Progress on Constraining the Strange Quark Contribution to the Nucleon Spin

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https://arxiv.org/abs/2402.10854 → **Phys. Rev. D 109, 093001**

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Axial form factor of the proton

$$G_A^{Z,p} = \frac{1}{2}\left(-G_A^u + G_A^d + G_A^s\right)$$

Critical to understanding neutral-current and charged-current interaction of neutrinos with matter.

$$G_A^{CC} = G_A^u - G_A^d$$

The up-down part is very well-known from decades of study of CC interactions.

$$\nu_\mu + n \rightarrow \mu + p \qquad n \rightarrow p + e + \bar{\nu}_e$$

$$G_A^s$$

The strange part is only directly accessible via NC scattering.

$$\nu + p \rightarrow \nu + p$$

Still only very limited information available on G_A^S!

Traditional models of G_A^s

Due to limited available information, most modeling of G_A^s is based on two ingredients:

- The Q^2-dependence is assumed to be the same as $G_A^{CC} = G_A^u - G_A^d$
  - But there is no physics to support this assumption.
- The value of G_A^s at $Q^2 = 0$ is the strange quark contribution to the proton spin, Δs. (Δs is a sum over strange and anti-strange.) A value for Δs is taken from a polarized deep-inelastic scattering measurement.
  - But there is no agreed-upon value for Δs from pDIS; could be anything from 0 to -0.2. Big uncertainty!

Our goal is to determine the Q^2-dependence of G_A^s and the value of Δs directly from elastic electron and neutrino scattering data.

From: "Global QCD analysis of spin PDFs in the proton with high-x and lattice constraints"
Cocuzza et al. https://arxiv.org/abs/2506.13616

"In the strange quark sector, a nonzero strange quark polarization may be expected in nature, along with differences between Δs and $\Delta \bar{s}$ [105–110], and in principle SIDIS kaon production data could be sensitive to a nonzero Δs or $\Delta \bar{s}$. In practice, however, the existing datasets described in Sec. IVA do not provide sufficient constraints, without introducing additional theoretical assumptions, such as SU(3) flavor symmetry. Employing the ansatz in Eq. (44e), the strange quark polarization is set equal to the flavor symmetric sea quark component, ΔS. Since the $\bar{u}$ and $\bar{d}$ polarizations have opposite signs and similar magnitude, this effectively means that the central values of the strange quark polarization will be close to zero, although with a very large uncertainty that renders Δs essentially unconstrained. Future, higher precision SIDIS kaon production data, at Jefferson Lab and at the future Electron-Ion Collider, may help to resolve a nonzero strange polarization."

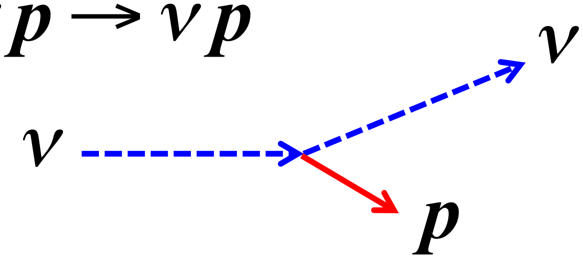
Form factor analysis can provide an answer sooner with elastic scattering data!

Measuring Low-Q^2 Neutral-Current ν Elastic Scattering

Not that simple, or someone would have done it already…

The observable part of the final state consists of a single isolated proton – that's all!

$$T = Q^2/2M_p \qquad \nu p \rightarrow \nu p$$



For $Q^2 = 0.1$ GeV^2, this means $T \sim 50$ MeV.

For a neutrino scattering experiment, you need a target/detector system composed of a solid or liquid material.

<u>You will need to measure a track (direction and momentum) that will be only a few cm in length!</u>
<u>For this reason, there is very little data on this reaction.</u>

Three experiments:
E-734 (BNL), MiniBooNE and MicroBooNE (FNAL)

Parity-violating elastic electron scattering (PVES)

Compare count rates for helicity-reversed elastic ep interactions.

Interference between γ-exchange and Z-exchange amplitudes creates a small asymmetry (~10^{-6}) in the count rates.

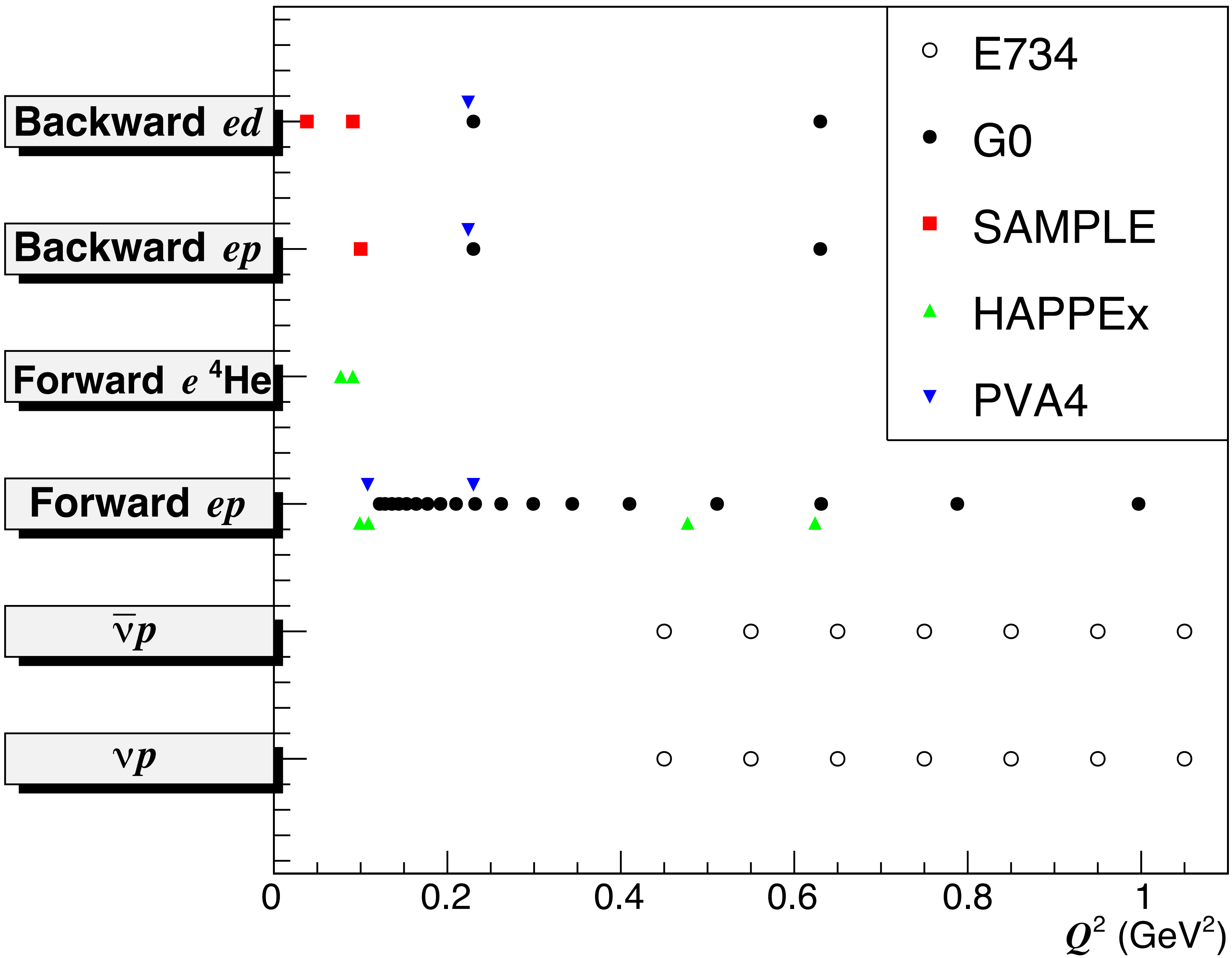
This asymmetry is sensitive to the strange quark contributions to the electric, magnetic and axial form factors: $\boldsymbol{G_E^s}$, $\boldsymbol{G_M^s}$, and $\boldsymbol{G_A^s}$.

Four experiments:
SAMPLE (MIT-Bates), HAPPEx and G0 (Jlab), PVA4 (Mainz)

Simultaneous determination of strange quark contribution to vector and axial form factors

- Our approach will be to determine G_E^s, G_M^s, and G_A^s together, by combining data from neutrino neutral-current elastic scattering (NCES) and parity-violating electron scattering (PVES)
- This was first done in PRL 92 082002 (2004) by combining BNL E734 NCES data with HAPPEx PVES data at $Q^2 = 0.477$ GeV^2.
- This analysis was expanded [PRC 78 015207 (2008)] to include points in the range $0.55 < Q^2 < 1.05$ GeV^2 when the G0 PVES data became available.

NCES and PVES data available for this analysis technique, not including MiniBooNE; 49 data points in total.



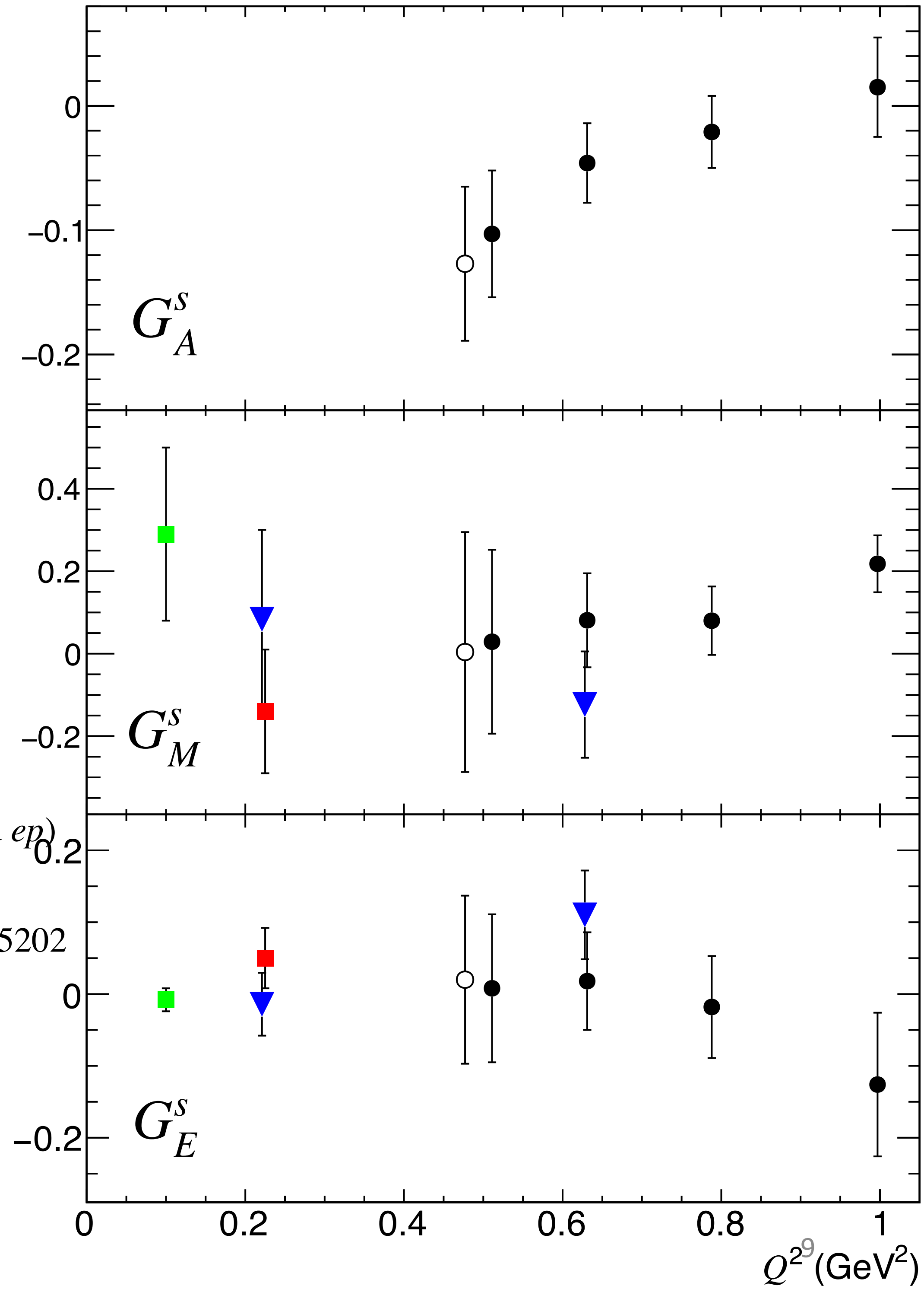
Determinations of G_E^s, G_M^s, and G_A^s using subsets of the E734, G0, HAPPEx, PVA4 and SAMPLE data.

