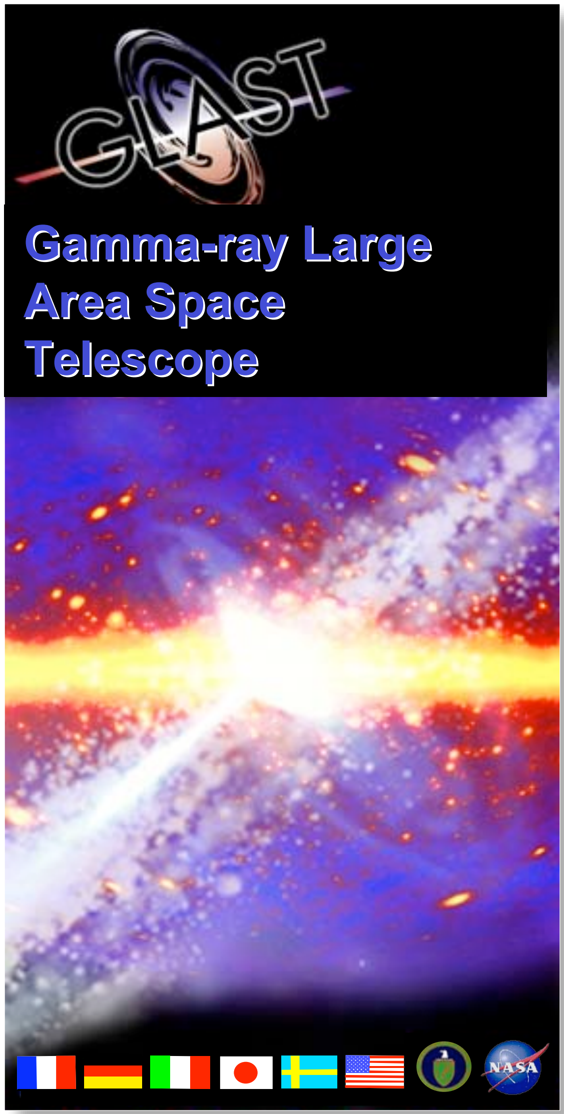


GLAST Large Area Telescope

LAT Science Working Group Review

Event Analysis & Performance

Bill Atwood

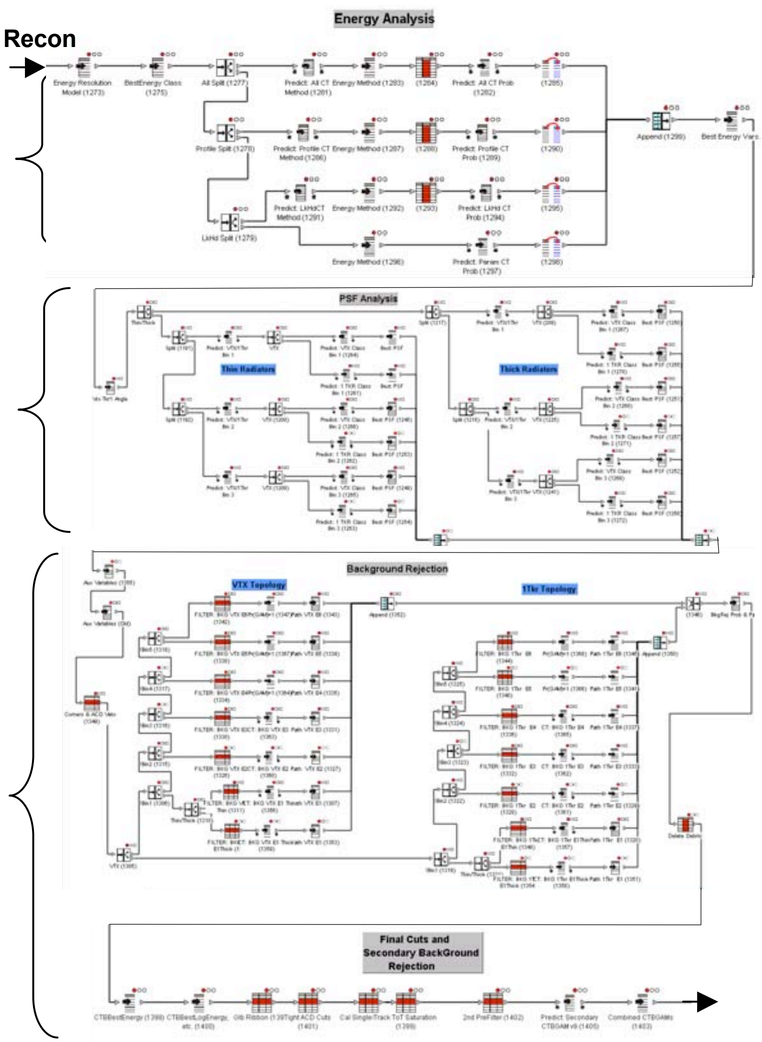
Event Analysis

- **Enormous data sets generated**
  - Backgrounds: >5 billion events, sampling orbit variations
  - Performance sample (All-Gamma) & Diffuse: > 30 million events
- **LAT Simulations provides detailed information each event.**
  - Allows significant improvements in energy reconstruction and resolution
  - In imaging ability (PSF)
  - In the trade of A_{eff} vs Background Contamination
- **Performance**
  - Performance is as much a function of Analysis Choices as hardware performance. Many "knobs" to turn. Analysis choices will be different for different science topic optimization.
  - Results shown here are for a baseline set of choices that generally represent the most challenging cases.

BIG PICTURE: 4 Stages of Post-Recon Event Analysis

- **Energy reconstruction selection**
  - select best energy method (among 3)
- **PSF- Image control**
  - select best gamma direction
- **Background Rejection**
  - (a) Divide events into catagories: Topology, Energy, and Location
  - (b) Develop cuts followed by Classification Tree eval. yielding a Bkg. Probability
  - (c) Global cuts and an additional global Classification Tree

Input: Recon



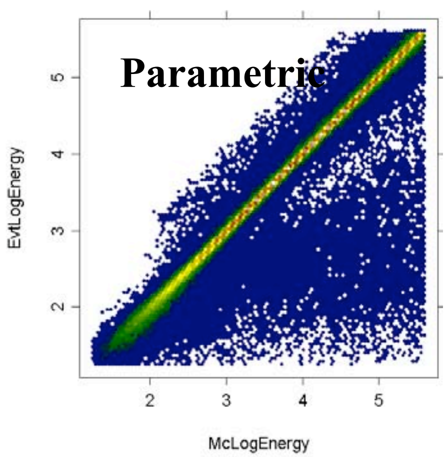
Output: GlastClassier

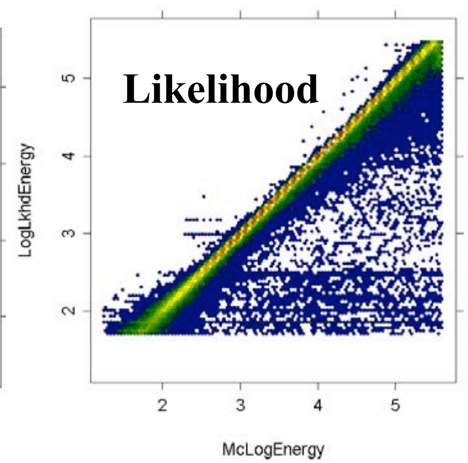
Tag – GR_v9r10

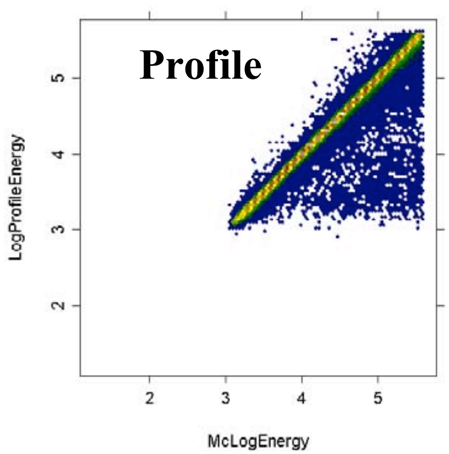
Energy Selection

3 Methods

2 Cover only a part of Glast Phase Space







Best Method selected by direct comparison against each (provided each is reporting an energy)

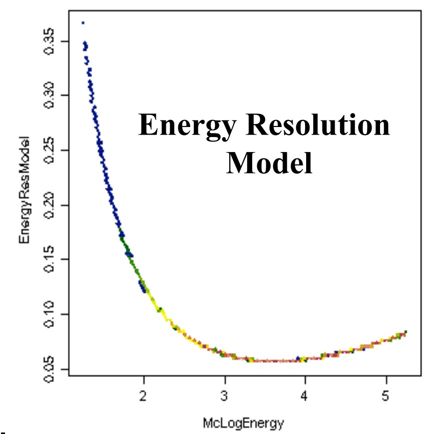
Method	% Computed	% Best Est.
Parametric	100	48.4
Profile	62.7	30.1
Likelihood	56.6	20.6

Only Parametric Available: 16.2%
This tends to be the Local Land Fill (City Dump!)
Unfortunately there are too many events here to simply throw out.

