



Particle acceleration at a 3D reconnection site

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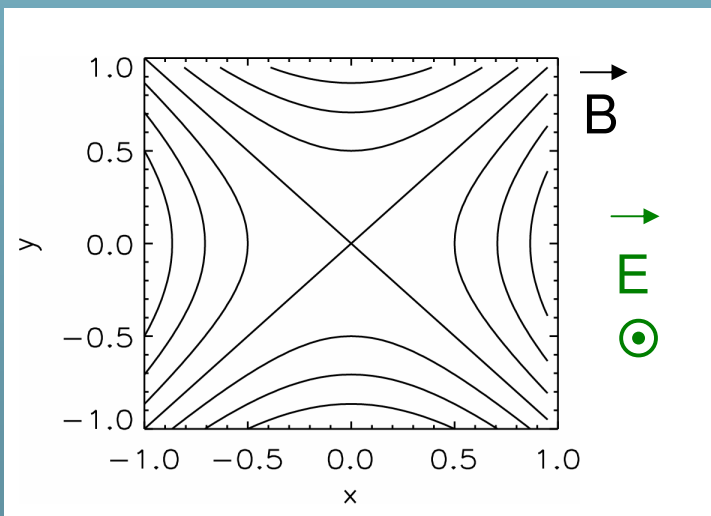


Introduction

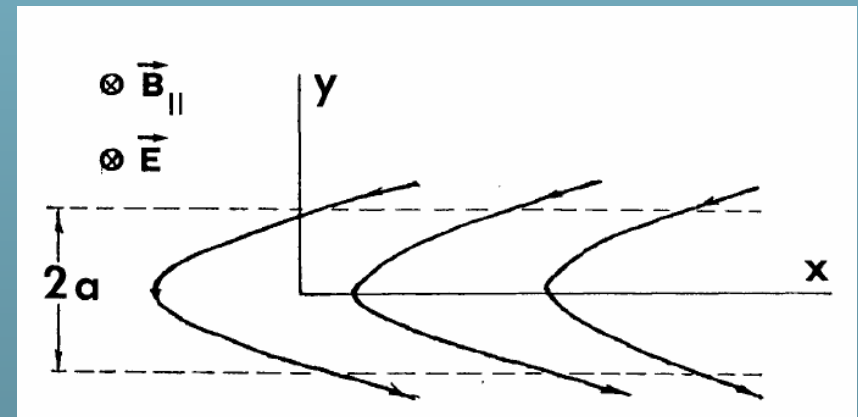
- **Magnetic reconnection** has been put forward as the process responsible for **particle acceleration** in a variety of astrophysical contexts, including the Sun (**solar flares**) and the Earth's magnetosphere.
- Understanding the transfer of energy in the large flares can help to clarify what happens in nanoflares – relevance to coronal heating.
- While 2D reconnection has been extensively researched, studies of reconnection in 3D are a recent development.

Particle acceleration at a reconnection site

- Particles are energised by the electric field in the reconnection region
- Typical approach used to study acceleration, is to take magnetic and electric field as given, and study trajectories of a single particle → **test particle approach**
- Example of 2D configurations:



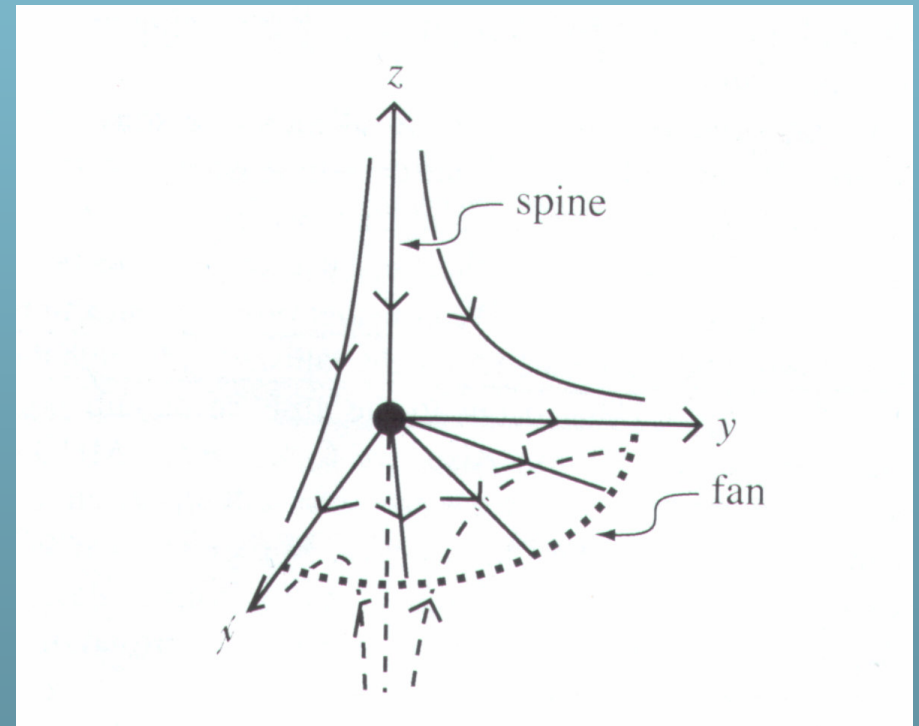
X-point. Eg: Deeg et al (1991), Browning & Vekstein (2001), Hamilton et al (2003).

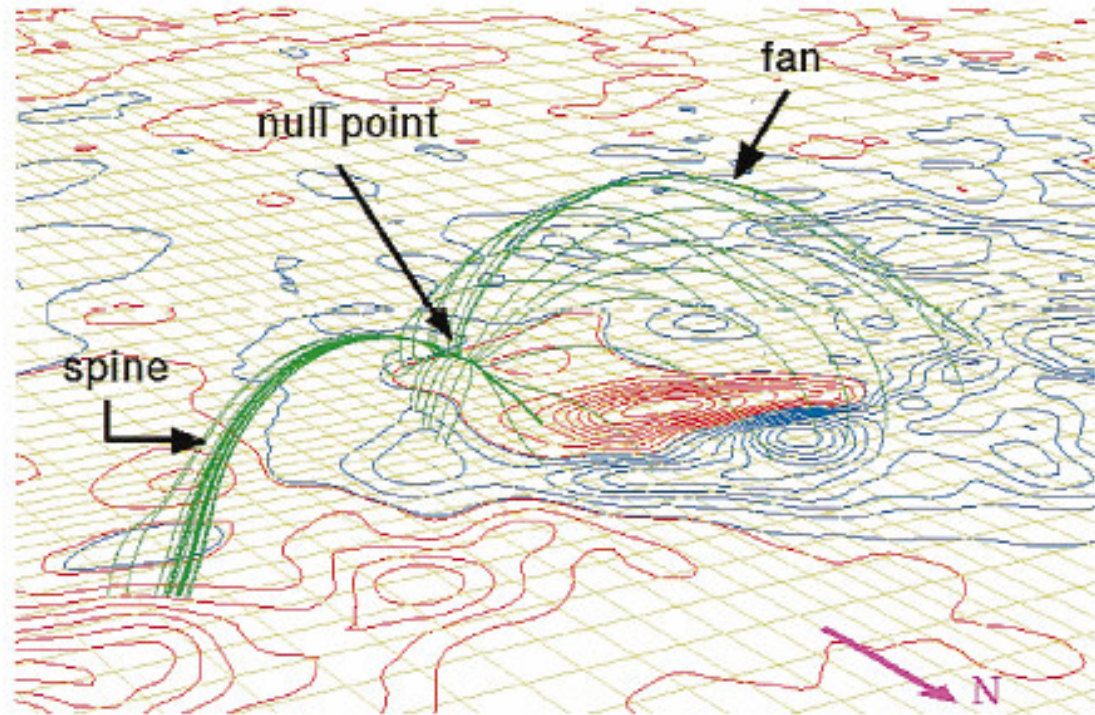
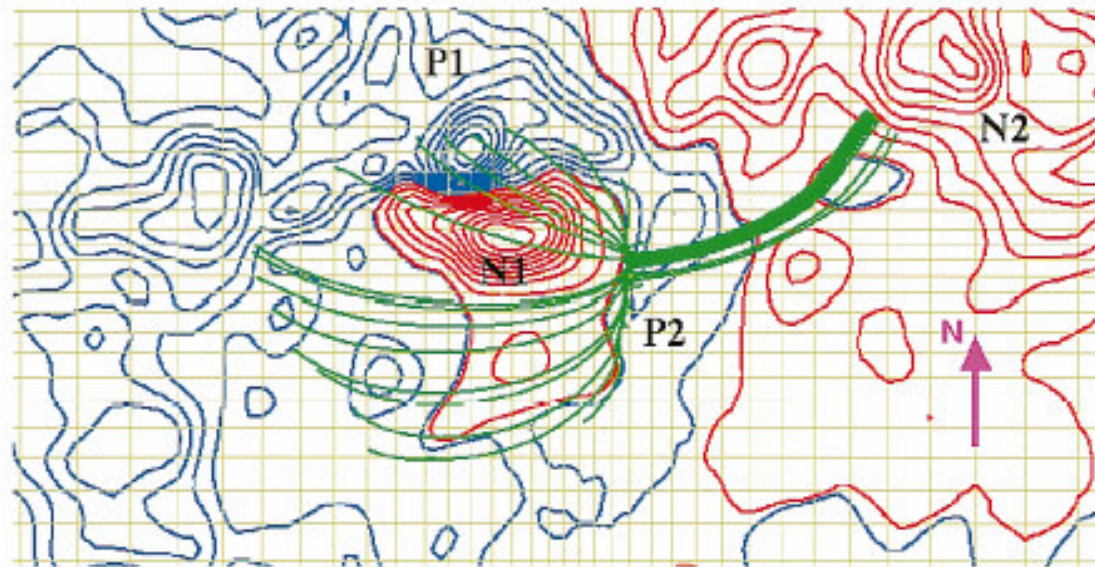


