Fermi Gamma-ray Space Telescope

Overview of Pass 8 and Fermi Event Analysis

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What is Pass 8?

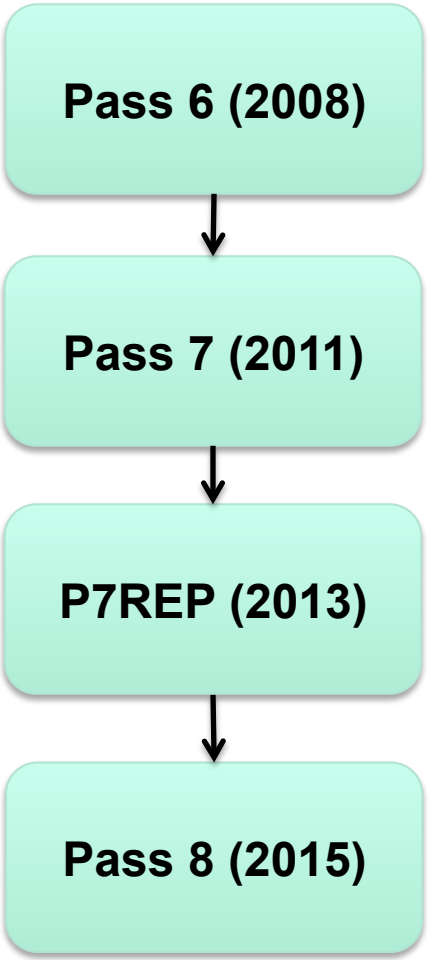
- Each Pass corresponds to a specific version of the LAT data, software, and models
  - Instrument Simulation
  - Reconstruction Software
  - Instrument Response Functions
  - Diffuse Models (Galactic IEM, Isotropic, etc.)

- Over the course of the mission the LAT team has released several Passes as understanding of the instrument has improved and more sensitive algorithms for event analysis and reconstruction are developed

- Pass 8 is the most recent iteration in this process and represents the most comprehensive update since launch in 2008

