The high-energy diffuse galactic neutrinos and gammas

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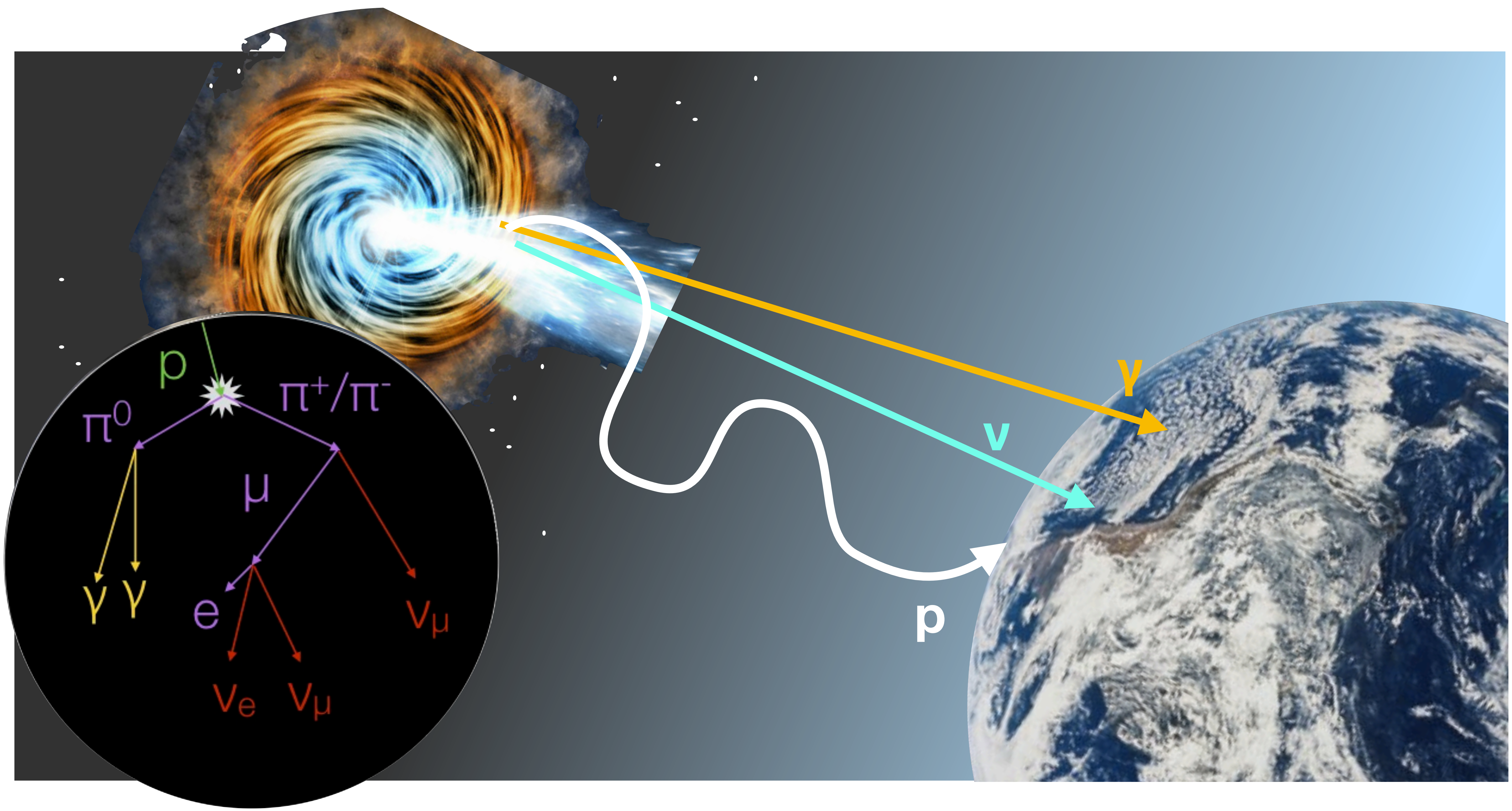
Based on work done in collaboration with G. Pagliaroli, F. L. Villante, V. Vecchiotti

High-energy neutrino astronomy

- neutrinos are not deflected in magnetic fields hence they travel in straight lines
- neutrinos are weakly interacting and not absorbed

