Workshop on Three-Nucleon Interactions and Nuclear Dynamics

Beckmanns Hof, Ruhr University Bochum

Dec 8 – 12, 2025

European Research Council

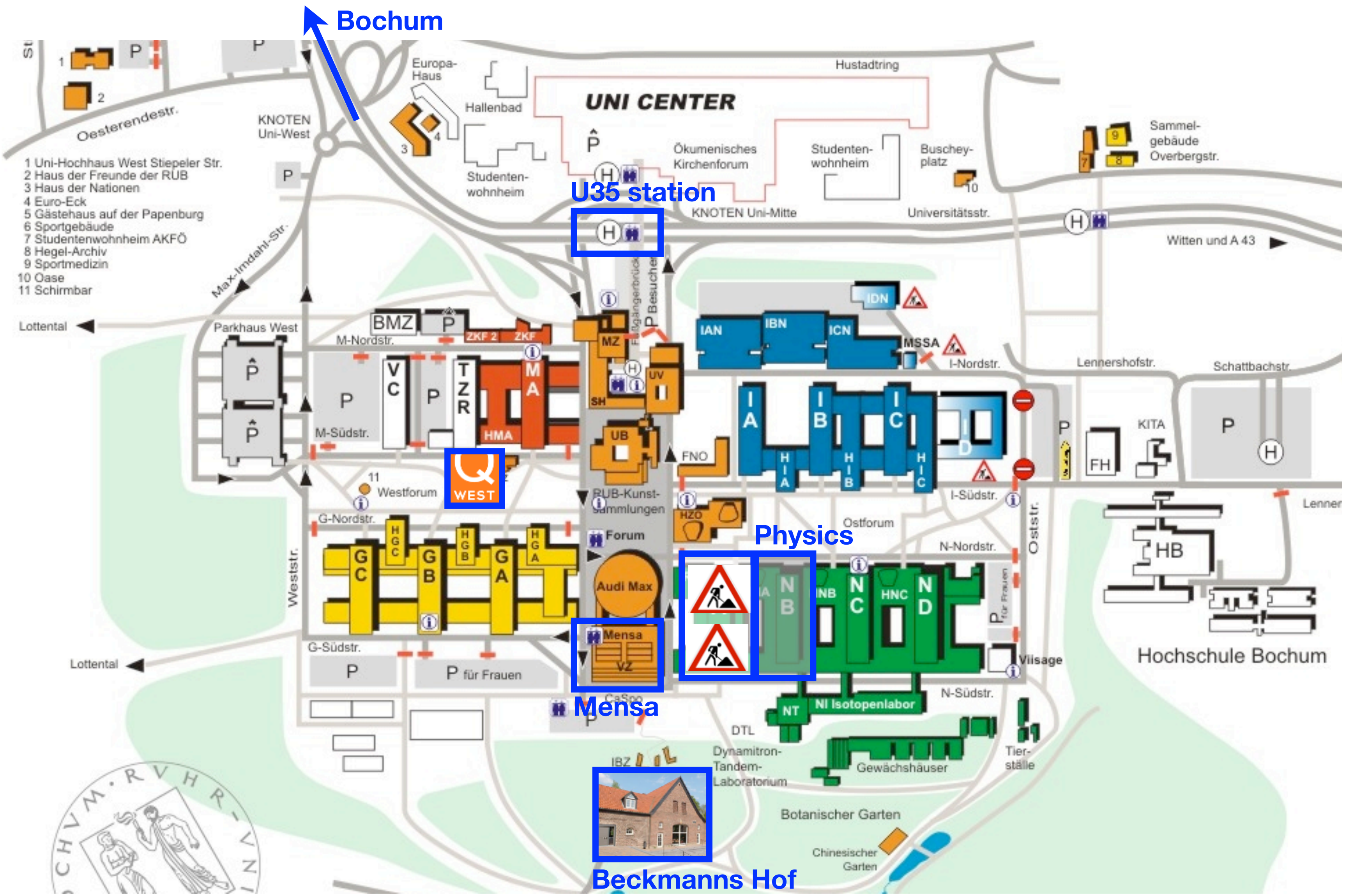
TOMOE

A bit of history…

January 2025 at Tohoku University in Sendai

Ruhr University Bochum gets on Japanese TV…

Organizational remarks



Menu for Mensa can be found here, and for Q-West here.

Workshop on Three-Nucleon Interactions and Nuclear Dynamics

	Monday	Tuesday	Wednesday	Thursday	Friday
9:30 am – noon	Talks	Talks	Talks	Talks	Talks
	Lunch	Lunch	Lunch	Lunch	Lunch
2:00 pm – 5:00 pm	Talks	Free discussions	Free discussions	Talks	

— Talks are for 20 + 5 or 40 + 10 min

— Feel free to ask questions during the talks!

