Fermi Gamma-ray Space Telescope

Deriving the contribution of point sources to the Fermi-LAT Extragalactic gamma-ray background with efficiency corrections and photon statistics

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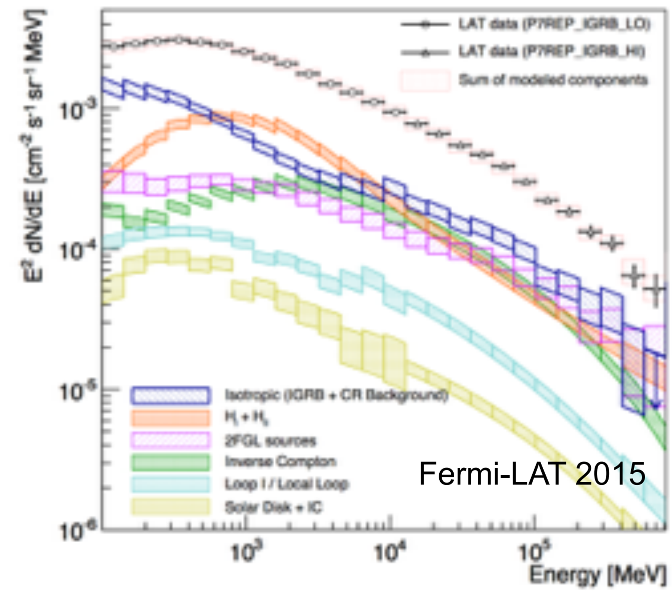
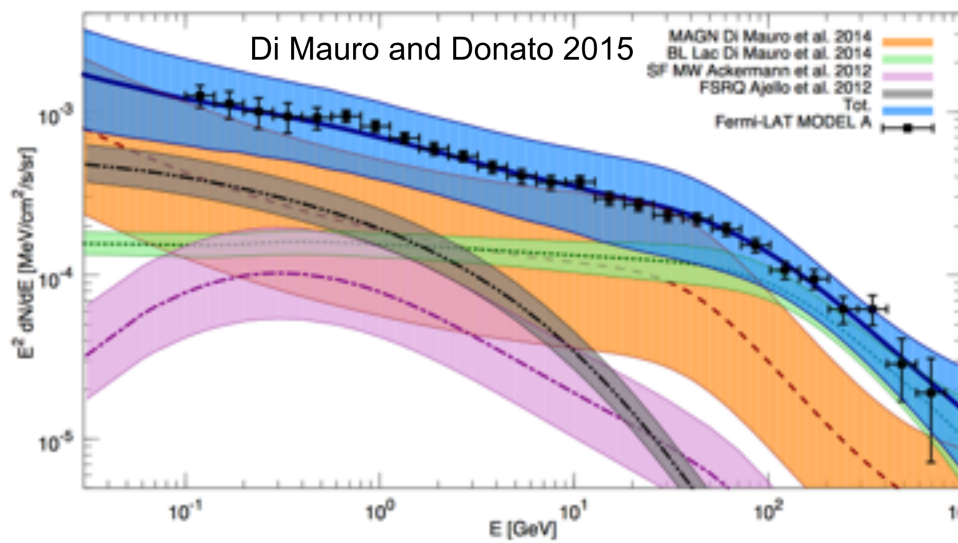
Interpretation of IGRB and EGB with population studies of Fermi-LAT sources

- **IGRB**: highly isotropic component of the gamma-ray sky whose composition is thought to be dominated by unresolved sources.
- **EGB**: sum of IGRB and detected sources.
- The EGB and the IGRB are interpreted with the gamma-ray emission of extragalactic sources: AGN and Star-Forming Galaxies (see e.g. Di Mauro et al. 2014 *ApJ* 780 161).
- These results are based on:
  - **Blazars**: gamma-ray population of Fermi-LAT sources **(40-60% of IGRB)**.
  - **Radio Galaxies and Star Forming Galaxies**: correlations between gamma-ray and radio or infrared emissions.
- These studies are based on extrapolations below the sensitivity of Fermi-LAT catalogs or on uncertain correlations between different wavelengths.





Efficiency corrections and 1pPDF methods

Goal: measure the dN/dS of the real sky independently with:

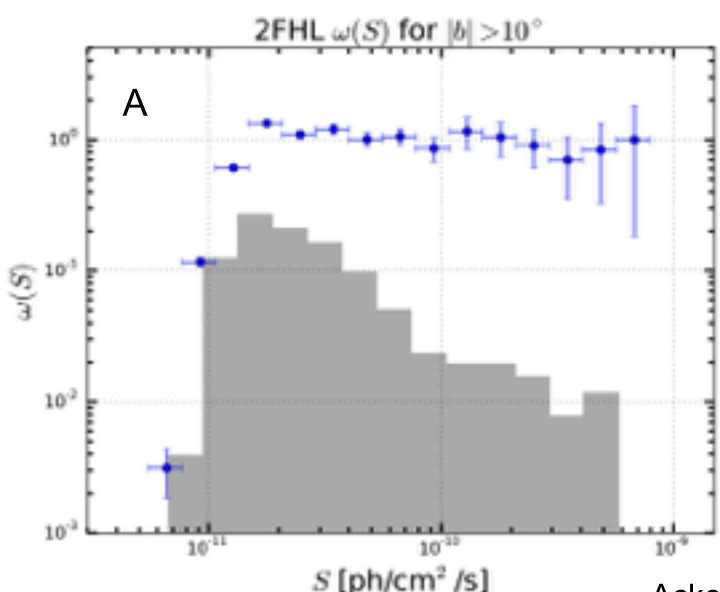
A. Efficiency method: correct the LogN-LogS of the catalog for the efficiency (see e.g. Ackermann et al 2015).

