Fermi
Gamma-ray
Space Telescope

The *Fermi* Bubbles

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on behalf of the *Fermi*-LAT Collaboration

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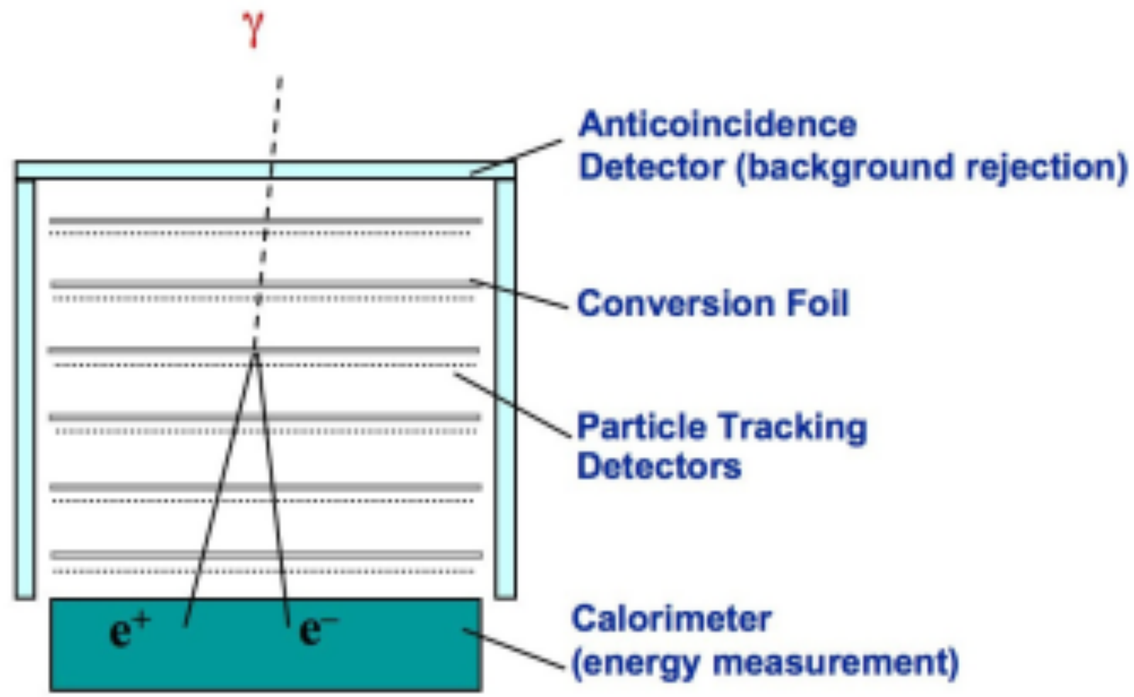
Fermi-LAT

- ***Fermi*** **Large Area Telescope – pair conversion gamma-ray space telescope**
- **5 years of data available for public use (since August 2008)**
- **Maximal mission: 10 years or more**
- **2.8 tons**
- **1.8 m x 1.8 m x 0.7 m**
- **650 watts**

Energy:	20 MeV to above 300 GeV
PSF:	< 1° above 1 GeV
Solid angle:	2.4 sr at 1 GeV
Eff. area:	6500 cm^2 at 1 GeV

