The First Fermi-LAT Catalog of Sources Above 10 GeV (1FHL catalog)

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Outline of this talk (not for the catalog)

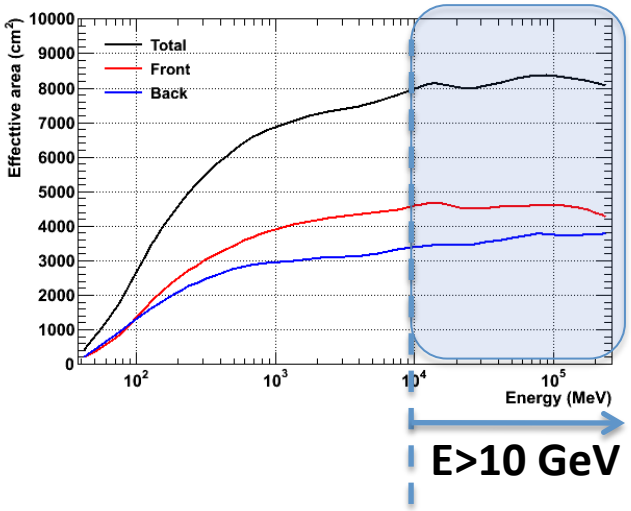
1 - Performance of LAT for astronomy above 10 GeV
2 - Motivation (differences with the 2FGL catalog)
3 – Some results (Preliminary !)
    3.1 - Detection, localization and spectral analysis with gtlike
    3.2 – Associated sources
    3.3 – Variability
    3.4 – Candidate sources for VHE detection with IACTs
7 – Conclusions

Performance of LAT for astronomy above 10 GeV

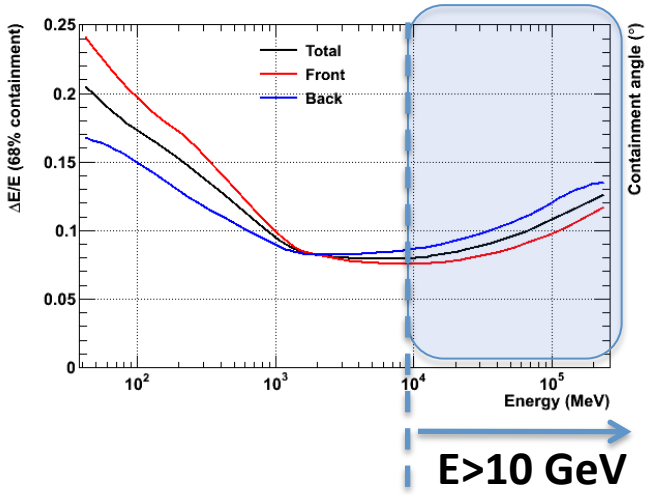
The LAT instrument → See "Highlights from Fermi" talk by Simona Murgia (this afternoon)

Performance of LAT for E> 10 GeV is excellent (compared to that for E>100 MeV)

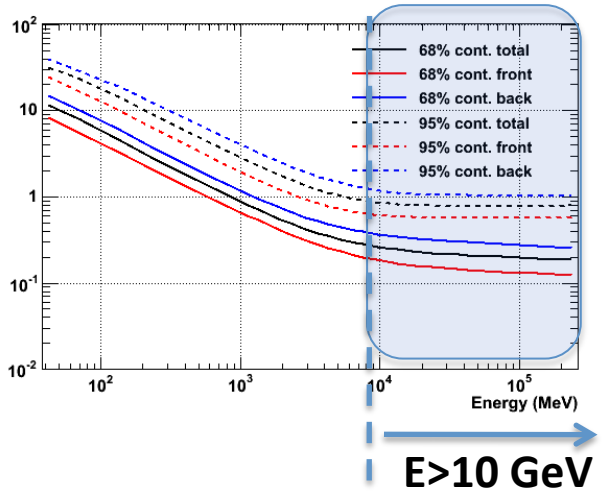
Effective Area



Energy resolution



Point Spread Function



https://confluence.slac.stanford.edu/display/SCIGRPS/Pass7_v6+Performance+page+for+public+use

Best possible effective area and PSF occur at the highest energies
Slightly worse energy resolution due to worse shower containment

The Challenge: Nature of the sources we want to detect…

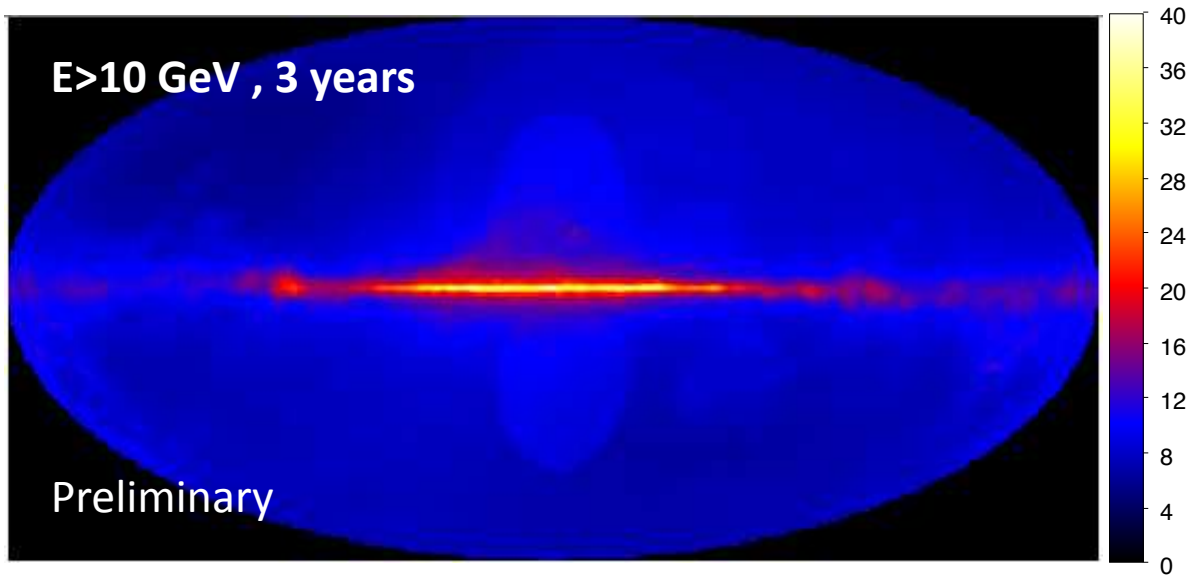
→ fluxes fall (typically) with power-law index of about 2.5

→ **We will have to deal with many detections with less than 10 photons**

Performance of LAT for astronomy above 10 GeV

Calculated point source flux limit using photons above 10 GeV after 3 years of operation

Minimum detectable flux in units of **10^{-11} ph/cm^2/s**



Apart from some structures (Galactic diffuse and Fermi bubbles) **the flux limit at >10 GeV after 3 years is about 10^{-10}ph/cm^2/s** and rather uniform (within factor of 2)

This sensitivity is good enough to be able to detect hundreds of sources

At E>100 GeV (3 years) the flux limit is about 3x10^{-11} ph/cm^2/s which is *only a factor of about 3 worse than the point source sensitivity in 50 hours from current IACTs*

Fermi-LAT provides a true >100 GeV scan of the sky with a sensitivity that could be comparable to 5 hours of (*good or effective time*) observation with a current IACT in every direction

Motivation (differences with the 2FGL catalog)

Dedicated source characterization at the highest LAT energies (>10 GeV).

