Modelling the East-West asymmetry of energetic particle fluence in large SEP events using the iPATH model

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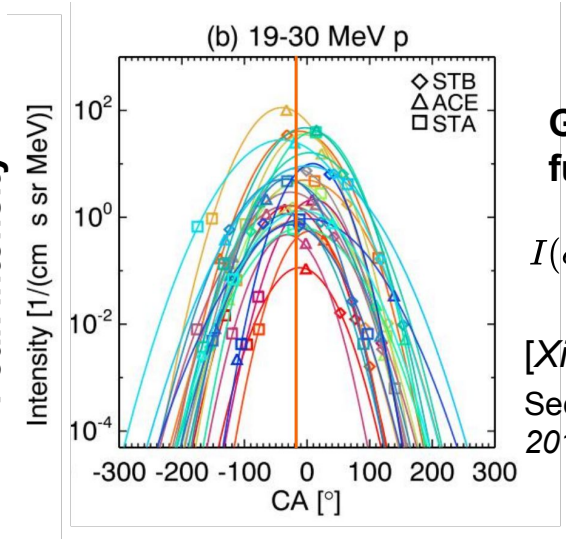
Introduction: the East-West asymmetry of SEP intensity

What :



Gaussian distribution function:

$$I(\phi) = I_0 exp[\frac{-(\phi-\phi_0)^2}{2\sigma^2}]$$

[*Xie et al. 2019*]

See also, e.g., *Lario et al. 2006, 2013,Cohen et al. 2017*

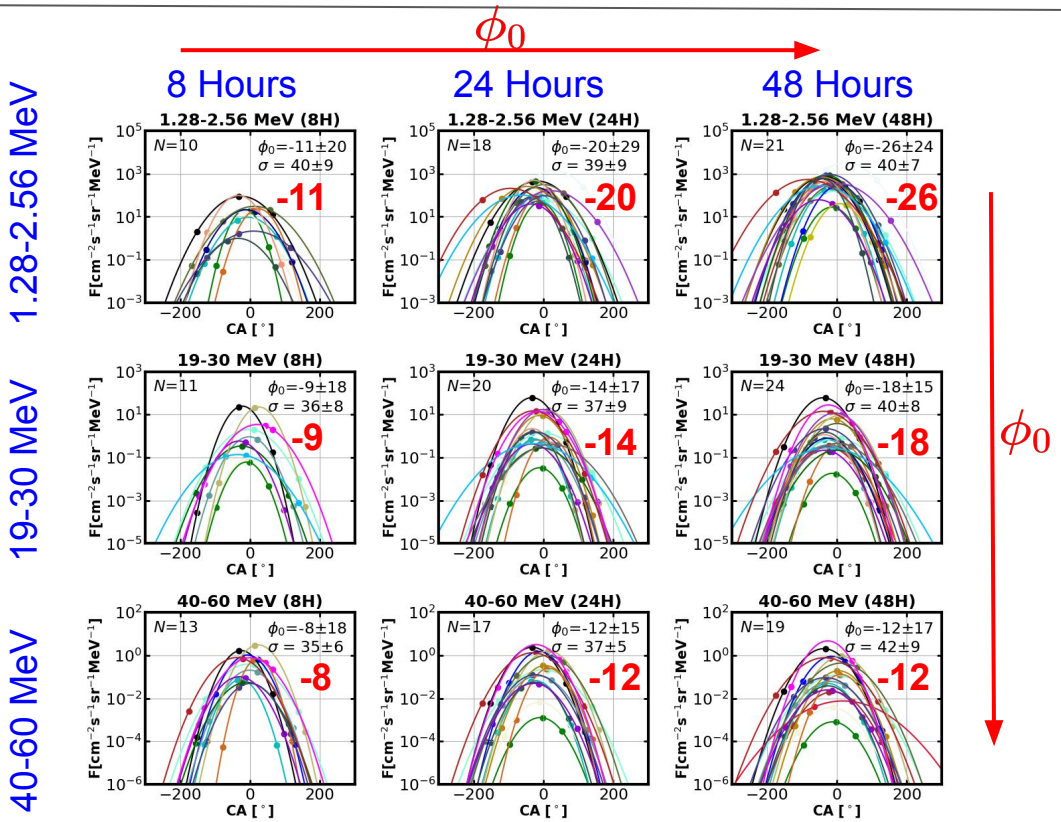
- 28 3-SC events
- Connection Angle (CA) = Lon_flare - Lon_footpoint
  CA > 0: The flare to the west of the magnetic footpoint of the SC.
  CA < 0: The flare to the east.

