Overview of Results in the MST Reversed Field Pinch

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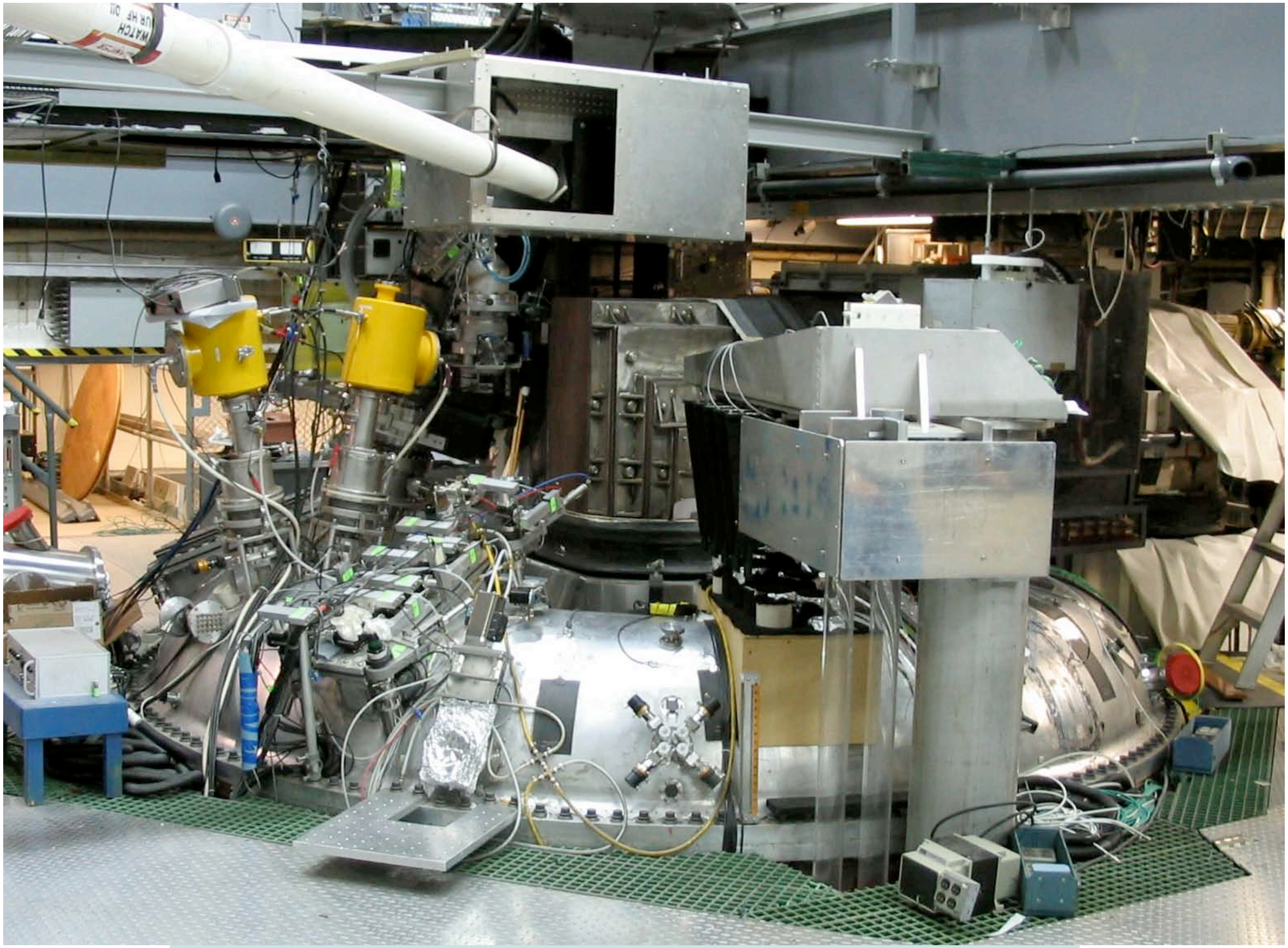
MST



a = 0.5 m, R = 1.5 m, I ~ 0.5 MA

Two physics regimes in the RFP

- Standard confinement

  large magnetic fluctuations

  large transport

  strong magnetic self-organization
  (reconnection, dynamo.....)

- Improved confinement

  reduced magnetic fluctuations

  reduced transport

  reduced magnetic self-organization

Standard regime

Vehicle for understanding magnetic self-organization

Improved confinement regime

new physics regime

($q < 1$ everywhere,
with tokamak-like confinement and high beta)

Outline

Standard confinement regime

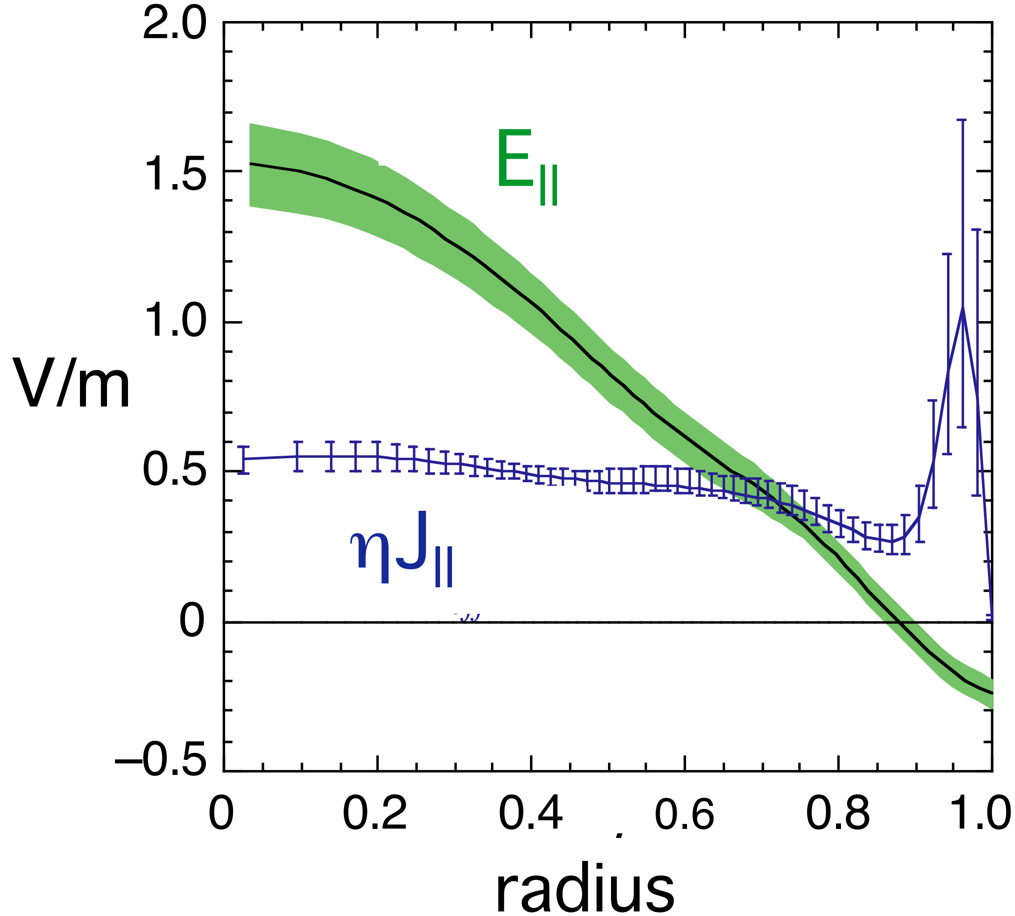
- Hall effects on dynamo and reconnection
- locking of tearing modes by wall eddy currents
- nonlinear origin of edge-resonant mode

