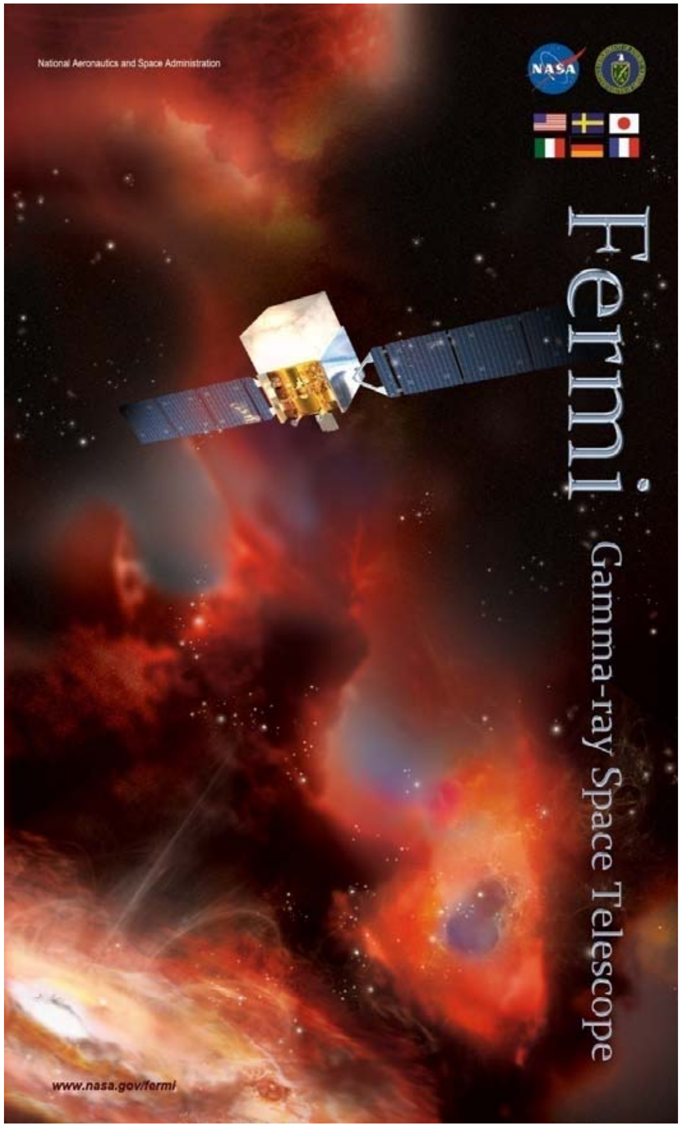

Introduction to Fermi-LAT Science Analysis Software

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REFERENCES

Fermi Science Support Center: http://fermi.gsfc.nasa.gov/ssc/

Fermi Newsletters: http://fermi.gsfc.nasa.gov/ssc/resources/newsletter/

Fermi Data Access: http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi

Fermi Science Tools Reference Manual:
http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/references.html

Fermi Analysis Threads:
http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/

Fermi - LAT Likelihood Algorithm description
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Likelihood/
Cash W. 1979, ApJ 228, 939
Mattox J. R. et al 1996, ApJ 461, 396
Protassov et al. 2002, ApJ 57, 545

LAT Performance Page: http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm
The Large Area Telescope on the Fermi Gamma-Ray Space Telescope Mission, W.B. Atwood, et. al., ApJ, 2009, 695, 1071.
The On-orbit Calibrations for the Fermi Large Area Telescope, A.A. Abdo, et al. arXiv:0904.2226v1

Likelihood Analysis: Introduction

The final aim of any data analysis work is to derive the best possible estimate for the characteristics of a source.

The Maximum Likelihood Analysis (MLA) has been successfully used in the analysis of gamma-ray data and it has also a central role in the LAT Data analysis.

The Fermi Science Analysis Software provides a tool to perform:

- **Unbinned Maximum Likelihood Analysis**
- **Binned Maximum Likelihood Analysis**

Source Model and Instrument Response

The total source model is the sum of contributions from individual point-like and diffuse sources:

$$S(\varepsilon, \hat{p}) = \sum_i S_i(\varepsilon, \hat{p}), \tag{1}$$

where ε is the true energy of the photon and $\hat{p}$ is the true direction on the sky. We assume spatial and spectral parts factor and that the sources are time-steady:

$$S_i(\varepsilon, \hat{p}) = s_i(\varepsilon)\tilde{S}_i(\hat{p}) \tag{2}$$

For a point source i,

$$S_i(\varepsilon, \hat{p}) = s_i(\varepsilon)\delta(\hat{p} - \hat{p}_i). \tag{3}$$

Typically, only the spectral part of the source models are fit, with relatively simple spectral models, e.g., power-laws:

$$s(\varepsilon) = N_0 \varepsilon^{-\Gamma}. \tag{4}$$

The instrument response is typically factored into three components:

$$R(\varepsilon', \hat{p}'; \varepsilon, \hat{p}, t) = A(\varepsilon, \hat{p}, t) P(\hat{p}'; \varepsilon, \hat{p}, t) D(\varepsilon'; \varepsilon, \hat{p}, t). \tag{5}$$

Here ε' and $\hat{p}'$ are the measured energy and direction of the photon, repectively. $P(\hat{p}'; \varepsilon, \hat{p}, t)$ is the point spread function; and $D(\varepsilon'; \varepsilon, \hat{p}, t)$ is the energy dispersion; both functions are pdfs. The effective area $A(\varepsilon, \hat{p}, t)$ is the cross-section of the LAT for detecting an incident photon with $(\varepsilon, \hat{p})$ at a time t. The time-dependence of each factor is required since $\hat{p}$ is in sky coordinates, and the LAT pointing is not fixed.

Binned Likelihood

The expected distribution of detected counts is

$$M(\varepsilon', \hat{p}', t) = \int_{\rm SR} d\varepsilon d\hat{p}\, S(\varepsilon, \hat{p}) R(\varepsilon', \hat{p}'; \varepsilon, \hat{p}, t) \quad (6)$$

$$= \sum_i \left[\int_{\rm SR} d\varepsilon d\hat{p}\, S_i(\varepsilon, \hat{p}) R(\varepsilon', \hat{p}'; \varepsilon, \hat{p}, t) \right] \quad (7)$$

$$= \sum_i M_i(\varepsilon', \hat{p}', t) \quad (8)$$

$\int_{\rm SR} d\varepsilon d\hat{p}$ is the integral over the "source region", which in principle, covers the whole sky and all energies. For data binned in $(\varepsilon', \hat{p}')$, the likelihood is

$$\mathcal{L} = \prod_j \frac{\theta_j^{n_j} e^{-\theta_j}}{n_j!}, \quad (9)$$

where n_j is the number of events in bin j, and θ_j is the predicted number of events lying in that bin given the model:

$$\theta_j = \int dt \int_j d\varepsilon' d\hat{p}' M(\varepsilon', \hat{p}', t) \quad (10)$$

Here $\int_j d\varepsilon' d\hat{p}'$ indicates the integral over the jth bin, and the time integral is over the duration of the observation.

