SciBooNE: a ν Experiment at Fermilab

R.J. Tesarek
Fermilab

University of Michigan Seminar 1/8/07

Outline

Neutrino Mixing/Oscillations

Oscillation Measurements Status/Future

Input to Oscillation Measurements

The SciBooNE Experiment

SciBooNE Physics

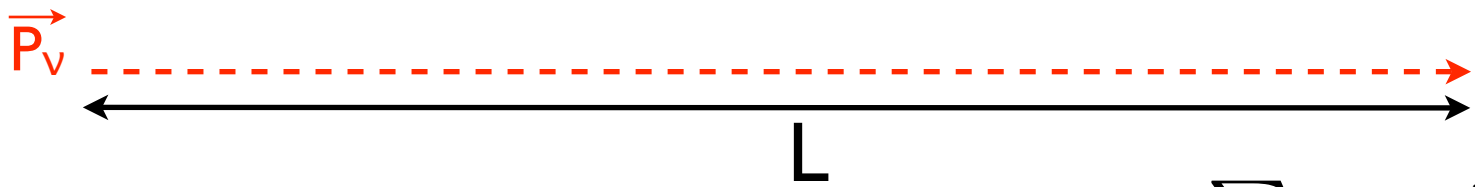
Status and Schedule

Summary

Neutrino Mixing/Oscillations

Example:

- Simple, 2 state quantum mechanical system:



$$|\nu_\alpha(0)>=\sum_i U^*|\nu_i> \qquad |\nu_\alpha(L)>=\sum_i U^*_{\alpha,i}e^{-i(m_i^2/2E)L}|\nu_i>$$

$$U=\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Assumptions:

- $E_\nu >> m_\nu$

$$P(\nu_\alpha\to\nu_\beta)=|<\nu_\alpha|\nu_\beta>|^2\approx\sin^2 2\theta\sin^2\left(1.27\frac{\Delta m^2 L}{E}\right)$$

For fixed Δm^2, P_{osc} depends on L/E

- modifies number of ν_α observed at L
- modifies $E(\nu_\alpha)$ observed at L

3 Component Oscillations/Mixing

Mixing similar to quark Cabibbo-Kobayashi-Maskawa (CKM) matrix

- 3 angles
- 1 phase (CP violating)
- Assuming no Majorana neutrinos ($\nu = \overline{\nu}$)

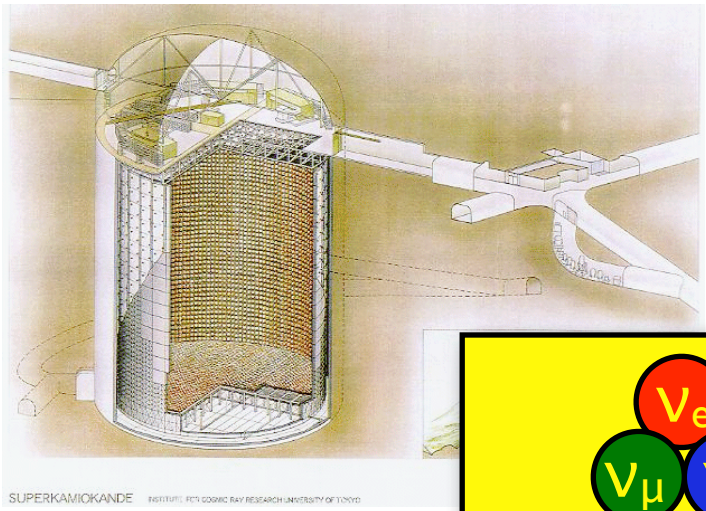
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

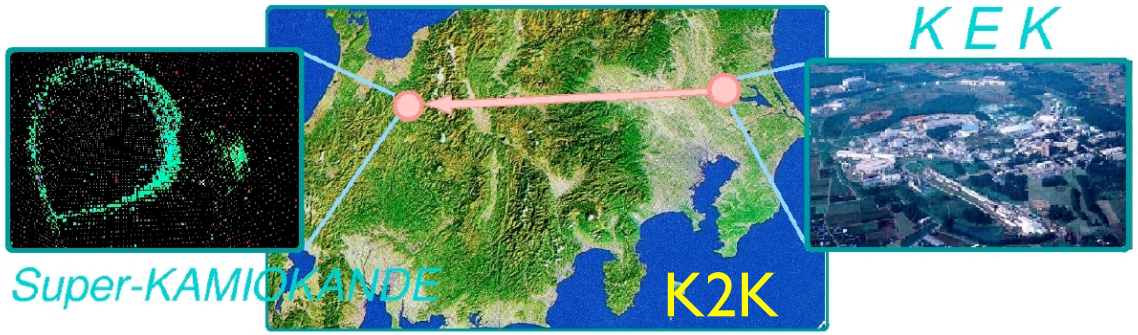
$$c_{ij} = \cos\theta_{ij}$$
$$s_{ij} = \sin\theta_{ij}$$

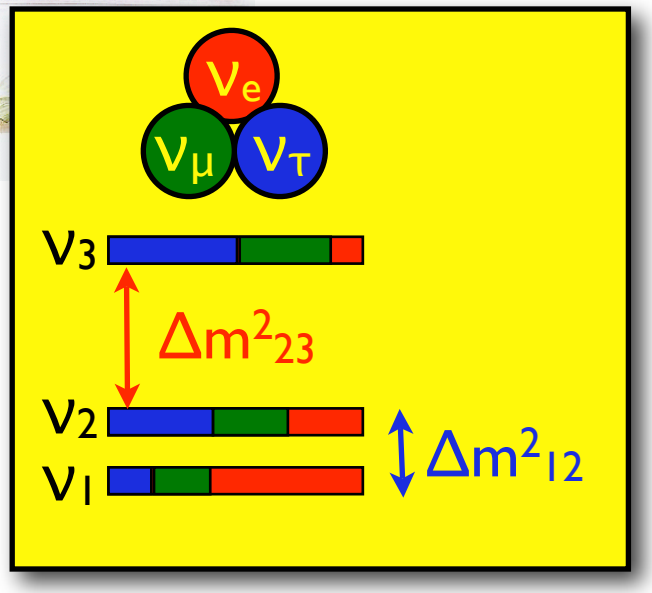
phase allows for CP violation

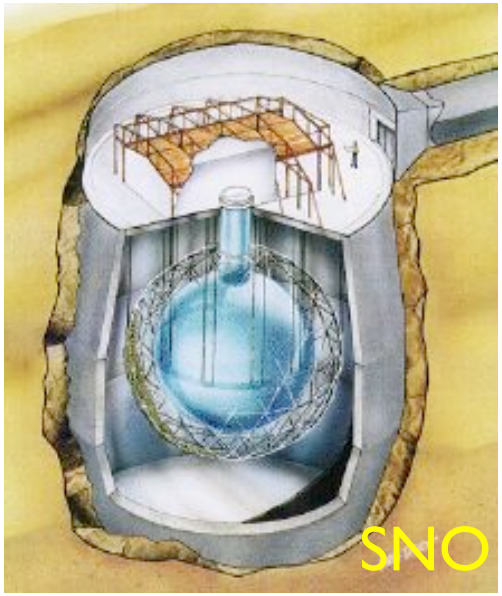
Neutrino Oscillations (1998 - 2005)

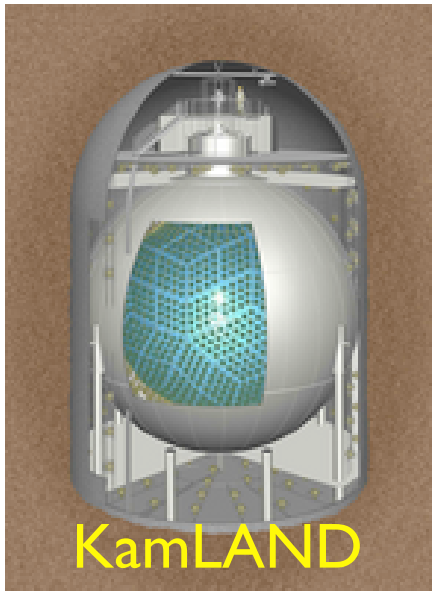
Super-Kamiokande









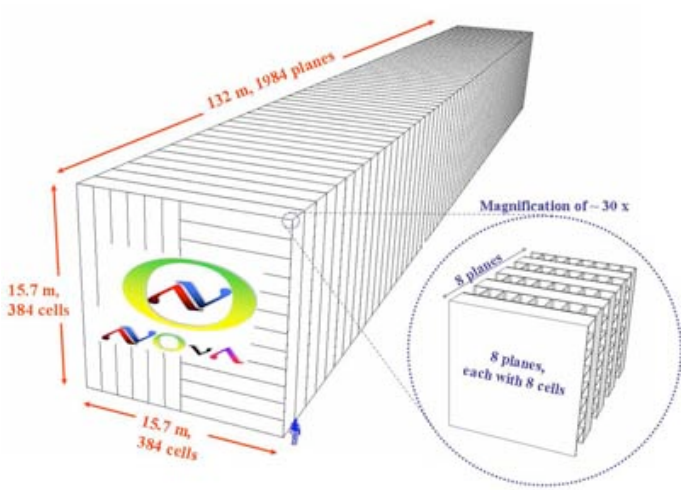


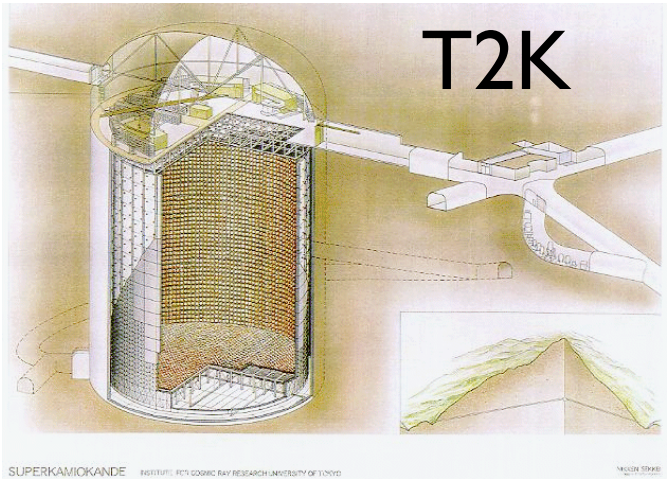
Measurements establish:

- Neutrino Masses (Δm^2_{12}, Δm^2_{23})
- Mixing Angles (θ_{12},θ_{23})

