Estimate for GLAST LAT Milky Way dark matter WIMP Line Sensitivity

Y. Edmonds, E. Baltz, E. Bloom, J. Cohen-Tanugi, G. Godfrey, L. Wai, P. Wang
KIPAC-SLAC, Stanford University

Jeff Scargle
NASA Ames Research Center

Jan Conrad
KTH Stockholm

***Abstract**:* The LAT Dark Matter and New Physics Working group has been developing approaches for the indirect astrophysical detection of annihilation of dark matter. Our work has assumed that a significant component of dark matter is a new type of Weakly Interacting Massive Particle (WIMP). The annihilation of two WIMPS mostly results in the production of a large number of high energy gamma rays (> 1 GeV) that can be well measured in the GLAST LAT. These searches involve strategies for observation of the galactic center, galactic halo (optimized diffuse all sky analysis), galactic satellites (almost point, high latitude, sources), and cosmological signals in the extra-galactic diffuse. There is also the possibility to observe lines from annihilation into gamma-gamma and/or gamma-Z final states. In the usual SUSY theories these line decays occur at the 0.01% to 1% branching fraction level. The estimates of LAT sensitivity (at 5 sigma) and upper limits (upper limit at the 95% confidence level) depend upon the WIMP model (e.g., line energy and 1 or 2 lines), the DM halo model, and other astrophysics backgrounds. Thus estimates of LAT sensitivity to lines can vary over orders of magnitude depending upon which models are chosen. Preparations for searches with the GLAST LAT for WIMP lines and example sensitivities will be presented.

This work is supported by Stanford University and the Stanford Linear Accelerator Center (SLAC) under DoE contract number DE-AC 03-76-SFO0515 and NASA grant number NAS5-00147 and the NASA Applied Information Systems Research Program. Non-US sources of funding also support the efforts of GLAST LAT collaborators in France, Italy, Japan, and Sweden.

WIMP annihilation cross section at freeze out versus the current time

- WIMP annihilation cross section can be written as $\sigma v = a + bv^2 + \ldots$

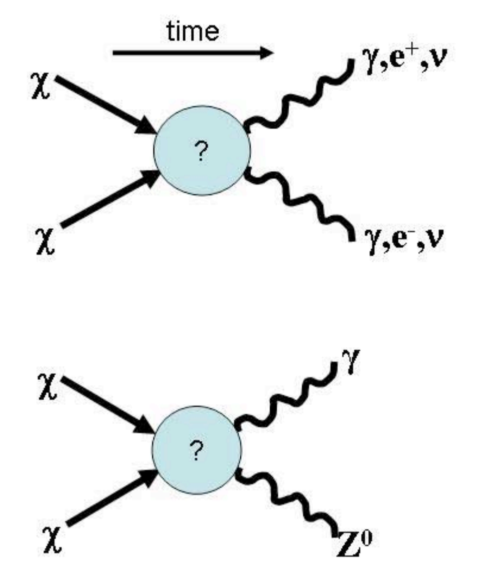
1. σv is independent of v
   Boltzmann equation => $\Omega_\chi h^2 = \frac{3\times10^{-27}cm^3s^{-1}}{<\sigma v>} \approx 0.1$ from W-Map
   After freeze out, the density of WIMP remains constant,
   $<\sigma v>_0 = <\sigma v>_f = \frac{3\times10^{-27}cm^3s^{-1}}{(\Omega_\chi h^2)_f} \approx 2.3\times10^{-26}cm^3s^{-1}$
   where the subscript f denotes the value at freeze out and the subscript 0 denotes the value today.
2. σv is weakly dependent on v, like LCC2 * and LCC4 *
   $<\sigma v>_0 \sim <\sigma v>_f \sim 10^{-26}cm^3s^{-1}$
   In this case, WIMP annihilation signal can be observed by GLAST LAT.
3. σv is strongly dependent on v, like LCC1 *
   $<\sigma v>_0 << <\sigma v>_f$ since $v_0(\sim 0.001c) << v_f(\sim 0.5c)$
   In this case, WIMP annihilation signal is not detectable by GLAST LAT.

