7th Fermi Symposium

Study of UGRB spatial anisotropy with P8 data

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on behalf of *Fermi*-LAT collaboration

with

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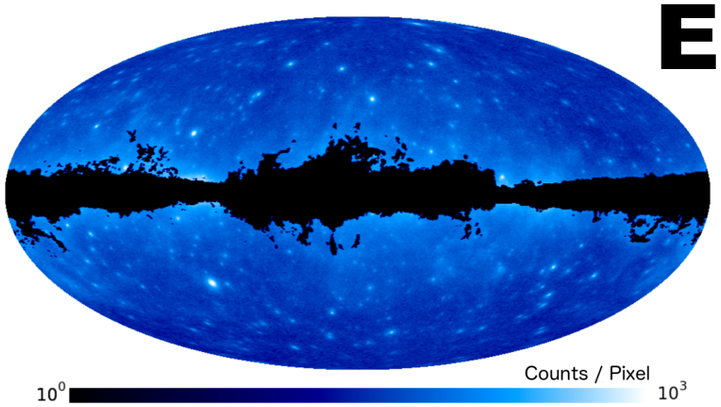
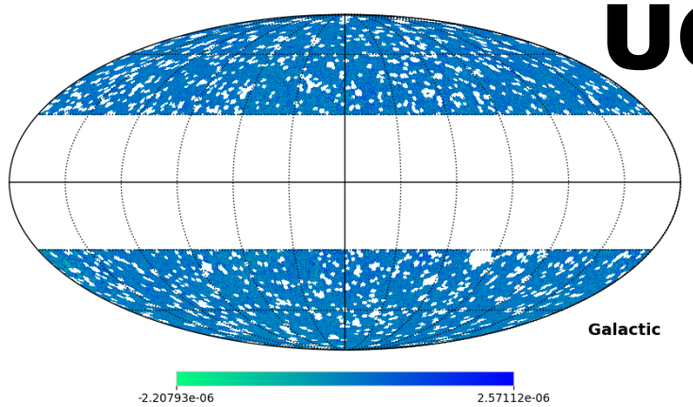
THE AIM

EGB



Extragalactic
Gamma-ray
Background

UGRB



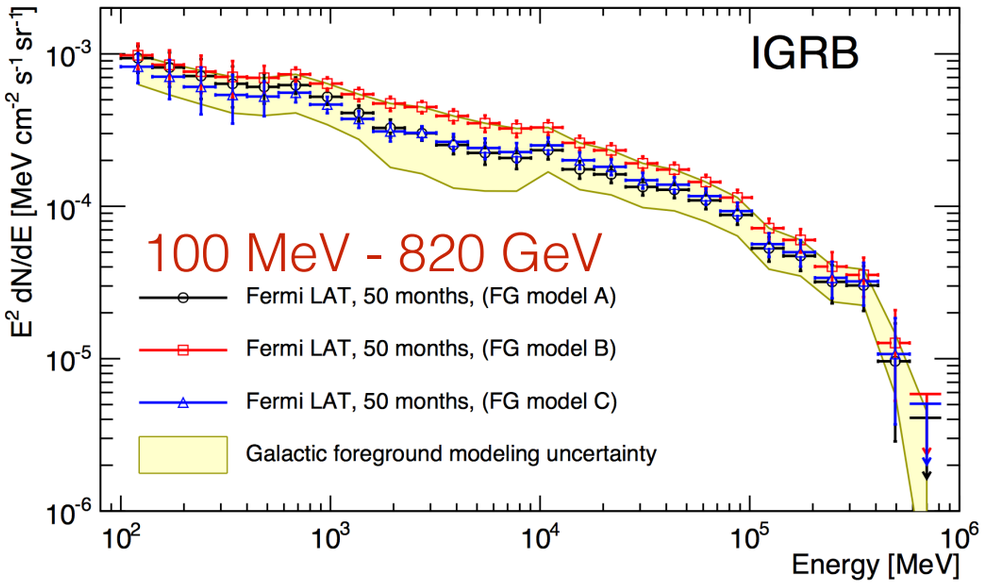
Unresolved
Gamma
Ray
Background

Explained by unresolved [2]

- Blazars
- Star-forming galaxies
- Radio galaxies

Different levels of anisotropies:
Angular Power Spectrum (APS) can constrain UGRB nature! [3]

Intensity spectrum of the UGRB [1]



Other ways:

- 1-point photon count probability distribution of the UGRB
- X-correlation:
  - UGRB - galaxies (**See poster by Simone Ammazzalorso**)
  - UGRB - galaxy clusters
  - UGRB - weak lensing of cosmic shear
  - UGRB - gravitational lensing of the cosmic microwave background

[1] M. Ackermann et al. (Fermi-LAT), Astrophys. J. 799, 86 (2015), arXiv:1410.3696 [astro-ph.HE].
[2] M. Ajello et al., Astrophys. J. 800, L27 (2015), arXiv:1501.05301 [astro-ph.HE]
[3] S. Ando et al., (2017), arXiv:1701.06988v1 [astro-ph.HE]

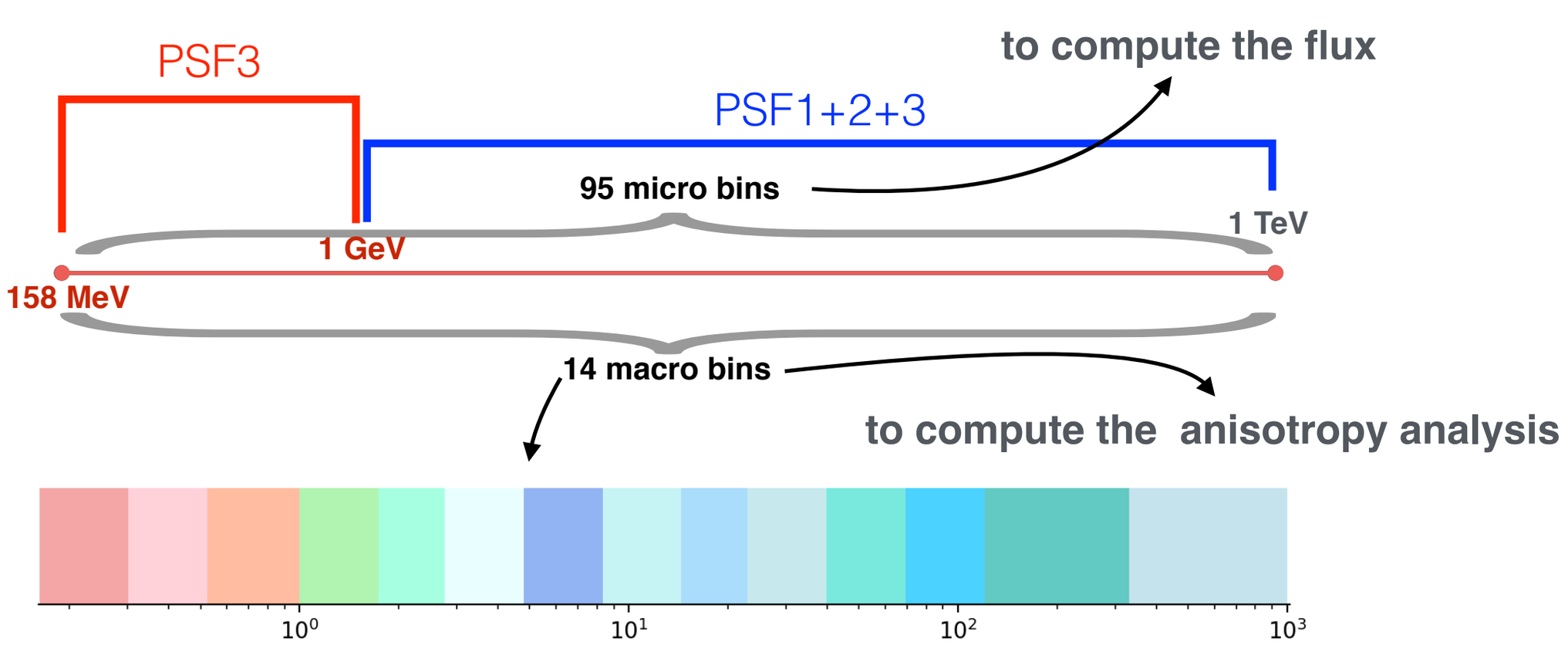
DATA SELECTION

Our selection:

- 8 years, Pass 8
- Event class: ULTRACLEANVETO (UCV)
- Event type:
  - PSF3 below 1 GeV
  - PSF1+PSF2+PSF3 above 1 GeV

Previous work [1]:

- 5 years, Pass 7 REP
- Event class: ULTRACLEAN
- Event type:
  - FRONT
- Energy range: 0.5 - 500 GeV



[1] M. Fornasa et al. (2016), arXiv:1608.07289 [astro-ph.HE].

