Parallel and Perpendicular Flows driven by Stochastic Magnetic Fields in MST

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GOAL: Identify the role of stochastic magnetic fields in momentum transport and flow generation during reconnection

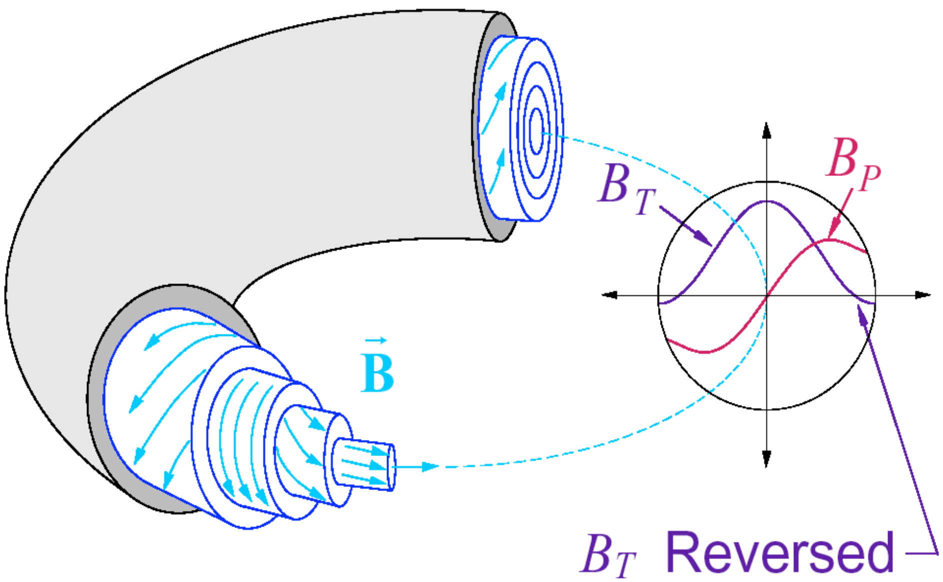
Results:

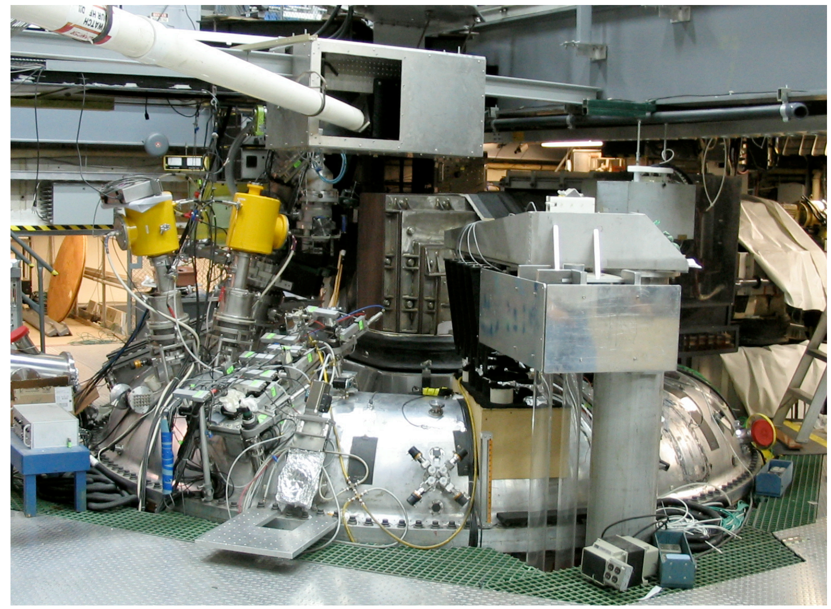
(1) transport of parallel momentum from stochastic fields is measured and found to be significant in the plasma core
……matching parallel velocity relaxation

(2) Stochastic field driven charge transport produces localized perpendicular flow and radial electric field (shear)
…….to be presented at poster

