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Searching for the footprint of prompt atmospheric neutrino flux and extra-galactic diffusive sources

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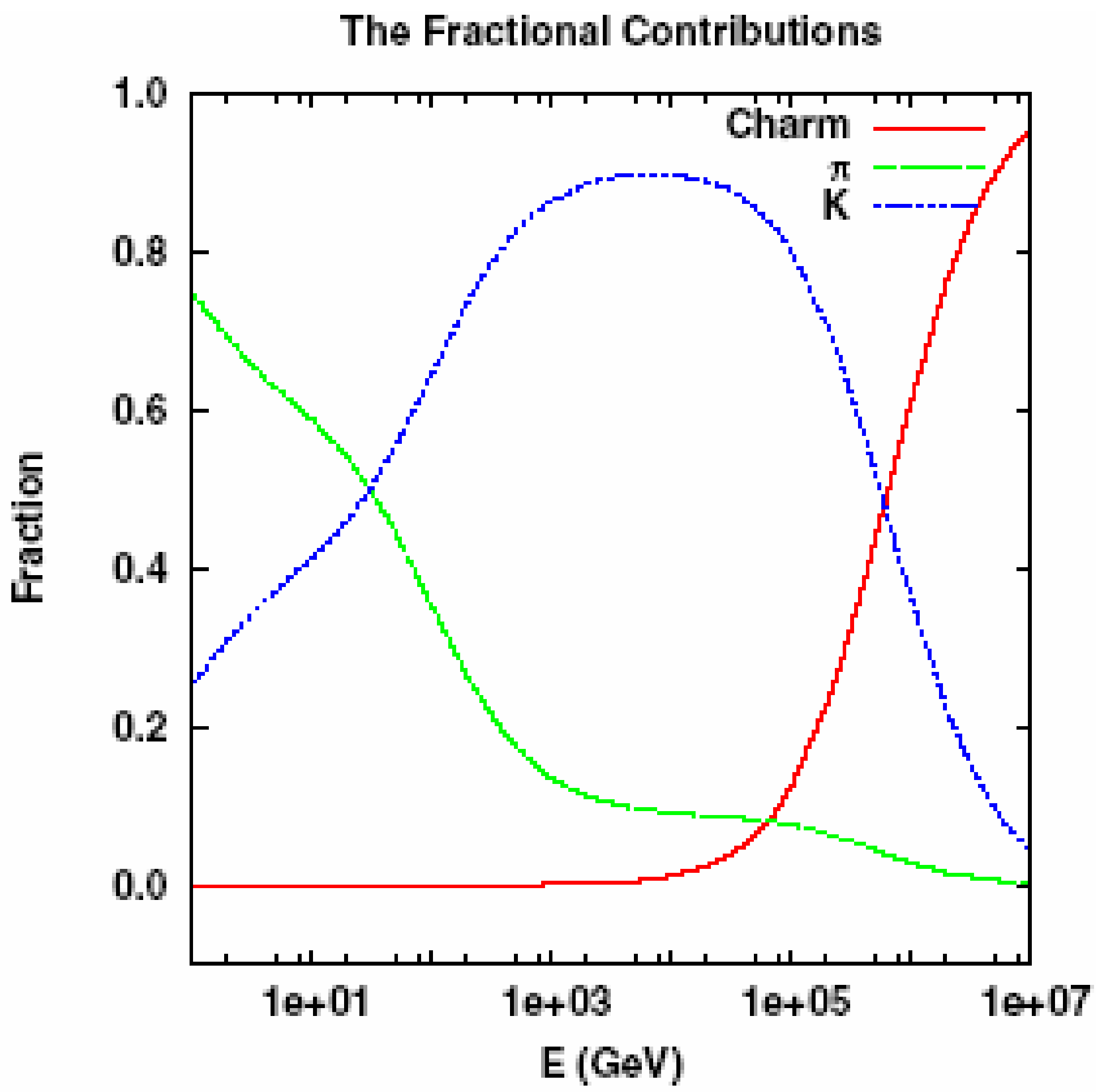