Compare each Method against a "standard" defining:

$$Good \equiv \frac{\Delta E}{E_{MC}} \leq N \cdot \sigma_{Model}$$

CTBBestEnergyProb
Taken a probability to
Exceed resolution model

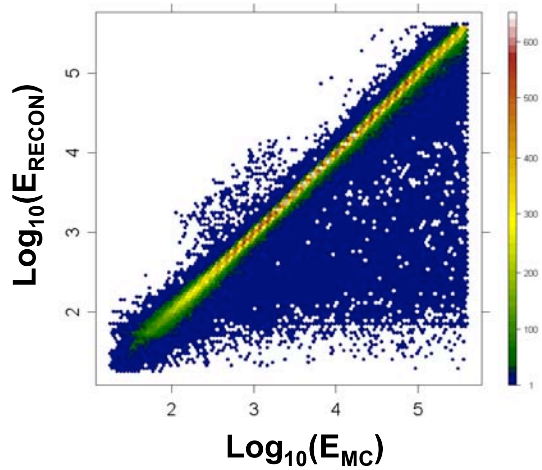


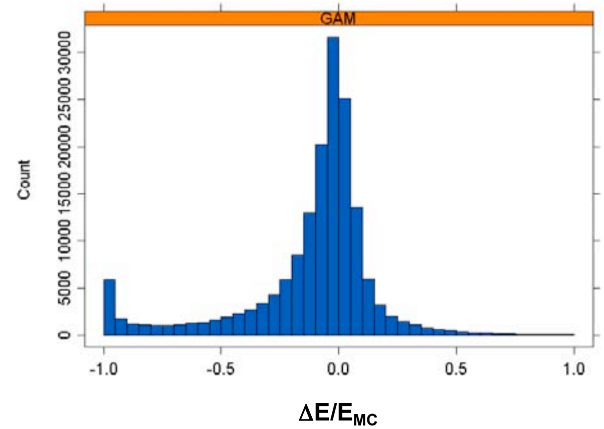
$\sigma_{Model} = .02+.6/(McLogEnergy)^{2.5} + .005*(McLogEnergy-2.)^2$

Energy Resolution Knob

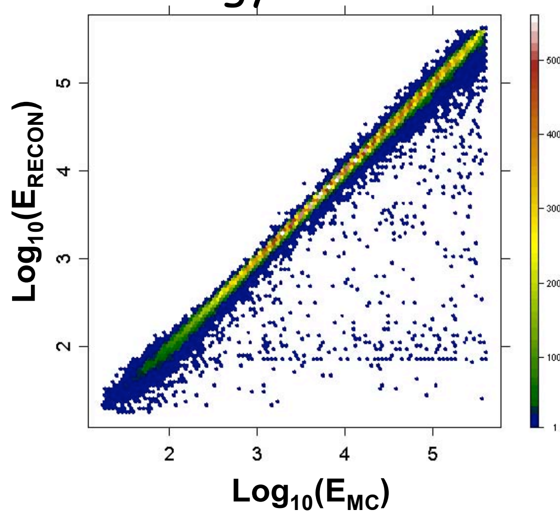
Requiring increasing probability that energy was well-reconstructed reduces both high side and low side tails while lowering the peak by 30%.

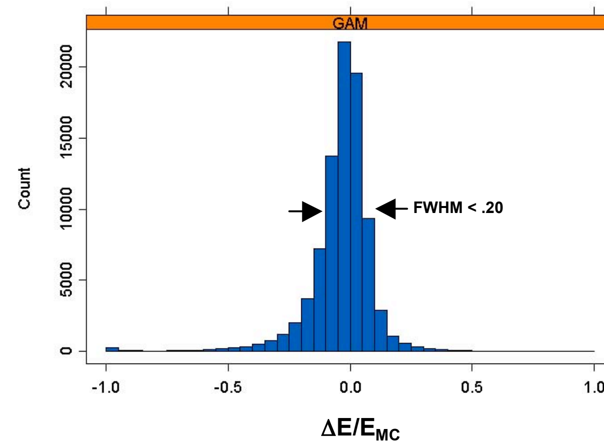
Energy Prob > 0.





Energy Prob > .65



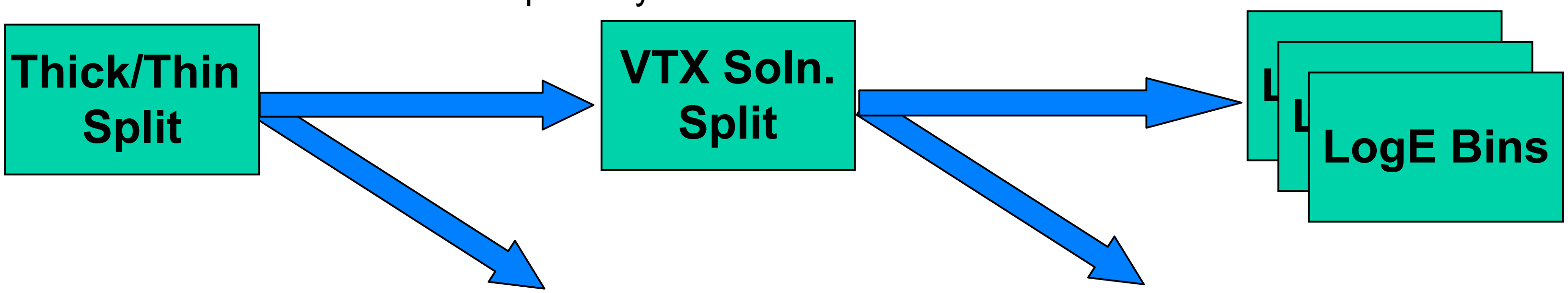


PSF Analysis

GLAST has 2 different Pair Conversion Radiator thickness and hence 2 separate PSFs.

Many events particularly below 1 Gev have a good vertexed solution as well as a "best track" solution. These are evaluated separately.

The event characteristics change significantly over the large energy range of GLAST (~ 4 orders of magnitude).



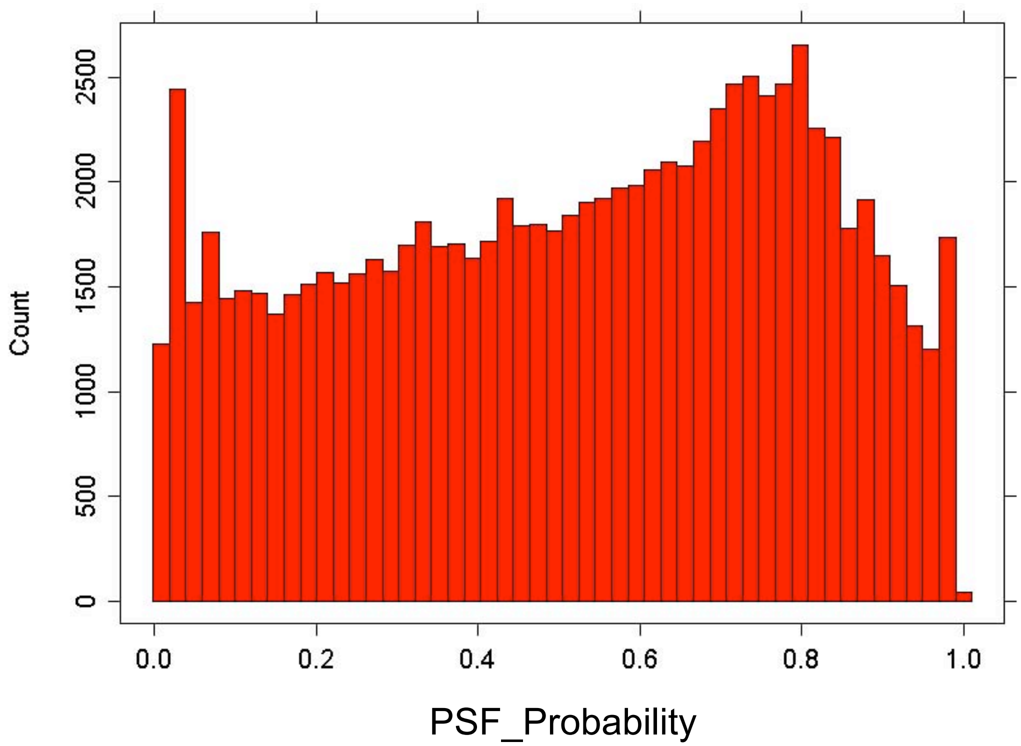
Total of 12 paths with 14 Classification Trees to

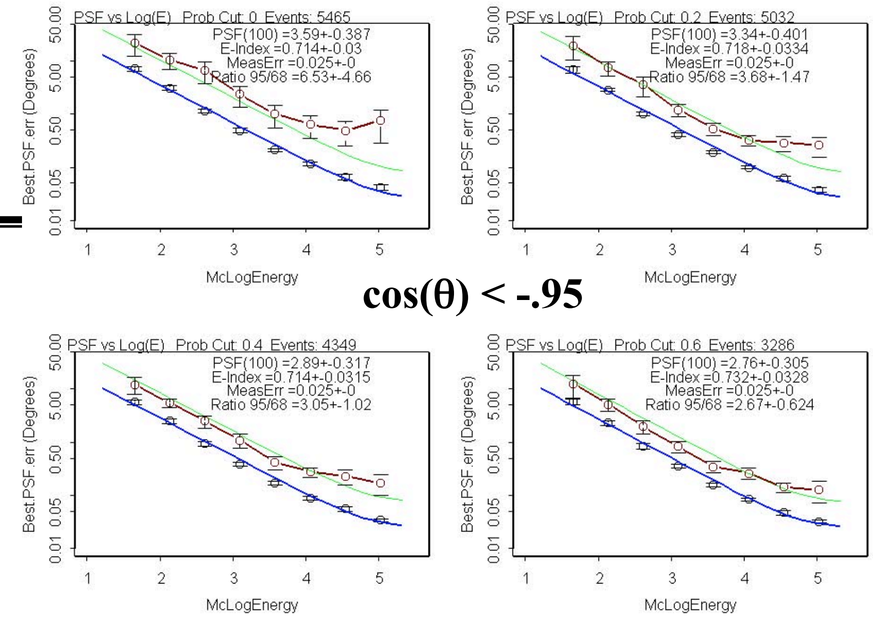
1) Decide on whether or not to use the VTX solution
2) To yield a probability that the track was well measured

PSF Analysis Results

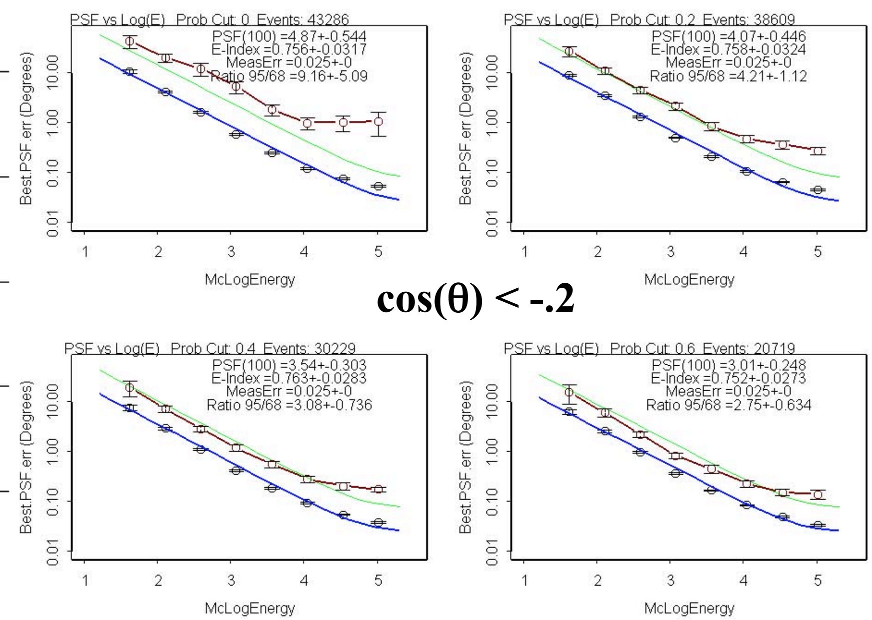
What PSF_Probability Does

- On Axis can vary PSF by ~ 30%
  (at the expense of A_{eff})
- The 95/68 Ratio improves significantly





