K^+ Analyses

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Motivation

- A major source of systematic uncertainty in the MiniBooNE ν_e oscillation appearance result comes from K^+ flux uncertainty (mostly from normalization).

- Measure K^+ normalization ratio(after selecting for K^+): $(Data_{candidates} - MC_{background})/MC_{signal}$

Introduction

- There are three independent samples with high percentage of ν from K^+:
  - ν_μ CC with two SciBar tracks (2-Track)
  - ν_μ CC with three SciBar tracks (3-Track)
  - ν_e CC

- All data (cosmic subtracted) and MC (SciBar + Dirt + ECMRD) are included and normalized to POT. No x-factor added.

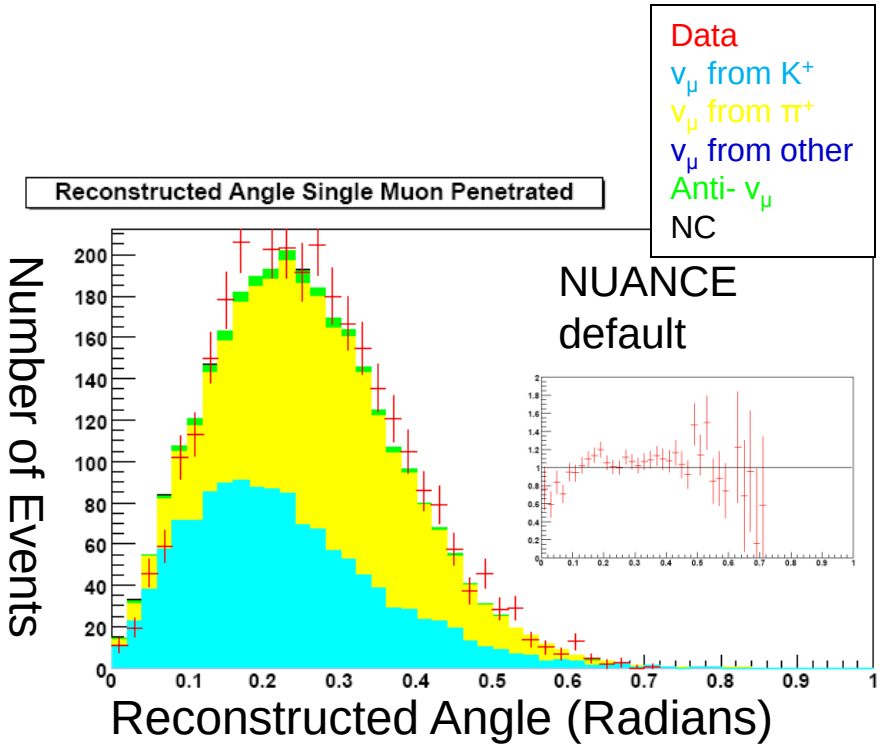
NUANCE and NEUT

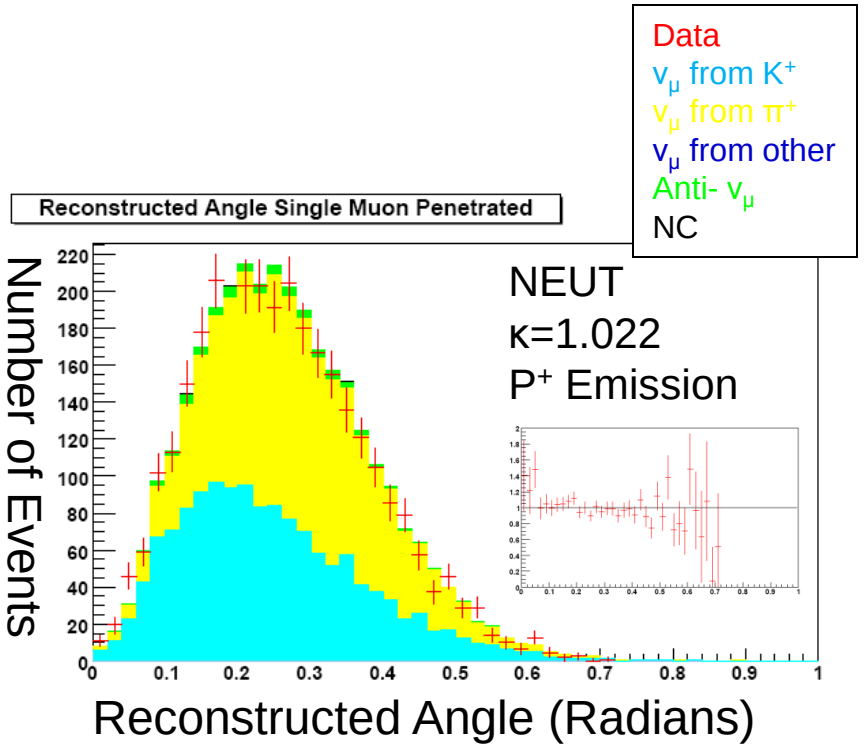
- Initially, there was discrepancy between ν numbers/plots after selection for NEUT and NUANCE.

- Discrepancy solved by using new version of NEUT with addition of emission of proton scattered from nucleus after absorption of highly energetic pion created from initial neutrino interaction (not originally implemented).

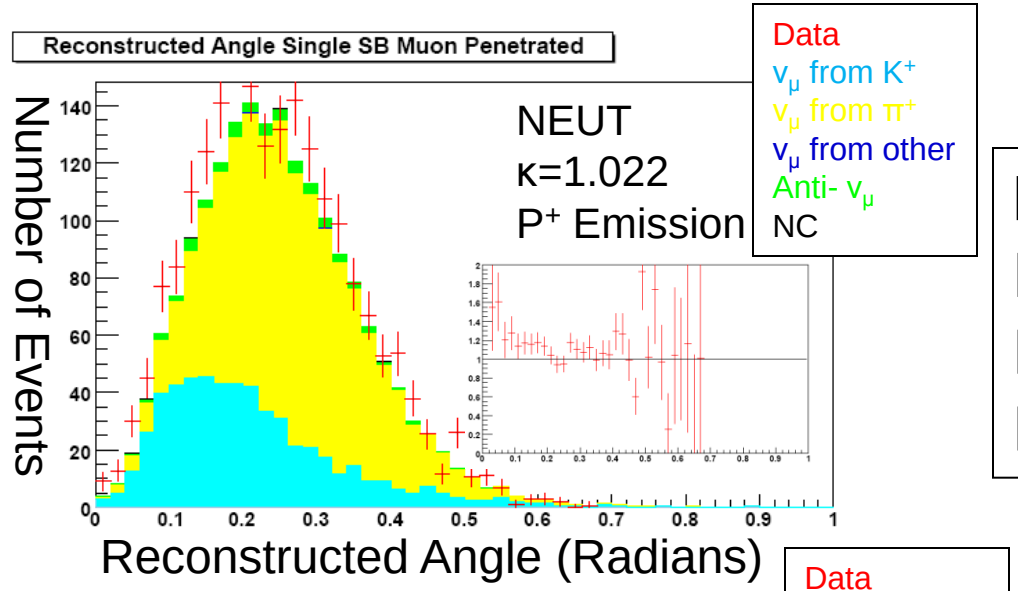
- Based off of measurements from pion-nucleus scattering.

