Future Neutrino Cross Section and Nuclear Effects Studies

The **νSNS** Experiment

The **SciBooNE** Experiment

The **FINeSSE** Experiment

The **MINERνA** Experiment

Jorge G. Morfín

Fermilab

Neutrino 2006

Santa Fe, New Mexico

Outline

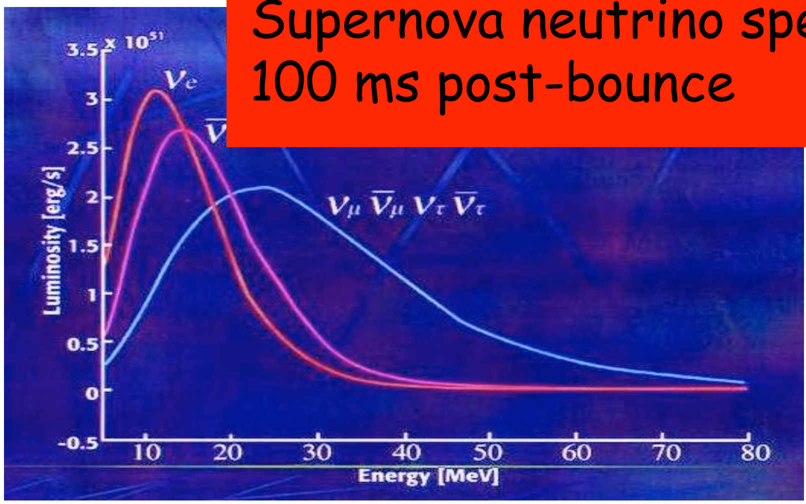
- Why Measure Cross Sections and Nuclear Effects?
  - Main drivers: Supernova studies and Neutrino Oscillation Physics
  - Plenty of inherent interest in low energy neutrino nucleus scattering
- The Experiments
  - Where are they?
  - Who are they?
  - What method do they employ?
- The Expected Physics Results

Motivation: Very Low Energy ν Physics

Understanding Supernova Core Collapse

- Core Collapse Supernovae are thought to be neutrino powered events with neutrino/electron capture on heavy nuclei playing an important role in all aspects of the core collapse supernova problem
- Observations of supernova neutrino luminosities are only as accurate as knowledge of neutrino interaction rates.
- Accurate neutrino-nucleus cross sections are essential and currently not available. Among the neutrino-nucleus interactions most relevant for supernova neutrino detection are neutrino interactions on 2H, C, O, Fe and Pb.
- **Currently, lack of data on very low-energy neutrino-nucleus interactions limits our understanding of the mechanism by which core collapse supernovae explode, our understanding of the resulting nucleosynthesis, and our ability to interpret the results of neutrino astronomy.**

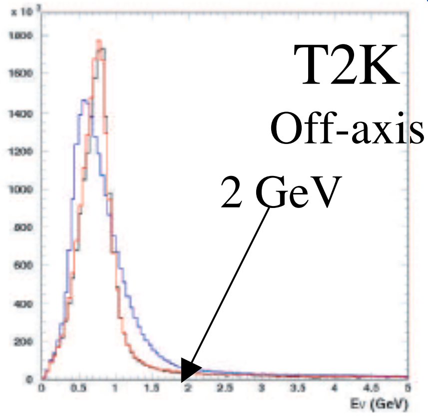
Supernova neutrino spectra
100 ms post-bounce

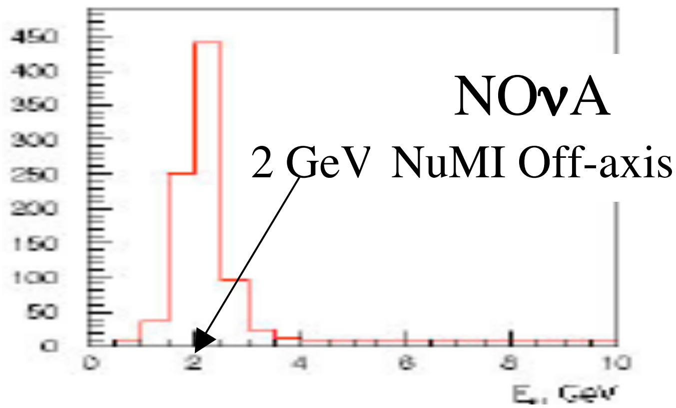


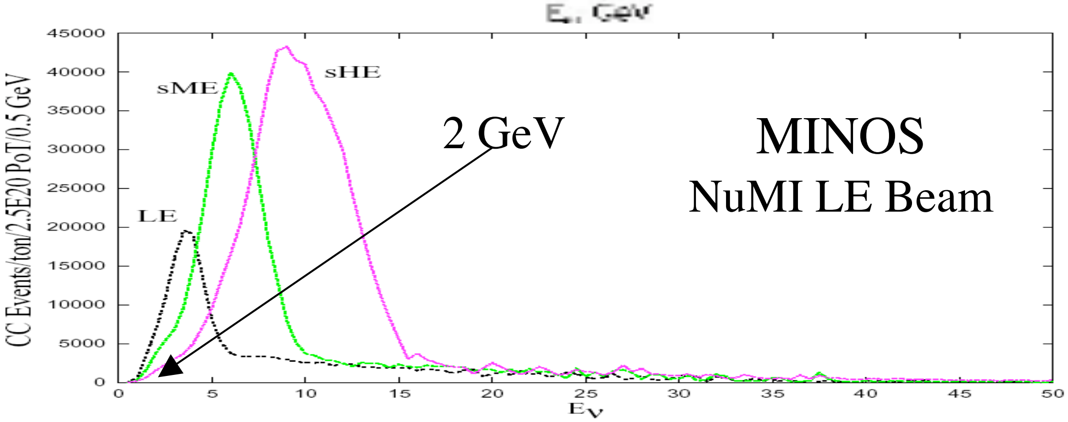
What We Know and Don't Know about Neutrino Production in Stars
Sylvaine Turck-Chieze
Session IV

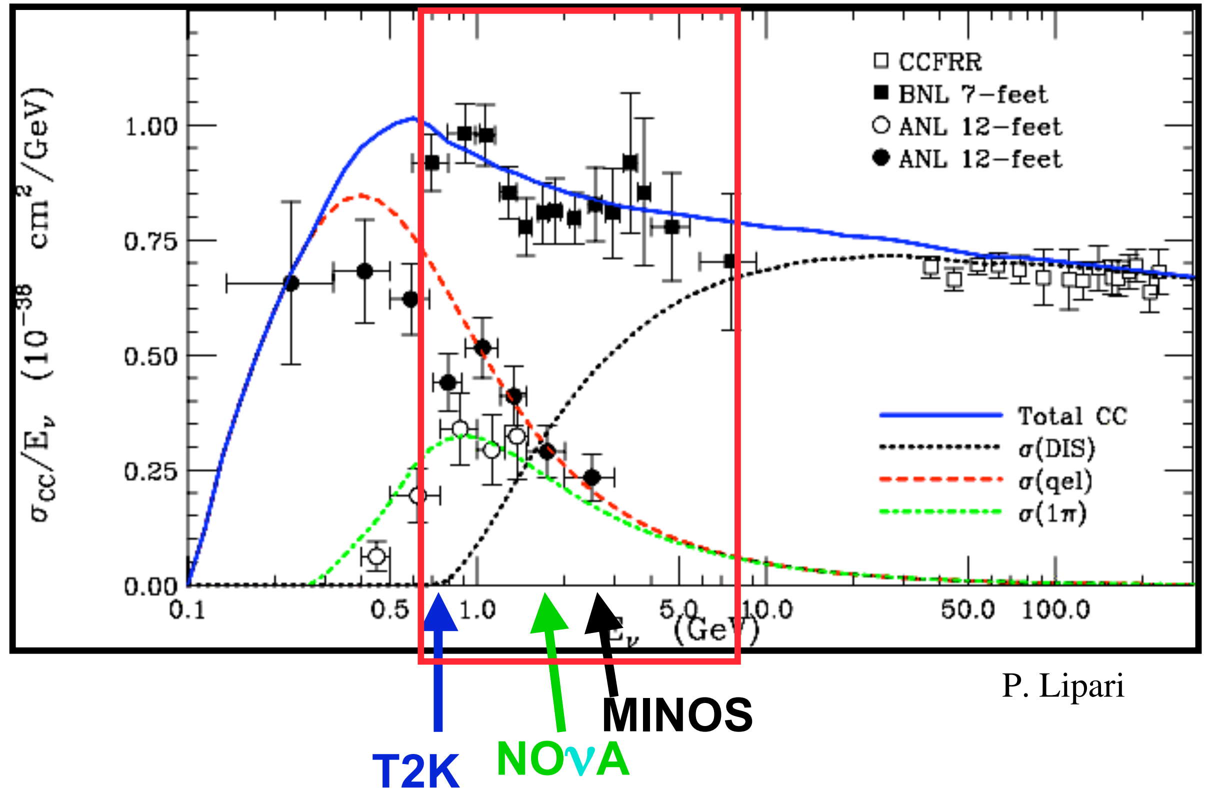
Motivation: Low energy ν scattering

Neutrino Oscillation Experiment Systematics







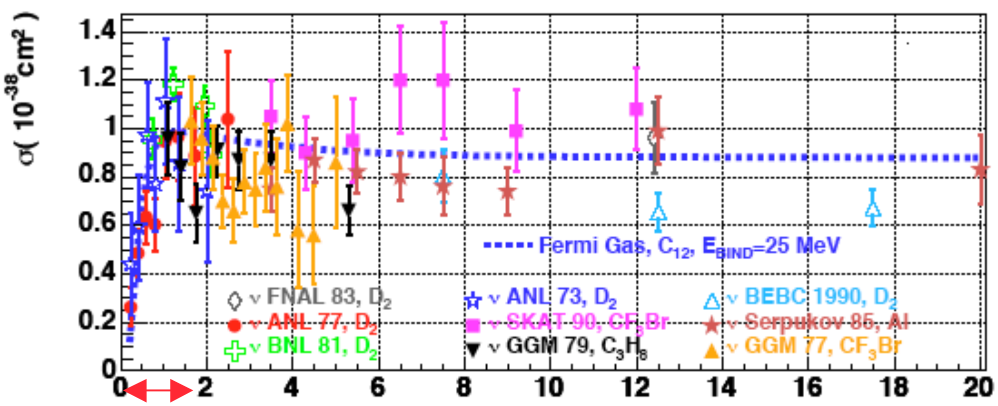


P. Lipari

We need to improve our understanding of **low energy ν-Nucleus** interactions for oscillation experiments!

