F e r m i - L A T observations of the gamma-ray emission from the Quescient sun – first 7 years in orbit

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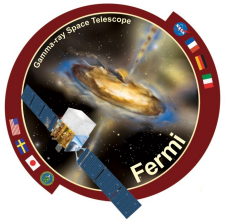
for the Fermi LAT Collaboration

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)**
  - Ackermann et al., Physical Review D, 93, 082001 (2016)
- **Quiet gamma-ray emission from the Sun has two components:**
  - **Extended emission: Inverse Compton (IC) due to the CR electron scattering off solar photons in the heliosphere**
  - **Pointlike emission: CR nuclei interactions with the solar atmosphere**

Not flaring Sources in the Solar System



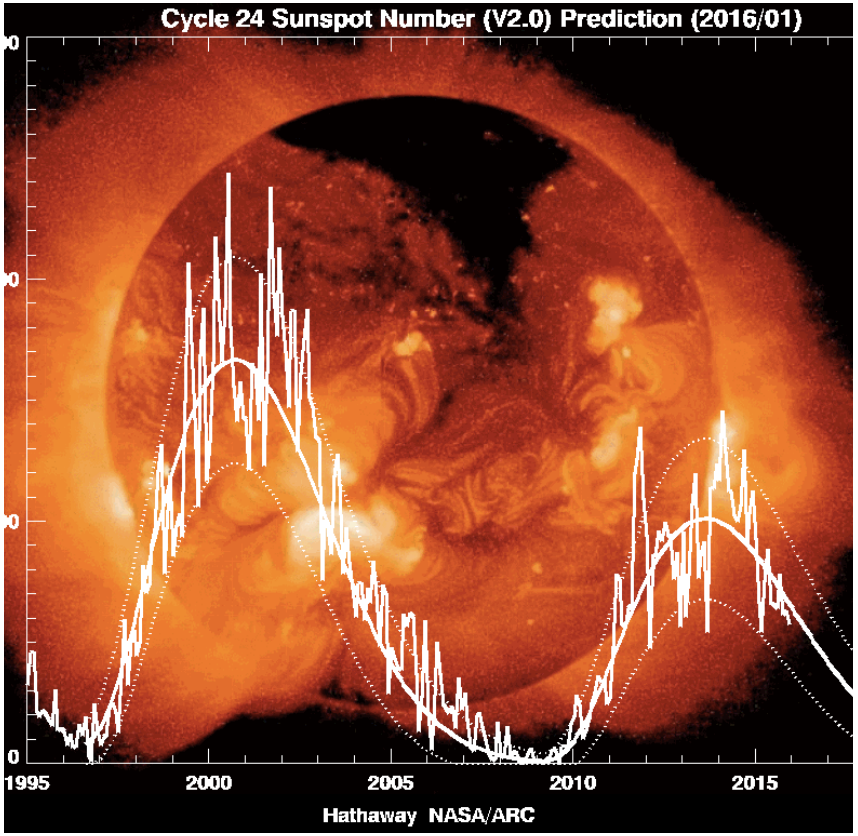
- Gamma-ray emission studies are **a sensible probe for CR fluxes** in the solar system and for electrons in the **inner heliosphere**
- Gamma-ray flux measurements depend on the **solar cycle**
- **IC solar emission is extended and is a background for many studies; a detailed knowledge of this emission is needed**

