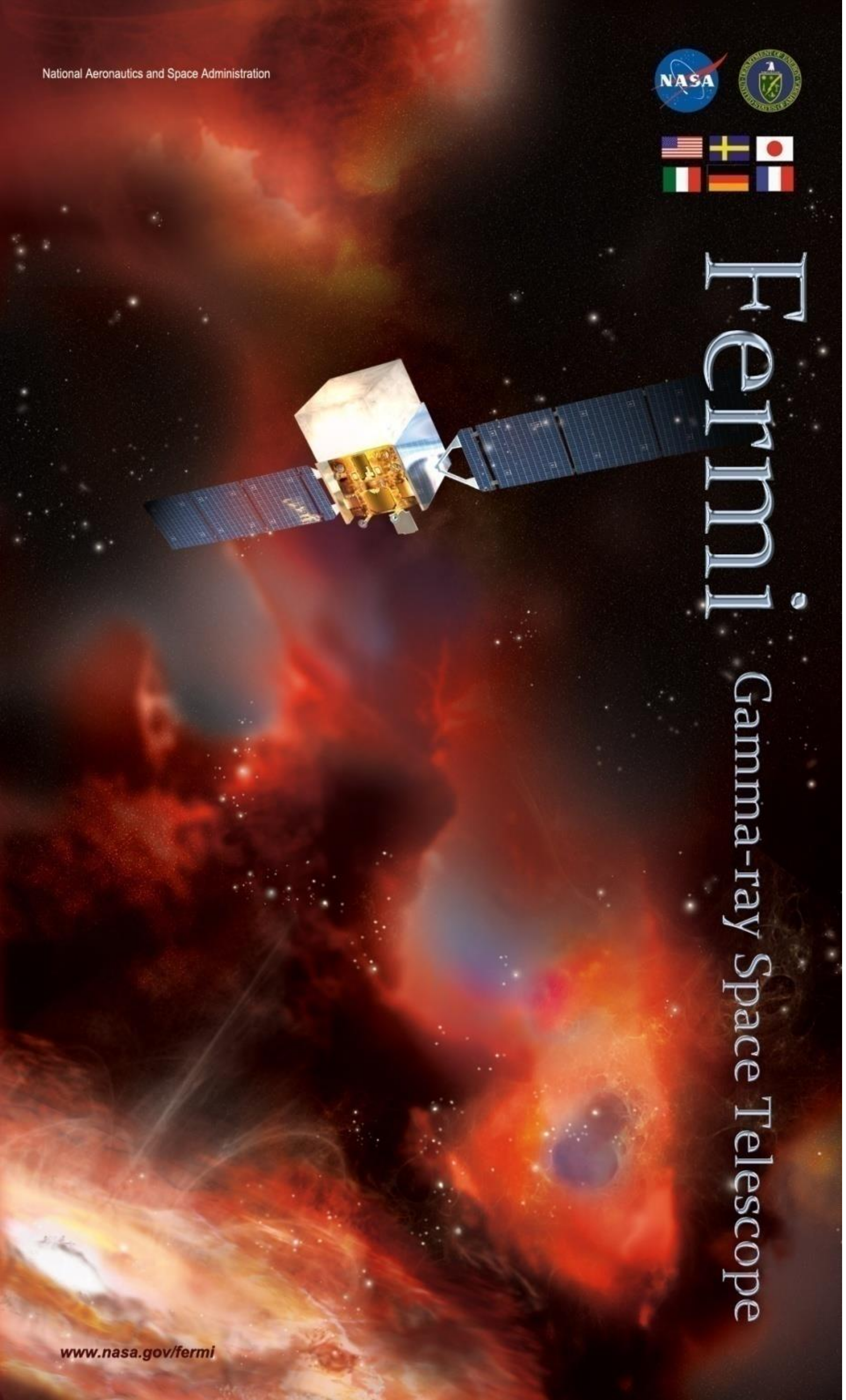

Search for features in the cosmic-ray electron and positron energy spectra

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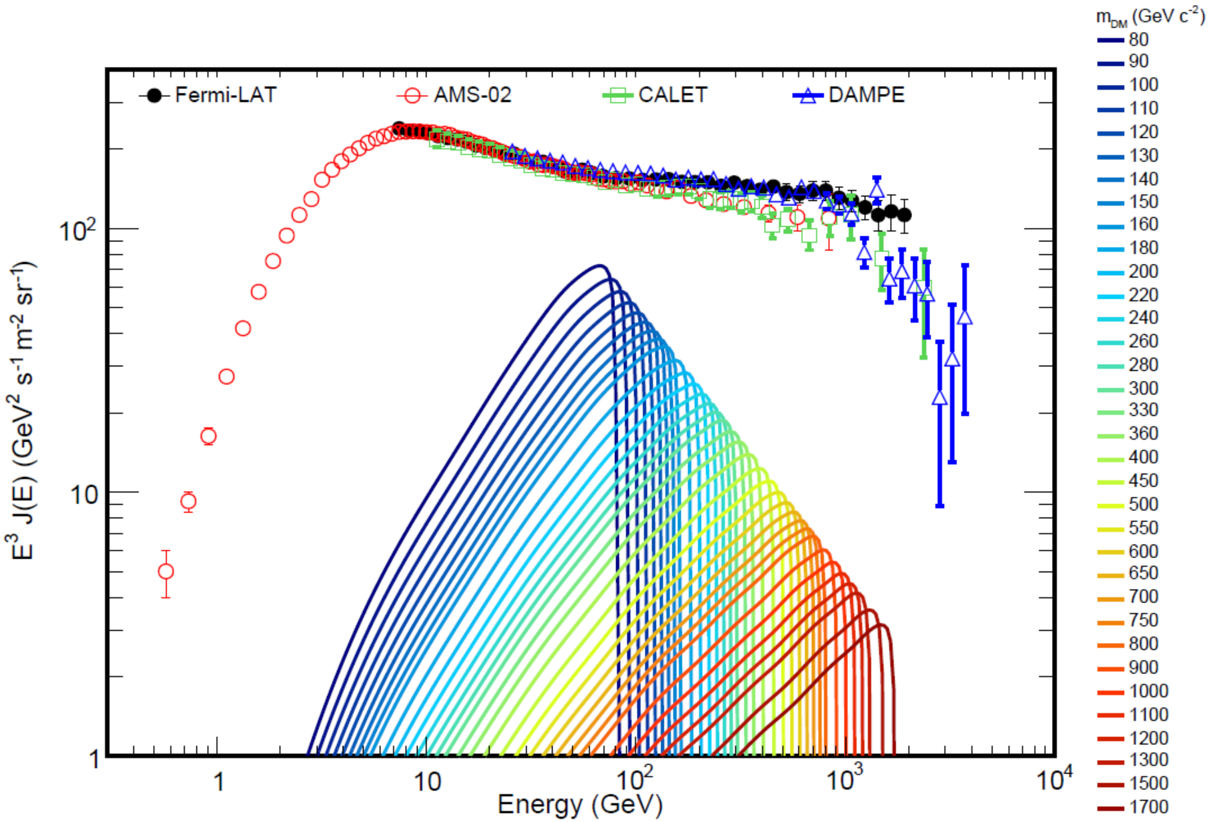
Outline

- The Fermi LAT is also a detector of cosmic-ray electrons and positrons (CREs)
  - We analyzed the CRE data sample collected by the LAT between August 4, 2008 and June 24, 2015 with E>42 GeV
  - 15M CRE events, 4.68 years live time
  - More details in PRD 95, 082007 (2017)
- Search for features in the CRE energy spectra
  - Analysis of Galactic CREs
    - Search for features from DM annihilations
    - Search for possible line features
      - not discussed here, see PRD 98, 022006 (2018)
  - Analysis of CREs from the Sun
    - Search for box-like and line-like features from DM annihilations
      - Box-like features from DM annihilations into light long-lived mediators decaying into CREs outside the Sun
      - Line-like features from DM annihilating into CREs outside the Sun

CREs from dark matter annihilations in the Milky Way

- DM particles in the Milky Way halo can directly annihilate into electron-positron pairs in the process:
  - $\chi\chi \to e^+e^-$
- The CRE energy spectra at Earth from DM annihilations depend on:
  - Dark matter mass m_χ and velocity-averaged DM annihilation cross section $\langle\sigma v\rangle$
    - Production yields evaluated following the prescriptions of Cirelli et al. [JCAP 1103, 051 (2011)]
  - DM density profile in the Galaxy
    - NFW profile with $\rho_\odot = 0.4\ GeV/cm^3$
  - Propagation of CREs in the Galaxy ➔ diffusion parameters
    - Calculation performed using the 3D version of DRAGON2
    - Diffusion parameters chosen to reproduce the B/C ratio measured by AMS-02 (details in PRD 98, 022006)
  - Propagation of CREs in the Solar system
    - Solar modulation described with the force-field approximation
    - Modulation potential $\varphi = 0.55 GV$
- CRE spectra at Earth expected to exhibit an edge-like feature at $E = m_\chi$

