PEV DM

(10^6 GeV)

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SI2013, Jirisan National Park
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work with K. Kohri (KEK),
C. Rott (IceCube, SKKU)

First surprise:

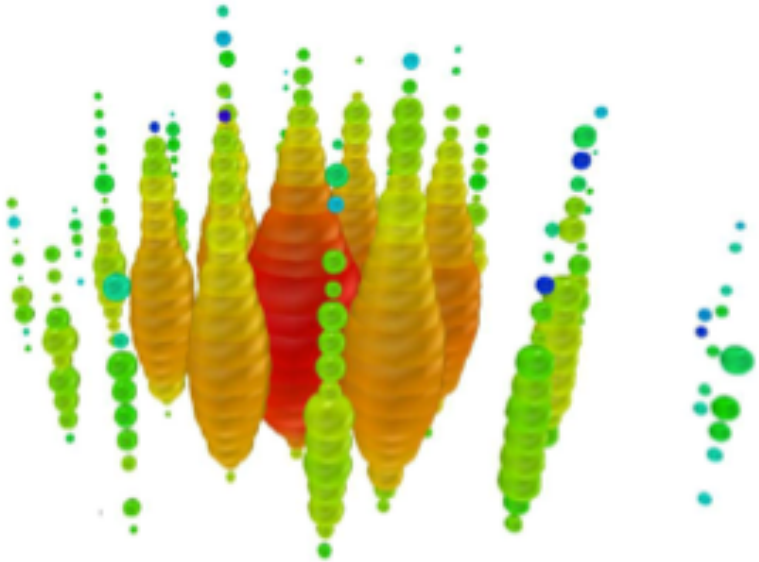
Two PeV neutrinos observed by IceCube

[Aartsen et. al. (IceCube) Phys.Rev.Lett. 111 (2013) 021103] arXiv:1304.5356

(a) "Bert"

1.04 ± 0.16PeV

(b) "Ernie"

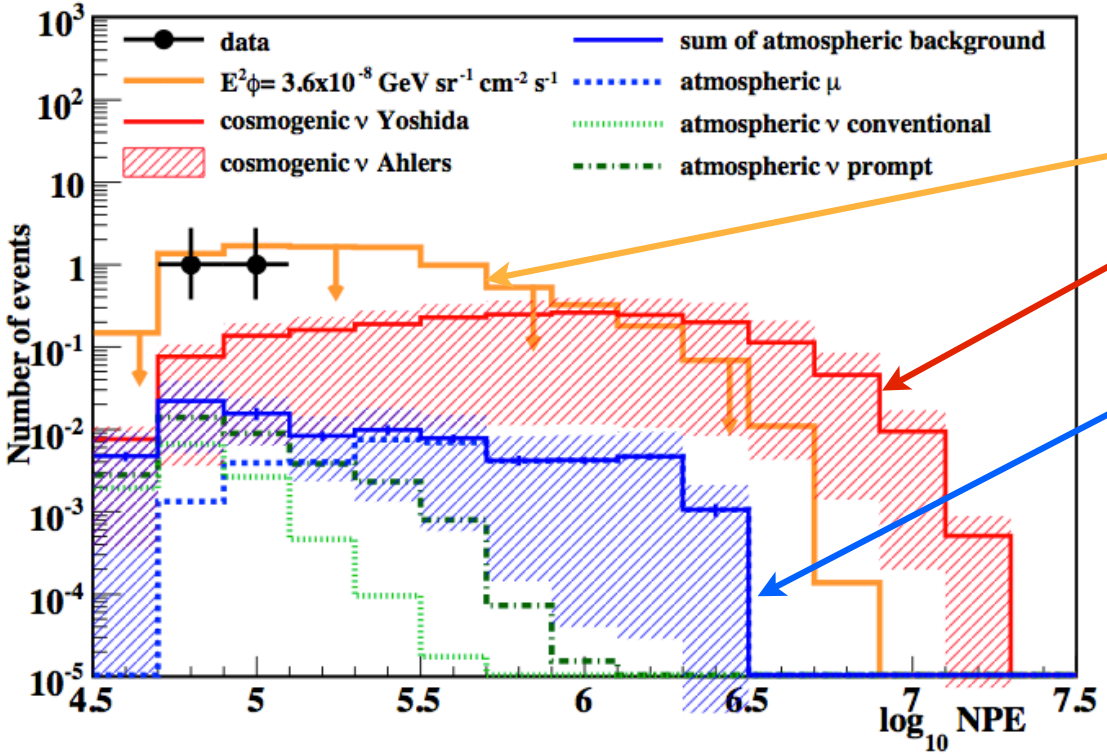


1.14 ± 0.17PeV

*consistent with CC & NC neutrinos at IceCube detector.

The observation looks odd ..

**Expected: $0.082 \pm 0.0024^{+0.041}_{-0.057}$



~E^{-2} ??

