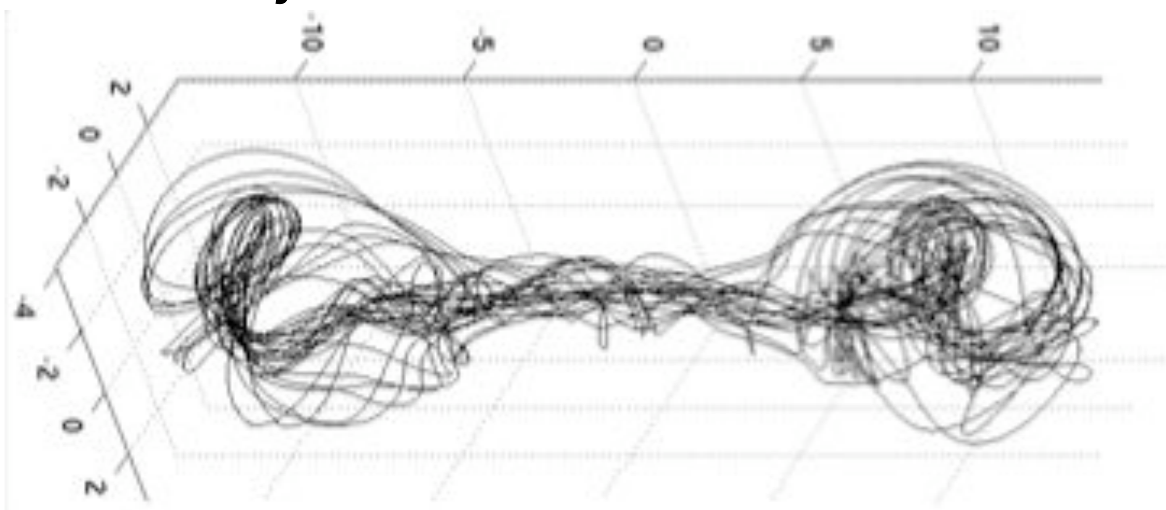
Flux-conversion dynamo in a lab plasma

The lab toroidal plasma dynamo

- Converts poloidal to toroidal flux
- Redistributes magnetic field
- Half of a classical dynamo
- Relevant to jets



MHD computation, (H. Li)

Flux conversion in both the jet column and the lobe, mechanisms similar to that of the lab

Mechanisms

- MHD alpha effect
  (with fluctuations arising from tearing instability)

- Effects beyond MHD

reconnection

(current-driven instability)

global magnetic structure

(dynamo effects)

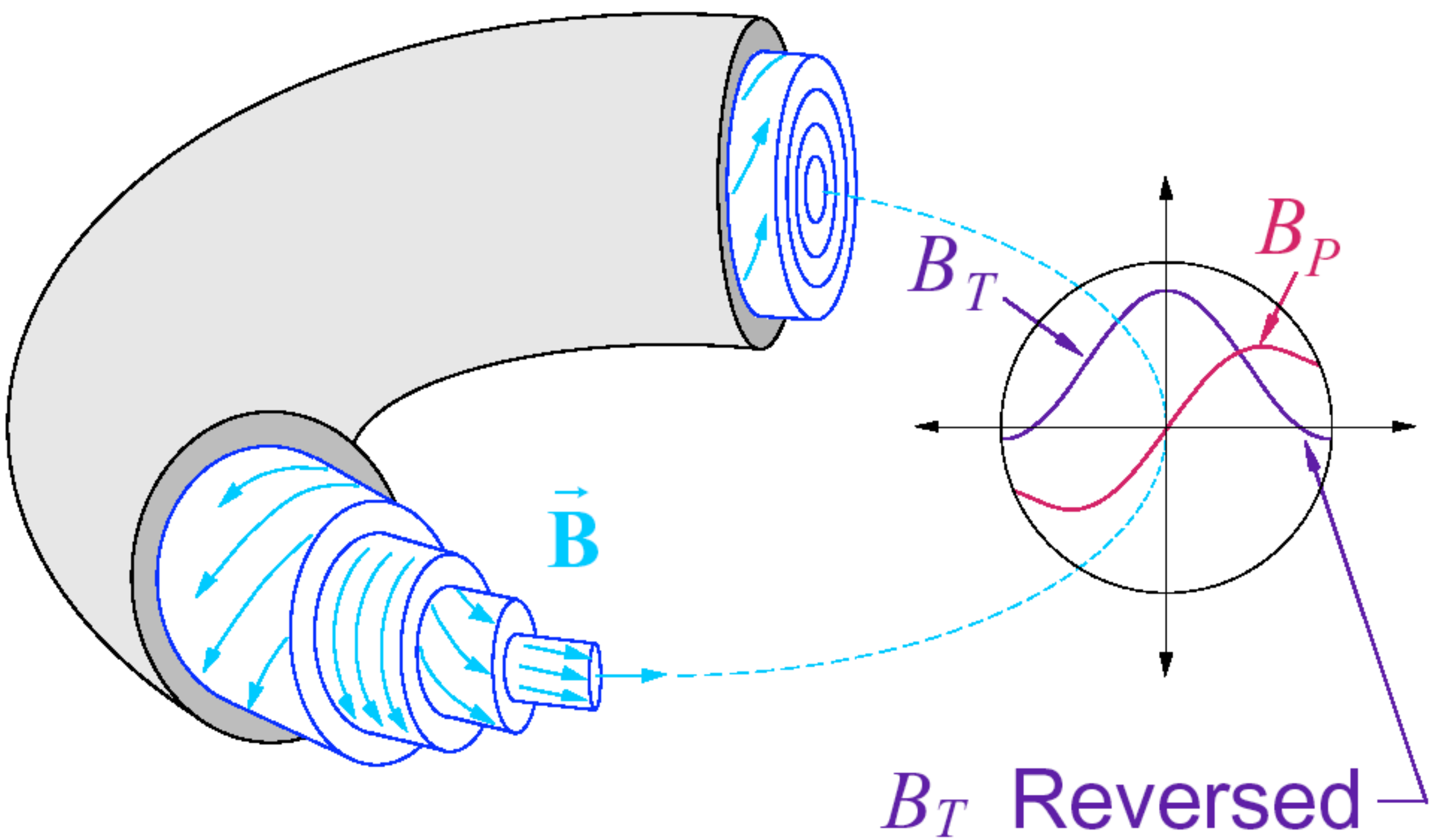
global flow structure

(momentum transport)

