Dark Matter and IceCube Connections

Stefano Morisi

Universita Federico II di Napoli - INFN

In collaboration with Boucenna*, Chianese*, Mangano, Miele, Pisanti, Vitagliano

To be submitted soon: arxiv 1507.xxxx

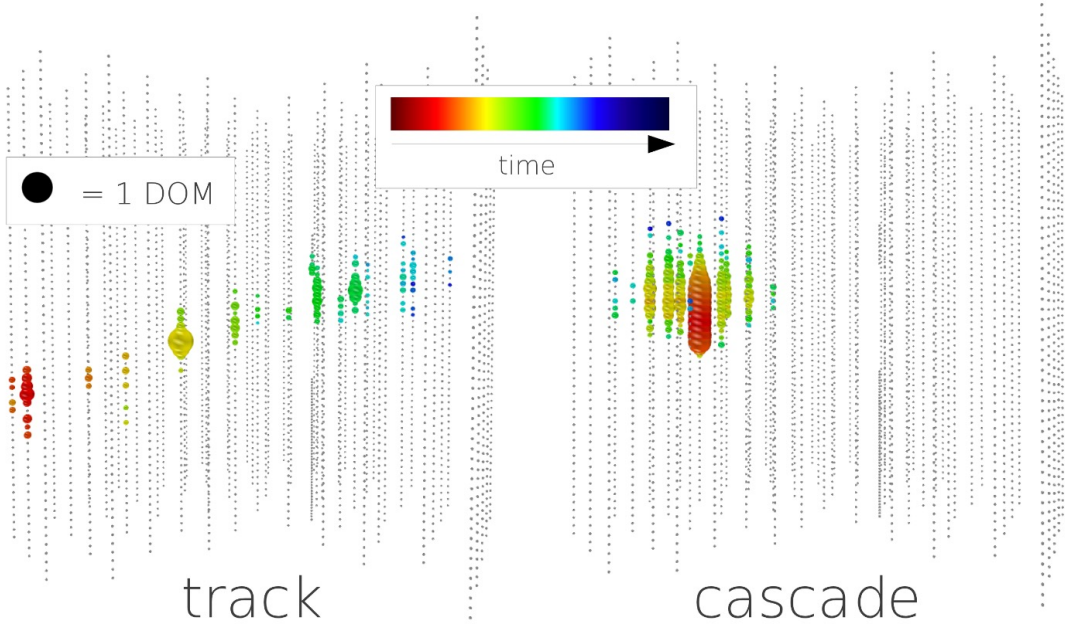
* at this workshop

IceCube: introduction

$\nu_e + N \rightarrow e + X$

$\nu_\mu + N \rightarrow \mu + X$ $\quad$ $\nu_x + N \rightarrow \nu_x + X$

See Halzen's talk



track

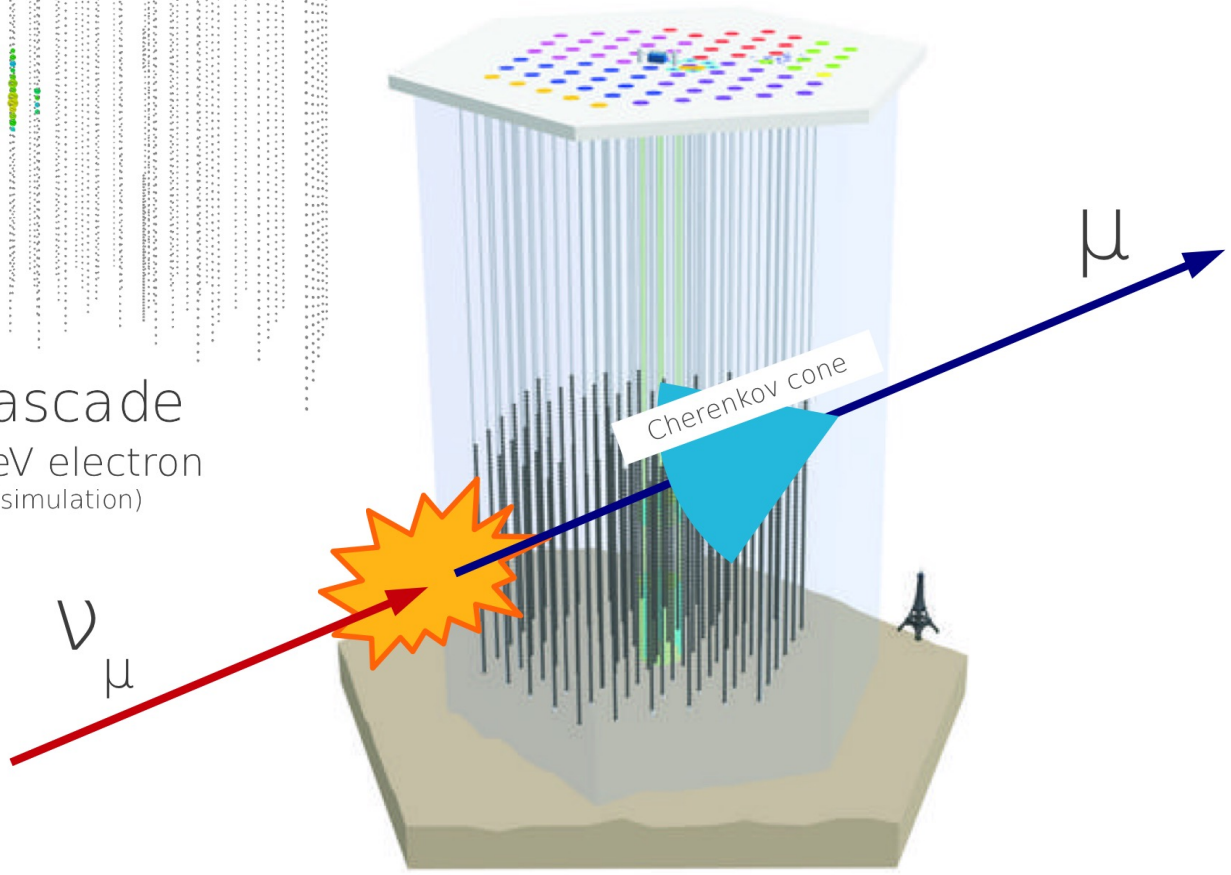
450 TeV muon

(simulation)

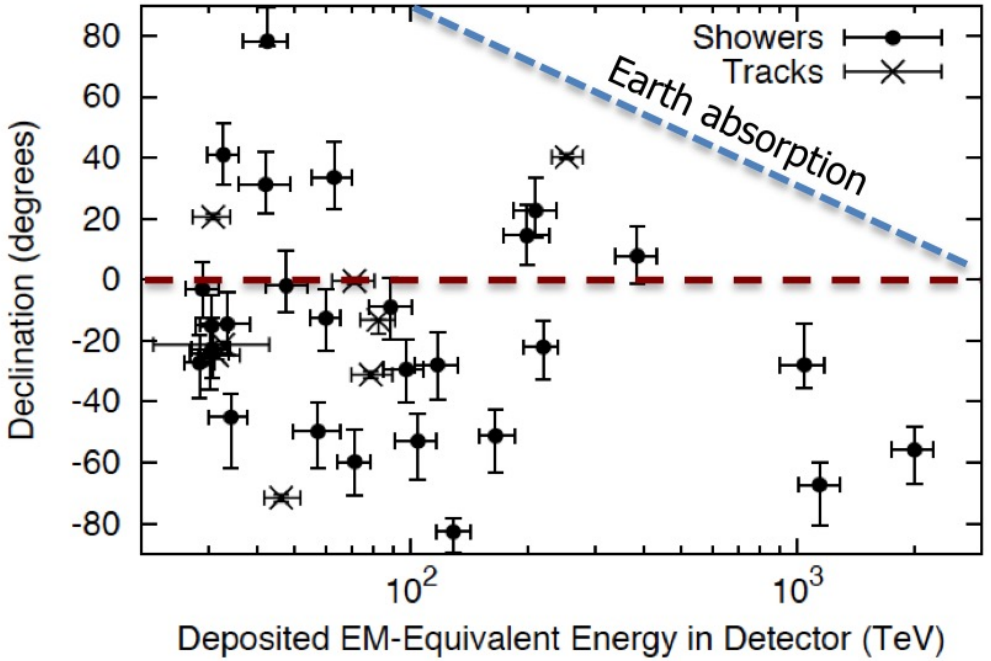
cascade

1 PeV electron

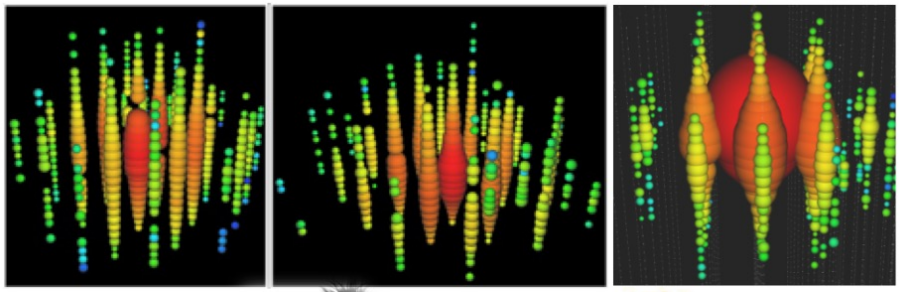
(simulation)



