K$^+$ Production from 8 GeV Protons using Neutrino Interactions in SciBooNE

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Why Measure $K^+$ Production from 8 GeV Protons?

• Reduce uncertainty for intrinsic $\nu_e$ background from $K^+$ decay in Fermilab Booster Neutrino Beam, currently at 40%. This background affects current and future oscillation analyses.

• Test Feynman scaling at the 8 GeV proton interaction level.
  - Feynman scaling works well at higher energies.
SciBooNE Experiment at Fermilab

SciBar
- scintillator tracking detector
- neutrino target

Muon Range Detector (MRD)
- 12 2”-thick iron + scintillator planes
- measure muon momentum with range up to 1.2 GeV/c

Electron Catcher (EC)
- spaghetti calorimeter

Two running modes:
- Neutrino mode
  - positive horn
  - 9.9x10^{20} POT
- Anti-neutrino mode
  - Negative horn
  - 1.51x10^{20} POT

Be target (K^+ production)

Booster
8 GeV p^+

Magnetic focusing horn
Decay region
Absorber
SciBooNE
Selection Cuts

Main $K^+$ selection criteria:
• $\nu_\mu$ at high energy (> 2 GeV) are mostly from $K^+$ decay.
• To select high energy $\nu_\mu$, **high energy muons** are selected. Hence, the penetrating muons.

1. Pick events with one MRD penetrating muon.
2. Separate events based on number of SciBar tracks: 1,2,3.

Neutrino Mode:
• Data (MC): 3090 (2921) events
• $K^+$ MC: 1194 events

Anti-neutrino Mode:
• Data (MC): 1699 (1360) events
• $K^+$ MC: 257 events
Analysis Method

- The $K^+$ production normalization is determined by fitting the reconstructed muon angle relative to beam axis for neutrino events.
  - different distribution shapes between $K^+$ and $\pi^+, \pi^-$

- Minimize standard covariance matrix $\chi^2$.

$$\chi^2 = \sum_{j,k}^{N_{bins}} (N_{j}^{obs} - N_{j}^{pred})(V_{sys} + V_{stat})^{-1}_{jk}(N_{k}^{obs} - N_{k}^{pred})$$

- Systematic Uncertainties:
  - Beam Errors
  - Cross-section and Nuclear Model Errors
  - Detector Errors
Final Result

- After Applying $K^+$ Production Normalization

- Insensitive to neutrino cross-section.
- Analysis is done with both NEUT and NUANCE. Good agreement.
- $K^+$ production uncertainty reduced from 40% to 14%.

$K^+$ production normalization: $0.87 \pm 0.12$ (stat. + sys.)
Backup
Comparisons

Before Any Correction (Default MC)

After Applying K⁺ Production Normalization w/ best fit cross-section values