Updated Spectral Line Search and Status of 133 GeV Feature with Pass 8 Data

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On behalf of the Fermi-LAT Collaboration
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Spectral Lines from WIMP annihilations

- Weakly Interacting Massive Particles (WIMPs) are a promising dark matter candidate
- WIMP annihilations in the Universe may produce gamma rays detectable by the Fermi Large Area Telescope (LAT)
- $\chi\chi \rightarrow \gamma\gamma, \gamma Z^0, \gamma H^0$ would produce a narrow feature
  - Sharp, distinct spectral feature ("smoking gun")
  - Likely a small branching fraction
- Signal predicted to be small (b.f. typically $\sim 10^{-2}$ to $10^{-4}$)

Gustafsson et al. PRL 99:041301, 2007
Inert Higgs doublet model with particularly large predicted lines
The Story Viewed Through Pass 7 REP

- There have been two line searches from the LAT Collaboration
  - 3.7 years, 5 GeV < $E_\gamma$ < 300 GeV, 5 ROIs
  - 5.2 years, 100 MeV < $E_\gamma$ < 10 GeV, 2 ROIs (A. Albert et al. JCAP10(2014)023)
    - LAT Col.: A. Albert, G. Gomez-Vargas, E. Bloom, E. Charles, M.N. Mazziotta, A. Morselli
    - External: C. Munoz, M. Grefe, & C. Weniger
  - No globally significant ($s_{global} < 2\sigma$) spectral lines detected
  - Too narrow feature in 133 GeV is seen. This feature had been previously reported (e.g. Bringmann et al. 2012, Weniger 2012)
Pass 8 Improvements Relevant for Line Search

100 GeV MC

- Increased acceptance with P8

- Improved energy reconstruction in Pass 8
  - Energy recon. above ~1 GeV optimized with better modeling of calorimeter shower (e.g. improve handling of gaps between modules and crystal saturation)
  - Increased effective area with equivalent energy resolution

- Event reconstruction and selection classes are new in P8
  - Pass 8 is a new “lens” we can view lines through
    - Important check for tentative 133 GeV feature
• **P8 has more event types available with IRFs for each type**
  – Similar to “front” vs. “back” IRFs
• **EDISP types select events based on energy recon quality**
  – 25% quantiles of “Best Energy Prob” as function of energy
  – In given energy range, each EDISP type has ~same acceptance
• Including EDISP types → ~10-15% improvement to signal sensitivity
  – Amount of improvement depends on energy
  – Similar to improvement in P7REP analysis using 10 Best Energy Prob bins
Region of Interest (ROI)

- Many have shown ROI optimization importance in line searches
  - e.g. C. Weniger JCAP 1208 (2012) 007
- Use same ROIs as 3.7 year line search
  - R3 (3° GC), R16 (Einasto Optimized), R41 (NFW Optimized), R90 (Isothermal Optimized), R180 (Decay Optimized)
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Can fit for “lines” in off-center Galactic plane to estimate level of systematically induced “lines”
Pass 8 Line Search

\( f_{\text{sys}} \) from Galactic Plane scans

- There are some common features likely from the effective area \((A_{\text{eff}})\)
- Displacement from 0 is mostly from \(A_{\text{eff}}\), while spread is from bkg. modeling
- Larger systematic effect with wider windows (since power-law approx. gets worse)

Scan in 31 ROIs per \(E_\gamma\) (10°x10° GP boxes)

0.25\(\sigma_E\) steps

\[ \delta f_{\text{sys}} > \delta f_{\text{stat}} \]

\[ \delta f_{\text{sys}} < \delta f_{\text{stat}} \]

