Shape and Current Profile Effects on Runaway Electron Confinement

by
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with
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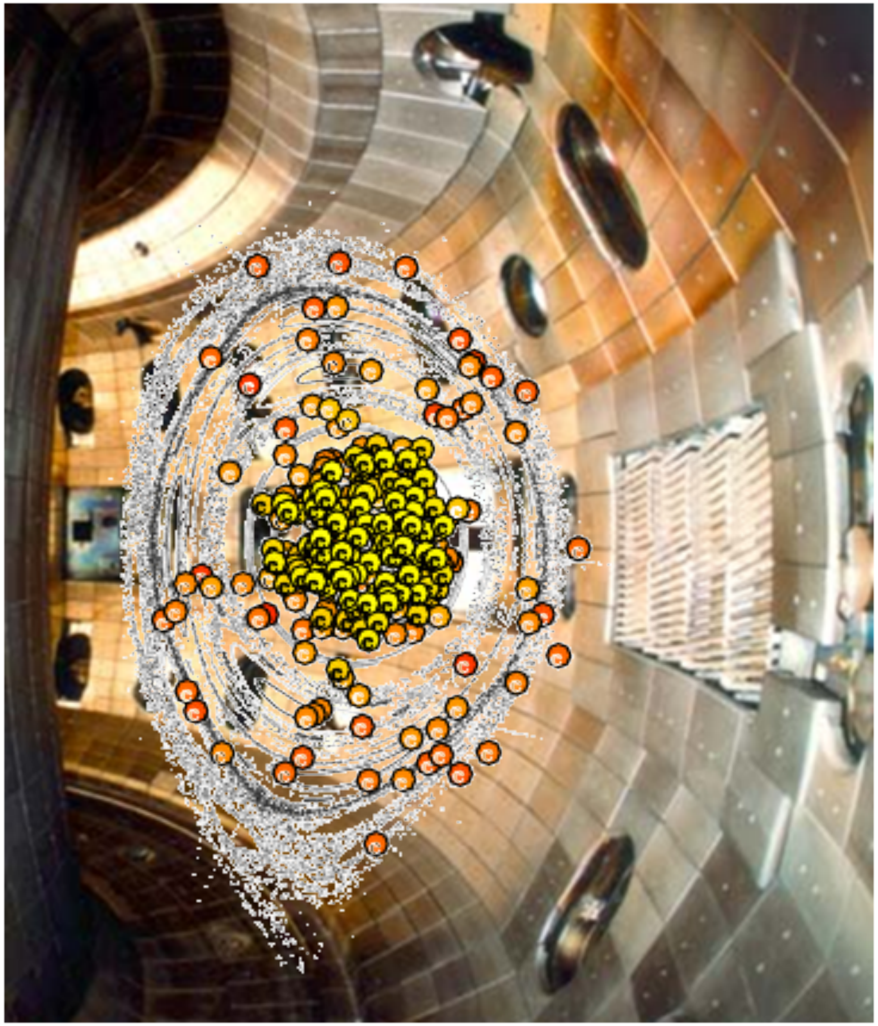