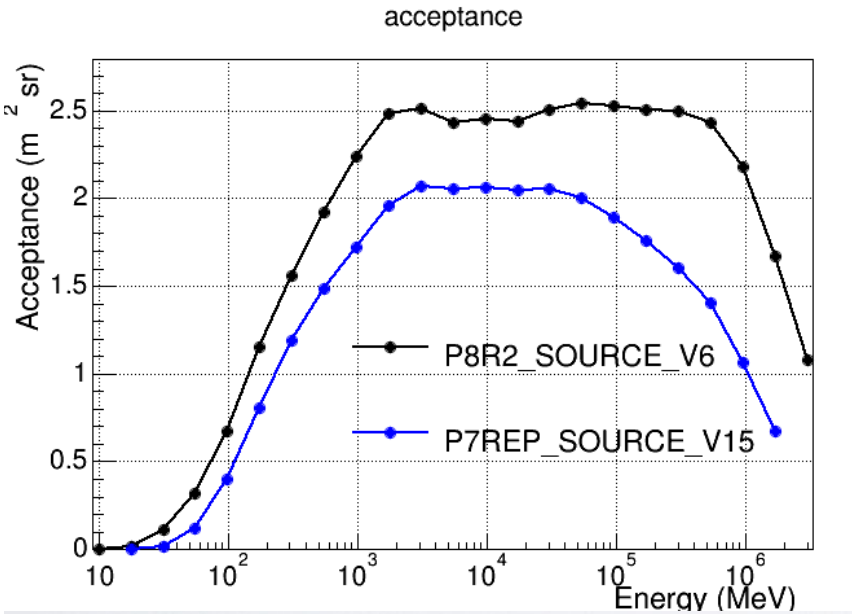
Timeline of LAT Passes

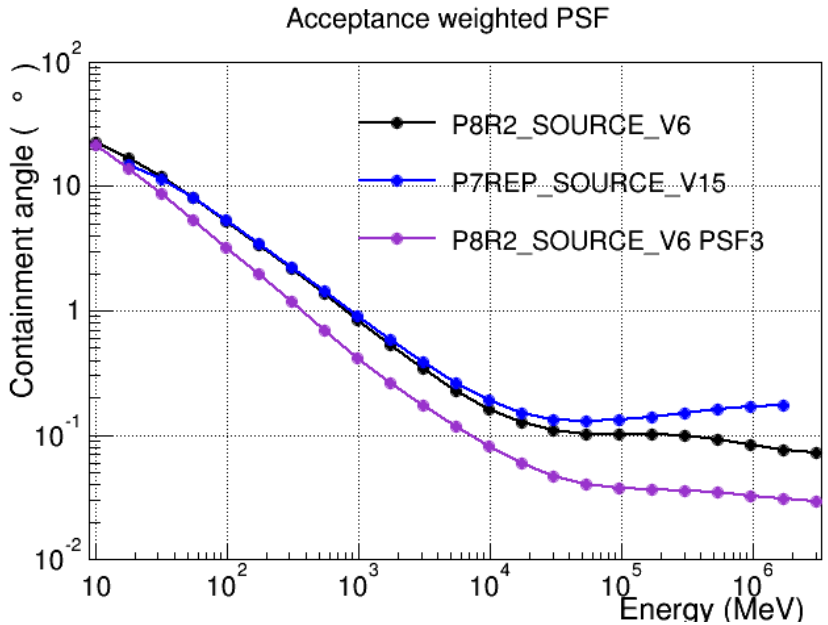
- **Pass 6**: Event analysis developed prior to launch and based primarily on MC models of the instrument performance. Later versions included updates to the instrument simulation to account for the effect of ghosts.
- **Pass 7**: Same reconstruction as Pass 6 but with selections optimized to take into account ghosts.
- **Pass 7 Reprocessed (P7REP)**: Improvements to instrument calibration which adjusted energy scale and improved PSF at high energies
- **Pass 8**: Complete revision of entire event analysis chain from reconstruction to classification



What did we gain with Pass 8?

- 30-40% increase in point-source sensitivity at 1-10 GeV
- Up to 2x gain in acceptance at very low (< 100 MeV) and very high (> 100 GeV) energies
- New event selections (PSF and EDISP types) that provide a more refined classification of events by their reconstruction quality

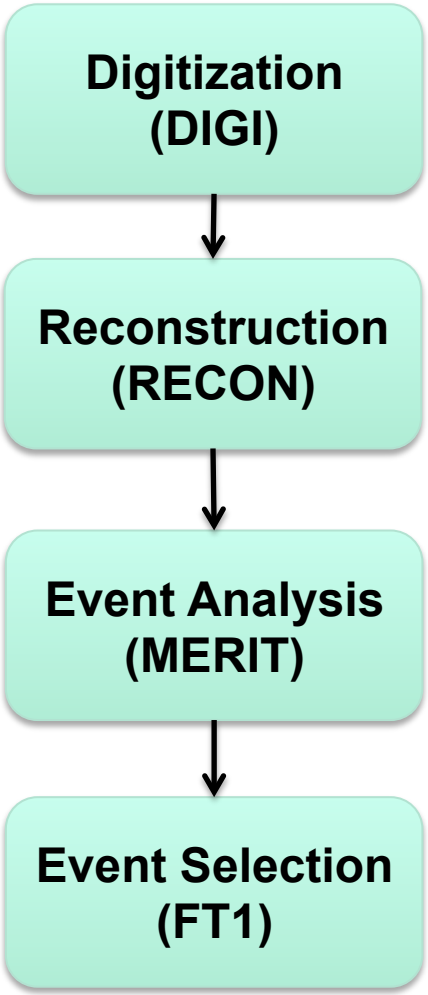




LAT Performance Plots:
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Stages of the LAT Data Reconstruction

