The Fermi Lines

Are they real?

Daniel Whiteson

UC Irvine

Hinchliffe's Rule

Hinchliffe's Rule:

If the title is a question, the answer is 'no'.

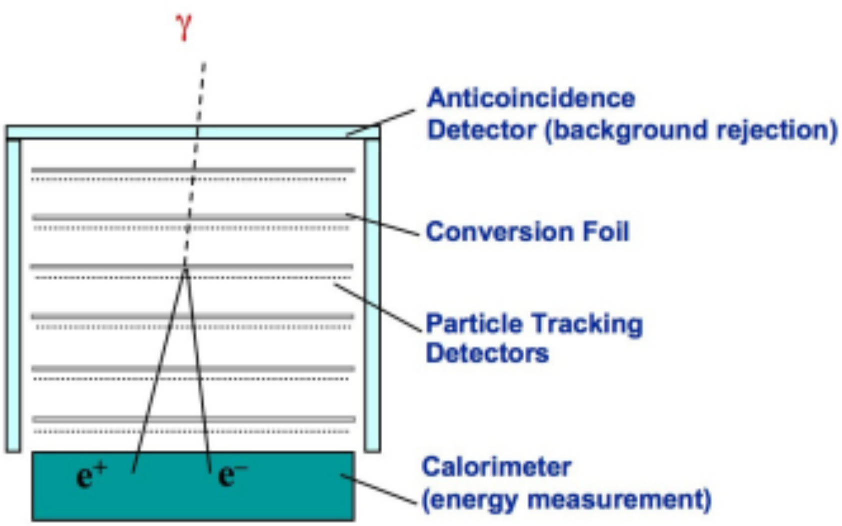
IS HINCHLIFFE'S RULE TRUE?

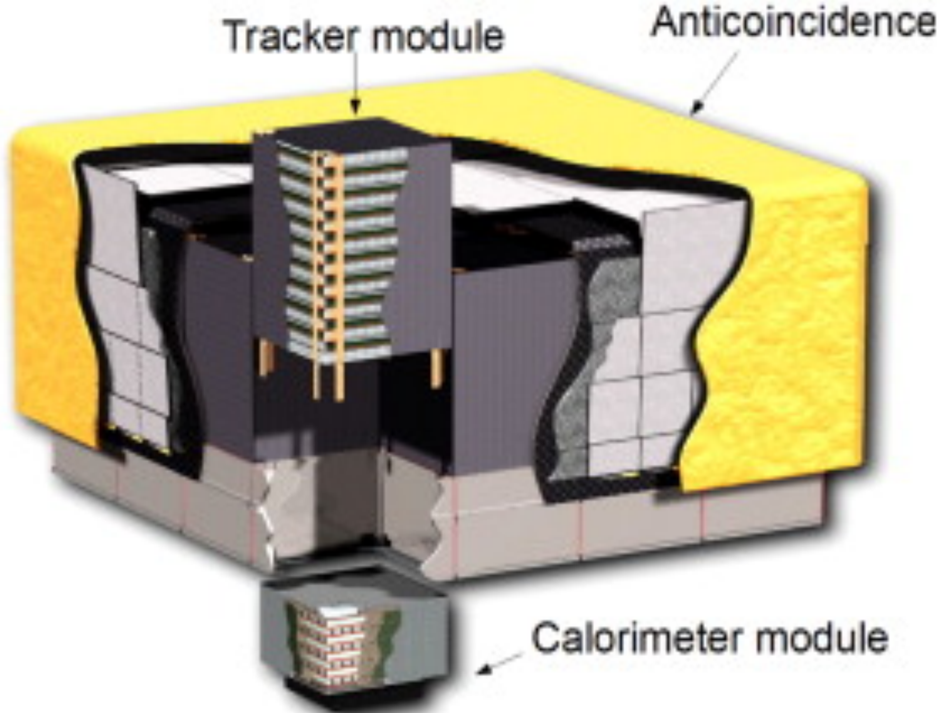
Boris Peon

Abstract

Hinchliffe has asserted that whenever the title of a paper is a question with a yes/no answer, the answer is always no. This paper demonstrates that Hinchliffe's assertion is false, but only if it is true.

Fermi-LAT


γ
Anticoincidence Detector (background rejection)
Conversion Foil
Particle Tracking Detectors
e+
e−
Calorimeter (energy measurement)


Tracker module
Anticoincidence
Calorimeter module

Disclaimer

I've been doing collider physics....

Search for resonant top plus jet production in $t\bar{t}$ + jets events with detector in pp collisions at $\sqrt{s} = 7$ TeV

Measurement of ZZ production in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous ZZZ and $ZZ\gamma$ couplings with the ATLAS detector

Search for a heavy particle decaying to a top quark and a light quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Search for pair-produced heavy quarks decaying to Wq in the two-lepton channel at $\sqrt{s} = 7$ TeV with the ATLAS detector

Search for same-sign top-quark production and fourth-generation down-type quarks in pp collisions a $\sqrt{s} = 7$ TeV with the ATLAS detector

Search for Dark Matter Candidates and Large Extra Dimensions in event photon and missing transverse momentum in pp collision data at $\sqrt{s}$ =7 Te ATLAS detector

Triangulating an exotic T quark

Search for a heavy vector boson decaying to two gluons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

Search for down-type fourth generation quarks with the ATLAS detector in events with one lepton and hadronically decaying W bosons

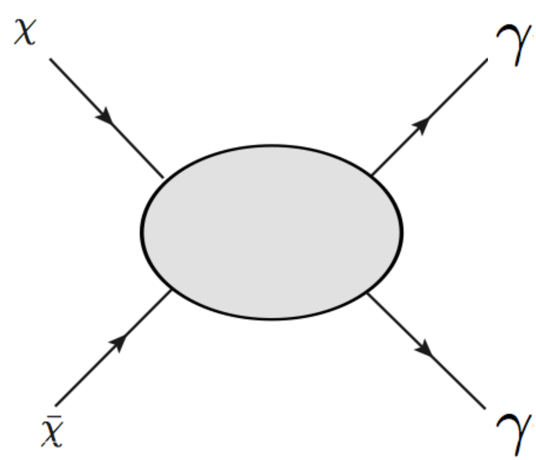
... I am not (yet) an astro-physicist!

Outline

I. One line or two?
II. Source of the photons
III. Instrumental features

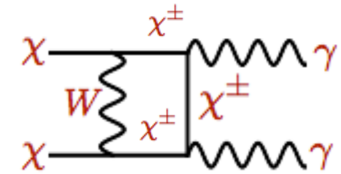
with brand new results

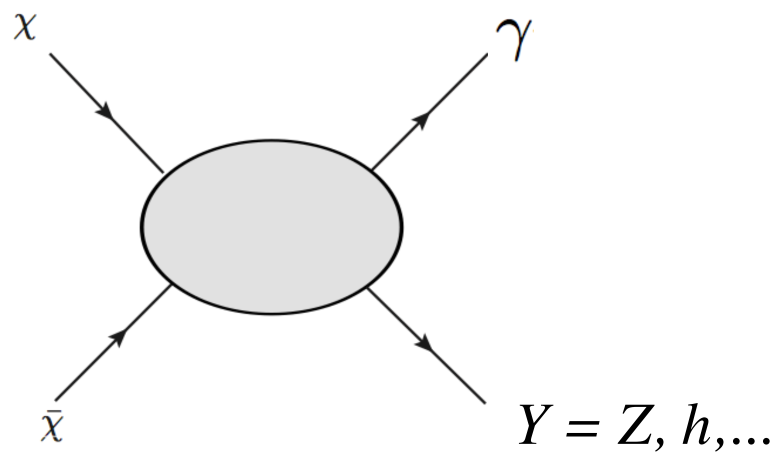
Lines



$E_\gamma = m_\chi$

Two lines, or not two lines?

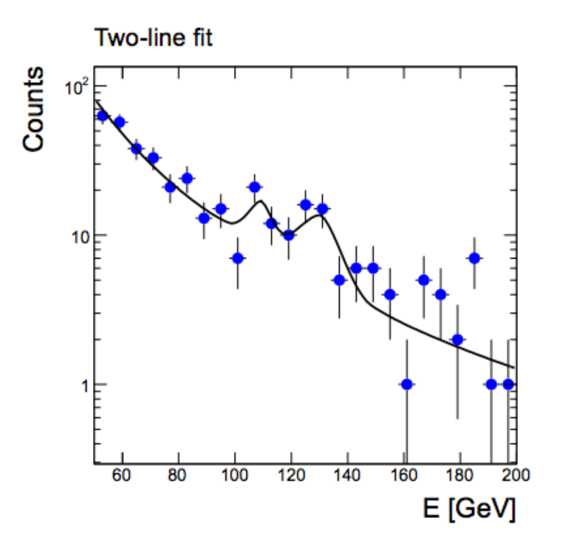


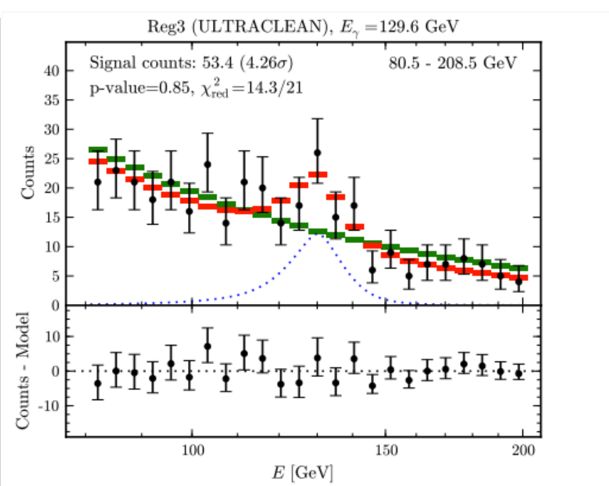


$$E_\gamma = m_\chi \left(1 - \frac{M_Y^2}{4m_\chi^2}\right)$$

Rajaraman, Tait, DW
1205.4723

Analysis

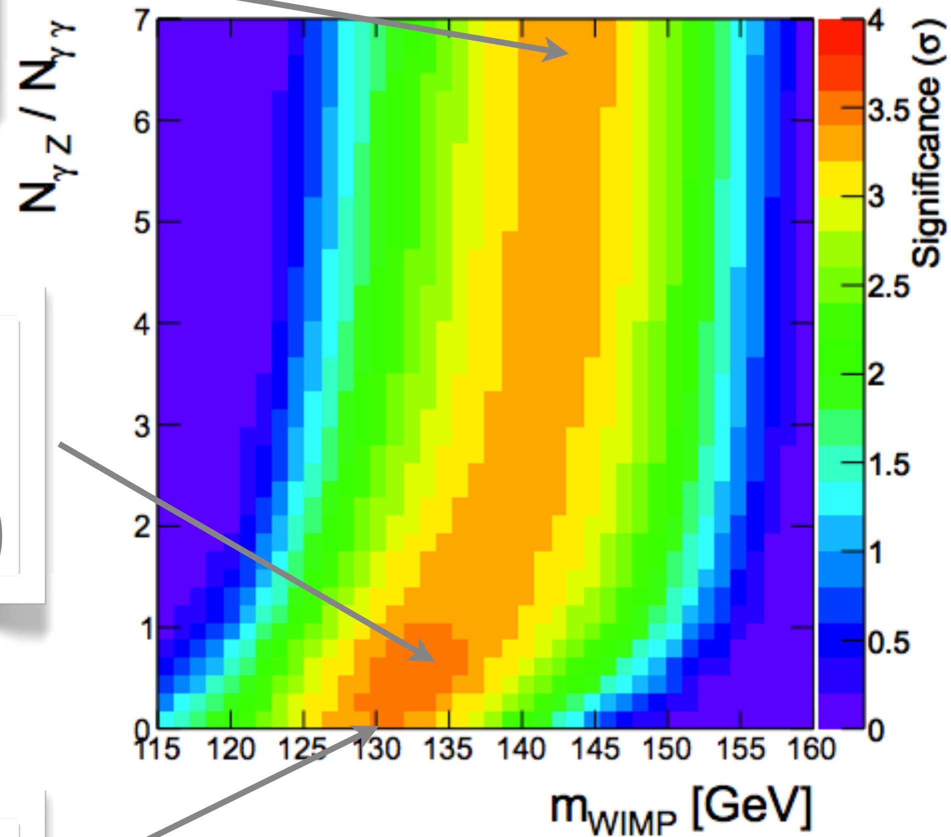




m_x = 145
E_γ=130 (γZ)

m_x = 130
E_γ=110 (γZ)
E_γ=130 ($\gamma\gamma$)

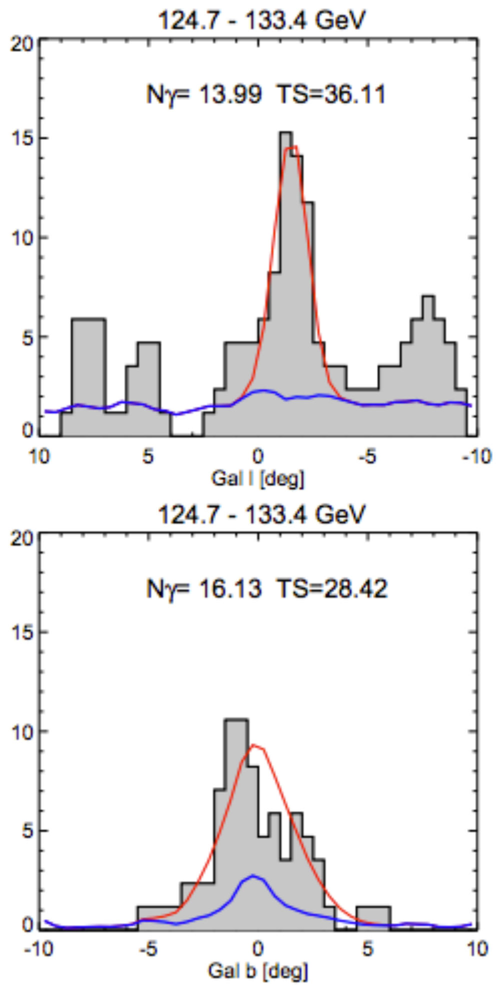
m_x = 130
E_γ=130 ($\gamma\gamma$)

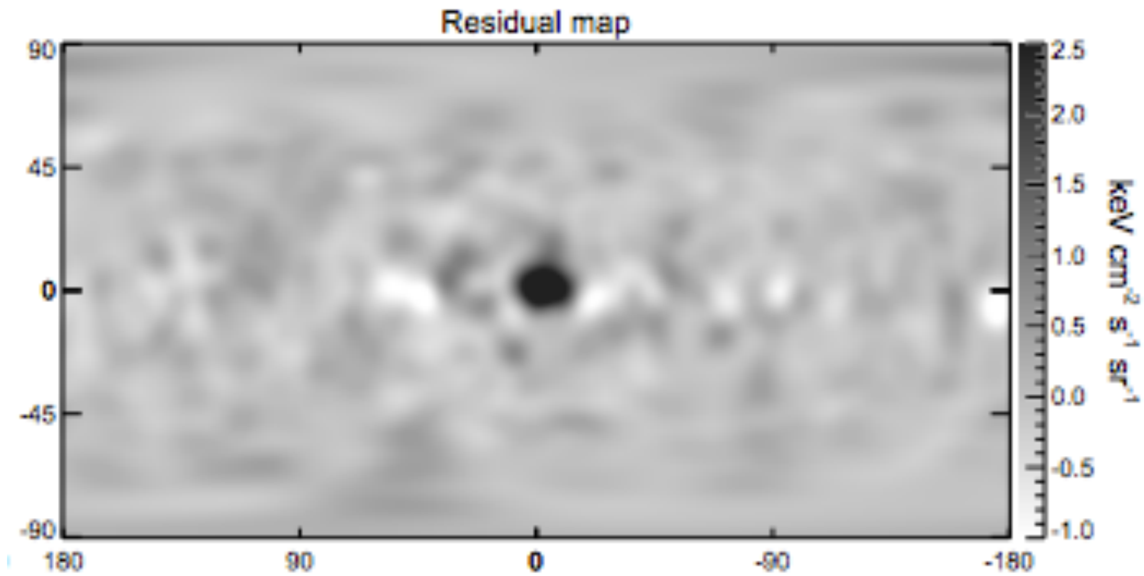


Rajaraman, Tait, DW
1205.4723

Source of the photons

Where are they from?

