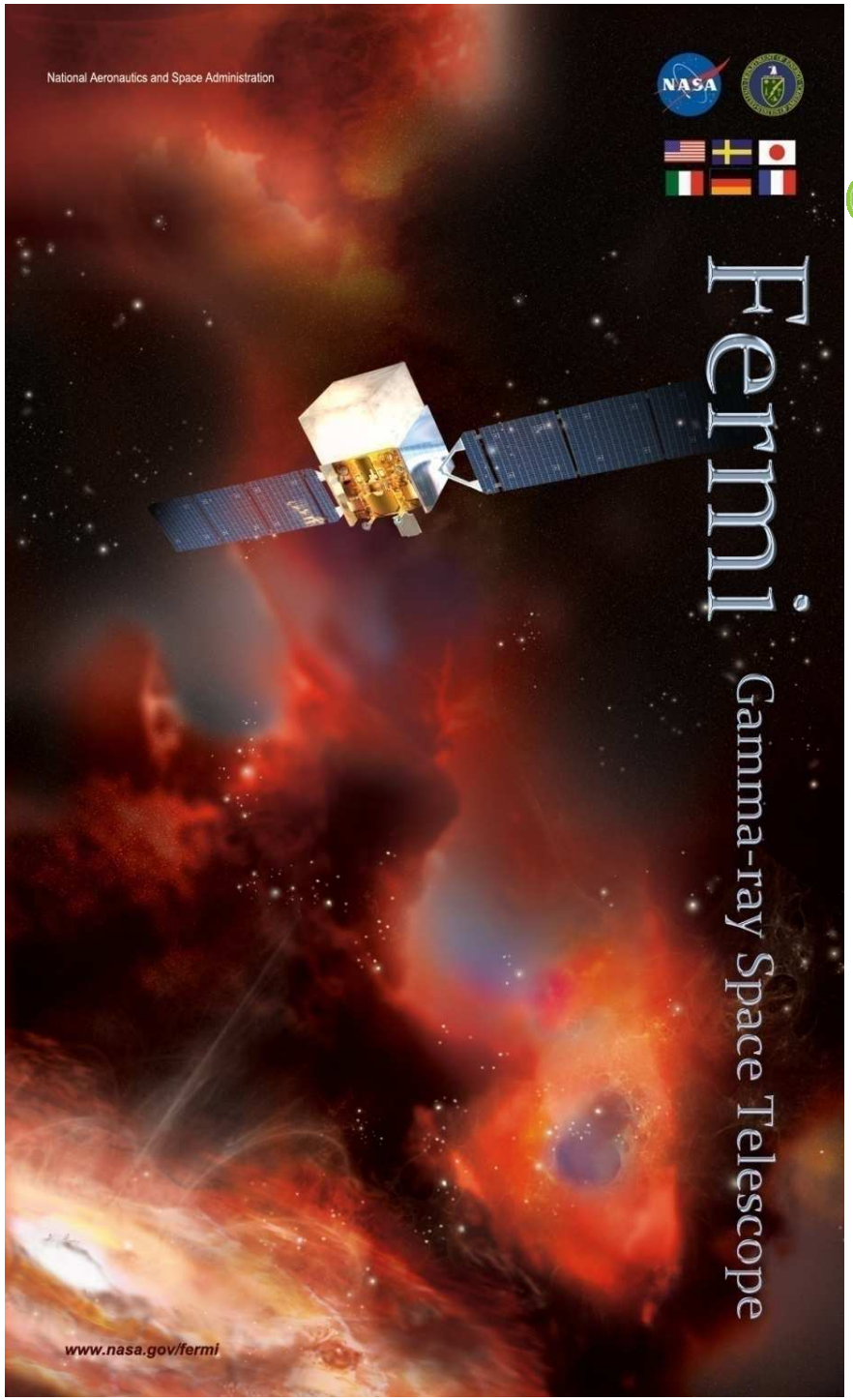

Search for Gamma-ray Spectral Lines in the Milky Way Diffuse with the Fermi Large Area Telescope

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The Ohio State University/CCAPP

with Brian Winer, Richard Hughes, and Elliott Bloom (KIPAC-SLAC)

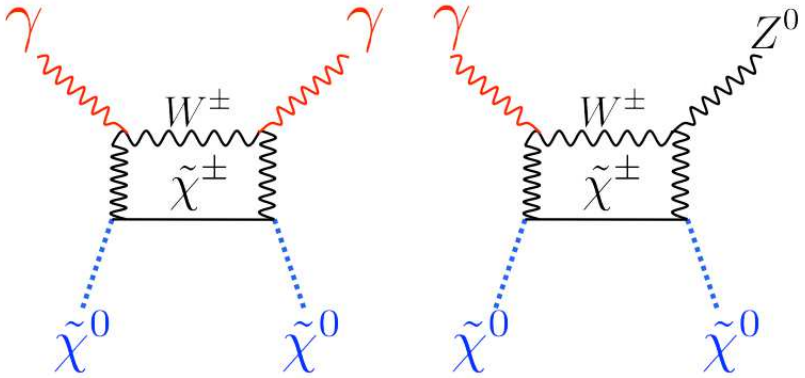
On behalf of the Fermi-LAT Collaboration