- Shape of the spectrum at > 10 GeV might not be well characterized if we use a single fit in the energy range 0.1 GeV – 100 GeV. *Low energies have larger stat. weight*

- The variability at the highest Fermi-LAT energies could be different from that at the lowest energies, which might indicate the presence of a separate population of particles which may radiate from the same/different location.

Are the sources more variable at HE than at LE ? or the other way around ?

Understand better the population of sources emitting above 10 GeV

Which are the source-types dominating the highest Fermi-LAT energies ?

Quantify differences with LogN-LogS for sources emitting at >0.1 GeV ?

What is the contribution to the Extragalactic Gamma-Ray Background (EGB) ?

Identify promising source candidates to lead current IACTs to new VHE discoveries

Fermi-LAT benefits from a large duty cycle and all-sky observation.

Useful to increase the efficiency in the searches for new TeV sources

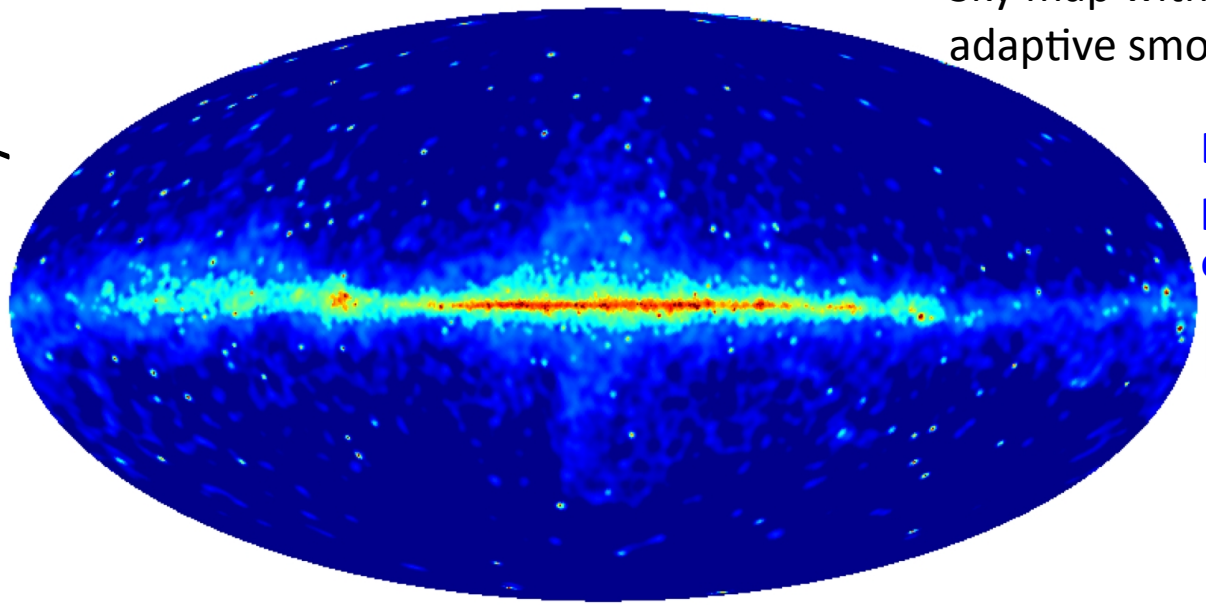
Through various Memoranda of Understanding, the Fermi-LAT collaboration has successfully helped IACTs to find new TeV sources since 2009

Detection, localization and gtlike analysis

LAT data from August 2008 through July 2011 (nearly three years)

P7_V6_Clean event selection

Sky map with > 10 GeV events and adaptive smoothing (10 photon kernel)



LAT sees more than 1.5×10^5 photon candidate events in only 3 years

Big improvement with respect to EGRET !!!
1.5×10^3 evts in 9 years
(Thompson et al 2005)

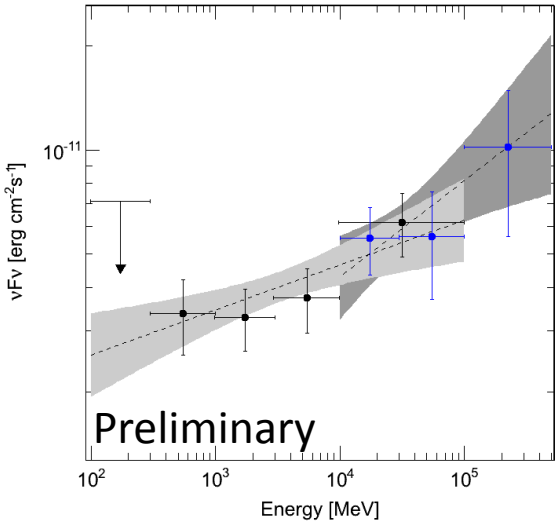
The analysis pipeline used is the same as that for the 2FGL catalog:
candidate sources ("seeds") are identified and localized, and then a maximum likelihood analysis extracts results on statistical significance, flux, and energy spectrum.
Galactic and isotropic diffuse background models similar to those used for the 2FGL catalog (available through the Fermi Science Support Center)

Only sources with a Test Statistic (TS) larger than 25 are reported

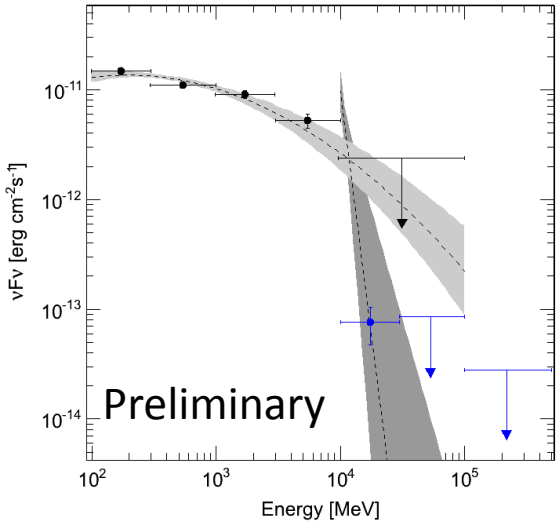
516 sources (***All sources could be fitted with a simple power law***)

