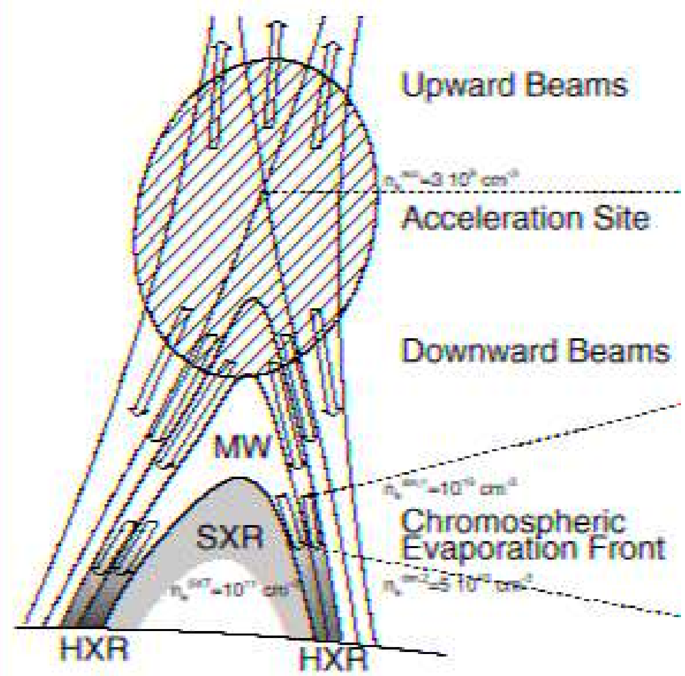
Analysis of the Solar Flare in DC2 Data

Jim Chiang
GLAST Science Support Center

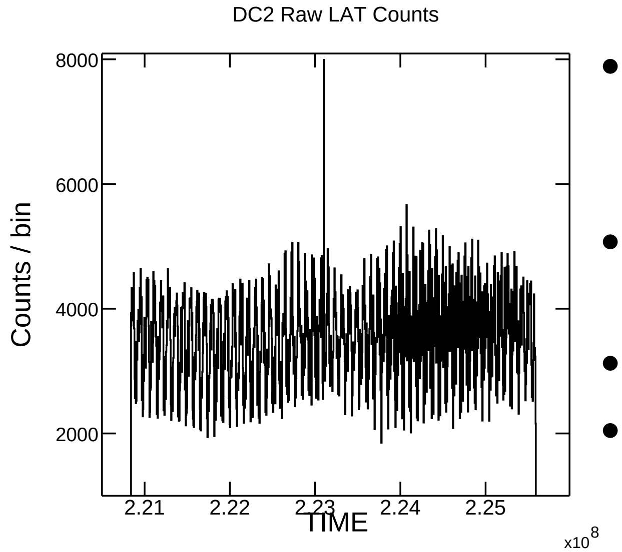
Physics of Solar Flares (thumbnail summary)

- A reconnection event occurs at the top of a magnetic loop, accelerating particles within the loop and expelling energetic particles from the top.
- Accelerated charged particles bounce back and forth within the loop, magnetically mirrored at the end points.
- Electrons emit synchrotron radiation (at radio wavebands) and bremsstrahlung at X-ray and soft gamma-ray energies.
- Protons interact with nucleons in the Solar atmosphere to produce X-rays and gamma-rays.