- Coannihilation
  - Like LCC3 *, at freeze out, in coannihilation with stau particle, total cross section $\sim 2.3\times10^{-26}cm^3s^{-1}$. As the universe further cooled, staus decayed away as they are not stable, and only the WIMP were left, and the WIMP has a much smaller annihilation cross section.

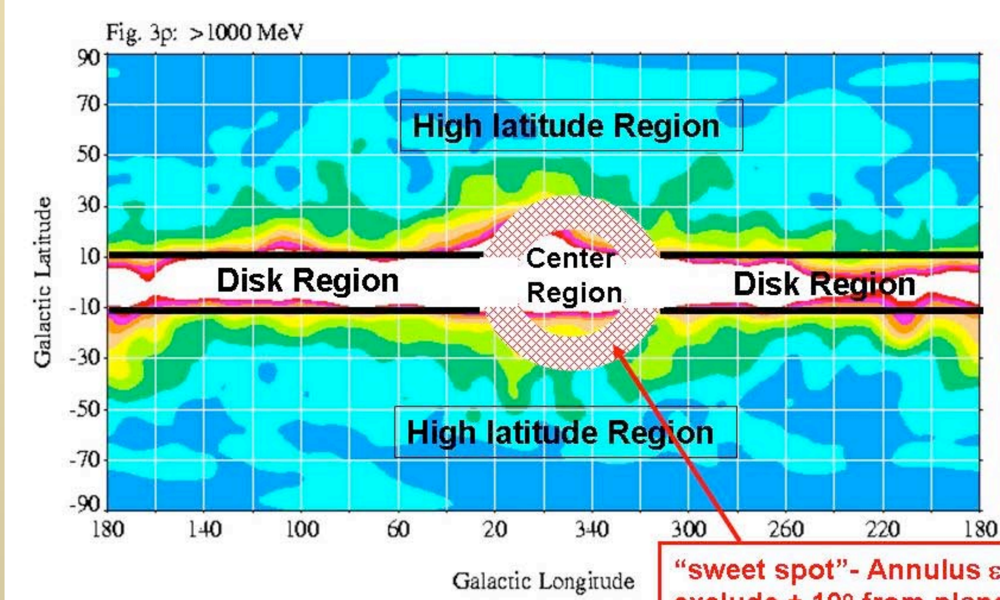
* SUSY model LCC# definitions from Baltz, et al, 2006

Spectral lines from WIMP Annihilation

- **For $\gamma\gamma$ lines, energy = WIMP mass; branching fraction is suppressed ~ 10^{-2} to 10^{-4} Br.**
- **e^+e^-, $\nu\nu$ lines are possible at tree level (especially for Dirac fermion or boson WIMPs)**
- **For WIMP masses > M_Z /2 can also have γZ^0 line**
- ***Measurement of line branching fractions would constrain particle theory, limits would be helpful as well***



