# THE LAT AT THE HIGHEST ENERGIES

Jeremy S. Perkins (NASA/GSFC) on behalf of the *Fermi*/LAT Collaboration
Fermi Symposium 2015, Washington, D. C.

- What's the motivation: Pass 8, Linear Increase, ~~Good~~ Amazing Science

- What do I mean by 'High Energy'?: Above 10 GeV

- What have we done in the past?

- What can we do in the future?

MOTIVATION: PASS 8
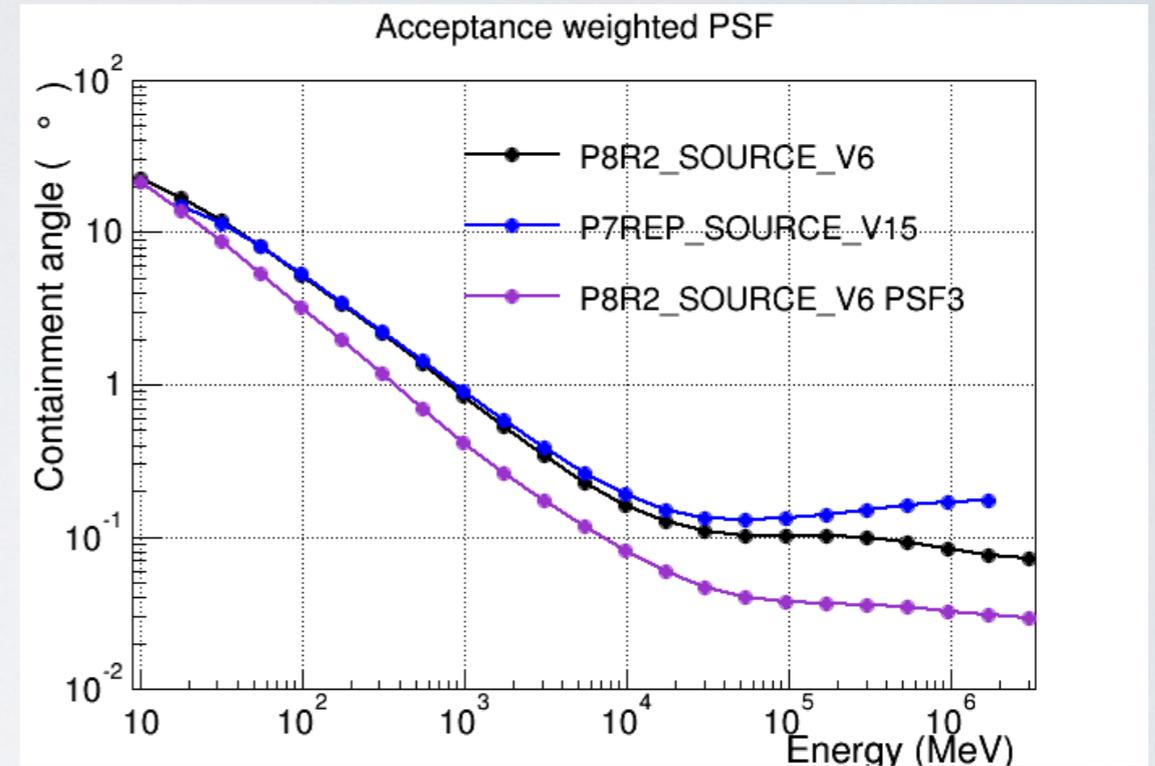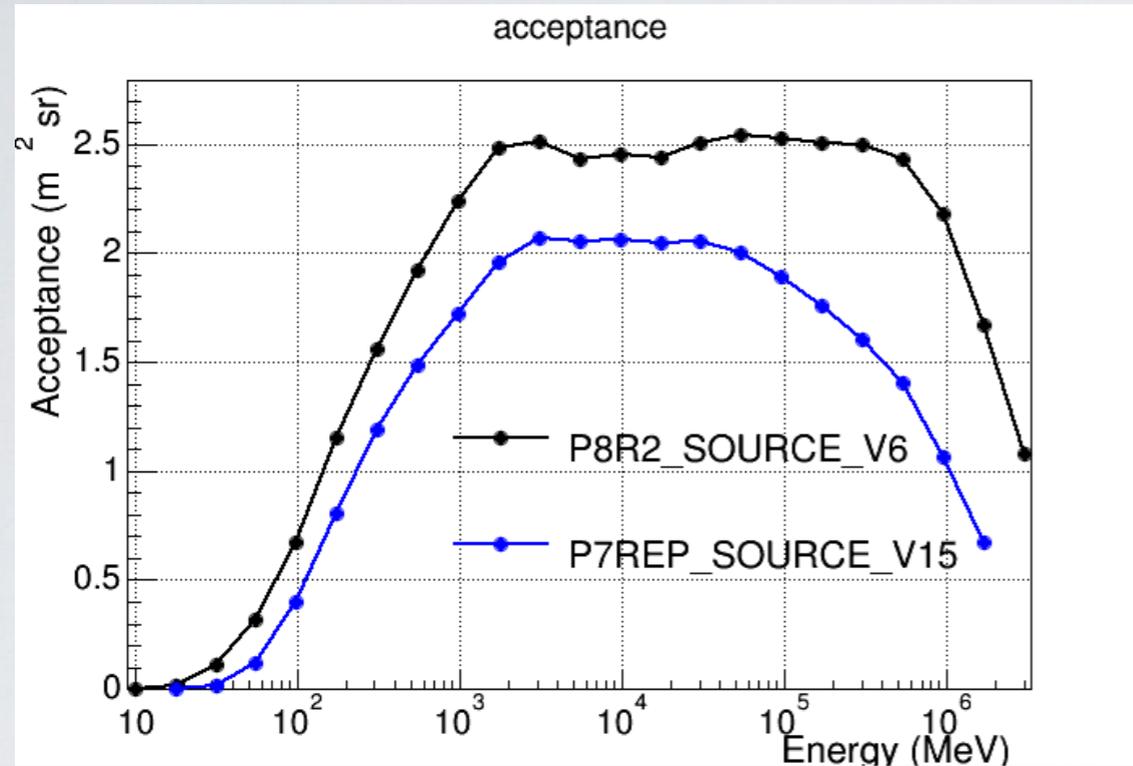
- Improved Performance above 50 GeV

  - Improved PSF and Acceptance (factor of 50 - 200%)

  - Low background and constant PSF (0.1 deg at 68%)

MOTIVATION: PHOTONS MATTER

- (ok, they always matter, but they matter more at high energies, also, bad pun, sorry)

- Can discover spatial extension

  - Example: 2FHL (5 new, including 3 PWNe)

- Better Energy Coverage

  - Example: AGN SED

- Measuring rise and decay times

  - Example: AGN Flare
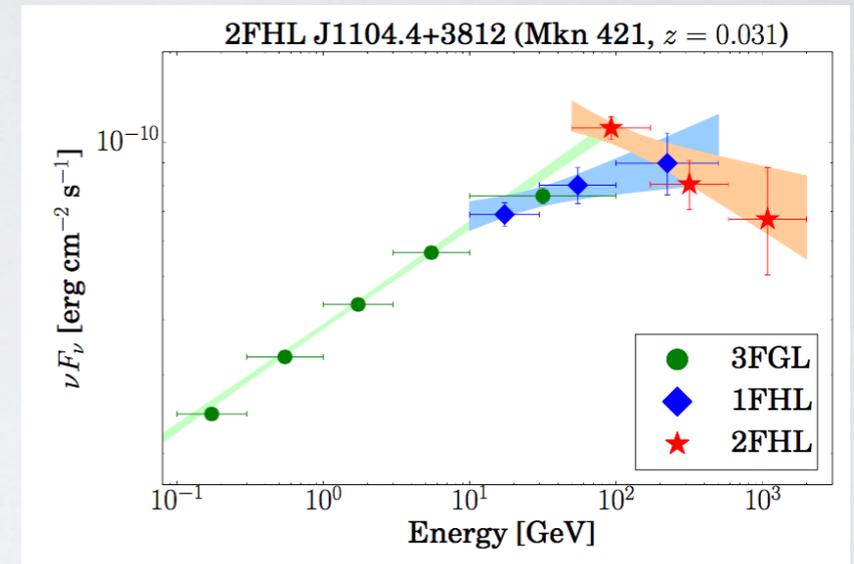
Fermi-LAT Collaboration 2015
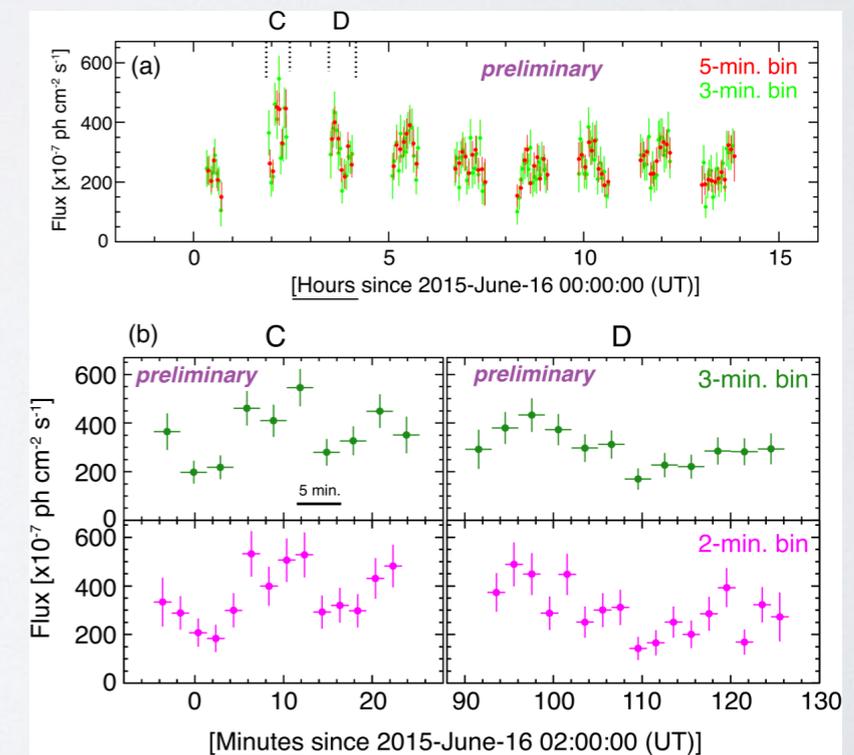
Hayashida et al., these proceedings (S9 Wednesday)

E > 100 MeV

NOT BACKGROUND DOMINATED

- Point source sensitivity improves linearly in time and is not systematics limited.

