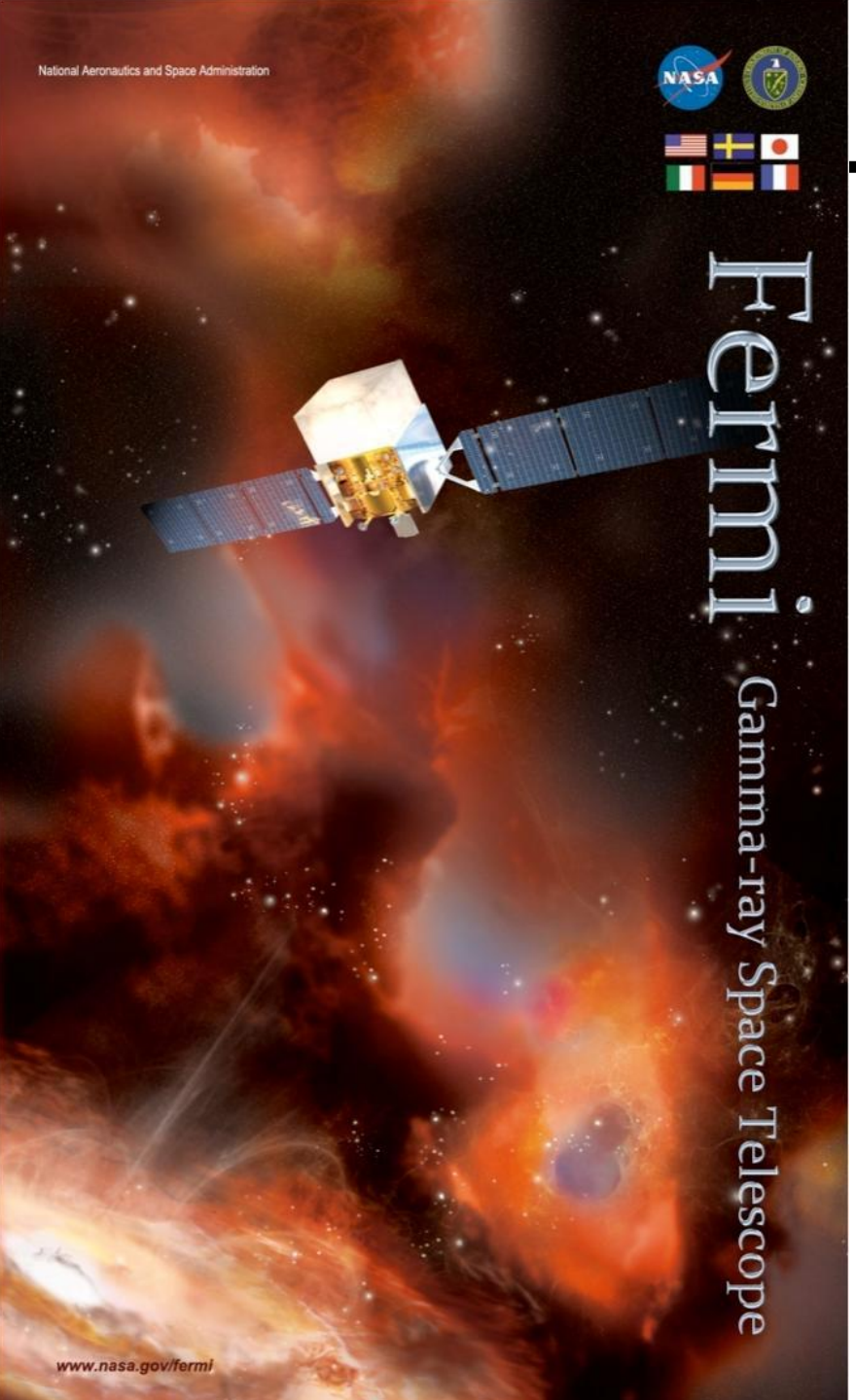


Blazars (and other AGNs) seen by the Fermi-LAT

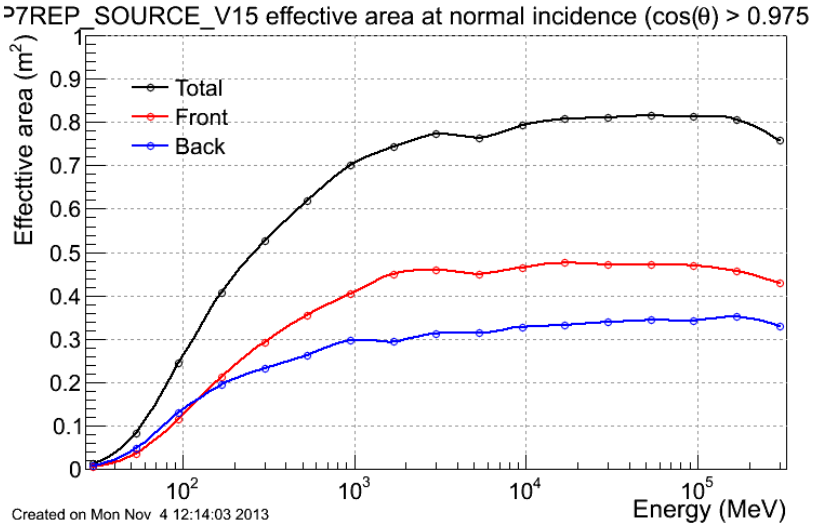
Benoît Lott
CEN Bordeaux-Gradignan
lott@cenbg.in2p3.fr
on behalf of the Fermi-LAT collaboration

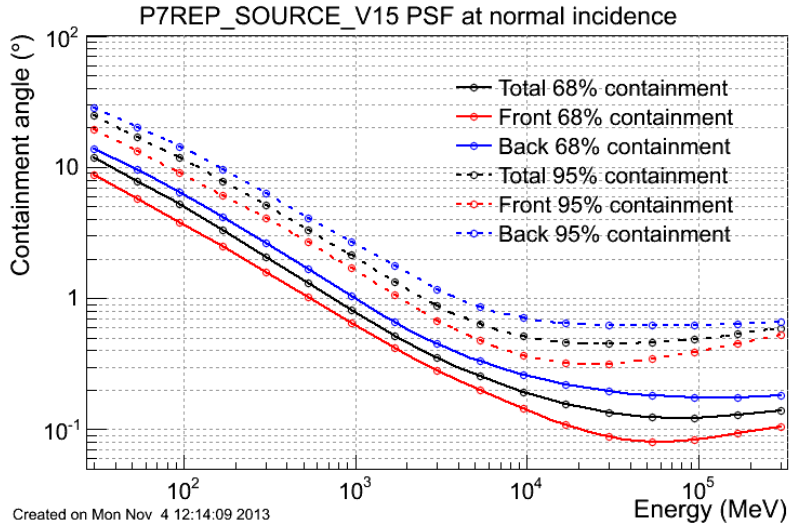
The Fermi-LAT

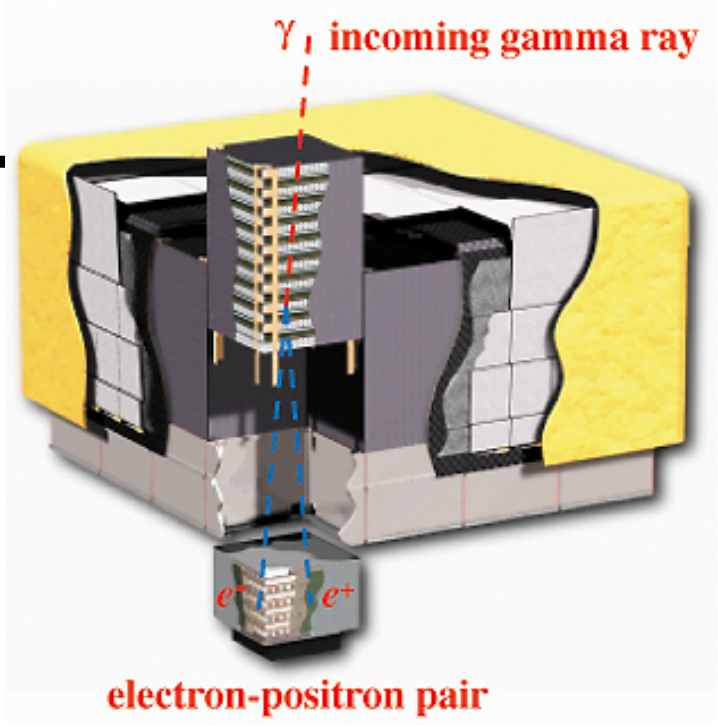
Benoît Lott

LAT performance

http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm





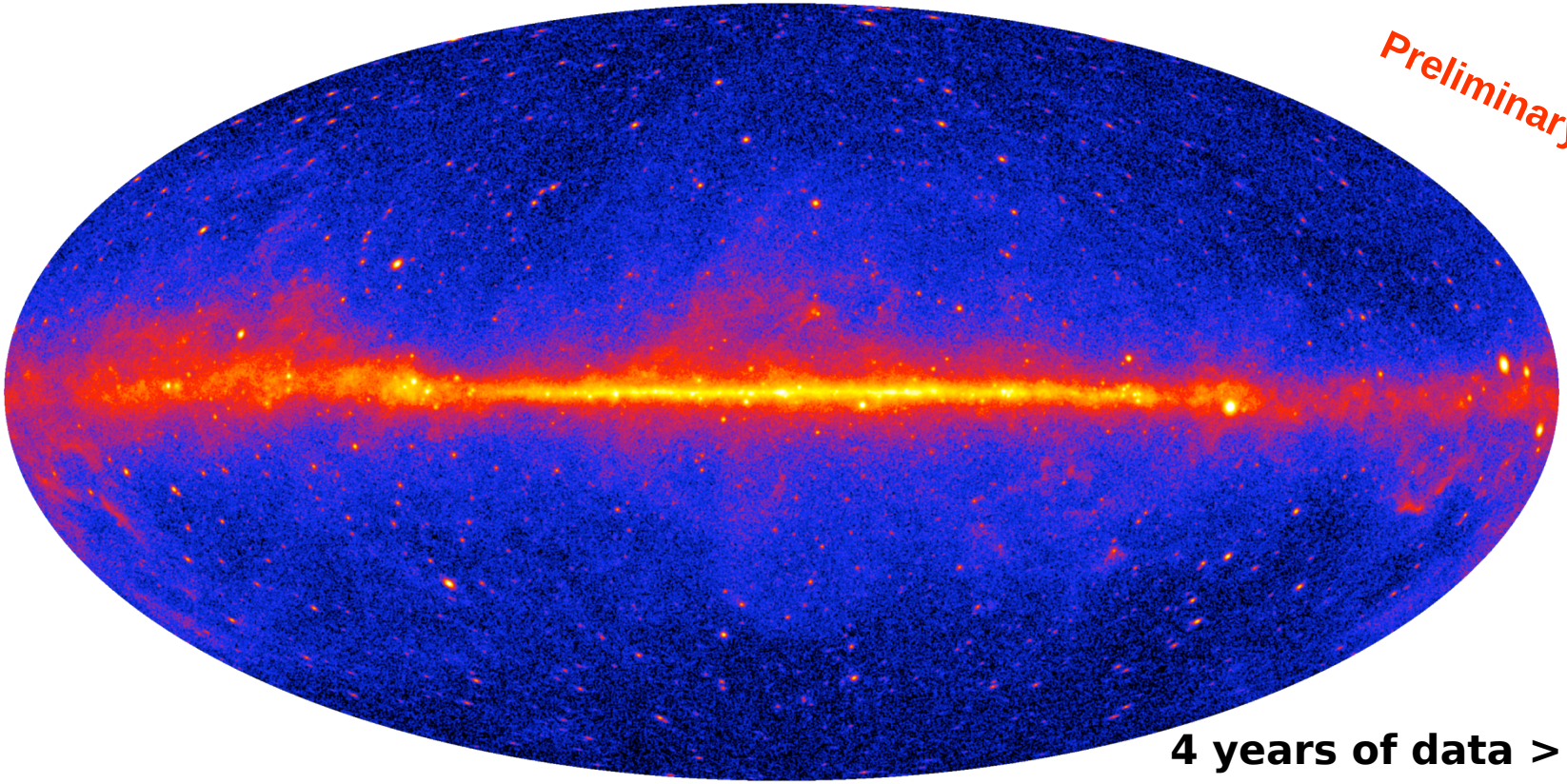


- energy range: 30 MeV - 300 GeV
- large FOV: 2.4 sr
- A_{eff}:~8000 cm^2 at 1 GeV
- PSF: $\theta_{68\%}$~0.8° at 1 GeV
- altitude: 565 km
- inclination: 25.6°
- orbital period: 91 min
- whole sky covered in 2 orbits in survey mode (rocking angle 50°)
- public data, available within 12 h
- operation garanteed until 2018

Gamma-Ray Blazar Populations

Benoît Lott

3FGL (arXiv:1501.02003)



4 years of data > 1 GeV

- **4 years, P7REP_SOURCE_V15, improved PSF**
- **Front/Back handled separately (different isotropic and Earth limb)**
- **Energy range 100 MeV - 300 GeV**

3033 sources, 2192 at |b|>10°

Association-Classification

Preliminary

Two associations methods:

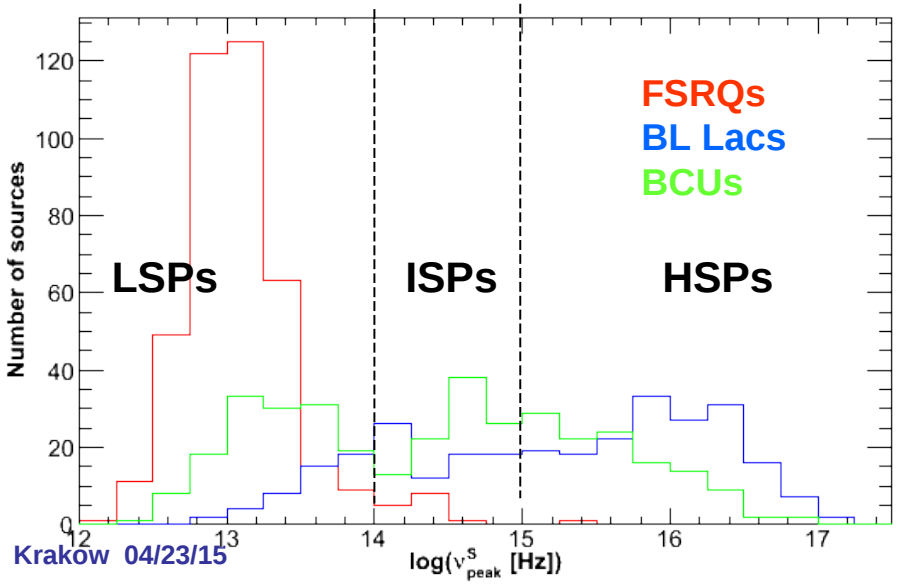
Bayesian method

Likelihood ratio (LR) method

Two classification schemes:

- **Optically-based (stength of broad lines): FSRQs, BL Lacs, BCUs (aka Sources of Unknown Type)**
- **SED-based: Low-, Intermediate-, High-Synchrotron-Peaked sources (LSPs, ISPs, HSPs resp.)**

3LAC: manually-controled SED fit



Catalogs used for association

- Véron-Cetty & Véron
- BZCAT
- VLBA Calibrator list
- CRATES
- CGRaBs
- TeVCat
- ATCA 20-GHz survey
- WISE gamma-ray blazar candidates
- 1WHSP
- NRAO VLA Sky Survey
- Sydney University Mongolo Sky Survey
- ROSAT All Sky Survey Bright and Faint Source Catalogs

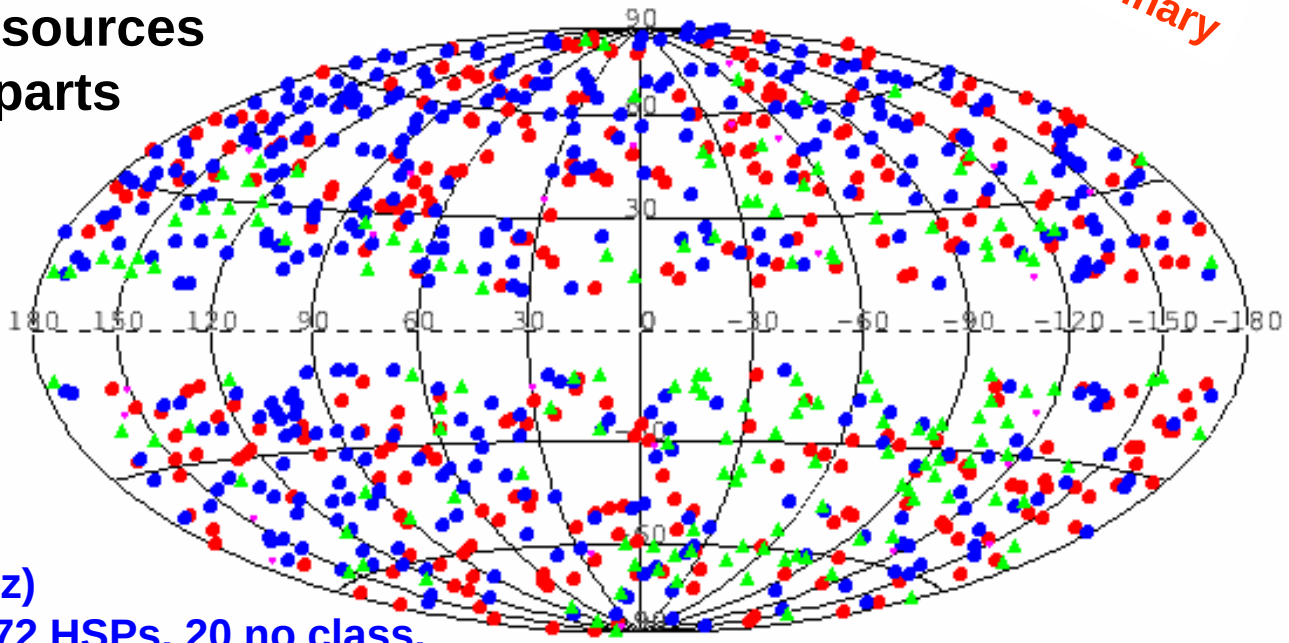
False-positive rate <2%

The Third LAT AGN catalog (3LAC)

Ackermann M. et al., arXiv:1501.06054

Preliminary

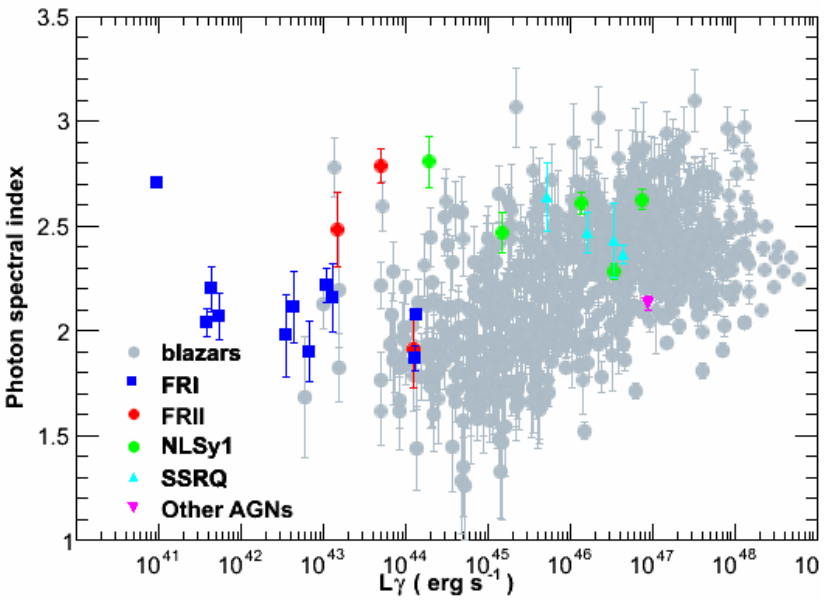
- **48 month data set**
- **2192 TS>25, |b|>10° sources**
- **3LAC: 1591 counterparts**
  1563 sources
- **1444 AGNs in *Clean Sample* (no dup., no flags)**



- **Census :**
  - **415 FSRQs**
  - **602 BLLacs**
    (~50% with measured z)
    162 LSPs, 178 ISPs, 272 HSPs, 20 no class.
  - **413 of unknown type (BCUs)**
  - **23 other AGNs**

- **Differences between Northern and Southern Hemispheres:**
  40% of BL Lacs in Southern Hemisphere

Non-Blazar and Misaligned AGNs



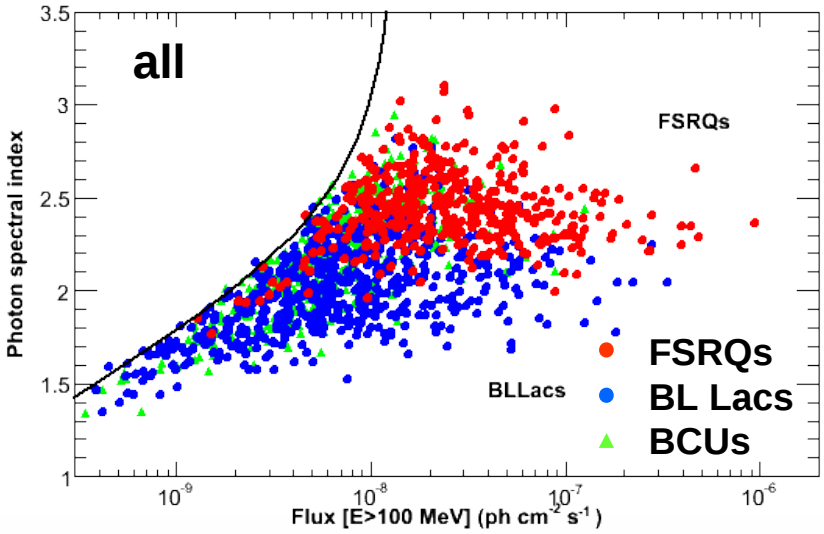
11 FRI
3 FRII | high core dominance
7 SSRQ or CSS
5 Radio-loud NLSyI
6 Other AGNs

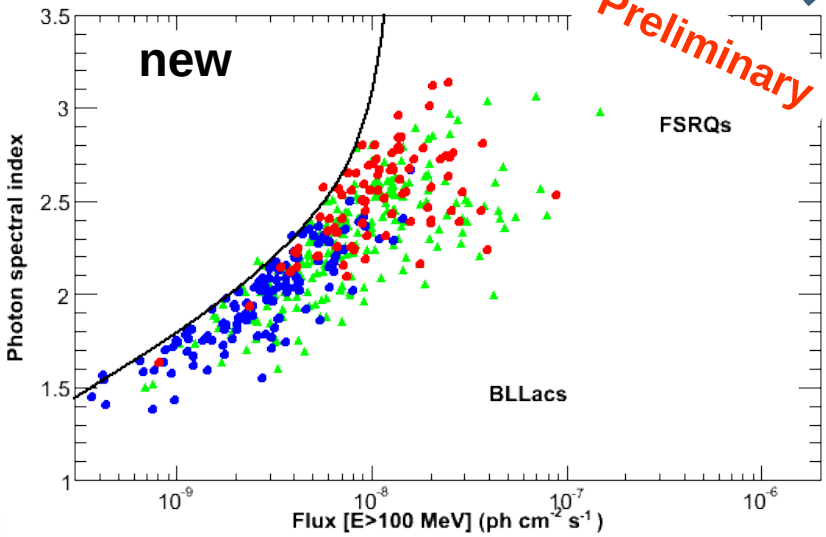
CSS: compact steep spectrum
SSRQ: steep-spectrum radio source

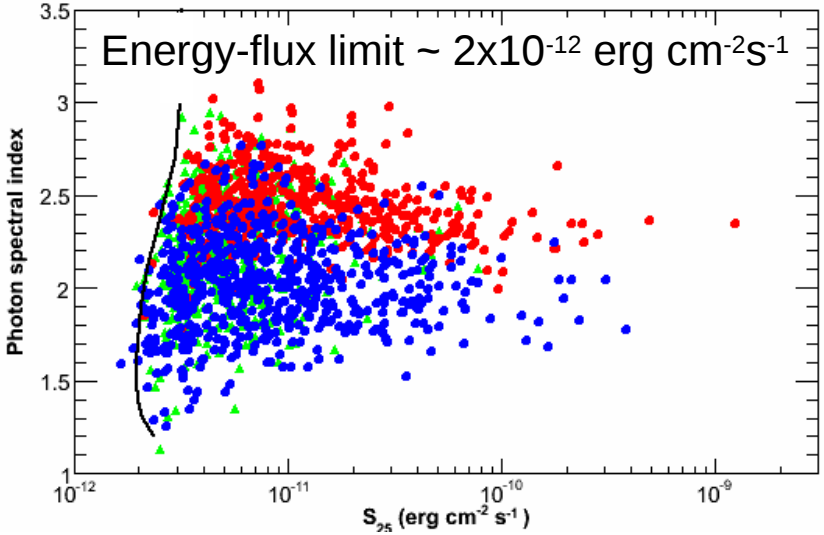
Preliminary

Name	3FGL	2FGL	1FGL		Photon index
NGC 1218	J0308.6+0408*	···	J0308.3+0403*	FRI	
IC 310	J0316.6+4119*	J0316.6+4119	···	FRI/BLL	
NGC 1275	J0319.8+4130*	J0319.8+4130*	J0319.7+4130*	FRI	2.07±
1H 0323+342	J0325.2+3410*	J0324.8+3408*	J0325.0+3403*	NLSy1	2.44±0.12
4C +39.12	J0334.2+3915*	···	···	FRI/BLL?	2.11±0.17
TXS 0348+013	J0351.1+0128*	···	···	SSRQ	2.43±0.18
3C 111	J0418.5+3813	···	J0419.0+3811	FRII	2.79±0.08
Pictor A	J0519.2−4542*	···	···	FRII	2.49±0.18
PKS 0625−35	J0627.0−3529*	J0627.1−3528*	J0627.3−3530*	FRI/BLL	1.87±0.06
4C +52.17	J0733.5+5153	···	···	agn	1.74±0.16
NGC 2484	J0758.7+3747*	···	···	FRI	2.16±0.16
4C +39.23B	J0824.9+3916	···	···	CSS	2.44±0.10
3C 207	J0840.8+1315*	J0840.7+1310	J0840.8+1310	SSRQ	2.47±0.09
SBS 0846+513	J0849.9+5108*	···	···	NLSy1	2.28±0.04
3C 221	J0934.1+3933	···	···	SSRQ	2.28±0.12
PMN J0948+0022	J0948.8+0021*	J0948.8+0020*	J0949.0+0021*	NLSy1	2.32±0.05
PMN J1118-0413	J1118.2-0411*	···	···	agn	2.56±0.08
B2 1126+37	J1129.0+3705	···	···	agn	2.08±0.13
3C 264	J1145.1+1935*	···	···	FRI	1.98±0.20
PKS 1203+04	J1205.4+0412	···	···	SSRQ	2.64±0.16
M 87	J1230.9+1224*	J1230.8+1224*	J1230.8+1223*	FRI	2.04±0.07
3C 275.1	J1244.1+1615	···	···	SSRQ	2.43±0.17
GB 1310+487	J1312.7+4828*	J1312.8+4828*	J1312.4+4827*	agn	2.04±0.03
Cen A Core	J1325.4−4301*	J1325.6−4300	J1325.6−4300	FRI	2.70±0.03
Cen A Lobe	J1324.0−4330e	J1324.0−4330e	J1322.0−4515	FRI	2.53±0.05
3C 286	J1330.5+3023*	···	···	SSRQ/CSS	2.60±0.16
Cen B	J1346.6−6027	J1346.6−6027	···	FRI	2.32±0.01
Circinus	J1413.2−6518	···	···	Seyfert	2.43±0.10
3C 303	J1442.6+5156*	···	···	FRII	1.92±0.18
PKS 1502+036	J1505.1+0326*	J1505.1+0324*	J1505.0+0328*	NLSy1	2.61±0.05
TXS 1613−251	J1617.3−2519	J1617.6−2526c	···	agn	2.59±0.10
PKS 1617−235	J1621.1−2331*	J1620.5−2320c	···	agn	2.50±0.23
NGC 6251	J1630.6+8232*	J1629.4+8236	J1635.4+8228*	FRI	2.22±0.08
3C 380	J1829.6+4844*	J1829.7+4846*	J1829.8+4845*	SSRQ/CSS	2.37±0.04
PKS 2004−447	J2007.8−4429*	J2007.9−4430*	J2007.9−4430*	NLSy1	2.47±0.09

