Experiments which observe magnetic field line reconnection within structures in a Magnetoplasma

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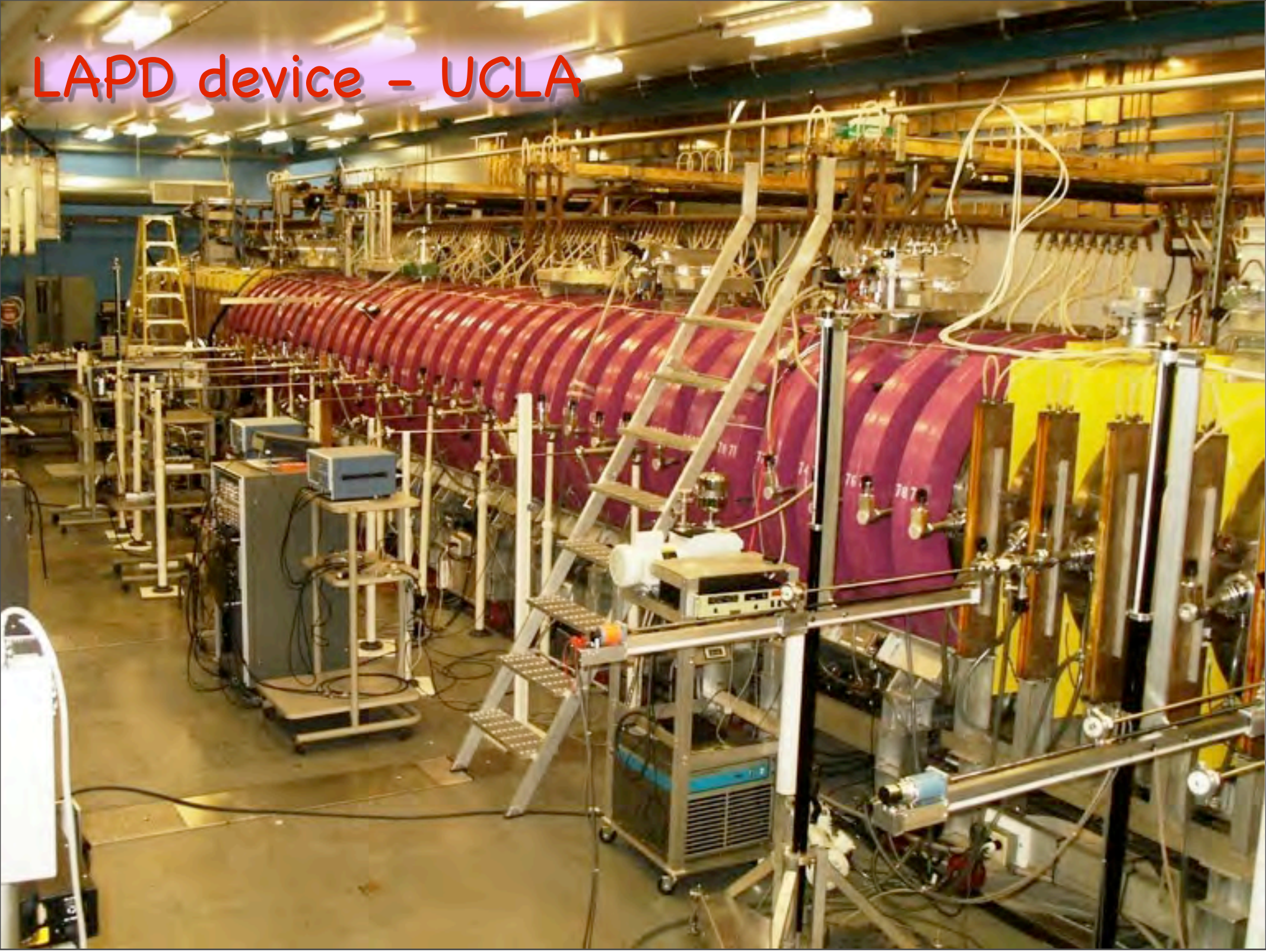
Recurrent questions in Space and Astrophysics

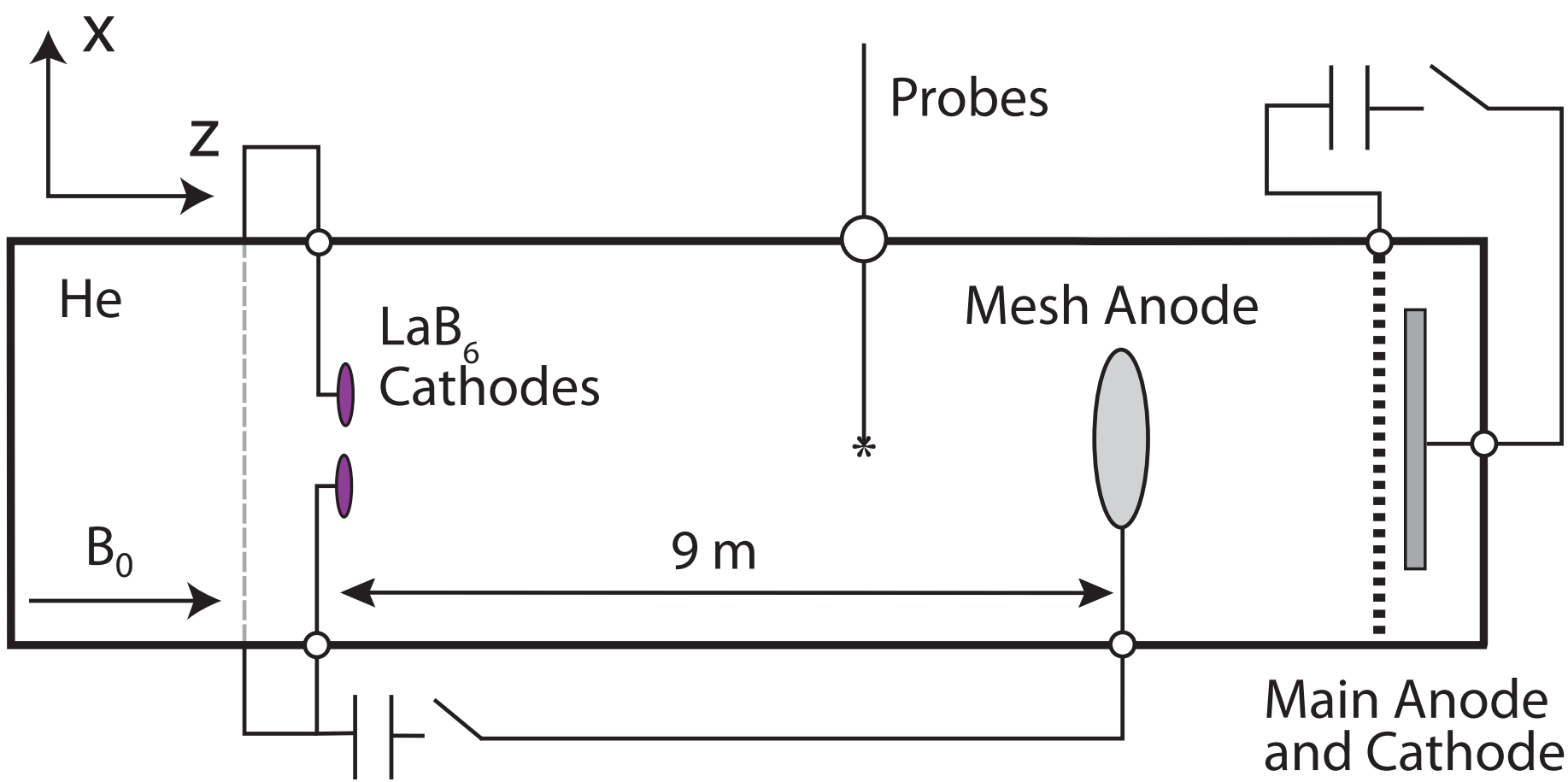
- Magnetic field generation (magnetic helicity)
- Relaxation of complex field geometries into simpler ones
- Magnetic Field Line Reconnection (what type?)
- Generation and interaction of magnetic flux ropes
- Role of waves (whistlers and Alfvén)
- Bursty verses steady phenomena (plasma instabilities)

Can we learn something from laboratory experiments?


LAPD device - UCLA

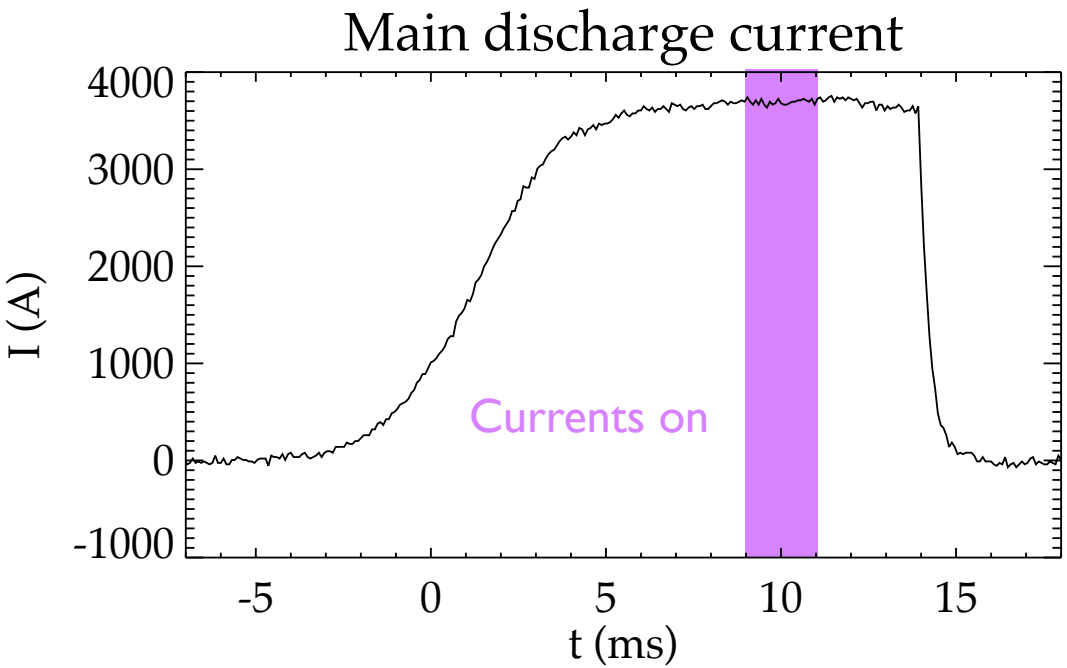
data acquired: 12 planes (20,000 spatial locations)

