Perturbative computation of neutron-proton scattering observables using χEFT up to N^{3}LO

Workshop on Progress in Ab Initio Nuclear Theory
TRIUMF, Vancouver 2024-02-29

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Introduction

- Make predictions of nuclear properties from first principles.
  - A model: χEFT
  - A power counting (PC): Hierarchy of importance among interactions.
  - Data: To constrain unknown interaction strengths (LECs).

- Singular attraction $\Longrightarrow$
  1. Keep cutoff finite.
  2. Demand cutoff independence $\Longrightarrow$ need to modify PC.

A. Nogga *et al.*, Phys. Rev. C **72**, (2005)

Modified power counting

- Need promoted counterterms in attractive triplet *NN* partial waves.
- Corrections beyond leading order (LO) need to be treated perturbatively.
- One-pion exchange treated perturbatively for ($l > 1$).

The Long & Yang PC

order	potential	non-perturbative (at LO) channels	purely perturbative channels	cumulative # LECs
LO	$V^{(0)}$	$V_{1\pi}^{(0)} + V_{\rm ct}^{(0)}$	0	4
NLO	$V^{(1)}$	$V_{\rm ct}^{(1)}$	$V_{1\pi}^{(0)}$	6
$\mathrm{N^2LO}$	$V^{(2)}$	$V_{2\pi}^{(2)} + V_{\rm ct}^{(2)}$	0	19
$\mathrm{N^3LO}$	$V^{(3)}$	$V_{2\pi}^{(3)} + V_{\rm ct}^{(3)}$	$V_{2\pi}^{(2)}$	33

B. Long, C. J. Yang,
Phys. Rev. C **84**, (2011),
Phys. Rev. C **85**, (2012),
Phys. Rev. C **86**, (2012)

B. Long and U. van Kolck,
Ann. Phys. **323**, (2008)

Perturbative amplitudes

- LO amplitude is computed by solving the Lippmann-Schwinger equation:

$$T^{(0)} = V^{(0)} + V^{(0)} G_0^+ T^{(0)}$$

- Sub-leading amplitudes are computed perturbatively:

$$\begin{aligned}
T^{(1)} &= \Omega_-^\dagger V^{(1)} \Omega_+, \\
T^{(2)} &= \Omega_-^\dagger \left(V^{(2)} + V^{(1)} G_1^+ V^{(1)} \right) \Omega_+, \\
T^{(3)} &= \Omega_-^\dagger \Big(V^{(3)} + V^{(2)} G_1^+ V^{(1)} + V^{(1)} G_1^+ V^{(2)} + \\
&\quad + V^{(1)} G_1^+ V^{(1)} G_1^+ V^{(1)} \Big) \Omega_+
\end{aligned}$$

$$\begin{aligned}
\Omega_+ &= \mathbb{1} + G_0^+ T^{(0)}, \\
\Omega_-^\dagger &= \mathbb{1} + T^{(0)} G_0^+,
\end{aligned}$$

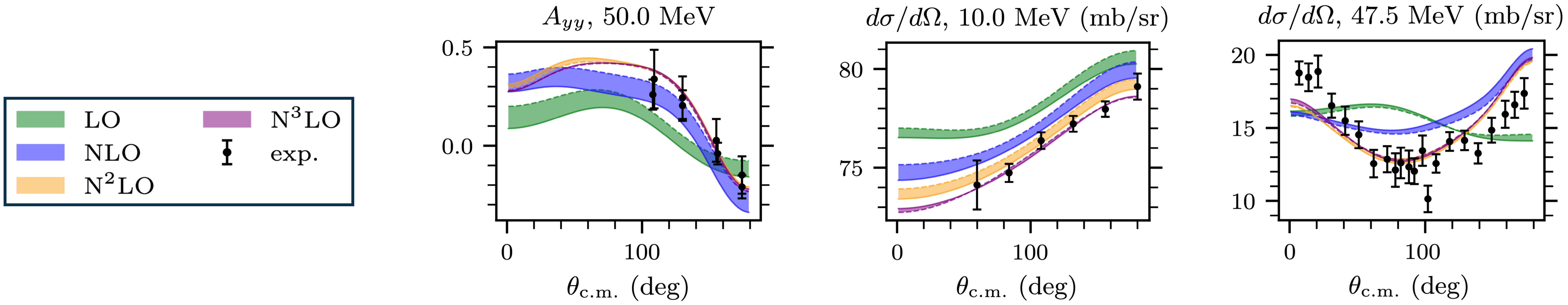
Outline of our work

- We are interested in studying the predictive power of the Long & Yang PC.
  - Confirm that scattering observables can be described.
  - Use data to infer LECs and construct quantitative potentials.

