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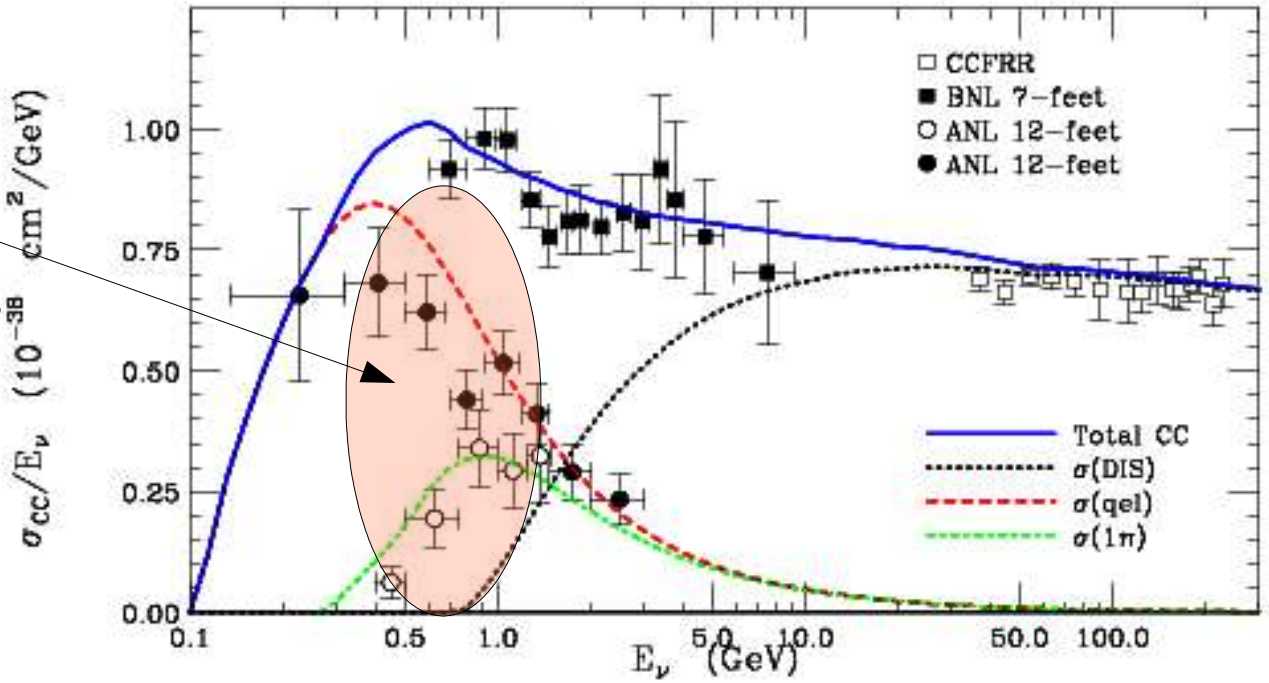
April 7th, 2005

Neutrino Cross Sections with FINeSSE

- What we can learn
- Measurements with FINeSSE's detector and beam
- Feasibility at Fermilab

Growing Interest in Low Energy Neutrino Cross Sections

- Cross sections at these energies of interest for oscillation physics
- Interesting in their own right



From the APS Neutrino Study:

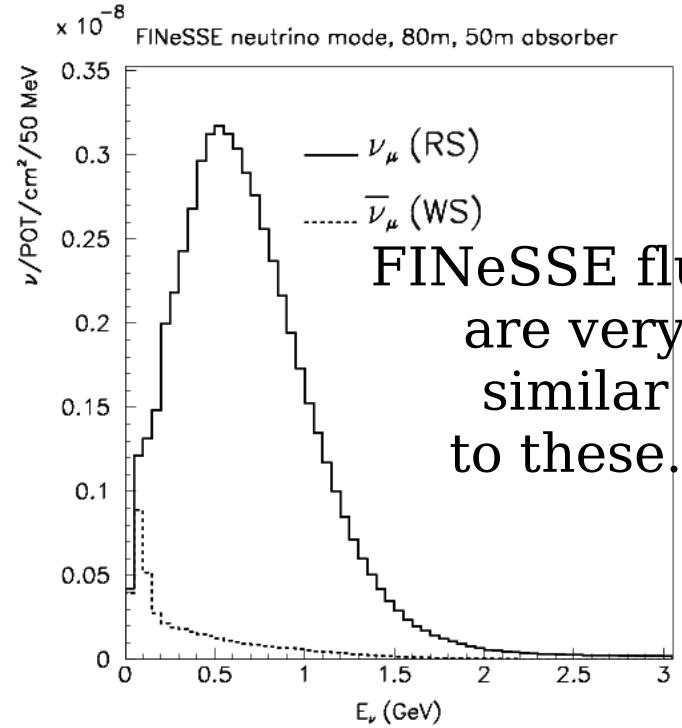
"Determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino oscillation physics ...Our broad and exacting program of neutrino physics is built upon precise knowledge of how neutrinos interact with matter."