Unbinned Likelihood

The log-likelihood for the binned case:

$$\log \mathcal{L} = \sum_j \left((n_j \log \theta_j - \theta_j) - \log n_j! \right) \tag{11}$$

$$= \sum_j n_j \log \theta_j - N_{\mathrm{pred}} \tag{12}$$

The predicted number of events within a given region-of-interest is

$$N_{\mathrm{pred}} = \int dt \int_{\varepsilon_{\mathrm{min}}}^{\varepsilon_{\mathrm{max}}} d\varepsilon' \int_{\Omega_{\mathrm{roi}}} d\hat{p}' M(\varepsilon', \hat{p}', t) \tag{13}$$

In the limit of very small bins, where we have 0 or 1 event per bin,

$$\theta_j = \delta\varepsilon'\, \delta\hat{p}'\, \delta t\, M(\varepsilon'_j, \hat{p}'_j, t_j) \tag{14}$$

Here j labels each detected photon, and we obtain the expression for our unbinned likelihood calculation:

$$\log \mathcal{L} = \sum_j \log M(\varepsilon'_j, \hat{p}'_j, t_j) - N_{\mathrm{obs}} \log(\delta\varepsilon'\, \delta\hat{p}'\, \delta t) - N_{\mathrm{pred}} \tag{15}$$

(Not) Handling Energy Dispersion

Writing the first term explicitly in equation 15:

$$\sum_j \log\left(\sum_i \int d\varepsilon\, s_i(\varepsilon) \int d\hat{p}\, \tilde{S}_i(\hat{p}) A(\varepsilon, \hat{p}, t_j) P(\hat{p}'_j; \varepsilon, \hat{p}, t_j) D({\varepsilon'}_j; \varepsilon, \hat{p}, t_j)\right) \tag{16}$$

For a point source at location $\hat{p}_i$,

$$\sum_j \log\left(\sum_i \int d\varepsilon s_i(\varepsilon) A(\varepsilon, \hat{p}_i, t_j) P(\hat{p}'_j; \varepsilon, \hat{p}_i, t_j) D({\varepsilon'}_j; \varepsilon, \hat{p}_i, t_j)\right) \tag{17}$$

For every evaluation of the log-likelihood, the integral over the energy dispersion must be computed for every event j and every source i. The situation is even worse for diffuse sources since the integral over $\hat{p}$ must also be folded in. The current implementation neglects this integral, simplifying the calculation to

$$\sum_j \log\left(\sum_i s_i({\varepsilon'}_j) A({\varepsilon'}_j, \hat{p}_i, t_j) P(\hat{p}'_j; {\varepsilon'}_j, \hat{p}_i, t_j)\right) \tag{18}$$

This speeds things up enourmously.

Diffuse sources

Making the same approximation for the diffuse sources,

$$\sum_j \log\left(\sum_i s_i(\varepsilon'_j)\left[\int d\hat{p}\,\tilde{S}_i(\hat{p})A(\varepsilon'_j,\hat{p},t_j)P(\hat{p}'_j;\varepsilon'_j,\hat{p},t_j)\right]\right) \tag{19}$$

The factor in square brackets can be precomputed for each event and stored as a single number. These are the diffuse response quantities produced by `gtdiffrsp`. If we were to include energy dispersion, we would need to store the equivalent computation as a function of energy for each event, i.e.,

$$\int d\hat{p}\,\tilde{S}_i(\hat{p})A(\varepsilon,\hat{p},t_j)P(\hat{p}'_j;\varepsilon,\hat{p},t_j)D(\varepsilon'_j;\varepsilon,\hat{p},t_j) \tag{20}$$

Installing the Fermi Science Tools

http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/

- You can install the Fermi Science Tools using either a source distribution or using a precompiled binary. The preferred method is to use the binary distribution.

- On a unix command line you can find your machine type with the command
  - uname -m

  and you should see something like i686, x86_64, or powerpc.

- To determine the version of libc you can try
  - ls /lib/libc-*

  and you should see something like
  - /lib/libc-2.3.4.so

  where the 2.3.4 is the libc version.

- Binary distributions are available for the following OS:
  - Scientific Linux 4.4 32 bit libc 2.3.4
  - Scientific Linux 5 32 bit libc 2.5
  - Scientific Linux 4 64 bit libc 2.3.4
  - Scientific Linux 5 64 bit libc 2.5
  - MAC OS X 10.4 powerpc
  - MAC OS X 10.4 intel
  - MAC OS X 10.5 powerpc
  - MAC OS X 10.5 intel

Binary Install of the Fermi Science Tools

- To install the Fermi Science Tools using the binary distribution, please follow these steps:
  1. Download the binaries for your system.
  2. Unpack the distribution package in e.g. $HOME/glast

     $ tar xzvf ScienceTools-v9r15p2-fssc-20090808-<PLATFORM>.tar.gz

     $cd ScienceTools-v9r15p2-fssc-20090808-<PLATFORM>/<PLATFORM>/BUILD_DIR

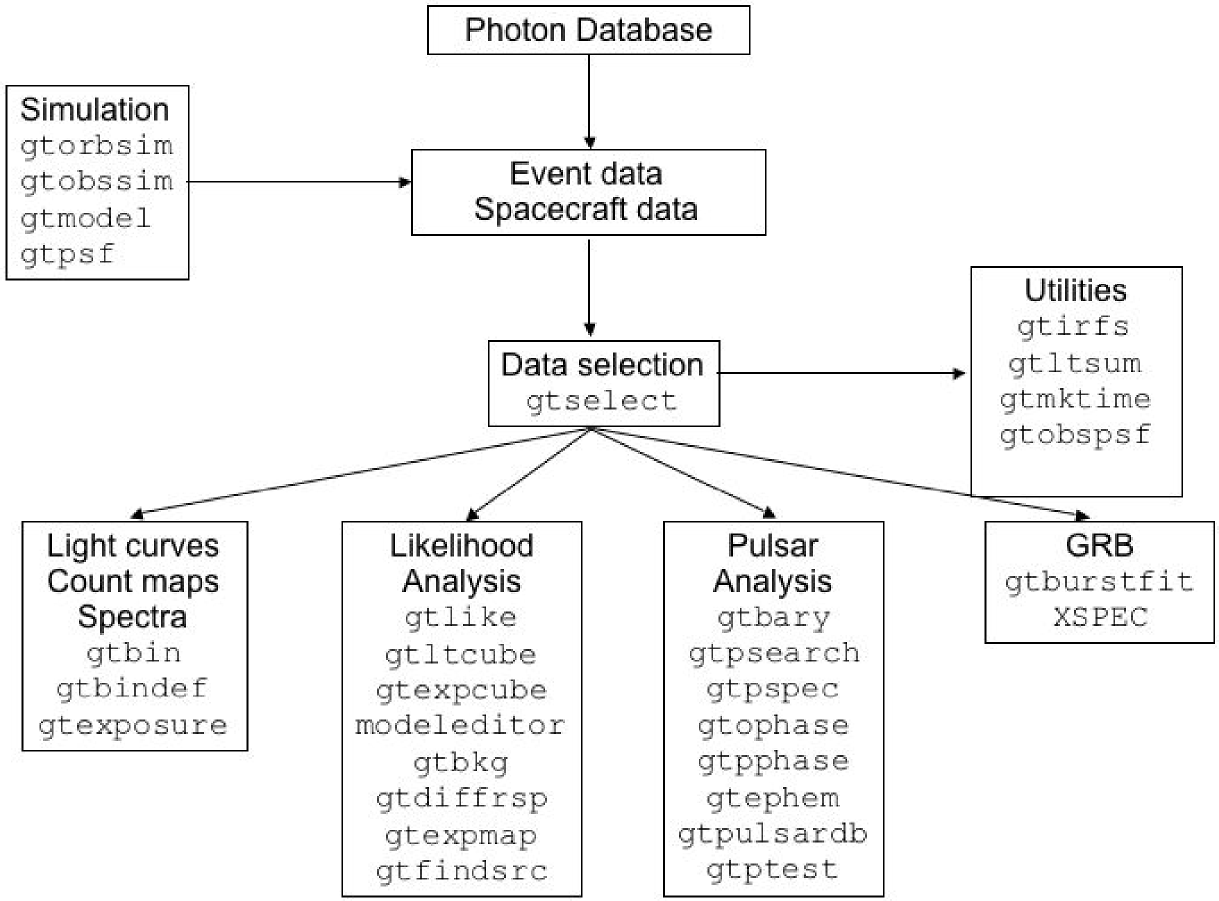
  3. Run the configure (e.g. in the bash shell):

