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

Andrea Albert (SLAC)

On behalf of the Fermi-LAT Collaboration

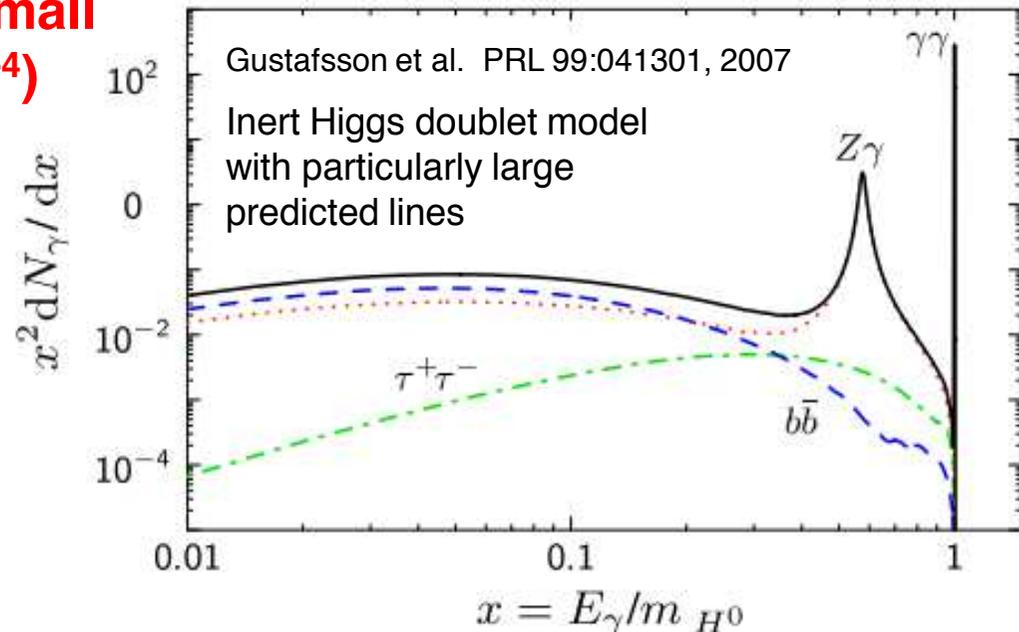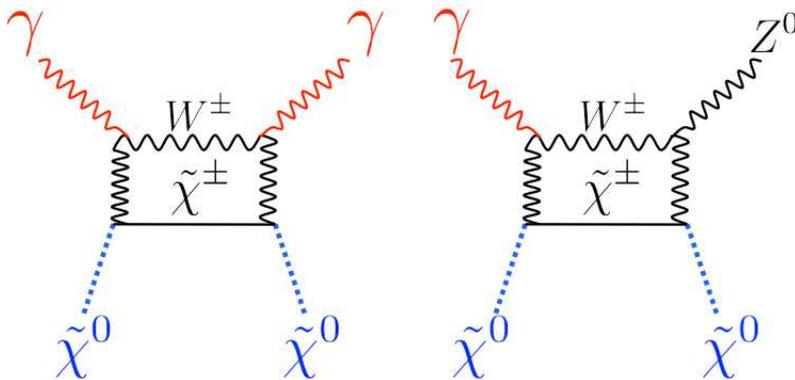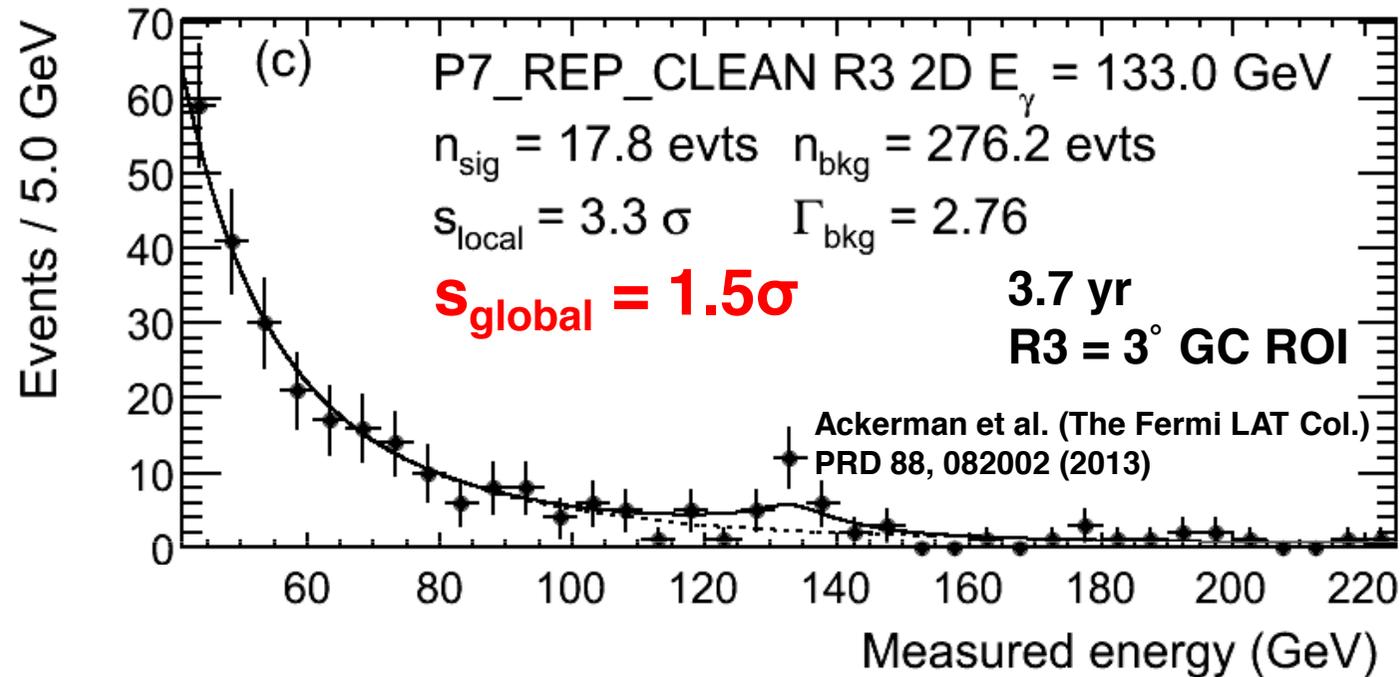**The Fermi Symposium**

