NuFact09

21th July - IIT, Chicago

Single pion production experiments review

Joan Catala - IFIC(U.Valencia/CSIC)

The scope of this talk is to review the recent results on neutrino induced pion production through resonance production and decay.

Coherent pion production will be covered tomorrow in H. Tanaka's talk.

Outline

Brief theoretical introduction
(for more details see U. Mosel talk)

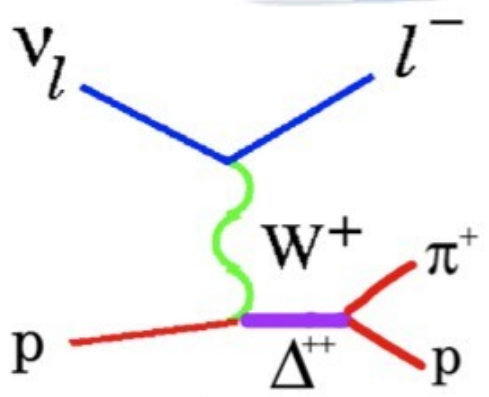
Experiments providing recent results.

CC resonant π^+ and π^0
NC resonant π^0

Upcoming experiments

Summary

Theory



14 Interactions through Δ resonance :

CC

$$\nu_\mu p \to \mu^- \Delta^{++} \qquad \Delta^{++} \to p\pi^+$$
$$\nu_\mu n \to \mu^- \Delta^{+} \qquad \Delta^{+} \to p\pi^0,\ \Delta^{+} \to n\pi^+$$
$$\overline{\nu}_\mu p \to \mu^+ \Delta^{0} \qquad \Delta^{0} \to n\pi^0,\ \Delta^{0} \to p\pi^-$$
$$\overline{\nu}_\mu n \to \mu^+ \Delta^{-} \qquad \Delta^{-} \to n\pi^-$$

NC

$$\nu_\mu p \to \nu_\mu \Delta^{+} \qquad \Delta^{+} \to p\pi^0,\ \Delta^{+} \to n\pi^+$$
$$\nu_\mu n \to \nu_\mu \Delta^{0} \qquad \Delta^{0} \to n\pi^0,\ \Delta^{0} \to p\pi^-$$
$$\overline{\nu}_\mu p \to \overline{\nu}_\mu \Delta^{+} \qquad \Delta^{+} \to p\pi^0,\ \Delta^{+} \to n\pi^+$$
$$\overline{\nu}_\mu n \to \overline{\nu}_\mu \Delta^{0} \qquad \Delta^{0} \to n\pi^0,\ \Delta^{0} \to p\pi^-$$

In the scheme I show the Δ(1232) resonance which is the main contribution to resonant processes. Several other resonances, together with a non-resonant background, contribute also to pion production at low neutrino energies. In MC codes, all measured resonances in the hadronic invariant mass region W<2 GeV are typically modeled.

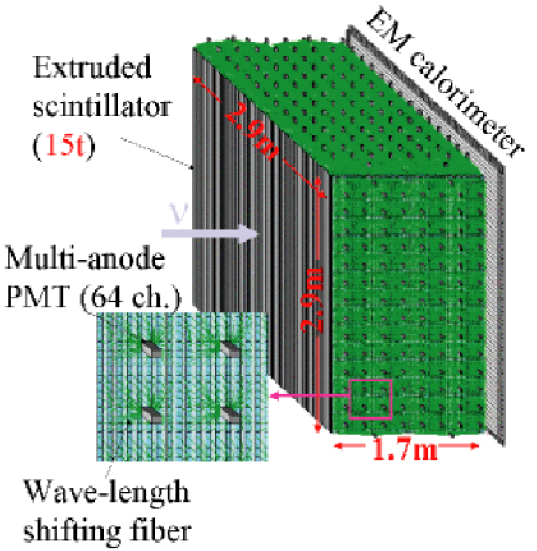
Experimental setups

K2K near detector

1.3 GeV mean energy ν-beam produced by 12 GeV protons on Aluminum

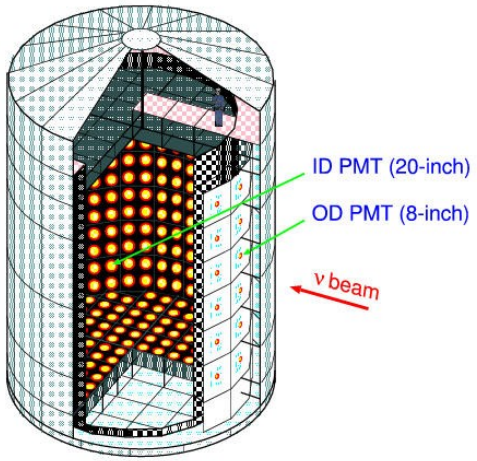
Fine grained detector

- SciFi (not used in the presented analyses)
- SciBar
  - Fully-active fine-grained scintillator detector.
  - 14592 bars (15 tons)
  - dE/dx particle identification
- EC
  - Scintillator-Lead spaghetti calorimeter.
  - Identifies e^- and pi0
- MRD
  - Used for muon tagging.



Water Cherenkov detector

- 1KT
  - 1,000 ton water Cherenkov detector.
  - 8.6m high, 8.6m diameter cylinder containing 680 50cm PMT's facing inward .
  - 40% photocatode coverage.

