The HAWC Upgrade with a Sparse Outrigger Array

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The gamma-ray sky above 1 TeV

The gamma-ray sky at the highest energies is of great interest since sources that emit gammas at these energies are most probably associated to the PeVatrons that accelerate the high energy cosmic rays and produce the astrophysical high energy neutrinos detected recently by IceCube [1]. Diffuse emission or extended sources at the highest energies could be indirect signatures of dark matter or of more exotic phenomena. Only 161 sources above 1 TeV are known, most discovered by the HESS, VERITAS and MAGIC air Cherenkov telescopes.

At the highest gamma energies the sky is even less well studied. It is therefore desirable to have a detector able to do a systematic survey of a large region of the sky with enough sensitivity above 10 TeV.

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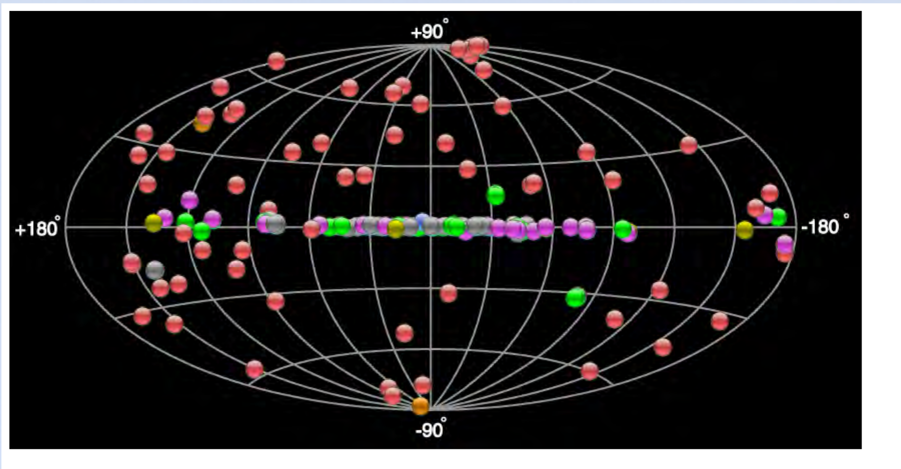
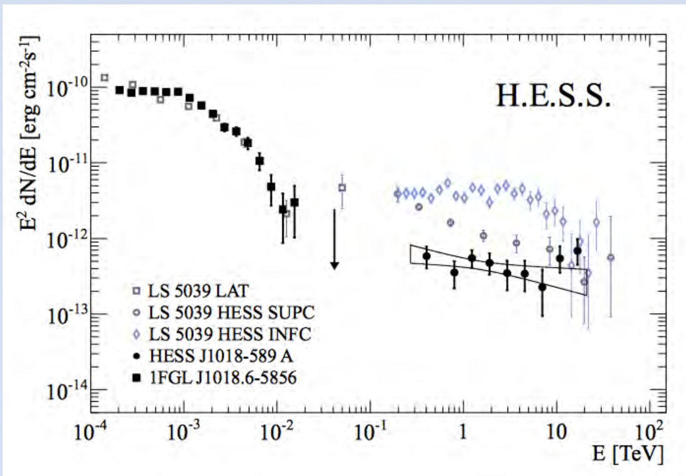
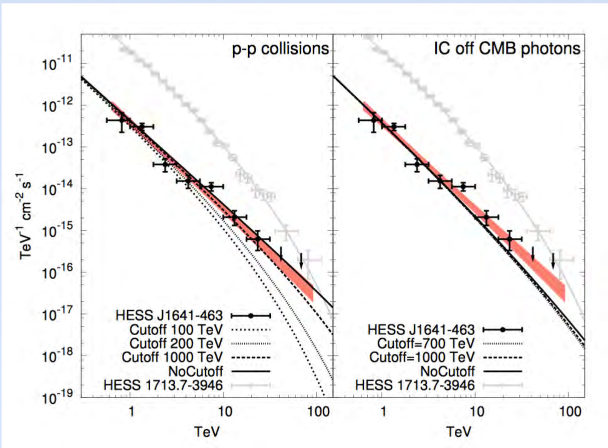