**10/24/2014**

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)**

- $\chi\chi \rightarrow \gamma\gamma$, 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 (b.f. typically ~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

(c) P7_REP_CLEAN R3 2D E_γ = 133.0 GeV
n_{sig} = 17.8 evts n_{bkg} = 276.2 evts
s_{local} = 3.3 σ Γ_{bkg} = 2.76

s_{global} = 1.5σ

3.7 yr
R3 = 3° GC ROI

Ackerman et al. (The Fermi LAT Col.)
PRD 88, 082002 (2013)

- **There have been two line searches from the LAT Collaboration**
  - **3.7 years, 5 GeV < E_γ < 300 GeV, 5 ROIs**
  - **5.2 years, 100 MeV < E_γ < 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} < 2σ) 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)**
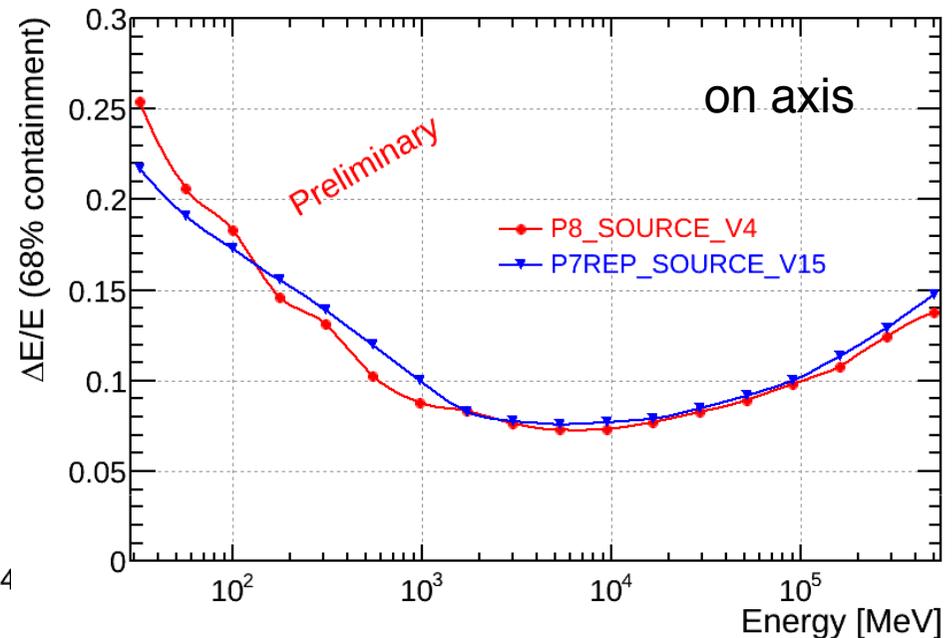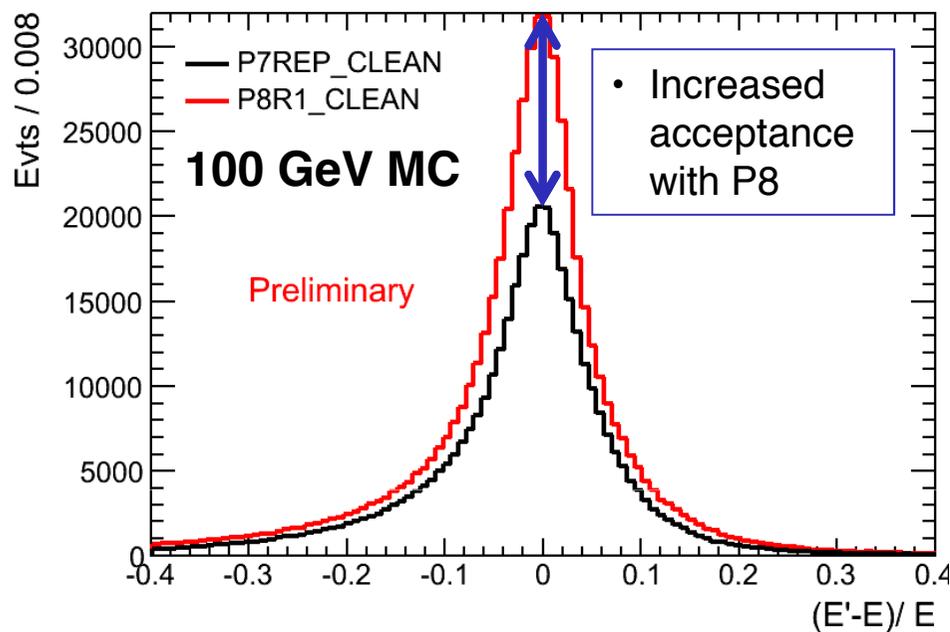
- **Improved energy reconstruction in Pass 8**
  - **Energy recon. above ~1 GeV optimized with better modeling of calorimeter shower (e.g. improve handling of gaps between modules and crystal saturation)**
  - **Increased effective area with equivalent energy resolution**
- **Event reconstruction and selection classes are new in P8**
  - **Pass 8 is a new "lens" we can view lines through**
    - **Important check for tentative 133 GeV feature**

