Tutorial on Fermi-LAT data analysis
the case of 3c454.3

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Material from P.Bruel, M.Razzano, S.Buson and R.Desiante

PhD course 2019 – Padova

Outline

- **Overview of the Fermi Large AreaTelescope**
  - **How it works**
  - **LAT data**
  - **LAT performance**

- **Fermi Science Tools**
  - **General Introduction**

- **Maximum Likelihood Overview**
  - **Source modeling**

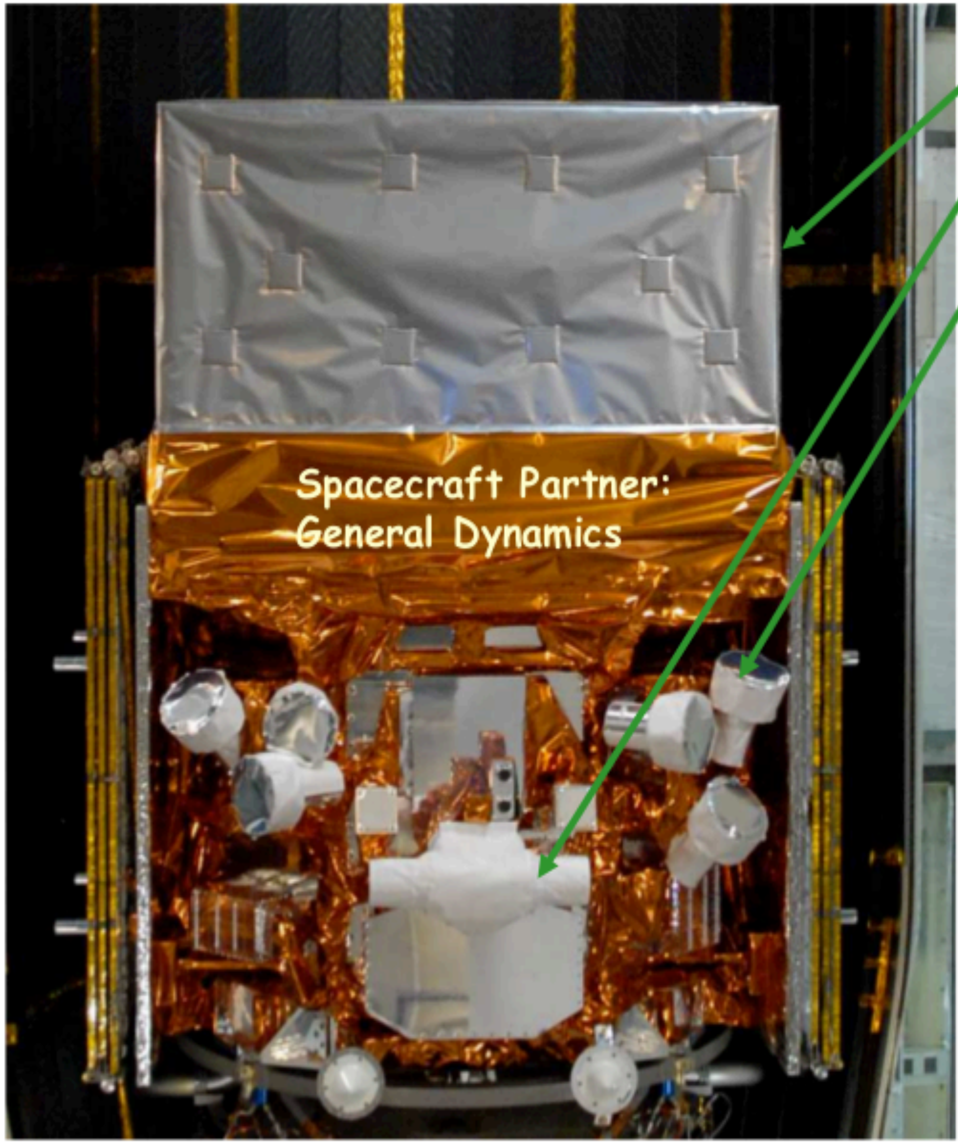
- **One study case:**
  - **3c454.3: analysis tutorial**

- **gtburst Analysis of GRBs**

Organization

- **Today**
  - Introduction to the LAT data analysis
  - LAT data introduction
  - LAT data exploration
  - LAT data preparation
  - Preparation of Sky models
- **Tomorrow**
  - Likelihood analysis of LAT data
  - Hands-on on an Extragalactic source
    - General LAT analysis with gtlike
    - Light curve with aperture photometry
    - SED (possibly)
    - gtburst tutorial

The observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

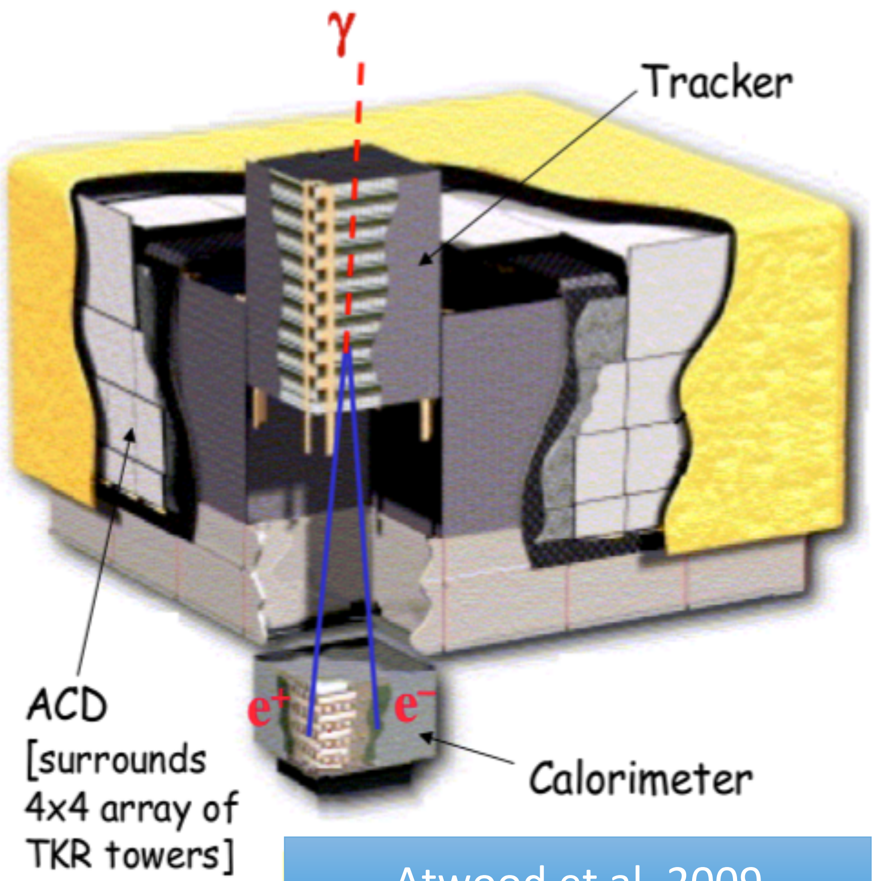
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 30 MeV

KEY FEATURES

- Huge field of view
  - –LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!
- Large leap in all key capabilities. Great discovery potential.

How the LAT works

- Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.

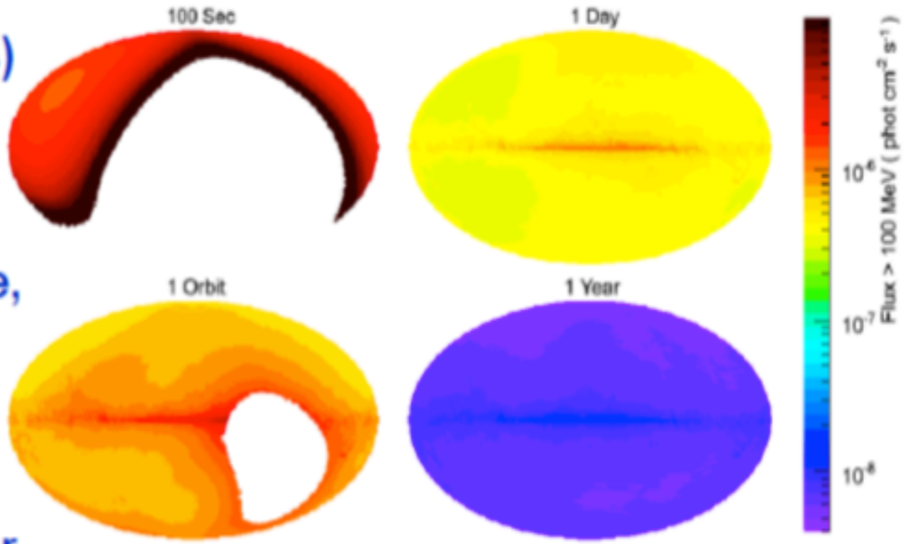


Atwood et al. 2009

Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

Operating Mode

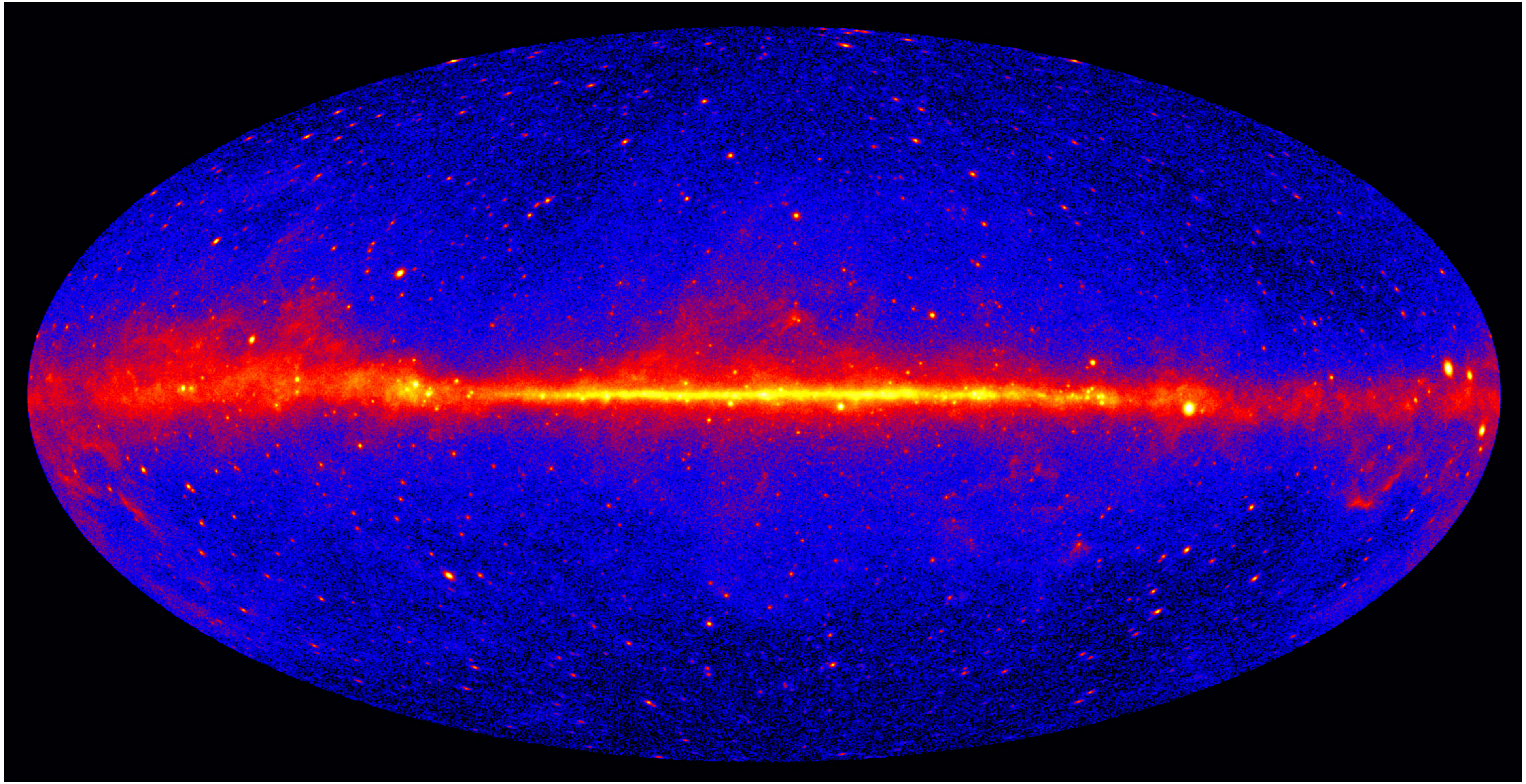
- Primary observing mode is Sky Survey
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates multiwavelength observation planning
  - Exposure intervals commensurate with typical instrument integration times for sources
  - EGRET sensitivity reached in days



• Pointed observations when appropriate (selected by peer review in later years) with automatic earth avoidance selectable. Target of Opportunity pointing.

• Autonomous repoints for onboard GRB detections in any mode.

The Fermi Sky



What do you need for the analysis

- **Data ...of course!**

LAT DATA ARE PUBLIC!!

  - LAT detected events
  - Spacecraft related stuff
  - Extras (Backgrounds , catalog sources, timing..)

- **Fermi Science Tools**
  - http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/

- **Other ancillary tools**
  - ftools, HEASOFT, DS9 etc..
  - http://heasarc.gsfc.nasa.gov/docs/software.html

- **Lots and lots of scripts!**
  - Fermi tools are already scriptable
  - You can also use your favourite scripting language ... but ..
  - Science Tools can be imported as Python modules!

LAT data analysis references

Fermi Data Analysis: starting points

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

How to access LAT Data

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

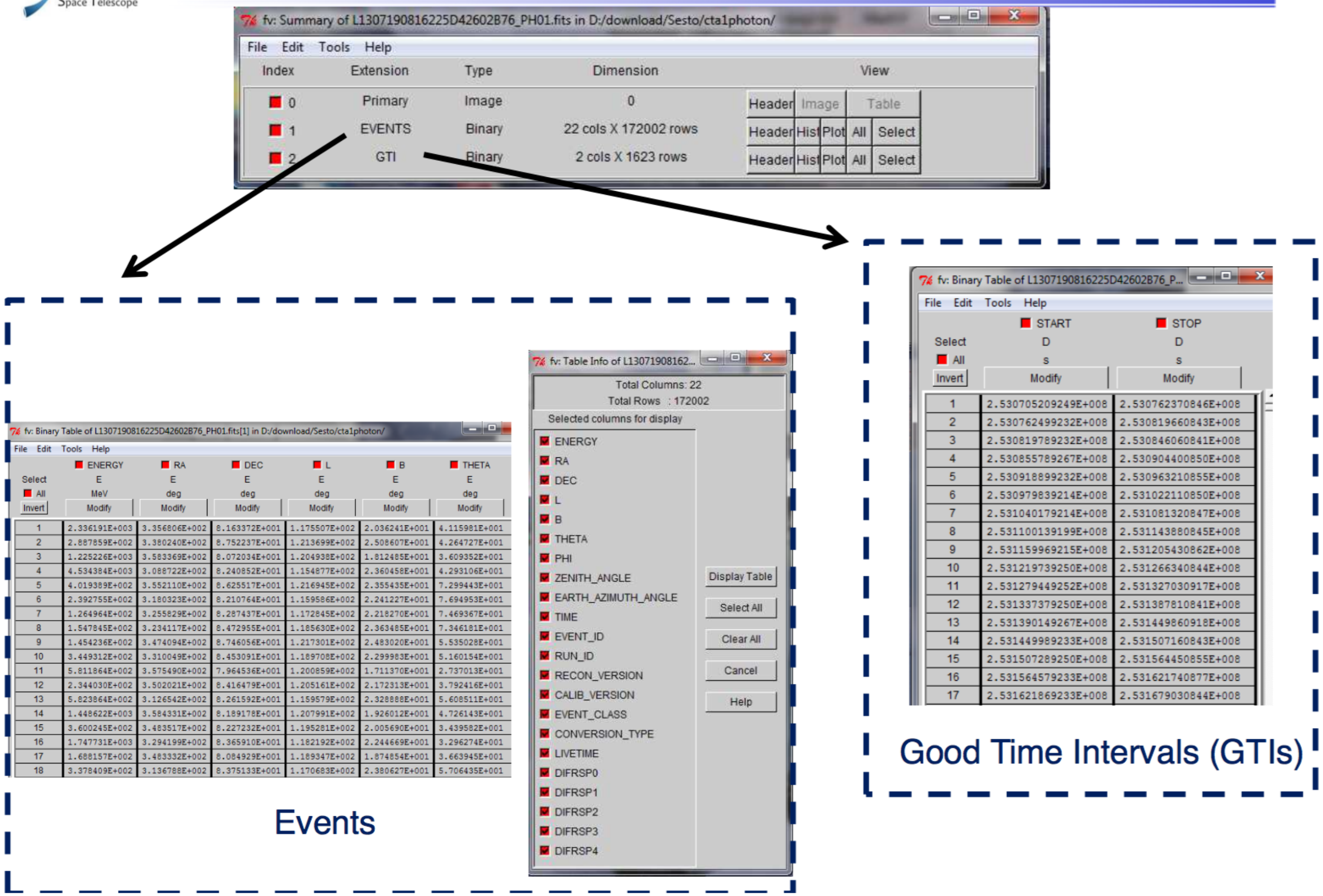
LAT Data

- **LAT data products can be downloaded by the FSSC website**
  - **LAT Data server** http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi
  - **Archive of weekly files**
  - ftp://legacy.gsfc.nasa.gov/fermi/data/

- **Two main data products (stored in FITS format)**
  - **Events file (FT1)**
  - **i. e. "what the LAT sees"**
    - (photons, their energy, coordinates, time, event classes etc..)

  - **Spacecraft files (FT2)**
  - **i. e. "where the LAT is"**
    - (position, angles..)

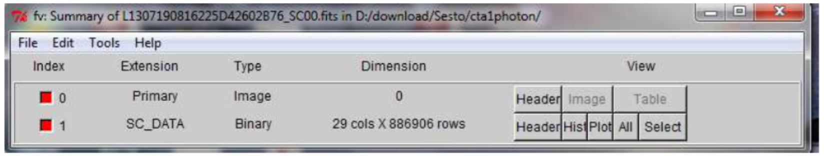
FT1: photons, photons…

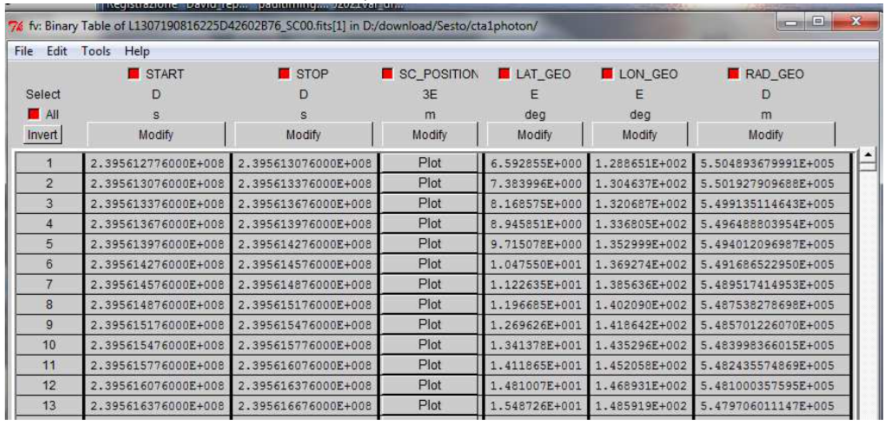


Events

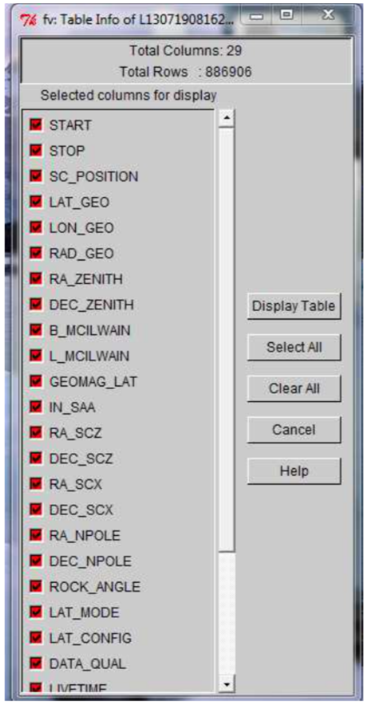
Good Time Intervals (GTIs)

FT2: where is Fermi ?





Select	START	STOP	SC_POSITION	LAT_GEO	LON_GEO	RAD_GEO
	D	D	3E	E	E	D
All	s	s	m	deg	deg	m
1	2.395612776000E+008	2.395613076000E+008	Plot	6.592855E+000	1.288651E+002	5.504893679991E+005
2	2.395613076000E+008	2.395613376000E+008	Plot	7.383996E+000	1.304637E+002	5.501927909688E+005
3	2.395613376000E+008	2.395613676000E+008	Plot	8.168575E+000	1.320687E+002	5.499135114643E+005
4	2.395613676000E+008	2.395613976000E+008	Plot	8.945851E+000	1.336805E+002	5.496488803954E+005
5	2.395613976000E+008	2.395614276000E+008	Plot	9.715078E+000	1.352999E+002	5.494012096987E+005
6	2.395614276000E+008	2.395614576000E+008	Plot	1.047550E+001	1.369274E+002	5.491686522950E+005
7	2.395614576000E+008	2.395614876000E+008	Plot	1.122635E+001	1.385636E+002	5.489517414953E+005
8	2.395614876000E+008	2.395615176000E+008	Plot	1.196685E+001	1.402090E+002	5.487538278698E+005
9	2.395615176000E+008	2.395615476000E+008	Plot	1.269626E+001	1.418642E+002	5.485701226070E+005
10	2.395615476000E+008	2.395615776000E+008	Plot	1.341378E+001	1.435296E+002	5.483998366015E+005
11	2.395615776000E+008	2.395616076000E+008	Plot	1.411865E+001	1.452058E+002	5.482435574869E+005
12	2.395616076000E+008	2.395616376000E+008	Plot	1.481007E+001	1.468931E+002	5.481000357595E+005
13	2.395616376000E+008	2.395616676000E+008	Plot	1.548726E+001	1.485919E+002	5.479706011147E+005



spacecraft Data

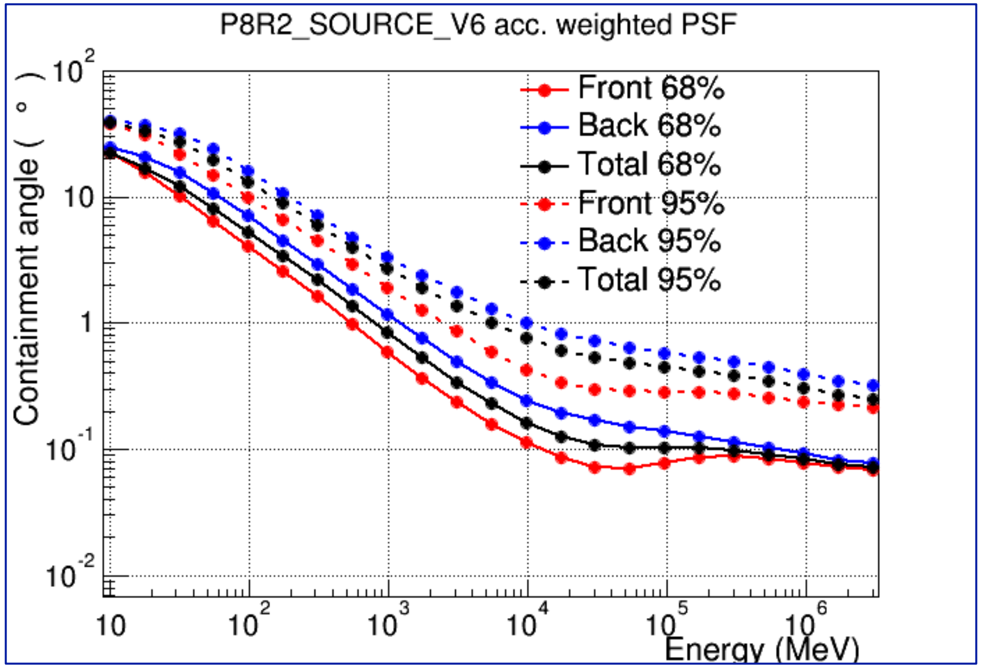
Extras - IRFs

•**LAT Instrument Response Functions (IRFs)**

–**Point Spread Function (PSF)**

–**Effective Area**

–**Energy Resolution**



• **Highly dependent on energy and arrival direction of incident photon**

• **Fundamental for analysis!!**

•http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Pass8 data

New Pass8 data

Fermi
Science Support Center

Home | Observations | Data | Proposals | Library | HEASARC | Help | Site Map

Data

- Data Policy
- Data Access
- **Data Analysis**
  - + System Overview
  - + Software Download
  - + Documentation
  - + Cicerone
  - + Analysis Threads
  - + User Contributions
- Caveats
- Newsletters
- FAQ

Using LAT's New Pass 8 Data

The FSSC is now serving Pass 8 LAT data for analysis. The new version of LAT data provides a number of improvements over the reprocessed Pass 7 data, and is considered the best dataset for all types of LAT analysis. As of the release date (June 24, 2015) reprocessed Pass 7 data is no longer being served. However, existing Pass 7 reprocessed data has been archived and is available from the FSSC's FTP server.

Pass 8 provides a full reprocessing of the entire mission dataset, including improved event reconstruction, a wider energy range, better energy measurements, and significantly increased effective area. In addition, the events have been evaluated for their measurement quality in both position and energy. This allows the user to select a subset of the events if appropriate to improve analysis results. To support the use of these data selections, there have been some structural changes to the *Fermi* Science Tools.

Here we discuss the changes to the data and tools, and how they affect your analysis.

Pass 8 Bottom Line

Pass 8 contains a lot of changes, and the rest of this page may seem overwhelming. If you just want to get started doing a standard LAT analysis, here's the bottom line:

- Recommended event class for source analysis is "P8 Source" class (*evclass*=128).
- Add *evtype* parameter to your gtselect call (*convtype* parameter is deprecated). Recommended event type for source analysis is "FRONT+BACK" (*evtype*=3).
- Recommended zenith angle cut to eliminate Earth limb events ("zmax") is 90 degrees for events at 100 MeV and above.
- Recommended source list for analysis is the 3FGL Catalog. A python script is available at the User-Contributed Tools page that creates XML model files using the 3FGL catalog FITS file.

http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Pass8_usage.html

What does Pass mean?