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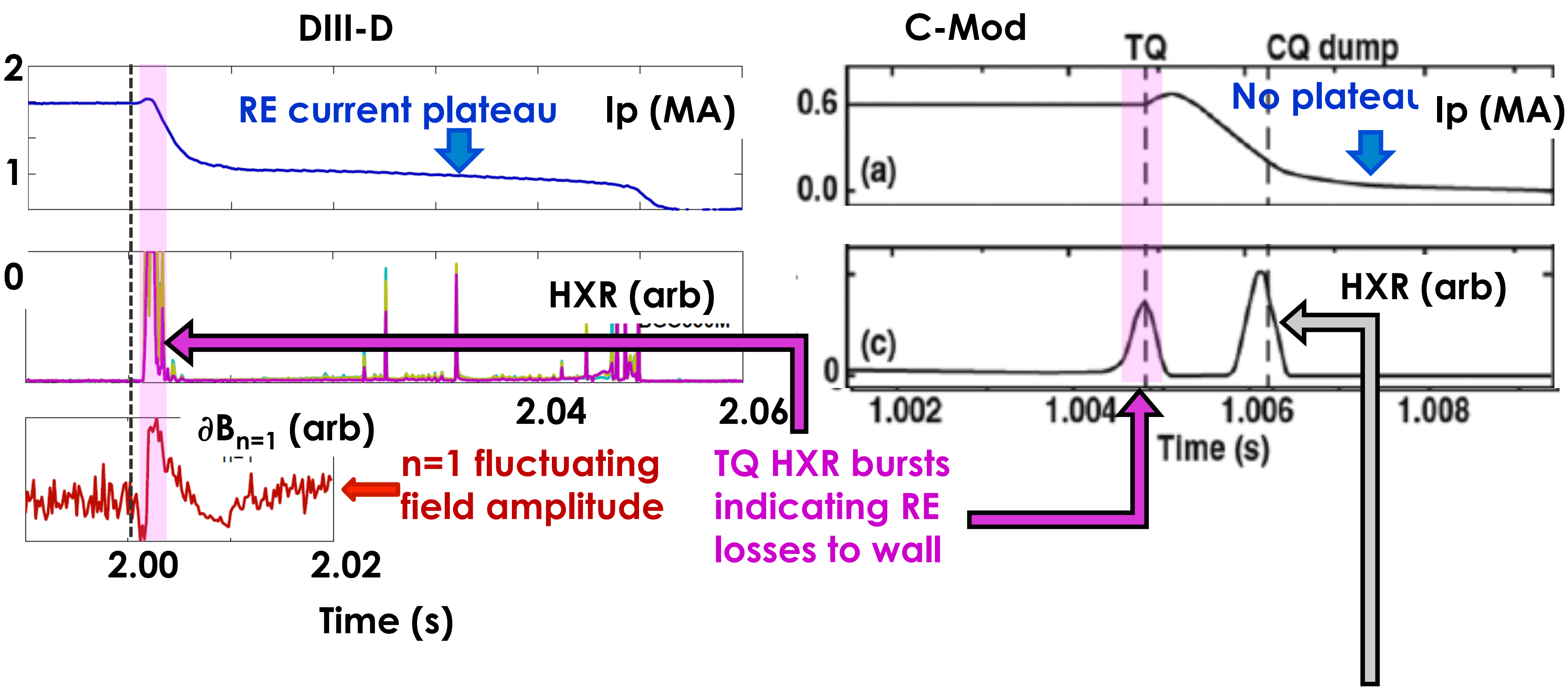
Conclusion

Appearance of post-thermal-quench runaway electrons depends critically on details of MHD fluctuations during the TQ

Part 1) Low-elongation, limited plasmas confine REs better than high-elongation, diverted plasmas

Part 2) In DIII-D diverted plasmas, variation in the target plasma current profile produces variation in TQ MHD, and thereby affects the final RE current amplitude

DIII-D and C-Mod RE Experiments Demonstrate Better RE Confinement in Limited Configuration

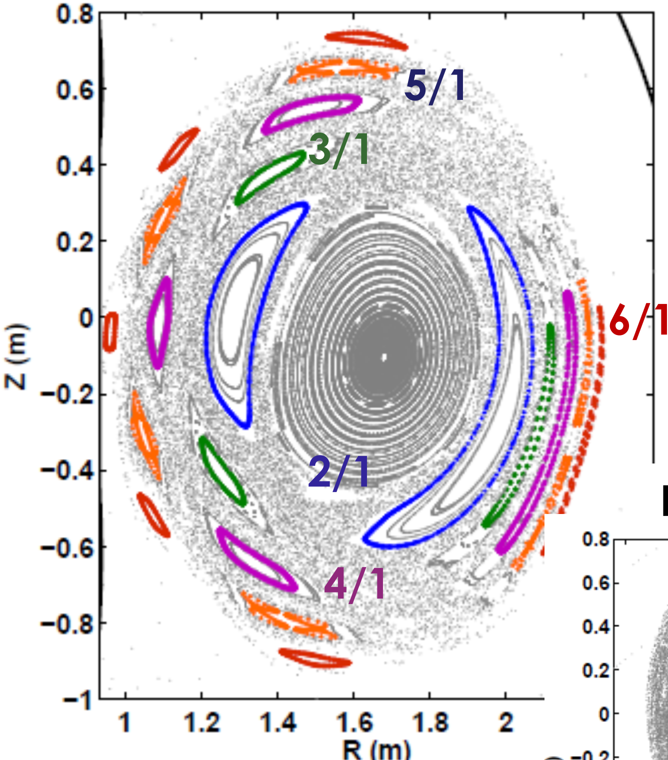


- Post-TQ RE current plateau *sometimes* appears, much more frequently in limited than diverted shots
- Second HXR burst at end of CQ occurs *only* for limited plasma shapes

