Proton energy spectra of Energetic Storm Particle events and relation with shock parameters and turbulence

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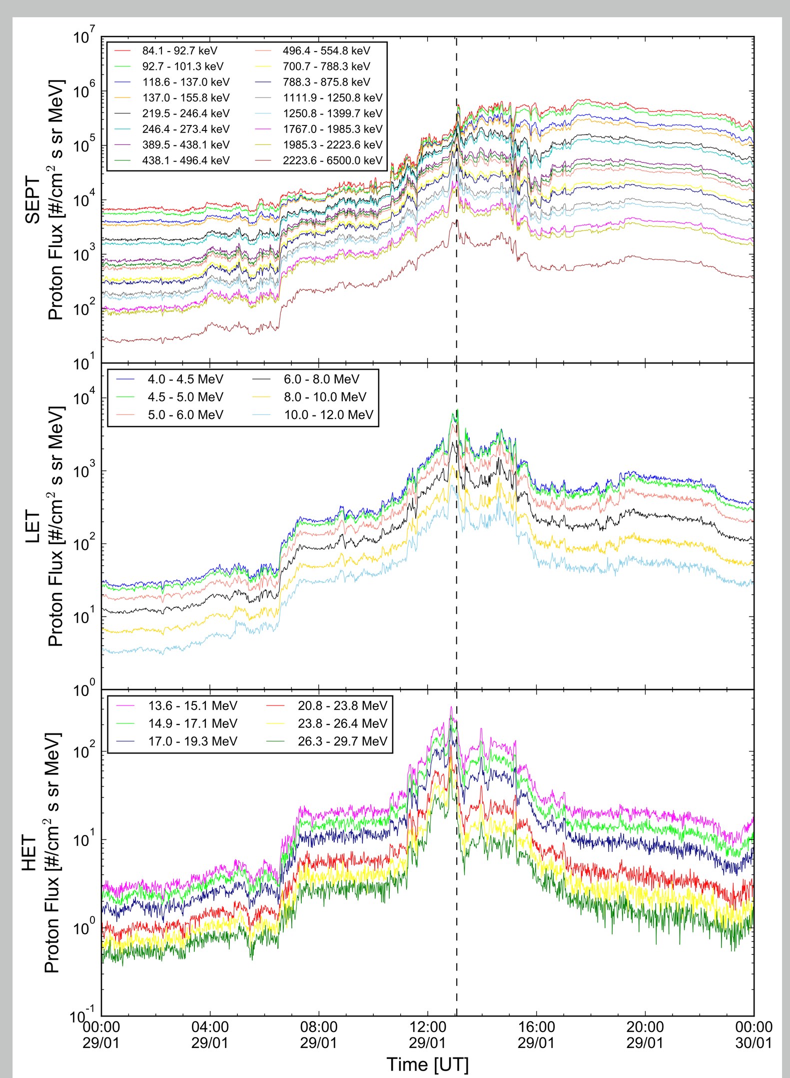
Abstract

- The proton energy spectra of 23 ESP events, occurring either in association with (16 events) or in absence of (7 events) Solar Energetic Particles, are investigated by using data from particle instruments aboard STEREO A in the energy range from 84.1 keV to 100 MeV.
- For the SEP events at quasi-perpendicular shocks, the Weibull distribution provides good fits to the spectra, over the whole energy range for some events, and only at high energies for the others, being lower energies explained by the power law predicted by the DSA.
- The SEP spectra at quasi-parallel shocks are better reproduced by a double power law.
- In the cases not associated with SEPs, an Ellison-Ramaty form fits the observed spectra.
- A significant correlation of the downstream turbulence level is found with the Weibull parameters for quasi-perpendicular shocks, and with the proton peak value in the intermediate energy range 4 – 6 MeV for all the 16 shocks.

