Baksan Neutrino Observatory of
Institute for Nuclear Research of the
Russian Academy of Sciences

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

Carpet-2 observation of *E>300 TeV* photons accompanying a *150 TeV* neutrino from the Cygnus Cocoon

Romanenko Viktor,
for the Carpet-3 Collaboration
vsrom94@gmail.com

July 2021

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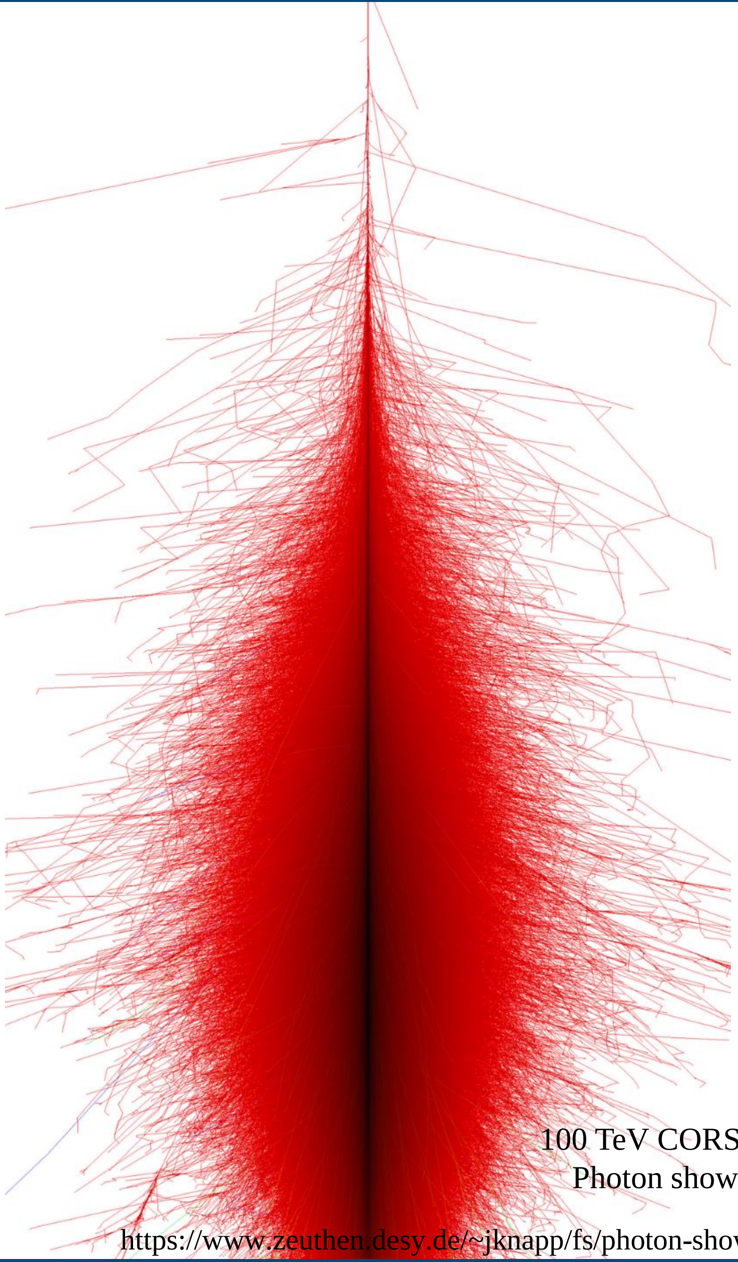
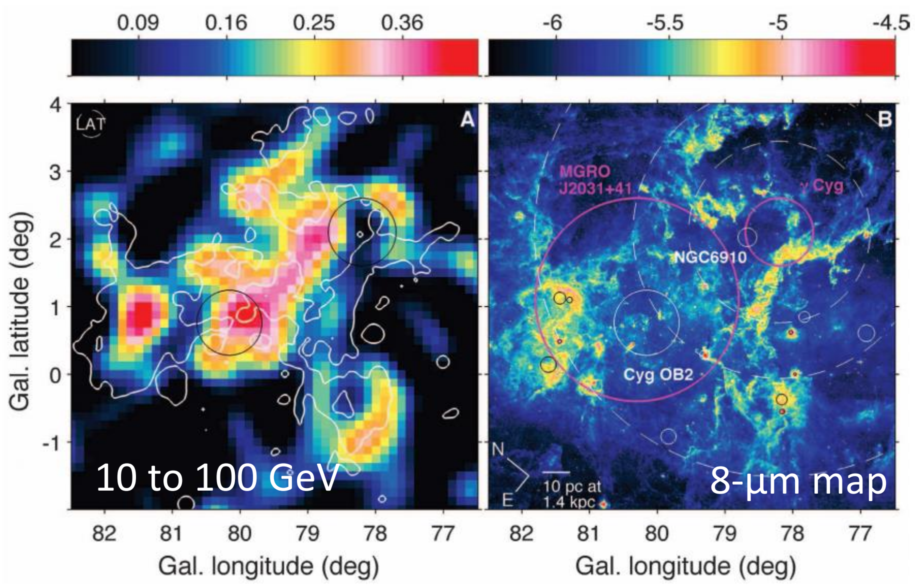