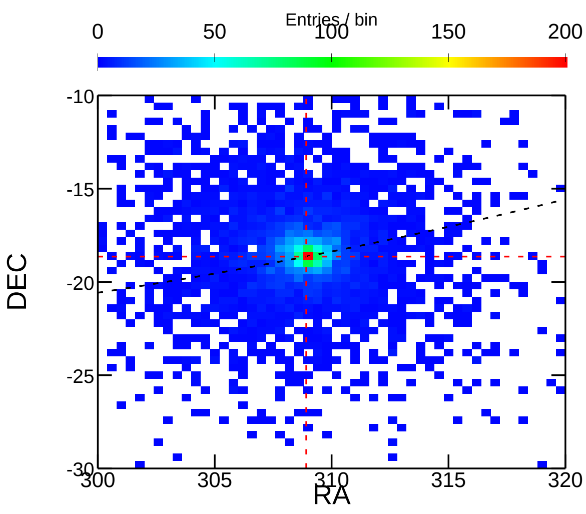


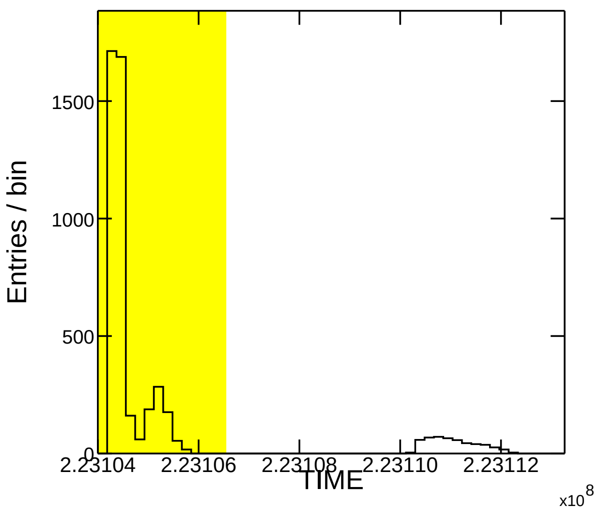
- In EGRET and LAT bands, $\gtrsim 50$ MeV, the main spectral components are pion decay ($\pi^0 \rightarrow \gamma\gamma$ and bremsstrahlung from secondary electrons) from pp interactions and electron (non)-thermal bremsstrahlung, e.g., 11 June 1991 flare (Kanbach et al. 1993).
- Pitch angle scattering off of magnetic turbulence in the loop causes the protons to diffuse out of the loop, thereby reducing the contribution to the flare intensity from pion decay at later times (Mandzhavidze & Ramaty 1992).

Identifying the DC2 Solar Flare



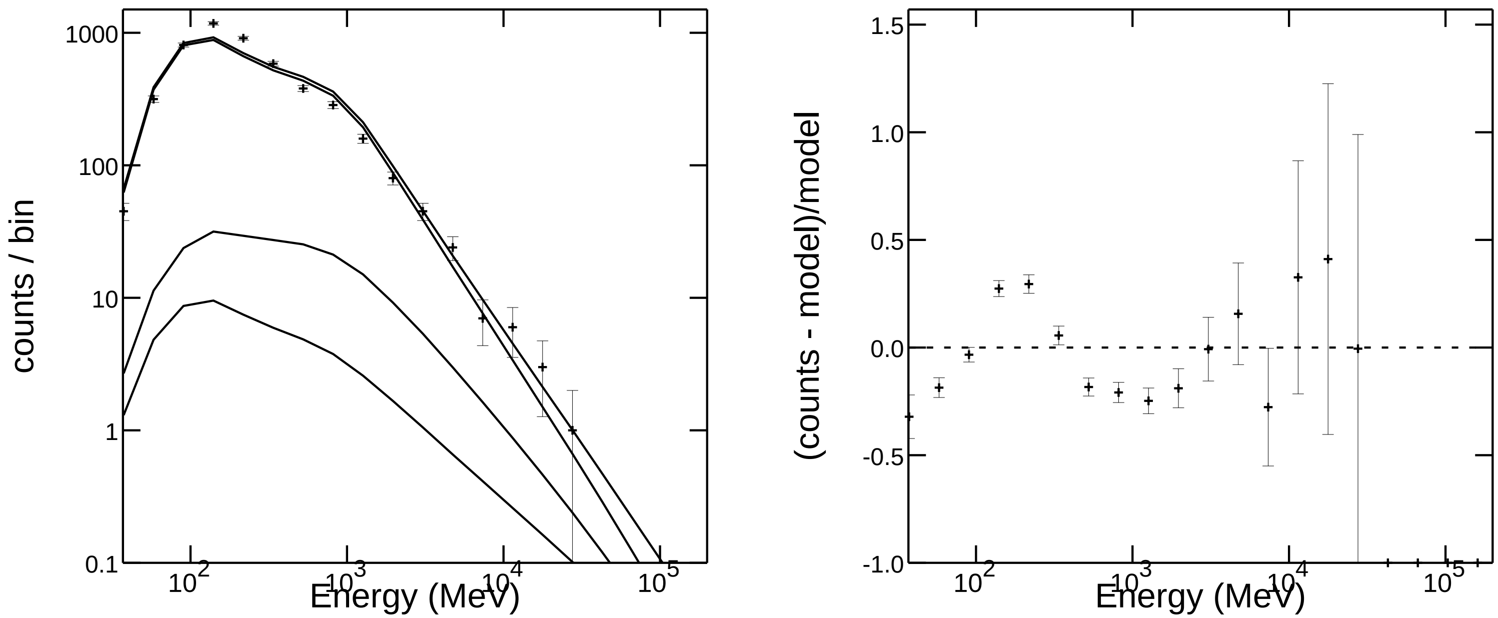
- Raw LAT counts, 5ks bins, reveals a > factor 2 flare at $t = 223104334$ s MET = 2008-01-27 05:25:34
- Flare location is (RA, Dec) = (309.00, -18.54) degrees.
- Flare duration is about 9200 s or 2.5 hours.
- This event was also found by David Band's LAT burst finding technique.