Milky Way dark matter halo Annulus about the Galactic Center

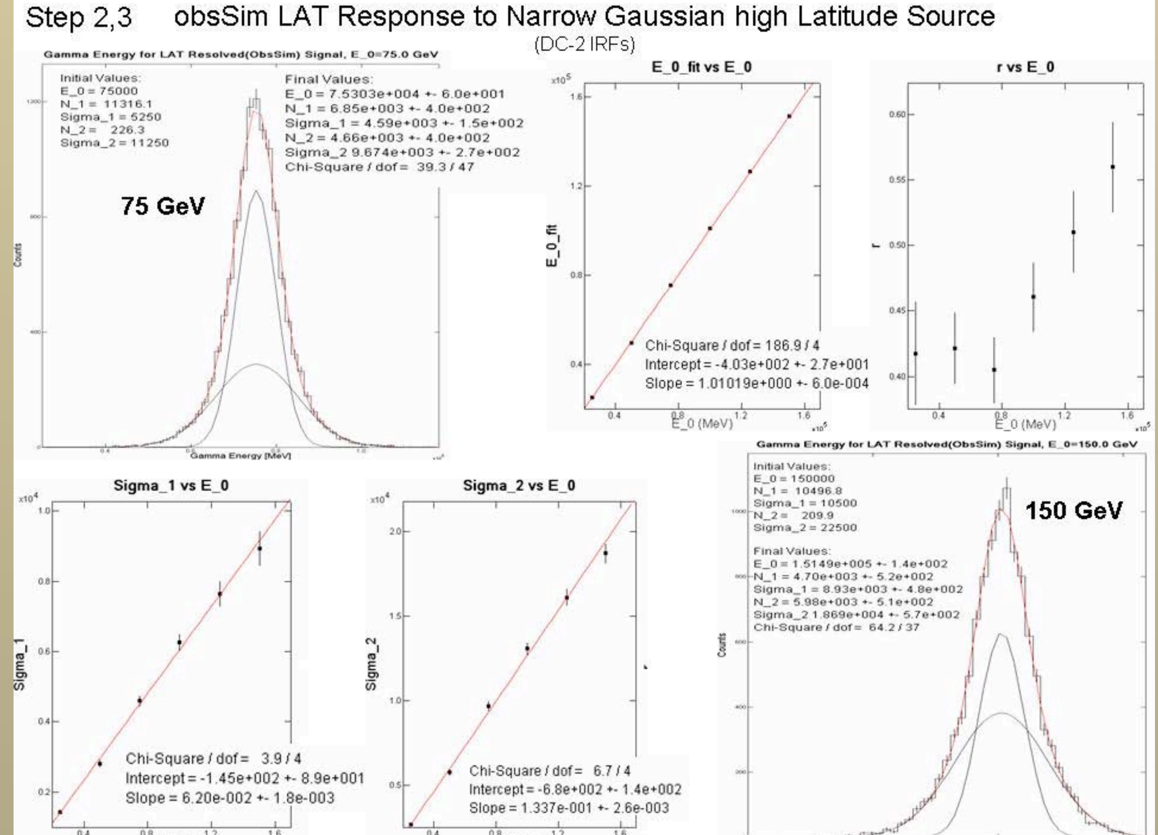


"sweet spot"- Annulus ε [25°,35°] exclude ± 10° from plane S/N ~ 12 times better than GC. (Stoehr et.al. 2003)

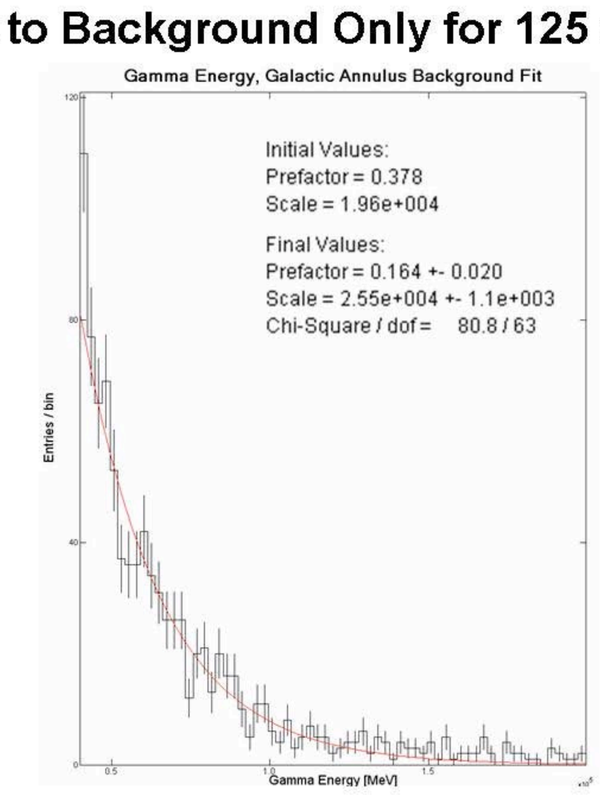
Procedure to Calculate LAT Line Sensitivity