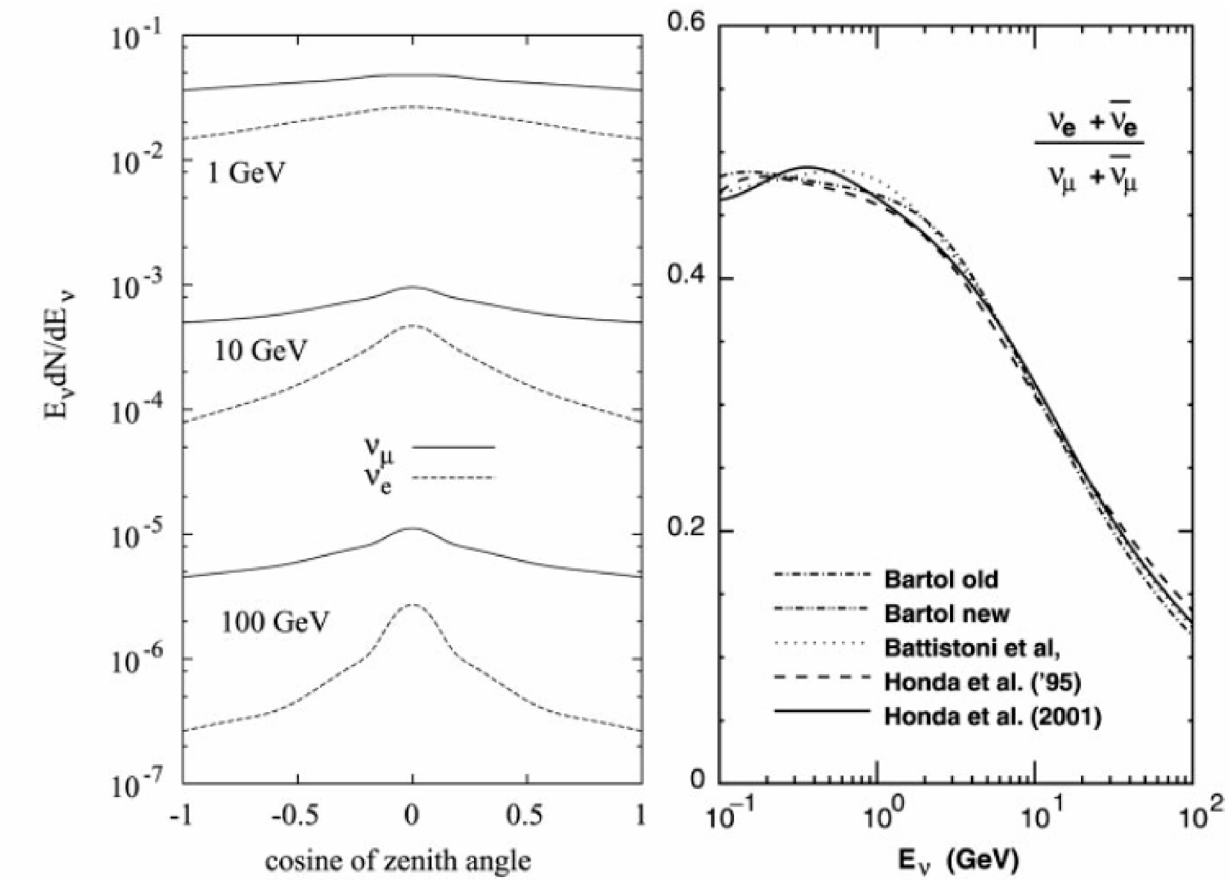
Charm hadrons live much shorter than π, K. Neutrinos produced by their decays are called prompt neutrinos.

Plotted are fluxes of down-going ν_μ

H. Athar, F.-F. Lee and G.-L. Lin, Phys. Rev. D 2005

The π, *K* production cross section taken from

T. K. Gaisser, Astropart. Phys. 2002



These are neutrinos from π and K decays, so called conventional component- a background to the prompt component.

T. K. Gaisser and M. Honda, Annu. Rev. Nucl. Part. Sci. 2002

- The background issue in the ν_e case is less severe- look for prompt ν_e

J. F. Beacom and J. Candia JCAP 2004.

- We observe that, in the conventional component, angular dependence increases with the energy. The prompt component is however isotropic!

The signature of prompt neutrinos and beyond

- Looking for shower signals from down going ν_e with muon veto.
- Observe the excess to the conventional atmospheric neutrino flux.
- Study the angular dependence of observed flux. Look for its deviation to the angular dependence of the conventional atmospheric neutrino flux.

The shower signature

- $CC\,\nu_e + N \rightarrow e^- + X$ EM + Hadronic

  $NC\,\nu_e + N \rightarrow \nu_e + X$ Hadronic

- $NC\,\nu_\mu + N \rightarrow \nu_\mu + X$, suppressed by $\langle y \rangle^{(\gamma\text{-}1)} \times \sigma_{NC}/\sigma_{CC}$

  enhanced by flux, $\langle y \rangle \approx 0.3-0.4, \gamma \approx 3-3.7$

  $\nu_\tau + N \rightarrow \nu_\tau + X$, suppressed due to small ν_τ flux

- $CC\;\; \nu_\tau + N \rightarrow \tau^- + X$: suppressed due to the small ν_τ flux.