Spectral photon index vs photon/energy flux



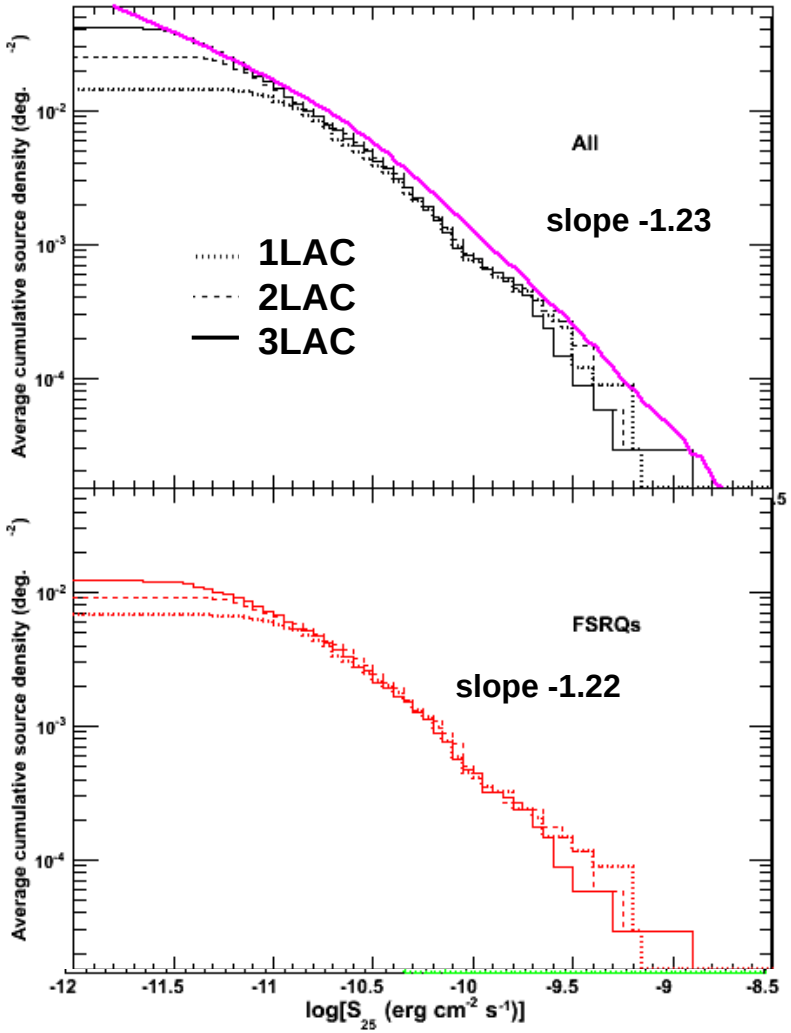


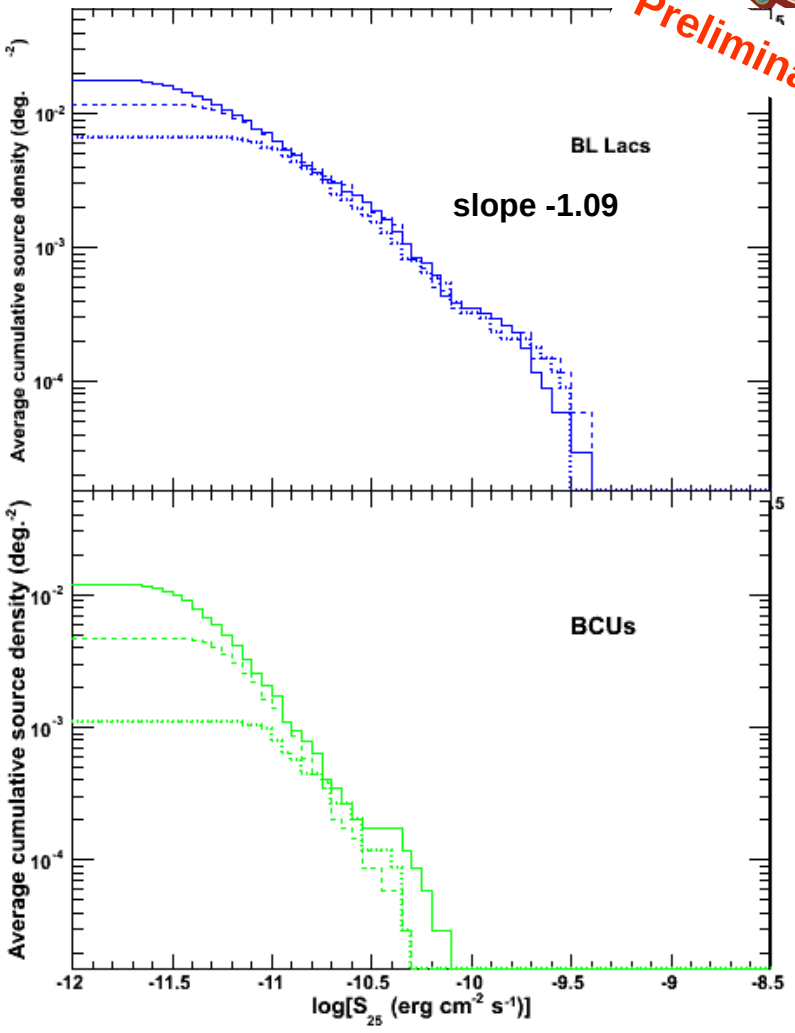


- **Strong bias in photon flux but not in energy flux and thus in luminosity neither**
- **Highest flux in flare: 8x10^{-5} ph cm^{-2}s^{-1} (3C 454.3)**

log N-log S

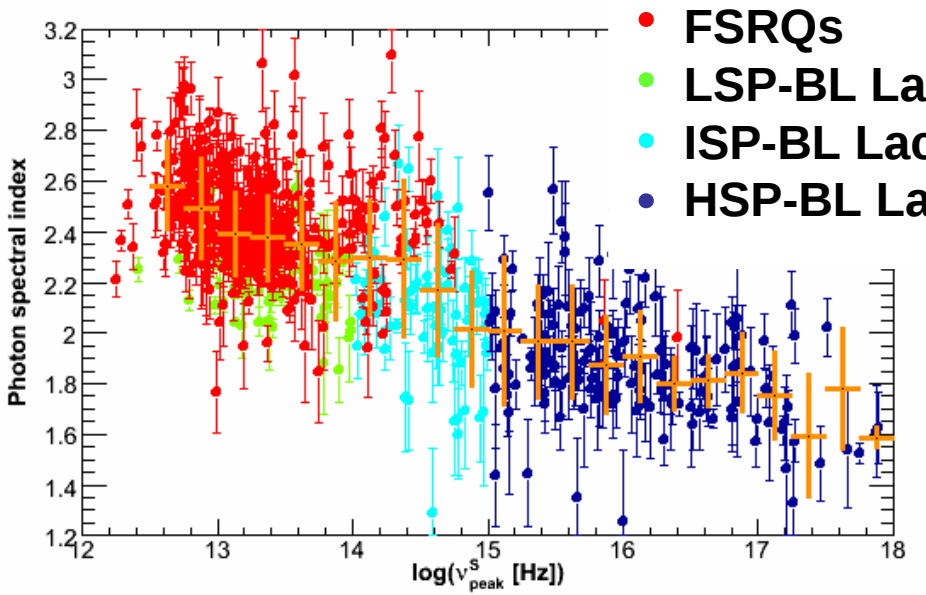
Preliminary



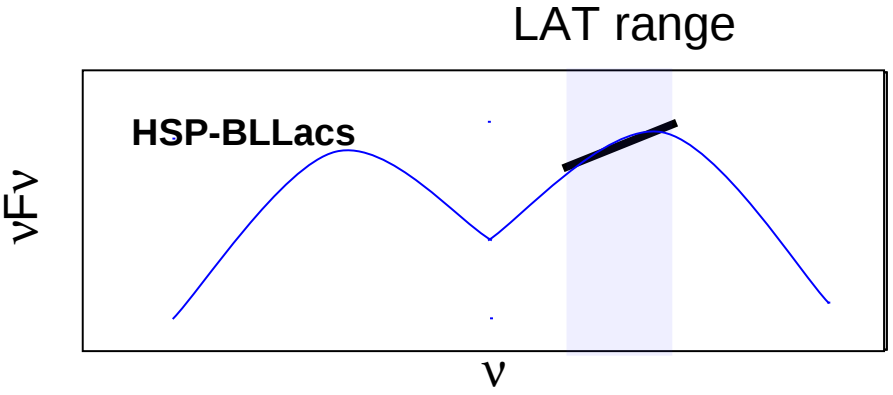


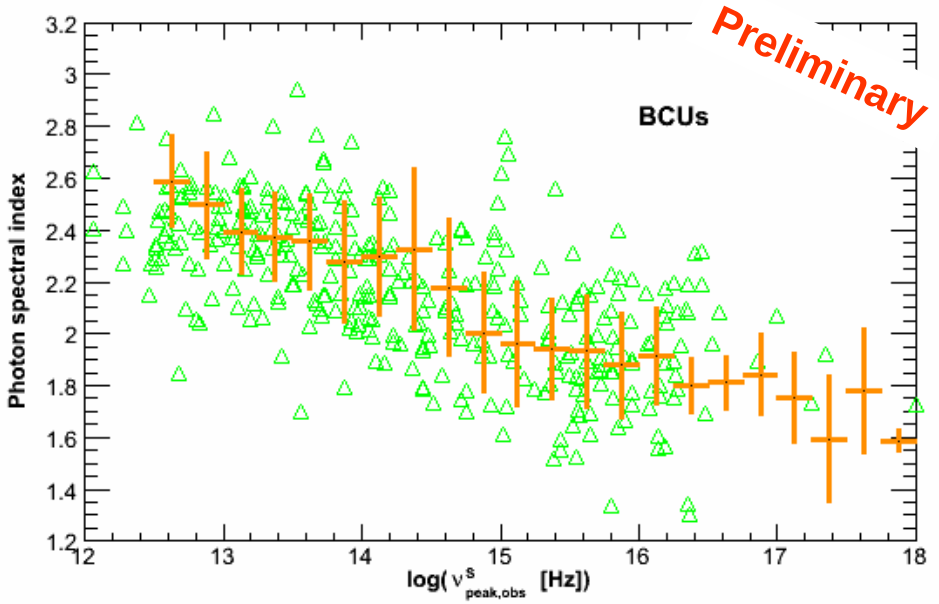
Allows the contribution of blazars to the diffuse gamma-ray background to be estimated

Spectral photon index vs ν_{peak}



- Correlation between spectral hardness and ν_{peak} confirmed
- Lowest index~1.5, as predicted by shock-acceleraton models
- Same correlation applies to BCUs



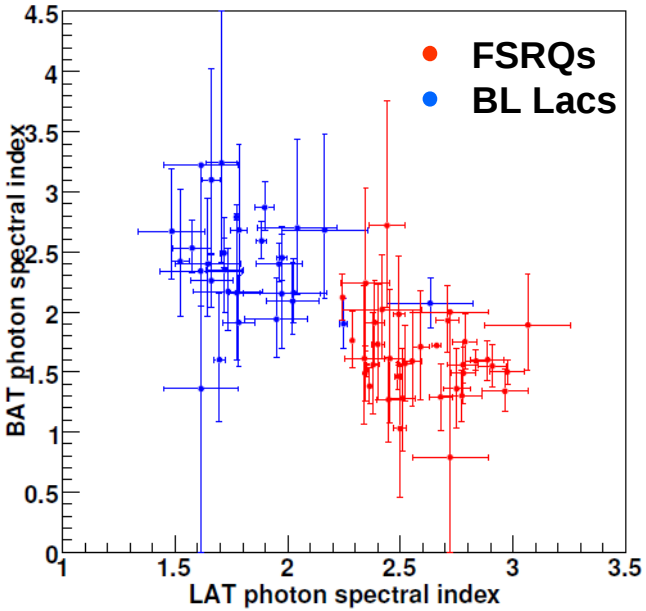


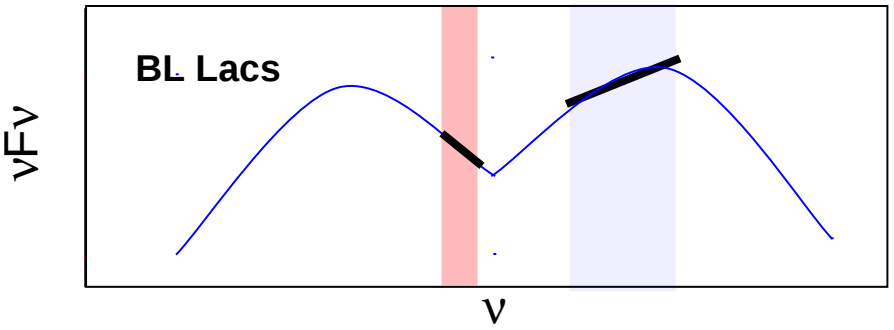
Synergy with neighboring bands

Preliminary

- 85 3LAC sources in the Swift BAT 70-month survey

only 9 BAT FSRQs and 7 BL Lacs missing in 3LAC





- 55 out of 56 TeV AGNs in 3LAC

28 found to be variable

- 96 3LAC AGNs in the V38 INTEGRAL Cat.