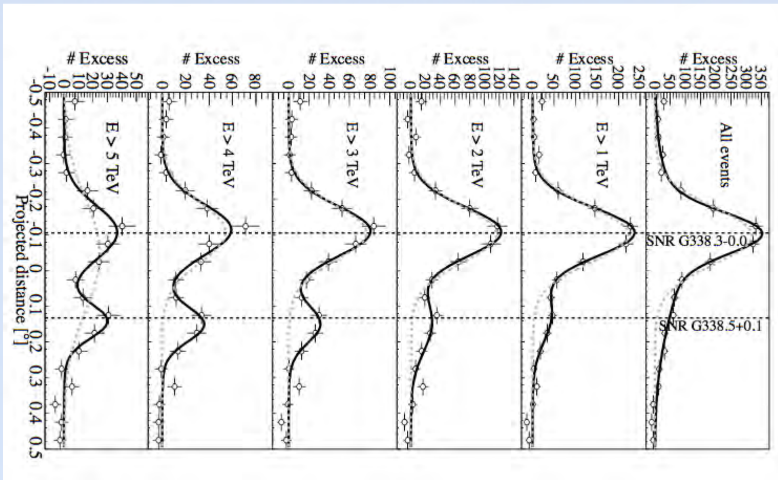
TeVCat plot of the 161 known high energy gamma sources



Fermi-LAT (below 0.1 TeV) and HESS (above 0.1 TeV) spectra of LS 5039 and J1018-589 A showing how variable the high energy part can be.



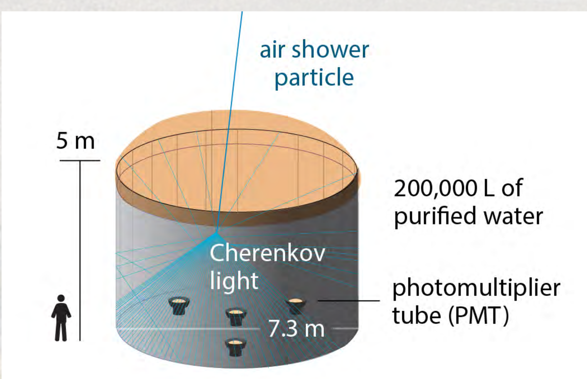
HESS gamma spectrum of J1641-463 with hadronic (left) and leptonic (right) model fits. It is at the highest energies where they be differentiated.

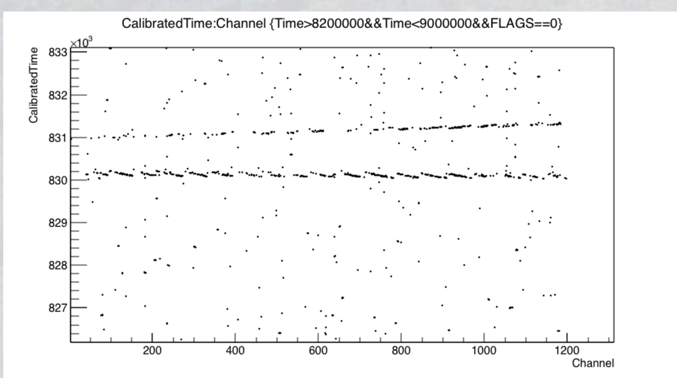


J1641-463 can well be resolved at the highest gamma energies due to its very hard spectrum.