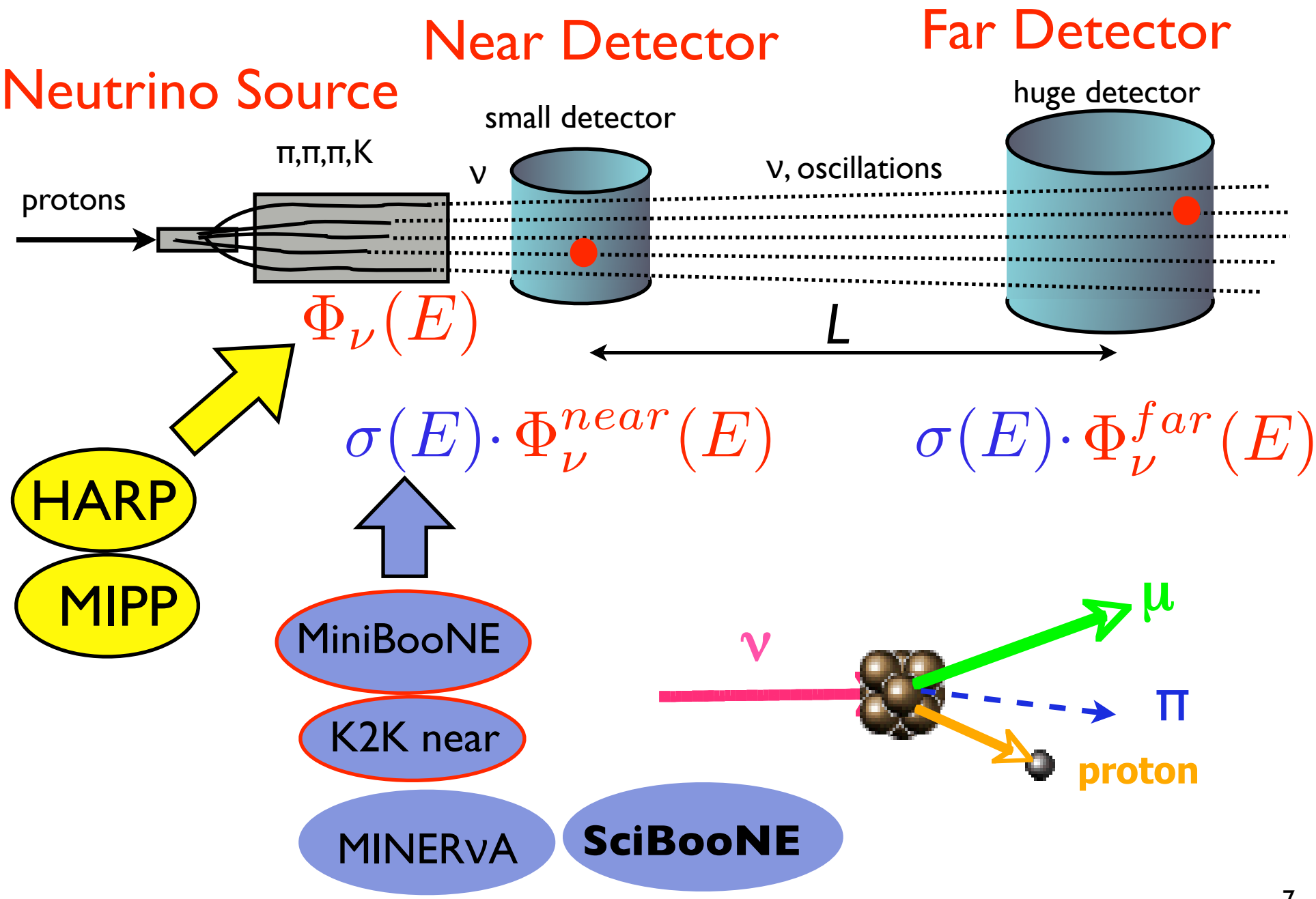
Next Step (2006 - 2015)

- Measure the last oscillation channel
  - θ_{13}
- CP violation in lepton sector (ν, $\bar{\nu}$)
  - δ
- Mass heirarchy
  - sign of Δm^2_{23}
- Test of standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations (Δm^2_{23}, θ_{23})



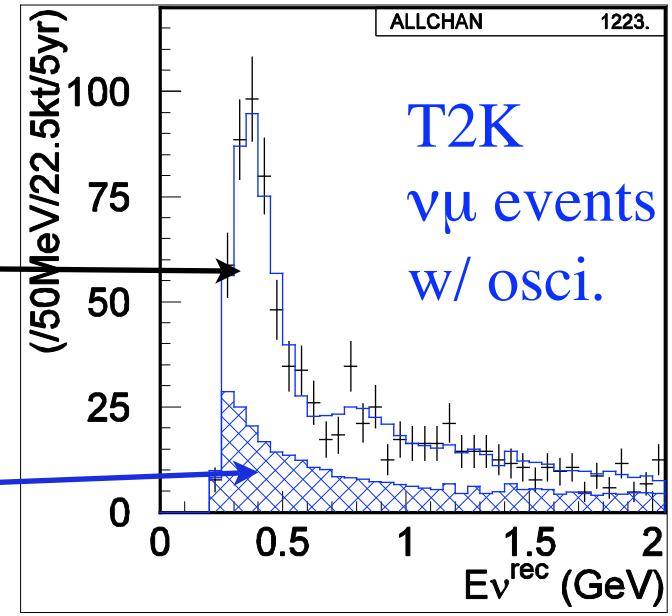


Accelerator based ν Oscillation Measurements

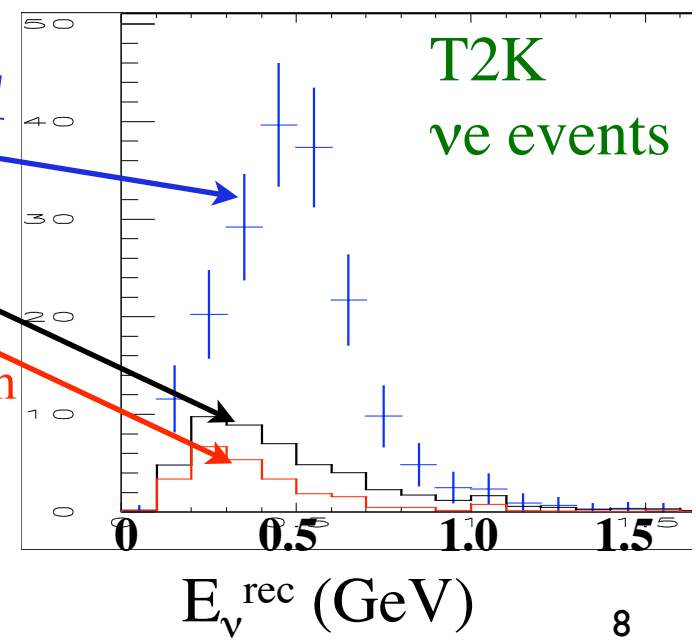


Impact of Neutrino Cross Sections on Oscillation Measurements

- $\nu_\mu \rightarrow \nu_\mu$: precision measurements (θ_{23} and Δm_{23}^2)
  - Signal: CC-QE ($\nu+n \rightarrow \mu+p$)
    - Energy Reconstruction from μ kinematics
  - Background: Mainly CC-1$\pi^\pm$ ($\nu+N \rightarrow \mu+\pi+N'$)
    - Cross section with **the visibility of π**
- $\nu_\mu \rightarrow \nu_e$: search for θ_{13}
  - Signal: CC-QE ($\nu+n \rightarrow e+p$)
  - Background
    - Beam ν_e
    - NCπ^0
      - Cross section as a function of the momentum



$\sin^2 2\theta_{13} = 0.1$

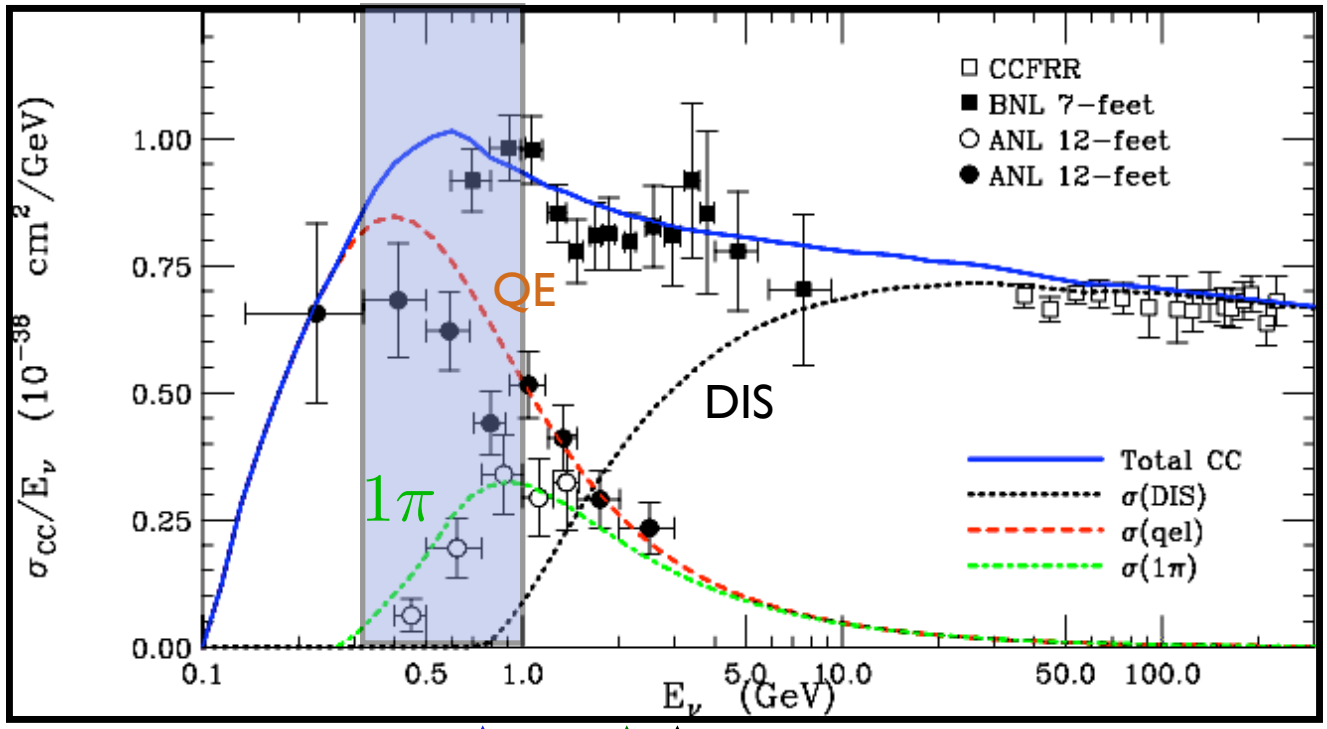


Anti-neutrinos for CP violation study

Unexplored Areas of Neutrino Physics

- **Data from old experiments** (1970~1980)
  - Low statistics
  - Systematic Uncertainties
- **Nuclear effects** (π/p/n absorption/scattering, shadowing, low Q^2 region)
  - Not well-modeled
- **New data** from MiniBooNE & K2K revealing surprises
- **More data at 1GeV with fine grained resolution will advance Neutrino Physics.**

σ_ν energy range of interest



MINOS, NuMI

K2K, NOνA

MiniBooNE, T2K, SciBooNE

Super-K atmospheric ν

Existing Cross Section Measurements

What's Missing from K2K and MiniBooNE Cross Section Measurements?

- Good Q^2 resolution to understand nuclear effects
  - Need true nuclear models in Monte Carlo
- Resonant/coherent separation for background measurements
- Multiparticle final states
- Antineutrino measurements
- Absolute σ measurements for non-QE channels

Needed to tune neutrino cross section Monte Carlos

All needed for next generation oscillation measurements

Prototype Experiment

Fine-segmented tracking detector with an intense low energy neutrino beam.

- SciBar Detector
  - + Well working tracking detector in K2K
  - + Fine granularity (2.5x1.3 cm^2) Fully Active
  - + Particle ID capability
- FNAL Booster Neutrino Beam
  - + Intense, low energy (~ 1 GeV) beam
  - + Both neutrinos and anti-neutrinos.
  - + Beam well-understood from hadron production experiments (HARP/BNL-E910).

SciBooNE Experiment

What is SciBooNE?