A. Albert (SLAC)
P8 Line Search
Accounting for $f_{\text{sys}}$ in Likelihood

- Search with 5.8 years of P8 Clean data for lines from $200 \text{ MeV} < E_\gamma < 500 \text{ GeV}$
  - Use $\pm 0.5 E_\gamma$ fit windows to optimize at low energies (where systematic limited) and high energies (where statistical limited)
- Include nuisance parameter ($n_{\text{sys}}$) for systematically-induced line-like features
  - Only detect a significant line if larger than the line-like features we see in the control regions
  - Introduced method in low-energy line paper (A. Albert et al. JCAP10(2014)023)
  - Similar technique used to incorporate J-factor uncertainties dSph analysis
    - Can be applied whenever accounting for systematic uncertainties is important

\[
C(E, \tilde{\alpha}) = \left( (n_{\text{sig}} + n_{\text{sys}}) S(E, E_\gamma) + n_{\text{bkg}} B(E, \Gamma_{\text{bkg}}) \right) \ast G_{\text{sys}}
\]

\[
\sigma_{\text{sys}} = \delta f_{\text{sys}} \ast b_{\text{eff}}
\]

\[
G_{\text{sys}} = \frac{1}{\sigma_{\text{sys}} \sqrt{2\pi}} e^{-n_{\text{sys}}^2 / 2\sigma_{\text{sys}}^2}
\]

\[
f = \frac{n_{\text{sig}}}{b_{\text{eff}}} \approx \frac{TS}{n_{\text{sig}}}
\]

\[
n_{\text{sys}} \text{ is constrained using } \delta f_{\text{sys}} \text{ estimated with control regions}
\]

\[
\text{Gaussian constraint on } n_{\text{sys}}
\]

Warning: cartoon, see paper for full $b_{\text{eff}}$ definition
A. Albert et al. JCAP10(2014)023
Spectral Line 95% CL Upper Limit R16

- No globally significant lines found
Spectral Line 95% CL Upper Limit R16

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Line-like Feature near 133 GeV

**P7REP_Clean**

- $P_7\_REP\_CLEAN$ R3 2D $E_\gamma = 133.0$ GeV
- $n_{\text{sig}} = 17.8$ evts, $n_{\text{bkg}} = 276.2$ evts
- $s_{\text{local}} = 3.3\sigma$, $\Gamma_{\text{bkg}} = 2.76$
- $f = 0.61 \pm 0.19$

**P8_Clean**

- 3.7 year
- $E_\gamma = 133.0$ GeV
- $\Gamma_{\text{bkg}} = 2.466$
- $n_{\text{sig}} = 16.67$ evts (2.02 $\sigma$)
- $f = 0.24 \pm 0.06$

![Graphs showing energy distribution and residual plots]

- **Same fit parameters as 3.7 year line search** (Ackerman et al. PRD 88, 082002 (2013))
  - Fits in R3, 3.7 year, $\pm 6\sigma_E$ fit window
- **No strong evidence of 133 GeV Feature in Pass 8**
  - Lower fractional size and significance
  - Energy recon. in P7 vs. P8 changes within expected energy resolution
Line-like Feature near 133 GeV

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**See poster by Regina Caputo for event-level investigation**
Line-like Feature near 133 GeV – 5.8 yr

$E_\gamma = 133.0$ GeV
$\Gamma_{\text{bkg}} = 2.466$
$n_{\text{sig}} = 7.27$ evts $(0.72 \, \sigma)$
$f = 0.07 \pm 0.02$

Preliminary

- Feature is even smaller in 5.8 year P8 Clean dataset
  - Consistent with statistical fluctuation in P7 REP 3.7 year dataset
Summary

• Search for line from 200 MeV < E_\gamma < 500 GeV using Pass 8 dataset
  – 5.8 year, 5 ROIs
  – Use “2D” energy dispersion model via Event Types
  – No significant lines detected

• Developed method to incorporate systematic uncertainties consistently in fit
  – Estimate level of systematic uncertainties with fits in control regions

• 133 GeV feature in Galactic Center even less significant in Pass 8
  – Smaller than P7REP feature in 3.7 year dataset
  – Continued to decrease with time
    • s_{local} = 0.72\sigma in 5.8 year dataset