Current sheet. Eg: Litvinenko and Somov (1993)

This work: trajectories near a 3D magnetic null point

- Priest and Titov (1996) described reconnection at a 3D null point.
- Spine reconnection
- Fan reconnection





Aulanier et al
(2000)

Trajectories for spine reconnection

- Solve equations of motion of a test particle:

$$\frac{d\mathbf{x}}{dt} = \frac{\mathbf{p}}{m\gamma}$$
$$\frac{d\mathbf{p}}{dt} = q \left(\mathbf{E} + \frac{1}{c} \frac{\mathbf{p}}{m\gamma} \times \mathbf{B} \right)$$

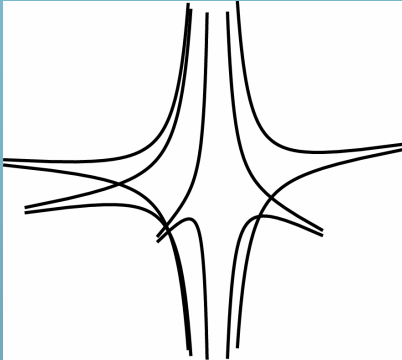
- with fields: where (R, ϕ, z) cylindrical coords in a system with z along spine.

$$\mathbf{B} = B_0 \frac{R}{L} \mathbf{e}_R - 2 B_0 \frac{z}{L} \mathbf{e}_z$$
$$\mathbf{E} = E_0 L \frac{\sin \phi}{R} \mathbf{e}_\phi$$

