F e r m i - L A T observations of the gamma-ray emission from the quescient sun – first 6 years in orbit

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Not flaring Sources in the Solar System

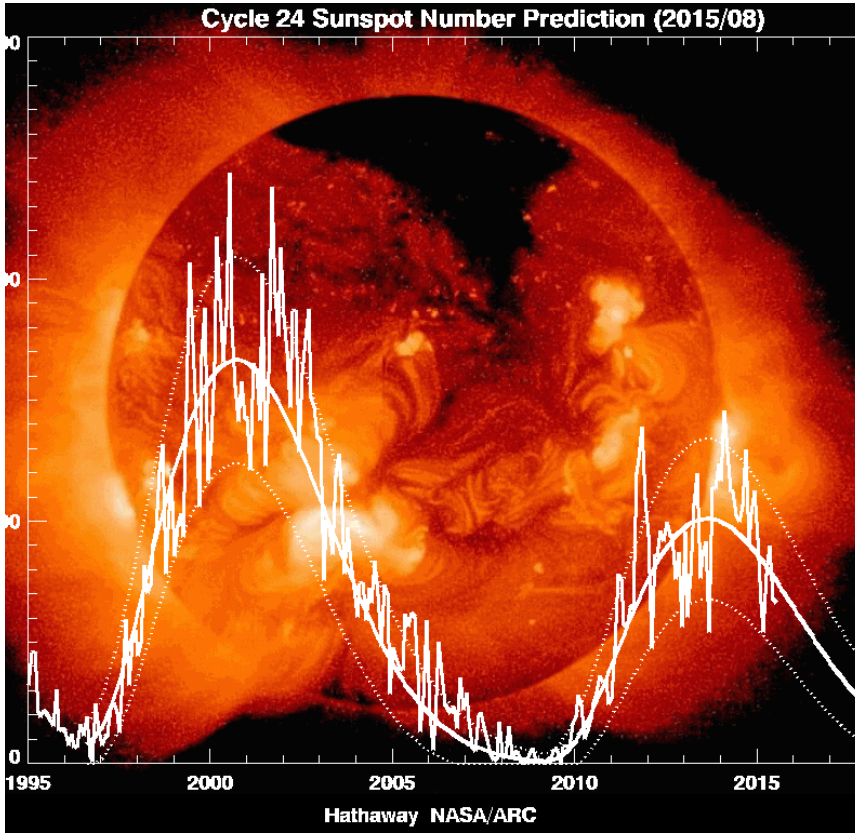
- Moon and Sun are bright solar system sources in gamma rays due to their interaction with Galactic cosmic rays (CR)
  - Moon gamma ray emission depends on the flux of CR nuclei near its surface (pointlike emission)
  - See F. Loparco and M.N.Mazziotta in the Poster Session
- Quiet gamma ray emission from the Sun has two components:
  - IC due to the CR electron scattering off solar photons in the heliosphere (extended emission)
  - CR nuclei interactions with the solar atmosphere (pointlike emission)
- Gamma ray emission studies are a sensible probe for CR fluxes in the solar system and for electrons in the inner heliosphere
- Gamma ray flux measurements depends on the solar cycle
- IC solar emission is extended and is a background for many studies; a detailed knowledge of this emission is needed

