Comparison of cross section models for neutrino-induced single pion production

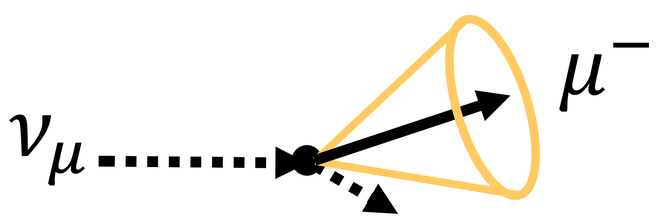
Koki Yamauchi, Masaki Ishitsuka, and Yoshinari Hayato[A]
Tokyo University of Science, [A]Kamioka Observatory, ICRR, The University of Tokyo

Introduction

Neutrino interactions for $E_\nu \geq 100$ MeV and difference in number of rings in water Cherenkov detectors

Charged-current quasi-elastic scattering (CCQE)

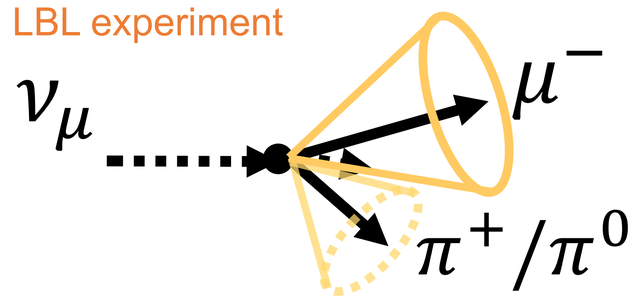
- Dominant at several hundred MeV
- Identified as a single-ring event
- E_ν can be reconstructed from the momentum of charged leptons.



Single pion production

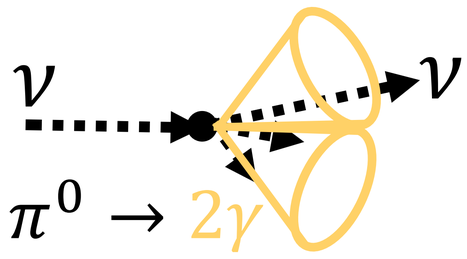
CC1π

- Major background process for proton decay via $p \to e^+\pi^0$ and $p \to \mu^+\pi^0$
- Can be misidentified as CCQE in case π^+ was not detected.
  → background contamination in LBL experiment



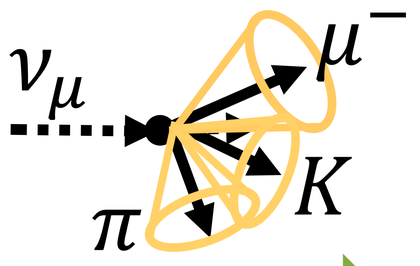
NC1π^0

- Misidentified as single-ring if the momentum of one γ is small or two γ's are overlapped.
  → background for ν_e CC events.



Deep inelastic scattering

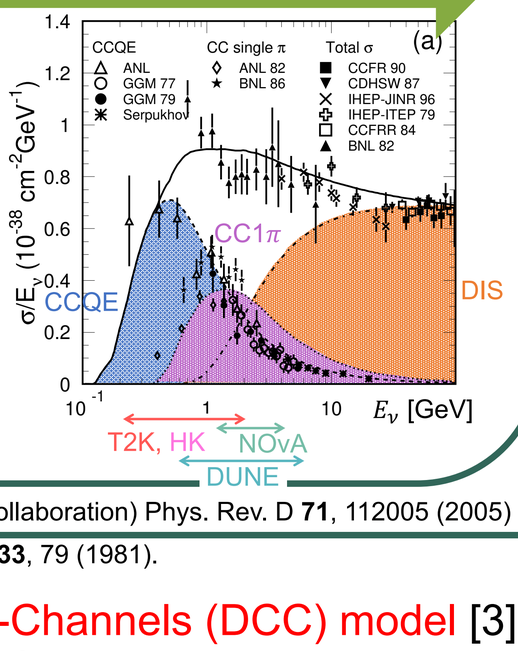
- Dominant at $E_\nu \geq$ several GeV
- Observed as multi-ring events with several hadrons.



100 MeV - several hundred MeV | several hundred MeV – a few GeV | several GeV or more

Importance of single pion production

- Neutrino oscillation measurement by atmospheric neutrino and accelerated neutrino
  Super-Kamiokande, Hyper-Kamiokande — T2K, Hyper-K, NOvA, DUNE
  plans to use multi-ring samples
  higher neutrino energy than T2K, more single pion events
- Proton decay search - atmospheric neutrino single pion production can be a background of proton decay.



It is important to understand the cross section and kinematics of single pion production to improve the precision of the neutrino oscillation measurement and proton decay searches.
We evaluated a new pion production model.