Reconstructed Angle Single Muon

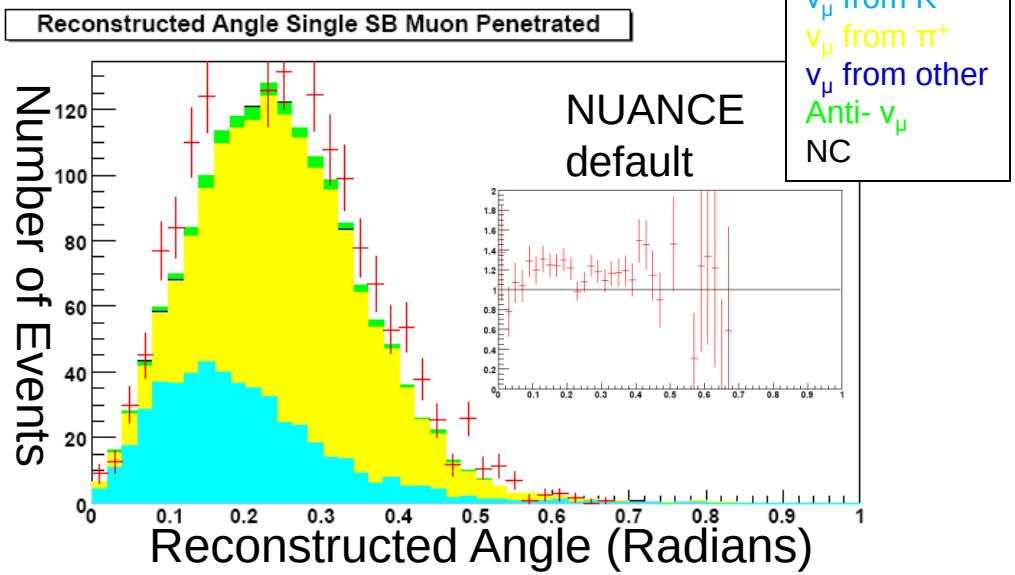




Reconstructed Angle 1-Track

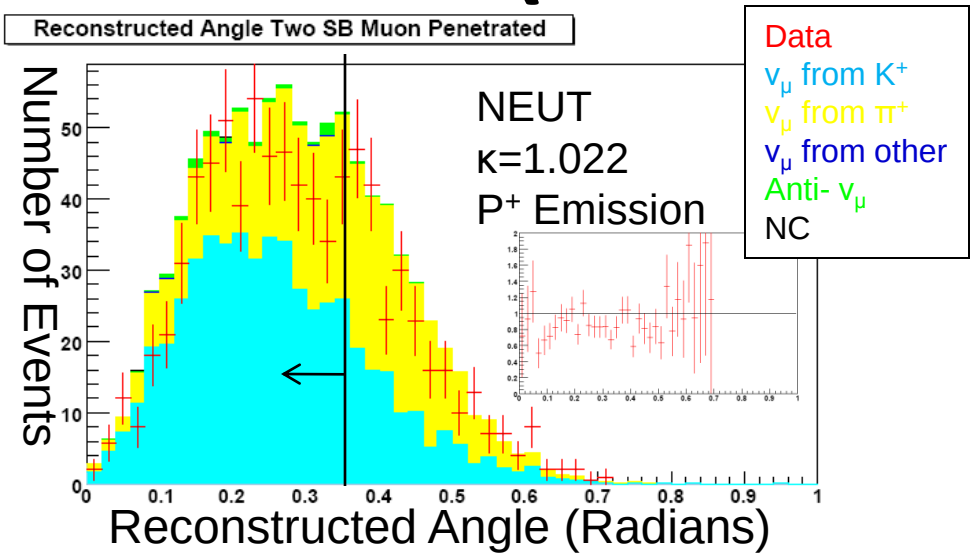


NEUT κ=1.022 P⁺ Emission
Data: 2049.6
MC: 1855.4
From K⁺: 555.9

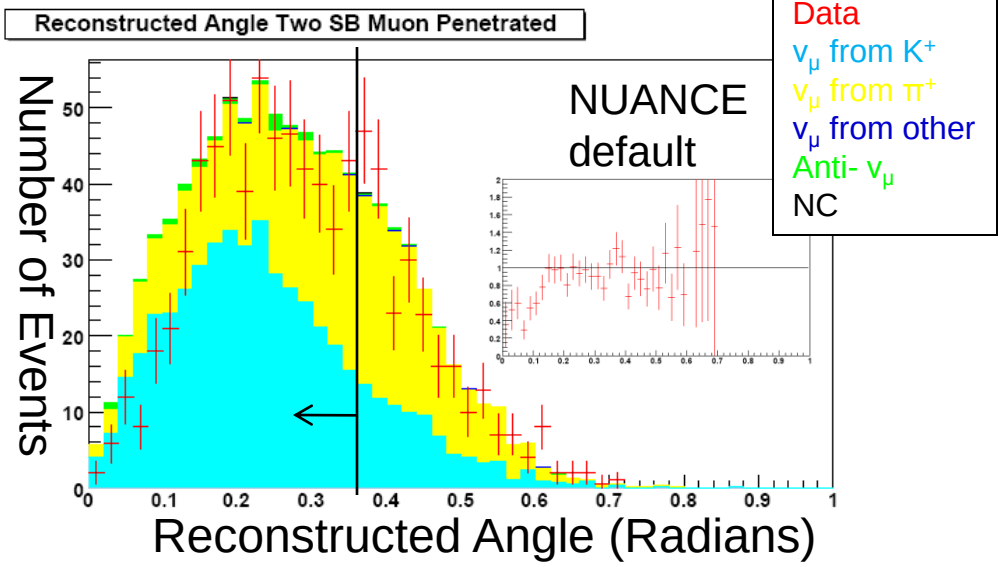


NUANCE Default
Data: 2049.6
MC: 1721.3
From K⁺: 507.7

Reconstructed Angle 2-Track (Before Angle Cut)



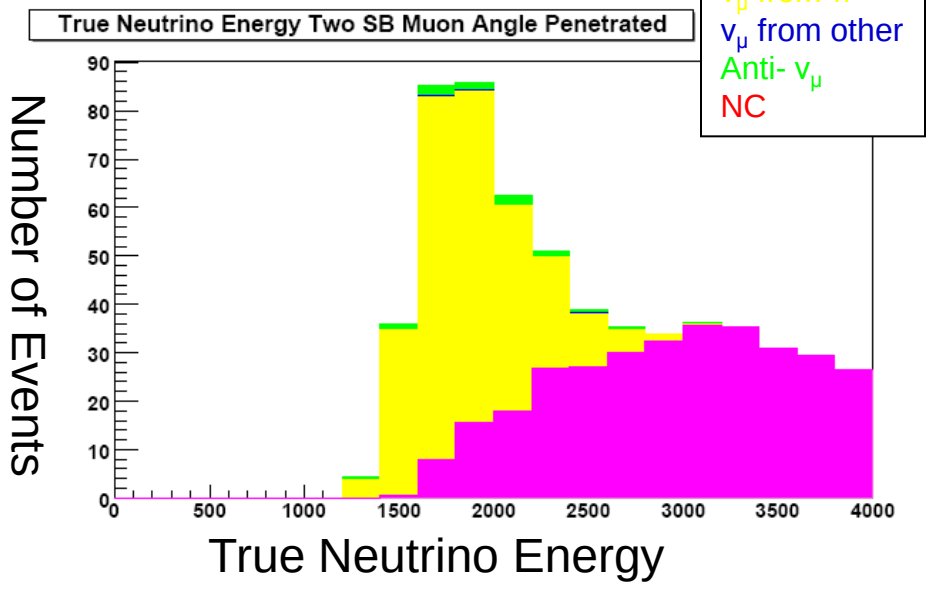
NEUT κ=1.022 P^+ Emission
Data: 581.4
MC: 684.1
From K^+: 428.1
K^+ Data/MC Ratio: 0.76



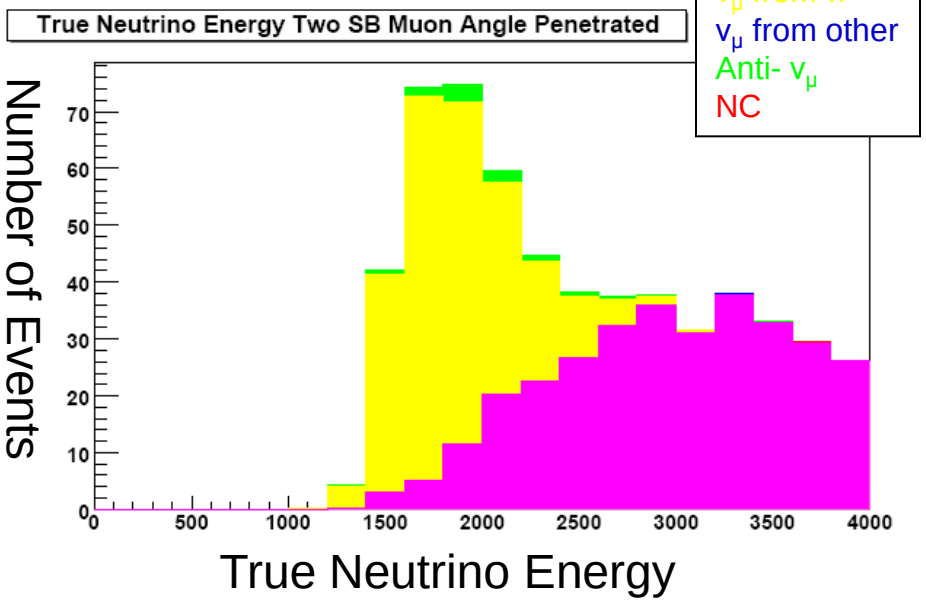
NUANCE Default
Data: 581.4
MC: 689.7
From K^+: 412.0
K^+ Data/MC Ratio: 0.74

True Neutrino Energy 2-Track (After Angle Cut)