$\cos(\theta) < -.95$



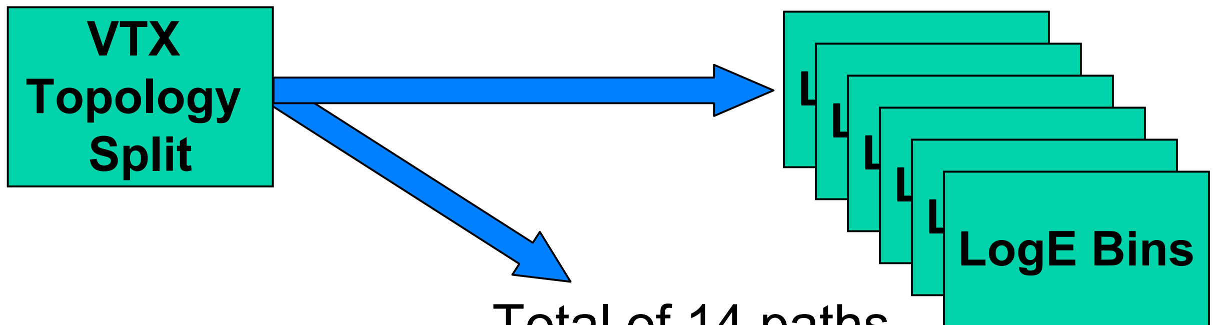
$\cos(\theta) < -.2$

Background Rejection Analysis

Stage 1

The topological signature of a "V" reduces the backgrounds by an order of magnitude. These events are handled independently.

The event characteristics change significantly over the large energy range of GLAST (~ 4 orders of magnitude). Events are divided into 6 bins in energy



Total of 14 paths

1) Lowest energy bin further divided into Thin and Thick Layers
2) Each path has a set of "hard cuts" followed by a Classification Tree yielding the probability that the event was background

Stage 2

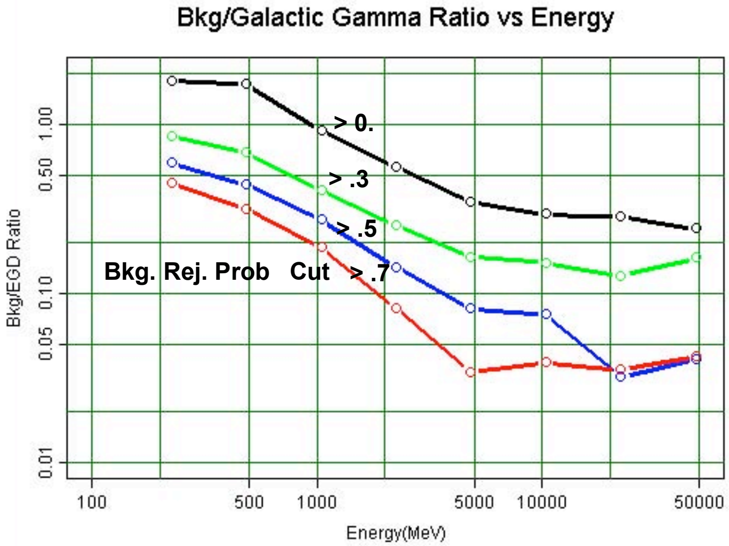
Merged Event stream now analyzed globally

1) A series of "hard cuts"
2) A global Classification Tree for events > 1 GeV

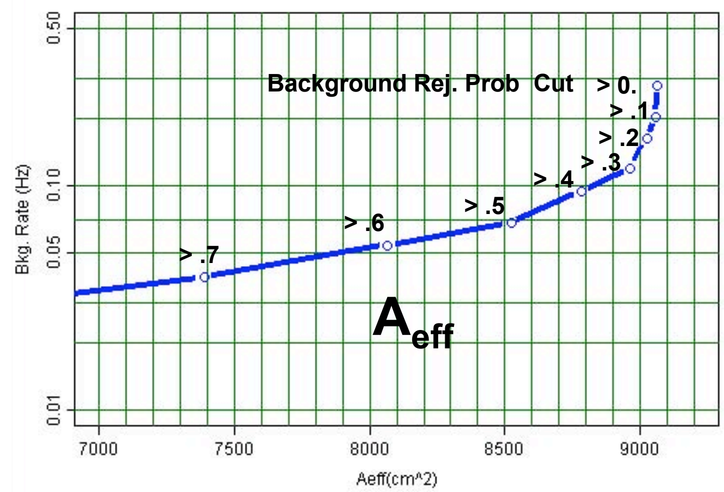
(in most of the energy bins > 1 GeV there were insufficient events left after the hard-cuts to allow CT Training)

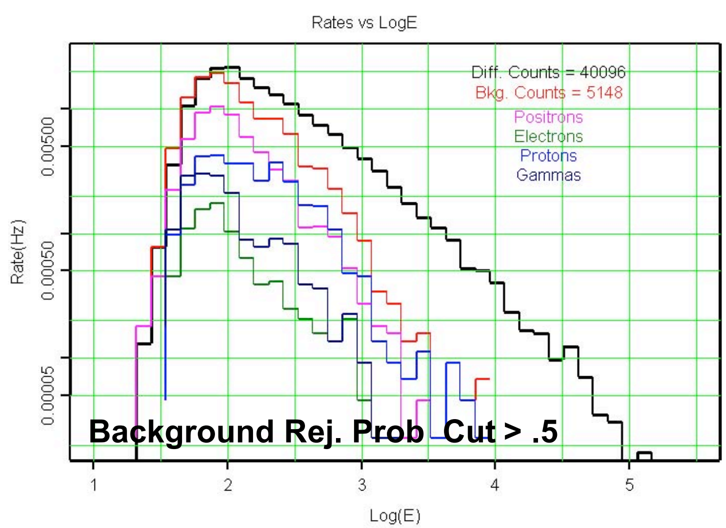
Background Rejection Results

The Gain Made:



The Price Paided:





A_{eff} x FoV

Pre-Ship Review Performance

All the components have now been described which led to the performance present at the LAT Hand-Off Review.

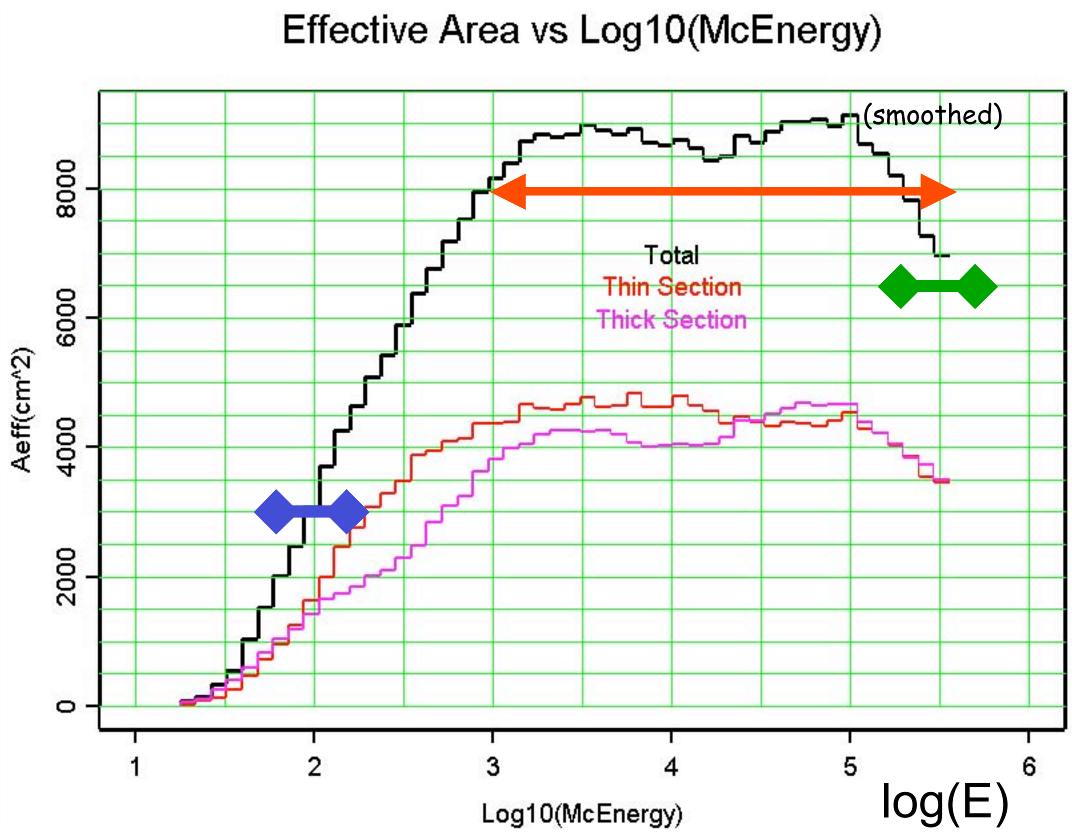
Here are the highlights as relate to the Science performance

On-Axis Aeff Science Req.

Peak A_{eff} > 8000 cm^2

A_{eff}(300 GeV) > 6400 cm^2

A_{eff}(100 MeV) > 3000 cm^2

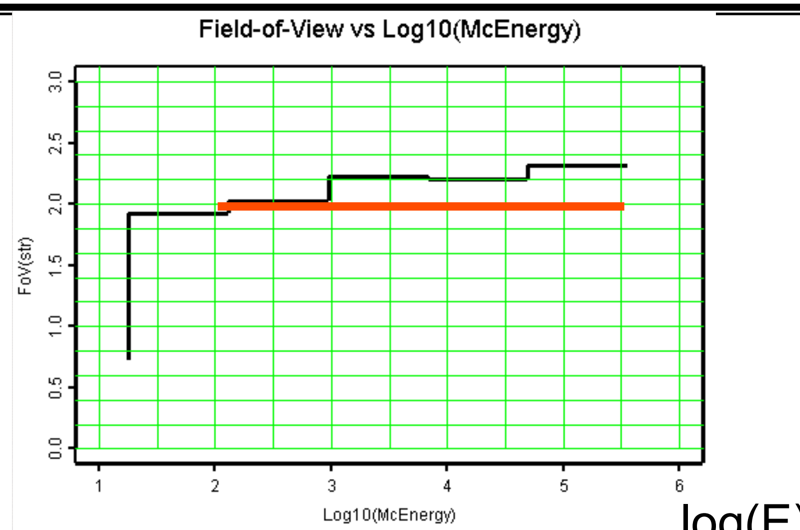


Pre-Ship Review Performance (cont'd)

Off-Axis A_{eff} Science Req.

