Spatial and Time Clustering of the High-Energy Photons collected by the *Fermi* LAT

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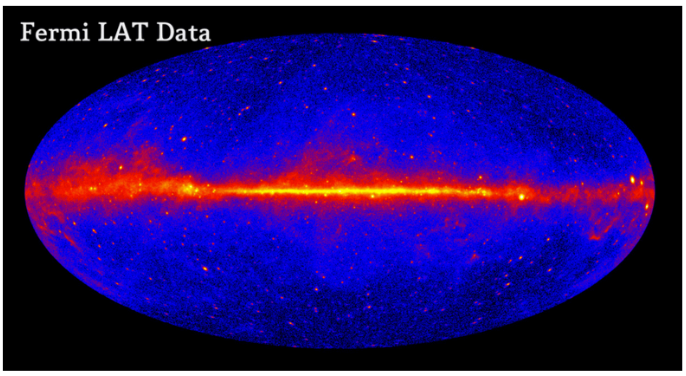
Aims:

- identify new potential Gamma-Ray sources, focusing high energy (HE, >**10 GeV**), which are the best candidate to be Very-High-Energy (VHE, **100 GeV**) emitters.
- study the Gamma-Ray properties of known HE sources, such as the variability.



Methodology:

- Analyse the whole Fermi LAT data set (about 7 years) as well as study shorter-time interval datasets
- **why?** to point out sources that underwent a **flare of short duration**.

Clustering Algorithm

data released	Pass 8
time acquisition	29 Oct 2008-11 Jan 2016
energy range	$[10\,GeV - 1\,TeV]$

- a photon belong to a cluster if:
  - angular distance between two photons

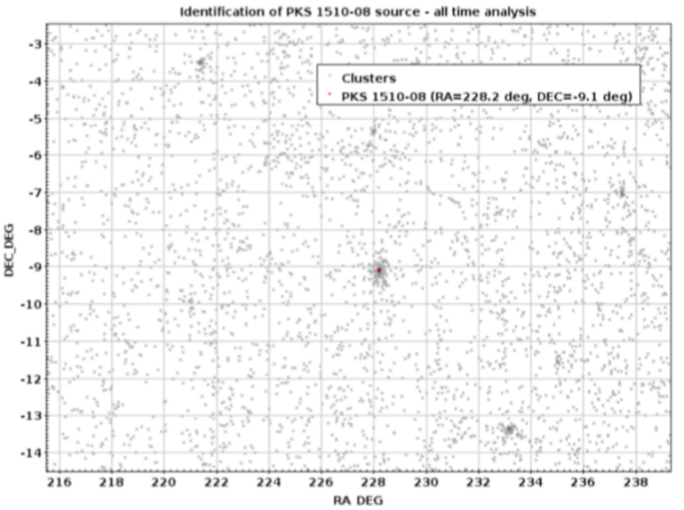
$$dist(i_{center} - j_{photon}) < CA95_i + CA95_j$$

  - cluster's radius: (empirical) estimator of cluster dispersion

- Test Statistic

$$TS = -2log(\frac{\mathcal{L}_{max,0}}{\mathcal{L}_{max,1}}) \sim \chi^2_n$$

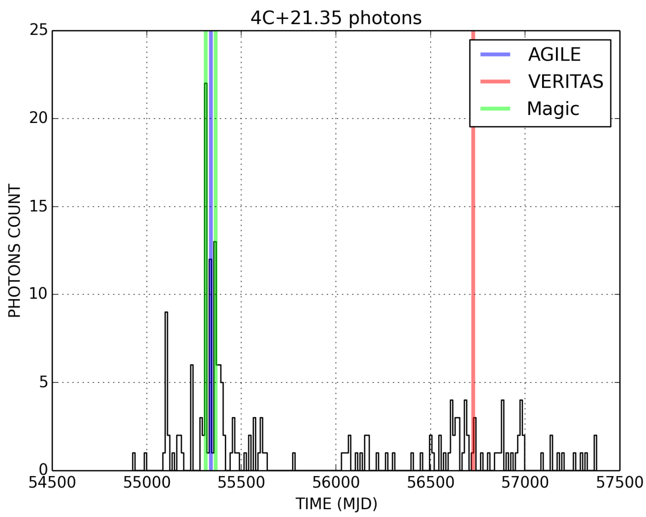
- photon uncertainty direction (CA95)