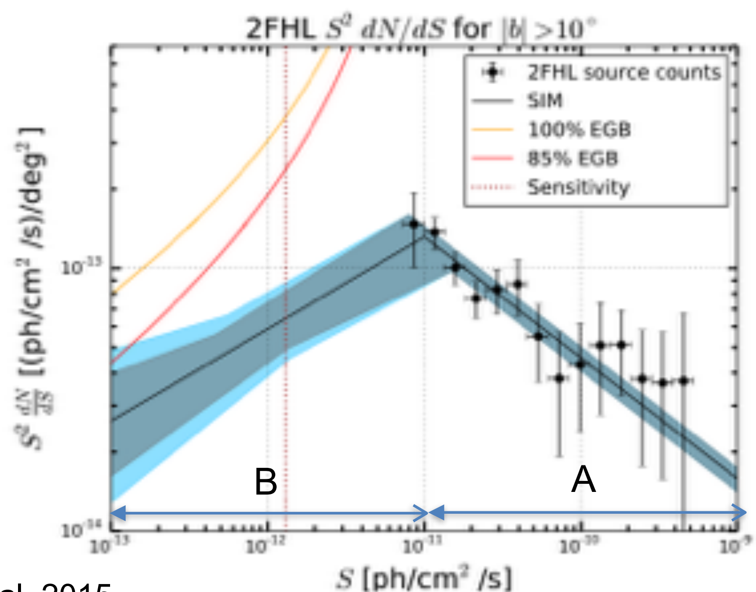
B. Photon statistics: 1pPDF method (Hannes et al. 2016/2017).

Part A. We are going to employ **Fermipy** (a python package that automates Science Tool (ST) analysis (http://fermipy.readthedocs.org/en/latest/index.html)).

Part B. We will use also the 1pPDF developed by Hannes et al. 2016/2017.

- We consider four energy bins: **1-3.16, 3.16-10, 10-50 and 50-2000 GeV.**





Ackermann et al. 2015

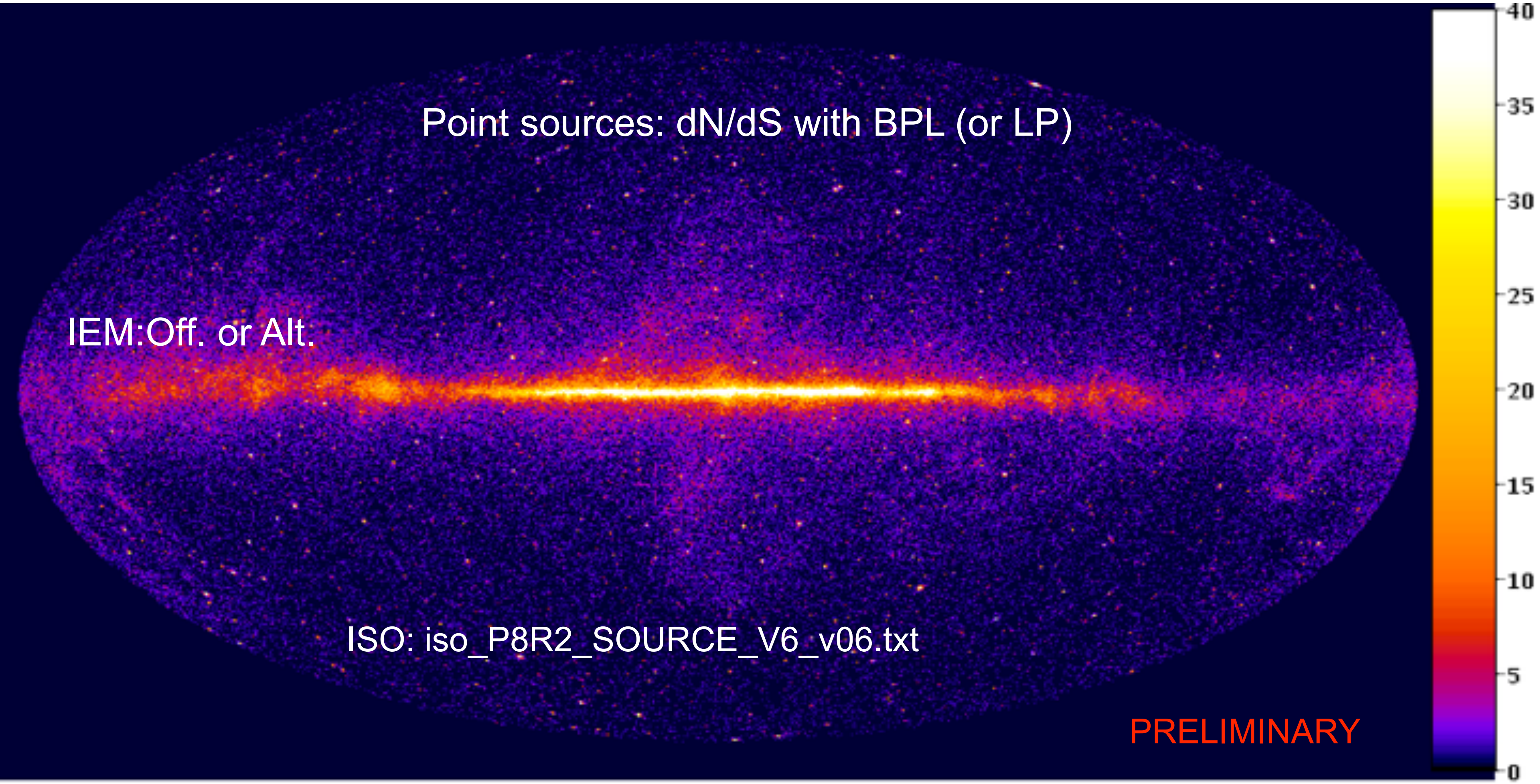
Pipeline for the efficiency correction method

- We use the tools included in **Fermipy** to find sources, make TS maps, simulate sources and create the fits file of the catalog.
- We divide the sky into **hundreds of ROIs**. Adjacent ROIs have an overlap of 2 deg.
- We run the pipeline **independently** in each ROI.
- The initial source model includes only the ISO and IEM templates. On top of this model a TS map is created and new sources are found.
- Fitting the ROI we find the SED parameters using a PL energy spectrum.
- We perform this source finding iteratively detecting first the highest TS sources and then fainter sources with TS>10.
- We employ the Official IEM released with Pass 8 data (**Off**., Acero et al. 2016) and the Sample model of the Pass 8 GC analysis (**Alt**., Ackermann et al. 2017).
- We simulate the flux of sources using a Broken Power Law (BPL) or Log Parabola (LP) shape for the dN/dS.

$$\frac{dN}{dS} = K \begin{cases} S^{-\gamma_1} S_b^{\gamma_1-\gamma_2}, & S \leq S_b \\ S^{-\gamma_2}, & S > S_b, \end{cases} \qquad \frac{dN}{dS} = K \left(\frac{S}{S_0}\right)^{-\alpha+\beta \log\left(\frac{S}{S_0}\right)}$$

Simulating the gamma-ray sky

We generate simulations with FermiPy including the following components.