Table 10. Properties of the VHE AGN detected by the *Fermi* LAT.

VHE Name	3FGL Name	Source Class	SED Type	Redshift	Spectrum Type[a]	1FGL/1FHL[b]
SHBL J001355.9−185406	J0013.9−1853	BL Lac	HSP	0.095	PL	···
KUV 00311-1938	J0033.6-1921	BL Lac	HSP	>0.51	PL	H
RGB J0136+391	J0136.5+3905	BL Lac	HSP	···	PL	H
RGB J0152+017	J0152.6+0148	BL Lac	HSP	0.08	PL	Y
3C 66A	J0222.6+4301	BL Lac	ISP	$0.3347 < z < 0.41$	LP	Y
1ES 0229+200	J0232.8+2016	BL Lac	HSP	0.139	PL	···
PKS 0301-243	J0303.4-2407	BL Lac	HSP	0.26	PL	H
IC 310	J0316.6+4119	Radio Gal	HSP	0.018849	PL	Y
RBS 0413*	J0319.8+1847	BL Lac	HSP	0.19	PL	Y
NGC 1275*	J0319.8+4130	Radio Gal	ISP	0.018	LP	Y
1ES0347−121	J0349.2−1158	BL Lac	HSP	0.188 (?)	PL	···
1ES 0414+009	J0416.8+0104	BL Lac	HSP	0.287	PL	Y
PKS 0447−439	J0449.4−4350	BL Lac	HSP	0.205	PL	Y
1ES 0502+675*	J0508.0+6736	BL Lac	HSP	0.341	PL	Y
PKS 0548-322	J0550.6−3217	BL Lac	HSP	0.069	PL	H
1ES 0647+250	J0650.7+2503	BL Lac	HSP	···	PL	H
RGB J0710+591 (1H 0658+595?)	J0710.3+5908	BL Lac	HSP	0.125	PL	Y
S5 0716+714	J0721.9+7120	BL Lac	ISP	$0.2314 < z < 0.27$	LP	Y
1ES 0806+524	J0809.8+5218	BL Lac	HSP	0.138	PL	Y
RX J0847.1+1133 (RBS 0723)	J0847.1+1134	BL Lac	HSP	0.199	PL	···
1RXS J101015.9-311909	J1010.2-3120	BL Lac	HSP	0.143	PL	H
1ES 1011+496	J1015.0+4925	BL Lac	HSP	0.212	PL	Y
1ES 1101−232	J1103.5−2329	BL Lac	HSP	0.186	PL	Y
Markarian 421	J1104.4+3812	BL Lac	HSP	0.031	PL	Y
Markarian 180	J1136.6+7009	BL Lac	HSP	0.046	PL	Y
1ES 1215+303	J1217.8+3007	BL Lac	HSP	···	PL	Y
1ES 1218+304	J1221.3+3010	BL Lac	HSP	0.182	PL	Y

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Redshifts

Preliminary

- slightly higher z for new FSRQs relative to 2LAC ones
<z>=1.33 vs. 1.17

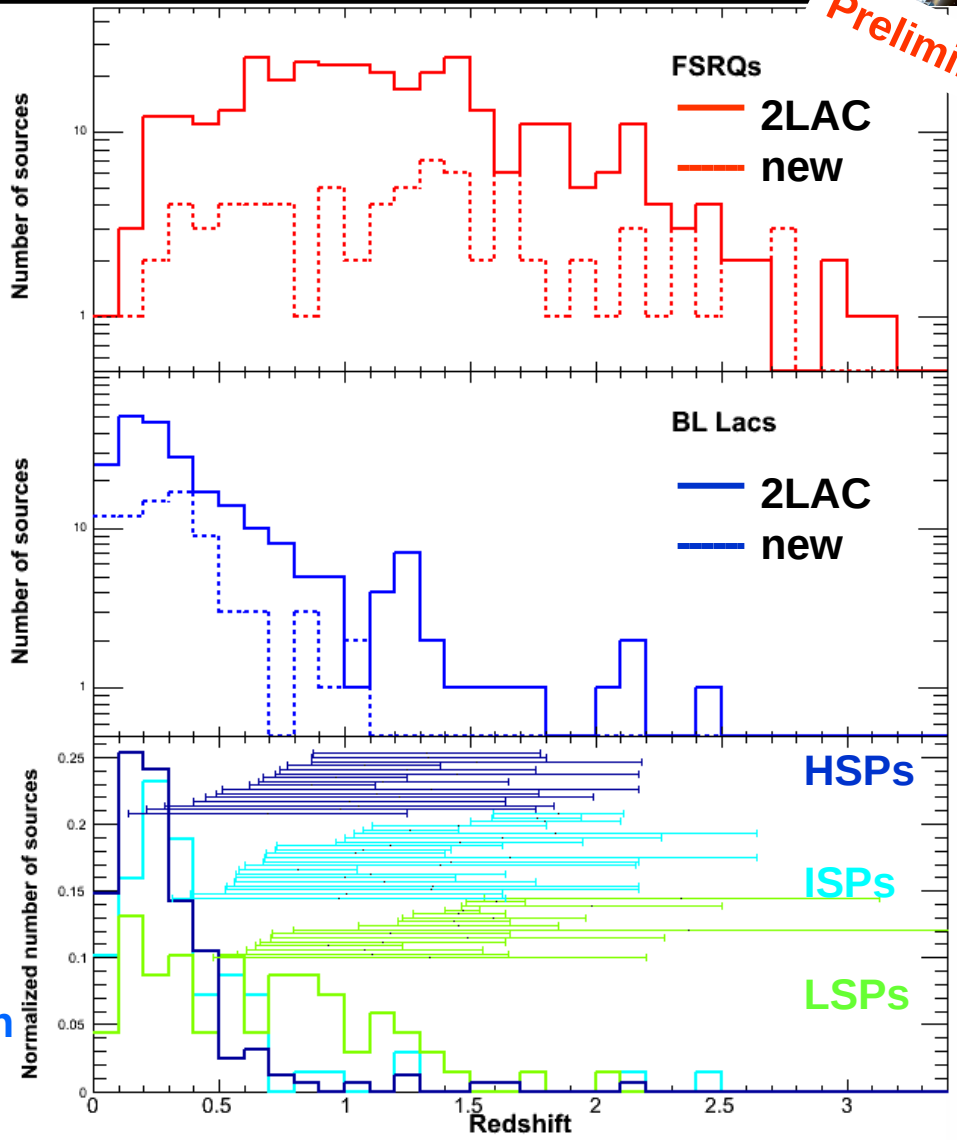
- maximum redshift still z=3.1

- 295/604 BL Lacs have no measured redshifts (55%, 61%, 40%) for (LSPs, ISPs and HSPs)

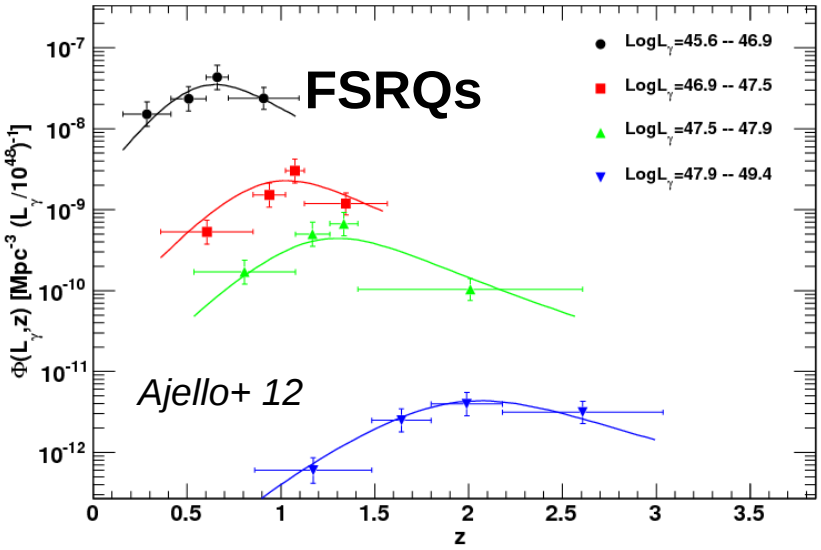
- 134 constraints from Shaw et al. (2013)

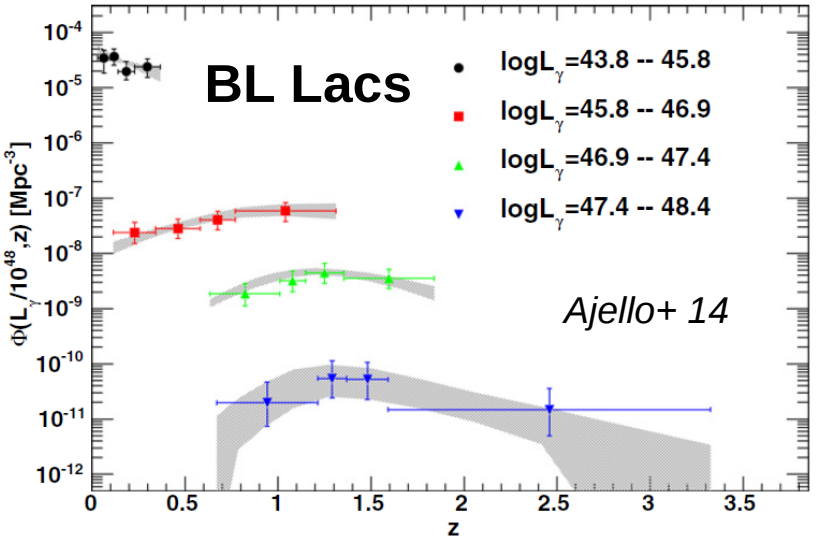
- Redshift limits for BL Lacs not compatible with measured redshifts: measured redshifts are biased low.

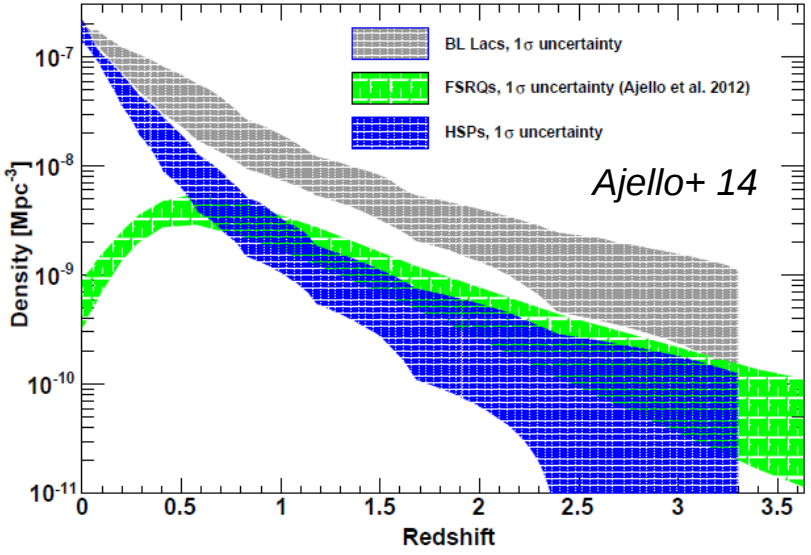
Are many BL Lacs FSRQs with emission lines swamped by the non-thermal continuum?