- Each pass corresponds to a version of the Fermi LAT data
- It implies a whole package:
  - Intrument simulation
  - Reconstruction code
  - Event selection
  - Instrument Response Functions (IRFs)
  - Systematic uncertainties
  - Isotropic template (which includes the cosmic-ray residual background)
  - And sometimes more (Galactic diffuse model, Earth limb template, Sun+Moon template)
- It's only when we have validated the whole package that we can release it to the public.

From Pass 6 to Pass 8

- Pass 6 (launch time)
  - Pass 6 reconstruction
  - Pass 6 selection
  - Based on pre-launch instrument simulation
  - First data revealed the issue of out-of-time pile-up (aka ghosts)
  - New: instrument simulation with ghosts -> correct IRFs
- Pass 7
  - Pass 6 reconstruction
  - New: Pass 7 selection optimized with simulations with ghosts
- Pass 8
  - New: improved instrument simulation
  - New: Pass 8 reconstruction, as ghost-proof as possible
  - New: Pass 8 selection

Pass8 Introduction

Pass 8 improvements

- Ghost handling
  - Tracker: ignoring ghost hits
  - ACD: partial deghosting
  - Calorimeter: clustering and cluster classification

- Improved direction measurement
  - Tree-based track finder

- Improved energy measurement
  - Extension of the energy range: from ~10 MeV to ~3 TeV

- Improved track/ACD matching information
  - Using the uncertainty of the tracker direction

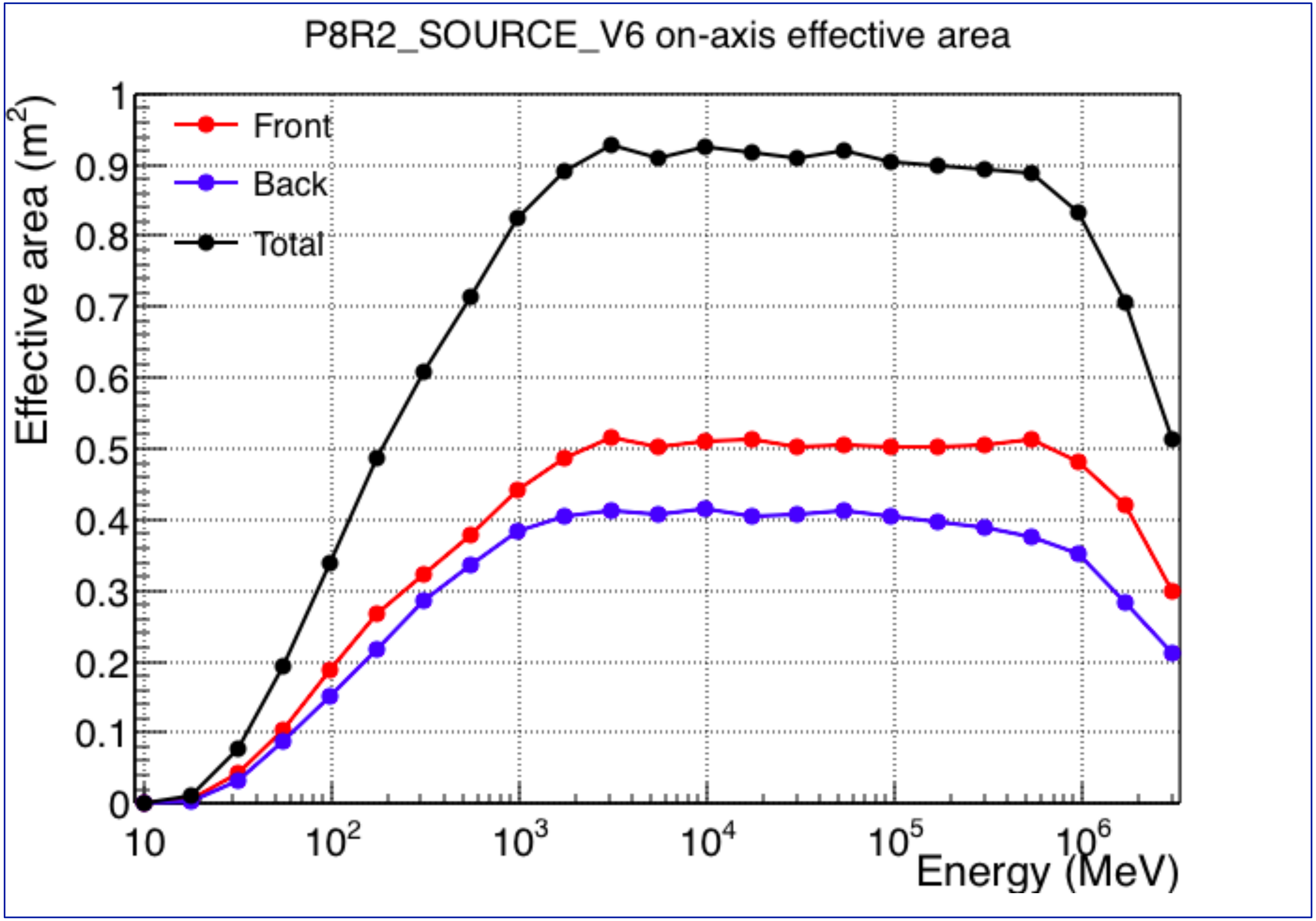
- Improved event selection
  - Using the ROOT TMVA package (tmva.sourceforge.net)

- Additional sub-classes of events

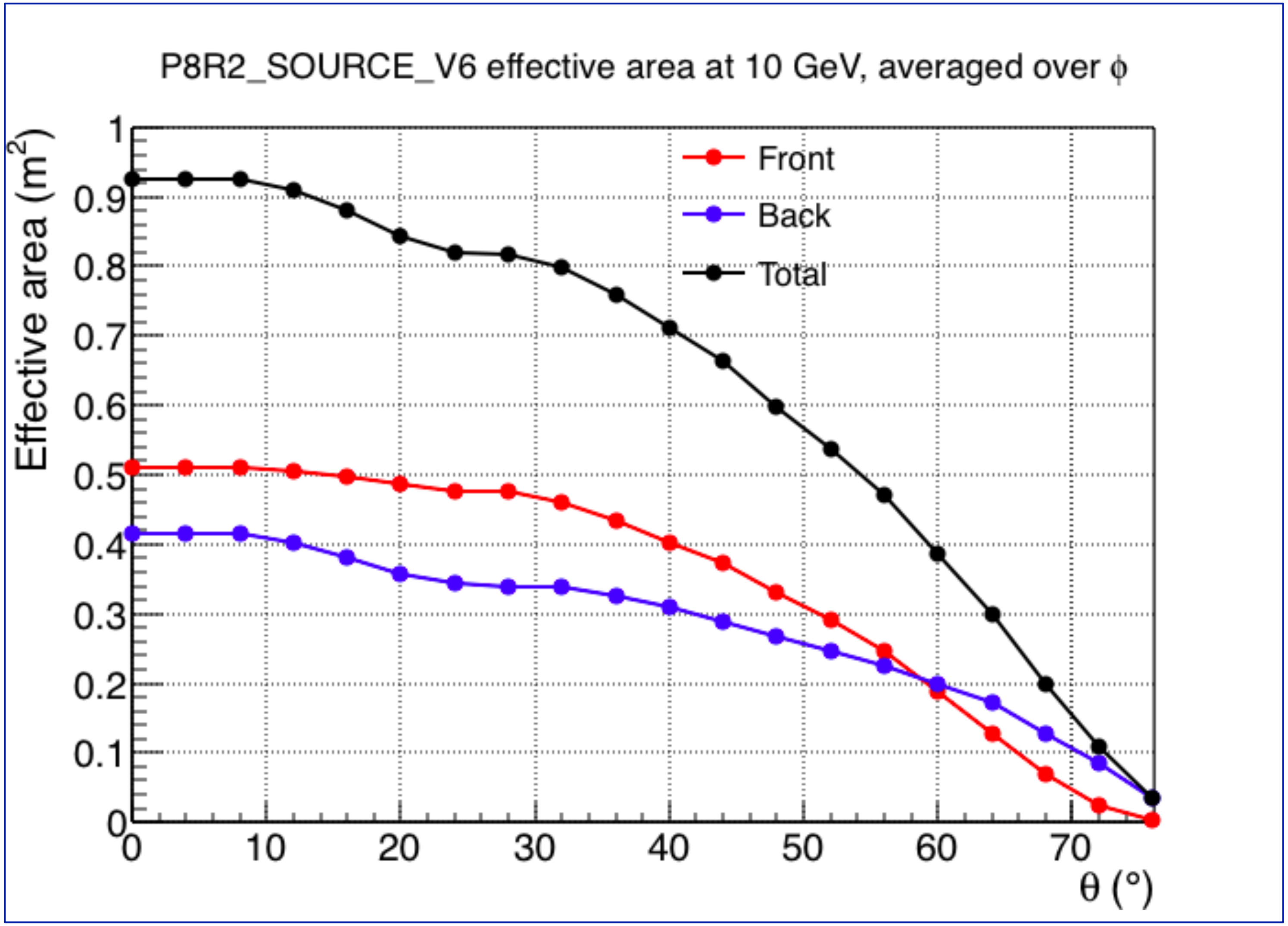
Pass8 performance

http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

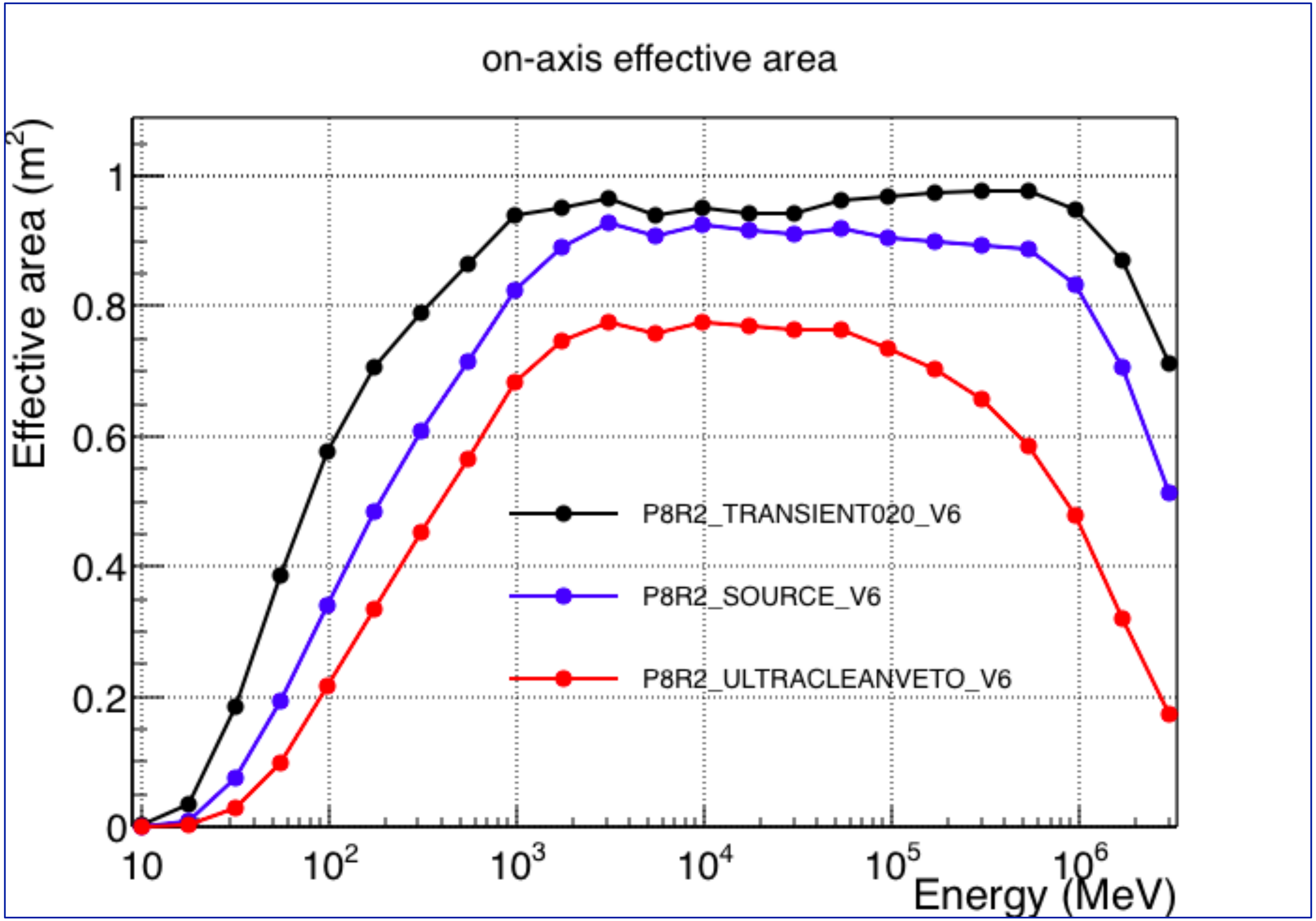
Effective Area



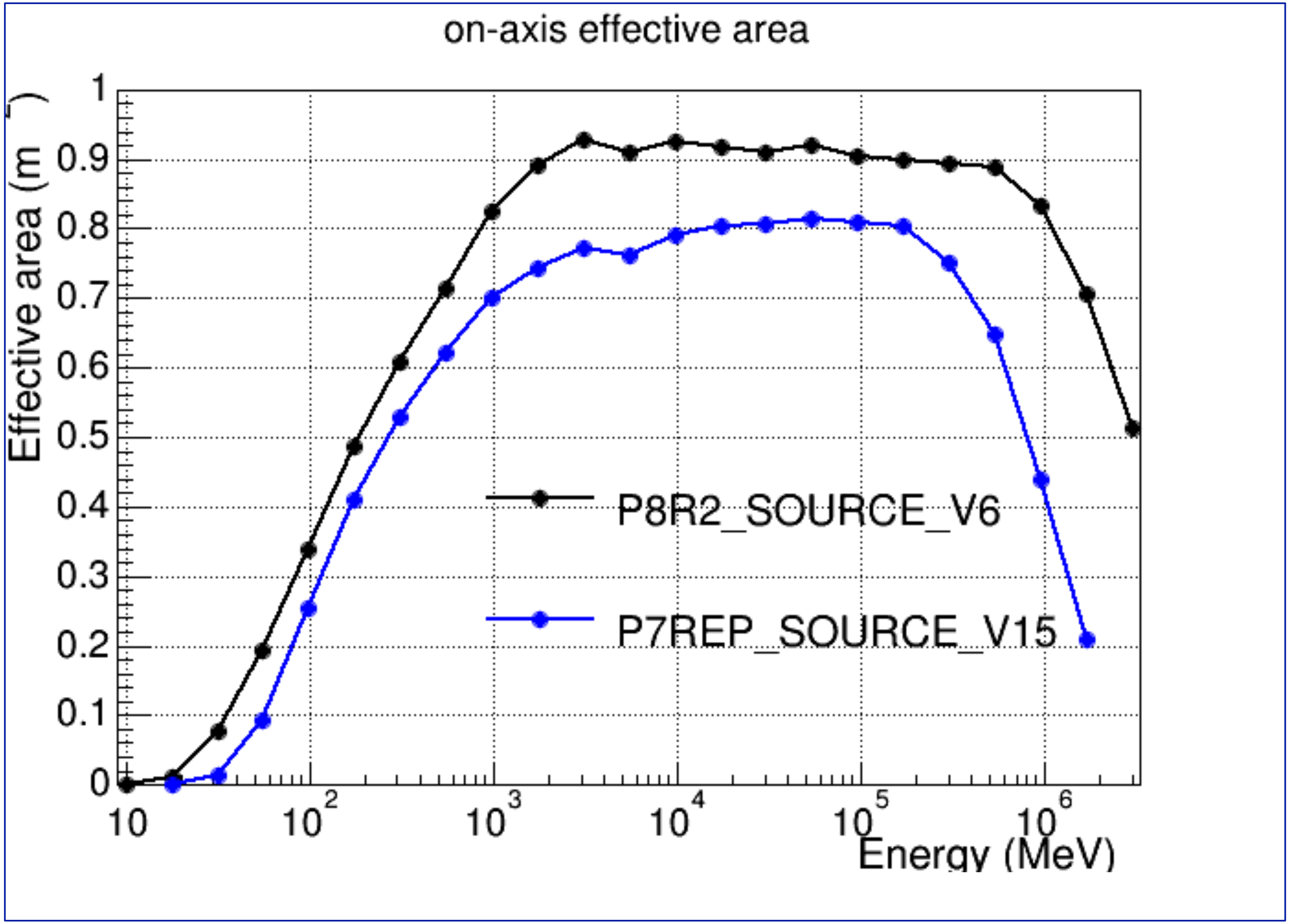
Pass8 Effective Area



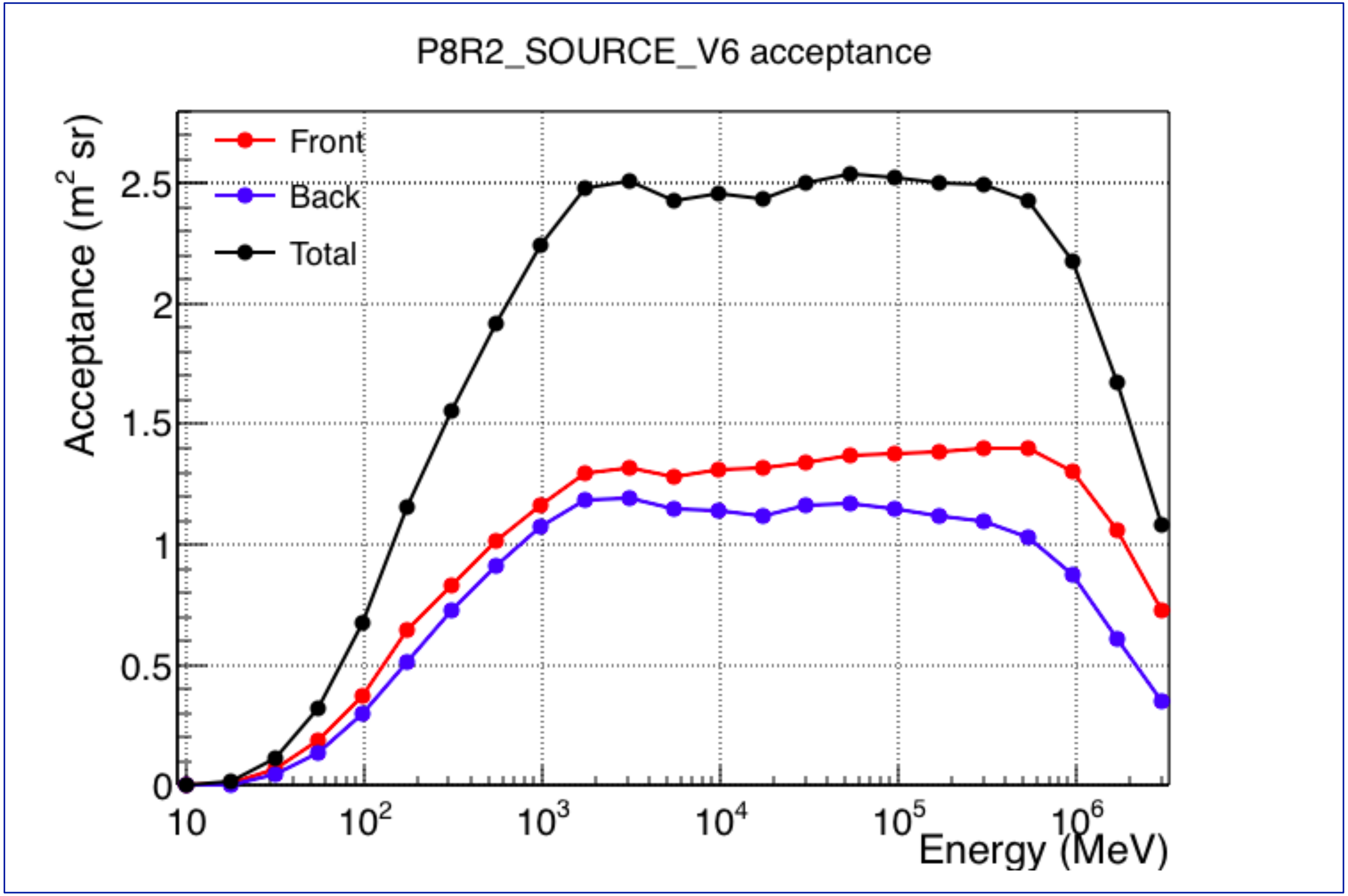
Effective Area



Effective Area

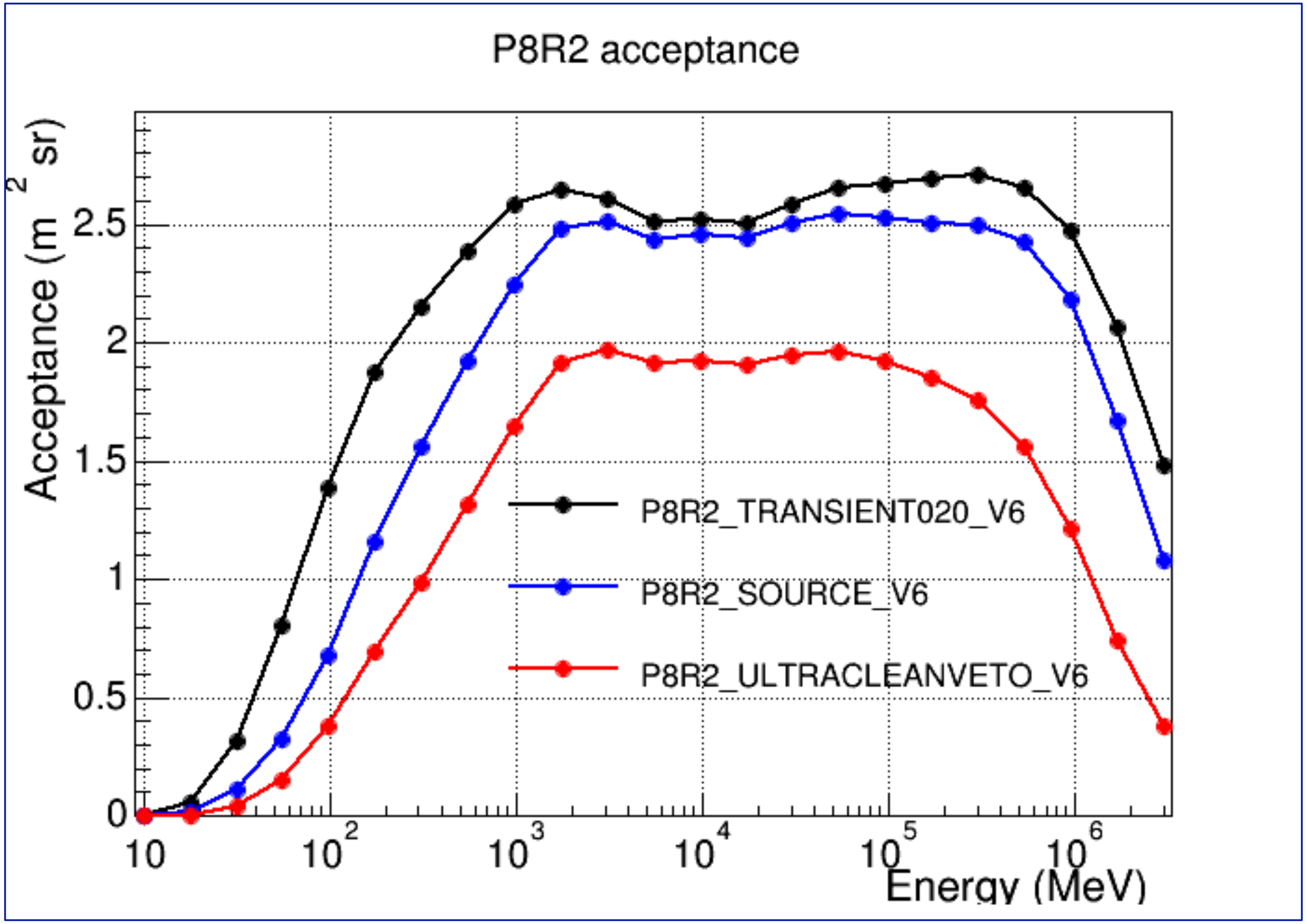


Acceptance

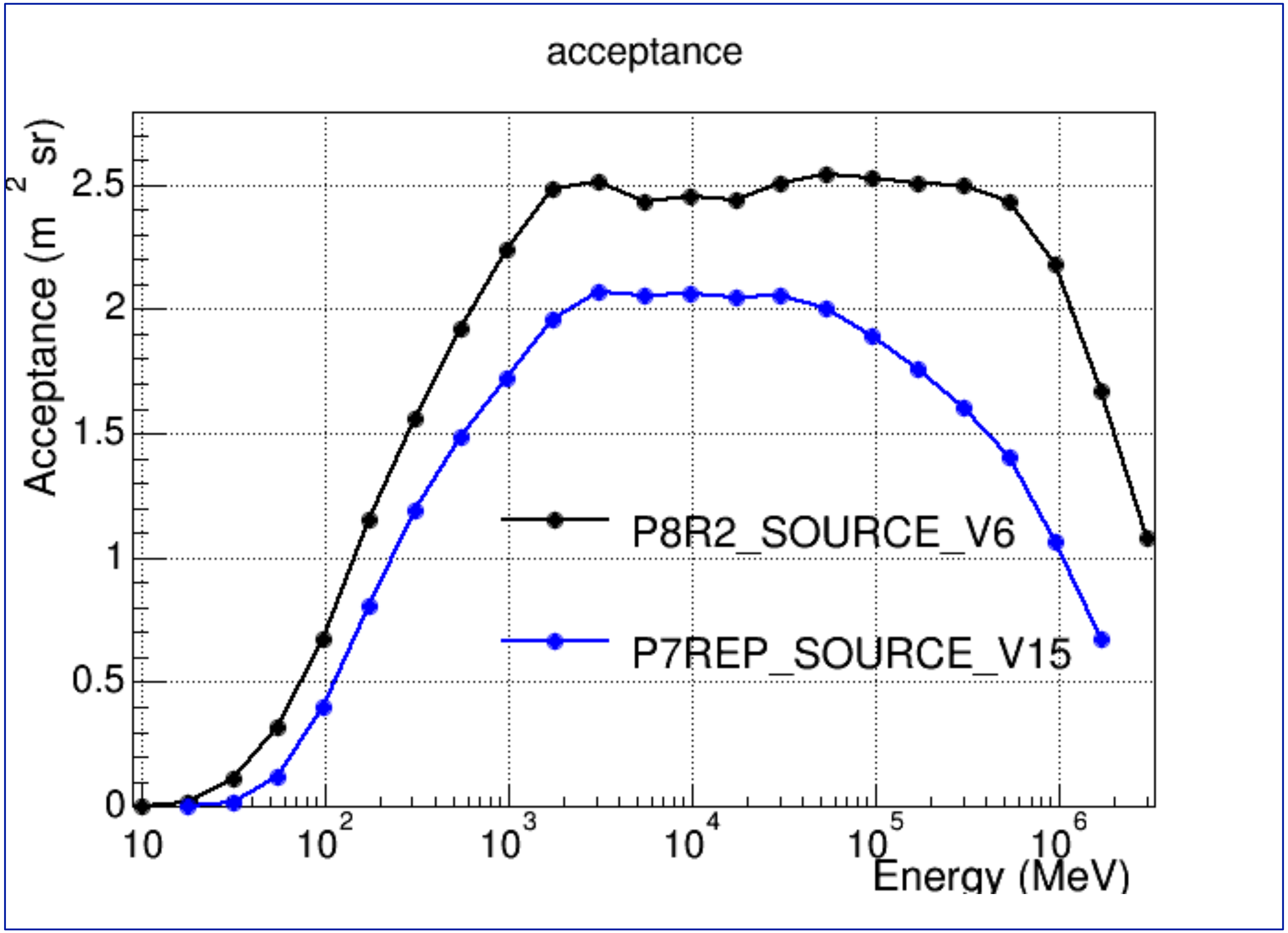


P8R2_SOURCE_V6 acceptance
Front
Back
Total
Acceptance (m^2 sr)
0
0.5
1
1.5
2
2.5
10
10^2
10^3
10^4
10^5
10^6
Energy (MeV)