Outline

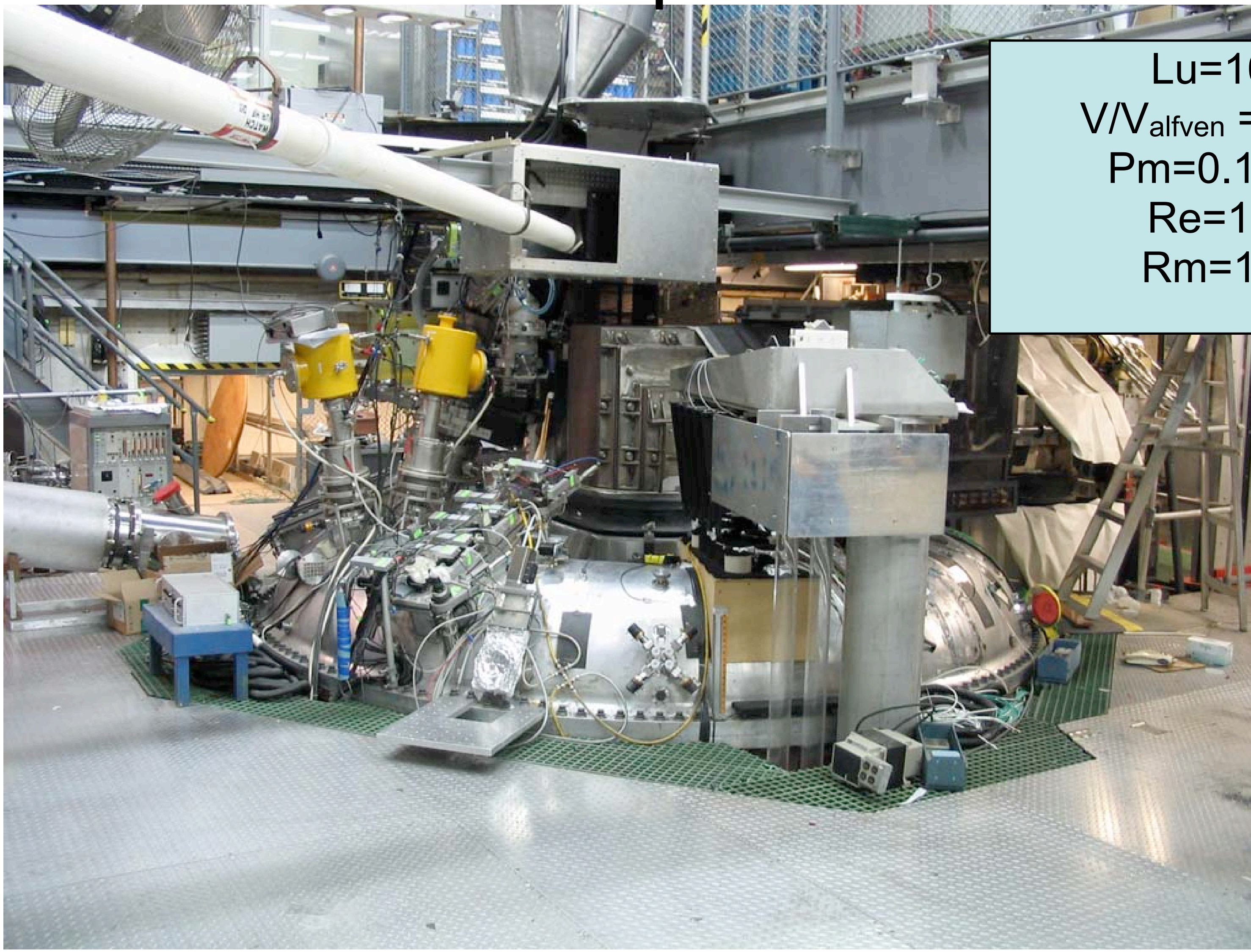
- MST description
- Observation of flux conversion dynamo events
- Mechanisms for dynamo

Magnetic field is helical



Reversed field pinch (RFP)