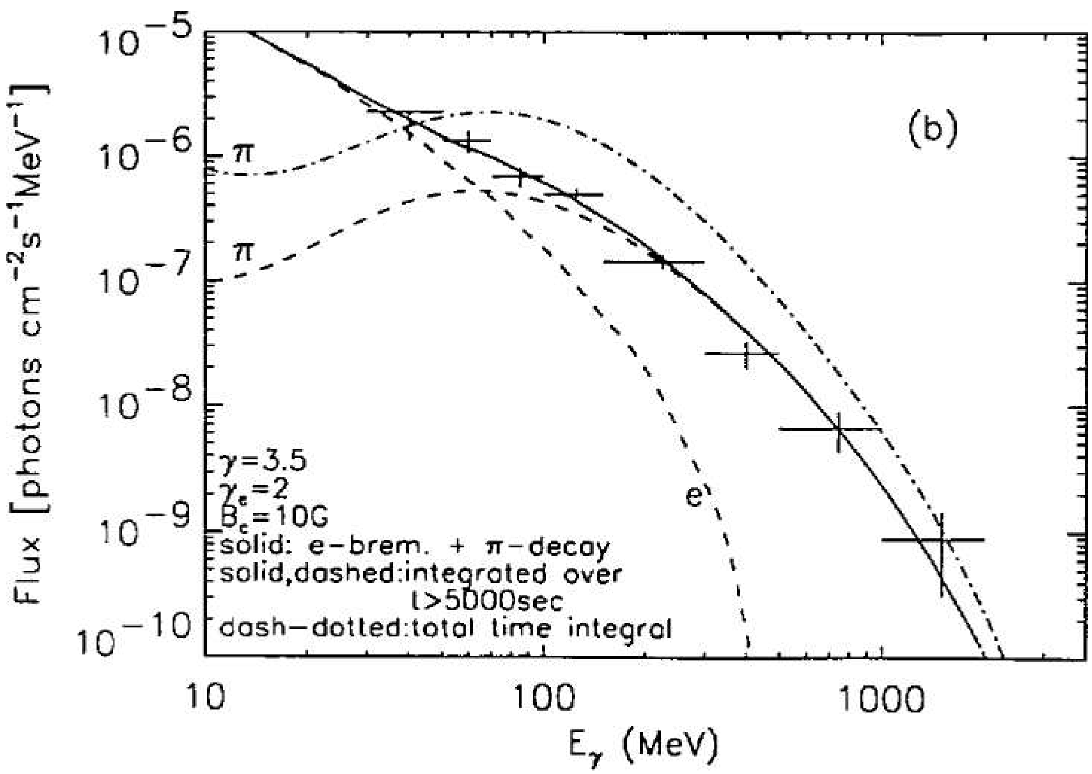
Overall Spectral Fit: First Attempt

- Data extracted for a 20 deg circle centered on (RA, Dec) = (309.00, -18.54) degrees, for energies 30–2×10^5 MeV, between times (223103093, 223112238) s MET (all 55+ days), and for both class A and B events.
- Model the flare as a broken power-law and include extragalactic and Galactic diffuse components to the fit:



Physical Emission Model

Mandzhavidze & Ramaty (1992) model the EGRET data for the 11 June 1992 flare using a composite spectrum of electron bremsstrahlung and pion decay:



Bremsstrahlung + Pion Decay Spectral Fit

- Model electron bremsstrahlung using an exponentially cut-off power-law,

$$\frac{dN}{dE} \propto E^{-\Gamma} \exp(-E/E_c), \quad (1)$$

  where $\Gamma = 1$ and $E_c \sim kT_e$ for thermal bremsstrahlung.

