Analysis of CALET Data for Anisotropy in Electron+Positron Cosmic Rays

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Introduction

In recent years, the precision of measurements of the electron+positron cosmic-ray spectrum has increased significantly, with space based direct measurements by CALET [1, 2] and DAMPE [3] reaching into the TeV energy region, which is expected to be dominated by very nearby supernova remnants (SNR), since radiative energy loss limits the propagation distance of electron cosmic rays reaching Earth at TeV energy to less than one kiloparsec (kpc) [4]. Detecting a signature of cosmic-ray acceleration in the nearby SNR is a physics goals of CALET [5], based on both the search for a dipole anisotropy [6] as well as spectral information. The preliminary analysis presented here aims at establishing the methods before testing for actual signtures based on flight data with higher statistics and refined understanding of systematics.

Summary

- The analysis of CALET data from about three years of flight data yields results on the dipole magnitude agreeing to what is expected from statistical fluctuations of an isotropic electron+positron cosmic-ray flux.
- These preliminary results set limits on the dipole anisotropy in the TeV region, not yet explicitly covered by other experiments.

Outlook

- A significant anisotropy could exist at TeV energy from electrons accelerated by the Vela SNR for standard emission and propagation conditions meeting the recently tightening experimental constraints.
- This presents a target for further measurements of CALET and future analyses with increased flight data statistics and refined methods potentially combining spectral and anisotropy information to enhance sensitivity.

References

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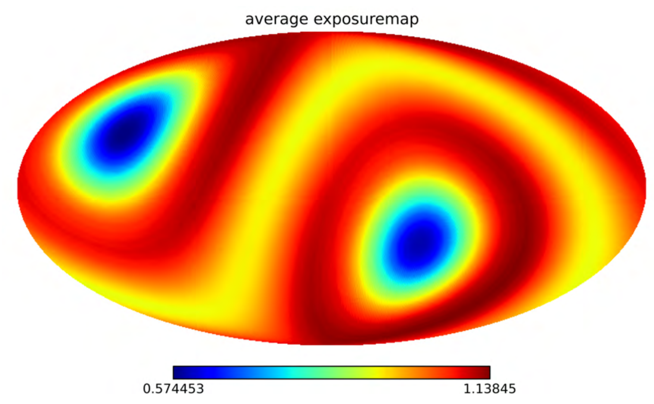
Data Sample, Analysis Method and Exposure Correction

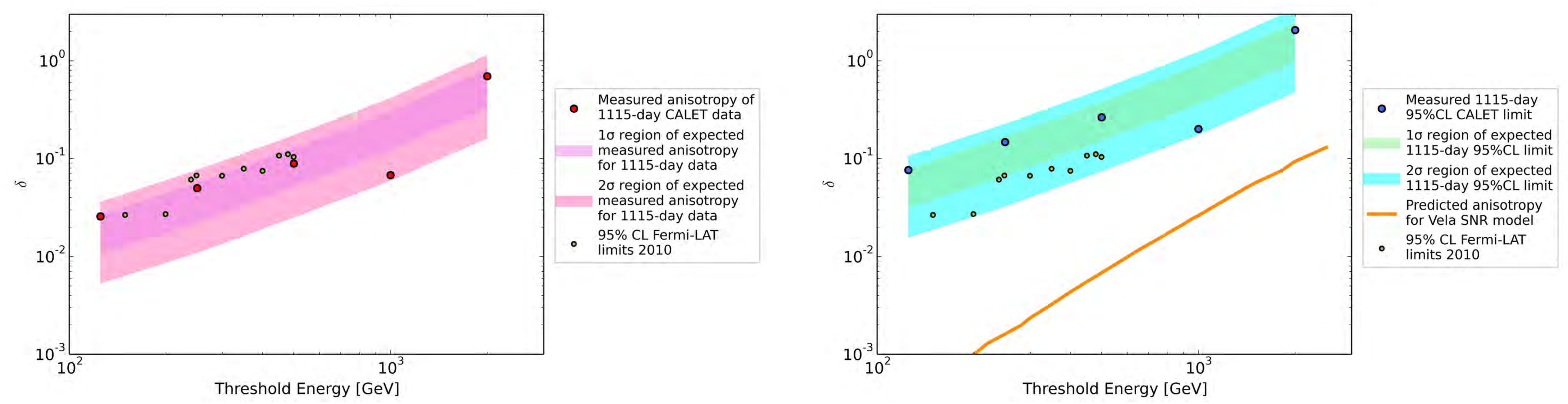
- Data from 2015/10/13 until 2018/10/31 used, 1115 day of observation in total.
- This analysis follows the methods used by Fermi-LAT collaboration in Ref. [7].
- Electron candidate events above threshold energy (125 GeV - 2 TeV , doubled in each step) are filled into HEALPix [8] maps in galactic coordinates.
- Multipole coefficients C_l for monopole (C_0), dipole (C_1), quadrupole (C_2) and octupole (C_3) are calculated with HEALPix anafast routine.
- Dipole amplitude $\delta = 3\sqrt{\frac{C_1}{C_0}}$; for a dominating dipole $\delta \approx \frac{\Phi_{max}-\Phi_{min}}{\Phi_{max}+\Phi_{min}}$.
- The Nnon-uniformity of the exposure to the sky (example exposure map to the right) is compensated by weighting each event with the inverse of the exposure for its direction, energy and event classification [2], normalized to the total exposure.