- Particle moving in these non-uniform fields has gradient and curvature drifts, plus electric field drift with velocity:

$$v_E = c \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

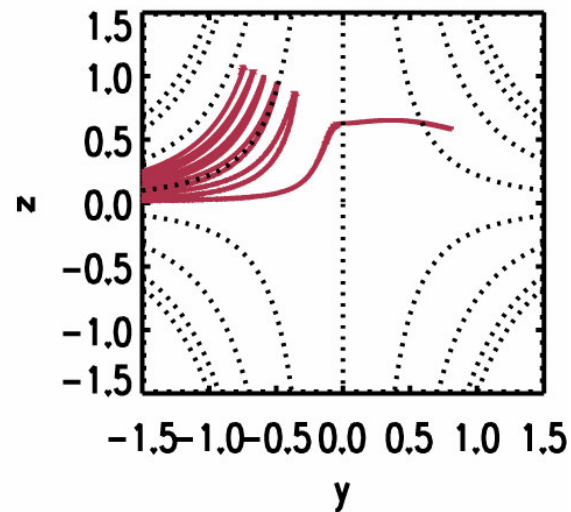
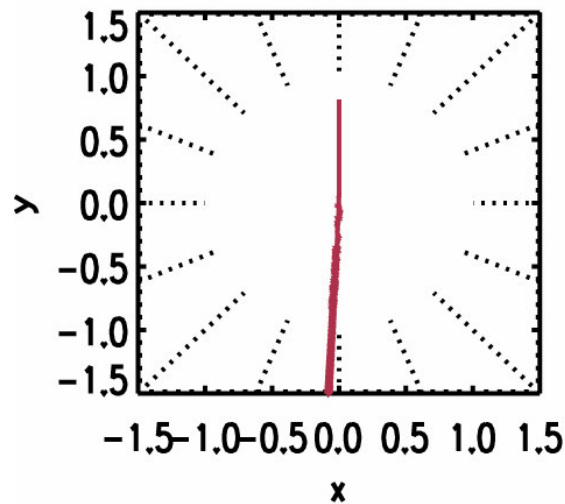
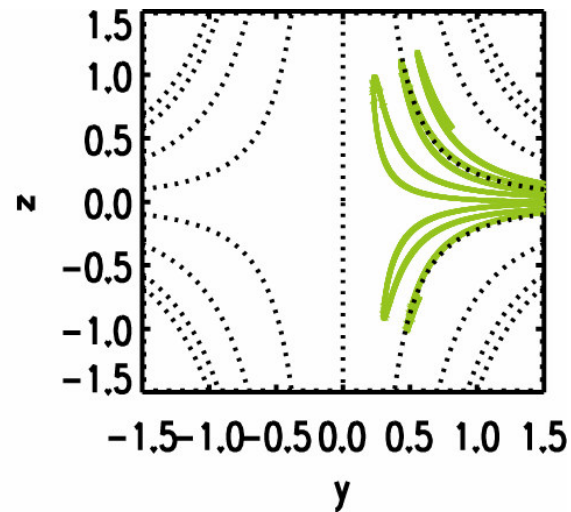
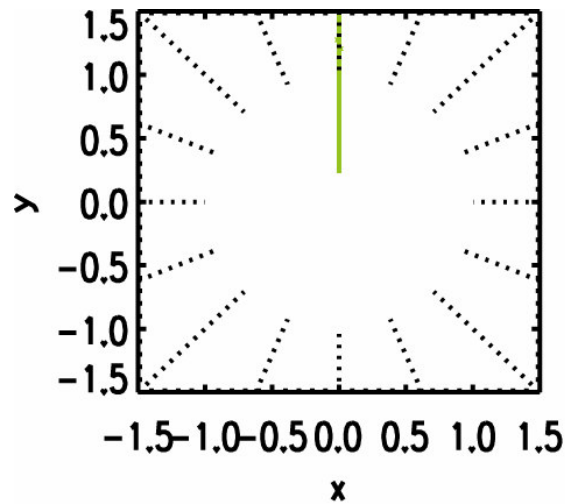
Trajectories for weak / strong electric field