● G0 (forward *ep*) + E734 (νp and $\bar{\nu} p$)
○ HAPPEx (forward *ep*) + E734 (νp and $\bar{\nu} p$)
Pate, Papavassiliou & McKee, PRC 78 (2008) 015207

■ (red) PVA4 (forward and backward *ep*)
Baunack et al., PRL 102 (2009) 151803

▼ (blue) G0 (forward and backward *ep*, and backward *ed*)
D. Androic et al., PRL 104 (2010) 012001

■ (green) HAPPEx (forward *ep* and $e\,^4$He) + G0 (forward *ep*)
+ SAMPLE (backward *ep* and *ed*) + PVA4 (forward *ep*)
near $Q^2 = 0.1$ GeV^2
Liu, McKeown & Ramsey-Musolf, PRC 76 (2007) 025202



⇒ G_E^s and G_M^s are flat and consistent with zero.
⇒ G_A^s has a definite Q^2-dependence, trending negative with decreasing Q^2.

Instead of calculating the form factors at individual Q^2 points using subsets of the data,
use all the data in a fitting procedure.

Neutral Current Elastic Scattering

G_E^s G_M^s G_A^s

Each kind of data is most sensitive to a different form factor.

Need all three kinds of data in our approach.

Parity-Violating Electron Scattering (forward $\vec{e}p$)

G_E^s G_M^s G_A^s

Parity-Violating Electron Scattering (backward $\vec{e}p$ & $\vec{e}d$)

G_E^s G_M^s G_A^s

Models for the Strangeness Form Factors

- G_E^s and G_M^s are consistent with zero and featureless; use simple zeroth-order model.

$$G_E^s = \rho_s \tau \qquad G_M^s = \mu_s \qquad [\tau = Q^2/4M^2]$$

- G_A^s appears to have a definite Q^2-dependence. We consider two different models for G_A^s.

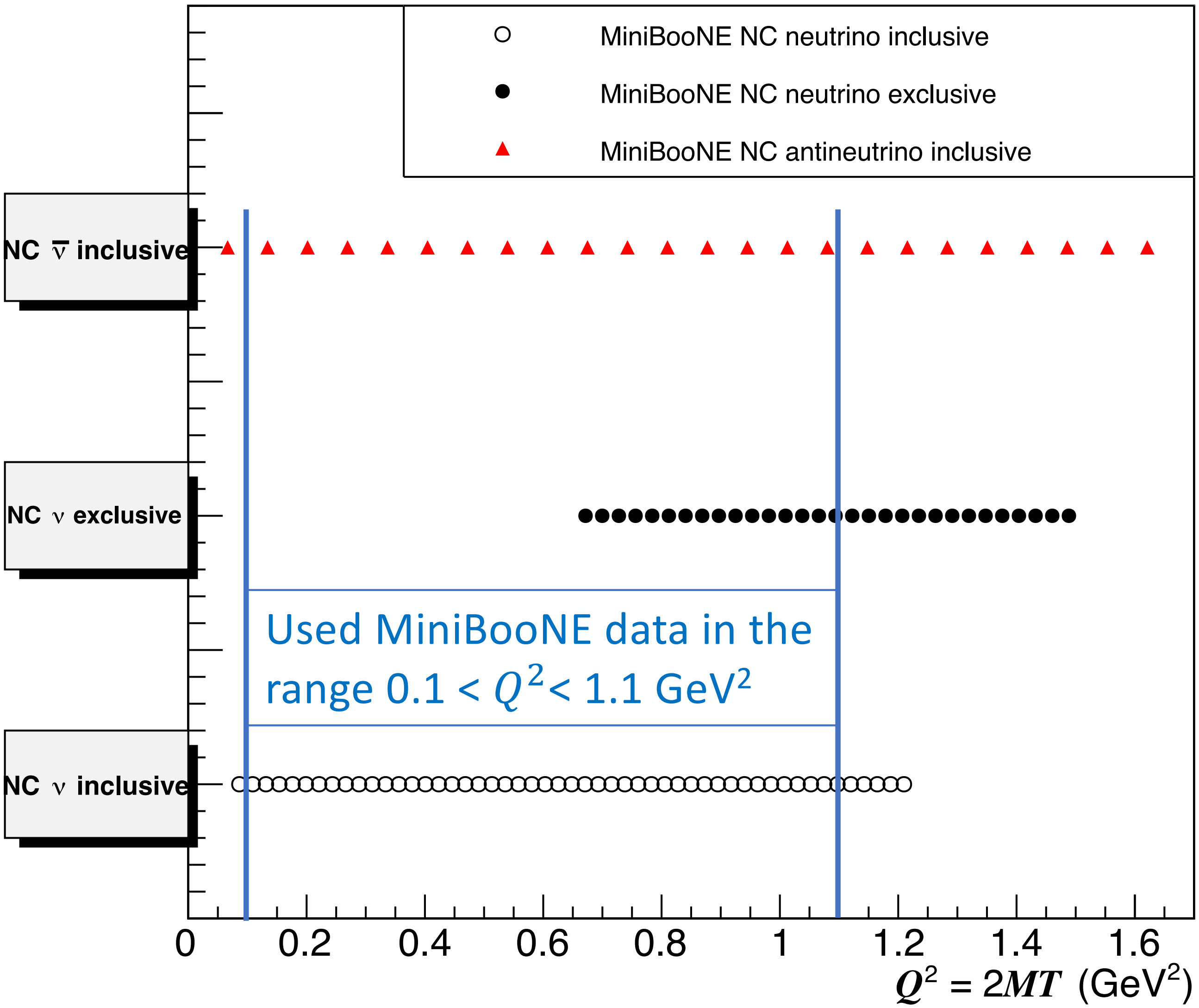
--- "Modified-dipole model"

$$G_A^s = \frac{\Delta s + S_A Q^2}{(1 + Q^2/\Lambda_A^2)^2}$$

--- "z-Expansion Model"

$$G_A^s = \sum_{k=0}^{6} a_k [z(Q^2)]^k \qquad z(Q^2) = \frac{\sqrt{(4m_\pi)^2 + Q^2} - \sqrt{(4m_\pi)^2}}{\sqrt{(4m_\pi)^2 + Q^2} + \sqrt{(4m_\pi)^2}}$$

NCES data from MiniBooNE available for this analysis. We use the data in the range $0.1 < Q^2 < 1.1$ GeV^2, bringing the total number of data points to 128.



Models for the ν–Carbon interaction; needed for the use of the MiniBooNE data

- Relativistic Fermi Gas (RFG): Carbon nucleus is described by a Fermi momentum k_F based on electron scattering data; nucleons are plane waves constrained by the Pauli principle.
- SuperScaling Approximation (SuSA): Scaling behavior of (e, e') data used to predict NC and CC neutrino-scattering cross sections.
- Spectral Function (SF): a spectral function $S(p, \mathcal{E})$ based on (e, e') data has been used to better describe single-nucleon removal.

$G_E^s = \rho_s \tau$

$G_M^s = \mu_s$

Modified-dipole model

$$G_A^s = \frac{\Delta s + S_A Q^2}{(1 + Q^2/\Lambda_A^2)^2}$$

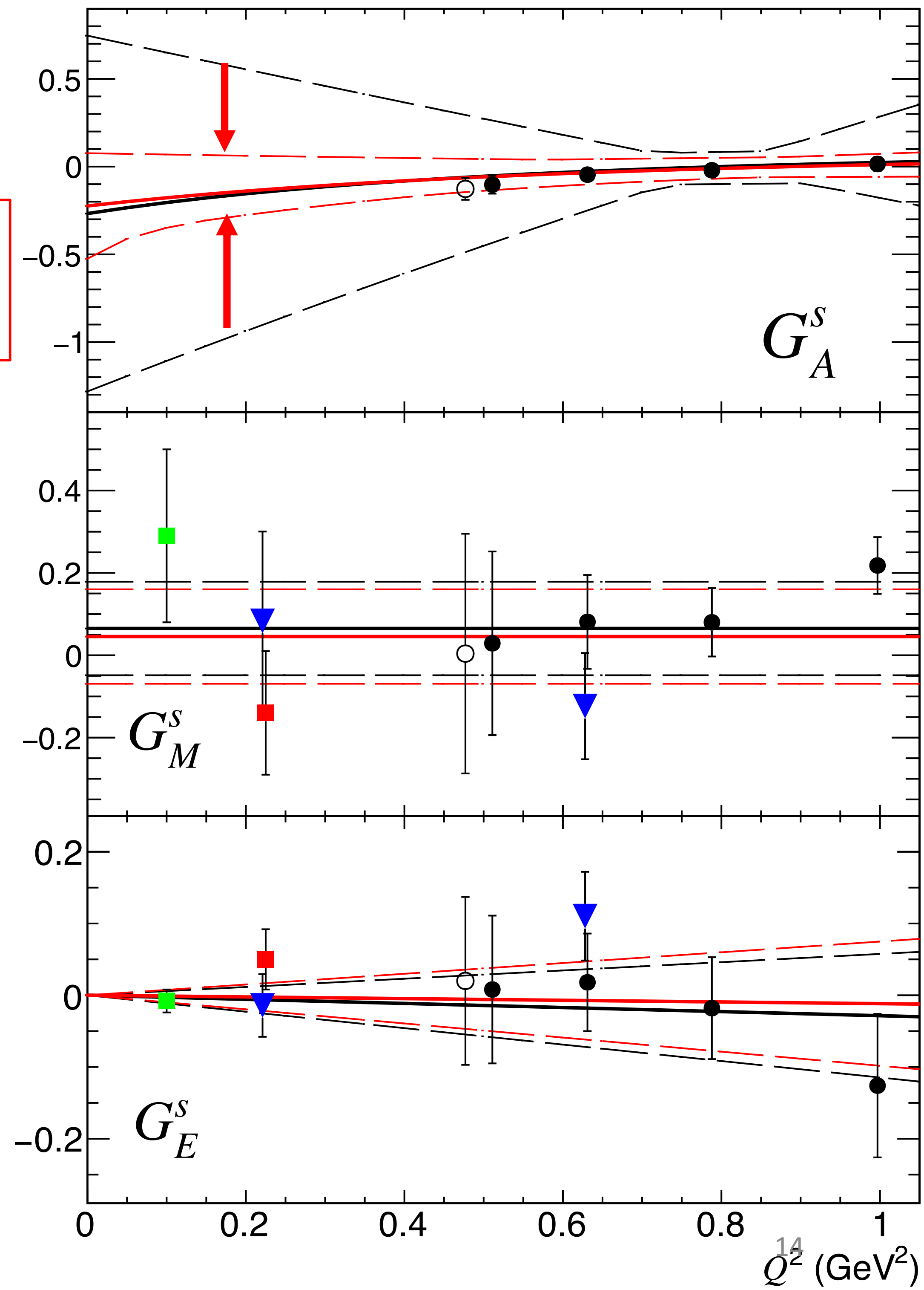
Improved constraint on G_A^s via inclusion of MiniBooNE data

Fit not including any MiniBooNE data. Uses data from BNL E734, HAPPEx, PVA4, G0 and SAMPLE. (49 data points)

Fit including also MiniBooNE data from NC neutrino and antineutrino scattering, using spectral function model. (128 data points)

Dashed lines show 70% confidence level.