IceCube:events



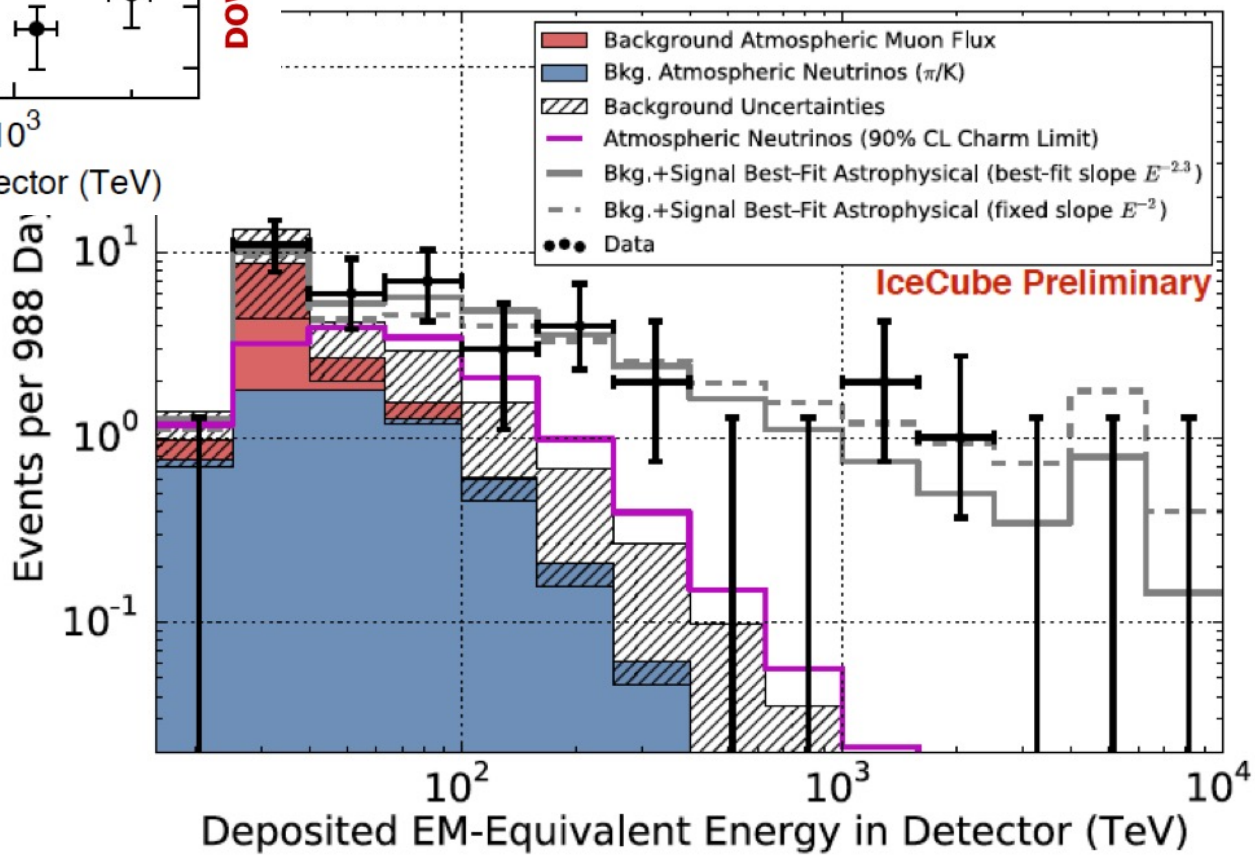
DOWNGOING



"Bert"
1.04 PeV
Aug. 2011

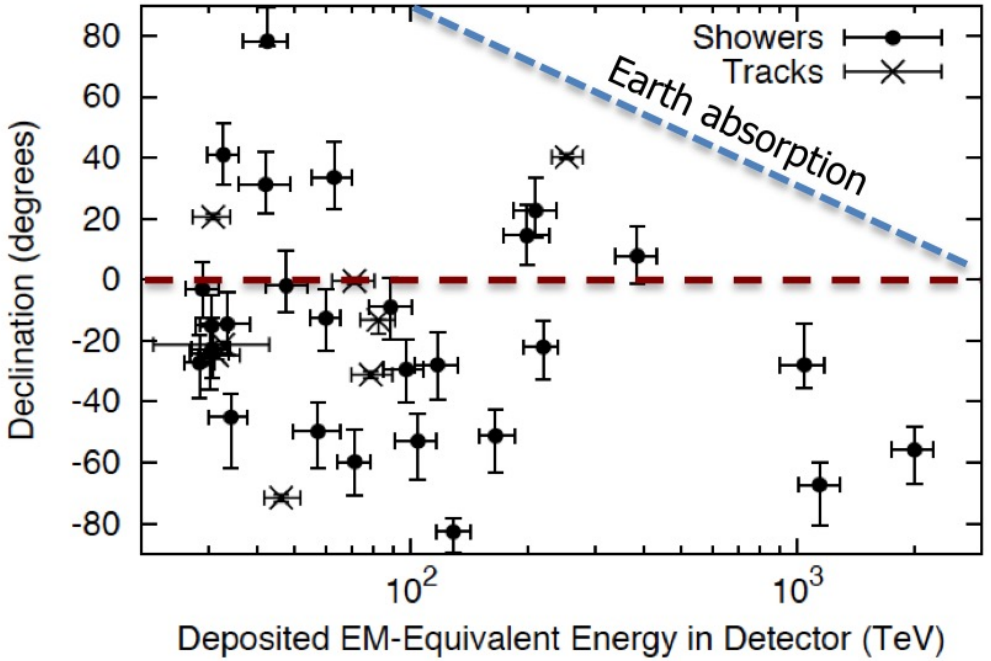
"Ernie"
1.14 PeV
Jan. 2012

"Big Bird"
2 PeV
Dec. 2012

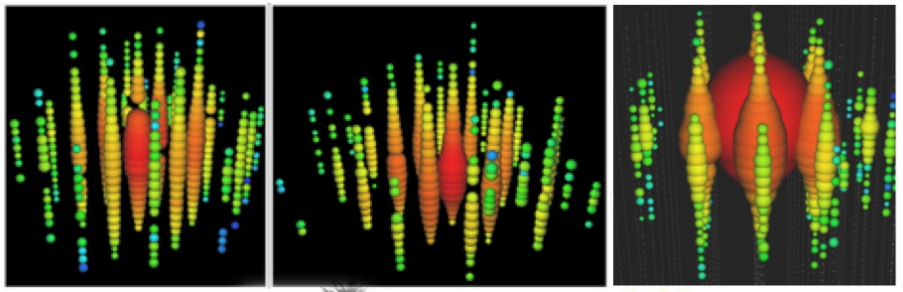


3yrs: 37 events in 988 days
5,7 sigma PRL (14)

IceCube:events



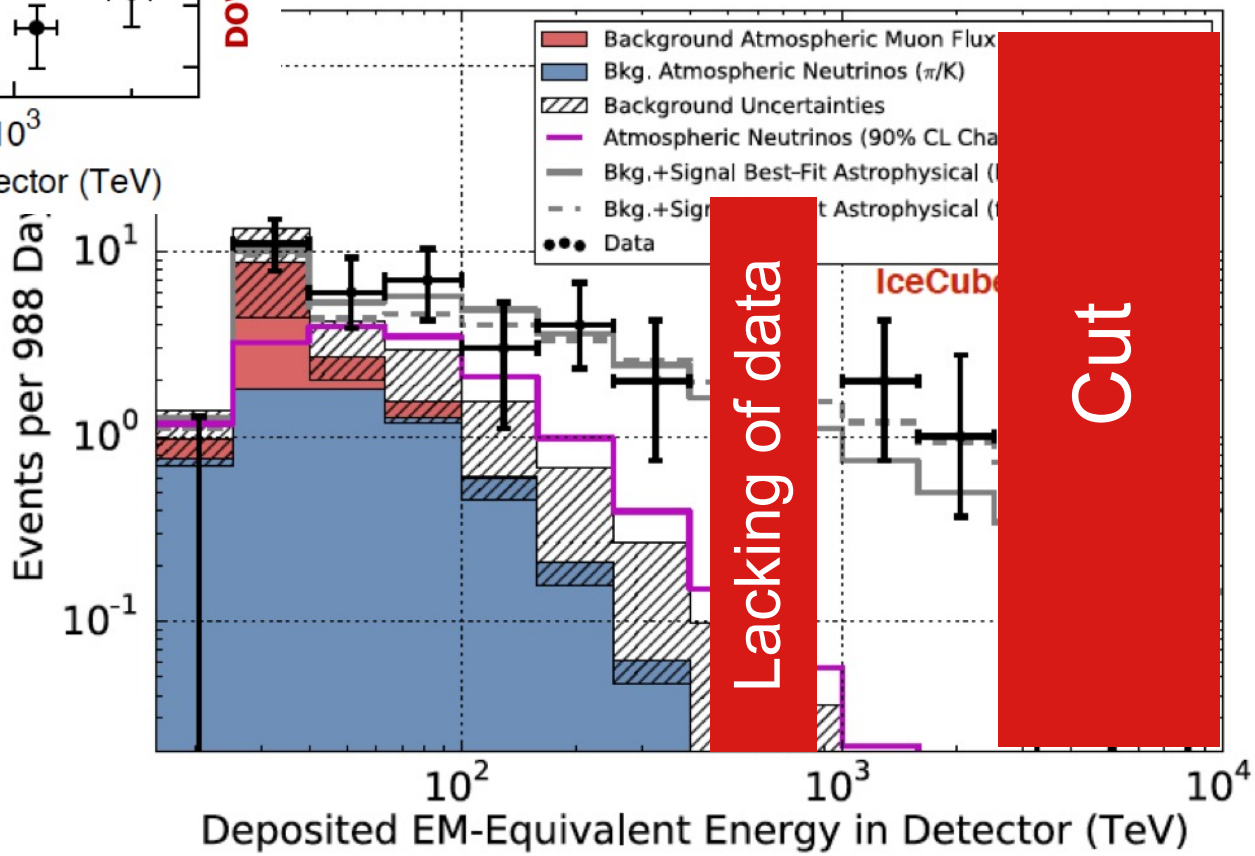
DOWNGOING



"Bert"
1.04 PeV
Aug. 2011

"Ernie"
1.14 PeV
Jan. 2012

"Big Bird"
2 PeV
Dec. 2012



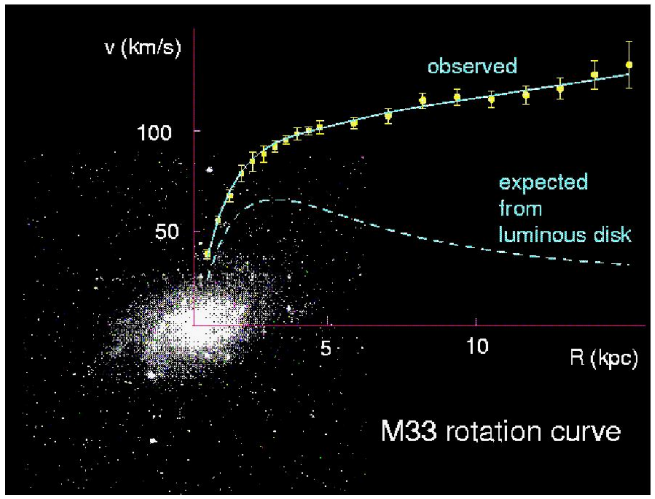
3yrs: 37 events in 988 days
5,7 sigma PRL (14)

Origin of IceCube events

Astrophysics

- Active Galactic Nuclei AGN
- Super Nova Remnants SNRs
- Gamma Ray Bursts GRBs
- .....