MASK (Φ, E)

- **|b| < 30 deg**
- **3FGL[1] point-like and extended sources**

POINT SOURCE MASK

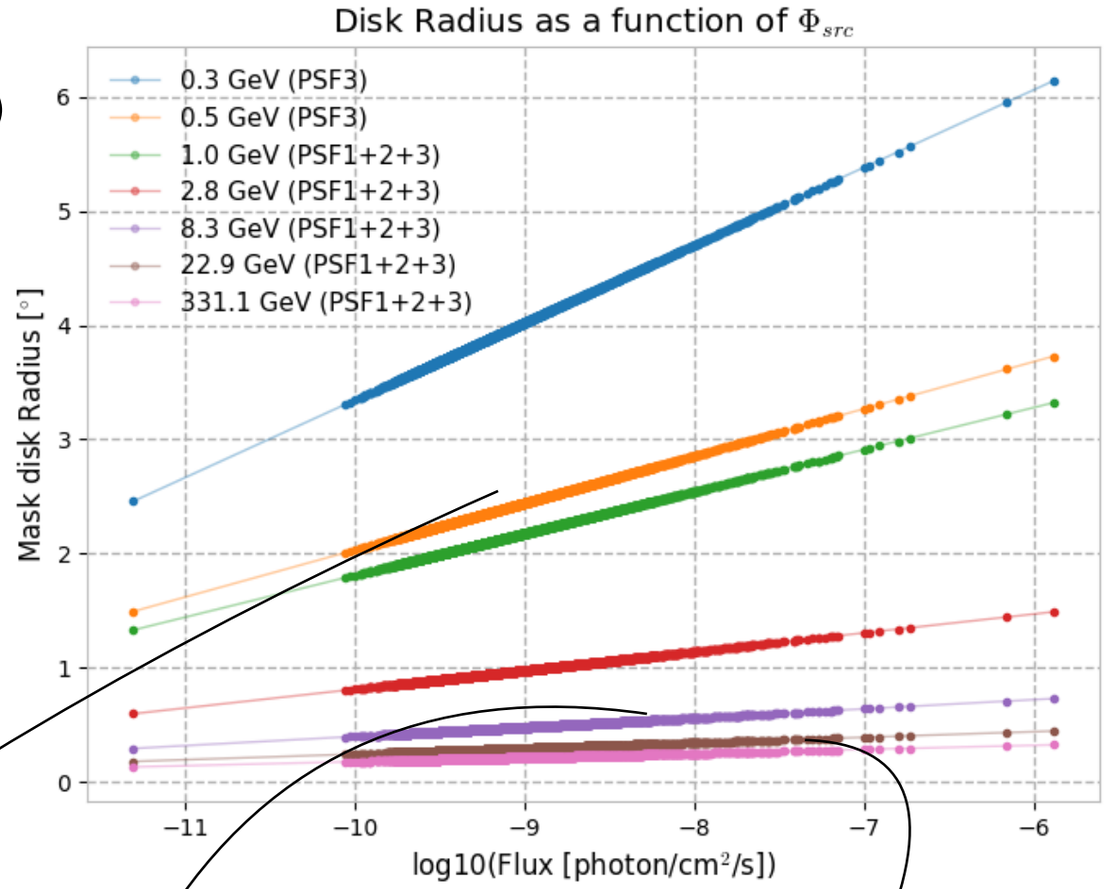
Circular region with **flux (Φ)** and **energy (E)** dependent radius:

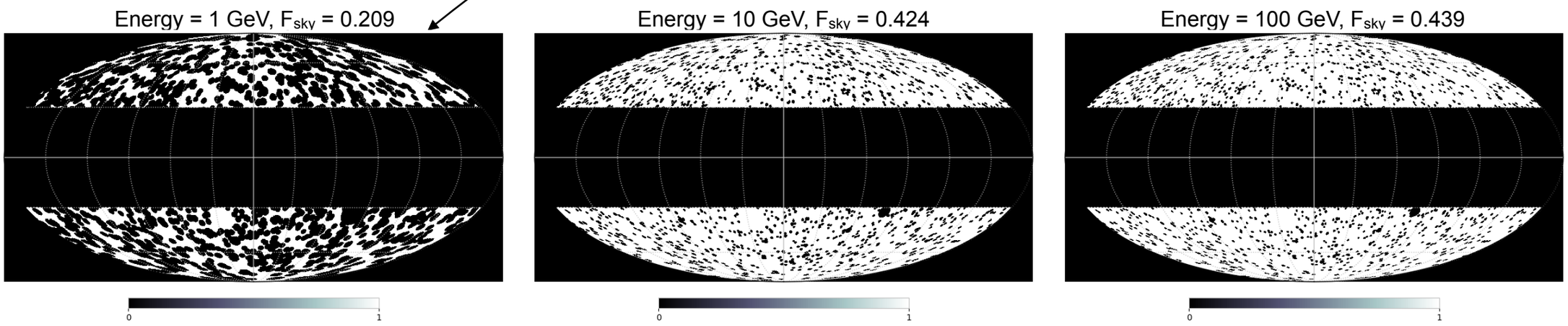
- 2 x PSF(E) @ Φ_{min}
- 5 x PSF(E) @ Φ_{max}
- Varying logarithmically with Φ

EXTENDED SOURCE MASK

Circular region with radius:

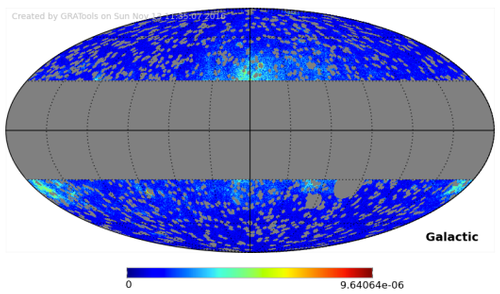
- 10x PSF(E) for CenA and LMC
- 5 x PSF(E) for all the others



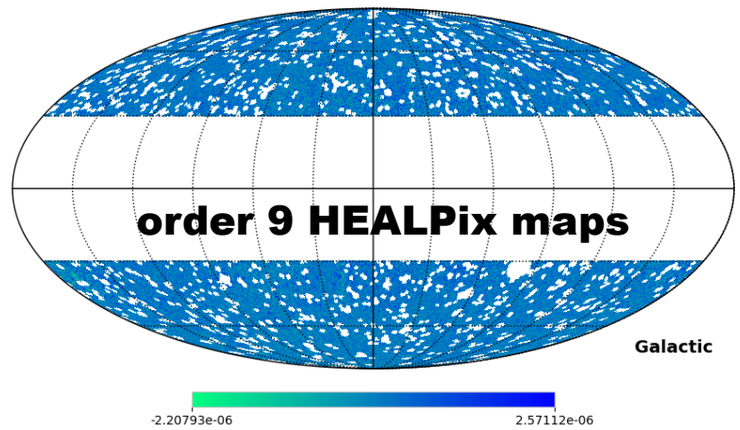


[1] F. Acero et al. (Fermi-LAT coll.) (2015), arXiv: 1501.02003v3 [astro-ph.HE]

ANGULAR POWER SPECTRUM



FOREGROUND SUBTRACTION [1]



From Intensity…

$$I(E,\theta)^{meas} = I(E,\theta)^{sig} \times PSF(E,\theta) + I_N(E)$$

decomposition into spherical harmonics:

$$C_l \approx \langle \| \int d\vec{n}\ \delta I\ Y(\vec{n})^* \|^2 \rangle$$

Using PolSpice [2]

$$C_{l,E}(l)^{PolSpice} = C_{l,E}(l)^{sig} \times W_E(l)^2 + C_{N,E}$$

… to Angular Power Spectrum

WHITE NOISE CORRECTION

$$C_N = \frac{n^i_{\gamma,pix}/\widehat{(A^i_{pix})^2}}{\Omega_{pix}}$$ [3]

$$C_{l,E}(l)^{sig} = \frac{C_{l,E}(l)^{PolSpice} - C_{N,E}}{W_E(l)^2}$$

PSF and RESOLUTION CORRECTION [3]

$$W_E(l) = \frac{\int_{E_{min}}^{E_{max}} W(E,l)\frac{dN}{dE}dE}{\int_{E_{min}}^{E_{max}} \frac{dN}{dE}dE}$$

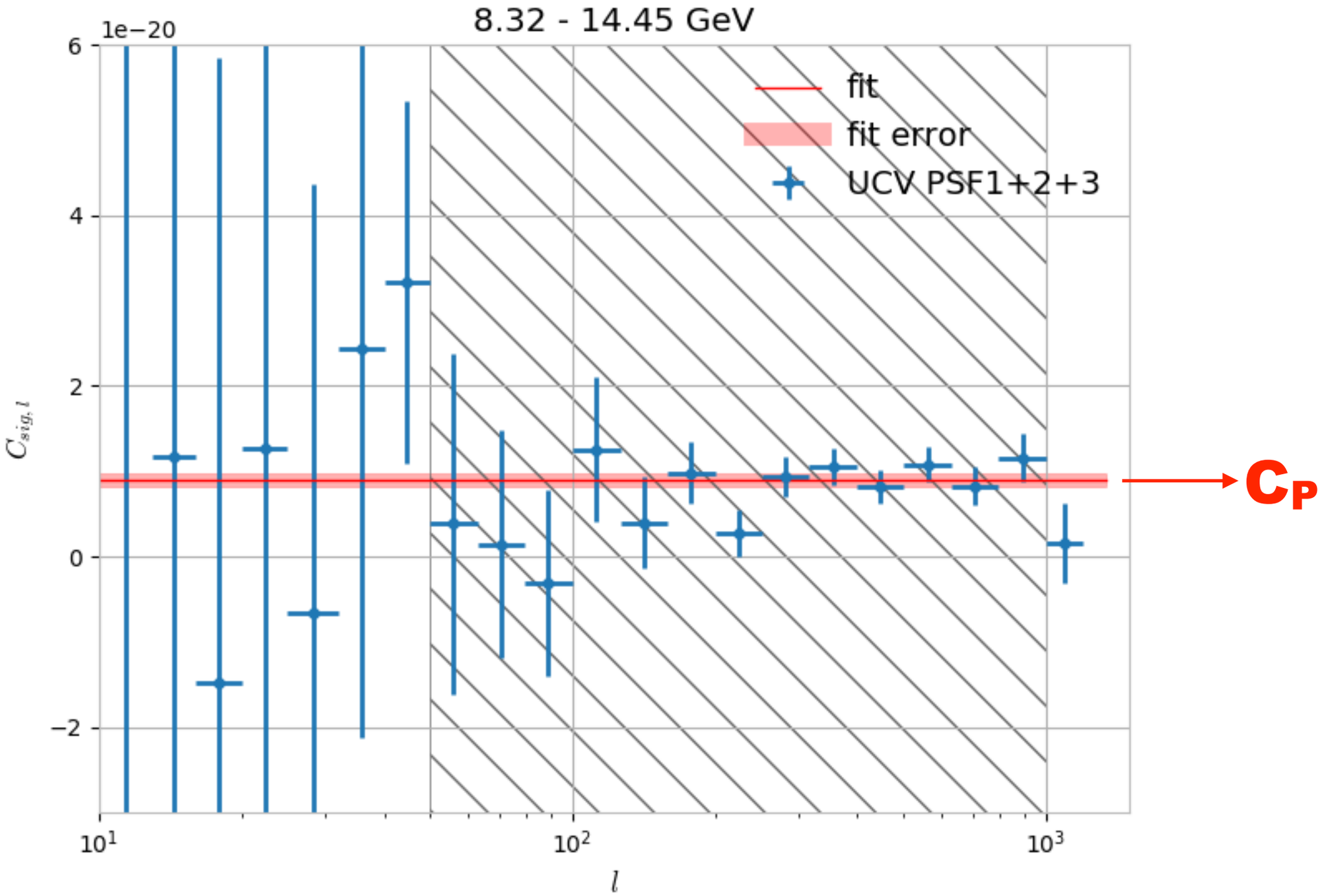
$$W(E,l) = W^{beam}(E,l) \cdot W^{pix}(l)$$

