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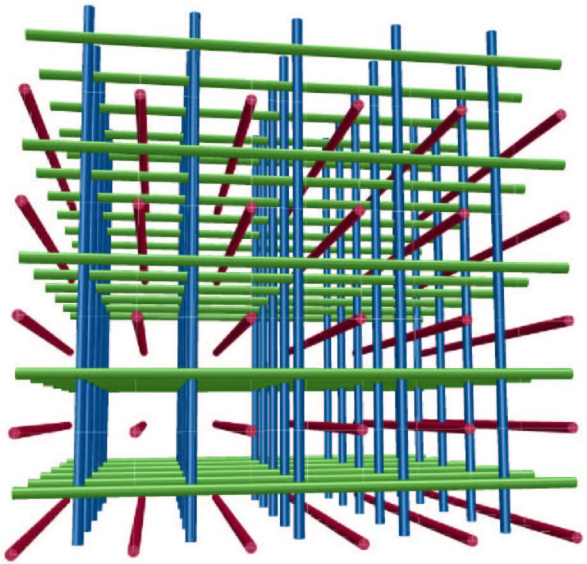
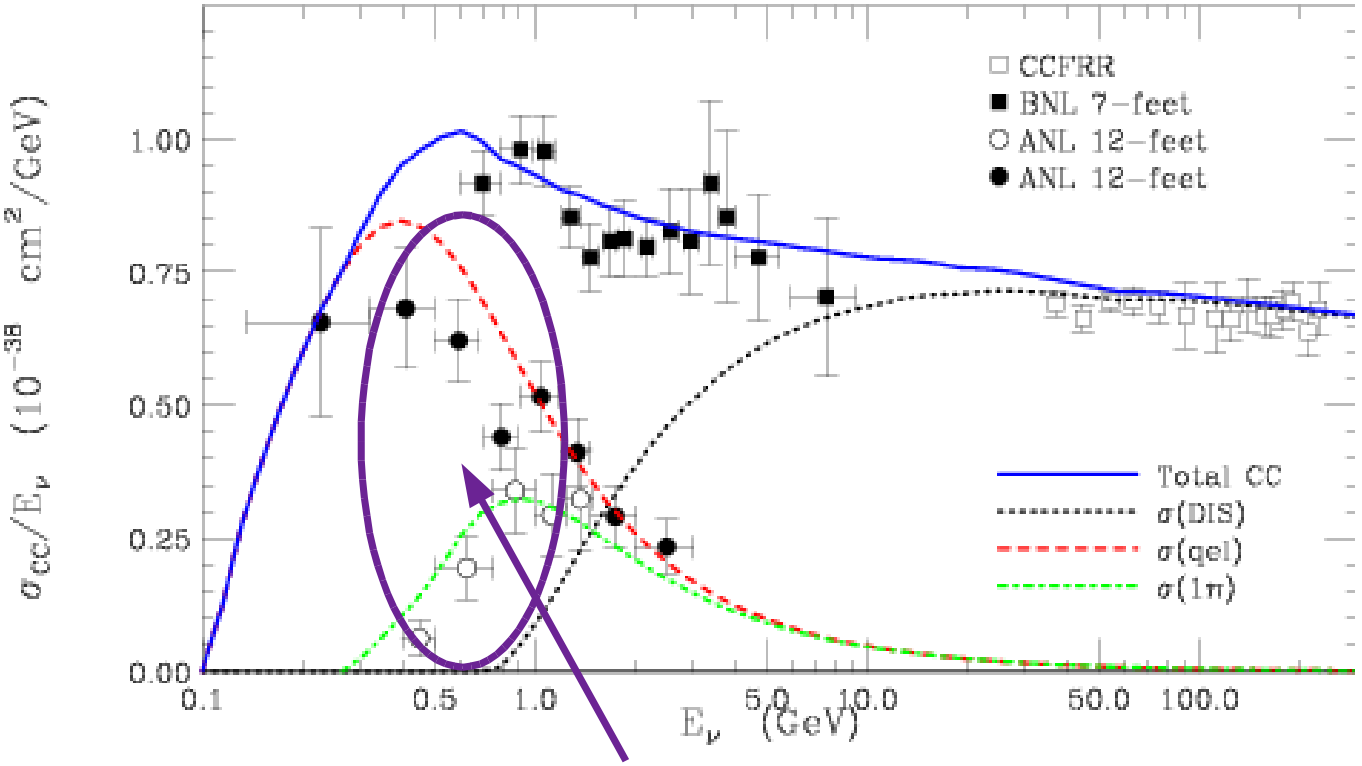
NuINT 2004
Gran Sasso Laboratory

Future Detectors: FINeSSE



- FINeSSE physics in the "SciBath" detector
- Detector prototype and simulation
- Construction and costs
- Other applications

Motivation for the FINeSSE "scibath" detector:
Low energy neutrino scattering physics: below DIS



Lots of physics to do at these low energies

- form factor measurements
- cross section measurements
- short baseline oscillation physics

measurement of Δs motivated the FINeSSE detector design

Low Q^2: Measure G_A^S $(Q^2=0)=\Delta s$

Δs=spin carried by the s and $\bar{s}$ sea

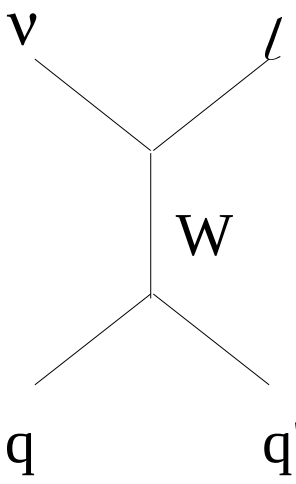
Fundamental aspect of nucleon structure:

- What carries the nucleon spin! valence quarks, sea quarks, gluons?
- Can we describe the proton in terms of a fundamental theory?

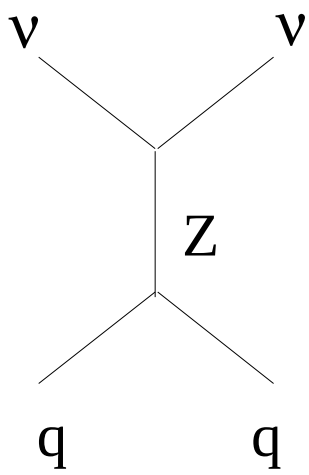
These are still open questions!

→ values of Δs determined from charged lepton experiments vary even in sign! Not well understood measurement!.

→ Δs is important for certain dark matter searches where the neutralino-nucleus cross section depends on quark spins.

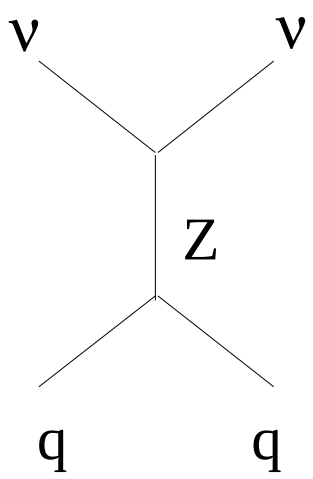


quasi-elastic
CC scattering
q=up and down
quarks only



Neutral current
scattering
q=any quark
in the nucleon
→ strange quarks

Neutrino-nucleon elastic scattering



- Nucleon Neutral Weak Current, J_μ , depends most strongly on
  G_A (axial) form factor... (somewhat on F_1,F_2)

- $G_A(Q^2) = -\tau_z g_A(Q^2) + G_A^s(Q^2)$
  - g_A known (nuclear β decay)
  - $G_A^s(Q^2=0) = \Delta s$

$\nu p \rightarrow \nu p$ NC cross section at low Q^2

Difficult to measure $\nu p \rightarrow \nu p$ *with large flux uncertainties:*
measure the ratio $\nu p \rightarrow \nu p / \nu n \rightarrow \mu p$

↓

Ratio of NC elastic scattering to CC quasi-elastic scattering:
$R(NC/CC) = \sigma(\nu p, NC)/\sigma(\nu p, CC)$

→ To measure Δs with error ≤ 0.04,
need R(NC/CC) to ~5% down to $Q^2=0.2$ GeV^2

→ the right Q^2:

not too low.....

