The 130 GeV Line in Gamma Rays

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Introduction

Fermi-LAT looks for (among many other things) gamma ray lines from the galactic center.

A collaboration analysis on two years of data showed no such feature.

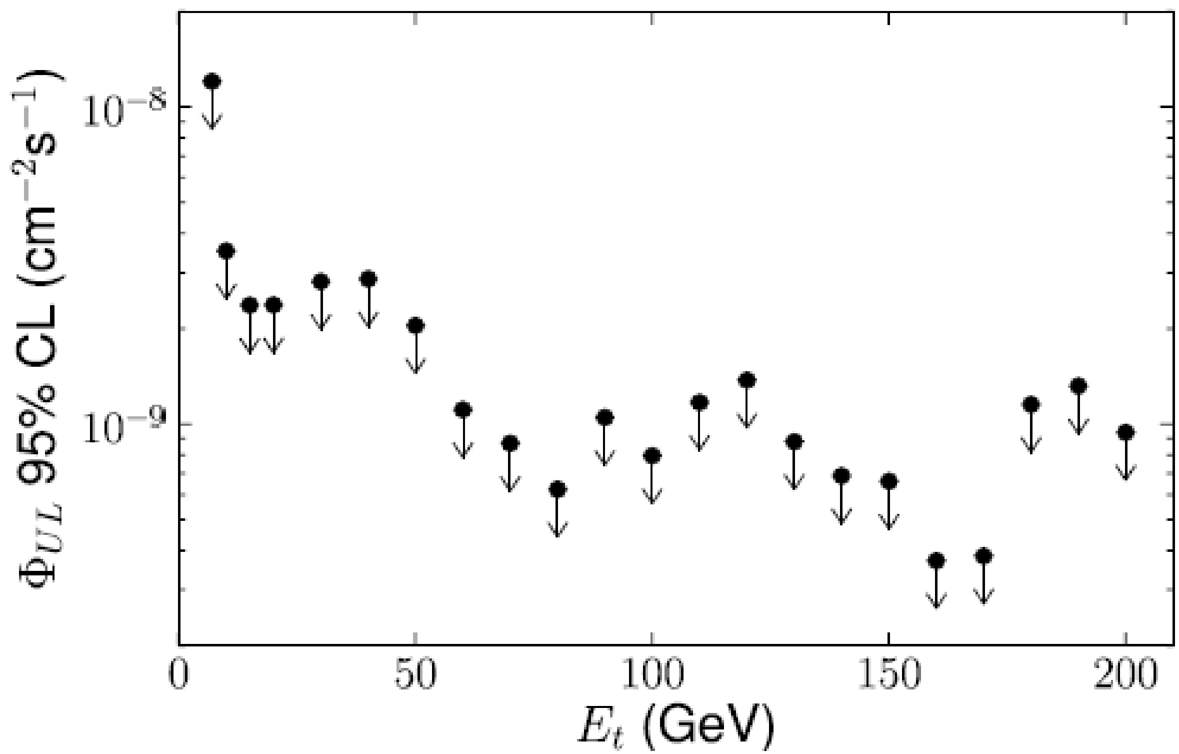
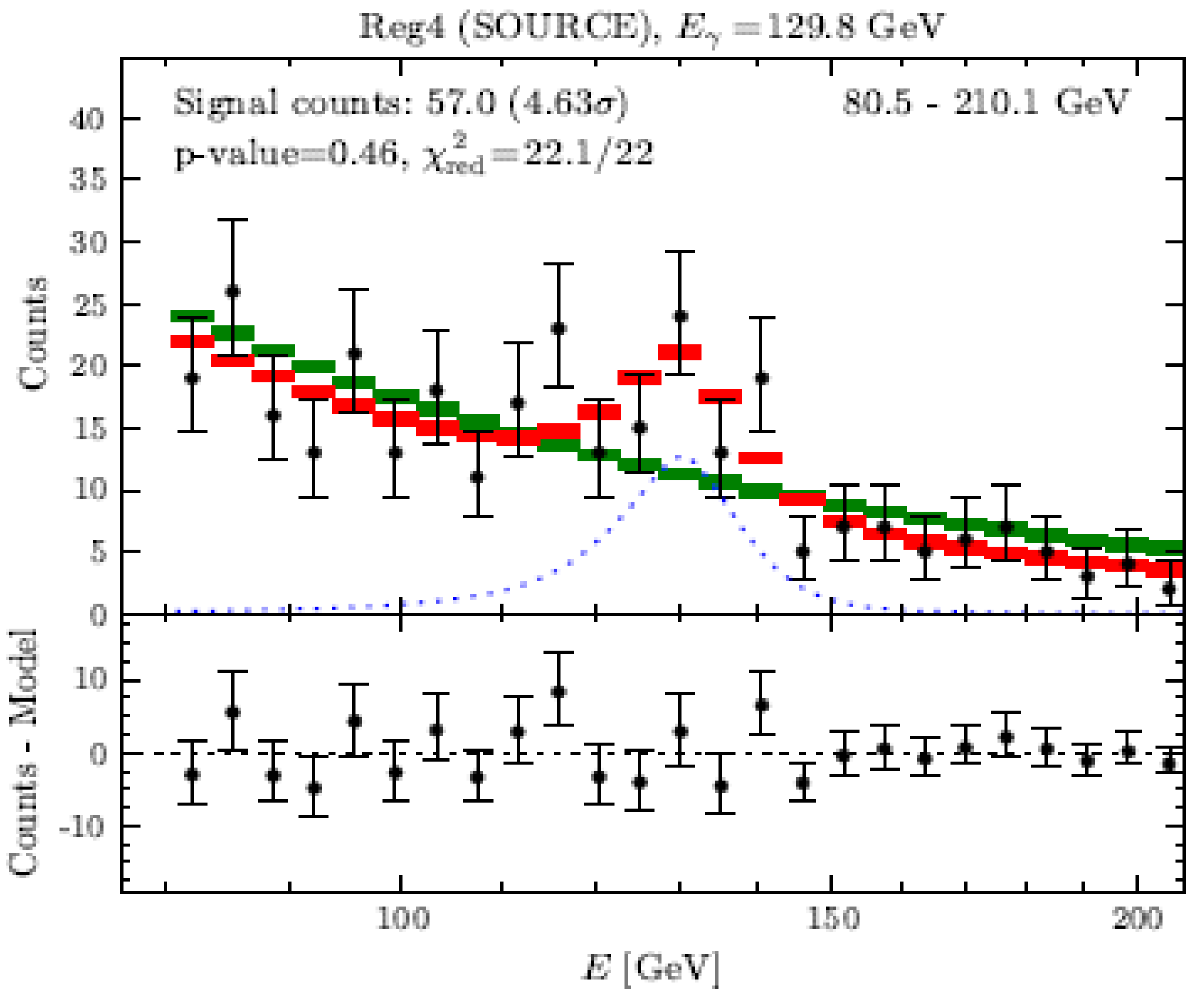