Improved confinement regime

- suppression of the dynamo
- restoration of magnetic surfaces
- suppression of transport from stochastic fields

The dynamo

Dynamo = self-generation of current by fluctuations



$E \neq \eta j \Rightarrow$ strong dynamo

How is the dynamo current generated?

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

MHD dynamo

The standard model

Hall dynamo,

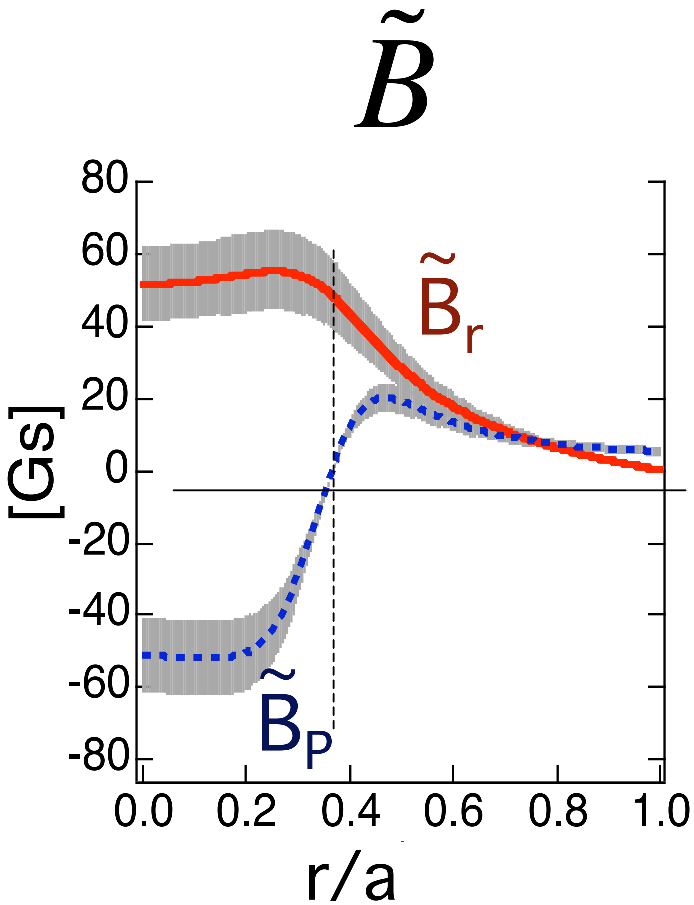
two-fluid effect

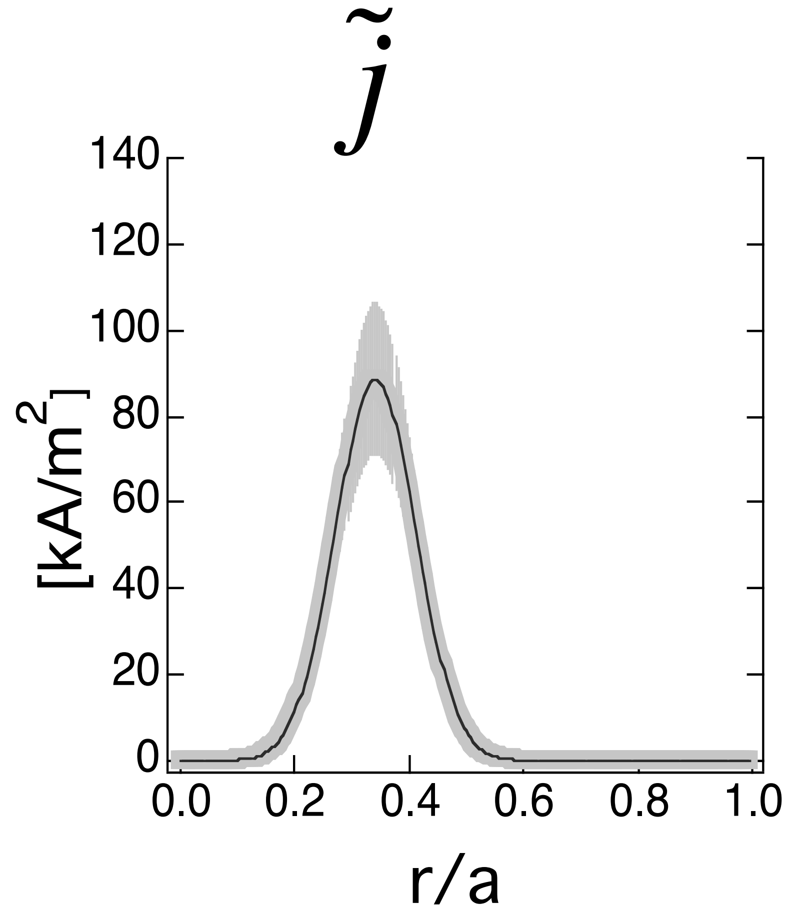
significant in quasilinear theory

$\tilde{j}$ and $\tilde{B}$ measured by Laser Faraday Rotation

(UCLA)