Blazar luminosity functions



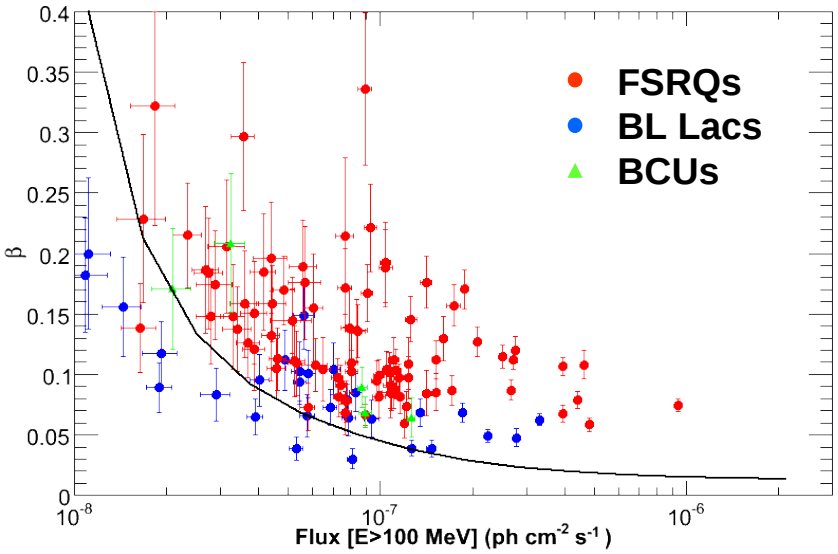




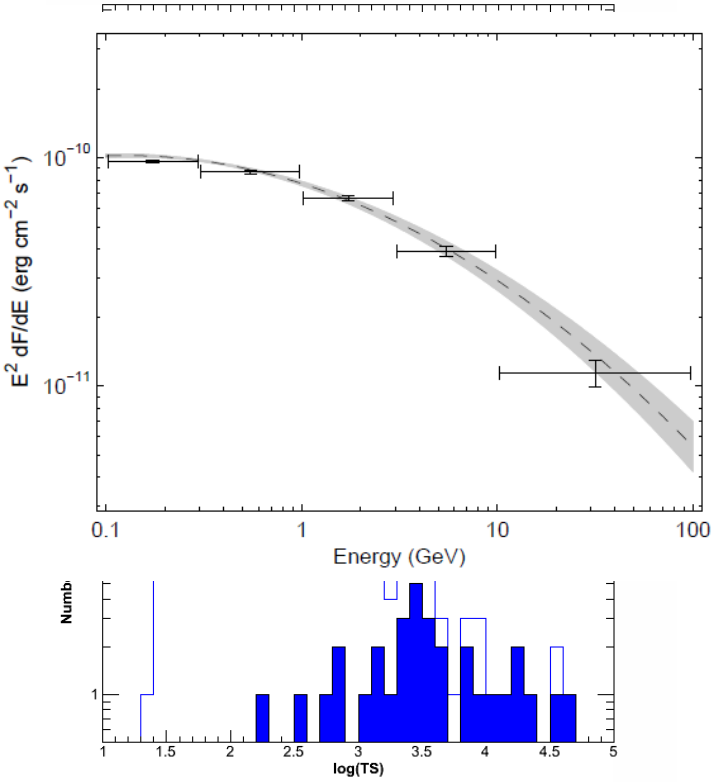
- **Rise in HSP-BL Lac density corresponds to a drop-off in FSRQ density**
- **Evolution of FSRQS into HSPs due to starvation of accreting mattter?**

Spectral curvature

Preliminary



$$N(E) = N_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta\log(\frac{E}{E_0})}$$



Feature first seen in 3C 454.3
91 FSRQs, 32 BL Lacs, 8 BCUs show significant spectral curvature

Abdo +09, Poutanen & Stern 10, 14, Cerruti+13, Dermer+14, Finke & Dermer 13, Hunger & Reimer 15 Kohler & Nalewajko 15

- **γγ-absorption**
- **superposition of different EC components**
- **superposition of different flares**
- **intrinsic curvature of electron energy distribution**

Variability

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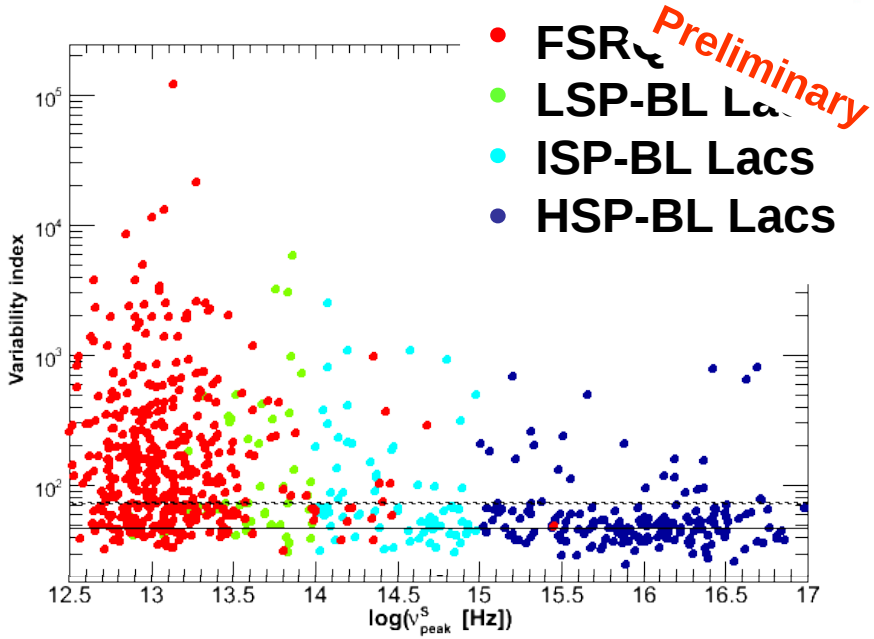
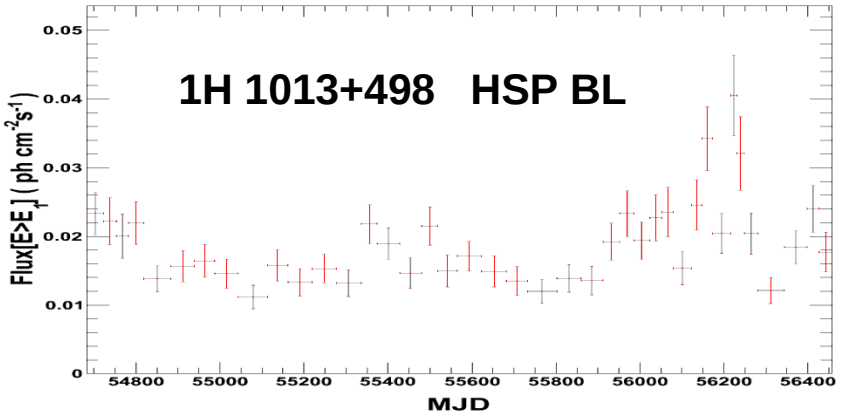
Variability

- Variability index distributed as a χ^2 with 47 d.o.f. for non-variable sources.
- Fractions of sources showing significant variability
  FSRQs: 69% BL Lacs: 23%
  (39%, 23%, 15%) for (LSP, ISP,HSP)
- The LAT samples different parts of the high-energy hump for the different classes.
- Monthly light curves to be extended beyond 48 months, continuously updated and posted on the ASDC site





PG 1553+113

HSP BL Lac

0.395 < z < 0.62

one of the brightest BL Lacs in the X-ray band

TeV source (HESS, MAGIC)

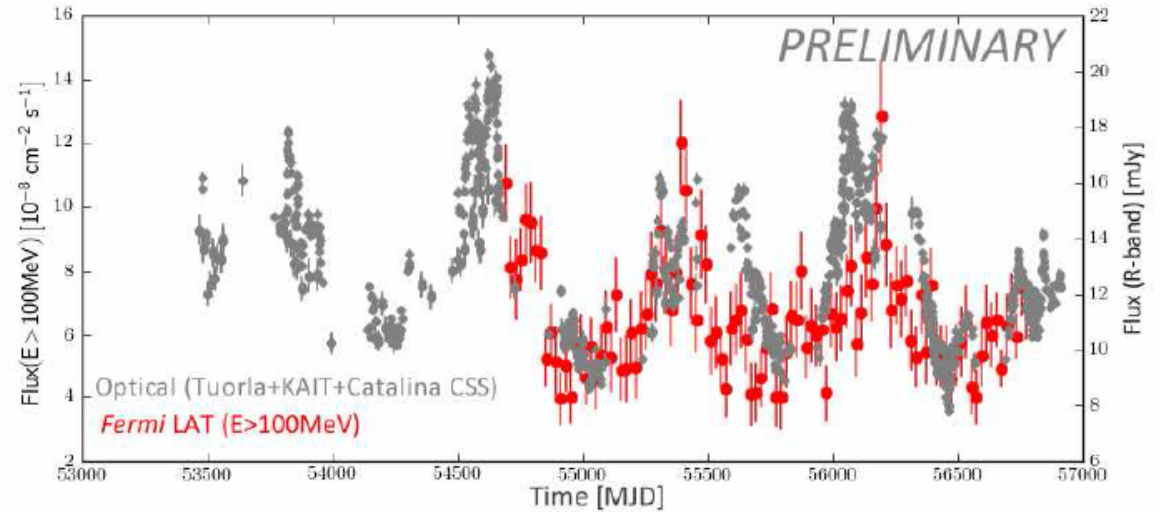
Indication for a periodic behavior in

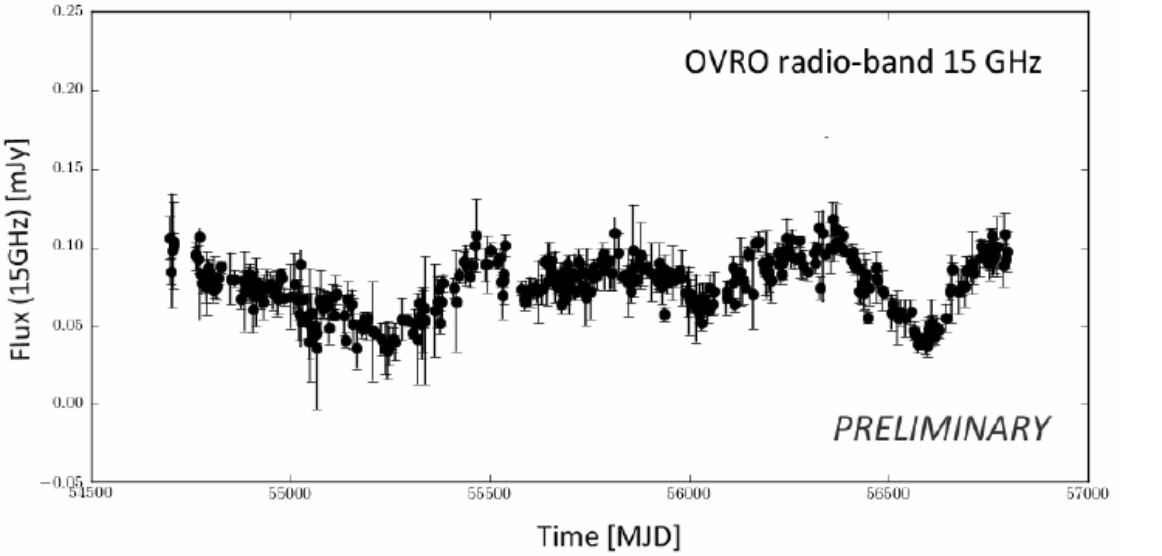
- **the radio (15 GHz)**
- **the optical (R-band)**
- **the LAT band**

Autocorrelation gives a peak at 750 days

Interpretation:

- **binary black hole?**
- **warped disk?**
- **other?**





Shortest timescales

Preliminary

Constraints on size and location of emitting zone

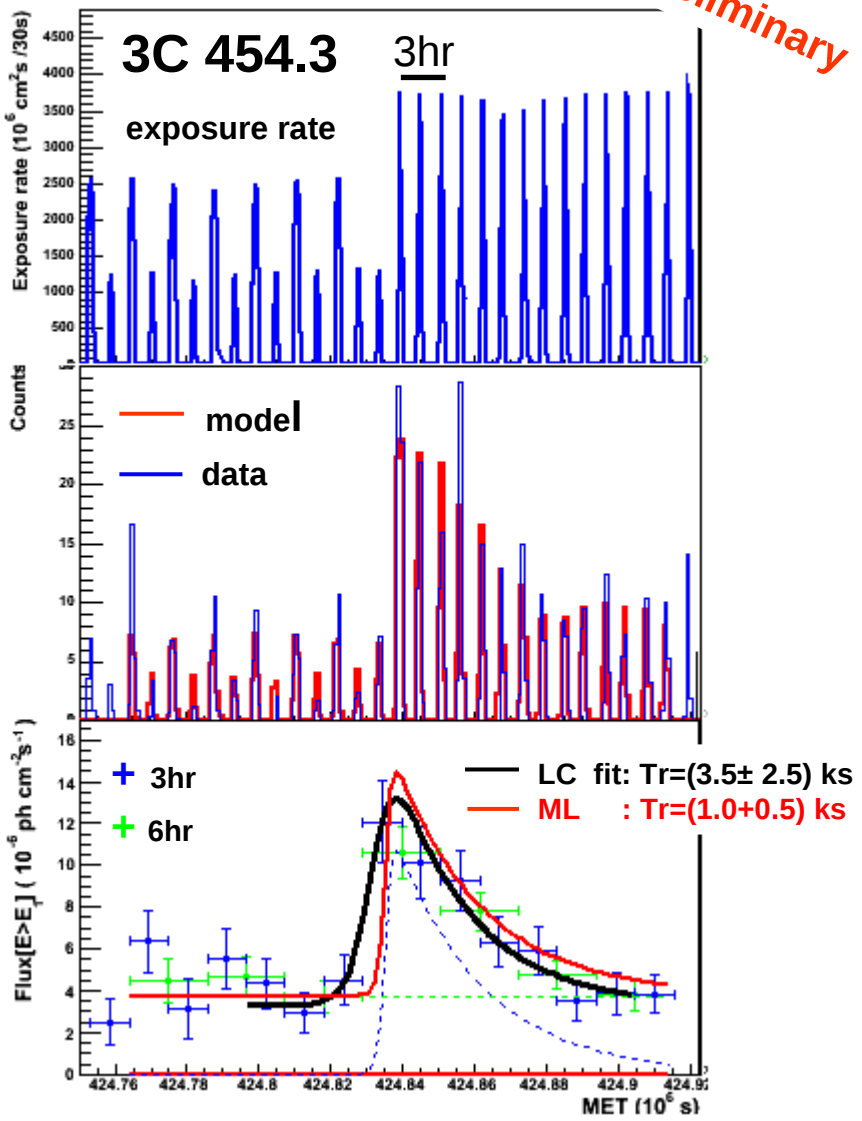
4 sources show T_{min} close to 3 hr:
3C 454.3, 3C 273, 4C+21.35, PKS 1510-089
$R_S/c \sim 10^4 M_9$ s