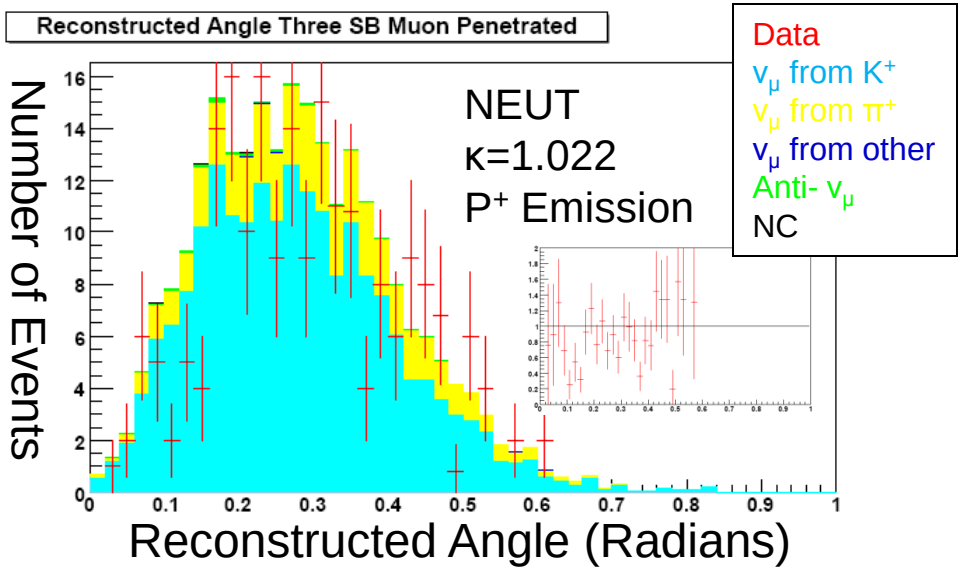
NUANCE
default



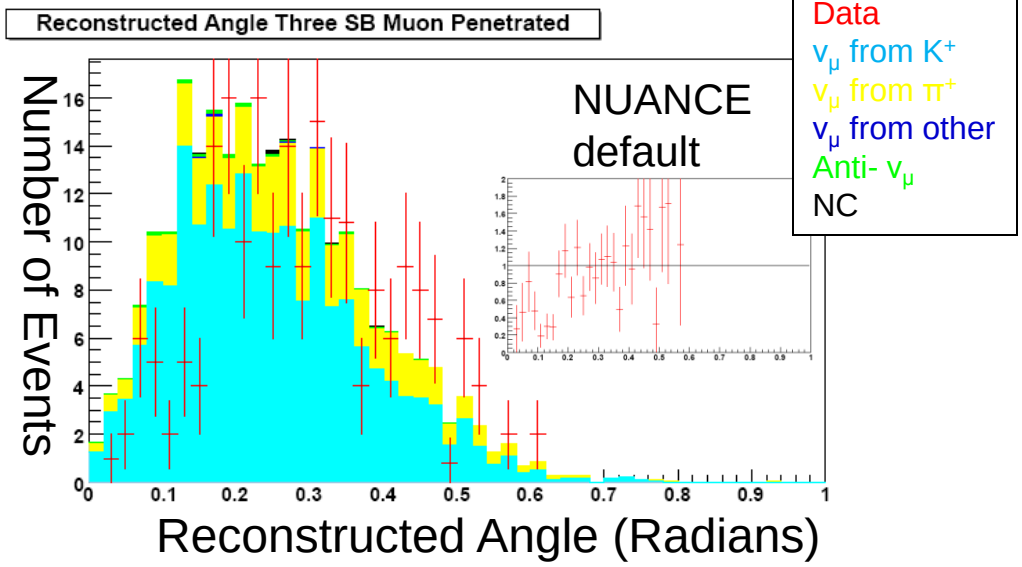
NEUT
κ=1.022
P^+ Emission



Reconstructed Angle 3-Track



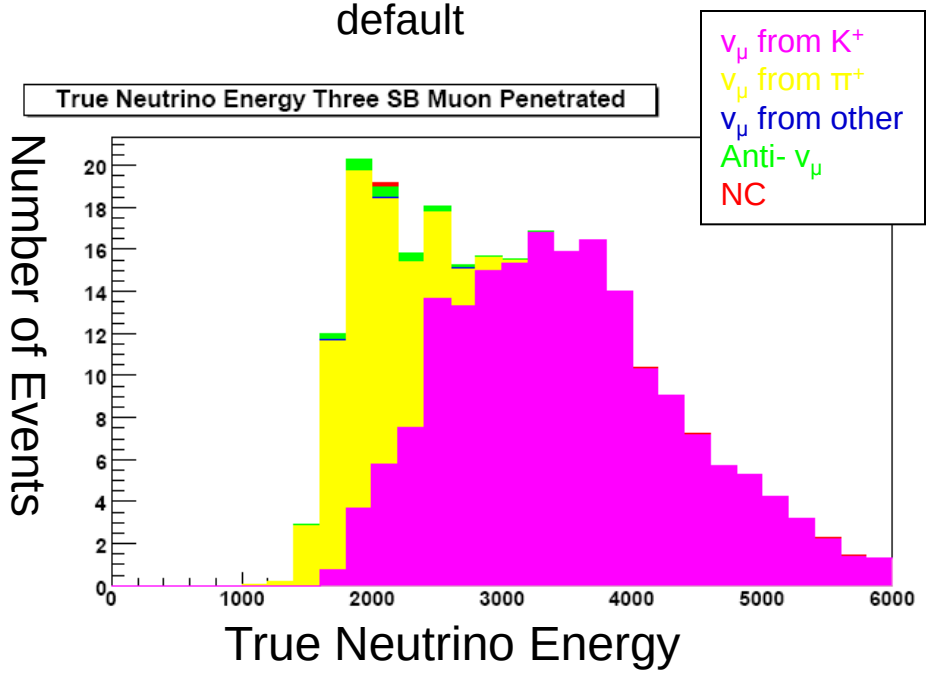
NEUT κ=1.022 P^+ Emission
Data: 205.6
MC: 249.5
From K^+: 195.4
K^+ Data/MC Ratio: 0.78



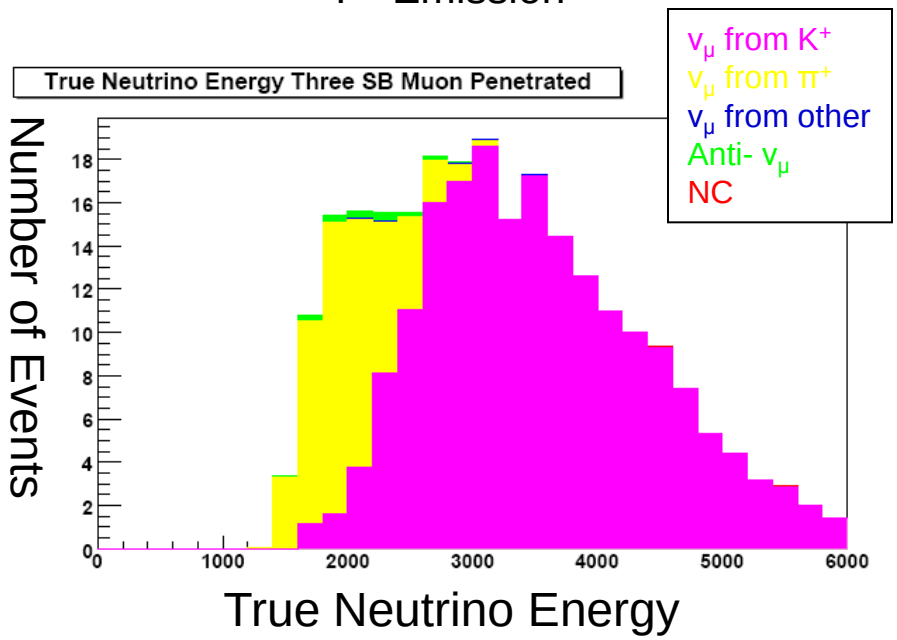
NUANCE Default
Data: 205.6
MC: 249.7
From K^+: 189.3
K^+ Data/MC Ratio: 0.77

True Neutrino Energy 3-Track

NUANCE
default



NEUT
κ=1.022
P^+ Emission

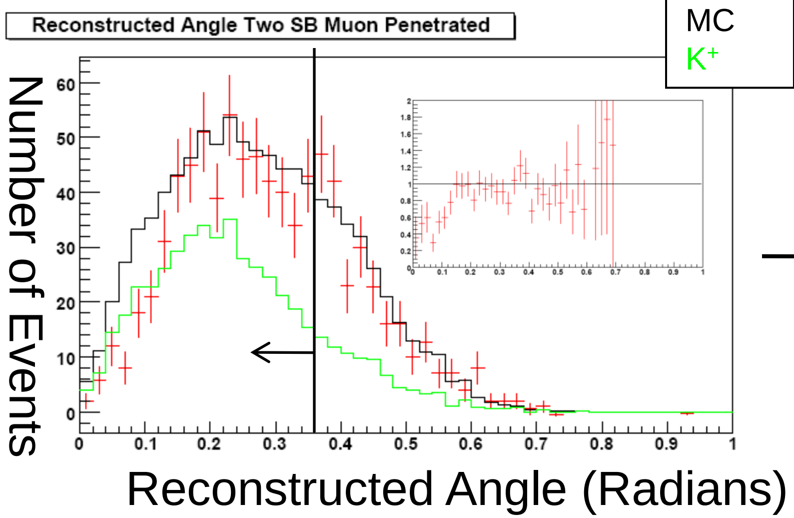


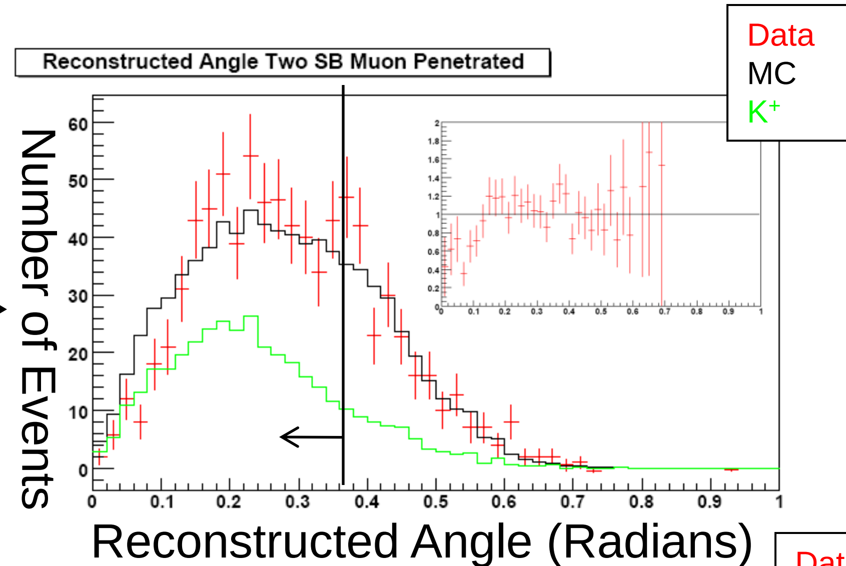
K^+ Normalization

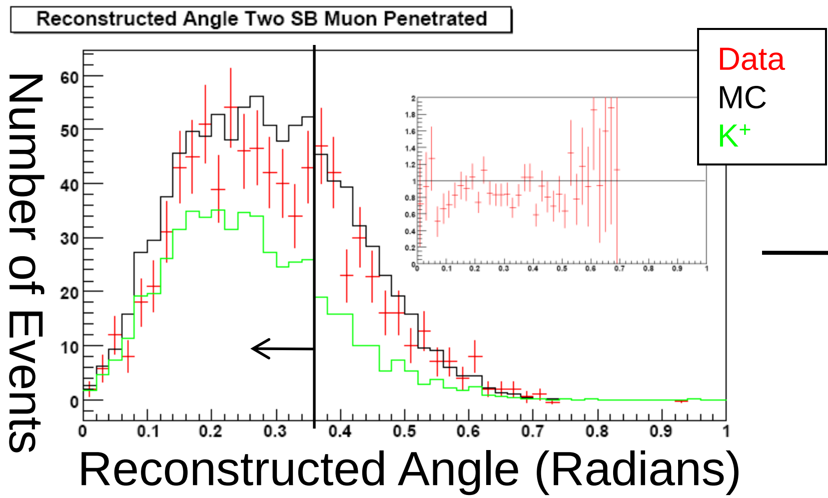
- After calculation of K^+ normalization ratio, I apply a normalization of 0.75 to K^+ events in MC to verify data/MC agreement.