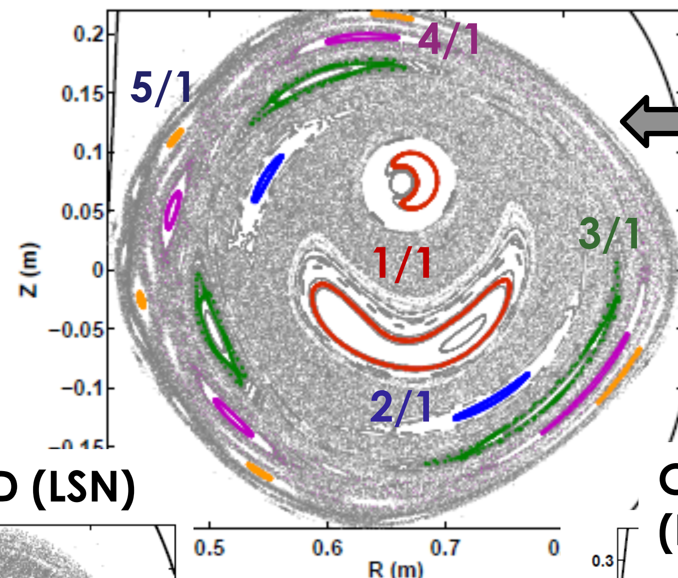
For more on DIII-D RE experiments, see N. Eidietis invited talk (VI3.00001), Thursday at 3:00 pm

NIMROD: Inner Wall Limited DIII-D and C-Mod Simulations Show Incomplete Island Overlap

DIII-D (IWL)

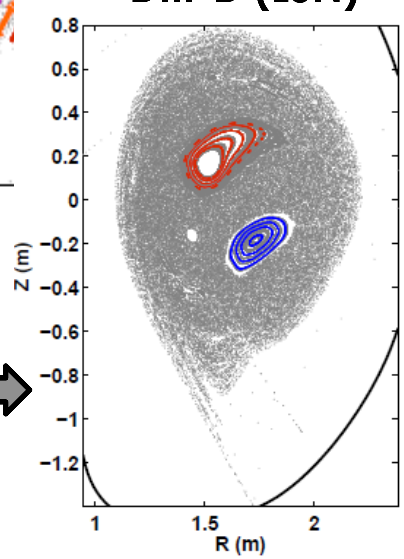


C-Mod (IWL)



Discrete n=1 islands for IWL, better RE confinement

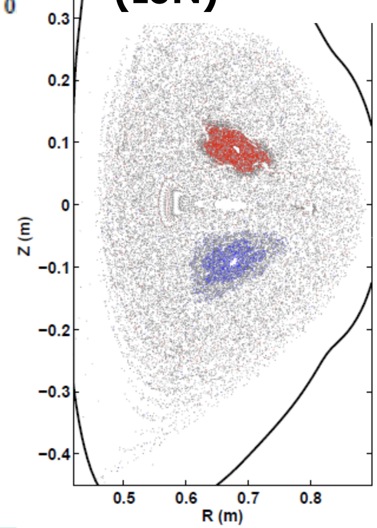
DIII-D (LSN)



Large stochastic regions for LSN

Strong qualitative cross-device similarity for both configurations

C-Mod (LSN)



See: Izzo, et al., *Nucl. Fusion* 51 063032 (2011)

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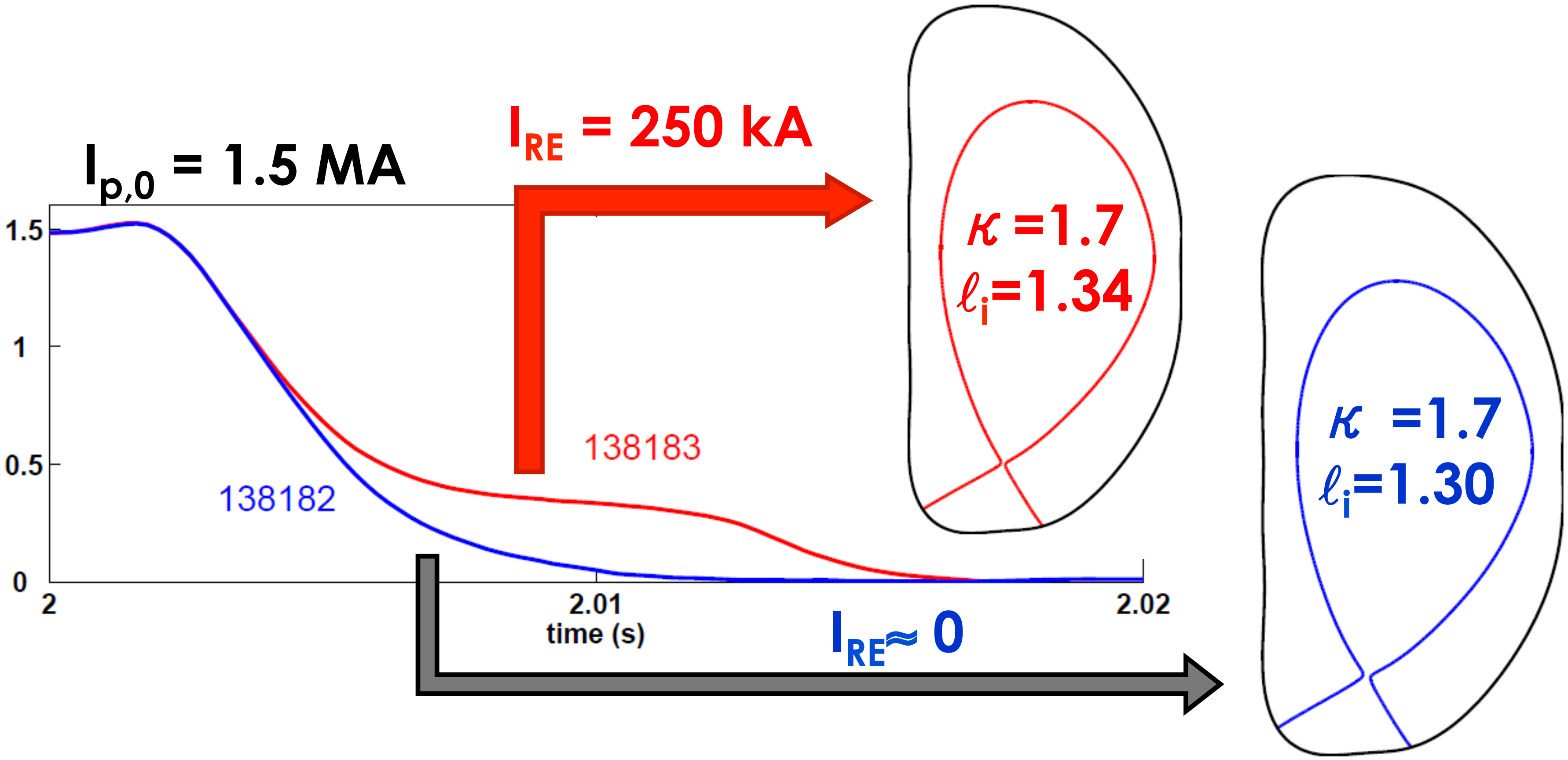
Appearance of RE Plateaus for Diverted Plasma Shapes is Very Unreliable on a Shot-to-shot Basis

