Bayesian Analysis of χEFT at Leading Order in a Modified Weinberg Power Counting

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Introduction

- Make predictions of nuclear properties in a well founded EFT framework

  - A model: χEFT — from low energy QCD
  - Power counting (PC): orders contributions to observables; LO, NLO, …
  - Data: to constrain low energy constants (LECs) $\Longrightarrow$ construct interaction models

- Weinberg PC have problems already at LO caused by the singular attraction of the one-pion exchange potential

A. Nogga, R. G. E. Timmermans, and U. van Kolck, Phys. Rev. C **72**, 054006 (2005)

$\Longrightarrow$ One solution is to promote additional contact terms to LO to counteract the singular behavior

Modified LO potential in χEFT

$$\langle \boldsymbol{p}' | V | \boldsymbol{p} \rangle = \frac{1}{(2\pi)^3} \left[\underbrace{-\frac{g_A^2}{4f_\pi^2} \frac{(\boldsymbol{\sigma}_1 \cdot \boldsymbol{q})(\boldsymbol{\sigma}_2 \cdot \boldsymbol{q})}{\boldsymbol{q}^2 + m_\pi^2} (\boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2)}_{\text{One pion exchange (OPE)}} + \underbrace{\tilde{C}_{^1S_0} + \tilde{C}_{^3S_1} + (C_{^3P_0} + C_{^3P_2})\, p' p}_{\text{Contact interactions}} \right]$$

B. Long, C. J. Yang, Phys. Rev. C **85**, 034002 (2012)

B. Long, C. J. Yang, Phys. Rev. C **86**, 024001 (2012)

LO contains only partial waves with $l \leq 1$ as well as $^3D_1$ and $^3F_2$

- This potential studied by Yang *et al.* C. J. Yang, A. Ekström, C. Forssén, and G. Hagen, Phys. Rev. C **103**, 054304 (2021)
  - Found that at LO the nuclear-binding mechanism fails for some nuclei with $A > 4$
  - LECs overfitted to phase shifts is a potential cause

Systematic Bayesian Inference

- Bayesian inference of LECs across a large range of momentum cutoffs

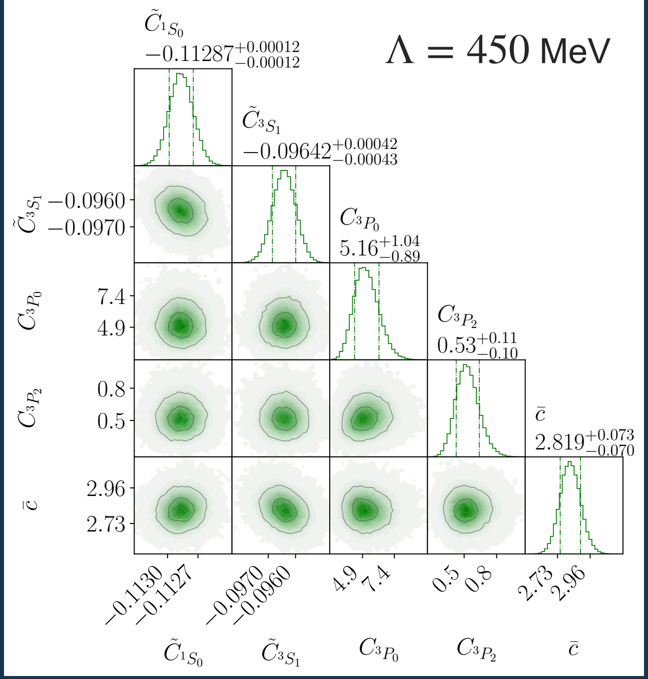
O. Thim, E. May, A. Ekström, C. Forssén, arXiv:2302.12624 (2023)

  - Theory of renormalization of singular potentials and study appearing limit cycles
  - History matching
  - Sample posteriors for LECs across momentum cutoffs $\Lambda = 400$ to 4000 MeV
  - Infer the magnitude of the EFT truncation error ($\bar{c}$) at each cutoff

R. J. Furnstahl *et al.*, Phys. Rev. C **92**, 024005 (2015)

  - Demonstrate RG-invariant posterior predictive distributions (ppds) for np - observables

Bayesian Posterior



Posterior $p\,(\boldsymbol{\theta}|D, I)$

$$\boldsymbol{\theta} = \left(\underbrace{\tilde{C}_{^1S_0}, \tilde{C}_{^3S_1}, C_{^3P_0}, C_{^3P_2}}_{\text{LECs}}, \bar{c}\right)$$