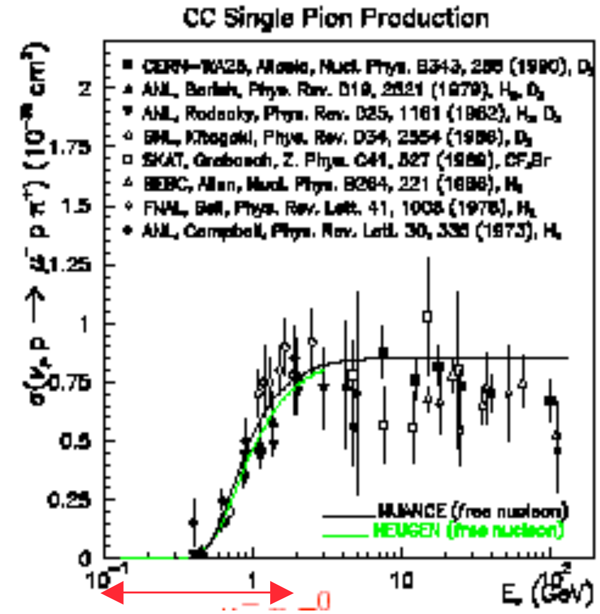
Exclusive/Total Cross-sections at Low E_ν

$\nu p \rightarrow \mu^- p$



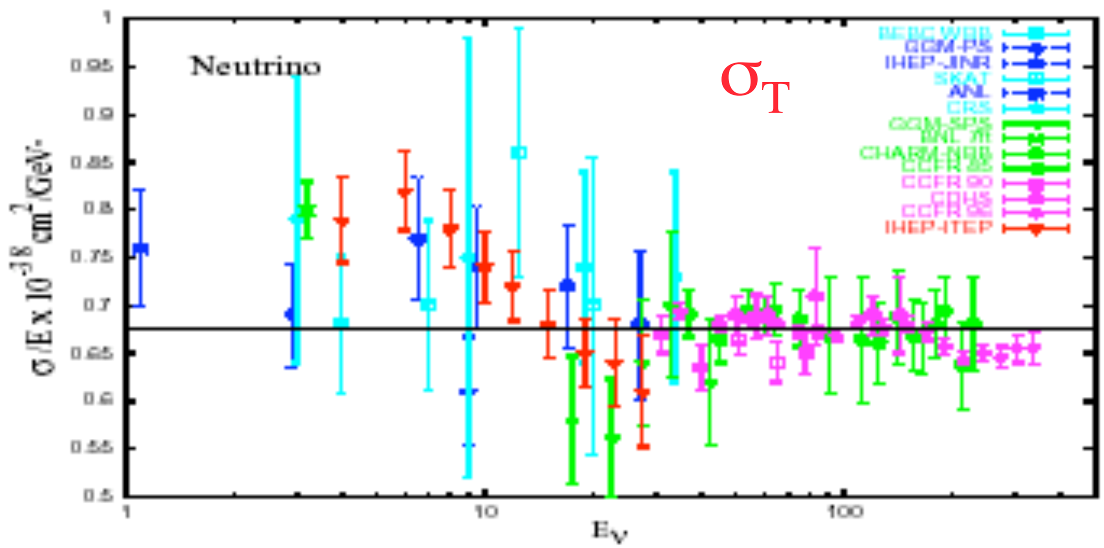
K2K and MiniBooNe

$\nu p \rightarrow \mu^- p \pi^+$



S. Zeller - NuInt04

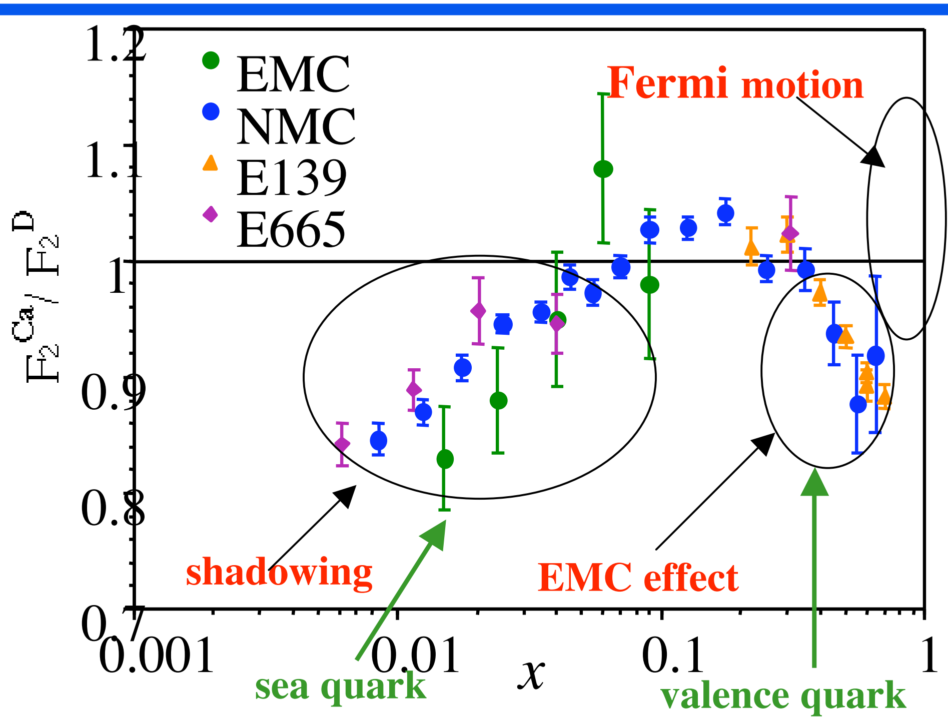
K2K and MiniBooNe

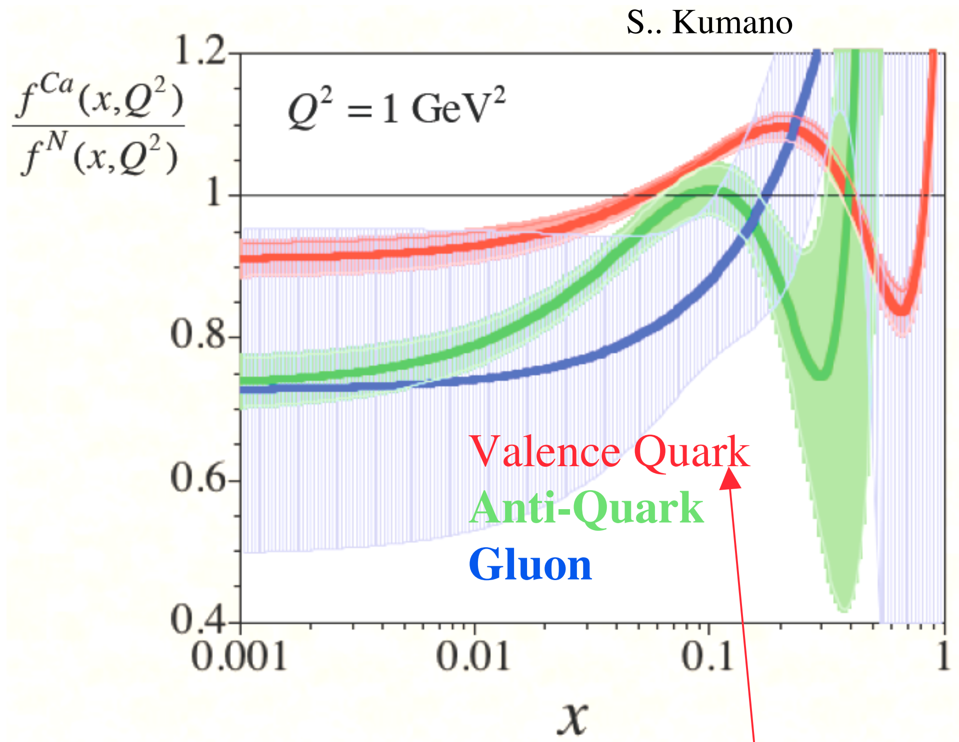


$\bar{\nu}$ cross section measurements are much worse

D. Naples

Knowledge of Nuclear Effects with Neutrinos: essentially NON-EXISTENT





- F_2 / nucleon changes as a function of x. Measured in μ/e - A **not in ν – A**
- Good reason to expect nuclear effects to be DIFFERENT in **ν - A**.
  - **Presence of axial-vector current.**
  - Nuclear effects are quark-flavor dependent --> different shadowing for xF_3 comp a d to F_2.

Further Motivation: ν – Nucleus Scattering Studies

The very low energy ν scattering program also provides a special opportunity to search for lepton flavor number violating processes due to the small ν_e flux. Opportunity to study ν-nucleus coherent scattering.

The low energy ν scattering program offers significant overlap with the Jefferson Lab physics kinematic region and introduces the axial-vector current into the mix.

- Nucleon Form Factors - particularly the axial vector FF
- Duality - transition from resonance to DIS (non-perturbative to perturbative QCD)
- Parton Distribution Functions - particularly high-x_{BJ}
- Generalized Parton Distributions - **flavor dependent** multi-dimensional description of partons within the nucleon

The Upcoming Experiments

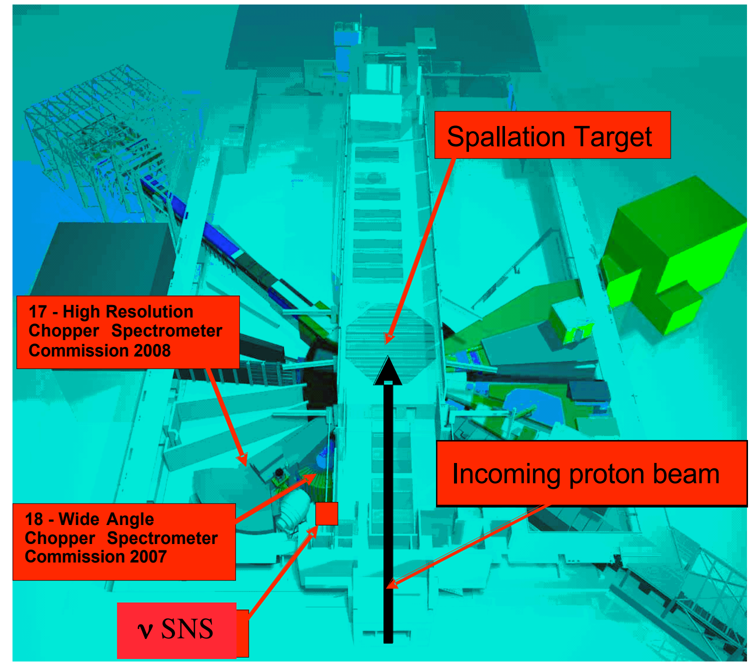
Source of Very Low Energy Neutrinos

V. Cianciolo and Y. Efremenko

http://www.phy.ornl.gov/workshops/nusns/

1 GeV beam of protons bombards a liquid mercury target in ~ 500 ns wide bursts

World's most intense pulsed neutrino source ~2×10^7 $\nu/cm^2/s$ @ 1 MW, 20 m from target



