Partial wave analysis of NN scattering data in chiral EFT

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The story so far...

Recently N^4LO semi-local momentum space regularized (SMS) potential [Eur. Phys. J. A54 (2018) 5, 86]

- New local regulator for long-range interaction
- Employs πN LECs from recent Roy-Steiner eq. analysis [Hoferichter et al. ‘15]
- NN contact LECs fitted to 2013 Granada database of NN scattering data

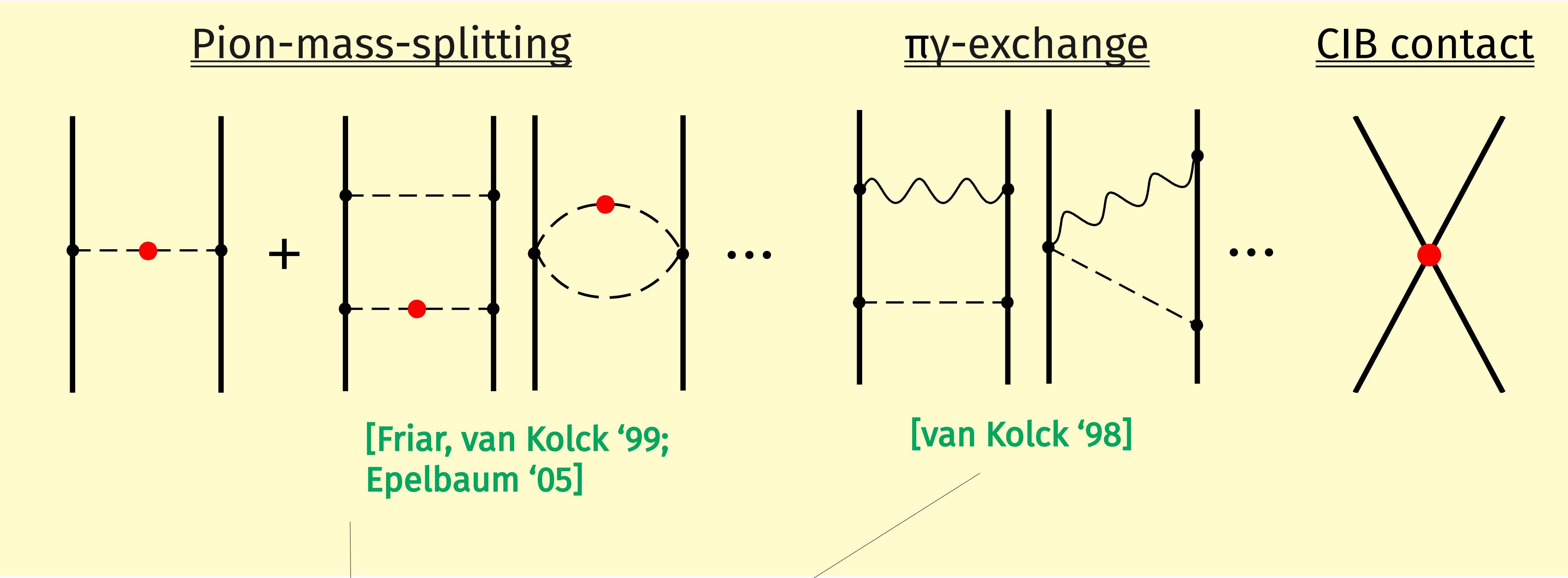
See talk by Evgeny Epelbaum

Introduction additional leading F-wave contact interactions (N^4LO^+) allowed precise description of data (χ^2/datum ~ 1)

Inclusion of isospin breaking effects limited to Pion-Mass splitting in OPE and charge-dependent short-range interactions in $^1S_0$

