Recent Results from MRX:

Particle dynamics
Guide Field Reconnection

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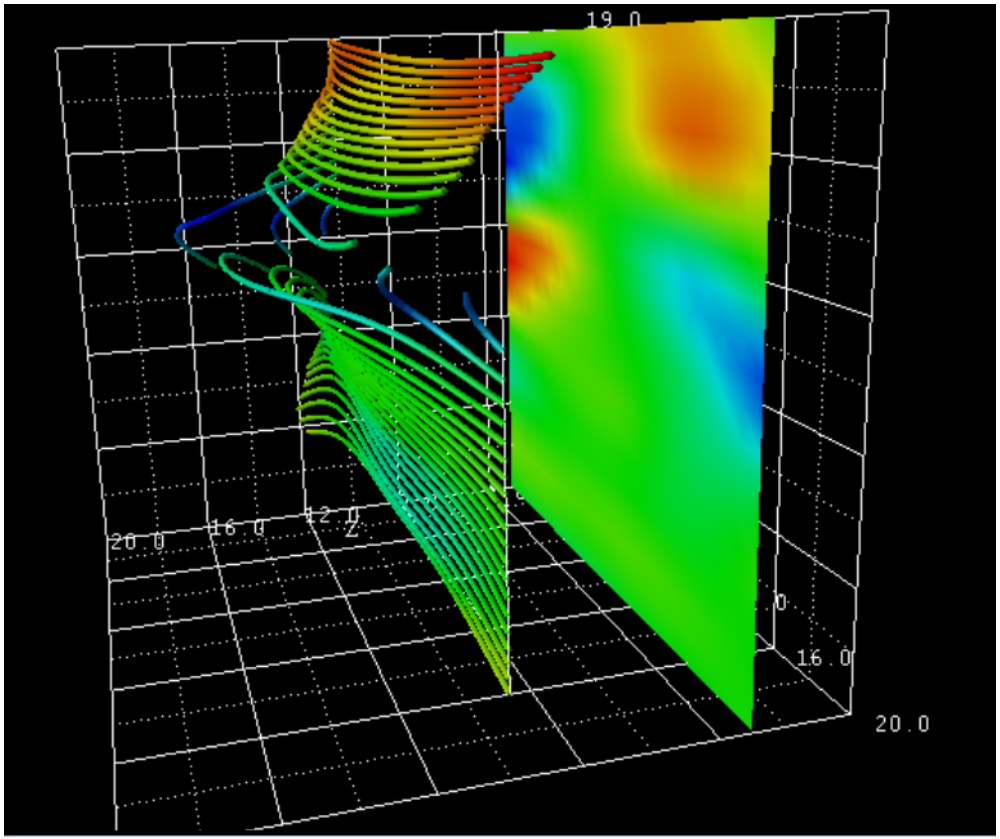
and MRX staff
10/26/2012

Major Results on Hall Reconnection in MRX

- Issues of particle dynamics
  - -Two-fluid physics
  - -Electron heating
  - - Ion acceleration and heating

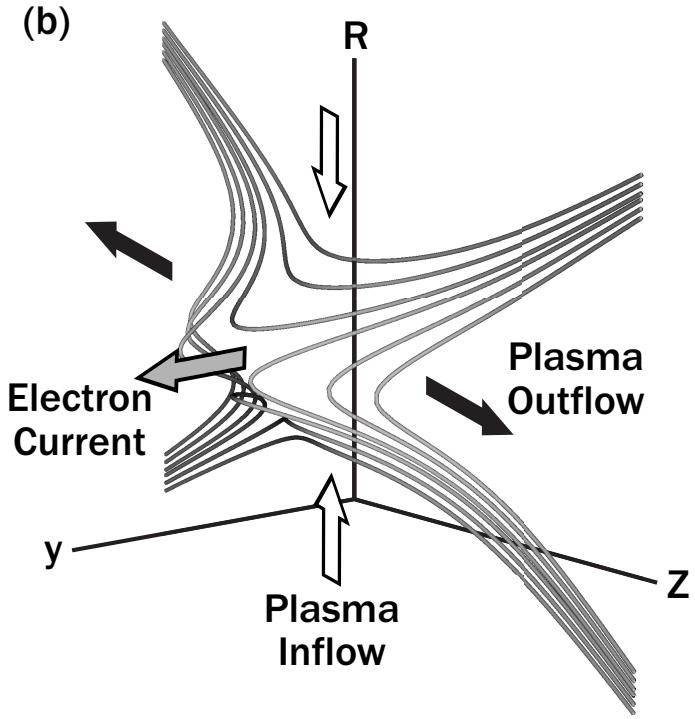
- Guide field reconnection
  - -Expectations
  - -Observations in MRX

Experimentally measured field line features in MRX



- Manifestation of Hall effects in MRX
- Electrons would pull magnetic field lines with their flow

Two-fluid physics dictates reconnection layer dynamics



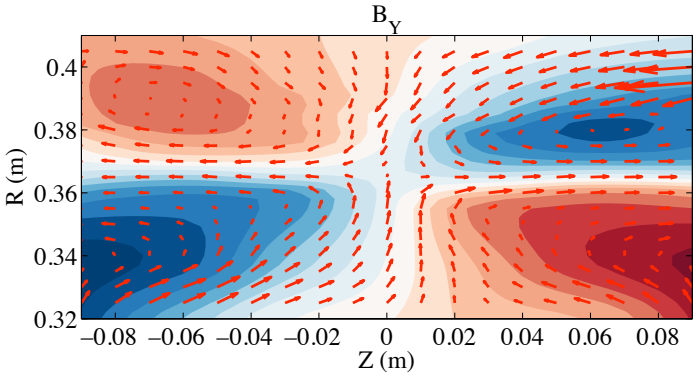
Sheath width ~ ρ_i ~ c/ω_{pi}

-- Electron acceleration and heating particularly on trapped ones

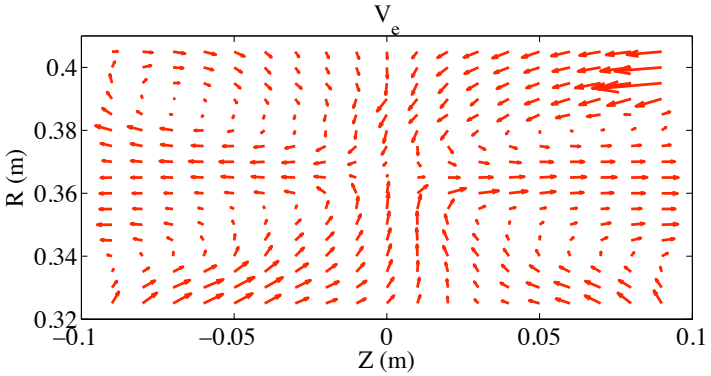
--Parallel component enhanced even after reconnection!

Out of plane magnetic field is generated during reconnection

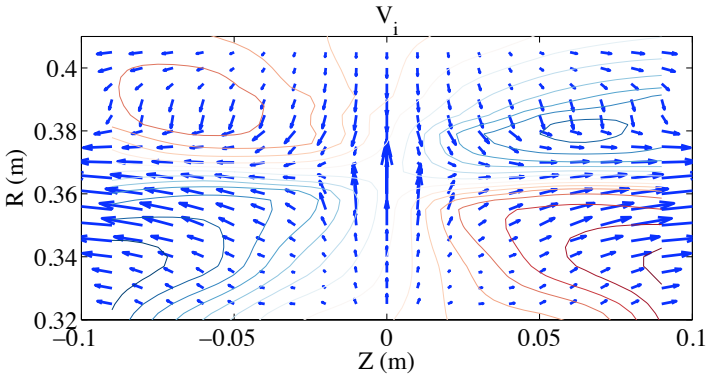
Simultaneous measurement of ion and electron flow vectors by plasma jogging