Solar activity and Cosmic rays

Max solar activity -> min cosmic-ray flux

Min solar activity -> max cosmic-ray flux

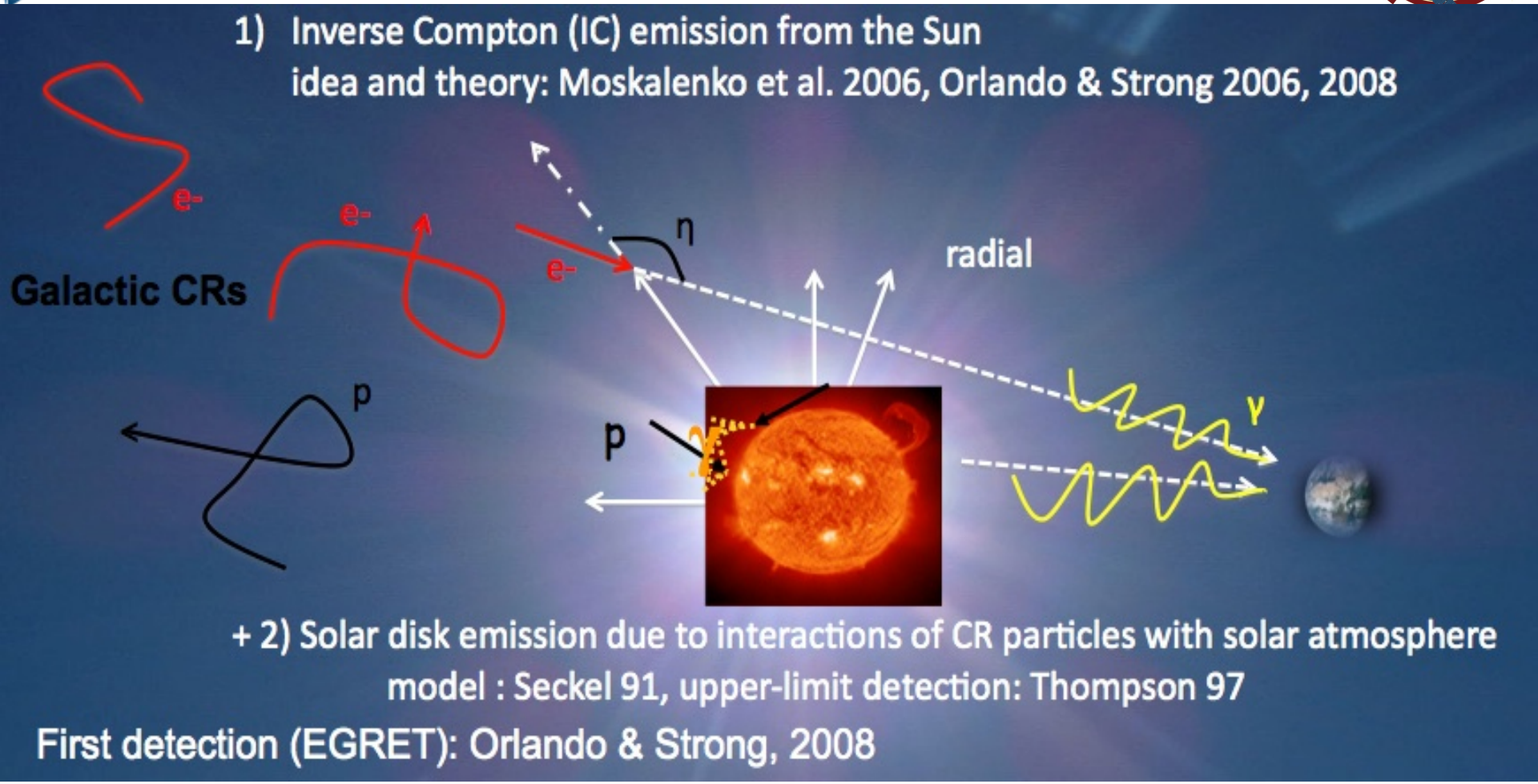
The gamma-ray flux depends on CRs flux intensities



Solar activity is now decreasing after having reached its peak in 2014

Gamma ray emission from the quiet Sun

1) Inverse Compton (IC) emission from the Sun
idea and theory: Moskalenko et al. 2006, Orlando & Strong 2006, 2008