- LAT Reconstruction involves several processing stages progressing from raw instrument level quantities (DIGI) to high-level photon lists (FT1)
- The most computationally intensive of these steps is the event reconstruction (track-finding, clustering, etc.)
- The rest of this talk will focus on the last two steps
  - Event Analysis
  - Event Selection



Event Analysis

- The LAT Event Analysis distills the 1000+ variables computed in the event reconstruction stage into a set of ~20 variables that are used to define the event selections

- The primary tool of the event analysis are Classification Trees (CTs) which are applied to the quantities computed in the event reconstruction

- For Pass 8 all CTs are trained with TMVA using the Boosted Decision Tree (BDT) classification algorithm
  - Training data sets are drawn from large MC productions of gamma-rays and on-orbit particle backgrounds
  - Each CT uses a set of 20-30 input variables
  - CT Response variables are saved to the ROOT event tree; some are also available in the Extended FT1 file

- CTs are used for two primary purposes
  - Classifying how likely an event is to be background
  - Characterizing the quality of the event reconstruction (direction and energy)

Elements of an Event Class

- After running the event analysis stage we use a set of selections to define **event classes**

- Pass 8 event classes are composed of three types of cuts
  - **Fiducial:** Basic geometric selections on the event trajectory through the LAT
  - **Background Rejection:** Selections to remove background (CR or back-entering gamma rays)
  - **Quality:** Selections to remove poorly reconstructed events

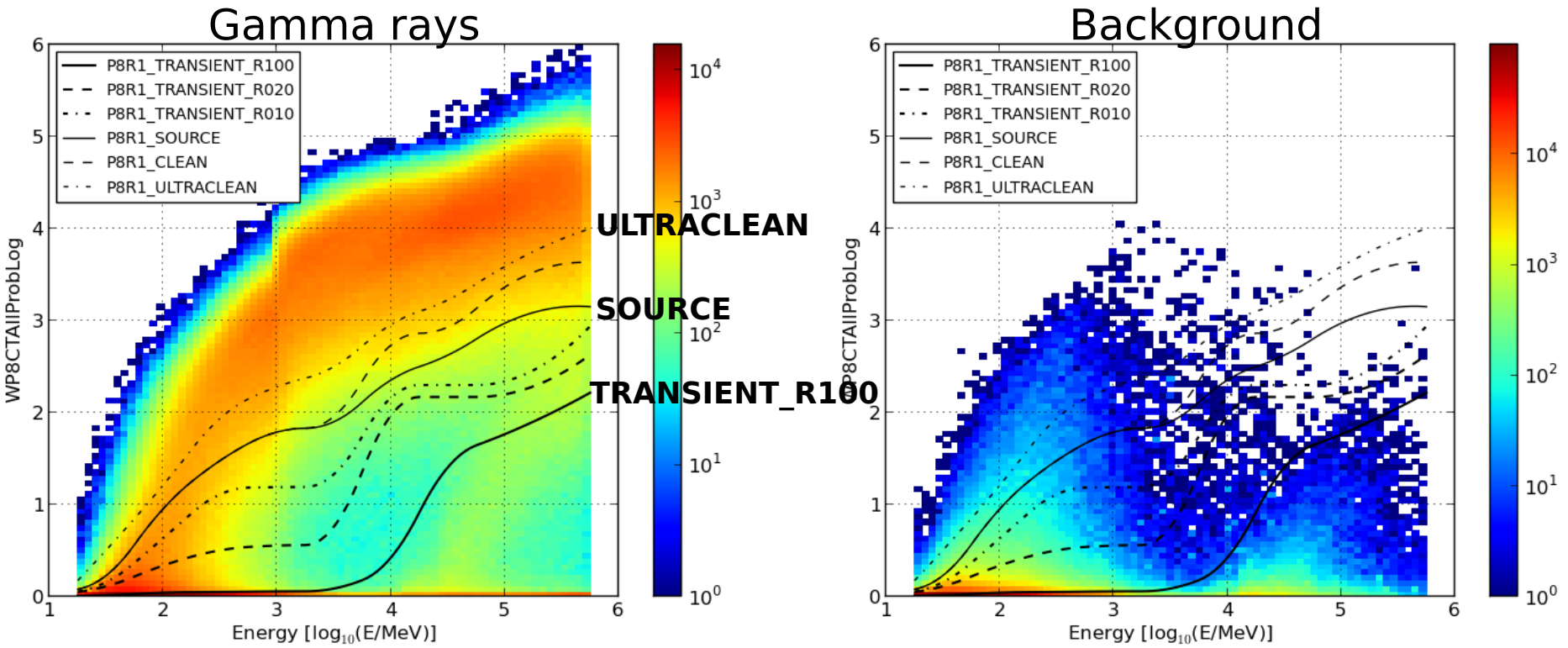
- Pass 8 classes are organized in three **hierarchies** that define a nested sequence of selections – most analyses can use the **Standard** class hierarchy

