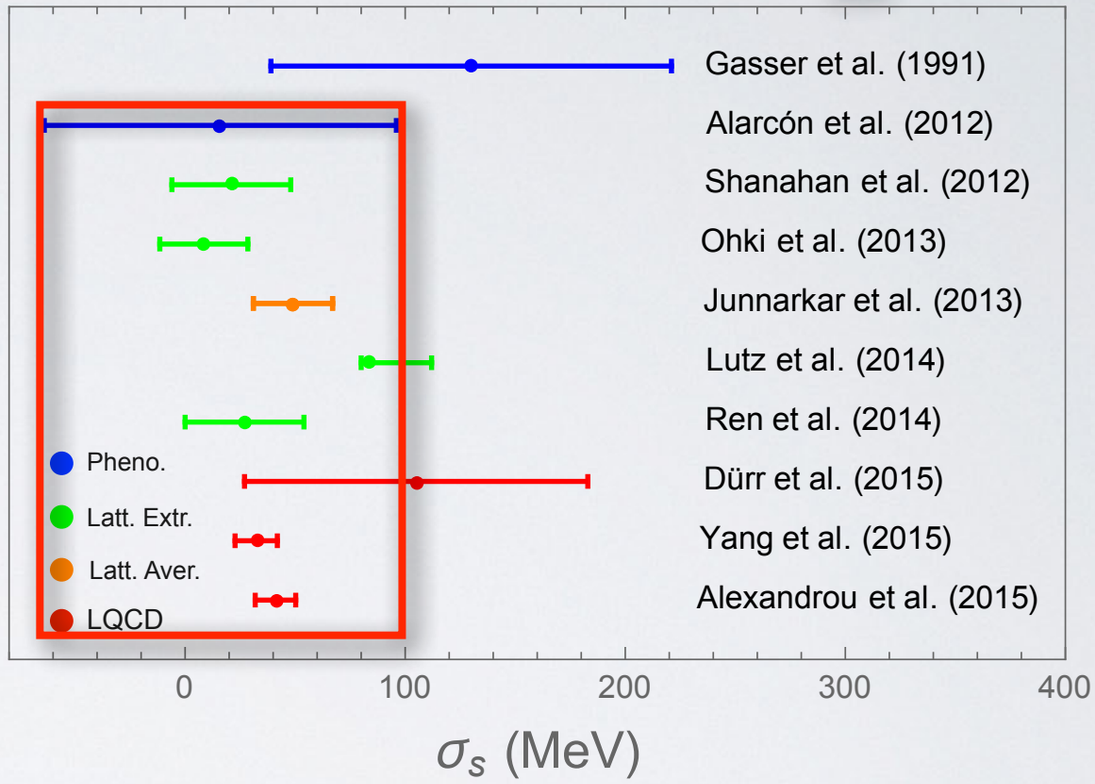

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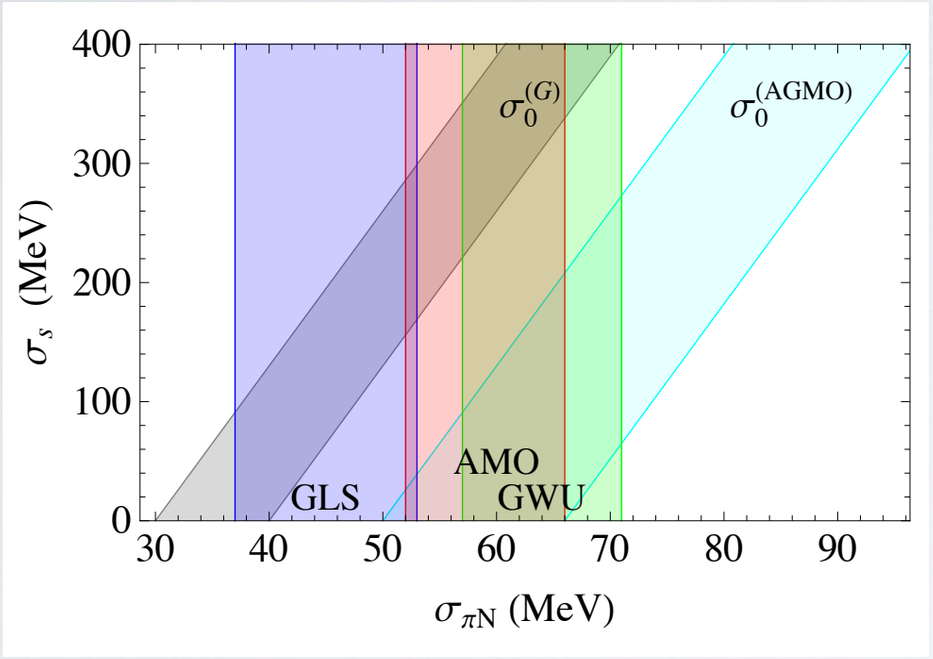