Acceptance

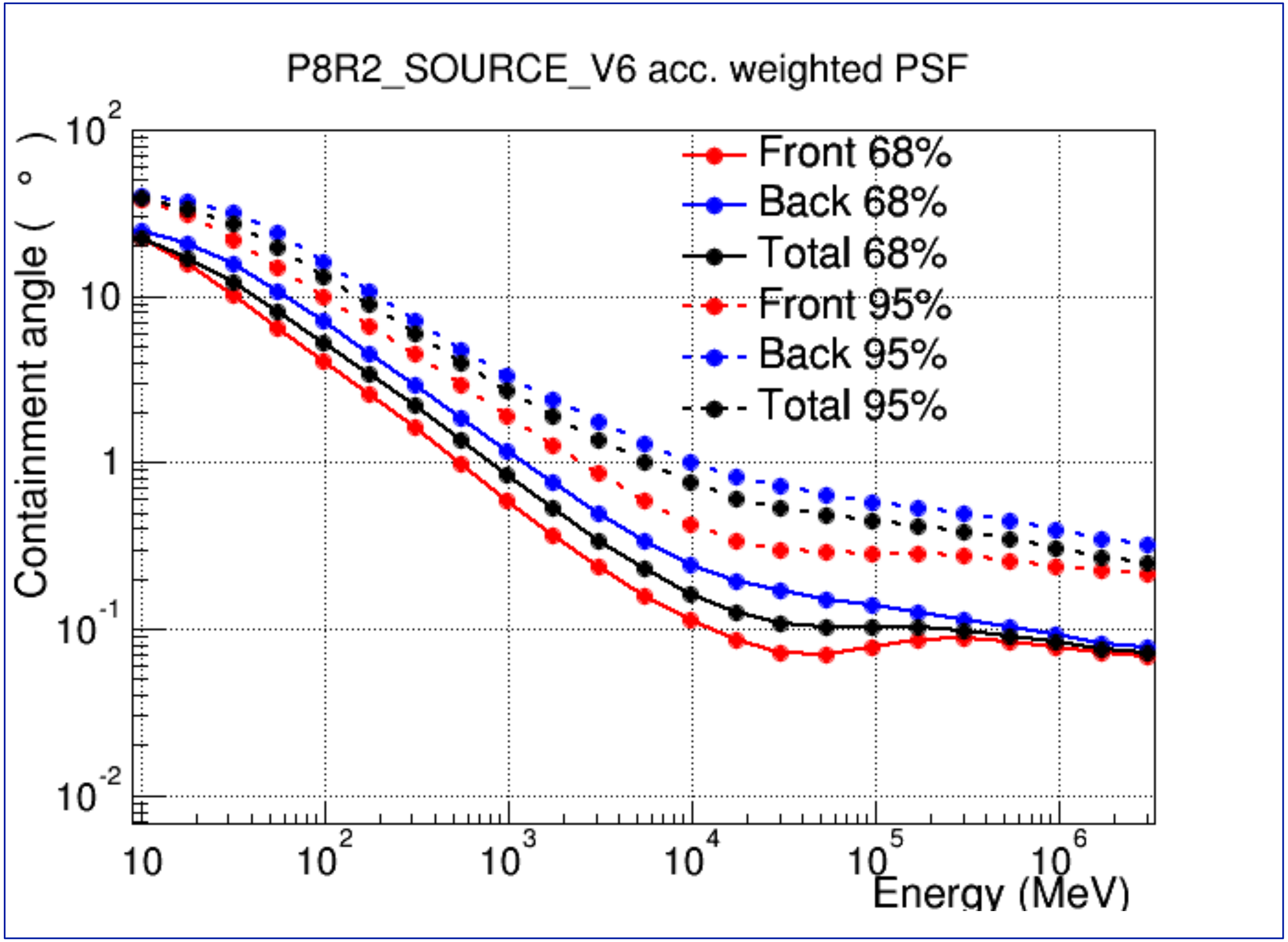

P8R2 acceptance
Acceptance (m^2 sr)
0
0.5
1
1.5
2
2.5
10
10^2
10^3
10^4
10^5
10^6
Energy (MeV)
P8R2_TRANSIENT020_V6
P8R2_SOURCE_V6
P8R2_ULTRACLEANVETO_V6

Acceptance

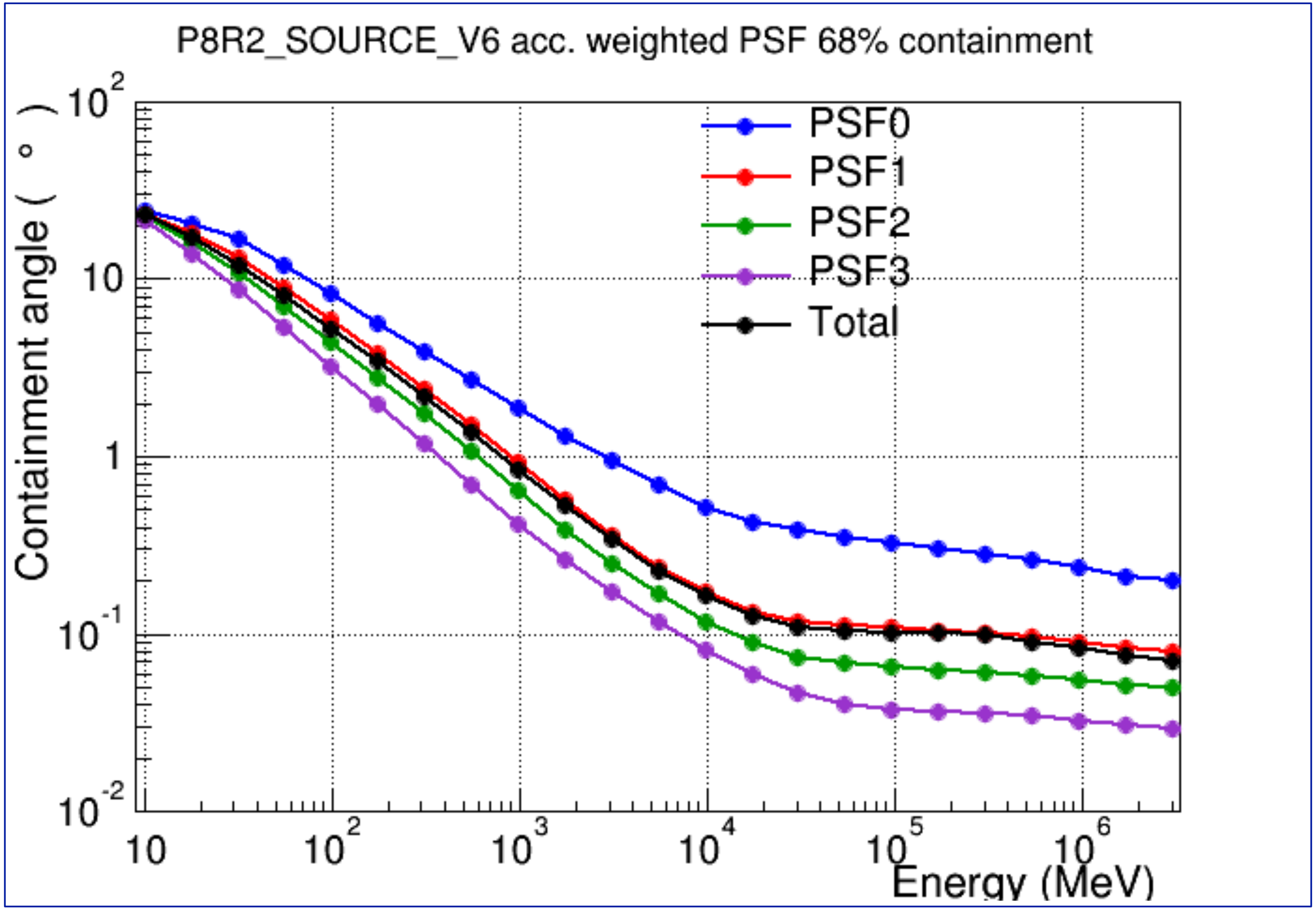


acceptance
Acceptance (m² sr)
2.5
2
1.5
1
0.5
0
10
10²
10³
10⁴
10⁵
10⁶
Energy (MeV)
P8R2_SOURCE_V6
P7REP_SOURCE_V15

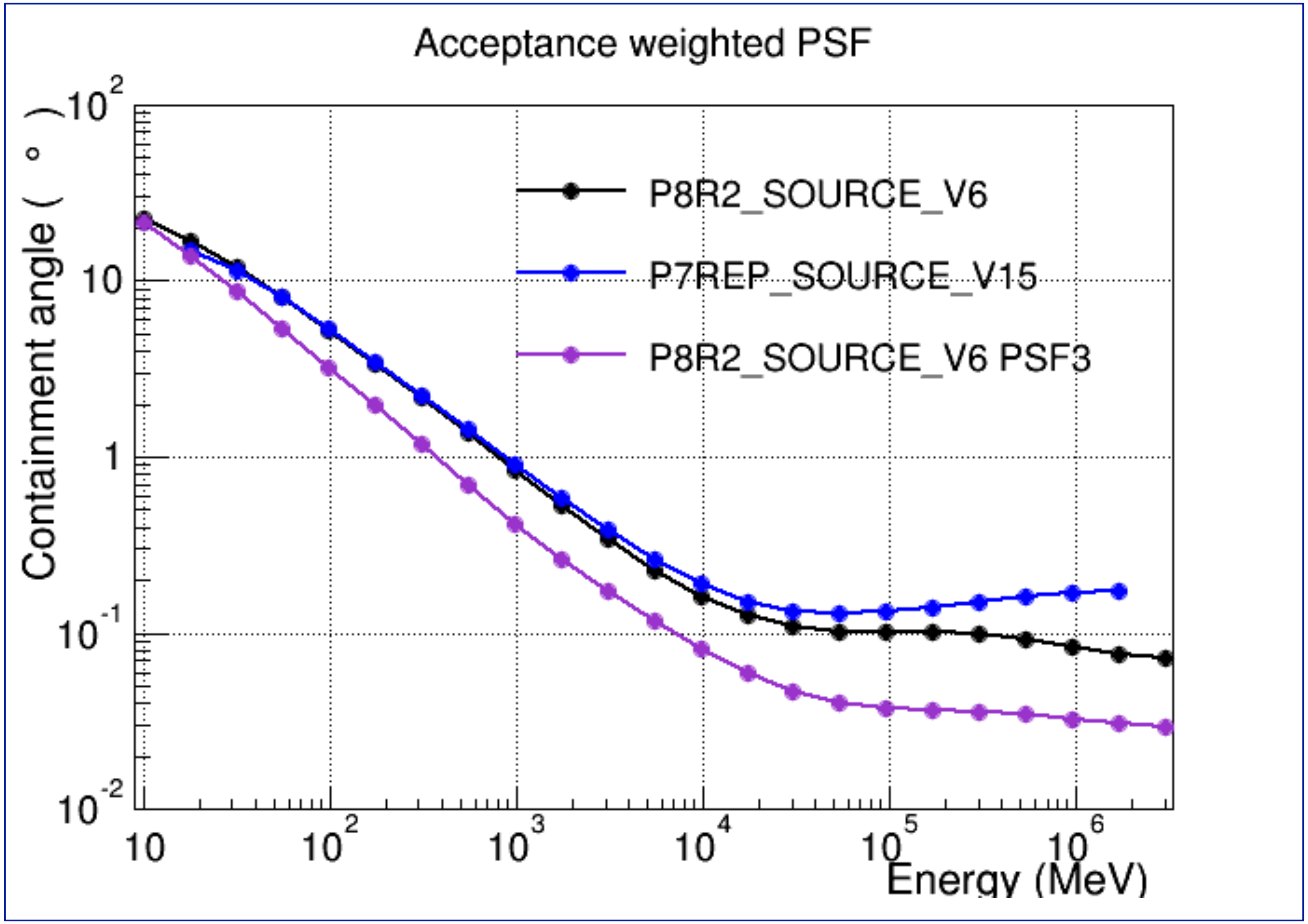
Point Spread Function



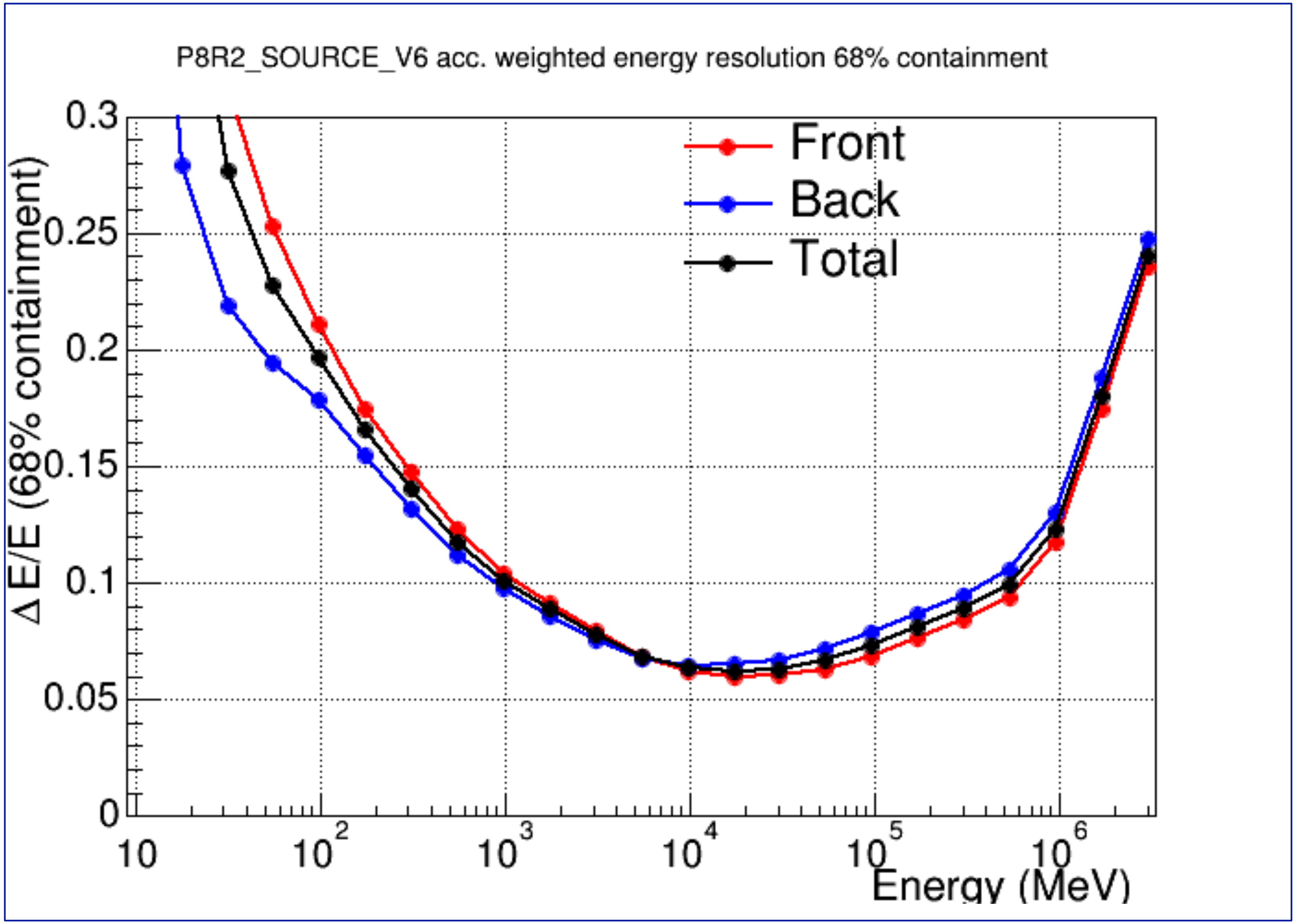
Point Spread Function



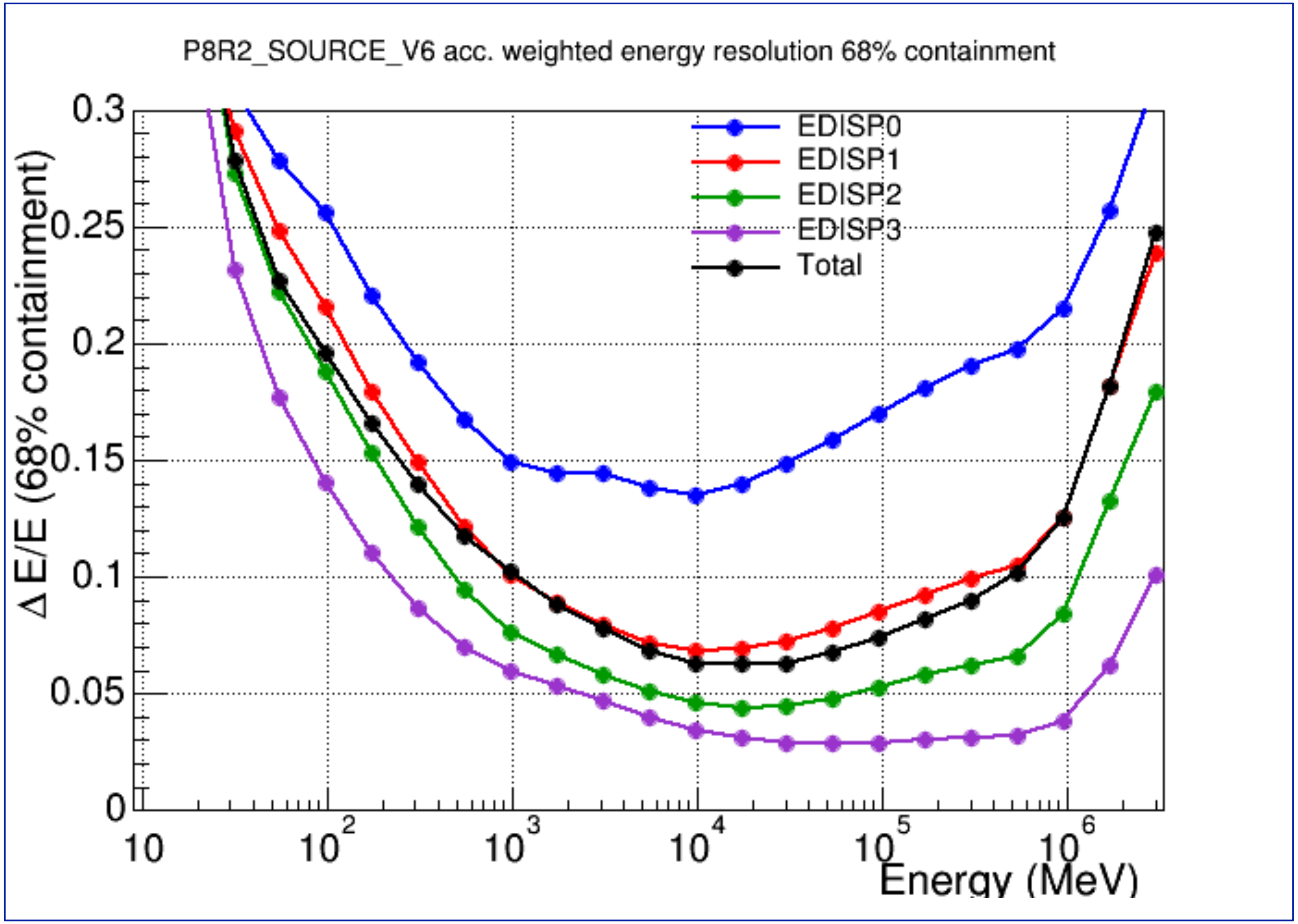
Point Spread Function



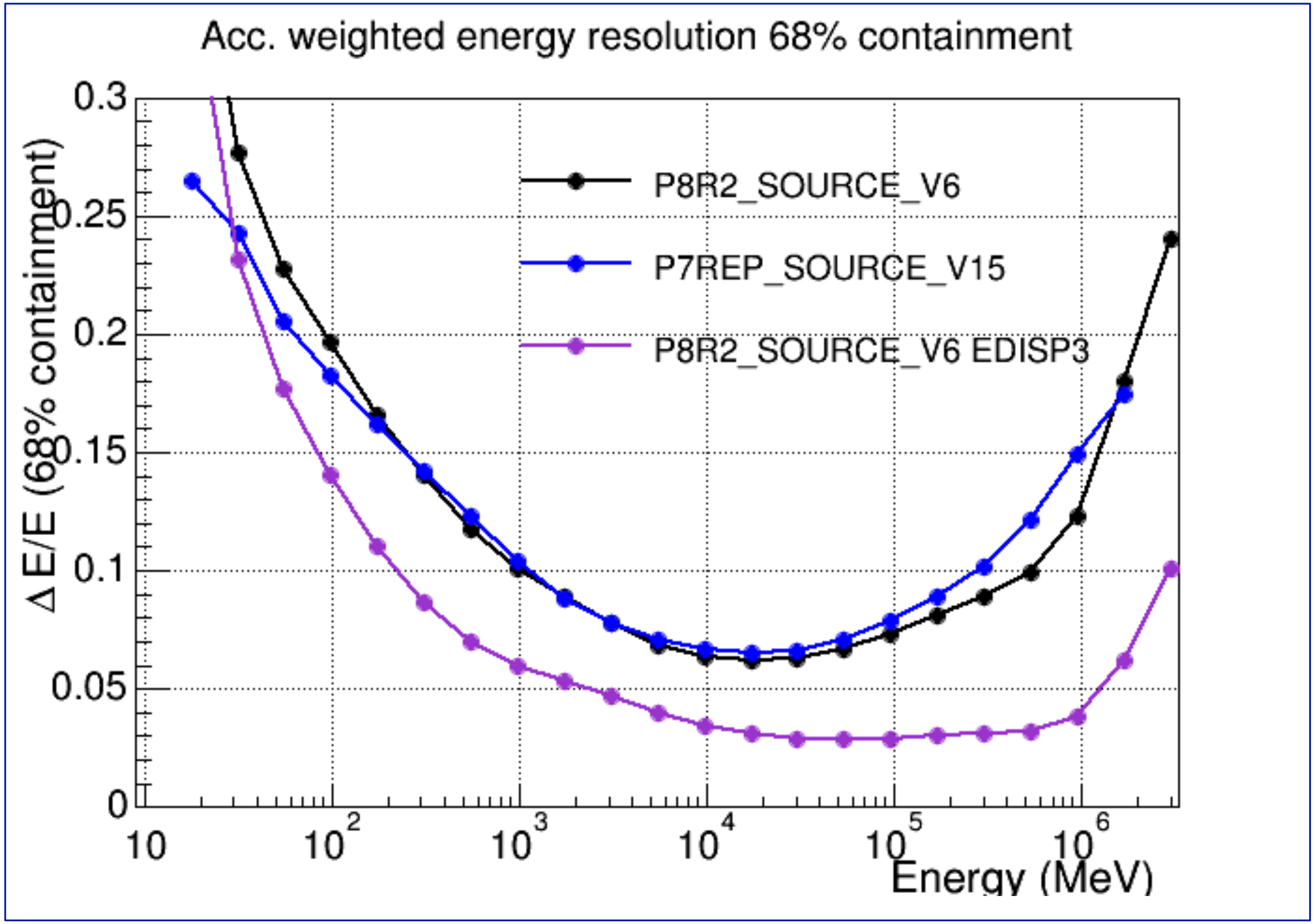
Energy resolution



Energy resolution



Energy resolution



Extras

•**Diffuse models (.txt & FITS files)**

–**To correctly take into accounts the galactic and extagalactic backgrounds**

–http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html

- **Source Catalogs (3FGL, 3FHL, PSRs, GRB, SNR …)**

- **Region of Interest model definition (stored in XML files)**
  - More on this later …

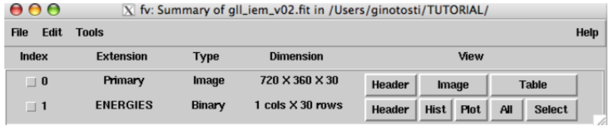
•**Choose the proper combination of**

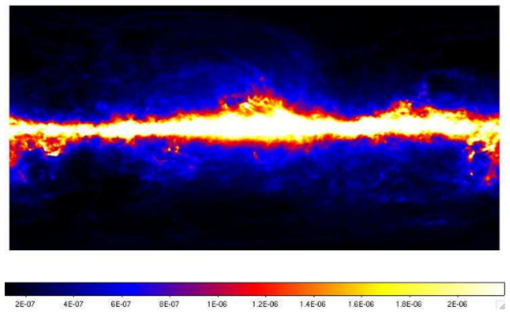
- event classes based on the probability of being a photon and background level
  - TRANSIENT (for very short events)
  - SOURCE (suggested for source analysis)
  - CLEAN and ULTRACLEAN (lowest particle contamination – for diffuse sources analysis)
- Event types based on conversion point or PSF or Energy reconstruction

LAT background models

Extras 2 : 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/BackgroundModels.html

LAT background models

LAT Background Models

Many analyses of LAT data require models of Galactic diffuse and isotropic emission. Detailed discussion of how the latest Galactic diffuse emission models, which are available from this web page, have been developed is available, Acero et. al. (2016). Please refer to the binned or unbinned likelihood analysis tutorials for some examples of how to incorporate theses models into your own Fermi data analysis. Here is a list of IRFs and diffuse models to be used with the various data sets. We have provided the model files for you to download. However, the files for the most recent data release are included in the Fermitools installation (in the $(FERMI_DIR)/refdata/fermi/galdiffuse/ directory). As a result, it is unlikely that you will need to download each file separately.