All signatures are included in our calculations.

The production of prompt atmospheric neutrinos

Primary comic ray proton spectrum

T. K. Gaisser and M. Honda, 2002

$$\phi_p(E_p) \equiv dN_p / dE_p,$$

$$\phi_p(E_p) = 1.49 \cdot \left(E_p + 2.15 \cdot \exp\left(-0.21\sqrt{E_p}\right)\right)^{-2.74}$$

in the unit $cm^{-2}s^{-1}sr^{-1}GeV^{-1}$.

Contributions from heavier nuclei do not affect our results based upon angular distribution.

$$p + \mathrm{Air} \rightarrow \mathrm{charm\ hadron}\ (h) + X$$

$$h : D^{\pm}, D^0, D_s, \Lambda_c$$

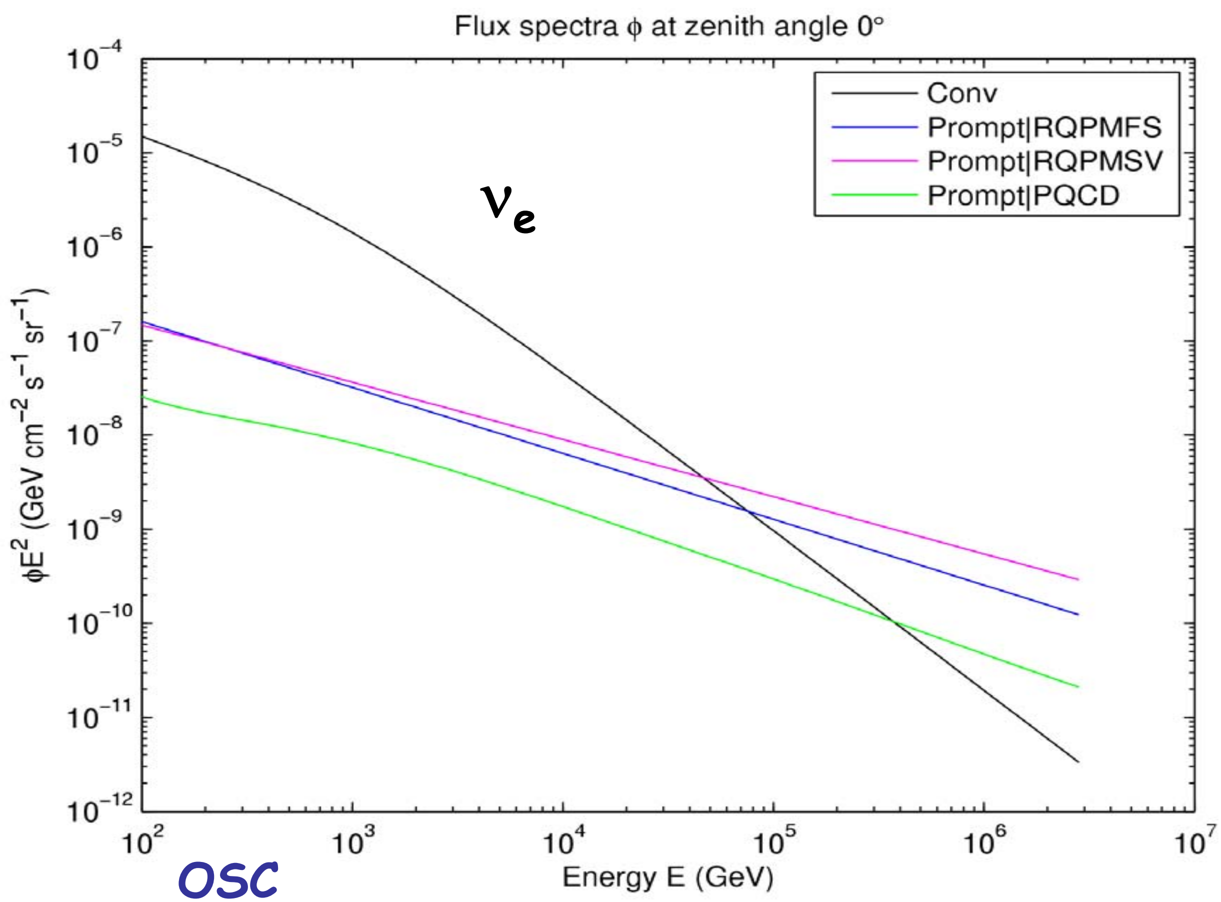
$$h \rightarrow \nu + Y$$

Tau neutrino only come from D_s decays.