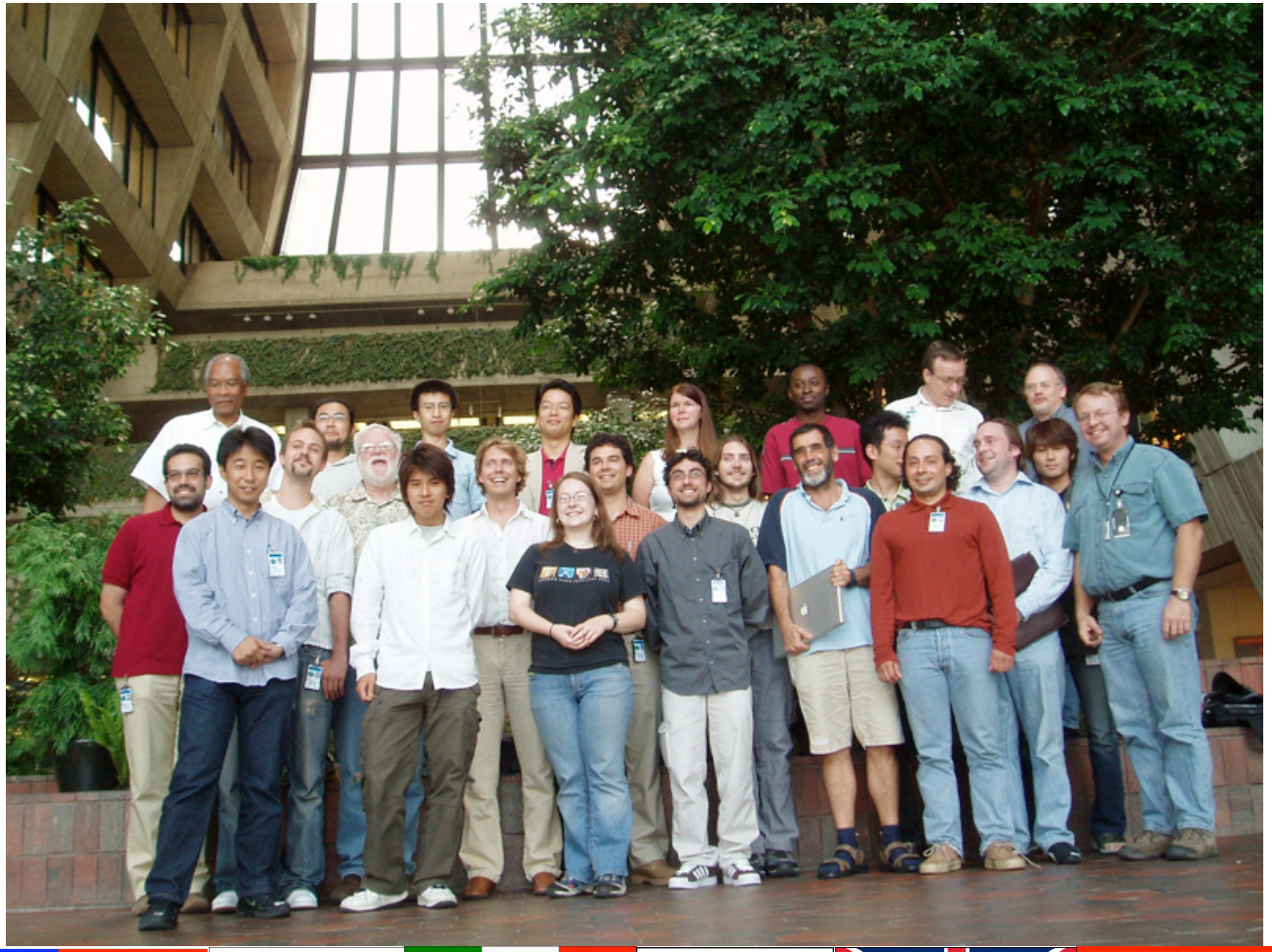
- A new Fermilab experiment to measure cross sections in the booster neutrino beam.
- Small, cheap, focused, short time scale experiment.

How to make a small, cheap focused short time scale experiment

- Re-cycle detector materials from previous experiments.
- Use an existing beam line
- Young, highly motivated collaboration

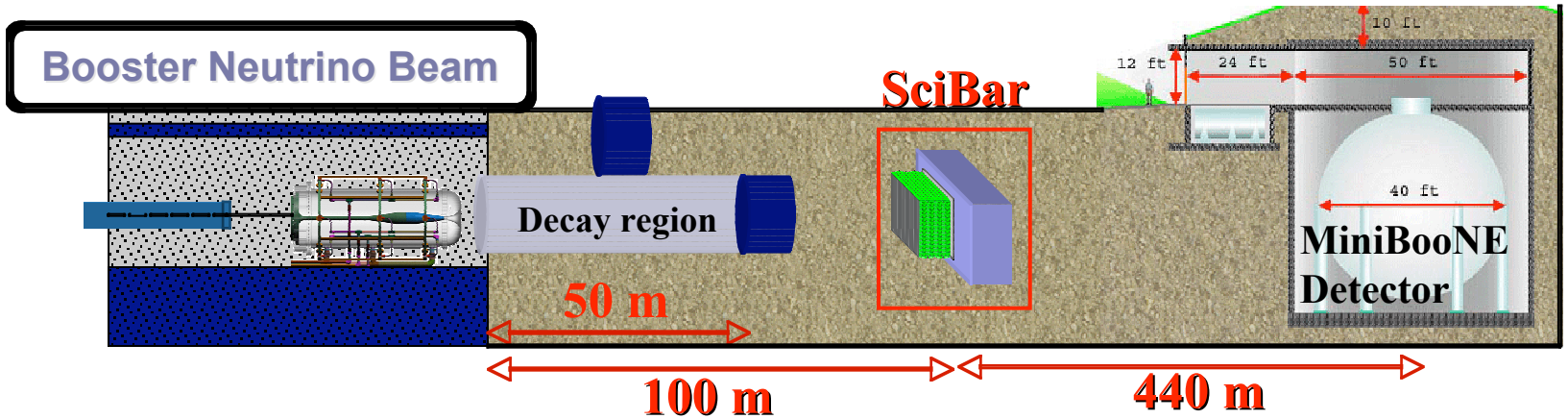
SciBooNE Collaboration

- Universitat Autonoma de Barcelona
- Chonnam National University
- University of Cincinati
- University of Colorado
- Columbia University
- Dongshin University
- Fermilab
- KEK
- Imperial College London
- Indiana University
- Institute for Cosmic Ray Research
- Kyoto Univerisity
- Los Alamos
- Louisiana State University
- Purdue University Calumet
- Universita degli Studi di Roma "La Sapienza"
- St Mary's University of Minnesota
- Seoul National University
- Tokyo Tech
- Universidad de Valencia



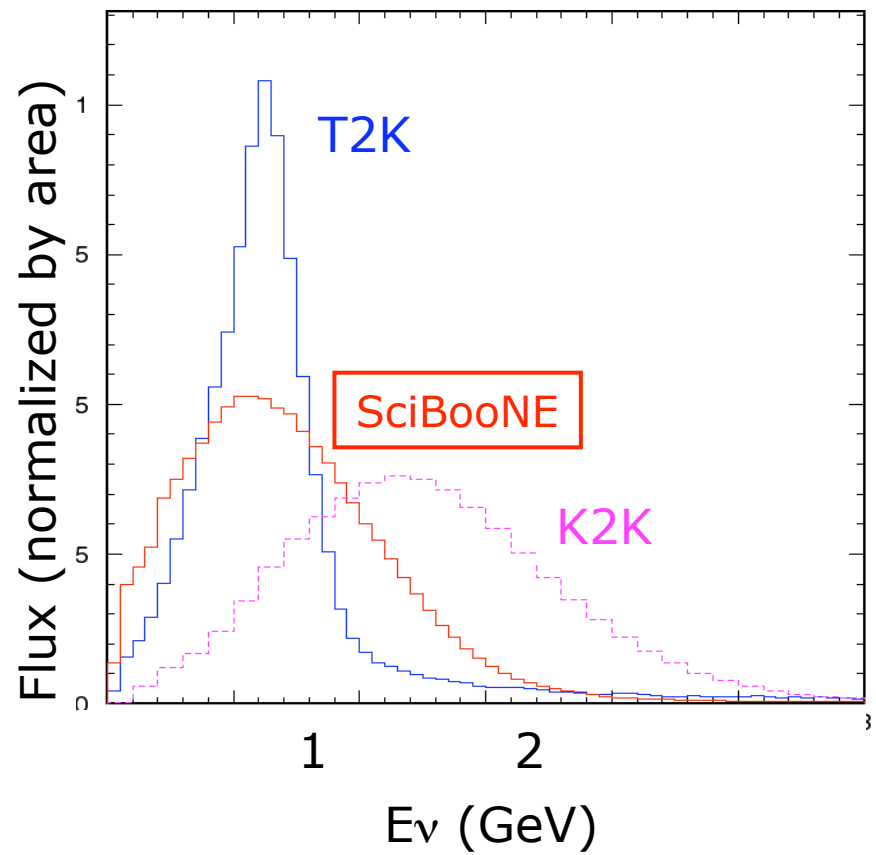
66 Collaborators 19 Institutions 6 Countries

SciBooNE Experiment

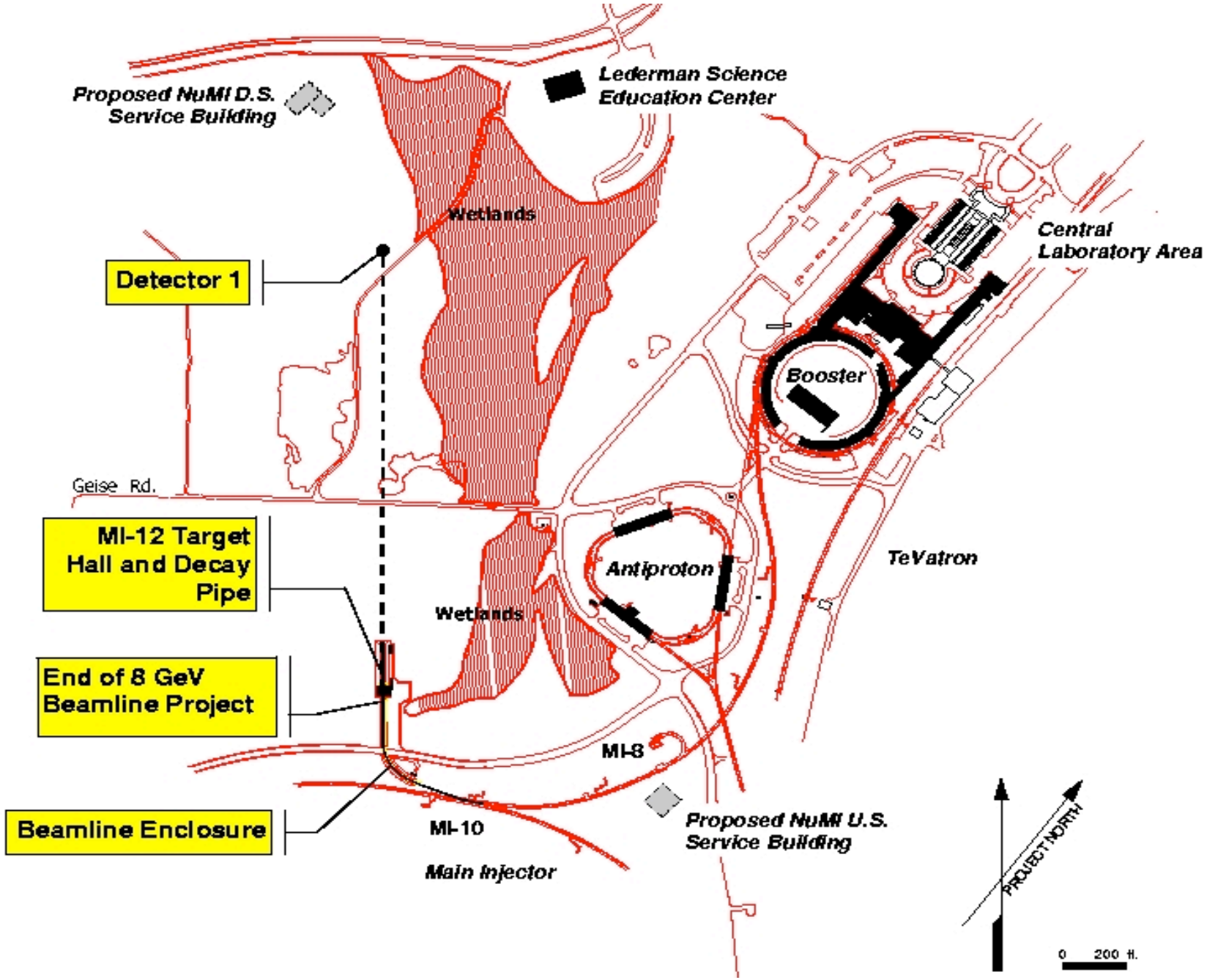


Booster Neutrino Beam

- 8 GeV protons on Be target
- Horn focuses 1 charge sign (π,K)
- π,K decay to neutrinos
- Undecayed beam & daughter particles stopped
- Neutrino spectrum similar to T2K

