SciNOνA: A measurement of neutrino-nucleus scattering in a narrow-band beam [1]

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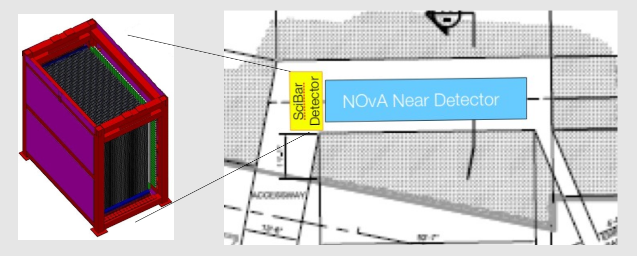
DPF 2011 @ Brown, 2011/08/11

[1] Proposal URL:
http://www.fnal.gov/directorate/program_planning/Nov2010PACPublic/1003_SciNOvA_Proposal_2010_15_10.pdf



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Outline

SciNOνA Basics

- A proposal to place a 15-ton fine-grained detector in the NOνA beam directly in front of the NOνA Near Detector
  - Offer a large increase in NOνA physics capacity with modest investment of labor, engineering, and money ($\sim$ $2.4 M)
- In narrow band beam (NBB) at 2 GeV
  - Would record $\sim$ 1 M events/year
  - Narrow band beam provides better knowledge of the incident neutrino energy than possible in wide band beam (WBB)
  - Narrow band beam allows for lower background from high energy feed down
- Will improve our knowledge of neutrino-neuclus scattering at 2 GeV
- Significant cross check of NOνA neutrino oscillation backgrounds to $\nu_\mu \rightarrow \nu_e$ search

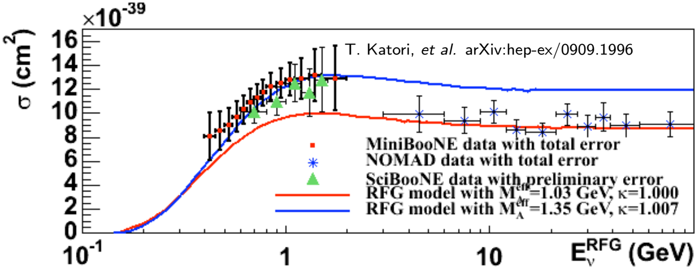
SciNOνA Physics

[1 year ν running with 10 kt fiducial volume from GENIE ($\times 10^3$)]

	Charged-Current ($\times 10^3$)	Neutral-Current ($\times 10^3$)
elastic	220	86
resonant	327	115
DIS	289	96
coherent	8	5
total	845	302
$\nu + A \rightarrow \pi^0 + X$	204	106

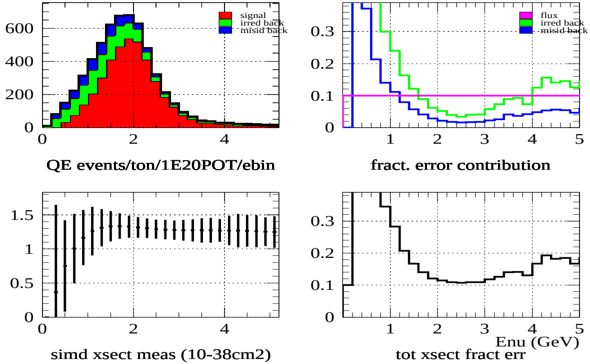
- "puzzle" in Charged-Current Quasielastic Scattering (CCQE)
    - 2 GeV low background measurement sits in the region between the current measurements
    - low threshold for detected recoil protons, enabling a search for di-nucleon QE final states
- Measure the NC photon production, may explain the MiniBooNE low energy excess and also an important background for $\nu_\mu \rightarrow \nu_e$ oscillations
- A robust, data-driven estimate of the instrumental backgrounds to the NOνA neutrino oscillation analysis

CCQE



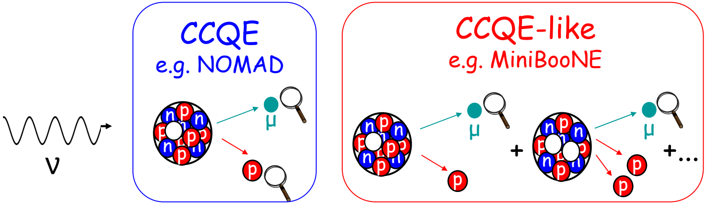
- CCQE "puzzle" - Recent CCQE results have larger M_{A}
  - A ~10% measurement of the cross section is satisfactory given the 30% discrepency of the MiniBooNE data with expectation
    - Error study shows SciNOνA can have 12% error measurement at 2 GeV
    - Estimated with bootstraping from MiniBooNE error anaysis and checked by predicting actual MiniBooNE errors
  - The multi-nucleon emission scenario can be tested in SciNOνA

