

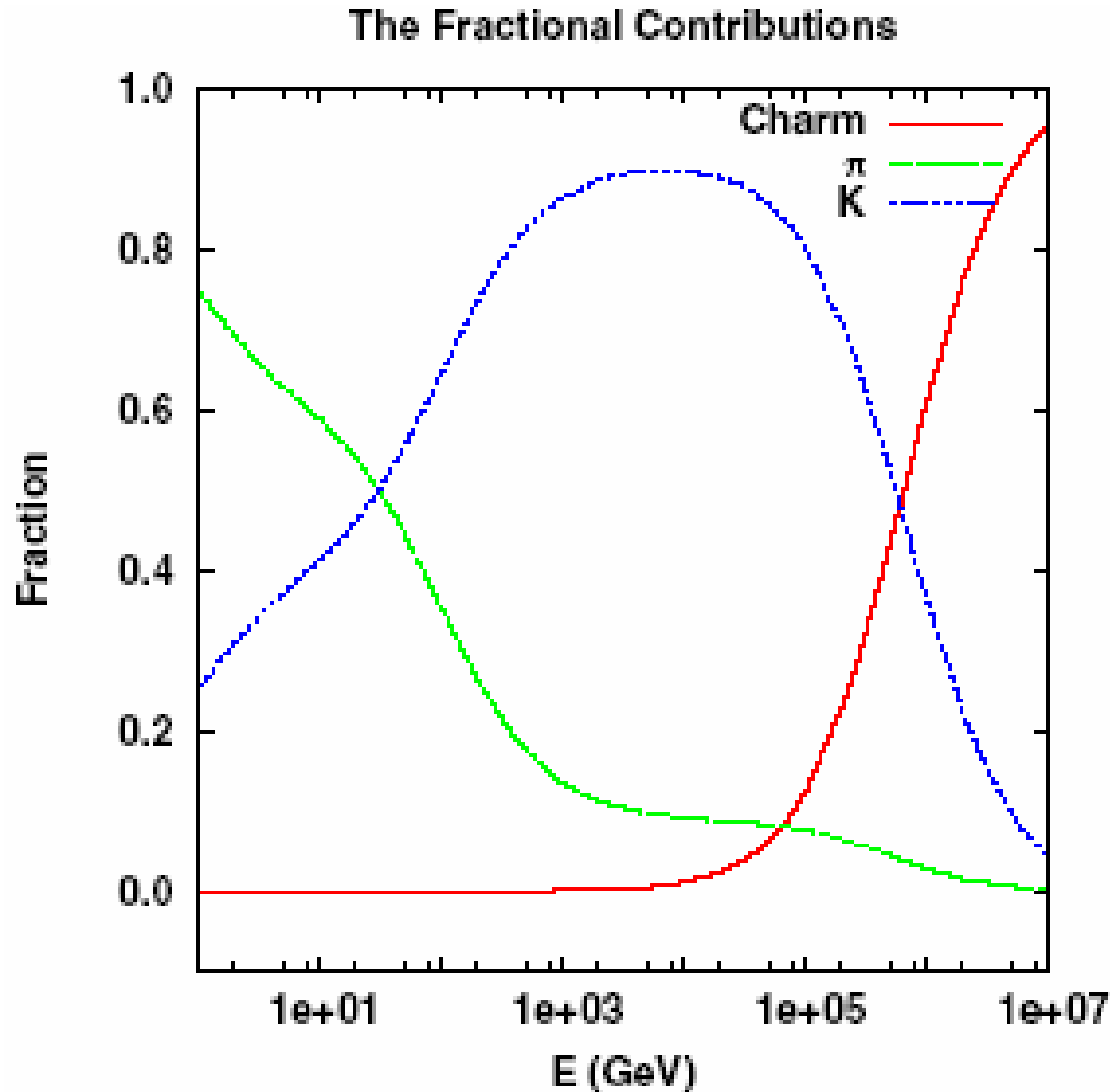
CosPA07, Nov. 13

Identifying Prompt Atmospheric  
Neutrinos and Neutrinos from  
Extra-Galactic Sources through  
Shower Angular Dependencies