FIG. 14. 95% CL flux upper limit (integrated over the entire ROI) for photons from spectral lines.

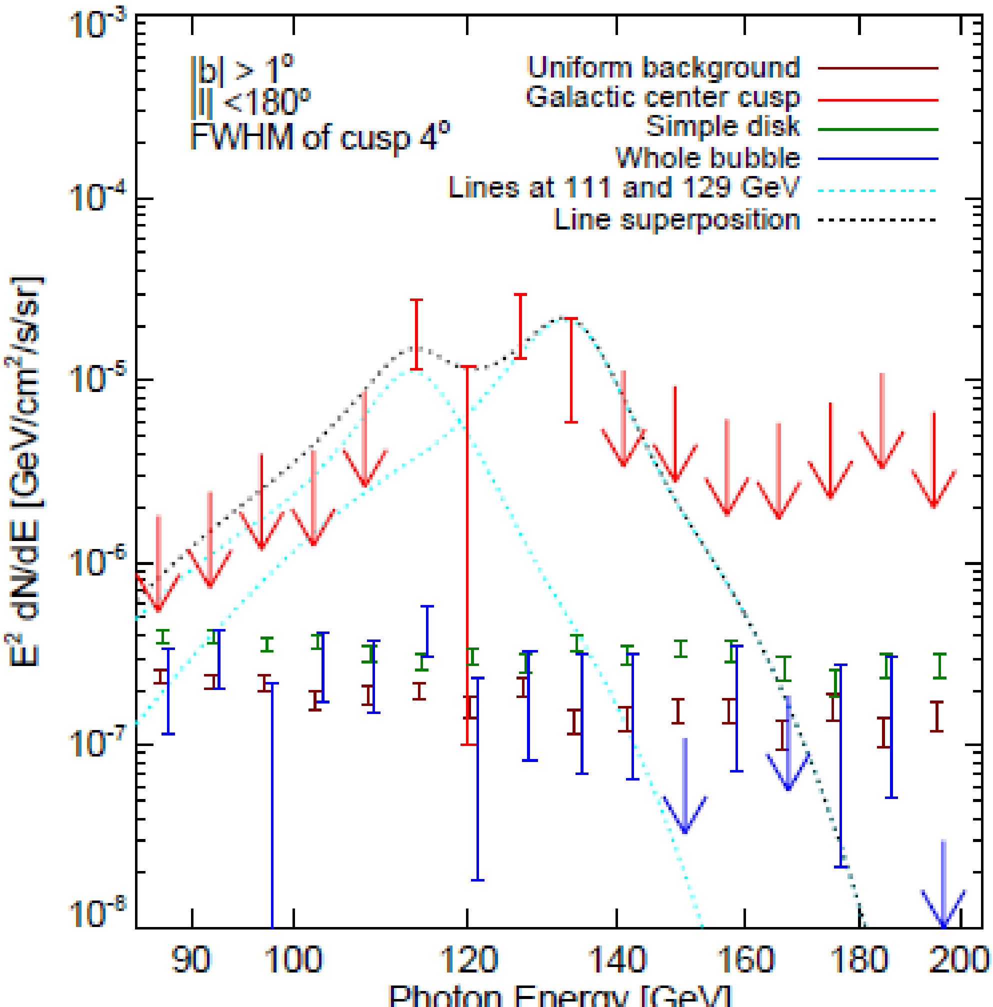
Introduction

An analysis by Weniger of 43 months of data found a feature at 130 GeV. Including look-elsewhere effects, the significance was 3.3 sigma.

