IceCube non-detection of GRBs:
Constraints on the fireball composition and implications for UHECRs

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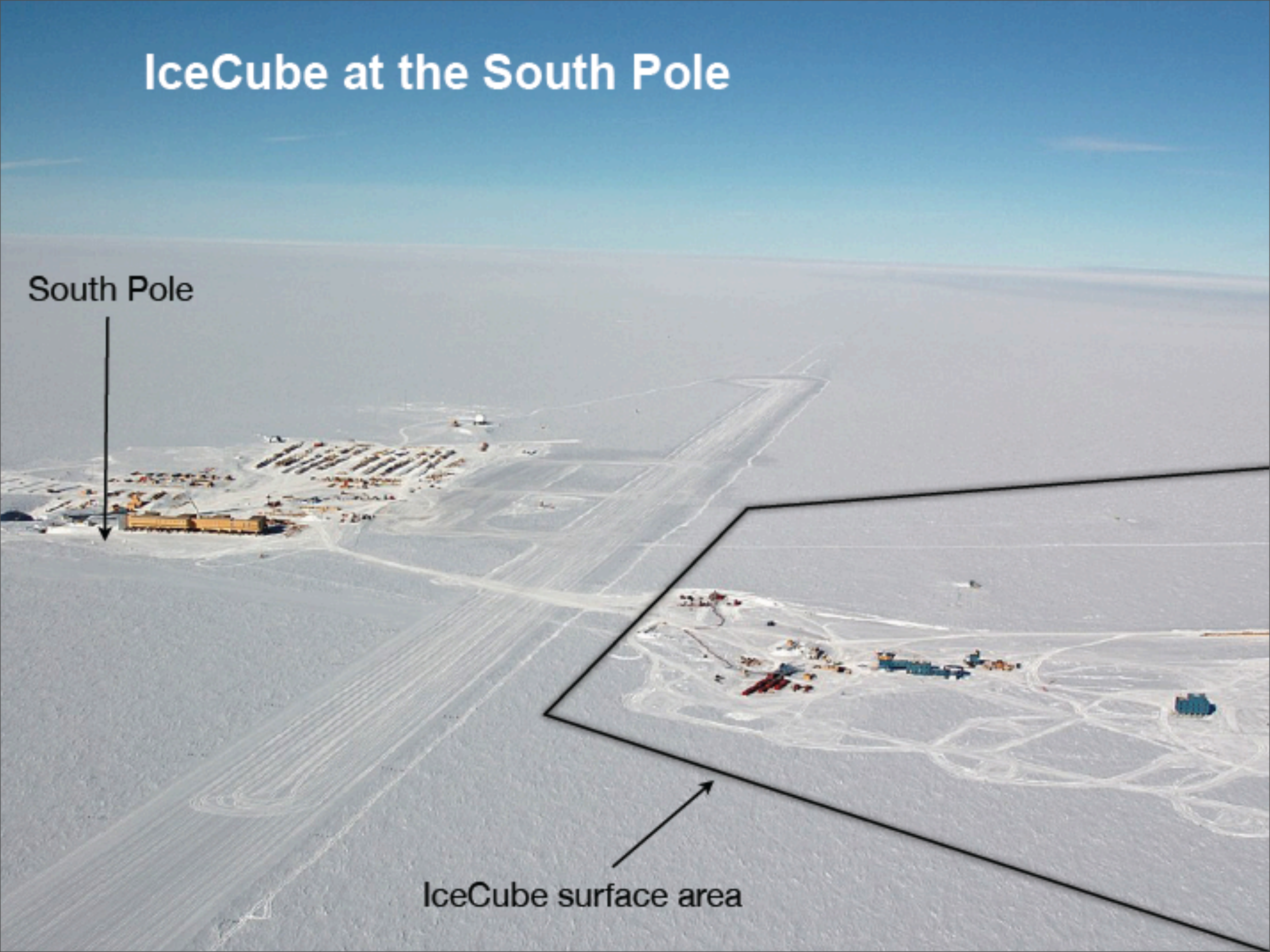
Outline

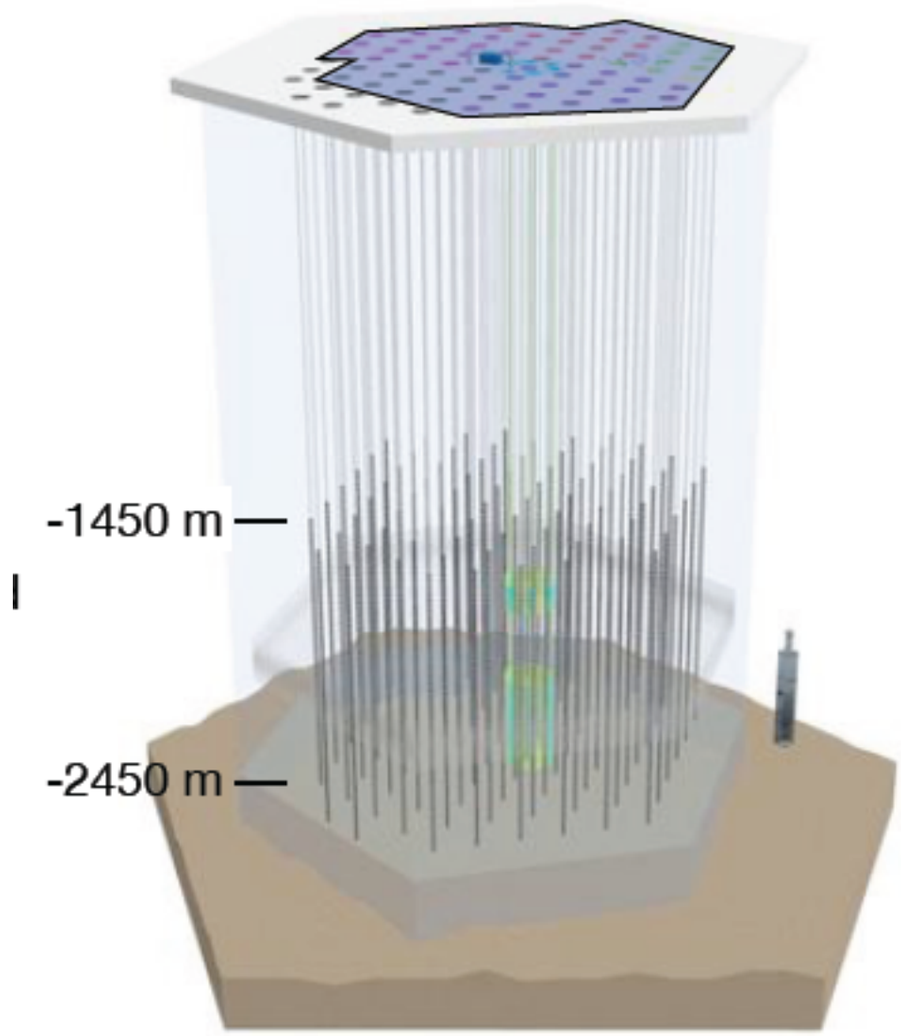
- The detection of GRB neutrinos by IceCube
- Our modifications for the calculation of neutrino spectrum
- Our results
- Conclusions