For Pass 8, each event class and event type combination has a dedicated IRF and isotropic model. Only a subset are shown here, as examples.

Galactic interstellar emission model	Event Selection/ IRF Name	Isotropic spectral template
gll_iem_v06.fits (see below for P8R3 usage notes)	Pass 8 Source (front+back, allPSF, allEDISP) P8R3_SOURCE_V2	iso_P8R3_SOURCE_V2.txt
	Pass 8 Source (front only) P8R3_SOURCE_V2::FRONT	iso_P8R3_SOURCE_FRONT_V2.txt
	Pass 8 Source (back only) P8R3_SOURCE_V2::BACK	iso_P8R3_SOURCE_BACK_V2.txt
	Pass 8 Clean (front+back, allPSF, allEDISP) P8R3_CLEAN_V2	iso_P8R3_CLEAN_V2.txt
	Pass 8 Clean (PSF0) P8R3_CLEAN_V2::PSF0	iso_P8R3_CLEAN_PSF0_V2.txt
	Pass 8 Clean (PSF1) P8R3_CLEAN_V2::PSF1	iso_P8R3_CLEAN_PSF1_V2.txt
	Pass 8 Clean (PSF2) P8R3_CLEAN_V2::PSF2	iso_P8R3_CLEAN_PSF2_V2.txt
	Pass 8 Clean (PSF3) P8R3_CLEAN_V2::PSF3	iso_P8R3_CLEAN_PSF3_V2.txt
	Pass 8 Ultraclean (front+back, allPSF, allEDISP) P8R3_ULTRACLEAN_V2	iso_P8R3_ULTRACLEAN_V2.txt

LAT catalogs

High-level Data Products

- Catalogs and associated products
  - LAT Point Source Catalog
    - LAT 8-year Point Source Catalog (4FGL)
    - Preliminary LAT 8-year Source List (FL8Y)
    - LAT 4-year Point Source Catalog (3FGL)
    - LAT 2-year Point Source Catalog (2FGL)
    - LAT 1-year Point Source Catalog (1FGL)
    - LAT 3-month Bright Source List (0FGL)
  - Aperture Photometry Light Curves
    - Aperture Photometry Light Curves for LAT 4-year Catalog Sources (Updated Weekly)
    - Flaring Sources in the LAT 4-year Aperture Photometry Light Curves (Updated Weekly)
    - Aperture Photometry Light Curves for the LAT 2-year Point Source Catalog
    - Flaring Sources in the LAT 2-year Aperture Photometry Lightcurves
  - LAT High Energy Source Catalog
    - LAT Third High Energy Source Catalog (3FHL)
    - LAT Second High-Energy Source Catalog (2FHL)
    - LAT First High-Energy Source Catalog (1FHL)
  - LAT Monitored Source List Light Curves
  - LAT Burst Catalog
  - Extended Sources in the Galactic Plane (FGES)
  - Second Fermi All-sky Variability Analysis Catalog (2FAV)
  - 1st Fermi-LAT SNR Catalog
  - LAT 3-year Catalog of Gamma-ray Pulsars
- Other useful data products
  - List of LAT GRBs announced via GCN notices (external)
  - List of LAT Sources announced via ATels
  - LAT List of Detected Gamma-Ray Pulsars (updated frequently)
  - LAT Pulsar Ephemerides from Publications
  - LAT Background Models
  - List of time gaps in LAT data

https://fermi.gsfc.nasa.gov/ssc/data/access/

Event classes

Standard Hierarchy for LAT Event Classes				
Event Class	**evclass**	**Photon File**	**Extended File**	**Description**
P8R3_TRANSIENT020	16		X	Transient event class with background rate equal to two times the A10 IGRB reference spectrum.
P8R3_TRANSIENT010	64		X	Transient event class with background rate equal to one times the A10 IGRB reference spectrum.
P8R3_SOURCE	128	X	X	This event class has a residual background rate that is comparable to P7REP_SOURCE. This is the recommended class for most analyses and provides good sensitivity for analysis of point sources and moderately extended sources.
P8R3_CLEAN	256	X	X	This class is identical to SOURCE below 3 GeV. Above 3 GeV it has a 1.3-2 times lower background rate than SOURCE and is slightly more sensitive to hard spectrum sources at high galactic latitudes.
P8R3_ULTRACLEAN	512	X	X	This class has a background rate very similar to ULTRACLEANVETO.
P8R3_ULTRACLEANVETO	1024	X	X	This is the cleanest Pass 8 event class. Its background rate is 15-20% lower than the background rate of SOURCE class below 10 GeV, and 50% lower at 200 GeV. This class is recommended to check for CR-induced systematics as well as for studies of diffuse emission that require low levels of CR contamination.
P8R3_SOURCEVETO	2048	X	X	This class has the same background rate than the SOURCE class background rate up to 10 GeV but, above 50 GeV, its background rate is the same as the ULTRACLEANVETO one while having 15% more acceptance.

Event classes

Extended Hierarchy				
Event Class	**evclass**	**Photon File**	**Extended File**	**Description**
P8R3_TRANSIENT020E	8		X	Extended version of the P8R3_TRANSIENT020 event class with a less restrictive fiducial cut on projected track length through the Calorimeter.
P8R3_TRANSIENT010E	32		X	Extended version of the P8R3_TRANSIENT010 event class with a less restrictive fiducial cut on projected track length through the Calorimeter.
NON-ACD Hierarchy				
Event Class	**evclass**	**Photon File**	**Extended File**	**Description**
P8R3_TRANSIENT015S	65536		X	Transient event class designed for analysis of prompt solar flares in which pileup activity may be present. This class has a background rate equal to 1.5 times the A10 reference spectrum.

Event types

Conversion Type Partition		
Event Type	**evtype**	**Description**
FRONT	1	Events converting in the Front-section of the Tracker. Equivalent to convtype=0.
BACK	2	Events converting in the Back-section of the Tracker. Equivalent to convtype=1.
PSF Type Partition		
Event Type	**evtype**	**Description**
PSF0	4	First (worst) quartile in the quality of the reconstructed direction.
PSF1	8	Second quartile in the quality of the reconstructed direction.
PSF2	16	Third quartile in the quality of the reconstructed direction.
PSF3	32	Fourth (best) quartile in the quality of the reconstructed direction.
EDISP Type Partition		
Event Type	**evtype**	**Description**
EDISP0	64	First (worst) quartile in the quality of the reconstructed energy.
EDISP1	128	Second quartile in the quality of the reconstructed energy.
EDISP2	256	Third quartile in the quality of the reconstructed energy.
EDISP3	512	Fourth (best) quartile in the quality of the reconstructed energy.

Recommendations

Event Selection Recommendations (P8R3)

Analysis Type	**Minimum Energy (emin)**	**Maximum Energy (emax)**	**Max Zenith Angle (zmax)**	**Event Class (evclass)**	**IRF Name**
Galactic Point Source Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R3_SOURCE_V2
Off-plane Point Source Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R3_SOURCE_V2
Burst and Transient Analysis (<200s)	100 (MeV)	500000 (MeV)	100 (degrees)	16	P8R3_TRANSIENT020_V2
Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R3_SOURCE_V2
Extra-Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	1024	P8R3_ULTRACLEANVETO_V2 or P8R3_SOURCEVETO_V2 (when interested in E>1 GeV energy range)
Impulsive Solar Flare Analysis	100 (MeV)	500000 (MeV)	100 (degrees)	65536	P8R3_TRANSIENT015S_V2

Recommendations

Time Selection Recommendations

Analysis Type	ROI-Based Zenith Angle Cut (roicut)	Relational Filter Expression (filter)
Galactic Point Source Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Off-plane Point Source Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Burst and Transient Analysis	yes	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Galactic Diffuse Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Extra-Galactic Diffuse Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Burst and Transient Analysis	yes	(DATA_QUAL>0||DATA_QUAL==-1)&& (LAT_CONFIG==1)

IMPORTANT: For analyses where an ROI-based zenith cut is NOT performed, an exposure correction must be made using the "zmax" option in the gtltcube tool.

Caveats

Caveats About Analyzing LAT Pass 8 (P8R3) Data

These caveats are relevant for the P8R3 version of the Pass 8 photon dataset. They supersede the set of caveats for analysis of the previous version of Pass 8 (P8R2), Pass 7 reprocessed (P7REP), Pass7 (P7_V6) and Pass 6 (P6_V3 and P6_V11) event selections and Instrument Response Functions (IRFs).

The LAT team is still working to validate all aspects of Pass 8 data and analysis. As a consequence it is expected that, in the coming year, the range of application of Pass 8 data will be increased, the tools and files will be improved and the systematic uncertainties will be decreased. These caveats will be modified accordingly.

The P8R3_V2 IRFs are defined between 5.62 MeV and 3.16 TeV but that does not mean that they have been fully validated over this whole energy range. Following the Pass 7 validation effort, the LAT team has started performing studies in order to check the consistency and precision of the instrument simulation and the instrument response representation provided by the IRFs. These studies are based on the analysis of Vela (E < 10 GeV), bright AGN (3 GeV < E < 100 GeV) and the Earth limb (E > 10 GeV). They include:

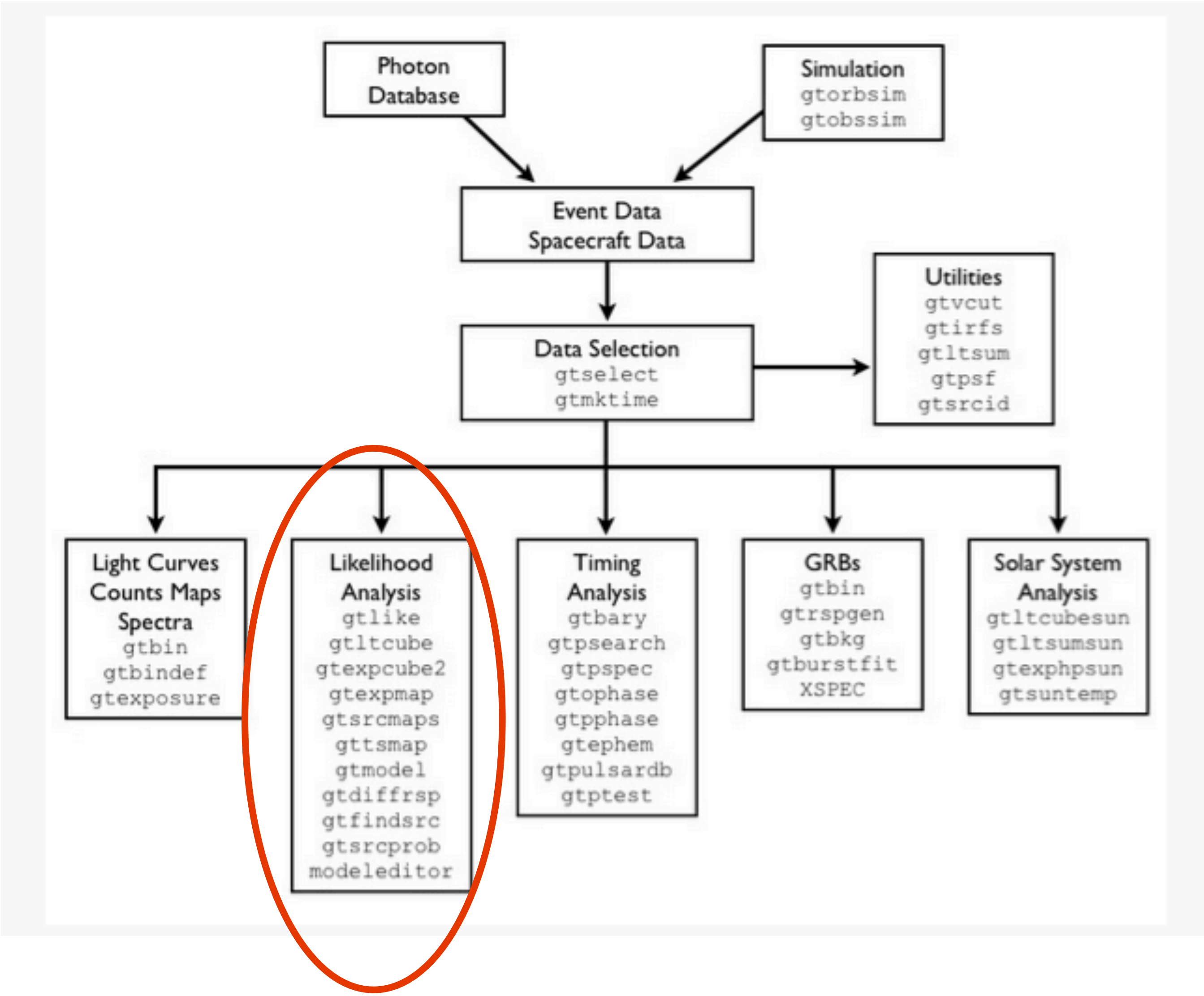
- comparing the distributions of reconstructed quantities between data and the simulation of the instrument for a given selection (e.g. SOURCE class)
- comparing the fraction of events of a loose selection (e.g. TRANSIENT020 class) that are accepted in a more stringent selection (e.g. SOURCE class) in data and as predicted by the instrument simulation or the IRFs
- comparing the fraction of events in each event type for a given selection in data and as predicted by the instrument simulation or the IRFs
- comparing the radial profiles of a point source in data and as predicted by the IRFs

Energy Range

Either because the disagreement between data and the IRFs prediction is too large or because the validation process was hampered by lack of statistics, using data below 30 MeV or above 1 TeV is strongly discouraged. The effect of energy dispersion is particularly large below 100 MeV where there is a non-negligible positive bias in the LAT energy reconstruction. Therefore it is highly recommended to take into account energy dispersion (see the Pass 8 analysis and energy dispersion page) when analyzing data below 300 MeV, and required below 100 MeV.

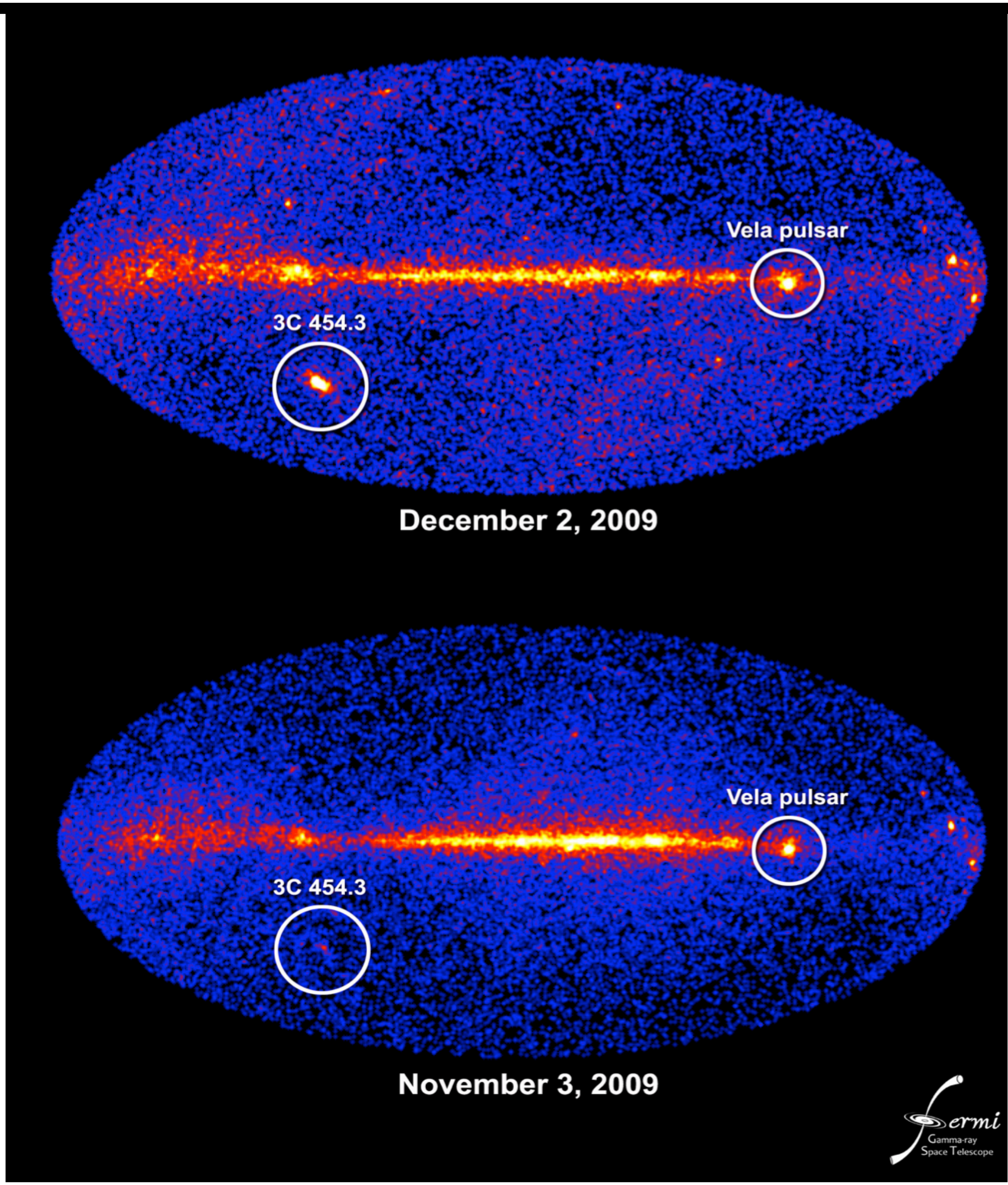
http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

Overview of Fermi Science Tools



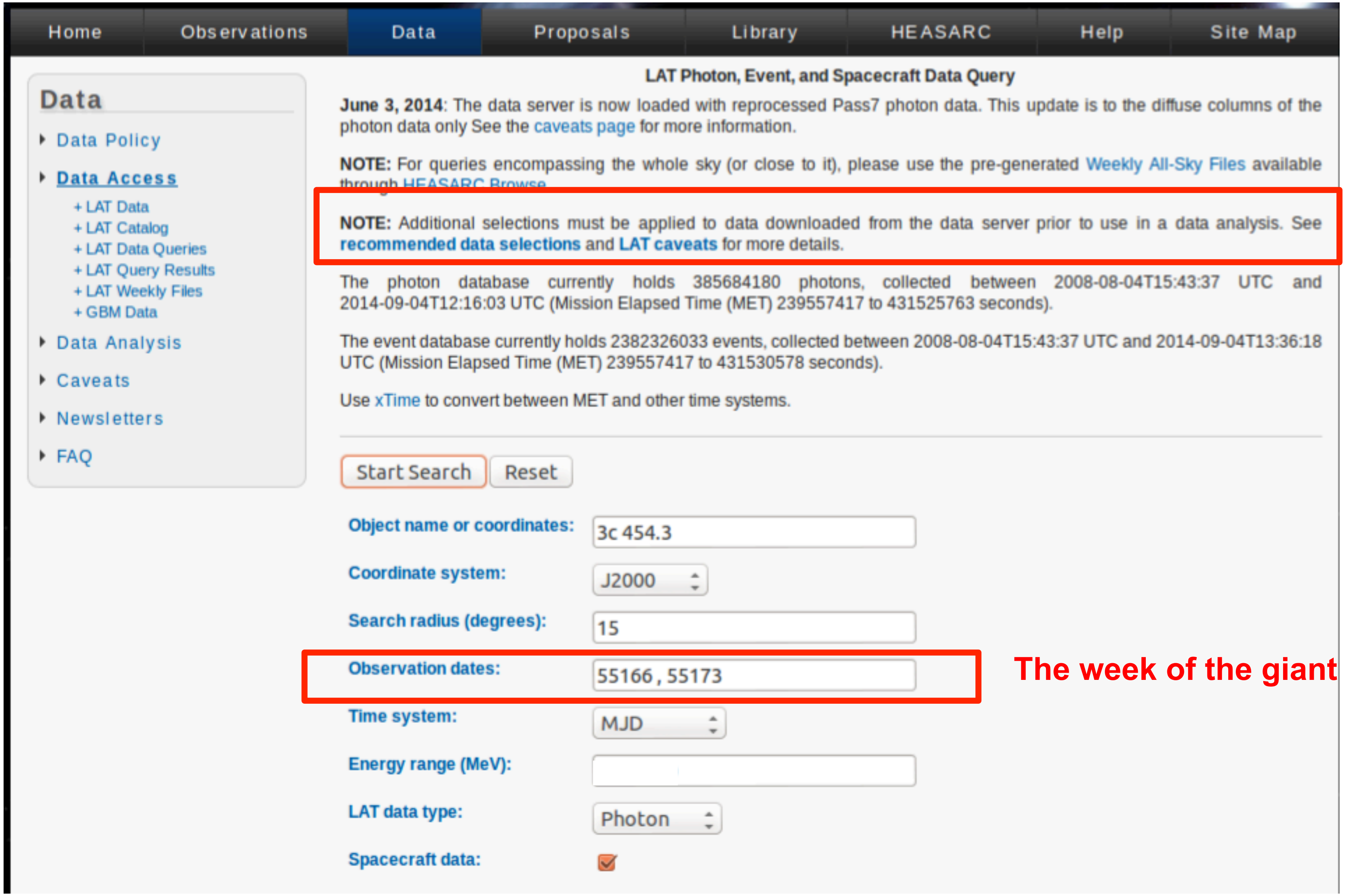
Analysis Tutorial - 1

Blazar one of … 3c454.3's record flares!



How to download data

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



The week of the giant outburst!!

Fermi Gamma-ray Space Telescope

→ Download both spacecraft and photon data ←

Take note of the start and stop MET

follow the link

- Data Policy
- **Data Access**
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

Your search criteria were:

Equatorial coordinates (degrees)	(343.491,16.1482)
Time range (MET)	(281318400,281923200)
Time range (Gregorian)	(2009-12-01 00:00:00,2009-12-08 00:00:00)
Energy range (MeV)	(100,300)
Search radius (degrees)	15

The state of your query is 2 (Query complete)

Server	Position in Queue	Estimated Time Remaining (sec)
Photon Server	Query complete	N/A
Spacecraft Server	Query complete	N/A

The filenames of the result files consist of the query ID string with an identifier appended to indicate which database the file came from. The identifiers are of the form: _DDNN where DD indicates the database and NN is the file number. The file number will generally be '00' unless the query resulted in a large data volume. In that case the data is broken up into multiple files. The values of the database field are:

- PH - Photon Database
- SC - Spacecraft Pointing, Livetime, and History Database
- EV - Extended Database

In the event that you do not see any files with the data type you requested listed below, you should try resubmitting your query as there may have been a problem.