➡ Framework and precision allow to study full inclusion of IB effects

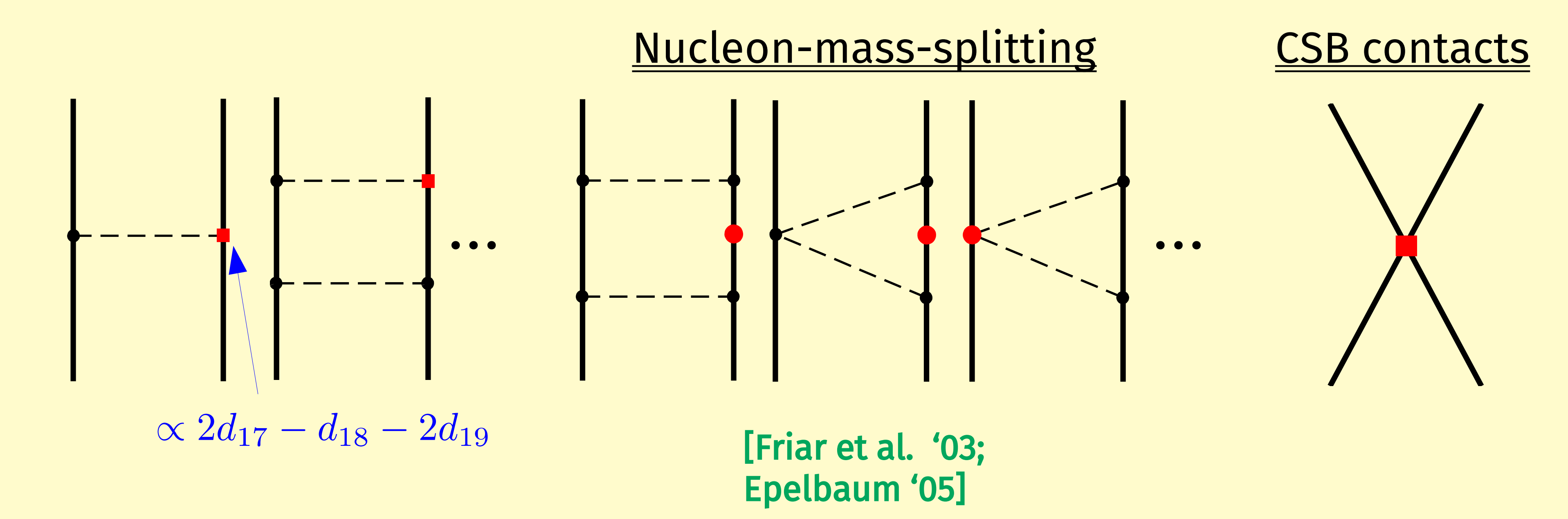
CIB interactions



Parameter-free for nuclear forces:

- $\delta M_\pi = M_{\pi^\pm} - M_{\pi^0}$
- Use physical pion masses: $M_{\pi^\pm} = 139.57$ MeV, $M_{\pi^0} = 134.98$ MeV

CSB interactions

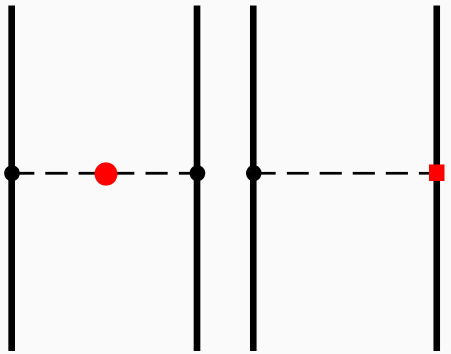


- Use physical nucleon mass shift $\delta m_N = -1.2933$ MeV where strong and e.m. mass shift contributions can be added together
- If not, use strong mass shift $\delta m_N^{\text{str.}} = -2.05$ MeV determined via Cottingham sum rule [Gasser, Leutwyler '82] See talk by Andre Walker-Loud

Have to determine:

- $2\mathrm{d}_{17} - d_{18} - 2d_{19}$ (contributes to CSB OPE and subleading CSB TPE)
- CSB contacts entering S- & P-Waves

Fitting of contacts & charge-dependent OPE



General OPE without Isospin limit:

$$V_{1\pi}(pp) = f_p^2\, V(M_{\pi^0})$$
$$V_{1\pi}(np) = -f_0^2\, V(M_{\pi^0}) + (-1)^{t+1} 2 f_c^2\, V(M_{\pi^\pm})$$
$$V_{1\pi}(nn) = f_n^2\, V(M_{\pi^0})$$