Dark matter

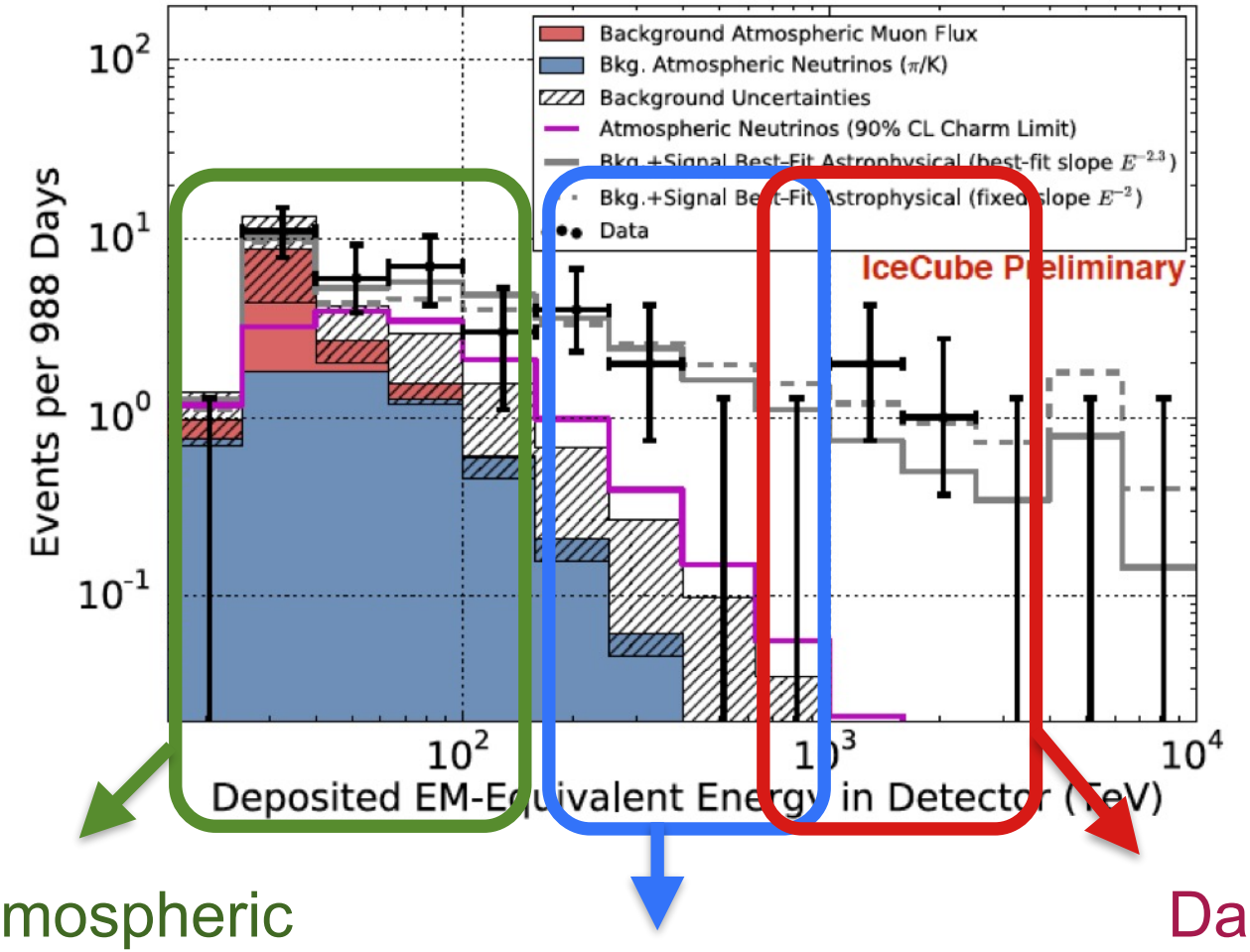


Rubin, Vera, AJ (70´)

X-ray: NASA/CXC/CfA/M.Markevitch et al.;
Optical: NASA/STScI;Magellan/U.Arizona/D.Clowe et al.;
Lensing Map: NASA/STScI; ESO WFI;
Magellan/U.Arizona/D.Clowe et al.

Origin of IceCube events: our assumption

- IC events could be related to the DM problem



Standard atmospheric Neutrino

Some astrophysical Source

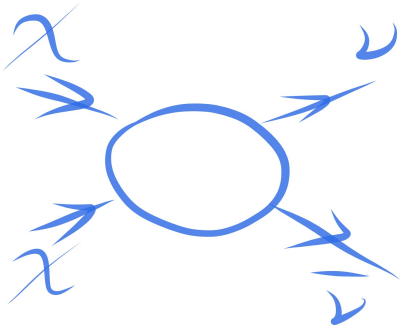
Dark matter Decay

Dark Matter & IceCube

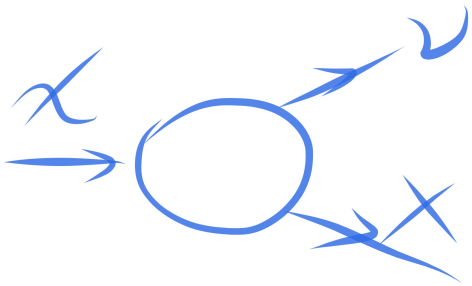
- We know very little about Dark Matter
- IC can provide important information on the nature of DM and give indications on the direction for future DM experiments
- We studied the possibility that the PeV events are due to DM decay
- The lack of data above 2 PeV and between 300TeV-1PeV is in favor of DM interpretation for PeV events

Dark Matter & IceCube

Stable



Decay



For PeV DM annihilation negligible respect decay

Fledstain et al, 1303.7320

$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N} \left(\frac{\rho_{\rm DM}}{m_{\rm DM}}\right)^2 \langle \sigma_{\rm Ann} v \rangle \lesssim 1 \text{ per few hundred years}$$

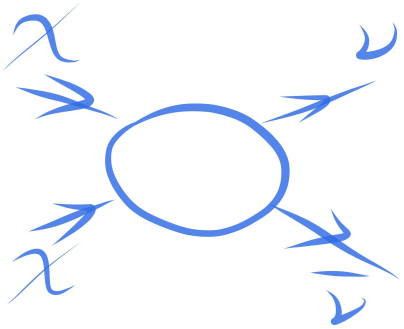
Annihilation

$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N}\, \frac{\rho_{\rm DM}}{m_{\rm DM}}\, \Gamma_{\rm DM} \sim \left(\frac{\lambda}{10^{-29}}\right)^2 / \text{ year}$$

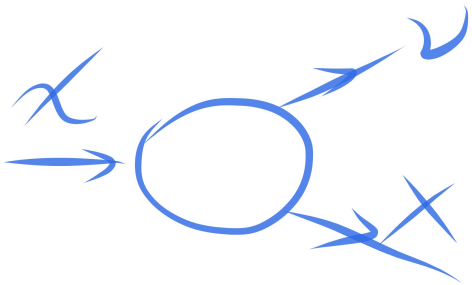
Decay

Dark Matter & IceCube

Stable



Decay



For PeV DM annihilation negligible respect decay

unless

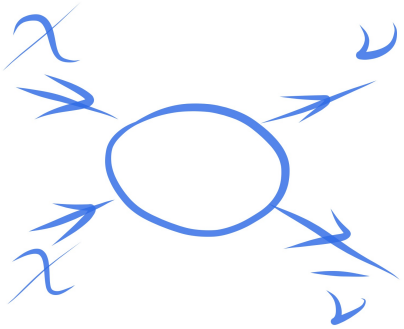
$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N} \left(\frac{\rho_{\rm DM}}{m_{\rm DM}}\right)^2 \langle \sigma_{\rm Ann} v \rangle$$

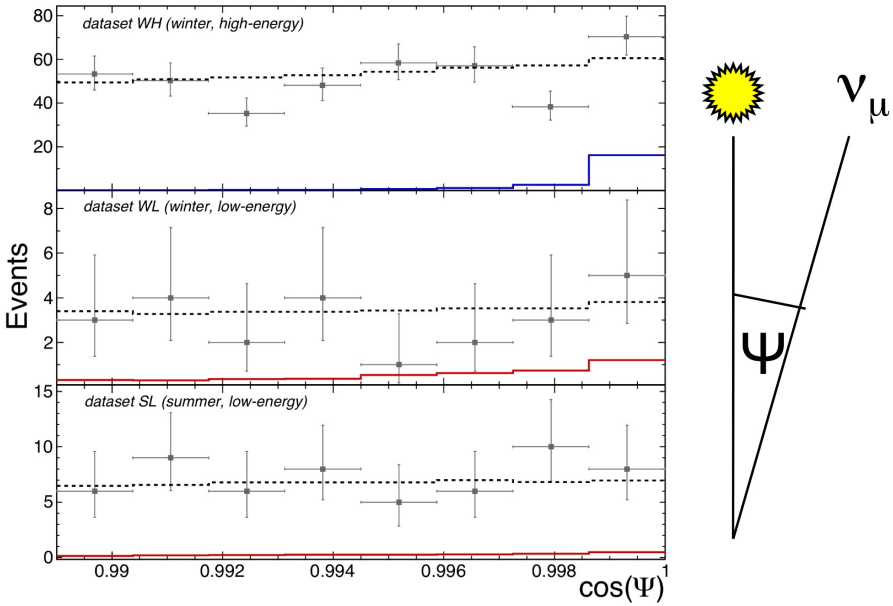
DM captured in large Celestial bodies like the sun or cluster of galaxies, enhancing the density

Silk et al, PRL(85), Gaisser et al, PRD(86), Gould AJ(88), ...

