Limits on the isotropic diffuse gamma-rays at ultra-high energies measured with KASCADE

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Summary

A sensitive search for the isotropic diffuse γ-rays at ultra-high energies is reported, using data measured by the KASCADE air shower array. An isotropic flux of radiation is not detected, but an 90% C.L. upper limit to the flux of ultra-high energy γ-gays in the primary cosmic-ray flux is determined, at energies from ~2*10^{14} eV to ~ 2*10^{16} eV. The fraction of γ-rays in 1.5*10^{15} and 3.7*10^{15} eV is presently the best , setting strong constraints on the distance of sources for an IceCube neutrino excess model.

The KASCADE experiment and data selection

Diffuse γ-rays are the sum of contributions from several components.

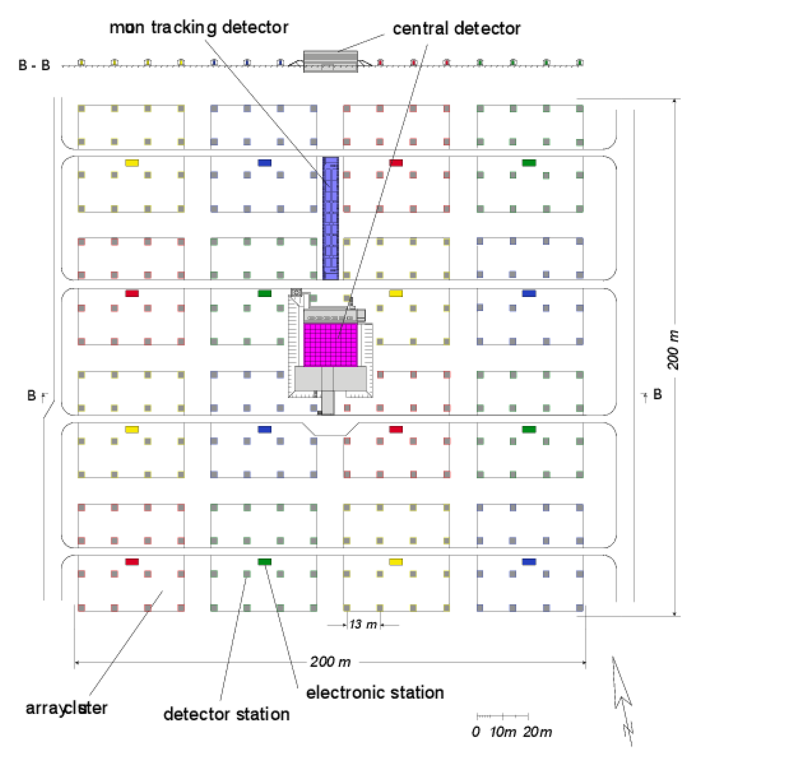
- The cascading products by the collision of cosmic rays with interstellar gas and dust in the disk of the Galaxy.

  the predicted integral intensity is concentrated in the galactic plane.

- The electromagnetic cascades induced by the interaction of ultra high energy cosmic rays (UHECRs) with the cosmic microwave background radiation and the unresolved point sources in extra galactic astronomical objects.

  Results in a uniform isotropic flux of secondary photons

  Topic of this work!