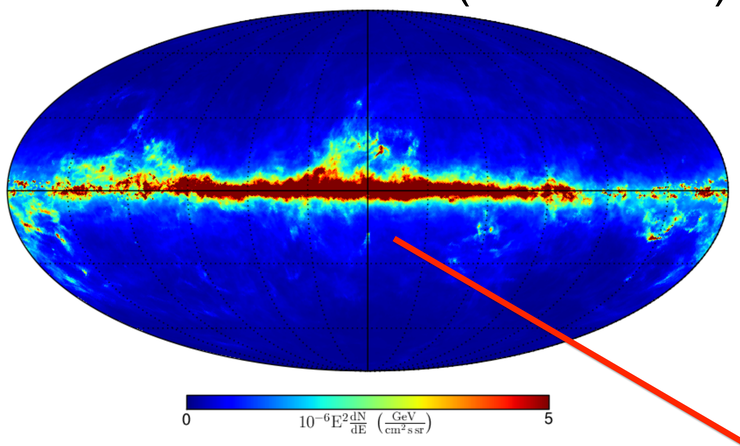


Data selection

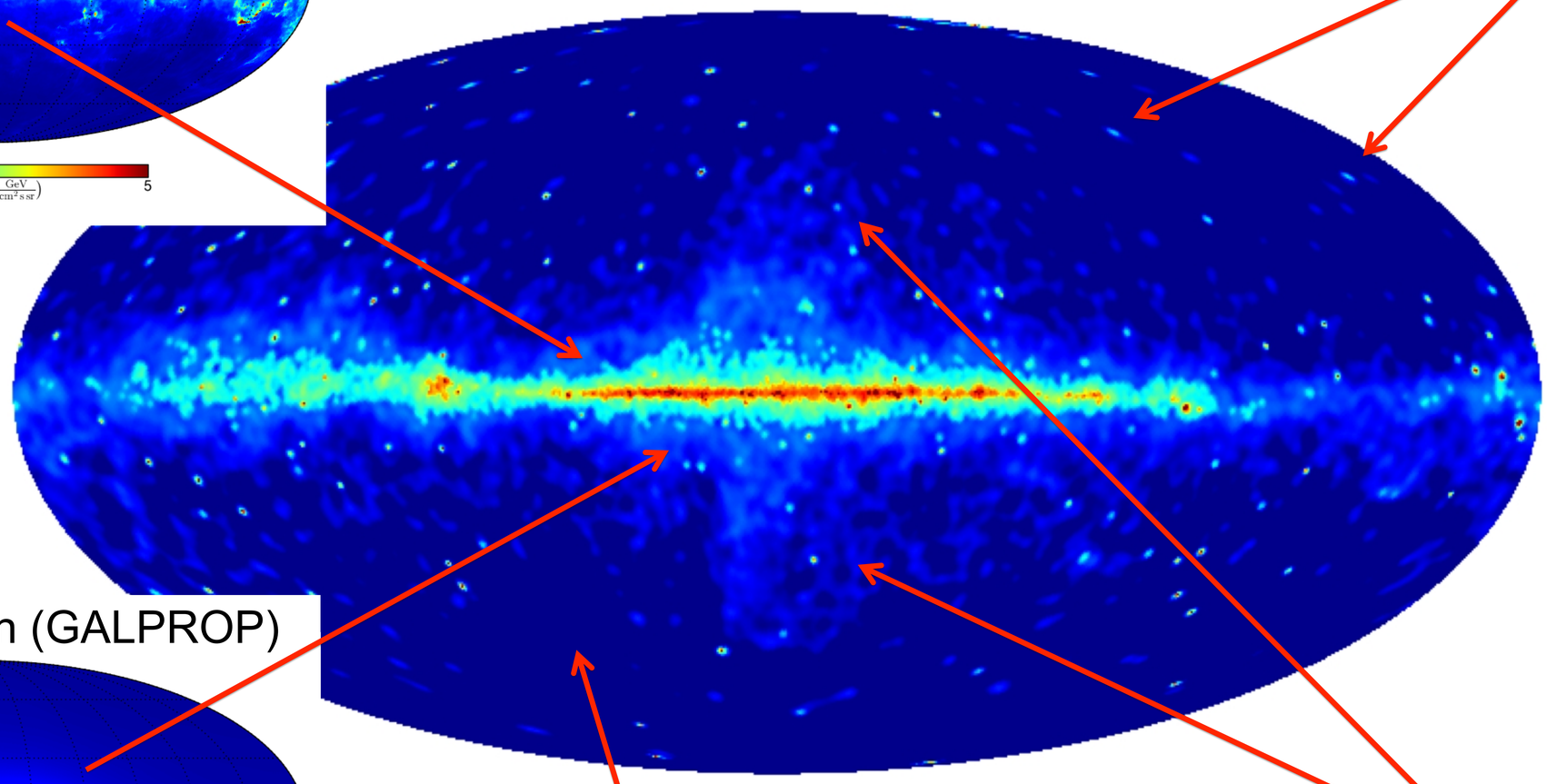
- **In the *Fermi* bubbles analysis, we use:**
  - **50 months of Pass 7 reprocessed data**
  - **100 MeV to 500 GeV (in 25 logarithmic energy bins)**
  - **Ultraclean class**
  - **Mask |b| < 10 deg**
  - **Zenith angle cut < 90 deg (to avoid the Earth limb)**

Gamma-ray emission

π^0 and brems (GALPROP)