$\delta x = \delta y = 3mm$, δz=64 cm, δt= 40 ns

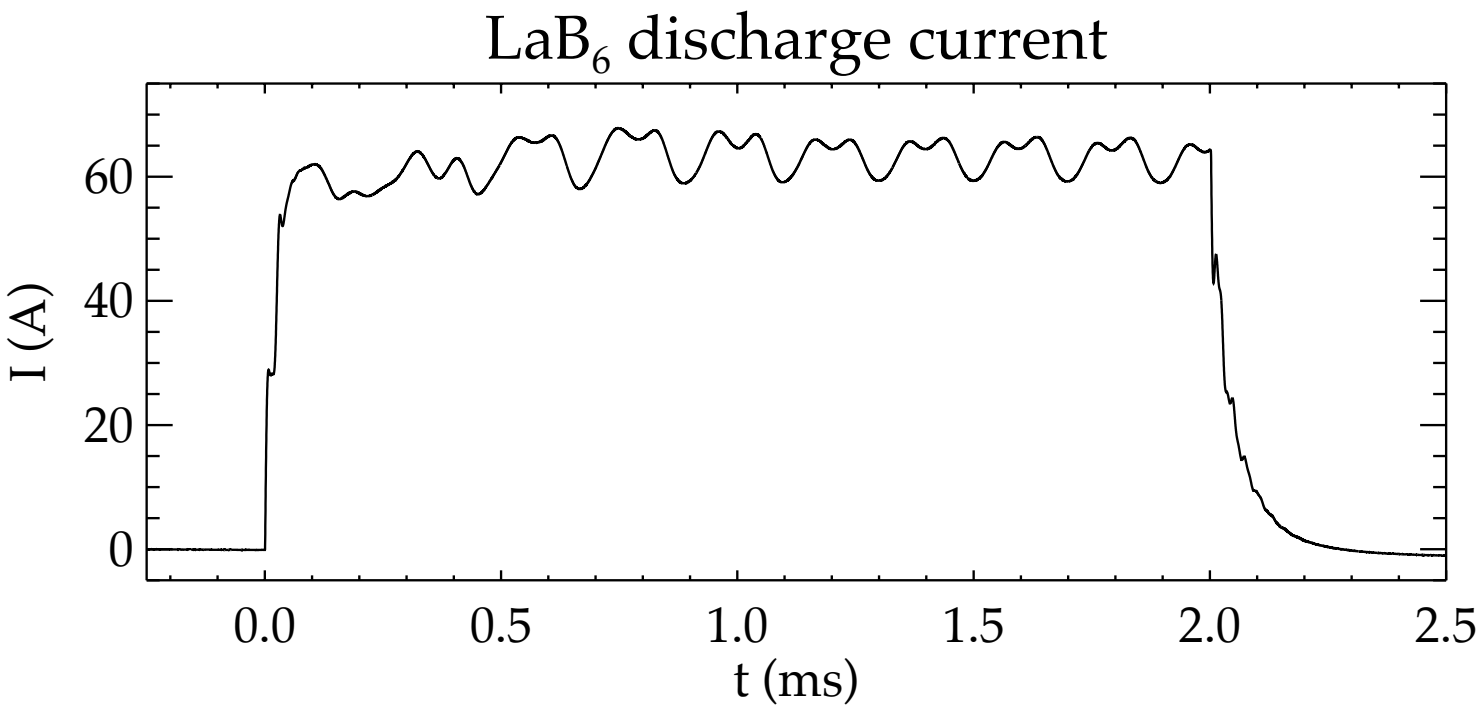


B_{0z} = 270 G

Discharge currents

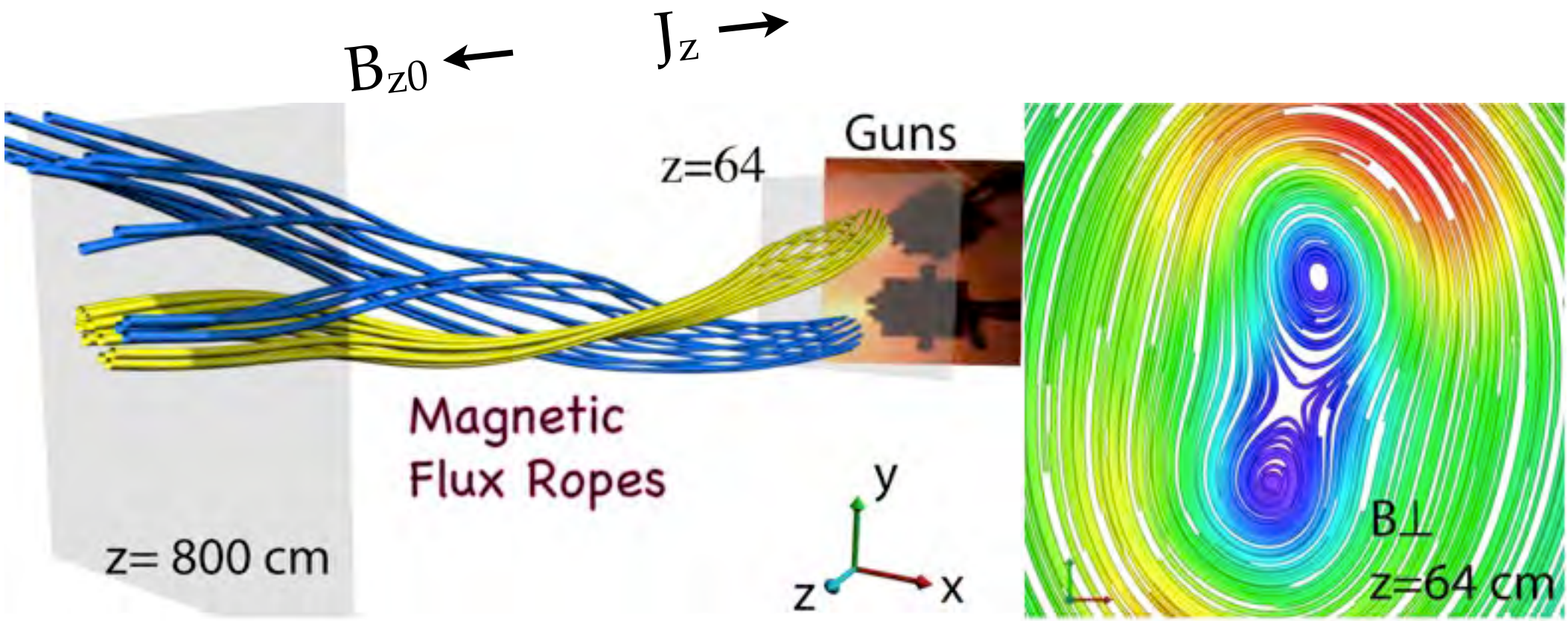


Small cathodes are biased to 100V for 2 ms during the main discharge. After 300 μs (~$3\tau_A$), spontaneous oscillations are seen in the LaB_6 discharge current.



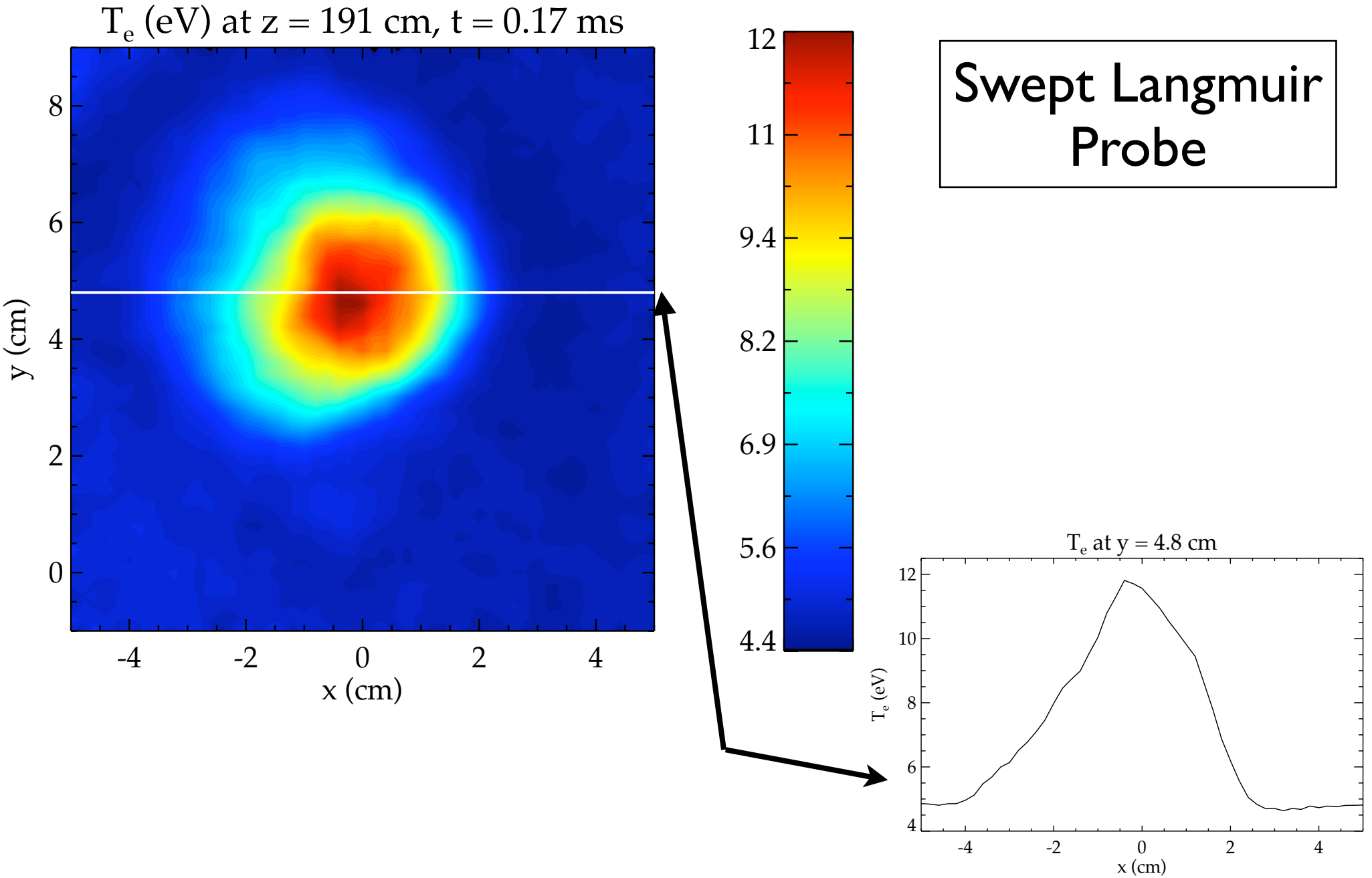
LaB_6 emitter
2.6 cm

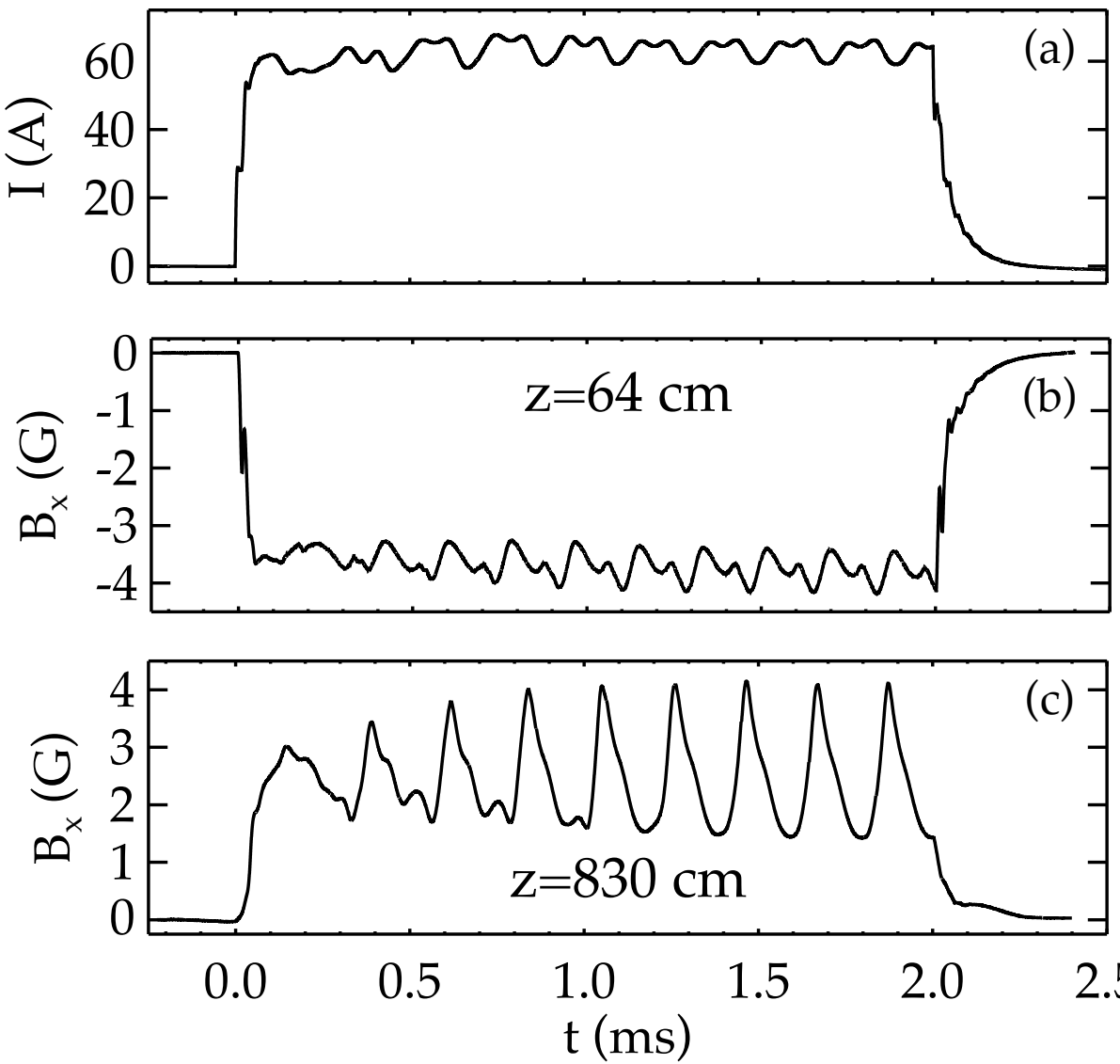
LaB6 heated to 1800 C
heater 570 Watt



- Flux tube cross section is elliptical at the far end.
- Twist ~ π-3π/2, writhe ~ π.