Do this at $Q^2 > 0.2$ GeV^2...
- minimize nuclear corrections (Carbon)
- proton detection ($T_p = Q^2/2m_p$)

not too high....

and $Q^2 < 0.5$ GeV^2...
- minimize worries about Q^2 evolution
- event rates higher as well

→ high intensity neutrino beam below DIS turn on

→ a detector that can reconstruct:
- νp elastic events (short distance scales)
- ν_μ CCQE (long distance scales)

at these energies and Q^2s

One option: near location on Booster Neutrino Beamline at FNAL

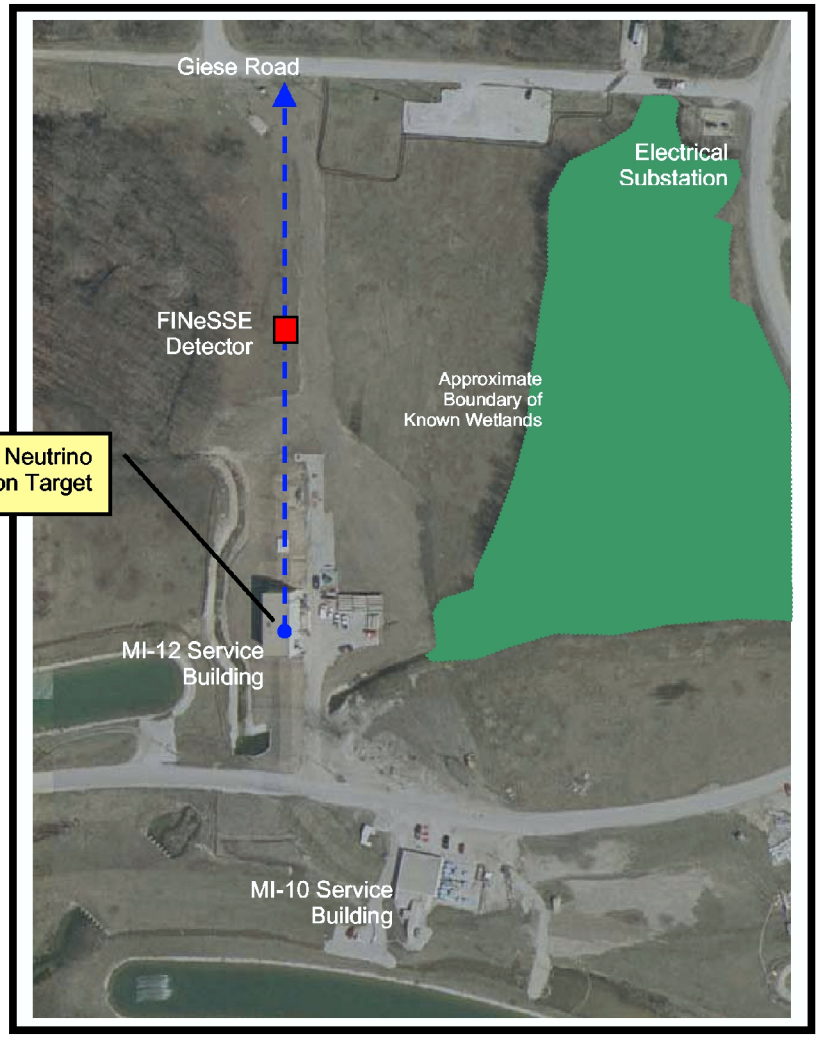
existing

- 500m from ν target: MiniBooNE...

- 100m from ν target:

open space...

available for FINeSSE



Other places to do this physics:

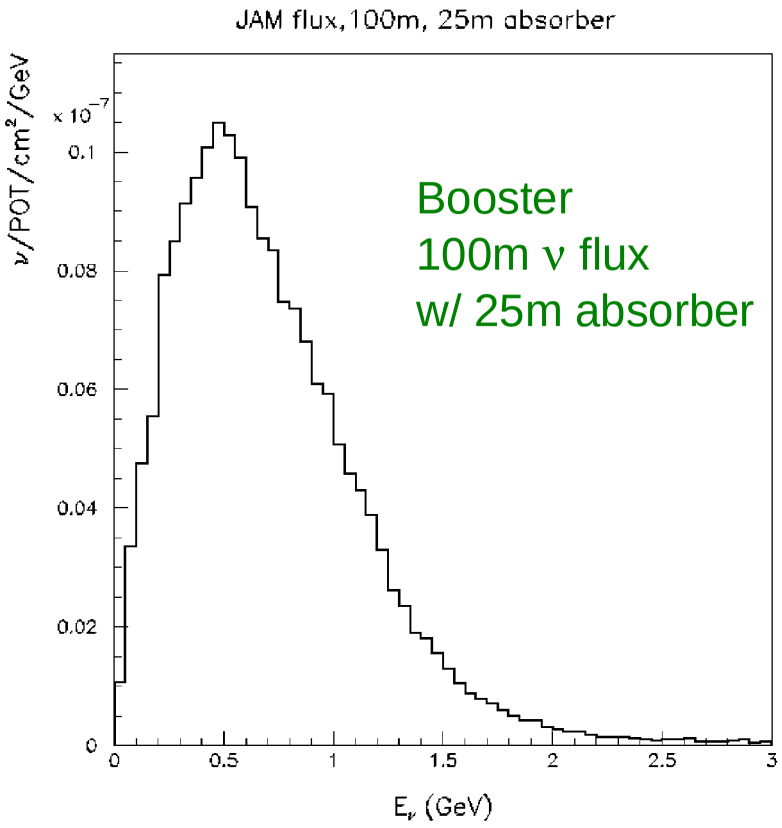
- near detector at JPARC?
- neutrino beam using 3 GeV BNL Booster?

Neutrino Flux

Booster flux at 100m:

- 9.55×10^{-9} ν_μ/POT/cm^2
- Mean E_ν = 700MeV
- Require 6×10^{20} POT total

at the 100m location



Excellent ν energy distribution for the Δs measurement

- E is high enough...
  - large elastic cross section
  - nuclear physics uncertainties small
- and low enough that backgrounds (e.g. pion prod., DIS) small
- little to no high-energy "tail"

- Low Duty Factor also => very small cosmic background

FINeSSE: Event Rates

Event Rates with a 9 ton (fiducial) detector, 6E20 POT @ 100m on Booster ν beamilne

~147k CCQE
~59k NC EL

signal channels are ~ 60% of total

ν Reaction	ν_μ 10^{20} POT 1 ton	$\overline{\nu_\mu}$ 10^{20} POT 1 ton	$\nu_e + \overline{\nu_e}$ 10^{20} POT 1 ton	ν_μ 6×10^{20} POT 9 ton
CC QE, $\nu_\mu n \to \mu^- p$	2,715	43	13	146,610
NC EL, $\nu_\mu N \to \nu_\mu N$	1,096	18	5	59,184
CC π^+, $\nu_\mu p \to \mu^- p \pi^+$	1,235	6	8	66,690
CC π^0, $\nu_\mu n \to \mu^- p \pi^0$	258	3	2	13,932
CC π^+, $\nu_\mu n \to \mu^- n \pi^+$	216	2	2	11,664
NC π^0, $\nu_\mu p \to \nu_\mu p \pi^0$	211	3	2	11,394
NC π^+, $\nu_\mu p \to \nu_\mu n \pi^+$	125	2	0	6,750
NC π^0, $\nu_\mu n \to \nu_\mu n \pi^0$	158	3	2	8,532
NC π^-, $\nu_\mu n \to \nu_\mu p \pi^-$	98	3	0	5,292
CC DIS, $\nu_\mu N \to \mu^- X$	80	0	3	4,320
NC DIS, $\nu_\mu N \to \nu_\mu X$	37	0	2	1,998
CC coh π^+, $\nu_\mu A \to \mu^- A \pi^+$	160	5	2	8,640
NC coh π^0, $\nu_\mu A \to \nu_\mu A \pi^0$	98	3	0	5,292
other	117	2	0	6,318
total	6,604	93	41	356,616