100 TeV CORSIKA
Photon shower

https://www.zeuthen.desy.de/~jknapp/fs/photon-showers.html

Cygnus Cocoon an overview

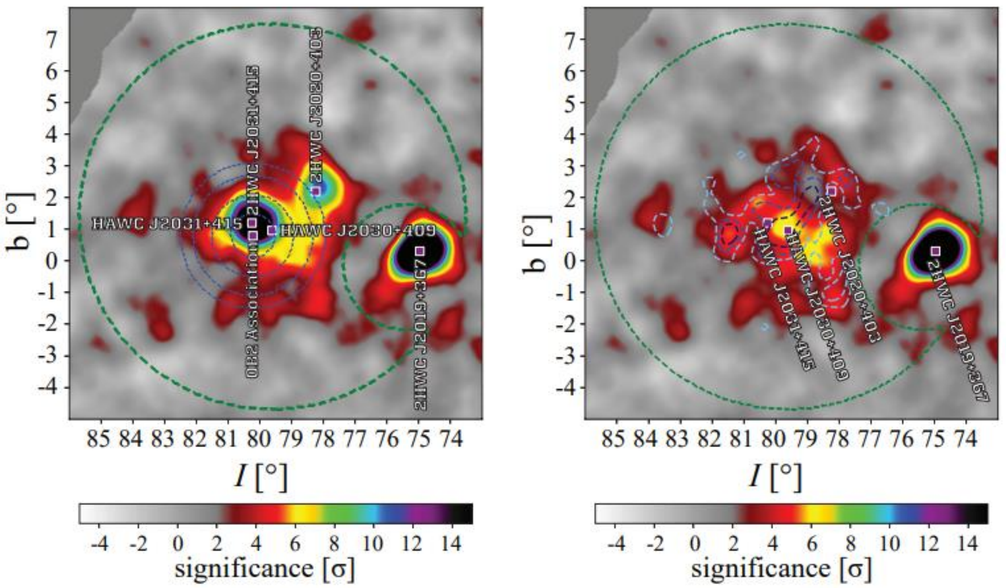
A Cocoon of Freshly Accelerated Cosmic Rays Detected by Fermi in the Cygnus Superbubble



Ackermann, Markus, et al.
Science 334.6059 (2011): 1103-1107.
DOI: 10.1126/science.1210311

Letter | Published: 11 March 2021

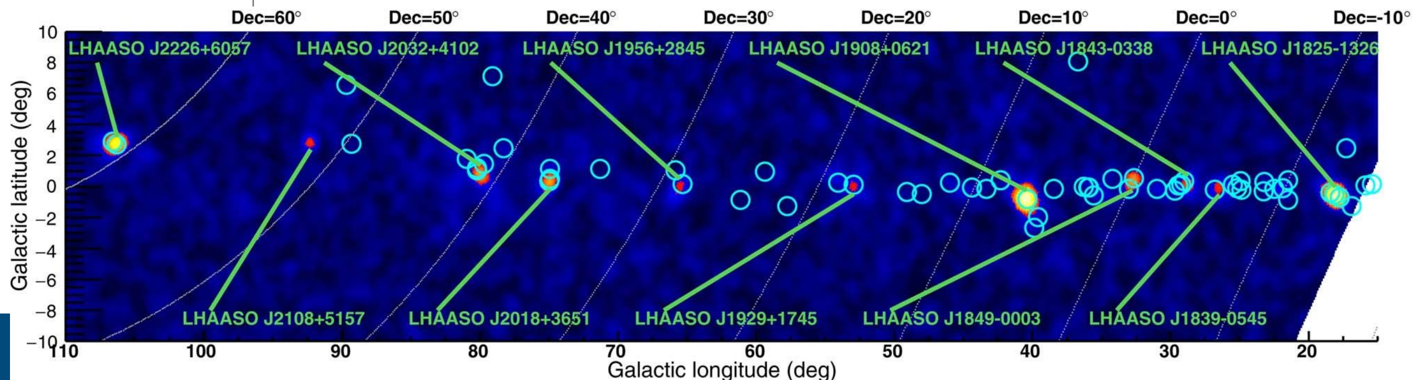
HAWC observations of the acceleration of very-high-energy cosmic rays in the Cygnus Cocoon



Abeysekara, A.U. et al. Nat Astron 5, 465–471 (2021).
https://doi.org/10.1038/s41550-021-01318-y
arXiv:2103.06820 [astro-ph.HE]

Article

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources



Cao, Z., Aharonian, F.A., An, Q. Et al.
Nature 594, 33–36 (2021).
https://doi.org/10.1038/s41586-021-03498-z

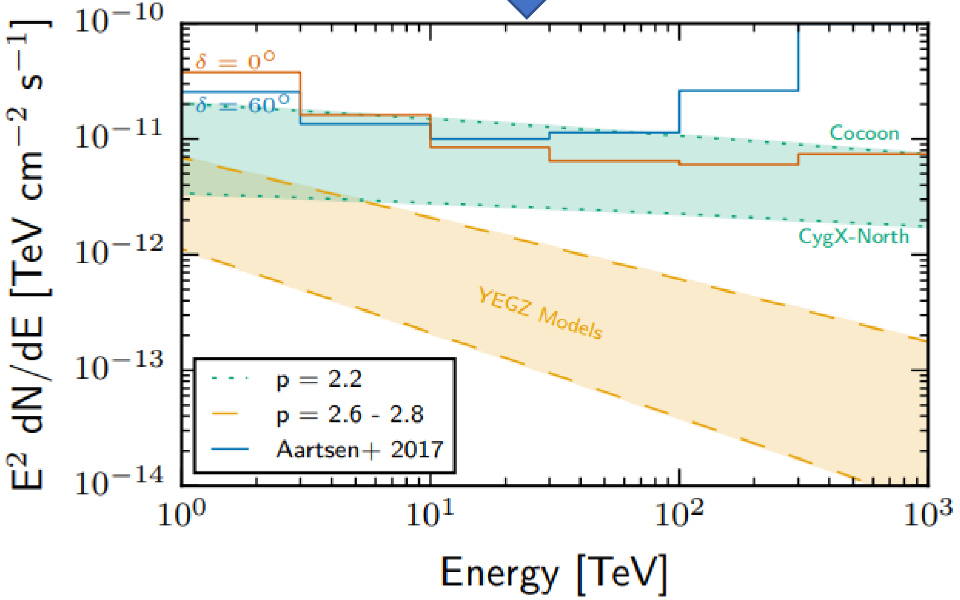
Cygnus Cocoon as possible neutrino source