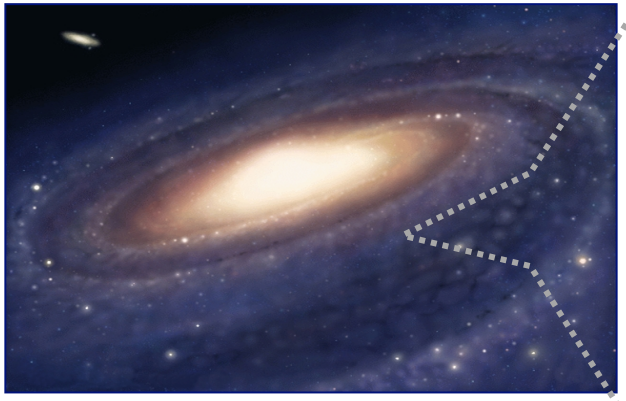


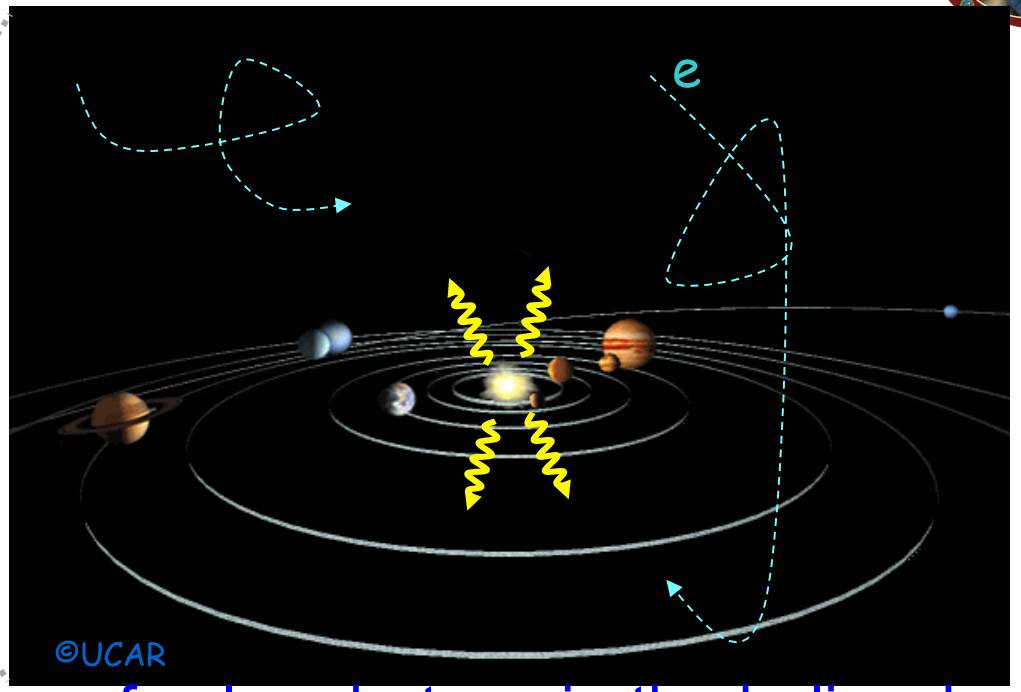
+ 2) Solar disk emission due to interactions of CR particles with solar atmosphere
model : Seckel 91, upper-limit detection: Thompson 97

First detection (EGRET): Orlando & Strong, 2008

Fermi-LAT observation of the Sun emission in the first 18 months data taking: Astrophysical Journal 734 (2011) 116

Inverse Compton Emission





Inverse-Compton scattering of solar photons in the heliosphere by Galactic CR electrons: the emission is predicted extended.

IC Models assumptions:

- ✧ **Electrons are isotropic**
- ✧ **Photons have a known radial angular profile**

NB the anisotropic nature of IC scattering on the solar radiation field is essential to the modelling