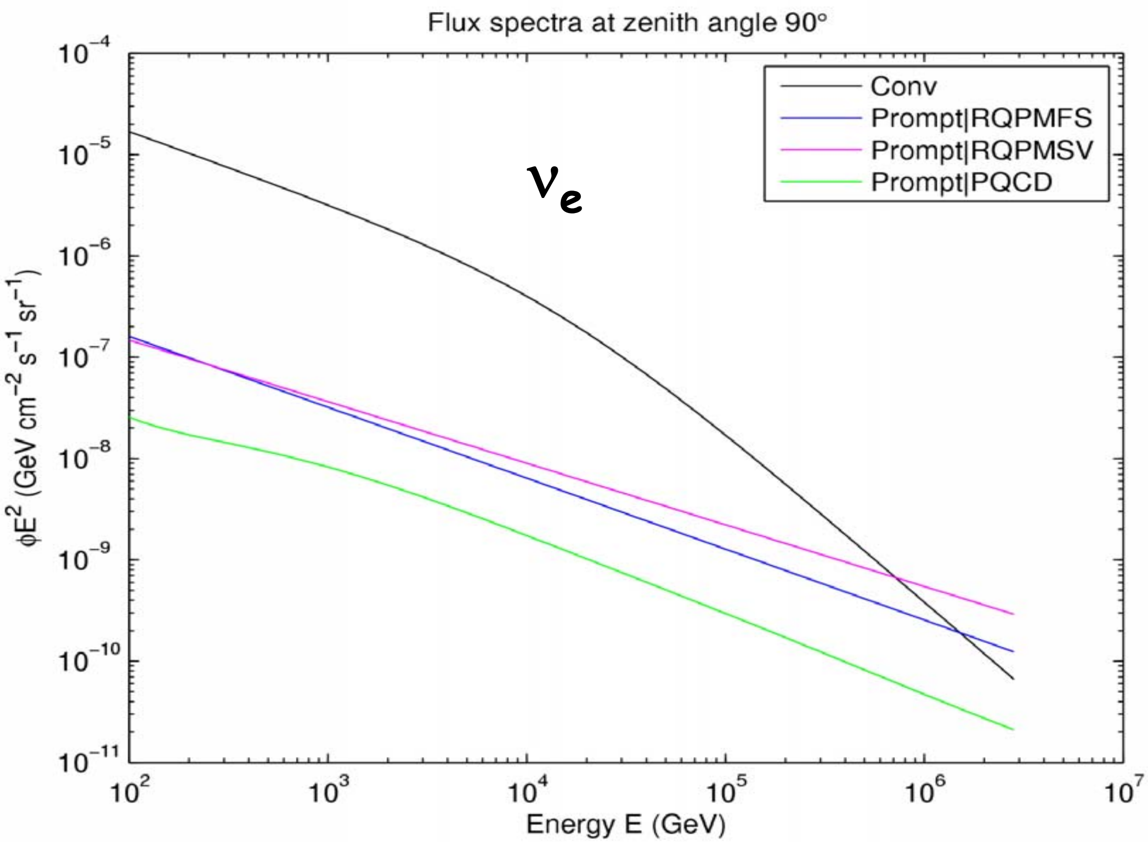
$$\Phi_{prompt}(\nu_e):\Phi_{prompt}(\nu_\mu):\Phi_{prompt}(\nu_\tau)=1:1:0.1$$

The absolute flux of prompt neutrinos are very model dependent.

