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

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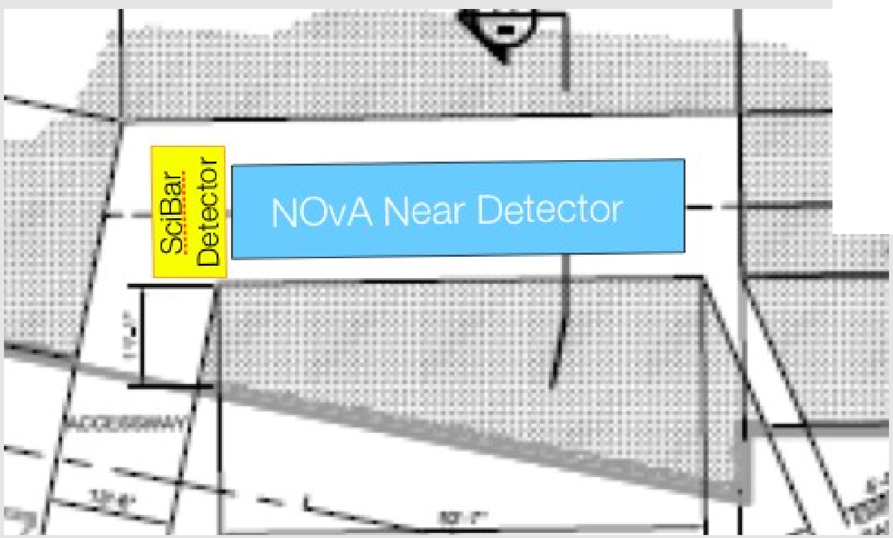
Outline:
- overview/updates
- science case:
  - ν scattering physics
  - NOvA oscillations
- experiment
- cost/schedule
- summary/requests



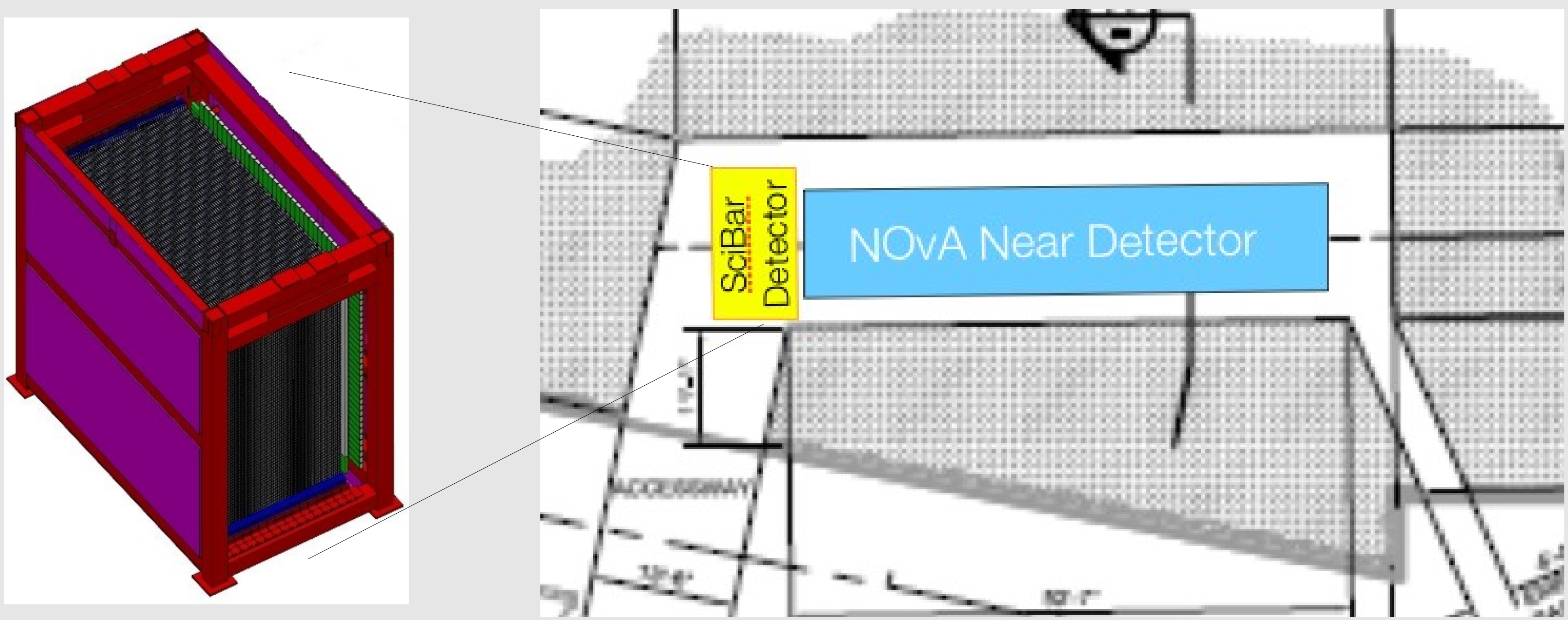
R. Tayloe,
FNAL PAC Meeting
11/10

SciNOvA: Overview

We propose to construct a new SciBar detector using an existing and proven design and deploy 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:

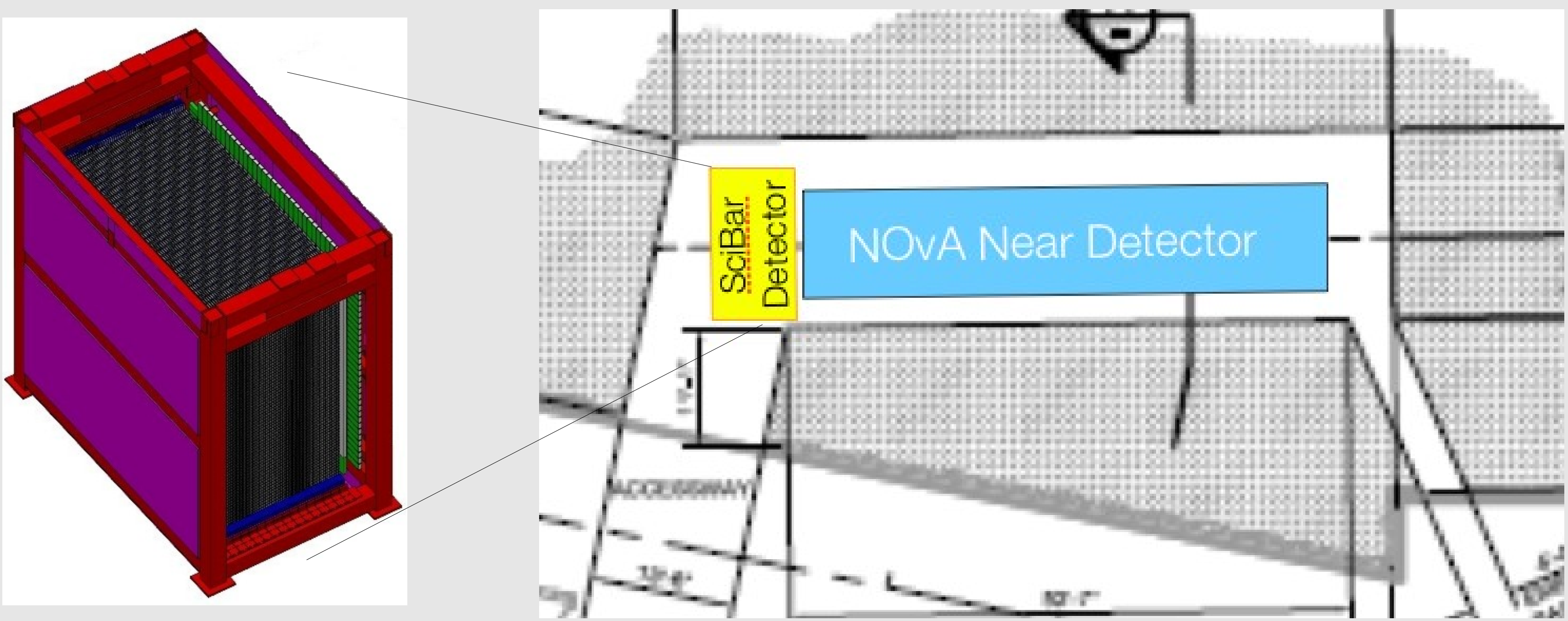
- important and unique ν scattering measurements including
  - a test of recent MiniBooNE results indicating anomalously large cross section in charged-current quasielastic scattering using a different ν source at slightly higher E_ν
  - Neutral-current differential cross sections, in particular $NC\pi^0$, crucial for ν_e appearance
- significant cross checks of NOvA ν oscillation backgrounds



SciNOvA: Overview

SciNOvA offers a large increase in NOvA physics capability with modest investment of labor, engineering, and money .

- no modifications to the planned NOvA near cavern required,
- only modest changes to the NOvA near detector structure needed, and
- it fits down the NUMI access shaft
- total project cost estimate: $2.4M



SciNOvA: Questions/issues from last PAC meeting...

3 questions/issues from 11/09 meeting:

> *The Committee was intrigued by this Expression of Interest to move and reinstrument the SciBar detector in front of the NOvA Near Detector in the NuMI hall. The Committee recommends that the proponents clarify and expand on the following two issues: (1) What is the complementarity and synergy with the MINERvA experiment on cross section measurement; and (2) In more detail, how does this detector help the NOvA experiment understand its off-axis neutrino beam? The Committee also recommends that the proponents confirm the availability of the SciBar detector in the near future.*

0) Availability of existing SciBar detector?

1) Complementarity to MINERvA cross section measurements?

2) Understanding of the NOvA off-axis beam?

SciNOvA: Questions/issues from last PAC meeting...

0) Availability of existing SciBar detector?

- Not available. Owned by Kyoto U. and will be used for solar particle detector in Mexico

- Effort has been funded, confirmed in ongoing discussions with Y. Itow

- To be disassembled from FNAL location starting in March

- However, cost estimate from Ana Pla-Dalmau of FNAL-SDD, shows new SciBar with same extrusions as original is ~25% of total project cost, so we have proceeded with project assuming a new SciBar.

