H.E.S.S. Extra Galactic Survey

Rencontres du Vietnam, Quy Nhon

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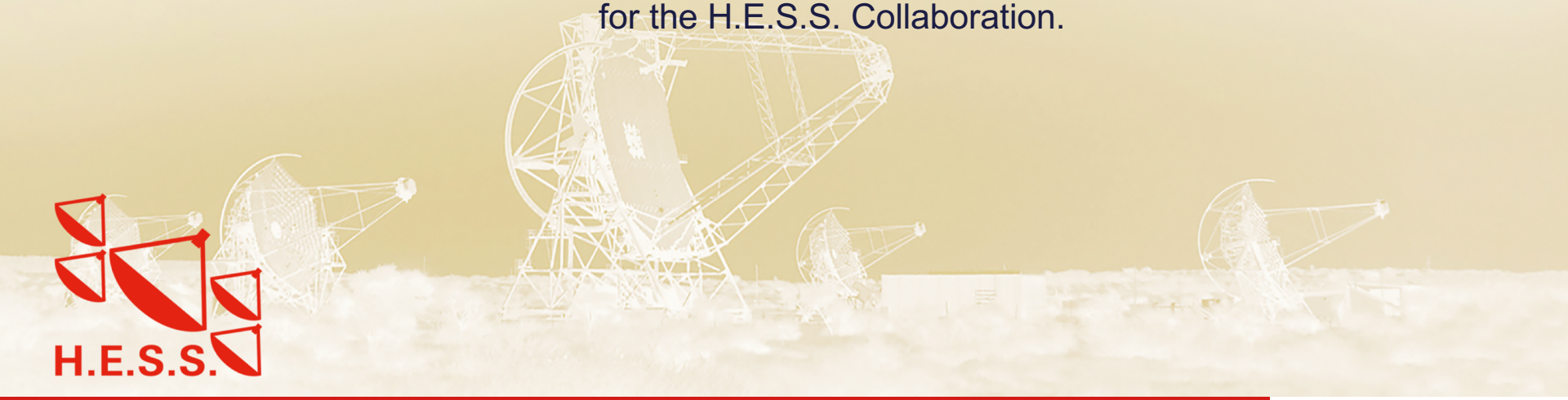
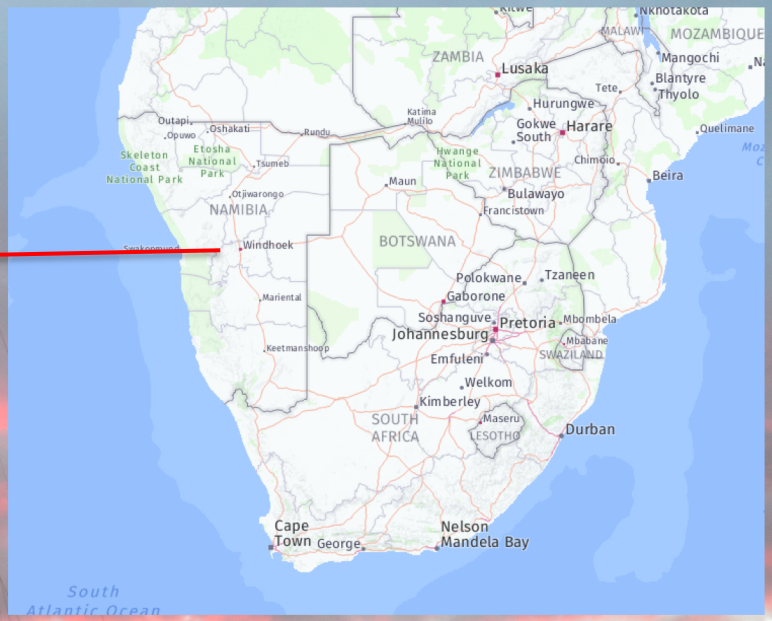
for the H.E.S.S. Collaboration.



The H.E.S.S. telescopes

H.E.S.S. array

- Located in the Khomas highland, Namibia (1800 a.s.l.).
- 4 x 12-m IACTs (CT1-4) + 1 x 28-m IACT (CT5).
- FoV of 5 degrees (CT1-4), 3.2 degrees (CT5).
- Energy threshold of 30 GeV at zenith.