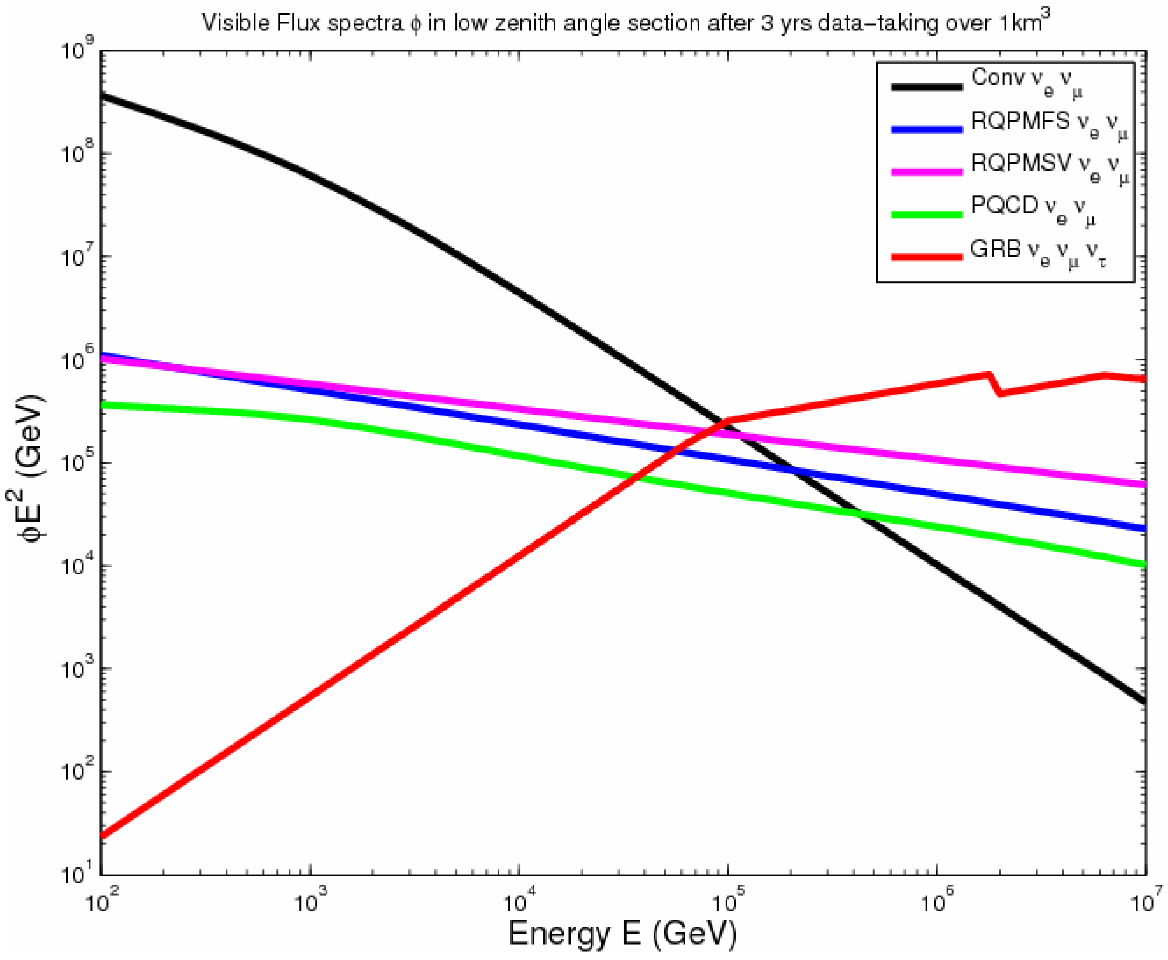
NLO QCD with MRSG parton distribution function
M. Thunman, G. Ingelman and P. Gondolo, Astropart. Phys. 1996
RQPM: non-perturbative
E. V. Bugaev et al. Phys. Rev. D 1998