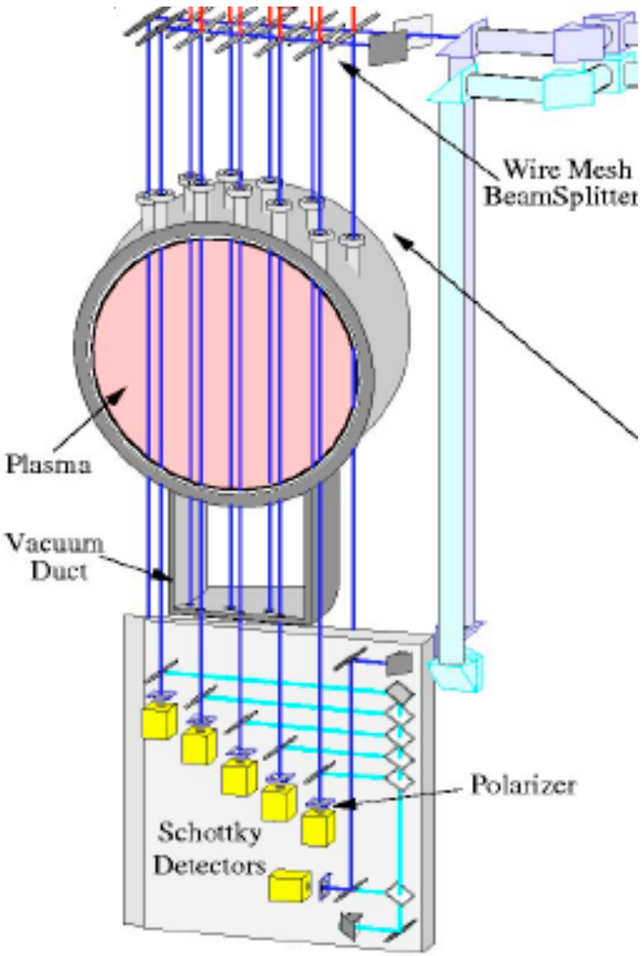
The MST experiment



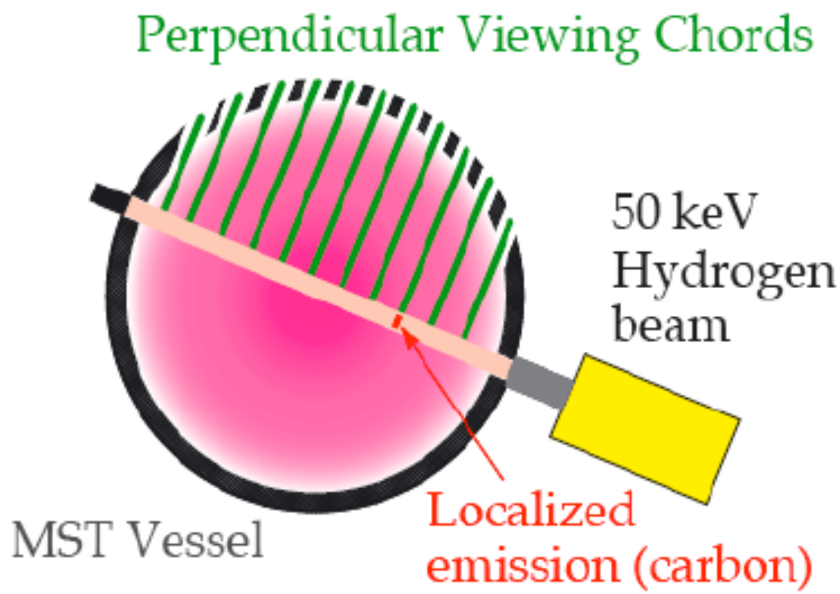
Lu=10^6
$V/V_{alfven} = 0.01$
Pm=0.1-0.5
Re=10^5
Rm=10^4

R = 1.5 m, a = 0.5 m, I ~ 0.5 MA (B ~0.4 T),
T ≤ 2 keV, n ≤ 4 x10^{13} cm^{-3}

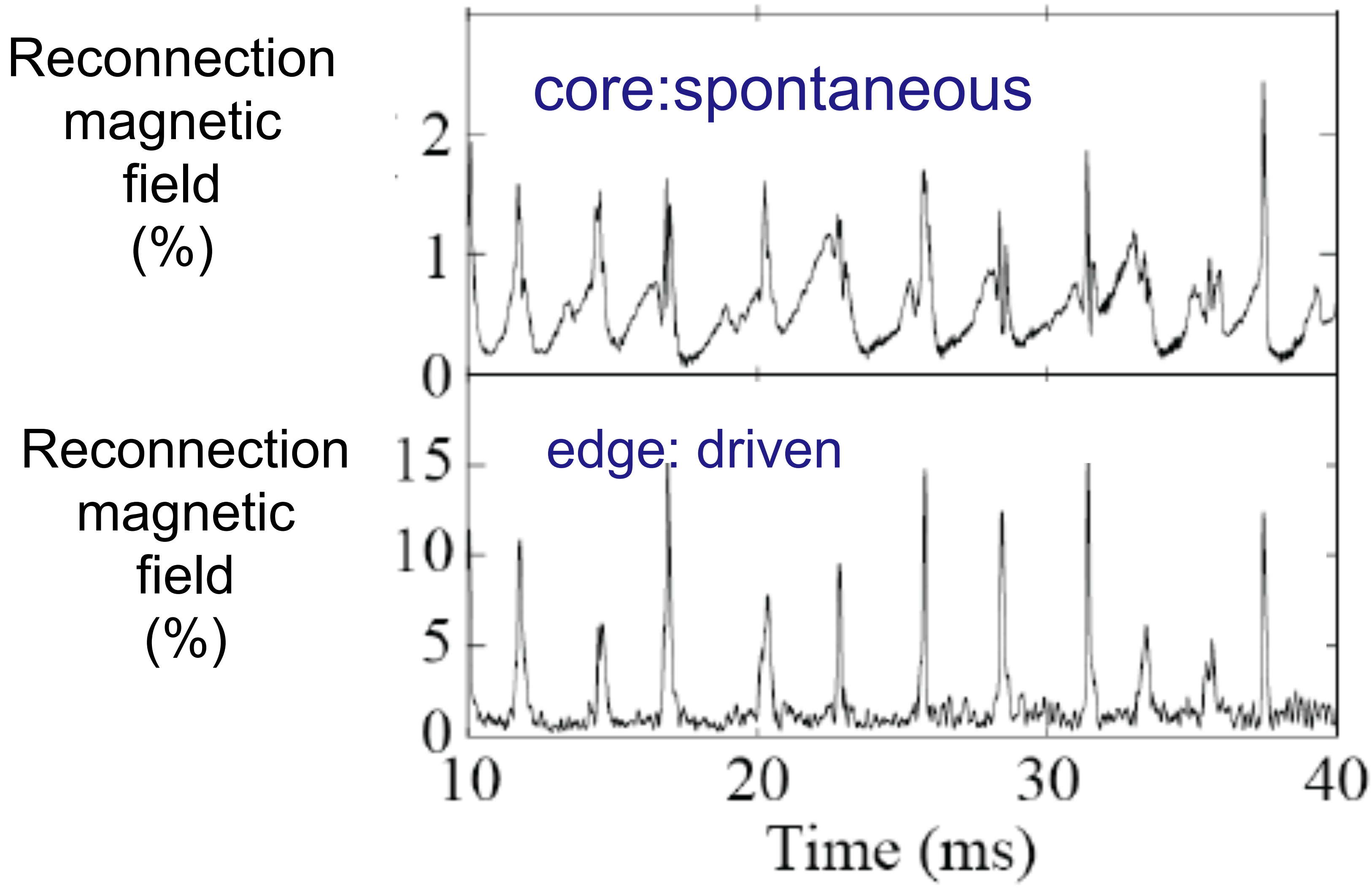
laser Faraday rotation
(for B, j)



active spectroscopy
(for v)