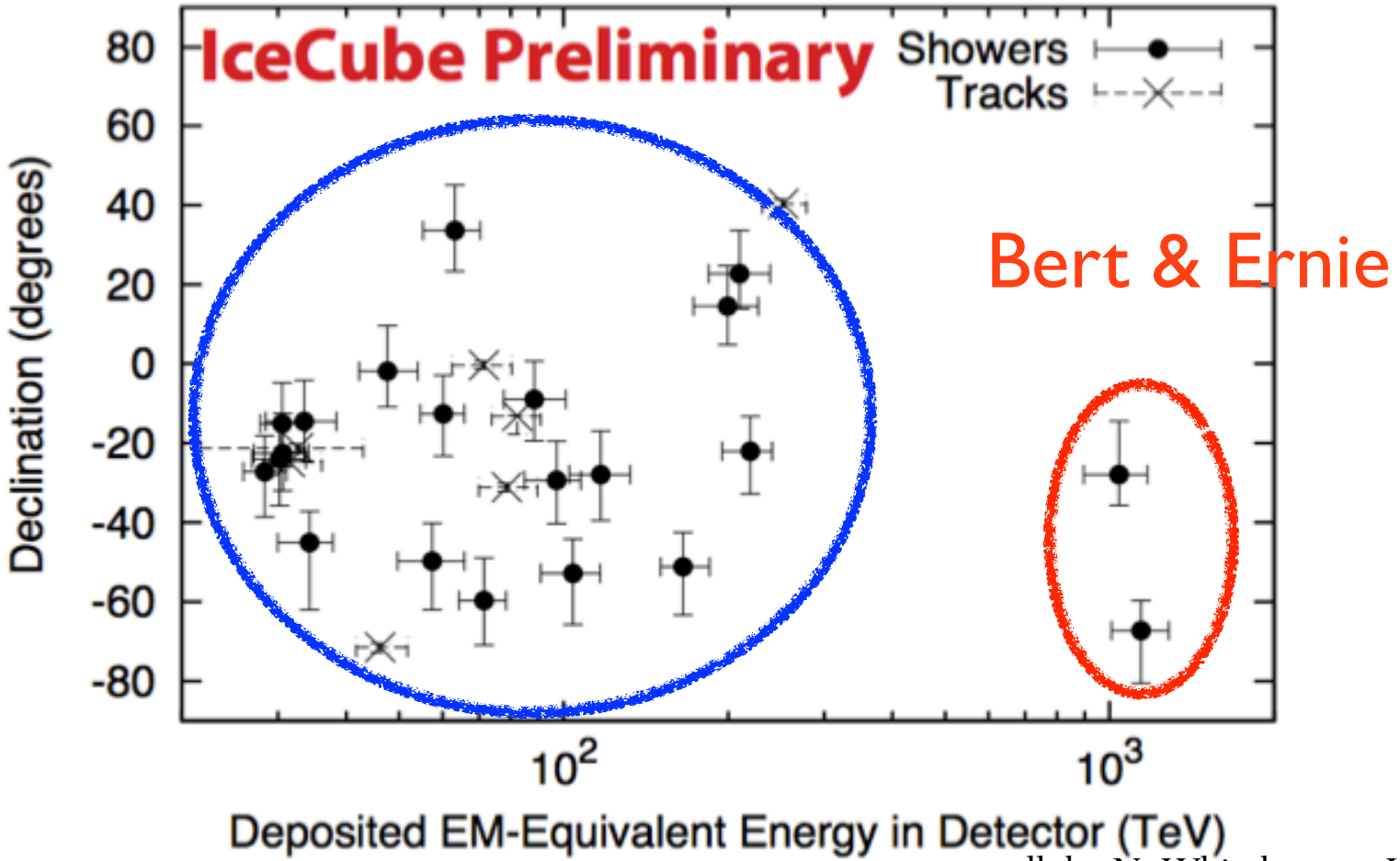
-Too low in energy for GZK

-Too high in energy for atmospheric nu.

Bottom line:

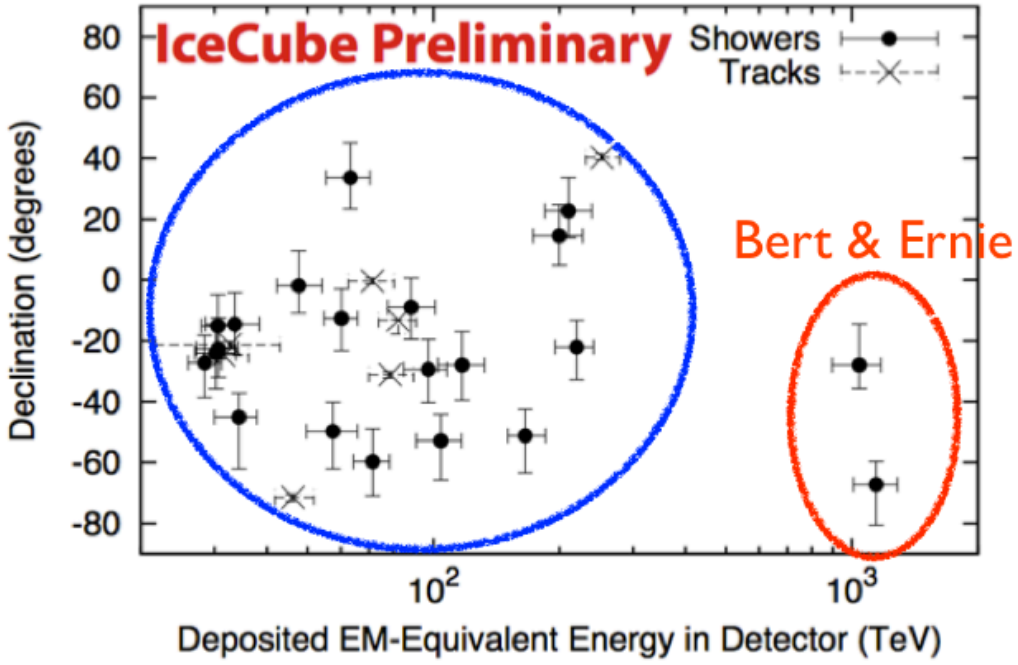
These events cannot be understood by known sources!