$$W_l^{beam}(E) = 2\pi \int_{\theta_{min}}^{\theta_{max}} P_l(cos\theta) PSF(\theta;E) sin\theta d\theta$$

[1] F. Acero et al.(Fermi-LAT coll.) (2016) arXiv:1602.07246v1 [astro-ph.HE]
[2] http://www2.iap.fr/users/hivon/software/PolSpice/
[3] M. Fornasa et al. (2016), arXiv:1608.07289 [astro-ph.HE].

FROM APS TO $C_P(E)$ - 1

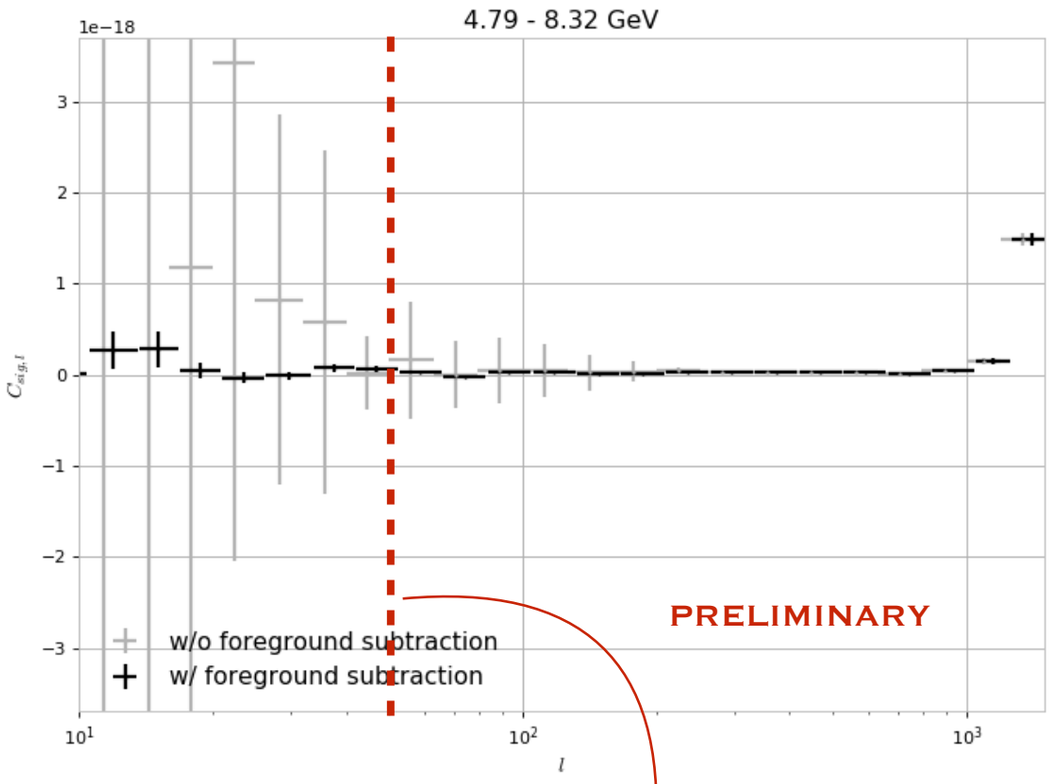
Hp: anisotropy dominated by shot noise of point-like sources —> random distribution —> **flat APS**



FROM APS TO $C_P(E)$ - 2

For each energy bin we define the range of multipoles to fit

@ LOW-MULTIPOLES
Residual foreground contamination



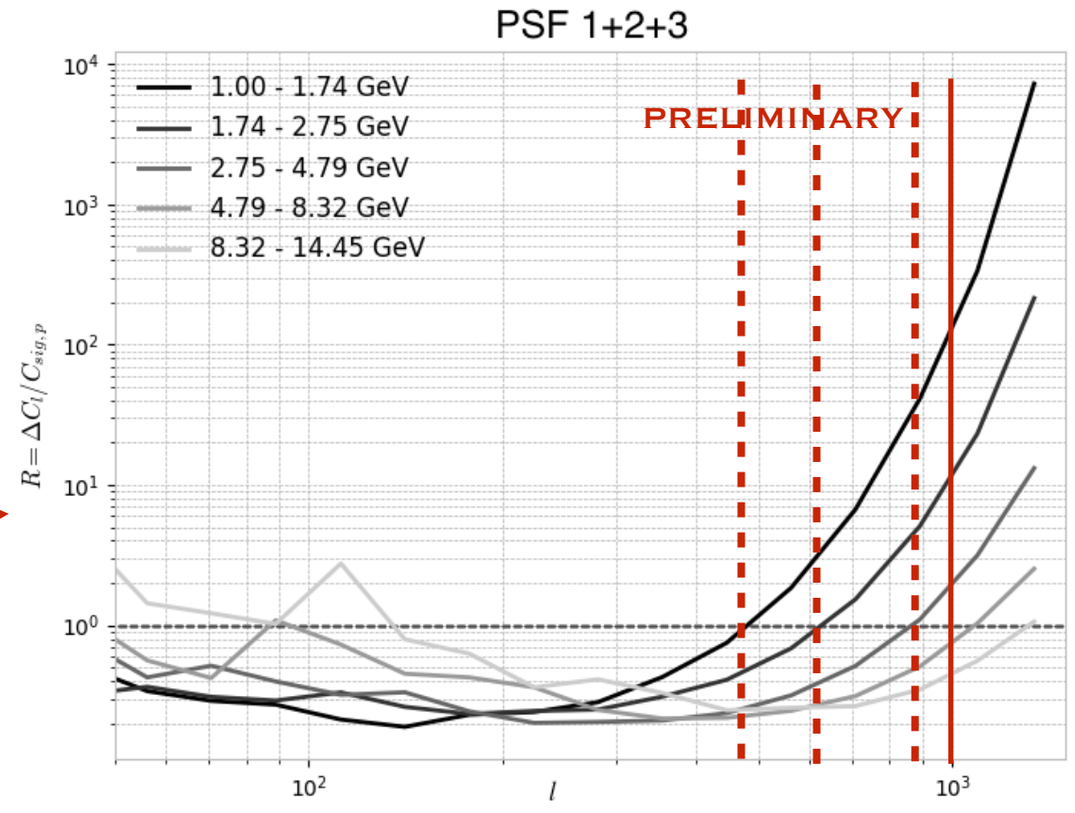
$\ell_{min} = 50$ [1]

