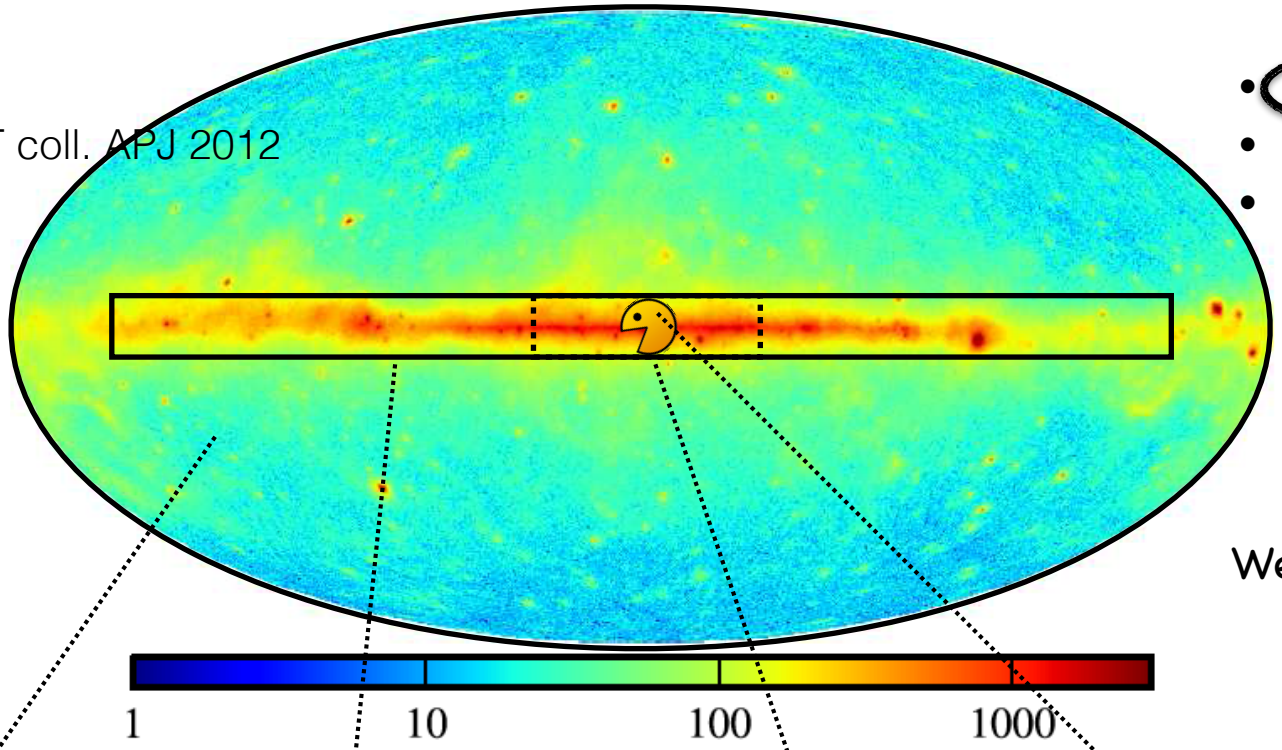
Modeling the galactic neutrino emission from GeV to PeV with a special look to neutrinos

Antonio Marinelli (INFN Pisa) - KM3NeT/ANTARES coll.

MANTS Meeting 2016 - Mainz (October 1-2)

We observe diffuse sea emission in gamma-ray

Fermi-LAT coll. APJ 2012



- Photopion
- Bremsstrahlung
- Inverse Compton

We expect also ν

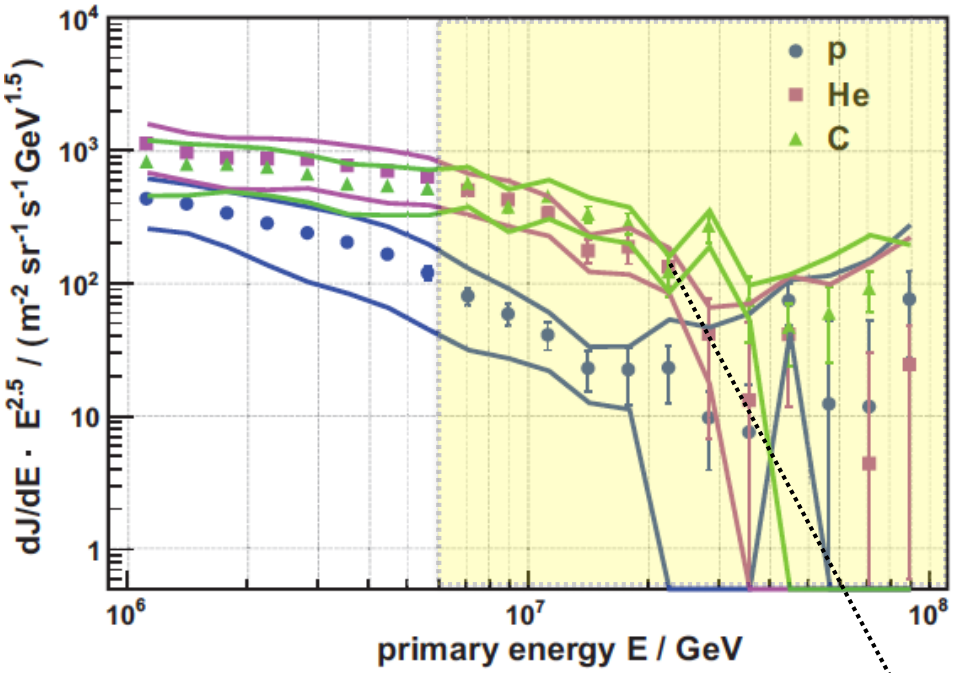
Observed Fermi-LAT counts in the energy range 200 MeV to 100 GeV after point-sources subtraction (log scale = counts/pixel)

How to find the diffuse ν signature with ANTARES-KM3NeT-IceCube?

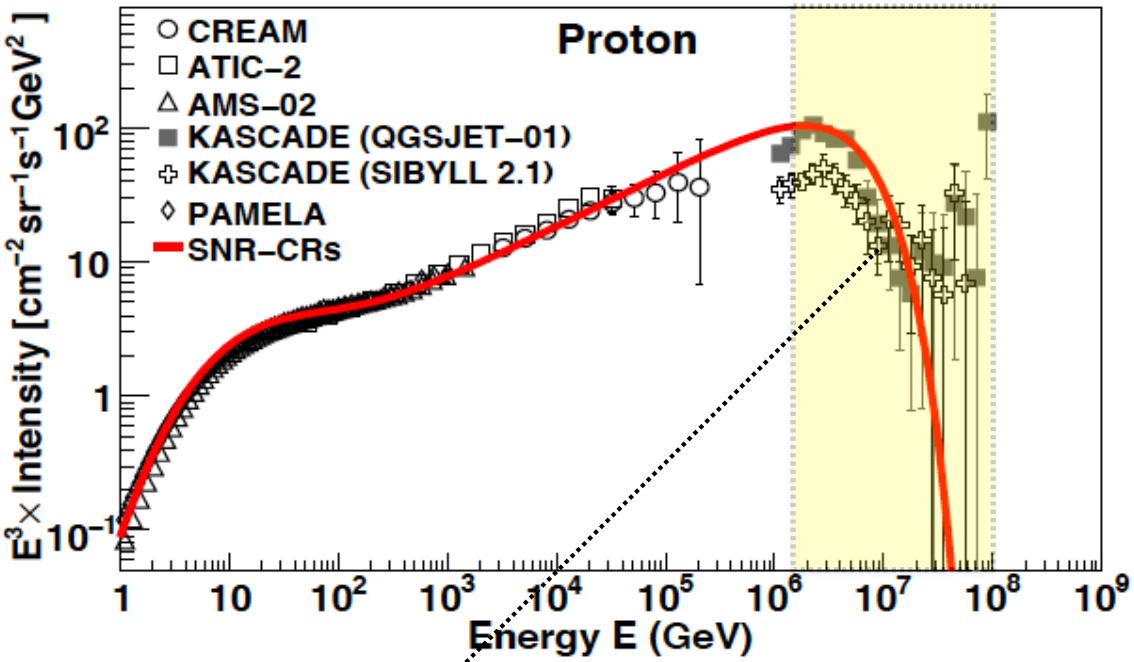
- Full sky analysis
- Galactic Plane Analysis
- Galactic Ridge analysis
- Pevatron analysis

We should have Pevatrons in our Galaxy

KASCADE_Grande coll. arXiv:1306.6283



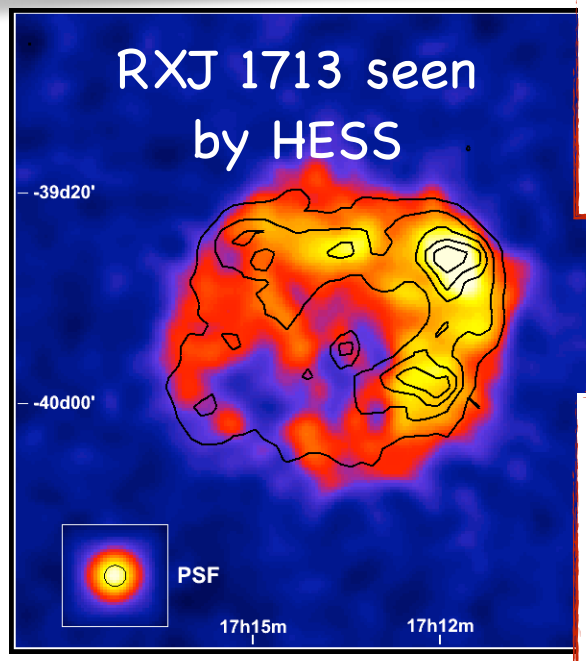
Thoudam et al. arXiv:1605.03111



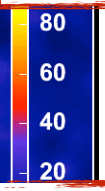
We should understand better the region between few PeV to 100 PeV, How is the spectrum? Where is the cut-off? Better understanding of the transition Galactic-Extragalactic.

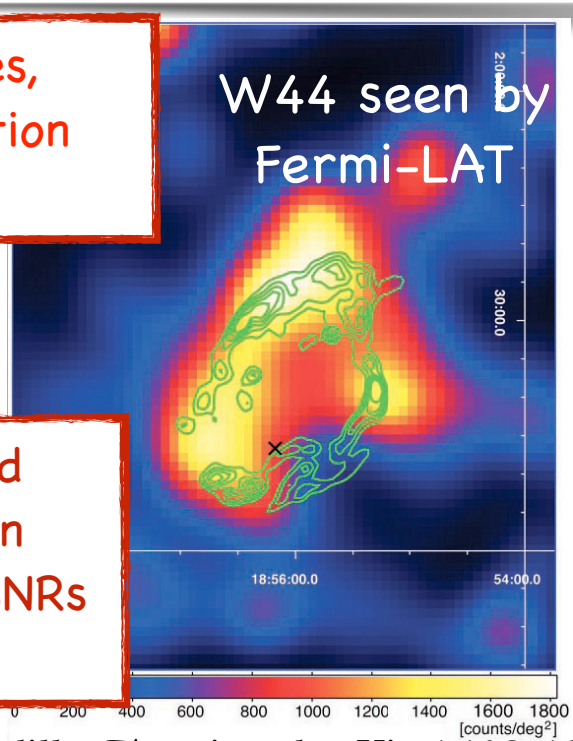
This is a KEY POINT to understand the galactic accelerators

Who accelerate CR up to PeVs in our Galaxy?



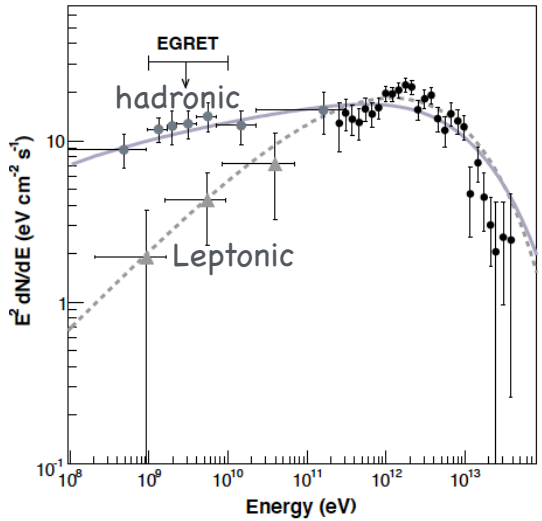
SNRs good candidates, proofs of CR acceleration and TeV emission



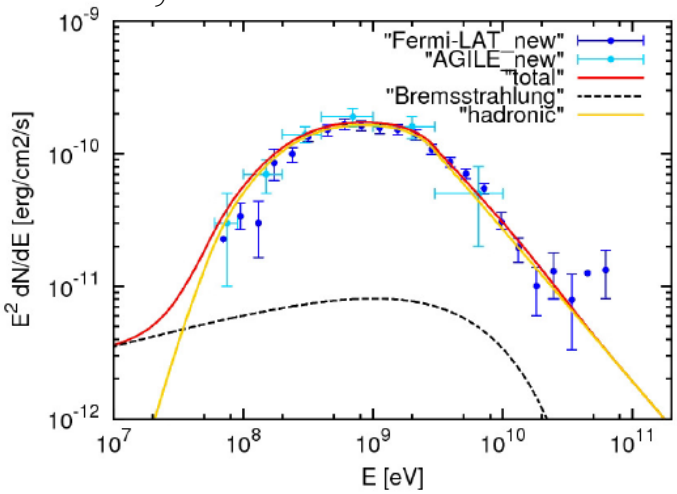


gamma-ray well fitted with hadronic emission however not observed SNRs as a Pevatron yet

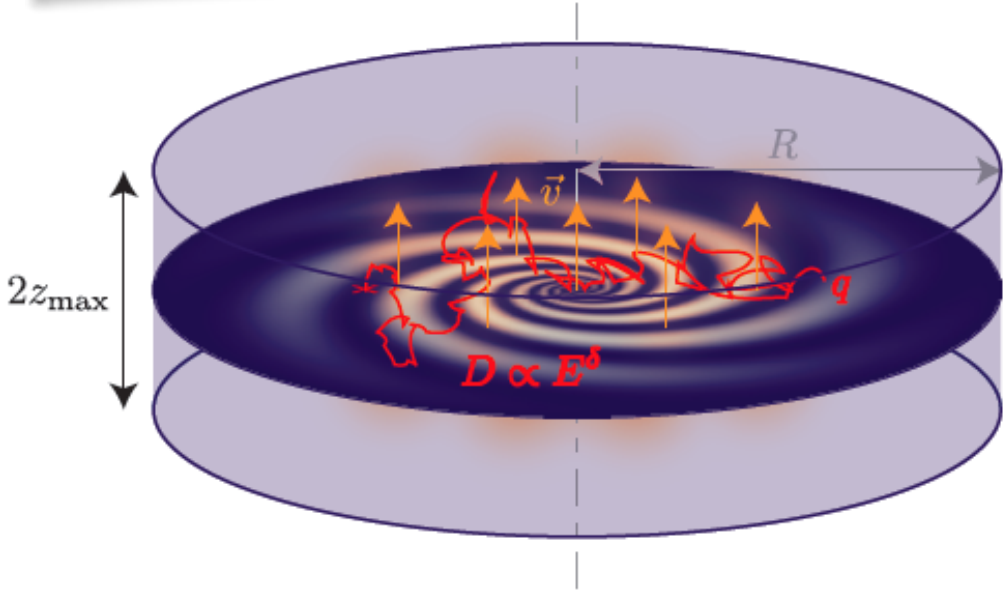
Fermi-LAT coll. arXiv:0902.1089



Cardillo, Tavani et al arXiv:1403.1250



How the CR trasport behaves in our galaxy?