     $./configure >& configure.out

  4. Set your FERMI_DIR environment variable to point to your installation,
     - $ export FERMI_DIR=$HOME/glast/ScienceTools-v9r15p2-fssc-20090808-<PLATFORM>/i686-pc-linux-gnu-libc2.3.4

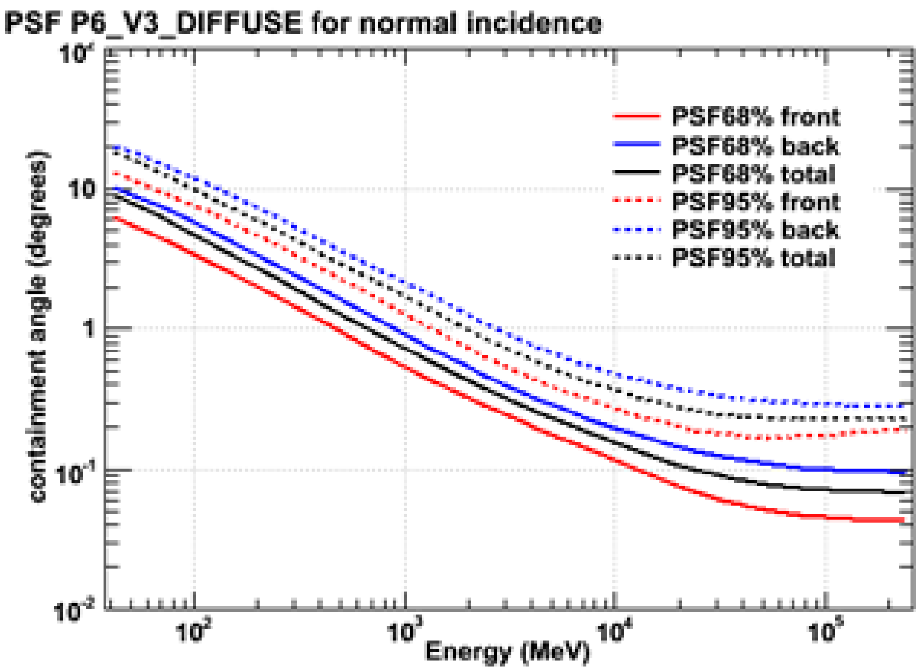
       or:
       $setenv FERMI_DIR $HOME/glast/ScienceTools-v9r15p2-fssc-20090808-<PLATFORM>/i686-pc-linux-gnu-libc2.3.4
  5. Execute the Fermi setup script:
     - bash: $source $FERMI_DIR/fermi-init.sh
     - csh: $source $FERMI_DIR/fermi-init.csh

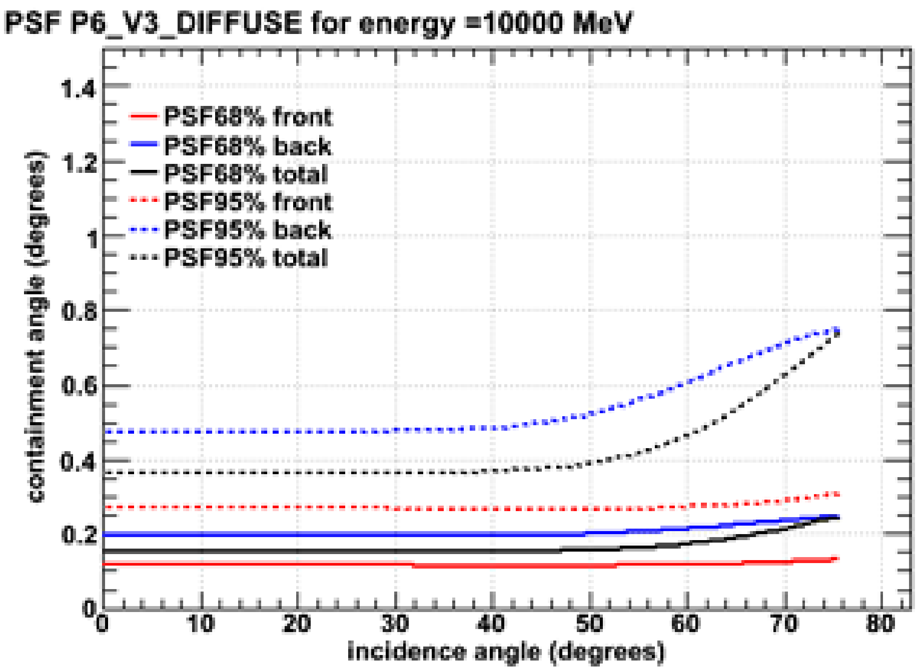
Overview


Photon Database
Simulation
gtorbsim
gtobssim
gtmodel
gtpsf
Event data
Spacecraft data
Utilities
gtirfs
gtltsum
gtmktime
gtobspsf
Data selection
gtselect
Light curves
Count maps
Spectra
gtbin
gtbindef
gtexposure
Likelihood
Analysis
gtlike
gtltcube
gtexpcube
modeleditor
gtbkg
gtdiffrsp
gtexpmap
gtfindsrc
Pulsar
Analysis
gtbary
gtpsearch
gtpspec
gtophase
gtpphase
gtephem
gtpulsardb
gtptest
GRB
gtburstfit
XSPEC

IRF-PSF

Starting from the front of the instrument, the LAT tracker (TKR) has 12 layers of 3% radiation length tungsten converters (THIN or FRONT section), followed by 4 layers of 18% r.l. tungsten converters (THICK or BACK section). These sections have intrinsically different PSF due to multiple scattering,