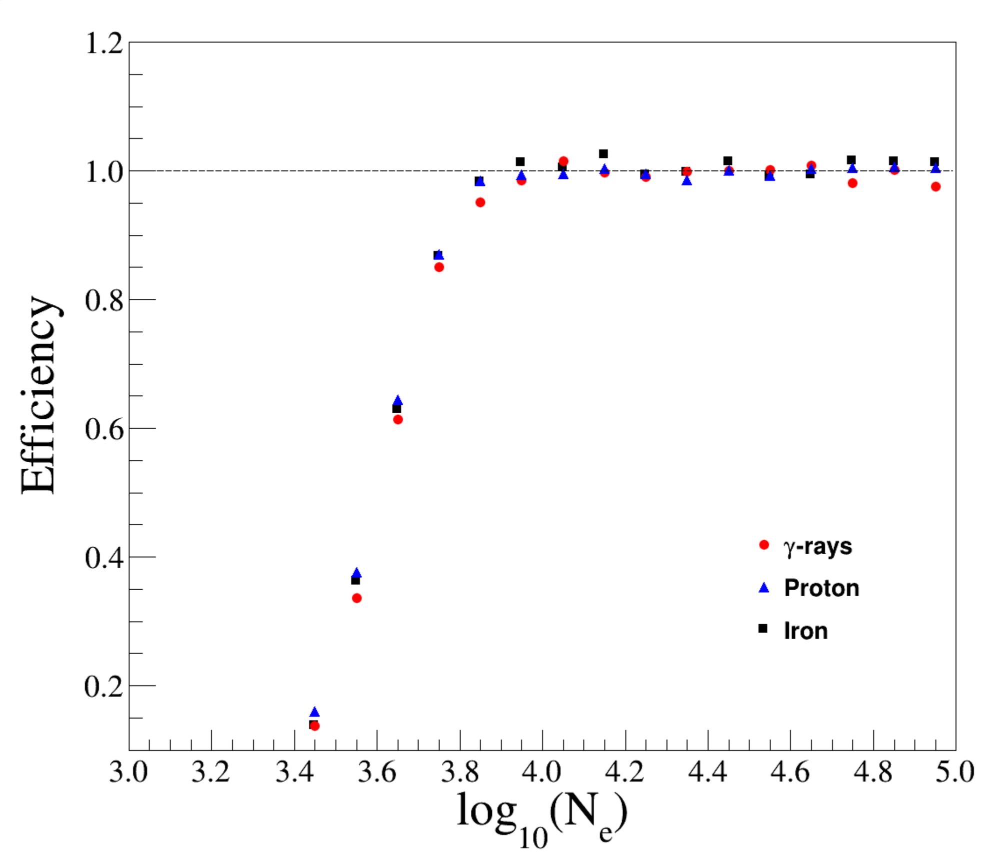
Layout of the KASCADE experiment

- The KASCADE experiment (8.4ºE, 49.1ºN, 110m a.s.l.) was successfully operated from 1996. to 2012.
- 200*200 m^2 scintillator array with 252 scintillation detector stations
- Good determination of shower sizes.
- Excellent time resolution and angular resolution better than 0.55º for $\log_{10}N_e$>4.
- The data set taken by KASCADE was checked by a comprehensive moon shadow analysis

- All the 16 clusters must be working
- Core position of showers inside a circular area of 91 m
- Zenith angle smaller than 20º for better gamma/hadron seperation.

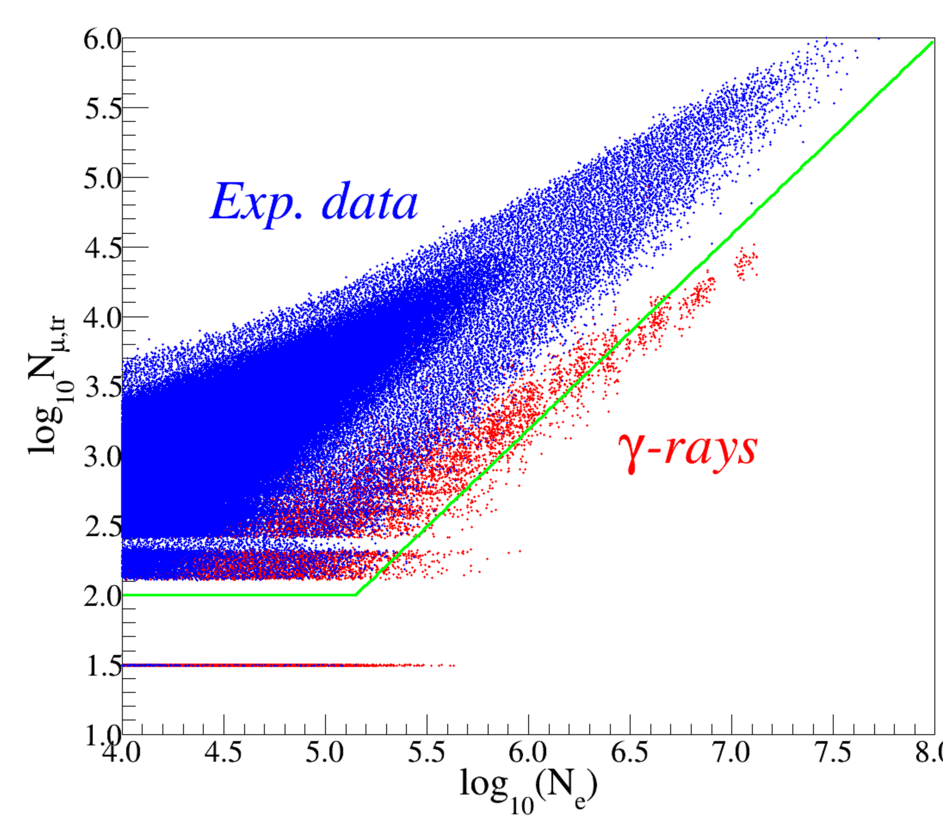
After the selection, in total, 1.0*10^8 events are recorded between 1996 Oct. and 2010 May, for an effective time of 4223.6 days.