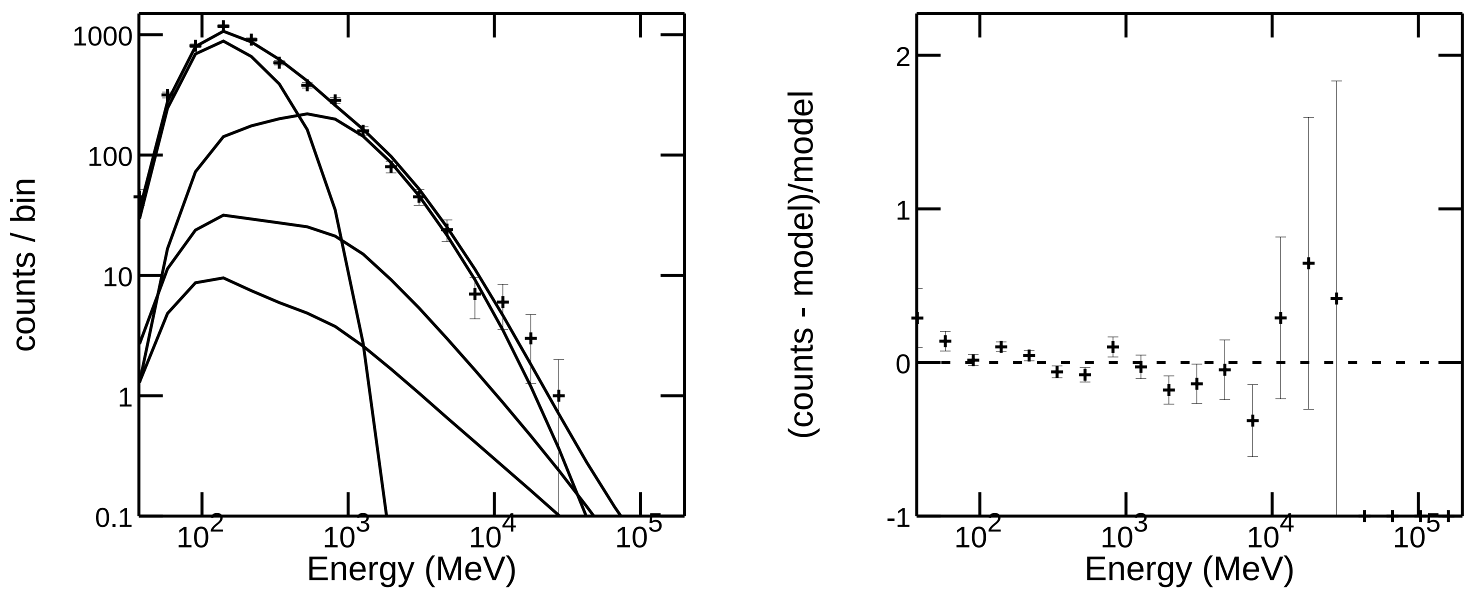
- Log-parabola,

$$\frac{dN}{dE} \propto E^{-(\alpha+\beta \log(E/E_b))}, \quad (2)$$

  where $E_b = 68\,\mathrm{MeV}$. Using this for the π^0-component was suggested by JCT based on his fits to detailed WIMP annihilation calculations. Typical shape parameters: $\alpha \sim \beta \sim 0.3$.

- Neglect modeling of secondary electron bremsstrahlung component.