Count map for E=[10,1000] GeV pixel size 0.2deg

Efficiency and corrected dN/dS

- We generate 10 simulations and we analyze them with FermiPy.
- Using the list of detected and simulated sources we can find the efficiency:

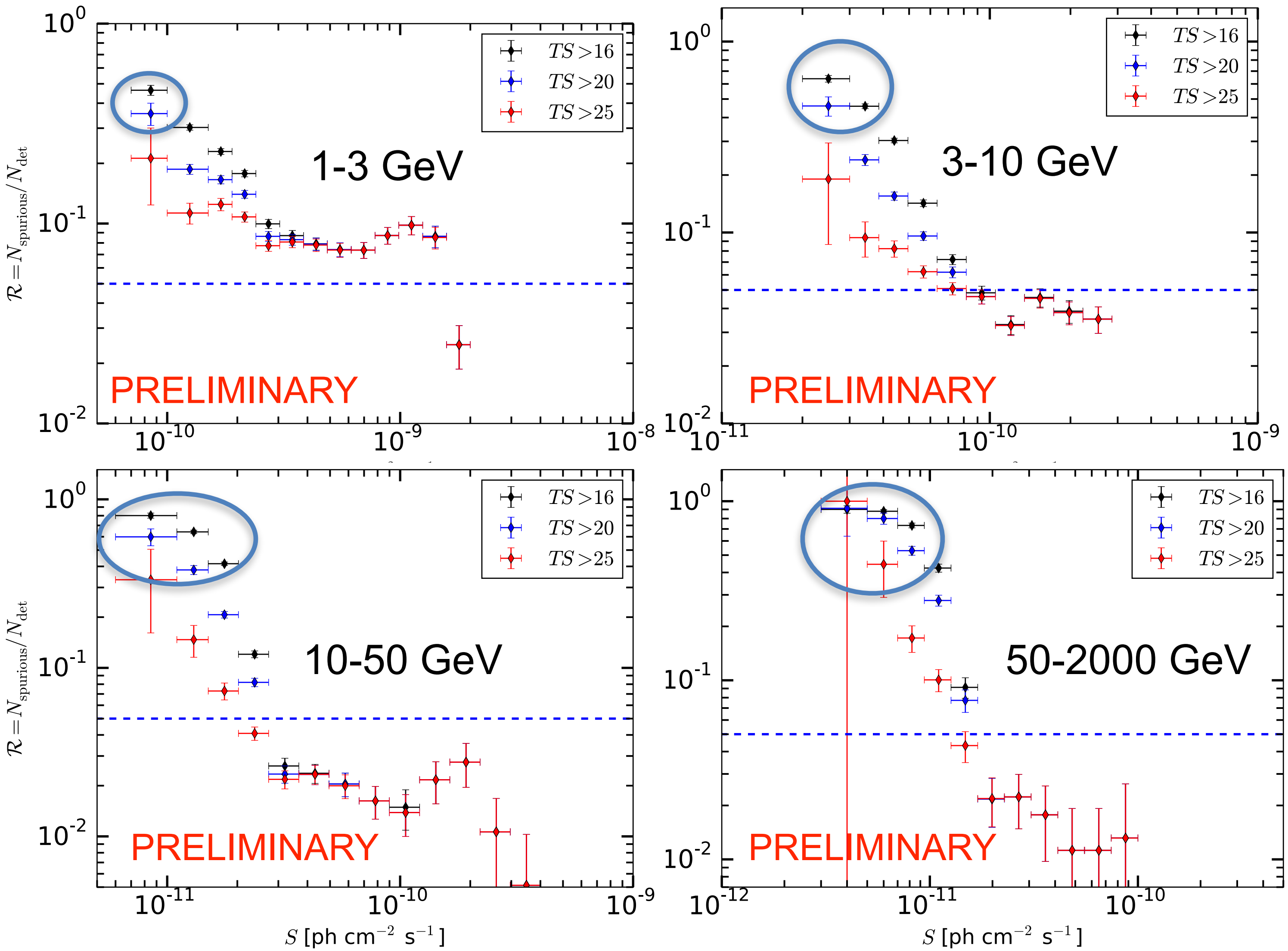
$$\omega(S_i) = N_{\mathrm{det,i}}(S_i^{\mathrm{obs}})/N_{\mathrm{sim,i}}$$

- We only select detected sources that have been simulated: we thus eliminate spurious sources.
- We use the 95% positional error of detected sources to select real sources.
- From the efficiency we can correct the observed dN/dS of the catalog and find the corrected source count distribution.