reconnection/dynamo events



The origin of reconnection

- Core reconnection is a linear tearing instability: spontaneous reconnection

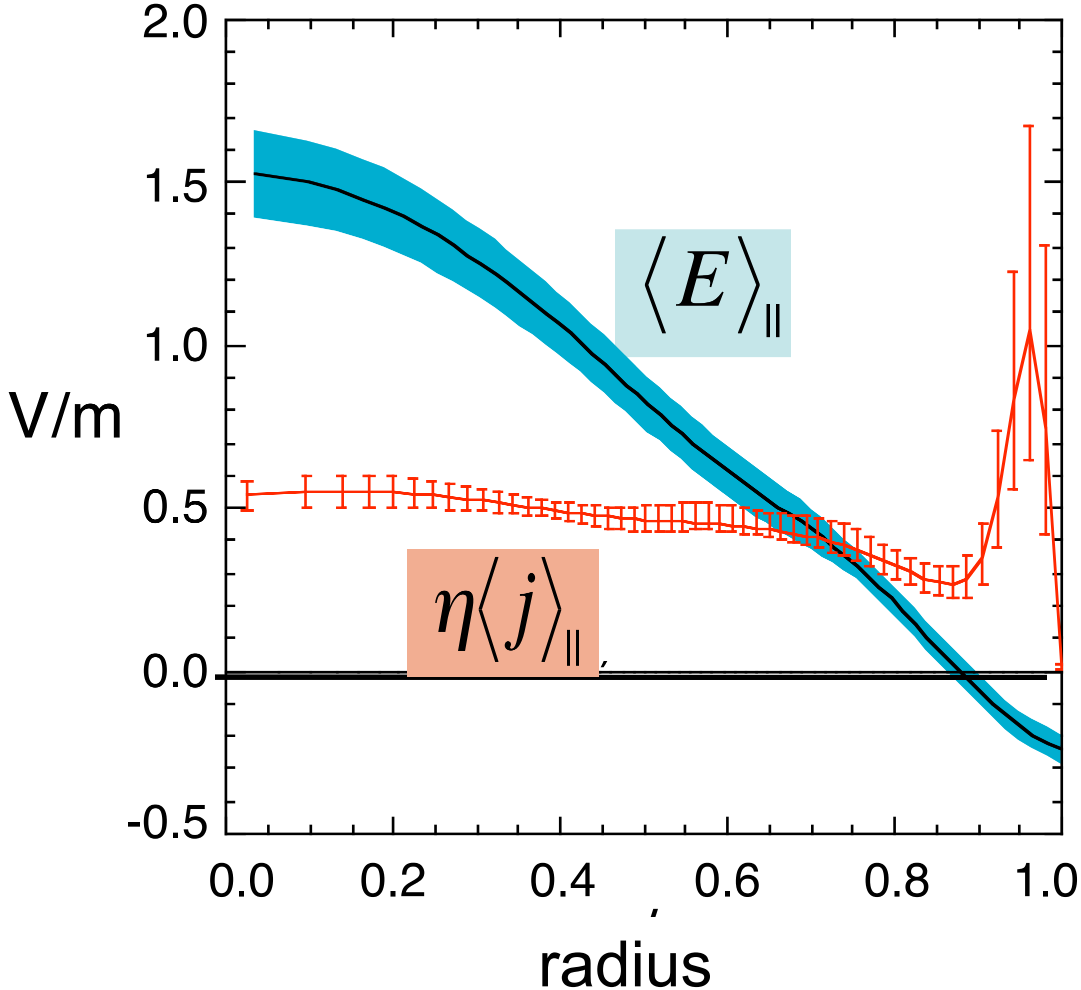
- Edge reconnection is driven nonlinearly by the core modes: driven reconnection

Tearing instability

- Current-driven, by $\nabla(J_{||}/B)$
- Resistive MHD instability
- Causes reconnection and dynamo

