A tentative gamma-ray line from dark matter annihilation at the Fermi-LAT

arXiv:1203.1312 with T. Bringmann, X. Huang, A. Ibarra, S. Vogl (accepted for JCAP),
arXiv:1204.2797 (accepted for JCAP)
& ongoing work with L. Bergström, G. Bertone, J. Conrad, C. Farnier

Christoph Weniger
Max-Planck-Institut für Physik, München

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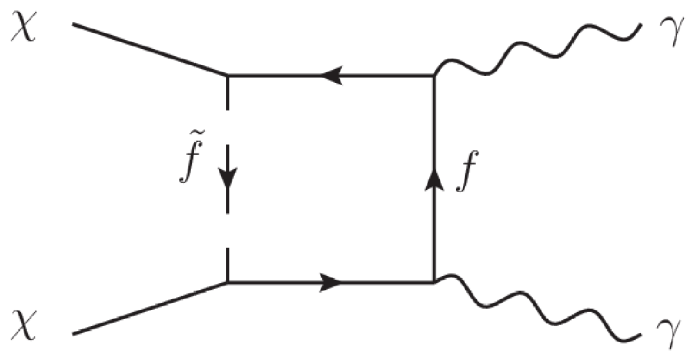
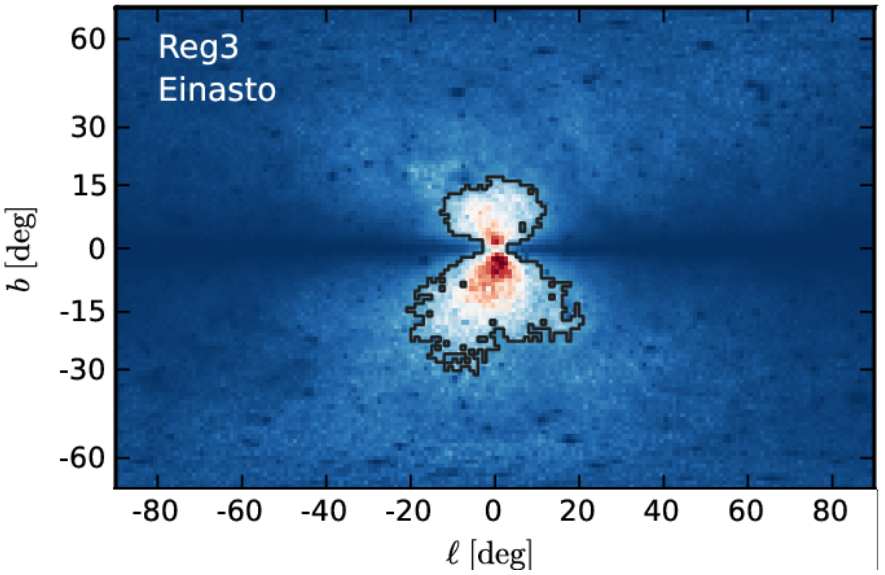
Line search with Fermi-LAT

$$\chi\chi \to \gamma\gamma,\ \gamma Z,\ \gamma h$$

$$\mathrm{BR}(\chi\chi \to \gamma\gamma) \sim \alpha_{\mathrm{em}}^2 \sim 10^{-4}$$

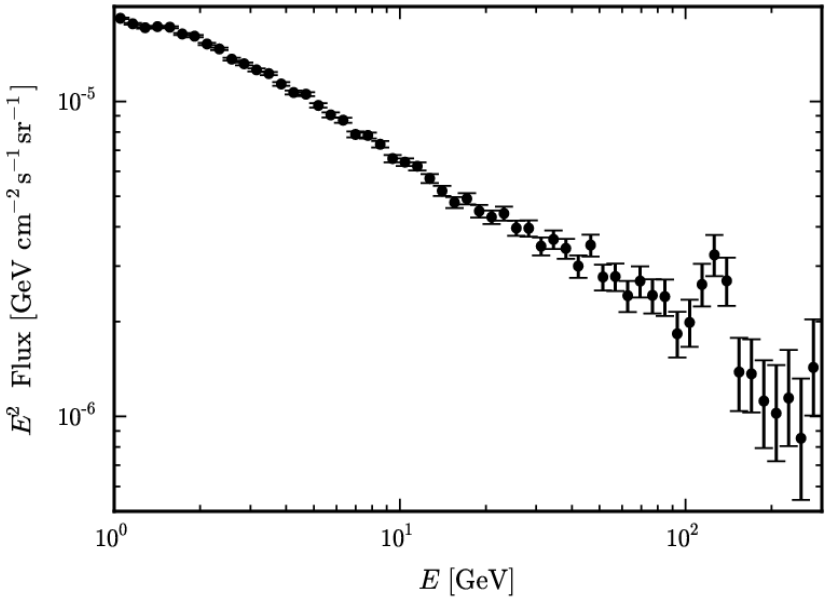


I) Target region selection



$$\int_{\Delta\Omega} d\Omega$$

II) Analysis of energy spectra



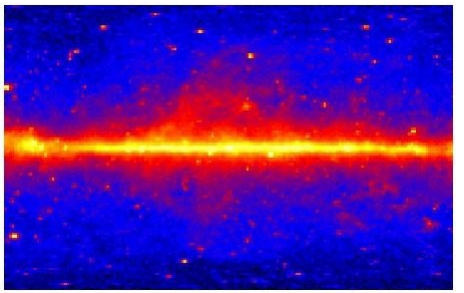
- Target: Annihilation signal from Galactic center
- Aim: Maximize signal-to-noise ratio
- Problem: Specification of signal & background morphologies

- Forget about spatial information (integral over dΩ)
- Perform a “bump-search” in the integrated energy spectrum

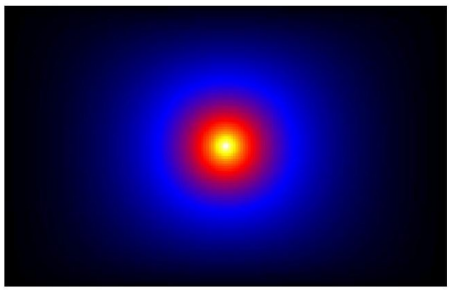
I) Adaptive target region selection

Fermi-LAT photons above 1 GeV are binned into 1x1deg^2 pixels.

- **Background morphology estimated from data**
  We use events between 1 and 20 GeV for background estimation, and search for lines above 20 GeV.



