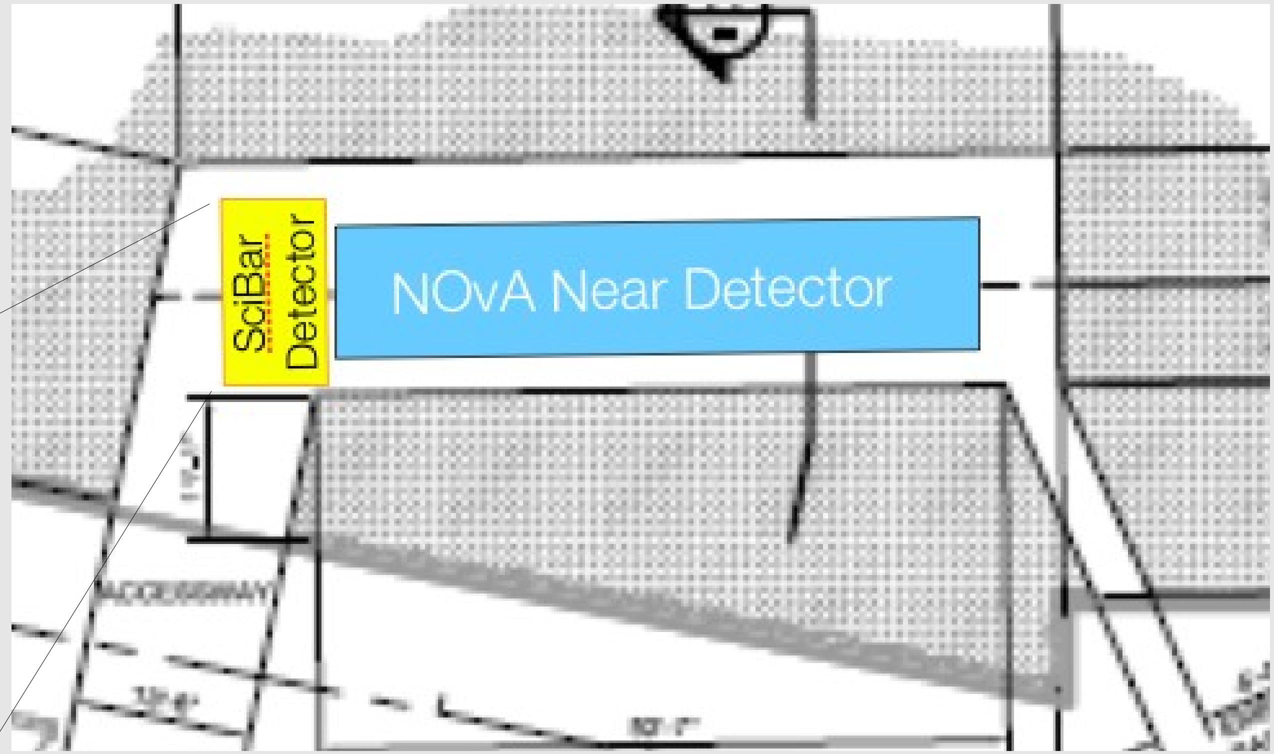
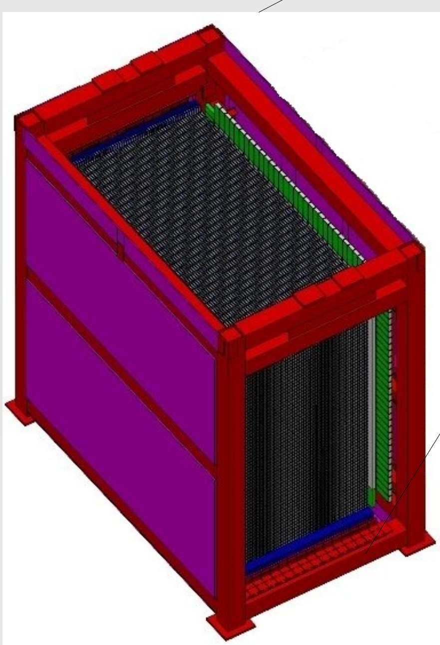
A Measurement of Neutrino-Nucleus Scattering in a Narrow-Band Beam: SciNOvA





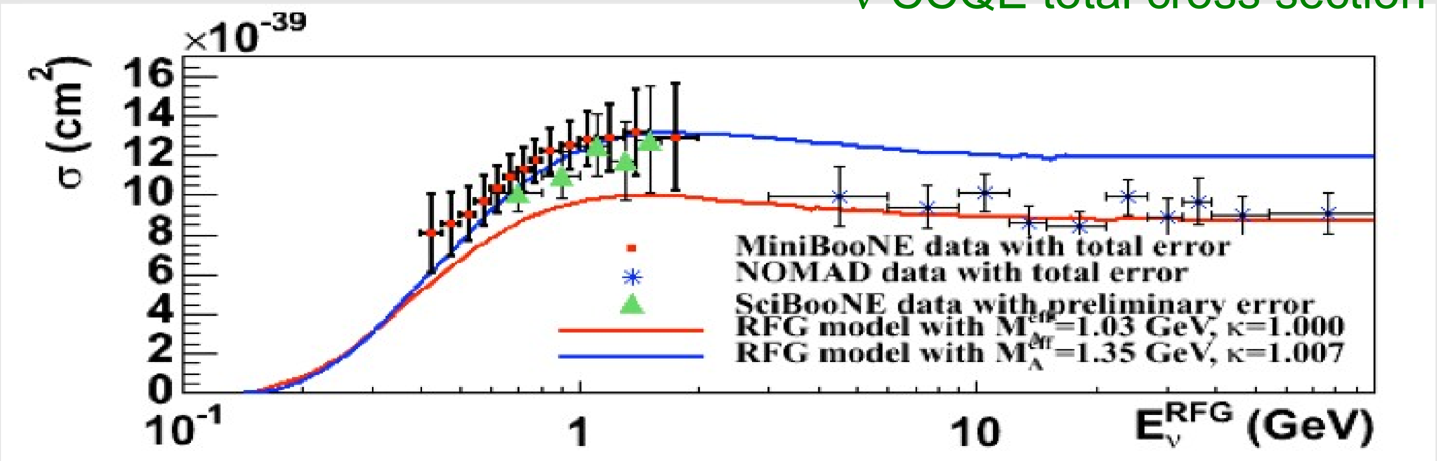
R. Tayloe, Indiana U.
ν WG meeting
FNAL, 11/11

Neutrino nucleus scattering measurements

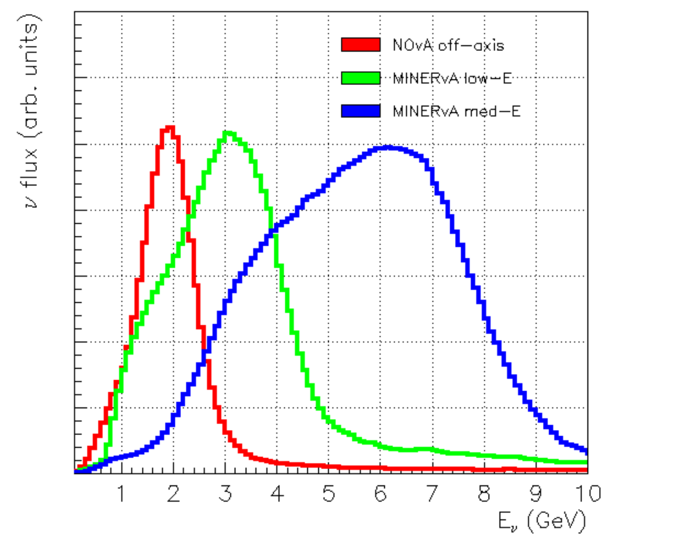
- To measure ν oscillations, it is crucial to understand the detailed physics of ν scattering.
- Recent results on ν - nucleus scattering, from K2K, SciBooNE, MiniBooNE, NOMAD indicate we dont yet have that understanding.

- EG: total CCQE xsections from SB, MB, NOMAD

ν CCQE total cross section



NUMI ν fluxes



- In near future MINERvA, T2K will add data. However these are challenging measurements: wide-band beams, large backgrounds, bound nucleons. and a complete theory will require lots of complementary data
- Cross section measurements on the NOvA, narrow-band, 2 GeV , ν and $\bar{\nu}$ beams, should be made

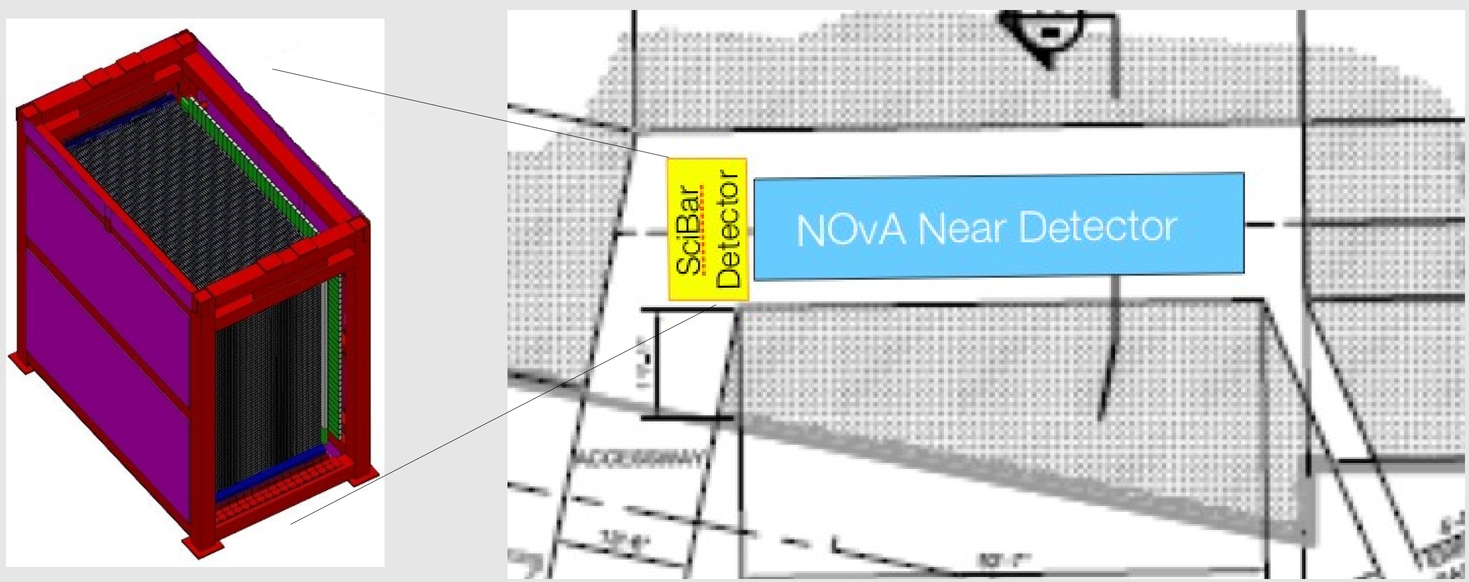
SciNOvA

A “SciBar” detector using an existing and proven design (from KEK/SciBooNE), deployed in front of the NOvA near detector in the NuMI off-axis, 2 GeV, narrow-band beam.