Measured radial structure of m = 1, n = 6 mode



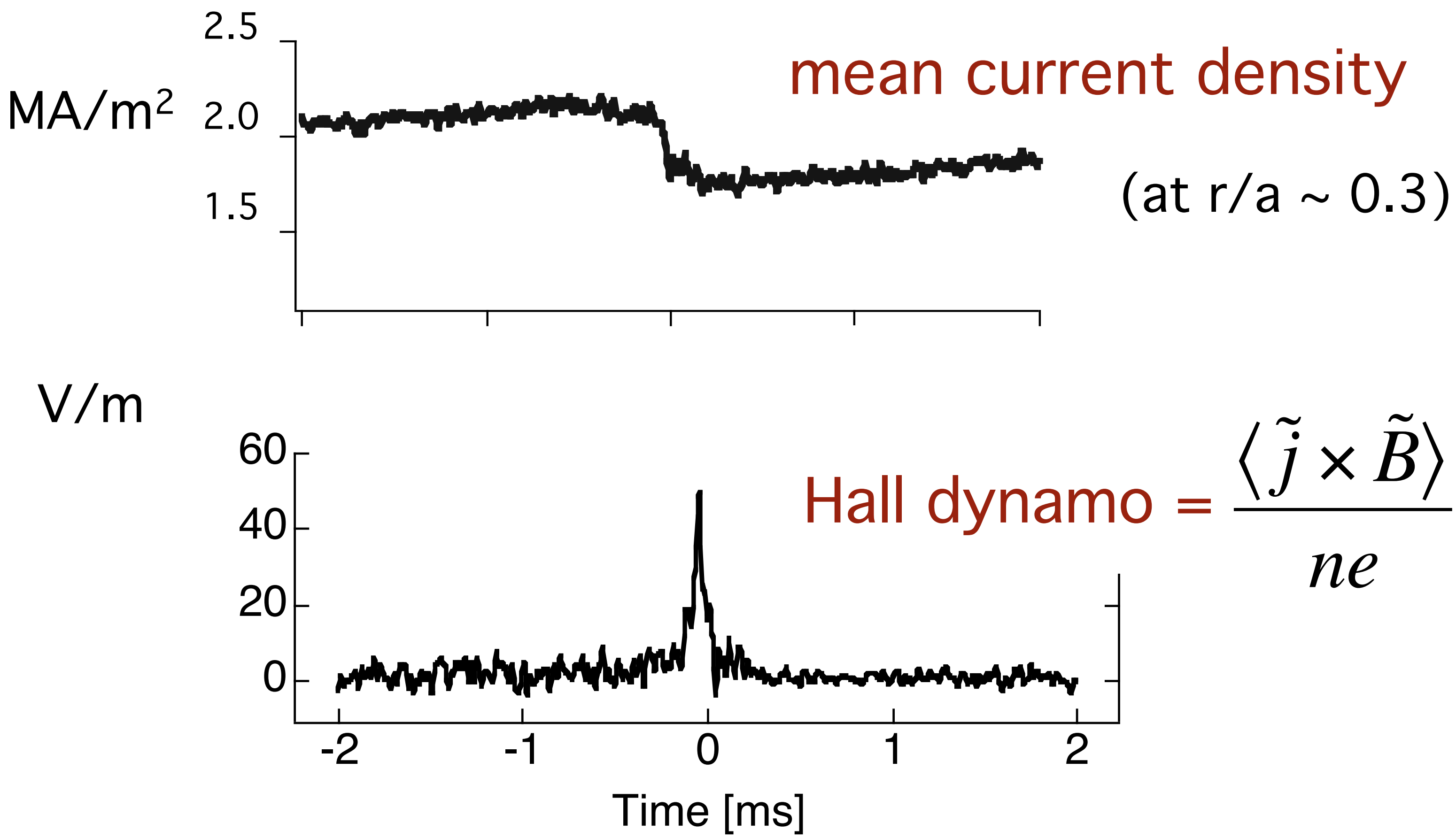


global

local,

but wider than MHD resistive layer

Hall dynamo is large near the resonant surface



Hall dynamo = $\dfrac{\langle \tilde{j} \times \tilde{B} \rangle}{ne}$

Hall effect contributes strongly to dynamo and reconnection

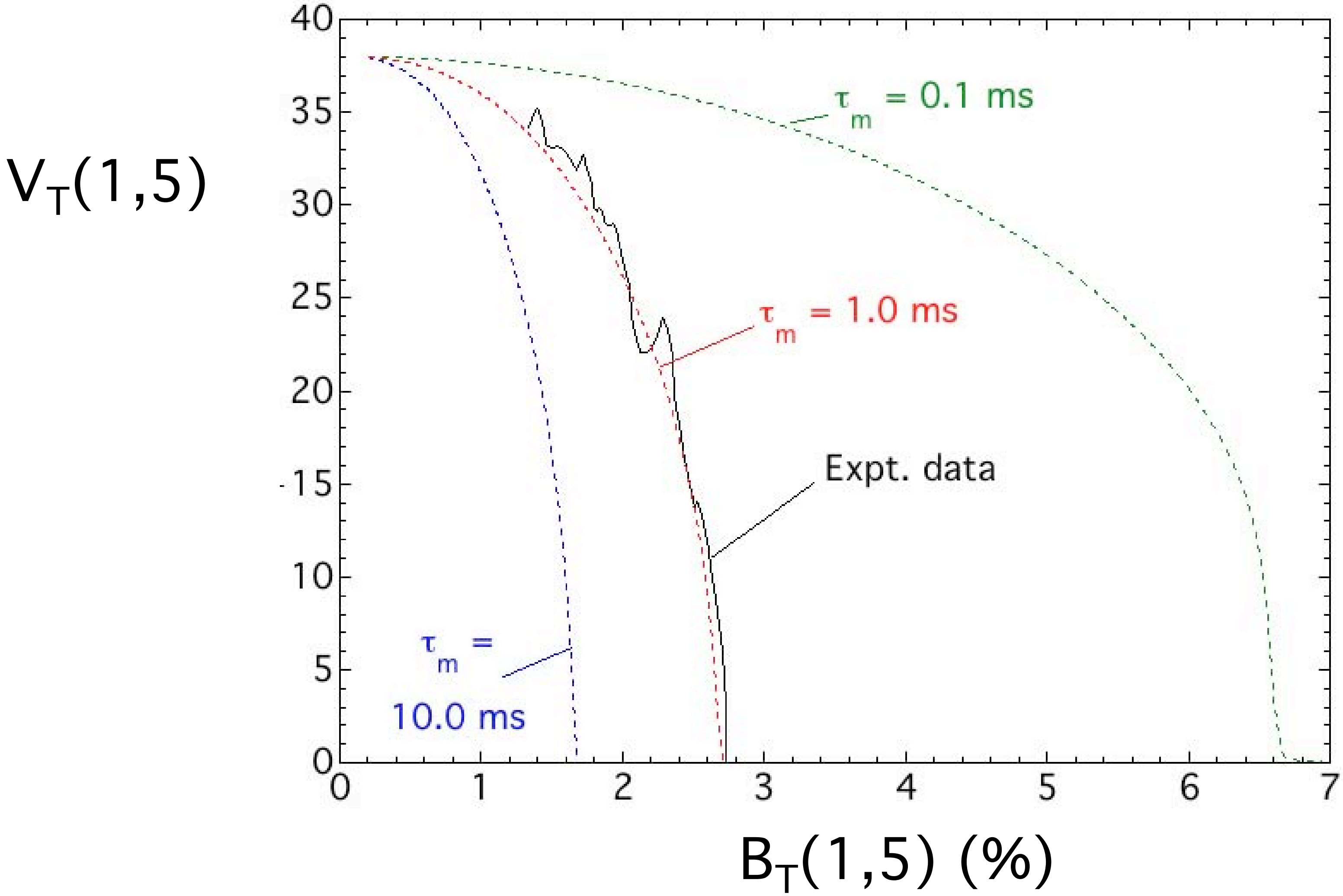
The tearing modes lock

- test theory of mode locking by wall eddy currents

- employ time-dependent theory (Fitzpatrick)