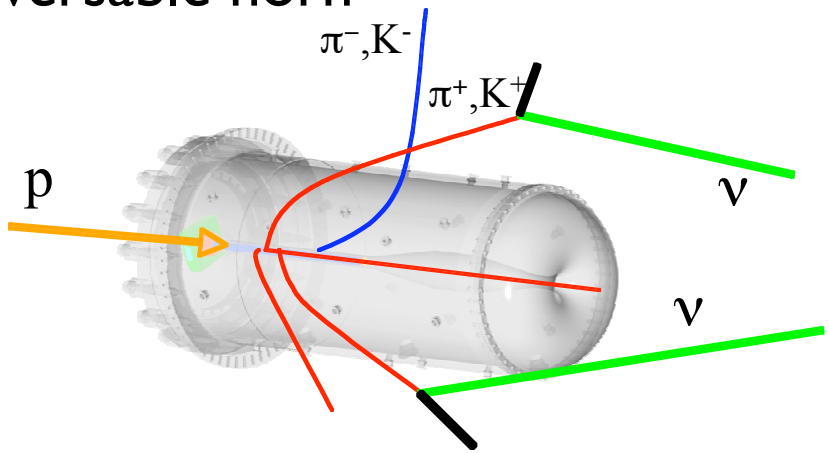


SciBooNE Location

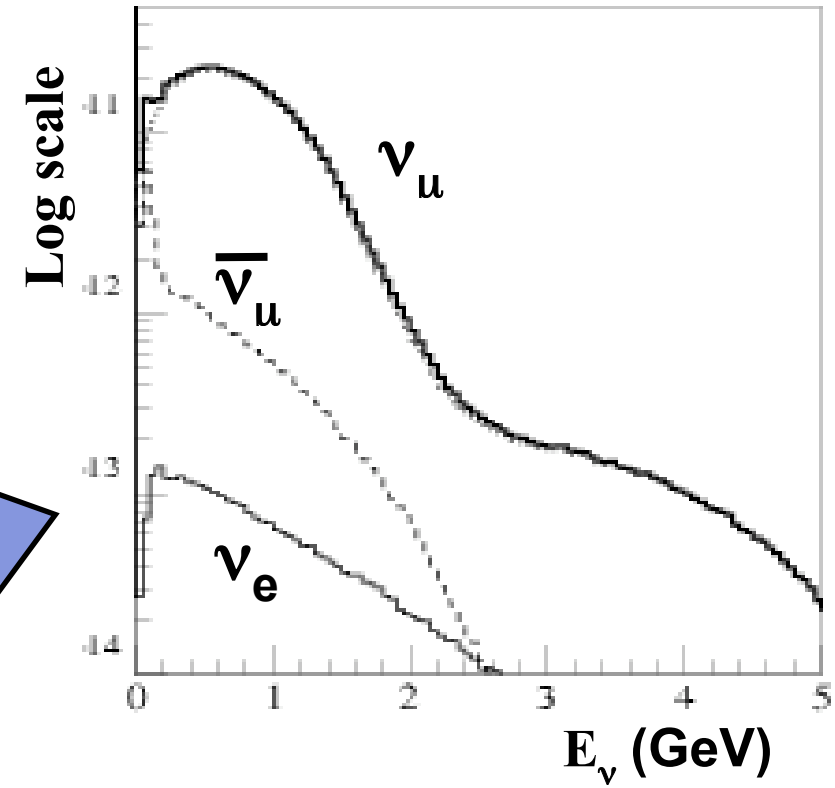


FNAL Booster Neutrino Beam

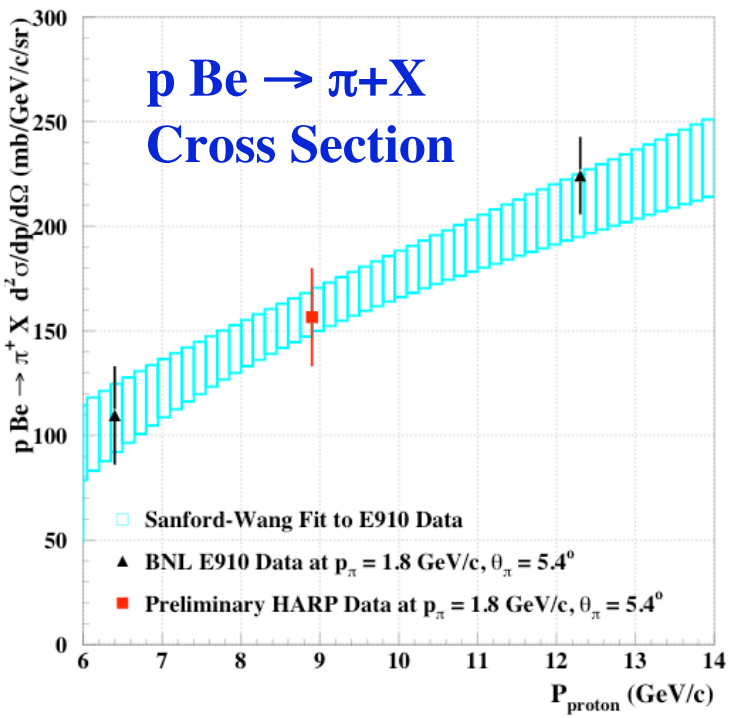
Reversable horn



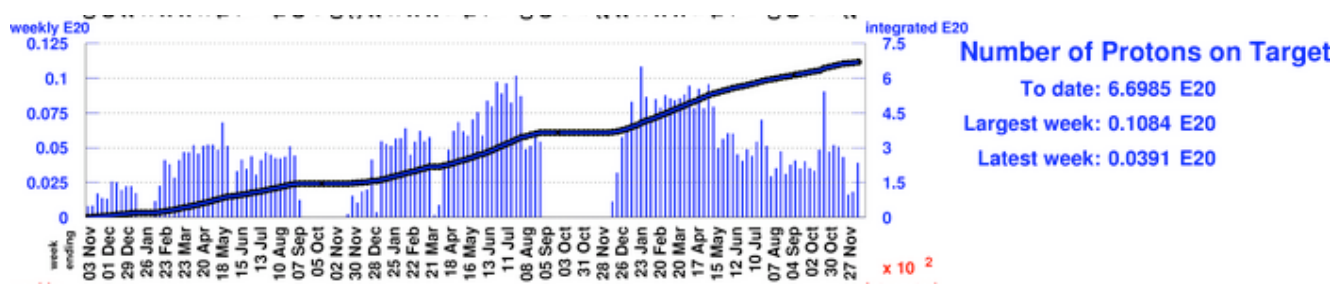
Relative neutrino fluxes



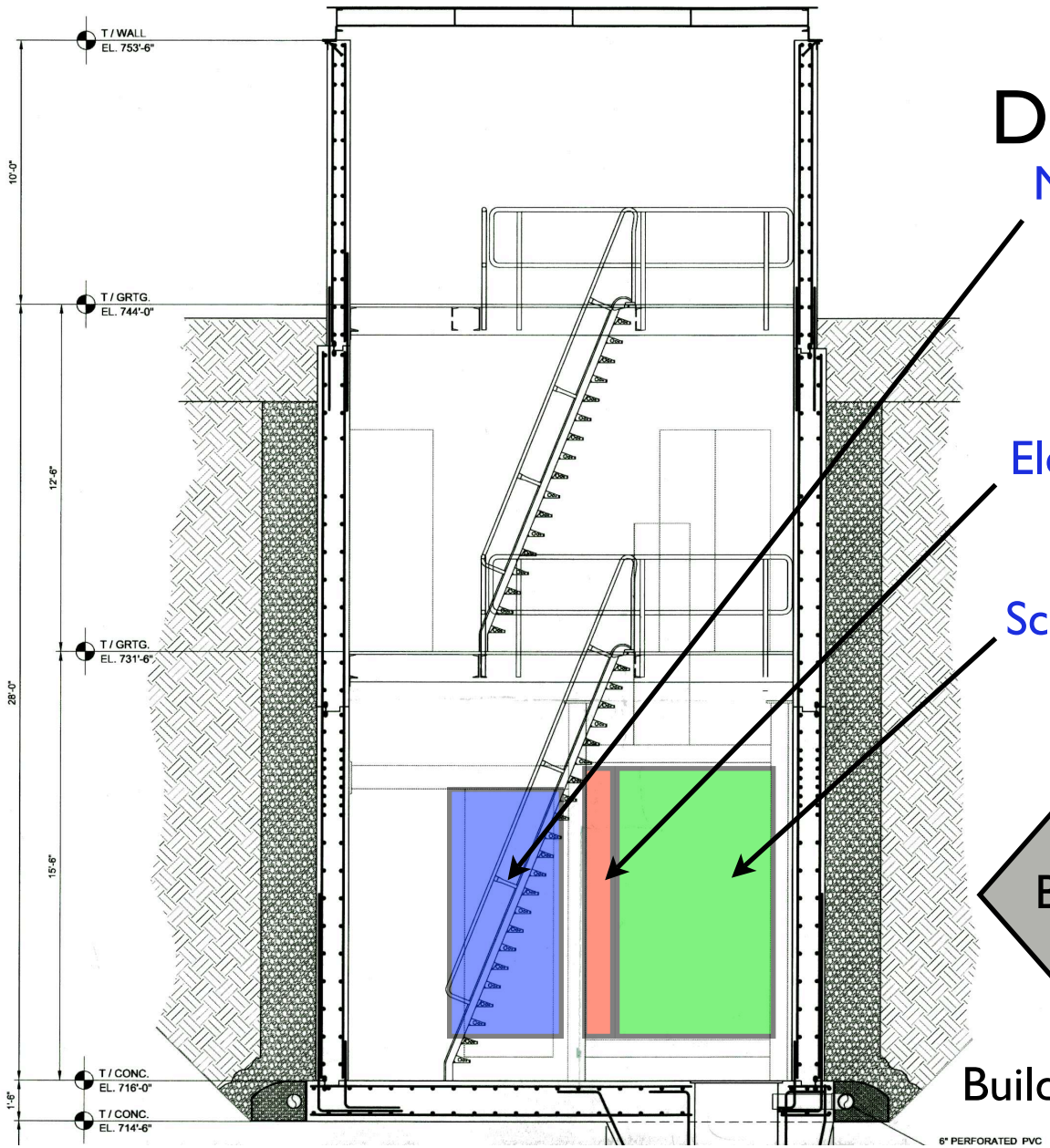
From BNL-E910



6.7E20 POT/3 years



Recycled Detectors



Detector:

Muon Range Detector
- re-used scintillator (E605)
- re-used steel plates (E605)
- re-use PMTs (KTeV, NuTeV, etc.)