$L=10$ km

$B_0=100$ gauss

Proton,
 $E=100$ eV



Weak electric
field

$T_{\text{final}}=2$ s

No acceleration

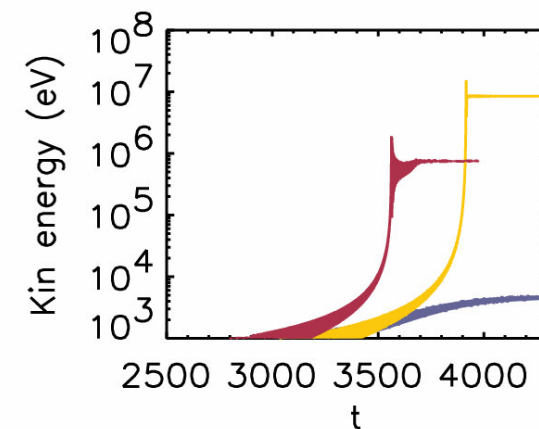
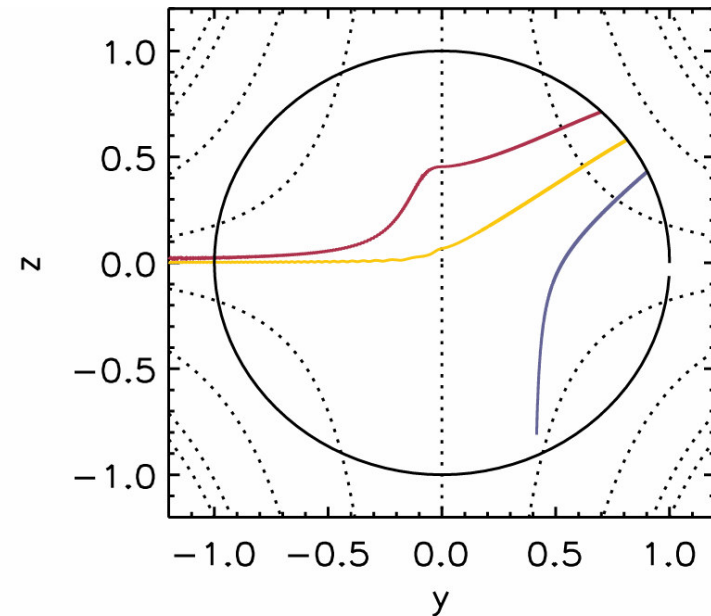
Strong electric
field