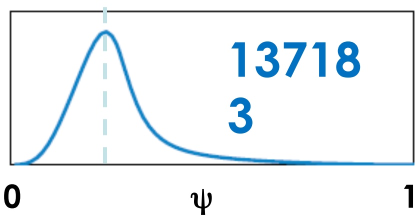


Hypothesis: Variations in seed RE deconfinement due to MHD produces this shot-to-shot variation in RE plateau current

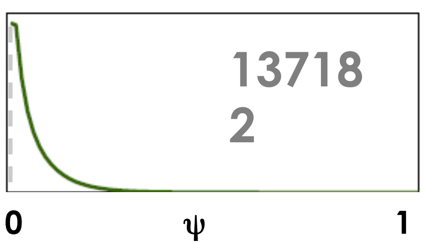
GATO Linear Stability Analysis Finds Relationship Between n=1 Eigenfunction and RE Plateau Current

Calculate radial profile of unstable n=1 mode after Ar pellet begins to cool plasma edge

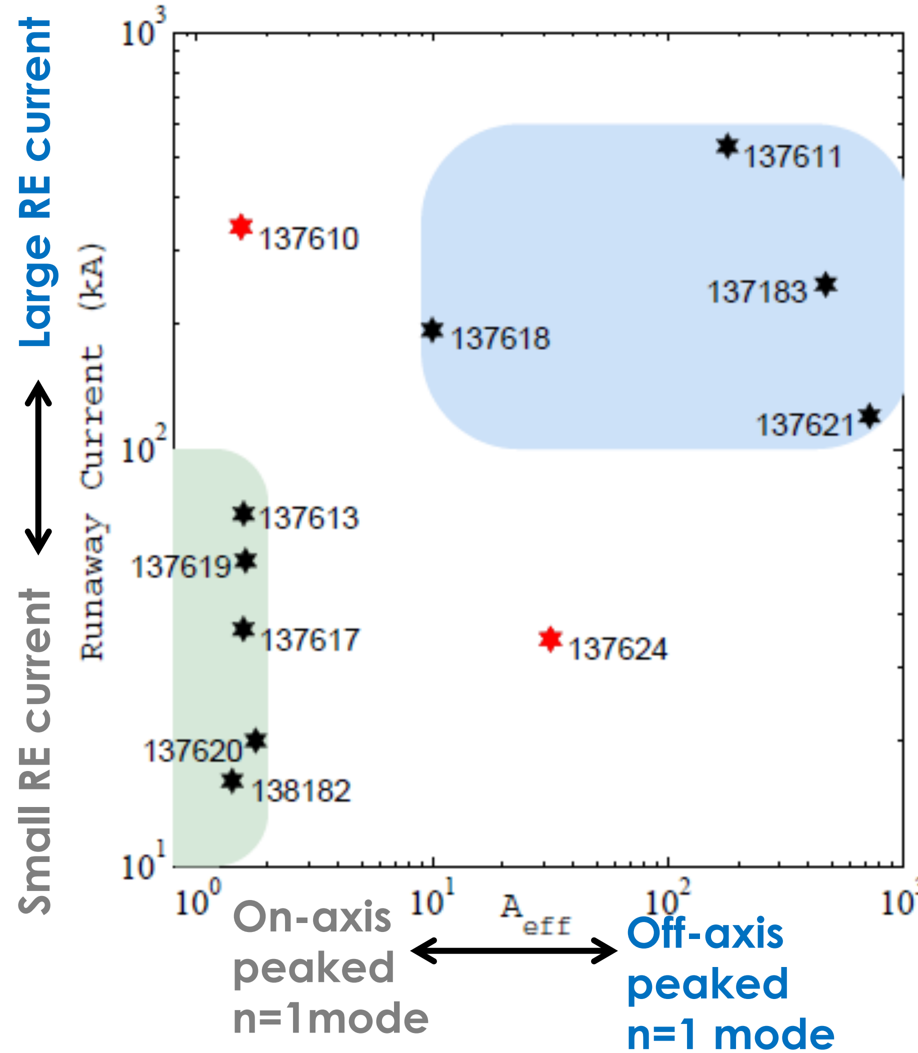
Large RE current → Off axis peaked n=1 mode (one exception)