ρ : particle rigidity

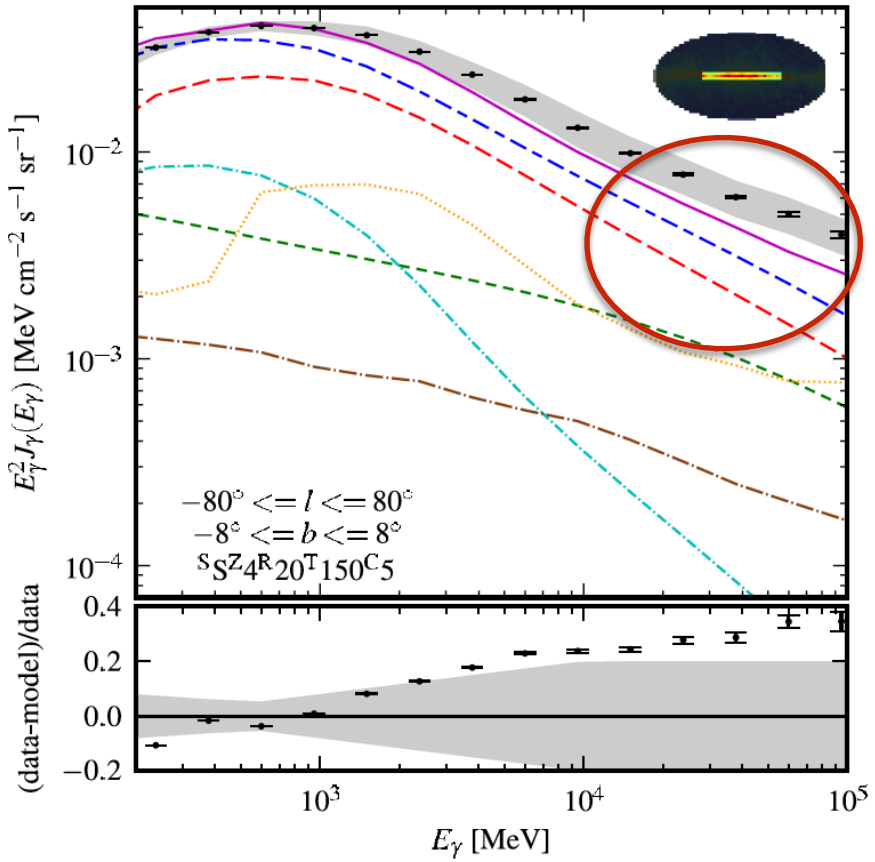
D : diffusion coefficient

R : distance from galaxy center

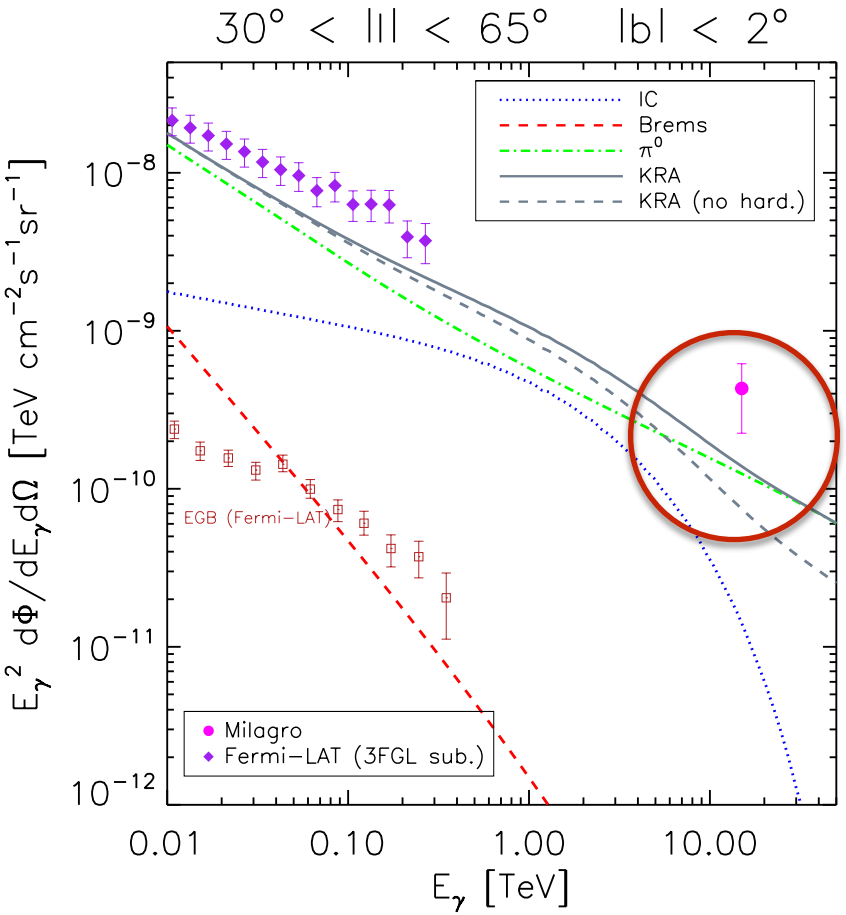
- The diffusion coefficient $D \propto \rho^{\delta}$, in a conventional scenario δ is constant.
- Parameters are tuned against local CR spectra and the secondary/primary ratios.
- These quantities however probe only few kpc's about our position. Propagation may behave quite differently in the inner few kpc of the Galaxy !

Anomalies in the GP diffuse emission understanding

Fermi-LAT coll. ApJ 2012



Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1504.00227



Fermi Benchmark model: δ=0.3

γp=2.72 (in the whole galaxy)

zh=4 kpc do not match

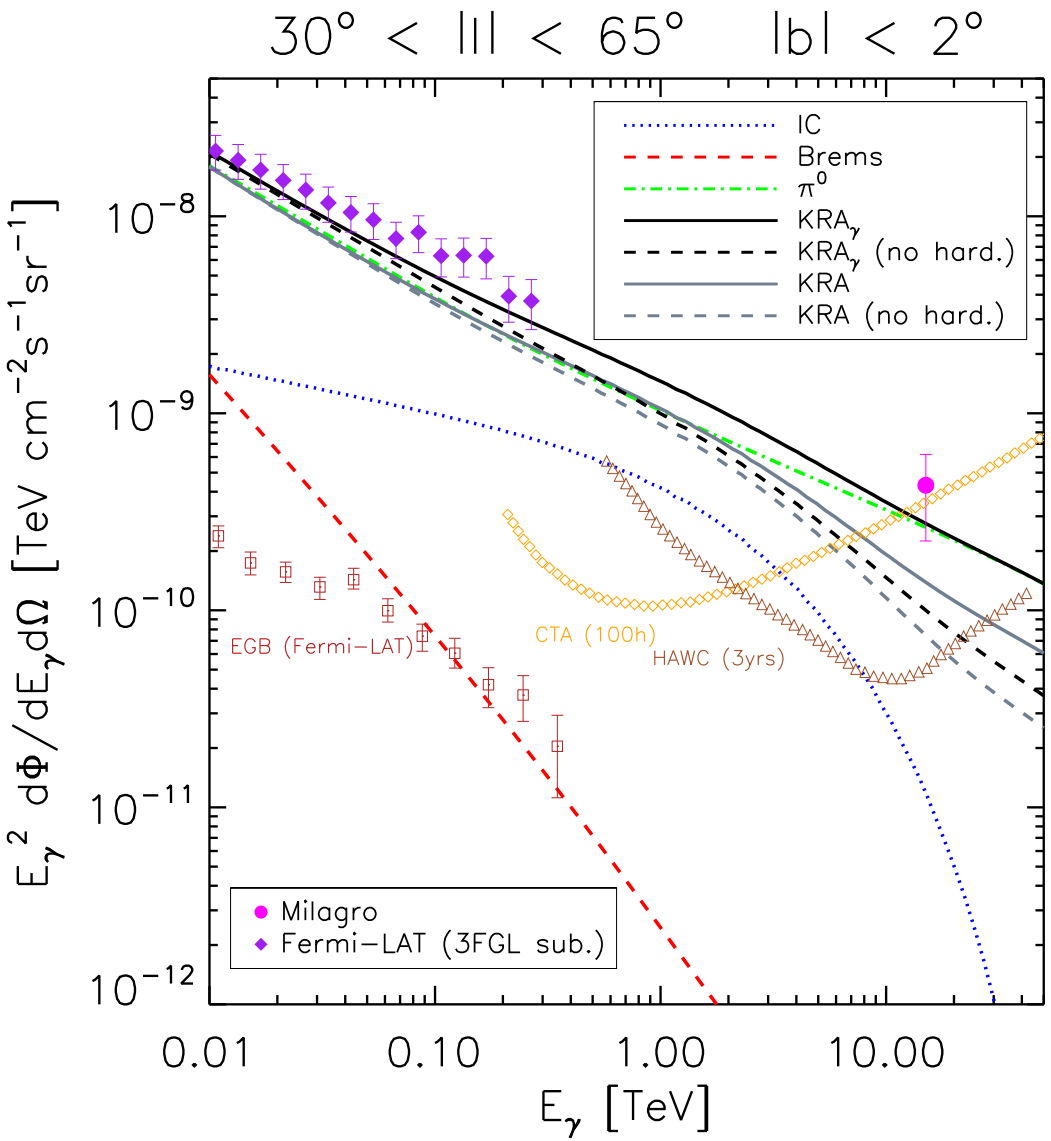
Fermi data of GP at high energies

Also Milagro excess is not explained with a conventional scenario

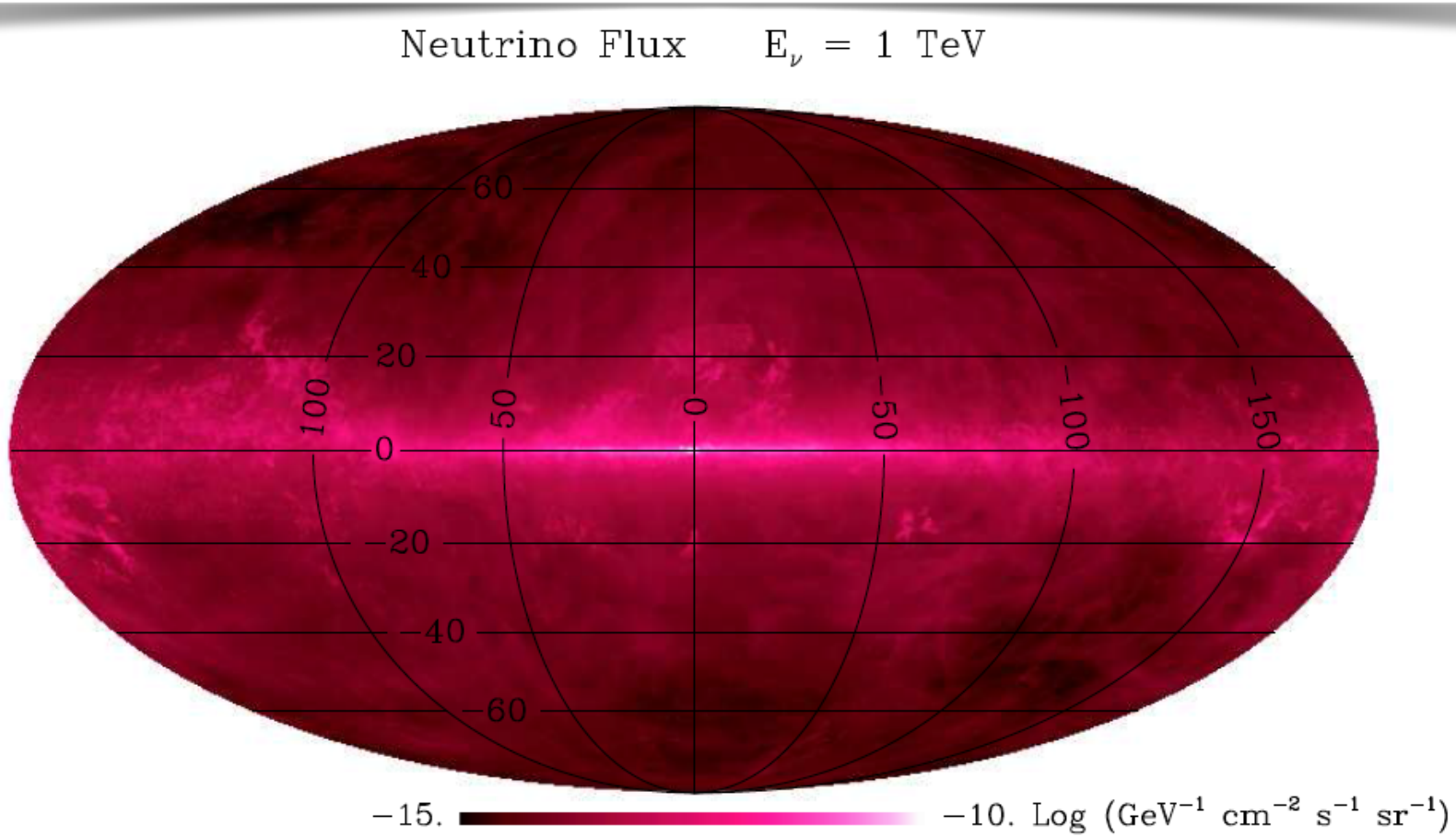
Introduction of KRA$_\gamma$ model

- Milagro measured the diffuse γ-ray flux from the inner Galactic plane @ 15 TeV
- Milagro flux exceeds the predictions of conventional models based on GALPROP. (This was a longstanding problem in CR physics)
- The KRA$_\gamma$ model consistently reproduces Fermi-LAT data (point sources properly subtracted) and Milagro. No extra-tuning required !
- CR hardening @ 250 GeV/n is crucial though not sufficient.