Field-of-View > 2 str

$$FoV(E) = \frac{1}{A_{eff}(E,0)} \int_{2\pi} A_{eff}(E,\theta) d\Omega$$



Error in A_{eff} (Level 3 Science Req.)

Error in Acceptance (A_{eff}) (Req.: < 25% (50% below 100 MeV))

Sources of uncertainty, estimates

- **geometry, active area of silicon detectors <2%**
- **material, probability of conversion <1%**
- **ACD material conversions <1%**
- **reconstruction inefficiencies <2%**
- **energy calibration impacts < 8% (<1% for E>1 GeV)**

Checks for consistency, and monitoring, will be done on orbit.

Result: <14% uncertainty, added linearly (< ~7% E>1 GeV)

Pre-Ship Review Performance (cont'd)

PSF Science Requirements

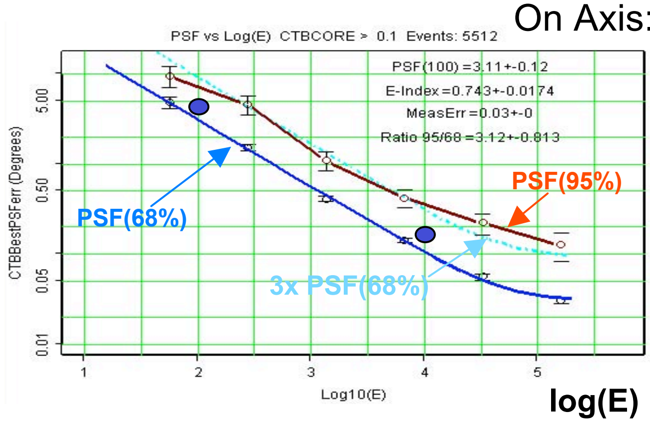
There are several here and are compared with the simulation results below

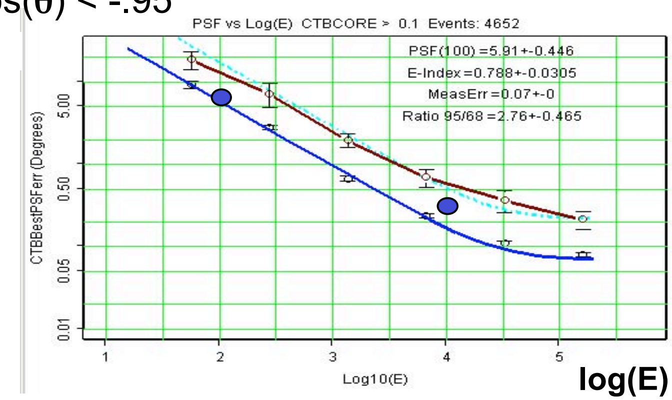
● = requirement, compare w/ blue line

Thin Radiator PSF

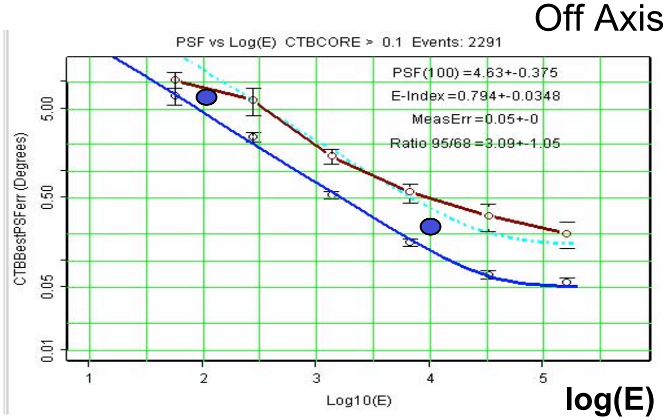
Thick Radiator PSF

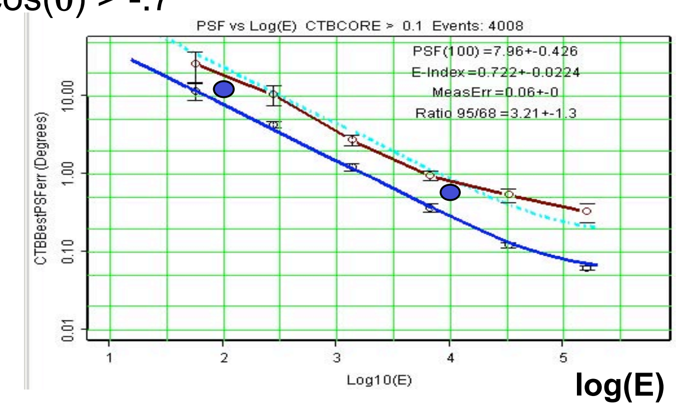
On Axis: cos(θ) < -.95





Off Axis: cos(θ) > -.7



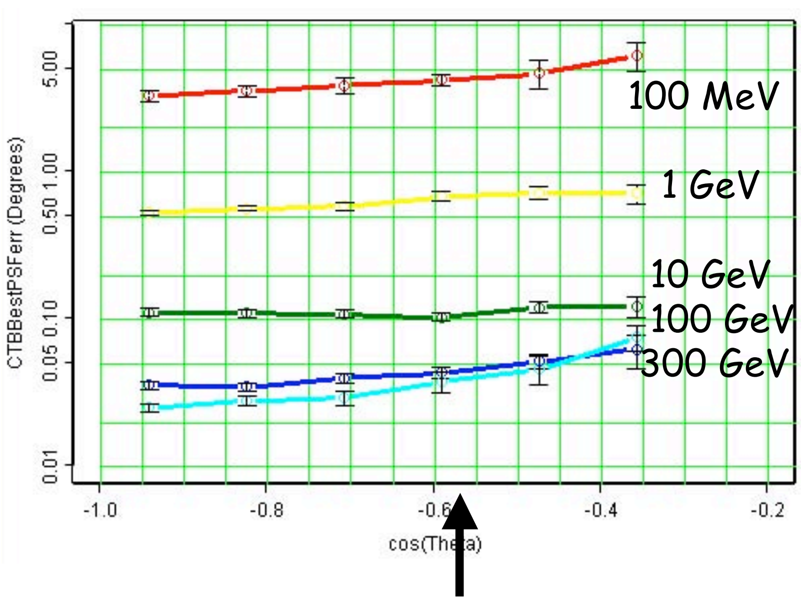


Pre-Ship Review Performance (cont'd)

Off-Axis PSF Science Requirement

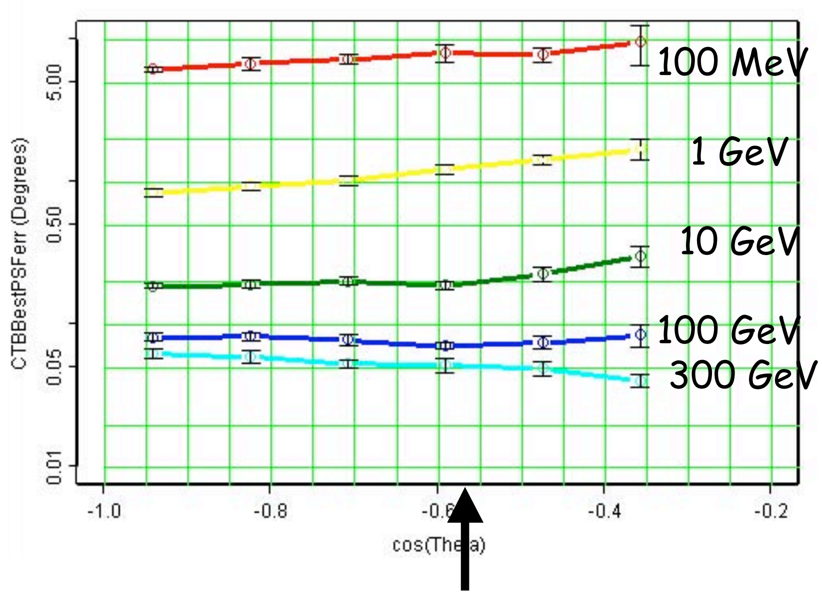
PSF(θ = 55°) < 1.7 x PSF(θ = 0°)

Thin (Front)



55°

Thick (Back)



55°

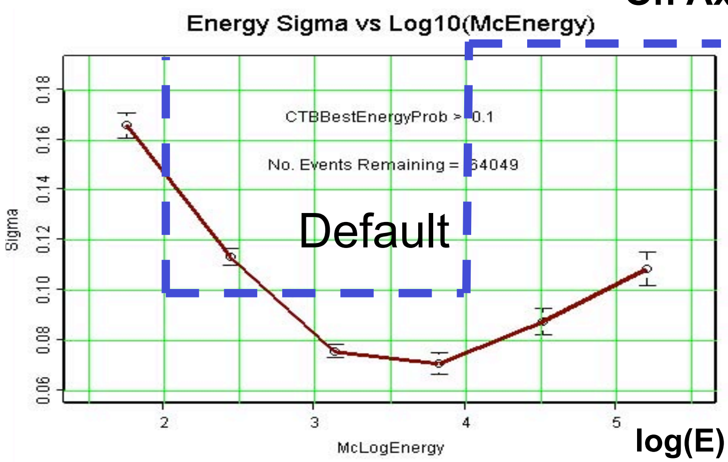
Worst case is Thin(Front) section @ 300 GeV: PSF(θ = 55°) < 1.5 x PSF(θ = 0°)

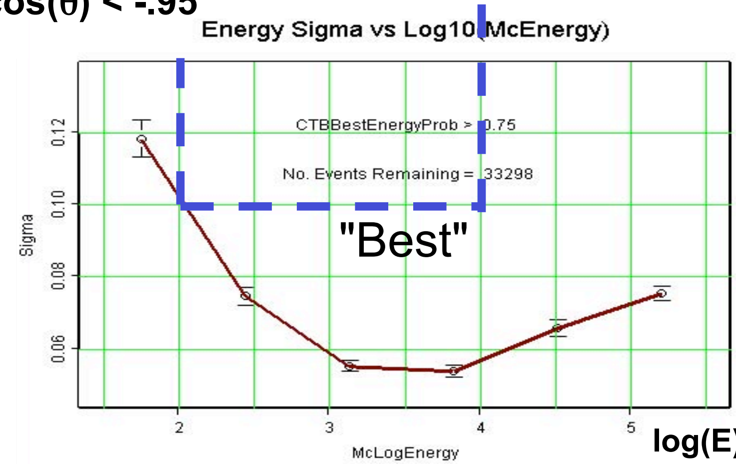
Pre-Ship Review Performance (cont'd)

Energy Resolution Science Req.