$$\frac{\chi^2}{\text{ndf}} = 1.1 - 1.2$$



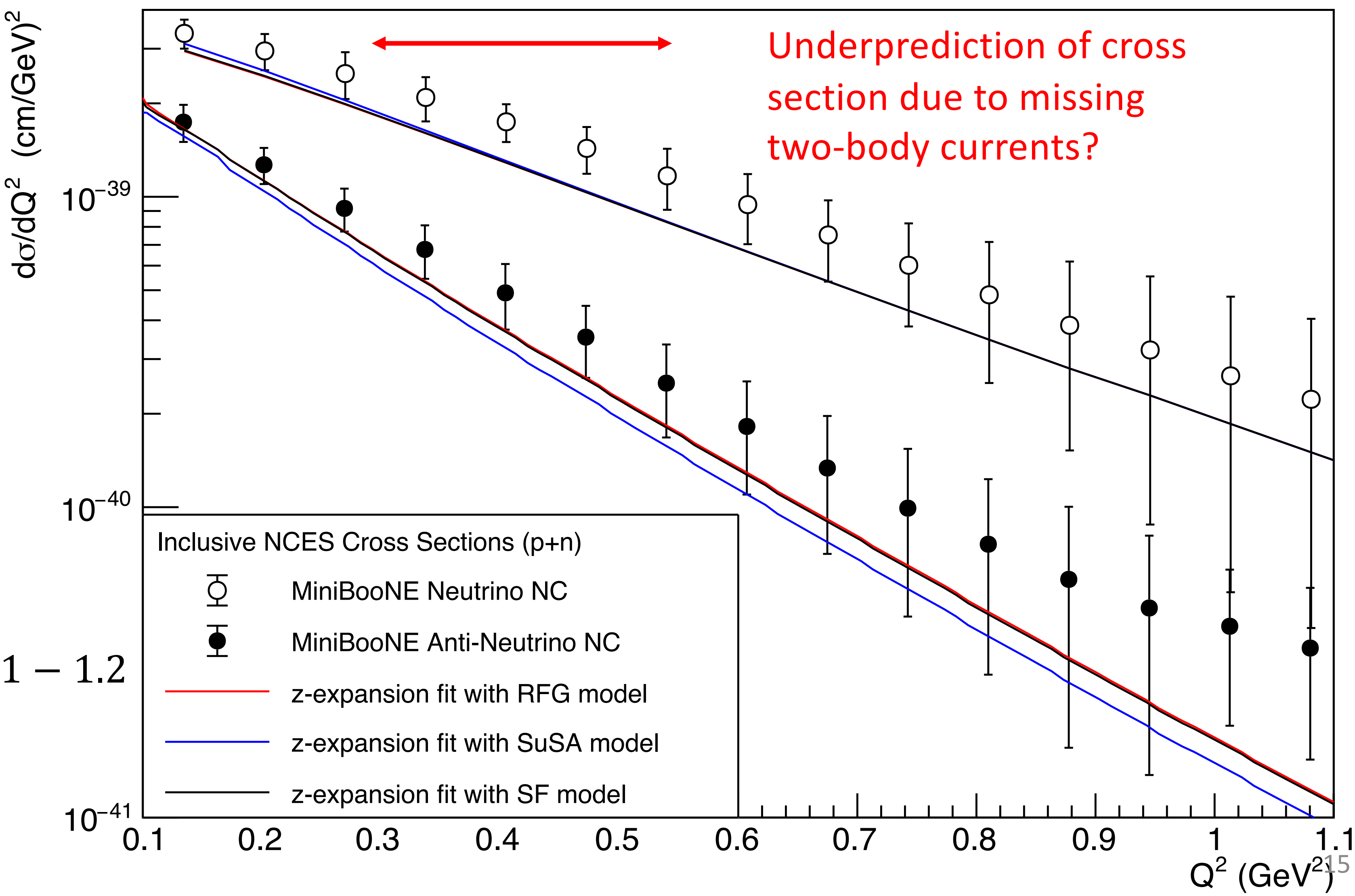
MiniBooNE NC inclusive cross sections on mineral oil

All three fits use the z-expansion model for G_A^s.

○ ν — RFG (red)

● $\bar{\nu}$ — SuSA (blue)

SF (black)



$$\frac{\chi^2}{\text{ndf}} = 1.1 - 1.2$$

$G_E^s = \rho_s \tau$

$G_M^s = \mu_s$

Modified-dipole model

$$G_A^s = \frac{\Delta s + S_A Q^2}{(1 + Q^2/\Lambda_A^2)^2}$$

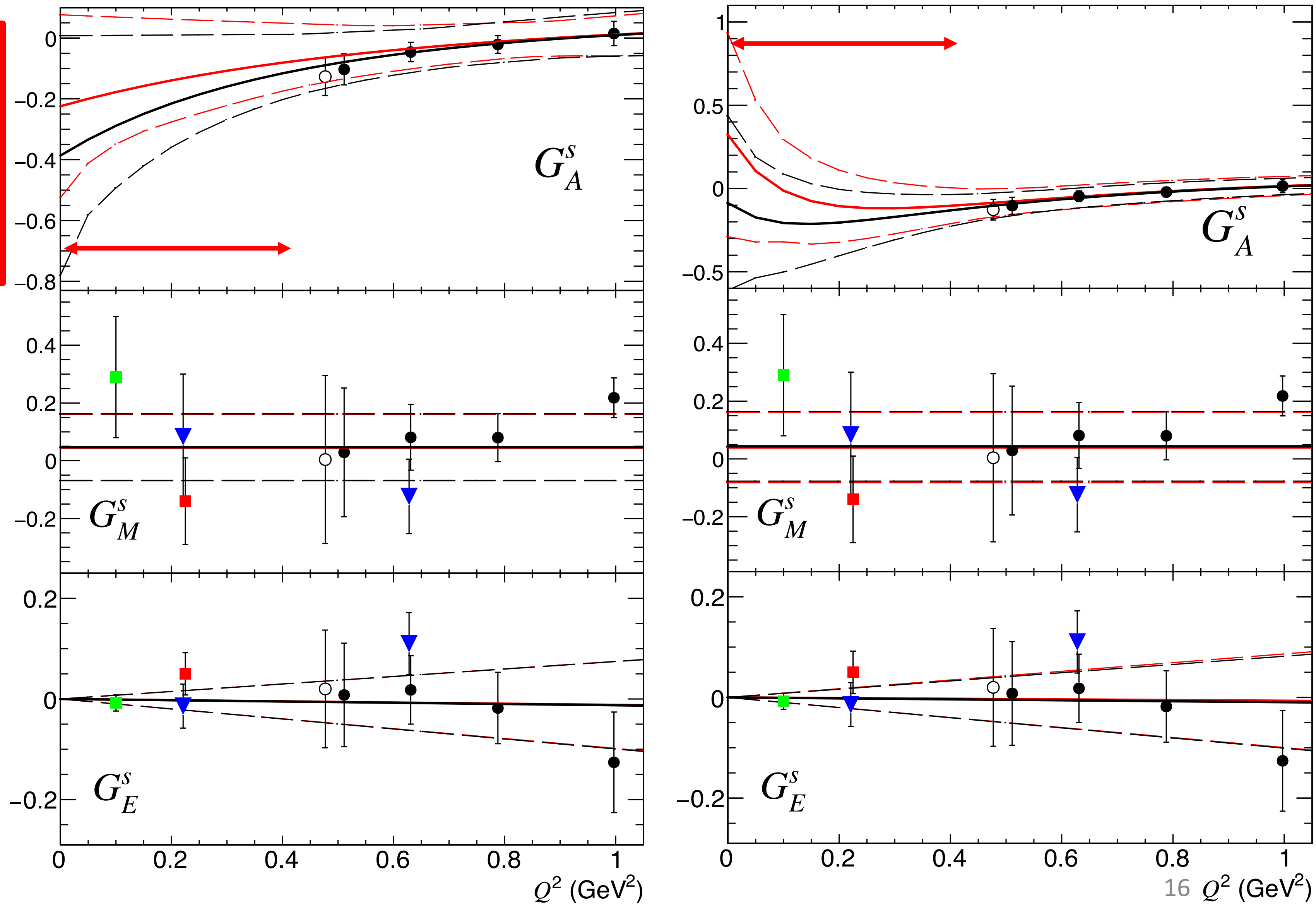
z-expansion model

$$G_A^s = \sum_{k=0}^{6} a_k [z(Q^2)]^k$$

Need exclusive NC data in low-Q^2 region to finalize this work

SuSA

SF



$$\frac{\chi^2}{\text{ndf}} = 1.1 - 1.2$$

Next Steps

- Inclusion of the MiniBooNE neutral-current data is a big step forward in advancing our knowledge of the strange quark contribution to the axial form factor.

https://arxiv.org/abs/2402.10854

Phys. Rev. D 109, 093001

- Modeling of NC scattering needs improvements (two-body currents, final-state interactions, …)

- Still need low-Q^2 exclusive neutral-current scattering data, with a single proton in the final state, such as will be available from MicroBooNE very soon.

L. Ren, JPS Conf. Proc. 37, 020309 (2022)

https://journals.jps.jp/doi/10.7566/JPSCP.37.020309

A preliminary NC1p ν-Ar calculation

Calculation courtesy of M. Ivanov, M. Barbaro and C. Giusti

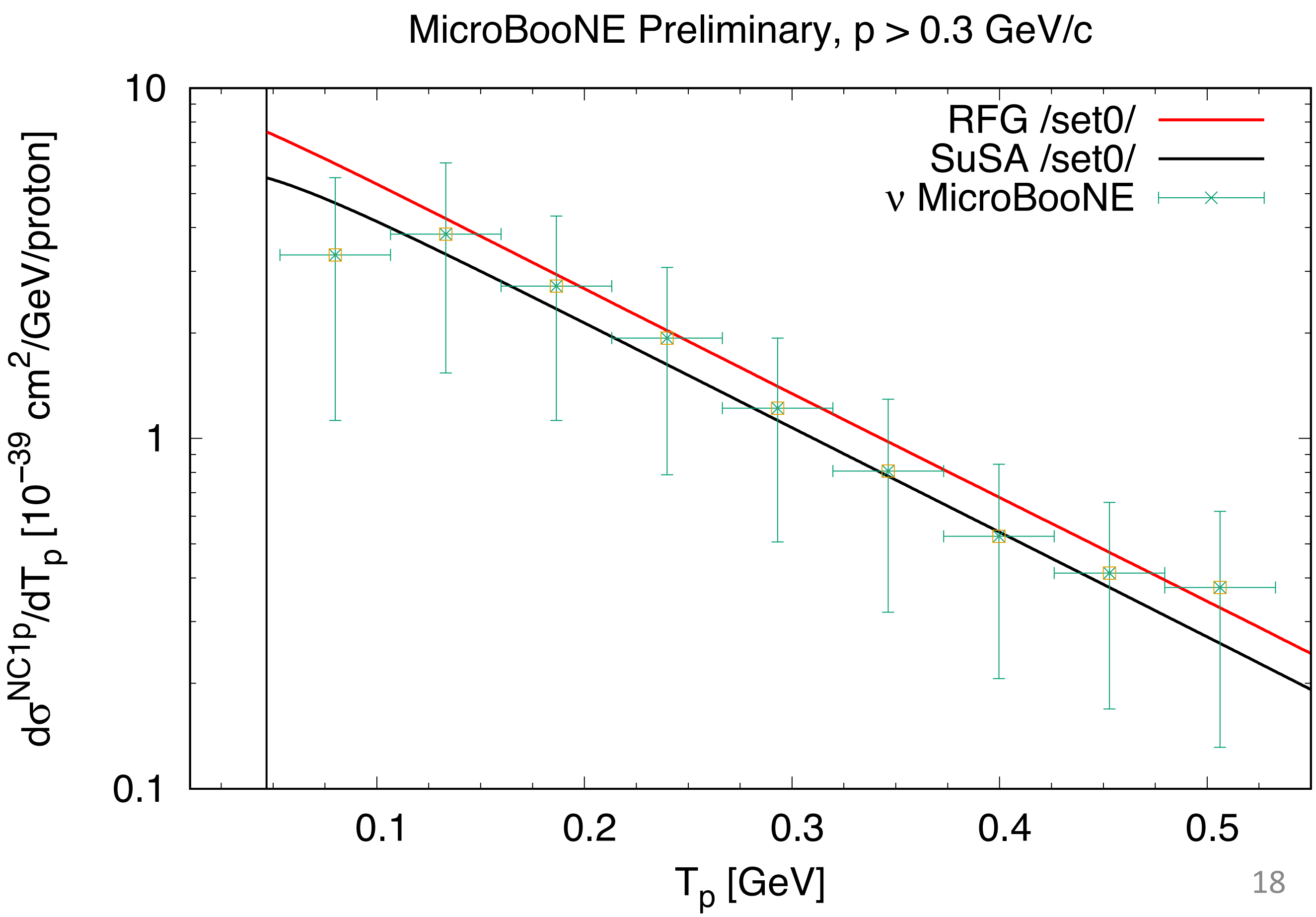
Final state proton must have $p > 0.3$ GeV/c

Form Factor Model: $\rho_s = -0.11$ $\mu_s = 0.065$
$\Delta s = -0.27$ $\Lambda_A = 1.2$ $S_A = 0.33$

Nuclear models: Quasi-elastic NC on proton; no 2p2h; SuSA contains FSI implicitly.