Neutrino beams are moving to lower and lower energies...

Proton Sources around the world…

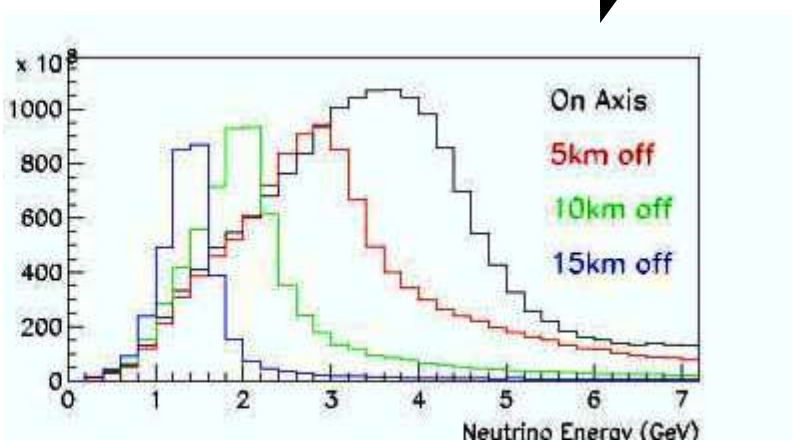
Name	Proton Energy (GeV)	p/yr	Power (MW)	Neutrino Energy (GeV)
KEK	12	1e20/4	0.0052	1.4
FNAL Booster	8	5e20	0.05	1
FNAL Main Injector	120	2.5e20	0.25	3-17
CNGS	400	4.5e19	0.12	25
J-PARC	40-50	1.1e21	0.75	0.77
BNL AGS	28	1.2e21	0.5-1.3	1-2

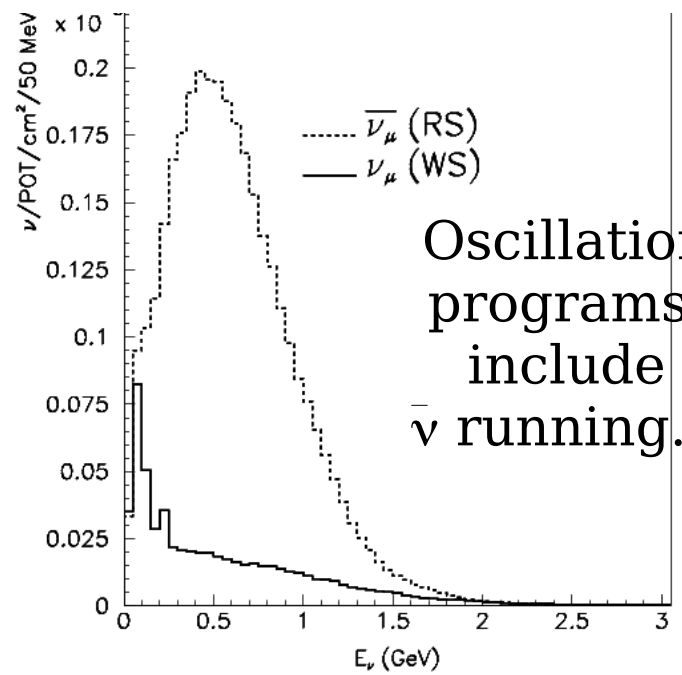
y 2004 Deborah Harris, Conventional Neutrino Beamlines 4



FINeSSE fluxes are very similar to these...

Go off-axis for low energy, clean beams





Oscillation programs include $\bar{\nu}$ running...