Binned light curves unsuitable to derive T_{min} accurately

Unbinned maximum-likelihood method

$$F = 2F_0(e^{(t_0-t)/T_r} + e^{(t-t_0)/T_f})^{-1}$$

Sub-hour variability (<20 min) is found for 3C454.3 and PKS 1510-089



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Preliminary

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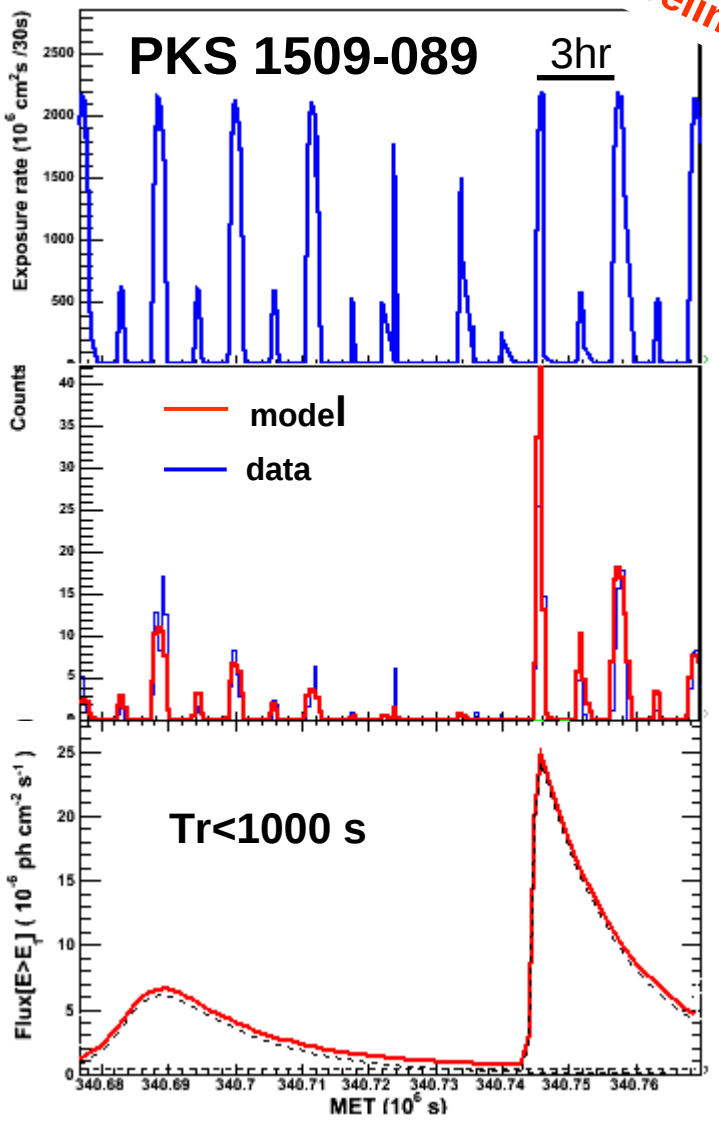
Sub-hour variability (<20 min) is found for 3C454.3 and PKS 1510-089

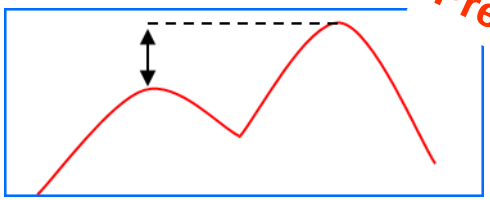


Correlations between Luminosity and Spectral Features

Benoît Lott

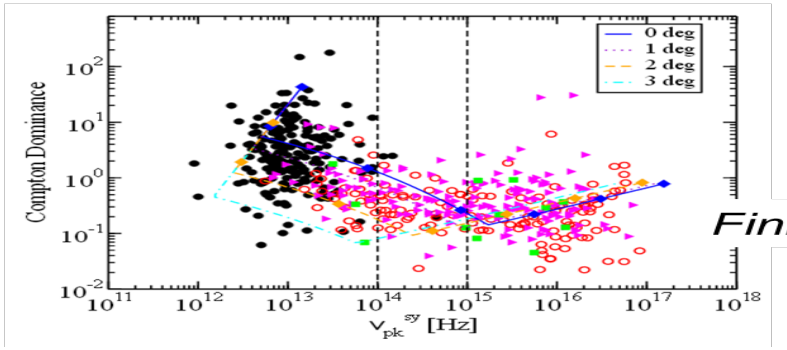
Compton dominance vs ν_{peak}

Preliminary



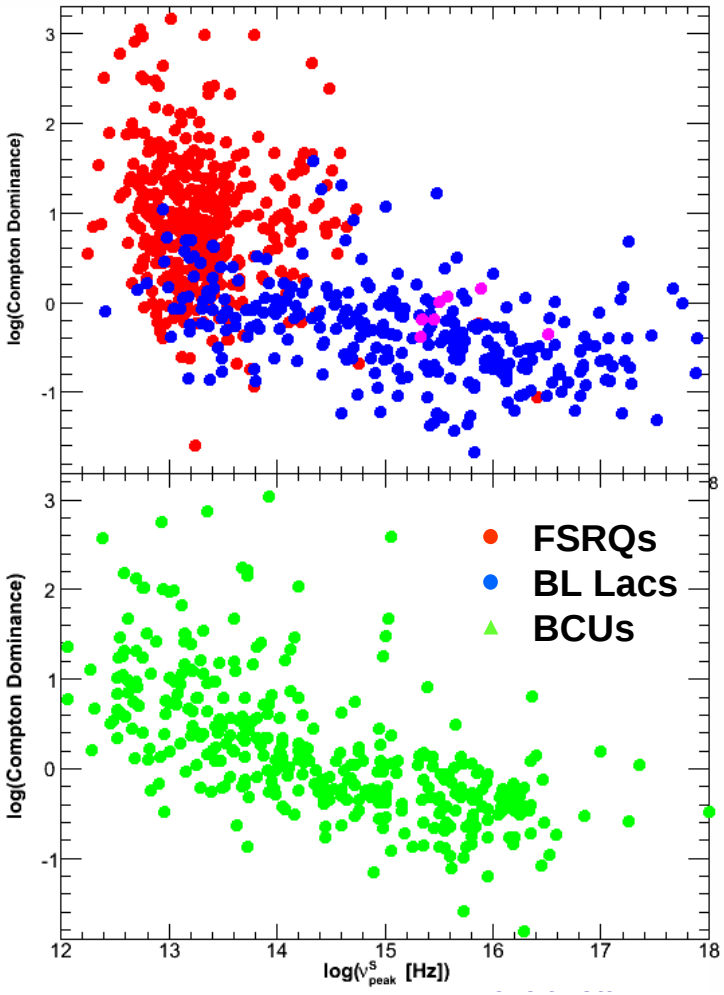
beyond the blazar sequence

Compton dominance independent of z



Finke 12

varying u_{ext}, B, beaming



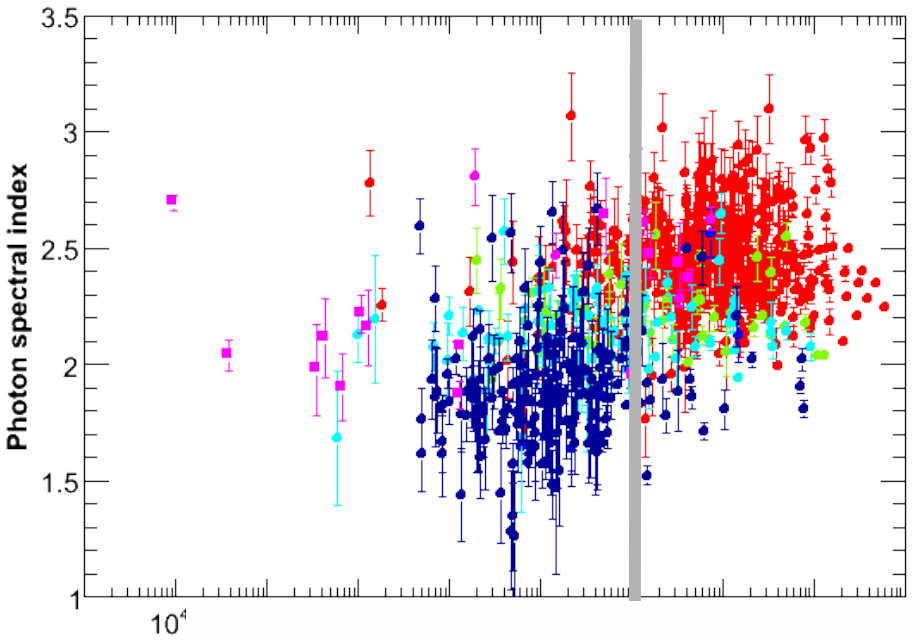
Spectral index- Lγ

Preliminary

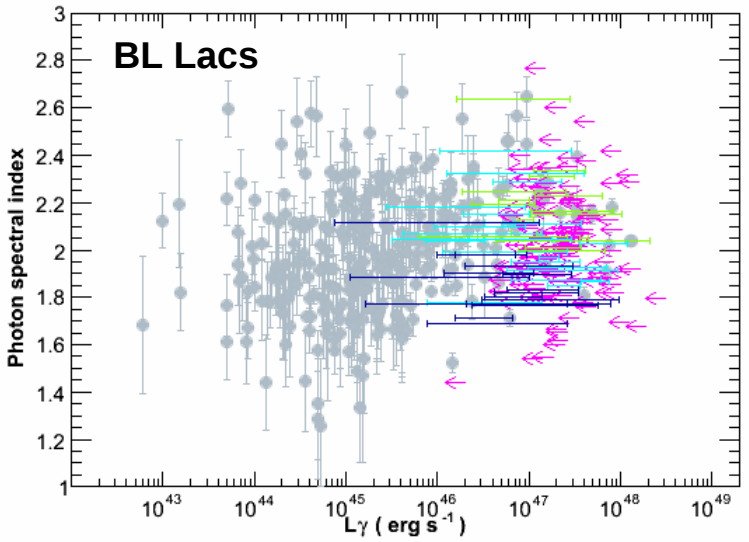
Led to the concept of « blazar divide » (Ghisellini + 09)

Soft spectra at high Lγ
Hard spectra at low Lγ

Change of accretion regime at 10^{46} erg s^{-1}



- FSRQs
- LSP-BL Lacs
- ISP-BL Lacs
- HSP-BL
- Lacs
- Other AGNs



Spectral photon index- ν_{peak} diagram

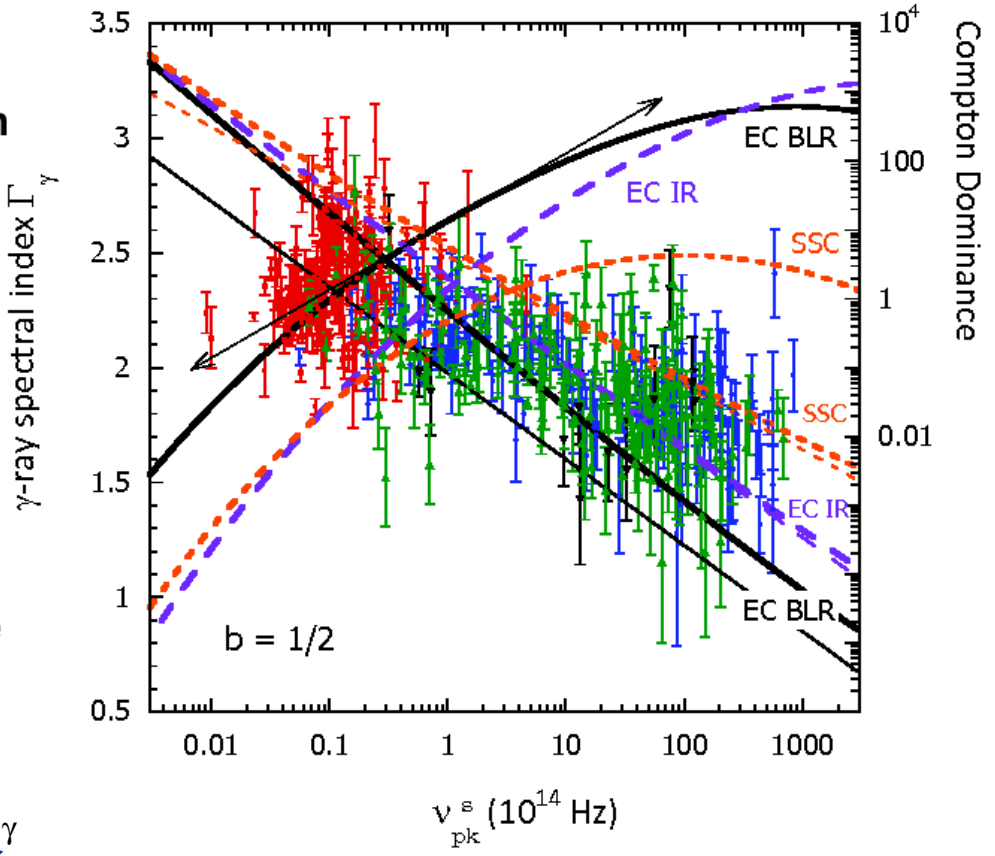
arXiv:1504.03228
C. Dermer et al.

