

# Lattice QCD and neutrino-nucleus scattering<sup>\*</sup>

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**Abstract.** This document is one of a series of white papers from the USQCD Collaboration. Here, we discuss opportunities for Lattice QCD in neutrino-oscillation physics, which inevitably entails nucleon and nuclear structure. In addition to discussing pertinent Lattice QCD calculations of nucleon and nuclear matrix elements, the interplay with models of nuclei is discussed. This program of Lattice QCD calculations is relevant to current and upcoming neutrino experiments, becoming increasingly important on the timescale of LBNF/DUNE and HyperK.

■ Topical Issue

- 192 William Detmold et al.  
**Topical Issue on Opportunities for Lattice Gauge Theory in the Era of Exascale Computing**  
*Editorial*
- 193 William Detmold et al.  
USQCD Collaboration  
**Hadrons and nuclei**  
*Regular Article – Theoretical Physics*
- 194 Alexei Bazavov et al.  
USQCD Collaboration  
**Hot-dense Lattice QCD**  
*Review*
- 195 Christoph Lehner et al.  
USQCD Collaboration  
**Opportunities for Lattice QCD in quark and lepton flavor physics**  
*Review*
- 196 Andreas S. Kronfeld et al.  
**Lattice QCD and neutrino-nucleus scattering**  
*Regular Article – Theoretical Physics*
- 197 Vincenzo Cirigliano et al.  
USQCD Collaboration  
**The role of Lattice QCD in searches for violations of fundamental symmetries and signals for new physics**  
*Review*
- 198 Richard C. Brower et al.  
USQCD Collaboration  
**Lattice gauge theory for physics beyond the Standard Model**  
*Review*
- 199 Bálint Joó et al.  
**Status and future perspectives for lattice gauge theory calculations to the exascale and beyond**  
*Regular Article – Theoretical Physics*

- 200 T. Wright et al.  
**Measurement of the  $^{13}\text{C}(n, \gamma)$  thermal cross section via neutron irradiation and AMS**  
*Regular Article – Experimental Physics*
- 201 P. Belli et al.  
**First direct search for  $2\epsilon$  and  $\epsilon\beta^+$  decay of  $^{144}\text{Sm}$  and  $2\beta^-$  decay of  $^{154}\text{Sm}$**   
*Regular Article – Experimental Physics*
- 202 C.S. Akondi et al.  
**Experimental study of the  $\gamma p \rightarrow K^0 \Sigma^+$ ,  $\gamma n \rightarrow K^0 \Lambda$ , and  $\gamma n \rightarrow K^0 \Sigma^0$  reactions at the Mainz Microtron**  
*Regular Article – Experimental Physics*
- 203 Daniel M. Siegel  
**GW170817 —the first observed neutron star merger and its kilonova: Implications for the astrophysical site of the r-process**  
*Regular Article – Topical Issue: First Joint Gravitational Wave and Electromagnetic Observations: Implications for Nuclear and Particle Physics*
- 204 Georgy Kornakov and Tetyana Galatyuk  
**An iterative method to estimate the combinatorial background**  
*Regular Article – Experimental Physics*
- 205 Lilin Zhu et al.  
**Centrality and transverse momentum dependencies of hadrons in Pb+Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02$  TeV and Xe+Xe collisions at  $\sqrt{s_{\text{NN}}} = 5.44$  TeV from a multi-phase transport model**  
*Regular Article – Theoretical Physics*

