

# Neutral weak axial form factor and neutrino-nucleon scattering

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*Using a combination of lattice QCD calculation of the strange-quark form factors, and experimental (anti) neutrino differential cross-section data in a regime where nuclear effects are shown to be negligible, we obtain a precise determination of the weak axial form factor in the regime  $0 \leq Q^2 \leq 1 \text{ GeV}^2$ , and of the corresponding weak-axial charge. We are thereby able to reproduce the MiniBooNE and BNL E734 data for the (anti) neutrino-nucleus differential cross section to high precision, showing that the nuclear corrections to the experimentally extracted cross section in this kinematic regime are very small. The calculation will play an vital role in understanding nuclear effects in neutrino-nucleus scattering.*

# Motivation

- Neutrino experiments are aimed at looking for neutrino oscillations - need precision knowledge of neutrino *nucleon* and neutrino *nucleus* scattering... ...+ neutrino flux/energy.

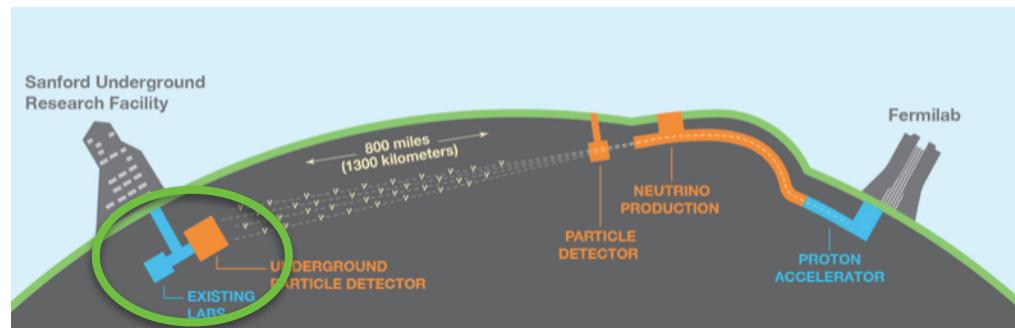
**B<sub>H</sub>e**  
BOOSTER NEUTRINO EXPERIMENT



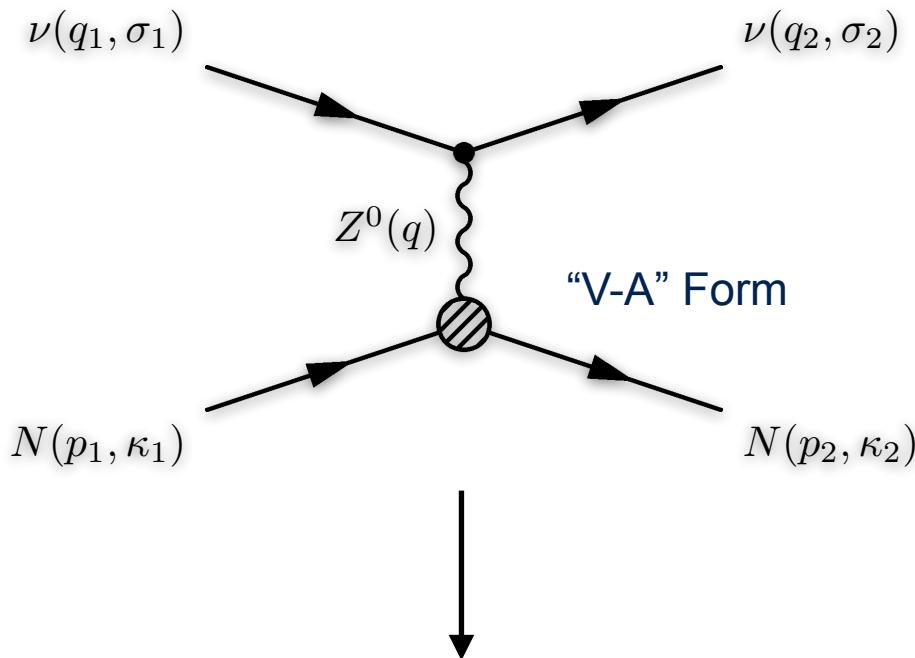
MiniBoone Detector

BNL E734

**DUNE** DEEP UNDERGROUND  
NEUTRINO EXPERIMENT



# Introduction



Measured in

$$\nu(\bar{\nu})N \longrightarrow \nu(\bar{\nu})N$$

**Gives access to Neutral-Current Form Factor**

$$\langle N(p_2) | J_Z^\mu | N(p_1) \rangle = \bar{u}(p_2) [F_1^Z(Q^2) + F_2^Z(Q^2) \frac{i\sigma^{\mu\nu}q_\nu}{2M_N} + G_A^Z(Q^2)\gamma^\mu\gamma_5] u(p_1)$$