— We plan to post talks online (upon your permission)

— For discussions, you can use this room (available till 5pm) or office space at TP2

— Coffee breaks are taken in a separate room (called „Tours“)

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9:30 am	Talks	Talks	Talks	Talks	Talks
noon	Welcome lunch	Lunch	Lunch	Lunch	Lunch
2:00 pm	Talks	Free discussions	Free discussions	Talks	
5:00 pm	Christmas market in Bochum		Dinner together in Dortmund + Opera Turandot	Workshop dinner	

Organizational remarks

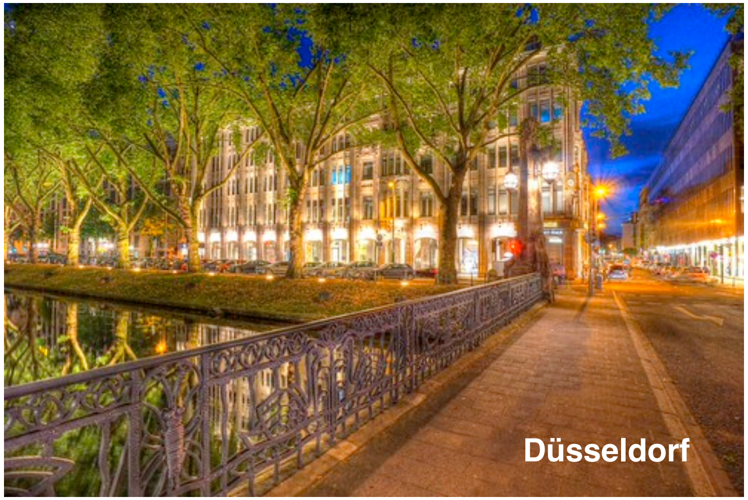
For dinner, you can find a plenty of restaurants in the Bochum downtown area, e.g. around Bermuda3eck

Some inspiration for free time:

— a small village near Bochum with a nice old town (half-timbered houses)

— easily reachable from Bochum via tram U308

— has a nice Christmas market



— takes about 40 min by train from Bochum HbF

Traveling recommendations

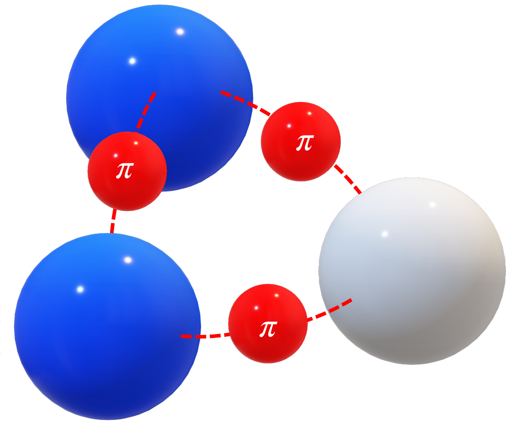
Plan sufficient time for your travel (especially on the way to the airport!)

Use the app DB Navigator (allows to buy tickets and provides information on delays)