A fine-grained SciBar detector in this location will provide:

- important and unique ν scattering measurements including:
  - A test of recent MiniBooNE results indicating anomalously large cross section in CCQE using a different ν source at slightly higher E_ν
  - a search for 2N correlations
  - Neutral-current differential cross sections, $NC\pi^0$, $NC\gamma$ - crucial for ν_e appearance
- significant cross checks of NOvA ν oscillation backgrounds, esp $NC\pi^0$

Cost: $2.4M

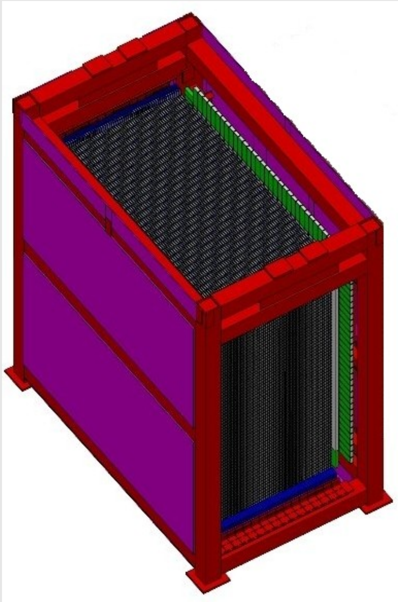


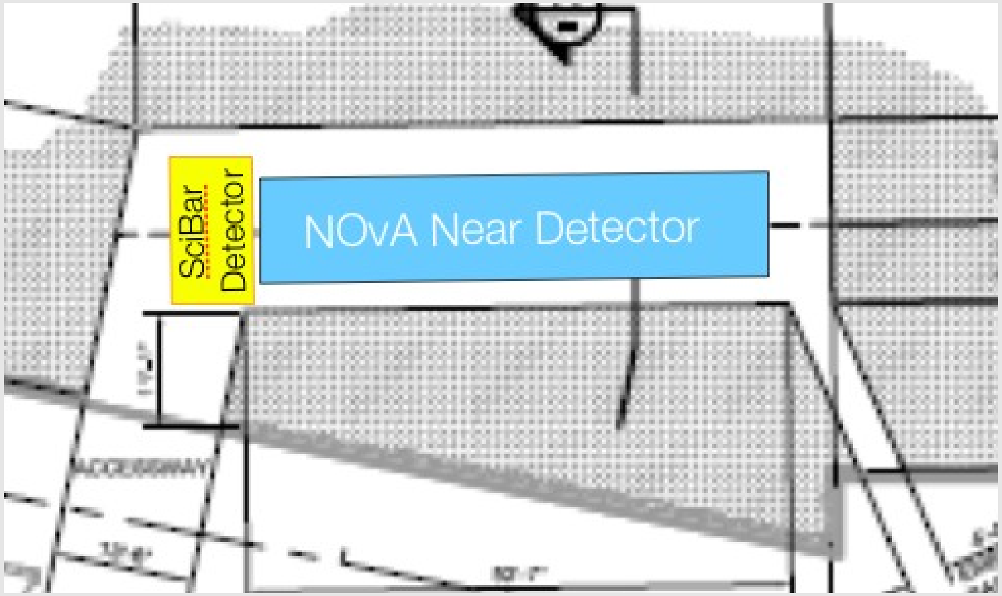
SciNOvA current status

- Presented to FNAL PAC, 11/10 - recommended that NOvA consider SciNOvA

• The NOvA collaboration supports the SciNOvA physics case and is seriously evaluating it as a possibility. Study group consisting of NOvA and non-NOvA physicists recently formed to answer remaining technical questions.

- Final decision by NOvA hinges on:
    - People power (contact us if interested!)
    - Earned contingency from NOvA and perhaps outside funding.

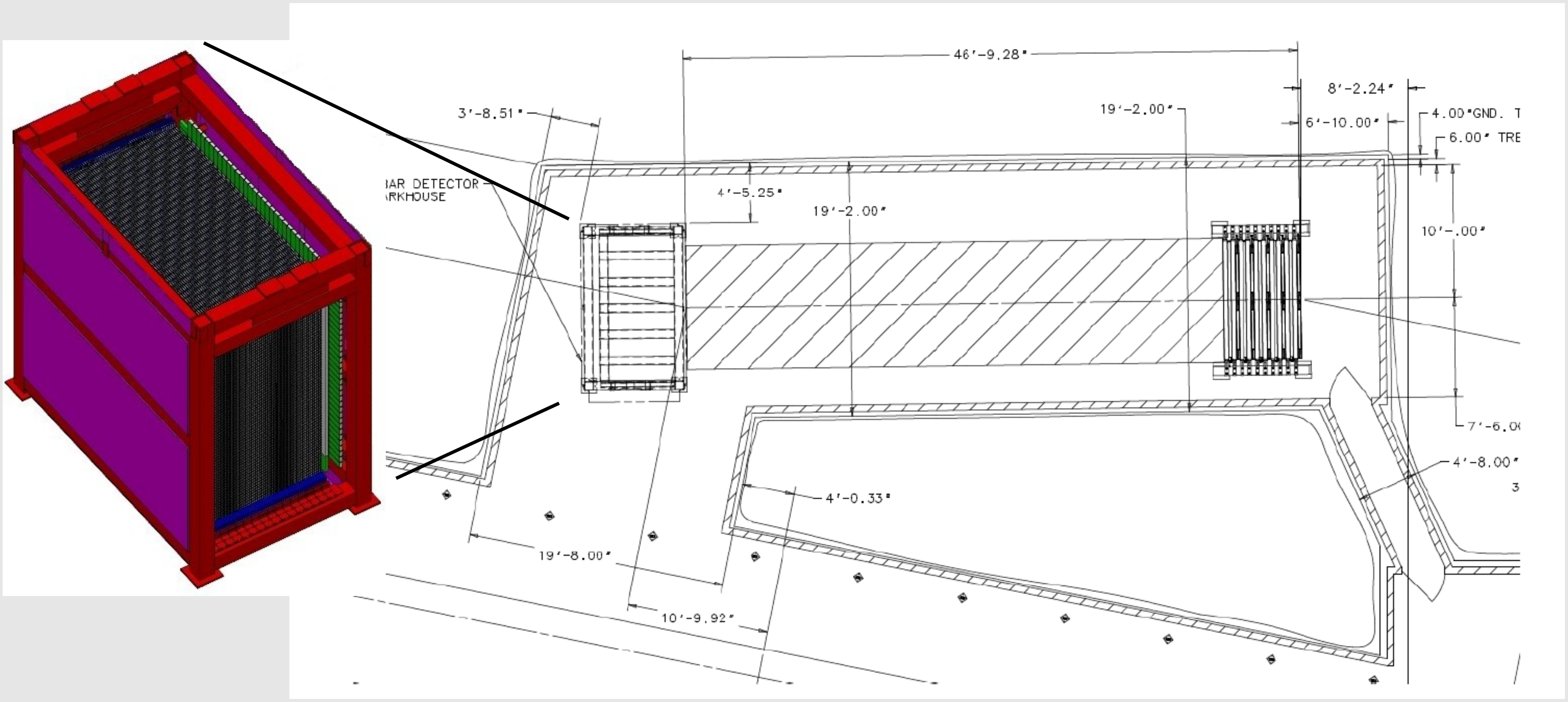




ADDITIONAL SLIDES for further perusal

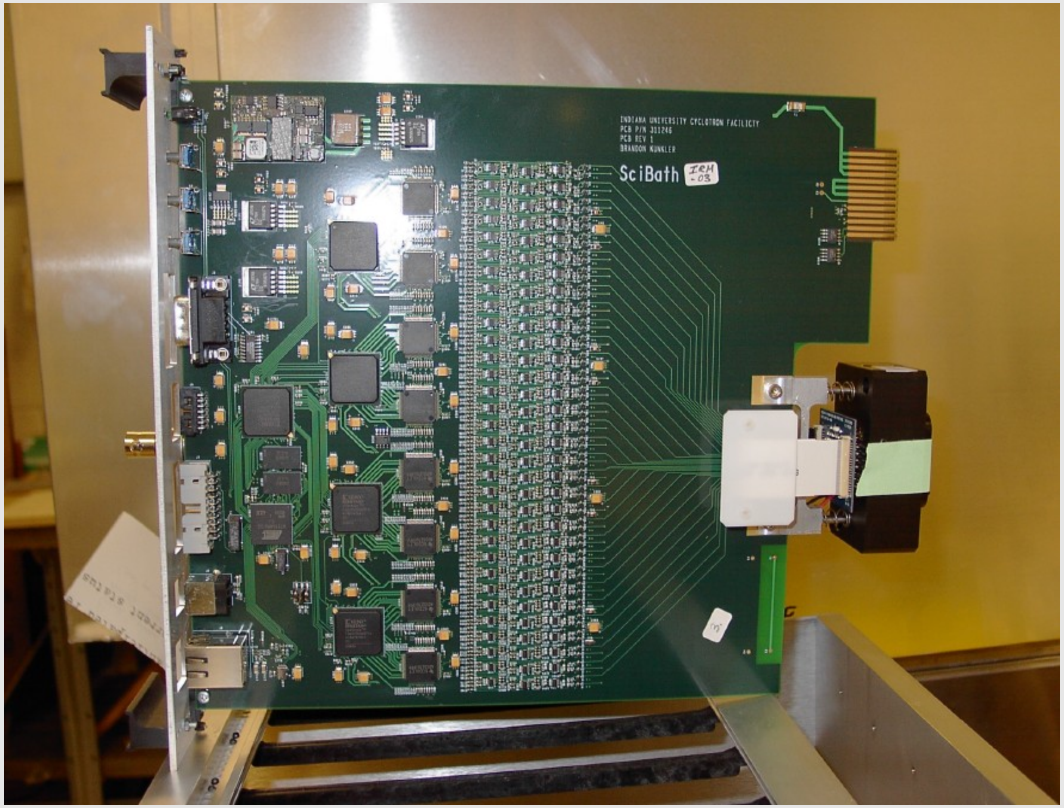
SciNOvA detector

- 15k-channel solid scintillator SciBar detector in front of NOvA near detector
  - no cavern changes required, slight modifications to detector support structure
- (FNAL-made) scintillator extrusions (1.3cmx2.5cm), same design as existing SciBar
- 1.5mm WLS fibers into 64 anode PMTS
- readout system based on existing (and running) design (IU IRM modules)