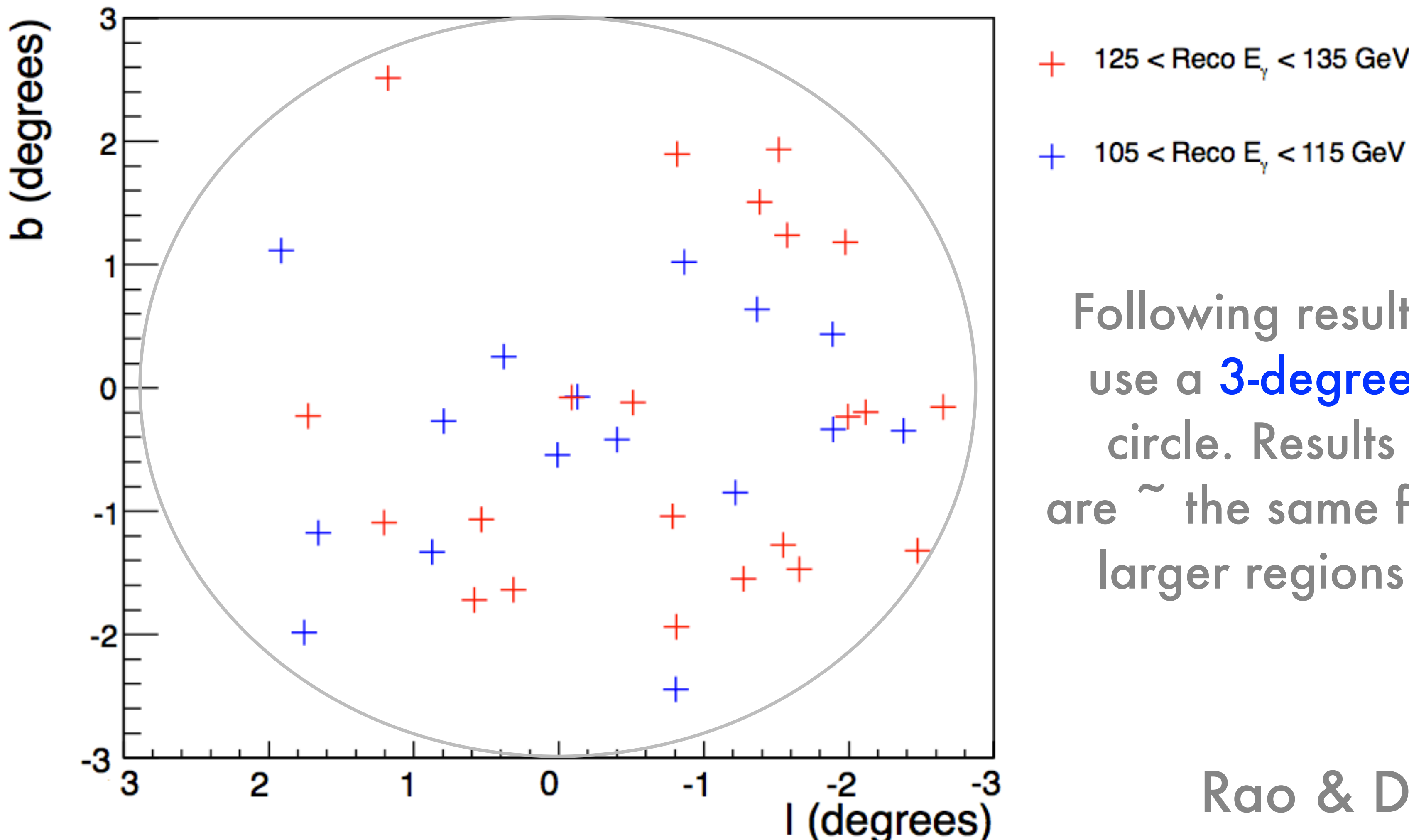




NFW density profile centered at $(\ell, b) = (-1.5°, 0°)$

Finkbiener&Su
1206.1616

The photons

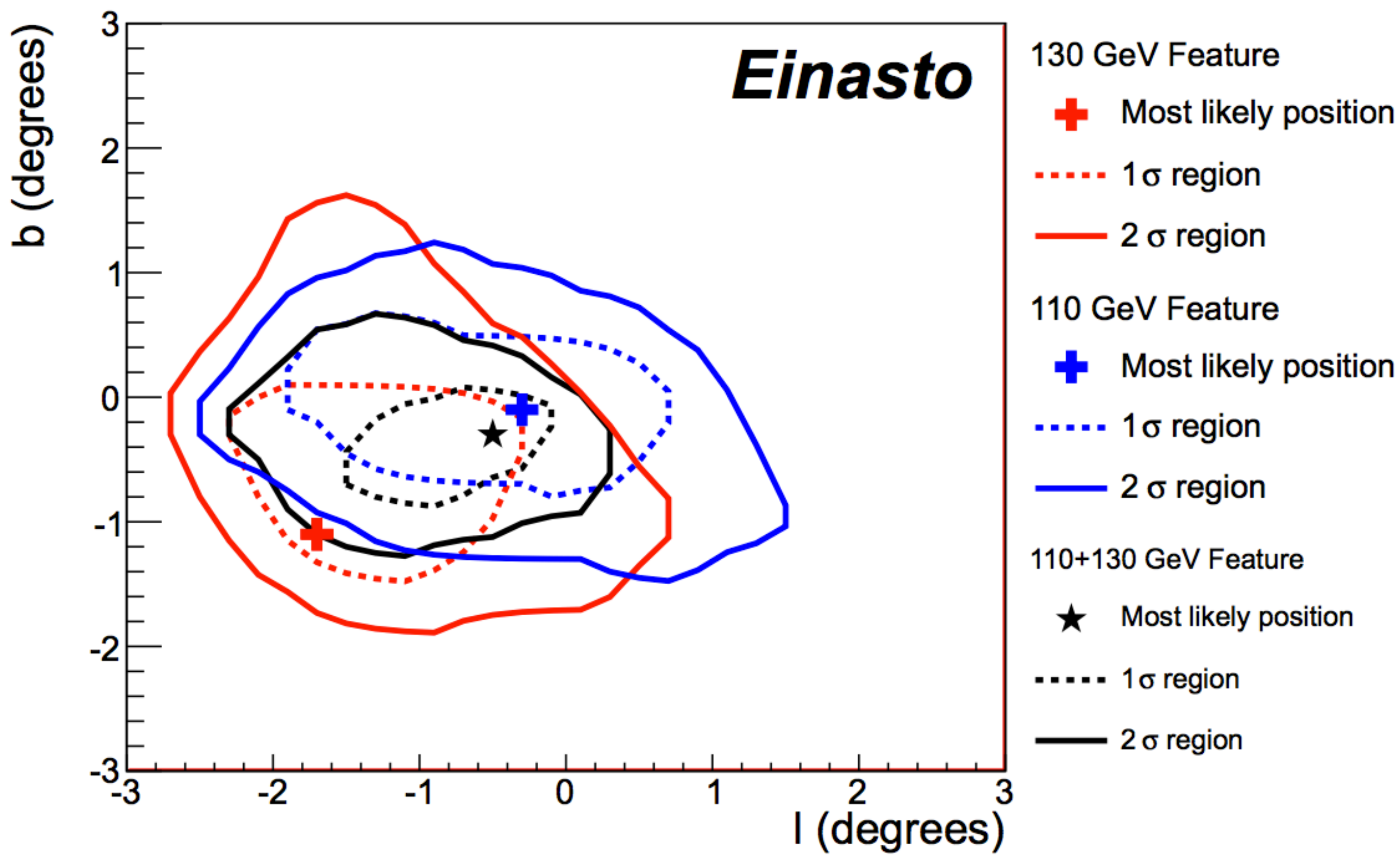


Following results use a 3-degree circle. Results are ~ the same for larger regions

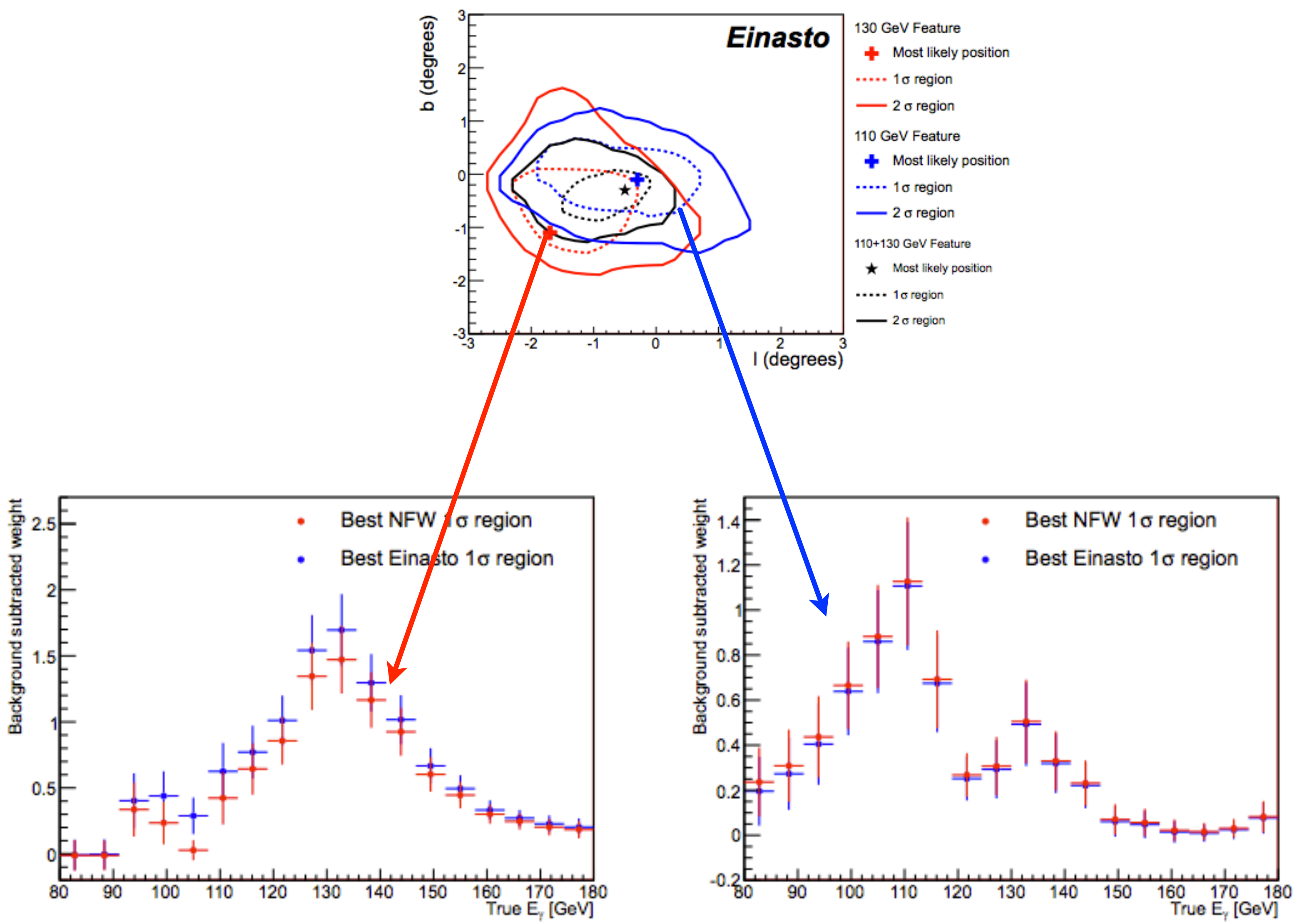
Rao & DW
1210.4934

Locations

Rao & DW
1210.4934



Zoom: 1 sigma



Rao & DW
1210.4934

Hypothesis tests

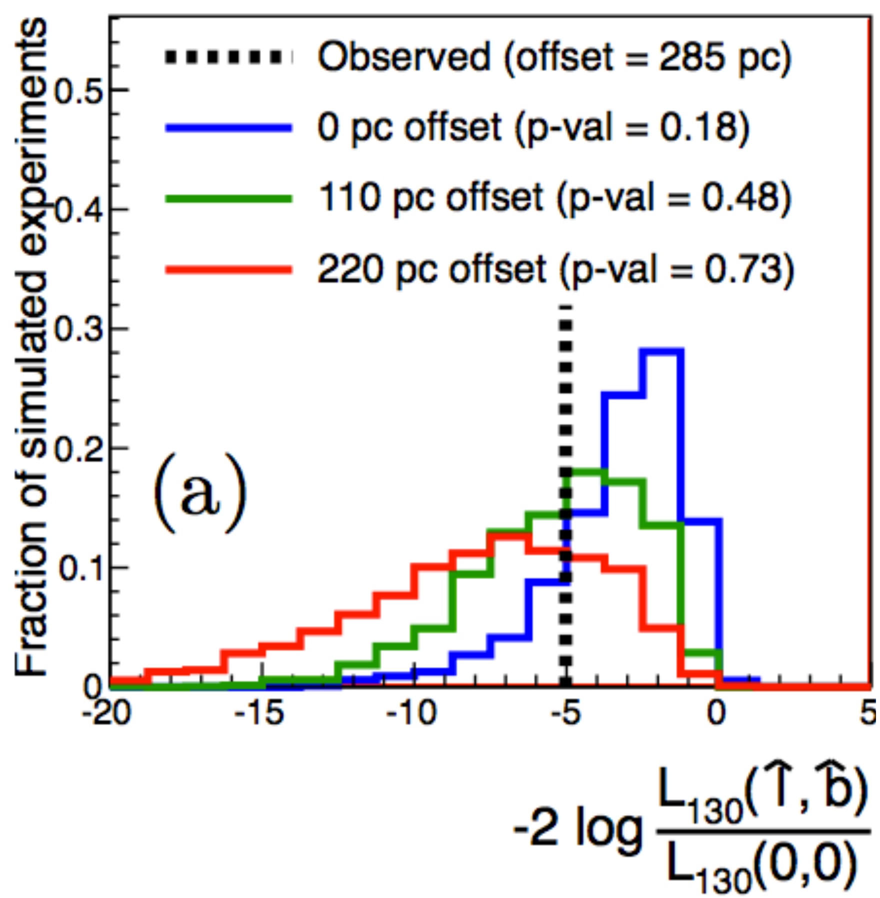
<u>(l,b) fit far from GC</u>

q → negative

$$q = -2\log\frac{L(l=\hat{l}, b=\hat{b})}{L(l=0, b=0)}$$

<u>(l,b) fit is close to 0,0</u>

q → zero



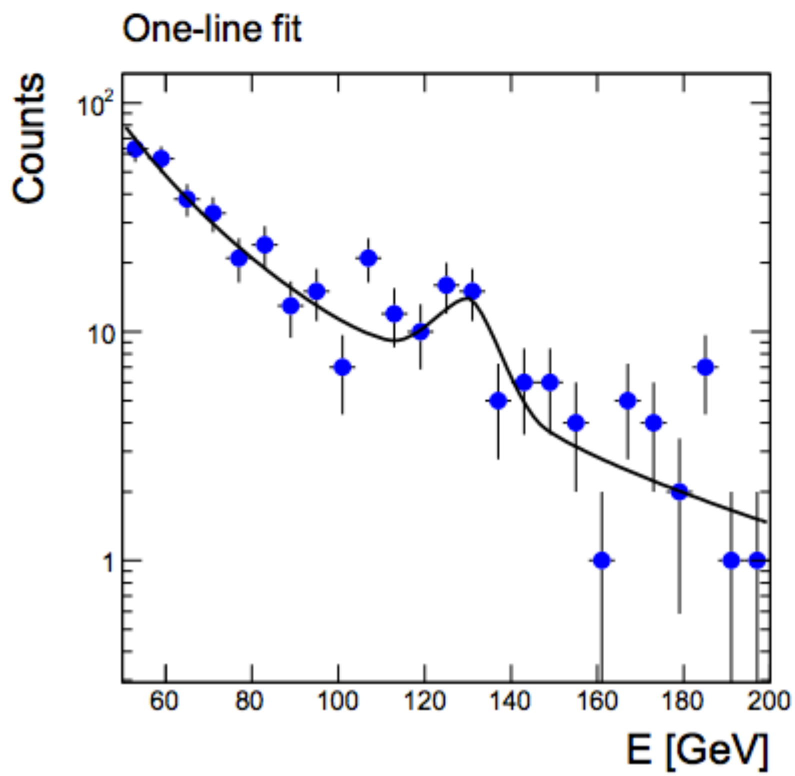
Locations

Conclusion:

The photon locations are easily consistent with a single DM halo at the GC

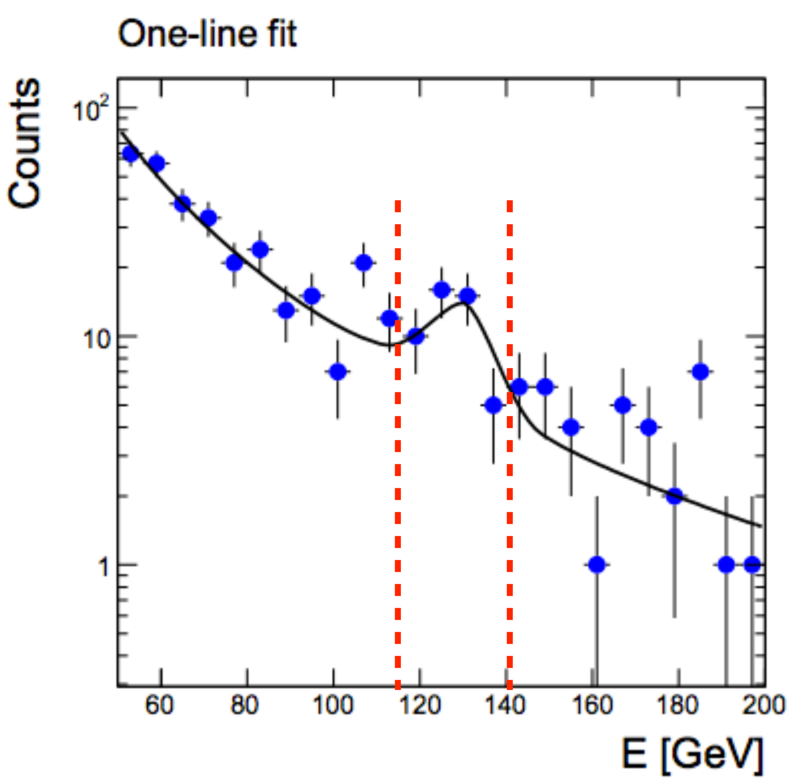
Instrumental issues

photons



Could the peak photons be spurious?
Are they different in some way?

First idea



Isolate signal photons

Use energy cut

But

S/B is not large.

Few signal photons.

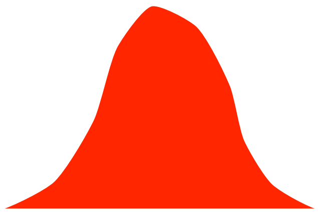
Can we do better?

sPlots

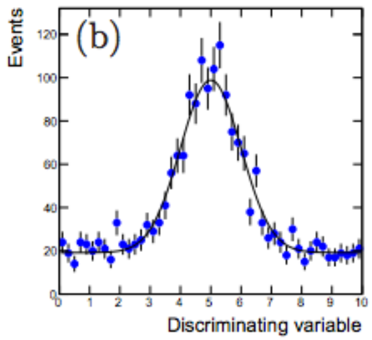
discriminating
variable

background

signal

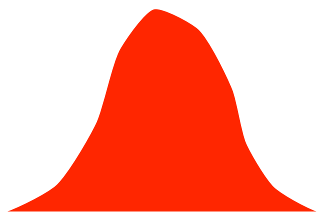
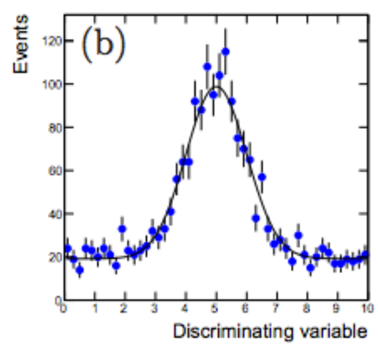


data



sPlots

(pdfs factorize)

	discriminating variable	unfolding variable
background		
signal		
data		

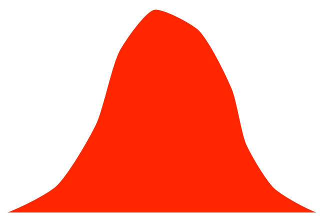
sPlots

(pdfs factorize)

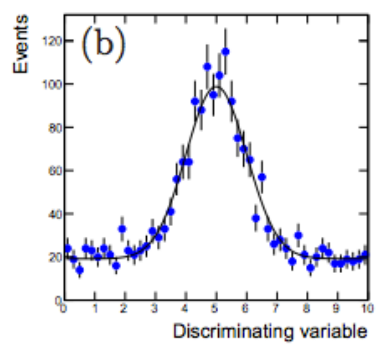
discriminating variable

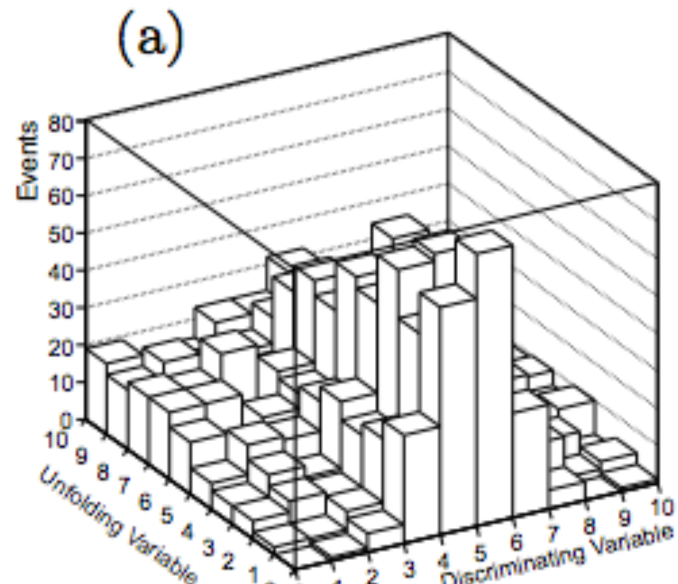
background

signal



data

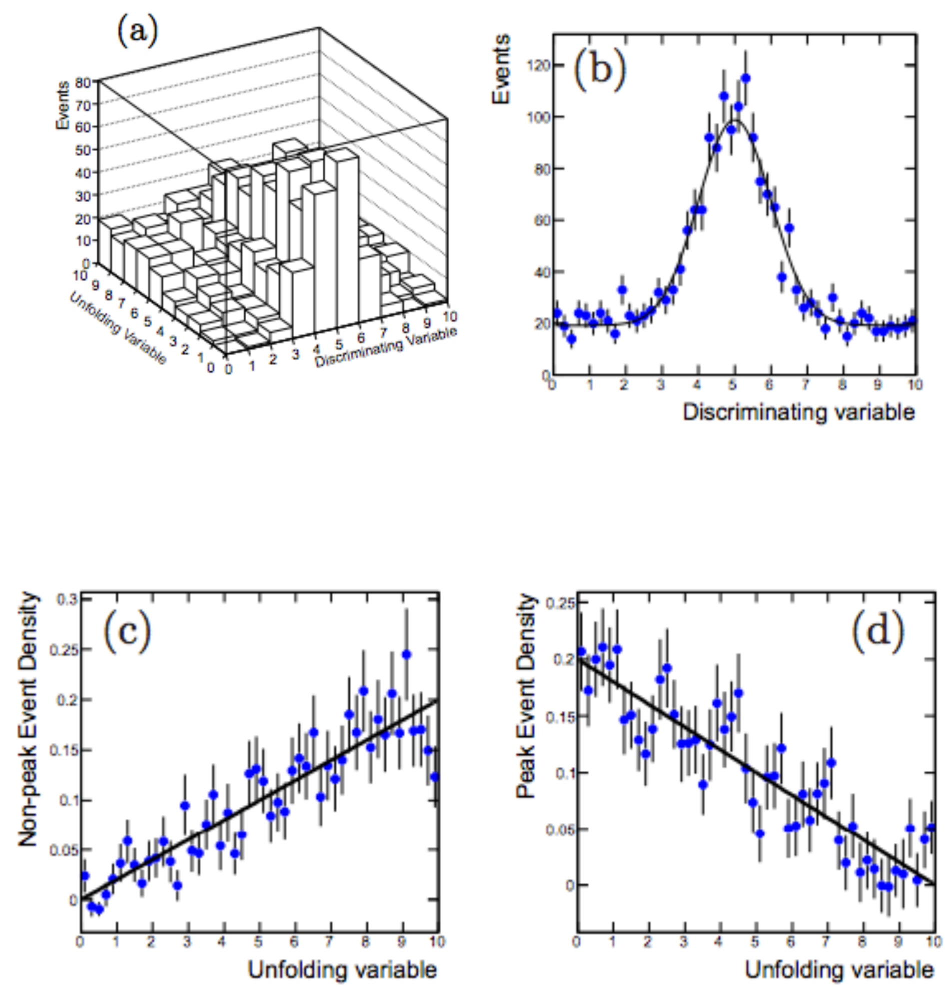




sPlots

$$f_{\rm peak}(x,y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(y-5)^2} \times \frac{10-x}{50}$$