Pass 8 Event Classes

- LAT event classes are primarily characterized by their level of background contamination with respect to the IGRB (the irreducible gamma-ray background)

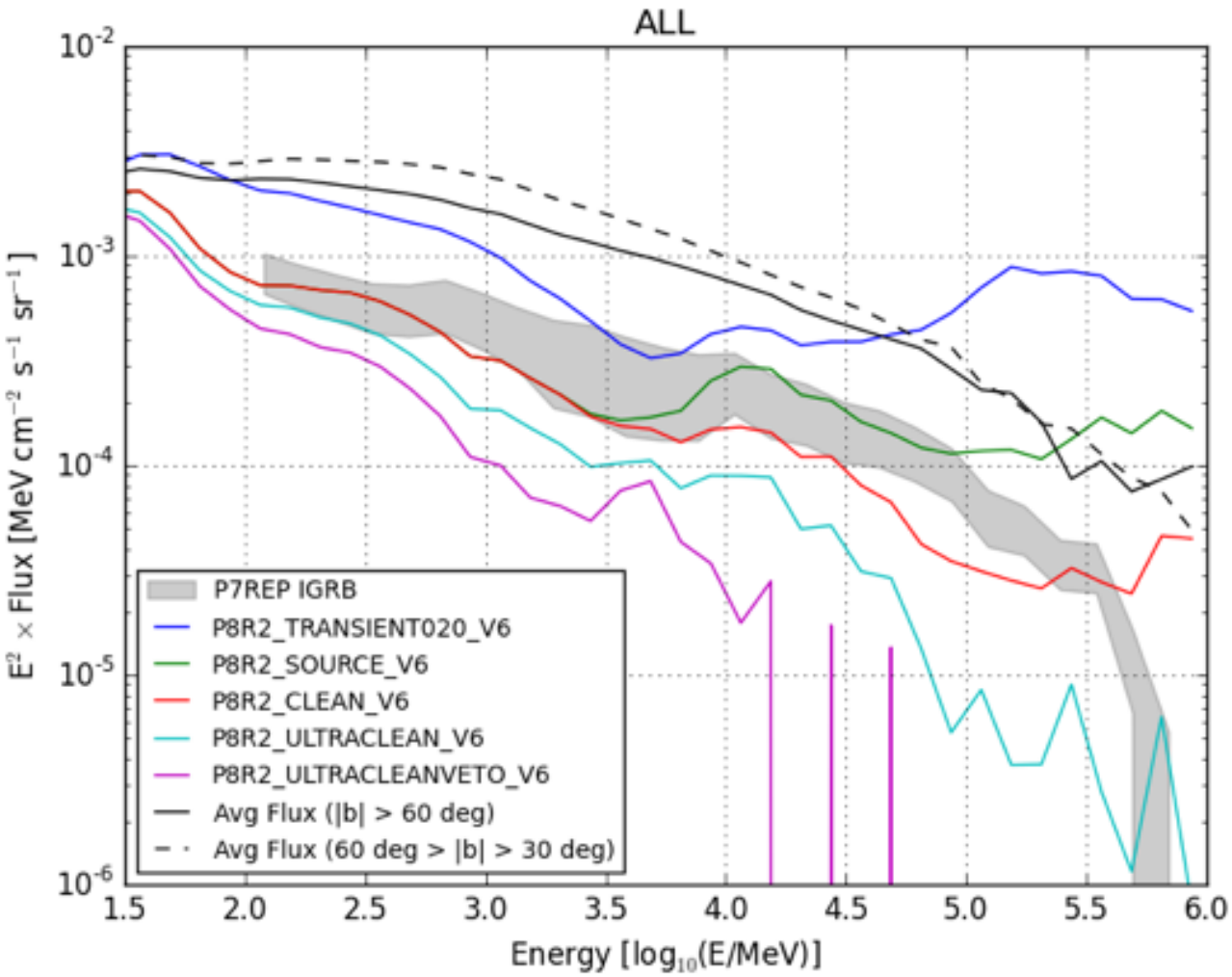
- Optimal background level depends on timescale and source morphology
  - **Point Source on Short Timescales (< 1000 s)**: Relaxed background requirement due to rejection factor from both time and spatial selections
  - **Point Source on Medium-Long Timescales (> 1000 s):** More stringent background requirements due to longer integration times
  - **Diffuse:** No time or spatial selection; potentially more sensitive to systematics induced by residual CRs
  - **IGRB:** Most stringent background requirements