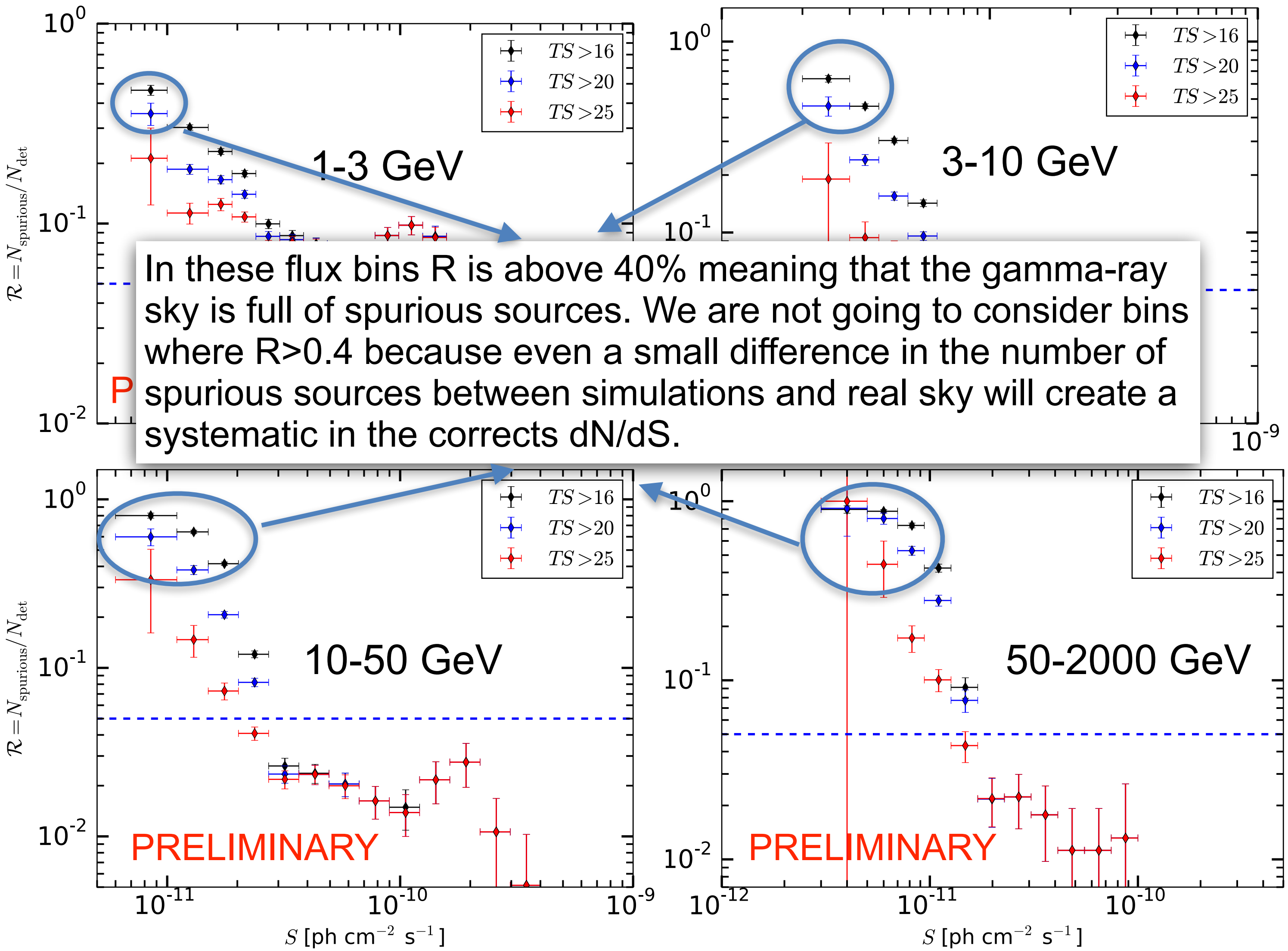
$$\frac{dN}{dS}(S_i) = \frac{1}{\Omega \Delta S_i} \frac{N_i(1-\mathcal{R}_i)}{\omega(S_i)}$$

→ R is the ratio of spurious and total number of detected sources per each i-th flux bin.