"2D" Line Model with Pass 8
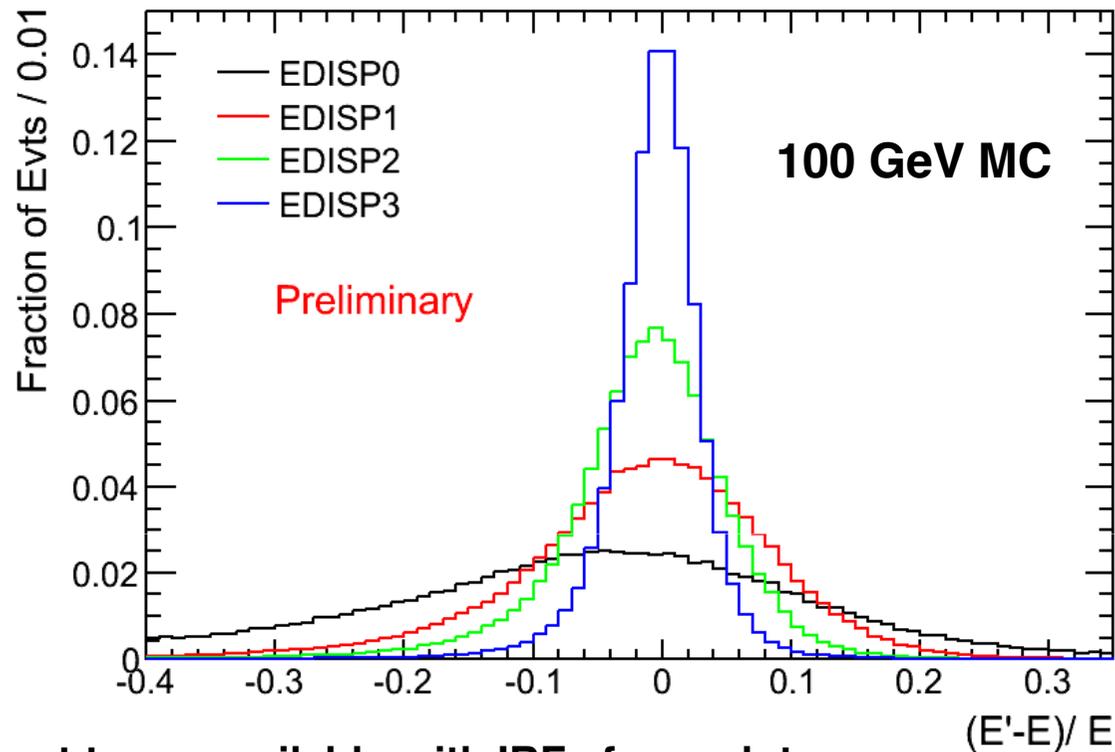
- **P8 has more event types available with IRFs for each type**
  - **Similar to "front" vs. "back" IRFs**
- **EDISP types select events based on energy recon quality**
  - **25% quantiles of "Best Energy Prob" as function of energy**
  - **In given energy range, each EDISP type has ~same acceptance**
- **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**