Data



Selection of events

We selected only shocks for which an effective enhancement in proton flux is observed at energies 4 – 6 MeV. In order to evaluate the real increase in proton flux, we took a pre-increase (background) value j_b where the solar wind is almost undisturbed and a maximum proton flux value within 3 hours around the shock j_p. If the relative enhancement in proton flux

$$j_n = j_p/j_b$$

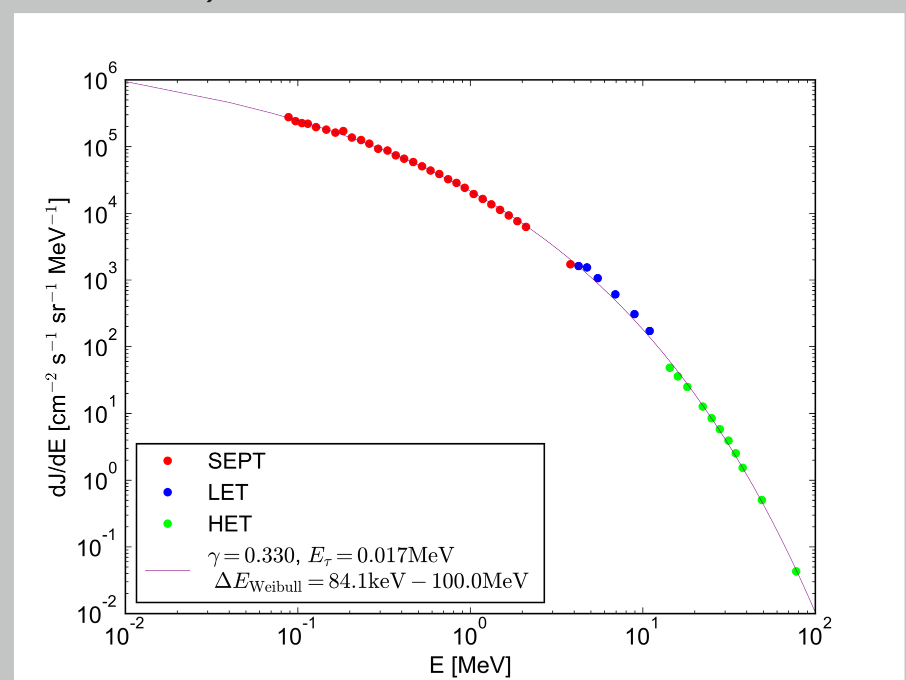
is higher than 1.5, the event is considered as an ESP event.

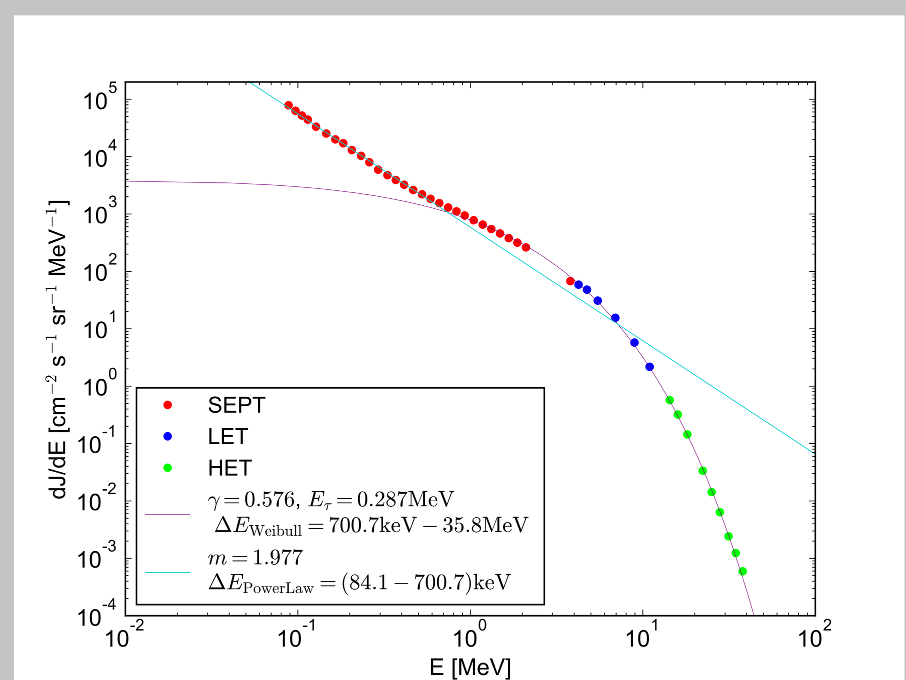
SEP spectra at quasi-perpendicular shocks

For the SEP events at quasi-perpendicular shocks we performed a fit of dJ/dE by using the distribution

$$\frac{dJ}{dE} = C\left(\frac{E}{E_r}\right)^{\gamma-1} E^{1/2} e^{-\left(\frac{E}{E_r}\right)^{\gamma}}$$

derived from the Weibull functional form (Frisch & Sornette, 1997).