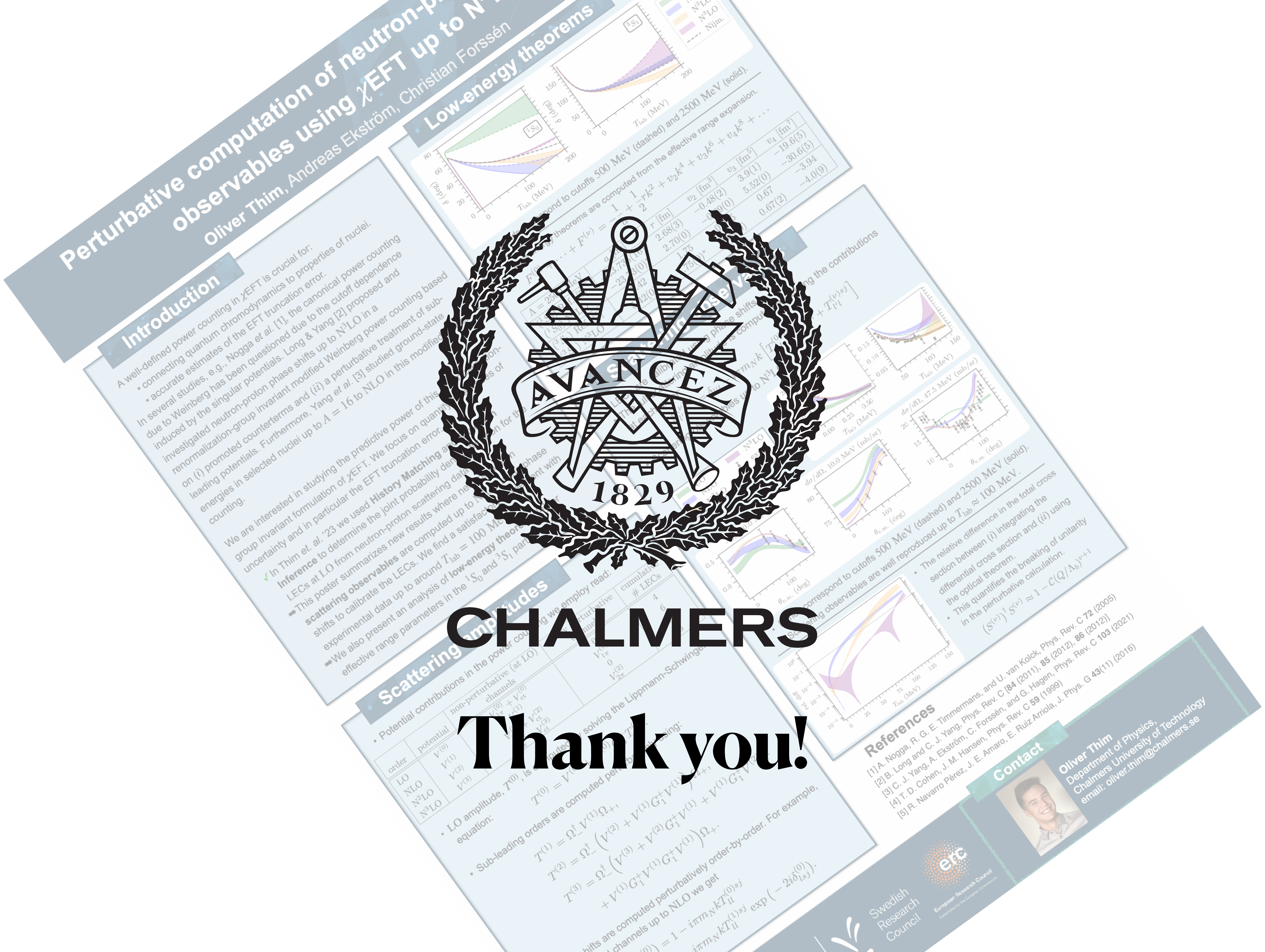
OT, E. May, A. Ekström, and C. Forssén, Phys. Rev. C **108**, (2023)
OT, A. Ekström, and C. Forssén, arXiv:2402.15325, (2024)

  - Study the convergence and breakdown of Δ-less and Δ-full χEFT.
  - Compute and predict bound-state properties in nuclei.

Neutron-proton scattering observables



- Conclusions:
  - Works sufficiently well to warrant a more detailed inference.
  - Hints that the breakdown scale can be as low as $\sim 200 - 300$ MeV.



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Thank you!