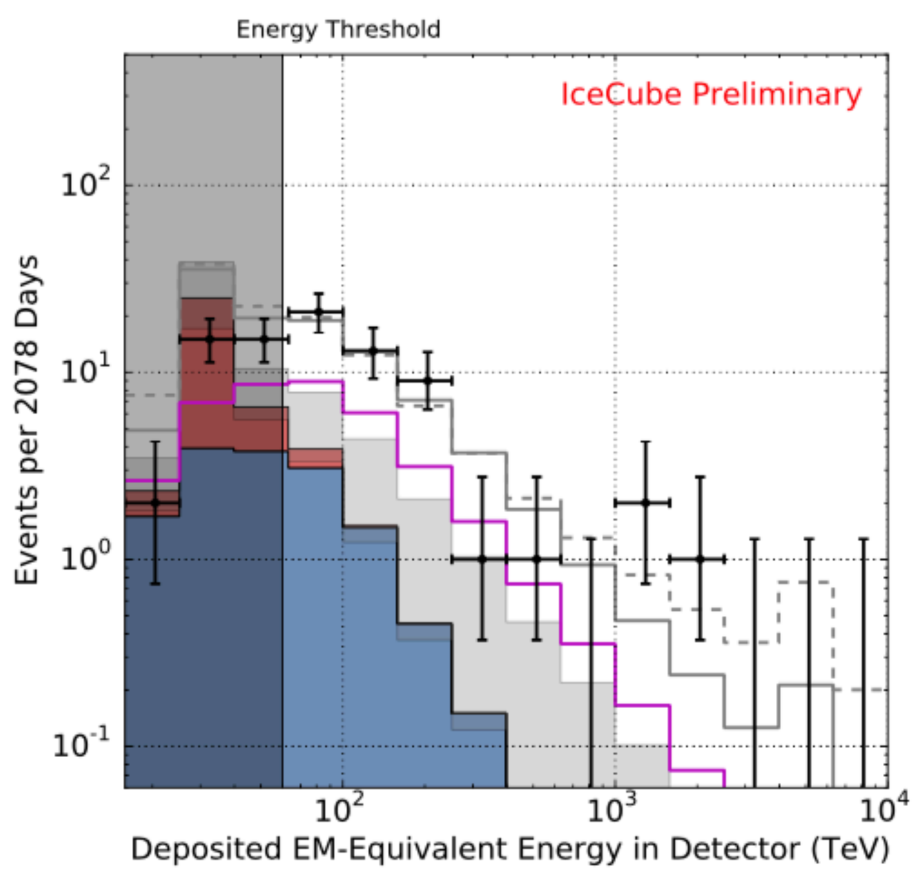


High-energy neutrinos (HEN): IceCube signal

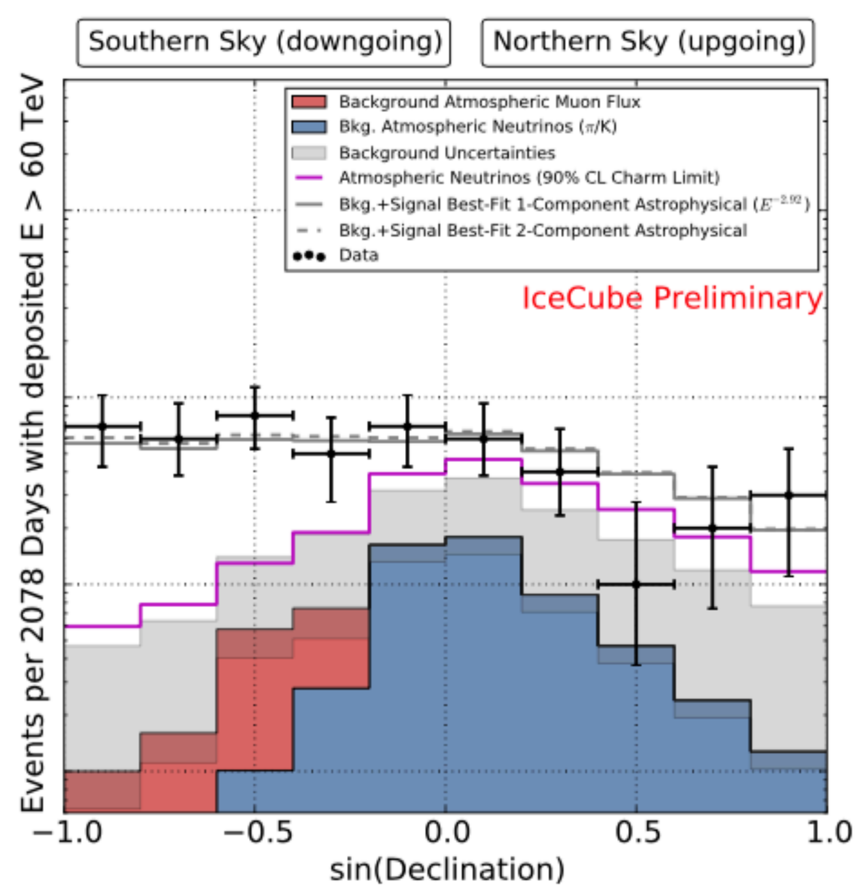
IceCube observes a signal compatible with an **isotropic flux** fitted by a power law dependece on the energy:

$$\mathcal{F}_{\rm iso}(E_\nu) = 6.8\times 10^{-10}\ \left[\frac{E_\nu}{100\ {\rm TeV}}\right]^{-(2.49\pm 0.08)}\ {\rm ergs\ cm^{-2}\ s^{-1}\ sr^{-1}}$$

The signal is of astrophysical origin confirmed with ~7σ of evidence.



(a) deposited energies

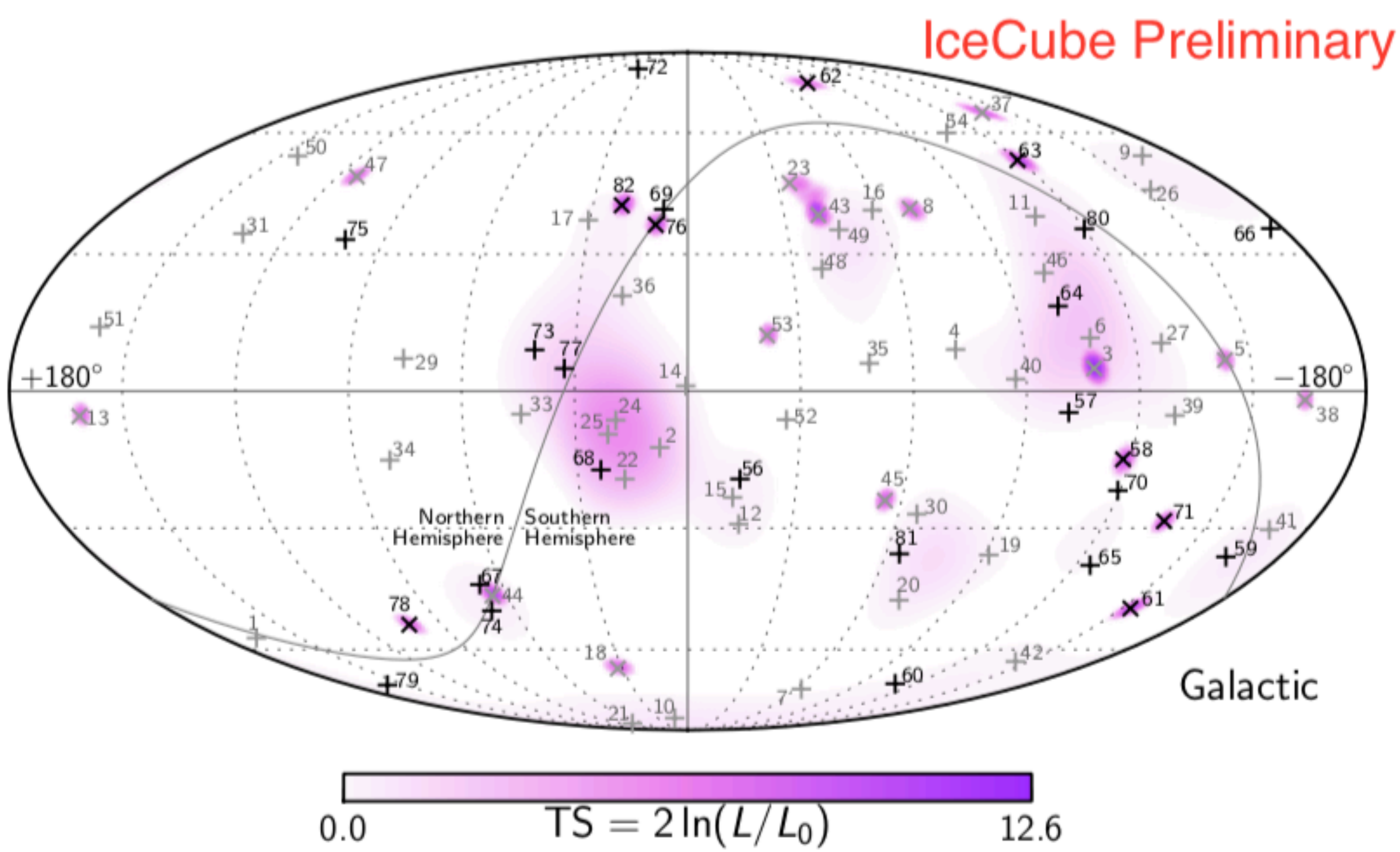


(b) arrival directions

[IceCube coll. 2017]

High-energy neutrinos (HEN): IceCube signal

There is still no clustering evidence of the events in the sky.