In addition, 26 more neutrinos observed in 1Tev-250Tev window, which is also beyond expected since bgrd is only 10.6+-4.5



-talk by N. Whitehorn at IPA2013

Closer look at the DATA



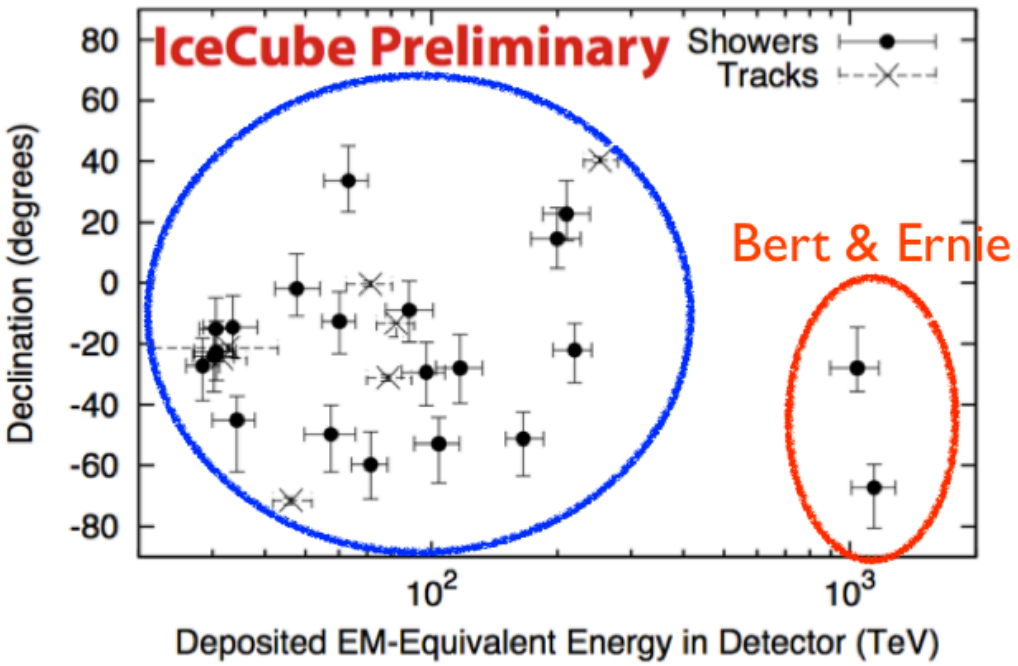
Properties of observed neutrinos

- "Continuous" in 1-250 TeV
- "Peak" at ~1 PeV
- Consistent with isotropic distribution
- 1:1:1 neutrino flavor