RFG and SuSA models: Slight difference in absolute scale for T_P dependence

MicroBooNE preliminary results from Note-1101-PUB



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Calculation courtesy of M. Ivanov, M. Barbaro and C. Giusti

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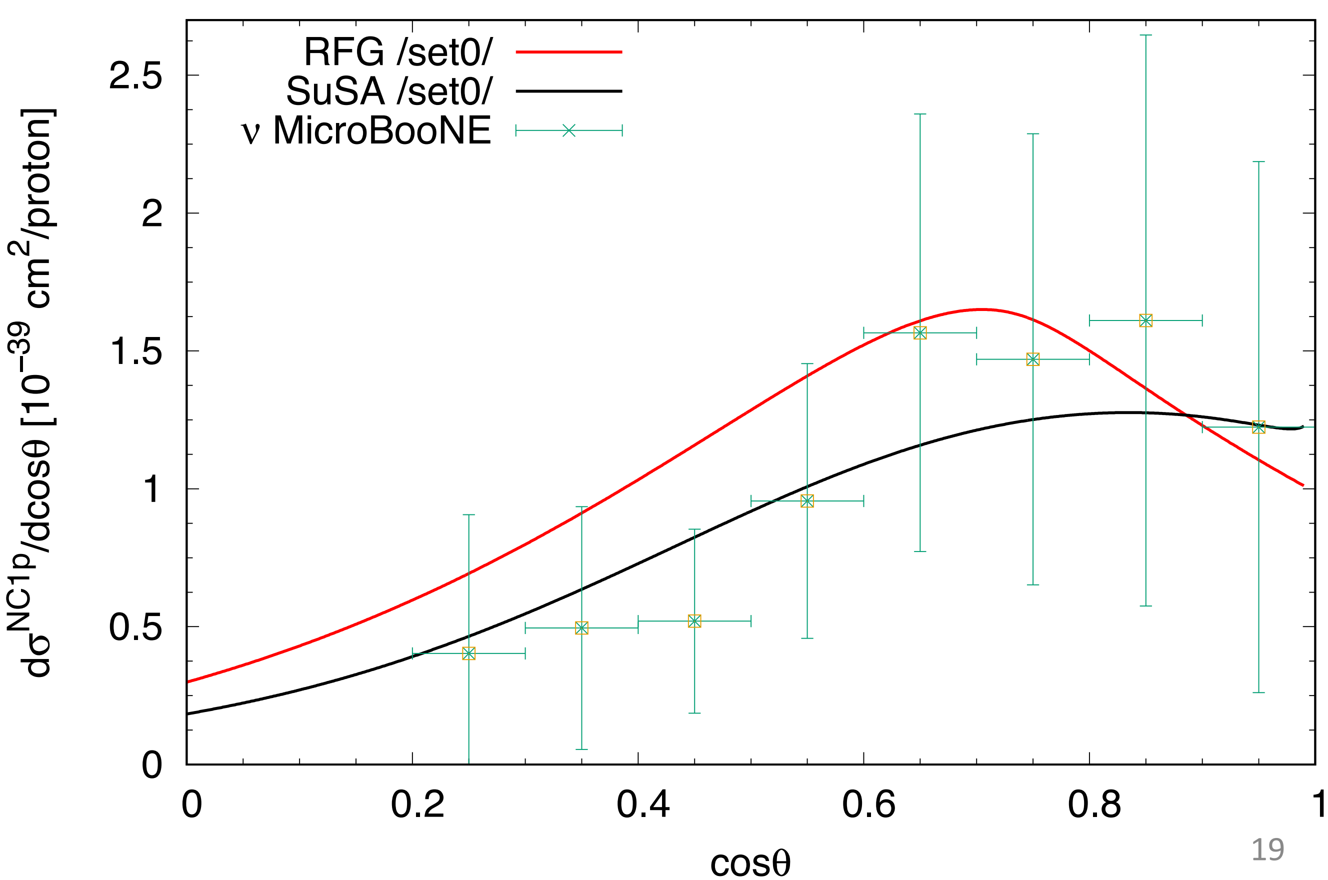
$\Delta s = -0.27$ $\Lambda_A = 1.2$ $S_A = 0.33$

Nuclear models: Quasi-elastic NC on proton; no 2p2h; SuSA contains FSI implicitly.

RFG and SuSA models: Big change in shape for $\cos\theta$ dependence!

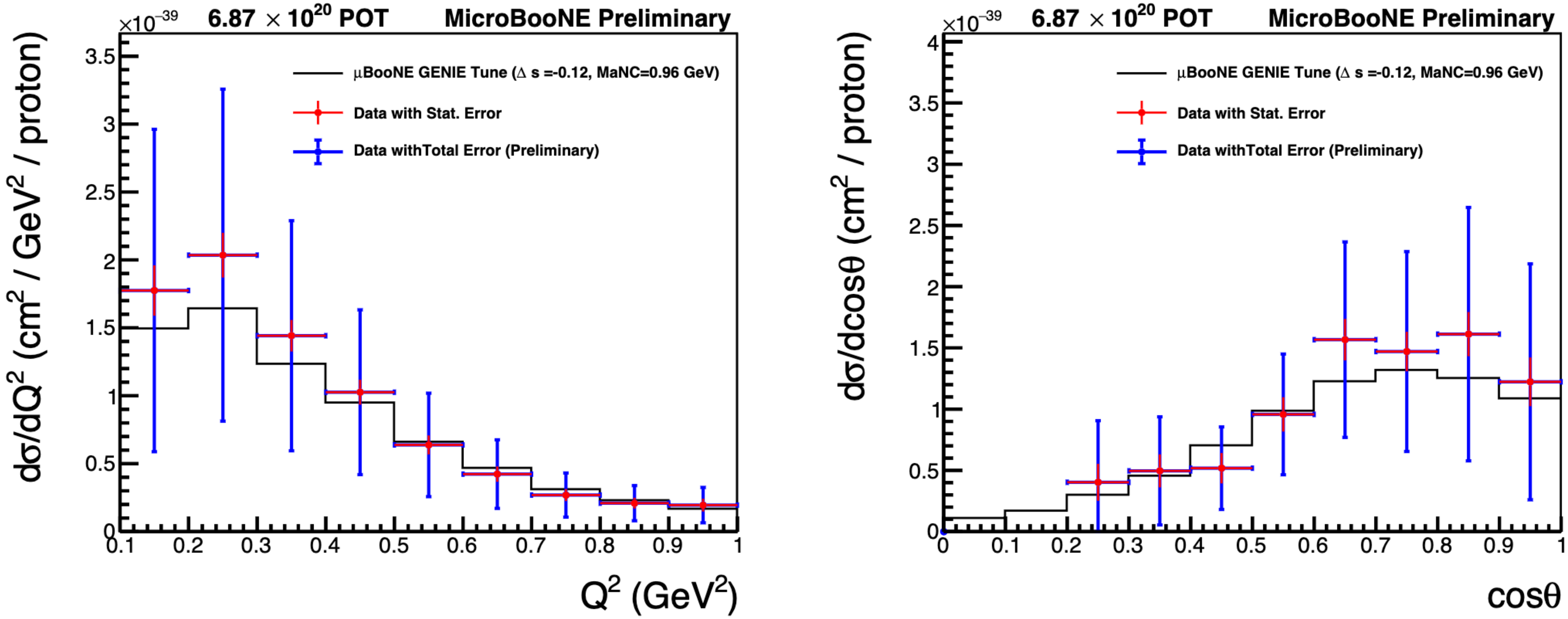
MicroBooNE preliminary results from [Note-1101-PUB]

MicroBooNE Preliminary, p > 0.3 GeV/c



Thank you!

Preliminary MicroBooNE Data (2022)

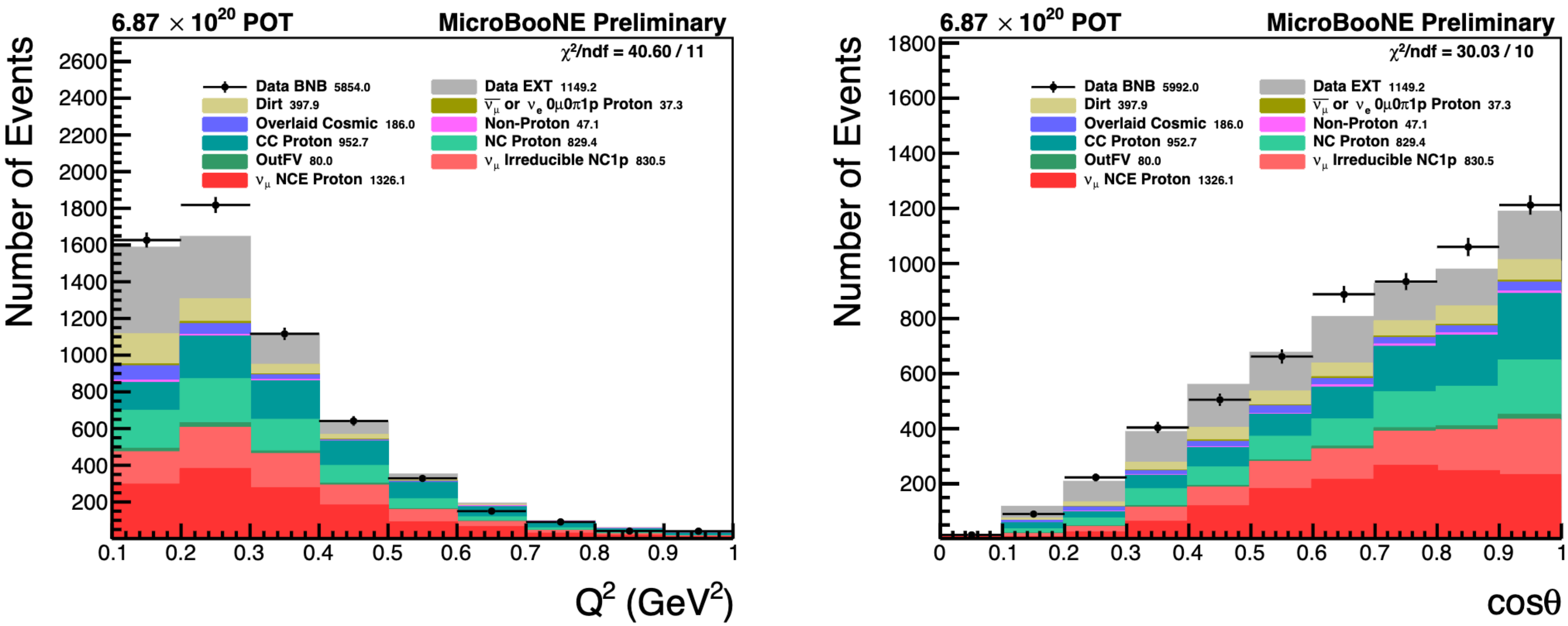


MicroBooNE have significantly reduced the systematic errors in the meantime.

Solid line is a GENIE calculation using a dipole model for G_A^s with $\Delta s = -0.12$ and $M_A^{NC} = 0.96$ GeV.

L. Ren, JPS Conf. Proc. 37, 020309 (2022)
https://journals.jps.jp/doi/10.7566/JPSCP.37.020309

Preliminary MicroBooNE Data (2022)



Breakdown of the yield into signal and background components, as a function of Q^2 and $\cos\theta$. Some backgrounds have been significantly reduced in the meantime.