Gaggero, Grasso, Marinelli, Urbano, Valli, APJ letter arXiv:1504.00227



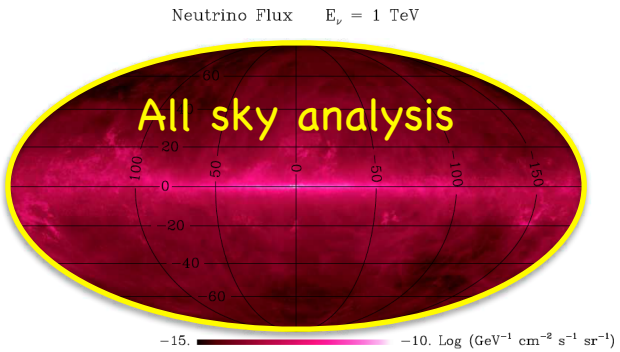
Galactic neutrino emission with KRA$_\gamma$ model

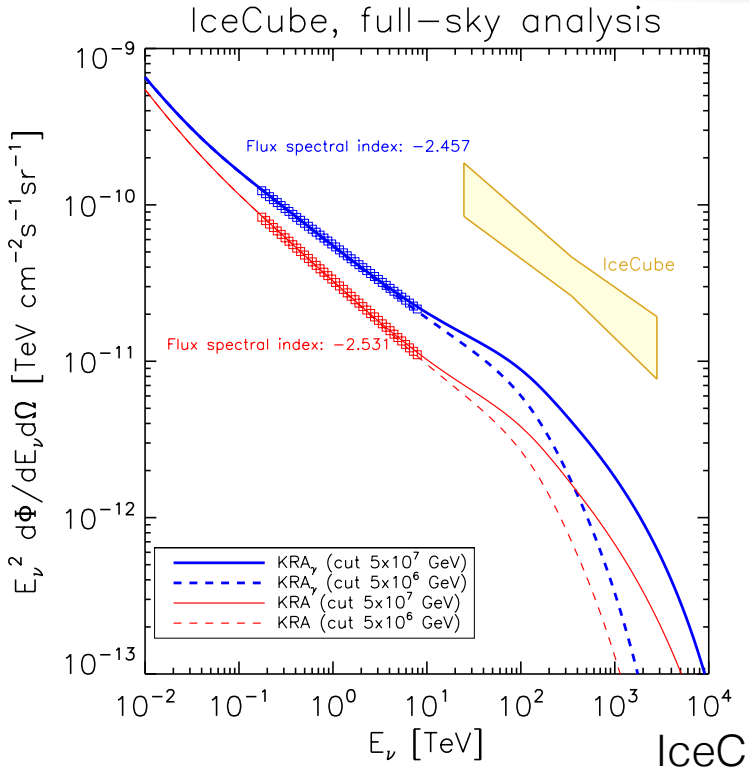


Skymap of neutrino flux produced with KRA$_\gamma$ model.

- The p-nucleon interaction is computed following Kamae et al. 2006
- The target gas distribution is the same used for gamma-ray production (as also used by the Fermi collaboration)

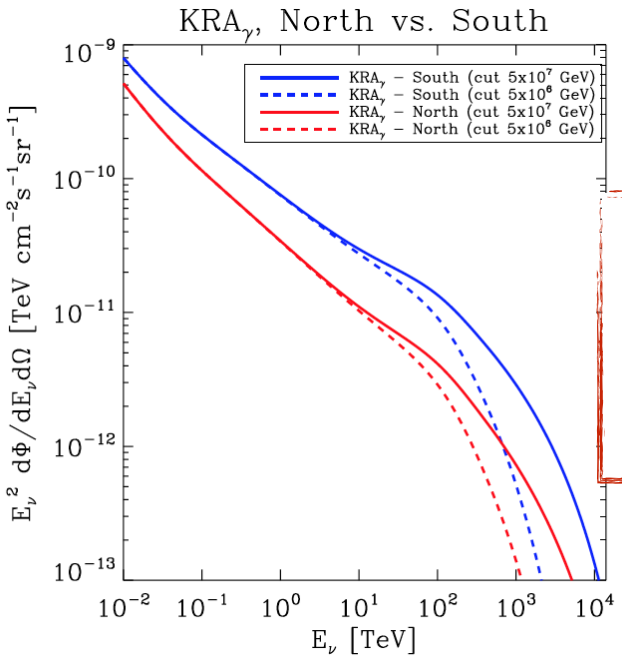
Full sky signature of ν from KRA$_\gamma$ model





Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1507.07796

15% of IceCube measured ET excess explained with galactic KRA$_\gamma$ neutrinos



Discrepancy North-South in IceCube spectrum cannot be explained just by the different galactic component!

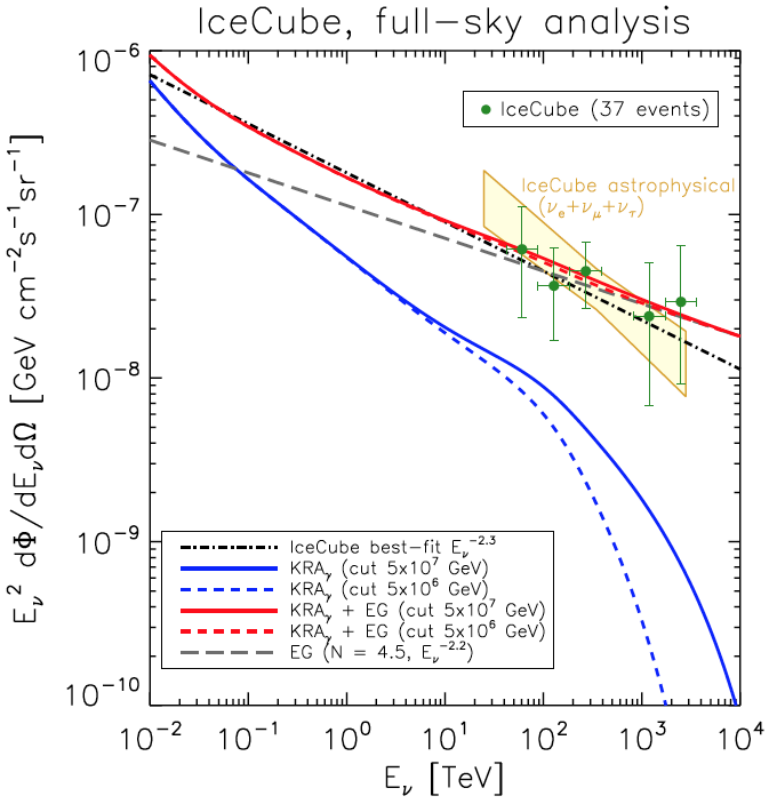
IceCube coll. arXiv:1507.03991

Parameter	Best fit	68% C.L.	90% C.L.
ϕ_N	2.1	$0.5 - 5.0$	$0.1 - 7.3$
γ_N	2.0	$1.6 - 2.3$	$1.2 - 2.5$
ϕ_S	6.8	$5.3 - 8.4$	$4.4 - 9.5$
γ_S	2.56	$2.44 - 2.67$	$2.36 - 2.75$

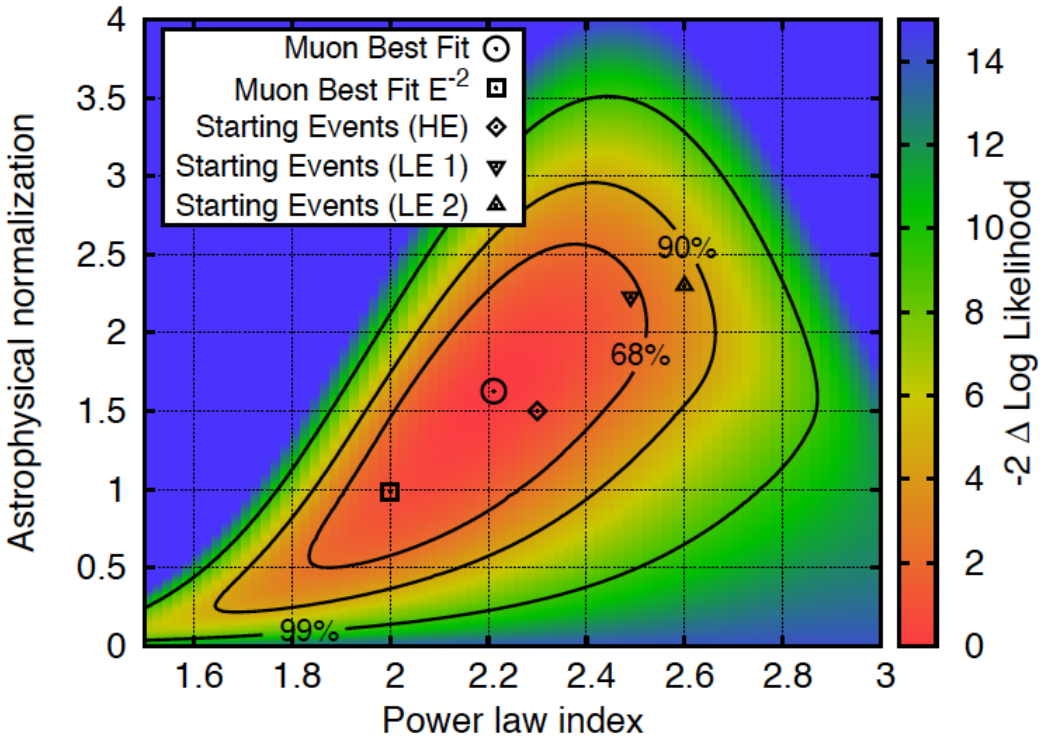
Note. — ϕ_N and ϕ_S are the all-flavor neutrino fluxes at 100 TeV in the northern and southern sky, respectively; γ_N and γ_S are the corresponding spectral indices. The fluxes are given in units of $10^{-18}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}$.

Full sky ν from KRA$_\gamma$ model + EG best fit

Gaggero, Grasso, Marinelli, Urbano, Valli,
VLVNT2015 arXiv:1604.05776



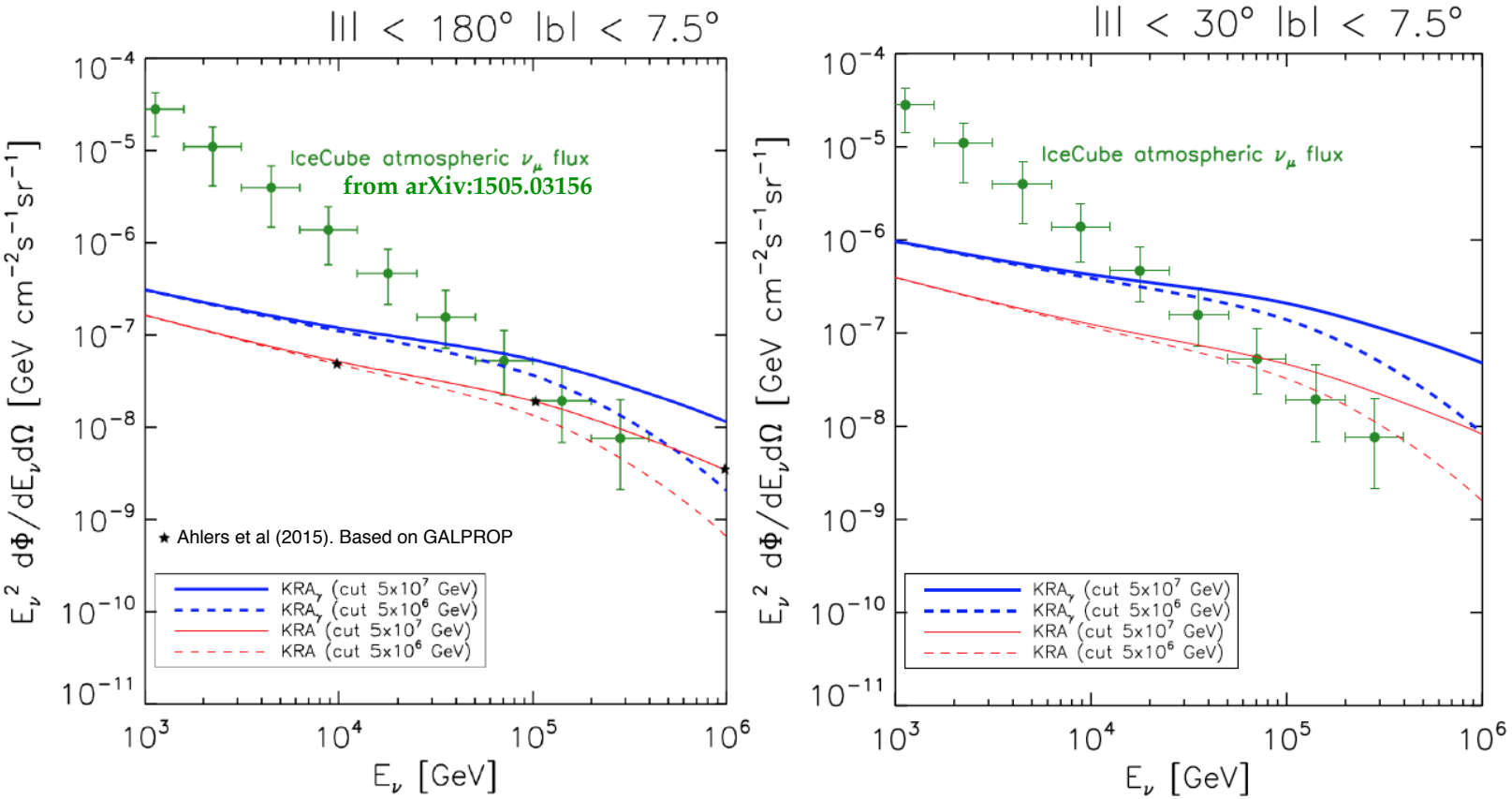
IceCube coll., PRL, vol.115, n.8, 2015



IceCube best fit of nu(mu) from northern hemisphere (May 2010- May 2012) + full sky KRA$_\gamma$ prediction are enough to explain the full sky spectrum of HESE 3 years