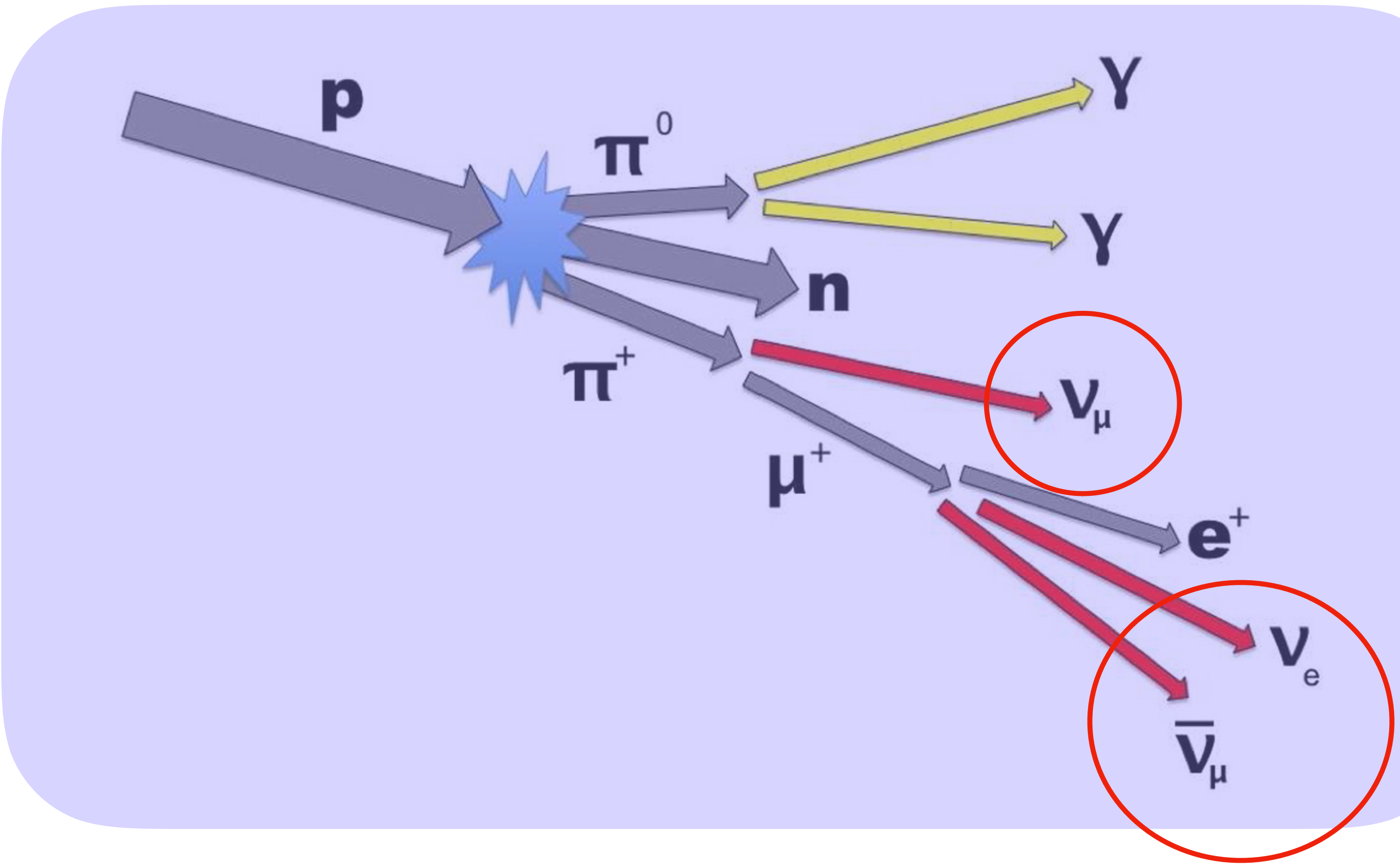
The recent observation of a neutrino-flare coincidence represents the only significative correlation evidence so far (TXS0506+056).

[IceCube coll. 2017]

Galactic diffuse neutrinos

Galactic neutrinos is a guaranteed component in the total signal. It is subdominant and it is not been observed yet.

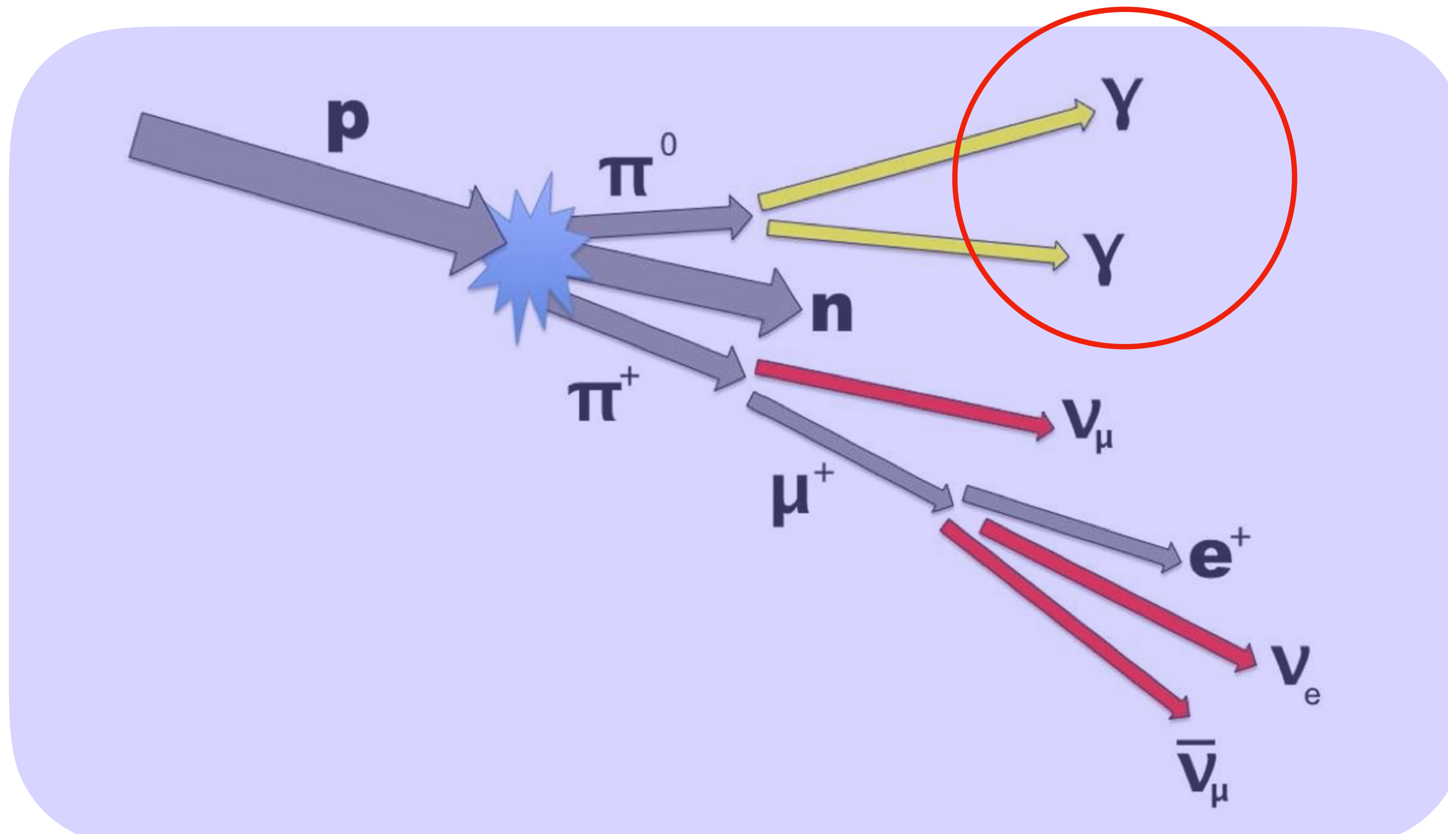
The interactions between cosmic rays and the interstellar gas produce an high-energy (HE) neutrino flux called **diffuse galactic flux.**



Ref. F. Vissani

Multimessenger approach

Neutrinos and photons are produced in the same hadronic interactions:



It is necessary a multimessenger study:
we combine results from both neutrinos (IceCube) and gammas (HESS, HAWC) observations.