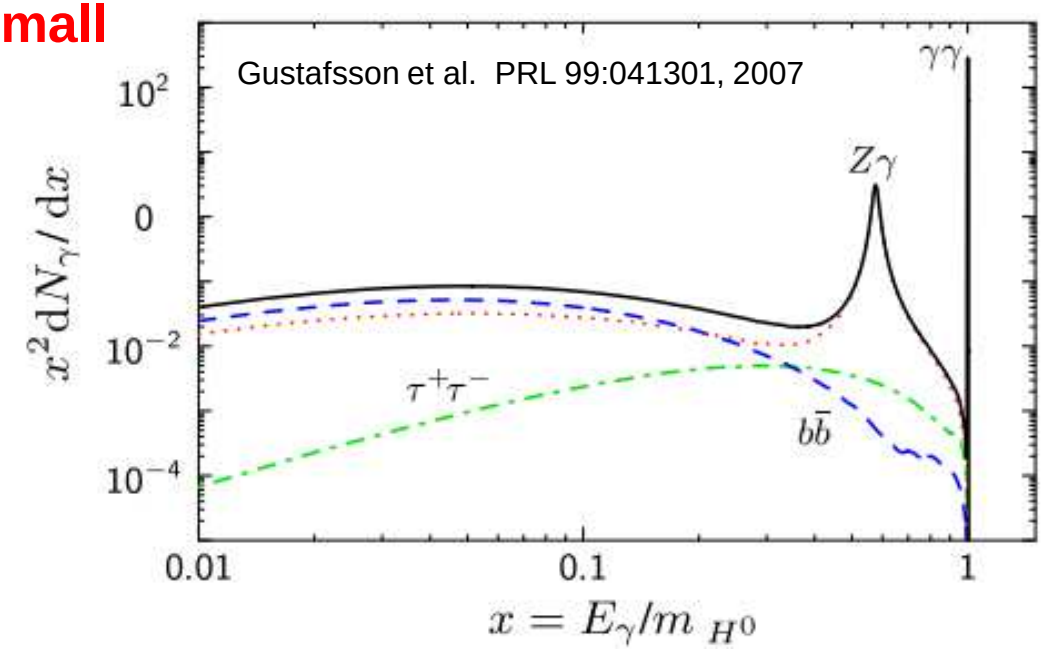
The Fermi Symposium

11/2/2012

Spectral Lines from WIMP annihilations

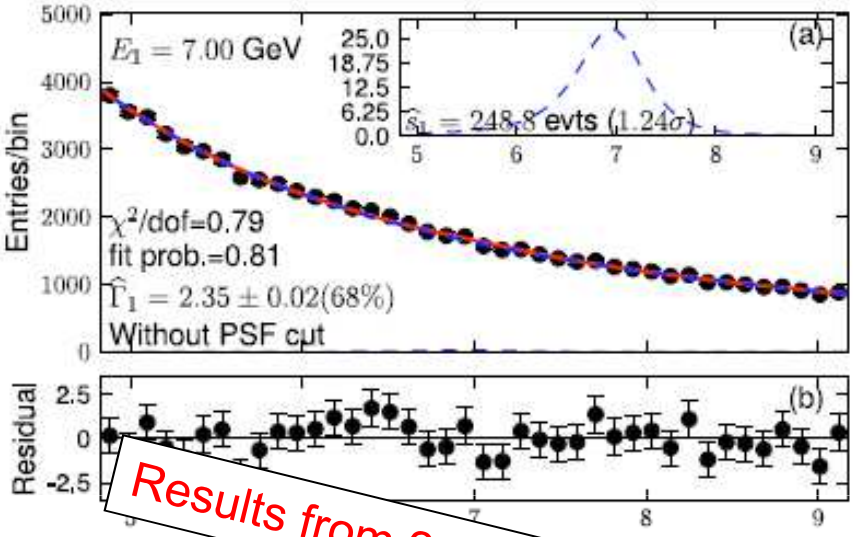
- **Weakly Interacting Massive Particles (WIMPs) are a promising dark matter candidate**
- **WIMP annihilations in the Milky Way may produce gamma rays detectable by the Fermi Large Area Telescope (LAT)**
- **$\chi\chi \rightarrow \gamma\gamma$, γZ^0, γH^0 would produce a narrow feature**
  - **Sharp, distinct spectral feature ("smoking gun")**
  - **Likely a small branching fraction**
    - **Signal predicted to be small**



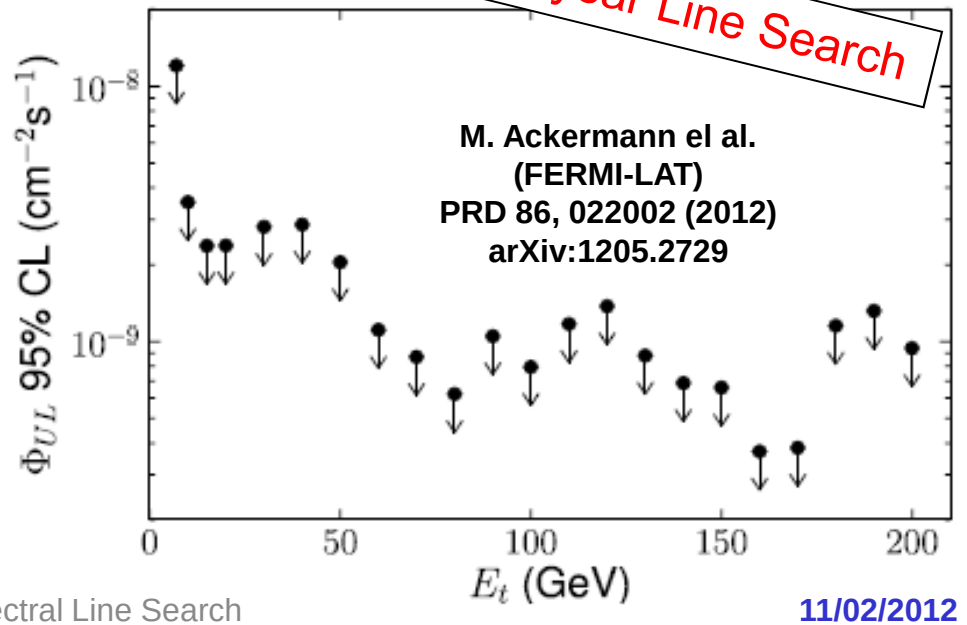


The Fermi LAT Line Search

- 2 year analysis accepted for publication in PRD
  - Current analysis uses similar method
- 4 year analysis nearing completion
  - Use Reprocessed "Pass 7 Clean" data
    - Low cosmic-ray contamination
    - Reprocessing shifts energy scale by 1-4% to account for slight radiation damage to calorimeter
    - See P7REP poster
  - Mask 2FGL Sources
  - Plan to submit paper to PRD end of December 2012
- Search for lines from 5 to 300 GeV
  - Maximum Likelihood Fit
  - Use sliding $\pm 6\sigma_E$ windows
  - Fit for energies in σ_E steps
    - Perform finer $0.5\sigma_E$ scan near significant energies
  - Model bkg as single powerlaw
  - Γ_{bkg} and f_{sig} free in fit