Galactic plane expected ν from KRA$_\gamma$ model

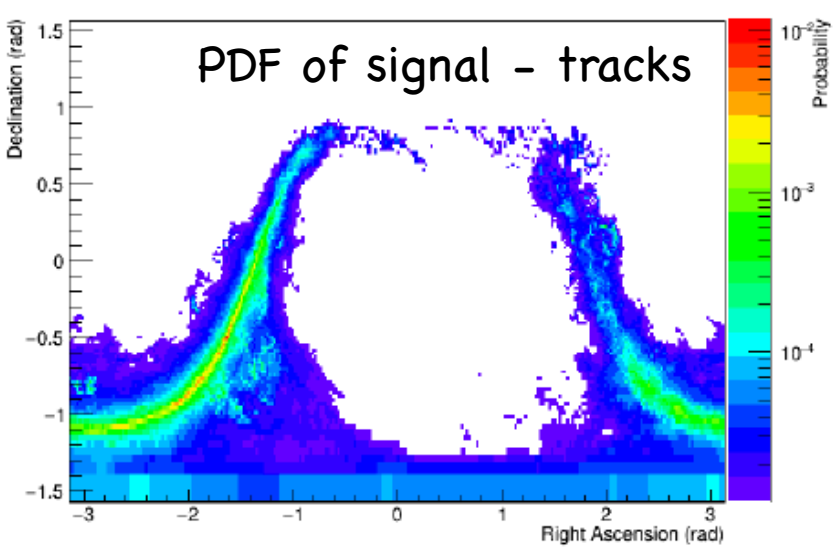
A.Marinelli et al. ICRC2015

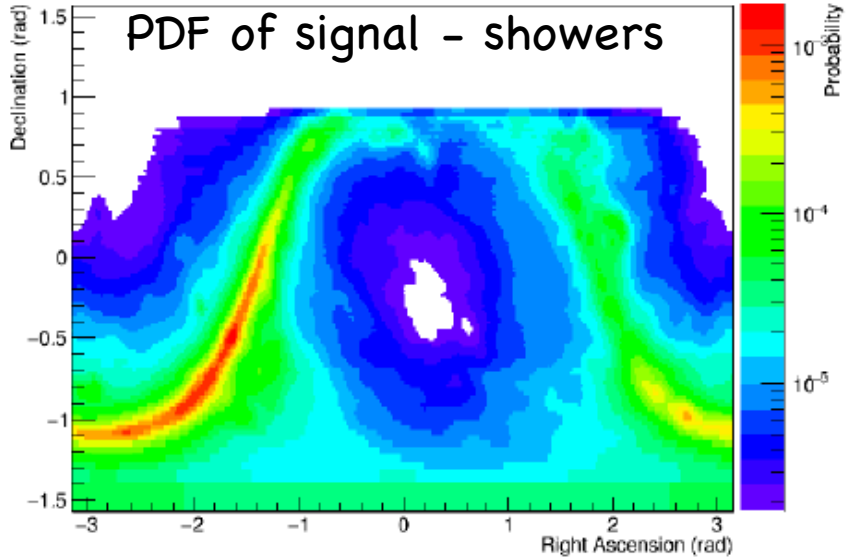


Comparison between neutrino spectrum produced with standard KRA model and the new KRA$_\gamma$ model from the whole galactic plane (on the left) and for the inner galactic plane (on the right).

Looking at diffuse galactic ν with IceCube and ANTARES

Timothée Gregoire Neutrino 2016





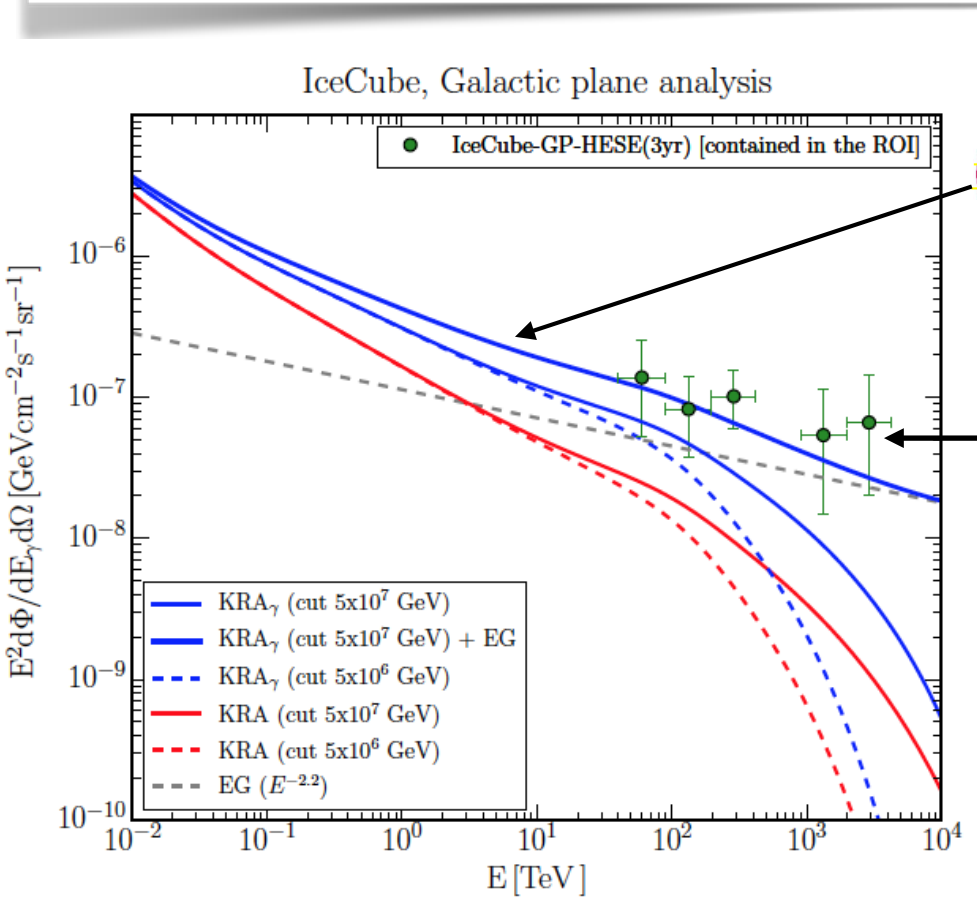
Ongoing full sky analysis with muonic neutrinos,
for ANTARES:

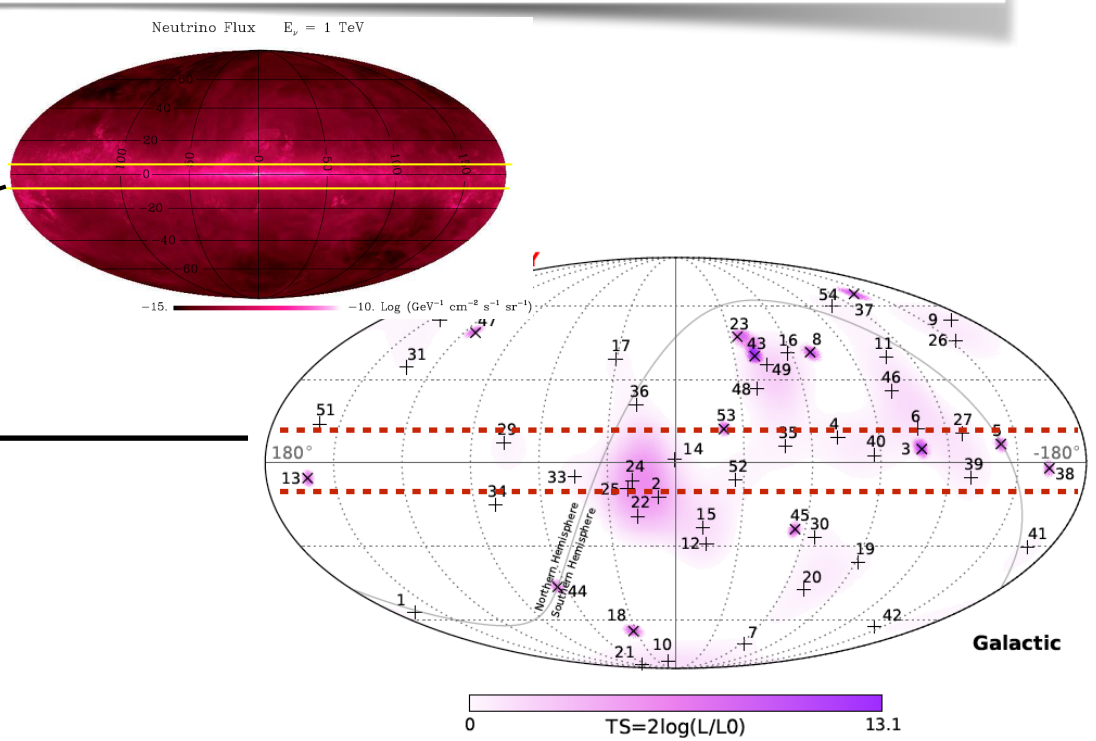
- Timothée Gregoire

For IceCube:

- Jon Dumm (will present lather the results), Kai Michael Krings, Christian Haack, Mike Richman (CASCADE + Tracks)

Galactic plane expected ν from KRA$_\gamma$ model



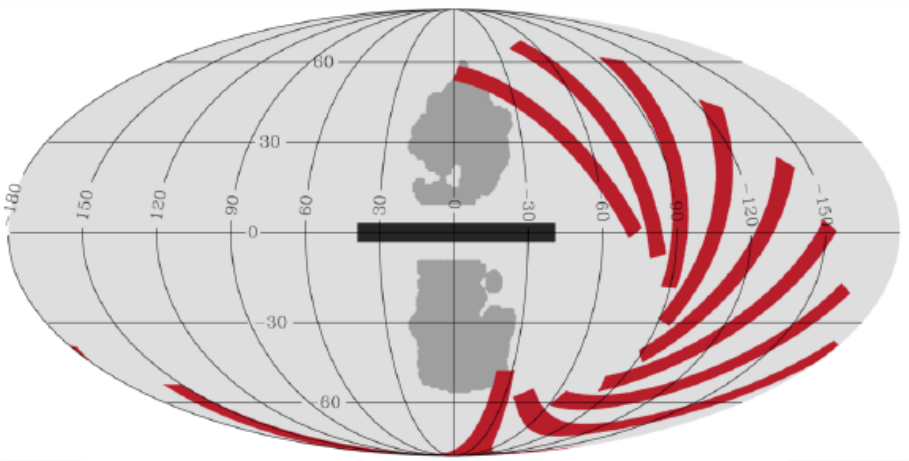


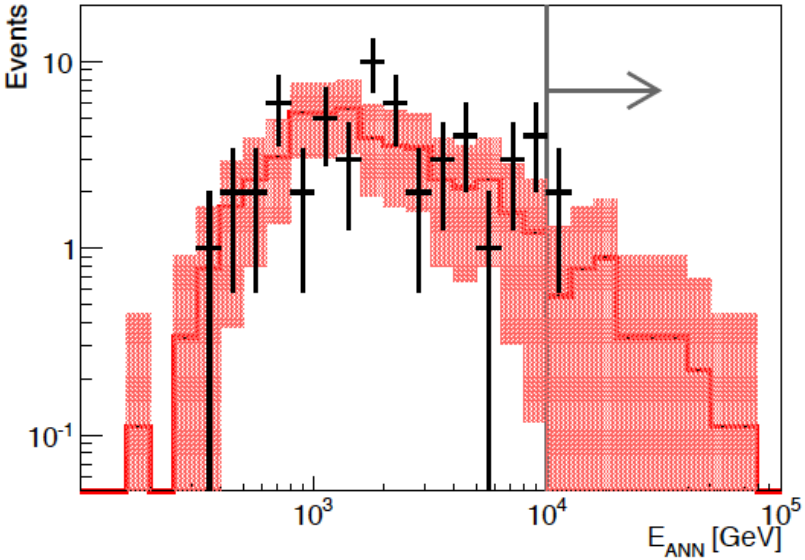
Gaggero, Grasso, Marinelli, Urbano, Valli, VLVNT2015 arXiv:1604.05776

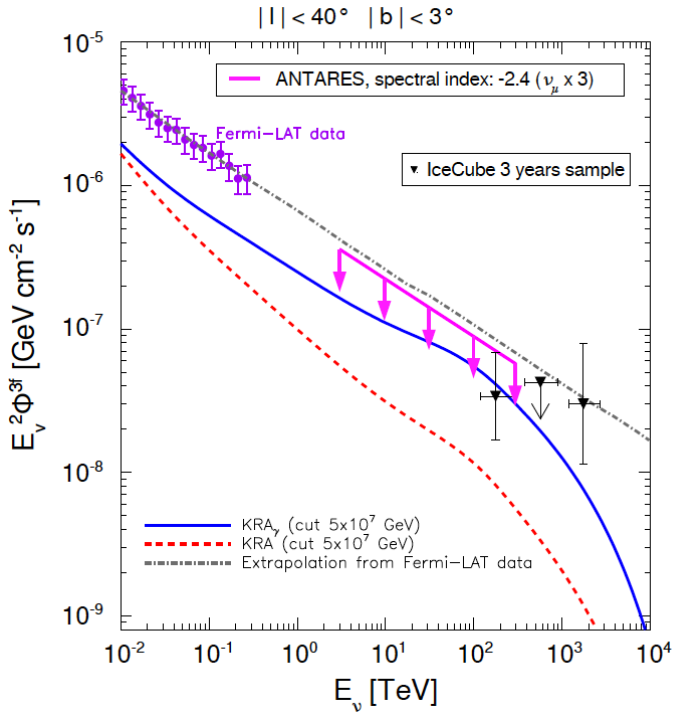
For the whole galactic plane with ϑ<7.5 half of astrophysical flux can be explained with KRA$_\gamma$ and the other half with EG best fit analysis. The IceCube spectrum is obtained considering the contained events for this region