- In the High energy catalogs (like the 2FHL) sources are detected with only 3 or 4 photons.

Fermi-LAT Collaboration 2015
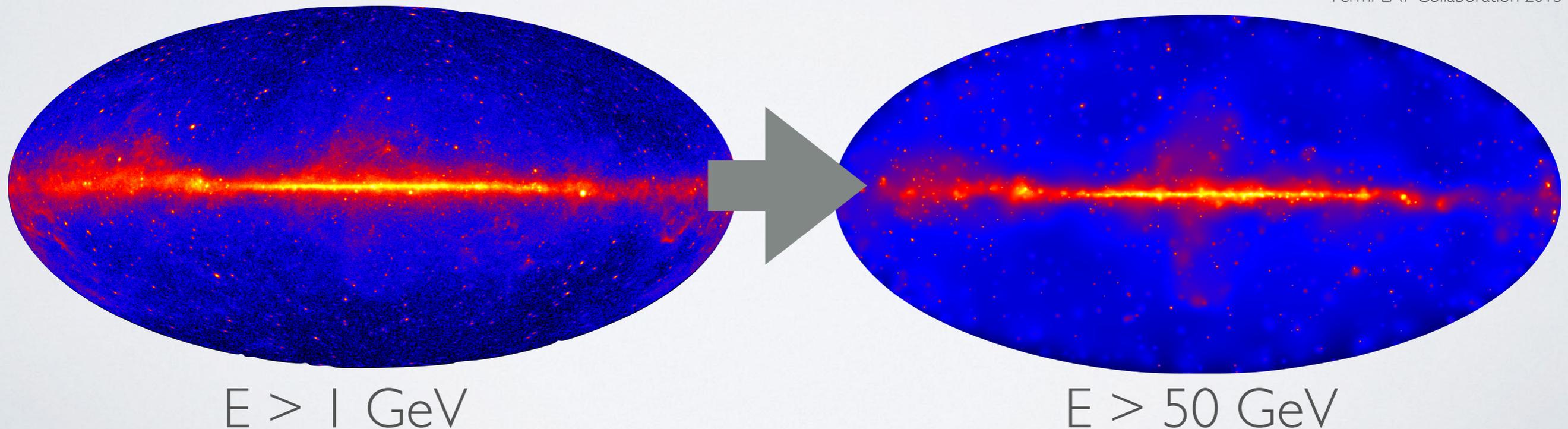
E > 1 GeV

E > 50 GeV

MOTIVATION: PRIMARY EXAMPLE (THE 2FHL)

- 2FHL: Like all of our catalogs it contributes greatly to our understanding of the sky but the added value is where we learn the most.

  - Since we are at high energies, a few (or a lot) more photons at HE gives distinguishing power.

61k photons E > 50 GeV
18k photons E > 100 GeV
2k photons E > 500 GeV

$\longrightarrow$ 1.5 ph/deg^2

Fermi-LAT Collaboration 2015
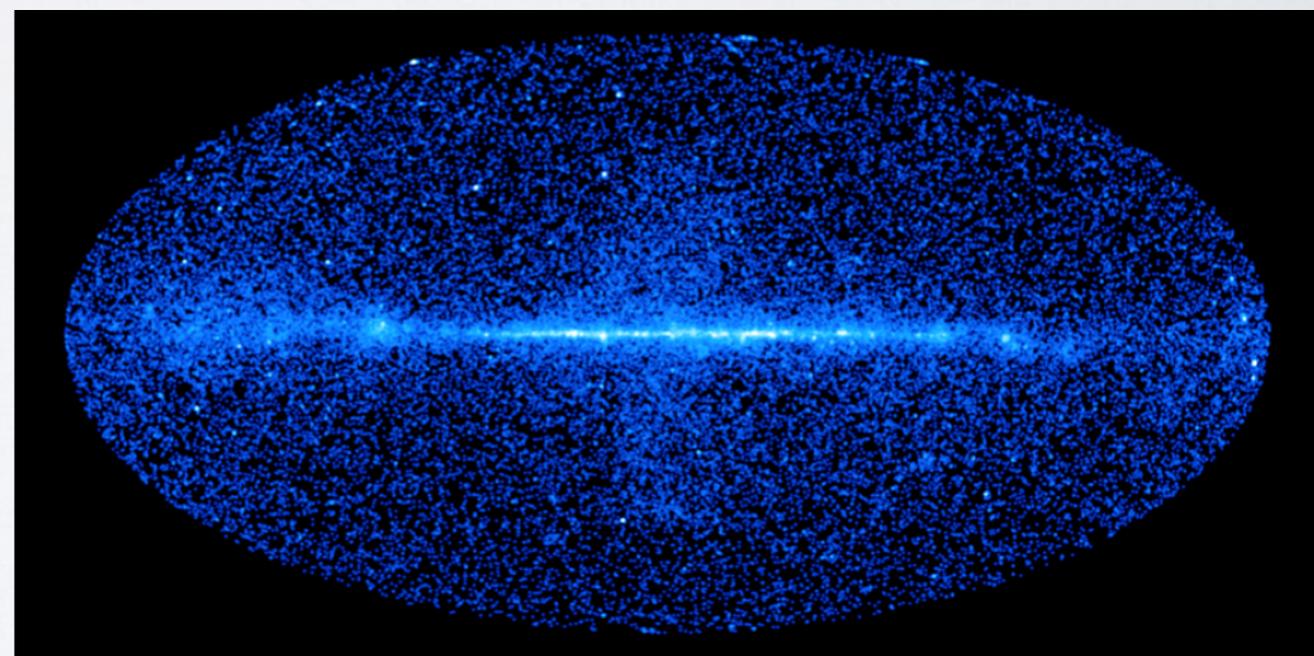
E > 50 GeV
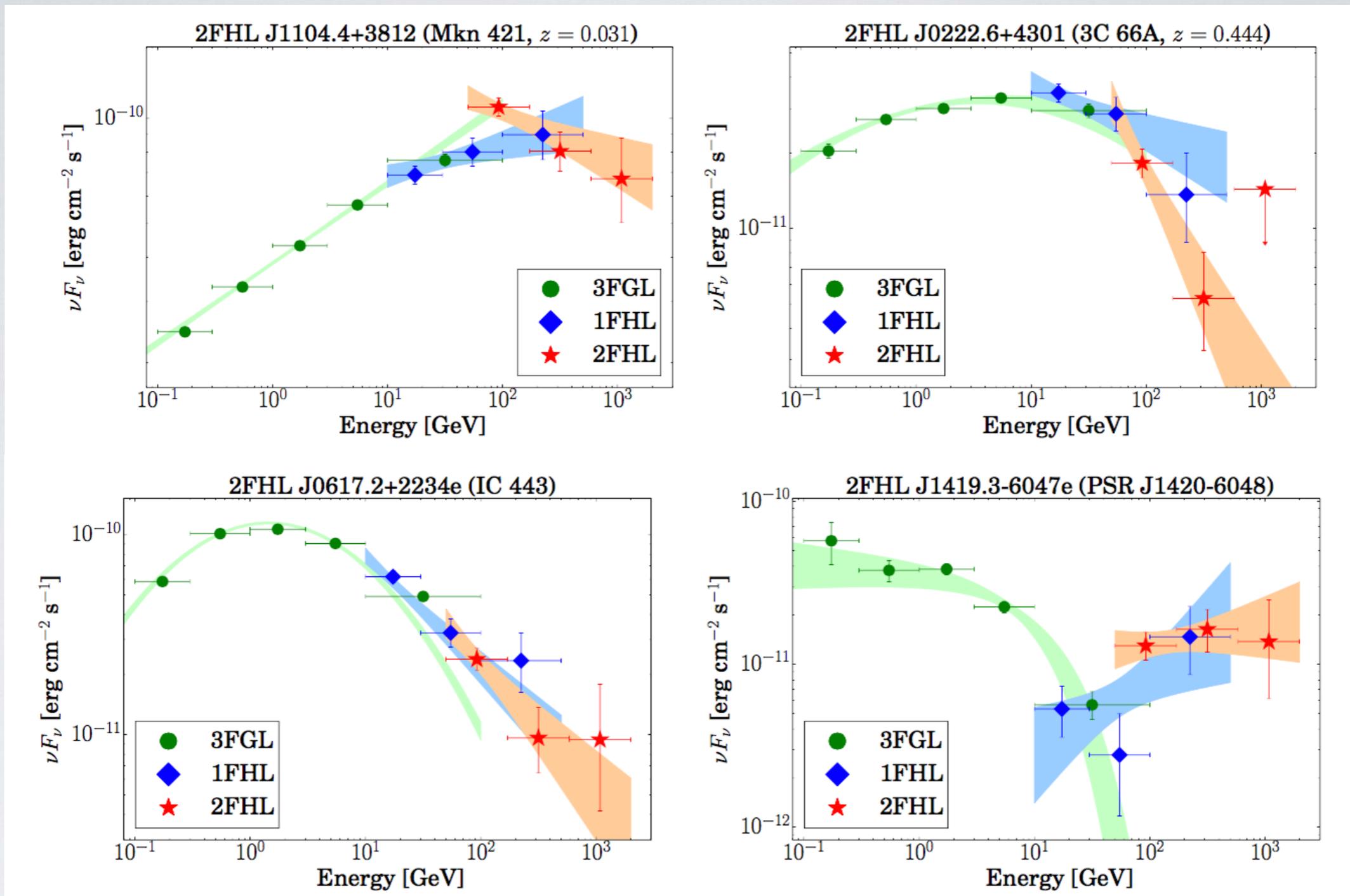
Fermi-LAT Collaboration 2015

We not only connect the high energy (E > 1 GeV) to the ground based very high energy (E > 100 GeV) but we're also connecting the two bands within the LAT.