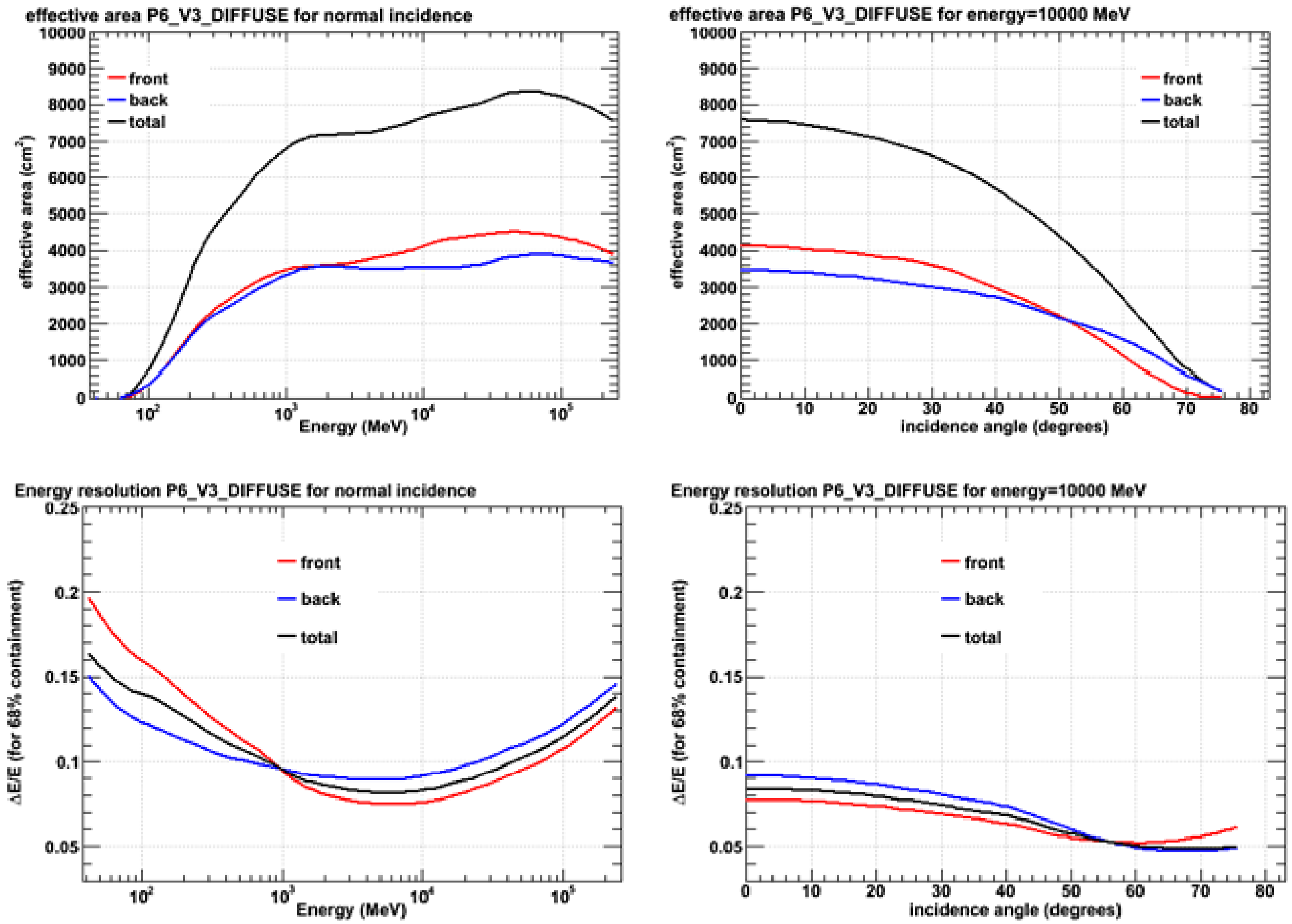




http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

The LAT IRFs are included in the ST

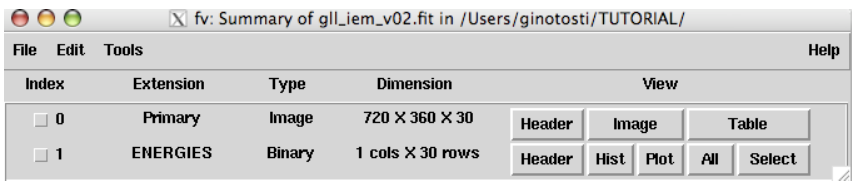
IRF-Effective Area - Energy Disperision

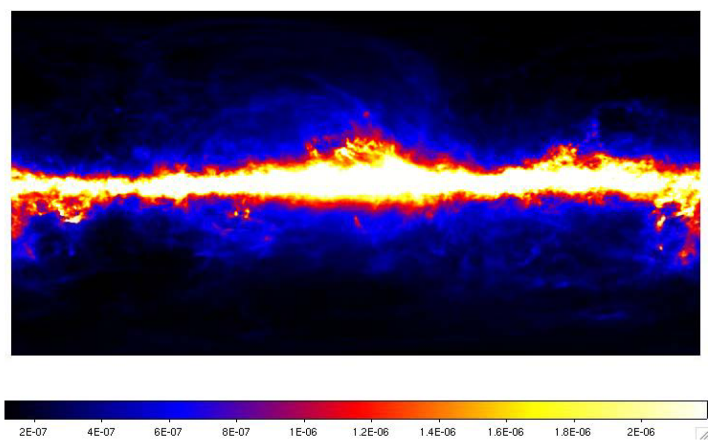


http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

Diffuse Models

Galactic diffuse model	gll_iem_v02.fit
Isotropic spectral template (all)	isotropic_iem_v02.txt
Isotropic spectral template (front)	isotropic_iem_front_v02.txt
Isotropic spectral template (back)	isotropic_iem_back_v02.txt
Detailed description	Model Description





39.3884	6.57144e-07	4.6946e-08
64.0414	4.09665e-07	5.72124e-09
104.125	1.72000e-07	8.35794e-10
169.296	6.60007e-08	2.15325e-10
275.257	2.24126e-08	7.58059e-11
447.539	7.21114e-09	2.95711e-11
727.651	2.20758e-09	1.16796e-11
1183.08	7.20365e-10	4.68072e-12
1923.57	2.35566e-10	1.93256e-12
3127.52	7.36933e-11	8.02165e-13
5085.02	2.75583e-11	3.52098e-13
8267.71	8.41675e-12	1.44008e-13
13442.4	2.61572e-12	6.04568e-14
21856	9.93124e-13	2.77996e-14
35535.5	4.07167e-13	1.32929e-14
57777	1.48419e-13	6.31664e-15
93939.4	6.49806e-14	3.22598e-15
152736	2.13205e-14	1.49108e-15
248332	6.498e-15	4.85176e-16
403761	2.1144e-15	2.60915e-16