Experimental Test of Theory

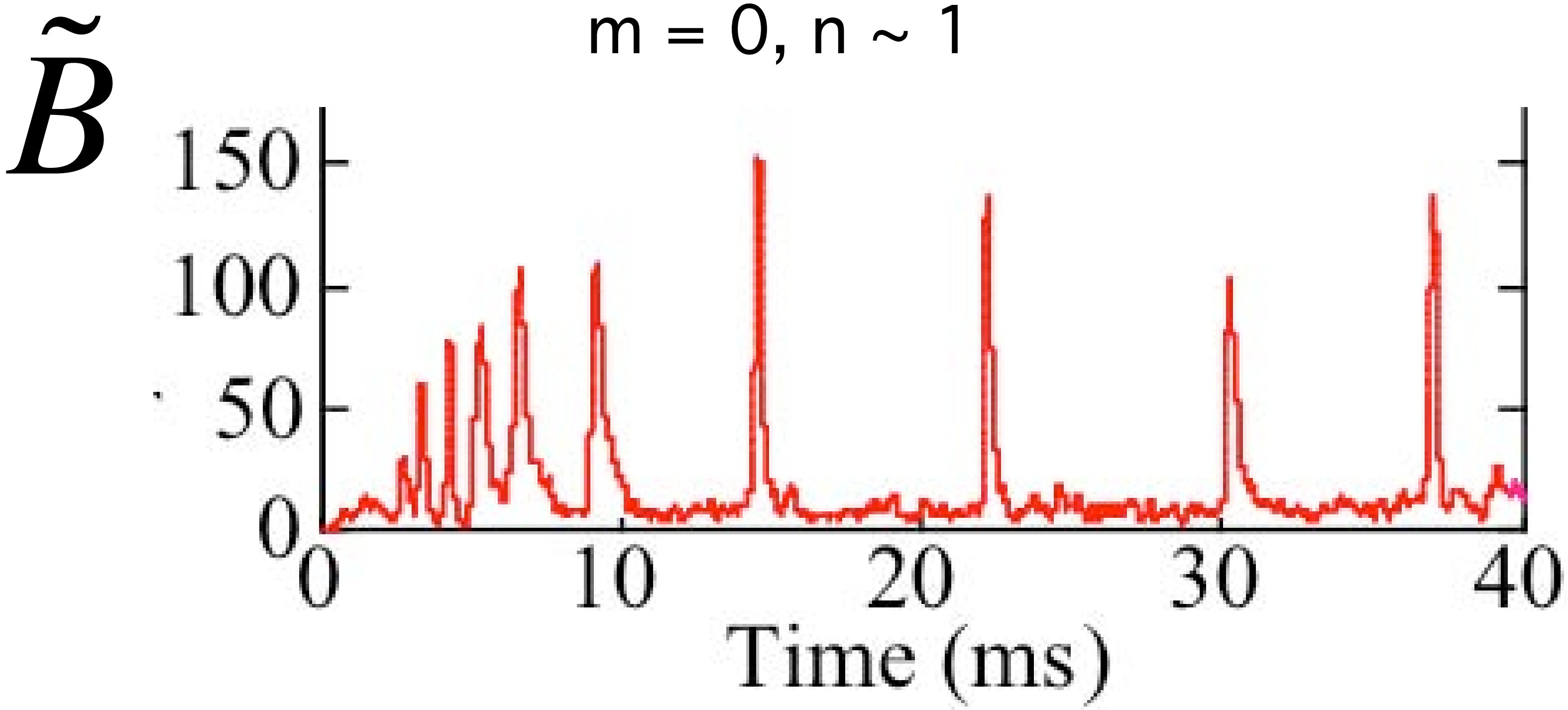
One free parameter: momentum confinement time



Experiment consistent with theory

A strong edge-resonant mode is observed

m = 0, n ~ 1



The mode drives transport and dynamo in the edge

What drives the m = 0 modes?

From MHD,

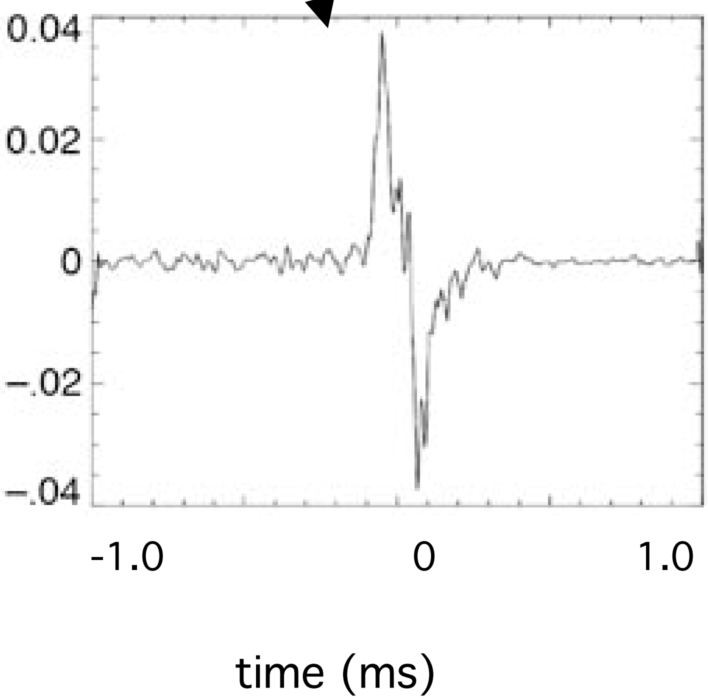
$$\frac{\partial\left\langle B_{0,1}^{2}\right\rangle}{\partial t} = \underbrace{\left\langle \vec{B}_{0,1} \bullet \nabla \times (v_{0,1} \times \langle B \rangle) \right\rangle}_{\text{linear drive}} + \text{nonlinear coupling}$$

