Neutrino-nucleon quasielastic scattering from lattice QCD

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CIPANP 2022

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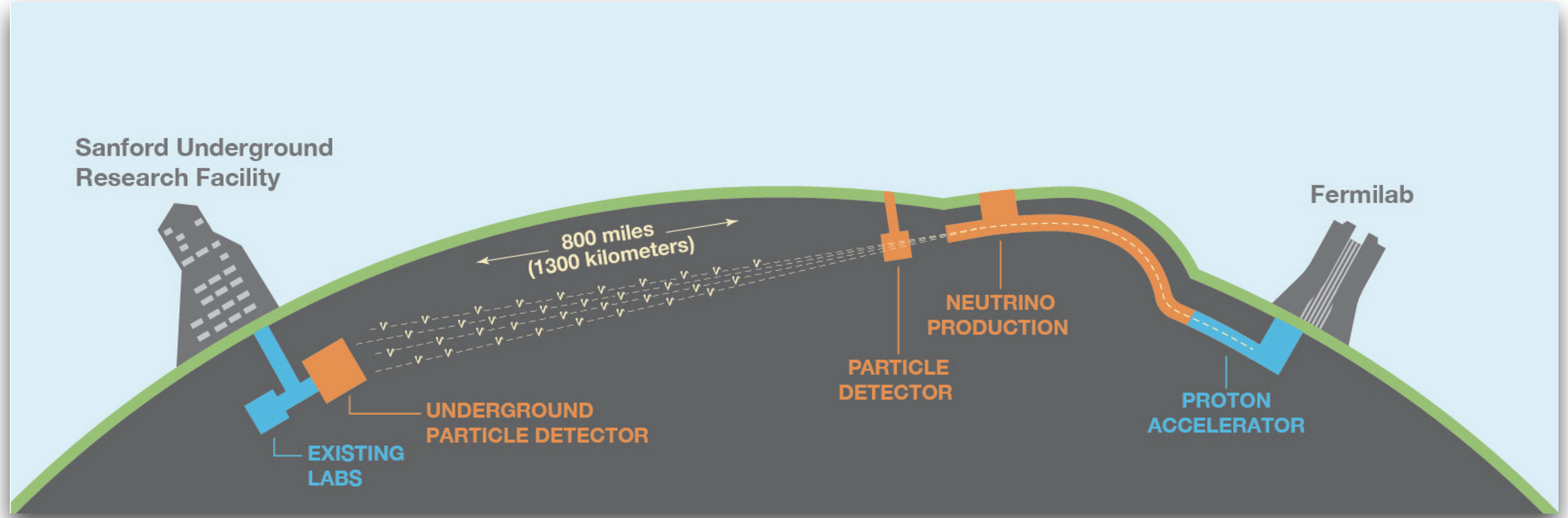
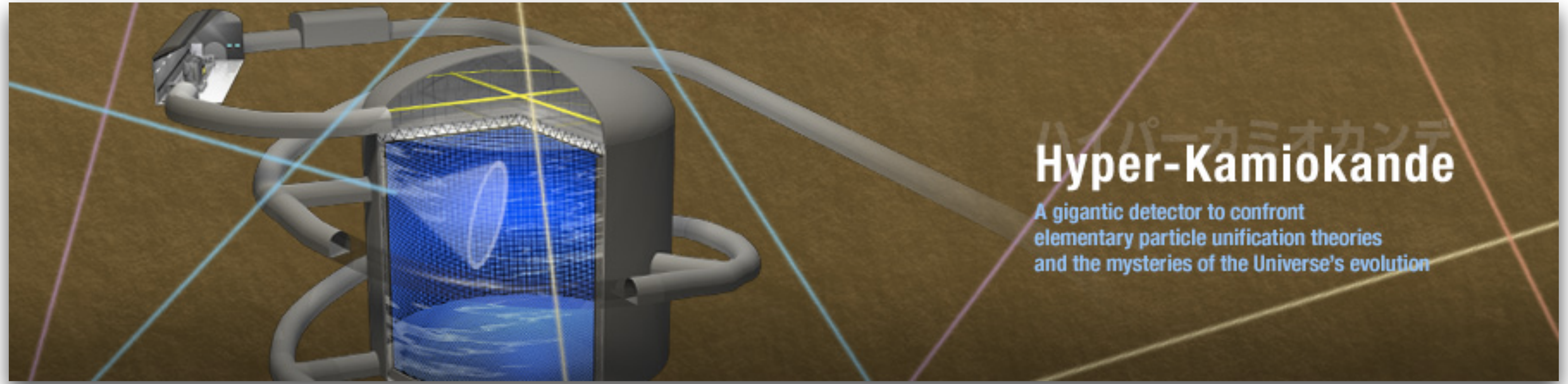
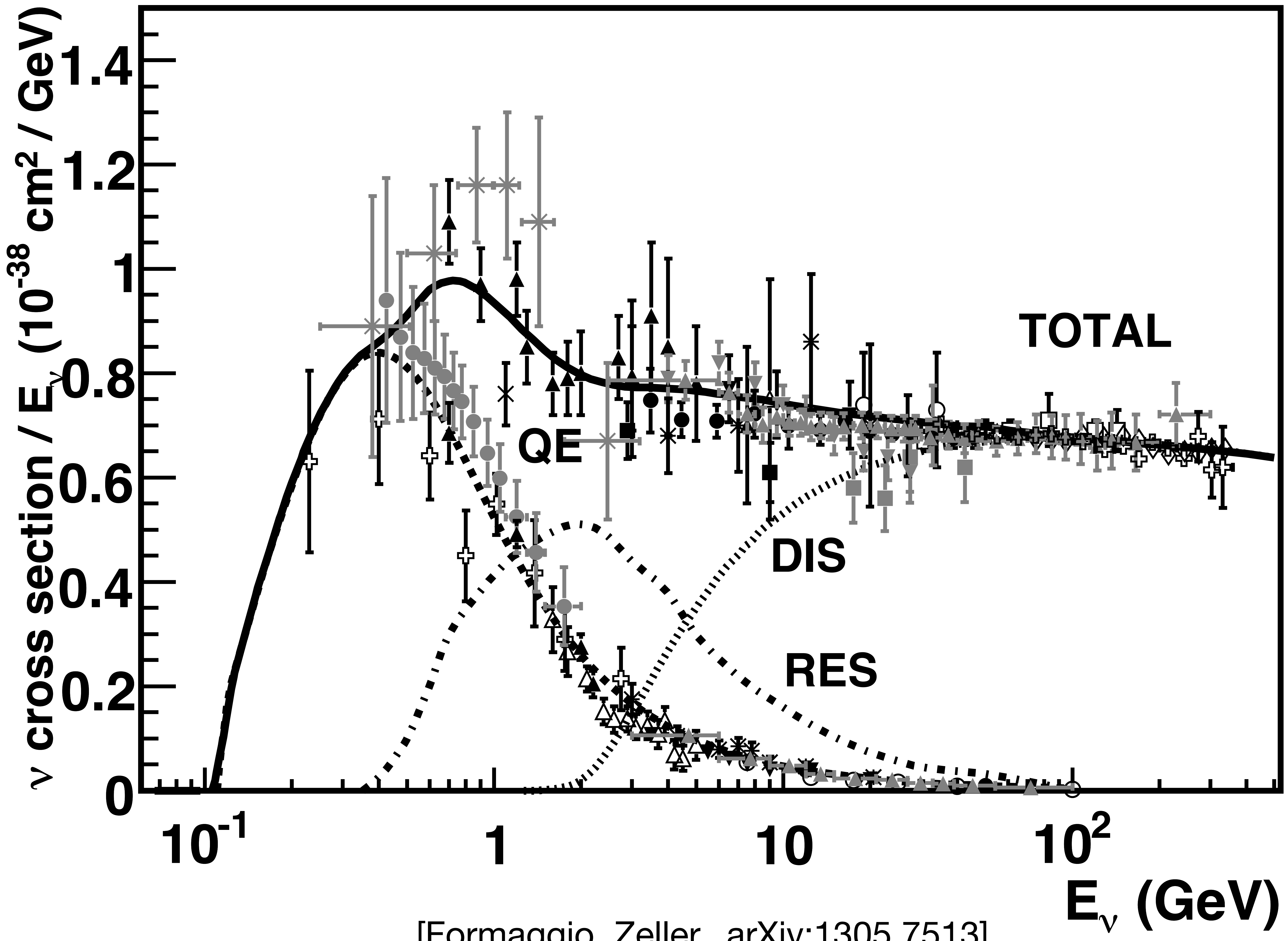
Long-baseline neutrino experiments





Neutrino-nucleus cross section



[Formaggio, Zeller, arXiv:1305.7513]

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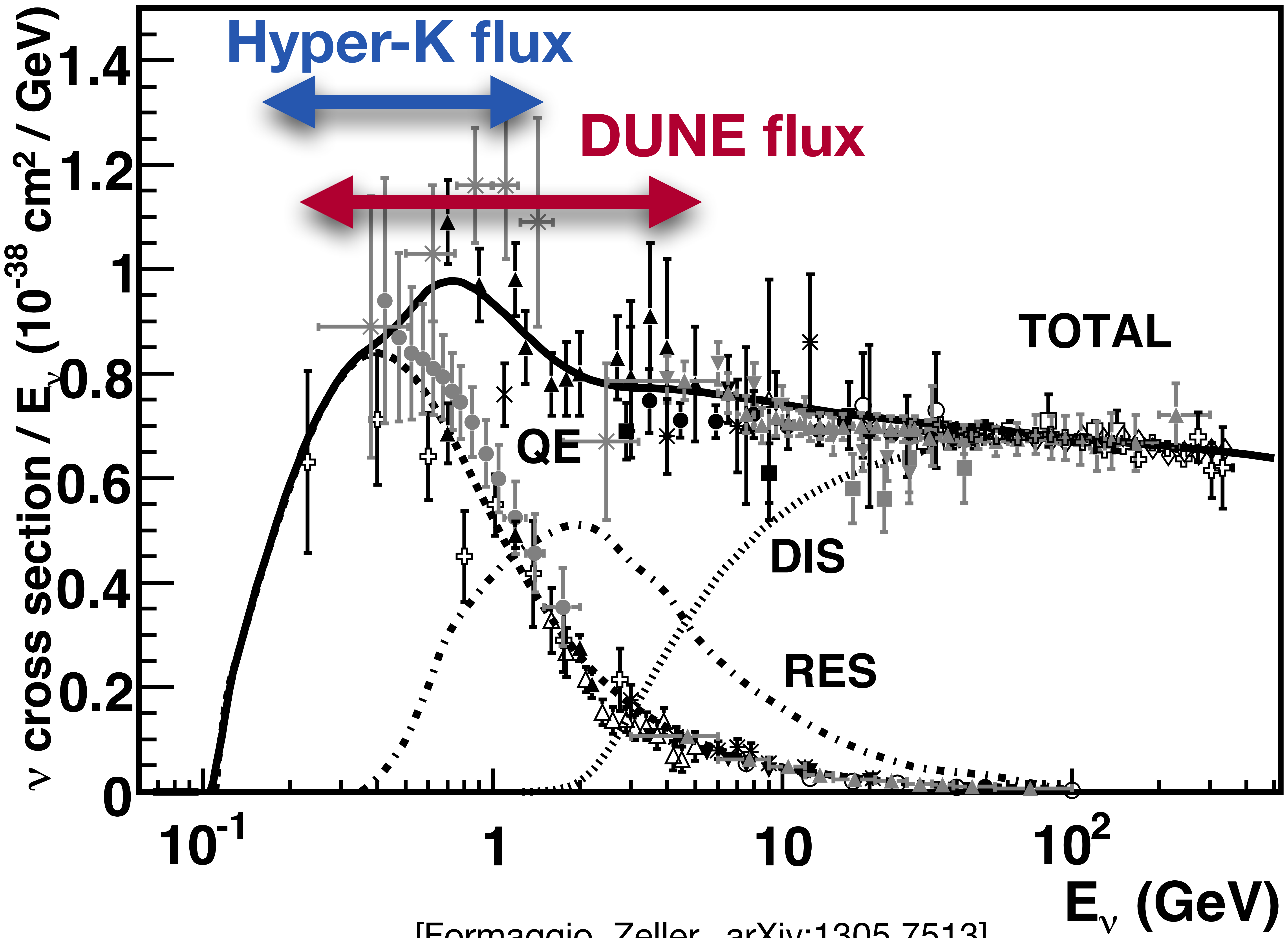

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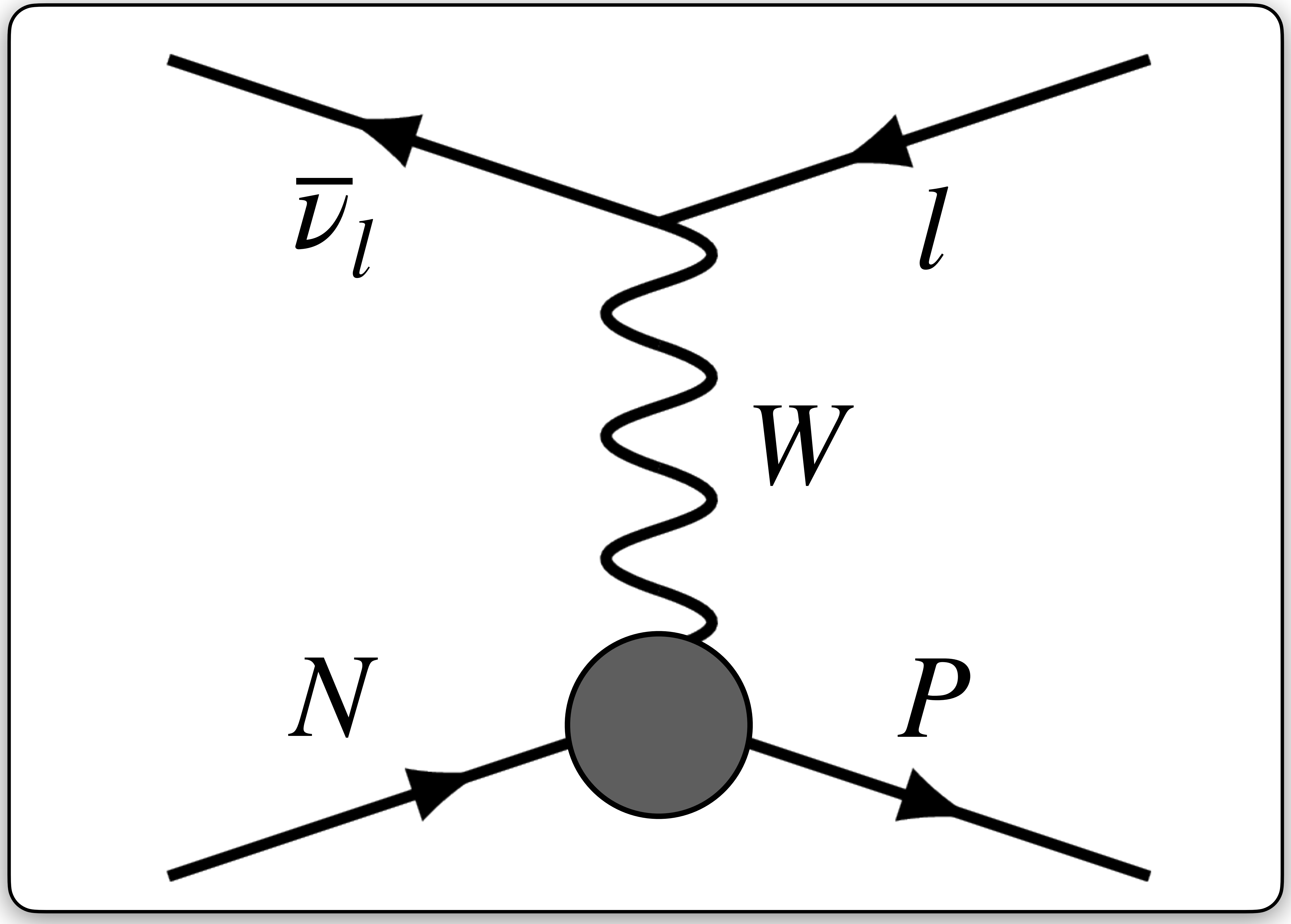
Charged-current neutrino-nucleon cross section