Alternatively, use this page to get information about delays

Workshop on Three-Nucleon Interactions and Nuclear Dynamics

— scientific introduction —



JUNE 15, 1939 PHYSICAL REVIEW

Many-Body Interactions in Atomic and Nuclear Systems

H. PRIMAKOFF, *Polytechnic Institute of Brooklyn, Brooklyn, New York*

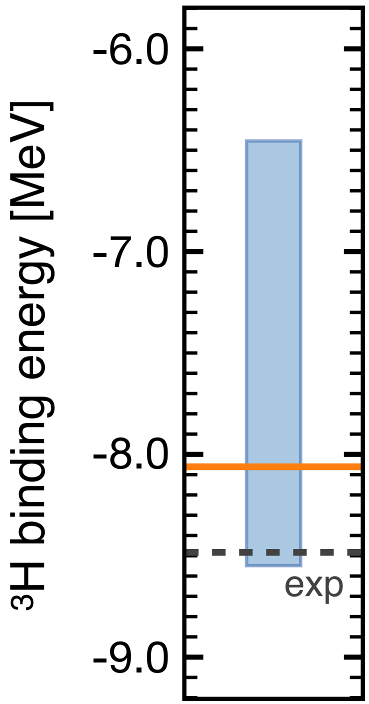
AND

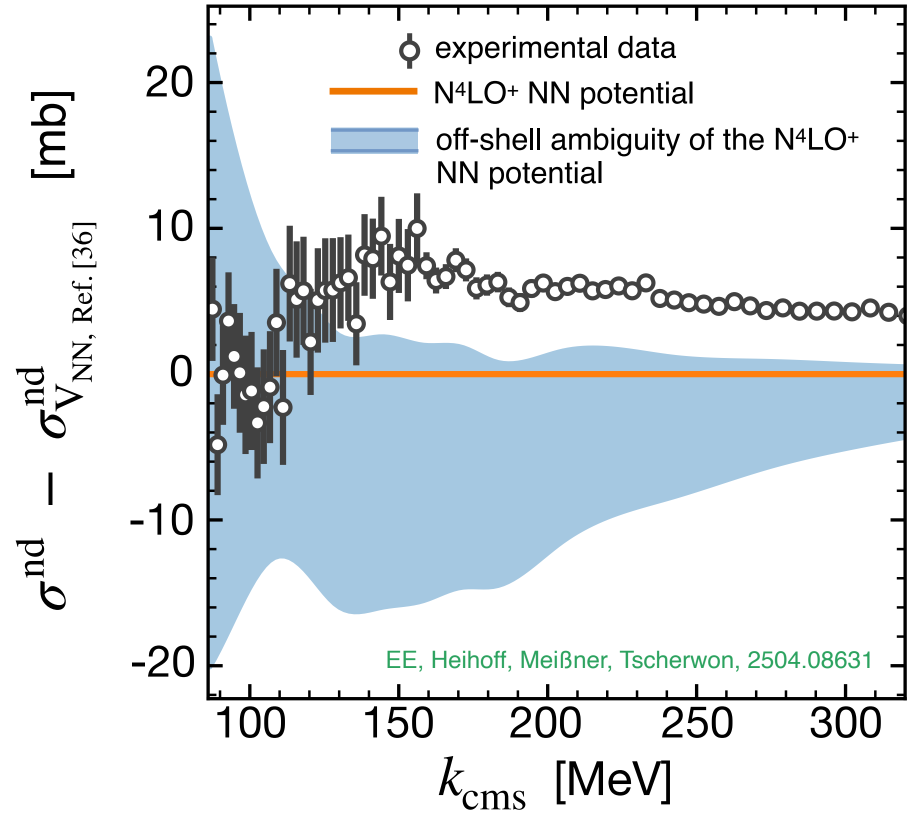
T. HOLSTEIN,* *New York University, University Heights, New York, New York*

(Received March 28, 1938)

When particles interact with each other through the intervening mechanism of a field, the description of their dynamical behavior by means of action-at-a-distance potentials is only of an approximate nature. Two-body, three-body, $\cdots$, m-body potentials may be regarded as successive stages of this approximation; their relative magnitudes are examined systematically for several types of classical and quantized fields, e.g., electromagnetic, mesotron, etc. It is found that the description of electrons in atomic systems by the customary two-body potentials is an excellent approximation; in nuclei, independent of the details of the field, one finds: three-body potentials $\cong (v_n/c) \times$ (two-body potentials) $\cdots$, m-body potentials $\cong (v_n/c)^{m-2} \times$ (two-body potentials), where v_n is the average velocity of the heavy particles in the nucleus. The usual description of nuclei in terms of two-body potentials cannot therefore be considered satisfactory, except in the case of the deuteron.

3NF effects in the 3N system





— 3NFs are small (but important) corrections to the NN interactions

— 3NFs depend on the (ambiguous) off-shell behavior of NN interactions Polyzou, Glöckle '90

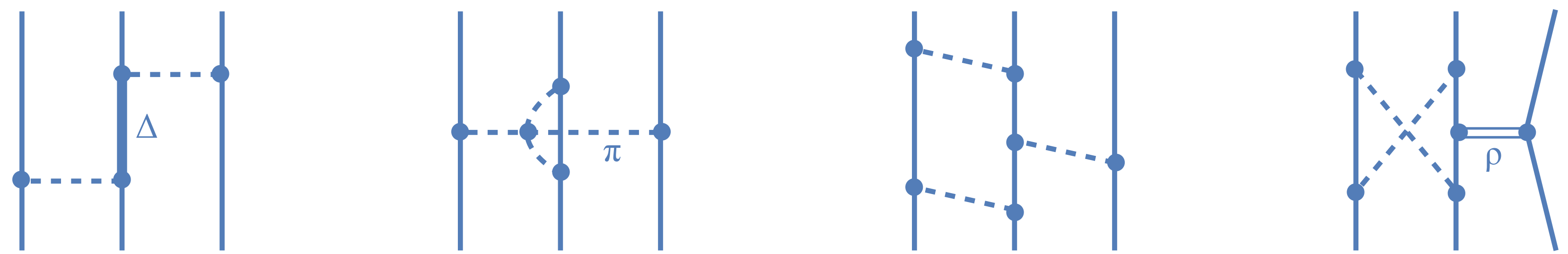
— Large discrepancies in Nd scattering [talk by Kimiko]; no existing 3NF model is capable of improving (globally) the description of Nd data Kalantar-Nayestanaki, EE, Messchendorp, Nogga '12