Inner Galactic plane expected ν and ANTARES analysis

ANTARES coll. Phys lett. B 2016.06.0511504.00227



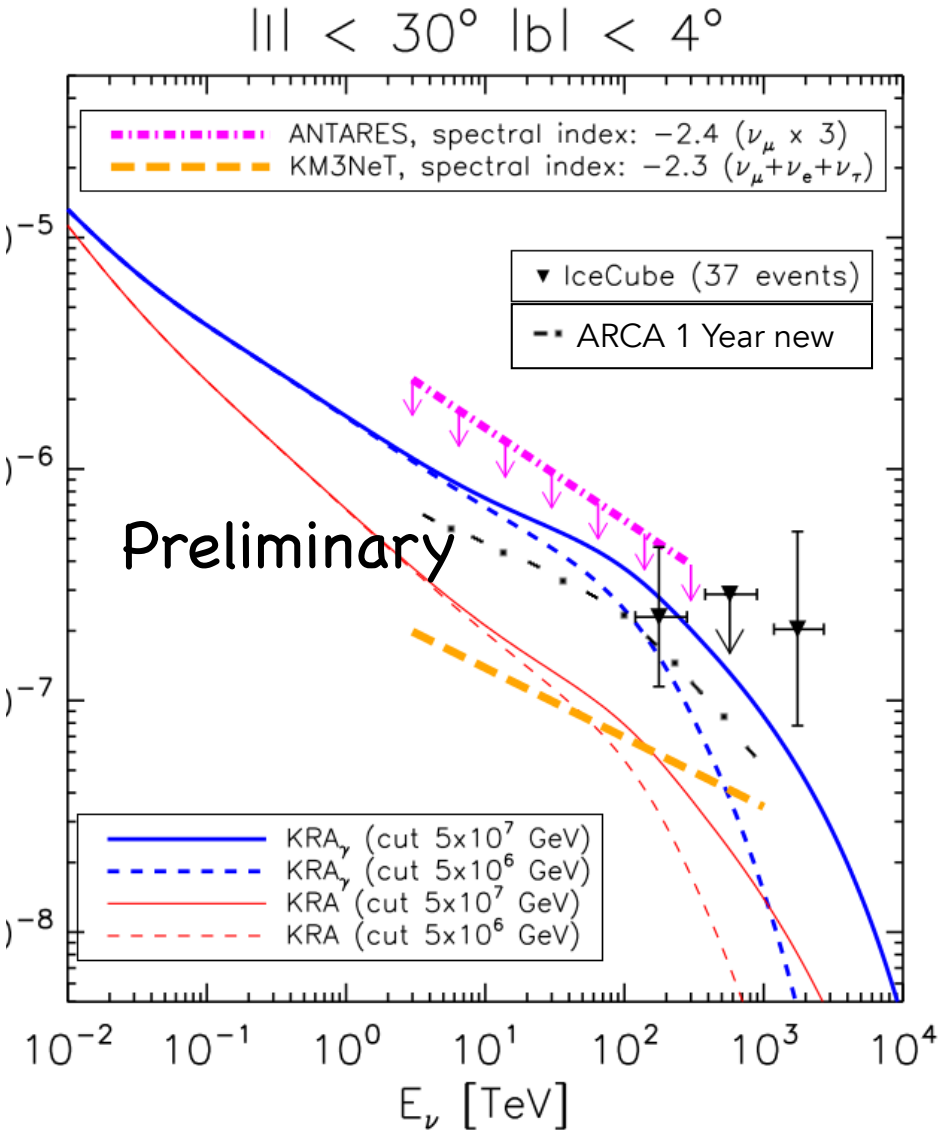


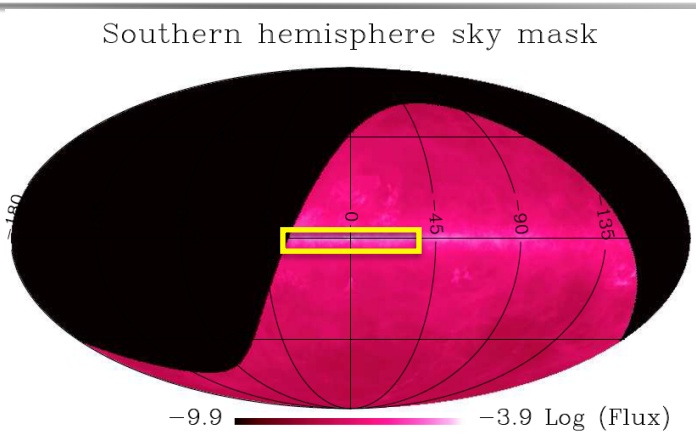


Upper limit set by ANTARES in the inner galactic plane with data from 2007 to 2013 and comparison with the KRA and KRAγ scenarios

Inner Galactic plane expected ν from KRA$_\gamma$ model

ICRC2015 Arxiv:1508.03681 ANTARES coll. Phys lett. B2016.06.0511504.00227



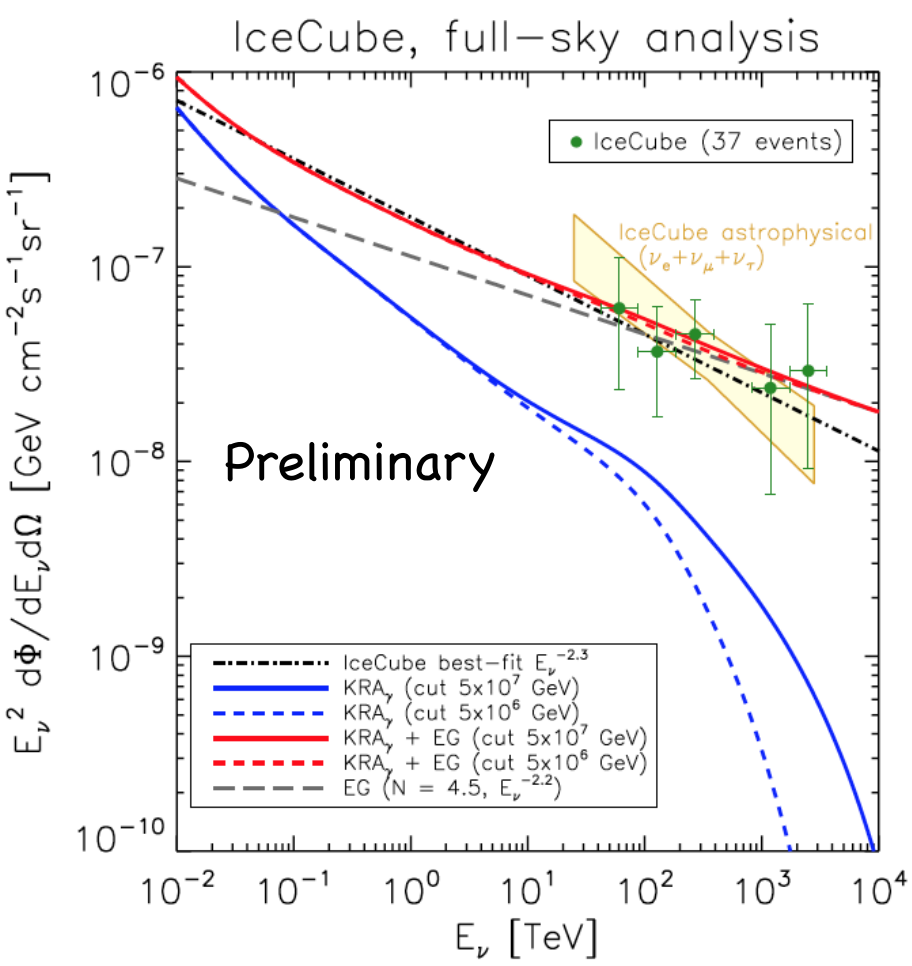


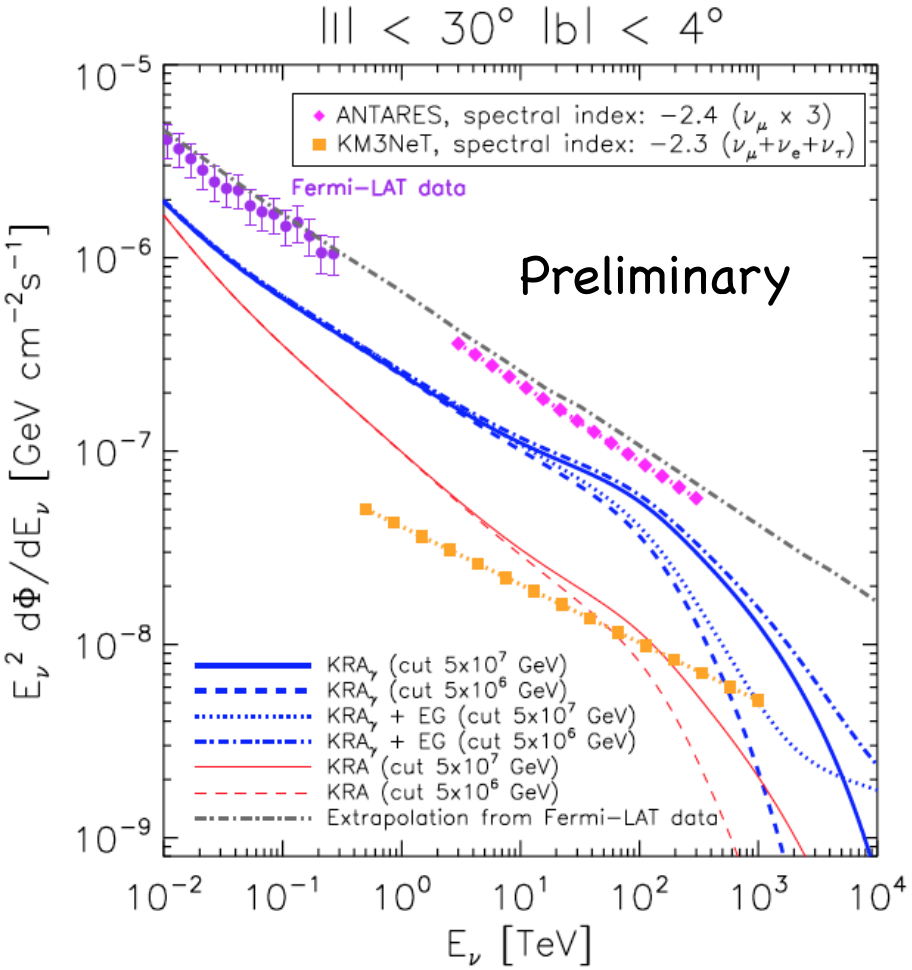
The KRA (δ uniform) and KRA$_\gamma$ (δ variable) produced ν spectra of the inner galactic plane compared to:

- ANTARES upper limits obtained with ν track events reconstructed in 1500 days of experiment live time.
- IceCube spectrum with 3 ν shower like events of HESE 3 years.
- KM3NeT/ARCA sensitivity for this region considering 1500 days and 1 year (latest sensitivity studies in the Rosa Coniglione talk)

Use the inner Galactic plane upper limits verify the EG

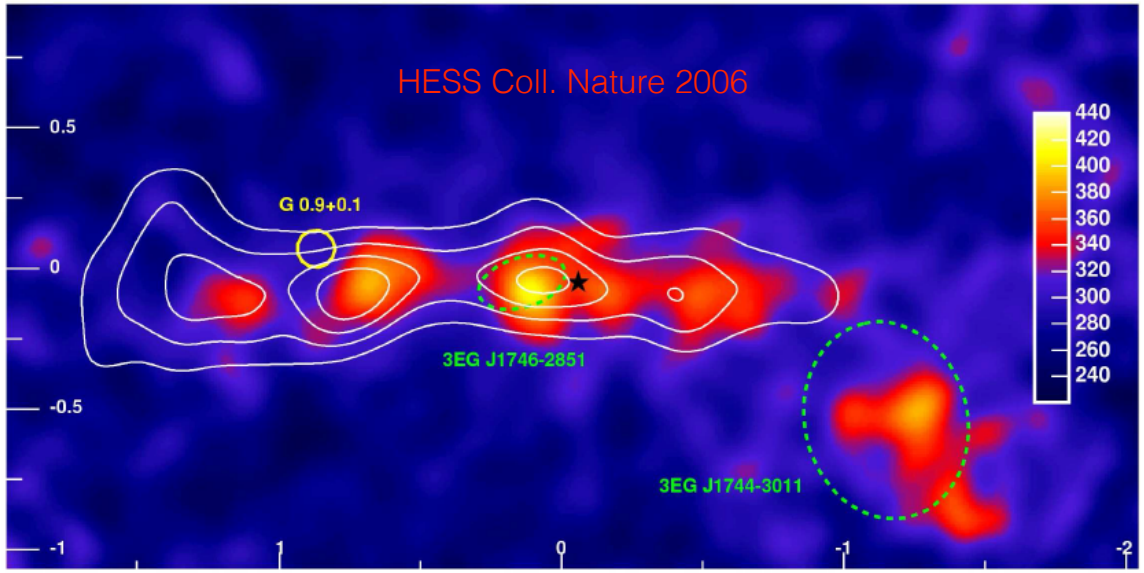
Gaggero, Grasso, Marinelli, Urbano, Valli, VLVNT2015 arXiv:1604.05776





The KRA_γ spectrum + extragalactic spectrum (obtained from the muon neutrino analysis of the Northern hemisphere) can account for the IceCube full sky measured spectrum and is still consistent, in the ridge region, with the Antares measured upper limits.

More detailed: Galactic ridge from HESS 2006

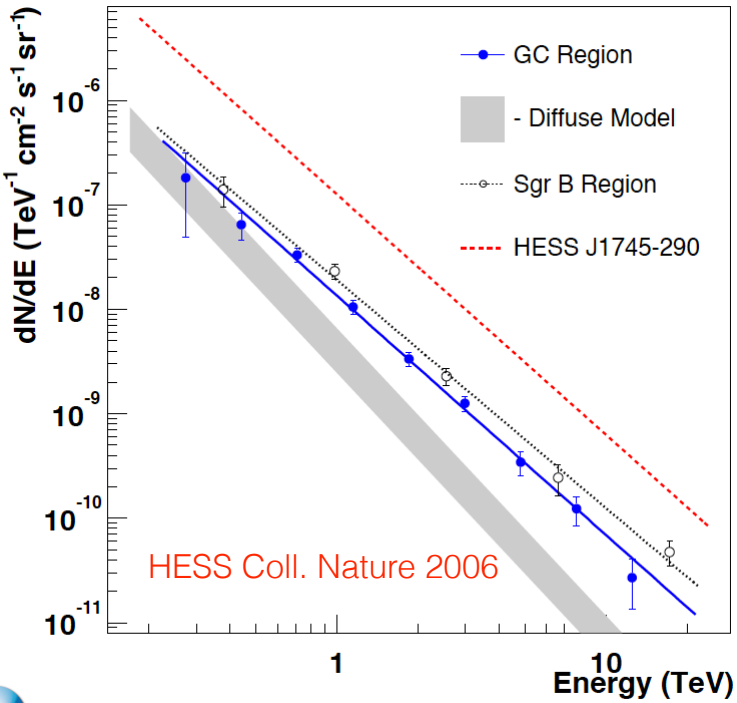


Diffuse gamma-ray emission measured by HESS collaboration after the subtraction of point-like components:

$-0.8° < |l| < 0.8°$ & $|b| < 0.3°$

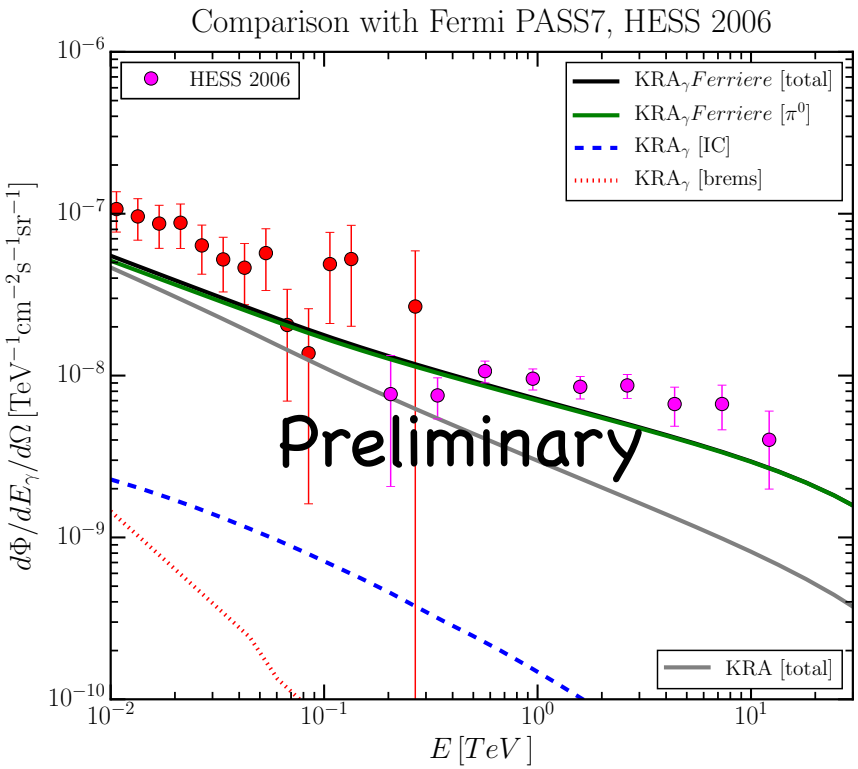
$\Gamma = 2.29 \pm 0.07$ stat ± 0.20 sys

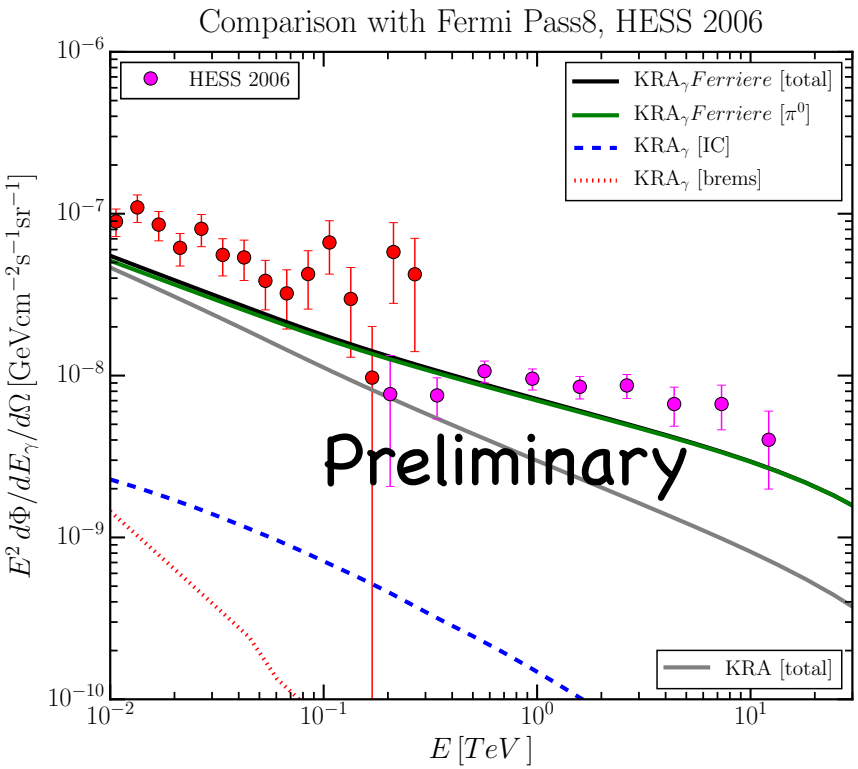
with a significance of 14.6 σ



The diffuse component expectation considering a CR spectral behavior similar to that one measured on earth seems far to the diffuse measured spectrum.

KRA$_\gamma$ expectation for the HESS ridge 2006

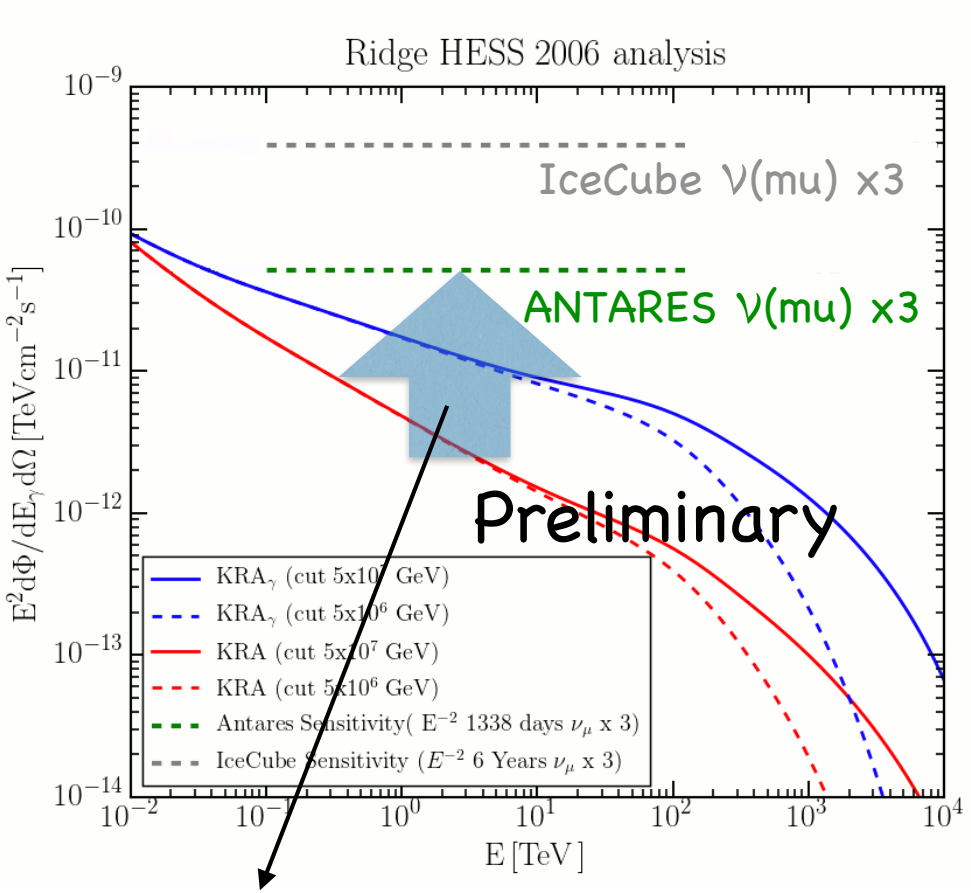


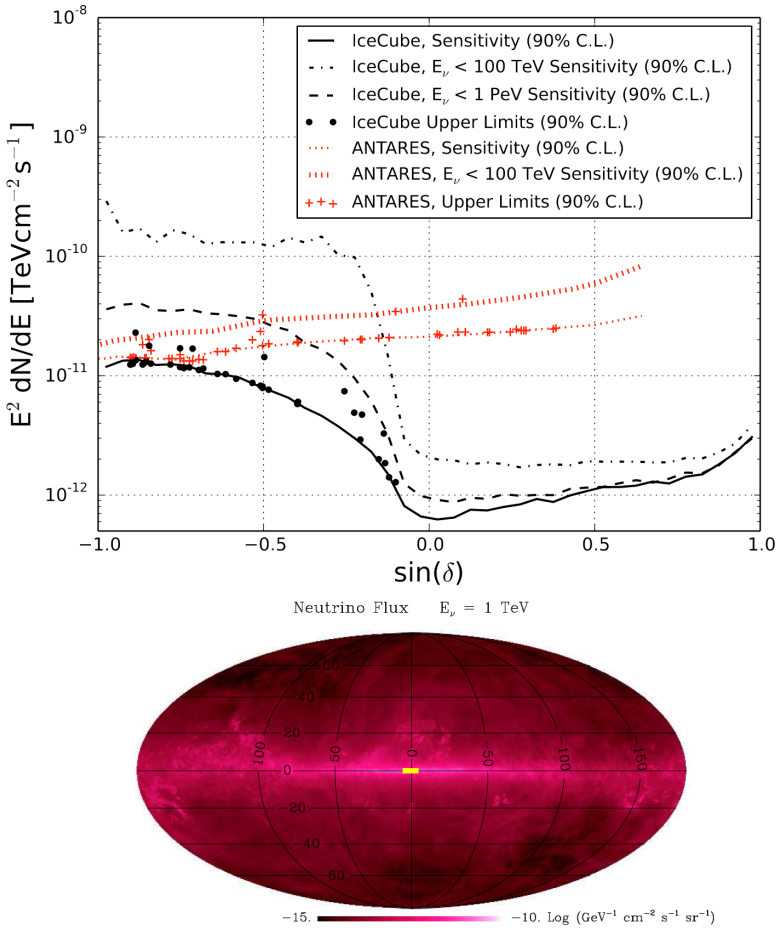


Connecting the Fermi PASS7 and Fermi PASS8 spectra with the HESS measurement of diffuse emission we can see that the emission from 100 GeV to 10 TeV is mostly dominated by the diffuse gamma-ray sea!

Neutrino expectation for the HESS ridge 2006

ANTARES & IceCube coll. APJ 05/2016

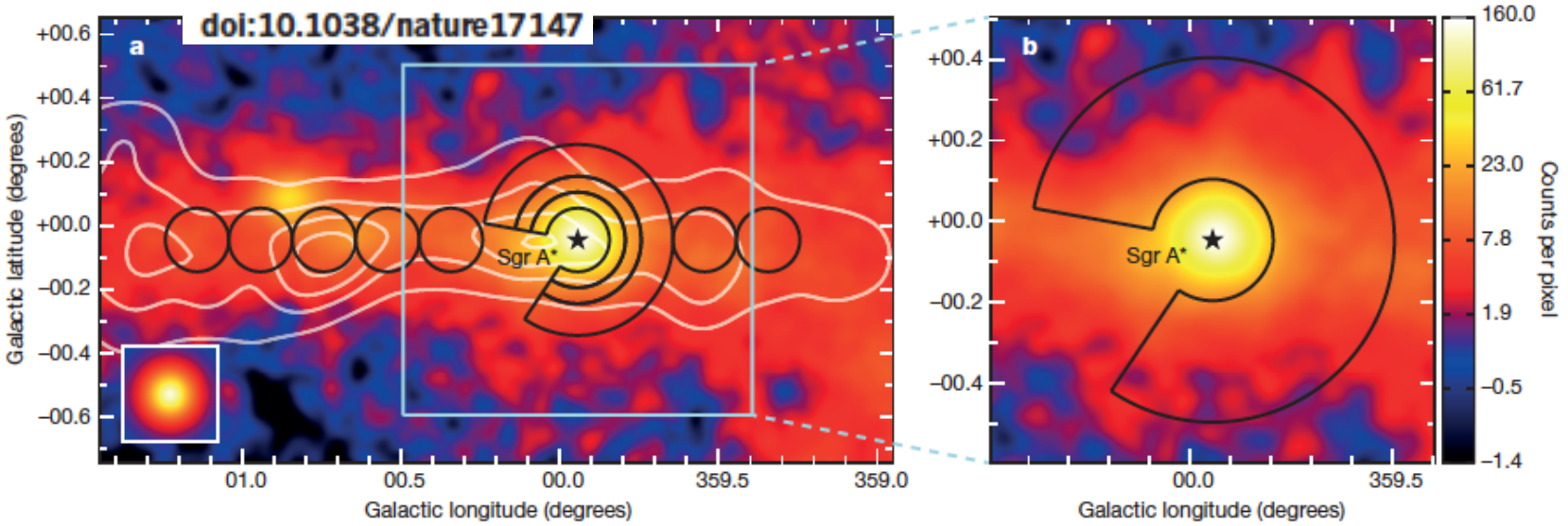




In addition to the diffuse KRA-gamma flux we can have additional hadronic components that cannot be disentangled by ANTARES, IceCube or KM3NeT, however the only way to see something!

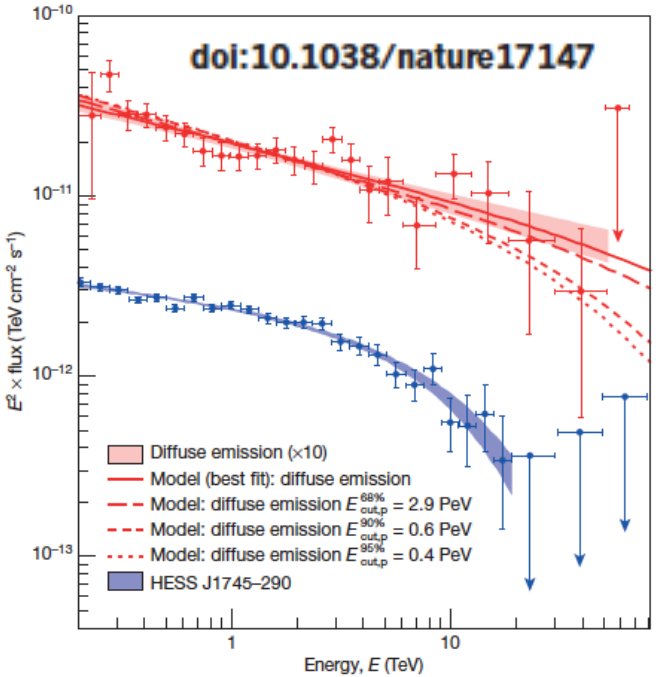
G0.9+01 SNR possible ν emission
HESS 1745-290 ν emission ?