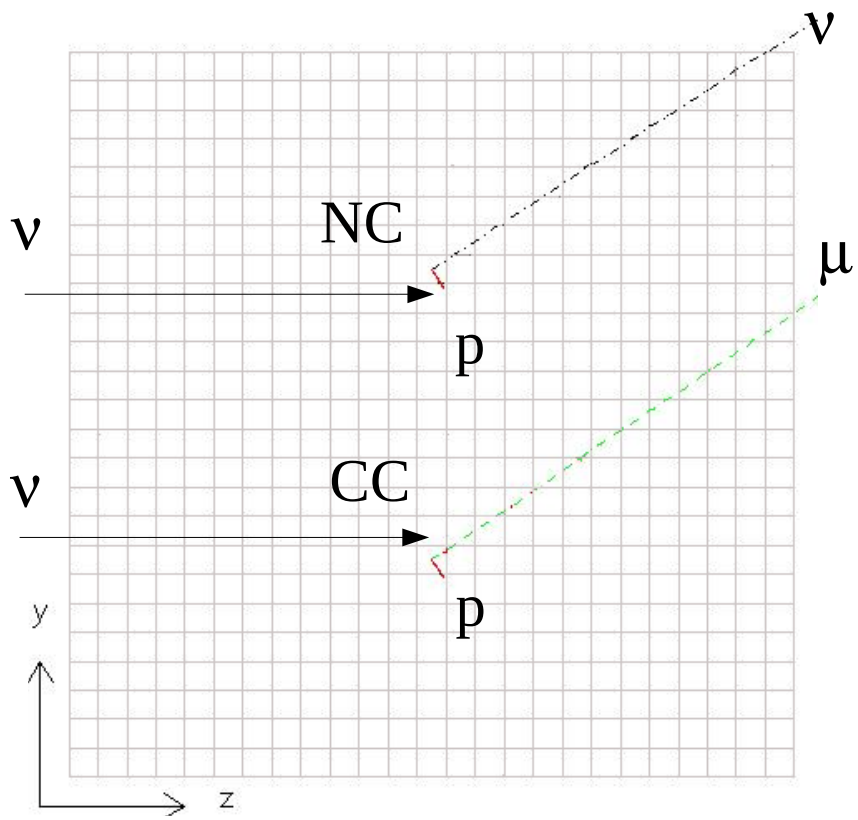
Measurement requirements:

To measure Δs with error ≤ 0.04, need R(NC/CC) to ~5% down to Q^2=0.2 GeV^2

-proton energy measurement down to T_p~100MeV (R~10cm)

- particle ID for NC/CC/background separation

-range out up to 1 GeV muons

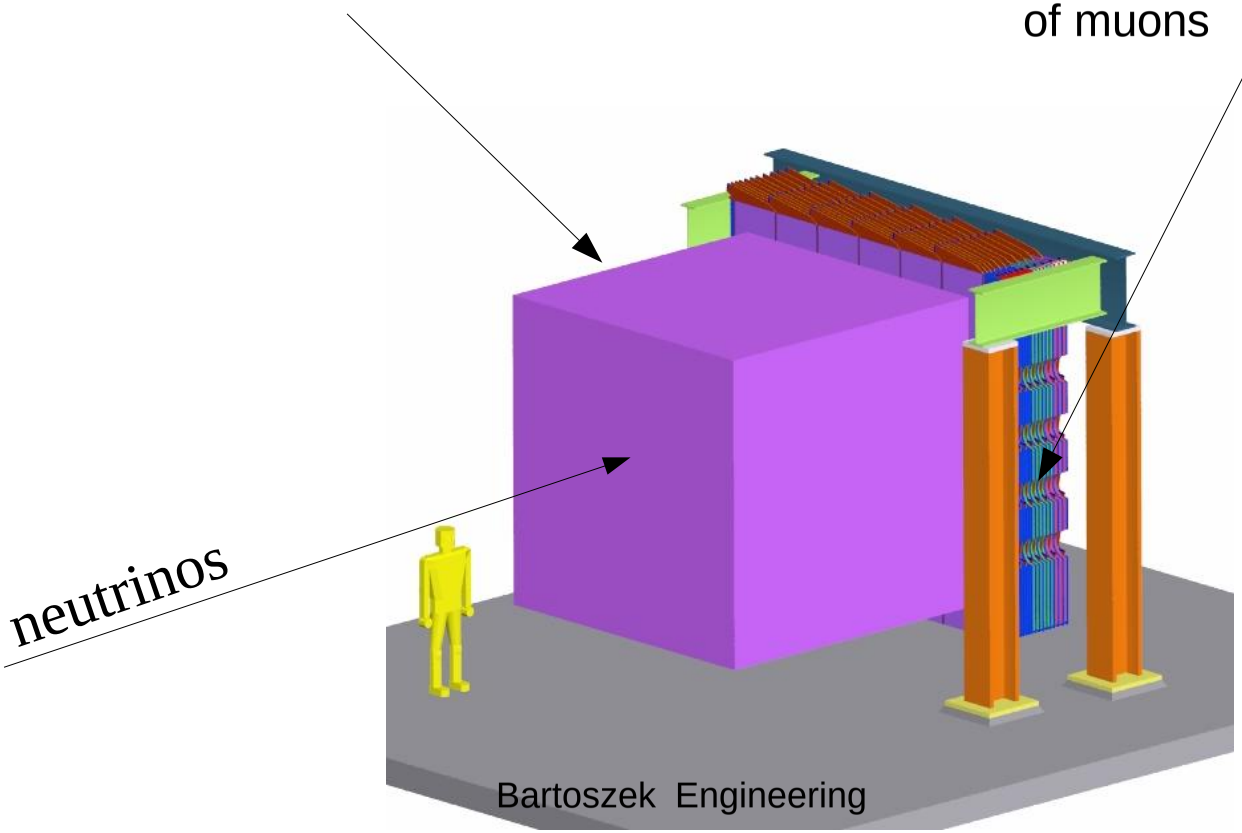


GEANT-generated events in scintillator:
Q^2 = 0.2 GeV^2, E_ν = 800MeV
T_p~100 MeV, T_μ~600 MeV

Two part detector

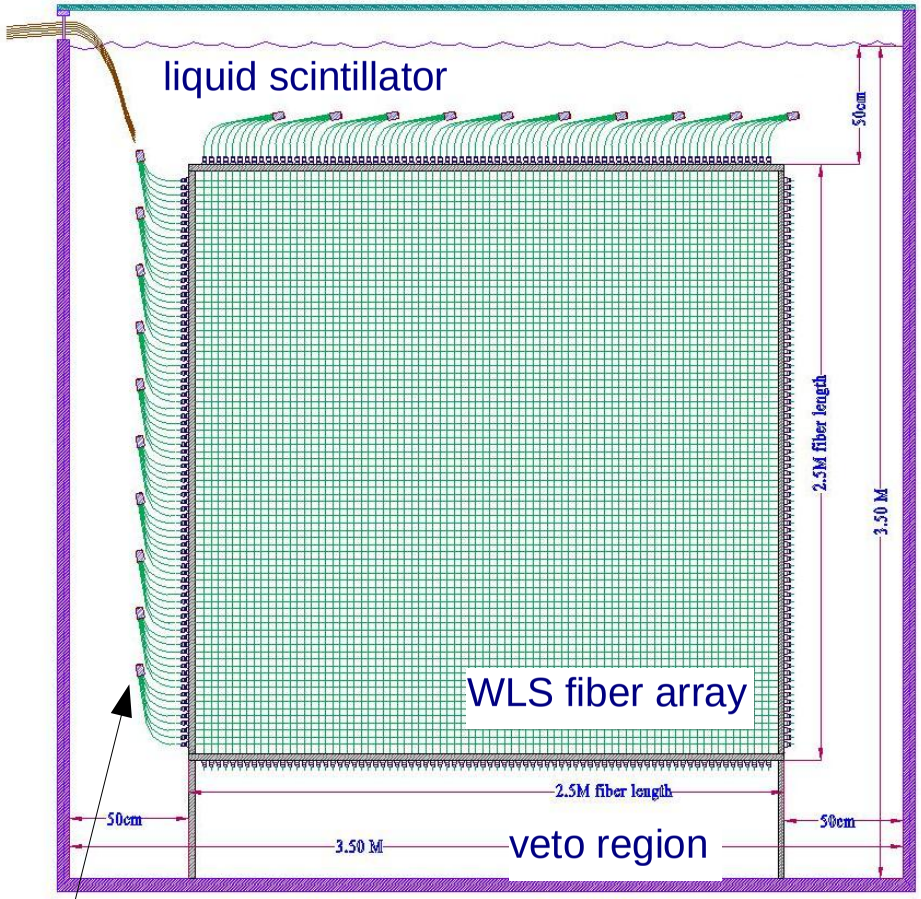
The Vertex Detector...
- to precisely track low-energy protons