Small RE current → On-axis peaked n=1 mode (one exception)



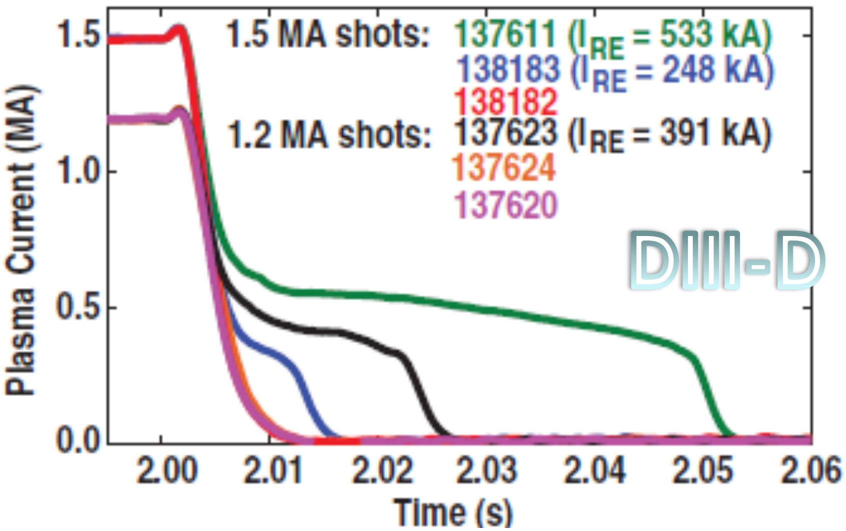
Clue that MHD de-confinement is the critical issue



GATO analysis by M. Kornbluth and D.A. Humphreys

RE Confinement Calculated Directly by NIMROD Simulations with Test-particle Drift Orbits

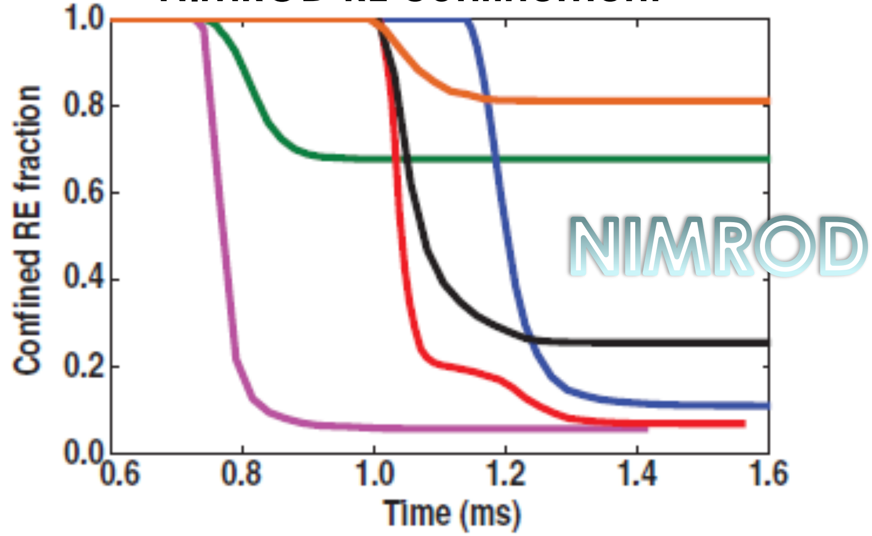
DIII-D Current Traces



- Nonlinear resistive MHD simulation models cooling due to Ar pellet, TQ and CQ phase
- Trace population of RE drift orbits are calculated as the MHD fields evolve