FINeSSE event rates:

One year of neutrino running

Reaction	ν_μ (RS) 10^{20} POT 1 ton	$\overline{\nu_\mu}$ (WS) 10^{20} POT 1 ton	ν_μ (RS) 2×10^{20} POT 9 ton
CC quasi-elastic	10,107	181	181,930
NC elastic	4,126	78	74,275
CC resonant $1\pi^+$	4,990	0	89,827
CC resonant $1\pi^-$	0	42	0
CC resonant $1\pi^0$	928	13	16,704
NC resonant $1\pi^0$	1,301	19	23,414
NC resonant $1\pi^+$	458	8	8,237
NC resonant $1\pi^-$	357	5	6,422
CC DIS	253	2	4,550
NC DIS	91	0	1,642
NC coherent $1\pi^0$	365	14	6,566
CC coherent $1\pi^+$	603	0	10,858
CC coherent $1\pi^-$	0	24	0
other (multi-π, etc.)	621	18	11,174
total	24,200	403	435,600

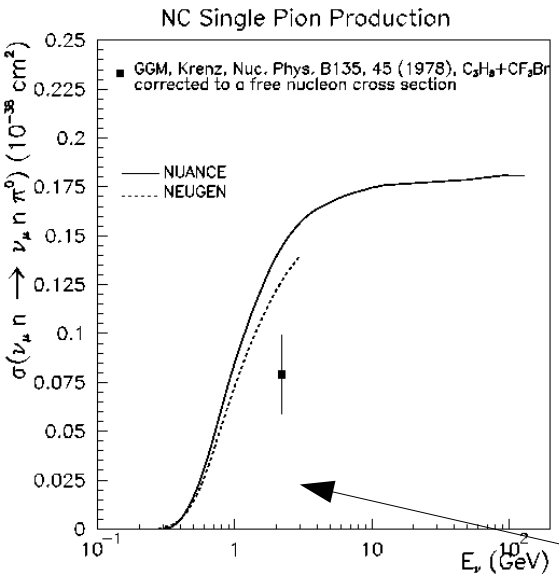
Two years of anti-neutrino running

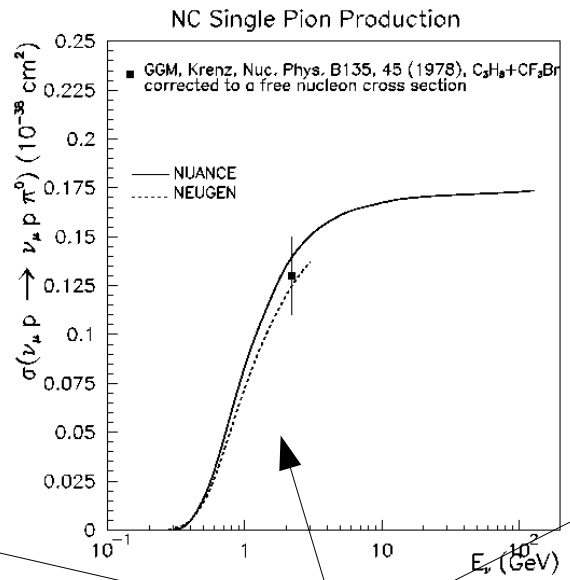
Reaction	$\overline{\nu_\mu}$ (RS) 10^{20} POT 1 ton	ν_μ (WS) 10^{20} POT 1 ton	$\overline{\nu_\mu}$ (RS) 4×10^{20} POT 9 ton
CC quasi-elastic	2,219	787	79,892
NC elastic	922	323	33,179
CC resonant $1\pi^+$	0	470	0
CC resonant $1\pi^-$	419	0	15,092
CC resonant $1\pi^0$	130	93	4,666
NC resonant $1\pi^0$	230	118	8,294
NC resonant $1\pi^+$	83	43	2,996
NC resonant $1\pi^-$	59	35	2,132
CC DIS	3	30	116
NC DIS	2	11	58
NC coherent $1\pi^0$	184	30	6,624
CC coherent $1\pi^+$	0	51	0
CC coherent $1\pi^-$	298	0	10,714
other (multi-π, etc.)	157	93	5,644
total	4,706	2,086	169,402

