Eur. Phys. J. A (2019) **55**: 196
DOI 10.1140/epja/i2019-12916-x

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Theoretical Physics

Lattice QCD and neutrino-nucleus scattering*

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Received: 21 August 2019 / Revised: 8 October 2019
Published online: 14 November 2019
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Communicated by U.-G. Meißner

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.

The European Physical Journal A

volume 55 · number 11 · november · 2019

■ Topical Issue

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volume 55 · number 11 · november · 2019

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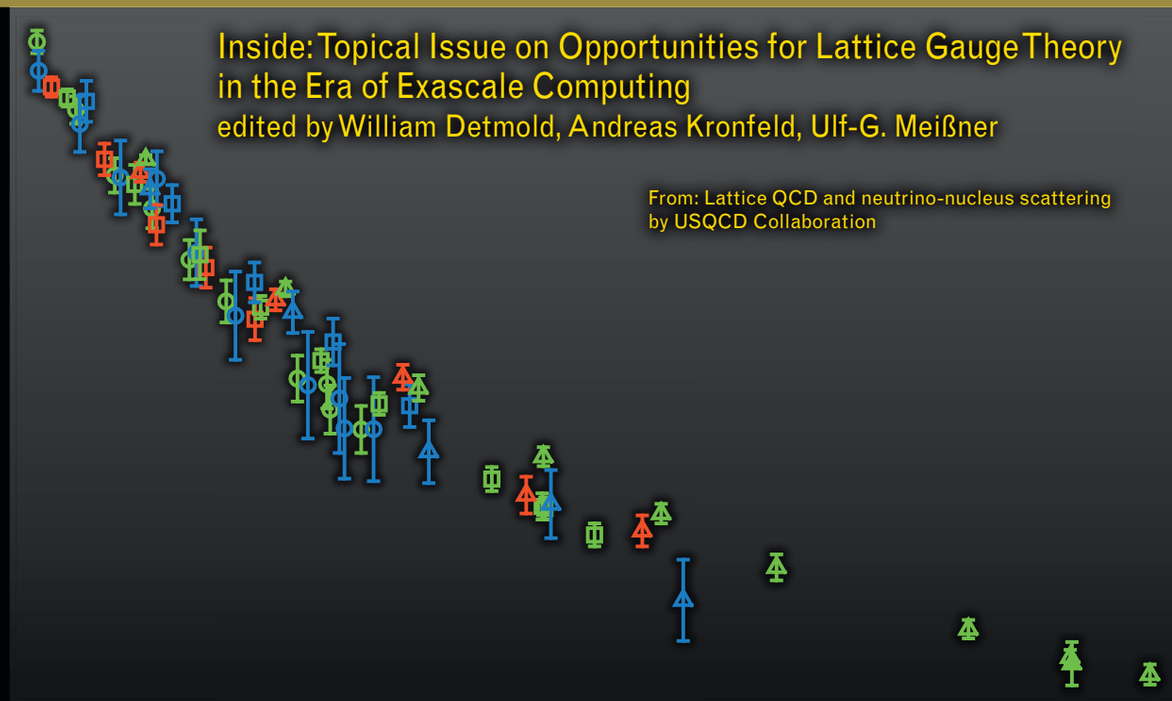
Hadrons and Nuclei



Inside: Topical Issue on Opportunities for Lattice Gauge Theory in the Era of Exascale Computing
edited by William Detmold, Andreas Kronfeld, Ulf-G. Meißner

From: Lattice QCD and neutrino-nucleus scattering
by USQCD Collaboration

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Lattice QCD: Nucleons & Nuclei

- 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);

