Pion Production

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Charged and neutral pions
Coherent and ‘regular’ pion production
I. ‘tension’ between nucleon and nucleus data for pion production

- For nucleon, only data is old bubble chamber (BNL, ANL)
  - Low statistics
  - Uncertain flux determination
- For nucleus, recent MiniBooNE data (Wilking, Nelson)
  - High statistics
  - Careful flux determination
- For someone with long history in hadron and electron scattering, this seems backward. Normally, quality nucleon data is core of all calculations.
Account for flux, syst errors

\[ v_\mu d \rightarrow \mu^- p \pi^+ n \]

\[ \sigma \left(10^{-38} \text{ cm}^2\right) \]

\[ E \text{ (GeV)} \]

\begin{itemize}
  \item ANL
  \item BNL (no \(\pi N\) cut)
\end{itemize}
Lalakulich, Mosel

Span N data

\[ \sigma_{\pi^+} (10^{-38} \text{ cm}^2) \]

\[ E_{\nu} (\text{GeV}) \]

\[ \nu n \rightarrow \mu^- n \pi^+ \]

\[ \pi^+ \]

\[ 8 \text{ cm}^2 \]

theoretical band:
ANL and BNL inputs
Lalakulich, Mosel

\[ \pi^0 \]

\[
\sigma_{\pi^0 p,} (10^{-38} \text{ cm}^2)
\]

\[ E_{\nu} \text{ (GeV)} \]

\[ \sigma_{1\pi^0} \times 10^{-3} \]

\[ E_{\nu}, \text{ GeV} \]

CCpi+ generator distributions  17 October 2012
π+ momentum distributions

FSI gives wrong shape
Solution?

- Is ANL or BNL better? (apparently not)
- Can they be reconciled? (Sobczyk vs. others)
- Can theory tell us what N data should be? (too many uncertainties)
- Can more data be taken?
  - Minerva might have D tgt in future (5 GeV beam)
  - Minerva might be able to pull H data out of CH data.
II. Lots of new data coming – Minerva $\pi^{\pm}$

Both $\nu$ and $\bar{\nu}$ bar (25, 80% of statistics) very high purity, not efficiency corrected
ISSUE: Avg $E_{\nu}$~3 GeV (~half $W<1.7$ GeV, rest DIS)
can they (do they need to) isolate resonant region?
Minerva $\pi^0$ and CC coherent

$\nu$ bar plastic (also $\bar{\nu}$ & $\nu$ bar plastic coherent)

ISSUE: Avg $\nu E \sim$ 5 GeV to get good eff, purity both inclusive and ‘exclusive’
T2K (ND280)

$\pi^0$ result (P0D)

$R = \frac{N_{\pi^0}^{\text{Data}}}{N_{\pi^0}^{\text{MC}}} / \frac{N_{CC}^{\text{Data}}}{N_{CC}^{\text{MC}}}$

$= 0.81 \pm 0.15(\text{stat}) \pm 0.14(\text{sys})$

$\pi^+ + \text{anticipated result (TPC)}$

peak energy $\sim 600$ MeV

easier for theorists

also lower energy $\pi^+$, CC $\pi^0$, 'coherent' future
Summary

- New calculation for $K, \eta$ production (Athar + collabs)
  - small, but measurable in Minerva
- New calculation for $\gamma$ emission (Alvarez-Ruso + collabs).
  - goal is to understand MiniBooNE deficit at low $E_{\nu}$.
- redo calculation of Hill with nuclear effects