Solar activity and Cosmic rays

Max solar activity -> min cosmic-ray flux

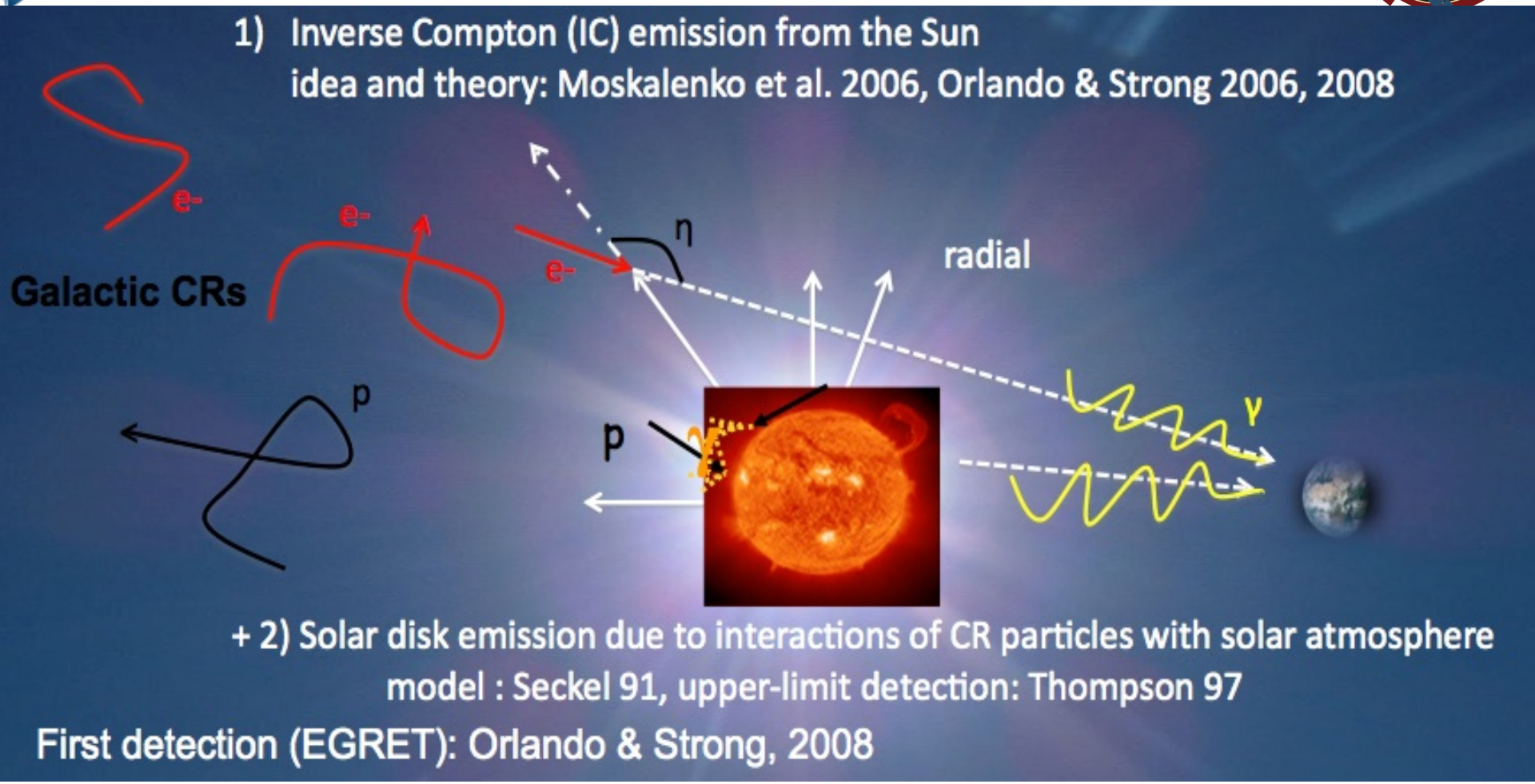
Min solar activity -> max cosmic-ray flux

The gamma-ray flux depends on CRs flux intensities



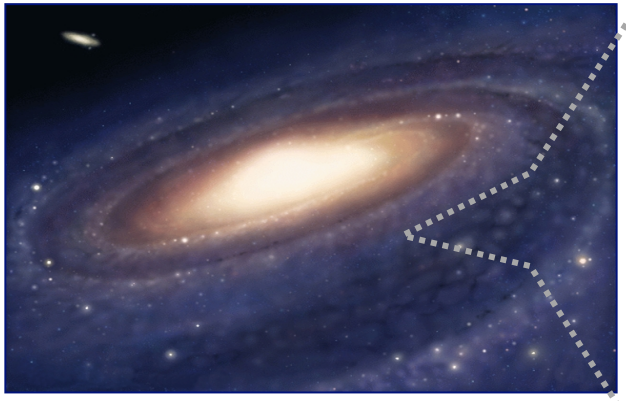
Solar activity is now decreasing after having reached its peak in 2014

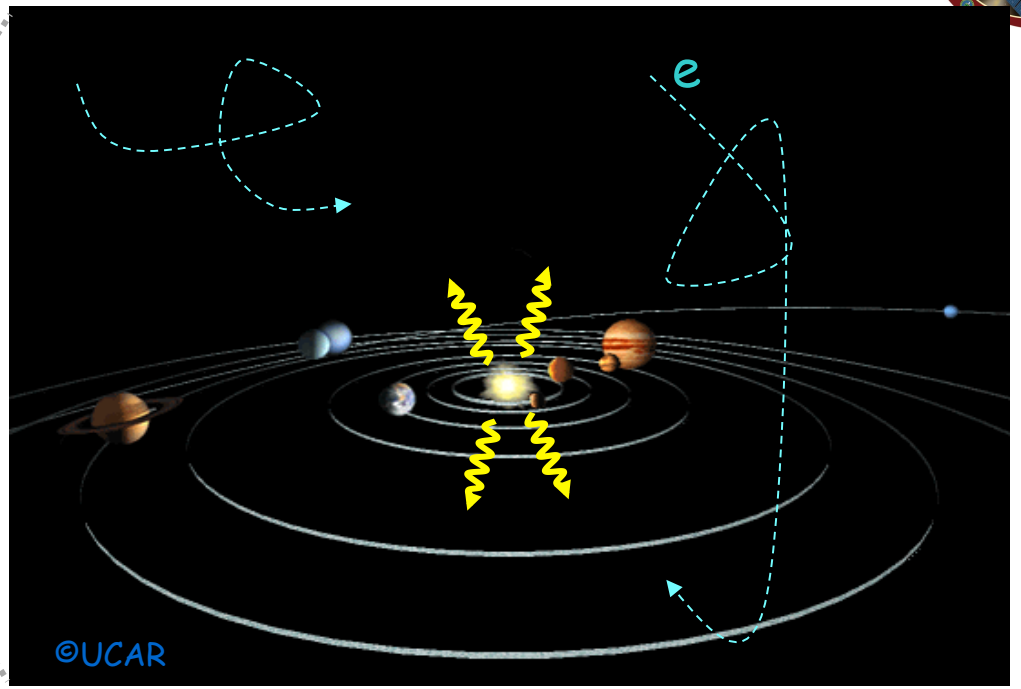
Gamma-ray emission from the quiet Sun



Fermi-LAT observation of the Sun emission in the first 18 months of 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**

