Neutron Background to Atmospheric Neutrino Analyses:

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- Recall: in February presented estimate of neutron flux at MINOS Far Detector from GEANT4 simulation

- This now written up

  NuMI-NOTE-SIM,ATM_NU-1085

- Here just mention results and a couple of things new since February

Neutron Rates at Far Detector from GEANT4 Simulation

	$E_\mathrm{n} > 100$ MeV	
	Events/y $[10^3]$	Neutrons/y $[10^3]$
Accompanied by muon	9.68±0.05	13.75±0.06
Without muon	8.10±0.04	10.01±0.05
Total	17.79±0.06	23.76±0.07
	$E_\mathrm{n} > 300$ MeV	
	Events/y $[10^3]$	Neutrons/y $[10^3]$
Accompanied by muon	3.52±0.03	4.46±0.03
Without muon	1.83±0.02	2.05±0.02
Total	5.54±0.04	6.51±0.04

Hadronic Interaction Models

- Approx. 64% of neutrons with $E_\mathrm{n} > 100$ MeV incident on detector are from secondary interactions

  $\Rightarrow$ Results sensitive to modelling of hadronic interactions

- Main simulation (as presented in February, results on previous slide) used (energy-dependent) parameterized models for inelastic hadronic processes ($\equiv$ LHEP physics list)

- Replace with different physics lists:

  - QGSP: theory-driven quark-gluon string model

  - QGSP_BERT: as QGSP but Bertini cascade for pions and nucleons below 3 GeV

  - QGSP_BIC: as QGSP but Bertini cascade for nucleons below 3 GeV

Hadronic Interaction Models

- Ratio of neutron fluxes to default simulation:

	$E_\mathrm{n} > 100$ MeV		$E_\mathrm{n} > 300$ MeV	
	Events/y	Neutron/y	Events/y	Neutrons/y
QGSP	0.86±0.02	0.87±0.02	0.81±0.03	0.85±0.03
QGSP_BERT	1.31±0.02	1.39±0.02	1.28±0.04	1.33±0.04
QGSP_BIC	1.20±0.02	1.22±0.02	1.24±0.04	1.26±0.04

- See variations up to 30–40%

- There are also uncertainies in the muon-nuclear interaction model, rock composition/density etc.

  Estimated rates probably reliable to ∼50%

Neutrons in Soudan 2

- Is GEANT4 estimate consistent with neutron rate observed in Soudan 2?

- In February, estimate from Soudan 2 data gave 200 n/y at MINOS WITH VISIBLE ENERGY $E_{\mathrm{vis}} > 300$ MeV

- But how does visible energy relate to neutron energy?

- Try to make estimate of rate with VISIBLE energy above 300 MeV

- Using GMINOS simulation of events output from G4 program, sum energy of secondary particles above Soudan 2 thresholds (e/γ 100 MeV/c, π 150 MeV/c, p 500 MeV/c)

- Most events have many particles, so consider 'visible energy' originating from highest energy neutron

- Number of events/year with $E_{\mathrm{vis}} > 300$ MeV = 1741

Neutrons in Soudan 2

- But many of these events also have visible muon and/or another neutron and would have been rejected as ν events by scanning at Soudan 2

- If also demand muon misses detector and no 'visible energy' from other particles, number of events/year reduced to 320

- Within factor of 2 of my estimation from Soudan 2 data (~200 events/year)