Electron temperature profile of a single channel





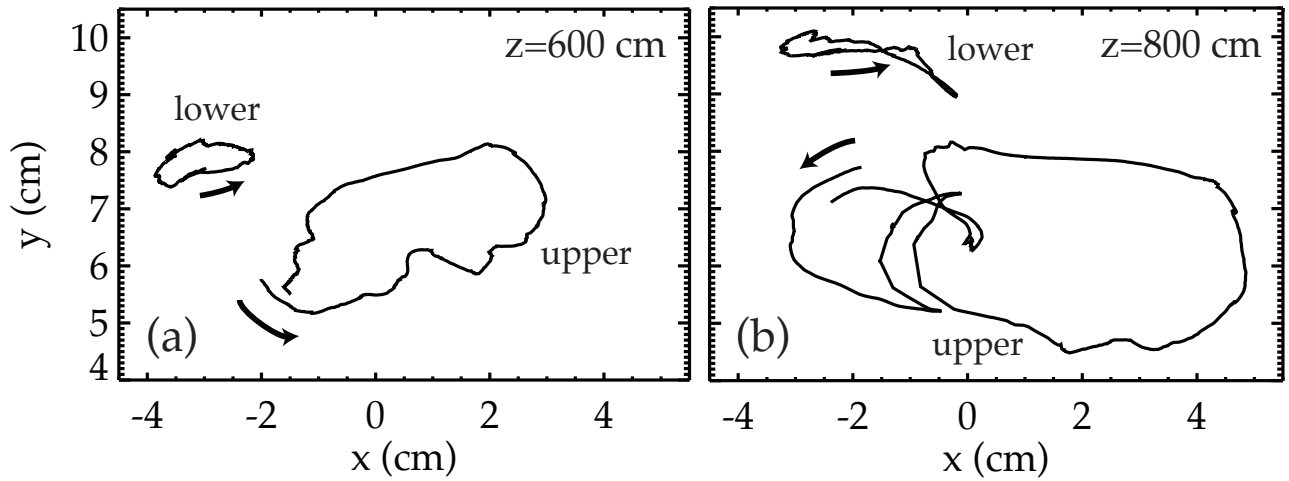
(a) emission current from LaB6 cathode

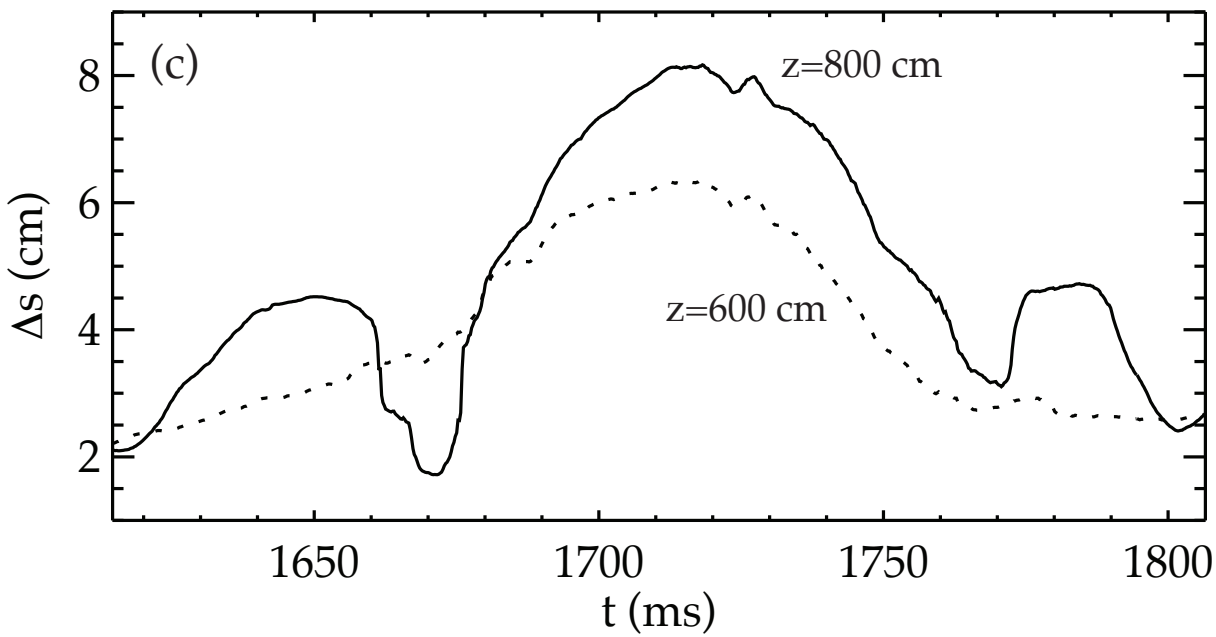
(b) Bx(t) , (0.0,2.7, z=64)

(c) Bx(t) , (-1.5,9.9, z=830)

(b) , (c) lie on same approximate flux surface on the lower flux rope

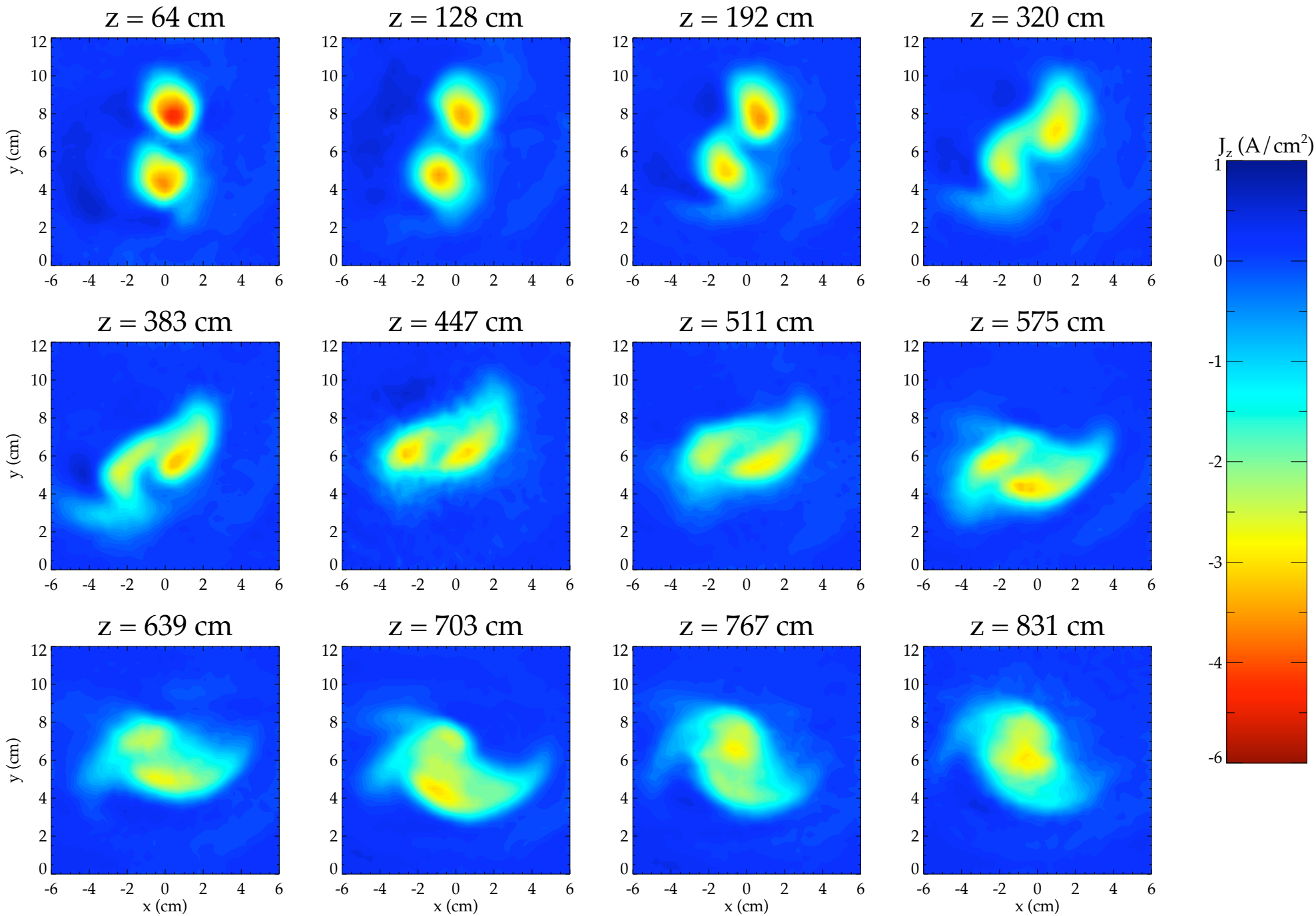
Hodogram of central field line in flux tubes





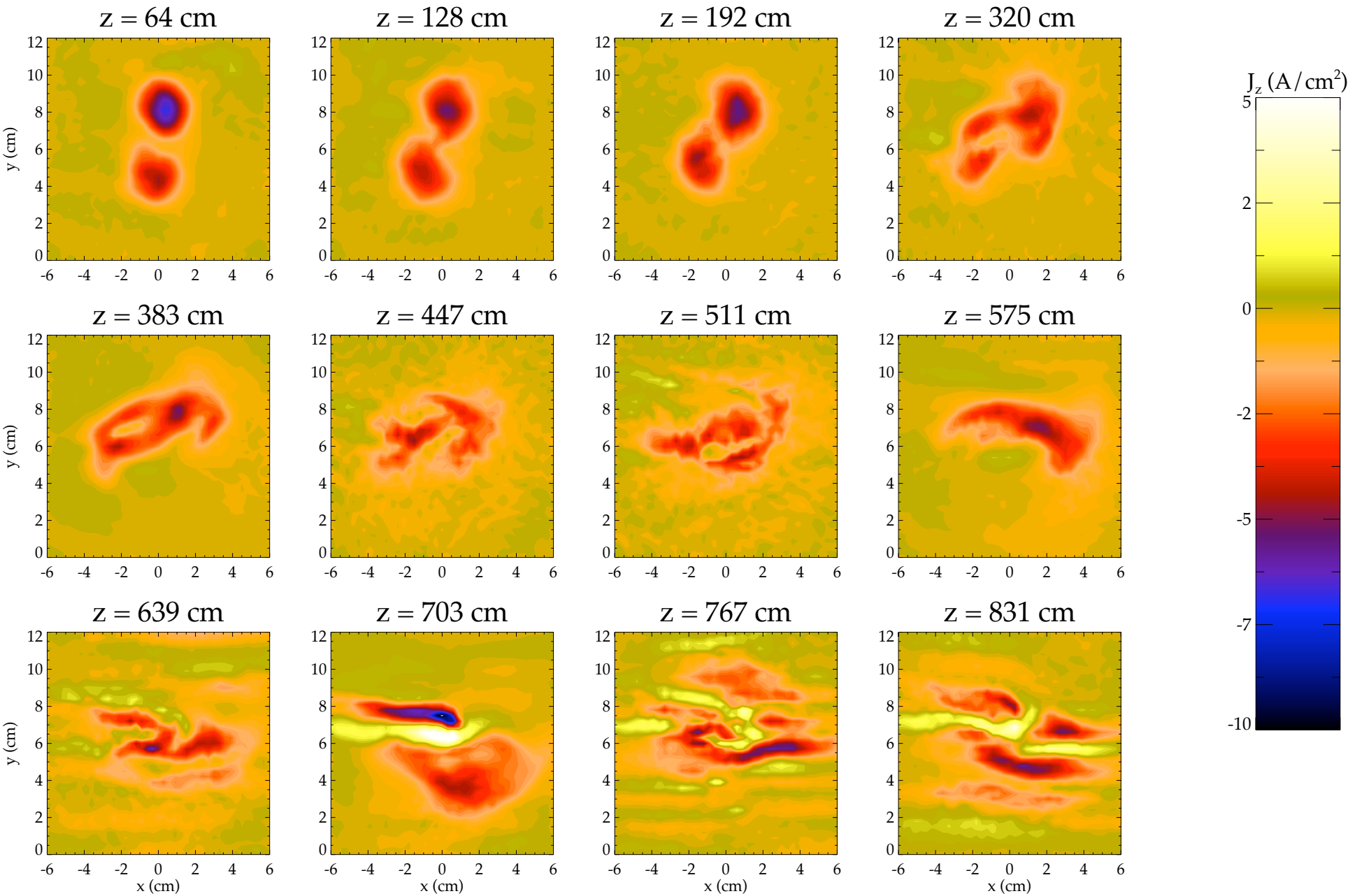
Distance between field lines (upper/lower) at two axial positions

J_z slices at t=190 μs (early in time)

