Nucleon Decay Backgrounds

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Motivation

- Background rejection unlikely to improve as size of detector scales up
  - (the opposite is likely, in fact)
- Improved knowledge of background will be required to extract convincing signal (or subtract it in limits)
- Level of background closely connected with detector design

Nucleon Decay Modes

- $p \rightarrow e^+ \pi^0$
- $p \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$
- $p \rightarrow \nu K^+$, $K^+ \rightarrow \pi^+ \pi^0$
- $p \rightarrow \mu^+ K_S$, $K_S \rightarrow \pi^+ \pi^-$
- $p \rightarrow \mu^+ K_S$, $K_S \rightarrow \pi^0 \pi^0$

Elements of Background Estimation

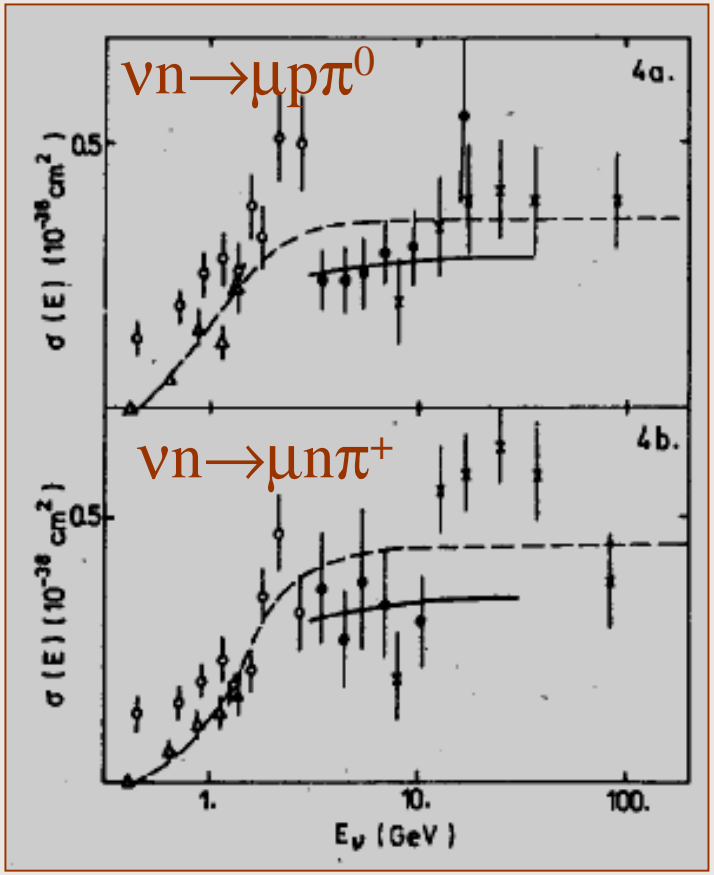
- Atmospheric Neutrino Fluxes
- Neutrino Cross-sections
- Nuclear Effects
- Hadron Interactions
- Detector Resolution

Atmospheric Neutrino Fluxes

- +/- 15% normalization uncertainty
  - 5-10% perhaps achievable
- Geomagnetic, solar effects important
- ν_μ disappearance (~35% effect)
- ν_τ appearance (~1 ev/kty)