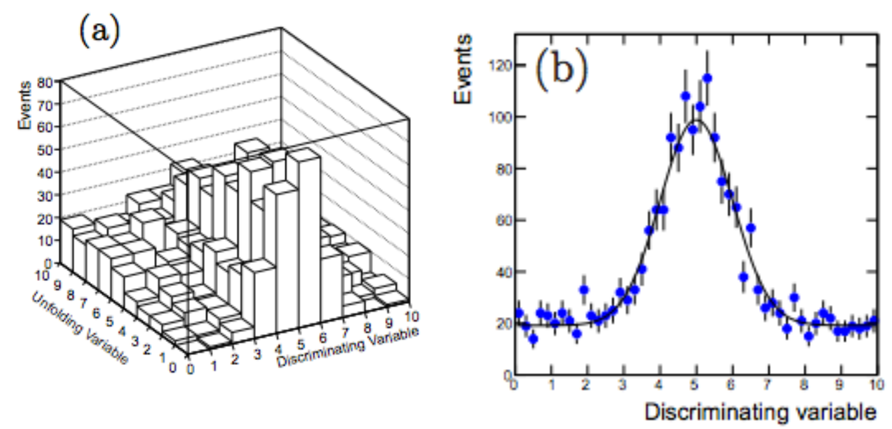
$$f_{\text{non-peak}}(x,y) = \frac{x}{50}$$

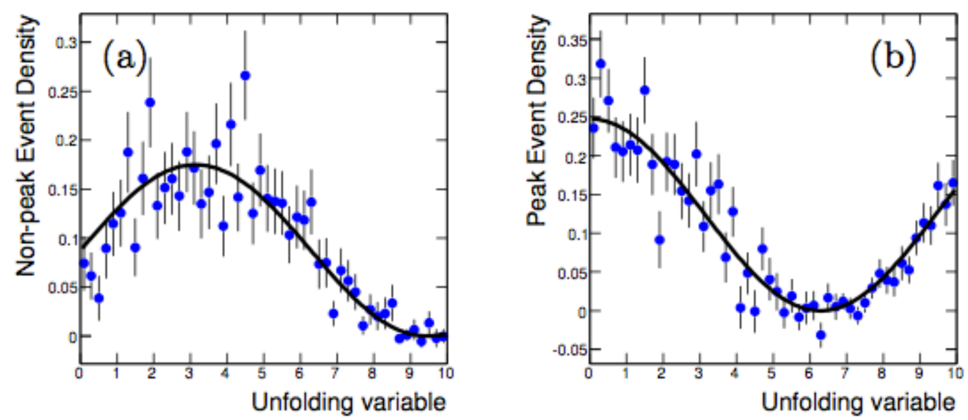


Whiteson
1208.3677

sPlots

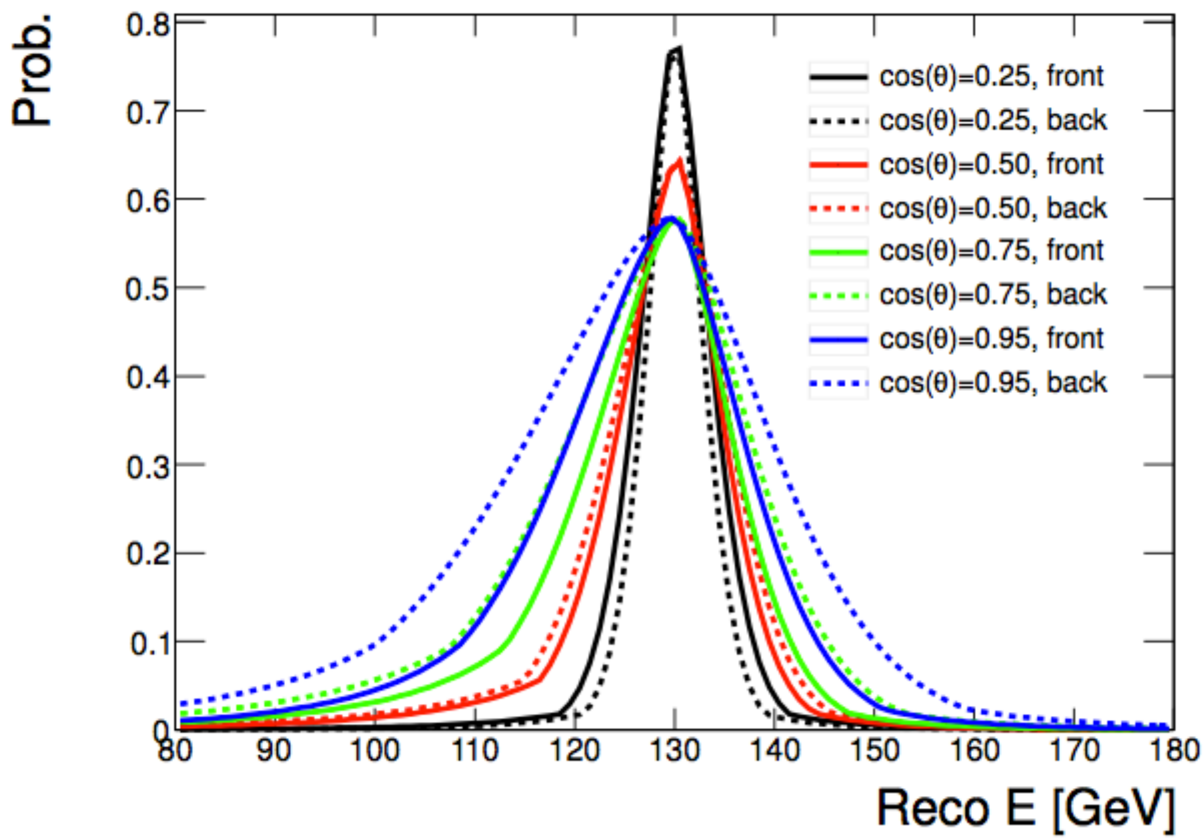
Also works
in a non-linear
case!

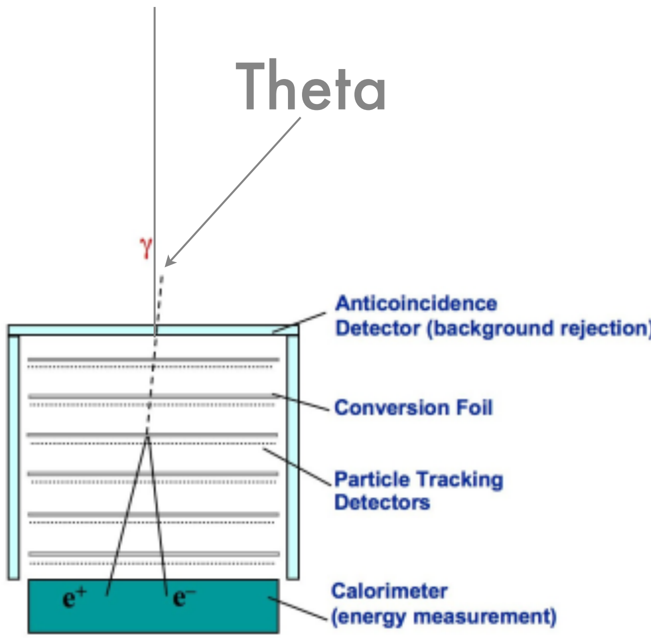




Whiteson
1208.3677

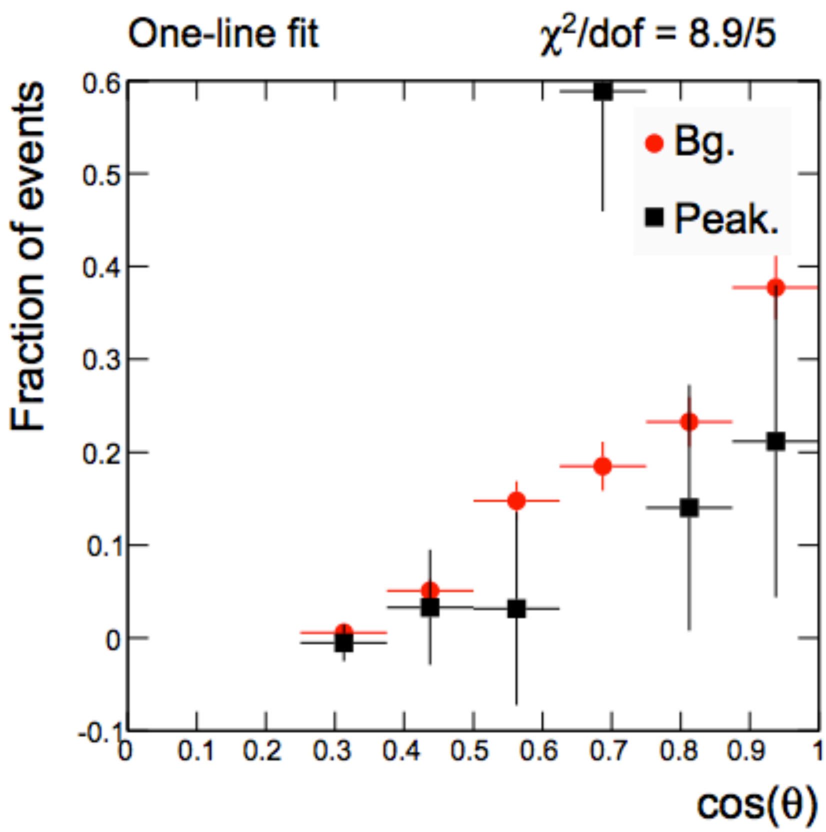
Performance

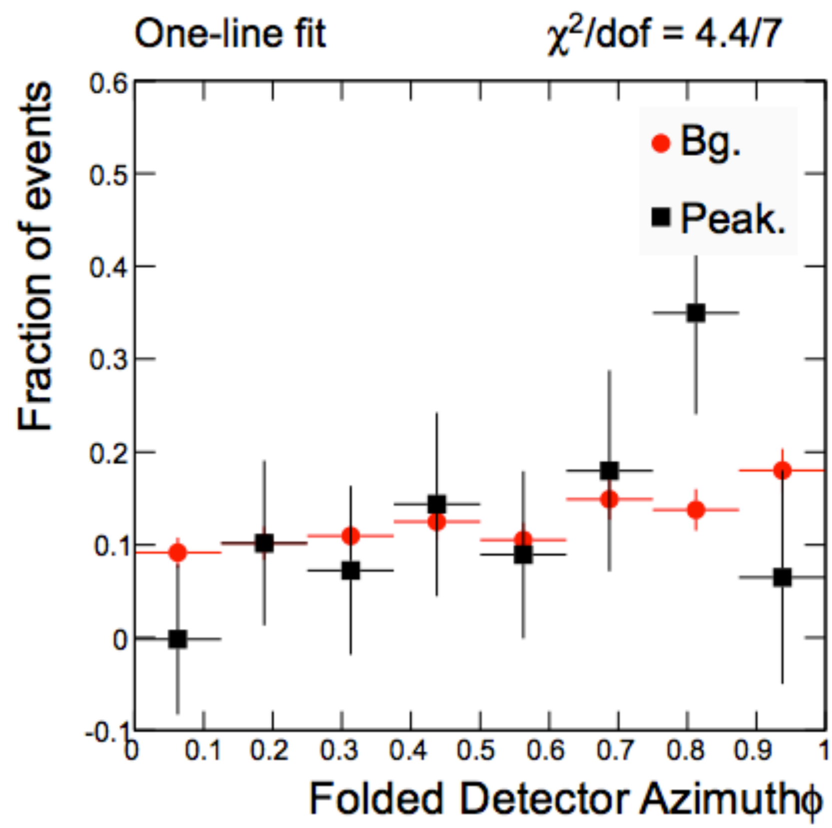




For true photon energy of 130 GeV

Results





- incident angle θ, measured with respect to the top-face normal of the LAT,
- azimuth angle ϕ, measured with respect to the top-face normal of the LAT, folded as described in Eq. (15) of Ref. [11].

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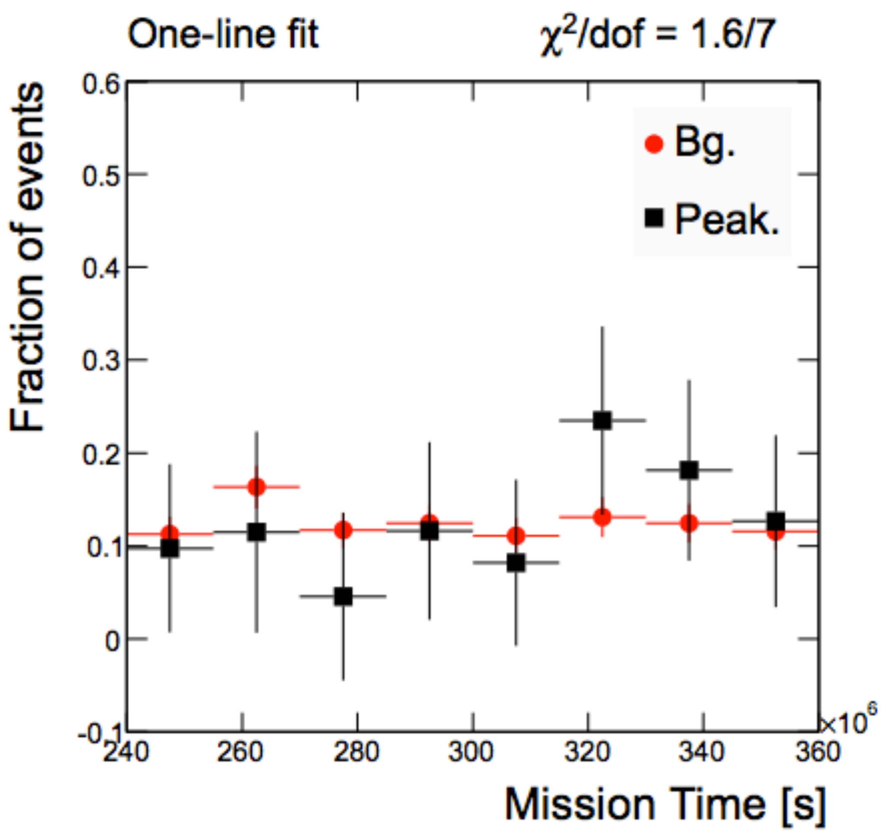
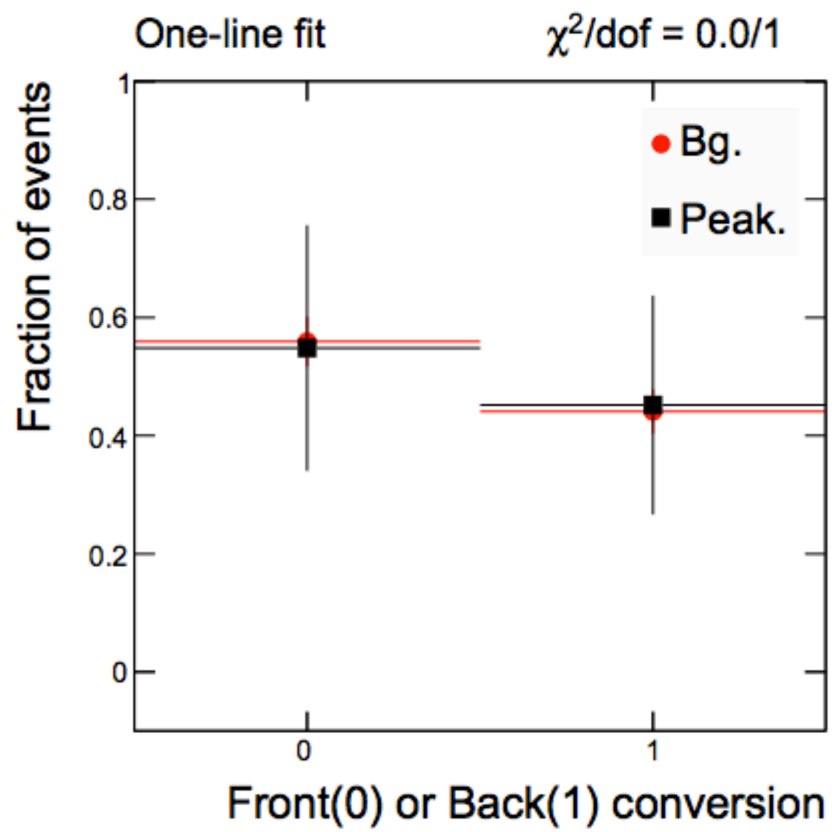
1208.3677

variables





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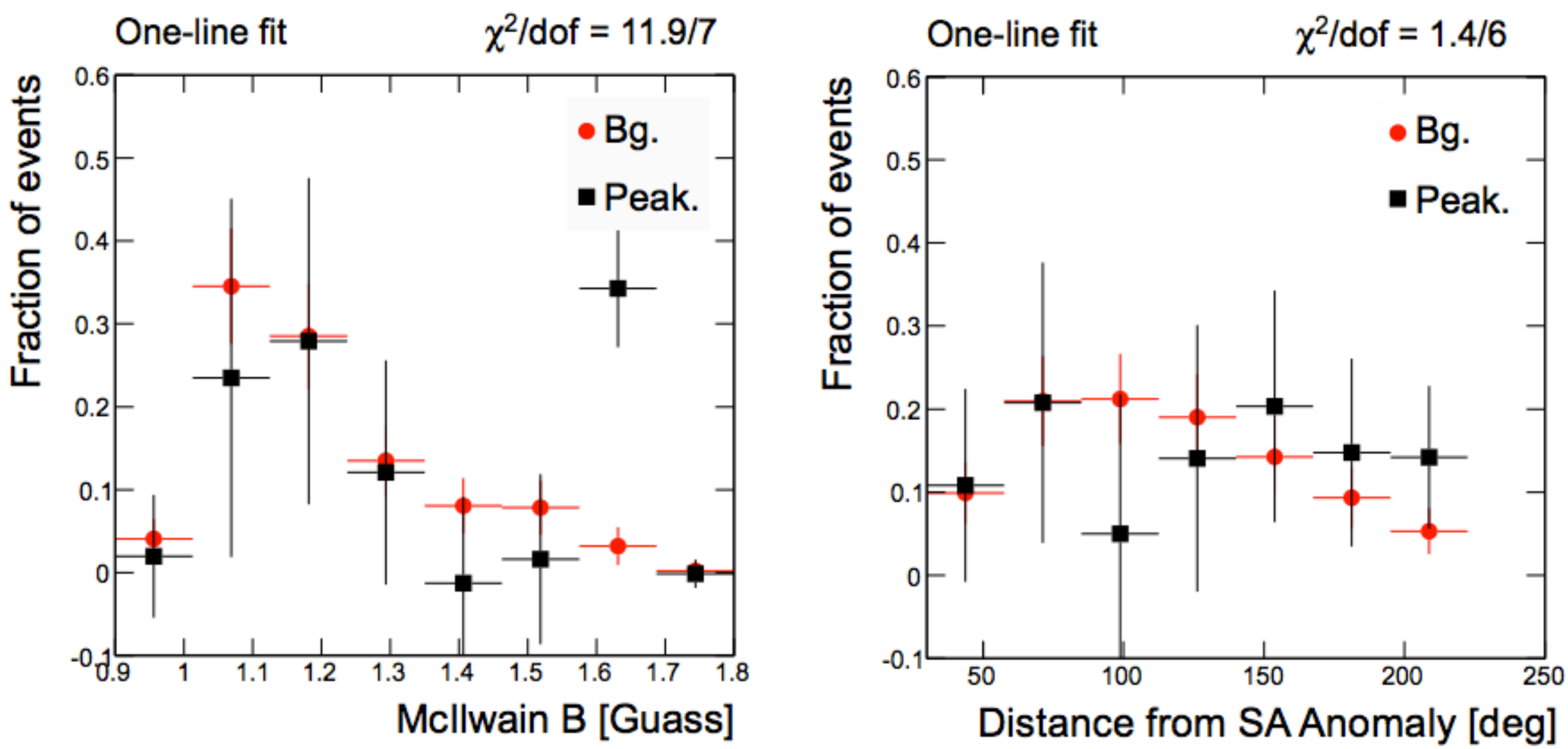
1208.3677

External issues?