Configuration used for the HEGS

- 4 x 12-m IACTs (CT1-4), FoV 5 degrees.
- Energy threshold of 200 GeV at zenith.
- Sensitivity: 1.5% Crab between 200 GeV and 100 TeV

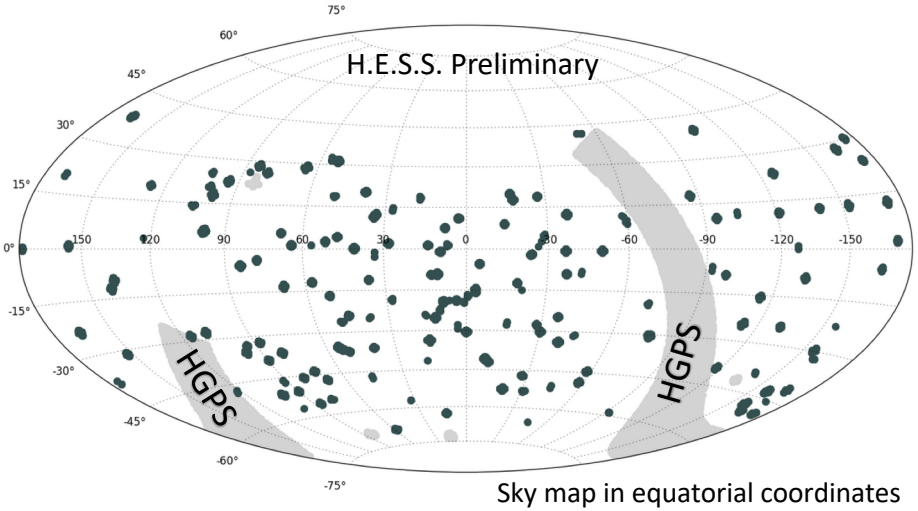
Data Selection and analysis

- We re-analysed all H.E.S.S. data taken between January 2004 and January 2013
  - Only H.E.S.S.I (CT1-4) data.

- Removal of sources in the Galactic plane (HGPS (2018A&A, 612A,1H)), LMC, SMC, Crab and SN 1006.

- Observation runs grouped in RunClusters using the DBSCAN algorithm from the scikit-learn library (http://scikit-learn.org).

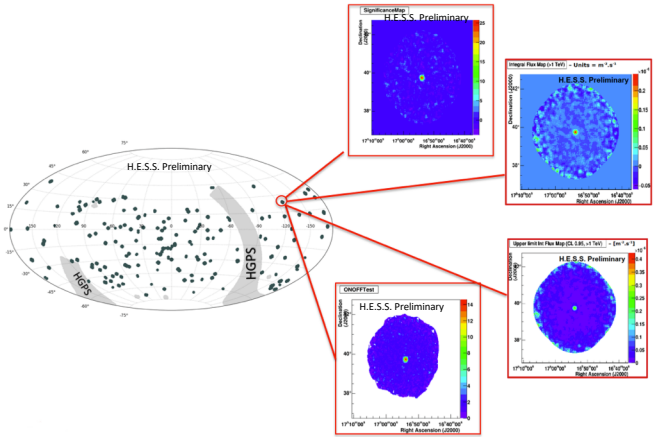
- If Runs are less than 4 degrees away they are gathered in a RunCluster.



Sky map in equatorial coordinates

Dataset:
- ✓ 123 resulting RunClusters;
- ✓ ~6500 observation runs;
- ✓ Livetime of ~2700 hours;
- ✓ Coverage: ~6.5 % of the sky;

Data Selection and analysis



- Main analysis is performed using the Model++ analysis (de Naurois & Rolland 2009).
- Production of maps for significance, flux, upper limits and variability.
  - Using set of scripts designed for the analysis of clusters.
- Flux-related products computed using a power law with a spectral index of -3.
- Cross-check done using the HAP analysis chain (Parsons, R. D. and Hinton, J. A. 2014) with an independant calibration and independant scripts.