L. Ren, JPS Conf. Proc. 37, 020309 (2022)
https://journals.jps.jp/doi/10.7566/JPSCP.37.020309

Strange Quark Contribution to Nucleon Spin Δs
Broad Physics Interest

- **Searches for heavy dark matter particles [Ellis, Olive, & Savage, Phys Rev D 77 (2008) 065026]**

- **Lattice QCD calculates a small value:**

$\Delta s = -\ 0.031(17)$ [M. Engelhardt, Phys. Rev. D 86 (2012) 114510];
$\Delta s = -\ 0.024(15)$ [Babich et al., Phys. Rev. D 85 (2012) 054510];
requires experimental verification

- **Simulations of supernovae are sensitive to the value of Δs [Melson, Janka, Bollig, Hanke, Marek, Mueller, Astro. J. Lett. 808 (2015) L42]**

- **Atomic PV experiments on hydrogen are sensitive to Δs [Gasenzer, Nachtmann, Trappe, EPJ D (2012) 66:113]**

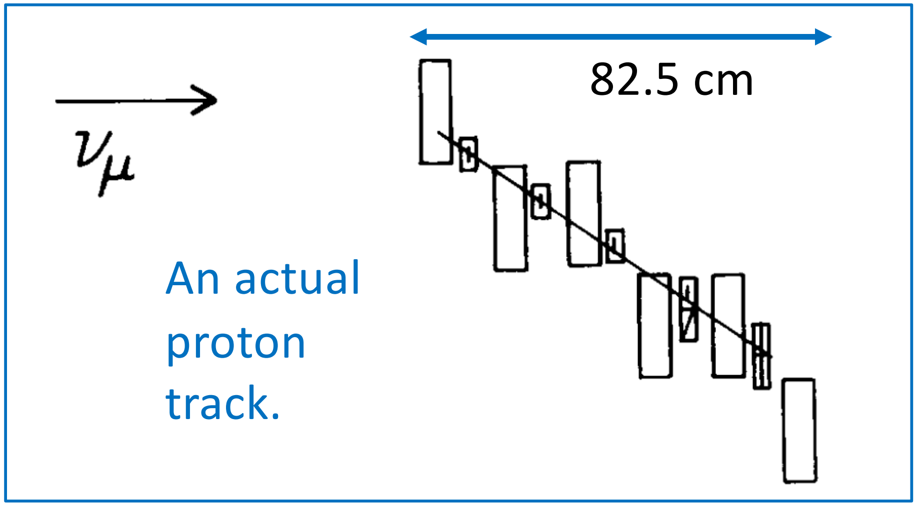
Neutral Current Elastic Neutrino Scattering

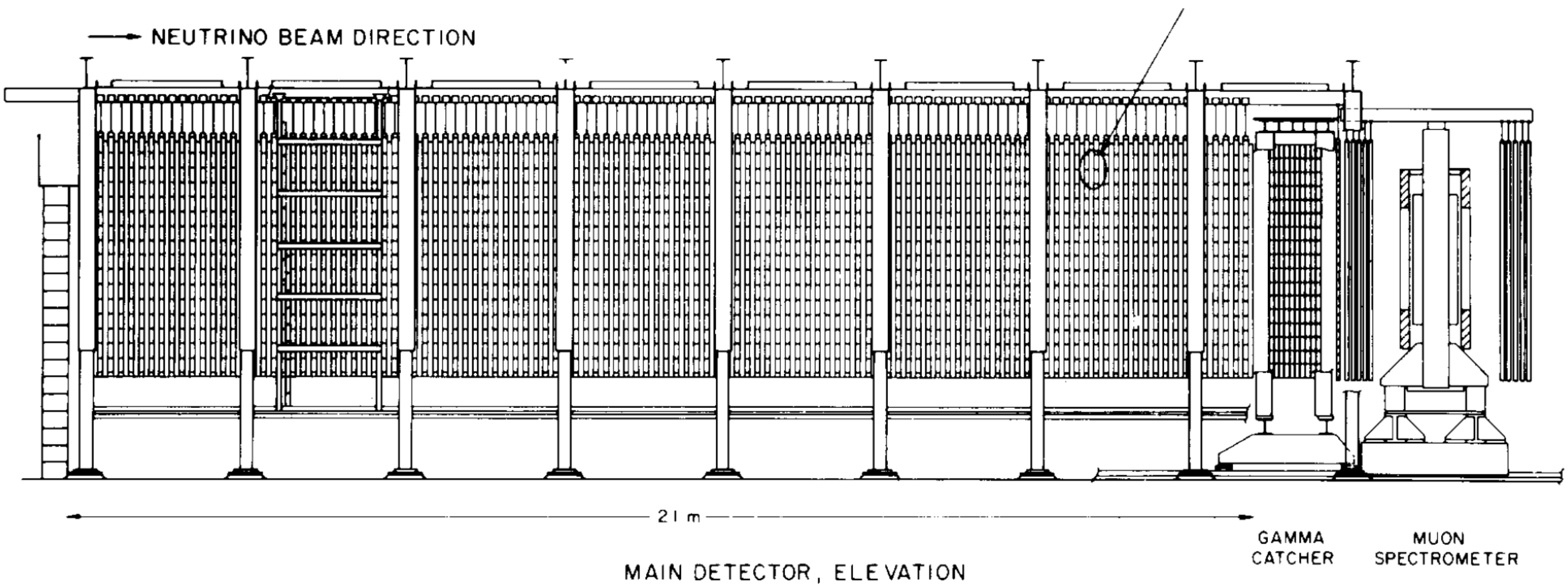
The E734 Experiment (Brookhaven)

Many alternating layers of scintillator (calorimetry) and drift tubes (tracking).

21 m in length!

NIMA, Volume 254, Issue 3, 1987, 515-528





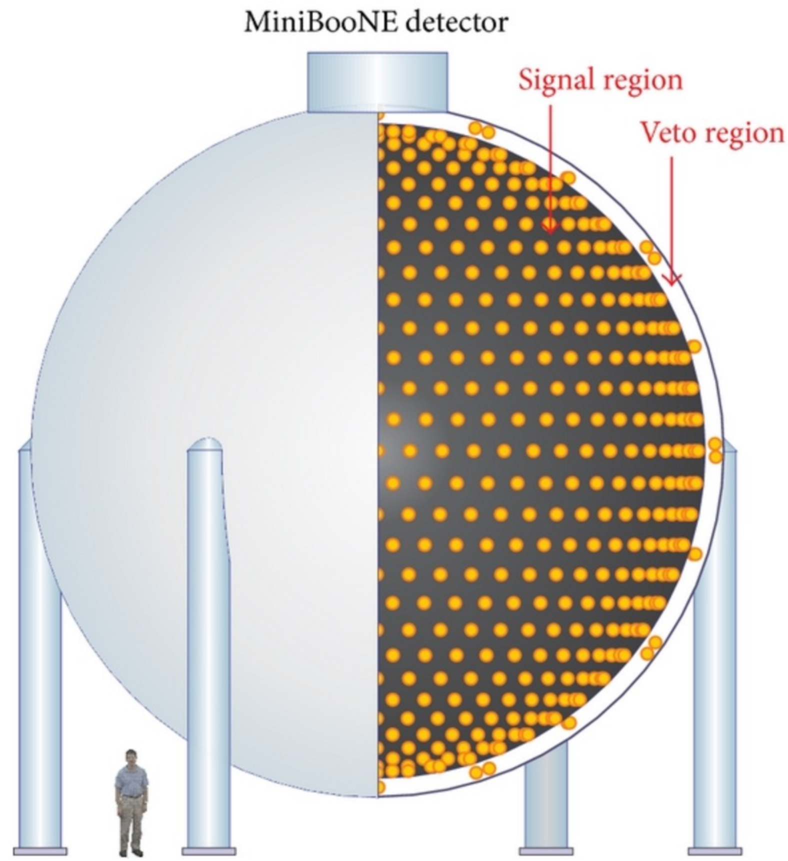
Neutral Current Elastic Neutrino Scattering

The MiniBooNE Experiment (Fermilab)

Large sphere containing mineral oil, lined with large phototubes.

Charged particles created in the mineral oil will produce:
(1) Scintillation light (isotropic)
(2) Cherenkov light (directional)

Analysis of these signals indicate the energy and momentum of the charged particle.



Neutral Current Elastic Neutrino Scattering

The MiniBooNE Experiment (Fermilab)

Two analyses:

Inclusive: Select events with scintillation light but no lepton (muon or electron) in the final state. The scintillation light gives the kinetic energy of the nucleon(s) emitted by the NC interaction. This includes both proton and neutron yields, which dilutes the sensitivity to G_A^s.

Exclusive: Select events with a Cherenkov signal consistent with a single proton; limited to $Q^2 > 0.7$ GeV^2. Strong sensitivity to G_A^s, but high Q^2 limit reduces sensitivity to Δs.

A.A. Aguilar-Arevalo et al. Phys. Rev. D 82 (2010) 092005

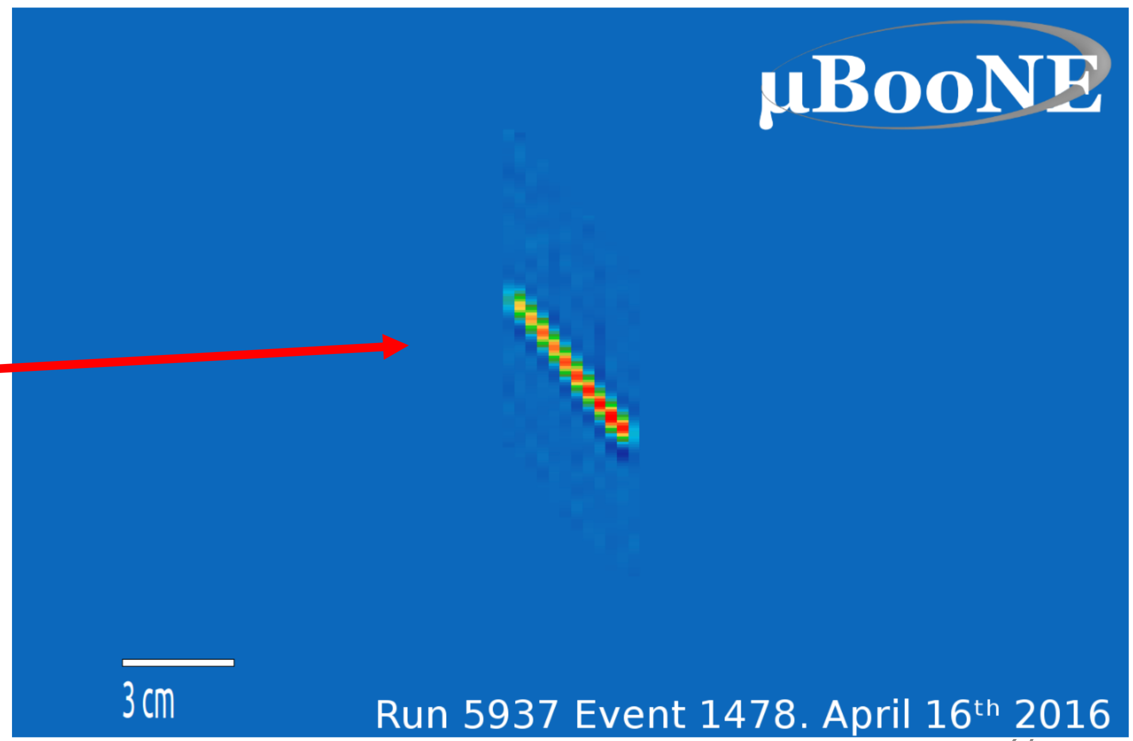
Neutral Current Elastic Neutrino Scattering

The MicroBooNE Experiment (Fermilab)

Liquid-argon time-projection-chamber (LArTPC).