Averaged and normalized exposure map for 1 TeV threshold energy.

Main Result: Measured Dipole Anisotropy and Limits

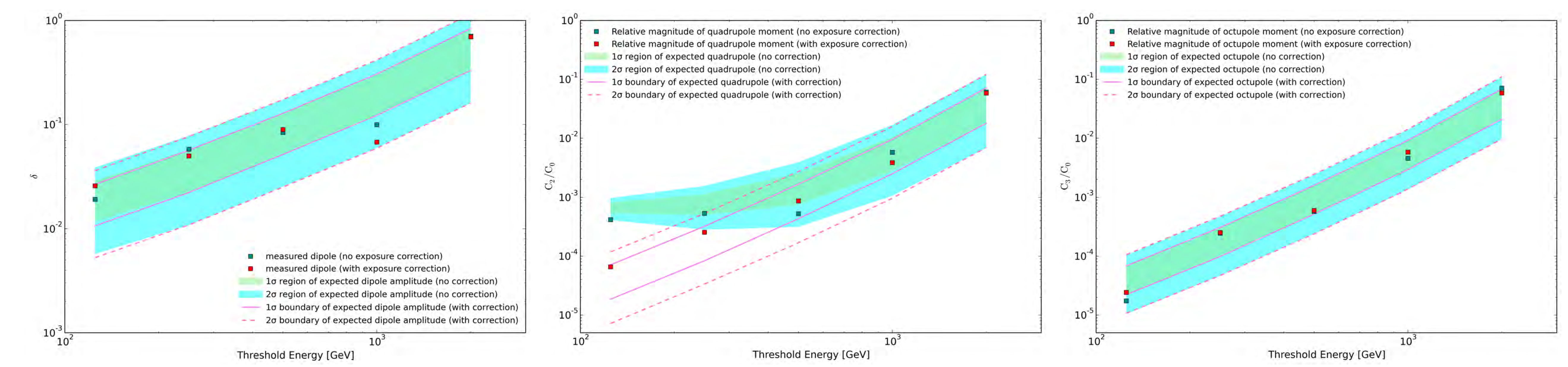
The measured dipole anisotropy and resulting 95% CL limits for the selected threshold energies fall within the 2-σ boundary of the expectation for statistical fluctuations of an isotropic cosmic-ray flux.



Measured and expected dipole anisotropy (left) and 95% CL limit (right), compared to limits by Fermi-LAT [7] and Vela SNR model.