$\ell_{max}(E)$

@ HIGH-MULTIPOLES
PSF correction can be inaccurate

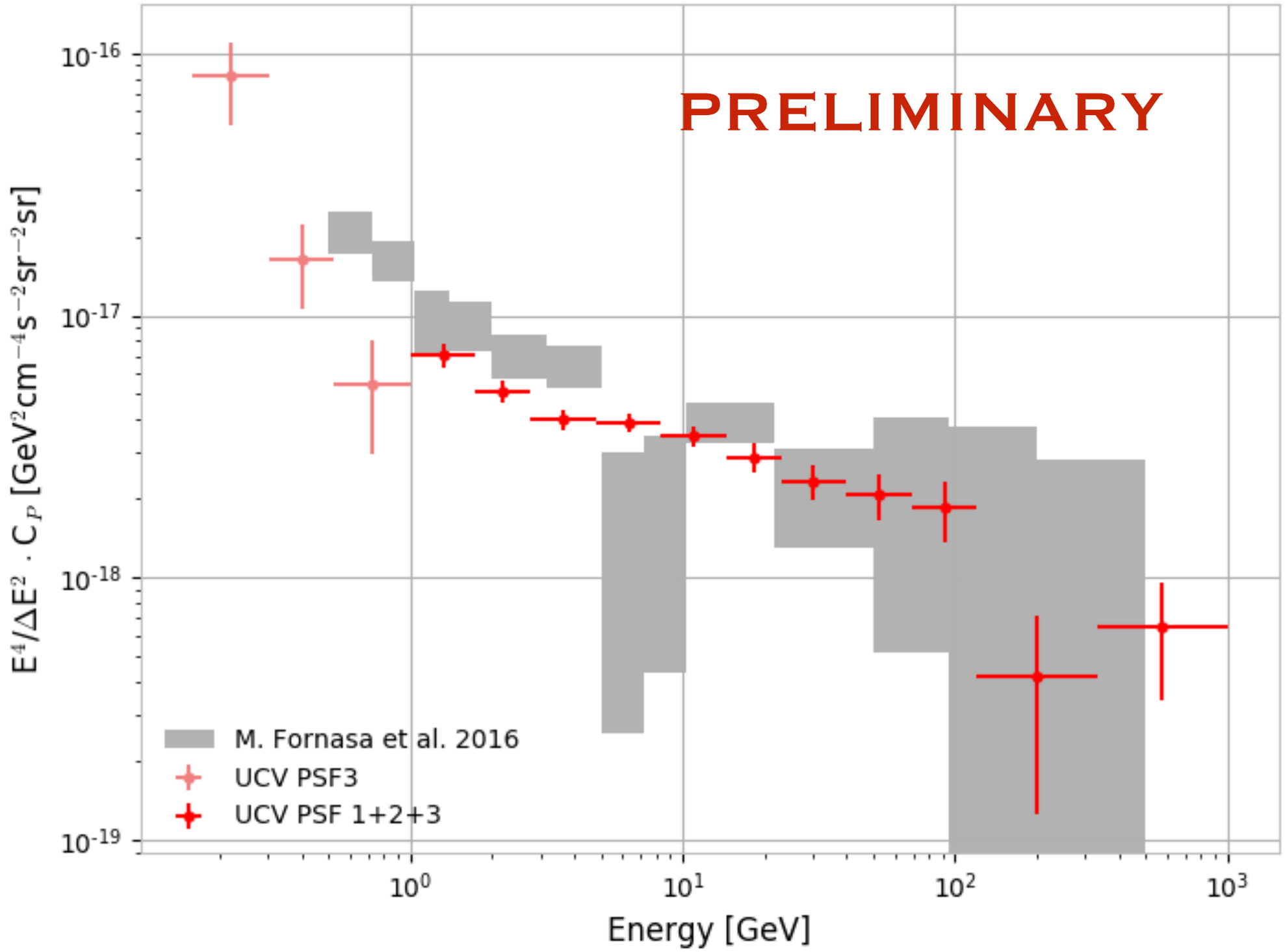
$$R(l_{max}) = \frac{\Delta C_l(l_{max})}{C_P^{l_{max}}} > 1$$

$$\Delta C_l = \sqrt{\frac{2}{(2l+1) f_{sky}}} \left(C_l + \frac{C_N}{W_l^2} \right)$$

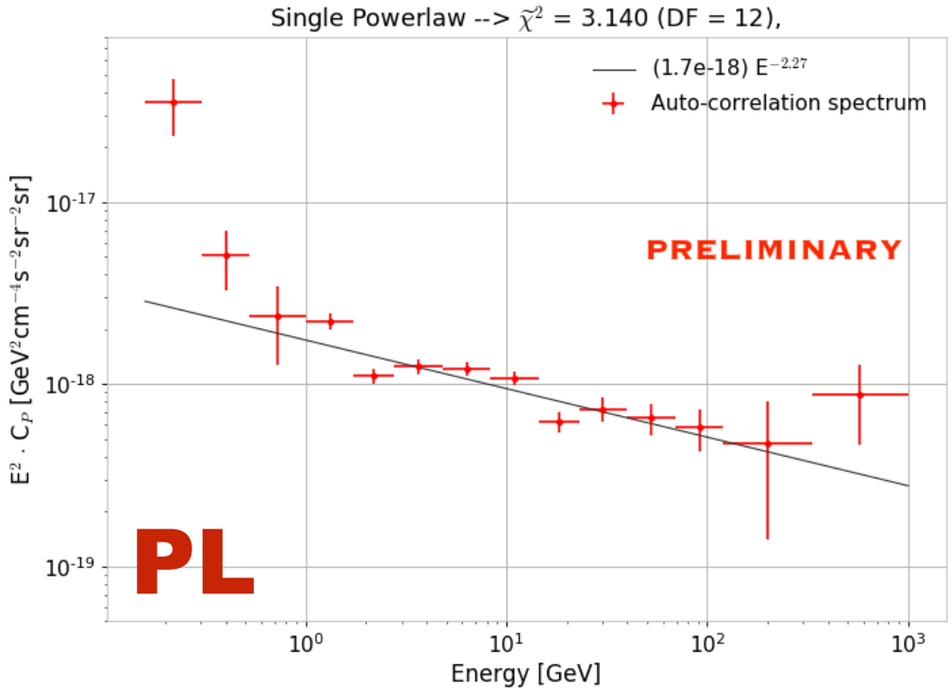


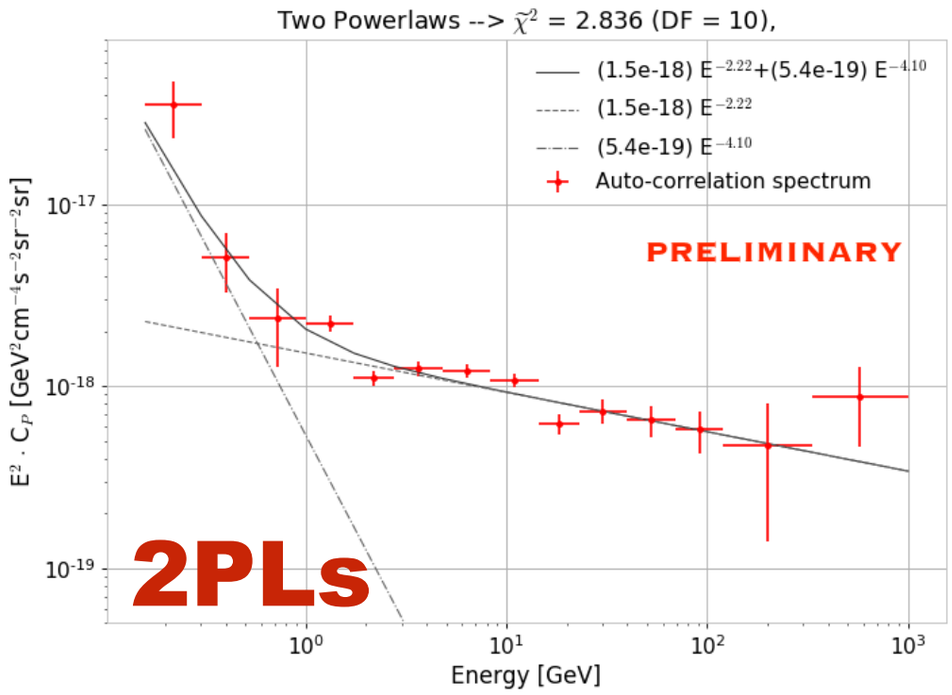
[1] M. Fornasa et al. (2016), arXiv:1608.07289 [astro-ph.HE].

ANISOTROPY ENERGY SPECTRUM



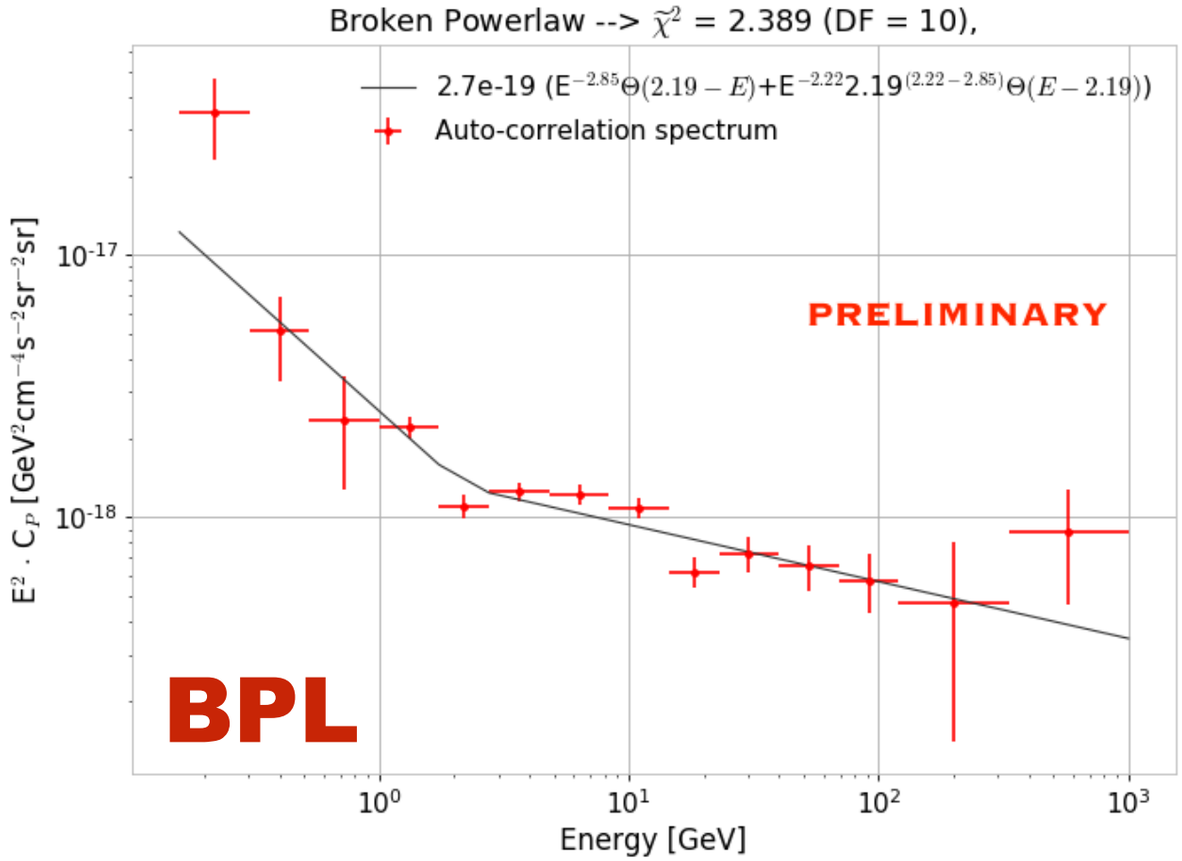
FIT OF AUTO-CORRELATION ENERGY SPECTRUM





Three hypothesis tested:

1. **PL** —> single power law
2. **2PLs** —> 2 power laws
3. **BPL** —> broken power law



"Break" scenario is favoured, which can mean:

1. one class of unresolved srcs with a break in the spectrum
2. two classes with PL spectra
3. ???