$T_{\text{final}}=2 \cdot 10^{-3}$ s

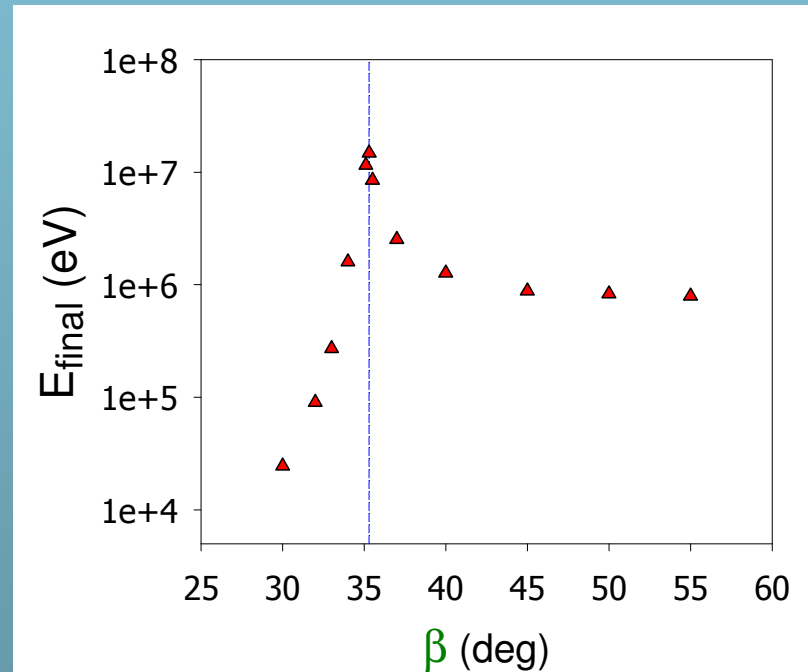
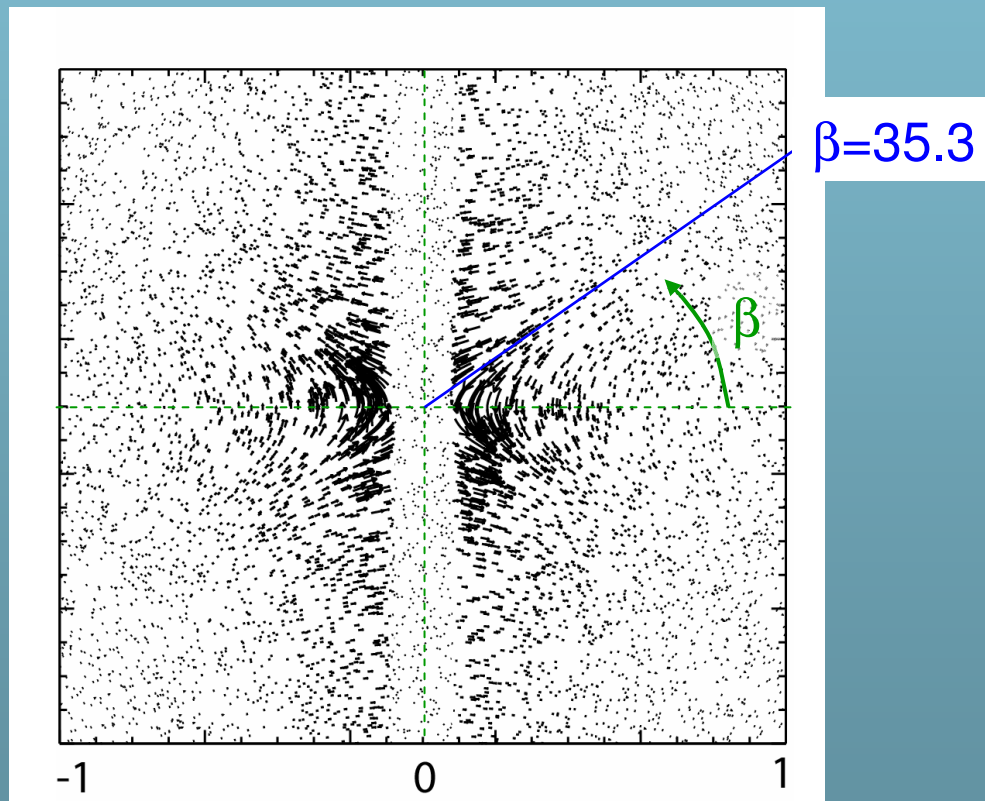
Strong acceleration

Dependence of final energy on initial position

- The energy gained by a particle strongly depends on its initial position.
- Particles passing close to null point gain the most energy as they become unmagnetised.