Proposal to use the SciBar detector as a solar energetic particle detector at a high altitude mountain in Mexico

The SciCR Collaboration

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(Solar-Terrestrial Environment Laboratory, Nagoya University, Japan)

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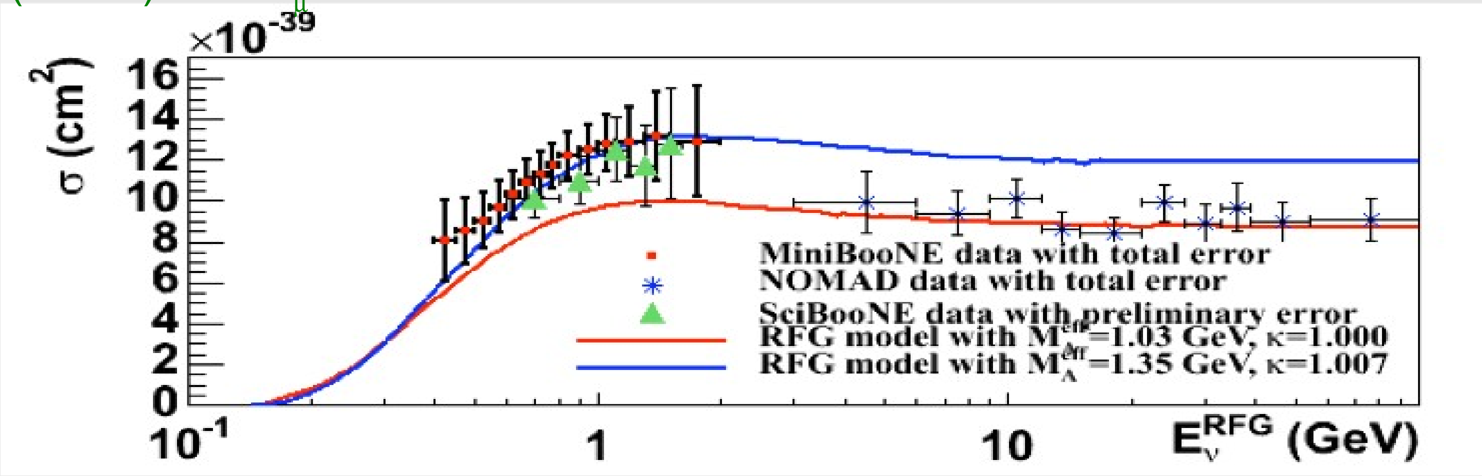
Jose Valdés-Galicia
(Instityto de Geofísica, Universidad Nacional Autóma de México, Mexico)

SciNOvA: Questions/issues from last PAC meeting...

1) Complementarity to MINERvA cross section measurements?

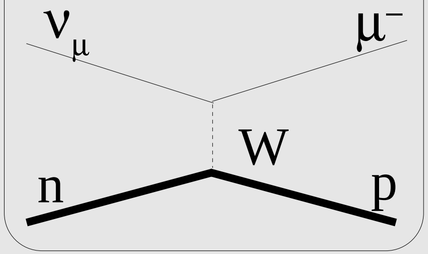
(recent) total ν_μ CCQE cross section measurments



- MiniBooNE has extracted total cross section for CCQE* for E_ν ~ 0.5-1.5 GeV. Data are 30% larger than predicted with ~10% error. To test, need cross section measurement near this energy with comparable errors.

ν_μ CCQE

$$\nu_\mu n \rightarrow \mu^- p$$

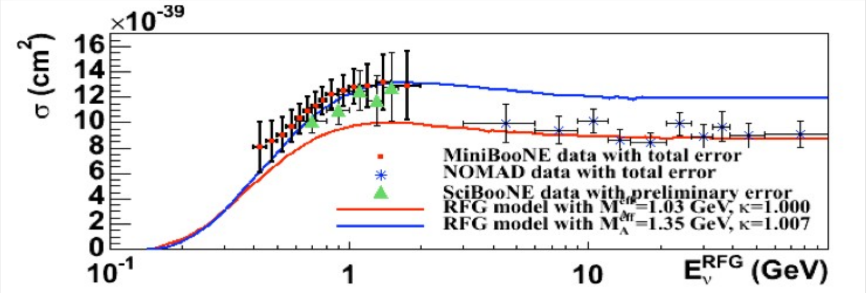


* "CCQE": ν_μ charged-current quasielastic process

SciNOvA: Questions/issues from last PAC meeting...

1) Complementarity to MINERvA? (cont)

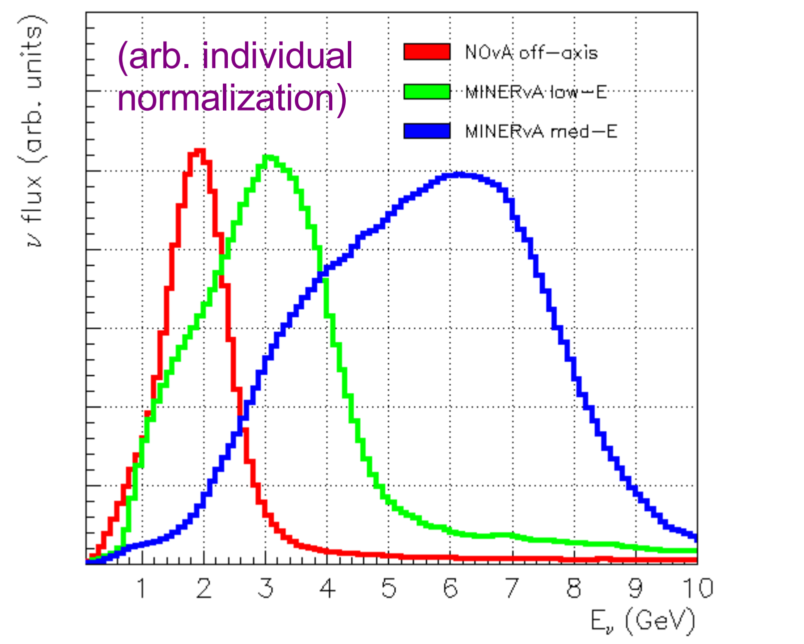
- Need the narrow-band low-energy NOvA beam. The precision of NUMI on-axis results at 1-2 GeV will not be sufficient to test the MiniBooNE results because of background channel "feed down" from higher energy.



Estimated errors for CCQE cross section measurements at E_ν ~2 GeV in NUMI:

NUMI flux config	total cross section estimated error (%)
14mrad off-axis (SciNOvA)	12
on-axis, low-energy (MINERvA)	23
on-axis, medium-energy (MINERvA)	35

NUMI ν fluxes



- more details offered on later slides

Enu (GeV)

SciNOvA: Questions/issues from last PAC meeting...

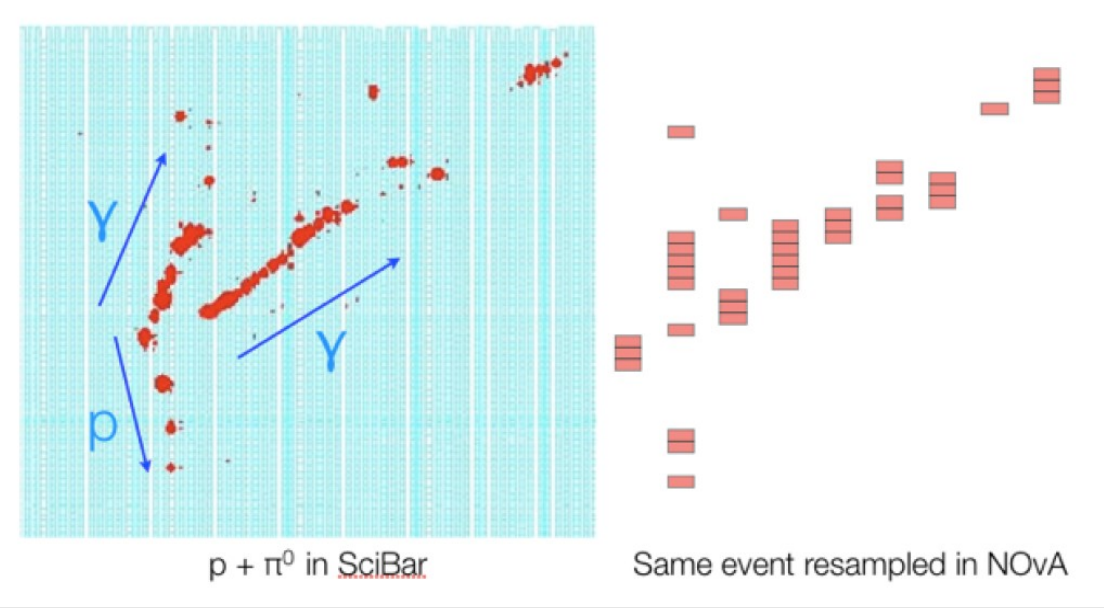
2) Understanding of the NOvA off-axis beam?

- Crucial to have cross checks to background calculations for oscillation search, esp. for small ν_e appearance signal

- A finer-grained SciNOvA detector will provide this for NC and CC backgrounds via a comparison of ID'd events in SciNOvA (1.3cm x 2.5 cm cells) with the NOvA near detector (6.2cm x 3.9cm).

- Utilizing a double scan technique of events in SciNOvA compared to resampled events in NOvA-near, results in a <3% relative cross check of NCπ^0 event efficiencies and mis-ID probability at 3σ sensitivity.

- more details offered on later slides



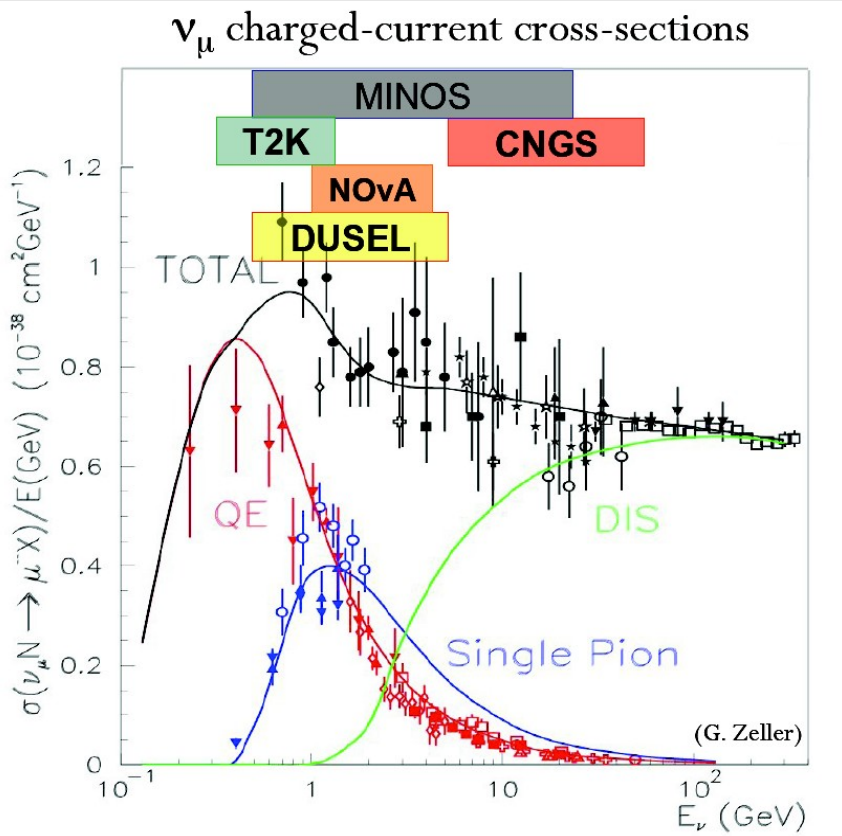
Science case: neutrino scattering measurements

In order to understand ν oscillations, it is crucial to understand the detailed physics of ν scattering (at 1-10 GeV)

- for NOvA as well as other experiments: MiniBooNE, T2K, DUSEL)
- especially for *precision* (e.g. 1%) measurements.

before MiniBooNE ~2000

Requires: Precise measurements to enable a complete theory valid over wide range of variables (reaction channel, energy, final state kinematics, nucleus, etc)



D. Schmitz, nufact'09

A significant challenge with neutrino experiments:

- non-monoenergetic beams
- large backgrounds
- nuclear scattering (bound nucleons)

SciNOvA, with narrow-band, 2 GeV, ν and $\bar{\nu}$ beams, would be ideally suited to contribute significantly.