CROSS-CORRELATIONS IN ENERGY BINS

CROSS-CORRELATION in ENERGY BINS

CROSS-CORRELATION COEFFICIENT [1]

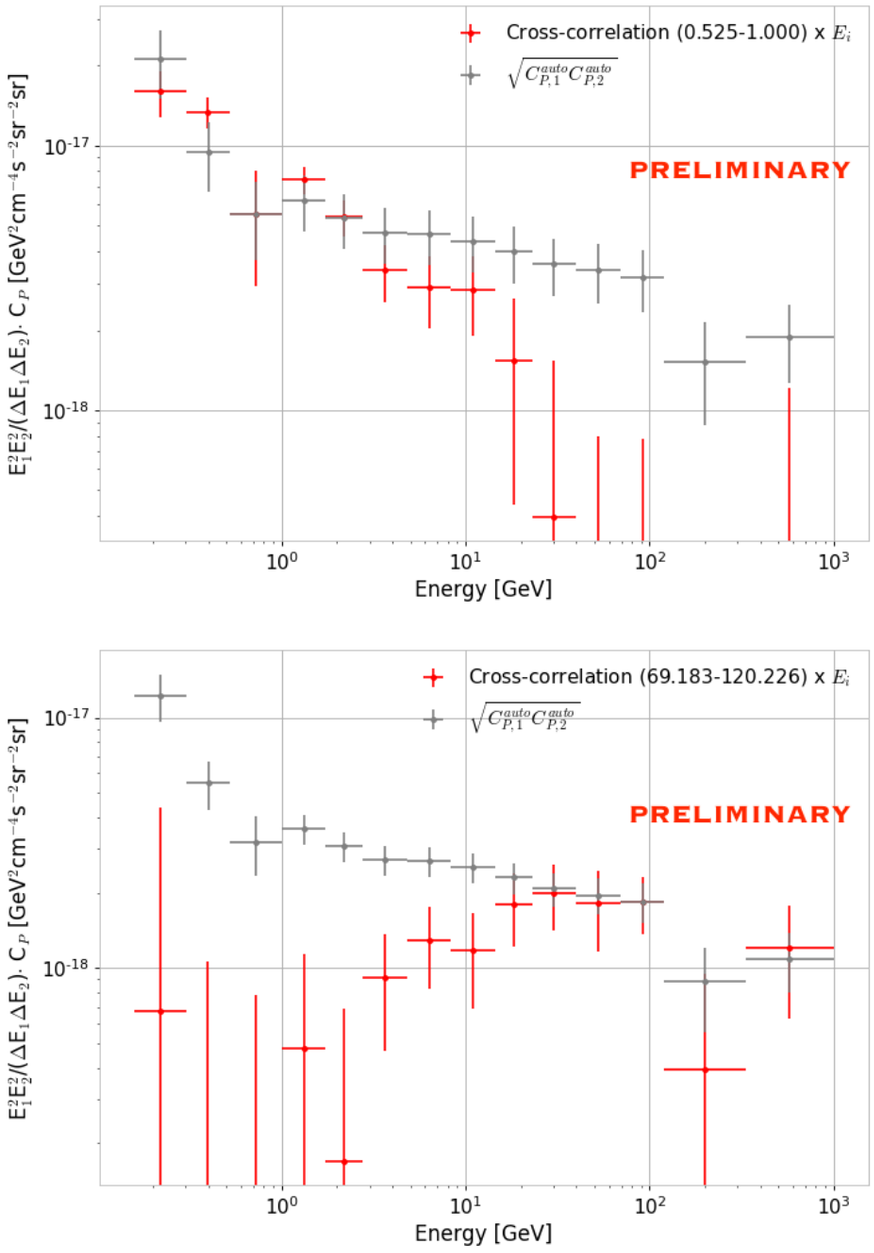
$$r_{ij} = \frac{C_P^{ij}}{\sqrt{C_P^{ii} C_P^{jj}}}$$