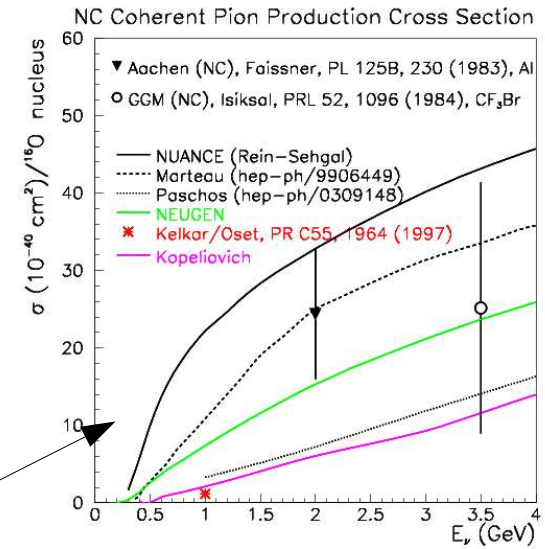
Beamline configuration:
detector at 80m, 50m absorber in place
2 x 10^{20} POT/year

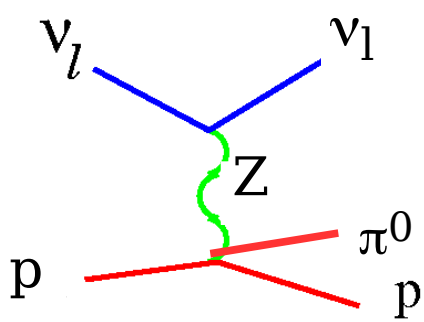
x3 increase in statistics allows for $\bar{\nu}$ run!

Neutral current π^0 production: biggest background for present and future $\nu_\mu \rightarrow \nu_e$ oscillation searches







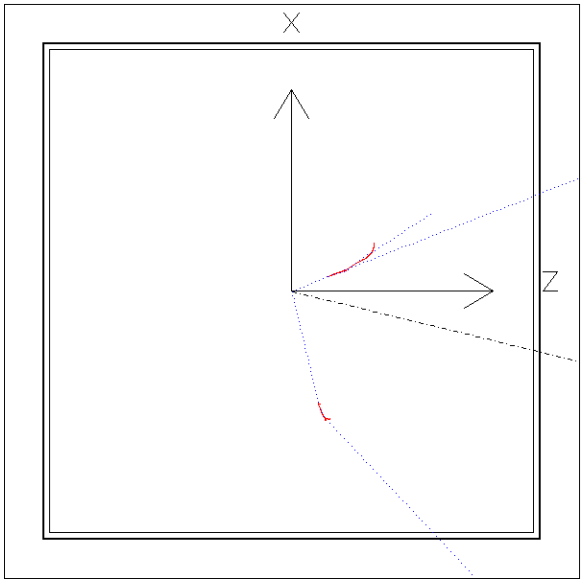


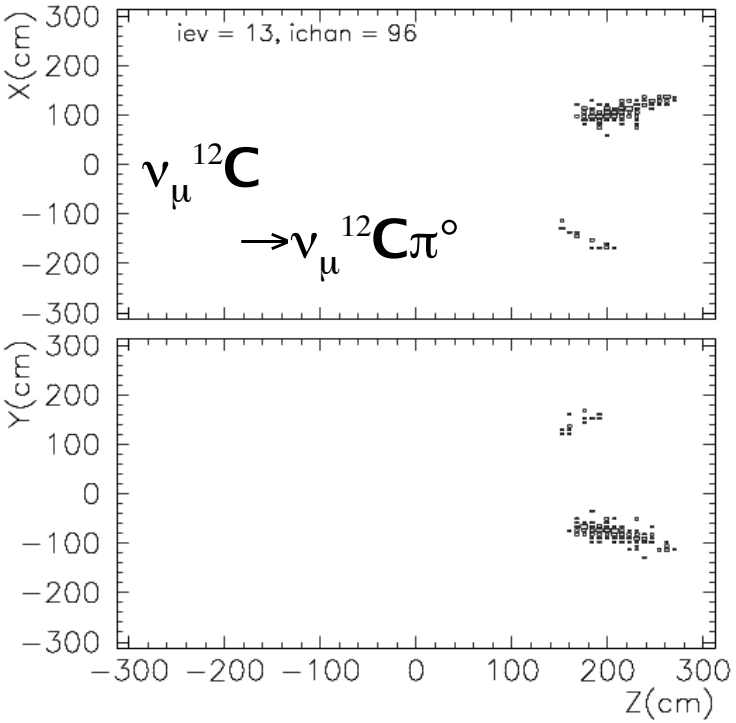
No data below 2 GeV

Lack of data and conflicting predictions →experiments assume 100% uncertainty

→ need fine-grained detector to distinguish π°s from ν_es

FINeSSE expects ~23,000 NC π° resonant events and ~6,500 NC coherent π° interactions