- **Signal morphology** derived for a few reference dark matter profiles (centered at Galactic center)
  - Cored isothermal
  - NFW
  - Contracted profiles
  - Einasto



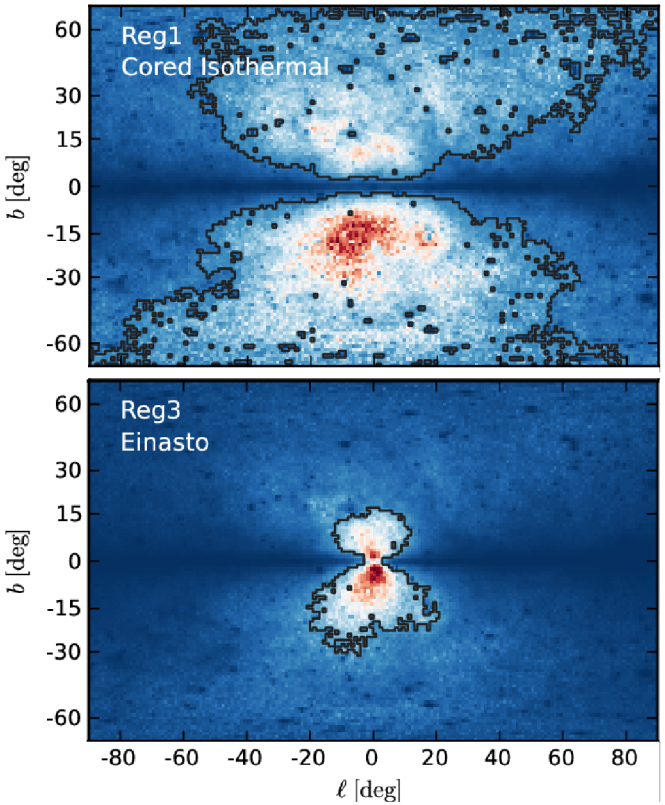
- **Pixel-by-pixel optimization of target region**
  Goal: Find subset of pixels T that maximizes S/N

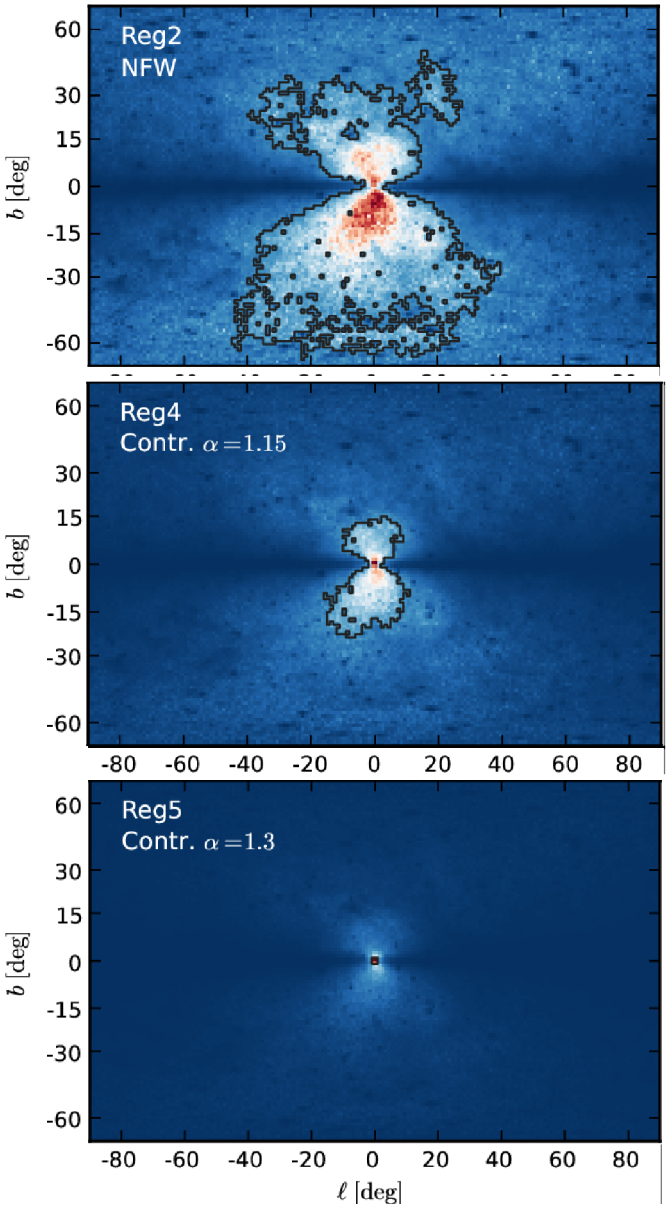
$$(\mathcal{S}/\mathcal{N})_T = \frac{\sum_{i\in T} \mu_i}{\sqrt{\sum_{i\in T} c_i^{1\mathrm{to}20\mathrm{GeV}}}}$$