Very detailed: Central "Pac-man" from HESS 2016



New observations of a diffuse gamma-ray spectrum possibly produced by a Pevatron source

1.4 x 10^-4 sr



Best Fit spectrum for the "pac-man" region:

Φ_0 =1.92 ± 0.08 stat ± 0.28 sys 10^-12 TeV^-1 cm^-2 s^-1

Γ = 2.32 ± 0.05 stat ± 0.11 sys

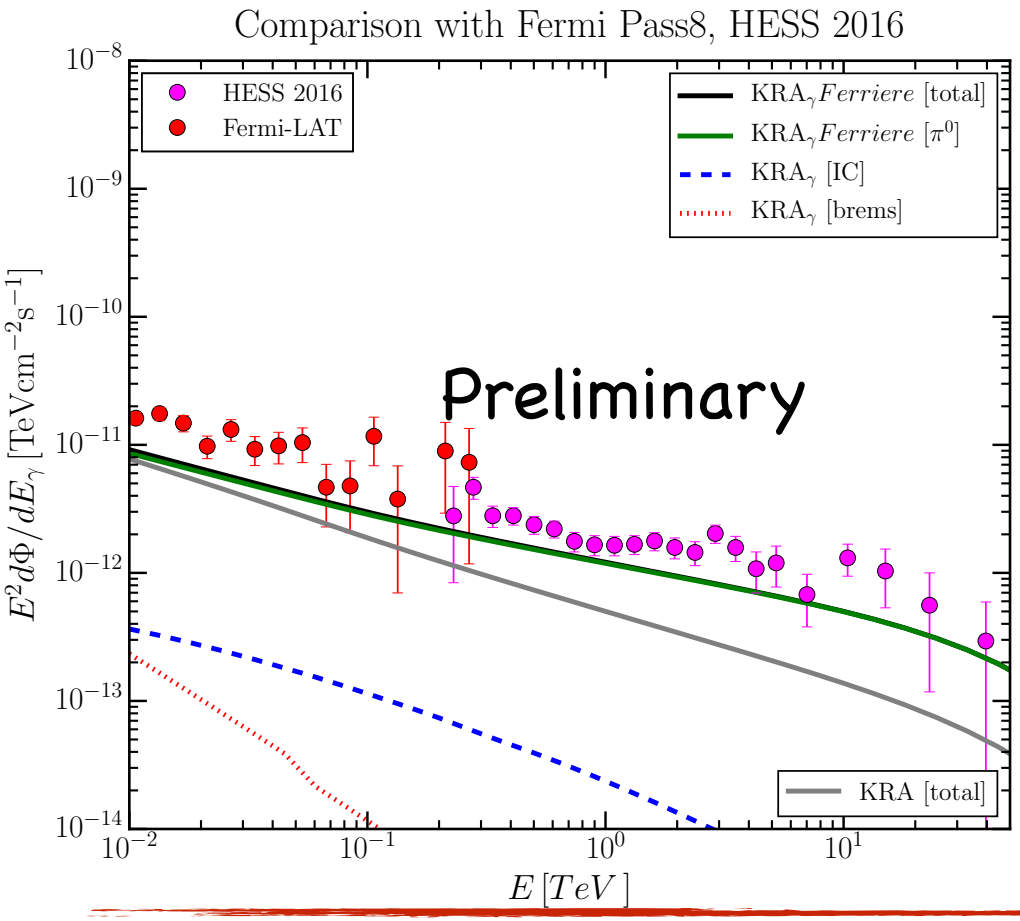
Best Fit spectrum for Sagittarius A*:

Φ_0 =2.55 ± 0.04 stat ± 0.37 sys 10^-12 TeV^-1 cm^-2 s^-1

Γ = 2.14 ± 0.02 stat ± 0.10 sys

Ecut= 10.7 ± 2.0 stat ± 2.1 sys TeV

"Pacman" gamma-ray profile with KRA$_\gamma$ model



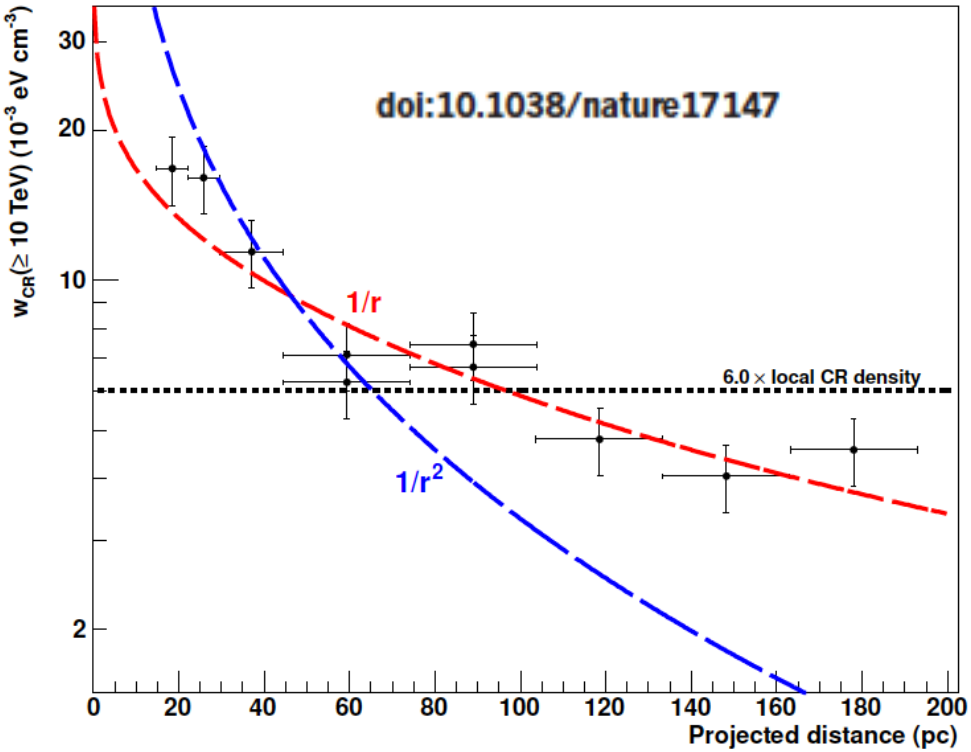
The diffuse sea is dominant inside the "Pacman" region!

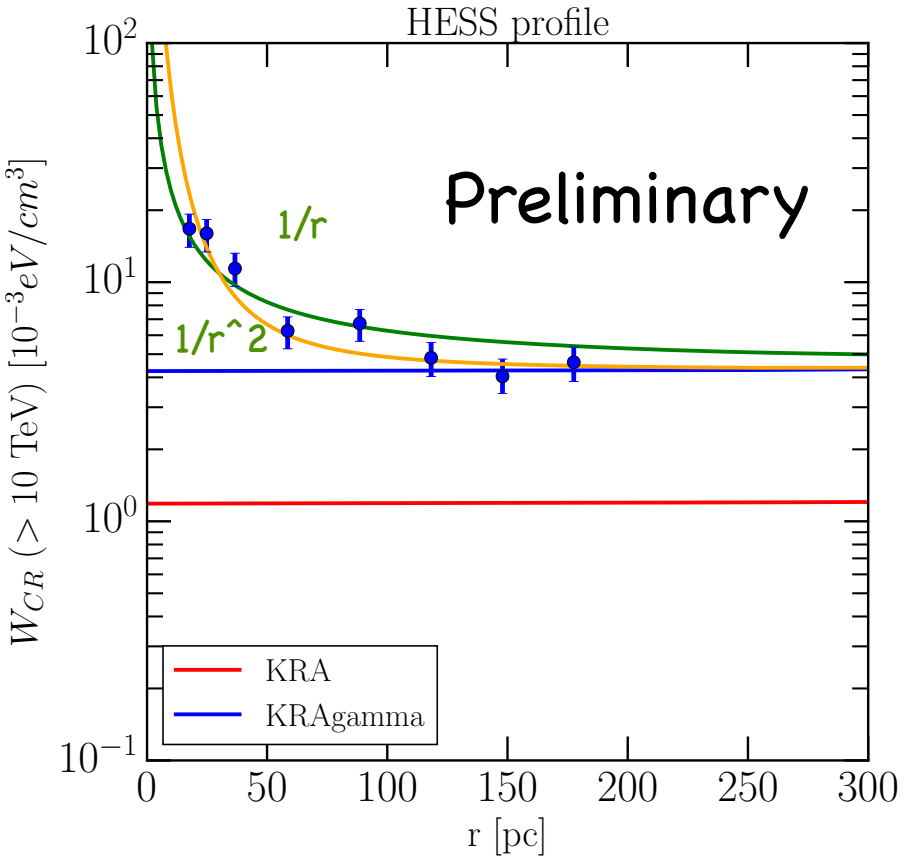
Not necessarily a relation of the measured spectrum in the "Pacman" with the Sagittarius A* (HESS J1745-290)!

Not needed a strong absorption from the central region to explained the disconnected spectra!

The Pevatron can be somewhere else, everywhere in the central molecular cloud a blob of gas can have a similar spectrum without a cutoff !!

Cosmic-ray density profile for the "Pacman region"





Rate of injection

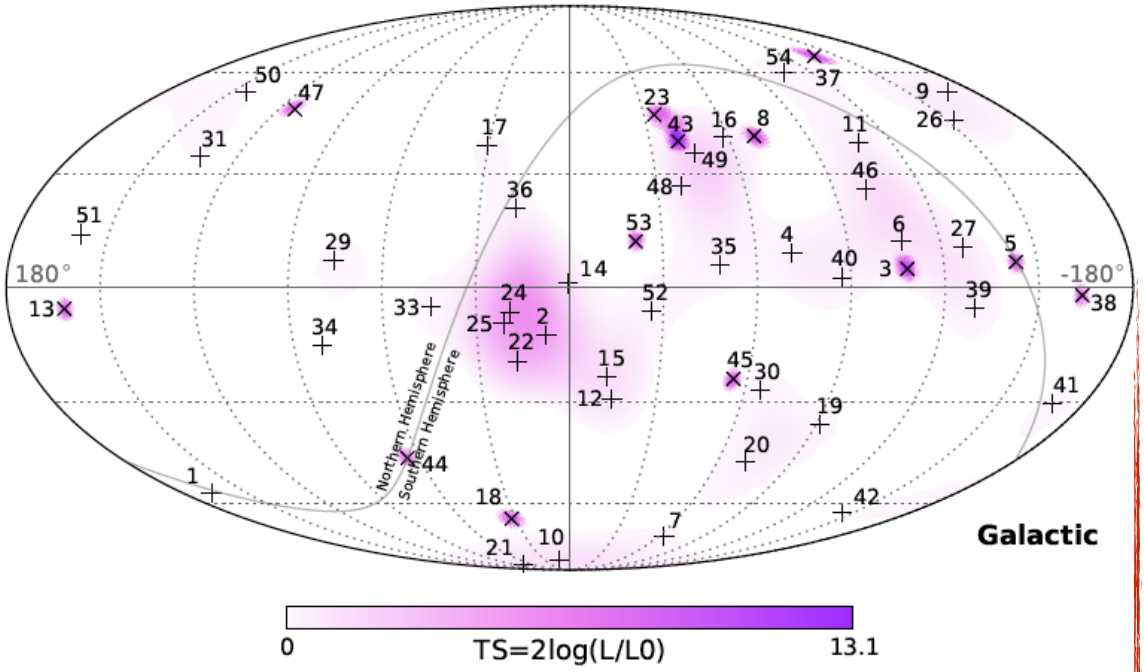
$$w_{\mathrm{CR}}(E,r,t) = \frac{\dot{Q}_p(E)}{4\pi D(E) r}\ \mathrm{erfc}(r/r_{\mathrm{diff}})$$

Diffusion Coefficient Radius

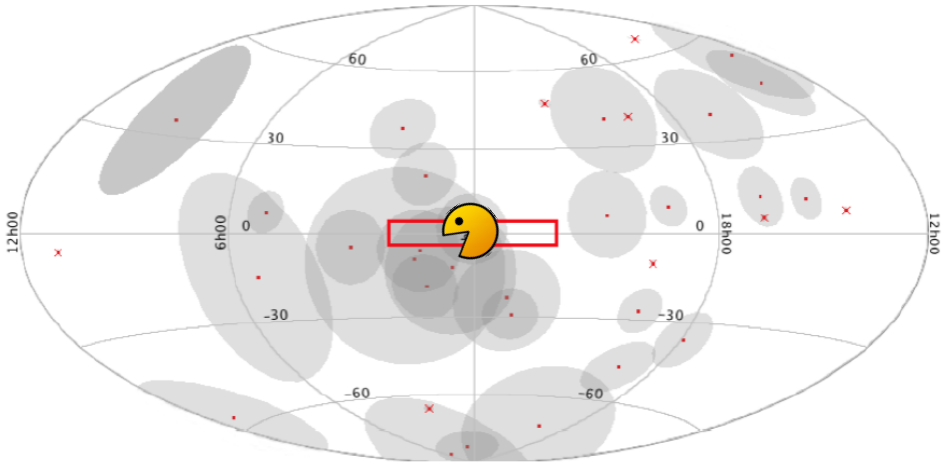
You can see from this plot that the plateaux is reached after 100 pc where the KRA$_\gamma$ CR density profile intercept the asymptotic behavior of 1/r^2

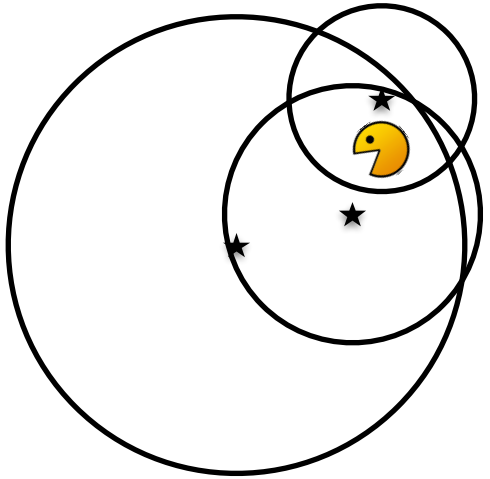
looking at possible nu signature from the "pac-man"

IceCube coll. ICRC 2015

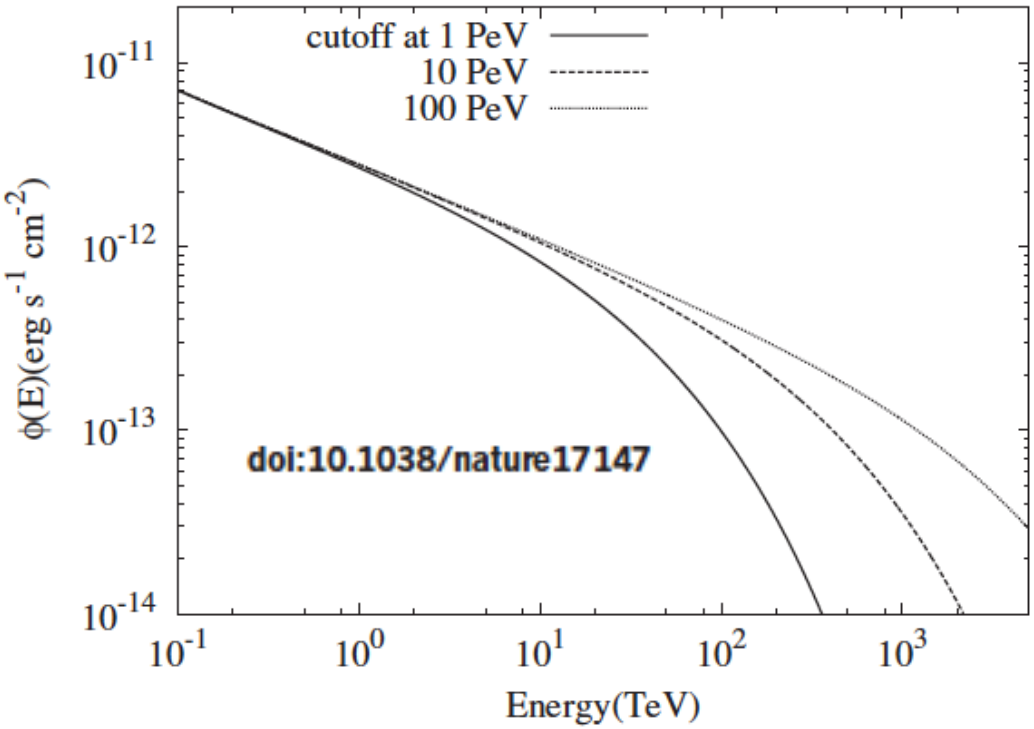


3 events of HESE 4 years compatible the "Pacman" position, No one contained inside the "Pacman", However low angular resolution due to the Shower-event types!

