Search for Gamma-ray Spectral Lines with the Fermi Large Area Telescope and Dark Matter Implications

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on Behalf of the Fermi-LAT Collaboration

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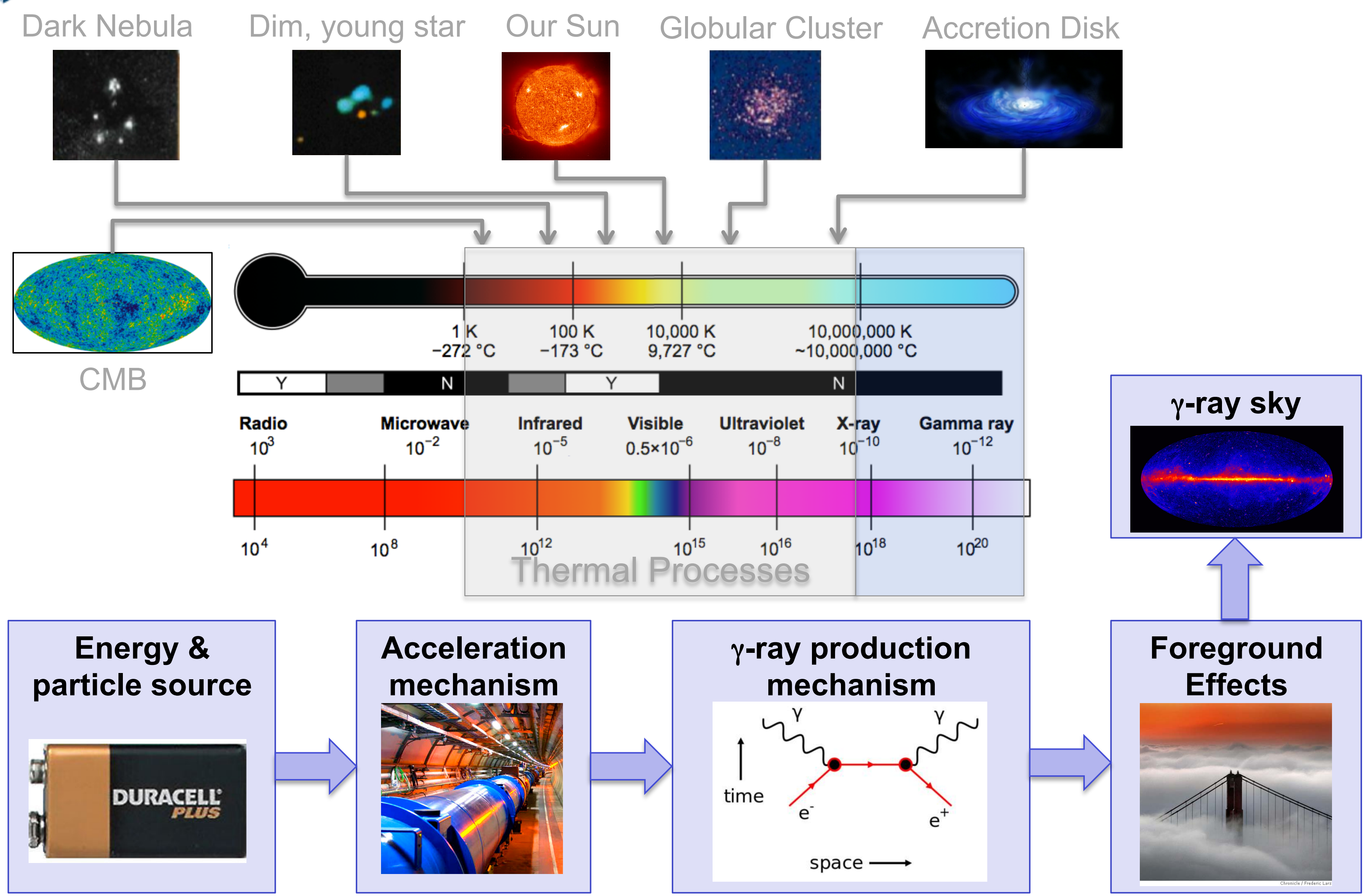
Outline

- Fermi-LAT and γ-ray Astronomy
- Indirect Searches for Dark Matter
- Evidence for 130GeV γ-ray Line?
- Fermi-LAT Line Search
  - Methodology: event selection, search region optimization, fitting procedures
  - Systematics: instrumental and methodological uncertainties
  - Results
    - Investigations of the Spectral feature at 130GeV
  - Upcoming developments
- Summary

THE FERMI-LAT AND γ-RAY ASTRONOMY

γ-rays Probe the Extreme, Non-Thermal, Universe

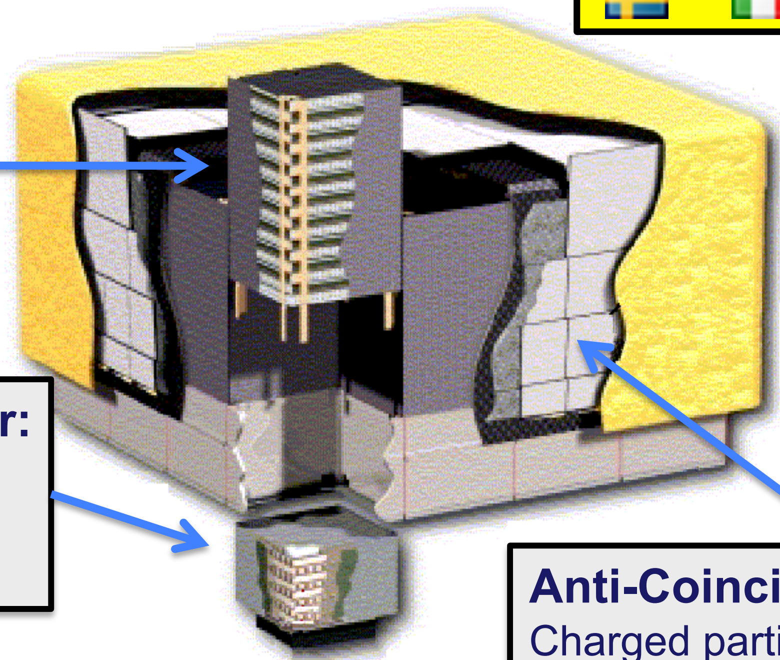


The Fermi Large Area Telescope

Public Data Release:
All γ-ray data made public within 24 hours (usually less)

Fermi LAT Collaboration:
~400 Scientific Members, NASA / DOE & International Contributions

Si-Strip Tracker:
convert $\gamma \rightarrow e^+e^-$
reconstruct γ direction
EM v. hadron separation



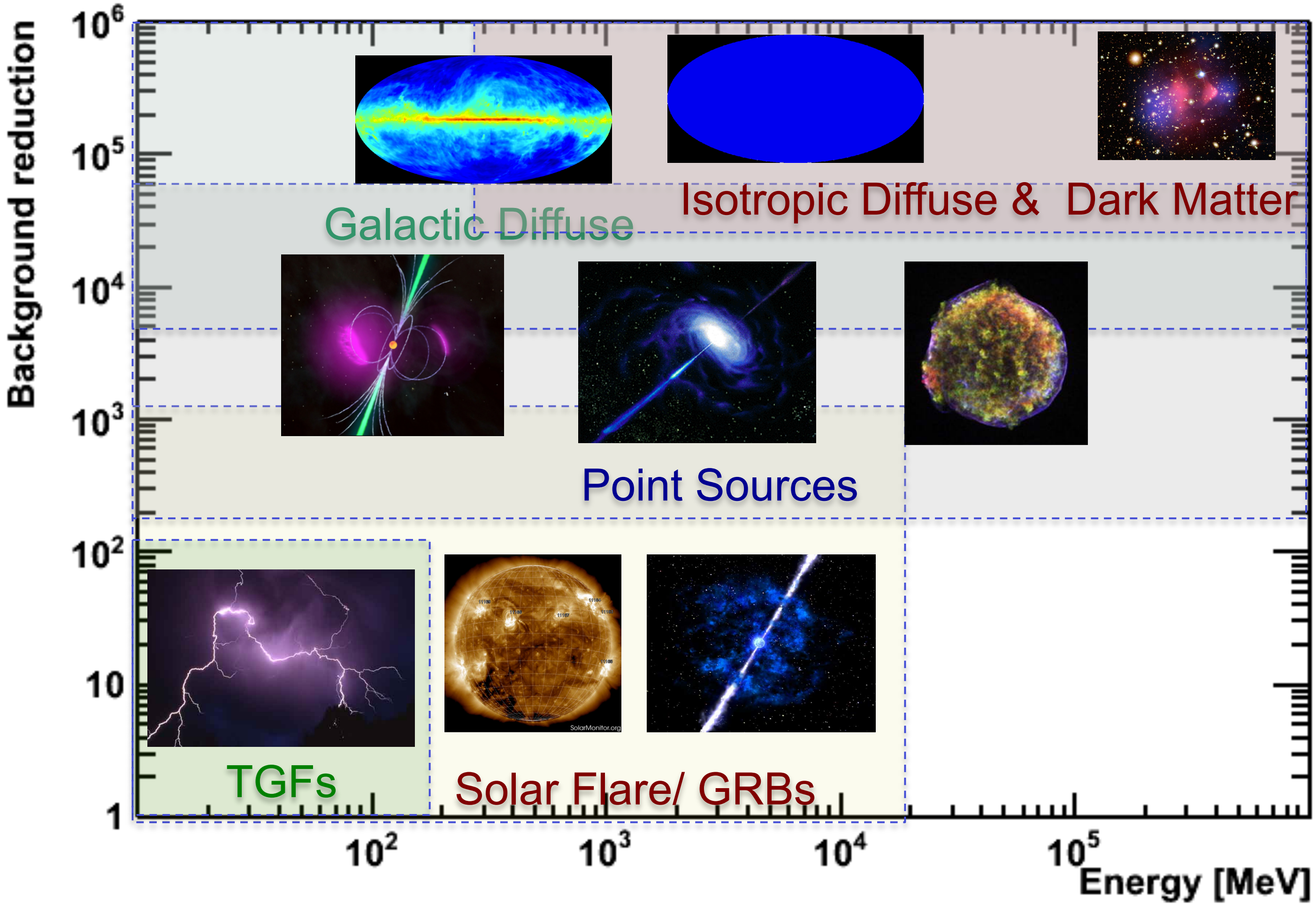
Hodoscopic CsI Calorimeter:
measure γ energy
image EM shower
EM v. hadron separation

Anti-Coincidence Detector:
Charged particle separation

Sky Survey:
With 2.5 sr Field-of-view LAT sees whole sky every 3 hours

Trigger and Filter:
Reduce data rate from ~10kHz to 300-500 HZ

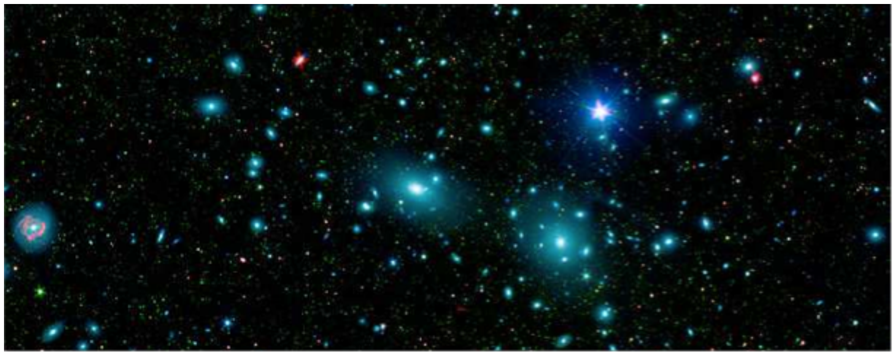
Fermi-LAT Science Covers Huge Phase-Space



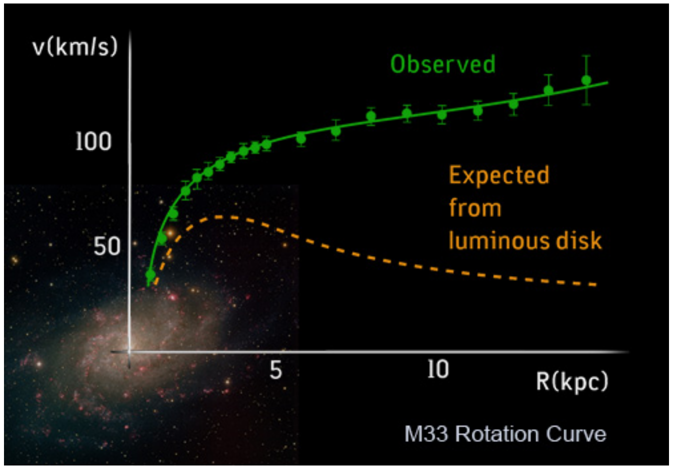
Different data selections for different science cases

INDIRECT SEARCHES FOR DARK MATTER

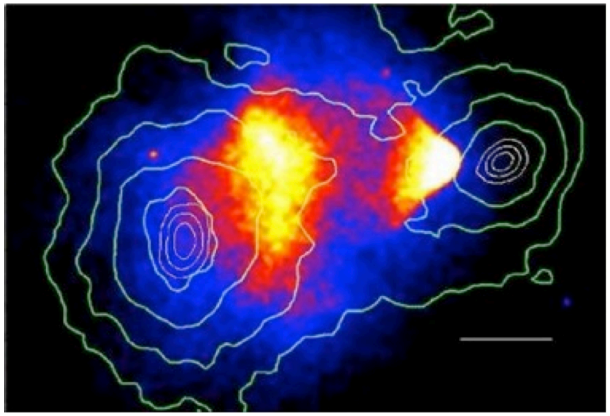
Evidence for / Salient Features of Dark Matter



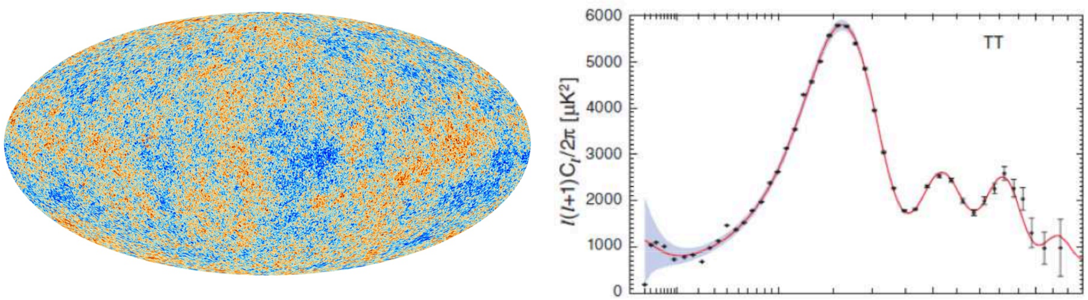
*Comprises **majority** of **mass** in Galaxies*
Missing mass on Galaxy Cluster scale
Zwicky (1937)



*Large **halos** around Galaxies*
Rotation Curves
Rubin+(1980)

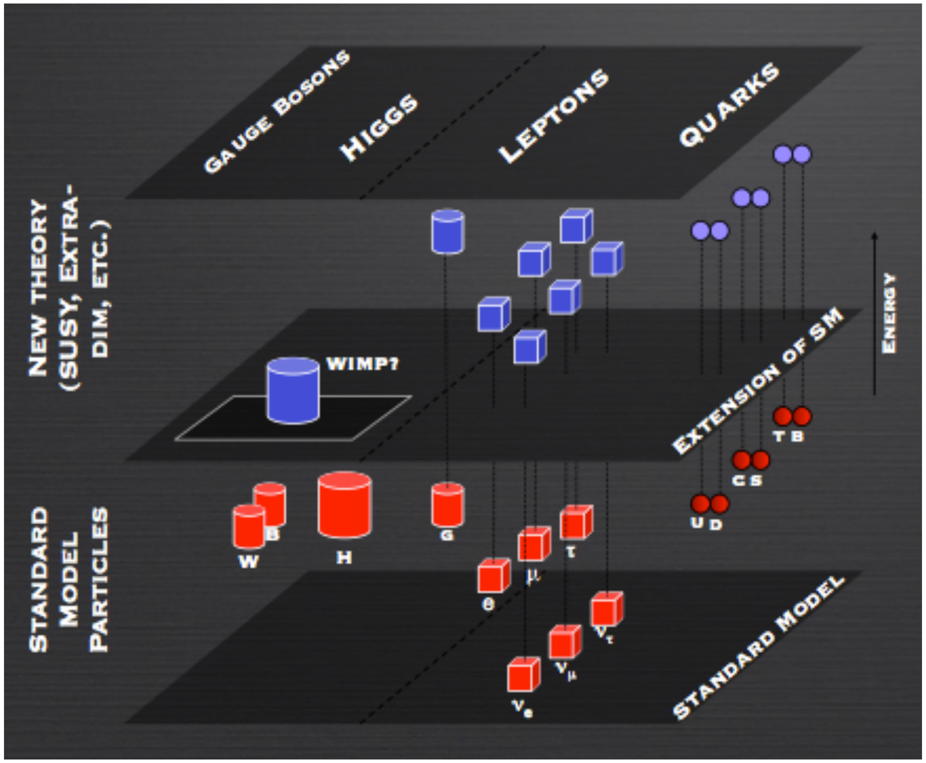


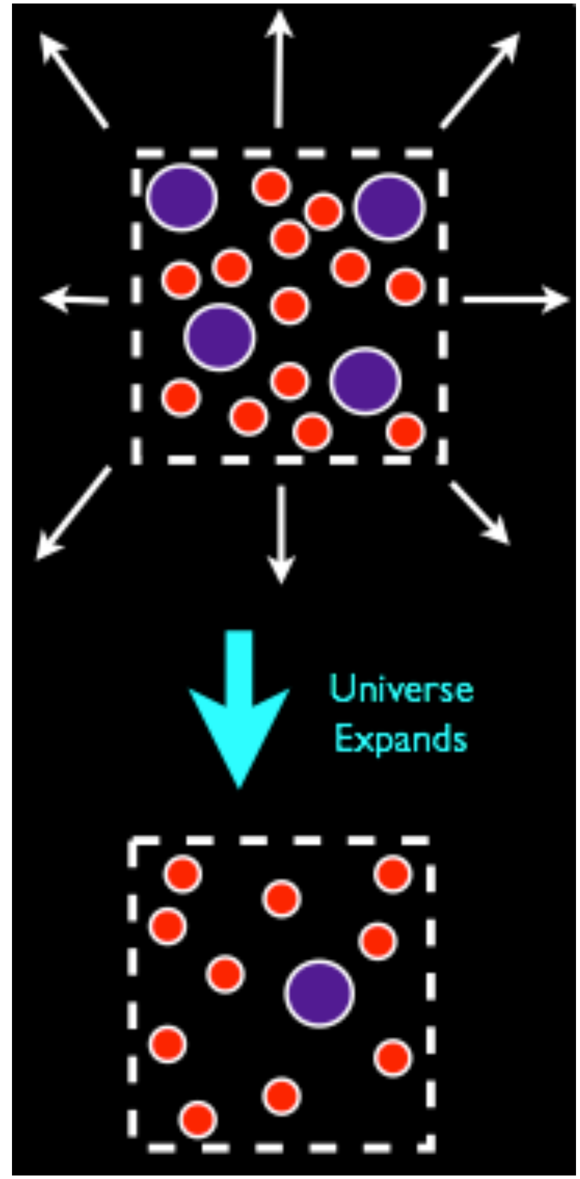
*Almost **collisionless***
Bullet Cluster
Clowe+(2006)