IceCube at the South Pole



86 strings in total

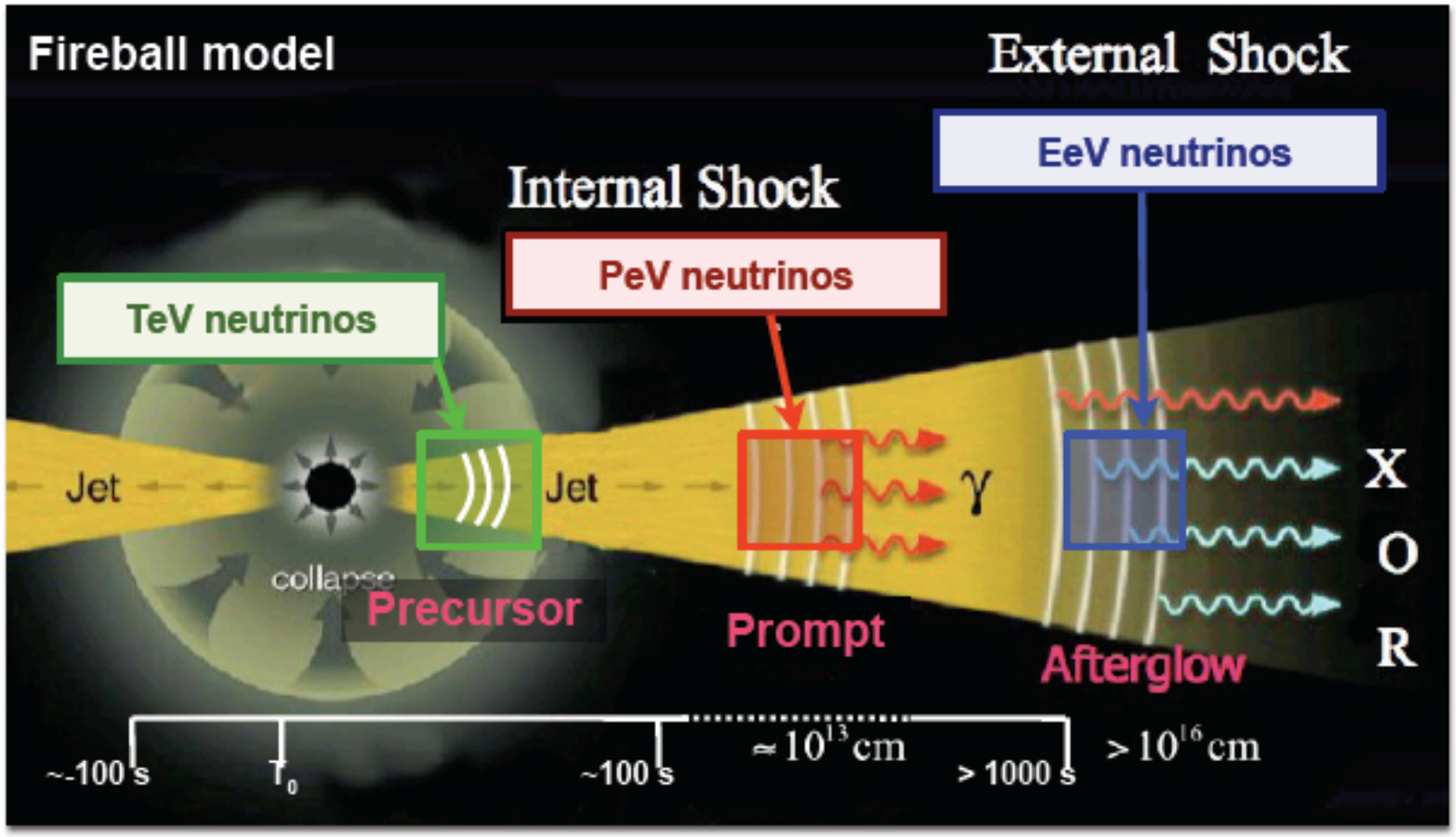
Now the 1 year data during the operation of a full construction, i.e., 86 strings, of IceCube is under analysis.