Dark Matter & IceCube

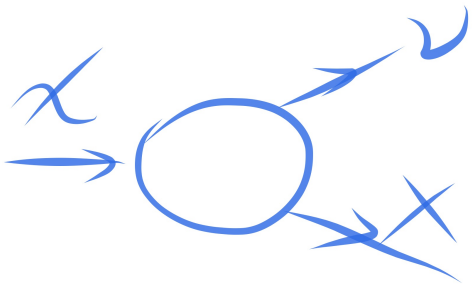
Stable

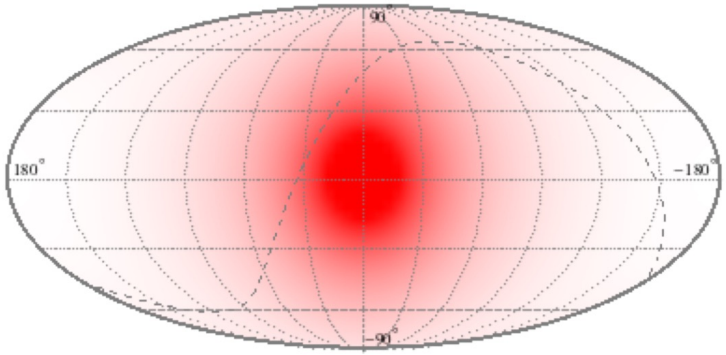




Search for DM in the sun, from IceCube

Decay





(a) PDF of DM decay

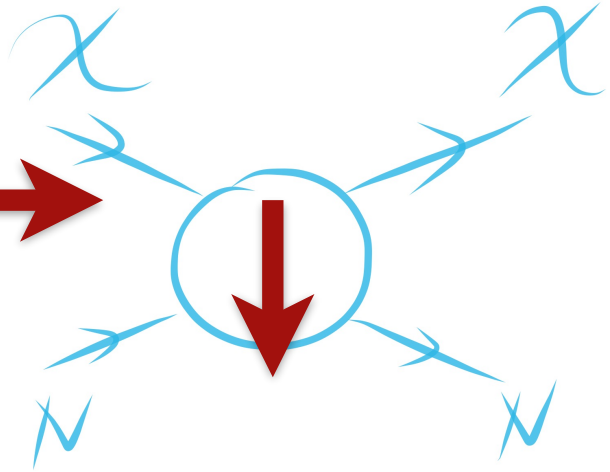
Esmaili, Kang, Serpico, JCAP14

Dark Matter & IceCube

Stable

Decay

Boost

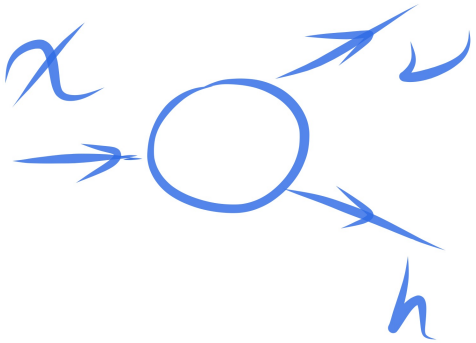


$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N} \left(\frac{\rho_{\rm DM}}{m_{\rm DM}}\right)^2 \boxed{\langle \sigma_{\rm Ann} v \rangle}$$

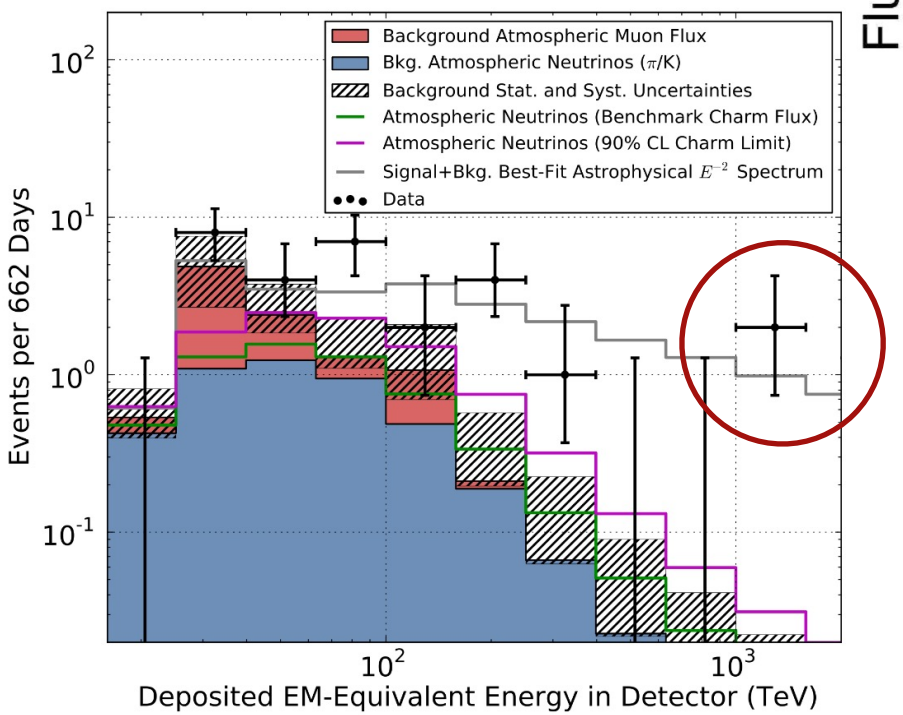
Boosted dark matter

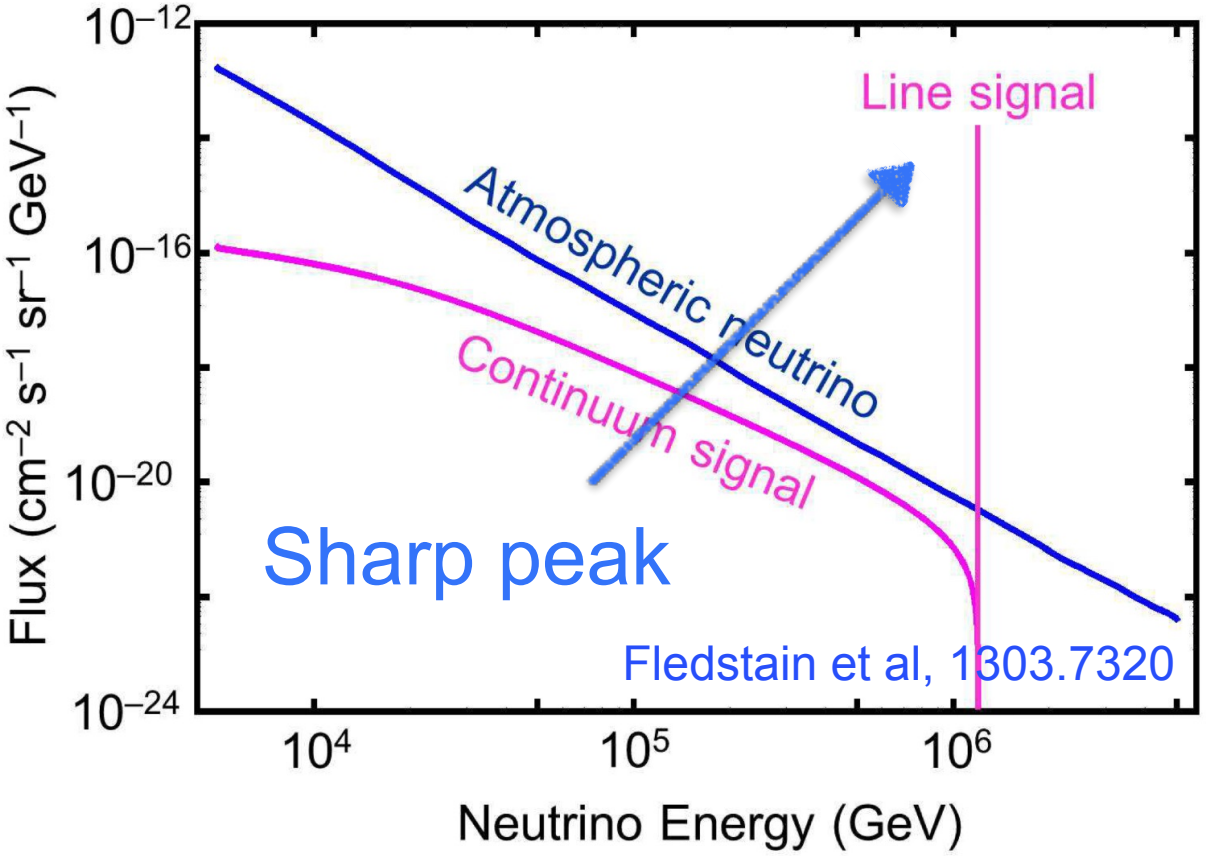
Bhattacharya et al JCAP15,
Agashe et al JCAP14
Berger et al JCAP15
Kopp et al JHEP15