- $20\ m^2 \times 6.5\ m$ (high) $\approx 70\ m^3$

Configured for two <u>simultaneously</u>, <u>independently</u> operating target/detectors

- Close to target ~ 20 m

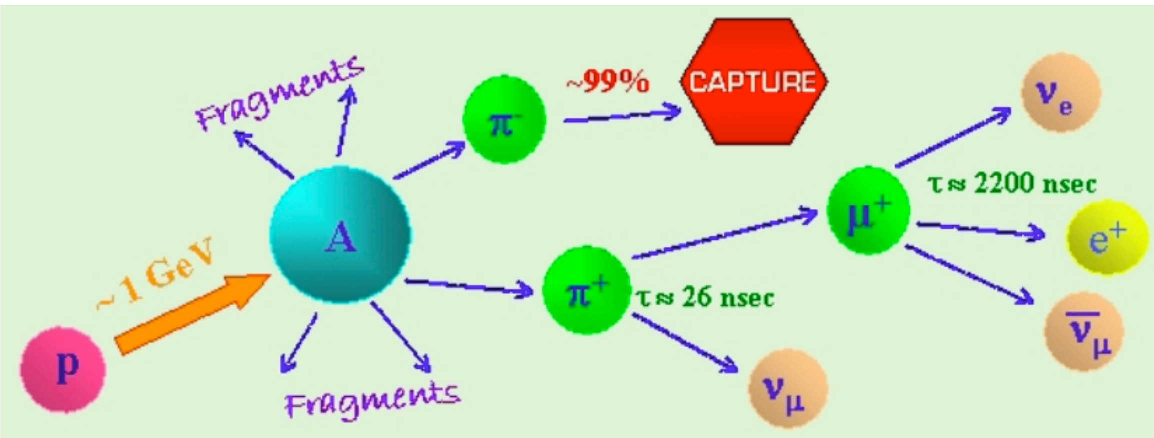
  2×10^7 $\nu/cm^2/sec$

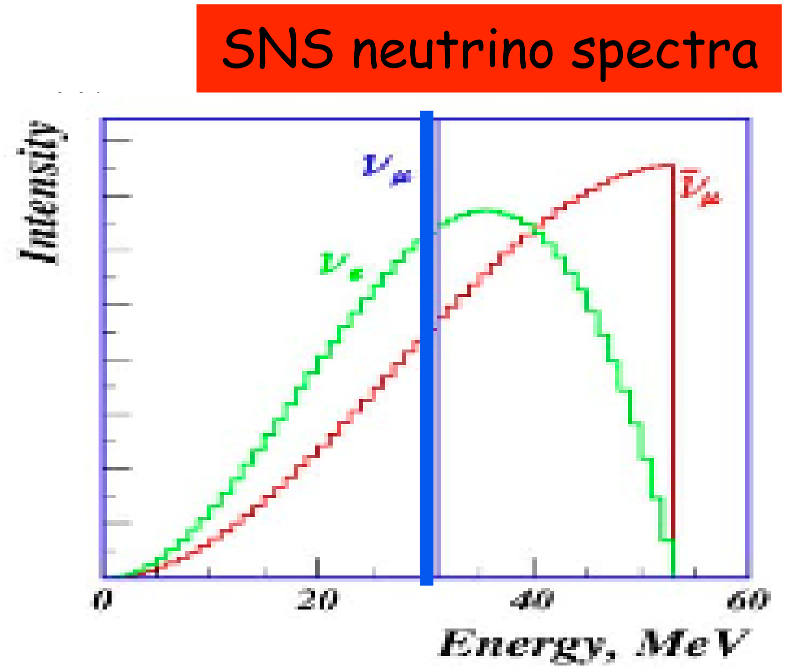
- $\theta = 165°$ to p and heavily shielded

  Lower backgrounds

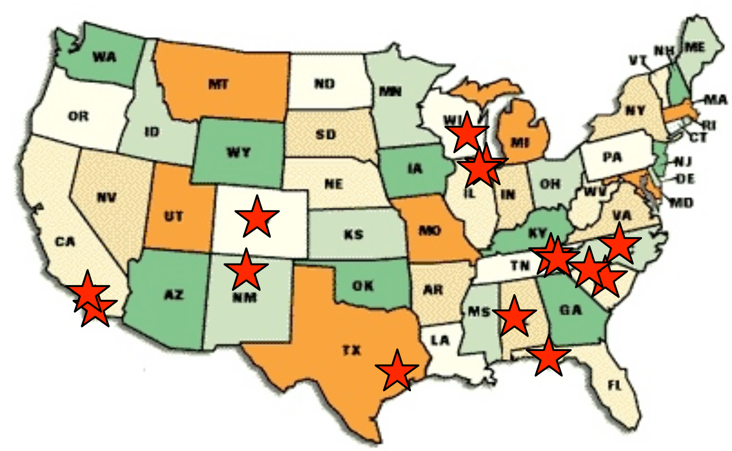
The νSNS Experiment

- Neutrino spectra from stopped-pions has significant overlap with supernova neutrino energy spectra…



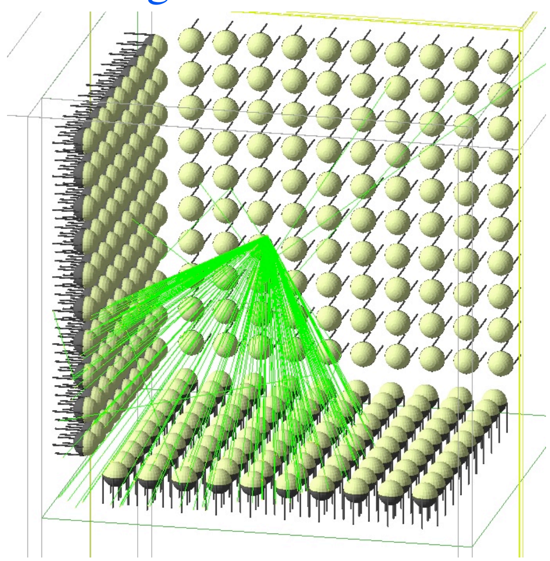


- The νSNS collaboration - 19 institutions, around 40 exp. & theorists
- The Proposed Schedule
  - Construction FY09 - FY11
  - Operations begin - FY12



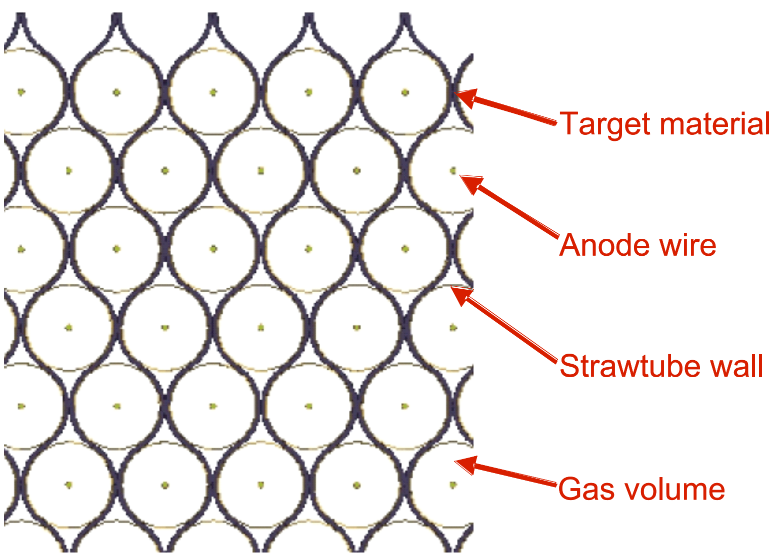
νSNS Detectors

Homogeneous Detector



- 3.5m x 3.5m x 3.5m steel vessel (43 m^3)
- 600 PMT's (8" Hamamatsu R5912)
  - Fiducial volume 15.5 m^3 w/ 41% coverage
- Robust well-understood design (LSND, MiniBoone)
- Current R&D
  - PMT arrangement
  - Neutron discrimination
  - Compact photosensors
- Geant4 simulations ongoing
  - $\delta E/E \sim 6\%$
  - $\delta x \sim$ 15-20 cm
  - $\delta\theta \sim 5° - 7°$

Segmented Detector



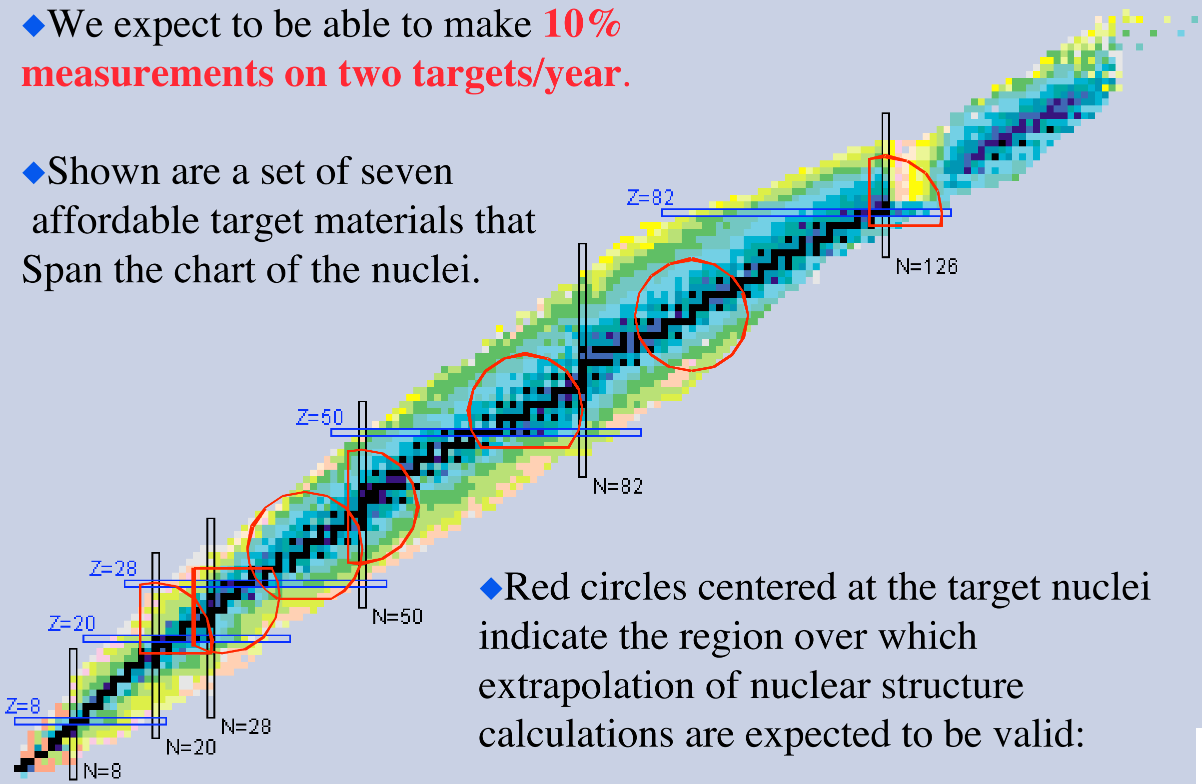
- Target - thin corrugated metal sheet (*Fe, Al, Ta or Pb*)
  - Total mass ~14 tons, 10 tons fiducial
- Detector
  - 1.4×10^4 gas proportional counters (strawtube)
  - 3m long x 16mm diameter
- 3D position by tube ID & charge division
- PID and energy by track reconstruction
- R&D focus:
  - Prototype testing and parameter optimization
    - » Diameters between 10-16 mm
    - » Lengths ranging up to 2 m
    - » Gases (Ar-CO_2, Isobutane, CF_4)

νSNS Expected Results

Capture Cross sections - Broad N/Z Coverage

◆We expect to be able to make **10% measurements on two targets/year**.

