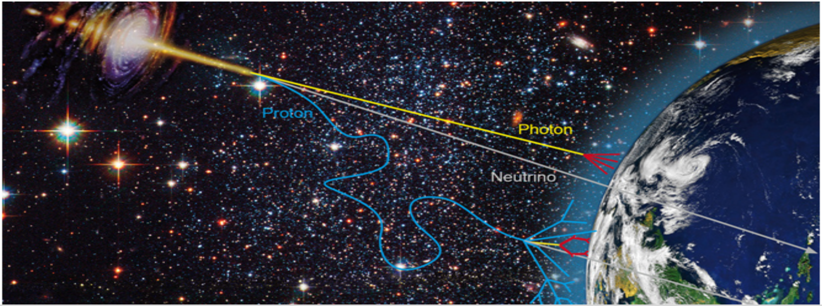
KASCADE ultra-high energy γ-ray search

DLC-19, Irkustk

V. Tokareva | 4 April 2019

INSTITUTE FOR NUCLEAR PHYSICS (IKP)



Motivation

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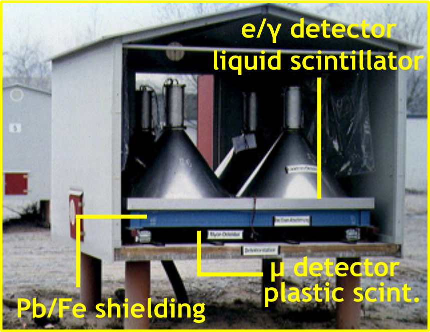
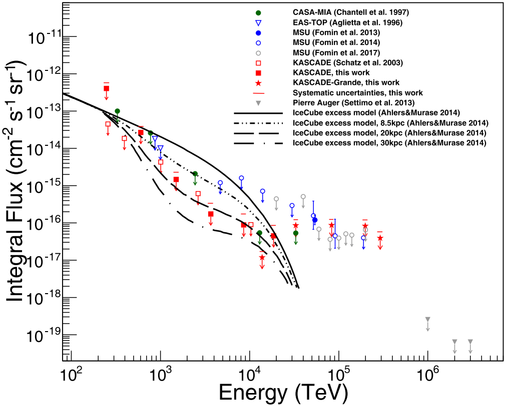
- γ-rays:
  - are not deflected by interstellar magnetic fields $\Rightarrow$ can be tracked to their origin;
  - can be used for point sources search;
  - γ-ray flux study could bring us insights on cosmic rays acceleration mechanisms.
- VHE and UHE γ-rays:
  - not so well-investigated because of flux intensity decrease for all CR particles at higher energies and because of a large absorption on the cosmic microwave background and interstellar matter;
  - are supposed to be produced by black holes, neutron stars, supernova remnants, super-bubbles / star-forming regions / young massive star clusters;
  - could improve our understanding about properties of matter in extreme states that cannot be studied in laboratories.

KASCADE experiment

- Location: 110 m a.s.l., 49°N, 8°E, KIT-Campus North, Karlsruhe, Germany;
- Operation time:
  1996 October – 2010 May $\Rightarrow$
  effective time $\sim$ 4223.6 days;
- Area: 200×200 m^2;
- 252 scintillator detectors;
- $E = 100$ TeV – 80 PeV;
- N_e (> 5 MeV);
- $N_{tr\mu}$ (> 230 MeV,
  $r = 40 - 200$ m).



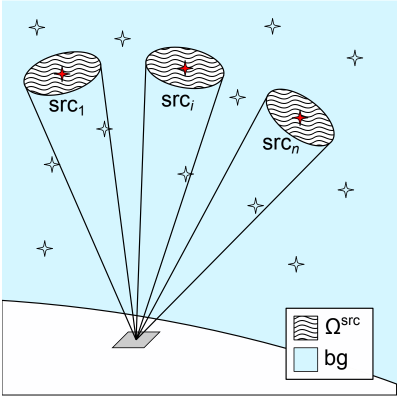
KASCADE-Grande γ ray searches



- Limits on the diffuse gamma-ray flux;
- Significant improvement of the limits around 5×10^{15} eV;
- The obtained values are compared to various IceCube excess models.

[1] W. Apel et al., *KASCADE-Grande Limits on the Isotropic Diffuse Gamma-Ray Flux between 100 TeV and 1 EeV*, 2017, ApJ, 848, 1.