Manifestations of the dynamo

Rearranging the magnetic structure

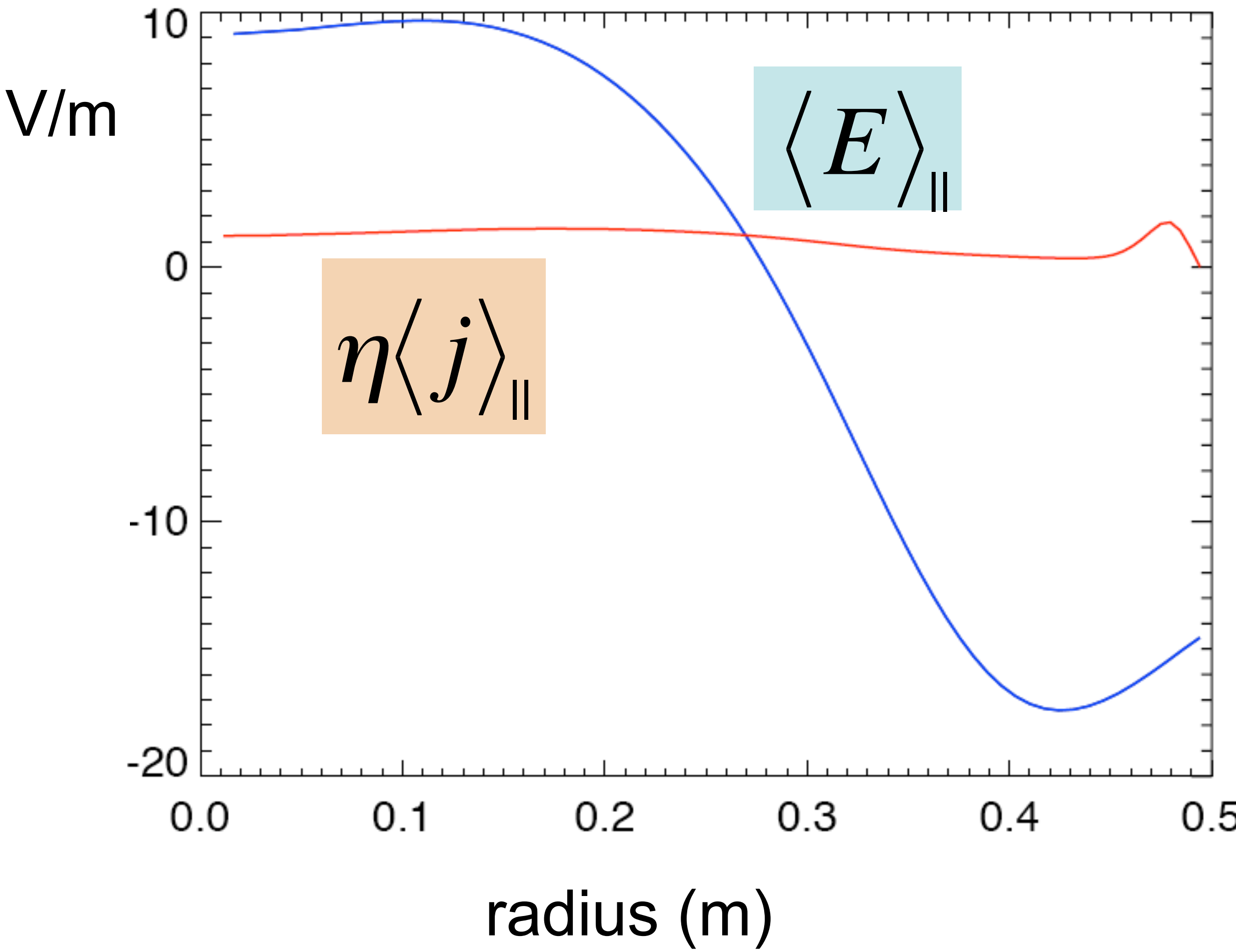


between events

$$\langle E \rangle_{\parallel} \neq \eta \langle j \rangle_{\parallel}$$

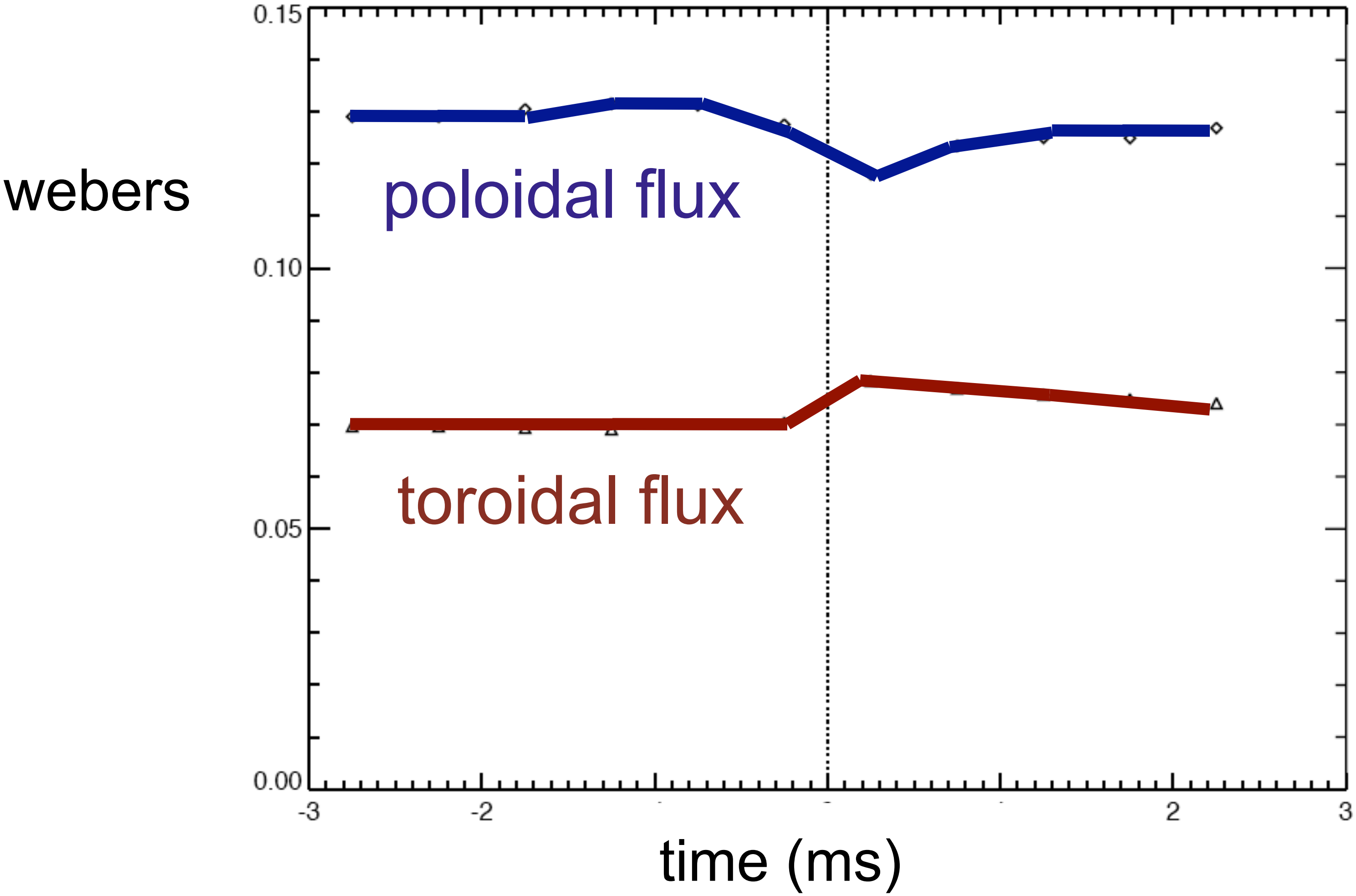
⇒ Radial transport of parallel current
(or field redistribution, flux conversion)

During a reconnection event



$$\langle E \rangle_{\parallel} >> \eta \langle j \rangle_{\parallel}$$

Flux conversion



half of a large-scale dynamo

converts poloidal to toroidal flux; not the inverse

The Standard MHD model

Mean field ohm's law

$$\langle E \rangle + \langle \tilde{v} \times \tilde{B} \rangle = \eta \langle j \rangle$$