GRB neutrinos

Assumptions:

Protons and electrons are accelerated in GRB fireball.
GRB is the major source of UHECRs.
Waxman & Bahcall 1997



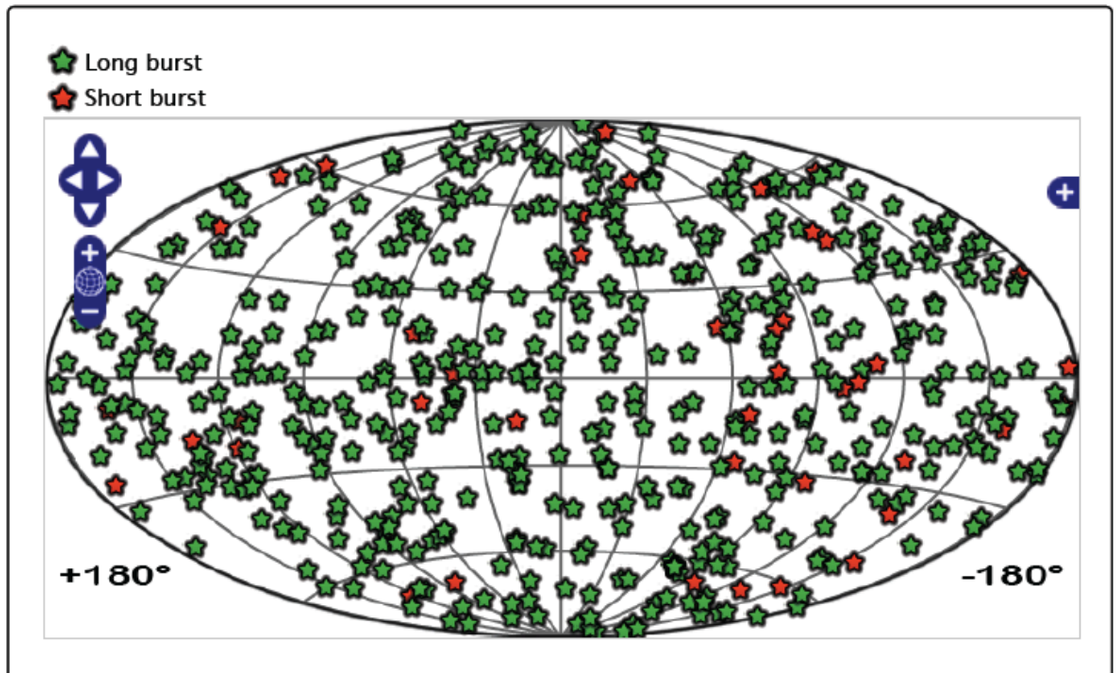
kappes' talk in kyoto, 2010

$$p\gamma \rightarrow \Delta \rightarrow n\pi^+$$
$$\pi^+ \rightarrow \nu_\mu \mu^+ \rightarrow \nu_\mu e^+ \nu_e \bar{\nu}_\mu$$

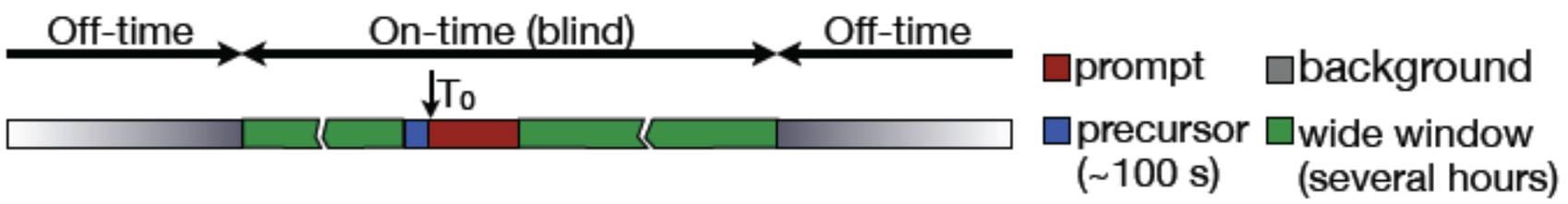
$$p\gamma \rightarrow \Delta \rightarrow p\pi^0$$

IceCube Data Analysis

GRBs Sky Map (2008.04.05-2010.05.30 during the operations of IceCube 40-string and 59-string configuration)



http://grbweb.icecube.wisconsin.edu

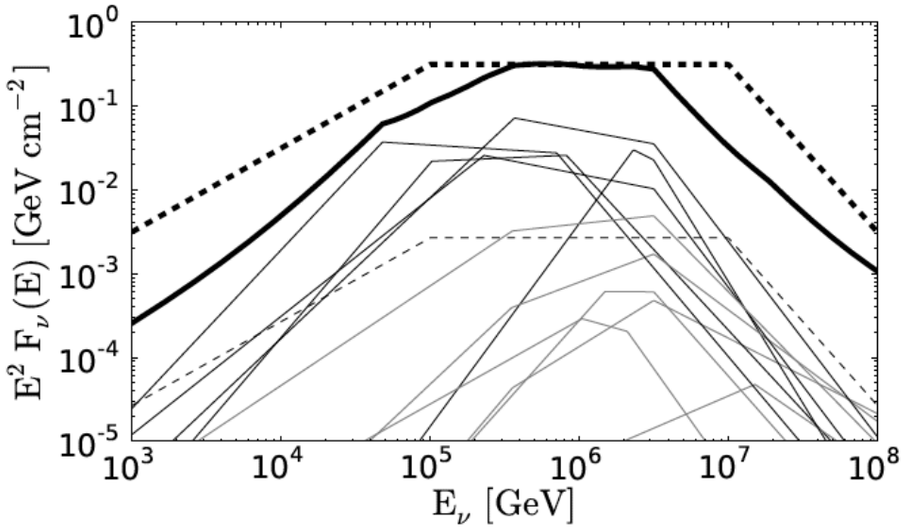


very low background → 1 event can be significant !