Detection, localization and gtlike analysis

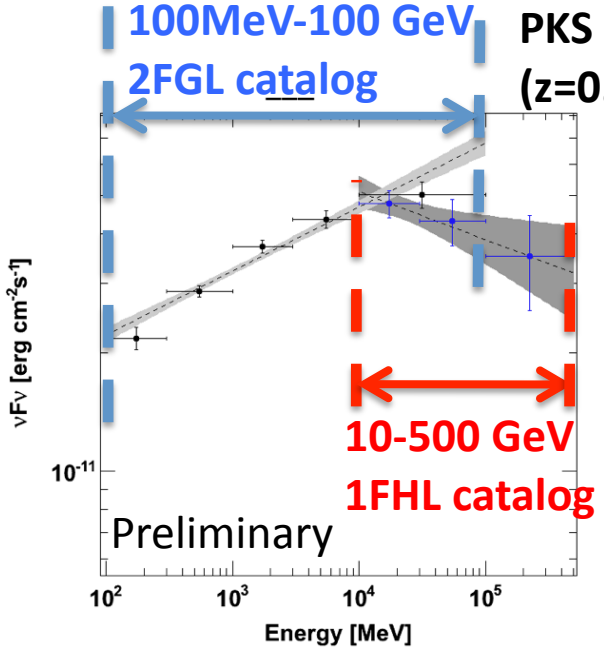
1ES 0033+595 (z=0.086)



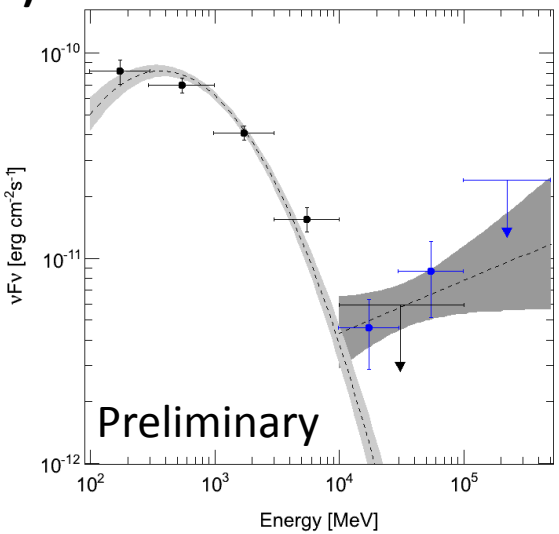
B2 2308+34 (z=1.8)



PKS 2155-304 (z=0.12)



LS 5039



Large diversity in the spectra obtained above 10 GeV (in comparison with that obtained when integrating above 100 MeV)

Some sources show a >10 GeV spectrum that is roughly a continuation of that at > 100 MeV

Others show internal breaks

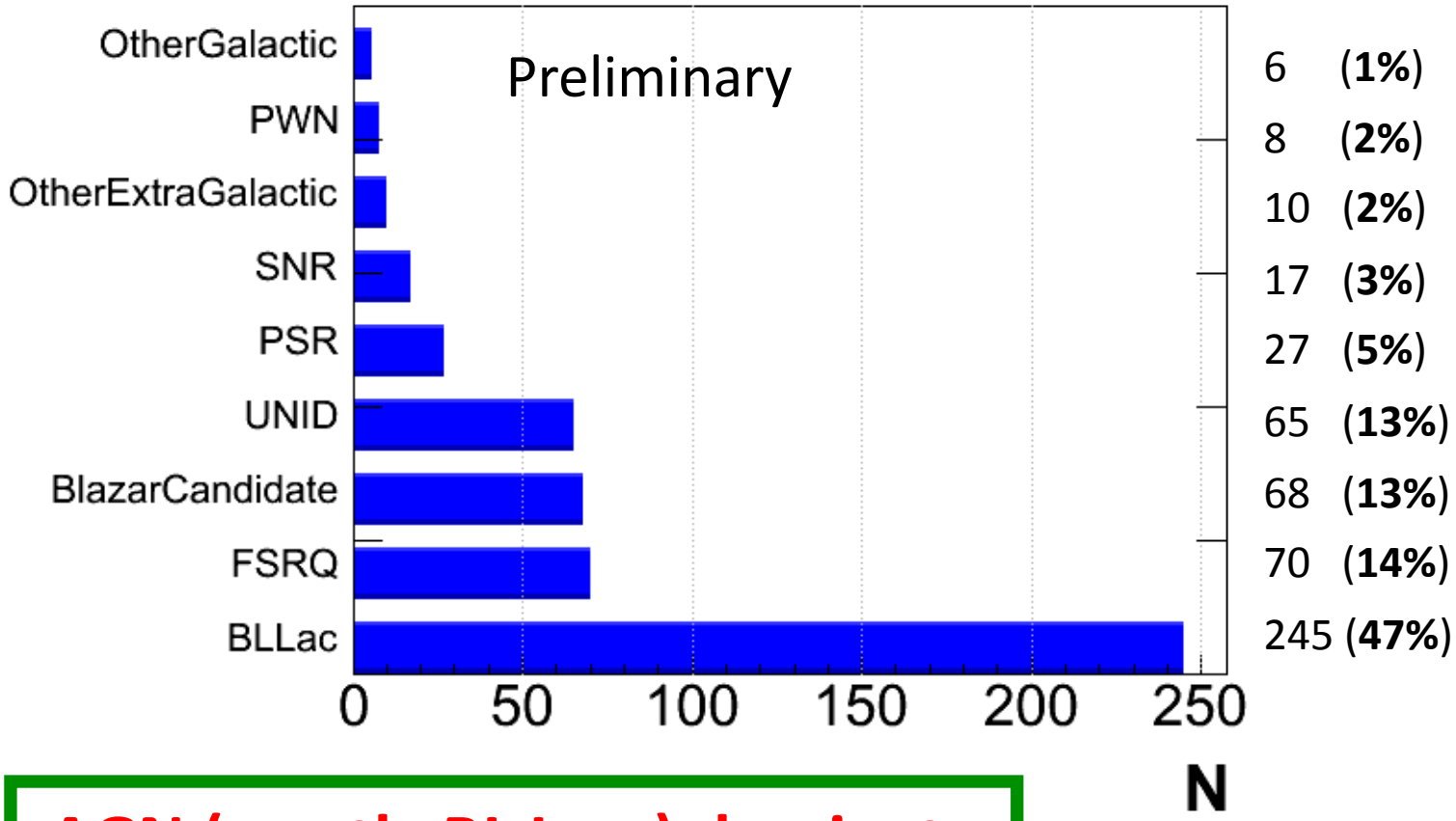
Others show attenuations due to the absorption in the EBL

Others show new components

Need 1FHL catalog to characterize Fermi sources at the highest energies

Associated sources (All)