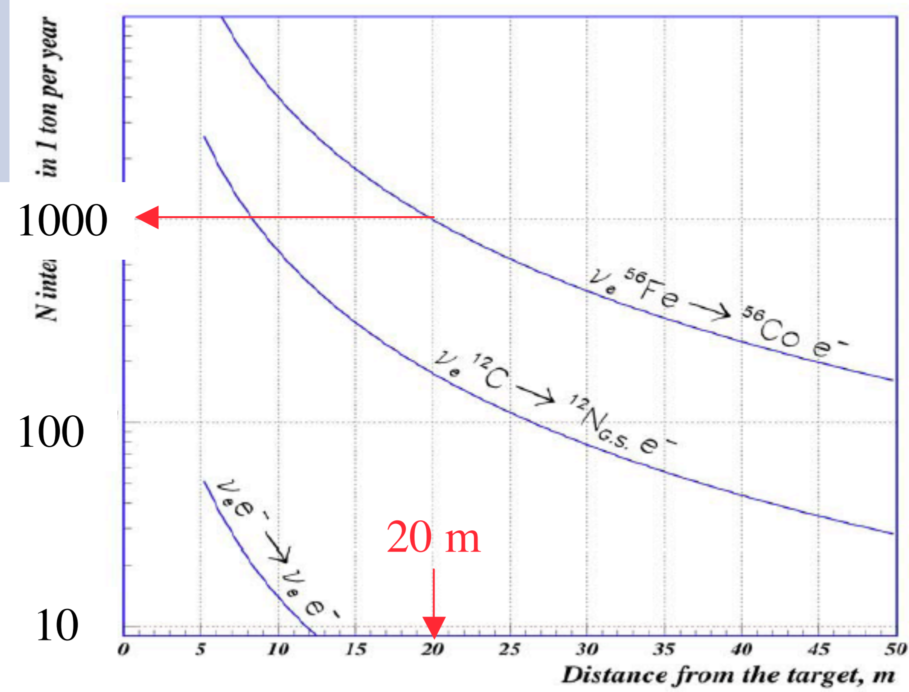
◆Shown are a set of seven affordable target materials that Span the chart of the nuclei.



◆Red circles centered at the target nuclei indicate the region over which extrapolation of nuclear structure calculations are expected to be valid:

Cross sections are small but, SNS will deliver ~ $1.9 \cdot 10^{22}$ neutrinos per year !!!

Interactions/ton/year



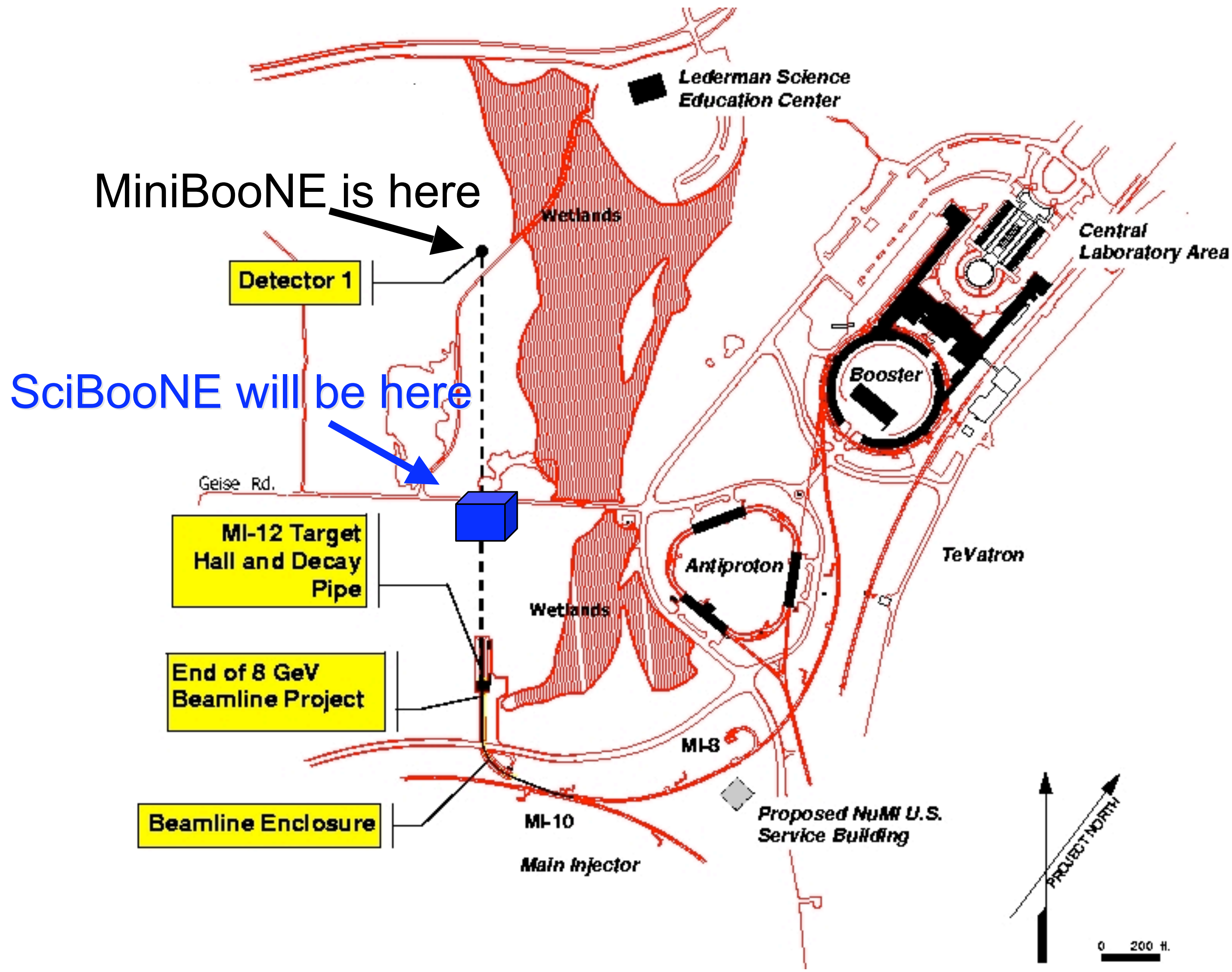
νSNS - Statistical Precision

Target	Assumed Cross Section (10^{-40} cm^2)	# Target Nuclei	Raw Counts	Assumed Efficiency	Statistical Significance
Segmented Detector (10 ton fiducial mass)					
Iron	2.5	1.1×10^{29}	3,200	35%	3.0%
Lead	41.0	2.9×10^{28}	14,000	35%	<1.4%
Aluminum	1.12	2.2×10^{29}	3,100	35%	3.0%
Homogeneous Detector (15.5 m^3 fiducial volume)					
Carbon	0.144	5.6×10^{29}	1,000	40%	5.0%
Oxygen	0.08	4.6×10^{29}	450	40%	7.4%

- Number of counts, combined with energy and angular resolution, should allow differential measurements.