- **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)**
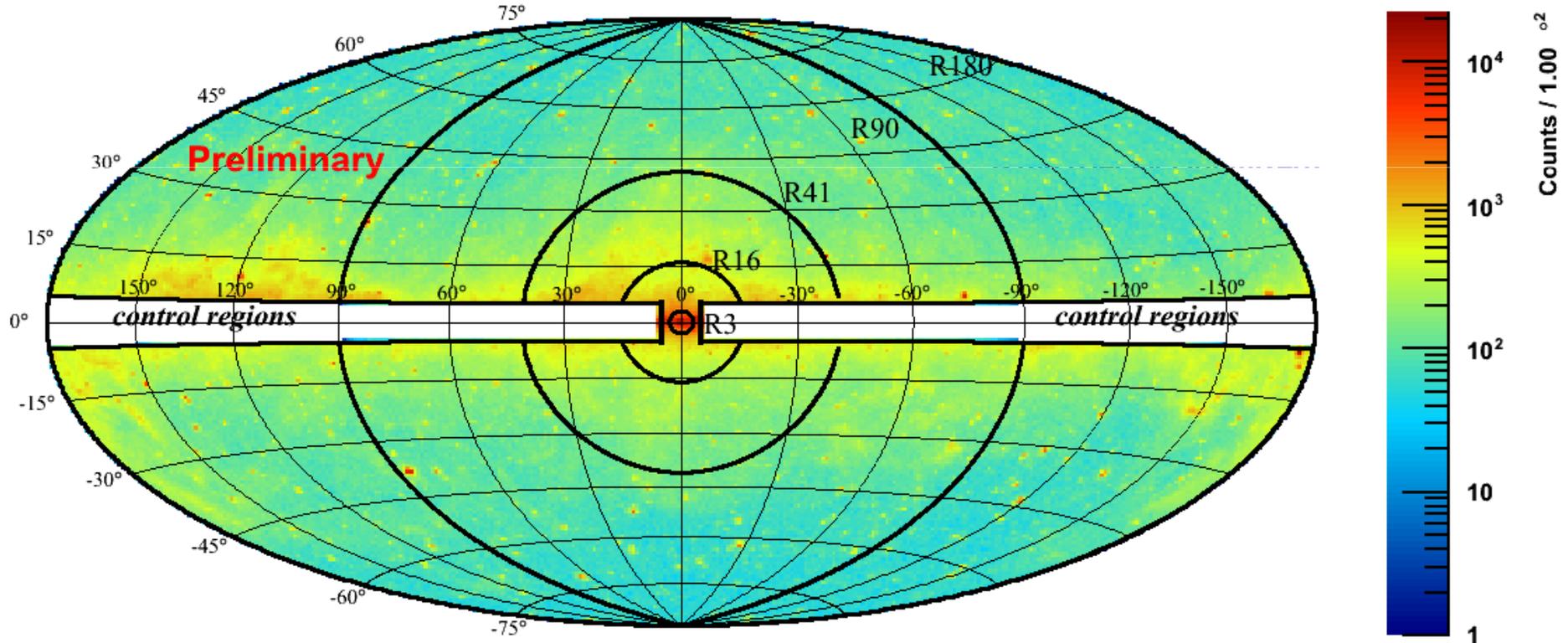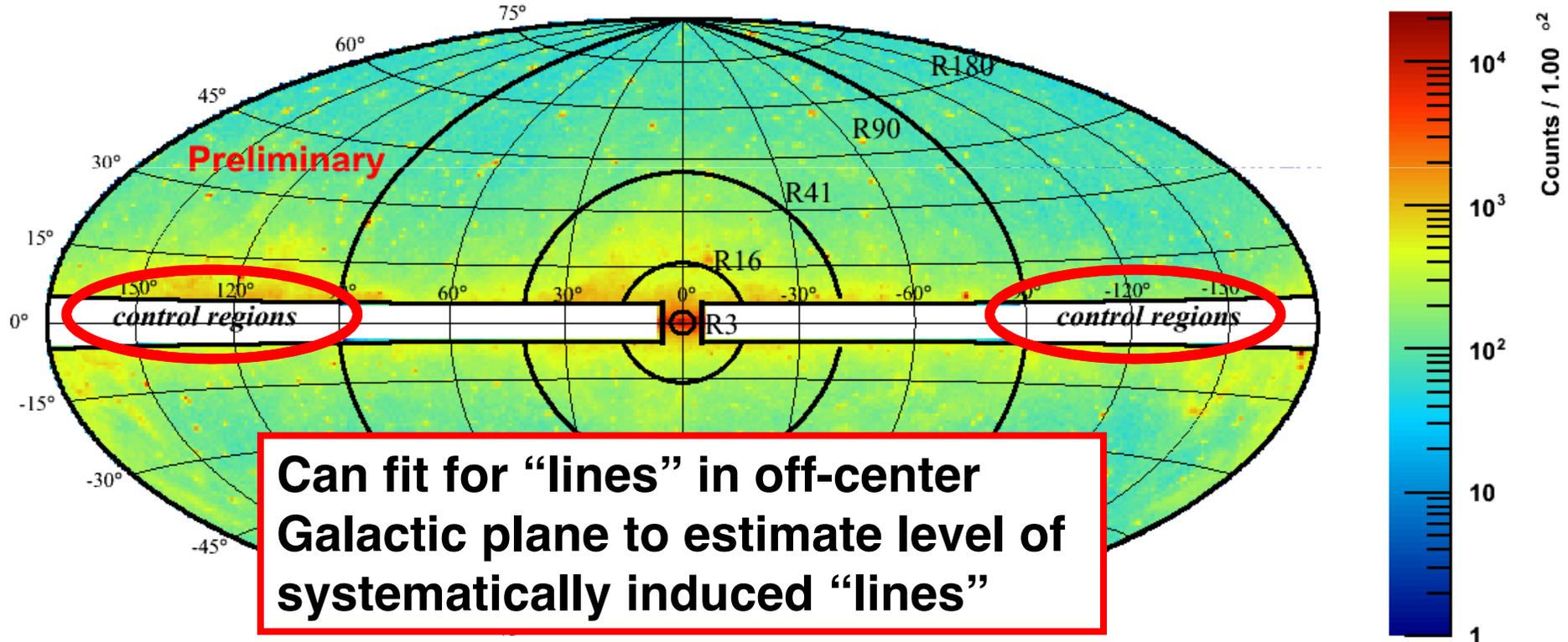
Region of Interest (ROI) Optimization

- 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)
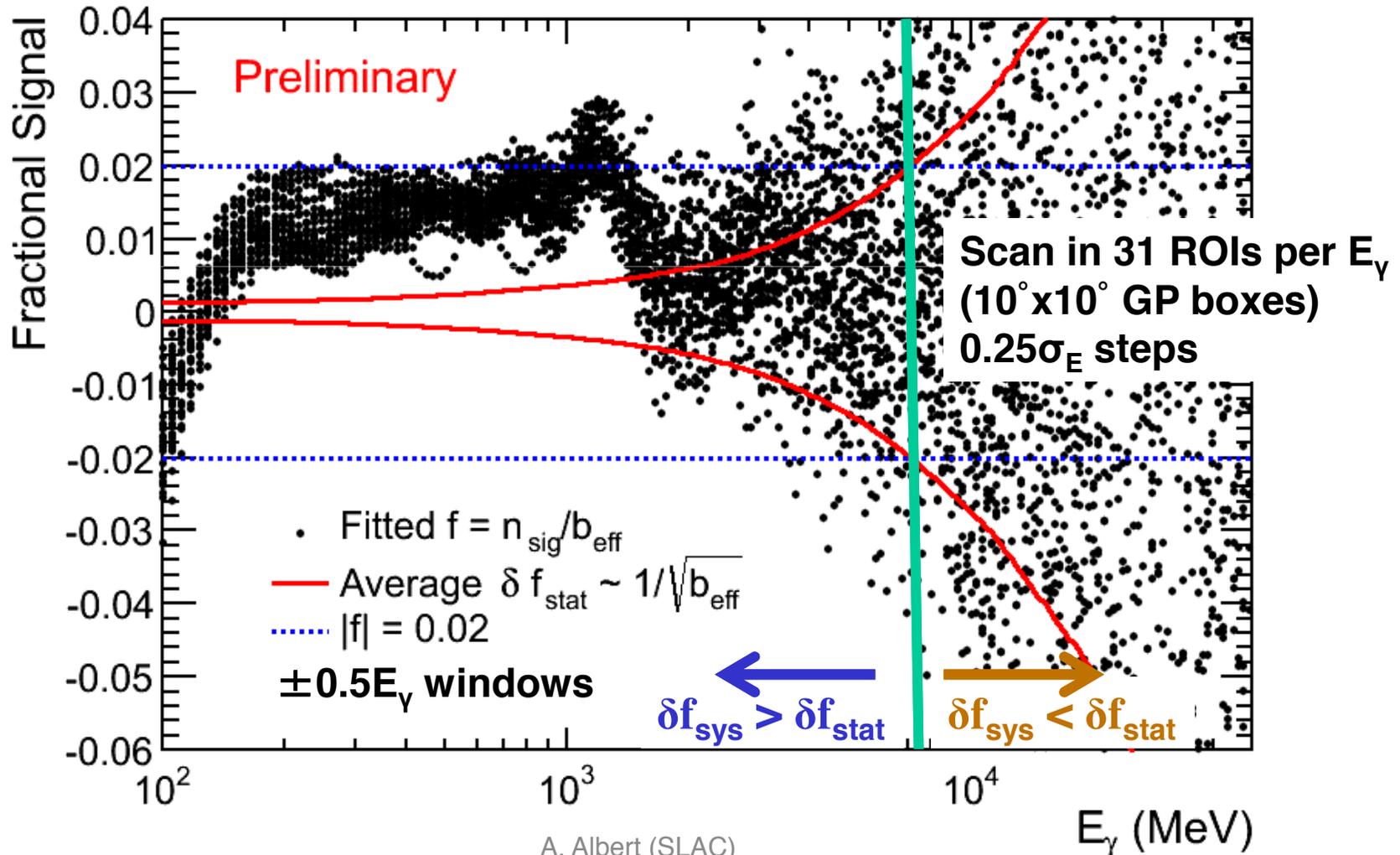