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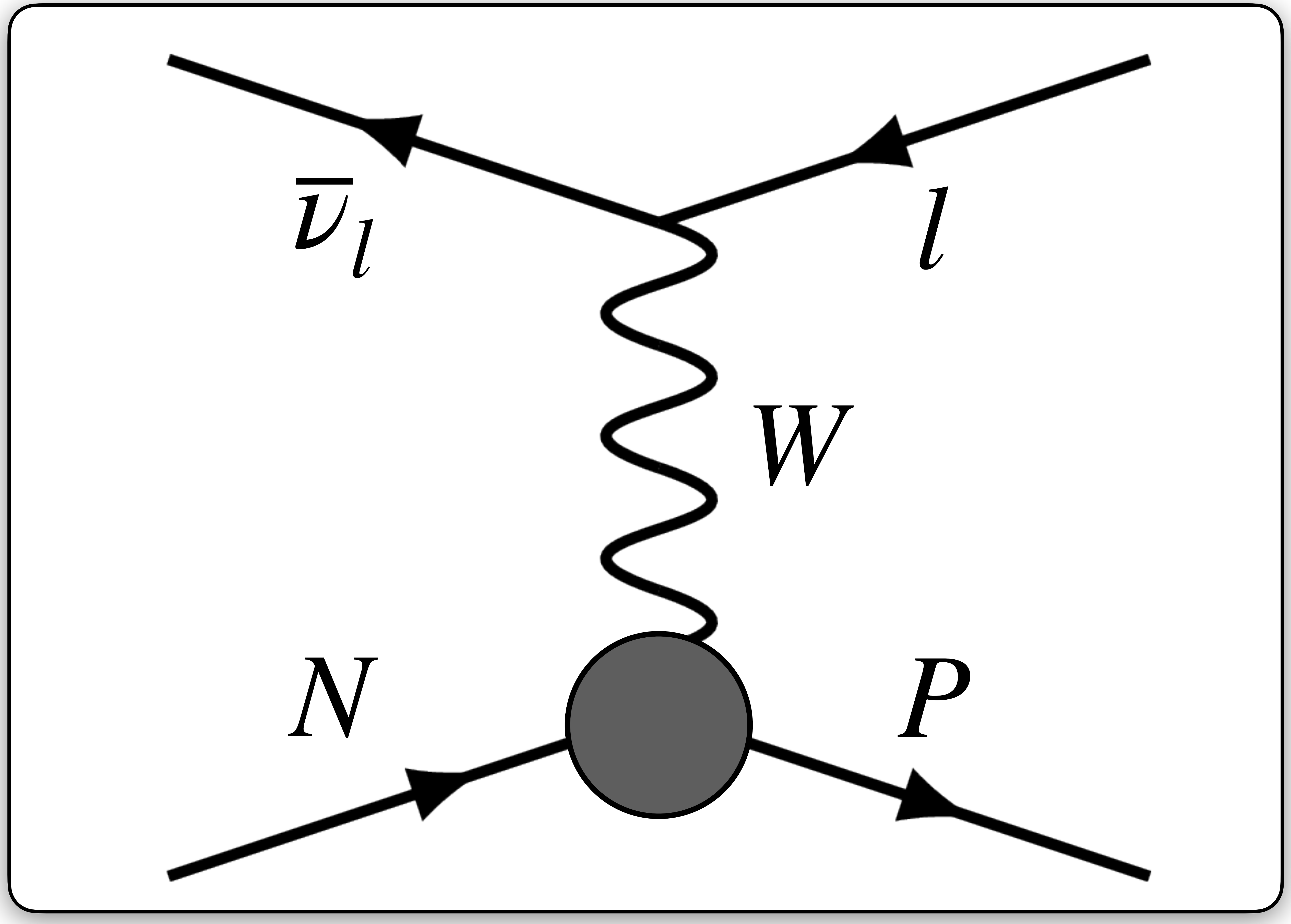
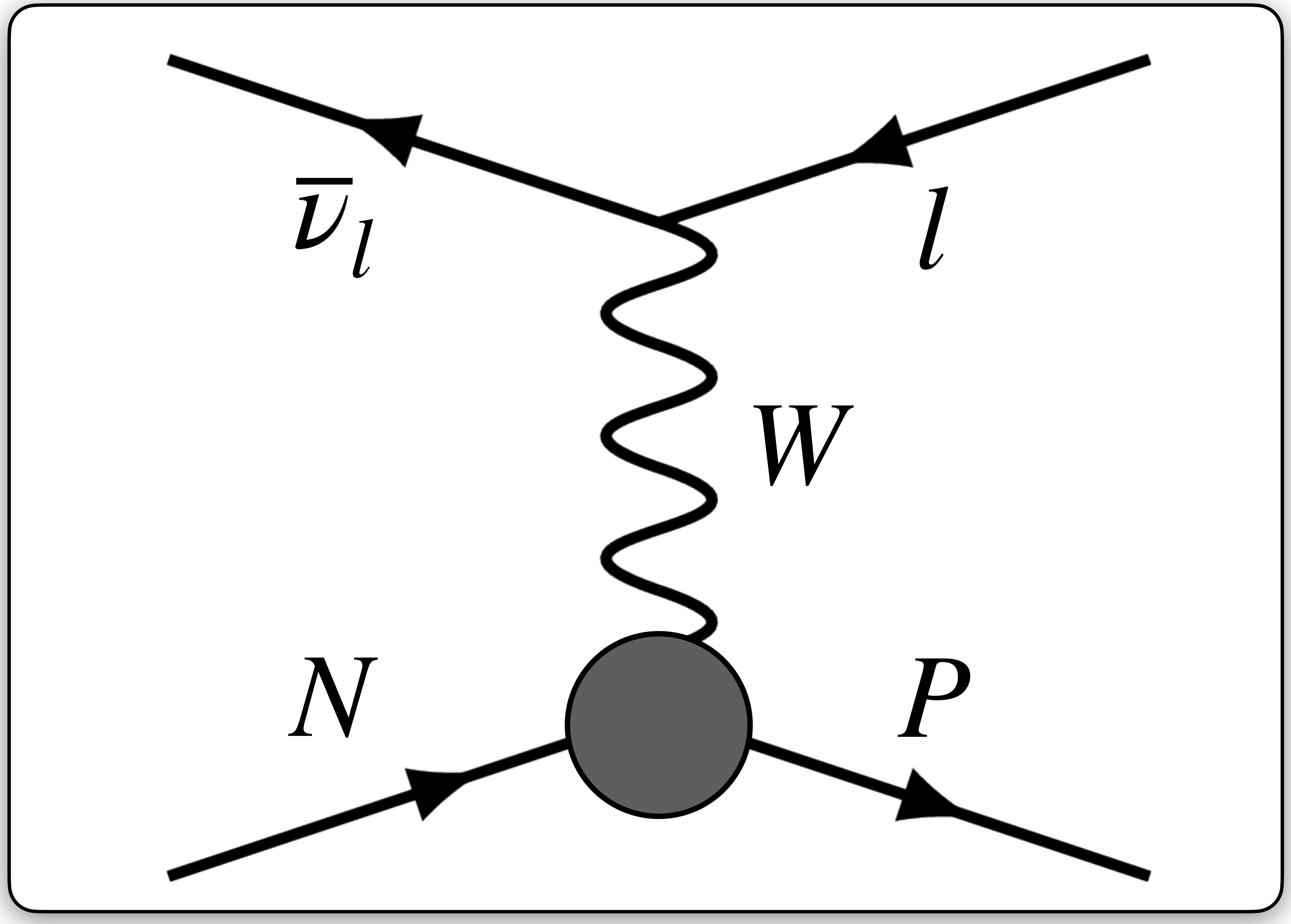


- Vector FFs: High statistics measurements from e^- scattering

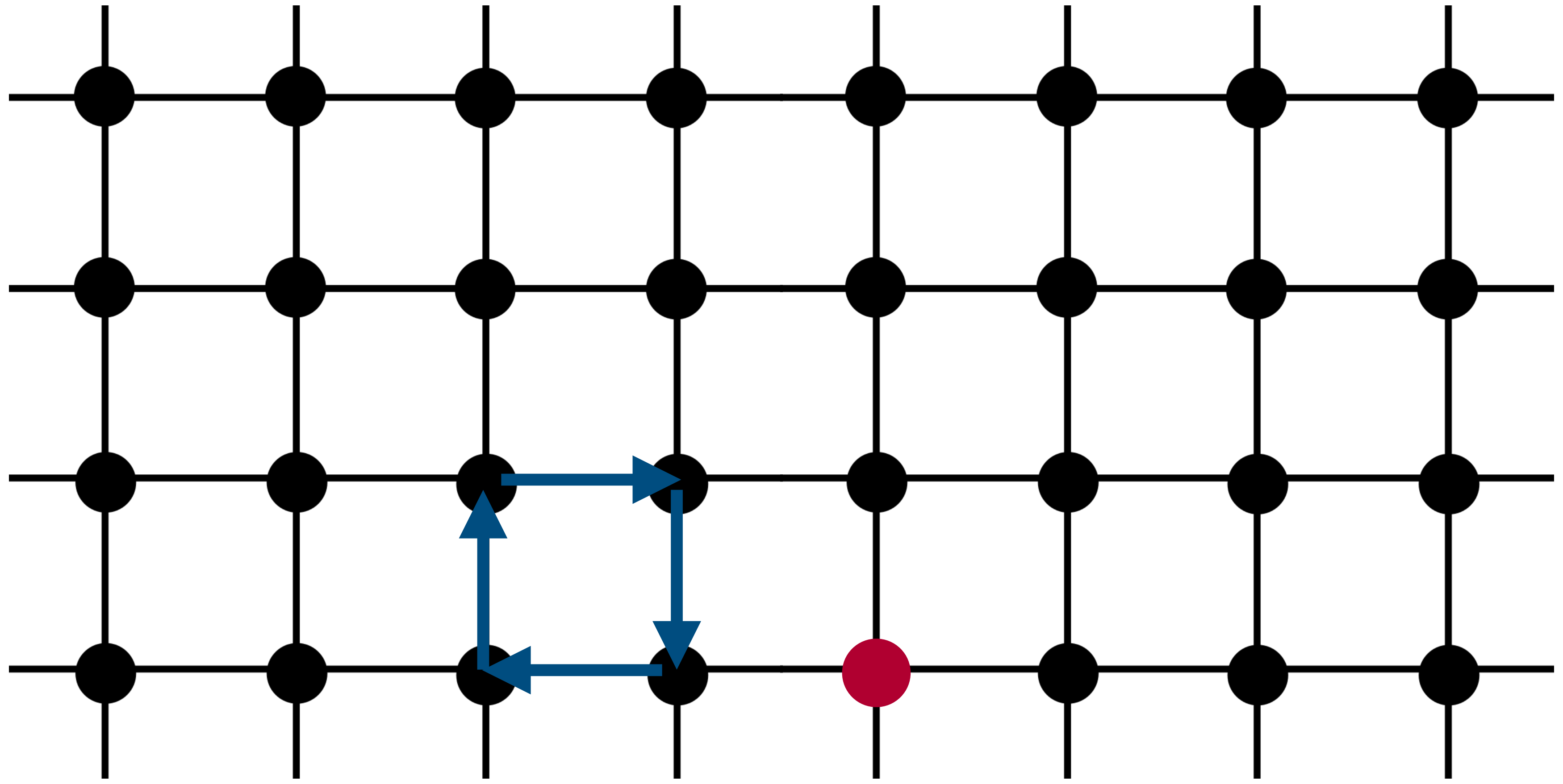
Charged-current neutrino-nucleon cross section



- Vector FFs: High statistics measurements from e⁻ scattering
- Axial FF: Lacking new data, dominant uncertainty