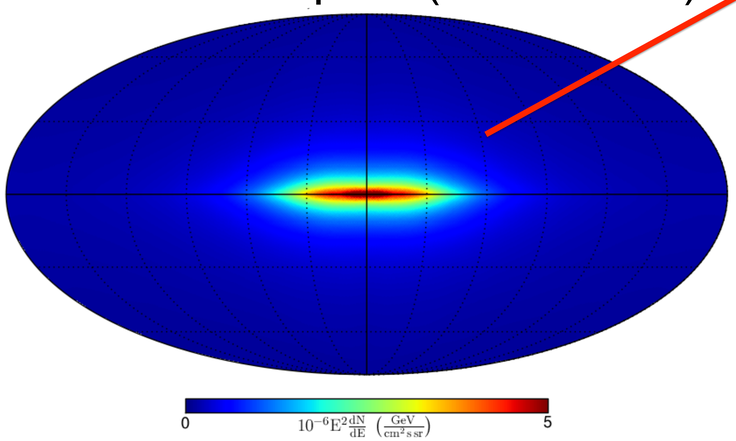


***Fermi*-LAT data (3 years, >10 GeV)**
(adaptively smoothed)



Point sources

Inverse Compton (GALPROP)



Isotropic background

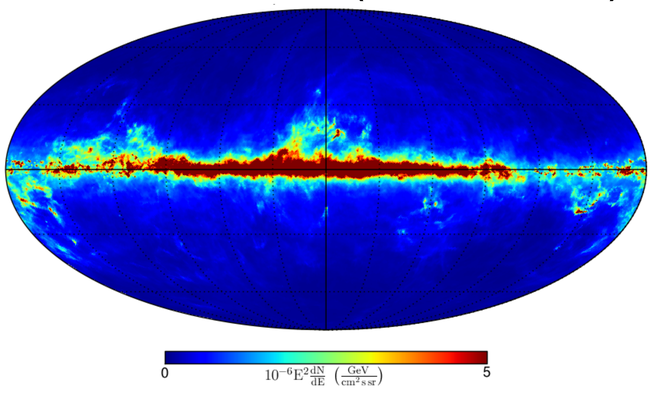
Fermi bubbles

The bubbles are visible in *Fermi*-LAT data at high energies without foreground subtraction.

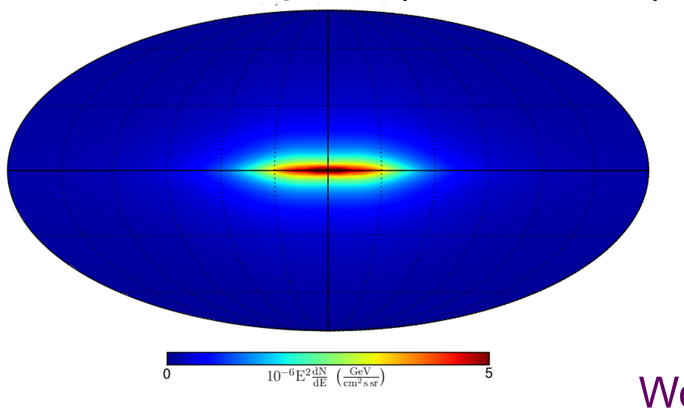
GALPROP Template Analysis

1. **Hadronic and bremsstrahlung:**
   - **CR source distribution (pulsars, supernova remnants)**
   - **diffusion in Galaxy (diffusion height and radius)**
   - **Target gas (H I, H II, H_2 in Galacocentric rings)**
2. **Inverse Compton (IC) scattering**
   - **Leptonic CR**
   - **Interstellar radiation field**
3. **Isotropic: CR contamination, extragalactic diffuse and unresolved point sources**
4. **Loop I**

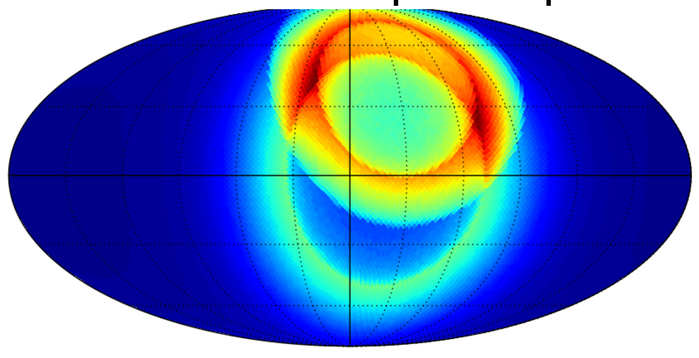
π^0 and brems (GALPROP)