Non-Baryonic
CMB Acoustic Oscillations
Planck (2013), WMAP(2010)

Particle Physics offers Dark Matter Candidates

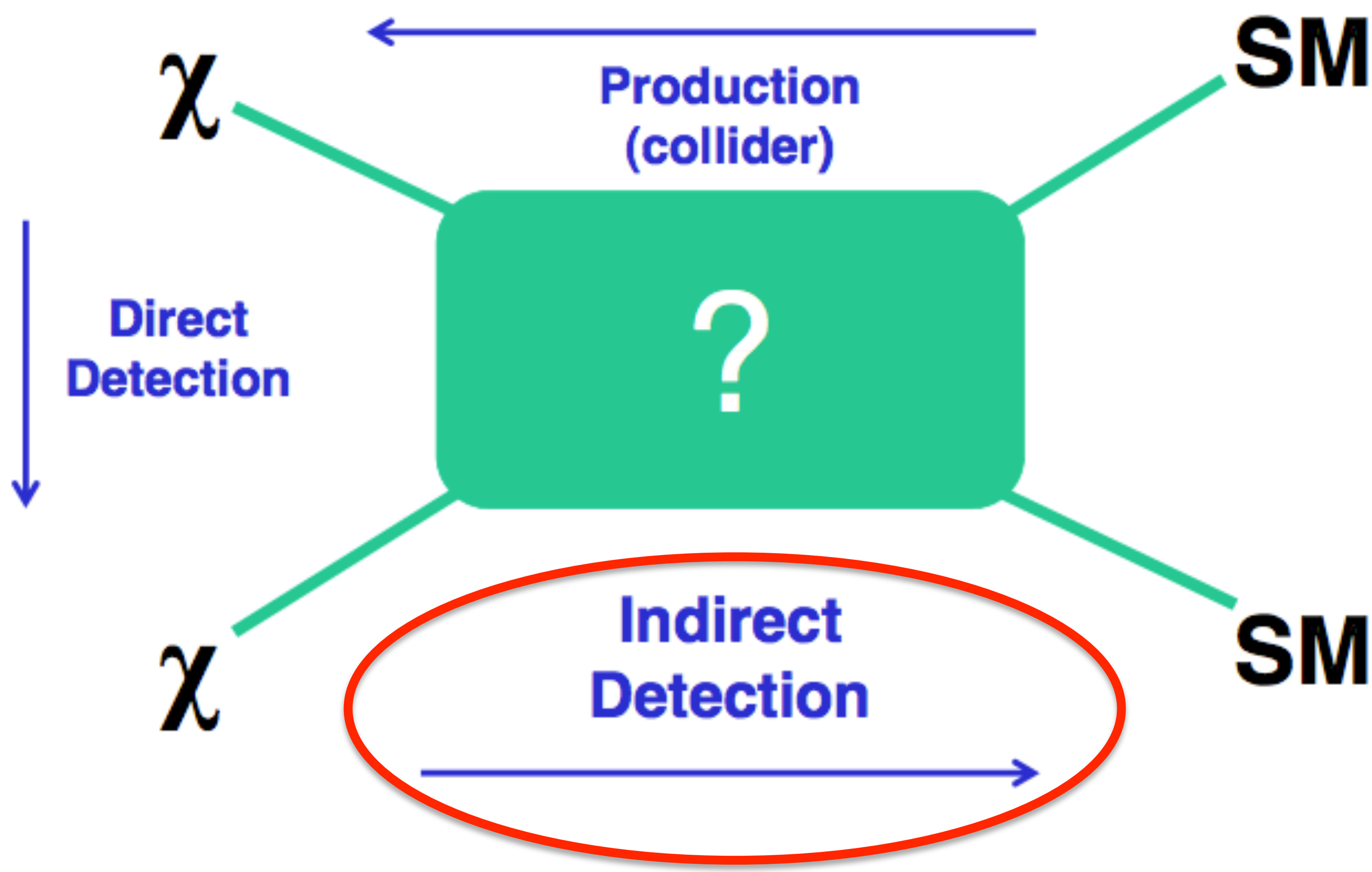




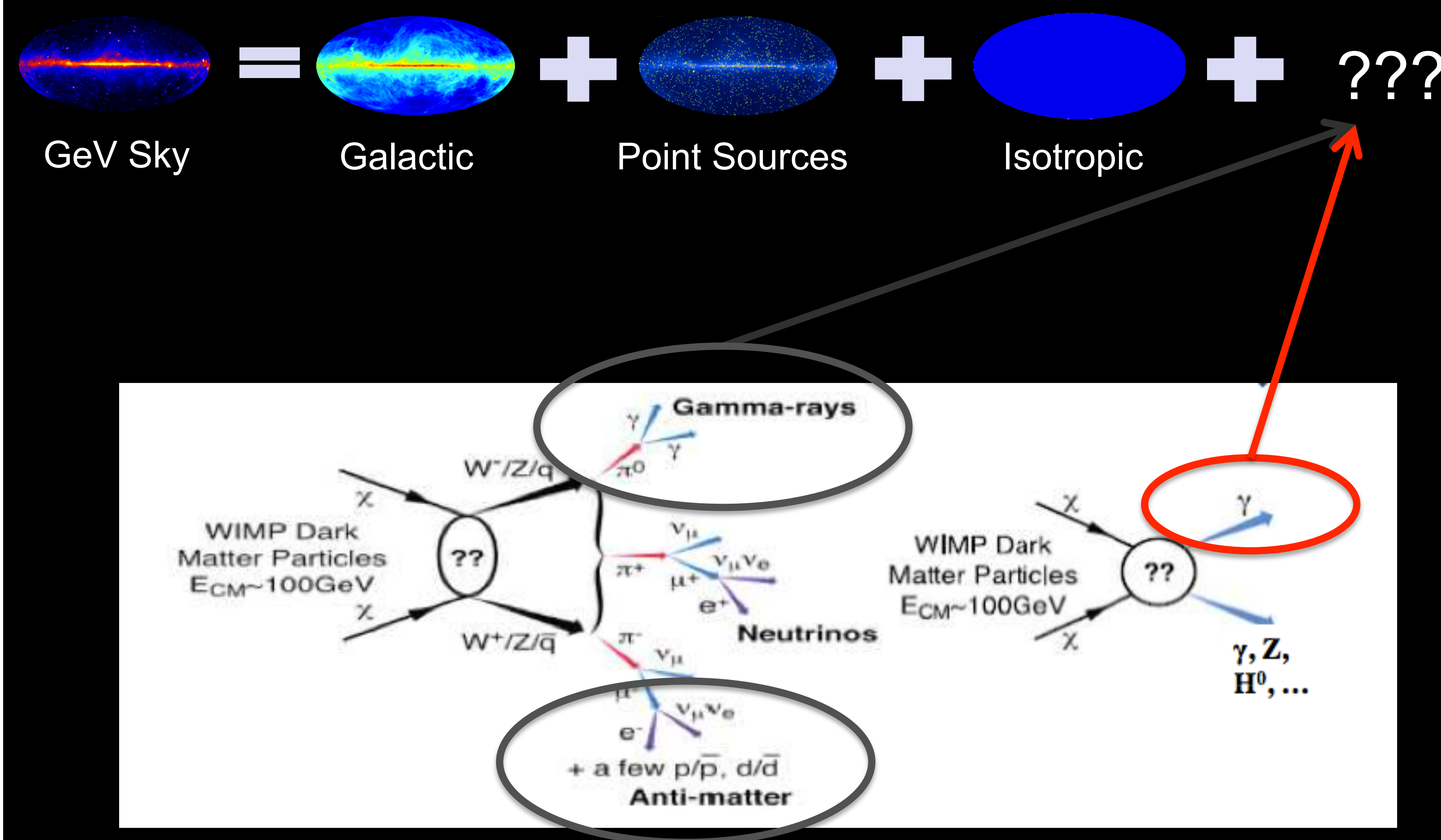
•Weakly Interacting Massive Particles (WIMPs) are an interesting DM candidate

•"WIMP Miracle", WIMPs as thermal relic:
Mass scale ~ 100 GeV
$<\sigma v> \sim 3\ 10^{-26}\ cm^3\ s^{-1}$

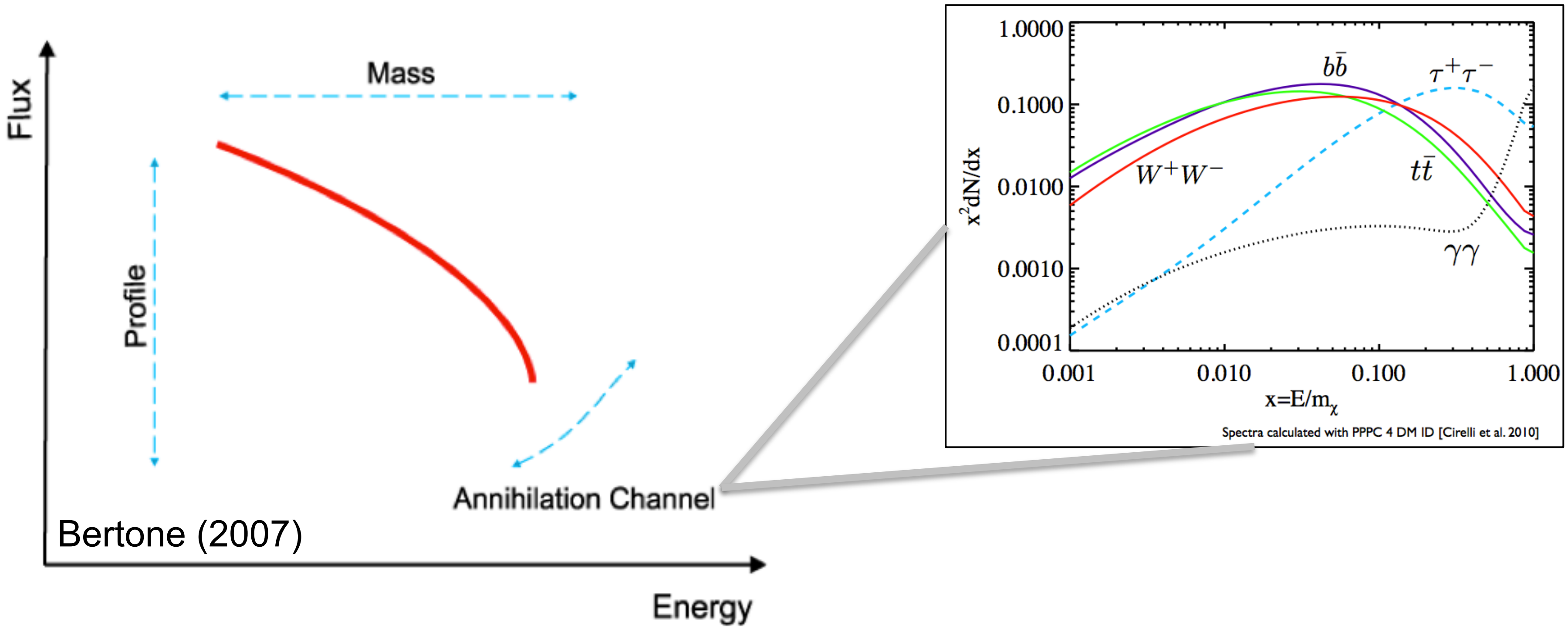
Dark Matter Searches



Indirect Searches for DM in the GeV Sky



Dark Matter Signatures in γ-ray Sky



Bertone 2007

Particle Physics

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta) = \frac{1}{4\pi}\frac{<\sigma_{ann}v>}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f$$

$$\int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\phi'))dl(r,\phi')$$

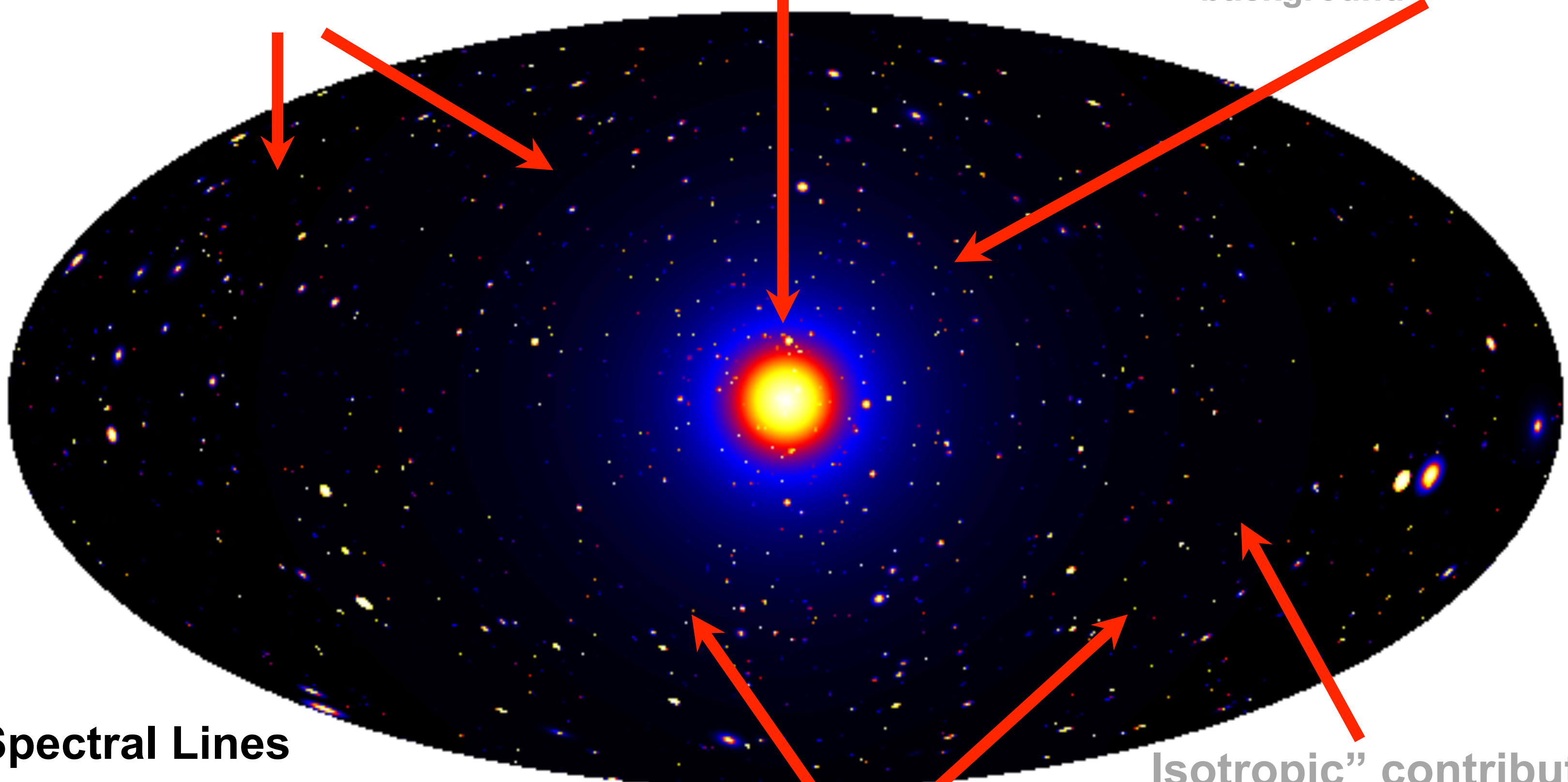
Astrophysics (J-Factor)

Dark Matter Search Strategies

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

Galaxy Clusters
Low background, but low statistics

Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

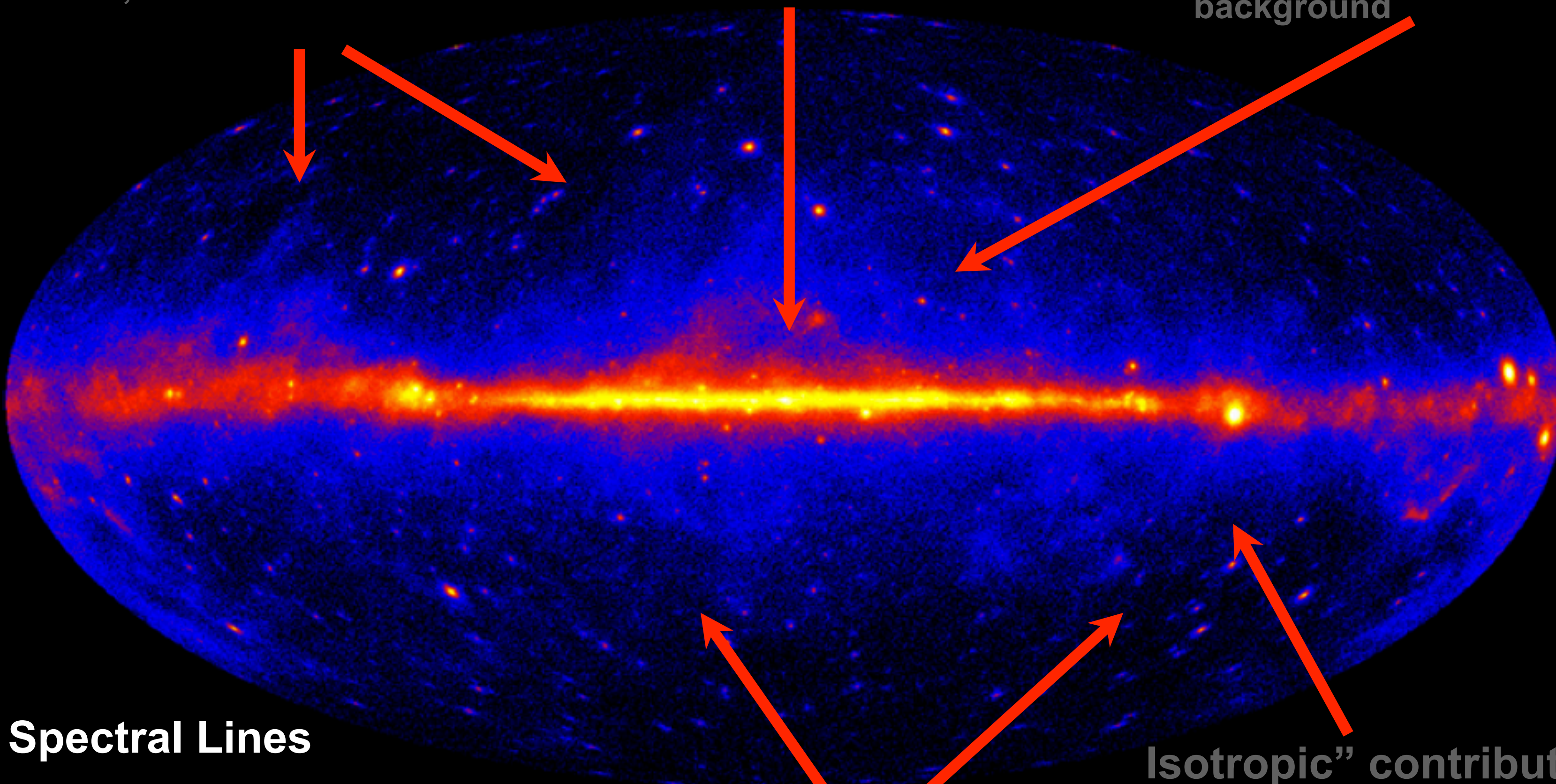
Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195