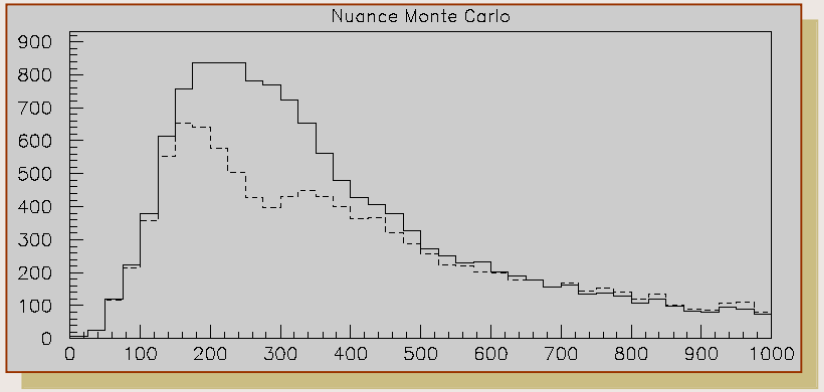
Neutrino Cross-sections

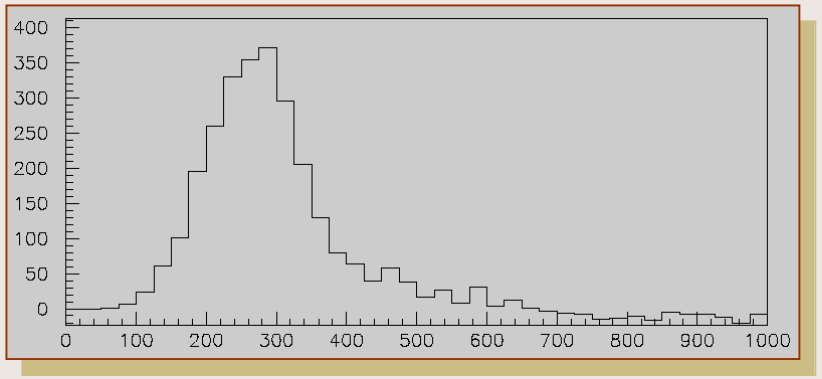
- Single-pion cross-sections for free nucleons uncertain to at least 25%!
- 1.4 < W < 2.0 GeV region difficult to model
- 10% effects in pion angular distribution



Nuclear Effects

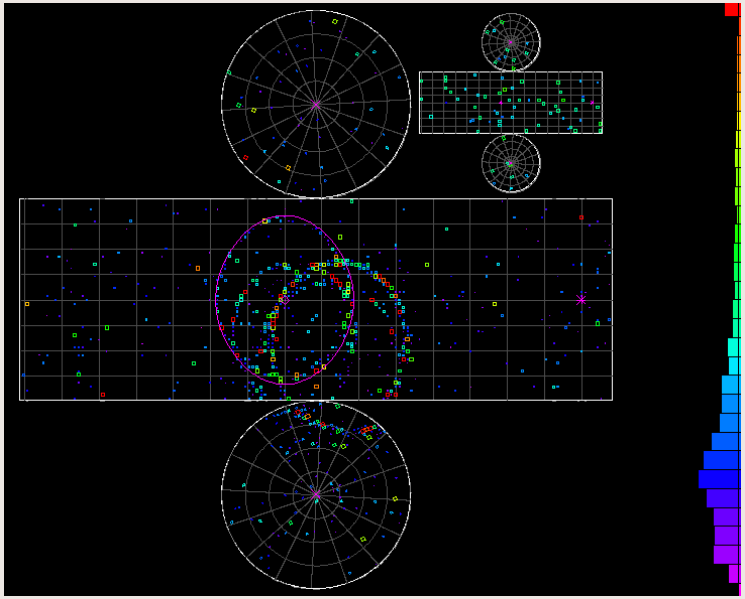
- Effect of nuclear medium on pions poorly understood, difficult to model
- $\Delta + N \rightarrow N + N$ may occur at 10~30% level
- Crude impulse approximation model of final-state interaction effects
- De-excitation signature crucial for $p \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$





Hadronic Interactions

- Hadrons interact in detector medium
- Must include physics processes far from the vertex for reliable picture of event signature



$p \rightarrow e^+\pi^0$

	$\varepsilon \times B_m$	Bkg/Mty
IMB-3	0.48	26.3
Kam-I	0.53	<15
Kam-II	0.45	<8
SuperK	0.43	1.6

$p \rightarrow \nu K^+$, $K^+ \rightarrow \mu^+ \nu$

	$\varepsilon \times B_m$	Bkg/Mty
Kam-I	0.41	1460
Kam-II	0.51	1830
Soudan-II	0.09	112
SuperK	0.093	16

$p \rightarrow \nu K^+$, $K^+ \rightarrow \pi^+ \pi^0$

	$\varepsilon \times B_m$	Bkg/Mty
Kam-I	0.1	307
Kam-II	0.1	203
IMB-3	0.086	2816
Soudan-II	0.055	308
SuperK	0.068	28

$p \rightarrow \mu^+ K_S$, $K_S \rightarrow \pi^+ \pi^-$

	$\varepsilon \times B_m$	Bkg/Mty
Kam-I	0.20	231
Kam-II	0.20	41
Soudan-II	0.16	45
SuperK	0.08	52

$p \rightarrow \mu^+ K_S$, $K_S \rightarrow \pi^0\pi^0$

	$\varepsilon \times B_m$	Bkg/Mty
Kam-I	0.11	15
Kam-II	0.10	8
Soudan-II	0.06	136
SuperK	0.06	16.4

Comment on K_L Modes

- 50% of μ^+K^0 decays produce K_L
- $c\tau$ = 15m ; K_L usually interacts before decay
- Possible to search for displaced vertex (with low background) in a very large detector?