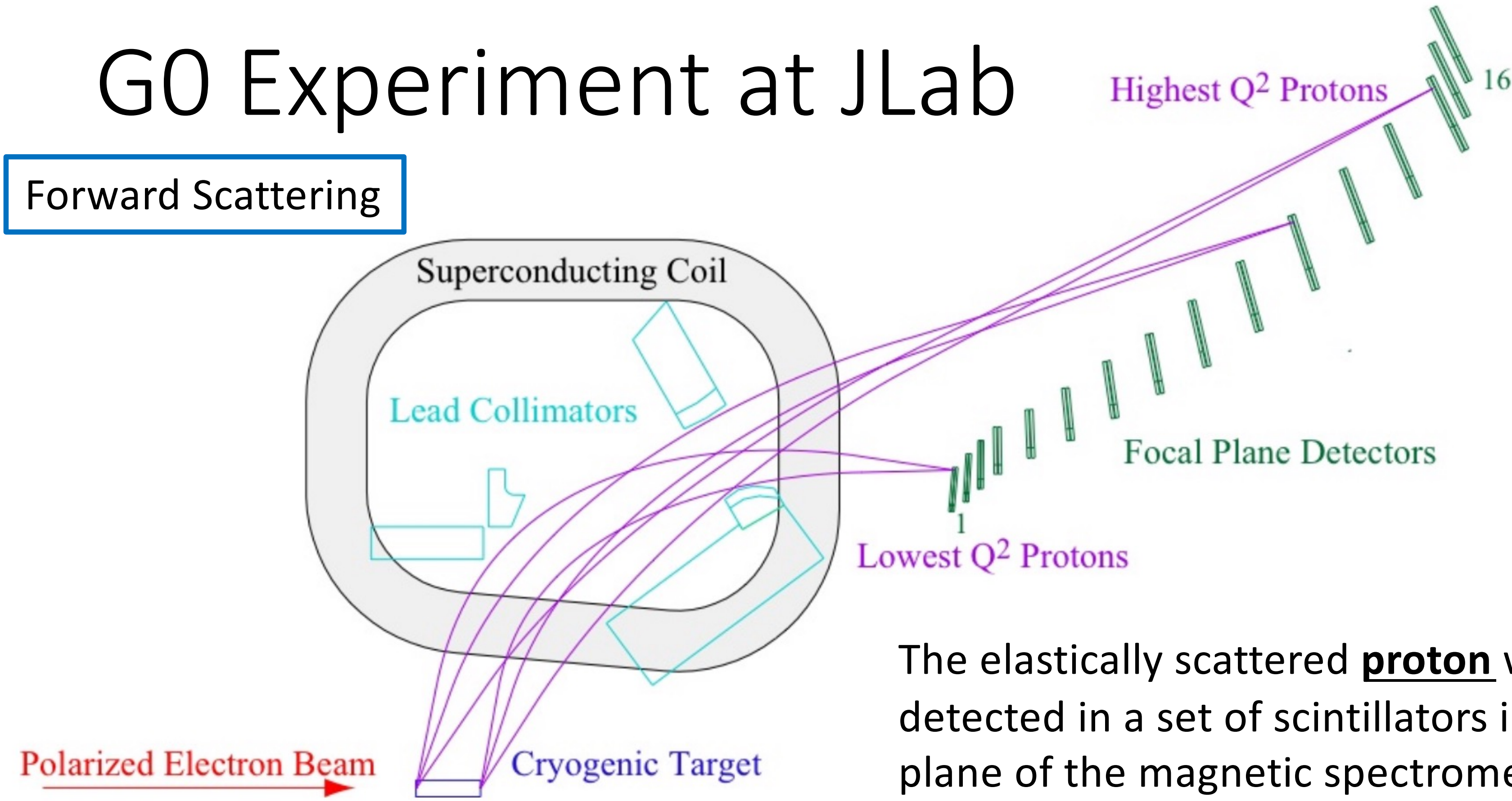
Charged particles created in the liquid argon will produce an ionization trail, which is swept out by a large electric field to a set of sense wires.

An image of an isolated proton track from a neutrino interaction in the detector.



G0 Experiment at JLab

Forward Scattering



3.0 GeV electron beam, 40 uA
20 cm long LH2 target

The elastically scattered **proton** was detected in a set of scintillators in the focal plane of the magnetic spectrometer. The momentum transfer range was $0.12 < Q^2 < 1.0$ GeV^2.

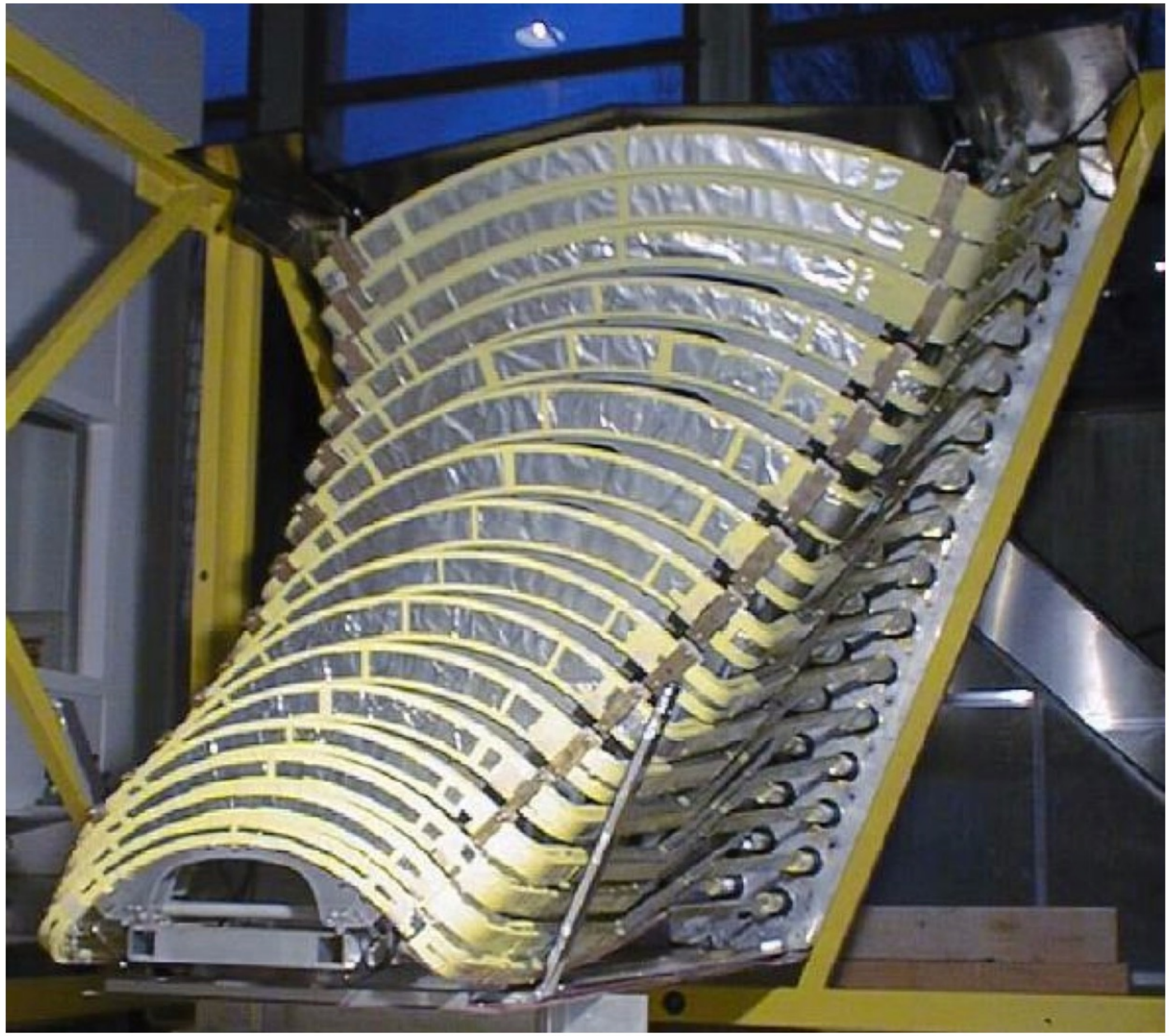
Backward Scattering

The entire apparatus was rotated 180° to face "backward", and the scattered **electron** was detected. Data was taken with LH2 and LD2 targets.

$E_e = 0.36$ GeV $\quad Q^2 = 0.22$ GeV^2

$E_e = 0.69$ GeV $\quad Q^2 = 0.63$ GeV^2

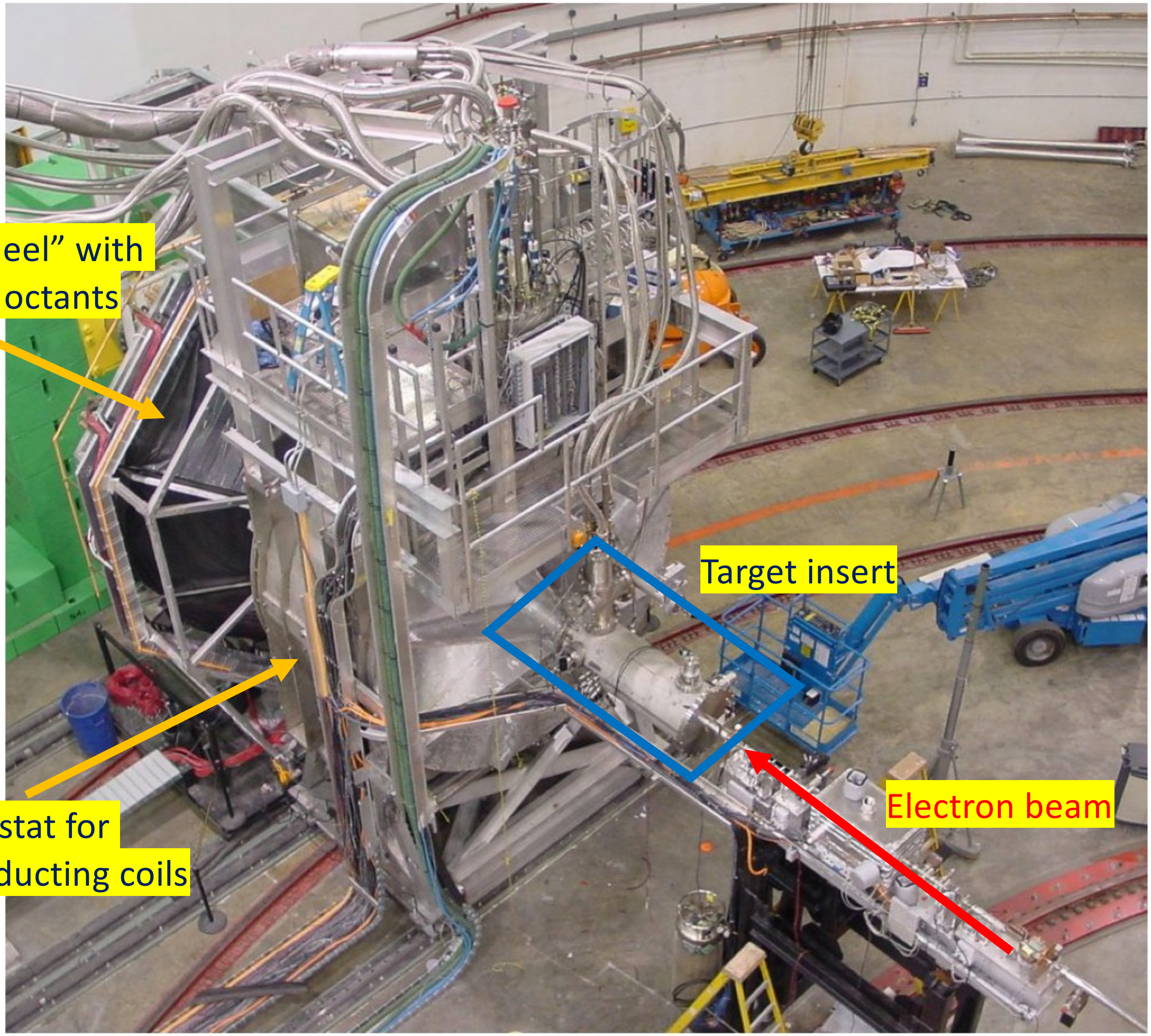
G0 Experiment at JLab



One “octant” of scintillators, to be positioned in the focal plane of the spectrometer. Each scintillator has two PMTs, one on each end. There are two layers of scintillators; a coincidence of both layers was required, to reduce backgrounds.