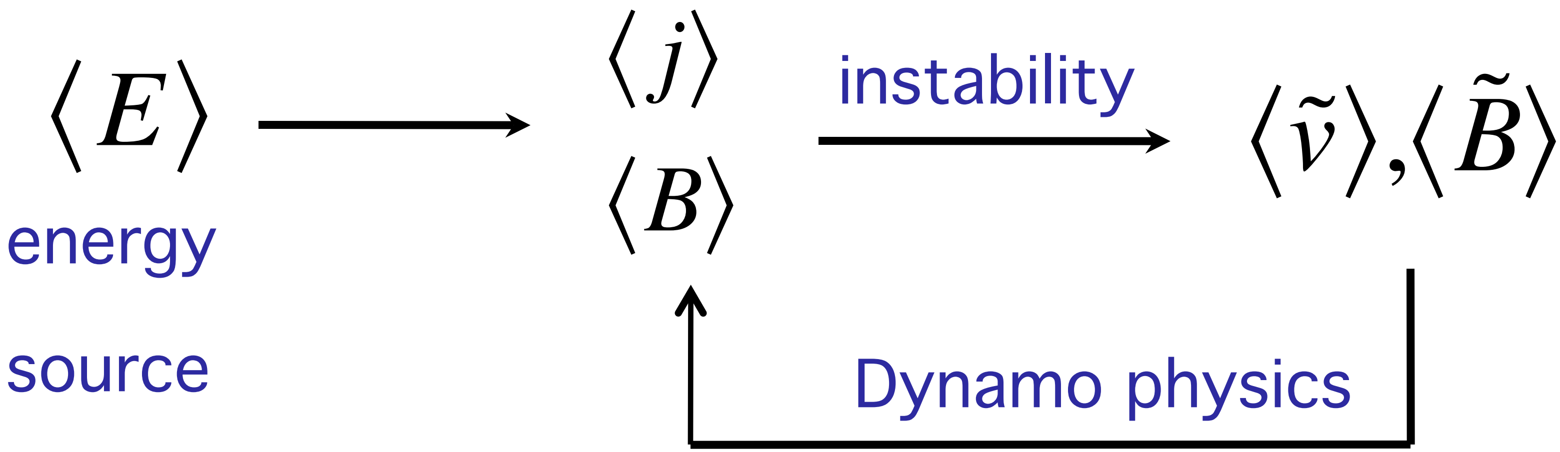
dynamo effect

$\tilde{v}, \tilde{B}$ are fluctuations from tearing modes

$\langle \ \rangle$ denotes mean quantities,

average over poloidal , toroidal directions;
depends on radius only

Altering the magnetic structure

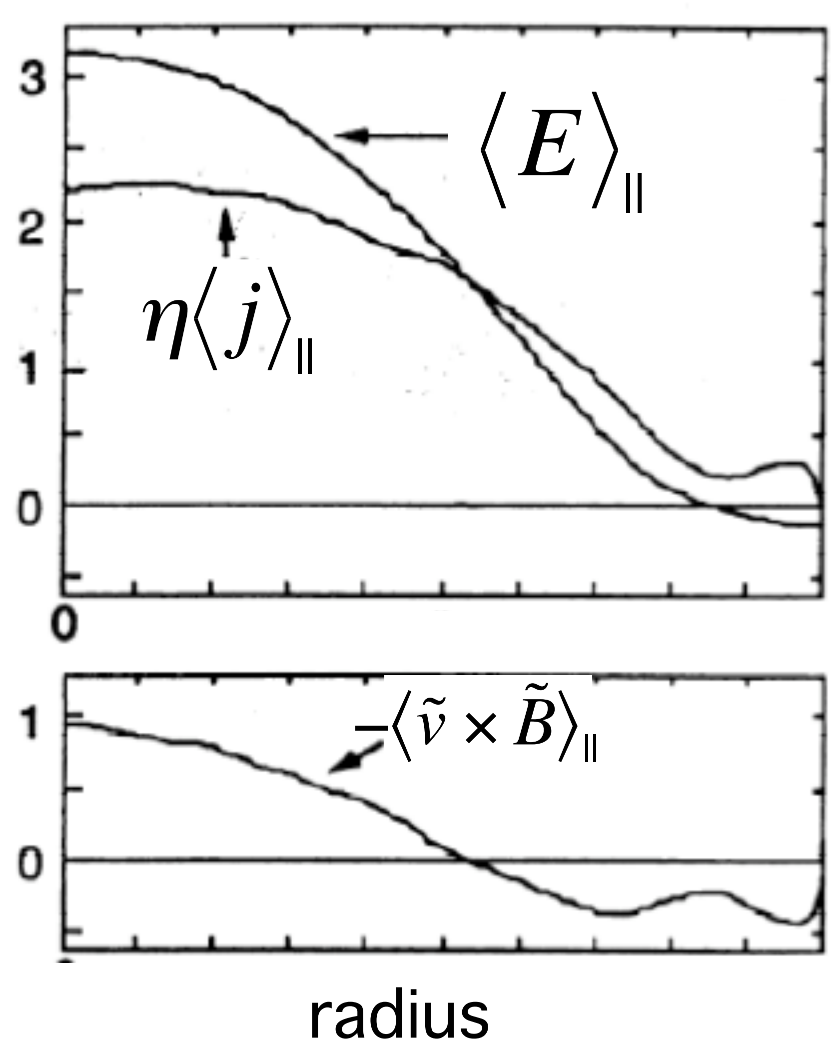


Quasilinear theory: $\langle \tilde{v} \times \tilde{B} \rangle \sim \nabla \bullet D \nabla \frac{\langle j \rangle}{\langle B \rangle}$ current diffusion

(Bhattacharjee, Hamieri;
Strauss;Boozer.....)

Nonlinear MHD computation: a complete description

From nonlinear MHD computation:

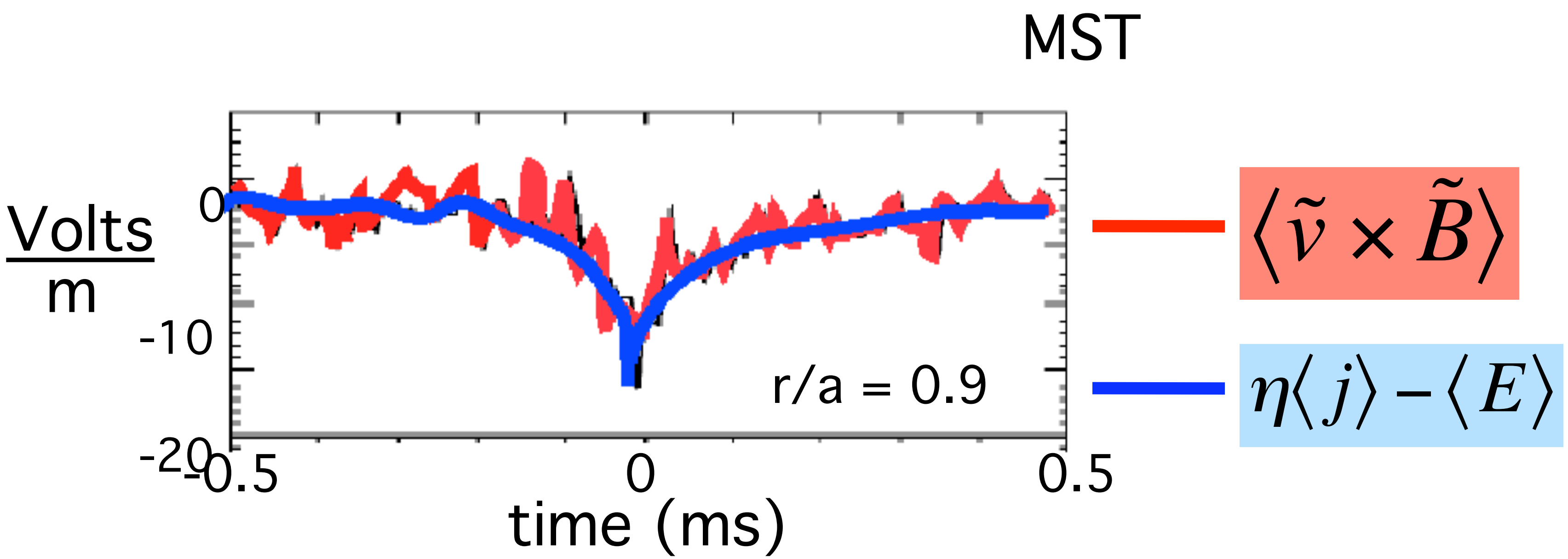


Schnack.....