Search Strategies (against the γ-ray Sky)

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

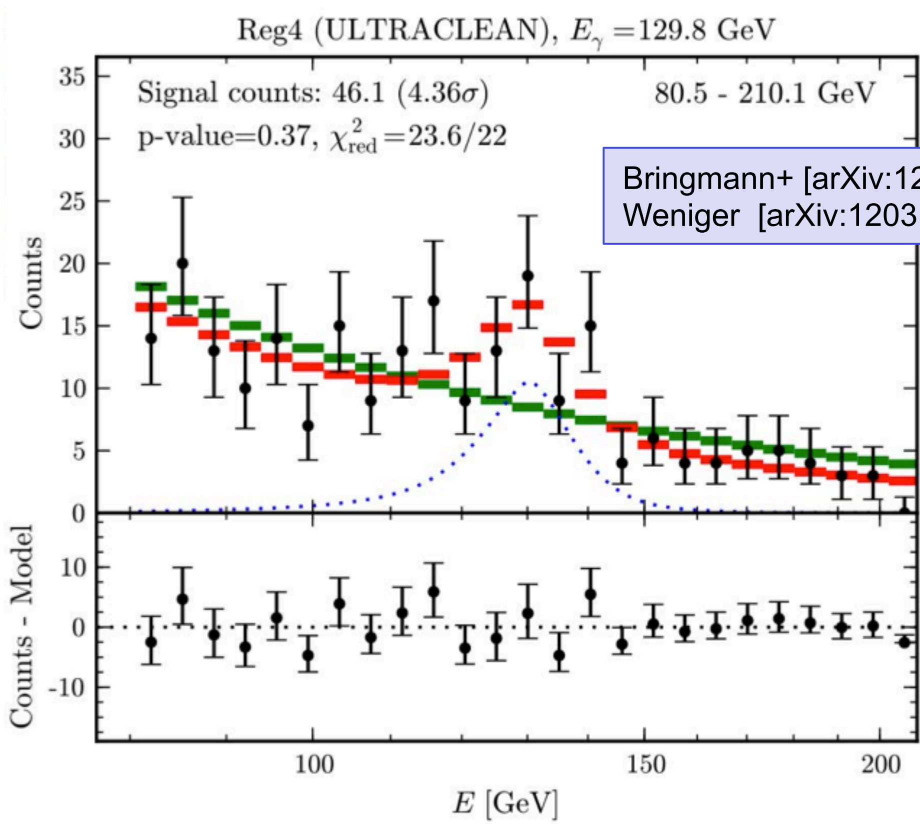
Galaxy Clusters
Low background, but low statistics

Isotropic” contributions
Large statistics, but astrophysics, galactic diffuse background

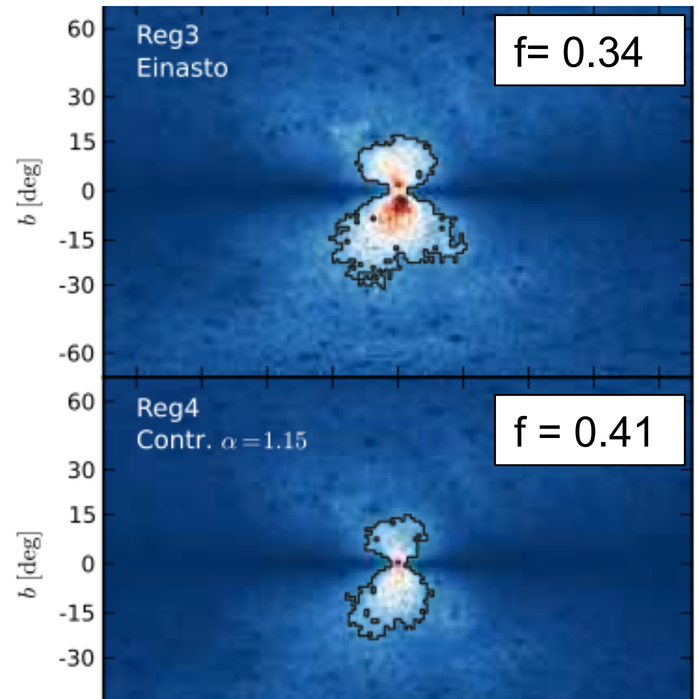
3 Years Sky > 1 GeV

EVIDENCE FOR 130GeV γ-RAY LINE?

The Context: Narrow Feature at 130 GeV



Bringmann+ [arXiv:1203.1312]
Weniger [arXiv:1203.2797]



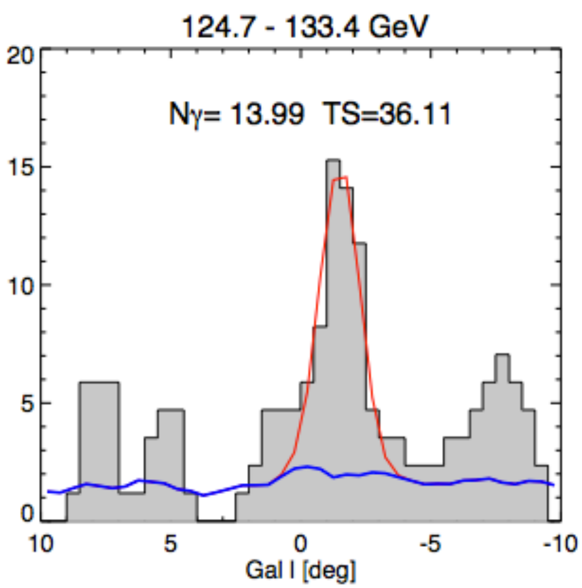
Fractional Residual (i.e., S/N):
$f = s_{local}^2 / n_s$

Bringmann et al. and Weniger showed evidence for a narrow spectral feature near 130 GeV near the Galactic center (GC).

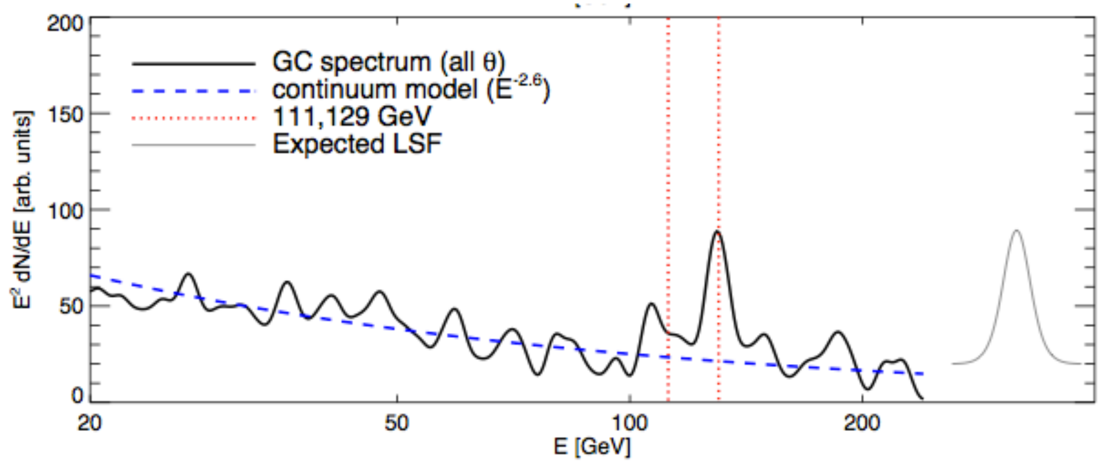
- Signal is particularly strong in 2 out of 5 test regions, shown above.
- Over 4σ, with S/N > 30%, up to ~60% in optimized regions of interest (ROI).

More Context

Gal. Long. Profile at ~130GeV



Energy Spectrum from GC



Su & Finbkbeiner [arXiv:1206.1616]

Su & Finkbeiner [arXiv:1206.1616v2] showed that the spectral feature was close to, but slightly offset from, the GC.
•Their likelihood analysis included the spatial morphology of signal, and a data-driven model of Galactic astrophysical backgrounds.
•They claimed **6.0σ** statistical significance, after a trials factor of ~6000, but acknowledge uncertainties of modeling the Galactic astrophysical backgrounds.

FERMI-LAT LINE SEARCH

Methodology: event selection, search region optimization, fitting procedures

Data Selection

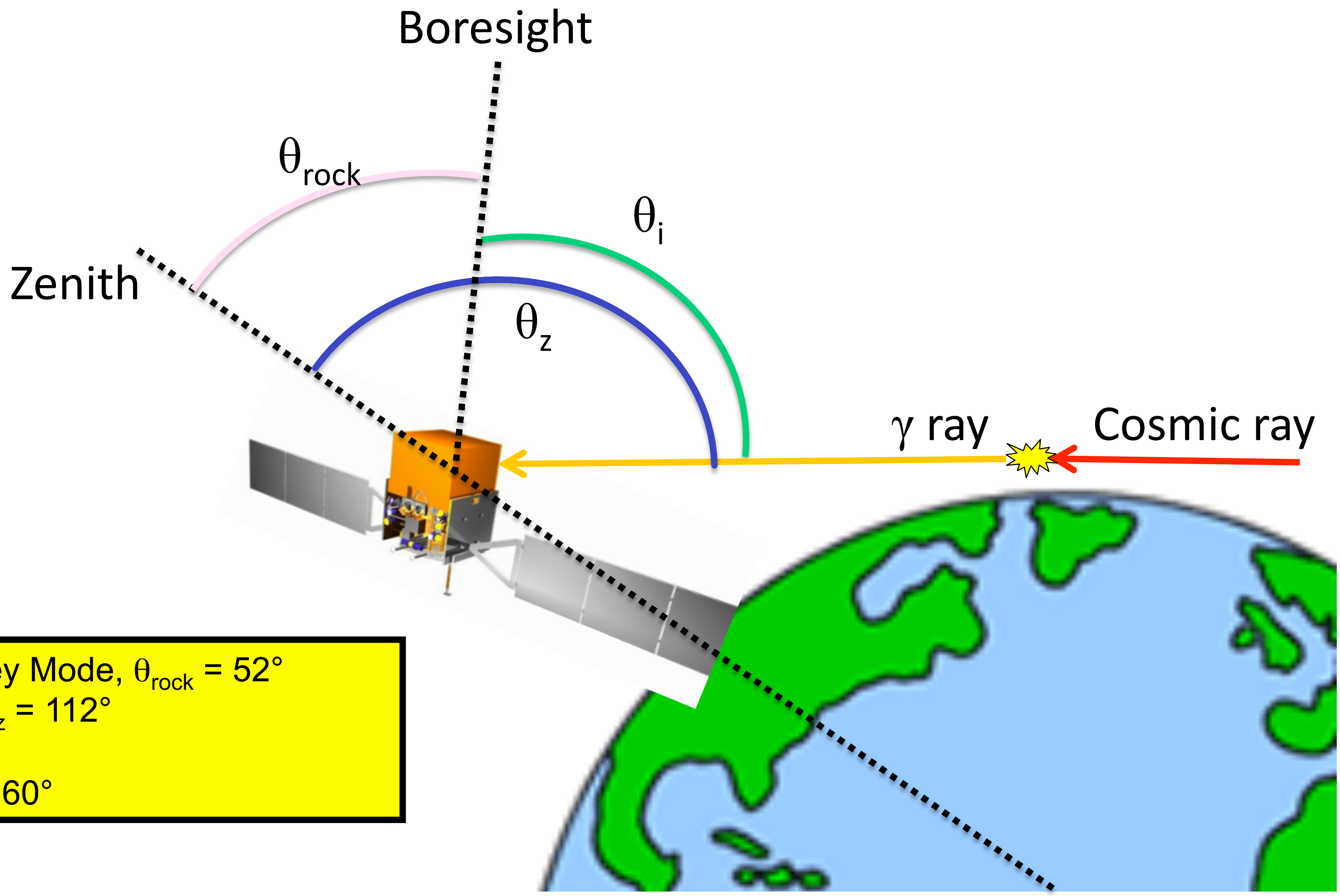
Parameter	Galactic data	Limb data
Observation Period	2008 August 4 – 2012 April 4	2008 August 4 – 2012 October 6
Mission Elapsed Time (s)	$[239557447, 356434906]$	$[239557447, 371176784]$
Energy range (GeV)	$[2.6, 541]$	$[2.6, 541]$
Zenith cut (°)	$\theta_z < 100$	$111 < \theta_z < 113$
Rocking angle cut (°) [a]	$\lvert\theta_r\rvert < 52$	$\lvert\theta_r\rvert > 52$
Data quality cut[b]	Yes	Yes
Source masking (see text)	Yes	No

[a] Applied by selecting on `ROCK_ANGLE` in *gtmktime*.

[b] Standard data quality selection `DATA_QUAL == 1 && LAT_CONFIG == 1` in *gtmktime*.

- Search for γ-ray lines from 5 to 300 GeV using 3.7 years of flight data
- We use the **P7_REP_CLEAN** event selections
    - Same selection criteria, updated calibibrations w.r.t. public **P7CLEAN**
    - Released to public once diffuse emission models / IRFs validated

The Earth Limb: Background & Control Sample

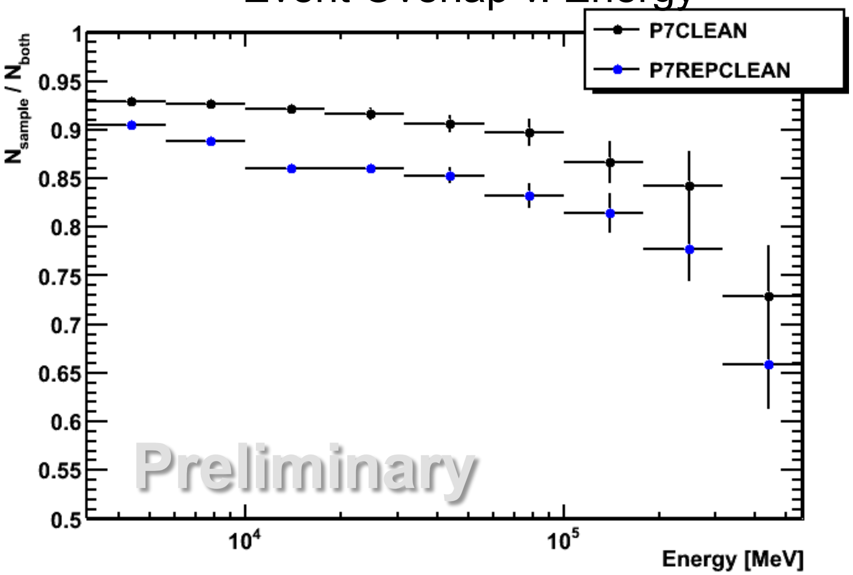


Sky Survey Mode, θ_{rock} = 52°
Limb at θ_{rz} = 112°

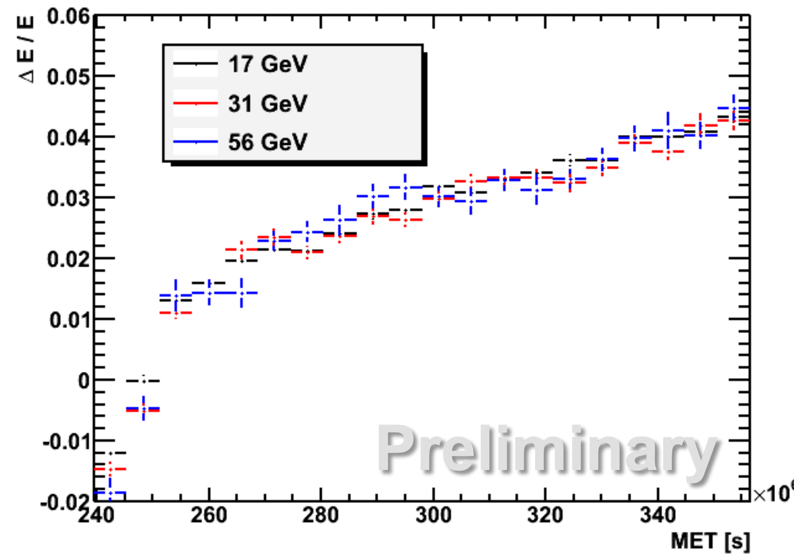
Limb: θ_i > 60°

Data Reprocessing with Updated Calibrations

Event Overlap v. Energy



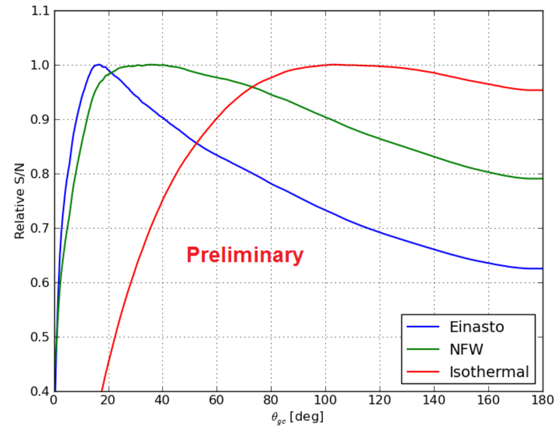
Energy Shift v. Time

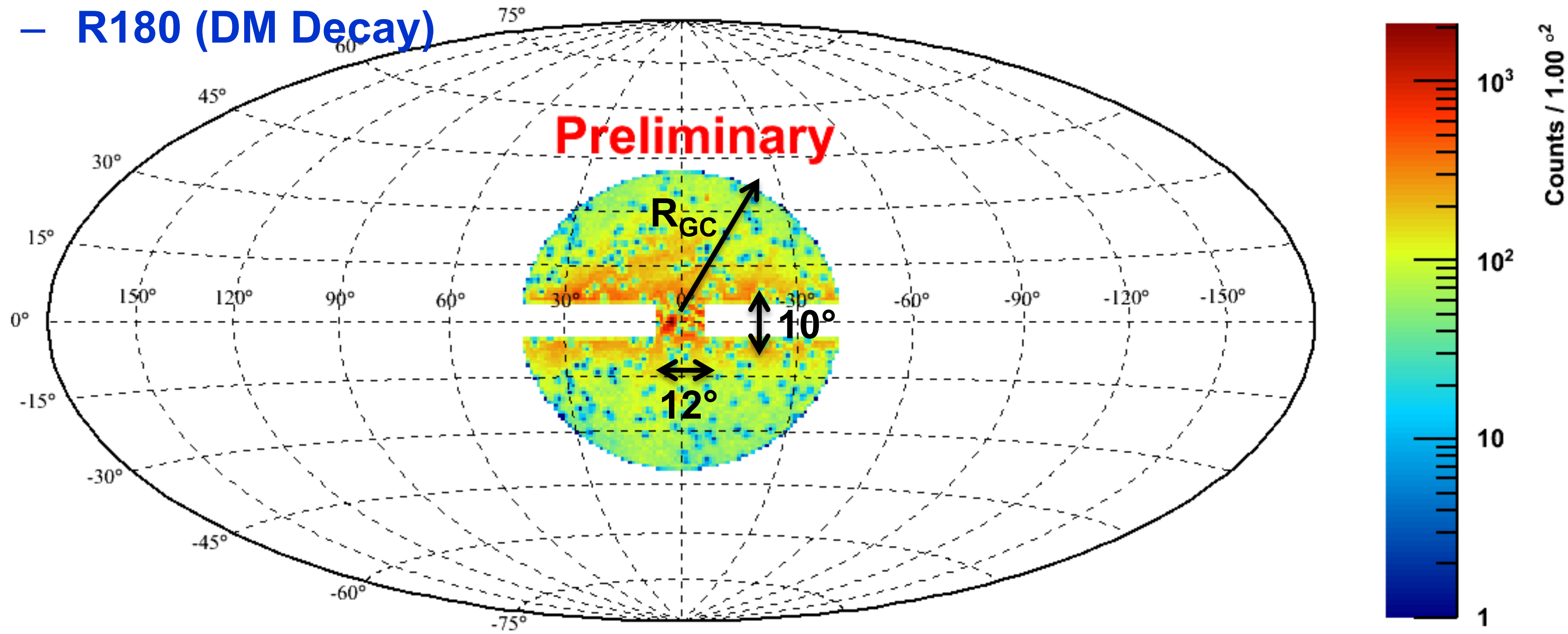


- Reprocessing Data with updated calibrations (primarily Calorimeter)
- Improves the agreement between the TKR direction and the CAL shower axis and centroid at high E, improving the direction resolution
- Corrects for loss in CAL light yield b/c of radiation damage (~4% in mission to date)
- 80%+ overlap in events between original and reprocessed samples