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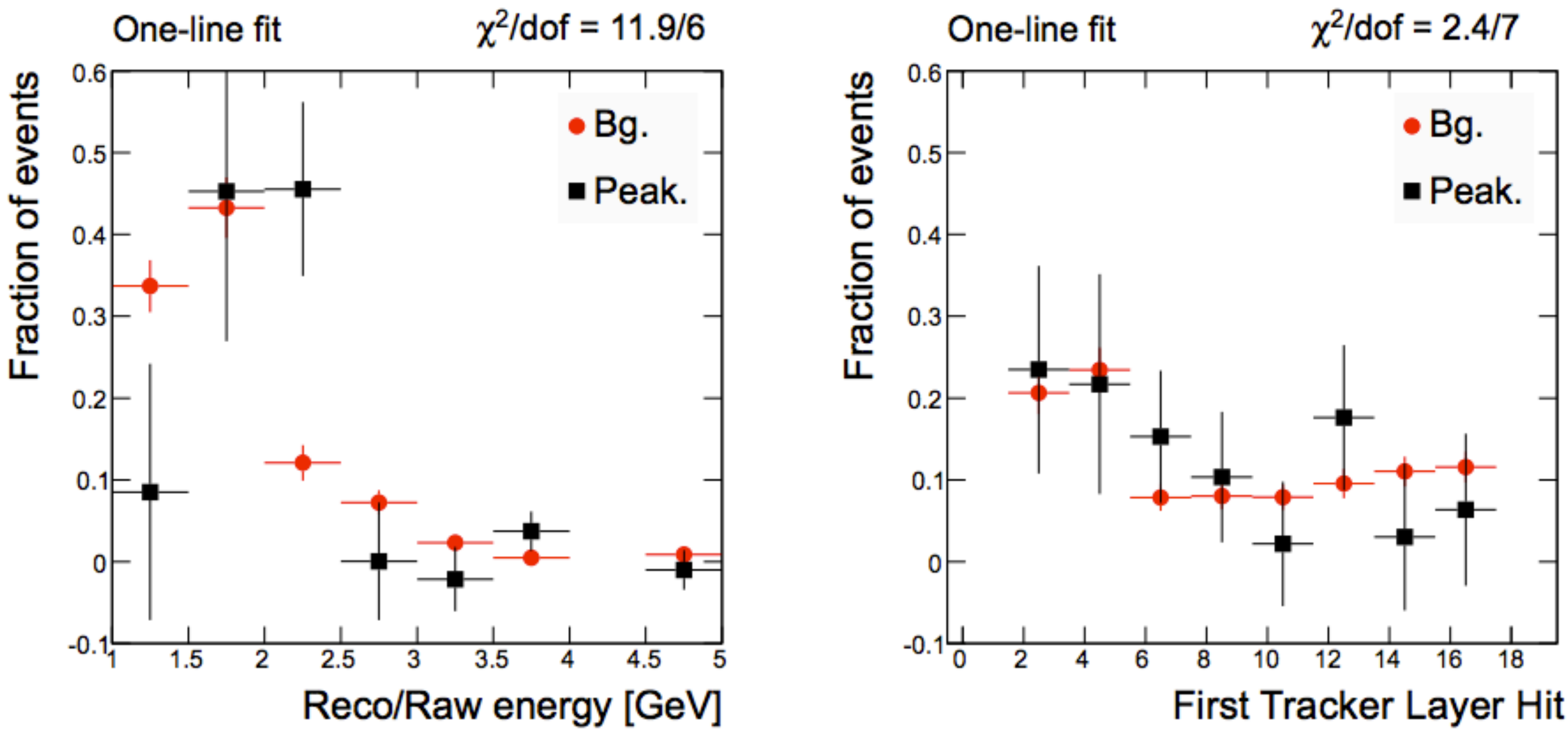
- the magnetic field in which the LAT is immersed, as parameterized by the McIlwain B and L parameters [14],

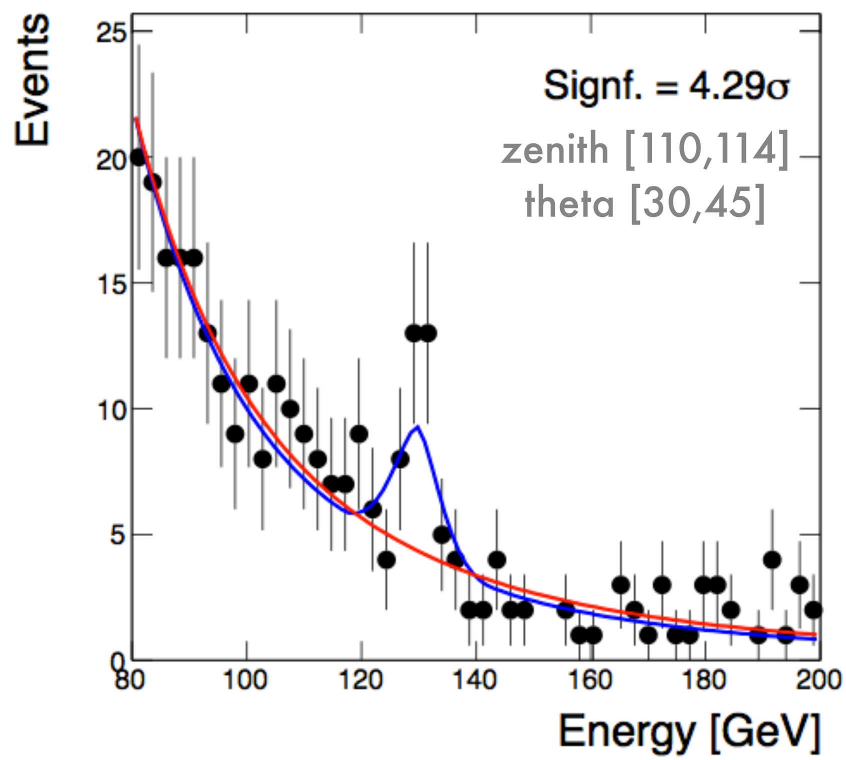
Reconstruction

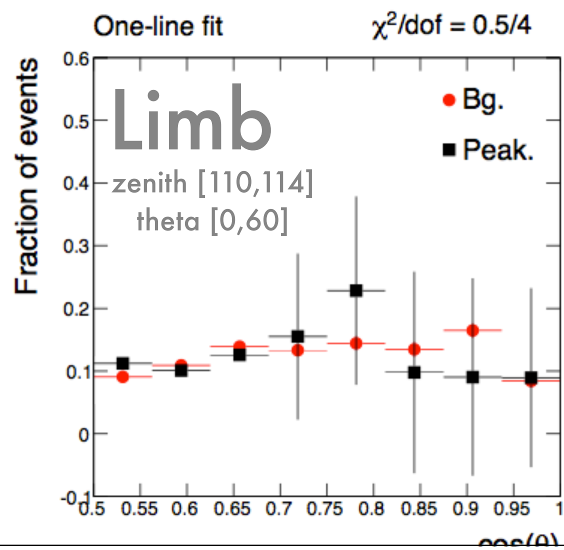


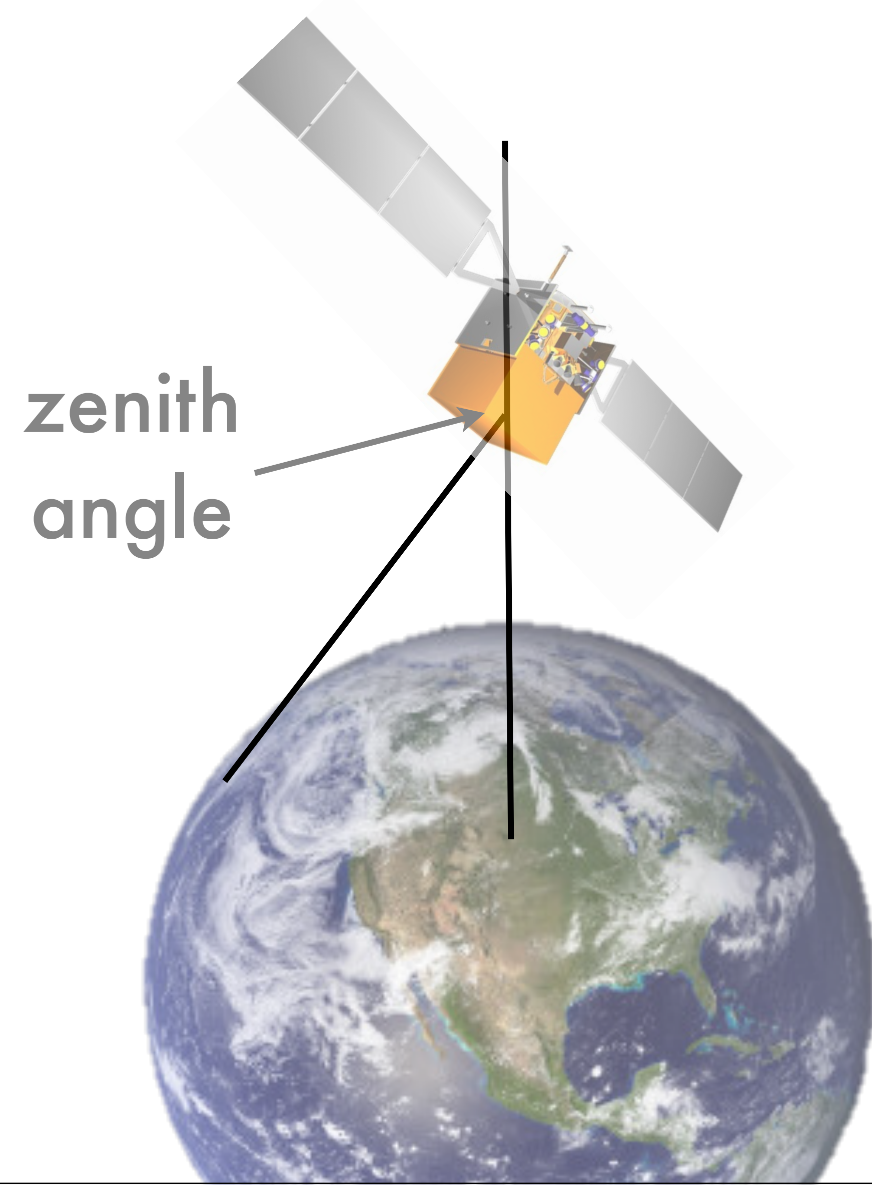
Whiteson
1208.3677

Limb

1st reported:
Finkbiener, et al
1209.4562







Limb

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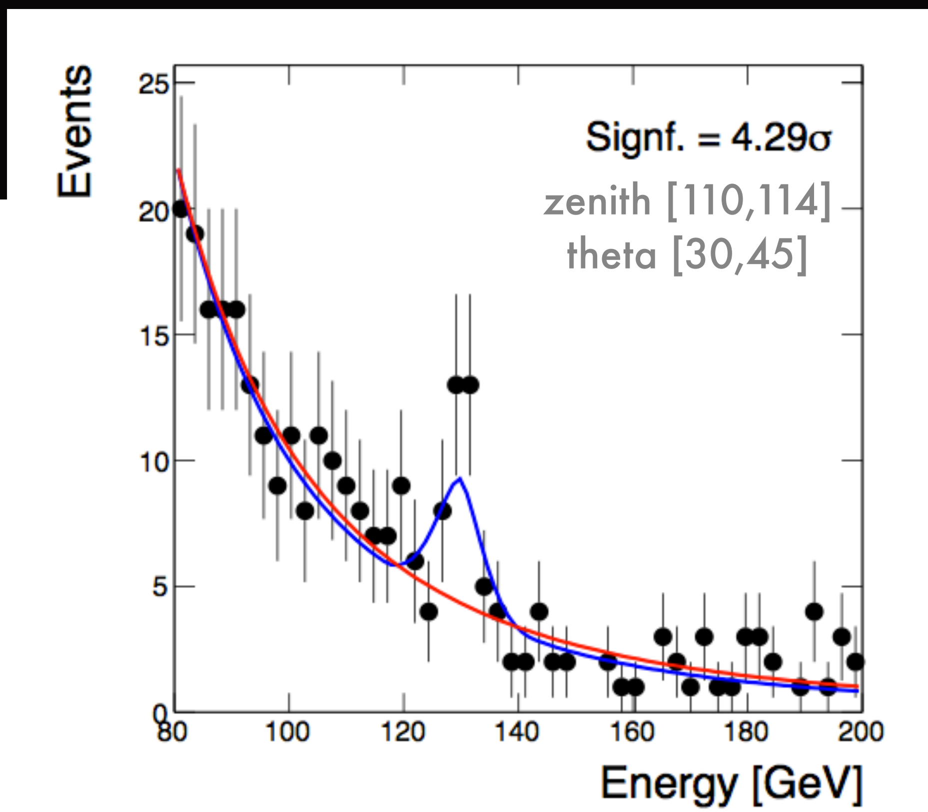
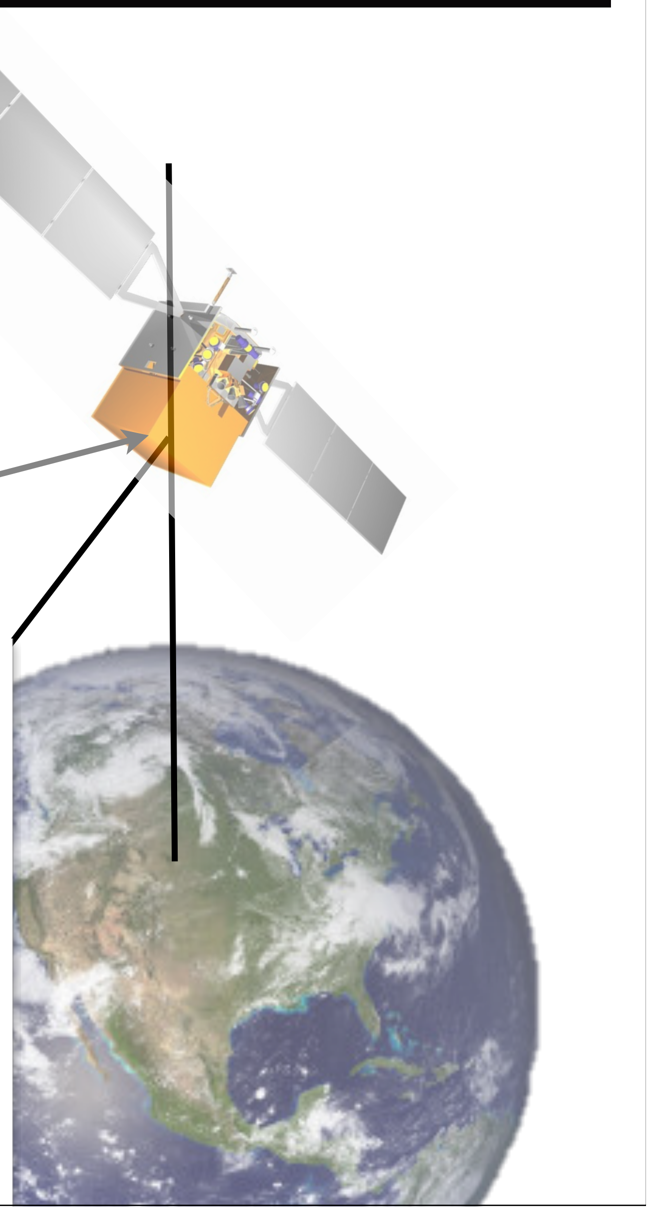
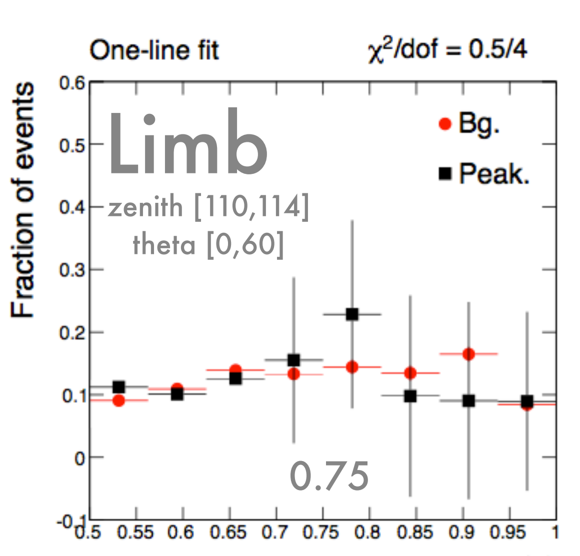
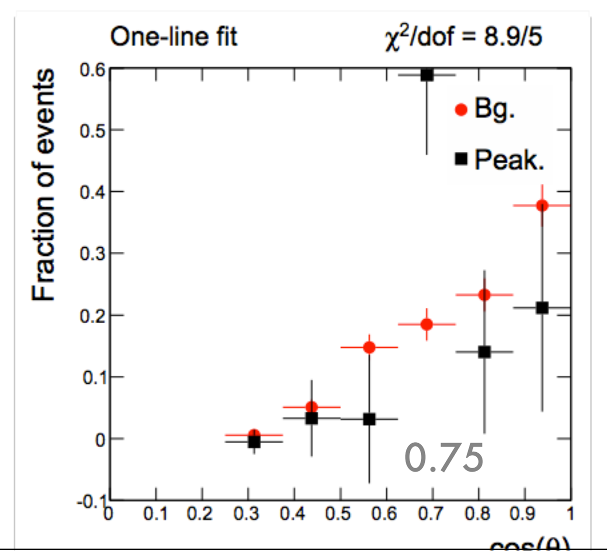
to appear







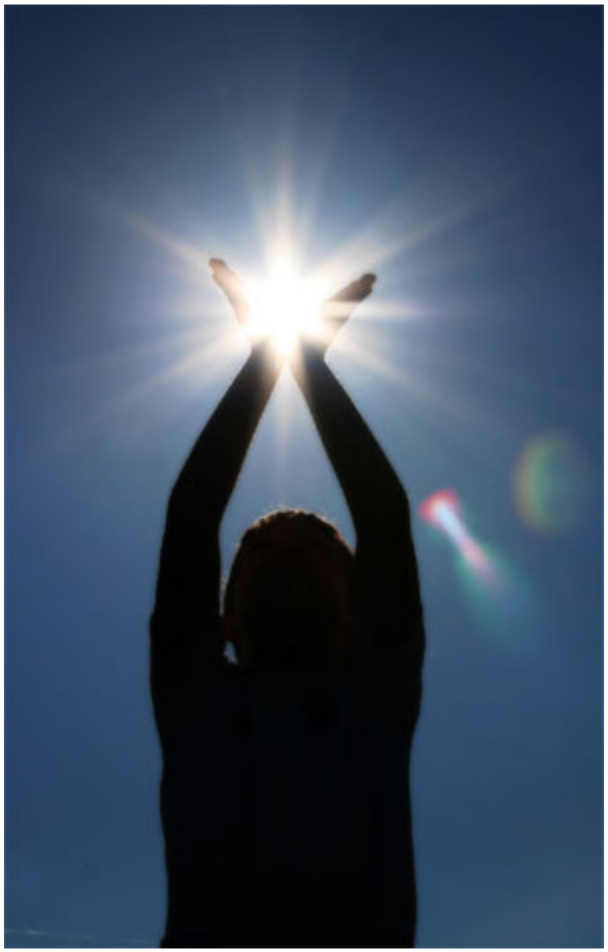


Other sources

Earth’s limb is a powerful control region.

Are there other regions?