Three-body force: A frontier in nuclear physics

Endo, EE, Naidon, Nishida, Sekiguchi, Takahashi, EPJA 61 (2025) 9

- Three-nucleon forces (3NF) are small but important corrections to the dominant NN forces

- 3NF mechanisms:



intermediate Δ-excitation
Fujita, Miyazawa '57

multi-pion interactions

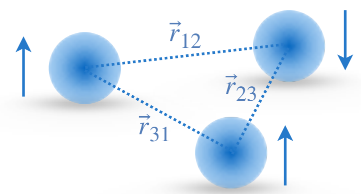
off-shell behavior of the V_{NN}
$V_{\rm ring} = \mathscr{A}_{3\pi} - V_\pi G_0 V_\pi G_0 V_\pi$

short-range

⇒ 3NF are not directly measurable and depend on the scheme (DoF, off-shell V_{NN}, …)

- 3NF have extremely rich and complex structure

— most general ***local*** 3NF: $V_{3N} = \sum_{i=1}^{20} O_i\, f_i(r_{12}, r_{23}, r_{31})$ + permutations
EE, Gasparyan, Krebs, Schat '15



— most general ***nonlocal*** 3NF: **320 (!)** operators Topolnicki '17

⇒ Guidance from theory indispensable — an opportunity for χEFT!

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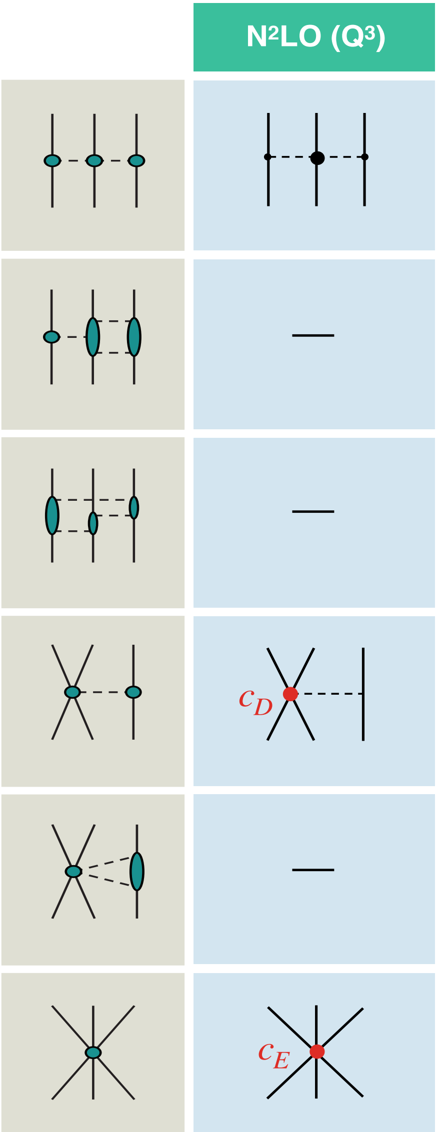
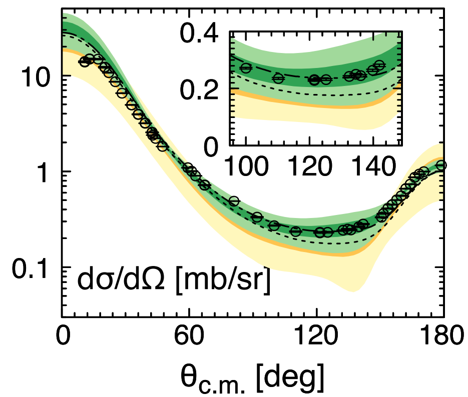
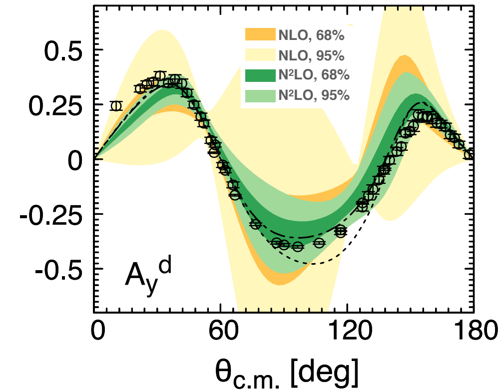
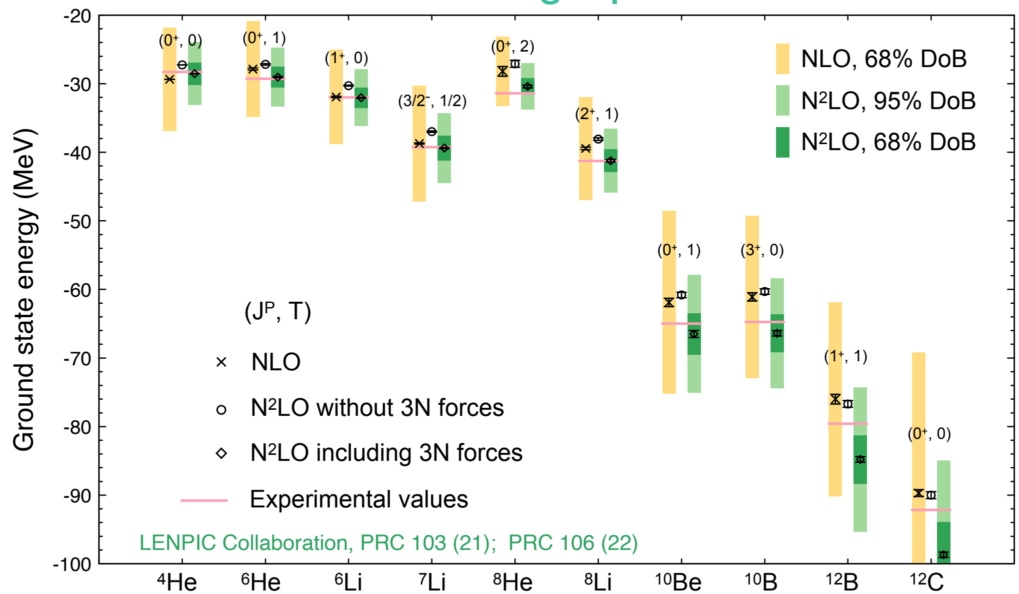