1. Run GLAST LAT obsSim for a point source at high latitude (l= -76°, b= 26°,) and with a very narrow Gaussian line energy distribution ($\sigma/E_0 = 10^{-3}$) for 55 days to obtain LAT response to line. DC-2 IRFs were used.
2. Fit the resulting LAT line obsSim output to a double Gaussian distribution for E_0 = 25, 50, 75, 100,125, 150 GeV.
   $$\phi_1(E; E_0, N_T, r, \sigma_1,\sigma_2) = \frac{N_T}{\sqrt{2\pi}}\left[\frac{(1-r)}{\sigma_1}e^{\frac{-(E-E_0)^2}{2\sigma_1^2}} + \frac{r}{\sigma_2}e^{\frac{-(E-E_0)^2}{2\sigma_2^2}}\right]$$
3. Find continuous interpolations for E_0, σ_1, σ_2, for all E ε [25, 150] GeV.
4. Generate 5 year all-sky diffuse background from ST-HEAD1.513 Galprop and extragalactic diffuse model (DC-2 IRFs). Select annulus region around GC and fit contained diffuse background to,
   $\phi_2(E; a, b) = a \times e^{-\frac{E}{b}}$, E ε [40, 200] GeV
5. An excellent fit for the background is obtained over this range of energies.
6. Estimate GLAST LAT 5-σ signal sensitivity for 5 years by bootstrapping obsSim diffuse background and MC generated signal from ϕ_1 with 1000 bootstraps per E_0. Fit to $\phi_1 + \phi_2$, and ϕ_2 alone and calculate $<\Delta\chi^2> = 25$.
7. Similarly, estimate 95 % CLUL sensitivity for GLAST LAT for 5 years by bootstrapping obsSim diffuse background and fitting $\phi_1 + \phi_2$ with no MC generated signal. Find $N_T(E) \pm \sigma_{NT}$. 95% CLUL is obtained from 1.64 σ_{NT} .
8. In these fits, r, σ_1, σ_2, are fixed from the obsSim resolution function fits. The bin width for each energy distribution is $\sigma_{fwhm}(E_0)/4$.

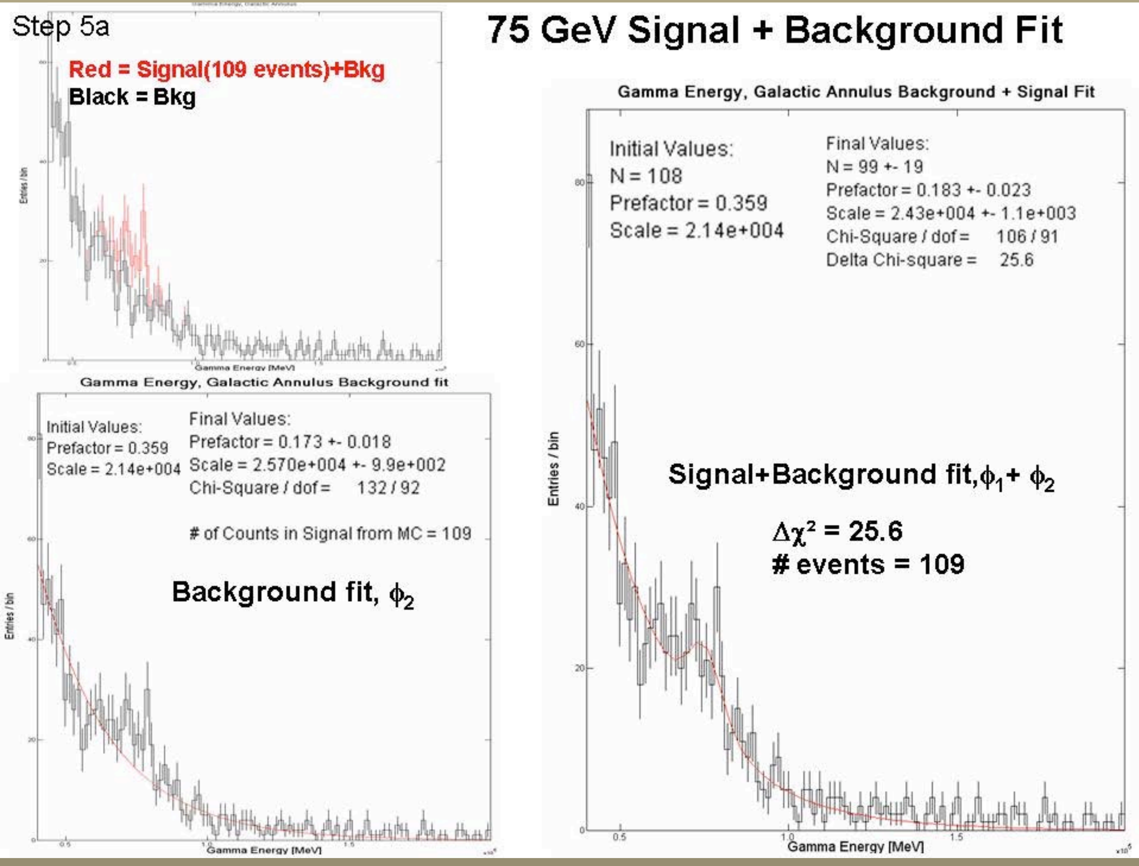
Step 2,3 obsSim LAT Response to Narrow Gaussian high Latitude Source (DC-2 IRFs)