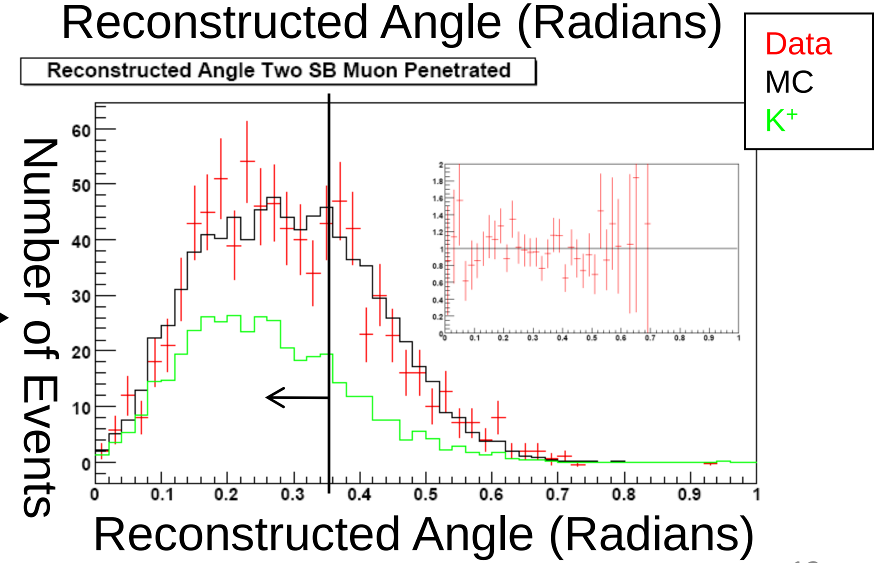
Reconstructed Angle 2-Track (Before Angle Cut)

NUANCE default





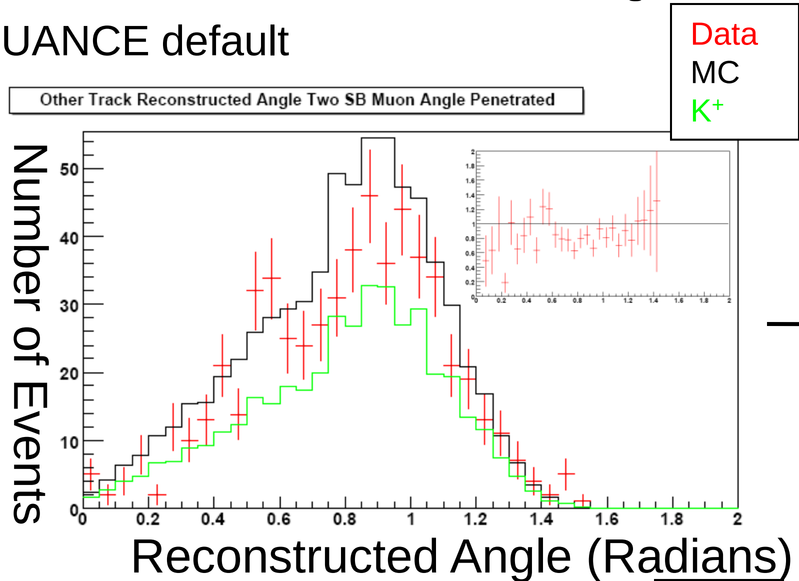




NEUT κ=1.022 P^+ Emission

Other Reconstructed Angle 2-Track (After Angle Cut)

NUANCE default



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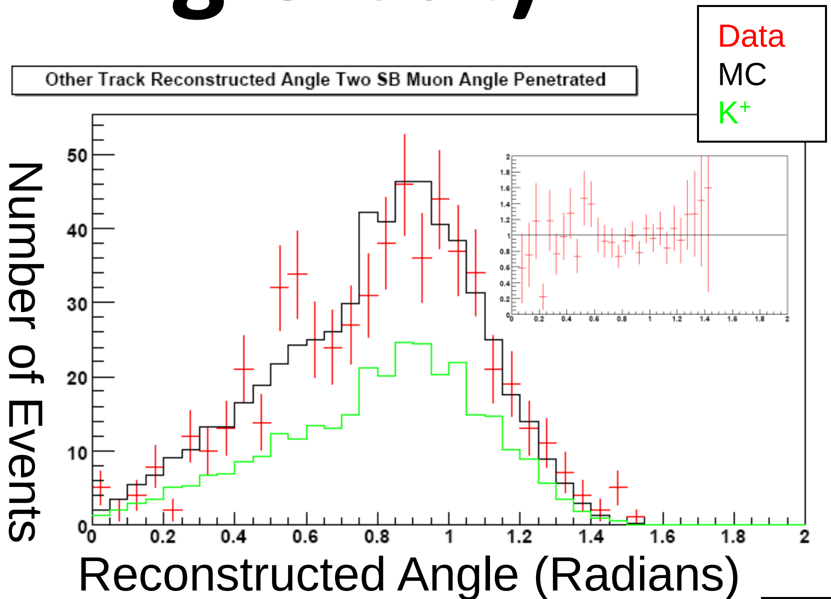

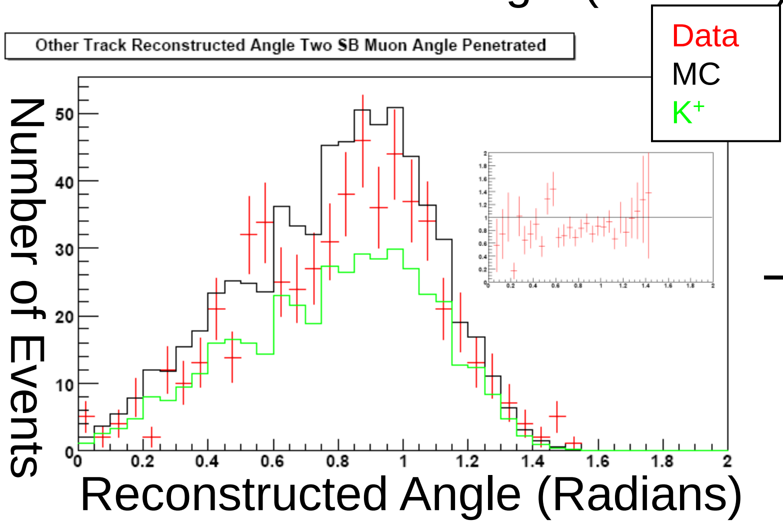

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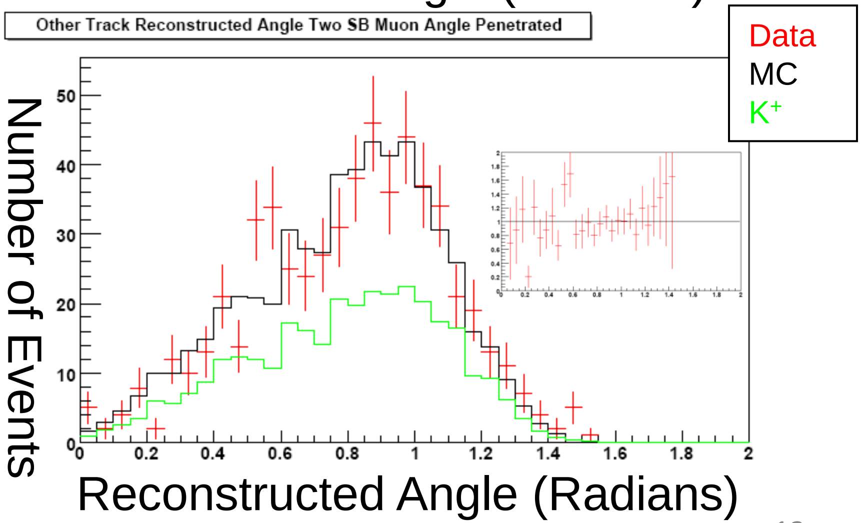
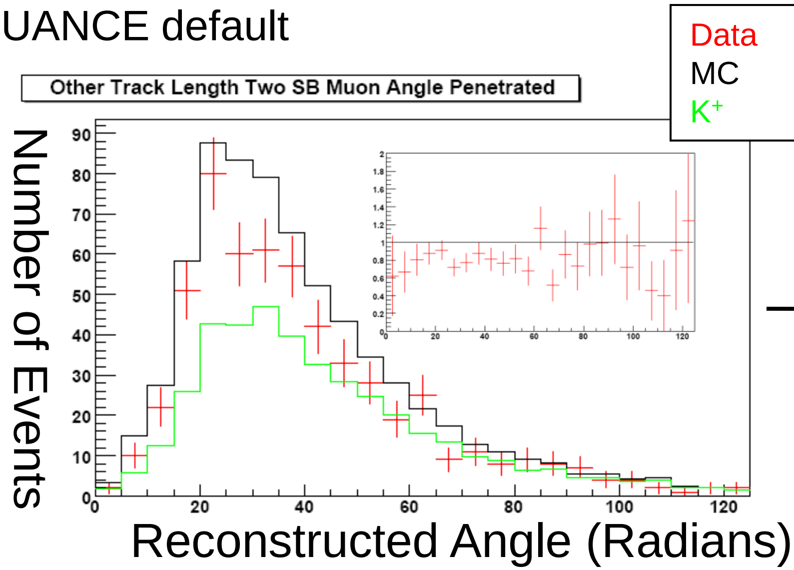
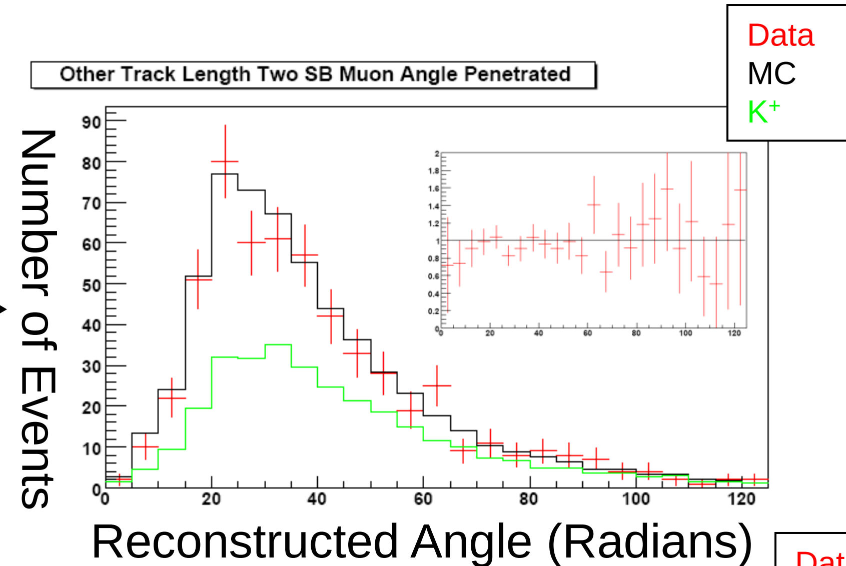