Source of Low Energy Neutrinos I - SciBooNE

Fermilab Accelerator Complex with **Booster (8 GeV p) Neutrino Beam (BNB)**



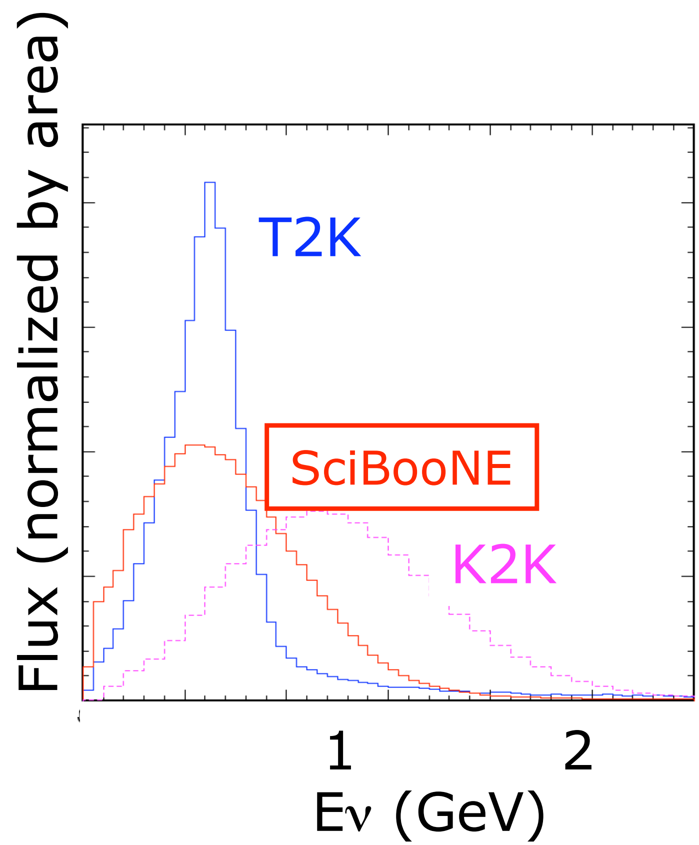
The SciBooNE Experiment

M. Wascko

http://www-sciboone.fnal.gov/

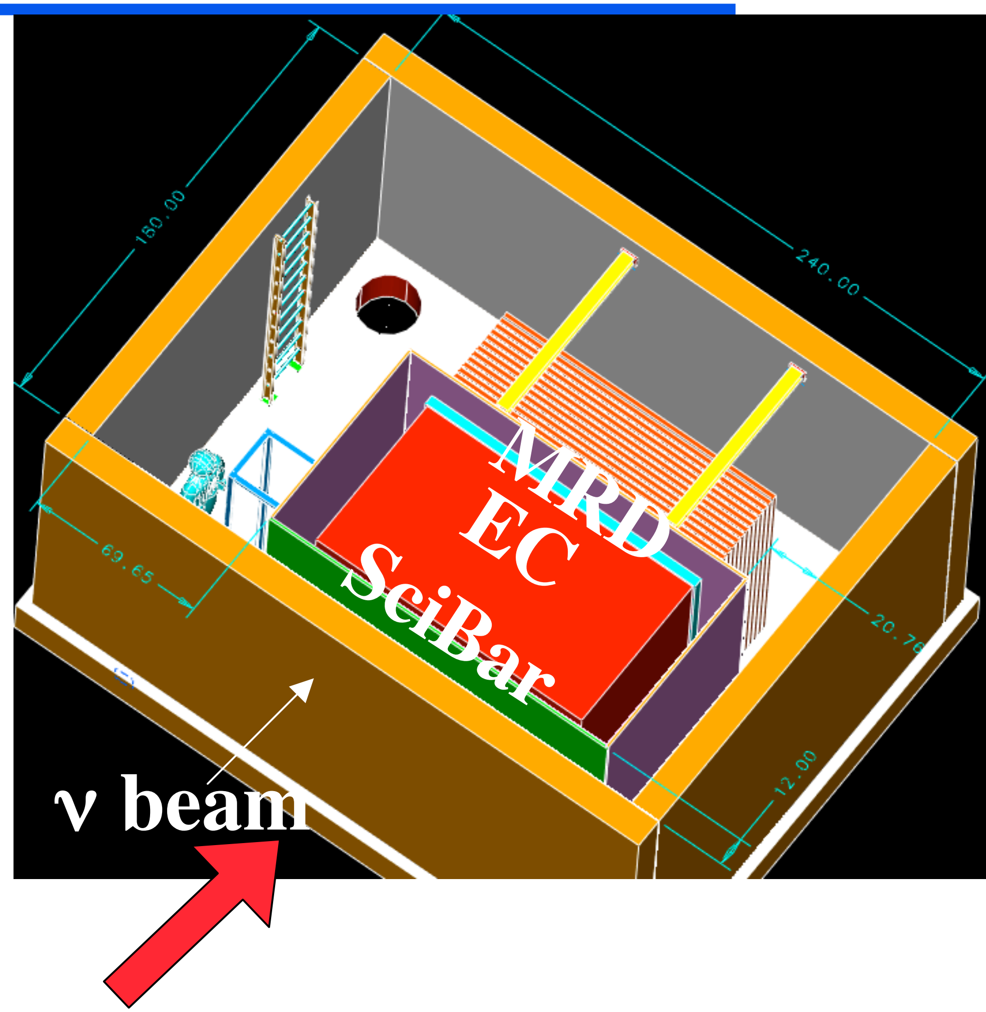
A fine-segmented tracking detector with an intense low energy neutrino beam for a precision neutrino interaction experiment.

- SciBar Detector
  - Well-working detector at K2K
  - Fine granularity ($2.5 \times 1.3 cm^2$) and Fully-Active
  - PID capability
- FNAL-BNB
  - An intense and low energy (~1GeV) beam.
  - Both neutrinos and anti-neutrinos.
- Propose $2 x 10^{20}$ POT run
  - $0.5 x 10^{20}$ POT neutrino mode
  - $1.5 x 10^{20}$ POT antineutrino mode
- The SciBooNe Collaboration
  - 11 institutions and 45 people



SciBooNE Detector and Schedule

- SciBar Detector
  - From KEK, Japan
- Electron Calorimeter
  - From KEK, Japan
- Muon Range Detector (MRD)
  - Will be built at FNAL from the parts of an old experiment (FNAL-E605).



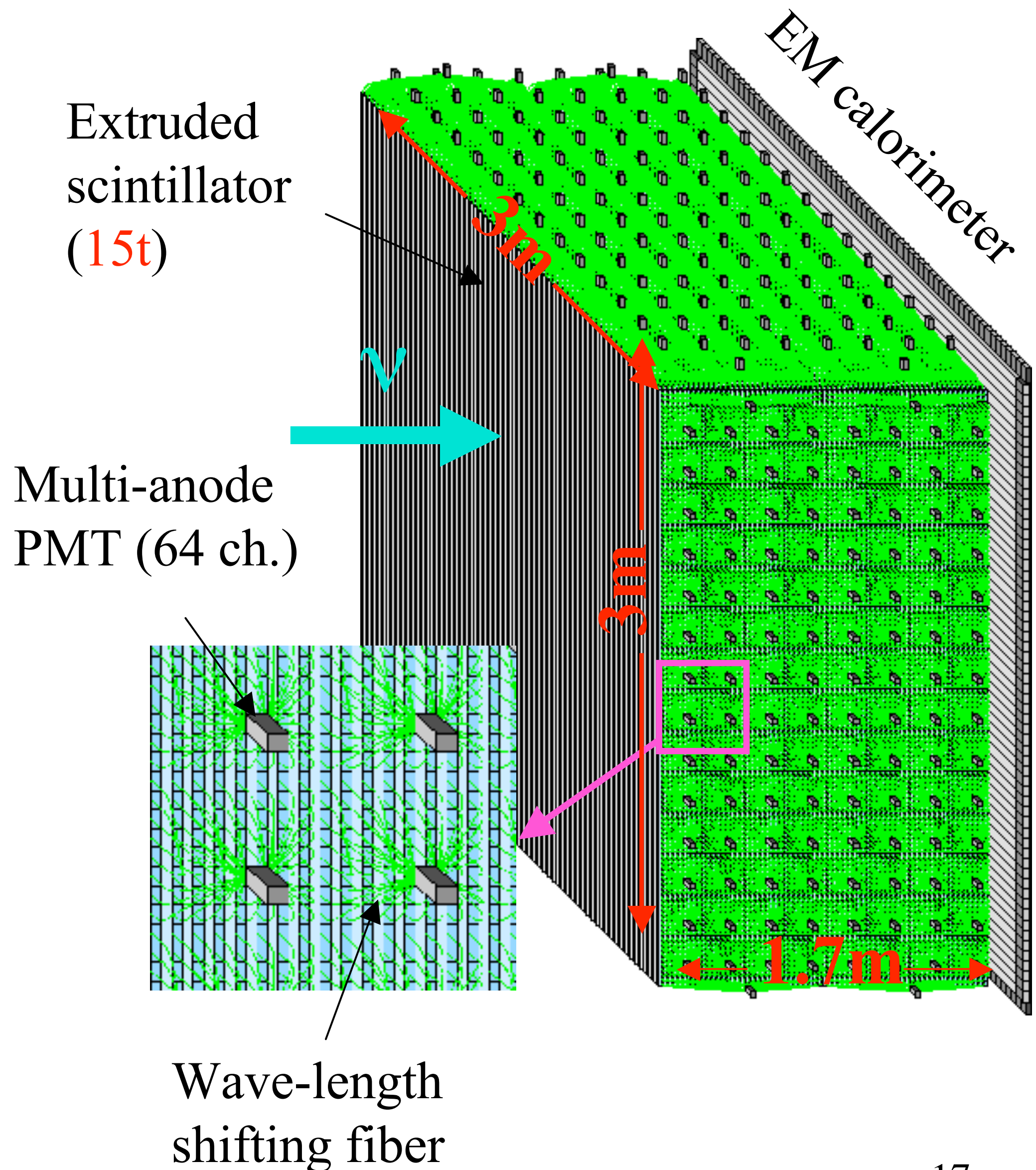
- SciBooNe Schedule
  - Begin enclosure this summer (9 months)
  - Detector move/reassemble (9 months) starting this summer.
  - Start data taking - 2006/2007

SciBooNE - SciBar Detector

Constructed and successfully used in K2K experiment

- SciBooNE will improve upon MiniBooNE's ability to measure multi-particle final states
- SciBooNE will have both ν and $\bar{\nu}$ exposures

- 2.5 x 1.3 x 300 cm^3 cell
- ~15000 channels
- Detect short tracks (>8cm)
- Distinguish a proton from a pion by dE/dx
- Total 15 tons
- High track finding efficiency (>99%)
- Clear identification of ν interaction process



SciBooNE - Expected Results (10 ton Fid. Volume)
78,000 ν_μ and 40,000 $\bar{\nu}_\mu$ events

- CC- $\sigma(1\pi^+)$
  - ν: statistics and systematics for **5 % Measurement**
- CCQE
  - ν: σ and M_A. – **< 5%** $\bar{\nu}$: σ and M_A – first measurements in this energy range
- NC π^0 measurement
  - ν: expect to make a **10 % measurement**
- Search for CC coherent π
  - ν: check K2K result and first measurement for $\bar{\nu}$ in this energy range
- Search for NC coherent π^0
- Search for radiative Delta decay (ν+N→μ+N'+γ)
  - Expect ~ 45 events after cuts in total run (ν and $\bar{\nu}$ mode)
- Intrinsic ν_e flux for BNB ($\nu_\mu \rightarrow \nu_e$ appearance search)
  - directly measure ν_e flux to 10-20% in ν mode

The FINeSSE Experiment

R. Tayloe
http://www-finesse.fnal.gov/

An intriguing detector concept looking for a home

Physics Motivation:

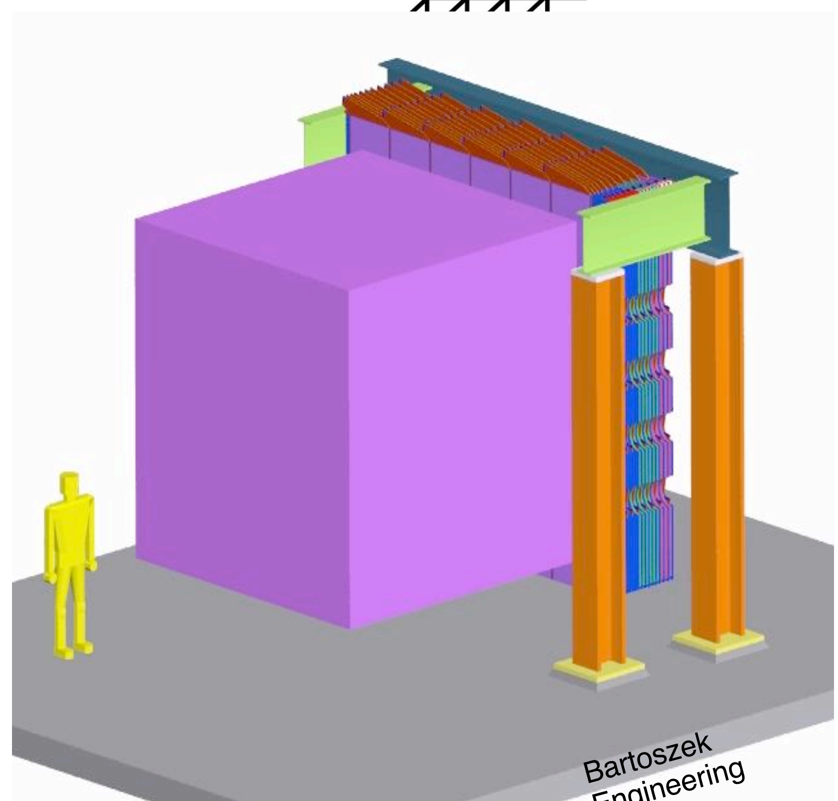
- A measurement of Δs (G_A^s) via low-Q^2 neutral-current elastic neutrino scattering
- Intermediate-energy cross sections