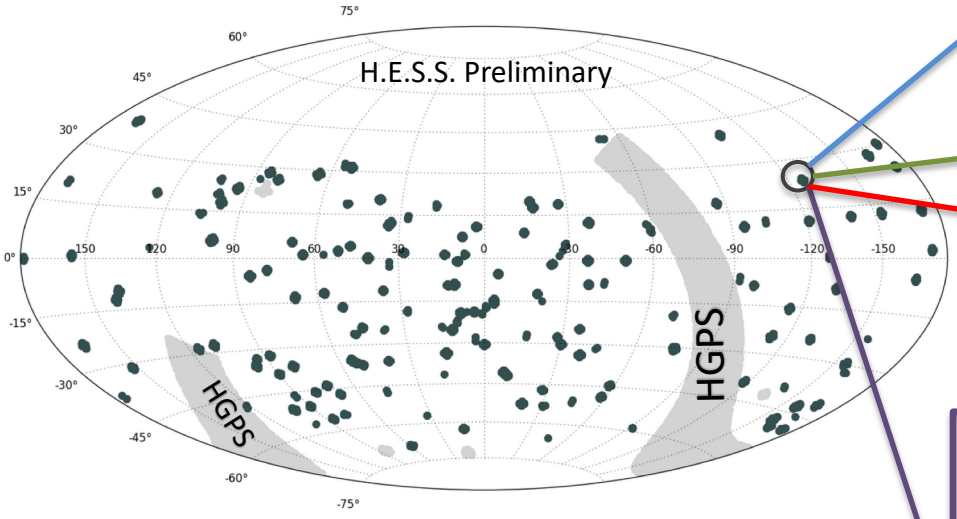
The analysis of all the data from the HEGS lead to:

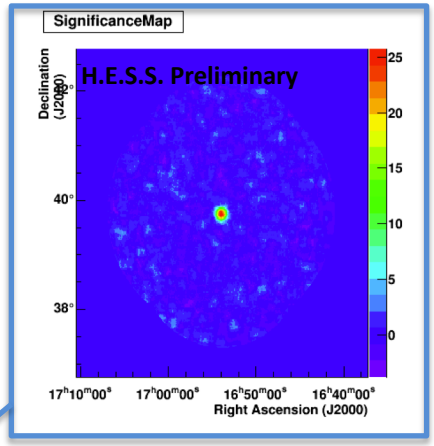
- 23 sources re-detected.
- 4 sources with significant variability.
- 2 hotspots (follow-up observations).

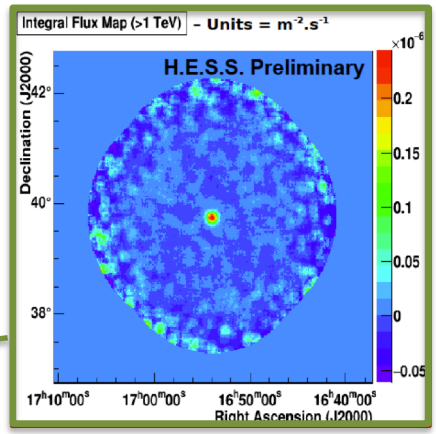
Release products

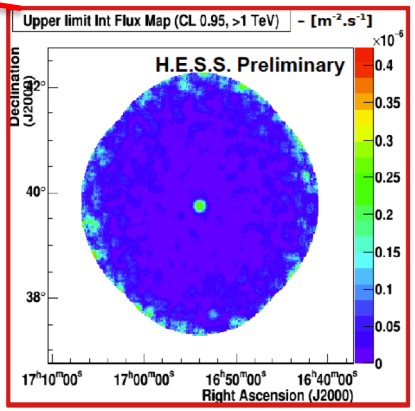
Example of the analysis products for Mrk 501

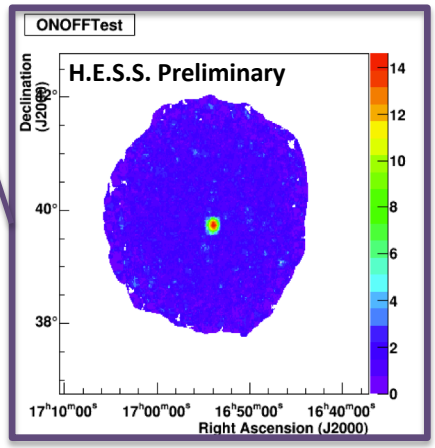
- Significance map;
- Flux map;
- Upper-limits map;
- Variability map;











- We also intend to release maps for all the RunClusters in FITS format.