Elastic Nd scattering at 135 MeV





Predictions for light p-shell nuclei



⇒ Guidance from theory indispensable — an opportunity for χEFT!

Three-body force: A frontier in nuclear physics

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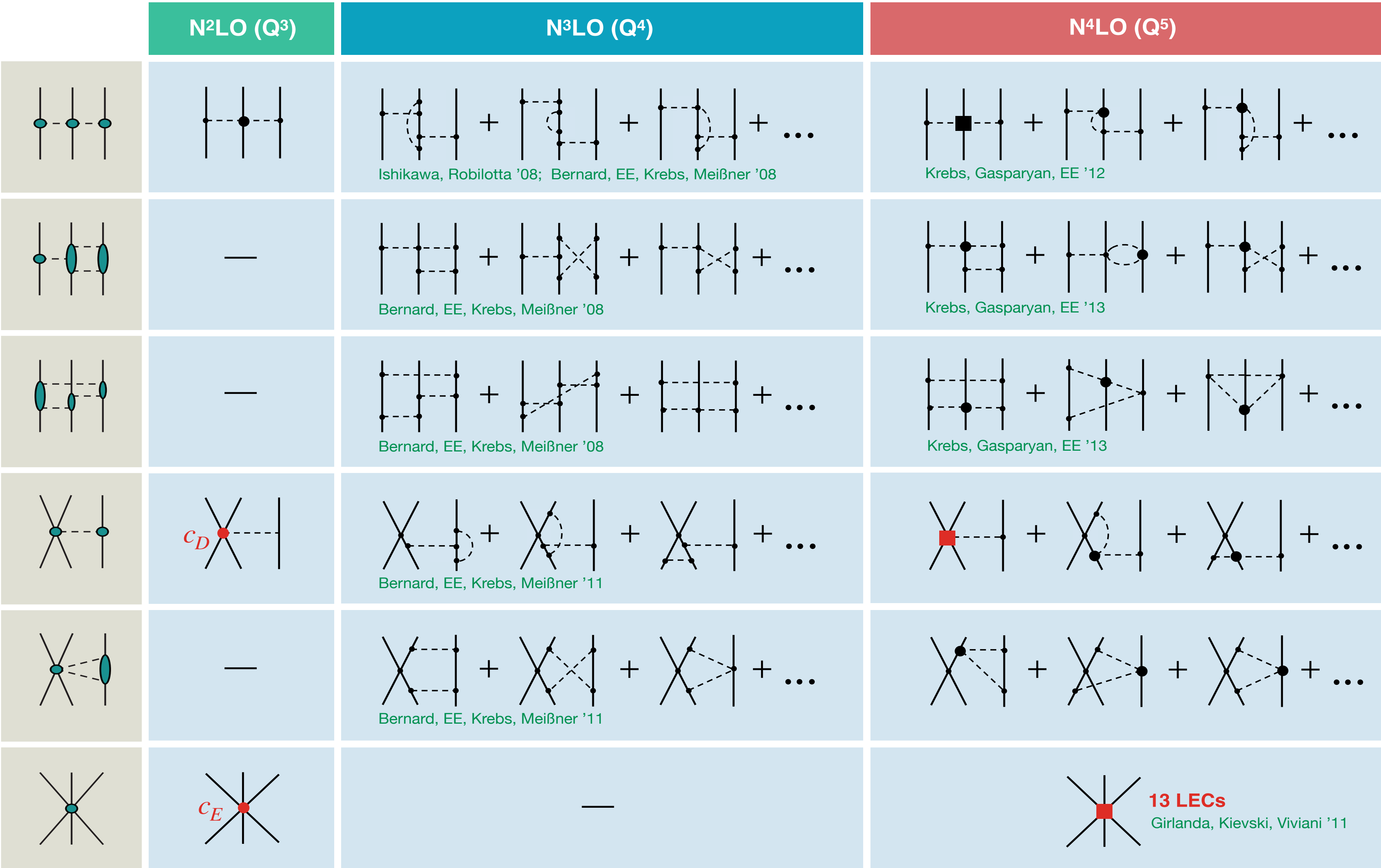