Madison Symmetric Torus - MST

MST Reversed-Field Pinch (RFP) is toroidal configuration with relatively weak toroidal magnetic field B_T (i.e., $B_T \sim B_p$)



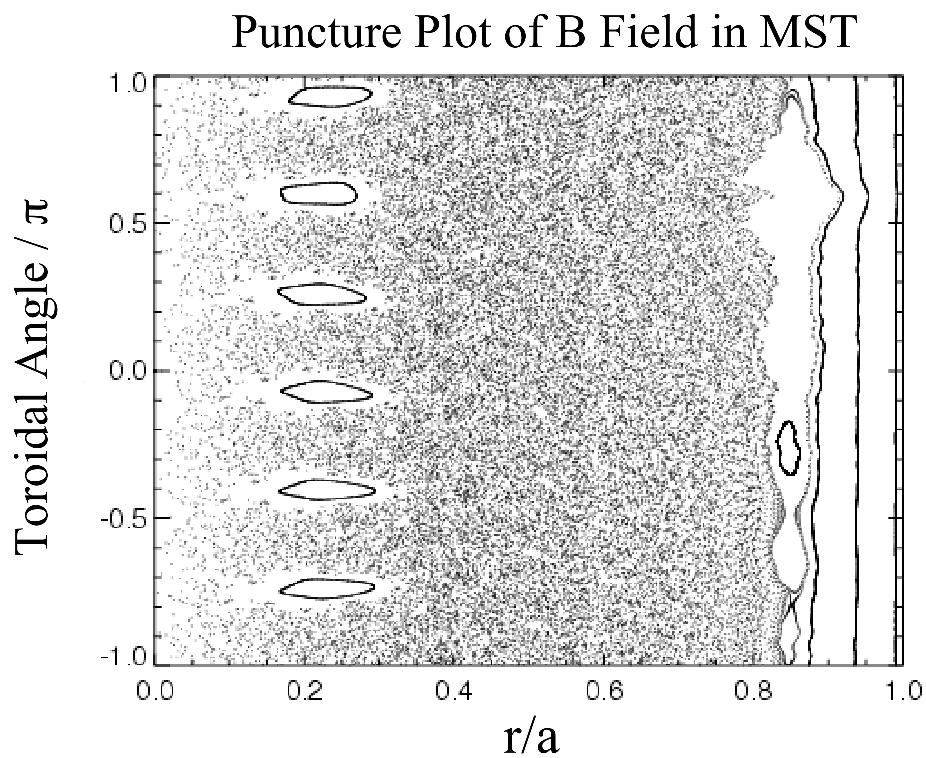


R_0 = 1.5 m, a = 0.51 m, I_p < 600 kA

B_T ~ 3-4 kG, $n_e \sim 10^{19}$ $m^{-3,}$ T_{e0} < 1.3 keV

τ_E ~ 10 ms, β =<p>/B^2(a)=15%

magnetic field in MST is typically stochastic and should contribute to momentum transport



- J. Finn (1991?) suggests momentum diffusion with $D \sim D_m\ c_s$
- Plugging in MST parameters: $\tau_m \sim 1$ ms in ambient case
  $\tau_m \sim 100\ \mu s$ during relaxation event

momentum transport by stochastic B field

• Momentum density in z direction being transferred in x direction is

$$\int f(\mathbf{x},\mathbf{v})\, m\, v_z v_x\, d^3v$$

• Assuming a strong B field with small fluctuations and taking z along B, we can write the contribution from parallel streaming particles using $v_z \cong v_{||}$ and $v_x \cong v_{||}(b_x/B)$ as

$$\int f(\mathrm{x},\mathrm{v})\, m\, v_{||}^2 \frac{b_x}{B} d^3v = \frac{p_{||} b_x}{B}$$

• Averaging over flux surface (z and y directions) we get the average momentum flux.

$$\frac{< p_{||} b_x >}{B}$$

• If $<b_x> = 0$, then we are left with

$$Flux: \quad \Gamma_r^{mom} = \frac{<\tilde{p}_{\|}\tilde{b}_x>}{B}$$

• In order for the momentum at x to change, need more flux coming in from –x than that leaving toward +x.