Gamma hadron discrimination



Trigger and reconstruction efficiency as a function of the number of electrons for air showers induced by primary photons, protons and iron nuclei.

- The detector array reaches full efficiency on the detection of showers for electron numbers $\log_{10}N_e$ > 4 for air showers induced by γ-rays, protons and iron primary particles
- approximately corresponds to a primary energy of 2.5*10^{14} eV for γ-rays and 3.3*10^{14} eV for CRs.



Distribution of the measured number of muons $\log_{10}N_{\mu,tr}$ and number of electrons $\log_{10}N_e$, superimposed with simulated γ-ray showers.

Following cuts were applied to select the muon-poor showers (γ-rays):

- $\log_{10}N_{\mu,tr}$ < 2 , $\log_{10}N_e$ < 5.15
- $\log_{10}N_{\mu,tr}$ < 1:4*$\log_{10}N_e$− 5:21 $\log_{10}N_e$ > 5.15

indicated by the green line

Analysis and results

- There is no possible excess of events seen in the data consistent with a gamma-ray signal.
- Hence, we assume that all events below the selection line are primary γ-rays and set upper limits on the gamma-ray fraction of the cosmic rays.
- This is a very conservative way in which the expected background is not subtracted from the event number below the cut line.

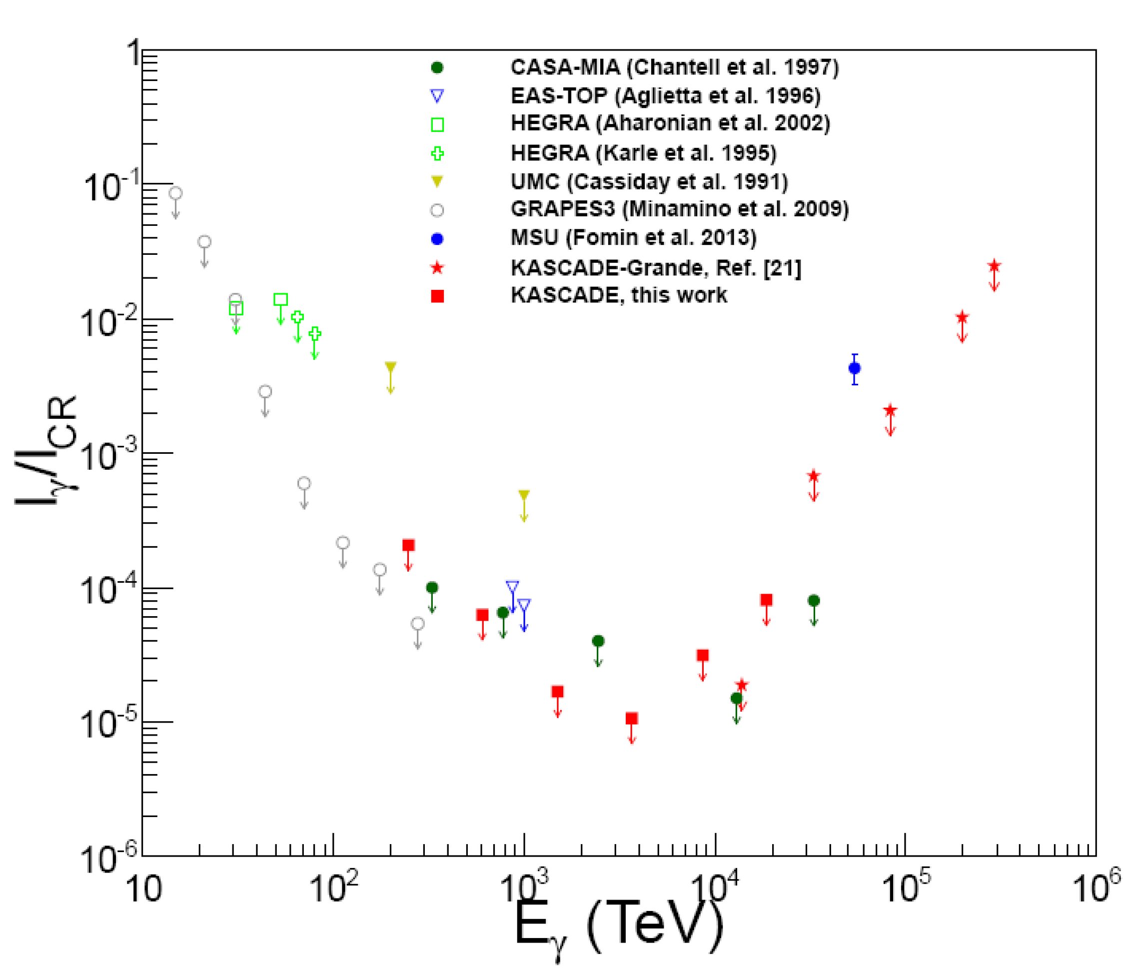
- N90, the 90% C.L. upper limit on the number of detected events is estimated using standard statistical methods.
- the efficiency for γ-ray detection is evaluated by simulations.
- The upper limit on the fraction of the γ-ray integral flux relative to the cosmic ray integral flux, $I\gamma / I_{CR}$, *is given by*