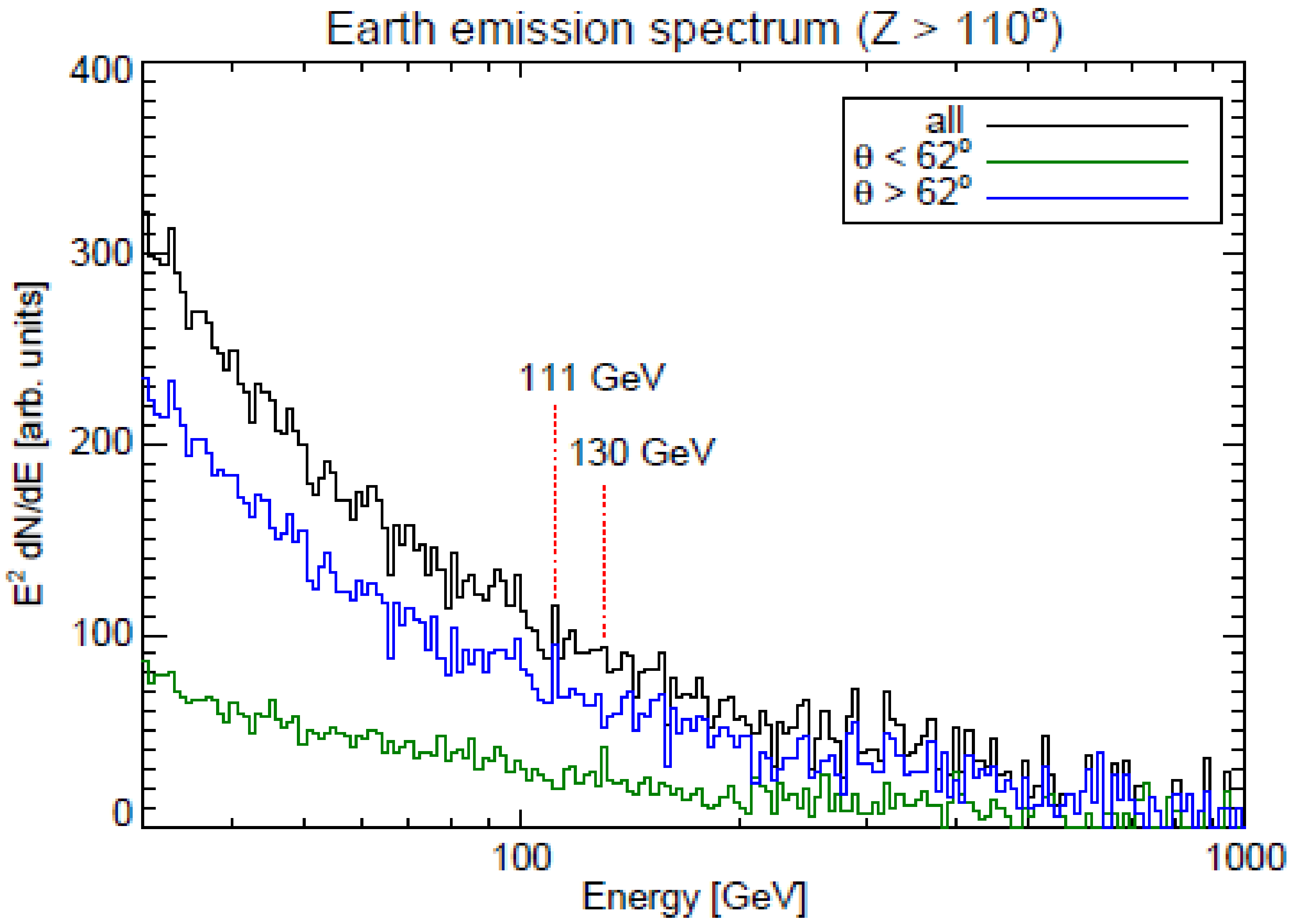


Introduction

A followup analysis by Su and Finkbeiner found a feature at a significance of over 5 sigma.



Instrumental?



Now what?

If real (these could be instrumental effects), what can we learn as theorists?

The issue is that if the dark matter interacts only with photons, through, for example, an operator $(DM)^2$ $(F)^2$, it is very hard to detect.

These interactions are presumably generated through loops of heavy charged particles; this implies that the suppression scale of the operators is at least a few hundred GeV.

Cross sections are then too small for direct detection.

Collider production is doubly electroweak; probably impossible to detect in minimal models.

So all information is from indirect detection.

Now what?

However: not much information in a line.

Position related to dark matter mass.

Height related to strength of coupling.

Can we say anything more about the nature of the couplings?

While we will focus on the 130 GeV line feature, this is a more general question for indirect DM searches.

Our approach: perform an effective field theory analysis of operators that can produce DM annihilations to photons; look for generic features.

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Operator analysis

Large number of operators.