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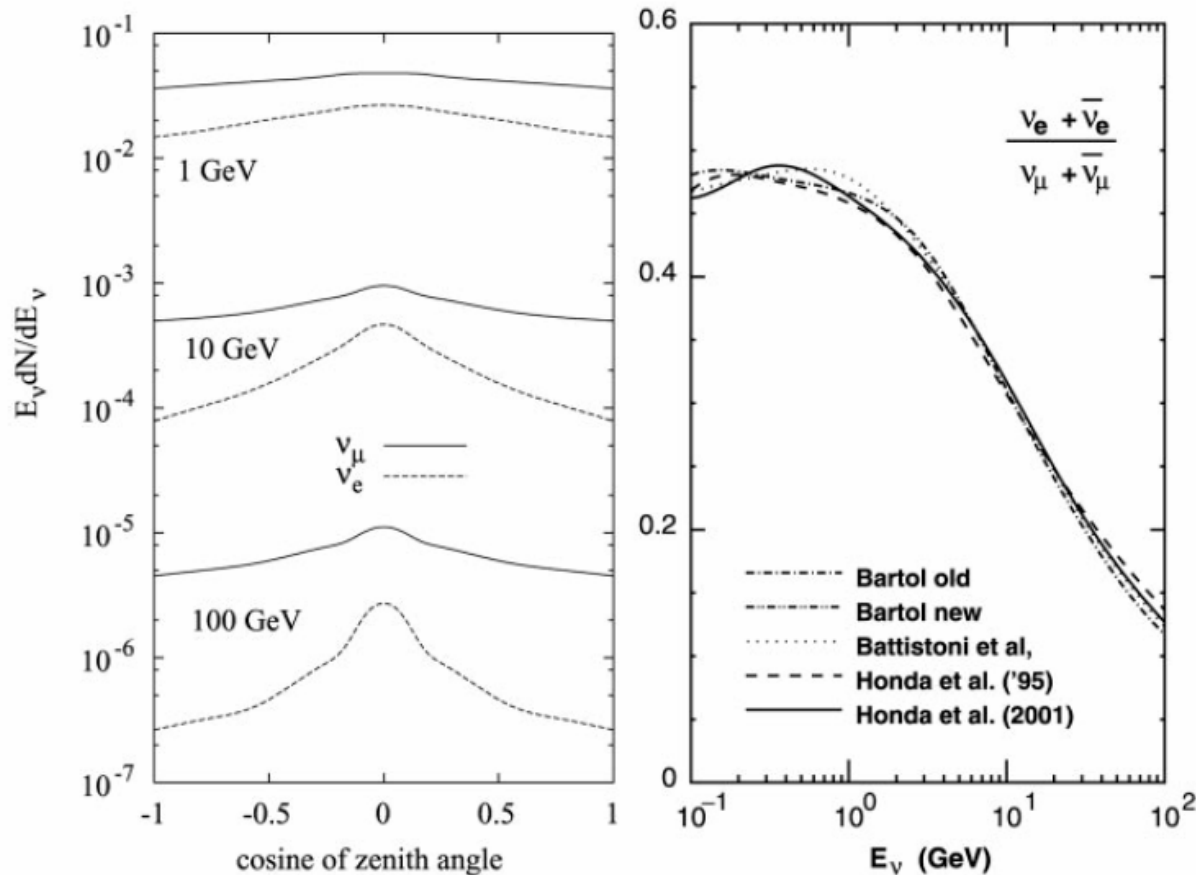
**Charm** hadrons live much shorter than  $\pi$ , K. Neutrinos produced by their decays are called **prompt neutrinos**.

Plotted are fluxes of down-going  $\nu_\mu$

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

The  $\pi$ , K production cross section taken from

T. K. Gaisser, Astropart. Phys. 2002



These are neutrinos from  $\pi$  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  $\nu_e$  case is less severe - look for prompt  $\nu_e$

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  $\nu_e$  and  $\nu_\mu$  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  $\langle y \rangle^{(\gamma-1)} \times \sigma_{\text{NC}} / \sigma_{\text{CC}}$   
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  $\nu_\tau$  flux
- $CC \nu_\tau + N \rightarrow \tau^- + X$  : suppressed due to the small  $\nu_\tau$  flux.