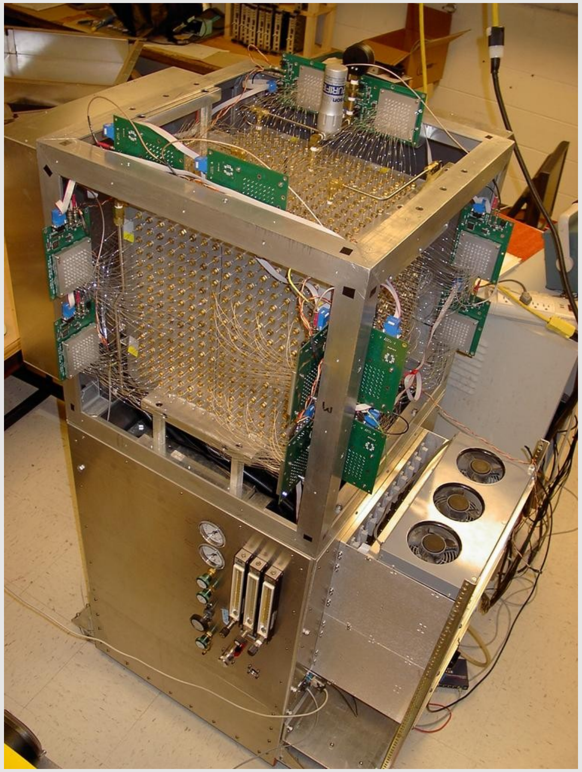
SciNOvA detector

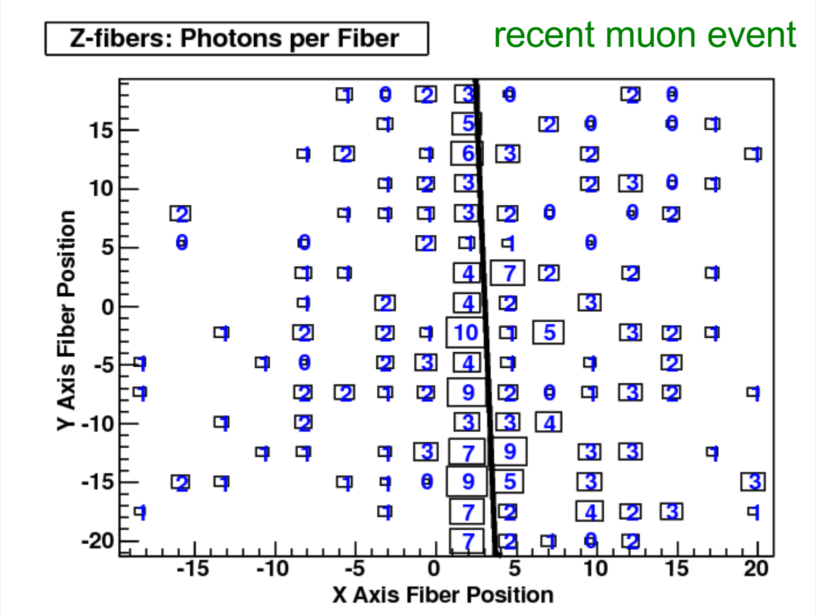
- (proposed) readout electronics:
  Integrated Readout Modules (IRMs) running now on “SciBath” detector at IU



IRM with attached PMT

SciBath detector





Scibath detector:
- WLS fiber/liquid scintillator (`100kg) for n/ν
- 12 64anode PMTs, 768 channels total
- testbeam run in MINOS this fall

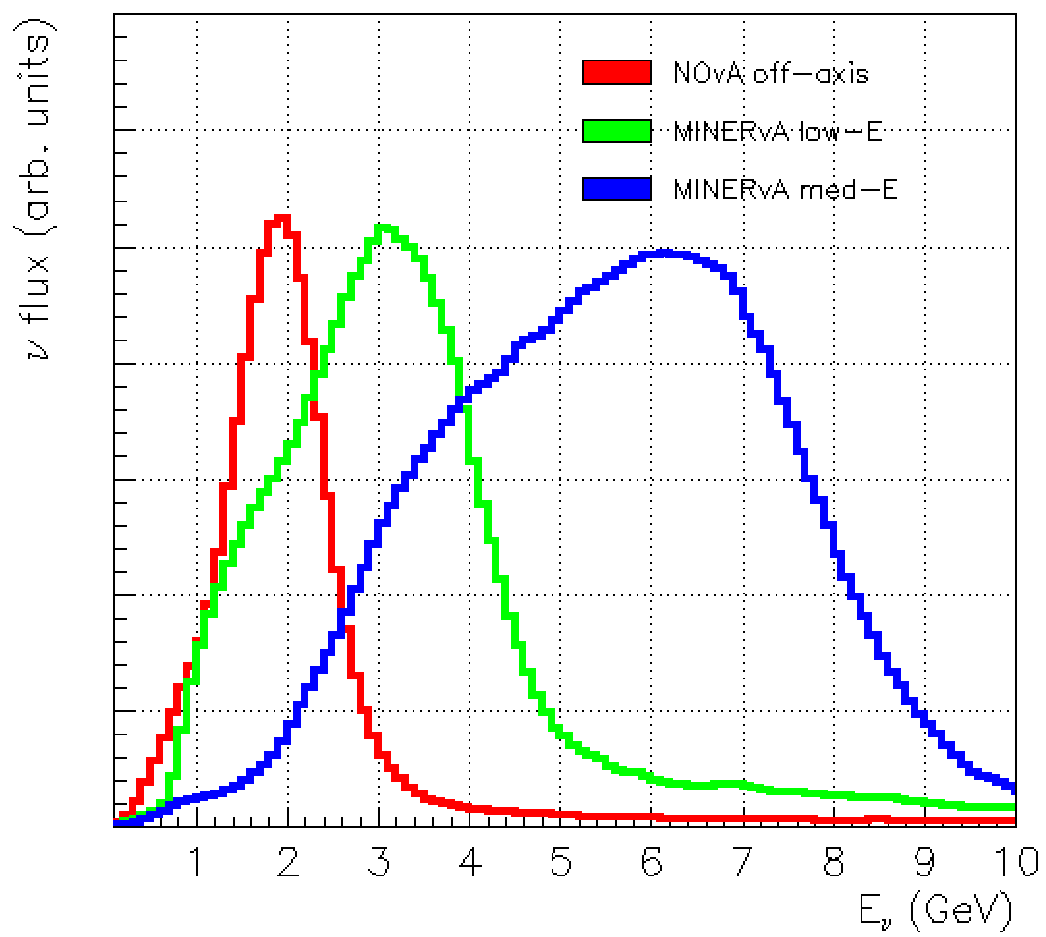
Narrow band beam

- ~2 GeV mean energy,

- lower energy and smaller energy spread than on-axis flux

- complementary to the NUMI on-axis cross section program

NUMI ν fluxes



Event rates

- High event rates in SciNOvA allowing measurements with excellent statistical precision.

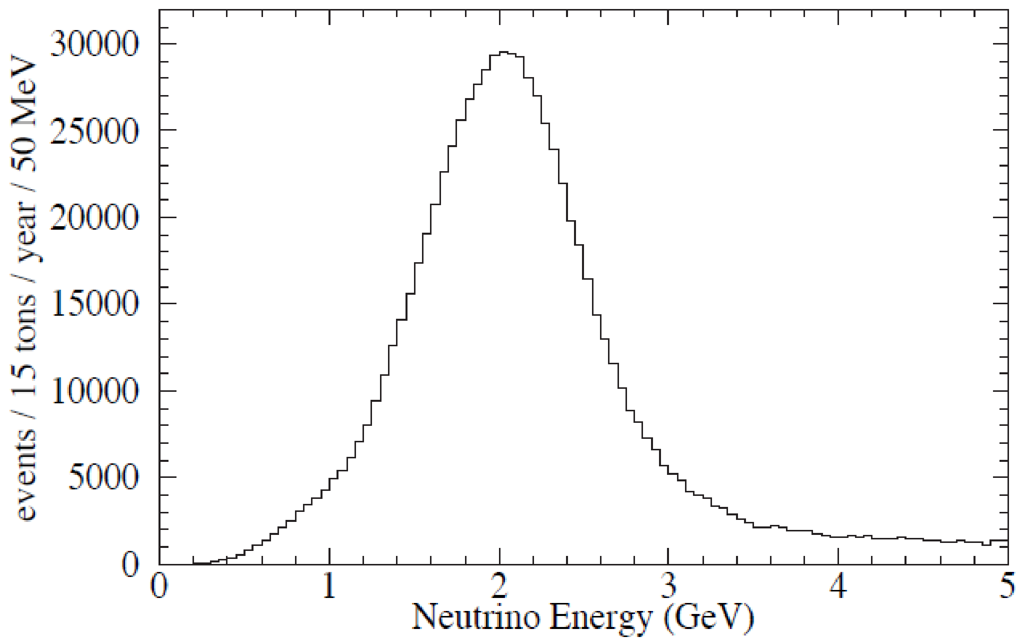
- Compare to MiniBooNE CCQE sample of ~150k events collected over 3yrs in 800ton detector.