Intro to lattice QCD

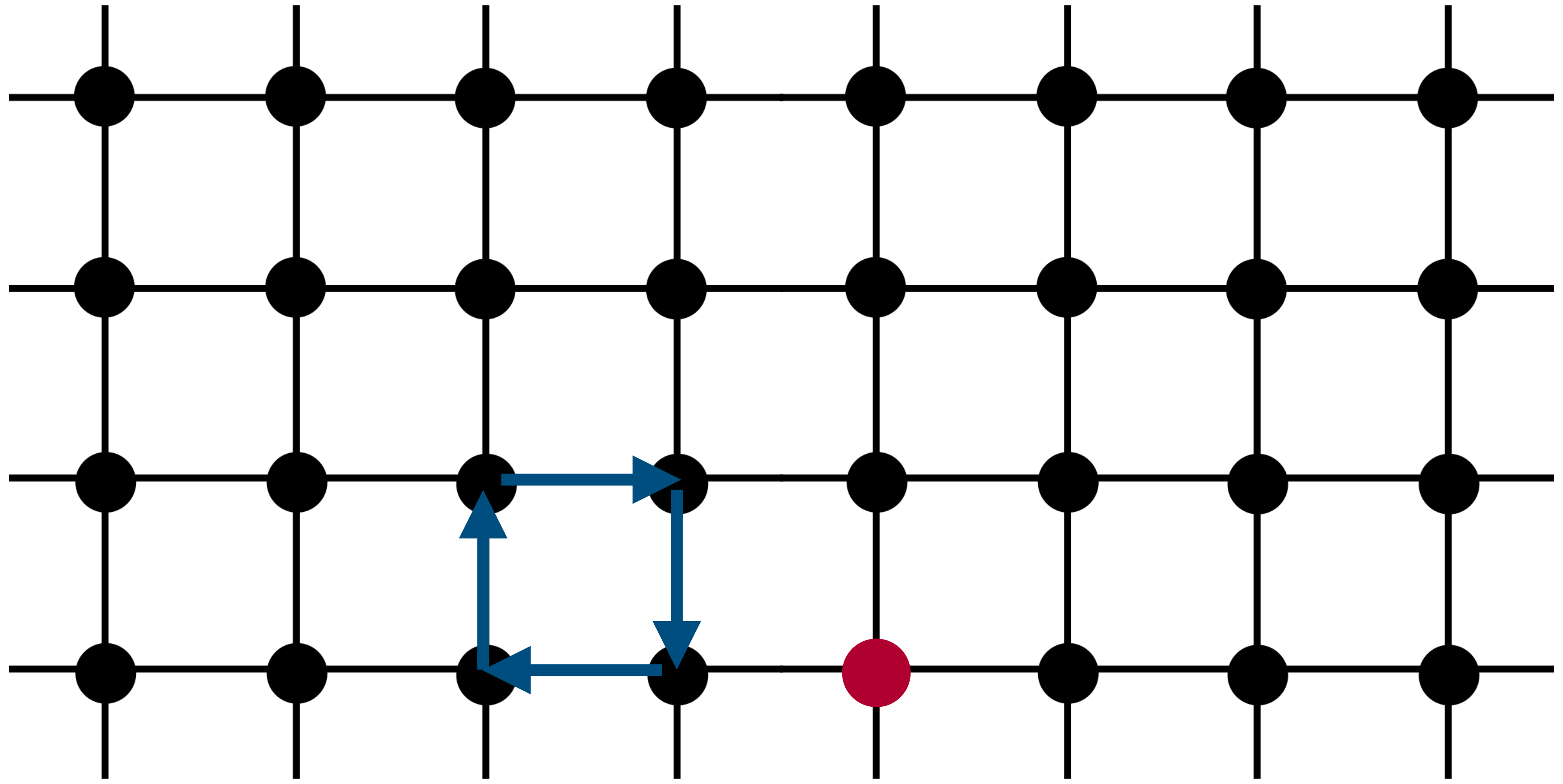
Lattice regularization of QCD



$U_\mu(x)$ $\psi(x)$, $\overline{\psi}(x)$

Lattice regularization of QCD

$$\langle O \rangle = \int \prod_n dU_n d\psi_n d\overline{\psi}_n \, \frac{e^{-S[U_n,\overline{\psi}_n,\psi_n]}}{Z} \, O[U_n, \psi_n, \overline{\psi}_n]$$



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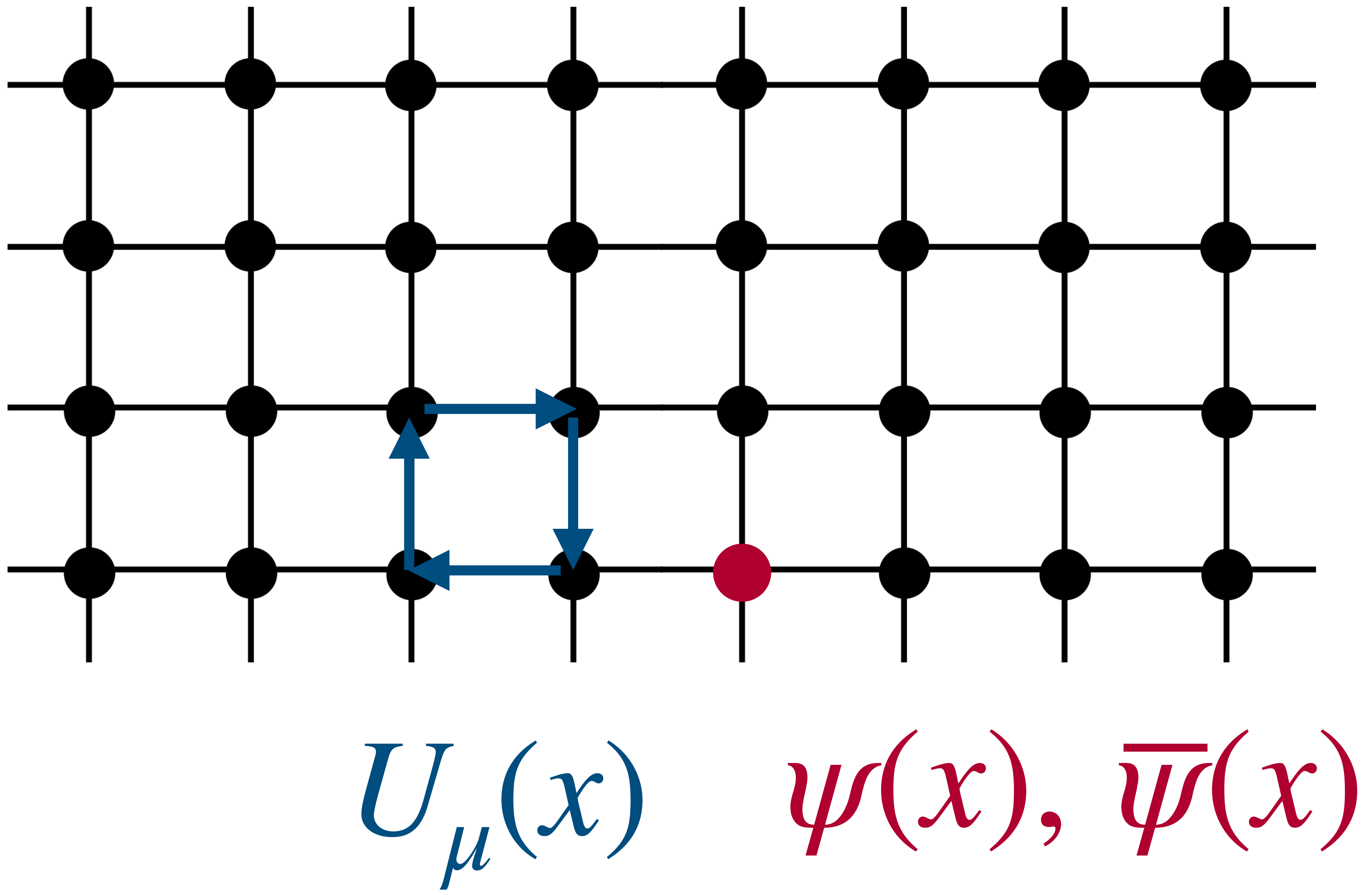

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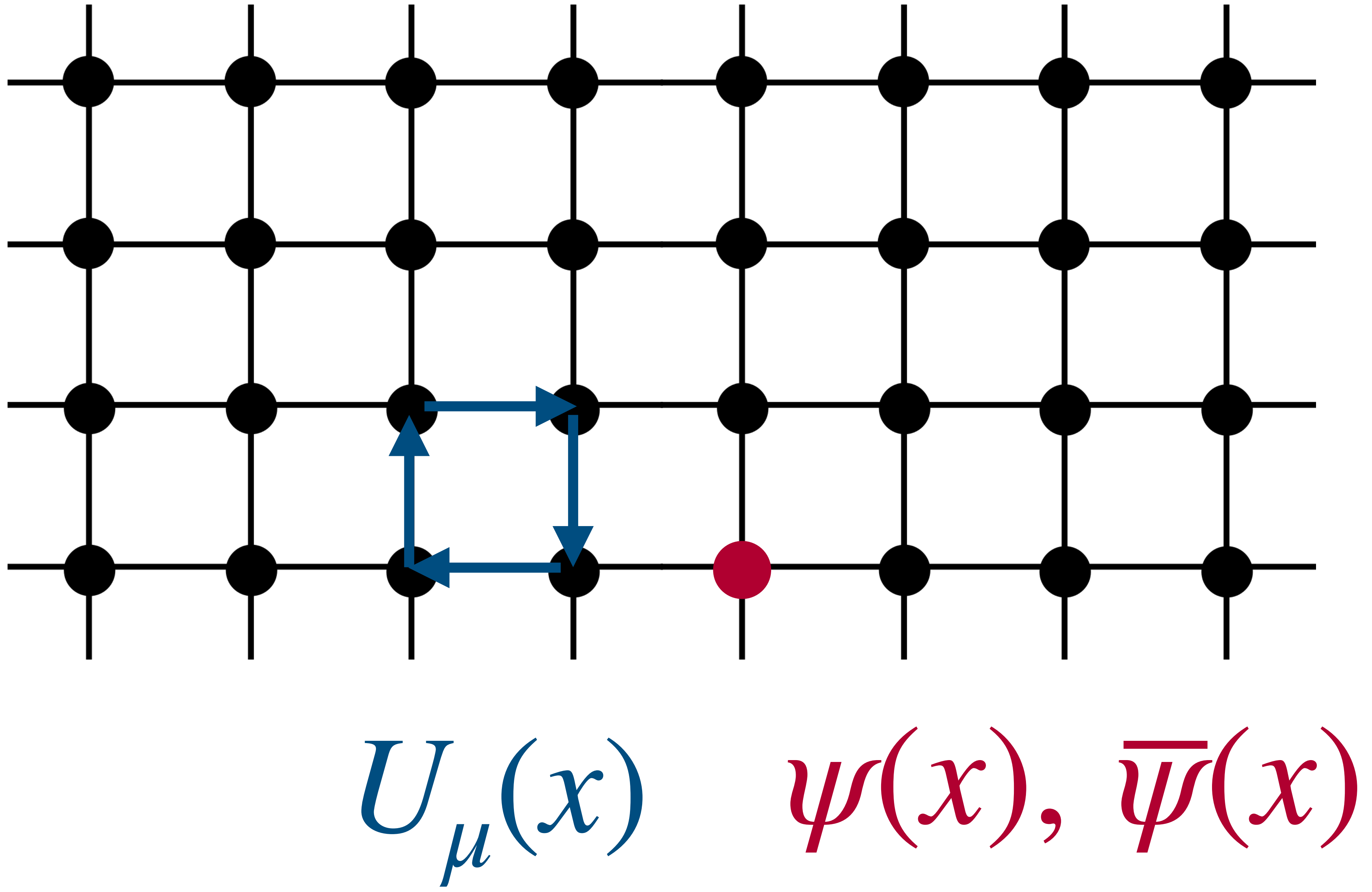

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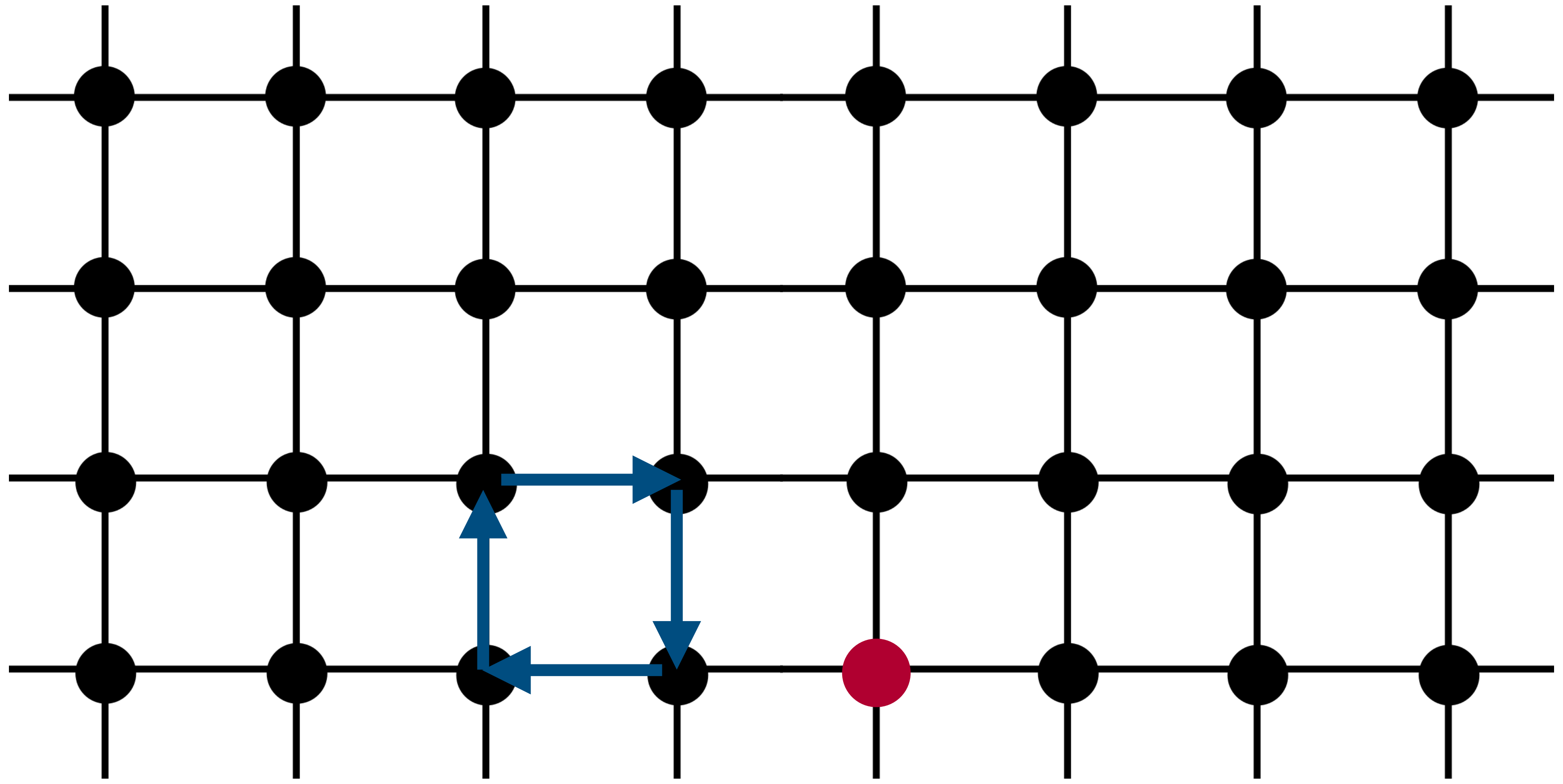