From magnetic data



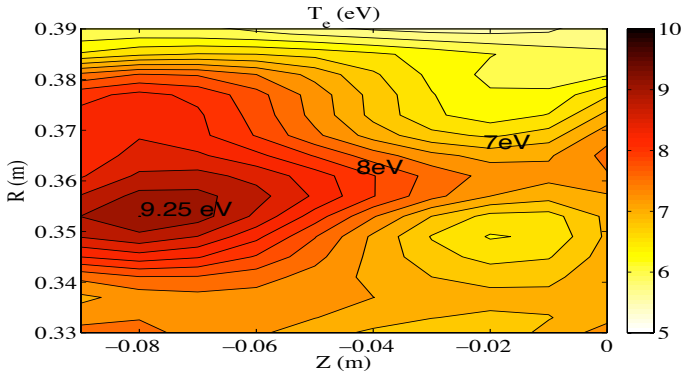
Electron flows

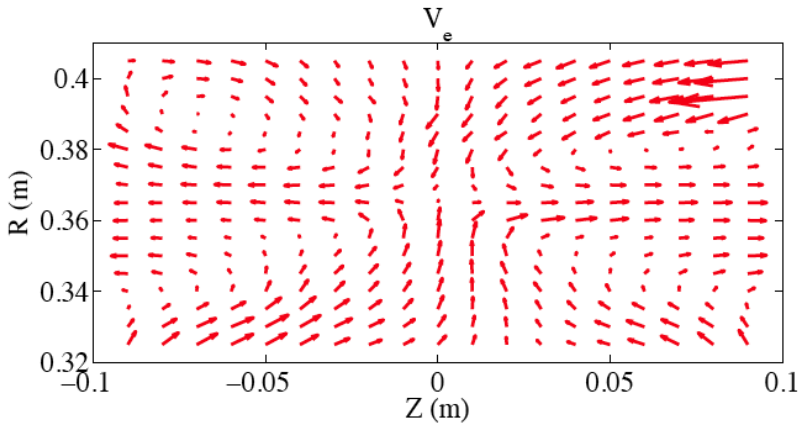


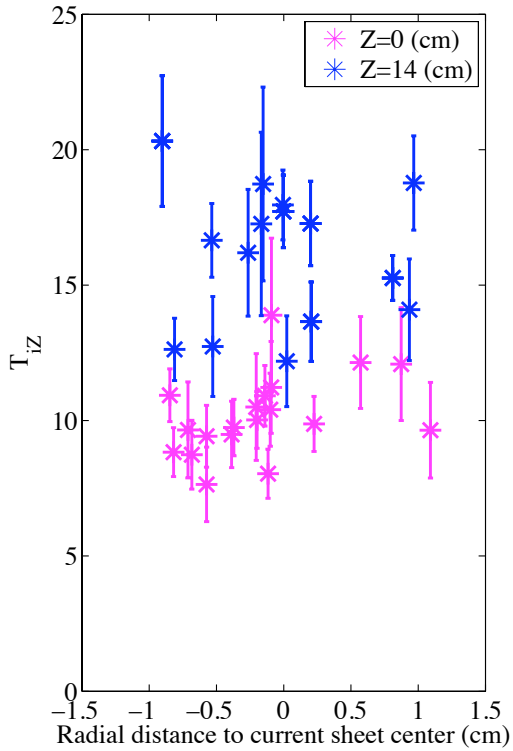
Ion flows
from Mach probe data

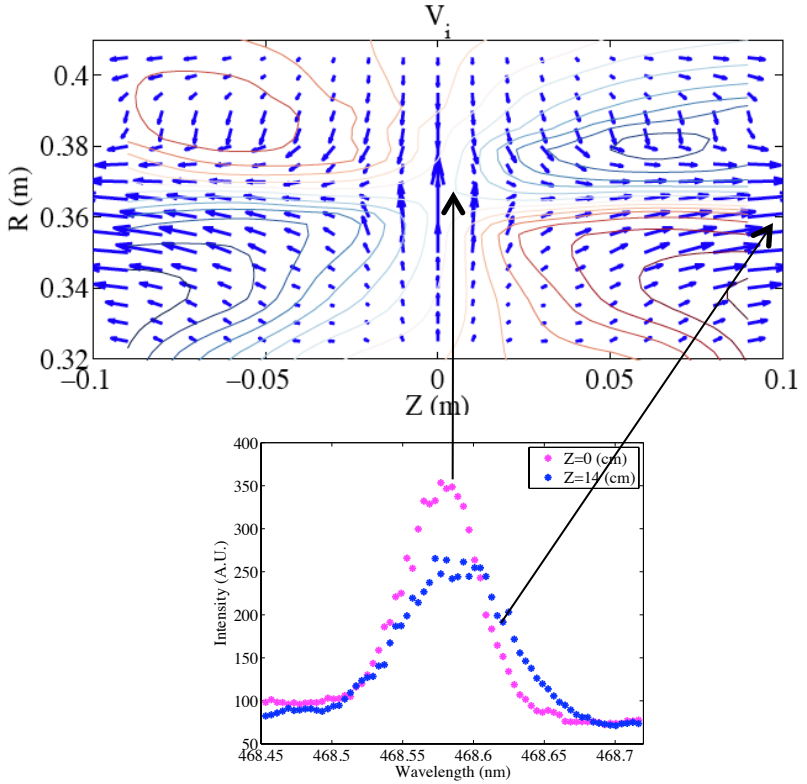
J. Yoo, 2011

Both ion and electron temperature measured by plasma jogging



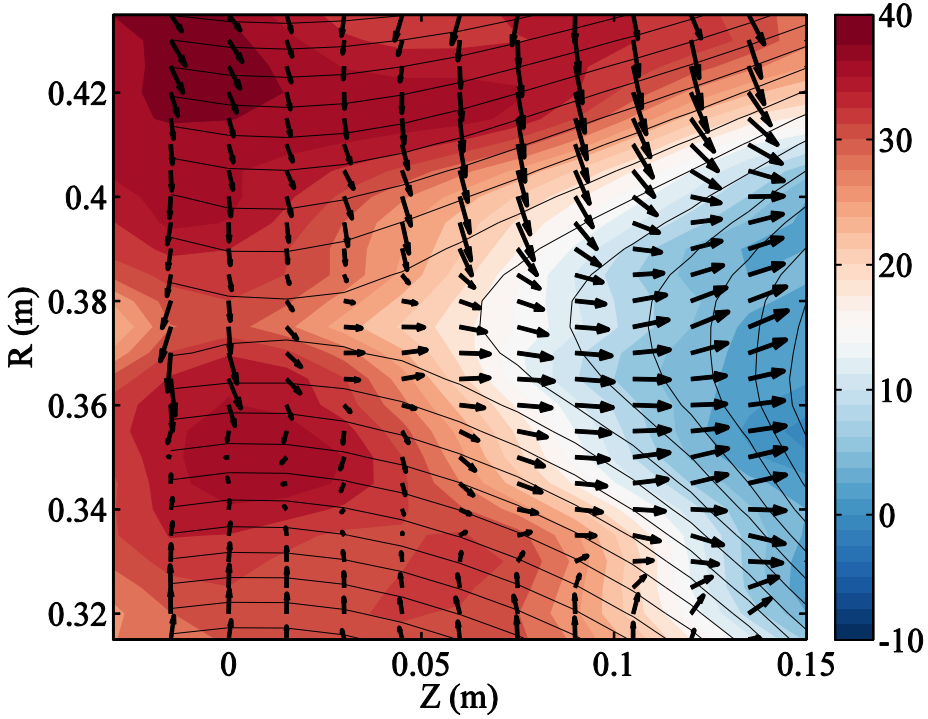






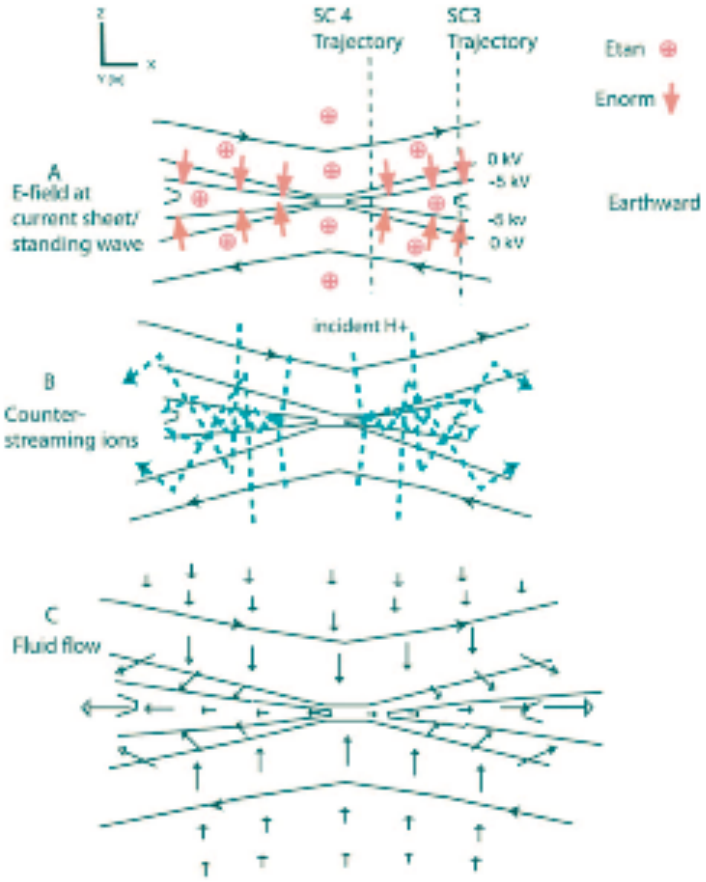
J. Yoo, 2012

Ion Acceleration

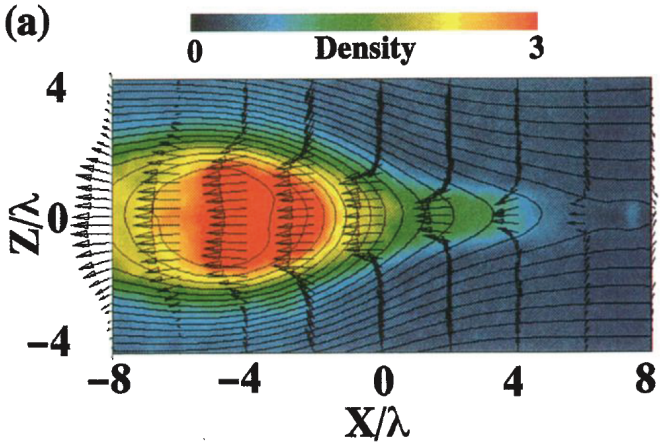


- Clear ion acceleration by the in-plane electric field.
- Asymmetry in the ion inflow is caused by asymmetry in the upstream density.