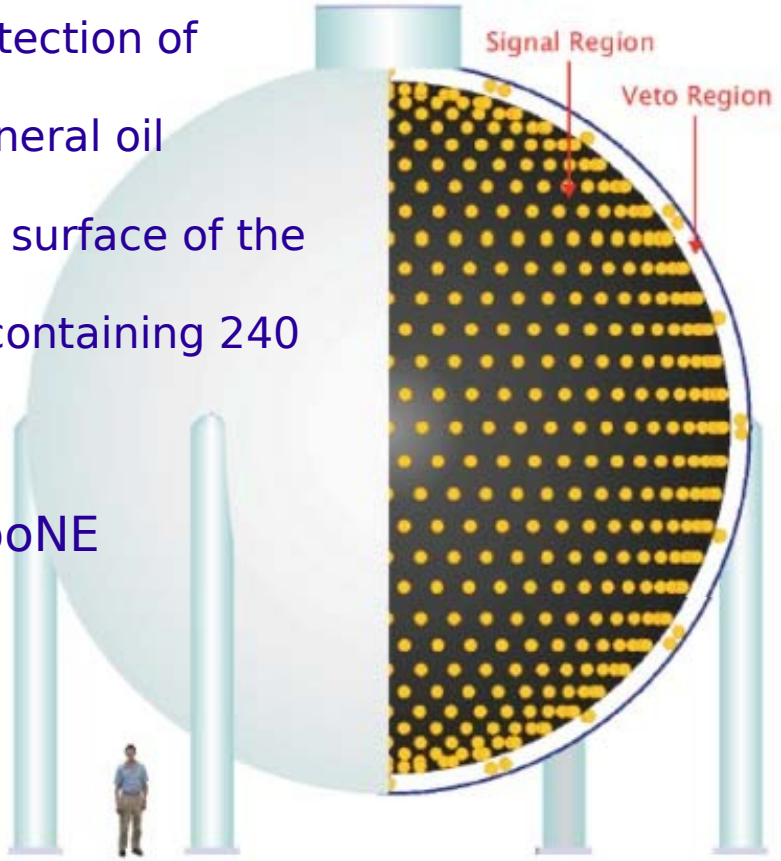


NEUT event generator is used in K2K.
Rein and Sehgal model for resonant pion production with an axial mass M_A=1.1GeV/c^2 is implemented

MiniBooNE

0.8 GeV mean energy neutrino/anti-neutrino beam produced by 8 GeV protons on Beryllium.

•Particle reconstruction is based primarily on detection of Cherenkov radiation
•The tank is filled with 800 tons of ultra-pure mineral oil (modeled as CH2)
•1280 8” photo-tubes are attached to the inside surface of the tank (10% coverage)
•Outside the main tank is a thin spherical shell containing 240 phototubes to veto entering particles

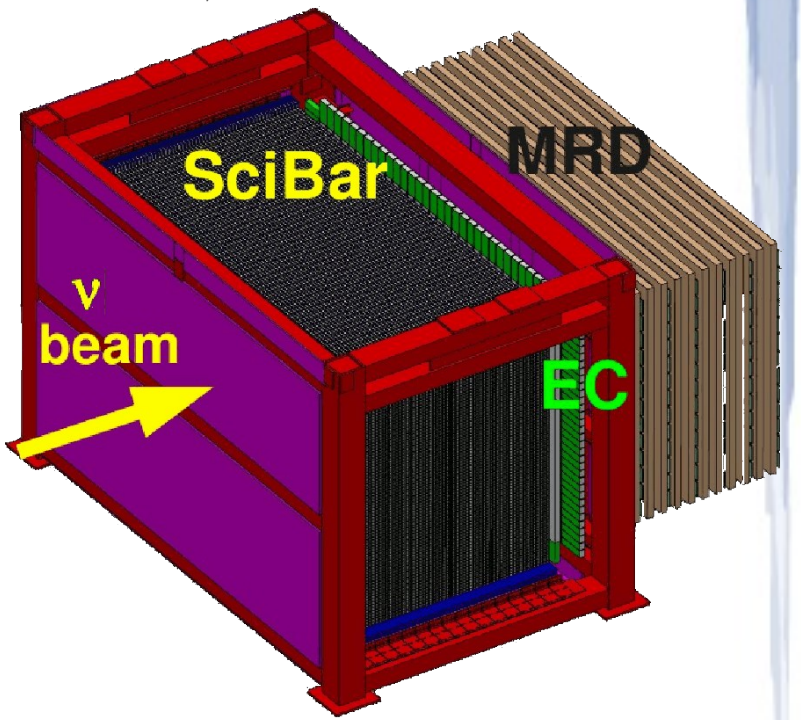


NUANCE event generator is used in MiniBooNE
•Resonant
- Rein-Sehgal with M_A = 1.1 GeV.
- Non-isotropic Δ decay

•Coherent
- Rein-Seghal with M_A= 1.03 GeV
- NC and CC rescaled to measured coherent fraction.
- NUANCE FSI model

SciBooNE

Same beam as MiniBooNE: 0.8 GeV mean energy neutrino/anti-neutrino beam produced by 8 GeV protons on Beryllium.



Detector setup:

- SciBar
  - Fully-active fine-grained scintillator detector.
  - 14336 bars (~15 tons)
  - dE/dx particle identification
- EC
  - Scintillator-Lead spaghetti calorimeter.
  - Identifies e^- and pi0
- MRD
  - Used for muon tagging only.

NEUT/NUANCE MC generators implemented. Only NEUT used in the presented analyses.
Rein and Seghal model with M_A=1.2 GeV