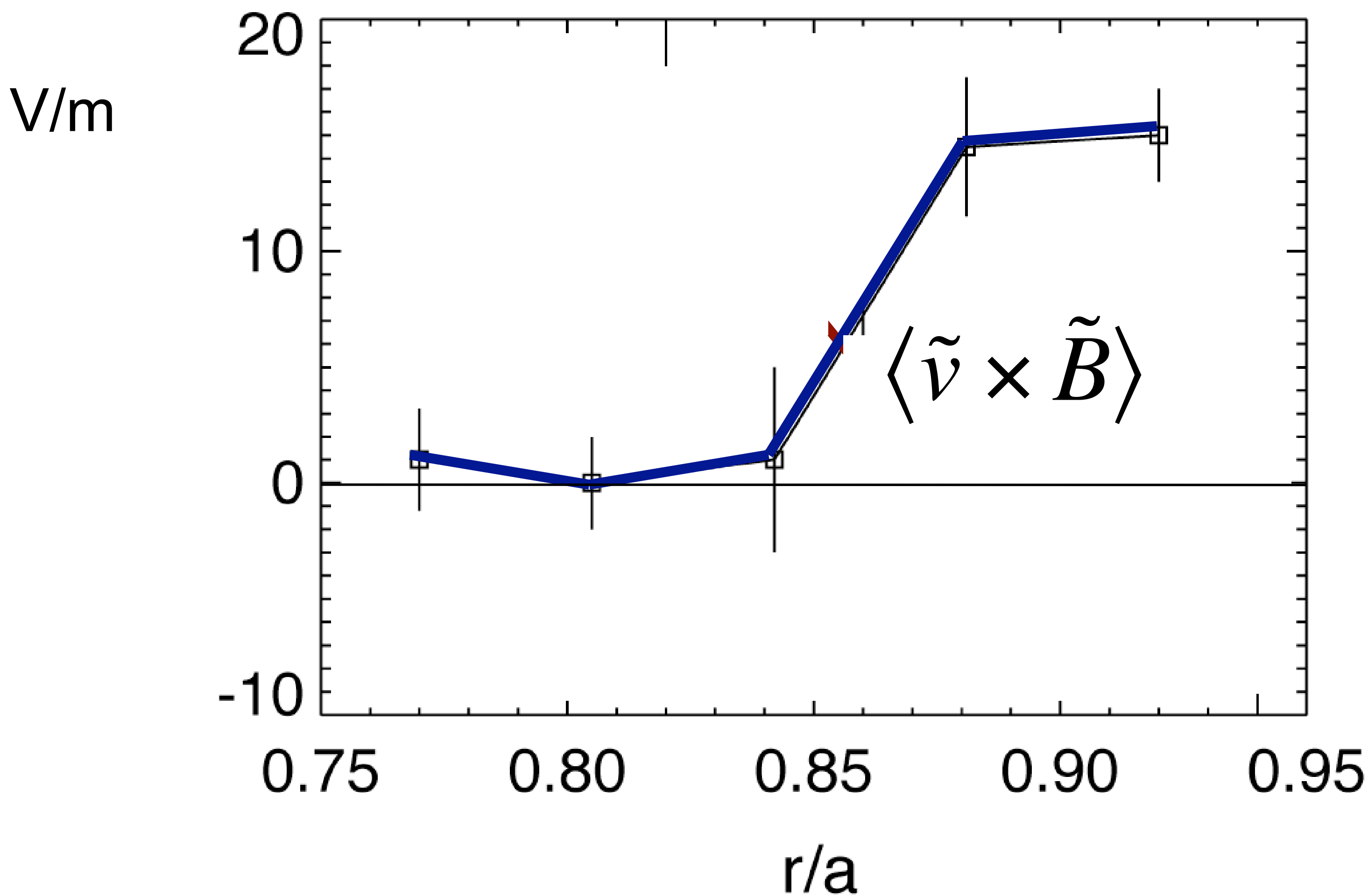
Predicts details of dominant magnetic fluctuations

MHD dynamo in experiment

MHD explains dynamo at some locations in MST



but not all locations..



another dynamo mechanism must be active

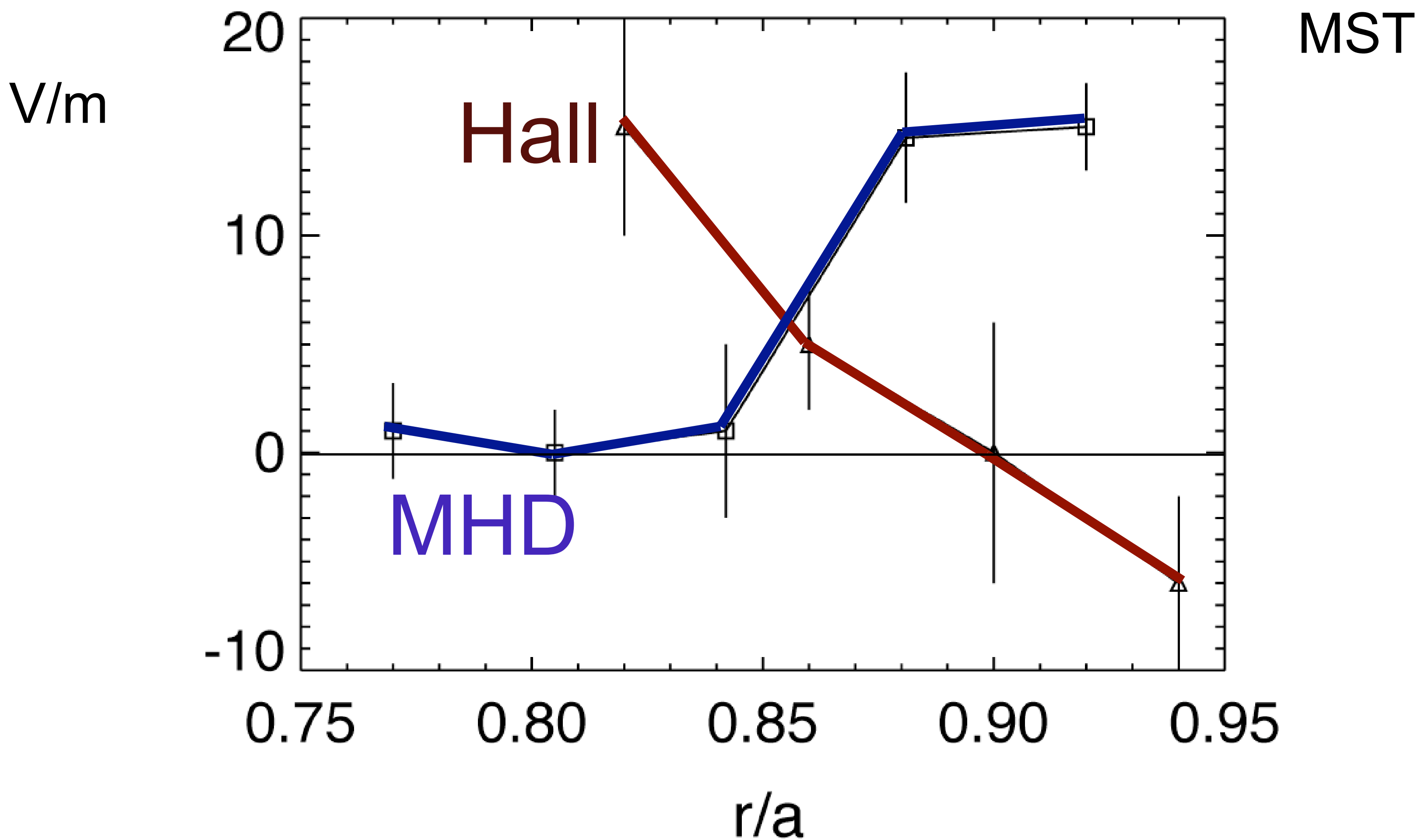
$$\langle E \rangle = \eta \langle j \rangle + \langle \tilde{v} \times \tilde{B} \rangle + \langle \tilde{j} \times \tilde{B} \rangle / ne + \ldots.$$