Results

1. Study of **temporal variation of known VHE sources** (listed in TeVCat)

2. Identification of **known transient** and **new candidate sources**



NAME	TIME(days)	RA(dec)	DEC(dec)	TS
B0218+357	2	35.28	35.94	653.78
GRB130427A	30	173.18	27.79	197.87
GRB090902462	30	264.93	27.34	61.66
Unk	30	159.58	45.16	30.22

Thanks!

Backup

Spatial and Time Clustering of the High-Energy Photons collected by the *Fermi* LAT

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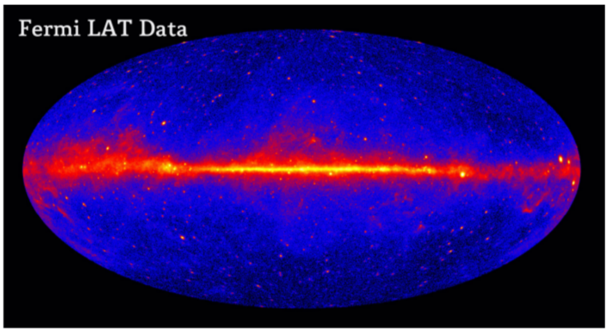

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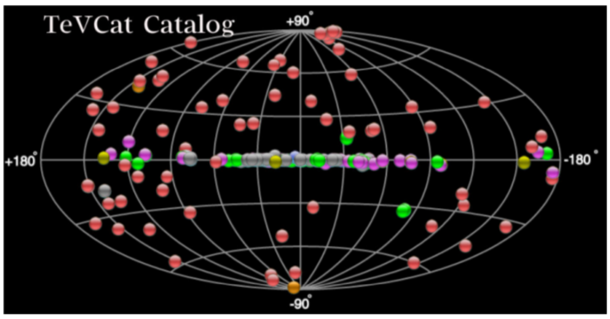

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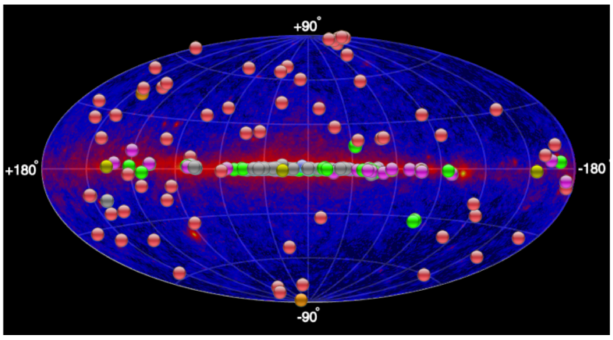

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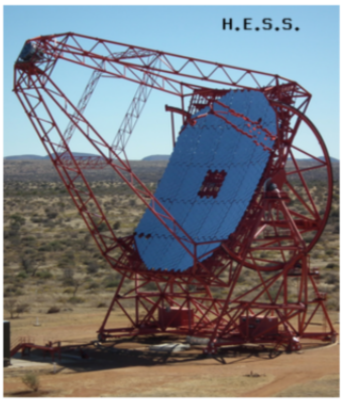
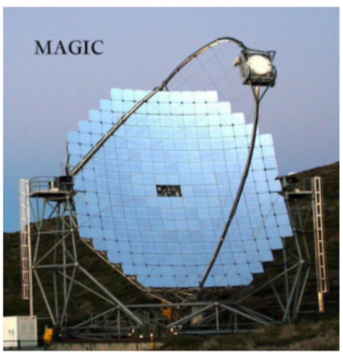
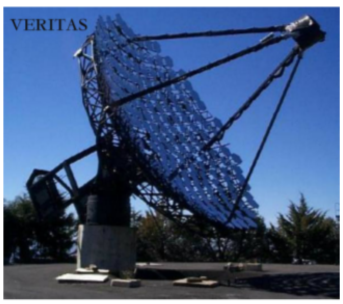
Why?