Spurious sources

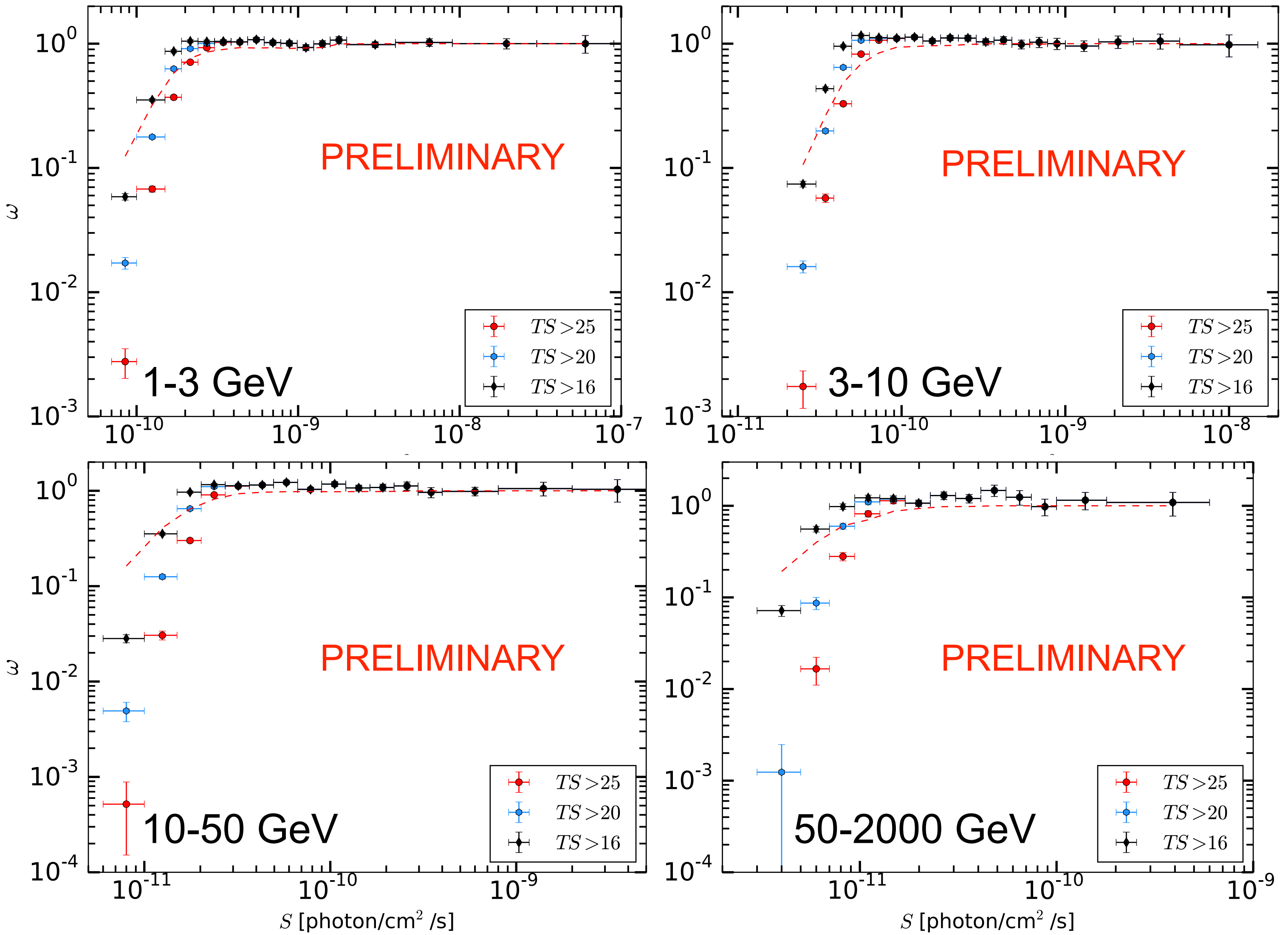


Spurious sources



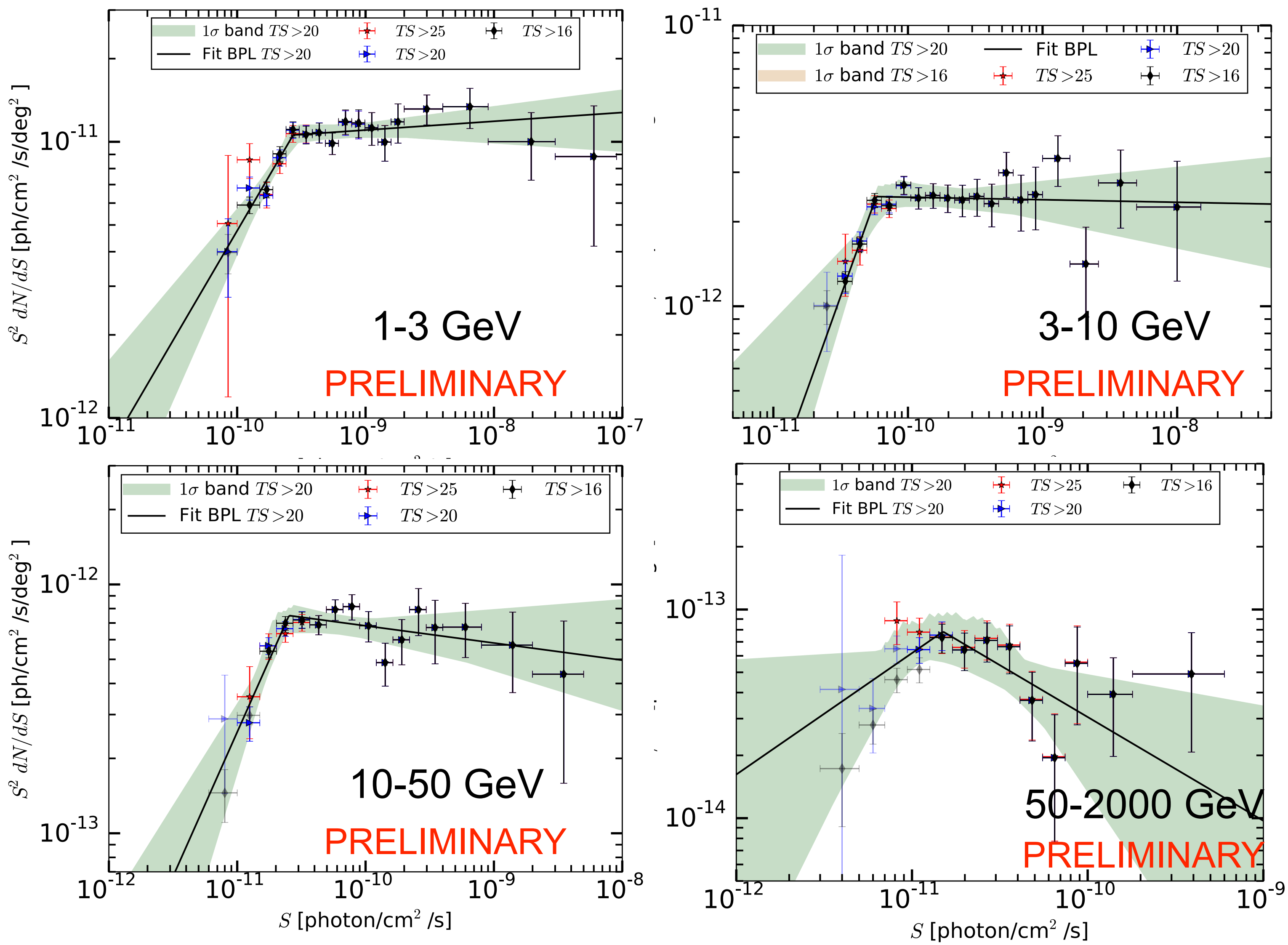
In these flux bins R is above 40% meaning that the gamma-ray sky is full of spurious sources. We are not going to consider bins where R>0.4 because even a small difference in the number of spurious sources between simulations and real sky will create a systematic in the corrects dN/dS.

Efficiency



PRELIMINARY
1-3 GeV
3-10 GeV
10-50 GeV
50-2000 GeV
TS >25
TS >20
TS >16
ω
S [photon/cm² /s]

Corrected LogN-LogS



Consequences 1

- dN/dS data derived with different cut in TS are compatible with each other.
- We detect a flux break for the bins 1-3, 3-10 and 10-50 GeV.
- We explain about **50%** of the EGB with detected and undetected point sources that in our catalogs are mostly blazars.
- **We need a faint population of sources that explains the remaining 50%!!!**

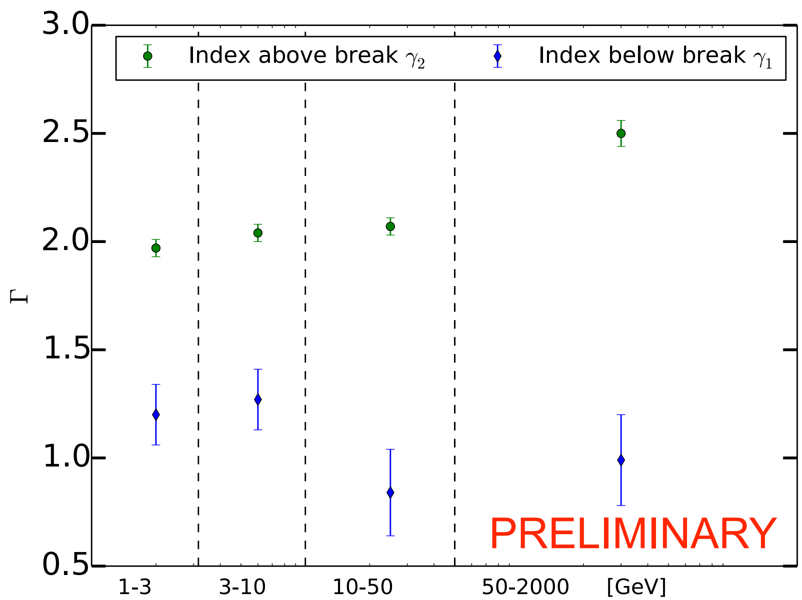
$$\mathcal{I} = \mathcal{F}_{\rm PS} + \int_0^{S_{\rm max}} S \frac{dN}{dS}(1-\omega)dS$$