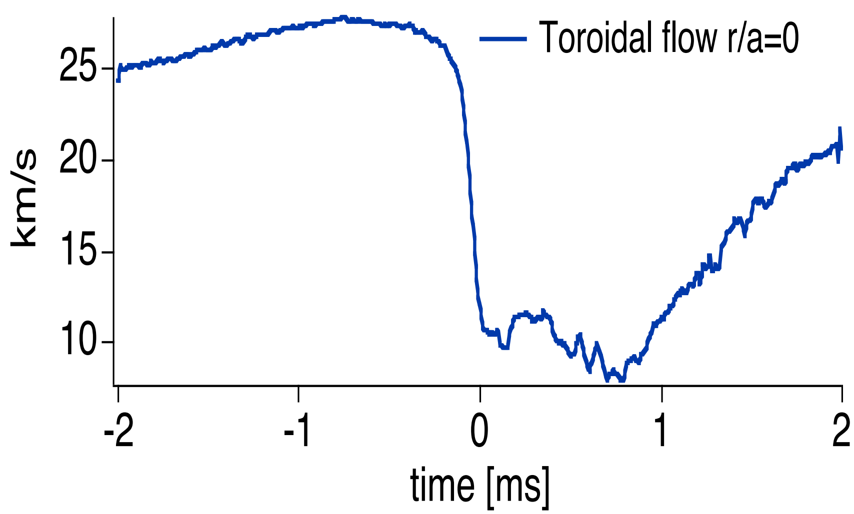
$$\frac{\partial <\rho v_{\|}>}{\partial t} \sim -\nabla\left(\frac{<\tilde{p}_{\|}\tilde{b}_x>}{B}\right)$$

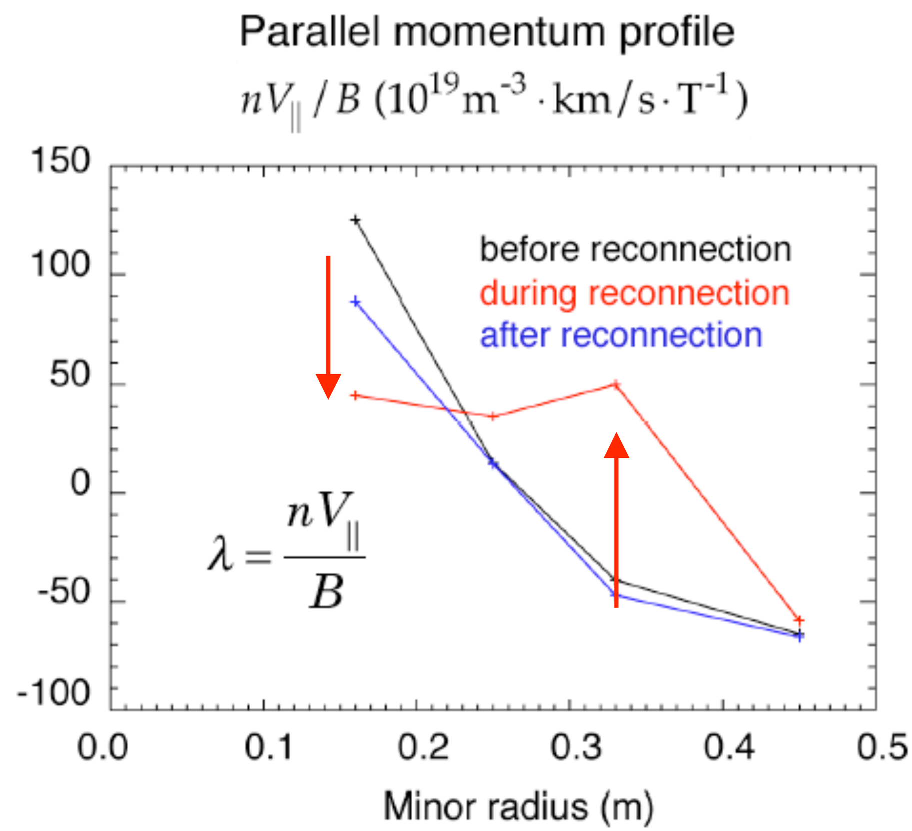
• above relation provides a direct measure of the transport of momentum along the mean magnetic field direction due to stochastic magnetic field.