Dimension 5 Operators	
A1	$\frac{1}{\Lambda_{A1}}\bar{\chi}\gamma^{\mu\nu}\chi B_{\mu\nu}$
A2	$\frac{1}{\Lambda_{A2}}\bar{\chi}\gamma^{\mu\nu}\chi\tilde{B}_{\mu\nu}$
Dimension 6 Operators	
B1	$\frac{1}{\Lambda_{B1}^2}\chi^2 B_{\mu\nu}B^{\mu\nu}$
B2	$\frac{1}{\Lambda_{B2}^2}\chi^2 W^a_{\mu\nu}W^{a\mu\nu}$
B3	$\frac{1}{\Lambda_{B3}^2}\chi^2 B_{\mu\nu}\tilde{B}^{\mu\nu}$
B4	$\frac{1}{\Lambda_{B4}^2}\chi^2 W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$
B5	$\frac{1}{\Lambda_{B5}^2}\chi\chi^* B_{\mu\nu}B^{\mu\nu}$
B6	$\frac{1}{\Lambda_{B6}^2}\chi\chi^* W^a_{\mu\nu}W^{a\mu\nu}$
B7	$\frac{1}{\Lambda_{B7}^2}\chi\chi^* B_{\mu\nu}\tilde{B}^{\mu\nu}$
B8	$\frac{1}{\Lambda_{B8}^2}\chi\chi^* W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$

Dimension 7 Operators	
C1	$\frac{1}{\Lambda_{C1}^3}\bar{\chi}\chi B_{\mu\nu}B^{\mu\nu}$
C2	$\frac{1}{\Lambda_{C2}^3}\bar{\chi}\chi W^a_{\mu\nu}W^{a\mu\nu}$
C3	$\frac{1}{\Lambda_{C3}^3}\bar{\chi}\chi B_{\mu\nu}\tilde{B}^{\mu\nu}$
C4	$\frac{1}{\Lambda_{C4}^3}\bar{\chi}\chi W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$
C5	$\frac{1}{\Lambda_{C5}^3}\bar{\chi}\gamma^5\chi B_{\mu\nu}B^{\mu\nu}$
C6	$\frac{1}{\Lambda_{C6}^3}\bar{\chi}\gamma^5\chi W^a_{\mu\nu}W^{a\mu\nu}$
C7	$\frac{1}{\Lambda_{C7}^3}\bar{\chi}\gamma^5\chi B_{\mu\nu}\tilde{B}^{\mu\nu}$
C8	$\frac{1}{\Lambda_{C8}^3}\bar{\chi}\gamma^5\chi W^a_{\mu\nu}\tilde{W}^{a\mu\nu}$
C9	$\frac{1}{\Lambda_{C9}^3}\bar{\chi}\gamma^{\mu\nu}\chi B_{\mu\alpha}\tilde{B}^{\alpha\nu}$
C10	$\frac{1}{\Lambda_{C10}^3}\bar{\chi}\gamma^{\mu\nu}\chi W^a_{\mu\alpha}\tilde{W}^{a\alpha\nu}$
C11	$\frac{1}{\Lambda_{C11}^3}\bar{\chi}\gamma^{\mu\nu}\chi B_{\mu\nu}\lvert\Phi\rvert^2$
C12	$\frac{1}{\Lambda_{C12}^3}\bar{\chi}\gamma^{\mu\nu}\chi\tilde{B}_{\mu\nu}\lvert\Phi\rvert^2$
C13	$\frac{1}{\Lambda_{C13}^3}\bar{\chi}\gamma^{\mu\nu}\chi\Phi^\dagger W^a_{\mu\nu}T^a\Phi$
C14	$\frac{1}{\Lambda_{C14}^3}\bar{\chi}\gamma^{\mu\nu}\chi\Phi^\dagger\tilde{W}^a_{\mu\nu}T^a\Phi$

Operator analysis

We can simplify life a little bit.

Dimension-5 operators (magnetic moment couplings) are excluded by direct detection searches.