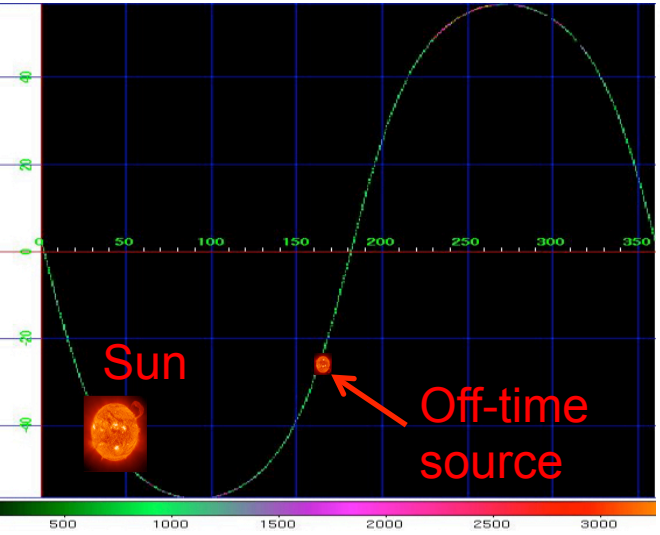
Fermi LAT Data selection

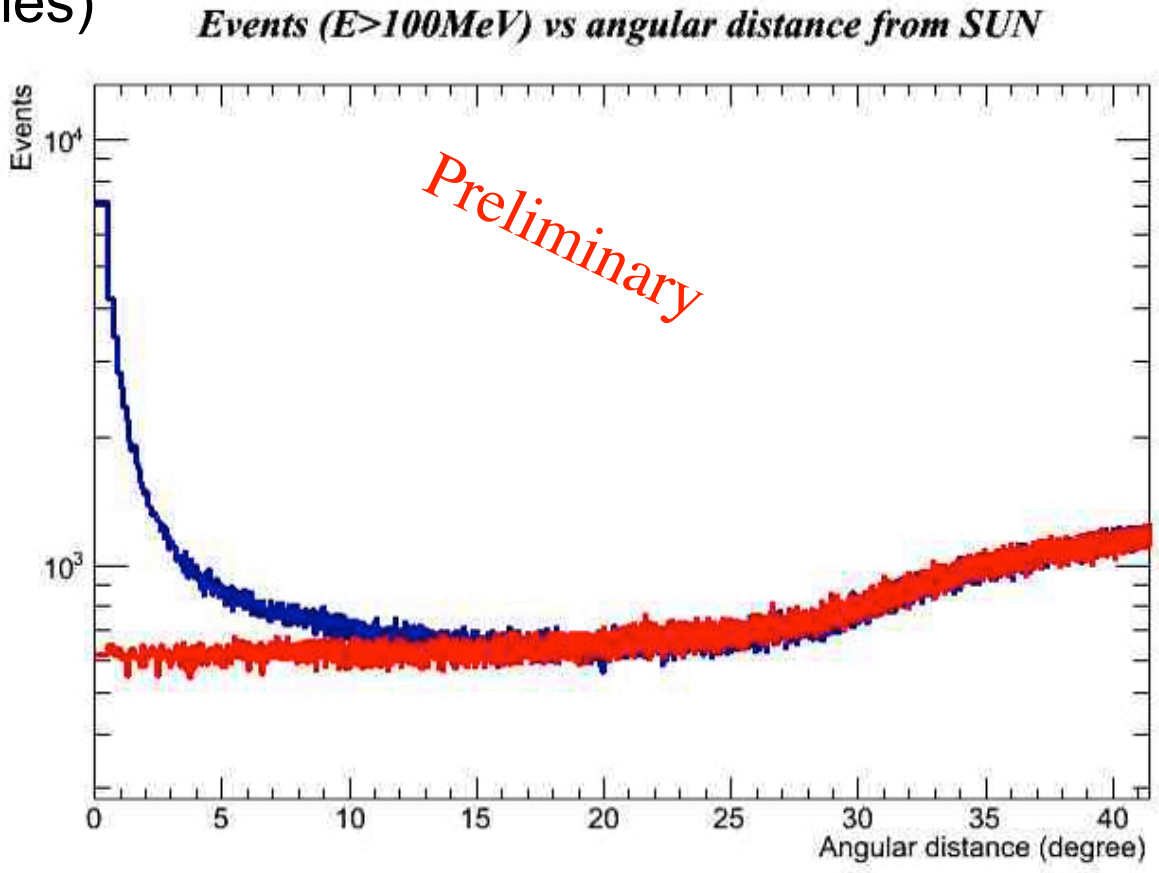
- Data sample: 7.5 years from August 4, 2008
- IRFs: P8R2_SOURCE_V6
- Sun centered data analysis
- Energy range: 50 MeV – 30 GeV
- Zenith angle: <100°
- Solar flares excluded
- Further selections:
  - Galactic plane cut: |b| >30°
  - Moon-Sun angular separation > 20°
  - Cut on bright sources with F(>100MeV) > 2 10^{-7} ph/cm^{2}s