PHYSICAL REVIEW D **96,** 043011 (2017)

Gamma-ray puzzle in Cygnus X: Implications for high-energy neutrinos

Tova M. Yoast-Hull,[1,2] John S. Gallagher III,[3] Francis Halzen,[1,2] Ali Kheirandish,[1,2] and Ellen G. Zweibel[1,3]
[1]*Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, USA*
[2]*Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin, Madison, Wisconsin 53703, USA*
[3]*Department of Astronomy, University of Wisconsin, Madison, Wisconsin 53706, USA*
(Received 13 September 2016; published 21 August 2017)

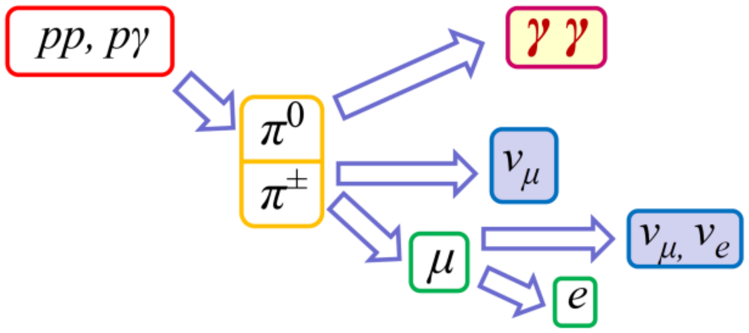
expected neutrino fluxes are close to an observation



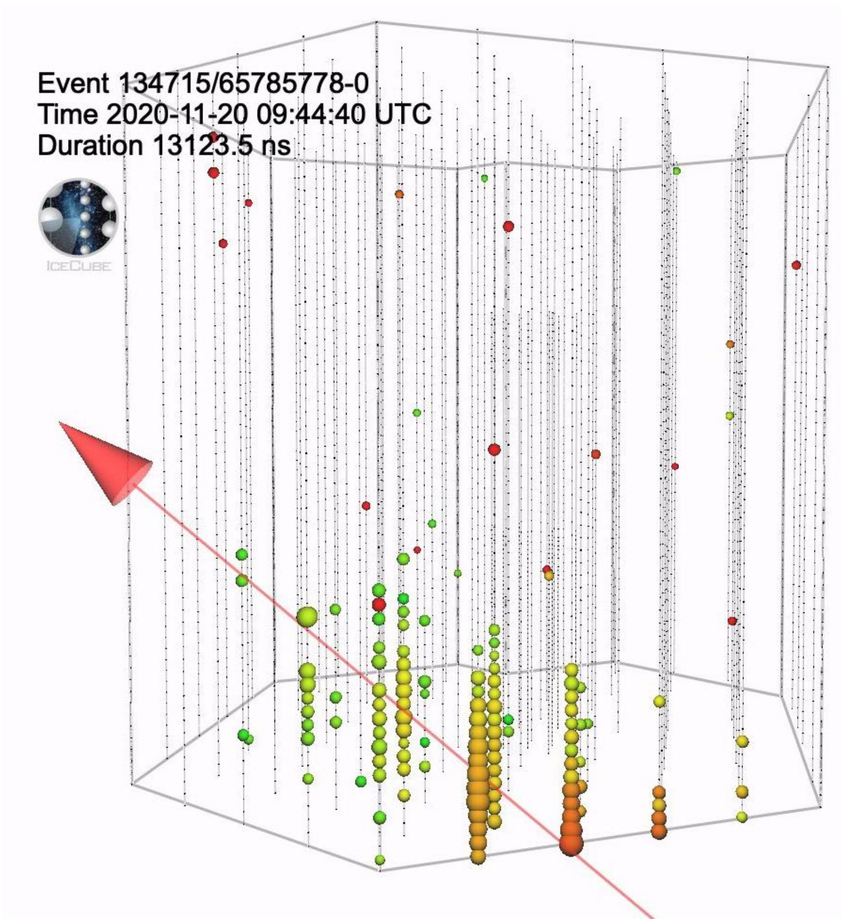
Space Sci Rev (2020) 216:42
https://doi.org/10.1007/s11214-020-00663-0

High-Energy Particles and Radiation in Star-Forming Regions

Andrei M. Bykov[1] · Alexandre Marcowith[2] · Elena Amato[3] · Maria E. Kalyashova[1] · J.M. Diederik Kruijssen[4] · Eli Waxman[5]