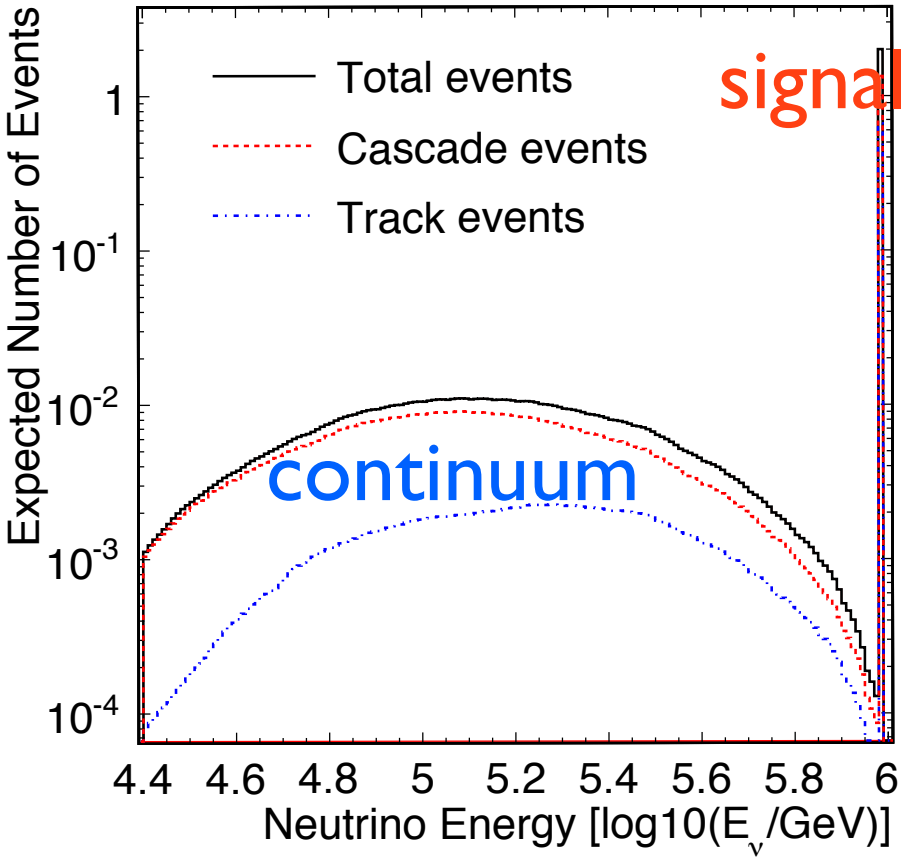
$$P(\nu_e \leftrightarrow \nu_e) = 0.56\,,$$
$$P(\nu_e \leftrightarrow \nu_\mu) = P(\nu_e \leftrightarrow \nu_\tau) = 0.22\,,$$
$$P(\nu_\mu \leftrightarrow \nu_\mu) = P(\nu_\mu \leftrightarrow \nu_\tau) = P(\nu_\tau \leftrightarrow \nu_\tau) = 0.39\,.$$

understandable since after a long enough propagation, neutrino flavor info. would disappear

The "continuum+peak" may imply particle DM!



$$\chi \to \nu_L + X(\nu + \cdots)$$



Ann vs Decay

[Feldman, Kusenko, Matsumoto, Yanagida 1303.7320]

Annihilating $\chi\chi \to \nu_L + X(\to \nu + \cdots)$

-less than one event/100 years
-unitarity bound M_{dm}<300 TeV

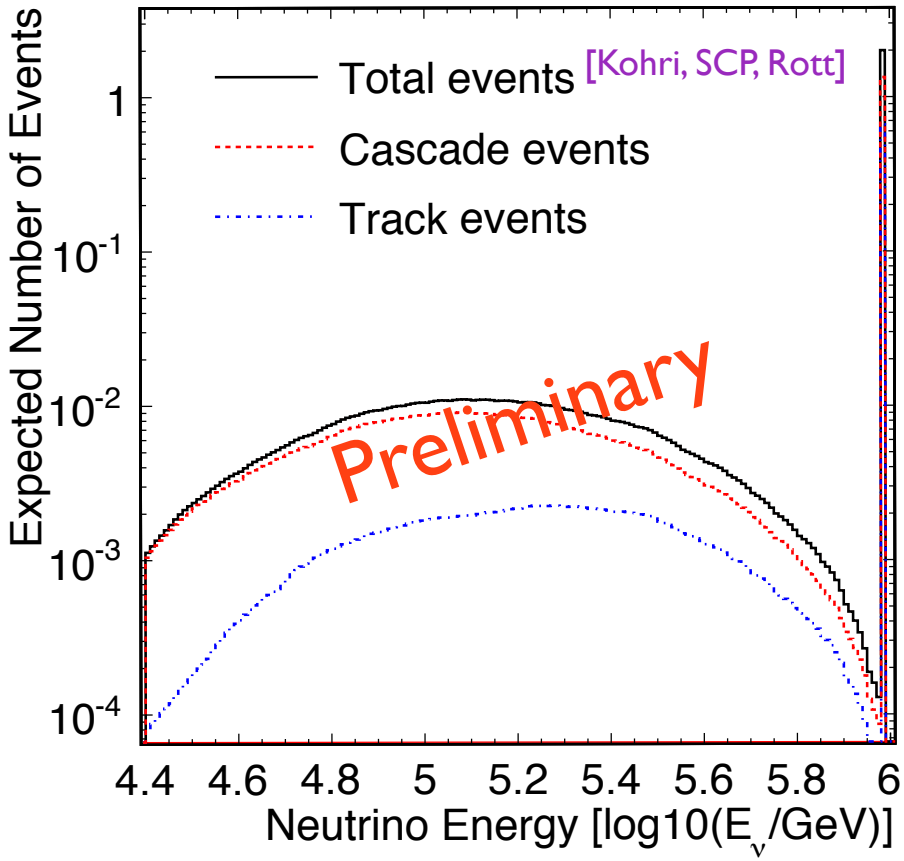
Decaying $\tau_\chi \sim 10^{28}\text{sec}$ would fit the "peak"

e.g. Several possibilities recently suggested mainly for "peak"

Gravitino w/RPV, hidden sector gauge, extra dimension (1303.7320), dm-2 nu's .. (1308.1105), pseudo Dirac neutrino(1307.5712), LQ(1305.6907)....

A simple case

We consider a simple decay $\chi \to \nu_L + H$ and found it can fit the observation pretty well!