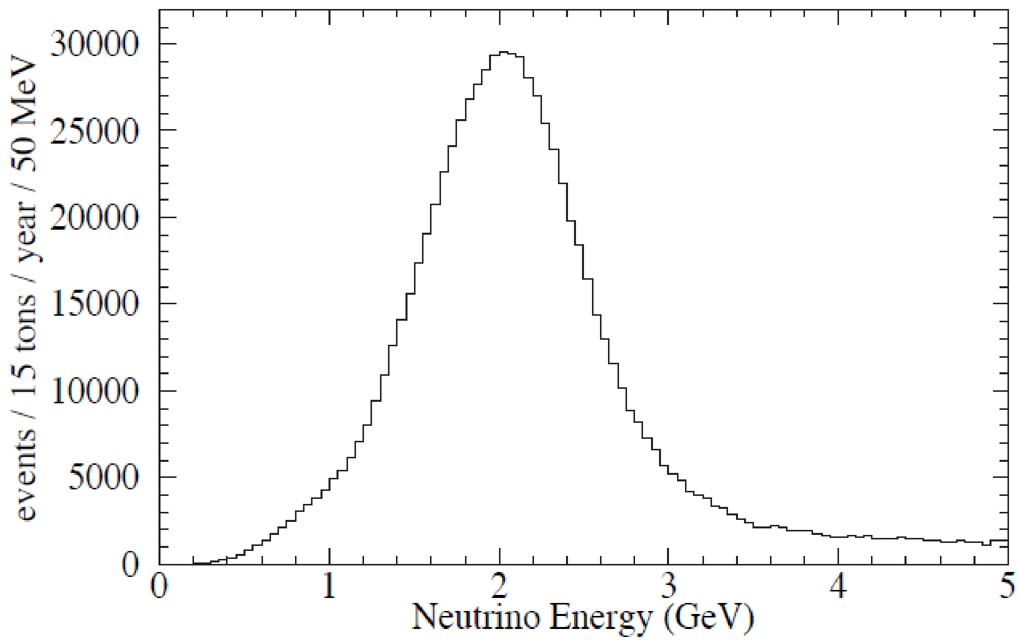
Science case: neutrino scattering measurements

Event rates are substantial in SciNOvA allowing excellent statistical precision.

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



Science case: CCQE scattering

In last year, MiniBooNE has finalized results on several ν_μ scattering channels:

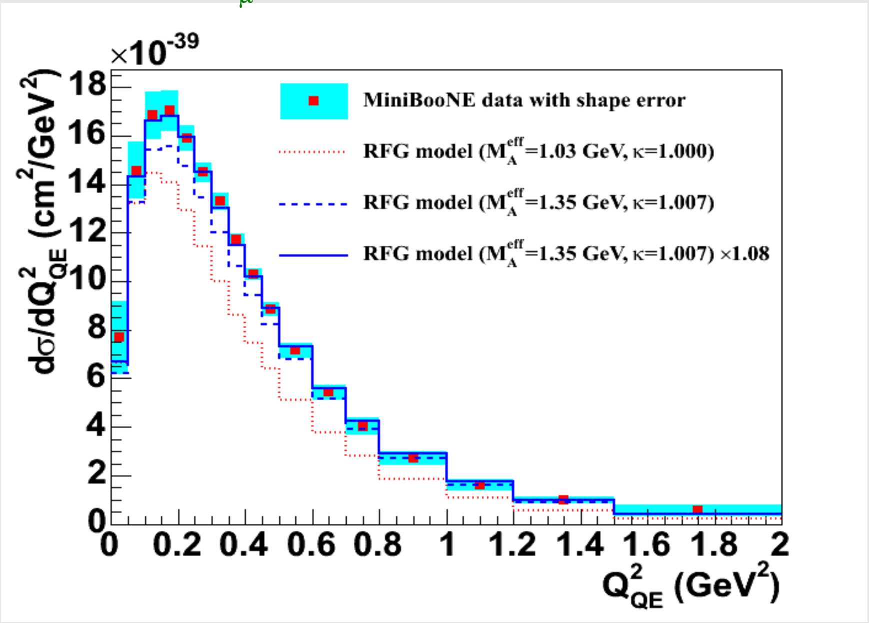
- CCQE, NC elastic (pub'd)
- $CC\pi^+$, $CC\pi^0$ (papers in prep)

A theme has continued to emerge. MiniBooNE measures flux-averaged cross sections that are O(30%) larger than state-of-art neutrino generator (with fermi-gas impulse approximation) predictions

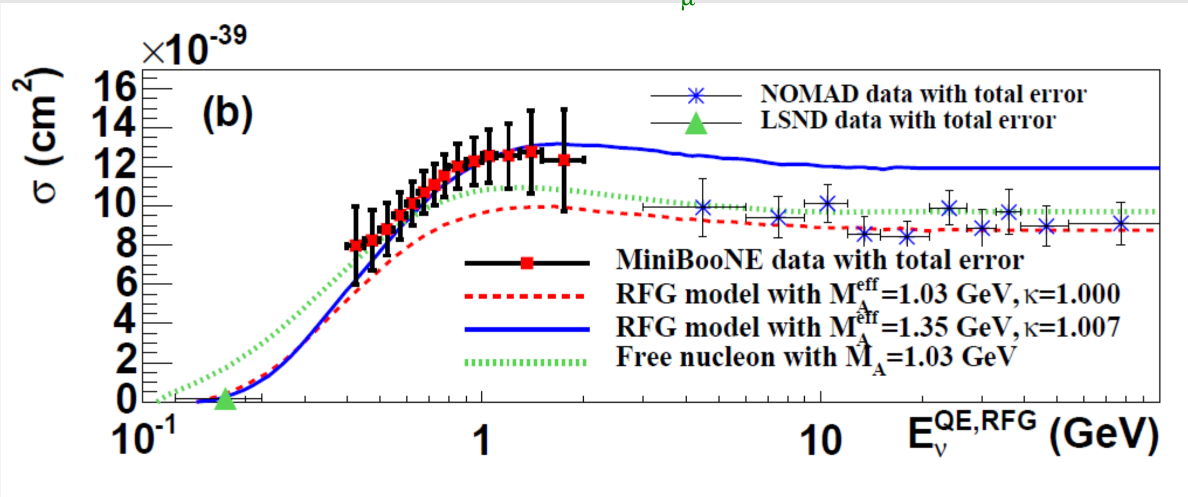
In particular, for the CCQE process.

This observation needs to be understood with additional measurements.

MiniBooNE ν_μ CCQE differential cross section



MiniBooNE ν_μ CCQE total cross section



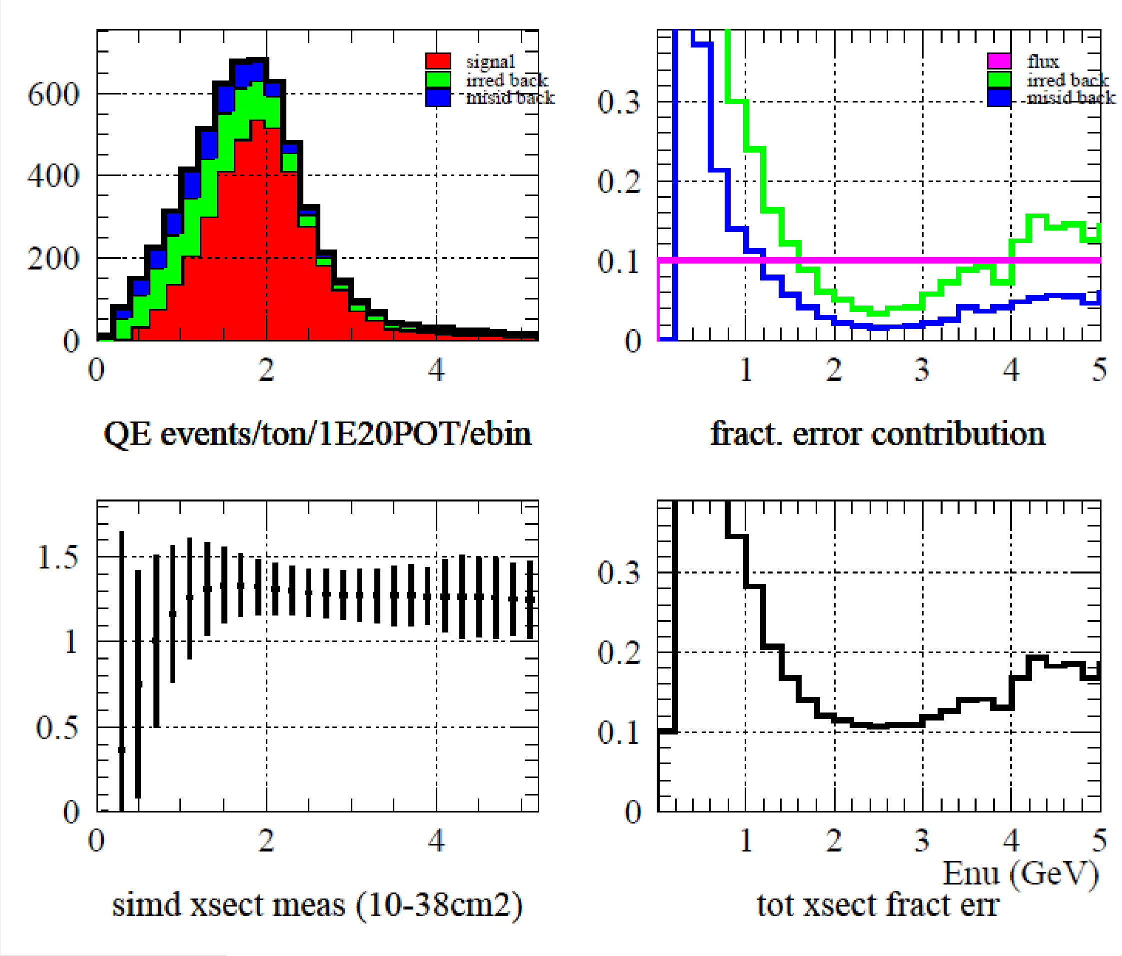
Science case: CCQE scattering

Estimated errors on SciNOvA CCQE total cross section measurement

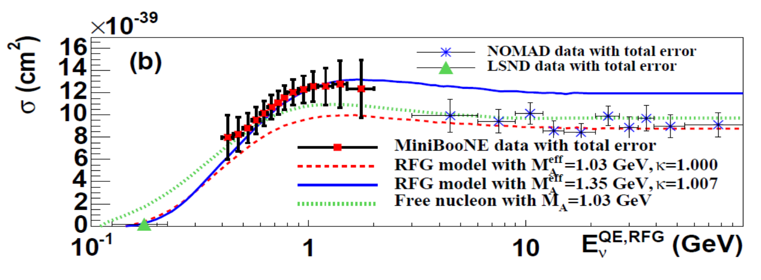
- estimated with bootstrapping from MiniBooNE error analysis
- checked by predicting actual MiniBooNE errors
- dominant background is CCπ feeddown from high "true" E_ν to lower recon'd E_ν due to lost pion (in detector medium or nucleus)