$$\frac{I_\gamma}{I_{CR}} < \frac{N_{90}}{N_{tot}\varepsilon_\gamma}\left(\frac{E_{CR}}{E_\gamma}\right)^{-\beta+1}$$

E_{CR} is the mean cosmic ray energy, Eγ is the mean gamma-ray energy, and β is the integral cosmic-ray spectral index (β =2.7, E γ < 4 × 10^{15}eV; β = 3.0, Eγ > 4 × 10^{15}eV).

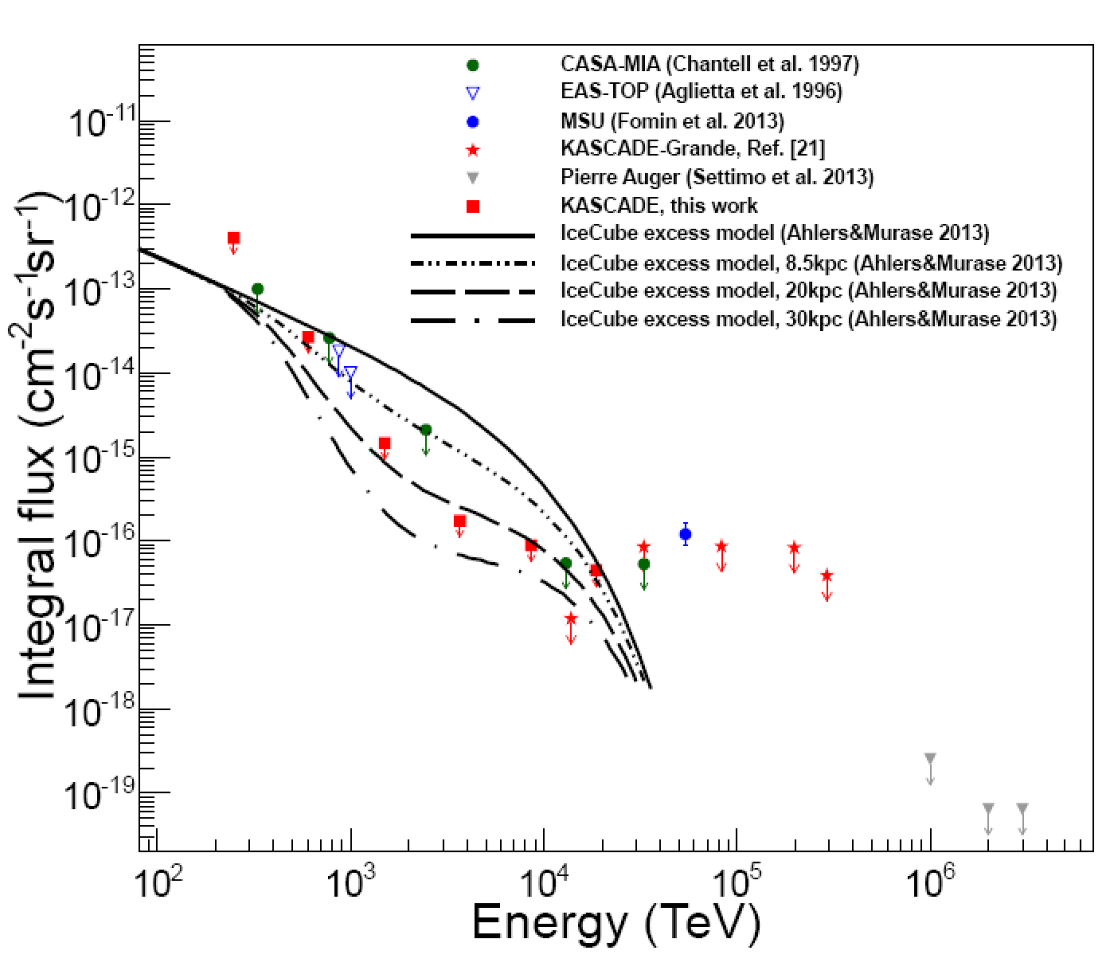
- Results of the search for diffuse ultra-high energy γ-rays at different threshold values of $\log_{10}N_e$.
- The median cosmic-ray energy, E_{CR} , and the median γ-ray energy, Eγ , are given in the fifth and sixth columns, respectively, in units of TeV.
- Iγ is the 90% C.L. upper limit on the integral γ-ray flux,in units of photons cm−2s^{-1}sr^{-1}.