Expected signal events

Measured events

Target regions for different dark matter profiles

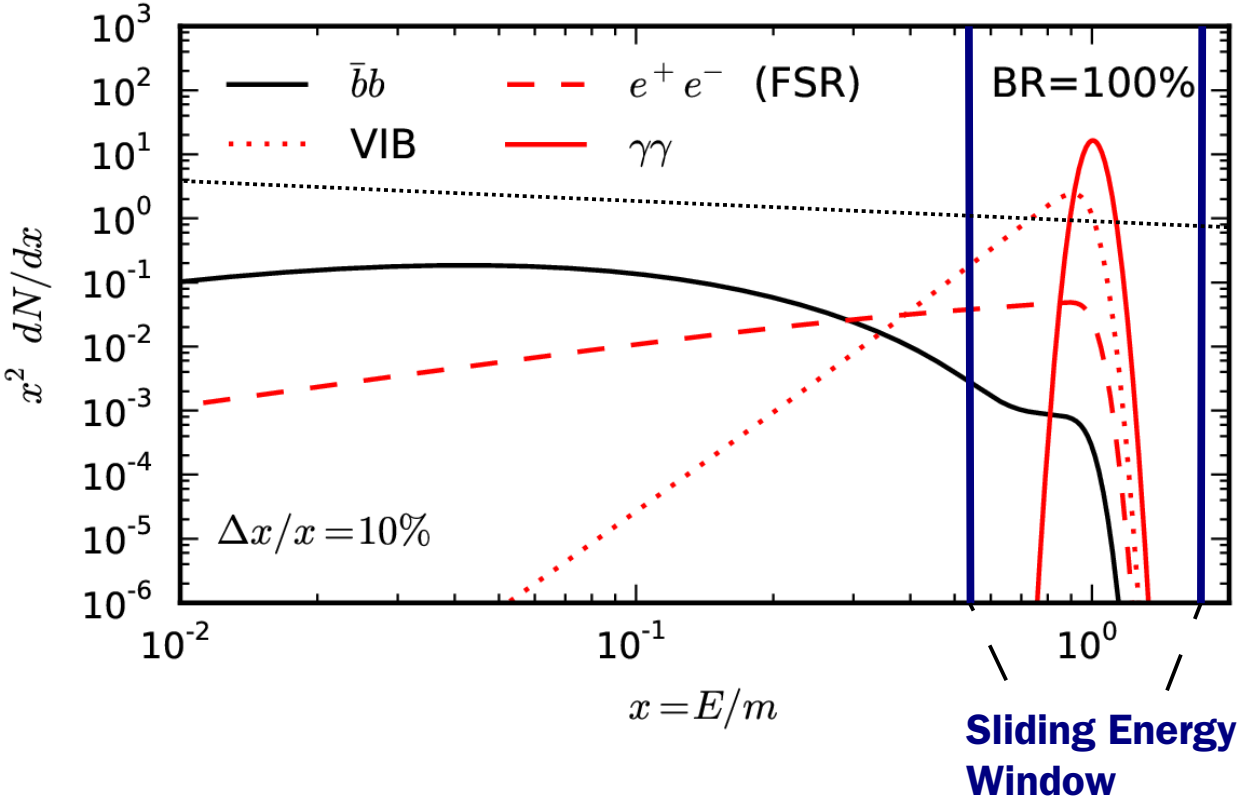




- Steeper dark matter halo profiles → smaller target region
- Galactic center always included (except for cored isothermal profile)
- Slight north/south asymmetry as consequence of asymmetric diffuse fluxes at ~1 GeV

II) Spectral Analysis: Bump hunting

All spectral fits are performed within a small energy window around the gamma-ray line position



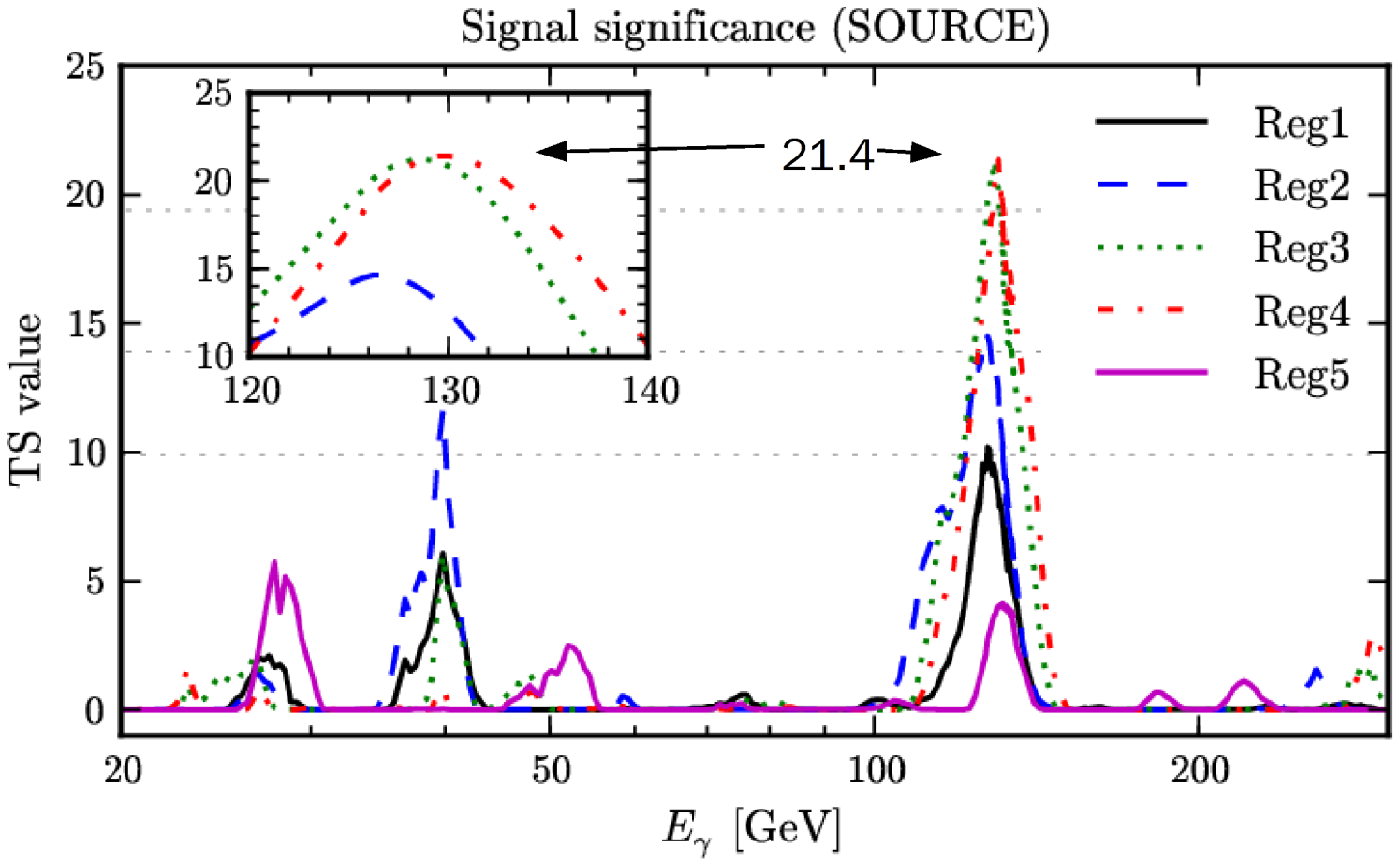
„Sliding energy window technique“

- Secondary photons from DM signal can be neglected
- Fit with a simple power-law background + line signal model (3 parameters):

$$\frac{dJ}{dE} = S\ \delta(E - E_\gamma) + \beta E^{-\gamma} \qquad TS = -2\ln\frac{\mathcal{L}_{\rm null}}{\mathcal{L}_{\rm alt}}$$