HAWC

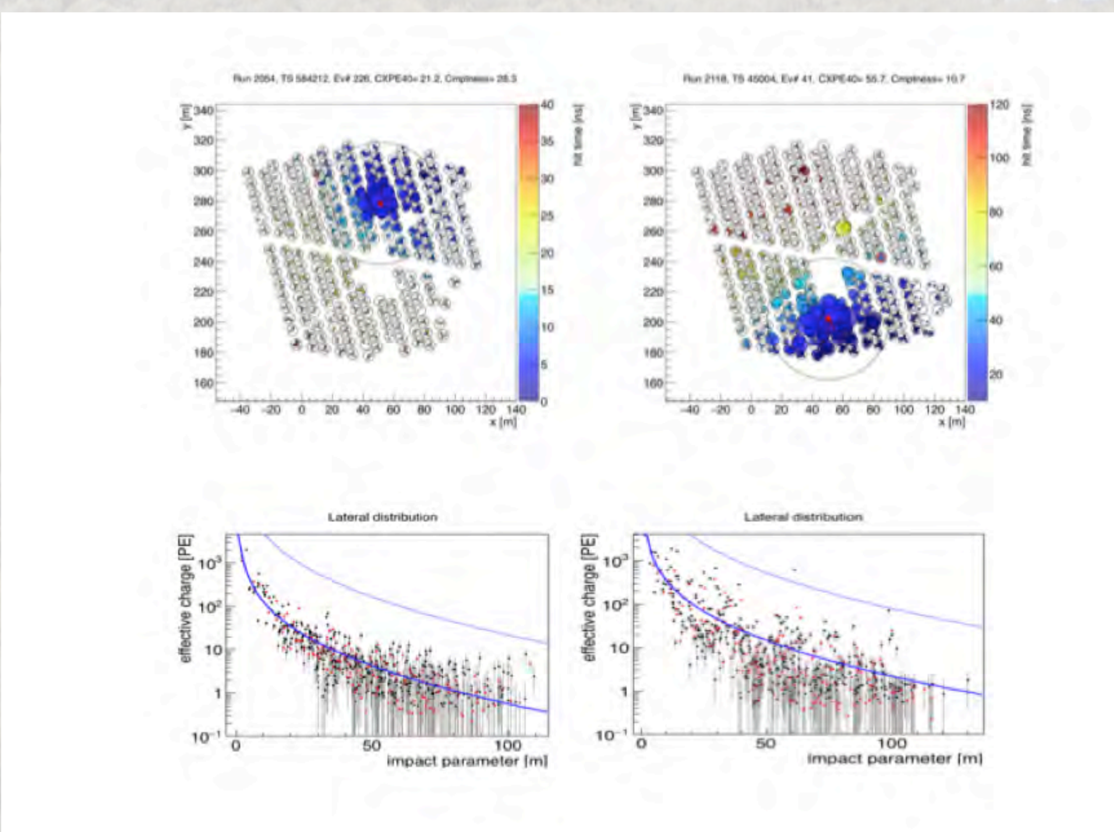
The HAWC observatory [5] is a second-generation water Cherenkov detector. It has been built on the Sierra Negra volcano in central Mexico at 4,100m above sea level. HAWC consists of an array of 300 closely packed cylindrical water Cherenkov detectors (WCD) and detects air shower particles from primary gamma and cosmic rays from 100 GeV to hundreds of TeVs. It surveys continuously 2 sr above it, scanning 2/3 of the sky every day.





Event reconstruction and gamma/hadron separation

The signals of the 4 PMTs of each of the 300 HAWC WCDs are digitized with the time over threshold (ToT) technique that provides their arrival time and pulse height amplitude. The resulting 500 MB/s data stream is inspected by an on-line processor farm that does the shower recognition and selection. By choosing events with more than 28 coincident signals in a 150 ns time window, we record showers at 24 KHz writing 2 TB of data on disk each day. Each event is reconstructed by finding the shower core position, then the shower plane is fitted using the arrival time of the signals at each PMT, including curvature corrections and the time spread of the shower particles from their travel through the atmosphere (shower age). The perpendicular to the shower front gives the direction of the incoming primary. The differences between electromagnetic and hadronic showers is used for selection, gammas have more compact uniform showers while hadrons are more "grainiy" and their traversing muons give very high Cherenkov light pulses.