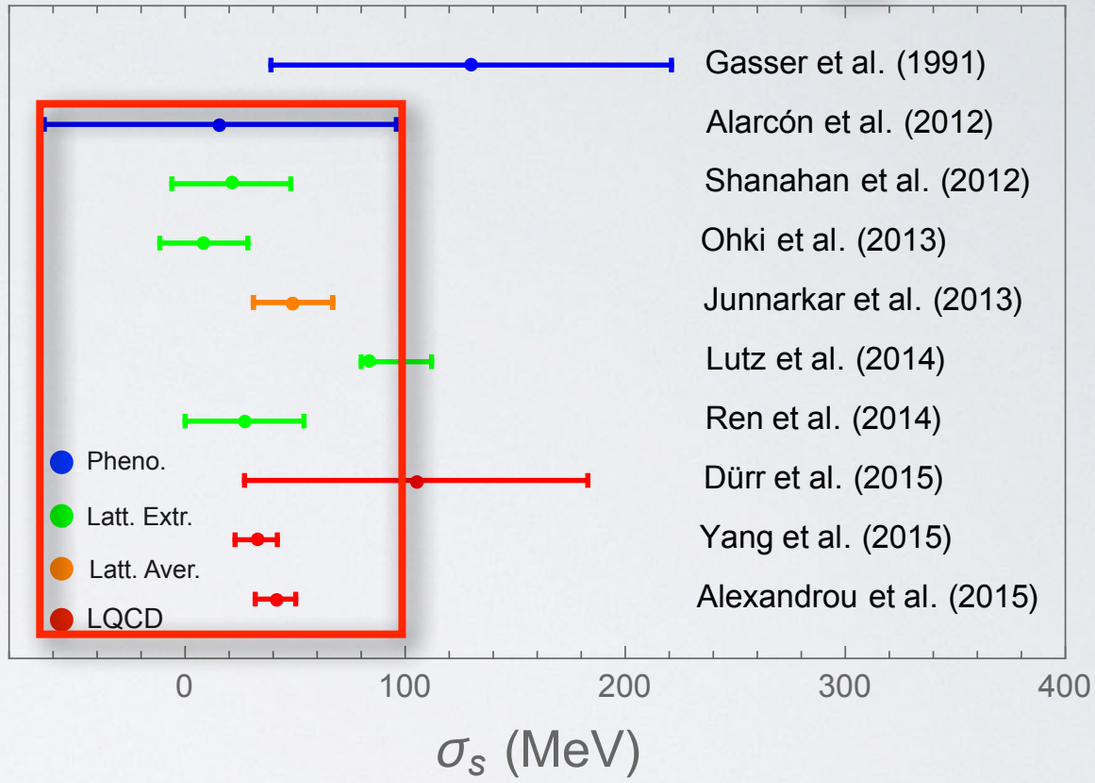

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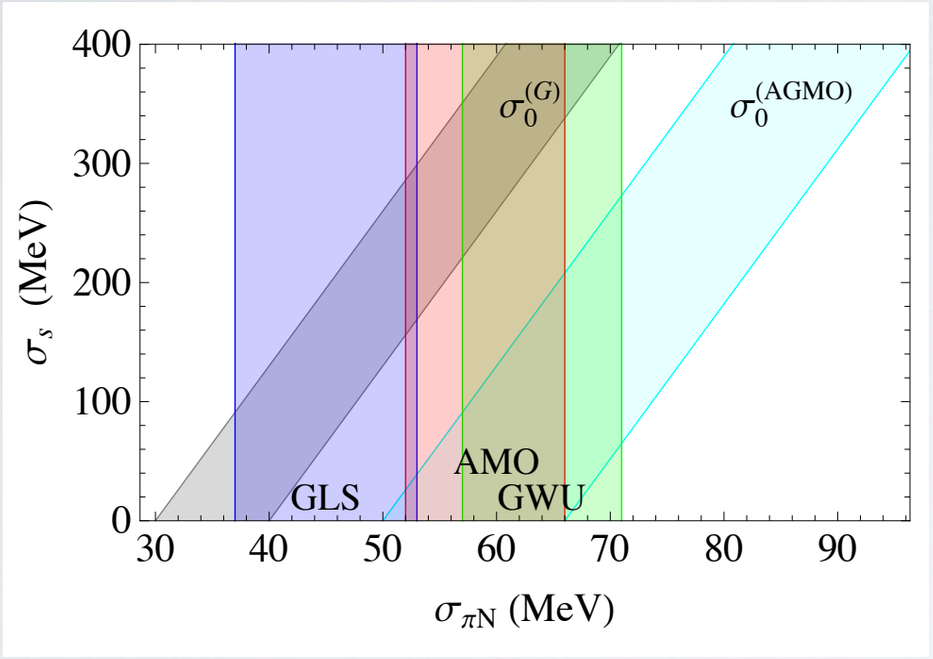