- ~equivalent event sample collected in ~1 year with fine-grained detector

SciNOvA ν kevent/yr (6E20POT) in 10 ton fiducial vol

	Charged-current	Neutral-current
elastic	220	86
resonant	327	115
DIS	289	96
coherent	8	5
total	845	302
$\nu + A \rightarrow \pi^0 + X$	204	106

energy distribution of events in SciNOvA



CCQE scattering

MiniBooNE has recently pub'd results on various ν_μ scattering channels, eg:

- CCQE, NC elastic, $CC\pi^+$, $CC\pi^0$

- In this data, (as well as for a few other experiments) the flux-averaged cross sections are O(30%) larger than state-of-art neutrino generator (with fermi-gas impulse approximation) predictions

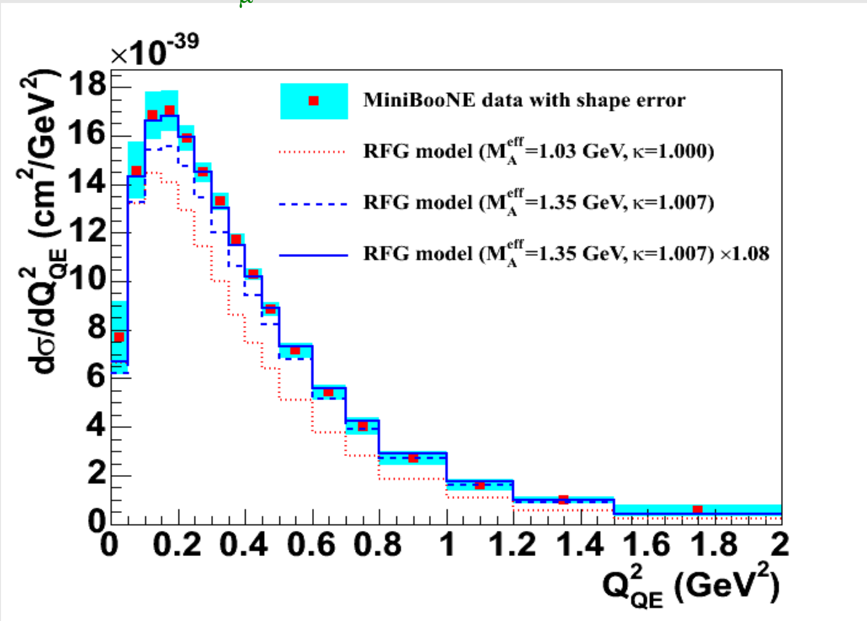
In particular, for the CCQE process.

This observation needs to be understood with additional measurements.

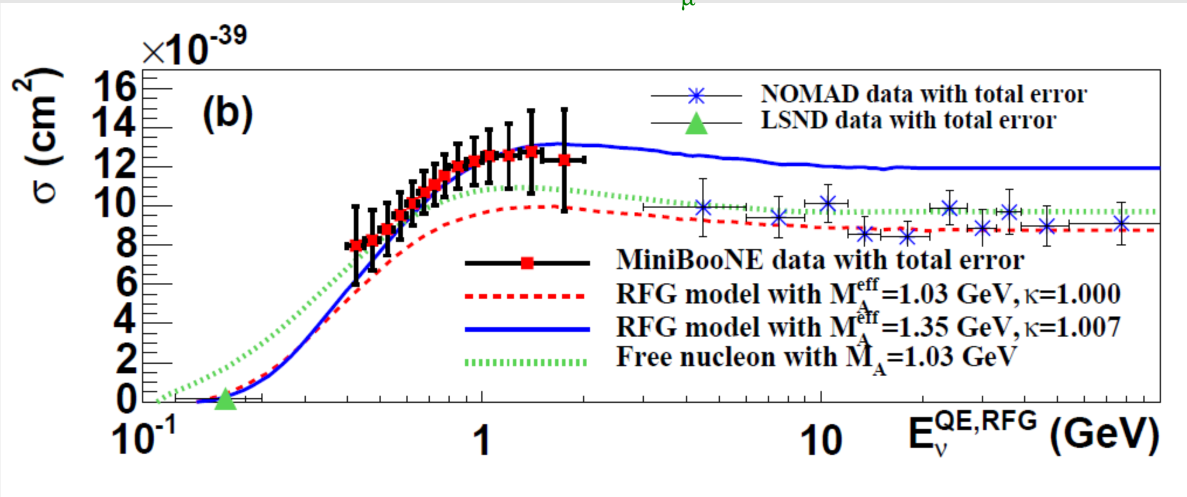
SciNOvA can provide this at 2GeV

complementary to MINERvA

MiniBooNE ν_μ CCQE differential cross section



MiniBooNE ν_μ CCQE total cross section



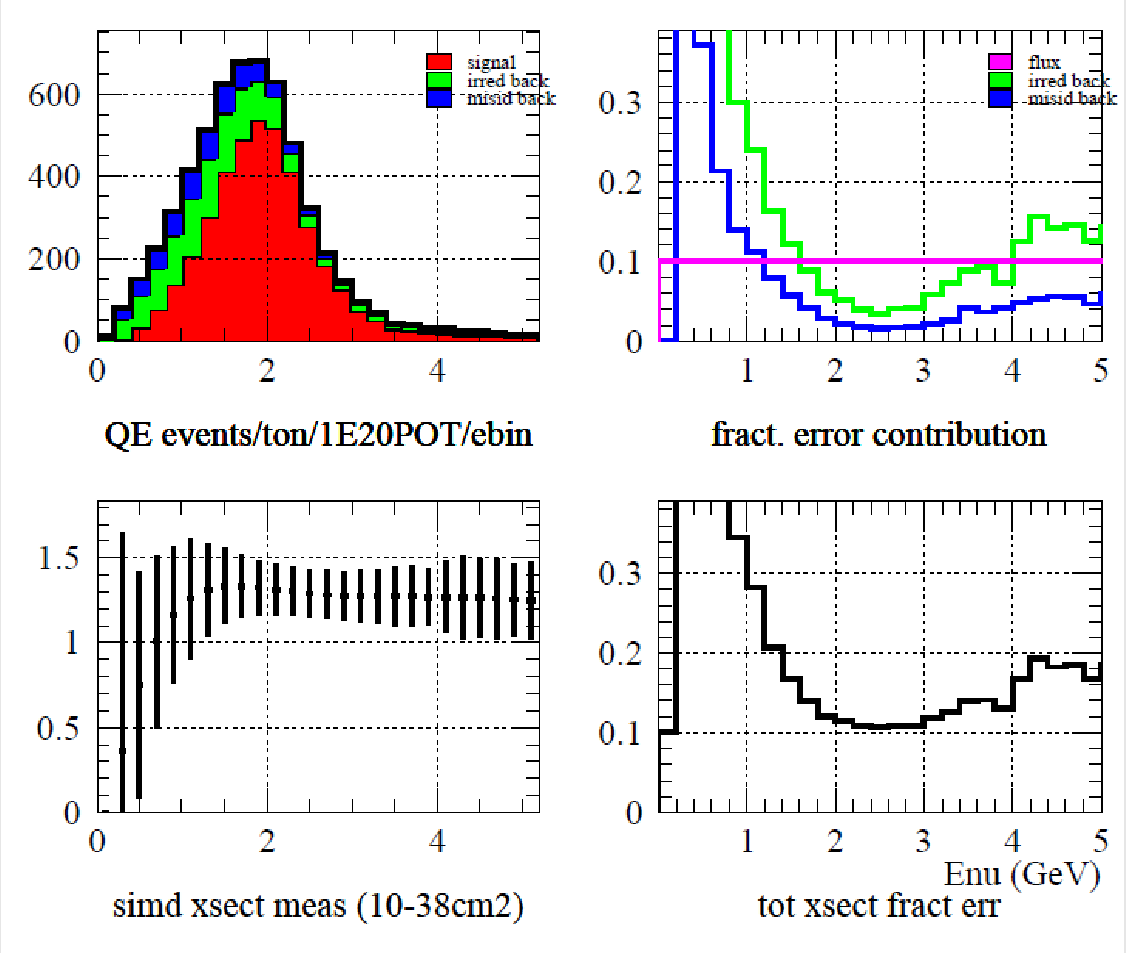
CCQE scattering measurement

Estimated errors on SciNOvA CCQE total cross section measurement

- estimated with bootstrapping from MiniBooNE error analysis
- checked by predicting actual MiniBooNE errors
- dominant background is CCπ feeddown from high "true" E_ν to lower recon'd E_ν due to lost pion (in detector medium or nucleus)

- resulting error at 2 GeV (flux-peak of NOvA beam) is 12%

- will provide important points in CCQE total cross section data and most-directly check MiniBooNE results



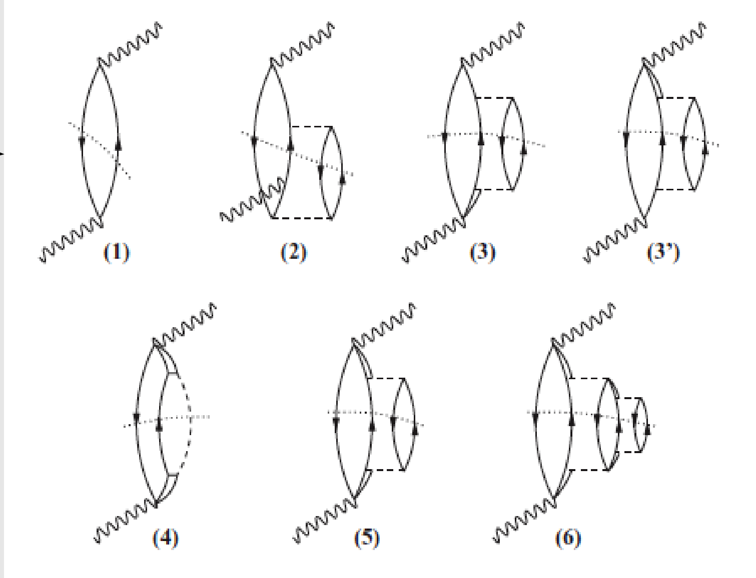
all plots as function of reconstructed E_ν (GeV)