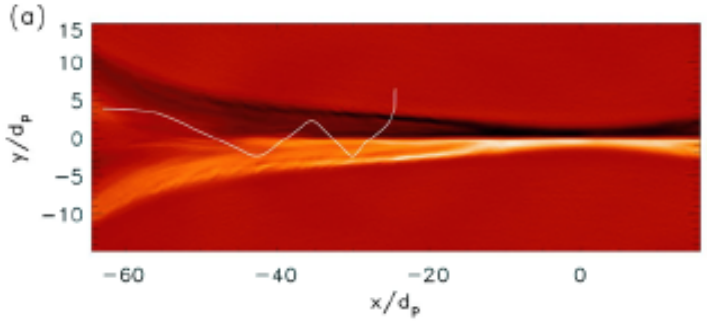
Ion acceleration data and simulation results



Wygant JGR 2005

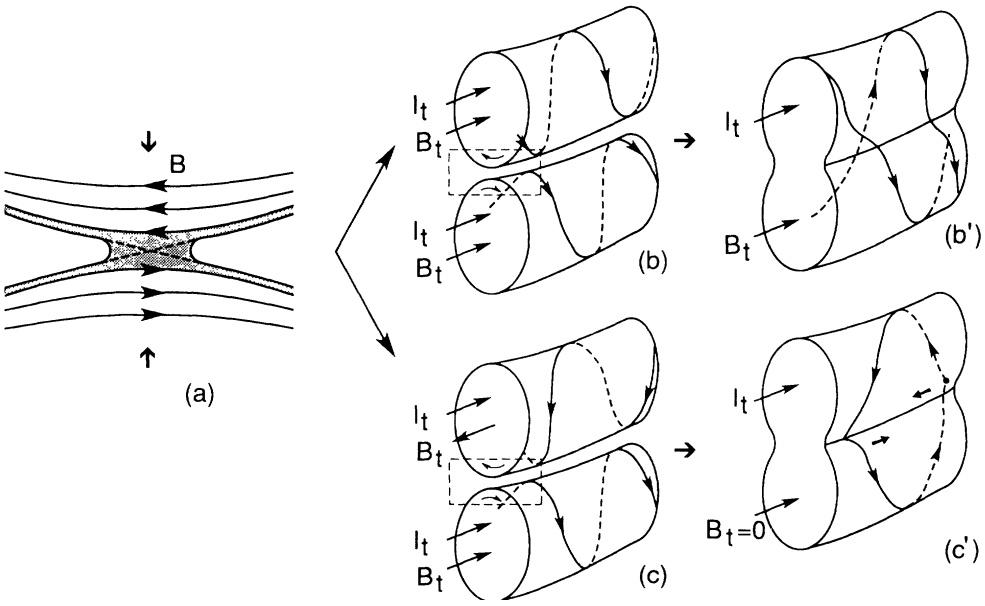


Hoshino et al 1998



Drake et al., 2009

It was found that guide field slows down reconnection notably



Yamada et al, PRL 1990

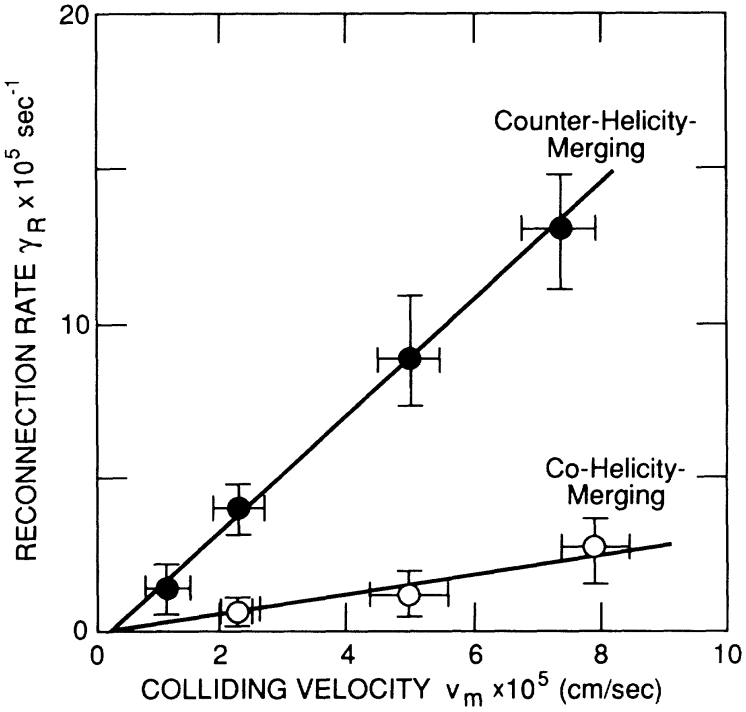
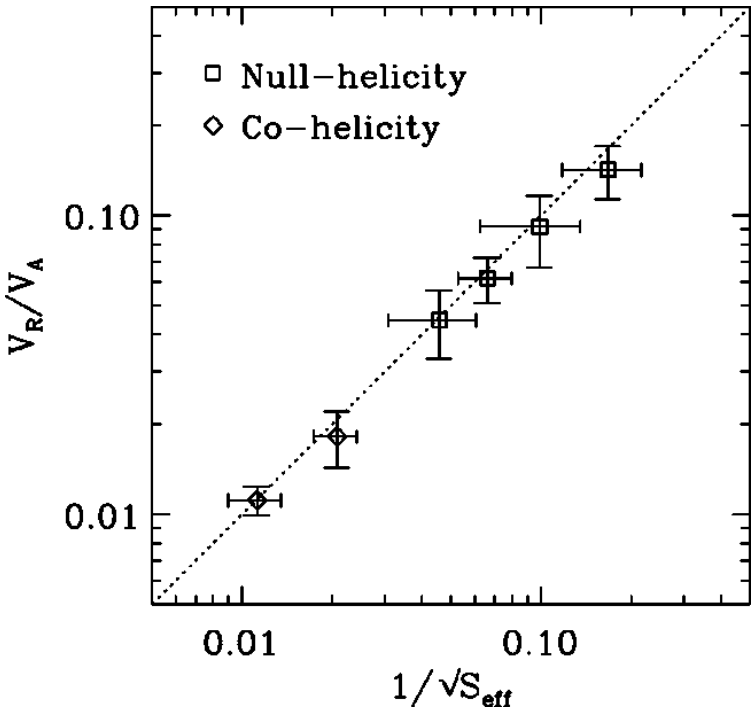


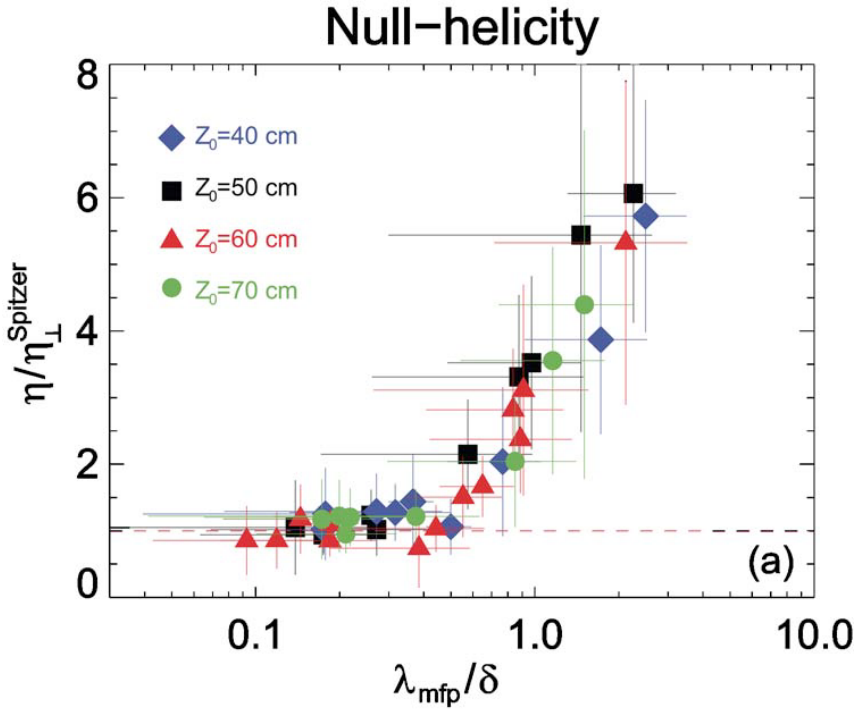
FIG. 5. Measured reconnection rate vs mutual colliding velocity v_m of two plasmas for cohelicity and counterhelicity merging.

Sweet-Parker model was experimentally tested and verified in high density MRX plasmas.



Conclusion:
Sweet-Parker model is valid, but only under certain plasma conditions (model assumptions must be satisfied).