**Vector**

**Axial-Vector**

# Introduction - II

Write the elastic differential cross section as

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2}{2\pi} \frac{Q^2}{E_\nu^2} \text{neutrino} (A \pm BW + CW^2)$$

where

$$\tau = \frac{Q^2}{4M_P^2} \text{anti-neutrino}$$

$$W = 4(E_\nu/M_p - \tau)$$

A, B, C involve both *neutral weak form factors* and vector form factors

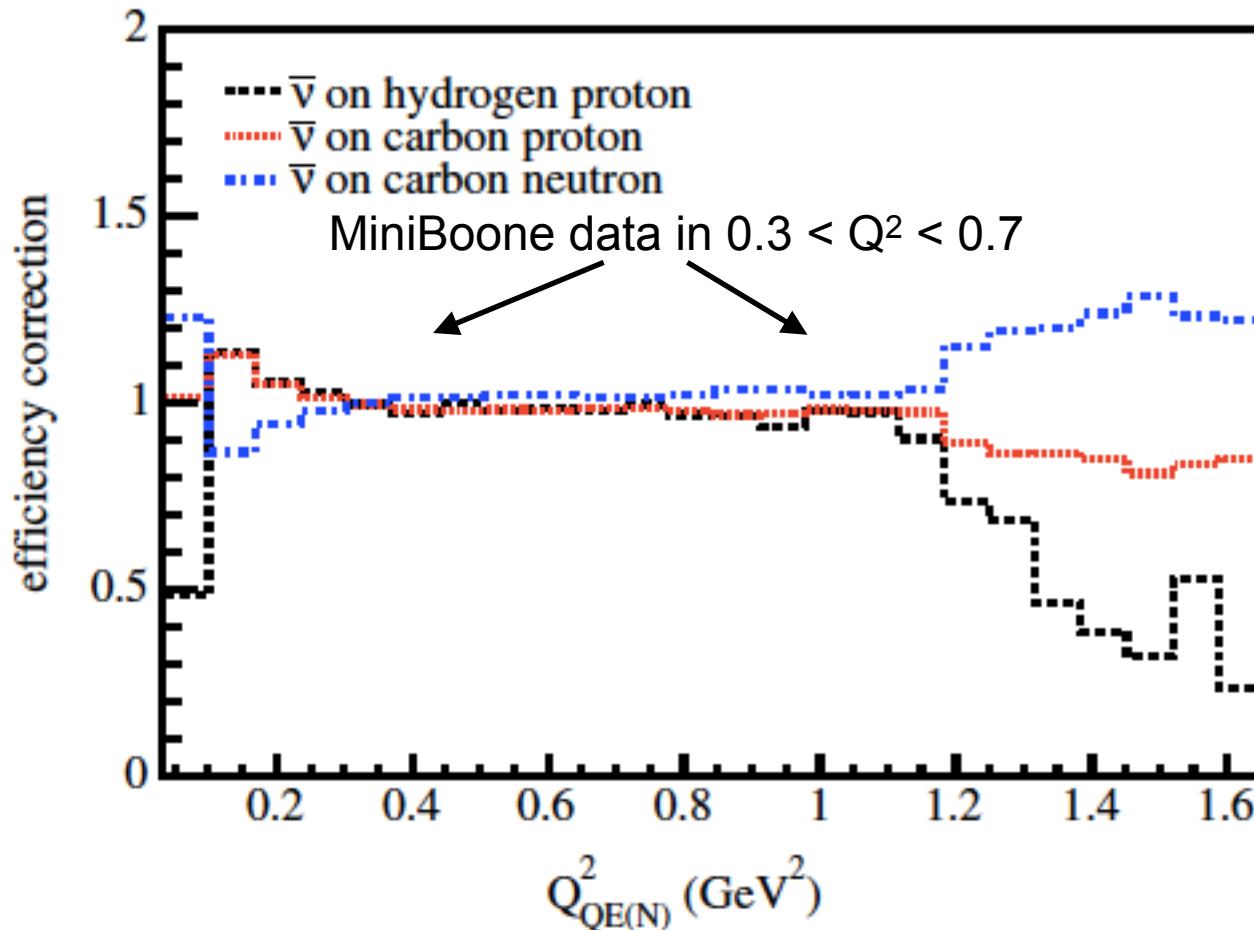
$$A = \frac{1}{4} [(G_A^Z)^2(1 + \tau) - \{(F_1^Z)^2 - \tau(F_2^Z)^2\}(1 - \tau) + 4\tau F_1^Z F_2^Z]$$