CCQE scattering and 2-N correlations

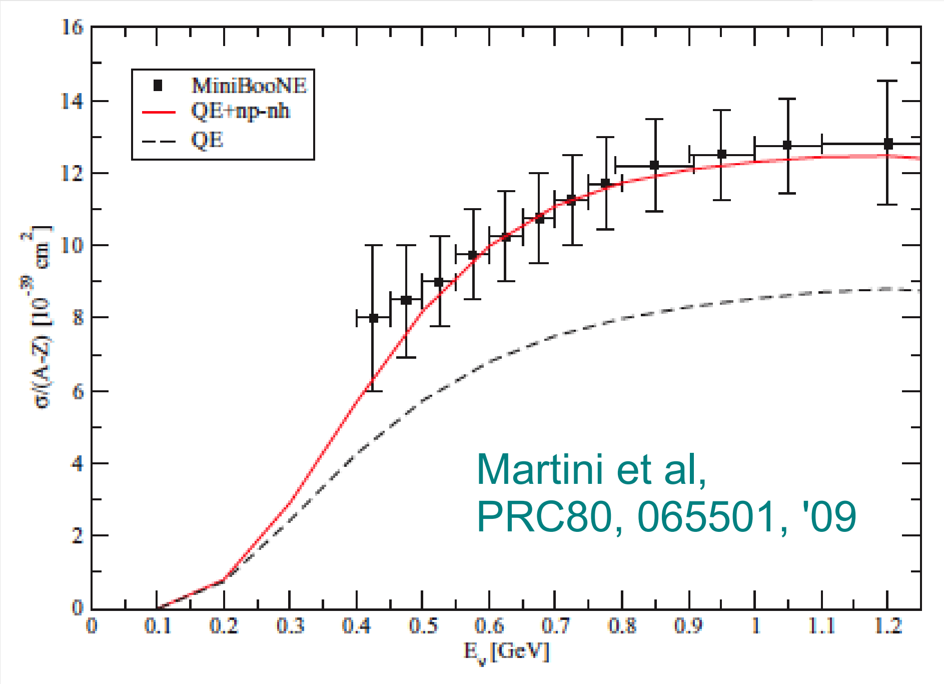
- Perhaps extra “strength” in CCQE from multi-nucleon correlations within carbon (Martini et al PRC80, 065501, '09)

- Related to neglected “transverse” response in noted in electron scattering? (Carlson etal, PRC65, 024002, '02)

- Expected with nucleon short range correlations (SRC) and 2-body exchange currents



CCQE total cross section



CCQE scattering and 2-N correlations

- multi-N correlation idea is gaining theoretical momentum
- eg:" Pionic correlations and meson-exchange currents in two-particle emission induced by electron scattering", J.E. Amaro, etal, Phys.Rev. C82 (2010) 044601
- e-scattering calculation

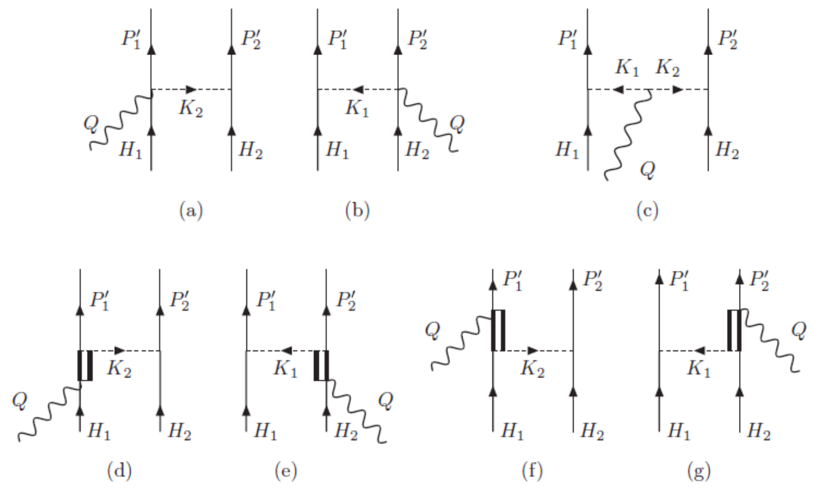


FIG. 1. MEC diagrams considered in the present study. Diagrams (a) and (b) correspond to the seagull, (c) to the pionic, and (d)–(g) to the Δ current, respectively.

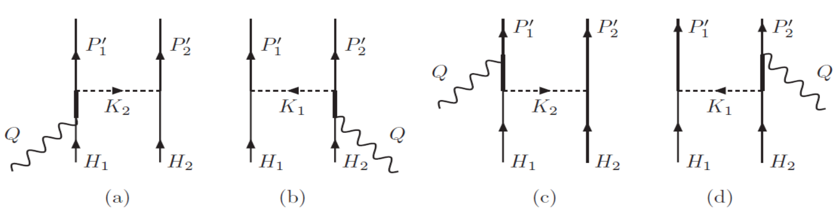


FIG. 2. Correlation diagrams considered in the present study. Diagrams (a) and (b) correspond to the forward, and (c) and (d) backward contributions, respectively.

predicted transverse response (on Fe)

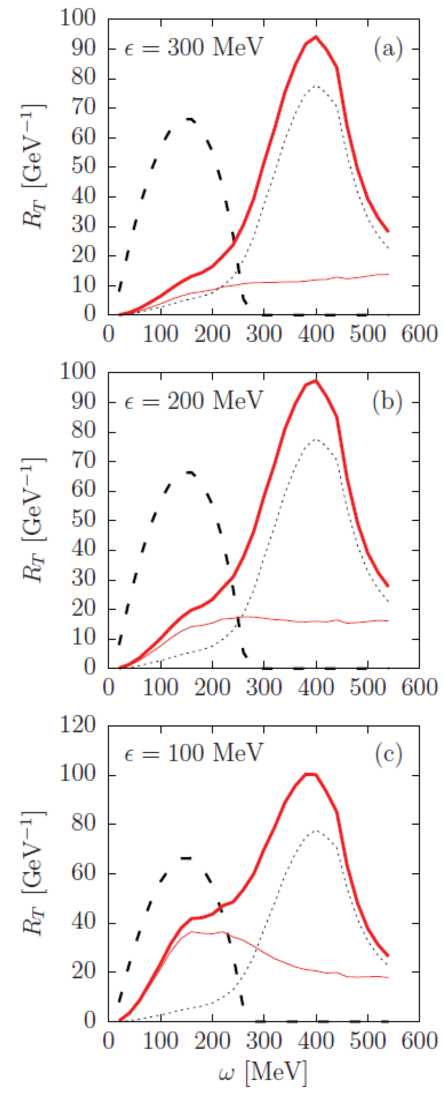
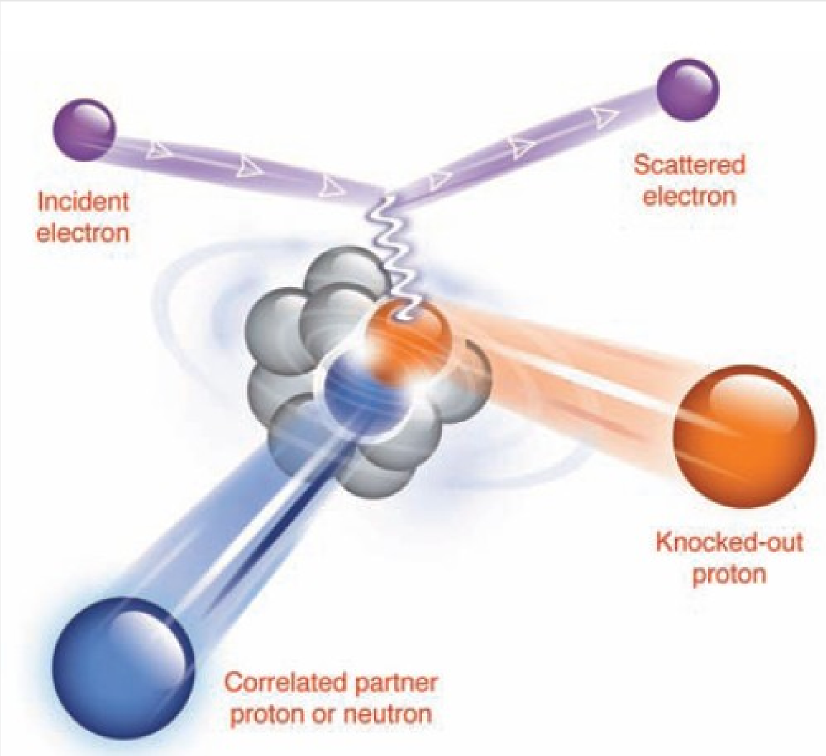


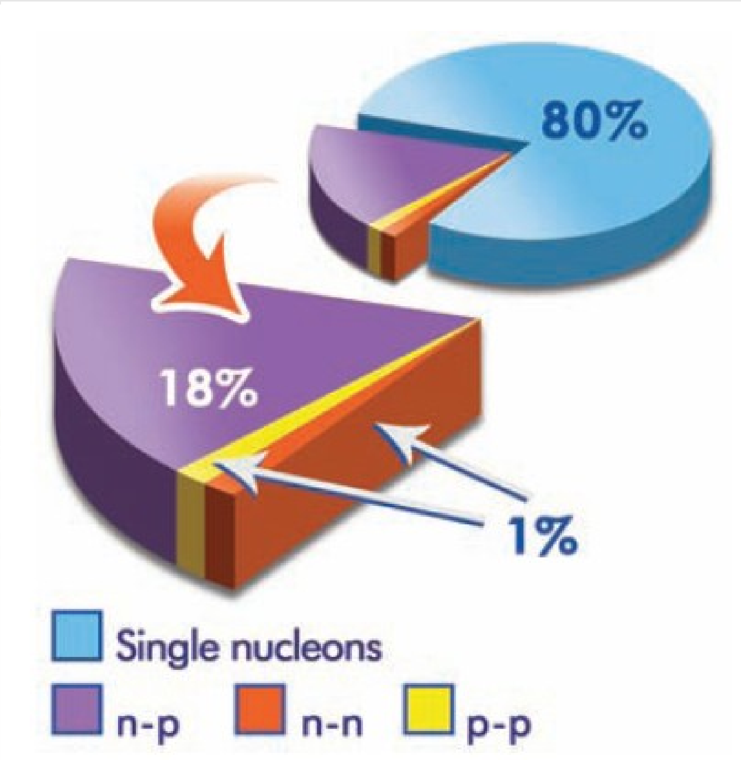
FIG. 3. (Color online) 2p-2h transverse response of ^{56}Fe at $q = 550$ MeV/c. Three values of the parameter ϵ are shown. Thin solid lines, correlation only; dotted lines, MECs only; thick solid lines, total; dashed, RFG OB results.

CCQE scattering and 2-N correlations

- Also, recent results from e-scattering suggest 20% of nucleons in carbon are in a “SRC state”

(R. Subedi etal, Science, 320, 1476 (2008))





This effect should result in distinguishable final states of multiple recoil nucleons.
Can be experimentally tested with SciNOvA.