-peak by ν_L
-continuum by nu from Higgs decay

$$m_\chi = 1\mathrm{PeV}$$
$$\tau_\chi = 9.7 \times 10^{28}\mathrm{sec}$$

gives

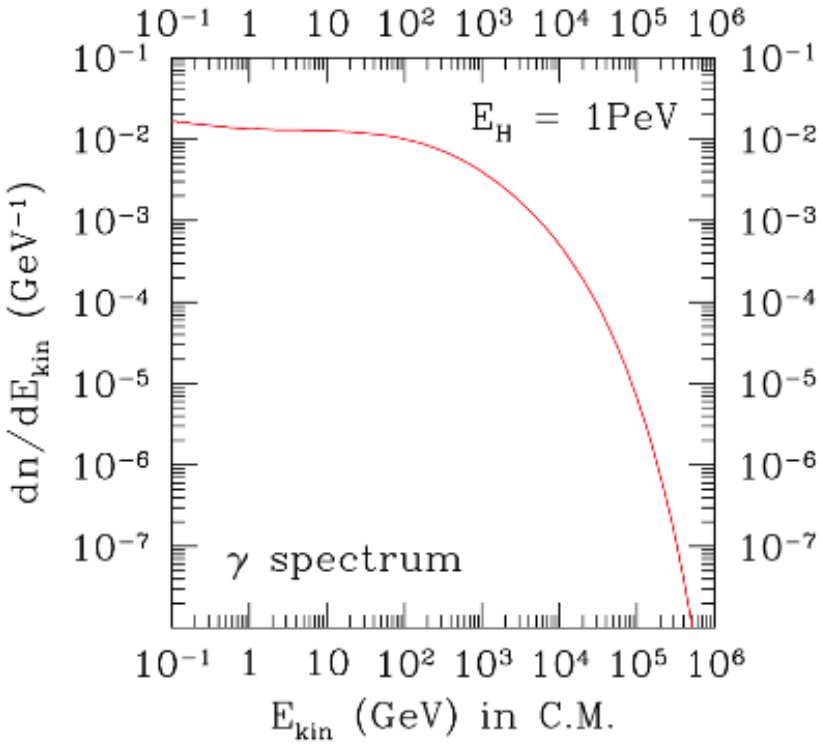
$$N_\nu(\mathrm{PeV}) = 2.04$$

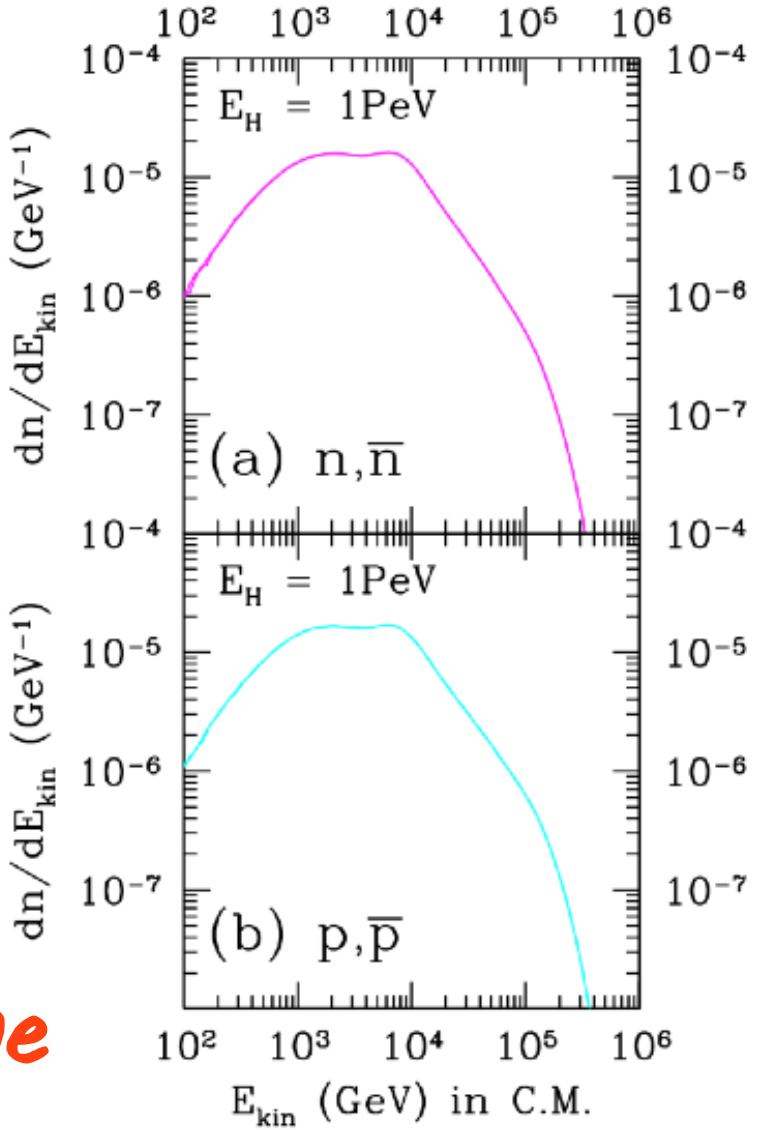
with continuum

[Kohri, SCP, Rott (2013)]