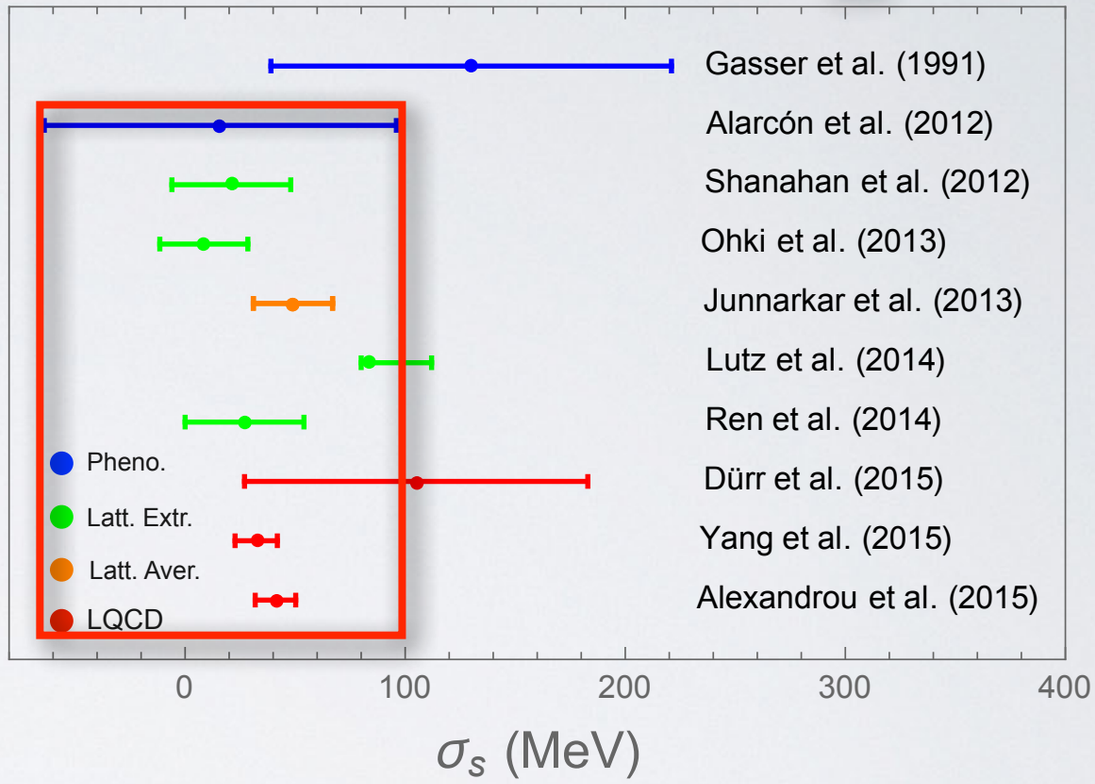

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- σ_s Compatible with LQCD.

Summary and Conclusions

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- Chiral EFT has made some important progress in the last years.
- It has provided some results, from first principles, required in searches of physics beyond the standard model.
- Relativistic baryon chiral EFT with explicit **Δ**(1232) pointed to a larger value of $\sigma_{\pi N}$ based on modern **πN** phase shifts + **π**-atoms scattering lengths:

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

[Alarcón, Martin Camalich and Oller, PRD 85 (2012)]

- This value is not at odds with a small strangeness content in the nucleon

$$\sigma_s = 16(80)\ \text{MeV}$$

[Alarcón, Geng, Martin Camalich and Oller, PLB 730 (2014)]

- Effective couplings for DM searches:

f_u^p	f_u^n	f_d^p	f_d^n	$f_s^{p,n}$	f_G	f_N
$0.021(2)$	$0.019(2)$	$0.041(5)$	$0.045(5)$	$0.017(85)$	$0.921(85)$	$0.28(7)$

FIN