Stacked analysis



$$\frac{\sum_{i=1}^{n} N_i^{\mathrm{src}}}{\sum_{i=1}^{n} \Omega_i^{\mathrm{src}}} \overset{?}{>} \frac{N^{\mathrm{bg}}}{\Omega^{\mathrm{bg}}}$$

N_i^{src} is a number of events for the i-th source,
Ω_i^{src} is a solid angle of the selected area of the sky around the i-th source,
N^{bg} is a number of background events,
Ω^{bg} is a solid angle of the area used for background estimation.

Example: recent work by Carpet-2

- UHE γ-ray search;
- 34 published IceCube high-energy neutrino events;
- 95% CL upper limit on total steady flux of $E_\gamma > 1$ PeV photons: 8.5×10^{-15} cm^{-2}s^{-1}.
- 95% CL upper limit on fluence of $E_\gamma > 1$ PeV photons for the IceCube EHE3 flare: 4.4×10^{-5} PeV/cm^2.

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[1] D.D. Dzhappuev et al., *Carpet-2 search for PeV gamma rays associated with IceCube high-energy neutrino events*, arXiv:1812.02662 [astro-ph.HE].

[2] D.D. Dzhappuev et al., *Search for astrophysical PeV gamma rays from point sources with Carpet-2*, arXiv:1812.02663 [astro-ph.HE].

HAWC highest-energy γ-ray sources

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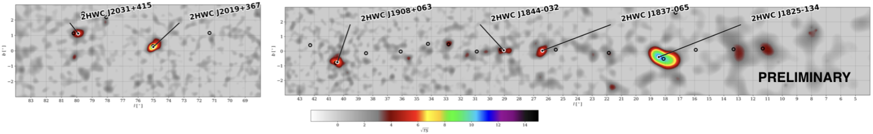
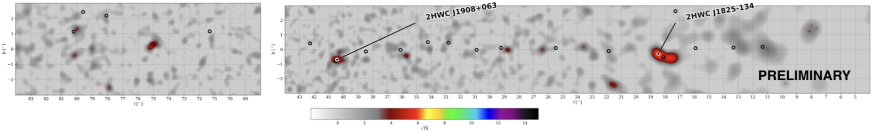
- six sources in the Galactic plane that emit above 56 TeV:

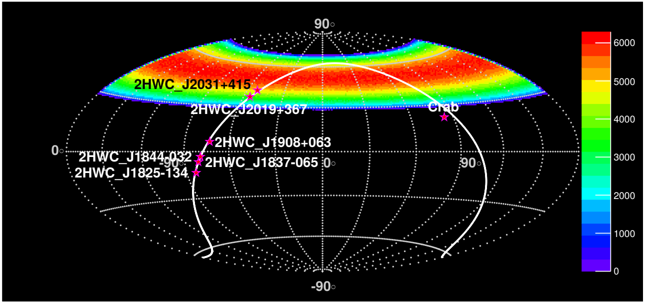


- two of them continue to emit past 100 TeV:

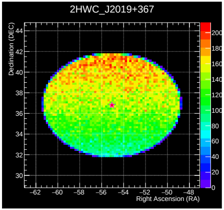


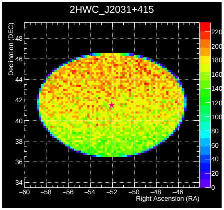
[1] Malone, K. (2018). *A survey of the highest-energy astrophysical sources with the HAWC Observatory (Doctoral dissertation)*. Retrieved from https://hawc-observatory.org/publications/docs/Malone-Dissertation.pdf

Sources in KASCADE field of view

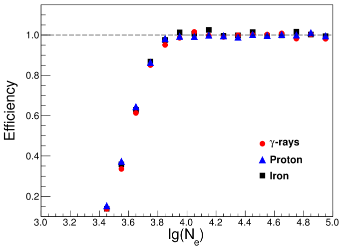


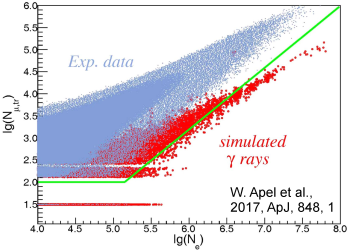
KASCADE event distribution map
with 6 HAWC sources
with energy E above 56 TeV.