The Muon Rangestack...
- to track and measure the energy of muons



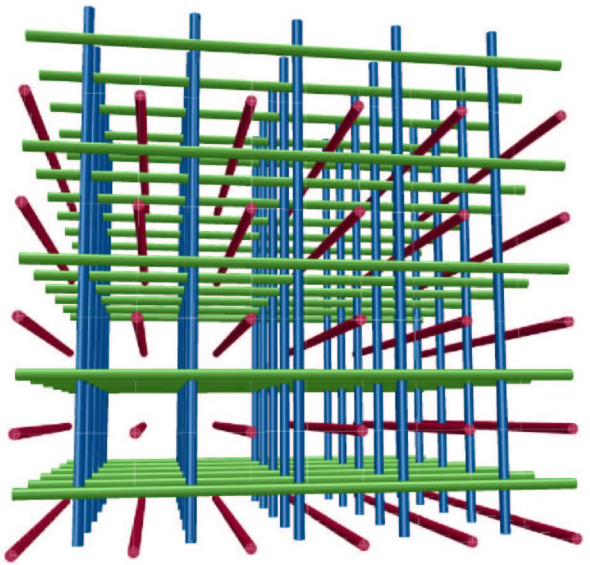
Vertex Detector: a large, low-threshold, 3D, tracking detector

Vertex Detector side view:



PMTs + on-board electronics

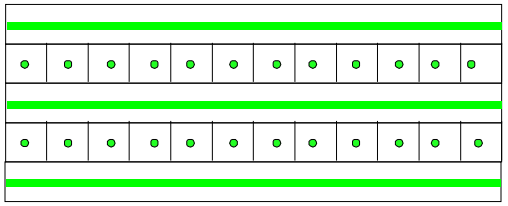
$(2.5m)^3$ active liquid scintillator volume
- 19200 (80x80x3) 1.5 mm WLS fibers on 3cm spacing with 3 orientations



WLS fibers in vertex detector

Considered a few different detector technologies for FINeSE.....

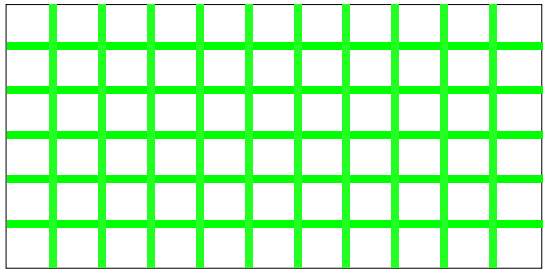
Scintillator stack



- optically isolated scintillator bars with wave length shifting fibers in each bar
- existing technology -- K2K Scibar detector
  -- MINOs/MINERvA detectors

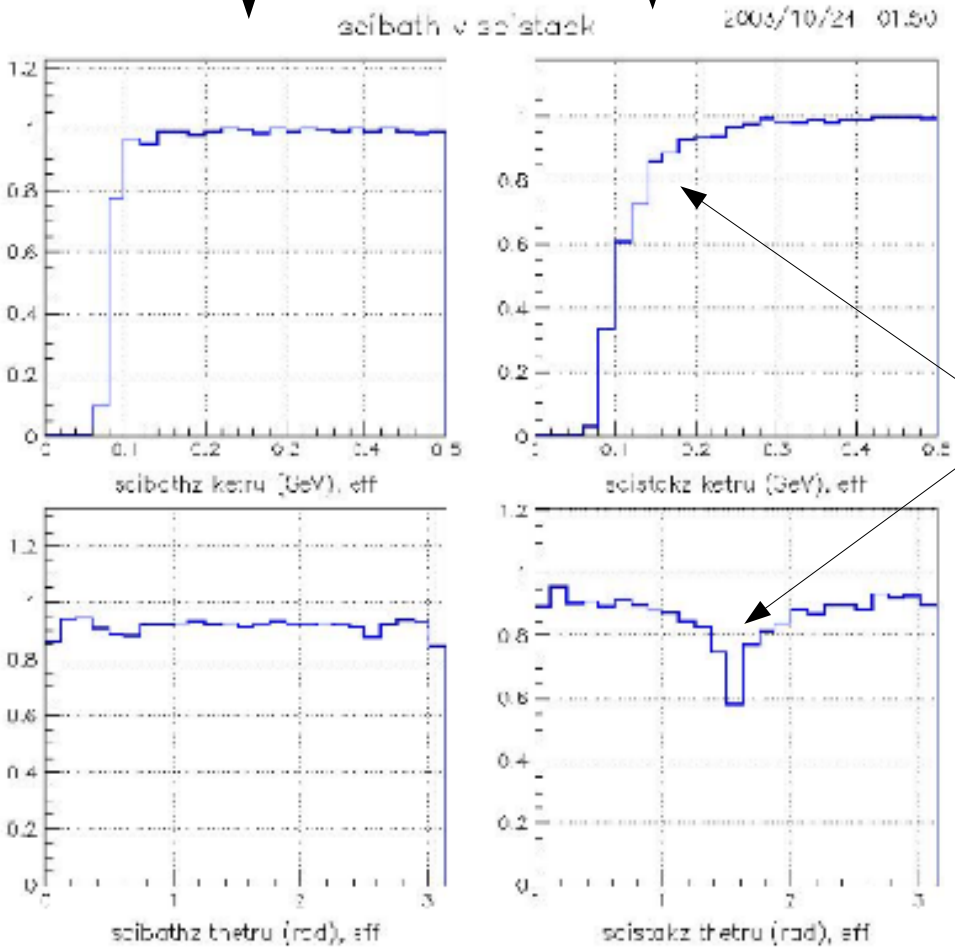
Scintillator bath

- not optically isolated
- information in 3D



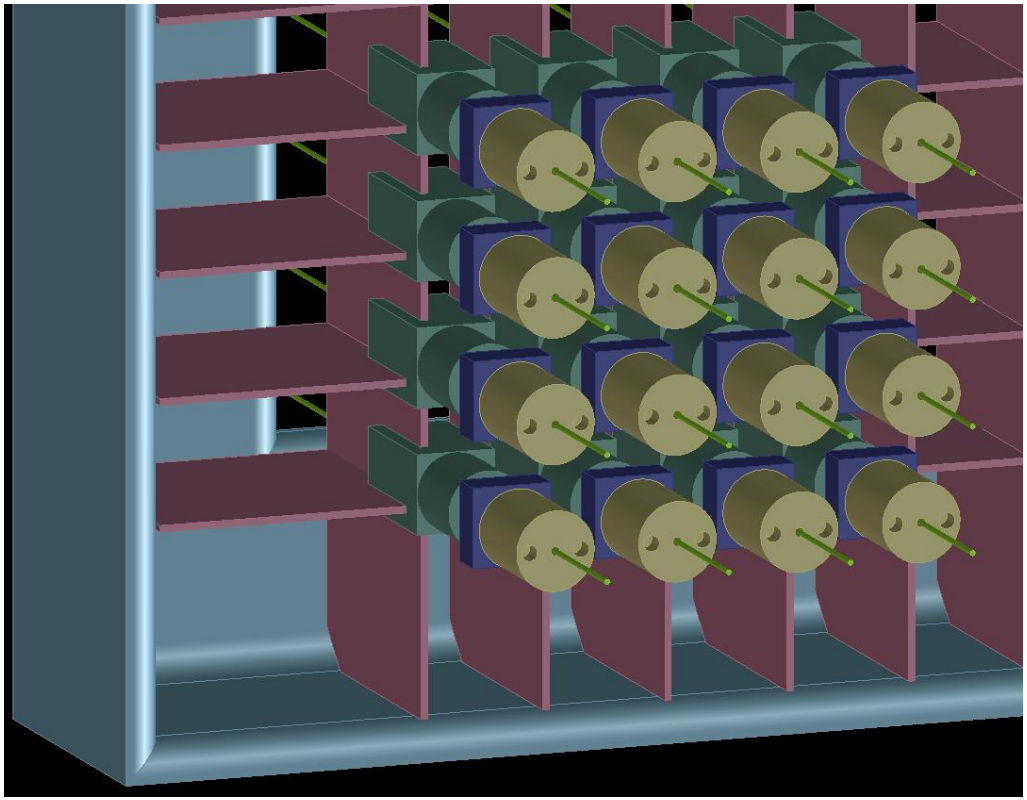
Scibath

Plastic scintillator stack

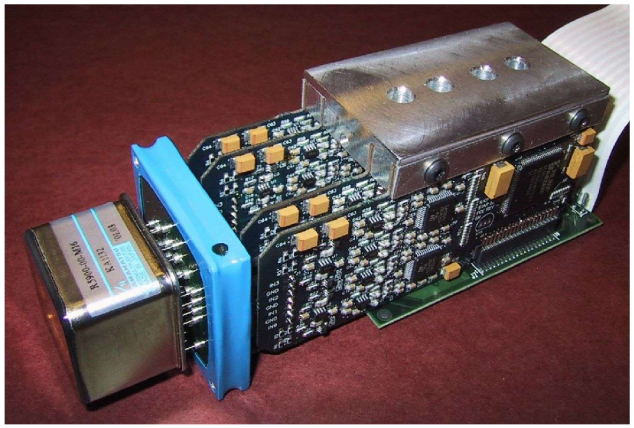


Lose events at high angles/low KE in scintillator bar type detector compared to Scibath

