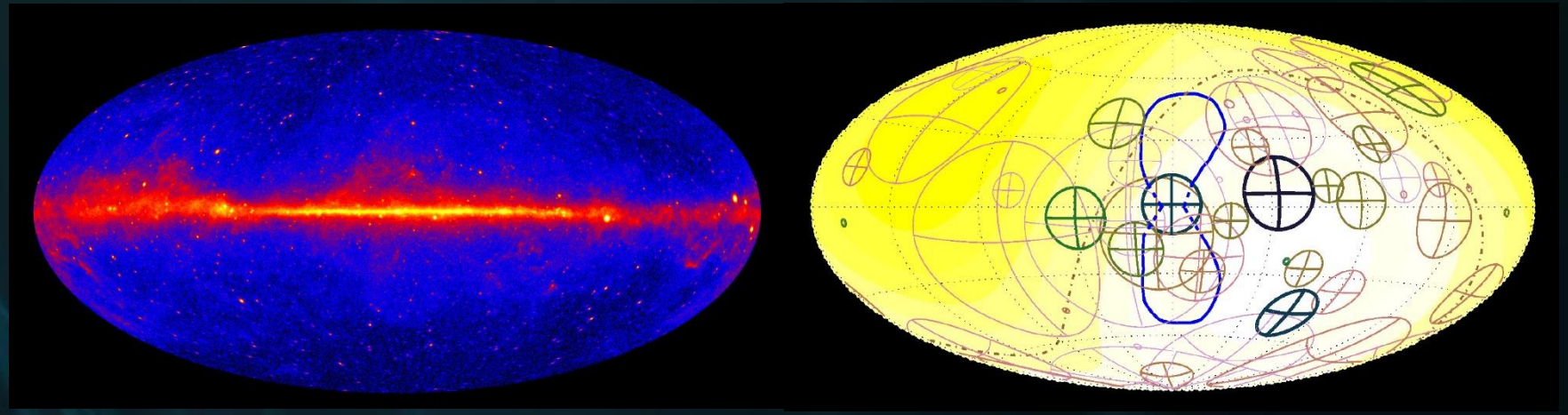


The high energy ν sky is dominated by the Galaxy

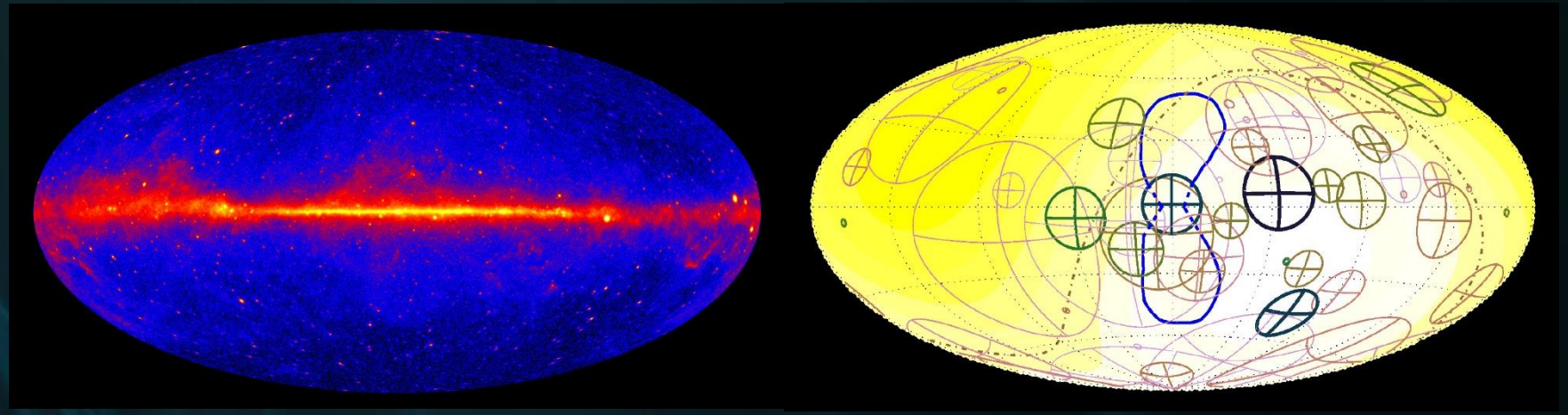
Ilya Gurwich[1], Uri Keshet[2] and Nimrod Sherf[2]

This research was supported by ISF-UGC grant No. 504/14 and IAEC-UPBC grant No. 257

Presented at the “Three elephants in the gamma-ray sky” workshop

[1]Department of Physics, NRCN

[2]Department of Physics, BGU



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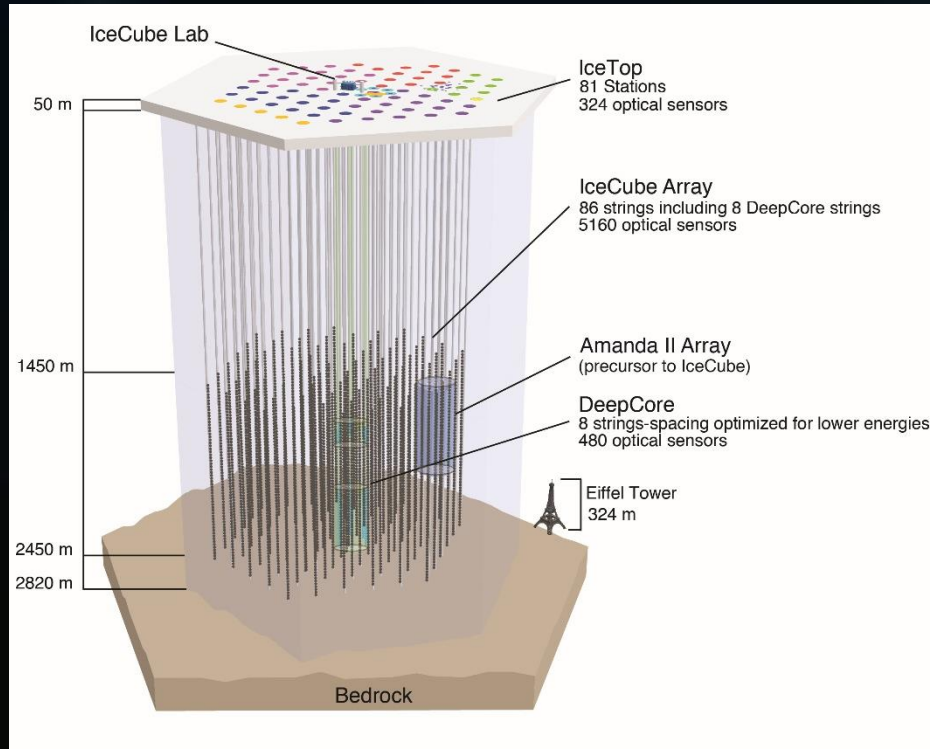
Contents

- Ridiculously short intro
- Examining the morphology of the astrophysical ν source
- Galactic ν emission
- ν from FBs?
- Conclusions and future endeavors

IceCube

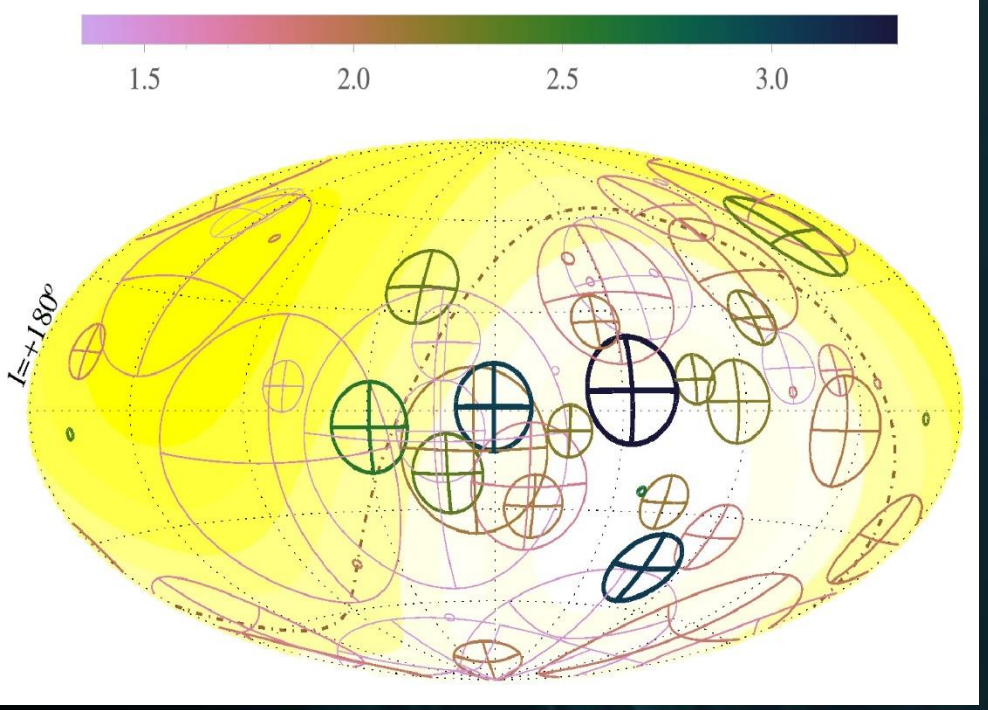
- The measurement of high energy astrophysical neutrinos opens a new age of multi-messenger high energy astrophysics.
- At present, the astrophysical ν signal in IC is interpreted as mostly extragalactic, implying:
  - Close to Waxman-Bahcall limit → CR accelerators are in dense and/or radiative environments.
  - Studying the MW ν signal is still out of reach
  - We can look for specific HE ν sources by contrast with an isotropic background.

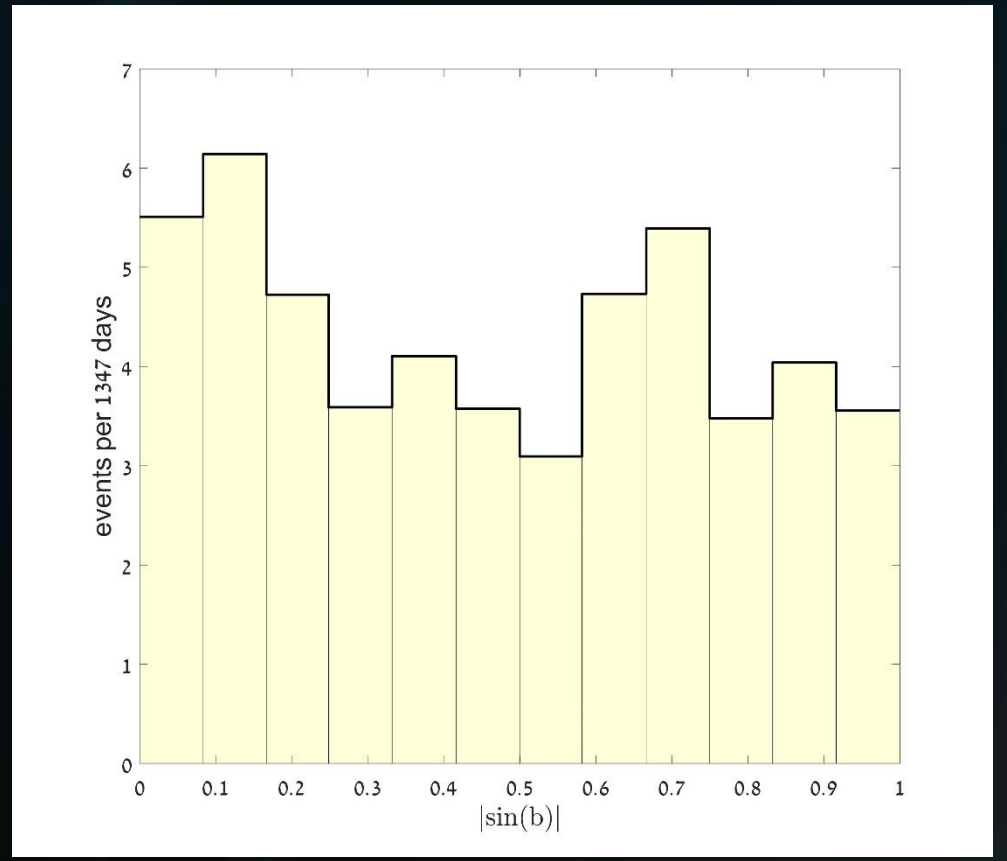


Scope

- We show that the astrophysical component of the (4-year) IC signal is prevalently Galactic and thus:
  - The extra-galactic component is far from the WB limit.
  - The MW is open to a multi-messenger study
  - Analyzing potential HE ν sources must take into account the varying Galactic foreground.
  - Sources at high Galactic latitudes are easier to detect.