516 sources in the 1FHL catalog



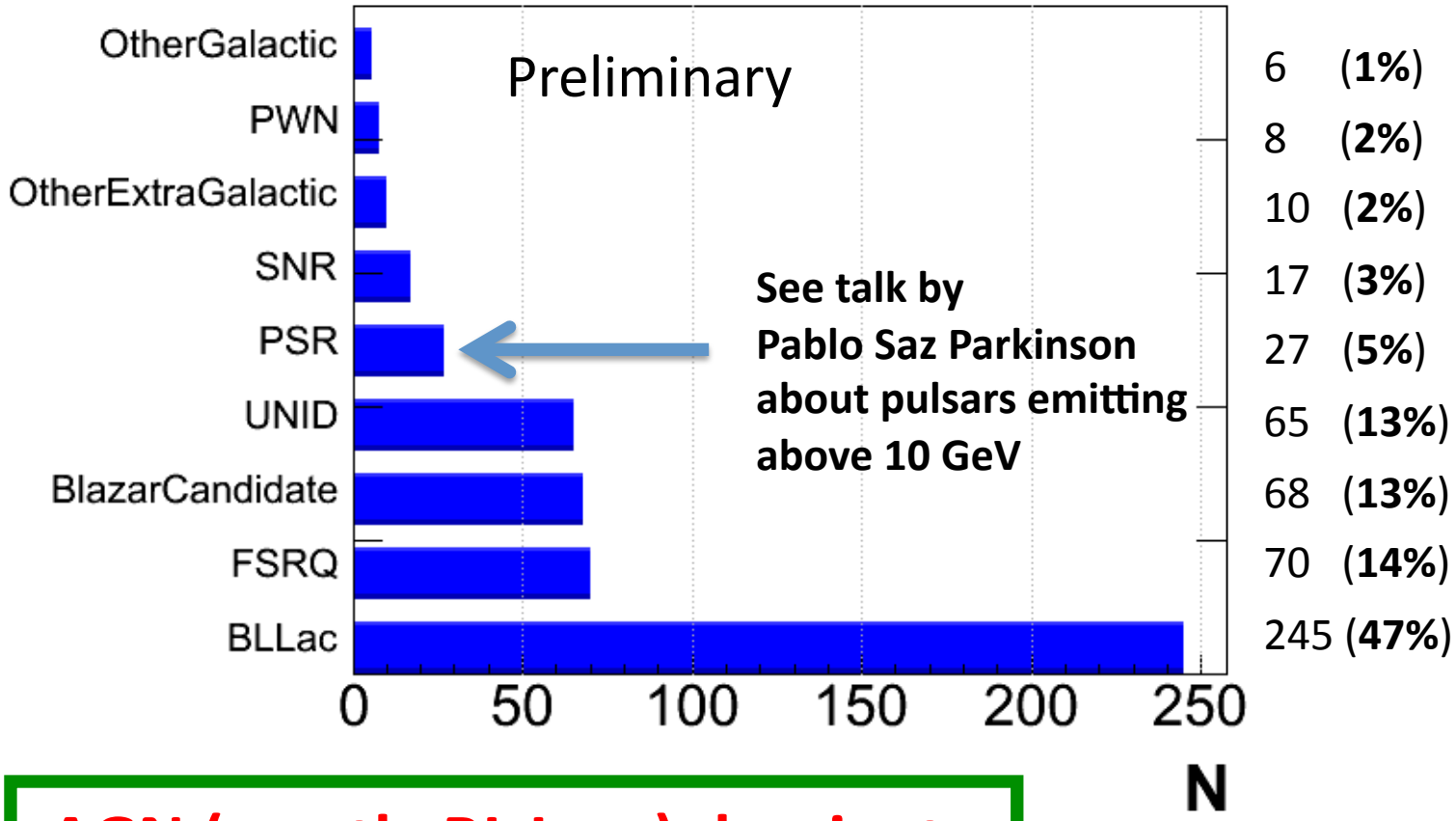
6 (**1%**)
8 (**2%**)
10 (**2%**)
17 (**3%**)
27 (**5%**)
65 (**13%**)
68 (**13%**)
70 (**14%**)
245 (**47%**)

AGN (mostly BL Lacs) dominate the Fermi-LAT sky above 10 GeV (392 objects→ 76%)

13% of the sources remain unassociated

Associated sources (All)

516 sources in the 1FHL catalog



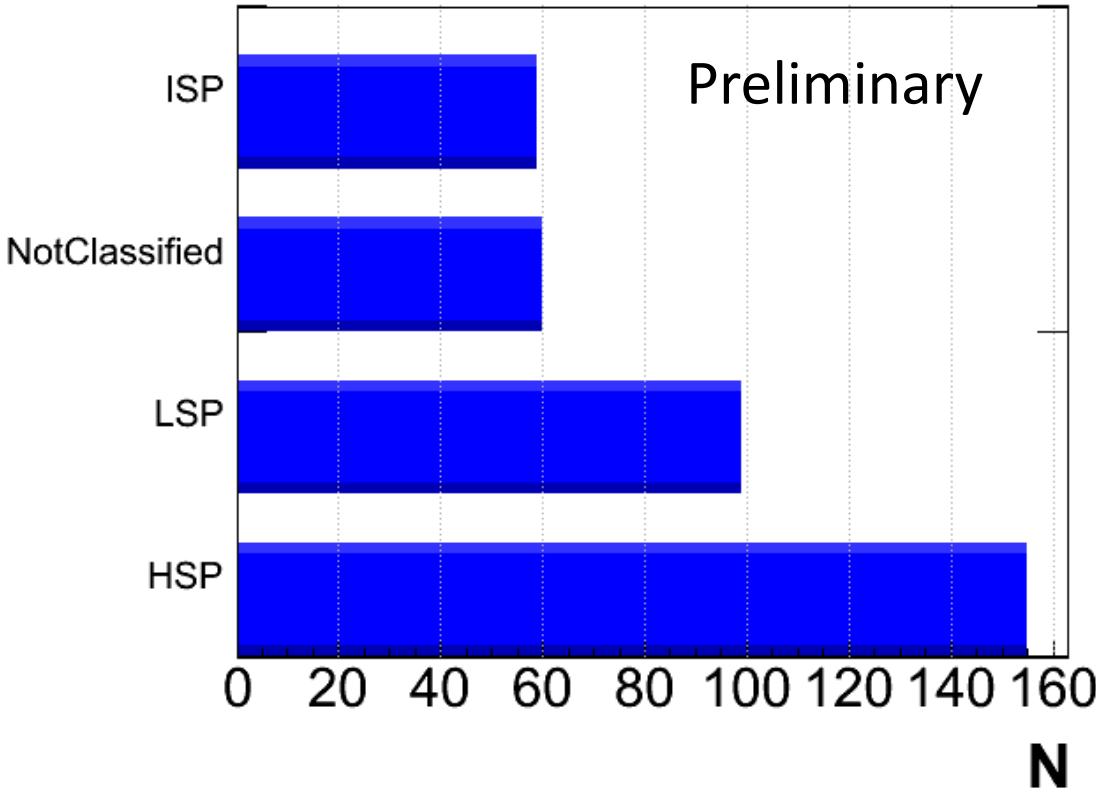
AGN (mostly BL Lacs) dominate the Fermi-LAT sky above 10 GeV (392 objects→ 76%)