**All signatures are included in our calculations.**

# The production of prompt atmospheric neutrinos

## Primary cosmic ray proton spectrum

$$\phi_p(E_p) \equiv dN_p / dE_p, \quad \text{T. K. Gaisser and M. Honda, 2002}$$

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

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

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



**Tau neutrino only come from  $D_s$  decays.**

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

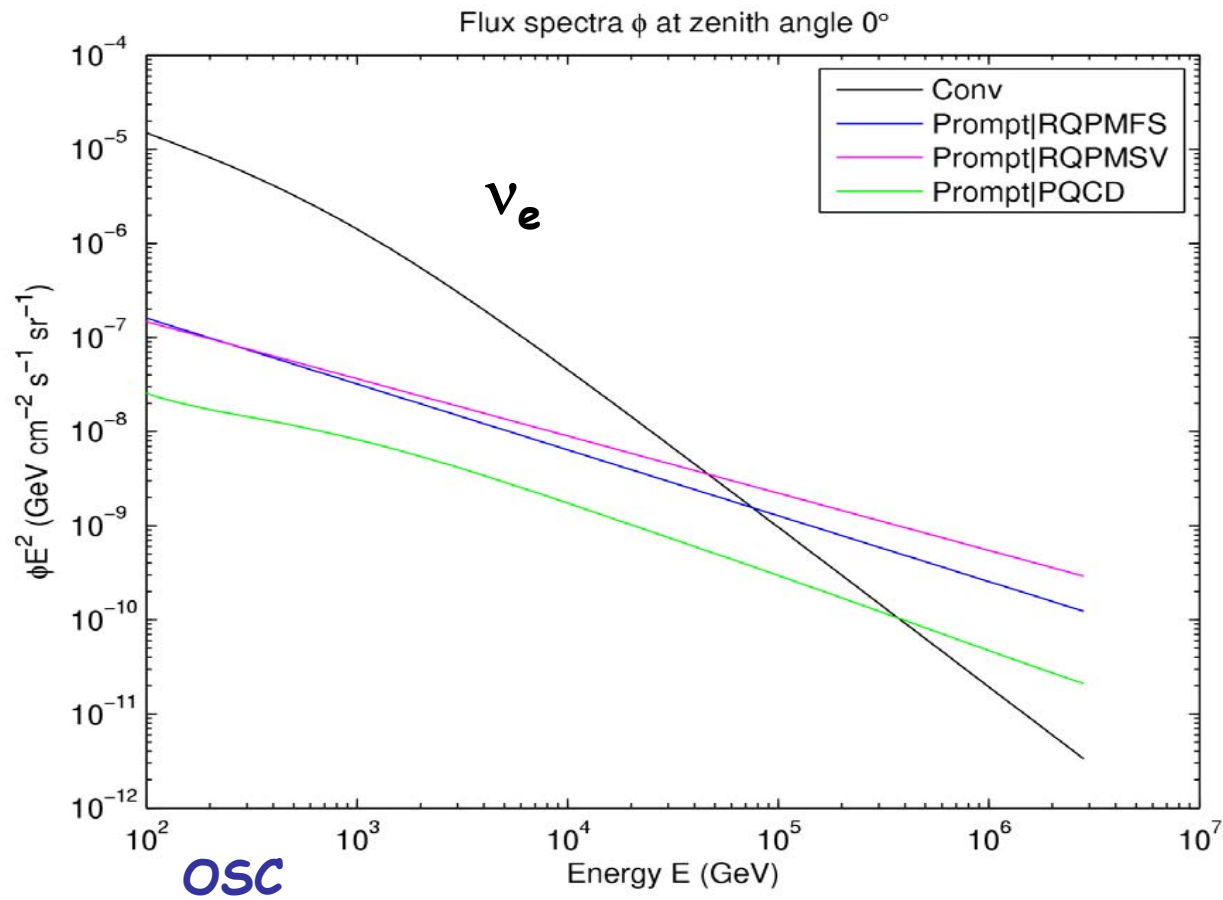
The absolute flux of prompt neutrinos are very model dependent.