$$B = \frac{1}{4} G_A^Z (F_1^Z + F_2^Z)$$

$$C = \frac{1}{64\tau} [(G_A^Z)^2 + (F_z^Z)^2 + \tau(F_2^Z)^2]$$

# MiniBoone Detection

CH<sub>2</sub> Target - *scattering off free nucleons (H) + bound nucleons (C)*



# Vector Form Factors: strategy

To *describe* differential cross section data, or to *extract* the neutral-current axial-vector form factor, we need to know the (neutral current) vector form factors. Related to electromagnetic form factors, but with different combination of “charges”:

$$F_{1,2}^Z = \left( \frac{1}{2} - \sin^2 \theta_W \right) (F_{1,2}^p(Q^2) - F_{1,2}^n(Q^2)) - \sin^2 \theta_W (F_{1,2}^p + F_{1,2}^n) - \frac{F_{1,2}^s}{2}$$

z-expansion to nucleon experimental  
EM form factor data

Ye, Arrington, Hill and Lee, Phys. lets B777,8 (2018)

Lattice results for  $G_{E,M}^s$

R. Sufian et al (XQCD), PRD96, 114504 (2017)

R. Sufian, Phys. Rev. D 96, 093007 (2017)

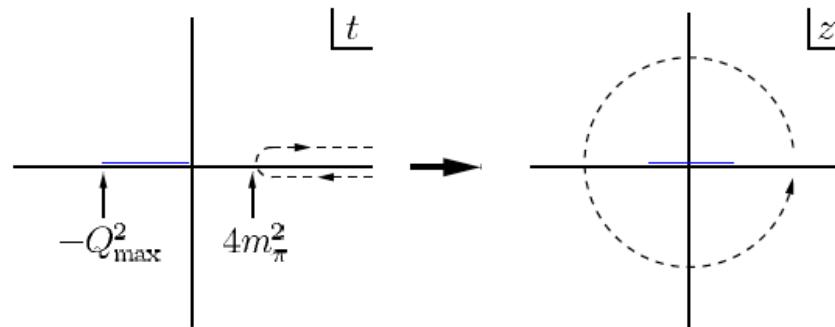
R.Sufian et al., XQCD,Phys. Rev. Lett. 118, 042001

# z-expansion

In timelike region, there is a *cut* in the EM form factor corresponding to  $\gamma \rightarrow \pi\pi$ , that is at  $t = 4m_\pi^2$ .

R.Hill, G.Paz, PRD82, 113005 (2010)