Inverse Compton (GALPROP)



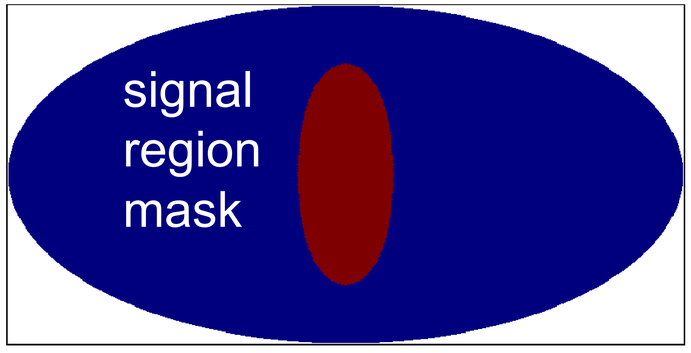
Geometric Loop I template



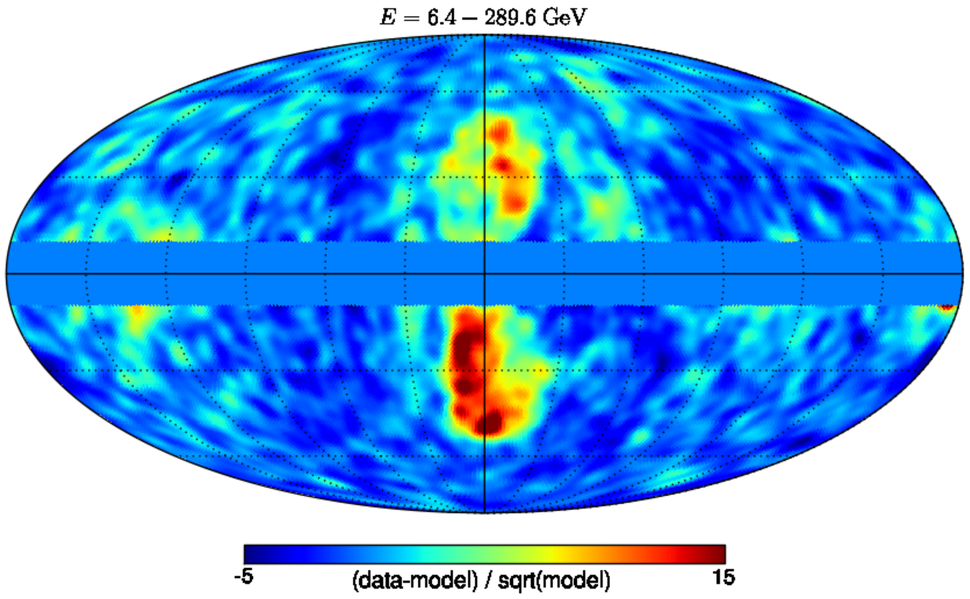
Wolleben, M. 2007, Astrophys.J., 664, 349