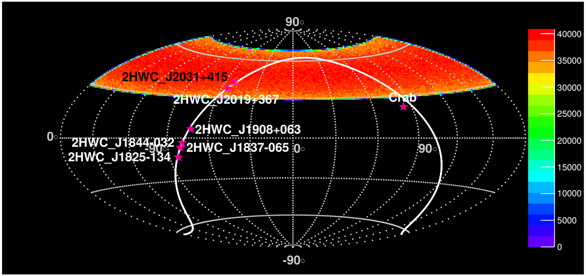




Data cuts and corrections







Estimation of the integral flux and the expected number of measured γ-rays for the *2HWC_J2013+415* source

$$F_{\text{int}}(E^*) = \int_{E^*}^{\infty} F_0 \left(\frac{E}{E_0}\right)^{-\alpha} dE,$$

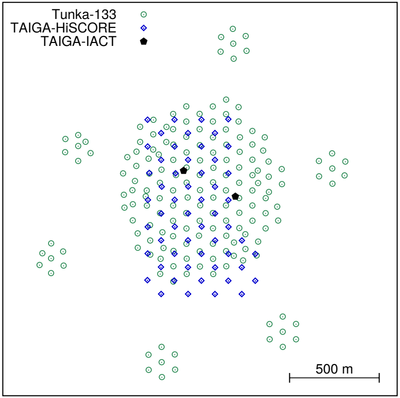
$$F_0 = 3.4 \times 10^{-14}\ \text{cm}^{-2}\text{s}^{-1}\text{TeV}^{-1},\ E_0 = 7\ \text{TeV},\ \alpha = 2.7.$$

E^* [TeV]	F_{int} [cm^{-2}s^{-1}]	N_γ(*expected*)
7	1.4×10^{-13}	441
56	4.1×10^{-15}	12.9
100	1.5×10^{-15}	4.8
1000	3.1×10^{-17}	0.096

With $\alpha \approx 2.7$ KASCADE can have few gamma events with $E^* > 100$ TeV in dataset.

Tunka-133 and TAIGA-HiSCORE

- Similarities to KASCADE:
  - located at the same latitude;
  - measure the same CR spectrum;
  - rely on the same hadronic interaction models for the interpretation of their data;
- Differences with KASCADE:
  - The experiments have different observation levels;
  - They are using different measurement techniques, namely scintillator arrays and air Cherenkov detectors respectively;



KASCADE-TAIGA joint analysis

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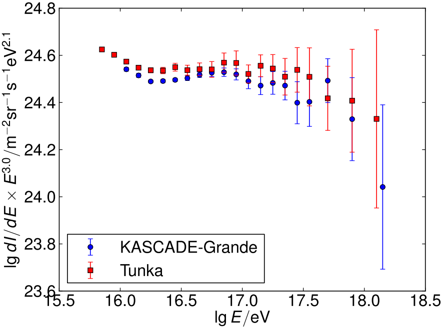
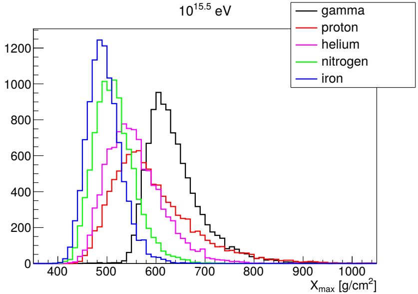
The possibility to map Tunka-133 and KASCADE-Grande spectra was shown at: W.D. Apel et al., *Tunka-Rex and LOPES Collaborations*, Phys. Lett. B **763** (2016) 179



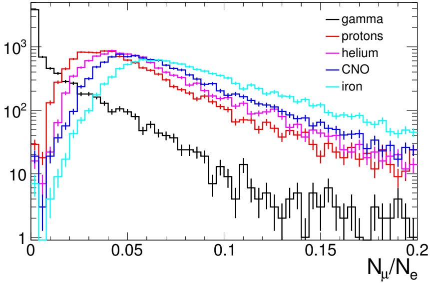
← Energy spectra of cosmic rays from KASCADE-Grande and Tunka-133: normalized flux per energy.

With a systematic increase of KASCADE-Grande energies by 4% (or a corresponding decrease of Tunka-133 energies) the average flux per energy of both experiments can be brought to agreement in this energy range.

TAIGA γ-proton separation



X_{max} for various primaries at $E = 10^{15.5}$ eV for Tunka-133.