Contents continued on cover page 3

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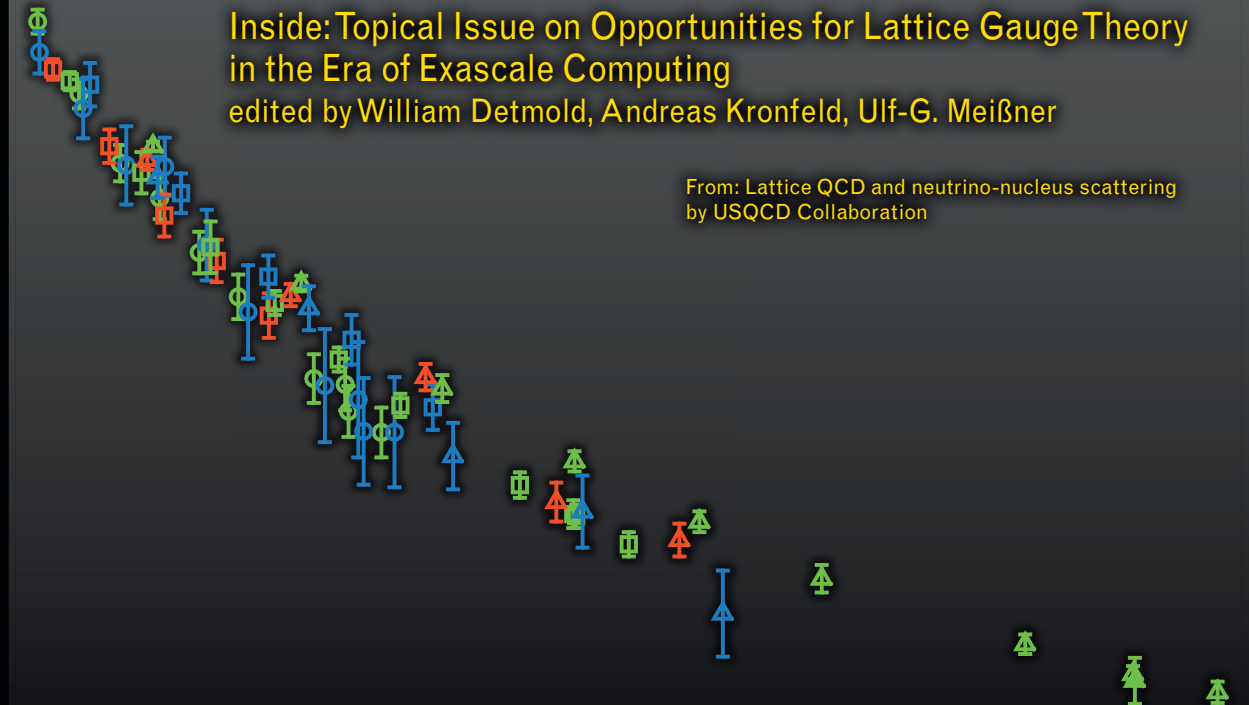