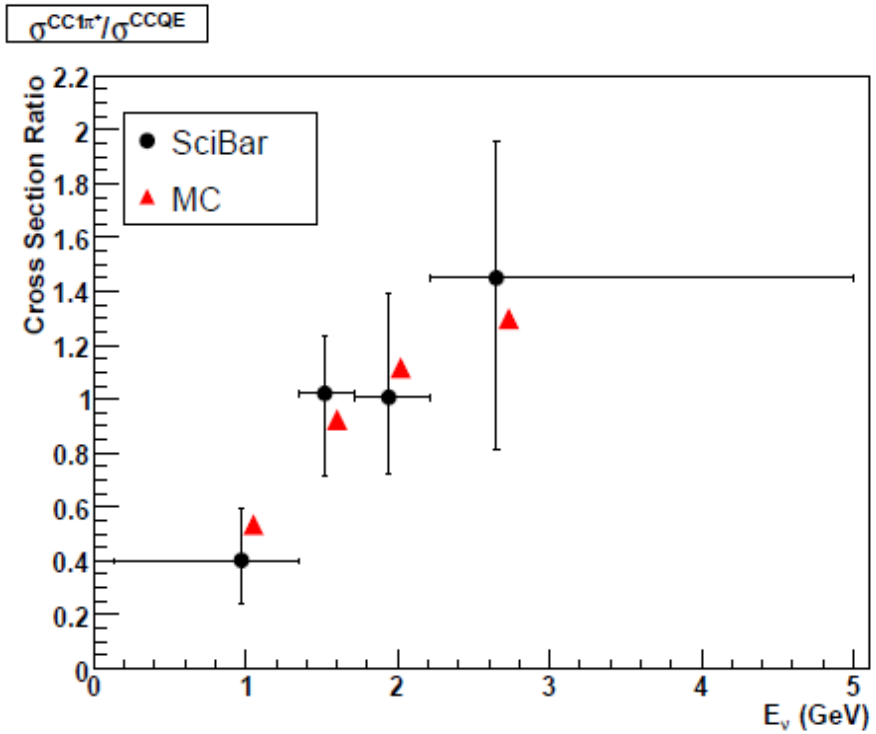
Charged Current

CC-π^+ K2K

CC-π^+ event definition:

- Neutrino interacting with the nucleon via CC-π^+, correcting for FSI.

CC1π experimental signature based on muon kinematics instead of full final state topology.



Dominant contribution: ν_μ p -> μ^- p π^+ , with small contribution from ν_μ n -> μ^- n π^+

CC-π^+ xsec measured relative to CC-QE one, to reduce impact of neutrino flux systematic uncertainties

Data in good agreement with MC prediction and also ANL data.

arXiv:0805.0186v2 [hep-ex]

$$\nu-induced\ \sigma^{CC1\pi^+}/\sigma^{CCQE} = 0.734 \pm 0.086(fit)^{+0.076}_{-0.103}(nucl.)^{+0.079}_{-0.073}(syst.)$$

CC-π^0 k2k

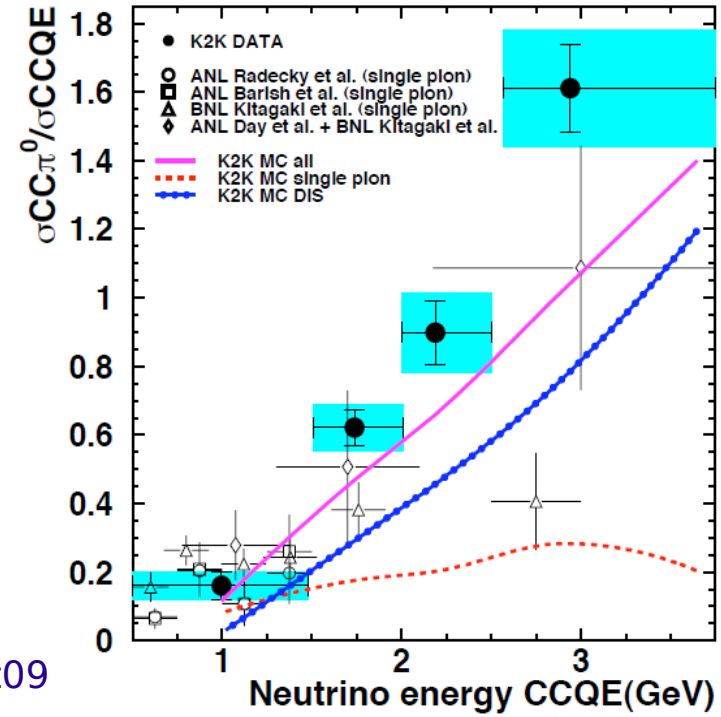
CC-π^0

- 1 or more π^0's from the neutrino interaction vertex
- 1 or more π^0's from a re-interaction inside the target nucleus;
- 1 or more η (decaying either in π^o's or photon pairs).

For this inclusive pi0 signal definition, about half of CC-pi0 is due to resonant processes, half to deep inelastic processes.

Identify muon with SciBar and MRD and two showers due to photon conversions from pi0 decay using SciBar and/or EC

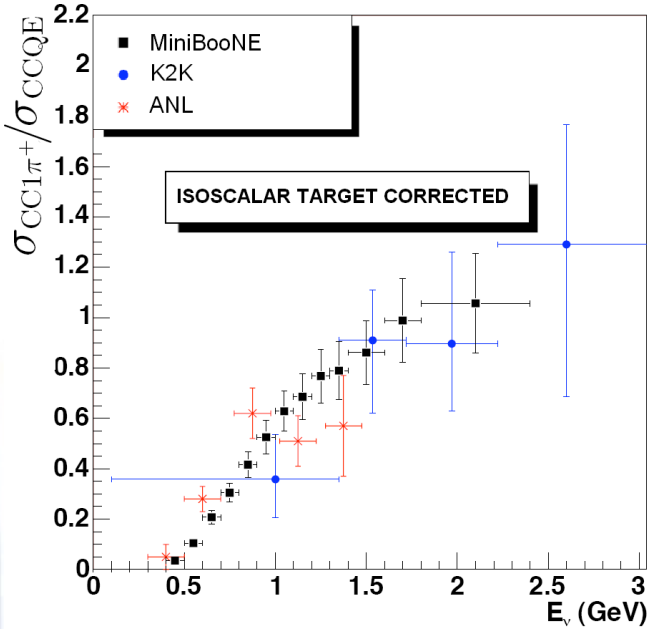
Data shows excess with respect to MC prediction, interpreted as excess in CC-DIS.