Do not yet have the tools to reconstruct these events, however, with simple pre-reconstruction cuts....
NC single π° interaction sample

Already x2 better than existing data

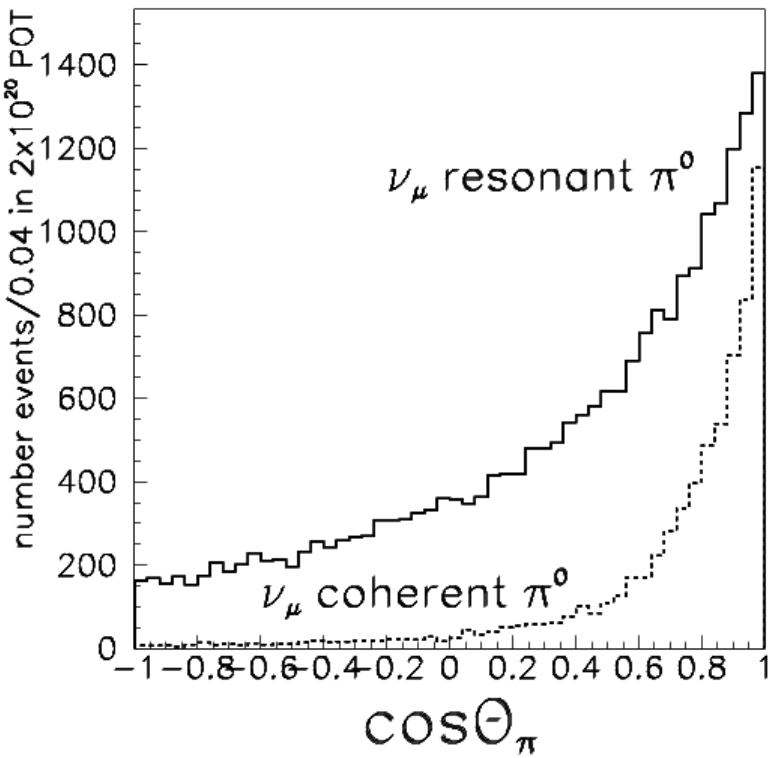
34% efficiency
54% purity

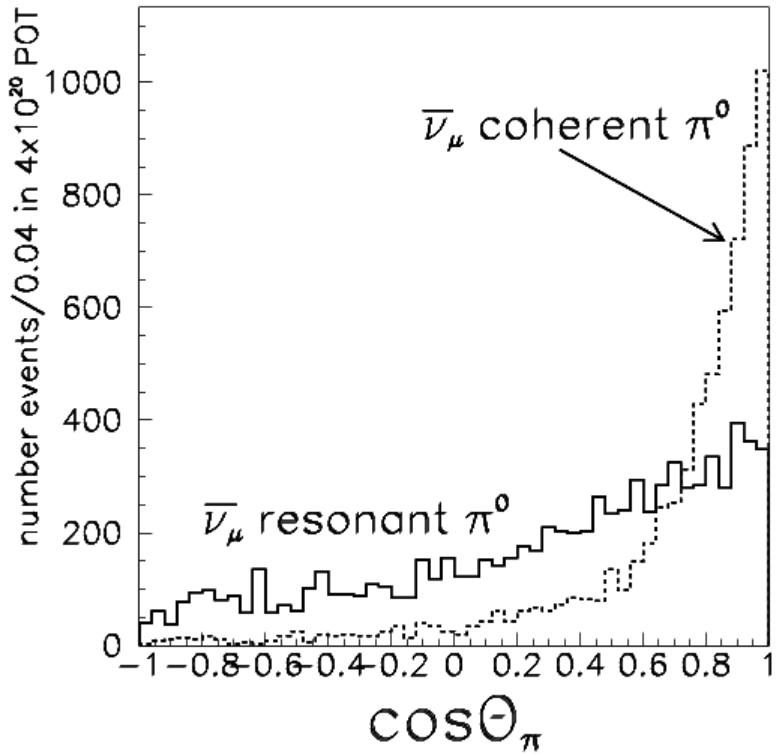
With reconstruction will dramatically improve

Both kinematics and rate of π°s are not well known...