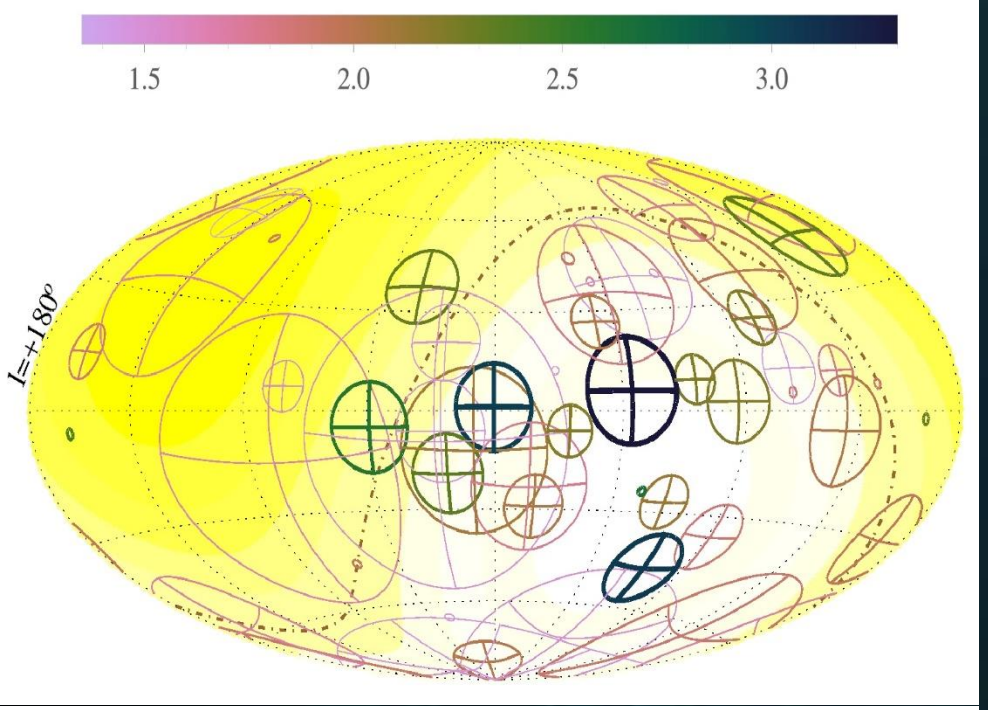
Morphology of the ν source

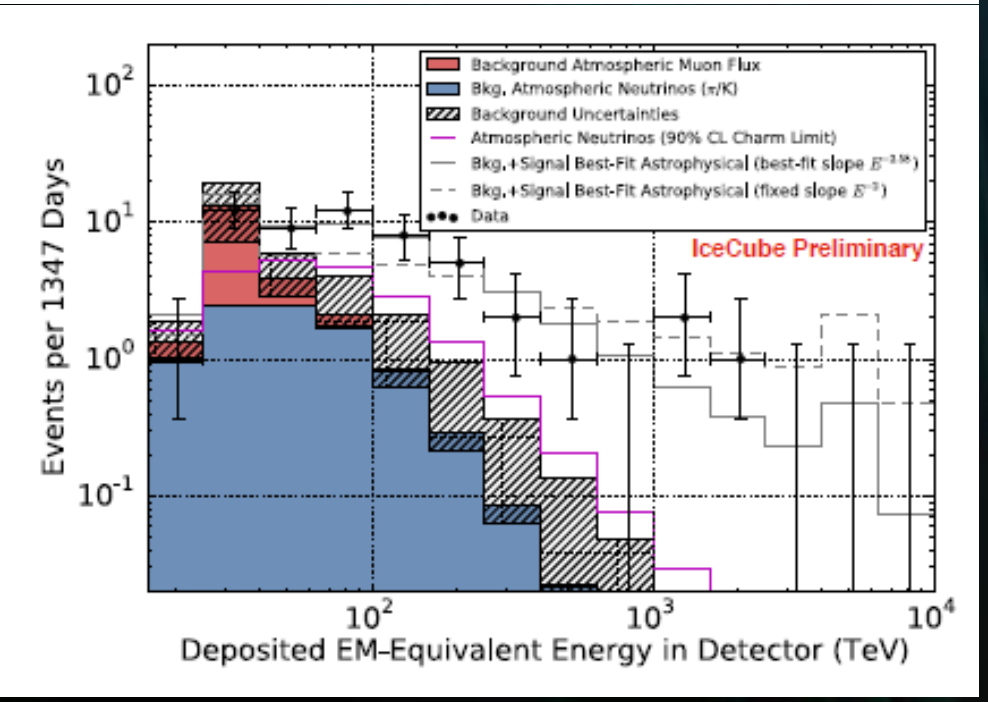


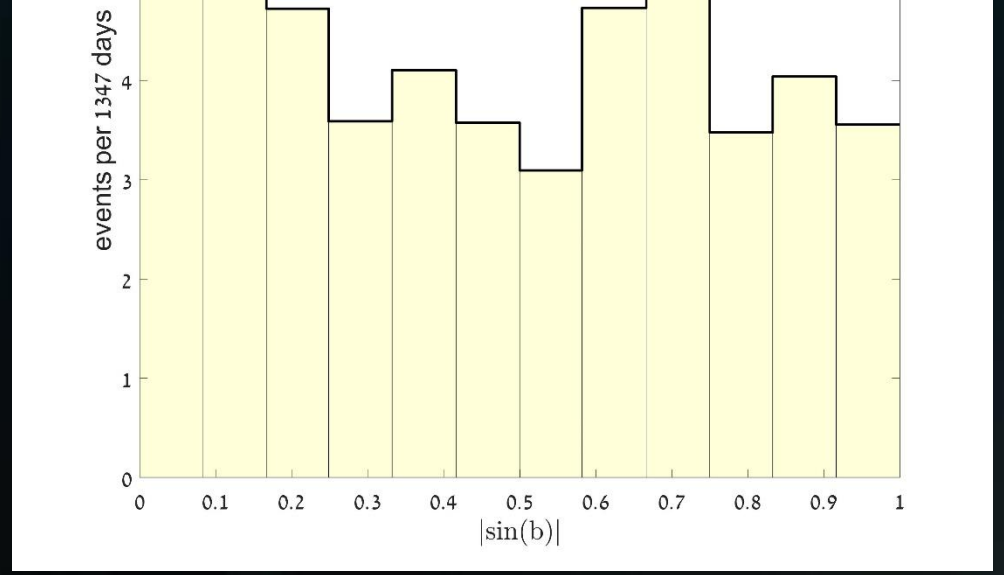


- The full signal does not appear to contain a clear Galactic signature.

Morphology of the ν source



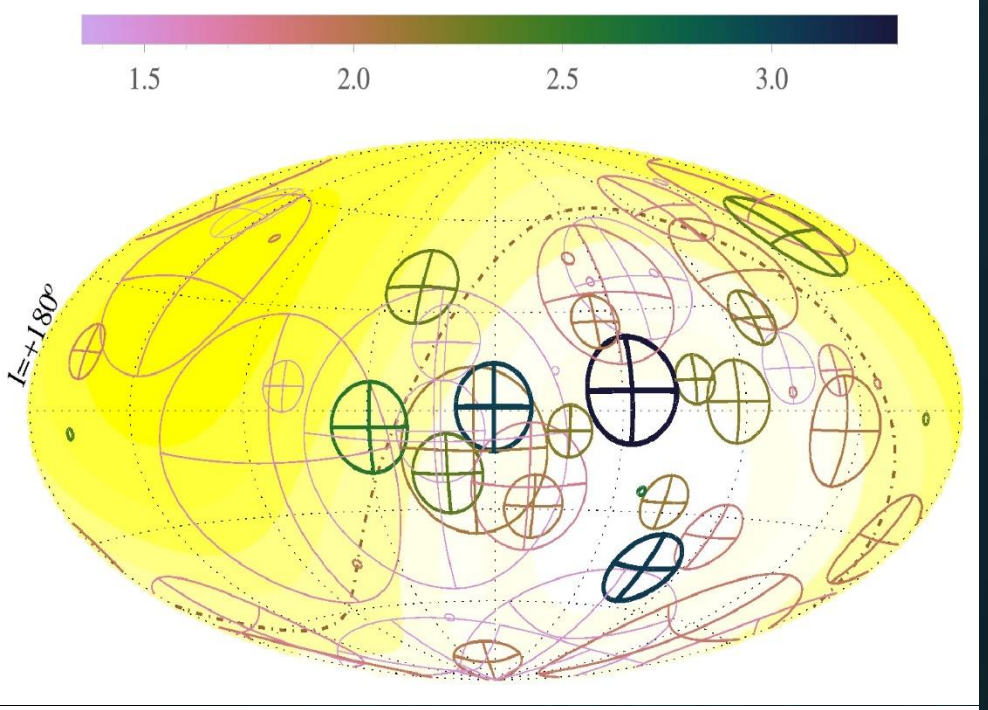


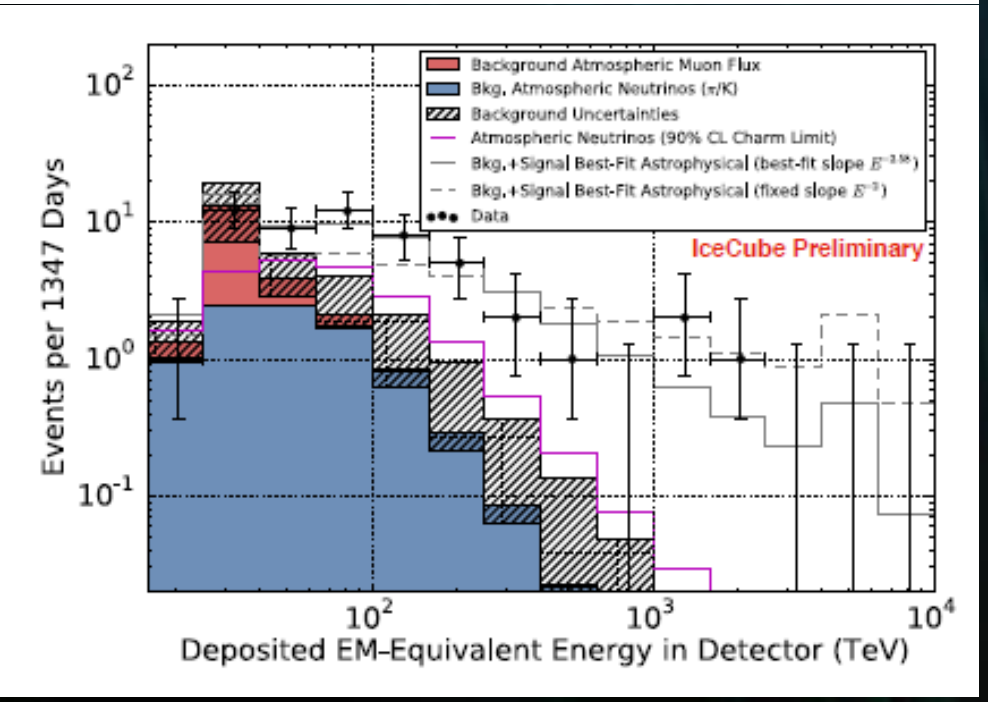


- The full signal does not appear to contain a clear Galactic signature.
- But is this a feature of the astrophysical ν or the atmospheric foreground?

Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Morphology of the ν source





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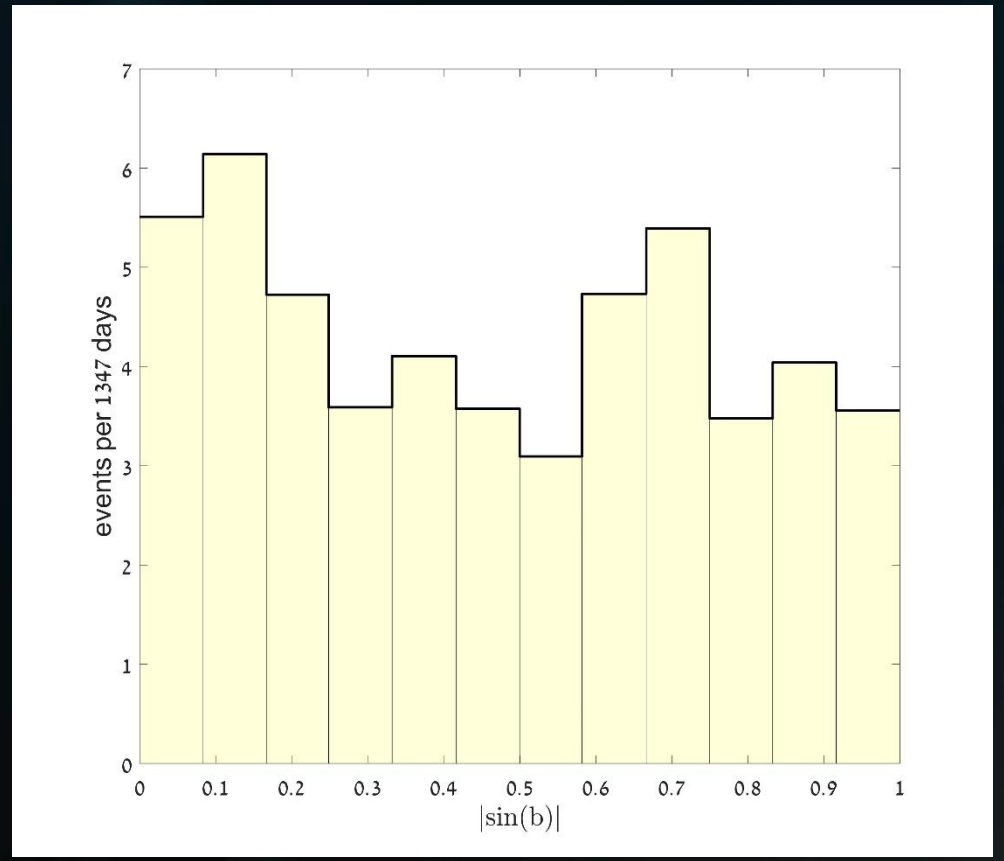
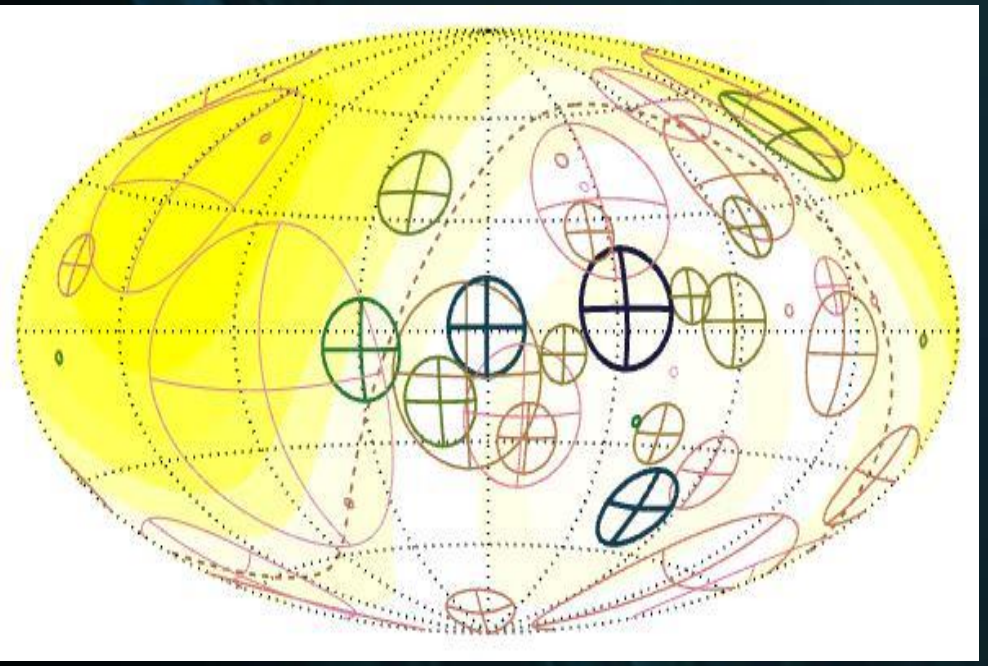
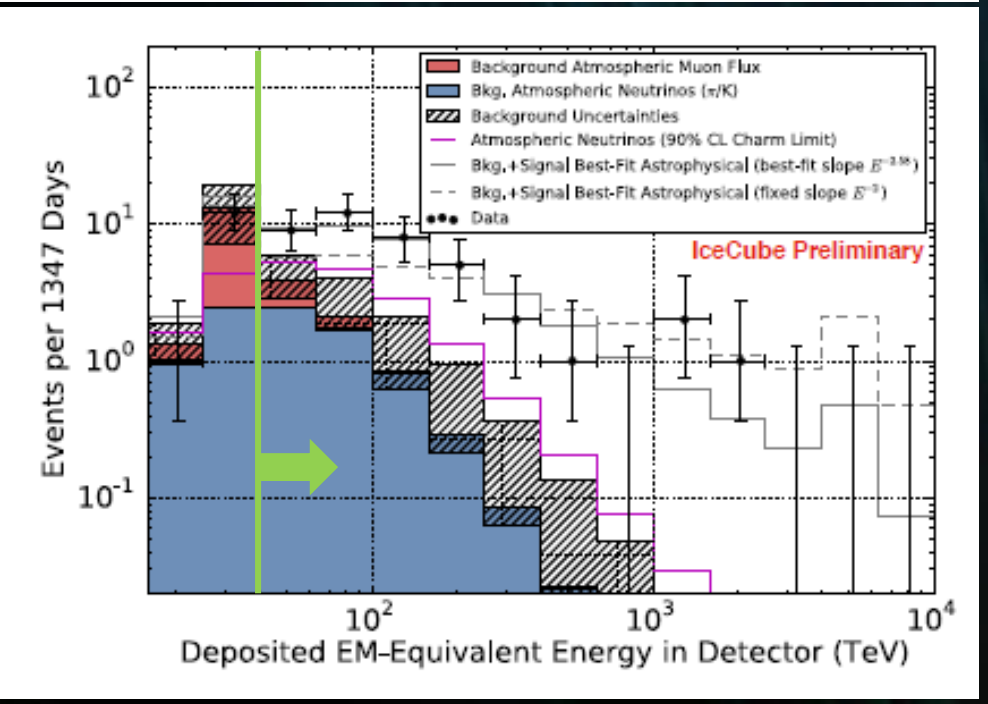
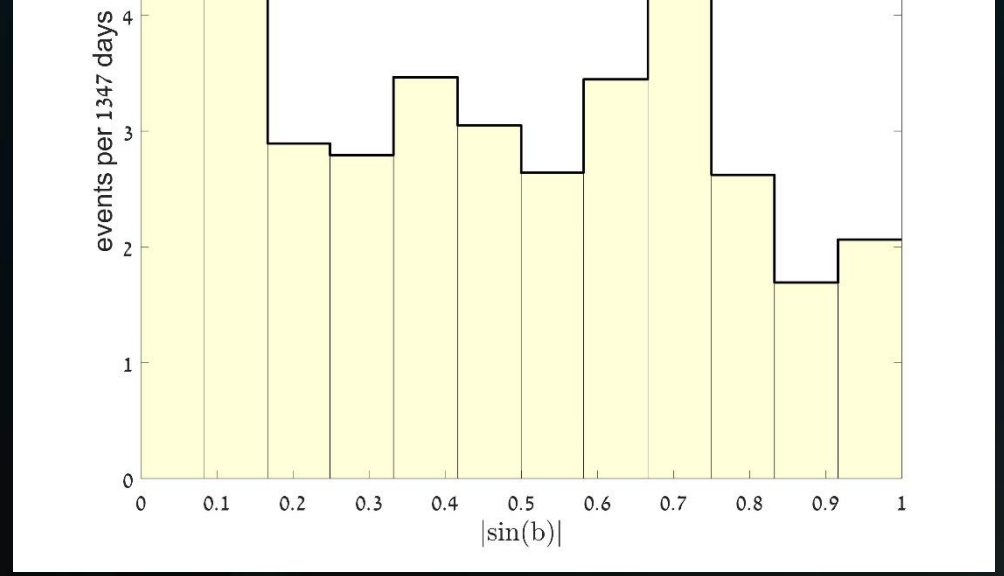