The GCN IceCube alert

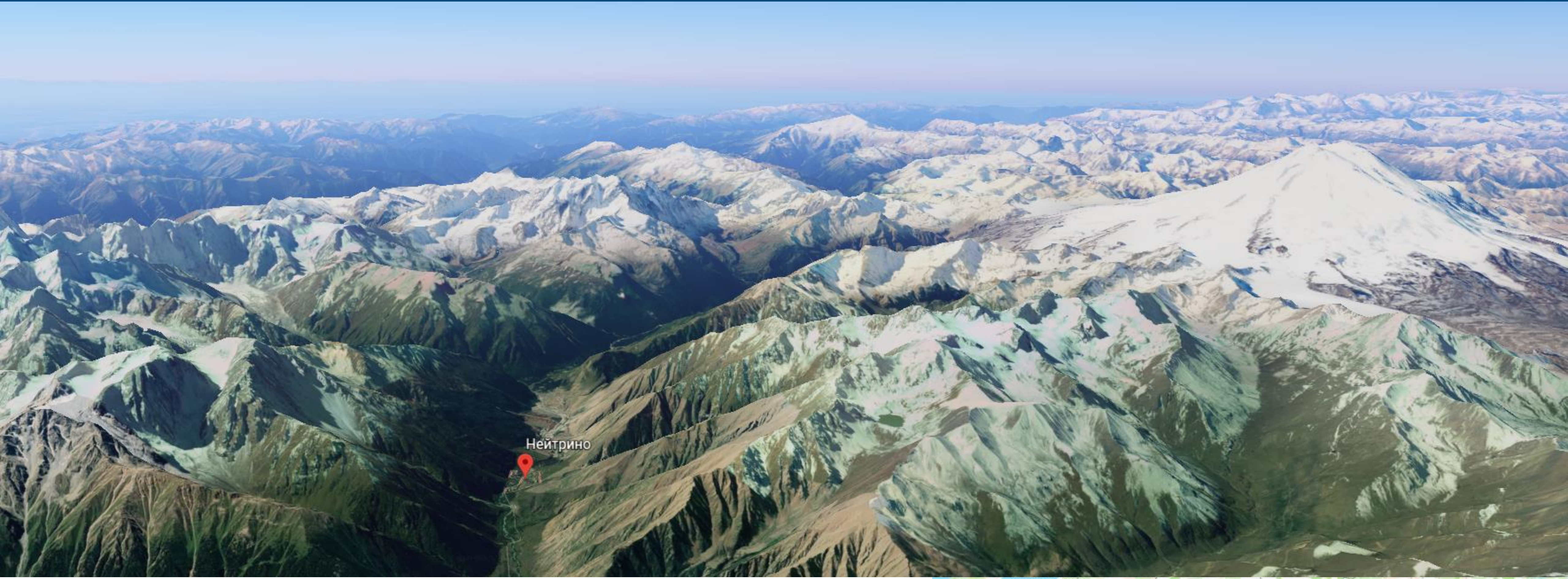


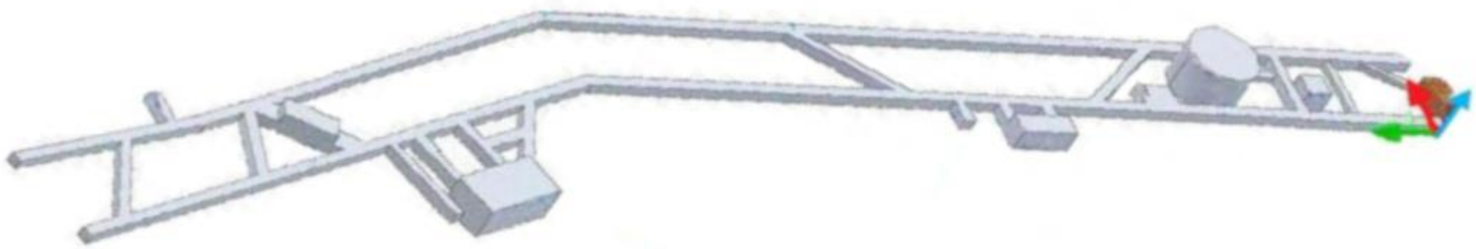

```
//////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  28927
SUBJECT: IceCube-201120A: IceCube observation of a high-energy neutrino candidate event
DATE:    20/11/20 13:57:56 GMT
FROM:    Cristina Lagunas Gualda at DESY  <cristina.lagunas@desy.de>

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 20/11/20 at 09:44:40.56 UT IceCube detected a track-like event with a moderate probability of being of astrophysical
origin. The event was selected by the ICECUBE_Astrotrack_Bronze alert stream. The average astrophysical neutrino purity for
Bronze alerts is 30%. This alert has an estimated false alarm rate of 0.295 events per year due to atmospheric backgrounds.
The IceCube detector was in a normal operating state at the time of detection.

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon_g_b/134715_65785778.amon), more
sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

Date: 20/11/20
Time: 09:44:40.56  UT
RA: 307.53 (+ 5.34 - 5.59 deg 90% PSF containment) J2000
Dec: 40.77 (+ 4.97 - 2.80 deg 90% PSF containment) J2000

Due to the topology of this event, with a short distance traversed through the detector, the updated angular uncertainty is
significantly larger than average error contours.

We encourage follow-up by ground and space-based instruments to help identify a possible
astrophysical source for the candidate neutrino.

There are several Fermi-LAT 4FGL sources inside the 90% localization region. The closest source is 4FGL J2028.6+4110e
(Cygnus Cocoon) located at RA 307.17 deg and Dec 41.17 deg (J2000), at a distance of 0.484 degrees from the best-fit
location.

The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector operating at the geographic South Pole, Antarctica.
The IceCube realtime alert point of contact can be reached at roc@icecube.wisc.edu
```

Despite poor localization, this event is exceptional:
the first neutrino alert associated with a plausible Galactic source