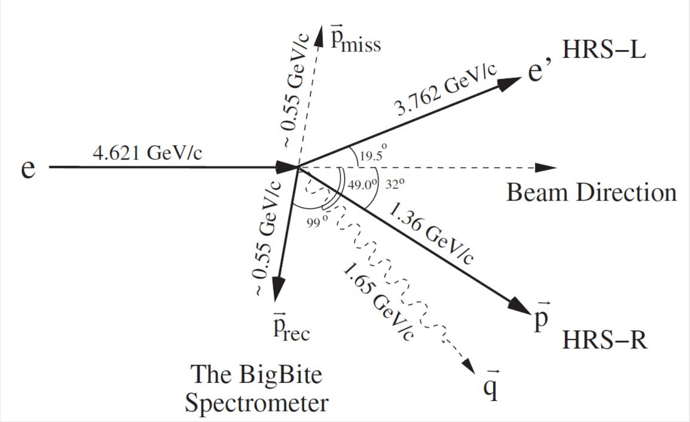
Measuring 2-nucleon correlations

missing momentum plots

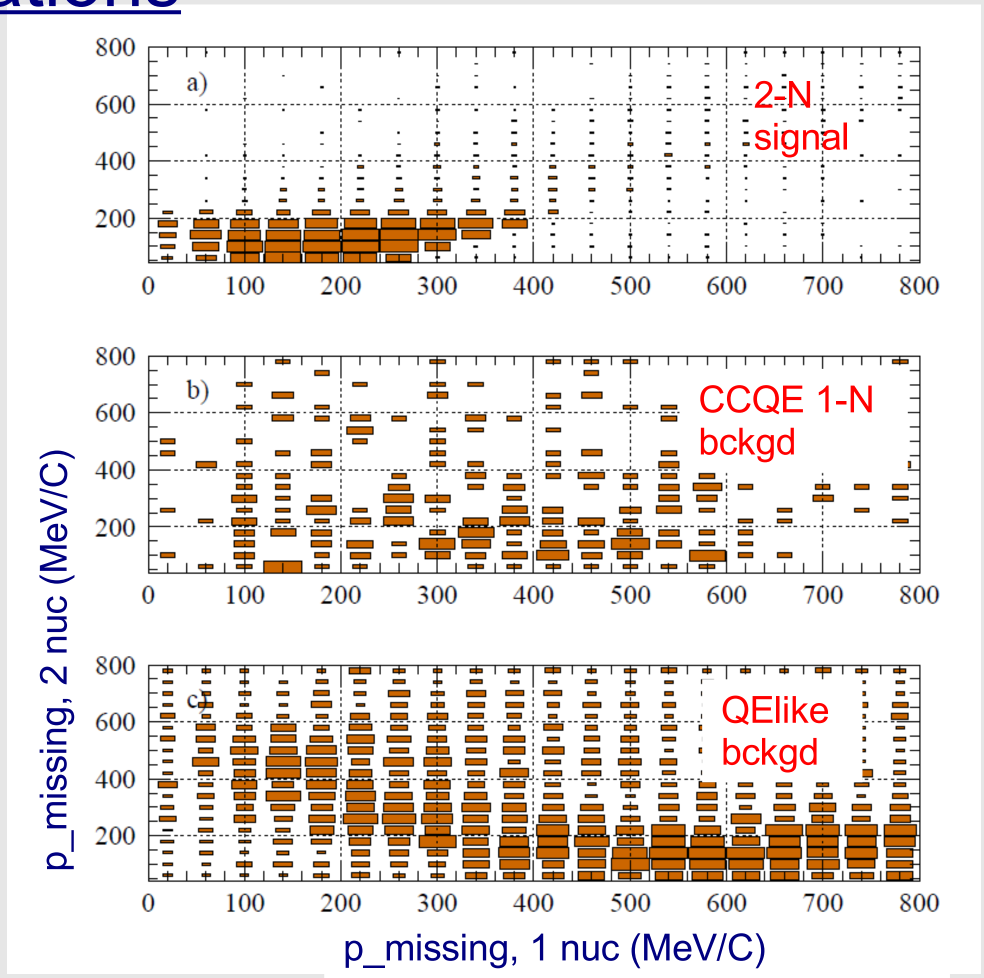
- A search for 2 nucleon correlations with SciNoVA is experimentally feasible and would provide the most direct test for MiniBooNE results.

Sketch of experimental method:

- Following method of JLab Hall A experiment:



- Find CCQE scattering events with 2 high-momentum recoil nucleons.
- Use transverse kinematics to eliminate neutrino energy unknown (all longnitudinal)
- look for transverse momentum balance when both nucleons considered.
- Separated from more mundane CCQE, CCπ events where energy should be shared with unobserved particles and recoil nucleus.
- Modeled with assumed extra 30% 2N events.

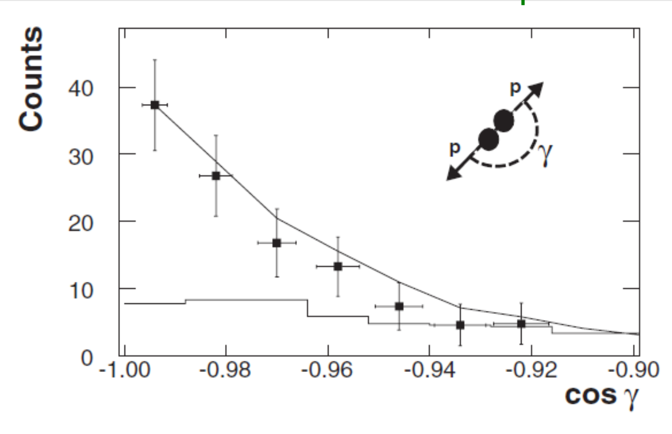


Measuring 2-nucleon correlations

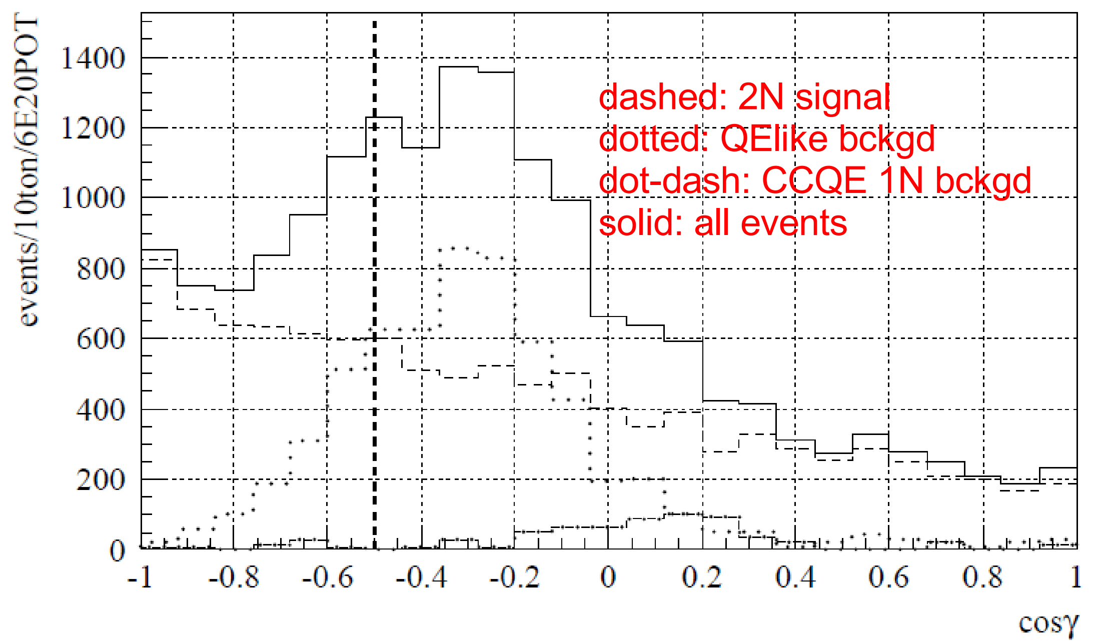
Experimental search with SciNOvA (continued)

- look at cos γ ,angle between 2 nucleons

from JLAB experiment



cos γ distribution



event totals past 2-N cuts

event type	events/10ton/6E20
2-nucleon signal	4119
CCQE 1-nucleon background	65
QElike background	1320
total background	1384

- Resulting, signal/background ~ 3...

- a sensitive search for this process

- and an important experimental constraint.

NC photon production

- MiniBooNE low-energy excess has spurred work on a possible background: NCγ production
- important background for ν_e appearance searches
- eg: R. Hill, Phys. Rev. D 81, 013008 (2010) and e-Print: arXiv:1002.4215 [hep-ph]

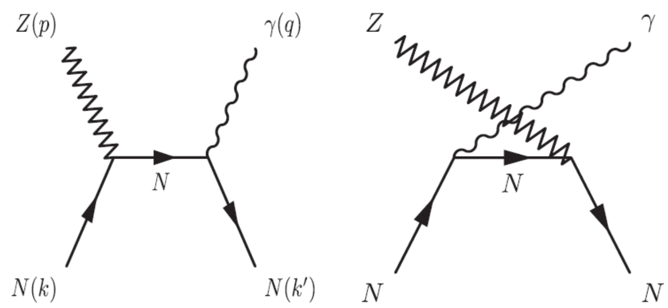


FIG. 1. Generalized Compton scattering.

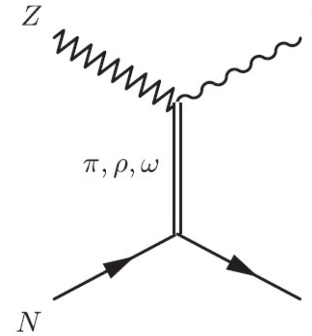


FIG. 2. Meson-exchange contribution to $Z^*N \to \gamma N$.

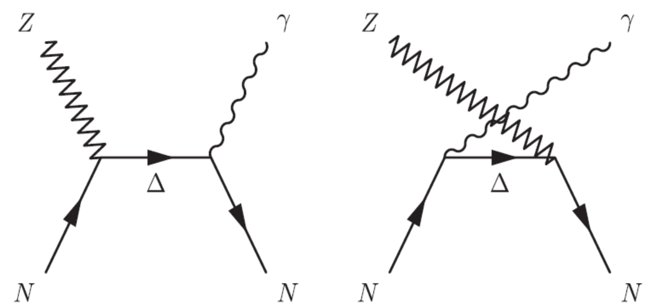


FIG. 3. Production of photons through the Δ resonance.