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/ring_for_FSSC_final4.pdf

Point Source Analysis

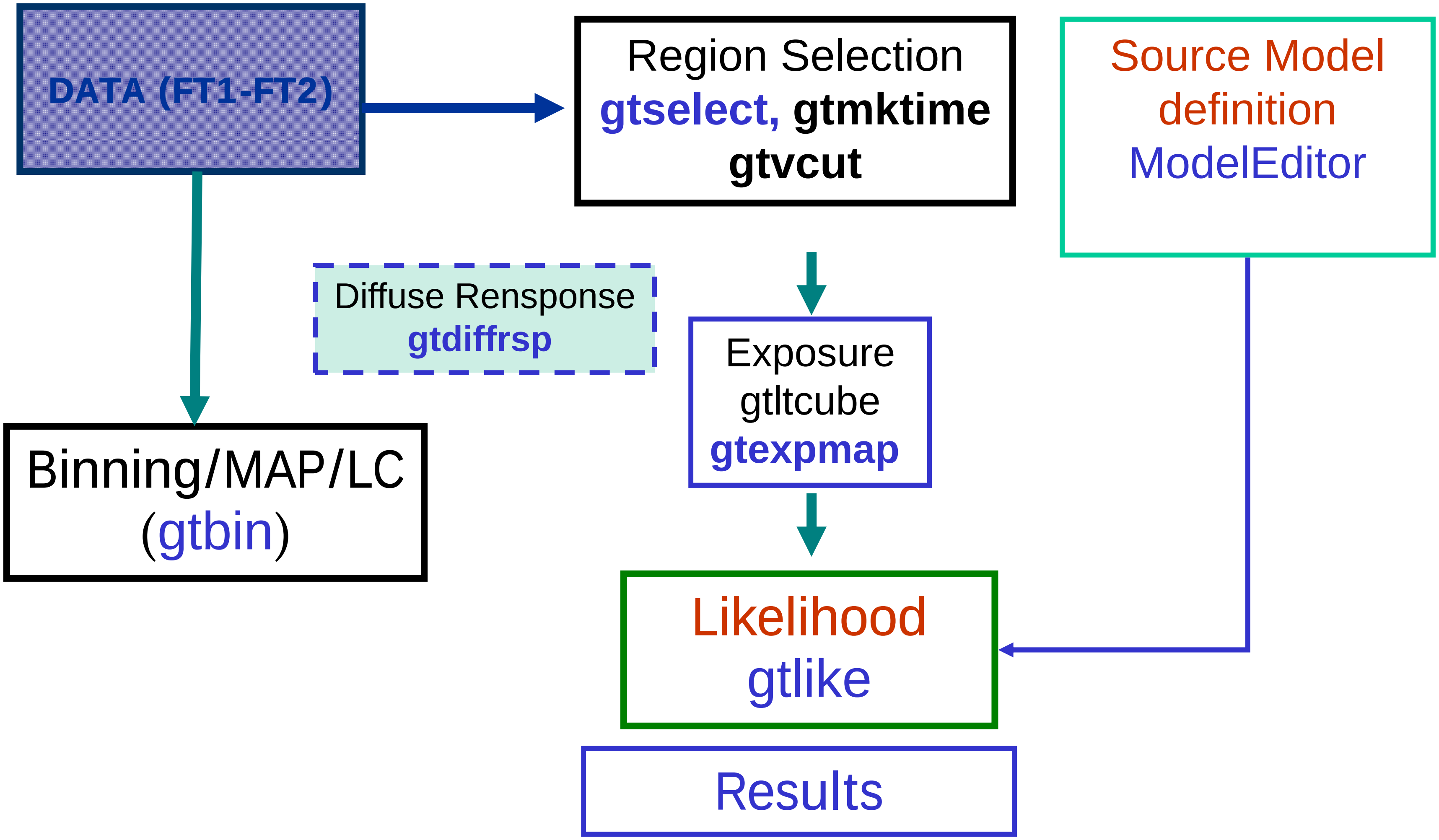
To start a point source analysis you have to fix:

1. Region of Interest (ROI) center (RA, DEC)
2. ROI Radius
3. Start Time (MET)
4. Stop Time (MET)
5. Minimum Energy
6. Maximum Energy
7. Event Class to Use (Transient, Source, Diffuse)

Source Region and ROI

- Due to the large LAT point spread function at low energies (e.g., 68% of the counts will be within 3.5 degrees at 100 MeV, see http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm for a review of LAT performance), to analyze a single source the counts within a region around the source have to be included.
- We call that region the "region of interest" (ROI). The ROI is selected from the original event file using the gtselect tool.
- The ROI should be several times the characteristic PSF size in order to satisfy the restrictions of the Likelihood package.
- Nearby sources will contribute counts to that region, so they have to be model as well. The region that includes that sources is called "Source Region". All these sources will be in the source model file that has to be input in gtlike.
- The "Source Region" is centered on the ROI, with a radius that is larger than the ROI radius by several PSF length scales. For example, when fitting a single point source, a ROI with a radius of 10 degrees and a Source Region radius of 20 degrees would be appropriate. Note that since the size of the LAT PSF goes roughly as (PSF_100MeV) x (E/100)^{-0.8} (with E in MeV), if you are considering only higher energy photons, e.g., > 1 GeV, smaller ROI and Source Region radii of just a few degrees may be used.

The Point Source Analysis Diagram

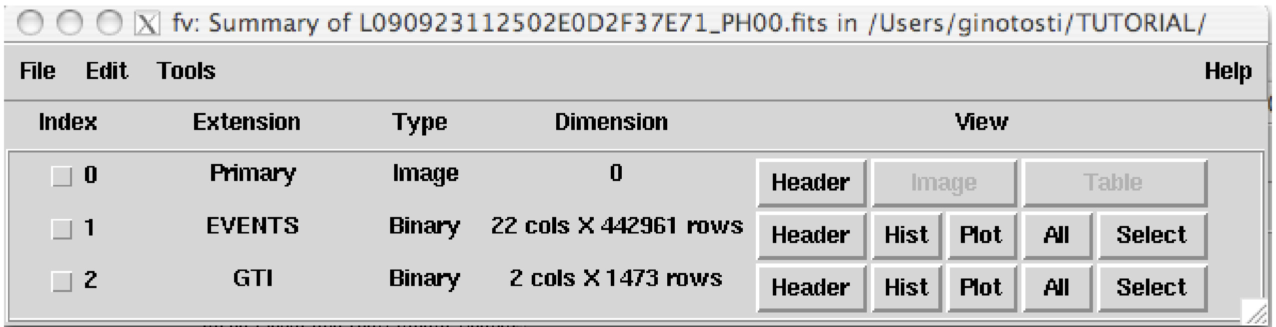


Data Access

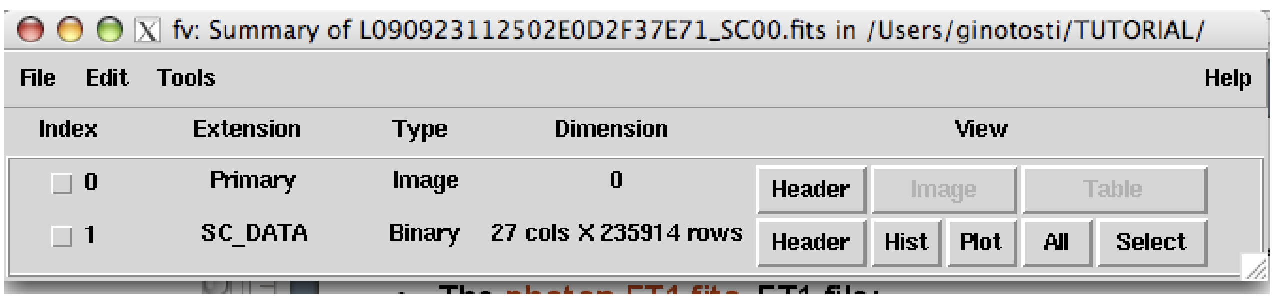
ftp download: ftp://legacy.gsfc.nasa.gov/fermi/data/lat/weekly/

INPUT DATA

- The photon FT1 fits FT1 file:
  - L090923112502E0D2F37E71_PH00.fits



- and the pointing and livetime history FT2 files.
  - L090923112502E0D2F37E71_SC00.fits



Step 1-Event Selection

$$$> gtselect evclsmax=3 evclsmin=3

Input FT1 file [] : L090923112502E0D2F37E71_PH00.fits

Output FT1 file [] : myROI_filtered.fits

RA for new search center (degrees) (0:360) [0] : 343.490616

Dec for new search center (degrees) (-90:90) [0] : 16.148211

radius of new search region (degrees) (0:180) [180] : 10

start time (MET in s) (0:) [0] : 266976000

end time (MET in s) (0:) [0] : 275369897

lower energy limit (MeV) (0:) [30] : 100

upper energy limit (MeV) (0:) [300000] : 300000

maximum zenith angle value (degrees) (0:180) [180]: 105

Scriptable form of the command:

gtselect infile= L090923112502E0D2F37E71_PH00.fits outfile=3c279_filtered.fits ra=193.98 dec=-5.82 rad=15 tmin=266976000 tmax= 275369897 emin=100 emax=100000 zmax=105 evclsmax=3 evclsmin=3

Step 1-Time Selection

$$$> gtmktime

Spacecraft data file [] L090923112502E0D2F37E71_SC00.fits

Filter expression [IN_SAA!=T] IN_SAA!=T && DATA_QUAL==1 && abs(ROCK_ANGLE)<52.