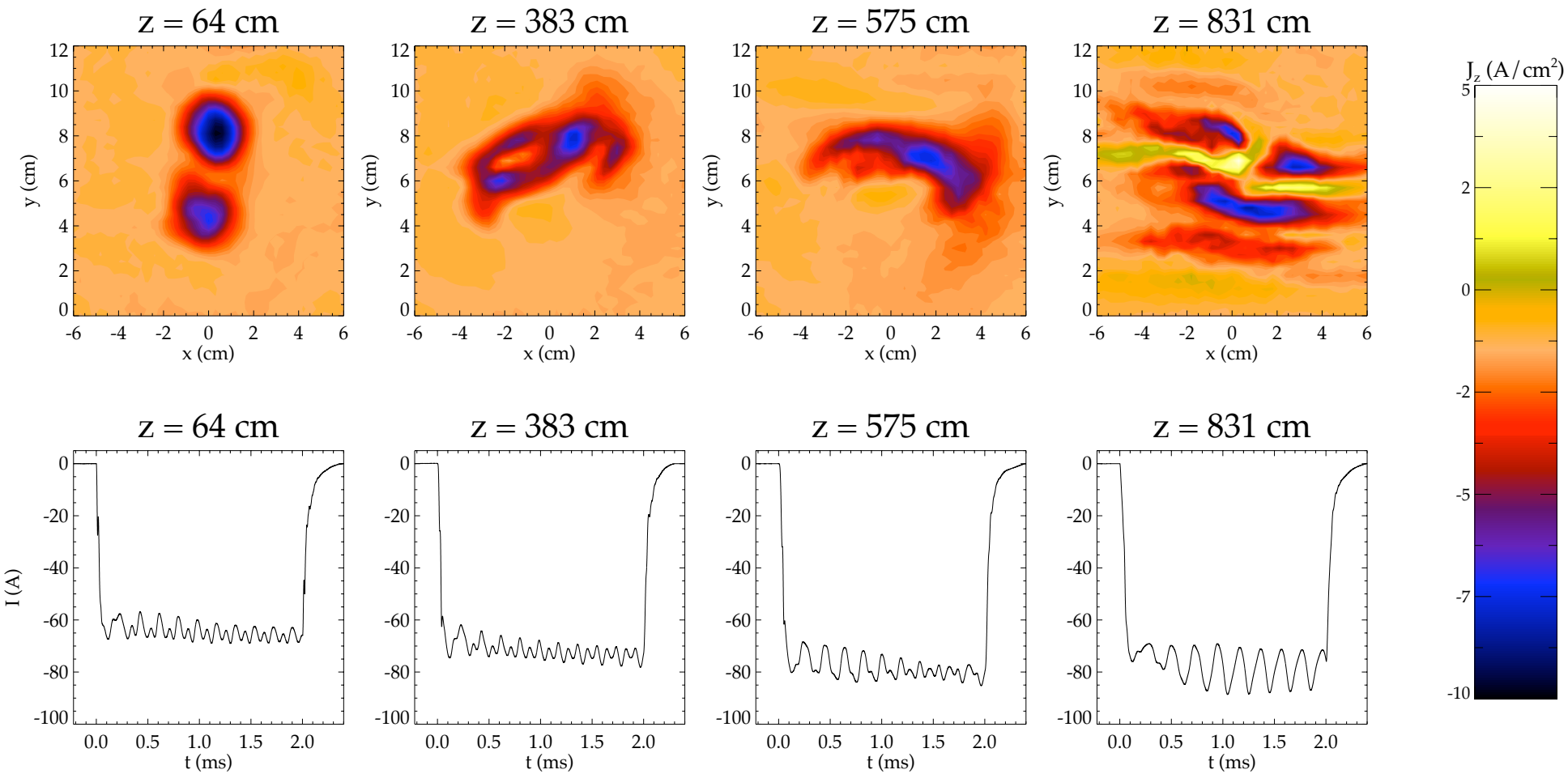


Jz profiles during oscillations in discharge current

t=1.7ms

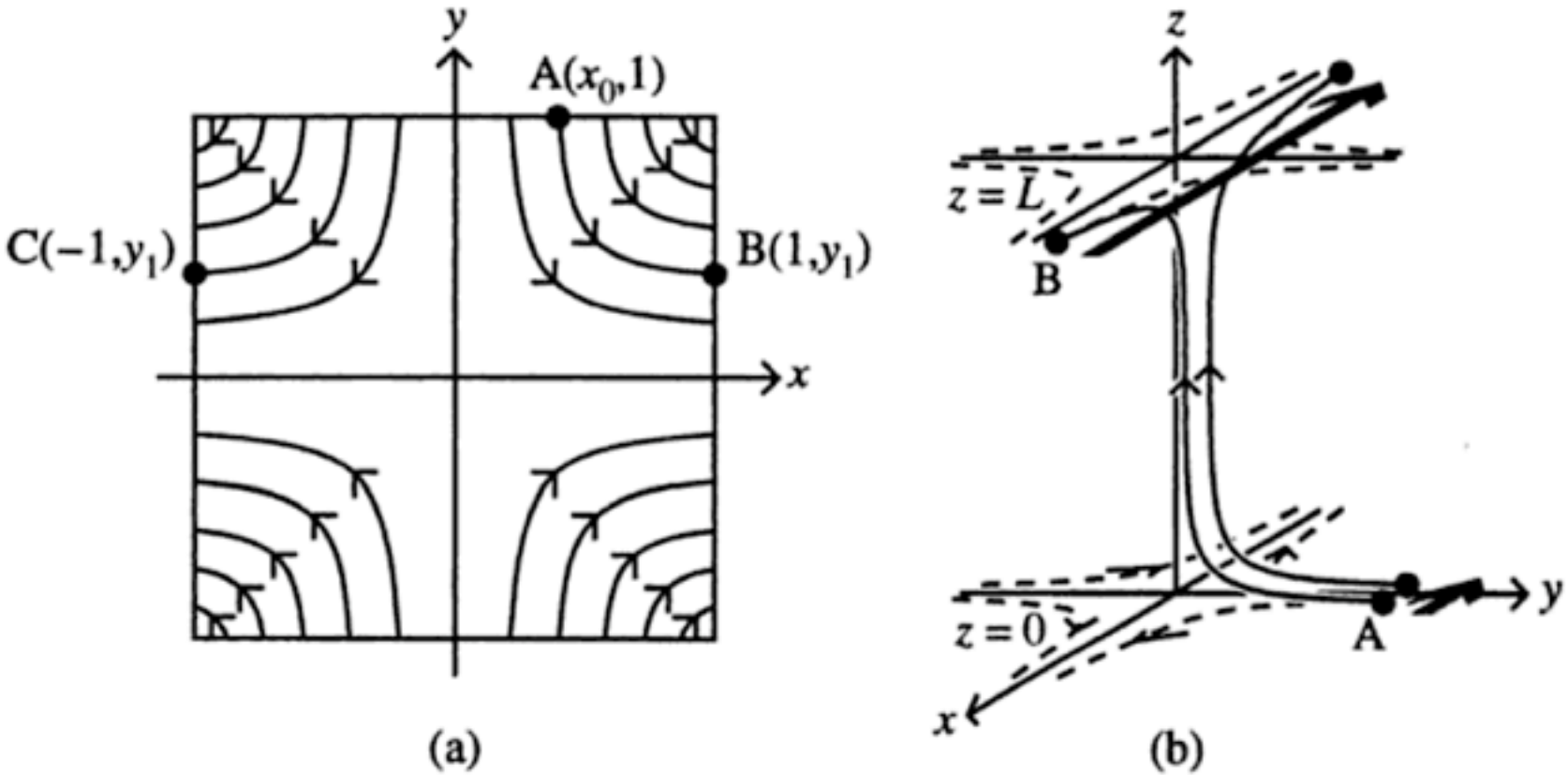


Integrated current density



Bottom traces show $\int J_z \, dz$ at various z positions.

Simple sheared X-point model



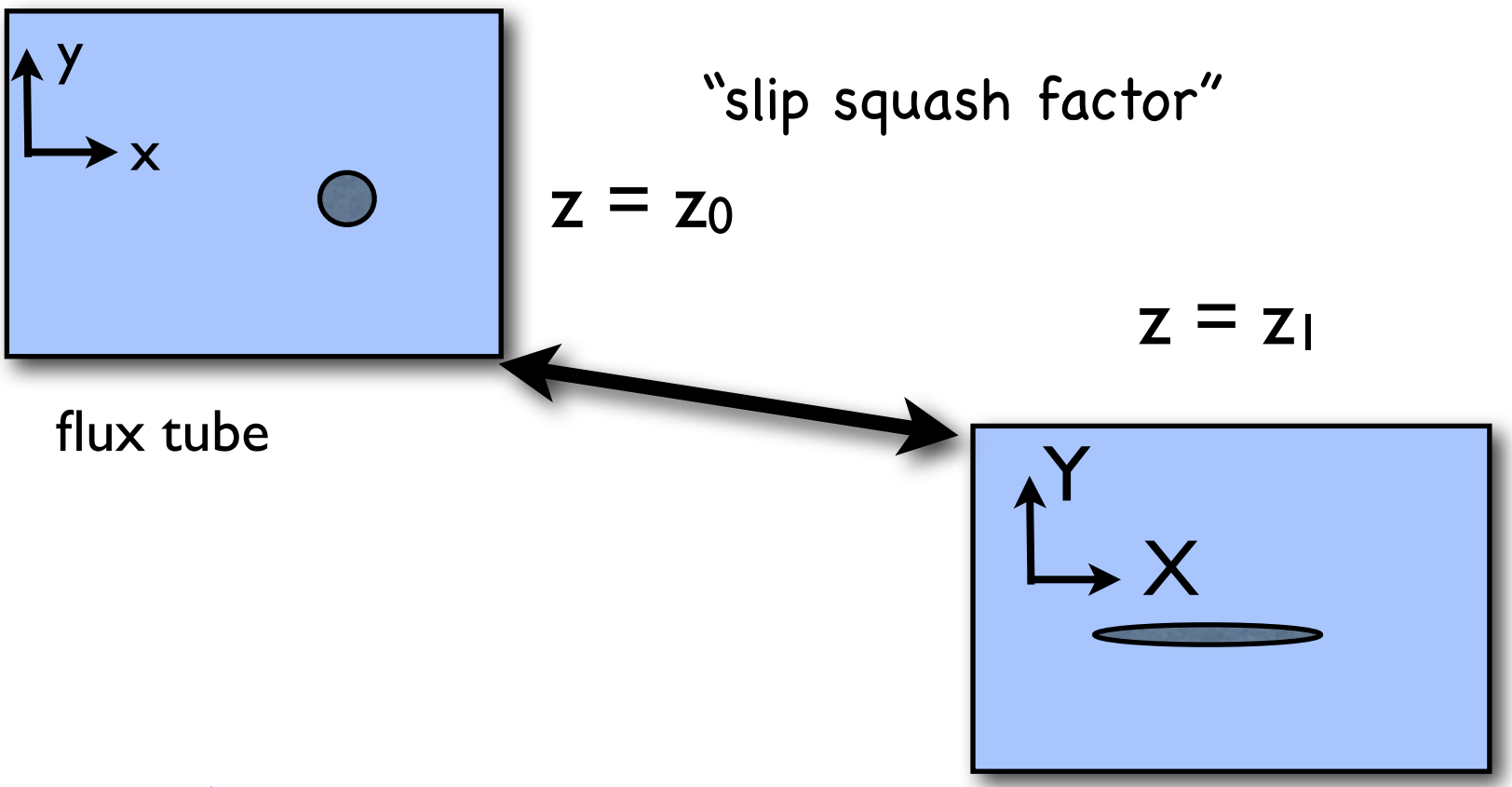
Small footpoint motions at point A would create a drastic shift at point B. In some cases point B can shift discontinuously [Priest and Forbes, 2000,Demoulin, 2006]