Preliminary

Can fit for "lines" in off-center Galactic plane to estimate level of systematically induced "lines"

- There are some common features likely from the effective area (A_{eff})
- Displacement from 0 is mostly from A_{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_γ
($10°\times10°$ GP boxes)
$0.25\sigma_E$ steps

Preliminary

Fractional Signal

- Fitted $f = n_{sig}/b_{eff}$
- Average $\delta f_{stat} \sim 1/\sqrt{b_{eff}}$
- $|f| = 0.02$

$\pm 0.5 E_\gamma$ windows

$\delta f_{sys} > \delta f_{stat}$ $\delta f_{sys} < \delta f_{stat}$

E_γ (MeV)

A. Albert (SLAC)

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- **Search with 5.8 years of P8 Clean data for lines from 200 MeV < E_γ < 500 GeV**
  - **Use $\pm$0.5 E_γ fit windows to optimize at low energies (where systematic limited) and high energies (where statistical limited)**

- **Include nuisance parameter (n_{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**

$$C(E, \vec{\alpha}) = \left((n_{sig} + n_{sys}) S(E, E_\gamma) + n_{bkg} B(E, \Gamma_{bkg}) \right) * G_{sys}$$

$$\sigma_{sys} = \delta f_{sys} * b_{eff}$$
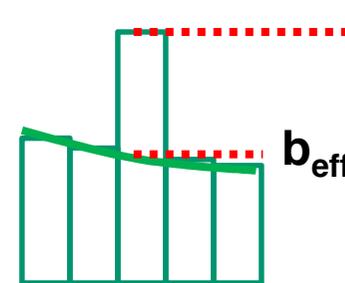
$$G_{sys} = \frac{1}{\sigma_{sys} \sqrt{2\pi}} e^{-n_{sys}^2 / 2\sigma_{sys}^2}$$

Gaussian constraint on n_{sys}

n_{sys} is constrained using δf_{sys} estimated with control regions
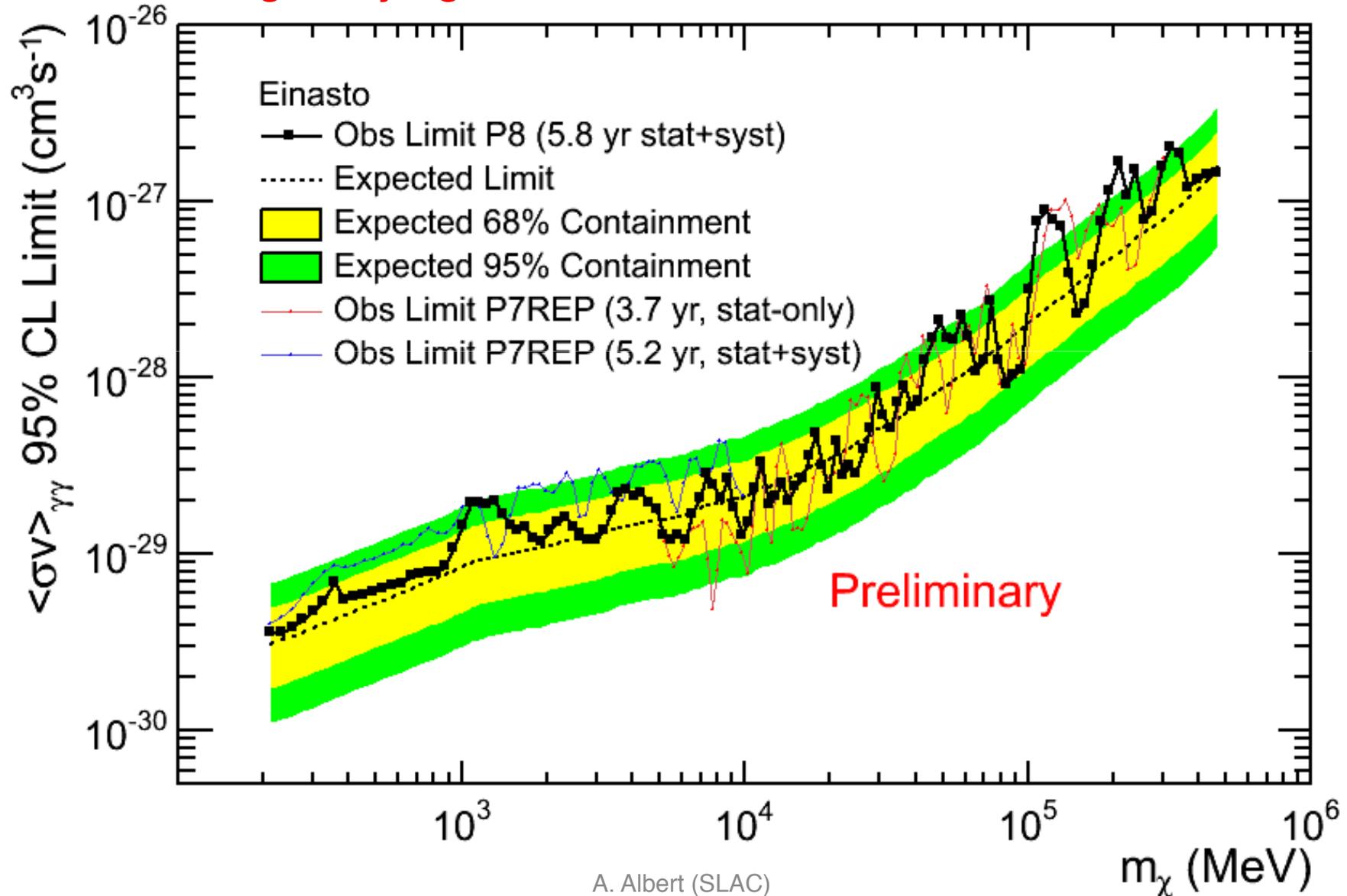
$$f = \frac{n_{sig}}{b_{eff}} \approx \frac{TS}{n_{sig}}$$