G0 Experiment at JLab

Forward Scattering



Improved constraints on strangeness form factors

$G_E^s = \rho_s \tau$

$G_M^s = \mu_s$

Modified-dipole model

$$G_A^s = \frac{\Delta s + S_A Q^2}{(1 + Q^2/\Lambda_A^2)^2}$$

Using Spectral Function model for ν-Carbon interaction

First uncertainty is statistical.
Second uncertainty is systematic, based on variation of other parameters associated with radiative corrections (for example).

parameter	w/o MiniBooNE data	w/ MiniBooNE data
ρ_s	$-0.107 \pm 0.121 \pm 0.058$	$-0.044 \pm 0.120 \pm 0.063$
μ_s	$0.065 \pm 0.036 \pm 0.030$	$0.045 \pm 0.036 \pm 0.032$
Δs	$-0.267 \pm 0.393 \pm 0.156$	$-0.224 \pm 0.121 \pm 0.033$
Λ_A	$1.20 \pm 1.36 \pm 1.69$	$1.31 \pm 0.64 \pm 0.12$
S_A	$0.335 \pm 0.491 \pm 0.195$	$0.253 \pm 0.139 \pm 0.041$

Nota bene: Each of the six fits (2 form factor models, 3 interaction models) gives a different central value for the G_A^s parameters. We need more data to nail this down.

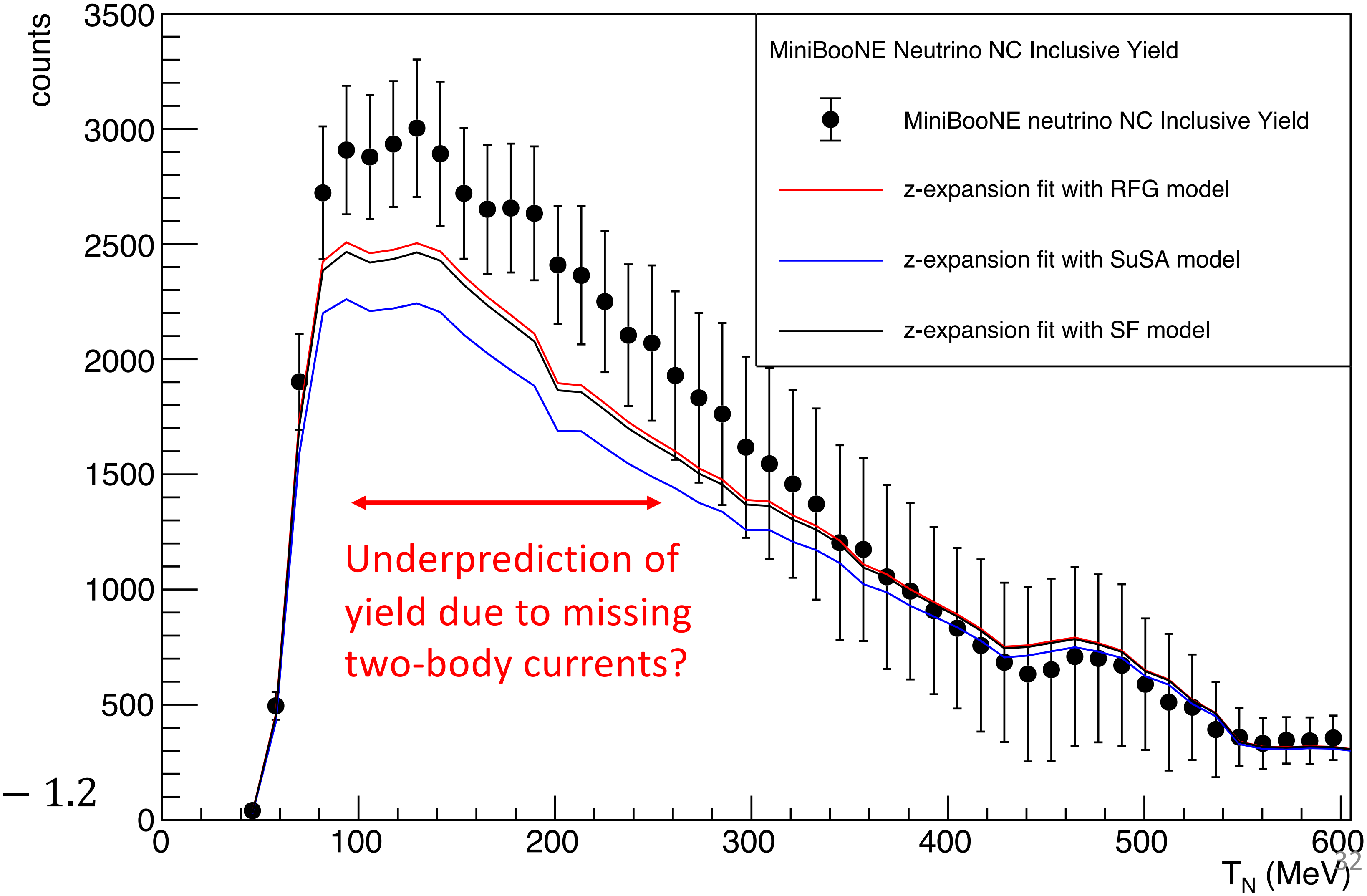
MiniBooNE NCES neutrino inclusive yield

All three fits use the z-expansion model for G_A^S.

RFG

SuSA

SF



$$\frac{\chi^2}{\text{ndf}} = 1.1 - 1.2$$

MiniBooNE NCES neutrino

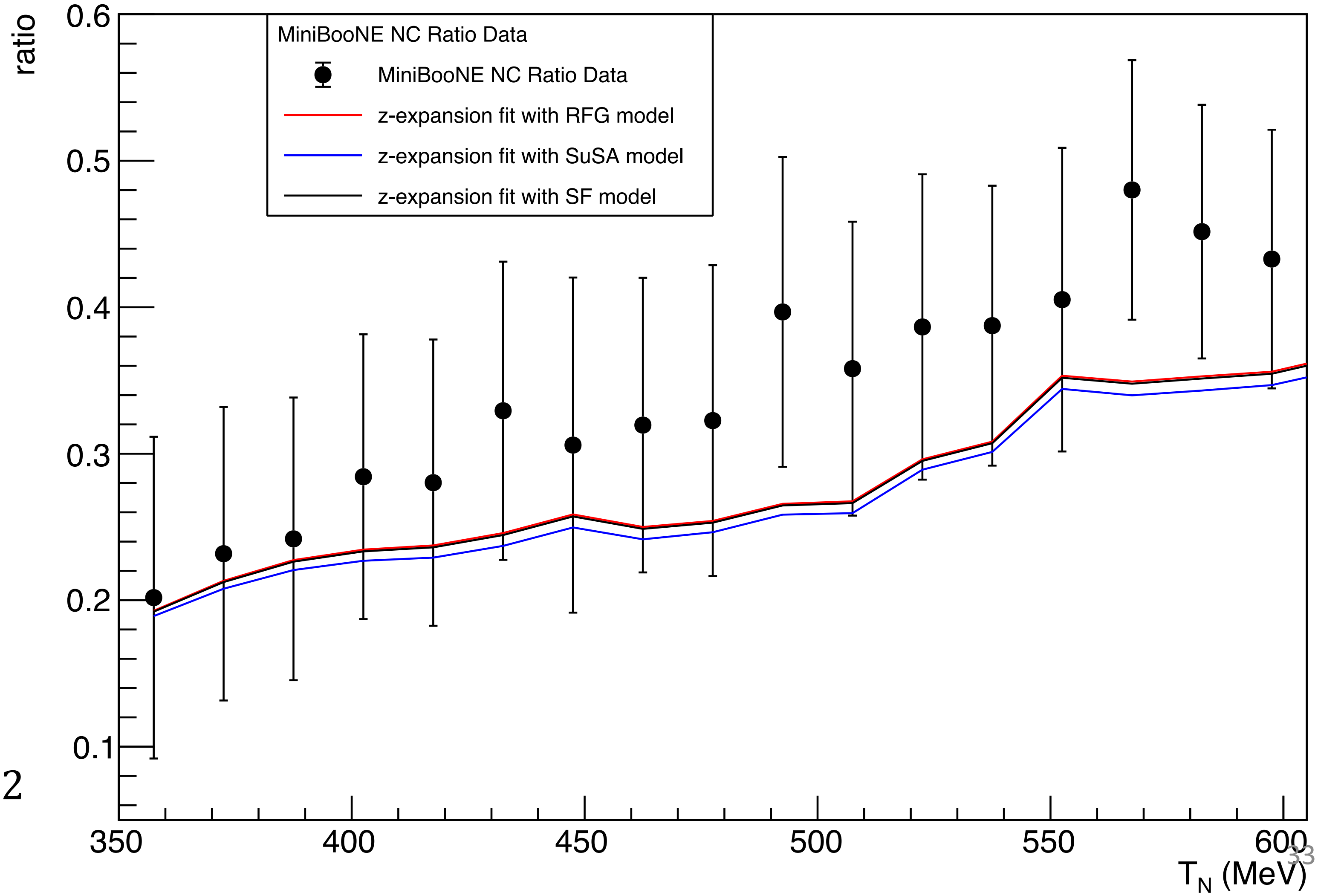
Exclusive/inclusive $p/(p+n)$ yield ratio

All three fits use the z-expansion model for G_A^s.

RFG

SuSA

SF



$$\frac{\chi^2}{\text{ndf}} = 1.1 - 1.2$$

Experimental effort to provide more NC1p data…

The MicroBooNE analysis is far advanced, and we hope to finish this up soon.

The other LArTPC experiments at Fermilab are much larger and will have much larger datasets available than MicroBooNE. (SBND already does.) Their analyses could lead to a doubly-differential NC1p cross section, which would be transformative.

Other neutrino experiments with good proton track identification should also look for NC1p events. All data is valuable!

A shout-out to Bryan Ramson and his crew who are developing a modern hydrogen bubble chamber!
(Neutral currents were discovered in a bubble chamber…)

Theoretical effort to reproduce these NC1p data…

… will need all neutrino-argon interactions that can contribute to the signal:

- Quasi-elastic NC on proton
- NC Δ-production, with FSI to absorb the pion/kaon
- NC DIS, with FSI to absorb the pion/kaon
- Quasi-elastic MEC and/or 2p2h and/or SRC, with FSI to absorb the 2nd nucleon

This work is in progress, and we welcome others to join the effort.

z-Expansion Model for G_A^s

$$G_A^s = \sum_{k=0}^{6} a_k [z(Q^2)]^k$$

$$z(Q^2) = \frac{\sqrt{t_{cut} + Q^2} - \sqrt{t_{cut} - t_0}}{\sqrt{t_{cut} + Q^2} + \sqrt{t_{cut} - t_0}}$$

$$t_{cut} = (4m_\pi)^2 \qquad t_0 = 0$$

Four constraints: $\left(\frac{d^n}{dz^n} G_A^s\right)_{z=1} = 0 \qquad n = 0,1,2,3$

$\Rightarrow$ only three parameters a_0, a_1, a_2

Richard J. Hill and Gil Paz Phys. Rev. D 82, 113005

Gabriel Lee, John R. Arrington, and Richard J. Hill Phys. Rev. D 92, 013013

Elastic NC neutrino-proton cross section

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2}{2\pi}\frac{Q^2}{E_\nu^2}\left(A \pm BW + CW^2\right) \qquad +(-) \Rightarrow \nu(\bar{\nu})$$

$$W = 4\left(E_\nu/M_p - \tau\right) \qquad \tau = Q^2/4M_p^2$$

$$\begin{aligned} A &= \frac{1}{4}\left[\left(G_A^Z\right)^2(1+\tau) - \left(\left(F_1^Z\right)^2 - \tau\left(F_2^Z\right)^2\right)(1-\tau) + 4\tau F_1^Z F_2^Z\right] \\ B &= -\frac{1}{4}G_A^Z\left(F_1^Z + F_2^Z\right) \\ C &= \frac{1}{64\tau}\left[\left(G_A^Z\right)^2 + \left(F_1^Z\right)^2 + \tau\left(F_2^Z\right)^2\right] \end{aligned}$$

G_A^{CC}

The best data on the *CC* axial form factor is from deuterium bubble chamber data from the 70s and 80s.

No background.

$$\nu_\mu + n \rightarrow \mu + p$$

No significant nuclear corrections.

Unambiguous event selection.