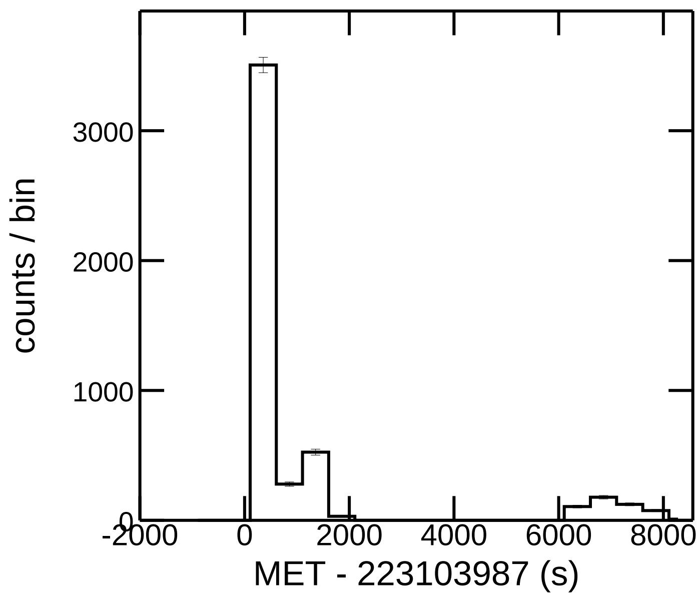
Overall Spectral Fit: Second Try

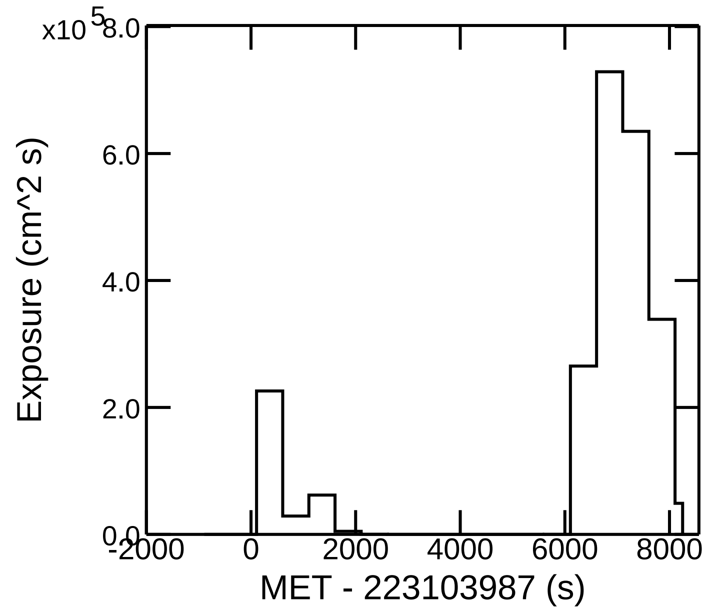


- $\Delta \log \mathcal{L} = 118$, 2 extra degrees-of-freedom.
- "Bremsstrahlung" component: $f_{\rm brem}(> 50{\rm MeV}) = 8.0 \times 10^{-4}$ photons cm^{-2}s^{-1}, $\Gamma = 1$
- "Pion decay" component: $f_{\pi^0}(> 50{\rm MeV}) = 1.9 \times 10^{-4}$ photons cm^{-2}s^{-1}, $\alpha \approx 0.4$, $\beta \approx 0.3$

Time Dependence

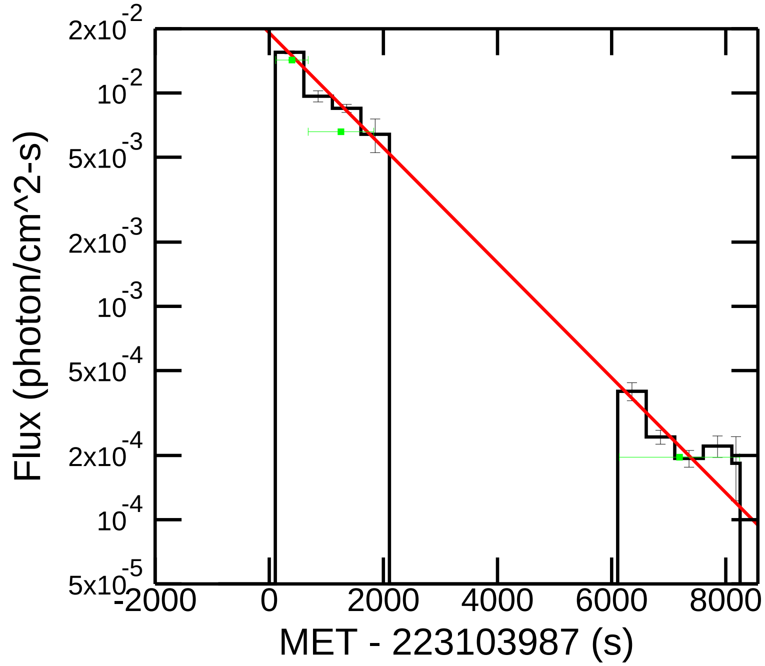
- This flare spans a few orbits, so a simple counts light curve has the imprint of the varying off-axis angle and Earth occultations in addition to the intrinsic variability.
- In order to convert the counts light curves to flux estimates, I wrote simple tool that calculates the exposure for arbitrary time intervals at a specific location on the sky, weighting by a spectral model.