- The full signal does not appear to contain a clear Galactic signature.
- But is this a feature of the astrophysical ν or the atmospheric foreground?
- As we look at higher energies, the foreground should fade away…

Cutoff the data below 40 TeV

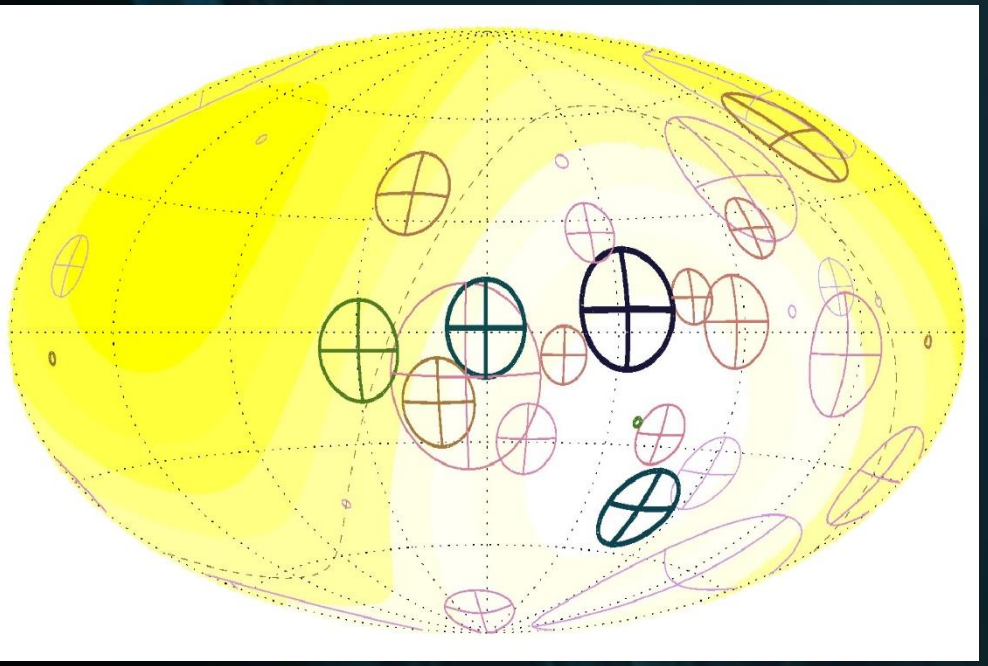


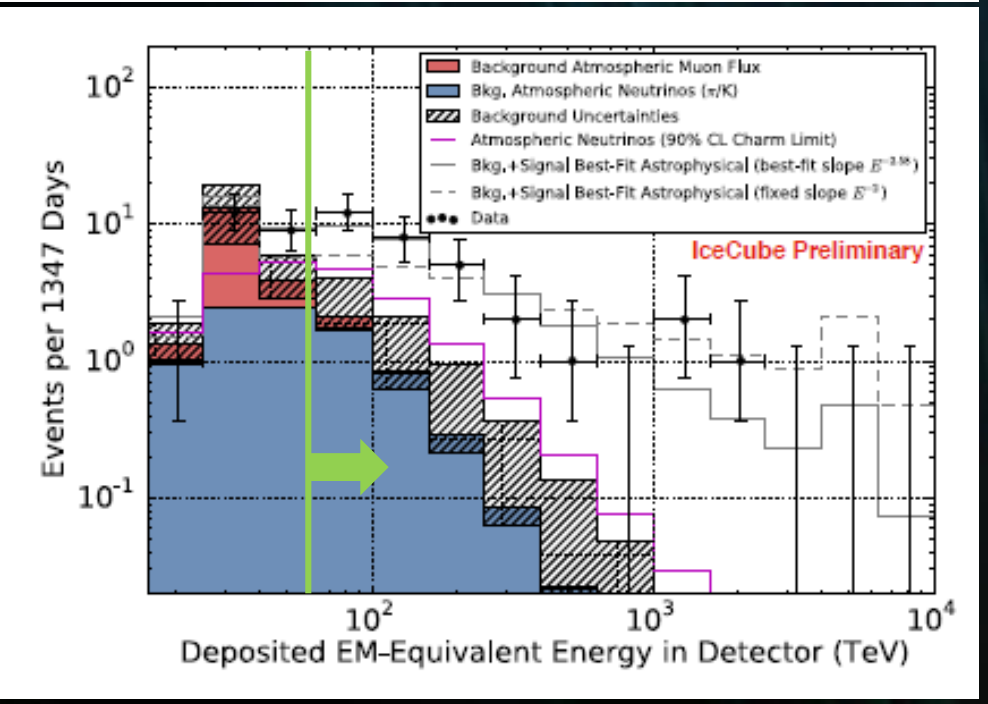


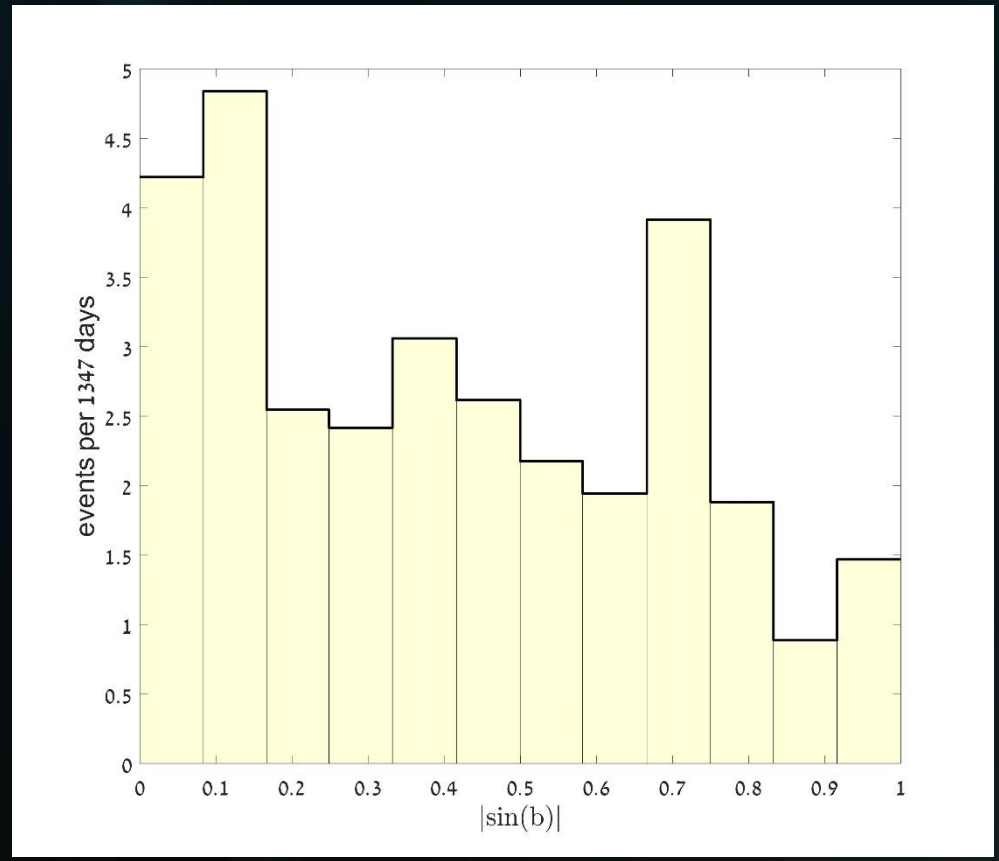


Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Cutoff the data below 60 TeV



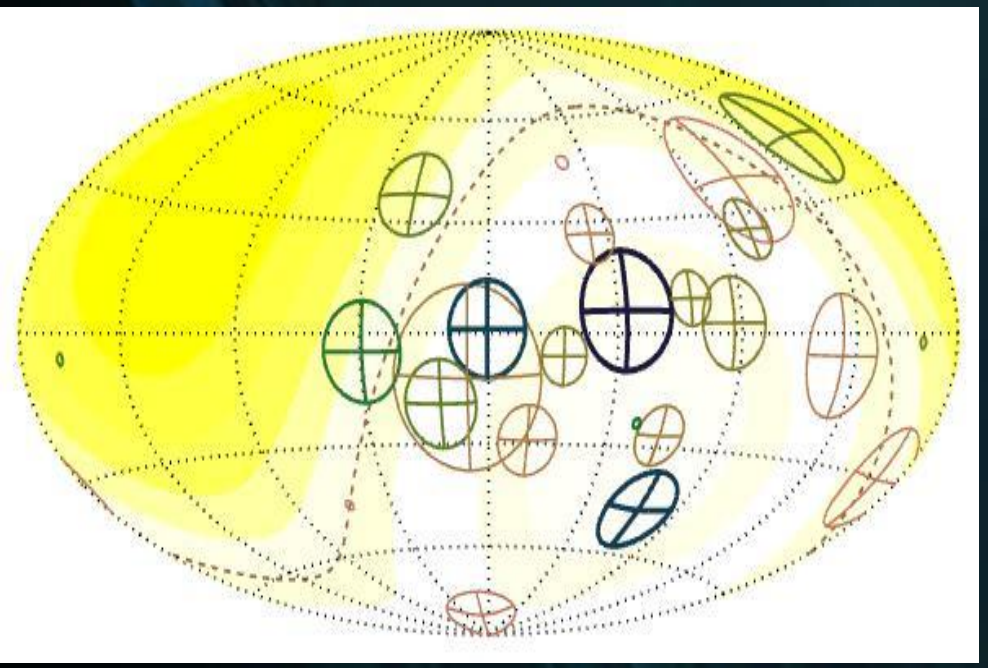


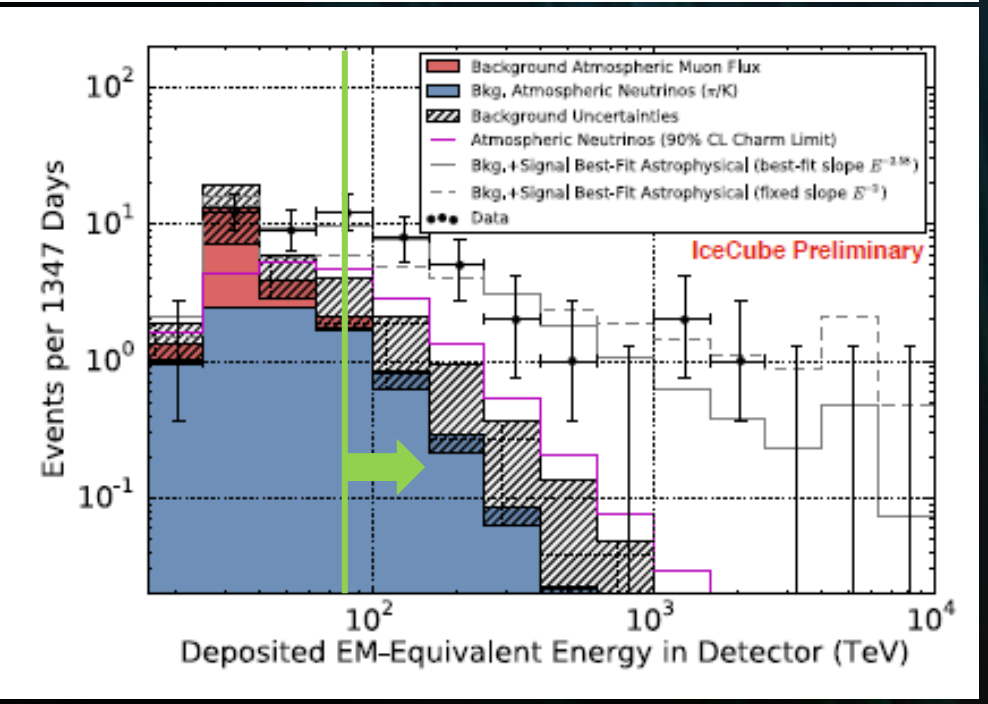


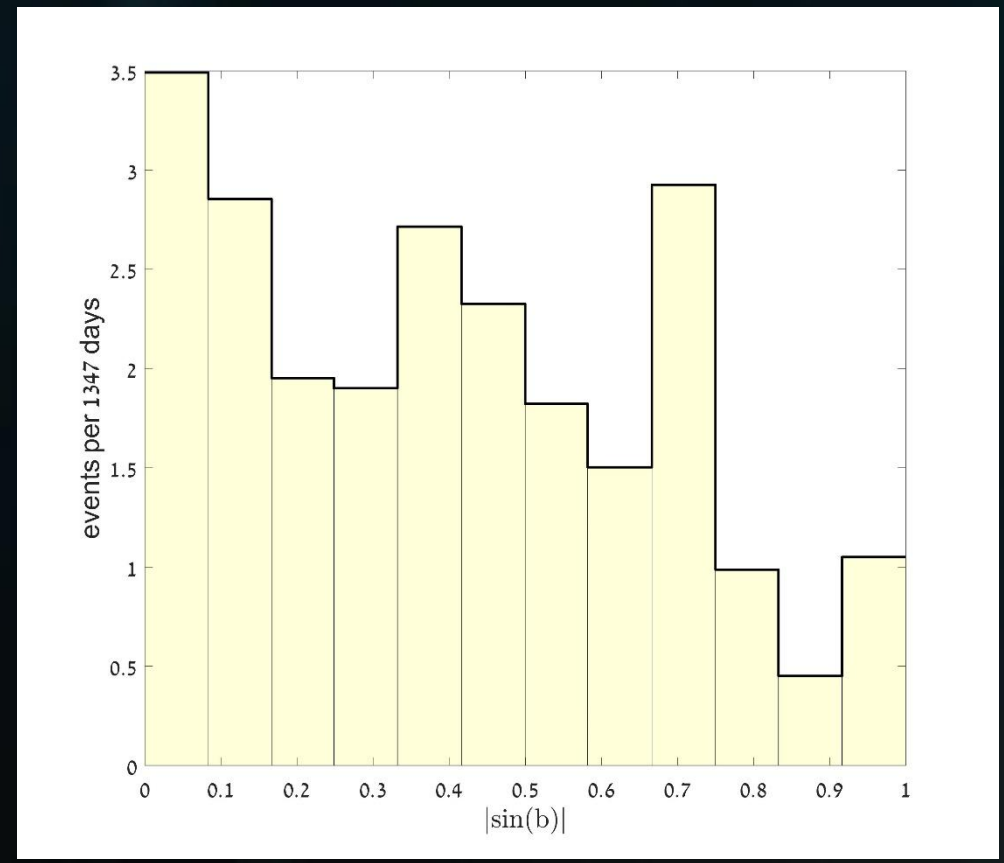
Hints of clustering around the Galactic disk…

Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Cutoff the data below 80 TeV

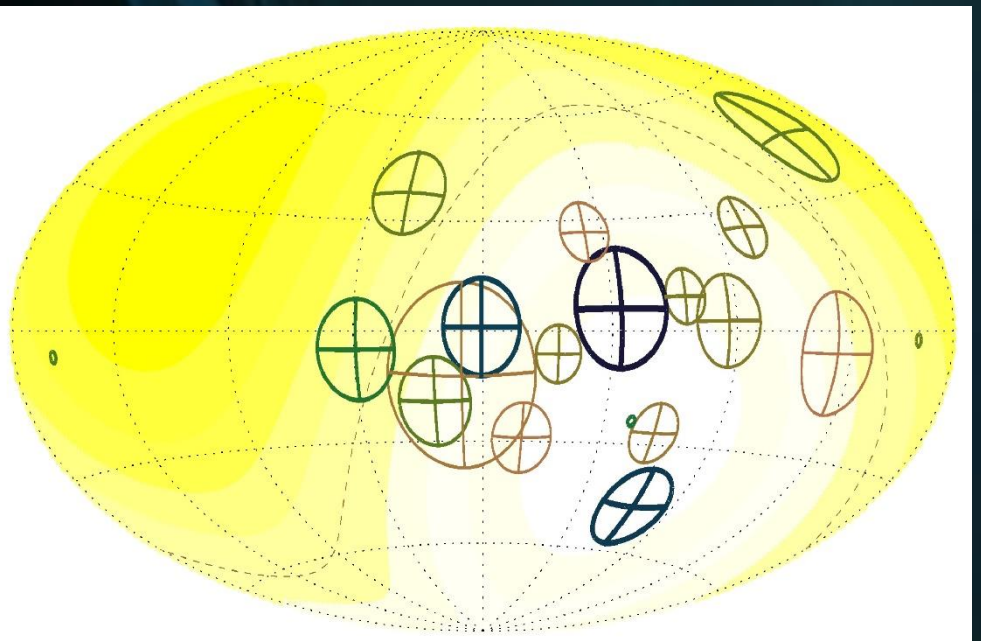


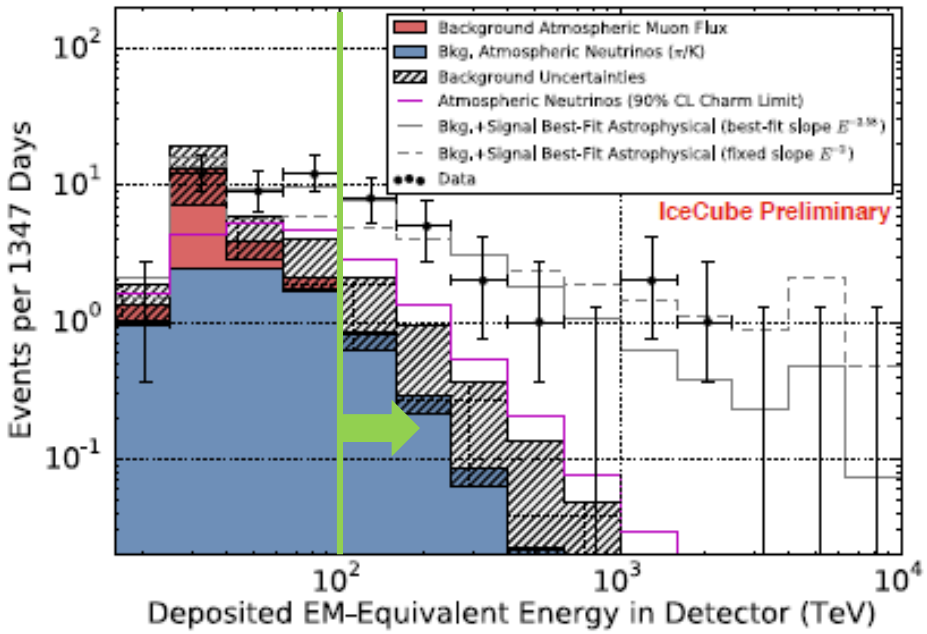


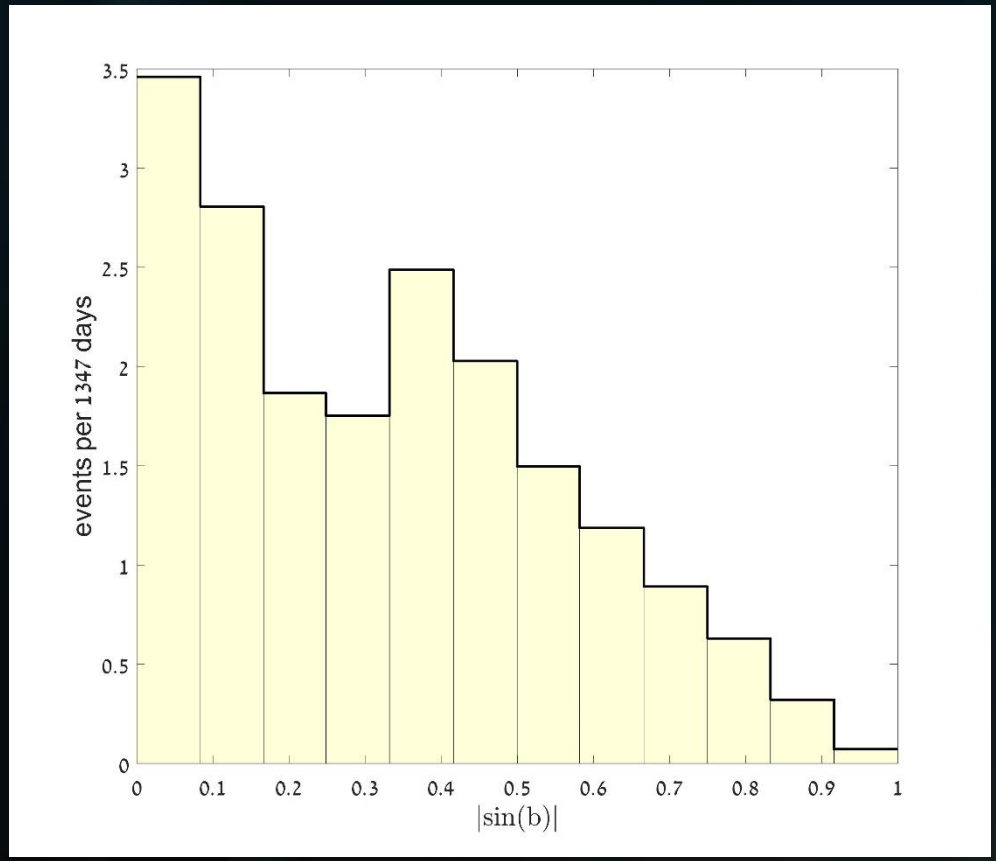


Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Cutoff the data below 100 TeV





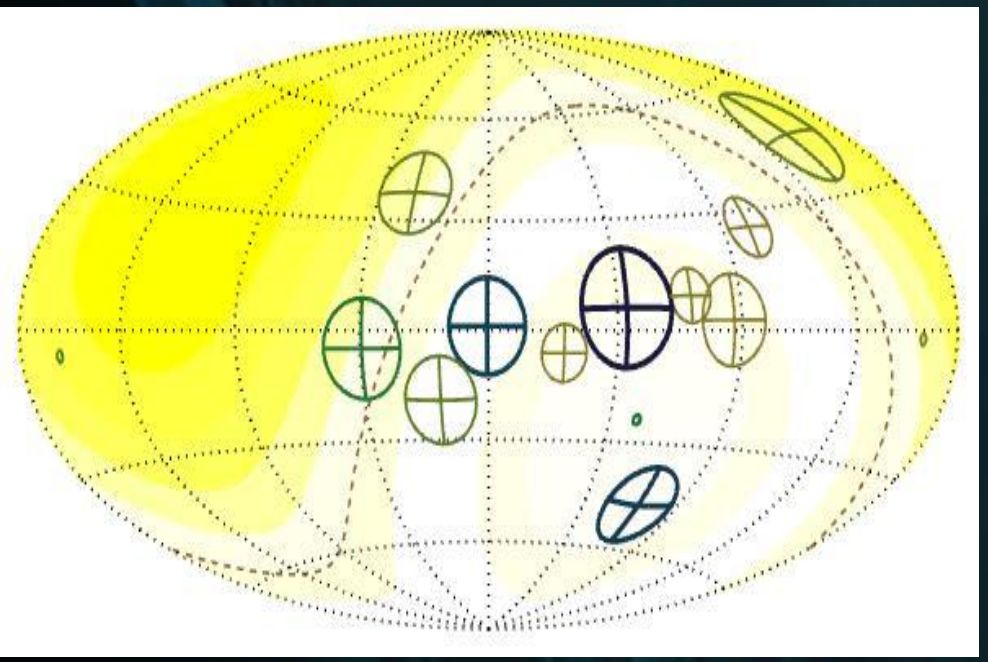


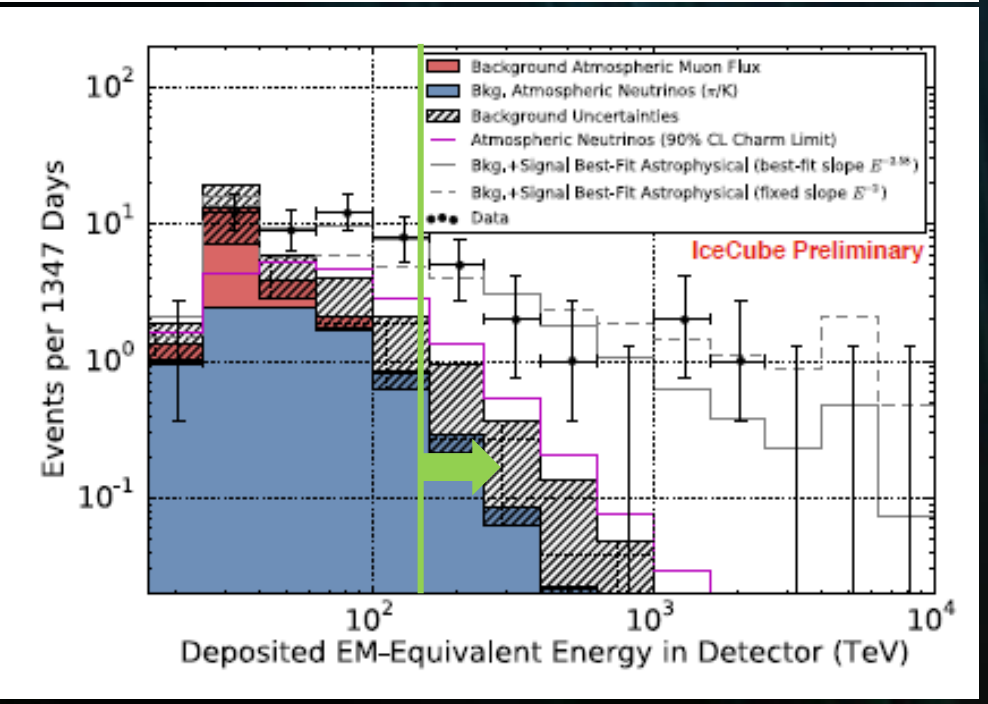
More than hints…

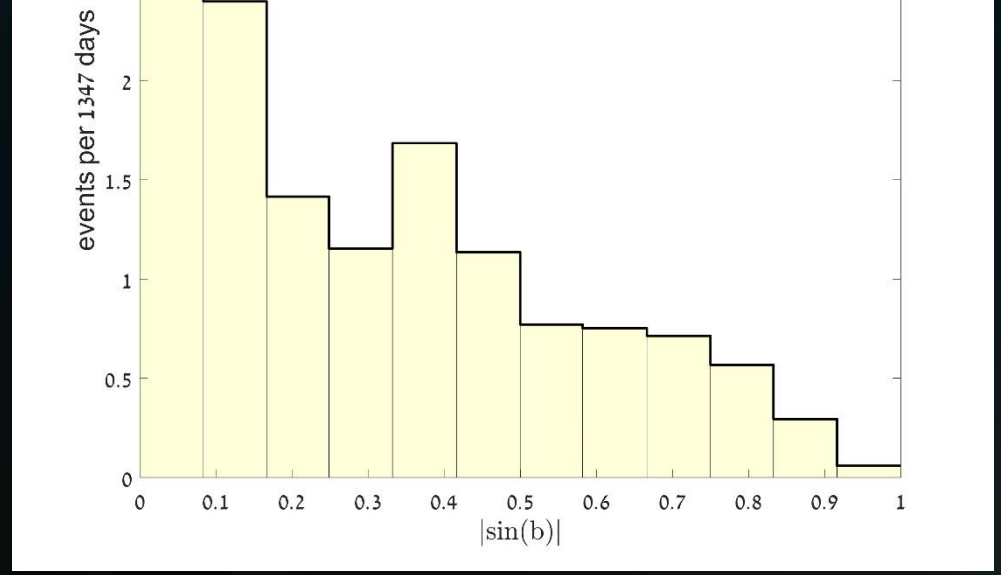
This was already noted by A. Neronov & D. Semikoz 2016

Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Cutoff the data below 150 TeV