Background Rejection



WP8CTAllProb is the primary CT variable used for background rejection
Energy-dependent cut on this variable is used to maintain a certain level of background vs. energy

Pass 8 Background Levels



Pass 8 Event Classes

	Class Name	Class Bit	Fiducial Selection	Description
Transients and Source Analysis at low Galactic Latitudes	**TRANSIENT100A**	0	AllTkr	Minimum Bias Selection
	TRANSIENT100E	1	TkrOnly	10x P6 IGRB w/ TkrOnly Events
	TRANSIENT100	2	CalTkr	10x P6 IGRB
	TRANSIENT020E	3	TkrOnly	2x P6 IGRB w/ TkrOnly Events
	TRANSIENT020	4	CalTkr	2x P6 IGRB
	TRANSIENT010E	5	TkrOnly	1x P6 IGRB w/ TkrOnly Events
	TRANSIENT010	6	CalTkr	1x P6 IGRB
Source/Diffuse Analysis	SOURCE	7	CalTkr	Point-Source Analysis
	CLEAN	8	CalTkr	Diffuse Analysis
	ULTRACLEAN	9	CalTkr	Diffuse/EGB Analysis
	ULTRACLEANVETO	10	CalTkr	Diffuse/EGB Analysis
Solar Flare	**TRANSIENT100S**	15	CalTkr	Prompt Solar Flare Analysis
	TRANSIENT015S	16	CalTkr	

Extended Files **Not available in public data products**

Additional Documentation:
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Data/LAT_DP.html

Pass 8 Event Classes (Standard Hierarchy)

	Class Name	Class Bit	Fiducial Selection	Description
Transients and Source Analysis at low Galactic Latitudes	**TRANSIENT020**	4	CalTkr	2x P6 IGRB
	TRANSIENT010	6	CalTkr	1x P6 IGRB
Source/Diffuse Analysis	SOURCE	7	CalTkr	Point-Source Analysis
	CLEAN	8	CalTkr	Diffuse Analysis
	ULTRACLEAN	9	CalTkr	Diffuse/EGB Analysis
	ULTRACLEANVETO	10	CalTkr	Diffuse/EGB Analysis