CRE spectra at Earth from DM annihilations in the Galaxy



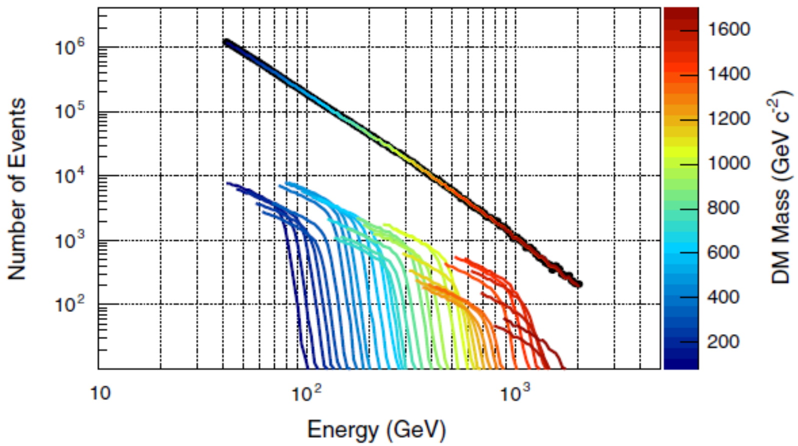
- **CRE spectra evaluated with** $\langle\sigma v\rangle = 3 \times 10^{-25} cm^3 s^{-1}$
- **DM spectra are compared with the overall CRE spectra measured by different experiments**

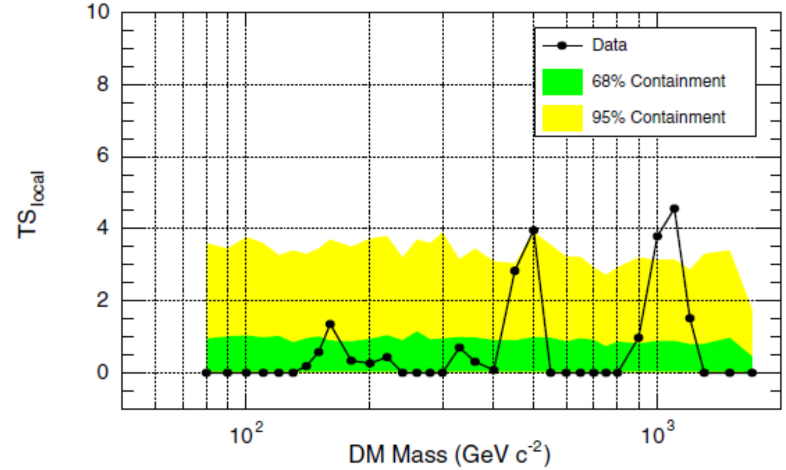
Fermi LAT data analysis

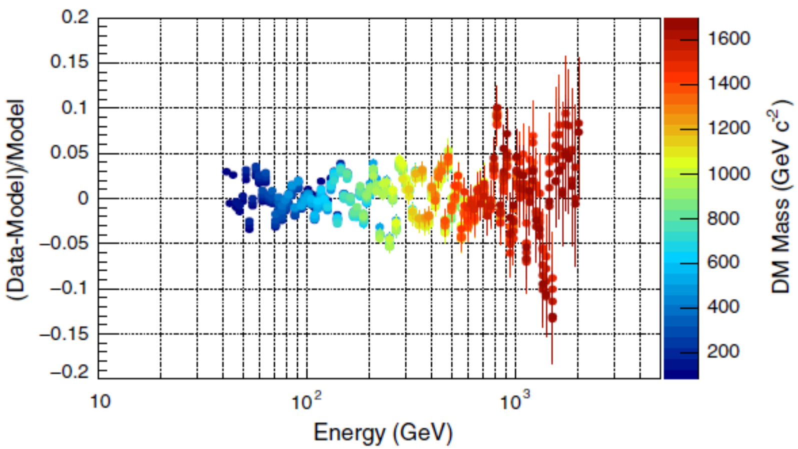
- Fit in sliding energy windows from 42 GeV to 2 TeV
  - The width of each window is $w = 0.5E_w$
- Spectral model: $I(E) = I_0(E) + I_f(E)$
  - Smooth component: $I_0(E) = k\left(\frac{E}{E_0}\right)^{-\gamma}$ $(E_0 = 1GeV)$
    - Parameters to be fitted: k, γ
  - Possible feature: $I_f(E) = sI_{DM}(m_\chi, \langle\sigma v\rangle_0, \dots)$
    - Parameter to be fitted: s (intensity of the feature)
    - $s = \langle\sigma v\rangle / \langle\sigma v\rangle_0$
      - $\langle\sigma v\rangle_0 = 3 \times 10^{-26} cm^3 s^{-1}$ is the reference cross section
- Fit procedure:
  - We minimize a χ^2 function: $\chi^2 = \sum_{j=1}^{N} \frac{(n_j - \mu_j)^2}{n_j + f_{syst}^2 n_j^2}$
    - n_j and μ_j are the observed and predicted counts in the j-th bin
    - f_{syst} takes systematic uncertainties into account
      - f_{syst} evaluated from the data
- Sensitivity and global significance of the fits evaluated with the pseudo-experiment technique
  - Simple power-law template in the whole energy range