Introduce mapping



**Model-independent expansion**

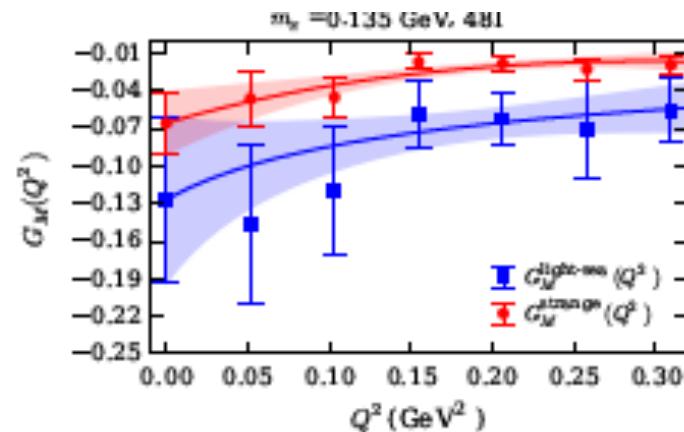
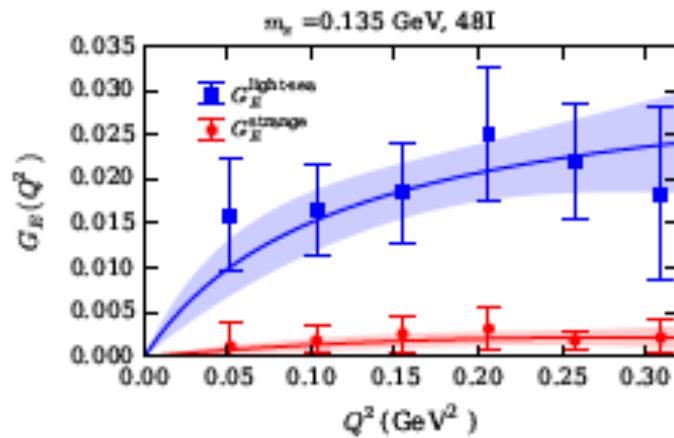
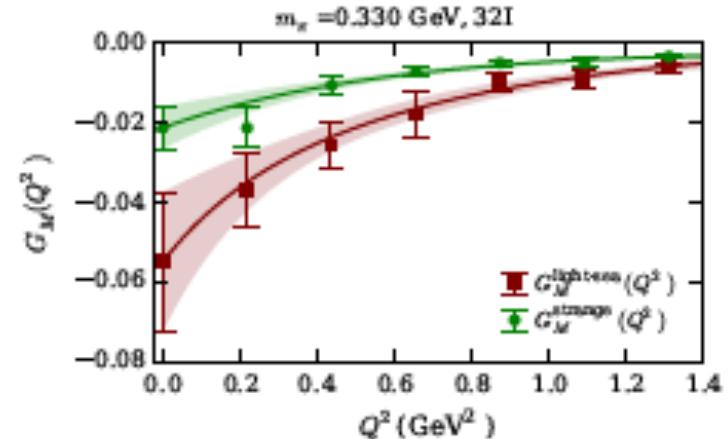
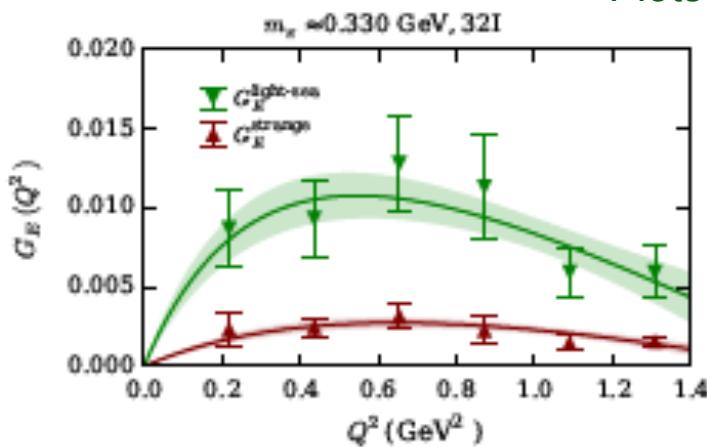
$$z = \frac{\sqrt{t_{\text{cut}} + t} - \sqrt{t_{\text{cut}}}}{\sqrt{t_{\text{cut}} + t} + \sqrt{t_{\text{cut}}}}$$