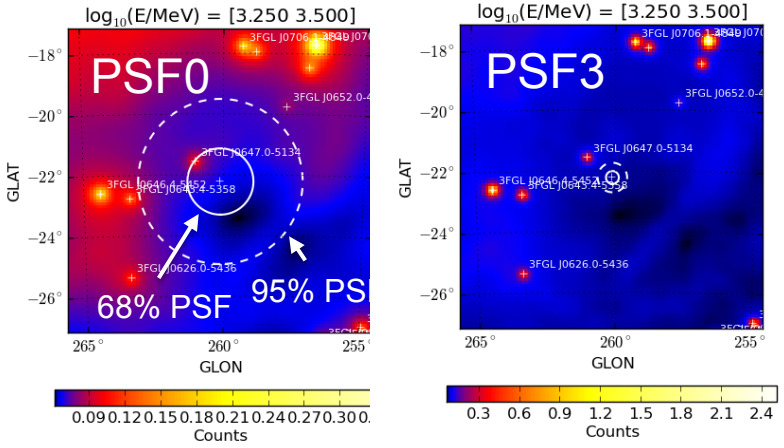
Extended Files

Additional Documentation:
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Data/LAT_DP.html

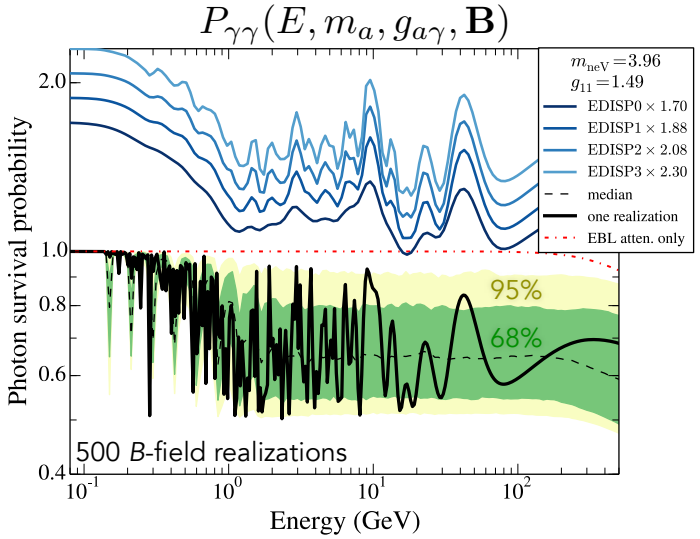
Event Types

- Event types partition events within a class according to certain characteristics such as reconstruction quality
- Pass 8 defines three event type partitions that define mutually exclusive subdivisions of the events within a class
  - **Conversion Type:** Conversion layer of first track (Front or Back); also available in all previous passes
  - **PSF Types:** Four quartiles (PSF0 to PSF3) for the PSF quality using WP8CTPSFCore
  - **EDISP Types:** Four quartiles (EDISP0 to EDISP3) for energy reconstruction quality using WP8BestEnergyProb
- Event types can be used individually or in a joint likelihood (optimal method)