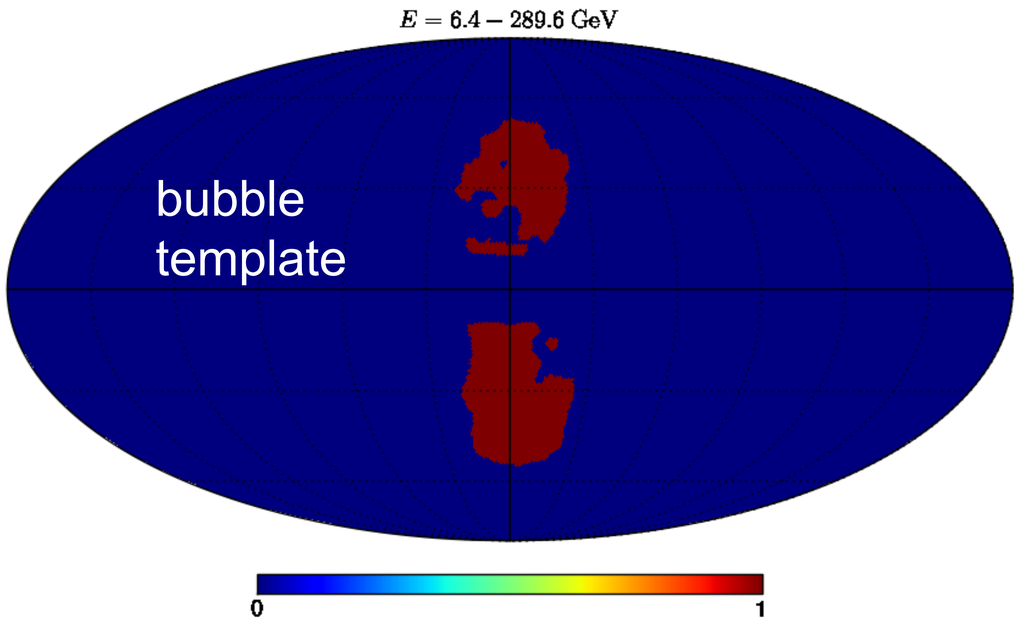
Bubbles Template

- **All sky fit including all templates BUT bubble template (signal region and the Galactic plane are masked)**



Integrated residual map from 6.4 to 300 GeV

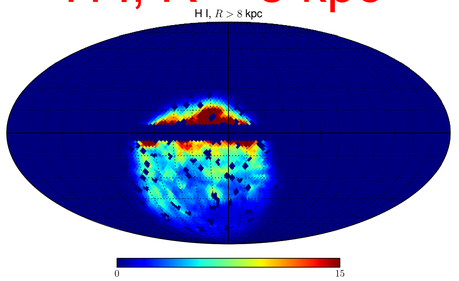




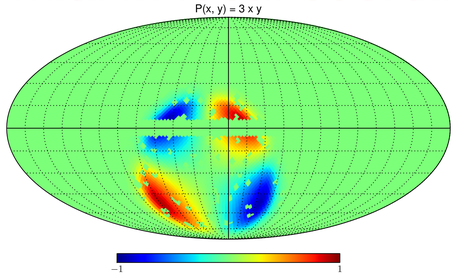
Local Templates Analysis

- **GALPROP: azimuthal symmetry around GC, specific IC model**
- **Separate the sky in local patches. In each patch, model**
  - **gas-correlated components as a combination of gas templates (21cm, CO)**
  - **non gas-correlated components (isotropic, IC, Loop I, bubbles) as a linear combination of polynomials in local coordinates**