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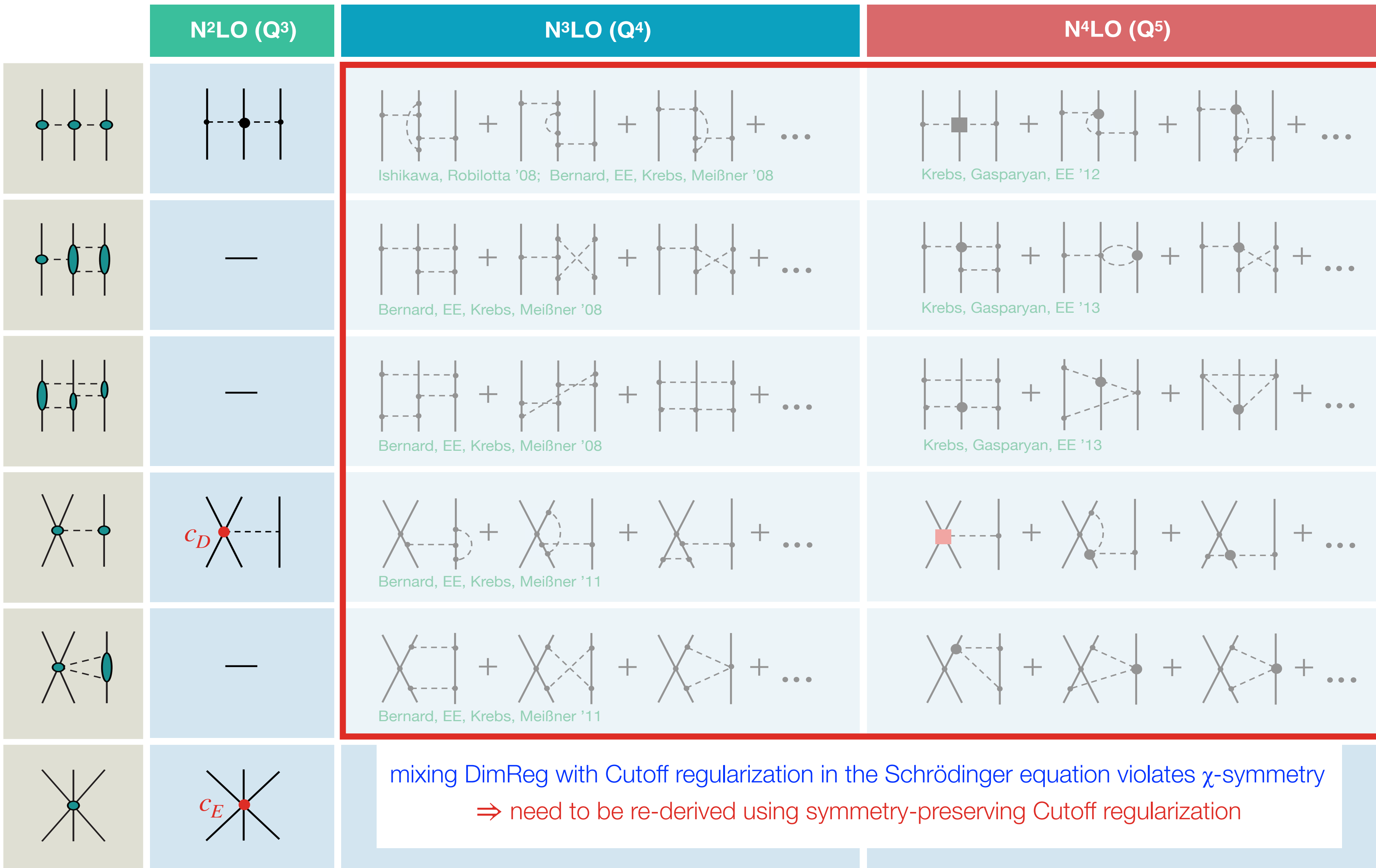