Kappes' talk in kyoto, 2010

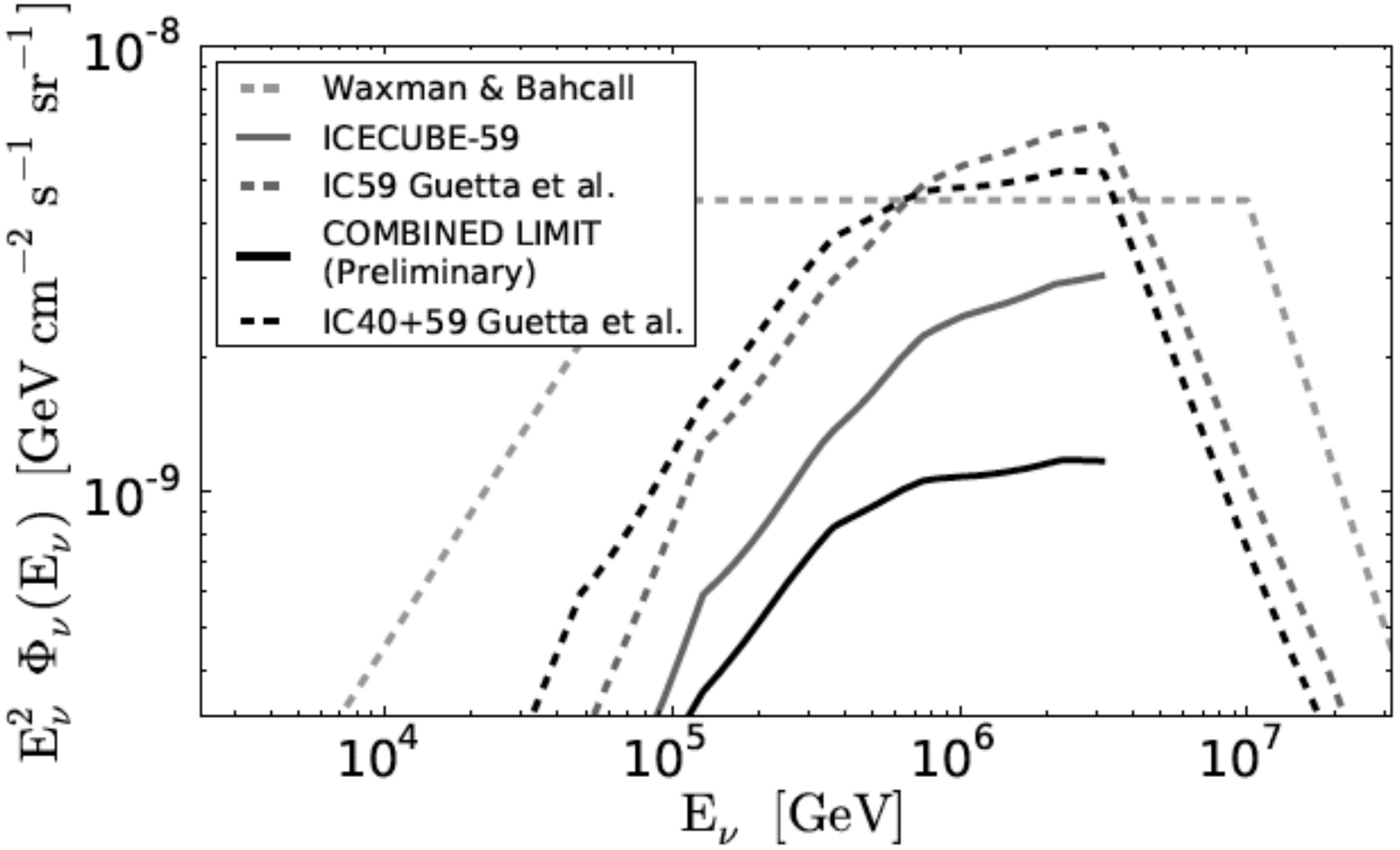
No events are detected for Ic40 and Ic59 data analysis.