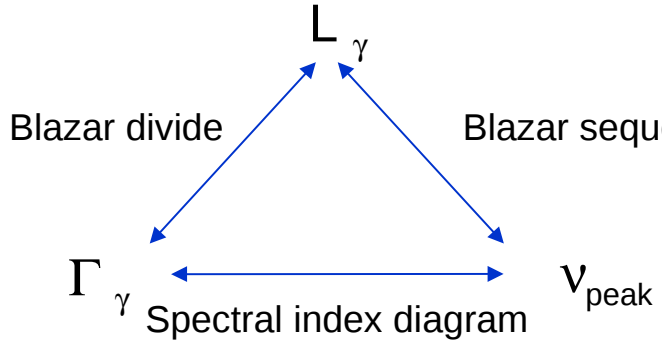
- **Log-parabola electron energy distribution in a near-equipartition model**

$$\gamma^{-2}N(\gamma) = K\left(\frac{\gamma}{\gamma_{peak}}\right)^{-b\,log\left(\frac{\gamma}{\gamma_{peak}}\right)}$$

SSC, EC IR (torus), EC BLR

- **good reproduction of data with b=1/2**
- **Compton Dominance becomes excessive for EC IR, BLR at large ν^{s}_{peak}**



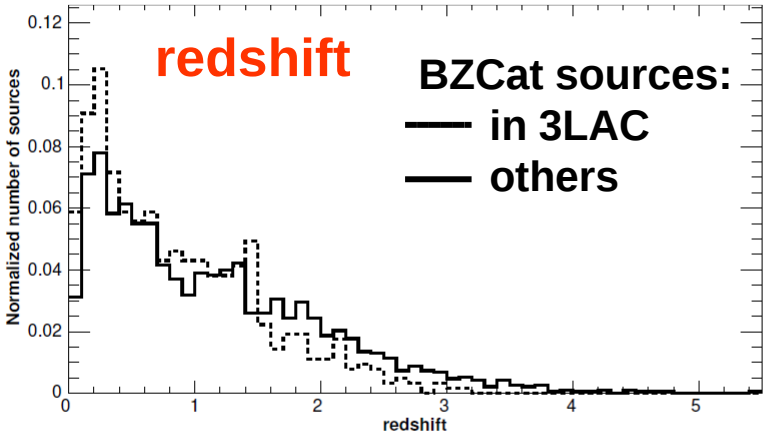


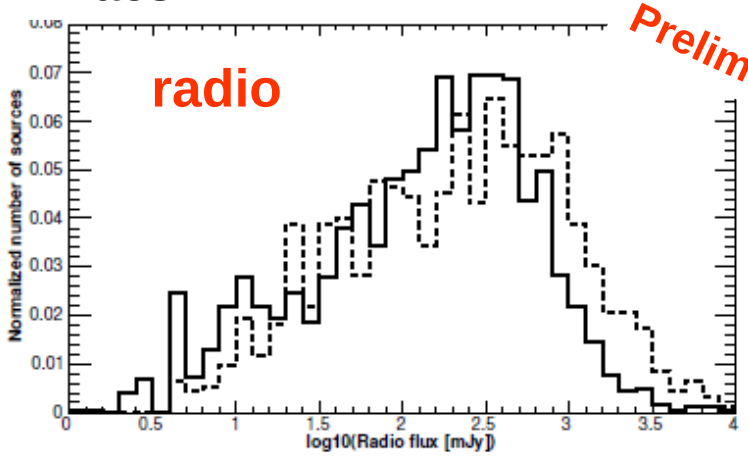
Gamma-ray loud vs. gamma-ray quiet blazars

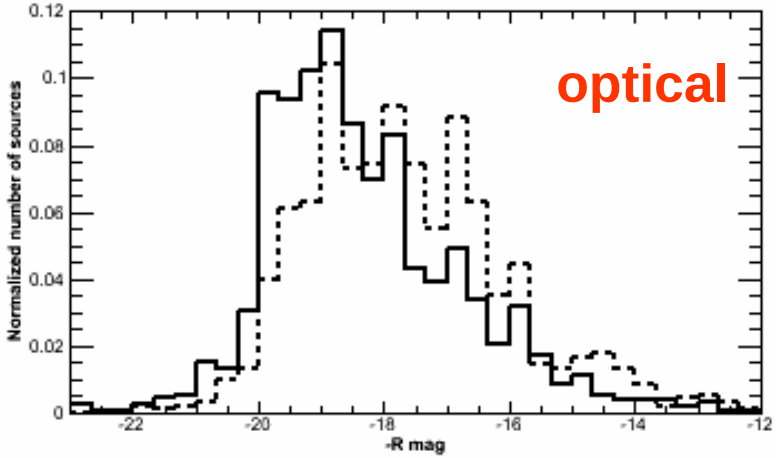
Benoît Lott

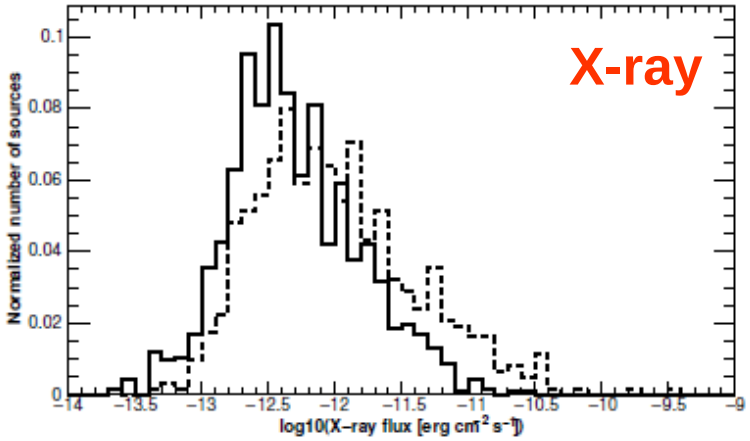
Connection between 3LAC and BZCat

LAT-detected fraction: 24% (409/1707) for FSRQs
44% (543/1221) for BL Lacs



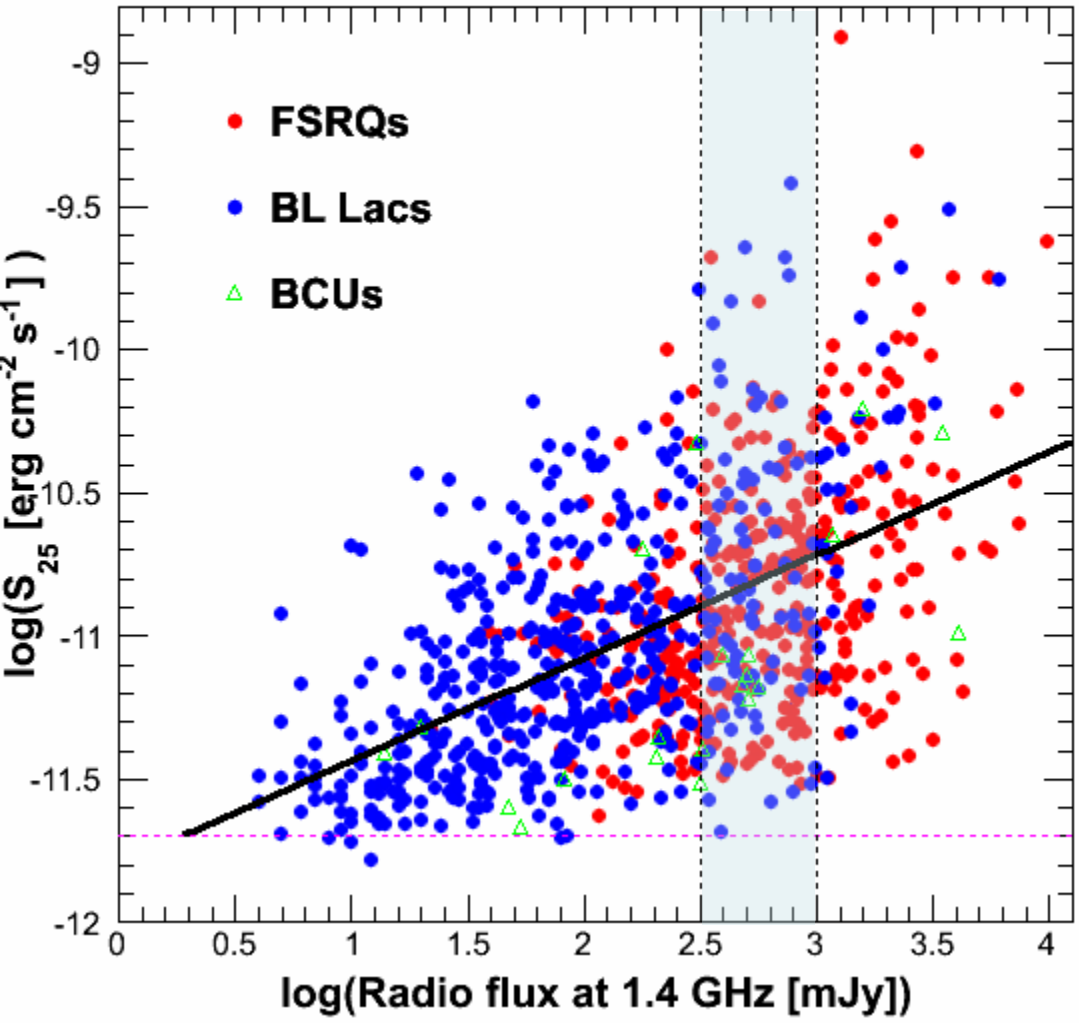




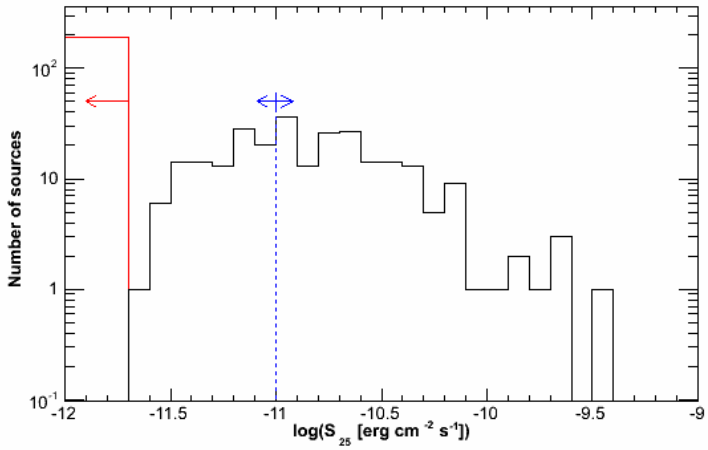


- gamma-ray sources slightly brighter than average in other bands,
- large overlap in distributions between gamma-ray loud and quiet blazars

Radio-gamma-ray connection



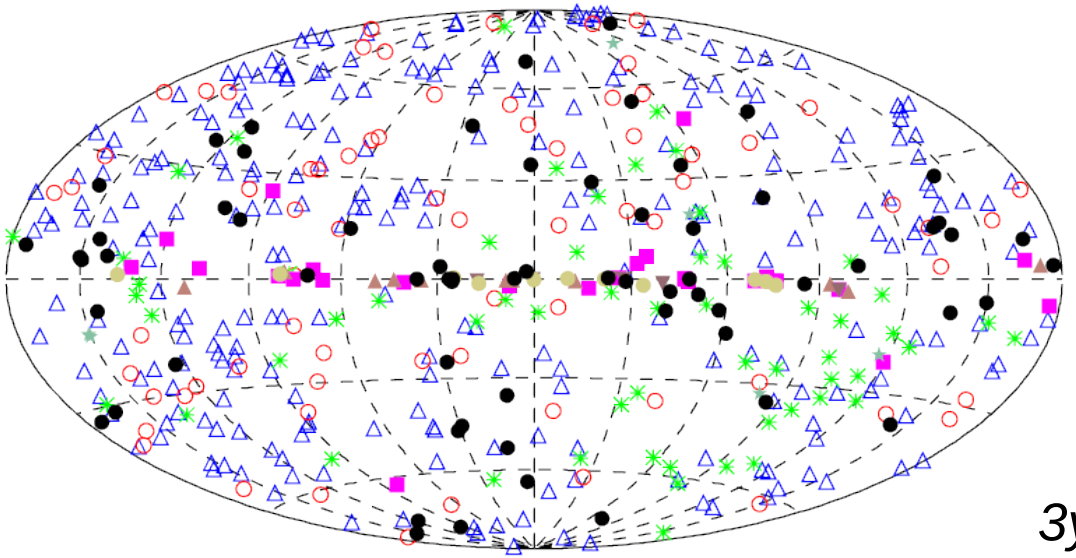
Pearson coefficient: 0.52



High-energy blazars

Benoît Lott

1FHL (E>10 GeV) 2013 ApJS 209,34

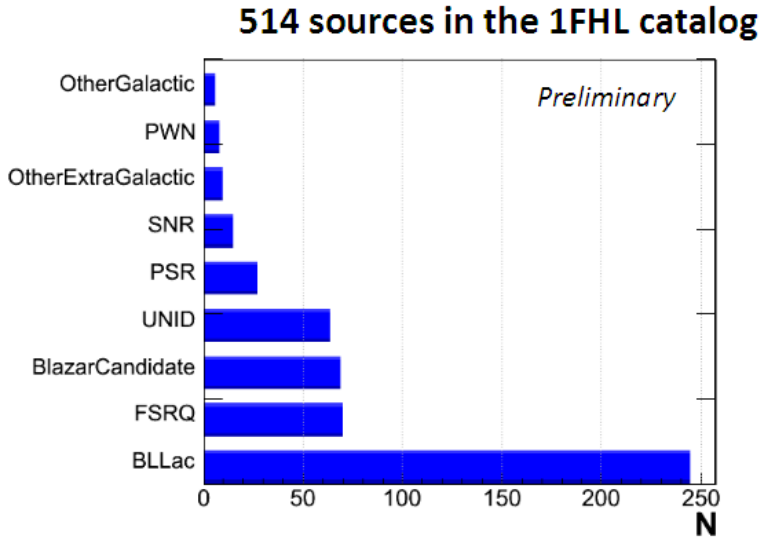


3y of data

△ BL Lac	○ FSRQ	✳ AGN of unknown type
■ PSR	▲ SNR	▼ PWN
● Other Galactic object	★ Other (non-beamed) Extragalactic object	● No association

