Measuring the Kaon Background

I. Using MiniBooNE Data

II. Special K_L^0 Measurement

III. Off-Beamline Detector for Neutrinos from Kaon

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- INTRINSIC ν_e BACKGROUND
  - From Table 4.5 of the Proposal
    - μ^- decay gives 960 events mostly at lower E_ν.
      Mike Shaevitz developed procedure for determining this background from the observed ν_μ events
    - $K^+ \to \pi^0 e^+ \nu_e$ gives 200 events
      $K_L^0 \to \pi^\pm e^\mp \overset{(-)}{\nu}$ gives 110 events
      Less significant than μ decay background.
      But still important to check.

- **Detector to Illustrate Concept**
  - $\sin\theta_{lab} = 0.15$
  - ~ 25 tons at ~ 100 m from the horn
  - $E_{\nu,max} = 0.2$ GeV from π^+ decay
  - $E_{\nu,max} = 1.57$ GeV from K^+ decay
  - Full range of E_K contribute
  - ~ 5500 ν_μ events $K \rightarrow \mu + \nu_\mu$ decay for 2.5×10^{20} pot

    ~ 420 ν_e events from K^+_{e3}

Kaon Flux Detector

- **Concept**
  - Simplified Example:
    π^+ and K^+ produced at 0° only
    $\pi^+ \to \mu^+ + \nu_\mu$ and $K^+ \to \mu^+ + \nu_\mu$ decays only
  - At fixed $E_{\nu,lab}$, the angular distribution of neutrinos from K decay is eight times broader than from π decay:

$$\sin\theta_{lab} = \frac{E^*_\nu \sin\theta^*}{E_{\nu,lab}}$$

where $E^*_\nu = 0.03$ GeV for π^+ decay
$E^*_\nu = 0.236$ GeV for K^+ decay

  - Thus a detector placed at a fairly large angle to the beam line will see only neutrinos from K decay above a certain energy
  - The maximum value of $E_{\nu,lab}$ occurs for $\sin\theta^* = 1$

$$E_{\nu,max} = \frac{E^*_\nu}{\sin\theta_{lab}}$$

- **Quantitative Analysis of Flux**
  - N-tuple supplied by N.Wadia
    - π and K production at target
    - horn focusing
    - decay tunnel, 50 m long and 1 m radius
  - Look at both ν_μ and ν_e:
    - $\pi \to \mu\nu_\mu$
    - $K \to \mu\nu_\mu$
    - $K^+ \to e^+\pi^0\nu_e$
    - $K_L^0 \to e^+\pi^-\nu_e$ and $e^-\pi^+\bar{\nu}_e$
  - For $\theta \gtrsim 0.1\ rad$ see more ν_μ from K^+ than from π^+ for $E_\nu > 0.5$ GeV
    - Kaons produced near $0°$ contribute if they decay with $\sin\theta^* \approx 1$
    - Pions contribute only if they are produced at large angles and decay before they hit the decay tunnel wall.
  - For $\theta \gtrsim 0.1$ radians, the ν_e arise almost entirely from K decays.

    Almost no contamination from π or μ decays.

- Can we make a good determination of the ν_e background in MiniBooNE using the ν_e and ν_μ samples obtained at $\theta = 0.15\ rad$?
  - These samples have a similar dependence on the horn and decay tunnel geometry as that of the ν_e background in MiniBooNE because they all arise from decays of the same kaon beam.
  - These samples have a similar dependence on the energy distribution of the kaon beam as that of the ν_e background in MiniBooNE
    - The ν_e's of a given energy come from K's with a broad energy spectrum. The shape of this spectrum is approximately the same at $\theta = 0.15\ rad$ as it is in MiniBooNE. Also, the shape of the spectrum is only weakly dependent on E_ν
    - The sample of ν_μ's at $\theta = 0.15\ rad$ just happens to arise from K's with a very similar energy spectrum as the ν_e background in MinBooNE
  - Thus the ν_e background in MiniBooNE can be accurately determined from both the ν_e sample and the ν_μ sample at $\theta = 0.15\ rad$

- **Possible DetectorType**
  - Oil Detector
    - Use Michel decay to help identify muons
    - Example: Micro BooNE
  - Shower Detectors
    - Example:
      - Iron plates 2" thick, 10'×10'
      - Scintillators 1" thick
      - Chambers
    - GEANT Simulation Performed
    - Good Seperation of ν_e and ν_μ events
    - Neutral current π^0 production events may look like ν_e events

- K_L^0 Background Measurement
  - K_L^0 is the only neutral particle that is a source of neutrinos
  - K_L^0 is not affected by the horn
  - Look at "electron" events with the horn off and a 25 m long decay tunnel.
    * The ν_μ flux drops by a factor of 16.3 for $E_\nu < 1$ GeV
    * The $\bar{\nu}_\mu$ flux $\approx 0.5\ \nu_\mu$ flux
      · Can measure the fraction of events due to $\bar{\nu}_\mu$, $R = \mu^+/(\mu^+ + \mu^-)$, to about 2% by measuring the fraction of muons which are captured.

• "ELECTRON" EVENTS

Sources	Horn on 50 m tunnel (events)	Horn off 25 m tunnel (events)	Reduction Factor
μ^- MisID	400	25	16.3
π^0 MisID	400	32	12.6
$\mu^\pm \to \nu_e, \bar{\nu}_e$	960	29	33
K^+_{e3}	200	13	15
K^0_L	110	91	1.2
Total	2070	190	

- The μ^- and π^0 misidentification backgrounds are well determined from the data.
- The ν_e background from $\mu^\pm$ decay is also well determined
- 55% of "electron" events come from K^+_{e3}, K^0_L
- Thus we can make a 13 % measurement of kaon contribution for $2.5{\times}10^{20}$ POT

- <u>**Determining Kaon Background from the Data**</u>
  - For ν_e from K^+_{e3}, K^0_L decays the distribution of E_K varies slowly with E_ν
  - Most high energy (1 to 1.5 GeV) ν_e events arise from kaon decays
  - So we can use the measured distribution of ν_e event above 1 GeV to constrain the kaon background below 1 GeV
  - The run with a 25 m decay tunnel will help determine the fractions of ν_e above 1 GeV due to K decays
    * lose ~20 % of ν_e from K decay
    * lose ~45 % of ν_e from oscillations

- **Conclusion**

  - In MiniBooNE Data,

    ν_e background at low E_ν is strongly constrained by ν_e background at high E_ν

  - K_L^0 Background Measurement

    Good option to be considered for second or third year of data taking

  - Off-Beamline Detector of Neutrinos from Kaon

    Could obtain clean measurement of flux from kaons.