THE GALACTIC PLANE
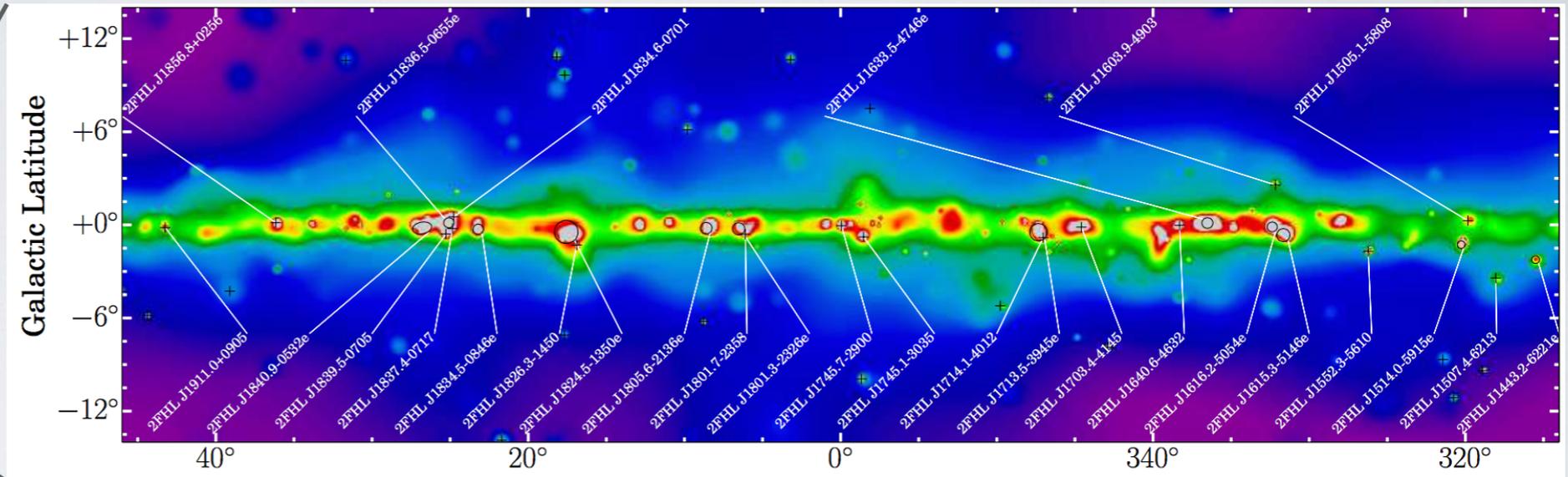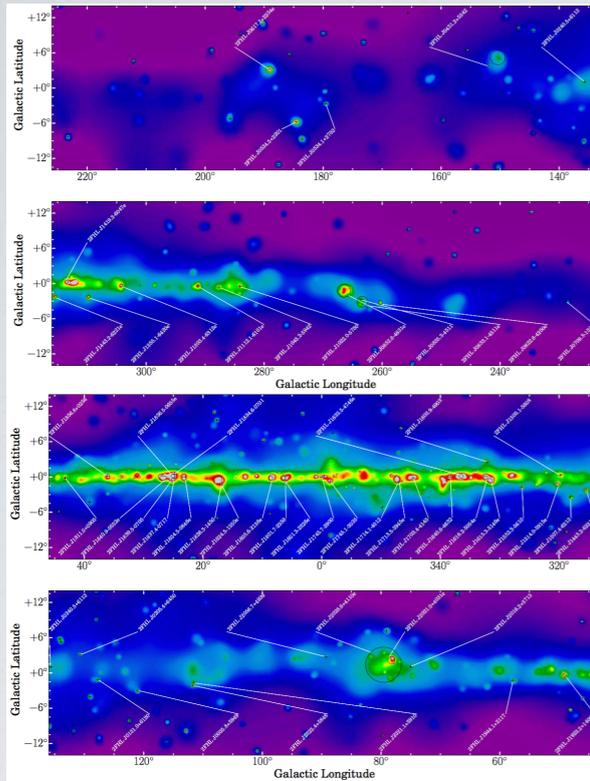
- 103 sources at |b| < 10 deg
  - 42 blazars, 38 Galactic Objects, 14 Unassociated, and 9 'dark accelerators'
  - PWNe/SNRs represent 87% of the Galactic Population
  - 1/2 of unassociated sources are hard and thus likely Galactic
- H.E.S.S. reports the detection of 69 sources reaching a sensitivity of ~2% of the > 1 TeV Crab Nebula Flux (in their survey region, c.f. Chaves et al. 2015)
- The LAT detects (in 2FHL) 36 sources in the same region reporting an average sensitivity of 3 - 4 % of the Crab Nebula flux

The improved (by P8) and intrinsically smaller PSF at high energies allows us to peer into the Galactic plane.

THE 2FHL: EMPOWERS FURTHER STUDIES
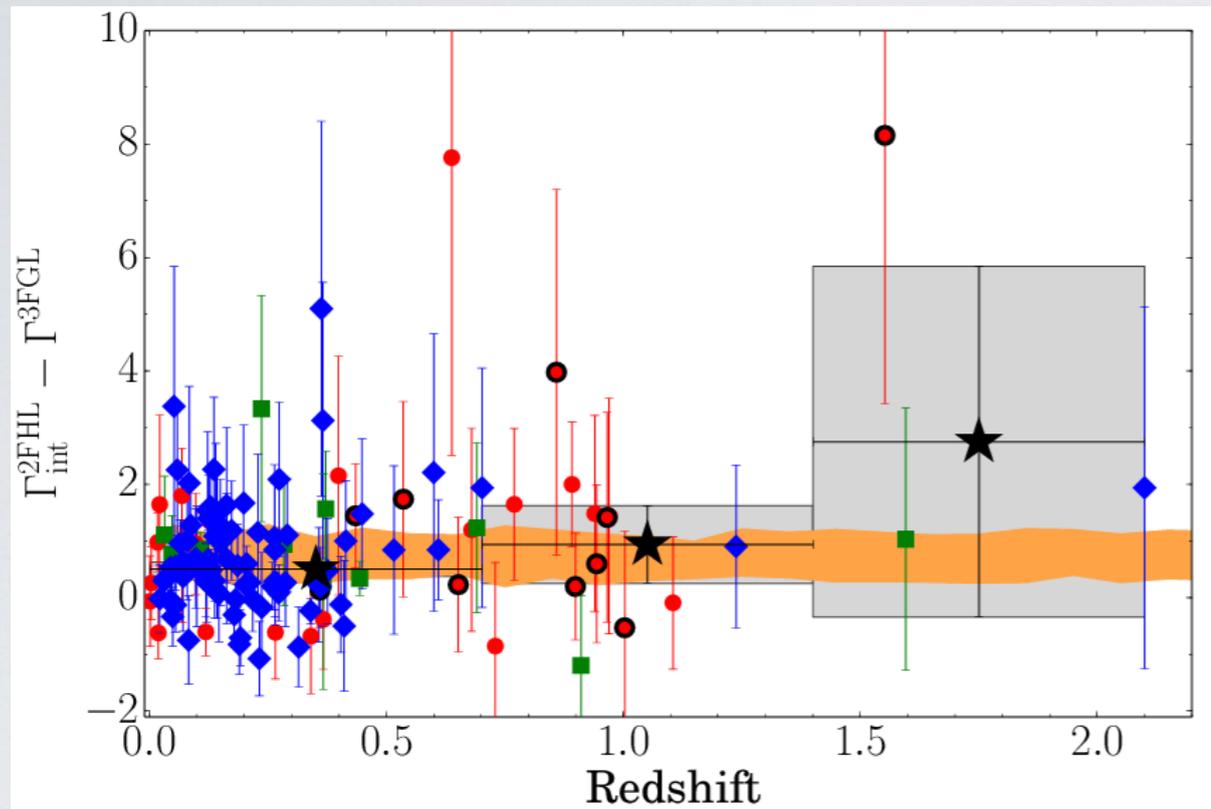
Domínguez & Ajello, 2015
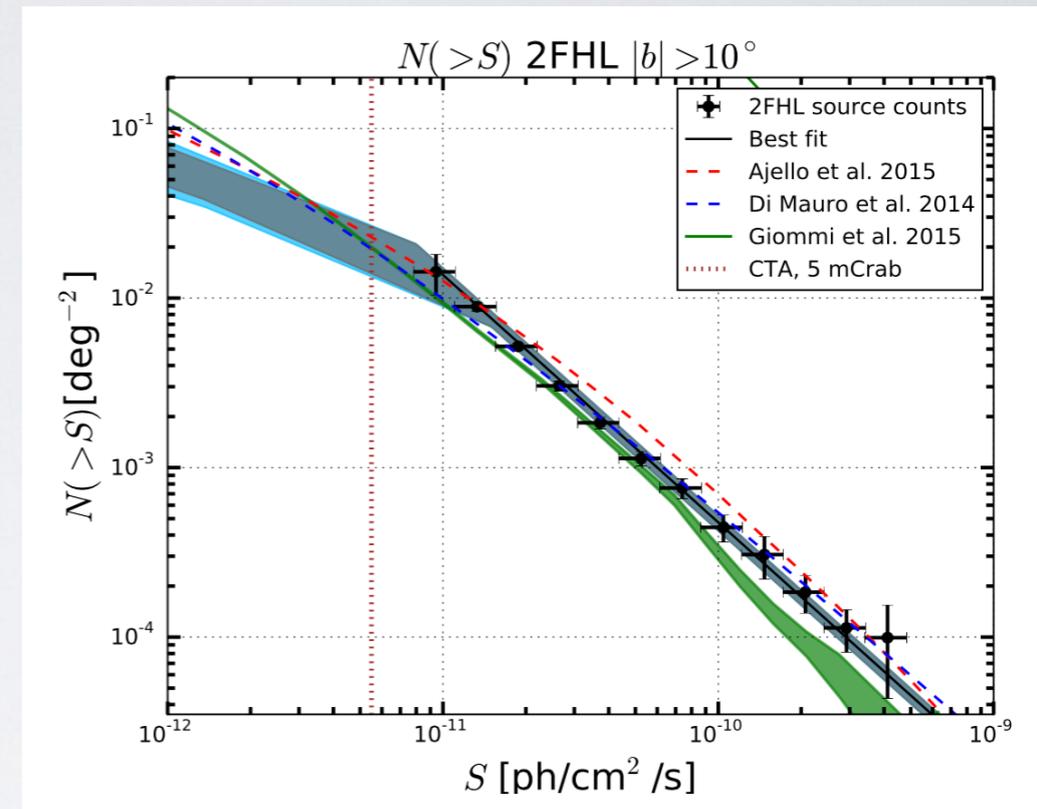

Ackermann et al. 2015 (submitted)

- Studies:

  - EBL

  - VHE follow-up (discovery space)

  - LogN-LogS

  - …and more!