- The analysis will produce a list of sources that are ideal candidates as VHE emitters. They will **constitute the best targets for the narrow field-of-view Cherenkov detectors**.
  This will be particularly useful in light of the forthcoming **Cherenkov Telescope Array (CTA)**.
- The detection of new VHE objects will improve our understanding of VHE γ-ray Active Galactic Nuclei (AGN).







Fermi LAT Instrument Response Functions (IRFs)

Measured Energy & Direction

$$R(E', \hat{v}'; E, \hat{v}) = A_{eff}(E, \hat{v}) P(\hat{v}'; E, \hat{v}) D(E'; E, \hat{v})$$

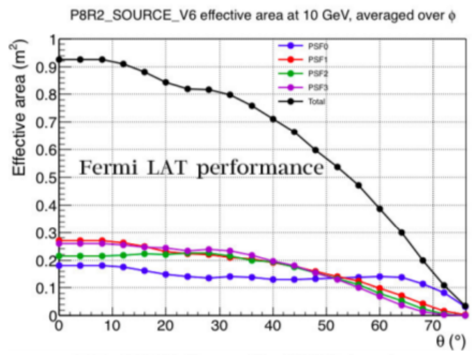
True Energy & Direction

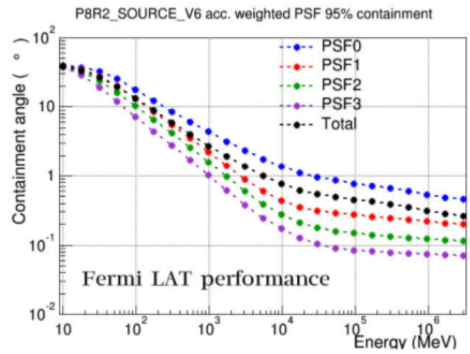
Effective Area

Point-spread Function (PSF)

Probability density to reconstruct an event with angular deviation dυ from the true direction

Energy Dispersion





IRFs provide a mapping between the measured distribution of energy and direction in the LAT data and the true flux of γ-rays on the sky.
The LAT team parametrizes IRFs as a function of γ-ray energy and its arrival direction in the LAT coordinate system.

File fits preparation

photon uncertainty position $\Rightarrow$ **containment angle** at **95%** (CA95) of the Point Spread Function (PSF)
$\rightarrow$ not a strong photon's energy dependence above 10 *GeV*
$\rightarrow$ strong θ dependence

- cut on $\theta >$ **70**$^\circ$ for photons of psf0, psf1 type
- cut on $\theta >$ **68**$^\circ$ for photons of psf2, psf3 type

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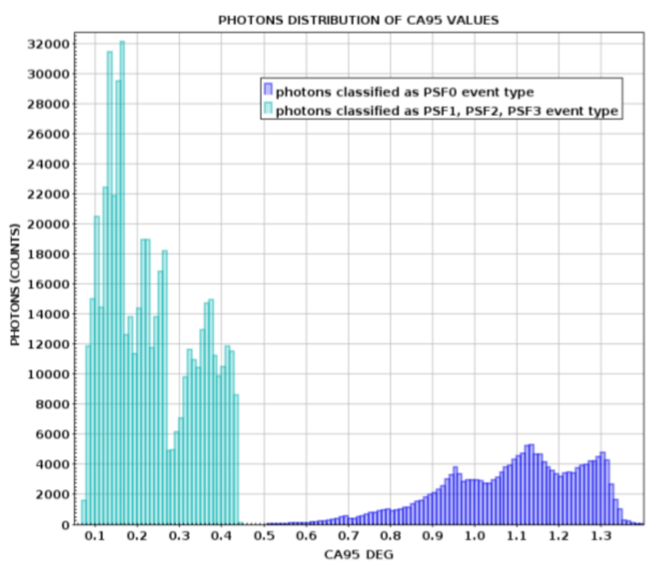
time acquisition	29 Oct 2008-11 Jan 2016
energy range	$[10\,GeV - 1\,TeV]$