n_{sig}

b_{eff}

Warning: cartoon, see paper for full b_{eff} definition A. Albert et al. JCAP10(2014)023

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- **No globally significant lines found**

Einasto
- —■— Obs Limit P8 (5.8 yr stat+syst)
- ·········· Expected Limit
- ▮ Expected 68% Containment
- ▮ Expected 95% Containment
- —— Obs Limit P7REP (3.7 yr, stat-only)
- —— Obs Limit P7REP (5.2 yr, stat+syst)

Preliminary

Y-axis: $\langle\sigma v\rangle_{\gamma\gamma}$ 95% CL Limit (cm^{3}s^{-1})

X-axis: m_χ (MeV)

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Einasto
- Obs Limit P8 (5.8 yr stat+syst)
- Expected Limit
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Preliminary
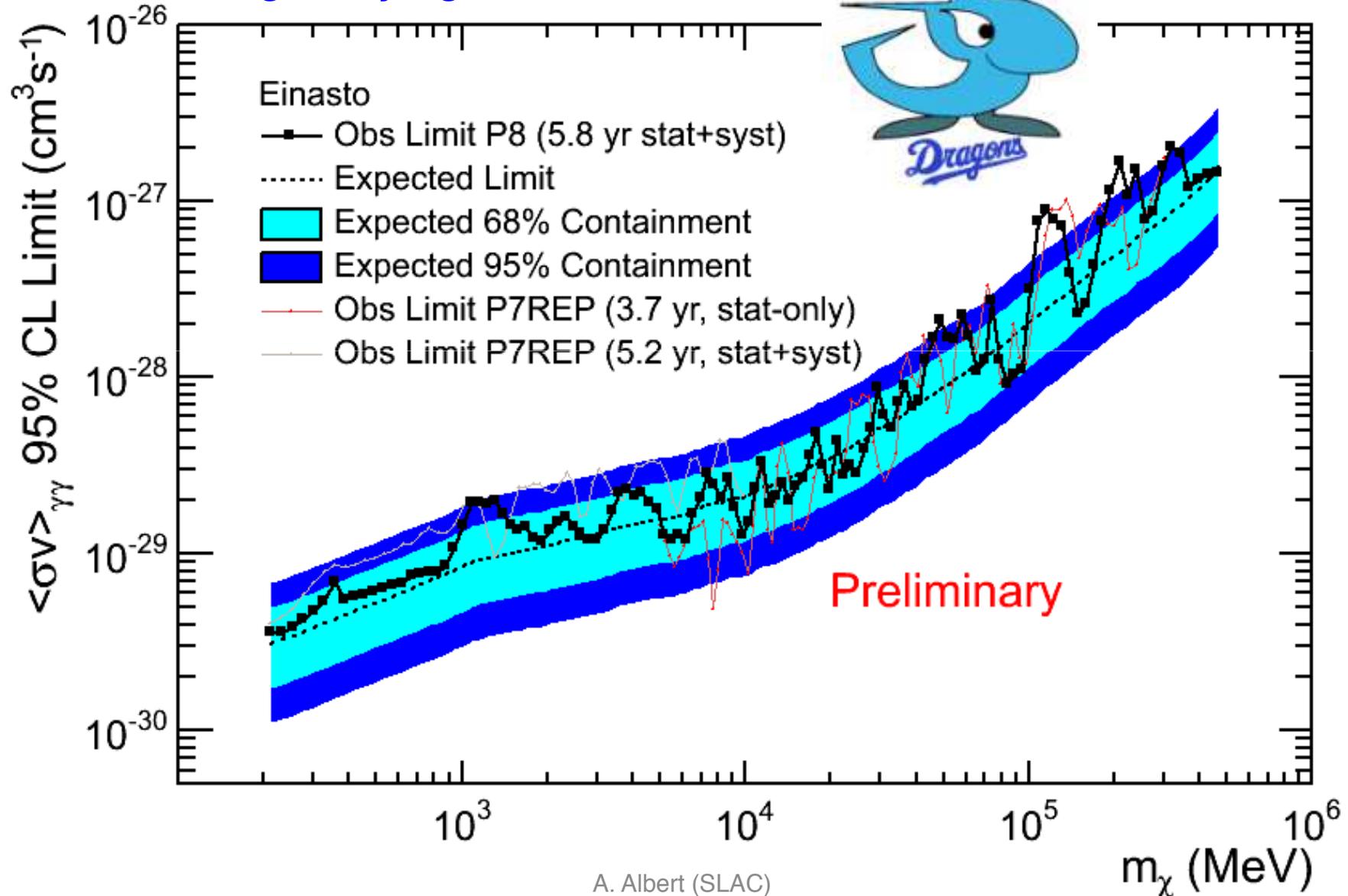
Line-like Feature near 133 GeV