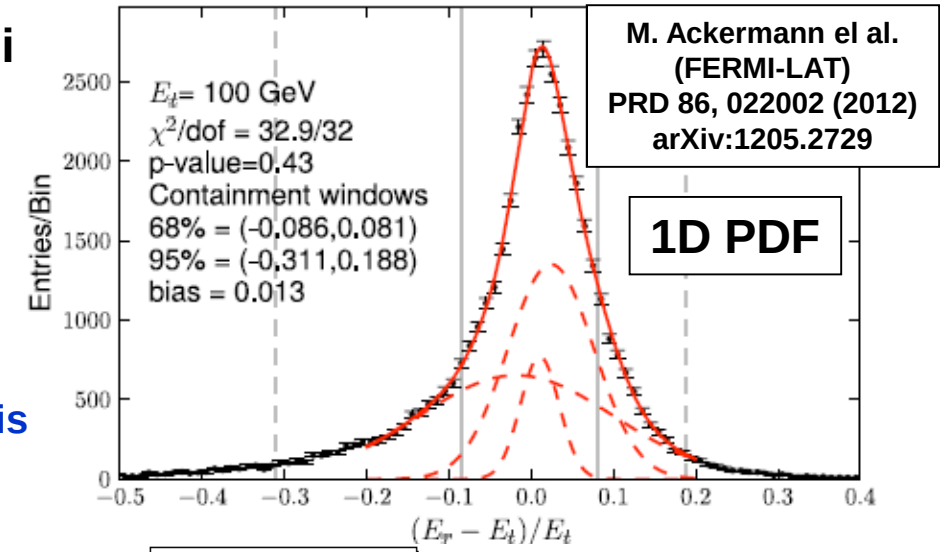
Results from 2 year Line Search

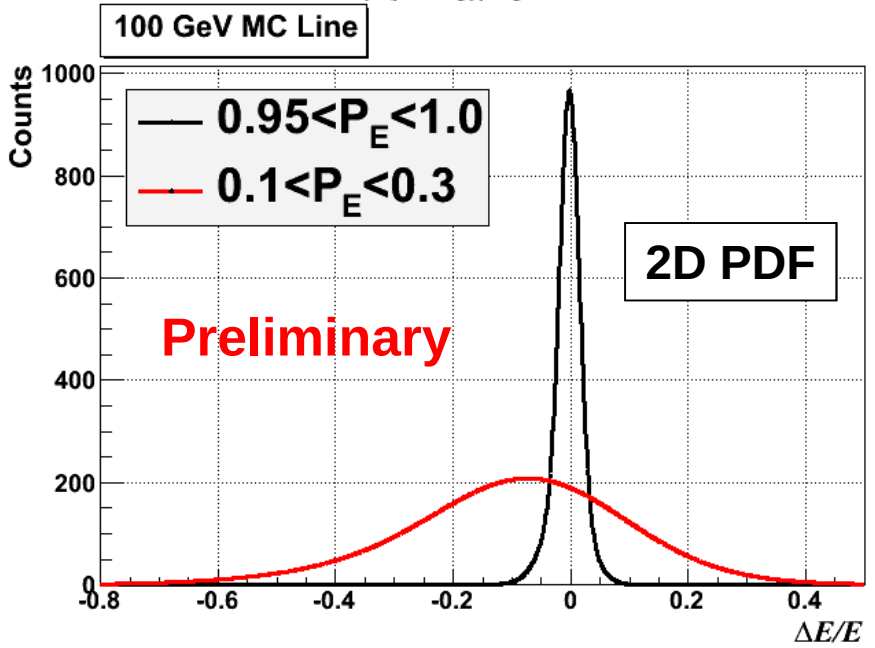


M. Ackermann el al.
(FERMI-LAT)
PRD 86, 022002 (2012)
arXiv:1205.2729

Improved Line Model

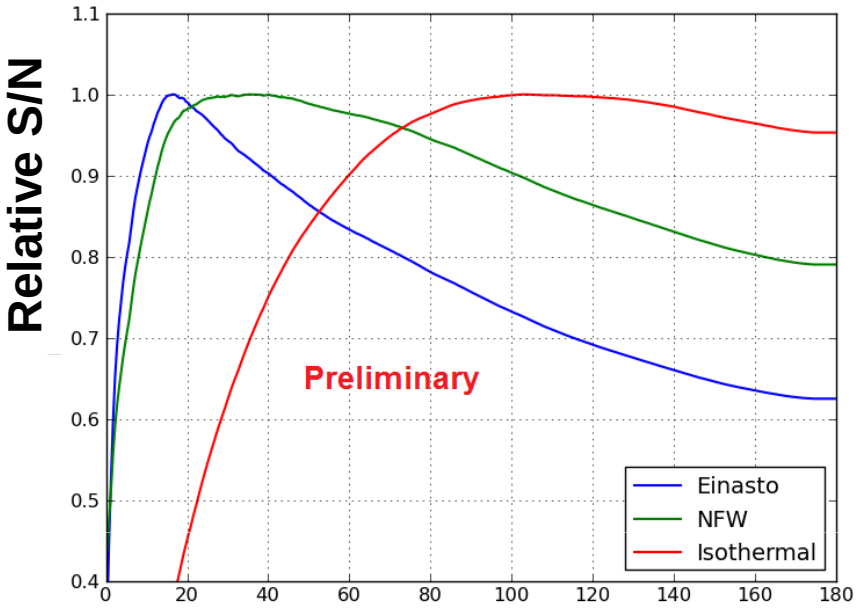
- Use full detector simulation to get Fermi LAT energy dispersion
- Previously modeled line with a triple gaussian fit ("1D PDF")
- This analysis adds a 2nd dimension to line model: P_E
  - P_E is the probability that measured energy is true energy
    - Labeled "CTBBestEnergyProb" in our extended data
  - "2D PDF" (a function of both energy and P_E)
- Break Line into 10 P_E slices and do triple gaussian fit in each slice separately
  - Fit explicitly at 9 energies and interpolate parameters in each slice to produce lines at other energies
- Including P_E → ~15% improvement to signal sensitivity (when there is signal) and counts upper limit (when there is no signal)