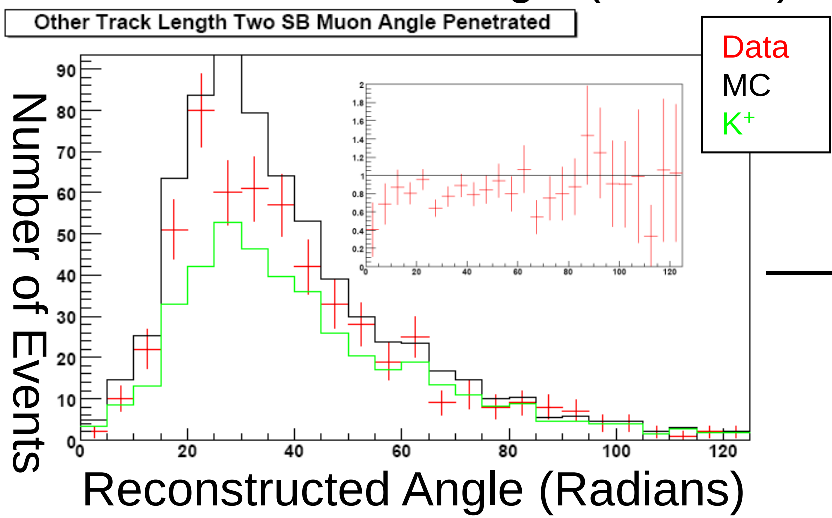
NEUT κ=1.022 P^+ Emission

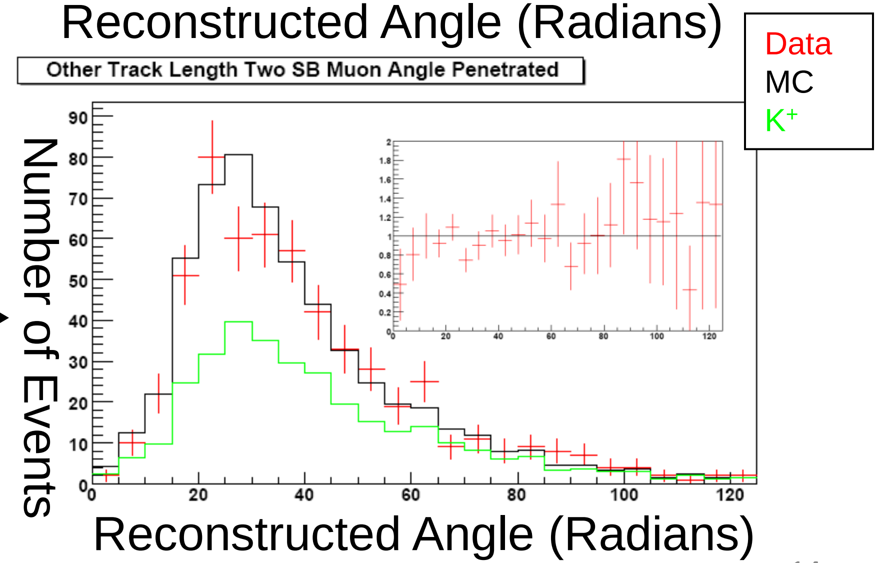
Other Track Length 2-Track (After Angle Cut)

NUANCE default





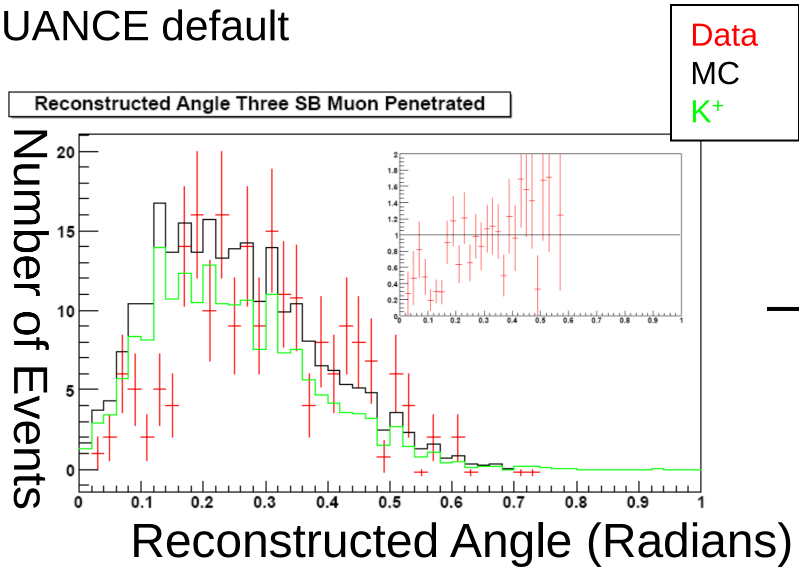




NEUT κ=1.022 P+ Emission

Reconstructed Angle 3-Track

NUANCE default



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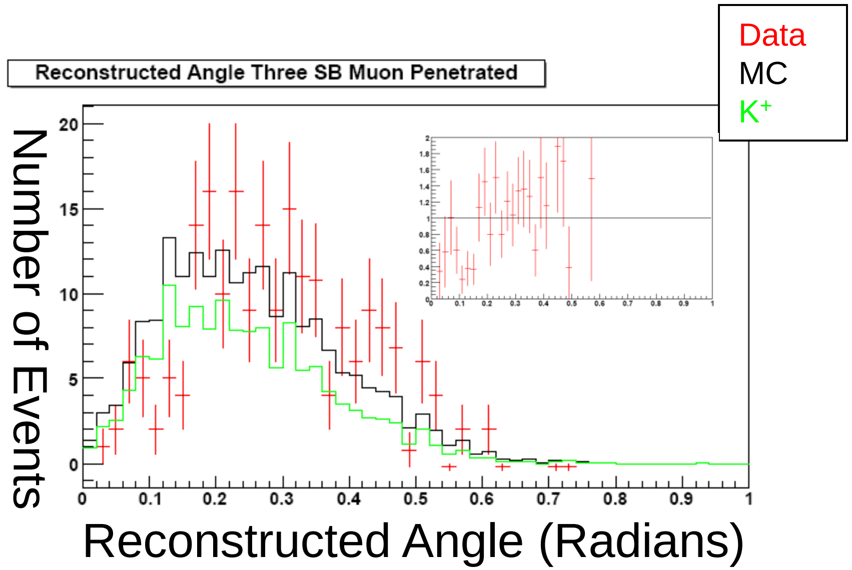