- 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

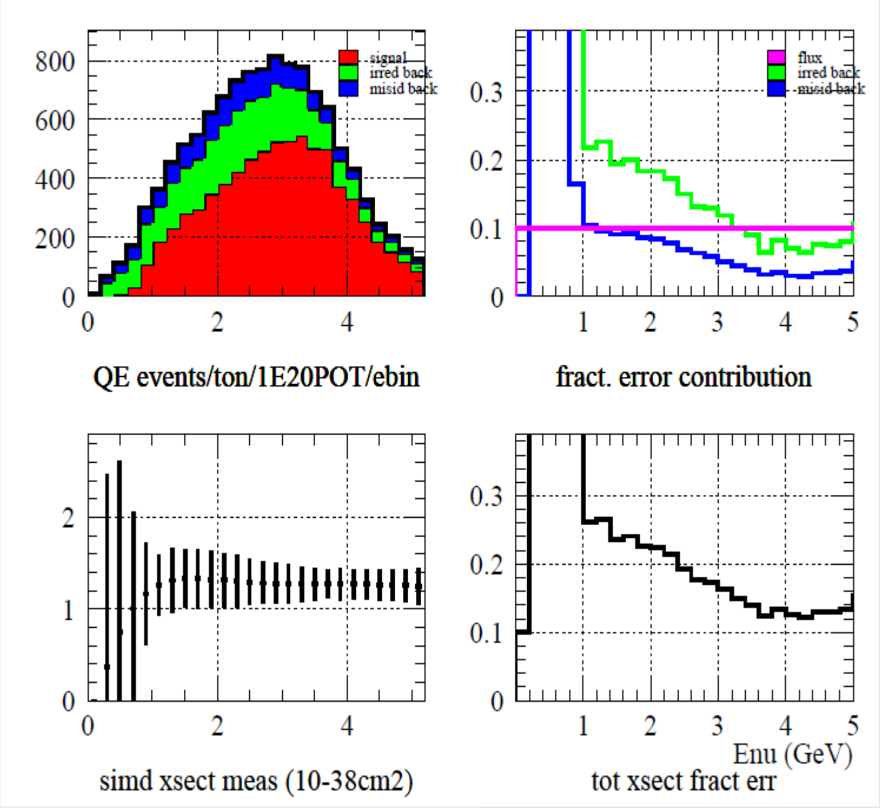


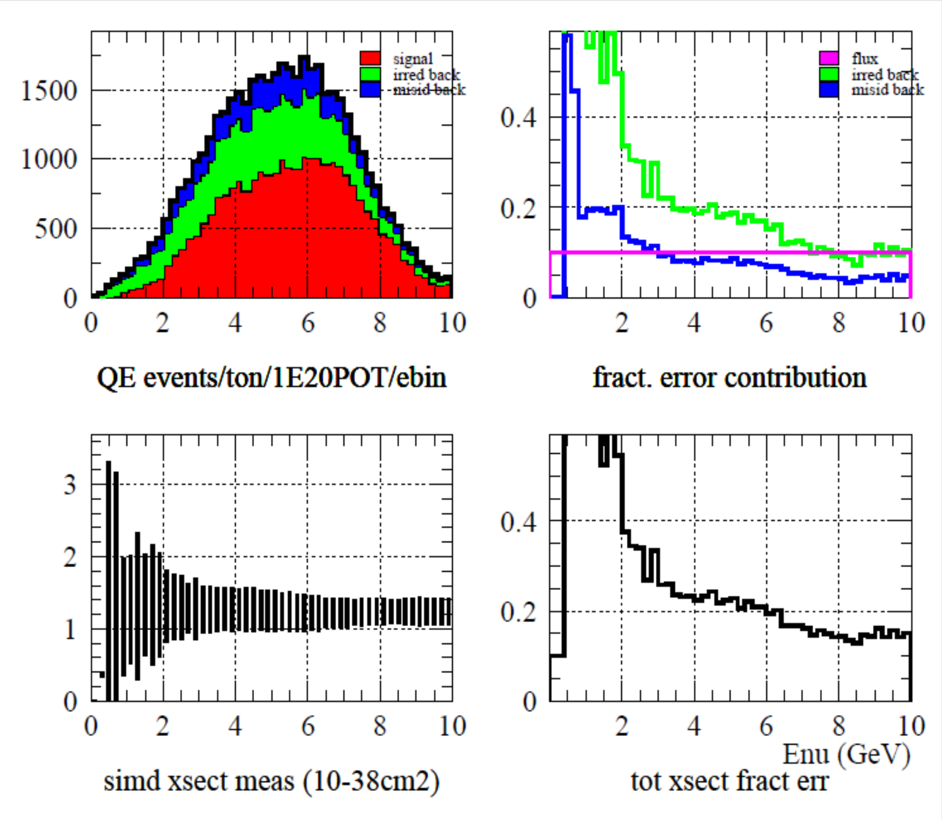
all plots as function of reconstructed E_ν (GeV)



Science case: CCQE scattering

Estimated errors on NUMI on-axis (low,med energy beam config) CCQE total cross section measurement, using same procedure:





all plots as function of reconstructed E_ν (GeV)

Estimated errors for CCQE cross section measurements at E_ν ~2 GeV in NUMI:

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14mrad off-axis (SciNOvA)	12
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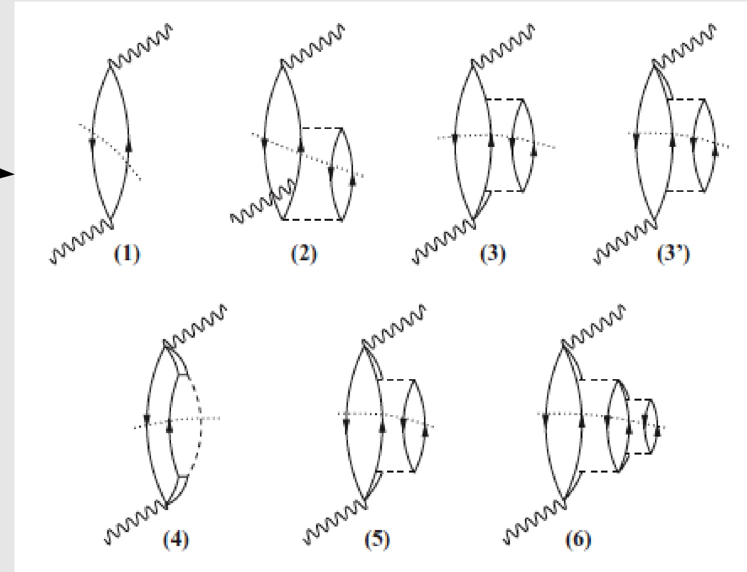
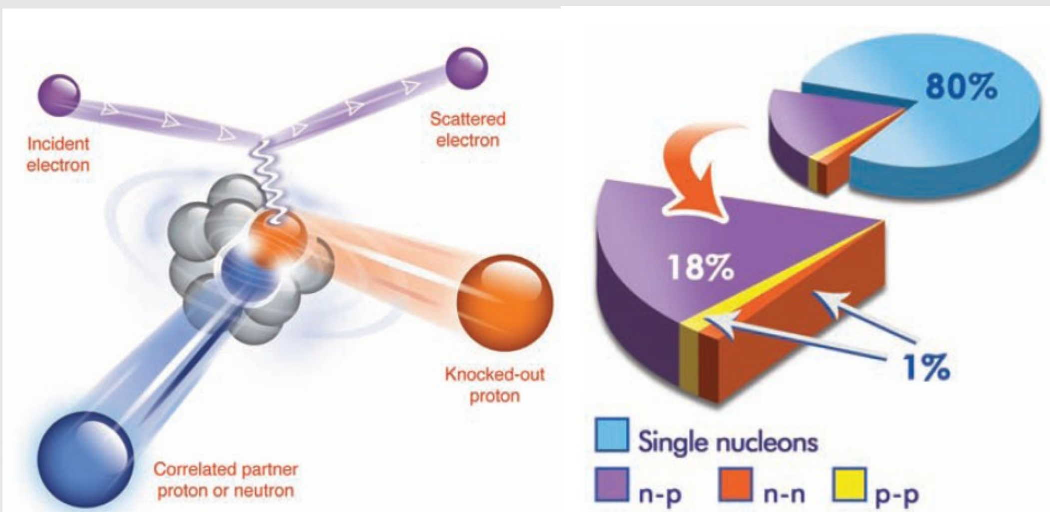
CCQE scattering and 2-nucleon correlations

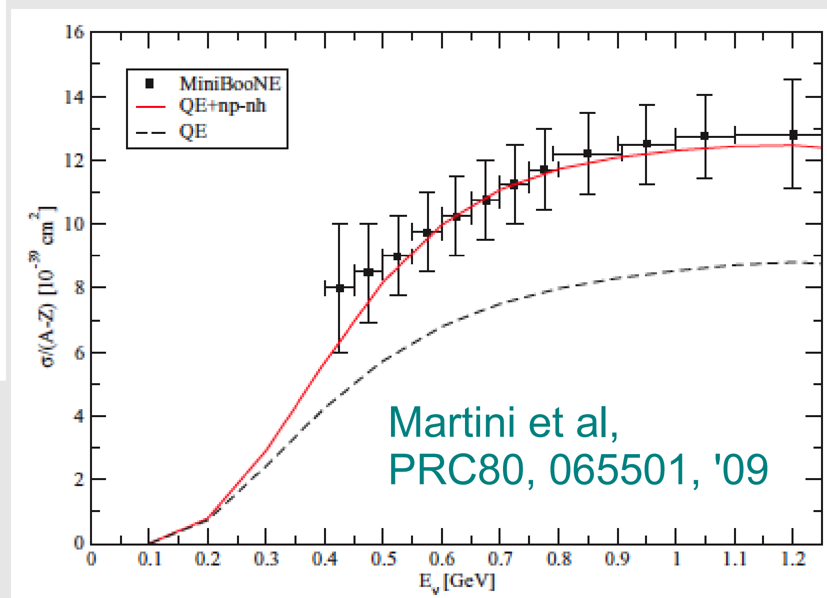
- perhaps the extra "strength" in CCQE is from multi-nucleon correlations within carbon (Martini et al PRC80, 065501, '09)
- related to neglected "transverse" response in noted in electron scattering? (Carlson etal, PRC65, 024002, '02)
- Expected with nucleon short range correlations (SRC) and 2-body exchange currents
- 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.