C. Mariani - NuInt09

$$\nu-induced\ \sigma^{CC\pi^0}/\sigma^{CCQE}=0.443\pm0.033\,(stat.)\pm0.036\,(syst.)$$

CC-π^+ MiniBooNE

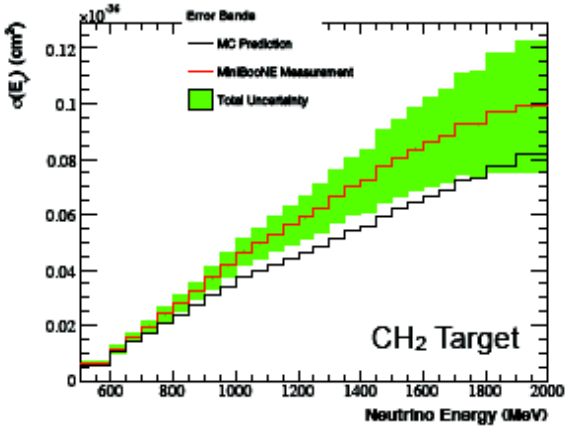


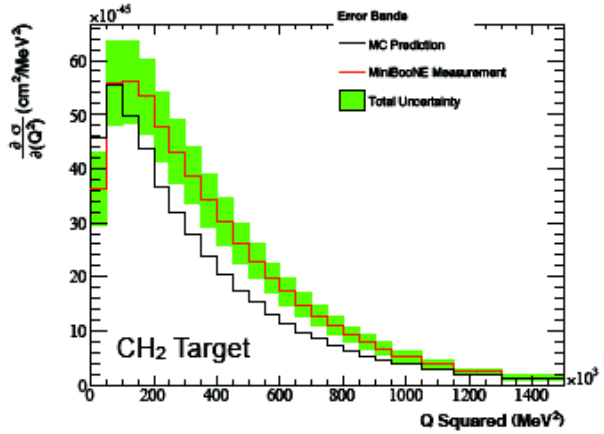
arXiv:0904.3159v1 [hep-ex]

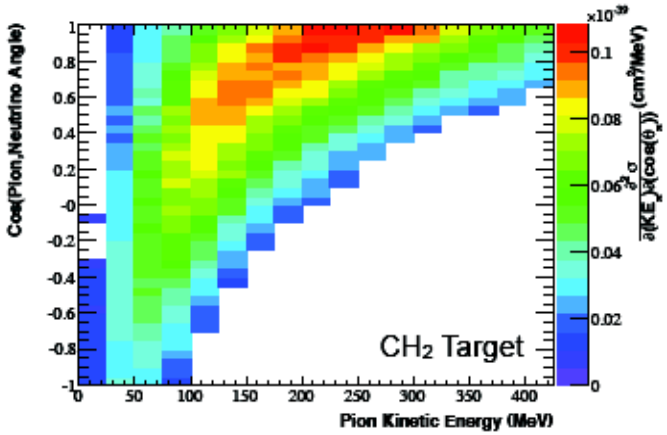
- An observed **CC-π^+** event is defined to be any interaction that produces the following final state:
- One and only one muon
- one and only one pion
- any number of photons and baryons from the breakup of the nucleus

Improved pion reconstruction. Event kinematics fully specified. No assumptions on Δ mass.

Absolute **CC-π^+** cross section in energy, Q^2 and pion energy and angle double differential:







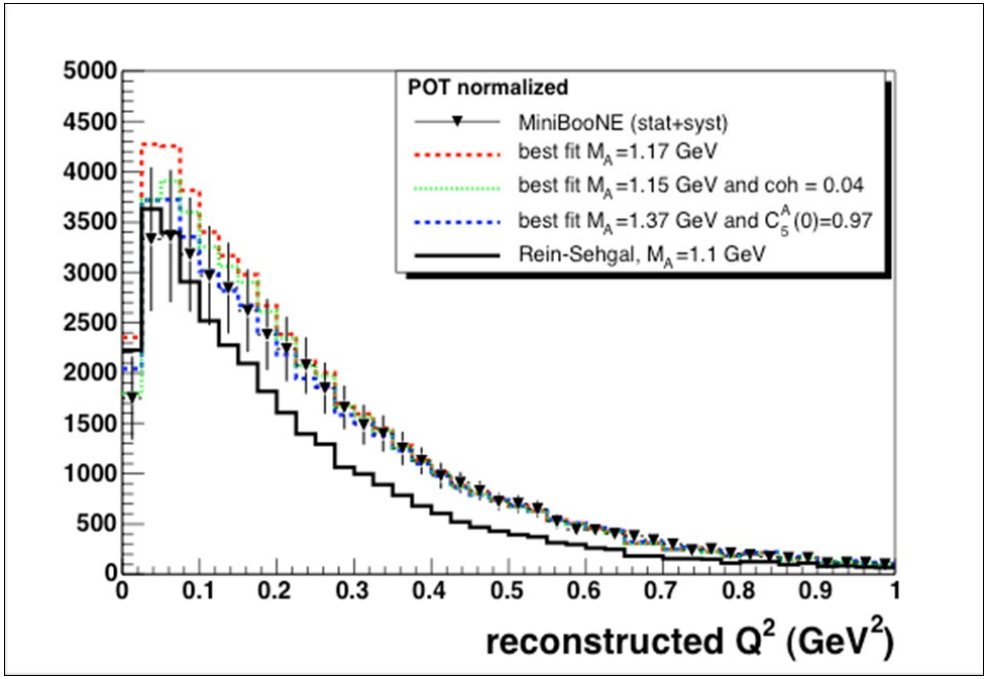
M. Wilking - NuInt09 Talk

CC-π^+ MiniBooNE

MiniBooNE CC- $1\pi^+$, resonant plus coherent, data also used to tune MC models.