With $V(M_i) = -\frac{4\pi}{M_{\pi^\pm}^2} \frac{\vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_2 \cdot \vec{q}}{\vec{q}^2 + M_i^2}\,, \quad f_0^2 = f_p f_n$

- Fit 24 + 6 IB contact LECs + f_p, f_n, f_c = 33 parameters
- Combined fit of np- and pp- scattering data from self-consistent 2013 Granada database [Perez et al '13]
- Additional input: B_d=2.224575(9) MeV and b_{np}=-3.7405(9) fm
- Increase energy range of data to E_{lab} = 0 – 280 MeV

χ^2/datum E_{lab} = 0-280 MeV:	Without additional IB effects		With additional IB effects	
	1.023	→	**1.016**	$(\Lambda = 450\ \mathrm{MeV})$

Charge-dependence of OPE coupling

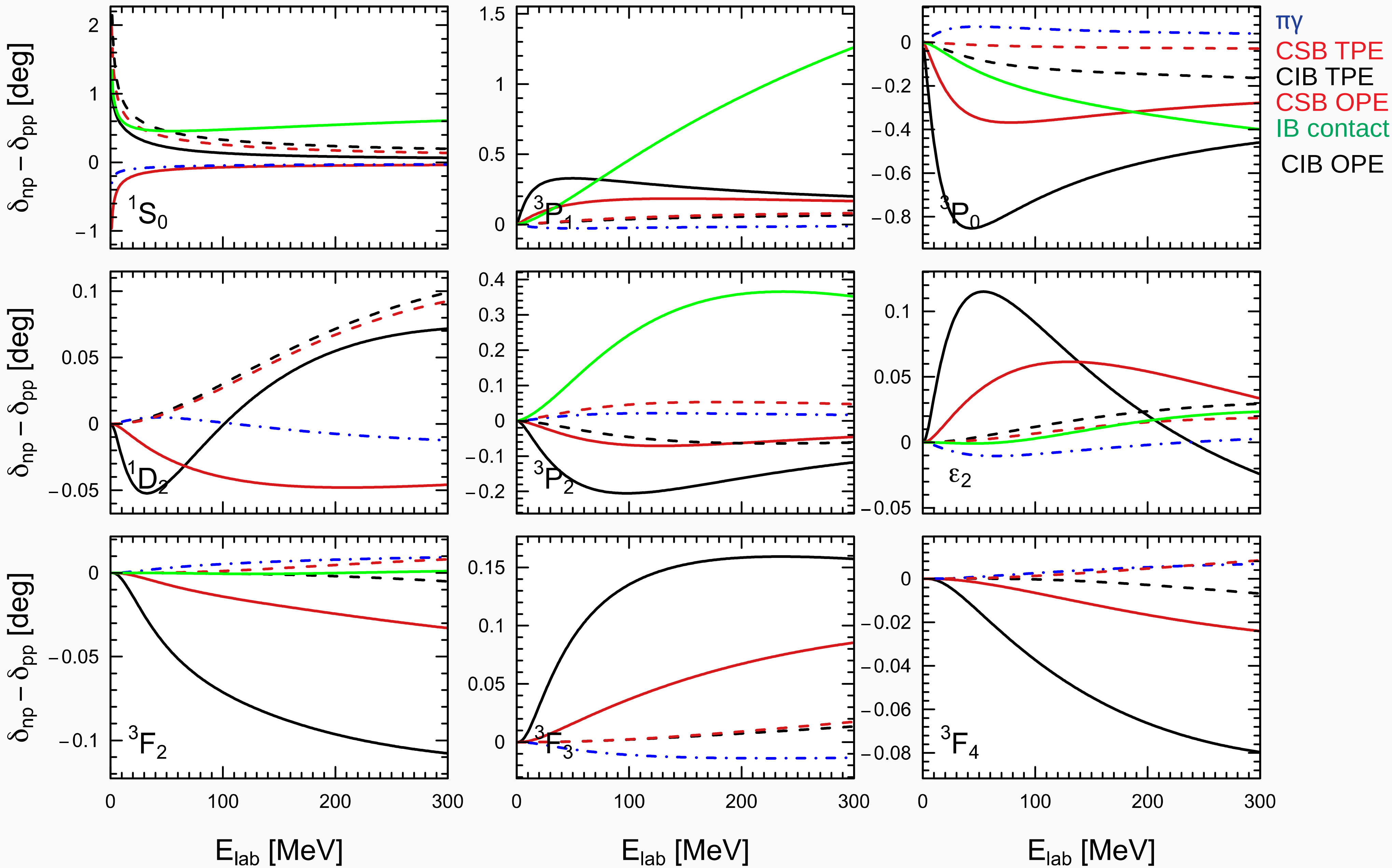
E_{lab} bin	SMS N^{4}LO$^+$	SMS N^{4}LO$^+$ add. IB
neutron-proton scattering data		
0–100	1.077	1.058 (+0.002)
0–200	1.070	1.055 (+0.002)
0–300	1.061	1.053 (+0.001)
proton-proton scattering data		
0–100	0.862	0.864
0–200	0.954	0.951
0–300	0.989	0.986