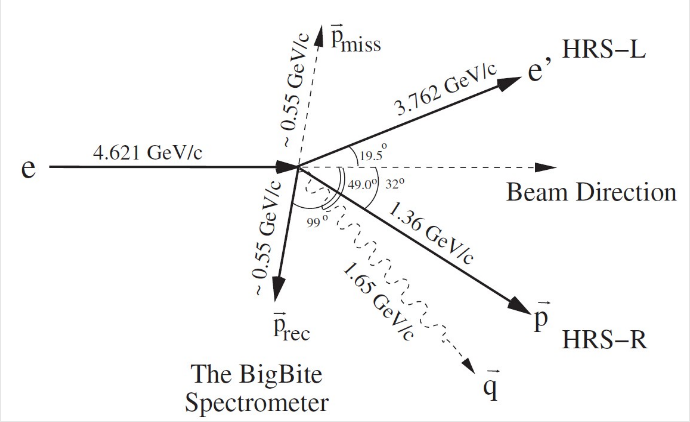
CCQE total cross section



measuring 2-nucleon correlations

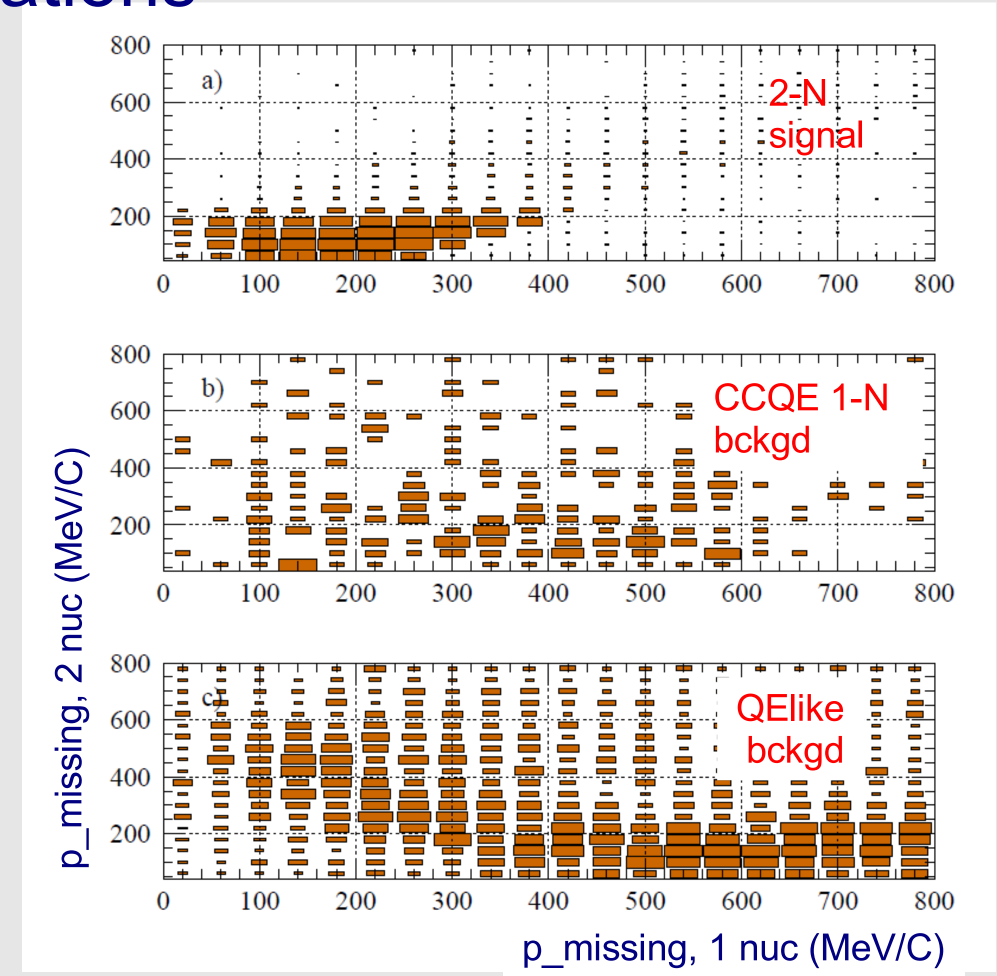
- A search for 2 nucleon correlations with SciNoVA is experimentally feasible and would provide the most direct test for MiniBooNE results.

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.

missing momentum plots

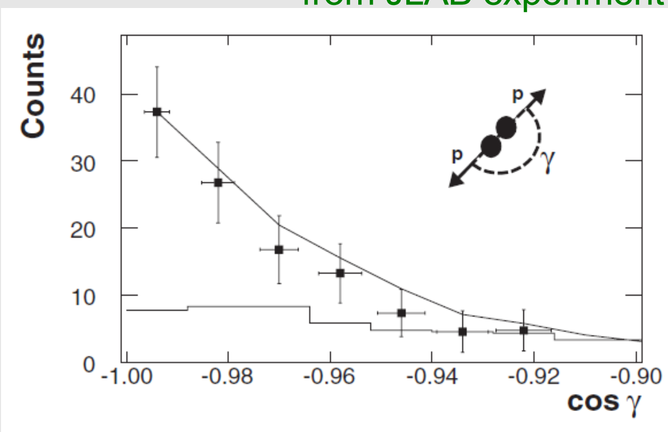


measuring 2-nucleon correlations

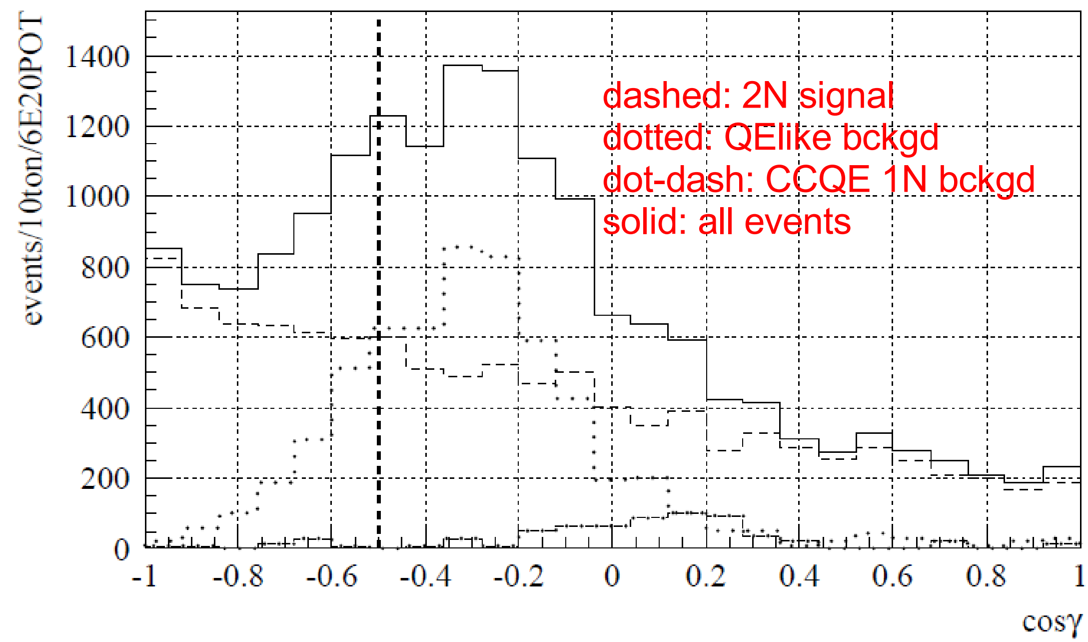
Experimental search with SciNOvA (continued)

- 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

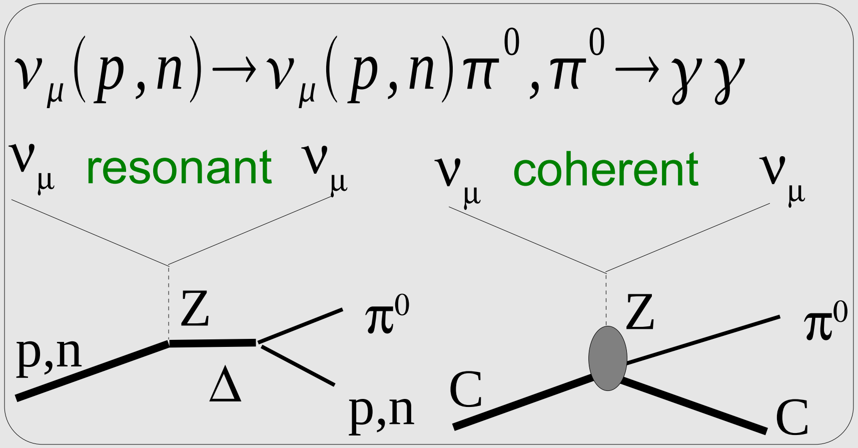
- Resulting, signal/background ~ 3...

a very sensitive search for this process.