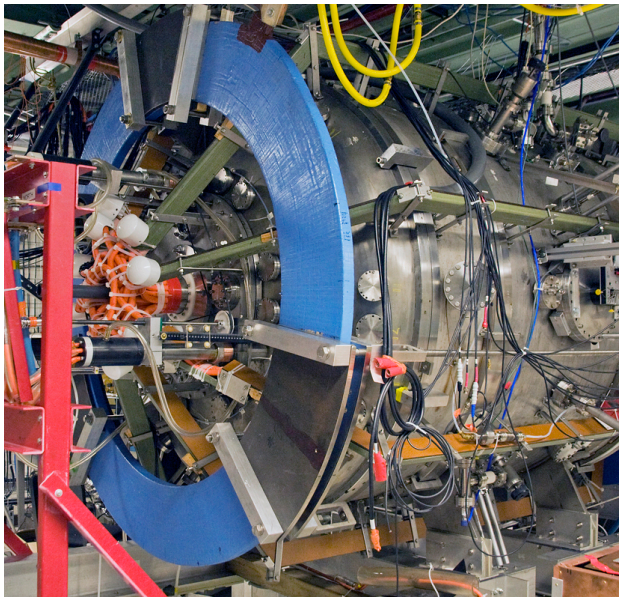
H. Ji, et. al., Physics of Plasmas (1999)

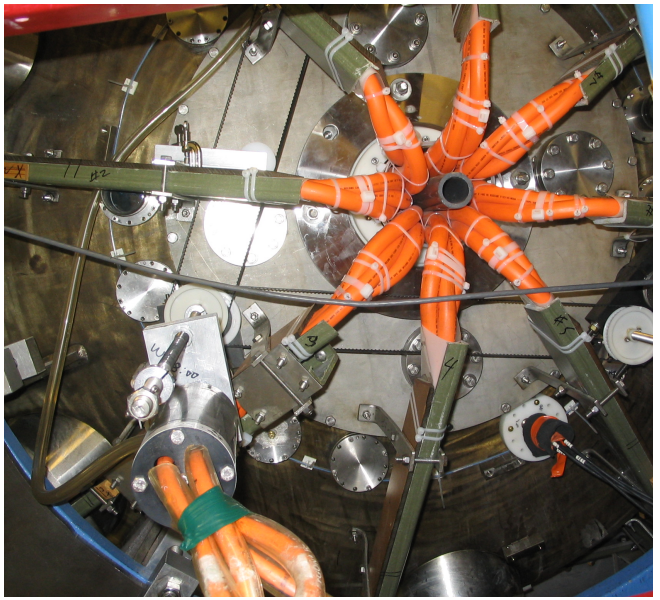


Guide field reconnection proceed much slower

A. Kuritsyn POP 2006

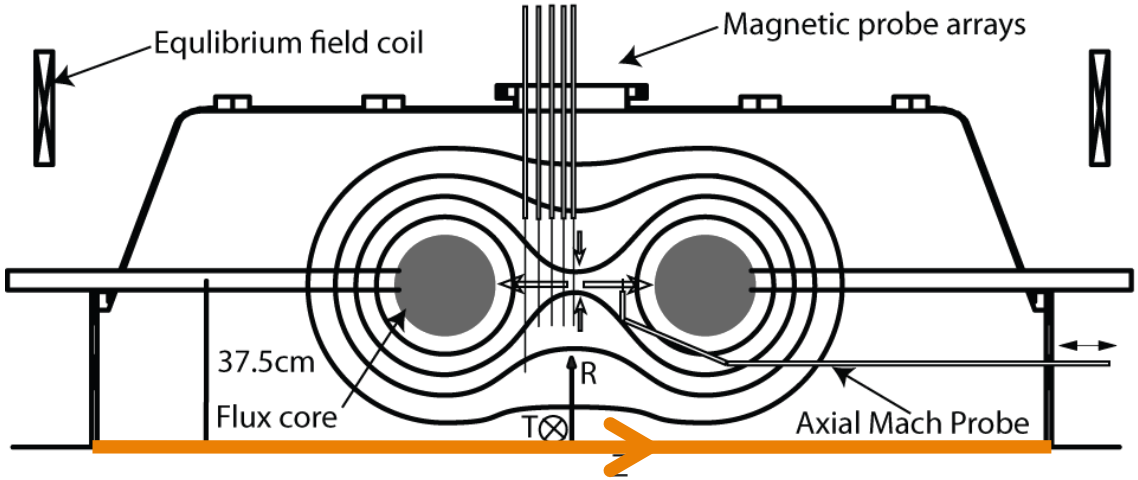
Now, a guide field coil has been added to MRX to study the effects of guide field on two-fluid reconnection





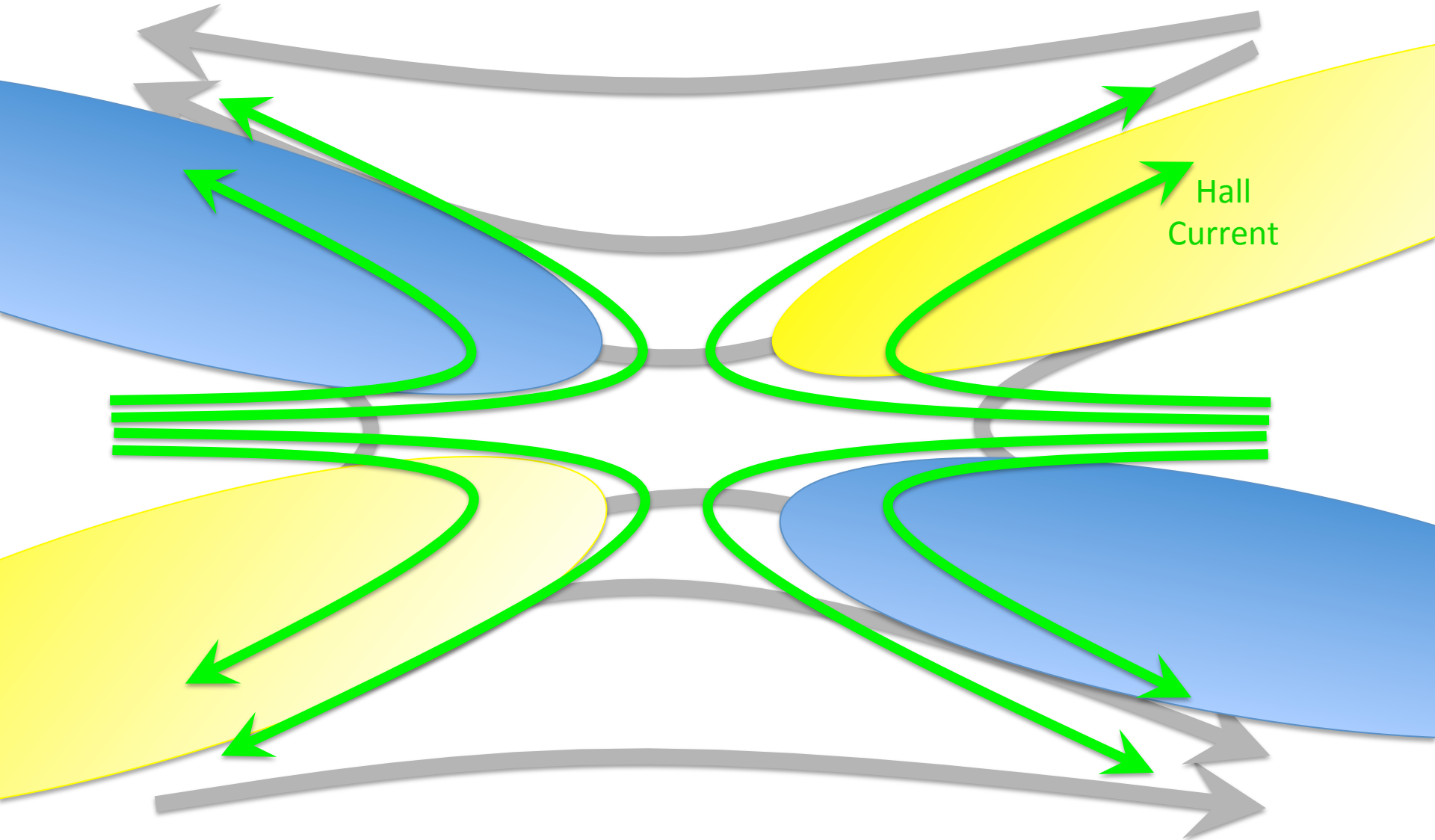
The guide field coil is capable of producing

$B_g > B_{rec}$.



Current sheet tilting

In-plane forces twist the plasma and the current sheet.



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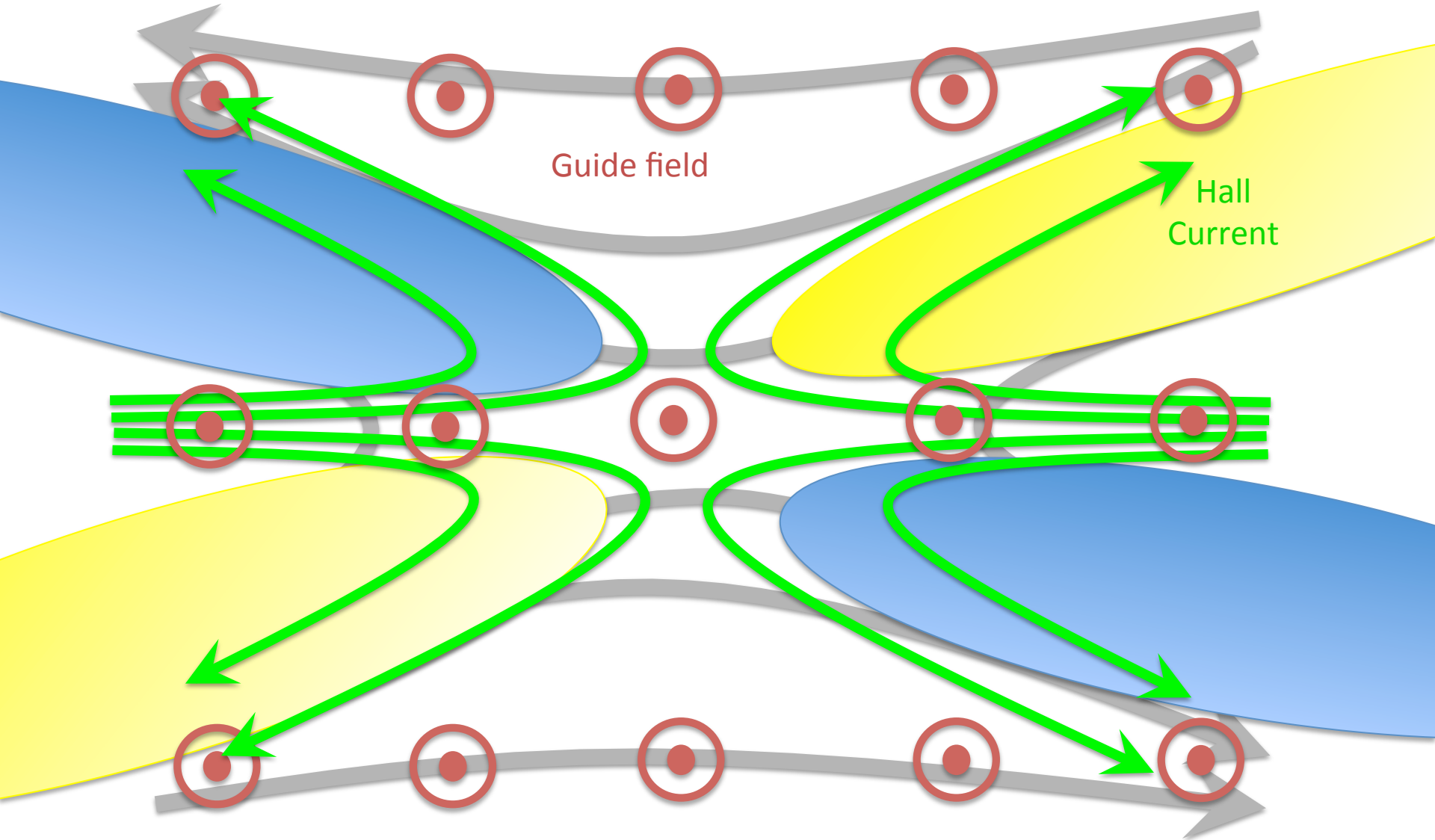