Readout with Hammamatsu MAPMTs and on board electronics



STAR PMT w/front-end electronics

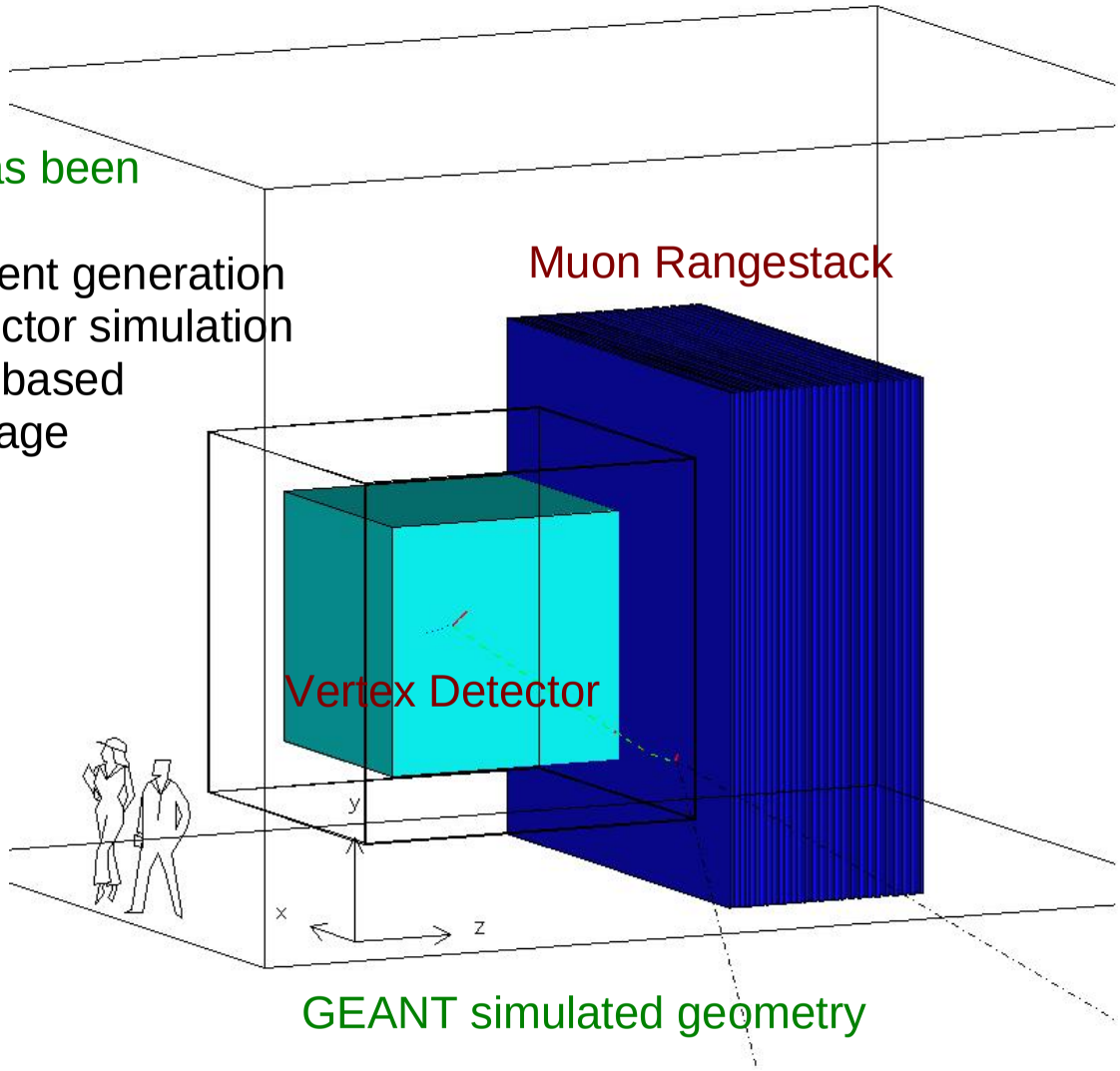


- similar scheme to that employed for STAR endcap calorimeter

FINeSSE Detector Simulation and Reconstruction

The FINeSSE detector has been simulated using:

- NUANCE for the event generation
- GEANT for the detector simulation
- A Hough-transform-based reconstruction package



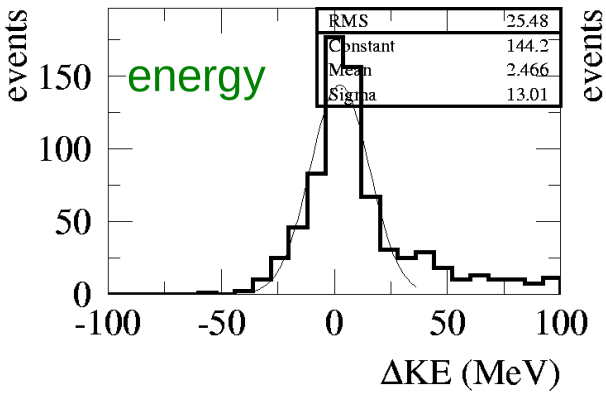
GEANT simulated geometry

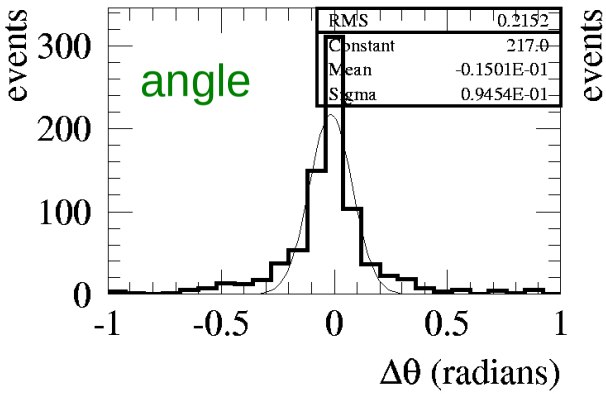
FINeSSE Detector Simulation and Reconstruction...

Simulation and reconstruction of 50-500 MeV protons and muons:

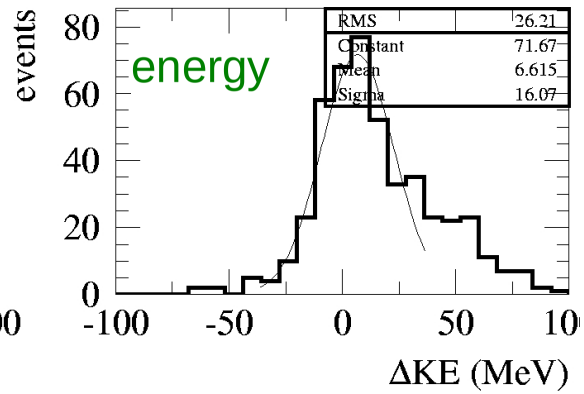
- ΔE ~15MeV
- ΔΘ ~6°

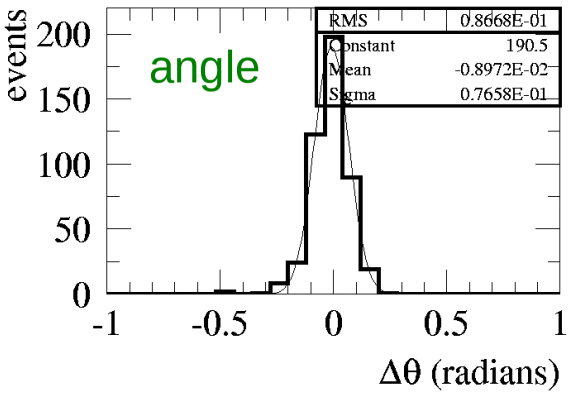
protons





muons

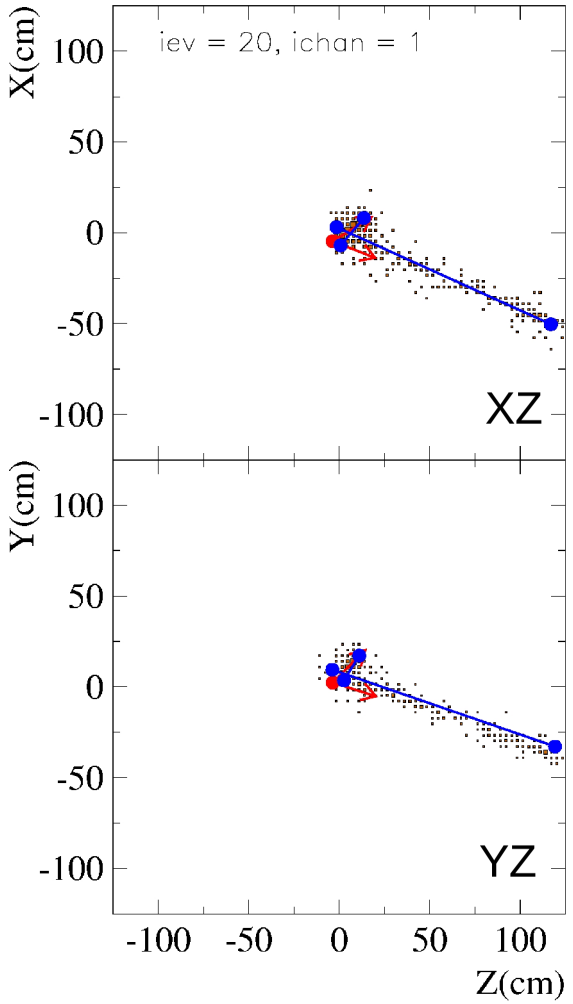




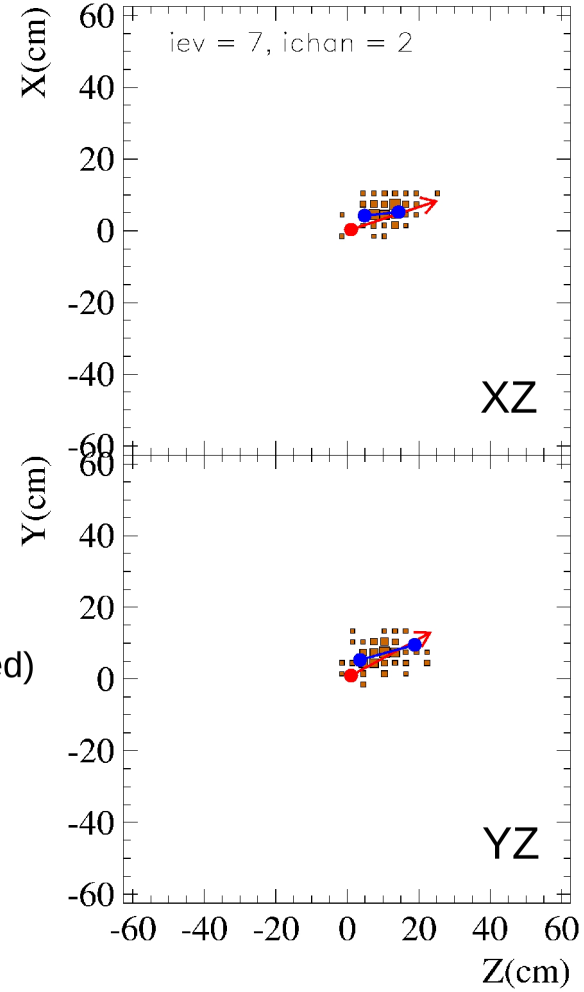
FINeSSE Detector Simulation and Reconstruction...

simulated hits and reconstructed tracks in the Vertex Detector

CCQE event



NCp event



fiber hits,
(size ∝ # γ collected)

generated

reconstructed

Simulation of R(NC/CC) measurement

NCp and CCQE cuts for R(NC/CC) measurement:

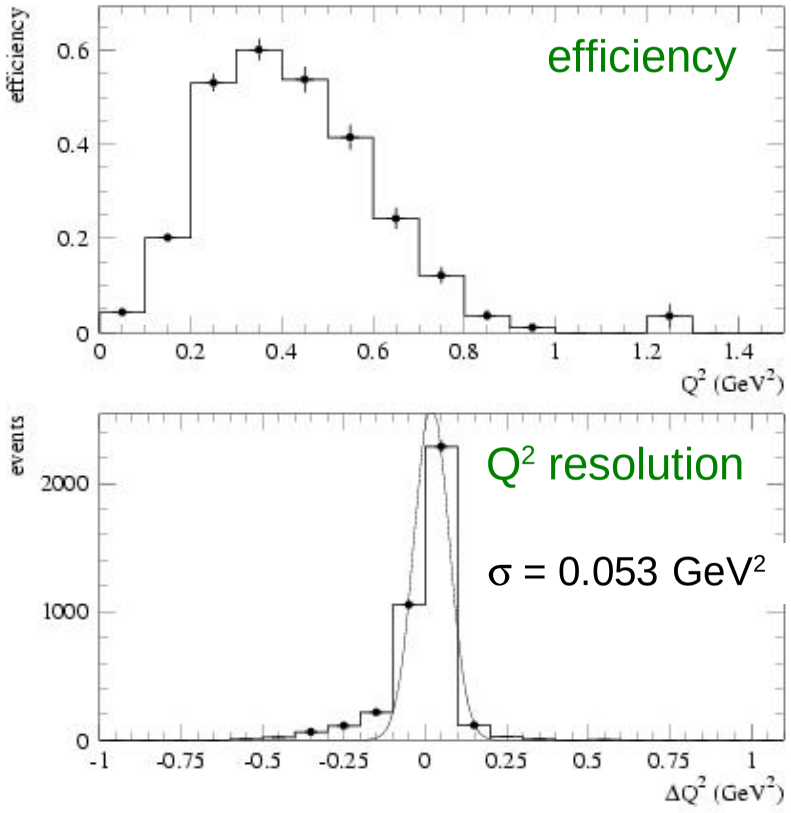
cut #	NCp cuts	CCQE cuts
0	edge distance $>$ 15cm	edge distance $>$ 15cm
1	# 3d tracks = 1	# 3d tracks.eq.2
2	$dE/dx(p) > 2.5$	$dE/dx(p) > 2.5, dE/dx(\mu) < 2.5$
3	$\theta(p) > 0.5$	$\theta(p) + \theta(\mu) > 1.5$
4	no "late" light in vertex det.	no "late" light in vertex det.
5	no veto or muon stack energy	low "remaining" energy

Resulting NCp and CCQE efficiencies from a 215k event sample:

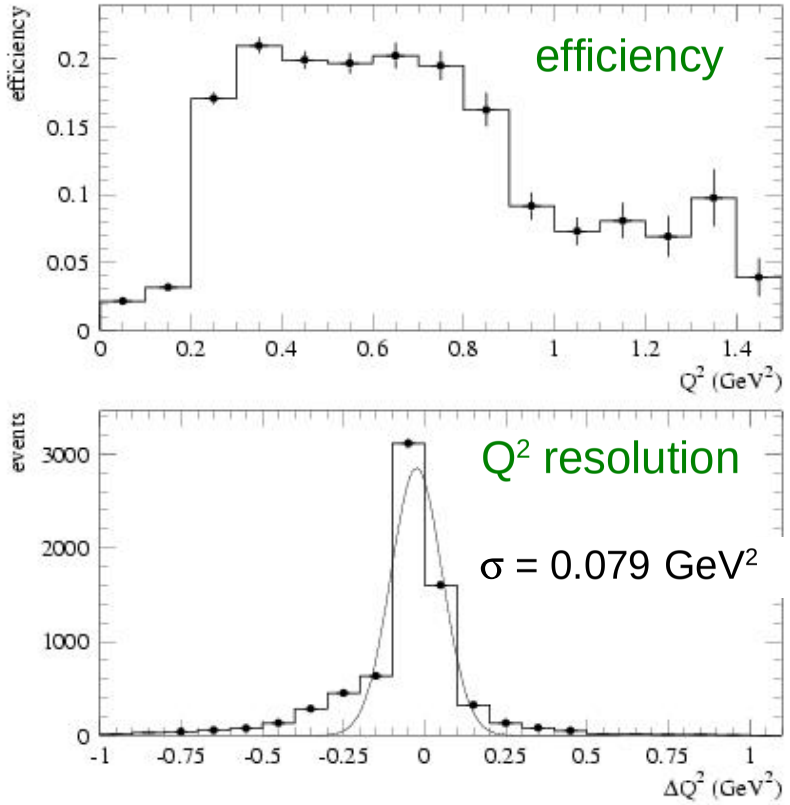
	reaction channel				
NCp cuts	NCp	NCn	NCπ	CCQE	CCπ
raw events	21219	20487	19062	100102	54107
passed events	3929	1162	167	48	4
efficiency (%)	18.5	5.7	0.9	0.0	0.0
fid. eff. (%)	27.1	8.3	1.3	0.1	0.0
purity (%)	74.0	21.9	3.1	0.9	0.1
CCQE cuts	NCp	NCn	NCπ	CCQE	CCπ
raw events	21219	20487	19062	100102	54107
passed events	165	76	581	7323	1322
efficiency (%)	0.8	0.4	3.0	7.3	2.4
fid. eff. (%)	1.1	0.5	4.5	10.6	3.6
purity (%)	1.7	0.8	6.1	77.4	14.0

Simulation of R(NC/CC) measurement...

NCp events:

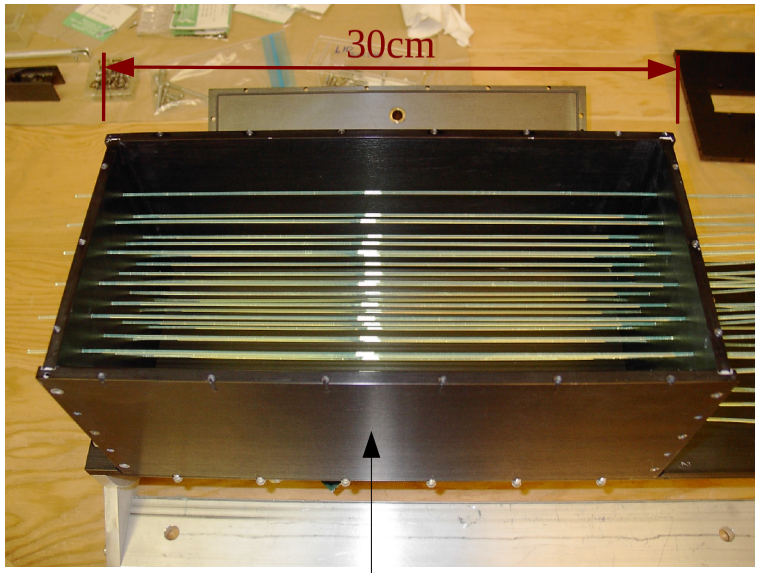


CCQE events:



Prototype "Scibath" detector built to test technology:

- 30cm x 16 cm x 16 cm box
- filled with scintillator oil
- 6x5 array of 1.5mm multi-clad WLS fiber
- readout via 16 anode MAPMT



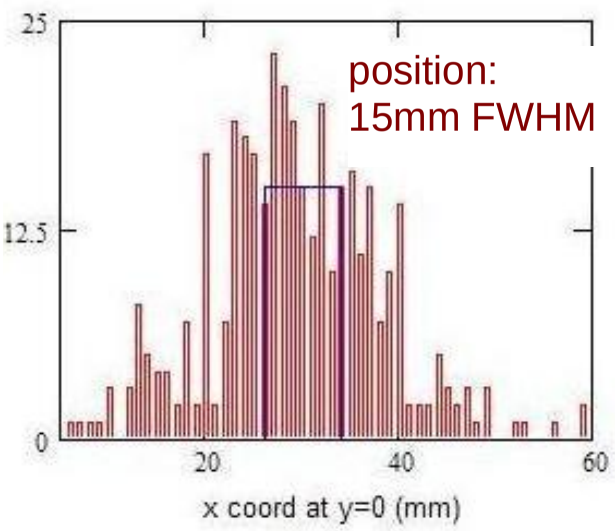
tested at the Indiana University Cyclotron Facility in summer 2003 using low intensity, 200 MeV protons

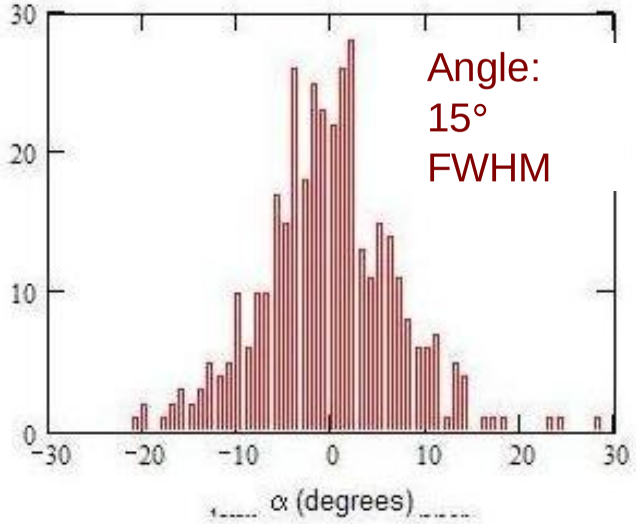
- 6x6 mm^2 beam profile
- beam scanned vertically, horizontally, and at angle to prototype

IUCF 200 MeV proton beam

Test results:

light seen from near proton tracks: 17±2 PEs





Short Baseline oscillation physics

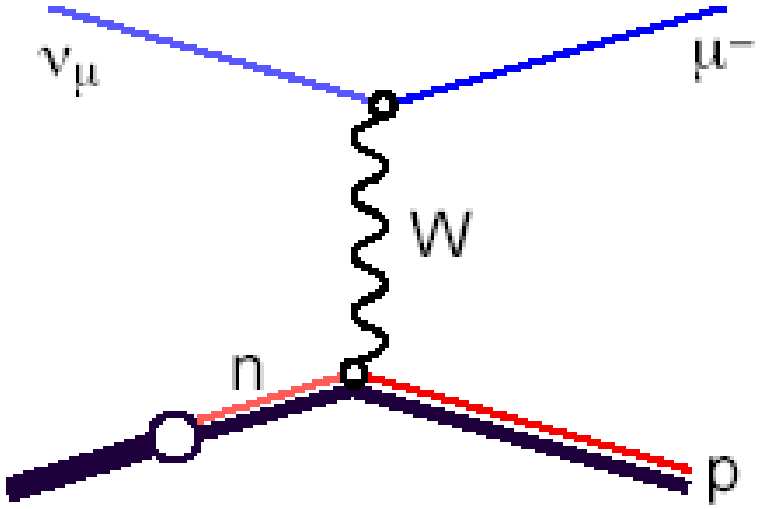
$\nu_\mu n \rightarrow \mu^- p$ event efficiency and resolution