2 body decay



$$\mathcal{L} \supset \lambda \bar{\psi} L H$$

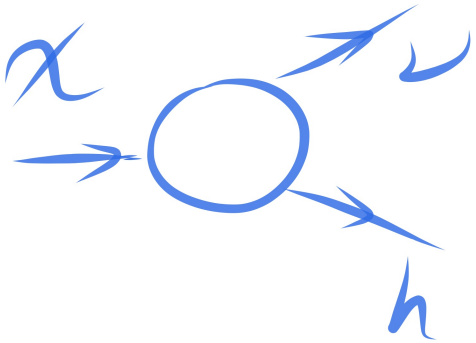




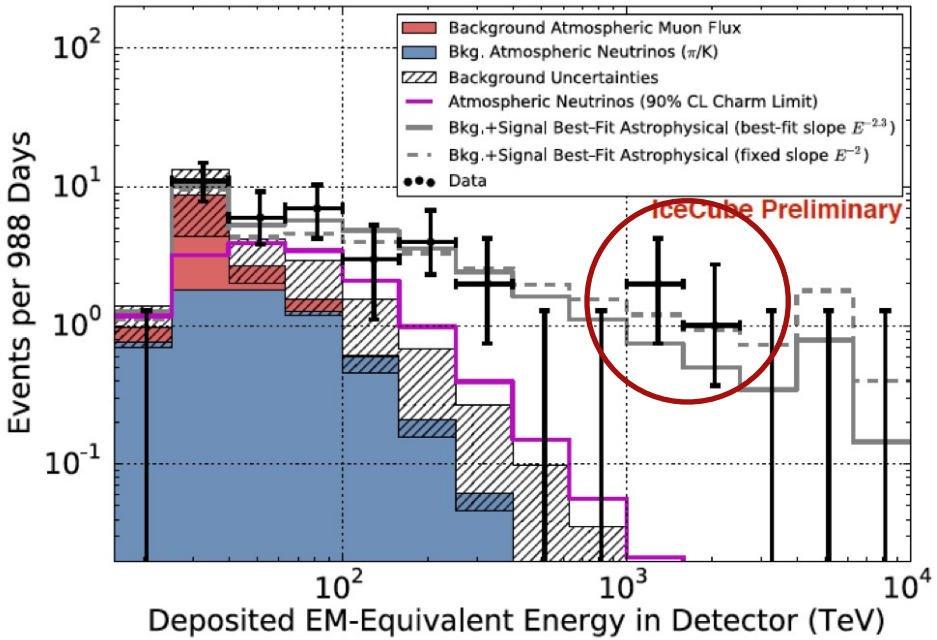
2yrs: 28 events in 662 days, Sience13

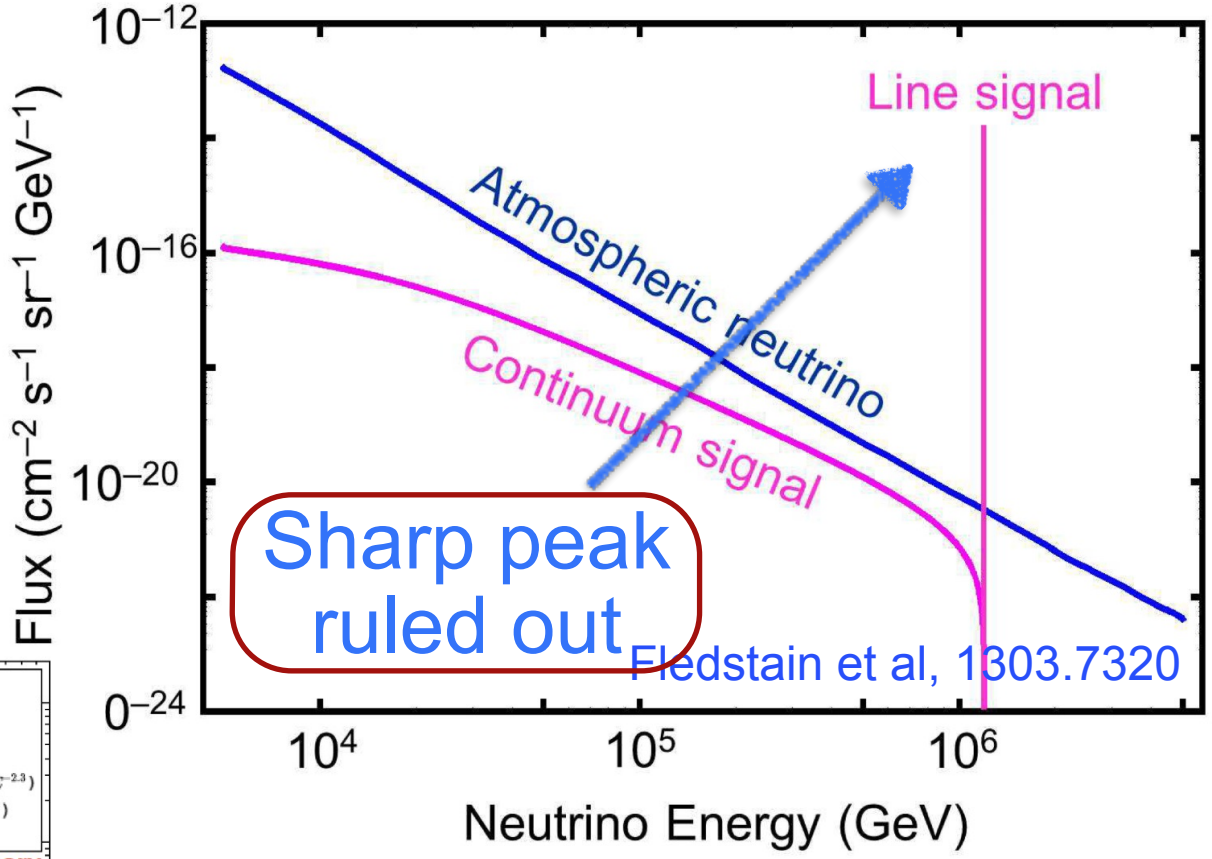
Only two events at 1 PeV, but....

2 body decay



$$\mathcal{L} \supset \lambda \bar{\psi} L H$$

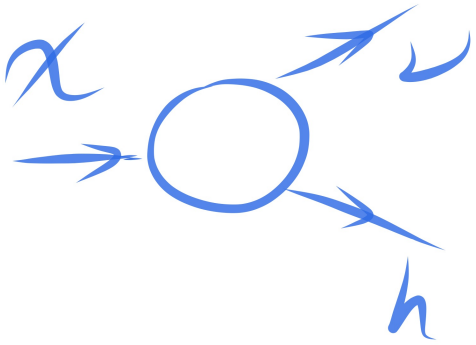




3yrs: 37 events in 988 days, PRL (14)