- Overall small improvement
- Largest effects for np data at low energies

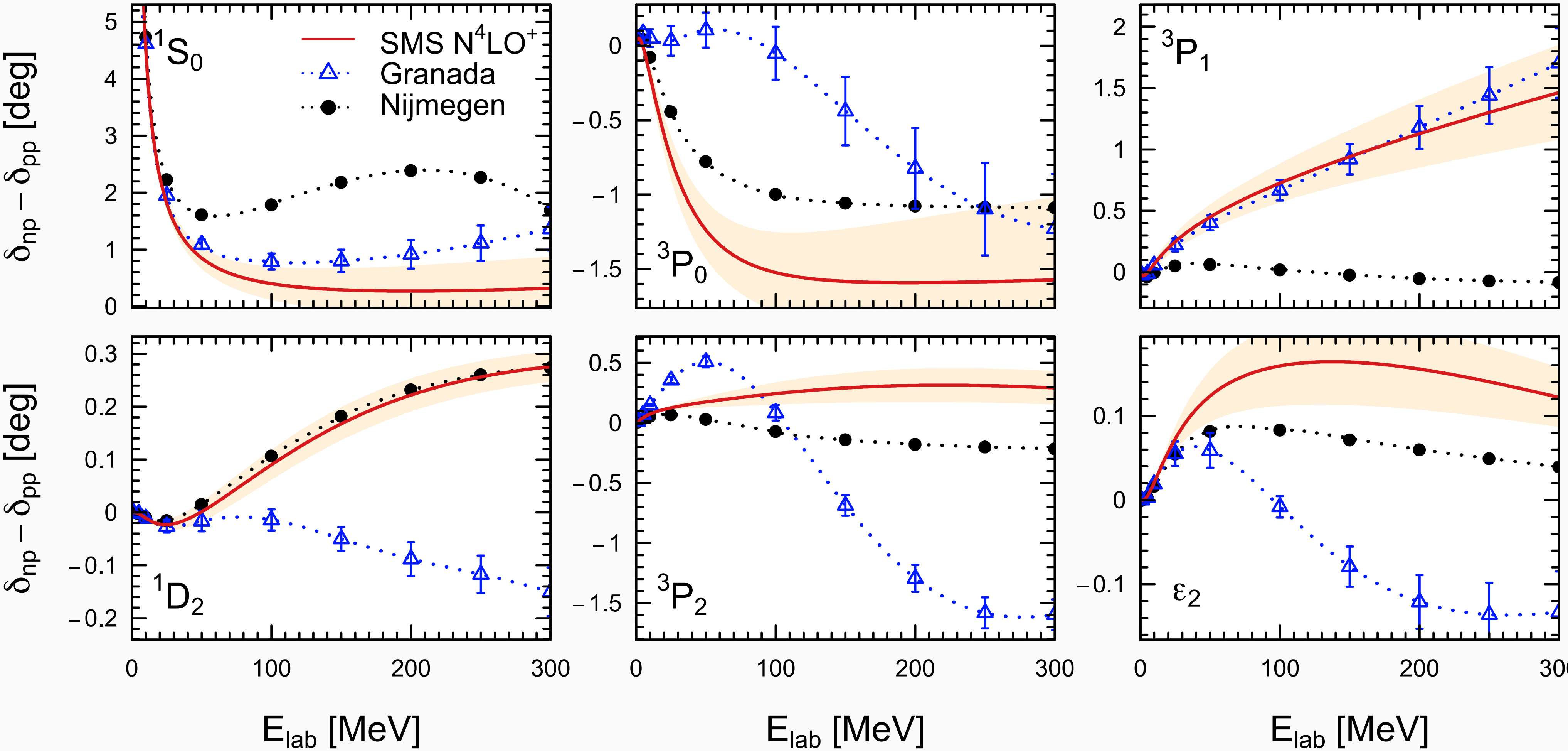
$(\Lambda = 450\ \text{MeV})$

	Nijmegen '93	Granada '17	N^{4}LO$^+$	
			$\Lambda = 450$ MeV	$\Lambda = 500$ MeV
f_p^2		0.0761(4)	0.0769(4)	0.0761(4)
f_0^2	0.075	0.0790(9)	0.0778(9)	0.0771(8)
f_c^2		0.0772(5)	0.0765(4)	0.0756(4)
		χ^2/datum:	**1.016**	**1.022**

np-pp phaseshift difference contrib. (preliminary)