Expected neutrino spectrum for IC40 and IC59 detection by IceCube Collaborator

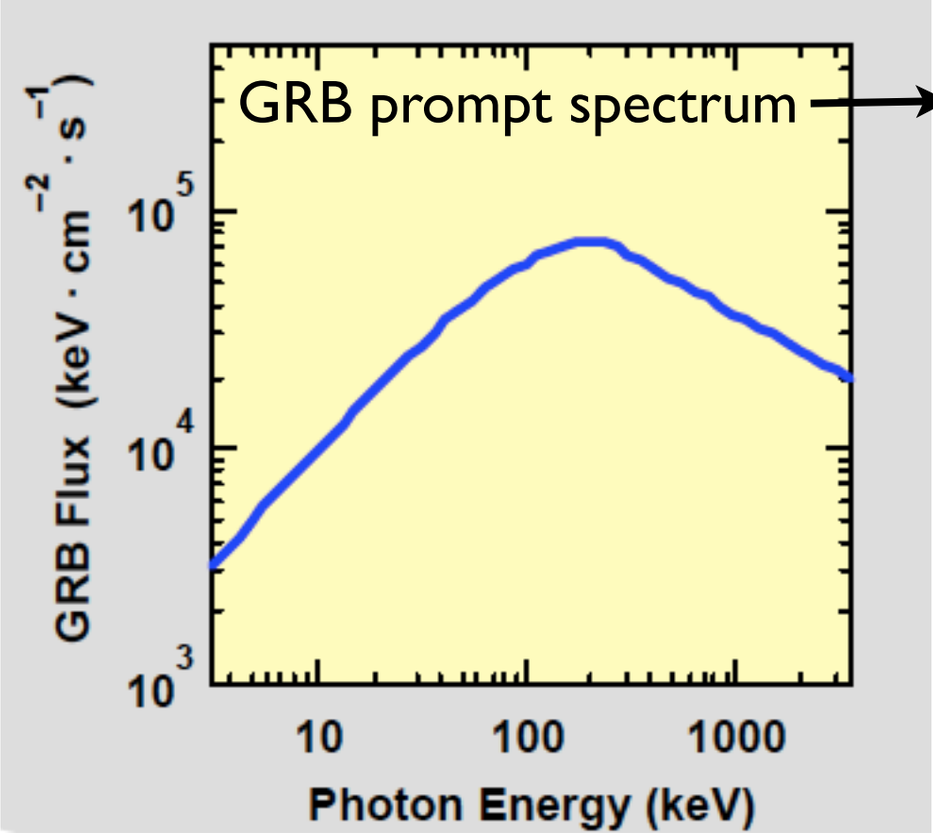


The IceCube collaboration 2011 a, b

IceCube group suggests that the assumption of GRBs as the major source of UHECR can be excluded at a high confidence.



One of the mistakes of IceCube's calculation



photon density is a function of energy.

The fraction of energy that proton converted into pions is a function of energy.

$$\epsilon_{\nu_\mu}\frac{dn_{\nu_\mu}}{d\epsilon_{\nu_\mu}}\mathrm{d}\epsilon_{\nu_\mu} = \frac{1}{8}f_{p\gamma}(\epsilon_p)\zeta(\epsilon_p)\epsilon_p\frac{dn_p}{d\epsilon_p}\mathrm{d}\epsilon_p$$

However, the IceCube collaborator treats the fraction of energy that proton converted into pions as the constant at the peak energy when doing the normalization of neutrino flux.

The IceCube collaborator overestimates the flux of neutrinos by a factor of 4-5 than Guetta et al. 2004.

Li 2011, Hummer et al. 2011, Murase et al. 2011, He,Liu,Wang,Nagataki +,2011, in prep.

The neutrino spectrum for 215 GRBs during the operations of Ic40 and Ic59 configurations