H I, R > 8 kpc

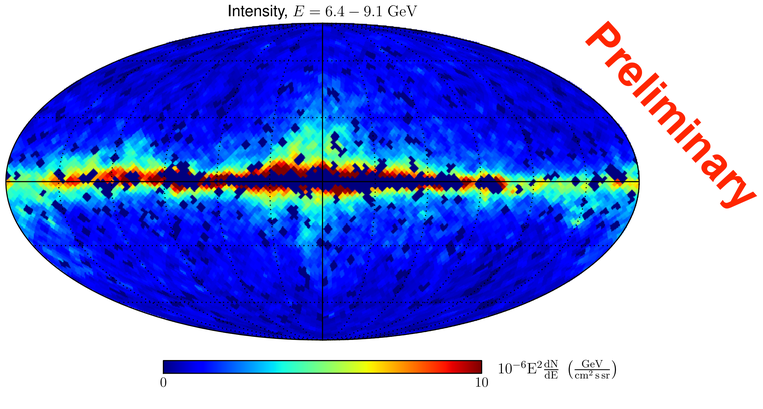


A polynomial in local coordinates

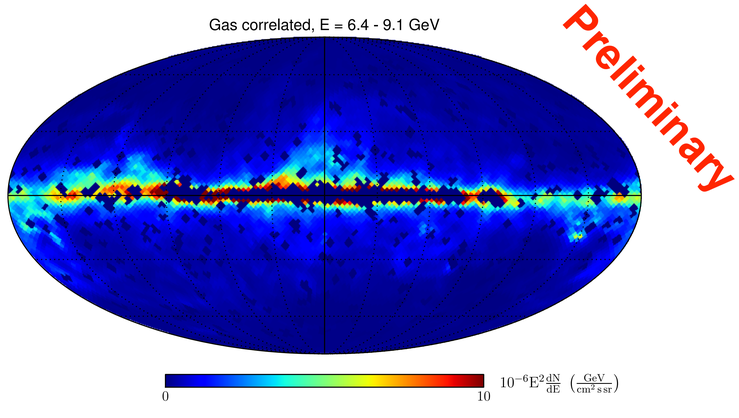


- **Fit the data in 24 local patches, merge the patches together**

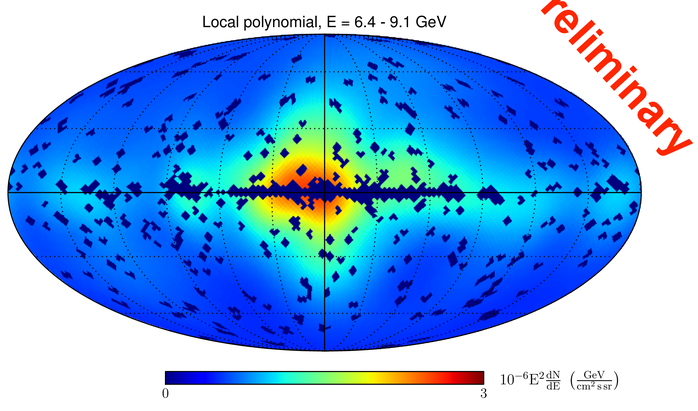
Intensity, E = 6.4 – 9.1 GeV



Gas-correlated



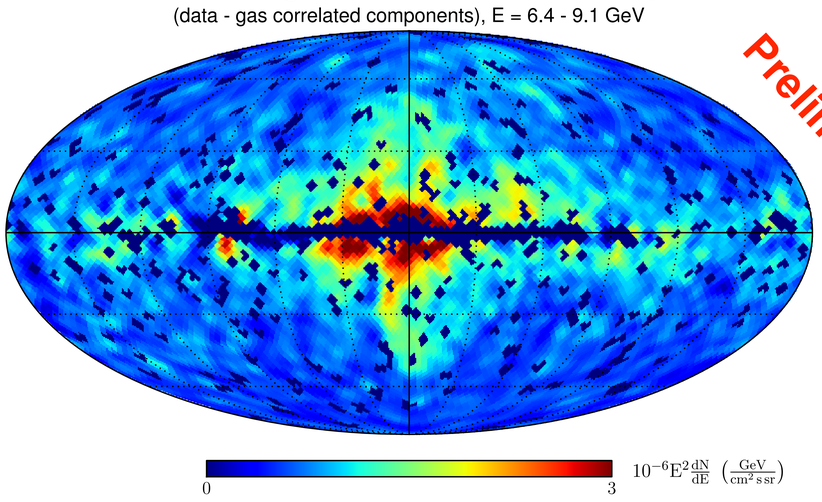
Local polynomials



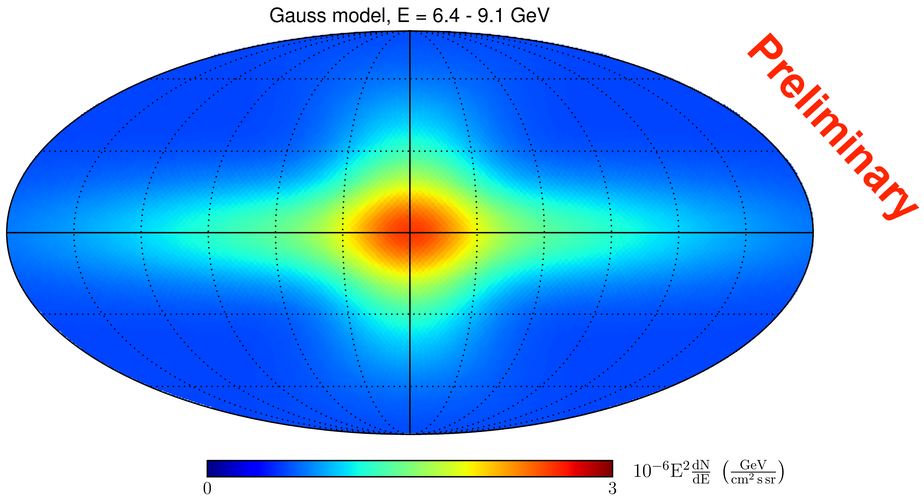
Local Templates Analysis

- **Subtract the gas-correlated component from the data**
- **Model the residual as a combination of**
  - **isotropic template**
  - **two 2D Gaussians: Gaussian along the Galactic plane models the IC emission, Gaussian perpendicular to the plane is a proxy for the Loop I and the bubbles**