TABLE I: Single photon and other backgrounds for MiniBooNE ν-mode in ranges of $E_{\rm QE}$. Ranges in square brackets are the result of applying a $20-30\%$ efficiency correction.

process	200-300	300-475	475-1250
1γ, non-Δ	$85[17-26]$	$151[30, 45]$	$159[32, 48]$
$\Delta \to N\gamma$	$170[34-51]$	$394[79-118]$	$285[57-86]$
$\nu_\mu e \to \nu_\mu e$	$14[2.7-4.1]$	$20[4.0-5.9]$	$40[7.9-12]$
$\nu_e n \to ep$	$100[20-30]$	$303[61-91]$	$1392[278-418]$
MB excess	45.2 ± 26.0	83.7 ± 24.5	22.1 ± 35.7
MB $\Delta \to N\gamma$	19.5	47.5	19.4
MB $\nu_\mu e \to \nu_\mu e$	6.1	4.3	6.4
MB $\nu_e n \to ep$	19	62	249

NC photon production

- more and recent work on this:

"Weak Pion and Photon Production off Nucleons in a Chiral Effective Field Theory", B. Serot, X. Zhang, arXiv:1011.5913 [nucl-th]

- related to and constrained by π production
- antineutrino predictions also

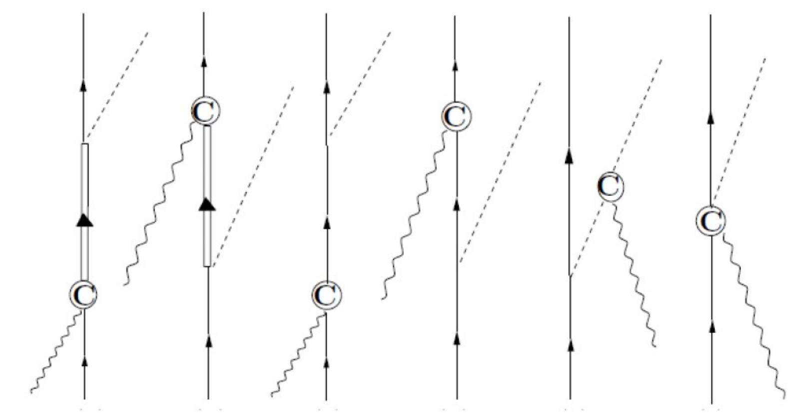


Fig.1: Feymann diagrams for pion production. Change the outgoing pion line to photon line for photon production. C indicates both vector and axial vector currents.

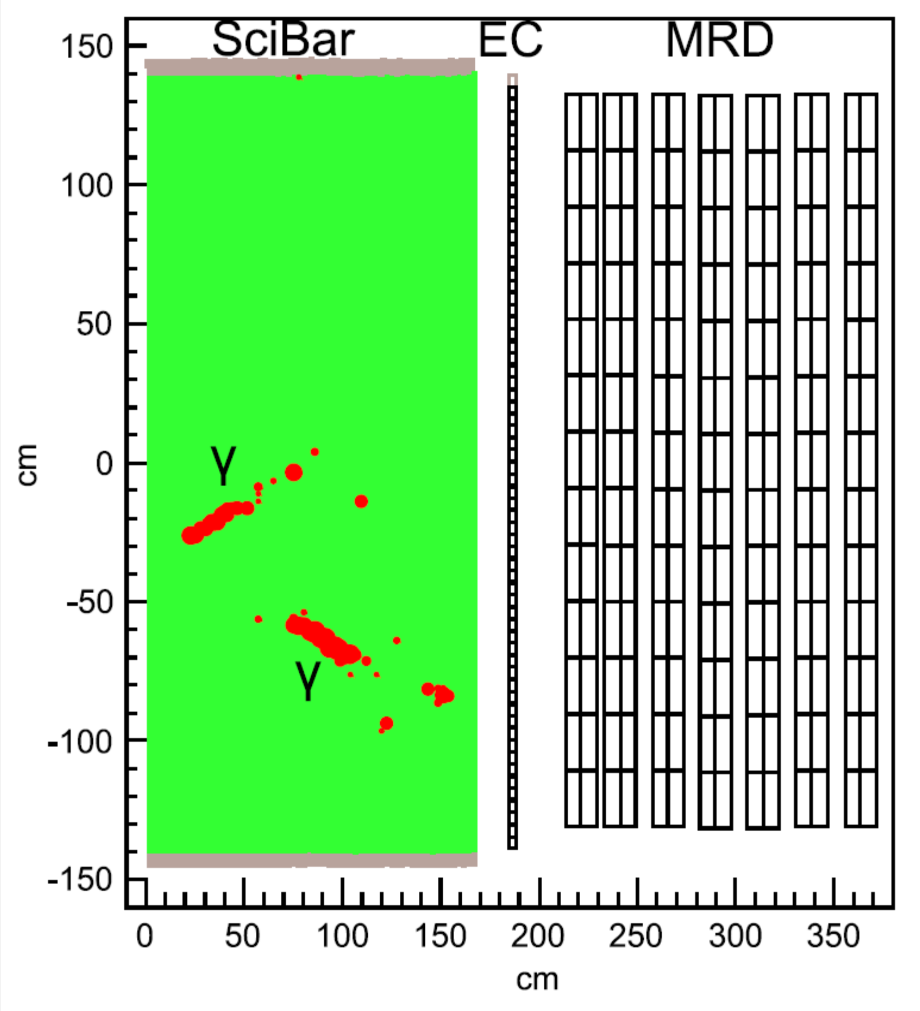
E_{QE}(GeV)	[0.2 , 0.3]	[0.3 , 0.475]	[0.475 , 1.25]
coh	3.1	10.37	5.59
incoh	$6 \times (1.01 + 1.01)$	$6 \times (3.64 + 3.62)$	$6 \times (2.90 + 2.88)$
total	15.22	53.93	40.27
MiniBN	19.5	47.5	19.4

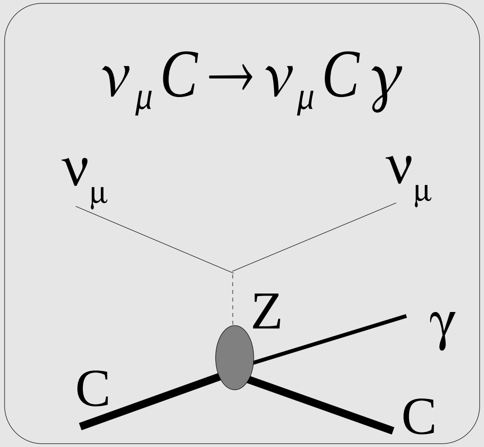
Tab.1: NC photon production event's EQE distribution in MiniBooNE for neutrino scattering.

Measuring NC photon production

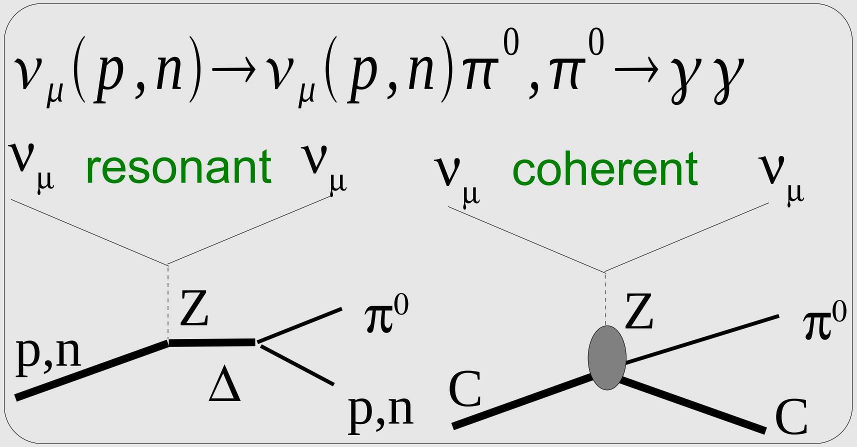
- a measurement is accessible in SciNOvA
(along with important NC π^0 channel)

NCπ^0 event in scibar/SciBooNE





NC γ production



NCπ^0 production

Measuring NC photon production

- SciNOvA event rates
- ~ equal to full MiniBooNE neutrino sample (but in 10 tons).
- NCγ cross sections are calculated to be O(10^{-3}) that of CCQE (from Hill or Serot/Zhang)
- resulting in sample of O(100) events in MB (same as 0.1% oscillations)
- SciNOvA will collect O(100) events of this type if calculations are correct
- photon recon down to ~100MeV and comparison with NCπ^0 channel allows a measurement of NCγ
- together with NCπ^0 channel will lend crucial info to ν_e appearance search (NOvA and others)

SciNOvA ν kevent/yr (6E20POT) in 10 ton fiducial vol

	Charged-current	Neutral-current
elastic	220	86
resonant	327	115
DIS	289	96
coherent	8	5
total	845	302
$\nu + A \rightarrow \pi^0 + X$	204	106

photon energy in NCπ^0 event in scibar/SciBooNE

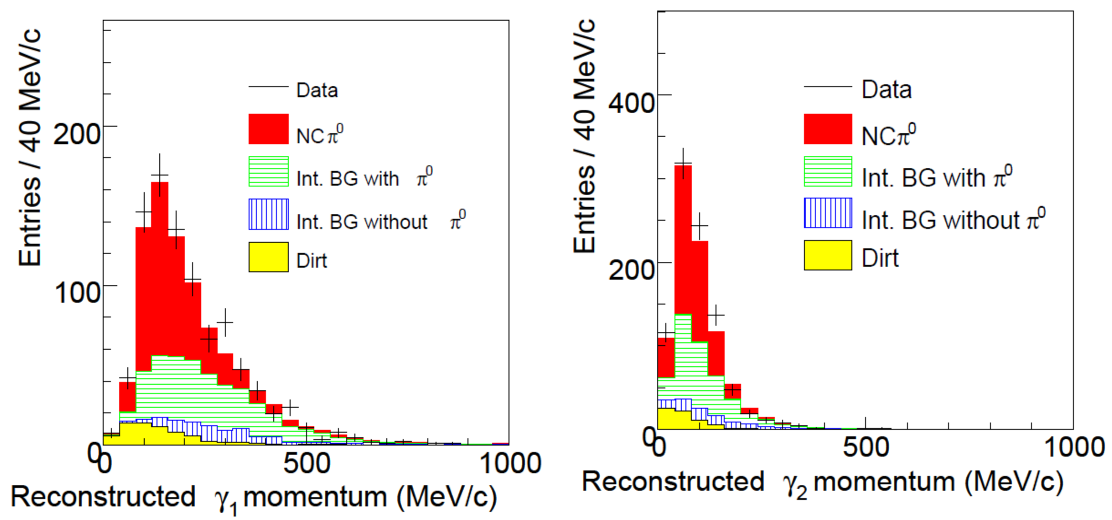


Figure 6.4: $E^{rec}_{\gamma 1}$ and $E^{rec}_{\gamma 2}$ before the π^0 mass cut ($E^{rec}_{\gamma 1} > E^{rec}_{\gamma 2}$)