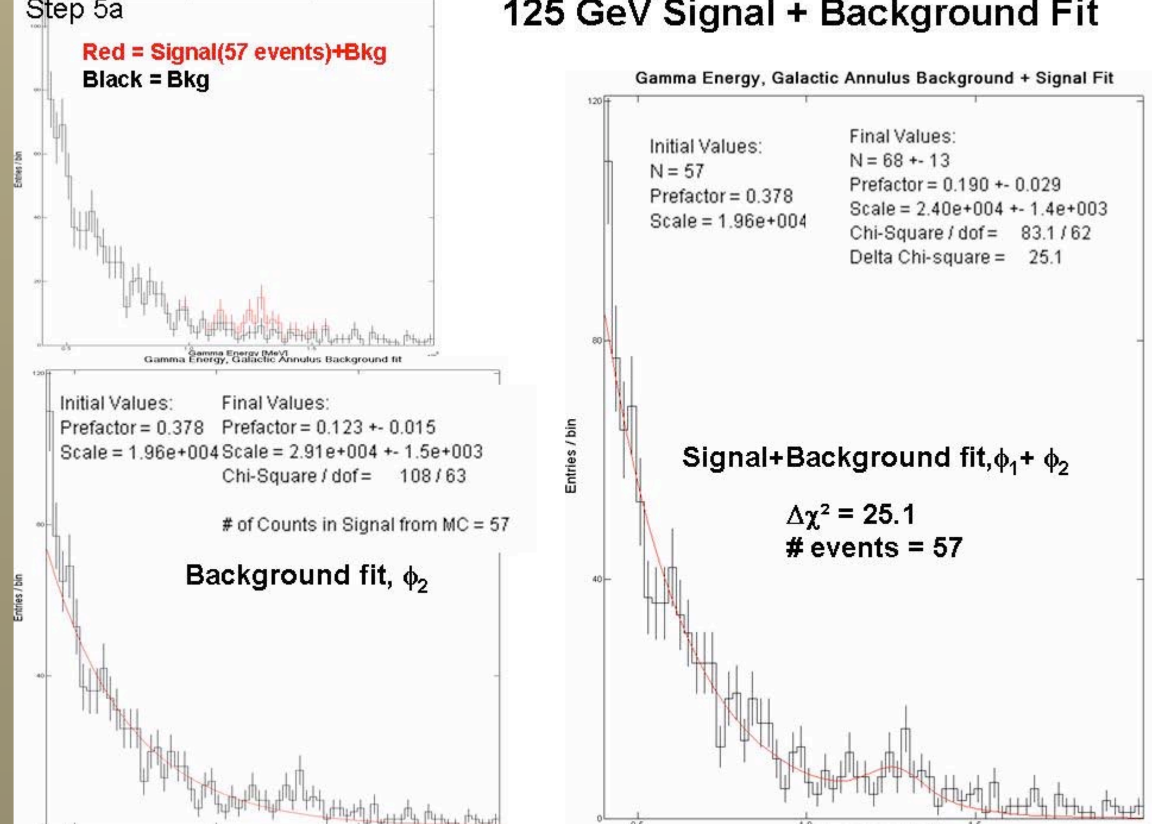
Step 4 **ϕ_2 fit to Background Only for 125 GeV**