where  $t = Q^2$  and  $t_{\text{cut}} = 4m_\pi^2$

then expand  $G(Q^2) = \sum_{k=0}^N a_k z^k(Q^2)$

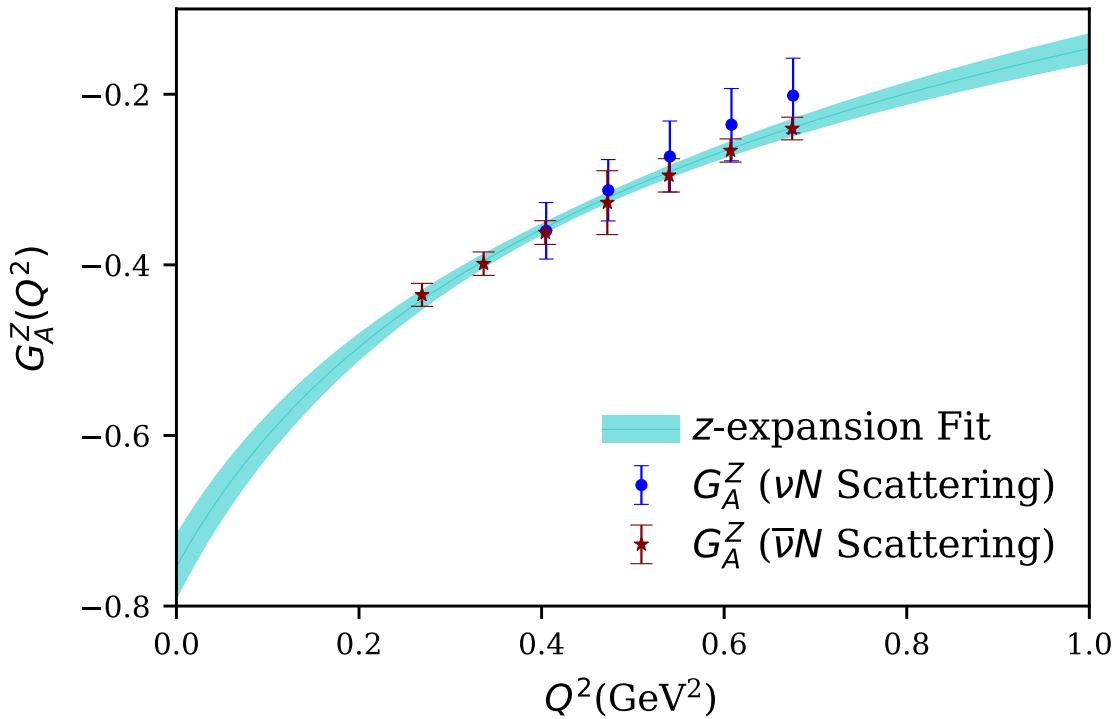
# Strange EM form factors

Plots from R. Sufian et al, PRD96, 114504 (2017)



Strange-quark contributions to GEM are very significant

# Neutral-current axial form factor



3<sup>rd</sup> order  $z$ -expansion fit

For *axial-vector current*, threshold

$$t_{\text{cut}} = (3m_\pi)^2$$

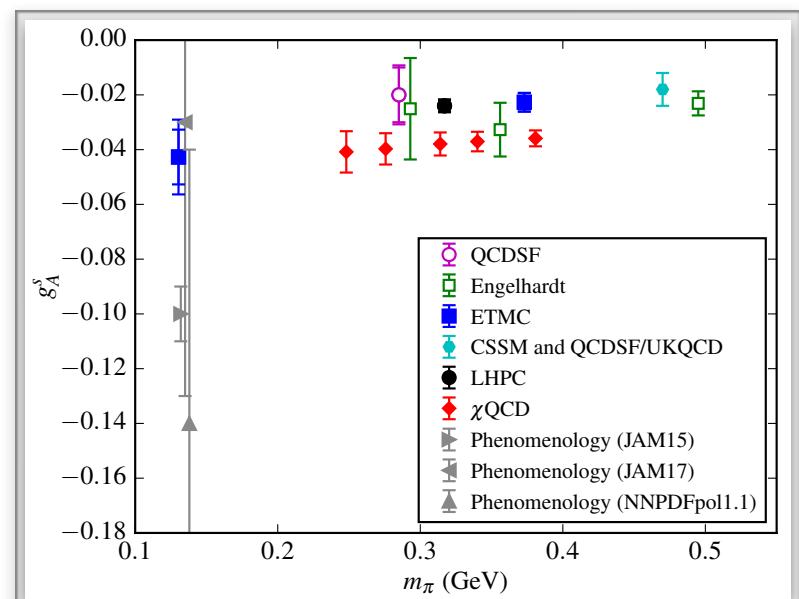
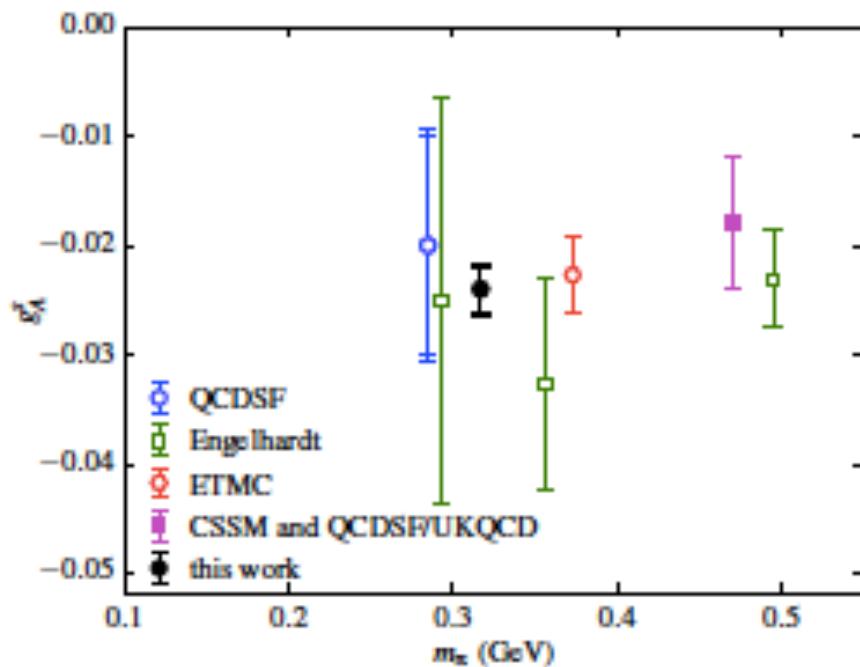
$$G_A^Z(0) = -0.754 \pm 0.040 \longrightarrow G_A^s(0) = -0.2357 \pm 0.08$$