https://gcn.gsfc.nasa.gov/gcn3/28927.gcn3

Baksan Neutrino Observatory, Neutrino village





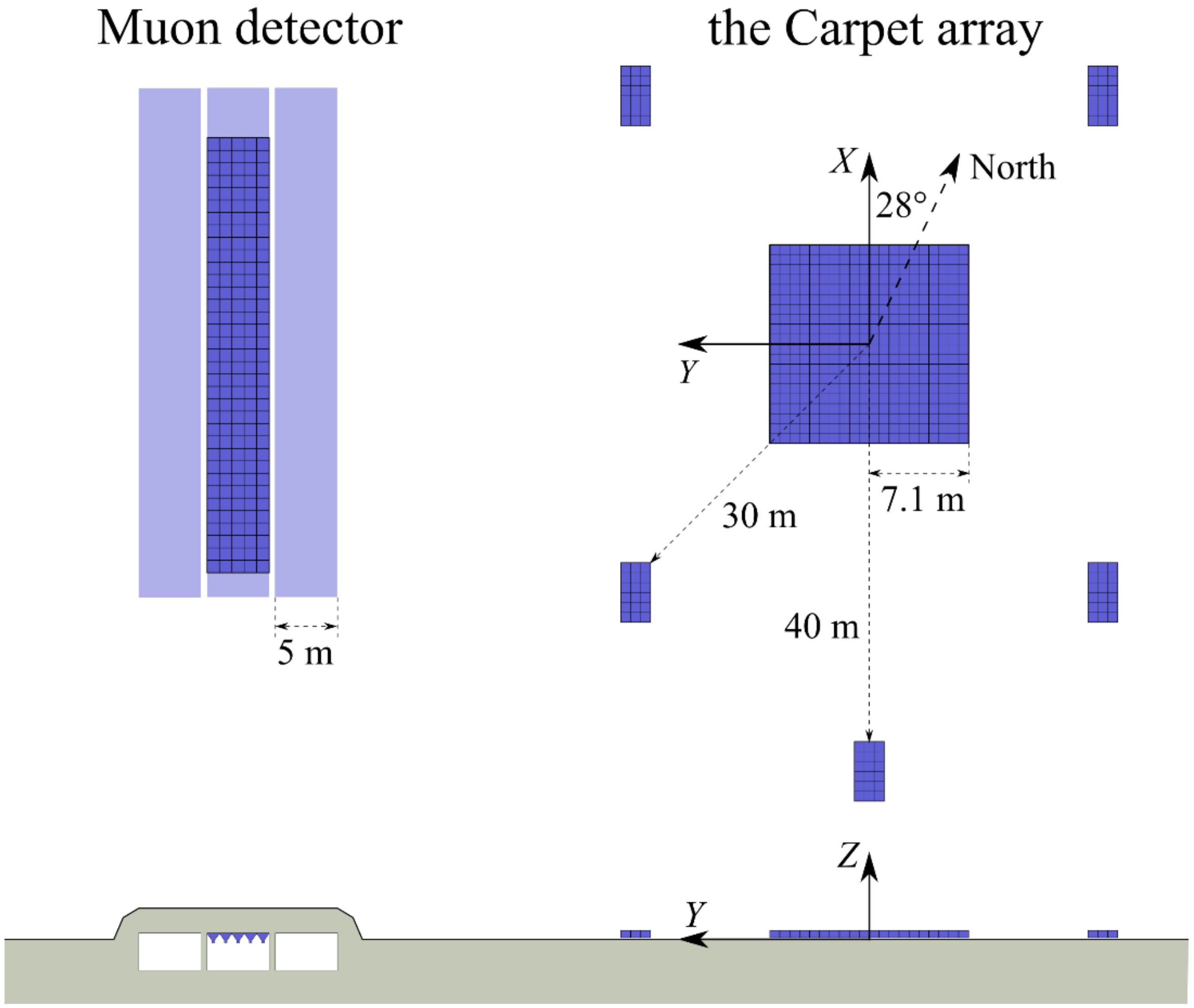
The Carpet-2 EAS array

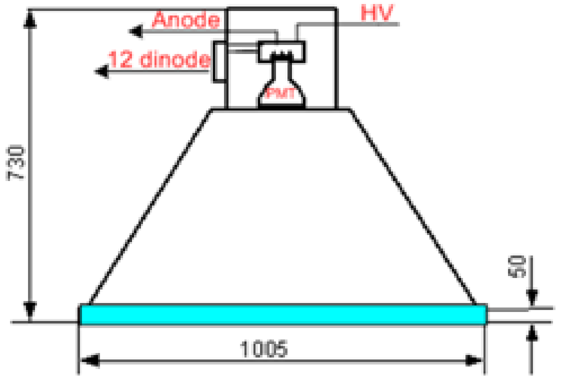
Ground base array

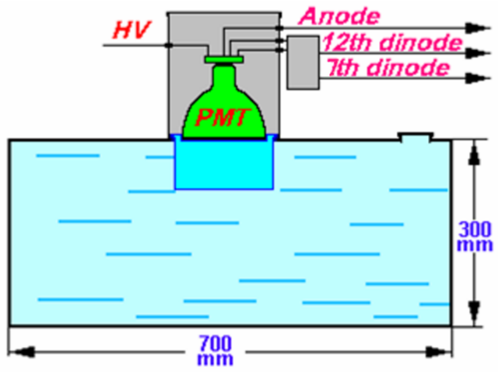
- Central Carpet array – 400 liquid scintillator, continuous area 196 m2
- 6 detectors around the Carpet array, 18 liquid scintillators, total area is 9 m2.

Underground Muon Detector

- 175 plastic scintillator, continuous area 175 m2
- 1 GeV energy threshold for vertical muons