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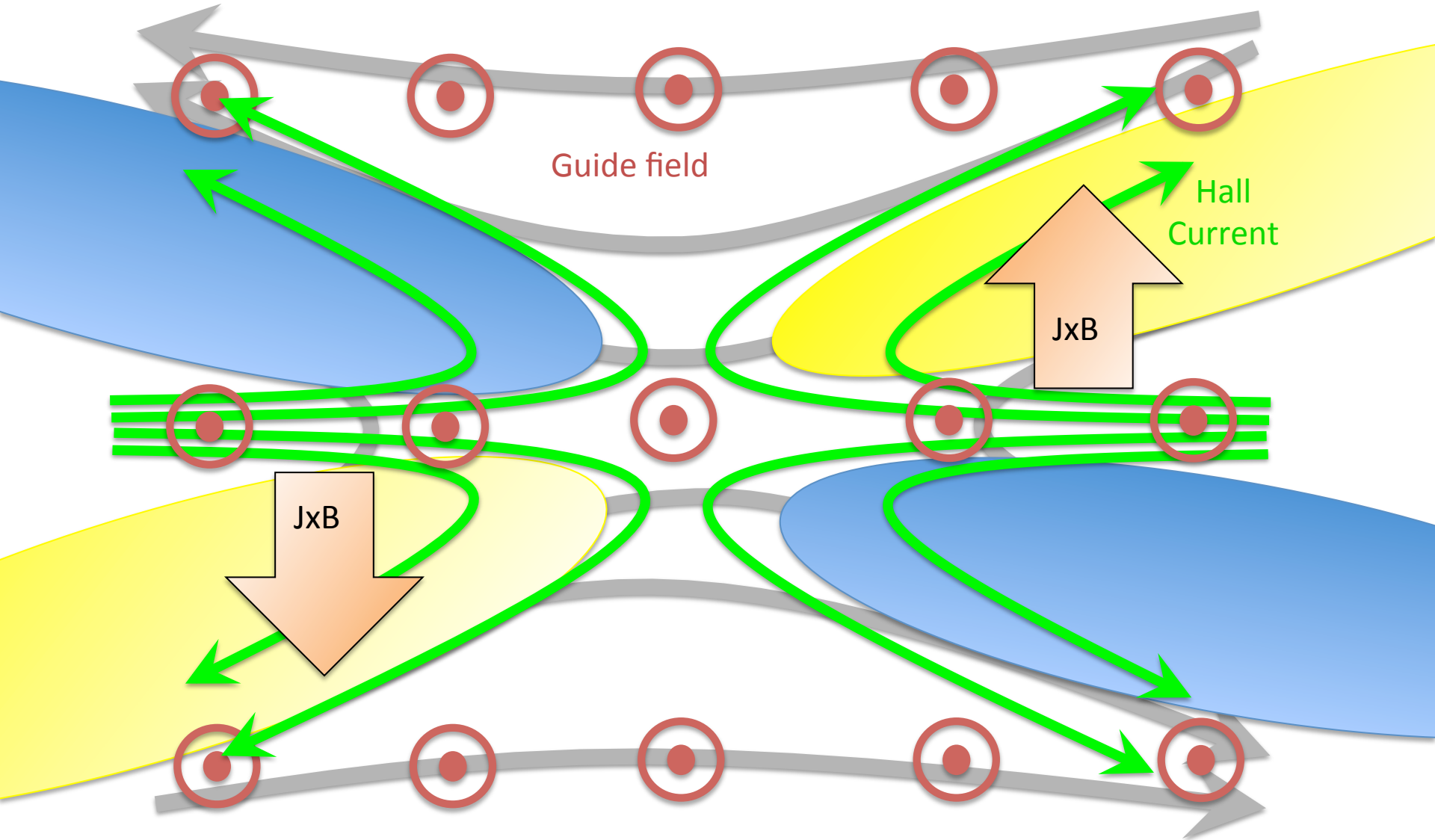

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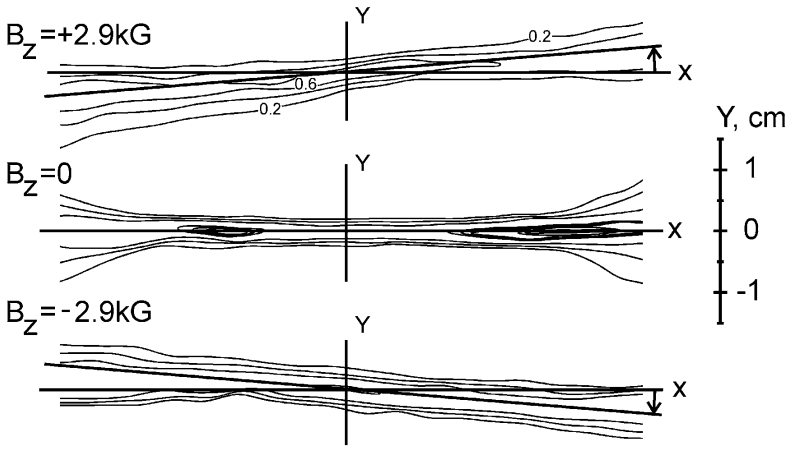
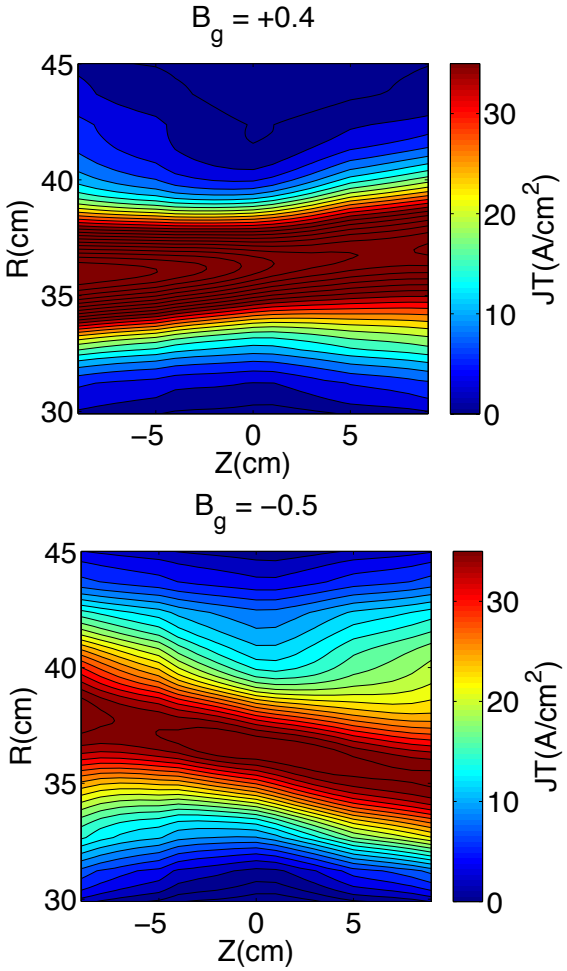


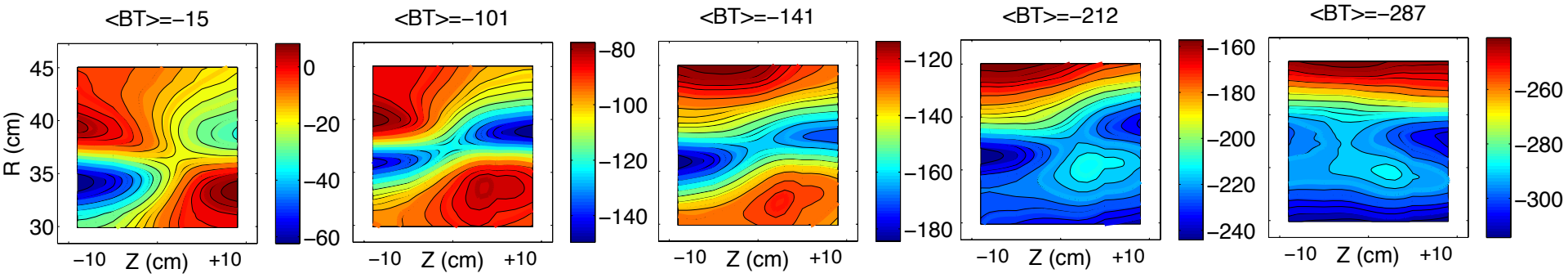
Previously observed by A. Frank, et. al., *Physics Letters A.* (2006); Yagi et al., 1985