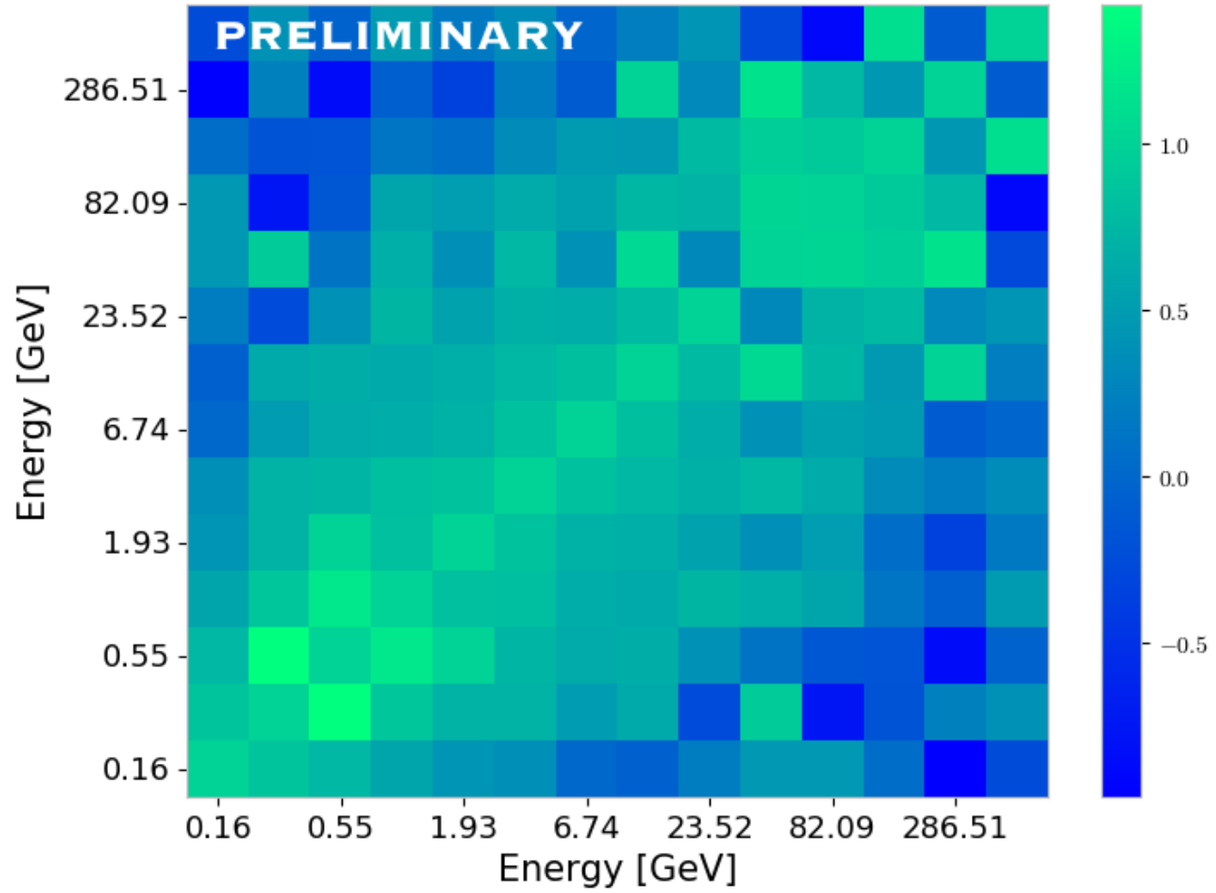
1. one class $r_{ij} = 1$

2. two classes $r_{ij} < 1$

$$C_p^{i,j} = \int \frac{dN}{dS} S^i S^j dS$$

$$S(E) \propto E^{-\beta}$$





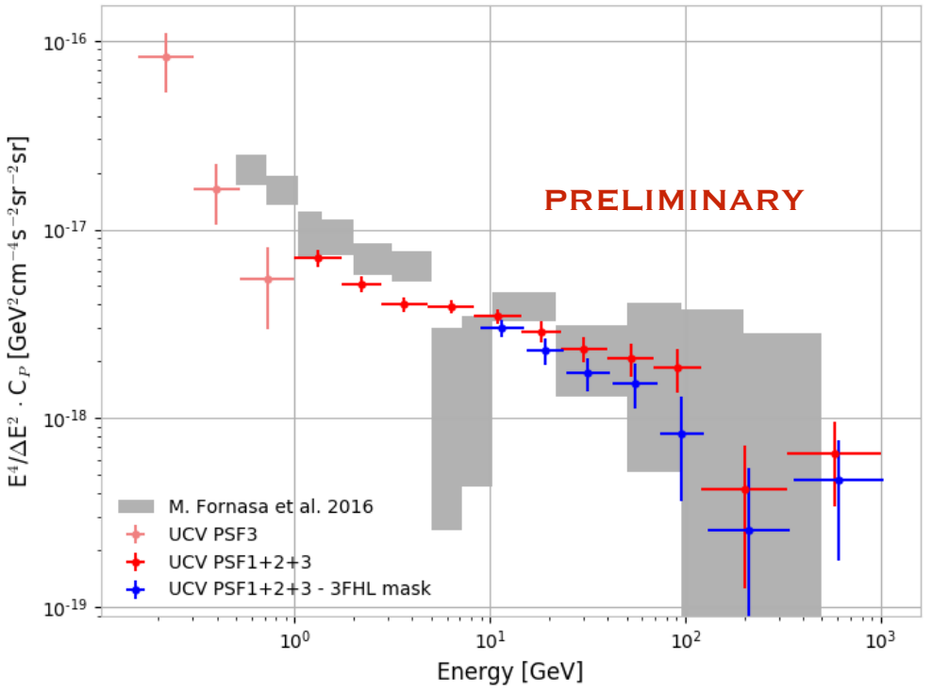
... unless due to threshold dependent effects...

[1] M. Fornasa et al. (2016), arXiv:1608.07289 [astro-ph.HE].

SOURCE CATALOG DEPENDENCE

ANISOTROPY ENERGY SPECTRUM CHANGES BY CHANGING THE MASKED SOURCE CATALOG

3FGL VS 3FHL[1] @ E > 10 GeV



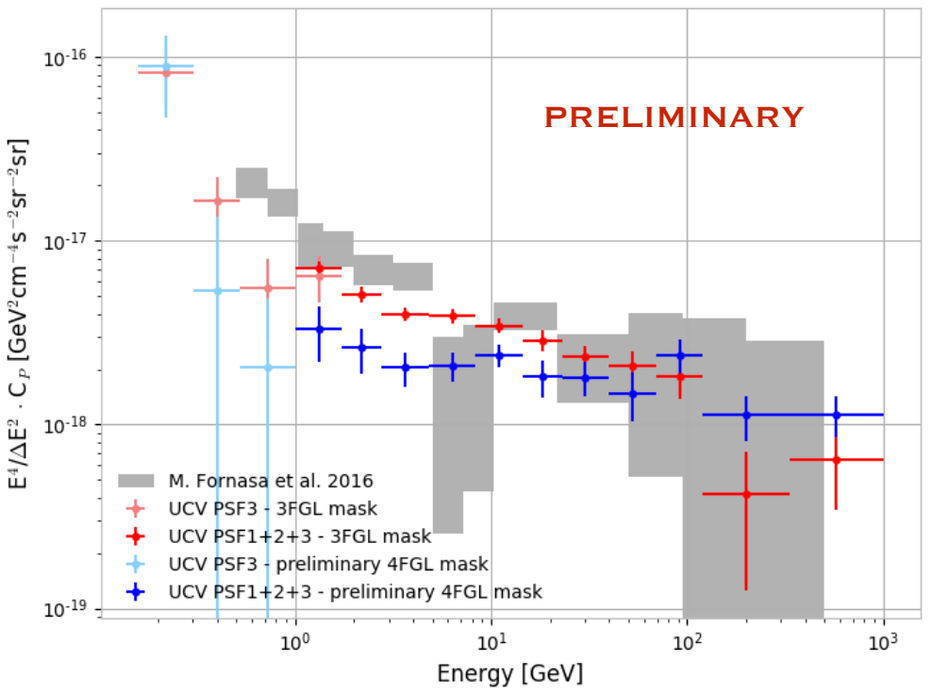
The physical interpretation is not trivial!

$$C_p = \int_0^{S_{max}} (1-\omega(S'))S'^2 \frac{dN}{dS'} dS'$$

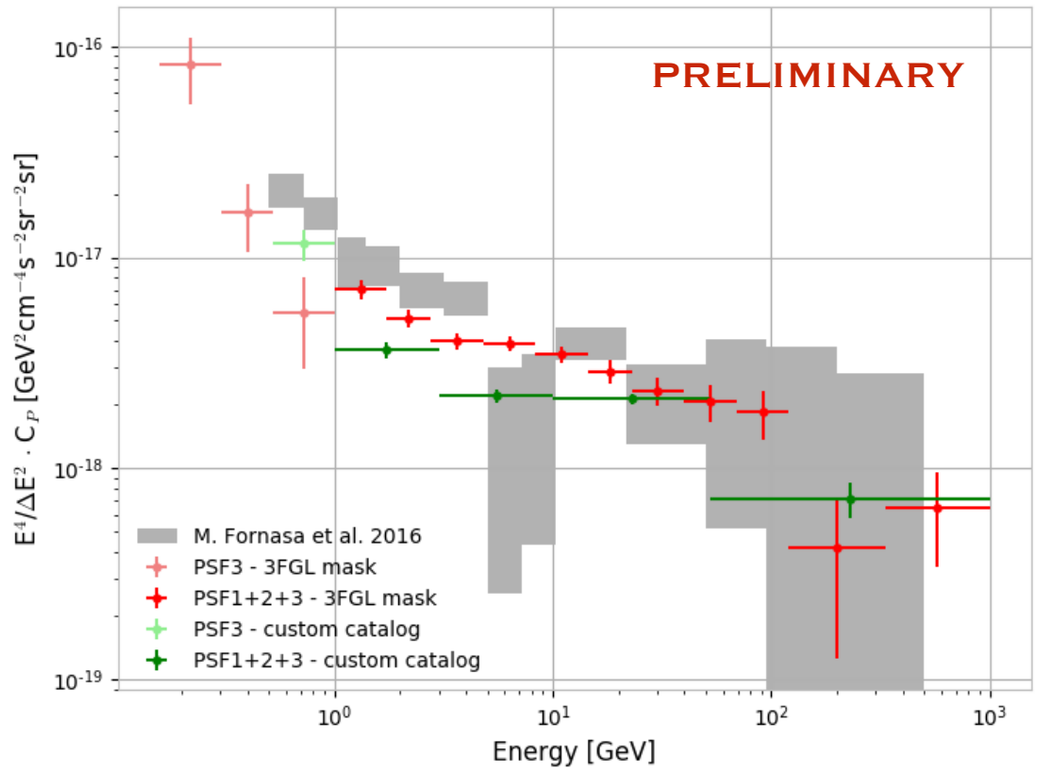
Need to know the **detection efficiency** of the instrument for the catalog used, possibly **in each energy bin**.

Future plans:
produce “custom catalogs" in different energy bins (Fermi Tools) and estimate the detection efficiency via simulations

3FGL VS ~4FGL[2]



3FGL VS Custom Src List[3] in 5 E bins



[1] M. Ajello et al. (Fermi-LAT coll.) (2017), arXiv: 1501.02003v3 [astro-ph.HE]
[2] Courtesy of Toby Burnett.
[3] Courtesy of Mattia Di Mauro.

SUMMARY & CONCLUSIONS

- Analysis aspects:
  - General improvement of data with Pass 8:
    - more statistics,
    - cleaner data selection and
    - PSF types
  - Energy-dependent analysis: Masks, multipole range
- APS and X-corr suggest multiple populations of unresolved sources, but interpretation needs more studies
- Assess APS dependance on point source catalog that is masked and its detection efficiency

SPECIAL ACKNOWLEDGMENTS

Doc. **Luca Latronico**

Prof.s **Nicolao Fornengo** and **Marco Regis**

Fermi-LAT Collaboration

THANK YOU FOR YOUR ATTENTION!

backup

WINDOW FUNCTIONS

$$W_l = W_l^{beam} \cdot W_l^{pix}$$

PIXEL WINDOW FUNCTION: RESOLUTION CORRECTION ~ 1 for order 9 maps

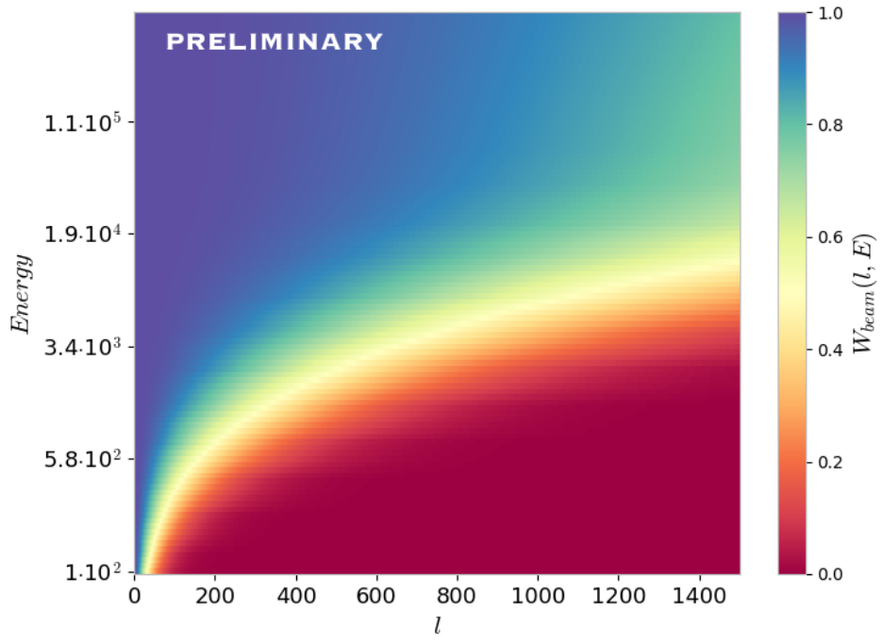
BEAM WINDOW FUNCTION: PSF CORRECTION

$$W_l^{beam}(E) = 2\pi \int_{\theta_{min}}^{\theta_{max}} P_l(cos\theta) PSF(\theta; E) sin\theta d\theta$$