What about the next catalog: the xFHL ('x' as in could be anything - above 50 GeV, above 10 GeV, 10 years, 15 years…)

XFHL?: NEW HIGH ENERGY CATALOGS

- Many more sources than previous high energy catalogs

  - Discovery space: 13% of the 2FHL are unassociated.

- EBL: We will be sensitive to an EBL cutoff.

  - We only have a few photons across the horizon (these are constraining already) but we will have many more than that.

  - Half of the blazars have no redshifts. A few redshifts matter…

- EGB:

  - If we can resolve all of the EGB in blazars (we're close!), we can exclude other populations (like star forming galaxies) from the neutrino background.

  - Can we measure the EGB up to 2 TeV?
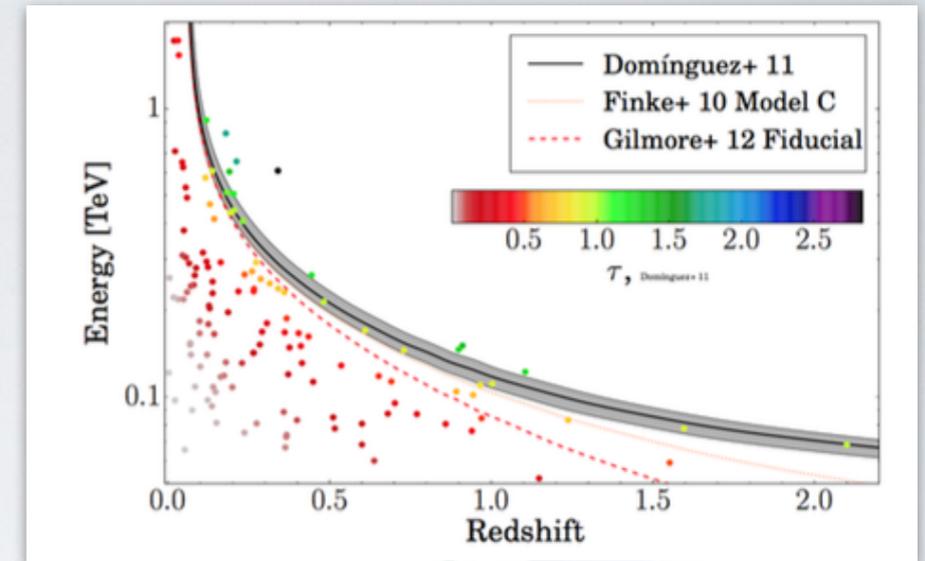
80 months
28k photons
270 extragalactic
sources

120 months
43k photons

150 months
50k photons

scaled to the number of photons

180 months
57k photons
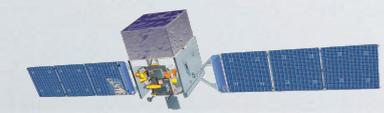
XFHL?: LOWER ENERGY THRESHOLD

>10 GeV, 80-month, Pass 8 source, adaptively smoothed

Preliminary

3FHL   1FHL

N(>S) [deg^{-2}]

□ Abdo et al. 2010, ApJ 720, 435

● This work

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-10} 10^{-9}

$S_{10-500 \text{ GeV}}$ [ph cm^{-2} s^{-1}]
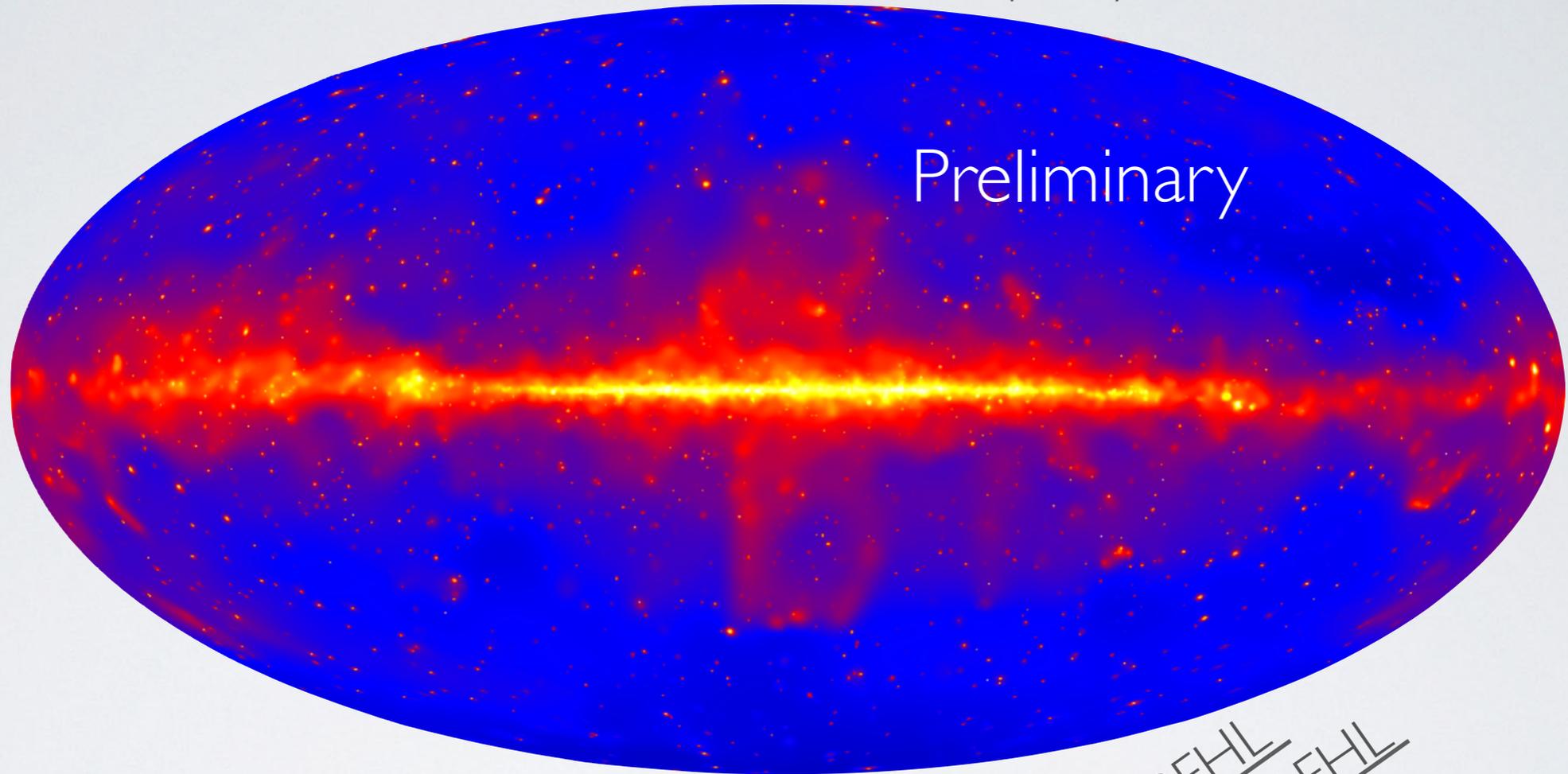
• Source detection above 10 GeV using the same exposure as the 2FHL (80m)

• # of sources is ~1500 (factor of 3 larger than 1FHL)

• Limiting flux went from 4e-11 ph/cm2/s to ~1e-11 ph/cm2/s

• This number is simply *incredible*. Scaled faster than linearly with time (P8).

Ackermann et al. 2013

The LAT at the Highest Energies; *Fermi* Symposium 2015, Washington, D.C.
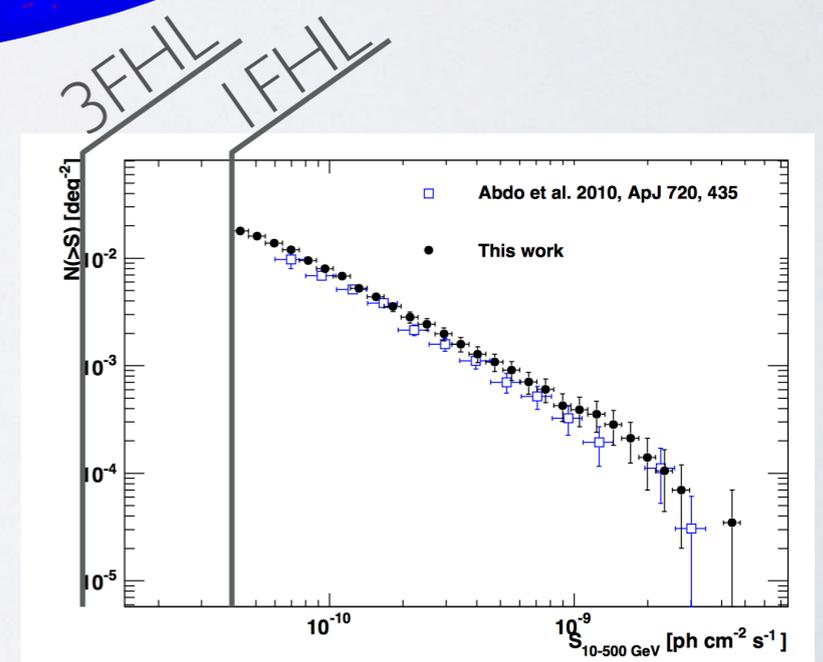
2FHL helps associate Galactic sources.