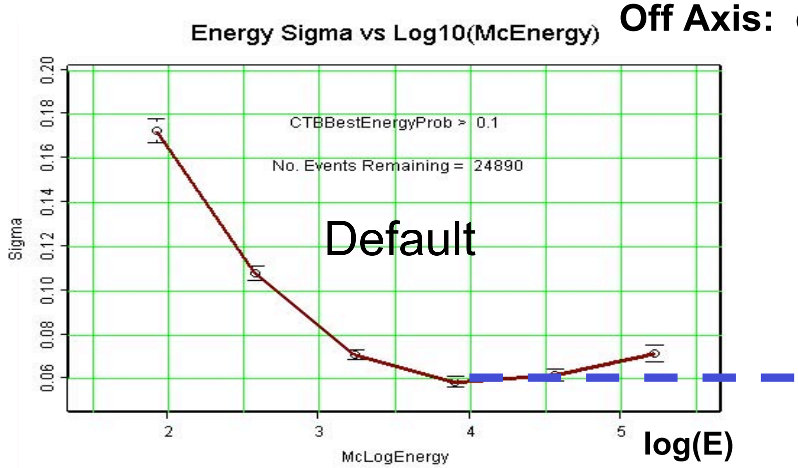
There are several here and are compared with the simulation results below by – – –

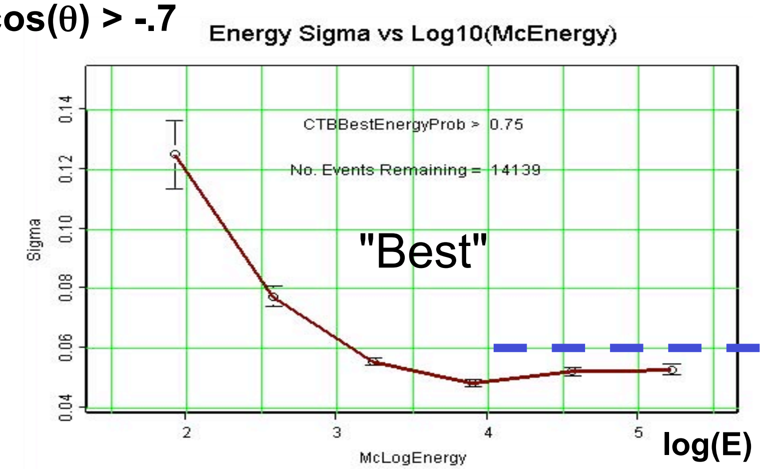
On Axis: $\cos(\theta) < -.95$





Off Axis: $\cos(\theta) > -.7$





Point source sensitivity and localization

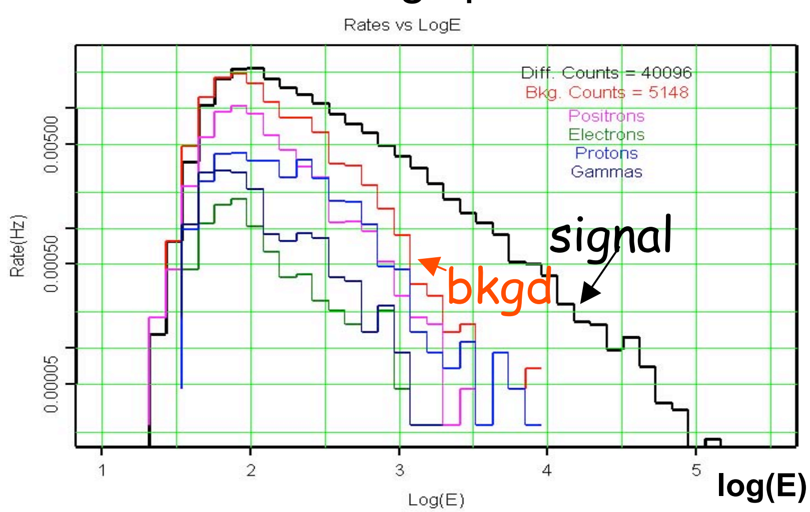
- Assumptions
  - Uniform background: 1.5×10^{-5} photons/cm^2/sr/s, E>100 MeV, spectral index -2.1, appropriate for high latitude (and specified to use by SRD)
  - Point source with spectral index -2.0, no cutoff
  - One year survey (80% of a calendar year)
  - Instrument response functions parameterized for DC2
  - Calculations are of the expected resolution, assuming unbinned maximum likelihood, and have been approximately verified with MonteCarlo
- Sensitivity: flux in photons/cm^2/s for E>100 MeV
  - Requirement: $<6 \times 10^{-9}$
  - Calculation: 3.8×10^{-9}, the Test Statistic is 25, corresponding to 5σ
- Localization: 1- σ error circle radius in arcmin for source with flux 10^{-7} photons/cm^2/s E>100 MeV
  - Requirement: <0.5
  - Calculation: <0.5*

*This results did not use the full event-by-event errors as calculated by the Reconstruction and so represents an upper limit.

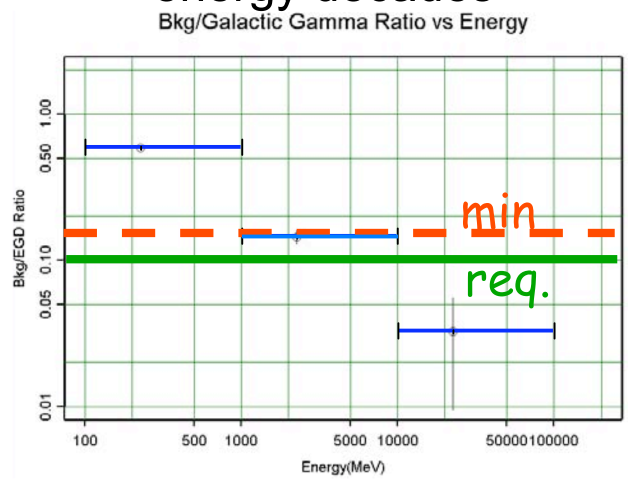
Pre-Ship Review Performance (cont'd)

Science Req.: LAT shall have a background rejection capability such that the contamination of the observed high latitude diffuse flux (assumed to be 1.5×10^{-5} cm^{-2} s^{-1} sr^{-1}) in any decade of energy (> 100 MeV) is less than 10%, assuming a photon spectral index of -2.1 with no spectral cut-off.

Resulting spectra



Background fraction by energy decades



LAT Complies directly for E>3 GeV. For the energy band 100 MeV < E < 3 GeV, the residual background contamination fraction is >10%. As will be shown it is not possible, in principle, to meet the requirement directly. For this energy range, the residual contamination will be subtracted from the measured diffuse spectrum.

The Nature of the Residual Background Events

Handscan the ½ of the 3110 Residual Background Events.

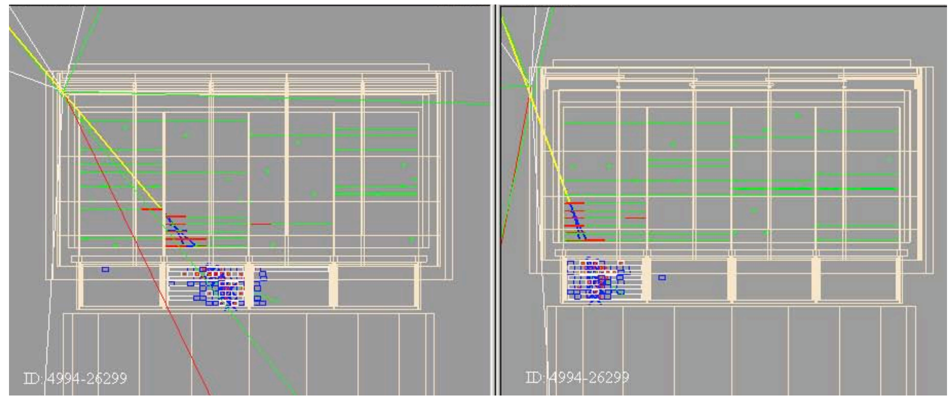
(Proton + Blanket) → π^0 → 2γ

Large Angle π^0

&

Small Angle π^0

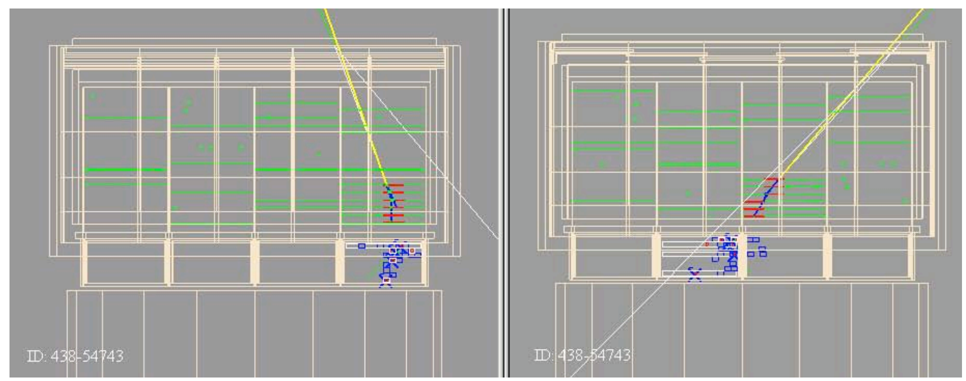
(Hi energy tail)



