Nucleon Axial Form Factor from Domain Wall on HISQ

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On behalf of the CalLat collaboration

UC Berkeley/LBNL

July 27, 2021

38th International Symposium on Lattice Field Theory

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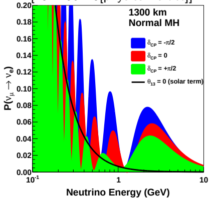
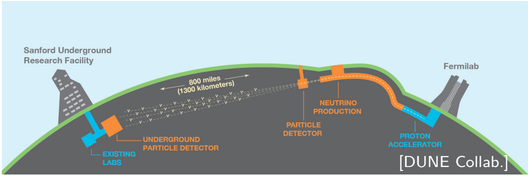
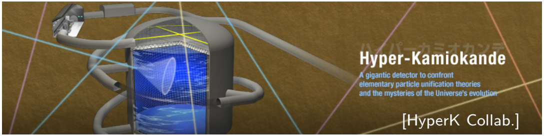
California Lattice Collaboration

Motivation from Neutrino Oscillation Expt

[1512.06148[physics.ins-det]]





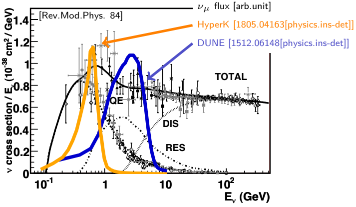


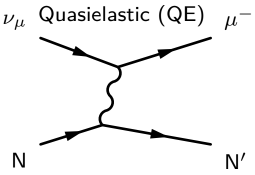
Flagship neutrino oscillation experiments
(DUNE, HyperK)

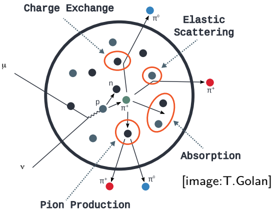
$V - A$ interaction $\implies$ weak current

Secondary beam $\implies$ ν flux probes range of E_ν

Axial Form Factor







Weak current $\implies$ large nuclear targets

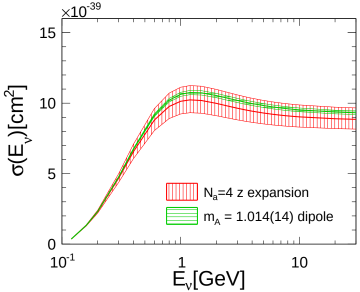
Multiple interaction regimes in play

Ideal factorization: Nucleon / Nuclear

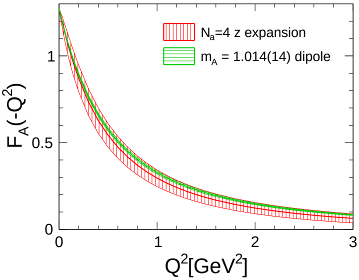
Quasielastic scattering:
- theoretically simple process
- dominates low energy interactions
- primary signal measurement

QE F_A from z Expansion

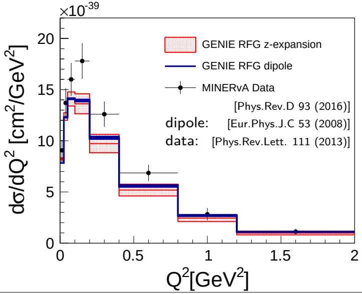
- Dipole $F_A(Q^2) = g_A/(1 + Q^2/m_A^2)^2$
  strict Q^2 shape,
  inconsistent w/ QCD
- Dipole FF ansatz significantly
  underestimates FF uncertainty



- Nucl. xsec uncertainty from FF
  same size as data-MC tensions
- Source of tensions unclear
  btw. nucleon/nuclear



- Model-independent parameterization
  Order of mag. larger $\delta\sigma$



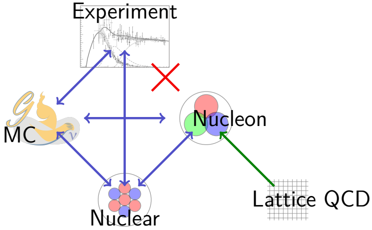
LQCD as Disruptive Technology

Ideal: Modern high stats ν-D_2 scattering bubble chamber expt

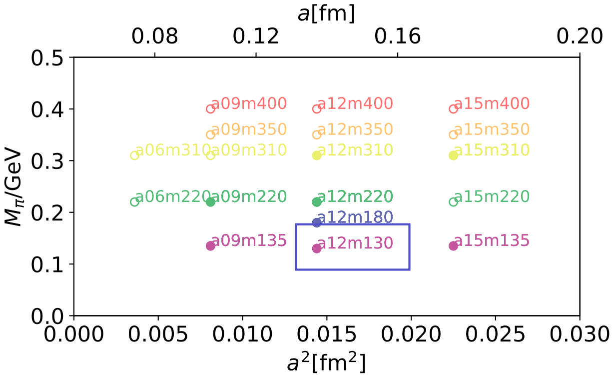
Some community push, safety concerns

$\Longrightarrow$ LQCD as a alternative/complement to expt

- ✓ No nuclear effects
- ✓ Realistic uncertainty estimates
- ✓ Systematically improvable
- ✓ Computers are (relatively) inexpensive