→ different contributions from resonant and coherent

Comparing FINeSSE ν vs $\bar{\nu}$ running
extract the forward peaked coherent contribution

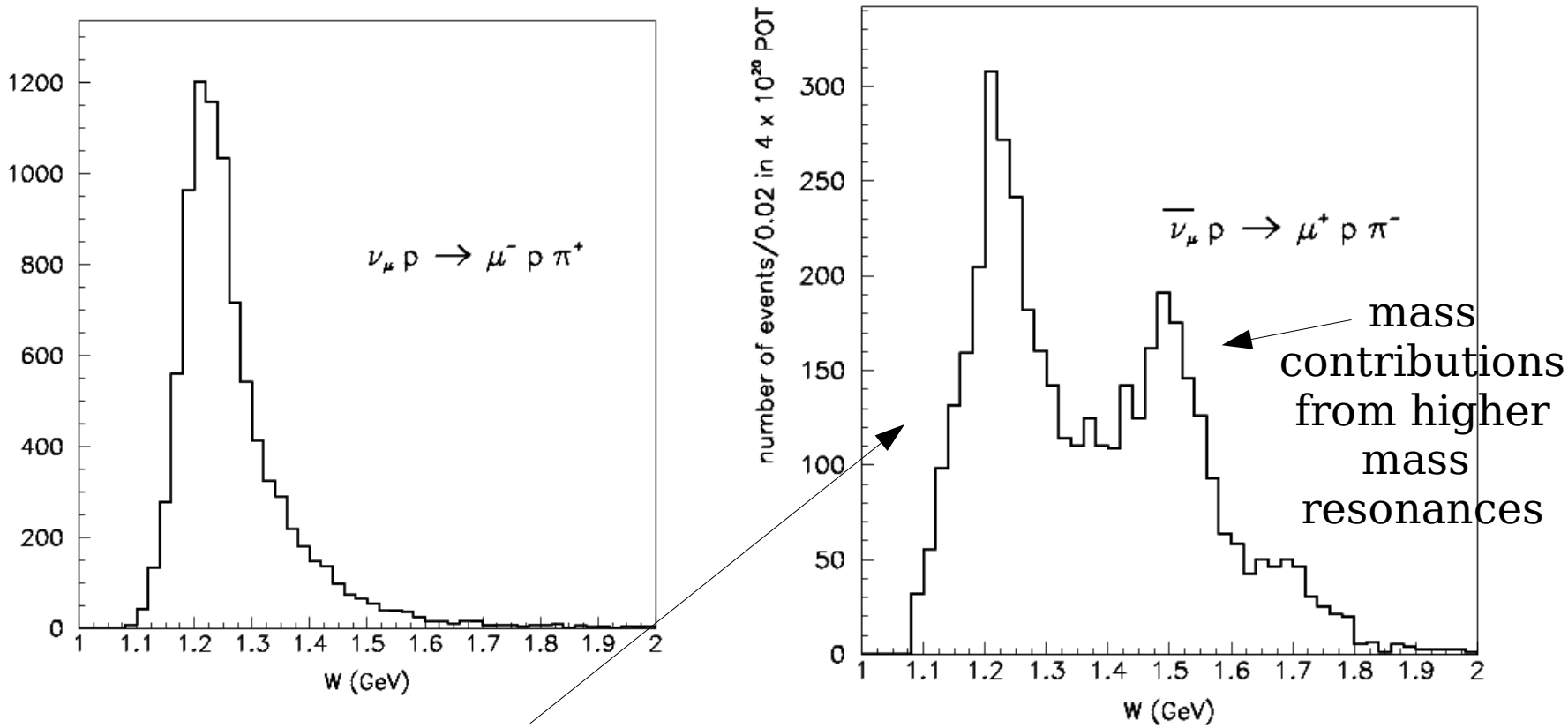




These measurements are particularly important for future $\nu_\mu \rightarrow \nu_e$ oscillation searches

CC resonant pion production:

Different isospin content in final state makes neutrino and anti-neutrino interactions distinct...