- Curve of confined REs vs. time is obtained in every case; RE losses highly variable
- RE loass rate is computed as: $(dN_{RE}/dt)/N_{RE}$ (inverse of confinement time)

NIMROD RE confinement



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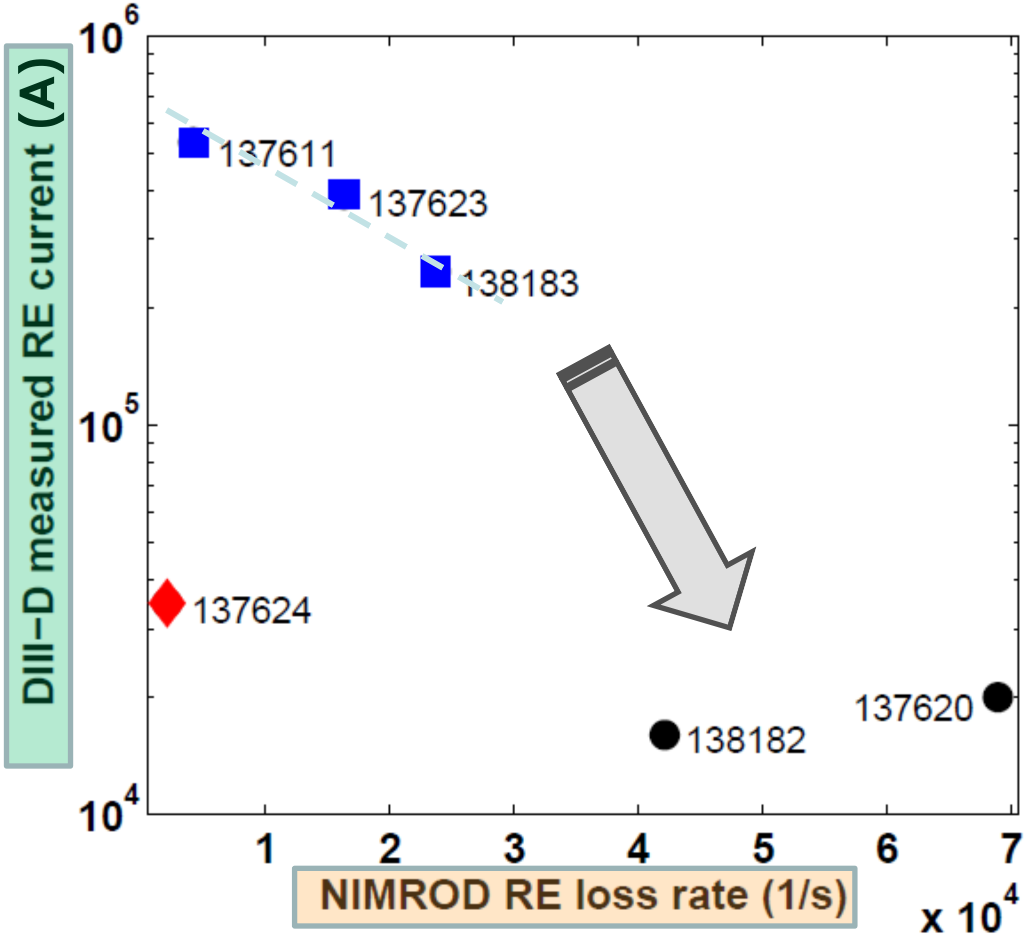
NIMROD Predicted RE Loss Rates Consistent with Experiment (with One Exception)

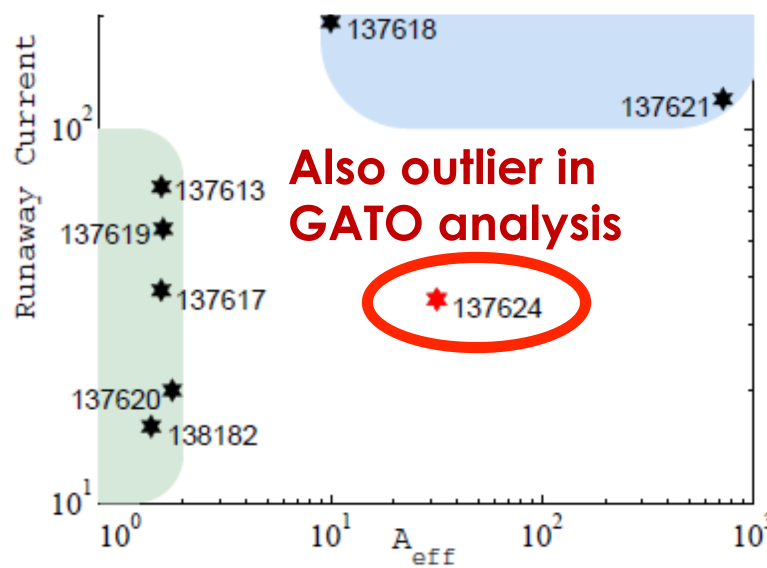


Cases with I_{RE}>100 kA show expected trend vs. predicted loss rate

$$\log(I_{RE}) = \left[\log(I_{seed}) + \gamma_A \tau_{CQ}\right] - \gamma_{RE} \tau_{loss}$$