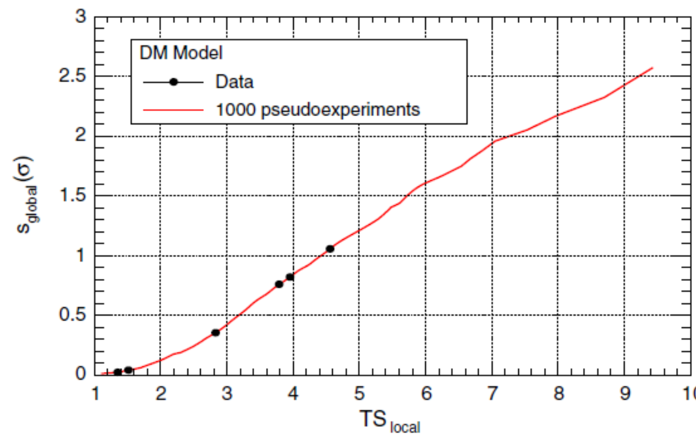
Search for DM signatures in the spectrum of galactic CREs

Possible DM features are not significant

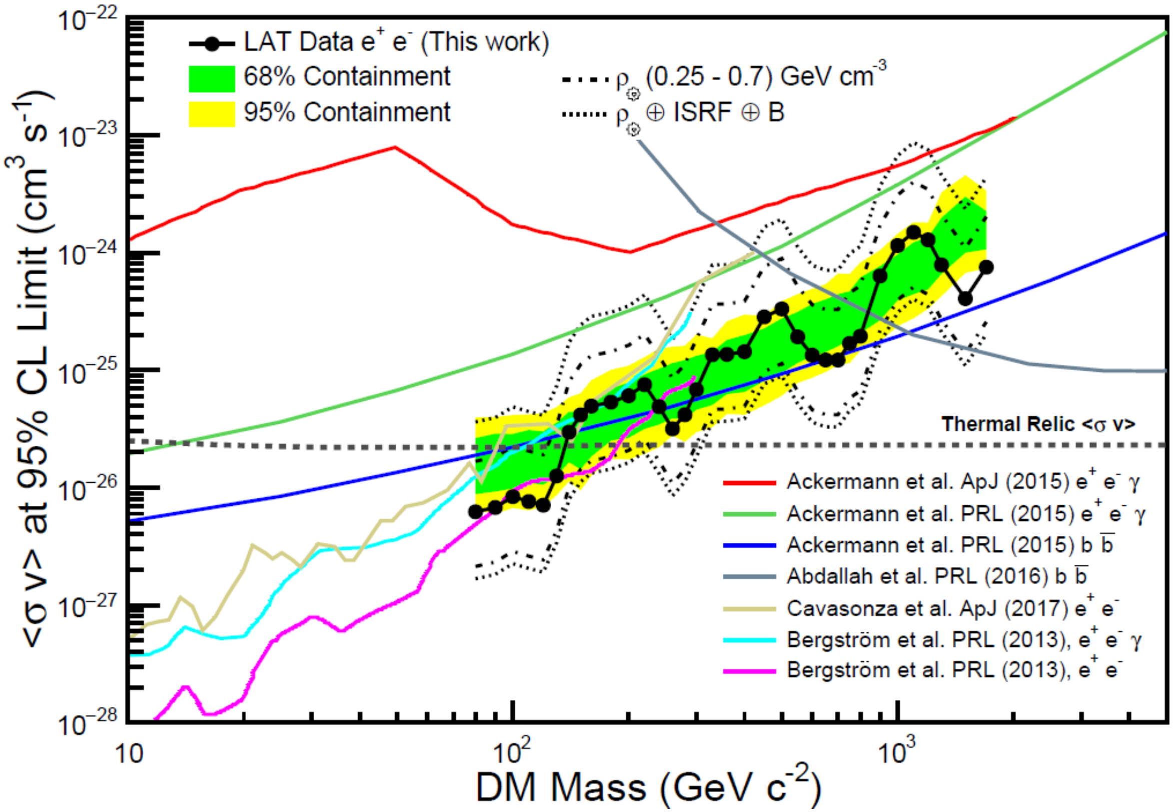








Upper limits on the velocity-averaged DM annihilation cross section

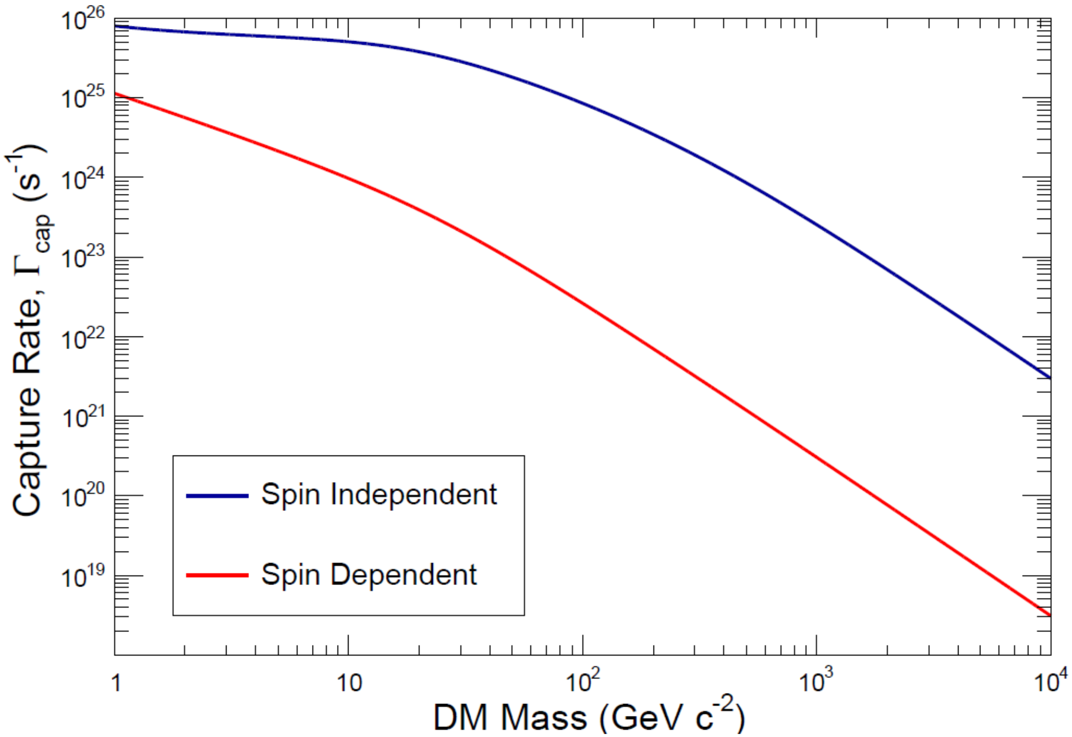


- **Limits on the strength of the feature are converted into limits on $\langle \sigma v \rangle$**
  - **Limits scale as $\rho_{\odot}^{2}$**
  - **Dependence on the interstellar radiation field and on the galactic magnetic field**
- **Constraints in agreement with previous results**

The Sun as a target for DM searches with cosmic-ray electrons

- DM particles from the galactic halo can be gravitationally trapped by the Sun through scattering interactions with the nuclei in the solar environment
- Two possible scenarios for CRE productions:
  - DM particles captured in external orbits annihilate outside the Sun into e^+e^- pairs which can reach the Earth
    - DM particles lose energy through inelastic scatterings with solar nuclei
    - Annihilations at rest: $\chi\chi \rightarrow e^+e^-$
    - Line-like feature in the CRE energy spectrum at $E = m_\chi$
  - DM particles sink in the solar core, annihilate into pairs of long-lived mediators ϕ escaping from the Sun and decaying into e^+e^- pairs which can reach the Earth
    - DM particles slowed through elastic scatterings with solar nuclei
    - Annihilations at rest: $\chi\chi \rightarrow \phi\phi$
    - Mediators exit from the Sun and decay: $\phi \rightarrow e^+e^-$
    - Box-like feature in the energy spectrum with upper edge at $E = m_\chi$
- In both cases a feature is expected on the top of a smooth spectrum
- Similar scenarios for gamma rays (see D. Serini's talk)