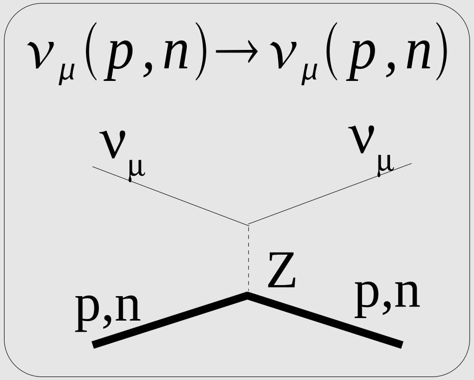
Science case: neutrino scattering measurements

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



NCπ^0 production



NC elastic

Science case: Application to NOvA

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

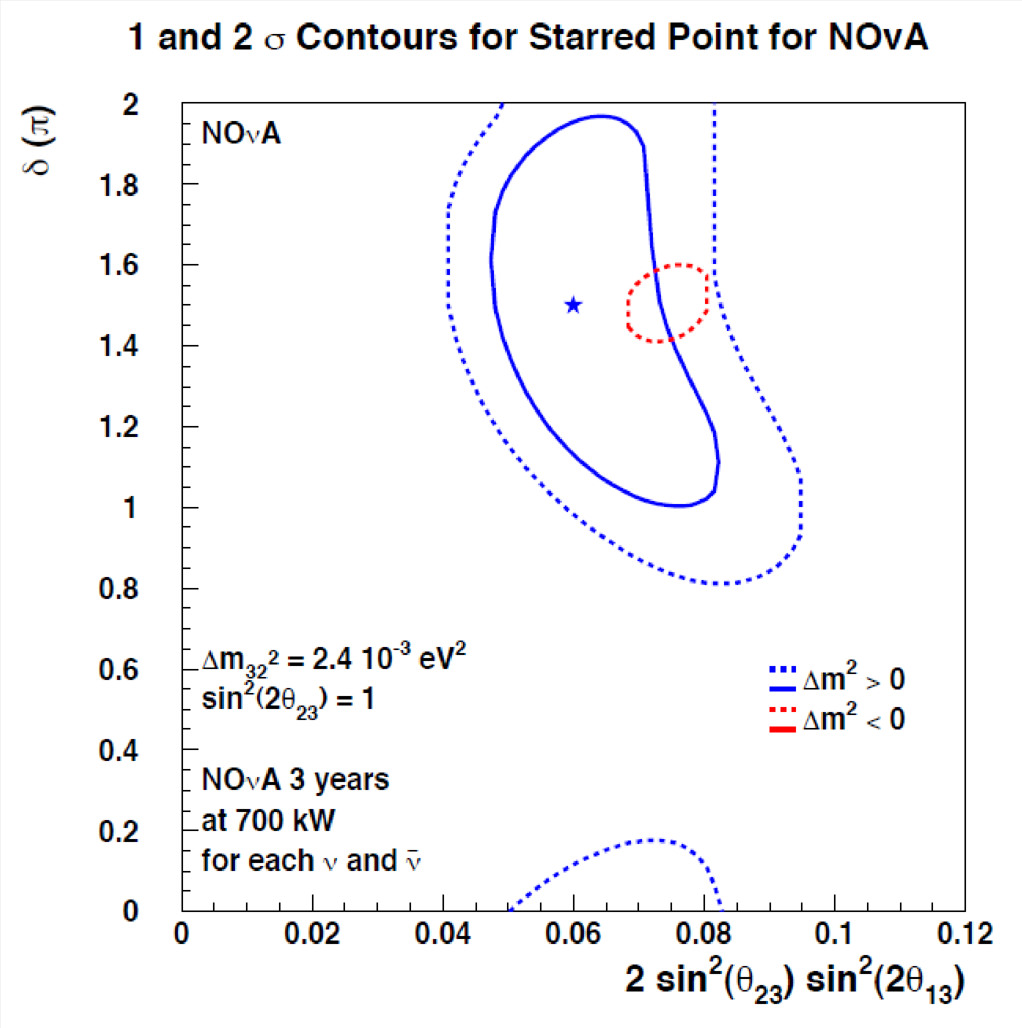
- Among most important questions in neutrino and particle physics today and central in FNAL intensity-frontier program.

- $\sin^2\theta_{13}$ 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.



Science case: Application to NOvA

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

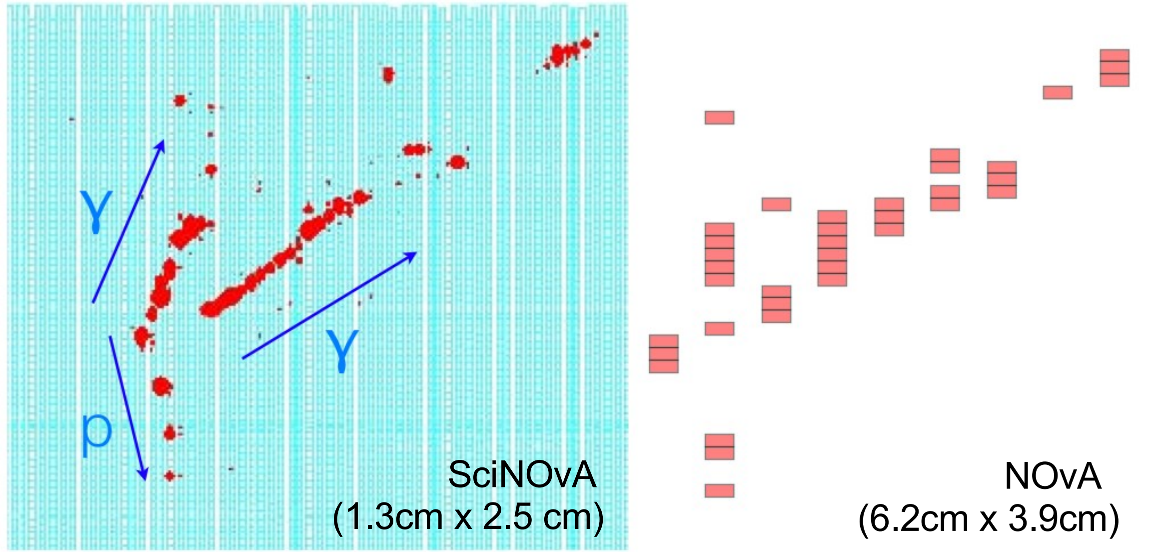
- ala bubble chamber double-scans to measure scanner efficiencies

- 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!



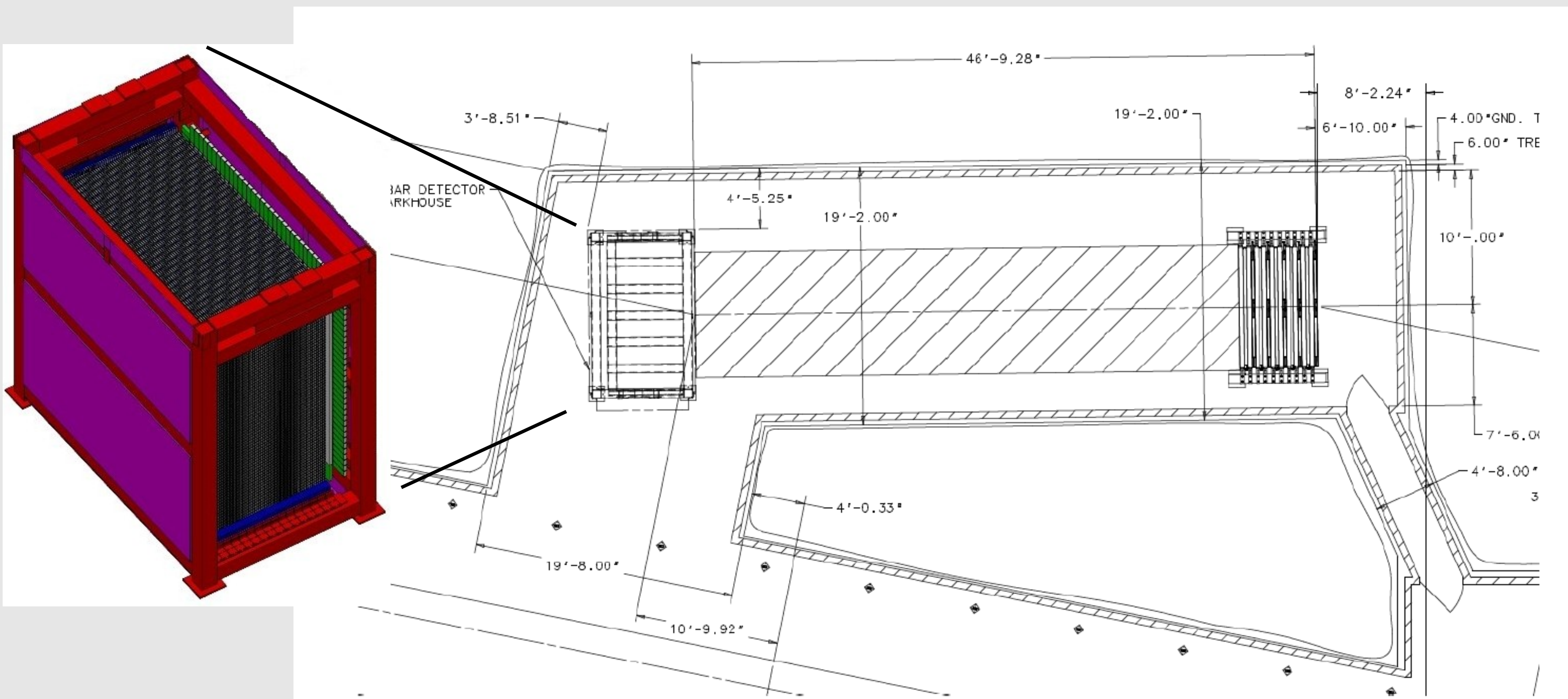
p + π[0] in SciBar   Same event resampled in NOvA

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

SciNOvA detector

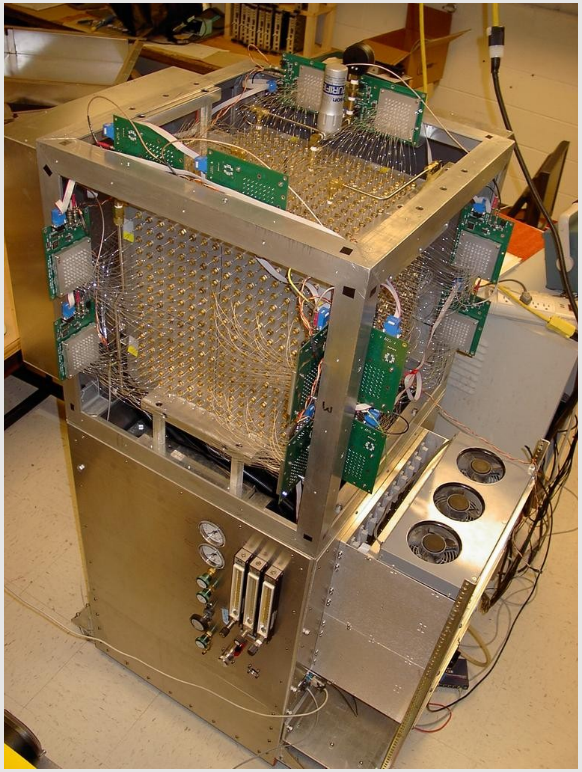
Requires:
- installation of 15k-channel solid scintillator SciBar detector in front of NOvA near detector
    - no cavern changes required, slight modifications to front detector support structure
    - utilize as much of SciBar support structure as cost-effective
- need to build/procure/manufacture:
    - (FNAL-made) scintillator extrusions (1.3cmx2.5cm), same design as existing SciBar
    - WLS fibers, PMT “cookies”
    - 64 anode PMTS
    - readout system, based on existing (and running) design (IU IRM modules)