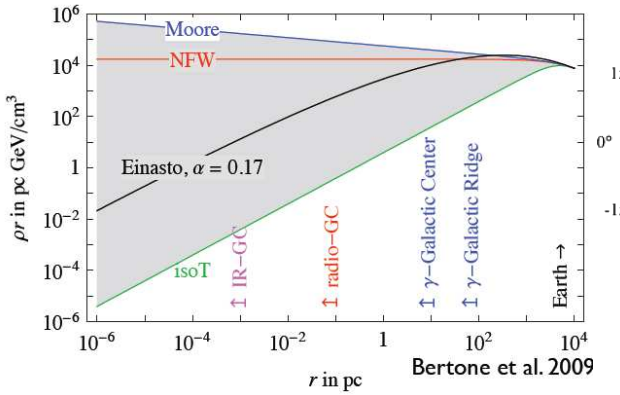


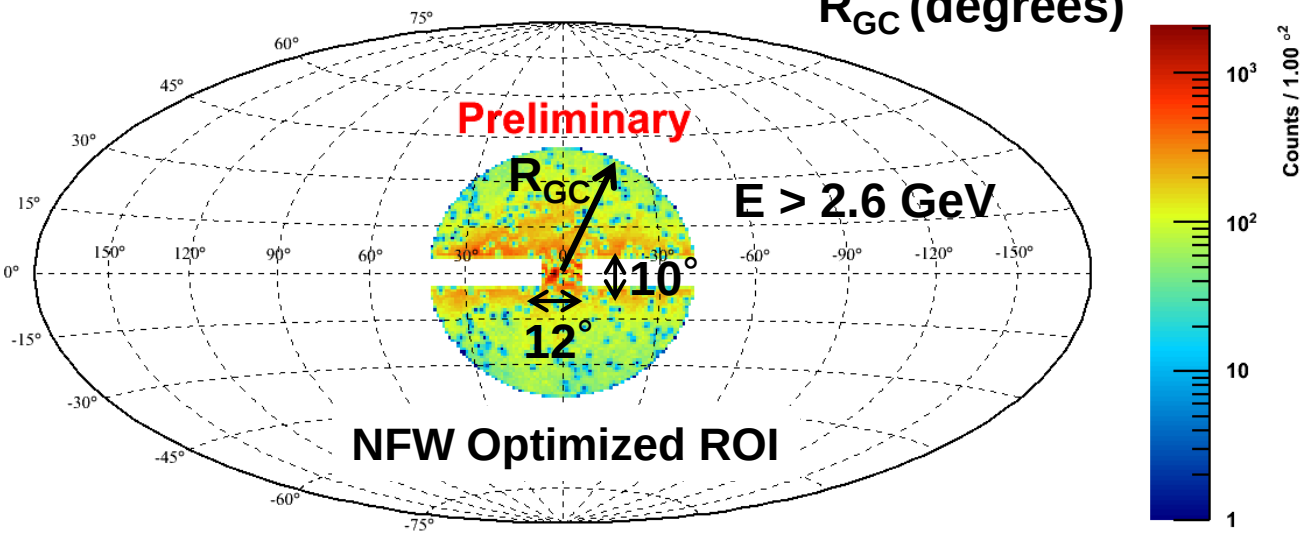


Region of Interest (ROI) Optimization

- Many have shown ROI optimization importance in line searches
  - e.g. C. Weniger JCAP 1208 (2012) 007
- Find R_{GC} that optimizes sig/sqrt(bkg)
  - ROI choices made a priori using MC
  - sig from J factor in that ROI
  - bkg from MC simulation of galactic diffuse model
    - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/Model_details/Pass7_galactic.html
- Search in 5 ROIs
  - R0 (12°x10° GC box)
  - R16 (Einasto Optimized)
  - R41 (NFW Optimized)
  - R90 (Isothermal Optimized)
  - R180 (2 year Analysis ROI)