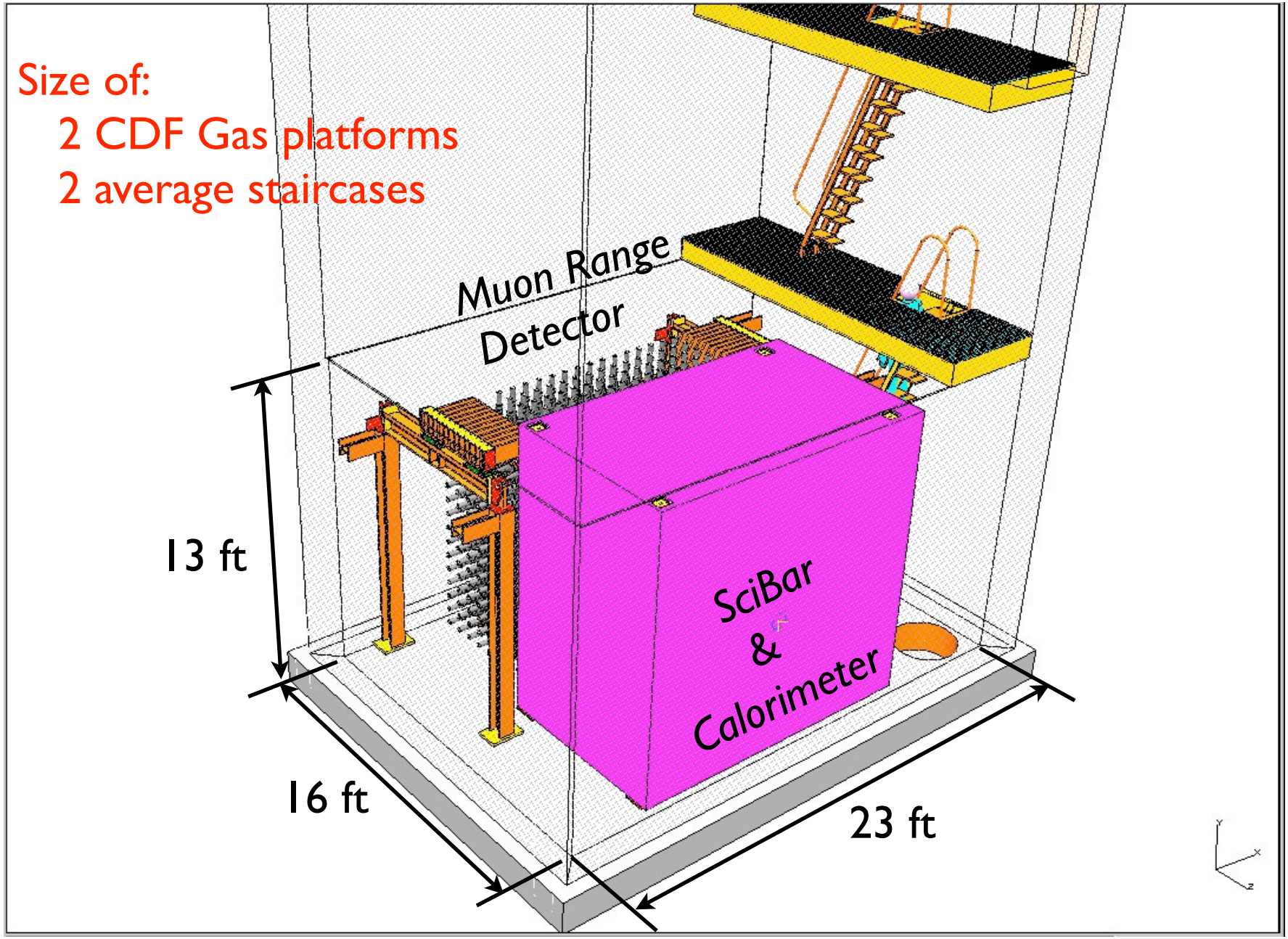
Electromagnetic Calorimeter
- re-used from K2K/CHORUS

SciBar (target/tracker)
- re-used from K2K

Booster Neutrino Beam

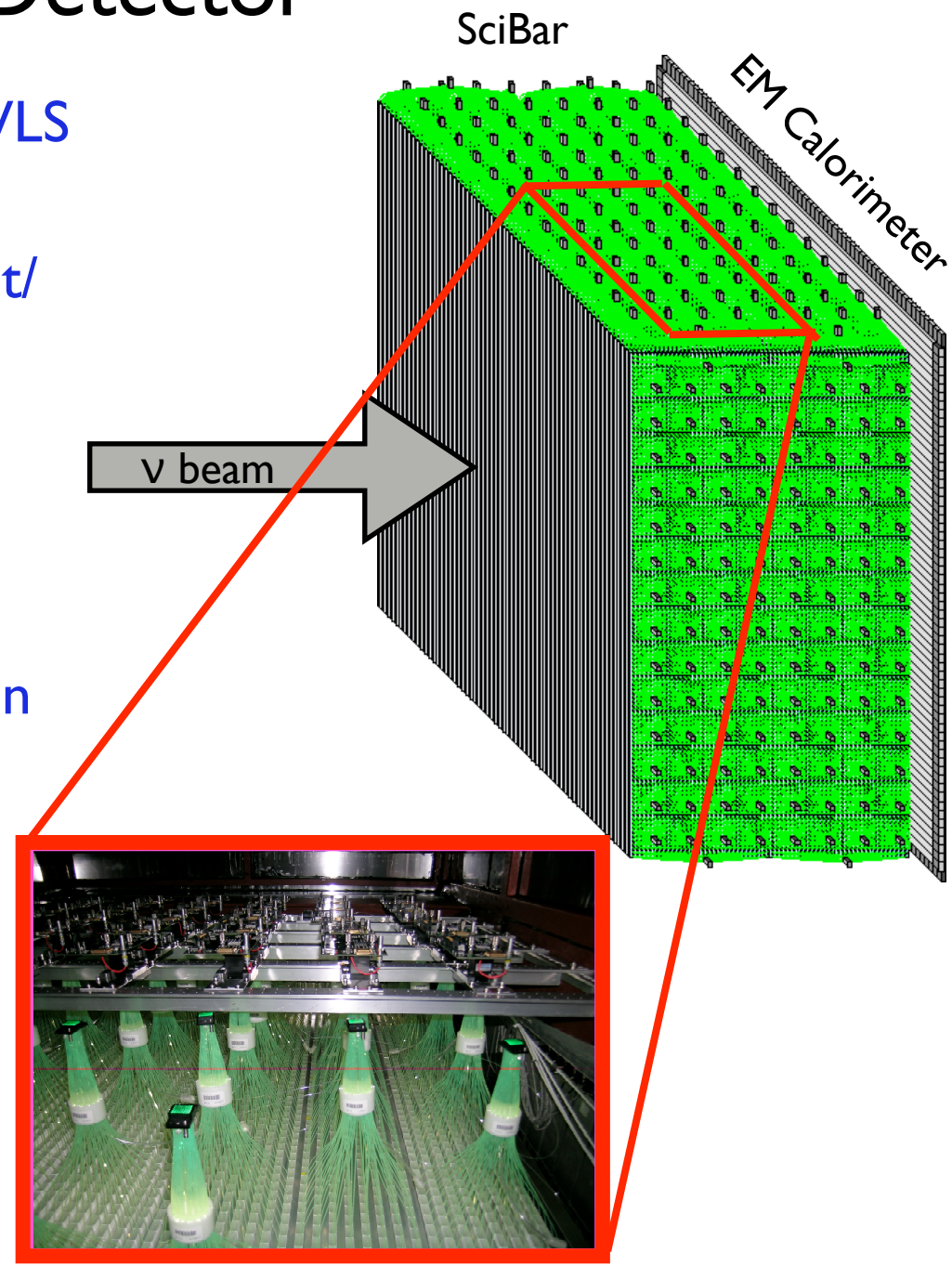
Building Dimensions: 19'x26'x28' deep

3D View of SciBooNE

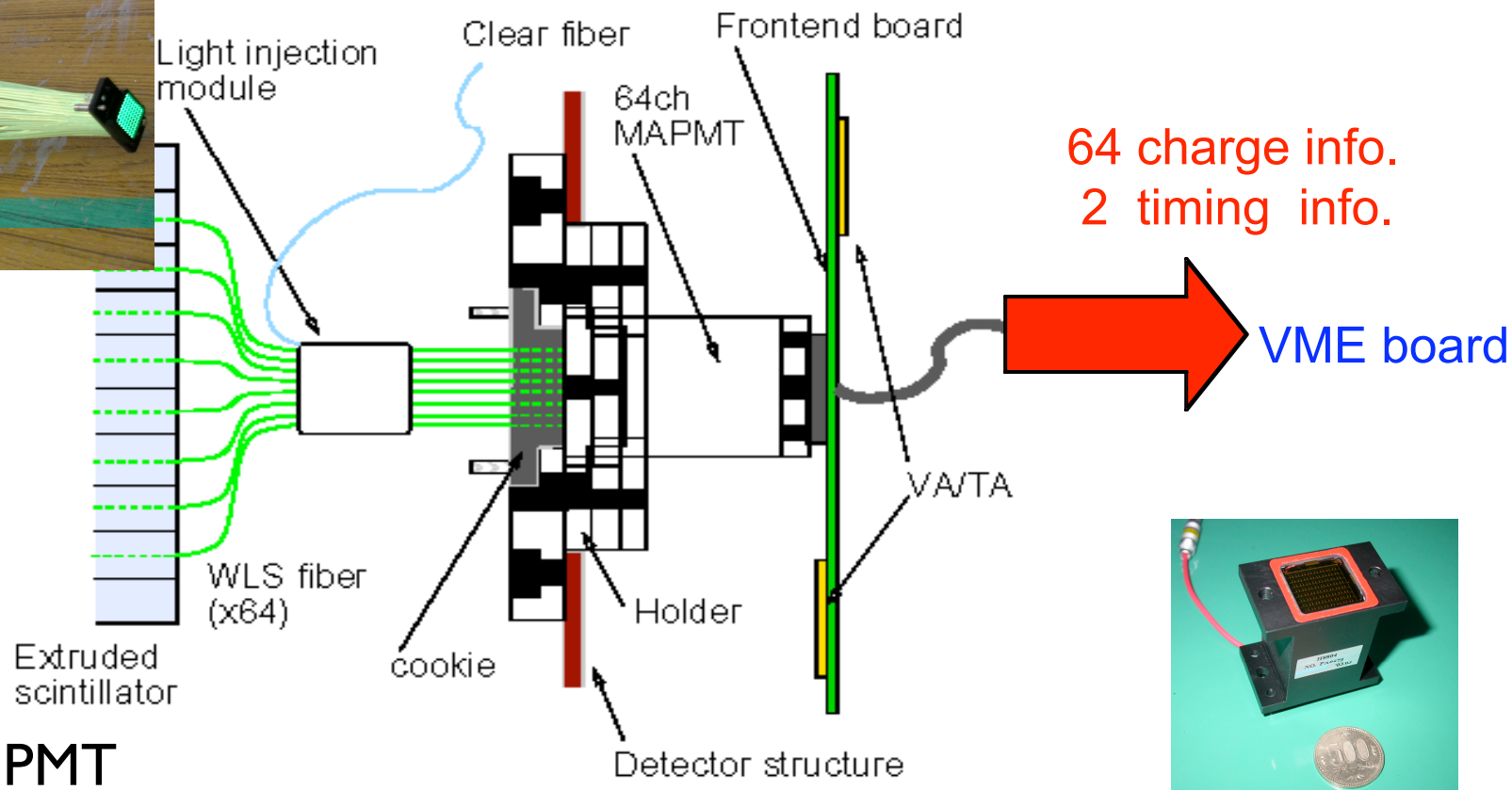


SciBar Detector

- Extruded scintillator with WLS fiber readout
- Scintillator is neutrino target/ tracker
- 2.5 x 1.3 x 300 cm3 cells
- 15000 channels
- detect short tracks (> 8cm)
- Distinguish proton from pion using dE/dx
- Total 15 tons
- High track finding efficiency (>99%)
- Clear identification of ν interaction process



SciBar Readout



Multi-Anode PMT

- 2x2 mm^2 pixel (3% cross talk @ 1.5mm dia.)
- Gain uniformity (20% RMS)
- Good Linearity (~200 p.e. @ gain = 6×10^5)

VA/TA Readout

- ADC for all 14,400 channels
- TDC for 450 stes (32 channel-OR)

SciBar Characteristics

Structure	Dimensions	3 m (horizontal), 3 m (vertical), 1.7m (thickness)
	Weight	15 tons
	Number of strips	14,848
	Number of PMTs	224
Scintillator	Material	Polystyrene with PPO(1%) and POPOP(0.03%)
	Size	$2.5 \times 1.3 \times 300$ cm^2
	Coating	0.25 mm (TiO_2)
	Emission wavelength	420 nm (peak)
Fiber	Type	Kuraray Y11(200)MS
	Diameter	1.5 mm
	Refractive index	1.59 (outer)/ 1.50 (middle)/ 1.42 (inner)
	Absorption wavelength	430 nm (peak)
	Emission wavelength	476 nm (peak)
	Attenuation length	350 cm
PMT	Model	Hamamatsu H8804
	Cathode material	Bialkali
	Anode	8×8 (2×2 mm^2/pixel)
	Quantum efficiency	12% for 500 nm photons
	Typical gain	6×10^5 at ~ 800 V
	Response linearity	200 PE at gain of 6×10^5
	Cross talk	4% (adjacent pixel)
DAQ	VA/TA ASIC	IDEAS VA32HDR11 and TA32CG
	Shaping time	1.2 μsec (VA), 80 ns (TA)
	Noise	0.3 PE
	Response linearity	5% at 300 PE
	TDC resolution	0.78 ns
	TDC full range	50 μsec