CalLat Computation

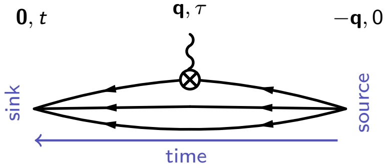


- Open symbol: g_A computation
- Filled symbol: existing $g_A(Q^2)$ data

Multiple volumes on many ensembles

$\Longrightarrow$ Only a12m130 in this talk

Setup



$$\mathcal{R}_{\mathcal{A}_z}(t,\tau,\mathbf{q}) = \frac{C^{\text{3pt}}_{\mathcal{A}_z}(t,\tau,\mathbf{q})}{\sqrt{C^{\text{2pt}}(t-\tau,\mathbf{0})C^{\text{2pt}}(\tau,\mathbf{q})}} \sqrt{\frac{C^{\text{2pt}}(\tau,\mathbf{0})}{C^{\text{2pt}}(t,\mathbf{0})} \frac{C^{\text{2pt}}(t-\tau,\mathbf{q})}{C^{\text{2pt}}(t,\mathbf{q})}}$$

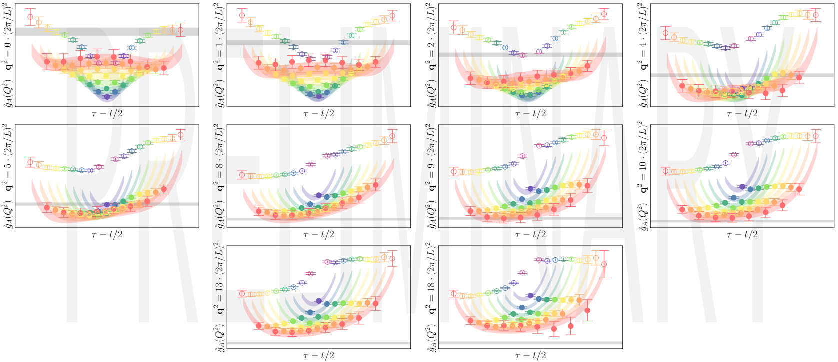
$$\xrightarrow[t-\tau,\tau\to\infty]{} \frac{1}{\sqrt{2E_{\mathbf{q}}(E_{\mathbf{q}}+M)}} \left[-\frac{q_z^2}{2M} \mathring{g}_P(Q^2) + (E_{\mathbf{q}}+M)\mathring{g}_A(Q^2) \right]$$

$$\mathcal{A}_z \text{ w/ } q_z = 0 \implies \mathcal{R}_{\mathcal{A}_z}(t,\tau,\mathbf{q}) \to \sqrt{\frac{E_{\mathbf{q}}+M}{2E_{\mathbf{q}}}} \mathring{g}_A(Q^2)$$

$\implies$ No induced pseudoscalar

$\implies$ Simplified analysis of $\mathring{g}_A(Q^2)$

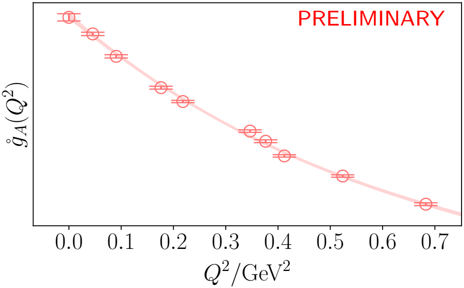
Three-Point Function Ratios



Global 3-state exponential fit $\times$ 10 momenta w/ $|q_i| \leq 3\cdot(2\pi/L)$

- colors: $t/a \in \{3, ..., 12\}$
- gray band: fit $\mathring{g}_A(Q^2)$
- All $q_z = 0$
- horizontal: τ, centered about midpoint
- vertical: $\sqrt{2E_\mathbf{q}/(E_\mathbf{q}+M)}\mathcal{R}_{\mathcal{A}_z}(t_\text{sep}, \tau, \mathbf{q}) \to \mathring{g}_A(Q^2)$
- Minimum time separation $\tau/a, (t-\tau)/a \geq 2$

Axial Form Factor Fit



Plotted: 4-parameter z expansion + 4 sum rules

$\delta g_A/g_A$: 0.6%; $\delta r_A^2/r_A^2$: 13%

Cf. $\delta r_A^2/r_A^2 \sim 48\%$ from D_2 [Phys.Rev.D 93 (2016)]

Results yield $M_{A,\mathrm{dipole}} \gtrsim 1.0$ GeV

Prelim dipole fit underestimates uncertainty $\times$ few

$$\implies r_A^2 = -(6/g_A) dF_A/dQ^2\Big|_{Q^2=0} \; ; \qquad r_{A,\mathrm{dipole}}^2 = (1\ \mathrm{GeV}^2/M_{A,\mathrm{dipole}}^2) \times 0.466\mathrm{fm}^2$$

Outlook

- Lattice QCD is the most practical approach to determine
  weak matrix elements for neutrino oscillation
- CalLat data for $g_A(Q^2)$ on several ensembles
- Large-scale global fits to several momenta @ M_π physical
- Good agreement across the board
- Future: more momenta, $p_z \neq 0$, other currents & tests of PPD...

Thanks for your attention!