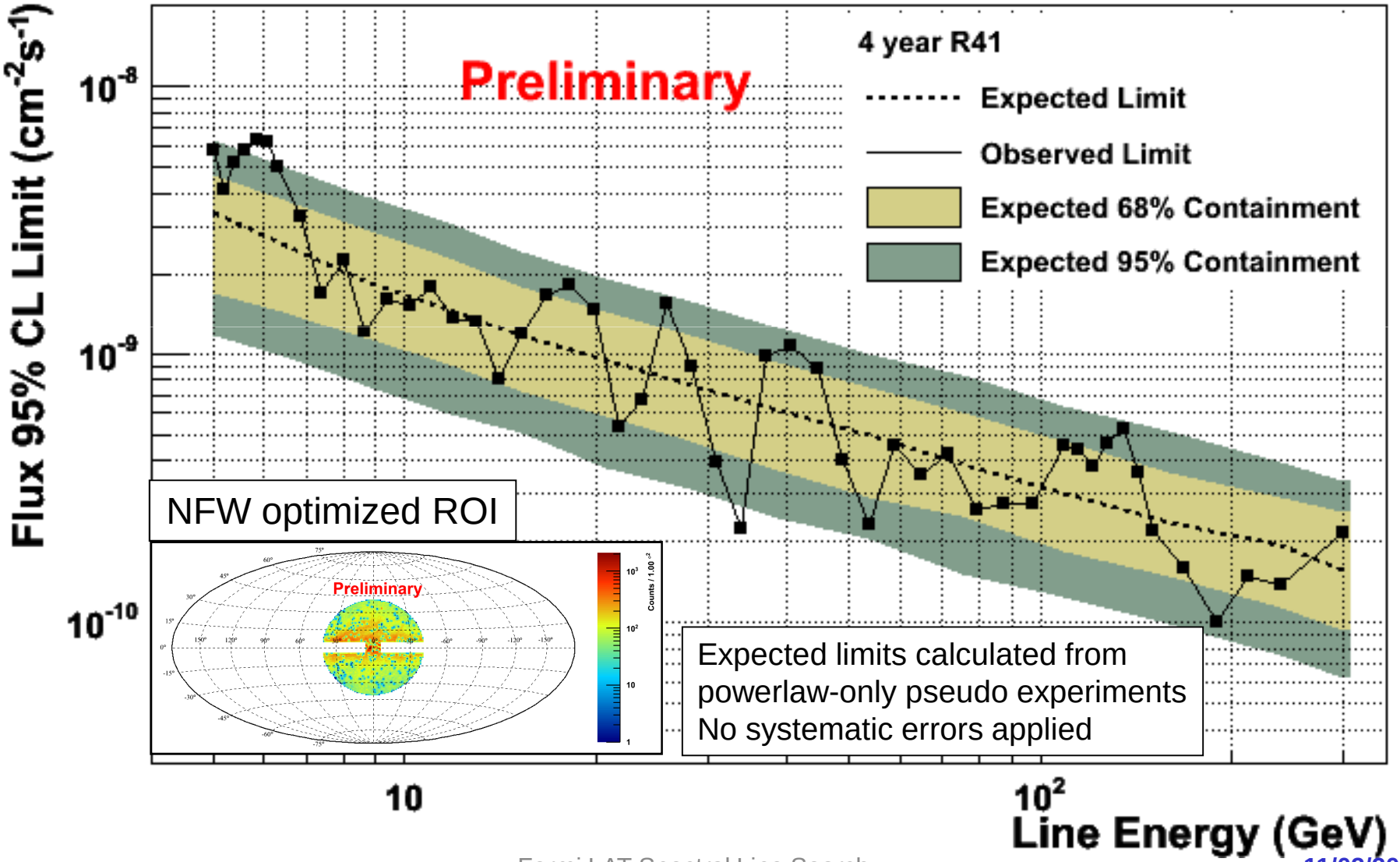




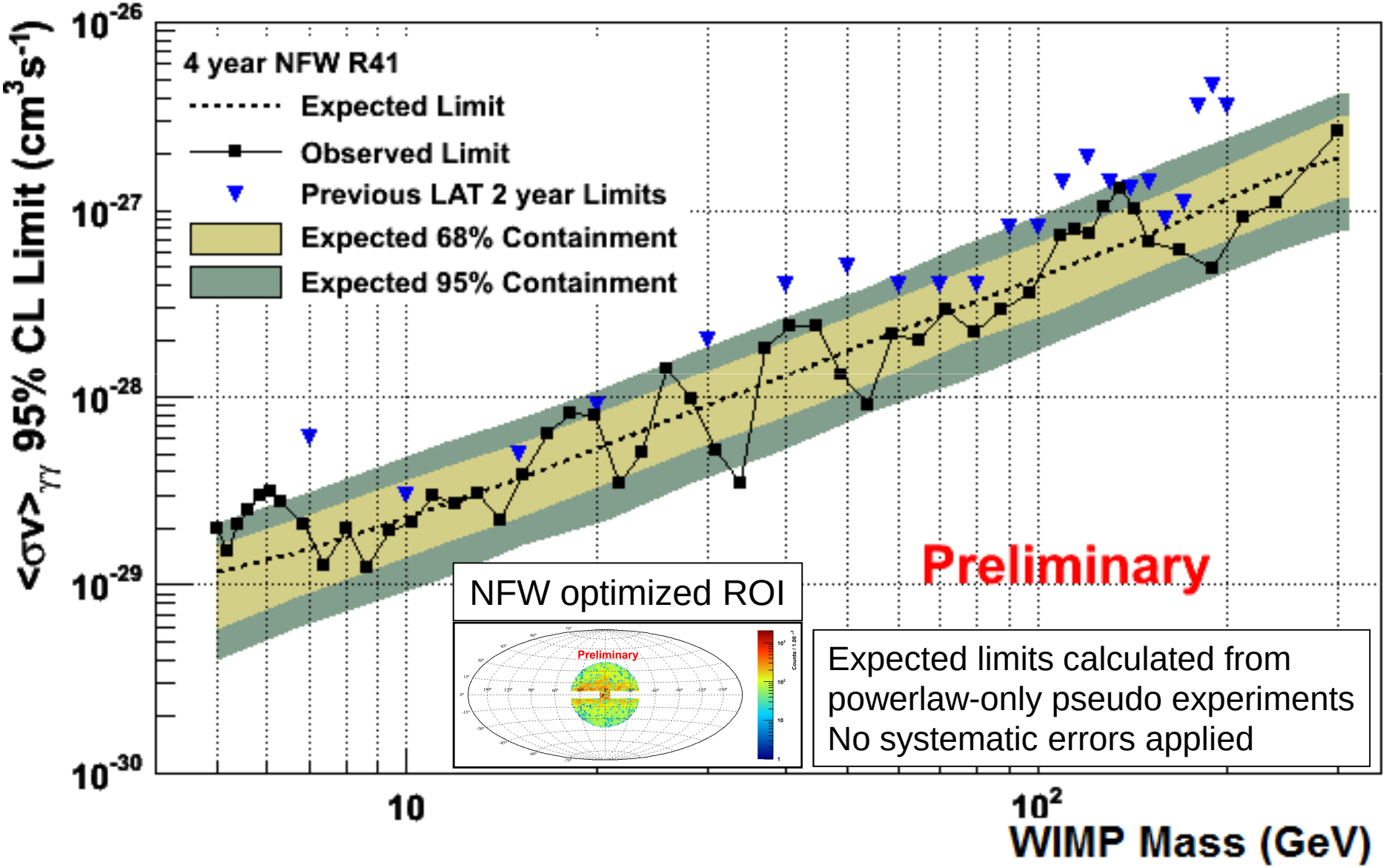


Spectral Line 95% CL Flux Upper Limit R41

- **No globally significant lines found**
  - **Most significant fit was in R0 at 5 GeV, ~2σ (3.7σ local)**



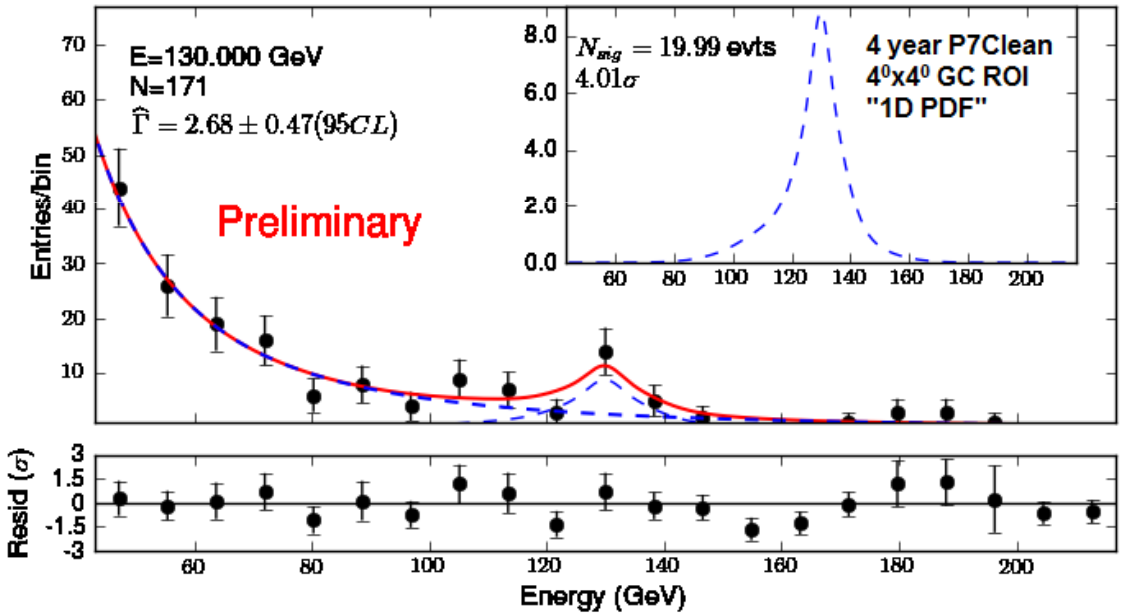
95% CL $\langle\sigma v\rangle_{\gamma\gamma}$ NFW Upper Limit R41