13% of the sources remain unassociated

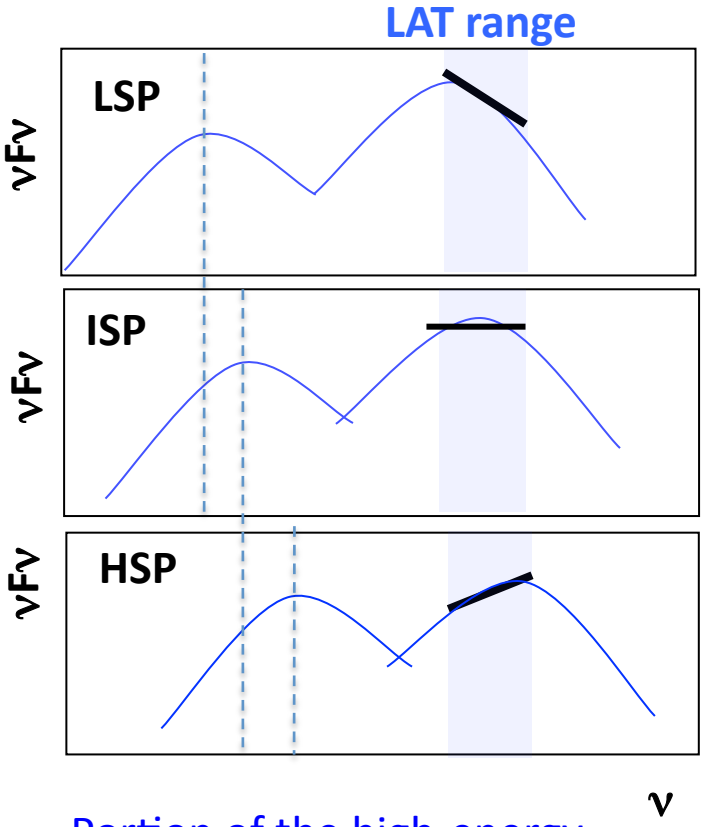
Associated sources (AGNs)

AGN SED classification

→ *according to location of Sync peak*



From the 392 AGN sources in the Hard Src list,
373 already existed in the 2nd LAT AGN Catalog (2LAC)

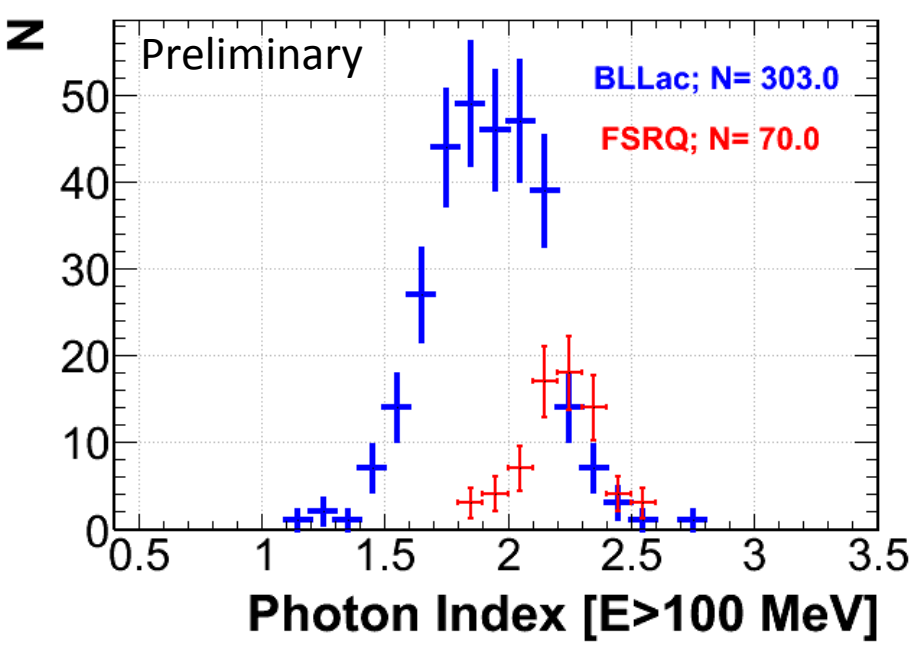


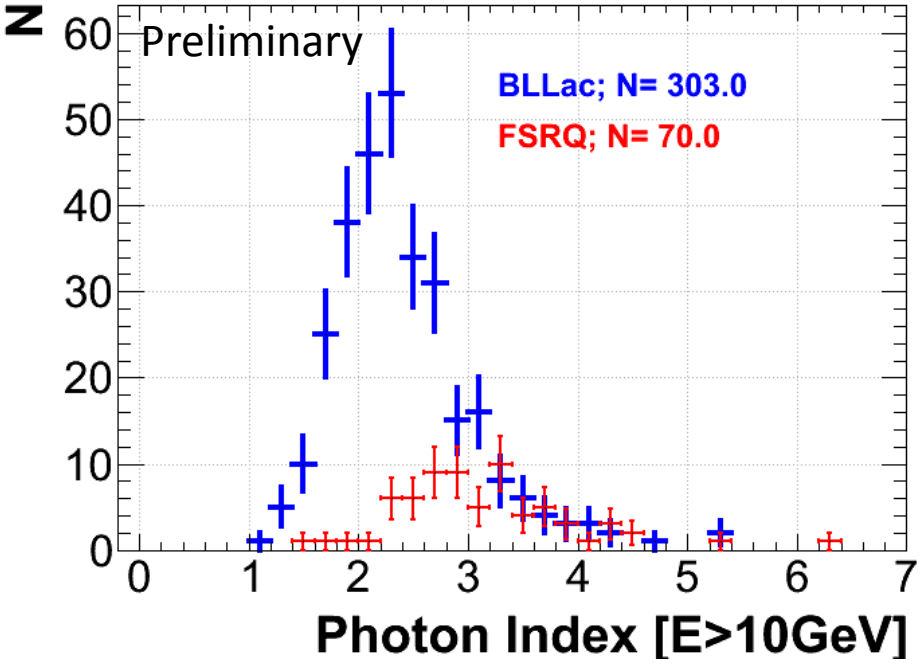
Portion of the high-energy bump covered by LAT depends on the blazar SED classification

HSP (155 objects, 42%) are the source class that dominates the Fermi-LAT sky above 10 GeV

Associated sources (AGNs)

Distribution of photon indices (from power-law fit) for the 373 1FHL sources contained in the 2nd LAT AGN Catalog (2LAC)





Photon indices get softer at E>10 GeV

→ Intrinsic softening of the AGN spectra

→ Impact of absorption of gamma-rays in the (UV) EBL

There is a large number of BL Lac objects with spectra harder than 2, even when the spectra are determined using E>10 GeV