terms measured directly in MST edge plasma

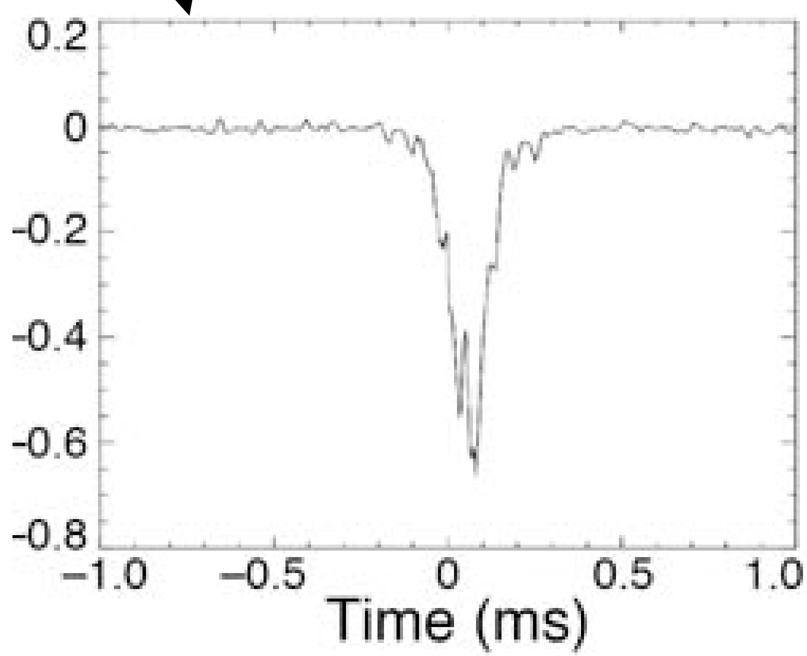
$$\frac{\partial\langle B_{0,1}^2\rangle}{\partial t} = \langle \vec{B}_{0,1}\bullet\nabla\times(v_{0,1}\times\langle B\rangle)\rangle$$

+ nonlinear terms

> 0 from initial measurements, nonlinearly driven



linearly damped



Improved confinement plasmas

The confinement problem in standard plasmas:

$E_{||}(r)$ is centrally peaked,

yields unstable $j_{||}(r)$ profile

fluctuations broaden $j_{||}(r)$, increase transport

Solution:

drive a flatter current profile

Technique:

apply flatter electric field, transiently

Confinement Summary

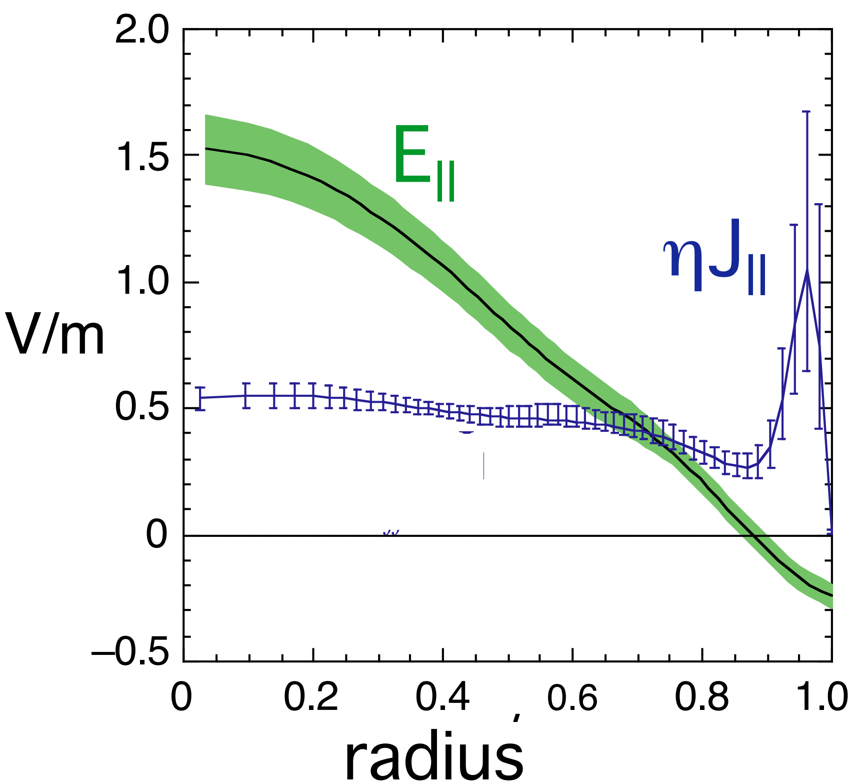
	Standard		Improved	
T_e	0.5 keV	→	1.3 keV	*nearly tripled*
beta	9%	→	15%	*nearly doubled*
τ_E	1ms	→	10 ms	*tenfold increase*
χ_e	50 m^2/s	→	5 m^2/s	

Comparable to tokamak of similar size and current

Suppression of dynamo

Standard Plasma

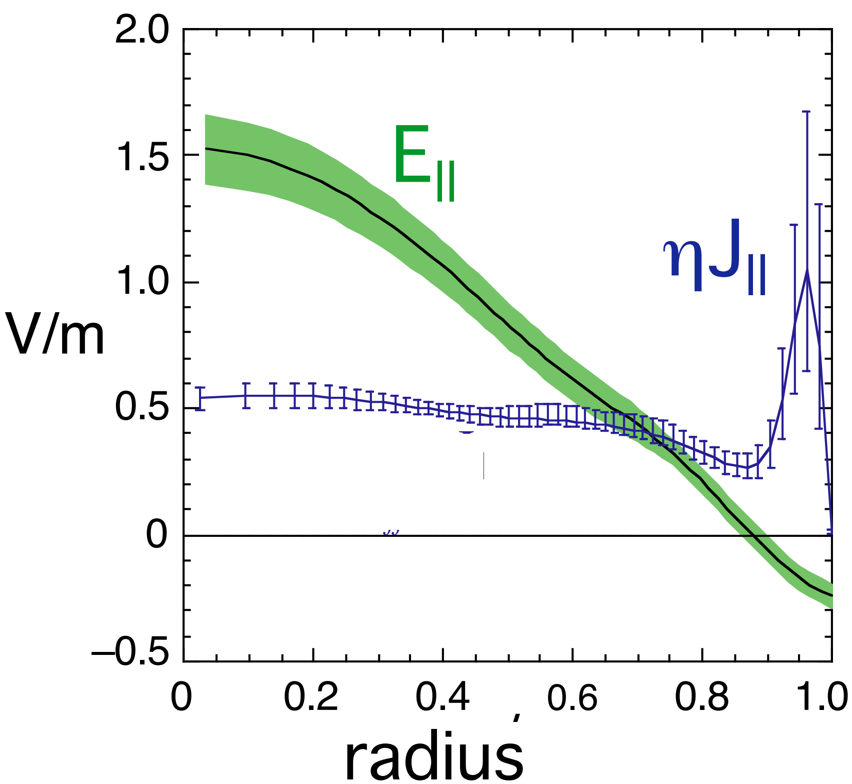
strong dynamo ($E \neq \eta j$)