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European Research Council
Established by the European Commission

LENPIC

Nuclear Theory from First Principles

WP1: Accurate and precise nuclear Hamiltonian

especially the 3NF…

neutron-neutron interaction

constraints at the physical quark masses

validation in A > 3 systems

WP2: Nuclear forces from matching to lattice QCD

m_q-dependence

WP3: Nuclear structure from first principles

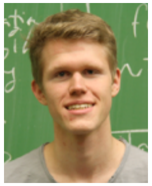
The three-nucleon-force team in Bochum:


PD Dr. Hermann Krebs


Dr. Arseniy Filin


Sven Heihoff


Josep Sola Cava


Patrick Walkowiak


Henri Huesmann

Ministerium für Kultur und Wissenschaft des Landes Nordrhein-Westfalen

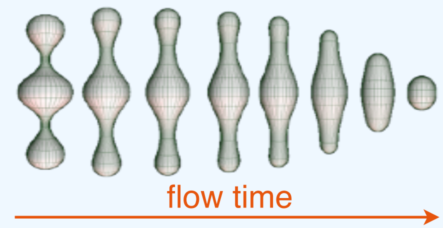
TOMOE

Chiral gradient flow

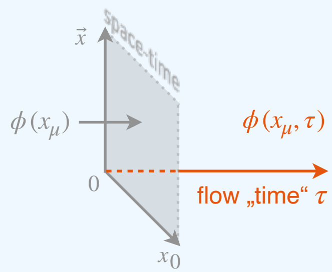
Hermann Krebs, EE, PRC 110 (2024) 044003; PRC110 (2024) 044003

Gradient flows: methods for smoothing manifolds

(e.g., Ricci flow used in the proof of the Poincaré conjecture)



Gradient flow as a regulator in field theory



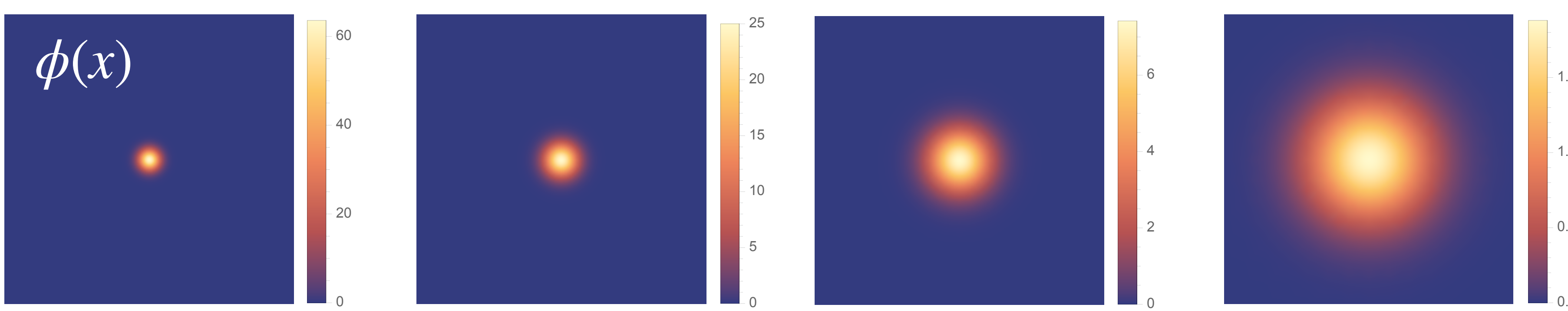
Flow equation: $$\frac{\partial}{\partial \tau}\phi(x,\tau) = -\frac{\delta S[\phi]}{\delta \phi(x)}\bigg|_{\phi(x)\to\phi(x,\tau)}$$

subject to the boundary condition $\phi(x,0) = \phi(x)$

Free scalar field:

$$G(x,\tau) = \frac{\theta(\tau)}{16\pi^2\tau^2} e^{-\frac{x^2+4M^2\tau^2}{4\tau}}$$

$$\left[\partial_\tau - (\partial^x_\mu \partial^x_\mu - M^2)\right]\phi(x,\tau) = 0 \quad \Rightarrow \quad \phi(x,\tau) = \int d^4y\, \underbrace{G(x-y,\tau)}_{\text{heat kernel}}\phi(y) \quad \Rightarrow \quad \tilde{\phi}(q,\tau) = e^{-\tau(q^2+M^2)}\tilde{\phi}(q)$$