CCQE cross-section - Off-axis Narrow Band Beam

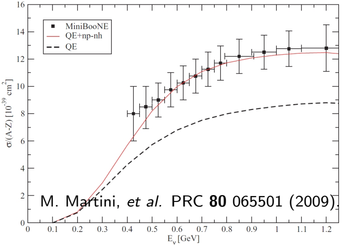


- The systematic error on the total cross section is dominated by the neutrino flux error (10%) in the region of the peak neutrino energy
- The CCπ^+ background errors (feeddown due to lost π^+ absorbed by nucleus/detector medium) dominate at low energies
- Sufficiently accurate measurement of the total CCQE cross-section in the region just above the MiniBooNE measurements at 2 GeV

CCQE multi-nucleon emission

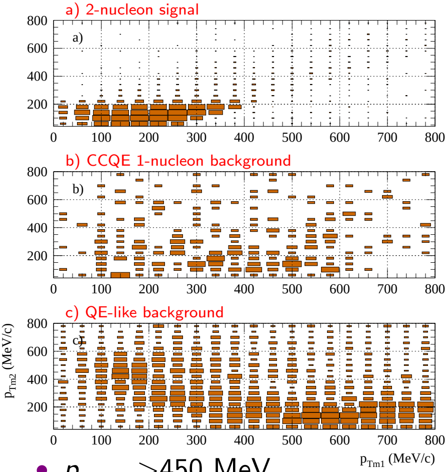


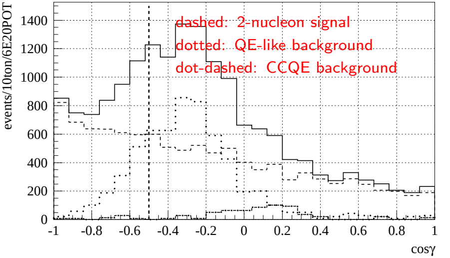
- QE + multineucleon emission channel (np-nh) agrees the MiniBooNE cross section without increasing M_{A}
- The multiple recoil nucleons can be measured in SciNOνA



M. Martini, *et al.* PRC **80** 065501 (2009).

CCQE multi-nucleon emission



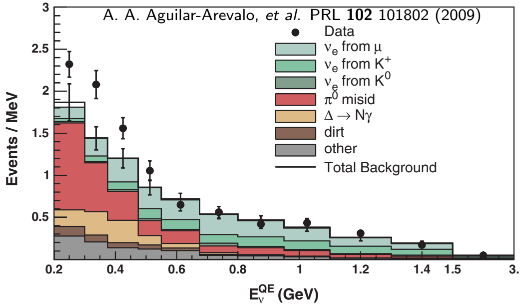


γ: the angle between the two proton momentum vectors

- $p_{p_1,p_2} > 450$ MeV
- $p^T_{m1} > p_{\rm Fermi}$, $p^T_{m2} < p_{\rm Fermi}$
- $\cos\gamma < -0.5$

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

NC Photon Production



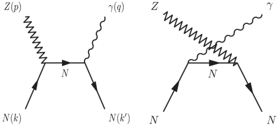


FIG. 1. Generalized Compton scattering.

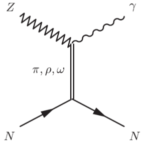


FIG. 2. Meson-exchange contribution to $Z^*N \to \gamma N$.

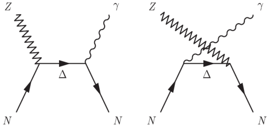


FIG. 3. Production of photons through the Δ resonance.

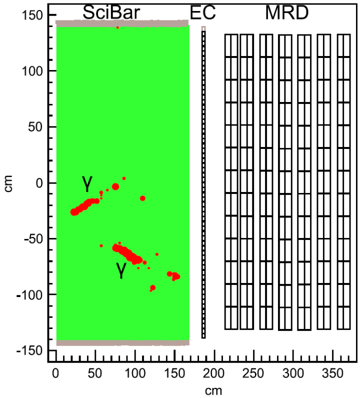
- MiniBooNE low-energy excess - NC photon production?
- Important background for ν_e appearance