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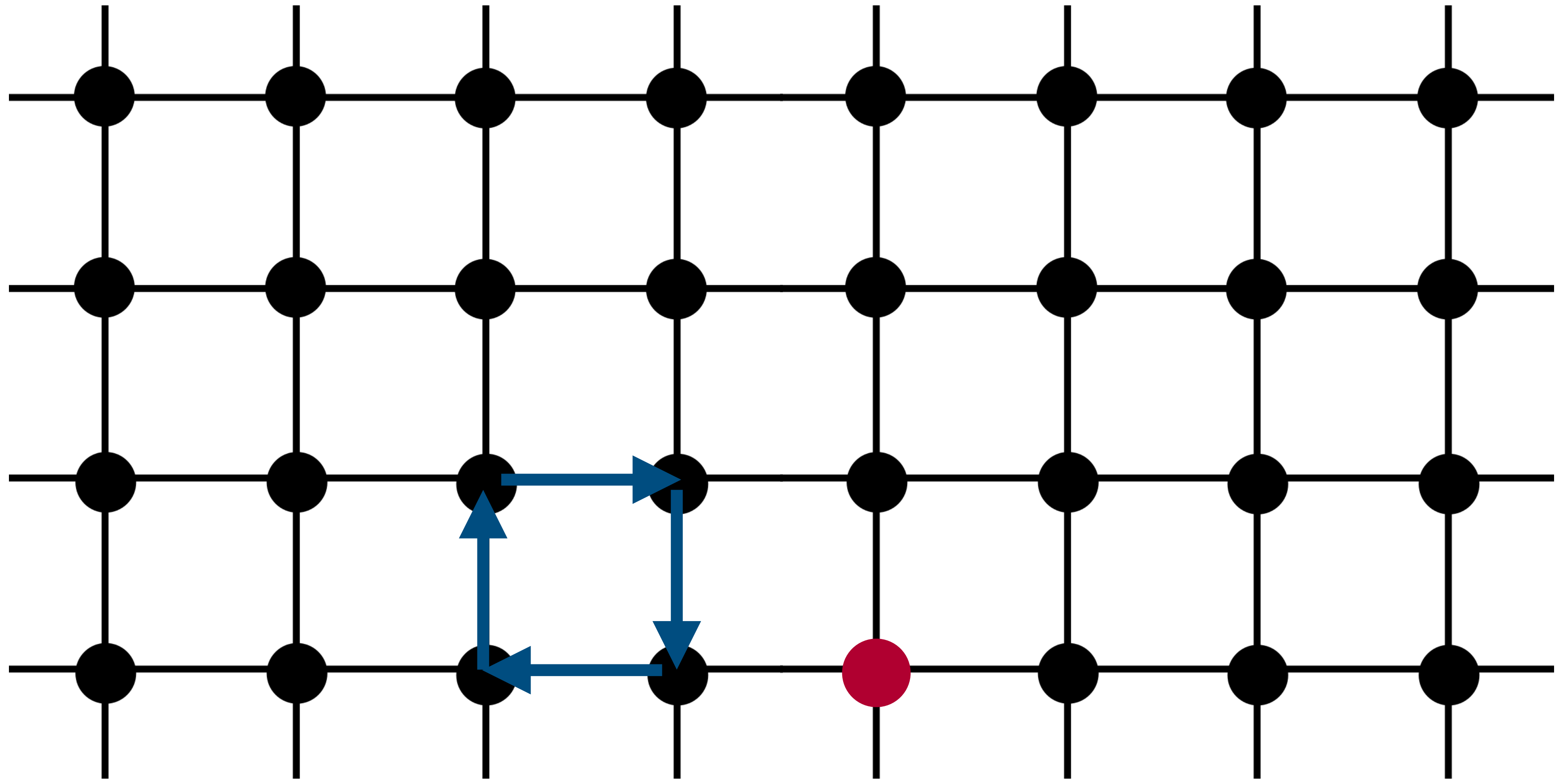
measure **probability density** **observable**



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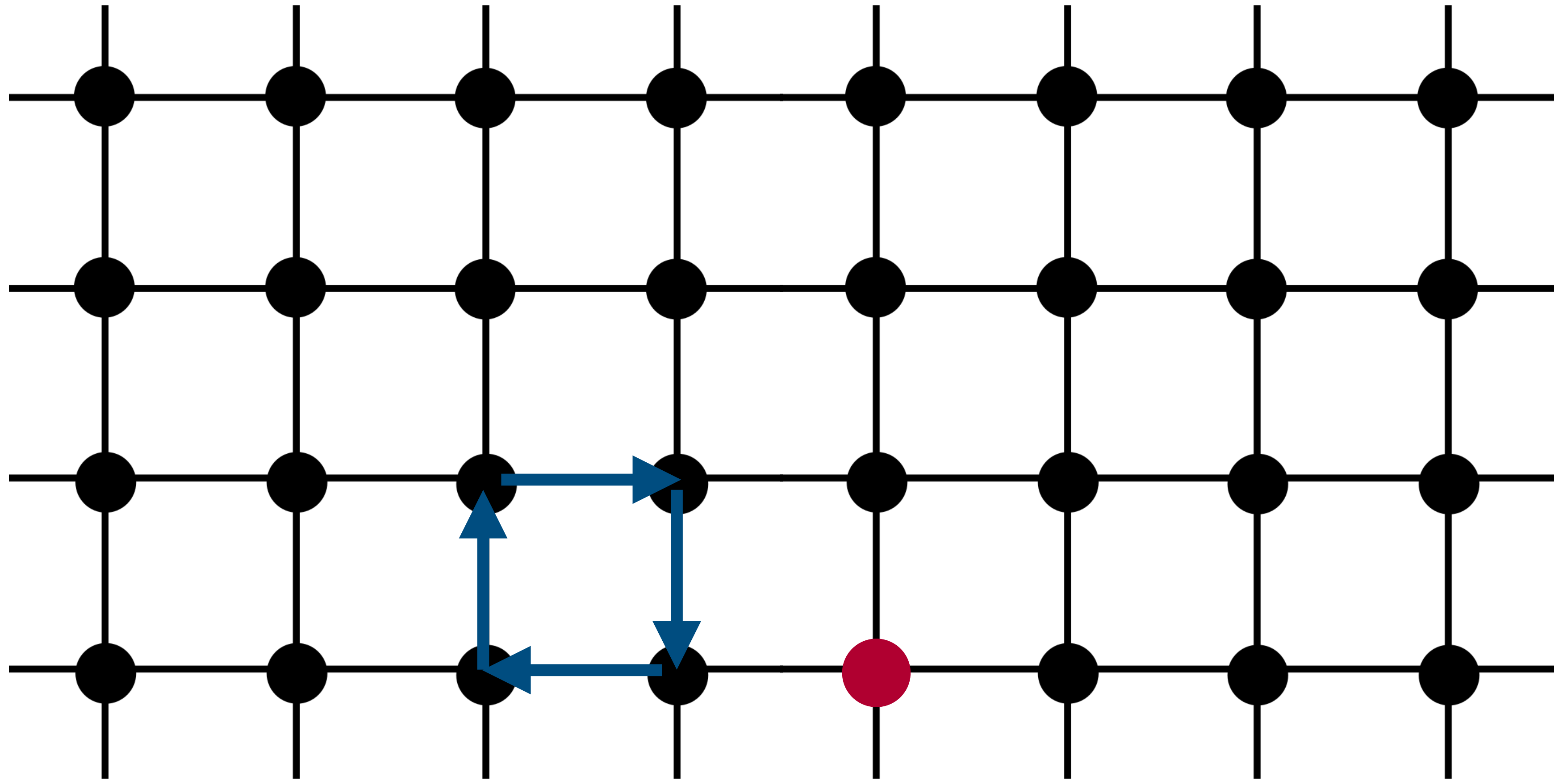


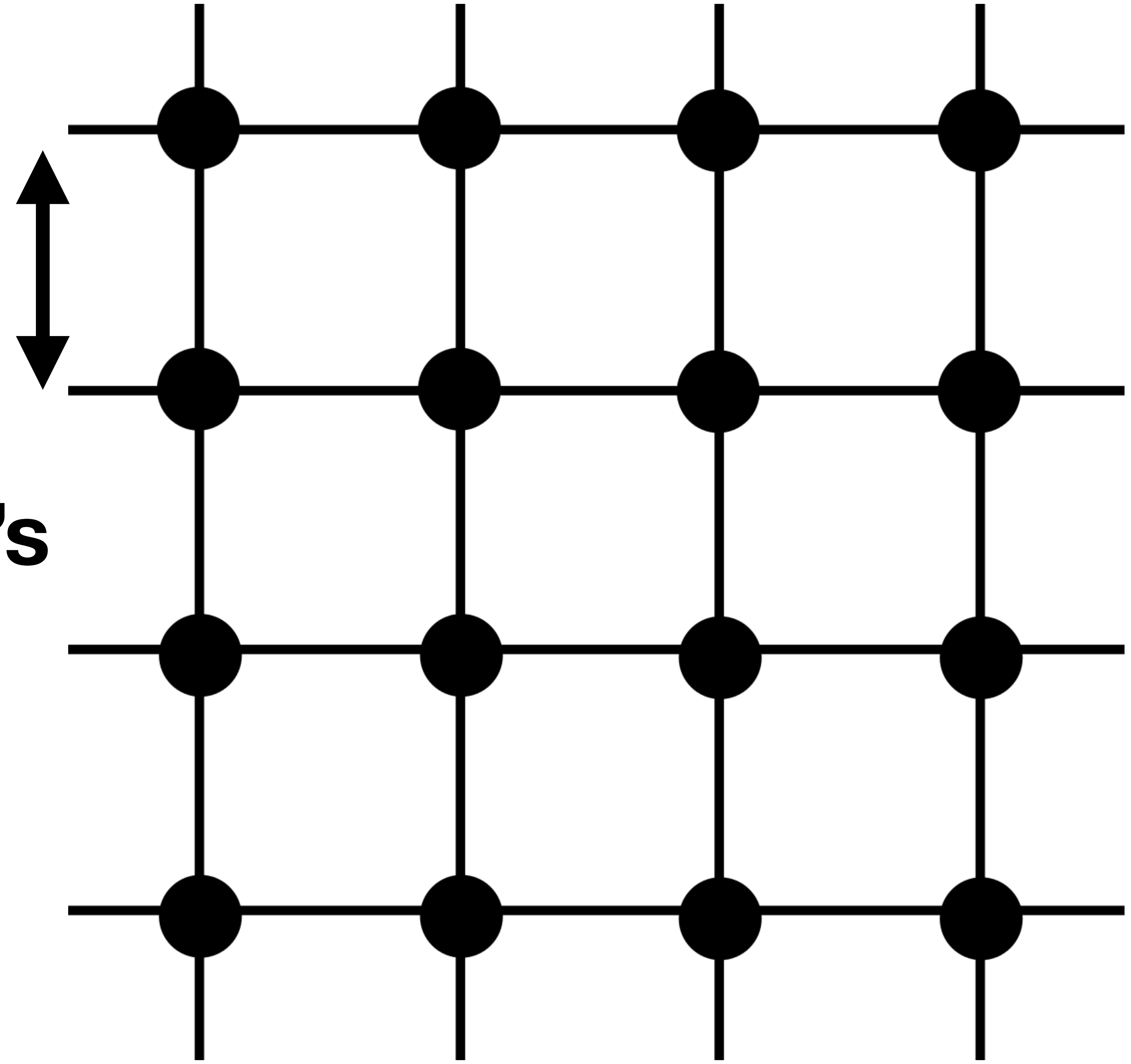
$U_\mu(x)$ $\psi(x), \overline{\psi}(x)$

Use Markov chain Monte Carlo (MCMC) method to compute integrals

How to compute with lattice QCD

$a \approx 0.1$ fm

$L \approx$ few fm's



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Lattice QCD observables

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"source"

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Lattice QCD observables

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- **Mass** $\quad C_{2pt}(t) \rightarrow Ae^{-m_N t}$

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- **Mass** $C_{2pt}(t) \to Ae^{-m_N t}$
- **Matrix element** $C_{3pt}(t,\tau)/C_{2pt}(t) \to K\langle N|J|N\rangle$