Definition of a quasi-separatrix layer

$$Q = \frac{N^2}{\left| \frac{B_z(z_0)}{B_z(z_1)} \right|}$$

$$N = \sqrt{\left(\frac{\partial X}{\partial x}\right)^2 + \left(\frac{\partial X}{\partial y}\right)^2 + \left(\frac{\partial Y}{\partial x}\right)^2 + \left(\frac{\partial Y}{\partial y}\right)^2}$$

in our experiment $Q \approx N^2$

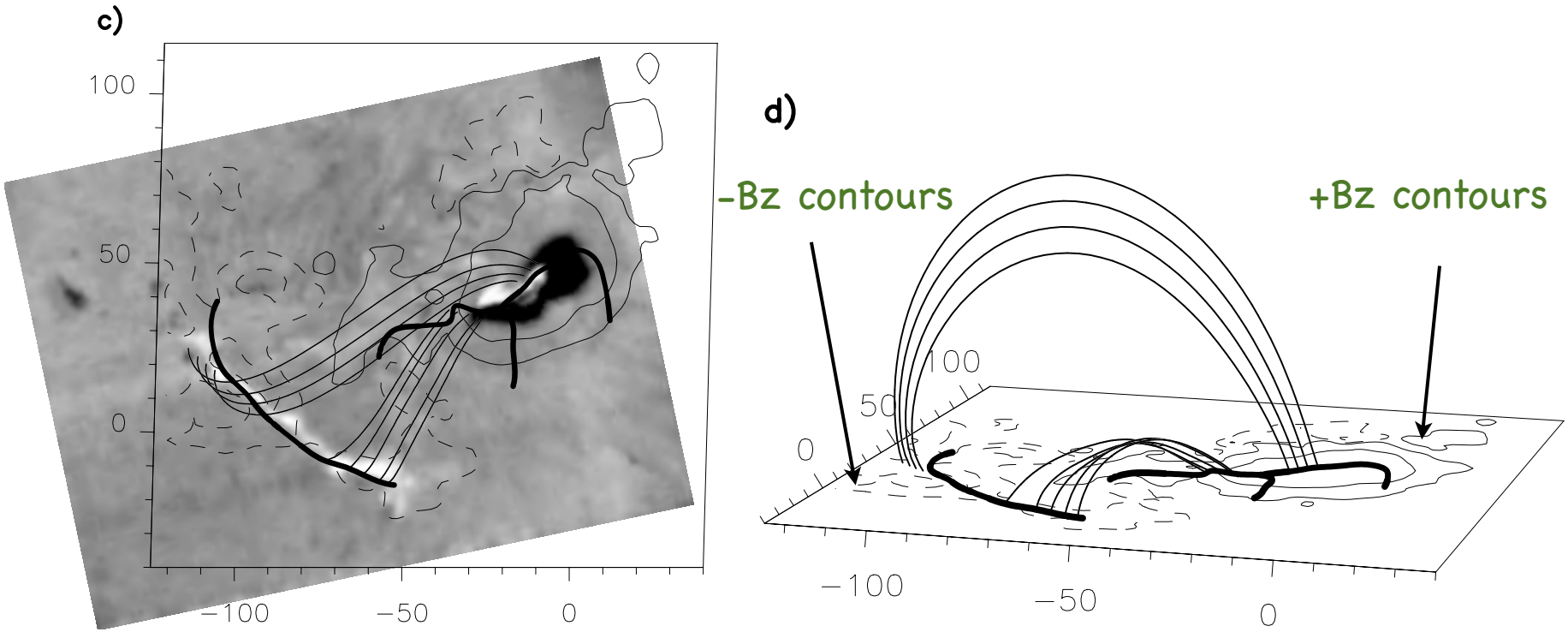


"slip squash factor"

Priest and Démoulin,JGR 1995,
Titov,As. J. (2007)

flux tube squashed: aspect ratio = Q

QSLs in solar flare observations



computed field lines

QSLs at boundaries (thick lines) coincident with H_α brightening in solar flares. [Bagalá et al. A&A 2000]

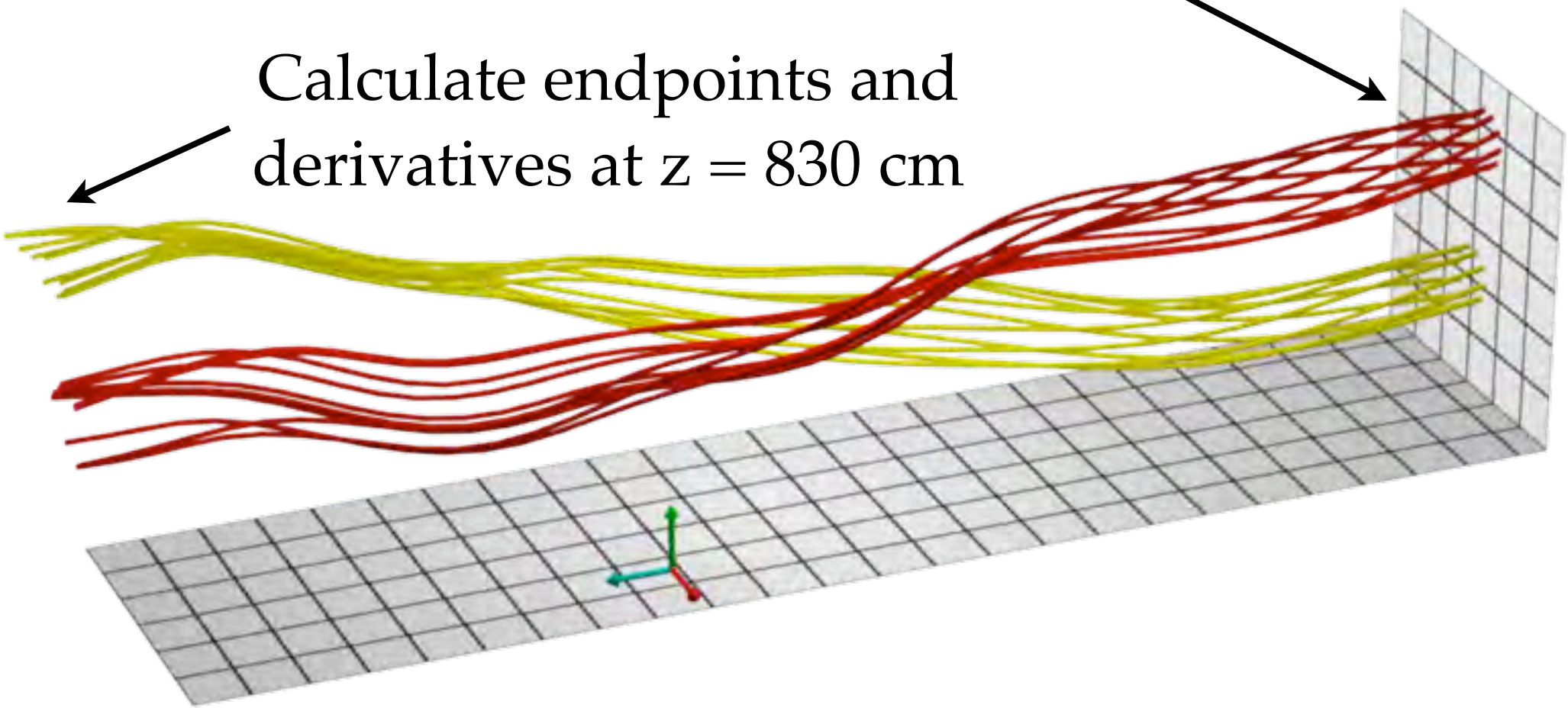
QSL calculation

QSL region if N>>1

in this experiment N=2000

Seed field lines at z = 64 cm

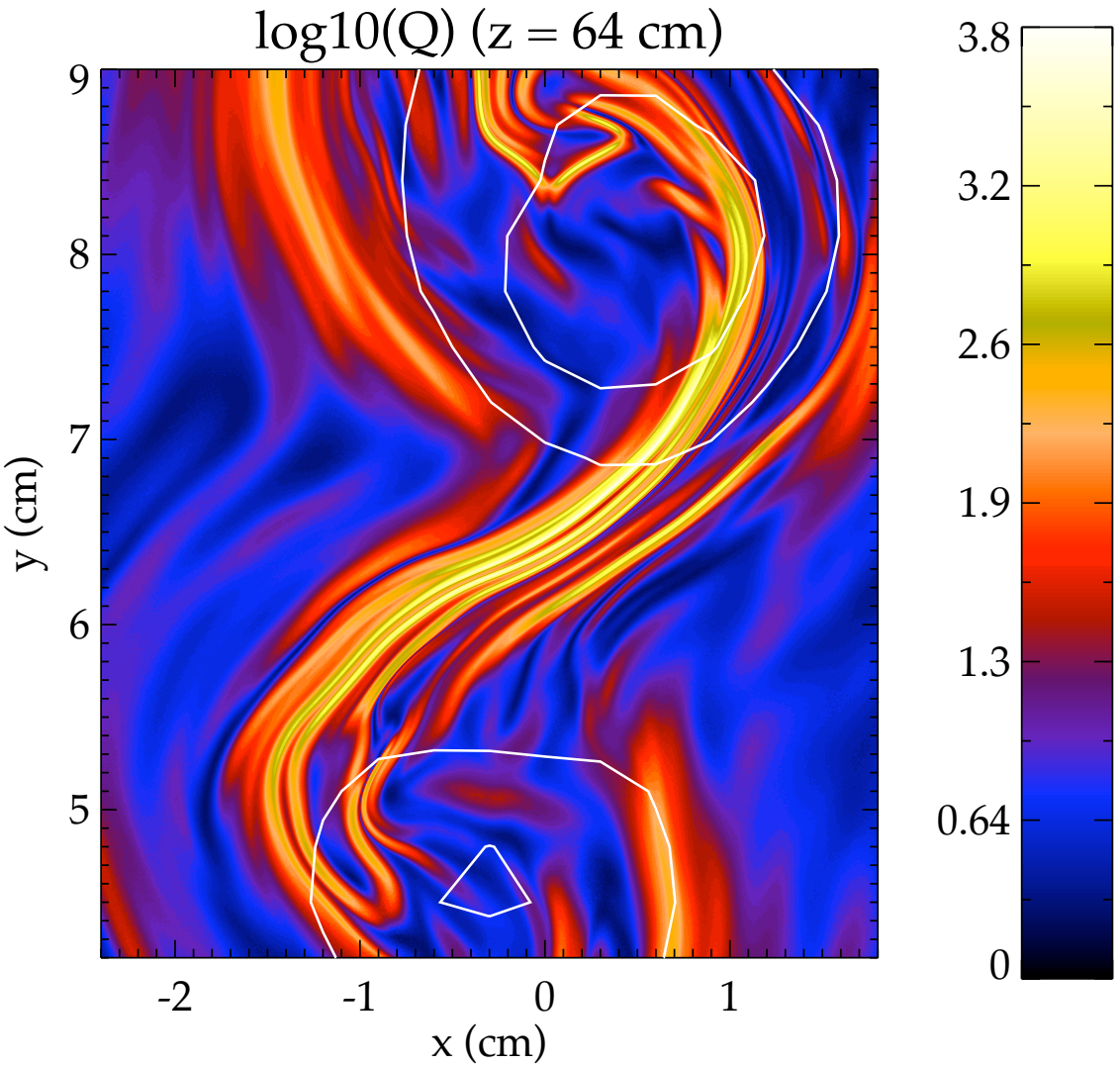
Calculate endpoints and derivatives at z = 830 cm



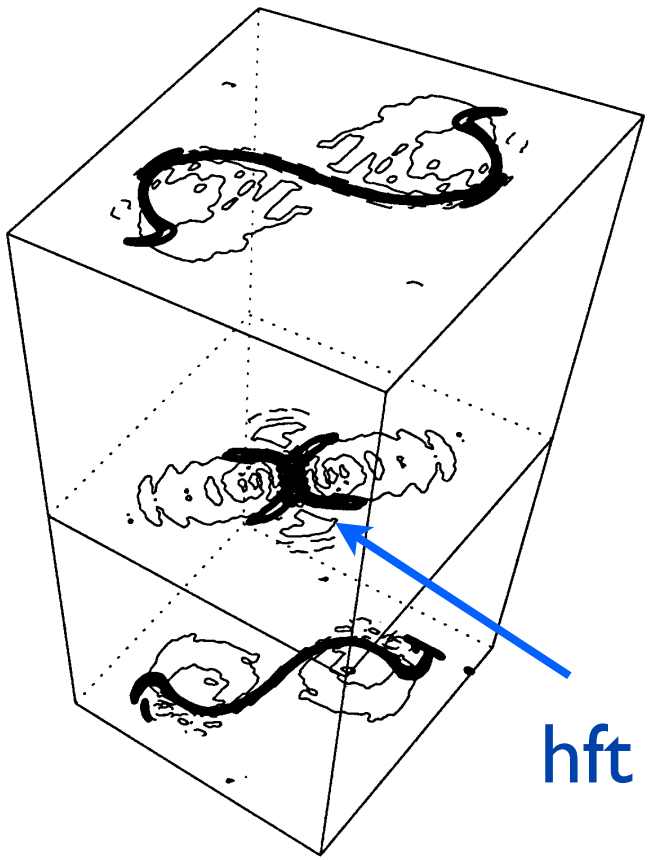
In the following slides, Q is shown during the merging phases