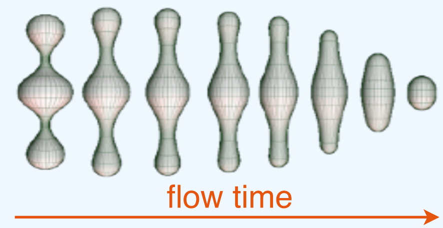


$\tau = 0$ $\quad$ $\tau = 1$ $\quad$ $\tau = 2$ $\quad$ $\tau = 4$

Chiral gradient flow

Hermann Krebs, EE, PRC 110 (2024) 044003; PRC110 (2024) 044003

Gradient flows: methods for smoothing manifolds
(e.g., Ricci flow used in the proof of the Poincaré conjecture)



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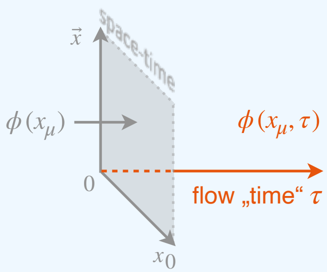

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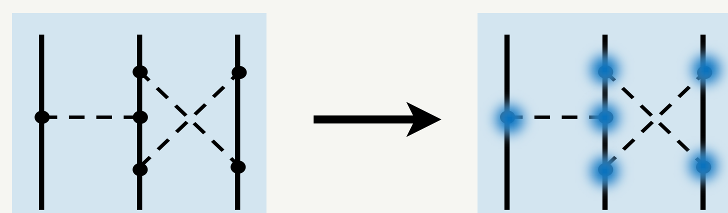
YM gradient flow Narayanan, Neuberger ’06, Lüscher, Weisz ’11: $\partial_\tau A_\mu(x,\tau) = D_\nu G_{\nu\mu}(x,\tau)$ ← extensively used in LQCD

Chiral gradient flow **Hermann Krebs**, EE, PRC 110 (2024) 044003

PRC 110 (2024) 044004

Generalize $U(x)$, $U(x) \to RU(x)L^\dagger$ to $W(x,\tau)$:

$$\partial_\tau W = -i\underbrace{w}_{\sqrt{W}}\,\mathrm{EOM}(\tau)\, w, \quad W(x,0) = U(x)$$



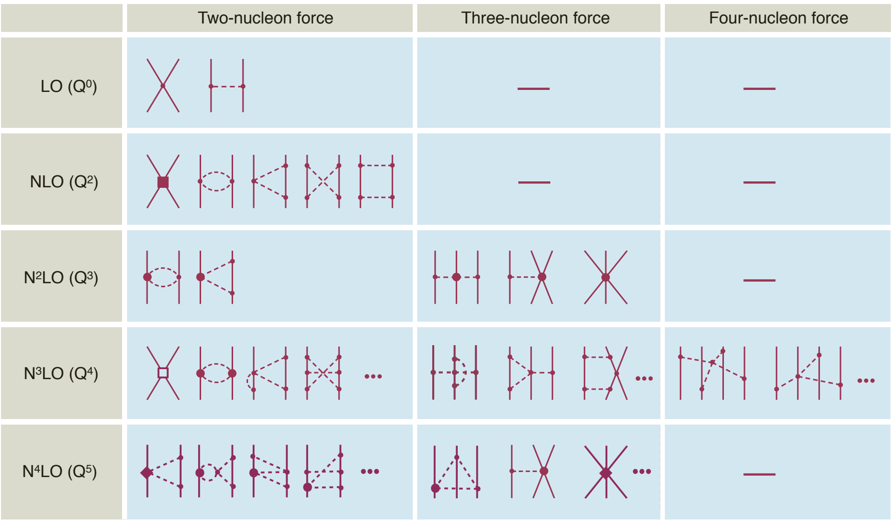
Recent and ongoing activities

- ✅ Derivation of the N³LO contributions to the 3NF using the GF method Hermann

- (✅) Partial wave decomposition of the 3NF@N³LO
  LENPIC — talk by Kai

- (✅) Re-determination of the πN LECs using the GF regulator Patrick

- ☑ Sensitivity studies of 3N scattering observables to the contact 3NF@N⁴LO Arseniy, Josep, Sven
  talks by Arseniy and Josep



- (✅) Sensitivity studies of 3N scattering observables to the off-shell LECs in the 2NF@N³LO Sven

- (✅) Derivation and implementation (partial wave decomposition) of c_D-like 3NF@N⁴LO Henri, Hermann, Arseniy
  talk by Henri

- ☑ Optimization/„emulation“ of 3N scattering calculations (needed to fix 3NF@N⁴LO) Sven, Arseniy

- ✅ NN interactions „on demand“ (local LO, local+separable, low-resolution) Sven

- (✅) Truncation uncertainty in chiral EFT via explicit marginalization over higher-order terms Sven
  talk by Sven

- ☑ Chiral gradient flow: Chiral extrapolations, 3NF@N4LO, 4NF, currents, … Hermann

Enjoy the talks and discussions!