Data minus gas correlated components



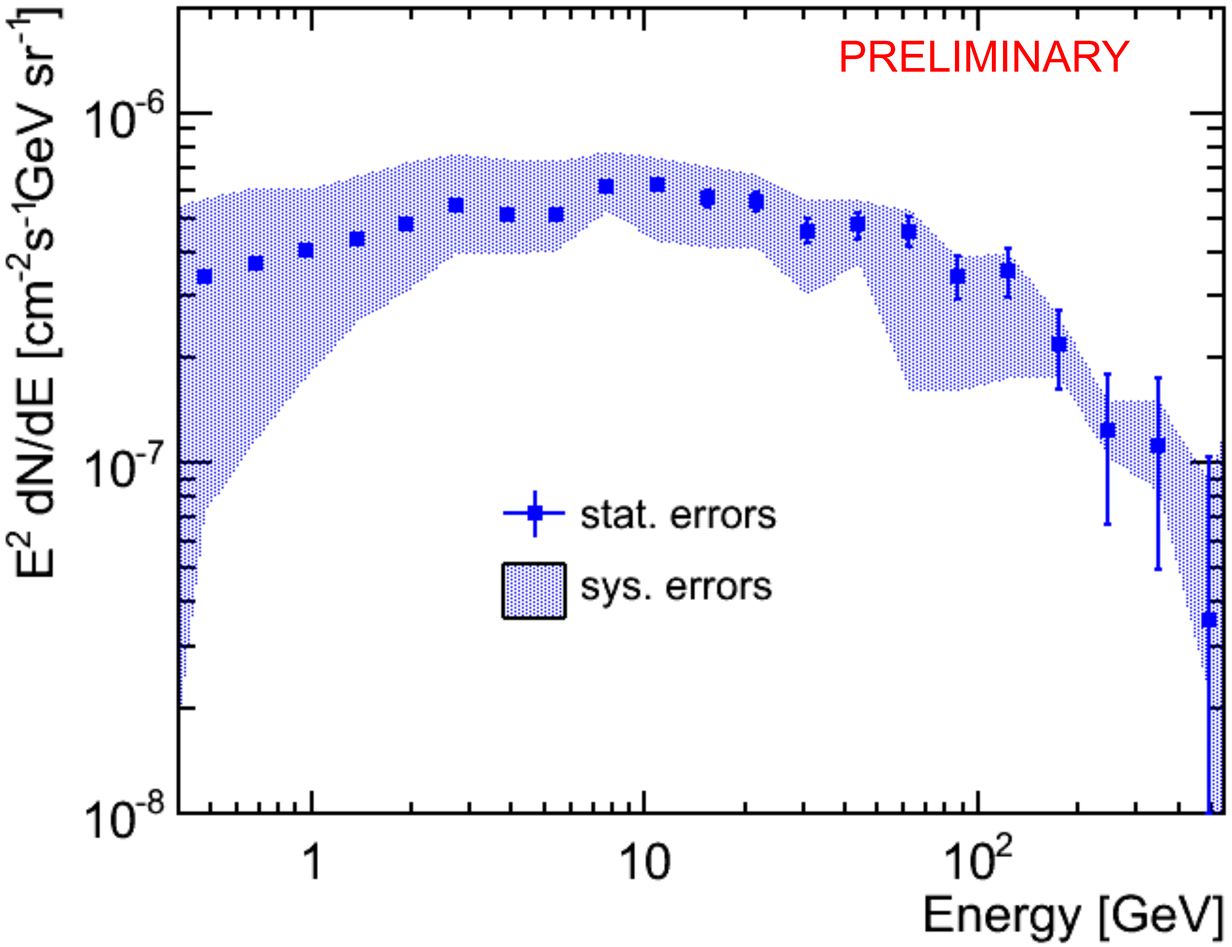
Gaussian model



- **Subtract gas-correlated, isotropic and IC emission from the data and define the bubbles and the Loop I templates**