Y. Ashie *et al.* (Super-Kamiokande Collaboration) Phys. Rev. D **71**, 112005 (2005)

Cross section models

[1] C. Berger and L. M. Sehgal, Phys. Rev. D **76**, 113004 (2007). [2] D. Rein and L. M. Sehgal, Ann. Phys. **133**, 79 (1981).
[3] S. X. Nakamura, H. Kamano, and T. Sato. Phys. Rev. D **92**, 074024 (2015).

Berger-Sehgal model [1]

- Currently used in Super-Kamiokande, based on Rein-Sehgal (1981 [2])
- Two-step process allows the calculation of other meson productions.

$$\nu + N \to l + \Delta(N^*)$$
$$\hookrightarrow \pi + N'$$

Compare

NEW Dynamical Coupled-Channels (DCC) model [3]

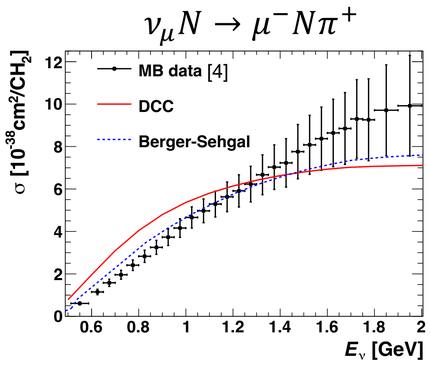
- Uses various data of pion production
- Determines the cross section of neutrino-induced single pion production to fit the data.

$\pi + N \to \pi + N'$, $\gamma + N \to \pi + N'$ } data —calculate→ $\nu + N \to l + \pi + N'$

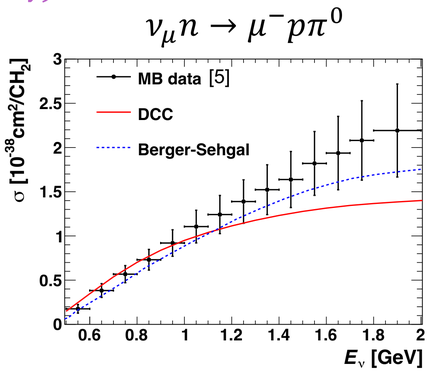
Results

$\sigma(E_\nu)$

$\nu_\mu N \to \mu^- N\pi^+$



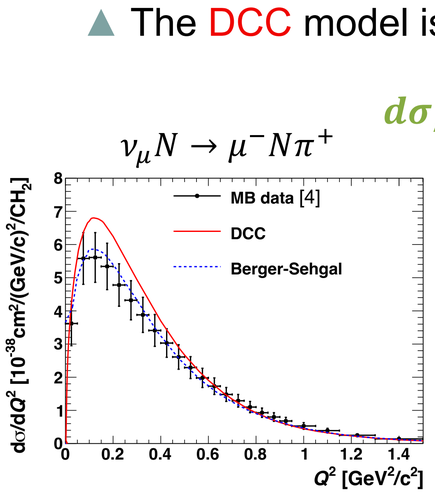
$\nu_\mu n \to \mu^- p\pi^0$



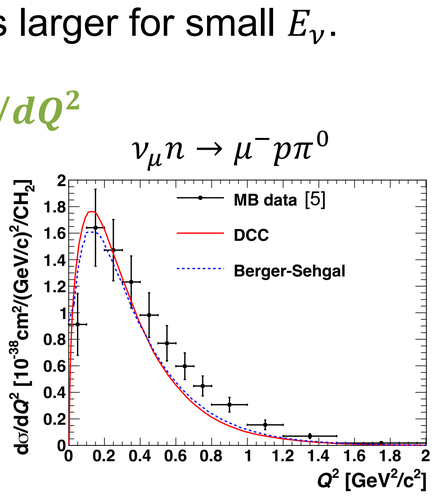
- The DCC model is larger for small E_ν.