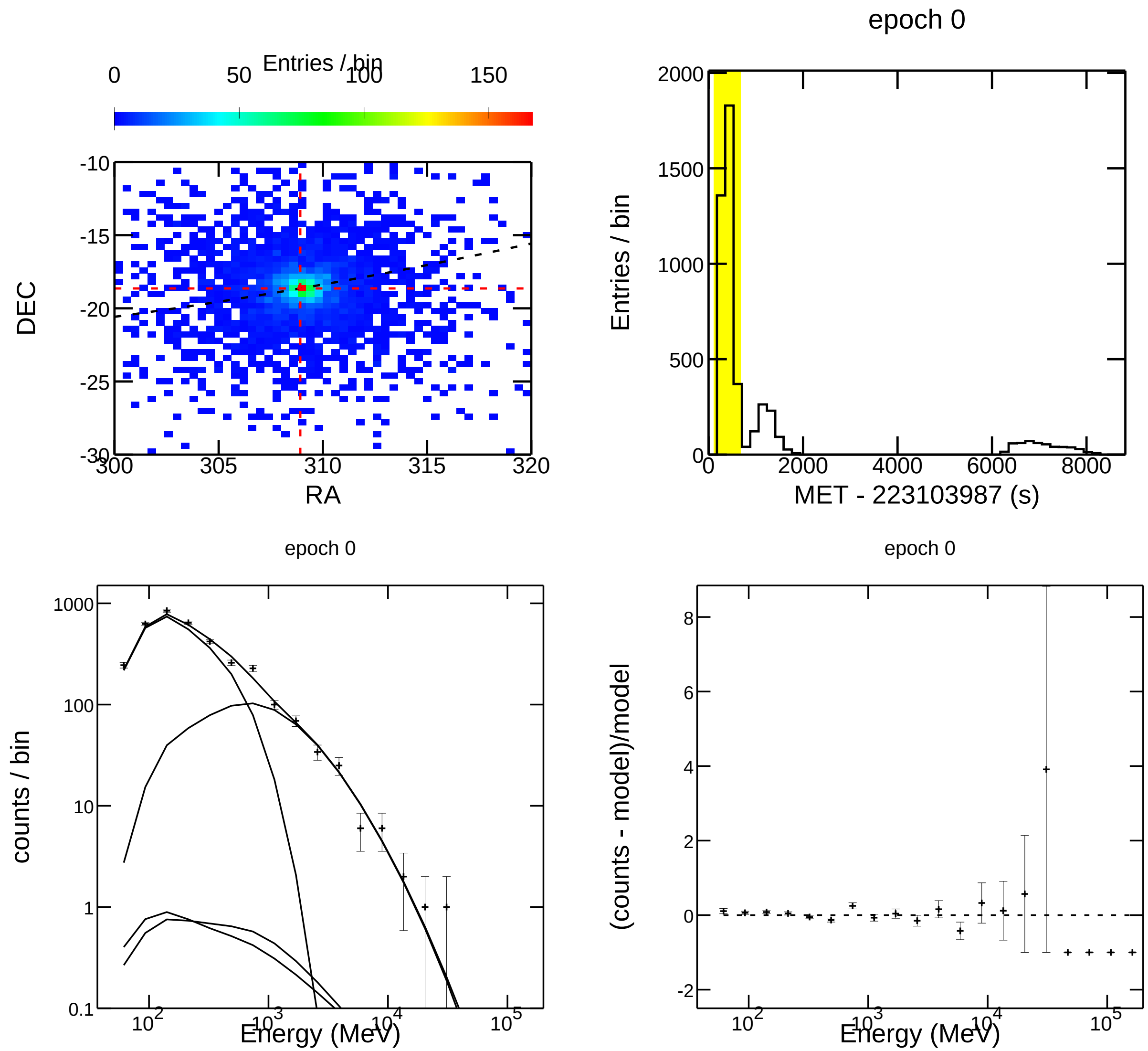


Time Dependence (continued)