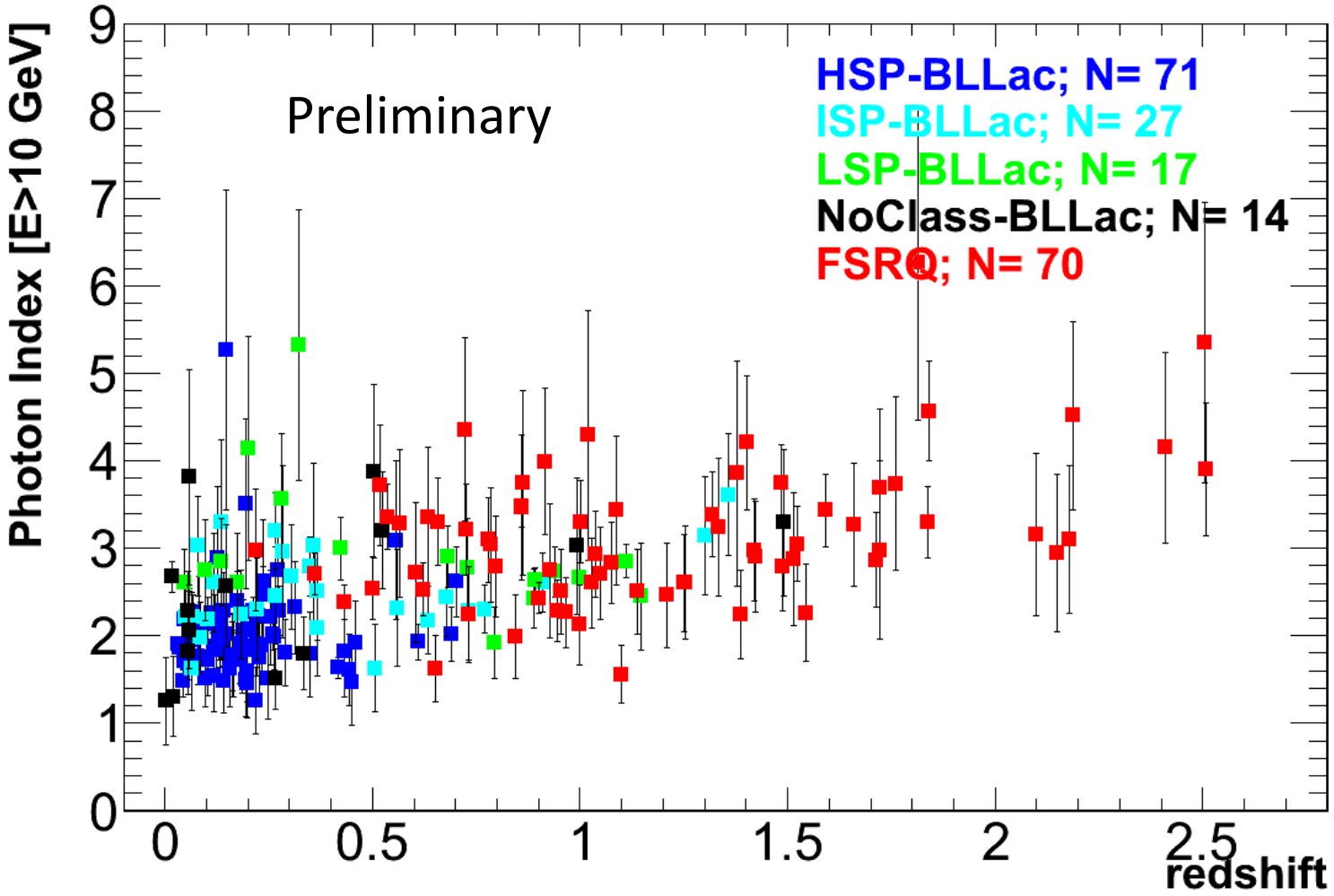
Associated sources (AGNs)

Index vs Redshift

199 associated sources have measured redshifts

(Photon Index is computed with events with Energy > 10GeV)

Sources get softer with redshift (possibly due to EBL). Such trend is less clear when using the photon index computed with E>100 MeV (see 2LAC catalog paper)



Quantification of variability

This is not an easy topic because many of those sources are VERY weak sources for Fermi-LAT

→ **we have very few photons to work with**

For the typical source we get about 10 photons (E>10 GeV) in 3 years (*range is 4 - 952*)

Because of the low photon count, the Bayesian Block algorithm proposed by Scargle in 1998 (ApJ 504, 405) is the most suitable method to evaluate potential flux variations

→ It takes the raw event count and determines "time blocks" with constant photon rate

→ More than one "time block" implies variability

→ The impact of the prior in number of blocks (*nc_prior*) can be quantified via simulations

→ Variability can be computed for several "false positive thresholds"

Preliminary

False positive threshold	Number of sources flagged as variable	Expected number of false positives
0.1%	27	0.5
1%	41	5
2%	56	10
5%	80	25

Photon statistics is a limiting factor to determine variability (at >10 GeV)

→ **Only few sources flagged as variable (if fake pos. thr. is stringent: 0.1—1%)**

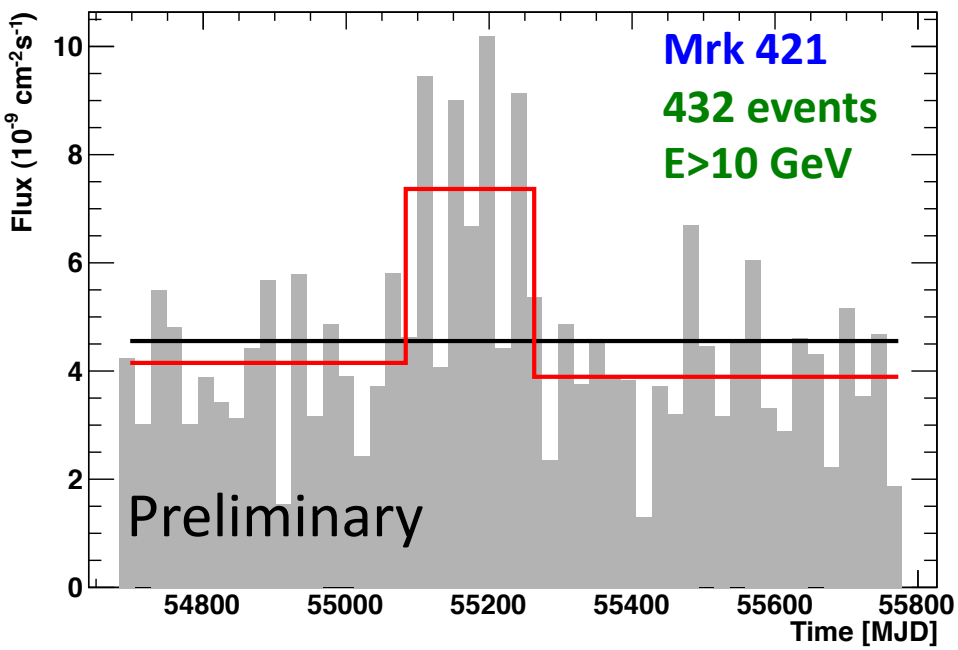
→ Brightest sources are NOT necessarily the ones with the highest variability