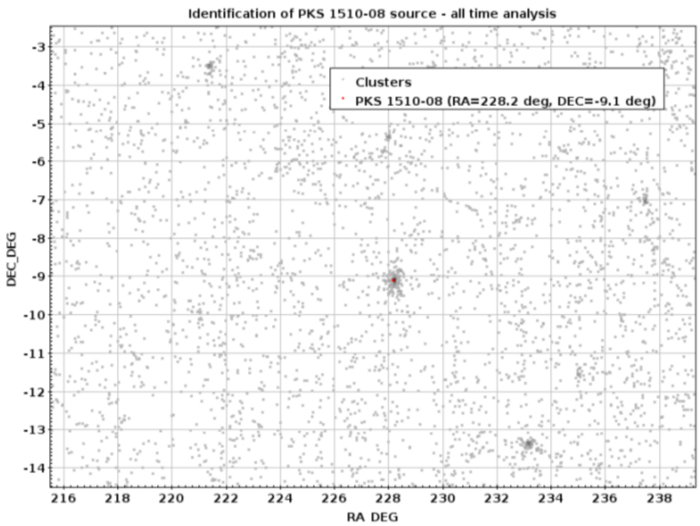
Clustering Algorithm

Condition for a photon to contribute to a cluster:

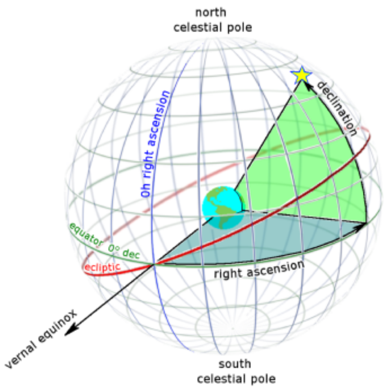
- angular distance between two photons
  $\mathbf{dist}(\mathbf{i_{center}} - \mathbf{j_{photon}}) < \mathbf{CA95_i} + \mathbf{CA95_j}$
- cluster's **radius**: (empirical) estimator of cluster dispersion

Redundant clusters in terms of position and of contained photons

- in a large data set they may **change** both parameters, for a greater contribution of IGRB
- in a small data set (as few days) they **do not change** both parameters



Clustering Issue

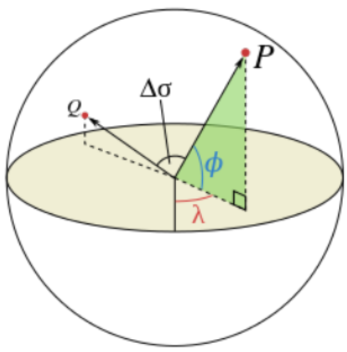


before we use **spherical law of cosine formula**, giving $\bar{v}_1, \bar{v}_2$ the vector in rectangular coordinate:

$$\Delta\sigma = arccos(\bar{v}_1 \cdot \bar{v}_2)$$

after we use a more suitable formula accurate for all distances:

$$\Delta\sigma = arctan\frac{|\bar{v}_1 \times \bar{v}_2|}{\bar{v}_1 \cdot \bar{v}_2}$$



Test Statistic (TS)

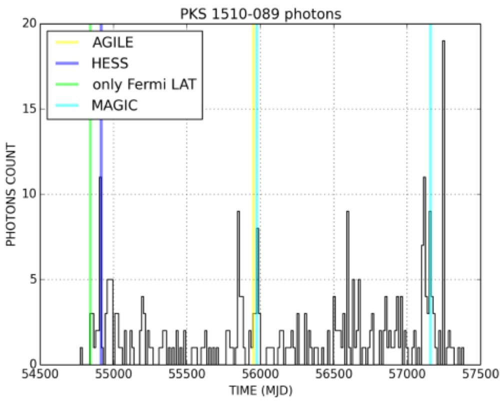
To get the best match of the model to the data we maximize the **Test Statistic (TS)**, defined as