P7REP_Clean

P8_Clean
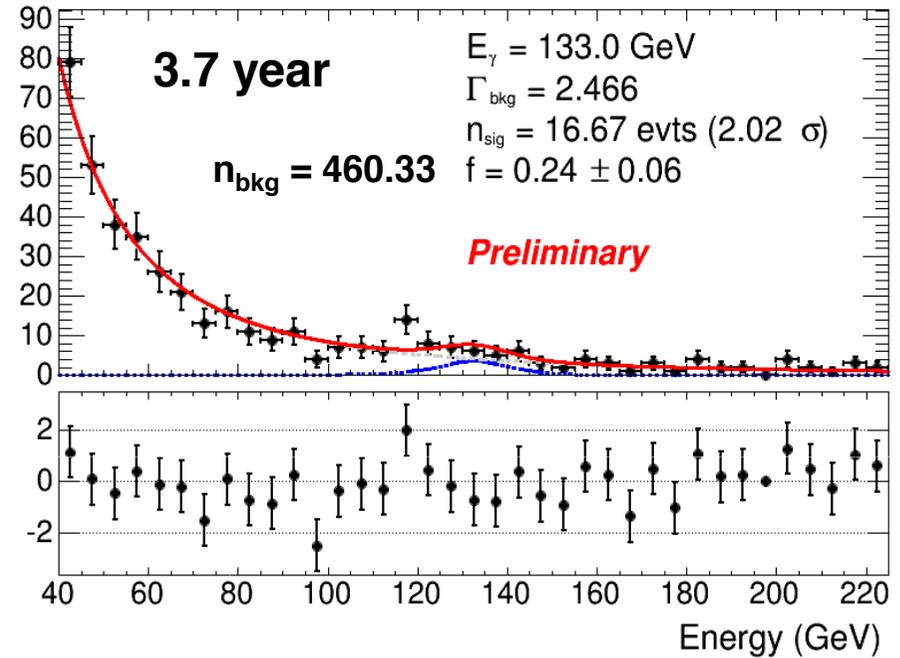
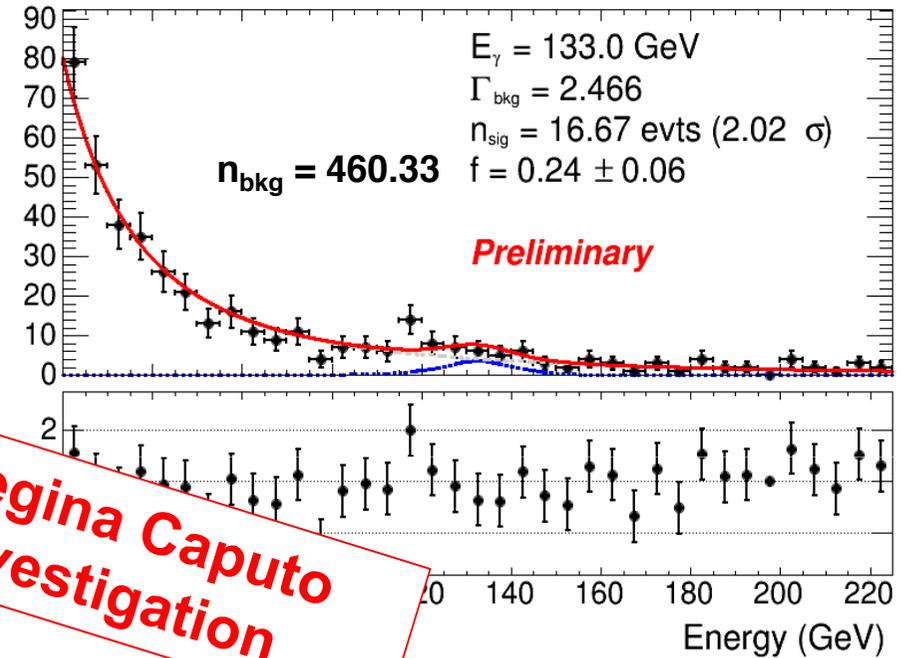Ackerman et al. (The Fermi LAT Col.)
PRD 88, 082002 (2013)

- **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

P7REP_Clean

(c) P7_REP_CLEAN R3 2D E_γ = 133.0 GeV
n_{sig} = 17.8 evts n_{bkg} = 276.2 evts
s_{local} = 3.3 σ Γ_{bkg} = 2.76

f = 0.61 ± 0.19

Ackerman et al. (The Fermi LAT Col.)
PRD 88, 082002 (2013)

P8_Clean

E_γ = 133.0 GeV
Γ_{bkg} = 2.466
n_{sig} = 16.67 evts (2.02 σ)
n_{bkg} = 460.33   f = 0.24 ± 0.06