Other sources

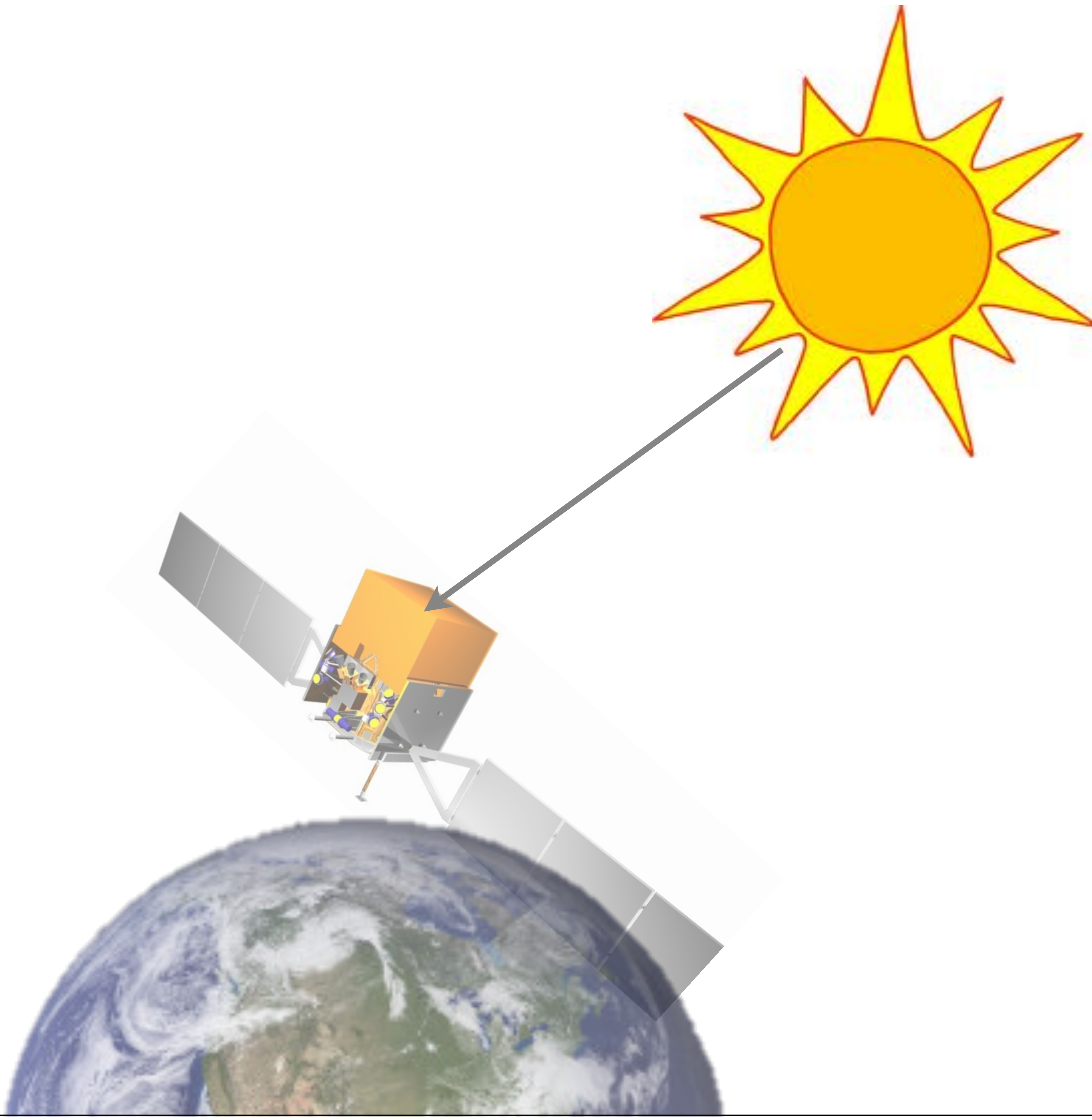


Earth's limb is a powerful control region.

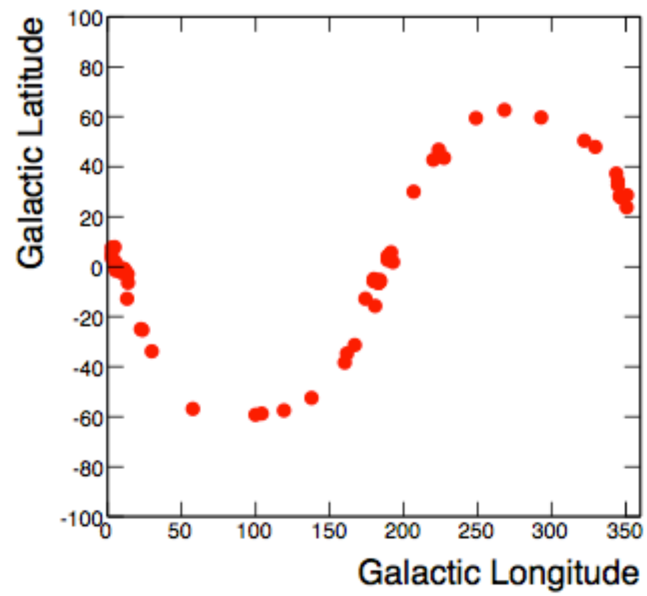
Are there other regions?

The Sun!

Solar region



Find galactic coord of solar photons



Solar region

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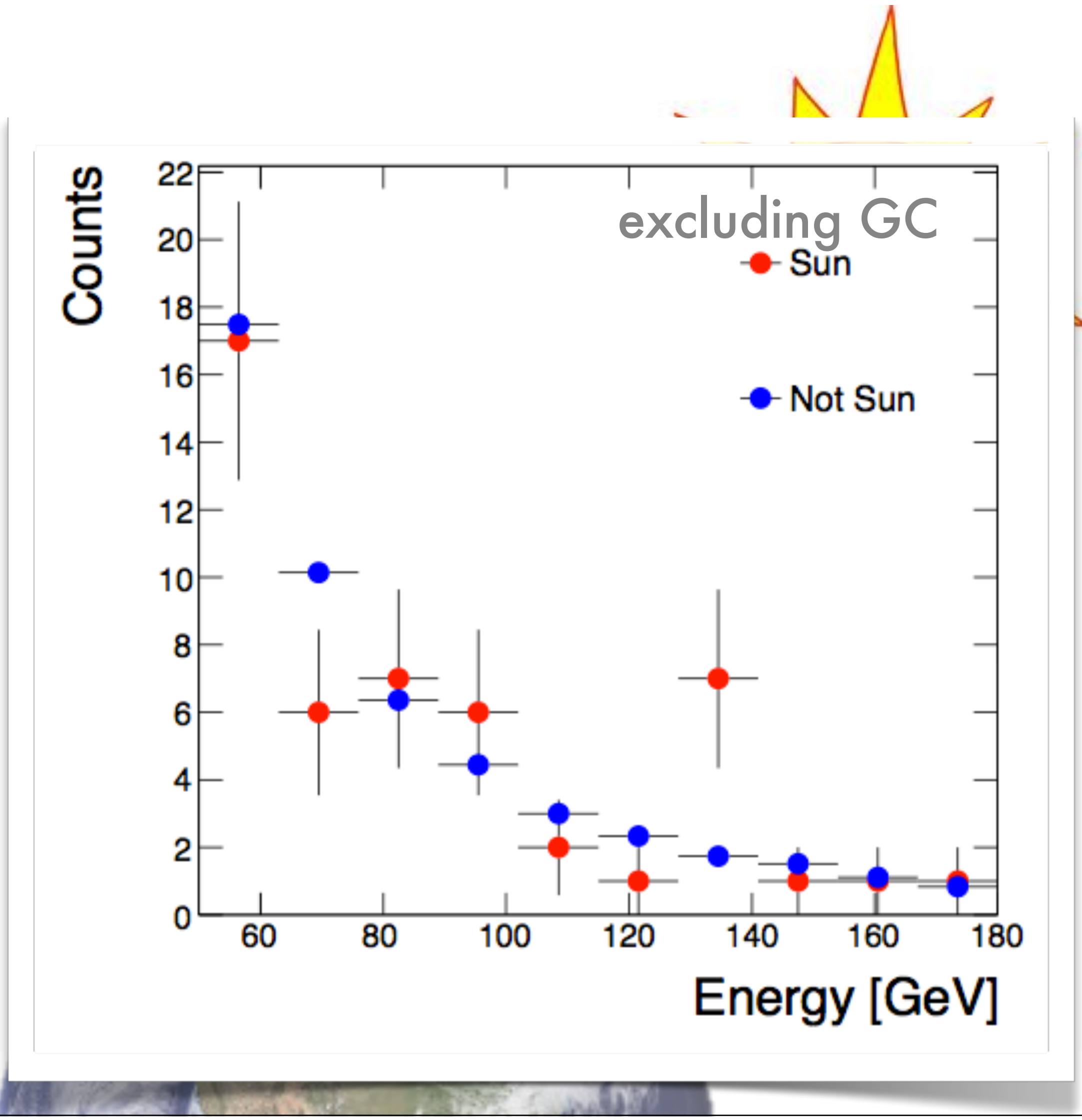
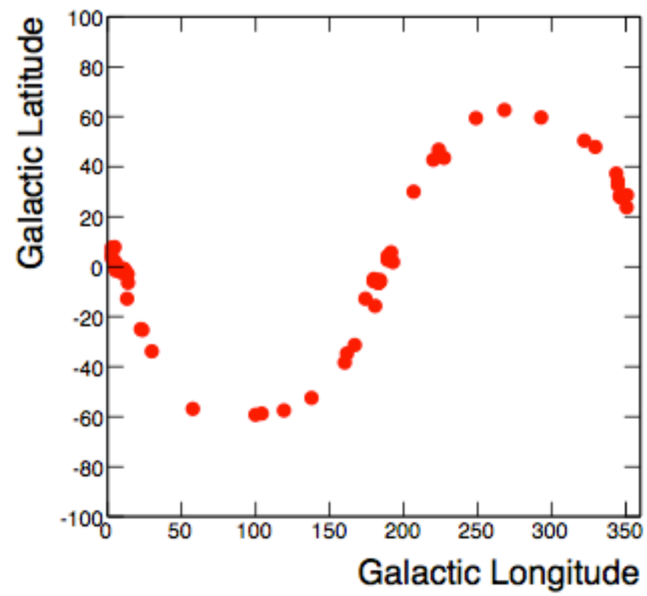


Find galactic coord of solar photons



Solar region

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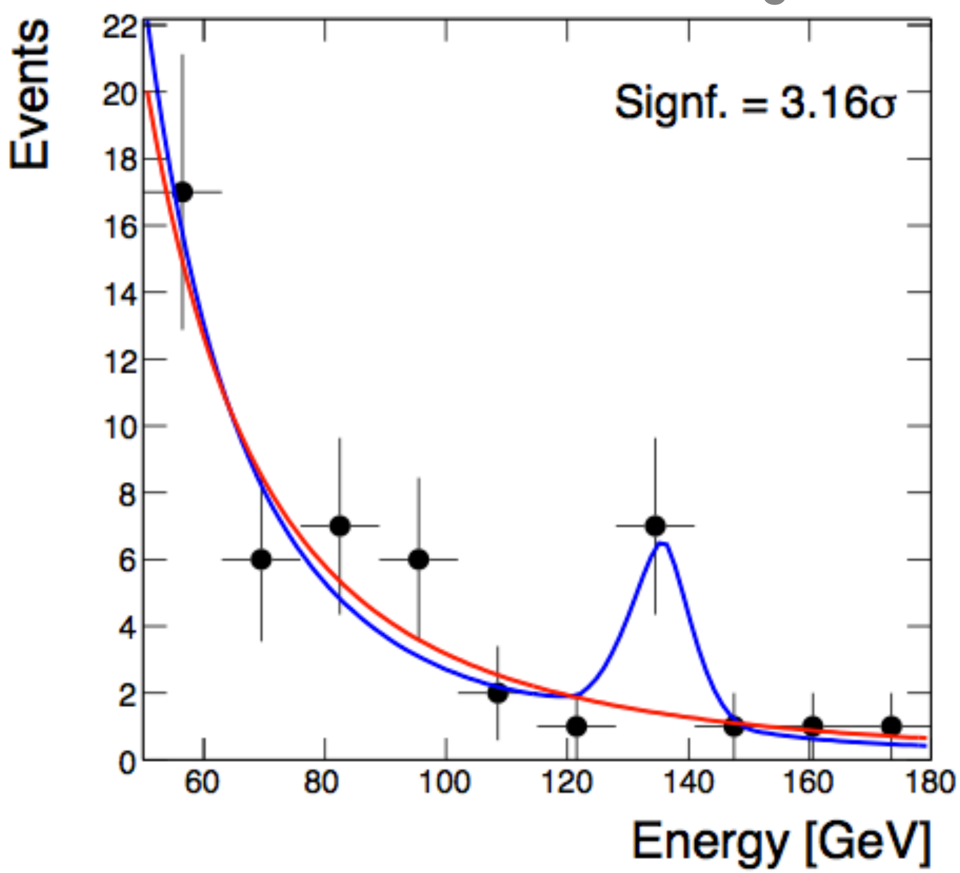
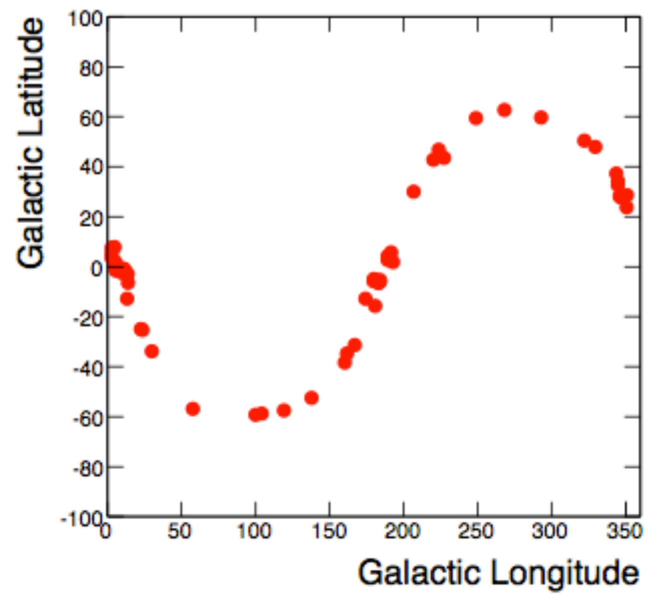
to appear

excluding GC



Find galactic coord of solar photons



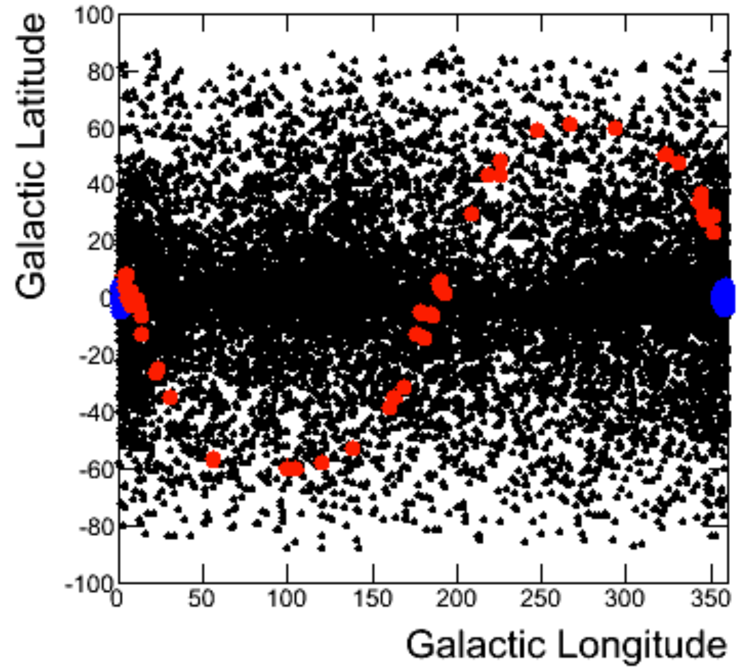
Common features

(1) Find common values of instr. variables across peaks:
GC / Limb / Sun

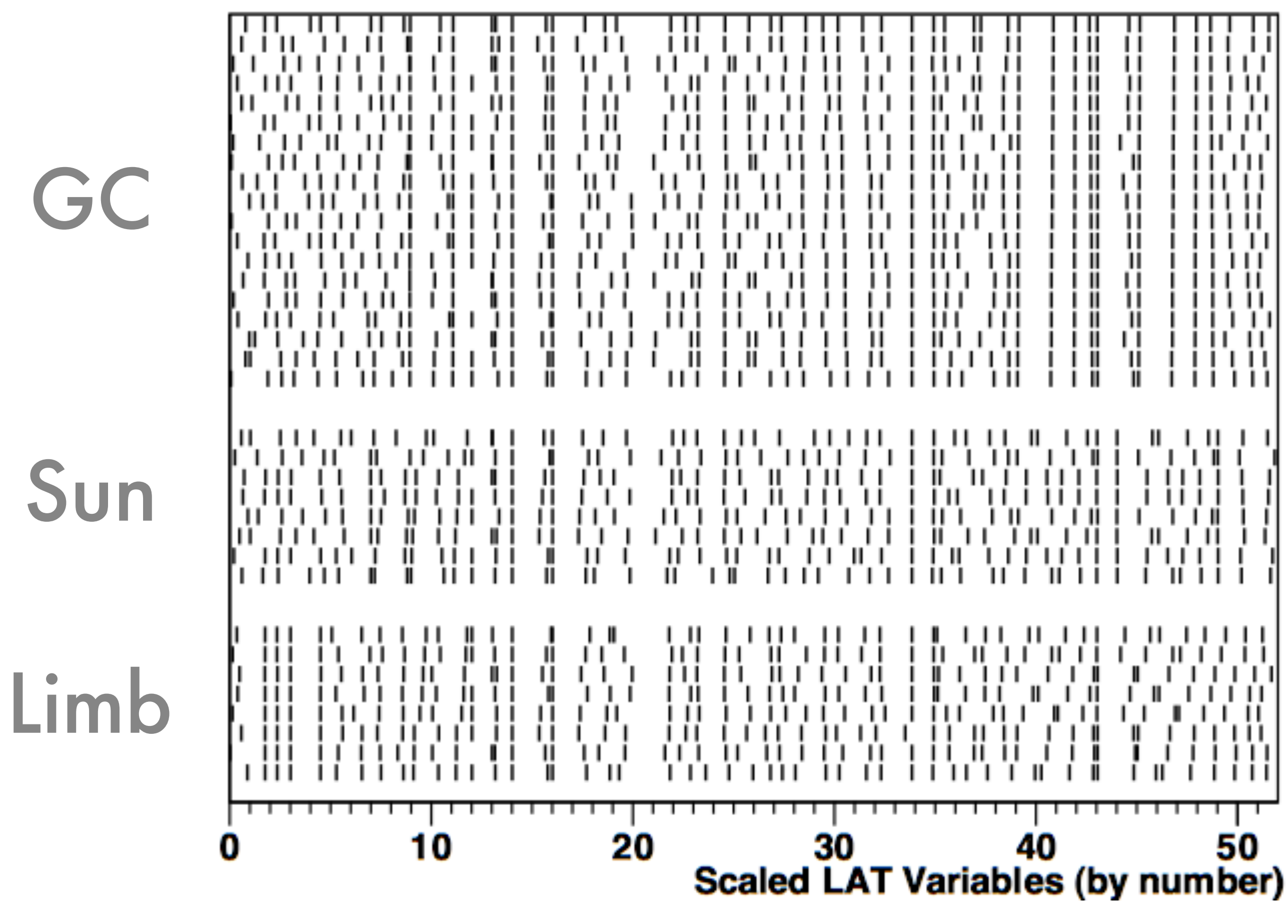
(2) Examine remainder of sky

Do those instrumental features produce a peak at 130?

GC
Sun
Sky-GC-Sun



DNA ...



Common features?