Ref. F. Vissani

Galactic diffuse neutrinos and gammas

The neutrino and gamma diffuse fluxes can be written as:

$$\varphi_{i,\mathrm{diff}}(E_i,\hat{n}_i) = A_i \left[\int_{E_i}^{\infty} dE \, \frac{\sigma(E)}{E} \, F_i\left(\frac{E_i}{E}, E\right) \int_0^{\infty} dl \, \varphi_{\mathrm{CR}}(E, \mathbf{r}_\odot + l\,\hat{n}_i)\, n_{\mathrm{H}}(\mathbf{r}_\odot + l\,\hat{n}_i)\right]$$

i = ν, γ

where: $A_\gamma = 1 \quad A_\nu = \frac{1}{3}$

$\frac{\sigma(E)}{E} \, F_i\left(\frac{E_i}{E}, E\right)$ is the nucleon-nucleon cross section [Kelner & Aharonian, PRD 2008, 2010]

$n_{\mathrm{H}}(r)$ Gas density — Galprop [http://galprop.stanford.edu]

$\varphi_{\mathrm{CR}}(E, \mathbf{r})$ Differential CR flux

Galactic diffuse neutrinos and gammas

To estimate the diffuse fluxes we used 3 different cosmic rays models:

Case A: The CR flux is homogeneous in the Galaxy

$$\varphi_{\rm CR}(E,\mathbf{r}) = \varphi_{{\rm CR},\odot}(E)$$

Case B: The CR flux follows the distribution of galactic CR sources (SNRs, PWN)

$$\varphi_{\rm CR}(E,\mathbf{r}) = \varphi_{{\rm CR},\odot}(E)\, g(\mathbf{r})$$

$$g(\mathbf{r}) = \frac{n_{\rm S}(\mathbf{r})}{n_{\rm S}(\mathbf{r}_\odot)}$$

$n_{\rm S}(\mathbf{r}) =$ source (SNRs, pulsars) density

Case C: The CR flux has a spectral index that depends on the galactocentric distance

$$\varphi_{\rm CR}(E,\mathbf{r}) = \varphi_{{\rm CR},\odot}(E)\, g(\mathbf{r})\, h(E,\mathbf{r})$$

$$h(E,\mathbf{r}) = \left(\frac{E}{\overline{\overline{E}}}\right)^{\Delta(\mathbf{r})}$$

$\Delta(r,z) =$ position dependent of the CR spectral index

and assuming $h(E,\mathbf{r}) \to \bar{h}(\mathbf{r}) = \left(\frac{E_{CR}}{\bar{E}}\right)^{\Delta(\mathbf{r})}$ $\quad E_{\rm CR} = 2\ {\rm PeV}$

Galactic diffuse neutrinos: results

The flux of high-energy neutrinos of each flavour at Earth (in the energy range 10 TeV—1 PeV) is:

$$\varphi_\nu(E_\nu, \hat{n}_\nu) = \mathcal{F}(E_\nu)\mathcal{I}(\hat{n}_\nu)$$

where: $\mathcal{I}(\hat{n}_\nu) = \mathcal{A}, \mathcal{B}, \mathcal{C}$ depending on the considered scenario

Case A A $\dfrac{\mathcal{F}(E_\nu)}{\mathcal{F}_{\rm iso}(E_\nu)} = 5\%$

Case B B $\dfrac{\mathcal{F}(E_\nu)}{\mathcal{F}_{\rm iso}(E_\nu)} = 7\%$ for $E_\nu = 100\ \mathrm{TeV}$

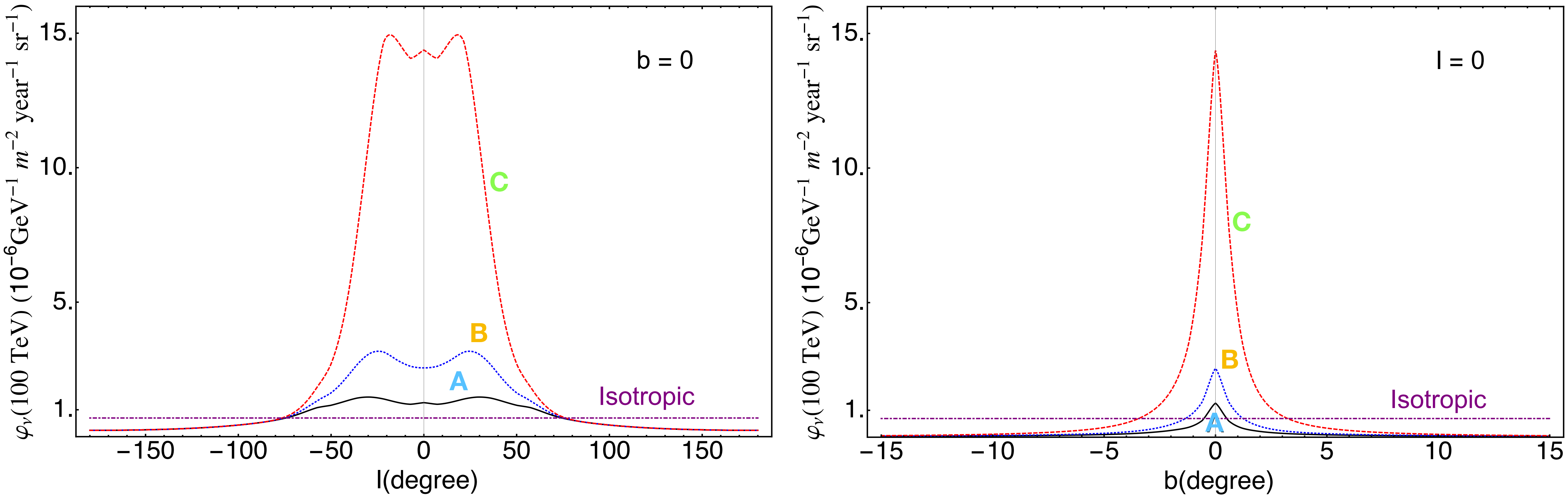
Case C C $\dfrac{\mathcal{F}(E_\nu)}{\mathcal{F}_{\rm iso}(E_\nu)} = 13\%$

The integrated galactic diffuse neutrino flux is always subdominant respect to the isotropic signal

[Pagliaroli, Villante JCAP 2017]

Galactic diffuse neutrinos: results

Galactic diffuse neutrinos as a function of the Galactic coordinates:



- It always exists a region where the galactic diffuse flux is comparable with or larger than the isotropic component.

- The region where galactic neutrinos dominate is quite narrow and the optimal detector should have a good pointing cabability or a large counting rate to extract this signal.