Table 6. LAT 3FGL Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	143	⋯	⋯
Pulsar, no pulsations seen in LAT yet	⋯		psr	
Pulsar wind nebula	PWN	9	pwn	2
Supernova remnant	SNR	12	snr	11
Supernova remnant / Pulsar wind nebula	⋯		spp	
Globular cluster	GLC	0	glc	15
High-mass binary	HMB	3	hmb	0

Note that identifications rely on other work.

TABLE 1
2FHL SOURCE CLASSES

Description	Associated	
	Designator	Number
Pulsar	psr	1
Pulsar wind nebula	pwn	14
Supernova remnant	snr	16
Supernova remnant / Pulsar wind nebula	spp	1
High-mass binary	hmb	2
Binary	bin	1
Star-forming region	sfr	1

Lots of potential for looking for hard extended sources.

Extended source search (E>10GeV and 6 years): new sources.

TABLE 5
NEW 2FHL EXTENDED SOURCES

2FHL Name	l [deg]	b [deg]	TS	TS_{ext}	TS_{2pts}	F_{50}	ΔF_{50}	Γ	$\Delta\Gamma$	Association	Class	Radius [deg]
J0431.2+5553e	150.384	5.216	87.9	83.4	26.2	11.70	2.11	1.66	0.20	G 150.3+4.5	snr	1.27
J1112.4−6059e	291.222	-0.388	80.9	68.3	22.5	12.80	2.36	2.15	0.28	PSR J1112−6103	pwn	0.53
J1355.2−6430e	309.730	-2.484	82.3	31.8	12.9	9.59	1.95	1.56	0.22	PSR J1357−6429	pwn	0.57
J1419.2−6048e	313.432	0.260	109.3	49.1	15.6	17.60	2.80	1.87	0.19	PSR J1420−6048	pwn	0.36
J1443.2−6221e	315.505	-2.239	75.6	29.9	19.2	7.23	1.70	2.07	0.30	SNR G315.4−2.3	snr	0.27

Preliminary

SNR G150.3+4.5

Cohen et al. (these proceedings, poster)

The LAT at the Highest Energies; *Fermi* Symposium 2015, Washington, D.C.
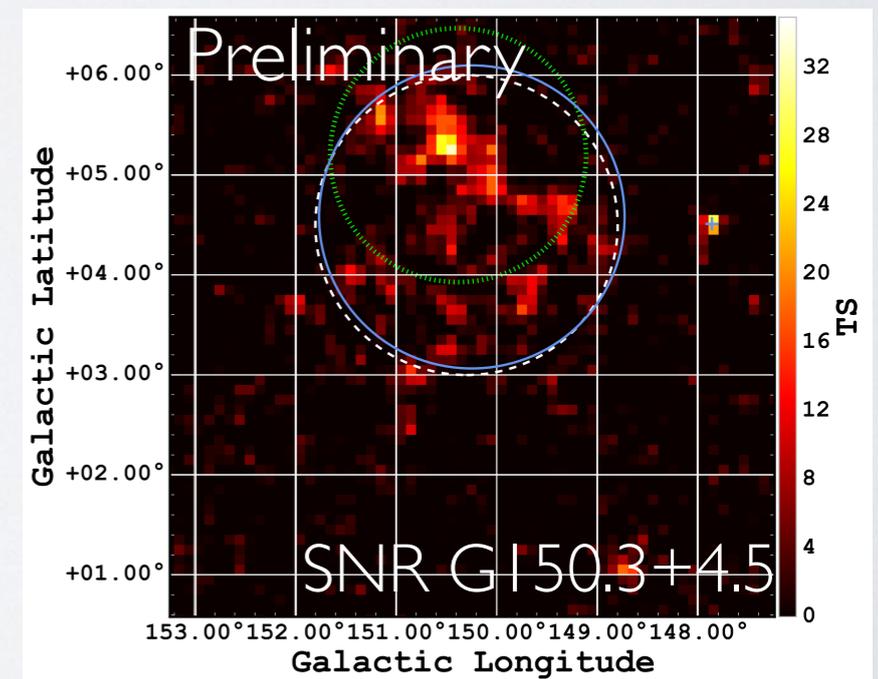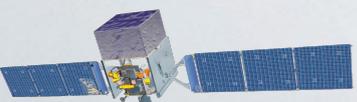
SCIENTIFIC IMPACT: SNR AND PWN

- Discriminate and find these in the galaxy (new extended ones in the 2FHL)

- Measure the SEDs and connect them to the VHE

- Discriminate different spatial and spectral components

SNR G 326.3-1.8
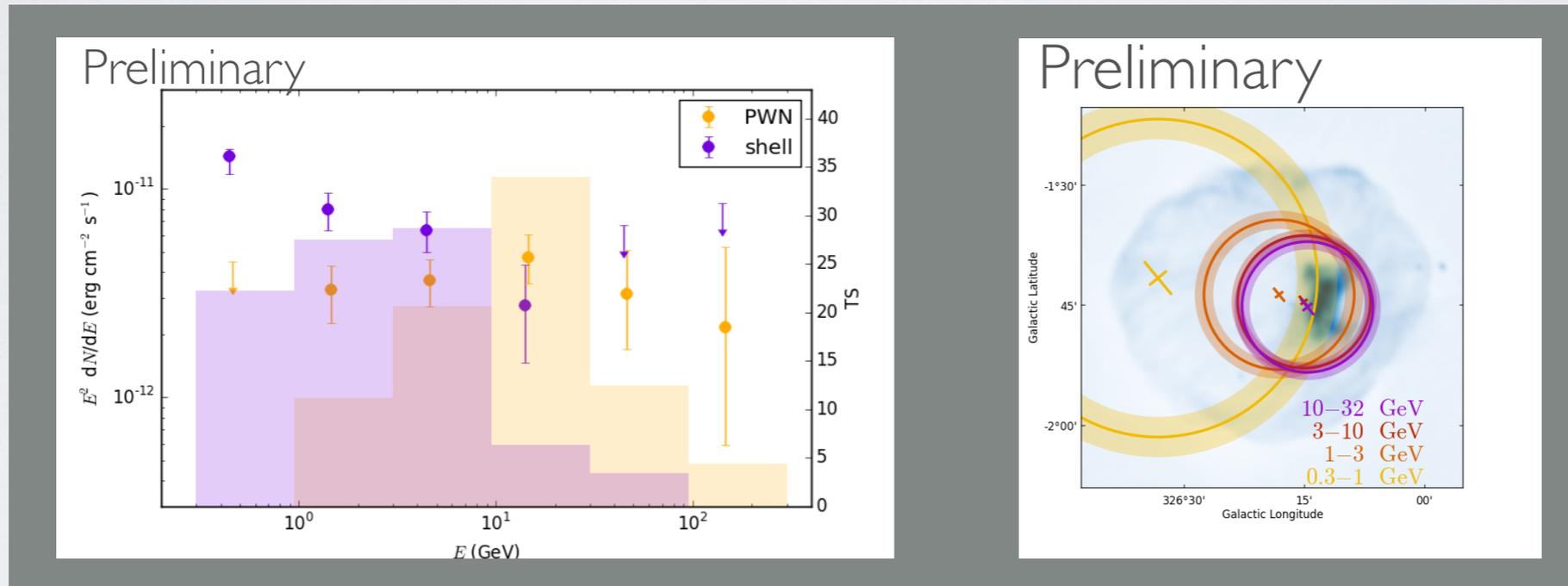
Acero et al. (these proceedings, S13 Thursday)

The LAT and IACT PSF has a width independent of energy from 10 GeV to > 1 TeV. This is a game changer for energy-dependent morphology studies where you want to constrain how relativistic particles propagate (e.g. PWNe evolution, CR escaped from SNRs) or separate sources in crowded regions.

SCIENTIFIC IMPACT: GRB

- Unique probe of the EBL at high redshift:

  - GRB average redshift ~1.6

  - They take over where the BL Lacs stop

- Connect the GeV to the VHE (cutoffs etc.)