Filename	Number of Entries	Size (MB)	Status
L14090420274034A4AC2B81_PH00.fits	3372	0.33	Available
L14090420274034A4AC2B81_SC00.fits	17120	2.52	Available

If you would like to download the files via wget, simply copy the following commands and paste them into a terminal window. The files will be downloaded to the current directory in the terminal window.

```
wget http://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L14090420274034A4AC2B81_PH00.fits
wget http://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L14090420274034A4AC2B81_SC00.fits
```

gtselect (select data)

[/home/]$ gtselect evclass=128 evtype=3
Input FT1 file[ph.fits]
Output FT1 file[filtered.fits]
RA for new search center (degrees) (0:360) [343.494812]
Dec for new search center (degrees) (-90:90) [16.1495]
radius of new search region (degrees) (0:180) [15]
start time (MET in s) (0:) [281318400]
end time (MET in s) (0:) [281923200]
lower energy limit (MeV) (0:) [100]
upper energy limit (MeV) (0:) [500000]
maximum zenith angle value (degrees) (0:180) [90]

Events with a high prob. to be gammas

Setting the max ZA, filter gammas from albedo events (gamma from the Earth that can be a significant source of background)

> gtselect evclass=128 evtype=3 infile=ph.fits outfile=filtered.fits \
ra=343.49 dec=16.15 rad=15 tmin=281318400 tmax=281923200 \
emin=100 emax=500000 zmax=90

Note: all analysis steps are scriptable via explicit assign parameters on command-line. Look at the manual for details.

gtmktime (cut the bad time intervals)

Filter out events collected while passing in SAA and other low-quality events

[/home/]$ gtmktime
Spacecraft data file[sc.fits]
Filter expression[(DATA_QUAL>0)&&(LAT_CONFIG==1)]
Apply ROI-based zenith angle cut[no]
Event data file[filtered.fits]
Output event file name[filtered_gti.fits]

Use ZA to filter only proper GTIs

gtbin (Counts Map)

[/home]$ gtbin

Type of output file (CCUBE|CMAP|LC|PHA1|PHA2|HEALPIX) [CMAP]

Event data file name[filtered_gti.fits]

Output file name[CMAP.fits]

Spacecraft data file name[sc.fits]

Size of the X axis in pixels[120]

Size of the Y axis in pixels[120]

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) [343.494812]

Second coordinate of image center in degrees (DEC or galactic b) [16.1495]

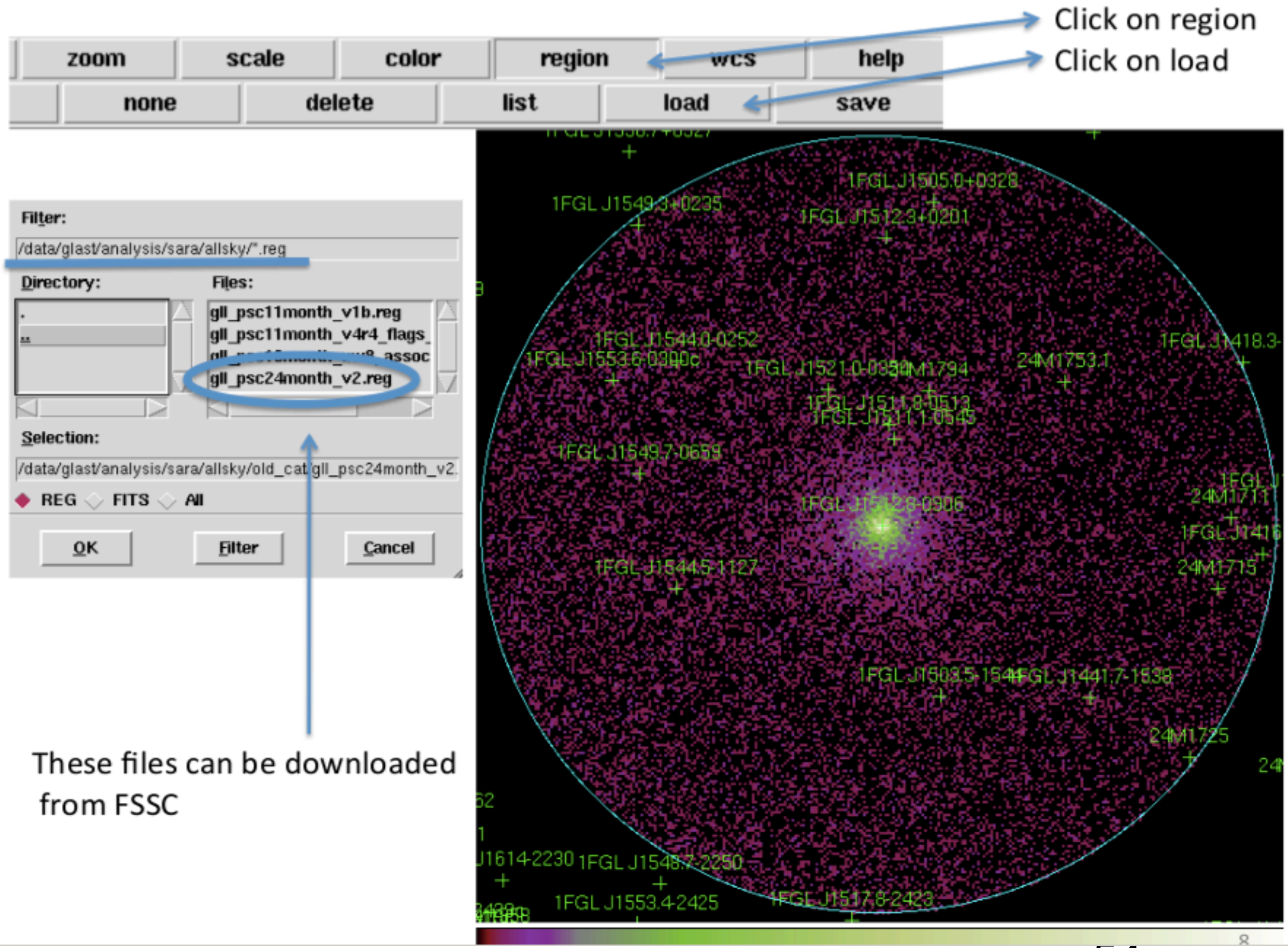
Rotation angle of image axis, in degrees[0]

Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN: [AIT]

Look at the counts map

Use DS9 to look at the counts map of your ROI and check for close-by sources

> ds9 CMAP.fits &



gtbin (Light Curve)

[/home]$ gtbin

Type of output file (CCUBE|CMAP|LC|PHA1|PHA2|HEALPIX) [LC]

Event data file name[filtered_gti_smallROI.fits] → NB selected at 1 deg

Output file name[LC.fits]

Spacecraft data file name[sc.fits]

Algorithm for defining time bins (FILE|LIN|SNR) [LIN]

Start value for first time bin in MET[281318400]

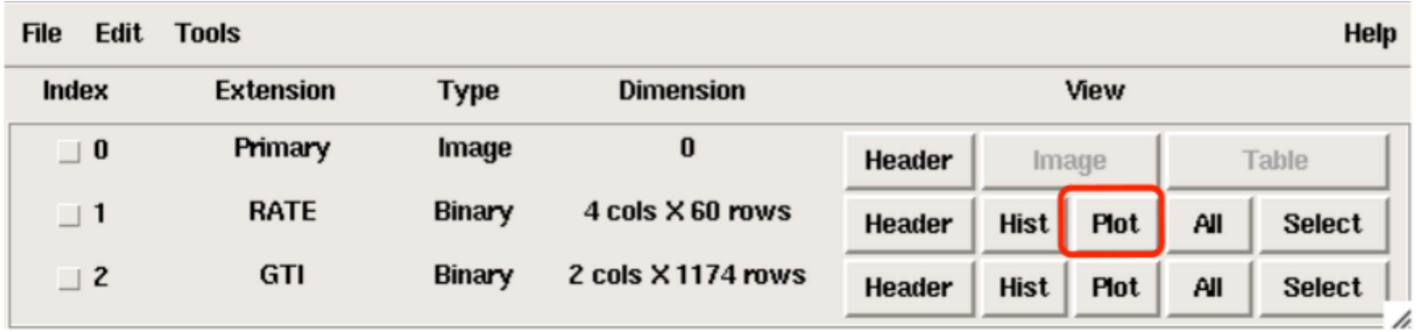
Stop value for last time bin in MET[281923200]

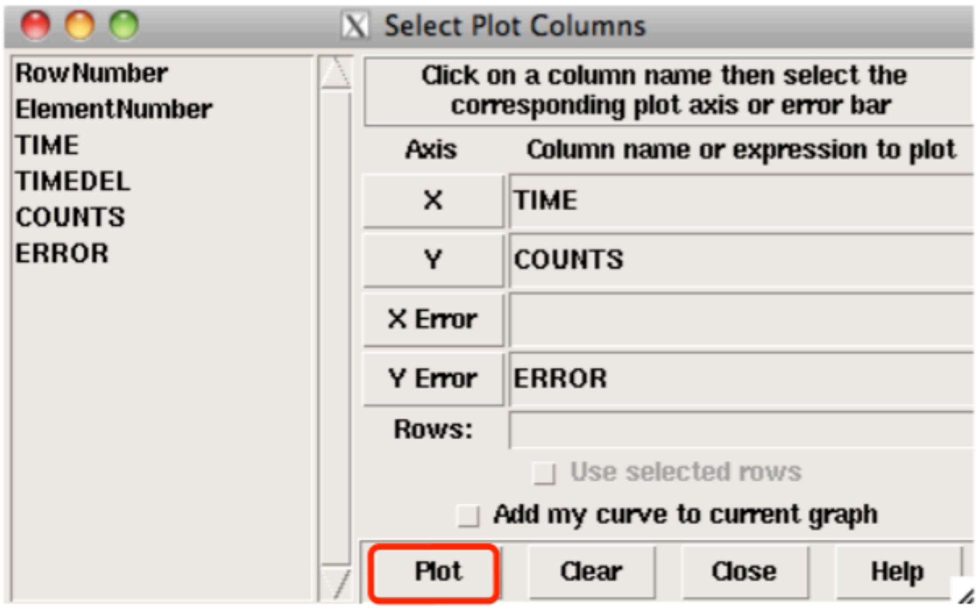
Width of linearly uniform time bins in seconds[86400]

Take care that just one source falls inside the gtselect'ed ROI
(and take out albedo and other low-quality gammas via gtmktime)

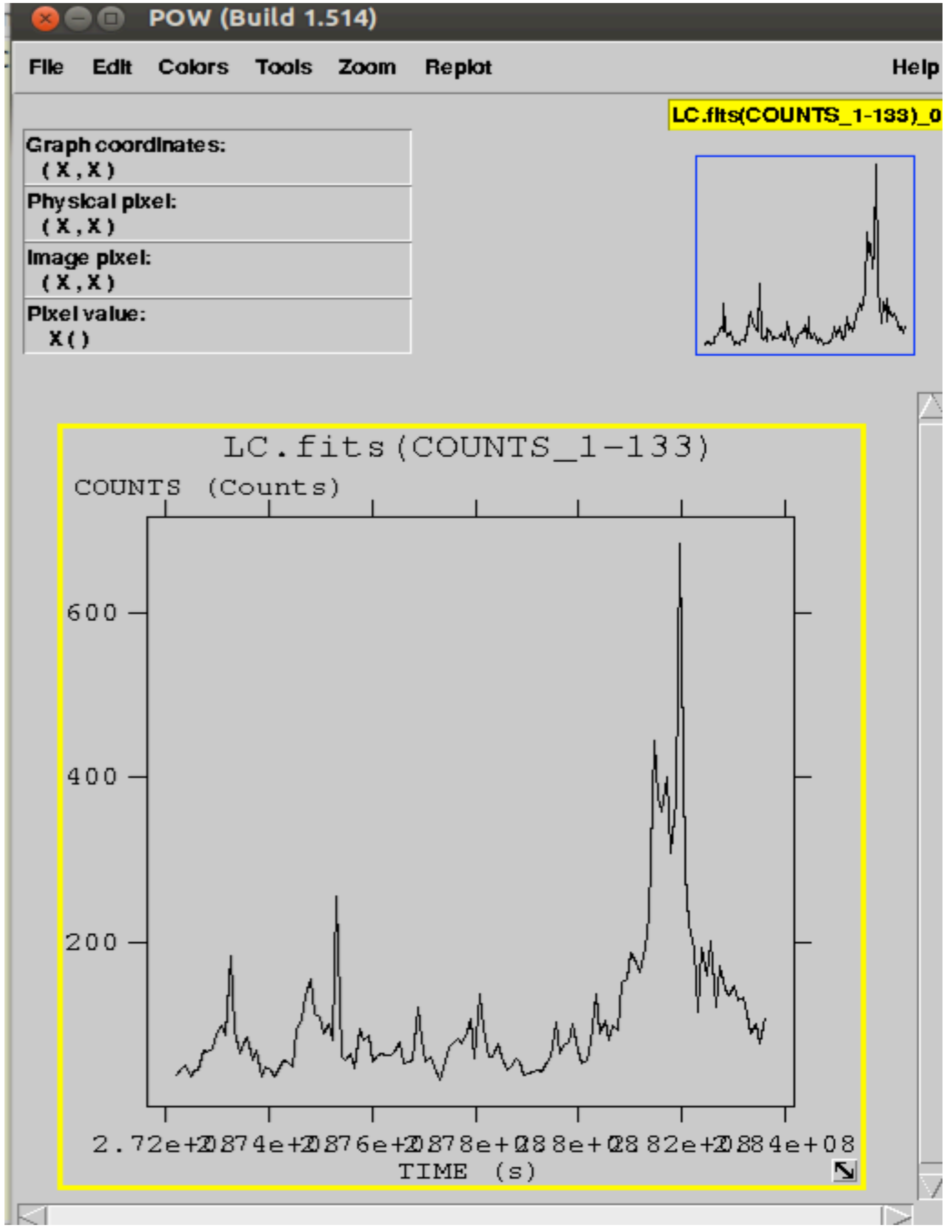
Light-curve: a quick-look

Use FitsView to look at the lightcurve:
> fv LC.fits & (rough estimate .. Not background subtracted)





Light-curve: a quick-look



Rough estimate of light curve (background not subtracted!)

gtbin – II (Light Curve)

[/home]$ gtexposure

Light curve file[] lc.fits

Spacecraft file[] sc.fits

Response functions[CALDB]

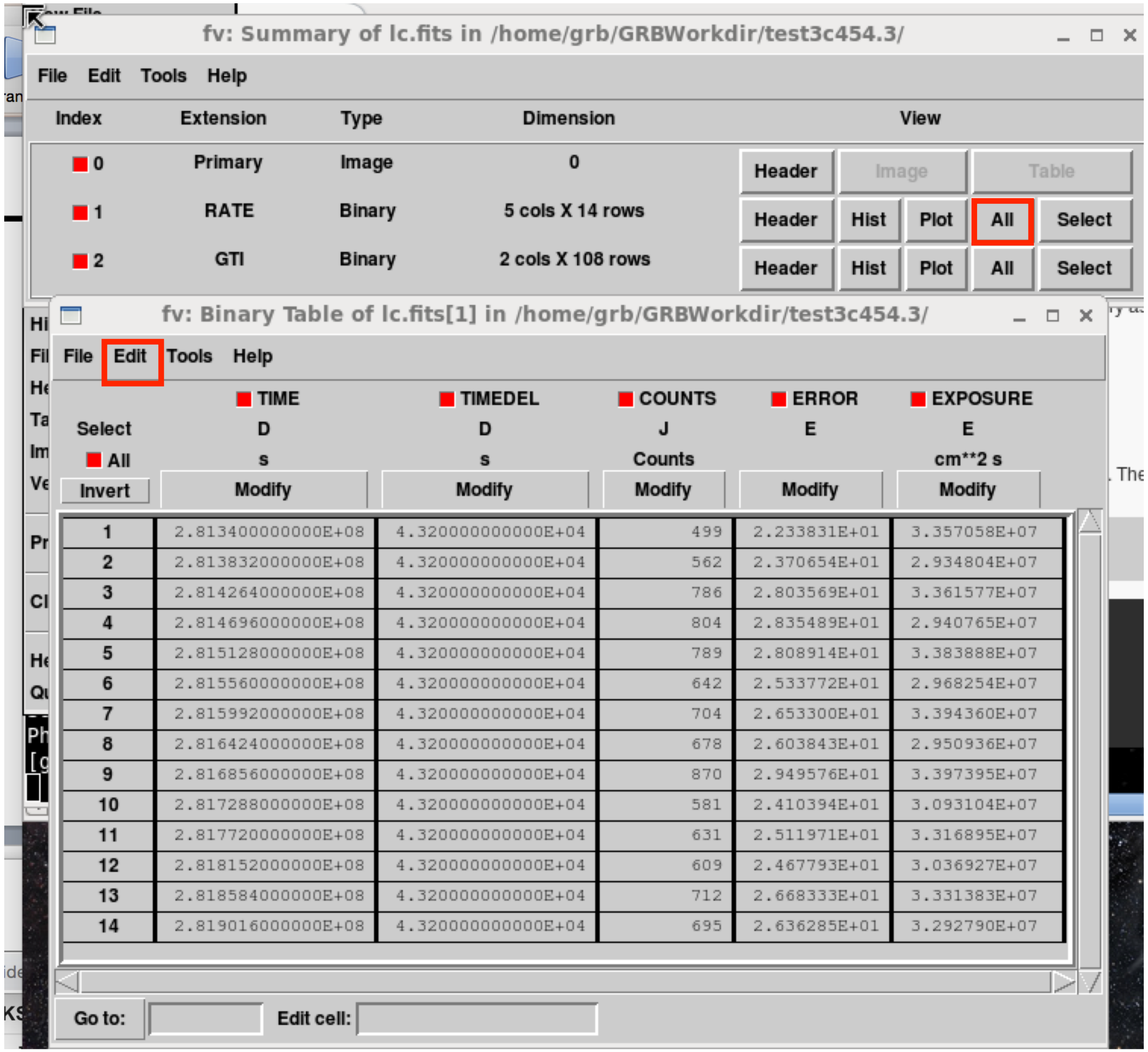
Source model XML file[none]

Photon index for spectral weighting[-2.1]

Light-curve: calculate fluxes

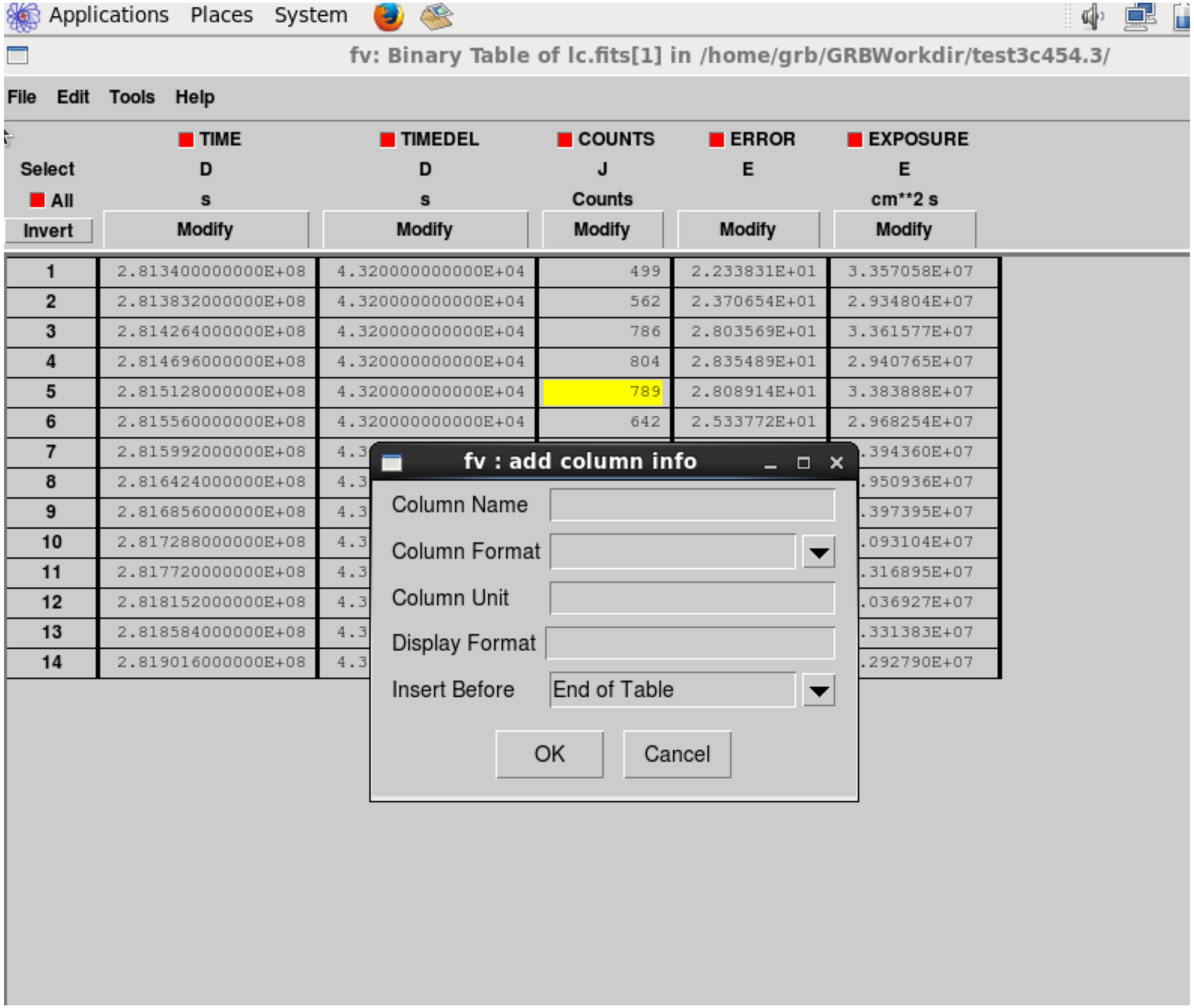
Use FitsView to look at the lightcurve:

> fv LC.fits &



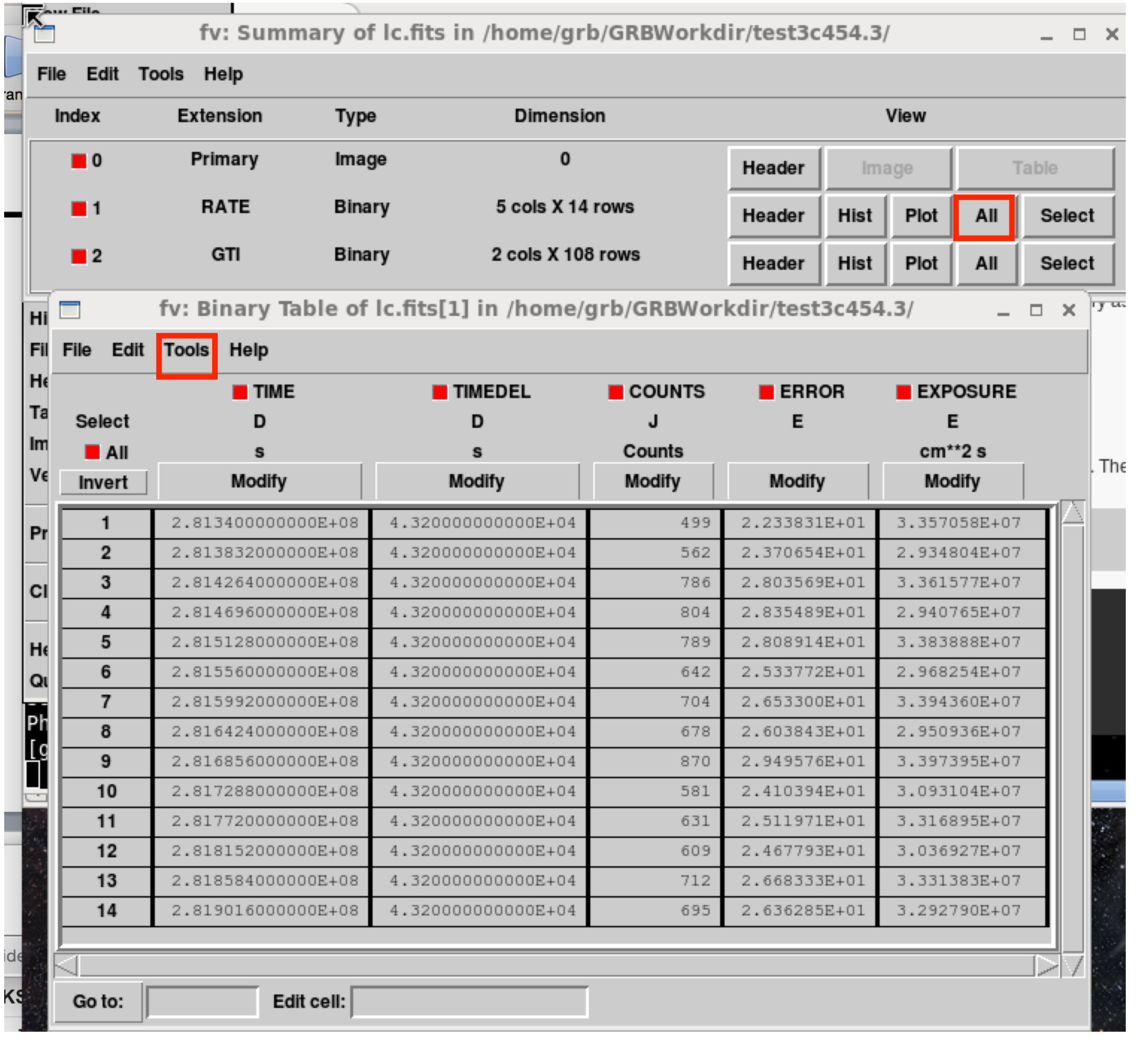
Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors



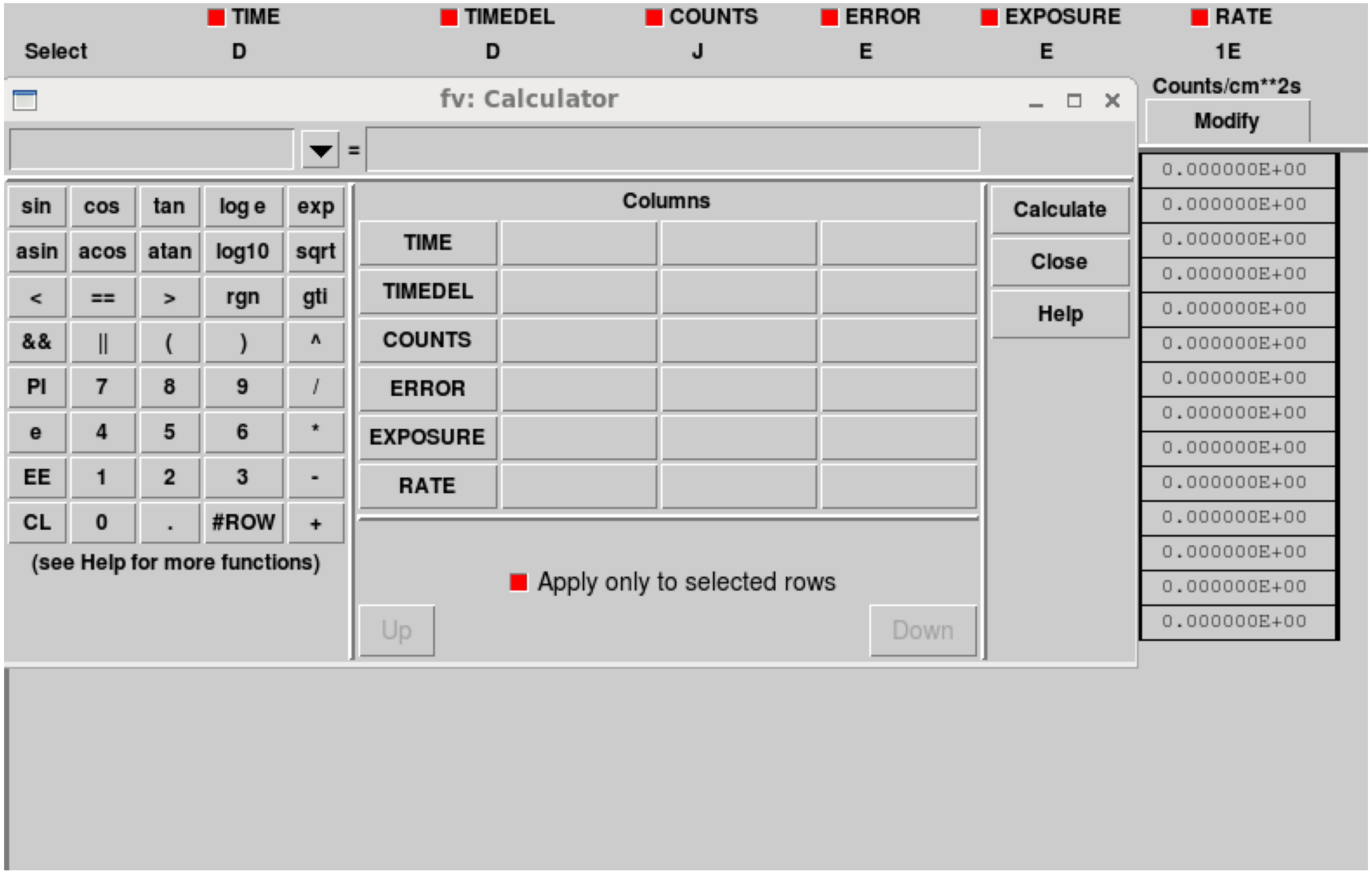
Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors

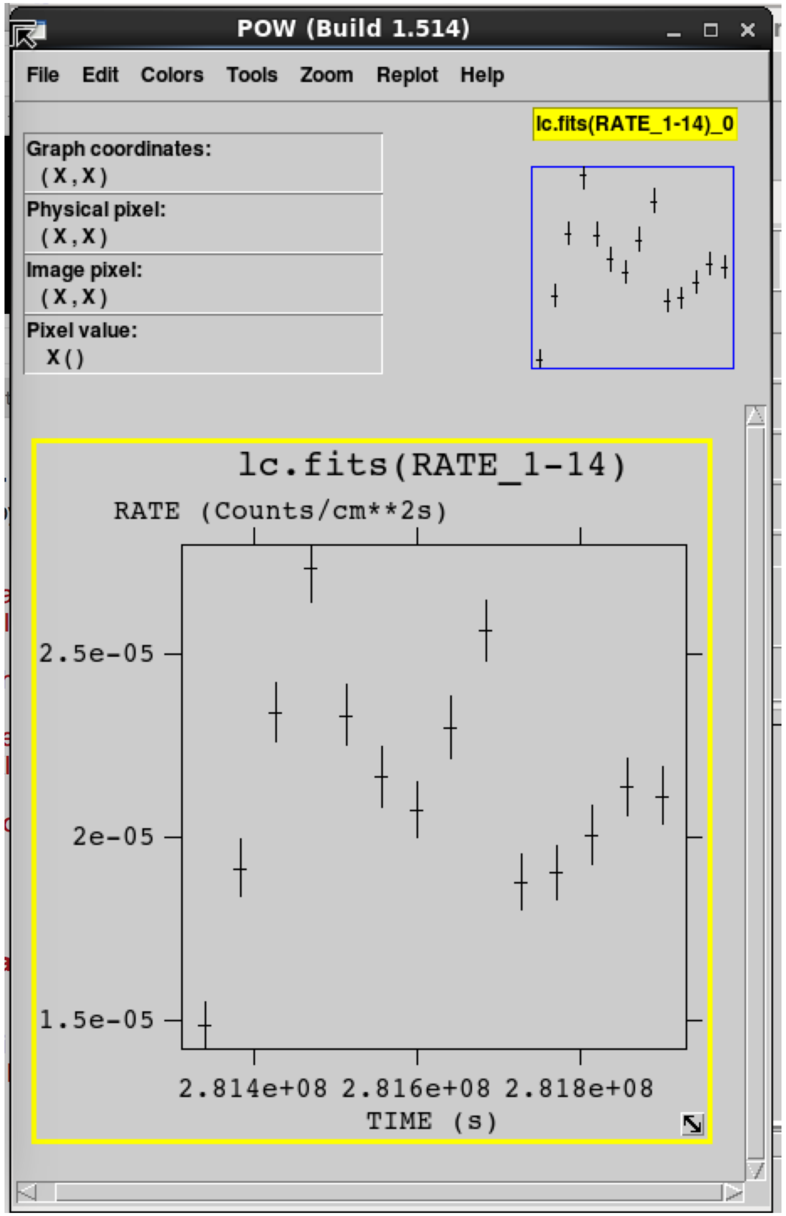


Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors



Light curve

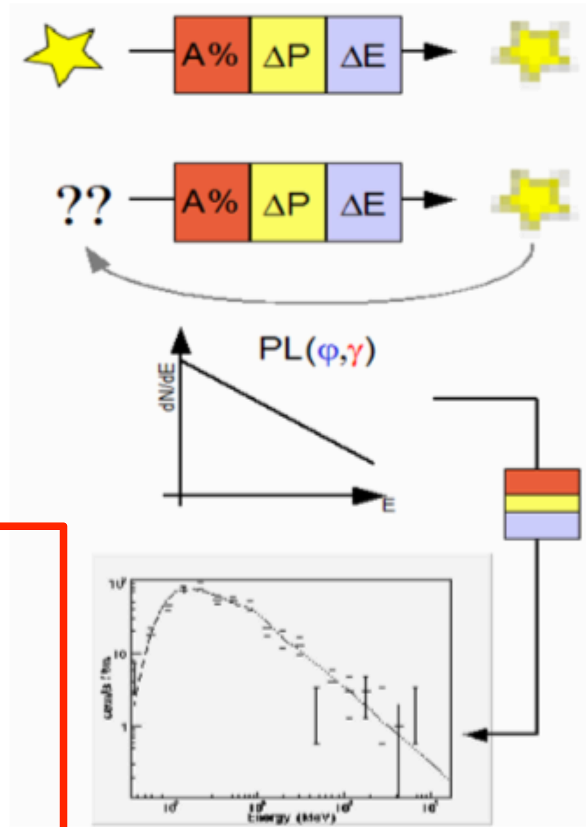


POW (Build 1.514)
File Edit Colors Tools Zoom Replot Help
lc.fits(RATE_1-14)_0
Graph coordinates:
(X,X)
Physical pixel:
(X,X)
Image pixel:
(X,X)
Pixel value:
X()
lc.fits(RATE_1-14)
RATE (Counts/cm**2s)
2.5e-05
2e-05
1.5e-05
2.814e+08 2.816e+08 2.818e+08
TIME (s)

Maximum Likelihood Overview

Perform the fit: the likelihood approach

In high energy gamma rays it is never possible to really isolate a source because of limited statistics and strong and structured background.
Therefore statistical techniques have to be applied.
The most used method is the likelihood analysis based on the Poisson statistics.
The method requires to assume a model for the signal detected by the telescope.



- Assume a **model**
- Model **convolved** with Instrument responce Function (IRF)
- Maximizing likelihood find the best set of parameters that reproduce the observed spectrum

Maximum likelihood technique

Given a set of observed data:

→ Produce a model that accurately describes the data, including parameters that we wish to estimate

→ derive the probability (density) for the data given the model (PDF)

→ treat this as a function of the model parameters (likelihood function)

→ maximize the likelihood with respect to the parameters - ML estimation.

Maximum likelihood ingredients

Data: $X = \{x_i\} = \{x_1, x_2, ..., x_N\}$

Model parameters: $\Theta = \{\theta_j\} = \{\theta_1, \theta_2, ..., \theta_M\}$

Likelihood: $\mathcal{L}(\Theta|X) = P(X|\Theta)$

Conditional probability rule for independent events: $P(A,B) \underset{\text{CPR}}{=} P(A)P(B|A) \underset{\text{Independence}}{=} P(A)P(B)$

For independent data:

$$P(X|\Theta) = P(\{x_i\}|\Theta) = P(x_1|\Theta)P(x_2,..,x_N|\Theta) = \cdots$$
$$= P(x_1|\Theta)P(x_2|\Theta)\cdots P(x_N|\Theta) = \prod_i P(x_i|\Theta)$$

$$\mathcal{L}(\Theta|X) = \prod_i P(x_i|\Theta)$$

$\mathcal{L}$ is the product of the probability of observing the detected counts in each bin.

Maximum likelihood estimation

Parameters can be estimated by maximizing likelihood.

→ Easier to work with log-likelihood:

$$\ln \mathcal{L}(\Theta) = \ln \mathcal{L}(\Theta|X) = \sum_i \ln P(x_i|\Theta)$$

Estimates of $\{\hat{\theta}_k\}$ from solving simultaneous equations:

$$\left.\frac{\partial \ln \mathcal{L}}{\partial \theta_j}\right|_{\{\hat{\theta}_k\}} = 0$$

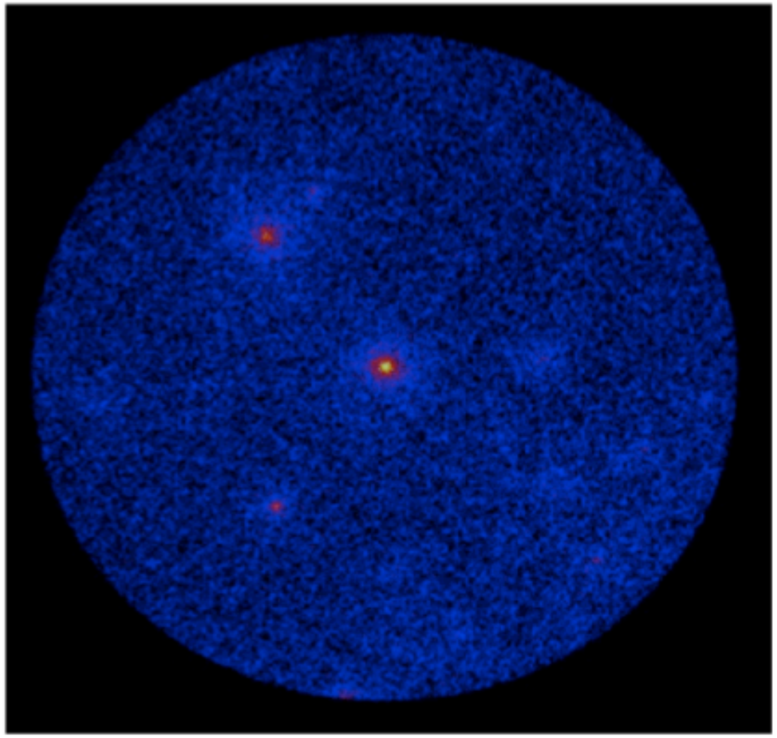
For one parameter, if we have: $\mathcal{L}(\theta) \sim e^{-\frac{(\theta-\hat{\theta})^2}{2\sigma_\theta^2}}$ **Gaussian approximation**

then: $$\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta^2}\right|_{\hat{\theta}} = -\frac{1}{\sigma_\theta^2}$$

so 2nd derivative is related to "errors"

The Challenge

- Gamma-ray data is a list of counts (photons) reconstructed in the detector.
- Qualitative exploration of the data suggests the presence of sources (spatial clustering).
- Quantitative analysis requires evaluating the significance of a 'model' of our region.



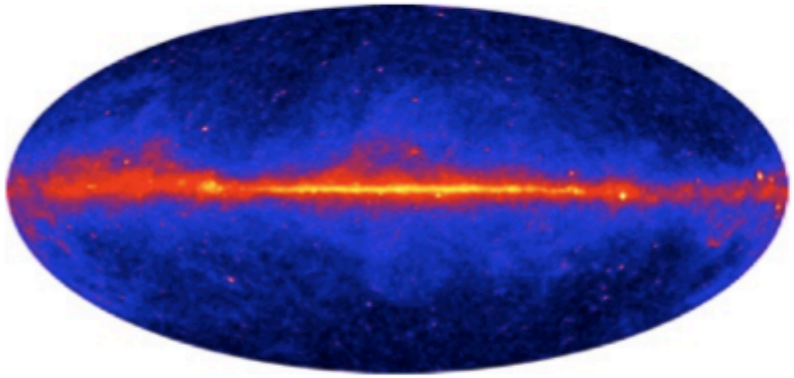
Count Map

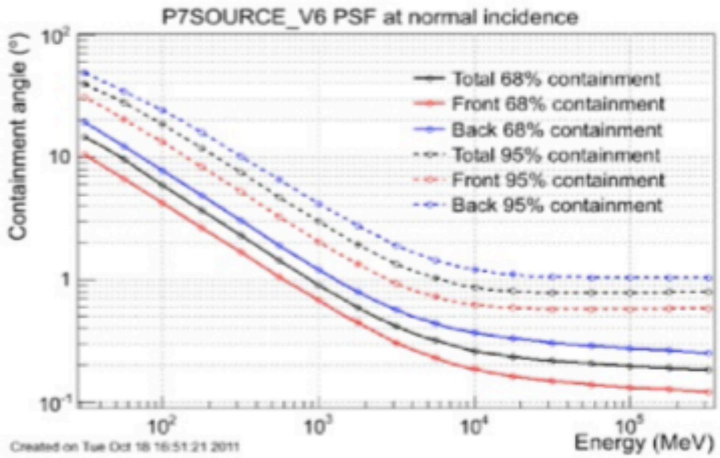
The Procedure

- Basically the initial '**model**' is a guess of the various parameters of the sources in our region:
  - location
  - spectral shape
  - flux
  - etc.
- The guess can be easier if you have a starting point like the 2FGL (3FGL).
- We quantify (using the Likelihood Method) the statistical significance of the model and vary the parameters to determine the most likely parameter values.

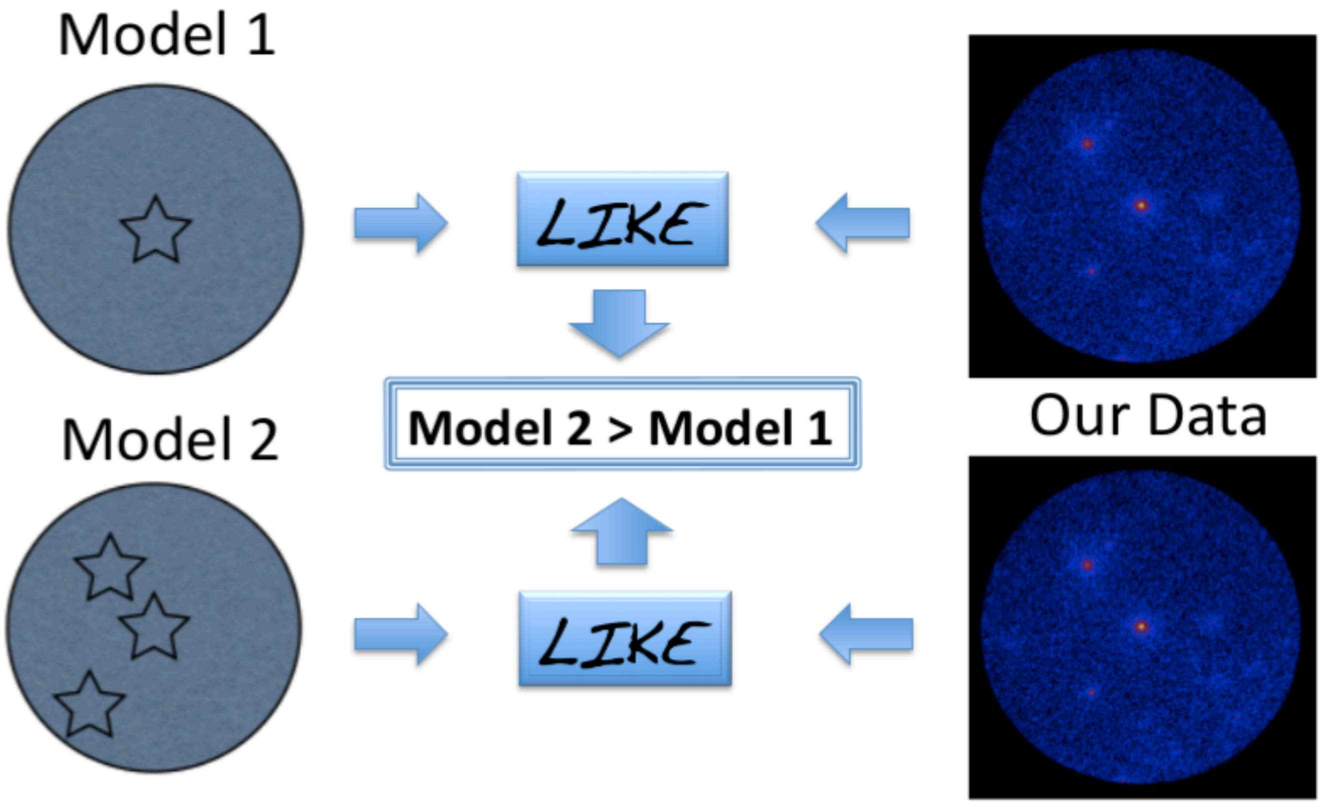
Why Model Fitting?

- We use the Likelihood method because the LAT data are limited by statistics, a bright diffuse background and a broad PSF.
- The model construction defines the questions we want to ask which means:
  - It will not answer a question you are not asking (ie. unknown parameters).
- The Likelihood will not tell you if a fit is 'good'. If the model does not represent your data well, the results will also not represent reality well.

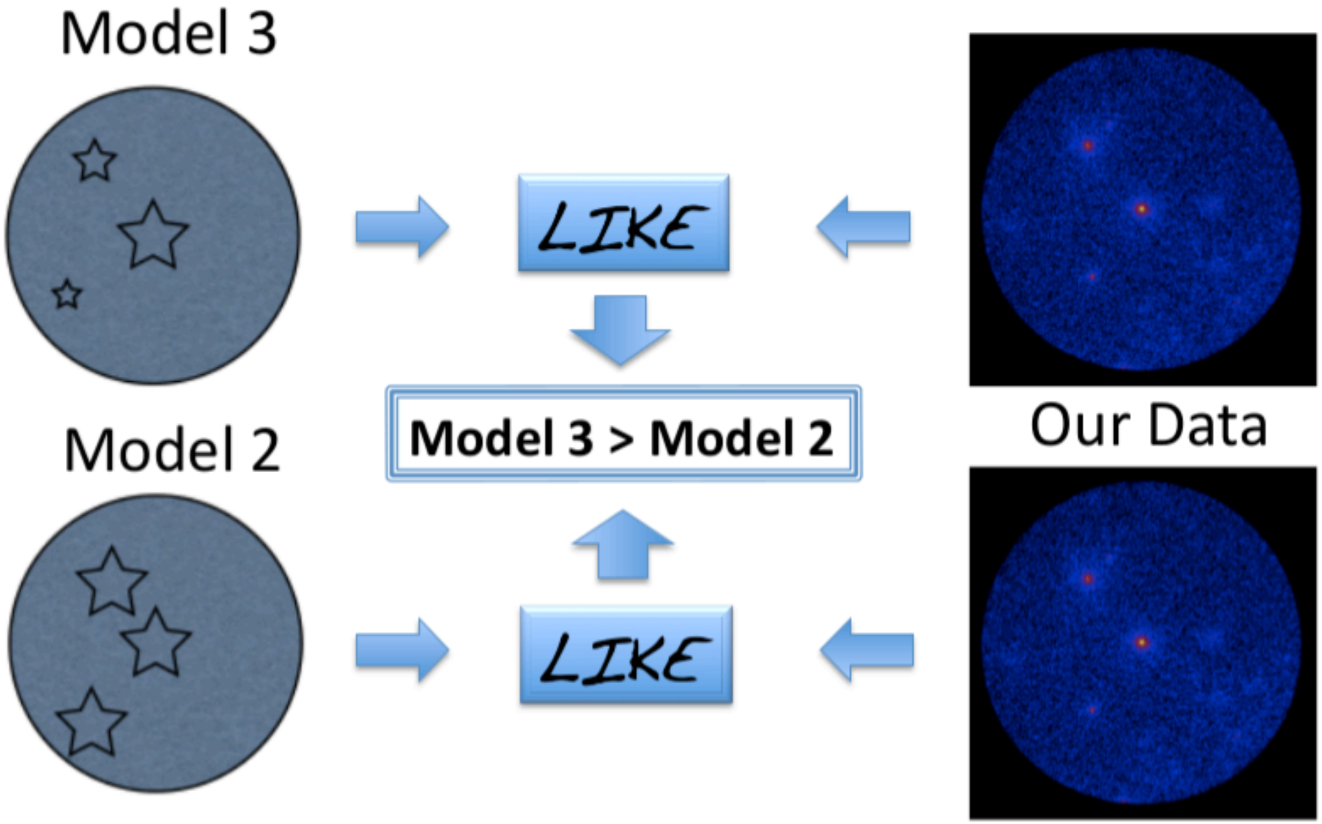




A Graphical Example



A Graphical Example



Fermi Gamma-ray Space Telescope

Likelihood Analysis

- The likelihood $\mathcal{L}$ is the probability of obtaining your 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.
- One will maximize $\mathcal{L}$ to get the best match of the model to the data. Given a set of data, one can bin them in multidimensional (energy, sky pixels, ...) bins.
- $\mathcal{L}$ is the product of the probabilities of observing the detected counts in each bin.

$$\mathcal{L} = \prod p_k$$

Write L as a function of the source model

- The source model is folded with the IRFs in order to obtain the predicted number of counts

- The IRFs can be decomposed into three funtions: Effective Area (proj area of the detector * efficency), Energy Dispesion, Point Spread Function

- Small number of counts in each bin --> Poisson distribuiton

- Bin size infinitesimally small

- Assume only steady source for standard analysis

The function to maximize is:

$$\log \mathcal{L} = \sum_j \log M(E'_j, \hat{p}'_j, t_j) - N_{\rm pred}$$

where the sum is performed over photons in the ROI. The predicted number of counts is $N_{\rm pred} = \int_{\rm ROI} dE' d\hat{p}' \, dt M(E', \hat{p}', t)$

Test Statistic

Null hypothesis max likelihood, *h* parameters

$$\mathrm{TS} = -2\ \log \frac{\mathscr{L}_0}{\mathscr{L}_1} \underset{N\to\infty}{\to} \chi^2_{m-h}$$

non fixed parameters

Alternative hypothesis max likelihood, *m* parameters

- In the limit of a large number of counts, Wilk's Theorem states that the TS for the null hypothesis is asymptotically distributed as χ_n^2 where n is the number of parameters characterizing the additional source.
- As a basic rule of thumb, the square root of the TS is approximately equal to the detection significance for a given source.

Fermi Gamma-ray Space Telescope

Summarizing

- Observed a photon from a location, at a time, with an energy.
- Assume a model:

$$S(E,\hat{p},t) = \sum_i s_i(E,t)\delta(\hat{p}-\hat{p}_i) + S_G(E,\hat{p}) + S_{eg}(E,\hat{p}) + \sum_l S_l(E,\hat{p},t),$$

Point Sources — Galactic & EG diffuse Sources — Other Sources

- Calculate the probability of that photon being detected assuming our model:

$$M(E',\hat{p}',t) = \int_{SR} dE\,d\hat{p}\,R(E',\hat{p}',t;E,\hat{p})S(E,\hat{p},t)$$

- Calculate the total number of predicted counts assuming our model.

$$N_{\text{pred}} = \int_{\text{ROI}} dE'\,d\hat{p}'\,dt\,M(E',\hat{p}',t)$$

- Adjust the model until this is maximized:

$$\log\mathcal{L} = \sum_j \log M(E'_j,\hat{p}'_j,t_j) - N_{\text{pred}}$$

- Calculate the TS:

$$\text{TS} = -2\,\log\frac{\mathcal{L}_0}{\mathcal{L}_1} \underset{N\to\infty}{\to} \chi^2_{m-h}$$

Perform the fit: the likelihood approach

- Absolute value of likelihood meaningless!
- Comparison between model w/ and w/o source to reject H_0 = no source
- Many variables may be calculated BEFORE selecting the models
- IRFs depend on inclination angle:
  Livetime Cube: seconds in $\Delta\Omega$ with a given *z*,
  the time that the LAT observed a given position on the sky at a given inclination angle
  Exposure Map: integration of the effective area over the FoV weighted by the livetime over a position-energy grid, $N_{model} = \int \Phi_{model}(\Omega, E(t)) \times A_{LAT}(\Omega, E)$

Keep in mind that ..

- Many variables may be calculated BEFORE selecting the models
- Very important to have a reliable model
- Absolute value of likelihood meaningless!
  - Likelihood function has no meaning itself, e.g., it is not a probability. Its usefulness comes from theorems such as the LRT.
- Comparison between model w/ and w/o source to reject null hypothesis = no source (TS large → reject null hypothesis)

Analysis Tutorial - 2

Likelihood 1st step: gtltcube

[/home]$ gtltcube zmax=90

Event data file[filtered_gti.fits]

Spacecraft data file[sc.fits]

Output file[ltCube.fits]

Step size in cos(theta) (0.:1.) [0.025]

Pixel size (degrees)[1]

……..

The “livetime cube” must be re-calculated when a new time-interval or a new ZA is selected

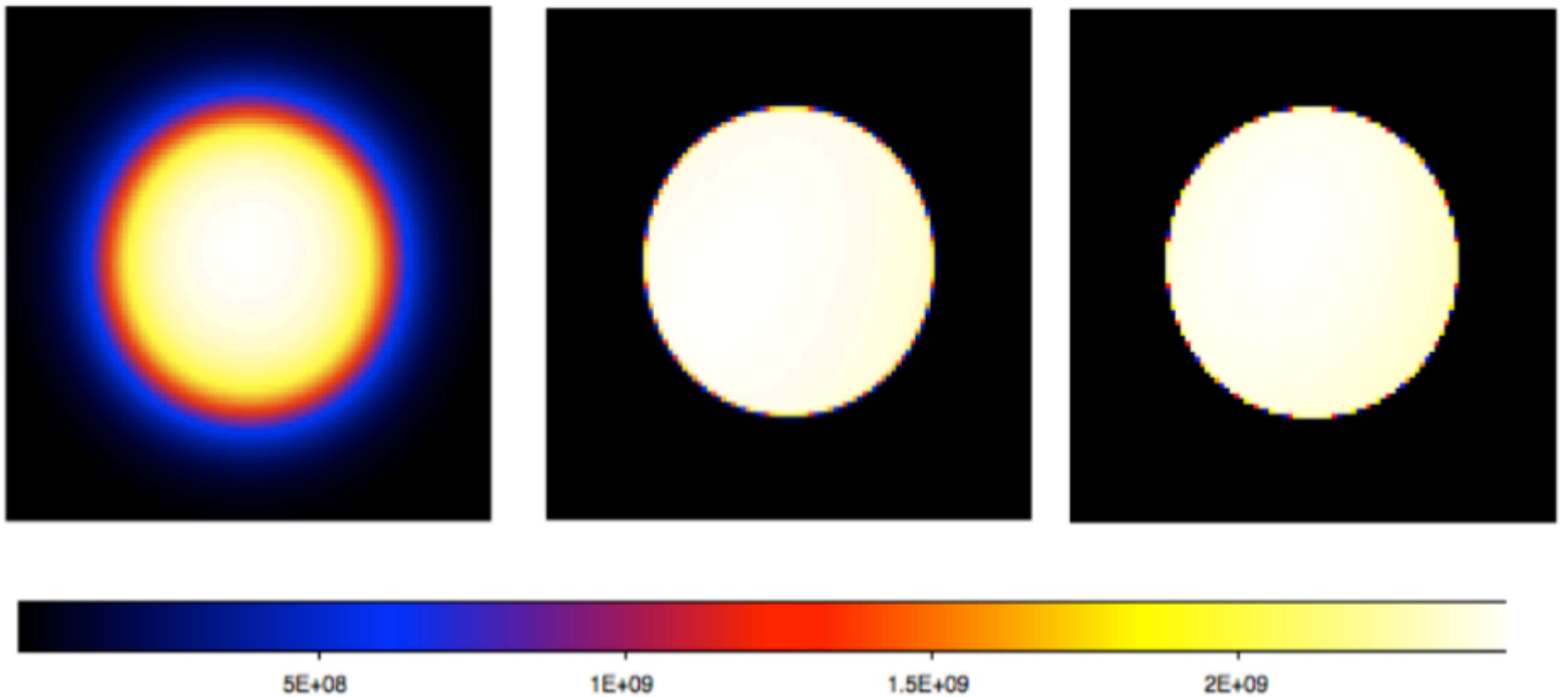
Likelihood 2nd step: gtexpmap

[/home/]$ gtexpmap
Event data file[filtered_gti.fits]
Spacecraft data file[sc.fits]
Exposure hypercube file[ltCube.fits]
output file name[expMap.fits]
Response functions[CALDB]
Radius of the source region (in degrees)[30]
Number of longitude points (2:1000) [120]
Number of latitude points (2:1000) [120]
Number of energies (2:100) [20]
Computing the ExposureMap using ltCube.fits
...