**Tracks (muon neutrinos)
**Cascades (sum of electron and tau neutrino events)

contributions to CR





*bottom line:
looks safe in <TeV regime
(numerical values still to be come)

A Model realization

$$\mathcal{L} = y\bar{\nu}Hn + \overline{(n^c, \chi)} \begin{pmatrix} M_n & \sigma \\ \sigma & M_\chi \end{pmatrix} \begin{pmatrix} n \\ \chi \end{pmatrix}$$

we can arrange
seesaw mech. to work + small mixing in n & DM
such that DM can decay through Yukawa
interaction to neutrino + Higgs

$$\Gamma_{\chi \to \nu_L + H} = \frac{(y\epsilon)^2}{8\pi} M_-$$

$$\epsilon \approx -\frac{\sigma}{M_n - M_\chi} \ll 1$$

$$M_- \approx \frac{1}{2}(M_n + M_\chi) - \sqrt{\delta^2 + \sigma^2}, \delta = \frac{1}{2}(M_n - M_\chi)$$

Conclusion

- IceCube observed 2 (background 0.082) with 1 PeV and 26 (background 10.6) neutrino events in 1Tev-250Tev
- Too low in energy for GZK neutrinos, too high in energy for atmospheric neutrinos.
- Can be explained by DM decay.
- DM -> nu+H, which is responsible for "peak" and "continuum" events with life time ~10^{28} sec, γ-ray, proton, neutron bounds look okay.
- A simple model based on seesaw + small mixing is suggested.

backups

Annihilation

[Feldman, Kusenko, Matsumoto, Yanagida]

$$\Gamma_{Events} \sim V L_{MW} n_N \sigma_N \times \left(\frac{\rho_{\rm DM}}{m_{\rm DM}}\right)^2 \langle \sigma_A v \rangle$$

with

$$\sigma_N \sim 9 \times 10^{-34} {\rm cm}^2 \qquad E \simeq 1.2 {\rm PeV}$$

$$n_N \simeq n_{\rm Ice} \simeq 5 \times 10^{23} / {\rm cm}^3$$

$$\rho_{\rm DM} \simeq 0.4 {\rm GeV}/{\rm cm}^3,$$

$$v \sim 10^{-3},$$

$$L_{\rm MW} \simeq 10 {\rm kpc}$$

$$V \simeq 1 {\rm km}^3$$

$$\sigma_A \leq 4\pi/(m_{\rm DM}^2 v^2)$$

$$\Gamma \lesssim 1 \text{ per few hundred years}$$

(essentially impossible)

Decay

[Feldman, Kusenko, Matsumoto, Yanagida]

$$\Gamma_{\rm Events} \sim V L_{\rm MW} n_N \sigma_N \frac{\rho_{\rm DM}}{m_{\rm DM}} \Gamma_{\rm DM}$$

$$\tau_{\rm DM} \simeq 1.9 N_\nu \times 10^{28} {\rm sec}$$

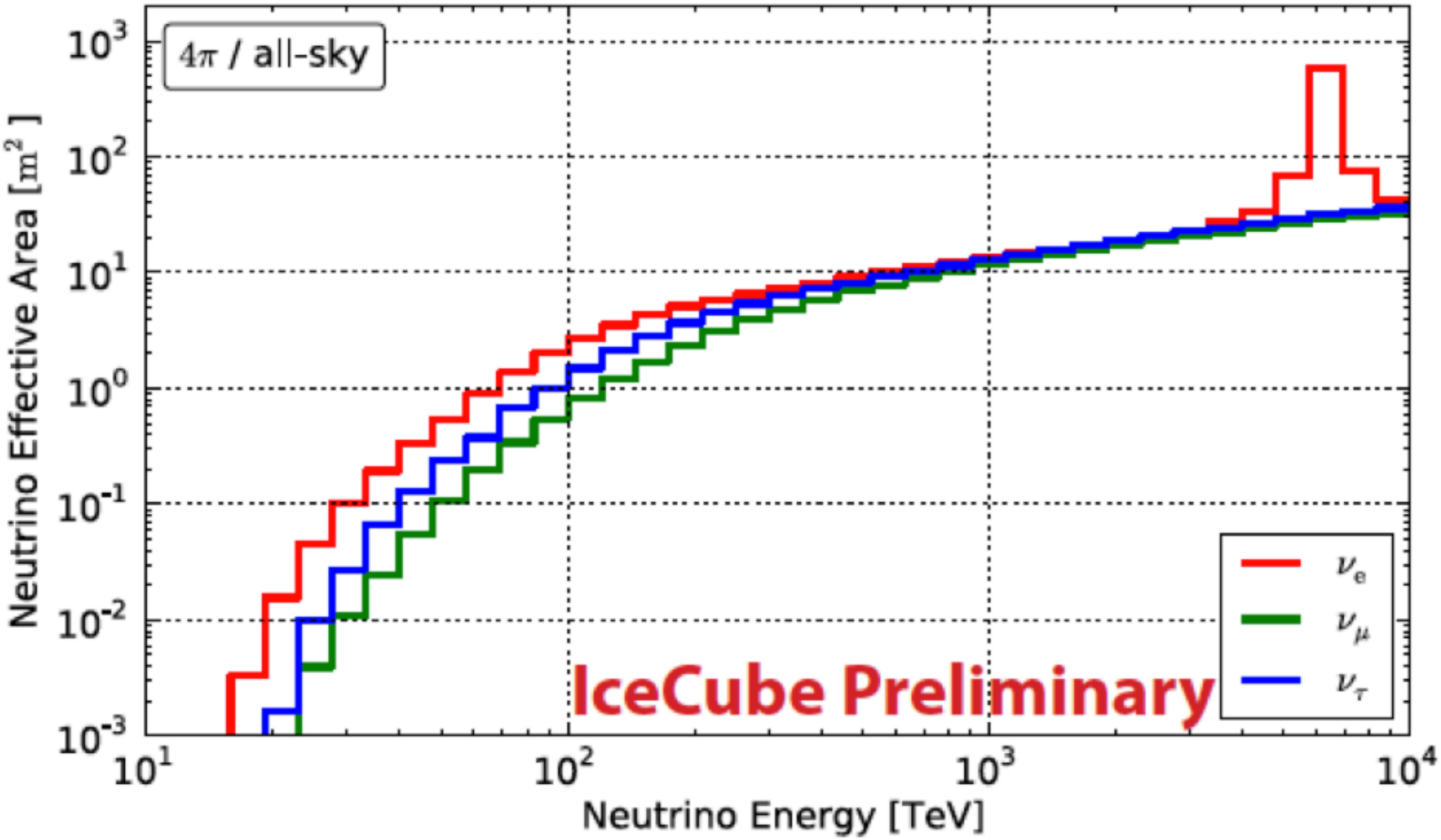
(ex)