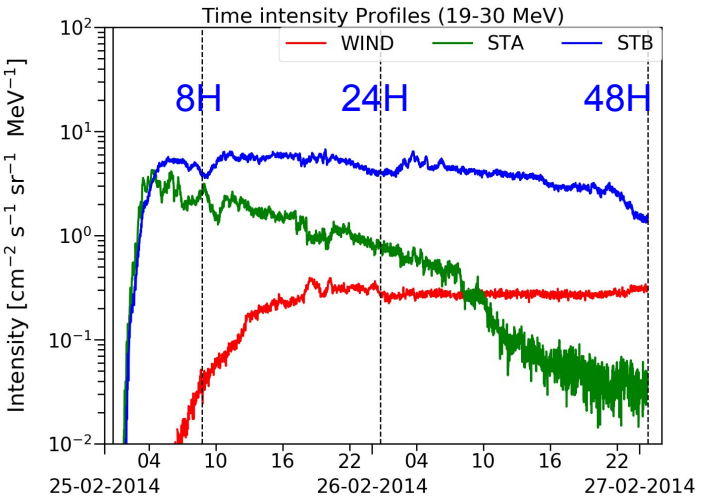
$$Mean(\phi_0) = -14.6^\circ$$

Why :

- Solar co-rotation (*Dröge et al. 2010; Giacalone et al. 2012*)
- Cross-field diffusion and the geometry of Parker spiral field lines (*e.g., Strauss et al. 2015, He et al. 2015*)
- **The extended shock acceleration and the geometry of Parker spiral field lines (*This work*)**

Observations: the East-West asymmetry of SEP fluence





Time-averaged fluence:

$$F_\tau(\mathrm{E}) = \frac{1}{\tau}\int_0^\tau \mathrm{j(E)}\ \mathrm{dt}$$

$$\tau = 8, 24, 48\ hrs$$

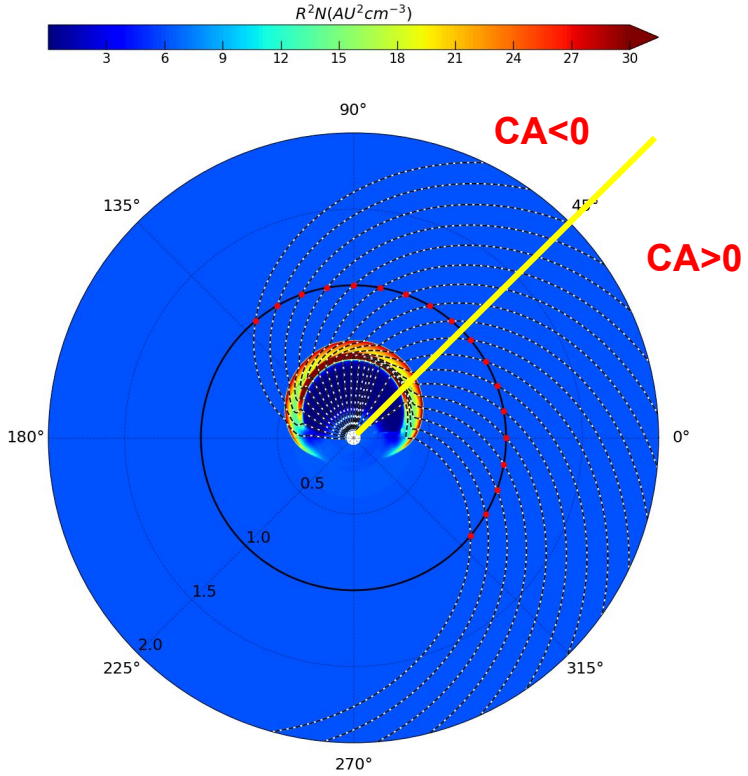
- The offset of the Gaussian center increases with duration.
- The offset of the Gaussian center decreases with increasing energy.

Simulations: the iPATH-2D model and the model setup

iPATH-2D improved Particle Acceleration and Transport in the Heliosphere

- 10 Rs to 2 AU using ZEUS 2D MHD codes
- Self-consistent and physic-based particle acceleration at the shock front
- Particle transport in the solar wind --solving the focused transport equation with cross-field diffusion.
- Capable of modeling a SEP event at multiple spacecraft simultaneously in the ecliptic plane

