Atmospheric Neutrino Event Rate

Pat Ward
University of Cambridge

- No MINOS analysis of atmospheric ν_e events yet
- Therefore need to estimate expected event rates:

  For ν_μ analysis

  Normalize MC
- All values here calculated assuming no oscillations

Atmospheric Neutrino Event Rates

Can calculate event rates from flux files and cross-sections:

$$R = \int \frac{\mathrm{d}N}{\mathrm{d}E} \times \sigma(E) \times n \times \mathrm{d}E$$

- $\frac{\mathrm{d}N}{\mathrm{d}E}$ = neutrino flux integrated over solid angle

  Flux usually tabulated in bins of $\log_{10}(E)$ with 20 bins / decade

  Integral evaluated using this binning

- $\sigma(E)$ = cross-section from NEUGEN

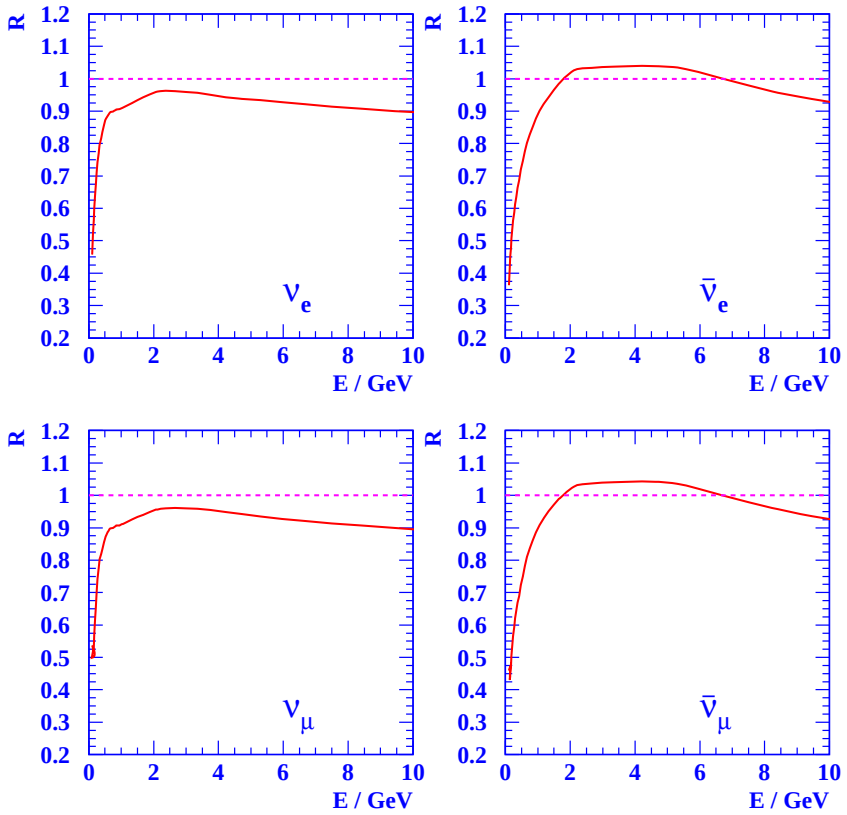
  Use Z=26, A=56 for MINOS

  Z=6, A=12 gives differences of $\lesssim$ 2%

- n = number of nuclei per kton (= 10^6 kg / (A * 1 a.m.u.))

Cross-sections

- Event rates calculated with NEUGEN2 cross-sections are ∼20% higher than those calculated with NEUGEN3 (for E_ν = 100 MeV–10 GeV)
- NEUGEN2 uses free nucleon cross-sections, not correct for bound nucleons – need correction for Pauli blocking
- Therefore all rates calculated using cross-sections from NEUGEN3



$$R = \sigma(\text{NEUGEN3})/\sigma(\text{NEUGEN2})$$

Flux Calculations

Event rates estimated for various flux calculations, at solar maximum and solar minimum:

- BARTOL96: V.Agrawal et al., Phys. Rev. **D53** (1996) 1314
  50 MeV $< E_\nu <$ 70000 GeV; 1D; TARGET1.0 for hadronic interactions
- Battistoni: G.Battistoni et al., Astropart. Phys. **19** (2003) 269
  100 MeV $< E_\nu <$ 100 GeV; 3D; FLUKA for hadronic interactions;
- Barr: http://barr.home.cern.ch/barr/fluxfiles/ (preliminary)
  100 MeV $< E_\nu <$ 10 GeV; 3D; TARGET2.1 for hadronic interactions