Electron Catcher

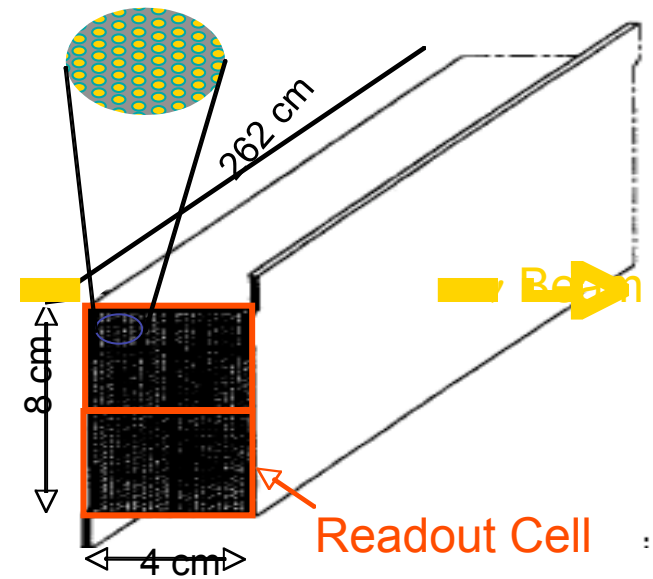
Spaghetti Calorimeter

- re-used from CHORUS
- 1 mm diameter fibers in grooves between lead foils
- 4x4 cm^2 cell read out from both ends
- 2 planes (11X_0)

  Horizontal: 32 modules

  Vertical: 32 modules

- Expected resolution 14%$\sqrt{E}$
- Linearity: better than 10%
- Total 256 channels

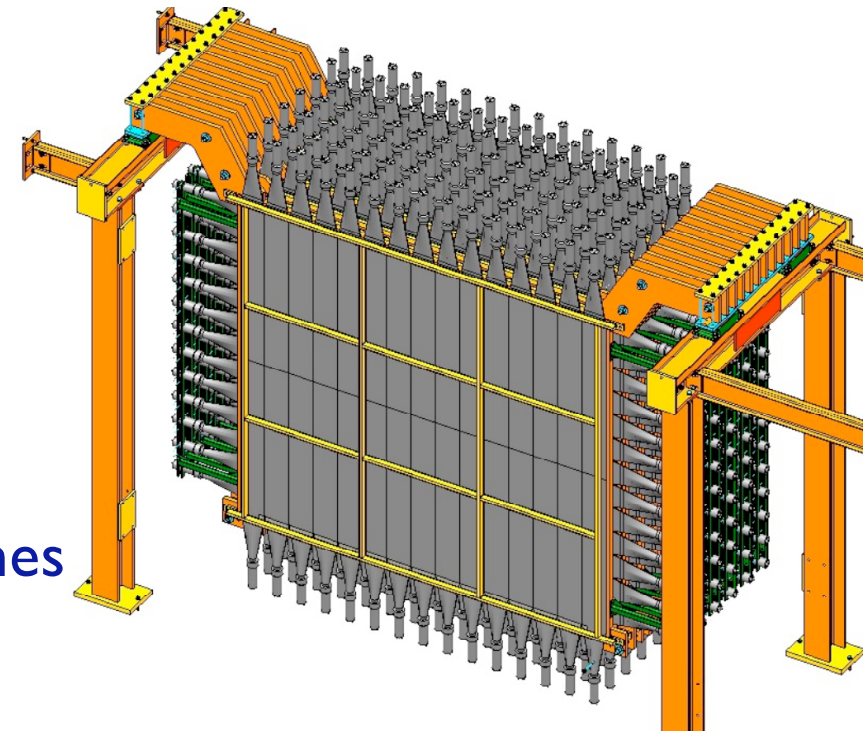


Readout

- Differential PMT signal read using CAEN ADC (VME)

Muon Range Detector

A new detector built with used scintillators, iron plates and PMTs to measure muon momentum up to 1.2 GeV/c



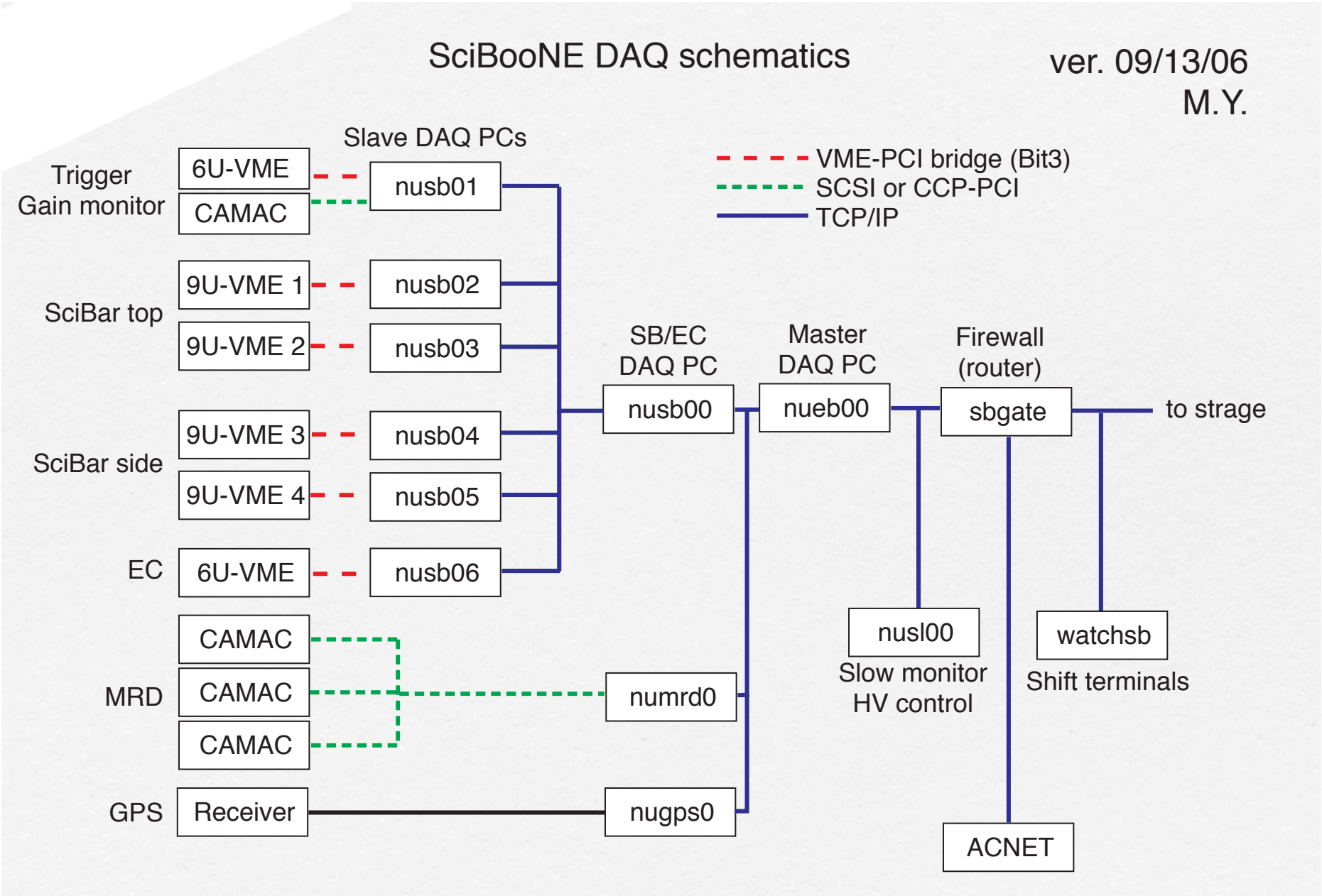
Detector:

- Iron Plate 305 x 247 x 5 cm^3
- Total 13 layers
- Scintillator for detector
- Alternating horizontal and vertical planes
- Total 362 channels

Readout:

- Lecroy FERA ADC/TDC (CAMAC)

DAQ


SciBooNE DAQ schematics
ver. 09/13/06
M.Y.
Slave DAQ PCs
VME-PCI bridge (Bit3)
SCSI or CCP-PCI
TCP/IP
Trigger
Gain monitor
6U-VME
CAMAC
nusb01
SciBar top
9U-VME 1
9U-VME 2
nusb02
nusb03
SciBar side
9U-VME 3
9U-VME 4
nusb04
nusb05
EC
6U-VME
nusb06
MRD
CAMAC
CAMAC
CAMAC
numrd0
GPS
Receiver
nugps0
SB/EC
DAQ PC
nusb00
Master
DAQ PC
nueb00
Firewall
(router)
sbgate
to strage
nusl00
Slow monitor
HV control
watchsb
Shift terminals
ACNET

SciBooNE Physics

Proposed ~2 year run, 2×10^{20} protons on target (POT)

Neutrino Run (0.5×10^{20} POT):

- CC-$1\pi^+$ cross section
- CC-$1\pi^0$ cross section
- Intrinsic ν_e contamination

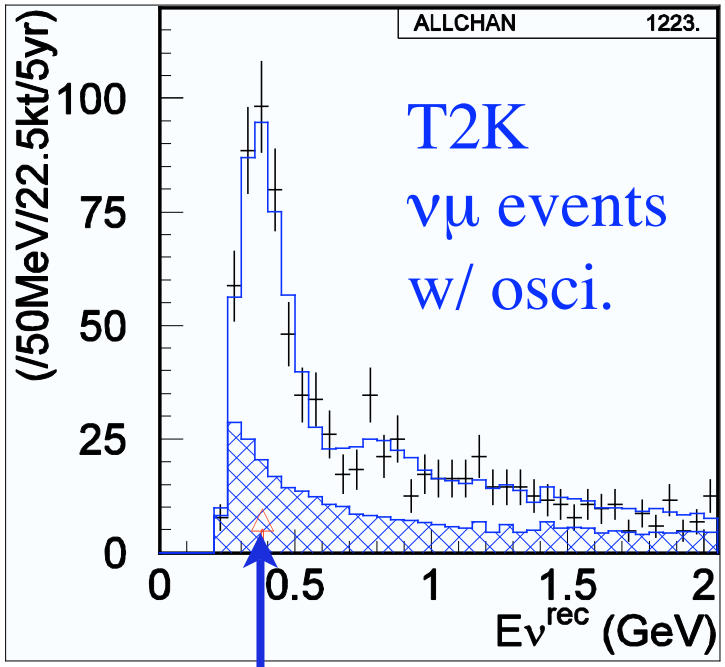
# of interactions in FV
ν_μ **~78,000**
ν_e **~ 700**
(cf. ν_μ~25,000 K2K)

Anti-neutrino run (1.5×10^{20} POT)

- CC-QE cross section
- neutrino background contamination
- CC- coherent π cross section

# of interactions in FV
ν_μ **~40,000**
ν_μ **~22,000**

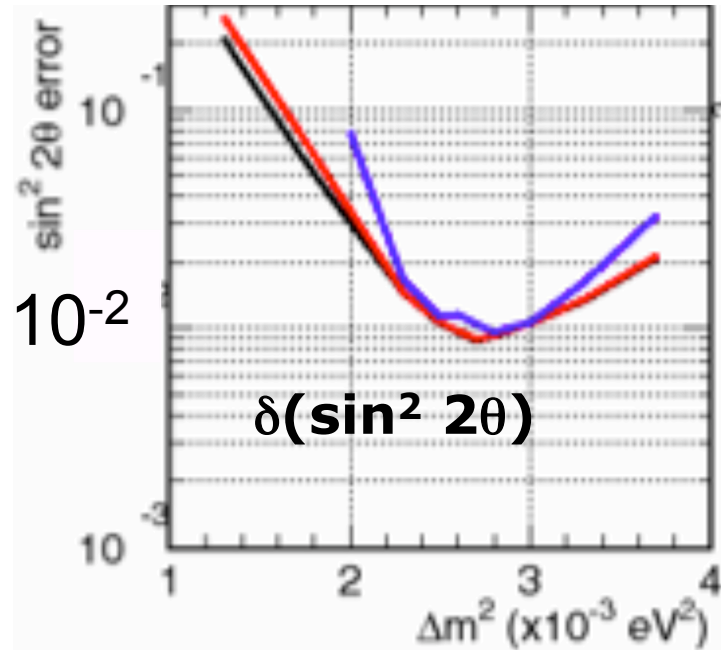
CC-1π⁺ Measurement



–Signal: CC-QE (ν+n→μ+p)
(Energy Reconstruction from μ kin.)