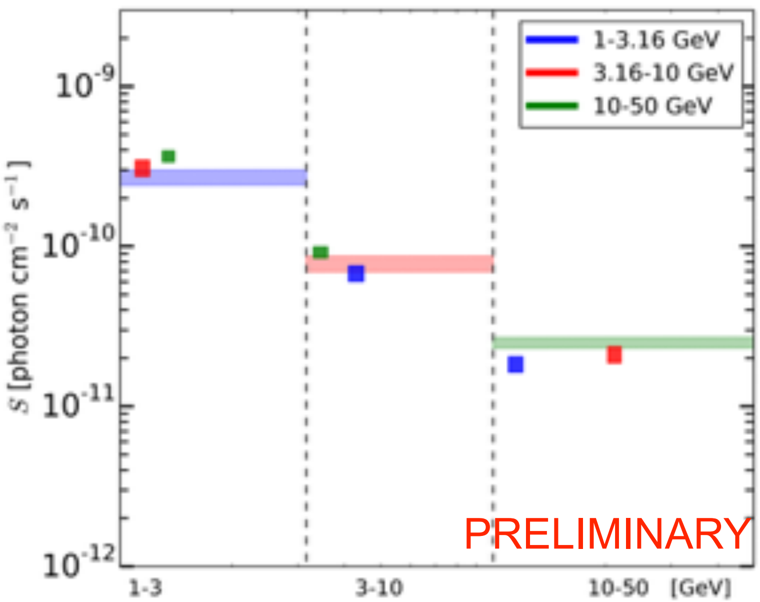
E [GeV]	γ_1	γ_2	S_b [ph cm^{-2}s^{-1}]	σ_b	$\mathcal{I}$/EGB [%]	$\mathcal{I}_{\rm IGRB}$ [ph cm^{-2} s^{-1} sr^{-1}]
$1-3$	1.20 ± 0.14	1.97 ± 0.04	$(2.7 \pm 0.3) \cdot 10^{-10}$	6.2	49^{+5}_{-5}	$(2.7^{+1.8}_{-0.9}) \cdot 10^{-8}$
$3-10$	1.27 ± 0.14	2.04 ± 0.04	$(7.8 \pm 0.9) \cdot 10^{-11}$	5.7	49^{+7}_{-7}	$(6.7^{+2.4}_{-2.3}) \cdot 10^{-9}$
$10-50$	0.84 ± 0.20	2.07 ± 0.04	$(2.6 \pm 0.2) \cdot 10^{-11}$	7.1	50^{+9}_{-9}	$(1.2^{+0.8}_{-0.7}) \cdot 10^{-9}$
$50-2000$	1.45 ± 0.68	2.50 ± 0.06	$(1.5 \pm 0.3) \cdot 10^{-12}$	1.0	40^{+60}_{-10}	$4.1 \cdot 10^{-11}$

Results for the sample of sources detected at TS>20

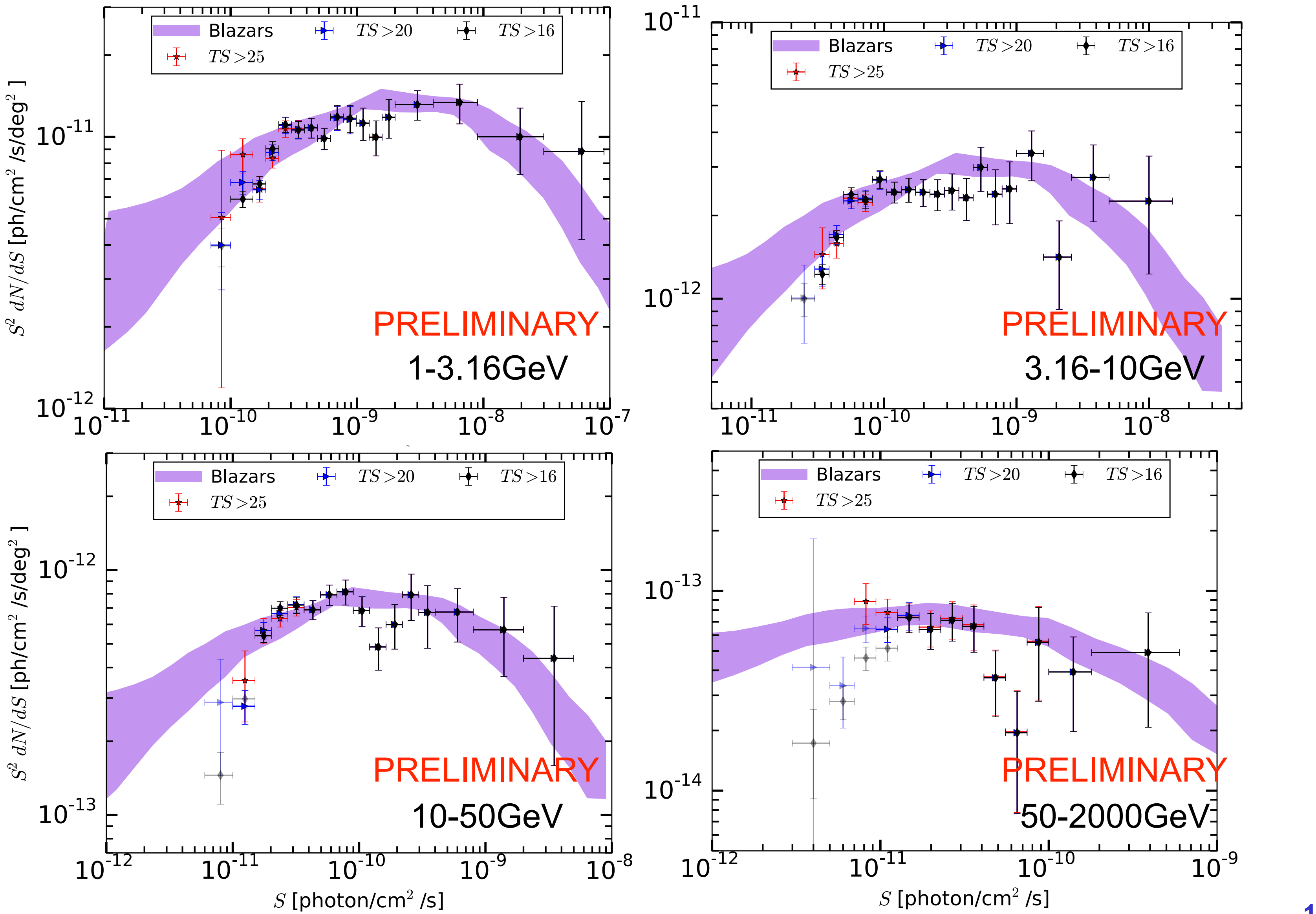
Consequences 2

- We detect at high significance the presence of a flux break for the first three bins.
- The slope above the break becomes softer while the slope below is constant around 1-1.5.
- **The flux break rescales quite well with the energy bins.**
- This implies that in the energy range 1-50 GeV we have the same population (blazars) for which the dN/dS rescales with the energy.