$d\sigma/dQ^2$

$\nu_\mu N \to \mu^- N\pi^+$



$\nu_\mu n \to \mu^- p\pi^0$

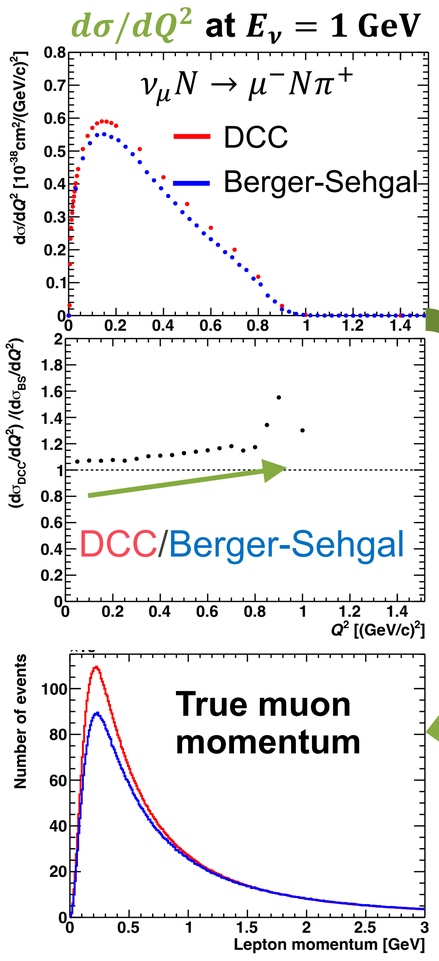


- Berger-Sehgal is in good agreement with the MiniBooNE data in CC1π^+ channel.

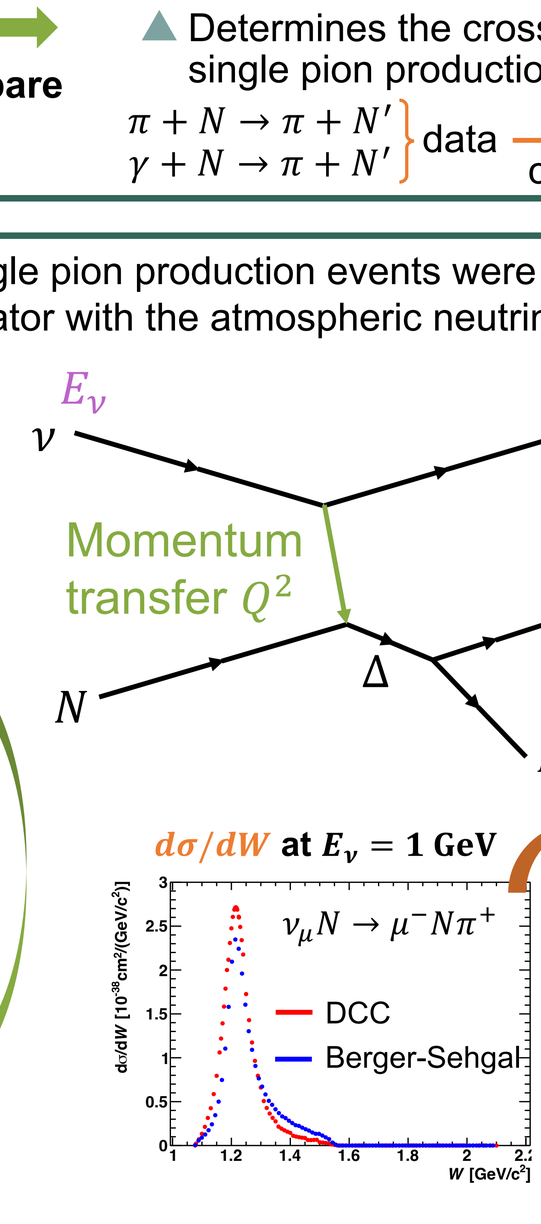
[4] A. A. Aguilar-Arevalo et al., Phys. Rev. D 83, 052007 (2011).
[5] A. A. Aguilar-Arevalo et al., Phys. Rev. D 83, 052009 (2011).

Neutrino-induced single pion production events were generated by the NEUT neutrino event generator with the atmospheric neutrino flux at Super-K.

$d\sigma/dQ^2$ **at $E_\nu = 1$ GeV**

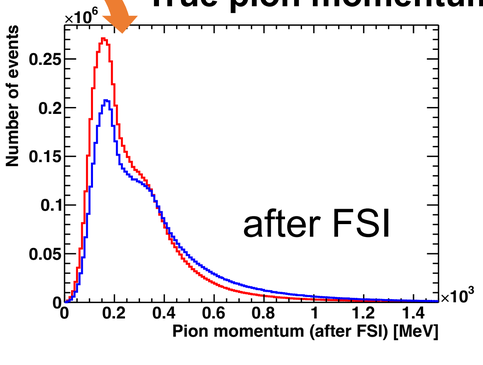


- $d\sigma/dQ^2$ in DCC is larger for large Q^2
  → Lepton momentum tends to be smaller with the DCC model.



$d\sigma/dW$ **at $E_\nu = 1$ GeV**

True pion momentum



- $d\sigma/dW$ in DCC is larger at $\Delta(1232)$ peak.
  → Pion momentum calculated using the DCC model tends to be lower.

Summary and prospects

- It is important to understand the cross section and kinematics of single pion production in order to precisely measure neutrino oscillation and extend the search of proton decay.
- **W is overall smaller in DCC than Berger-Sehgal, which leads to lower pion momentum calculated using DCC.**
- We will compare the two models by observables such as the number of Cherenkov rings and verify them using data.