N_μ/N_e for various primary CR components for KASCADE.

- γ-proton separation can be performed quite well at KASCADE using electron-muon discrimination;
- The separation using X_{max} at Tunka-133 is much more uncertain.
- It could be possible to select muon-poor showers using data from the Tunka-Grande setup.

Conclusion

- UHE and VHE γ-ray point source search;
- Stacked analysis of KASCADE events for HAWC sources with $E > 56$ TeV;
- *2HWC_2019+367* and *2HWC_J2013+415*;
- Expected gamma flux is calculated for *2HWC_J2013+415* up to 1 PeV;

Future plans

- Study the possible background exceed within a 5° radius around the sources;
- Extend to the data from the TAIGA experiment;
- Check other sources within our galaxy.

Bonus slides

German-Russian Astroparticle Data Life Cycle Initiative*

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НИИЯФ МГУ

TAIGA

KIT
Karlsruher Institut für Technologie

IKP
Institut für Kernphysik

ИРКУТСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ
1918

SCC
Steinbuch Centre for Computing

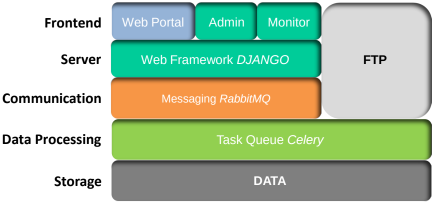
Matrosov Institute for System Dynamics and Control Theory

KASCADE - Grande
KArlsruhe Shower Core and Array DEtector - Grande

*Granted by RSF-Helmholtz Joint Research Groups

KASCADE Cosmic-ray Data Center (KCDC)

- providing free, unlimited, reliable open access to KASCADE cosmic ray data at https://kcdc.ikp.kit.edu;
- almost all KASCADE data is available;
- selection of fully calibrated quantities and detector signals;
- information platform: physics and experiment backgrounds, tutorials, meta information for data analysis;
- archive of KASCADE software and data;
- uses modern and open source web technologies.



KASCADE and TAIGA data rates

- KASCADE:
  - 450 000 000 events
  - $\sim$ 4 TB of measured data
- planned TAIGA rate: $\sim$ 20 TB/year
  - HiSCORE: $\sim$ 18 TB/year
  - IACT: $\sim$ 1.5 TB/year
  - others: $\sim$ 0.5 TB/year
- current TAIGA rate:
  - $\sim$ 50 Tb of raw data;
  - $\sim$ 8 TB/year of reconstructed data:
    - HiSCORE: $\sim$ 6.4 TB/year
    - IACT: $\sim$ 1 TB/year
    - others: $\sim$ 0.5 TB/year

Machine and deep learning opporutities

- Search for anisotropies — Clasterization;
- Distinguishing gamma/not gamma (distribution-based [β]) — Classification.

The German-Russian Astroparticle Data Life Cycle collaboration I

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TAIGA

TAIGA—Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy (see taiga-experiment.info);

KASCADE - Grande
KArlsruhe Shower Core and Array DEtector - Grande

KASCADE-Grande—KArlsruhe Shower Core and Array DEtector—Grande (see www-ik.fzk.de/KASCADE_home.html);

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KIT-IKP—Institute for Nuclear Physics Karlsruhe Institute of Technology

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SCC—Steinbuch Centre for Computing Karlsruhe Institute of Technology

The German-Russian Astroparticle Data Life Cycle collaboration II

SINP MSU—Skobeltsyn Institute Of Nuclear Physics Lomonosov Moscow State University

ISU—Irkutsk State University

ISDCT—Matrosov Institute for System Dynamics and Control Theory

References

- Berghöfer T., Agrafioti I. *et al.* Towards a model for computing in European astroparticle physics, Astroparticle Physics European Coordination committee, 2016,
  web-source: `http://appec.org/wp-content/uploads/Documents/Docs-from-old-site/AModelForComputing-2.pdf`;
- KCDC—**K**ASCADE **C**osmic Ray **D**ata **C**enter,
  web-source: `http://kcdc.ikp.kit.edu`;
- KASCADE-Grande official site,
  web-source: `http://www-ik.fzk.de/KASCADE_home.html`;
- TAIGA collaboration official site,
  web-source: `http://taiga-experiment.info`;
- Astroparticle.online—outreach resource,
  web-source: `http://astroparticle.online`.