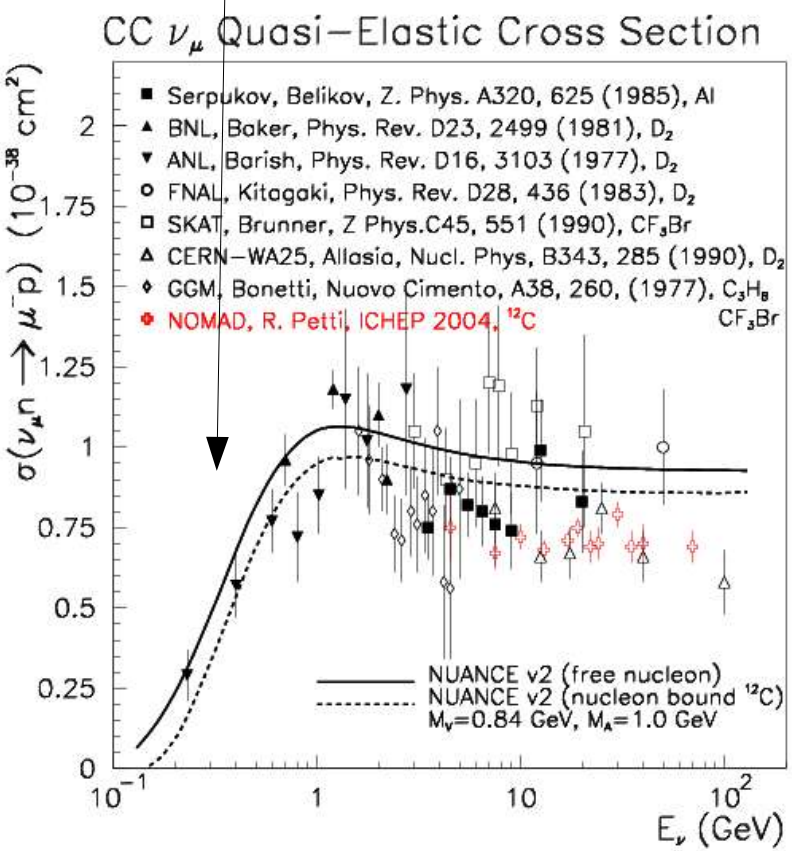
Sensitive beyond Δ(1232)

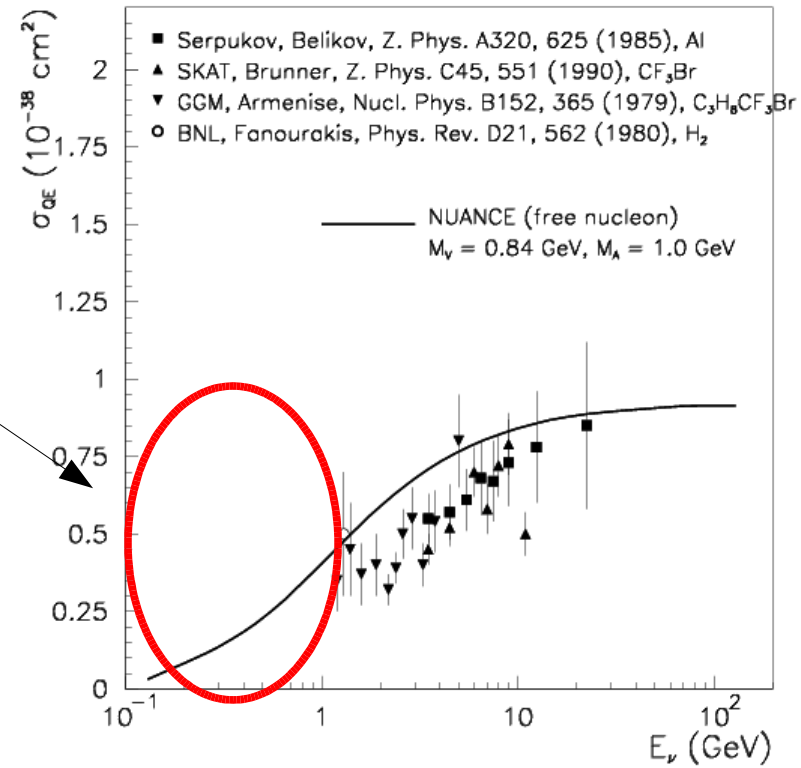
- resonant and non-resonant effects
- interference terms