Performed the fits for three different models (R-S with updated vector and axial FF):

- $M_A^{1\pi}$ for $Q^2>0.2$GeV
  - $M_A^{1\pi} = 1.17 \pm 0.13$ GeV
- Coherent contribution and $M_A^{1\pi}$
  - $M_A^{1\pi} = 1.15$ GeV
  - Coherent < 0.04
- $M_A^{1\pi}$ and $C_5^A(0)$
  - $M_A^{1\pi} = 1.37$ GeV
  - $C_5^A(0) = 0.97$



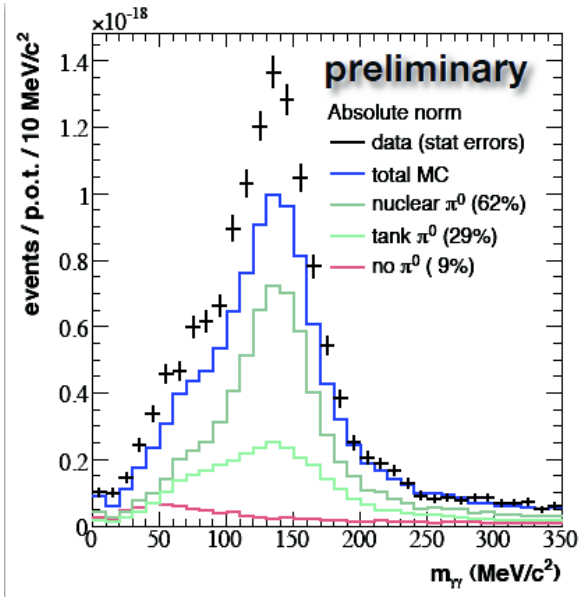
J. Nowak - NuInt09

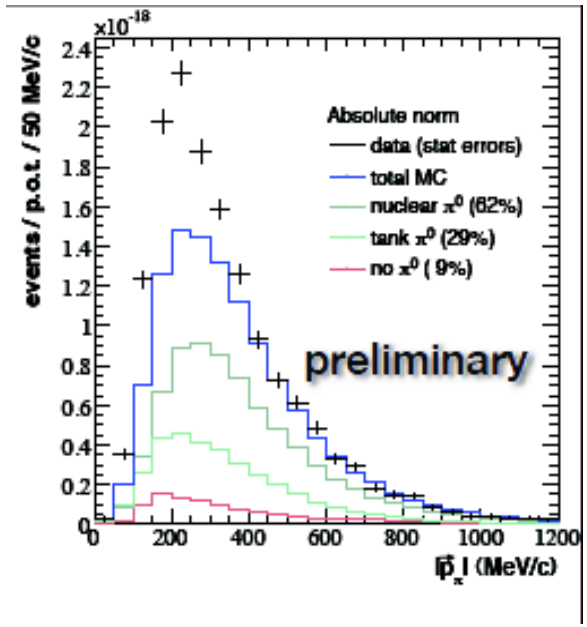
CC-π^0 MiniBooNE

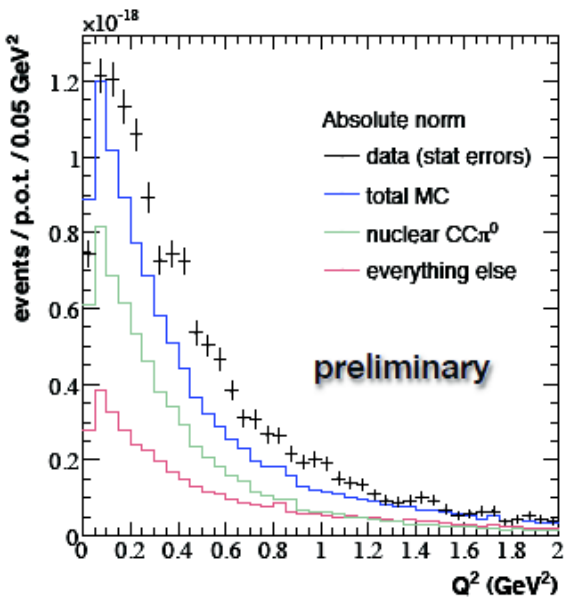
An observed **CC-π^0** event is defined to be any interaction where a π^0 exits the interaction nucleus.
•charge exchanged events are included.

Reconstruct muons and two gammas in the final state with three Cherenkov ring fitter, assuming target nucleon at rest and incoming neutrino direction, full event kinematics can be constructed.

With respect MC, softer pi0 momentum distribution and larger rate.