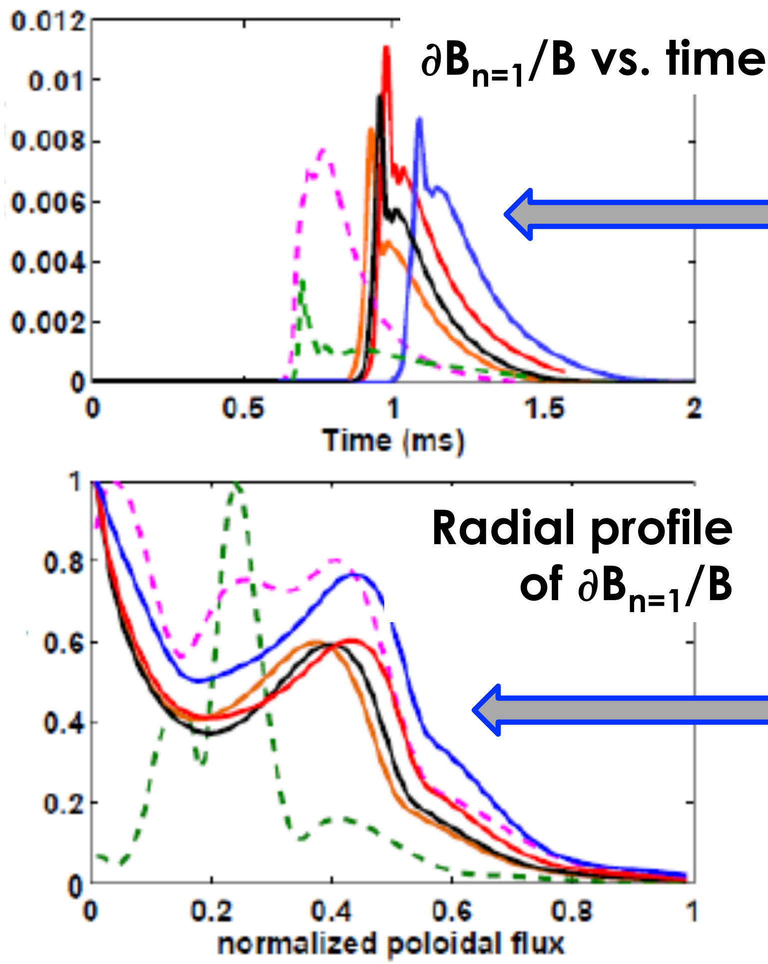
Cases with predicted loss rate > $4x10^4$/s have negligible RE current

Single outlier: 137624



Four Simulations with $q_0<1$ All Have Same Qualitative MHD Behavior

Solid curves have $q_0<1$



Amplitudes of n=1 vs. time have same qualitative trend, variations only in timing, peak amplitude

Radial profile of saturated n=1 mode is nearly identical in every $q_0<1$ case

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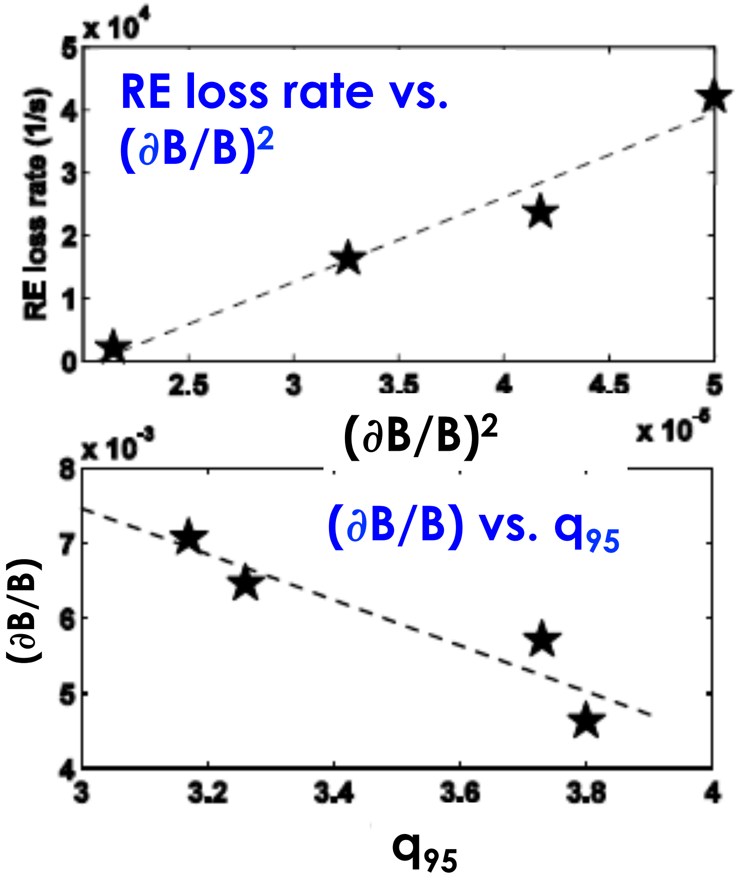
Expected Correspondence Between n=1 Mode Amplitude, Confinement for $q_0<1$