Now observed in MRX

Modified Quadrupole Field

There isn't a simple analytic model for this, but measurements qualitatively match two-fluid simulations



GF=0

GF~B0

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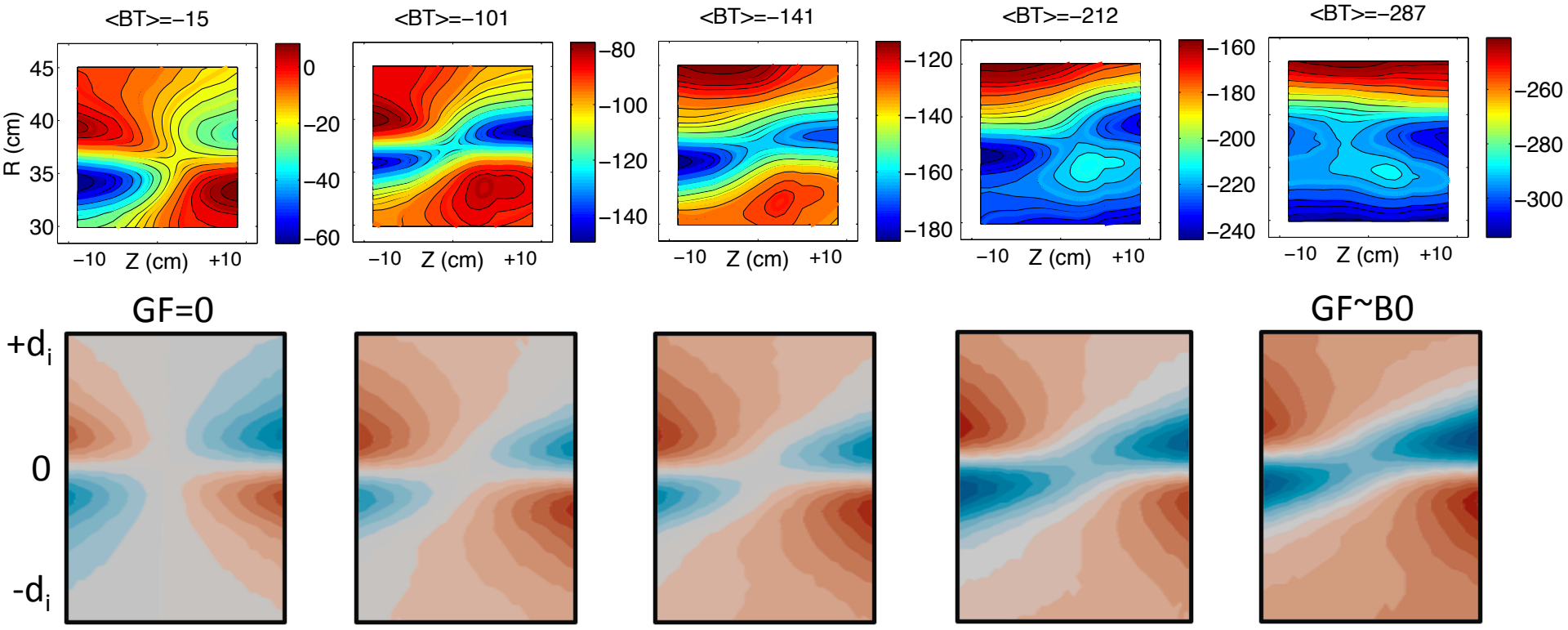
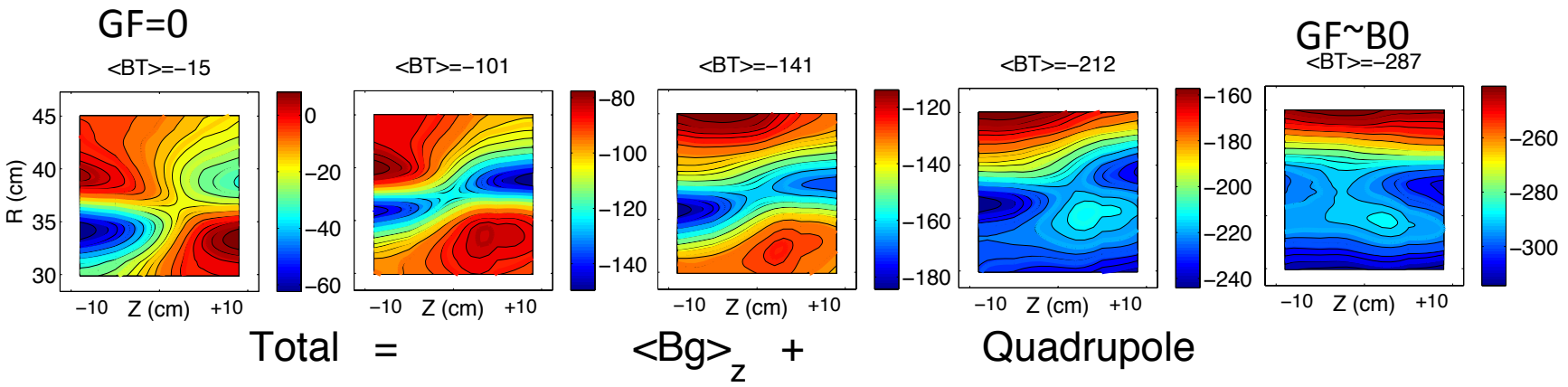
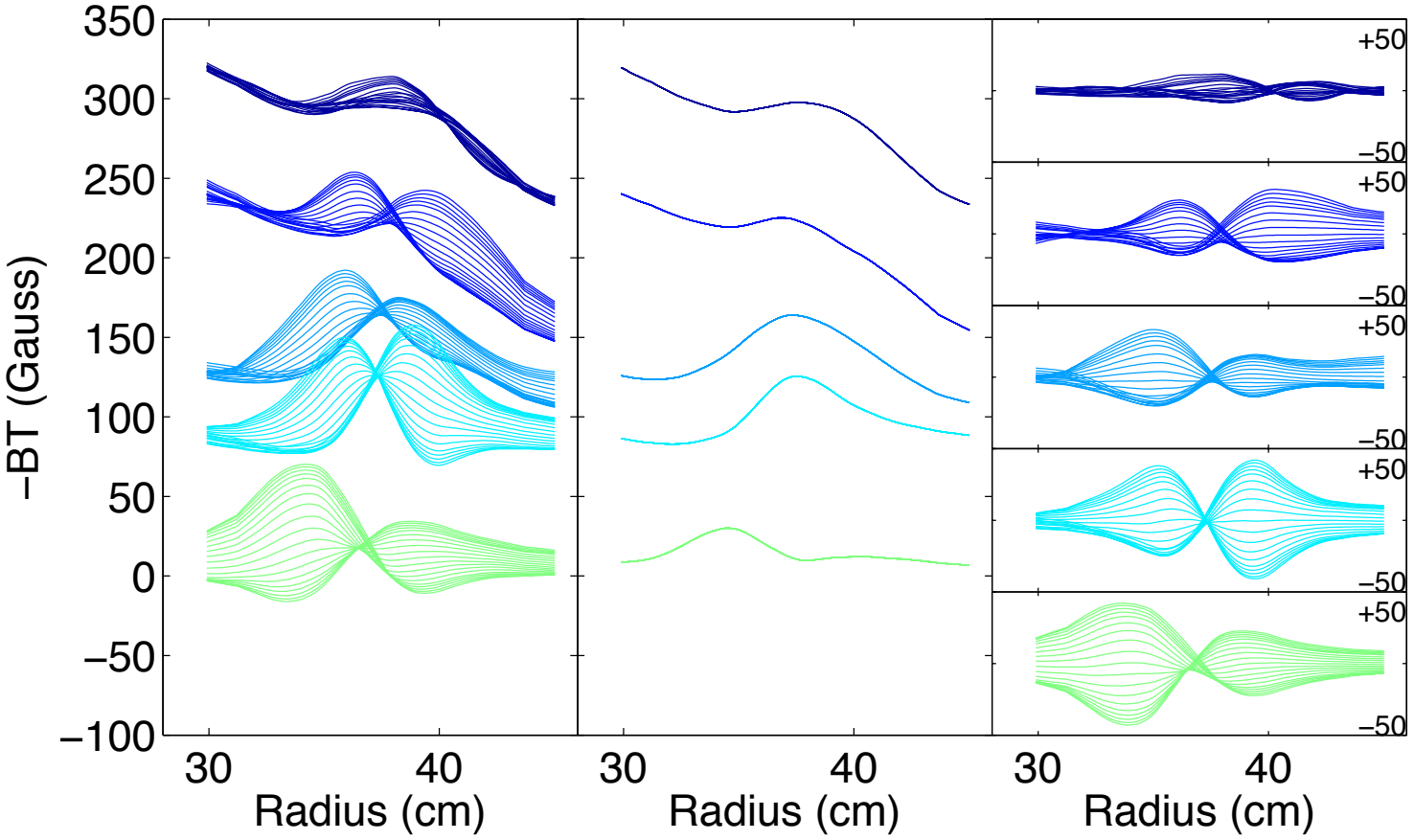


Simulations performed by A. Bhattacharjee, B. Sullivan, and Y. Huang at UNH.