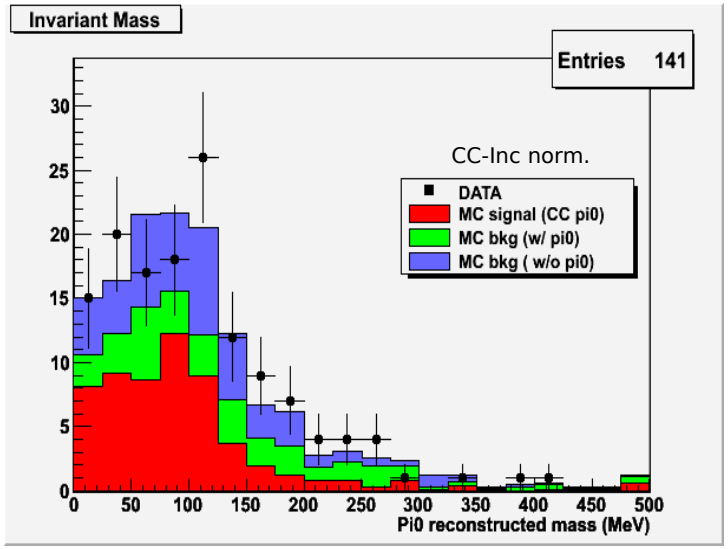


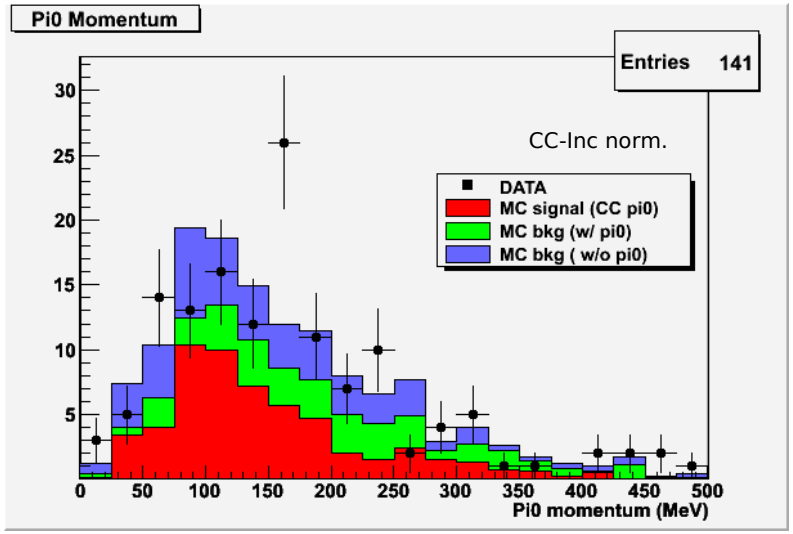
R. Nelson - NuInt09

CC-π^0 SciBooNE

•CC-π^0: One muon and one π^0 coming out from the interaction nucleus.

Reconstruct μ with SciBar plus MRD and two gammas contained in SciBar (EC not used)





Analysis improvements since plots above were produced (new results are coming soon):

-Narrower invariant mass peak.
-Bias in π^0 momentum has been reduced, increasing the number of high momentum pions.

Neutral Current

NC-π^0 k2k

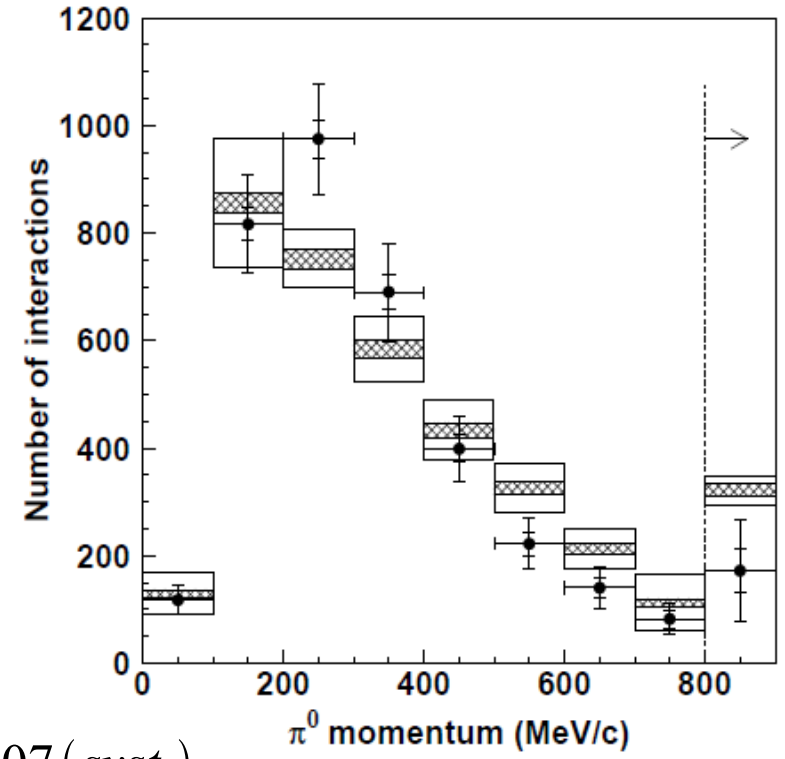
Using the 1KT water detector.

Signal definition:
A neutral pion and no other mesons emitted in the final state from the nucleus.

Reconstruct 2 cherenkov rings from e-like, fully contained tracks, with invariant mass close to pi0 mass (85-215 MeV).

MC is normalized by the number of total events in the fiducial volume

MC prediction for σ (NCπ^0/CC-inc) = 0.065



$$\nu-induced\ \sigma^{NC\pi^0}/\sigma^{CC-inc}=0.064\pm0.001(stat.)\pm0.007(syst.)$$