$$\mathcal{L} = \lambda \bar{\psi} L H \qquad \Gamma_\psi = \frac{\lambda^2}{16\pi} m_{\rm DM} \qquad m_{\rm DM} \simeq 1.2 {\rm PeV}$$

$$rate \sim \frac{\lambda^2}{10^{-58}} / {\rm year}$$

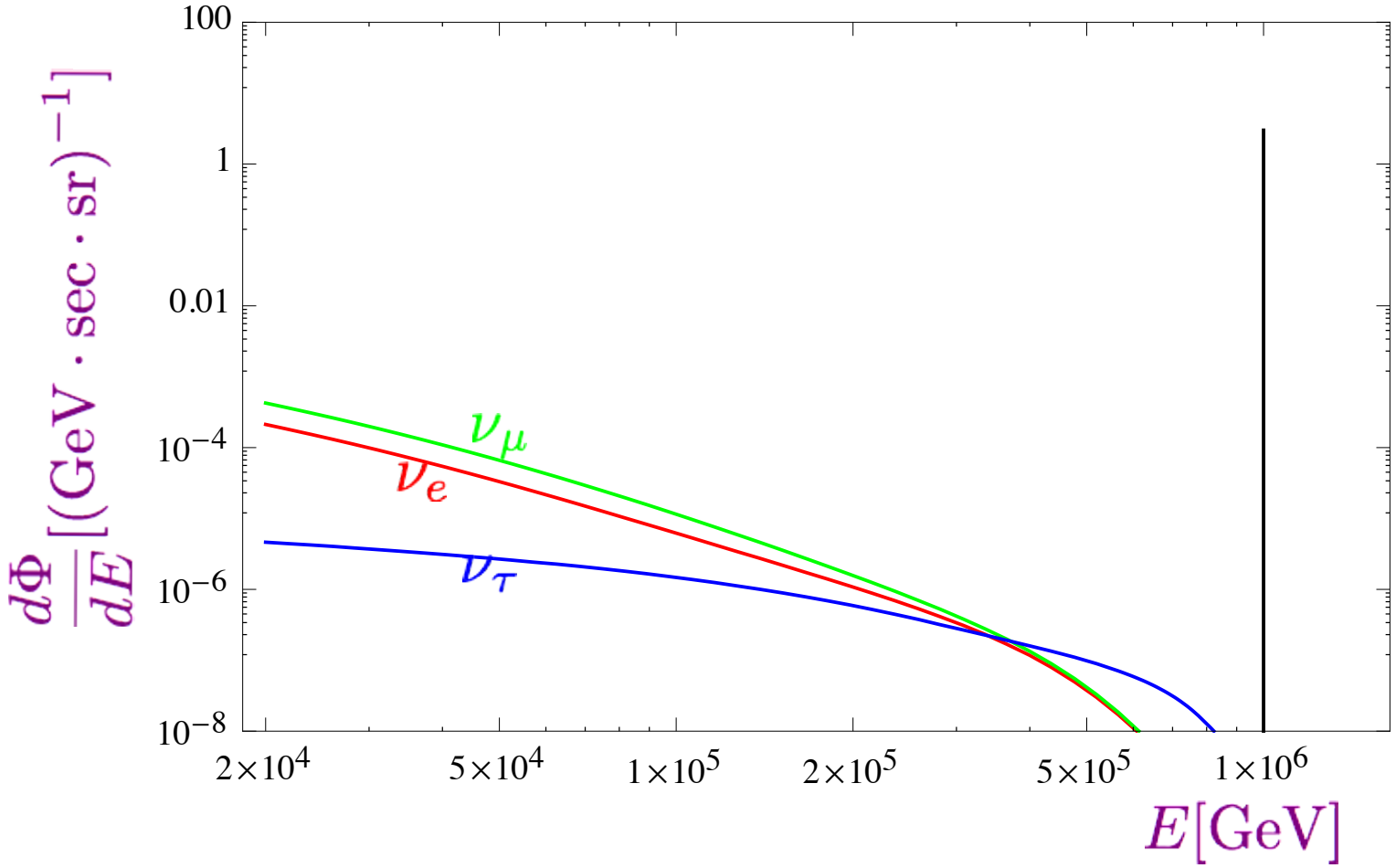
can you make lambda this small?