  - Important with HAWC in operation

- A Hard Spectrum High-Z GRB (like GRB090510) will extend Lorentz invariance violation limits

AGN

Ackermann et al. (2012)

z~1.0
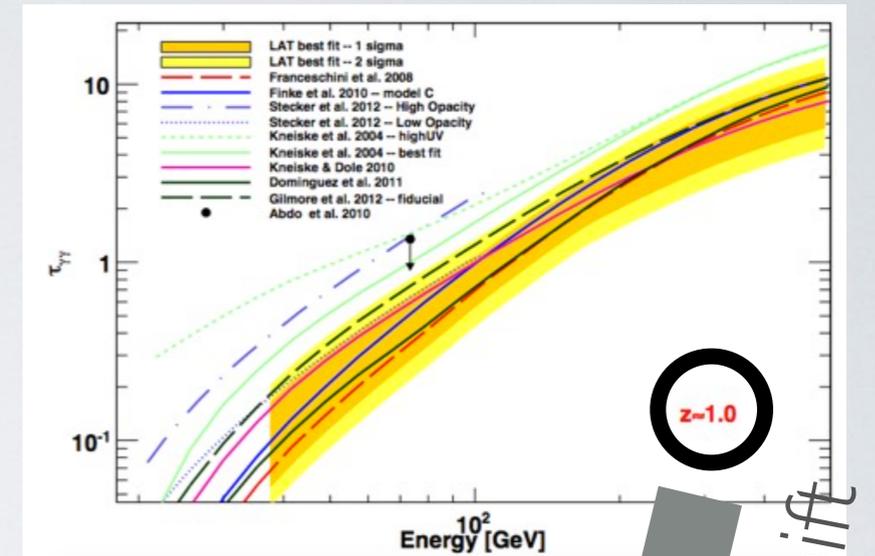
GRB130427A

Aliu et al. 2014

Preliminary

Average Redshift

z≈1.6
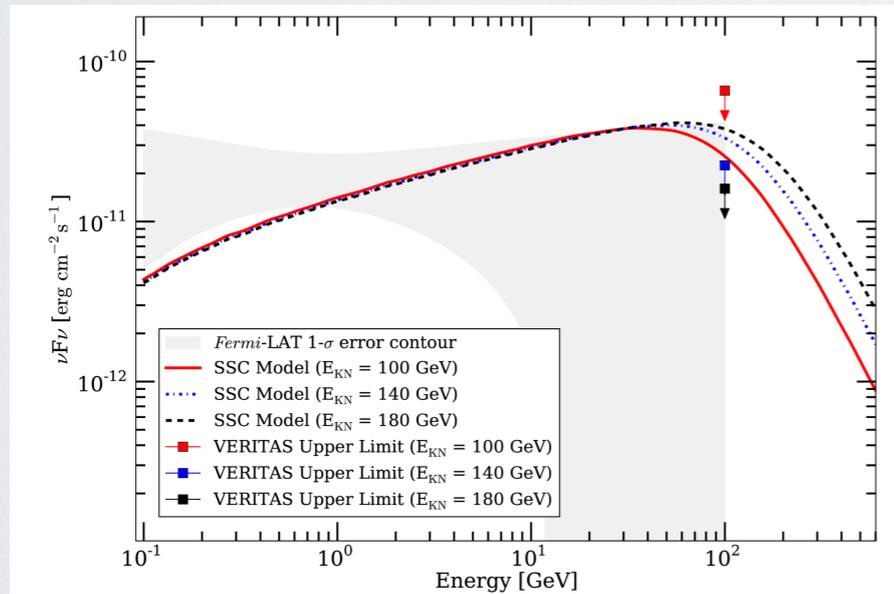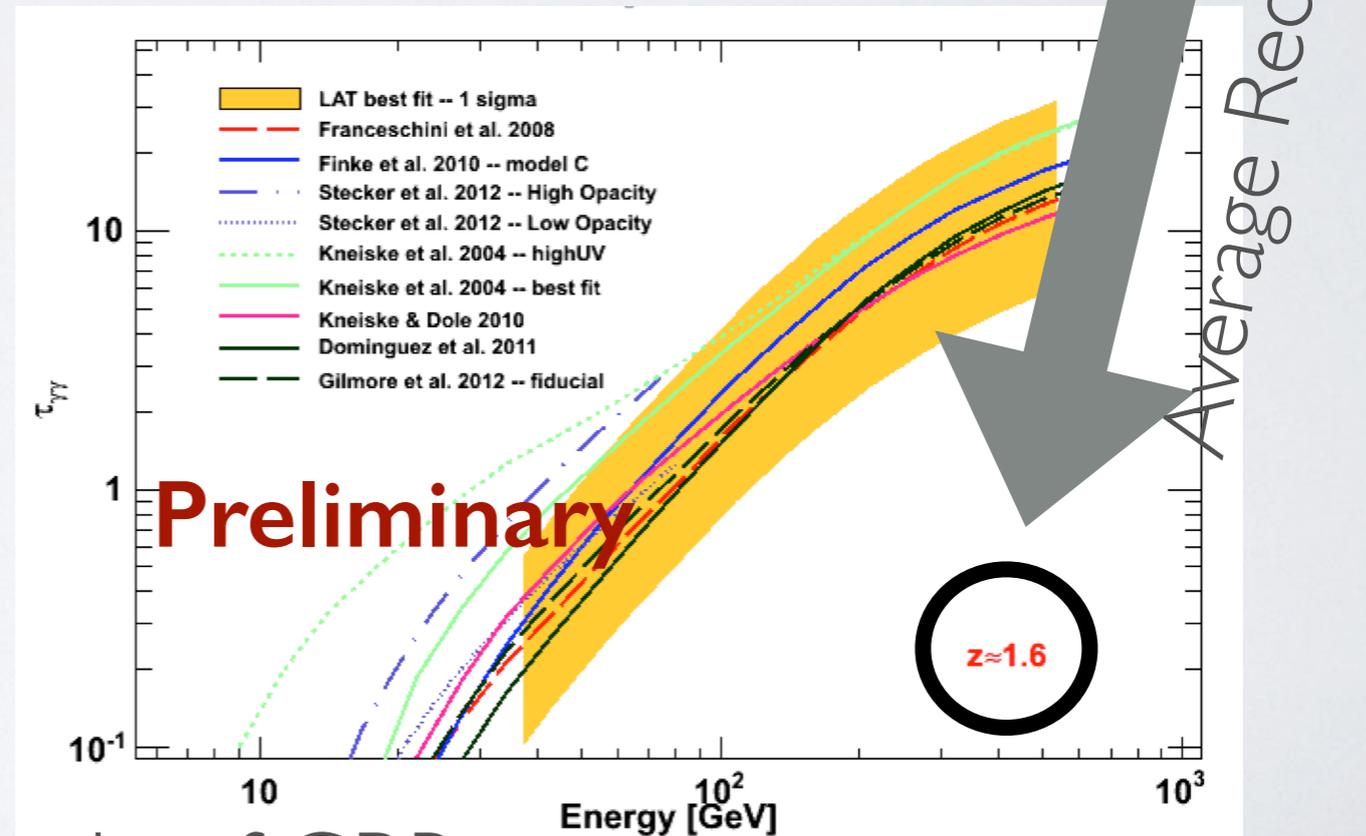
Sample of GRBs   Omodei et al. these proceedings (S10, Wednesday)

SCIENTIFIC IMPACT: PULSARS

- What's happening between the HE and the VHE in the Crab?

  - Different components? (c.f. Harding et al.)

  - We can look for this in other pulsars even if we don't see VHE from the ground.

- 13 Pulsars detected above 25 GeV

  - See Pablo Saz Parkinon's contribution (these proceedings)
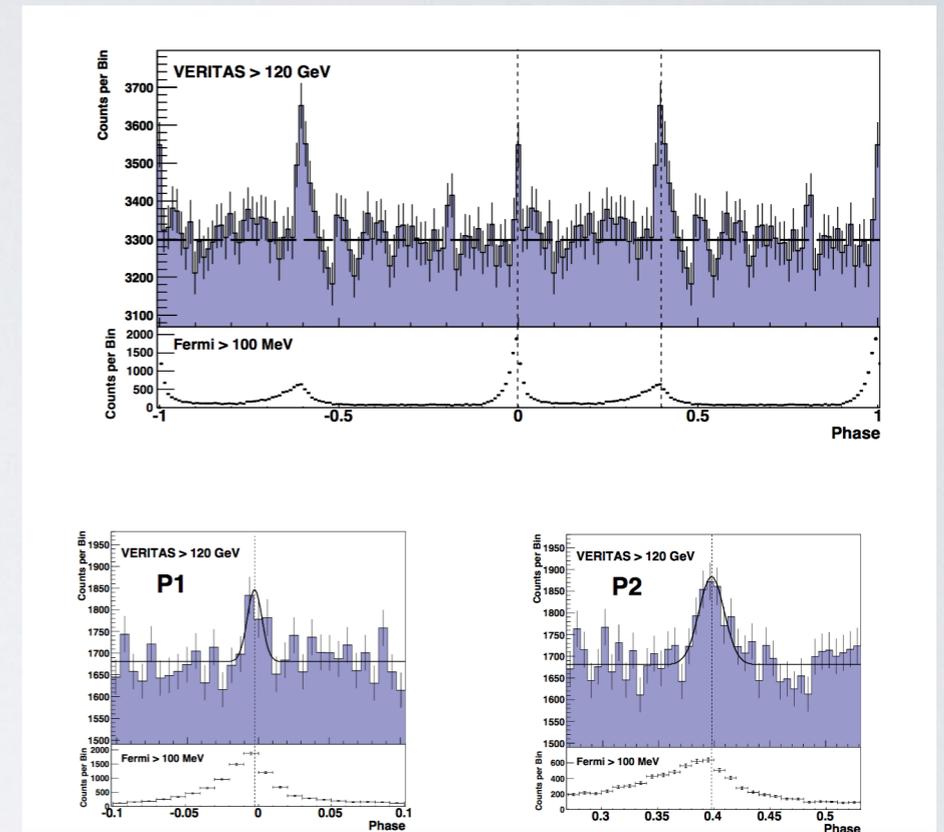
Aliu et al. 2011
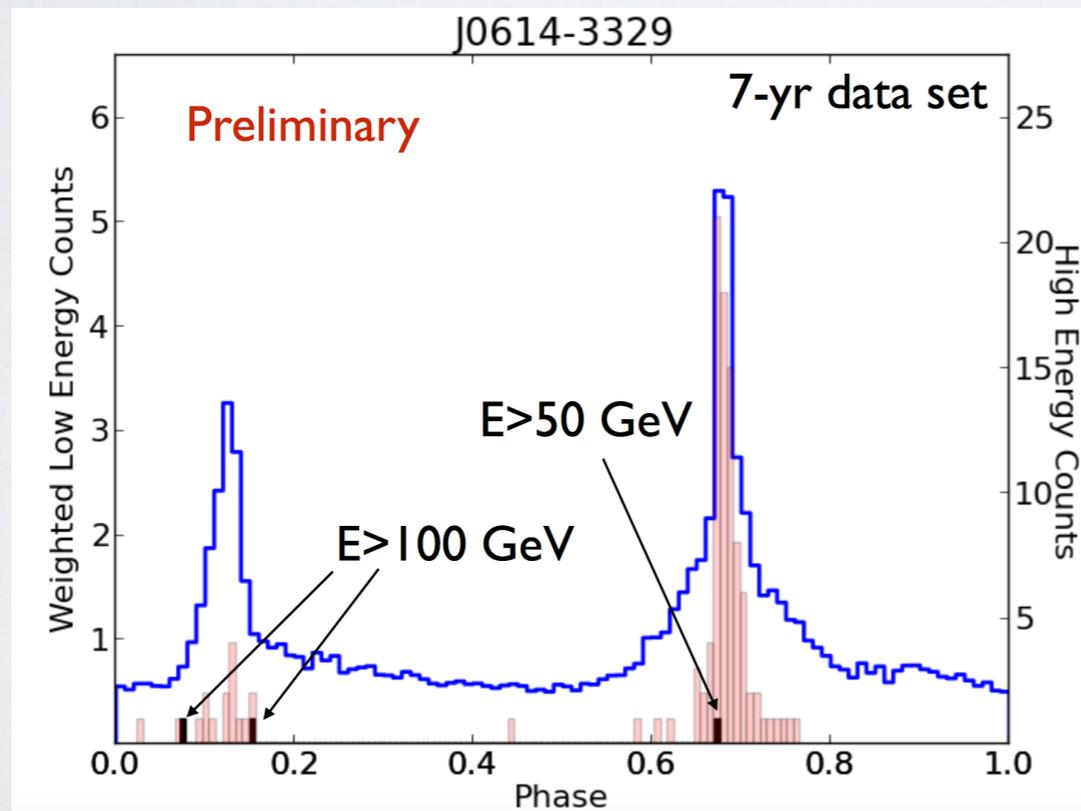
Saz Parkinson (these proceedings, S12B Wednesday)
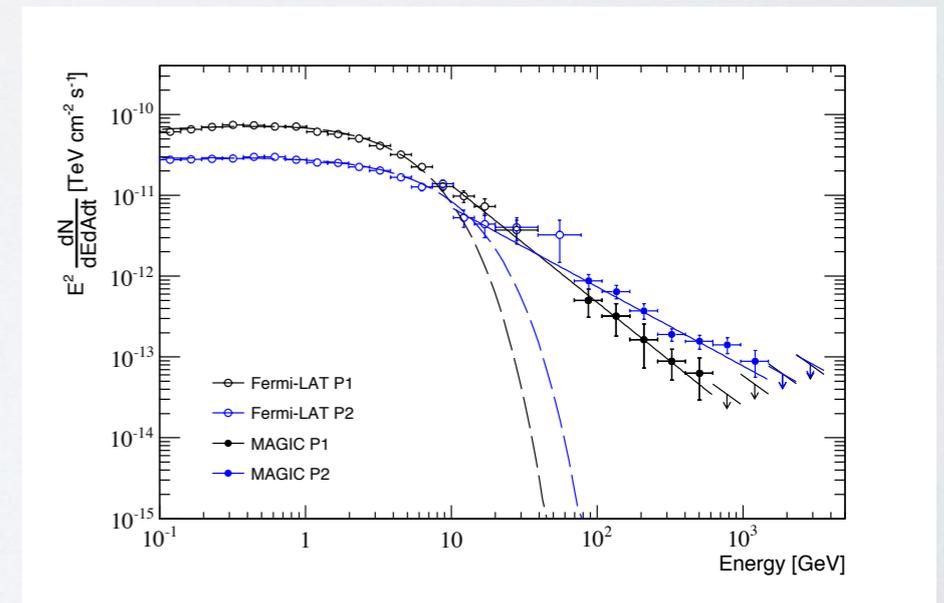