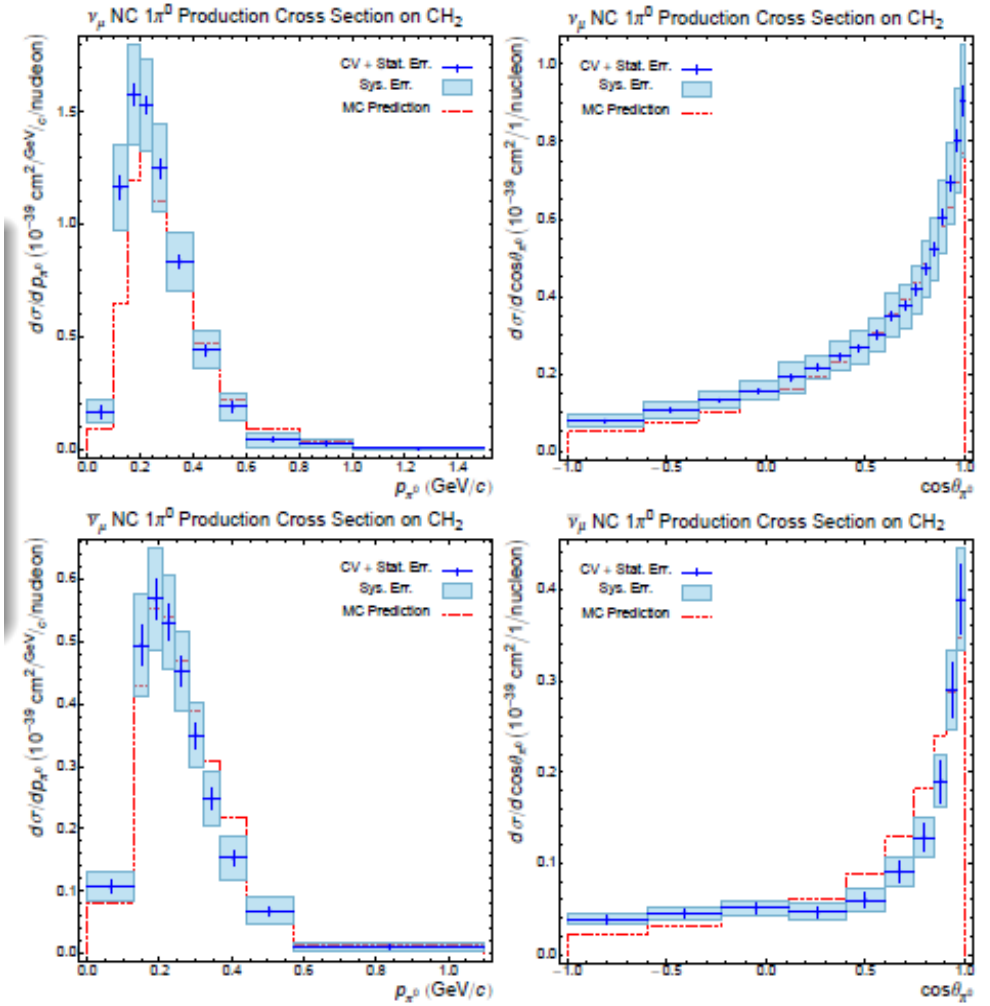
arXiv:hep-ex/0408134v1

NC-π^0 MiniBooNE

Signal definition:
Neutral Current events with a π^0 exiting from the target nucleus and no other mesons.

Event selection similar to K2K 1KT one.

First absolute differential xsec measured for NC-pi0 production using neutrinos and antineutrinos.



C. Anderson - NuInt09

$$\nu - induced\ \sigma = (4.54 \pm 0.04_{stat.} \pm 0.71_{sys}) \times 10^{-40}\ cm^2/nucleon$$

$$\bar{\nu} - induced\ \sigma = (1.43 \pm 0.03_{stat.} \pm 0.23_{sys}) \times 10^{-40}\ cm^2/nucleon$$

NC-π^0 SciBooNE

Signal definition: At least 1 π^0 coming out from the target nucleus.

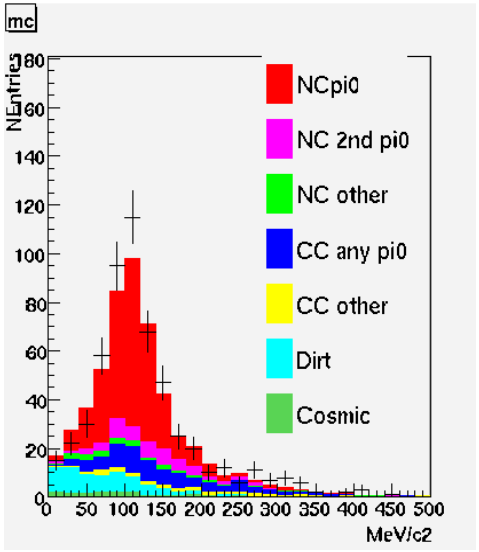
Two gammas reconstructed with SciBar and EC

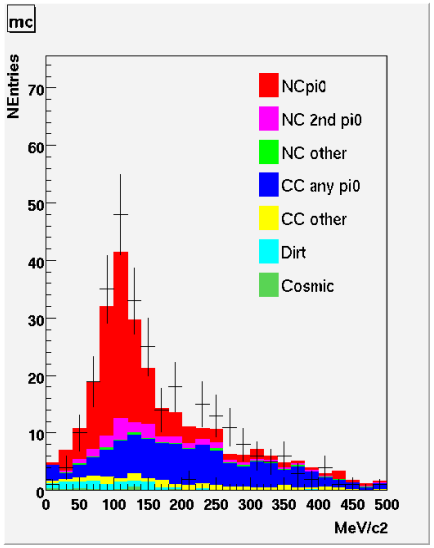
Two samples:

- SciBar contained events (systematics included)
- SciBar + EC events (not all systematics included)

Good agreement with MC prediction, normalized to CC-inclusive events.

Same energy region, both samples can be combined.





Y. Kurimoto - NuInt09

$$\nu-induced\ contained\ \sigma^{NC\pi^0}/\sigma^{CC-inc}=0.075\pm0.00574_{stat.}\ ^{+0.00756}_{-0.00901}(sys.)$$

$$\nu-induced\ non-contained\ \sigma^{NC\pi^0}/\sigma^{CC-inc}=0.073\pm0.00924_{stat.}\ ^{+0.00626}_{-0.00838}(sys.)$$