Suppression of dynamo

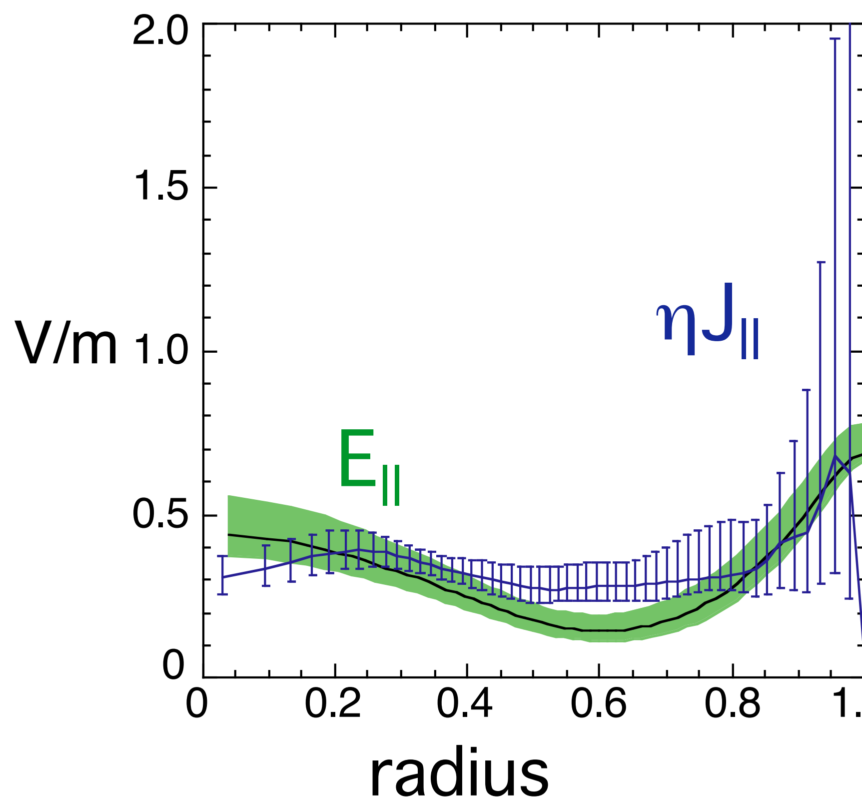
Standard Plasma

strong dynamo ($E \neq \eta j$)



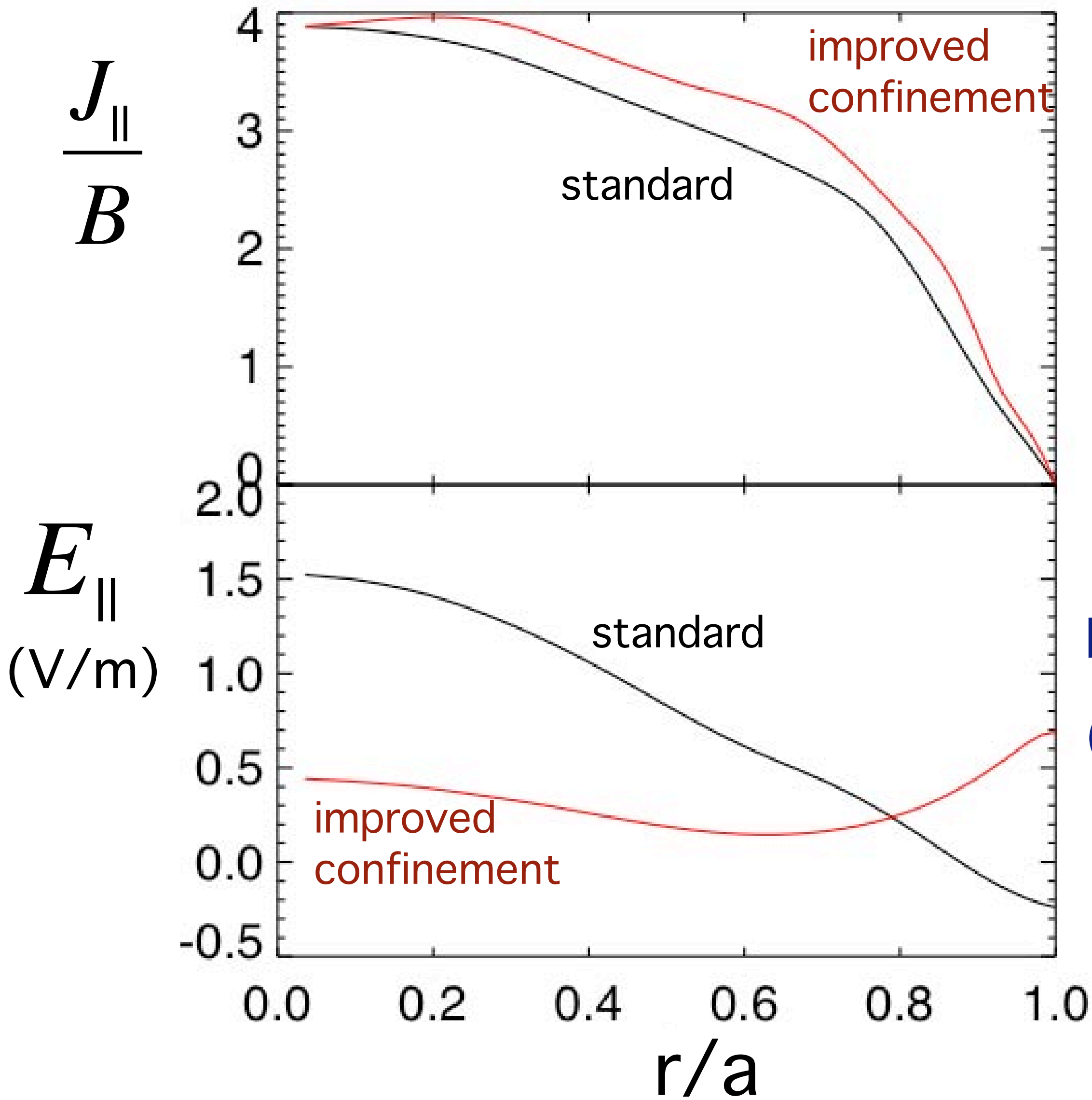
Improved Confinement

reduced dynamo ($E \approx \eta j$)



driven current replaces dynamo current

$J_{||}/B$ and $E_{||}$ profiles



J/B profile changes slightly,

near marginal stability

E profile changes greatly

("driven" current changes)