Experiment:

- a near (~100m) location of an intense ν source
- with a novel 2 part detector:
  - 10 ton open-volume liquid-scintillator/fiber vertex detector
  - muon rangestack

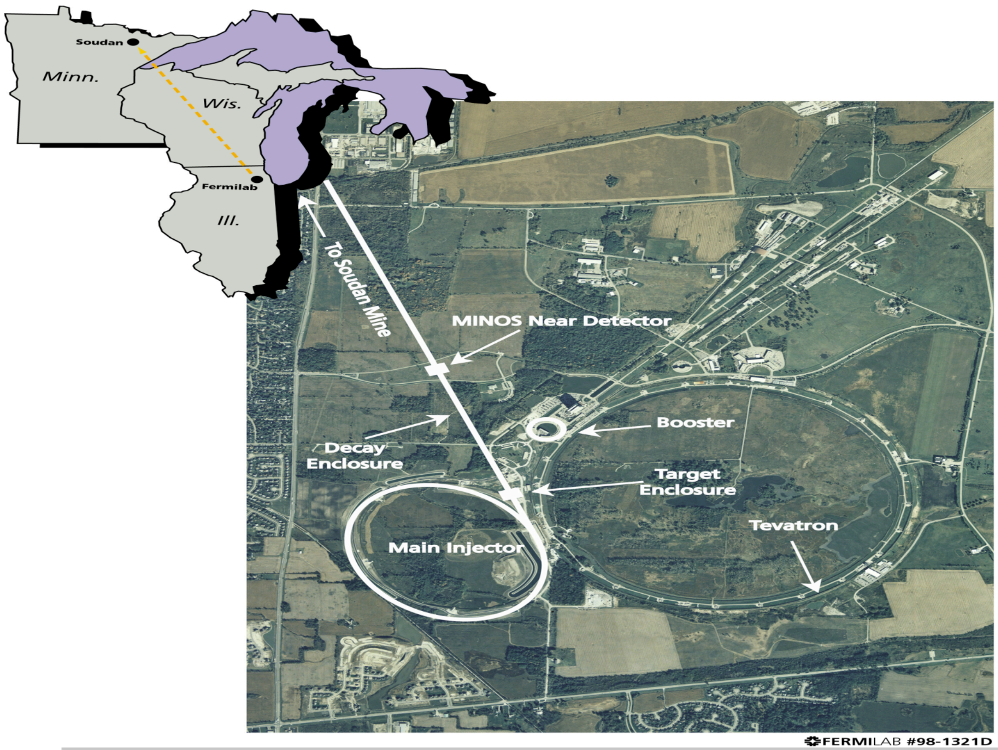
Possible locations:

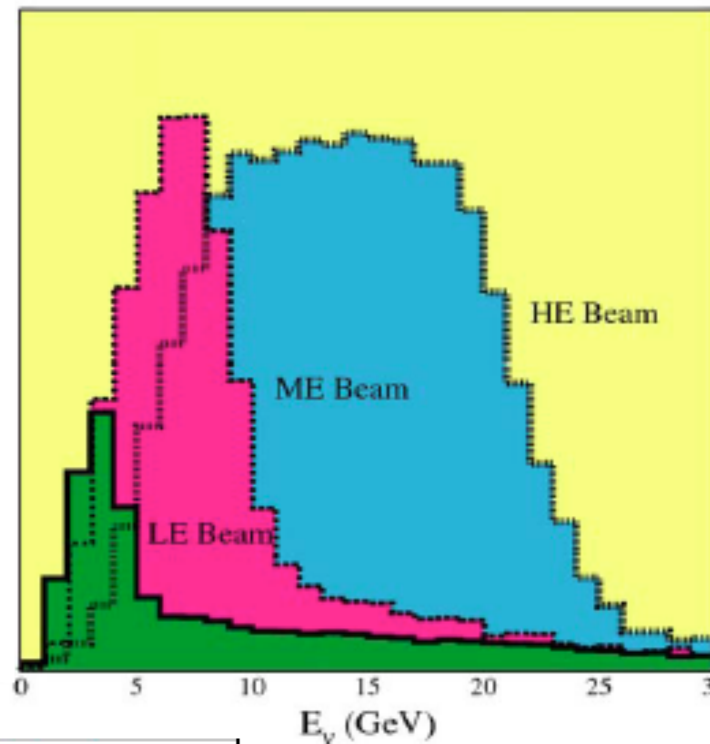
- FNAL: 8GeV booster ν source
- BNL: AGS ν source
- JPARC: T2K beam

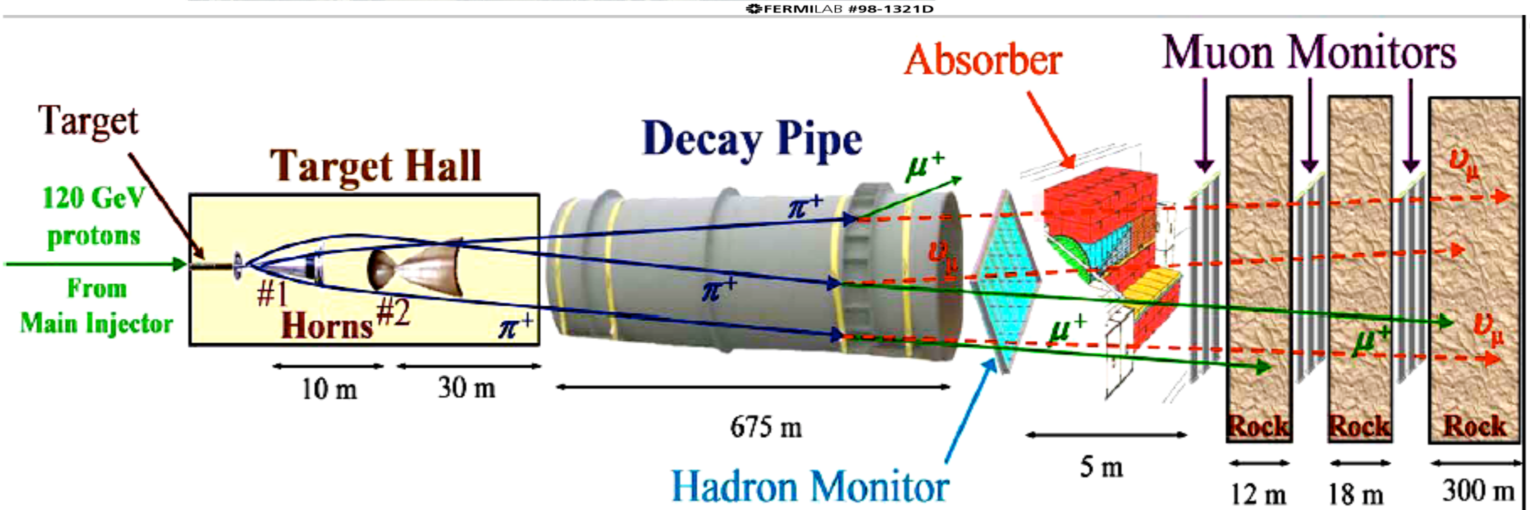


Source of Low Energy Neutrinos II - MINERνA

Fermilab Accelerator Complex with MI (120 GeV p) **NuMI Neutrino Beam**







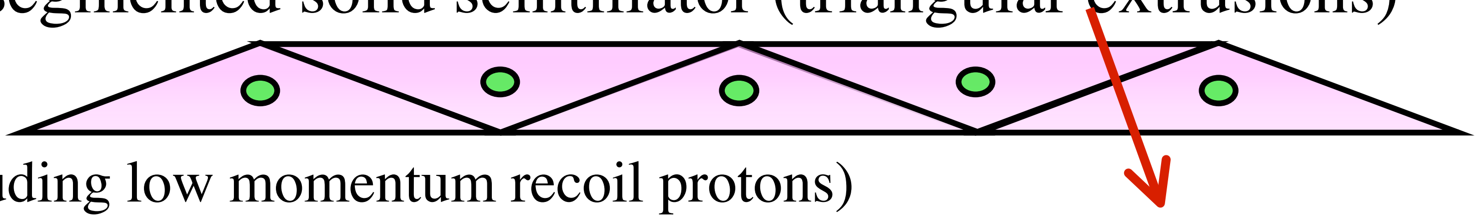
The MINERνA Experiment

http://minerva.fnal.gov/

- MINERνA
  - a dedicated low-energy neutrino nucleus scattering experiment
  - A low-risk detector with simple, well-understood technology
  - installed in the NuMI near hall just upstream of the MINOS near detector.
- MINERνA goals
  - measurements of low-energy exclusive and inclusive total and differential neutrino cross sections
  - studies of the nuclear effects on these cross sections and on neutrino-induced hadron showers.
- MINERνA provides
  - critical input for reducing the systematics of the NuMI and T2K program
  - an opportunity to use the axial current for studies of nucleon structure and nuclear effects topics of joint interest to the HEP and NP communities
- The MINERνA Collaboration - 19 institutions, 76 people
  - Experts from two communities - HEP and NP