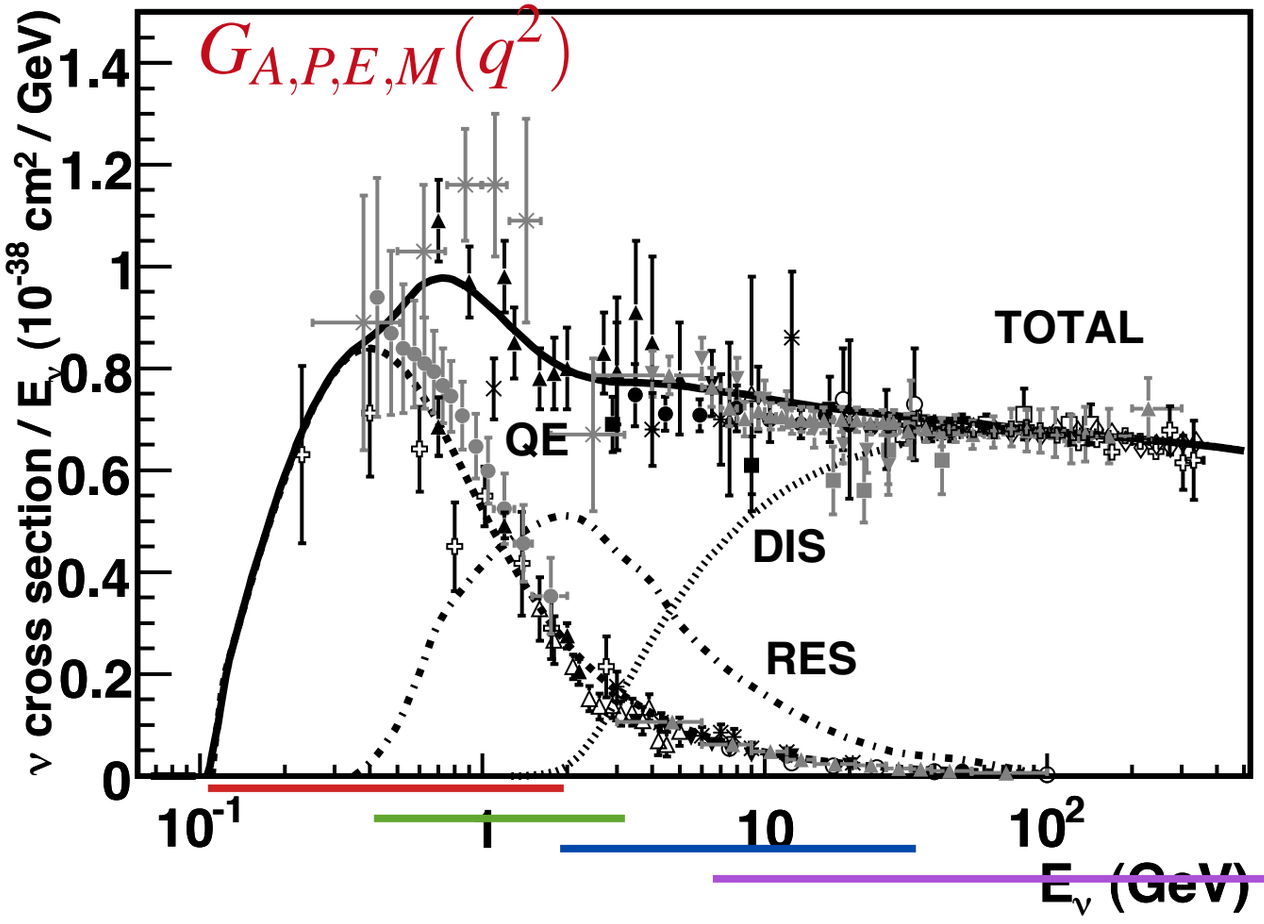
  - highest statistical precision for the pion, then other mesons, then baryons;

  - scattering and bound states need more math and more data.

nuclei

Baryons

- Nucleon matrix elements are ingredients for nuclear physics:
  - includes PDFs in DIS;
  - includes $N \rightarrow$ resonance;
  - includes NN initial/final state.
- New ideas (realizations) for multi-hadron final states:
  - "quick & dirty" form factors for resonances;
  - hadron tensor for shallow (as well as deep) inelastic scattering.



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

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

Nuclei

- 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}H and ^{3}He, even ^{4}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}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.