Optimizing the Region of Interest (ROI)

- Optimize ROI for a variety of DM profiles
  - Find R_{GC} that optimizes S/sqrt(B)
- Search in 5 ROIs
  - R3 (3° Circle)
  - R16 (Einasto Optimized)
  - R41 (NFW Optimized)
  - R90 (Isothermal Optimized)
  - R180 (DM Decay)





Standard "1D" PDF for Line Search

Predicted Spectrum | Signal Model | Background Model

$$C(E'|\vec{\alpha}) = n_{\rm sig} D_{\rm eff}(E'|E_\gamma) + \frac{n_{\rm bkg}}{c_{\rm bkg}} \left(\frac{E'}{E_0}\right)^{-\Gamma_{\rm bkg}} \eta(E')$$

$$D_{\rm eff}(E';E_\gamma) = \int^{FoV}\int^{ROI} D(E';\theta|E_\gamma)\frac{I_{\rm sig}(\hat{p})\mathcal{E}(\hat{p},\theta,E_\gamma)}{n_{\rm sig}} d\Omega d\Omega_{\hat{v}}$$

Effective Energy Dispersion

$$\eta(E') = \int^{FoV}\int^{ROI} \frac{I_{\rm bkg}(\hat{p})\mathcal{E}(\hat{p},\theta,E_\gamma)}{n_{\rm bkg}} d\Omega d\Omega_{\hat{v}}$$

Effective Area Corrections

Perform Likelihood Fitting to Total Energy Spectrum in ROI

•Signal model is effective instrument resolution

•Background model is power-law X effective area corrections

Fit for:

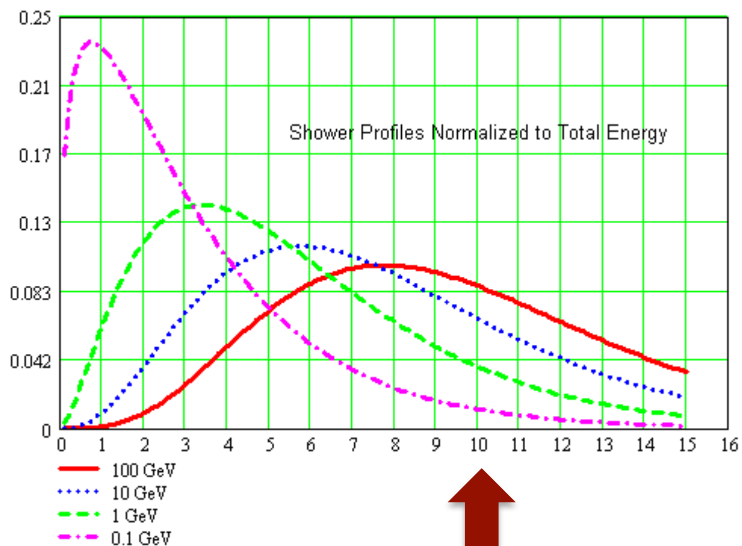
•power-law index ($\Gamma_{\rm bkg}$)

•number of signal and background events ($n_{\rm sig}$, $n_{\rm bkg}$)

$c_{\rm bkg}$ is given by normalization of background model

θ-Dependence of Energy Resolution

The Shower Profile from 100 MeV -> 100 GeV



Total LAT depth on axis = 10.1 X_0

Energy Dispersion for Several θ

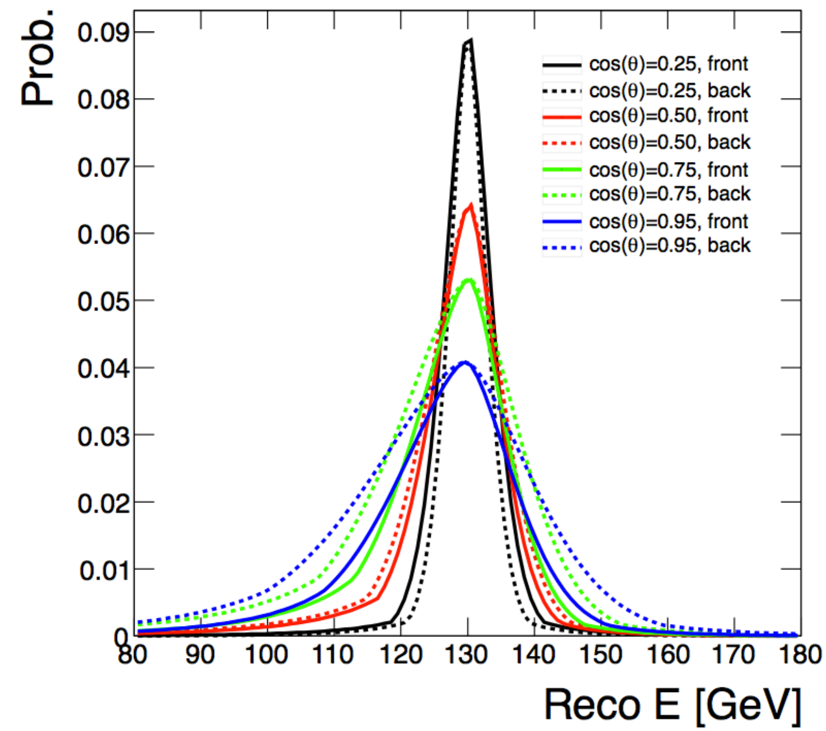
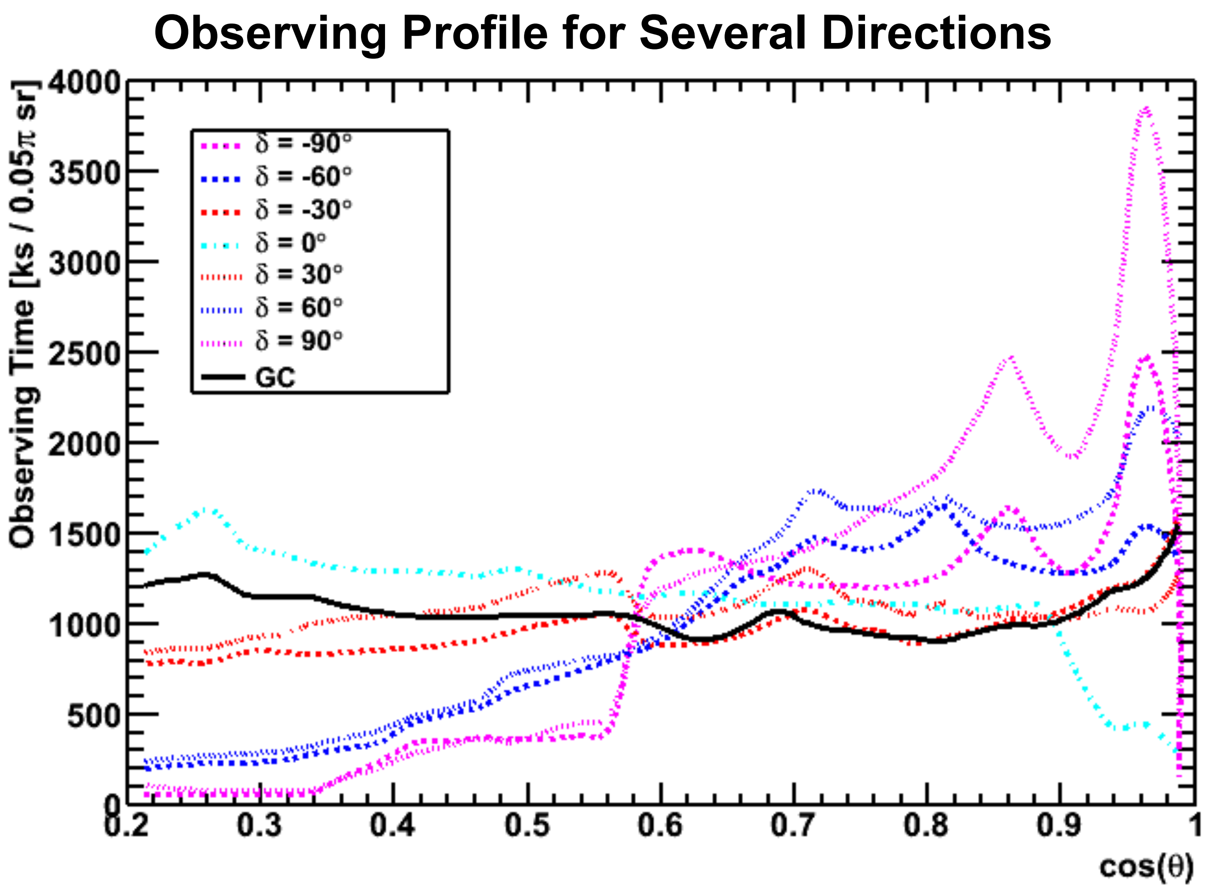


Fig. from Whiteson JCAP11(2012)008 [arXiv:1208.3677v2]. Made using Fermi-LAT *ScienceTools* energy dispersion parameterization for P7CLEAN_V6 event class.

At high energies (>10GeV) EM showers are not fully contained.
The Energy resolution improves off-axis as the projection effect increases the containment fraction.

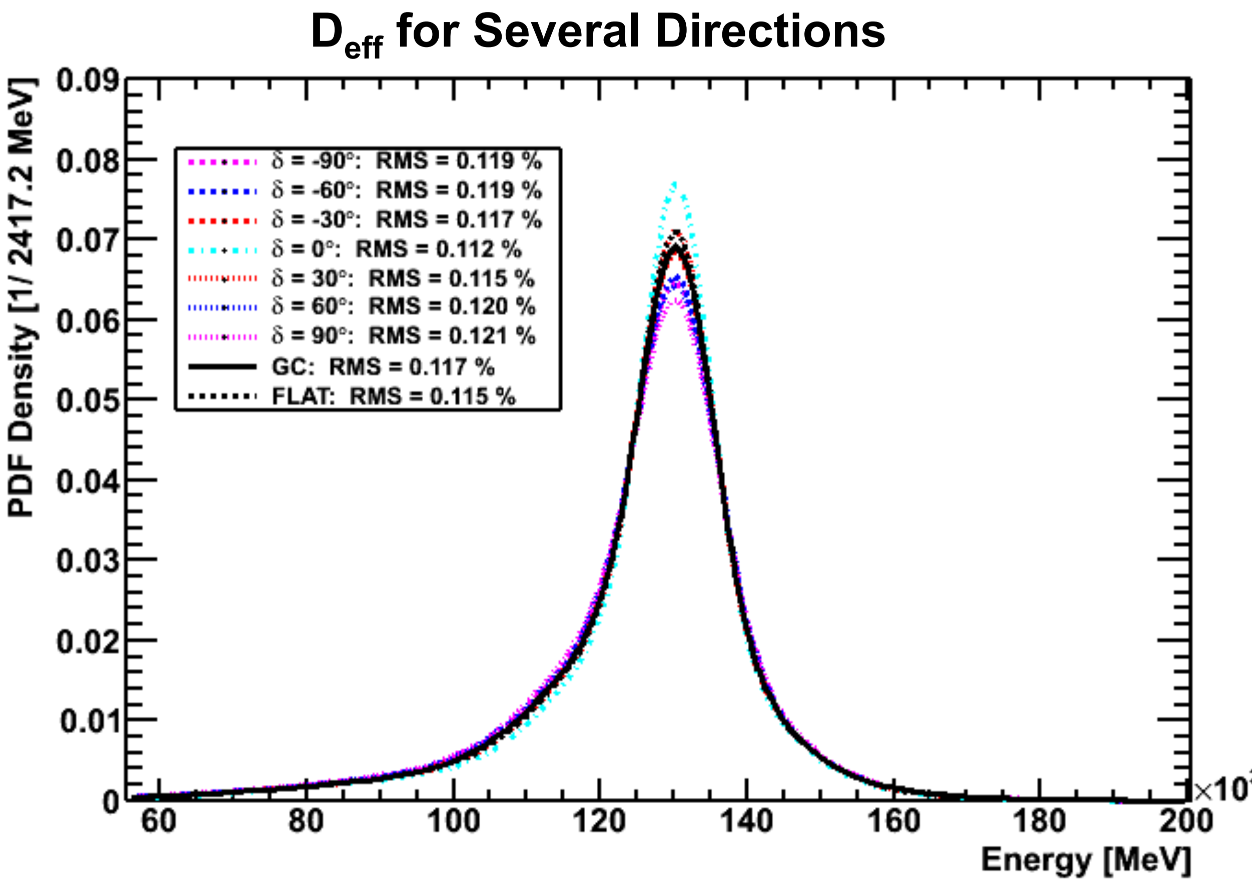
Observing Profiles Variations



•Averaged over years, the observing profile depends primarily on the DEC of the Region of Interest (ROI).

•The Galactic Center gets somewhat more time right on-axis than other sources (and less time slightly off-axis). This is because DEC_{GC} ~ $Inclination_{orbit}$

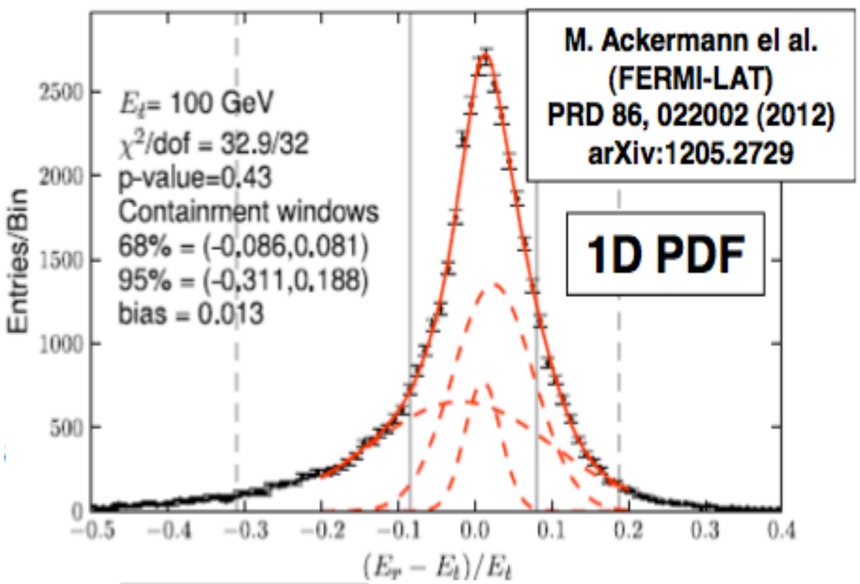
θ-averaged Energy Resolution by Declination

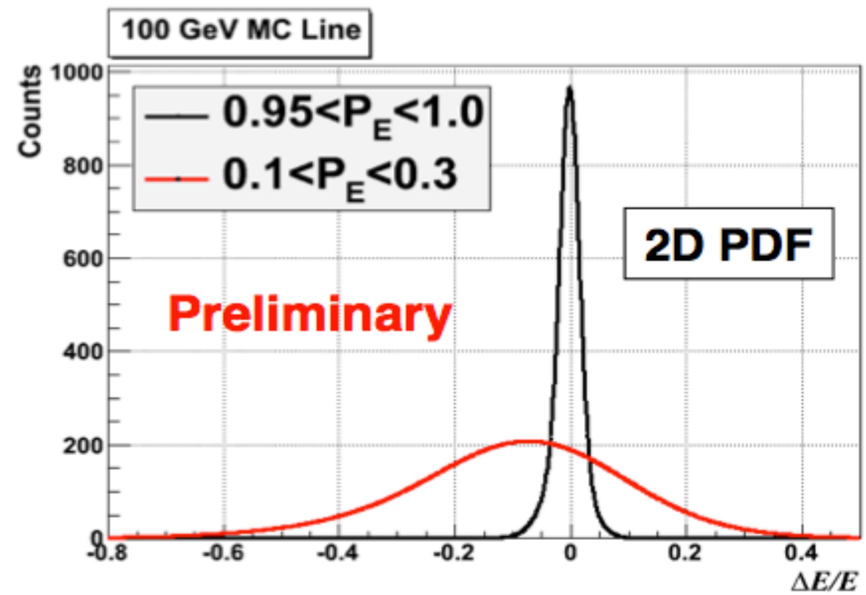


- The θ-averaged D_{eff} weighted for observing profile varies moderately with declination (δ).

- Using the wrong profile will not induce a signal, but can scale the n_{sig} and the significance of a signal by up 25%.

Improved Energy Resolution Model





- Updated analysis adds a 2nd dimension to line model: P_E.
    - P_E is the probability that measured energy is close to the true energy.
- "2D PDF" (a function of both energy and P_E).
    - Break Line into 10 P_E slices and fit triple Gaussian in each slice.
- Similar to public IRF description, which uses cosθ instead of P_E
- Including $P_E \rightarrow$ ~15% improvement to signal sensitivity (when there is signal) and counts upper limit (when there is no signal).