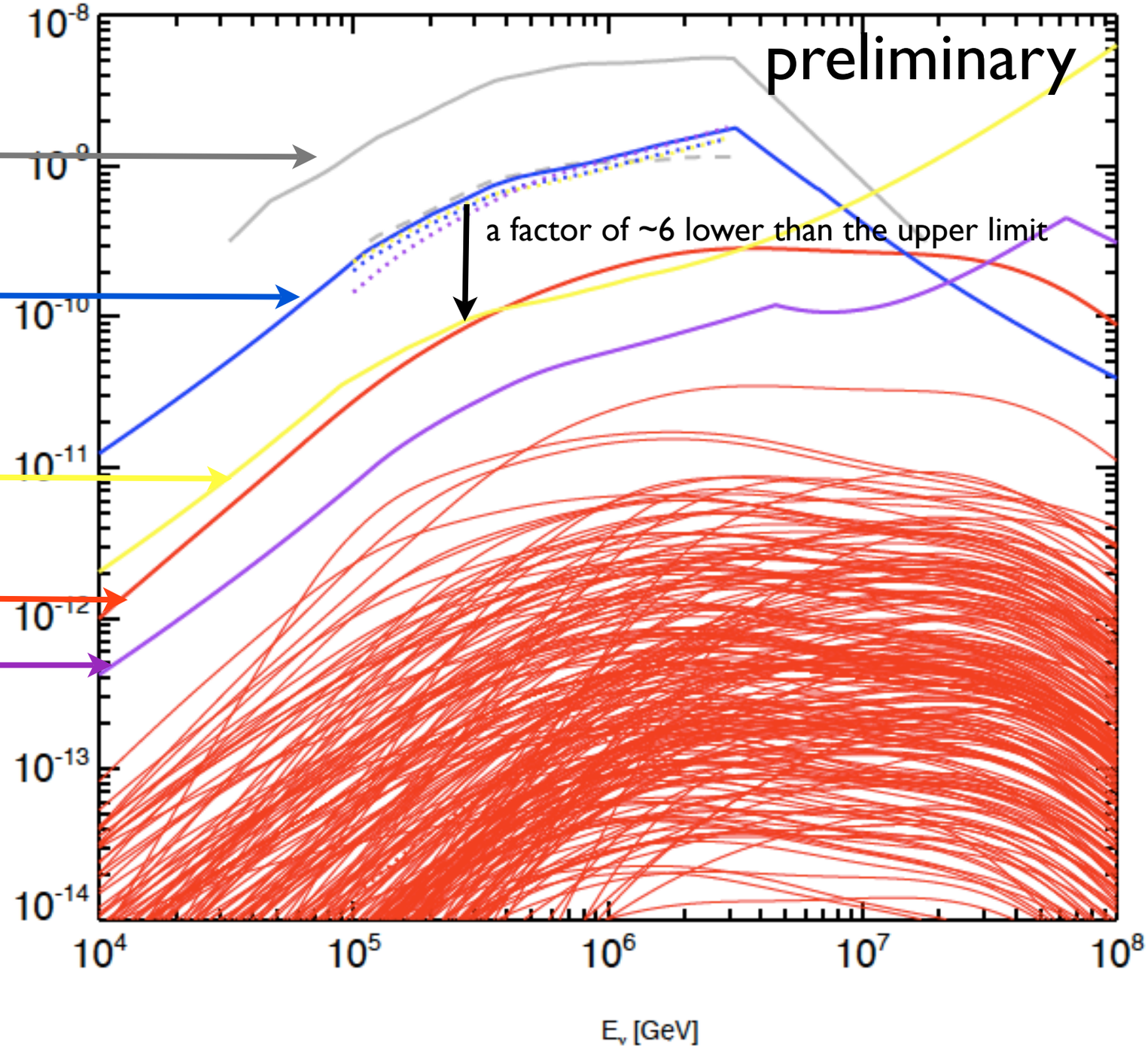
IceCube collaborator
n_exp=7.89

Guetta et al. 2004
n_exp=2.2

Waxman & Bahcall 1997
n_exp=0.33

Our numerical calculation
n_exp=0.34

Our analytical calculation
n_exp=0.21



$R = 2\Gamma^2 c t_v \quad \Gamma = 10^{2.5}$

$L_\gamma = 10^{52} \mathrm{erg\,s^{-1}} \quad \eta_p = 10$

$t_v = 0.01\mathrm{s}$ for long GRBs

Constraints on the fireball model from the null result

$$\epsilon_{\nu_\mu}\frac{dn_{\nu_\mu}}{d\epsilon_{\nu_\mu}}\mathrm{d}\epsilon_{\nu_\mu} = \frac{1}{8}f_{p\gamma}(\epsilon_p)\zeta(\epsilon_p)\epsilon_p\frac{dn_p}{d\epsilon_p}\mathrm{d}\epsilon_p \rightarrow U_p = \eta_p F_\gamma \times 4\pi d_L^2$$

$$f_{p\gamma} \propto L_\gamma R^{-1}\Gamma^{-2}\epsilon_{\gamma b}^{ob,\beta-2}$$

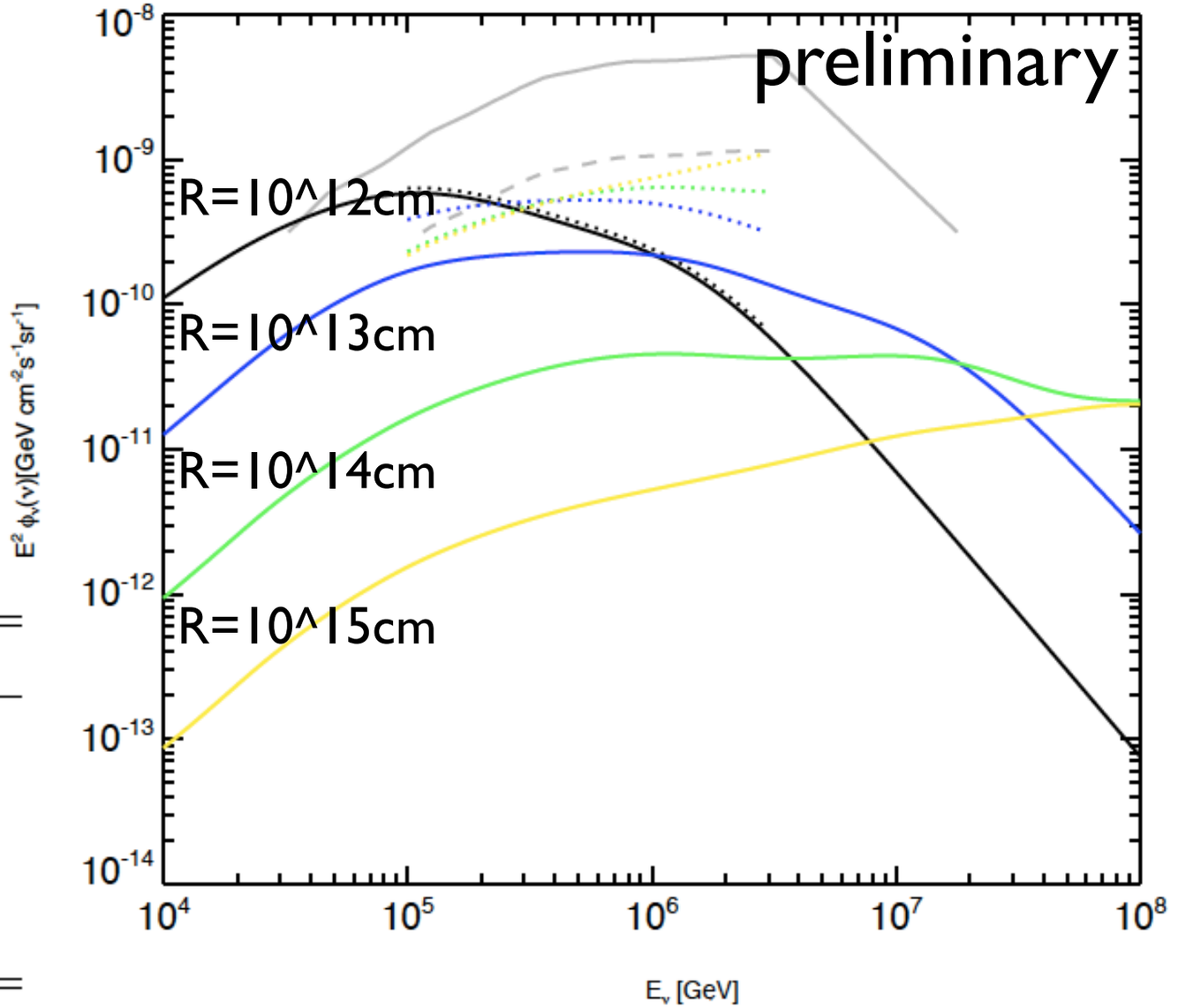
$$f_{p\gamma} \propto L_\gamma \Gamma^{-4} t_{\rm v}^{-1}\epsilon_{\gamma b}^{ob,\beta-2} \qquad R = 2\Gamma^2 c t_{\rm v}$$

Constrain the ratio of energy of accelerated protons to that of accelerated electrons

Constrain the acceleration radius, or the Lorentz factor of internal shock and the variability timescale.