• Substituting $\tilde{p}_{//} = T_{//}\tilde{n} + n\tilde{T}_{//}$, we get two terms

$$\frac{\partial <\rho v_{\|}>}{\partial t} \sim -T_{\|}\nabla\left(\frac{<\tilde{n}\,\tilde{b}_x>}{B}\right) - n\nabla\left(\frac{<\tilde{T}_{\|}\,\tilde{b}_x>}{B}\right)$$

Momentum transported from core to the edge during reconnection





During reconnection, parallel momentum redistributes within ~100 μs, much faster than classical collision time.

Stochastic field-driven transport is directly measured (first term only)

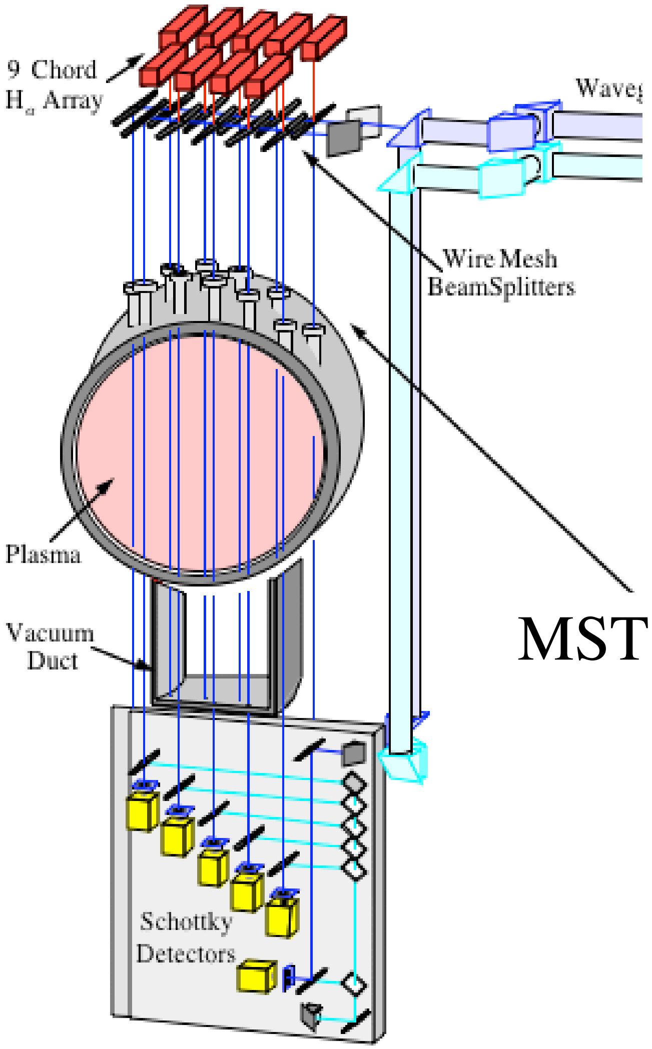
$$\frac{\partial < \rho v_{\parallel} >}{\partial t} \sim \boxed{-T_{\parallel} \nabla \left(\frac{< \tilde{n}\, \tilde{b}_r >}{B} \right)} - n \nabla \left(\frac{< \tilde{T}_{\parallel}\, \tilde{b}_r >}{B} \right)$$