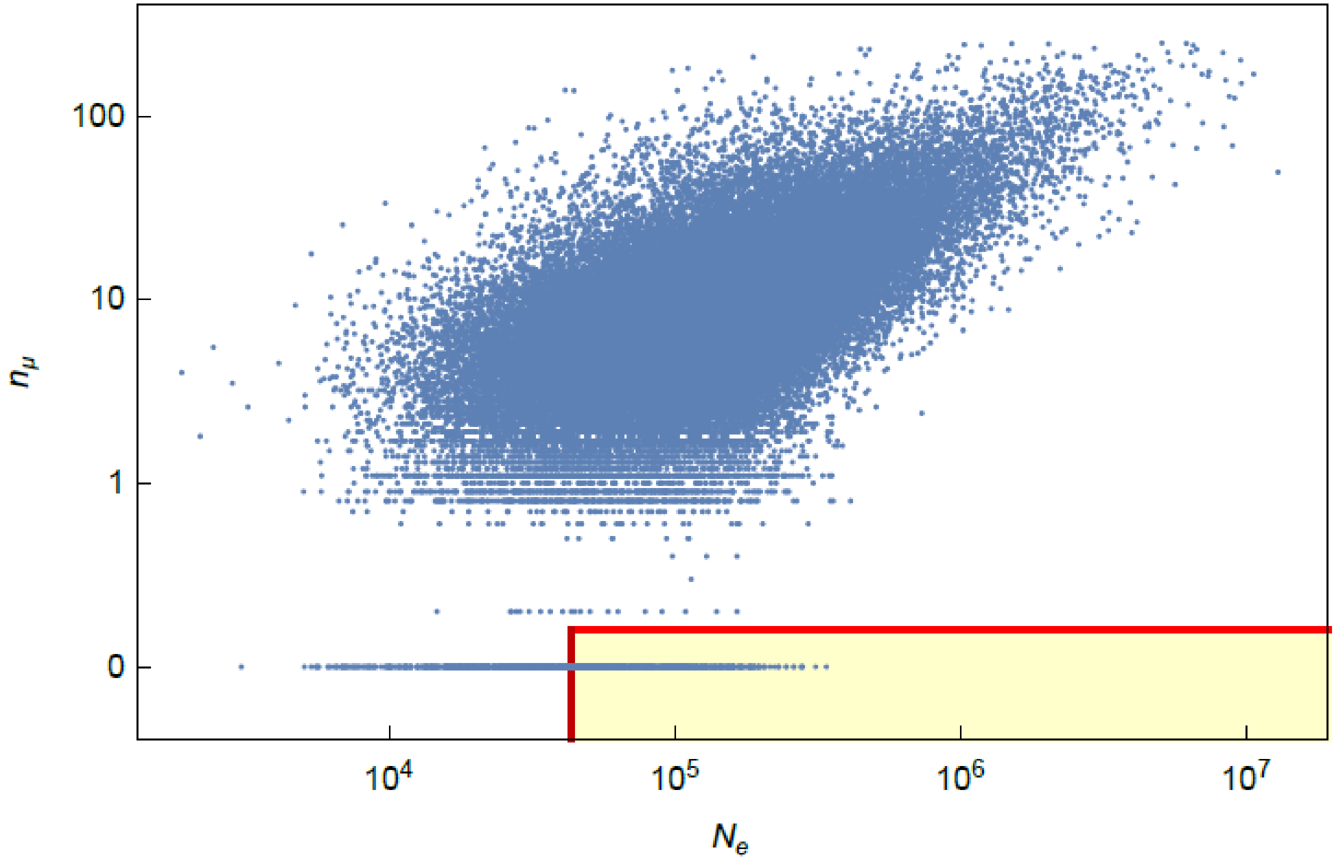


Dataset and photonic candidates

Dataset II (Since April 2018)

(Aim: E>300 TeV)

- 2018-2021
- 829 Live days
- 54756 events with **E>300 TeV**
- 708 gamma candidates



Criteria for photonic candidates

(Based on the Monte-Carlo simulations)

- min N_e: E>300 TeV photons
- max n_μ/N_e – 50% of E>300 TeV photons

More detail about criteria for photonic candidates:

D. Dzhappuev, et al. 36th International Cosmic Ray Conference (ICRC2019). Vol. 36. 2019.

Abraham, J., et al. *Astroparticle Physics* 29.4 (2008): 243-256.

Carpet-2 search for E>300 TeV gamma candidates

Standard alert procedure:
(test fixed circle (6.15°) centered at the best-fit neutrino direction)

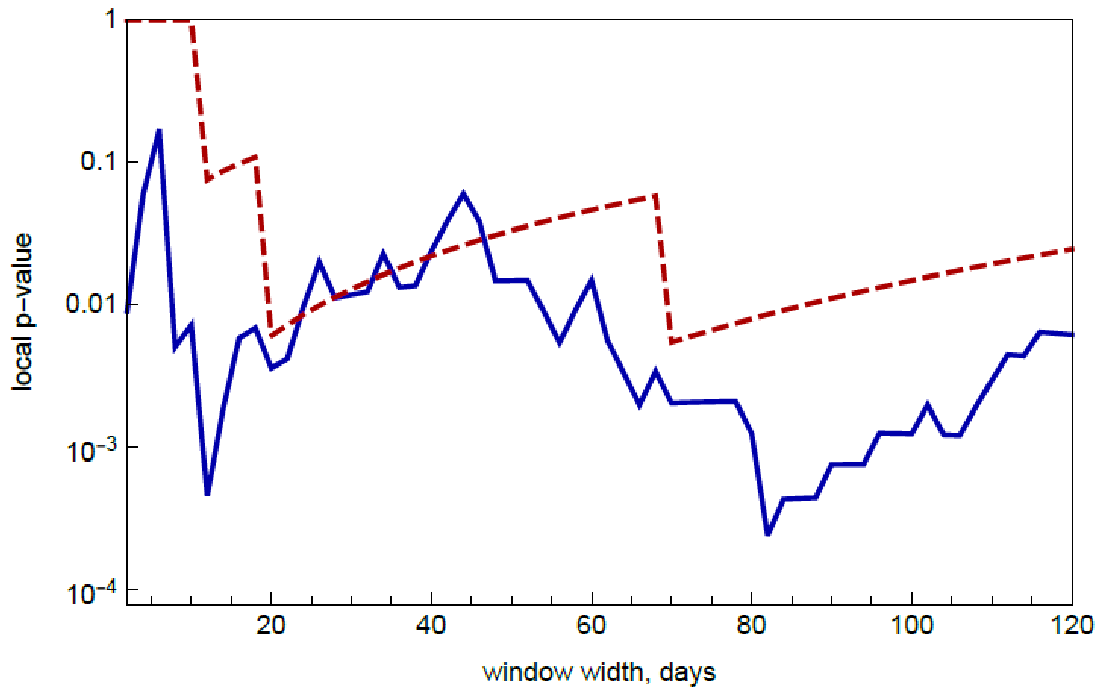
- ±1000 sec (**just outside FOV this time**)
- ±12 h (**no excess**) ATel #14237
- ±15 days (**2 events**) ATel #14255