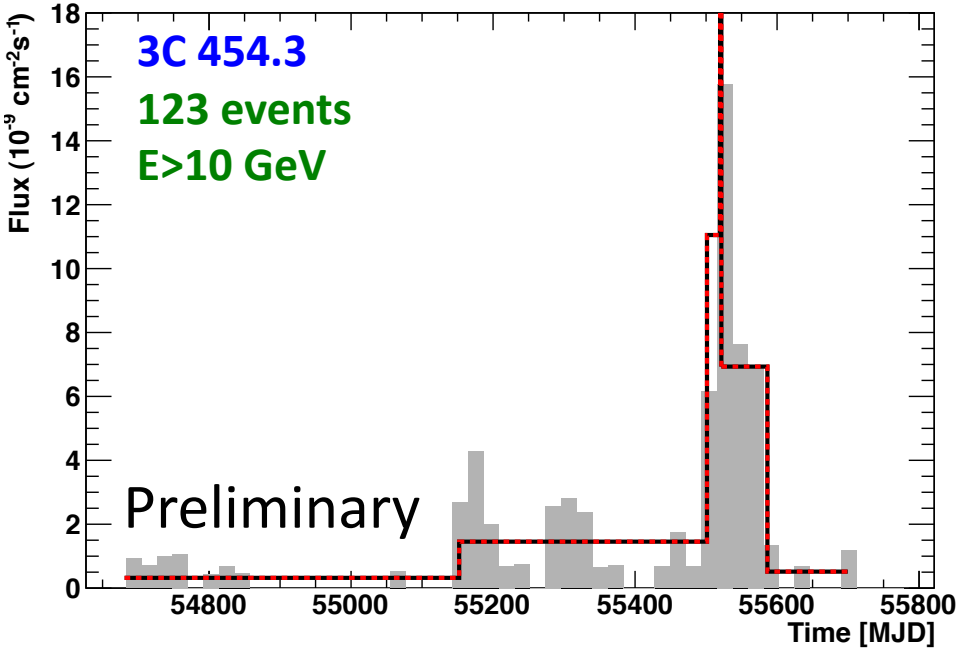
Bayesian blocks (with light curves overlayed)

→ *More than one block indicates variability*

Black → 1% false positive threshold

Red → 5% false positive threshold



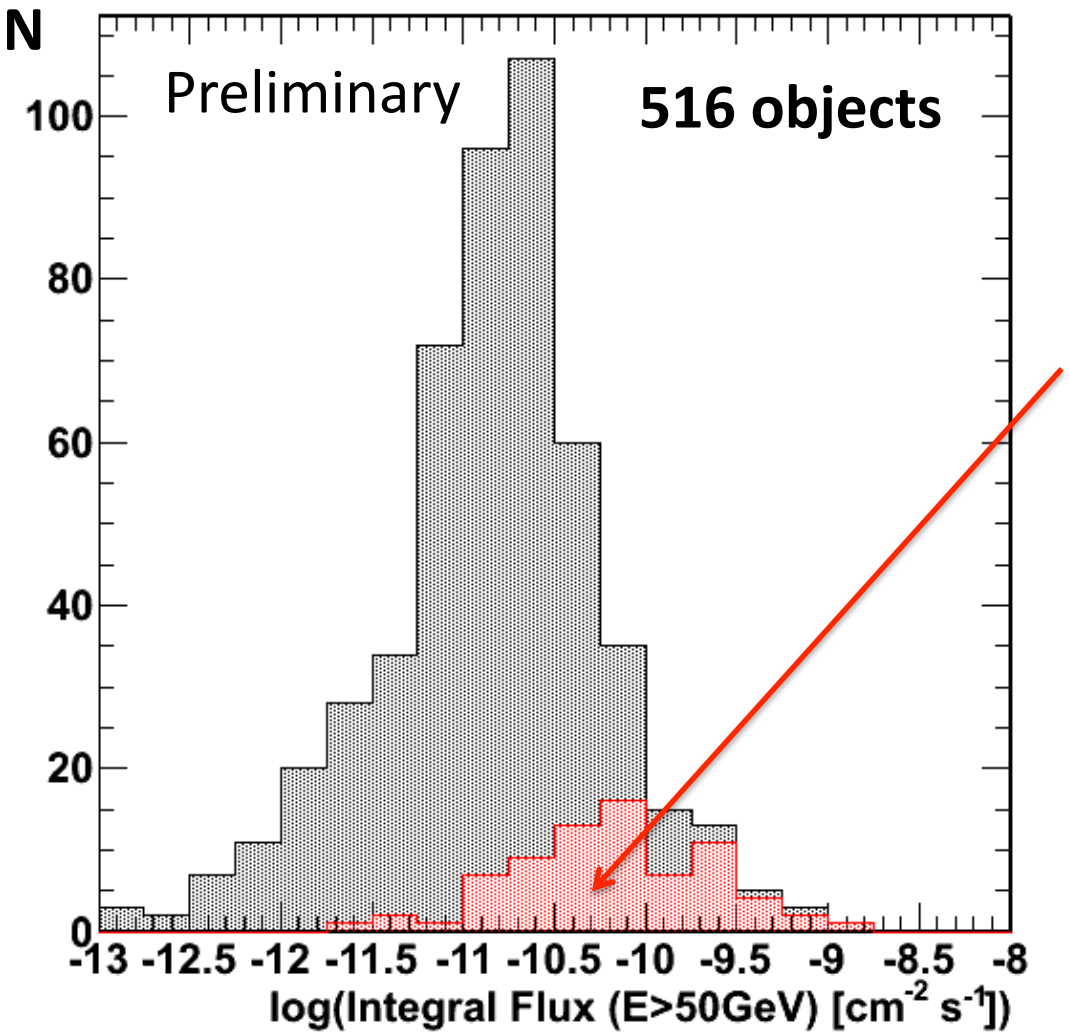


Variability observed in Mrk 421 only if using a (loose) false positive threshold of 5%. Yet in 2010, Mrk 421 showed VHE flux variations larger than one order of magnitude (*see posters by Fortson et al and Sun et al*). **Similar situation for other HSPs (PKS 2155-304, Mrk 501 …)**

High-significant variability typically detected for sources which are "not-too-faint" and for which Fermi-LAT sees the falling edge of the high-energy SED bump (→ LSPs)
Example: PKS 1222, 3C 454, 3C 279, BL Lac …

Source candidates to be detected at VHE

Distribution of LAT flux above 50 GeV



Flux above 50 GeV determined using the power law fit derived with events above 10 GeV

75 sources have been already detected with IACTs at VHE.