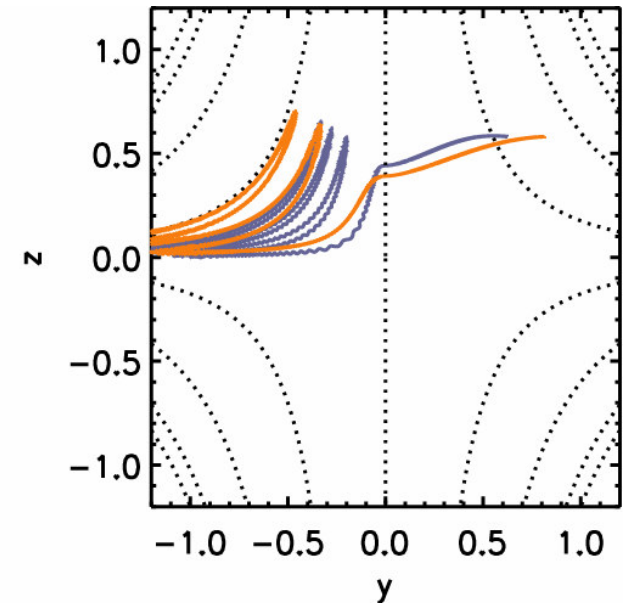
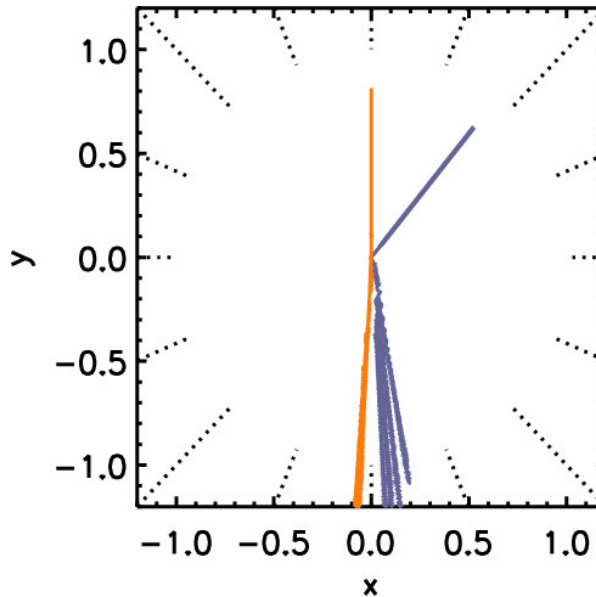
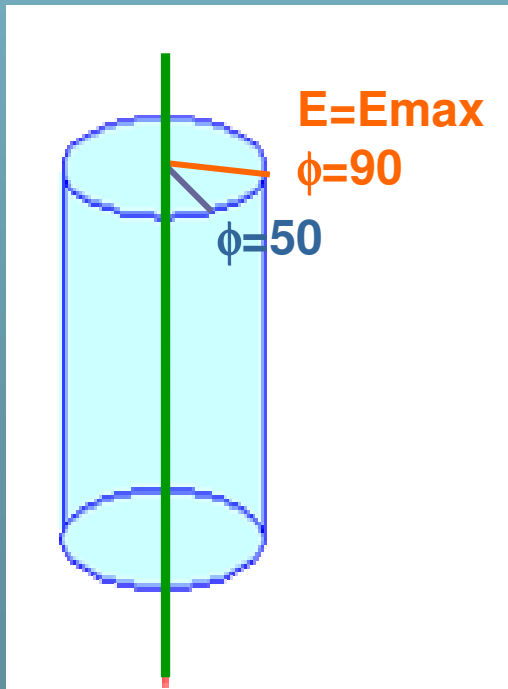
Final energy vs initial position



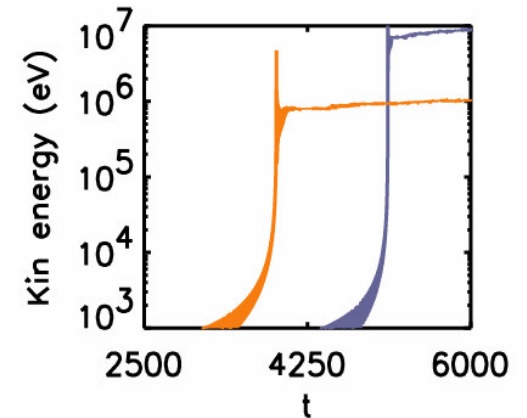
- Optimal approach angle $\beta = 35.3$ in R-z plane gives maximum acceleration

Dependence of final energy on ϕ

- The electric field in spine reconnection has a $\sin \phi$ dependence.



- Particle in plane $\phi=50$ gains more energy but in a longer time.



Conclusions

- Efficient particle acceleration can take place during spine reconnection at a 3D magnetic null point, in the strong electric field regime.
- The final energy is strongly dependent on the angle of particle approach in an R-z plane. Optimal angle is 35.3.
- Particles injected in planes at an angle ϕ to the plane where the electric field is maximum are also accelerated, though the process takes longer in this case.

Dimensionless variables

$t \rightarrow$ gyroperiod

$x \rightarrow L$

$v \rightarrow c \cdot 10^{-4}$

$B \rightarrow B_0$

$E \rightarrow B_0 \cdot 10^{-4}$