$$TS = -2log(\frac{\mathcal{L}_{max,0}}{\mathcal{L}_{max,1}})$$

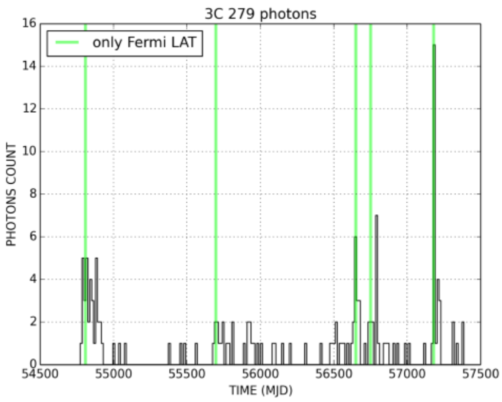
In the limit of a large number of counts, **Wilk's Theorem** states that the TS for the null hypothesis is asymptotically distributed as χ^2_n where n is the number of parameters characterizing the additional source.

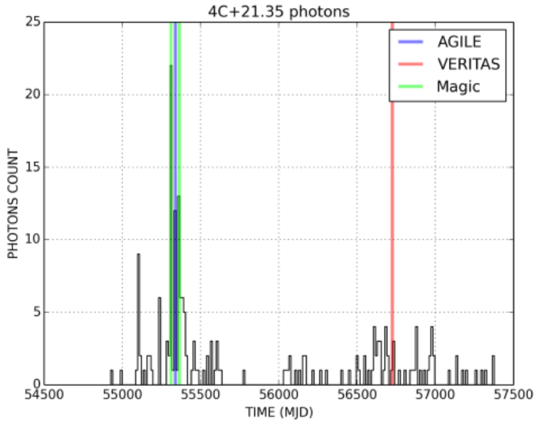
The square root of the TS is approximately equal to the detection significance for a given source.

Results



1. study of **temporal variations of known VHE sources** listed in TeVCat, restricted to FSRQs sources (a subclass of AGNs)

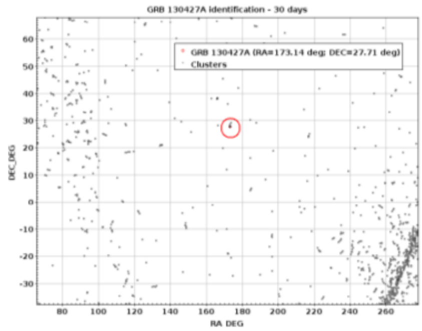


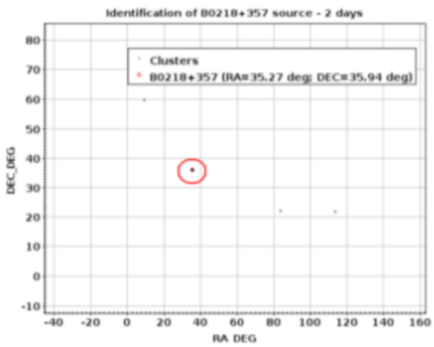


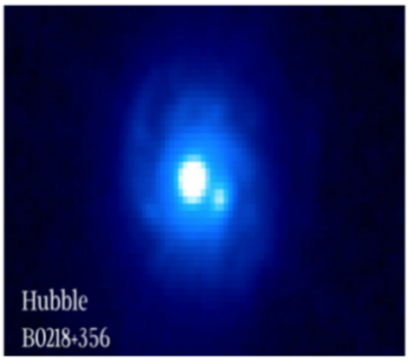
Results

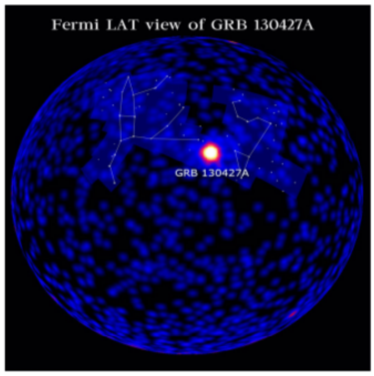
2. identification of **known transients**, detected by *Fermi* LAT Collaboration

name	time	RA (deg)	DEC (deg)	TS
B0218+357	2days	35.28	35.94	653.79
GRB 130427A	30days	173.18	27.79	197.87