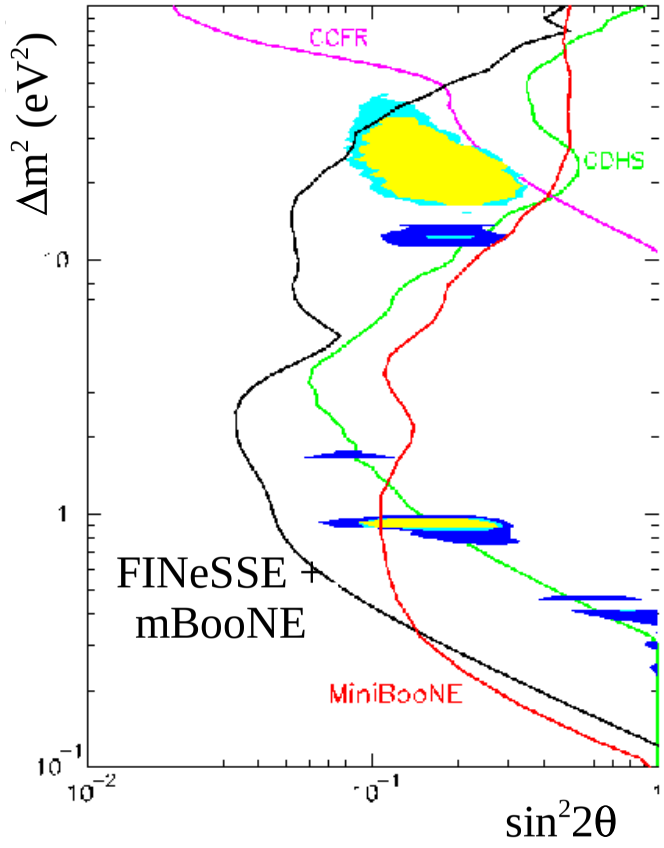
(from NUANCE v3 sample of 100K events)

	CCQE	NC	CCπ	NCπ	Coh.
raw events	4201	6968	1968	1118	450
after cuts	3555	7	1159	217	163
efficiency (%)	85	0.1	59	19	36

Cuts require:
- reconstruction
- long tracks
- low late light

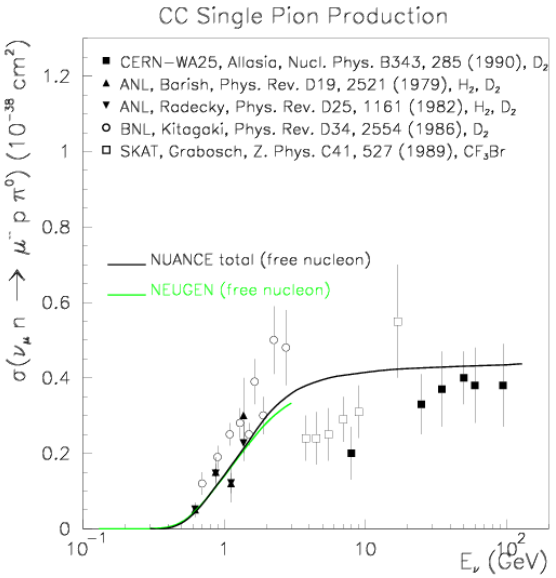
146K events x 86% acceptance
then x 85% efficiency
107K events





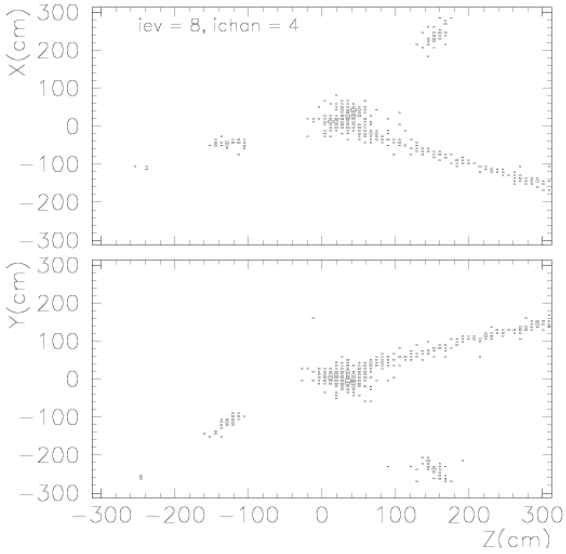
Cross section measurements:

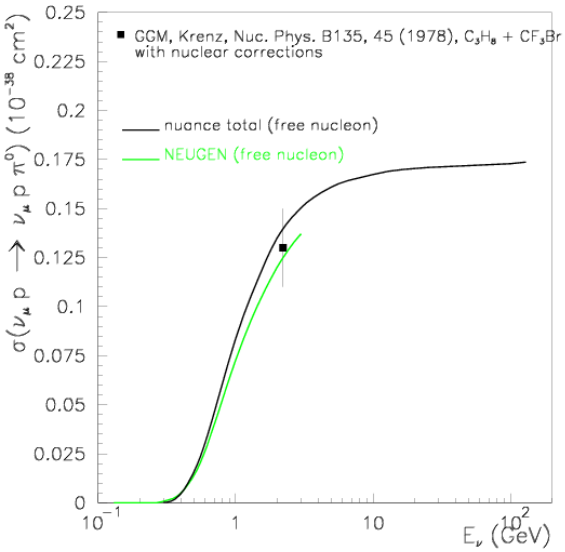
π^0 production: dominant background in $\nu_\mu \rightarrow \nu_e$ oscillation searches



$\nu_\mu n \rightarrow \mu^- p \pi^0$: existing data at low energy on light targets

in FINeSSE

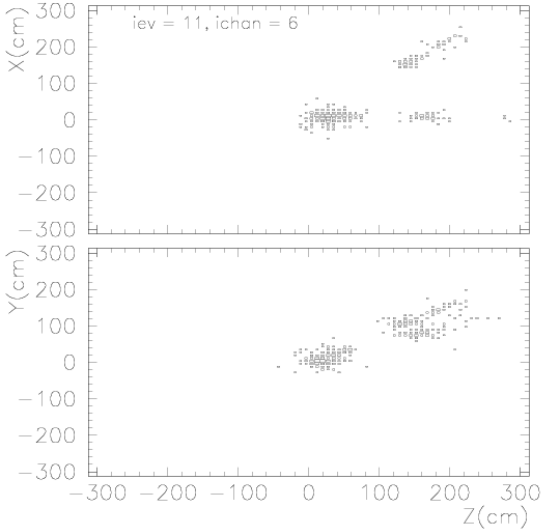




$\nu_\mu p \rightarrow \nu_\mu p \pi^0$

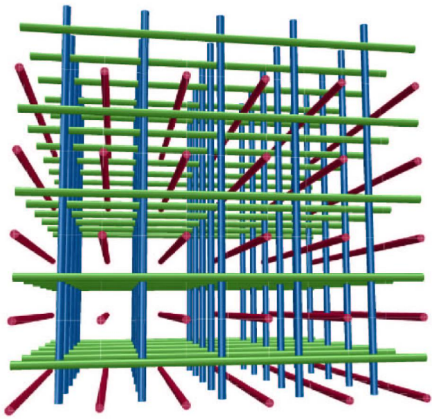
very little NC single pion production data

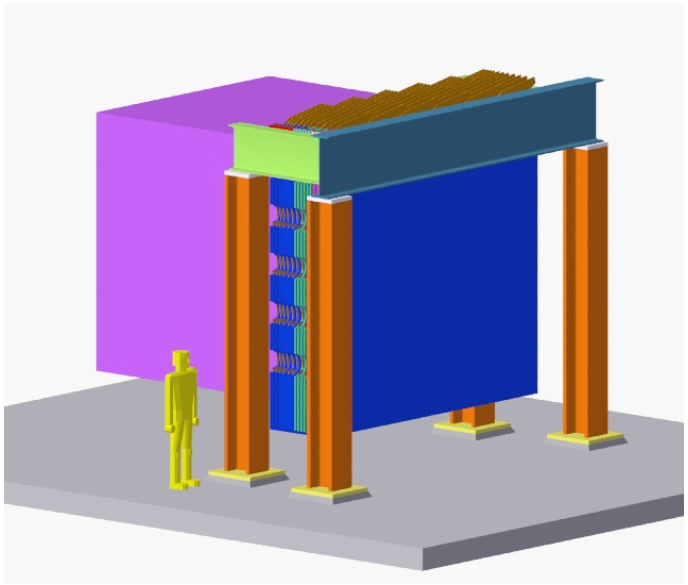
in FINeSSE



Detector costs:

Vertex Detector:	
36 tons Scintillator oil	$185K
tank and fiber grid	$209K
WLS fiber	$119K
19968 channels	$434K
312 MAPMTs	$398K
Muon Rangestack:	
Scintillator and fiber	$36K
34 MAPMTs	$43K
2176 channels	$45K
Iron planes	$327K
Computing &Installation	$254K





→ Total: 2.8 Million (including contingency)

Scibath detector designed to measure
νp elastic scattering at low Q^2

→ simple, low cost detector

Presently considering/testing with different targets

- scintillator oils
- deuterated scintillator
- water