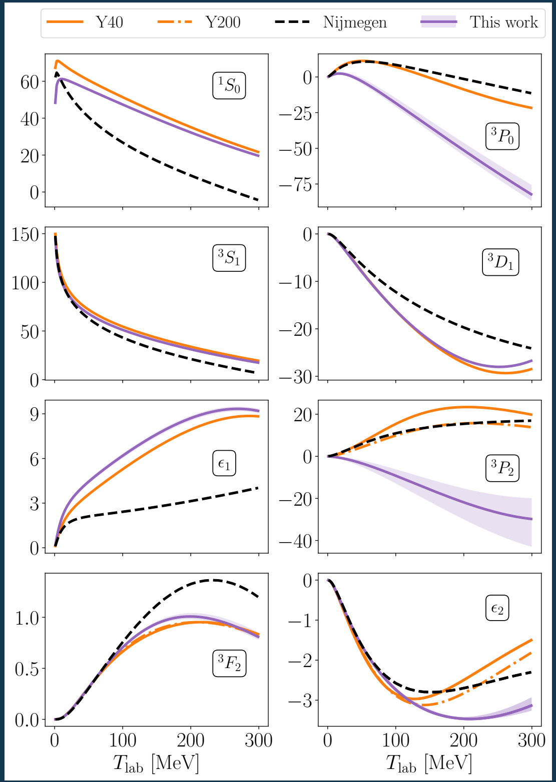
LECs

$\bar{c}$: magnitude of EFT error

S: 10^4 GeV^{-2}, *P*: 10^4 GeV^{-4}

Bayesian ppds

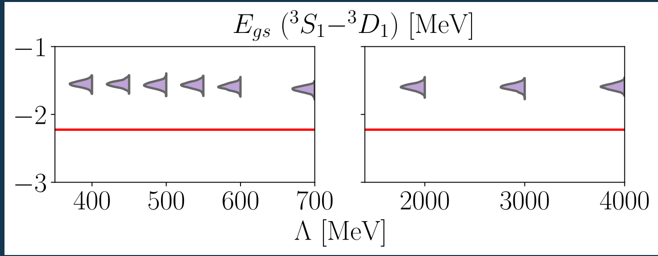
δ [deg], $\Lambda = 450$ MeV



$$p\left(y|D,I\right) = \int d\boldsymbol{\theta}\; p\left(y|\boldsymbol{\theta},D,I\right) p\left(\boldsymbol{\theta}|D,I\right)$$

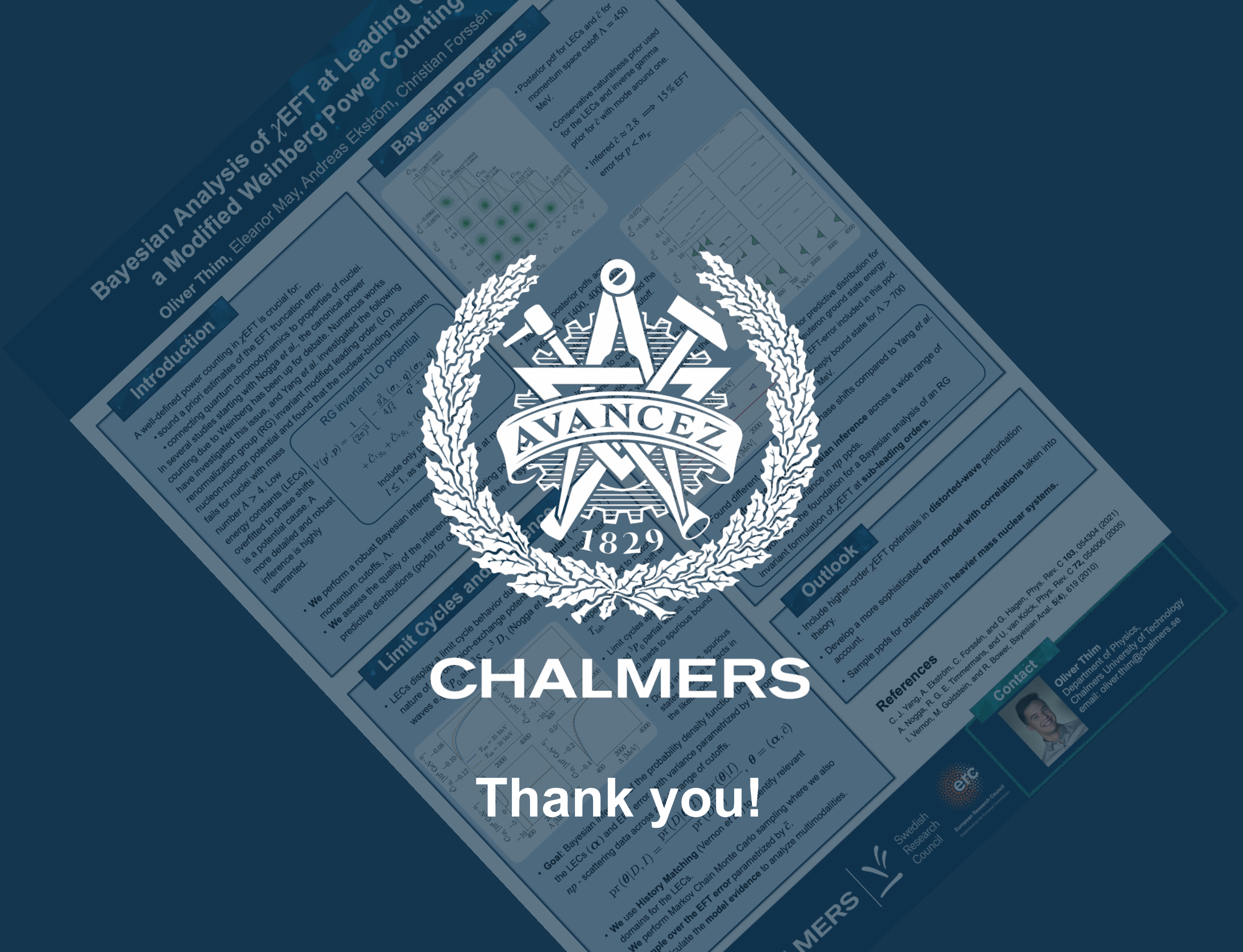
- Y40 and Y200 from C. J. Yang *et al.* Phys. Rev. C **103**, (2021)

Posterior predictive distribution for the deuteron ground state energy



Outlook

- Include subleading orders in distorted wave perturbation theory
- Investigate EFT convergence, e.g. Lepage plots
- Compute predictions in heavier nuclei
- Develop and use more sophisticated error models
- Compare different power counting proposals in a quantitative Bayesian framework



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Thank you!