Neutrino spectrum for different acceleration radius

A larger acceleration radius leads to a lower flux of neutrinos



We roughly assume all the GRBs have the same acceleration radius and luminosity.

R /cm	$L_\gamma / erg\, s^{-1}$	η_p	$n_{\rm exp}$	$\eta_{p,c}$
10^{12}	10^{52}	10	1.78	10.9
10^{13}	10^{52}	10	0.848	22.8
10^{14}	10^{52}	10	0.136	142
10^{15}	10^{52}	10	0.0135	1430

$$\Gamma = 10^{2.5}$$

The neutrino spectrum adopting different luminosity and Lorentz factor

$$L_{\gamma Y,52} = 23.4\left[\epsilon^{\rm ob}_{\gamma {\rm b,MeV}}(1+z)\right]^{2.0}, \quad \Gamma_L = 118 E^{0.26}_{\rm iso,52}$$

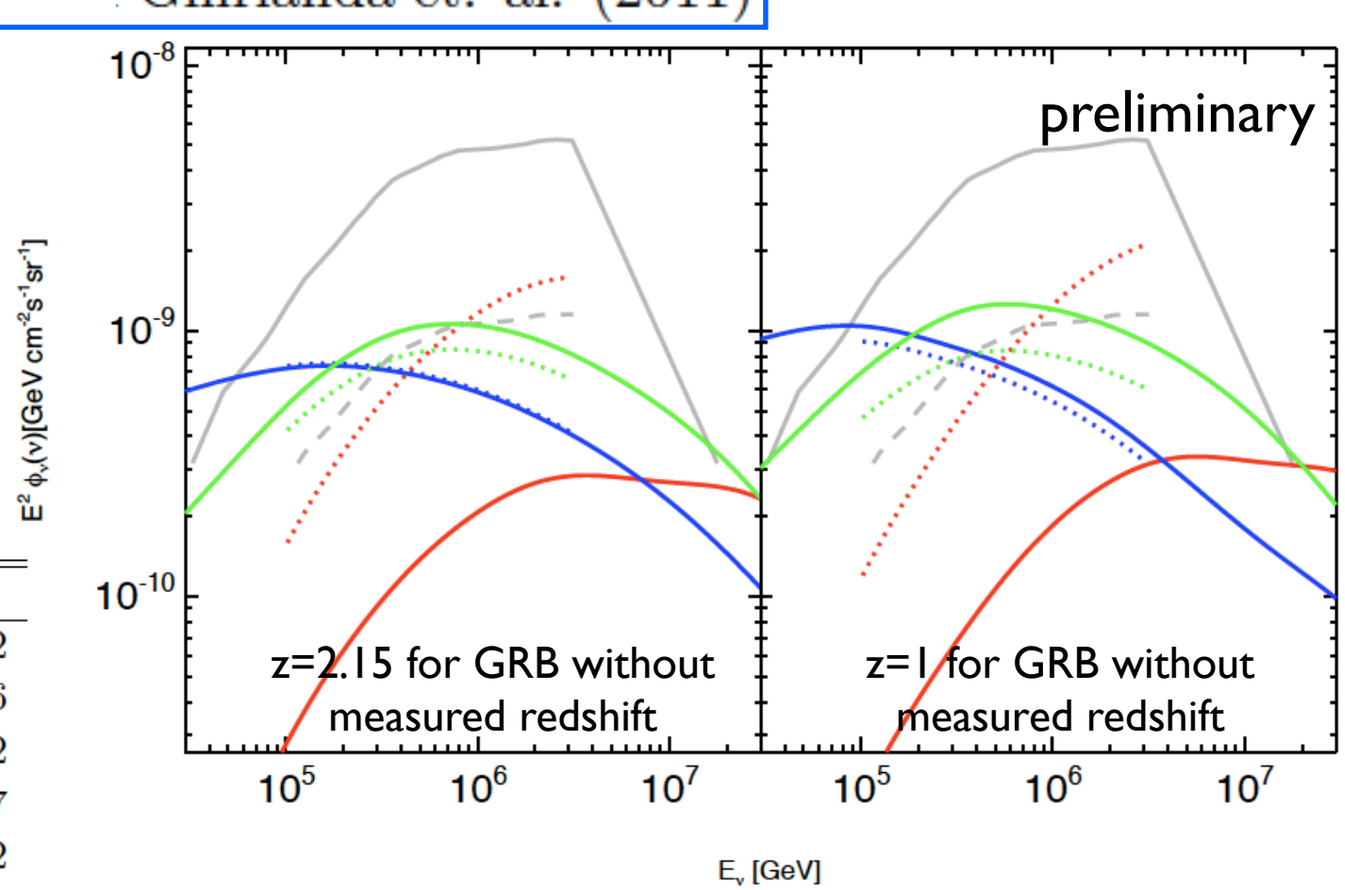
Yonetoku et. al. (2004) Lv et. al. (2011)

$$L_{\gamma G,52} = 7.54\left[\epsilon^{\rm ob}_{\gamma {\rm b,MeV}}(1+z)\right]^{1.75}, \quad \Gamma_G = 29.8 E^{0.51}_{\rm iso,52}$$

Ghirlandar et. al. (2011) Ghirlanda et. al. (2011)

$$L_\gamma = 10^{52}{\rm erg\,s^{-1}} \quad \Gamma = 10^{2.5}$$

model	L_γ	Γ	$t_{\rm v}$/s	η_p	z	$n_{\rm exp}$	$\eta_{p,c}$
A-model	$L_{\gamma,A}$	Γ_A	0.01	10	2.15	0.344	56.2
					1	0.288	67.6
G-model	$L_{\gamma,G}$	Γ_G	0.01	10	2.15	1.90	10.2
					1	2.21	8.77
L-model	$L_{\gamma,Y}$	Γ_L	0.01	10	2.15	2.41	8.02
					1	1.51	12.8