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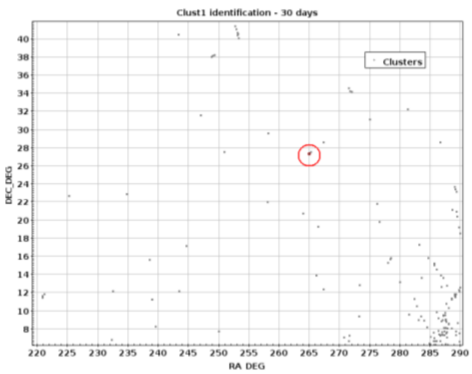
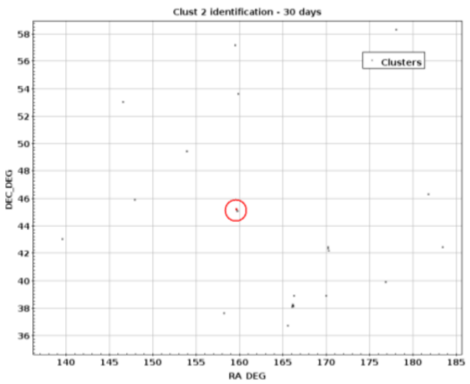
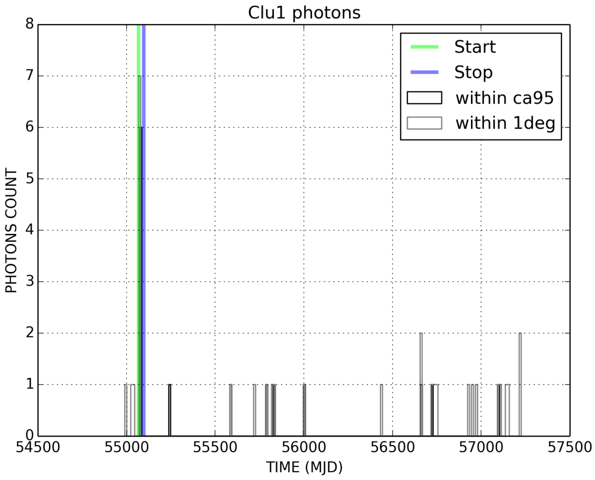


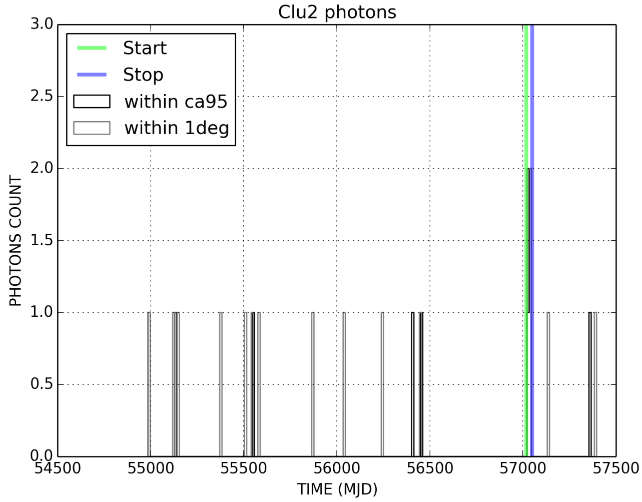


3. identification of **new candidate sources**, which were not detected by analysing the whole *Fermi* LAT data set