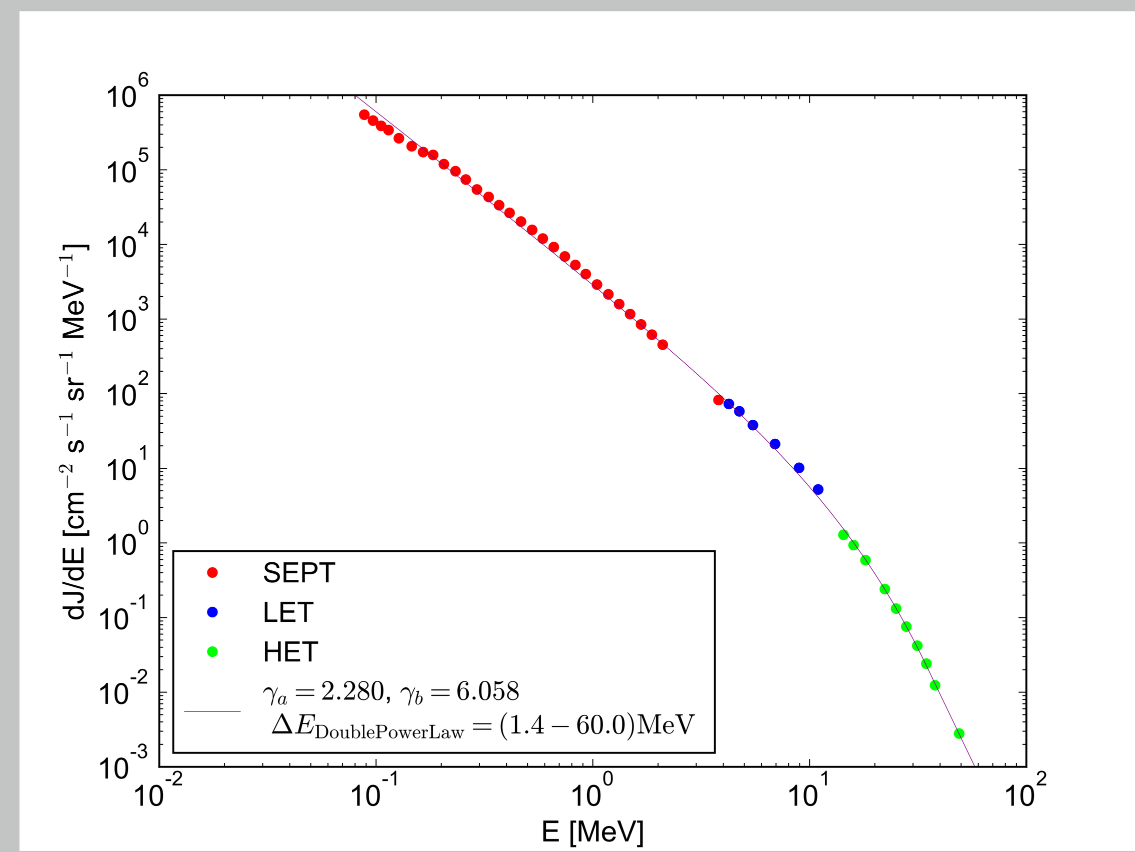


SEP spectra at quasi-parallel shocks

Proton energetic spectra of quasi-parallel events are quite well described by the double power law proposed by Band (1993),