Convection

- Measure $T_{//,\mathrm{ion}}$ with Rutherford Scattering (or CHERS)
- Measure b_r and B with FIR laser Faraday Rotation
- Measure $\tilde{n}$ *and* $\nabla\tilde{n}$ with differential FIR interferometer

- *Measurement details provided at poster….*

FIR Polarimeter-Interferometer System



Interferometer $\longrightarrow \tilde{n}$

$$\phi \sim \int n dl + \int \tilde{n} dl$$

Differential Interferometer $\longrightarrow \nabla\tilde{n}$

$$\frac{\Delta\tilde{\phi}}{\Delta x} \quad \Delta x \sim 1\, mm$$

Faraday rotation $\longrightarrow \tilde{b}$ *and* $\tilde{j}$

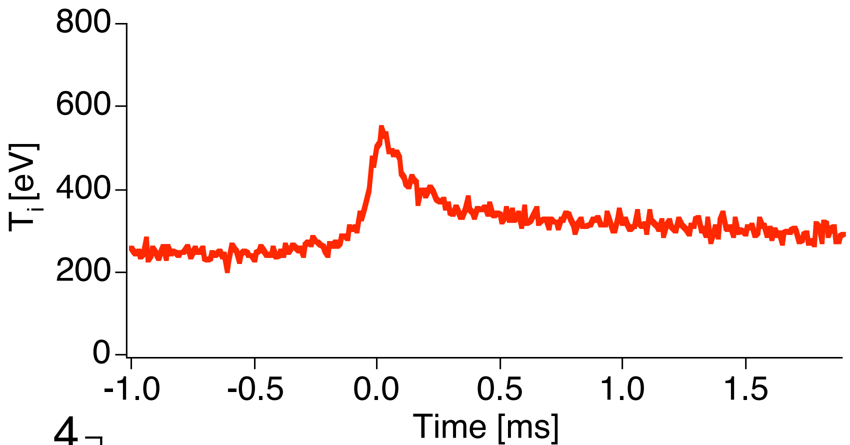
$$\Psi \sim \int n\vec{B} \bullet d\vec{l} + \int n\vec{\tilde{b}} \bullet d\vec{l} + \int \tilde{n}\vec{B} \bullet d\vec{l}$$

$$\oint_L \vec{\tilde{b}} \bullet d\vec{l} = \mu_0 \tilde{I}_\phi \approx \frac{\tilde{\Psi}_1 - \tilde{\Psi}_2}{c_F \bar{n}_0} \Rightarrow \tilde{j}_\phi$$

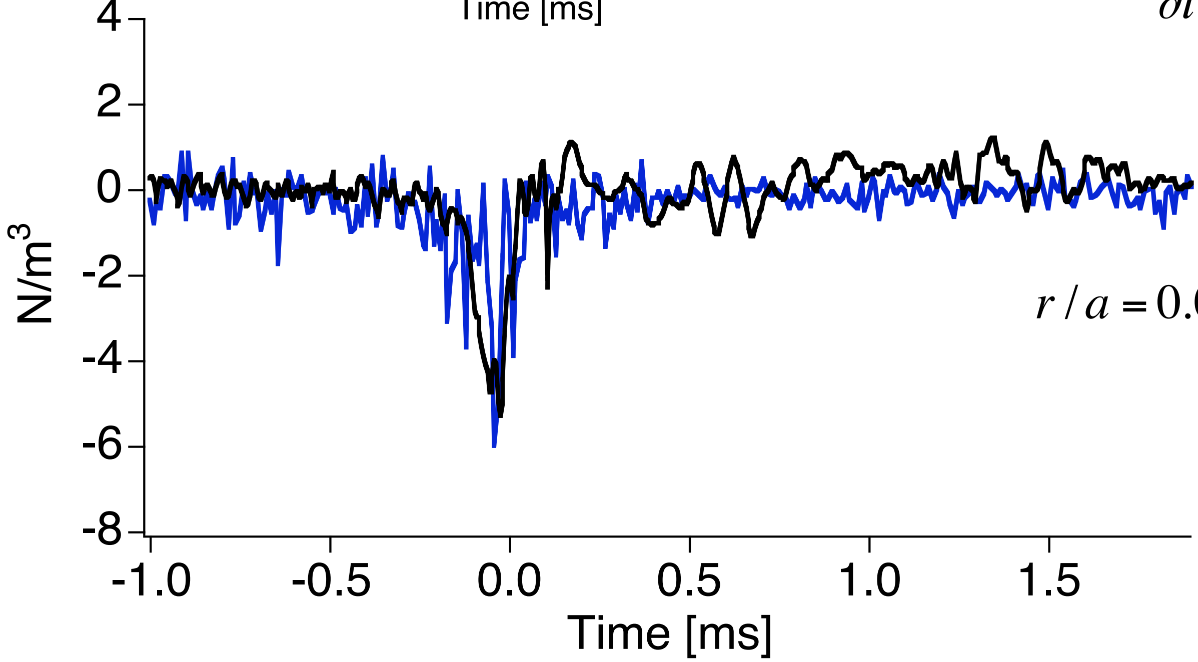
11 chords, Δx~ 8 cm, Δϕ~ 0.05º , Δt~ 1µs