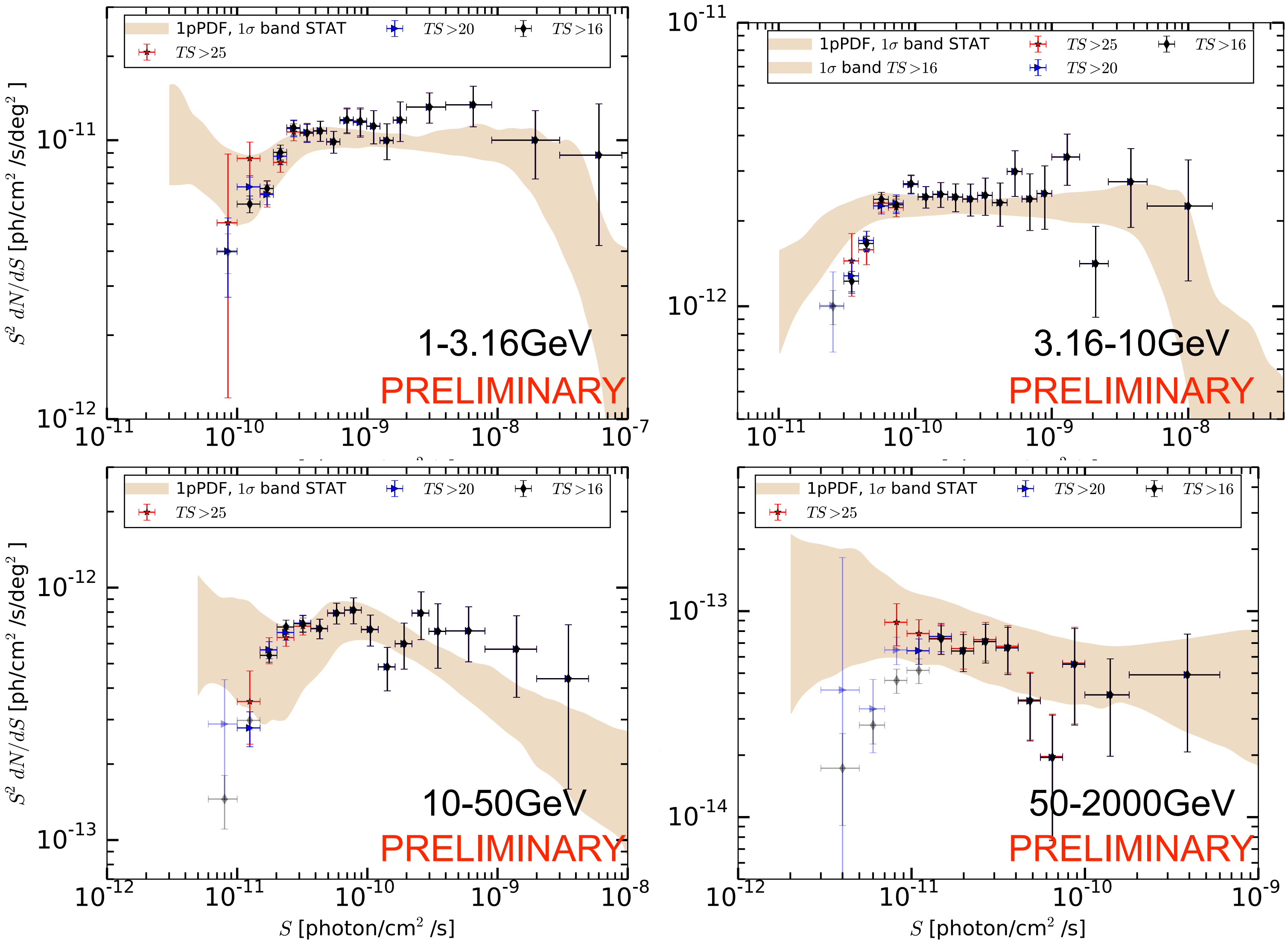
Comparison with model of blazars



Luminosity function of blazars from Ajello et al. 2016 with LDDE model.

Comparison between 1pPDF and efficiency corrections

- We use ULTRACLEANVETO with PSF3, HEALPix order 7 (Hannes et al. 2015 and 2016).