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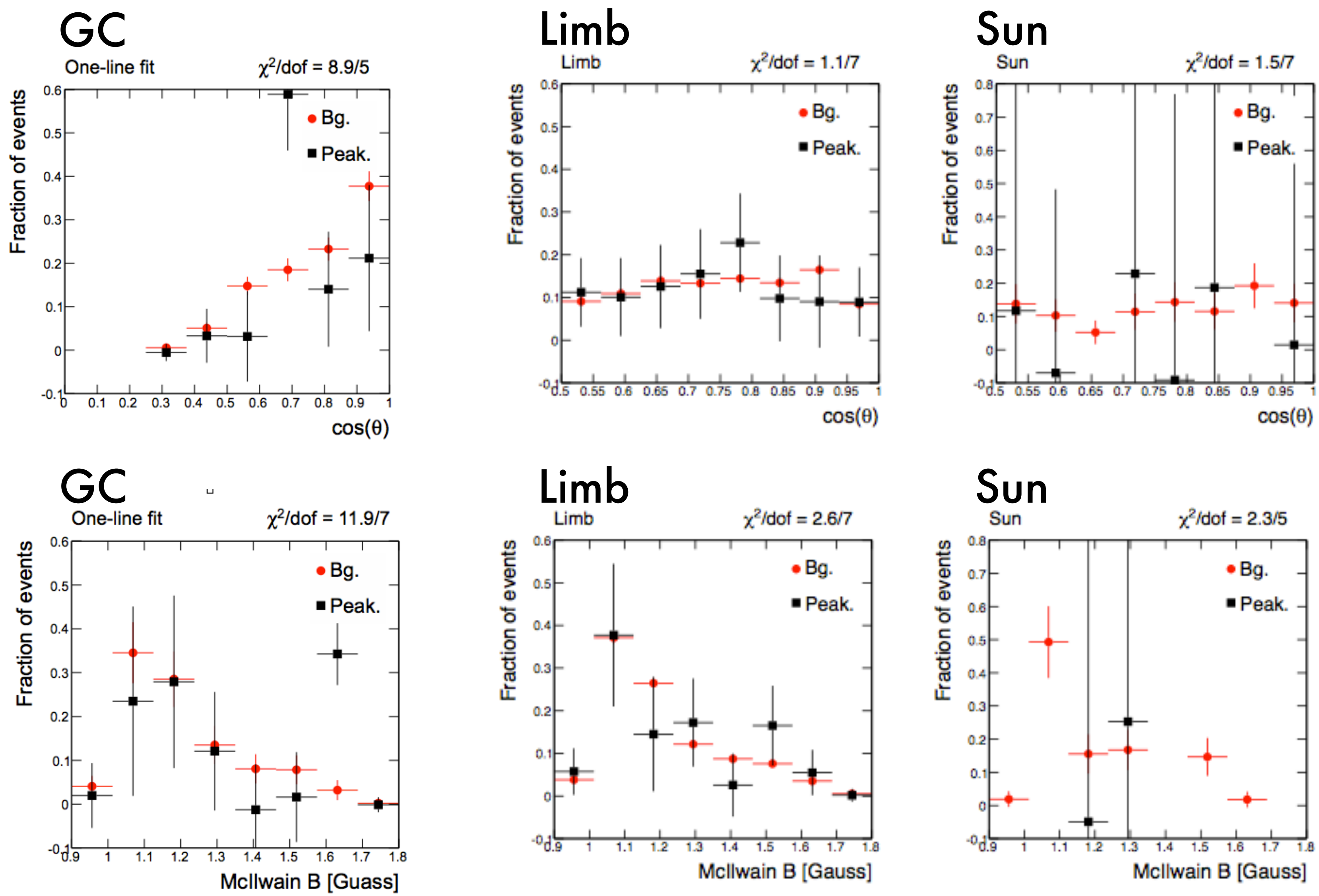

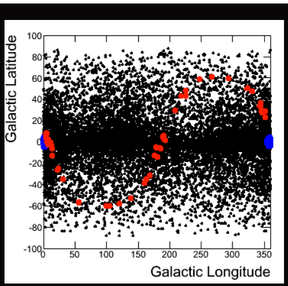

GC
Sun
Sky-GC-Sun

theta

PRELIMINARY
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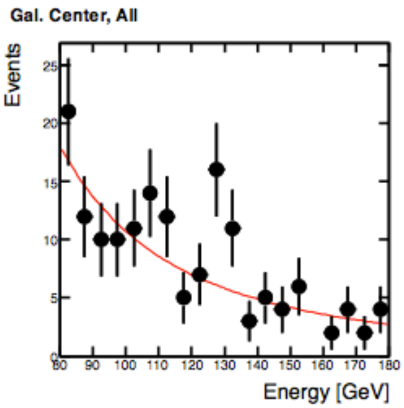
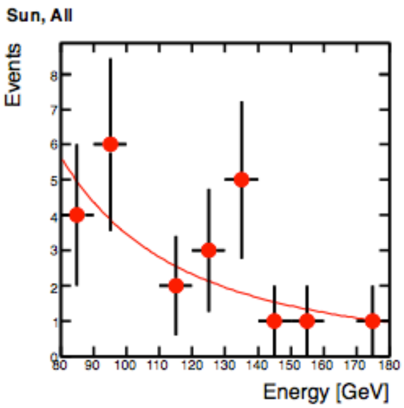
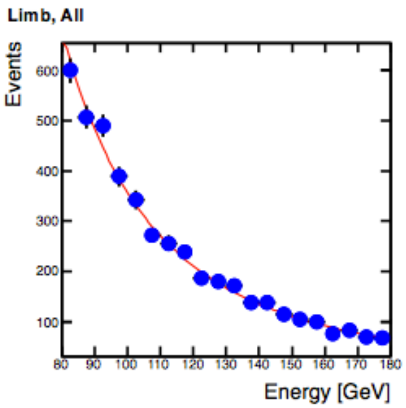
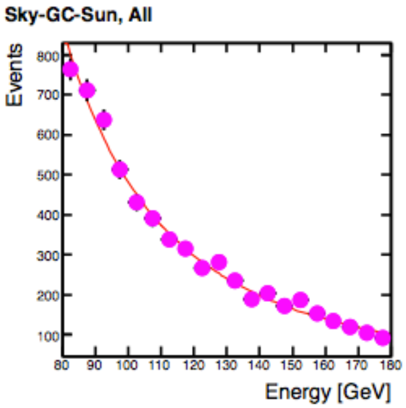
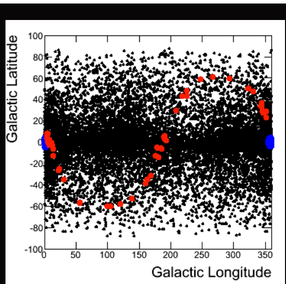
to appear

	GC	Sun	Limb	Sky-GC-Sun
All				



GC
Sun
Sky-GC-Sun

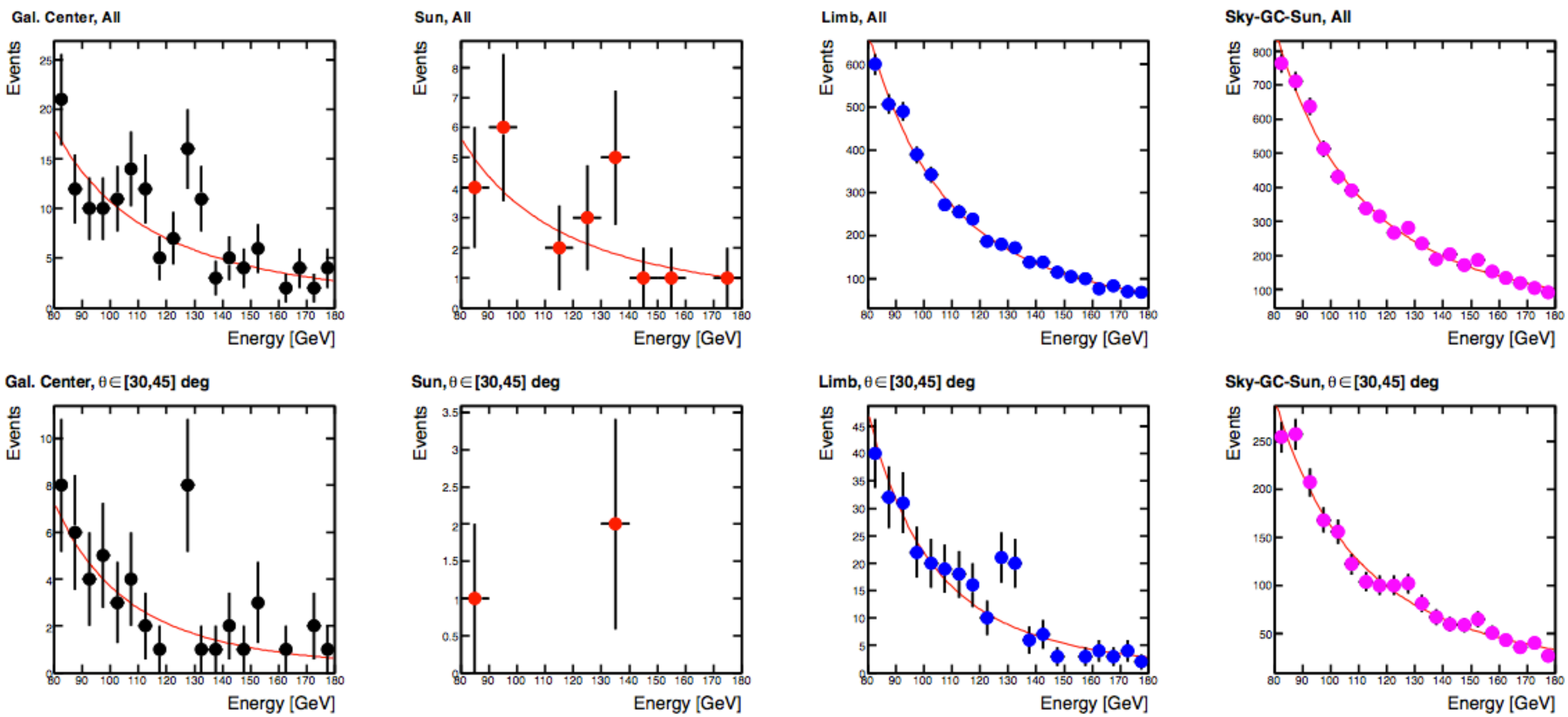
theta

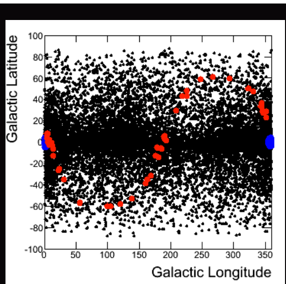
PRELIMINARY
Whiteson
to appear

GC | Sun | Limb | Sky-GC-Sun

All

Theta [30,45]





GC
Sun
Sky-GC-Sun

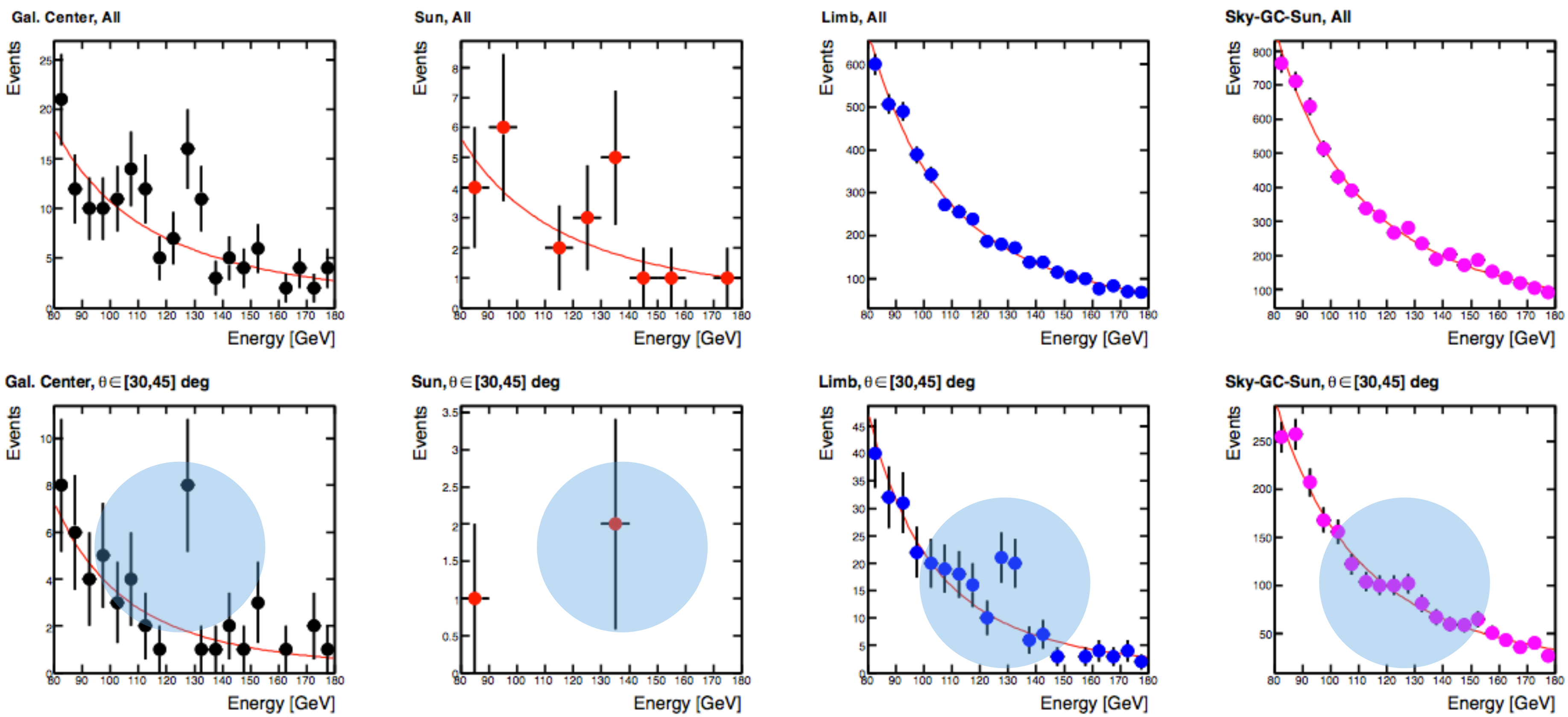
theta

PRELIMINARY
Whiteson
to appear

GC | Sun | Limb | Sky-GC-Sun

All

Theta [30,45]



Discussion

<u>Theta restriction</u>

- reveals Limb peak, feature in Sky-GC-Sun
- reduces GC, Solar peaks

<u>What is going on? One possibility:</u>

- correlation of Theta and some other not-yet-identified var X
- Sun/Limb/GC sweep out different paths in theta-X space
- particular geometry of Limb correlated to other variable X, effectively restricts Theta
- we see a hint in the sky spectrum just from theta

  if we could identify X, might enhance feature in sky

Conclusions

Supporting evidence

Features
- strong stat power

Locations
- consistent with GC

No clear instrumental issue
- identified *so far*

Concerns

Background assumptions
- fair to assume featureless?

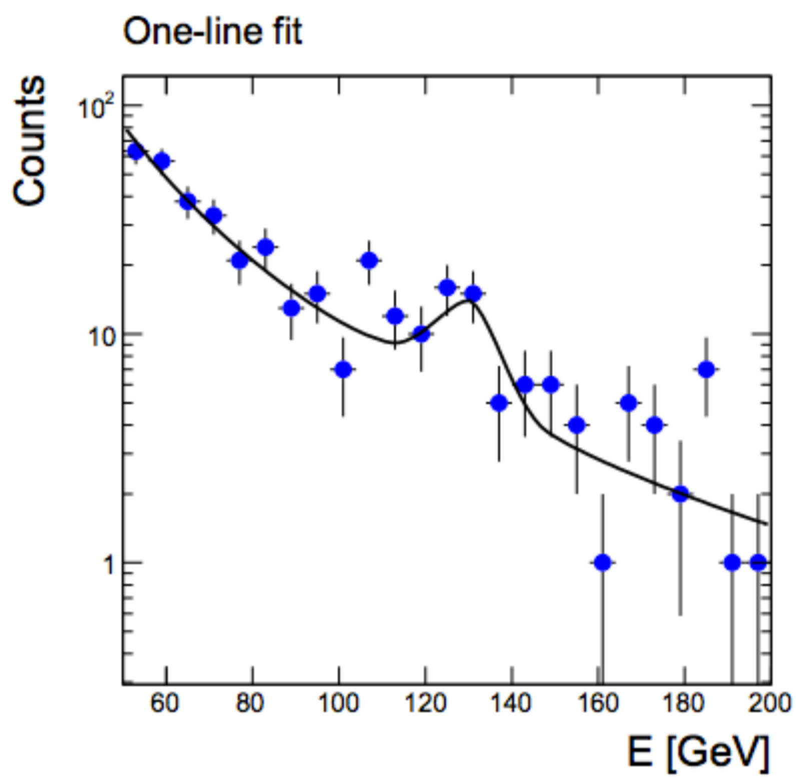
No Continuum
- requires some theory gymnastics

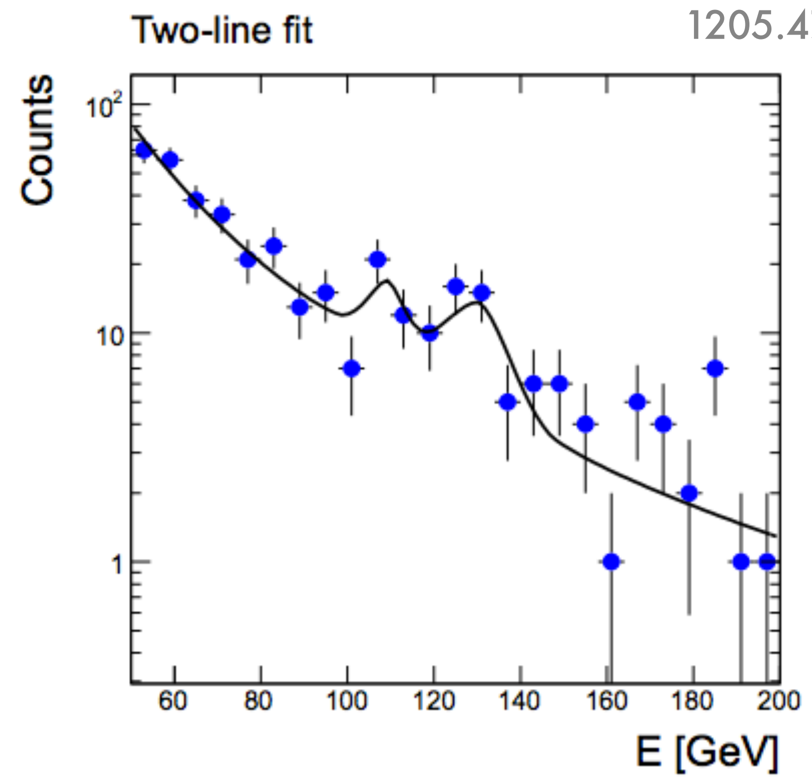
Limb, solar, sky signals
- needs resolution
- some strange theta issues

Backup

Lines!