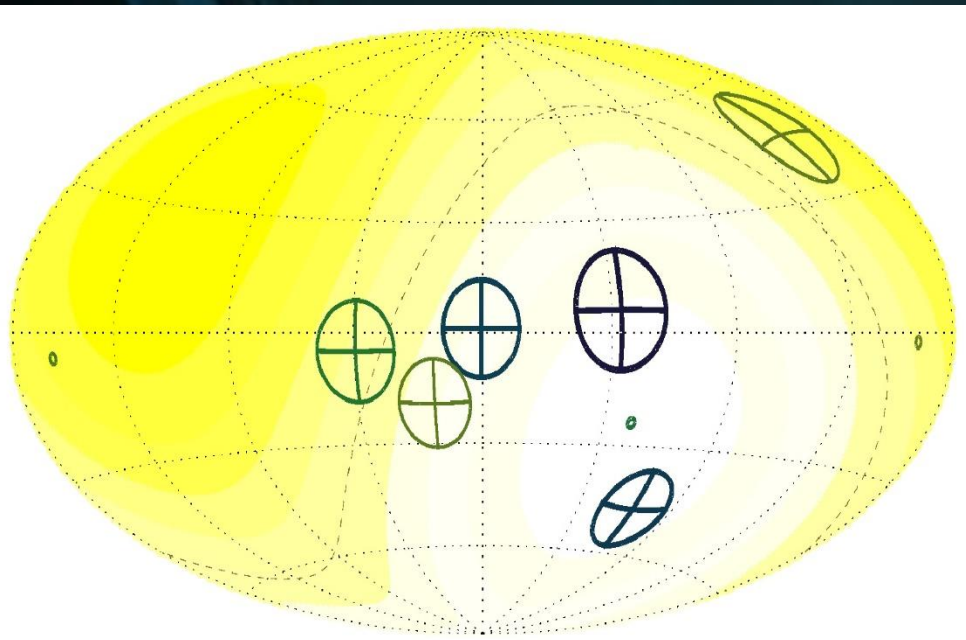


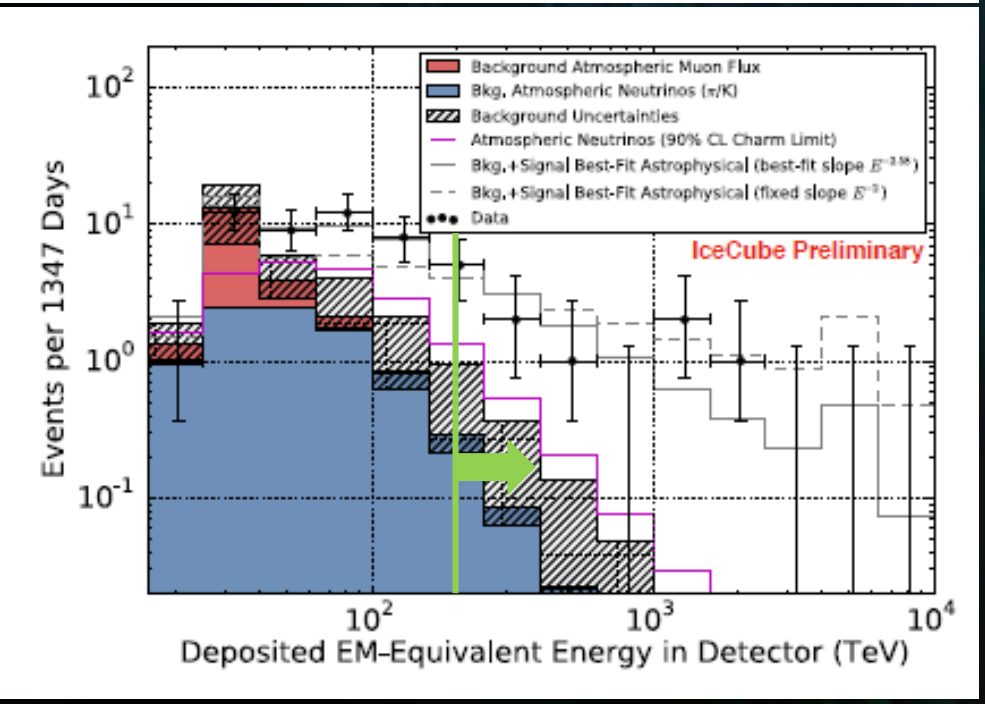


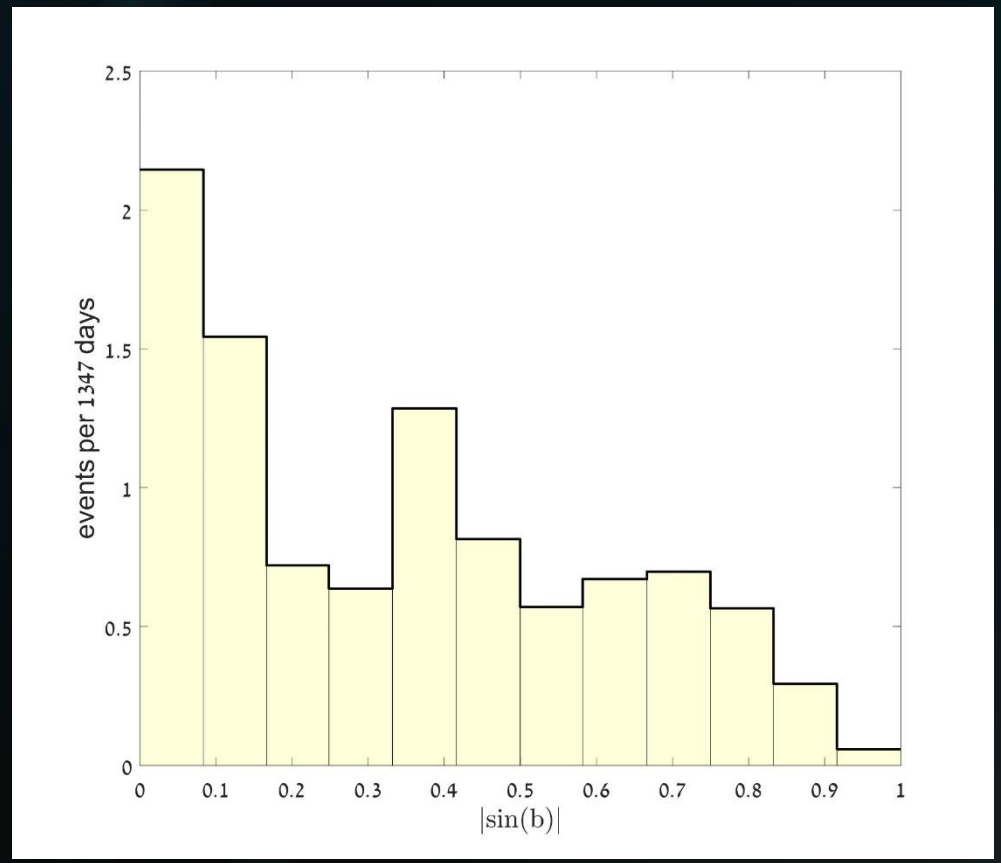


Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Cutoff the data below 200 TeV