Apply ROI-based zenith angle cut[yes] : yes

Event data file [] : myROI_filtered.fits

Output event file name [] : myROI_filtered_time.fits

Scriptable form of the command:

gtmktime scfile= L090923112502E0D2F37E71_SC00.fits filter= IN_SAA!=T && DATA_QUAL==1 && abs(ROCK_ANGLE)<52 roicut=yes
Evfile= myROI_filtered.fits
outfile= myROI_filtered_time.fits

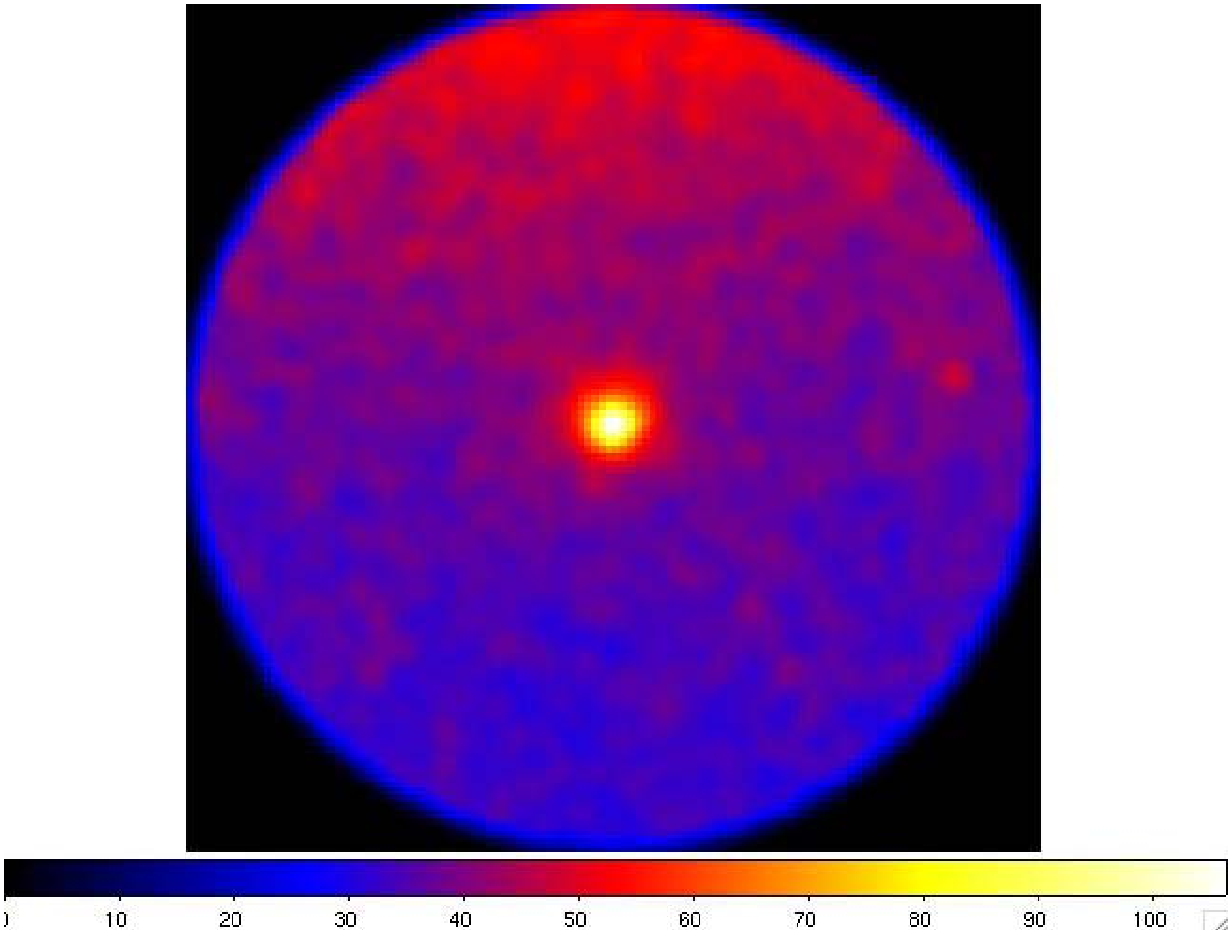
Step 2: Counts Map

$$$> gtbin
This is gtbin version ScienceTools-v9r15p2-fssc-20090808
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [PHA2] CMAP
Event data file name[] myROI_filtered.fits
Output file name[] myROIcounts_map.fits
Spacecraft data file name[NONE]
Size of the X axis in pixels[] 80
Size of the Y axis in pixels[] 80
Image scale (in degrees/pixel)[] 0.25
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL]
First coordinate of image center in degrees (RA or galactic l)[] 343.490616
Second coordinate of image center in degrees (DEC or galactic b)[]16.148211
Rotation angle of image axis, in degrees[0.]
Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[AIT]

Scriptable form of the command:

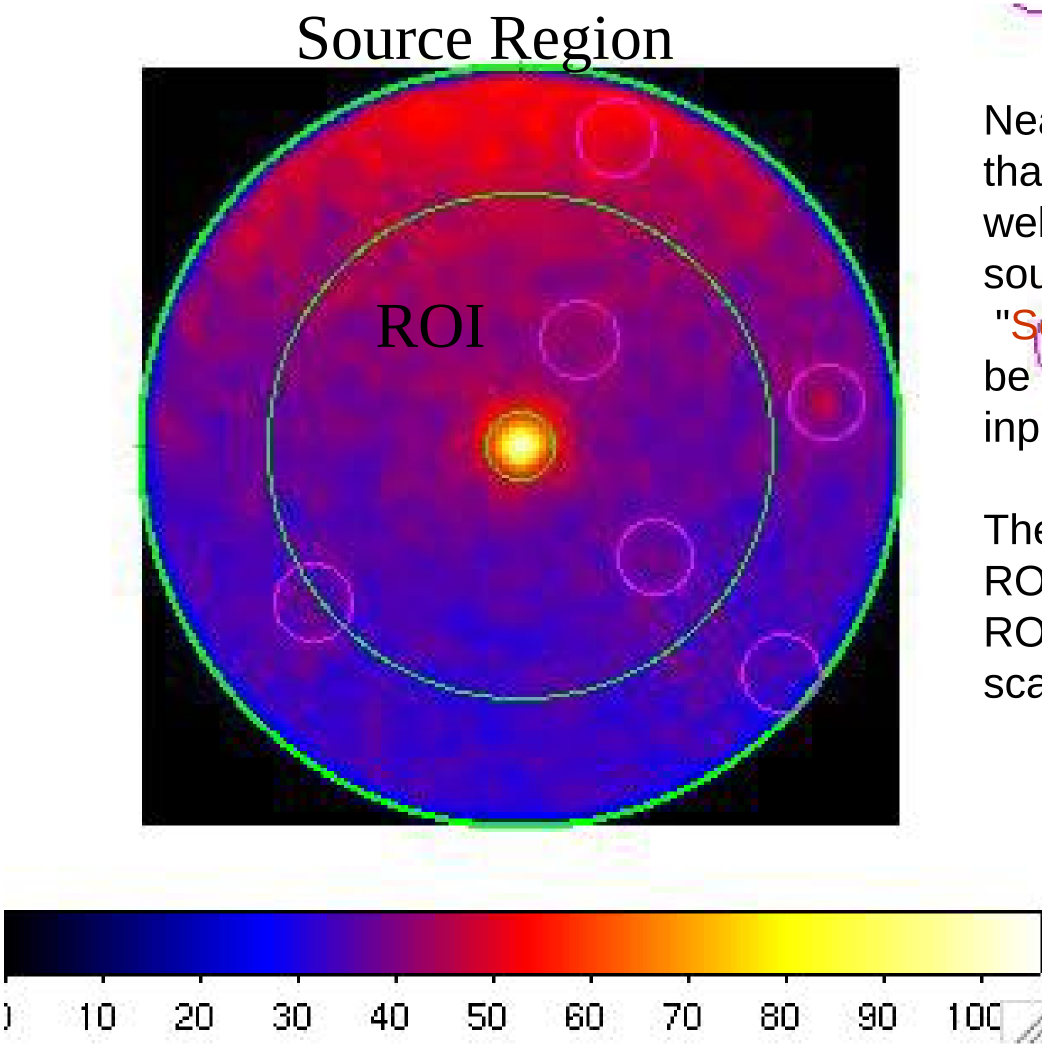
```
gtbin evfile=events_filtered.fits   scfile=NONE outfile=counts_map.fits
  algorithm=CMAP nxpix=120 nypix=120 binsz=0.25 coordsys=CEL xref=343.49 yref=16.14
  axisrot=0 proj=AIT
```

Step 2-Counts Map



Step 3:The Source Model

http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/xml_model_defs.html#xmlModelDefinitions



Nearby sources will contribute counts to that region, so they have to be model as well. The region that includes that sources is called "Source Region". All these sources will be in the source model file that has to be input in gtlike

The "Source Region" is centered on the ROI, with a radius that is larger than the ROI radius by several PSF length scales.

Step 3:The Source Model

http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/xml_model_defs.html#xmlModelDefinitions

```
- <source_library title="source library">
    <!-- Diffuse Sources -->
  - <source name="GAL_v02" type="DiffuseSource">
    - <spectrum type="PowerLaw">
        <parameter free="1" max="10" min="0" name="Prefactor" scale="1" value="1.22"/>
        <parameter free="0" max="1" min="-1" name="Index" scale="1.0" value="0"/>
        <parameter free="0" max="2e2" min="5e1" name="Scale" scale="1.0" value="1e2"/>
      </spectrum>
    - <spatialModel file="/net/users/ddavis/lat/bkg/gll_iem_v02.fit" type="MapCubeFunction">
        <parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>
      </spatialModel>
    </source>
  - <source name="EG_v02" type="DiffuseSource">
    - <spectrum type="FileFunction" file="/net/users/ddavis/lat//bkg/isotropic_iem_v02.txt">
        <parameter free="1" max="10" min="1e-2" name="Normalization" scale="1" value="1"/>
      </spectrum>
    - <spatialModel type="ConstantValue">
        <parameter free="0" max="10.0" min="0.0" name="Value" scale="1.0" value="1.0"/>
      </spatialModel>
    </source>
    <!-- Target Sources -->
  - <source name="_3c454" type="PointSource">
    - <spectrum type="PowerLaw2">
        <parameter free="1" max="10000" min="0.0001" name="Integral" scale="1e-07" value="15.6325"/>
        <parameter free="1" max="5" min="1" name="Index" scale="-1" value="2.507"/>
        <parameter free="0" max="500000" min="30" name="LowerLimit" scale="1" value="100"/>
        <parameter free="0" max="500000" min="30" name="UpperLimit" scale="1" value="300000"/>
      </spectrum>
    - <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360" min="-360" name="RA" scale="1" value="343.490616"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1" value="16.148211"/>
      </spatialModel>
    </source>
  </source_library>
```

$$$>modeleditor

Step 4-Livetimes

$$$> gtltcube

Event data file [] : myROI_filtered_time.fits

Spacecraft data file [test_scData_0000.fits] : L090923112502E0D2F37E71_SC00.fits
Output file [expCube.fits] : expCube.fits
Step size in cos(theta) <0. - 1.> [0.025] : 0.025
Pixel size (degrees) [1] :

More info on the Sky pixelization used by gtlivetimecube can be found here HEALPix (http://healpix.jpl.nasa.gov/)

To add two livetimeCube you can use:

$$$>gtltsum

Livetime cube 1 or list of files [expCube_00.fits] : expCube0.fits
Livetime cube 2 [expCube_01.fits] : expCube1.fits
Output file [expCube.fits] : expcube_01.fits

Scriptable form of the command:
gtltcube evfile= myROI_filtered_time.fits scfile=L090923112502E0D2F37E71_SC00.fits outfile=expCube.fits dcostheta=0.025 binsz=1

(Step 5-Diffuse Source Responses)

$$$> gtdiffrsp

Event data file [test_events_0000.fits] : myROI_filtered_time.fits
Spacecraft data file [] : L090923112502E0D2F37E71_SC00.fits
Source model file [my_source_model.xml] : mymodel.xml
Response functions to use [DC2] :P6_V3_DIFFUSE

This step is not necessary for the FT1 file provided by FSSC already has pre-computed diffuse response columns!!!

Step 5-Exposure Map

$$$> gtexpmap

Event data file [test_events_0000.fits] : myROI_filtered_time.fits

Spacecraft data file [test_scData_0000.fits] : L090923112502E0D2F37E71_SC00.fits

Exposure hypercube file [expCube.fits] : expCube.fits

output file name [expMap.fits] : expMap.fits

Response functions [DC2] : P6_V3_DIFFUSE

Radius of the source region (in degrees) [30] :15

Number of longitude points <2 - 1000> [120] :120

Number of latitude points <2 - 1000> [120] : 120

Number of energies <2 - 100> [20] : 20

Scriptable form of the command:

gtexpmap evfile= myROI_filtered_time.fits scfile= L090923112502E0D2F37E71_SC00.fits expcube= expCube.fits outfile=expMap.fits irfs=P6_V3_DIFFUSE srcrad=15 nlong=120 nlat=120 nenergies=20

gtlike

- ✓ The gtlike tool performs unbinned and binned likelihood analysis of the LAT data.
- ✓ The likelihood statistic L is the probability of obtaining observational data given an input model. In our case, the input model is the distribution of gamma-ray sources on the sky, and includes their intensity and spectra.
- ✓ We use this statistic to find the best fit model parameters. These parameters include the description of a source's spectrum, its position, and intensity
- ✓ The data will be too sparse in many cases to allow the use of CHI2 as test statistic. In that case, a full Poisson likelihood optimization is needed for model parameter estimation.
- ✓ For a small number of counts the unbinned likelihood can be calculated rapidly, but as the number of counts increases the time to calculate the likelihood becomes prohibitive, and the binned likelihood must be used.
- ✓ Like in EGRET we use the Test Statistics (TS) to establish the significance of the detection of a source. The TS value is defined as:

$$TS = 2\,(\log L - \log L0)$$

(L0 is the likelihood value for the null hypothesis**)**

Step 7: Unbinned Likelihood

$$$> gtlike

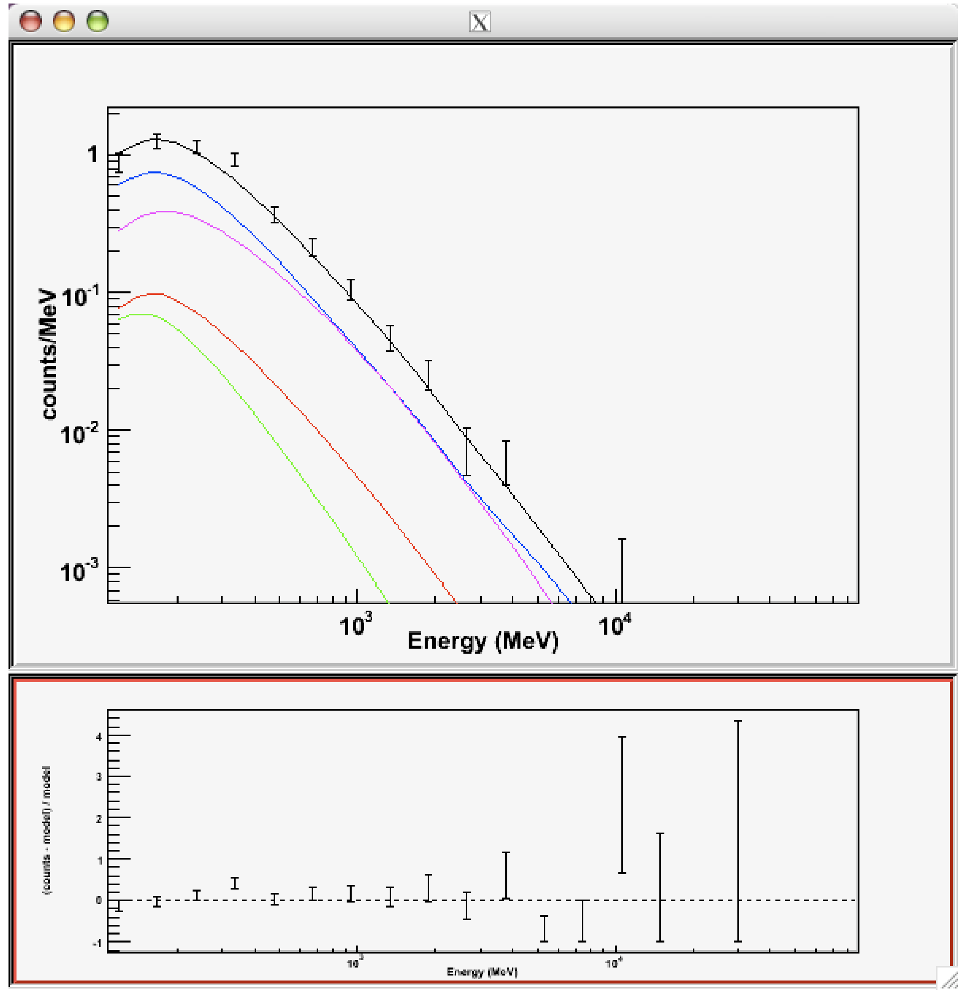
Statistic to use <BINNED|UNBINNED> [UNBINNED] :
Spacecraft file [] : myROI_filtered_time.fits
Event file [] : L090923112502E0D2F37E71_SC00.fits
Unbinned exposure map [LAT_tut_expMap.fits] : expMap.fits
Exposure hypercube file [LAT_tut_expCube.fits] : expCube.fits
Source model file [ac_source_model.xml] : mymodel.xml
Response functions to use [DC2] :
Optimizer] (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [DRMNFB]: MINUIT

The results are stored in the file: result.dat

Scriptable form of the command:
gtlike irfs=P6_V3_DIFFUSE expcube=expCube.fits srcmdl=mymodel.xml statistic=UNBINNED optimizer=MINUIT evfile= myROI_filtered_time.fits scfile= L090923112502E0D2F37E71_SC00.fits expmap=expMap.fits

Step 7: Unbinned Likelihood
Results

```
3C 273:
Prefactor: 10.7154 +/- 4.79318
Index: -2.39036 +/- 0.261339
Scale: 100
Npred: 28.651
ROI distance: 10.4409
TS value: 58.0328

3C 279:
Prefactor: 8.97673 +/- 5.45668
Index: -2.8986 +/- 0.470354
Scale: 100
Npred: 13.8568
ROI distance: 0
TS value: 17.8267

EG_v02:
Normalization: 1.11606 +/- 0.234866
Npred: 278.964

GAL_v02:
Value: 1.161 +/- 0.328156
Npred: 199.892
WARNING: Fit may be bad in range [100, 146.235] (MeV)
WARNING: Fit may be bad in range [4472.14, 6539.83] (MeV)

Total number of observed counts: 521
Total number of model events: 521.364

-log(Likelihood): 5979.486023
```



http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/likelihood_tutorial.html

gtlike

http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/python_tutorial.html

```
$$$ python
Python 2.5.1 (r251:54863, Aug  8 2009, 12:04:48)
[GCC 4.0.1 (Apple Inc. build 5465)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> import pyLikelihood
>>> from UnbinnedAnalysis import *
>>> my_obs = UnbinnedObs('events_diffuse_filtered_gti.fits', 'spacecraft_data_file.fits',
expMap='expMap.fits', expCube='expCube.fits', irfs='P6_V3_DIFFUSE')
>>> analysis = UnbinnedAnalysis(my_obs, 'src_model.xml', optimizer='NewMinuit')
>>> analysis.plot()
>>> like.fit(verbosity=0)
>>> like.oplot()
```

CAVEAT and systematics

http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

- Use **"Diffuse" class for diffuse, extended, and point source analysis**.
- **Data below 100 MeV can not be used for spectral analysis**
- **Data above 10 GeV currently have non-negligible background contamination from charged particles**.
- Given the current limited statistics at hundreds of GeV, **we recommend limiting spectral analysis to energies smaller than 300 GeV.**
- **Systematics:** 10% at 100 MeV, decreasing to 5% at 560 MeV, and increasing to 20% at 10 GeV and above
- **At energies >32 GeV the width of the PSF may be underestimated by a factor of ~2.**
- The absolute LAT energy scale, at this early stage of the mission, is determined with an uncertainty of +5% -10%.

Conclusion

To analyze the time & spectral variations of a source you have to run iteratively the likelihood tool, using procedures similar to the following

- **Step 1 - Download data for your ROI from the DATA server over the entire time interval (T) where you want to study variability;**
- **Step 2 - Build a Source Model for your ROI**
- **Step 3 - Divide T in N time bins, and for each bin obtain a FT1 file with gtselect/gtmktime;**
- **Step 4 - Compute the livetimecube (gtltcube) for each time**
- **Step 5 - Calculate the ExposureMap (gtexpmap)**
- **Step 6 - Run gtlike and rename the output result file**

Repeat steps 4-6 for each time bin……write a script to do this work……

A complete tutorial can be found here:
http://fermi.gsfc.nasa.gov/workshops/da2010_boston/agenda.html