(e^+ + Blanket) → 2γ

Annilation

Also we have e^+ & e^- **Bremstrahlung** in the Blanket



These Events are Irreducible

a γ is produced outside the ACD within the FoV

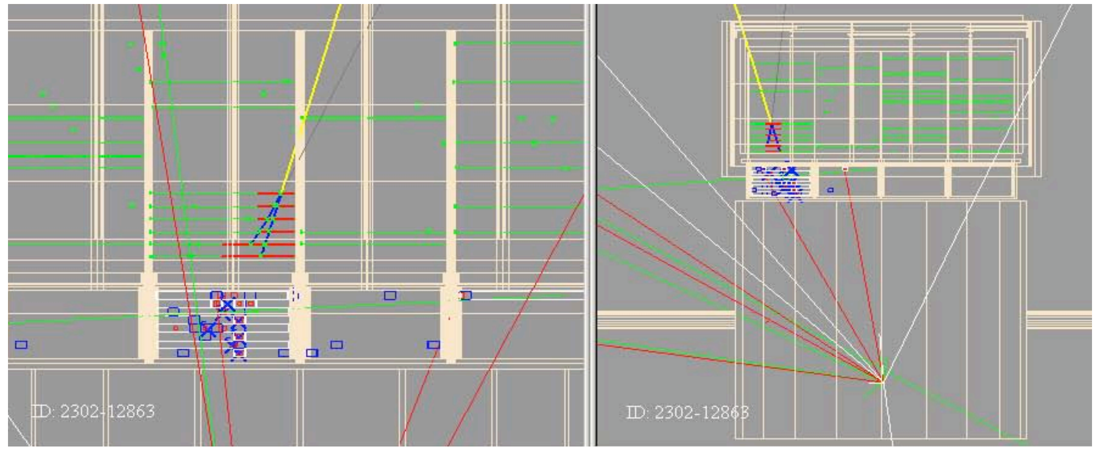
More Background Event Categories

Space Craft Interaction with Stopping Stub(s)

Proton + Space Craft

Cal Shower

Stubs in Tracker

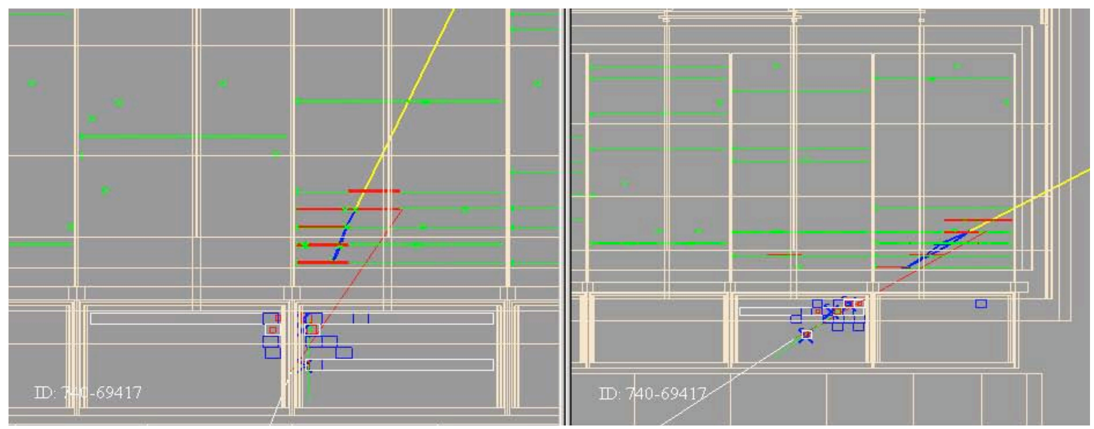


Electromagnetic showers from below

Albedo γ

Cal Shower

Stubs in Tracker



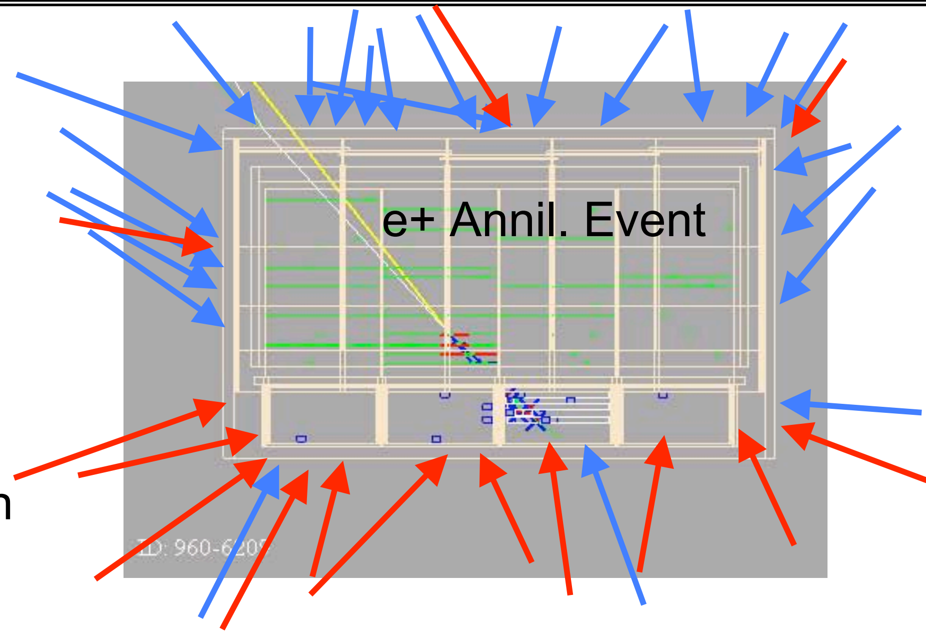
These showers from below as well as the Horizontal entering – Track wall Interactions

These Events are Reducible (could in principle be eliminated)

Irreducible and Reducible Events in Pictures

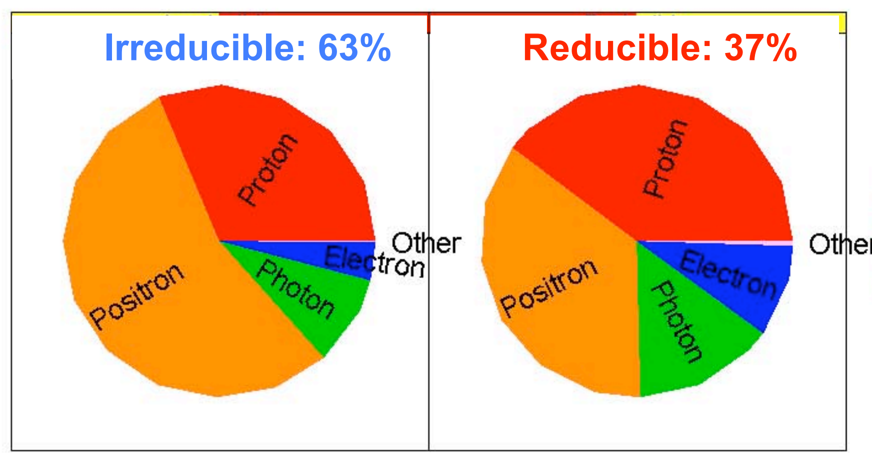
Irreducible Events

- Photons generated within FoV
- Originating particle typically in FoV
- Mostly e^+ and protons
- Not Rejectable
- Require incoming flux meas. and MC to subtract contamination



Reducible Events

- Typically back-entering
- Shower by-product appears in Tracker
- Events have non-photon signature
- Should be rejectable
- <u>Contaminate topology classes differently</u>
- MC needed to normalize levels of contamination



Extra-Galactic-Diffuse Background Subtraction Strategy

Irreducible Component

- Acquire the incoming particle fluxes (e+, e-, and proton) via a combination of LAT data and other satellite experiments (e.g. PAMELA)

- Use MC Simulations to predict the level of contamination

Reducible Component

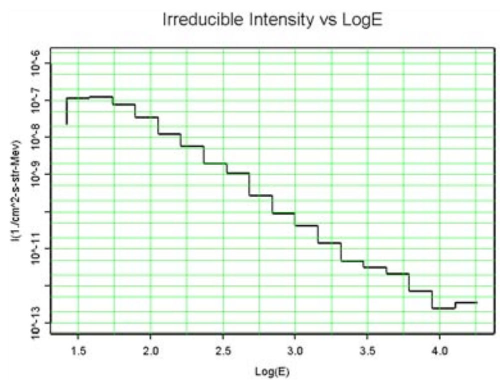
- Observation: events with reconstructed vertices have ~ an order of magnitude less background (this is the reason why we divide the events up according to topology at the start of the Background Rejection)

- Use the differences between the 1-Track sample and the VTX sample to measure the residual reducible background

- Either use a fit to the above extracted spectrum or spectrum directly to subtract this component

Estimating the Irreducible Intensity

For now - use MC
To predict
Irreducible Intensity



Use as is *or* fit to a power law

In either case, correct upwards by ratio to Handscan

$$I_{Irred} = \frac{715}{613} \cdot I_{Irred}(BkgClass) = 1.23 \cdot I_{Irred}(BkgClass)$$

Ratio of events with McZDir < -.2 to total from Handscan

Post Launch Plan

Use e^{+}+e^{-} Rate (LAT measurement) to determine the Combined Flux & Spectral Shape
Use e^{+}/e^{-} Ratio
(from PAMELA or LAT by annihilation identifications)
Use MC to predict e^{+}+e^{-} Brems. Background & e^{+} Annihilation Background

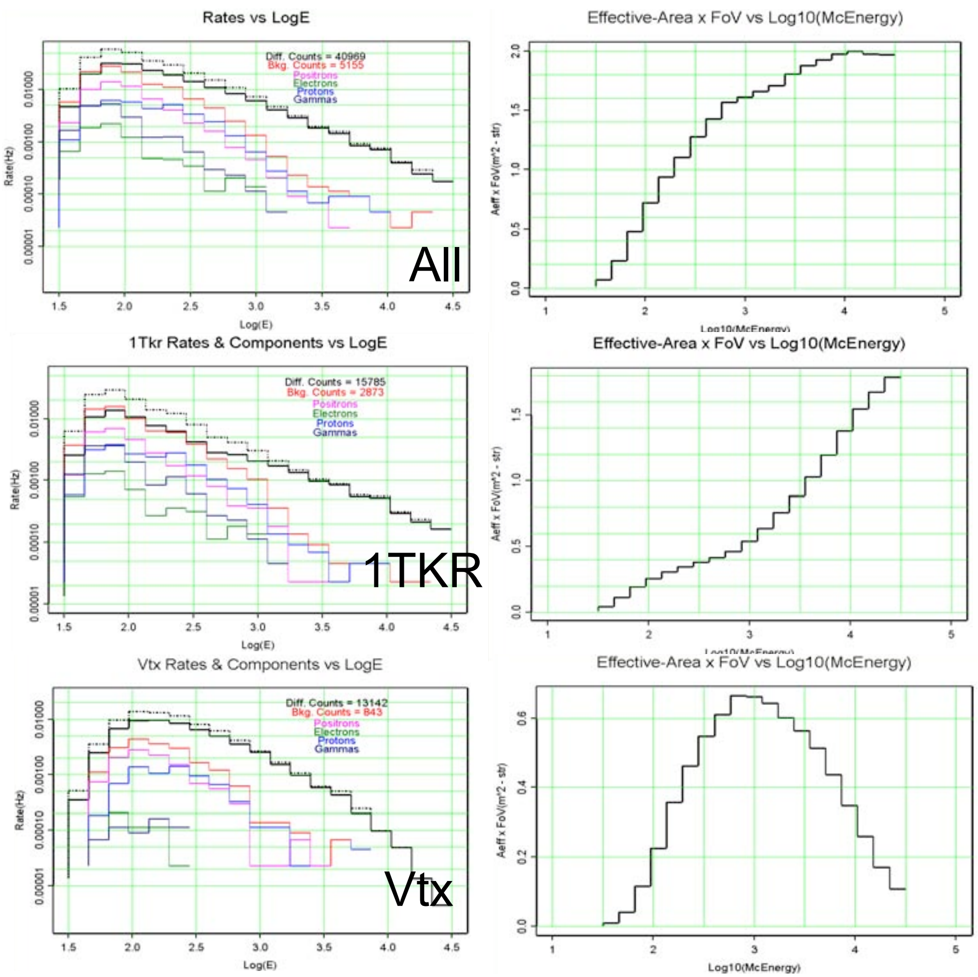
Small error here - and
~ *Larger* overall contribution