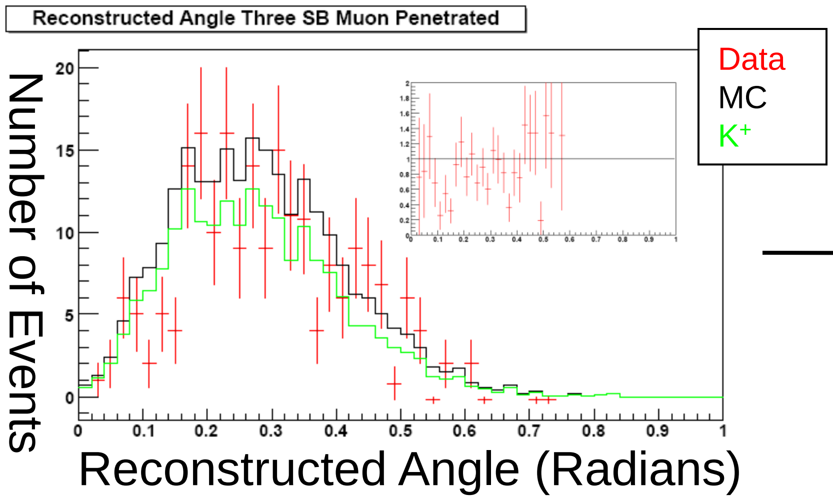

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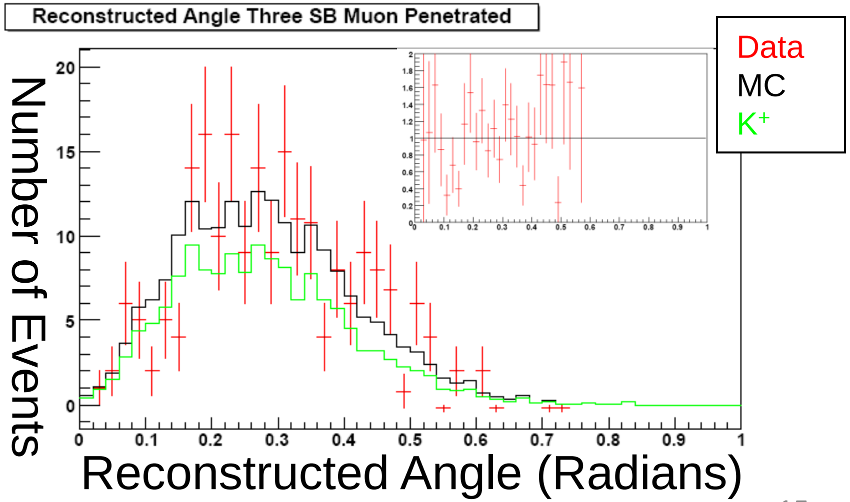
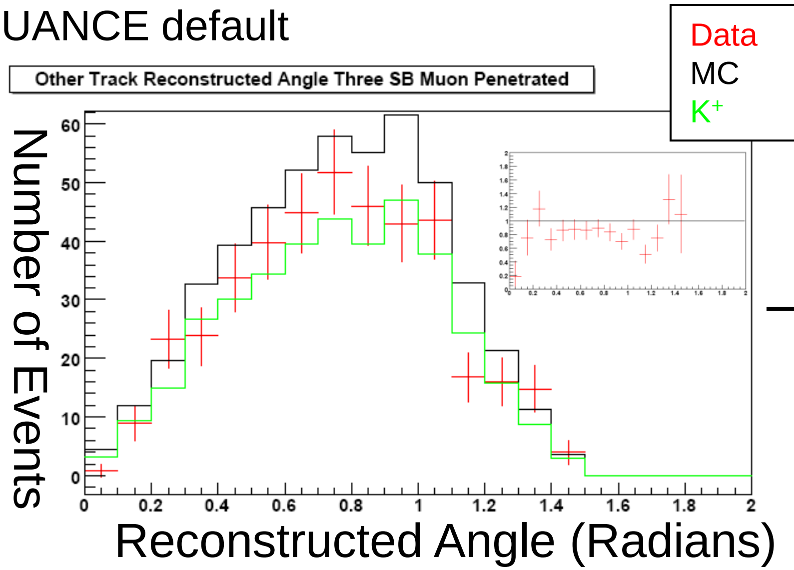
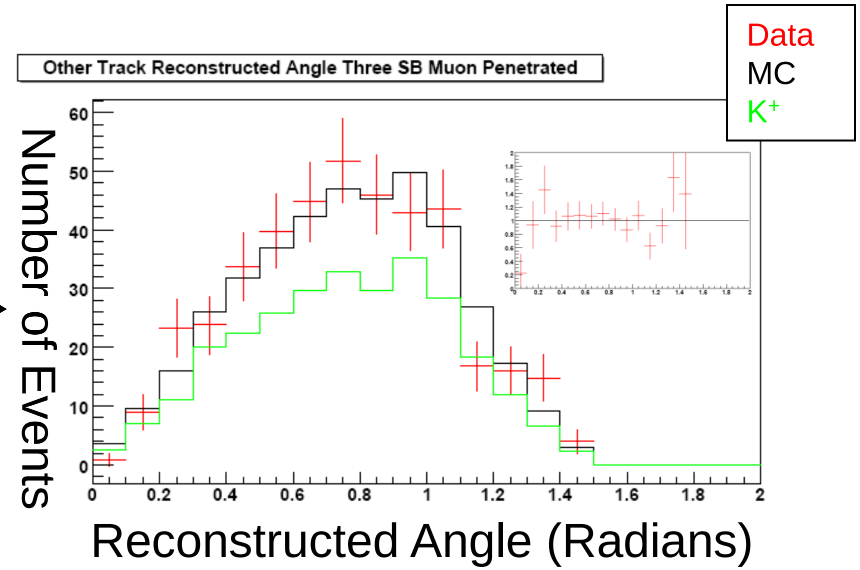


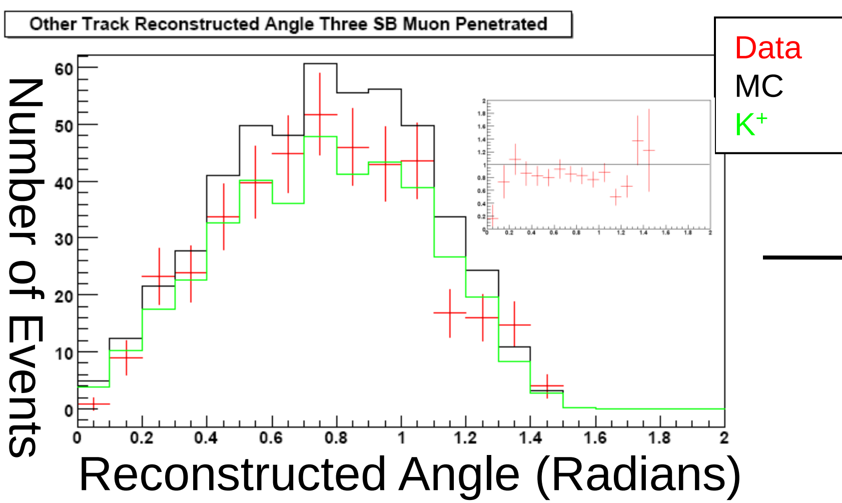
NEUT κ=1.022 P^+ Emission

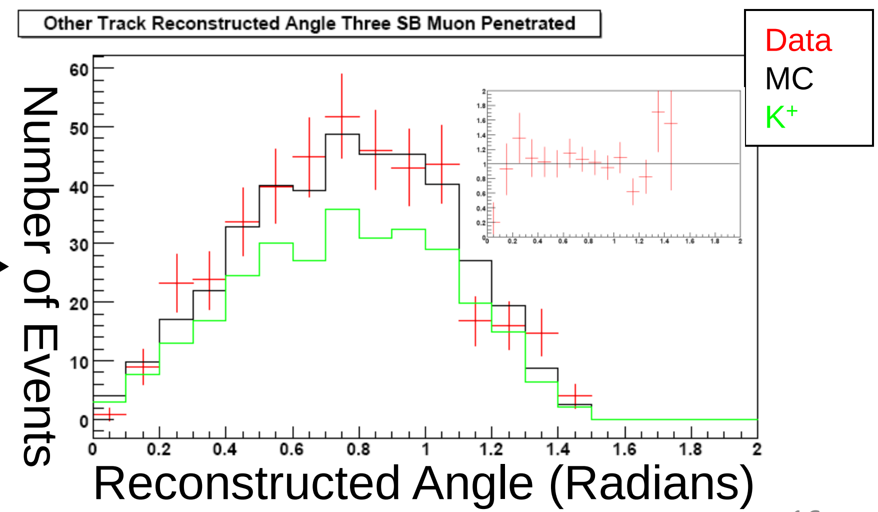
Other Reconstructed Angle 3-Track

NUANCE default





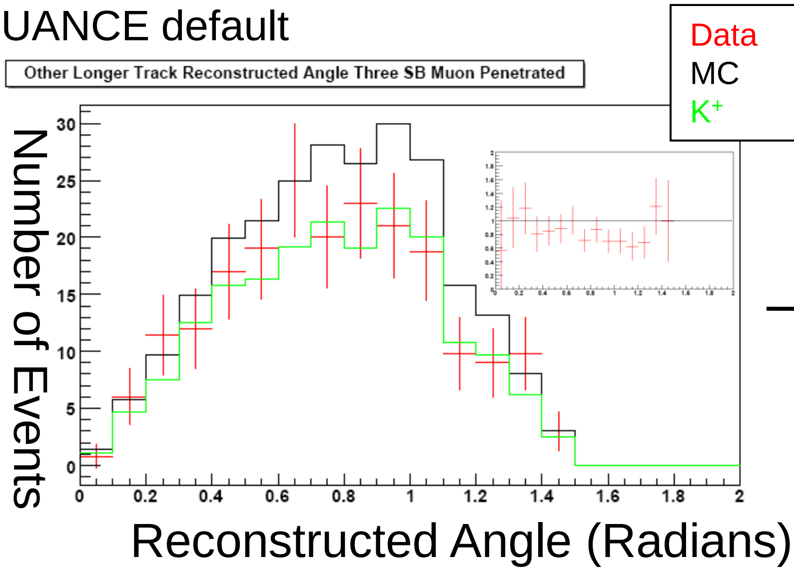




NEUT κ=1.022 P^+ Emission

Other Longer Track Length 3-Track

NUANCE default



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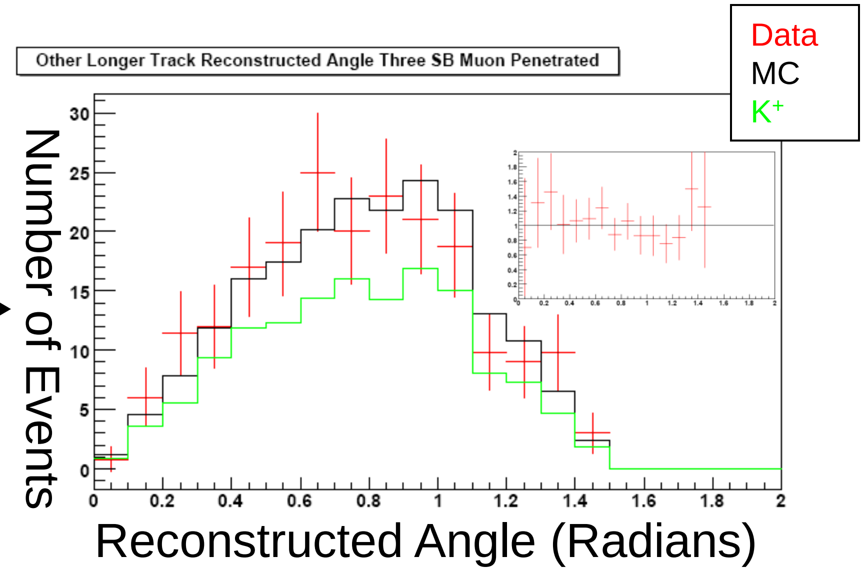