Improved “2D” PDF for Line Search

Predicted Spectrum — Signal Model — Background Model

$$C(E', P_\mathrm{E}|\vec{\alpha}) = n_\mathrm{sig} D_\mathrm{eff}(E', P_\mathrm{E}|E_\gamma) w_\mathrm{sig}(P_\mathrm{E}) + \frac{n_\mathrm{bkg}}{c_\mathrm{bkg}} \left(\frac{E'}{E_0}\right)^{-\Gamma_\mathrm{bkg}} \eta(E') w_\mathrm{bkg}(P_\mathrm{E})$$

$$D_\mathrm{eff}(E'; E_\gamma) = \int^{FoV} \int^{ROI} D(E'; \theta|E_\gamma) \frac{I_\mathrm{sig}(\hat{p})\mathcal{E}(\hat{p}, \theta, E_\gamma)}{n_\mathrm{sig}} d\Omega d\Omega_{\hat{v}}$$

Effective Energy Dispersion

$$\eta(E') = \int^{FoV} \int^{ROI} \frac{I_\mathrm{bkg}(\hat{p})\mathcal{E}(\hat{p}, \theta, E_\gamma)}{n_\mathrm{bkg}} d\Omega d\Omega_{\hat{v}}$$

Effective Area Corrections

Including P_E in energy dispersion model:

- Include distributions of P_E for signal, $w_\mathrm{sig}(P_\mathrm{E})$, and background, $w_\mathrm{bkg}(P_\mathrm{E})$ in PDF.
- Take both from flight data for entire ROI & energy fit window.
- As for “1D” model, we fit for Γ_bkg, n_sig, n_bkg
- c_bkg is given by normalization of background model

Test Statistic, Significance & Trials Factors

- **Test Statistic (TS) and local significance (s_{local}) given by ratio of likelihood of best fit to null hypothesis:**

$$TS = 2\ln\frac{\mathcal{L}(n_{\rm sig} = n_{\rm sig,best})}{\mathcal{L}(n_{\rm sig} = 0)}$$

$$s_{\rm local} = \sqrt{TS}$$

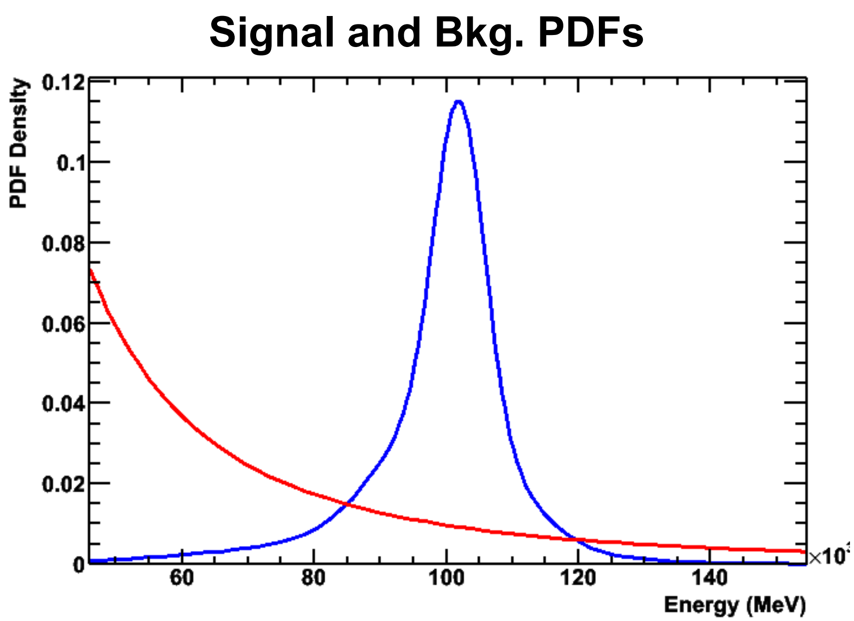
- **Estimate trials factor using method of Gross & Vitells**
  - **See [arXiv:1005.1891v3] and [arXiv:1105.4355v1]**

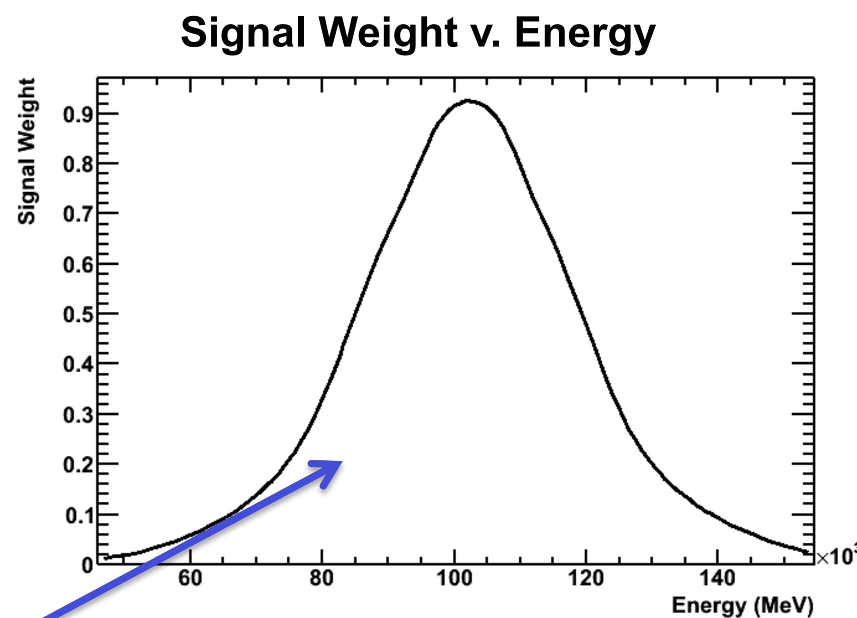
Systematics: instrumental and methodological uncertainties

Three Types of Systematic Uncertainties

- Uncertainties that affect the conversion from n_{sig} to $\Phi_{\gamma\gamma}$
  - E.g., exposure, express as $\delta\varepsilon / \varepsilon$
  - Do not affect fit significance
- Uncertainties that scale n_{sig}
  - E.g., modeling energy dispersion, express as $\delta n_{sig}/n_{sig}$
  - Affect significance, but will not induce false signals
- Uncertainties that induce or mask a signal
  - Express as uncertainty in fractional signal, δf

"Effective Background"





$$b_{eff} = N \int \frac{C_{\rm sig}(E')}{C_{\rm sig}(E') + C_{\rm bkg}(E')} dE'$$

$$f = \frac{n_{\rm sig}}{b_{\rm eff}} \simeq \frac{s^2_{\rm local}}{n_{\rm sig}}$$

- To consider instruments effects it is useful to look at the potentially induced fractional residual (f, i.e., the Signal-to-noise ratio).
- It is important to consider only the background "under" the signal peak ($b_{\rm eff}$).

Uncertainties of $\delta\epsilon/\epsilon$

- **Exposure variation across ROI**
  - **Depends on ROI, from <1% (R3) to ~14% (R180)**
  - **Can be removed by re-calculating J-factors for specific DM model**
- **Uncertainty of A_{eff} scale**
  - **Estimated at 10% for consistency checks on flight data**

These are smaller than the typical statistical variation on the upper limits which are typically ~50%.

Uncertainties of $\delta n_{sig}/n_{sig}$

- **Fit energy grid spacing**
  - **0.5 σ_E steps would miss at most 10% of signal**
- **Energy resolution**
  - **From CERN beam-test we estimate energy resolution know to 10%**
  - **MC studies show that this yields $\delta n_{sig}/n_{sig}$ = 7%**
  - **Also applicable to intrinsic broadening (e.g., from $Z^0\gamma$)**
- **P_E distribution variation**
  - **Varying P_E gives $\delta n_{sig}/n_{sig}$ = 1%**
- **Energy dispersion model θ-variation**
  - **Varying θ distribtuion gives $\delta n_{sig}/n_{sig}$ = 2%**

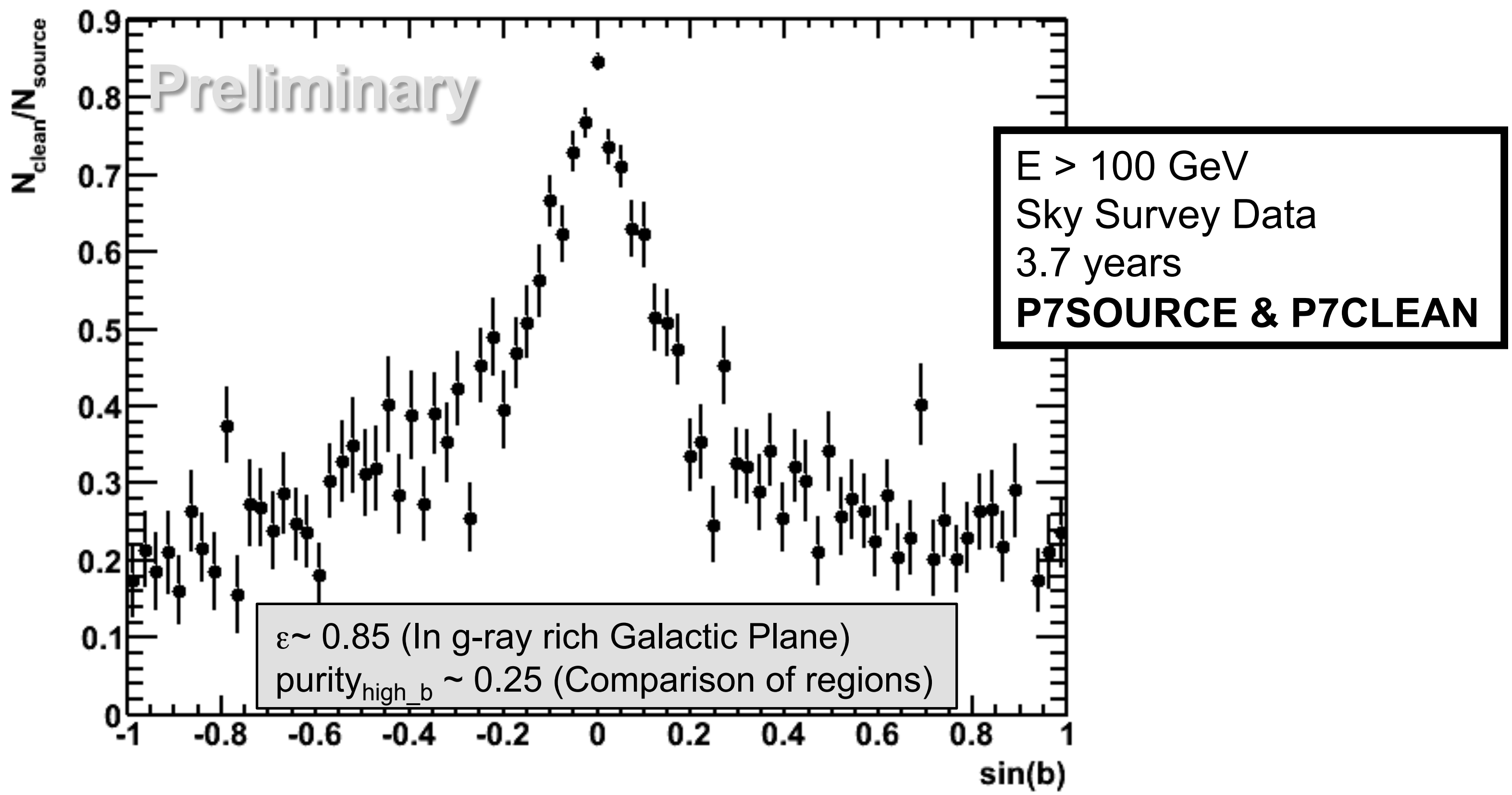
•These are smaller than the typical statistical variation.
•For a 5σ signal the systematic uncertainty would be 0.6σ, as compared to the expected statistical variation of 1σ.

Uncertainties of δf

- Cosmic-ray contamination
- Un-modeled effective area variations
- Astrophysical background modeling

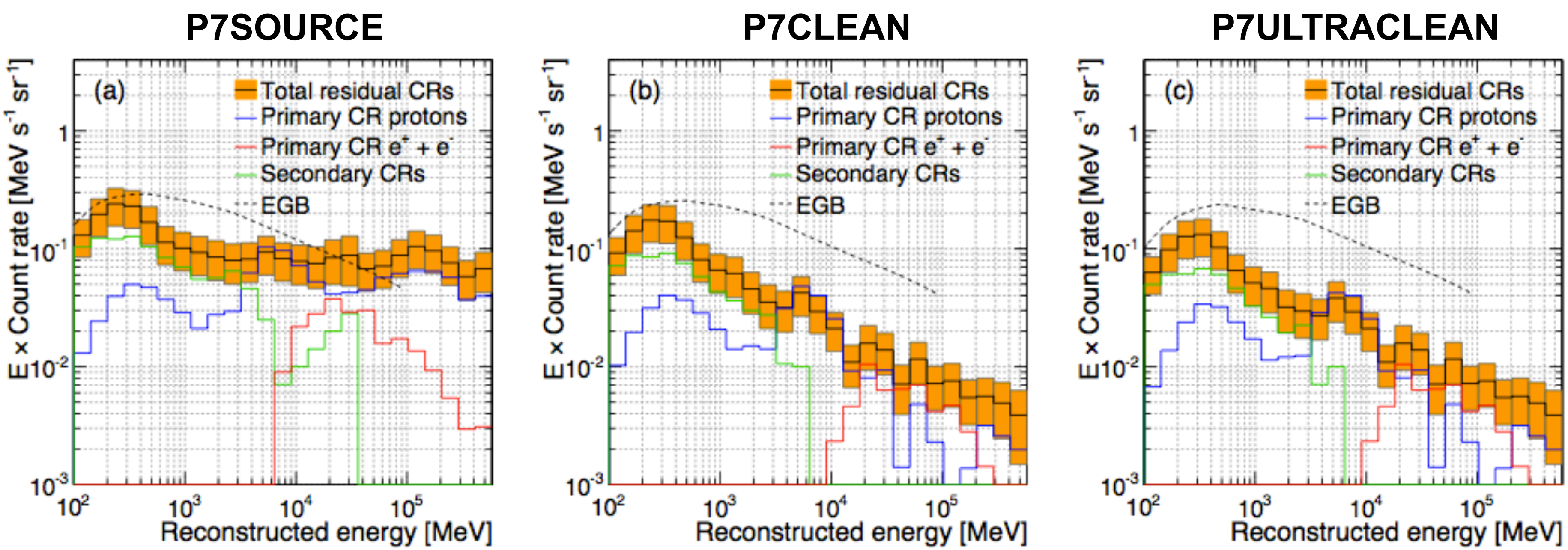
Cosmic-ray Background Contamination

Fraction of P7CLEAN events in P7SOURCE. vs. Gal. Lat.



- Above 100 GeV most of the high-latitude events in P7SOURCE that are not in P7CLEAN are not γ rays.
- CR-background reconstructed as γ rays will show a variety of spectral features, which can corrupt and compromise the sideband fit as well as induce fake signals.

Background Contamination Rates

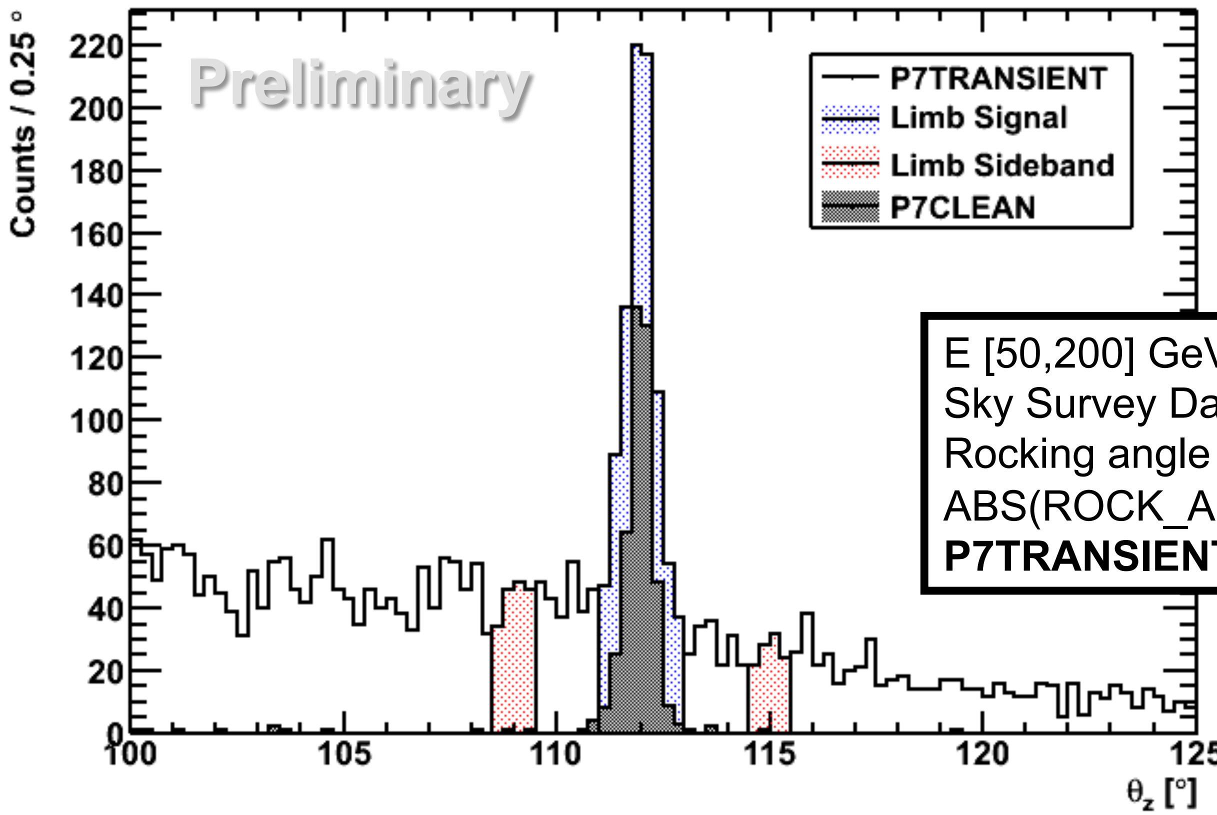


ApJS, 203, 4. [arXiv:1206.1896]

- Comparing P7SOURCE fits for small ROI in the galactic plane to large ROI where the P7SOURCE class is dominated by CR background is dangerous.
- The effect of residual contamination in P7CLEAN is small for large ROI (δf=0.014 for R180) and is **negligible** for smaller ROI near the GC ($\delta f < 0.01$ for R3)