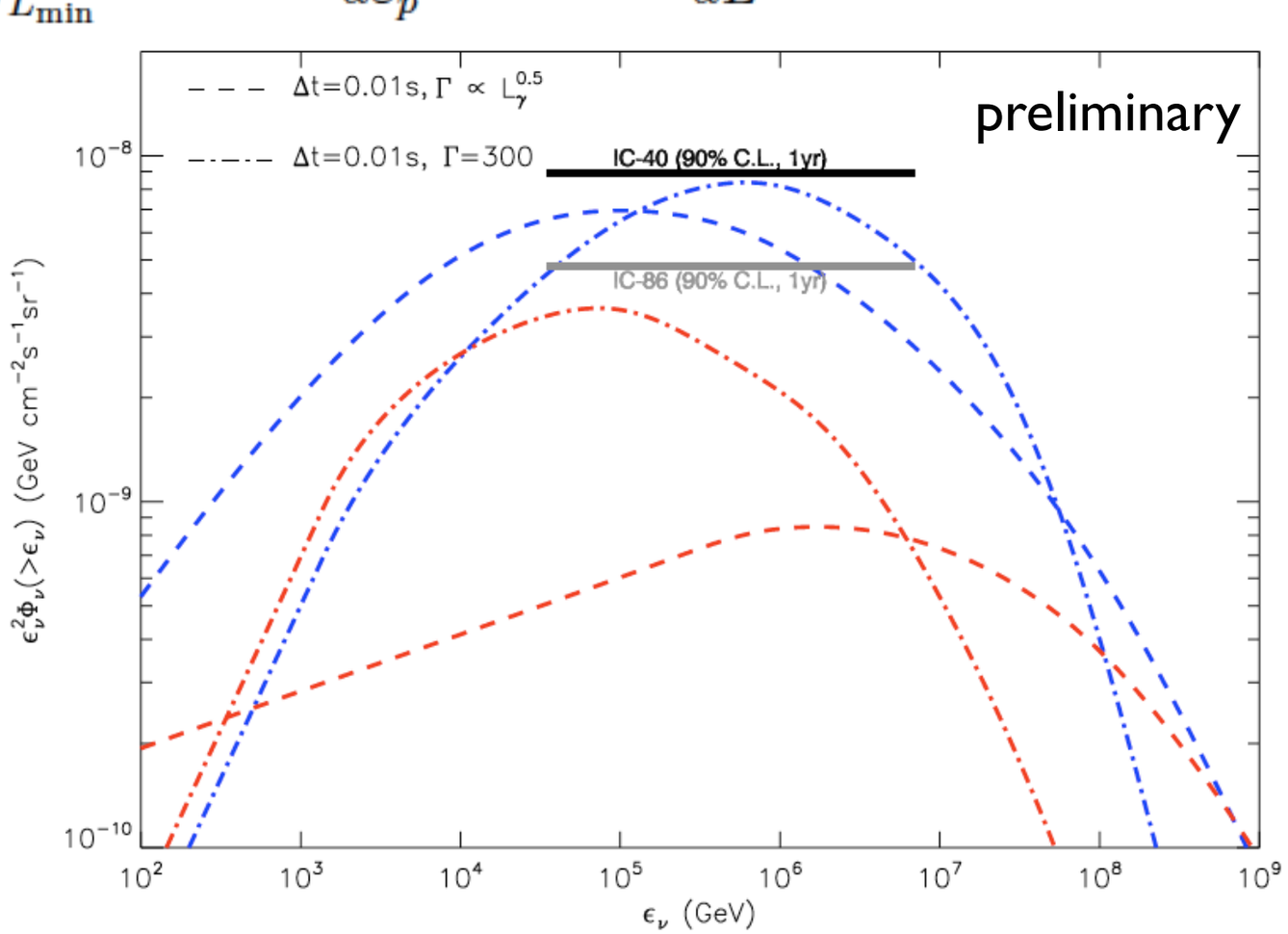


Diffuse GRB neutrino spectrum

$$\frac{dN}{dL} = \rho_0 \Phi_0 \left[\left(\frac{L}{L_\mathrm{b}} \right)^{\alpha_1} + \left(\frac{L}{L_\mathrm{b}} \right)^{\alpha_2} \right]^{-1}$$ Liang et al. (2007)

$$\frac{dN_p}{dE_p}(L) = U_p(L) \frac{E^{-s}}{\int dE E^{1-s}}$$

$$\varepsilon_\nu^2 \frac{dN_\nu}{d\varepsilon_\nu}(\varepsilon_\nu) = \frac{1}{8} \frac{c}{4\pi H_0} f_z \int_{L_\mathrm{min}}^{L_\mathrm{max}} f_\pi(L) \varepsilon_p^2 \frac{dN_p}{d\varepsilon_p} \zeta_\pi (1+\zeta_\mu) \frac{dN}{dL} dL$$



Conclusions

- Our modified numerical calculation predict GRB neutrinos whose flux is a factor of ~20 lower than that predicted by IceCube group.
- The uncertainties of GRBs parameters affect the flux and shape of the neutrino spectrum.
- For the null result of IceCube, we can constrain the GRB model and the flux of protons.
- We cannot exclude the proposal that GRBs are the major sources of UHECRs so far.
- We expect that full IceCube operation in 3 years will become deep enough to test whether GRBs are the major sources for UHECRs or give a tight constraints on the GRB model.

Thank you!