Modified Quadrupole Field





The Hall field is reduced with larger guide field.

A Reduced Quadrupole Field is related to a Reduced Reconnection Rate

A local relationship between the Reconnection Rate and the Quadrupole Field is expected to hold:

Ohm's law includes the two-fluid Hall term:

$$E + v \times B = \eta J + \frac{1}{ne} J \times B$$

A few cm from the x-point, we expect the Hall term to dominate:

$$E_{rec} = \left(\frac{J_r \times B_z}{ne} \right)_{\text{inflow}} = \left(\frac{J_z \times B_r}{ne} \right)_{\text{outflow}}$$

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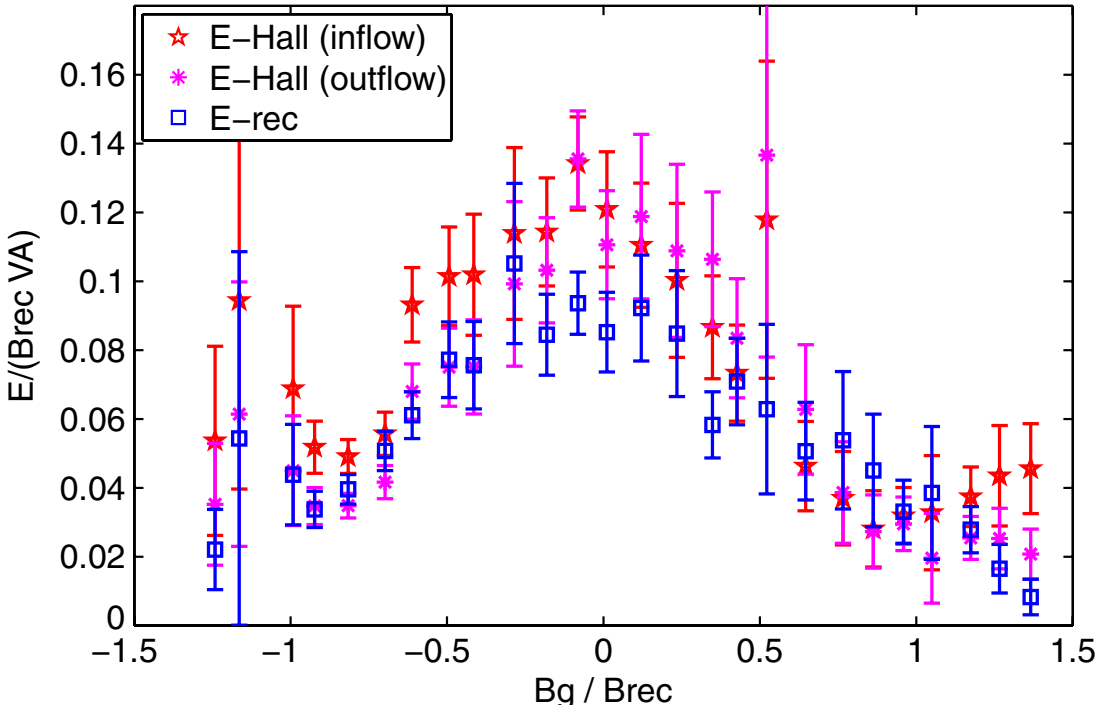

- Verified over large range of guide fields.
- Quantifies reduction of quadrupole field.

A Reduced Quadrupole Field is related to a Reduced Reconnection Rate

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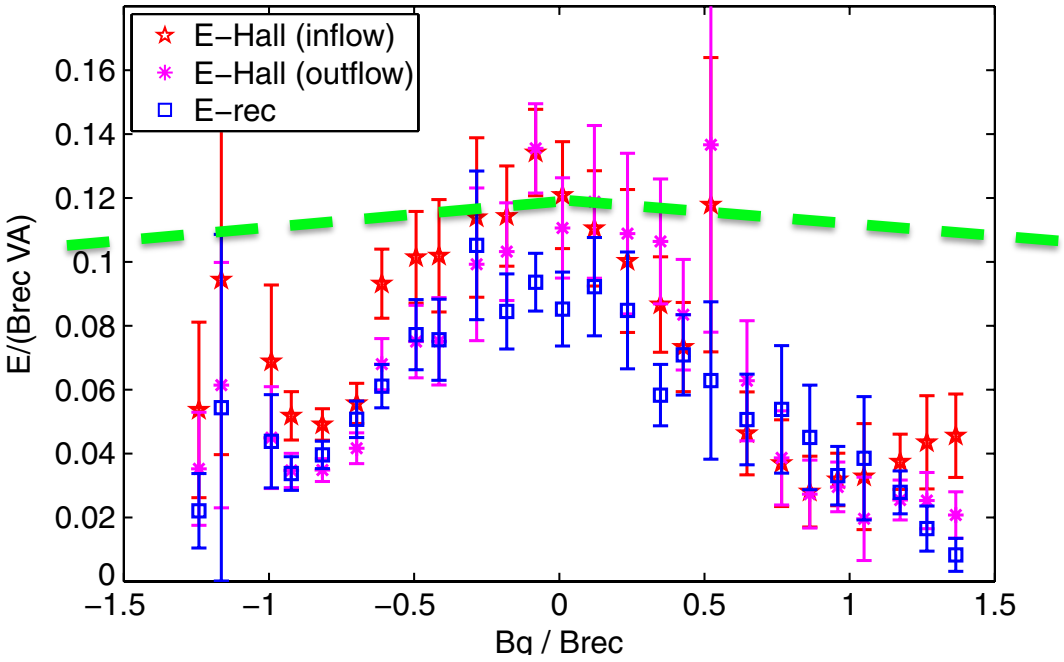
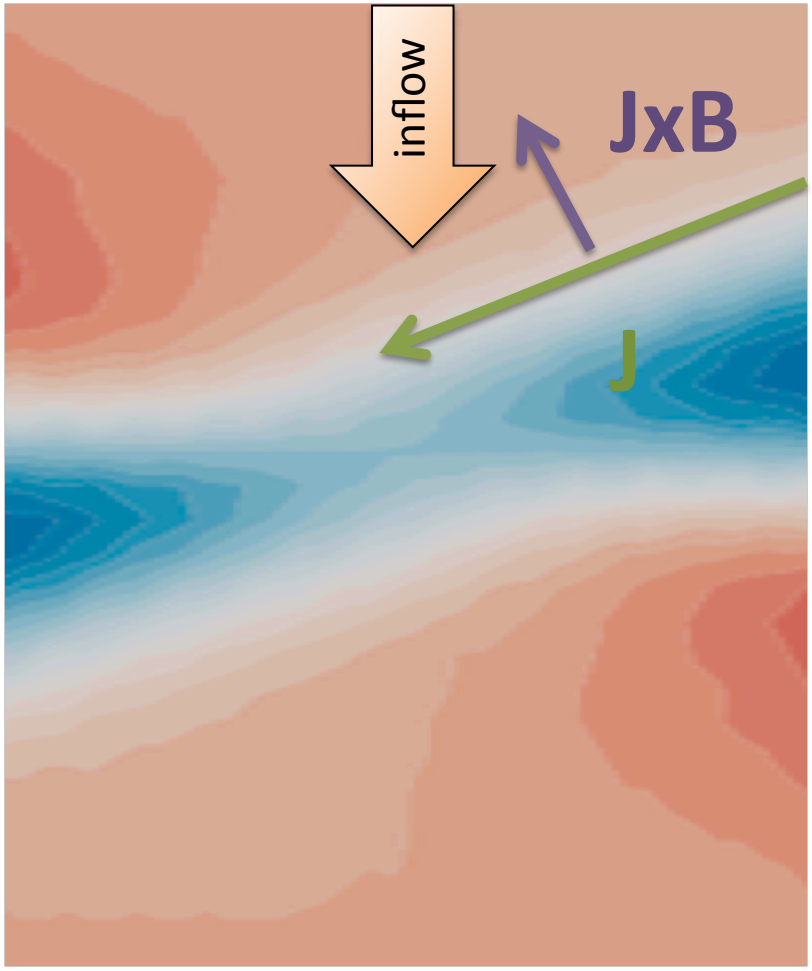


- Verified over large range of guide fields.
- Quantifies reduction of quadrupole field.
- But, rate reduction is stronger than expected!

What Causes a Reduced Reconnection Rate?

Simulations show weakly reduced reconnection rate due to interaction between Hall Currents and Guide Field.