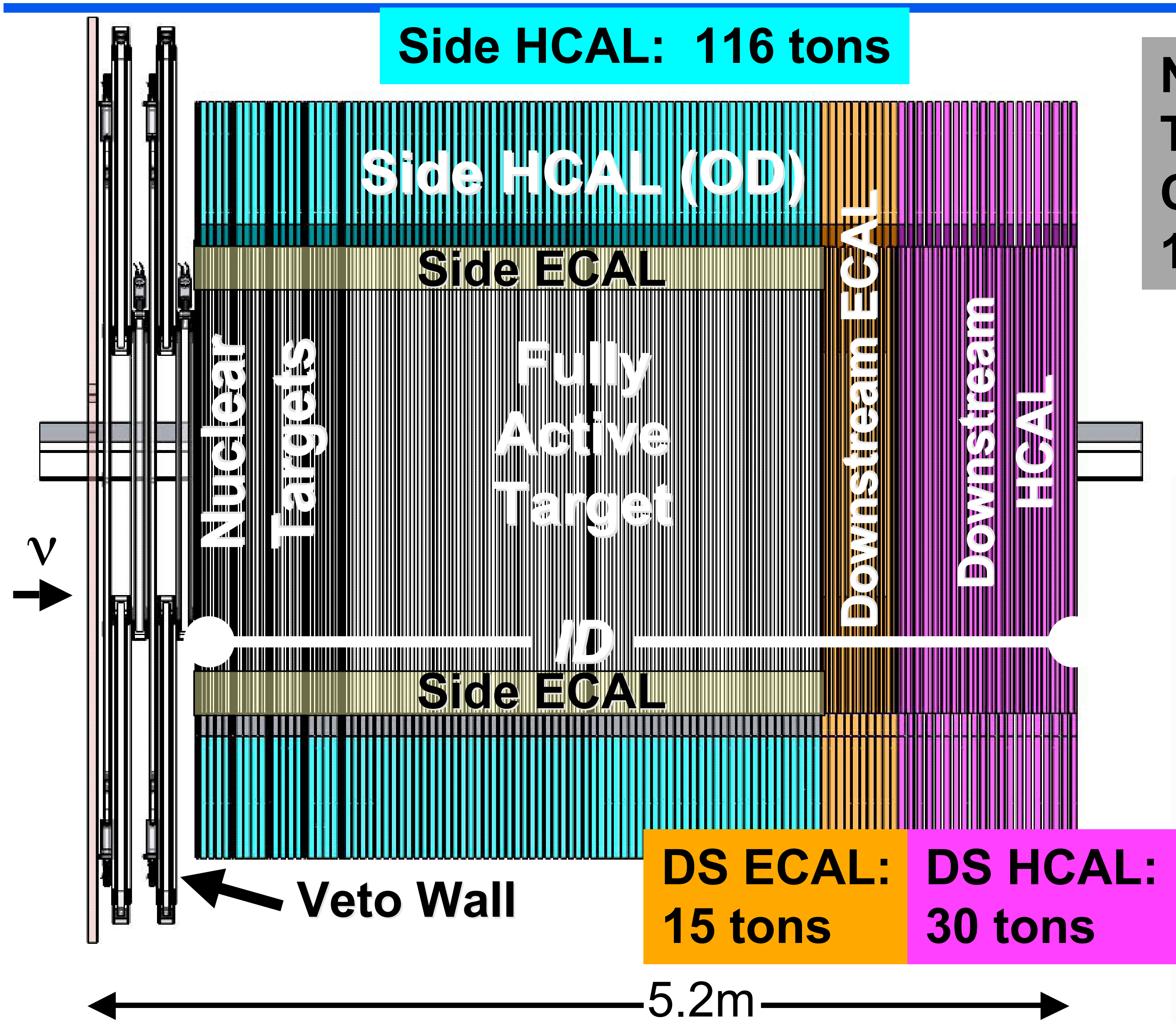
The MINERνA Detector and Schedule

- Active core is segmented solid scintillator (triangular extrusions)



  - tracking (including low momentum recoil protons)
  - particle identification (many dE/dx samples)
  - few ns timing (track direction, identify stopped $K^{\pm}$)
- Surrounded by electromagnetic and then hadronic calorimeters
  - photon (π^0) and hadron ($\pi^{\pm}$) energy measurement
- C, Fe and Pb nuclear targets upstream of solid scintillator core
- MINOS Near detector as high-energy μ spectrometer.
- Schedule
  - 2006 Continue R&D
  - 2007 Build Tracking Prototype (≈ 20% of detector)
  - 2008 Construction Begins
  - 2009 Installation and begin data taking

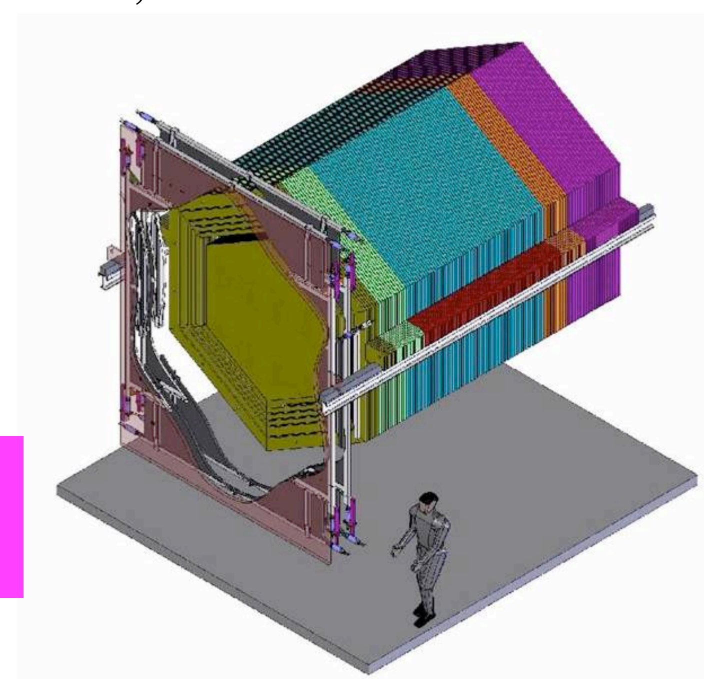
MINERνA Detector



Nuclear Targets: C, Fe and Pb 1.5 tons

Fully Active Target: 8.3 tons

x, u and v stereo views



MINERνA Expected Results

13 Million total CC events in a 4-year run in the NuMI Beam

Assume 16**.0x10^{20} in LE and ME NuMI beam configurations in 4 years**

Fiducial Volume = 3 tons CH, ≈ 0.6 t C, ≈ 1 t Fe and ≈ 1 t Pb
Expected CC event samples:
8.6 M ν events in CH
1.5 M ν events in C
1.5 M ν events in Fe
1.5 M ν events in Pb

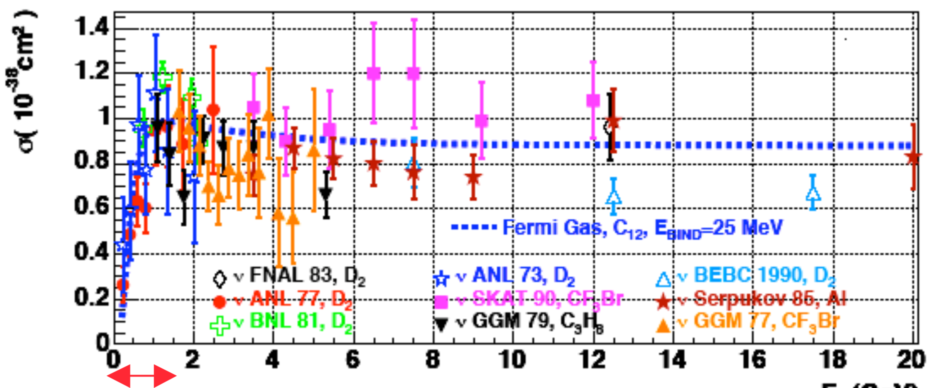
Main CC Physics Topics (Statistics in CH)

◆ Quasi-elastic	0.8 M events
◆ Resonance Production	1.6 M total
◆ Transition: Resonance to DIS	2 M events
◆ DIS, Structure Fncs. and high-x PDFs	4.1 M DIS events
◆ Coherent Pion Production	85 K CC / 37 K NC
◆ Strange and Charm Particle Production	> 230 K fully reconstructed events
◆ Generalized Parton Distributions	order 10 K events
◆ Nuclear Effects	C:1.5 M, Fe: 1.5 M and Pb: 1.5 M

MINERνA Expected Results

- σ_{QE}

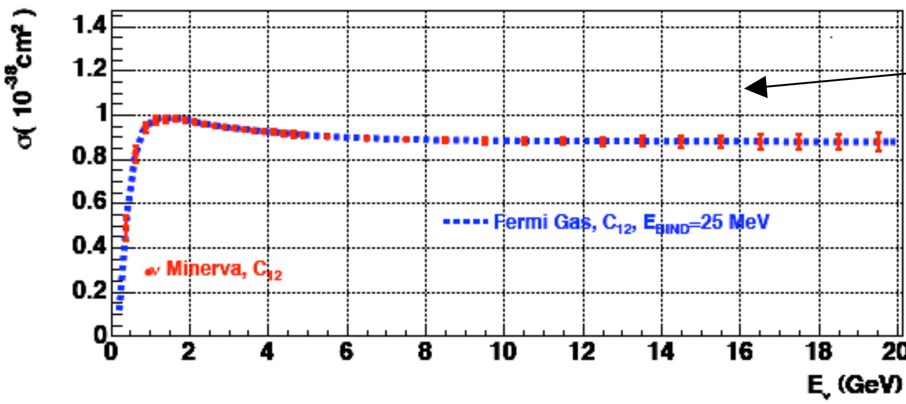
Current Results



K2K and
MiniBooNe

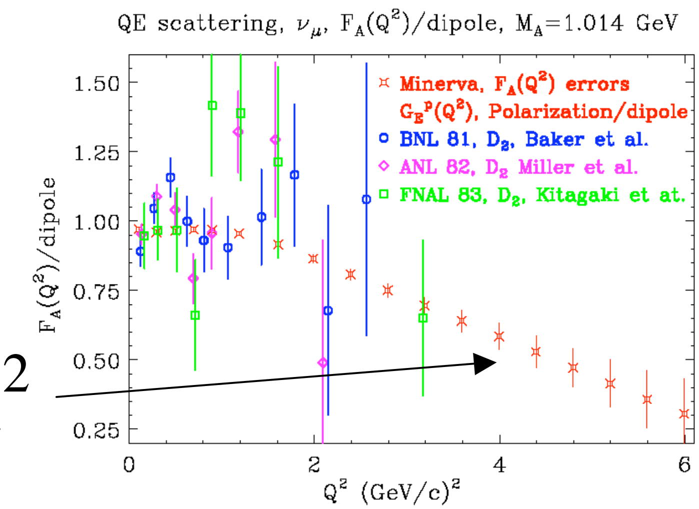
MINERνA Expected Results

- σ_{QE} and high Q^2 axial form factor of nucleon
  (complements high Q^2 vector FF from JLab)