Rajaraman, Tait, DW
1205.4723





m_x = 130
E_γ =130 ($\gamma\gamma$)

m_x = 145
E_γ = 130 (γZ)

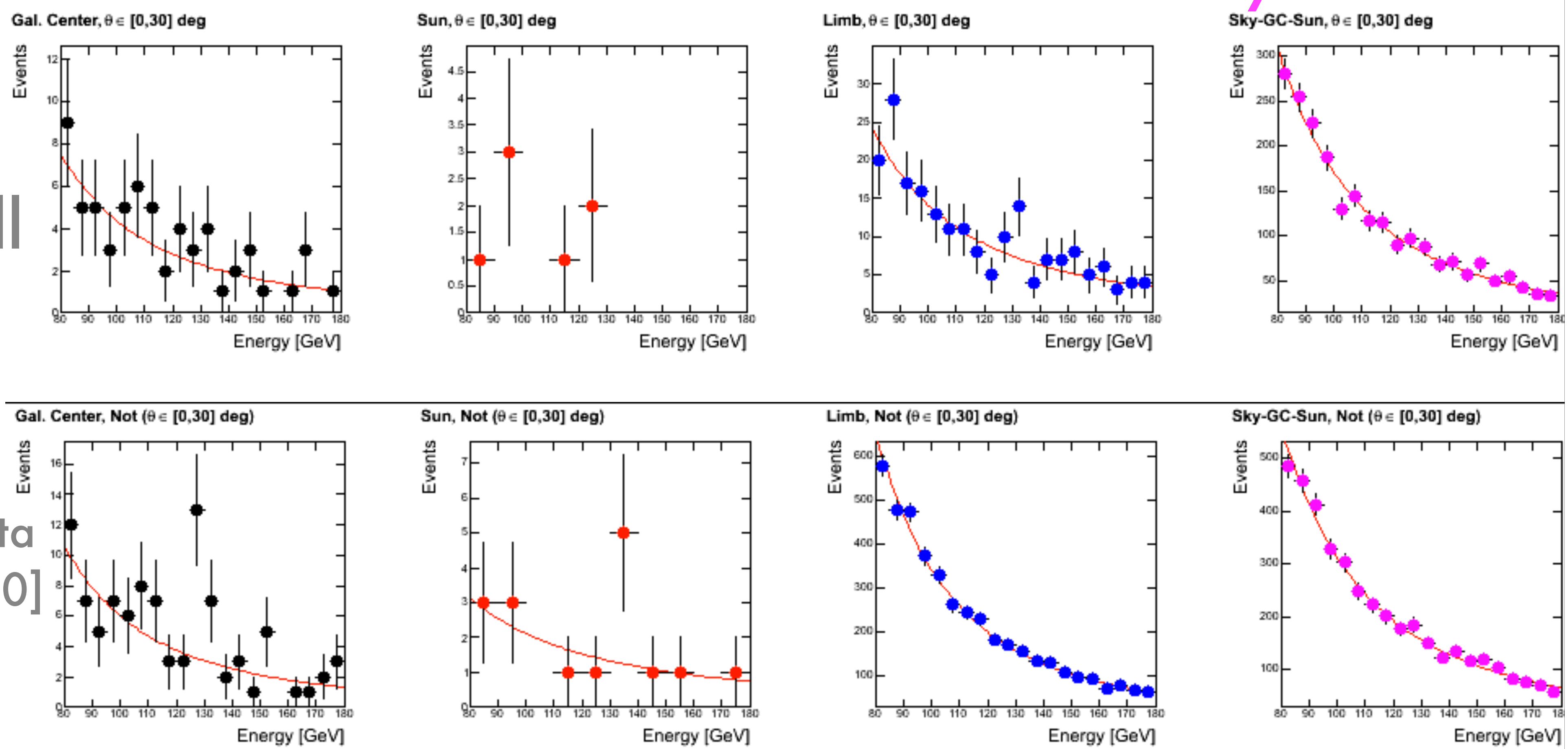
m_x = 130
E_γ = 110 (γZ)
E_γ = 130 ($\gamma\gamma$)

Other thetas: 0-30

GC | Sun | Limb | Sky-GC-Sun

All

Theta [0,30]

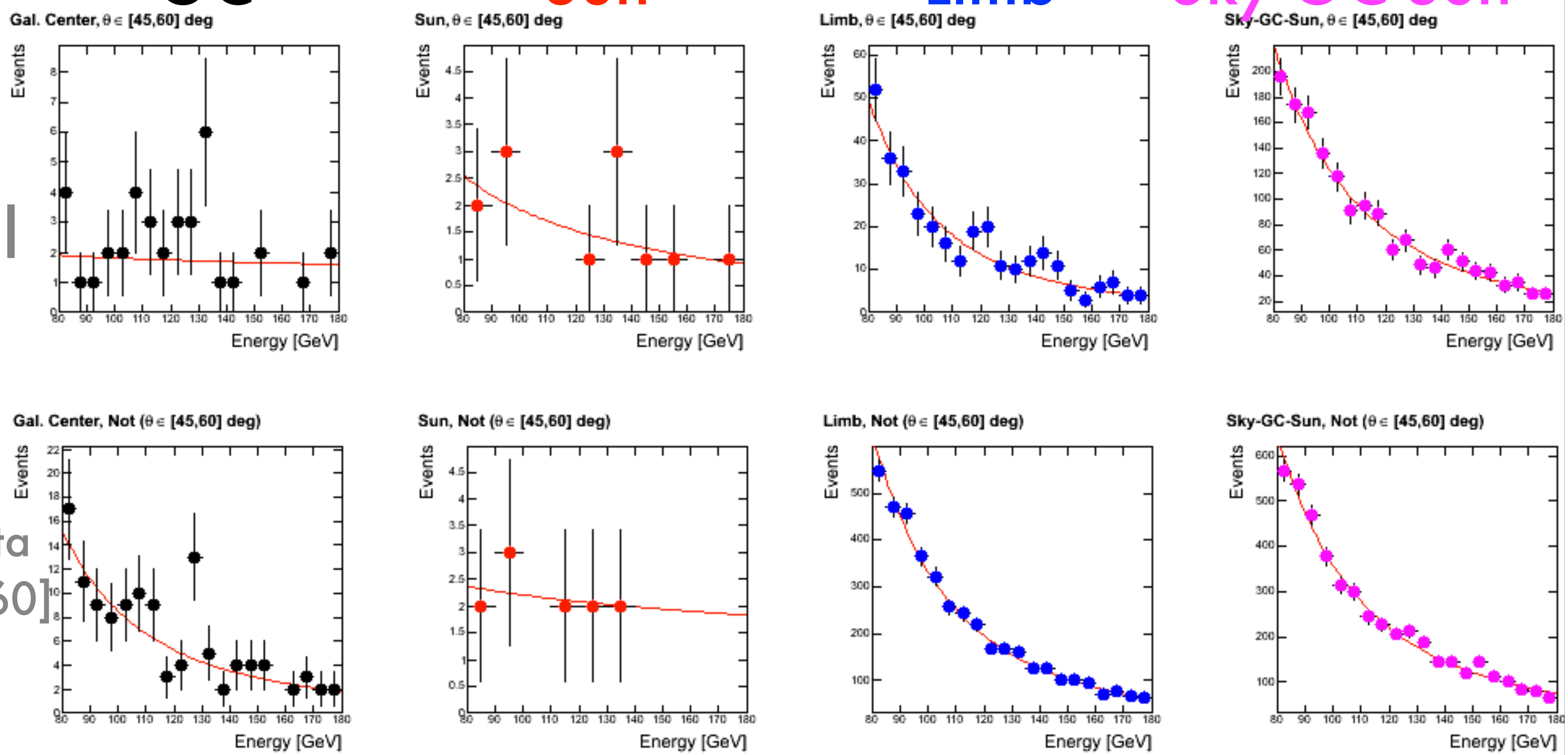


Other thetas: 45-60

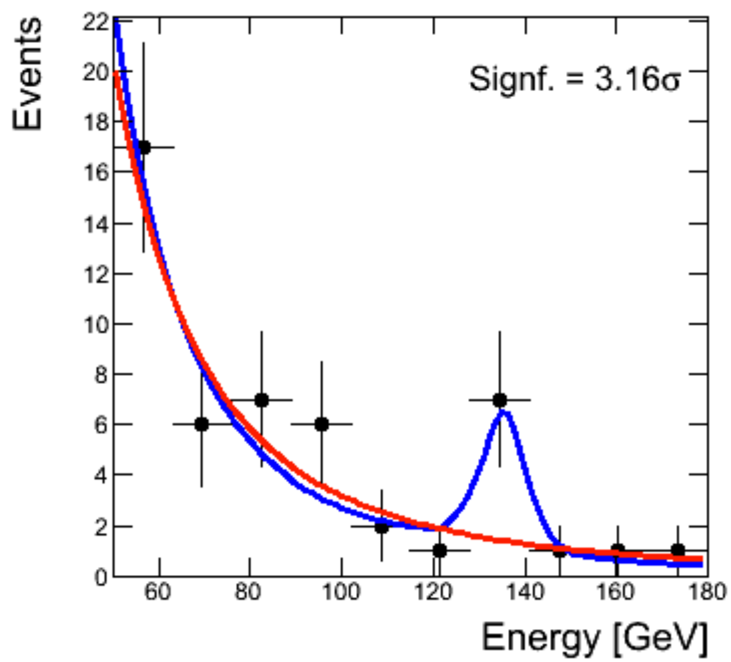
GC | Sun | Limb | Sky-GC-Sun

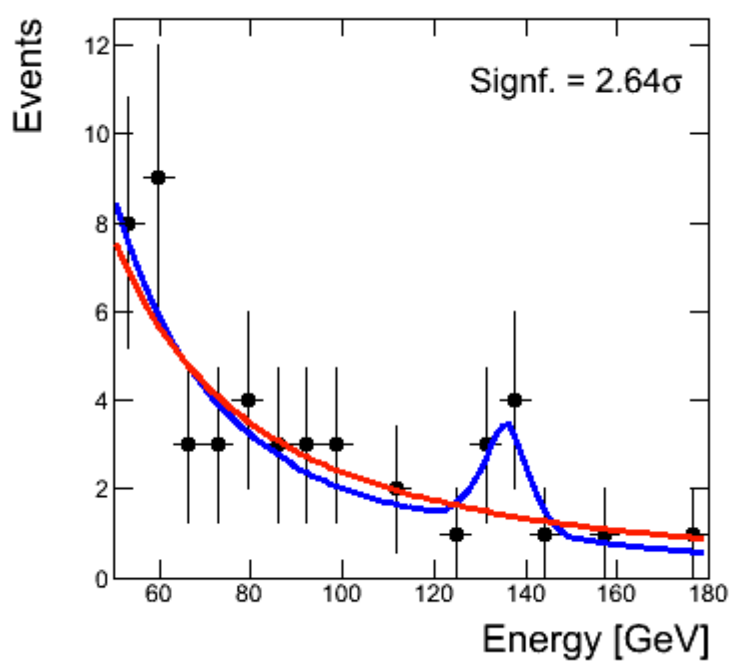
All

Theta [45,60]



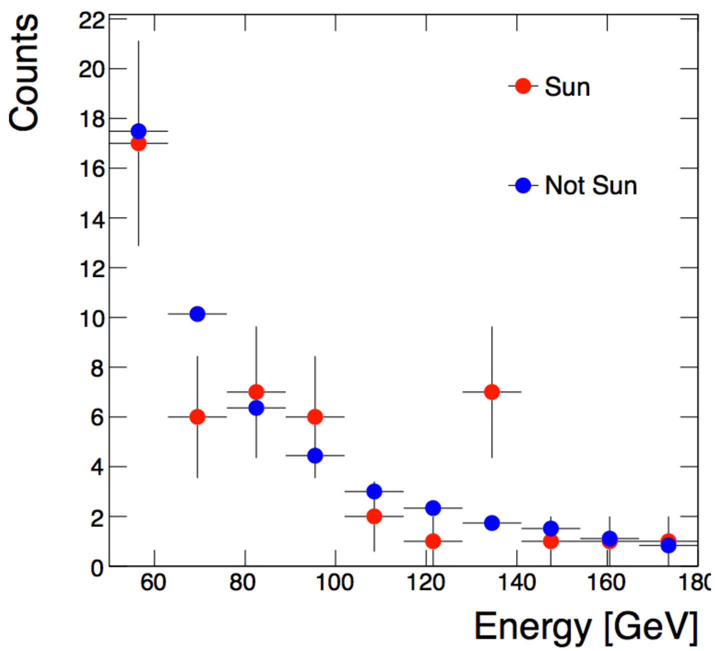
Sun binning



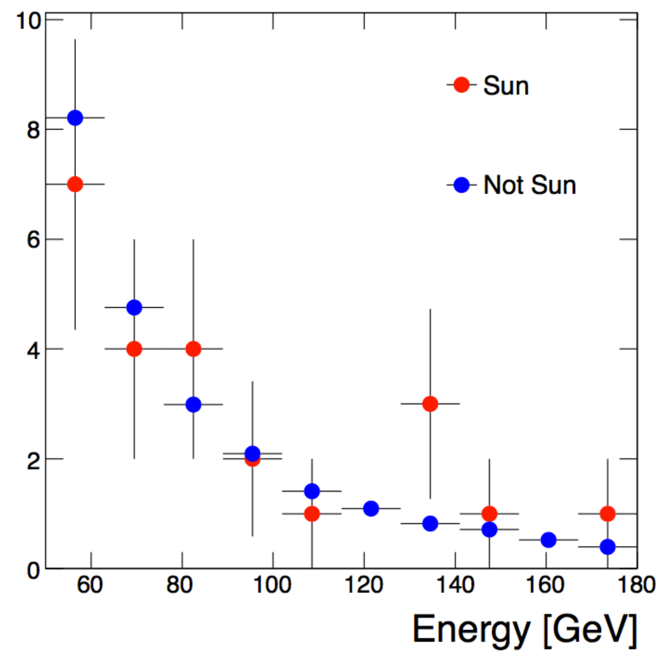


Sun Zoom

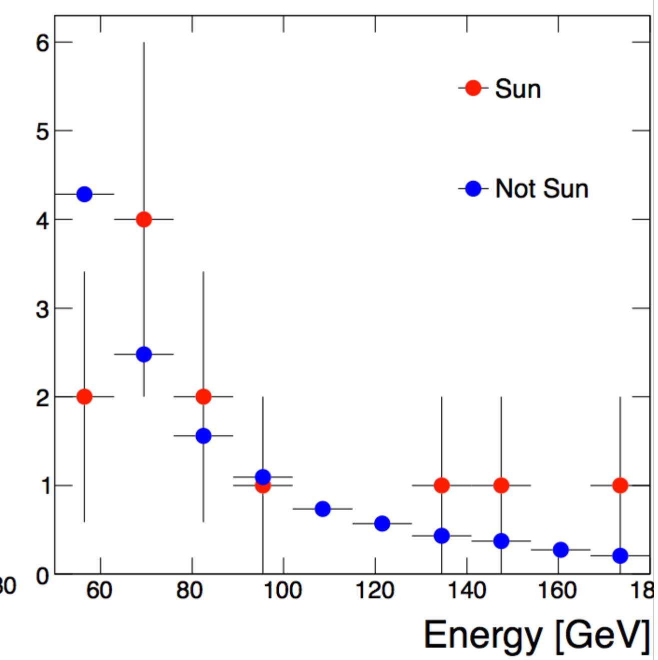
deltaR<5



deltaR<3



deltaR<1



sPlots

Given pdfs for two sources $f_1(y)$, and $f_2(y)$ in the discriminating variable y, one can construct a histogram in another unfolding variable x using weights for each source class, sP_1 and sP_2, defined as:

$$sP_1(y) = \frac{\mathbf{V}_{11} f_1(y) + \mathbf{V}_{12} f_2(y)}{N_1 f_1(y) + N_2 f_2(y)}$$

$$sP_2(y) = \frac{\mathbf{V}_{21} f_1(y) + \mathbf{V}_{22} f_2(y)}{N_1 f_1(y) + N_2 f_2(y)}$$

$$\mathbf{V}_{ab}^{-1} = \sum_{i=1}^{N} \frac{(N_1 + N_2) f_a(y_i) f_b(y_i)}{(N_1 f_1(y_i) + N_2 f_2(y_i))^2}$$

Questions

- Are the two features consistent with emission from a single source?
- Are the features consistent with emission from a dark matter halo at the galactic center?