Vertical down-going ν_e flux

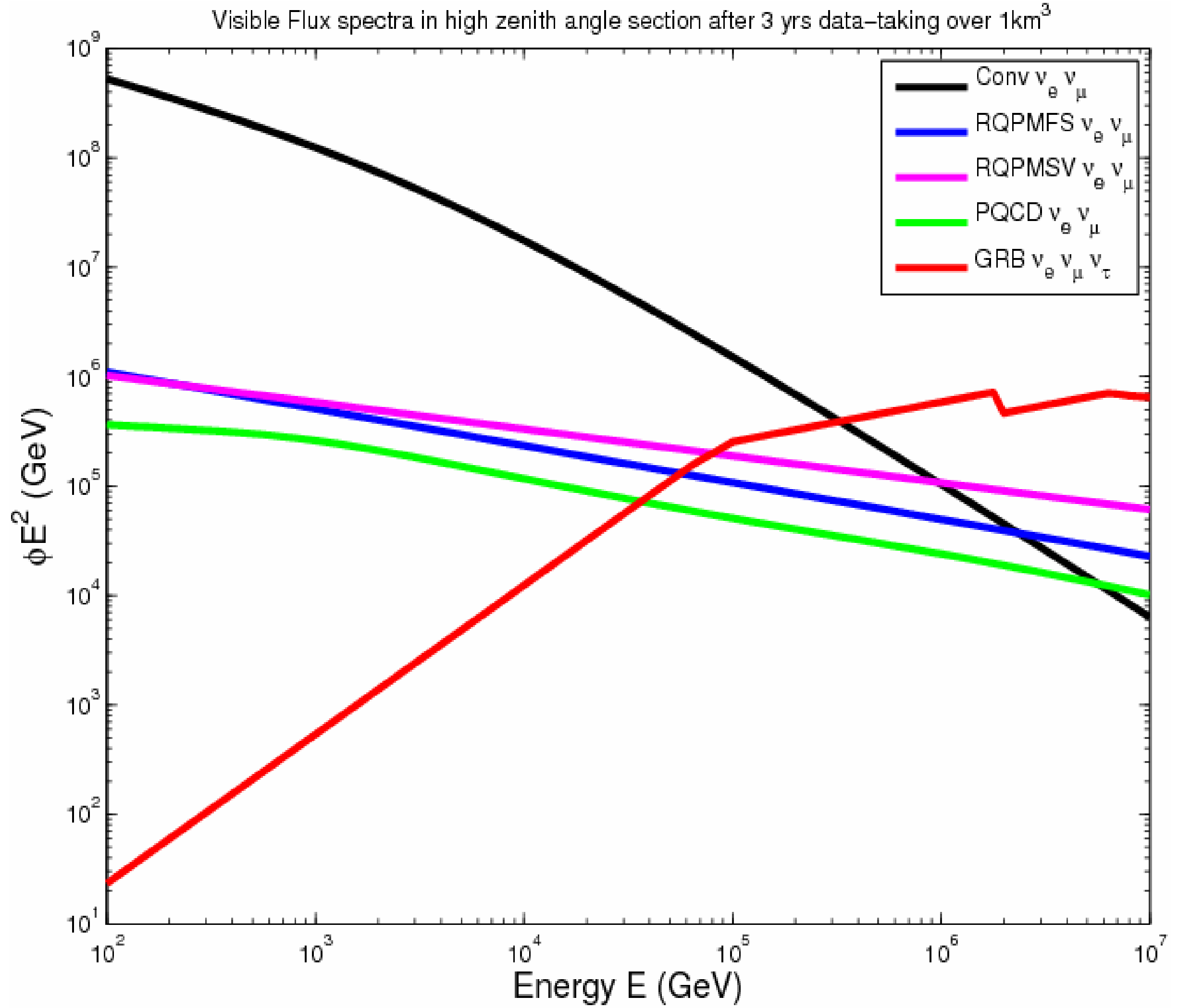


Horizontal coming ν_e flux

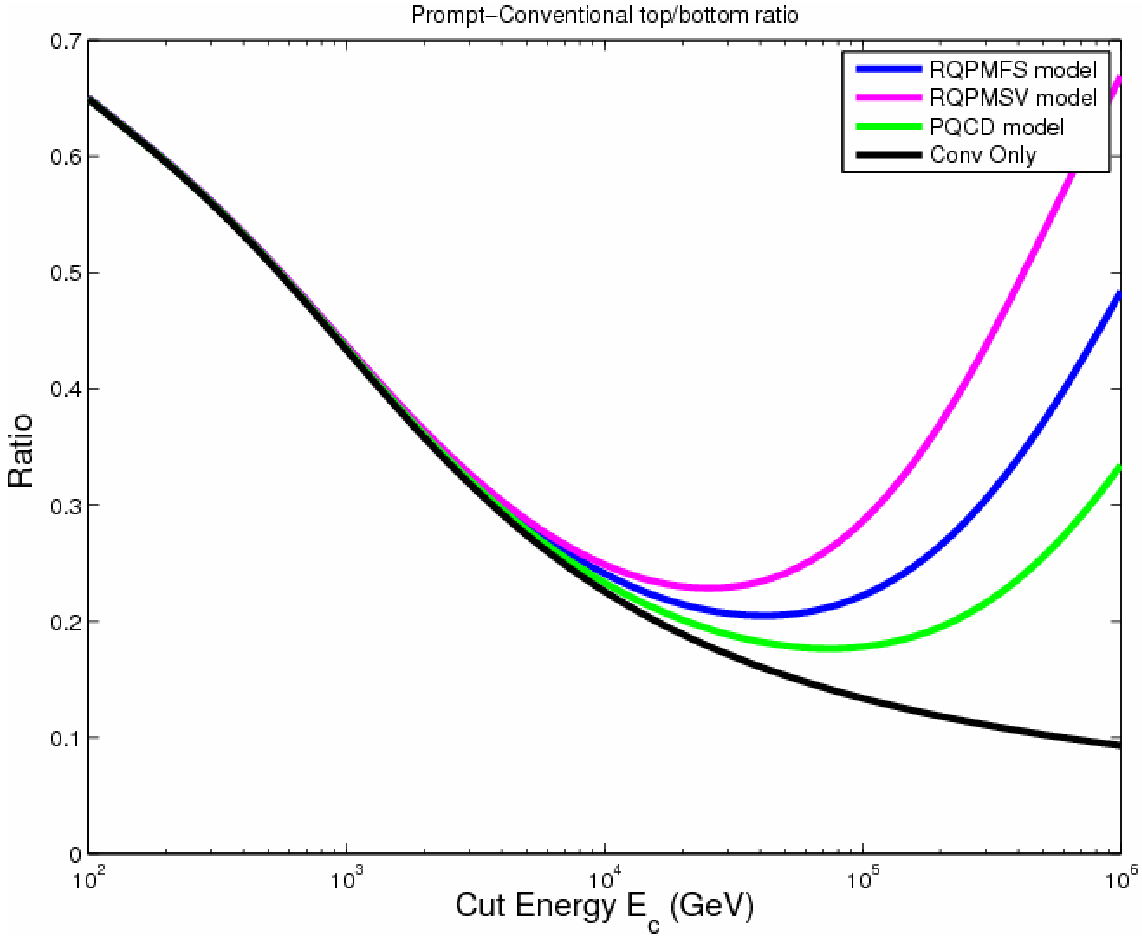


Event number spectra for 3 years of data-taking in km^3 water Cherenkov detector-cosθ=[0.5,1]

GRB flux Eli Waxman and John Bahcall Phys. Rev. D 1998



Event number spectra for 3 years of data-taking in km3 water Cherenkov detector- cosθ=[0,0.5]



Ratio(R)=Small zenith/Large zenith

For $E_c=10^5$ GeV, R=0.13 with only conventional atm. flux,

R=0.17 with PQCD-calculated prompt atm. flux included

R=0.28 with RQPM-calculated prompt atm. flux included

R=0.21 with RQPMFS-calculated prompt atm. Flux included

$E_c=10^5$ GeV, 10 years of data taking (Icecube)
Conventional and prompt in blue and red respectively