Measuring Efficiency with the Earth Limb

Zenith Angle Distribution for P7TRANSIENT & P7CLEAN

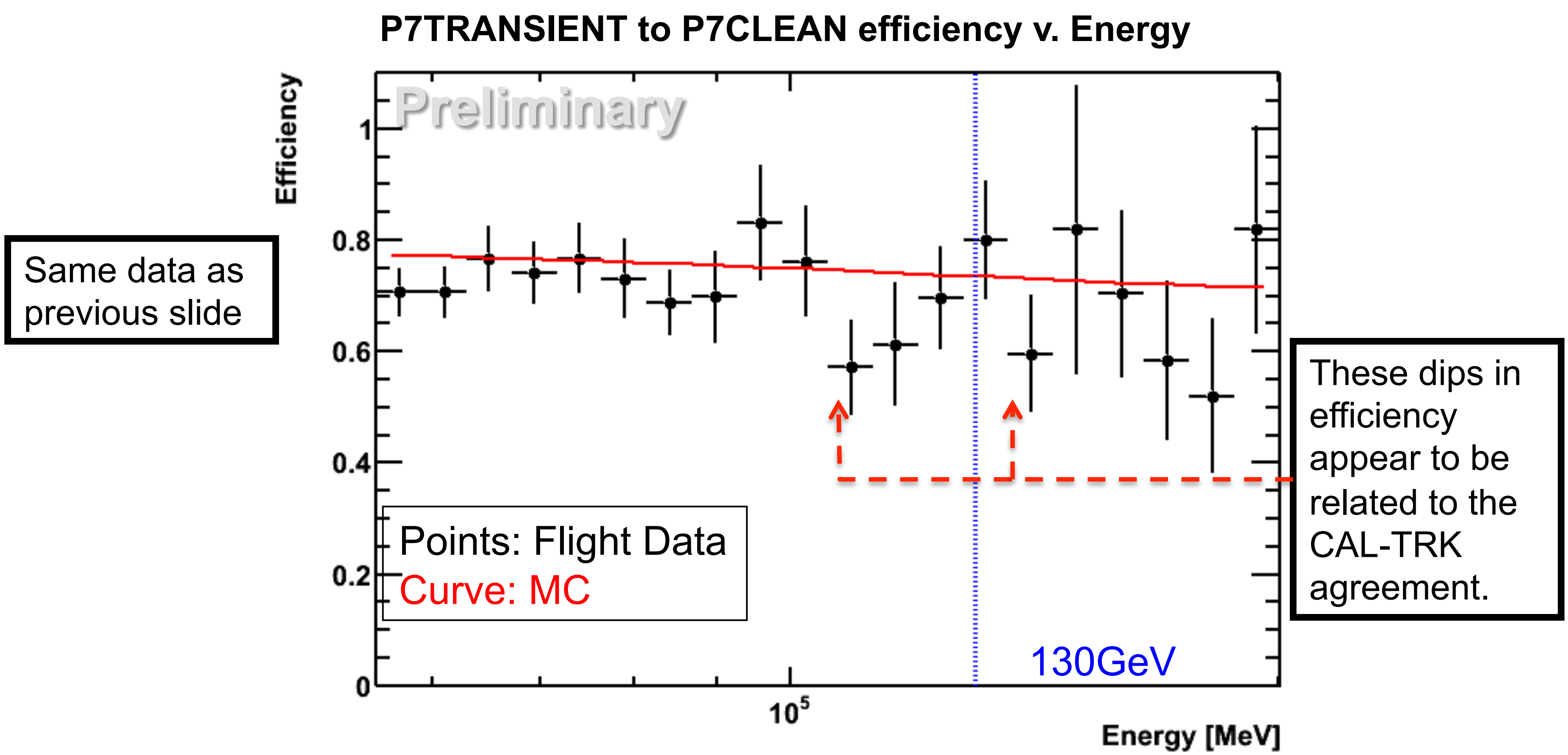


E [50,200] GeV
Sky Survey Data
Rocking angle cut reversed
ABS(ROCK_ANGLE)>52
P7TRANSIENT & P7CLEAN

•The Earth Limb is unique in that it can be seen in the loose P7TRANSIENT event class at high energies.

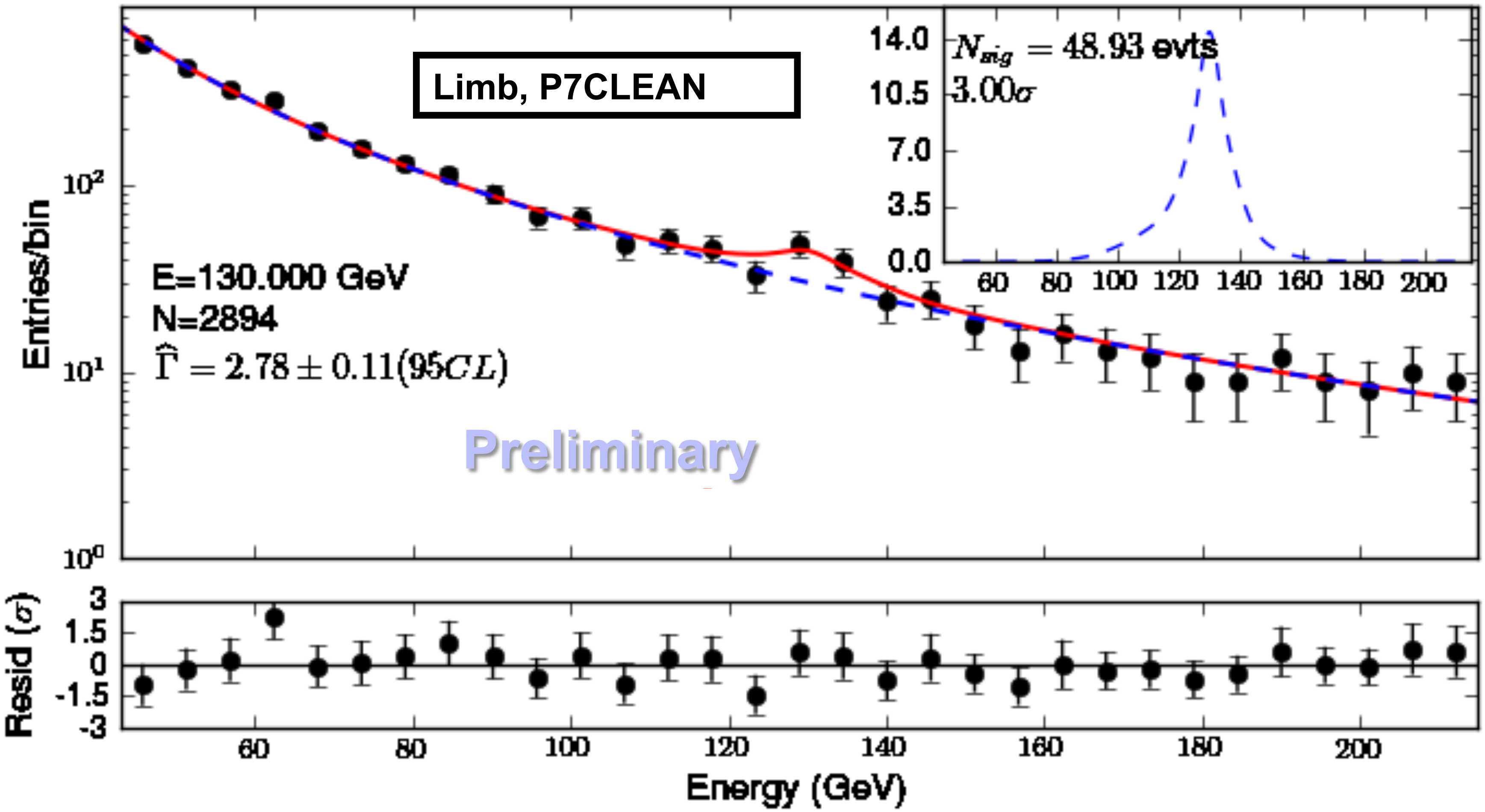
•This allows us to use it to measure efficiencies for tighter event classes as a function of energy.

P7TRANSIENT to P7CLEAN Efficiency



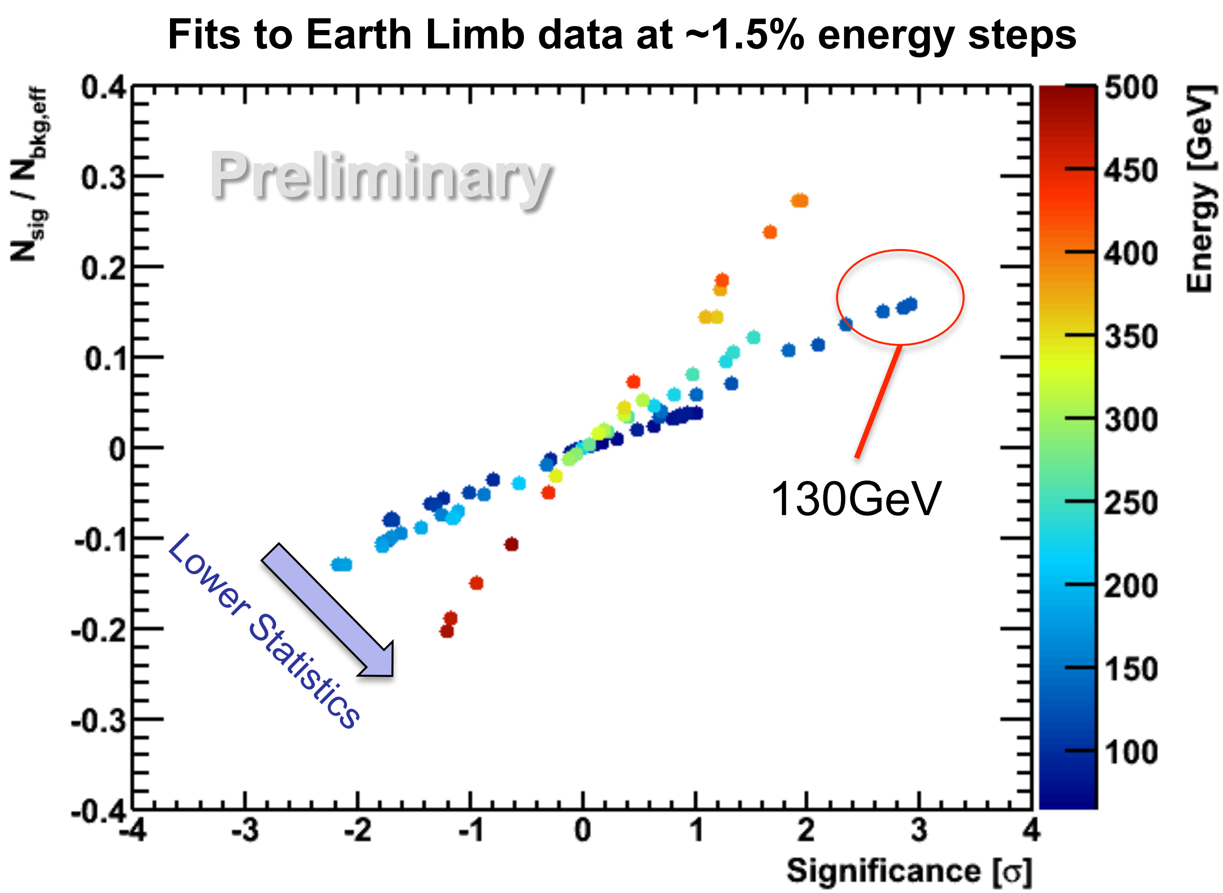
- The efficiency at ~115Gev is 0.57/0.75 = 75% of the MC prediction.
- This would cause something < 30% boost in signal at 130 GeV relative to the prediction from nearby energy bins.

Fitting the Earth Limb



- Fit to Earth Limb data results in a 3.0σ signal, with a fractional residual of f~20%
- Reduced to 2.0σ (f=14%) in P7_REP_CLEAN data

Earth Limb Residuals as a Function of Energy

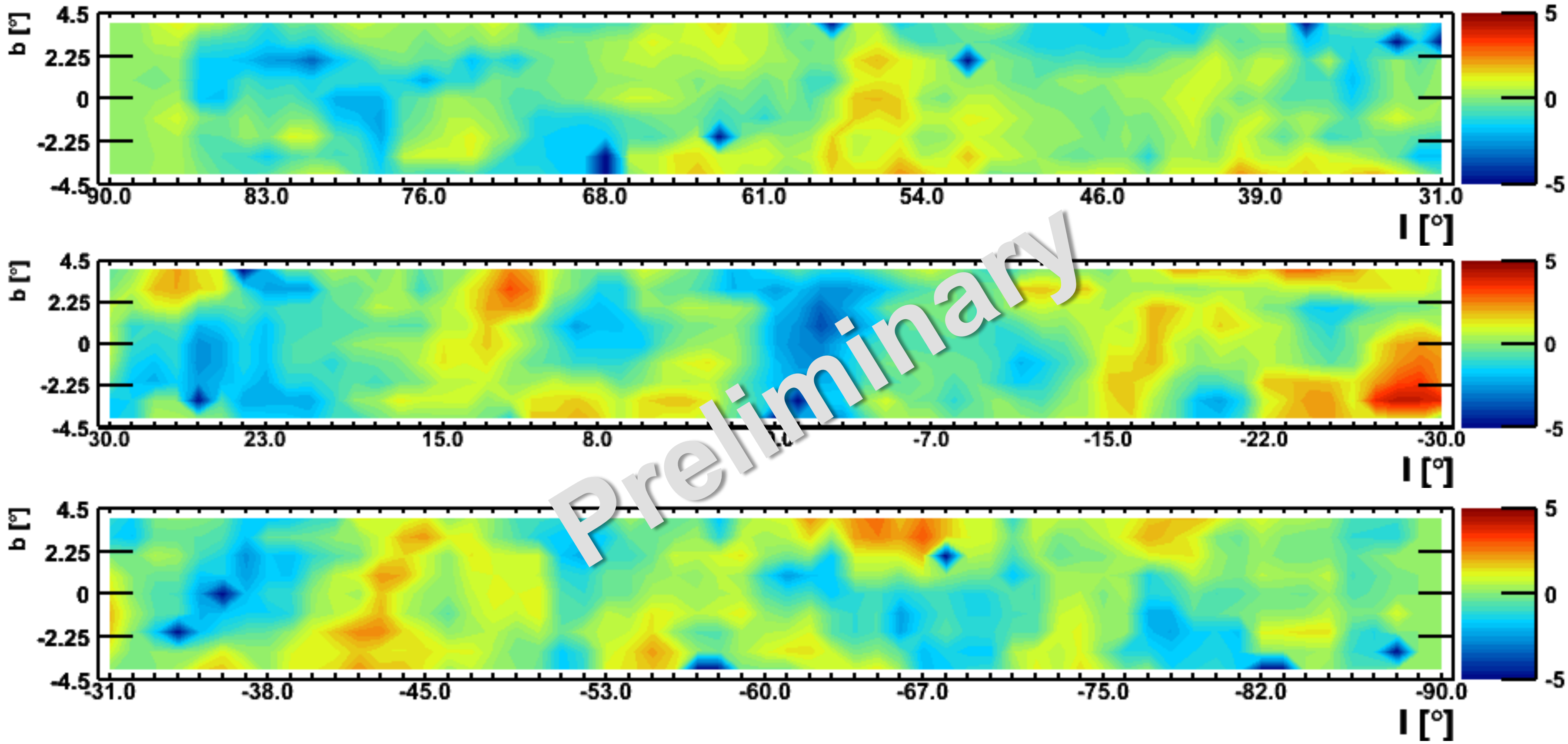


•Below 100 GeV the residuals in the limb are small (δf < 0.02).
•At higher energies make it difficult to exclude large fractional residuals.   At 130GeV we see S/N~18% and 3.0σ significance residuals.

Astrophysical background modeling

- Empirically, the assumption that large regions of the sky can be adequately modeled as a power-law holds very well
- However, we need to quantify the uncertainties associated with this approximation
- We use two methods:
  - Scanning many ROIs & energy and looking at the distribution of significances to quantify non-random behavior
  - Simulating data with a broken power-law, and fitting for a line at the break energy

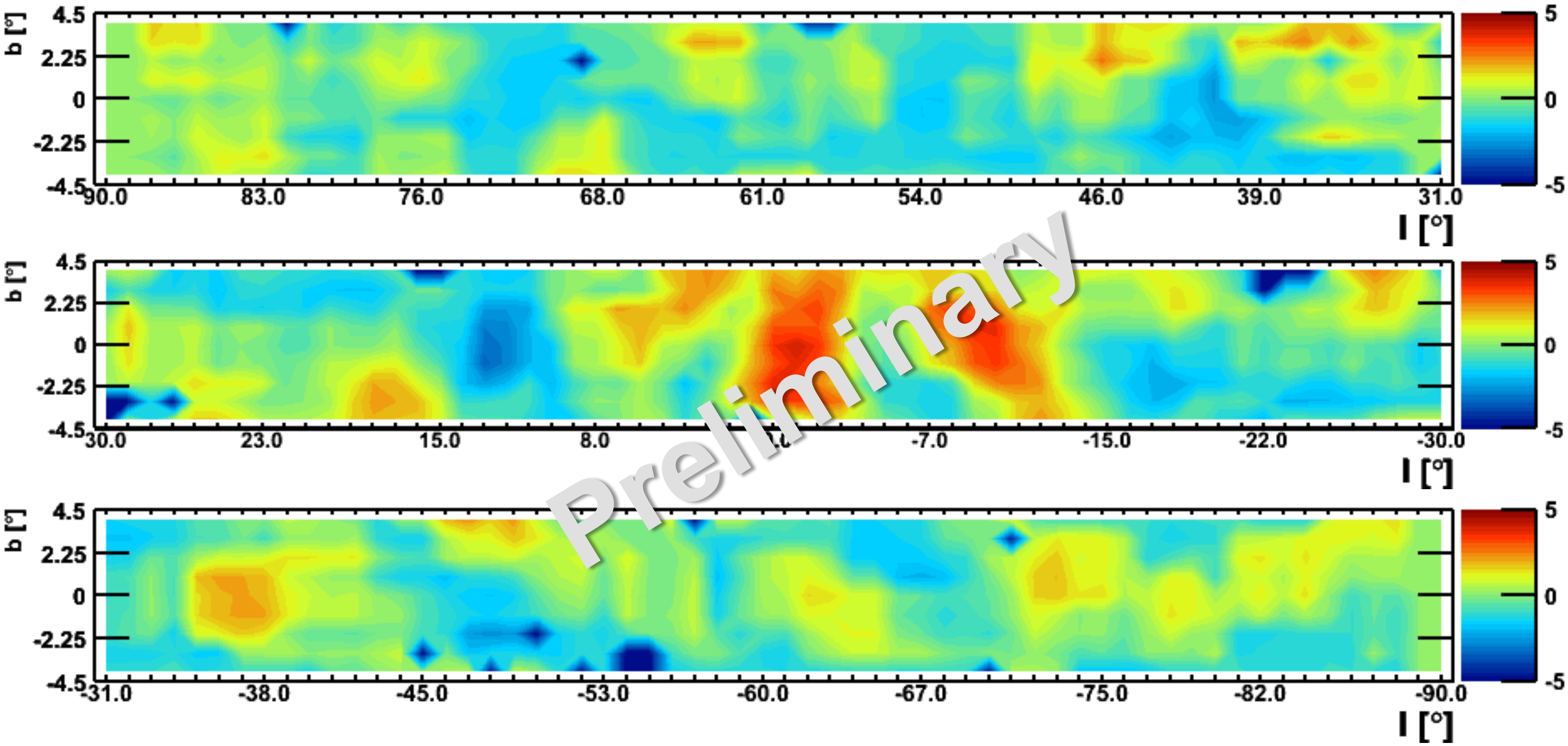
Fitted Excesses Along the Plane at 89GeV



•Signal significance in fit to power-law + 1D signal PDF at 130 GeV for 4°x4° boxes along the Galactic plane in 1° steps.