- Trading systematical for statistical errors

III) Results



$$E_\gamma = 129.8 \pm 2.4^{+7}_{-13}\,\mathrm{GeV}$$

Local significance: 4.6σ

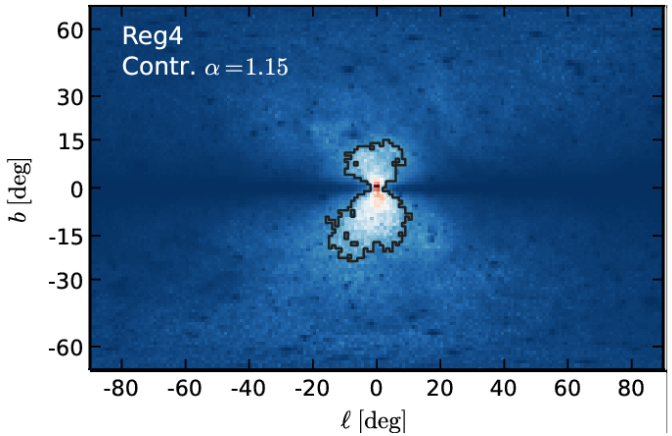
Assuming Einasto profile with 0.4 GeV/cm^3 local density:

$$\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} = 1.27 \pm 0.32^{+0.18}_{-0.28} \times 10^{-27}\,\mathrm{cm}^3/\mathrm{s}$$

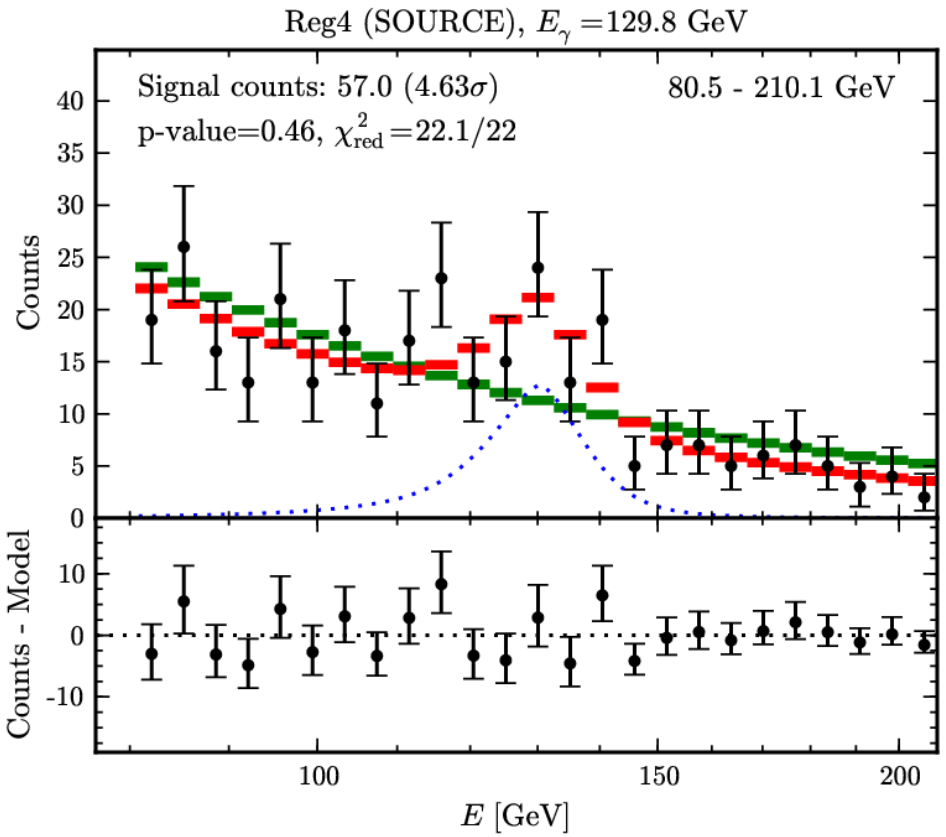
Global significance (spatial and spectral trial correction): ~3.3σ

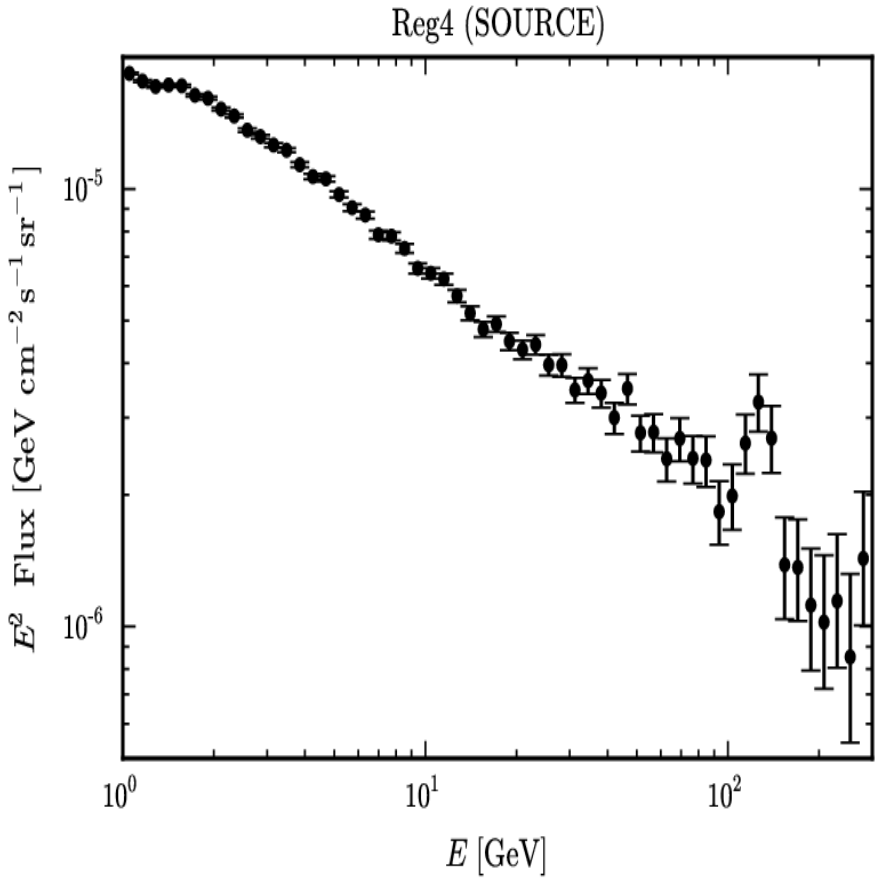
Based on 43 month of P7V6 source class, similar for clean events.