MHD

dynamo

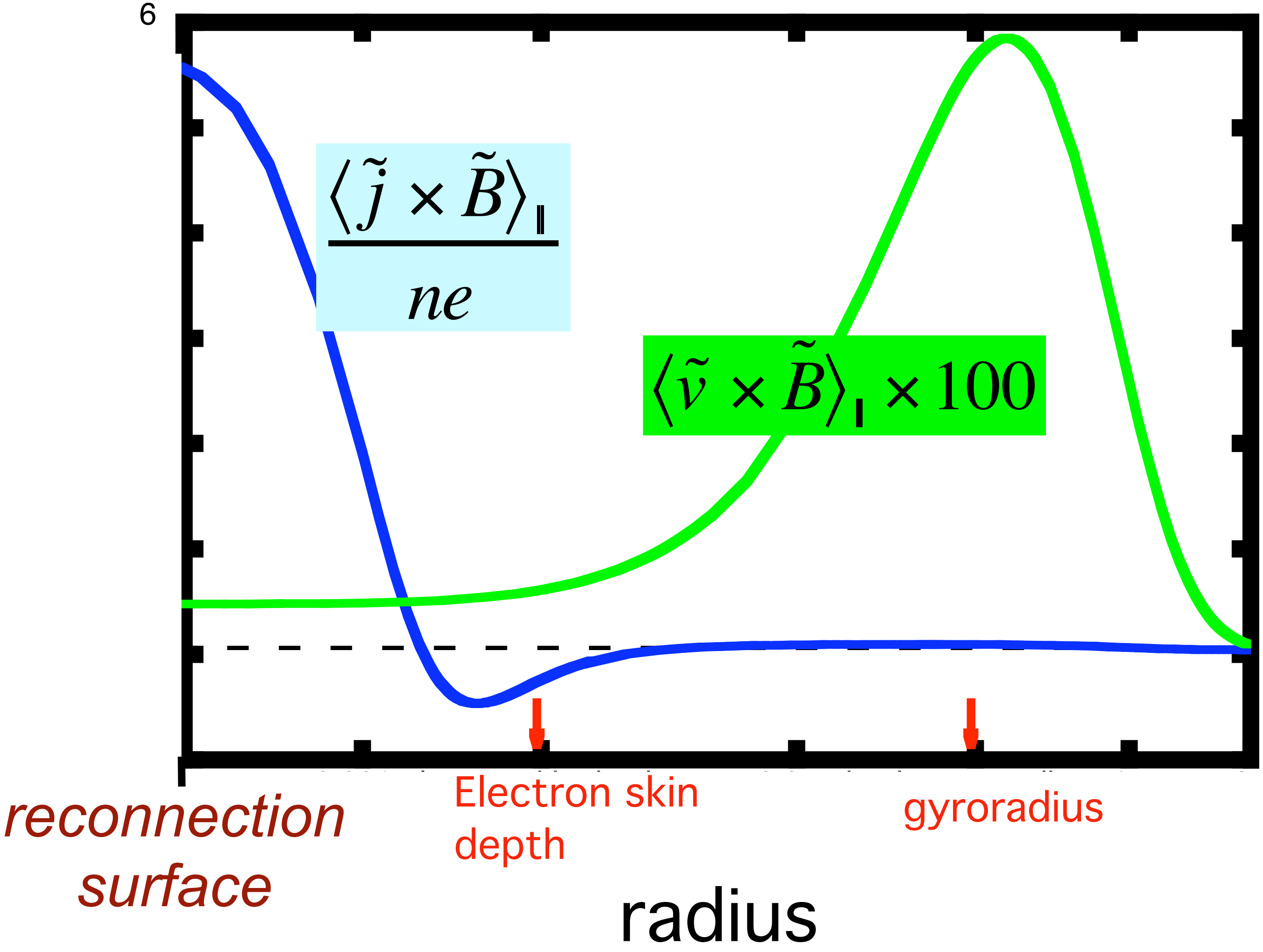
Hall

dynamo



MHD and non-MHD dynamo effects add to produce self-organized state

From quasilinear theory



Two-fluid nonlinear computation underway

Compare to magnetorotational instability

Tearing instability	MRI
Resistive MHD instability	Ideal MHD instability
Current gradient driven	Flow gradient driven
Transport by fluid stresses	same
Transport amplified by nonlinear coupling	?
Mode saturates by transporting current,momentum transport is parasitic	Mode saturates by transporting momentum (partly)
In lab, alters flow	In disk, drives particles inward
Mode does NOT saturate by generating mean flow	Mode also saturates by generating mean magnetic

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Hall dynamo = Lorentz force

$$\rho \frac{\partial \langle v \rangle_{\parallel}}{\partial t} = -\rho \langle \tilde{v} \bullet \nabla \tilde{v} \rangle_{\parallel} + \langle \tilde{j} \times \tilde{B} \rangle_{\parallel}$$

Reynolds stress

Maxwell stress

Hall dynamo ⇨ plasma flow altered

dynamo and momentum transport are coupled

Summary

- Flux conversion robust in lab plasma
- Two-fluid effects are important

  (related to two-fluid reconnection, but dynamo is a nonlinear effect)
- Indicates strong effect of correlated intermediate-scale flows and fields
- Two-fluid effects possibly important in flux conversion in jets