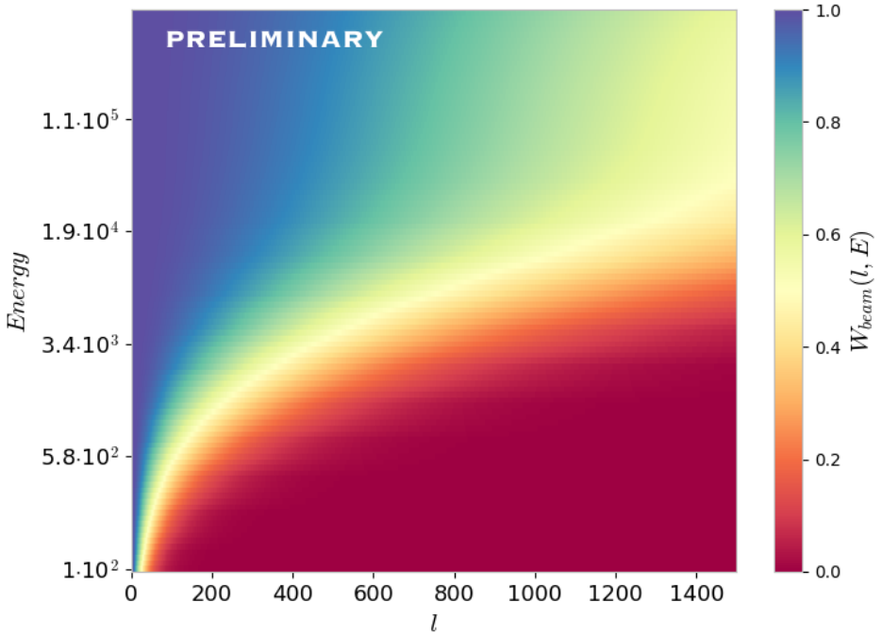
$$\langle W_l \rangle = \frac{\int_{E_{min}}^{E_{max}} W_l(E) \frac{dN}{dE} dE}{\int_{E_{min}}^{E_{max}} \frac{dN}{dE} dE}$$

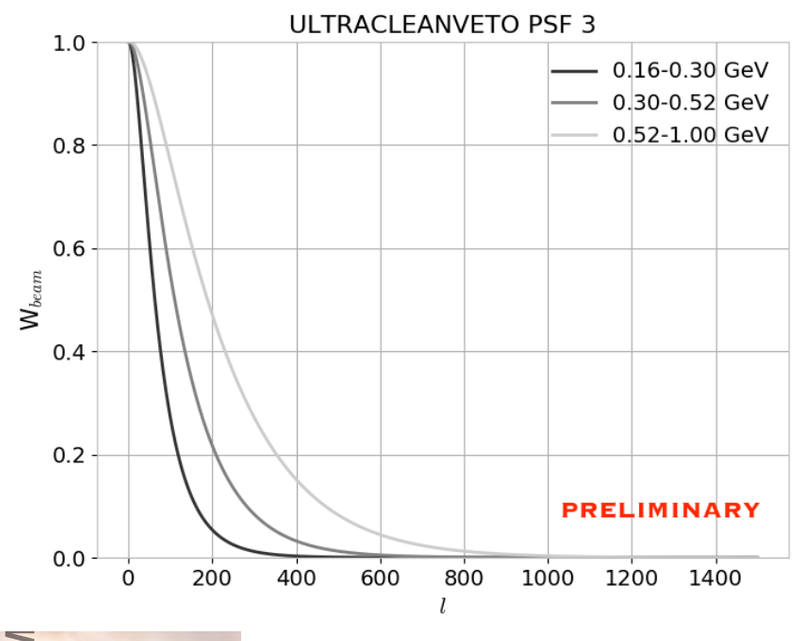
dN/dE ~ E$^{-2.3}$

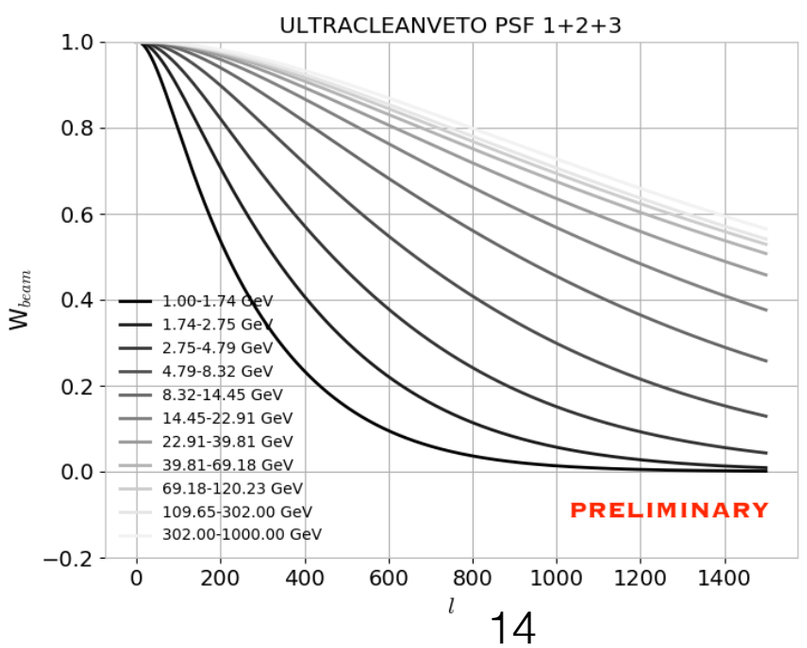
PSF 3



PSF 1+2+3







FOREGROUND SUBTRACTION

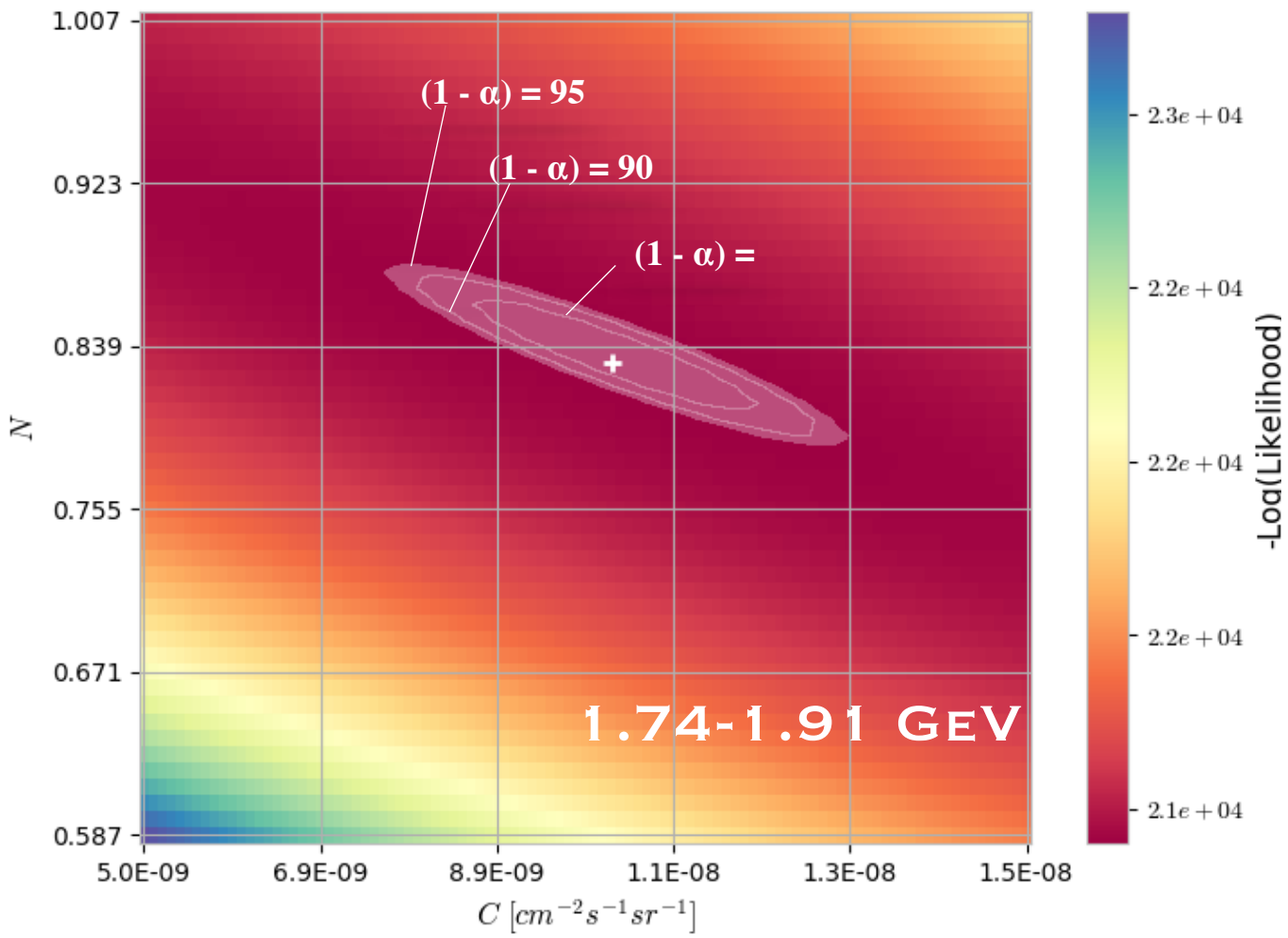
Galactic diffuse emission model: **gll_iem_v6.fits**