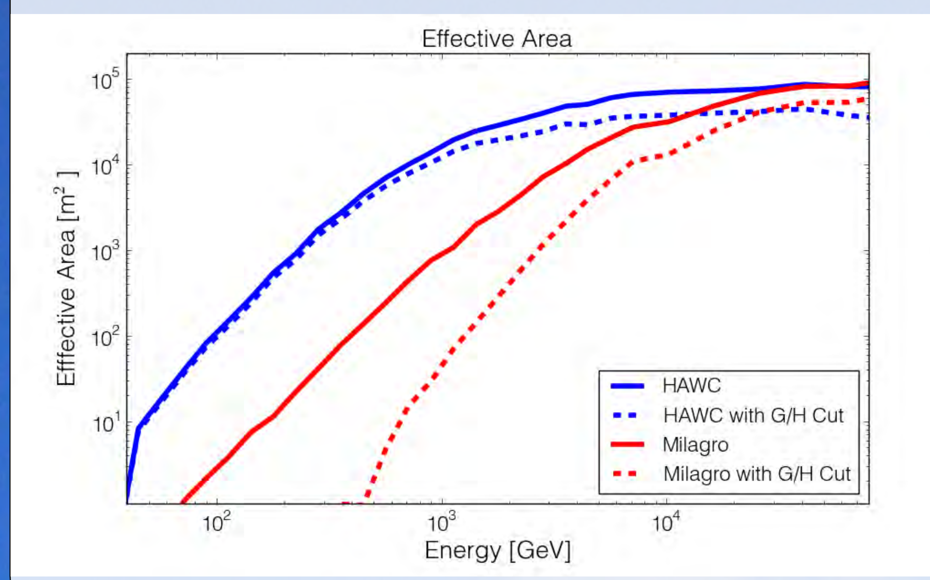


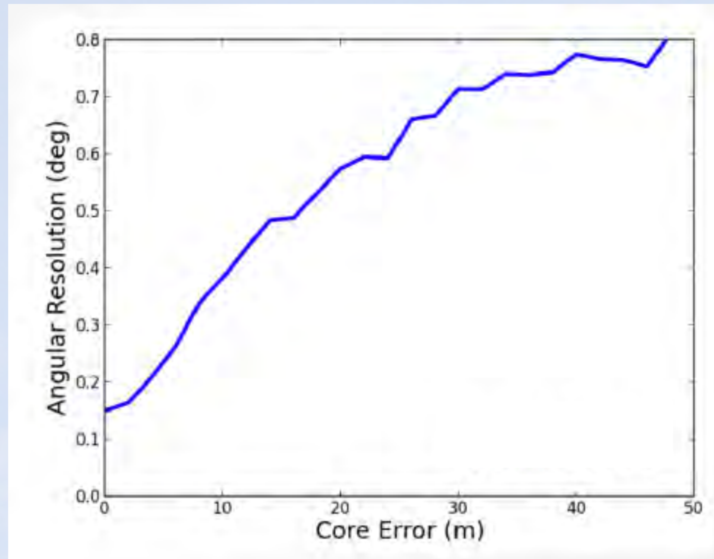
HAWC events of a hadronic shower (left) and an electromagnetic one (right) showing the PMT signals on the array (top row) and as function of the distance from the shower core with the NKG fit (bottom row).

Effective area

The trigger effective area reaches 100,000 m2 for the highest energies because the footprint of the showers can be ~200 m radius. Nevertheless there is a large fraction of showers in the trigger where the core falls outside of the HAWC array, that leave enough information in the WCDs to do a gamma/hadron discrimination, but for which there is an ambiguity in the distance of the core position, the direction of the shower and the shower size. To recover a large fraction of these showers specially at the highest energies, where we are already limited by the statistics, is a desirable upgrade program for the HAWC observatory.

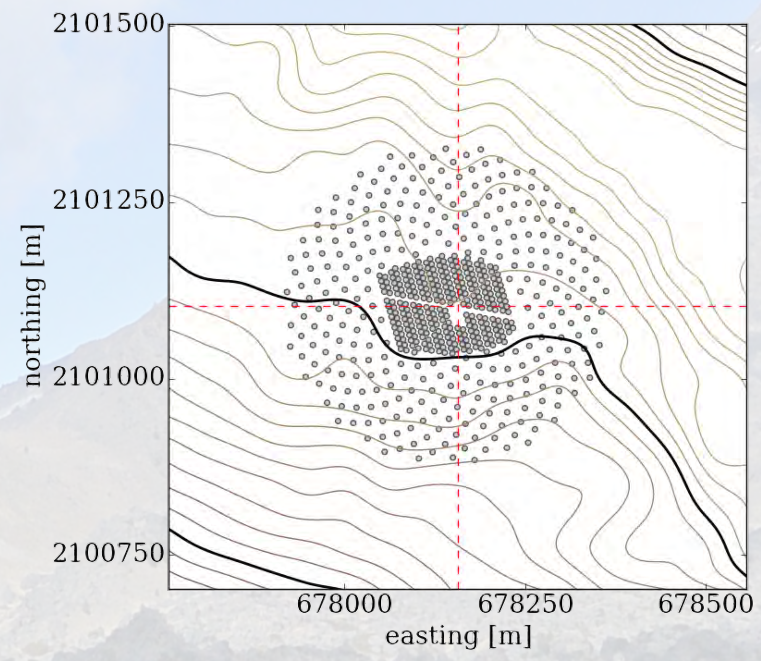
If one could determine the shower core position when the fall outside of the array with enough precision, then there is no longer an ambiguity and the direction of the primary can be measured with good resolution.