dSph DM Analysis

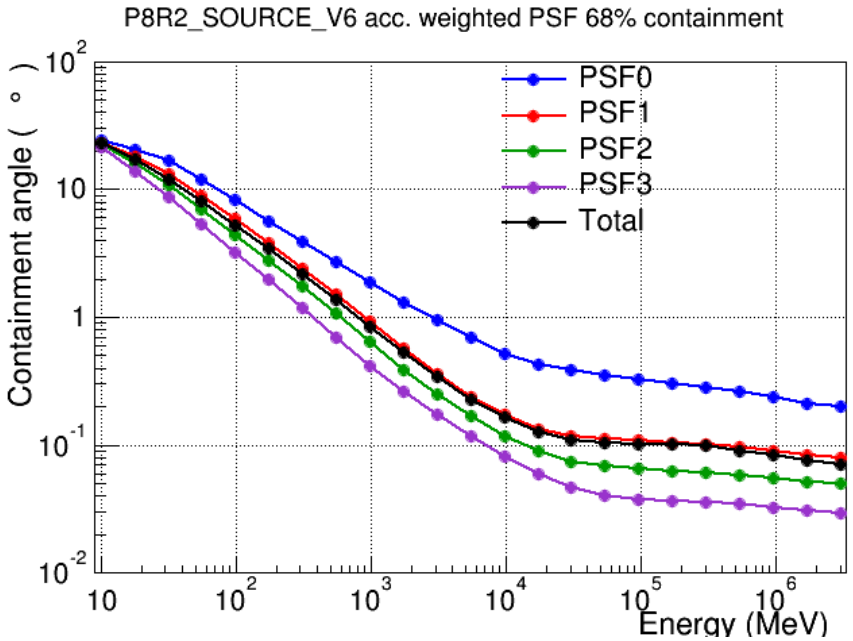


ALP Search in NGC1275

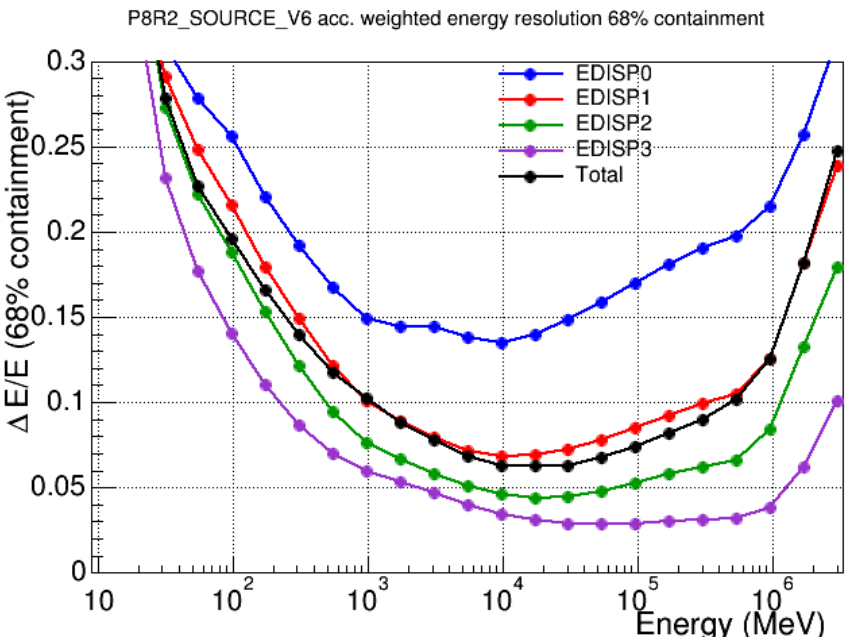


Event Type Performance

PSF Types



EDISP Types



Pass 8 Event Types

Subclass Name	Event Type Bit	evtype argument	Description
FRONT	0	1	Front-converting
BACK	1	2	Back-converting
PSF0	2	4	0-25 % Quantile of WP8CTPSFCore
PSF1	3	8	25-50 % Quantile of WP8CTPSFCore
PSF2	4	16	50-75 % Quantile of WP8CTPSFCore
PSF3	5	32	75-100 % Quantile of WP8CTPSFCore
EDISP0	6	64	0-25 % Quantile of WP8CTBestEnergyProb
EDISP1	7	128	25-50 % Quantile of WP8CTBestEnergyProb
EDISP2	8	256	50-75 % Quantile of WP8CTBestEnergyProb
EDISP3	9	512	75-100 % Quantile of WP8CTBestEnergyProb

Fermi STs also support superposition of multiple types within a partition (e.g. evtype=48 for PSF2&&PSF3) **Note**: Information about cross-membership among partitions is not available (i.e. no IRF exists for PSF0 && EDISP0)