Obtain Proton spectrum
(from PAMELA verified by LAT observations of Proton flux))
Use MC to predict spectrum of observed γs
from: p+(Blanket) ⟹ π^0 + X ⟹ γ + X'

Large error here - but
~ *Smaller* overall contribution
(*est. p/$e^{+}e^{-}$ = ½ from Vtx Sample*)

Estimating the Reducible Background Intensity

First obtain the Rates vs Log(E) for the event classes VTX, 1-TKR, and ALL

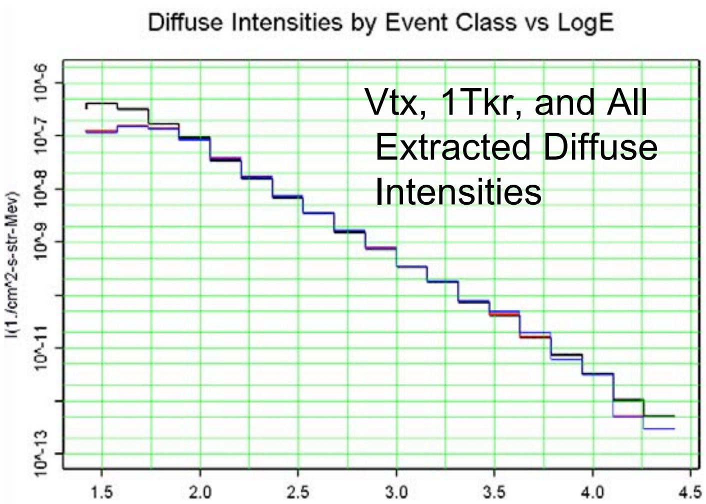


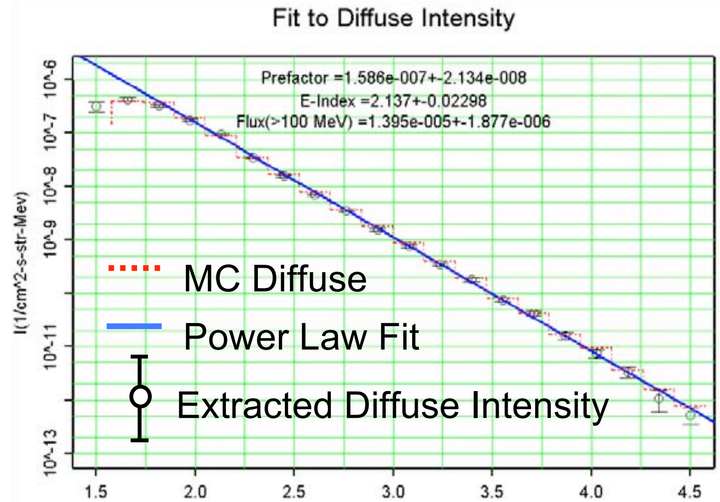
Notice the large variation in the shape and the normalizations in these plots.

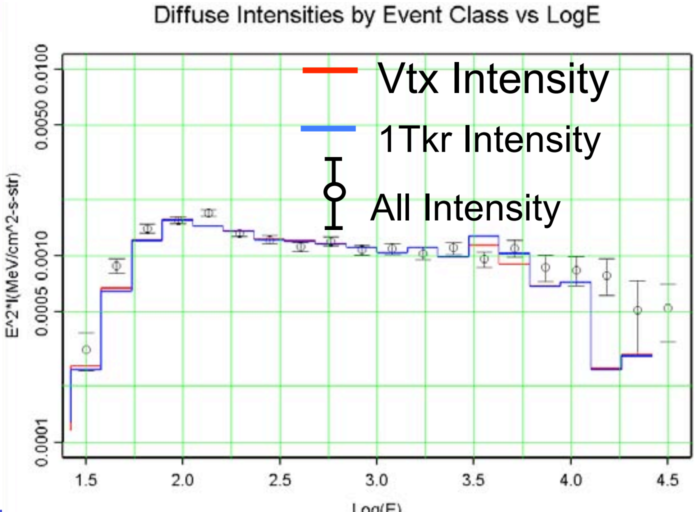
As will be shown they all give the same Intensities

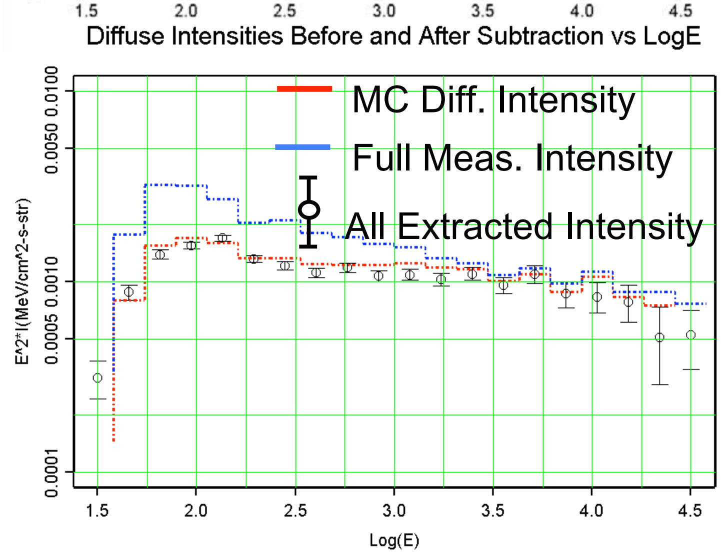
Subtraction Results

Extracted Intensity = $I(E) = I_{Meas} - I_{Irred} - I_{Red}$

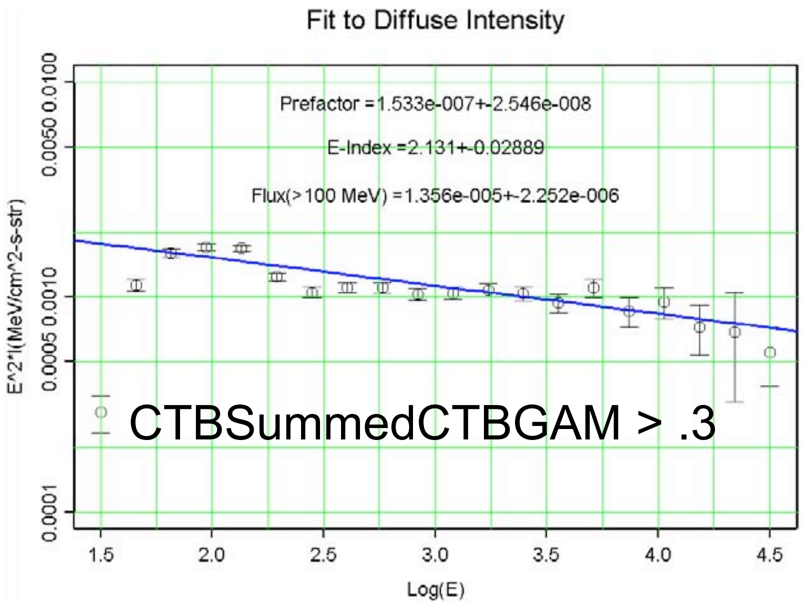


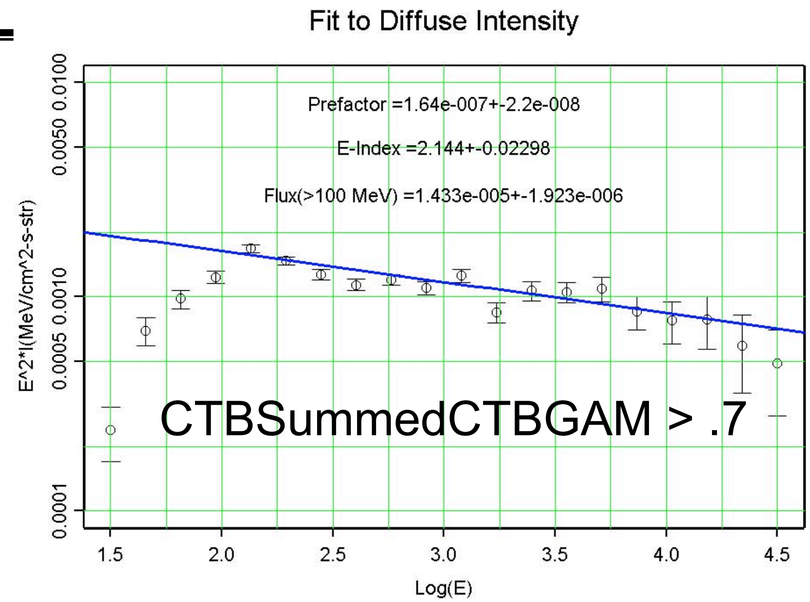






Sensitivity to Level of Background Contamination





Comparison of Results

Knob	#Reduc. Events	C_{1TKR}	C_{VTX}	C_{OTHER}	C_{ALL}	Flux(> 100 MeV)	E-Index
.7	1807	1.25	.230	.481	.663	1.43+-.19 x 10^{-5}	2.144+-.023
.5	3135	1.14	.153	.313	.541	1.40+-.19 x 10^{-5}	2.137+-.023
.3	5359	1.09	.101	.230	.579	1.36+-.23 x 10^{-5}	2.131+-.029

Systematic Error Sources

Irreducible Background Flux

1) Proton differential cross-section for inclusive π^0 production - Verified by B.T.
2) Assumption that e^+ spectrum = e^- spectrum - Meas.'d - Us or others
3) e^+ fraction of charged lepton rate - Meas.'d - Us or others

Reducible Background Flux

1) Reducible background fractions in the Event Classes **- MC**
2) Angular dependence (not yet looked for…)

Summary

1) Separating Irreducible from Reducible backgrounds allows for systematic treatment of each separately
2) Using different event classes to extract the Reducible backgrounds
   - Directly measures spectral shape
   - Requires only small MC corrections due to cross-contamination (~ 14%)
   - Can be cross-check using MC prediction for Reducible Contamination
3) Method shown to be robust w.r.t. Background Rejection Knob.