•The significance distributions look like noise with a few noticeable features of marginal significance (e.g., l,b = -28°,-4°).

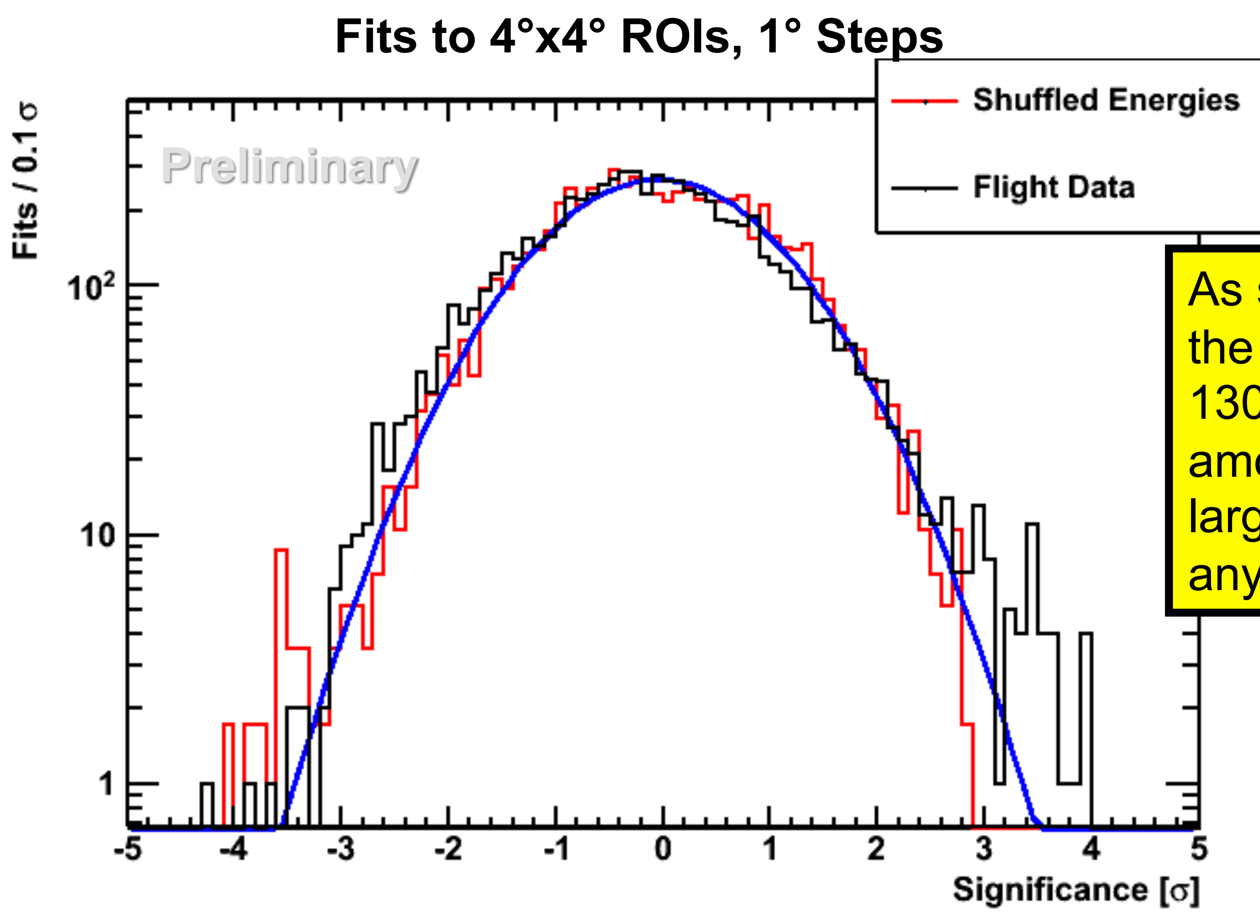
Fitted Excesses Along the Plane at 130 GeV



- The excesses near the GC at 130 GeV are among the largest seen at any energy at the 4°x4° scale, and stand out particularly at 8-16° scales

- Integrating the Galactic plane outside ±10° shows no excess at 130 GeV

Distribution of Significances



As stated earlier, the excess at 130GeV is among the largest seen at any energies.

- Distribution of significances for all ROI centered within a 20°x40° around the Galactic center.
- Signal energy scanned in 0.25σ energy steps between 65 and 500 GeV.
- Fits are to a powerlaw + 1D signal PDF.
- The red histogram shows fits using data with shuffled energies. The black histogram is flight data. The blue curve is a fit to the shuffled data, consistent with a unit width Gaussian with mean zero.

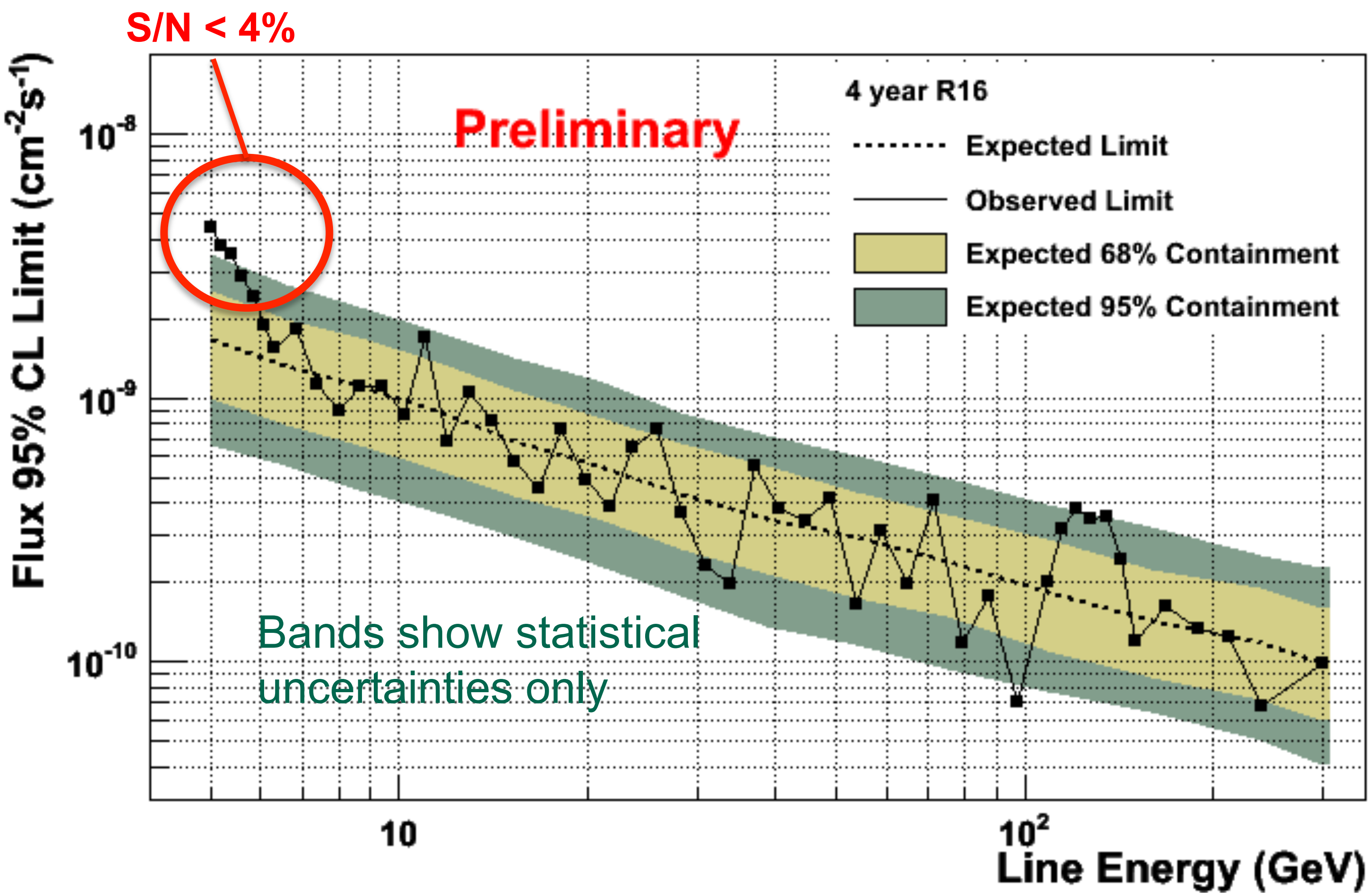
"Toy" Studies with a Broken Power-law

- **Estimated the size of the potential induced bias from modeling the Galactic astrophysical background as a power-law with "toy" experiments**
  - **Simulated background as a broken power-law**
  - **Fit for a signal at the break energy**
  - **A "reasonable" break (Γ 2.50 -> 2.65) induces a signal with $\delta f = 0.023$**

•We estimate the uncertainties of δf to be between 0.03 and 0.05, depending on the energy and ROI.
•Although this is small, with the very large statistics available at lower energies the systematic uncertainties can exceed the expected statistical uncertainties.
•This is true even up to energies > 100GeV in the largest ROI (R180).

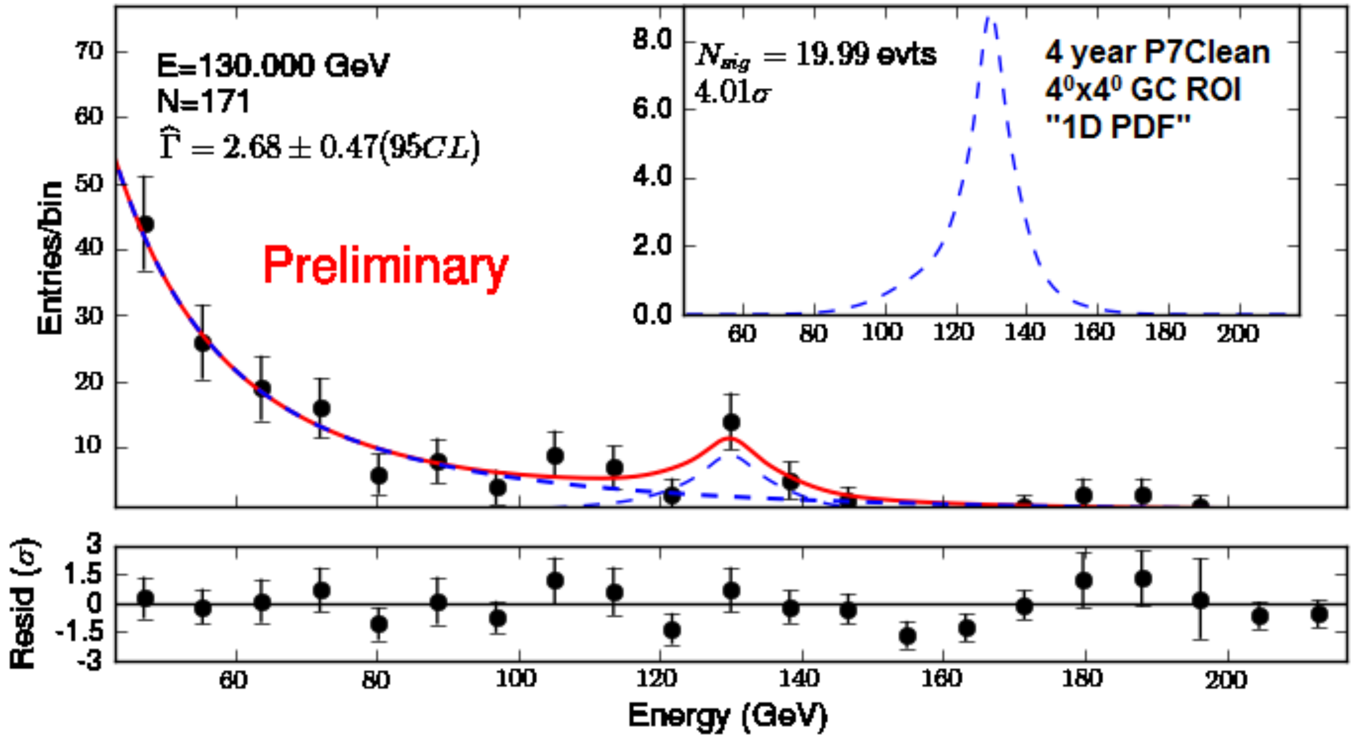
Results

Fermi-LAT Line Search Flux Upper Limits



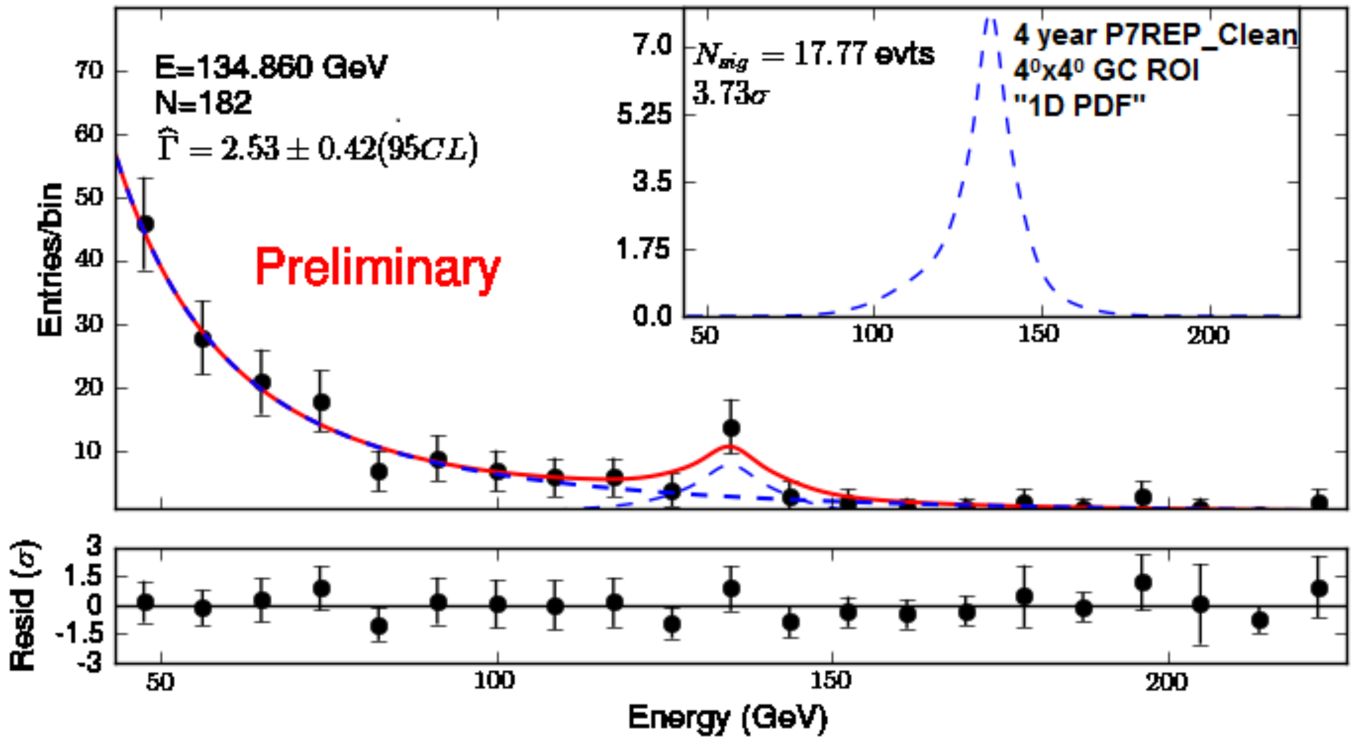
- Most of the limits fall within the expected bands.
- Near 135 GeV the limits are near or slightly above the upper edge of the bands.
- The excess at low energies .

Fermi-LAT Team Line Search at 135 GeV



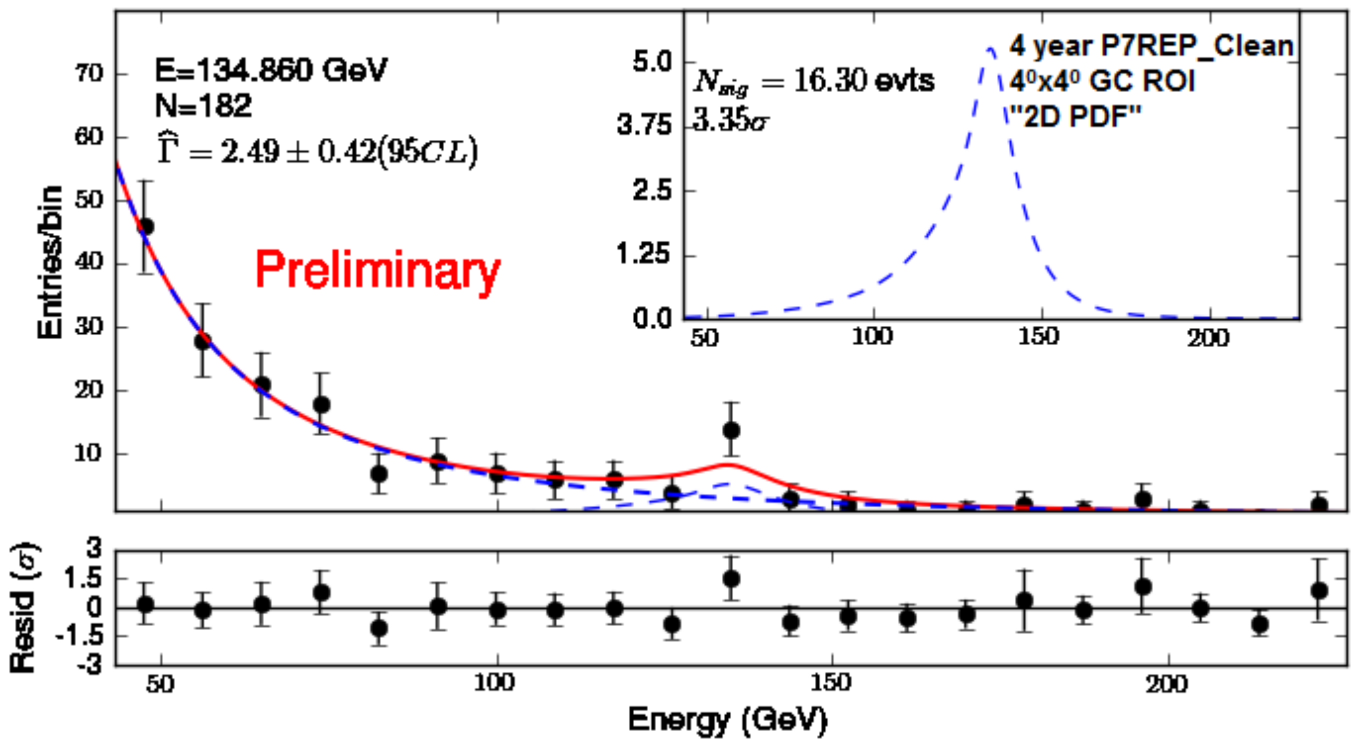
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)