R. J. Hill, PRD **81** 013008 (2010).

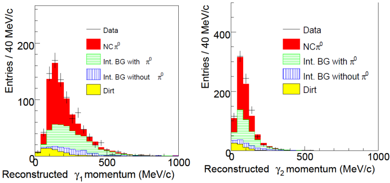
NC Photon Production

A measurement of NC photon is accessible in SciNOνA:

- SciNOνA event rates equal to full MiniBooNE neutrino sample
- NC photon cross sections are calculated to be $O(10^{-3})$ that of CCQE [a]
  - $O(100)$ events in MiniBoone $\sim$ 0.1% oscillations
  - SciNOνA will collect $O(100)$ events of this type if calculations are correct
- Photon reconstruction down to $\sim$ 100 MeV
- Together with NCπ^0 channel will lend crucial information to ν_e appearance search



Y. Kurimoto, *et al.* PRD **81** 033004 (2010)

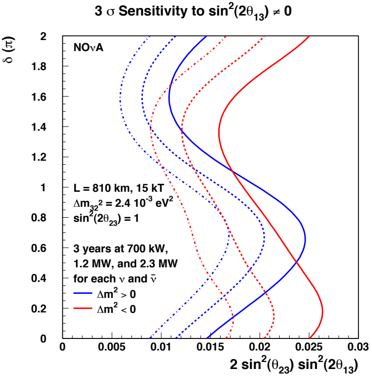


[a] Serot & Zhang, arXiv:nucl-th/1011.5913

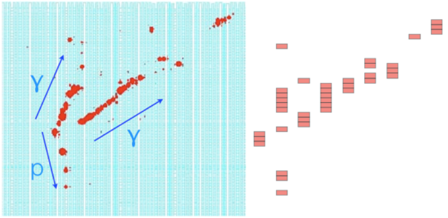
Other Neutrio-Nucleus Scattering Measurements

- Incoherent CC/NC single pion production
  - NC π^0 - very important ν_e appearance background if one of the two photons from π^0 decay is not detected
  - CC $\pi^{\pm}$ - very important ν_μ disappearance background if the $\pi^{\pm}$ misID as proton or absorbed by the nuclei
- Coherent $\pi^{\pm,0}$ production
  - NC Coherent π^0 - important ν_e appearance background
    - $\sim$20% of total NC π^0 at low energies
  - CC Coherent π^+ "puzzle"
    - High energy measurements agree with the PCAC based prediction very well, both NC and CC
    - Recent low energy measurements (K2K, SciBooNE) found no evidence on CC coherent pion production, but MiniBooNE and SciBooNE do observe NC pion production
  - Can we use the CC Coherent π^+ to better constrain the energy scale?
    - $\mu^-\pi^+$ in neutrino vs $\mu^+\pi^-$ in antineutrino
- ν_μ NC elastic scattering $(\nu + p \rightarrow \nu + p)$
  - Important complementary channel to CCQE, add valuable information to the nucleon spin puzzle

Benefit to NOνA



- For NOνA: ν_e CC efficiency $\sim$ 35%, NC background acceptance $\sim$ 0.4%, and ν_μ-CC background mis-ID probabilities $\sim$ 0.1%
- A double-scan method will result in a $<$ 3% (relative error) cross check of the background mis-ID probabilities.

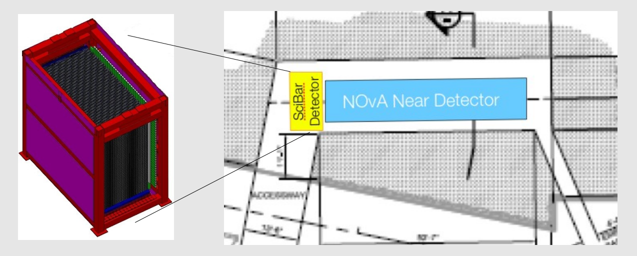


p + π⁰ in SciBar   Same event resampled in NOνA

- NOνA expects a 10% uncertainty in the background at the Far Detector
- With added data from SciNOνA it may be possible to reduce this uncertainty to 5%
  - Adding 10% more mass to NOνA Far Detector would cost $\sim$ \$13 M, which is $\sim 5\times$ the cost of SciNOνA
- Additional handles on the background increase confidence in the NOνA oscillation results