Line-like Feature near 135 GeV

- **Our blind search does not find globally significant feature near 135 GeV**
  - **Reprocessing shifts feature from 130 GeV to 135 GeV**
  - **Most significant fit was in R0, 2.23σ local (<0.5σ global)**
- **Much interest after detection of line-like feature localized in the galactic center at 130 GeV**
  - **See C. Weniger JCAP 1208 (2012) 007 arXiv:1204.2797**

- **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)**



Note: Fit in 4˚x4˚ GC ROI
Not one of our a priori ROIs

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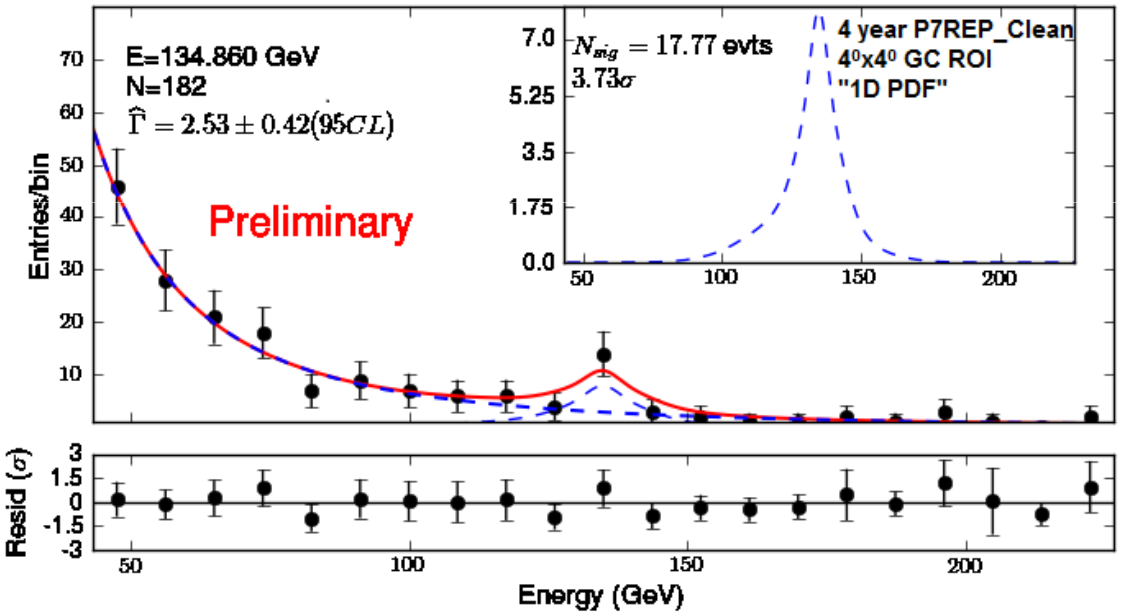

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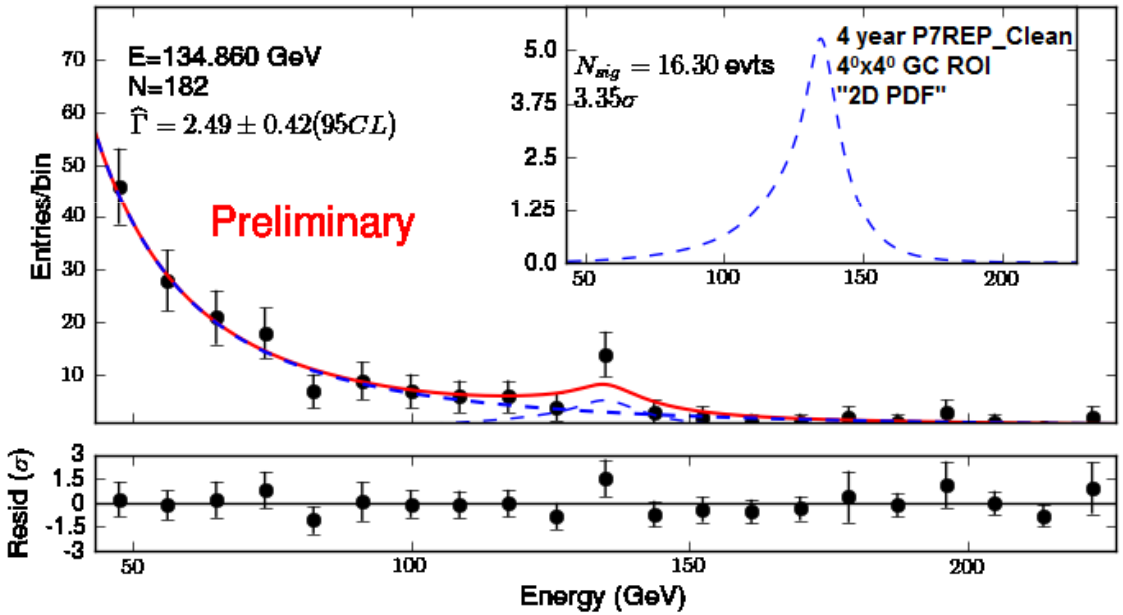
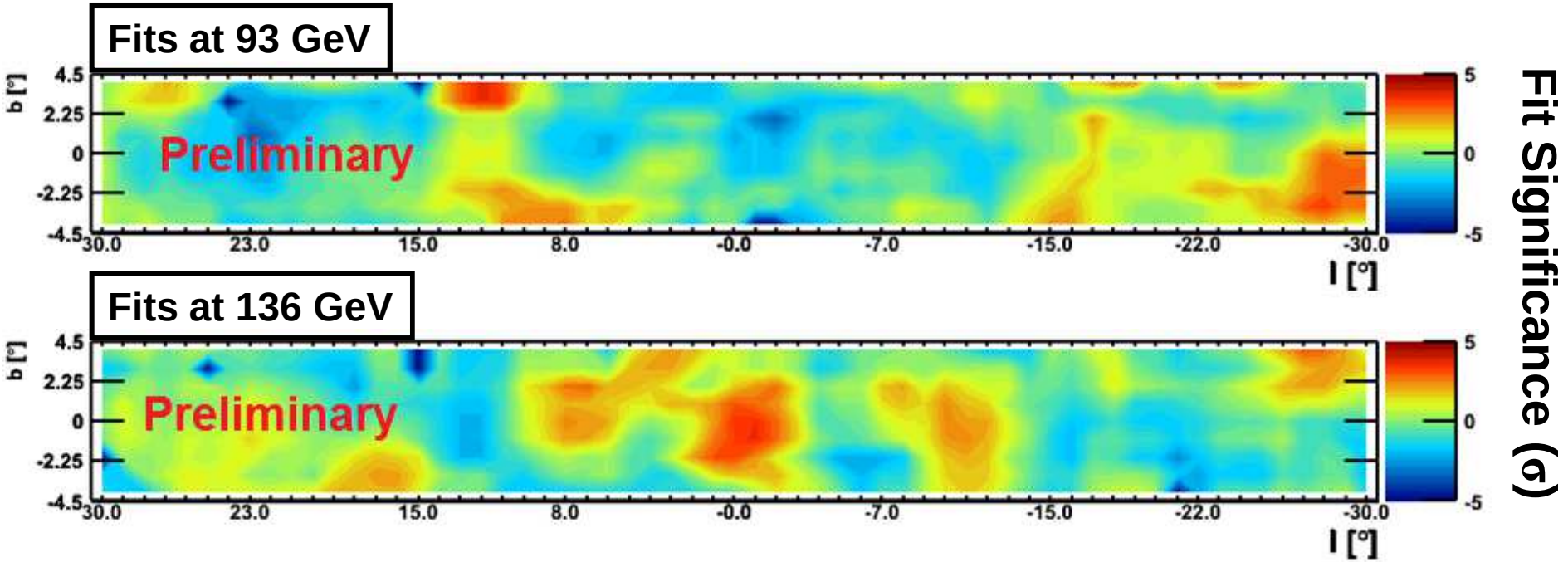
  - **Look in 4°x4° GC ROI**
  - **Use 1D PDF (no use of P_E)**
- **3.35σ (local) 2D fit at 135 GeV with 4 year reprocessed data**
  - **Look in 4°x4° GC ROI**
  - **Use 2D PDF**
    - **P_E in data → feature is slightly narrower than expected**
  - **<2σ global**