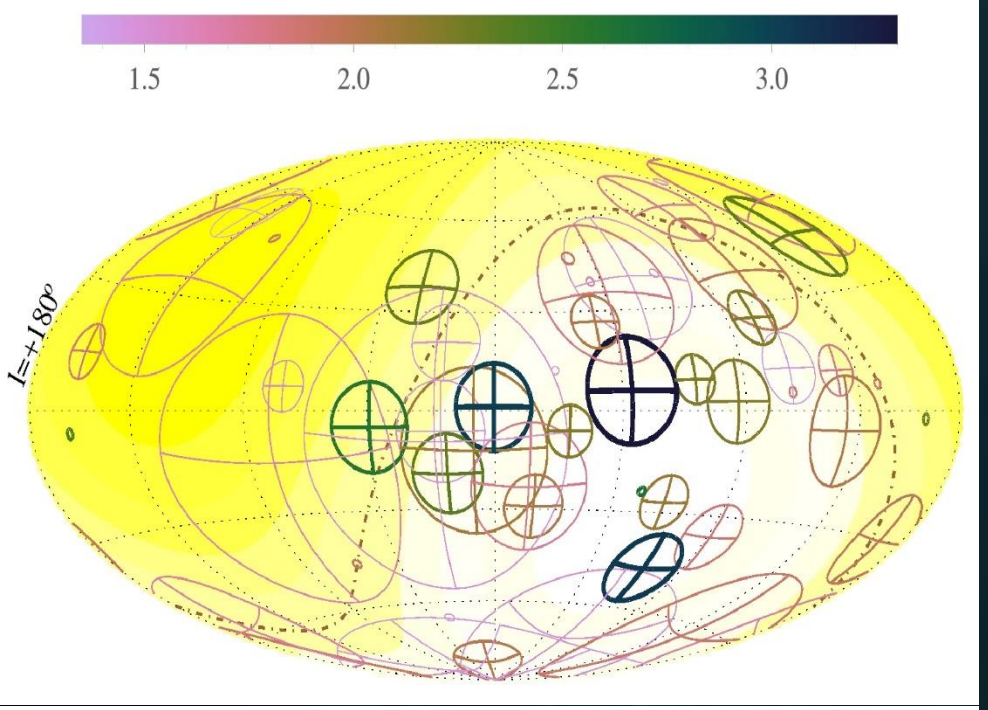


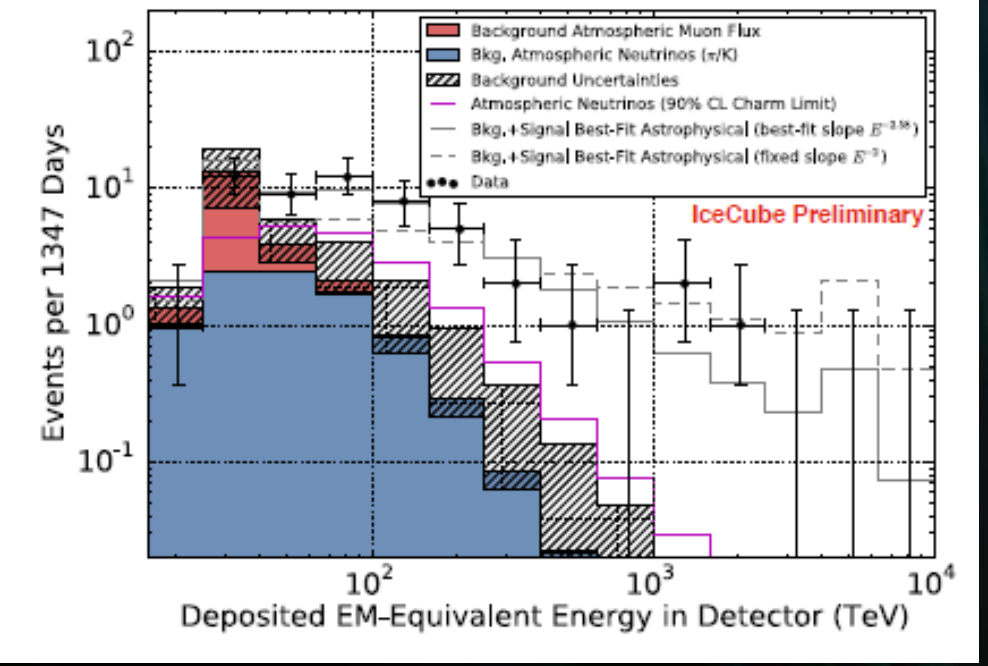


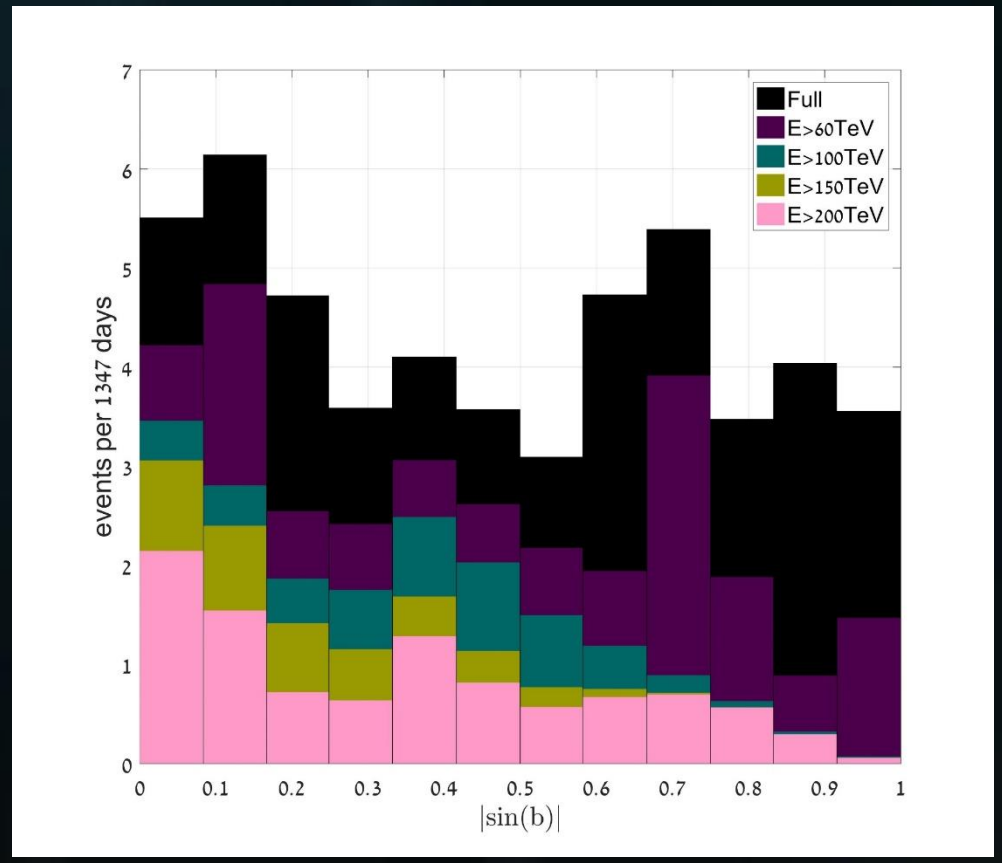


Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Morphology of the ν source



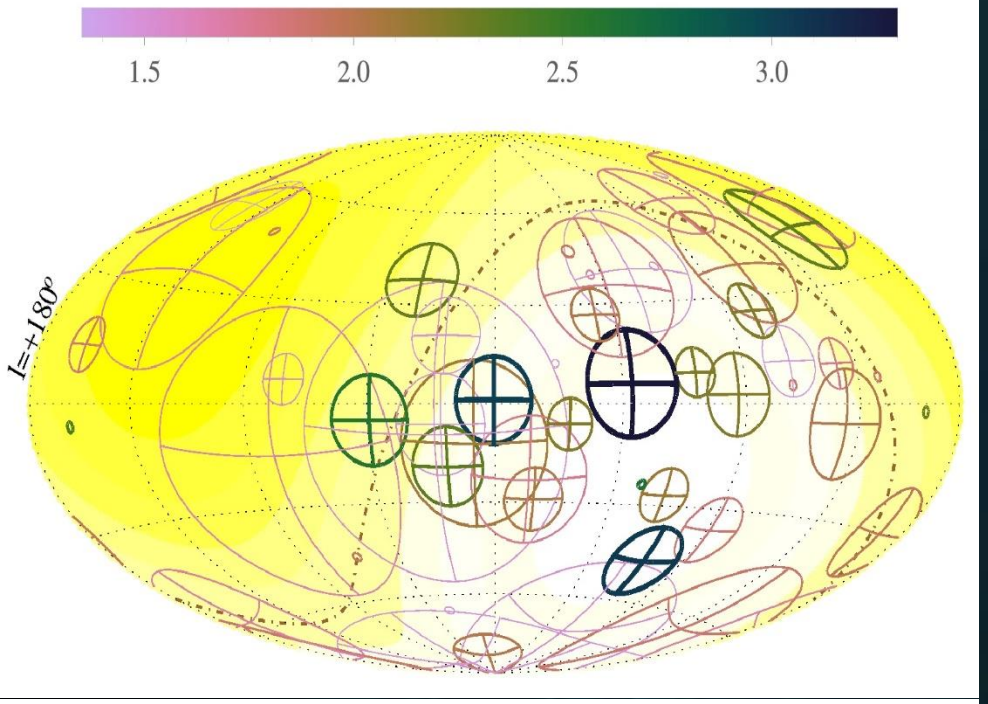


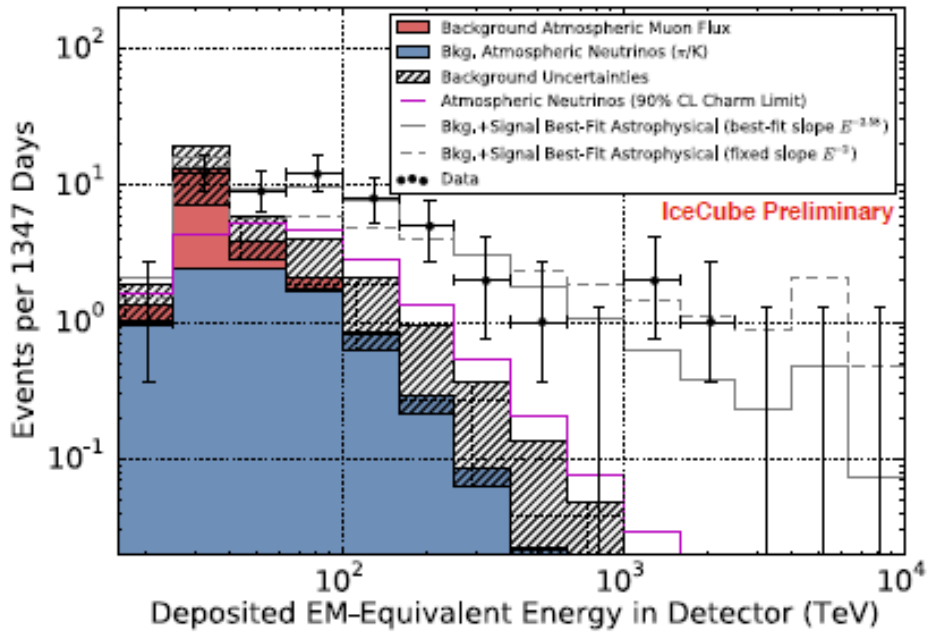


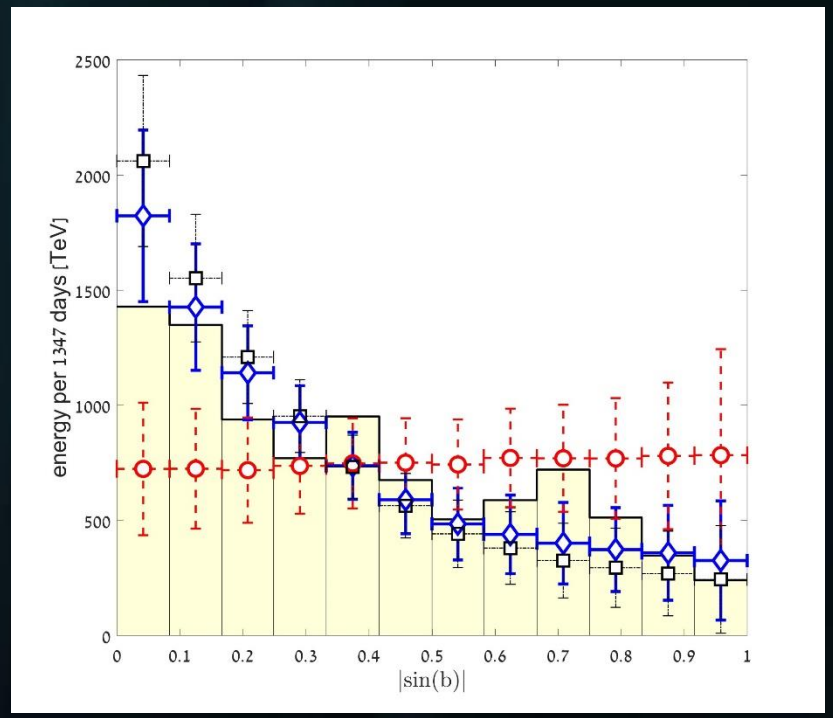
- At high energies the signal is dominated by the Galaxy
- **This implies that the astrophysical ν source is mostly Galactic.**
- We need a better metric than number of events for likelihood analysis

Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Morphology of the ν source







- Deposited energy rather than number of events gives more weight to energetic events.
- **An isotropic source is then excluded at 4.5σ confidence level.**
- **Higher confidence levels can be achieved by choosing a more elaborate metric…**

Taken from Kopper, C., Giang, W., & Kurahashi, N., ICRC, Vol. 34, 1081 (2015)

Implications

- Purely Galactic signal + atmospheric background is excluded at the 3σ level.

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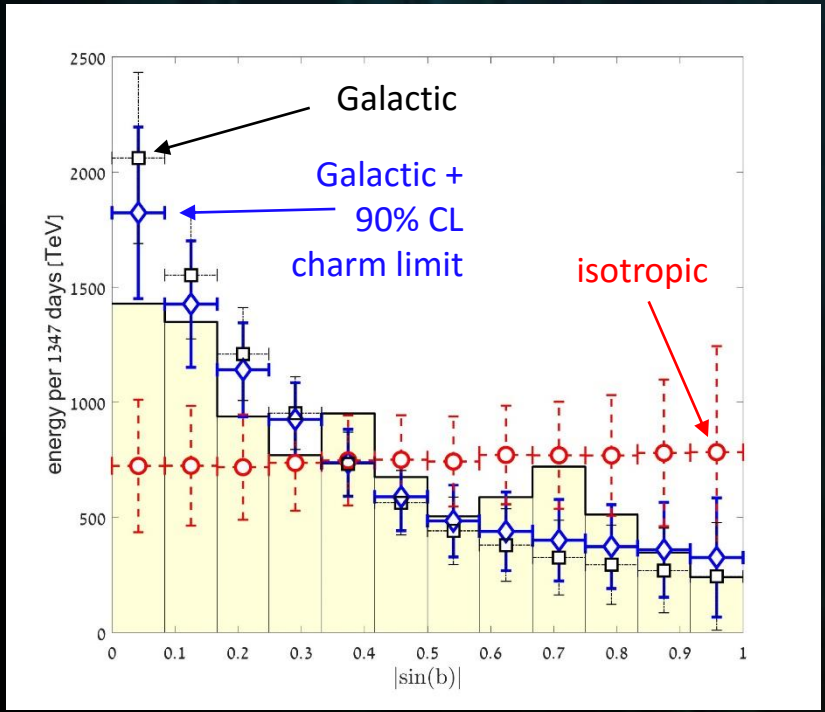
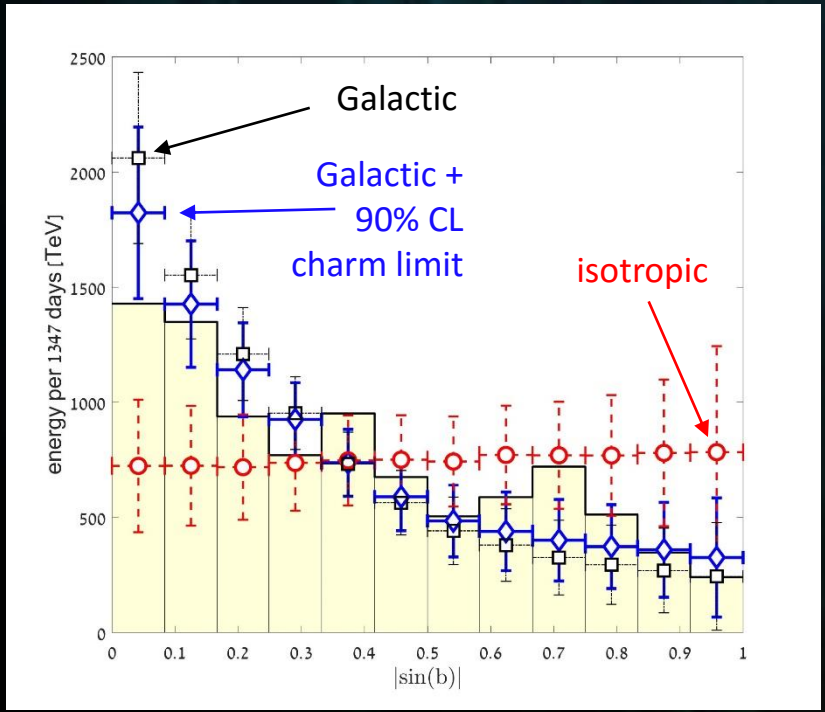
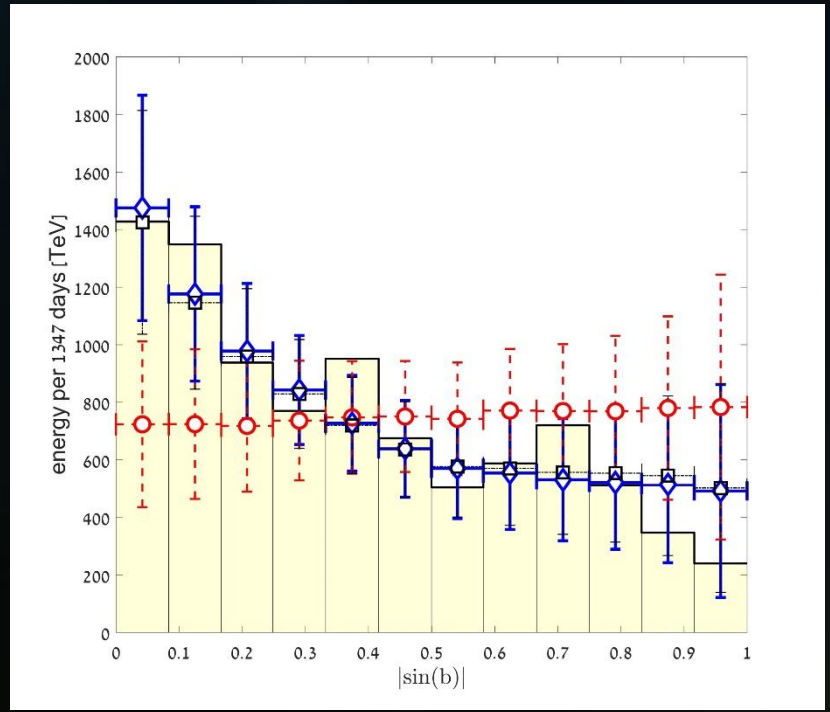


Implications

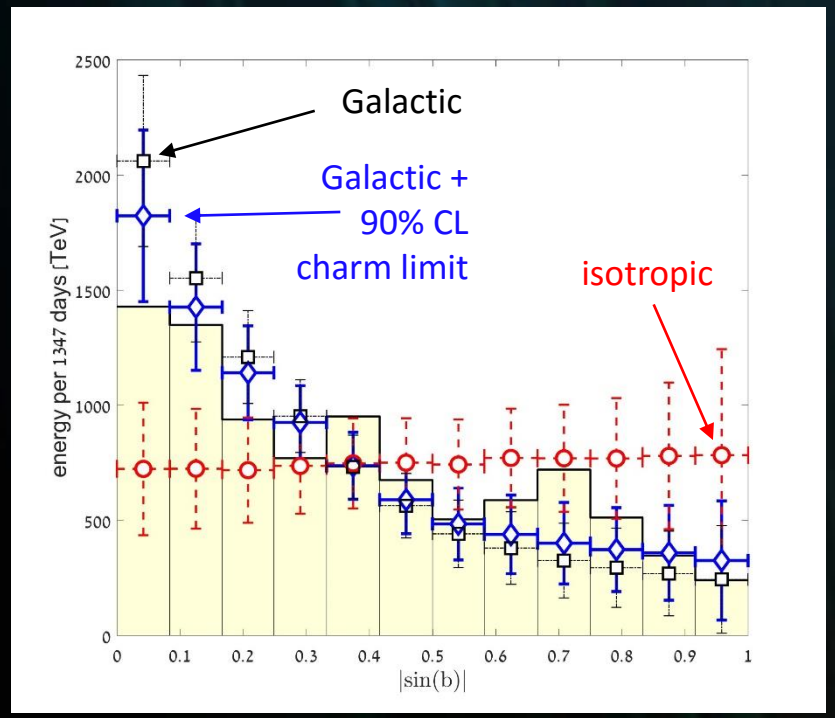
- Purely Galactic signal + atmospheric background is excluded at the 3σ level.
- Either the atmospheric foreground needs to be greater by a factor of ~2 (underestimated charmed events?)

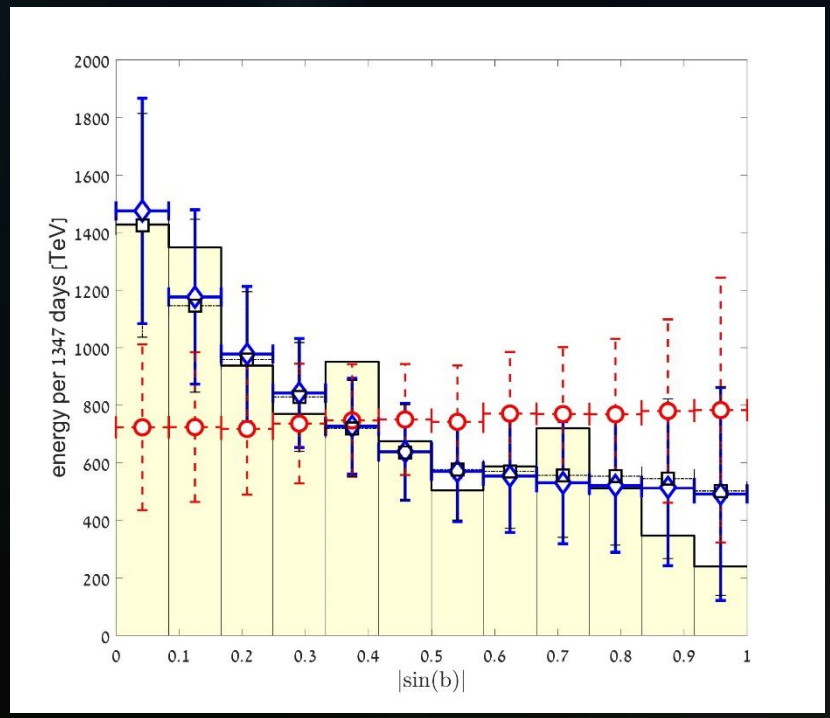




Implications

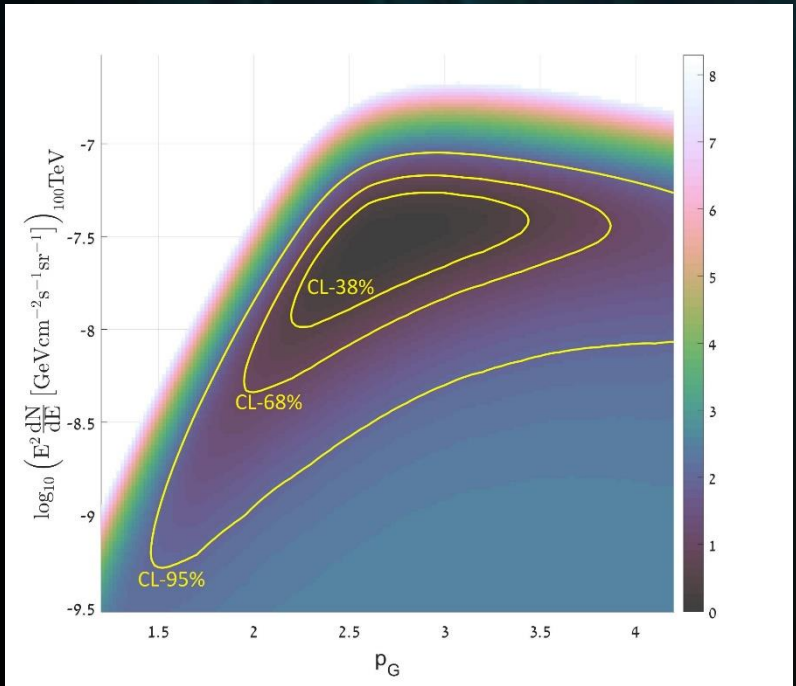
- Purely Galactic signal + atmospheric background is excluded at the 3σ level.
- Either the atmospheric foreground needs to be greater by a factor of ~2 (underestimated charmed events?)
- Or an isotropic extra-galactic component must be added.