The signature is sharp



Signal width <17% (95%CL)





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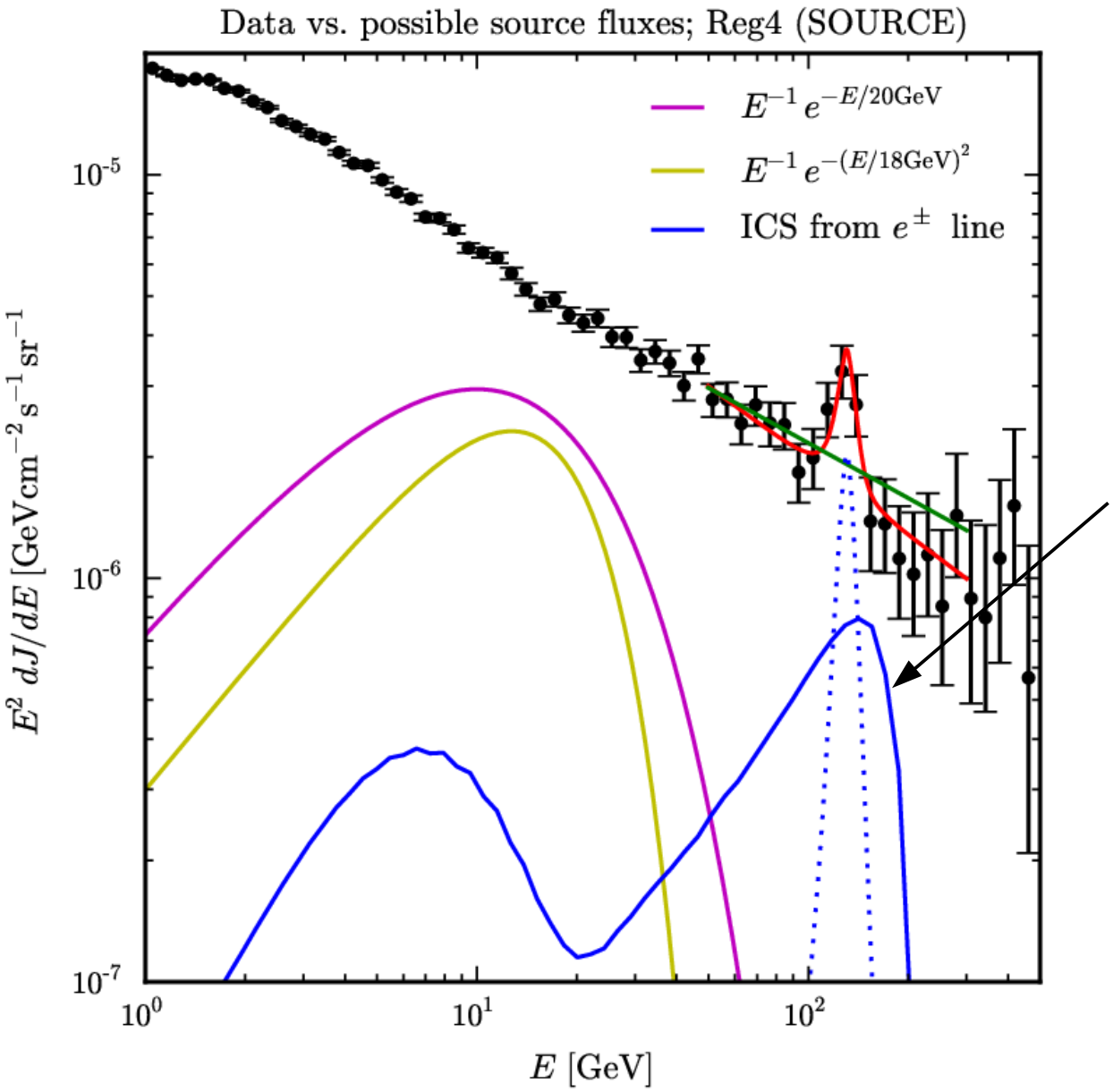
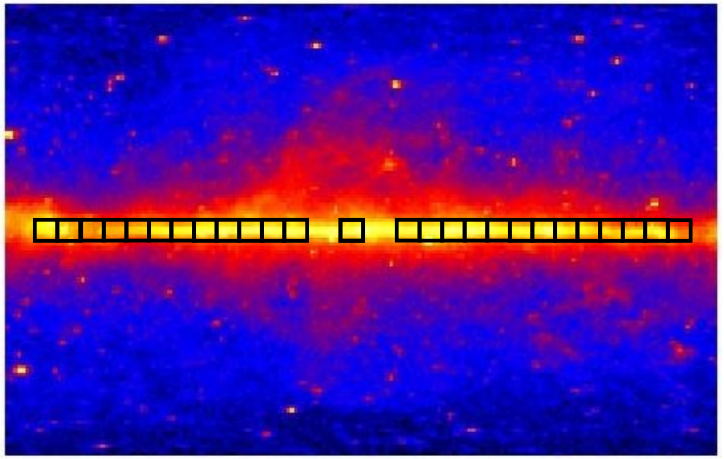