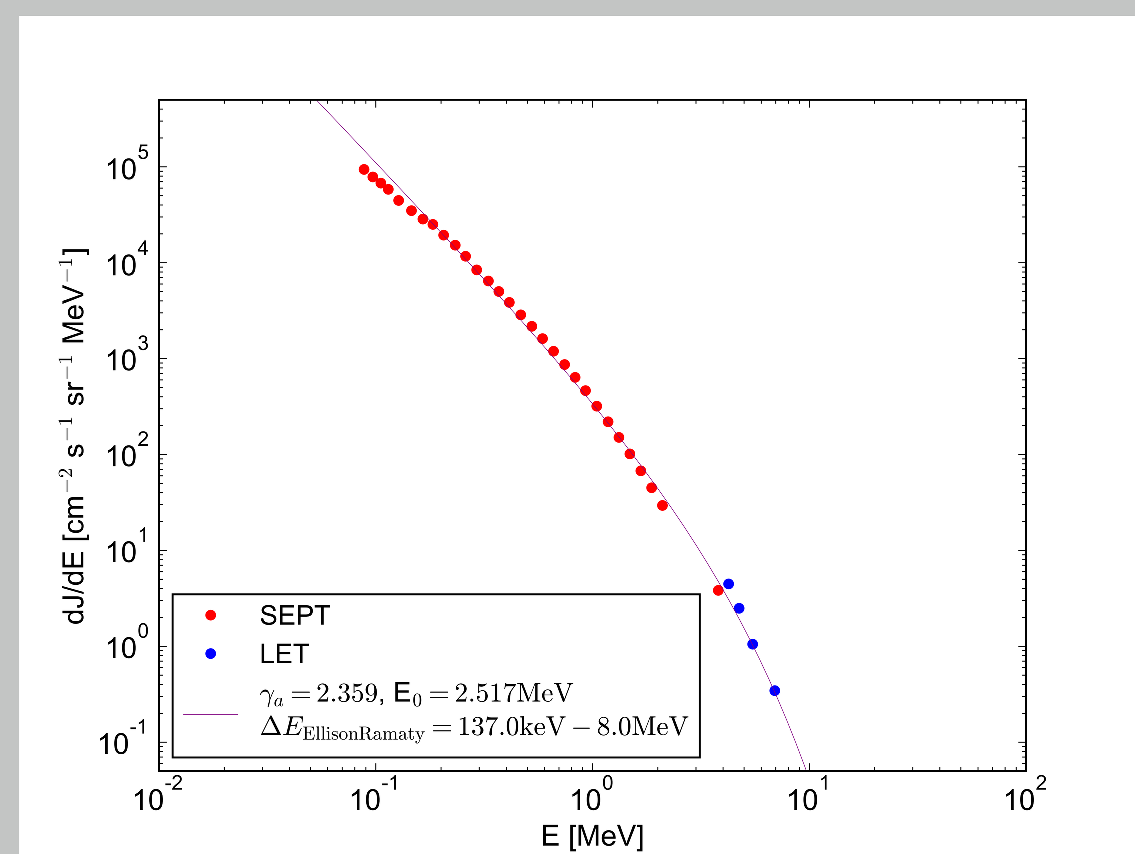
$$\frac{dJ}{dE} = C\,E^{-\gamma_a} e^{-\left(\frac{E}{E_0}\right)} \text{ for } E \le (\gamma_b - \gamma_a)E_0$$

$$\frac{dJ}{dE} = C\,E^{-\gamma_b}\left\{\left[(\gamma_b - \gamma_a)E_0\right]^{(\gamma_b-\gamma_a)} e^{(\gamma_a-\gamma_b)}\right\} \text{ for } E \ge (\gamma_b - \gamma_a)E_0$$



ESP not associated with SEPs

Below the transition energy of the double power law, the trend is equal to the Ellison–Ramaty form (Ellison & Ramaty, 1985) obtained for ESP events not associated with SEPs.