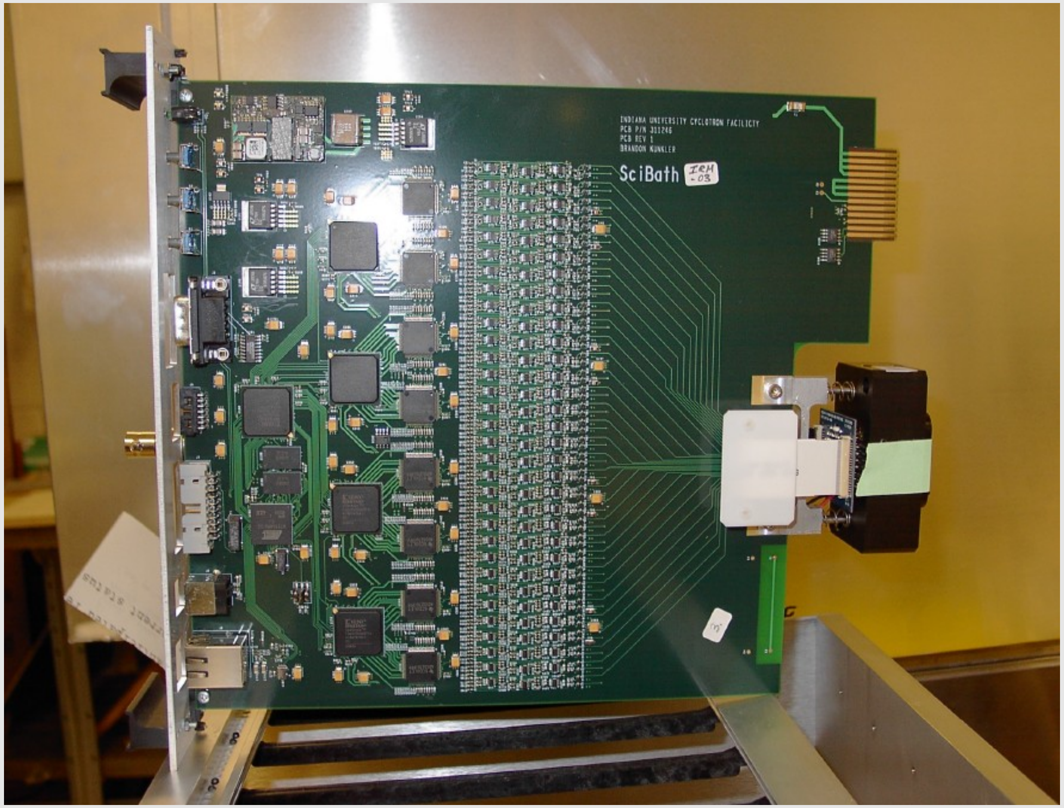


SciNOvA detector

- Proposed readout electronics:
  Integrated Readout Modules (IRMs) running now on "SciBath" detector at IU

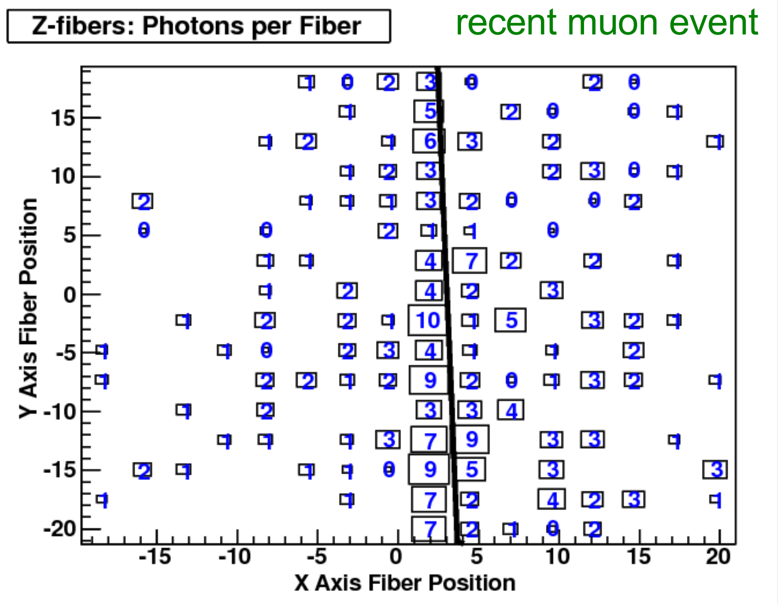
SciBath detector





IRM with attached PMT

recent muon event



SciNOvA: costs

Total project costs:

- FNAL costs:
  - those involved with scibar support structure, rigging, underground installation.
  - costs based on recent SciBooNE/SciBar experience

- scint extrusions costs estimate from A. Pla-Dalmau

- all labor, engineering, DAQ programming (excluding physicists) included

- Intend to seek outside funding for non-FNAL costs

- Total: $2.41M

SciNOvA project cost estimate

Item	costs ($)	totals($)	est FNAL costs ($)
scibar		**804818**	
extrusions: 15k 3m strips, 2.5cmx1.3cm	410218		
WLS fiber: 48km@$2/m	192000		
fiber/PMT cookie assemblies	25000		
fabricate new scibar cradle	120000		120000
HVAC system	8000		8000
material and fab for assembly, lifting jigs	24000		24000
labor: assembly rigging	25600		25600
IRMs		**1465770**	
assembled boards: 250	1106028		
clock board system	3380		
IRM power system	26212		
DAQ computer/enet hardware	40000		
elec design/testing/debug for IRMs	87900		
mechanical design for IRMs	58600		
final board assembly, repair	37400		
DAQ firmware, software	106250		
detector installation		**141800**	
engineering	51200		51200
rigging	25600		25600
material and fab for installation, lifting jig	30000		30000
misc underground infrastructure	35000		35000
project total		**2412389**	319400

SciNOvA: schedule

SciNOvA project schedule:

- assumed start in Fall '11, ready Aug '13 (23mos)
- SciBar extruded, assembled at FNAL
- readout board, PMT, fiber interface work at collaborating institutions and with vendors

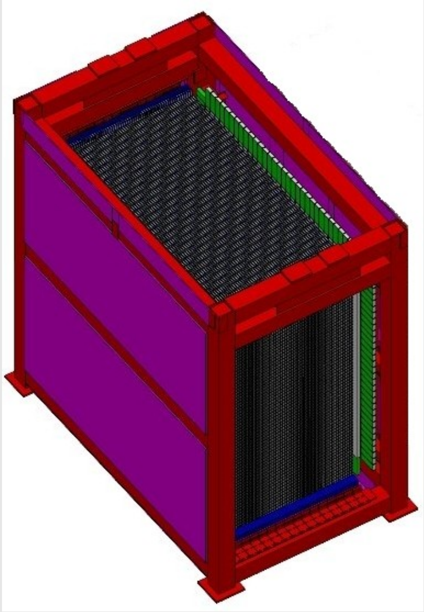
task	duration (days)	start	end
start of project	0	10/01/11	10/01/11
scibar	0	10/01/11	03/14/13
manufacture scintillator	200	10/01/11	04/18/12
fabricate cradle	120	10/01/11	01/29/12
assemble scibar	180	04/18/12	10/15/12
install in tunnel	60	01/13/13	03/14/13
IRM (readout boards)		10/01/11	04/23/13
update PCB design	100	10/01/11	01/09/12
PCB procurement/assembly	60	01/09/12	03/09/12
testing	60	02/08/12	04/08/12
IRM-PMT interface		10/01/11	01/29/12
design	60	10/01/11	11/30/11
manufacture	60	11/30/11	01/29/12
PMTs		10/01/11	05/28/12
procurement	180	10/01/11	03/29/12
testing	180	11/30/11	05/28/12
PMT module assembly	180	05/28/12	11/24/12
full module assembly	60	11/24/12	01/23/13
firmware/software development	360	10/01/11	09/25/12
install system in tunnel	90	01/23/13	04/23/13
commissioning	120	04/23/13	08/21/13
project ready	0	08/21/13	08/21/13

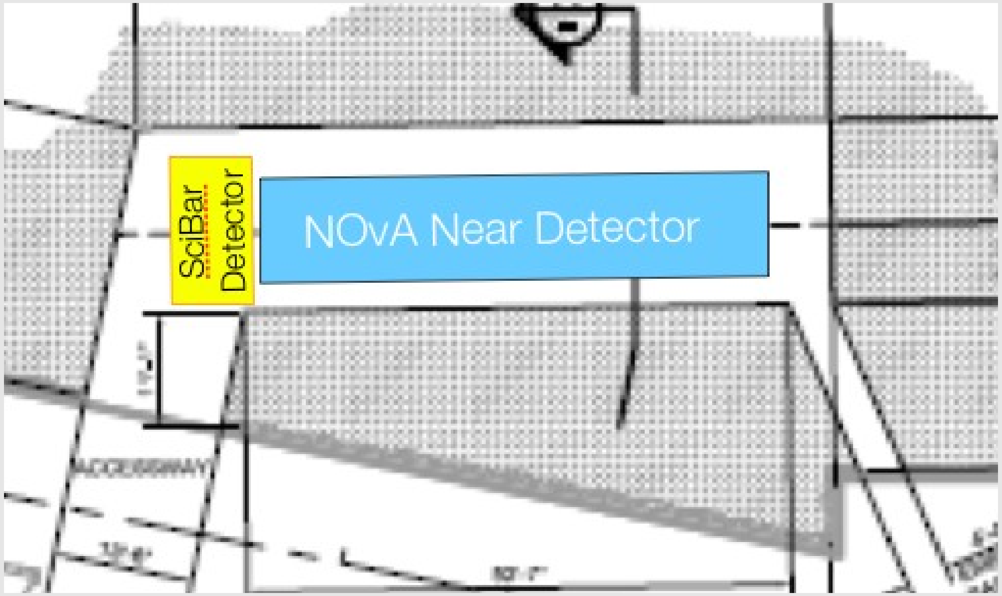
Conclusions/Request:

- 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.

We are requesting:
- Endorsement of the science case so we may expeditiously pursue external funding.
- Assistance from FNAL to further our assembly, installation, rigging plan and double checks of associated costs.