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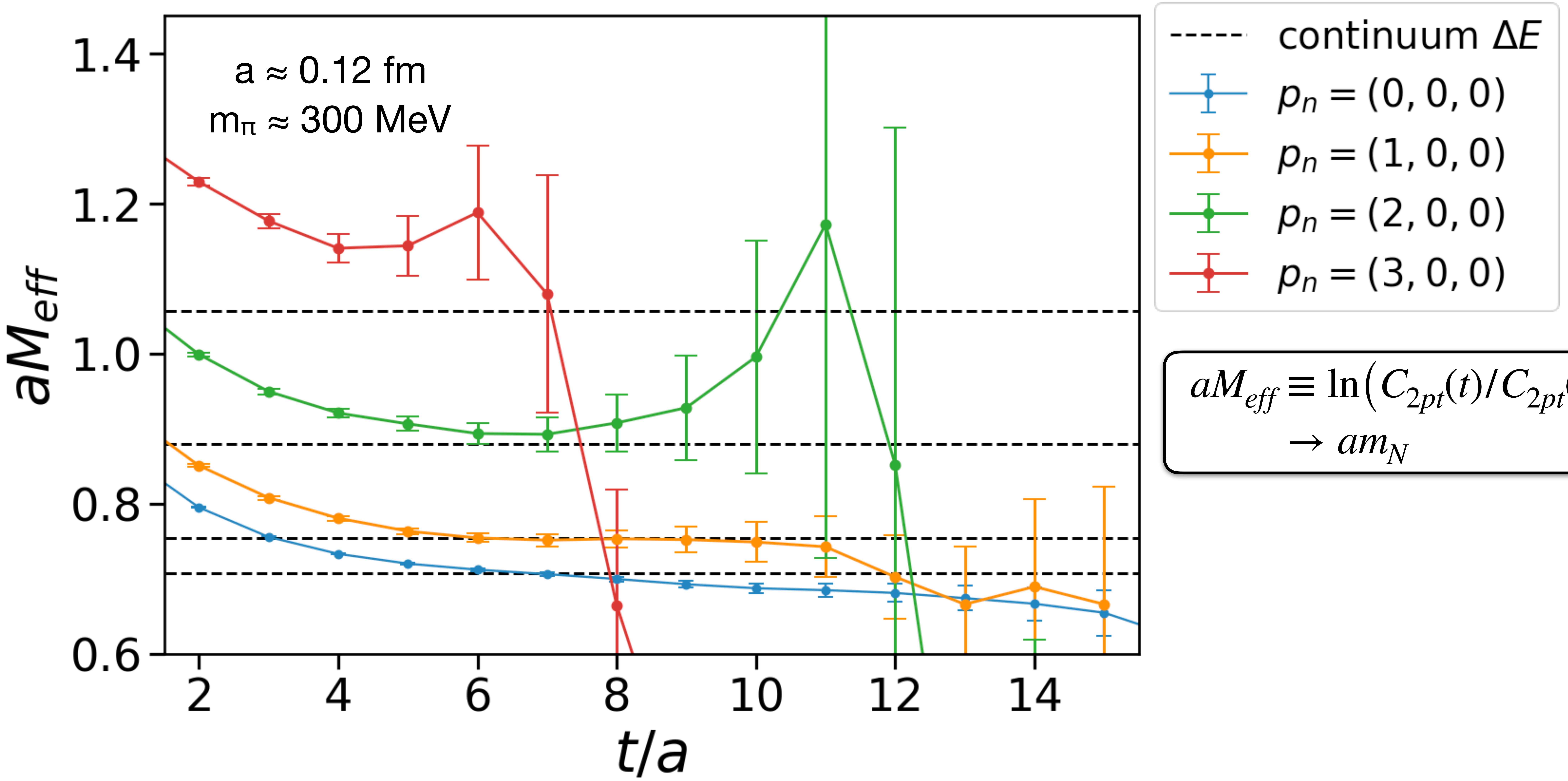
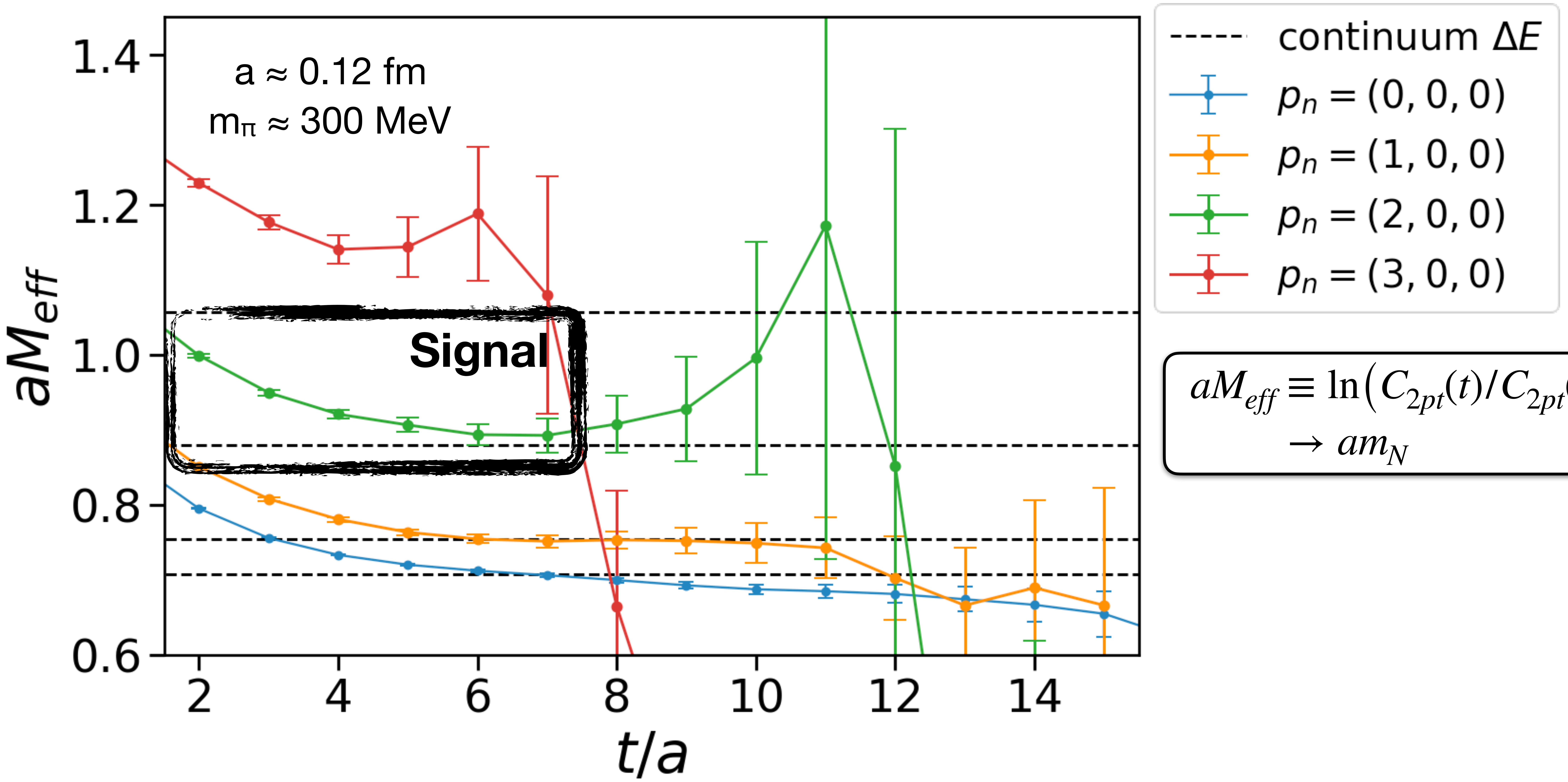
Signal-to-noise problems in practice



$$aM_{eff} \equiv \ln\left(C_{2pt}(t)/C_{2pt}(t+a)\right) \to am_N$$

Signal-to-noise problems in practice



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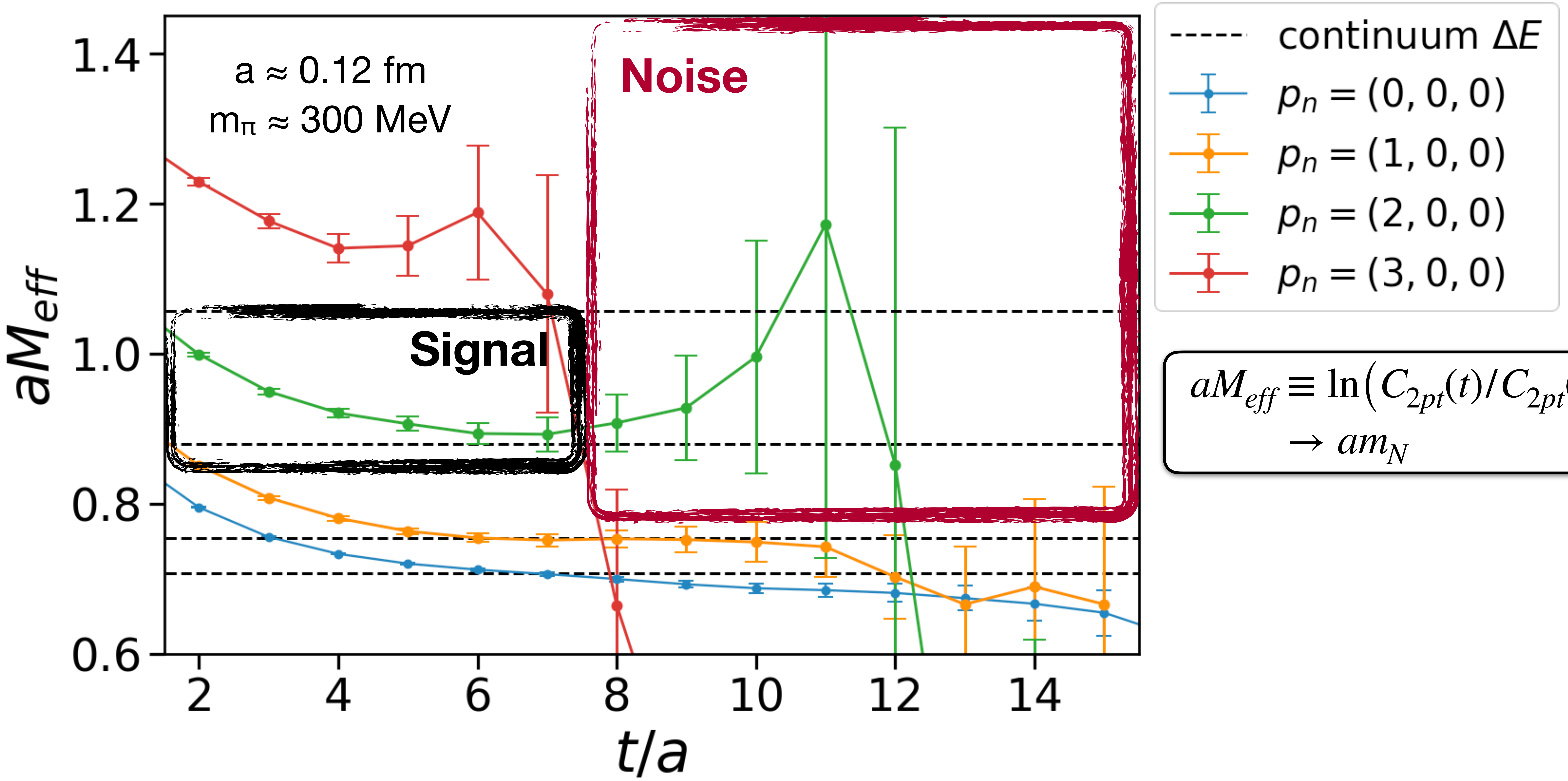

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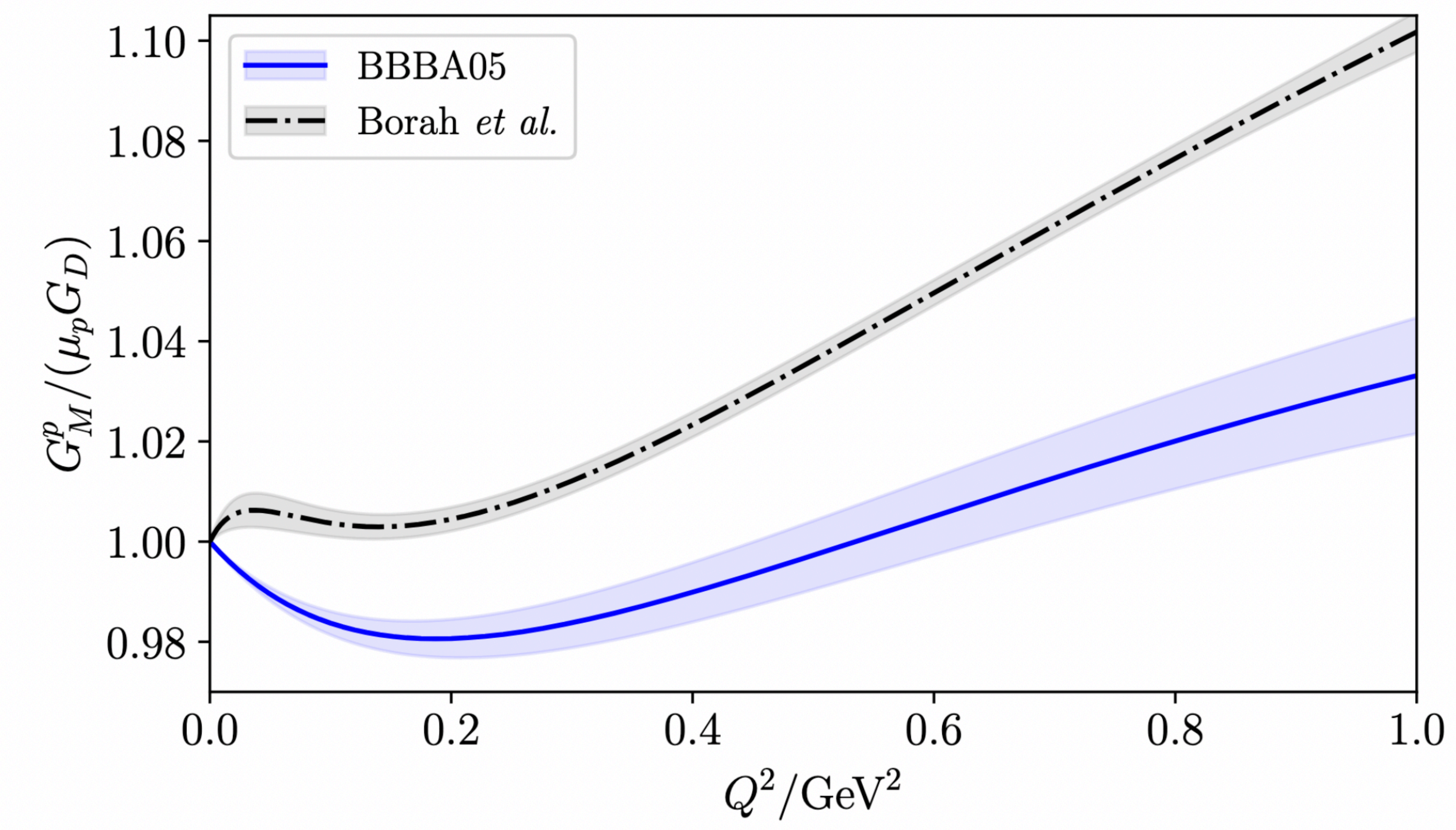
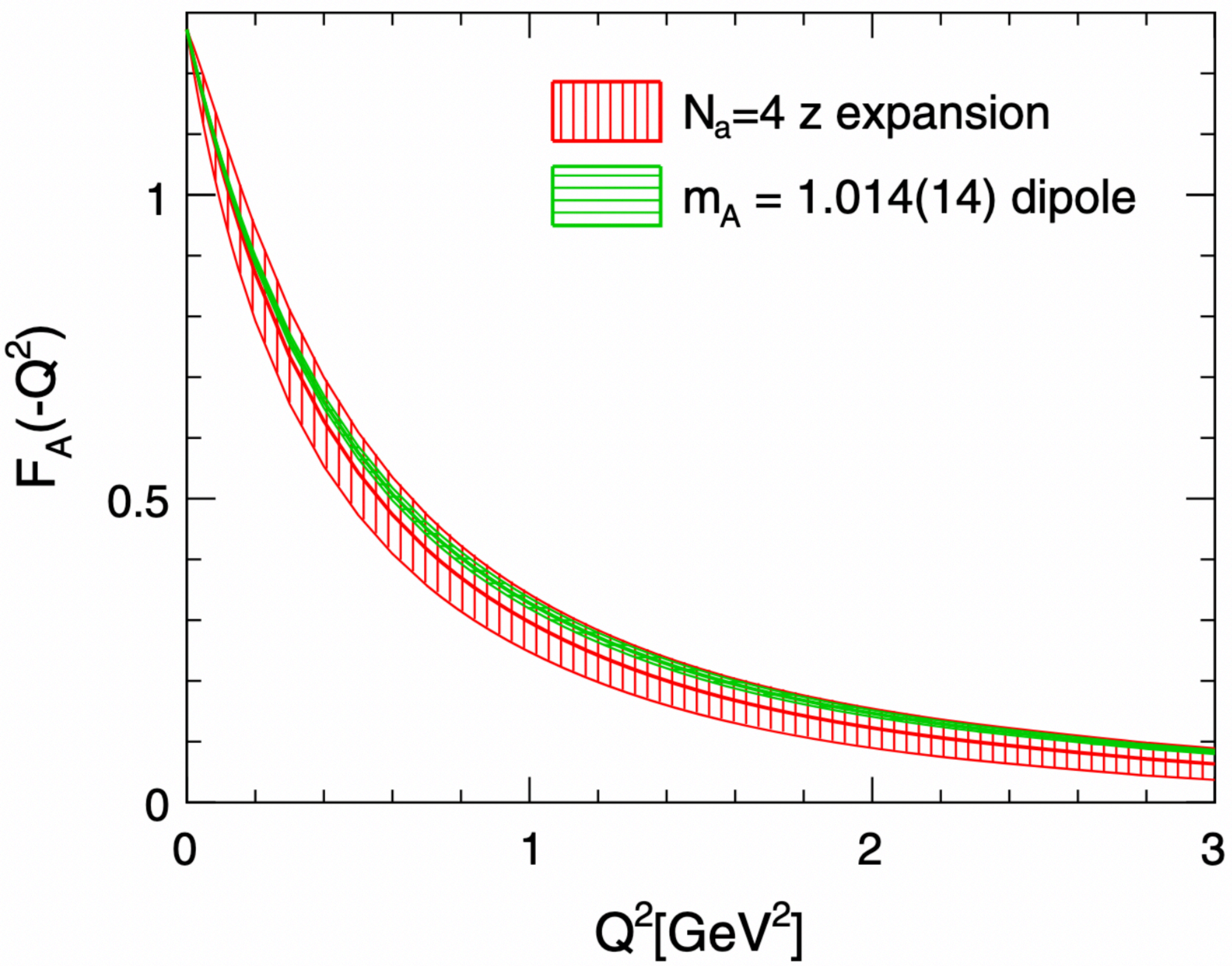
Nucleon form factors