Model	PQCD	RQPM	RQPM -FS
Small zenith angle	(9.8 3.6)	(9.8 16)	(9.8 7.5)
Large zenith angle	(75 3.6)	(75 16)	(75 7.5)
S/L≡R	0.17	0.28	0.21

R=0.13
For conventional atmospheric ν's.

$E_c = 2.5 \times 10^5$ GeV, 10 years of data taking conventional and prompt in blue and red respectively

Model	PQCD	RQPM	RQPM -FS
Small zenith angle	(1.1 1.1)	(1.1 4.4)	(1.1 2.2)
Large zenith angle	(10 1.1)	(10 4.4)	(10 2.2)
S/L≡R	0.20	0.38	0.27

R=0.11 atmospheric ν's.

$E_c = 5 \times 10^5$ GeV, 10 years of data taking
Conventional and prompt in blue and red respectively

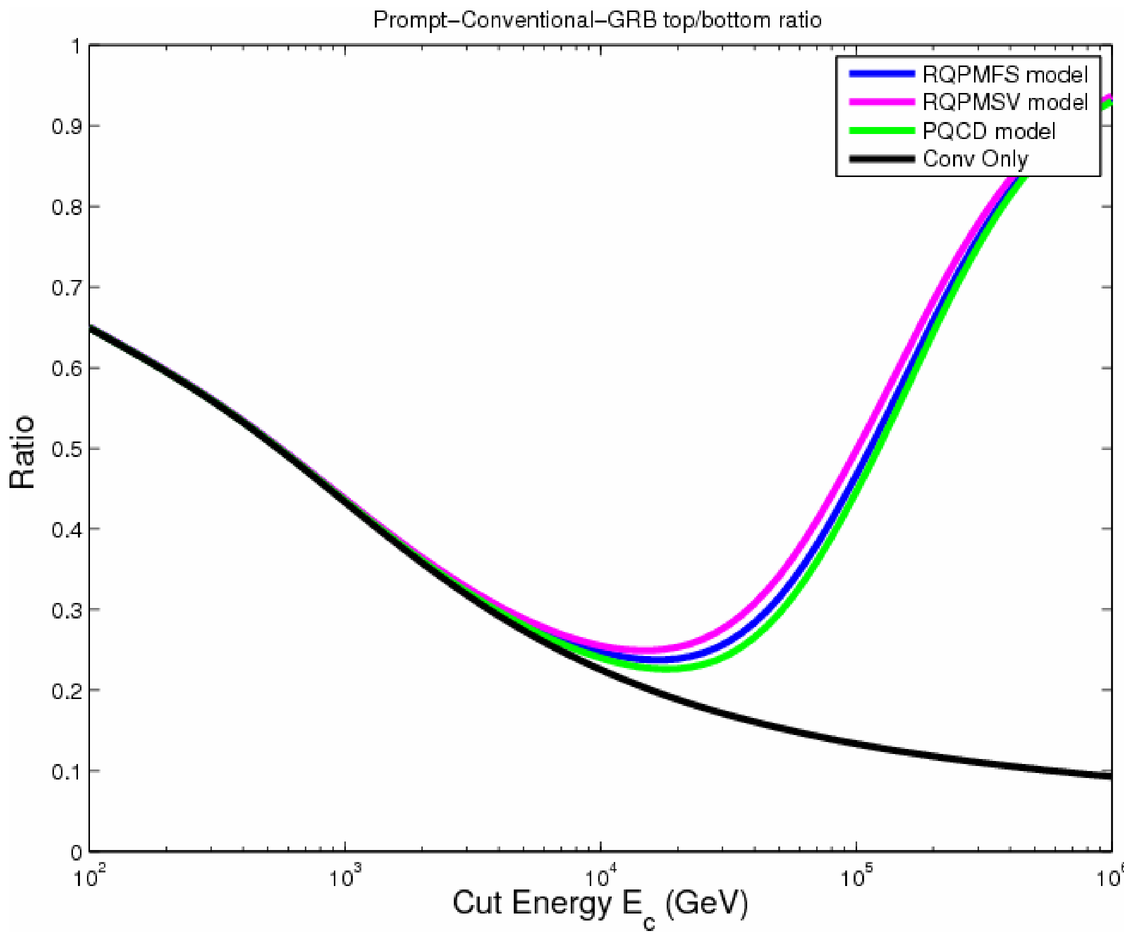
Model	PQCD	RQPM	RQPM -FS
Small zenith angle	(0.23 0.4)	(0.23 1.9)	(0.23 0.88)
Large zenith angle	(2.3 0.4)	(2.3 1.9)	(2.3 0.88)
S/L≡R	0.24	0.51	0.35