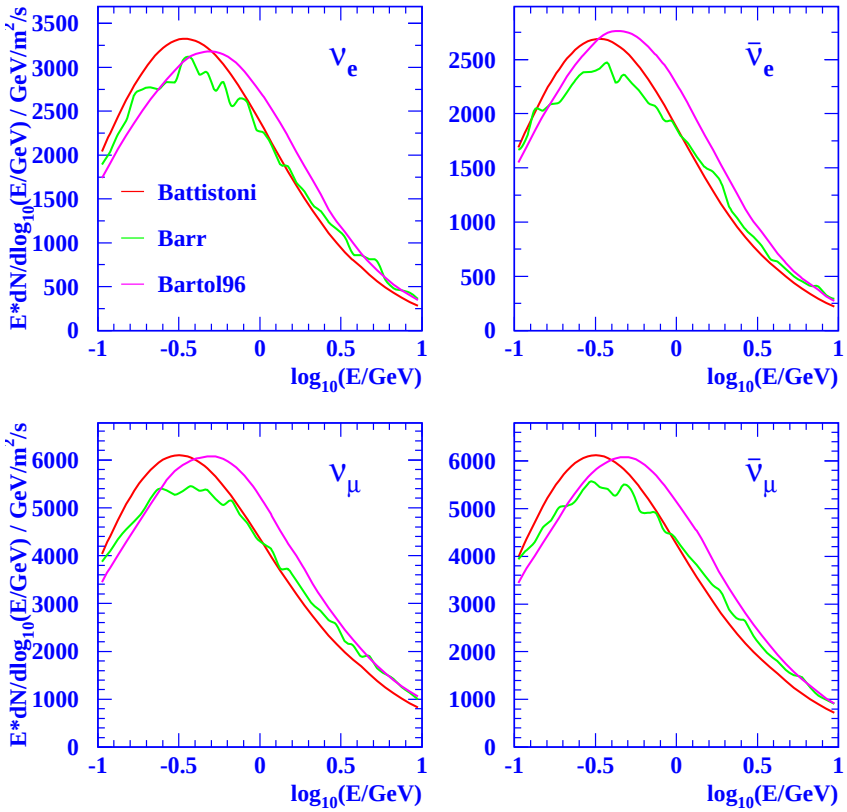
Atmospheric neutrino analysis uses Battistoni flux as default; Monte Carlo events also generated with Barr flux.

Flux Calculations

Significant variations between flux predictions arise from:

- Input primary cosmic ray spectrum: 20%
- Hadronic interaction package: 15%
- Atmospheric and geomagnetic modelling 2%

Overall normalization uncertainty estimated to be 20–25%



Comparison of Event Rates

- Total events / kton-year calculated using NEUGEN3 cross-sections, summing $\nu_{\rm e} + \overline{\nu}_{\rm e} + \nu_{\mu} + \overline{\nu}_{\mu}$:

	Solar Max			Solar Min		
E_ν / GeV	Battistoni	Barr	Bartol96	Battistoni	Barr	Bartol96
0.1 – 10	278.6	273.3	302.8	308.5	317.5	354.4
0.5 – 10	168.2	173.9	199.7	180.2	188.6	215.0
1.0 – 10	95.4	104.9	118.4	99.8	110.3	122.1

- For $E_\nu > 1$ GeV, Barr flux gives $\sim$10% higher event rate than Battistoni, Bartol96 gives 20–25% higher rate
- For $E_\nu > 500$ MeV event rate at solar minimum is 7–8% higher than at solar maximum ($\sim$ 5% for $E_\nu > 1$ GeV)

Atmospheric Neutrino Event Rate

- Current data collected between August 2003 and April 2004
- Assume sinusoidal interpolation between solar min and solar max to estimate event rate at 1st January 2004 (Battistoni flux)

E_ν / GeV	ν_{e}	$\overline{\nu}_{\mathrm{e}}$	ν_μ	$\overline{\nu}_\mu$	total
$>$ 0.5	46.8	12.8	90.7	30.8	181.1
$>$ 1.0	24.9	8.1	53.0	20.7	106.6

- Variation between August 2003 and April 2004 is 1.2% for $E_\nu > 500$ MeV, 0.8% for $E_\nu > 1$ GeV

Atmospheric Neutrino Event Rate

- Normalization uncertainty in flux calculations estimated to be 20–25%
- How about measurements from Soudan, which has analysed ν_μ and ν_e events?
- Fit to event rates finds normalization = 85$\pm$7% of BARTOL96 flux
- Full oscillation fit: within 90% c.l. region of ($\Delta m^2, \sin^2 2\theta$) normalization 85–92% of BARTOL96; 91% for best fit
- Similarly, best fit gives normalization of 105% for Battistoni flux

Conclusion

- Using Battistoni flux with 20% normalization uncertainty for current analysis seems reasonable