Search for variability
On-off method

- We investigated the variability for all the RunClusters:

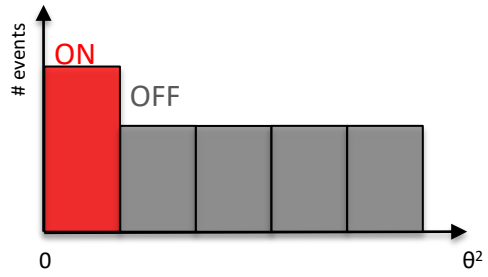
  - From the maps obtained, we can for all RunClusters, for each observations at any position extract:
    - number of gamma-like events and detector's acceptance.

  - We developed a method that uses this information to search for variability in the time-scale domain.

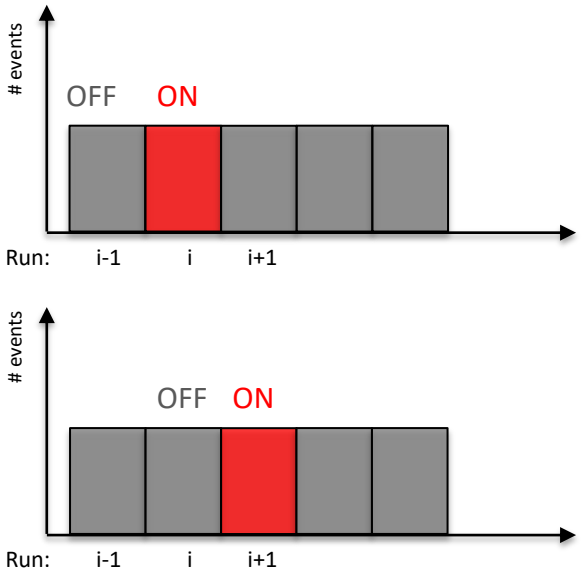
  - It is analogous to that used for on-off excess in the space-domain (significance map, theta^2 histogram).

  - Compute the excess of gamma rays at a given position (pixel) and given time (run/night) with respect to other observations at same position.

Search for signal (space domain)



Search for variability (time domain)



Search for variability
On-off method

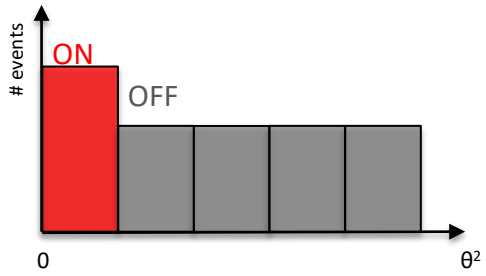
- For N runs of observations at a given position, the excess is $N_{ex} = Non_I - \alpha_I * Noff_J$
  - Non_I= number of events in run I
  - $Noff_J$ = number of events in the N-1 other runs
  - α_I = ratio of acceptance integrated in the ON and OFF regions

- The significance of the excess is computed using eq. 17 of the Li&Ma publication (Li and Ma, 1983).

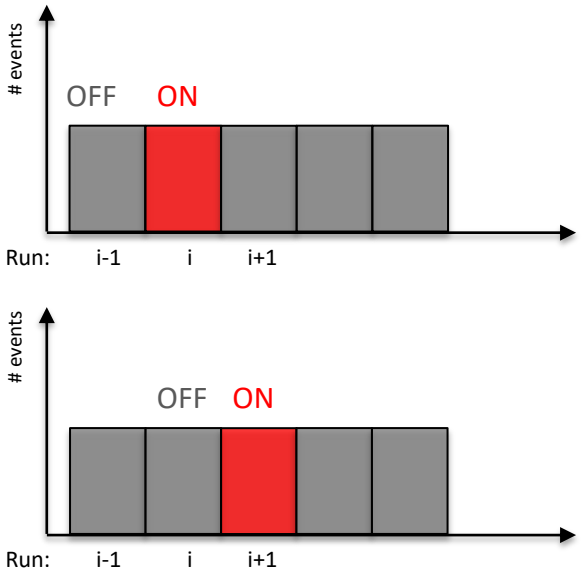
- The significance is corrected by the number of trials (number of bins).