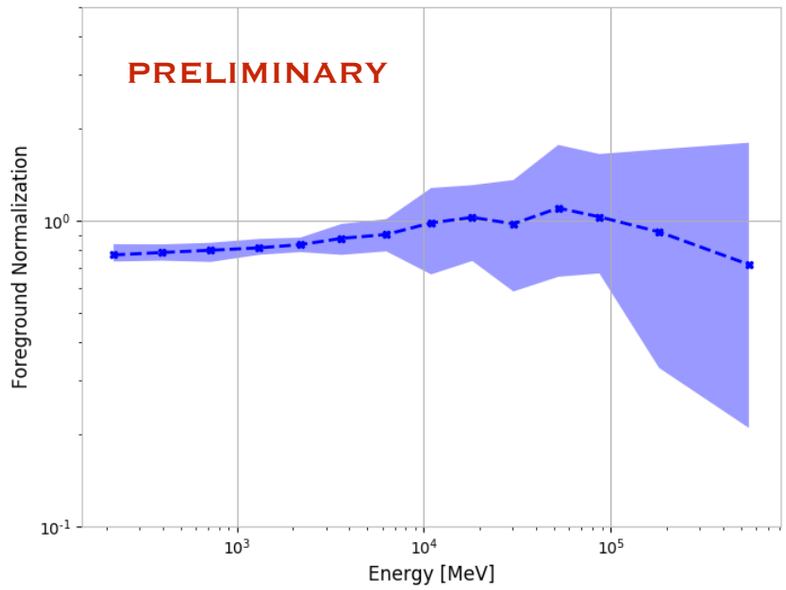
$$\Phi_{data} = N\Phi_{model} + C$$

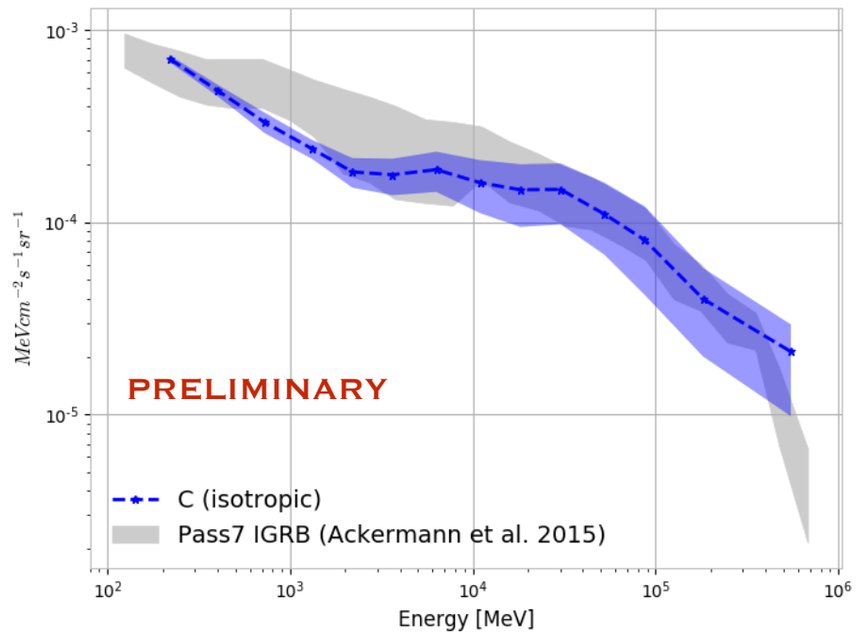
$$log(L) = \sum_{i^{th}_{pixel}} D_i log(F_i) - F_i - log(D_i!) \quad [1]$$

$$F_i = N\Phi_{fore} + C$$

pixels outside the mask

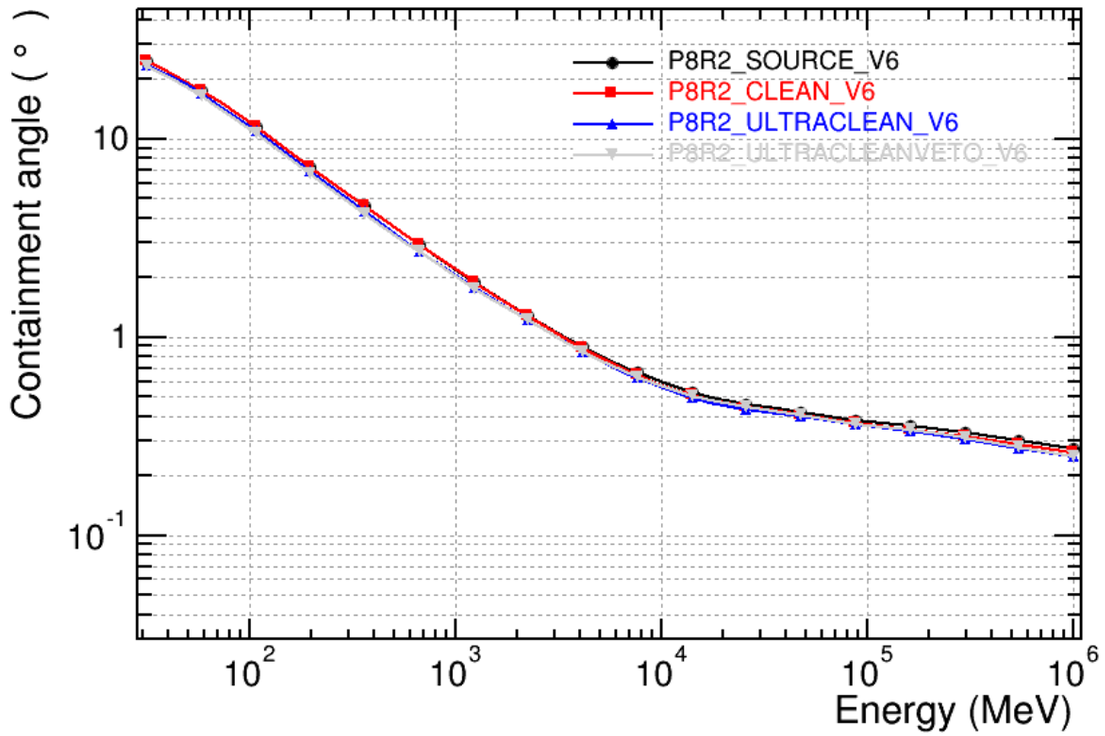


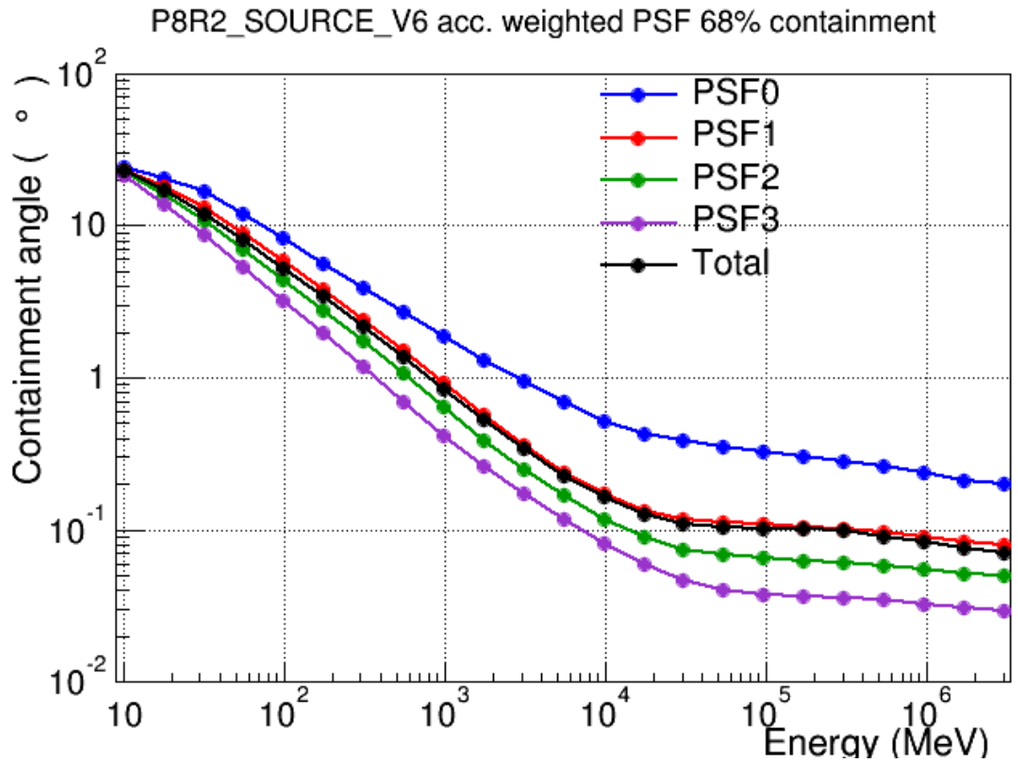




[1] F. Acero et al.(Fermi-LAT coll.) (2016) arXiv:1602.07246v1 [astro-ph.HE]

Pass 8 PSF 68% cont. [1]





[1] SITO LAT PERFORMANCES