Mediator scenario: DM capture rate

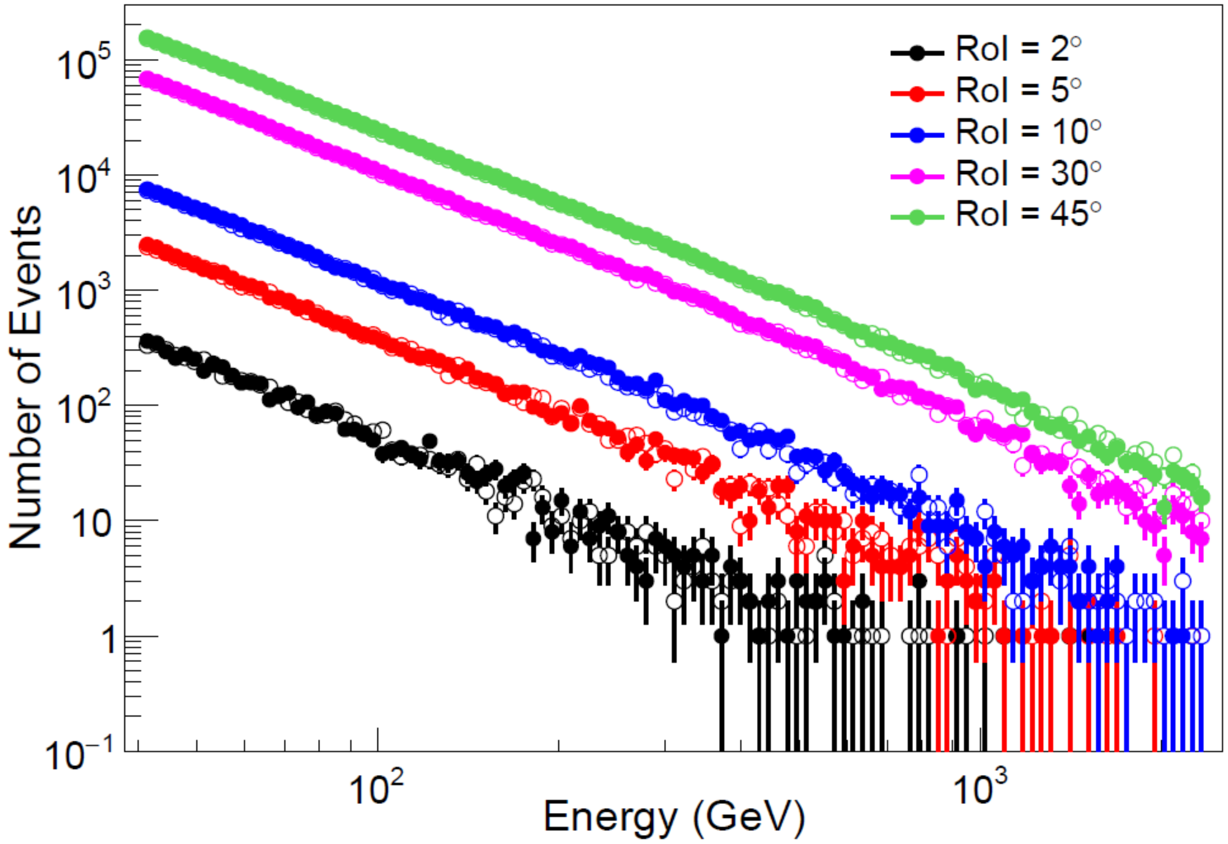


- **Evaluated with DARKSUSY 6.1.0 assuming default settings**
  - **local DM density $\rho_{\odot} = 0.3\ GeV/cm^3$**
  - **Maxwellian velocity distribution with $v_{\odot} = 220\,km/s$ and $v_{rms} = 270\,km/s$**
  - **DM-nucleon cross section $\sigma = 10^{-40}cm^2$**

Fermi LAT data analysis

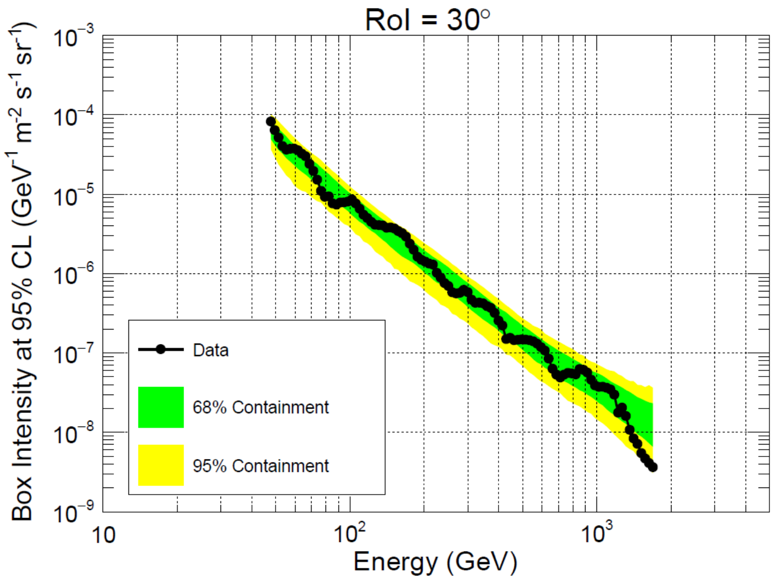
- Combined analysis of the data from two regions:
  - Signal region centered on the Sun
  - Control region centered on the Anti-Sun
  - Analysis performed with RoIs of different radii, from 2° to 45°
- Analysis performed in sliding energy windows
  - The width of each window is $w = 0.35E_w$
- Spectral models:
  - $I_S(E) = I_0(E) + I_f(E)$
  - $I_B(E) = I_0(E)$
  - Smooth component: $I_0(E) = k\left(\frac{E}{E_0}\right)^{-\gamma}$
  - Feature: $I_f(E) = s\delta(E_w - E)$ or $I_f(E) = s\Theta(E_w - E)$
- Fit procedure:
  - We minimize a χ^2 function: $\chi^2 = \sum_{j=1}^{N}\left[\frac{\left(n_j^S-\mu_j^S\right)^2}{n_j^S+\left(f_{syst}n_j^S\right)^2} + \frac{\left(n_j^A-\mu_j^A\right)^2}{n_j^A+\left(f_{syst}n_j^A\right)^2}\right]$
    - n_j^S, n_j^A and μ_j^S, μ_j^A are the observed and predicted counts in the j-th energy bin
    - f_{syst} takes systematic uncertainties into account
- Sensitivity and global significance of the fits evaluated with the pseudo-experiment technique
  - Simple power-law template in the whole energy range