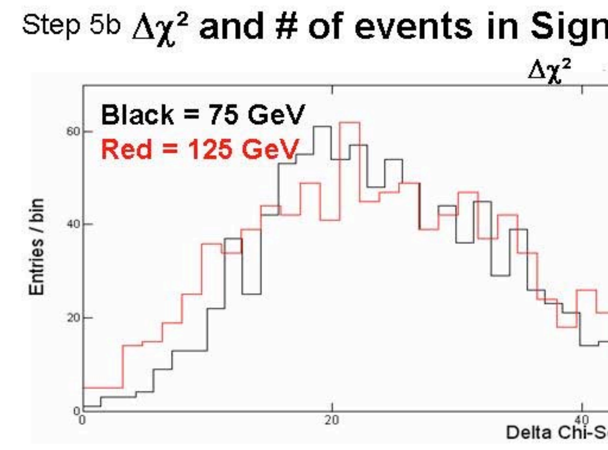
Step 5a **75 GeV Signal + Background Fit**



Step 5a **125 GeV Signal + Background Fit**

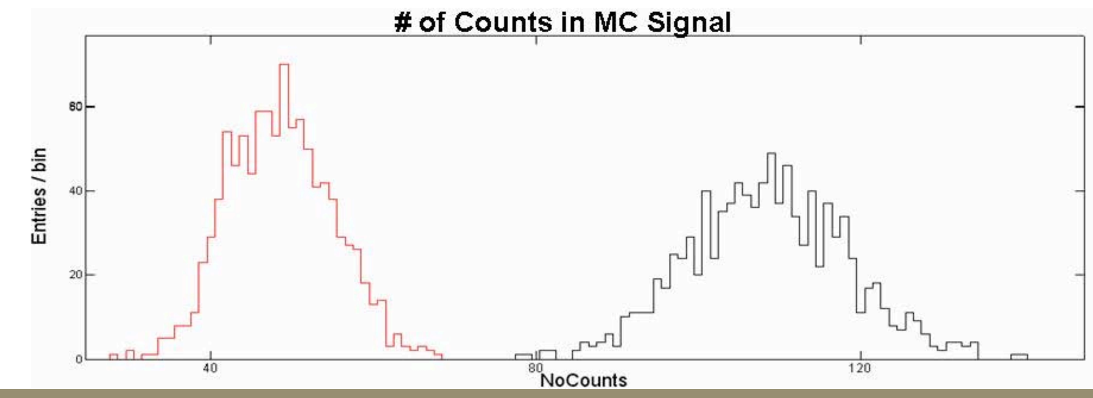


Step 5b **$\Delta\chi^2$ and # of events in Signal for 75 and 125 GeV**

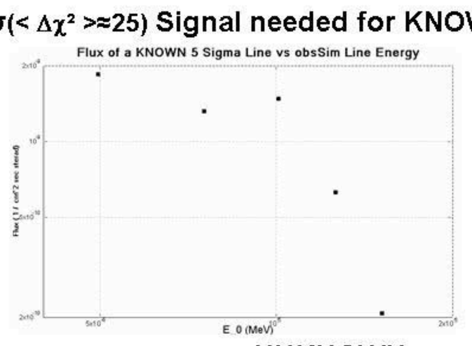


Line Energy (GeV)	<Δχ²>	<Signal Counts>
50	25.3	155
75	25.4	108
100	25.6	118
125	25.8	49
150	25.0	16

# of Counts in MC Signal



Flux of a ~5σ(< $\Delta\chi^2$ >≈25) Signal needed for KNOWN Line Energy

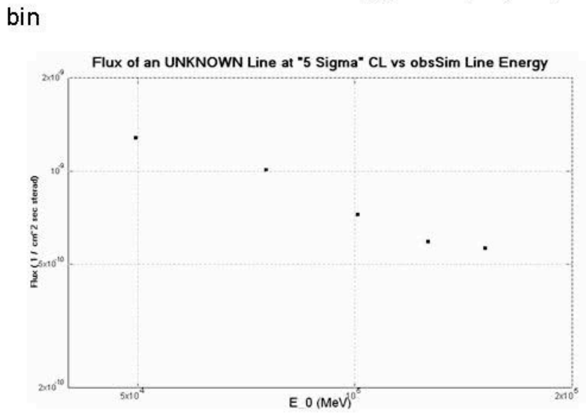


Flux of a "5σ" (10^{-5}% CL) signal needed for UNKNOWN Line Energy from [40,150]GeV