Ahnen et al. 2015

SCIENTIFIC IMPACT: COSMIC RAYS

- It's obvious that other experiments (like AMS) are designed to do this. The LAT will do better above ~20 GeV than AMS for e +/e-

- However, we now can extend LAT spectral measurements of e+/e- and protons up to 2 - 3 TeV

electrons+positrons
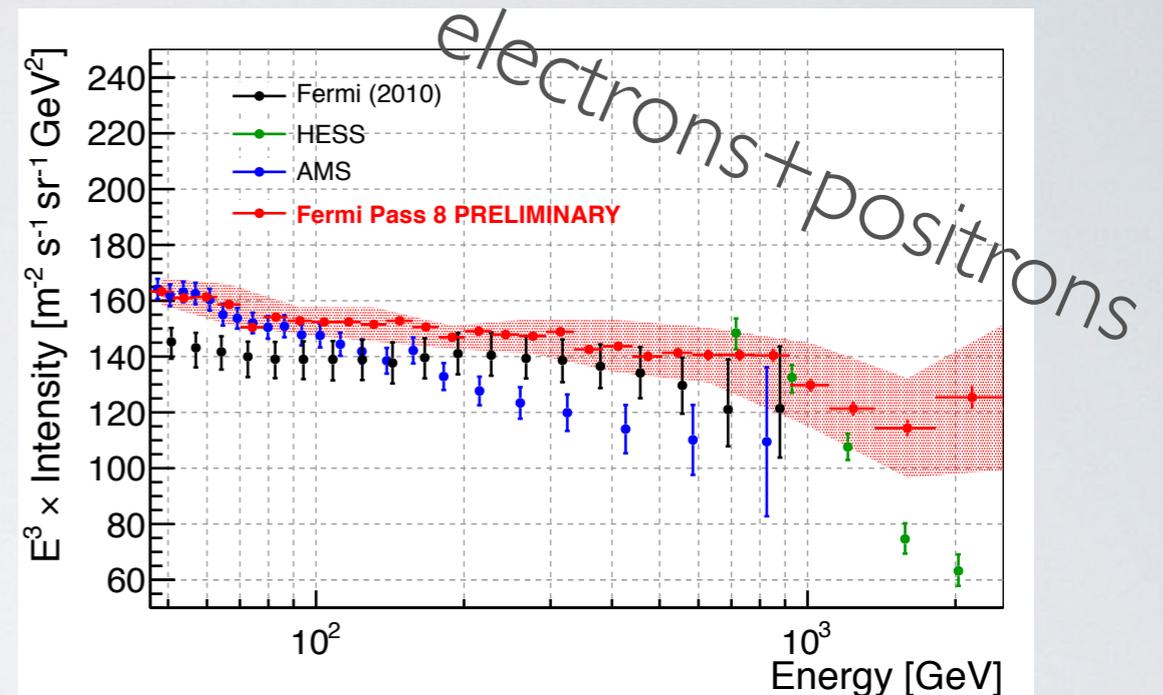
Bonino et al. (these proceedings, S13 Thursday)

interpretation
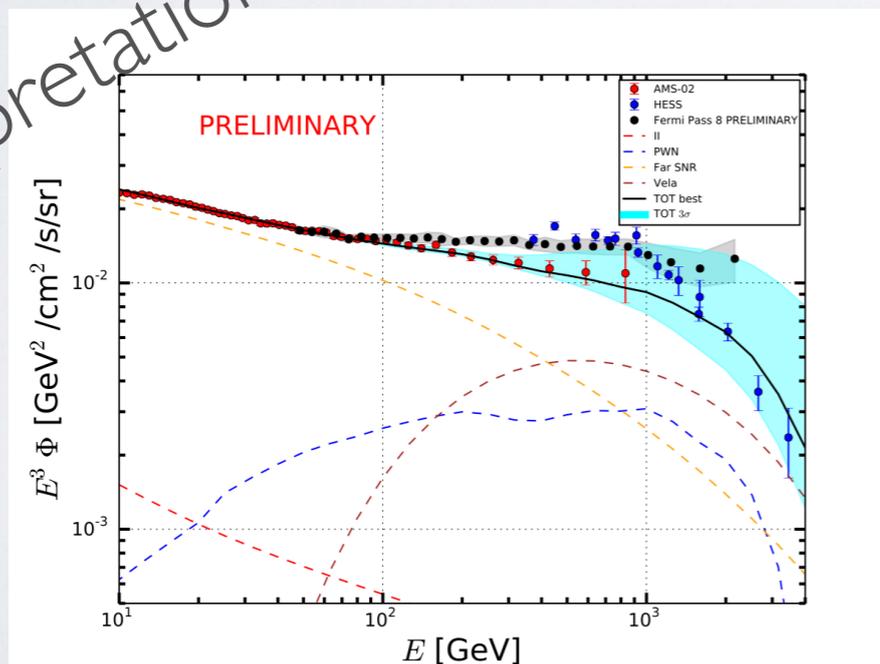
Donato et al. (these proceedings, poster)

protons
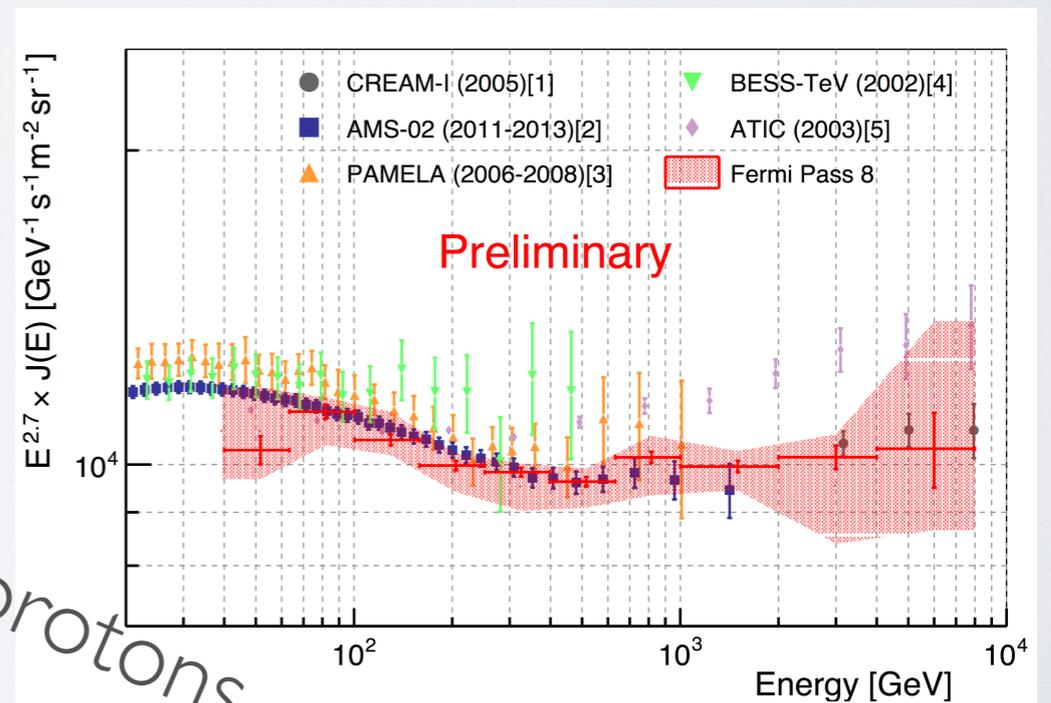
Green et al. (these proceedings, poster)

