Single pion production in NEUT

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Single pi production updates  
by P. Rodriguez and A. Bercellie

Pion interactions in nucleus updates  
by P. de Perio and R. Tacik
Single pion production via resonance in NEUT

Use the model by Rein and Sehgal

- Code to calculate the helicity amplitude
  Provided by the authors

- Calculation of the cross-section \( \frac{d\sigma}{dq^2dW} \)
  Follow the formula in the publications

  Add helicity amplitudes as proposed in the original article
  to take into account the interference of the resonances

- Lepton mass corrections by the same authors
  have been included

- Two form factors are implemented
  Original form factor by Rein & Sehgal
  \( M_A = 1.21 \text{ GeV}/c^2 \) was chosen
  Revised form factor by K.M. Graczyk and J.T. Sobczyk
  (explained later)
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Known issue in the Rein-Sehgal model

electro-pion production cross-section can not reproduce data if we use the vector part

Interestingly, results for neutrino agrees pretty well. ( Including axial current component makes the cross-section similar. )
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Attempts to improve the vector form factor in Rein-Sehgal model

Prescription by K.M. Graczyk and J.T. Sobczyk
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Parametrization

Parameters were fit with the bubble chamber data (ANL & BNL)

- Best fit: $M_A^{\text{res}} = 0.95$, $C_5^A(0) = 1.01$
- non-resonant background scale factor = 1.3

- Parameters in nucleon model:
  
  $C_5^A(0)$ Value of axial FF at $Q^2 = 0$. Main effect is normalization of total xsec
  
  $M_A^{\text{res}}$ Mass parameter in axial FF. Affects both shape of $d\sigma/dQ^2$ and overall normalization.
  
  BG Scale of $J = 1/2$ nonresonant background terms

- Try to reparametrize ($M_A^{\text{res}}$, $C_5^A(0)$) into (shape, norm) for convenience
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$$\nu p \rightarrow \mu^- p \pi^+$$

Cross-section comparison (new vs old)
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For the interaction in nucleus, initial interactions are modified

- Pauli-blocking effect is taken into account
  Momentum of nucleon after the decay of delta has to be larger than the Fermi surface momentum.
  (2 ~ 3% of the interactions are prohibited.)

- Pion-less delta decay has been implemented
  20% of the delta are assumed to be absorbed.

\[ \nu N \rightarrow l \Delta \]
\[ \Delta N N \rightarrow N N \]

~ no pion is produced but lepton and nucleon are ejected for the interaction in nucleus.

*) Recently, meson exchange current interaction was independently added
  and this feature has been turned off by default in the latest release.
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Pion interactions in nucleus, which change the observables.

• Simulated with the cascade model
• Simulated interactions
  inelastic scattering
    incl. charge exchange & particle production ( \( \pi N \rightarrow \pi \pi N \) )
  absorption
• Interaction probability \( \sim \) Mean free paths
  \( P_\pi < 500 \text{ MeV/c} \)
    Density dependent mean free path
      Originally from E. Oset et. al. model
      Scaled by fitting the \( \pi A \) scattering data
  \( P_\pi > 500 \text{ MeV/c} \)
    Density independent mean free path
      \( \pi \)-N scattering data + \( \pi A \) scattering data
• Kinematics determination
  \( \pi N \) phase shift analysis with medium correction ( R. Seki et al. )
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\( \pi \) Carbon scattering interaction cross-sections

\[ \pi^+ \text{ Initial Momentum} \ (\text{MeV/c}) \]

\[ \pi^- \text{ Initial Momentum} \ (\text{MeV/c}) \]

\( \pi^+ \) Oxygen scattering differential cross-sections

\[ \frac{d\sigma}{d\Omega} \ (\text{mb/sr}) \]

\[ \theta_{\text{lab}} \]
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Comparisons with data from MiniBooNE

CC $1\pi^+$ $d\sigma/dq^2$

CC $1\pi^0$ $d\sigma/dq^2$

NC $1\pi^0$ $d\sigma/dp^*$

(a) MiniBooNE CC1$\pi^+$

(b) MiniBooNE CC1$\pi^0$

(c) MiniBooNE NC1$\pi^0$
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Comparisons with data from K2K and SciBooNE

K2K NC $1\pi^0 p_\pi$

SciBooNE NC $1\pi^0 p_\pi$

SciBooNE NC $1\pi^0 \theta_\pi$
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Data points are from the results presented by B. Eberly titled “Probing Nuclear Physics with Neutrino Pion Production at MINERvA” (Joint Experimental-Theoretical Seminar at Fermilab, Feb. 7 2014)
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Nucleon emission after $\pi$ absorption

- # of nucleon emitted after $\pi$ absorption
  - Based on the experimental data\(^1\)

- Momentum of nucleons for 2 body decay
  - measurements\(^2\)

Other cases
  - Isotropically