R=0.10
For conventional atmospheric ν's.

The effect from GRB flux

Eli Waxman and John Bahcall

Phys. Rev. D 1998



Ratio(R)=Small zenith/Large zenith

$E_c = 10^5$ GeV, 10 years of data taking

R=0.13
for conv. Atm..

Model	PQCD	RQPM	RQPM -FS	GRB alone
Small zenith angle	(9.8 3.6)	(9.8 16)	(9.8 7.5)	14
Large zenith angle	(75 3.6)	(75 16)	(75 7.5)	14
S/L≡R	0.17	0.28	0.21	
with GRB	0.30	0.38	0.32	

$E_c=2.5\times10^5$ GeV, 10 years of data taking

R=0.11
for conv. Atm..

Model	PQCD	RQPM	RQPM -FS	GRB alone
Small zenith angle	(1.1 1.1)	(1.1 4.4)	(1.1 2.2)	7.4
Large zenith angle	(10 1.1)	(10 4.4)	(10 2.2)	7.4
S/L≡R	0.20	0.38	0.27	
with GRB	0.52	0.59	0.55	

$E_c = 5\times10^5$ GeV

R=0.1 for Conv. Atm.

Model	PQCD	RQPM	RQPM-FS	GRB alone
Small zenith angle	(**0.23** **0.4**)	(**0.23** **1.9**)	(**0.23** **0.88**)	**4.2**
Large zenith angle	(**2.3** **0.4**)	(**2.3** **1.9**)	(**2.3** **0.88**)	**4.2**
S/L≡R	0.24	0.51	0.35	
with GRB	0.7	0.75	0.72	

Conclusions

- We have proposed to identify prompt atmospheric neutrinos and neutrinos from extragalactic sources through the angular dependencies of measured shower events with muon veto.
- We pointed out that, for conventional atmospheric neutrinos, the ratio of shower event between small (0 to 60 degrees) and large zenith angles (60 to 90 degrees) decreases monotonically as we raise the shower energy threshold.

Continued

- **In contrast, both the prompt atmospheric neutrino flux and the neutrinos from extra-galactic diffusive sources are isotropic. Their presence raises the above-mentioned ratio.**
- **The identification of prompt atmospheric neutrinos is more likely with RQPM charm-production model. Certainly an updated PQCD calculation for prompt atmospheric neutrino flux is very much needed.**
- **The detection of GRB neutrino flux is promising if this flux does exist. The angular distribution of neutrino flux is altered significantly by the presence of GRB neutrino flux.**

continued

- **On the other hand, GRB flux dominates that of prompt atmospheric neutrinos at the energy range where both of them emerge from conventional atmospheric neutrino background.**
- **A parallel analysis with respect to the detection of upcoming muon neutrino flux is underway. The upcoming ν flux is subject to more severe background and Earth attenuation effect. However, the range of high energy muon makes up some of the suppressions.**