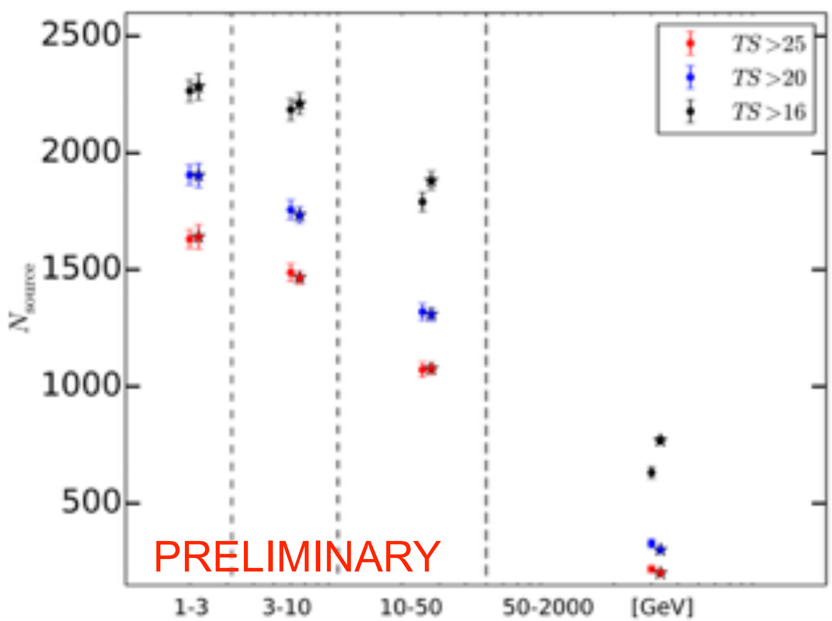
Conclusions

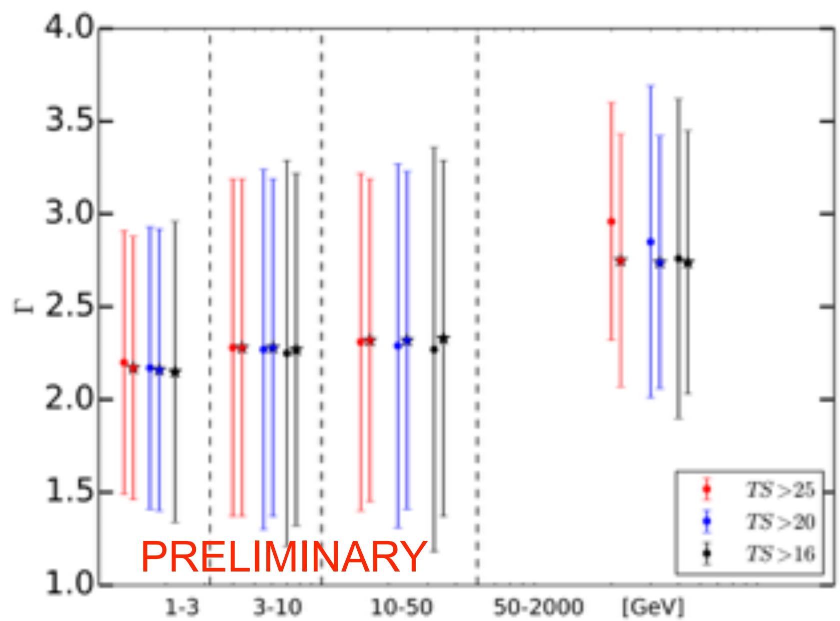
- We used efficiency correction and 1pPDF methods to find the sources count distribution of blazars between 1-2000 GeV
- We detect a flux break in the first three energy bins (1-3, 3-10, 10-50 GeV).
- The results found with efficiency corrections and 1pPDF are compatible!
- **The contribution of extragalactic sources, mainly blazars, is about 50% of the EGB.**
- **Where does the remaining 50% come from? Stay tuned.**

Backup slides

Number and photon index of simulated sources

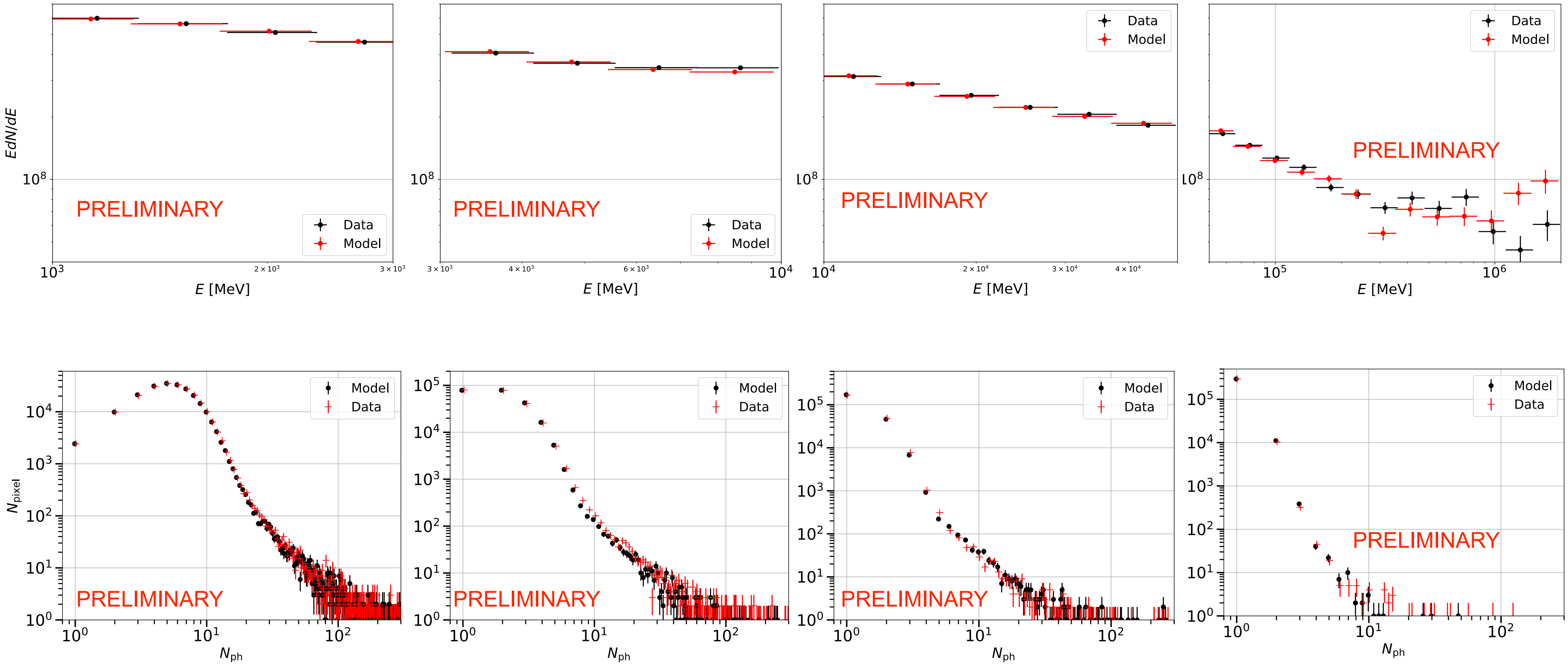
- We choose the dN/dS and the photon index distribution of simulated sources in order to reproduce the number and index distribution of real sky catalog of sources.





Check on the energy spectrum and Pixel Counting

- The ISO and IEM are tuned in order to reproduce correctly the pixel counting and energy spectrum of the real sky.



1-3.16 GeV | 3.16-10 GeV | 10-50 GeV | 50-2000 GeV

Comparison with Lisanti et al. 2016