Background Estimation

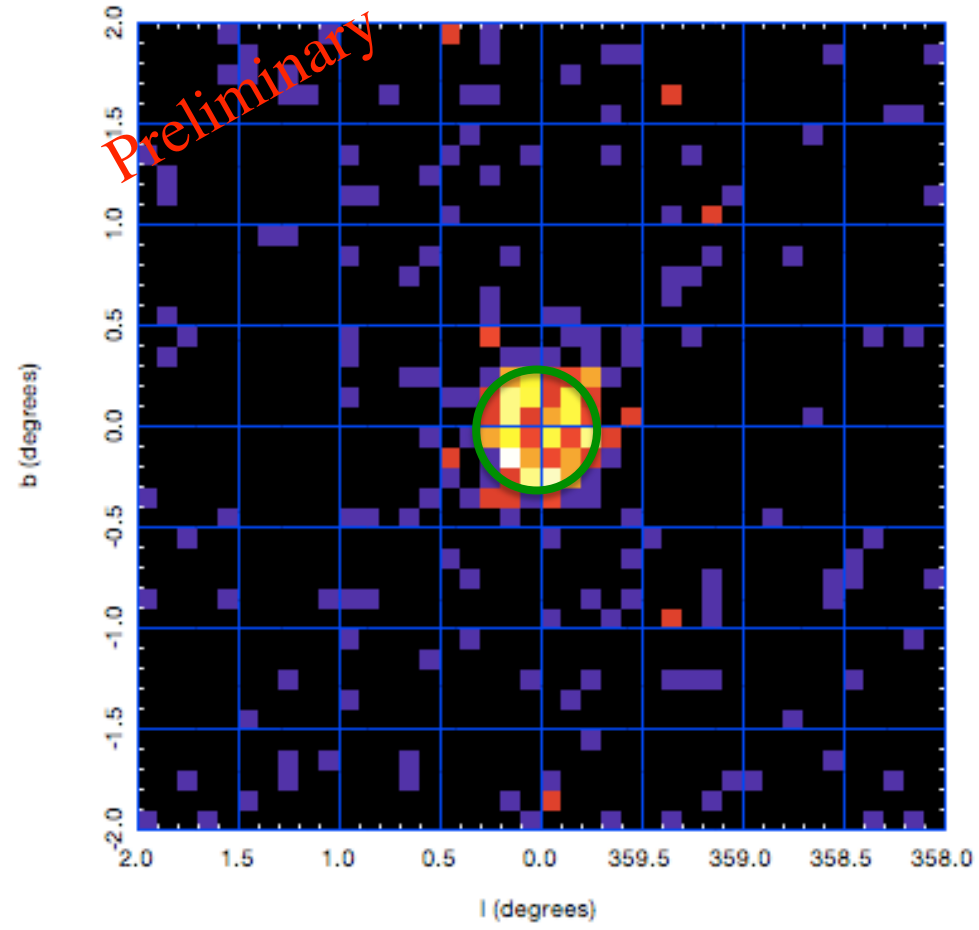
The “off-time” source method:

An off-time source follows the path of the real source but at different times and at 90° distance (passes through the same areas in the sky but at different times)





High Energy Raw Data



Photons count map:

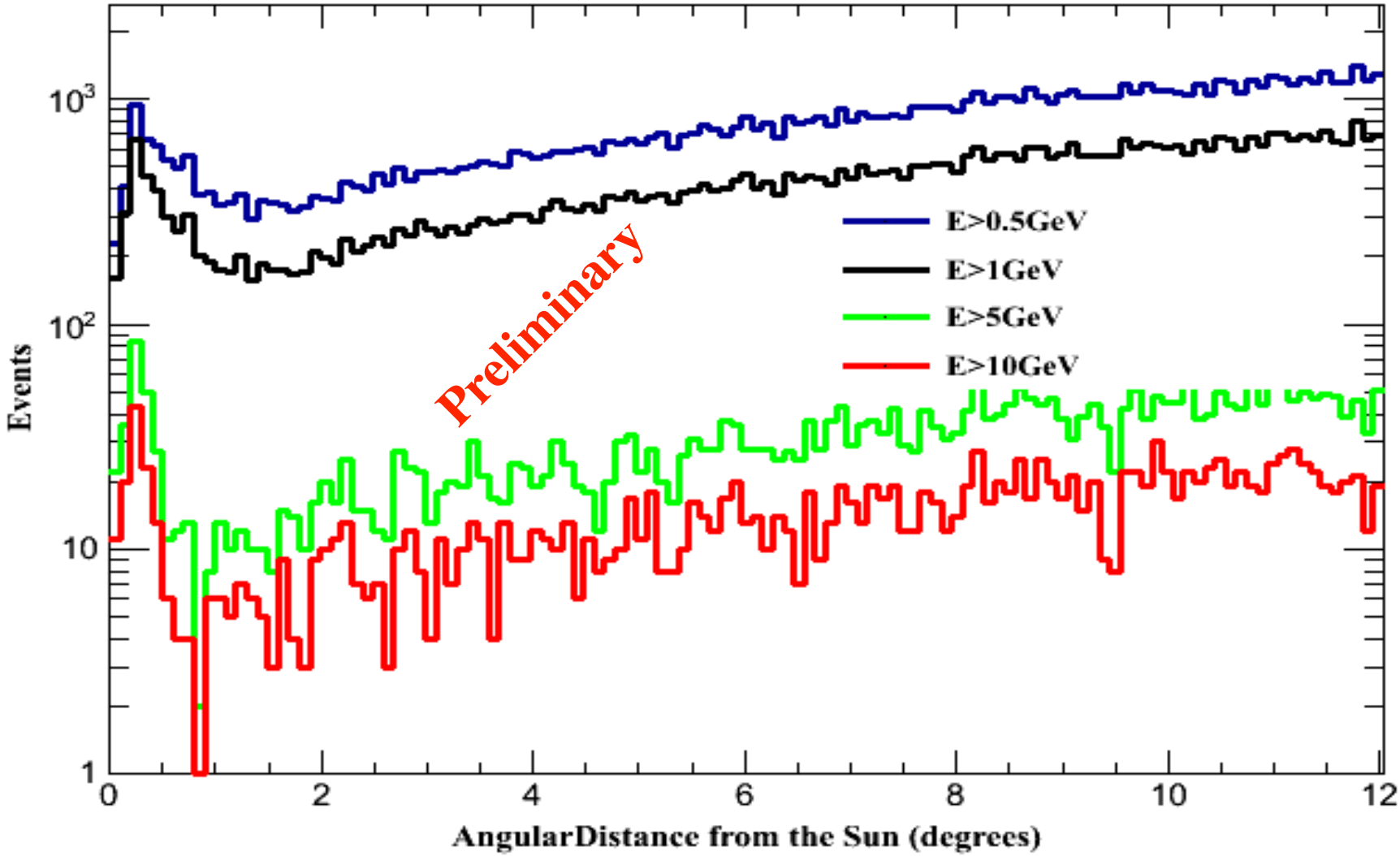
- E>10GeV
- 7.5 years data
- solar flares excluded

Coordinates are offsets from the Sun position in ecliptic coordinates.

The green circle represents the sun disk

High Energy Raw Data

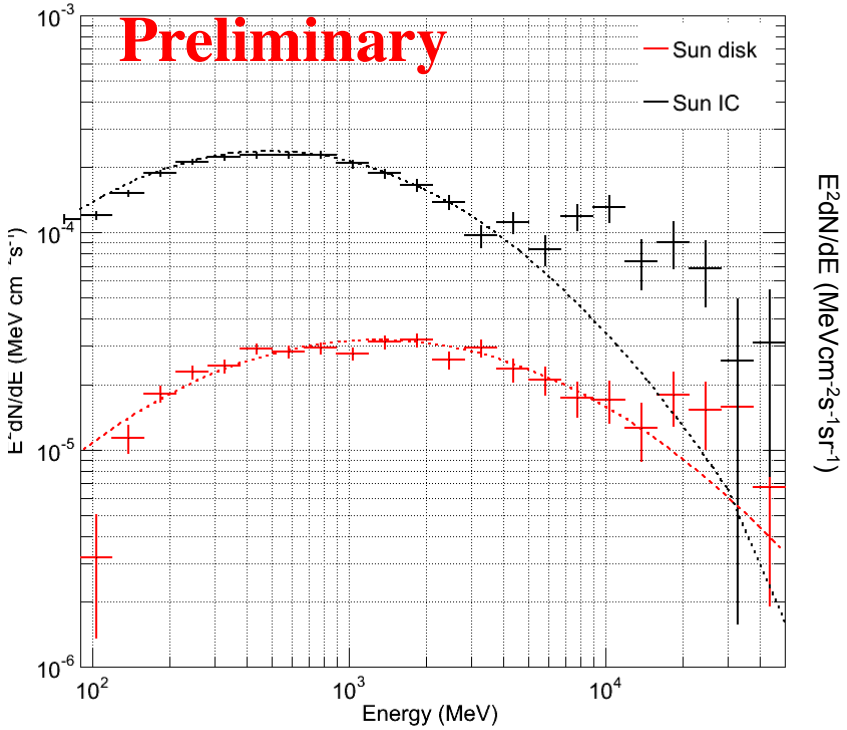
Sun events vs angular distance from the SUN for different energy thresholds



Full sample analysis

- **Full 7.5 years, Pass 8 data sample**
- **Background model:**
  - Background from off-source masked near the solar disk
- **Disk emission as point-like source (Log parabolic spectrum)**
- **IC emission from the SUN:**
  - **Model independent:**
    - generic **1/θ** radial dependence fitted on data (θ= angular distance from Sun)
    - parametric energy spectrum

Spectral Energy Distribution



SED for each solar component in the first 3 years:

- The disk component is well fitted by a Log Parabola
- The IC emission is also well represented by a logparabolic function