Proton magnetic form factor



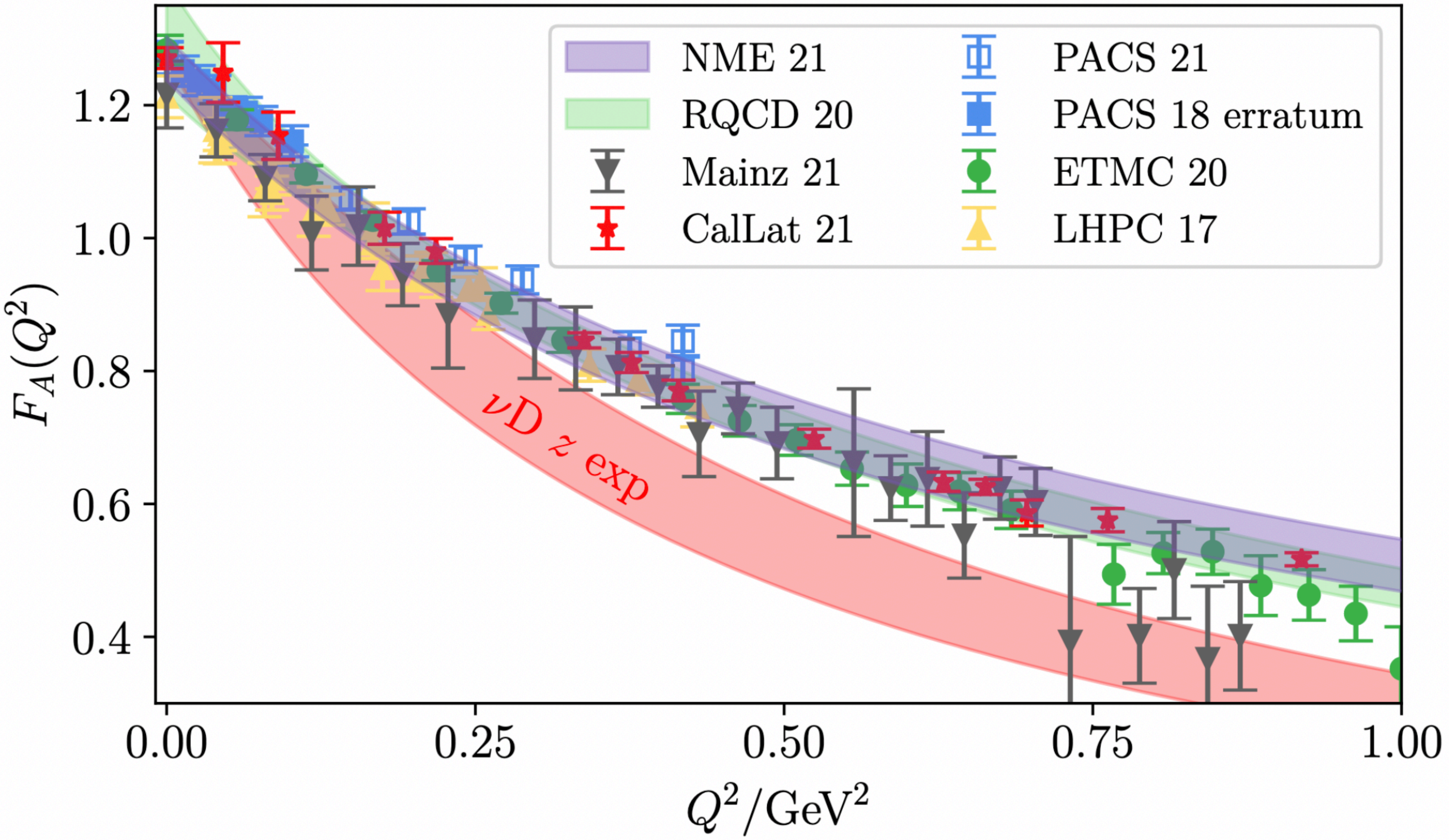
[K. Borah, R. Hill, G. Lee, O. Tomalak, arXiv:2003.13640]
[A. Meyer, A. Walker-Loud, C. Wilkinson, arXiv:2201.01839]

Isovector nucleon axial form factor



[A. Meyer, M. Betancourt, R. Gran, R. Hill arXiv:1603.03048]

Isovector nucleon axial form factor on lattices



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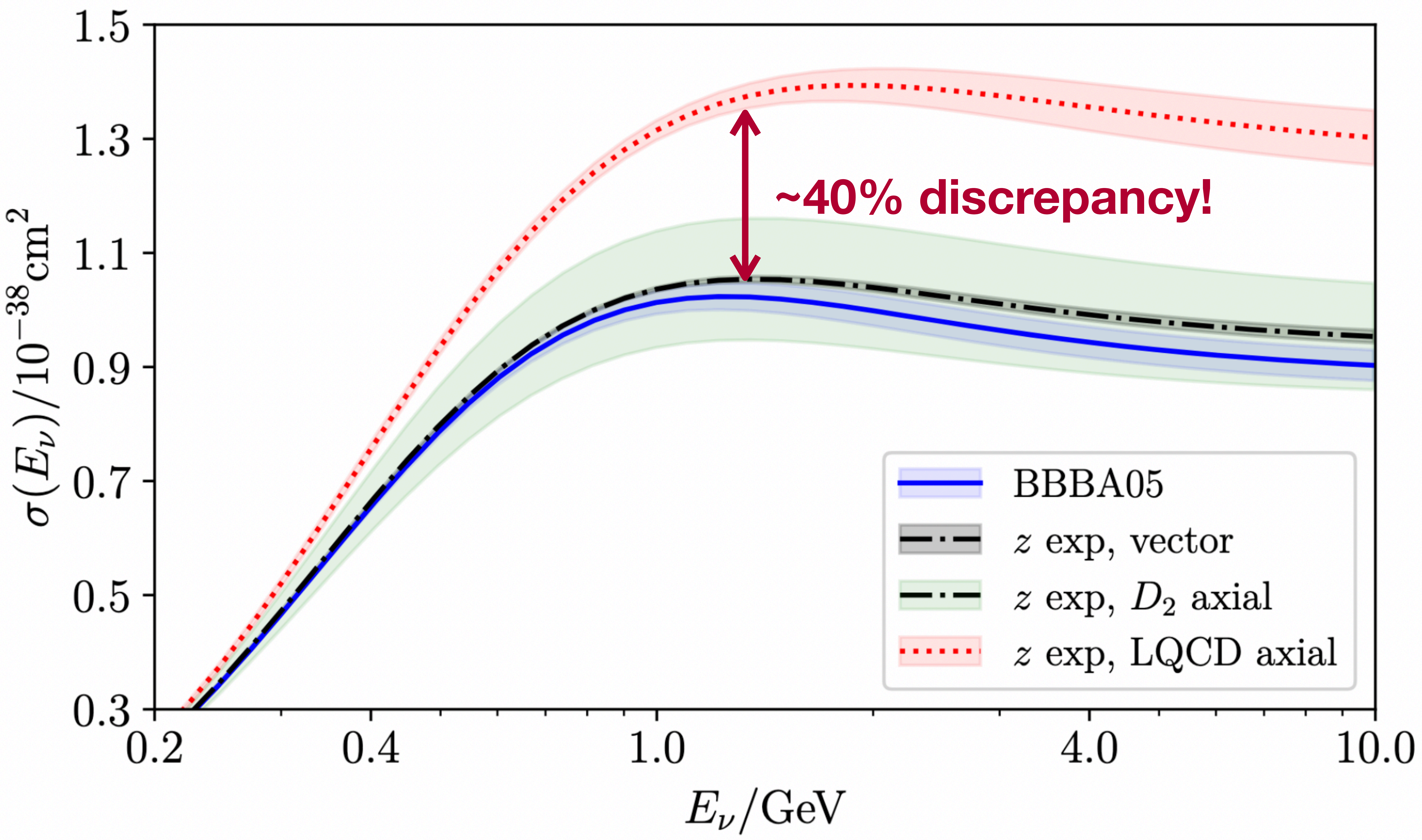
Neutrino-neutron cross section



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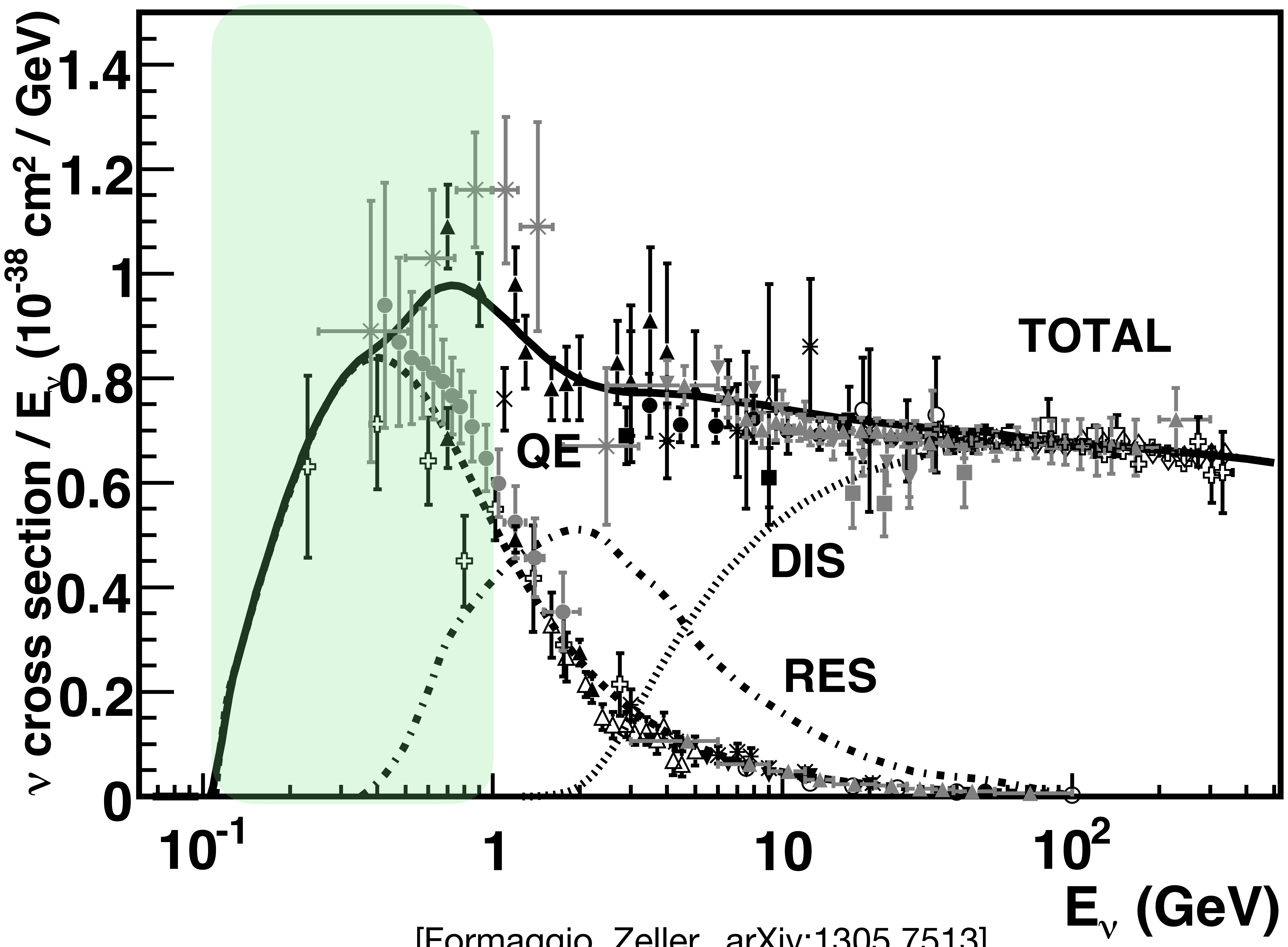
Neutrino-neutron cross section