QSL forms between flux ropes

Experiment

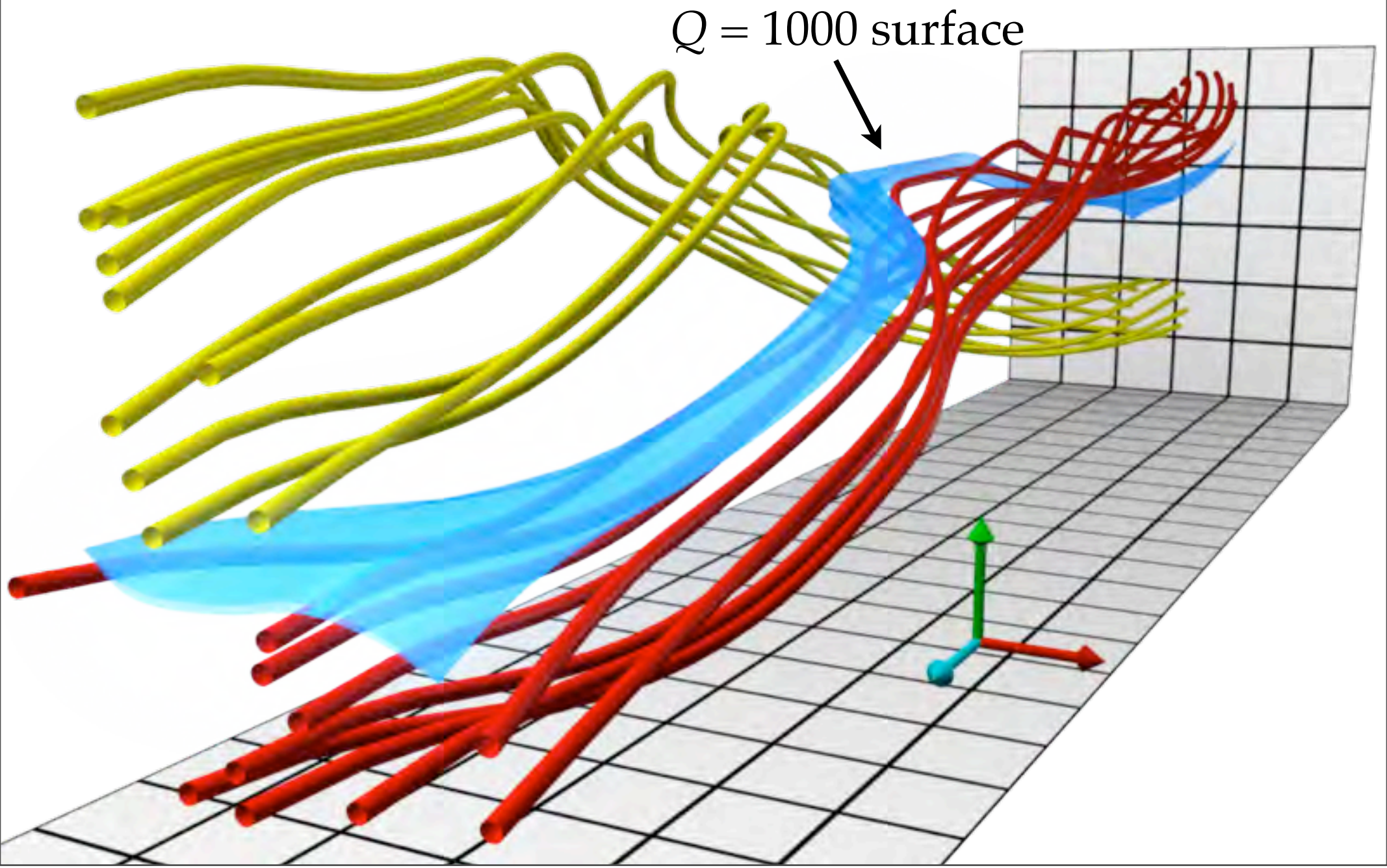


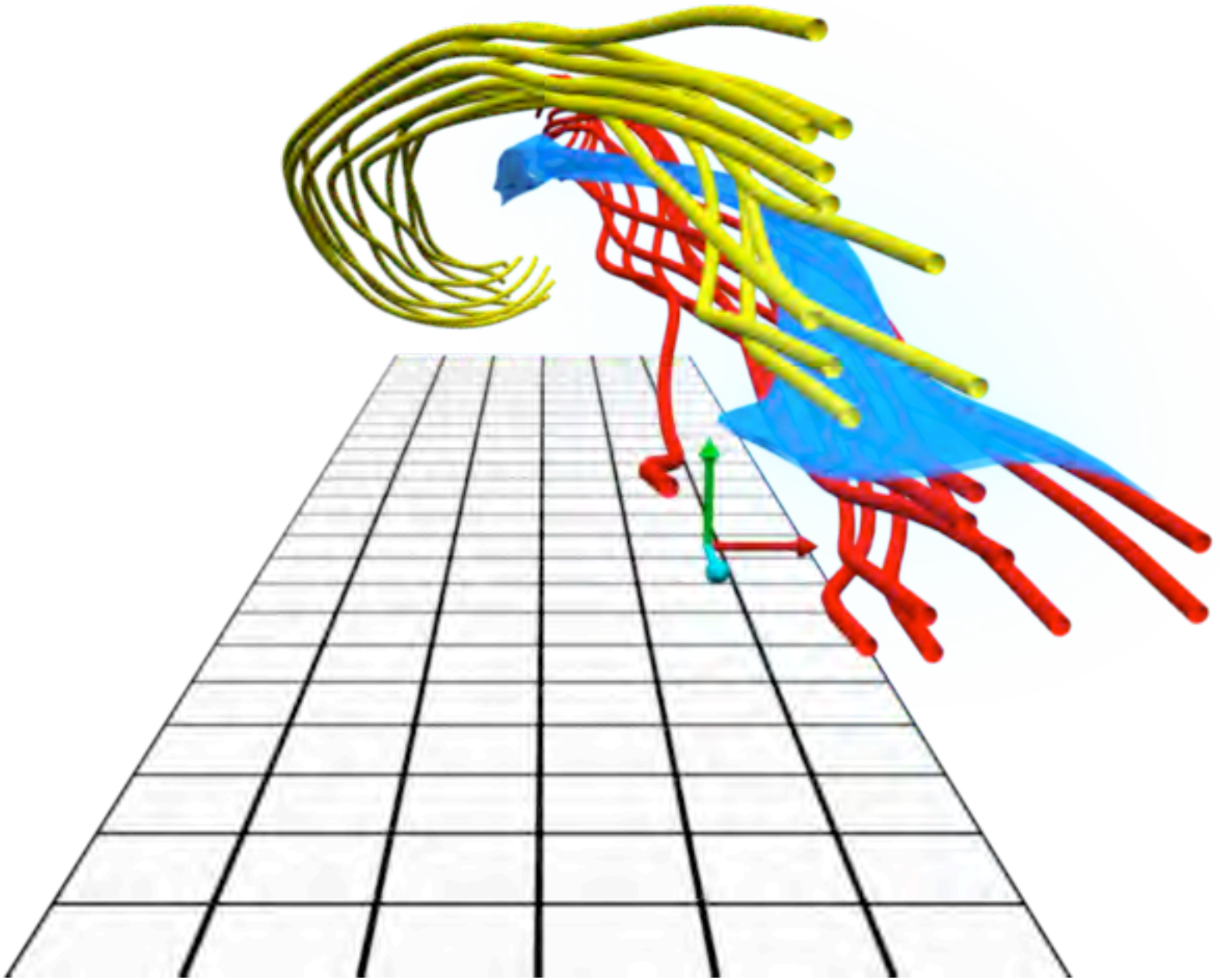
Q calculated between $z = 64$ cm and $z = 830$ cm planes at $t = 1.7$ ms.
J_z =-5.5,-3 A/cm^2 contours overplotted.



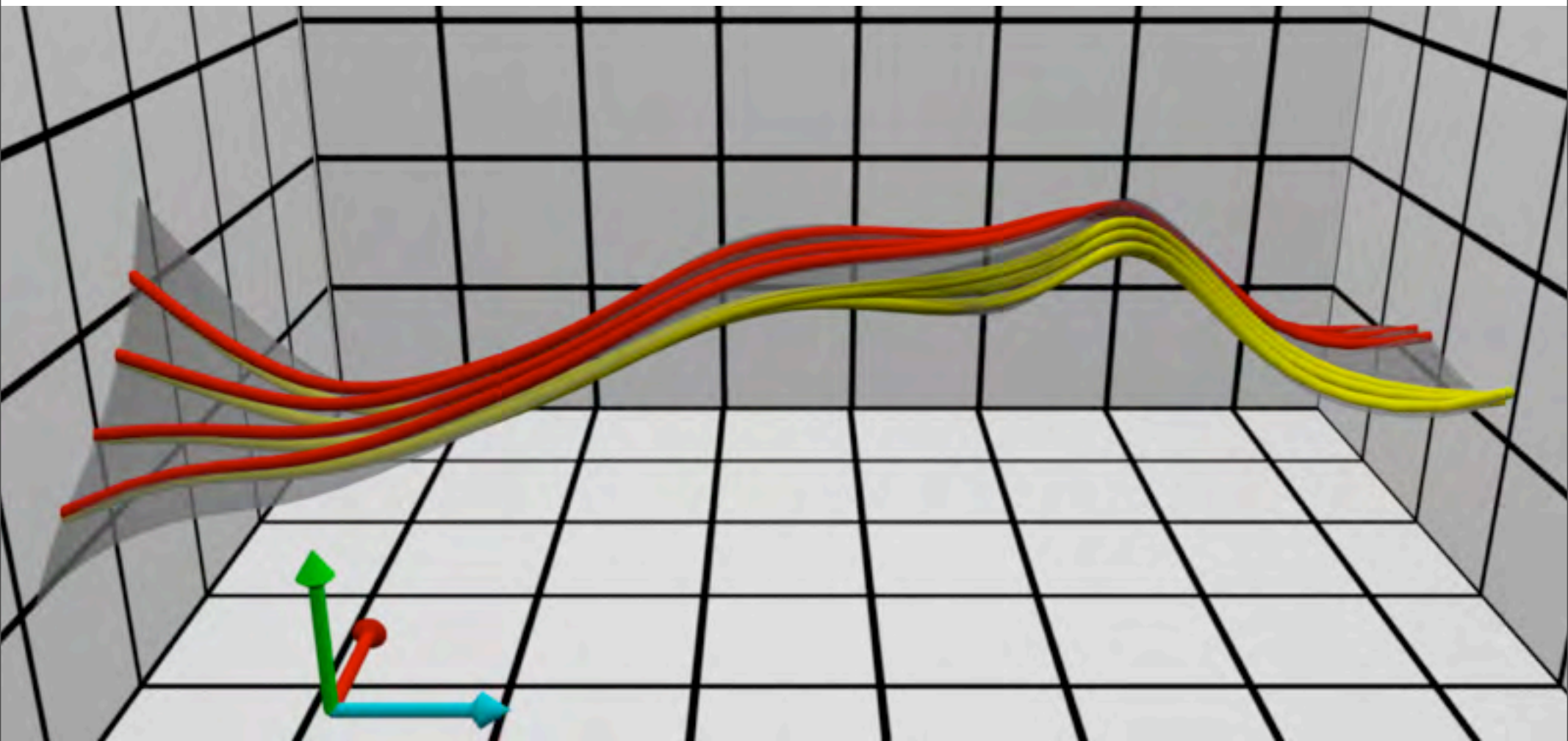
Numerical simulations of merging twisted flux tubes [Milano, et al. ApJ 1999]

QSL forms between flux ropes





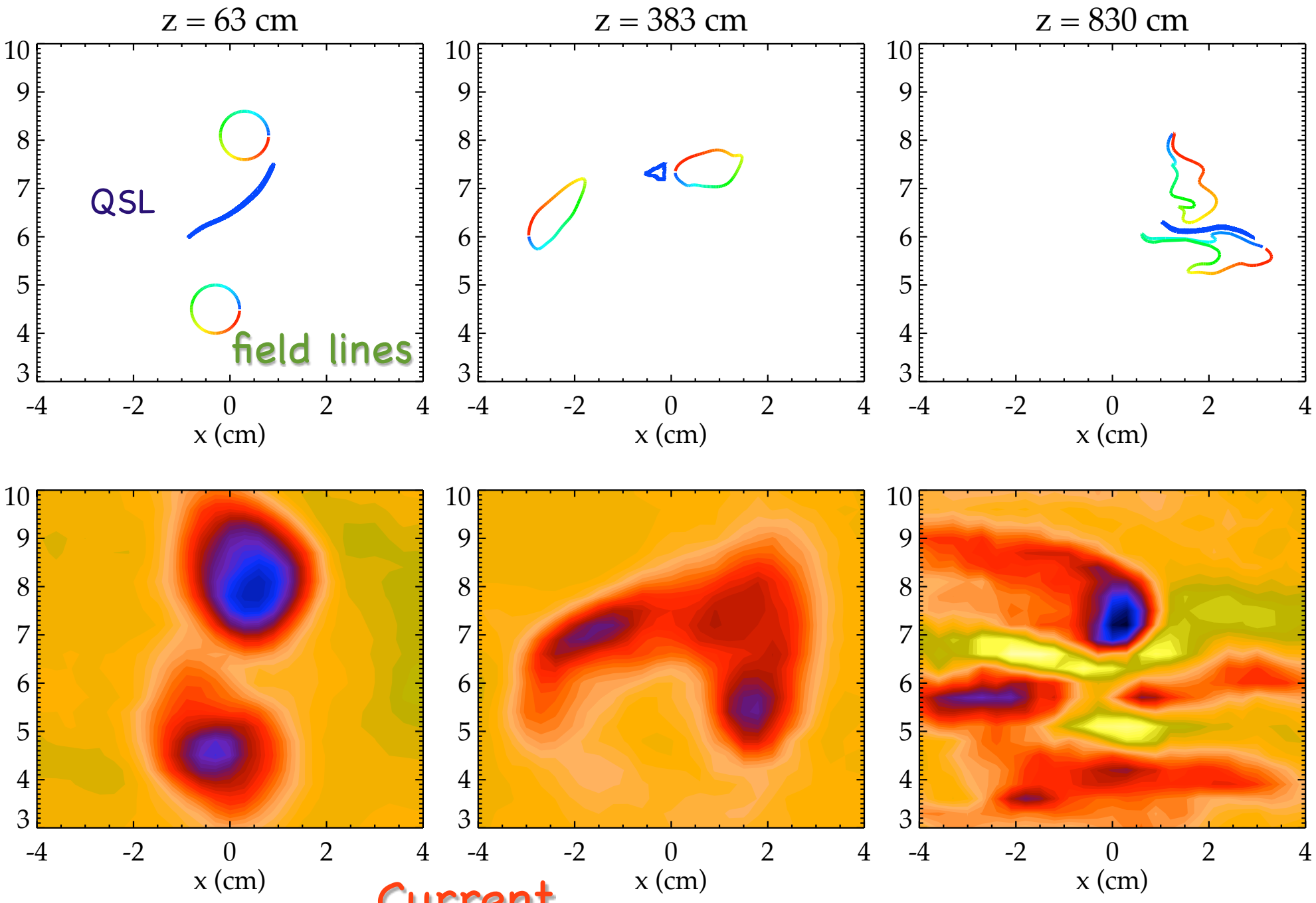
QSL has hyperbolic flux tube geometry



compressed 100x axially

- Initial field line separation is ~0.05 cm, but diverges to ~3 cm.