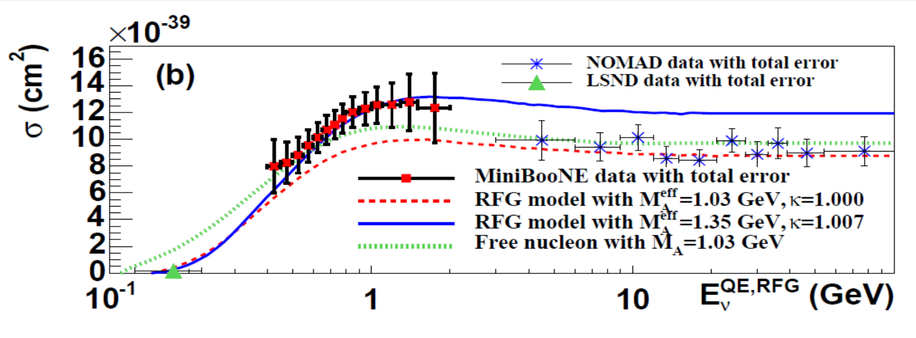


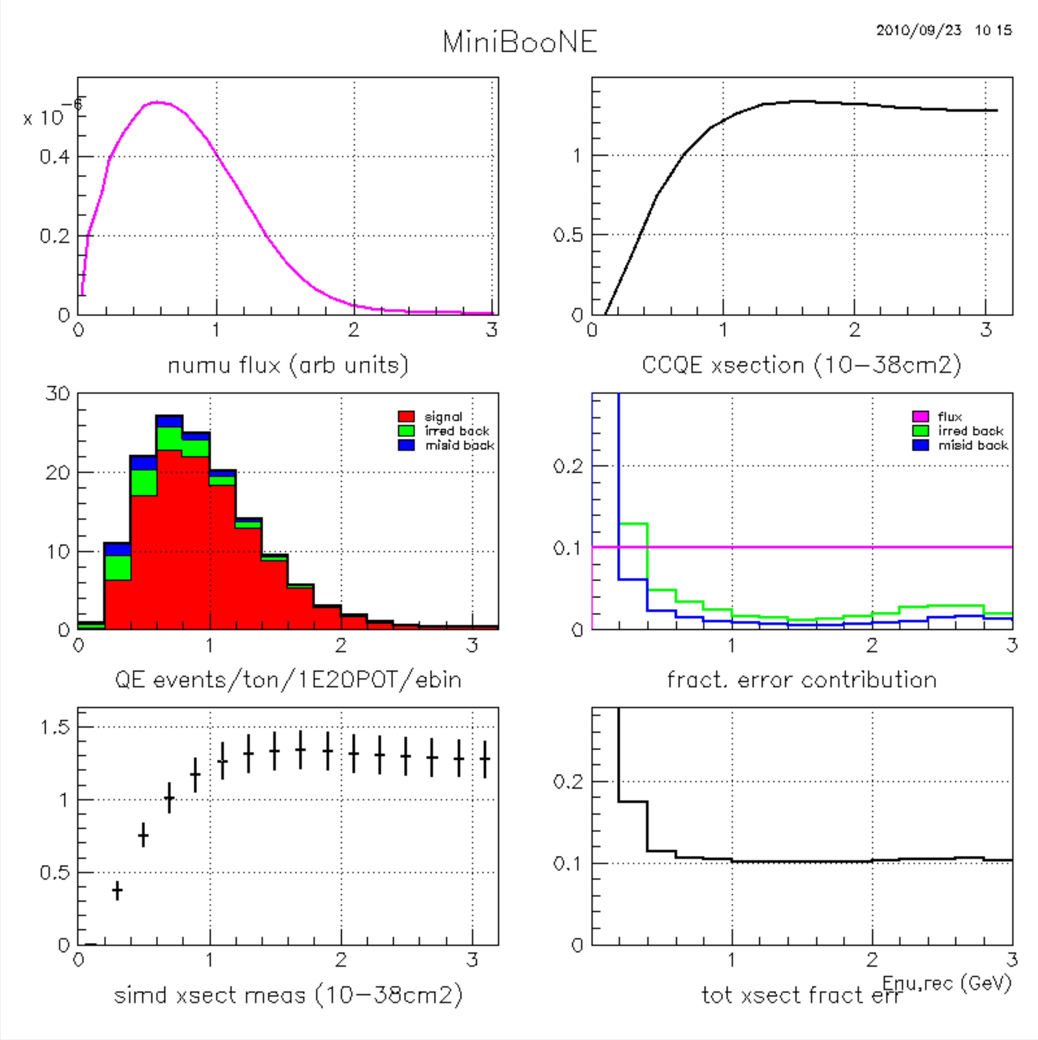
extra slides

Science case: CCQE scattering

Estimated errors on MiniBooNE
CCQE total cross section measurement

- check of method with MiniBooNE
- underestimates error slightly off flux peak due to naive treatment of flux error





SciNOvA detector

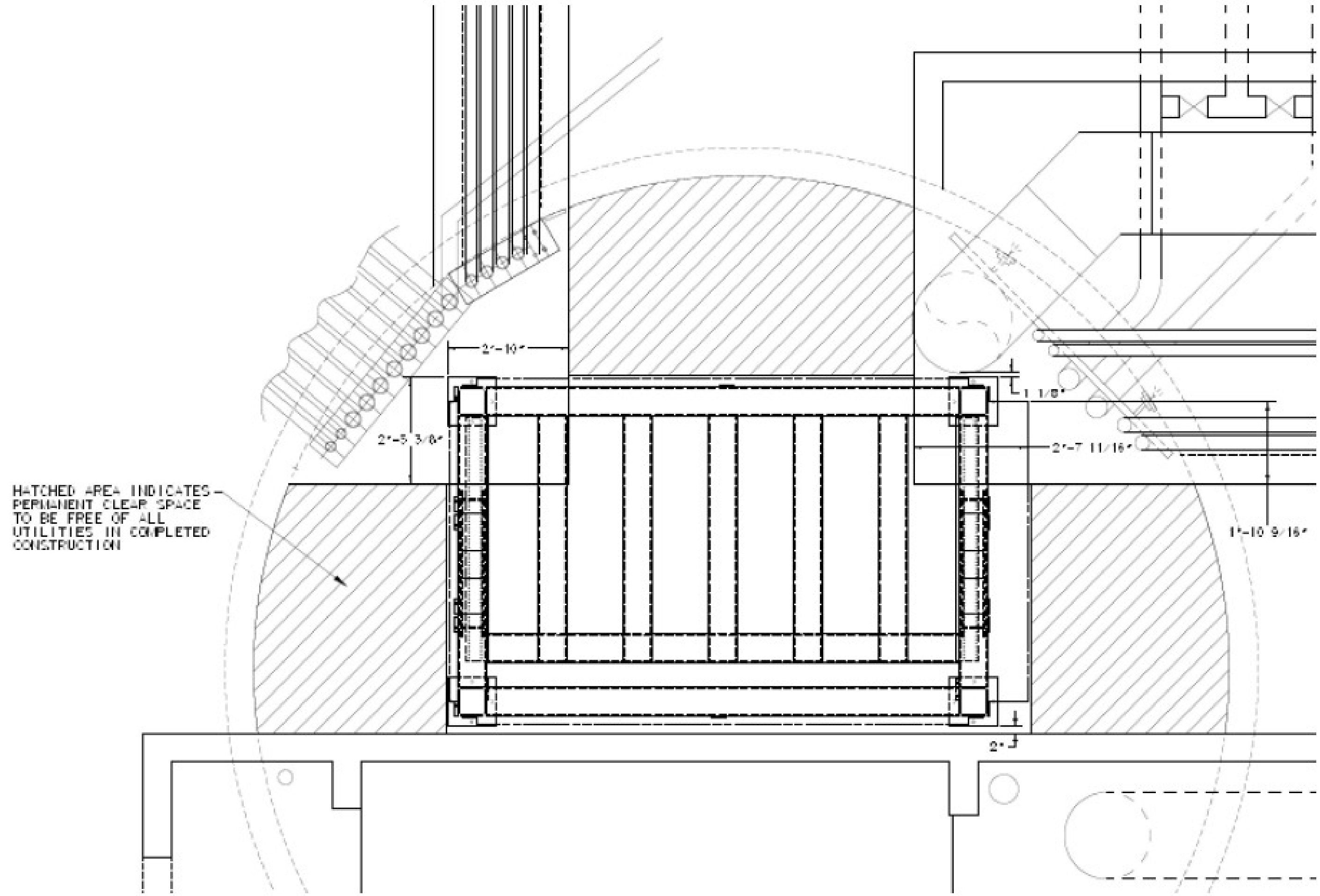


Figure 20: The SciBar cradle superimposed on the NUMI access shaft showing the clearance issues.

SciNOvA: costs

IRM readout board cost breakdown

IRM component	qty	costs each	total
assembled PCB with components	250	$2,515.00	$628,750
integrated HV supply	250	$32.63	$8,158
MAPMTs	250	$1,600.00	$400,000
PMT base PCB assembly	250	$95.00	$23,750
PMT mounting parts, ribbon cable	250	$142.84	$35,710
chasis mounting parts, connectors	250	$15.71	$3,928
Fans	250	$22.93	$5,733
total IRM costs			**$1,106,028**
cost/board			$4,424
cost/channel			$69.13

SciBar scintillator extrusions cost estimate

COST ESTIMATE FOR SCINOVA

Requested by Mark Messier at Indiana University
Prepared by Anna Pla-Dalmau
Date: May 13, 2010

IMPORTANT: PROJECT WILL BE BILLED AT ACTUAL COSTS. THIS IS AN ESTIMATE.

Scintillator bars with titanium dioxide coating with one hole for a WLS fiber: 2.5 cm x 1.3 cm at 300 cm
Total amount of scintillator: 36,000 m (12,000 strips)

	Estimated Materials and Services Cost ($)	Estimated Time (hours)	Rate (hours)	Estimated Labor Cost ($)	Total Estimated Cost Materials and Labor ($)
R&D Material					
Die	$10,000.00				
Polystyrene pellets (1,480 Kg @ $2.65 each)	$3,922.00				
Dopants (34 bottles @ $190 each)	$6,460.00				
Titanium dioxide pellets (40 Kg @ $7.85 each)	$314.00				
Nitrogen gas (10 LN_2 dewars @ $126 each)	$1,260.00				
Consumables (jars, labels, QC tools,...)	$1,000.00				
R&D Labor					
Extrusion preparation and operation		120	$60.00	$7,200.00	
Extrusion assistance	$3,400.00	100	$34.00		
Extrusion assistance and QC		60	$35.00	$2,100.00	
Set-up and tear-down (half-day each, 2 people)		20	$60.00	$1,200.00	
Production Material					
Polystyrene pellets (14,800 Kg @ $2.65 each)	$39,220.00				
Dopants (340 bottles @ $190 each)	$64,600.00				
Titanium dioxide pellets (400 Kg @ $7.85 each)	$3,140.00				
Nitrogen gas (50 LN_2 dewars @ $126 each)	$6,300.00				
Consumables (jars, labels, QC tools,...)	$1,500.00				
Production Labor					
Extrusion preparation and operation		800	$60.00	$48,000.00	
Extrusion assistance	$14,960.00	440	$34.00		
Extrusion assistance and QC		400	$35.00	$14,000.00	
Project coordination		80	$65.00	$5,200.00	
Set-up and tear-down (half-day each, 2 people)		20	$60.00	$1,200.00	
Crating and Shipping					
Crate - 12 wooden crates	$3,600.00			$3,600.00	
Shipping*	$6,000.00				
Extrusion Equipment Maintenance	$3,000.00				
Estimated Direct Cost	$168,676.00			$82,500.00	$251,176.00
FNAL Indirect Charges (14.4% M&S)	$24,289.34				$24,289.34
FNAL Indirect Charges (63.89% Labor)				$52,709.25	$52,709.25
TOTAL Estimated Cost					$328,174.59

*This is an estimate.