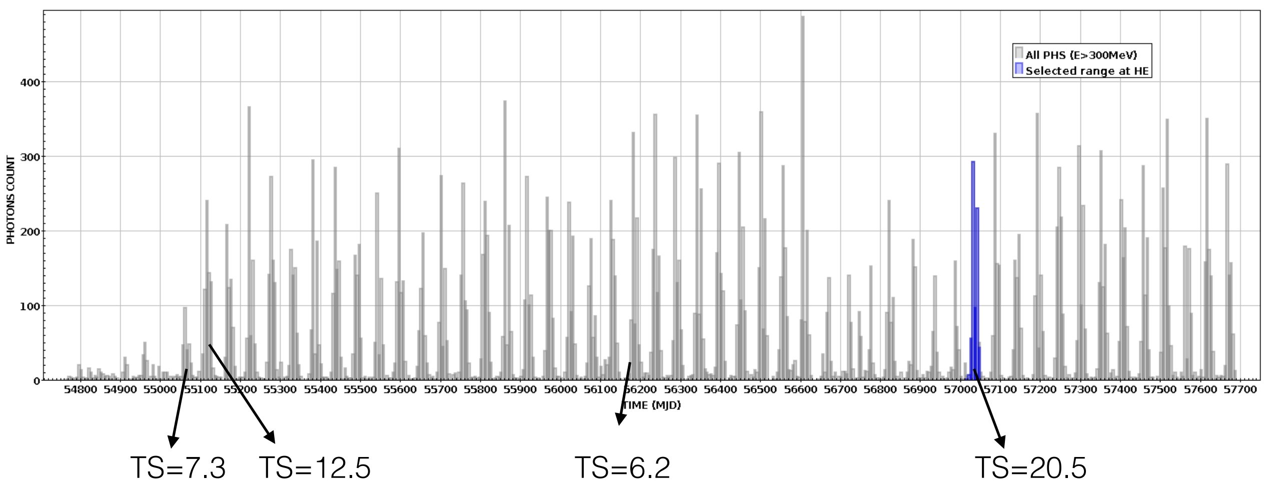
name	time	RA (deg)	DEC (deg)	TS
Clust1	30days	264.93	27.34	61.66
Clust2	30days	159.58	45.16	30.22



GRB 090902462
GCN Name 090902B
MET 273582310
RA 264.94°
DEC 27.32°
Error 0.0001°



Photons of Clu2 within 1° (300 MeV - 1 TeV)



Conclusions

We **developed** and **tested** a new spatial and time clustering algorithm, which sets the pace:

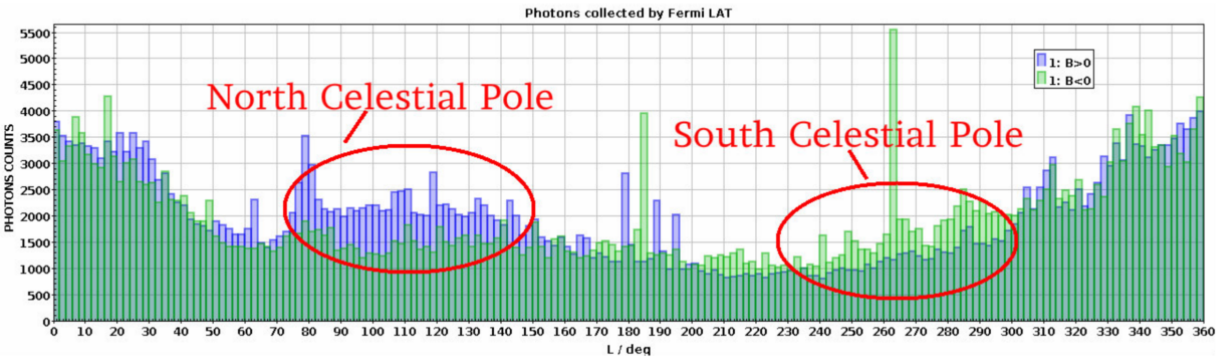
- study temporal variation of known sources
- identify new candidate VHE sources

Future studies should provide:

1. a suitable method to **merge clusters**
    - complicated by the sample numerosity (704902 photons) and the resources in memory requested by the algorithm which scales as N^2
2. for instance a **better estimator of the radius**, the cluster's dispersion

3. Identification of **new candidate sources**, which were not detected analyzing the whole Fermi LAT dataset

Fermi LAT Exposure



The difference of collected photons between the two highlighted circles that represents the North and South Celestial Pole is about 10%.