- This method allows for blind search variability across the field of view.

Search for signal (space domain)



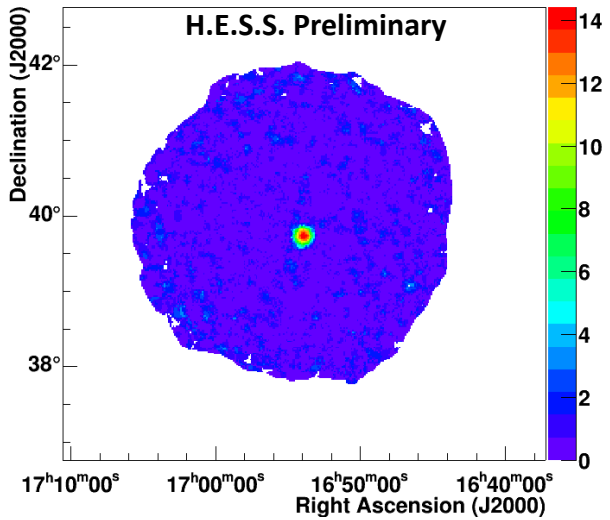
Search for variability (time domain)



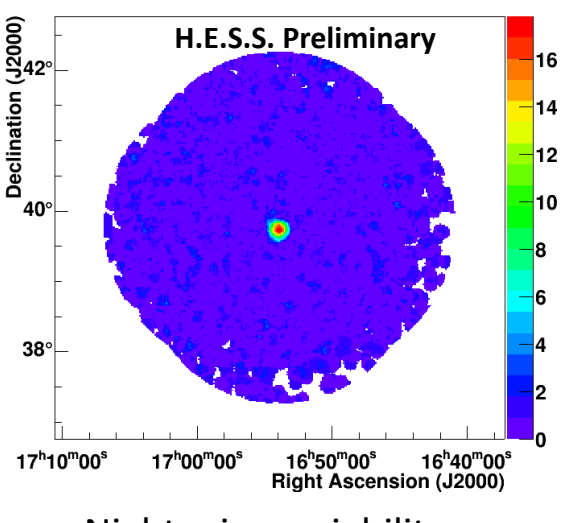
Search for variability
Variability maps

- Variability searched for:
  - runs, on period of 28 minutes.
  - nights, merging the statistics of all the run belonging to the same night.

Example of variability map for Mrk 501 for run and night scales.



Run-wise variability map



Night-wise variability map

Significant variability detection for 4 sources within the HEGS FoV.

Data interpretation
Comparison with Fermi-LAT data

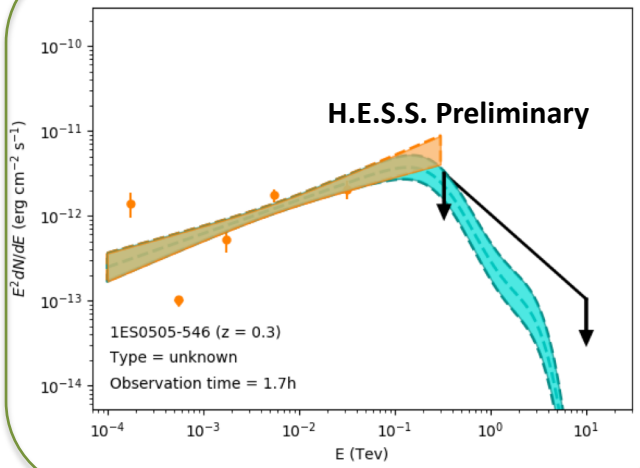
We compared our results to those of the Fermi-LAT by:

- Checking the Fermi-LAT sources present in this data sample
- Constraining the spectral shape using H.E.S.S upper limits