Momentum flux and parallel momentum change

$$\Gamma_{mom} = T_{//,i} \frac{<\tilde{n}\tilde{b}_r>}{B}$$



$$\frac{\partial <\rho V_{//}>}{\partial t} + T_{//,i} \nabla \frac{<\tilde{n}\tilde{b}_r>}{B} \approx 0$$



$r/a = 0.04$

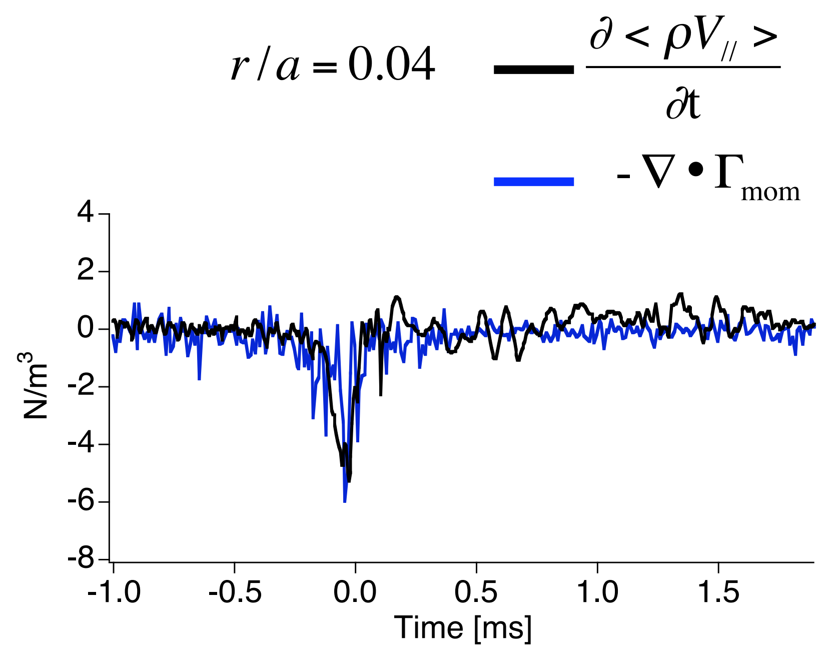
Blue line: $-T_{//,i} \nabla \frac{<\tilde{n}\tilde{b}_r>}{B}$