Outline

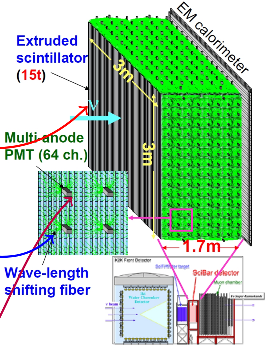
The SciNOνA Detector

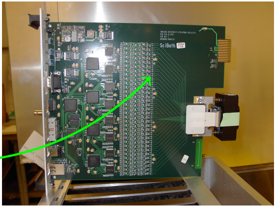


- Installation of 15 k channel solid scintillator SciBar detector in front of NOνA near detector
  - No cavern changes required, slight modifications to front detector support structure
  - Utilize as much of SciBar support structure as cost-effective
- Need to build/procure/manufacture
  - Scintillator extrusions
  - WLS fibers, PMT "cookies"
  - 64 anode PMTs
  - Readout system, based on existing and running design (Indiana U. IRM modules)

Baseline Detector Components (No EM calorimeter)

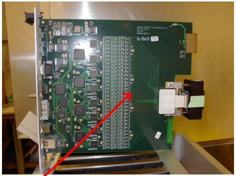
- Scintillator strips
  - Polystyrene doped with PPO and POPOP, co-extrueded with a TiO_2 reflective coating 0.25 mm thick
  - Strip - 1.3×2.5×290 cm^3, active volume - 2.9×2.9×1.7 m^3
  - 14848 arranged in 64 layers
  - Each layer has X and Y plane, each plane containing 116 strips
- Wavelength-shifting fiber collects light
  - Fiber diameter 1.5 mm, ∼48 km in total
  - Readout on only one end
  - 64-fiber bundle to PMT-interface “cookie”
- 64 anode multianode photomultiplier tubes converts light to electrical signal (232)
  - Quatum efficiency ∼ 12%
- Readout
  - A 12-PMT system has been built and is running at Indiana U.
  - Scibath Integrated Readout Module (IRM) - prototype for FINeSSE experiment

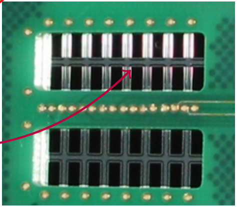


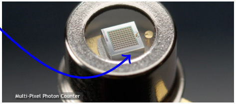


Technology options

- Scintillator strips shape
  - Is the basline design (1.3×2.5 cm) the best geometry for use by NOνA when scientific performance and practicality are considered?
- Photo Detector technology choice
  - M64s : SciBar and SciBath
  - APDs : NOνA
  - SiPMs : T2K and groups at FNAL
- Readout choice
  - A choice of photo detector implies a need for an appropriate readout scheme







Outline

SciNOνA Cost and Schedule

- Total cost is about $2.41 M
  - SciBar - $0.8 M
  - IRMs - $1.5 M
- Different technologies are under consideration and need another cost exercise
- Estimated time from start to ready $\sim$ 22 months
  - Expect to start next summer and ready when the NOνA Far Detector is ready

SciNOνA Current Status

- Presented to Fermilab Physics Advisory Committee, 11/10 - recommended that NOνA consider SciNOνA
- The NOνA collaboration supports the SciNOνA physics case and is seriously evaluating it as a possibility. Study group consisting of NOνA and non-NOνA physicists recently formed to answer remaining technical questions.
- Final decision by NOνA hinges on
  - Man power
  - Earned contingency. Maybe $\sim$1 year before NOνA knows if it has earned enough contingency to complete SciNOνA

Summary

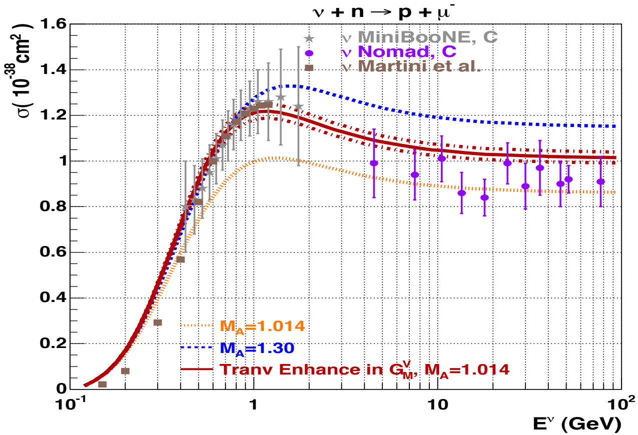
The proposed SciNOνA detector

- Existing and proven design, modest investment
- Enhance the NOνA physics program substantially
- Unique and complementary to wide band neutrino program
  - Neutrino-nucleus scattering, M_{A} "puzzle" from CCQE
  - Important cross checks of background for NOνA ν_e appearance program