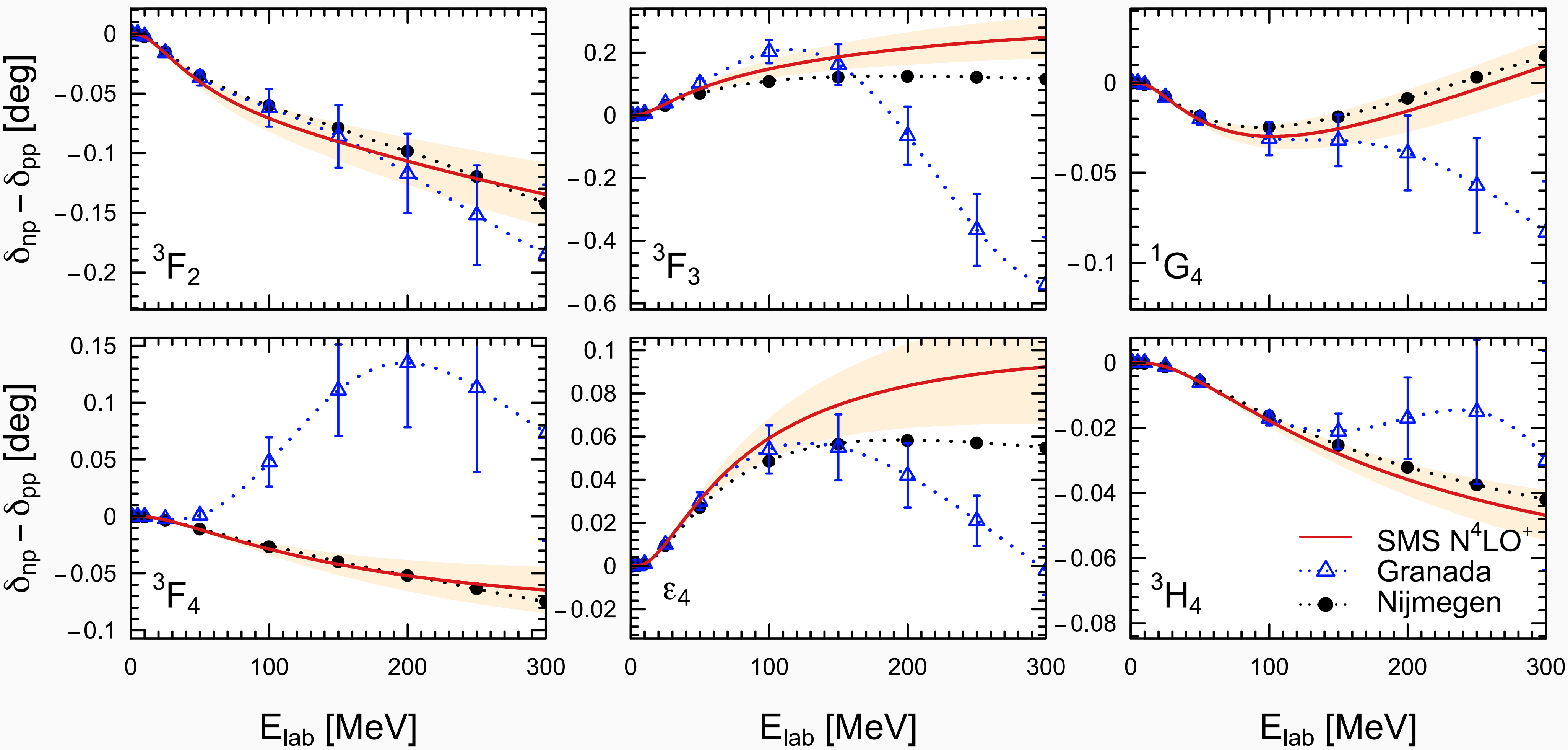


np-pp phaseshift difference (lower partial waves)



preliminary

np-pp phaseshift difference (higher partial waves)



preliminary

Isospin-breaking nn interaction (preliminary)

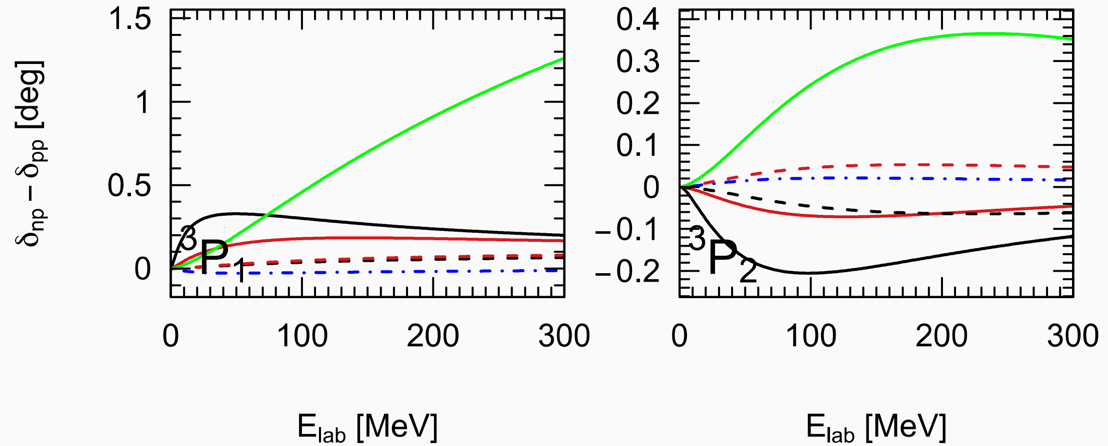
Pinning down (short-range) CSB effects is difficult due to our poor knowledge of the nn-interaction

Only used $^1S_0$ scattering length a_{nn} = -18.90 fm up to now (fix $\tilde{C}^{nn}_{1S0}$)

<u>What about IB C_i's?</u>

Large contributions from IB contact interactions in P-Waves:

Problem: How much of it is CIB / CSB ?



3N bound state energies (Λ=450 MeV, based on 2NF only):