Quasi-Elastic Scattering

neutrinos:
< 2 GeV
- light targets
- little data
- large uncertainties

anti-neutrinos
<2GeV
- no data





FINeSSE:
- measure CCπ^+ contamination
- reduce uncertainties
- compare with anti-neutrino data!

Ingredients for precision, low energy, neutrino cross section measurements

....goals for this experiment

- High intensity beams → high event rates

reduced statistical errors

- Minimize flux uncertainties
  - 15-20% in the past → 5% expected by MiniBooNE and less by MINOS/MINERvA

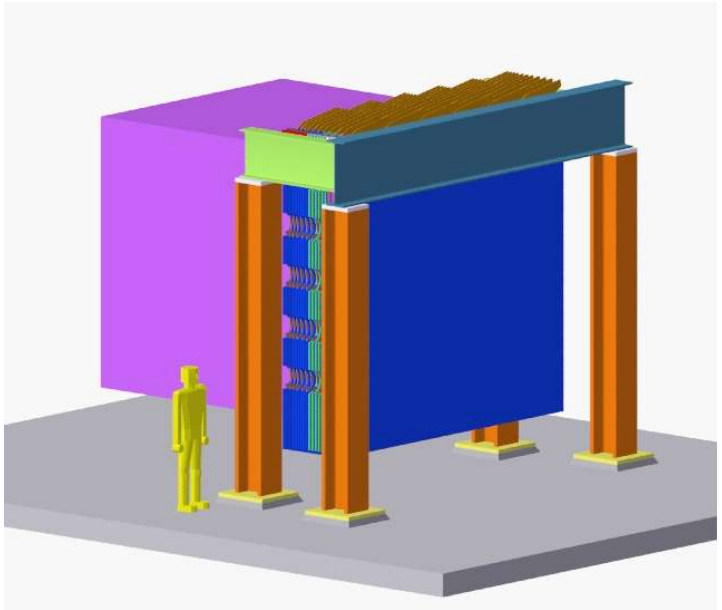
- Minimize background contamination
  - low energy neutrino spectrum (below DIS turn-on and with small high energy tail)
  - fine-grained detector →good final state separation

reduced systematic errors

Funding, construction, and timing

Detector costs:
2.8M with contingency
(FY2003 dollars)

Funding for detector:
- NSF MRI
- DOE sources



Below grade enclosure (on beam axis) to house detector
(~1.6M fully loaded, FY2003 dollars)
- Request support from FNAL

Provided approval and funding are timely
FINeSSE physics run to start in 2008

Conclusions:

Δs

- Fundamental property of the nucleon (still) not understood! Understand the fundamental theory of the nucleon.

- Robust measurement, free from model dependencies of non-neutrino measurements

- Greatly improved sensitivity compared to previous neutrino measurement:

$$\sigma(\Delta \mathbf{s}) = 0.025 \text{ in neutrino mode}$$

  - much more precise and lower in Q^2 than BNL734
  - x2 improvement over previous FINeSSE proposal
  - $\bar{\nu}$ running allows for global fit to further improve sensitivity (possible with new beamline configuration)

Conclusions cont.

Low Energy Neutrino Cross Sections

- Precision neutrino cross section measurements in regions of interest for current and future oscillation experiments
  - Proton driver physics program at FNAL: 8 GeV beamline along with 120 GeV beamline

- $\bar{\nu}$ running at low energies (no existing data!)
  - Anti-neutrino cross sections necessary for planning the future off-axis/long baseline neutrino program.
  - Insight into interactions in neutrino vs anti-neutrino mode (ie: coherent versus resonant)

We ask for your feedback:

- Encouragement to take this to the proposal stage
- Assumptions for the proposal stage on
  - Beam delivery rate
  - Funding scenarios
  - FINeSSE timeline

Thank you for your consideration