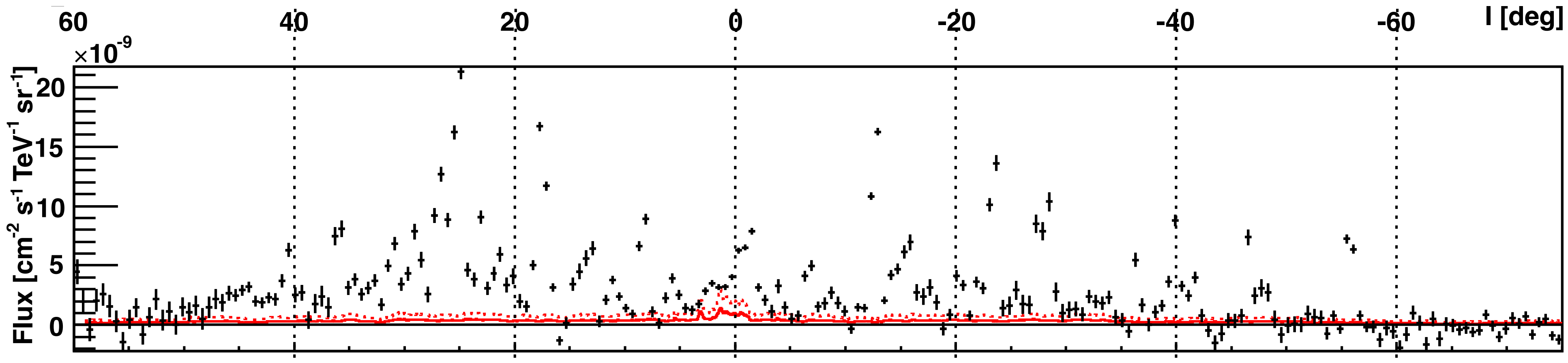
[Pagliaroli, Villante JCAP 2017]

Gamma-rays: HESS and HAWC

Observe the total high-energy γ-ray flux on 2 windows on the galactic disk:

HESS:

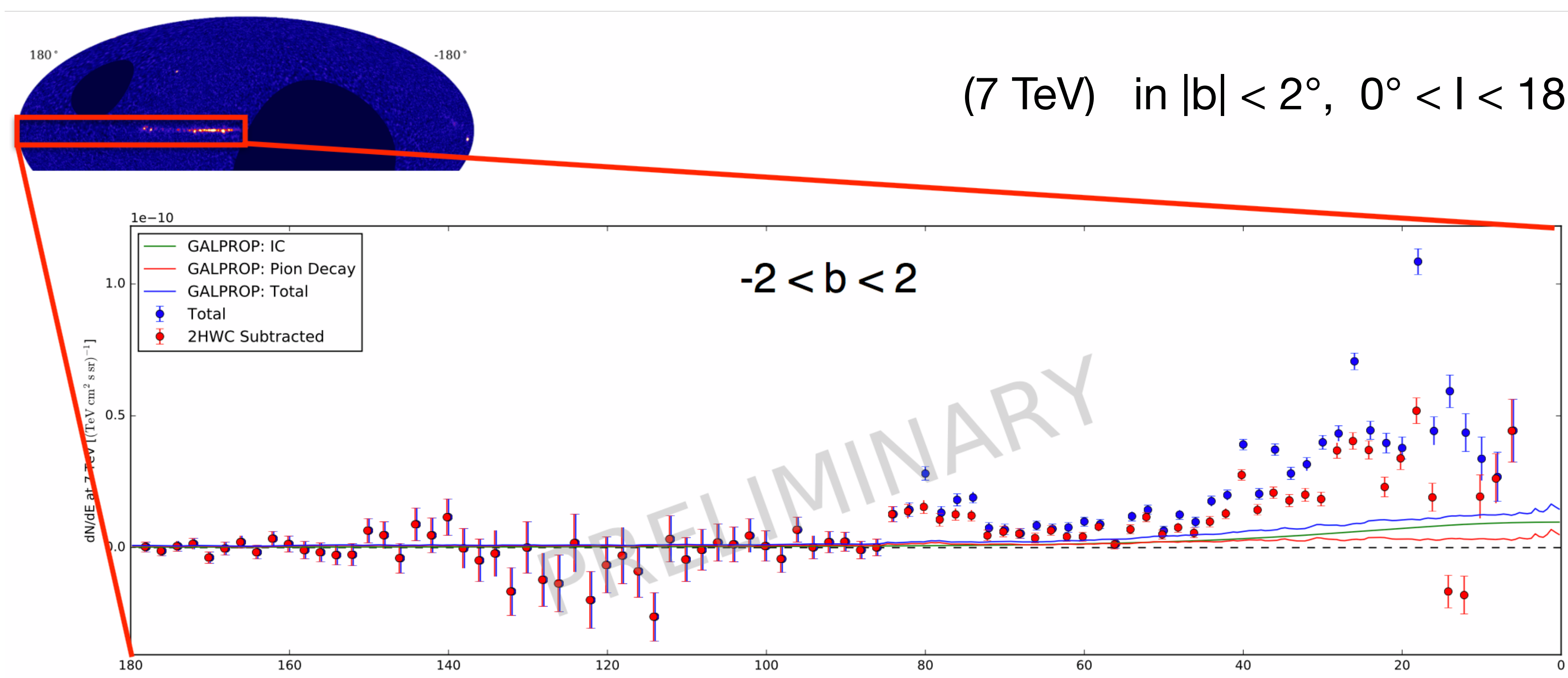
(1 TeV) in $|b| < 2°$, $-75° < l < 60°$



[HESS coll. 2014]

HAWC:

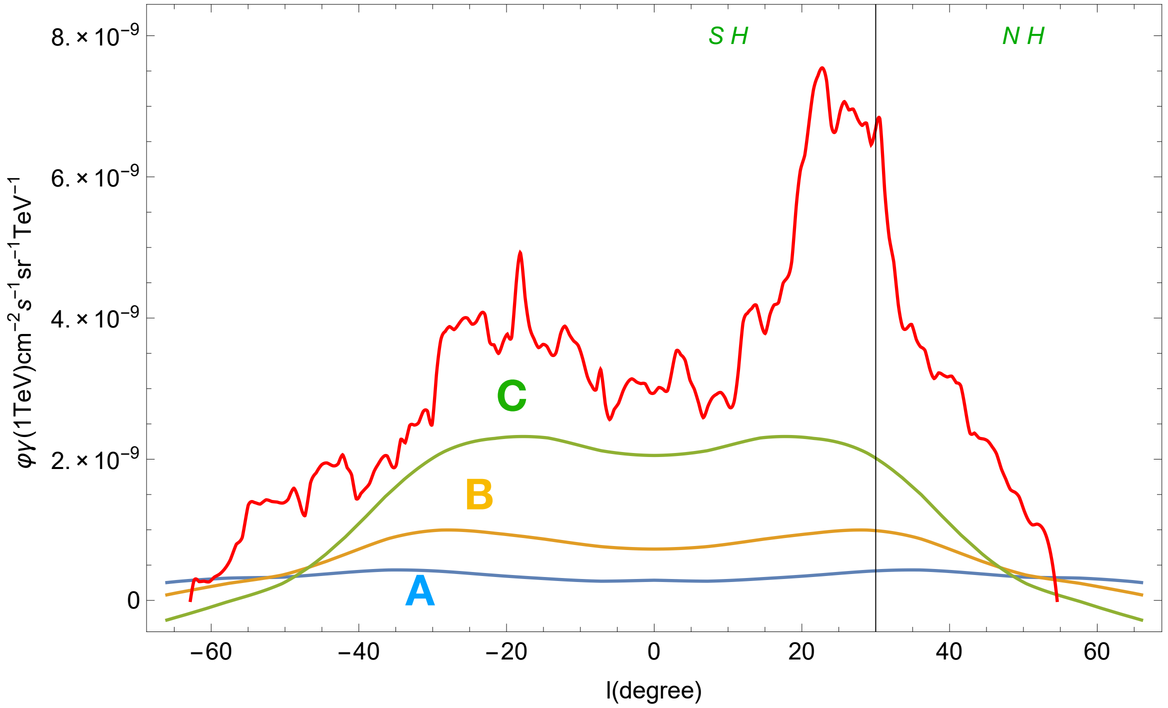
(7 TeV) in $|b| < 2°$, $0° < l < 180°$



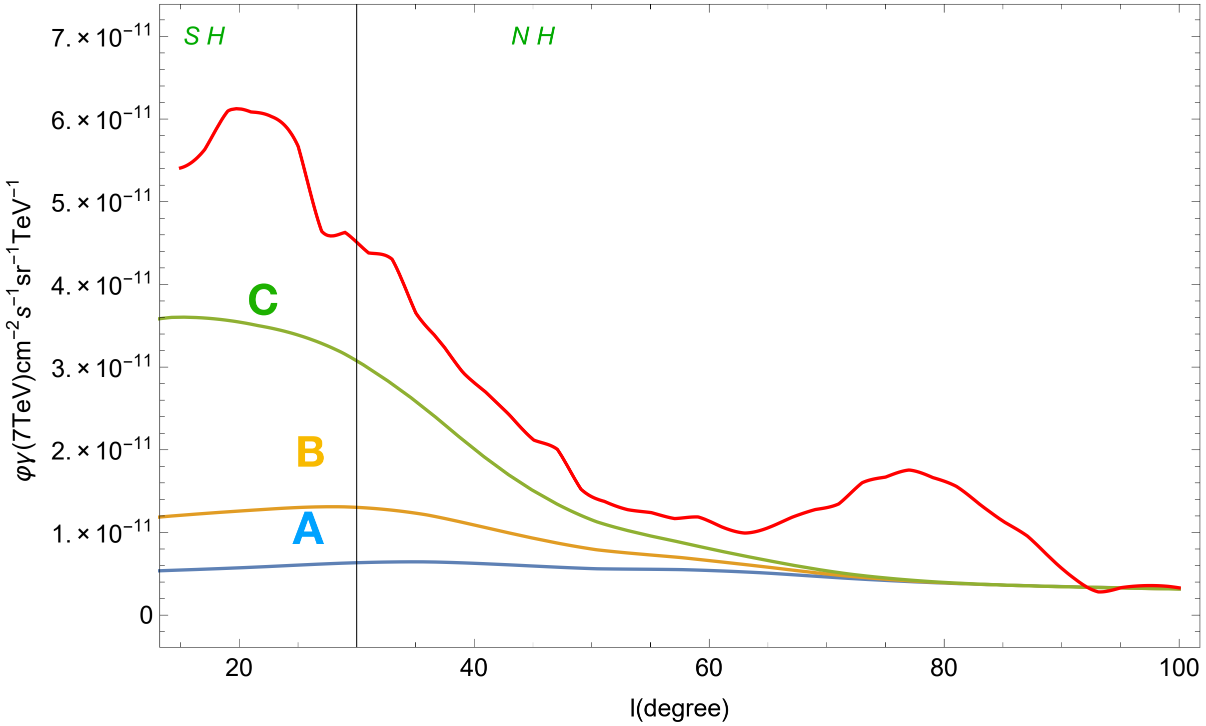
[HAWC coll. 2017]

Galactic diffuse gamma-rays: results

Comparison with the total flux of HESS 2014 (1 TeV):



Comparison with the total flux of HAWC 2018 (7 TeV):



[work done in collaboration with G. Pagliaroli, F. L. Villante, V. Vecchiotti]

Conclusions

We estimated the contribution of diffuse galactic fluxes of neutrinos and gammas based on 3 assumption on cosmic rays distribution in the galaxy.

We compared the diffuse fluxes with experimental data:

- The diffuse neutrino flux is subdominant respect to the isotropic signal observed by IceCube
- The diffuse gamma flux is compatible with both the total fluxes observed by HESS and HAWC

Work in progress:

- Include the contribution of the galactic sources.

Thank you

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The CR flux: local determination

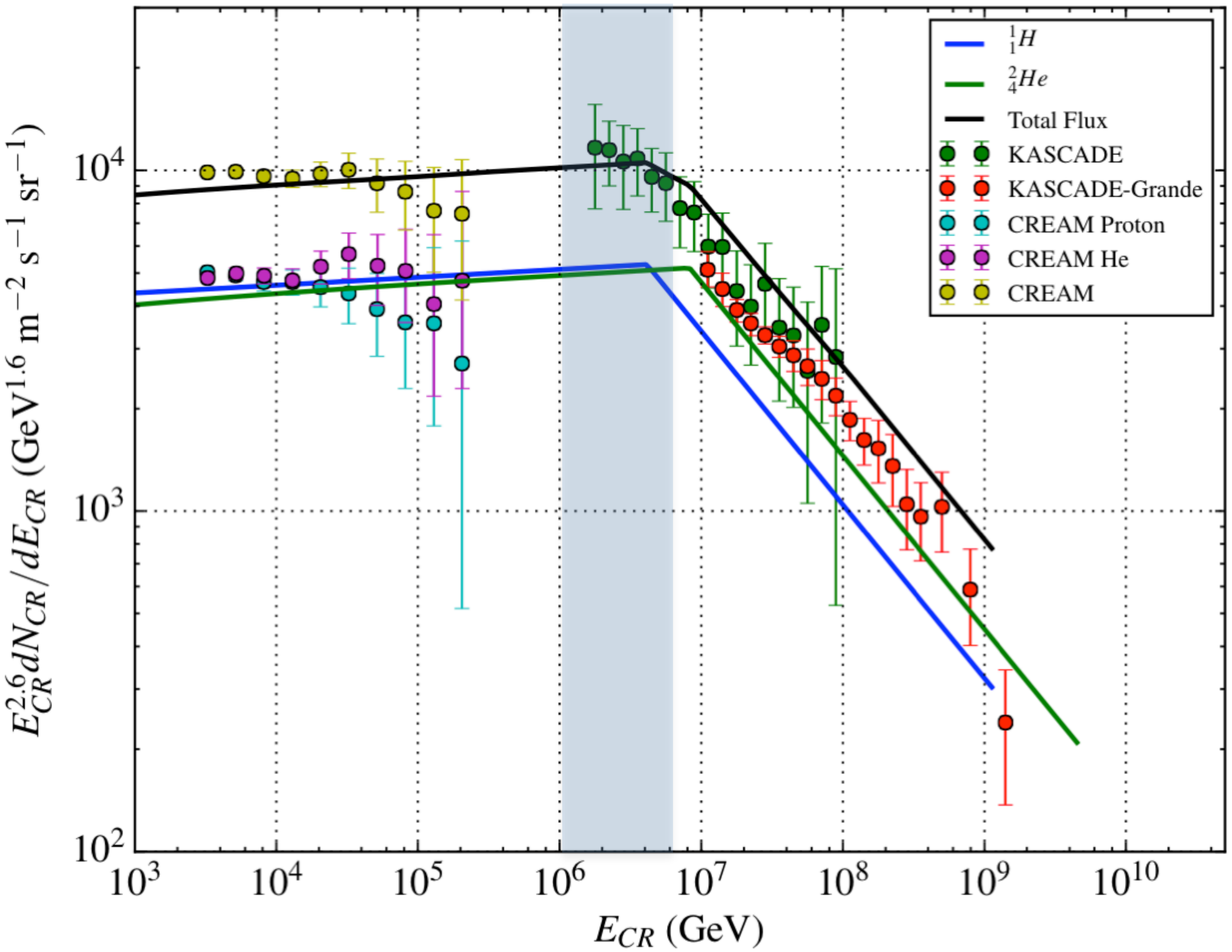
The neutrino flux at E_ν=100 TeV is determined by CR flux at:

$$E \simeq 20\,E_\nu = 2\,\mathrm{PeV}$$

At the Sun position the CR flux is constrained by observational data [CREAM, KASCADE, KASCADE-Grande]