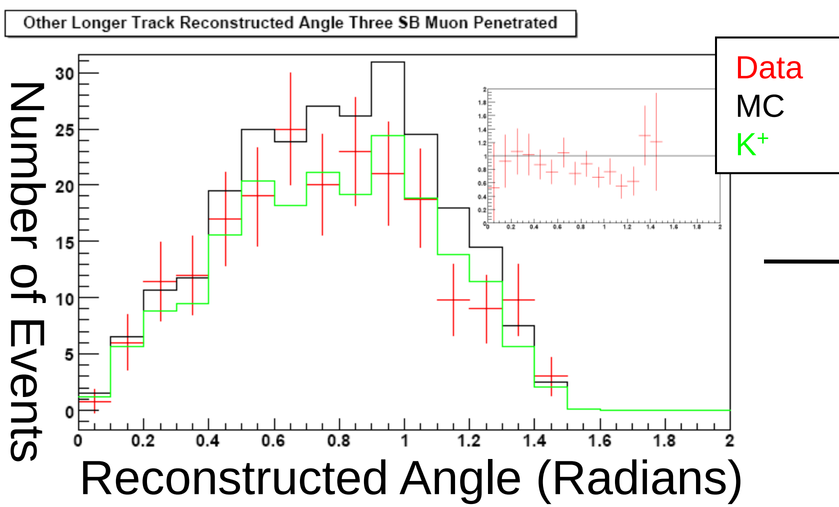

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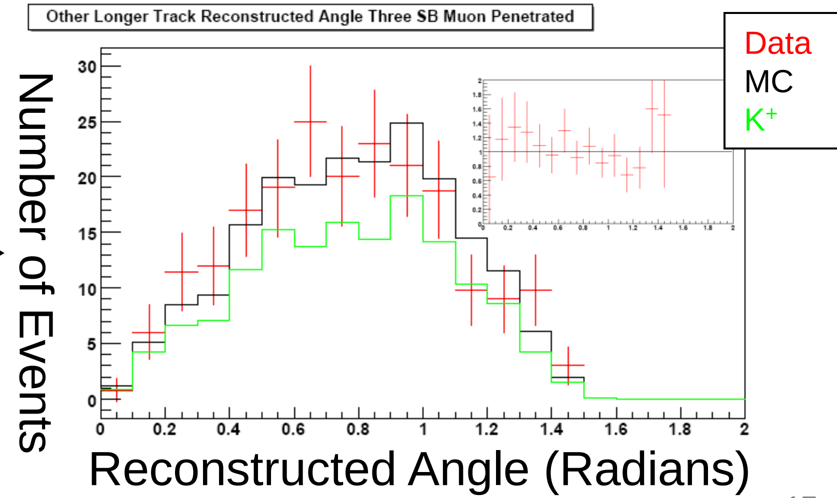
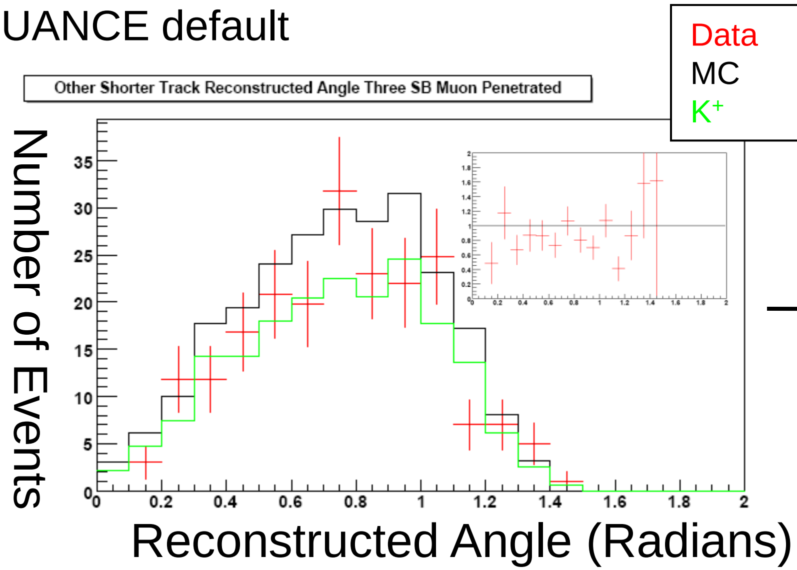
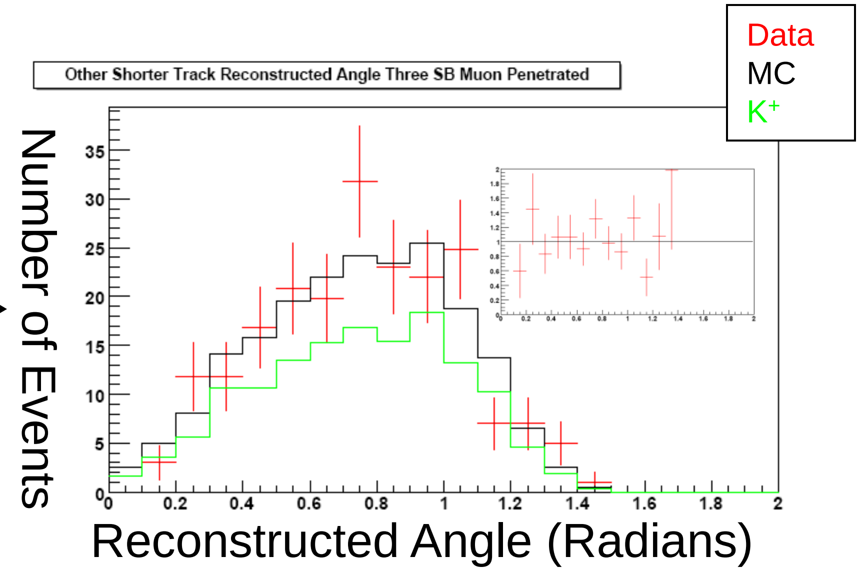


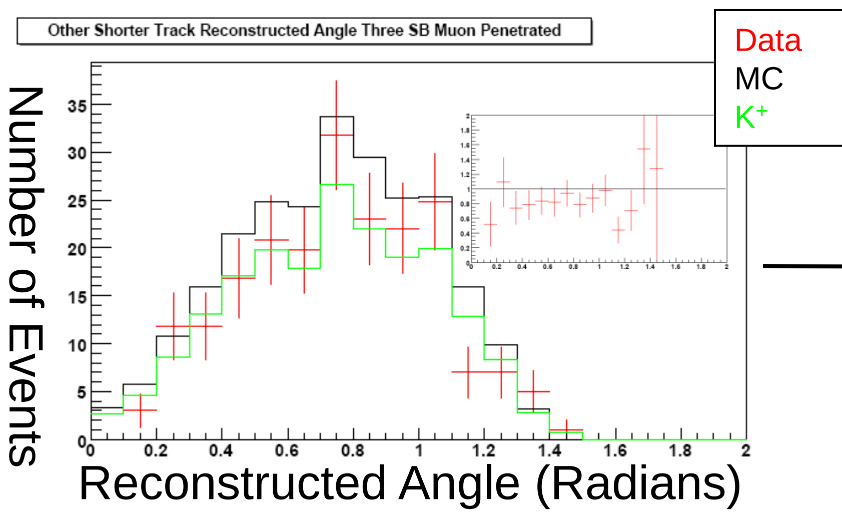
NEUT κ=1.022 P^+ Emission

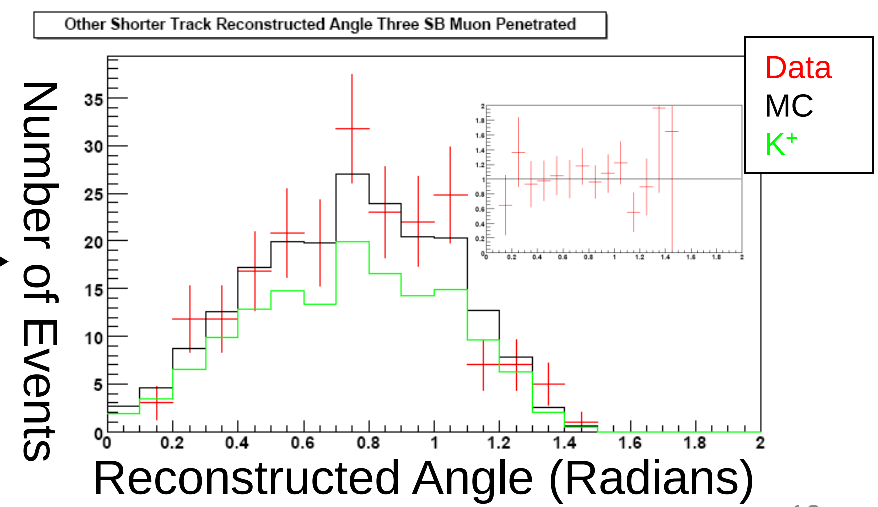
Other Shorter Track Length 3-Track

NUANCE default









NEUT κ=1.022 P^+ Emission

Systematic Errors

- Systematic errors are calculated using NUANCE when possible in order to relate to MiniBooNE.
- M_A,κ systematics done by reweighting events:
  - M_A QE: 1.234 GeV (±0.234 GeV)
  - Kappa: 1.022 (±0.022)
  - M_A Resonant π: 1.1 GeV (±0.275 GeV)
  - M_A Multi-π: 1.30 GeV (±0.52 GeV)
- Also vary certain cross-section normalizations:
  - CC resonant π: ±25%
  - CC multi π: ±40%
  - DIS: ±25%

Nuclear Effects Systematic Errors

- Additional weight calculated by NuclrPionWeight Package (by Kurimoto-san). Only implemented using NEUT.