Restoration of magnetic surfaces

Earlier work on energetic electron confinement:

Hard xray emission up to 100 keV

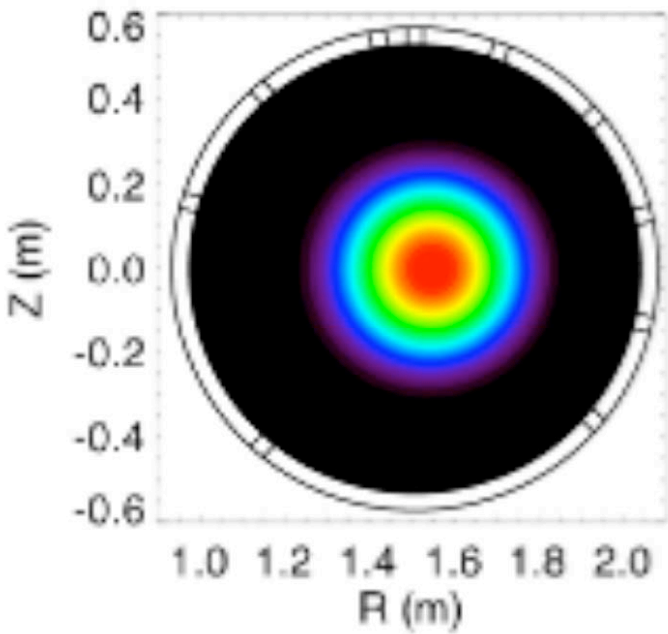
Fokker-Planck modeling -->

$D_e \sim 5\ m^2/s$, independent of electron speed, inconsistent with stochastic magnetic fields

SXR tomography

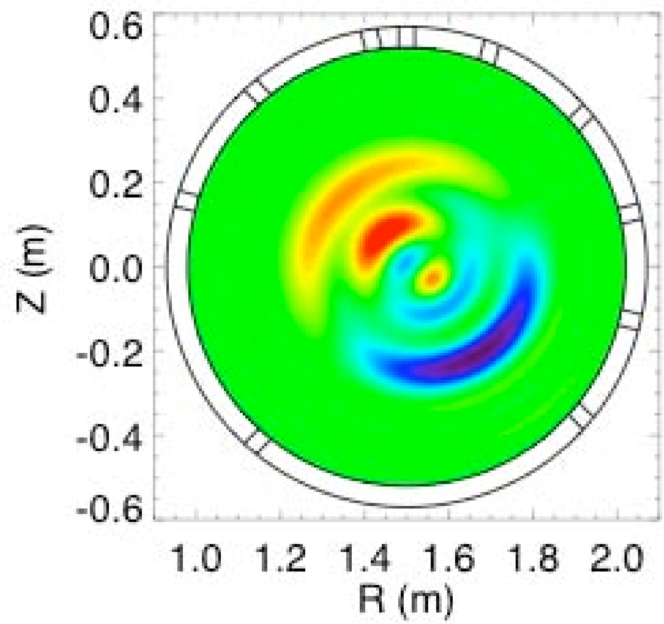
RFX group

standard plasmas



consistent with stochasticity

improved confinement



magnetic islands appear

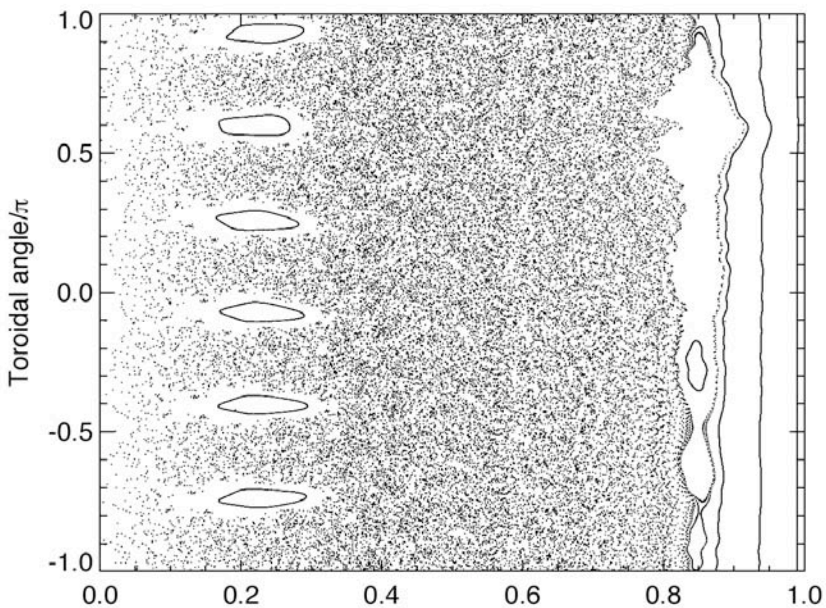
(equilibrium contribution removed)