Hypothesis tests

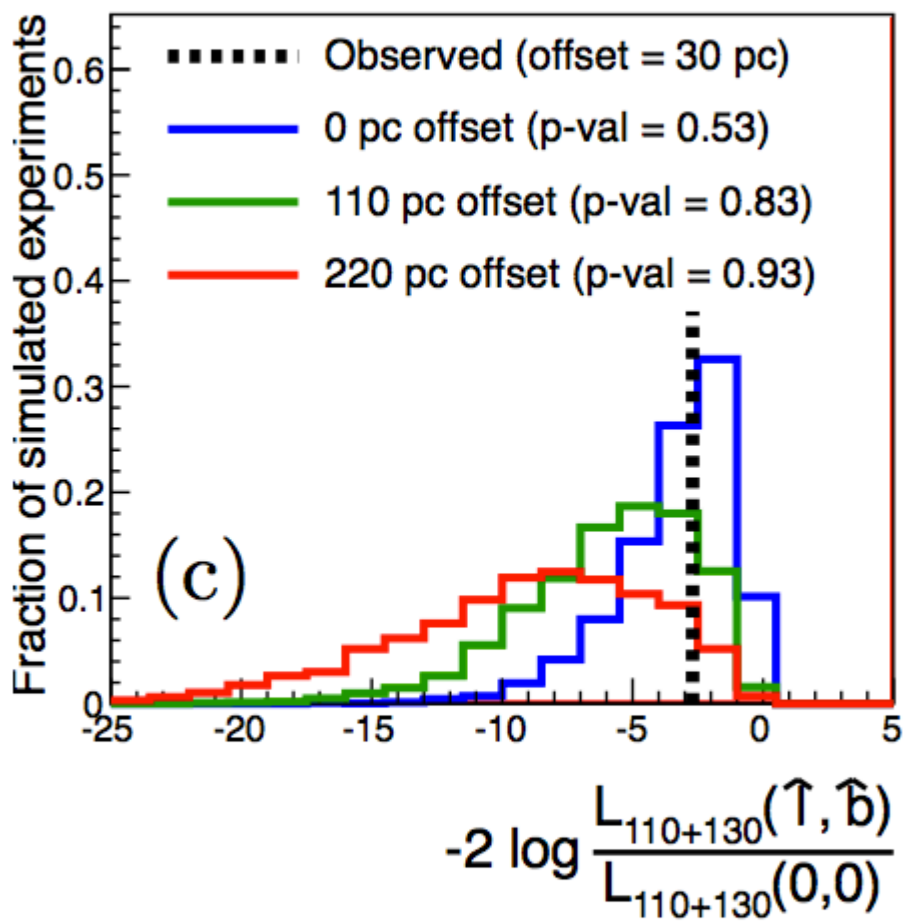
<u>(l,b) fit far from GC</u>

q → negative

$$q = -2\log\frac{L(l=\hat{l}, b=\hat{b})}{L(l=0, b=0)}$$

<u>(l,b) fit is close to 0,0</u>

q → zero



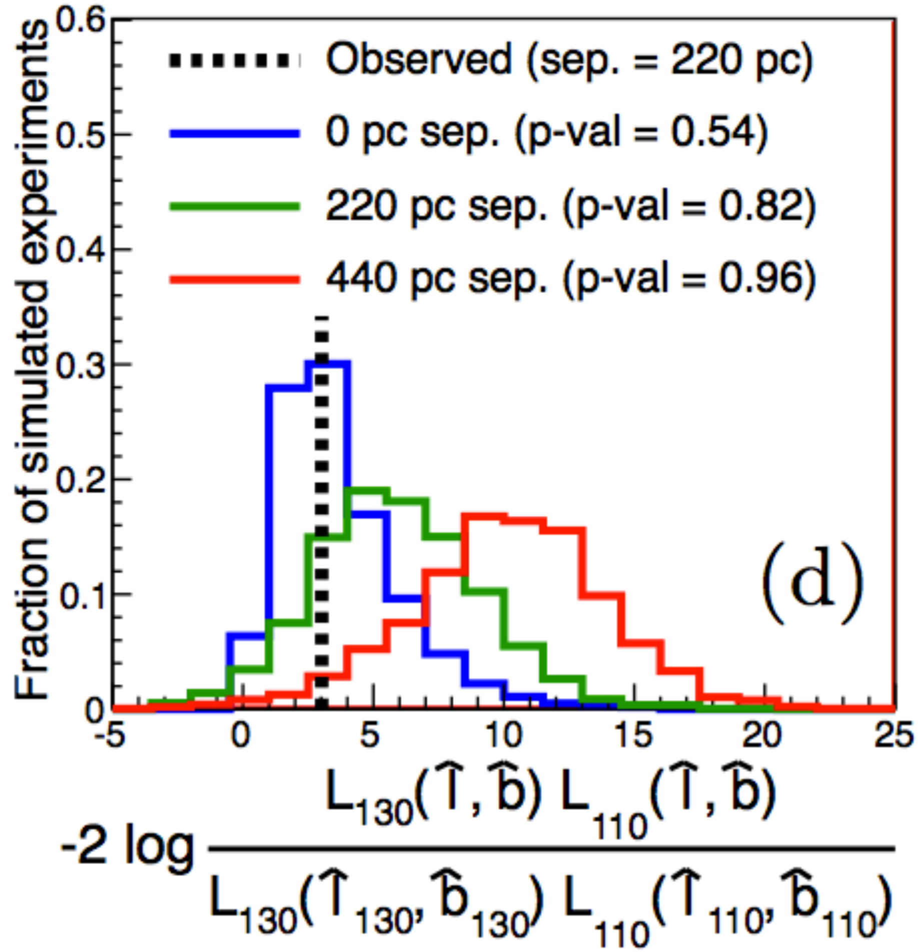
Hypothesis tests

<u>separate fits are better</u>

q → larger

<u>joint fit is better</u>

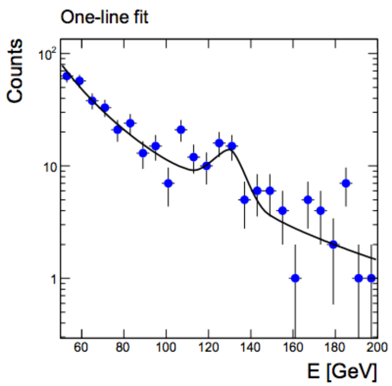
q → smaller



Sensitivity

Whiteson
1208.3677

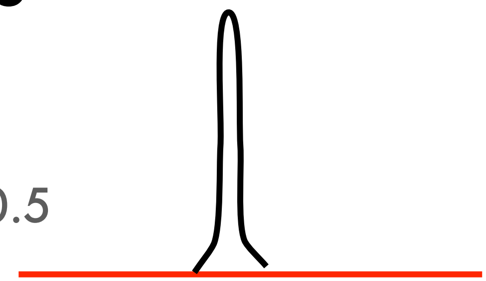
Discriminating var

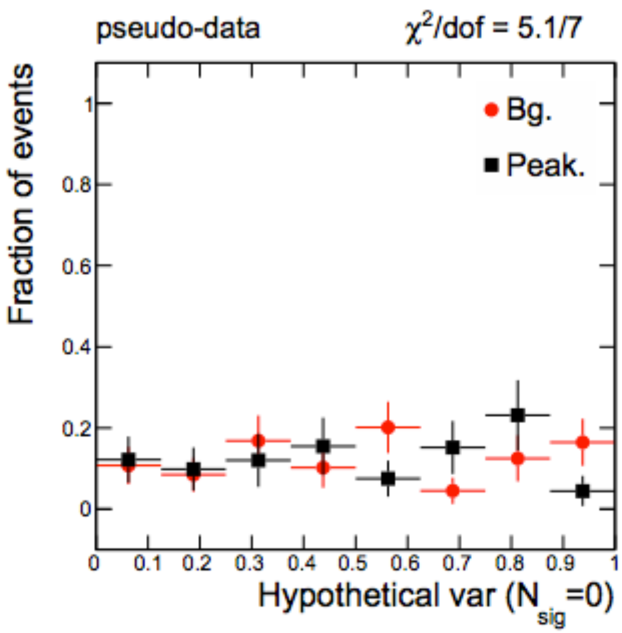


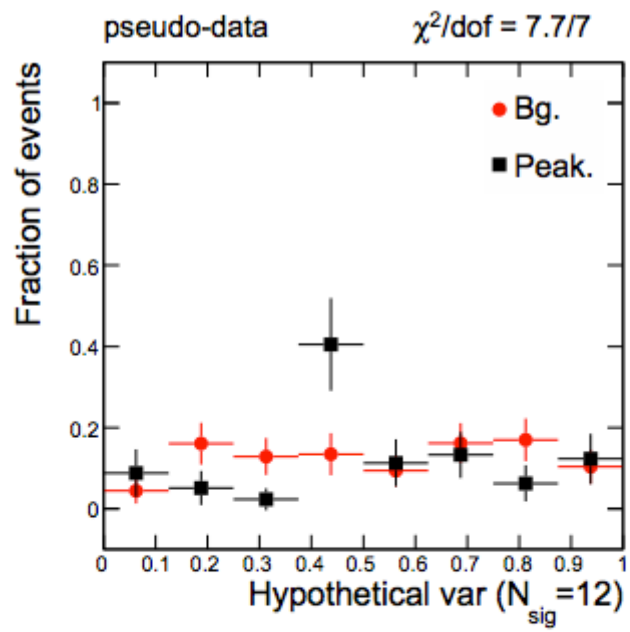
Unfolding var

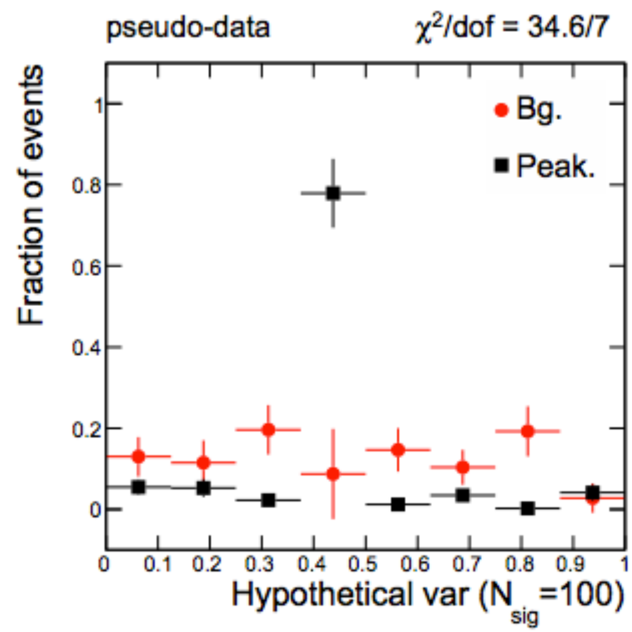
Background: flat

Signal: delta func at 0.5





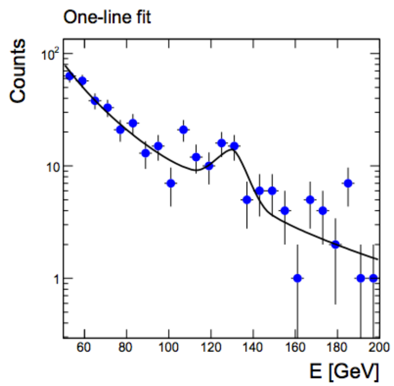




Sensitivity

Whiteson
1208.3677

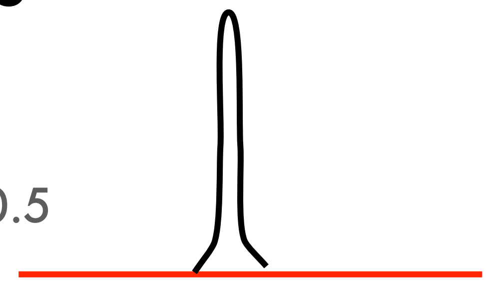
Discriminating var



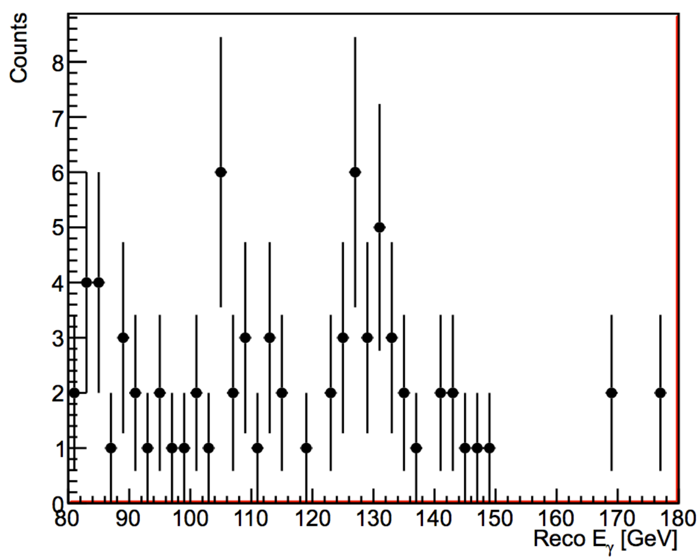
Unfolding var

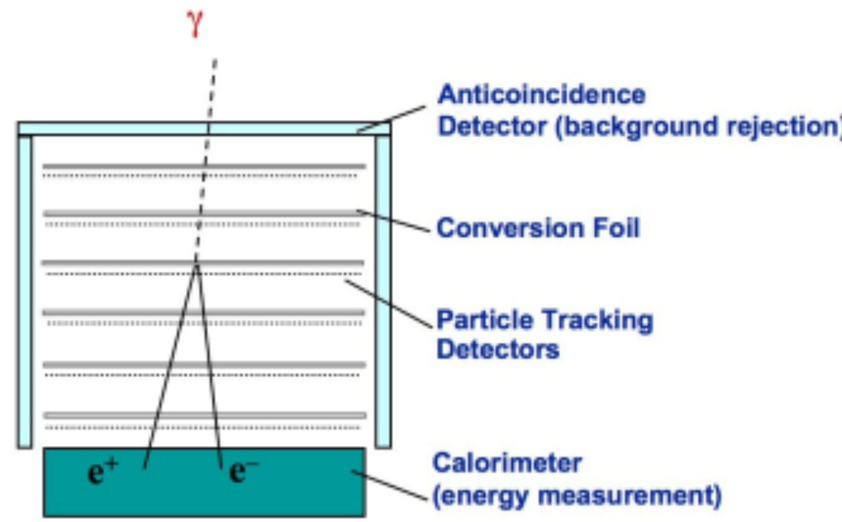
Background: flat

Signal: delta func at 0.5

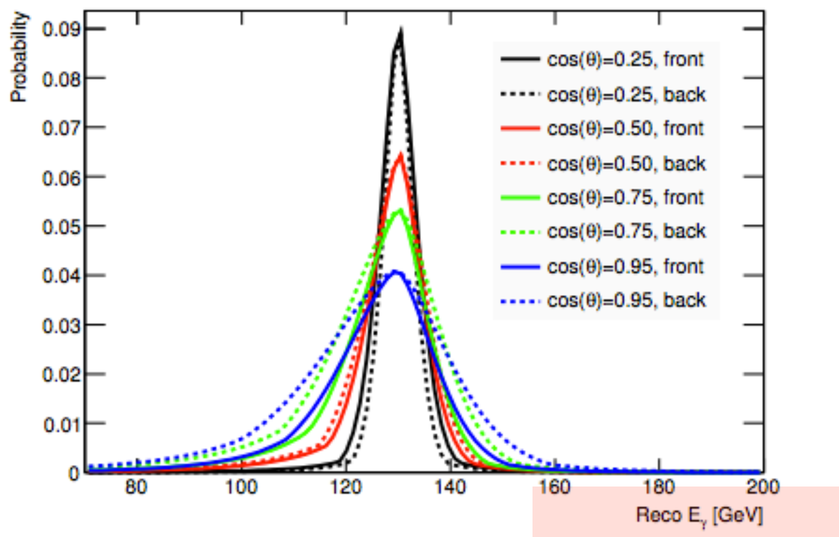


angles

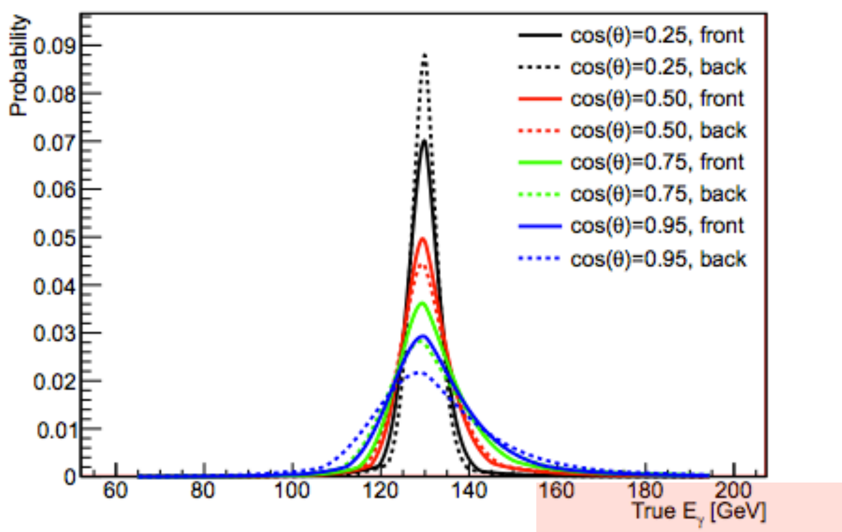

Counts
Reco E$_\gamma$ [GeV]


γ
Anticoincidence Detector (background rejection)
Conversion Foil
Particle Tracking Detectors
Calorimeter (energy measurement)
e+
e−

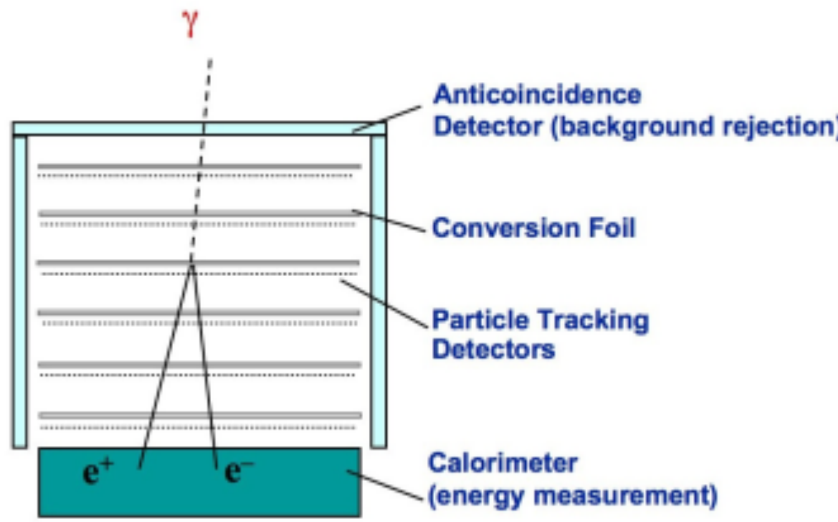
Angles



Probability
cos(θ)=0.25, front
cos(θ)=0.25, back
cos(θ)=0.50, front
cos(θ)=0.50, back
cos(θ)=0.75, front
cos(θ)=0.75, back
cos(θ)=0.95, front
cos(θ)=0.95, back
Reco E$_\gamma$ [GeV]

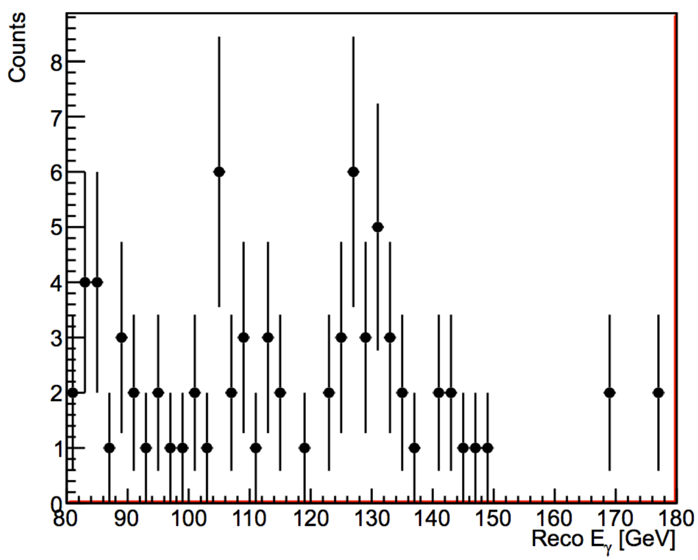


Probability
cos(θ)=0.25, front
cos(θ)=0.25, back
cos(θ)=0.50, front
cos(θ)=0.50, back
cos(θ)=0.75, front
cos(θ)=0.75, back
cos(θ)=0.95, front
cos(θ)=0.95, back
True E$_\gamma$ [GeV]

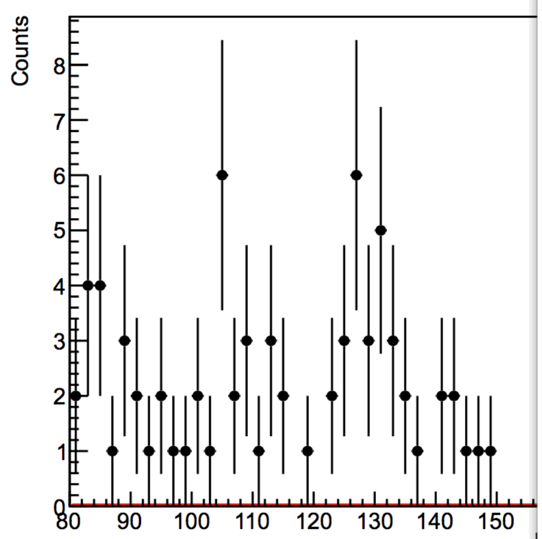


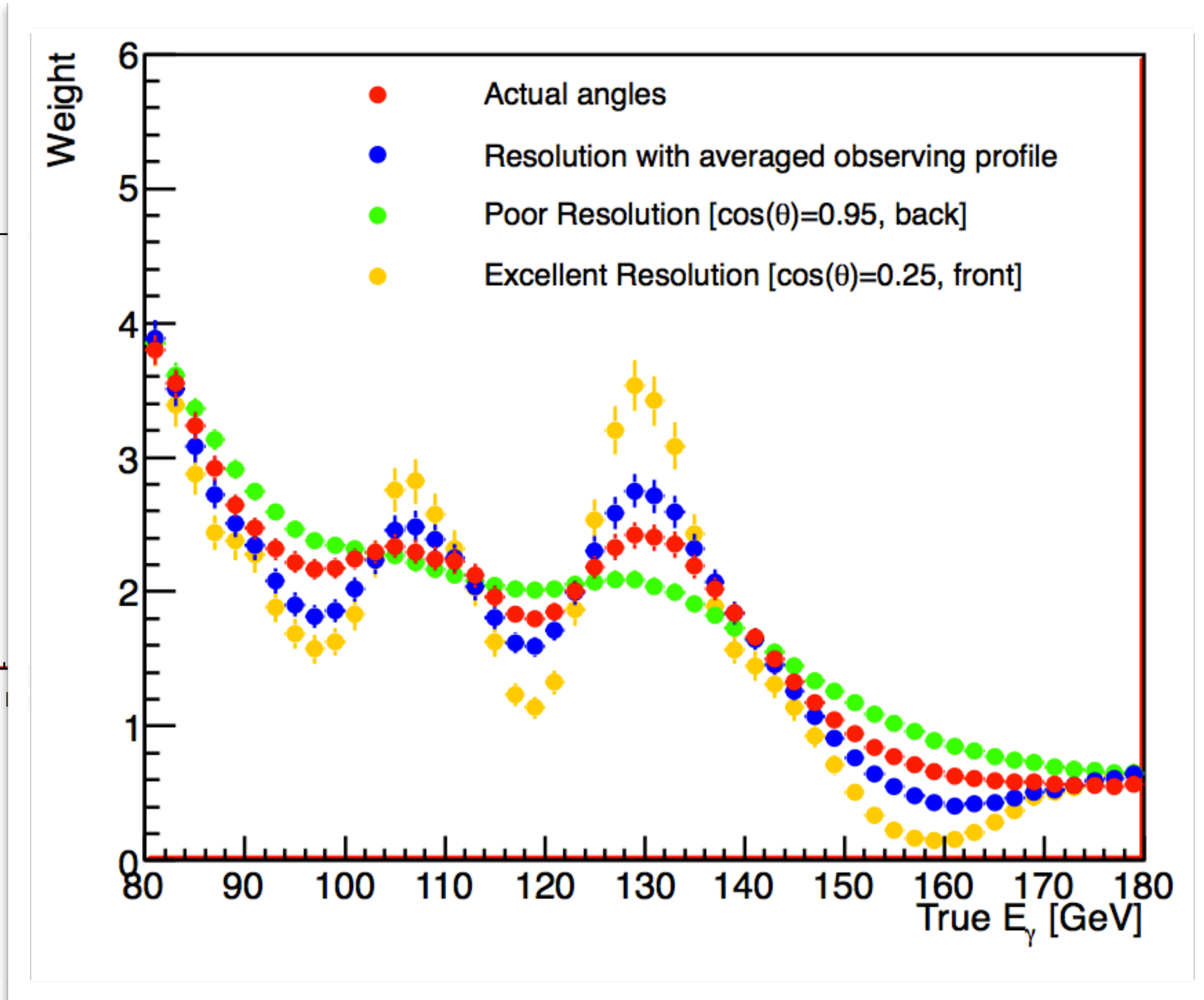
γ
Anticoincidence Detector (background rejection)
Conversion Foil
Particle Tracking Detectors
e+
e−
Calorimeter (energy measurement)

Angles


Counts
0
1
2
3
4
5
6
7
8
80
90
100
110
120
130
140
150
160
170
180
Reco E_γ [GeV]

Angles


Counts
0
1
2
3
4
5
6
7
8
80
90
100
110
120
130
140
150


Weight
True E_γ [GeV]
Actual angles
Resolution with averaged observing profile
Poor Resolution [cos(θ)=0.95, back]
Excellent Resolution [cos(θ)=0.25, front]
0
1
2
3
4
5
6
80
90
100
110
120
130
140
150
160
170
180

Hypothesis tests

<u>(l,b) fit far from GC</u>

q → negative

$$q = -2\log\frac{L(l=\hat{l}, b=\hat{b})}{L(l=0, b=0)}$$

<u>(l,b) fit is close to 0,0</u>

q → zero