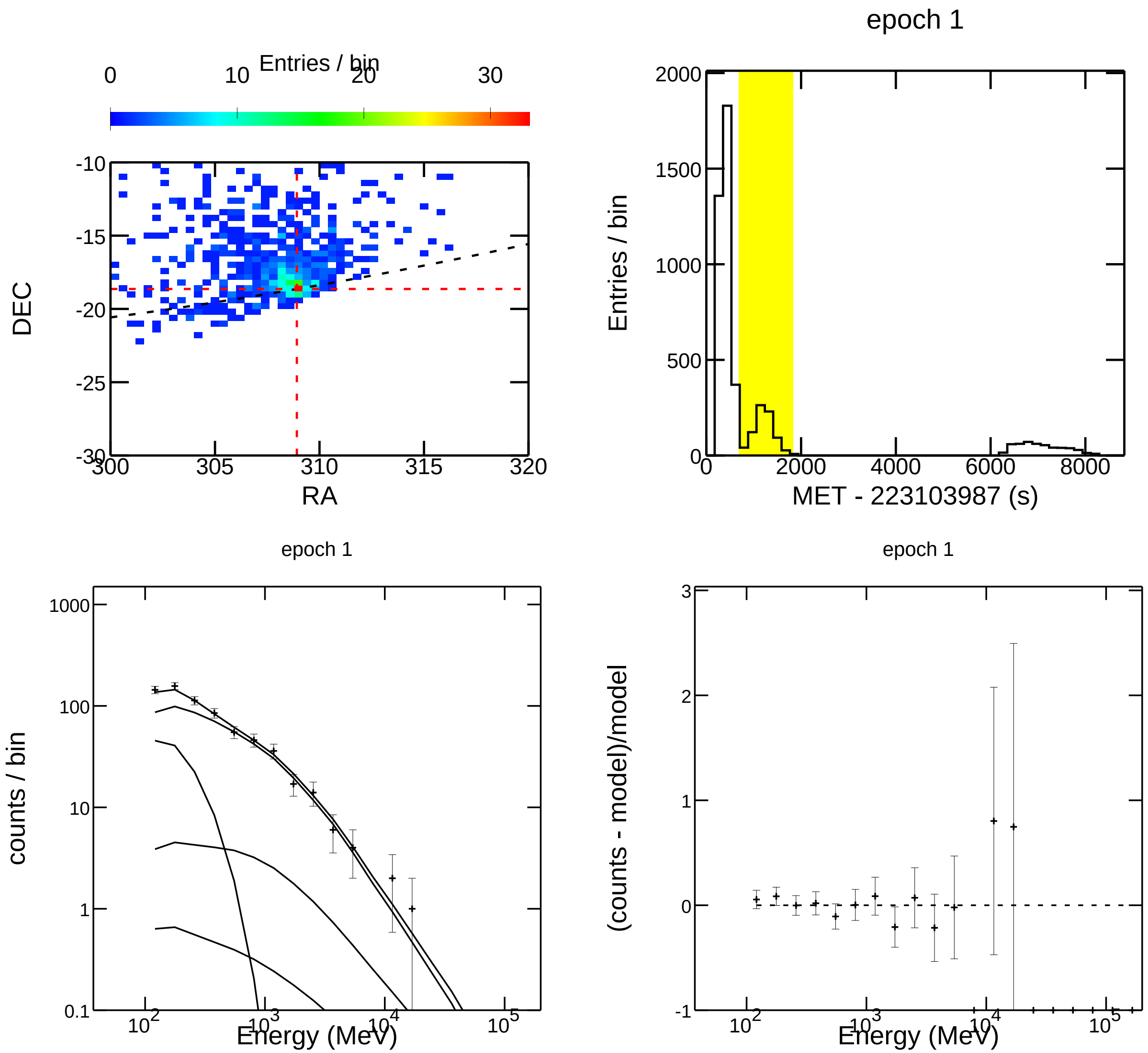
- Using the broken power-law spectral fit, I find an exponential decaying light curve with time scale 1600 s = 27 minutes. The 11 June 1991 Solar flare seen by EGRET had two e-folding time scales of 25 minutes and 255 minutes.
- Green data points are the fluxes obtained by fitting the bremsstrahlung + pion decay model using likelihood.



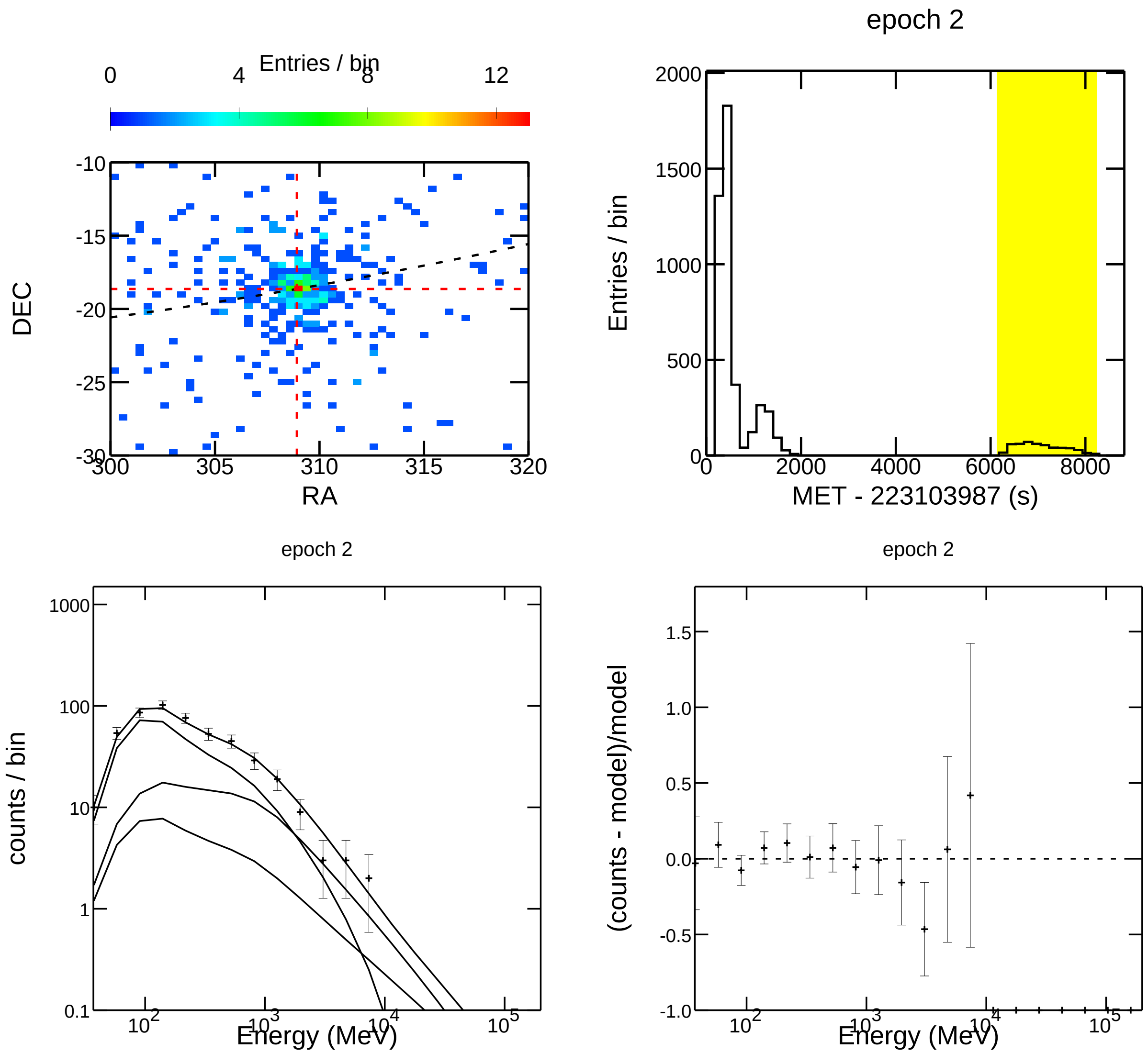
Epoch 0: $(t_{\rm min}, t_{\rm max}) = (115, 682) + 223103987$ s MET