Relationship between saturated mode amplitude and RE loss rate is predicted by Rechester-Rosenbluth model for electron heat transport on stochastic fields:

$$D_{RE} \sim (1/\tau_{RE}) \sim (\partial B / B)^2$$

Fluctuating field amplitude correlates (0.93) with value of q95, shows no clear systematic trend for any other current profile parameter considered

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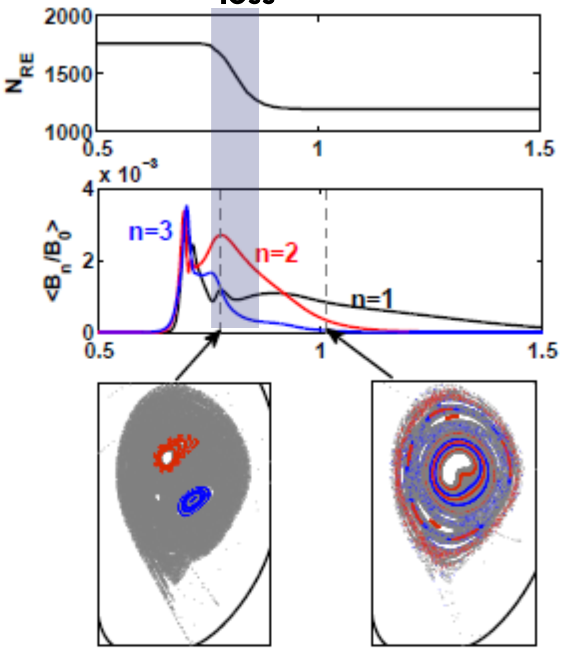
Comment on ITER Implications

Two important time scales happen to be comparable in DIII-D…
but they may not scale the same

τ_{loss} ~ 0.1 ms



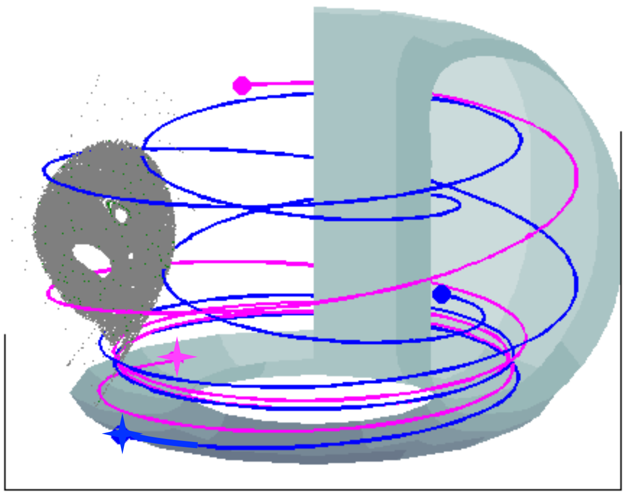
τ_{loss} -
Time interval during which REs are lost.

Related to "re-healing" of flux surfaces after mode saturation

τ_{RE} -
RE confinement time when fields are stochastic

Depends on saturated mode amplitude and machine size

τ_{RE} ~ 0.1 ms



"Marginal confinement regime" may explain shot-to-shot non-reliability in DIII-D, but how do these times scale relative to each other? Do current profile details matter in the case of ITER?

Conclusion

Appearance of post-thermal-quench runaway electrons depends critically on details of MHD fluctuations during the TQ

Part 1) Low-elongation, limited plasmas confine REs better than high-elongation, diverted plasmas

→ Supported by evidence from both experiment and simulation for both DIII-D and C-Mod

Part 2) In DIII-D diverted plasmas, variation in the target plasma current profile produces variation in TQ MHD, and thereby affects the final RE current amplitude

→ NIMROD successfully predicts the shot-to-shot variation in RE loss rates for all but one case, but relationship to equilibrium current profile is more complex than a single parameter (e.g. q_{95} is important, but only for $q_0<1$)