Axial slices show HFT (hyperbolic flux tube) structure



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A QSL has been observed when magnetic flux ropes merge and there is reconnection

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The flux rope current system becomes, sheetlike, complex and return currents appear.

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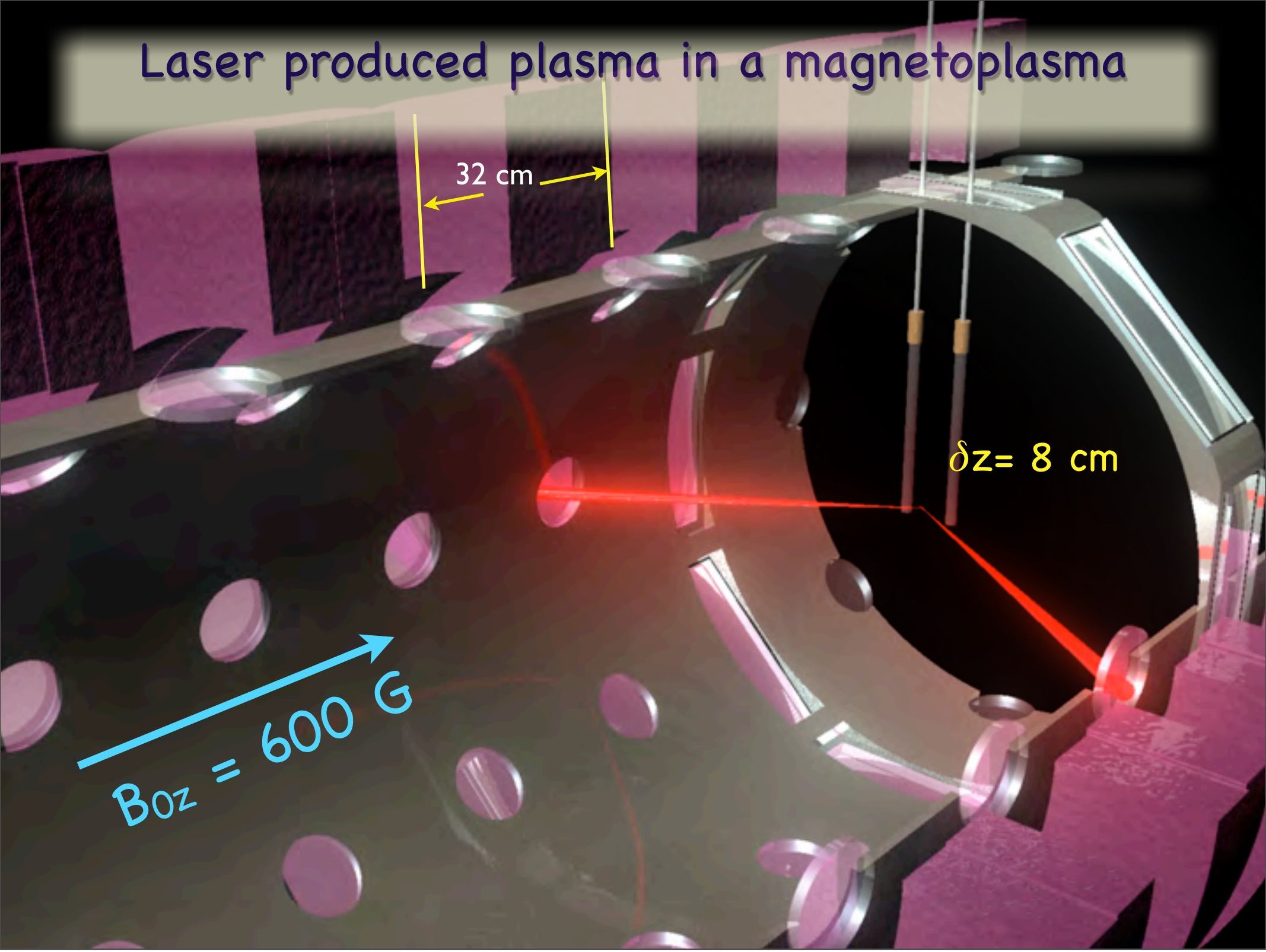
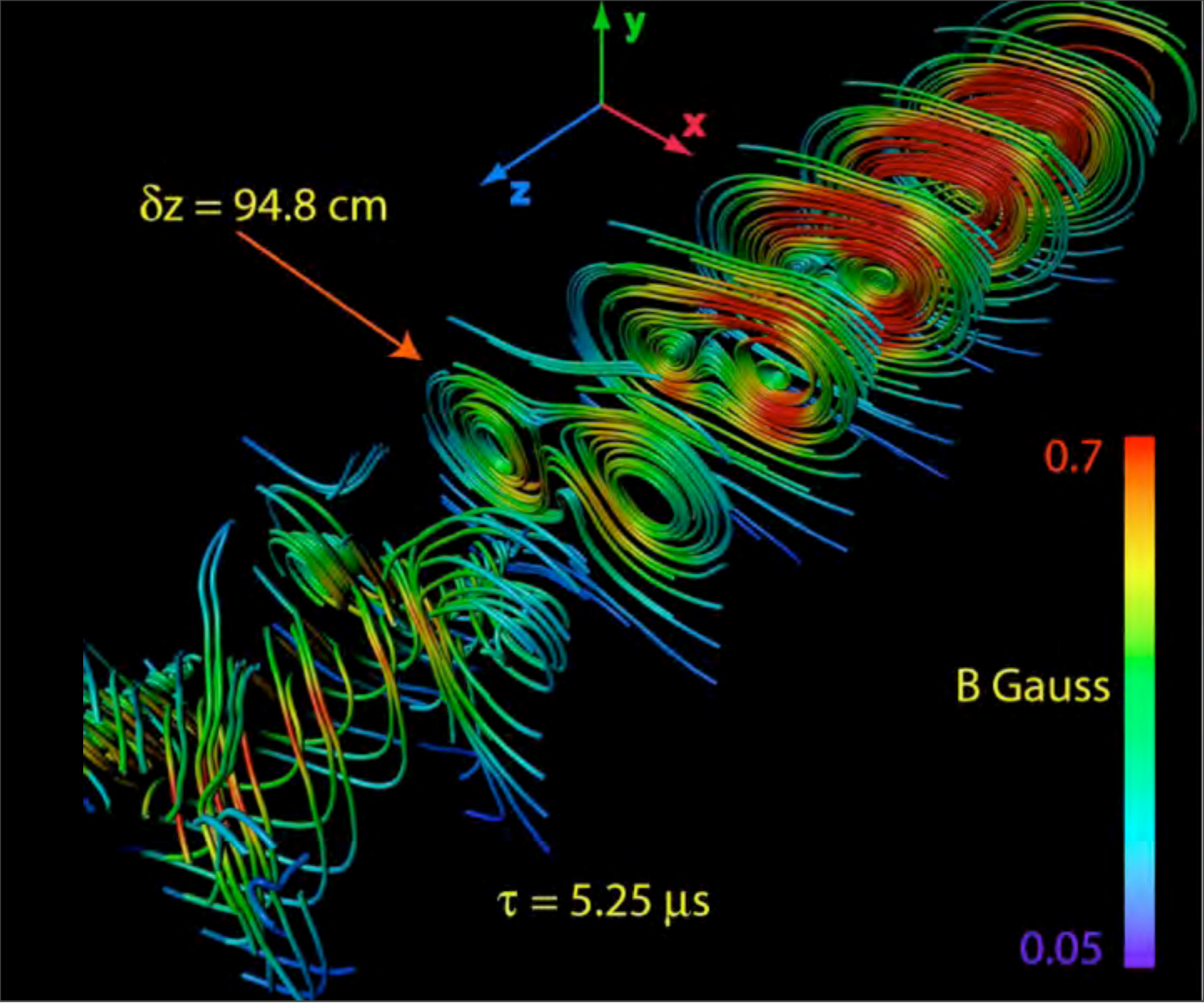
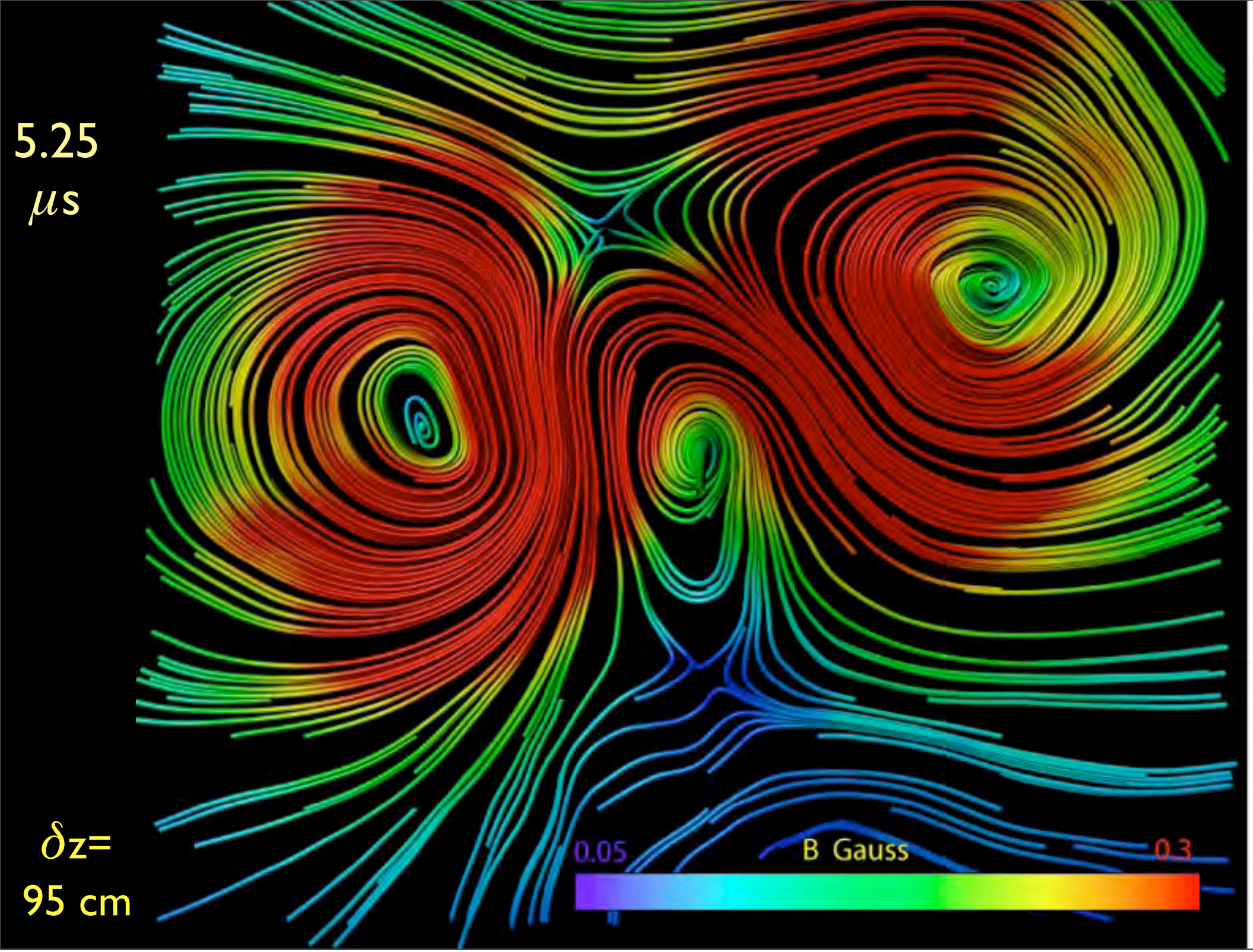
The flux rope current system becomes, sheetlike, complex and return currents appear.