$$G_A^Z = \frac{1}{2}(G_s^A - G_A^{\text{CC}})$$

$$G_A^s(0) = -0.2357 \pm 0.08$$

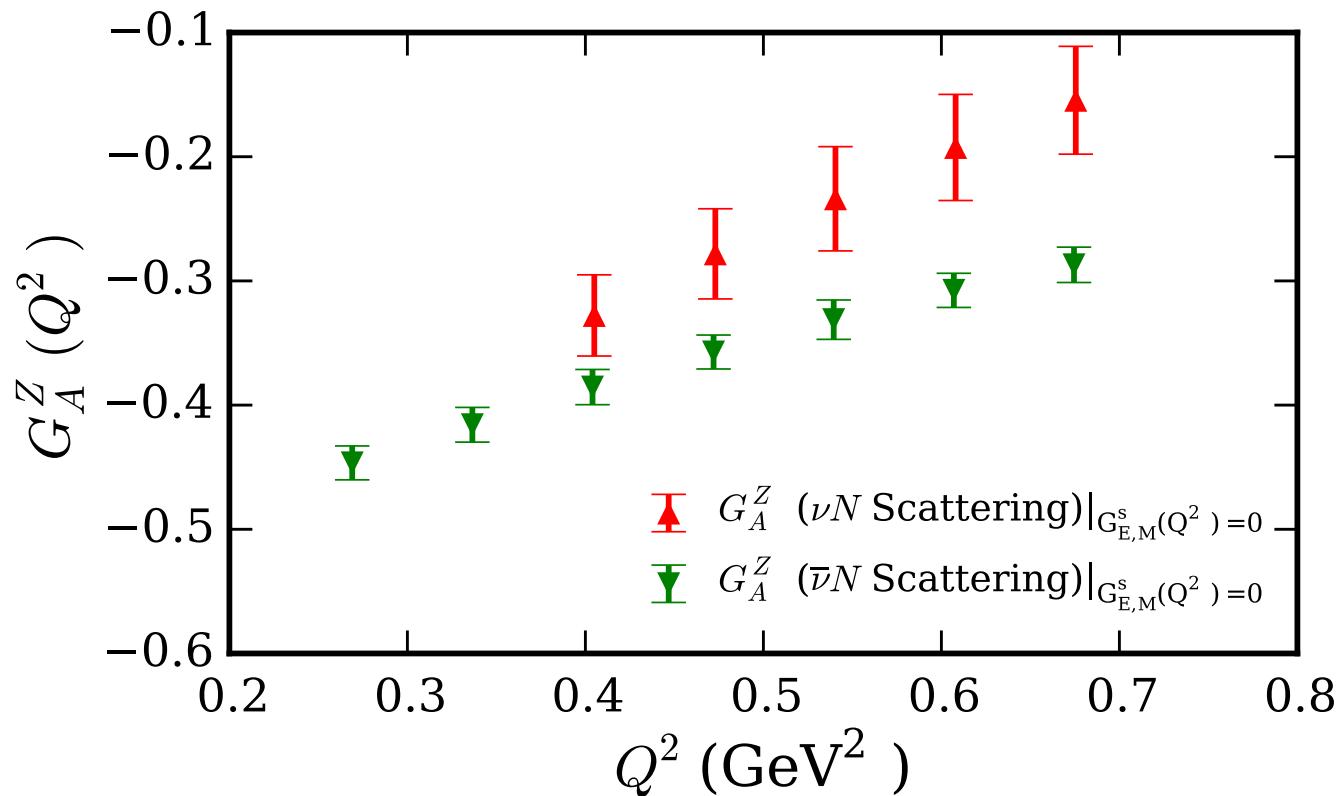
LHPC, Phys. Rev. D 95, 114502 (2017)