CRE count spectra

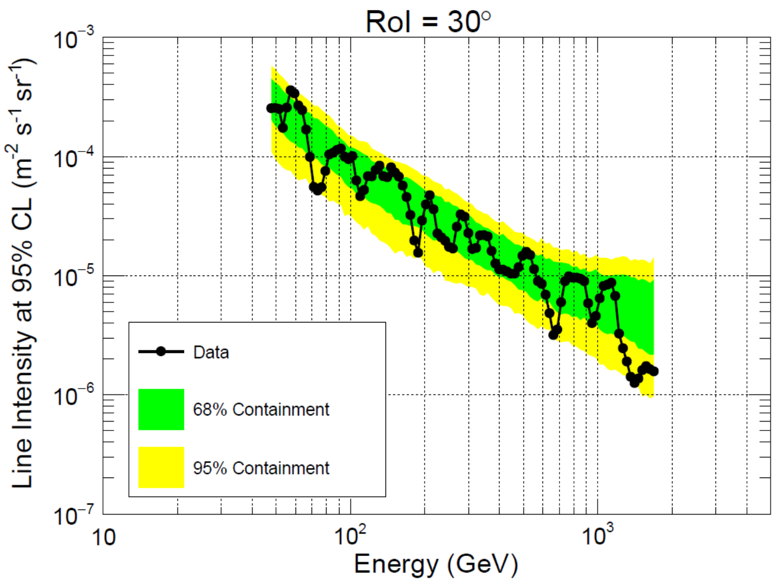


- **Full markers = signal region**
- **Open markers = control region**

Box-like features

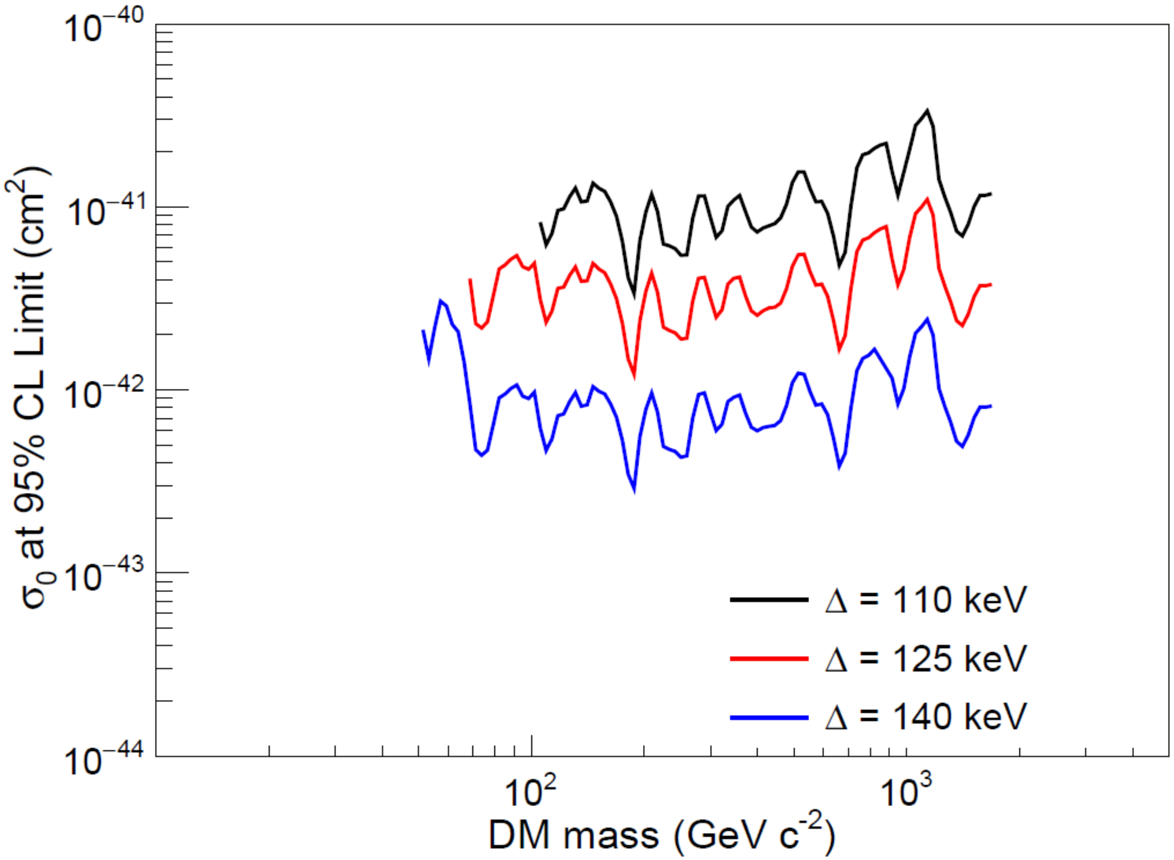


Line-like features



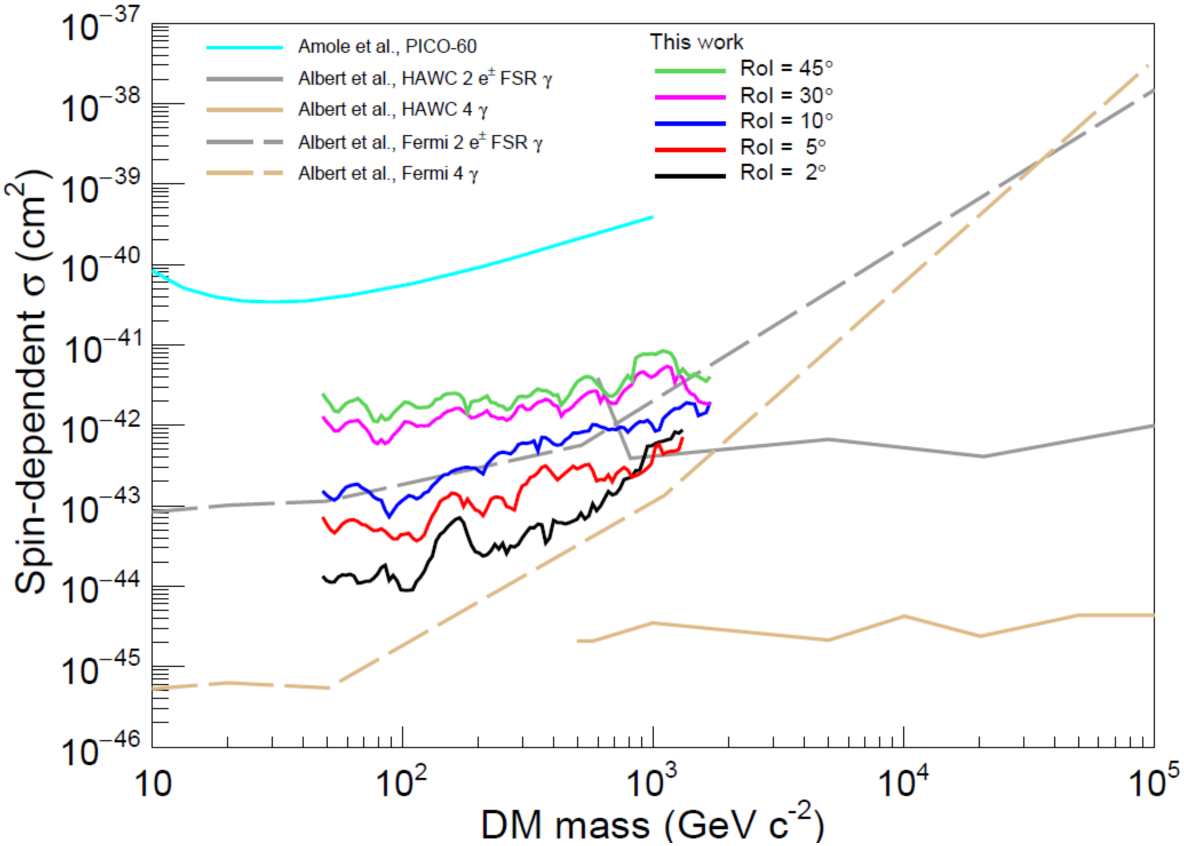
- **No evidence of features**
- **All locally significant possible features turn out to be globally insignificant**

Limits on the DM-nucleon inelastic scattering cross section



- Limits on the intensity of the line-like features are converted into limits on the inelastic scattering cross section for the process $\chi + N \rightarrow \chi^* + N$
- Limits depend on the mass splitting $\Delta = m_{\chi^*} - m_\chi$

Limits on the DM-nucleon elastic scattering cross section



- **Limits on the intensity of the box-like features are converted into limits on the elastic scattering cross section for the process $\chi + N \rightarrow \chi + N$**
- **Constraints are consistent with the results from other experiments and other channels**

Conclusions

- We have studied the energy spectra of CREs measured by the Fermi LAT
  - Analysis of galactic CREs
  - Analysis of CREs from the Sun
- All analyses yield no evidence of possible DM signals
- Constraints consistent and competitive with results from other experiments and from gamma-ray analyses
- For further details:
  - M. N. Mazziotta et al., "Search for features in the cosmic-ray electron and positron spectrum measured by the Fermi Large Area Telescope", Phys. Rev. D98 (2018), 022006
  - A. Cuoco et al., "Search for dark matter cosmic-ray electrons and positrons from the Sun with the Fermi Large Area Telescope", Phys. Rev. D101 (2020), 022002