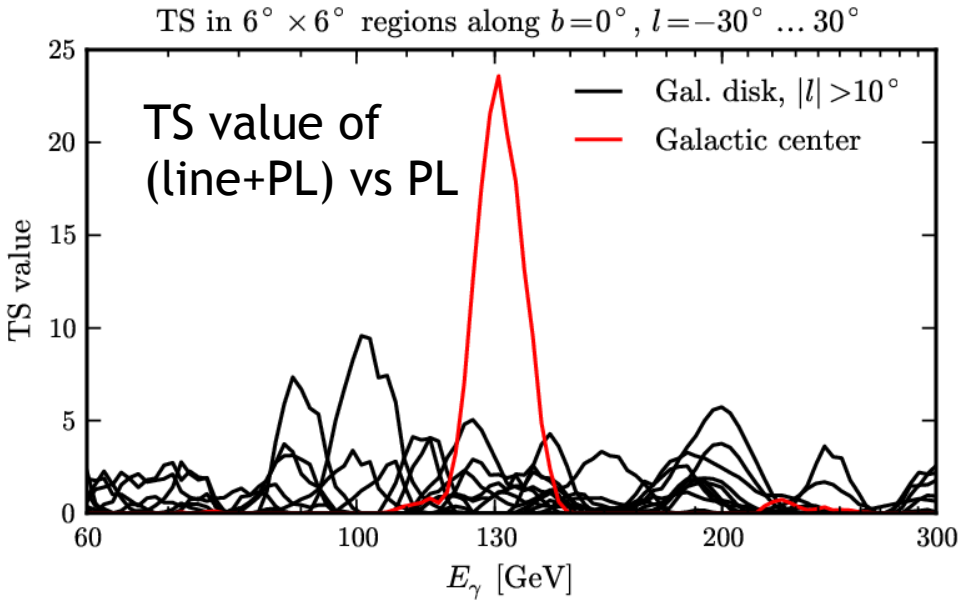
Line: TS = 21.4

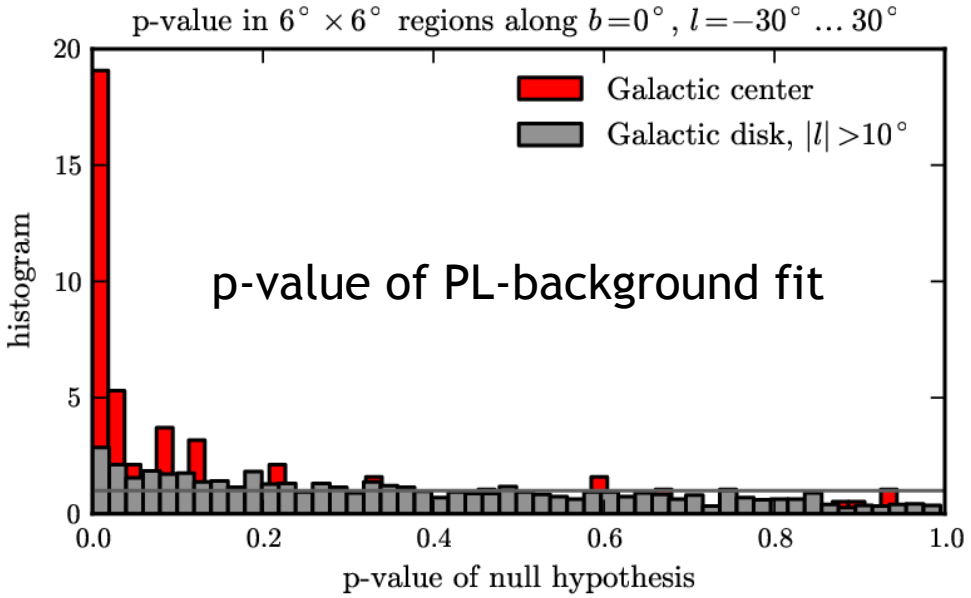
ICS from monoenergetic electrons: TS ~ 12

At Galactic center only

Scan along the galactic disk:

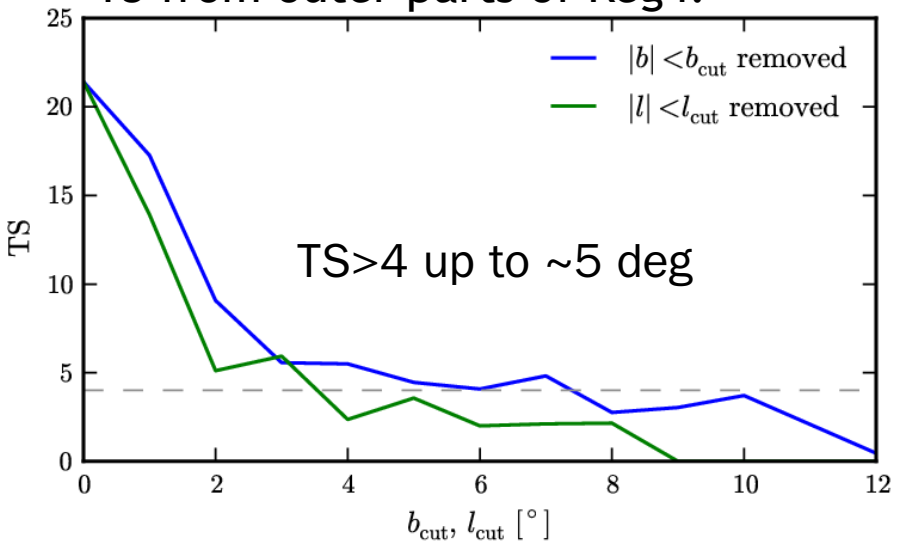




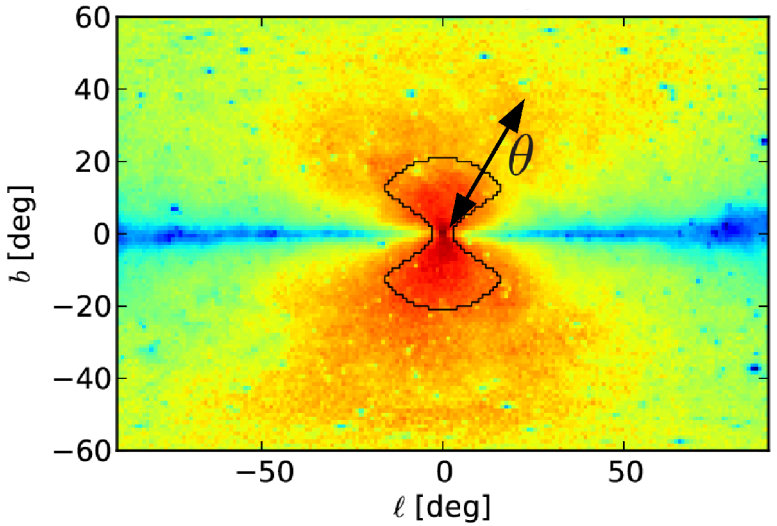


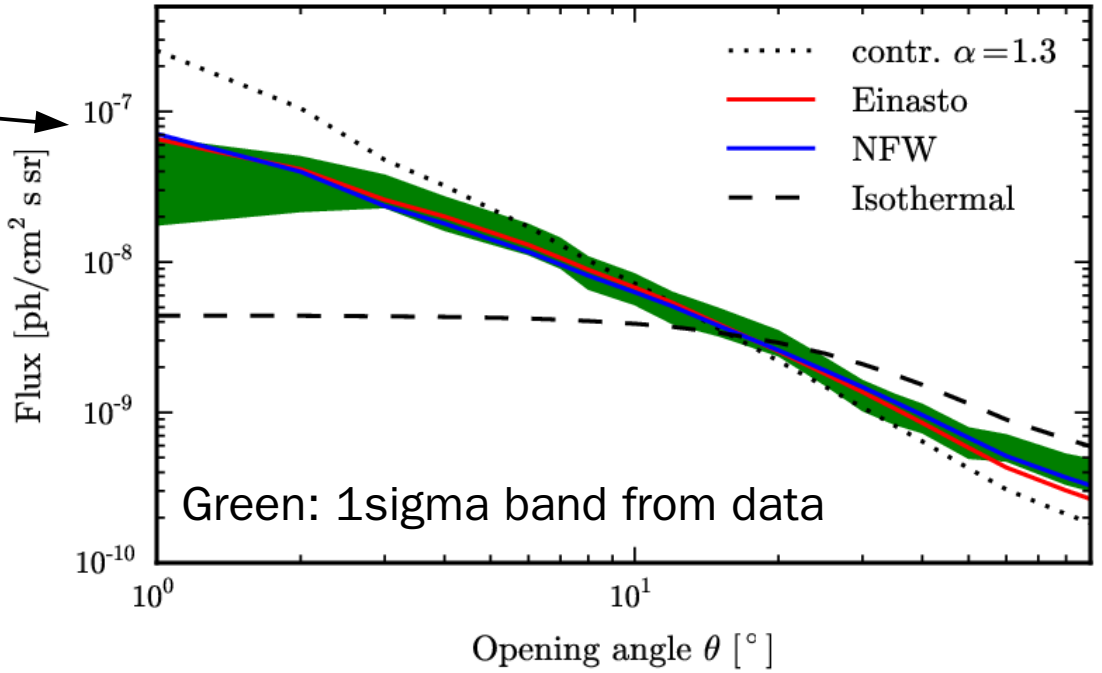
Spatially extended

TS from outer parts of Reg4:

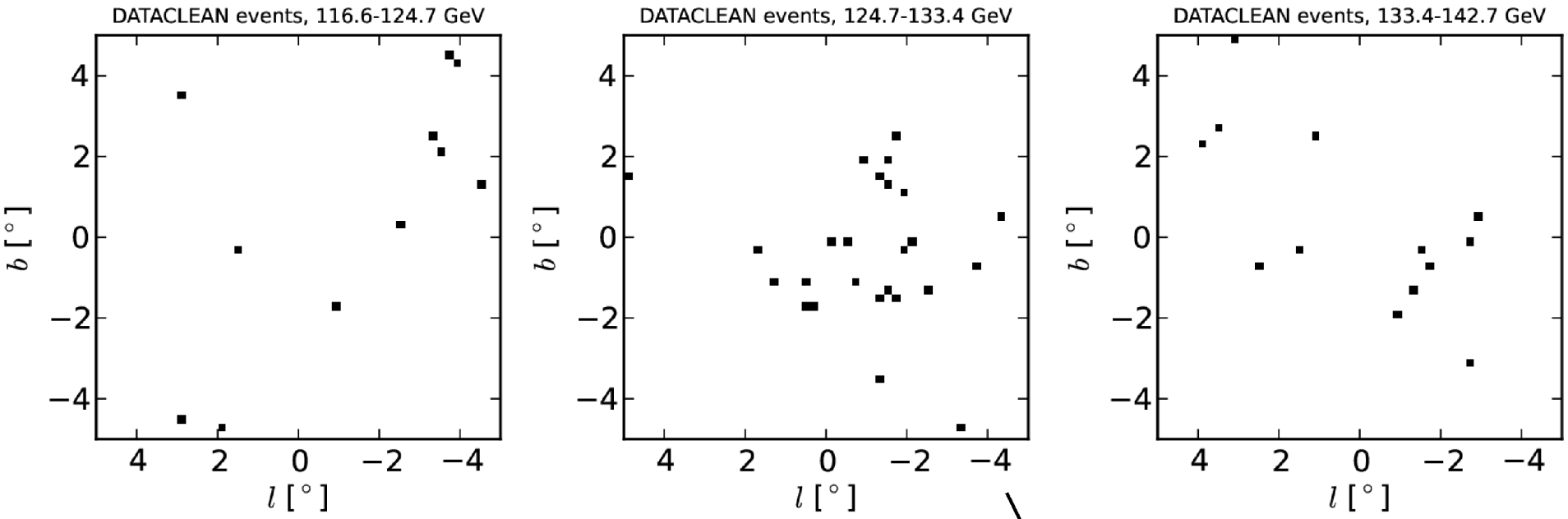


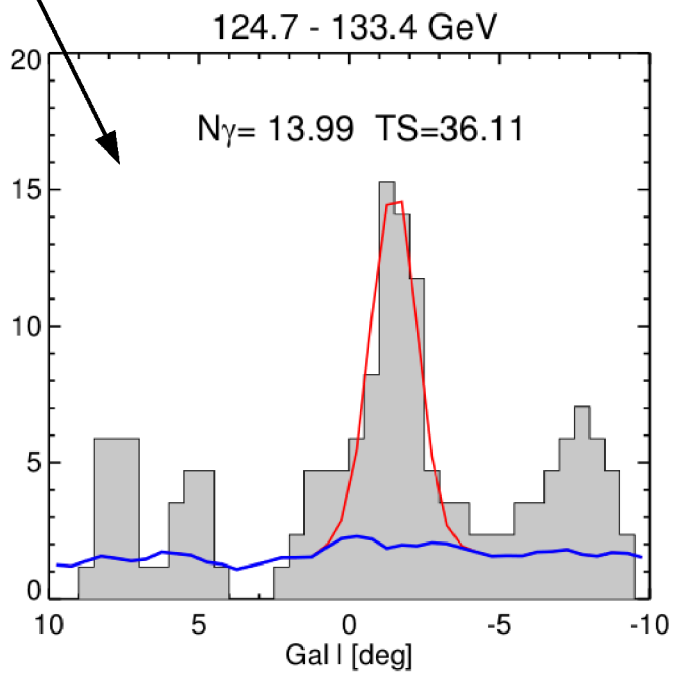
Target region with variable size:





Displaced from the Galactic Center

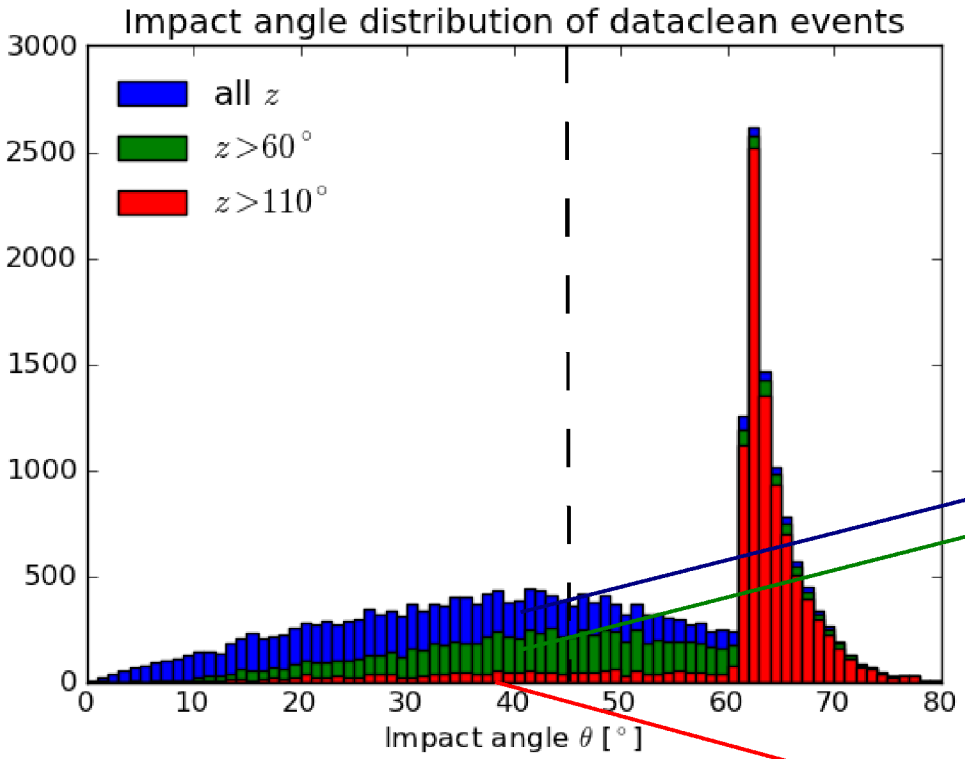


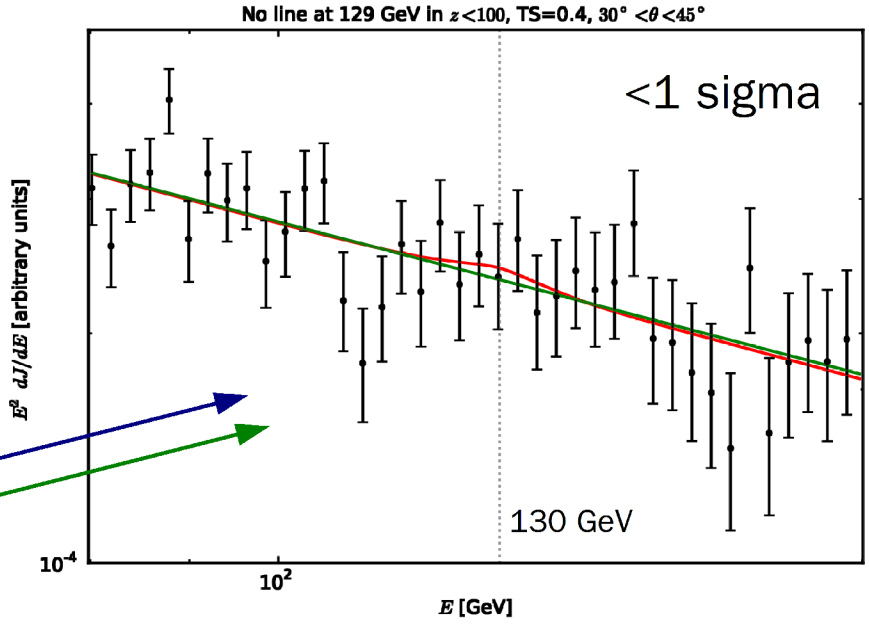


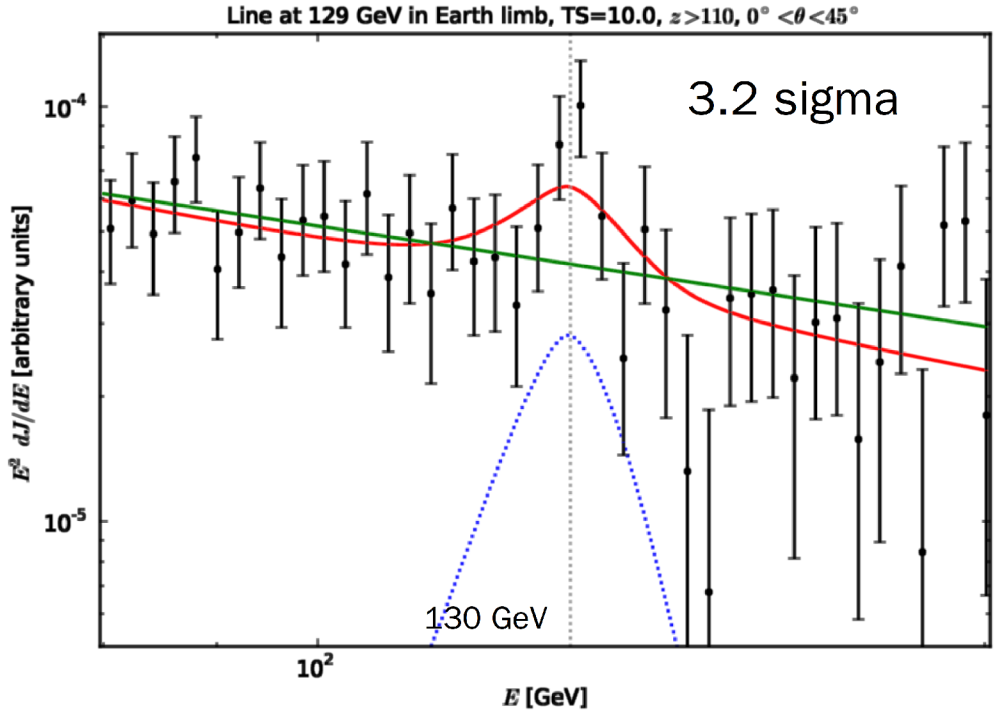
Photons responsible for high TS appear to be significantly displaced by O(100pc) (if GC is origin).

[Su/Finkbeiner 2012]

Instrumental indications?







A 130 GeV line in low impact angle events from the earth atmosphere:
- statistical (comes with a large trial factor)?
- systematic (why only there and at the GC)?

Conclusions

- Fermi-LAT data contains a significant excess of ~130 GeV events close to the Galactic center
- The signature is:
  - extended (at least ~5 deg)
  - significant (4.6sigma before trials)
  - consistent with monochromatic photons at 130 GeV
  - consistent with morphology of a dark matter annihilation signal
- The signature is very local in the sky. Bumps in effective area & problems with energy reconstruction should naively affect larger regions.

- It is imperative to follow this up:
  - More LAT data (Pass8, changed observational strategy, albedo run)
  - Study of instrumental effects
  - HESS-II, GAMMA-400, CTA, ...

Thank you