Clear relation:
sources detected at VHE with IACTs have high fluxes above 50 GeV

Source candidates to be detected at VHE

Few candidate sources for detection >100 GeV with IACTs (sorted with decreasing F>50 GeV)

→ Information shared with IACTs through Memoranda of Understanding

Association	Distance	Src Type
PMN J1603-4904	?	BL Lac (LSP)
η Carinae	2.4 kpc	Binary System
PKS 0537-441	z= 0.892	BL Lac (LSP)
B3 0133+388	z>0.4	BL Lac (HSP)
PKS 0301-243	z=026	BL Lac (HSP)
KUV 00311-1938	z=0.61	BL Lac (HSP)
4C +55.17	z=0.899	FSRQ (LSP)
PG 1246+586	z=0.8	BL Lac (ISP)

→ **See poster Reitberger et al**

Majority of sources are blazars, some of **them with very high redshift !**

Detecting the high-redshift blazars with IACTs has a large scientific return (blazar physics and cosmology)

Should detected at VHE (>100 GeV), these sources could be used as tools to study a large variety of things related to the environment traversed by the detected gammas-rays:

1 - Extragalactic Background Light (EBL)
2 - Intergalactic Magnetic Fields (IGMF)
3 – Tests of Lorentz Invariance Violation
4 - Search for Axion Like Particles (ALPs)

Source candidates to be detected at VHE

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IACT Observation triggered by the information provided by LAT collaboration back in October 2009

VHE detection with MAGIC announced in this conference

→ Highlights from MAGIC (D. Mazin)

VHE detection with HESS announced in this conference

→ Highlights from HESS (C. Stegmann)

Search for new VHE AGNs is best when performed in 3 dimensions: RA, Dec and Time

Fermi-LAT data can help to determine WHERE and WHEN to look with IACTs

Conclusions

Searched for gamma-ray sources at E>10 GeV using data from LAT accumulated during the first 3 years of the Fermi Gamma-ray Space Telescope mission.

Detected 516 sources (TS>25), measured their spectra, quantified their variability, and studied their associations with cataloged sources at other wavelengths. *This list, **the 1FHL catalog**, complements the 2FGL catalog, which was based on 2 years of data extending down to 100 MeV and so included many sources with softer spectra.*

About 87% of the objects could be associated with known sources.
76% are AGNs, ~5% are pulsars, and ~5% are SNR/PWN .
Observed trend of *softer spectral index with increasing redshift*

Variability is found for 41 objects (8%).

→ The most variable source-type above 10 GeV is LSP blazars (not HSP !!)

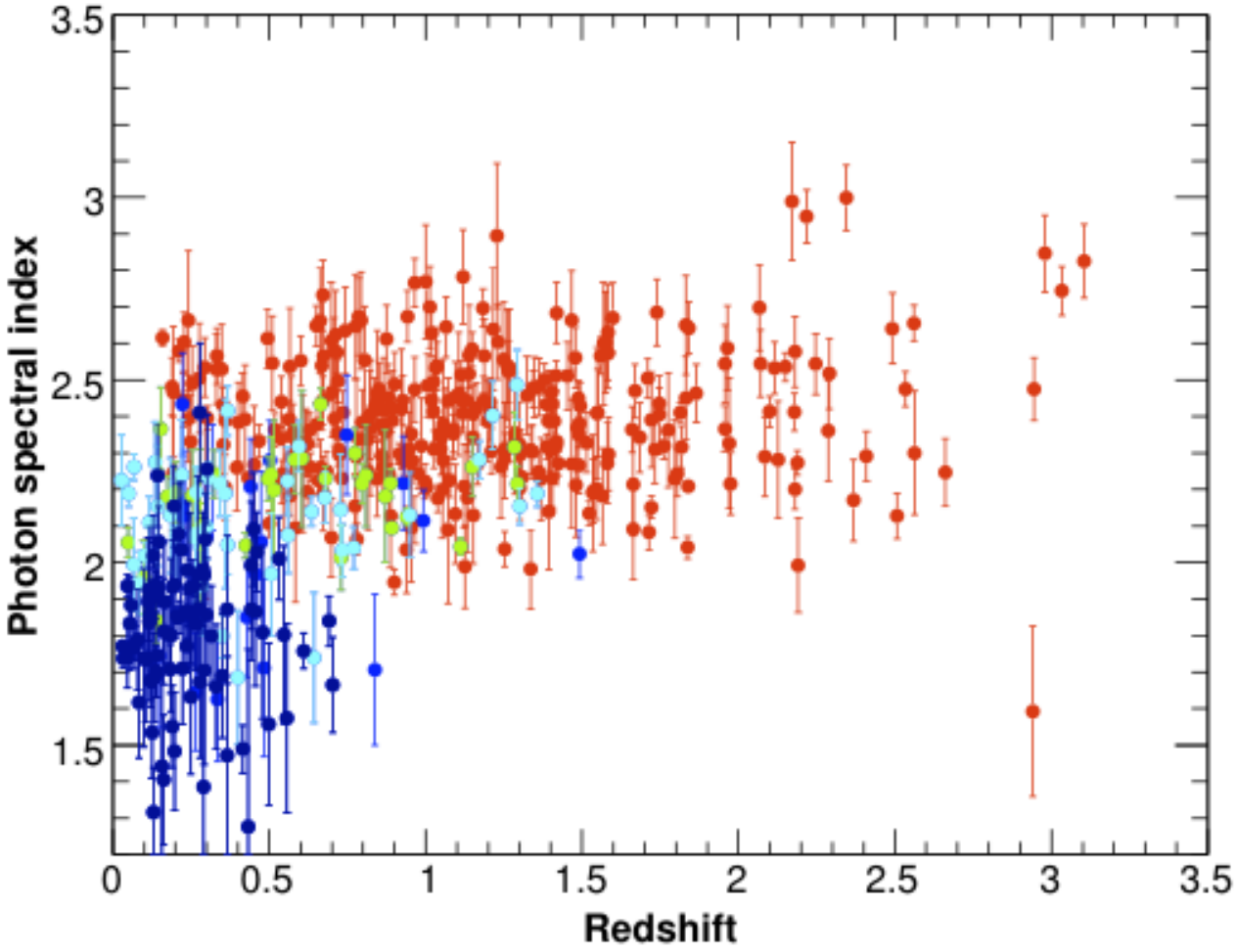
→ *Sources for which Fermi-LAT sees the falling segment of the high-energy SED peak are more variable than sources for which Fermi-LAT sees the rising segment*

Several good candidates for detection with current IACTs were identified. They have variety of natures: SNRs, Binary system, UNIDs and Blazars (with redshift of up to 1)

→ *Gamma-ray (and optical/X-ray) variability can further increase the chances for detection of new blazars at VHE*

backup

Photon index vs redshift for the 2LAC sources with redshift



There is no trend of sources getting softer with increasing redshift