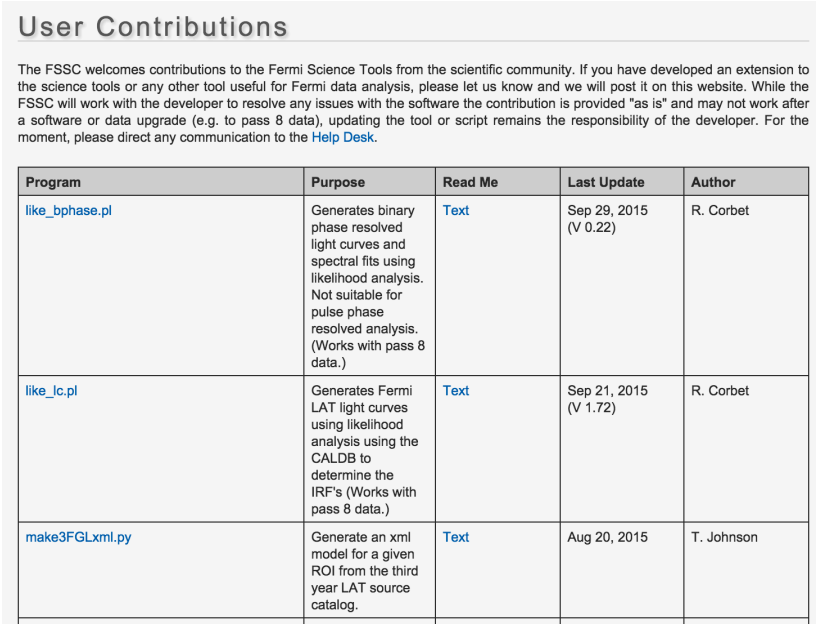
Python tools for LAT Data Analysis

- LAT Science Tools can naturally be used in a python analysis framework through the pyLikelihood interface (SWIG wrapper to underlying C++ libraries)

- Many tools exist for extending or automating different aspects of STs analysis
  - enrico
  - LATAnalysisScripts
  - make3FGLxml
  - many others…

- **fermiPy** is a new python package that was specifically designed to support some of the new functionality available in Pass 8

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



User Contributions

The FSSC welcomes contributions to the Fermi Science Tools from the scientific community. If you have developed an extension to the science tools or any other tool useful for Fermi data analysis, please let us know and we will post it on this website. While the FSSC will work with the developer to resolve any issues with the software the contribution is provided "as is" and may not work after a software or data upgrade (e.g. to pass 8 data), updating the tool or script remains the responsibility of the developer. For the moment, please direct any communication to the Help Desk.

Program	Purpose	Read Me	Last Update	Author
like_bphase.pl	Generates binary phase resolved light curves and spectral fits using likelihood analysis. Not suitable for pulse phase resolved analysis. (Works with pass 8 data.)	Text	Sep 29, 2015 (V 0.22)	R. Corbet
like_lc.pl	Generates Fermi LAT light curves using likelihood analysis using the CALDB to determine the IRF's (Works with pass 8 data.)	Text	Sep 21, 2015 (V 1.72)	R. Corbet
make3FGLxml.py	Generate an xml model for a given ROI from the third year LAT source catalog.	Text	Aug 20, 2015	T. Johnson

fermiPy

- Goals of fermiPy
  - Provide a flexible and general framework for joint likelihood analysis
  - Modular and extensible with emphasis on providing classes that can be easily integrated into existing python analysis scripts
  - Speed-up certain operations that are currently very slow in the framework of the STs (extension fitting, TS maps, etc.)

- Project is still in the development/testing phase but many features are already available
  - SEDs
  - Extension Fitting

- More information:
  - **Documentation**: http://fermipy.readthedocs.org/en/latest/index.html
  - **GitHub**: https://github.com/fermiPy/fermipy

- Full walkthrough with basic analysis examples will be provided in the tutorial session