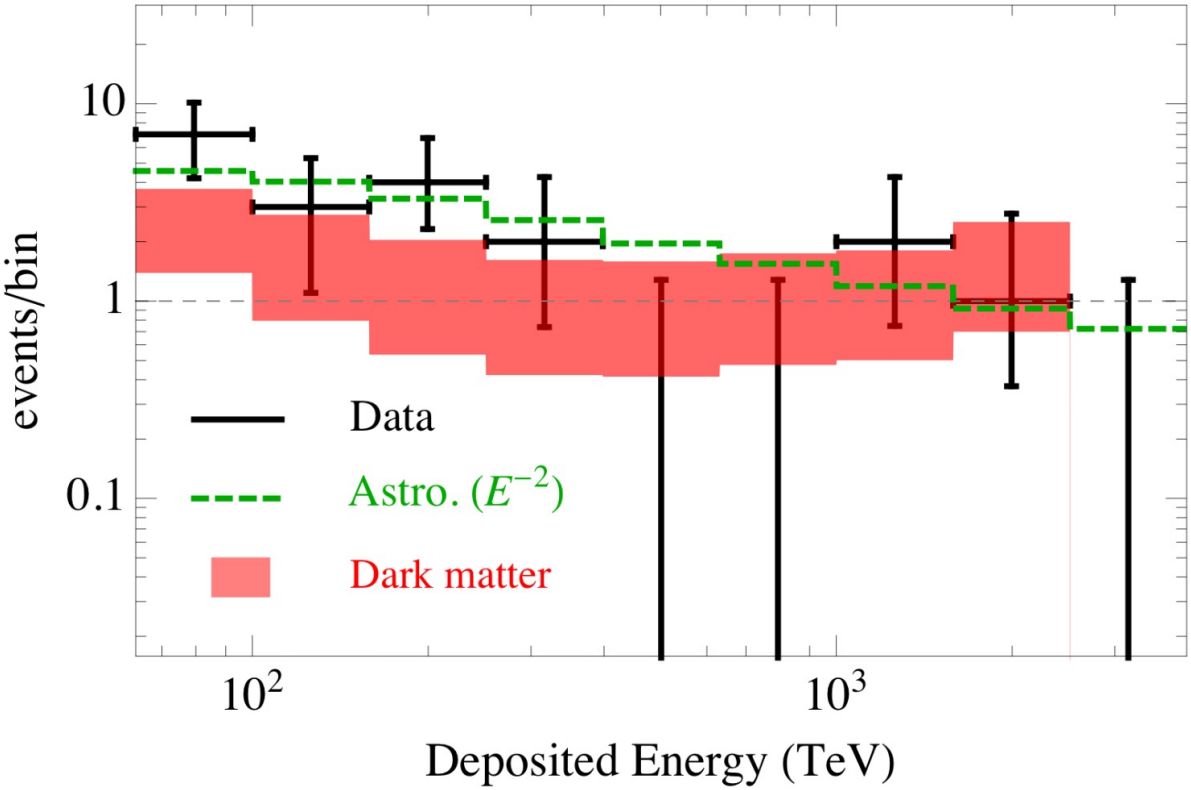
two events at 1 PeV, and one at 2 PeV

2 body decay



$$\mathcal{L} \supset \lambda \bar{\psi} L H$$

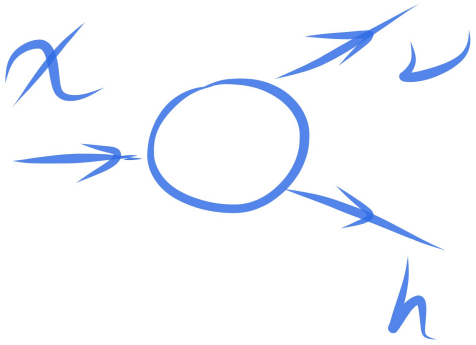
$$\mathcal{O}(10^{-30})$$



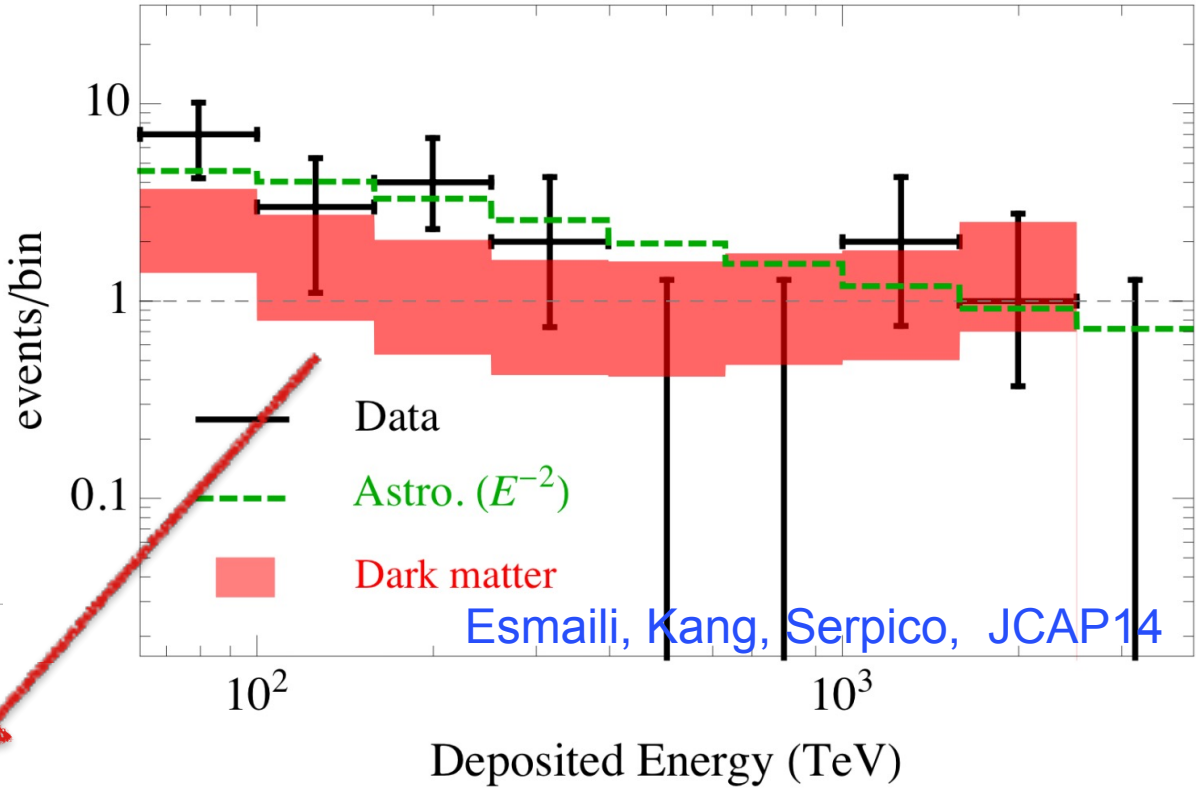
Esmaili, Kang, Serpico, JCAP14

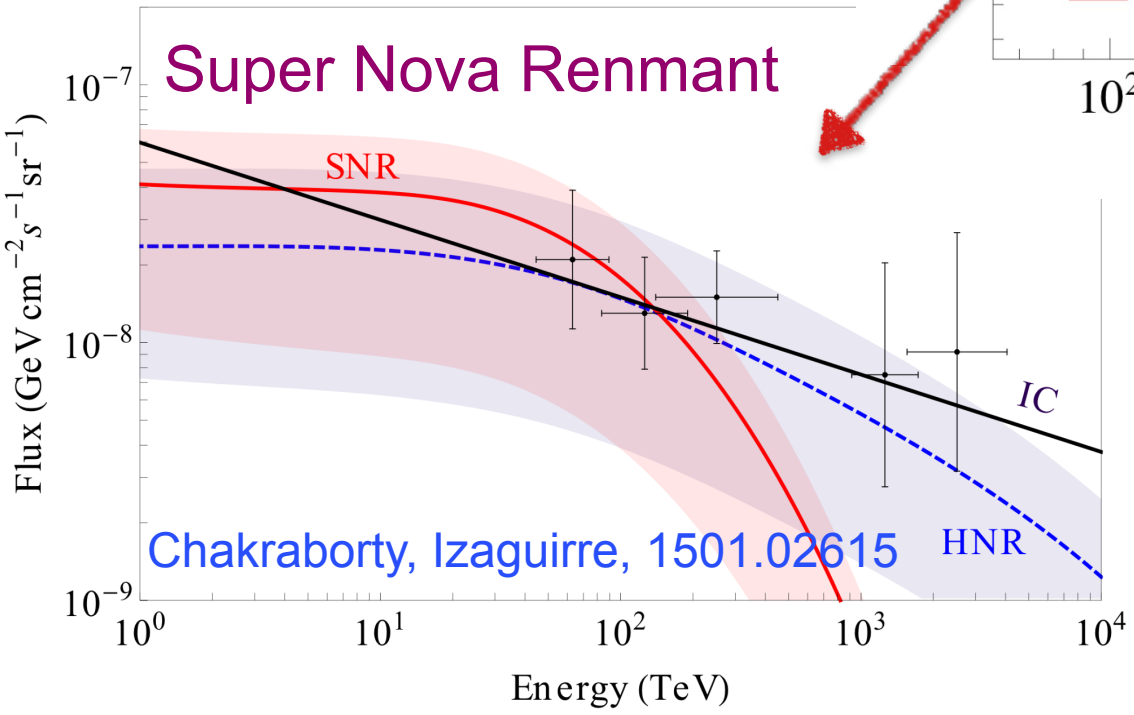
Secondary neutrinos allow to fit all data even with the 2 bodies decay, but...

2 body decay



$$\mathcal{L} \supset \lambda \bar{\psi} L H$$





Could be in contrast with known astrophysical sources

Fermion singlet DM & 3 body decay

All the allowed SM-DM couplings are:

Dimensions	DM decay operators
4	$\bar{L}H^cX$ Haba et al., 1008.4777
5	–
6	$\bar{L}E\bar{L}X$, $H^\dagger H\bar{L}H^cX$, $(H^c)^tD_\mu H^c\bar{E}\gamma^\mu X$, $\bar{Q}D\bar{L}X$, $\bar{U}Q\bar{L}X$, $\bar{L}D\bar{Q}X$, $\bar{U}\gamma_\mu D\bar{E}\gamma^\mu X$, $D^\mu H^cD_\mu\bar{L}X$, $D^\mu D_\mu H^c\bar{L}X$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^cX$, $W^a_{\mu\nu}\bar{L}\sigma^{\mu\nu}\tau^aH^cX$

Fermion singlet DM & 3 body decay

All the allowed SM-DM couplings are:

Dimensions	DM decay operators
4	$\bar{L}H^cX$
5	–
6	$\bar{L}E\bar{L}X$, $H^\dagger H\bar{L}H^cX$, $(H^c)^tD_\mu H^c\bar{E}\gamma^\mu X$, $\bar{Q}D\bar{L}X$, $\bar{U}Q\bar{L}X$, $\bar{L}D\bar{Q}X$, $\bar{U}\gamma_\mu D\bar{E}\gamma^\mu X$, $D^\mu H^cD_\mu\bar{L}X$, $D^\mu D_\mu H^c\bar{L}X$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^cX$, $W^a_{\mu\nu}\bar{L}\sigma^{\mu\nu}\tau^aH^cX$

- DM lifetime suppressed by a large scale;
  The multi body final state Spreads the flux

Haba et al., 1008.4777

Fermion singlet DM & 3 body decay

All the allowed SM-DM couplings are:

Dimensions	DM decay operators
4	$\bar{L}H^cX$
5	–
6	$\bar{L}E\bar{L}X$, $H^\dagger H\bar{L}H^cX$, $(H^c)^tD_\mu H^c\bar{E}\gamma^\mu X$, $\bar{Q}D\bar{L}X$, $\bar{U}Q\bar{L}X$, $\bar{L}D\bar{Q}X$, $\bar{U}\gamma_\mu D\bar{L}\gamma^\mu X$, $D^\mu H^cD_\mu\bar{L}X$, $D^\mu D_\mu H^c\bar{L}X$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^cX$, $W^a_{\mu\nu}\bar{L}\sigma^{\mu\nu}\tau^aH^cX$

Haba et al., 1008.4777

- DM lifetime suppressed by a large scale; The multi body final state Spreads the flux
- direct coupling with neutrino allows primary neutrino flux

Fermion singlet DM & 3 body decay

All the allowed SM-DM couplings are:

Dimensions	DM decay operators
4	$\bar{L}H^cX$
5	–
6	$\bar{L}E\bar{L}X$, $H^\dagger H\bar{L}H^cX$, $(H^c)^tD_\mu H^\dagger\bar{E}\gamma^\mu X$, $\bar{Q}D\bar{L}X$, $\bar{U}QL\bar{X}$, $\bar{L}DQ\bar{X}$, $\bar{U}\gamma_\mu D\bar{L}\gamma^\mu X$, $D^\mu H^\dagger D_\mu\bar{L}X$, $D^\mu D_\mu H^\dagger\bar{L}X$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^cX$, $W^a_{\mu\nu}\bar{L}\sigma^{\mu\nu}\tau^aH^cX$

Haba et al., 1008.4777

- DM lifetime suppressed by a large scale; The multi body final state Spreads the flux
- direct coupling with neutrino allows primary neutrino flux
- DM-leptophillic imply negligible contribution at low energy

Fermion singlet DM & 3 body decay

All the allowed SM-DM couplings are:

Dimensions	DM decay operators
4	$\bar{L}H^cX$
5	–
6	$\bar{L}E\bar{L}X$, $H^\dagger H\bar{L}H^cX$, $(H^c)^t D_\mu H^\dagger \bar{E}\gamma^\mu X$, $\bar{Q}D\bar{L}X$, $\bar{U}Q\bar{L}X$, $\bar{L}D\bar{Q}X$, $\bar{U}\gamma_\mu D\bar{E}\gamma^\mu X$, $D^\mu H^\dagger D_\mu \bar{L}X$, $D^\mu D_\mu H^\dagger \bar{L}X$, $B_{\mu\nu}\bar{L}\sigma^{\mu\nu}H^cX$, $W^a_{\mu\nu}\bar{L}\sigma^{\mu\nu}\tau^a H^cX$

Haba et al., 1008.4777

- DM lifetime suppressed by a large scale; The multi body final state Spreads the flux
- direct coupling with neutrino allows primary neutrino flux
- DM-leptophillic imply negligible contribution at low energy

In order to allow only such operator, one can assume (non)Abelian flavor symmetry

Leptophillic 3 bodies decay

$$\frac{y_{\alpha\beta\gamma}}{\Lambda^2}\,\overline{L_\alpha}\,\overline{L_\beta}\ell_\gamma\chi$$

The phenomenology will depend from the specific model:

- $\{\alpha,\beta,\gamma\} \equiv \{\ e,e,e\}$;
- $\{\alpha,\beta,\gamma\} \equiv \{\ \tau,\tau,\tau\}$;
- $\{\alpha,\beta,\gamma\}_{U(1)} \equiv \{\tau,\tau,\mu\}$
- $\{\alpha,\beta,\gamma\}_{A_4} \equiv \{\ e,\mu,\tau\}$