NLO QCD with MRSG parton distribution function

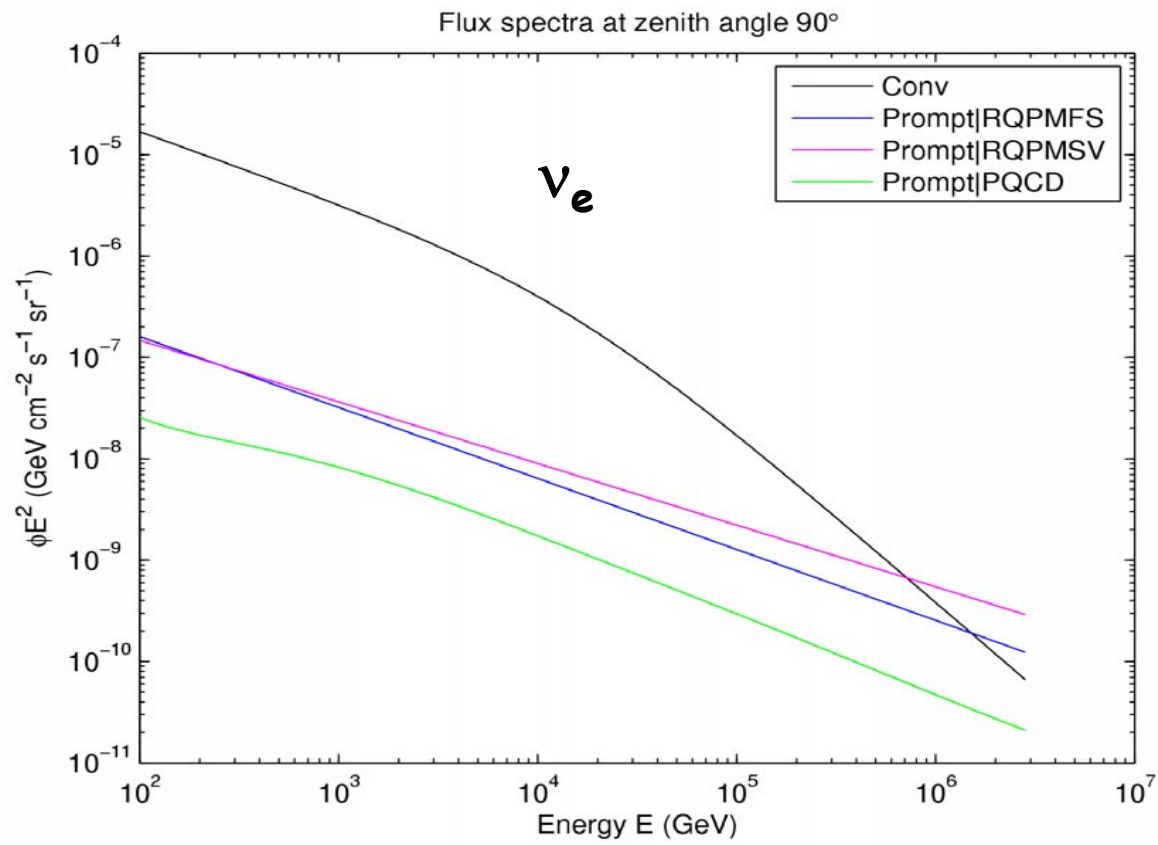
M. Thunman, G. Ingelman and P. Gondolo,  
Astropart. Phys. 1996