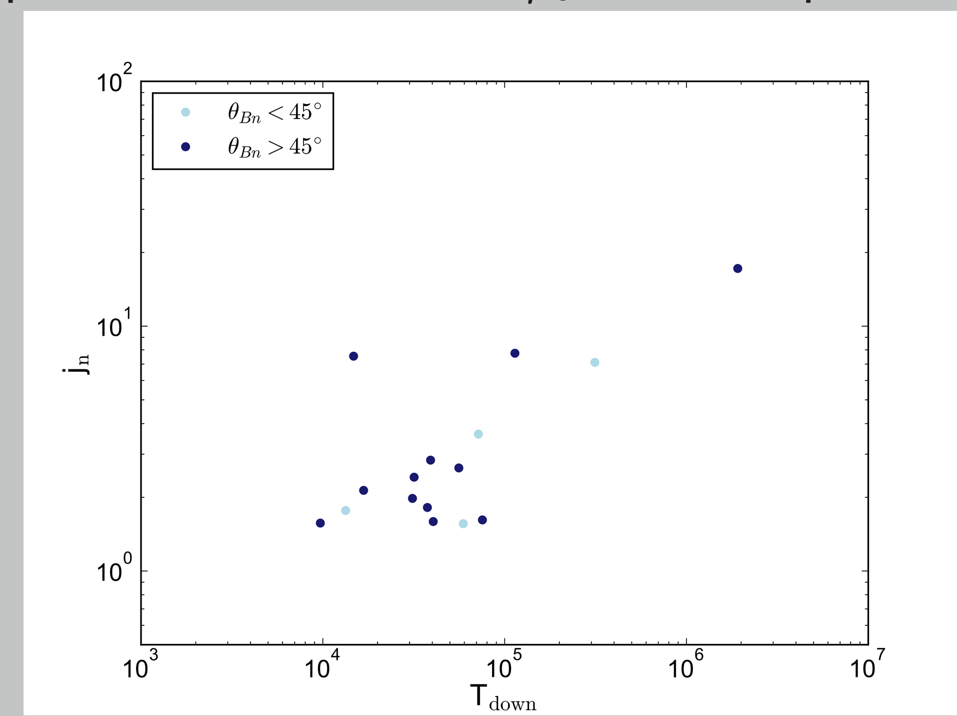


Relation with Turbulence Level

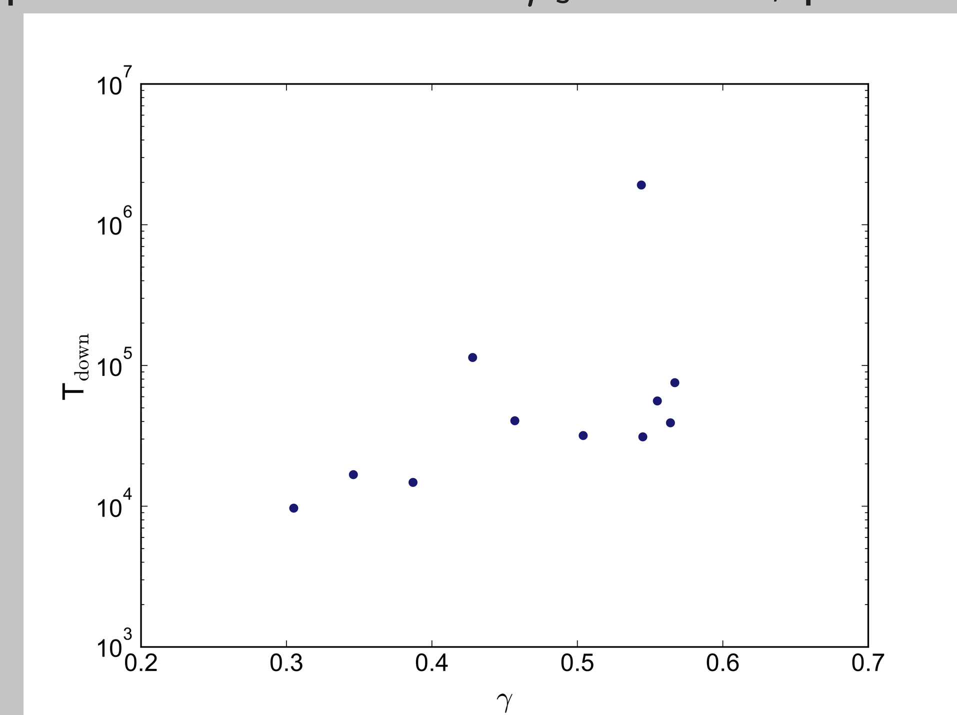
To quantify the magnetic field turbulence level, we used the Fast Fourier transformation and define a turbulence measure T_{down} between two frequency limits, the Nyquist frequency $f_{max} = 1/2t_{min}$ and the lower limit f_{min} by the inverse of the total sampling time t_{max}, as proposed by Claßen et al. (1999),

$$T_{down} = \sum_{i=f_{min}}^{f_{max}} |F(i)|$$

Spearman's correlation: $\rho_s = 0.424$, p= 0.102



Spearman's correlation: $\rho_s = 0.564$, p= 0.071



Conclusions

Our results suggest that the downstream turbulence is a relevant factor in particle acceleration and that stochastic acceleration can be a plausible mechanism for re-acceleration at interplanetary shocks.

For more details see (Chiappetta F., Laurenza M., Lepreti F., Consolini G., 2021)

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