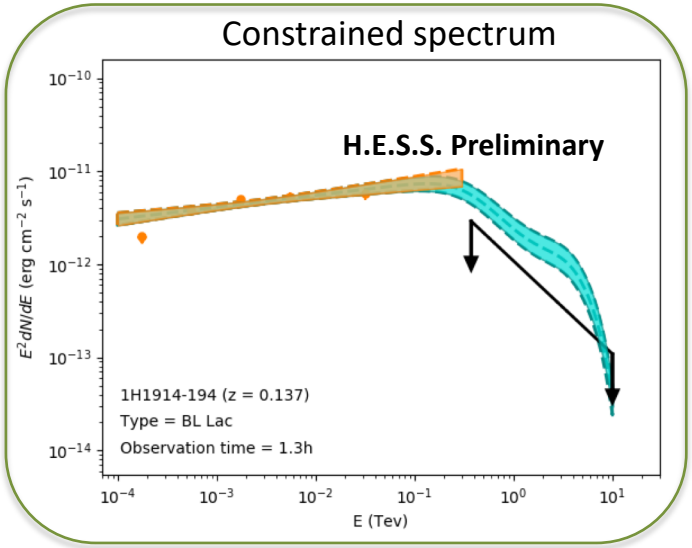
Comparison with the 3FGL

- 216 sources from the 3FGL (Acero et al. 2015) were observed in this dataset:
  - For 204 sources the H.E.S.S. upper limits are not constraining.
  - For 12 sources the H.E.S.S. upper limits are constraining.

Not Constrained spectrum



Constrained spectrum

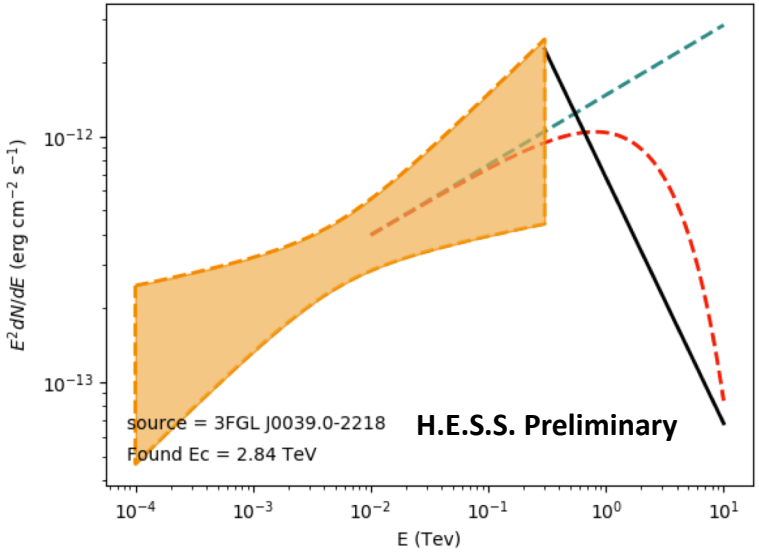


- 3FGL spectrum (orange) from 100 MeV to 100 GeV.
- EBL absorption in blue (Franceschini et al. 2008).

Data interpretation
Search for break

- Sources constrained by H.E.S.S. upper limits must exhibit a break:
  - At which energies does the break occur?
  - How to compare Fermi-LAT extrapolation with H.E.S.S. ULs?

Fermi spectrum (orange) + exp-cutoff (red) and H.E.S.S. UL (black)