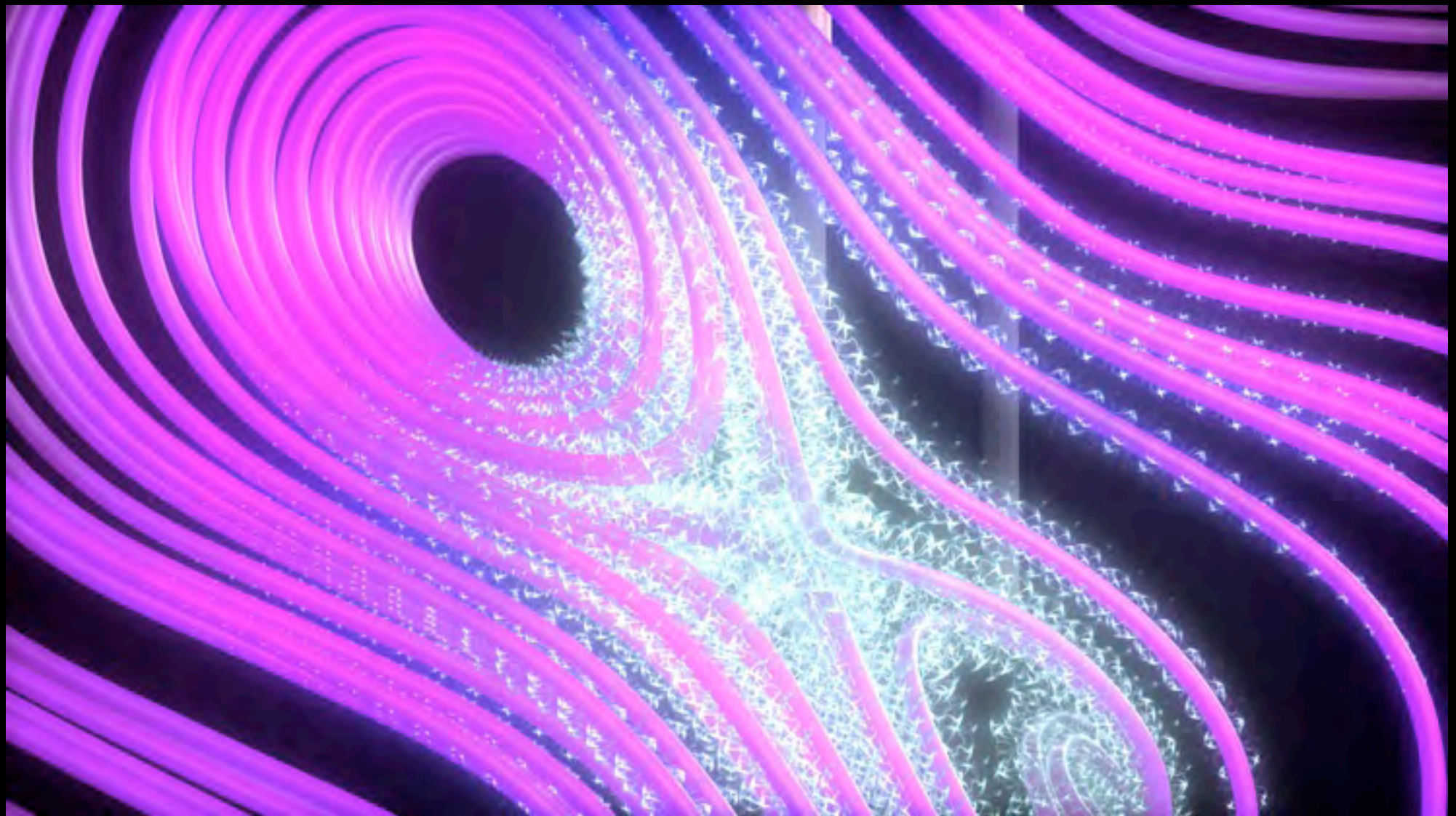
The QSL is an indicator that reconnection is occurring, we await a relationship between Q and the reconnection rate.

Laser produced plasma in a magnetoplasma




y
x
z
δz = 94.8 cm
0.7
B Gauss
0.05
τ = 5.25 μs

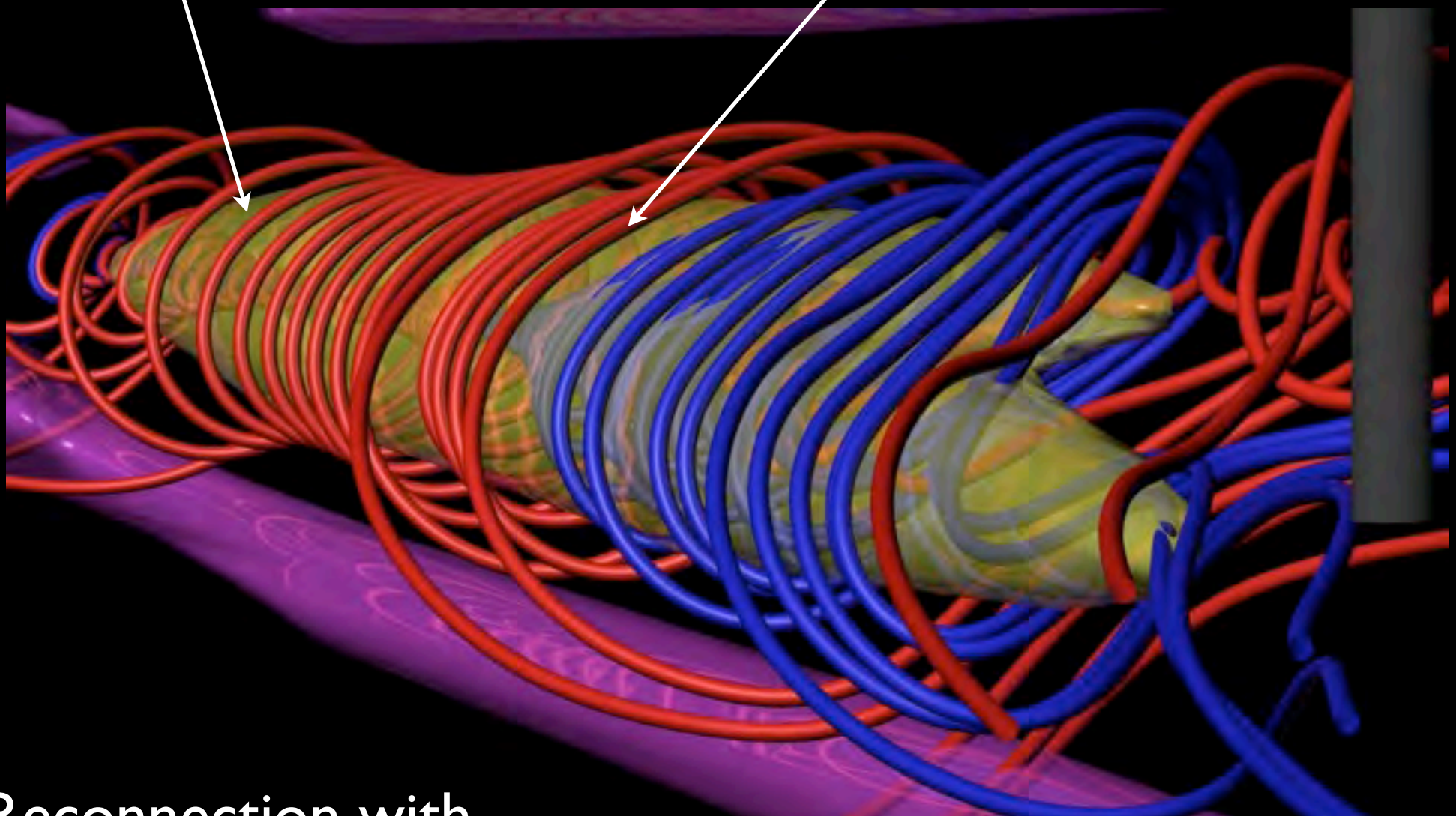

5.25
μs
δz=
95 cm
0.05
B Gauss
0.3



t = 5.12 μs

Blines, E field

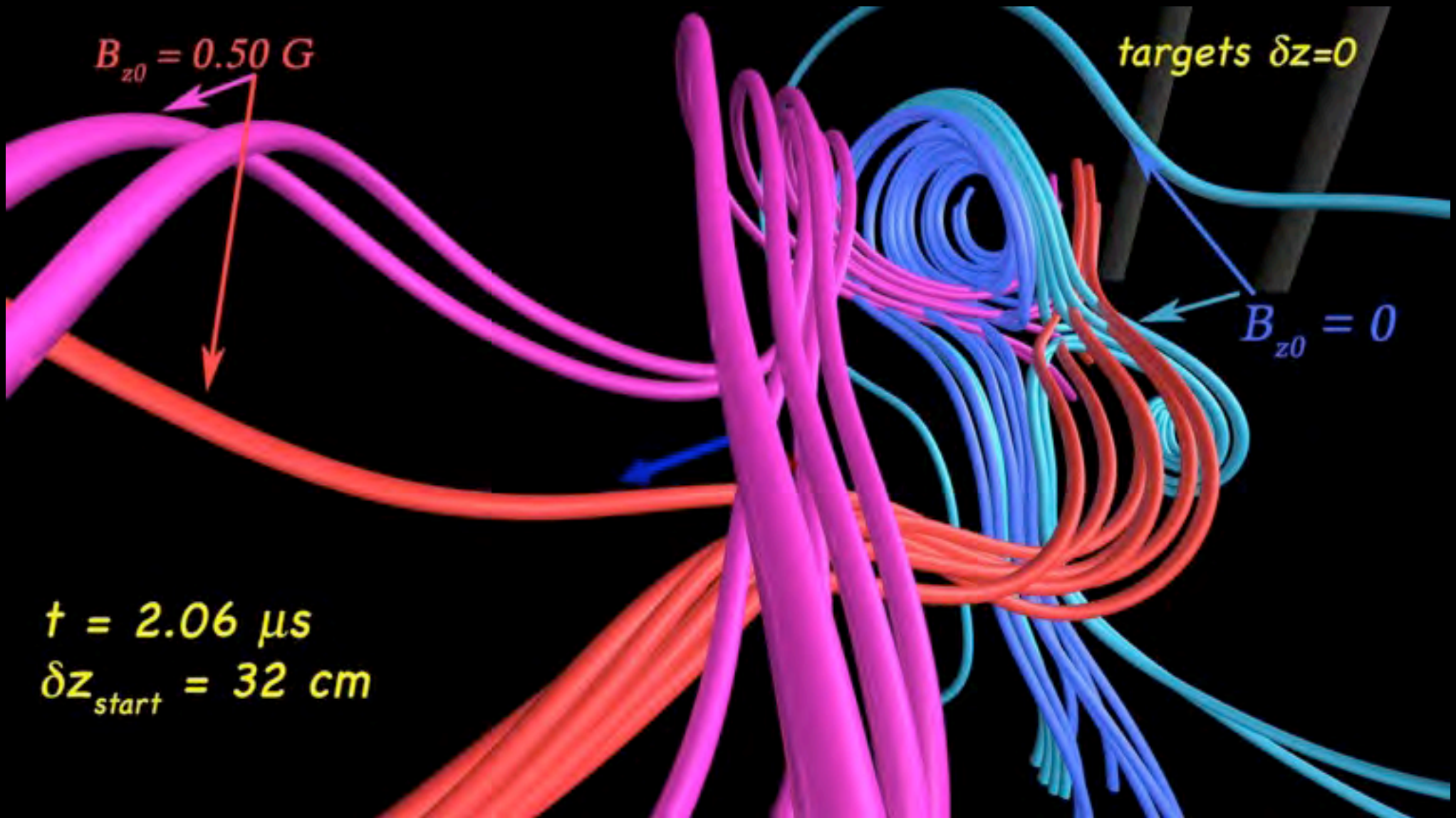
Colliding laser produced plasmas



Reconnection with Alfvén waves (Ipp)

τ = 5.5 μs

add small guide field



In general (in nature) Magnetic Field line reconnection is three dimensional and is one aspect of what transpires within 3 dimensional current systems.

Reconnection is part of the picture but not the whole story