J. Green



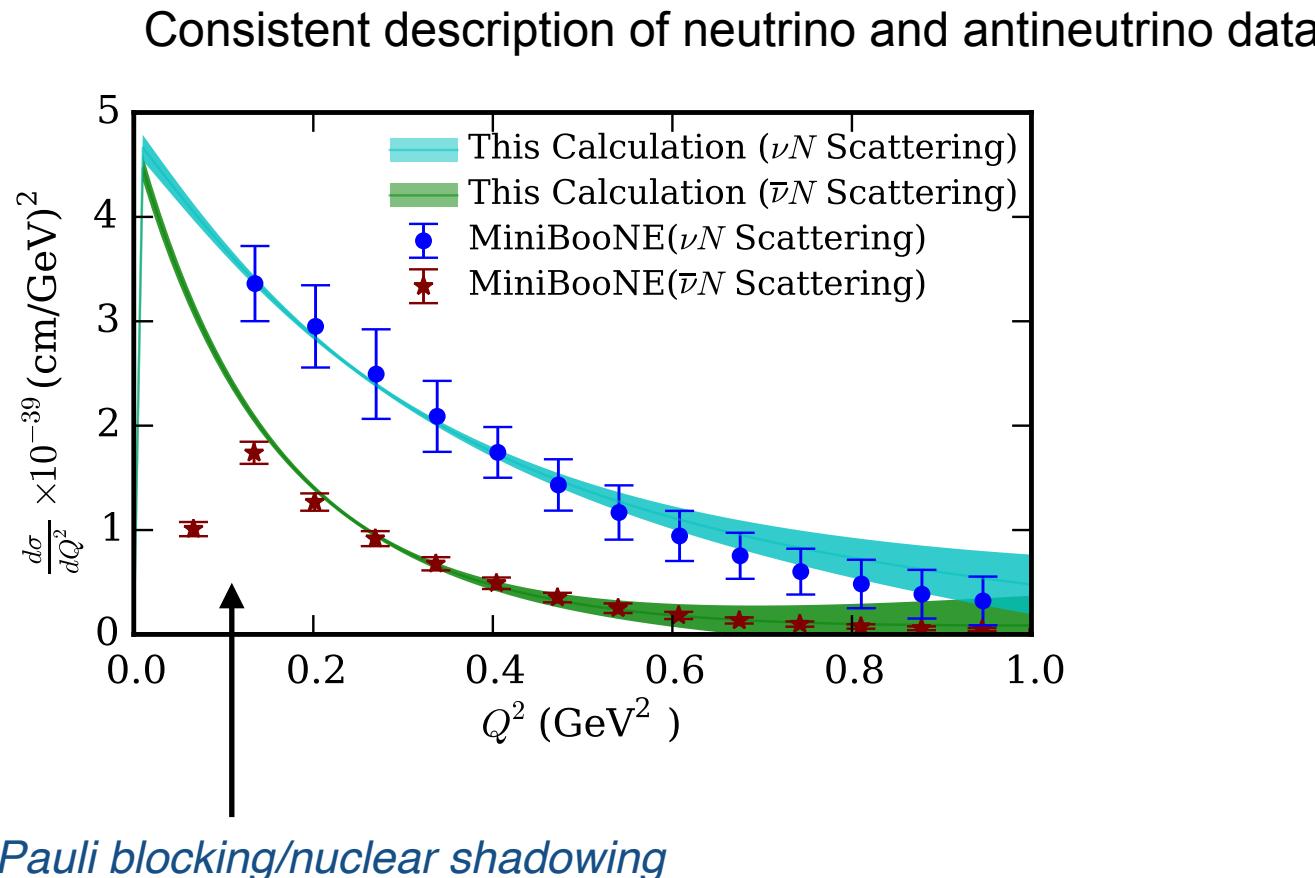
# Axial-current Form Factor - II

...inconsistent description of neutrino and antineutrino data if assume  $G^s$  zero