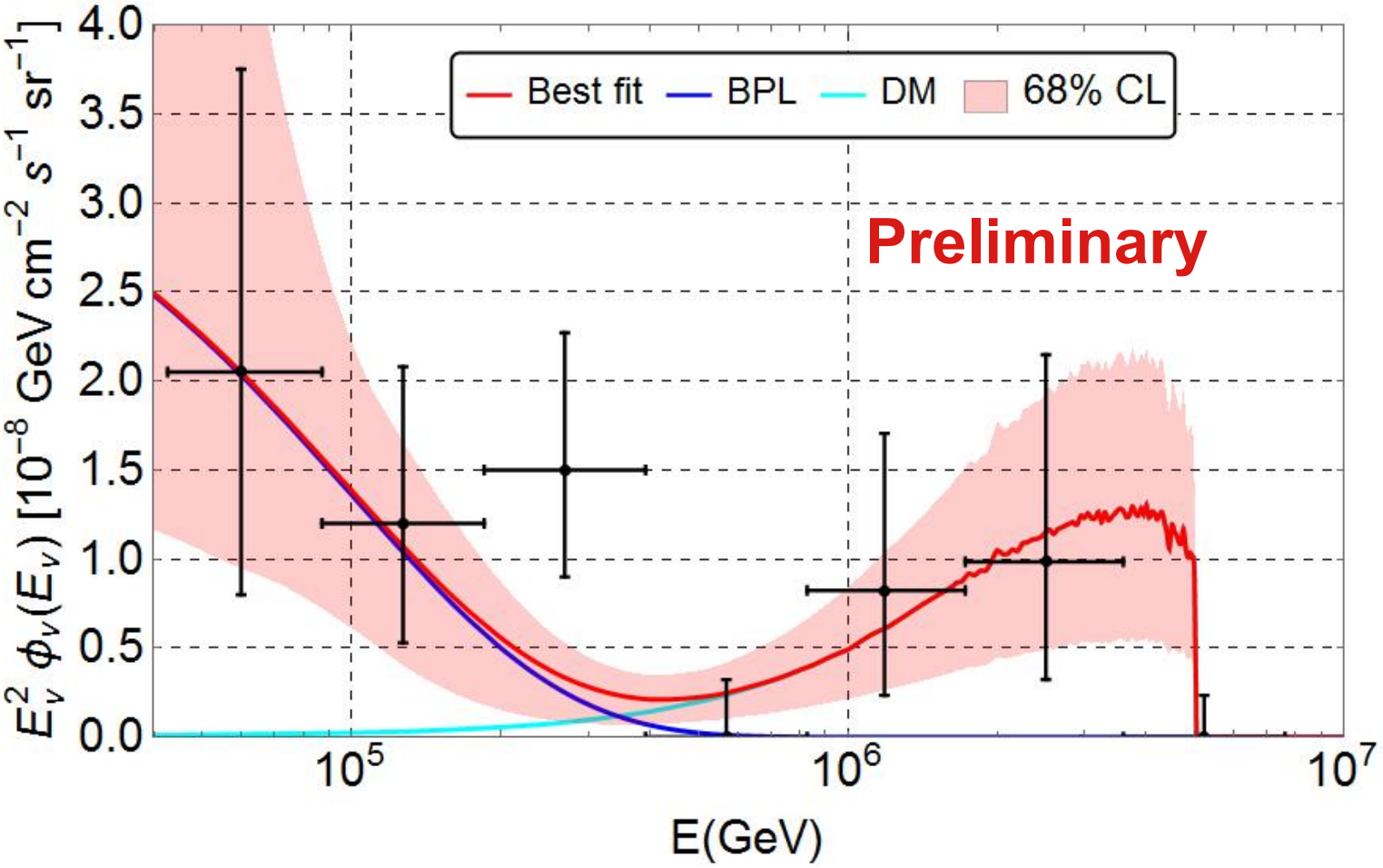
No secondary neutrinos

Max number of secondary neutrinos

Haba et al., 1008.4777

Broken Power Low & DM

$$E^2\phi = \phi_0 .10^{-8}\left(\frac{E}{100TeV}\right)^{-\gamma} e^{-E/E_0} GeV\,\mathrm{cm}^{-2}s^{-1}sr^{-1}$$



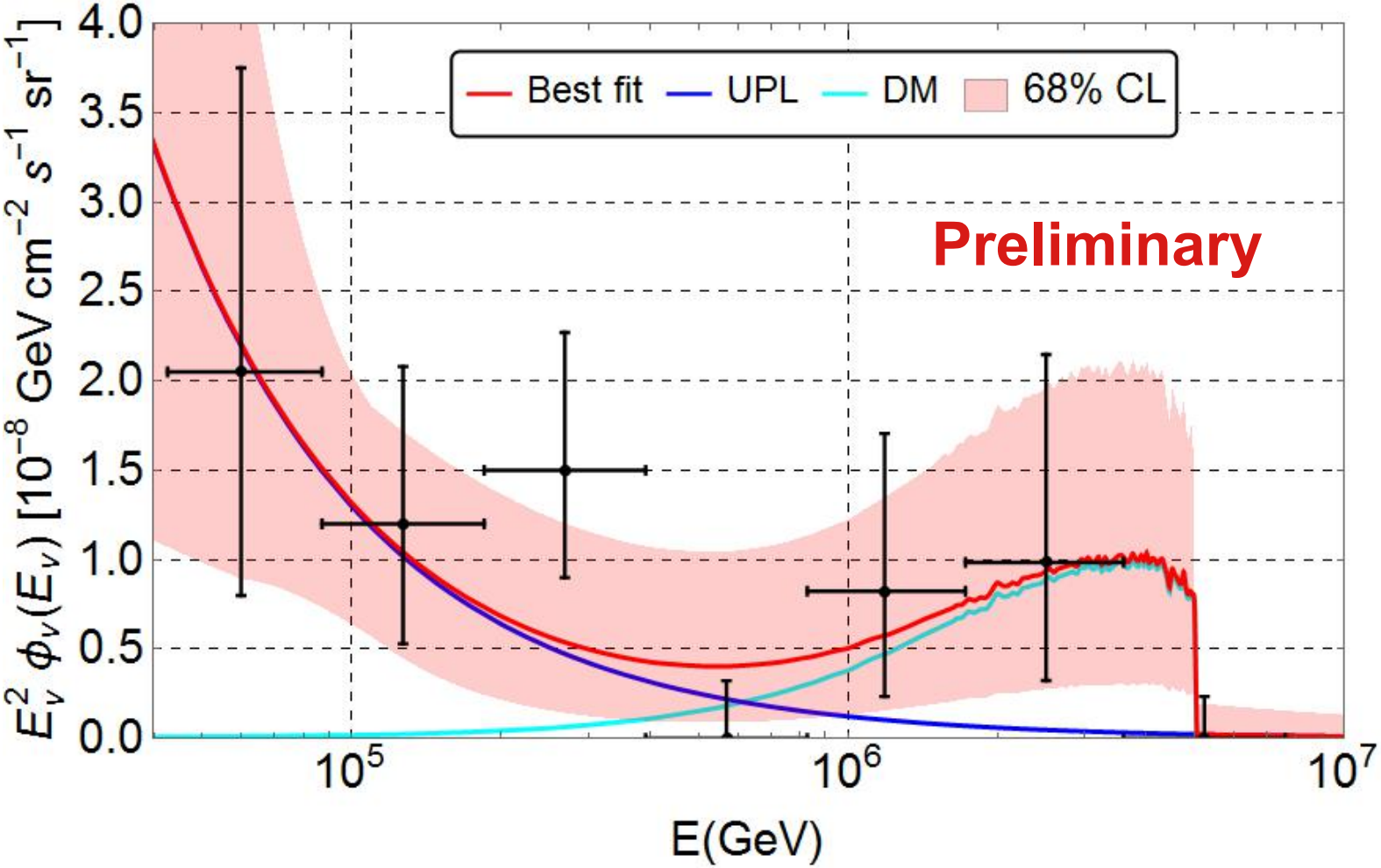
$E_0 = 100TeV$

$\gamma = 0$

$\phi_0 = 3.7$

Un-Broken Power Low & DM

$$E^2\phi = \phi_0 .10^{-8}\left(\frac{E}{100TeV}\right)^{-\gamma} GeV\,\mathrm{cm}^{-2}s^{-1}sr^{-1}$$