Preliminary

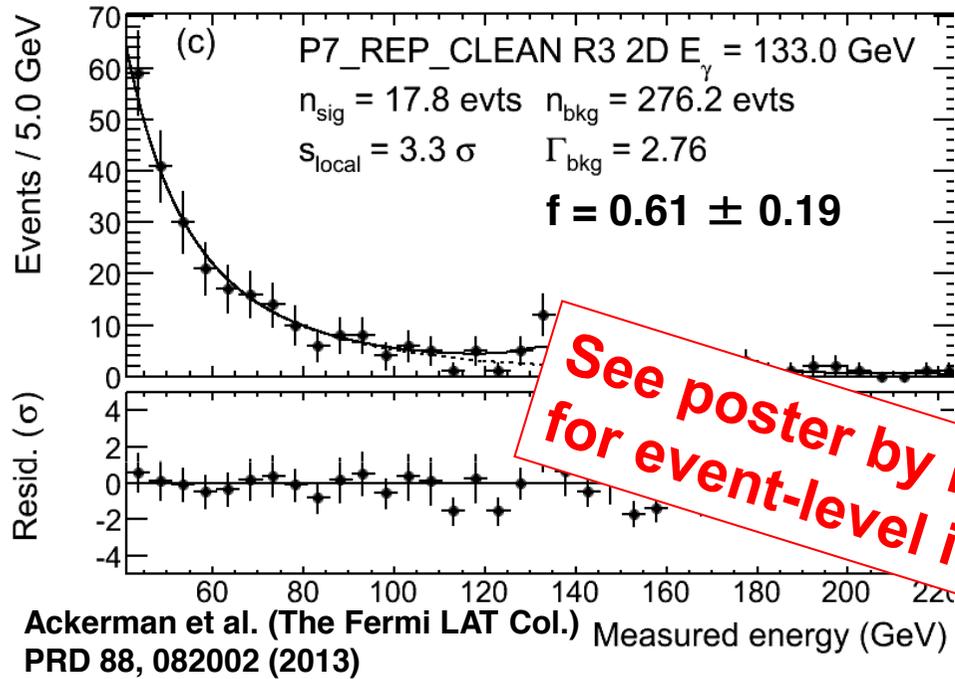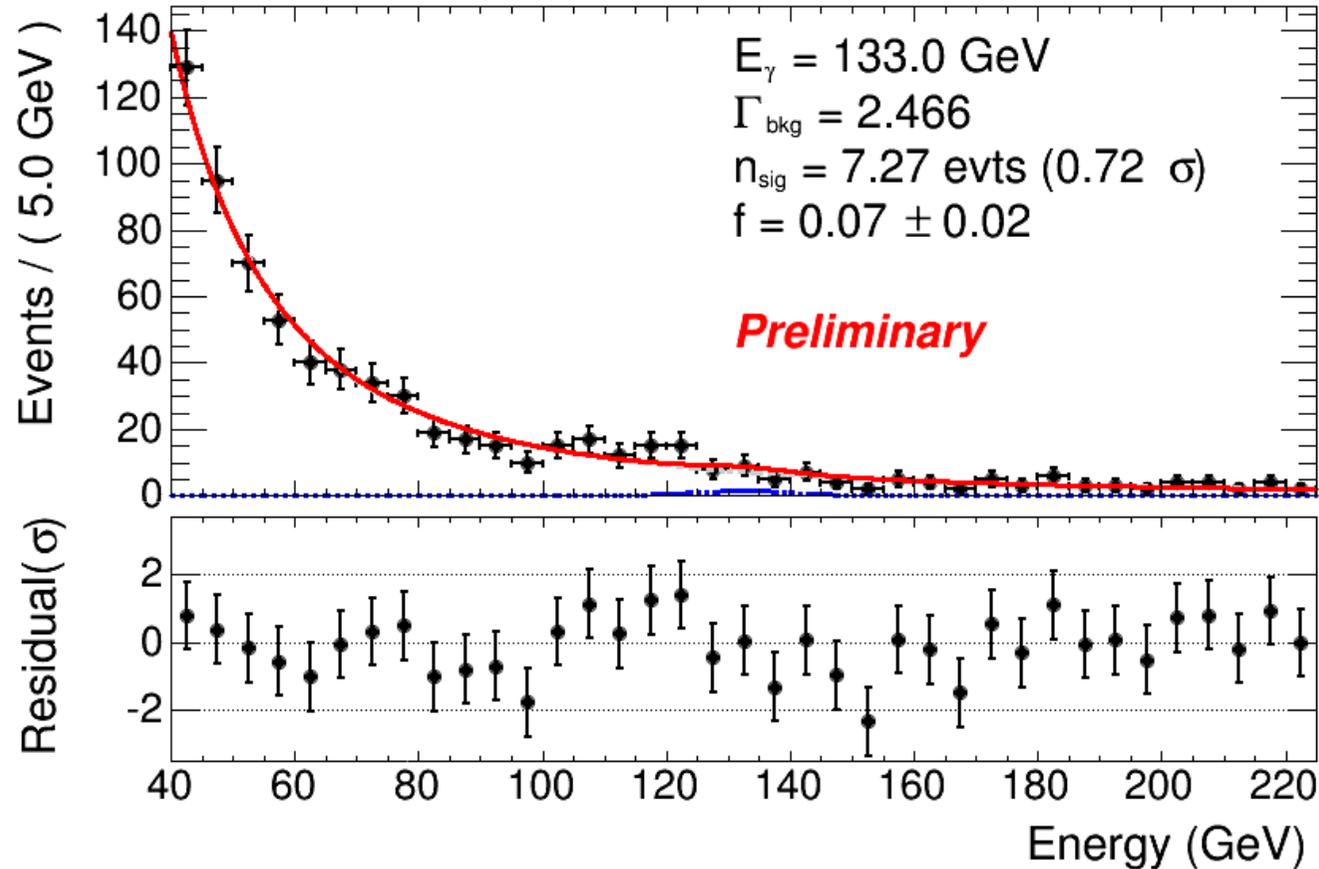**See poster by Regina Caputo for event-level investigation**

- **Same fit parameters as 3.7 year line search (Ackerman et al. PRD 88, 082002 (2013))**
  - **Fits in R3, 3.7 year, ±6σ_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**

The plot shows:

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

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_γ < 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} = 0.72σ in 5.8 year dataset**