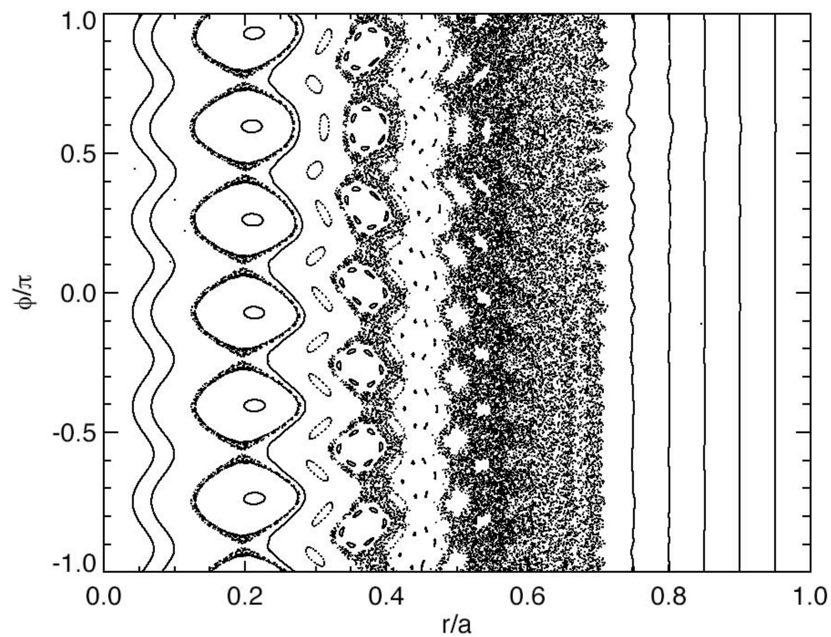
Magnetic Field Puncture Plots

standard plasmas

improved confinement

toroidal
angle



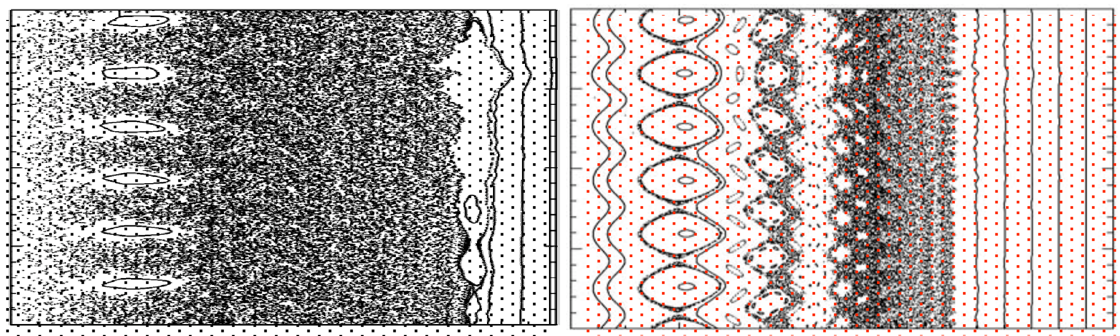


radius

radius

shows restoration of magnetic surfaces

compare thermal conductivity to expectation from stochastic transport



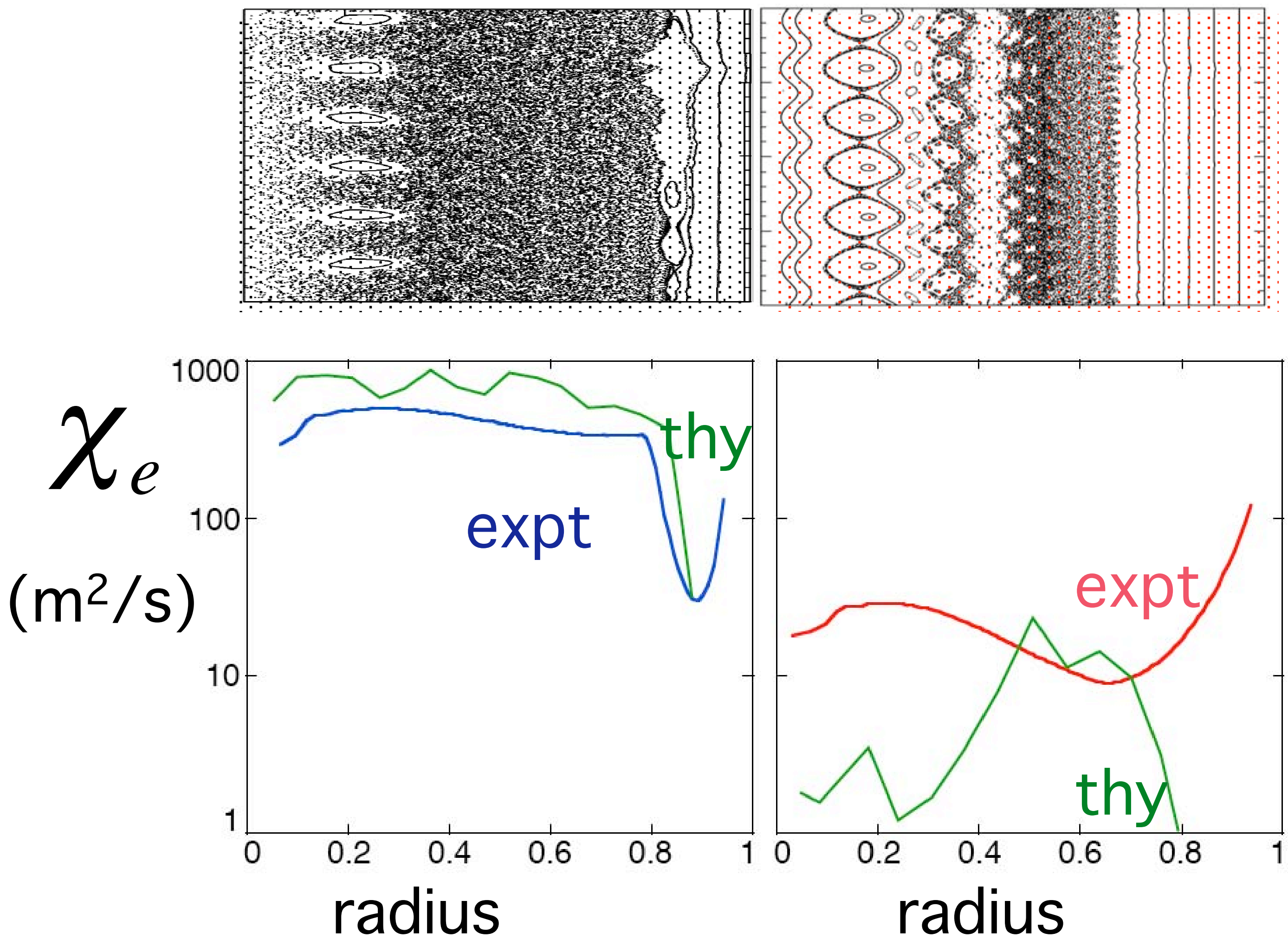
$\Longrightarrow$ magnetic diffusivity D_m

$\Downarrow$

$$\chi_{theory} = v_{th} D_m$$

(

compare thermal conductivity to expectation from stochastic transport



$\Longrightarrow$ magnetic diffusivity D_m

$\Downarrow$

$$\chi_{theory} = v_{th} D_m$$

stochastic transport

not stochastic, except in narrow layer

Summary

RFP can operate in two distinct physics regimes

Strong magnetic self-organization and transport

Hall effects, mode locking, nonlinear coupling

Suppressed self-organization (transiently)

transport is tokamak-like

dynamo and stochasticity is suppressed

possibly dominated by electrostatic fluctuations

more confinement gains underway

a new physics regime, beginning to investigate

What is the ultimate confinement and beta in the RFP?

Can improved confinement be sustained?

To answer these questions we are applying

- Lower hybrid current drive
- Electron Bernstein wave current drive
- Neutral beam injection
- Oscillating field current drive
- Pellet injection

See posters by W. Ding, D. Craig