SCIENTIFIC IMPACT: COSMIC RAYS

E > 60 GeV Cosmic Ray e+/e- Maps (Mazziotta et al., These Proceedings, poster)
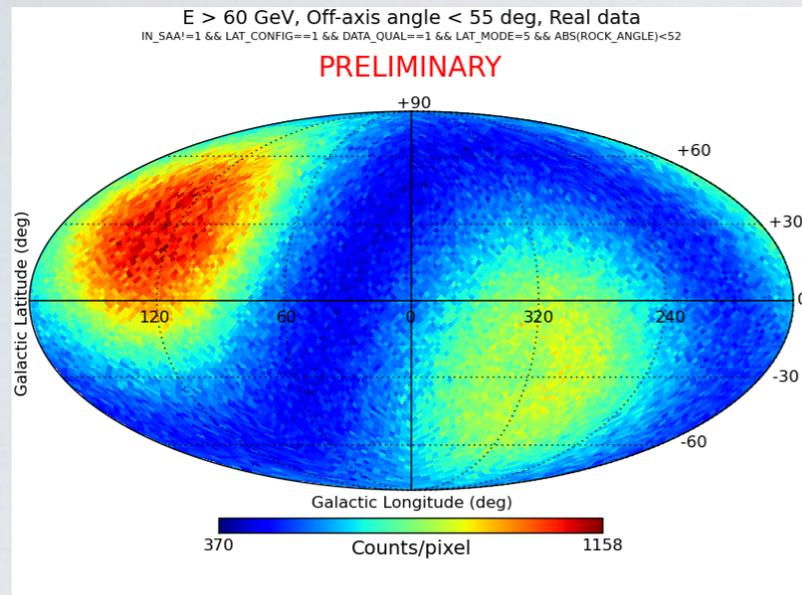

Real
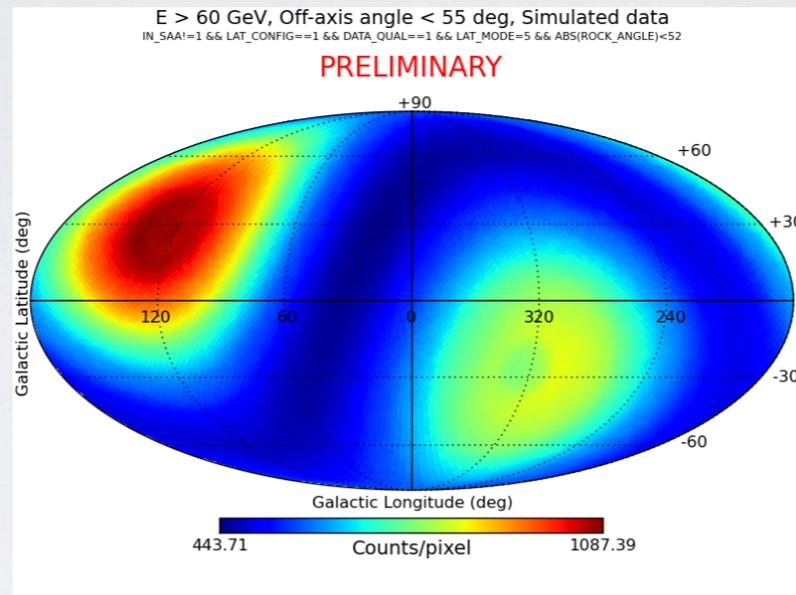
Shuffled
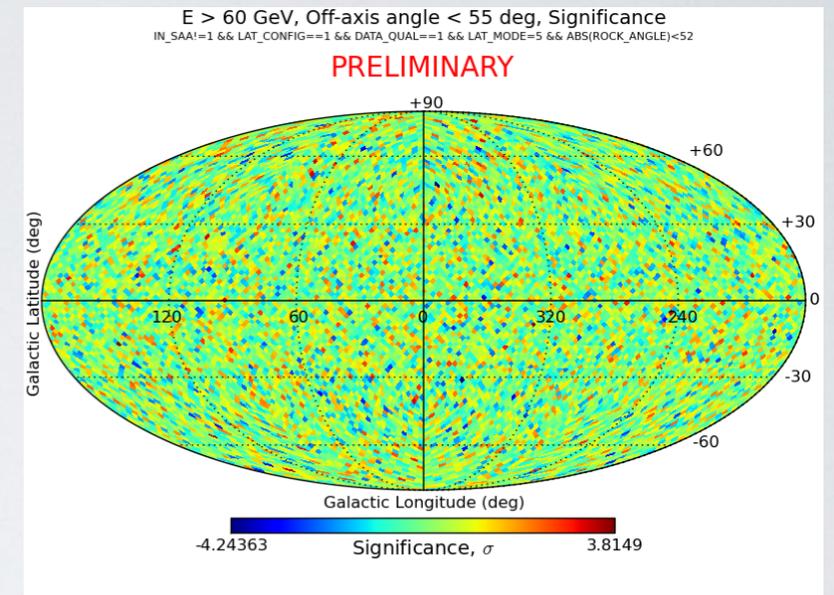
Significance

- The LAT is unique and unrivaled with respect to anisotropy measurements:

  - Large Acceptance

  - Excellent Angular Resolution

  - Large FoV and Uniform Sky Exposure

The LAT could be **the reference** on anisotropy for many years to come.

MULTIWAVELENGTH PARTNERS

- It's important to remember that the answers cannot be answered with the LAT alone and partnerships with lower and higher energies as well as multi messenger are critical.

- The full SED is needed to understand the physics

- This is a great time for MW studies and it's about to get better (HAWC, Astro-H, CTA…)

- Remember: The LAT surveys the entire sky at high energies and the LAT > 50 GeV is well matched to the IACTs
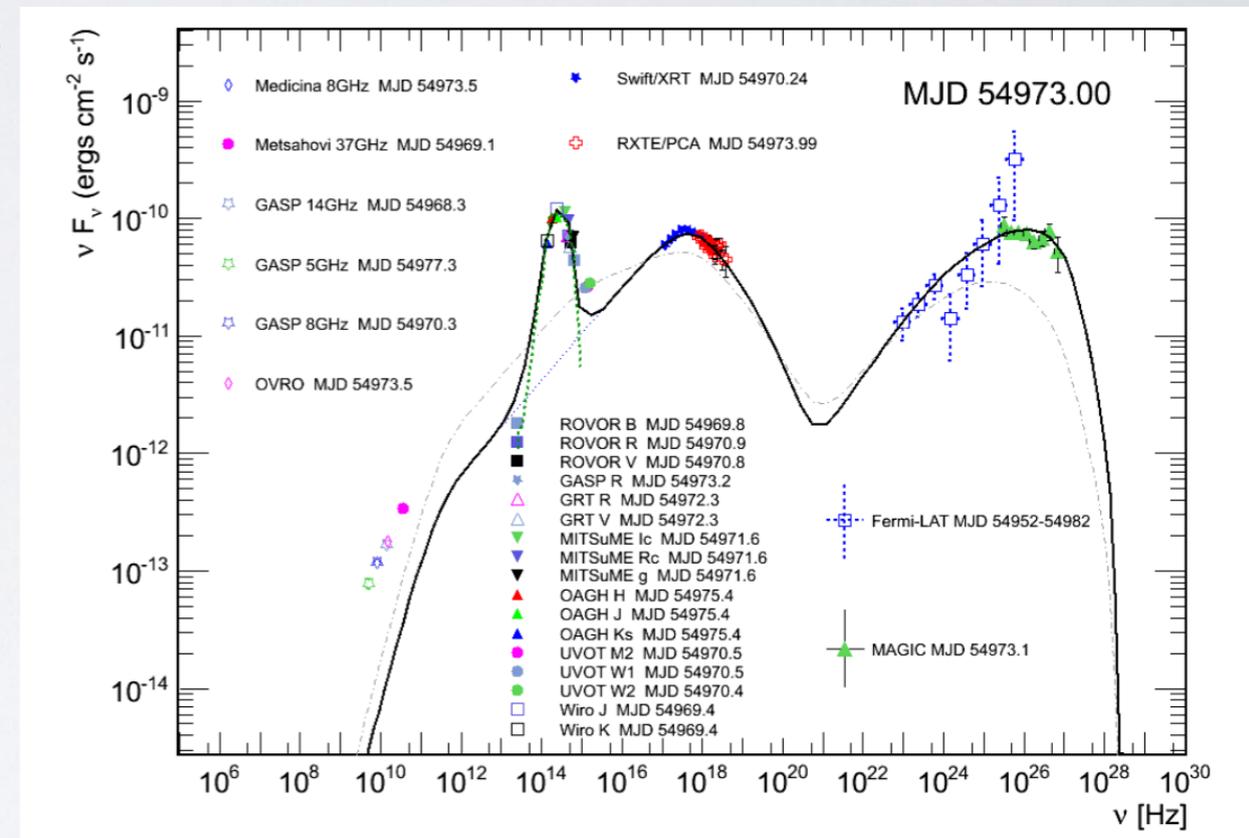
Snapshot of Mrk 501

Gamma-ray Sky Map for E > 10 GeV