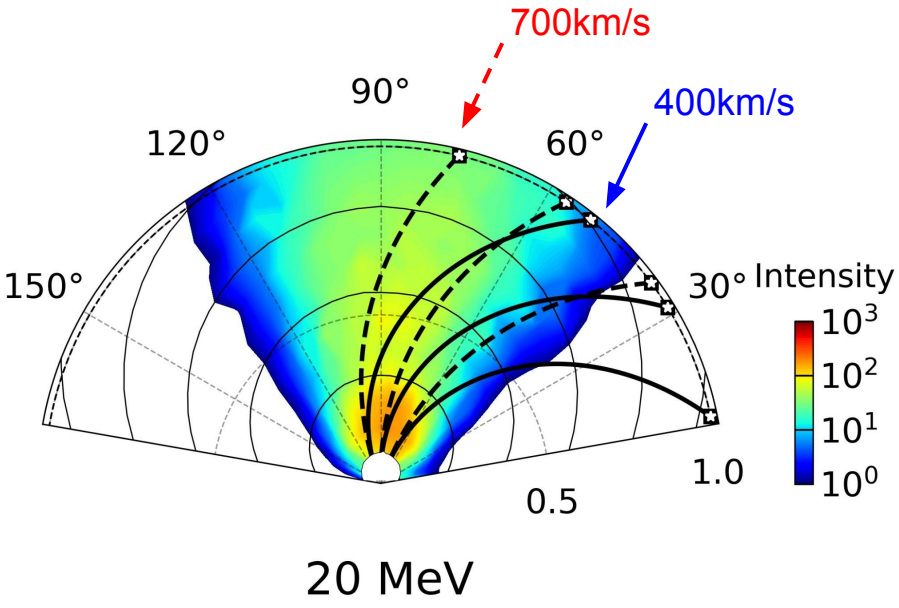
[See Hu et al. 2017, 2018]



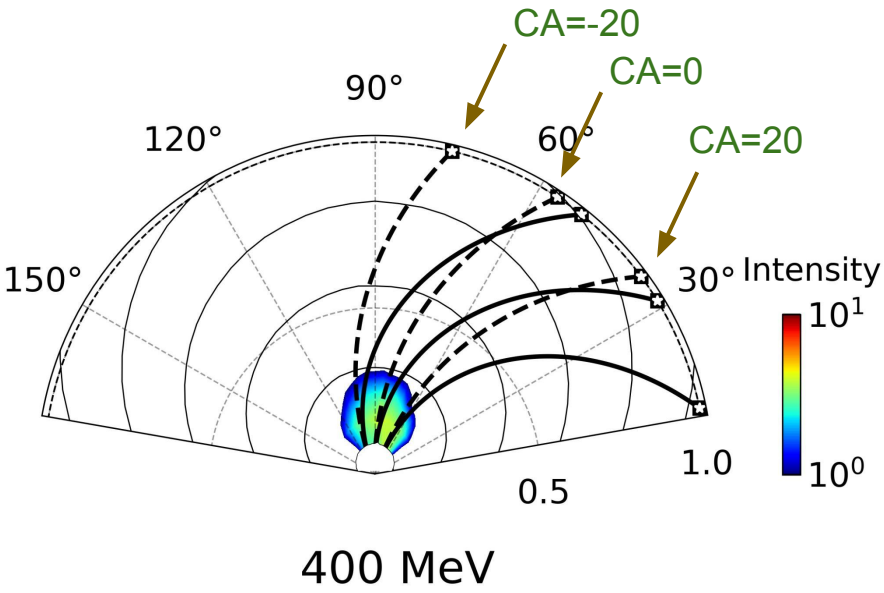
Case I:

- CME eruption speed = 2000 km/s
- Uniform solar wind speed = 400 km/s
- 16 virtual observers at 1 AU