- Pion absorption, charge exchange, inelastic scattering set to ±30%.

- Example of additional weight factor (pion absorption):
  - Absorbed pion events: 1.3
  - Other pion interaction events: 1
  - All other pion events: $(1 - P_{\text{other pion interaction}} - 1.3*P_{\text{absorbed pion}})/(1 - P_{\text{other pion interaction}} - P_{\text{absorbed pion}})$

Detector Systematic Errors

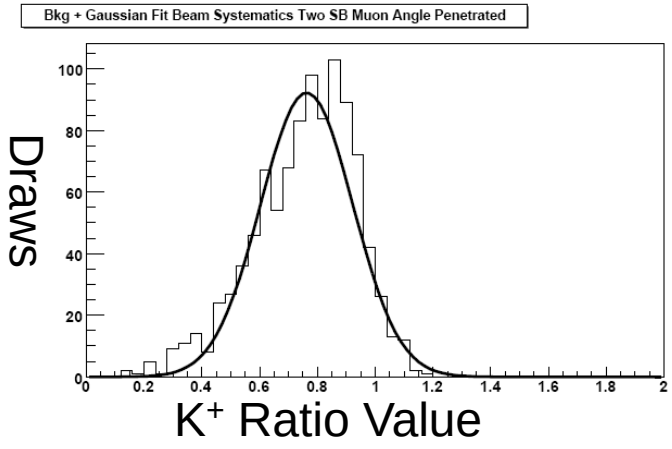
- Separate NEUT MC files (SciBar only) for upper and lower variations.

- Standard Systematic Errors: Scintillator Quenching Birk's Constant (0.0208±0.0023 cm/MeV), PMT Crosstalk (3.15%±0.4%), PMT Resolution (0.5±0.2), Hit Threshold (2±0.4 p.e.), TDC Deadtime (55ns±20ns).

Beam Systematics

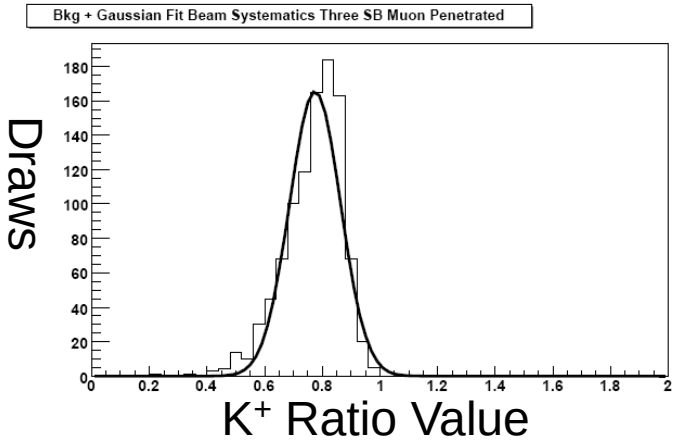
- Beam systematics (NUANCE) calculated from central value and sigma of 1000 multi-sims. Same formalism used by Kurimoto's analysis.
- Beam systematics applied only to K^+ background.

2-Track



Default: 0.74
Central Value: 0.76
Sigma: 0.16
Beam Sys. Uncertainty: +0.18(u)/-0.14(l)

3-Track



Default: 0.77
Central Value: 0.77
Sigma: 0.09
Beam Sys. Uncertainty: +0.09(u)/-0.09(l)

Table of Errors 1

	high energy ν_e	MRDMatched Penetrated 2-track ν_μ	MRDMatched Penetrated 3-track ν_μ
default (NUANCE default)	**2.69**	**0.74**	**0.77**
statistical (NUANCE default)	±0.58	±0.06	±0.08
default (new NEUT κ = 1.022)	1.24	0.76	0.78
M_A QE (1.234±0.234 GeV) (NUANCE default)	-0.35(u)/+0.47(l)	-0.08(u)/+0.09(l)	-0.04(u)/+0.03(l)
kappa (1.022±0.022) (NUANCE default)	+0.35(u)/-0.22(l)	+0.00(u)/+0.00(l)	+0.00(u)/+0.00(l)
M_A res. π (1.1±0.275 GeV) (NUANCE default)	-0.45(u)/+0.55(l)	-0.12(u)/+0.19(l)	-0.16(u)/+0.24(l)
M_A multi π (1.3±0.52 GeV) (NUANCE default)	-0.07(u)/+0.07(l)	-0.02(u)/+0.02(l)	-0.07(u)/+0.07(l)
Cross-section 1π (±25%) (NUANCE default)	-0.41(u)/+0.48(l)	-0.16(u)/+0.21(l)	-0.15(u)/+0.20(l)
Cross-section multi-π (±40%) (NUANCE default)	-0.07(u)/+0.07(l)	-0.02(u)/+0.02(l)	-0.06(u)/+0.05(l)
DIS (±25%) (NUANCE default)	-0.07(u)/+0.07(l)	-0.01(u)/+0.00(l)	-0.02(u)/+0.01(l)

Table of Errors 2

	high energy ν_e	MRDMatched Penetrated 2-track ν_μ	MRDMatched Penetrated 3-track ν_μ
pion absorption (old NEUT κ = 1.022)	-0.02(u)/+0.02(l)	+0.02(u)/-0.02(l)	+0.06(u)/-0.05(l)
charge exchange (old NEUT κ = 1.022)	+0.01(u)/-0.01(l)	+0.00(u)/+0.00(l)	+0.00(u)/+0.01(l)
inelastic scattering (old NEUT κ = 1.022)	+0.01/+0.00(l)	+0.01(u)/+0.00(l)	+0.03(u)/-0.02(l)
birk's constant (old NEUT default)	-0.04(u)/-0.08(l)	-0.01(u)/+0.02(l)	+0.03(u)/-0.04(l)
pmt crosstalk (old NEUT default)	-0.05(u)/-0.09(l)	-0.01(u)/+0.02(l)	+0.03(u)/+0.01(l)
pmt resolution (old NEUT default)	+0.01(u)/-0.02(l)	+0.04(u)/-0.01(l)	+0.00(u)/+0.03(l)
hit threshold (old NEUT default)	-0.02(u)/+0.02(l)	+0.01(u)/-0.01(l)	+0.01(u)/-0.01(l)
tdc deadtime (old NEUT default)	+0.01(u)/+0.00(l)	+0.01(u)/+0.01(l)	+0.01(u)/+0.01(l)
EC energy scale (old NEUT default)	-0.49(u)/+0.43(l)	+0.00(u)/+0.00(l)	+0.00(u)/+0.00(l)
scibar angle resolution (NUANCE default)			
muon momentum (NUANCE default)			
beam systematics (NUANCE default)	+0.60(u)/-0.12(l)	+0.18(u)/-0.14(l)	+0.09(u)/-0.09(l)

Final Ratio (very conservative)

- From ν_e:
  - $2.69 \pm 0.58(\text{stat.}) \pm {}^{1.20}_{0.91}(\text{sys.})$ (preliminary)
- From ν_μ 2-Track:
  - $0.74 \pm 0.06(\text{stat.}) \pm {}^{0.35}_{0.26}(\text{sys.})$ (preliminary)
- From ν_μ 3-Track:
  - $0.77 \pm 0.08(\text{stat.}) \pm {}^{0.35}_{0.27}(\text{sys.})$ (preliminary)

Next Steps

- Write technical note for K^+ analyses.

- Work on anti-ν analyses.

Backup

NEUT and NUANCE Parameters

- NUANCE Default:
  - M_A QE = 1.234±0.077 GeV
  - p_F = 220±30 MeV/c
  - E_B = 34±9 MeV
  - κ = 1.022±0.022
  - M_A Resonant π = 1.1±0.275 GeV
  - M_A Coherent π = 1.03±0.275 GeV
  - M_A Multi-π = 1.3±0.52 GeV
  - ΔS = 0±0.1
- NEUT Default:
  - M_A QE = 1.21-0.1 GeV
  - p_F = 217±5 MeV/c
  - E_B = 27 MeV
  - κ = 1.000
  - M_A Resonant π = 1.21 GeV
  - M_A Coherent π = 1.03 GeV
  - M_A Multi-π = 1.3 GeV
  - ΔS = 0

MRDMatched Penetrated 2-Track

- 1st Cut: MRDMatched (Pick only penetrated events).
- 2nd Cut: Single reconstructed muon.
- 3rd Cut: Two SciBar reconstructed tracks.
- 4th Cut: Reconstructed SciBar angle cut at ≤0.36 radians.

MRDMatched Penetrated 3-Track

- 1st Cut: MRDMatched (Pick only penetrated events).
- 2nd Cut: Single reconstructed muon.
- 3rd Cut: Three SciBar reconstructed tracks.

ν_e CC

- FV for upstream edge and beam timing of longest SciBar track.
- Longest SciBar track ≤ 0.7 radians.
- No reconstructed MRD track.
- SciBar track must point towards EC fiducial area:
  - -121.8 cm ≤ X ≤ 121.8 cm for Vertical Plane
    (3 EC semi-module width from each end)
  - -121.8 cm ≤ Y ≤ 121.8 cm for Horizontal Plane
    (3 EC semi-module width from each end)
- Existence of both vertical and horizontal EC cluster.
- Highest energy EC cluster within directed SB track V: 5 cm H: 6.5 cm
- Directed EC Clusters from SciBar
  - ≥230 MeV in 5 cm of Vertical Plane
  - ≥25 MeV in 6.5 cm of Horizontal Plane
- EC Energy outside EC Clusters
  - ≤5 MeV outside 5 cm of Vertical Plane
  - ≤5 MeV outside 6.5 cm of Horizontal Plane