Many operators are suppressed by the velocity of the dark matter, and can be ignored (would require new light charged particles which are excluded).

Reduces number of operators significantly.

Remaining operators have a generic feature:

Each operator produces two lines, not just one;
the lines correspond to annihilations to γZ and $\gamma\gamma$, or γZ and γh.

Two Lines or Not Two Lines

We verified that the original analysis of Weniger was indeed compatible with the presence of two lines.

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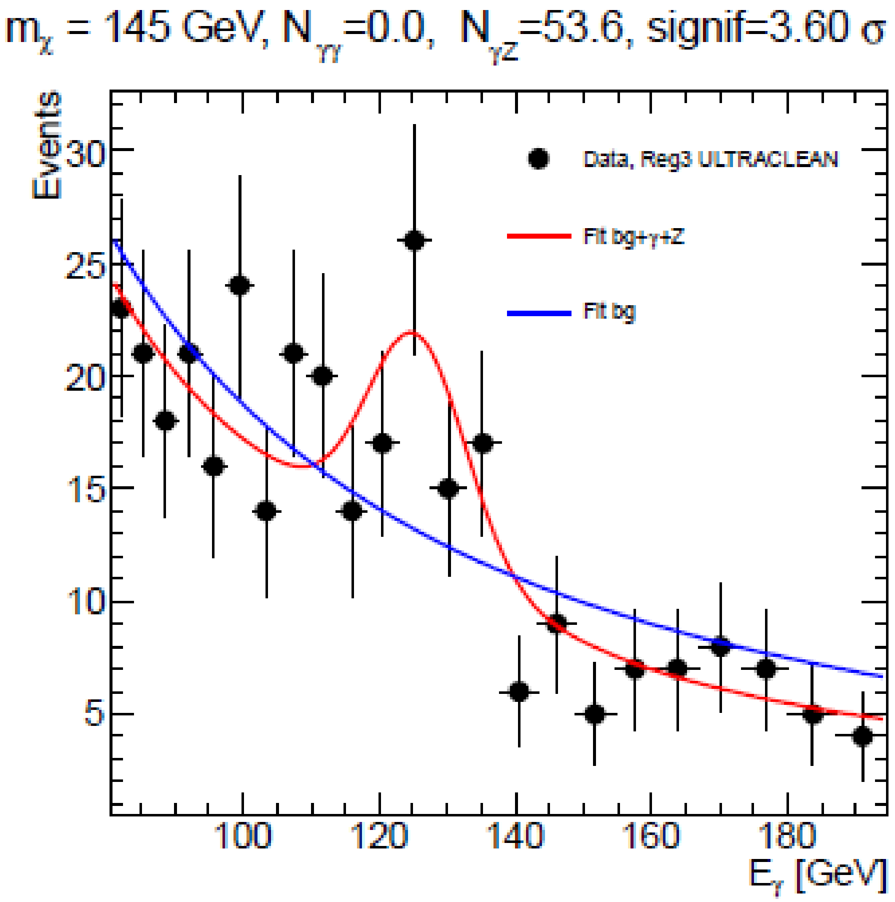
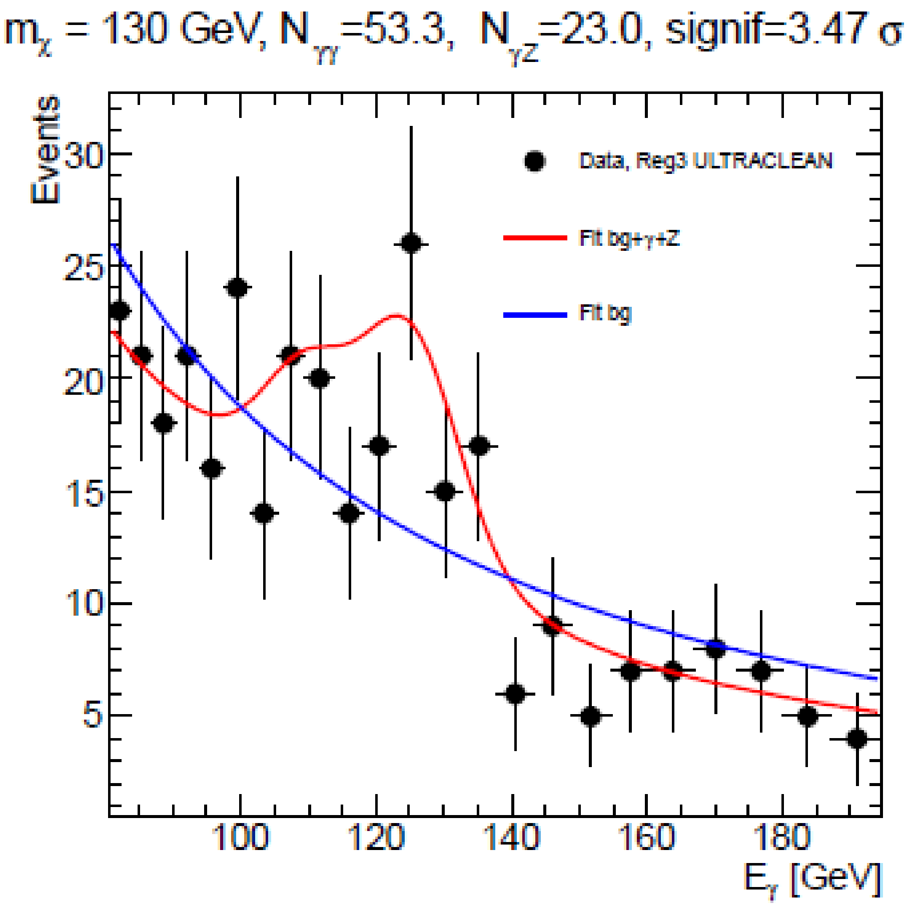
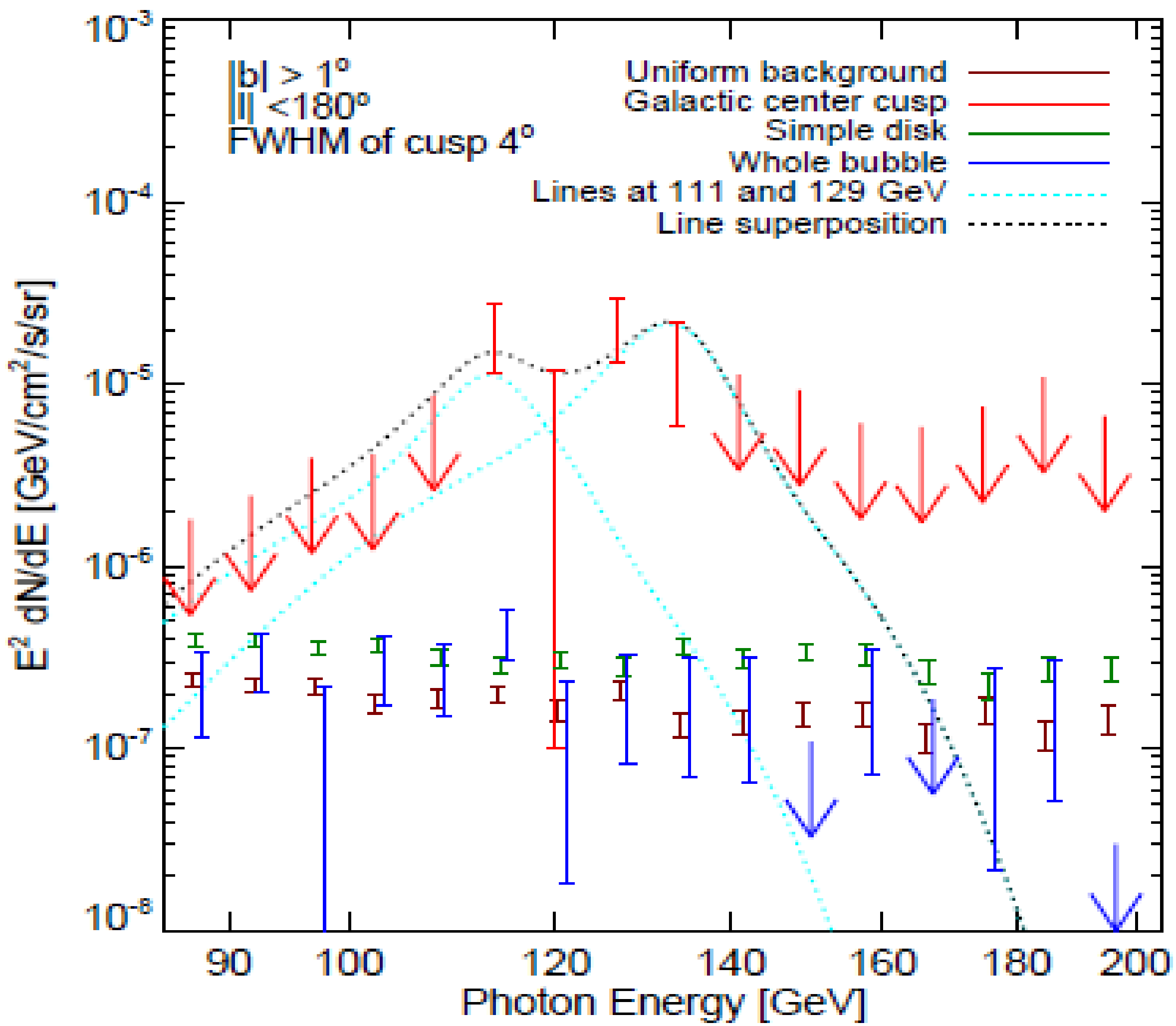