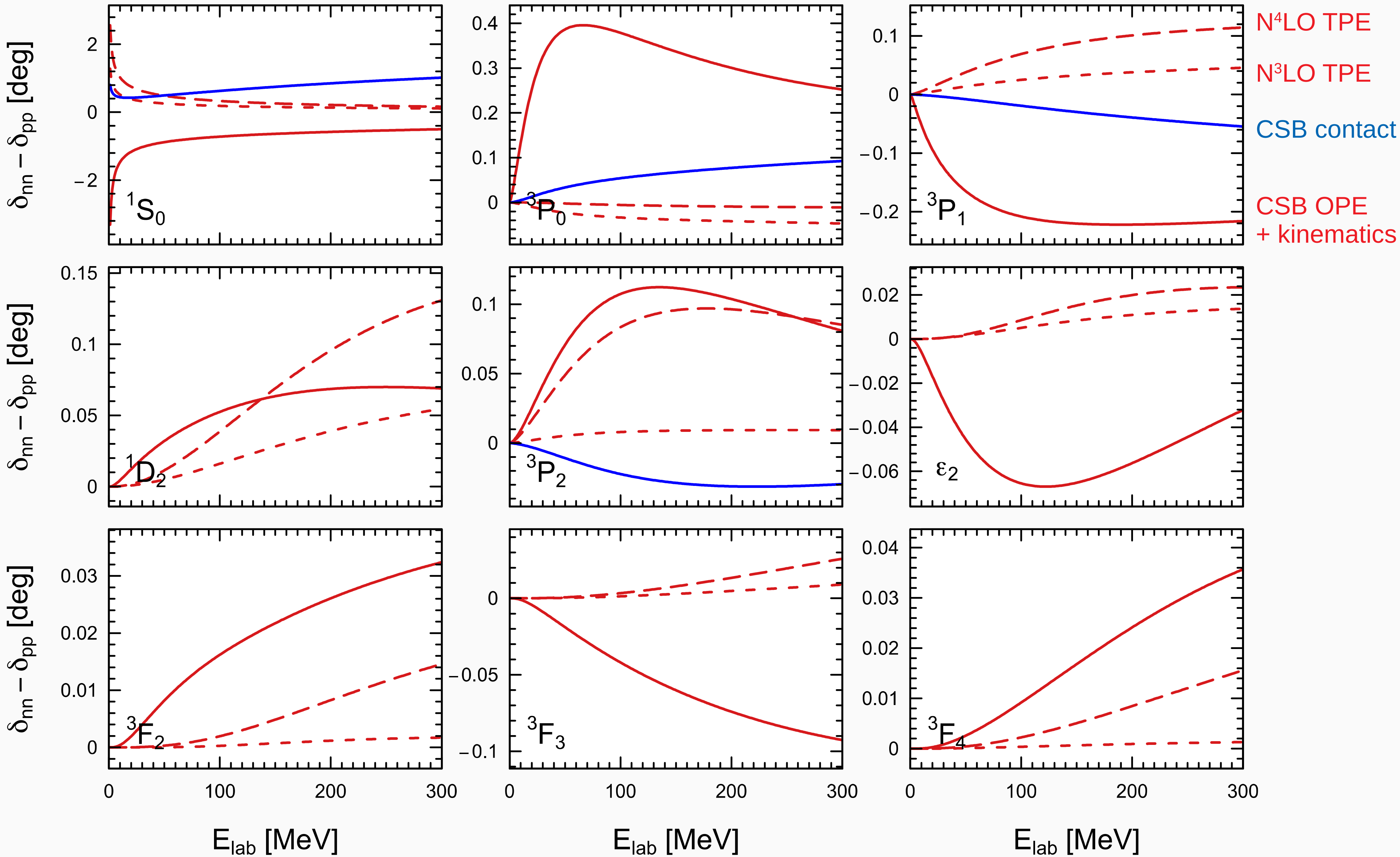
^{3}He: -7.368 MeV

^{3}H: -8.130 MeV (IB C_i's full CSB)

-8.090 MeV (IB C_i's full CIB)

→ 40 keV variation in binding energy difference

nn-pp phaseshift difference (preliminary)



Summary

1. Extension of SMS potential with complete treatment of isospin breaking effects
2. Small changes/improvements in np force & corresponding 2N observables at low energies
3. Results for charge dependence of OPE coupling constant are consistent with zero, but no definite statement yet
4. Lack of data to determine short-range IB details of nn force

Database

Use self-consistent 2013 Granada database
[Phys. Rev. C 88.064002]

- Includes scattering data from 50ies up to 2013
- uses ”3σ-criterion” to reject non-normal-distributed data
- rejection rate 0-300 MeV: np: 31%, pp: 11%

Comparison between theory and experiment via standard χ^2 approach:

$$\chi_j^2 = \sum_{i=1}^{n_j} \left(\frac{O_i^{exp} - Z O_i^{theo}}{\delta O_i} \right)^2 + \left(\frac{Z-1}{\delta_{sys}} \right)^2$$

- Z (inverse relative norm) is chosen to minimze χ^2_j