Purely Galactic source

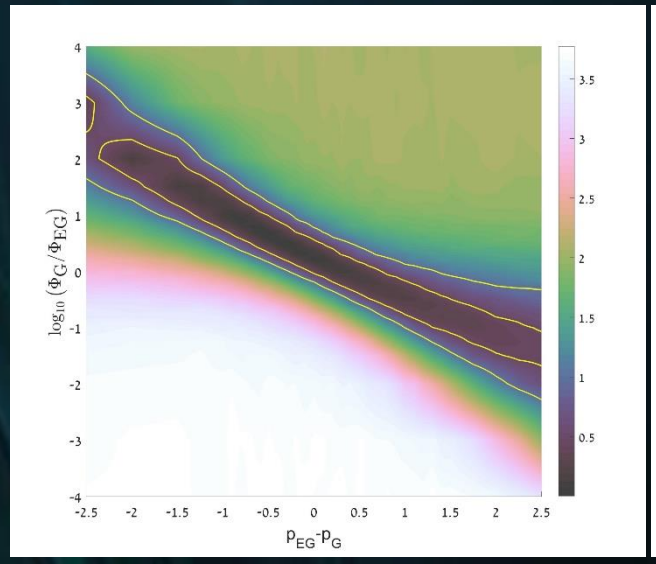
- We use McMillan 2011 model for the MW density profile and assume uniform CR density.
- Under these assumptions, the Galactic ν flux at a 100 TeV is expected to be $\approx 6.4 \times 10^{-8}\ GeV\ s^{-1}cm^{-2}sr^{-1}$ (averaged over solid angle) – Very similar to the astrophysical ν flux estimated by IceCube.

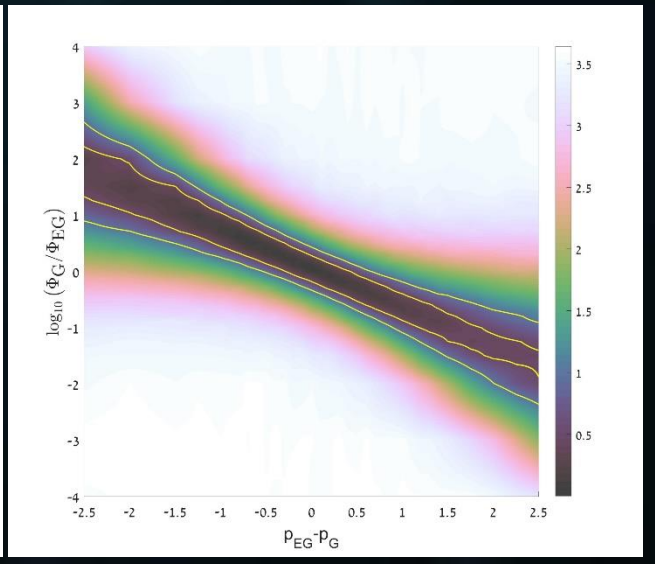


- By increasing the atmospheric (charm) foreground we can fit the data using a purely Galactic source.
- The Galactic flux at 100 TeV is then $(3.5 \pm 2) \times 10^{-8}\ GeV\ s^{-1}cm^{-2}sr^{-1}$
- With a spectral index of 2.7±0.5.

Galactic + extra galactic

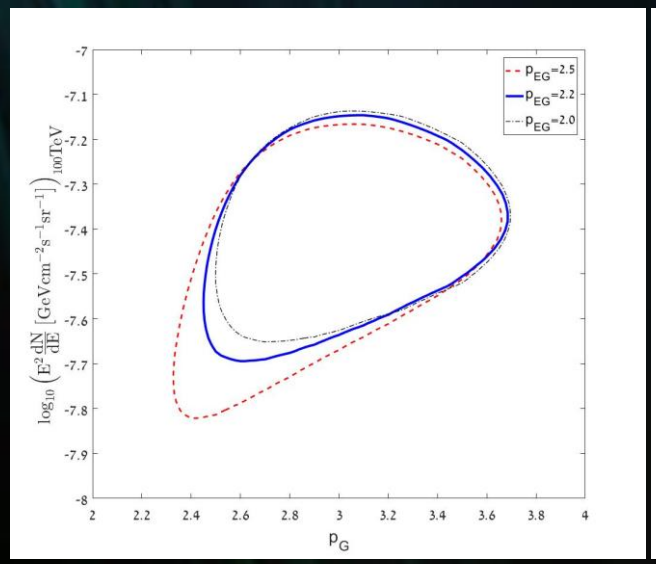
- Fixing the atmospheric foreground we need to add an extra galactic source

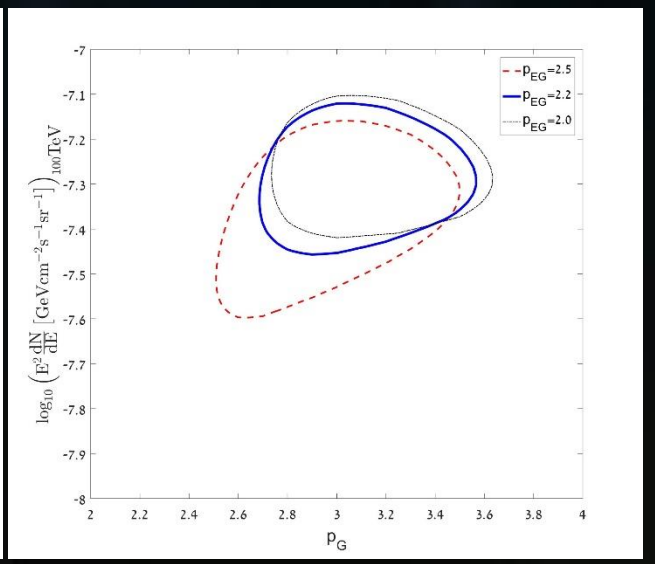




90% CL charm limit

Nominal foreground

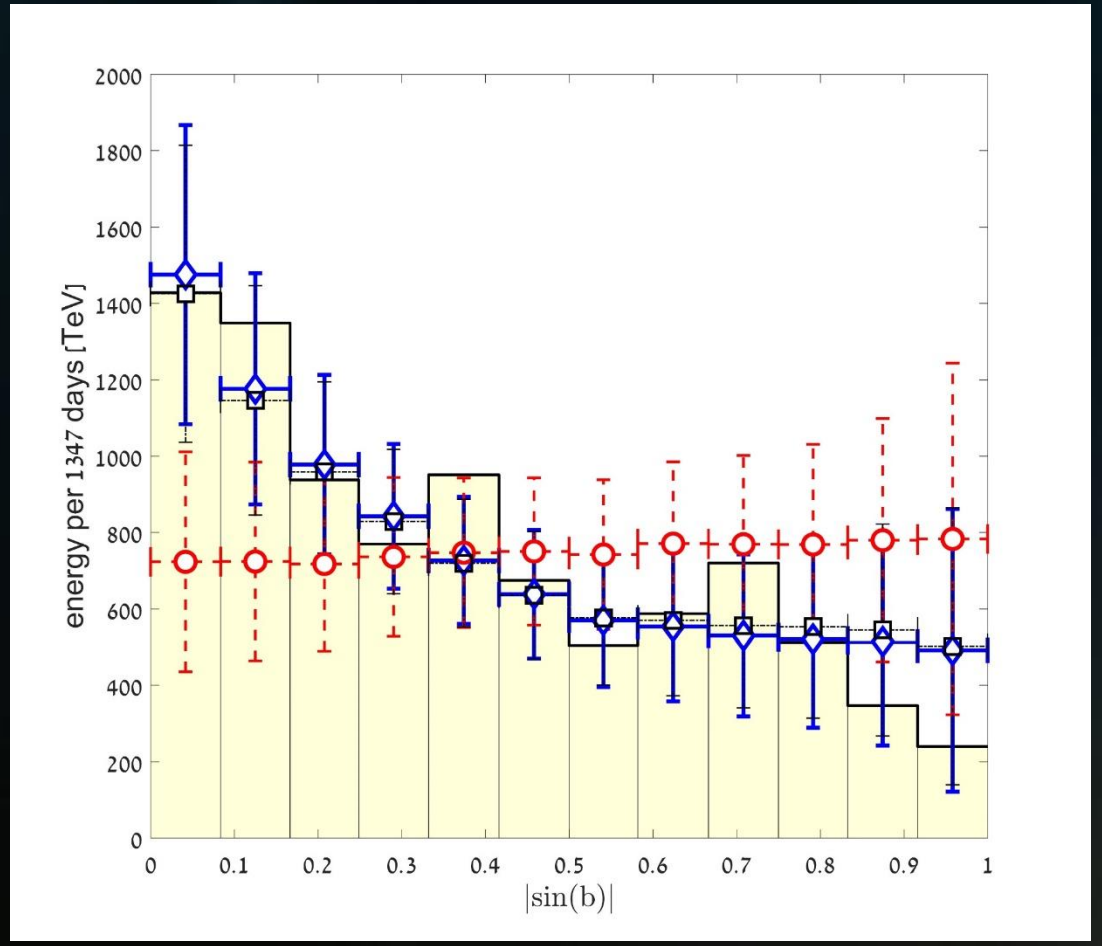




Galactic + extra galactic

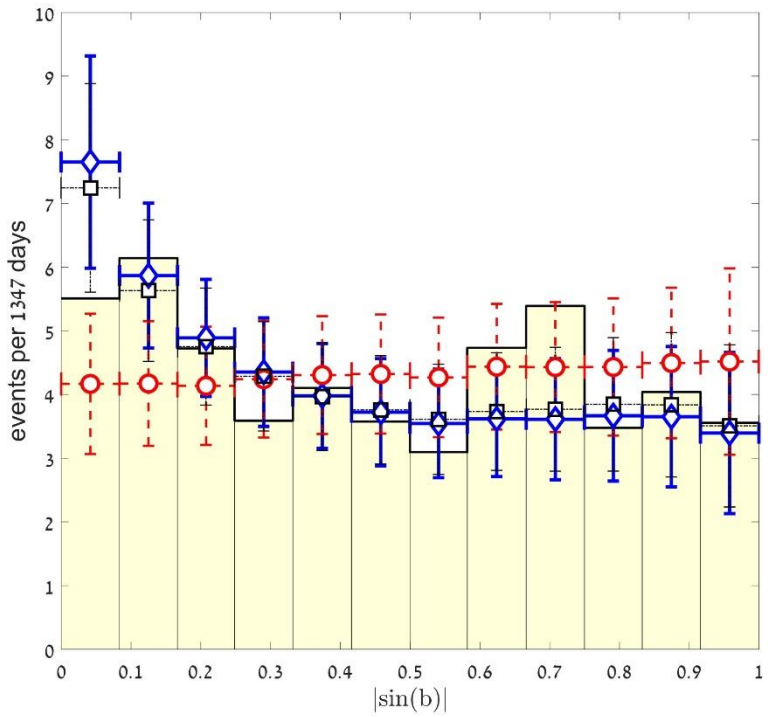
- For a hard extra galactic background (p<2.2) We find a Galactic flux at 100 TeV of $(\mathbf{5.5 \pm 1.5}) \times \mathbf{10^{-8}}\ \boldsymbol{GeV\ s^{-1} cm^{-2} sr^{-1}}$
- With a spectral index of **3.05±0.3**
- TS of ~20 indicates a 4σ confidence level of the MW detection.

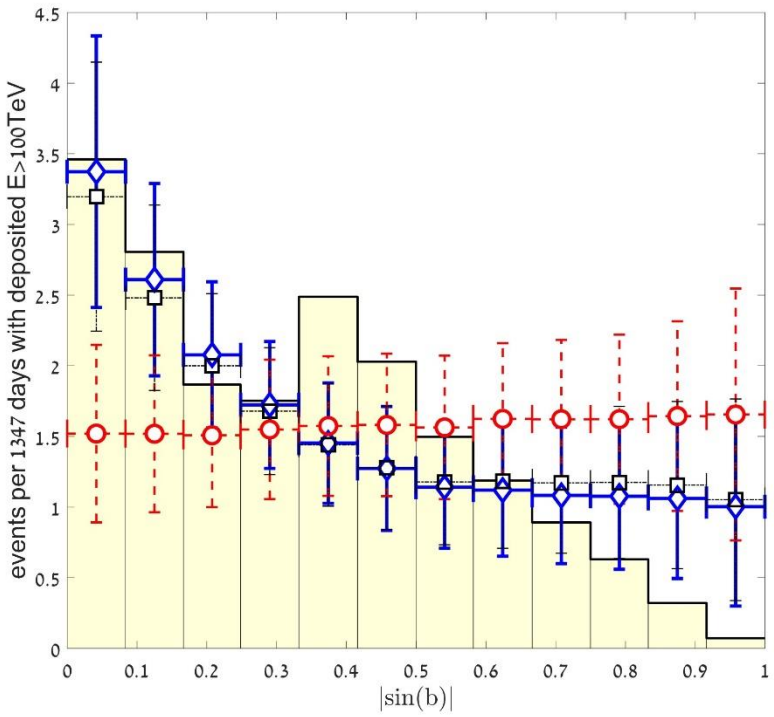
- For a flat (p=2) extra galactic background the extra galactic flux is $(0.5 \pm 0.3) \times 10^{-8}\ GeV\ s^{-1} cm^{-2} sr^{-1}$
- **This is 5 times less than current IceCube estimates.**