Disk Integral Flux(E>100MeV) = (1.93±0.07) 10^{-7} ph $cm^{-2}s^{-1}$

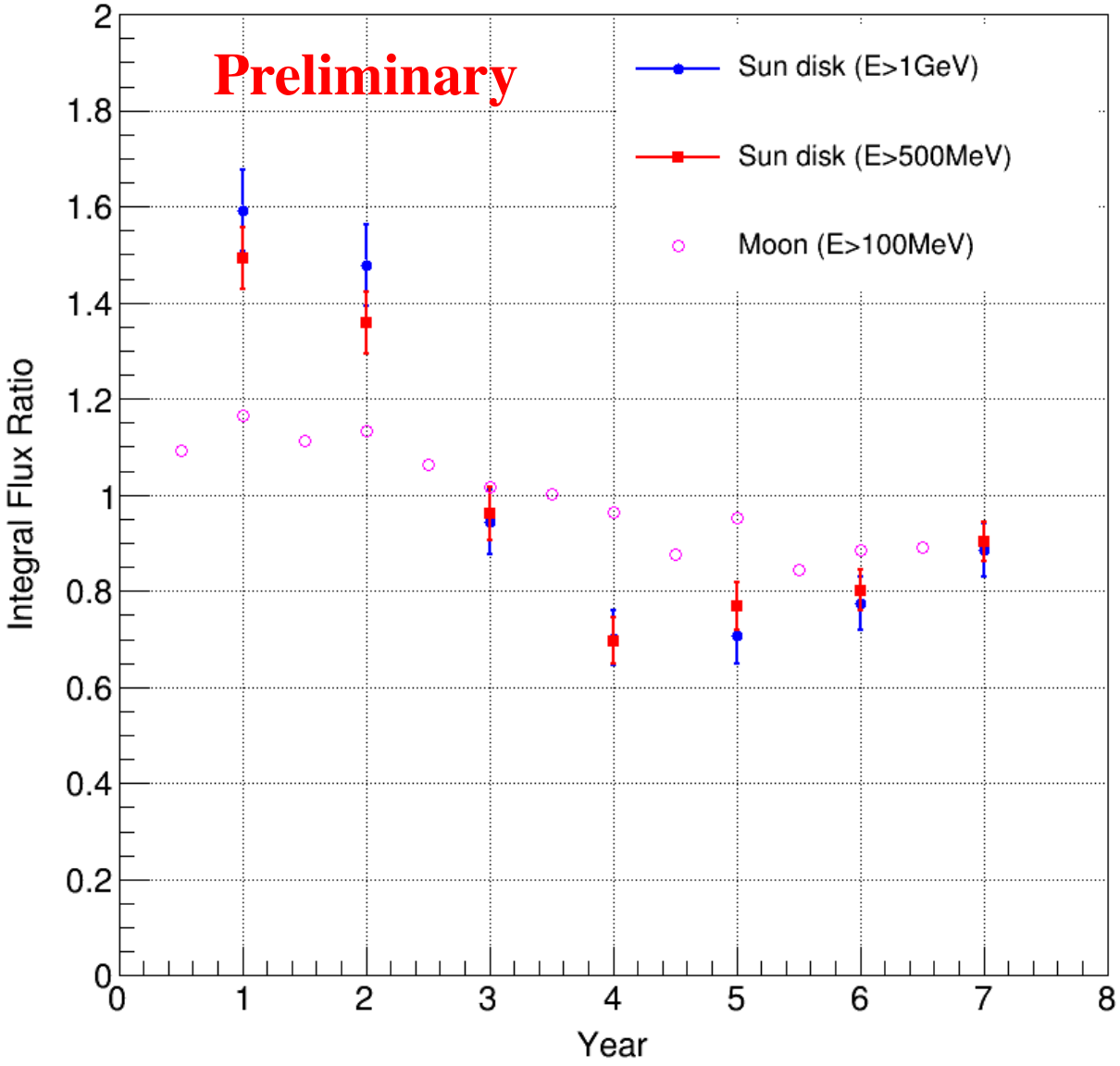
Sun IC Integral Flux (E>100MeV) = (2.02±0.02)10^{-6} ph $cm^{-2}s^{-1}sr^{-1}$