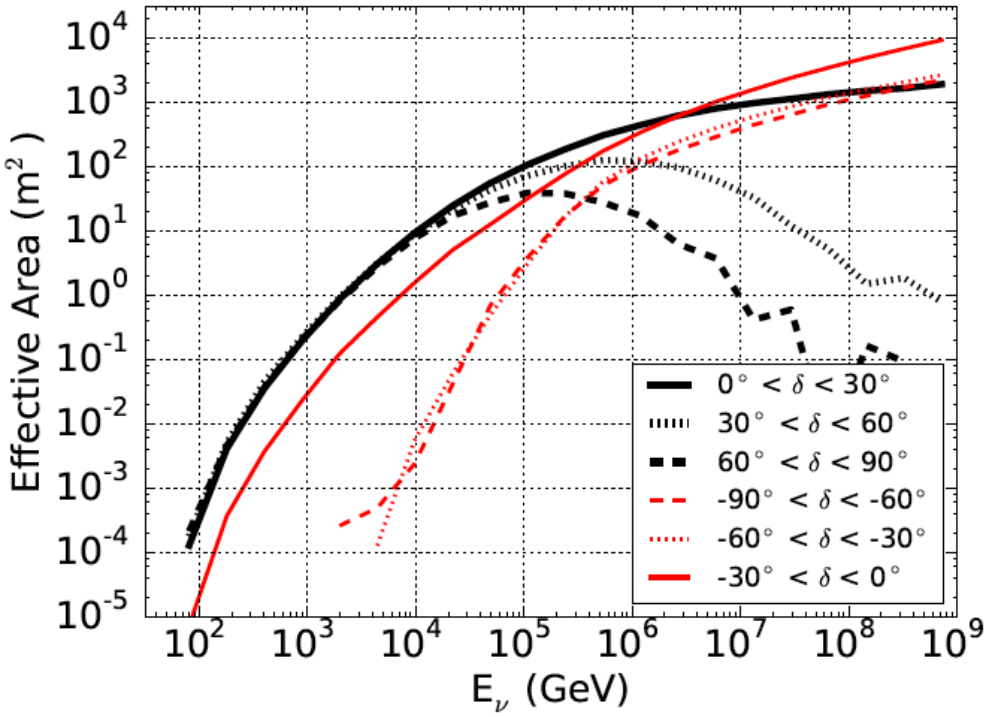




Neutrino events from the pac-man expected in IceCube

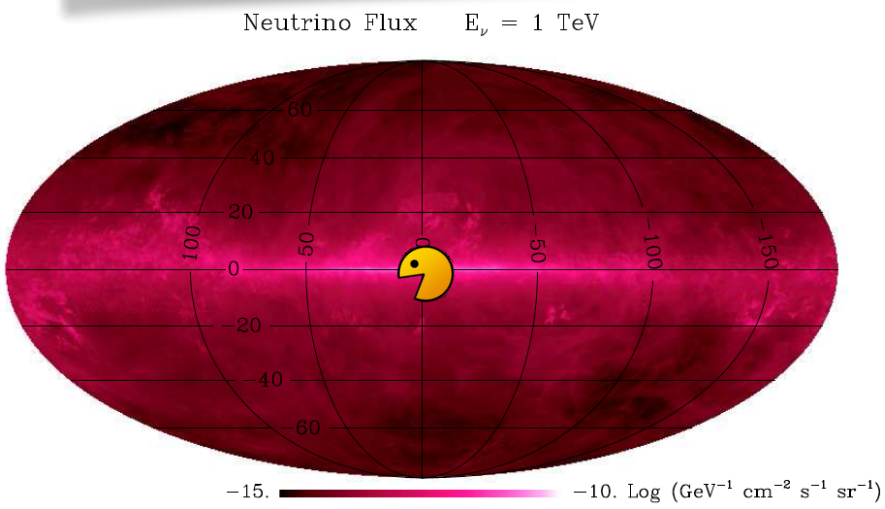


IceCube coll. ApJ. 796, 2, 109, 2014

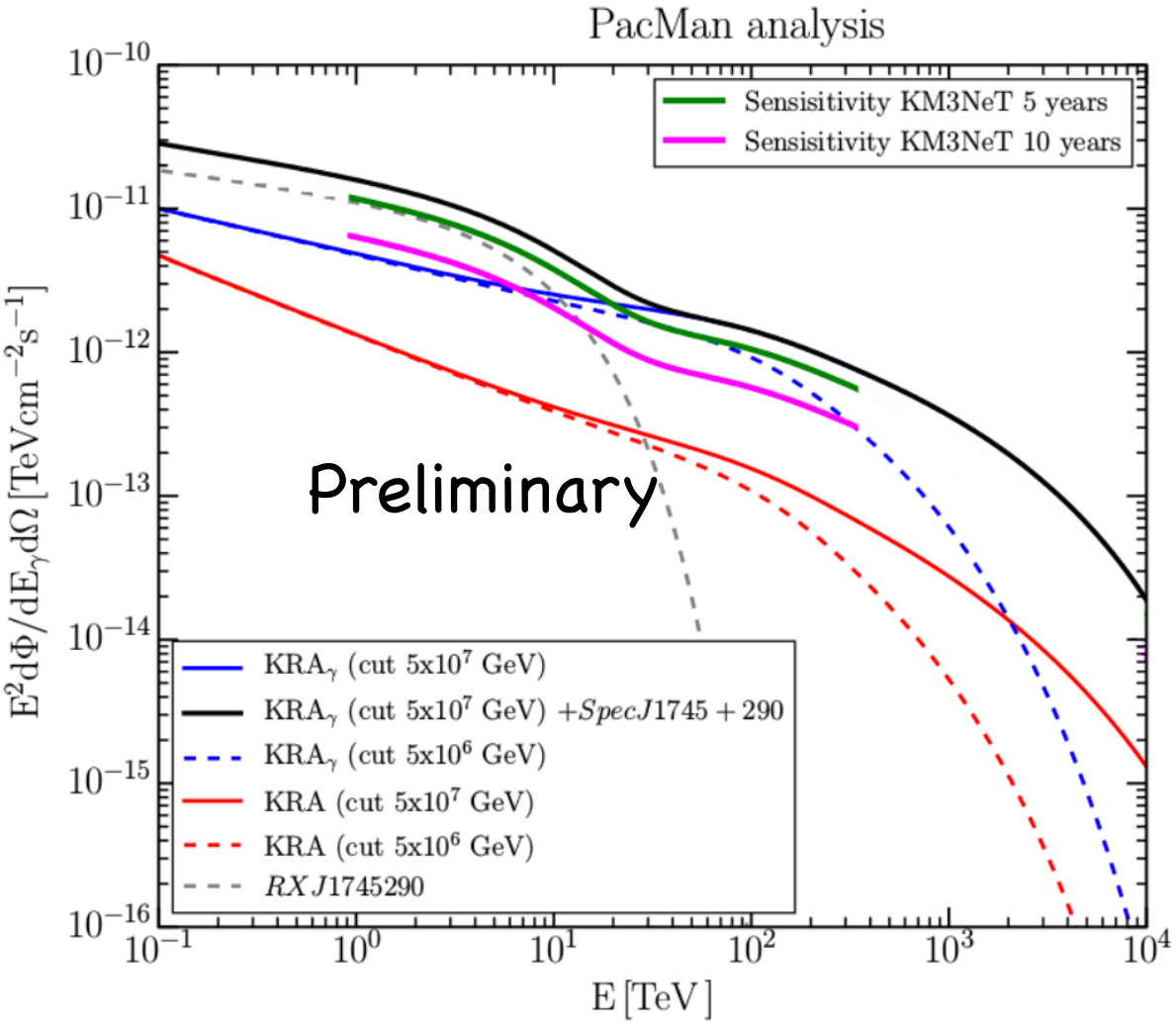


nu evts IC 4 y	Cut-off 1 PeV	Cut-off 10 PeV	Cut-off 100 PeV
E > 25 TeV	4 x 10^-2 evt	0,127 evt	0,189 evt
E >10 TeV	9 x 10^-2 evt	0,2 evt	0,27 evt
E > 1 TeV	0,26 evt	0,40 evt	0,47 evt

Ecpected neutrinos from the "Pacman" with KRA$_\gamma$ model



Within 5 years KM3NeT/ARCA will be able to see something if J1745-290 add to the "Pacman" a additional neutrino component.
With 10 Years of KM3NeT/ARCA also the "Pacman" can be seen.



Sensitivity studies will be presented lather by Rosa Coniglione

SUMMARY

- The galactic diffuse emission has been observed with gamma-ray up to several thens of TeV, after modeling in a good way the CR transport and interaction with dust we obtain the expected neutrino counterpart (KRA$_\gamma$)

- We should understand the best region where focusing our analysis on galactic diffuse emission and eventually combine IceCube, ANTARES data and KM3NeT/ARCA phase 1.0

- For the full sky likelihood analysis we probably need more data

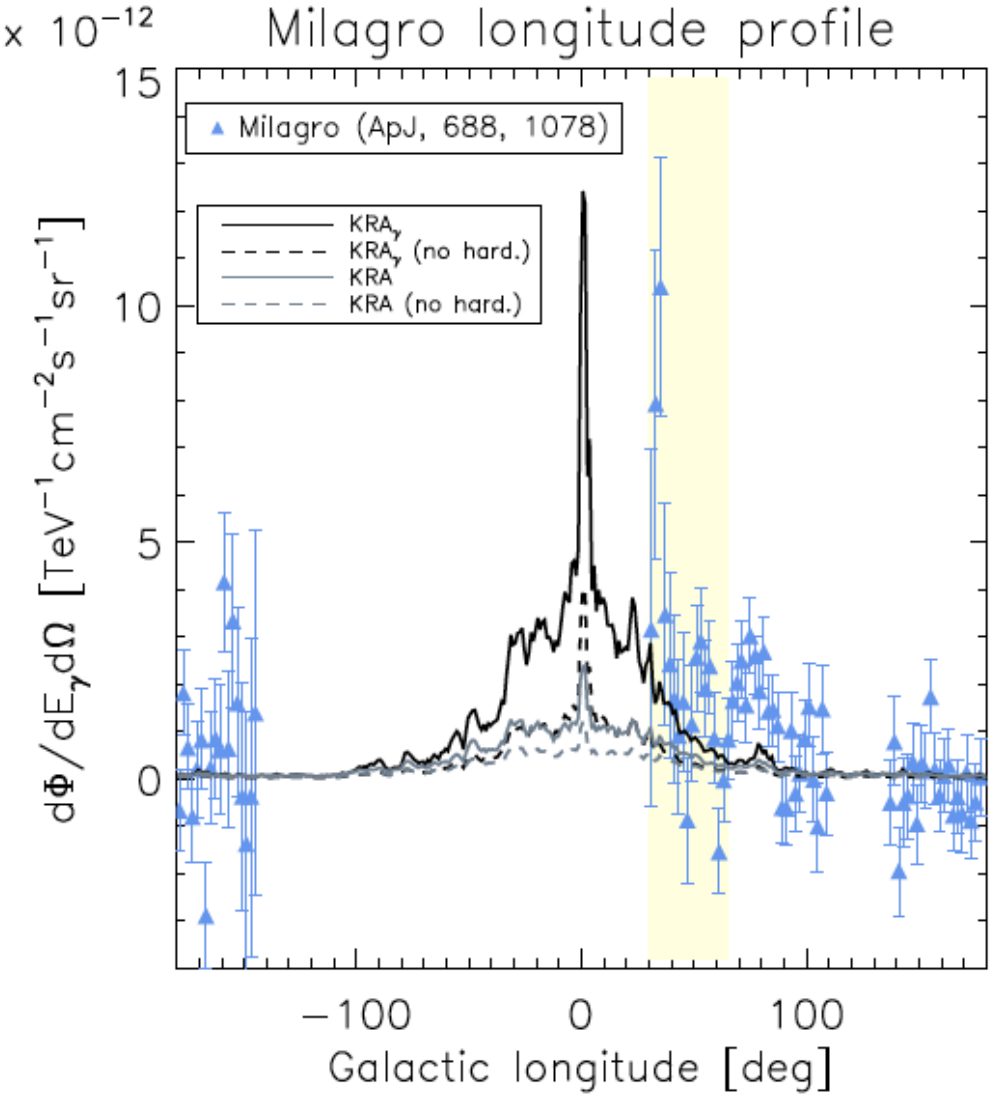
- The HESS ridge 2006 and the "Pacman" 2016 are not really preferential regions of the sky, only if we connect DF+PS emission became interesting

- The ridge $|l|<30°$ and $|b|<4°$ seems a more exciting region

- All the molecular clouds inside the central molecular ring (extended enough) can be in principle good candidates: Spectrum extend up to hundred of TeVs without cutoffs for neutrinos

Backup slides

Galactic gamma-ray profile with KRA$_\gamma$ model



Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1507.07796

We can see from this plot how the diffuse gamma-ray profile from the galactic plane obtained with KRA$_\gamma$ (scenario with a variable diffusion coefficient) better reproduce the measured Milagro profile respect to the KRA (standard scenario).