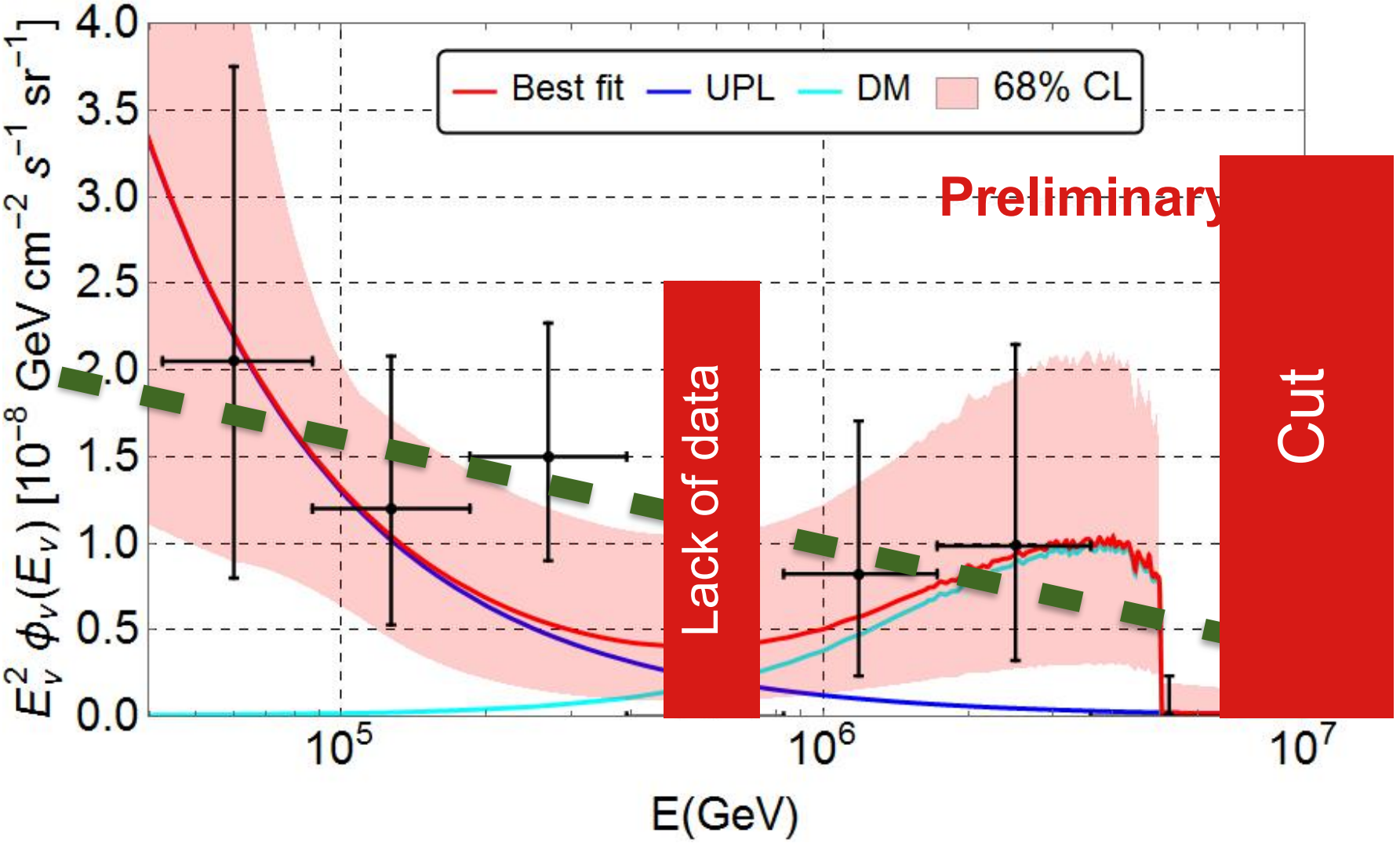


$\gamma = 1$

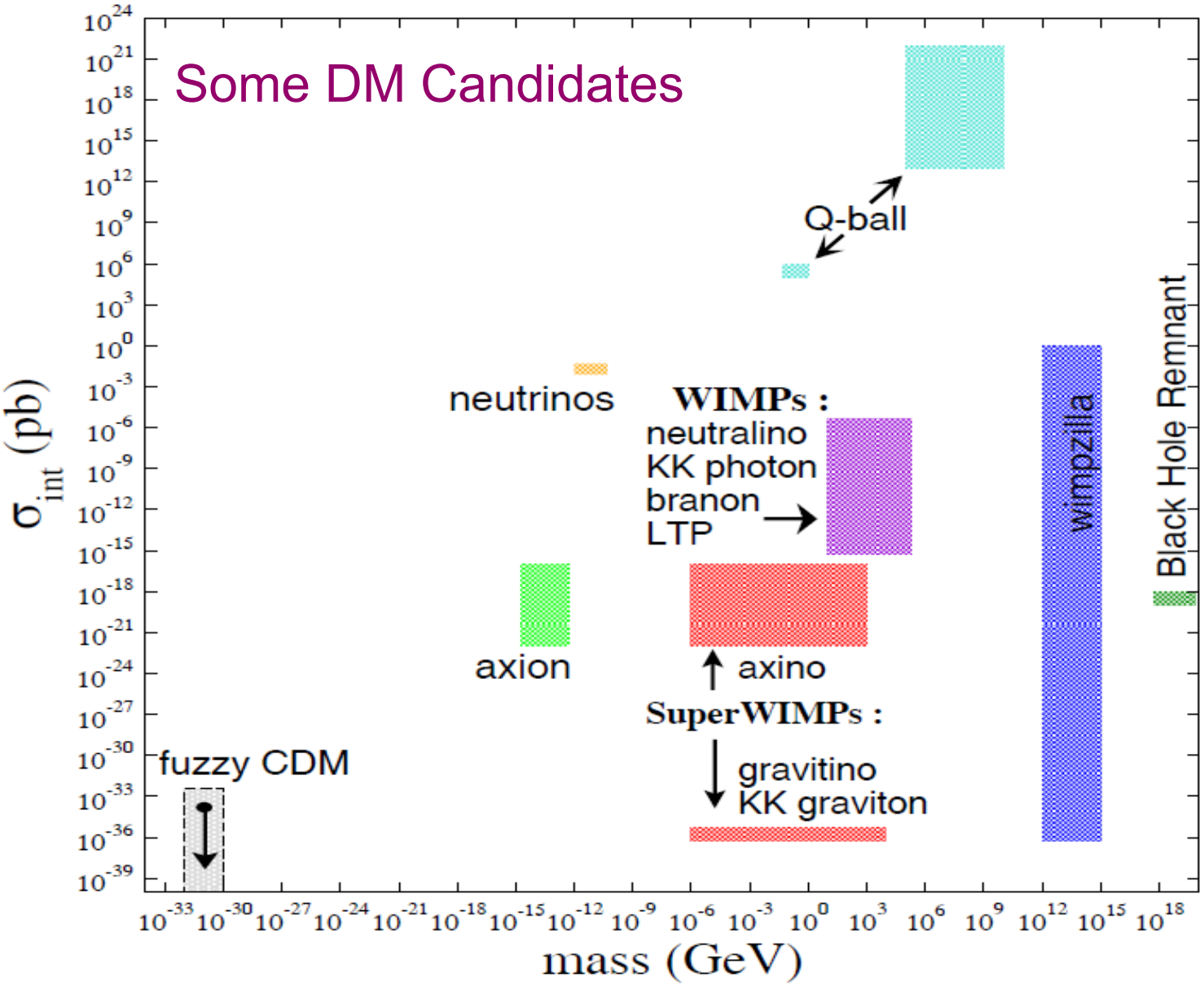
$\phi_0 = 1.3$

Un-Broken Power Low & DM

$$\phi = \phi_0 E^{-\gamma}$$

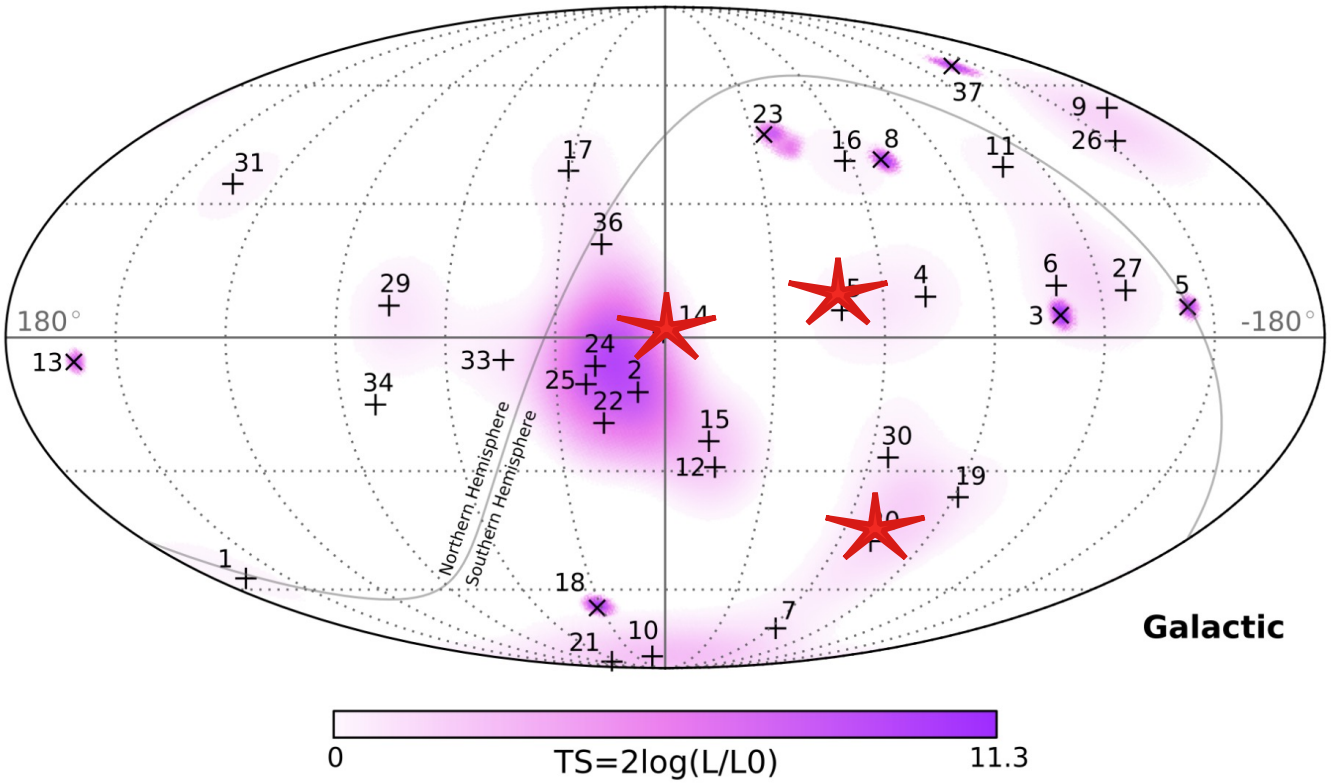


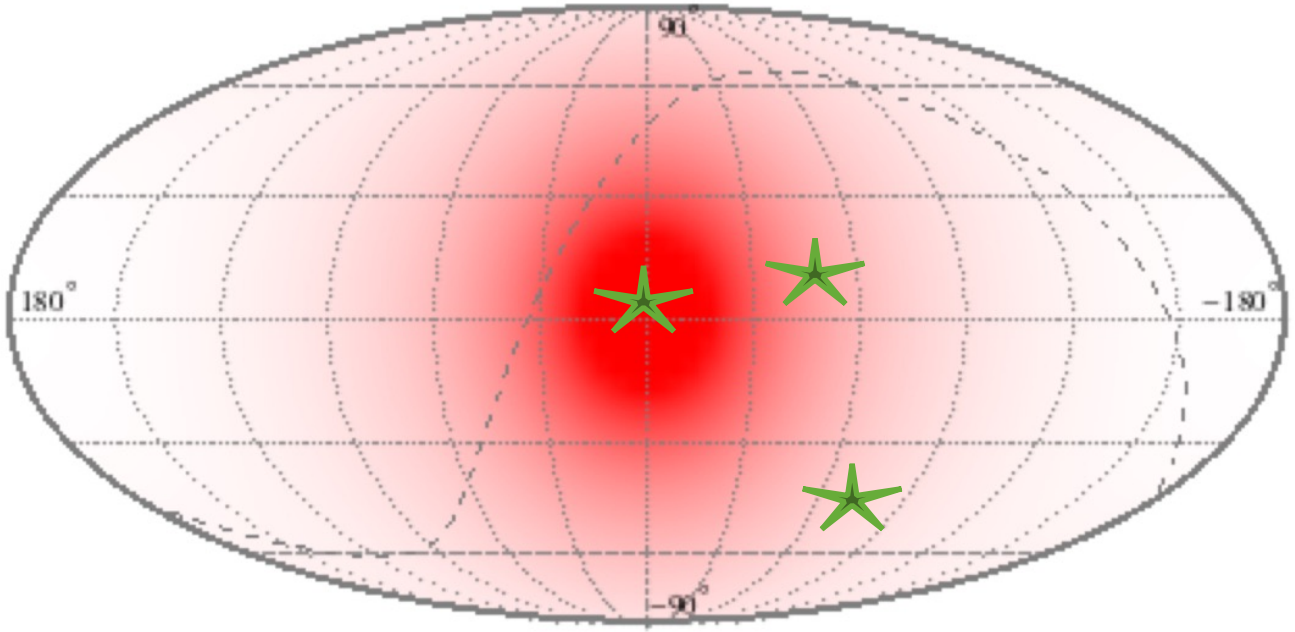
Dark Matter candidates



from Dark Matter Scientific Assessment Group (DMSAG) report (2007)

http://science.energy.gov/~/media/hep/pdf/files/pdfs/dmsagreportjuly18_2007.pdf


180°
-180°
Northern Hemisphere
Southern Hemisphere
Galactic
0
TS=2log(L/L0)
11.3


90°
180°
−180°
−90°

conclusions

- IceCube PeV events could be related to dark matter
- We discussed decaying dark matter and we compared the 2 and 3 body decay cases
- 3 body leptophillic decay case seems to describe data better if low energy astrophysical sources are also considered in the analysis
- DM can be distinguished from astrophysical background if some correlation with the galactic center will be observed

Work in progress....flavor ratio at IceCube to distinguish models