Solar disk modulation

Solar disk emission trend in the first 7 years of data taking for

- **E>1 GeV**
- **E> 500 MeV**

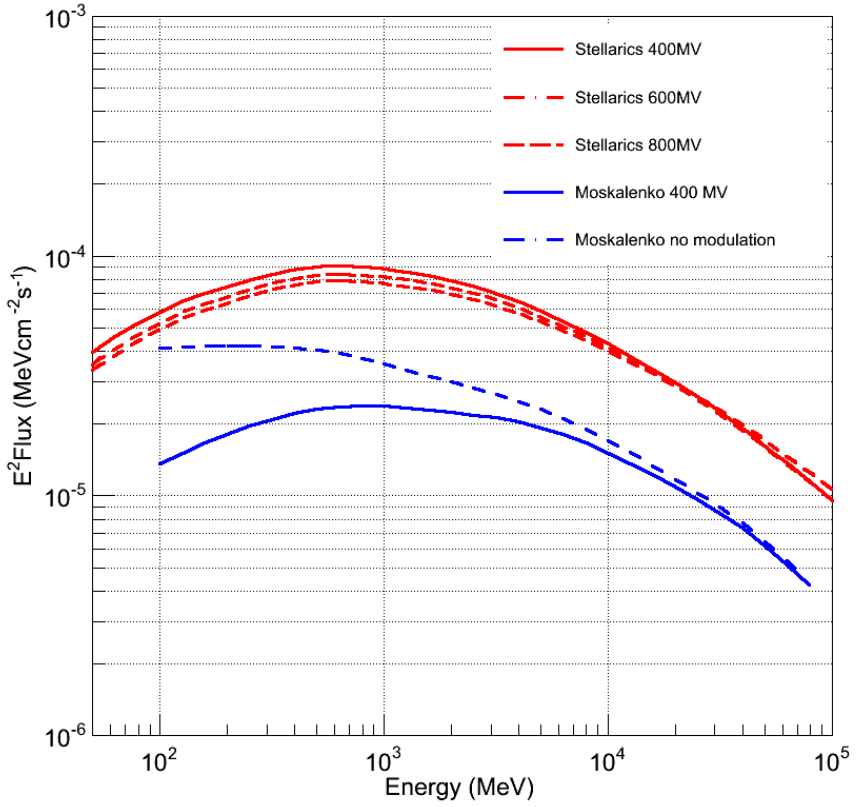
Superimposed the lunar flux ratio trend above 100 MeV

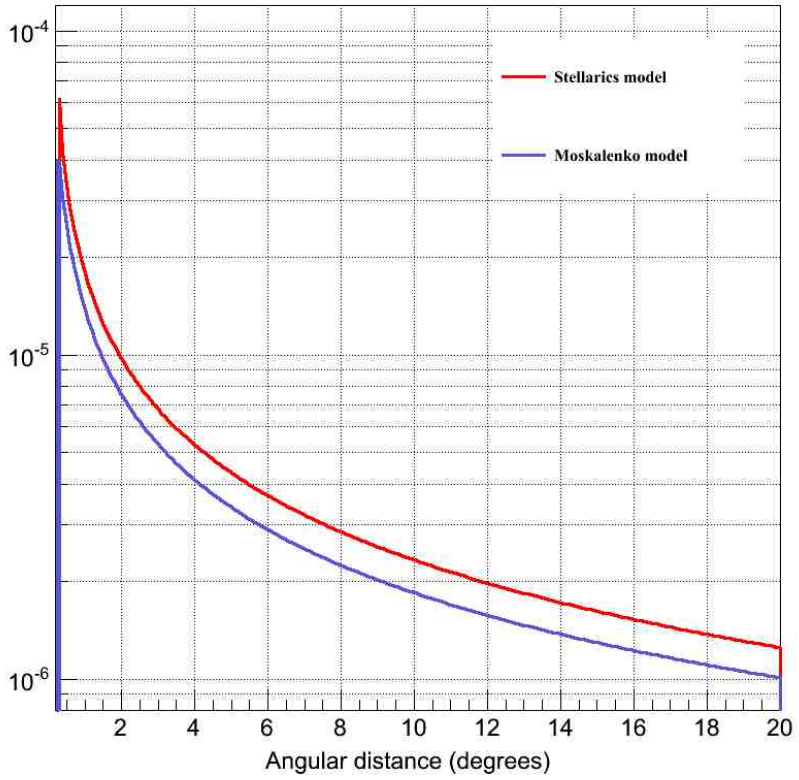


IC emission models

IC radial profile integrated over 30 MeV-30 GeV energy range according to two different models:
Stellarics package (arxiv:1307.6798v1) and Moskalenko model

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





Conclusions and Perspectives

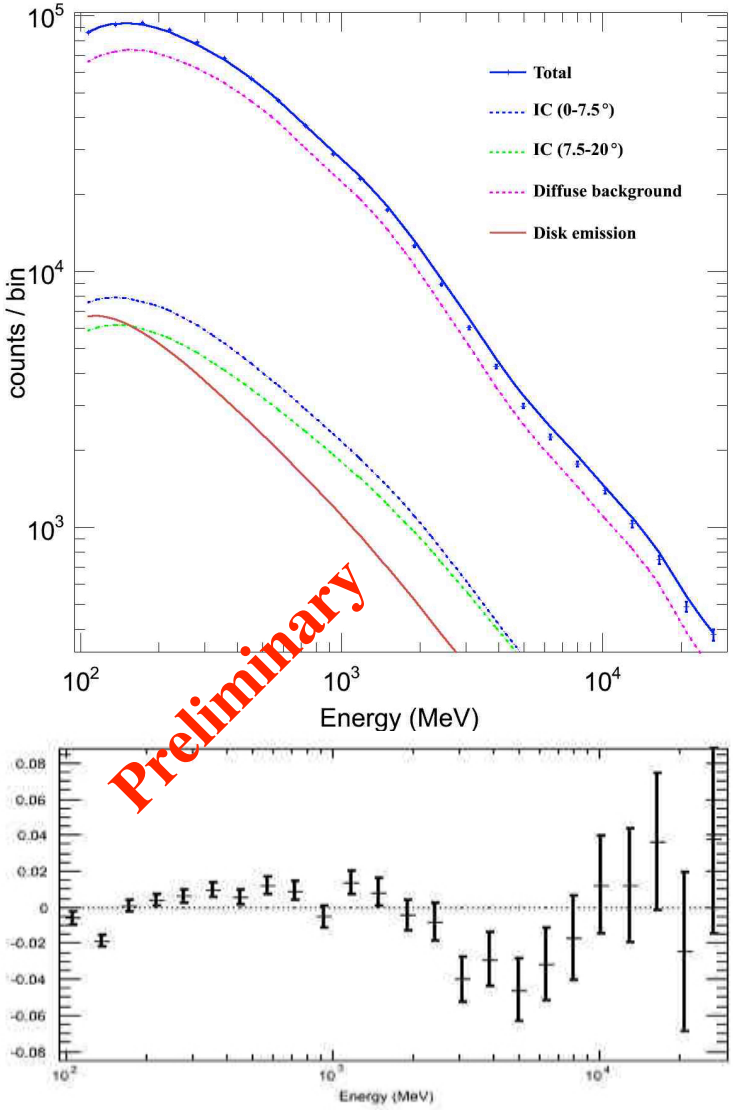
Currently we have considered a very simplified data modeling consisting of IC model, a disk emission plus background. This analysis is in progress and model description will be improved but some indications are provided:

- **The disk component has a total flux similar to that published on the first analysis**
- **The IC profile seems to be similar to what predicted by the models**
- **The solar disk component demonstrates a clear trend in anticorrelation with solar activity.**

We are finalizing this analysis to confirm these results, complete the analysis on the solar modulation and study the systematics

Back-up slides

Analysis Results



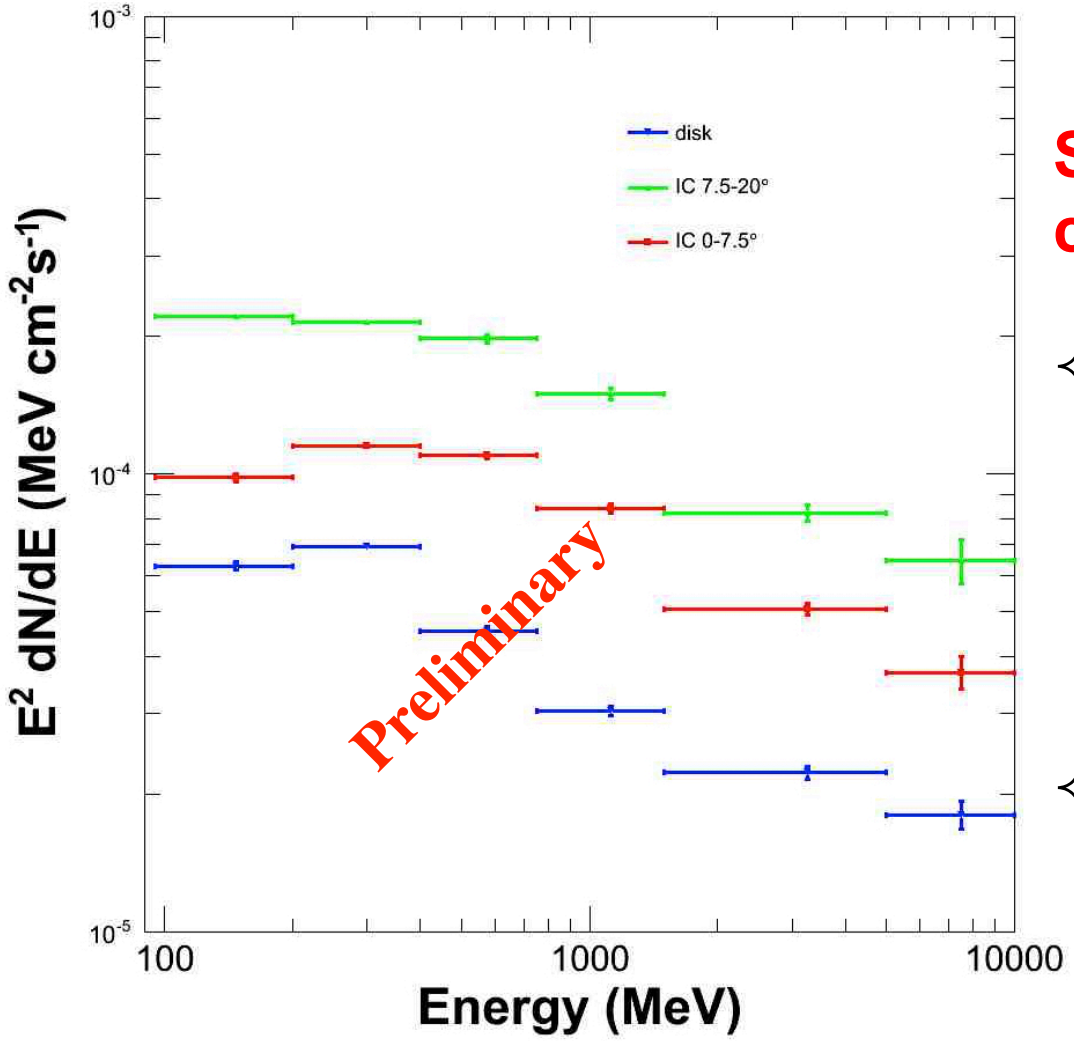
Fit results using a model with:

- ✧ 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