[Previous | Next | ADS]

Carpet-2 observation of two E>100 TeV photon-like events associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon

ATel #14255; *D. Dzhappuev, A. Kudzhaev, V. Petkov, S. Troitsky on behalf of the Carpet-2 group (INR RAS)*
on ***9 Dec 2020; 12:27 UT***
Credential Certification: Sergey Troitsky (st@ms2.inr.ac.ru)

Related
14255 Carpet-2 observation of two E>100 TeV photon-like events associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon
14237 Carpet-2 limits on E>100 TeV gamma rays associated with the IceCube 201120A neutrino alert in the Cygnus Cocoon



Cygnus Cocoon test:
4.7° centered at the Fermi LAT Cygnus Cocoon center:

- Total 346 events
  - Best window width is 82 days
- 5 are photon candidates
  - Best window width is 70 days

The statistical significance of a flare

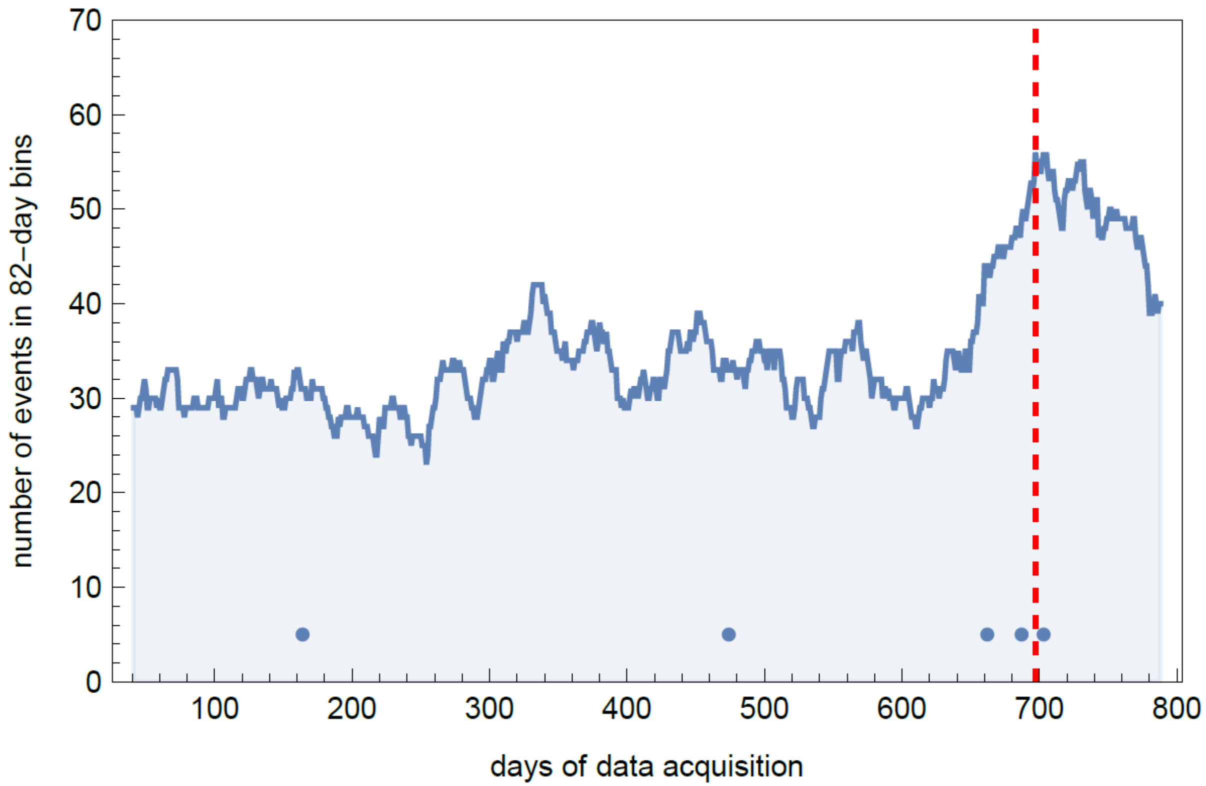
Pre-trial probability:

- Full set, $p = 5.5\times10^{-4}$ (**3.67 σ**)
- Photon candidate, $p = 5.8\times10^{-3}$ (**2.78 σ**)

An introduced correction for window-width trials based on the Monte-Carlo simulation reduces the statistical significance of the probable flare.

Post-trial probability:

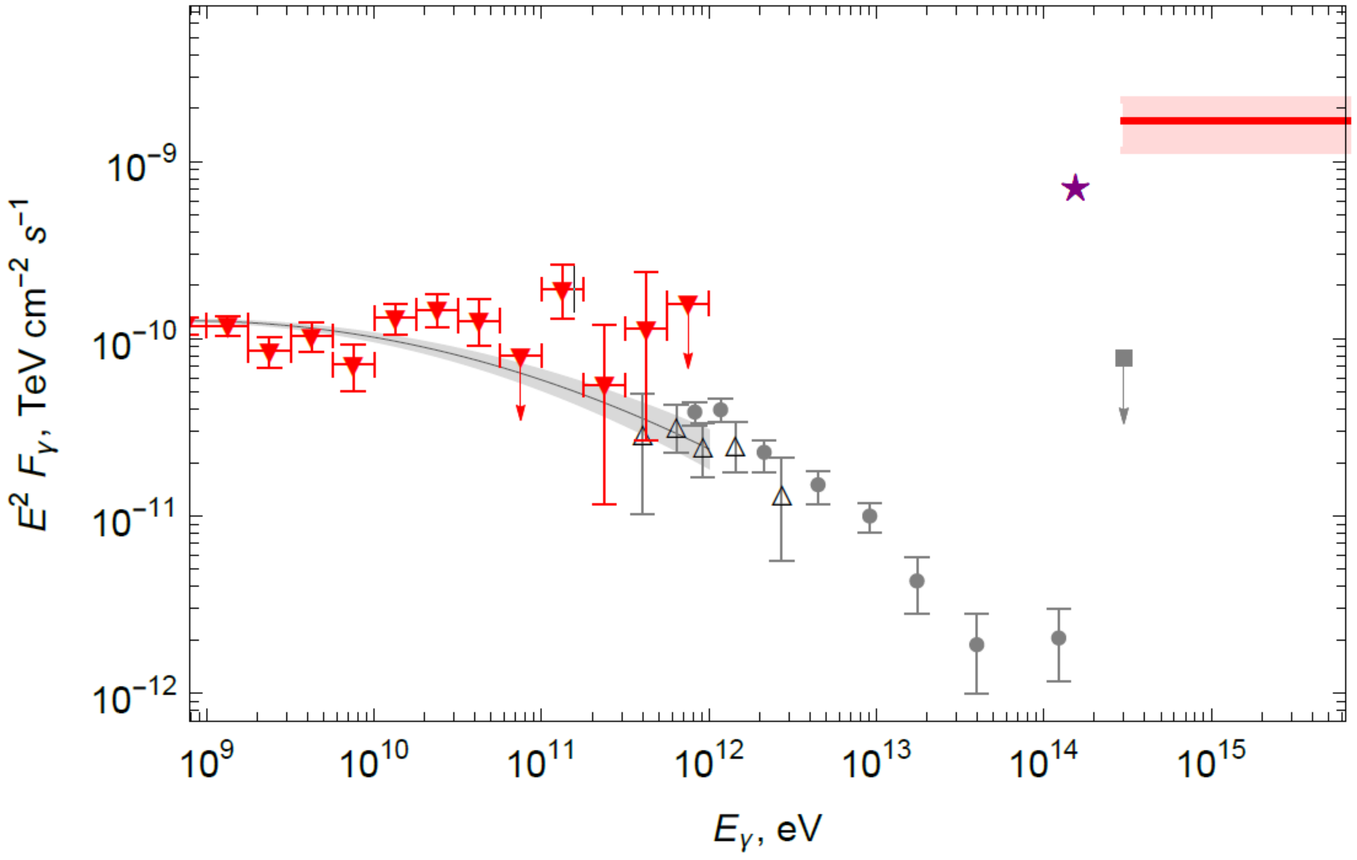
- Full set, $p = 3.7\times10^{-3}$ (**3.17 σ**)
- Photon candidate, $p = 9.8\times10^{-3}$ (**2.55 σ**)



Blue dots correspond to arrive gamma candidate;

The line indicates the neutrino arrival time;

Spectral energy distribution of Cygnus Cocoon above 1 GeV.



Spectral energy distribution averaged over the same d = 82-day period around the neutrino arrival using publicly available data of the Fermi Large Area Telescope (Fermi-LAT)

Time-averaged

4FGL flux model (Abdollahi et al. 2020)

ARGO (Bartoli et al. 2014)

HAWC (Abeysekara et al. 2021)

Carpet-2, this work

Flare

Fermi LAT

Carpet-2, this work

Estimate of the IceCube neutrino fluence

Conclusion

- **An excess of events was observed from Cygnus Cocoon in temporal coincidence with IceCube neutrino alert.**

- **Statistical significance of the excess is 3.1 σ post-trial**

- **A possible interpretation is E>300 TeV photon flare with the duration of ~ 3 months around the neutrino event and the fluence of 13±4 GeV/cm2.**
  That requires additional searching in the recorded data of other gamma-ray and neutrino experiments.

- **This observation agreed with scenarios of the origin of a part of observed high-energy neutrinos in pi-meson decays in Galactic sources.**

More details in
arXiv:2105.07242 [astro-ph.HE]

Collaborators and Acknowledgment

D. D. Dzhappuev,[1] Yu. Z. Afashokov,[1] I. M. Dzaparova,[1, 2] T. A. Dzhatdoev,[3, 1] E. A. Gorbacheva,[1] I. S. Karpikov,[1] M. M. Khadzhiev,[1] N. F. Klimenko,[1] A. U. Kudzhaev,[1] A. N. Kurenya,[1] A. S. Lidvansky,[1] O. I. Mikhailova,[1] V. B. Petkov,[1, 2] E. I. Podlesnyi,[4, 3, 1] V. S. Romanenko,[1] G. I. Rubtsov,[1] S. V. Troitsky,[1] I. B. Unatlokov,[1] I. A. Vaiman,[4, 3] A. F. Yanin,[1] Ya. V. Zhezher[1, 5] And K. V. Zhuravleva[1]

[1] Institute for Nuclear Research of the Russian Academy of Sciences, 60th October Anniversary Prospect 7a, Moscow 117312, Russia
[2] Institute of Astronomy, Russian Academy of Sciences, 119017, Moscow, Russia
[3] D.V. Skobeltsyn Institute of Nuclear Physics, M. V. Lomonosov Moscow State University, Moscow 119991, Russia
[4] Physics Department, M. V. Lomonosov Moscow State University, Moscow 119991, Russia
[5] Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Kashiwanoha, 5-1-5, 277-8582, Japan

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https://www.zeuthen.desy.de/~jknapp/fs/photon-showers.html