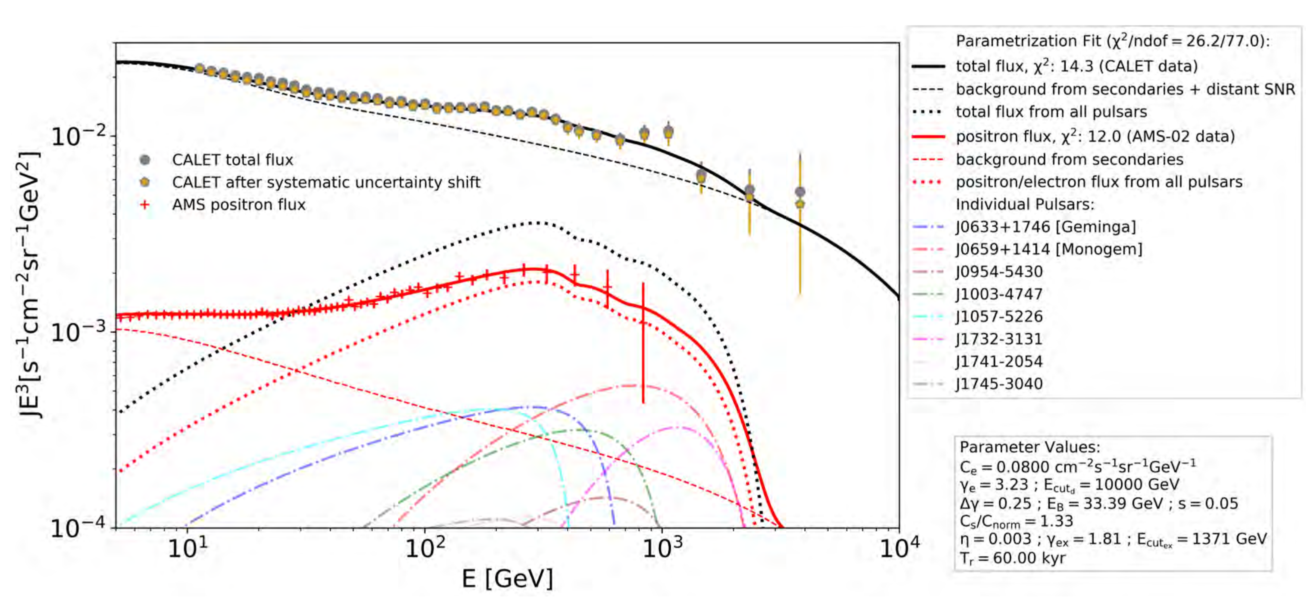
Higher Multipole Moments and Effect of Exposure Correction

The quadrupole moment showns the influence of the exposure correction since the non-uniformity of the exposure is quadrupole-shaped. This is detected at low energy as expected and successfully compensated by the correction.
The octupole moment is not influenced by the exposure correction and results are in the expectation range.



Measured and expected dipole amplitude; quadrupole, octupole moments (from left to right), with and without exposure correction.