–Background: Mainly CC-1π⁺
(ν+N→μ+π+N')

ν_μ disappearance measurement error (90%CL)

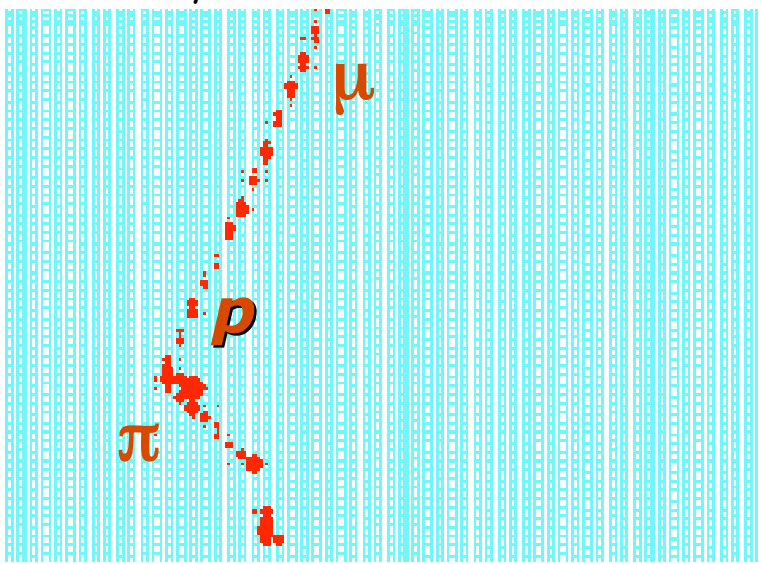


stat. only
δ(nQE/QE)= 5%
δ(nQE/QE)=20%

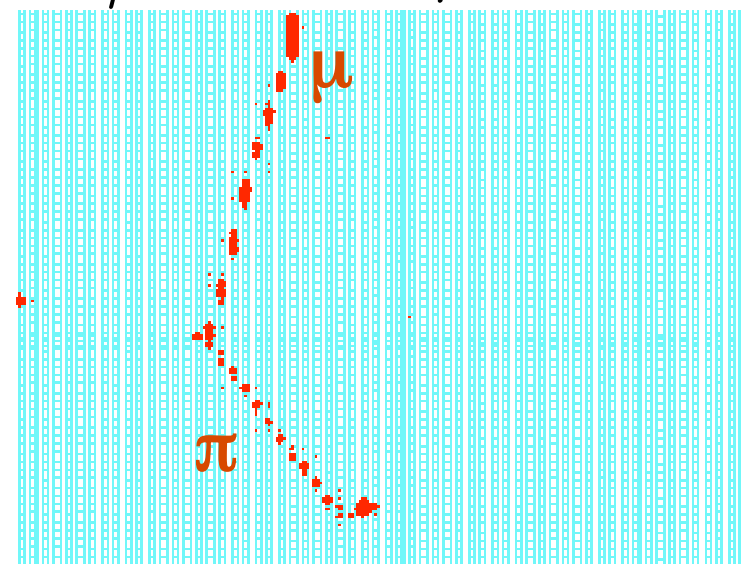
T2K needs to know uncertainty of nonQE/QE at ~5% level.

CC-1π$^+$ at SciBooNE

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



$$\nu_\mu + n \rightarrow n\mu^-\pi^+$$



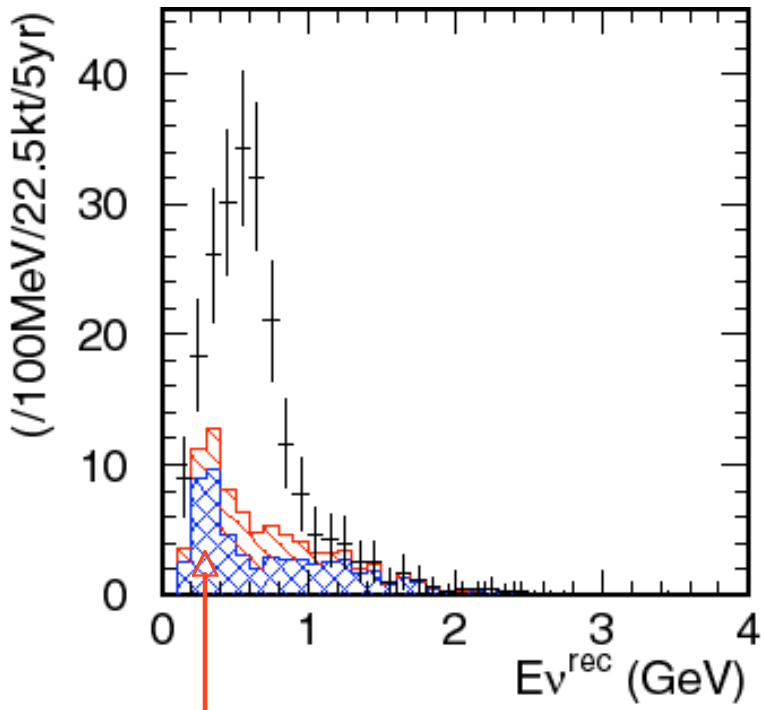
Vertex requirements allow clear separation between proton and neutron interactions

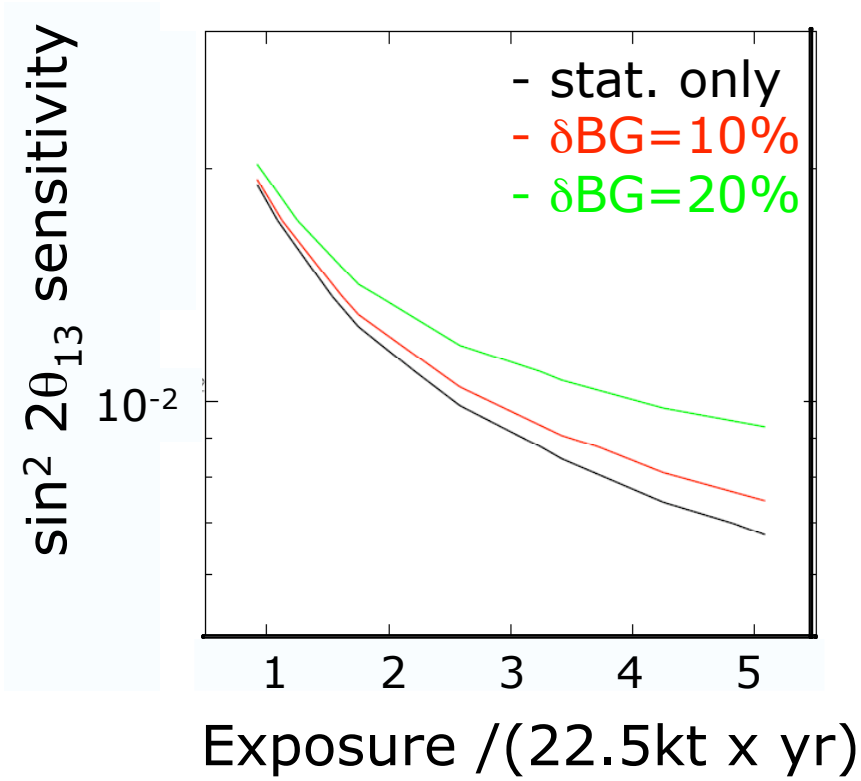
Expect ~1400 CC-1π$^+$ events

~5% measurement

NC-1π^0 Measurement

NC-1π^0 dominant background for ν_e appearance search



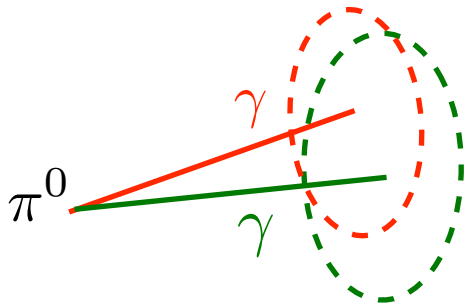


- Signal: CC-QE (ν+n→e+p)
- Background
  - Beam ν_e
  - NCπ^0

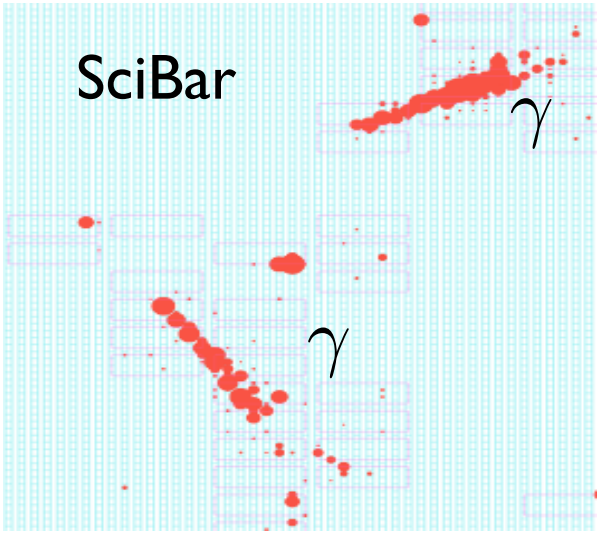
T2K needs ~10% uncertainty on NC-1π^0 cross section