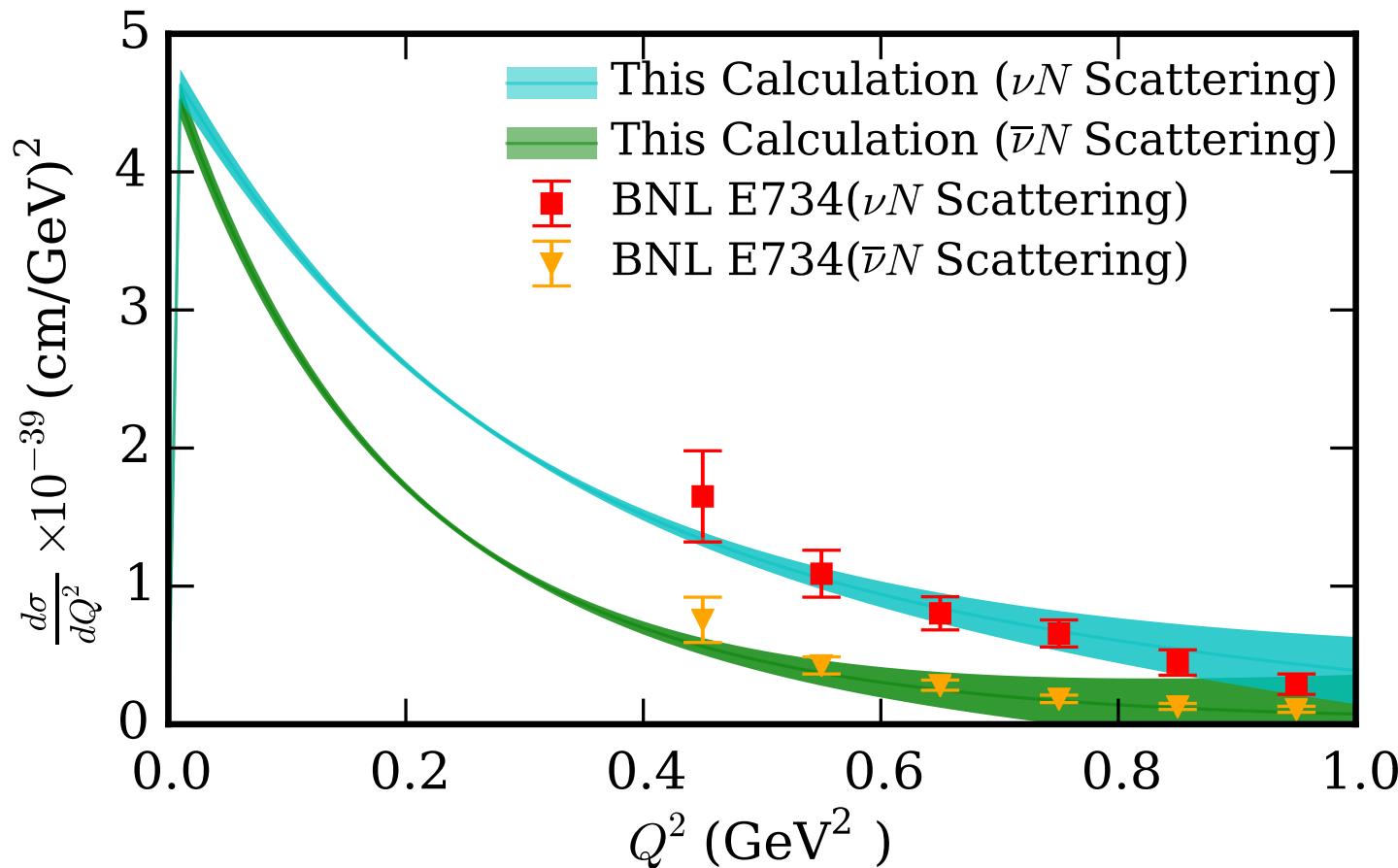


# Reconstruction of cross section

- Now reconstruct the MiniBoone differential cross section over the whole range  $0 < Q^2 < 1 \text{ GeV}^2$



# BNL Data



Provides faithful description of BNL data *that was not used in analysis*

# Summary and Conclusions

- Used combination of parametrisations of experimental EM form factor data and lattice calculations of strange quark EM form factors to extract neutral-current form factors from MiniBoone data  $0.3 \leq Q^2 \leq 0.7 \text{ GeV}^2$
- Parametrization provide good description to  $Q^2 \leq 1 \text{ GeV}^2$  for both MiniBoone and (independent) BNL data.
- Precise knowledge of vN scattering differential cross-section allows us to refine knowledge of nuclear effects.
- Comparison with *ab initio* calculations of neutral-current axial-vector form factors.