RQPM: non-perturbative

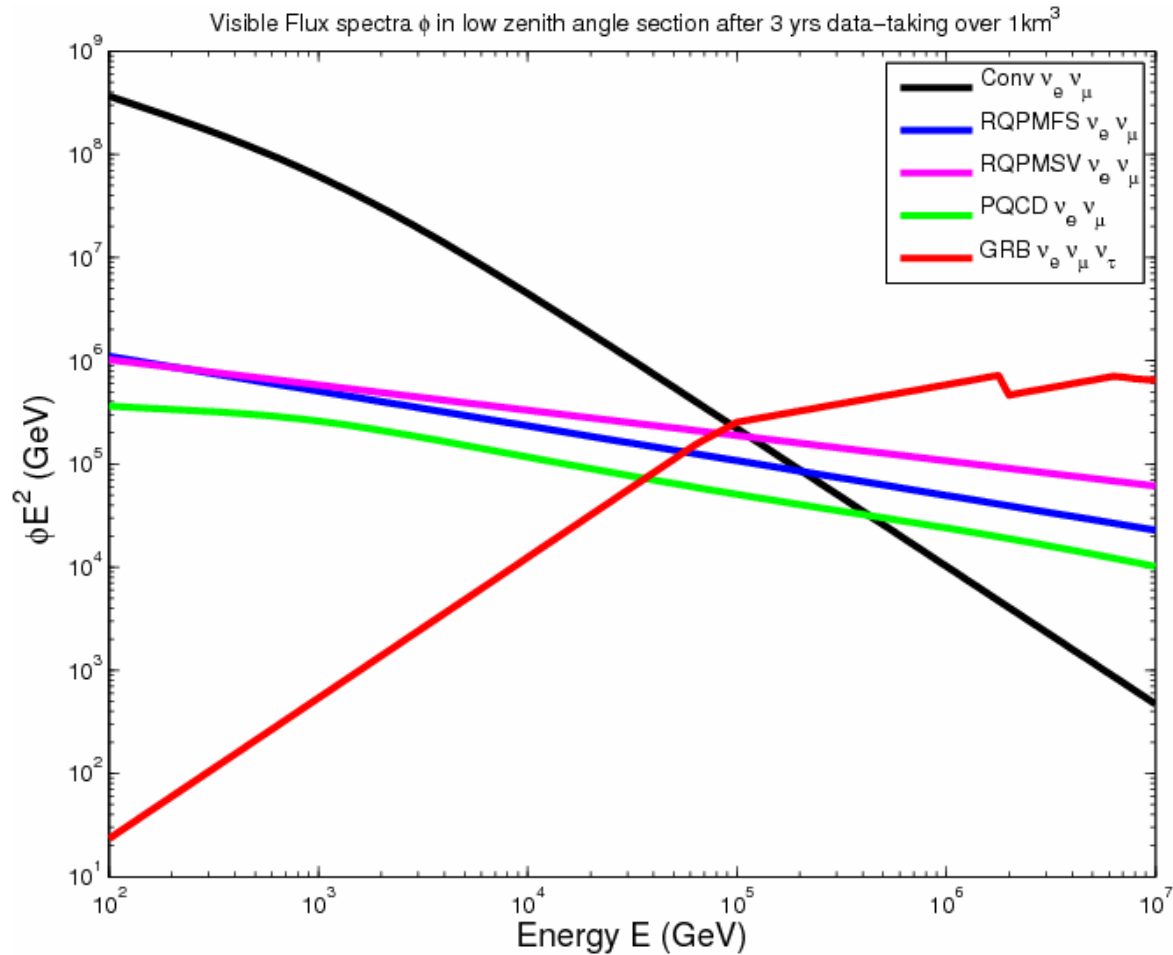
E. V. Bugaev et al. Phys. Rev. D 1998



Vertical down-going  $\nu_e$  flux



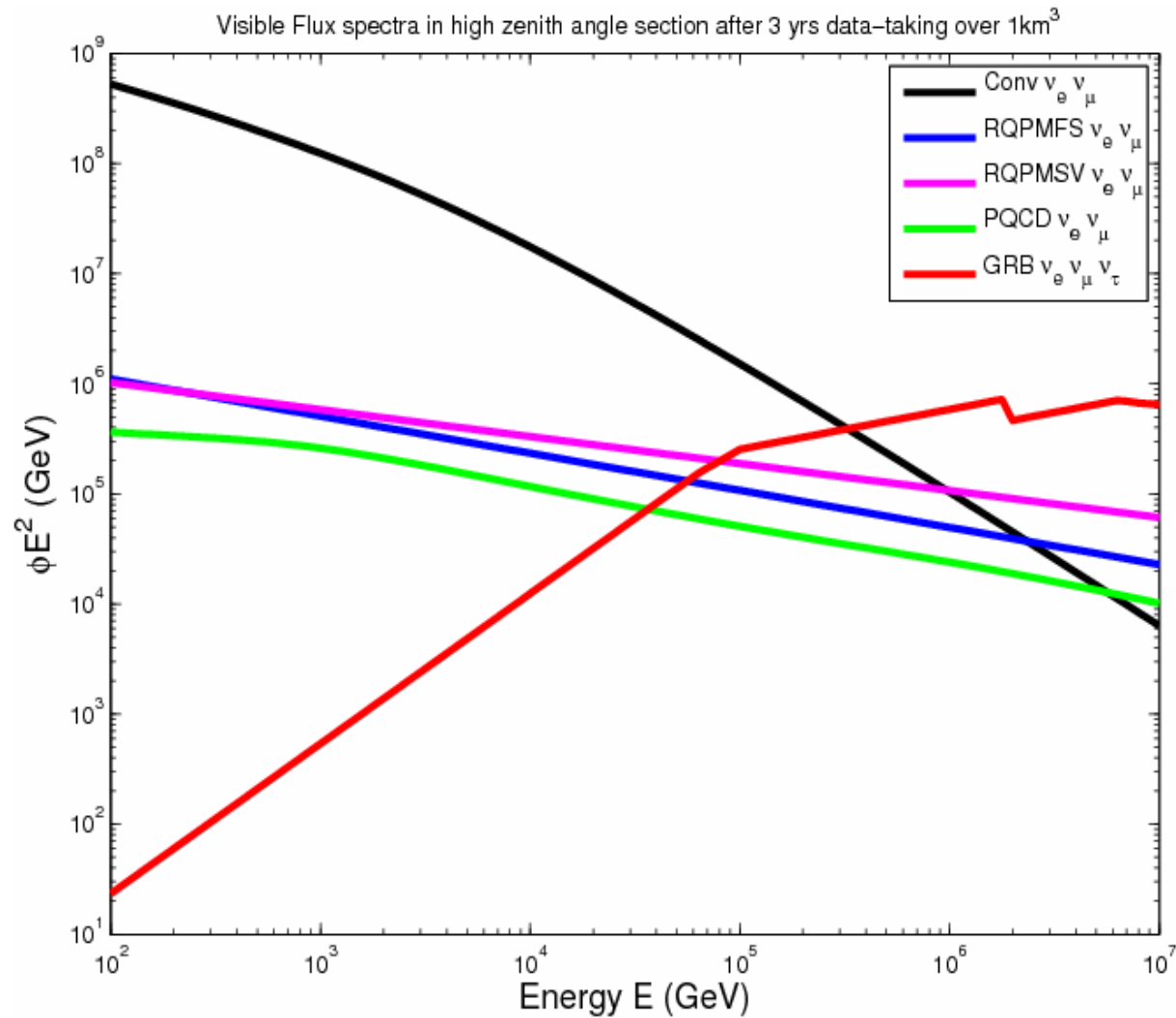
Horizontal coming  $\nu_e$  flux



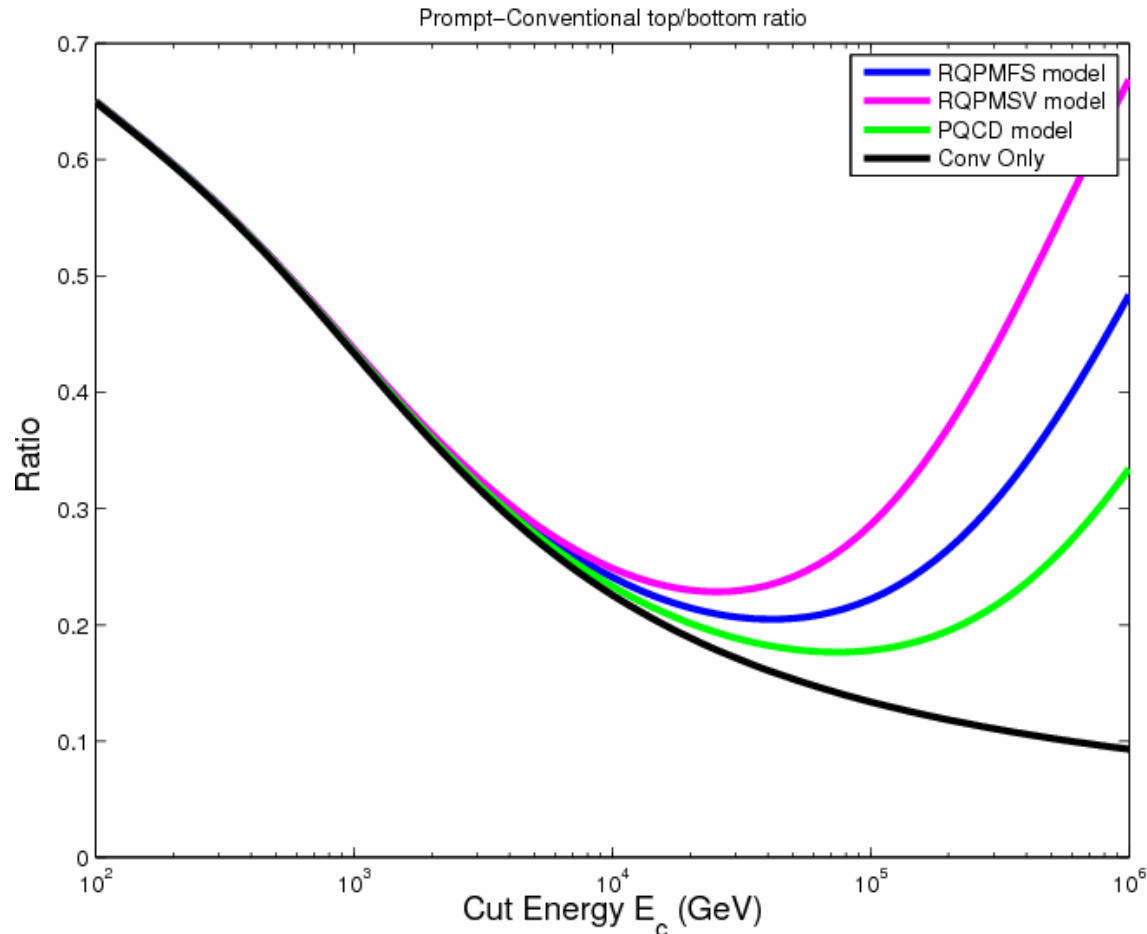
Event number spectra for 3 years of data-taking in  $\text{km}^3$  water Cherenkov detector-  
 $\cos\theta=[0.5, 1]$

Small zenith angle

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



Event number spectra for 3 years of data-taking in km<sup>3</sup> water Cherenkov detector-  
 $\cos\theta=[0,0.5]$   
 Large zenith angle



**Ratio(R)=Small zenith/Large zenith**

For  $E_c=10^5$  GeV,  $R=0.13$  with only conventional atm. flux,  
 $R=0.26$  with PQCD-calculated prompt atm. flux included  
 $R=0.40$  with RQPM-calculated prompt atm. flux included  
 $R=0.30$  with RQPMFS-calculated prompt atm. Flux included

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

Model	PQCD	RQPM	RQPM -FS
Small zenith angle	(1.4 <b>1.9</b> )	(1.4 <b>5.0</b> )	(1.4 <b>2.7</b> )
Large zenith angle	(11 <b>1.9</b> )	(11 <b>5.0</b> )	(11 <b>2.7</b> )
S/L $\equiv$ R	<u>0.26</u>	<u>0.40</u>	<u>0.30</u>