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Hadrons and Nuclei

Inside: Topical Issue on Opportunities for Lattice Gauge Theory in the Era of Exascale Computing  
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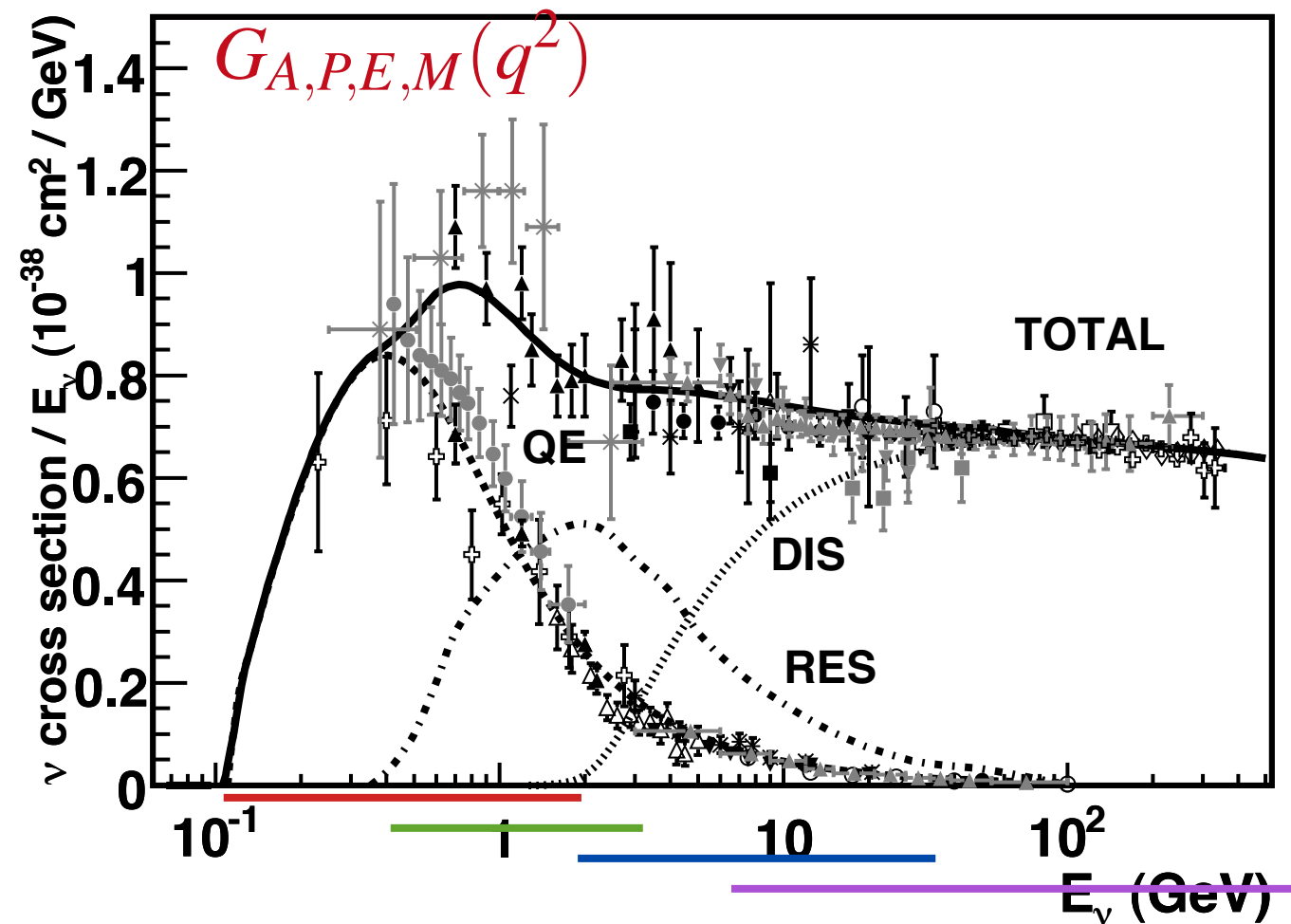
# Lattice QCD: Nucleons & Nuclei

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- Calculate matrix elements of electroweak currents directly from the QCD Lagrangian.
- Ensembles of gauge fields + effective field theory.
- Finite volume (finite memory) and Euclidean time signature (finite human lifetime) imply:
  - highest statistical precision for hadron masses, hadronic matrix elements with 1 initial hadron and 0 or 1 final hadron(s);
  - highest statistical precision for the pion, then other mesons, then baryons;
  - scattering and **nuclei** need more math and more data.

# Baryons

- Nucleon matrix elements are ingredients for nuclear physics:
  - includes PDFs in DIS;
  - includes  $N \rightarrow \text{resonance}$ ;
  - includes  $NN$  initial/final state.
- New ideas (realizations) for multi-hadron final states:



$$G_{A,P,E,M}(q^2)$$

$$\langle N | J(x) J(0) | N \rangle$$

$$\langle N | \mathcal{O}(0) | N \rangle$$

- “quick & dirty” form factors for resonances;
- hadron tensor for shallow (as well as deep) inelastic scattering.

# Nuclei

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- Simple calculations for small nuclei are already underway, but all need a few more years before all uncertainties will be under control:
  - up to  ${}^3\text{H}$  and  ${}^3\text{He}$ , even  ${}^4\text{He}$ ;
  - magnetic moments,  $g_A$  quenching.
- Plan is to push to physical pion mass for these nuclei, and to push to larger nuclei (at first with 800 MeV):
  - carbon in 15 years?!  ${}^{40}\text{Ar}$  with quantum computers?!?
- These calculations are needed to test and improve the effective theories that are the foundation of modern nuclear theory: pointless EFT; chiral EFT.