Note: Fit in 4°x4° GC ROI
Not one of our a priori ROIs

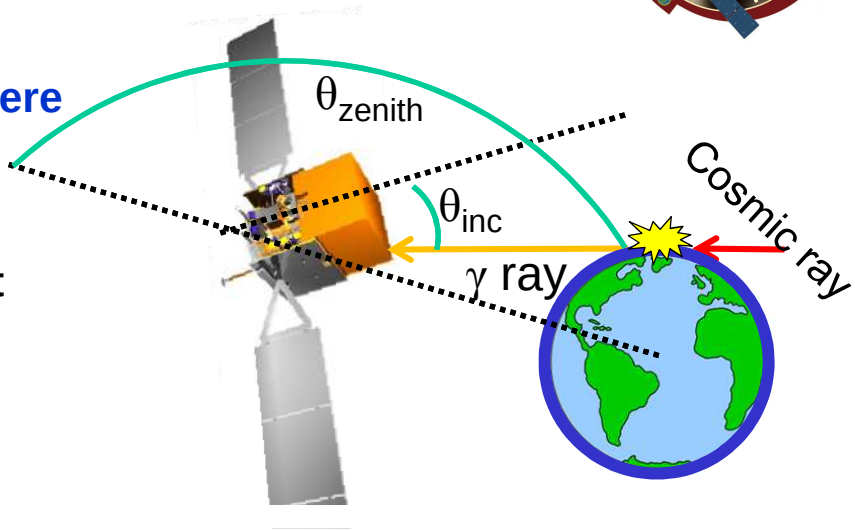
Spatial Morphology of Features in Galactic Plane

- Fit in 4˚x4˚ ROIs along the galactic plane in 1˚ steps
  - Fit with “1D PDF”
    - To find where the counts are coming from
- Find excess near ~135 GeV near GC
  - But find similar features at other energies along the GP
  - Some indication the 135 feature not smooth, but 2-3 smaller “hot spots”
  - Excess near 135 GeV is one of the largest and near GC, but is not otherwise unique
  - See talk by E. Charles for more details

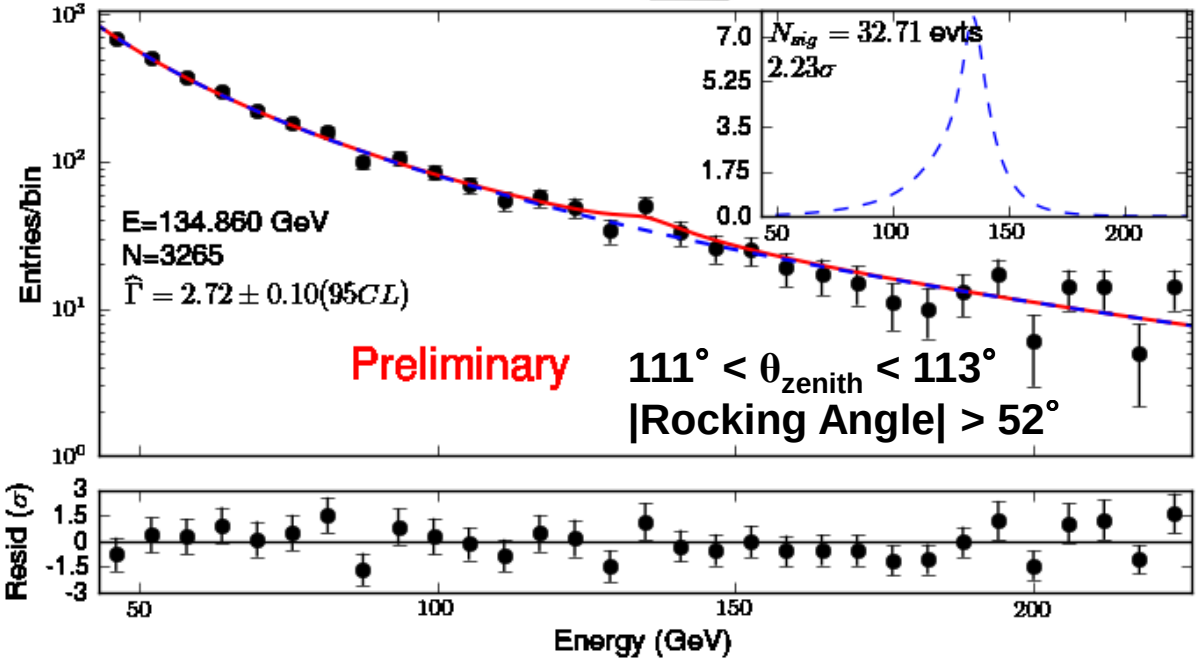


135 GeV in the Earth Limb spectrum

- **Earth Limb is a bright gamma-ray source**
  - **From cosmic-ray interactions in the atmosphere**
    - **Expected to be a smooth power-law**
  - **Can be used to study instrumental effects**
- **Have made changes to increase our Limb dataset**
  - **Pole-pointed observations each week**
  - **Extended "targets of opportunity" (ToOs)**
    - **Trace limb while target is occulted**