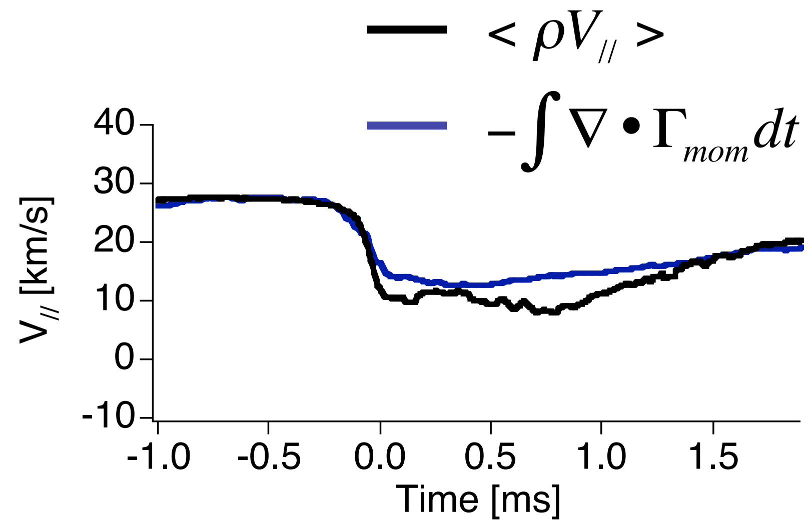
Black line: $\frac{\partial <\rho V_{//}>}{\partial t}$

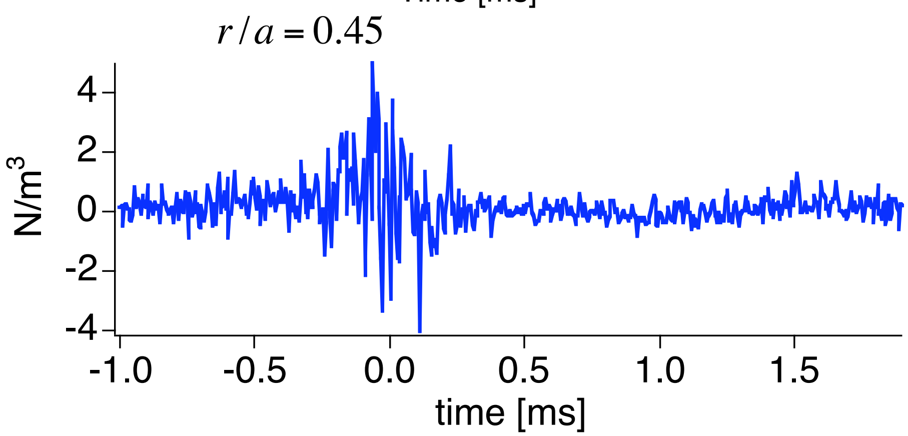
m=1, n=6,7,8,9

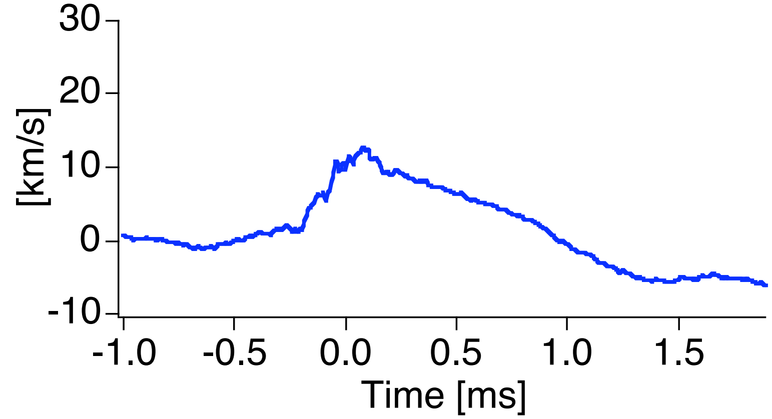
Magnetic fluctuation-induced (convective) flux drives parallel momentum drop

Momentum flux changes direction away from magnetic axis









Direction change consistent with momentum transport (not total momentum loss)

Summary: Stochastic magnetic fields drive parallel and perpendicular flows

Measurements indicate :