Backup Slides

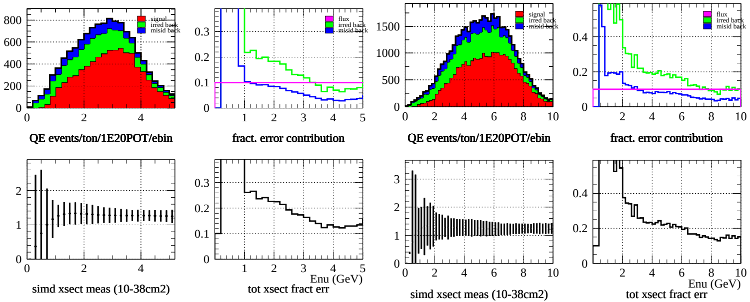
Transverse Enhancement

A. Bodek, H.S. Budd and M. E. Christy, hep-ph/1106.0340



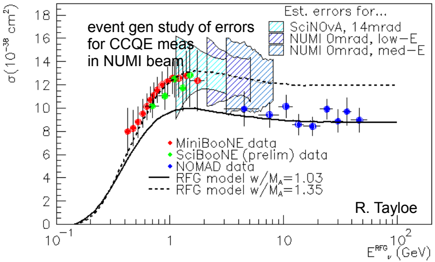
The “Axial Mass Anomaly” can be explained by the transverse enhancement observed in electron scattering.

CCQE cross-section - On-axis Wide Band Beam



NuMI flux config	Est. err. @ 2 GeV (%)
14 mrad off-axis (SciNOνA)	12
On-axis, LE (MINERνA)	23
On-axis, ME (MINERνA)	35

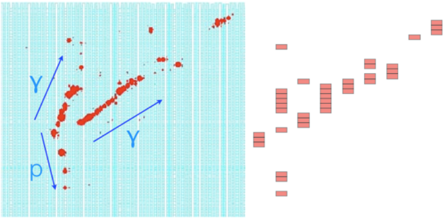
total CCQE xsection data



Benefit to NOνA

- For NOνA: ν_e CC efficiency $\sim$ 35%, NC background acceptance $\sim$ 0.4%, and ν_μ-CC background mis-ID probabilities $\sim$ 0.1%
- A double-scan method comparing SciNOvA and NOvA-near can provide signal efficiency and background misID probabilities.

- Classify events labeled as signal/background in SciNOνA compared to those resampled with larger pixel size (as NOνA) $N_{\rm ss}$, $N_{\rm sb}$, $N_{\rm bs}$, $N_{\rm bb}$
- Can then determine NOνA efficiency, $\epsilon_{\rm N}$ and NOνA, SciNOνA misID probabilities: $\gamma_{\rm N}$, $\gamma_{\rm SN}$
- Results in a $<$ 3% (relative error) cross check of $\epsilon_{\rm N}$, $\gamma_{\rm N}$, $\gamma_{\rm SN}$ at 3σ

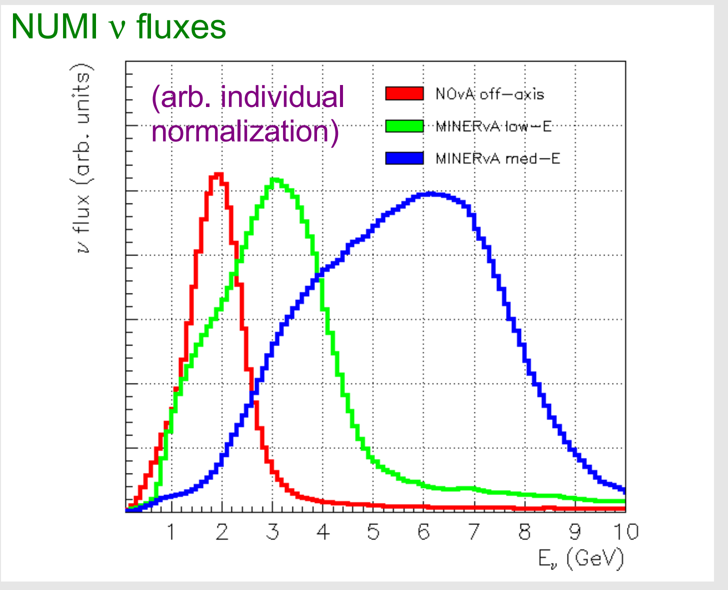


p + π^0 in SciBar

Same event resampled in NOvA

	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

NuMI Flux


NUMI ν fluxes
ν flux (arb. units)
(arb. individual normalization)
NOvA off−axis
MINERvA low−E
MINERvA med−E
1
2
3
4
5
6
7
8
9
10
E_ν (GeV)