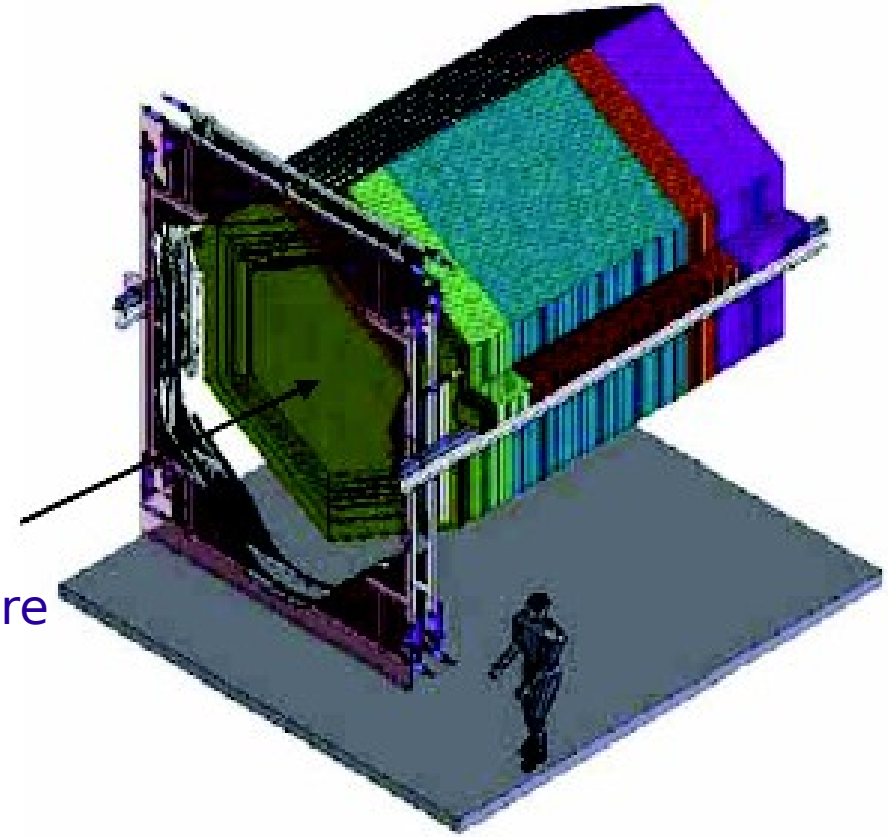
Upcoming measurements

Minerνa

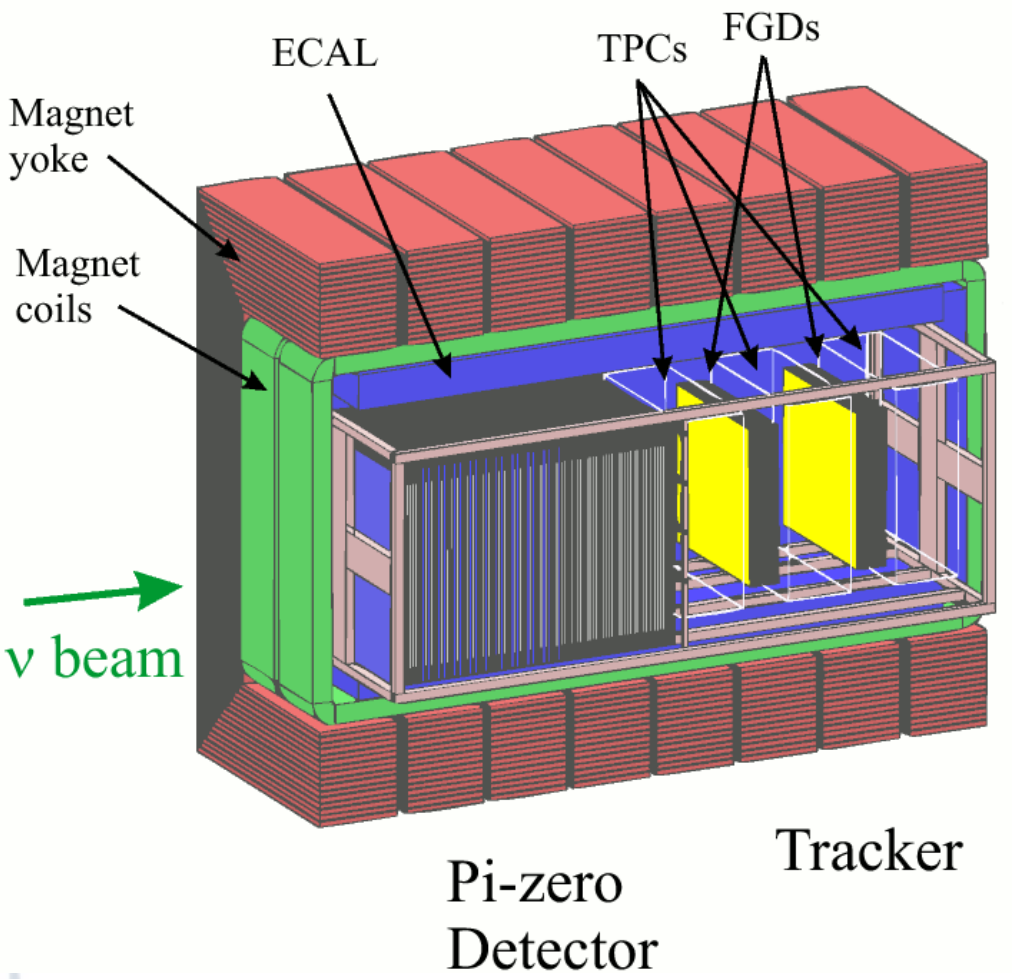
•Will be able to measure total resonance cross sections with 5-10% estimated error (using MIPP data).

•$d\sigma/dQ^2$ and $d\sigma/dW$ differential cross sections will also be calculated.
The largest error will likely be from bias in the energy reconstruction.

•Will be able to measure exclusive final states on a variety of nuclei (He, C, Fe and Pb) allowing to measure final state nuclear effects.



T2K ND280



- CC-1π will be measured precisely by the tracker (TPC's plus FGD's)
- Specific π^0 detector P0D will be able to precisely measure inclusive neutral pion production rate as well as various CC and NC exclusive π^0 production.
- Water and carbon targets are used in order to reduce nuclear effects uncertainties.

Conclusions

- Many results presented recently on resonant pion production.
- Improvement on many measurements:
  - Better accuracy
  - Differential Cross-sections obtained
  - Several exclusive channels and final state effects studied
- New experiments will come with higher statistics.

Historical measurements

Charged current neutrino cross sections.