Simulations: time evolution of proton intensity at shock fronts



20 MeV



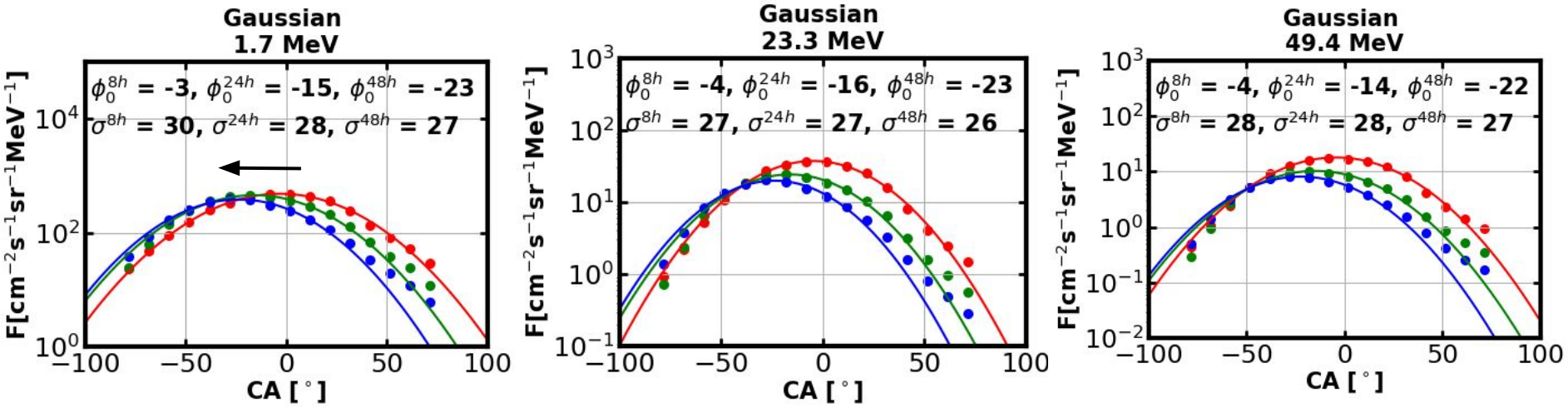
400 MeV

$$Fluence(E) \propto \int_{path} I(E)ds$$

- An extended shock acceleration
- The curvature of Parker field lines.

Simulations: the East-West asymmetry of fluence in case I

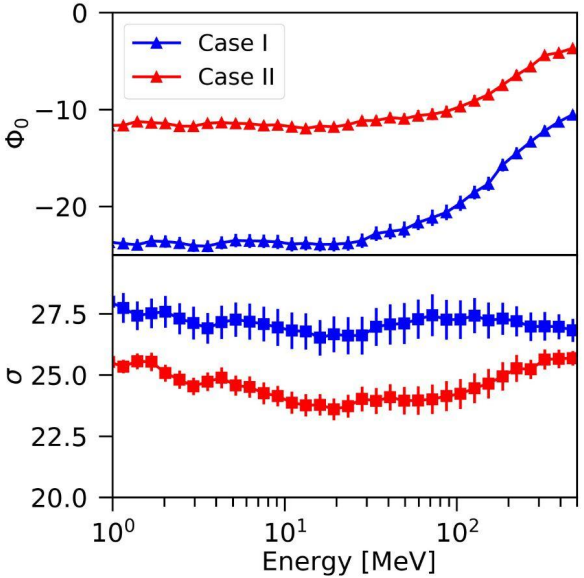
Red=8H, Green=24H, Blue=48H

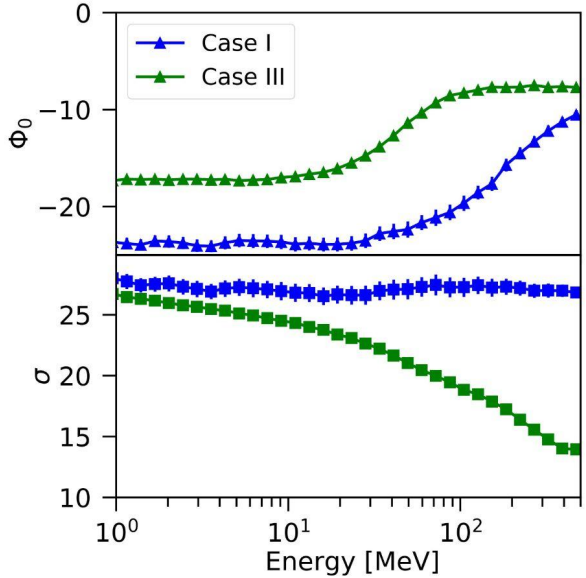


The offset of the Gaussian center increases with duration.

—— Due to the extended shock acceleration

Simulations: dependence of CME speeds and solar wind speeds





Case I: Vcme = 2000 kms/ and Vsw = 400 km/s
Case II: Vcme = 2000 km/s and Vsw = 700 km/s
Case III: Vcme = 1000 km/s and Vsw = 400 km/s

- the offset of Gaussian center decreases with increasing energy.
- Case I and II:
  the offset of Gaussian center decreases with the increasing solar wind speed (Curvature of field lines).
- Case I and III:
  the offset of Gaussian center and the Gaussian width depend highly on the CME speed (Shock strength).

Summary

- The time-averaged fluence of SEPs shows an East-West asymmetry with respect to the source flare locations
- The East-West asymmetric distribution of fluence can be explained by the combined effect of an **extended shock acceleration** and the geometry of the Parker magnetic field lines.
- The background solar wind speed and the CME speed are key factors affecting this asymmetry.

[Ding et al. 2022, under review]

Thanks

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