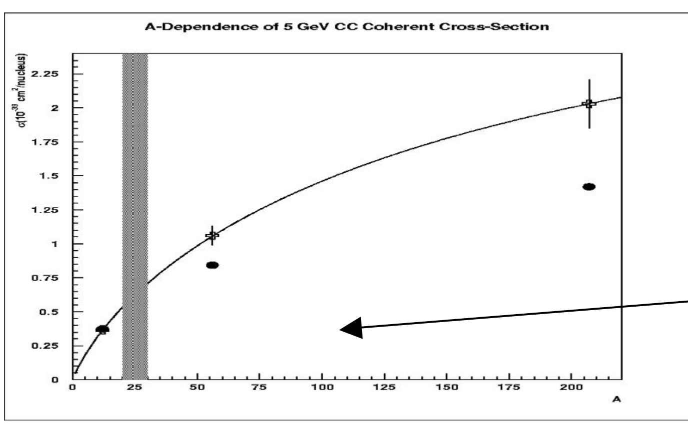


σ vs E_ν

F_A vs Q^2

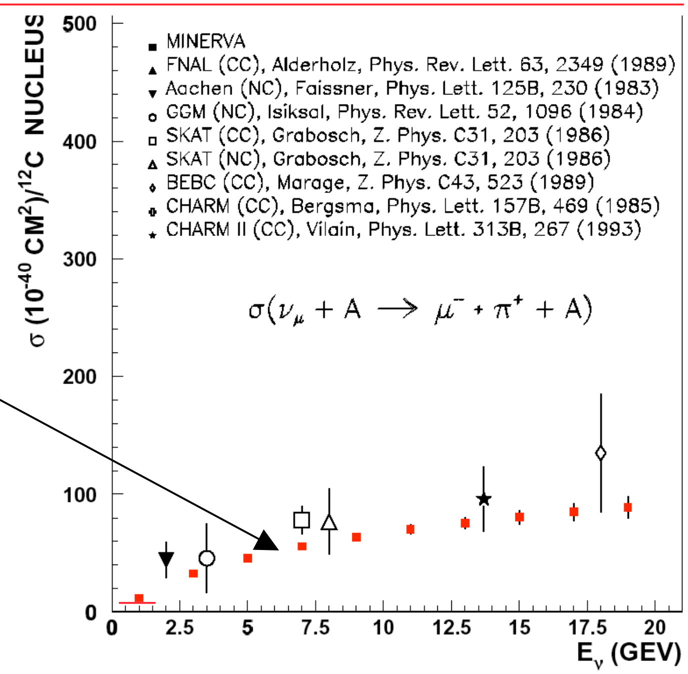


- Coherent cross-sections vs. energy
  (exploit resolution, containing detector)



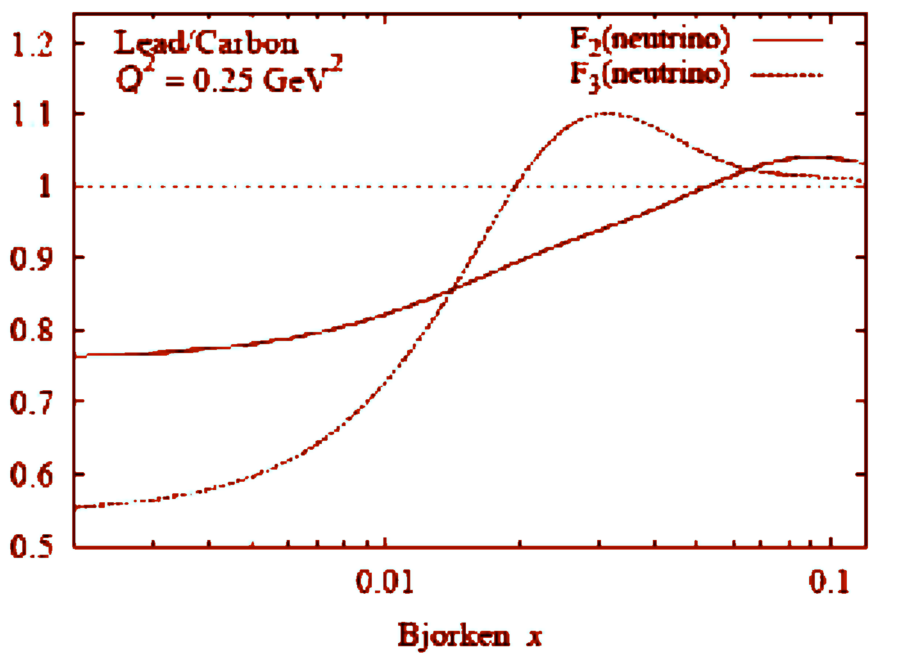
σ vs E_ν

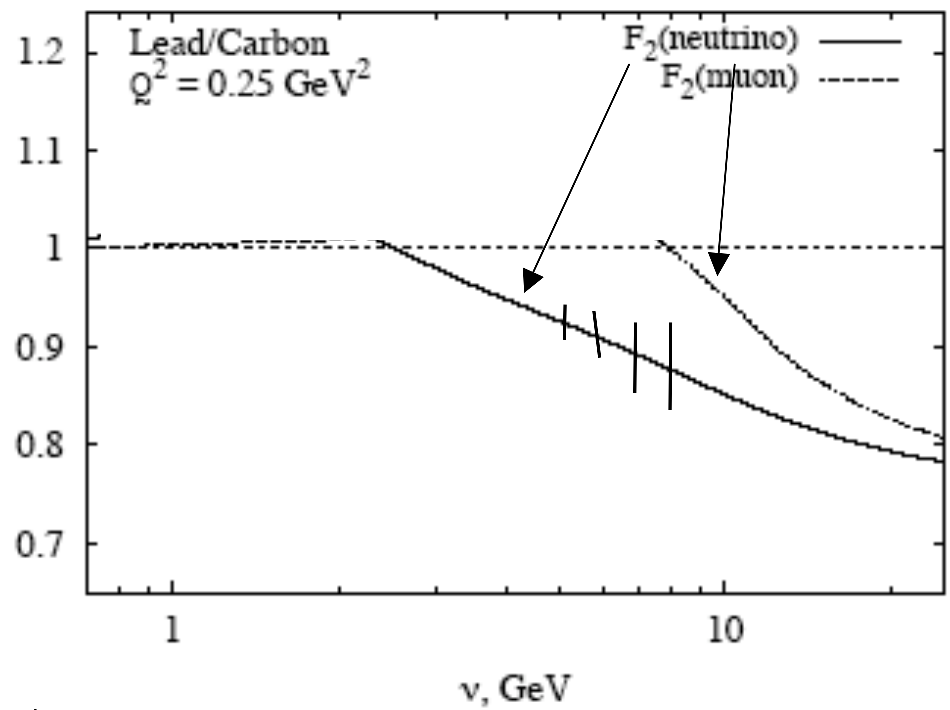
σ vs A



MINERνA Physics Results

- Nuclear Effects:
  - Detect the difference in nuclear effects between μ/e and ν
  - exclusive final states (nuclear re-interactions)
  - Direct measurement of flavor-dependent nuclear effects in (F_2, xF_3)



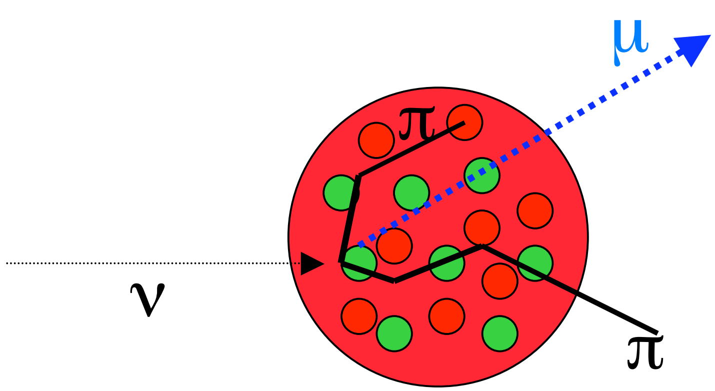


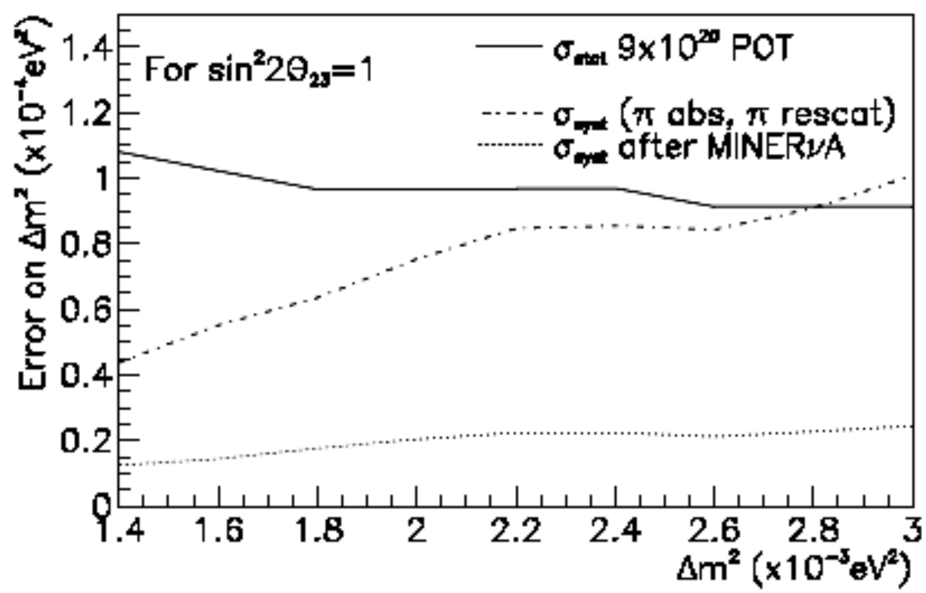
S. Kulagin

Neutrino Interaction Uncertainties and Oscillation Measurements

D. Harris et al. hep-ex/0410005

- How MINERνA helps **MINOS**
  - MINOS goal - precision Δm^2 from ν_μ disappearance vs. E_ν
  - Biggest systematic concern: **correctly measuring the E_ν**?
    - » π absorption, rescattering and charge exchange
    - » Cross sections for 1,2..n π production





Reduction in total error via reduced systematic error equivalent to 1 full year of protons on the NuMI target

Summary

- **There is an obvious and crucial need for the measurement of exclusive cross sections and the study of nuclear effects for neutrinos in the 10 MeV to 10 GeV energy range**

- **νSNS** will measure ν capture cross sections in a range of nuclei relevant for the study of supernova core collapse

- **SciBooNE** in the Fermilab BNB will measure cross sections (ν **and** ν) at energies relevant for T2K oscillation studies

- **MINERνA** in the Fermilab NuMI beam will measure cross sections and nuclear effects (ν **and** ν) at energies relevant for T2K and NuMI oscillation studies and study nucleon structure from quasi-elastic, resonance, through the transition region to DIS

- **Theorists** have also been active. Paschos - Lalakulich and Lee - Sato have been studying ν-resonance production. More details, experimental and theoretical, can be found in the NuInt series of workshops with NuInt07 to be held at FNAL 5/07