$$\text{event rate} = A_{\text{eff}}^{IceCube} \times \text{Flux}$$

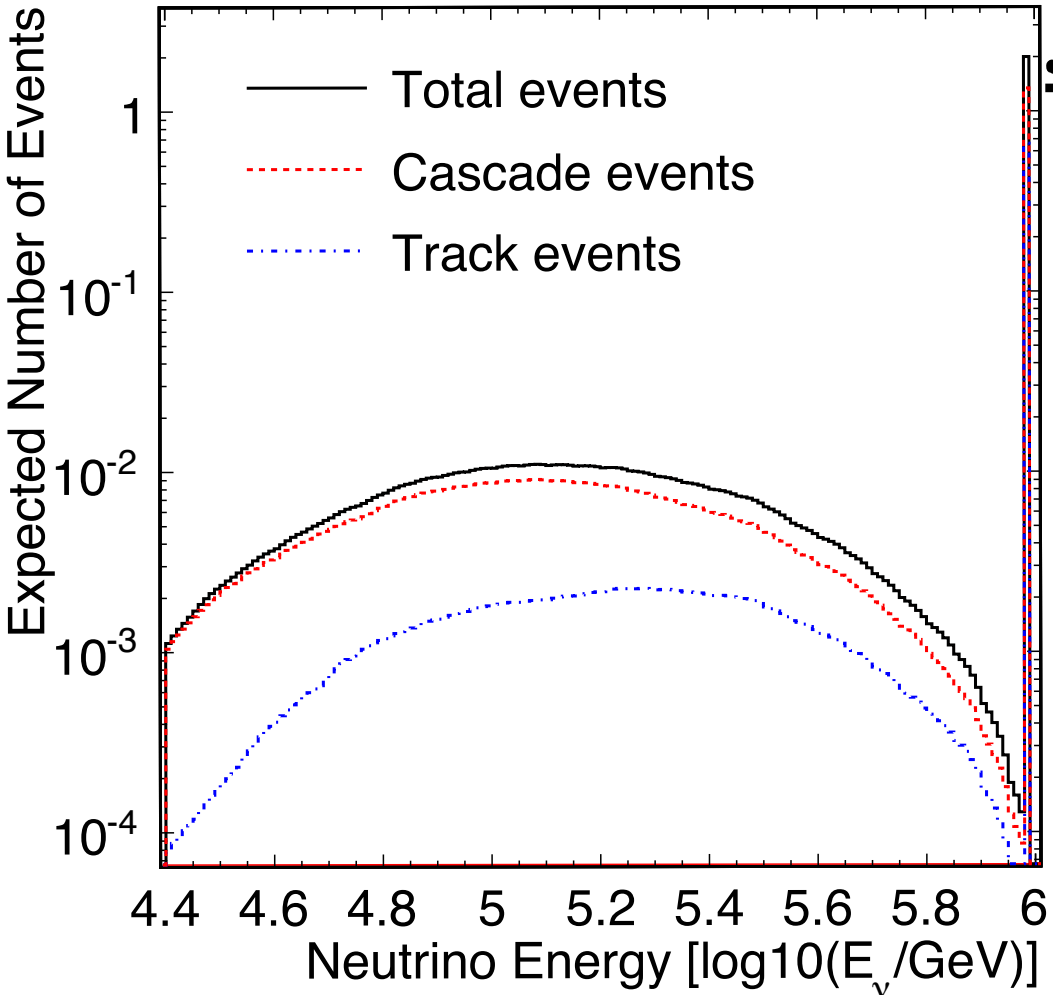


$$X \to \nu + \cdots$$

Flux= $$\frac{d\Phi}{dE} = \frac{1}{4\pi}\frac{1}{m_{\rm DM}\tau_{\rm DM}}\frac{dN_\nu}{dE}J \qquad J = \int_{\rm l.o.s} \rho_{\rm halo} d\vec{\ell}$$



Expected Events



2 events

**Tracks (muon neutrinos)

**Cascades (sum of electron and tau neutrino events)