$$\langle N | J^\mu | N \rangle$$



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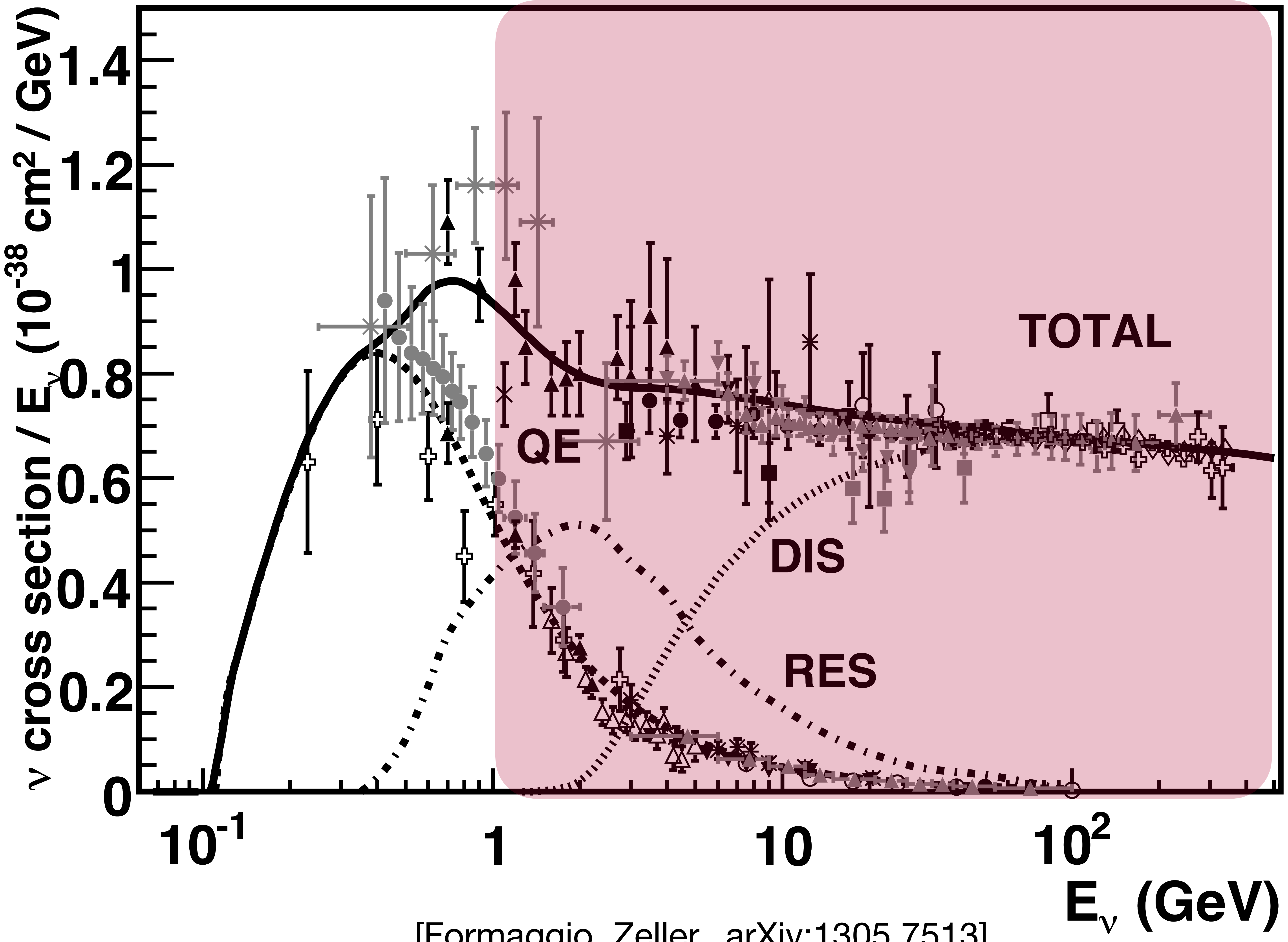


[Formaggio, Zeller, arXiv:1305.7513]

PDF

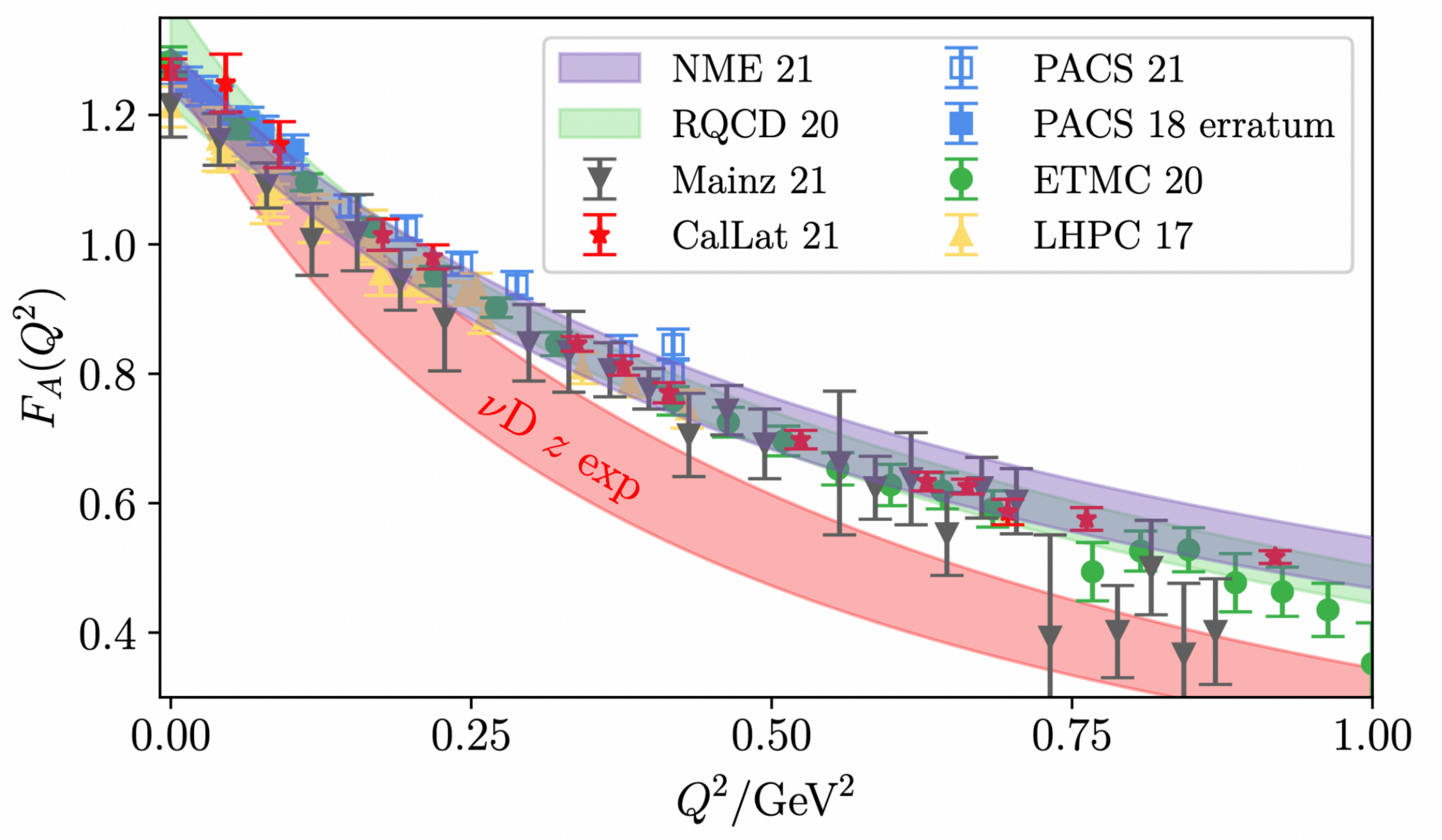
$$\langle N | J^\mu J^\nu | N \rangle$$

$$\langle N | J^\mu | \text{res.} \rangle$$

[USQCD white paper, arXiv:1904.09931]

Summary

- Lattice QCD results on the nucleon axial form factors are converging
  $\longrightarrow$ higher values at large Q^2
- Fully controlled systematics in the near future (new experiments?)
- Exploratory calculations of other processes (resonance transition form factors, hadronic tensors, and pdfs)



Also see Michael Wagman's plenary talk tomorrow for more!

Signal-to-noise problems

$$C_{2pt} \equiv \langle X \rangle = \langle O_N(t)\overline{O}_N(0) \rangle \to Ae^{-m_N t}$$

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Parisi-Lepage argument

$$\langle X^2 \rangle \to Be^{-3m_\pi t}$$

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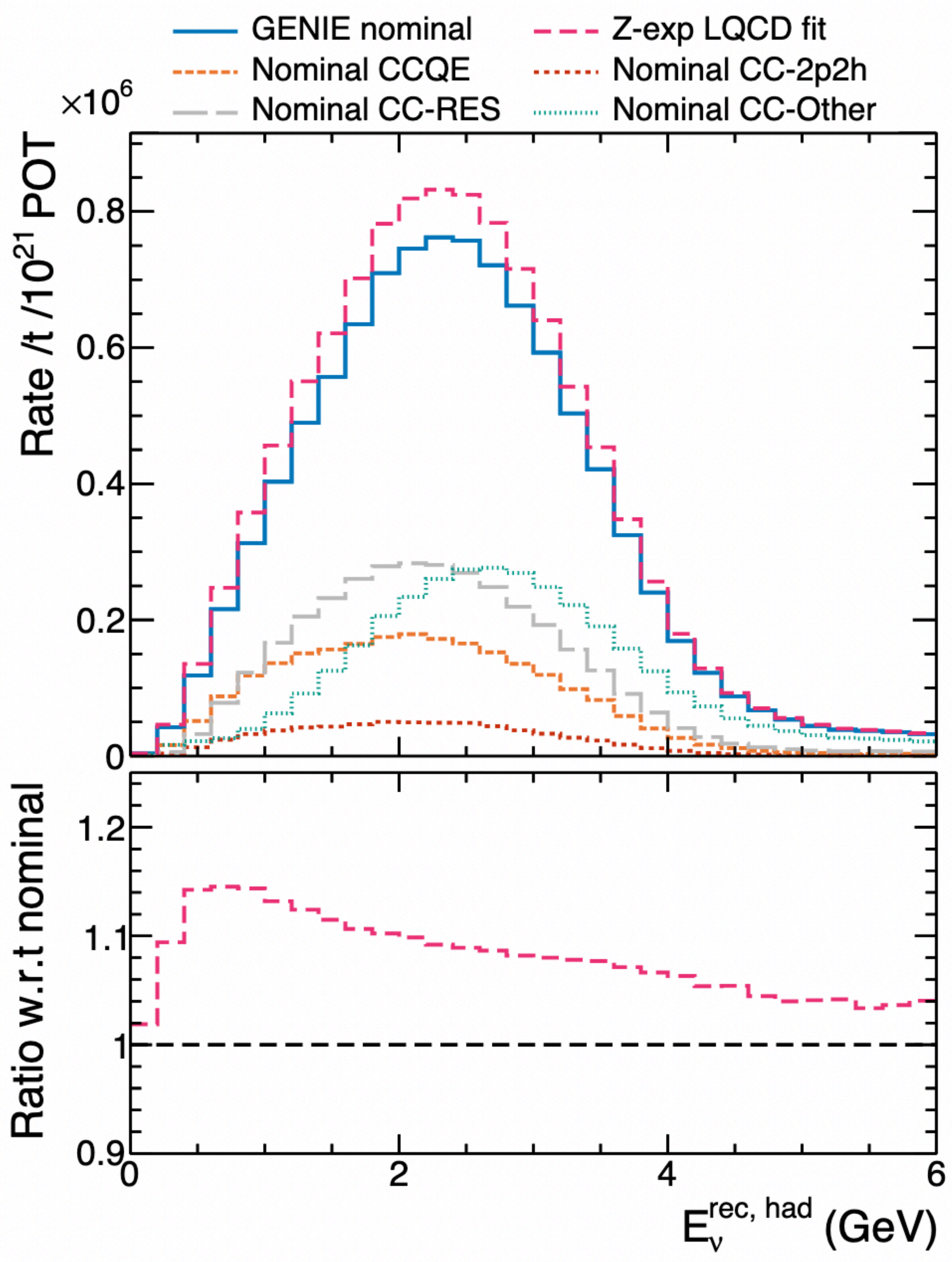
Parisi-Lepage argument