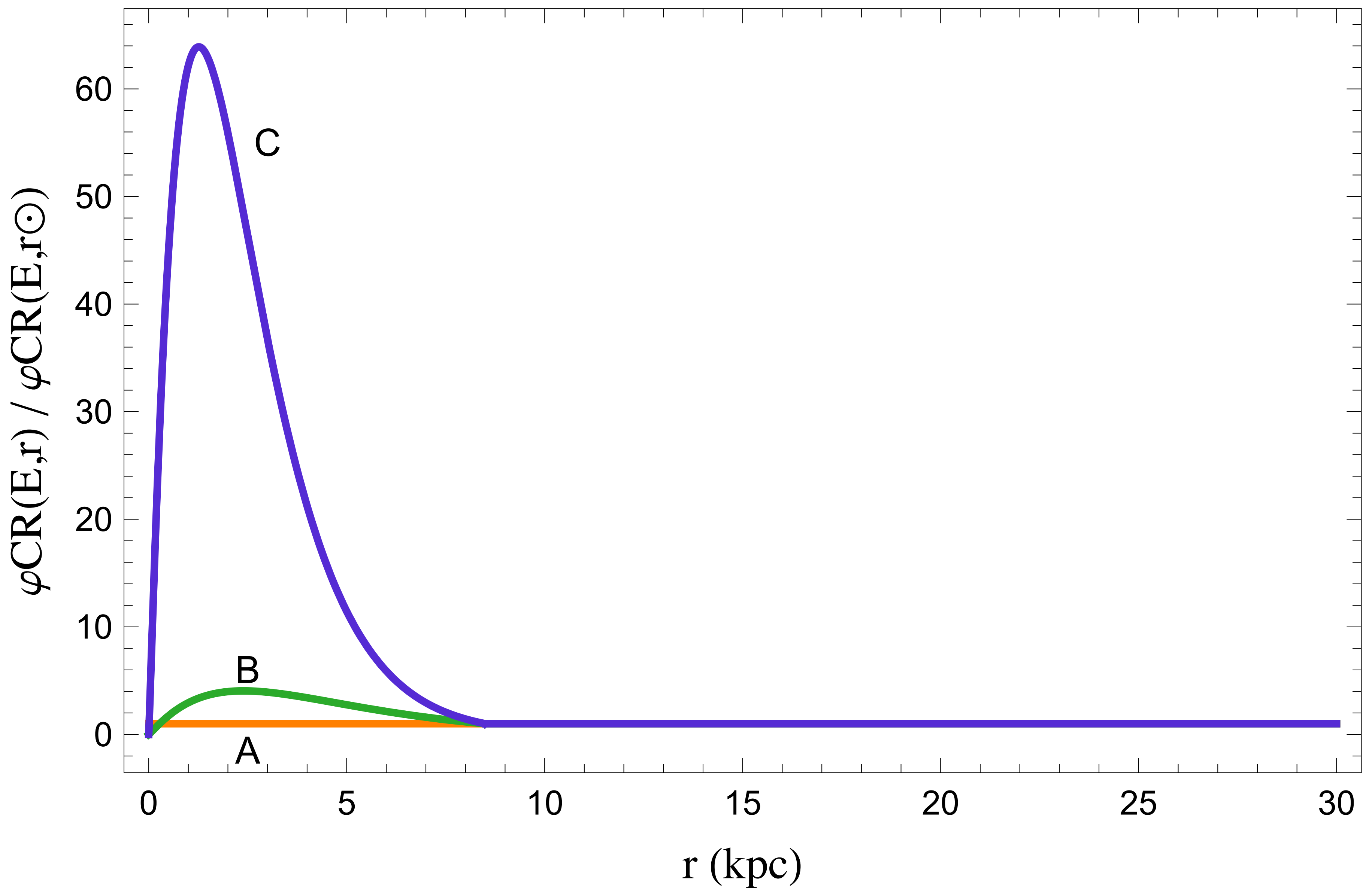
$$\varphi_{\mathrm{CR},\odot}(E) \equiv \sum_A A^2 \frac{d\phi_A}{dE_A d\Omega_A}(AE)$$

Broken Power Law – Ahlers et al., PRD 2016



The CR distribution: A, B, C

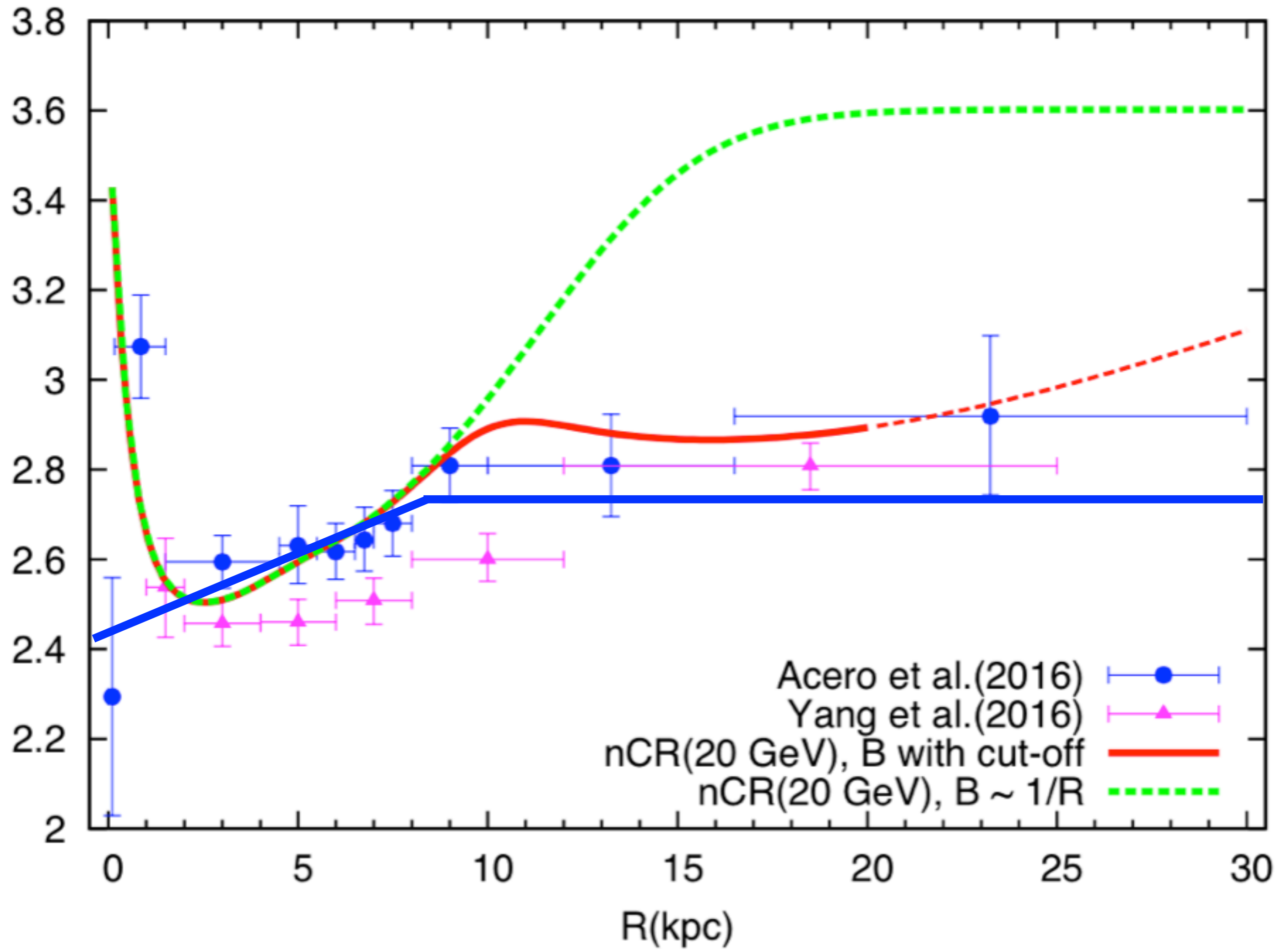
Plots of the Cosmic Rays distributions in the Galaxy for the 3 cases depending on the galactocentric distance at E = 2 PeV :