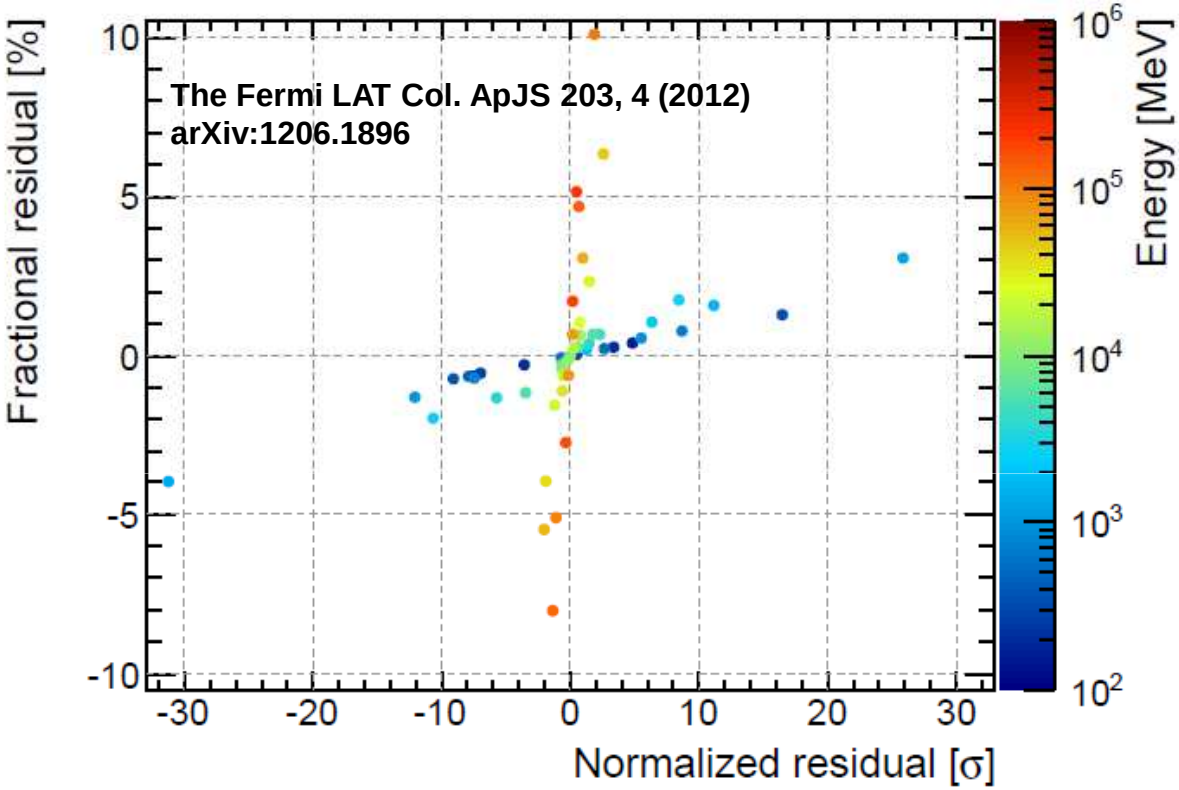


- **Line-like feature in the limb at 135 GeV**
  - **Appears when LAT is pointing at the Limb**
    - **|RockAngle| > 52°**
  - **Surprising since limb should be smooth**
  - **On-going systematic studies have found interesting results**
    - **See talk by E. Bloom**
    - **See talk by E. Charles**



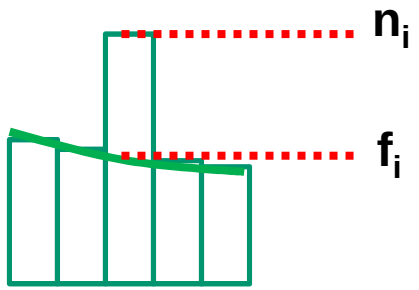
Fractionally small, but significant deviations

- **We see fractionally small, but significant fluctuations in the galactic data and limb spectrum at low energies**
  - **Fractional deviation ≈ or smaller than uncertainties in A_{eff}**
  - **See similar features in earth limb at low energies**
    - **See section 7.5 of Pass 7 performance paper**
      - **The Fermi-LAT Col. ApJS 203, 4 (2012)**
  - **Need to consider both fit significance *and* fractional deviation**



$$resid_{frac} = \frac{(n_i - f_i)}{f_i}$$

$$resid_{norm} = \frac{(n_i - f_i)}{\sqrt{f_i}}$$



Summary

- **Improved Line Search**
  - 2D Line model includes P_E
  - Reprocessed dataset with corrected energy scale
  - Chosen optimized ROIs a priori using MC background model
- **Use Galactic Plane and Earth Limb to study potential line-like features**
  - 135 GeV feature in Galactic Center not smooth, but seems to be from 2-3 “hot spots”
    - See similar features at other energies along the Galactic Plane
  - Earth Limb should be a smooth powerlaw
    - See feature at 135 GeV
    - See significant features that are fractionally small in low energies
- **Performed a search for spectral lines from 5 to 300 GeV with 4 years of data in 5 a priori ROIs**
  - No globally significant lines detected and strong $\langle\sigma v\rangle_{\gamma\gamma}$ limits are set
- **Line search has raised many interesting questions. Our understanding will continue to get better with future studies and more data from the Fermi LAT**
  - Implementing strategies to increase limb dataset
  - Mission extended through at least 2016
  - Pass 8 reconstruction will improve A_{eff} and energy reconstruction