Epoch 1: $(t_{\rm min}, t_{\rm max}) = (682, 1831) + 223103987$ s MET

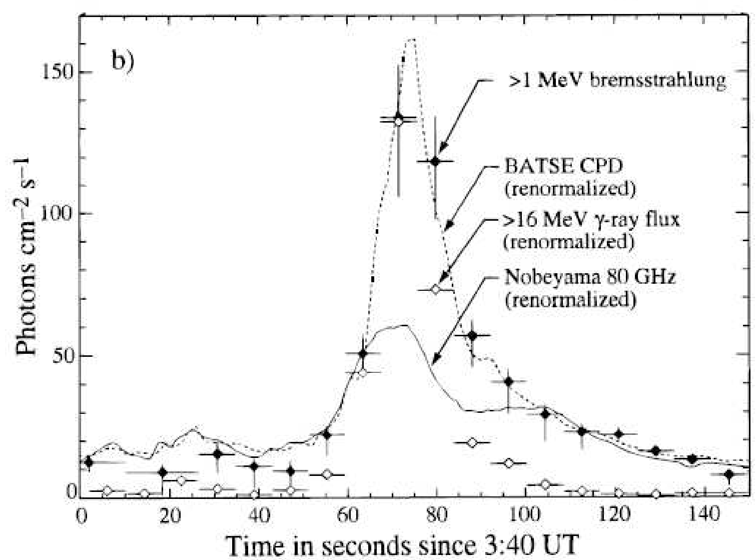


Epoch 2: $(t_{\rm min}, t_{\rm max}) = (1831, 8244) + 223103987$ s MET



Comparisons to Previous Solar Flare γ-ray Observations

- Early time fluxes of $\sim 10^{-2}$ photons cm^{-2} (for $E > 30$ MeV) make this flare comparable to other X-class Solar flares: 3 June 1982, 4 June 1991, 11 June 1991, 15 June 1991
- Decay time scale of 27 minutes matches fast e-folding decay constant seen for 15 June 1991 flare, but this event seems to lack the component with a 255 minute time scale that is attributed to pion decay emission by Mandzhavidze & Ramaty (1992) implying that proton diffusion (driven by pitch angle scattering off MHD turbulence) out of the trapping region is efficient.
- Lower energy emission probably should have triggered the GBM (cf. 4 June 1991 flare, Murphy et al. 1997):



Summary and Conclusions

If this were real data....

- One should, of course, correlate analysis of LAT data with GBM and measurements at other wavelengths. In particular, there is a wealth of nuclear γ-ray line data in the 1–10 MeV range.
- It would be useful to fit the LAT data with real pion decay and electron bremsstrahlung models to see if these components can be constrained separately.

As far as DC2 goes....

- Being able to compute exposures for arbitrary time intervals at specific locations on the sky can be extremely useful at least for brighter sources (or for longer time scale periodicity analysis) where effective area variations as a function of off-axis angle are important.
- Spectral fitting is an *interactive* endeavor. Although it is a blunt tool, looking at the counts spectra is an important sanity check, and excessive reliance on automation can lead to trouble.

- Example: Epoch 1 data at high inclination wrt LAT z-axis.