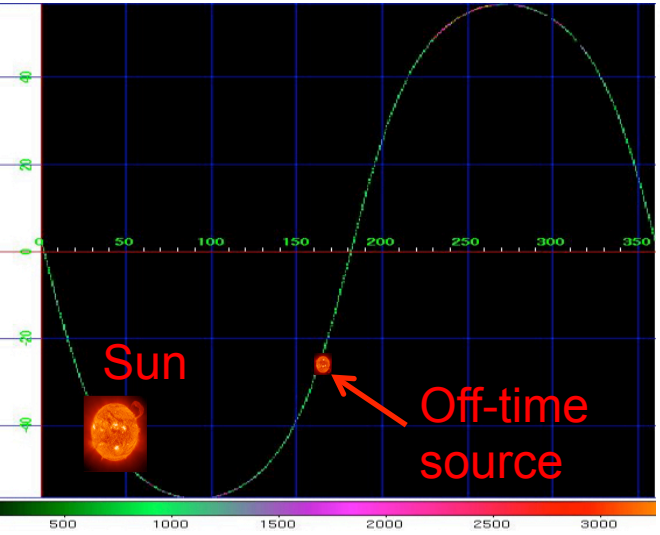
Fermi LAT Data selection

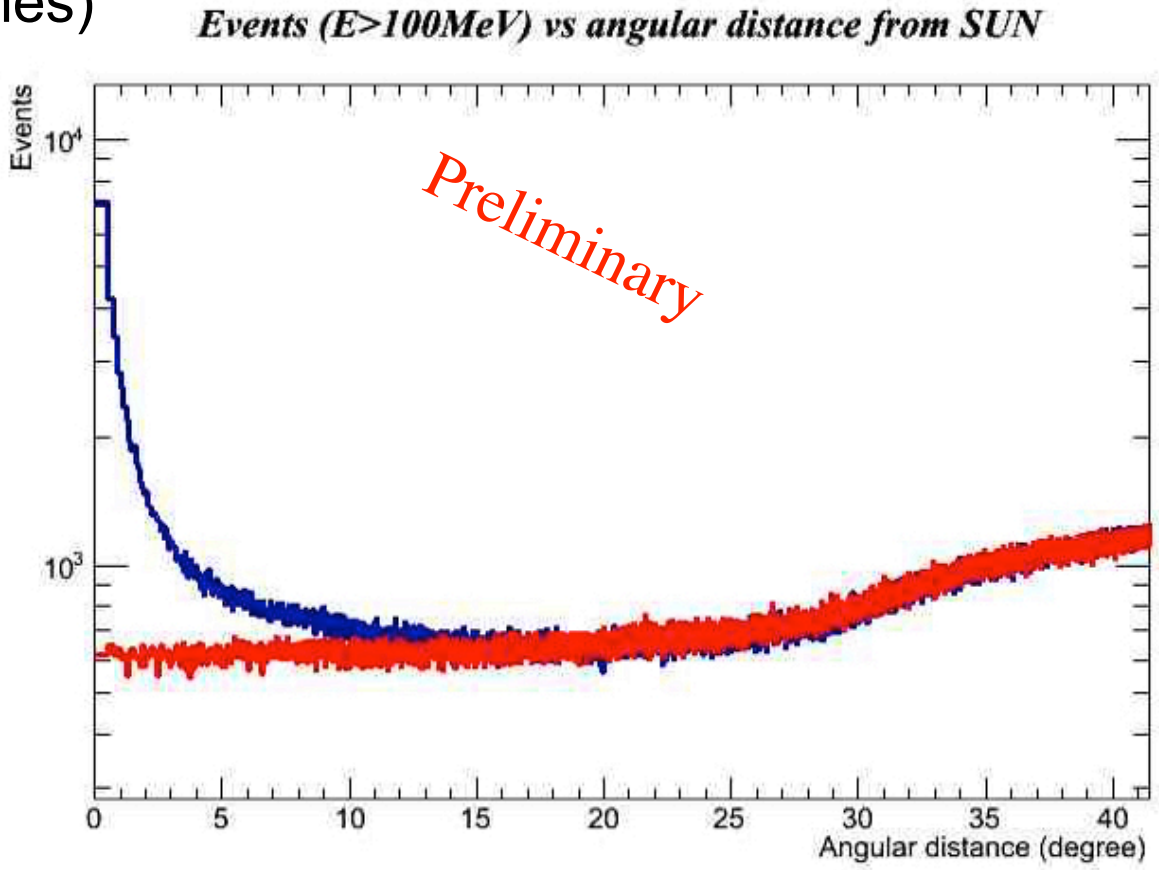
- Data sample: 6 years from August 4, 2008
- IRFs: P8R2_SOURCE_V6
- Sun centered data analysis
- Energy range: 30 MeV – 30 GeV
  - 94 MeV – 30 GeV
- Zenith angle: <100°
- Trial off time source at distance 90° to 180°from the SUN
- Further selections:
  - Galactic plane cut >30°
  - Moon-Sun angular separation > 20°

Background Estimation

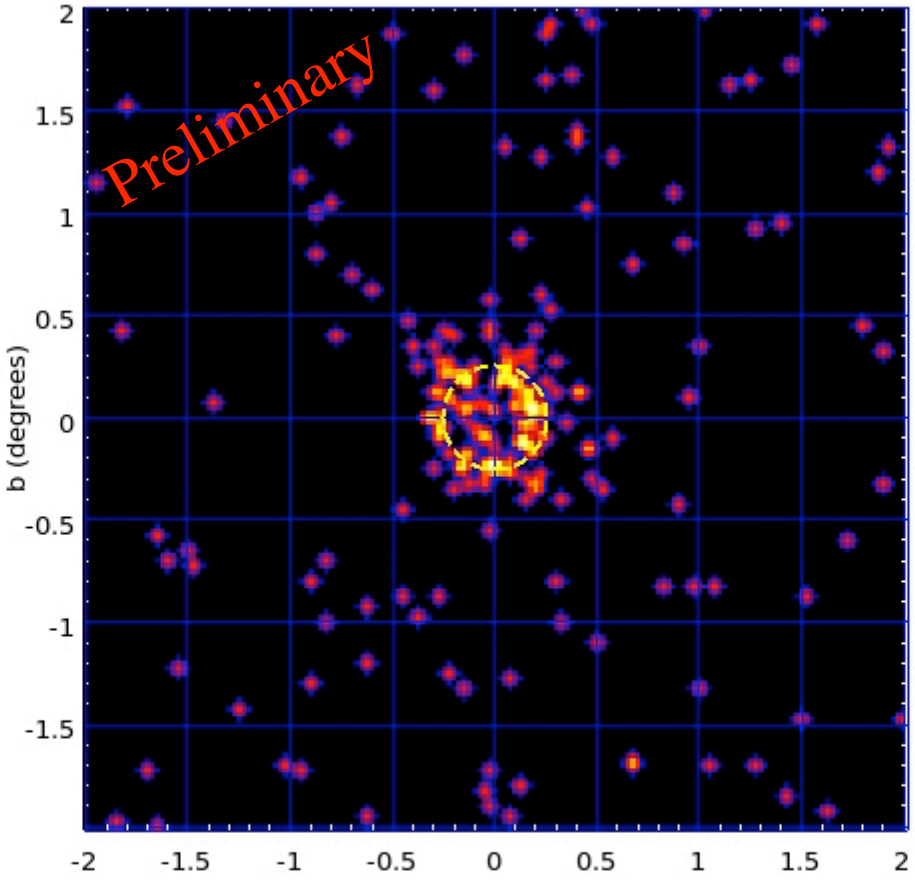
The “off-time” source method:

A off-time source follow the path of the real source but at different times and at 90° distance (passes through the same areas on the sky but at different times)





High Energy Raw Data



Photons count map:

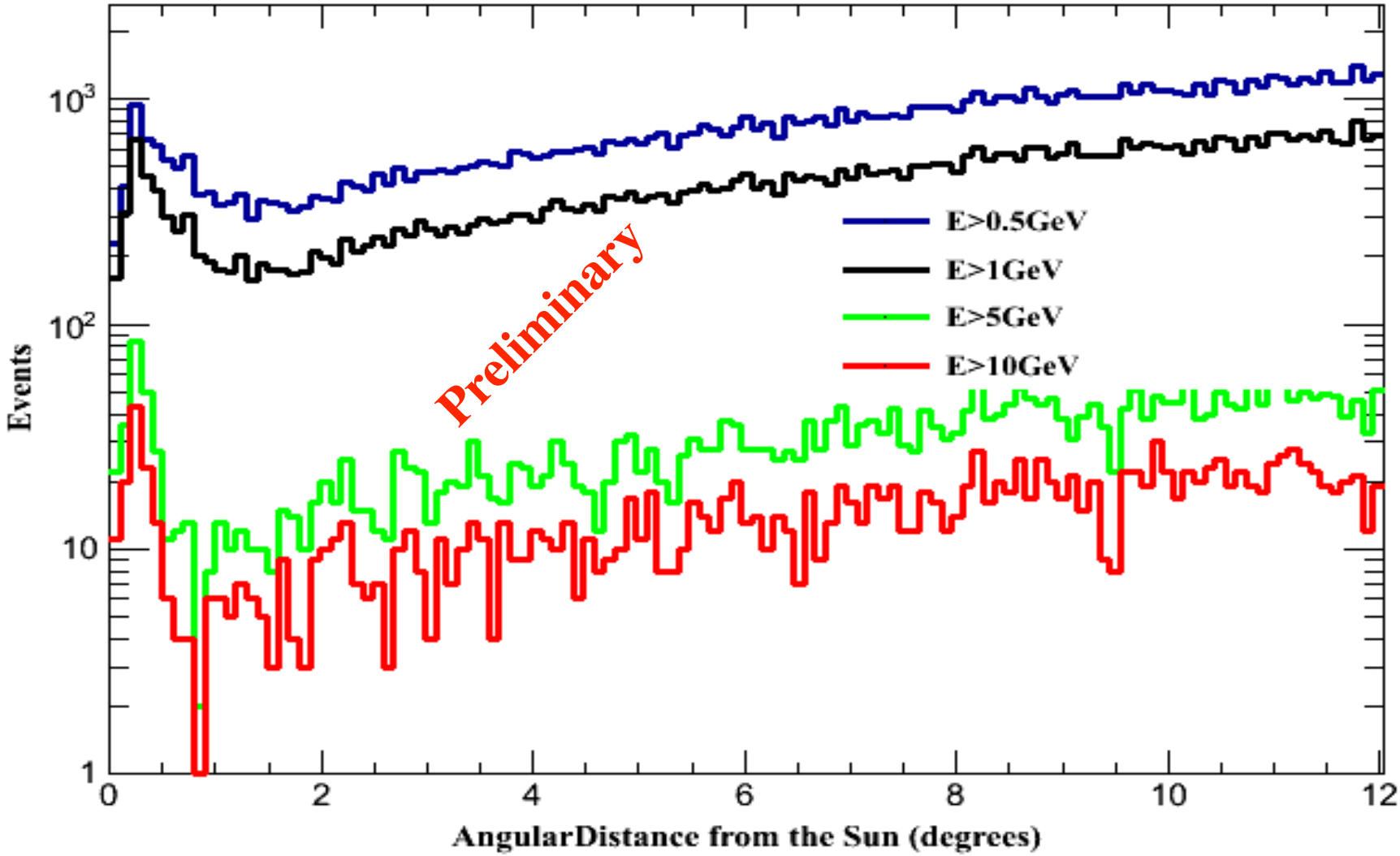
- 10GeV<E<20GeV
- 6 years data
- solar flares excluded

Coordinates are offsets from the Sun position in ecliptic coordinates.