Add 15° to the ROI radius

gtexpmap

Quick check with DS9: fields must be homogenous



Likelihood 3rd step: the XML model

5. Create a source model XML file

The gtlike tool reads the source model from an XML file. The model file contains your best guess at the locations and spectral forms for the sources in your data. A source model can be created using the model editor tool, by using the user contributed tool **make3FGLxml.py** (available at the user-contributed tools page), or by editing the file directly within a text editor.

Here we cannot use the same source model that was used to analyze six months of data in the Unbinned Likelihood tutorial, as the 2-year data set contains many more significant sources and will not converge. Instead, we will use the 3FGL catalog to define our source model by running make3FGLxml.py. To run the script, you will need to download the current LAT catalog file and place it in your working directory:

```
prompt> make3FGLxml.py gll_psc_v16.fit 3C279_binned_gti.fits -o 3C279_input_model.xml
-G $FERMI_DIR/refdata/fermi/galdiffuse/gll_iem_v06.fits -g gll_iem_v06
-I $FERMI_DIR/refdata/fermi/galdiffuse/iso_P8R2_SOURCE_V6_v06.txt
-i iso_P8R2_SOURCE_V6_v06 -s 120 -p TRUE -v TRUE
This is make3FGLxml version 01r0.
The default diffuse model files and names are for pass 8
and assume you have v10r00p05 of the Fermi Science Tools or higher.
Creating file and adding sources from 3FGL
Added 312 point sources, note that any extended sources in ROI were modeled as point sources
because psForce option was set to True
prompt>
```

Note that we are using a high level of significance so that we only fit the brightest sources and we have forced the extended sources to be modeled as point sources. This only affects the lobes of Centarus A which are just outside the FOV.

It is also necessary to specify the entire path to location of the diffuse model on your system. The resulting XML model contains 312 sources. Clearly, the simple 4-source model we used for the 6-month Unbinned Likelihood analysis would have been too simplistic.

This XML file uses the spectral model from the 3FGL catalog analysis for each source. (The catalog file is available at the LAT 4-yr Catalog page.) However, that analysis used a subset of the available spectral models. A dedicated analysis of the region may indicate a different spectral model is preferred. For more details on the options available for your XML models, see:

- Descriptions of available Spectral and Spatial Models
- Examples of XML Model Definitions for Likelihood

Likelihood 3rd step

./make3FGLxml.py gll_psc_v16.fit filtered_gti.fits -o 3c454.3.xml –G $FERMI_DIR/refdata/fermi/galdiffuse/gll_iem_v06.fits -g gll_iem_v06 –I $FERMI_DIR/refdata/fermi/galdiffuse/iso_P8R2_SOURCE_V6_v06.txt -i iso_P8R2_SOURCE_V6_v06 -s 120 -p TRUE -v TRUE

Likelihood 3rd step: the XML model

•Backgrounds

```
<!-- Diffuse Sources -->
<source name="galactic_background"   type="DiffuseSource">
<spectrum type="PowerLaw">
<parameter free="1" max="10" min="0" name="Prefactor" scale="1" value="1"/>
<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="gll_iem_v06.fits" type="MapCubeFunction">
<parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>
</spatialModel>
</source>
<source name="extragalactic_background" type="DiffuseSource">
<spectrum file="iso_P8R2_SOURCE_V6_v06.txt" type="FileFunction">
<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>
```

XML model

- **Typical source entry for an assumed powerlaw**

<source name="......" type="PointSource">...
</source>
Your sources here

```
<source name="3c454.3" type="PointSource">
<spectrum type="PowerLaw2">
<!-- Source is in ROI center -->
<parameter error="0.00" free="1" max="1000" min="1e-06" name="Integral" scale="1e-04"
value="1.000"/>
 <parameter error="0.00" free="1" max="0" min="-5" name="Index" scale="1" value="-2.000"/>
                    <parameter free="0" max="3e6" min="20" name="LowerLimit" scale="1"
value="100."/>
        <parameter free="0" max="3e6" min="20" name="UpperLimit" scale="1" value="300000."/>
        </spectrum>
<spatialModel type="SkyDirFunction">
<parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="343.494812"/>
<parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="16.149500"/>
</spatialModel>
</source>
```

XML model

Test different models... power law * HE exponential cut-off

```
<source name="3c454.3" type="PointSource">
<spectrum type="PLSuperExpCutoff">
<parameter free="1" max="1000" min="1e-05" name="Prefactor" scale="1e-07" value="1"/>
<parameter free="1" max="0" min="-5" name="Index1" scale="1" value="-1.7"/>
<parameter free="0" max="1000" min="50" name="Scale" scale="1" value="200"/>
<parameter free="1" max="30000" min="500" name="Cutoff" scale="1" value="3000"/>
<parameter free="0" max="5" min="0" name="Index2" scale="1" value="1"/>
</spectrum>
```

- **Look here for source model definition and XML model definitions:**

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

- **Useful python script to load 2FGL sources that belongs to your ROI in your XML file model (make3FGLxml.py)**

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

Diffuse response

[/home/]$gtdiffrspEvent data file[]filtered_gti.fits

Spacecraft data file[] sc.fits

Source model file[] 3c454.3.xml

Response functions to use[] CALDB

Finally... gtlike
performing the actual fit

[/home/]$ gtlike plot=yes
Statistic to use (BINNED|UNBINNED) [UNBINNED]
Spacecraft file[sc.fits]
Event file[filtered_gti.fits]
Unbinned exposure map[expMap.fits]
Exposure hypercube file[ltCube.fits]
Source model file[../xml_models/_3c454.3_model_ROI15.xml]
Response functions to use[CALDB]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [DRMNFB]

Typically use DRMNGB/DRMNFB to find a rough estimate of the likelihood maxima and refine later on with **MINUIT (or NEWMINUIT)**

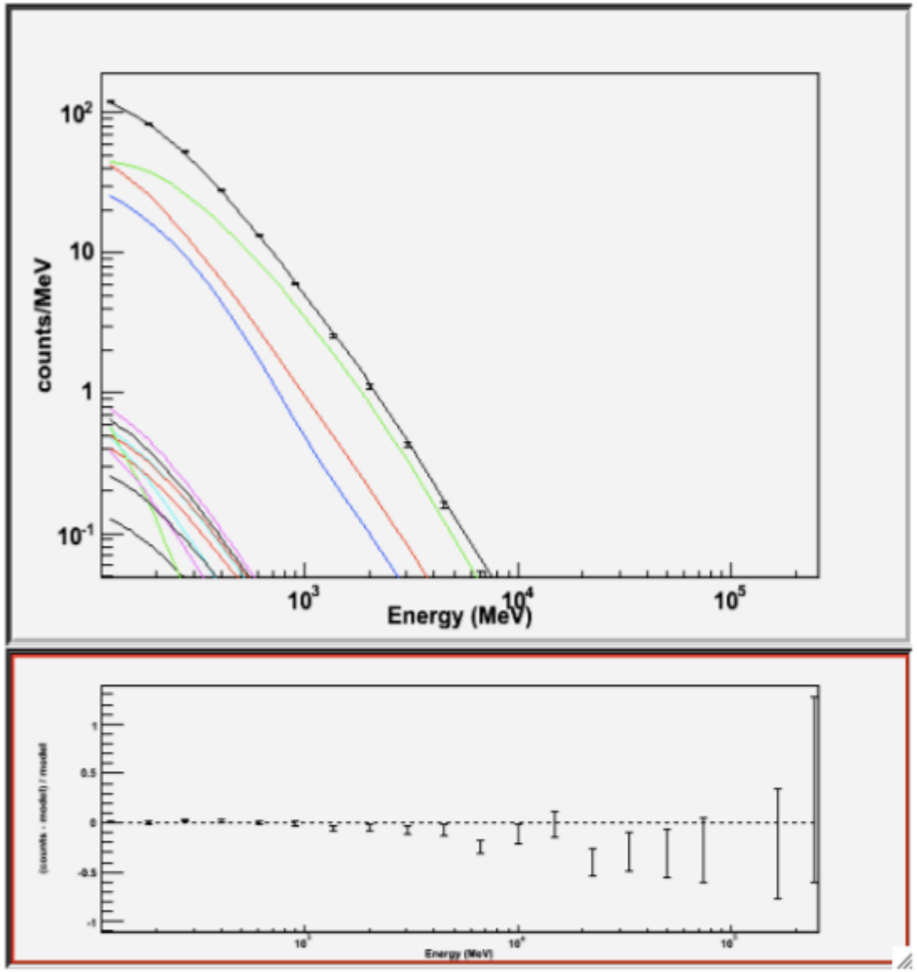
Fermi Gamma-ray Space Telescope

Likelihood output

{'3c454.3': {'Integral': '0.146106 +/- 0.00271733',
'Index': '-2.29973 +/- 0.017189',
'LowerLimit': '100',
'UpperLimit': '300000',
'Npred': '4171.85',
'ROI distance': '0',
'TS value': '17548.4',
'Flux': '1.46192e-05 +/- 2.7178e-07',
…
extragalactic_background': {'Normalization': '1.20197 +/- 0.23541',
'Npred': '643.953',
'Flux': '0.000170707 +/- 3.34331e-05',
},
'galactic_background': {'Prefactor': '0.739969 +/- 0.251827',
'Index': '0',
'Scale': '100',
'Npred': '357.929',
'Flux': '0.000215978 +/- 7.35023e-05',

gtlike creates two output files:
1) results.dat: fit results
2) counts_spectra.fits: the counts in a proper energy binning

Plot



Solid lines follows the order as they are listed in the file results.dat:

black) ROI fit

red) 1st source (pks1510)

green) 2nd source (galactic)

blue) 3rd source (istropic)

Magenta) 4th source

Cyan) 5th source

...

Comparison of different models

Powerlaw * HE exp cut-off

{'3c454.3': {'Prefactor': '0.39194 +/- 0.00793161',

'Index1': '-2.12802 +/- 0.03056',

'Cutoff': '5495.55 +/- 934.857 (MeV)

'Npred': '4157.04',

'ROI distance': '0',

'TS value': '17604.2',

'Flux': '1.41693e-05 +/- 2.72878e-07'

(ph cm-2 s-1)

----> Comparing TS values for different models!

For this source, in this time interval, the model with the HE exponential cutoff is favoured with respect to the Simple Powerlaw

You can repeat analyses by yourself also following instructive and complete Tutorials on the FSSC web-site:

- Standard Likelihood: http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/likelihood_tutorial.html
- PyLike: http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/python_tutorial.html

SED modeling

Generate Spectral Points

To generate spectral points to plot on top of the butterfly that we just produced, you need to go back to the data selection part and use gtselect (filter in python) to divide up your data set in energy bins and run the likelihood fit on each of these individual bins. Luckily, there's a script that does this for us that we'll employ to get a final result. This script also generates the butterfly plot we just produced so you won't have to redo that again and it also does a lot of checks on the data to make sure that everything is going ok. If you've made it this far, you might be a little curious as to why we didn't jump right into using this tool but now you're in a position to play with the python tools and make them do what you want them to. The script is also much more careful in handling units and saving everything to files than we have been in this interactive session.

So download the likeSED.py user contributed tool (it's in the SED_scripts package) and load it up into python. You can find information on the usage of this tool on the same page where you downloaded it. It can be used to generate an SED plot for both binned and unbinned analyses but we're only going to work on a binned analysis here.

```
>>> from likeSED import *
This is likeSED version 12.1, modified to handle Pass 7 selections.
```

Now you need to create a likeInput object that takes our unbinnedAnalysis object, the source name and the number of bins we want as arguments. We're going to make 9 bins here like in the paper and we're also going to make custom bins and bin centers. You can have the module chose bins and bin centers for you (via the getECent function) but we're going to do it this way so we can have the double-wide bin at the end. We're also going to use the 'fit2' file (the result of our fit on the full dataset with the NewMinuit optimizer) for the fits of the individual bins but we need to edit it first to make everything fixed except for the integral value of PG 1553+113. Go ahead and do that now. We're basically assuming that the spectral index is the same for all bins and that the contributions of the other sources within the ROI are not changing with energy.

```
>>> inputs = likeInput(like,'3FGL J1555.7+1111',nbins=9)
>>> inputs.plotBins()
```

SED modeling

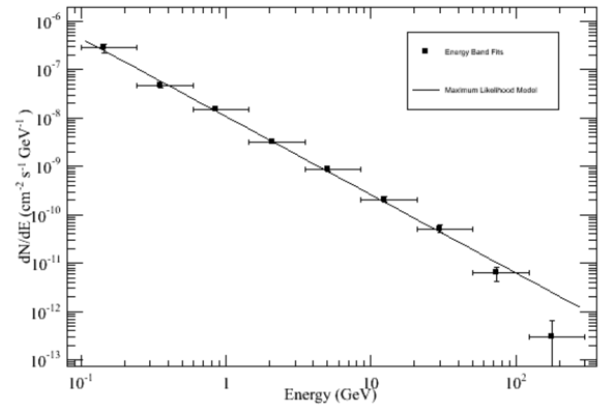
This last step will take a while (approximately 30 minutes) because it's creating an expmap and event file for each of the bins that we requested (look in your working directory for these files). Once it is done we'll tell it to do the fit of the full energy band and make sure we request that it keep the covariance matrix. Then we'll create a likeSED object from our inputs, tell it where we want our centers to be and then fit each of the bands. After this is done, we can plot it all with the Plot function.

```
>>> inputs.fullFit(CoVar=True)
Full energy range model for 3FGL J1555.7+1111:
3FGL J1555.7+1111
Spectrum: PowerLaw
32 Prefactor: 5.928e-01 2.586e-02 1.000e-04 1.000e+04 ( 1.000e-11)
33 Index: 1.621e+00 2.674e-02 0.000e+00 1.000e+01 (-1.000e+00)
34 Scale: 1.448e+03 0.000e+00 3.000e+01 5.000e+05 ( 1.000e+00) fixed

Flux 0.1-300.0 GeV 7.2e-08 +/- 4.2e-09 cm^-2 s^-1
Test Statistic 3141.46
>>> sed = likeSED(inputs)
>>> sed.getECent()
>>> sed.fitBands()
-Running Likelihood for band0-
-Running Likelihood for band1-
-Running Likelihood for band2-
-Running Likelihood for band3-
-Running Likelihood for band4-
-Running Likelihood for band5-
-Running Likelihood for band6-
-Running Likelihood for band7-
-Running Likelihood for band8-
>>> sed.Plot()
```

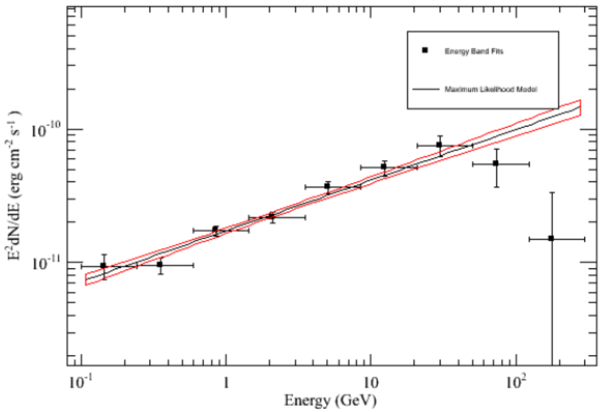
This produces the following three plots: a TS plot, a counts spectrum, and a butterfly plot (statistical errors only):

SED modeling

The TS plot shows the TS value for each bin in the spectrum produced by likeSED. Notice that the last bin is double-wide.



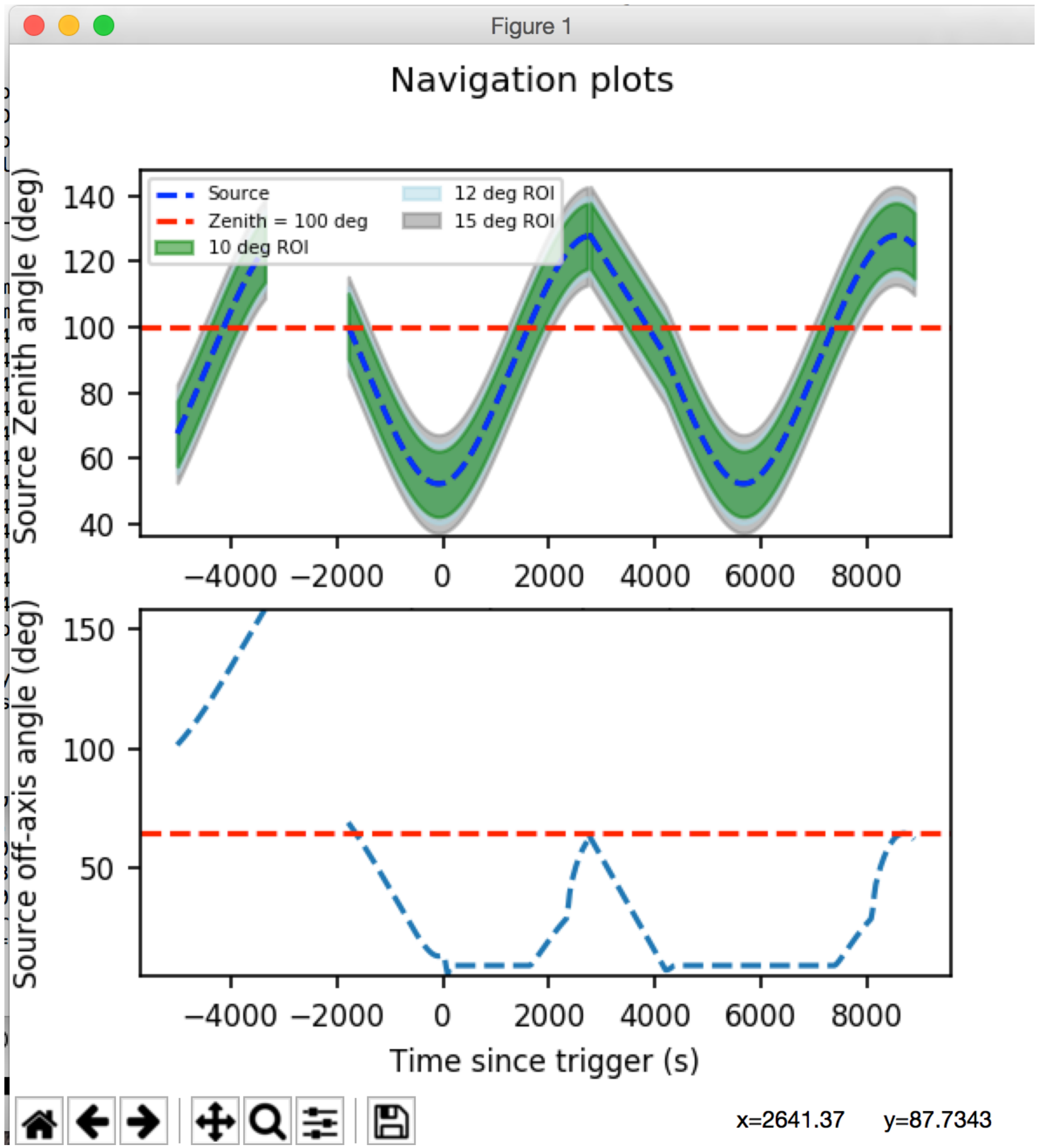
Counts spectrum produced by likeSED along with the spectral points.



Fermi Gamma-ray Space Telescope

Analysis Tutorial – 3
likelihood analysis with gtburst

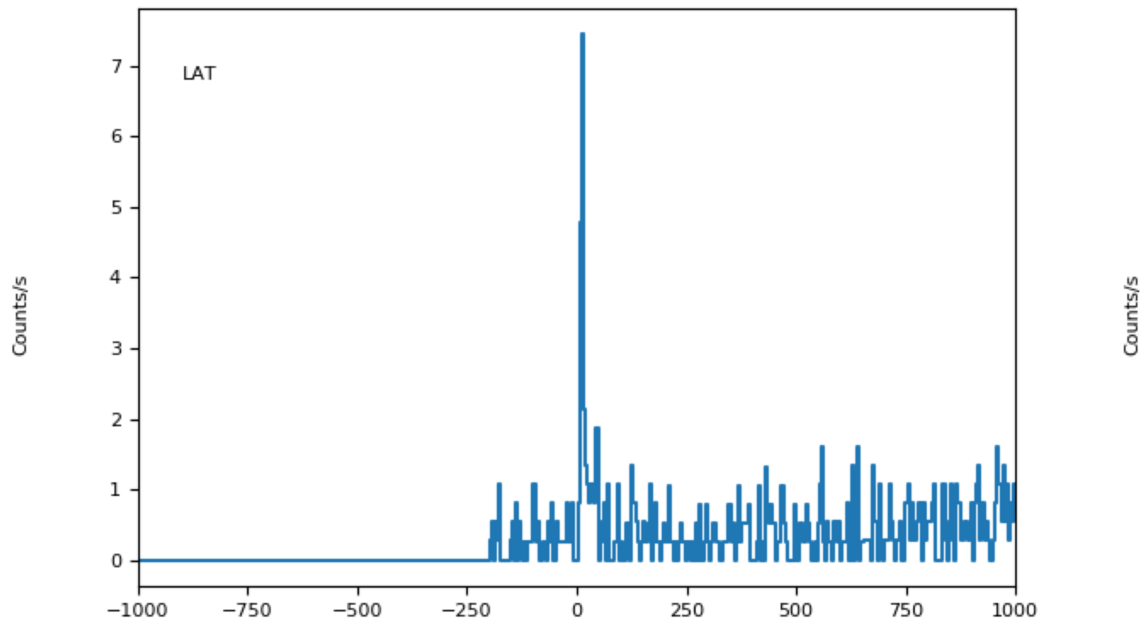
Check the "Navigation" plot



Likelihood with gtburst

Fermi bursts analysis GUI

Trigger name	bn160905471
R.A. (J2000)	162.245
Dec. (J2000)	-50.801
Trigger date (MET)	494767139.912



Detectors to display in the LC:

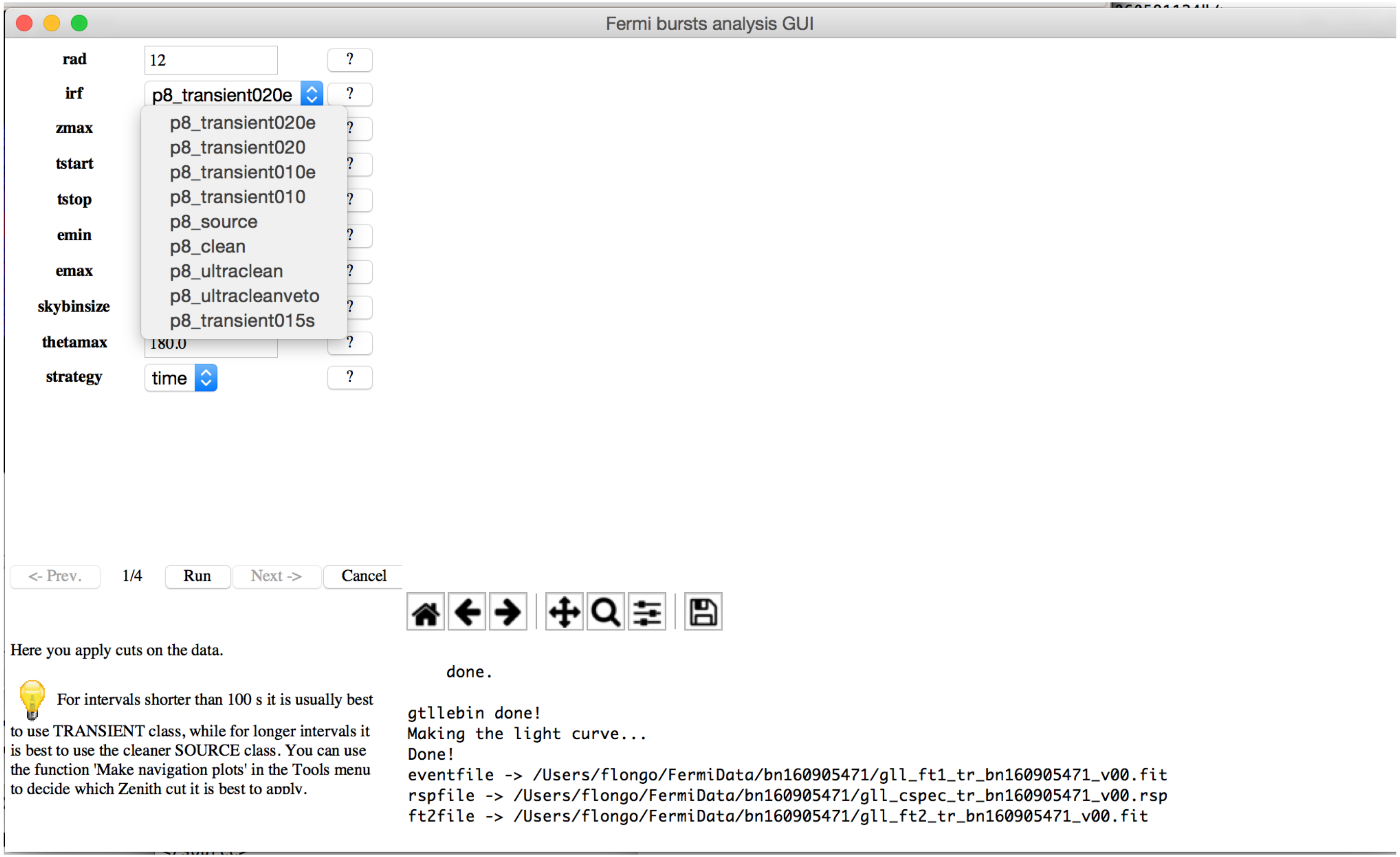
- [x] LAT (16 deg)

Loaded datasets: LAT

You can zoom/pan the light curve using the toolbar at the bottom of the figure. For help on the use of the toolbar, see http://matplotlib.org/users/navigation_toolbar.html

```
    done.

 *  Updating keywords in the headers of the CSPEC file...

    done.

gtllebin done!
Making the light curve...
Done!
```

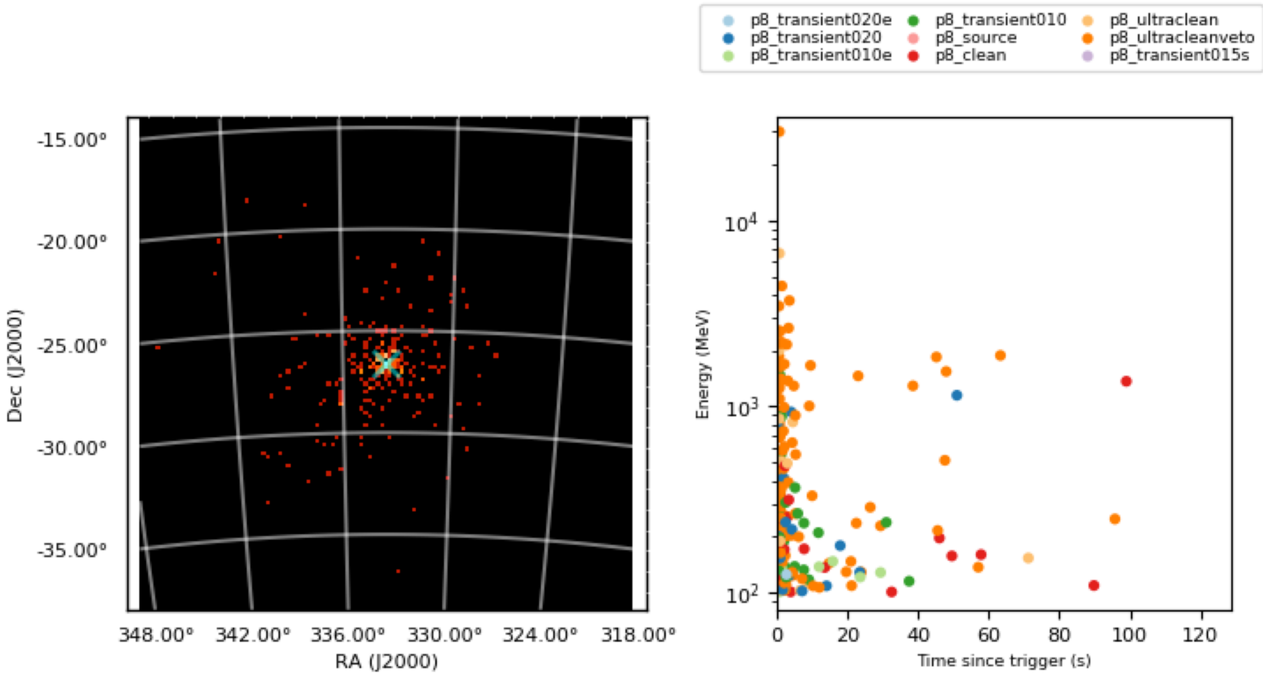
Select event class



See count map and list of photons

rad	12	?
irf	p8_transient020e	?
zmax	100	?
tstart	0	?
tstop	100	?
emin	100	?
emax	100000	?
skybinsize	0.2	?
thetamax	180.0	?
strategy	time	?