Fermi bubbles spectrum

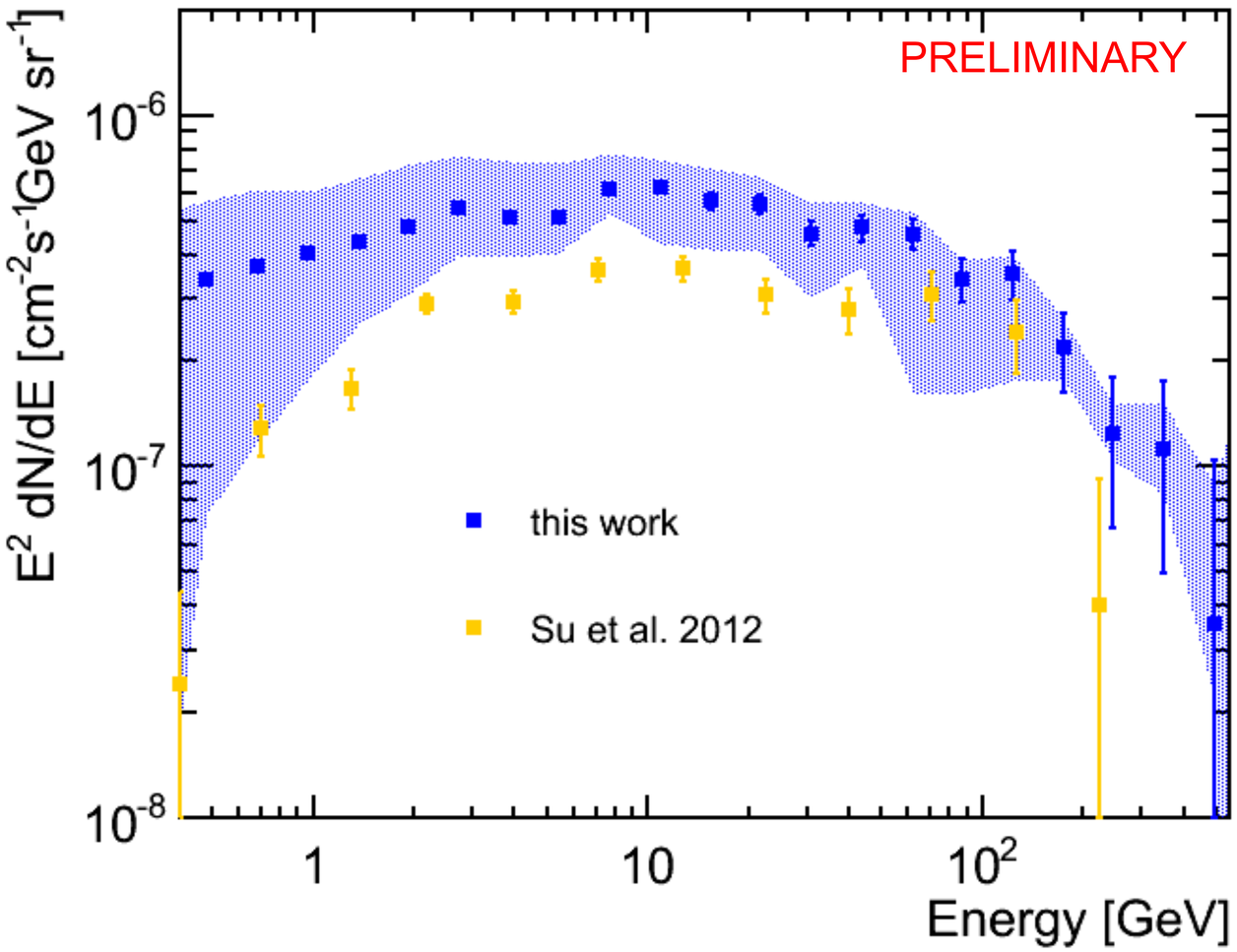
- **Points with error bars: baseline model (GALPROP) with statistical uncertainties**
- **Shaded region: envelope of the *Fermi* bubbles spectra obtained with different foreground models**



- **There is a softening above 100 GeV**
- **Large systematic uncertainties at low energies: Loop I, foreground modeling**

Comparison with Su et al (2012)

- **Spectra have similar shape**
- **There is a shift in normalization**



The shift in normalization is due to:

- **Different foreground modeling**
- **Different masking of the Galactic plane (10 vs 20 deg)**
- **Different definition of the bubble template resulting in different area of the template**

Outlook

- **A paper is in preparation within the *Fermi*-LAT collaboration**
- **Systematic uncertainties:**
  - **Galactic emission model**
  - **Definition of Loop I and bubbles templates**
- **Study of the spectral shape (power law, power law with an exponential cutoff, log parabola)**
- **Morphology and variation of spectrum:**
  - **Spectrum in latitude stripes**
  - **Cocoon spectrum**
  - **Search for a jet**
  - **Estimation of the width of the boundary**
- **Physical interpretation in terms of hadronic and IC gamma-ray production. Comparison of associated synchrotron emission with WMAP and Planck haze.**