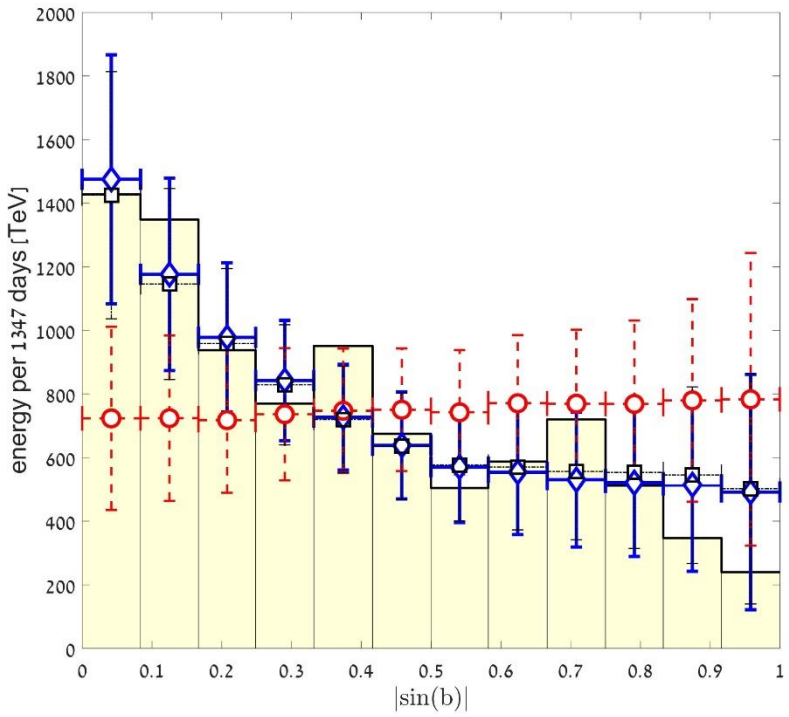


Galactic + extra galactic

- The model gives a good fit in all energy bands



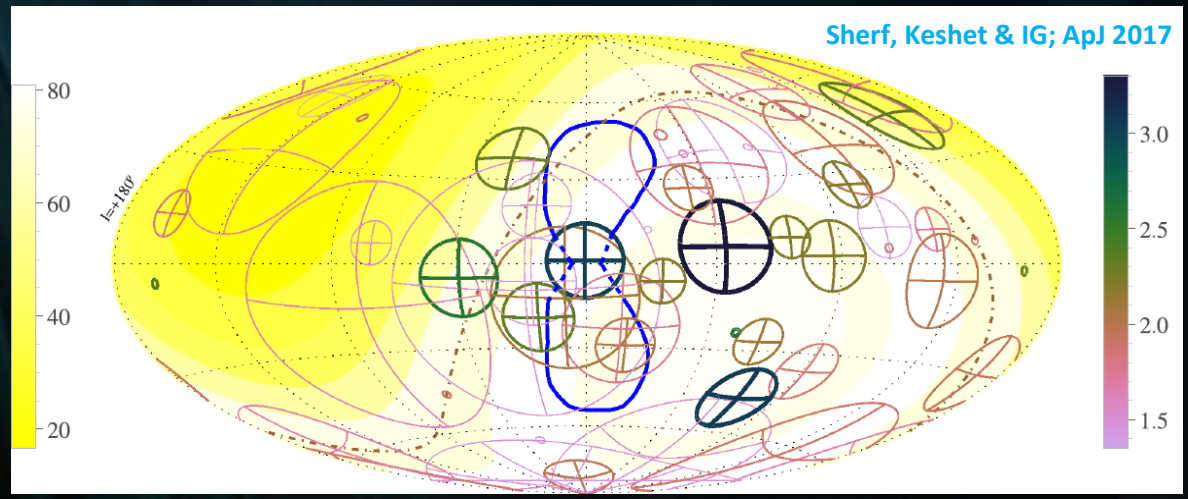




Let us address one of the elephants

- The FBs are a prime candidate for IceCube detection as they are expected to accelerate CRs to high energies.

  Hillas energy of $\mathrm{Ze}\beta BL \approx 500\left(\frac{ZB}{5\mu G}\right)\left(\frac{t}{3Myr}\right)^{-1} PeV$ means the FBs are expected to emit ν with energies up to at least 20PeV
- So do we see clustering of events in the FB region?



- The analysis so far (Sherf, Keshet & IG ApJ2017, Fang et al. 2017) was done assuming an isotropic background.

The search for FBν

- The results show that both in terms of number of events, or in terms of deposited energy, there is no significant clustering in the FBs

Object	# of events	Expected # of events	Deposited energy	Expected deposited energy
FB	3.7	4.4	910TeV	770TeV
FB edges (5^o thick)	1.3	1.7	270TeV	290TeV

Sherf, Keshet & IG; ApJ 2017

- Taking the Galactic emission into account does not change this result.

- The implication of this non-detection is an upper bound on the CRI population in the FBs (assuming there is no break/cutoff in the CR spectrum below ~PeV)

Implications for FBs

- Assuming a flat spectrum this would imply that the FB contain no more than $U_{CR} < 4 \times 10^{54} \left(\frac{n}{10^{-3} cm^{-3}}\right)$erg with a CL of 95%.

- If the γ radiation from the bubbles is leptonic, this implies an electron-to-proton ratio of no less than η>0.006$\left(\frac{n}{10^{-3} cm^{-3}}\right)$

- **The numerical value in the final constraint is weakly dependent on the spectral index.**

Conclusions

- The astrophysical ν signal measured by IceCube is primarily Galactic!
- The extragalactic flux is < 20% WB limit.
- Galactic ν flux consistent with uniform CR distribution throughout the Galaxy.
- FB are not yet detected by IceCube – Implying CR electron-to-proton ratio of $\eta > 0.006$.

Further research

- Better estimates for the Galactic, extragalactic and FB ν fluxes with more data (6 years of events are now available)
- Understanding the MW CR population using combined ν-γ study
- Searching for additional HE ν sources in the data.

  some clues are already there

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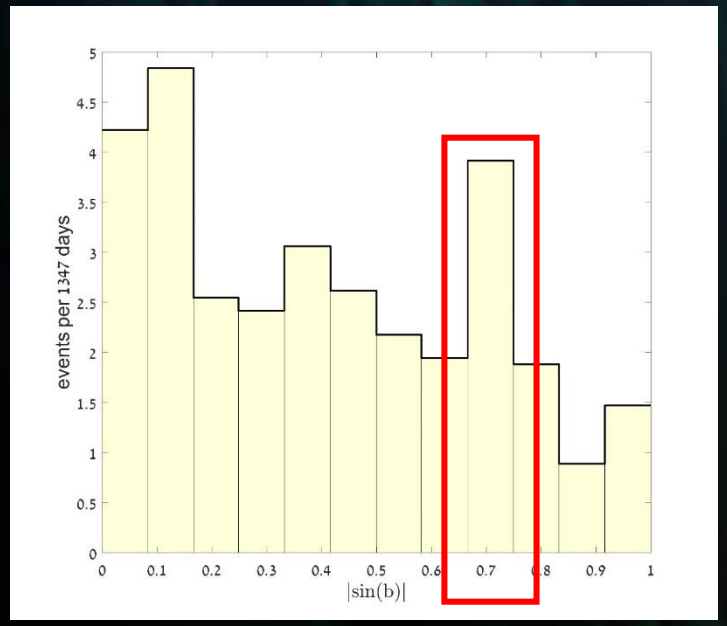

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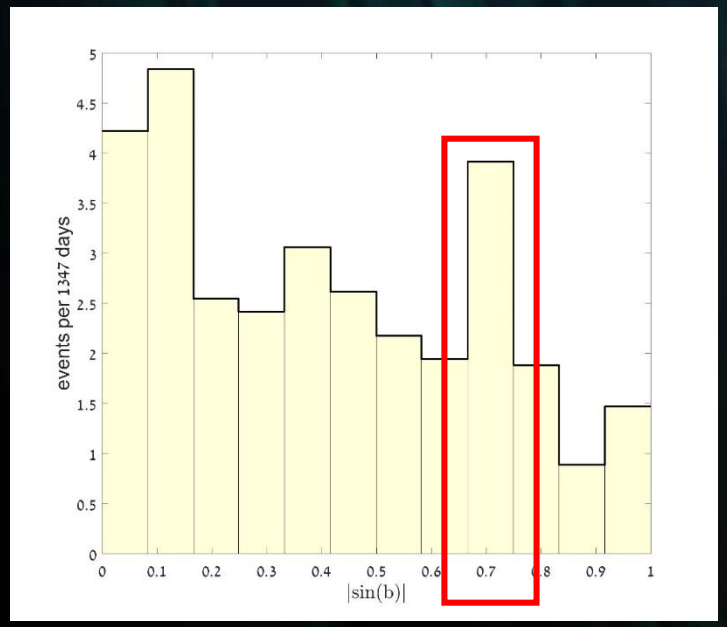

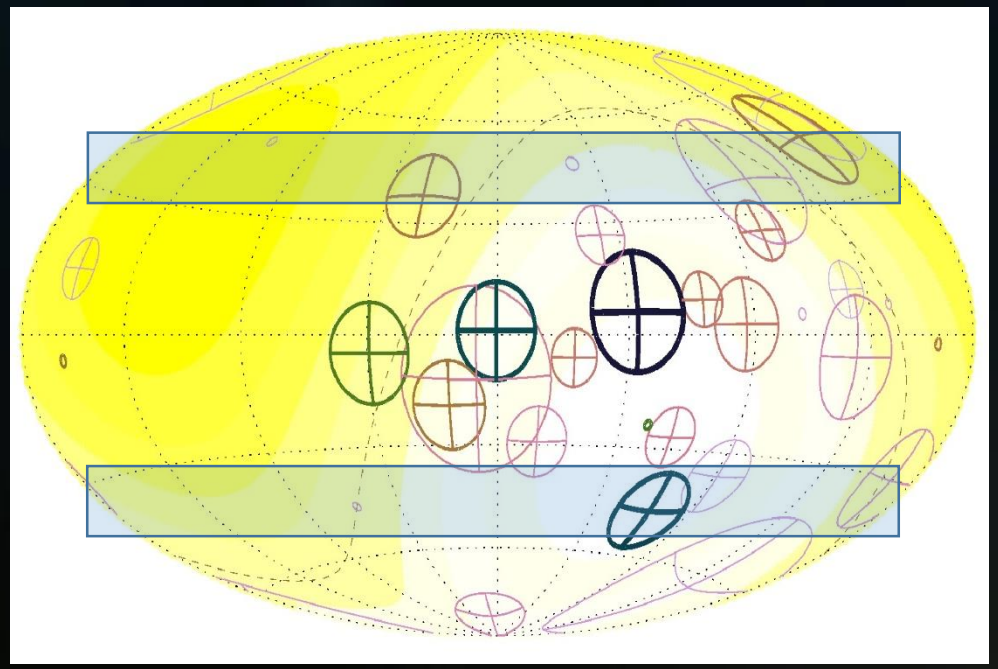

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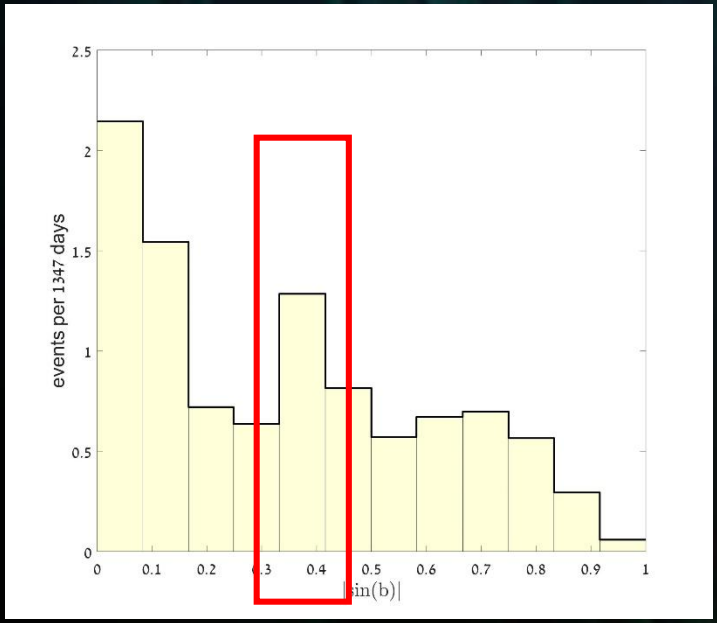

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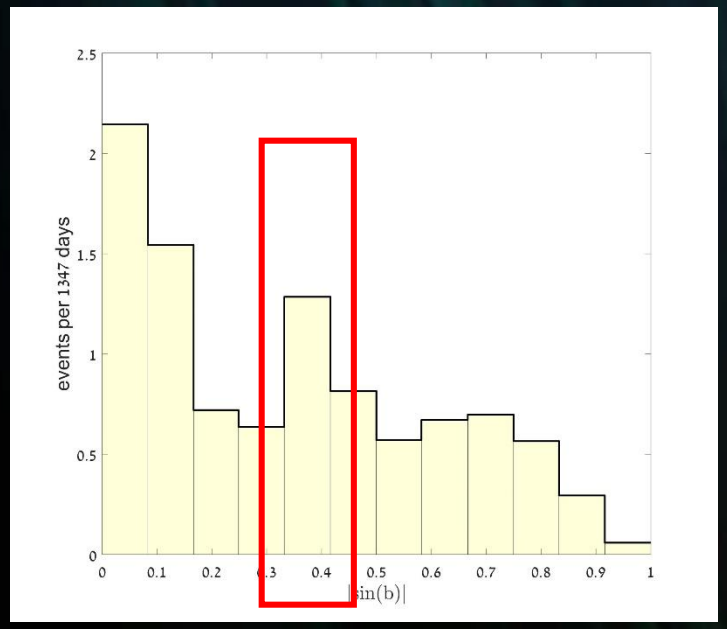

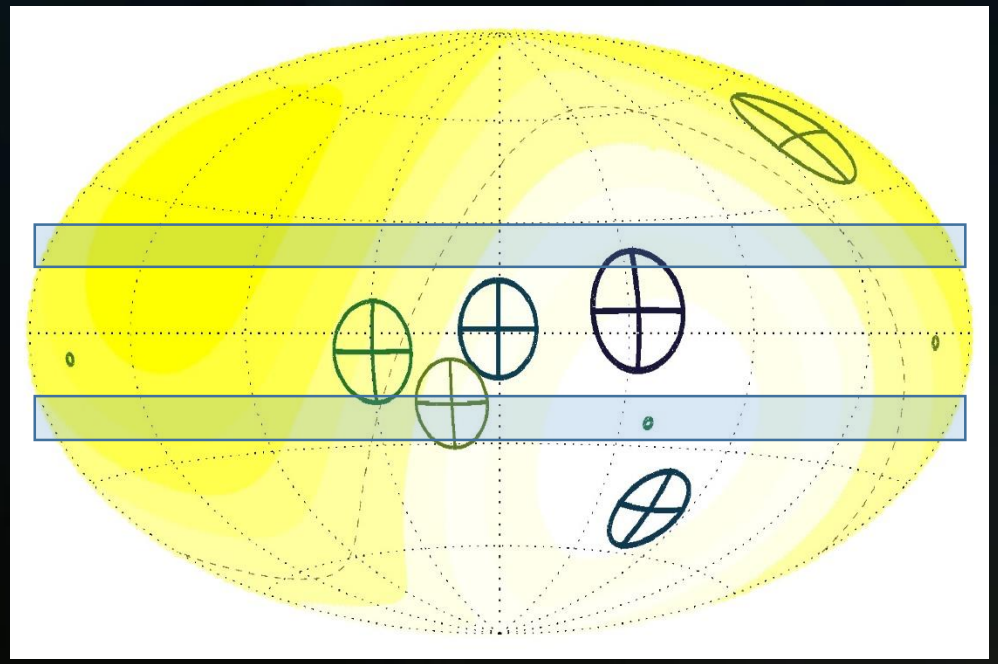

Thank you!

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Are you convinced?