Fermi-LAT spectrum + H.E.S.S. IRFs

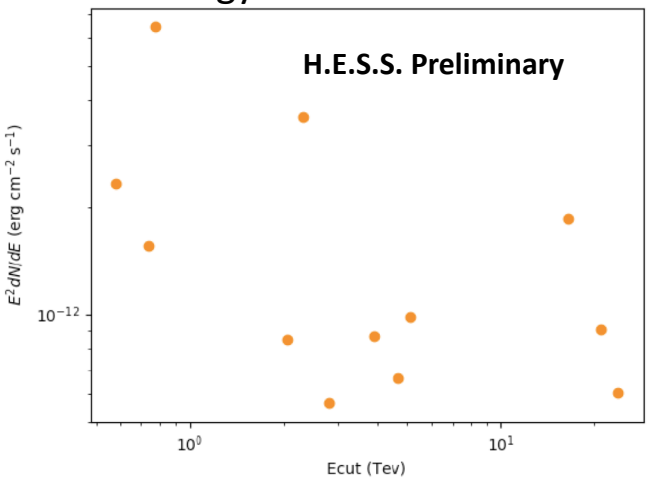
- ✓ An exponential cutoff is added to the Fermi-LAT extrapolation + EBL absorption.
- ✓ For each run the H.E.S.S. energy threshold, livetime is computed.
- → Predict number of detected gamma rays.

H.E.S.S. analysis

Upper limits on the number of detected gamma rays

Upper limit on cutoff energy found when number of predicted gamma rays = number of detected gamma rays.

Energy cut off distribution



Data interpretation
Sky Simulation

- Sky simulations were made in order to estimate the number of sources that should be detected in the HEGS.

- Simulation of $5 \cdot 10^6$ sources using the emcee python package (Foreman-Mackey et al. 2013) according to the luminosity function from Ajello et al. 2011 for FSRQs and Ajello et al. 2013 for BL LAC.

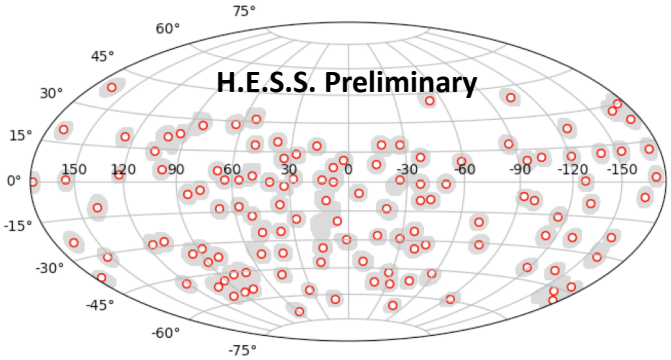
- The spectra of the sources were extrapolated and corrected for EBL.

- Comparison with HEGS sensitivity map for a 5 sigma detection.

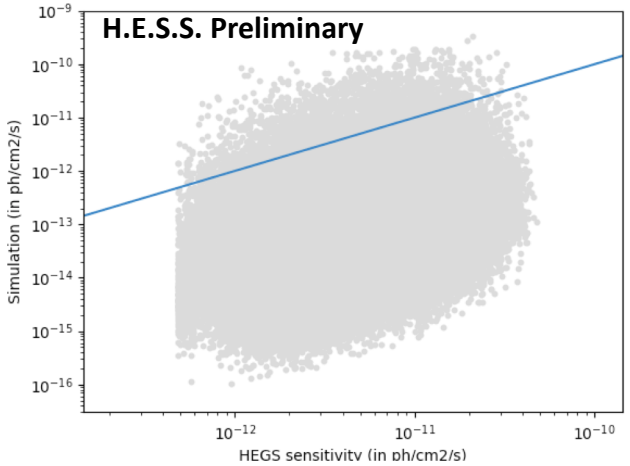
Results:
- FSRQ → Simulation: 1, detection: 0;
- BL LAC → Simulation: 4, detection: 2;

Propagation of errors from normalization of luminosity function to be taken into account.

Simulated position



Simulated sources Vs H.E.S.S. sensitivity



Summary

- The H.E.S.S. Extragalactic Survey has been built re-analyzing all the H.E.S.S. data from January 2004 up to January 2013 (CT1-4 only).
  - We gathered 2700 hours of data over ~6.5% of the sky.
  - A set of statistical (significance, flux, upper limits, variability) maps was computed for each RunClusters.
  - A new method used for the study of the variability led to a significant variability detection of 4 sources.
  - The Fermi-LAT data together with the HEGS data were used to constrain the spectral energy cutoff of 12 sources.
  - A simulation of the sky was done in order address the compatibility of the HEGS results with the luminosity function inferred by Fermi.

Thank you!