$log_{10}N_e$	N_{tot}	N_{90}	ε_γ	E_{CR}	E_γ	I_γ/I_{CR}	I_γ
>4	1.02×10^{8}	11653.5	0.33	333	248	$<2.1\times10^{-4}$	$<4.02\times10^{-13}$
>4.5	2.19×10^{7}	583.3	0.27	783	605	$<6.3\times10^{-5}$	$<2.67\times10^{-14}$
>5	3.92×10^{6}	19.0	0.18	1994	1502	$<1.7\times10^{-5}$	$<1.46\times10^{-15}$
>5.5	5.76×10^{5}	2.3	0.20	5247	3673	$<1.1\times10^{-5}$	$<1.73\times10^{-16}$
>6	6.75×10^{4}	2.3	0.44	14618	8603	$<3.1\times10^{-5}$	$<8.77\times10^{-17}$
>6.5	6.66×10^{3}	2.3	0.44	44952	18610	$<8.1\times10^{-5}$	$<1.47\times10^{-17}$



Measurements of the fraction of γ-rays relative to cosmic rays at ultra-high energies.

- The upper limit of the fraction of γ-rays at 1.5*10^{15} eV is 1.7*10^{-5}, while 1.1*10^{-5} at 3.7*10^{15} eV. These **are the lowest upper limits in the world up to now.**



Comparison of integral flux of γ-rays with previous results and with theoretical curves by an IceCube neutrino excess model.

- The flux limits on the γ-ray flux of this work at 1.5*10^{15} eV and 3.7*10^{15} eV is lower than the theoretical prediction of the IceCube excess model coming from 20kpc.
- This result set some strong constrains on the distance of sources for the IceCube neutrino excess model.

Reference

[1] Berezinsky V.S. et al., Astropart. Phys. 1 (1993) 281
[2] Halzen A.F. et al., Phys. ReV. D 41 (1990) 342
[3] Sigl G., Schramm D.N., and Bhattacharjee P., Astropart. Phys. 2 (1994) 401
[4] Antoni, T., et al. 2003, Nucl. Instrum. Methods Phys. Res. A, 513, 490
[5] Greisen, K. 1956, in Progress in cosmic ray Physics 3, ed. J. G. Wilson (Amsterdam: North-Holland)
[6] Kamata, K., & Nishimura, J. 1958, Prog. Theor. Phys. Suppl., 6, 93
[7] Antoni, T., et al. 2001, Astropart. Phys., 14, 245
[8] Heck D, Knapp J, Capdevielle J N, Schatz G, Thouw T, 1998, Report FZKA 6019
[9] Antoni, T., et al., Astroparticle Physics 24 (2005) 1ÍC25
[10] Glasstetter, R., cosmic ray Energy And Mass Estimator, http://www-ik.fzk.de/ ralph/CREAM.php.
[11] Antoni, T., et al., 2003, Astropart. Phys., 19, 703
[12] O. Helene, Nucl. Instr. Meth. 212 (1983) 319
[13] M. C. Chantell et al. , Phys. Rev. Lett. 79, 1805 (1997)
[14] C. Amsler et al. (Particle Data Group), Physics Letters B667, 1, (2008)
[15] M. Aglietta et al. , Astropart. Phys. 6, 71 (1996).
[16] A. Karle et al. , Phys. Lett. B 347, 161 (1995)
[17] , F. A. Aharonian et al. , Astropart. Phys. 17, 459 (2002)
[18] J. Matthews et al. Astrophys. J. 375, 202 (1991).
[19] M. Minamino et al. , Pro. of the 31st Int. Cosmic Ray Conf., Lodz, Poland (2009).
[20] Yu.A. Fomina, N.N. Kalmykova, G.V. Kulikova, V.P. Sulakova and S.V. Troitskyb, arXiv:1307.4988v1
[21] D. Kang et al. KASCADE-Grande Collaboration, Proc. 34th Int. Cosmic Ray Conf., The Hague, The Netherlands (2015), ID785 of these proceedings.
[22] G. Schatz et al., KASCADE Collaboration, Proc. 28th Int. Cosmic Ray Conf., Tsukuba, Japan (2003).
[23] Ahlers, M., & Murase, K. 2014, PRD, 90, 023010