The yellow circle corresponds to the solar disk size.

High Energy Raw Data

Sun events vs angular distance from the SUN for different energy thresholds



Full sample analysis

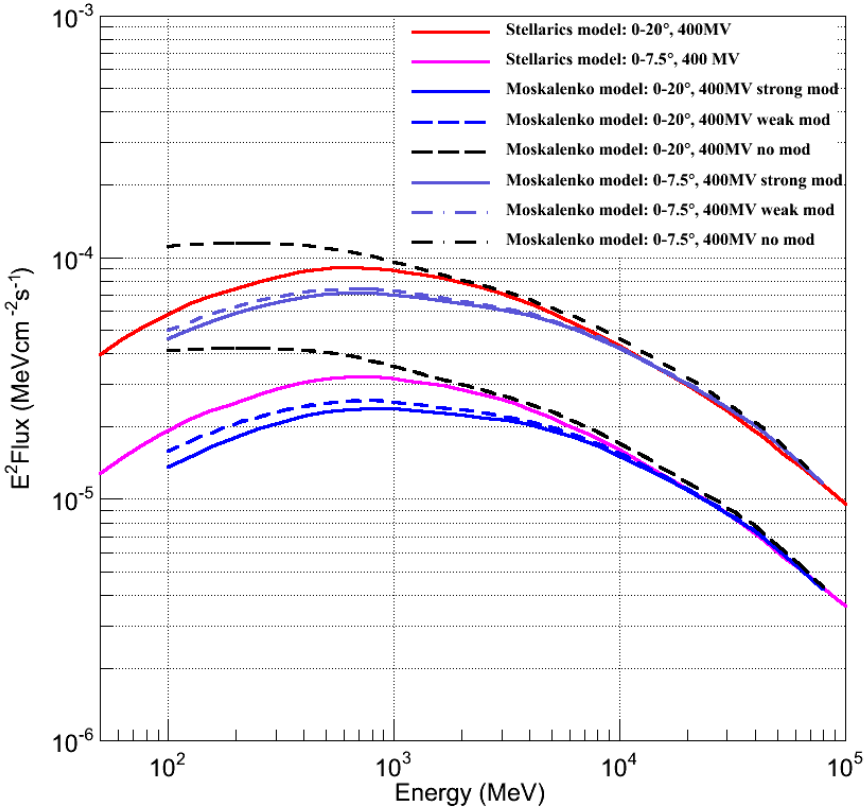
- **Full 6 years, Pass 8 data sample**
- **Background model:**
  - Background from off-source masked near the solar disk
- **Disk emission as point-like source (PL spectrum)**
- **IC emission from the SUN:**
  - **Model independent:**
    - generic **1/θ** radial dependence fitted on data
    - parametric energy spectrum
  - **Derived from "StellarICs" package (http://sourceforge.net/projects/stellarics/), updated to the most recent AMS02 and Fermi electron spectra**
    - E.Orlando et al arXiV: 1307.6798,
    - E. Orlando & A.Strong, Nucl. Phys B Proc. Suppl., Vol. 239-240, pp 266-269 (2013)
  - **Igor Moskalenko model (the electron spectrum is not updated)**
    - I.Moskalenko, T.Porter & S.Digel, ApJ 652, L65 (2006)

IC emission models

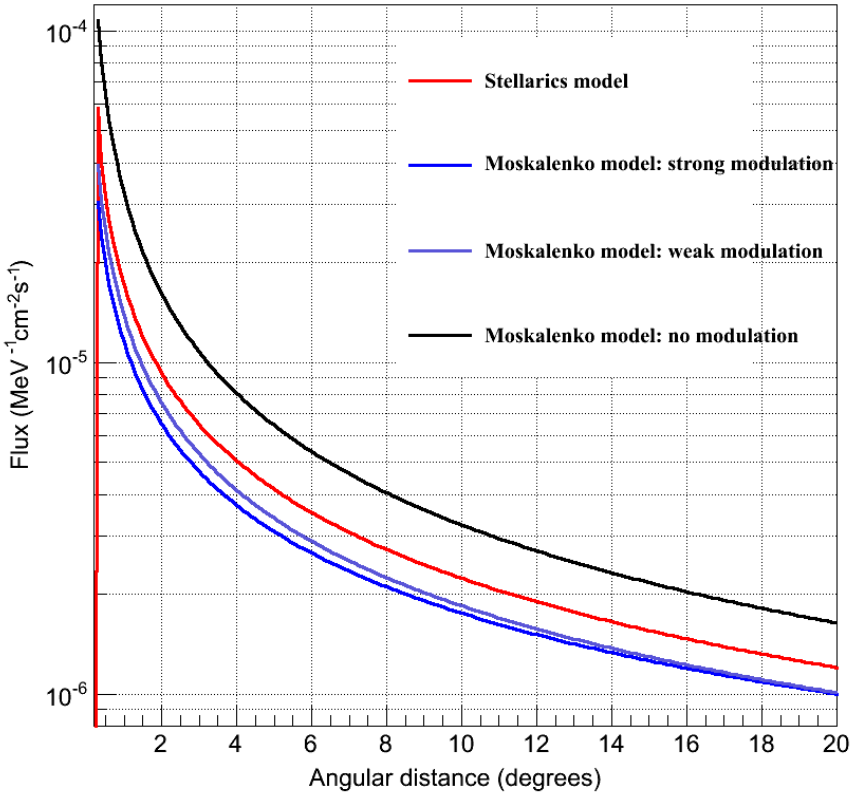
IC radial profile integrated over 30 MeV-30 GeV energy range according to:

Stellarics package and

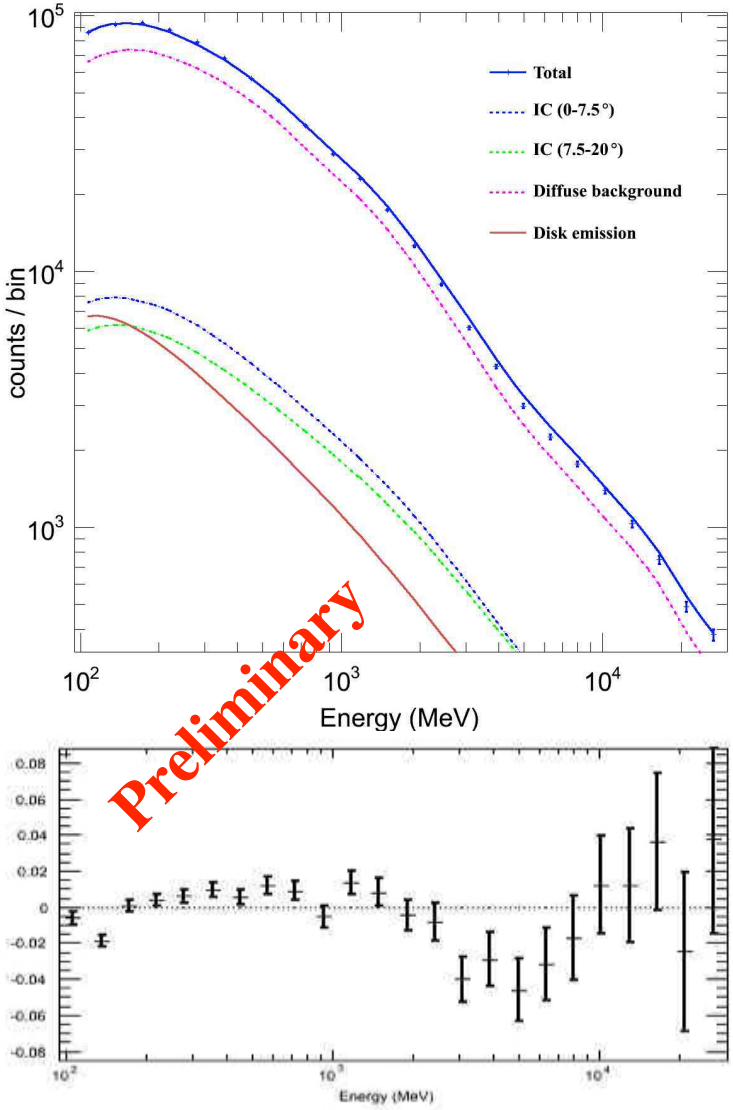
Moskalenko model



Radial profile as a function fo the distance from the Sun for the same models



Analysis Results



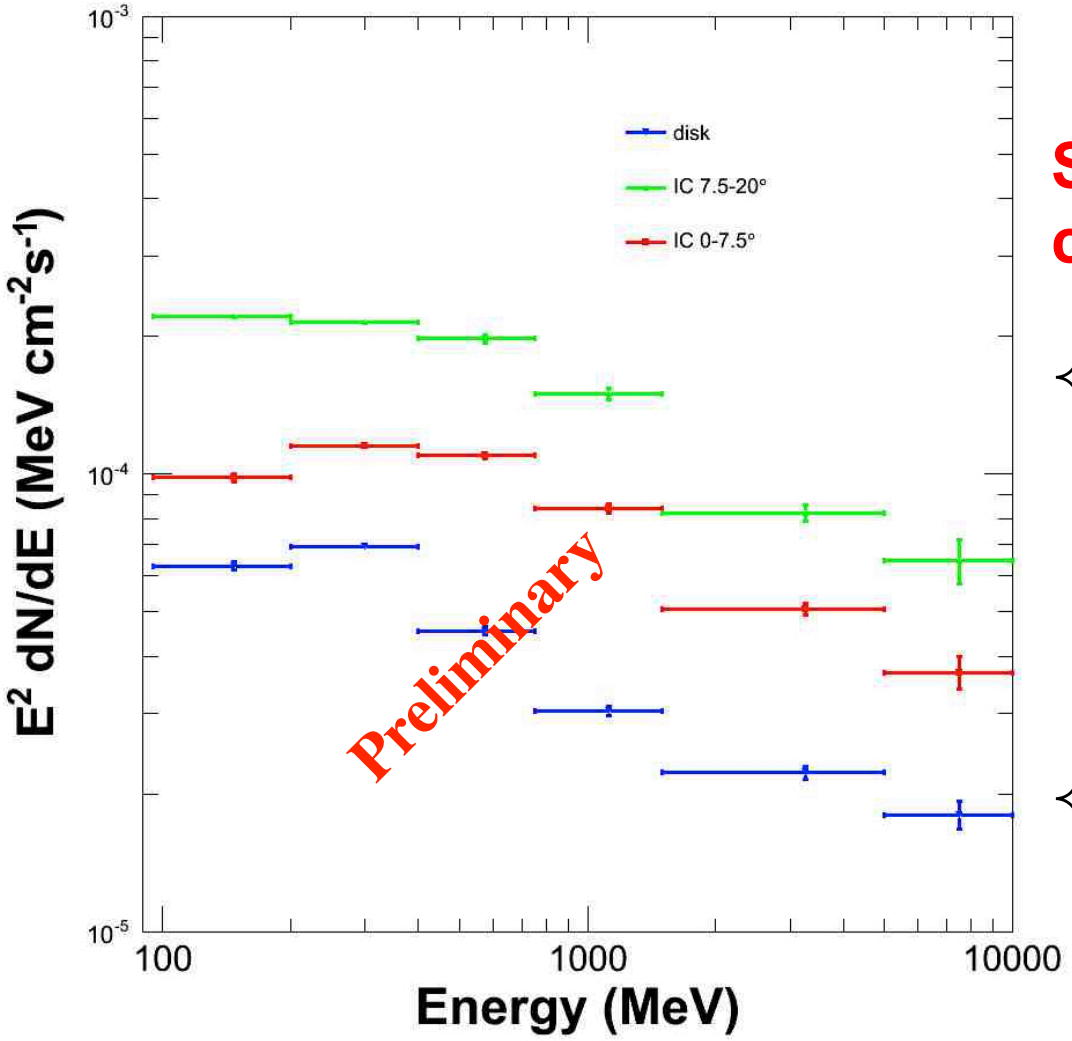
Fit results using a model with:

- ✧ Background
- ✧ Disk emission (PL spectrum)
- ✧ IC components (model independent) evaluated over two regions:
  - ✧ **Inner up to 7.5° from the Sun**
  - ✧ **Outer from 7.5 to 20° from the Sun**

IC Total flux:

IC (total): $(1.91 \pm 0.01) \cdot 10^{-6}$ cm^{-2}s^{-1}

SED



SED for each solar component (6years):

- the inner-outer part of the IC emissions have different spectra at low energies and the same slope above about 250 MeV.
- The disk component differs from a perfect power-law

Modulation

	Start	Stop	Disk Integral Flux $*10^{-7}$ ($cm^{-2}s^{-1}$)	IC Integral Flux $*10^{-6}$ ($cm^{-2}s^{-1}$) <20°
1	2008 Aug 4	2009 Aug 3	2.96±0.1	2.81±0.08
2	2009 Aug 4	2010 Aug 3	2.94±0.1	1.90±0.06
3	2010 Aug 4	2011 Aug 3	2.29±0.1	1.71±0.06

Conclusions and Perspectives

Currently we have considered a very simplified data modeling consisting of a 2 regions IC model, a disk emission plus background. This analysis is in progress and model description will be improved but some indications are provided:

- **The IC emission from the region closer to the Sun seems to have different spectrum with respect to the external regions**
- **The IC profile seems to be similar to what predicted by the models**
- **The disk component has a total flux similar to that published on the first analysis**

We are finalizing this analysis to confirm these results and study the systematics and finally the solar modulation