Fermi-LAT Team Line Search at 135 GeV



- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- **3.73σ (local) 1D fit at 135 GeV with 4 year reprocessed data**
  - **Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)**

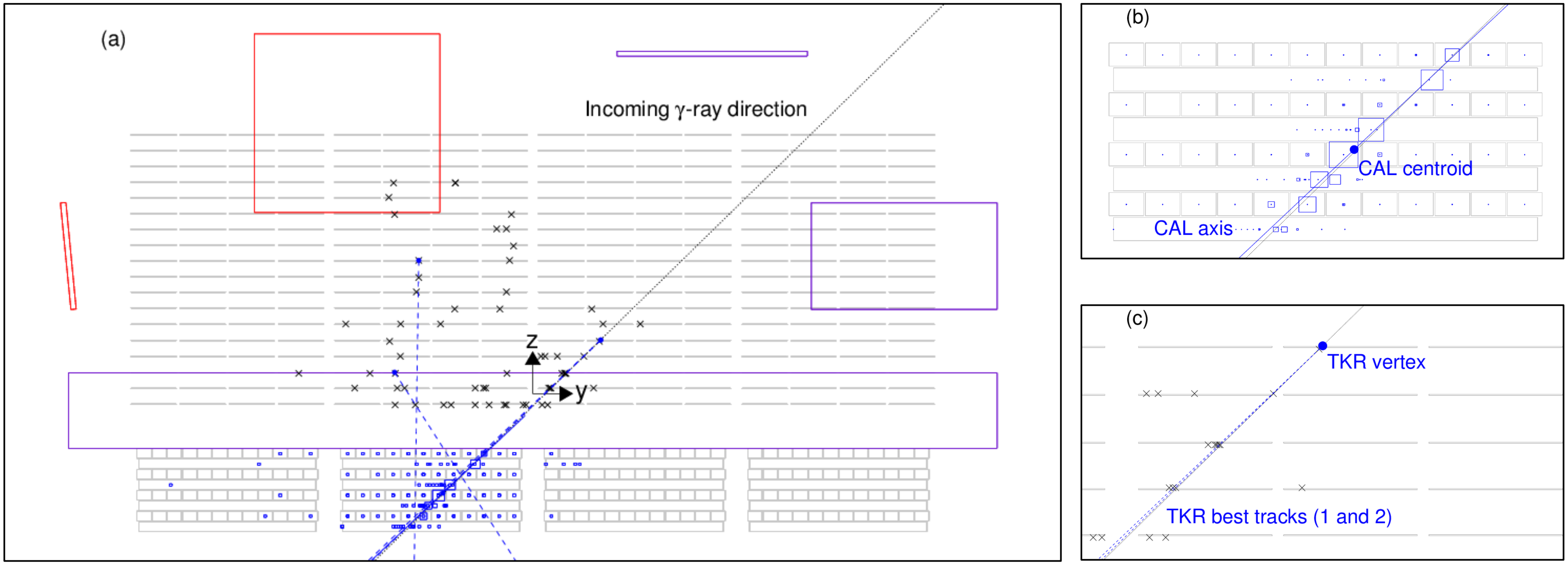
Fermi-LAT Team Line Search at 135 GeV



- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- 3.73σ (local) 1D fit at 135 GeV with 4 year reprocessed data
  - Look in 4°x4°GC ROI, Use 1D PDF (no use of P_E)
- **3.35σ (local) 2D fit at 135 GeV with 4 year reprocessed data**
  - **Look in 4°x4°GC ROI, Use 2D PDF (P_E in data)**
  - **<2σ global significance after trials factor**

Investigations of the Spectral Feature at 130 GeV

CAL/TKR Agreement, High Energy PSF, etc..



- CalTrackAngle: angle between CAL axis and TKR direction
- CalTrackDoca: Distance of Closest Approach (DOCA) between track and CAL centroid
- P_{CORE}: Probability that event is within the CORE of the PSF

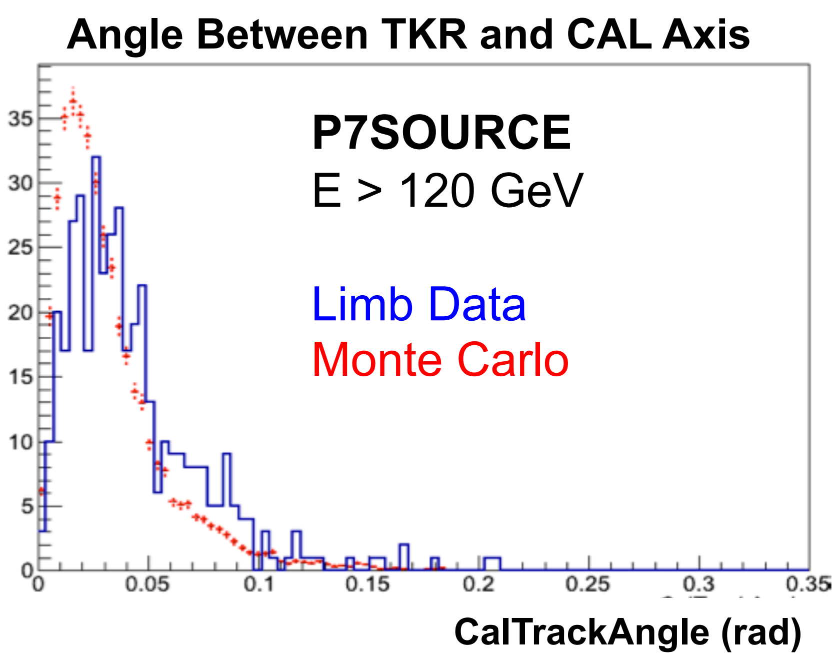
- Above ~10GeV the backsplash from the CAL causes many hits in the TKR and increases the probability of picking the wrong hit for a track and pulling the track direction well into the tails of the PSF.
- We use the TKR /CAL agreement to mitigate this and also to reduce CR background.

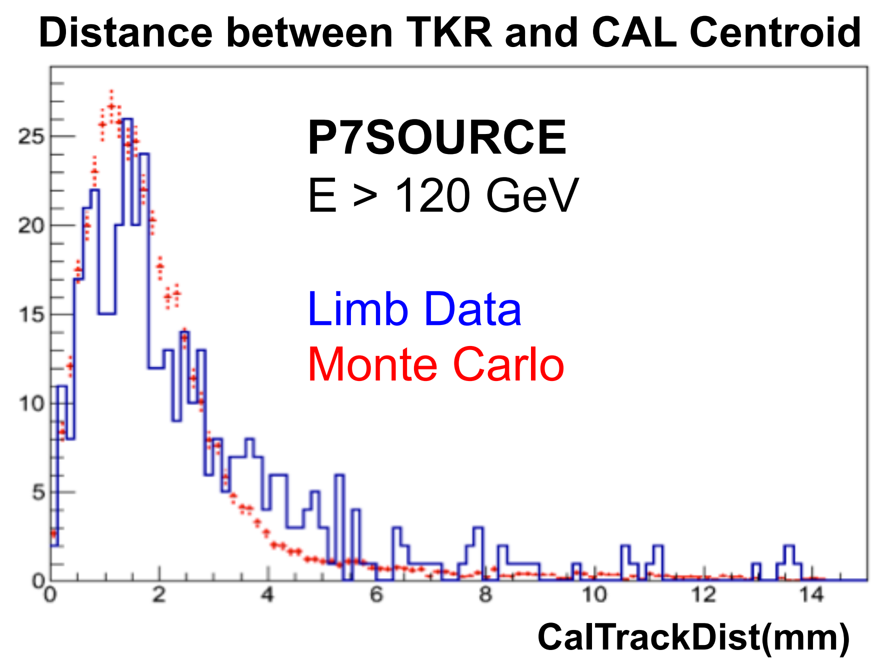
Event Selection Cuts

Selection	CUT	Comments
P7TRANSIENT	Quality Cuts	
	Charged Particle Veto Analysis	
	Loose cut on P_{all} (0.2)	Small feature in MC (S/N ~0.05)
P7SOURCE	CAL & TKR Vetos	
	Reject MIPs with CAL & TKR	
	CAL / TKR Agreement	
	PSF Quality	Depends on CAL/TKR agreement
	Tight cut on P_{all} (0.996 at 130GeV)	Depends on CAL/TKR agreement
P7CLEAN	Reject MIPs, but lose A_{eff}	
	Shape of event in CAL	
P7ULTRACLEAN	Tighter cut on P_{all} below 10GeV	

The two cuts in red appear to account for most of the difference between Earth Limb data and MC at high energies.

Data / Monte Carlo Comparisons

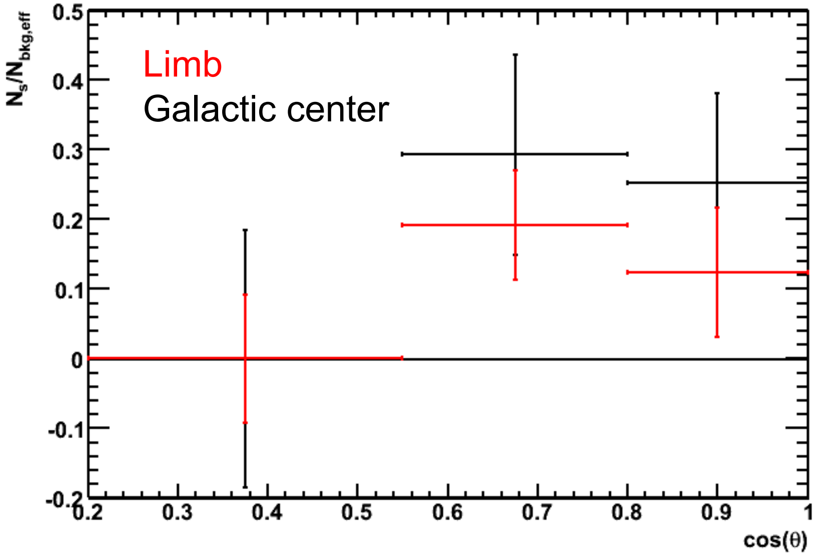




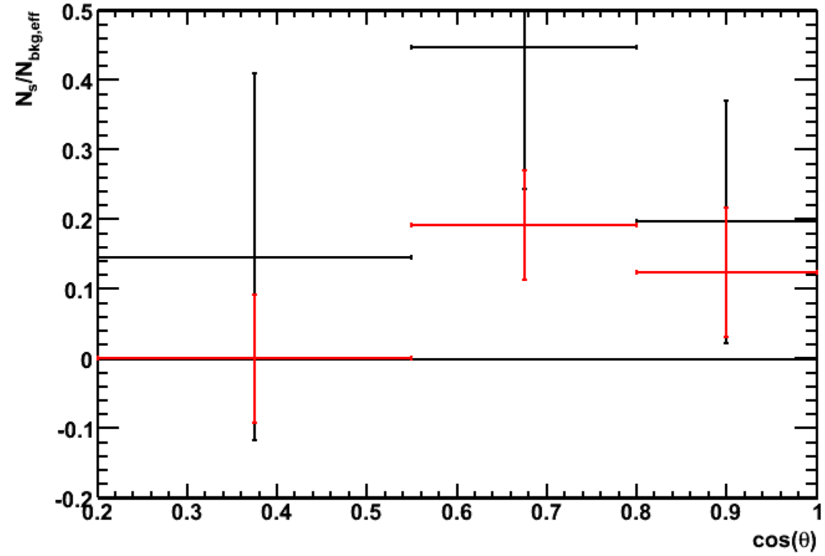
- Detailed comparisons between flight data and Monte Carlo simulations show that the CAL/TKR agreement is somewhat worse in the flight data than in the simulations.
    - Improved with reprocessed data
- These two variables are among the most important in the Classification Tree analyses used for event selection and classification.

Signal to Noise of Excess as a function of θ

12°x12° box around GC



8°x8° box around GC



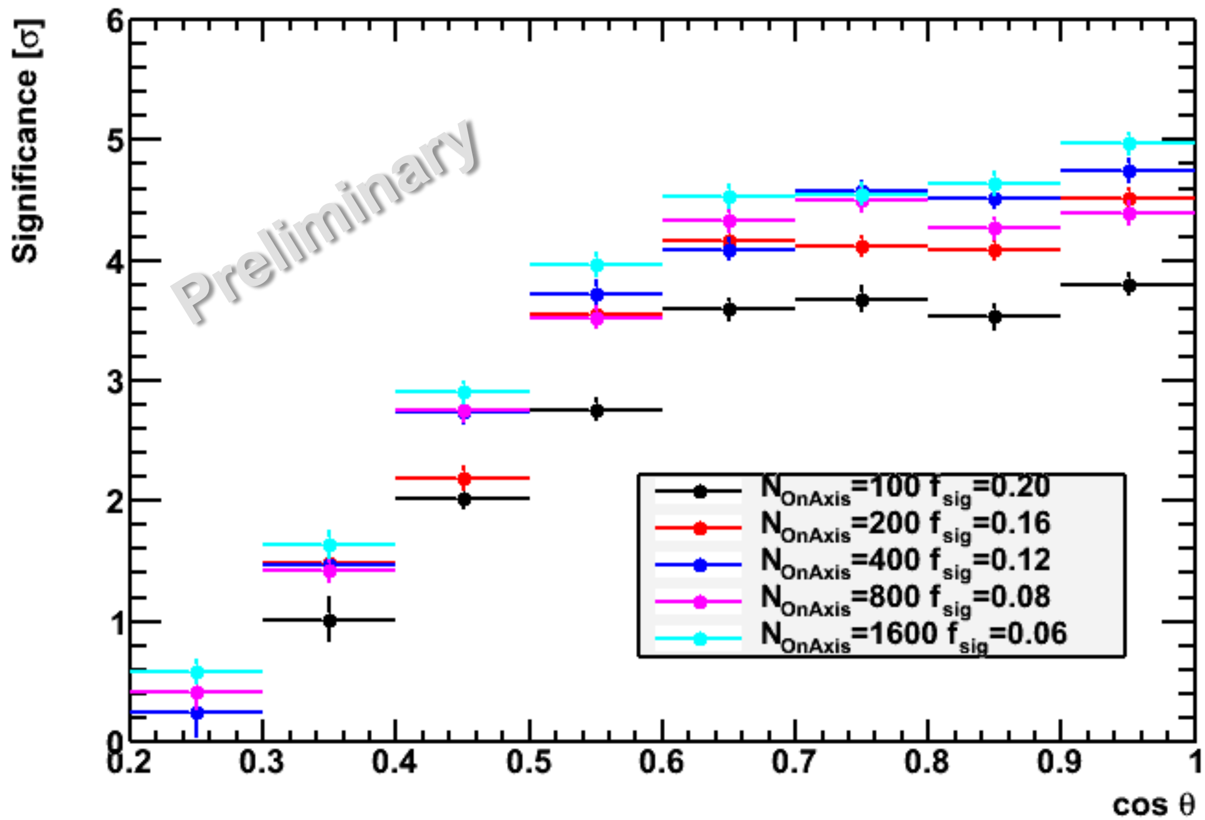
•Many people have noted that the spectral excess in both the the GC and the earth limb is largest near cos(θ)=0.7.

•By comparing the fractional residuals we see that the features in the Earth Limb could account for about 50% of the excess in a 12°x12° box around the GC, but only about a 30% of the excess in a smaller 8°x8° box where the feature is brighter.

New and Upcoming Developments

Modified Observing Strategy?

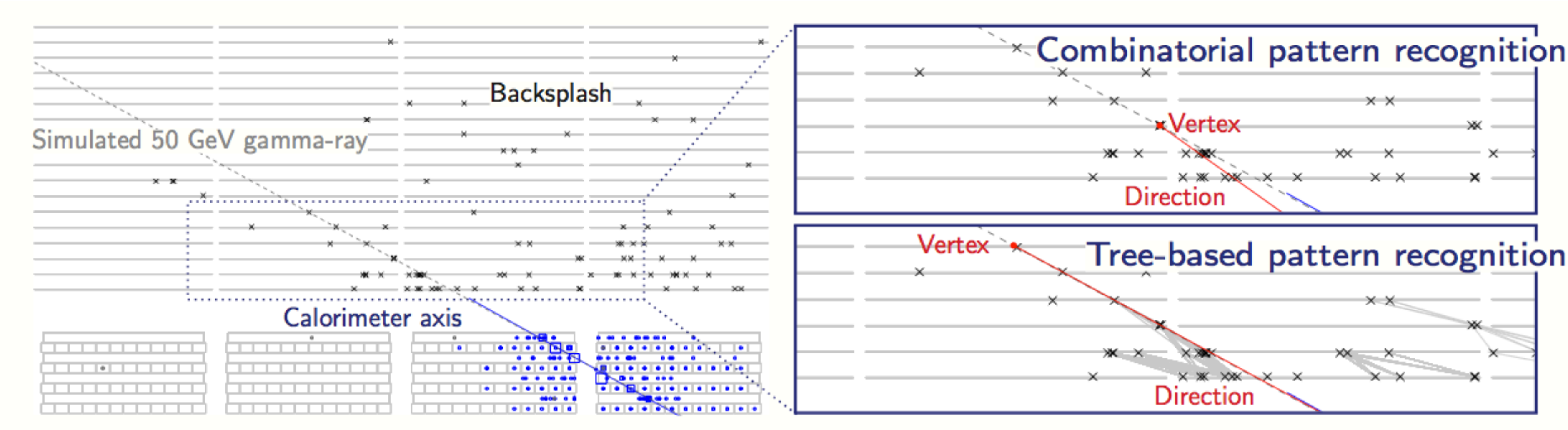
Simulated Sensitivity to 130GeV Line as a Function of θ



•Toy MC simulations of sensitivity to a 130GeV line for a range of signal-to-noise ratios favor energy resolution over A_{eff} slightly more than naïve scaling predictions.

Out to about θ=50°, the improving energy resolution balances out the decreasing A_{eff}. Less sensitivity past θ=60°.

Pass 8 Event Reconstruction



- Improved TKR and CAL reconstruction algorithms mitigate issues with CAL /TKR agreement, help avoid features in A_{eff} curve.

- Expect ~25% increase in acceptance above ~10 GeV from using improved reconstruction information for event selection.

- Expect better energy resolution at high energies from improved shower profile fitting.

Pass 8 event analysis, nearing completion (expected in 2013) will improve our prospects for answering questions about the spectral feature at 130 GeV.

Summary

- Spectral feature at 130 GeV near the GC is a potentially interesting hint of DM annihilation
  - Fractional residual up to 60% in 4°x4° box around GC
  - Not caused by background contamination
- Similar feature seen in the Earth Limb and may be attributable to dips in efficiency at energies just above and below 130 GeV
  - The Earth Limb features could explain between 30%-50% depending on the ROI under consideration.
- Data have been reprocessed with updated CAL calibrations and analyzed with improved "2D" energy dispersion model
  - Signal significance has fallen w.r.t. previous analysis
    - s_{local} 4.1σ -> ~3.35σ: still consistent w/ Weniger (2012)
  - Feature energy increased to ~135 GeV
- Too soon for definitive statements