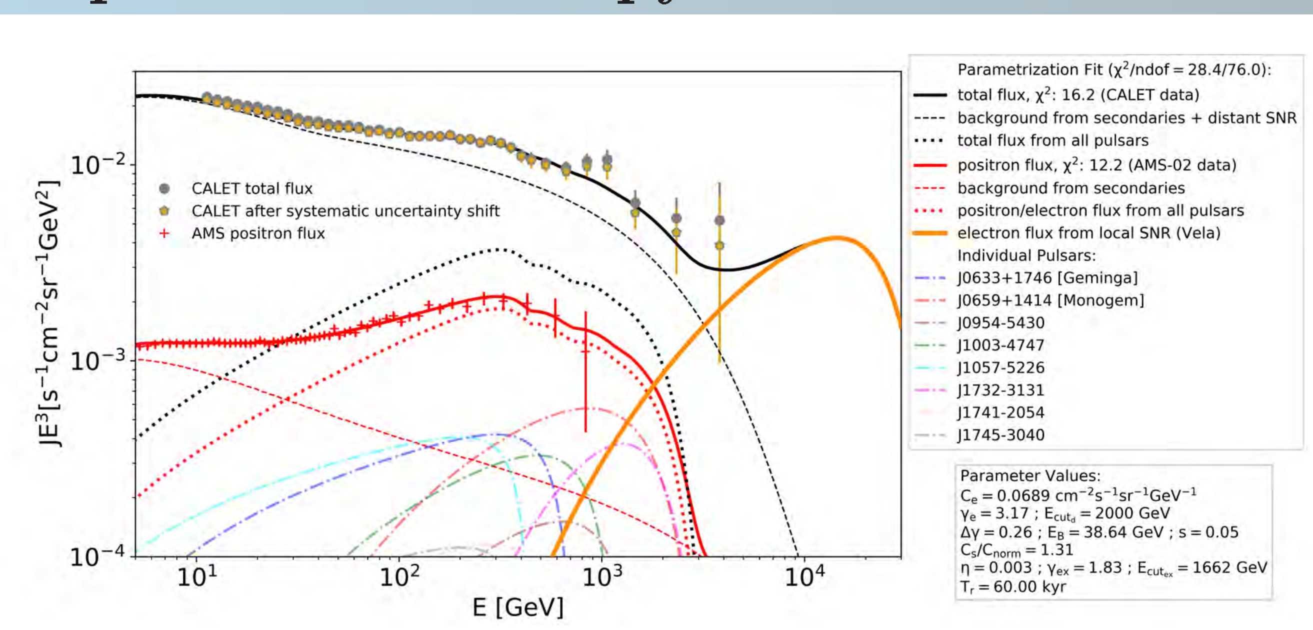
Model for Isotropic Flux and Calculation of Expectation Ranges



Model for isotropic flux estimation fitted to CALET [2] electron+positron and AMS-02 [9] positron-only data.

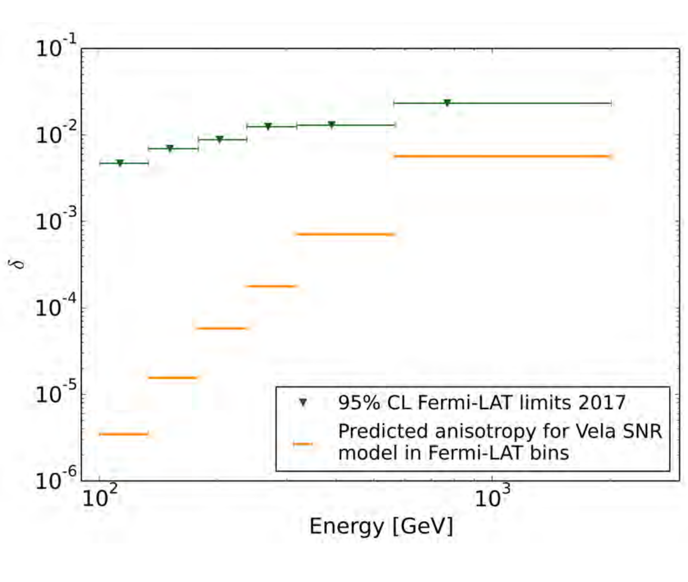
For flux estimation, a model for electron and positron spectra combining direct parametrization (primary electrons as power law with a soft spectral break at low energy and high energy cutoff) with analytical (for the multi pulsar source of the positron excess) and numerical propagation calcualtion with DRAGON [10] (constraint of propagation parameters by nuclei spectra, secondary electrons and positrons) is used.
The predicted number of events from the model is distributed as a flat healpix map, which is multiplied with the exposure map before the random event number in each pixel is assigned following the Poisson distribution. For each threshold energy, 20000 samples are created and analyzed in the same way as the flight data, yielding the expectation bands in the figures above.

Expected Anisotropy from the Vela SNR



Modification of above model with the Vela SNR as a distinct source for which the expected anisotropy is calculated with DRAGON.

The Vela SNR is modelled as a point source with an exponentially cut-off power-law injection spectrum with index γ_i = -2.32 and cut-off energy E_c = 100 TeV, with constant emission for 5000 years. The total energy of emitted cosmic-ray electrons with E>1 GeV is normalized to $2.5 \cdot 10^{47}$ erg.



This model is not excluded by Fermi-LAT limits from Ref. [11].