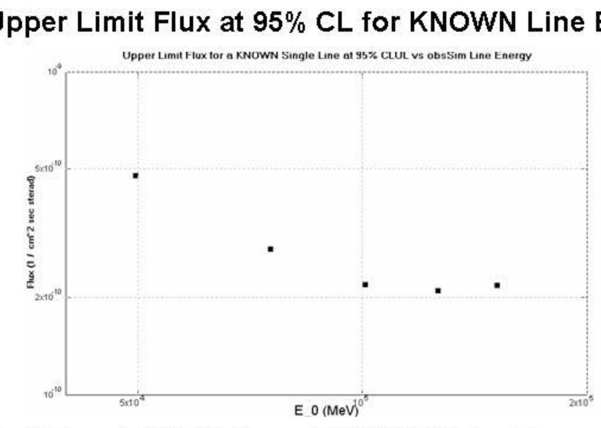
q = Probability of no detection in a single bin
$= (1-P)^{1/\#\text{ of energy bins}}$
$= \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\#ofSigmas} e^{-x^2/2}dx$

P = Probability of detecting a significant signal in any one (or more) bin
$= 10^{-7}$

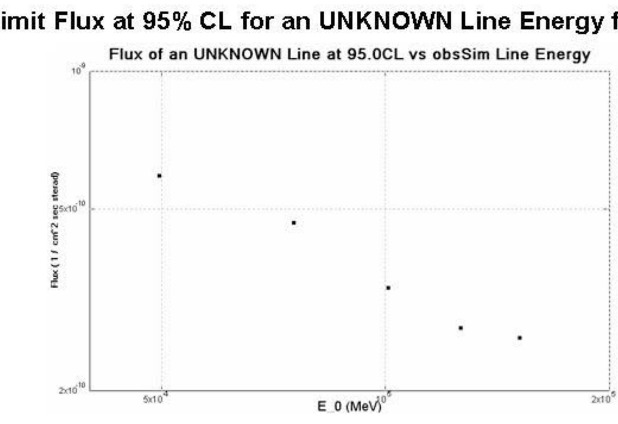
Bin width = $\sigma_{fwhm}(E) \approx 8\%E$
$\sigma_{signal} = \sqrt{2B}$
B = # of bkg counts in a bin centered on E_0 with width $\sigma_{fwhm}(E_0)$



Step 6 **Upper Limit Flux at 95% CL for KNOWN Line Energy**



Upper Limit Flux at 95% CL for an UNKNOWN Line Energy from [40,150]GeV



Summary

- These results are preliminary as they depend on the DC-2 IRFs, and the statistical methods need refinement.
- The energy range for the WIMP line sensitivity is cut off at 150 GeV in this poster. This is due to our use of the current LAT Instrument Response Functions (IRFs) that are preliminary and cut off at 200 GeV. This energy cut off of < 300 GeV is the result of the optimization of event selection and analysis cuts being to-date focused on the 'core' energy range for the LAT. Work is underway in the LAT collaboration to extend the IRFs to much higher energies in the near future.
- A double Gaussian fits the obsSim data well for a high latitude point source with a narrow Gaussian energy distribution. The σ_1 and σ_2 parameters are approximately linear as a function of point source energy.
- The flux needed for a 5σ signal of known energy on a 5 year diffuse galactic annulus background was estimated using a bootstrapped fit corresponding to a $\Delta\chi^2$ distribution with $<\Delta\chi^2> = 25$. Sensitivity in the case of an unknown line energy was calculated using a probabilistic approach to account for the number of energy bins.
- The 95% CLUL flux at a known line energy for a 5 year diffuse galactic annulus background was calculated as $1.64\sigma_{NT}$,where σ is from a $\phi_1 + \phi_2$ fit to a diffuse background. The unknown sensitivity was found using the method mentioned previously.
- Next: refined statistical methods, greater statistics, higher energies, 2 line models.