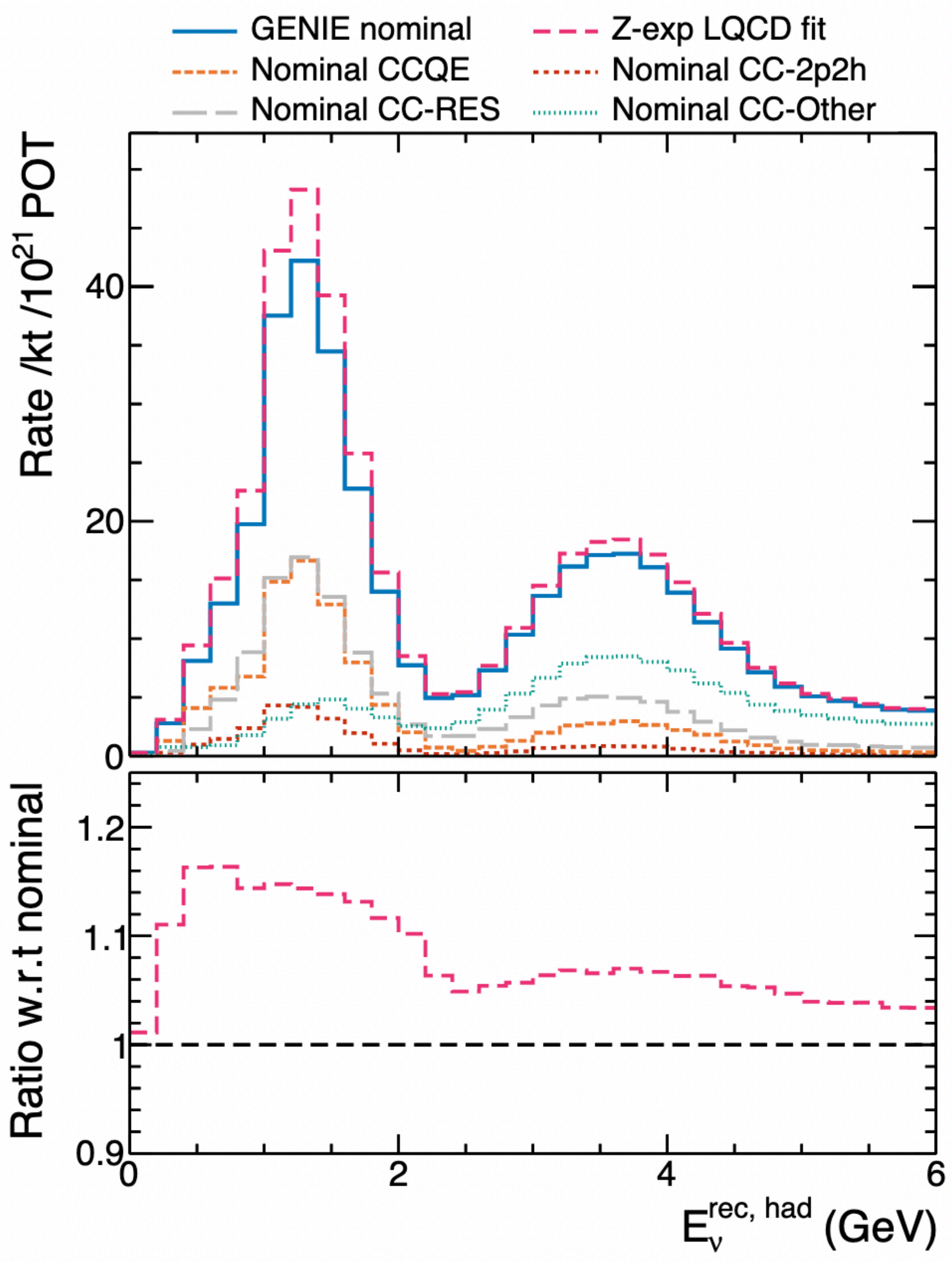
$$\langle X^2 \rangle \rightarrow Be^{-3m_\pi t}$$

$$SNR \equiv \frac{\langle X \rangle}{\sqrt{Var(X)}/\sqrt{N}} \rightarrow C\sqrt{N}e^{-(m_N-(3/2)m_\pi)t}$$

Neutrino-argon cross sections at DUNE



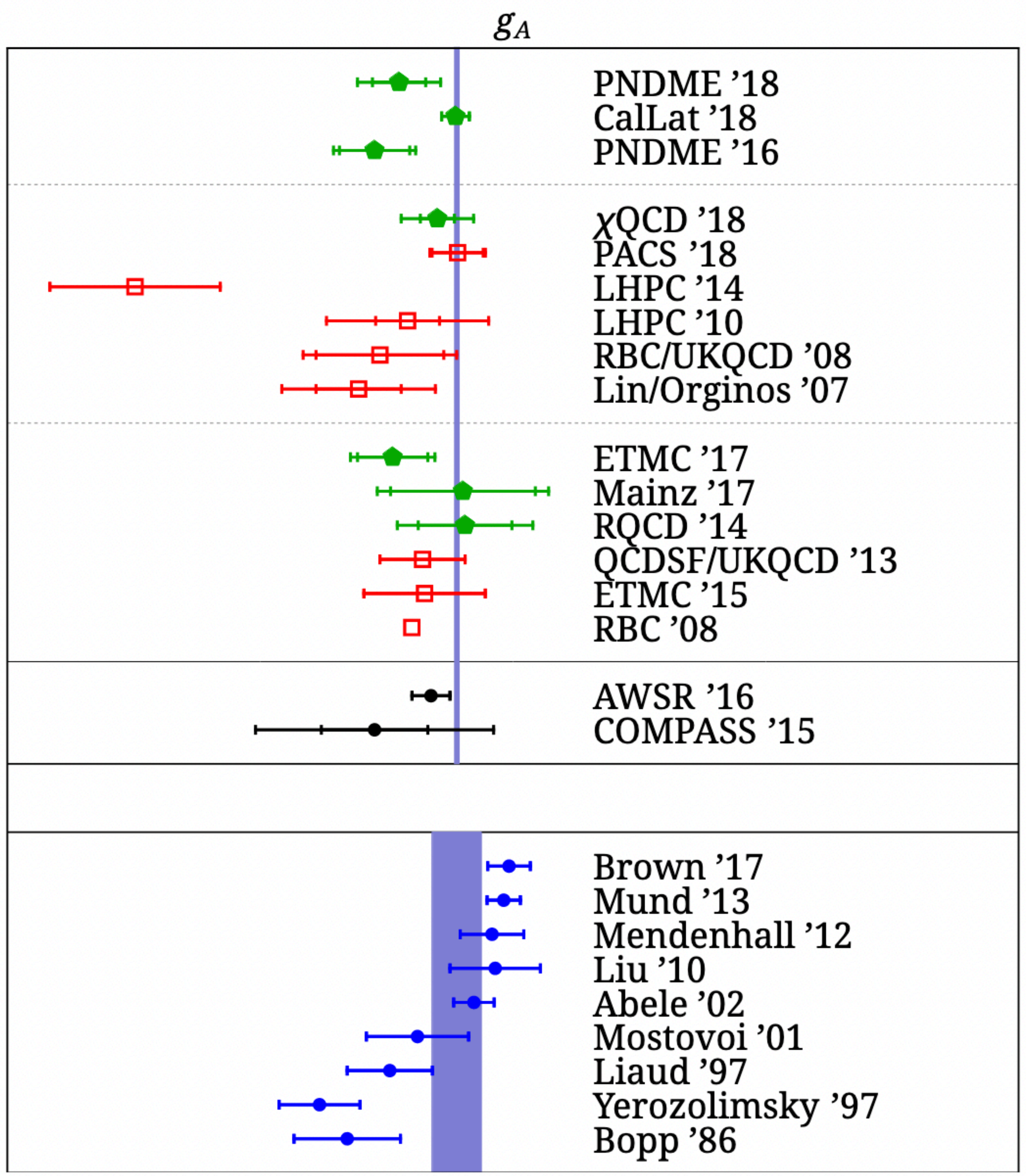
(a) ND



(b) FD

[A. Meyer, A. Walker-Loud, C. Wilkinson, arXiv:2201.01839]

Nucleon axial charge



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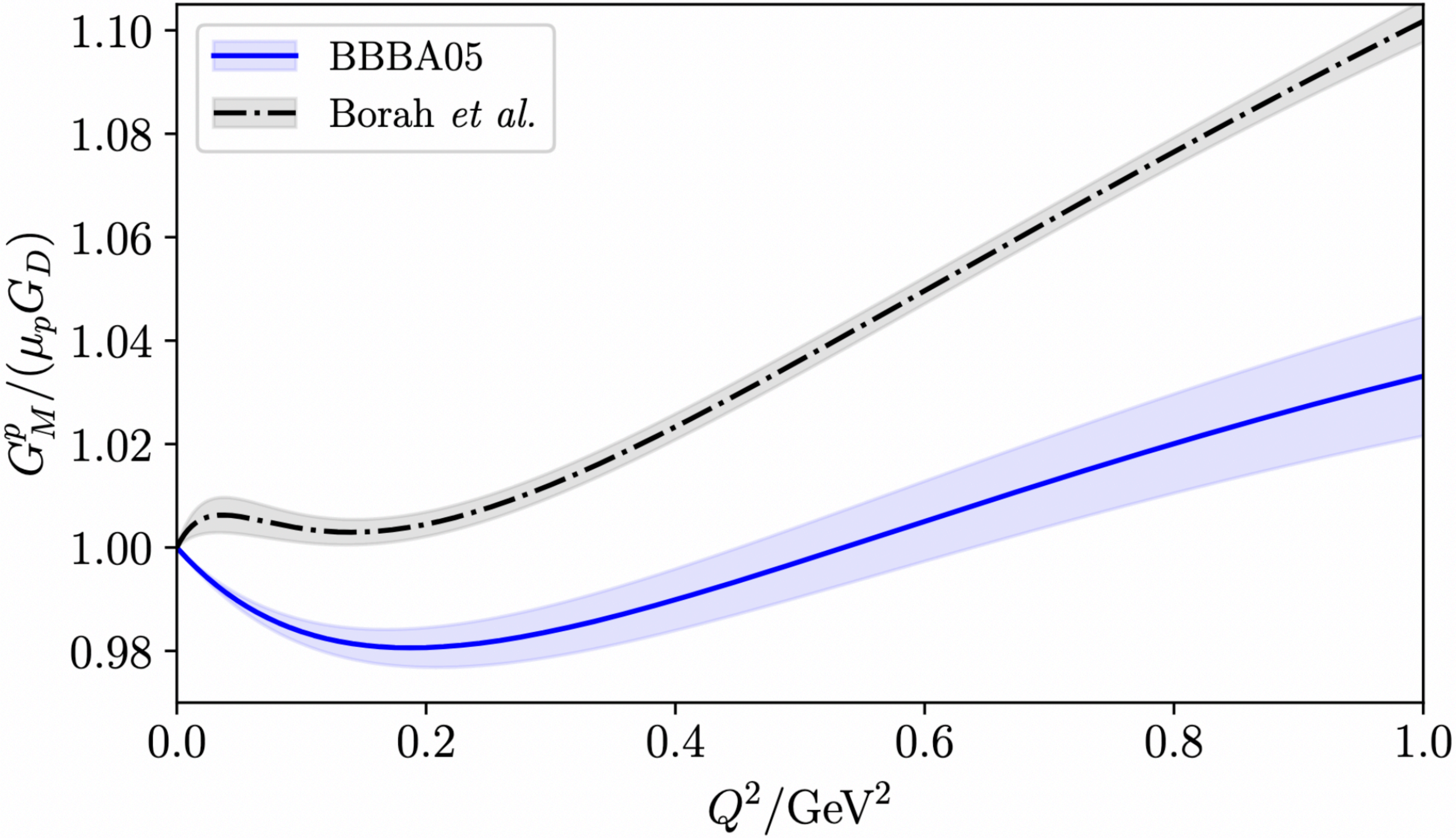

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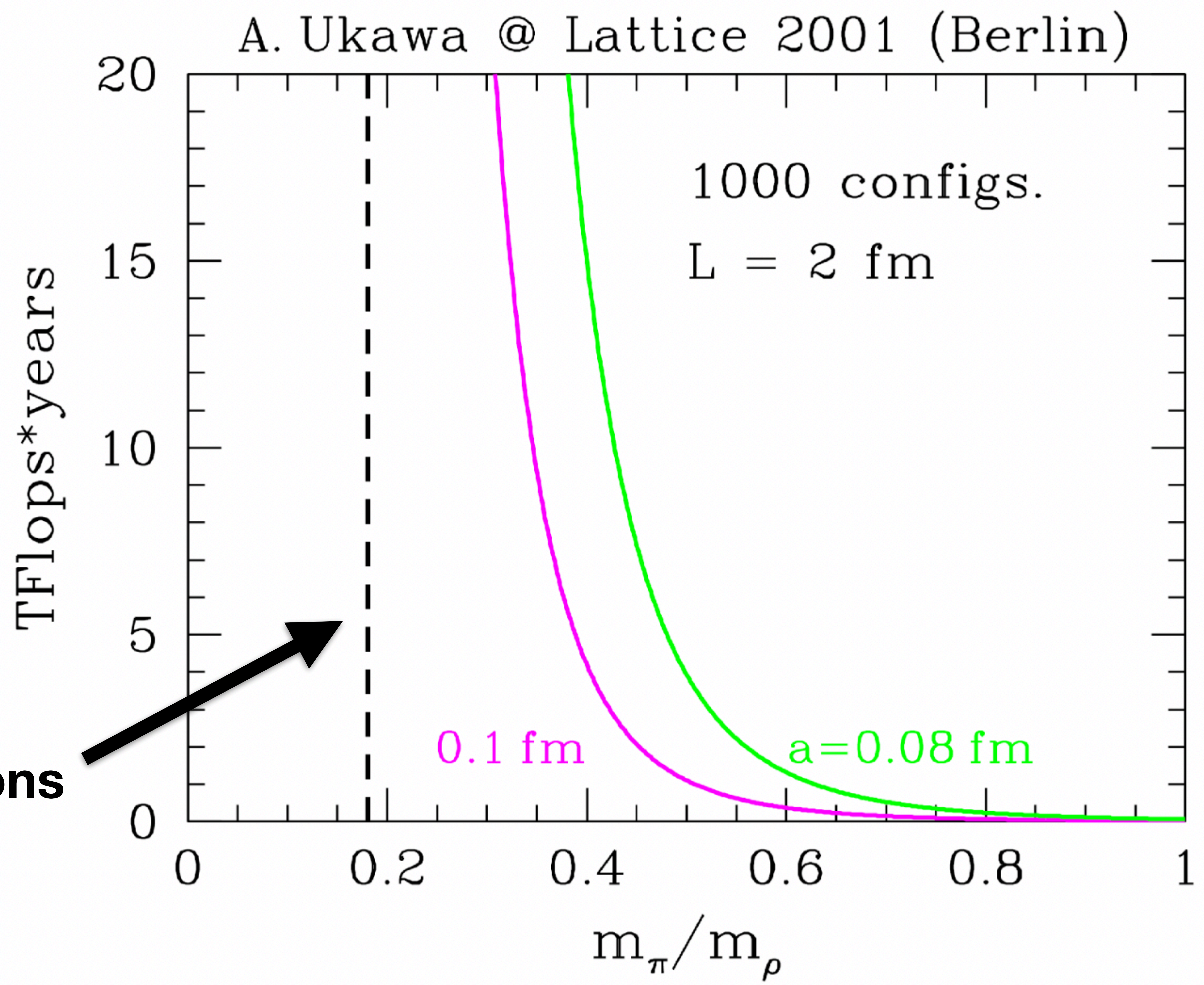
Berlin Wall plot



physical pions