Two Lines or Not Two Lines

Confirmed by Su and Finkbeiner. For two-line search, significance was 5.4 sigma.



Two Lines or Not Two Lines

We can be even more specific; the energies of the two lines must differ by a specific amount. For a decay to a photon and a particle Y, the photon line has energy

$$E_\gamma = m_\chi \left(1 - \frac{M_Y^2}{4m_\chi^2}\right)$$

We could in principle use the difference in peak positions to work out the masses of the products in the decay.

On the other side, experimental searches should be able to use this theoretical input to increase the signal significance.

Two Lines or Not Two Lines

Unfortunately, for this particular pair of lines, the signal is consistent with either

1) a DM particle of mass 127 GeV annihilating to γZ and $\gamma\gamma$

or

2) a DM of mass 141 GeV annihilating to γZ and γh (with a 125 GeV Higgs).

The peak positions do not help us here.

Only other handle here: heights of the two lines.

Can we use this?

Two Lines or Not Two Lines

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The operators which produce γZ and γh annihilations are of the form

$$-\bar{\chi}\gamma_\mu\chi B^{\mu\alpha}\Phi^\dagger D_\alpha \Phi$$

We then find that the relative heights of the two peaks are completely fixed; the ratio of the heights scales as

$$\frac{m_Z^2}{2p_h^2} \sim 0.32$$

Higher energy peak should be of smaller height.

Appears to be in tension with the peaks found by Su and Finkbeiner.

Suggests annihilation is actually to γZ and $\gamma\gamma$.

Conclusions

Effective field theory arguments indicate that indirect detection searches for dark matter have a richer structure than one might expect.

Any signal of DM in gamma rays should produce at least two lines corresponding to annihilations to γZ and $\gamma\gamma$, and/or γZ and γh.

The positions and heights of these two peaks can be used to probe the underlying physics of DM.

This theoretical input can also be used by experiments to reduce backgrounds.