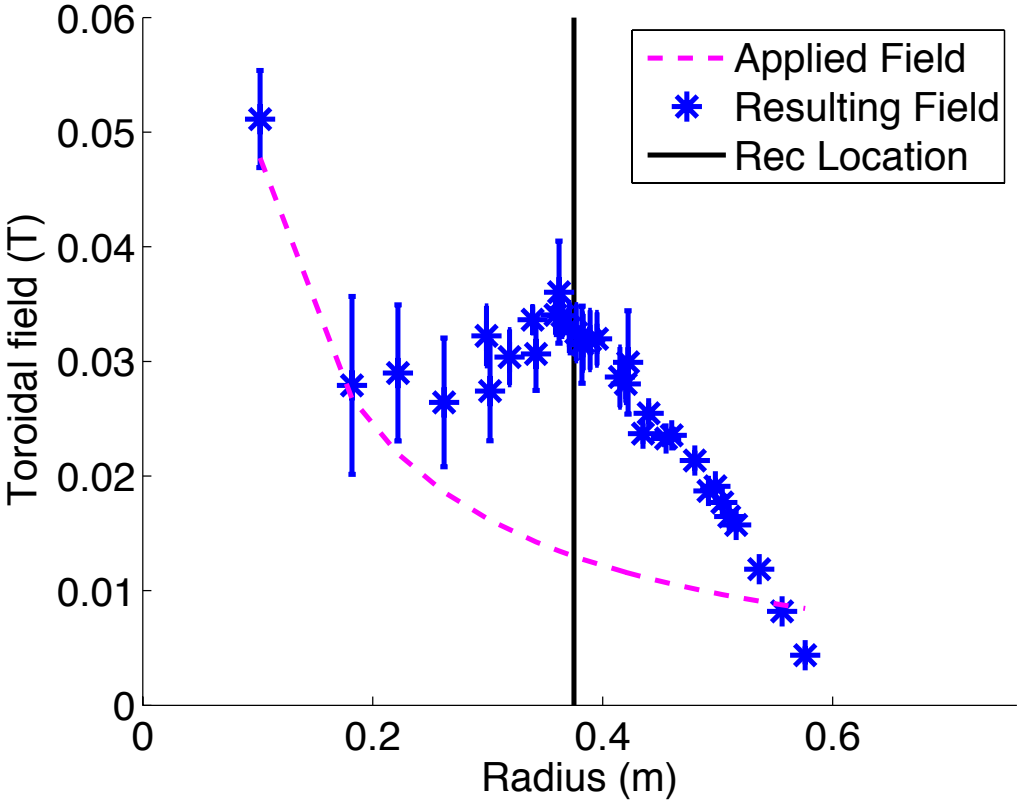
On average, JxB forces oppose the reconnection flow, causing a reduced reconnection rate.

Simulations typically see rate reduced by a factor of ~2 for $B_g = 5\ B_0$

Reconnection rate in experiment is reduced much more strongly than this!

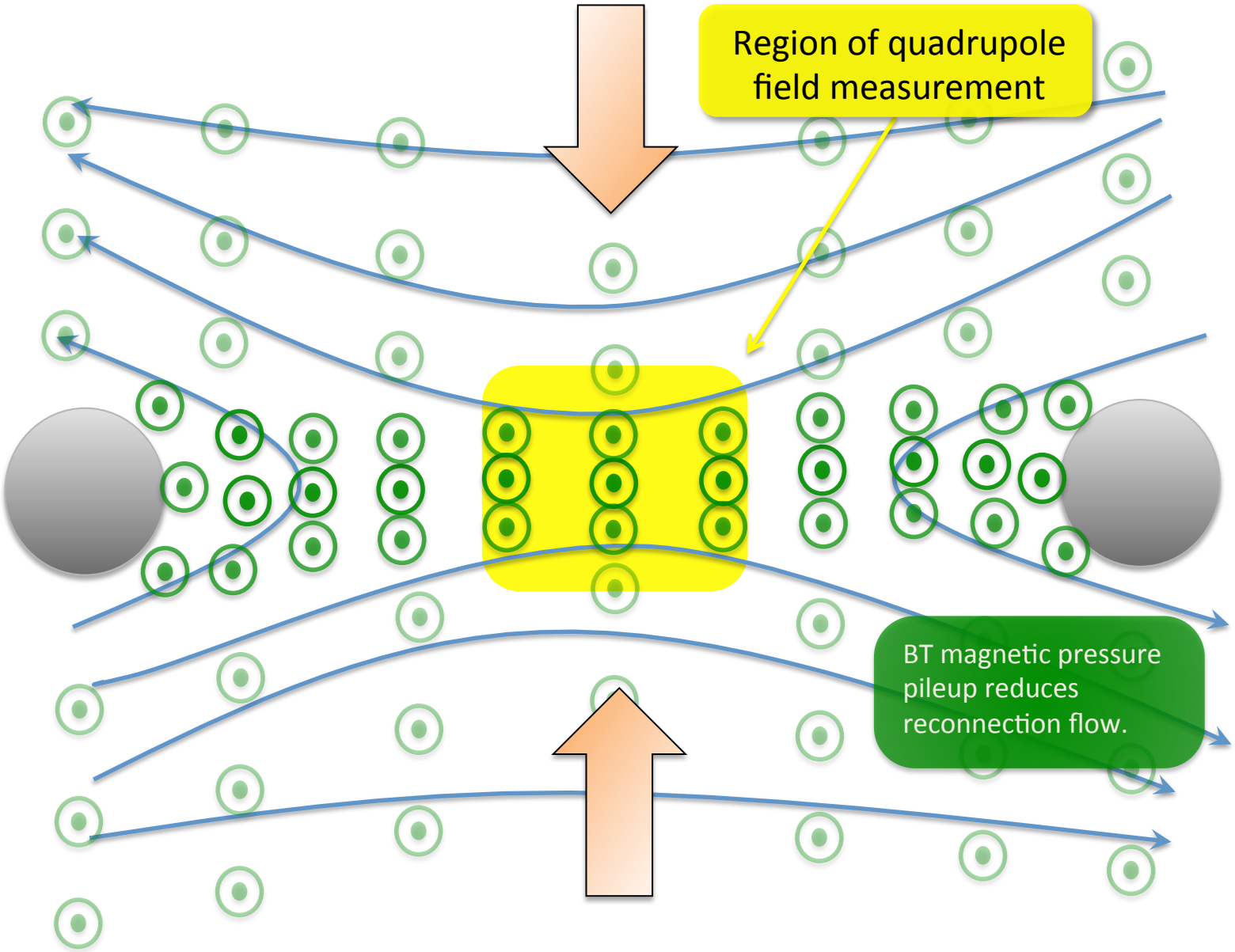
Guide field compression

Guide field compression can explain strong rate reduction.



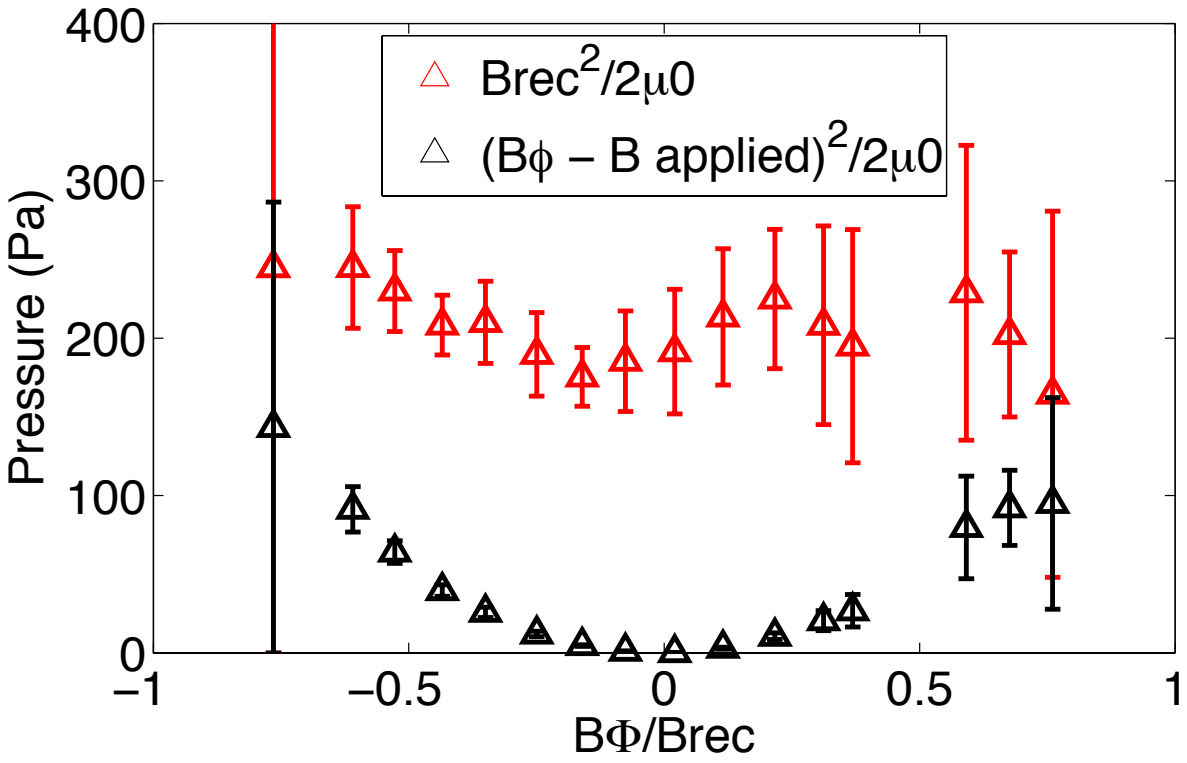
Uniform (~1/r) guide field is applied, but guide field is compressible and piles up at reconnection layer on large scale.

Guide field compression



Guide field compression

Pileup effects are enough to contribute significantly to global pressure balance.



Reconnection field magnetic pressure (drives outflow).

Guide field compression pressure (reduces outflow).

In Summary…

We have observed four major effects of guide field on a two-fluid plasma:

1) **Current sheet tilting**

2) **Modified and reduced Quadrupole Field**

3) **Reduced reconnection rate**

4) **Guide field compression**

Effects **(1)** & **(2)** agree with expectations based on simulations past and present, while **(3)** is stronger than expected because of **(4)**, which is an unanticipated effect discovered by this work.


Thank you!