75% of sources are blazars

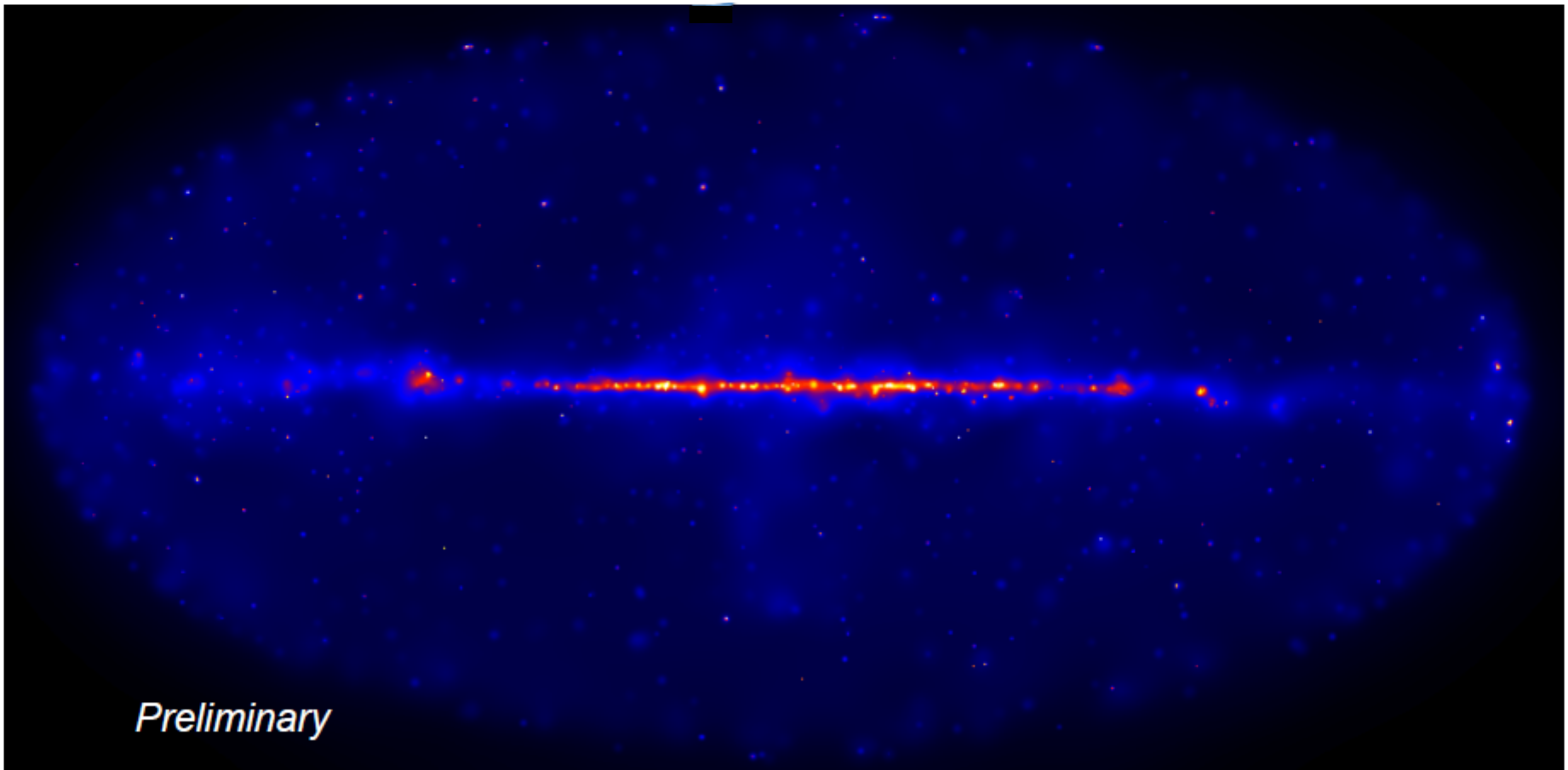
262 BL Lacs
59 FSRQs
58 BCUs
5 Radio Galaxies



Second Fermi Hard-Source List (2FHL)

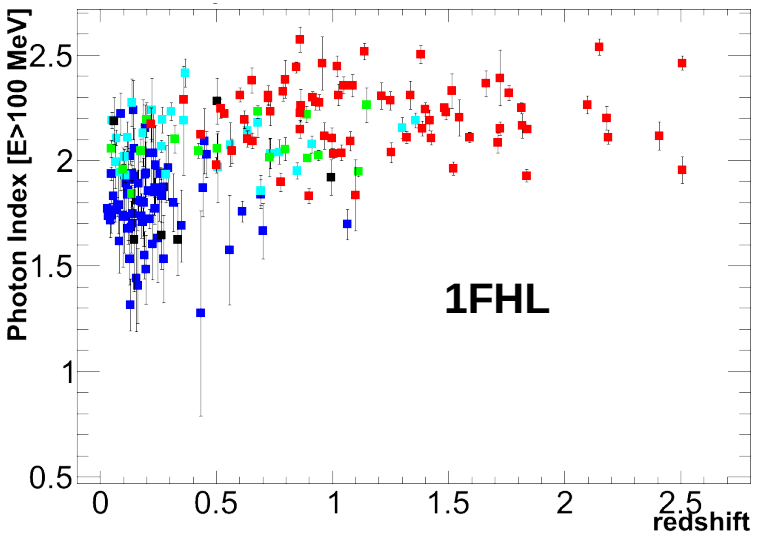
Preliminary

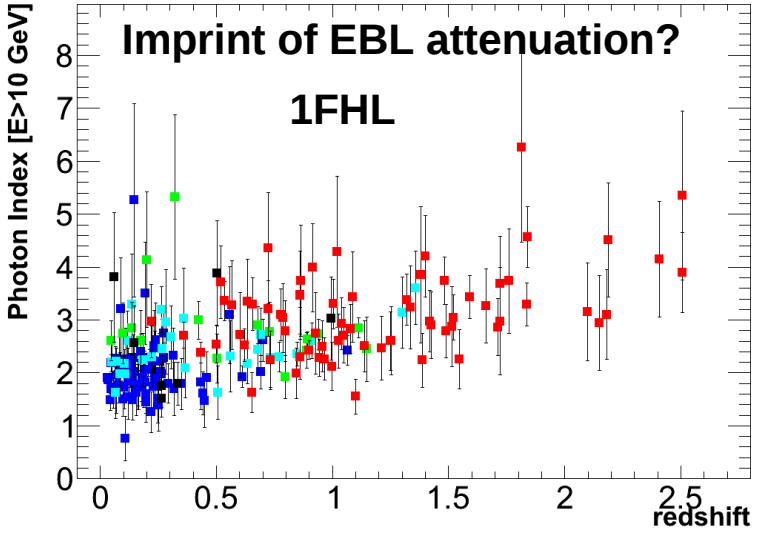
- 6 years of Pass8 data
  at E > 50 GeV increase in Aeff of 25%, in PSF of 20% at 50GeV (50% at 500GeV)
- 51,000 photons E> 50 GeV ~ 1 ph /deg ^{2} (EGRET: 1500 ph E>10 GeV)
  18,000 photons E>100 GeV
  2,000 photons E>500 GeV
- Fills the gap between Cherenkov ground-based observations and GeV all sky survey



Second Fermi Hard-Source List (2FHL)

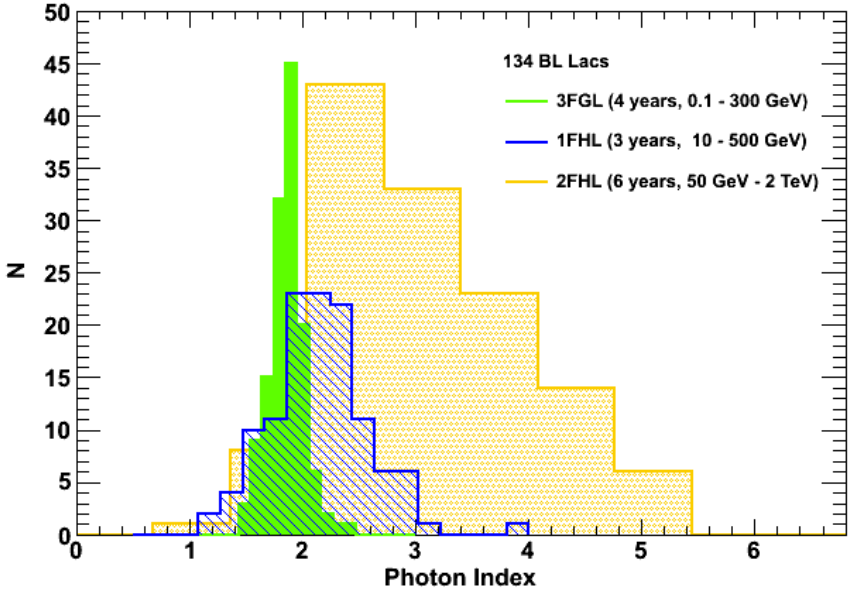
Preliminary





Detections

- 320 sources
- 71 detected by ACTs (TeVCat)
- 249 not detected by ACTs
- 206 in 1FHL
- 60 new sources



Conclusions

The 3LAC is a signicant improvement over 2LAC, with 71% more sources.

General trend:
FSRQs → BL LSPs → BL ISPs → BL HSPs
for redshift, photon index, spectral curvature, variability…

The LAT average photon index is a robust parameter, well correlated with blazar class. Interesting correlations discovered.

Assesment of shortest variability timescales is hampered by the LAT survey mode, but there are strong indications of subhour timescales.

First evidence for a periodic oscillation in the GeV range.

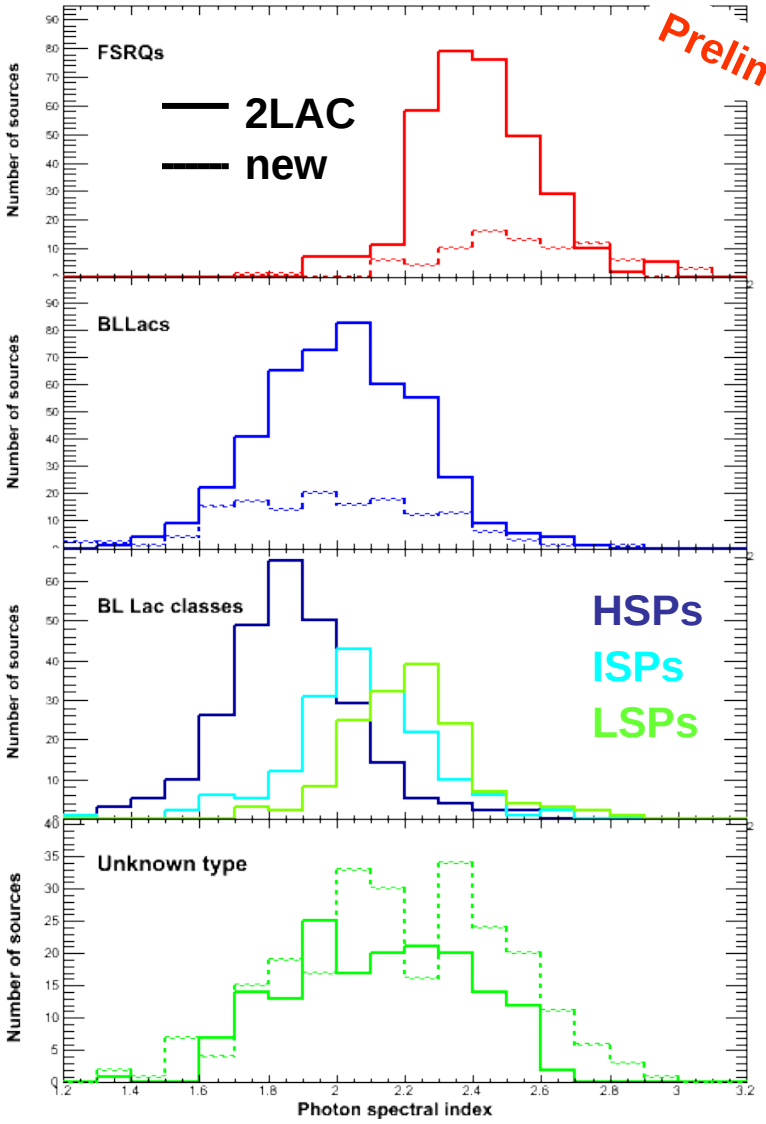
On-going/future efforts: 2FHL
4LAC (~6 years of data, Pass8)

Benoît Lott

Backup slides

Spectral photon index

- Little overlap between FSRQs and BL Lacs
- New FSRQs slightly softer than 2LAC ones: (<Γ>=2.53 vs. 2.41), not so for BL Lacs
- Lowest index~1.5, as predicted by shock-acceleraton models
- BCUs index distribution straddling the two classes' and extending beyond 2.5



Contribution to EGB

EGB total intensity of 1.1×10^{-5} ph cm^{-2} s^{-1} sr^{-1}

Blazars contribute a grand-total of (5-7)× 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

– Resolved sources : ~4× 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

– Unresolved blazars: ~(2-3)×10^{-6} ph cm^{-2} s^{-1} sr^{-1} (in agreement with Abdo+10)

Blazars, star-forming galaxies and radio galaxies can explain the intensity and the spectrum of the EGB