NC-1π^0 at SciBooNE

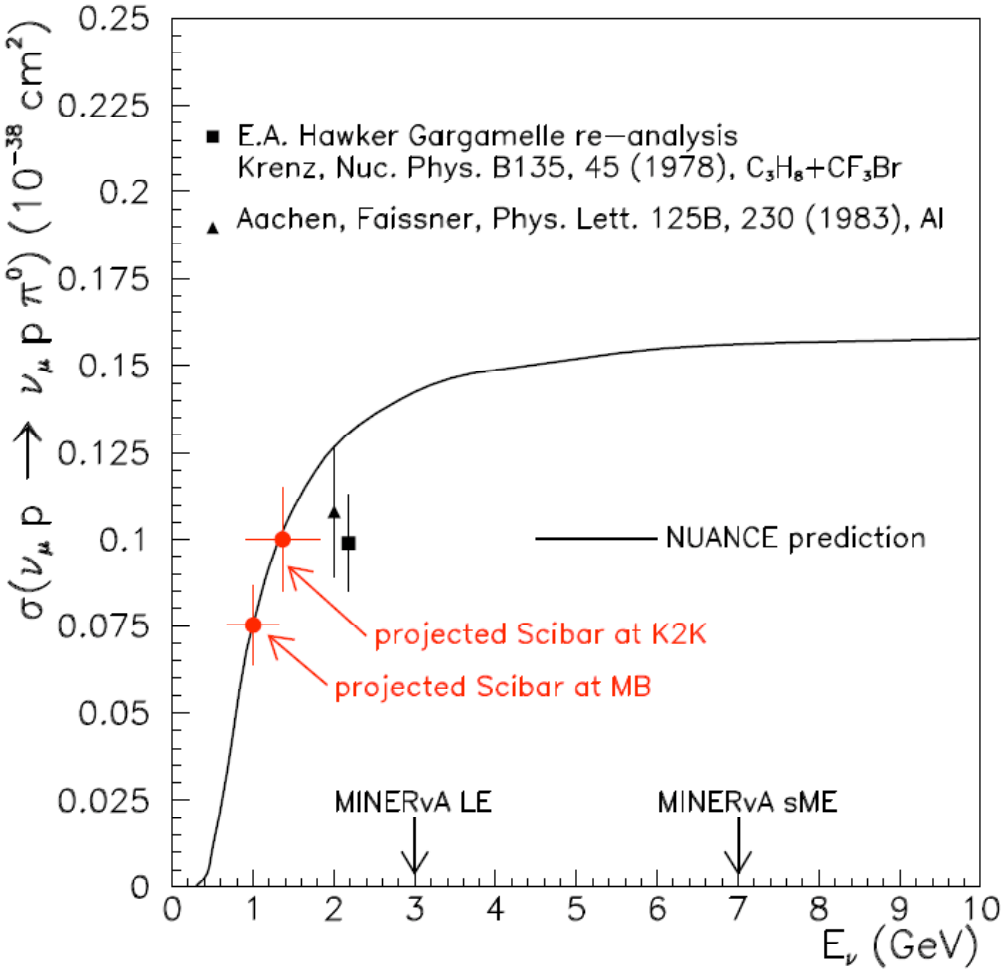
Super Kamiokande



Overlapping Cerenkov Rings



γ track separation

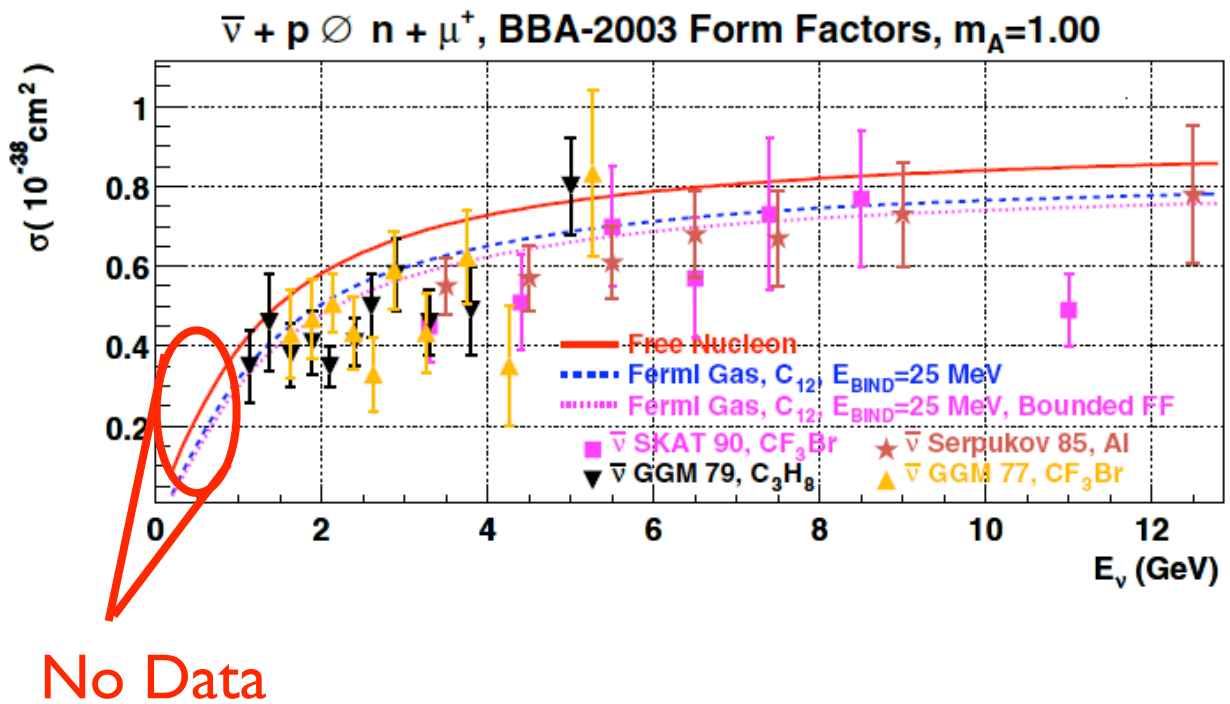


SciBooNE (0.8GeV) and K2K (1.3GeV) results provide the first mapping of energy dependence of the cross section below 2GeV.

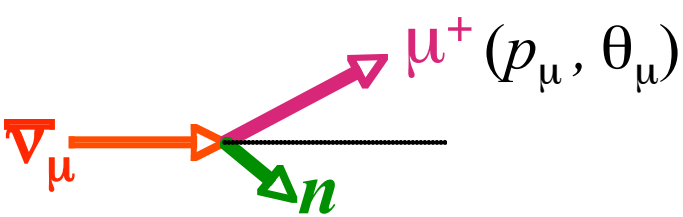
Anti-neutrino CCQE Measurement

Physics motivation

- Important for T2K phase-II
  - CP violation search
- Free proton scattering: check of nuclear model



No Data



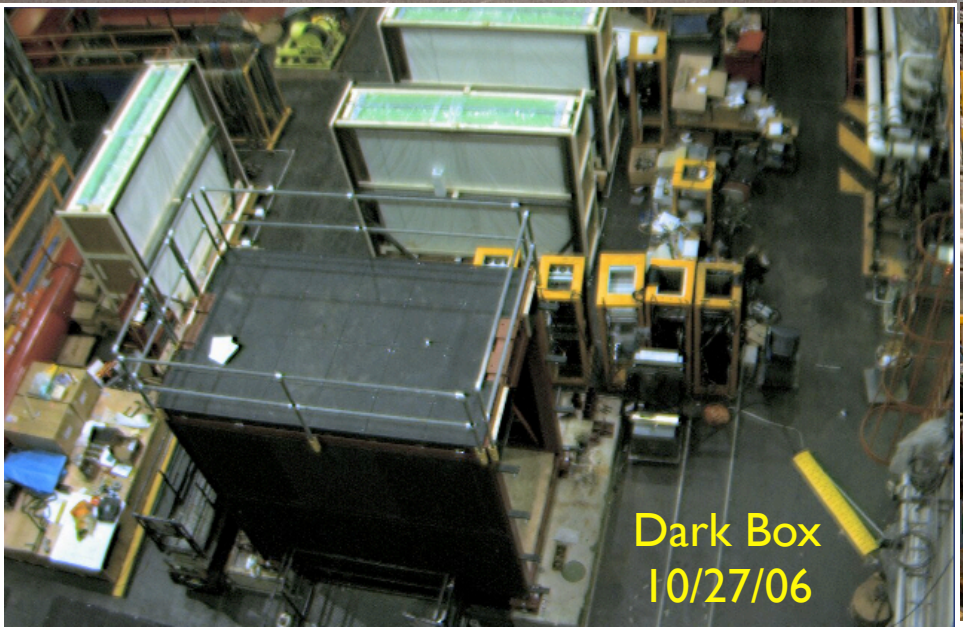
Expect ~9,000 CCQE events after cuts, 80% purity

SciBooNE Civil Construction

SciBar

SciBar arrives at CDF
7/17/06

Support structure arrives
7/17/06


Dark Box
10/27/06

Last Module
12/6/06

EM Calorimeter

Downstream layer sees cosmic ray signals 12/4/06

Muon Range Detector

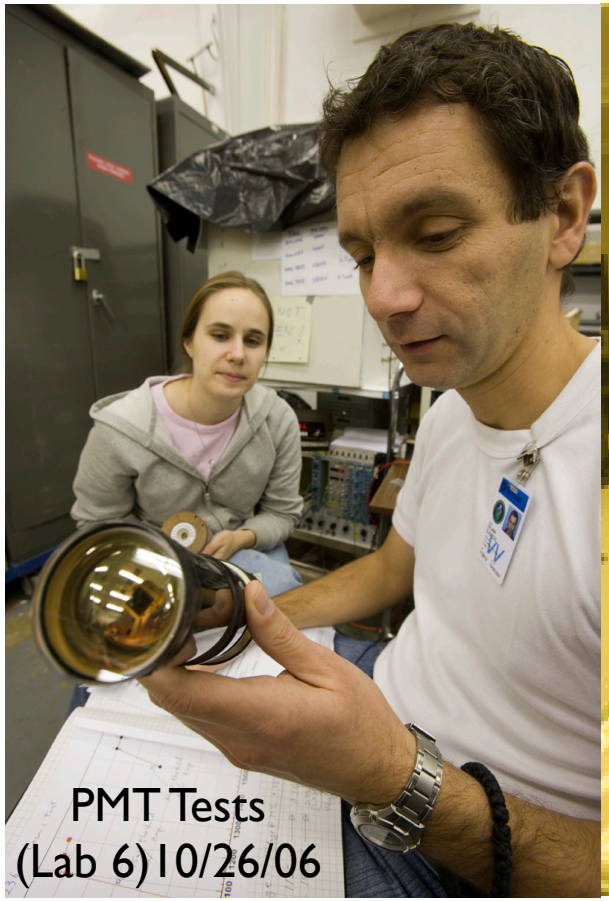
Counter Assembly
(Lab 6) 7/06

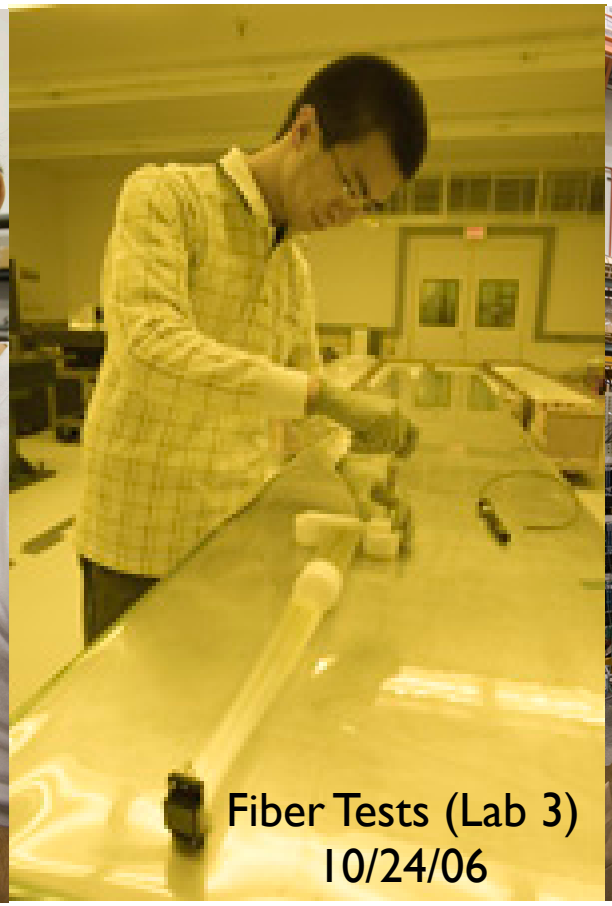
Counters (Lab 6)
10/06

MRD Steel (Lab F)
10/27/06

MRD Frame (Lab F)
12/23/06

Misc. Tests





Live Web Cam to monitor construction @ CDF
http://131.225.233.90/

Schedule

Mar. 2005	K2K Ends
Nov. 2005	Submit proposal to FNAL
Dec. 2005	Proposal Approved
Feb. 2006	SciBar/EC disassembled
Jun. 2006	Ship detectors to FNAL
Jul. 2006	Detectors @ FNAL
Sep. 2006	Civil construction starts
Nov. 2006 - Feb. 2007	Detector assembly/staging
Feb. - Apr. 2007	Installation
Apr. 2007	Commissioning
May. 2007	Beam Data

Summary

SciBooNE is an experiment to measure (anti-) neutrino cross sections

Combine well understood beam and detector

Neutrino beam matched to T2K

Detector assembly well underway

Begin taking neutrino data in May 2007.

References

SciBooNE:

http://www-sciboone.fnal.gov

SciBooNE Proposal: hep-ex/0601022 v1

SciBar (K2K):

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M. Hasegawa, *et al.,* (K2K Collaboration), Phys. Rev. Lett. **95**(2005) 252301. hep-ex/0506008

M.H. Ahn, *et al.,* (K2K Collaboration), Phys.Rev. **D74**(2006) 072003, hep-ex/0606032

E. Aliu, *et al.,* (K2K Collaboration, Phys.Rev.Lett **94**(2005)081802. hep-ex/0411038.

MiniBooNE (Booster Neutrino Beam):

I.Stancu, *et al.,* (MiniBooNE Collaboration) (2001) **FERMILAB-TM-2207**.