The results of these experiments still form the basis for our understanding of G_A^{CC} and continue to be used in fits and comparisons to model calculations.

$$G_A^{CC} = \frac{g_A}{(1 + Q^2/M_A^2)^2}$$

$g_A = 1.2670 \pm 0.0030$ Cabibbo et al., Ann. Rev. Nucl. Part. Sci. 53, 39-75, 2003

$M_A = 1.014 \pm 0.014$ Bodek et al., Eur. Phys. J. C 53, 349-354, 2008

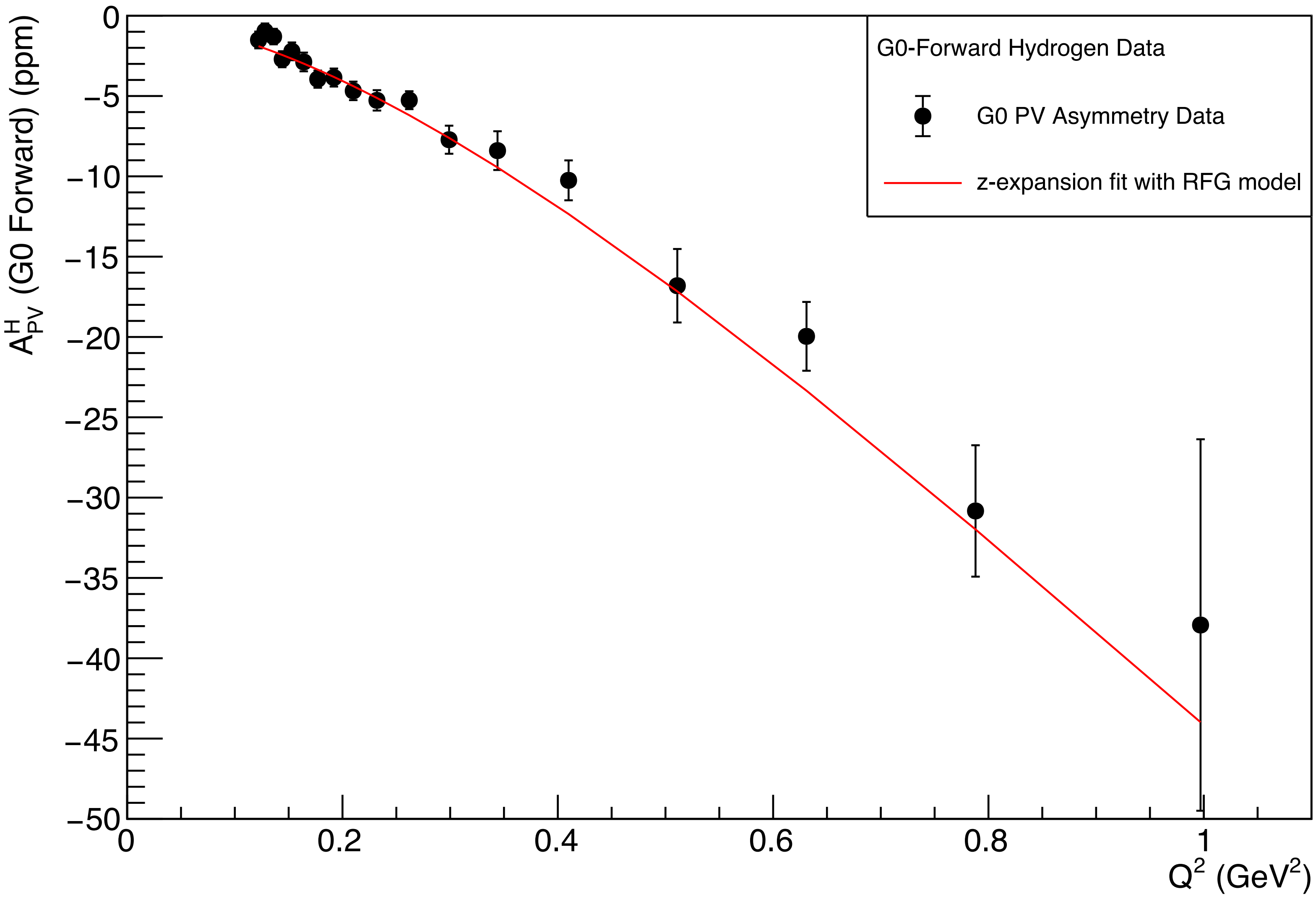
TABLE III. Summary of the results of the fits performed with three nuclear models (RFG, SuSA, and SF) and two strangeness axial form factor models (modified-dipole and z-expansion); also shown are the results when no MiniBooNE data are included. The central value and uncertainty is given for each fit parameter, and also the χ^2 per number of degrees of freedom at the optimal fit point. The first uncertainty is that arising from the fit itself, and the second uncertainty is a systematic due to the uncertainties in the quantities in Table I as described in the text.

		RFG	SuSA	SF	w/o MiniBooNE Data
Modified-Dipole	ρ_s	$-0.043 \pm 0.120 \pm 0.063$	$-0.047 \pm 0.120 \pm 0.064$	$-0.044 \pm 0.120 \pm 0.063$	$-0.107 \pm 0.121 \pm 0.058$
	μ_s	$0.045 \pm 0.036 \pm 0.032$	$0.047 \pm 0.036 \pm 0.032$	$0.045 \pm 0.036 \pm 0.032$	$0.065 \pm 0.036 \pm 0.030$
	Δs	$-0.203 \pm 0.115 \pm 0.030$	$-0.386 \pm 0.155 \pm 0.055$	$-0.224 \pm 0.121 \pm 0.033$	$-0.267 \pm 0.393 \pm 0.156$
	Λ_A	$1.37 \pm 0.73 \pm 0.13$	$1.04 \pm 0.33 \pm 0.08$	$1.31 \pm 0.64 \pm 0.12$	$1.20 \pm 1.36 \pm 1.69$
	S_A	$0.230 \pm 0.133 \pm 0.037$	$0.422 \pm 0.178 \pm 0.070$	$0.253 \pm 0.139 \pm 0.041$	$0.335 \pm 0.491 \pm 0.195$
	χ^2/ndf	133/123	144/123	134/123	55/44
z-Expansion	ρ_s	$-0.022 \pm 0.128 \pm 0.071$	$-0.036 \pm 0.125 \pm 0.070$	$-0.025 \pm 0.127 \pm 0.070$	$-0.080 \pm 0.126 \pm 0.045$
	μ_s	$0.038 \pm 0.038 \pm 0.034$	$0.044 \pm 0.037 \pm 0.034$	$0.040 \pm 0.038 \pm 0.034$	$0.055 \pm 0.038 \pm 0.024$
	a_0	$0.403 \pm 0.222 \pm 0.183$	$-0.087 \pm 0.199 \pm 0.150$	$0.323 \pm 0.220 \pm 0.191$	$1.07 \pm 0.33 \pm 1.39$
	a_1	$-8.09 \pm 2.44 \pm 1.98$	$-3.18 \pm 2.27 \pm 1.58$	$-7.25 \pm 2.42 \pm 2.07$	$-14.8 \pm 3.4 \pm 15.1$
	a_2	$44.5 \pm 11.3 \pm 8.2$	$25.1 \pm 10.8 \pm 6.4$	$41.1 \pm 11.3 \pm 8.6$	$71.4 \pm 14.8 \pm 62.7$
	χ^2/ndf	130/123	143/123	131/123	53/44

from https://arxiv.org/abs/2402.10854

G0 PVES forward-scattering A_{PV} data on hydrogen.

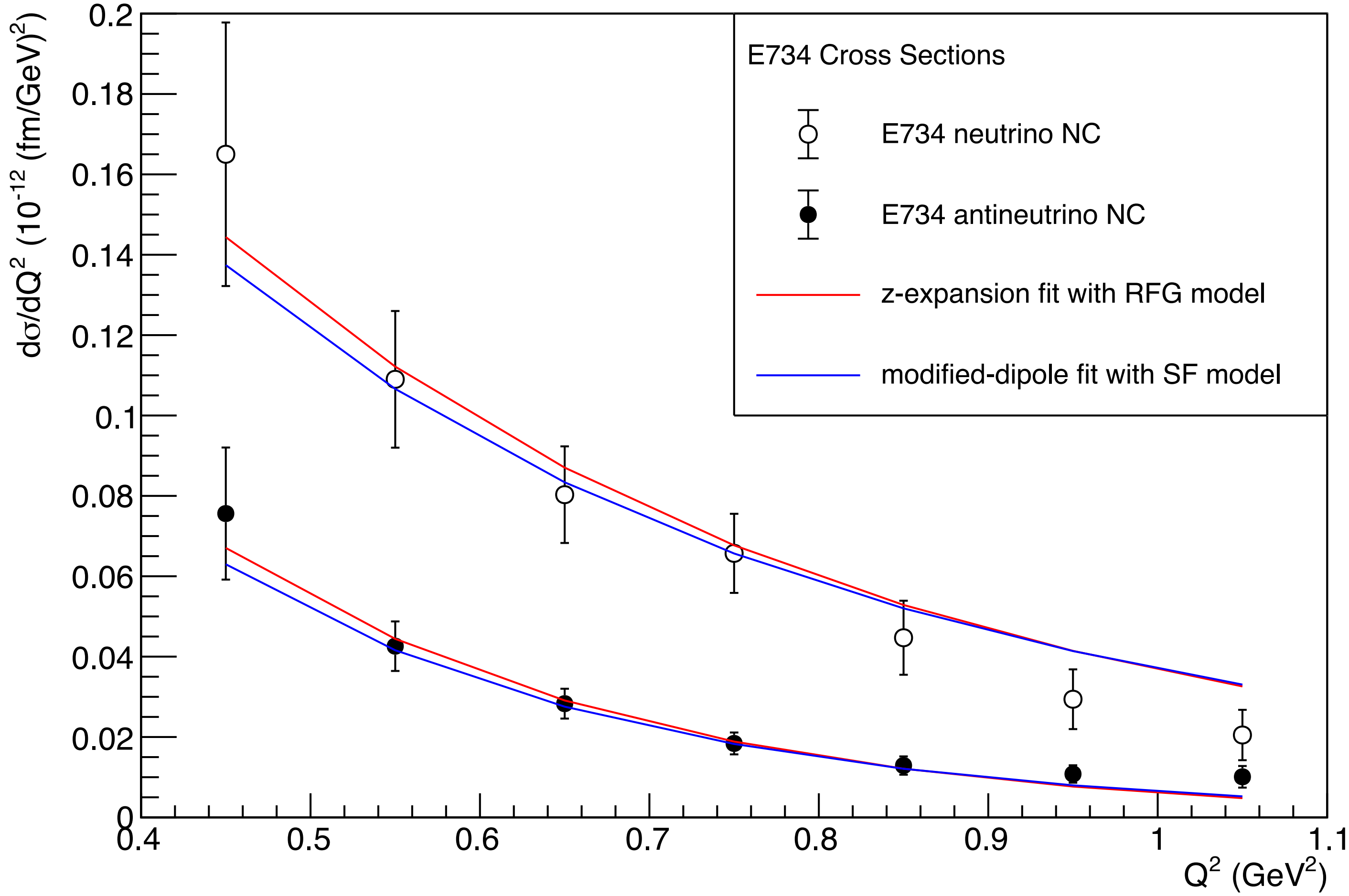
Fit uses z-expansion model for G_A^S and RFG nuclear model.



BNL E734 NC neutrino and antineutrino data.

Fit uses z-expansion model for G_A^S and RFG nuclear model.

Fit uses modified-dipole model for G_A^S and SF nuclear model.



A Brief History of Δs

First experimental data came from measurements of the ***inclusive*** deep-inelastic scattering of polarized muons from polarized hydrogen (EMC). ➔ $\Delta s < 0$
This has been confirmed in all subsequent ***inclusive*** measurements (SMC, SLAC, HERMES, COMPASS, JLab).
N.B. This analysis always assumes SU(3) flavor symmetry, combining the extrapolated integral of the DIS measurements with the triplet and octet axial charges determined from hyperon β-decay.

Later, it became possible to observe ***semi-inclusive*** deep-inelastic scattering, where the leading hadron (pion or kaon) served to "tag" the struck quark. ➔ $\Delta s \sim 0$
(SMC, HERMES, COMPASS).
N.B. This analysis does not use SU(3) flavor symmetry, but does rely on an understanding of quark→hadron fragmentation functions.

This dichotomy exists today: Analyses of leptonic DIS and polarized *pp* collision data still show a discrepancy in the determination of Δs.

de Florian, Sassot, Stratmann, and Vogelsang [PRD 80 (2009) 034030]
Nocera, Ball, Forte, Ridolfi, and Rojo [NPB 887 (2014) 276-308]
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Hirai and Kumano (AAC) [Nucl. Phys. B 813 (2009) 106]
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