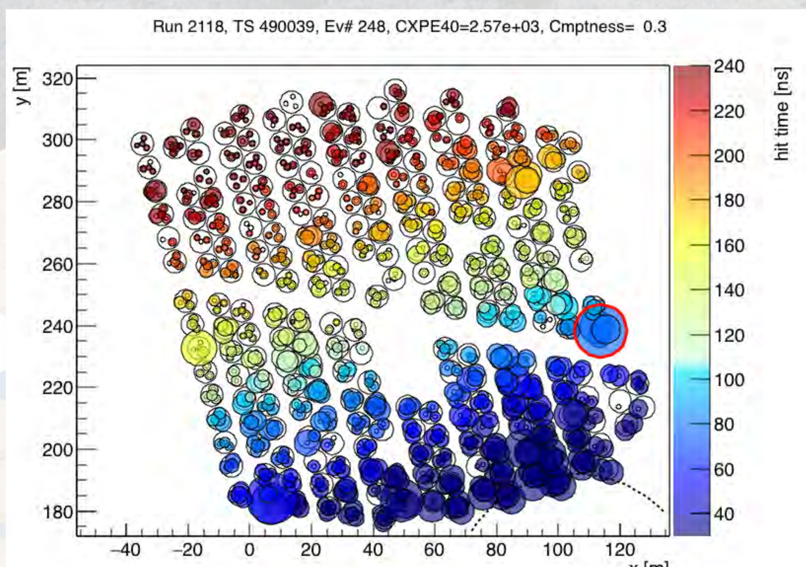
Outrigger array

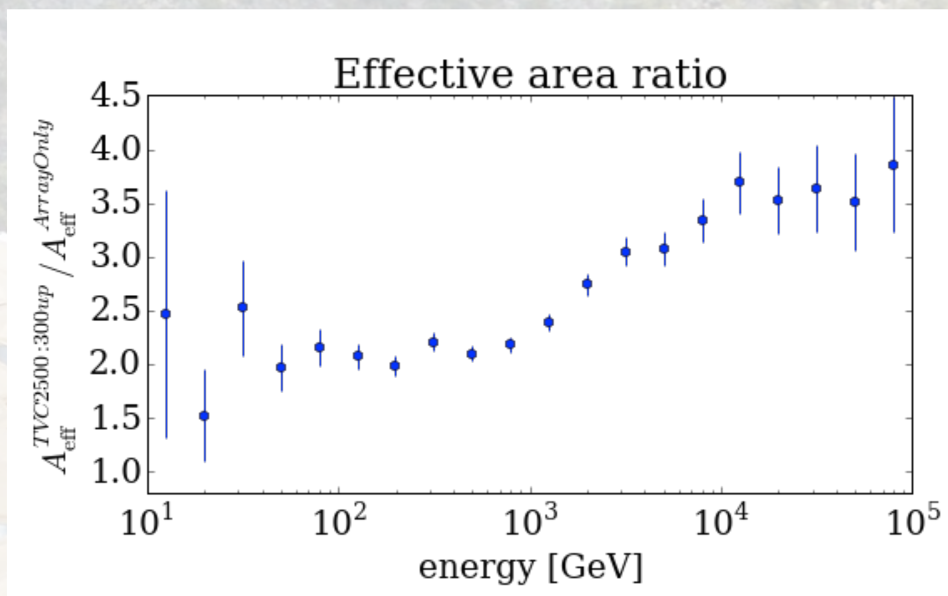
The aim of a sparse, small detector outrigger array is to determine the position of the shower core for showers falling outside the HAWC WCD array and that still leave enough information in HAWC to reconstruct the shower front and discriminate between gamma and cosmic-ray initiated showers.
In order to optimize the outrigger geometry, detailed Monte Carlo simulations are being performed. A general outrigger geometry with 300 tanks arranged in a sunflower spiral manner is used with CORSIKA and GEANT4. To study different sizes of the outrigger array, any of the 300 tanks can be switched off at the event reconstruction level.



Increse of sensitivity for >10TeV gammas

First simulations results show that with a sparse outrigger array of 4 times the area we can recover a factor of 3-4 of the triggered gamma showers with energies above 10 TeV that had fallen outside of the main HAWC array. This improvement will be a great advantage for a 10 year unbiased survey of the gamma sky above 10 TeV.





References

[1] IceCube Collaboration, M.G. Aartsen et al., Phys. Rev. Lett **113** (2015) 101101.

[2] HAWC Collaboration, A.U. Abeysekara et al., Astropart. Phys. **50-52** (2013) p26-32.

[3] HESS Collaboration, A. Abramowski *et al.* 2014 *ApJ* **794** L1

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