The CR distribution: spectral index

Cosmic-rays spectral index distribution respect to the galactocentric distance:

CR spectral index
[re-adapted from Morlino et al, 2016]



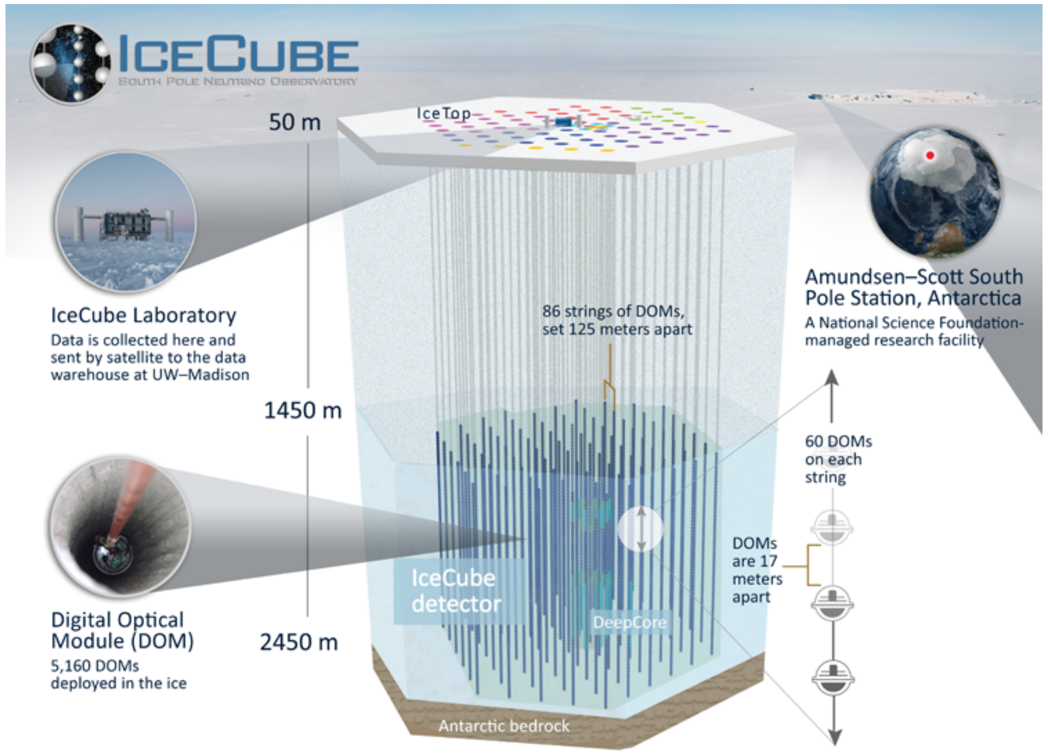
$$\Delta(r) = 0.3\left(1 - \frac{r}{r_\odot}\right) \quad \text{for} \quad r \leq r_\odot$$

IceCube

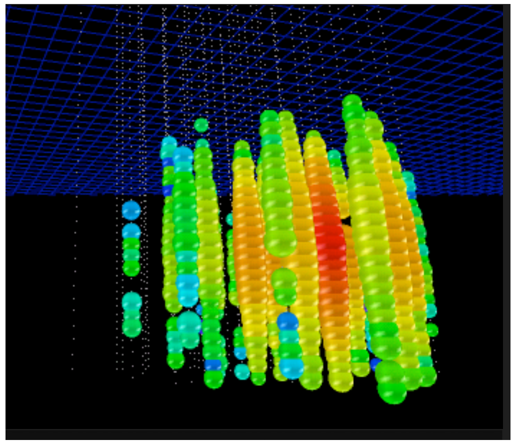
Neutrino telescope in Antarctica;

Ice is the interaction medium;

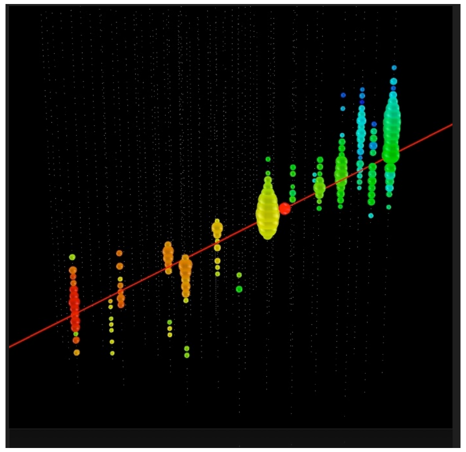
It observes Cherenkov light of particles produced in the interactions of neutrinos in ice.



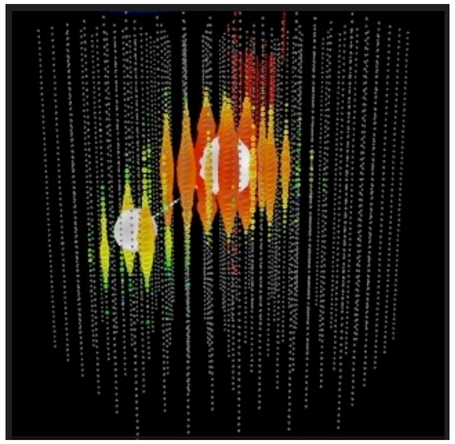
3 event topology:



Showers
(ang. resolution 15°)



Tracks
(ang. resolution 1°)



Double-Bang