More neutrino scattering channels

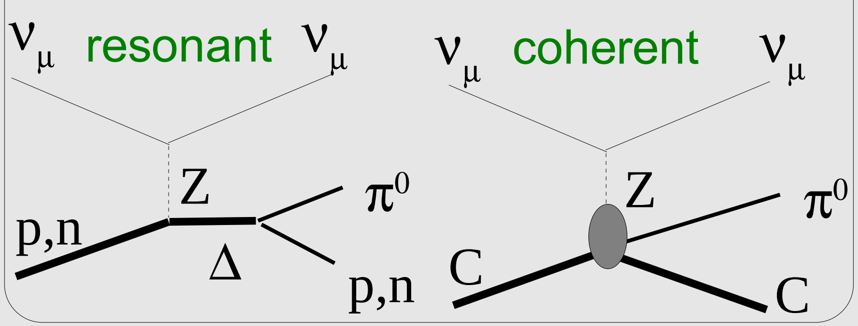
Other neutrino scattering channels to be measured with SciNOvA:

- ν_μ NC production of neutral pions
  - very important oscillation background
  - sizeable coherent production?
  - narrow band beam offers lower background from higher energies

- ν_μ neutral-current (NC) elastic (NCel)
  - important complementary channel to CCQE
  - extra contributions to axial form factor from strange quarks?

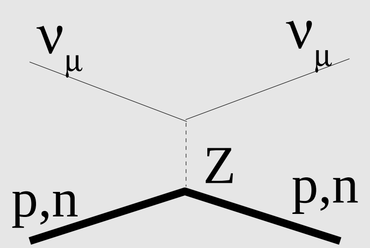
- ν_μ CC production of π^+, π^0
  - insight into models of neutrino pion production via nucleon resonances

$$\nu_\mu(p,n)\rightarrow\nu_\mu(p,n)\pi^0,\pi^0\rightarrow\gamma\gamma$$



NCπ^0 production

$$\nu_\mu(p,n)\rightarrow\nu_\mu(p,n)$$



NC elastic

Application to NOvA

NOvA will conduct ν_e and $\bar{\nu}_e$ appearance search to probe θ_{13}, mass hierarchy, CP phase δ

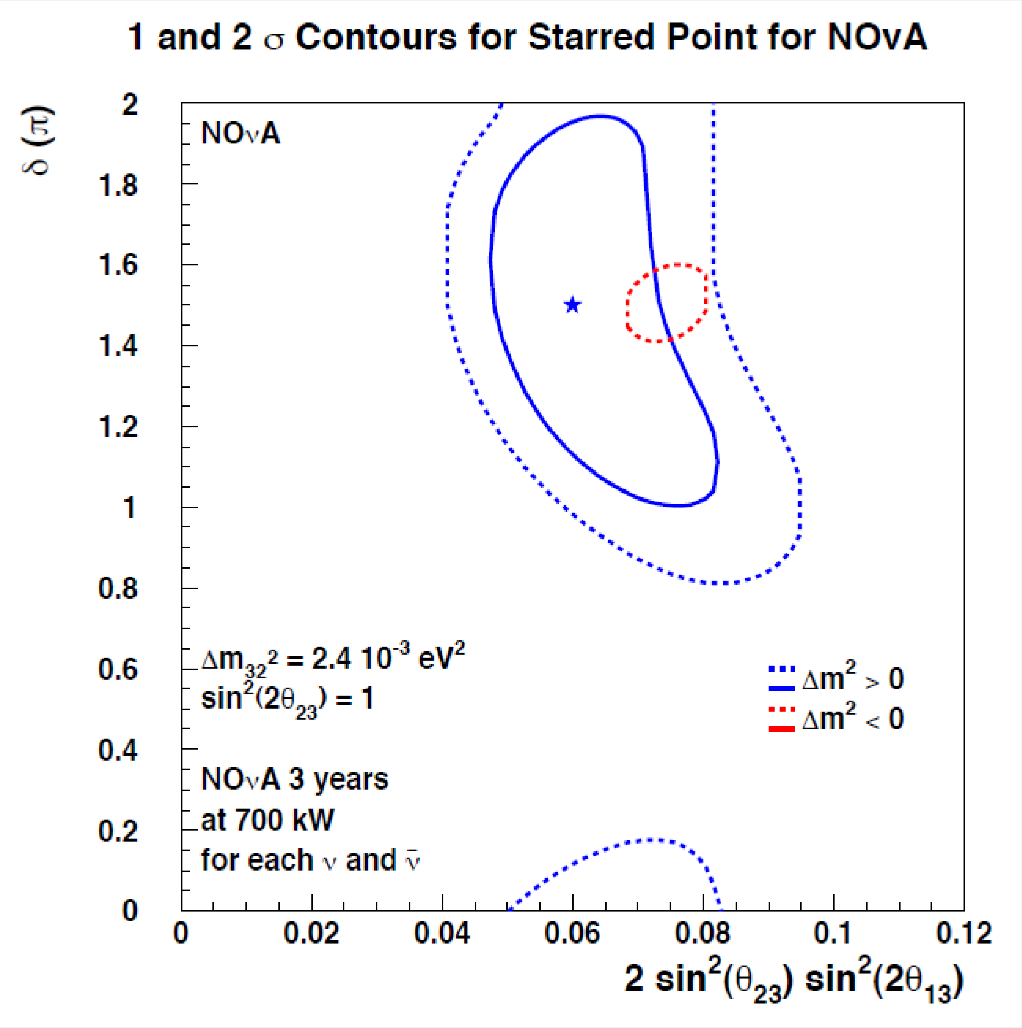
- Among most important questions in neutrino and particle physics today and central in FNAL intensity-frontier program.

- $\sin^2\theta_{13}$ sensitivity down to 0.01 at 90% CL

- with estimated ν_e efficiency ~35% and NC, ν_μ CC background mis-ID probabilities ~ 0.4%, 0.1%

- Any additional tests of these numbers will be extremely valuable for NOvA

- The fine-grained SciNOvA detector can provide this.



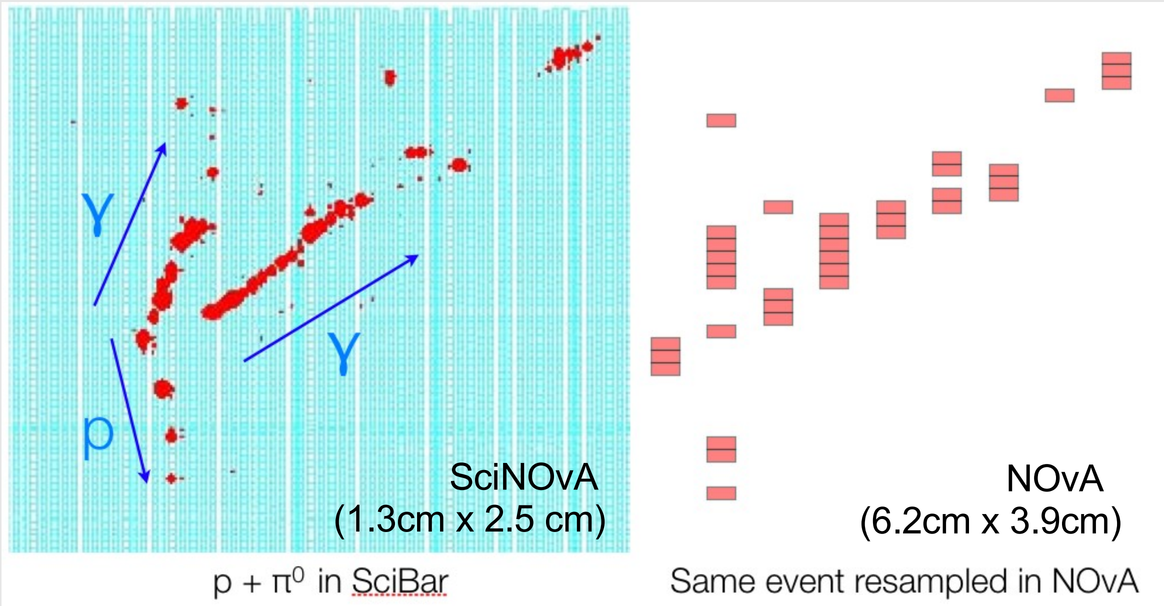
Application to NOvA

- A double-scan method comparing SciNOvA and NOvA-near can provide signal efficiency and background misID probabilities.

- ala bubble chamber double-scans to measure scanner efficiencies

Method:
- Classify events labeled as signal/bckgd in SciNOvA compared to those resampled with larger pixel size (as NOvA) Nss, Nsb, Nbs, Nbb

- can then determine NOvA efficiency, ε_N and NOvA, SciNOvA misID probabilities: γ_N, γ_{SN}



- results in a <3% (relative error) cross check of ε_N , γ_N, γ_{SN} at 3σ.

- a sensitive cross check!

test case simulated event totals in 1-yr SciNOvA running

	N_{ss}	N_{sb}	N_{bs}	N_{bb}	χ^2
Nominal	15500	50300	66600	10867600	-
γ_N higher by 10%	-	-	+4300	-4300	279
γ_N and γ_{SB} higher by 10%	-	+2200	+4300	-6500	371
B higher by 10%	-1500	-2800	-2300	+6600	403

Conclusions

- The addition of the SciNOvA detector to the NOvA near detector in the narrow-band beam would increase the NOvA physics program substantially for modest investment.

- This will allow:
    - new insight into neutrino scattering, particularly follow-up on the interesting and unexplained MiniBooNE neutrino cross section results.
    - important cross checks of backgrounds for the flagship NOvA ν oscillation program.