NNN Sensitivity

	$\varepsilon \times B_m$	Bkg/Mty	τ/β (1Mty)
$p \rightarrow e^+\pi^0$	0.50	1.5	4.5×10^{34}
$p \rightarrow \nu K^+ \rightarrow \mu^+\nu$ $p \rightarrow \mu^+ K_S \rightarrow \pi^0\pi^0$	0.10	15	4.4×10^{33}
$p \rightarrow \nu K^+ \rightarrow \pi^+\pi^0$	0.07	25	3×10^{33}

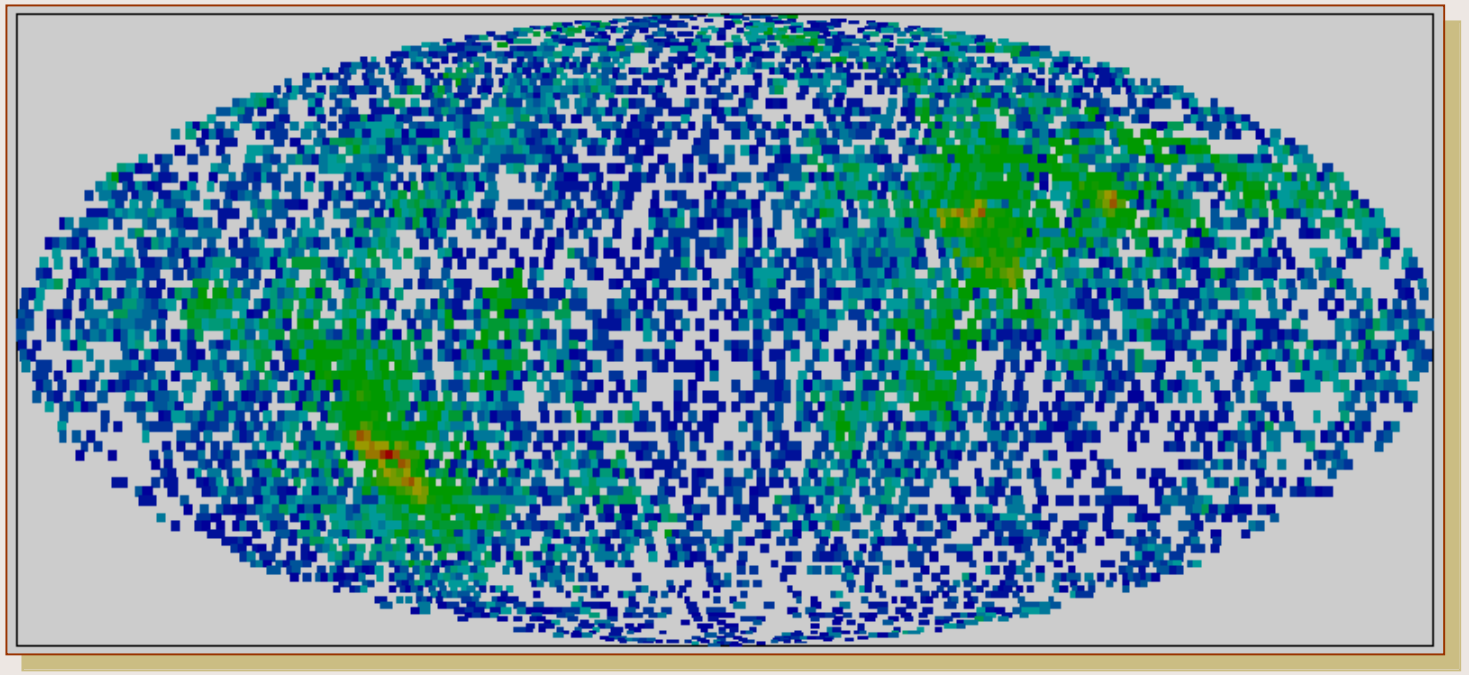
The Future: Using K2K (1kt) Data

- 1kt (near) detector for K2K will collect ~200,000 neutrino interactions
- Beam spectrum similar to atmospheric
- Equivalent to ~2 Mty exposure of SuperK or NNN

The Future: Fast Detector Simulation

- Fast simulation in development to allow study of large event samples
- Ignore Cherenkov photons; use track segments
- Includes all physics processes
- Put in assumed detector resolution by hand to study effects

Fast Simulation $e^+\pi^0$ Event



Conclusions

- Large uncertainties in background estimation:
  - Cross-sections
  - Nuclear Effects
- Difficult to compare backgrounds of different experiments with different cuts
- Only $e^+\pi^0$ mode is (nearly) background free in NNN
- Difficult to trade off resolution and still meet physics goals
- 1kt data and fast simulation will help in designing and understanding NNN