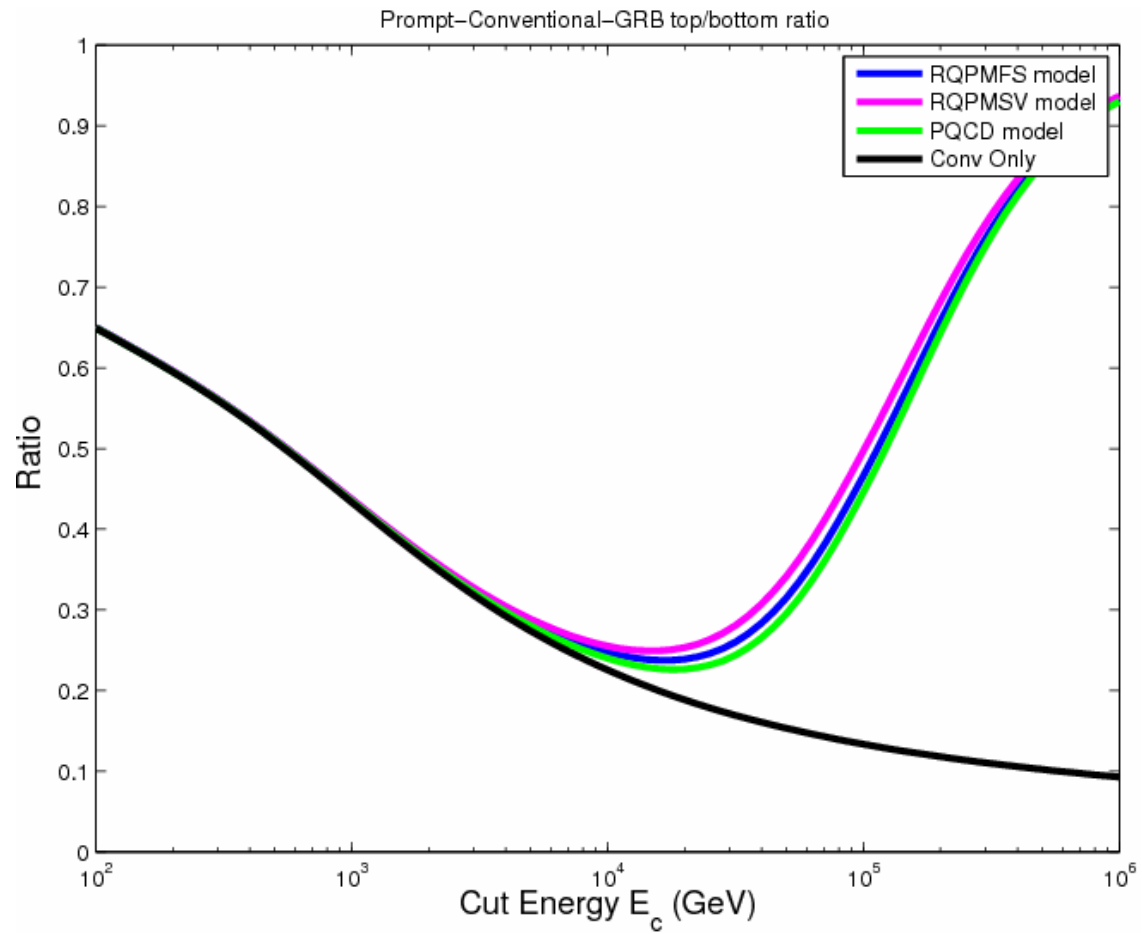
R=0.13  
 For conventional  
 atmospheric  $\nu$ 's.

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

Model	PQCD	RQPM	RQPM -FS
Small zenith angle	( <b>0.16</b> <b>0.55</b> )	( <b>0.16</b> <b>1.6</b> )	( <b>0.16</b> <b>0.78</b> )
Large zenith angle	( <b>1.50</b> <b>0.55</b> )	( <b>1.50</b> <b>1.6</b> )	( <b>1.50</b> <b>0.78</b> )
S/L≡R			

# The effect from GRB flux

Eli Waxman and John Bahcall  
Phys. Rev. D 1998



**Ratio(R)=Small zenith/Large zenith**

$E_c = 10^5 \text{ GeV}$ , 10 years of data taking

$R = 0.13$   
for conv. Atm..

Model	PQCD	RQPM	RQPM -FS	GRB alone
Small zenith angle	(1.4 1.9)	(1.4 5.0)	(1.4 2.7)	12
Large zenith angle	(11 1.9)	(11 5.0)	(11 2.7)	12
S/L $\equiv$ R	<u>0.26</u>	<u>0.40</u>	<u>0.30</u>	
with GRB	<u>0.61</u>	<u>0.66</u>	<u>0.63</u>	

$E_c = 2.5 \times 10^5 \text{ GeV}$ , 10 years of data taking

$R = 0.11$   
for conv. Atm..

Model	PQCD	RQPM	RQPM -FS	GRB alone
Small zenith angle	( <b>0.16</b> <b>0.55</b> )	( <b>0.16</b> <b>1.6</b> )	( <b>0.16</b> <b>0.78</b> )	<b>6.1</b>
Large zenith angle	( <b>1.50</b> <b>0.55</b> )	( <b>1.50</b> <b>1.6</b> )	( <b>1.50</b> <b>0.78</b> )	<b>6.1</b>
S/L≡R				
with GRB				

# 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 (20%-30% from PDF)
- 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  $\nu$  flux is subject to more severe background and Earth attenuation effect. However, the range of high energy muon makes up some of the suppressions.