Systematic Error Analysis Summary

Use the MC & Handscan to break down the Irreducible component according to Intereaction type as well as Particle type

Irreducibles		Interact							Totals
		Annil	Brem	Conv	LApi0	SApi0	SS	Zoo	
McSource.Type	Earth10	0	0	4	0	0	57	1	62
	HeavyIon	0	0	0	1	0	0	0	1
	P Primary	0	0	0	141	53	1	5	200
	P ReEntrant	0	1	0	15	1	0	2	19
	P Splash	0	0	0	6	0	0	3	9
	e+ ReEntrant	396	25	1	1	0	1	0	424
	e+ Splash	2	14	0	0	0	2	0	18
	e- ReEntrant	0	13	0	0	0	0	0	13
	e- Splash	0	4	0	0	0	1	0	5
Totals		398	57	5	164	54	62	11	751

1) Brems: 57 / 751 = 7.6% $e^+ + e^-$ Spectrum < 2.2% .2%

2) Annihilations: 398 / 751 = 53.0% e^+ Spectrum from e^+/e^- < 3% 1.6%

3) π^0: (164+54) / 751 = 29.0% $\sigma(p \rightarrow \pi^0)$ 20%; p Spectrum < 10% 6.5%

4) Albedo γ: 62 / 751 = 8.3% γ Spectrum < 10% .8%

5) Other: 16 / 751 = 2.1% Mis-Tracking, etc. < 20% .4%

QuadratureTotal < 6.8%

6) Irreducible Bkgs: 6.8% x .63 = 4.3%

7) Reducible Bkgs: From previous work - Error < 4/140 = 2.9%

Quadrature Total = 5.2%

Reasons for the small systematic error

1) The main component of the Irreducible backgrounds is well understood Physics and well measured input spectra (e^+ & e^-).

2) The proton induced Irreducible component comes from primary cosmic rays. This incoming flux has a distinct orbital signature which will server as a cross check on this largest piece of the systematic error.

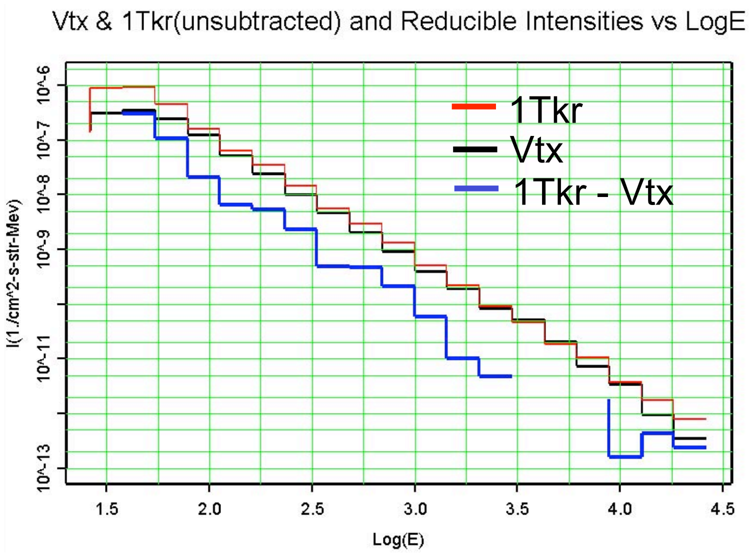
3) In the Reducible component, the VTX sample has almost 7x less background then the 1-Tkr sample. Hence the subtractions yields almost a direct measure of the Reducible component (albeit a ~ 15% correction)

Summary

- LAT meets or beats Science Requirements
  - instrument data idiosyncrasies and relevant real-world behavior (e.g., bad channels) uncovered during testing incorporated into the simulation.
  - beam test results will be used to update the simulation.
  - further analysis to be performed on background rejection and effective area knowledge requirements. these are analysis tasks that are decoupled from instrument shipment schedule.

Backup Charts

Extracting the Reducible Intensity



$$I_{Vtx} = \frac{R_{Diff}^{Vtx} + R_{Irred}^{Vtx} + R_{Red}^{Vtx}}{A_{Vtx}}$$

$$I_{1Tkr} = \frac{R_{Diff}^{1Tkr} + R_{Irred}^{1Tkr} + R_{Red}^{1Tkr}}{A_{1Tkr}}$$

$$I_{1Tkr} - I_{Vtx} = \left(\frac{R_{Diff}^{1Tkr}}{A_{1Tkr}} - \frac{R_{Diff}^{Vtx}}{A_{Vtx}}\right) + \left(\frac{R_{Irred}^{1Tkr}}{A_{1Tkr}} - \frac{R_{Irred}^{Vtx}}{A_{Vtx}}\right) + \left(\frac{R_{Red}^{1Tkr}}{A_{1Tkr}} - \frac{R_{Red}^{Vtx}}{A_{Vtx}}\right)$$

0 0

$$I_{1Tkr} - I_{Vtx} = \frac{R_{Red}^{1Tkr}}{A_{1Tkr}}\left(1 - \frac{R_{Red}^{Vtx} / R_{Red}^{1Tkr}}{\tilde{A}_{Vtx} / \tilde{A}_{1Tkr}}\right) = I_{Red}^{1Tkr}\left(1 - \frac{115/859}{11682/10774}\right) = .877 \cdot I_{Red}^{1Tkr}$$

So…

$$I_{Red}^{1Tkr} = 1.14 \cdot (I_{1Tkr} - I_{Vtx})$$

$$I_{Red}^{Vtx} = \frac{115}{859} \cdot 1.14 \cdot (I_{1Tkr} - I_{Vtx}) = .153 \cdot (I_{1Tkr} - I_{Vtx})$$

$$I_{Red}^{Other} = \frac{236}{859} \cdot 1.14 \cdot (I_{1Tkr} - I_{Vtx}) = .313 \cdot (I_{1Tkr} - I_{Vtx})$$

$$I_{Red}^{All} = \frac{\tilde{A}_{Vtx}}{\tilde{A}_{All}} I_{Red}^{Vtx} + \frac{\tilde{A}_{1Tkr}}{\tilde{A}_{All}} I_{Red}^{1Tkr} + \frac{\tilde{A}_{Other}}{\tilde{A}_{All}} I_{Red}^{Other} = .541 \cdot (I_{1Tkr} - I_{Vtx})$$

Notice that the contamination of reducible Background is ~ 14% in the Vtx sample.

This is what makes this method a success.

XXX **Coefficients determine from MC**

Systematic Error Discussion

1) Bremstahl spectrum error depends on MC Physics, MC material audit, and the input e+ + e- spectrum
   - The MC Physics errors is neglible
   - Material Audit error < 2%
   - $e^+ + e^-$ spectrum is self monitored by LAT. As such errors in acceptance will cancel and we've demonstrated particle type separation for this channel to be ~ 92% pure and the error will be at most be ~ 1%

     $1\% \oplus 2\% = 2.2\%$ in an overall 7.6% contributions: Hence < .2%

2) e^+ Annihilations: Will need Pamela data for Ratio(e^+/e^-) . As this is a ratio and Pamela is essential charge sysmetric the error will be essentially just statistical and this will be very small. The main source of concern in the Pamela ratio will be mis-identified protons as e^+'s. Pamela combats this with both ToF as well as shower development analysis: est. < 3% error in a 53% contributions: Hence 1.6%

3) π^0 from Protons: By far our biggest uncertainty. Contributors are uncertainty in the inclusive cross-section fro p to make π^0 and the incoming proton spectrum. We will take the later from Pamela while the former will be constrained by the LAT Beamtest as well as inter-hadronic interactor comparisons within the Geant 4 context. Conservatively we assume the cross-section error will be < 20% while the absolute flux from Pamela will

Systematic Error Discussion (cont'd)

3)$_{\text{cont'd}}$ < 10%: Hence overall we estimate < 22.3% uncertainty in this 29% contribution for an overall of < 6.5%

4) Albedo γ's: These events come in at the edge of the acceptance. LAT will measure the Albedo spectrum to < 10%. Hence this 8.3% component will contribute .8%

5) Other: These are events which are mis-tracked for a multitude of reasons. The overall fraction of these is < 1% however they are concentrated in the residual backgrounds (no surprise). From Hand-scans as well as MC-Truth driven Tracking we will know the mis-tracked fraction to << 1%. However due to the uncertainties in this area we conservatively assign a < 20% error. Hence this 2.1% contributions yields an uncertainty in the overall Irreducible flux of .4%

6) The quadrature sum of the Irreducible error is 6.8% and this constitutes at the very most .60 (Total background fraction at 100 MeV) x .63 (Irreducible Fraction) x 6.8% = 2.6%

Systematic Error Discussion (cont'd)

7) The Reducible Subtraction method was demonstrated to have an error which can be conservatively estimated at 4/140 = 2.9%
The main reason for the small error on the Reducible component is that the VTX sample is ~ 7x cleaner w.r.t. background then the 1-Tkr sample. Hence the difference (1-Tkr - VTX) is almost a direct monitor of the Reducible component. The main correction to the subtract spectrum is compensation for the residual Reducible background in the VTX sample itself and this is small (<20%). Hence even relatively large uncertainties in the this residual have little effect.

Reasons for the small systematic error

1) The main component of the Irreducible backgrounds is well understood Physics and well measured input spectra (e^+ & e^-).
2) In the Reducible component, the VTX sample has almost 7x less background then the 1-Tkr sample. Hence the subtractions is almost a direct measure on the Reducible component (albeit a ~ 15% correction)