<- Prev. 1/4 Run Next -> Cancel



Here you apply cuts on the data.

For intervals shorter than 100 s it is usually best to use TRANSIENT class, while for longer intervals it is best to use the cleaner SOURCE class. You can use the function 'Make navigation plots' in the Tools menu to decide which Zenith cut it is best to apply.

```
Class p8_transient010 only:          47
Class p8_source only:                0
Class p8_clean only:                 32
Class p8_ultraclean only:            19
Class p8_ultracleanveto only:        123
Class p8_transient015s only:         0

 ============================================================
```

Create XML model

Select the parameters of the model

Fermi bursts analysis GUI

Double click on a parameter to change it.

Source Name	Name	Value	Error	Min	Max	Scale	Free	Source Type	Feature	Feature Type	Fe
bn090510016	Integral	0.01		1e-05	1000.0	0.00	1	PointSource	spectrum	PowerLaw2	
bn090510016	Index	-2		-6.0	0.01	1.0	1	PointSource	spectrum	PowerLaw2	
bn090510016	LowerLimit	100		20.0	200000.	1.0	0	PointSource	spectrum	PowerLaw2	
bn090510016	UpperLimit	1e+(		20.0	500000	1.0	0	PointSource	spectrum	PowerLaw2	
bn090510016	RA	333.		-360.	360.0	1.0	0	PointSource	spatialMode	SkyDirFunction	
bn090510016	DEC	-26.(		-90.0	90.0	1.0	0	PointSource	spatialMode	SkyDirFunction	
IsotropicTemplat	Normalizatio	1		0.1	10.0	1	1	DiffuseSourc	spectrum	FileFunction	[..]/iso_P8R2_TRA
IsotropicTemplat	Value	1		0.0	10.0	1.0	0	DiffuseSourc	spatialMode	ConstantValue	
GalacticTemplate	Value	1		0.7	1.3	1.0	1	DiffuseSourc	spectrum	ConstantValue	
GalacticTemplate	Normalizatio	1		0.001	1000.0	1.0	0	DiffuseSourc	spatialMode	MapCubeFunctio	[..]/gll_iem_v06_cu

Done Save

Fit plots

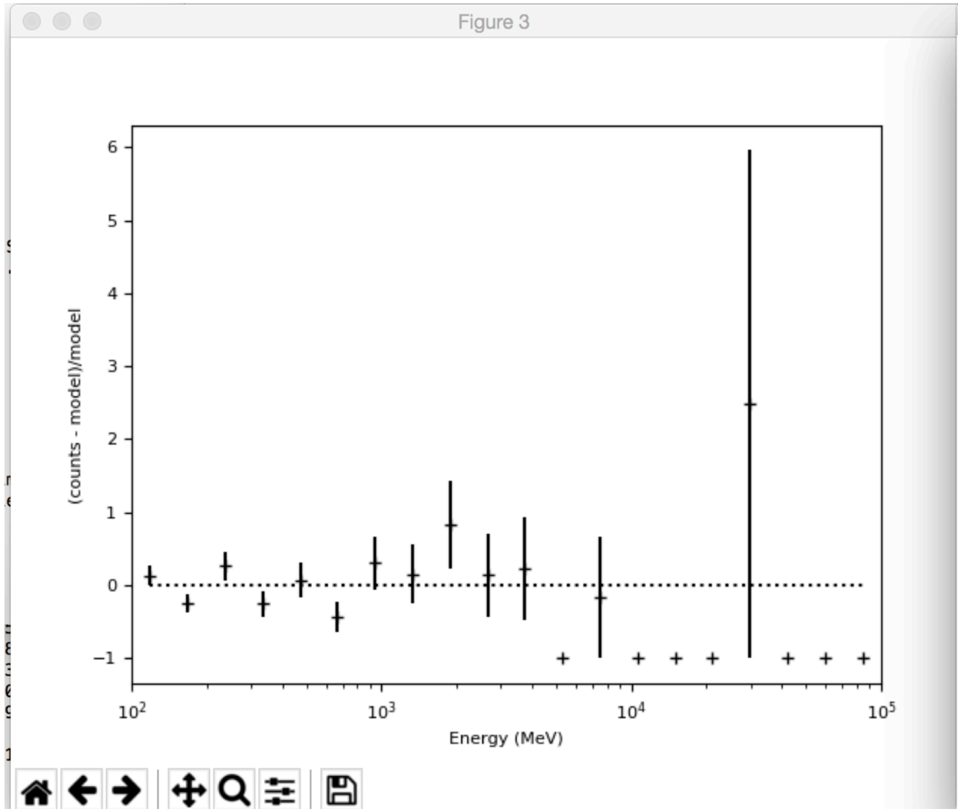


Figure 3
(counts - model)/model
Energy (MeV)

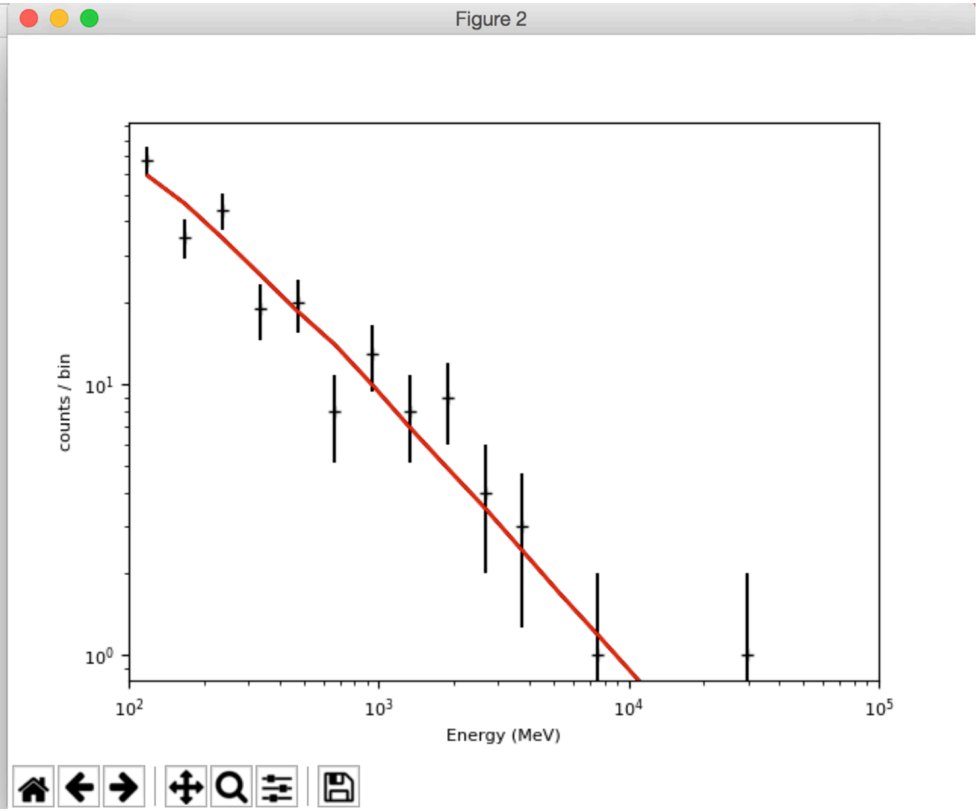


Figure 2
counts / bin
Energy (MeV)

Fit results

Likelihood results

Source name	Par. Name	Value	Error	Units	TS
GalacticTemplate					0
	Value	1	0.15	-	
	Energy flux	2.1e-07	3.14e-08	erg/cm2/s	
	Photon flux	0.000443	6.63e-05	ph./cm2/s	
IsotropicTemplate					1
	Normalization	0.426	1.32	-	
	Energy flux	4.75e-08	1.47e-07	erg/cm2/s	
	Photon flux	0.000134	0.000413	ph./cm2/s	
bn090510016					2056
	Integral	0.000363	2.31e-05	ph./cm2/s	
	Index	-2.03	0.0628	-	
	LowerLimit	100	n.a. (fixed)	MeV	
	UpperLimit	1e+05	n.a. (fixed)	MeV	
	Energy flux	1.33e-07	8.44e-09	erg/cm2/s	
	Photon flux	0.00033	2.2e-05	ph./cm2/s	

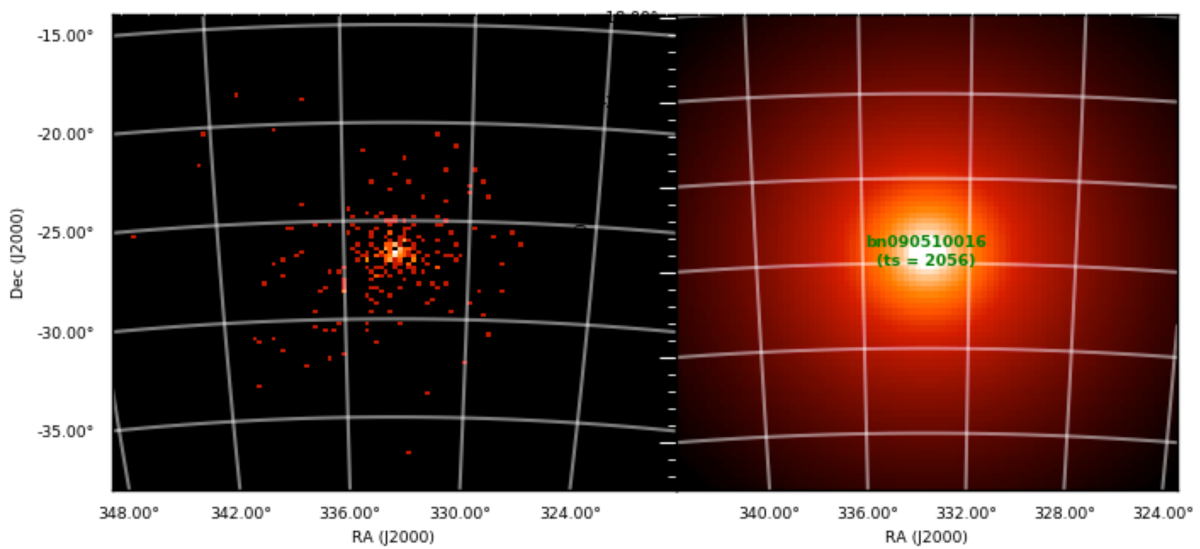
```
*** All fluxes and upper limits have been computed in the 100.0 - 1000.0 energy range.
*** Upper limits (if any) are computed assuming a photon index of -2.0, with the 95.0 % c.l.
Log(likelihood) = 769.199818608

New localization from gtfindsrc:

(R.A., Dec)                     = (333.567, -26.625)
68 % containment radius        =  0.028
90 % containment radius        =  0.040
Distance from initial position  =  0.039
```

Results of the last likelihood analysis. Select 'close' from the file menu to close this window.

Fit results

Fermi bursts analysis GUI

tsmin	20	?
optimizeposition	yes	?
showmodelimage	yes	?
spectralfiles	yes	?
liketype	unbinned	?
clul	0.95	?
flemin	100	?
flemax	1000	?



<- Prev. 4/4 Run Finish! Cancel

Here you will perform a likelihood analysis on the data you selected in the first step, using the model you selected in the 2nd step.

The likelihood analysis should take between 5 and 10 minutes to complete.

```
90 % containment radius        =  0.040
Distance from initial position  =  0.039

NOTE: this new localization WILL NOT be used by default. If you judge it is a better localization than
the one you started with, update the coordinates yourself and re-run the likelihood

 ============================================================
```

New Tools

Fermipy

Fermipy
latest

Search docs

Installation
Quickstart Guide
Configuration
Output File
ROI Optimization and Fitting
Customizing the Model
Developer Notes
Advanced Analysis Methods
Validation Tools
fermipy package
fermipy.jobs subpackage
fermipy.diffuse subpackage
Changelog

Docs » Welcome to Fermipy's documentation!

Edit on GitHub

Welcome to Fermipy's documentation!

Introduction

This is the Fermipy documentation page. Fermipy is a python package that facilitates analysis of data from the Large Area Telescope (LAT) with the Fermi Science Tools. For more information about the Fermi mission and the LAT instrument please refer to the Fermi Science Support Center.

The Fermipy package is built on the pyLikelihood interface of the Fermi Science Tools and provides a set of high-level tools for performing common analysis tasks:

- Data and model preparation with the gt-tools (gtselect, gtmktime, etc.).
- Extracting a spectral energy distribution (SED) of a source.
- Generating TS and residual maps for a region of interest.
- Finding new source candidates.
- Localizing a source or fitting its spatial extension.

https://fermipy.readthedocs.io/en/latest/

Fermi
Gamma-ray Space Telescope

3ML fitting tool

The Multi-Mission Maximum Likelihood framework
latest

Search docs

- Installation
- Intro
- Minimization
- Bayesian Posterior Sampling
- Time-energy fit
- Plugins
- Modeling
- Features
- Tutorials
- Frequently Asked Questions
- API
- threeML

Docs » <no title>

Edit on GitHub

3ML
The Multi-Mission Maximum Likelihood framework

Astrophysical sources are observed by different instruments at different wavelengths with an unprecedented quality. Putting all these data together to form a coherent view, however, is a very difficult task. Indeed, each instrument and data type has its own ad-hoc software and handling procedure, which present steep learning curves and do not talk to each other.

The Multi-Mission Maximum Likelihood framework (3ML) provides a common high-level interface and model definition which allows for an easy, coherent and intuitive modeling of sources using all the available data, no matter their origin. At the same time, thanks to its architecture based on plug-ins, 3ML uses under the hood the official software of each instrument, the only one certified and maintained by the collaboration which built the instrument itself. This guarantees that 3ML is always using the best possible methodology to deal with the data of each instrument.

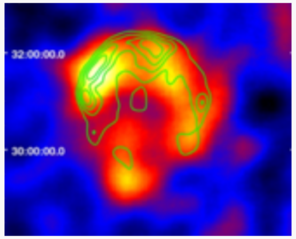
Traditionally the Astrophysics community have been using frequentist techniques, but in recent years Bayesian methods and approaches have been gaining consensum and momentum. In 3ML both analysis are possible. Moreover, the 3ML Python interface allows for combinations with all available packages for data analysis and mining.

Next

https://threeml.readthedocs.io/en/latest/

10 years of Fermi !

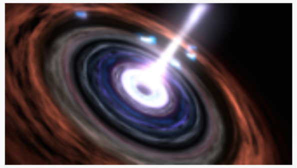
Exploring the Extreme Universe



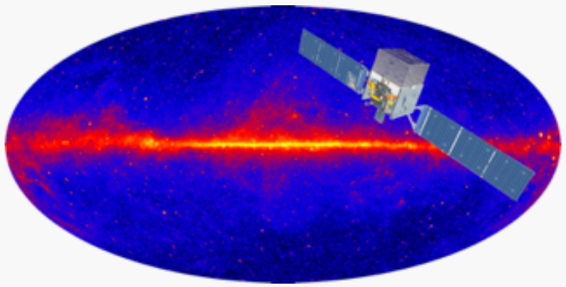
Supernova Remnants

Gamma-ray Bursts

Pulsar Wind Nebulae



Active Galactic Nuclei



About Fermi

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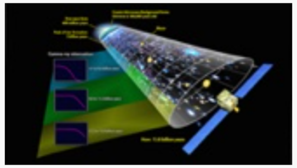
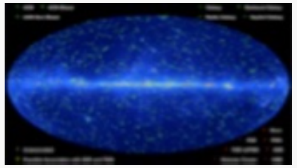
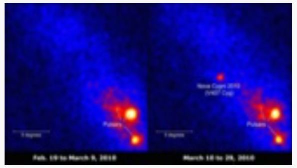


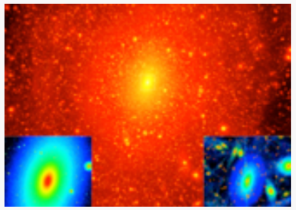
Extragalactic Background



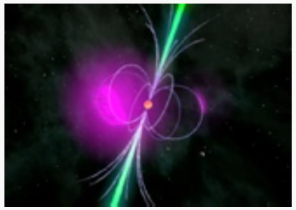
Catalogs



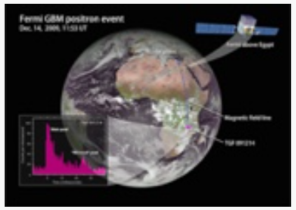
Binary Sources



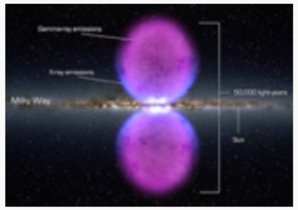
Dark Matter



Pulsars

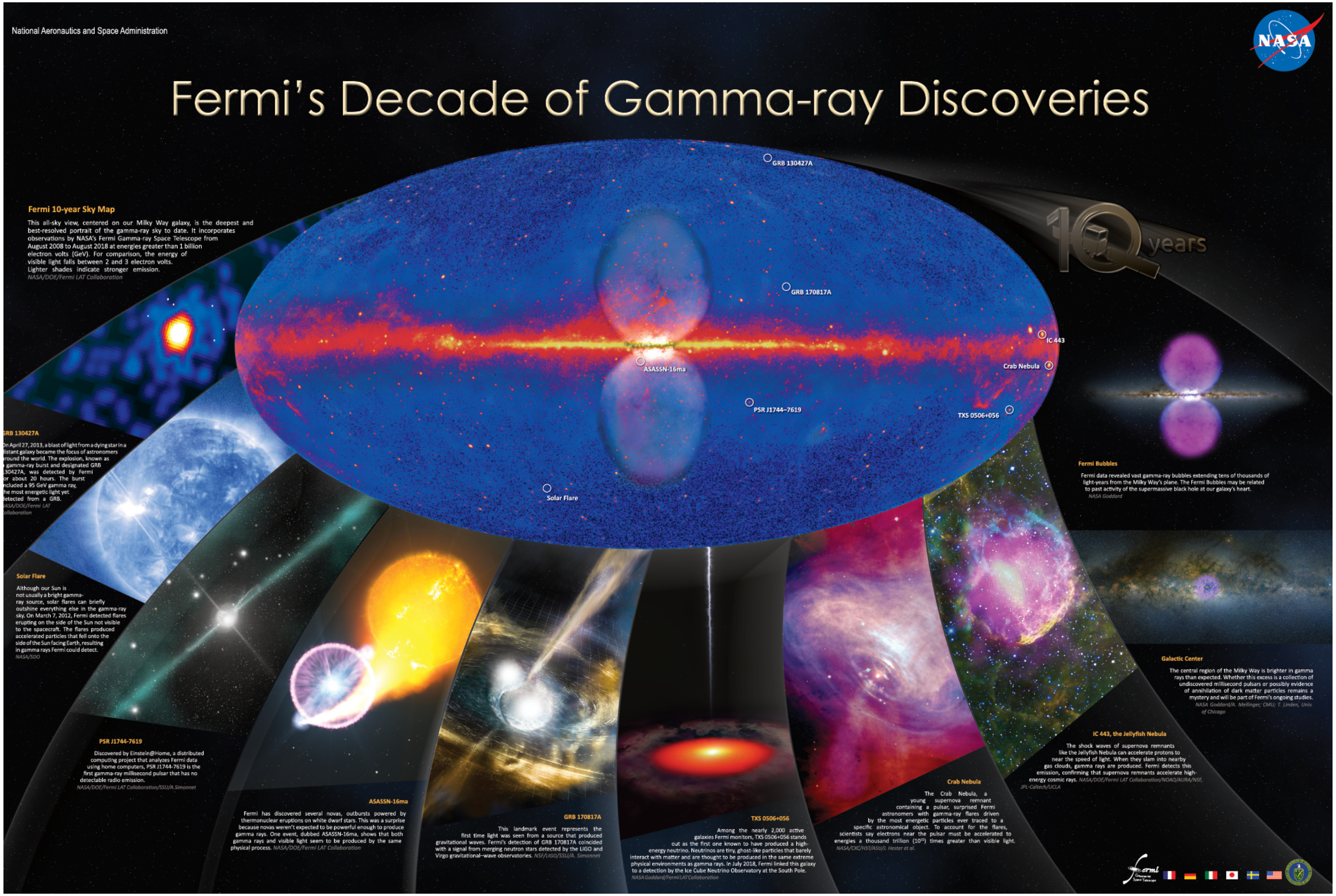


Terrestrial Gamma-ray Flashes

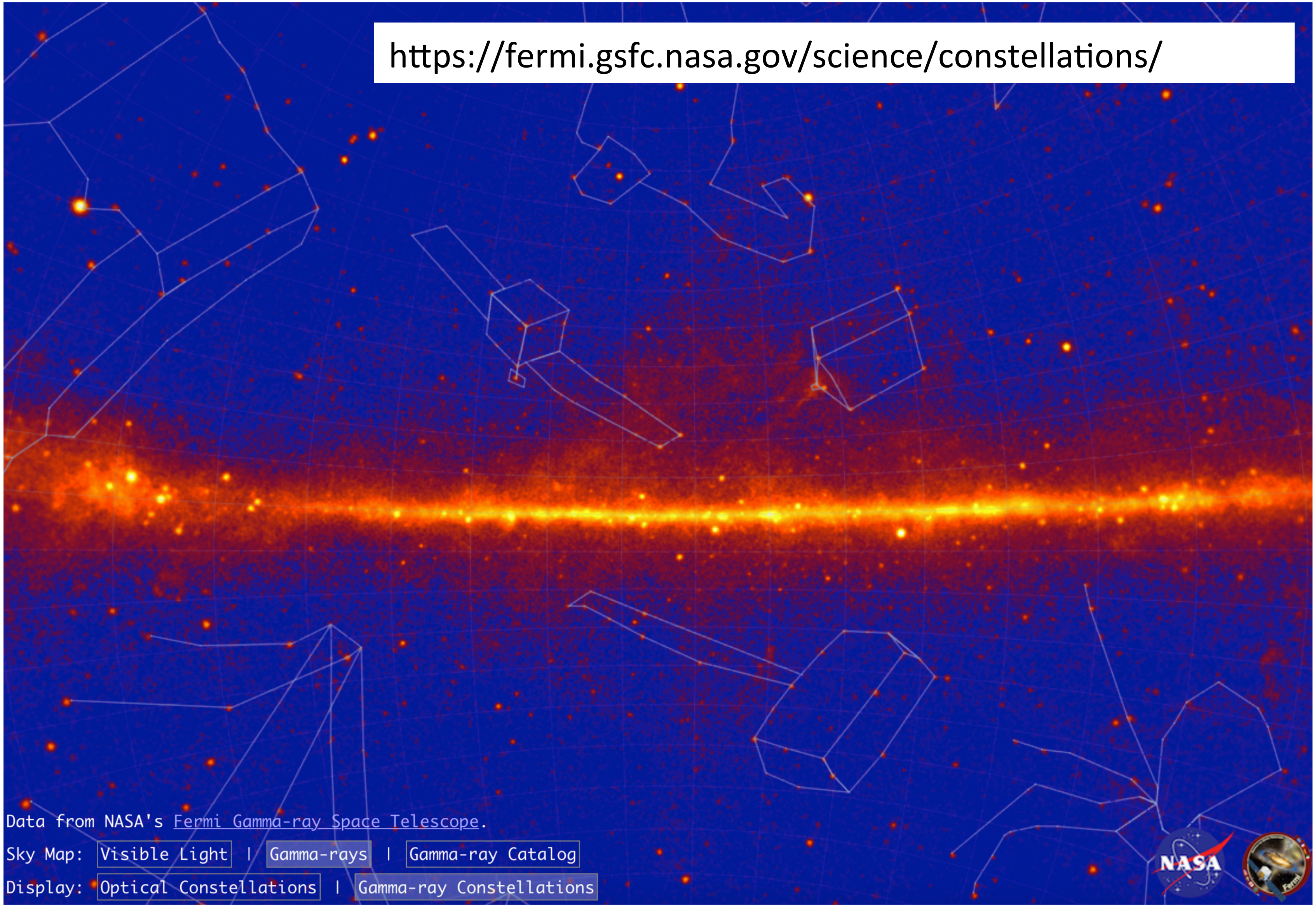


Diffuse Gamma Radiation

10 years of Fermi !



Have Fun !


https://fermi.gsfc.nasa.gov/science/constellations/
Data from NASA's Fermi Gamma-ray Space Telescope.
Sky Map: Visible Light | Gamma-rays | Gamma-ray Catalog
Display: Optical Constellations | Gamma-ray Constellations


Fermi