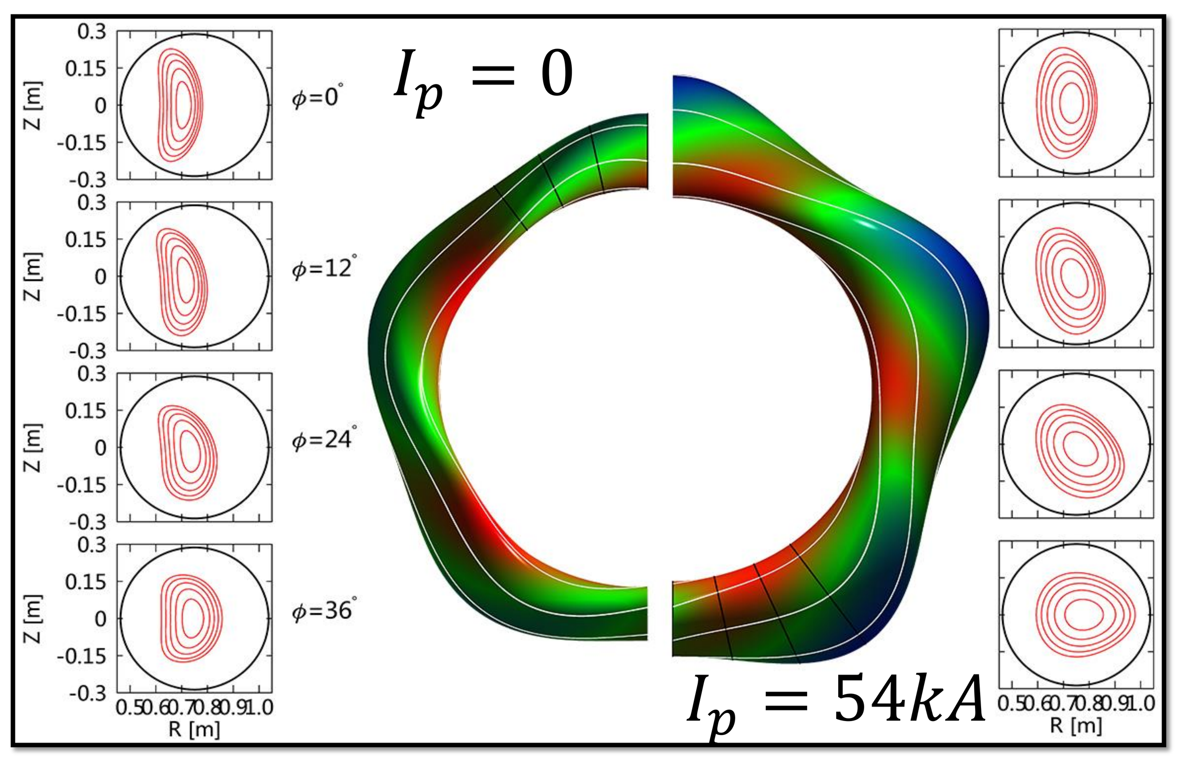
Non-axisymmetric equilibrium reconstruction on the Compact Toroidal Hybrid Experiment using external magnetic and soft x-ray measurements

X. Ma
M. Cianciosa, J.D. Hanson, G.J. Hartwell, S.F. Knowlton, D.A. Maurer, D.A. Ennis, J.L. Herfindal
Auburn University

Introduction & Motivation

- **Compact Toroidal Hybrid (CTH) is a small torsatron/tokamak hybrid device with magnetic configuration that can be strongly modified by ohmic plasma currents.**
- **Reconstruction of non-axisymmetric, three-dimensional (3D) plasma equilibria is important for understanding intrinsic 3D confinement and stability in stellarators.**
- **3D equilibrium reconstruction on this device attempts to determine the internal current profile, net rotational transform profile in order to understand the stability and disruptive characteristics of these hybrid stellarator/tokamak plasmas.**
- **Previous work has shown that density limit disruption can be avoided with additional helical vacuum transform.**

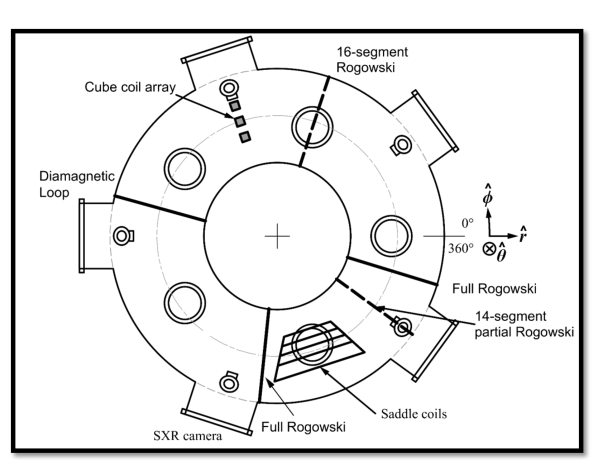
Non-axisymmetric plasma in CTH



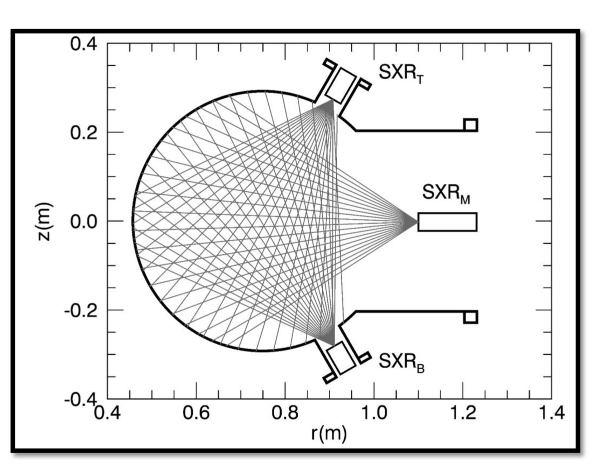
- The poloidal cross-section of CTH discharges becomes less elliptical with addition of plasma current.
- The underlying toroidal n=5 stellarator periodicity is enhanced.
- 3D reconstruction is required in CTH hybrid discharges

Diagnostics Used in Reconstructions

Magnetic diagnostics



Two-color SXR system

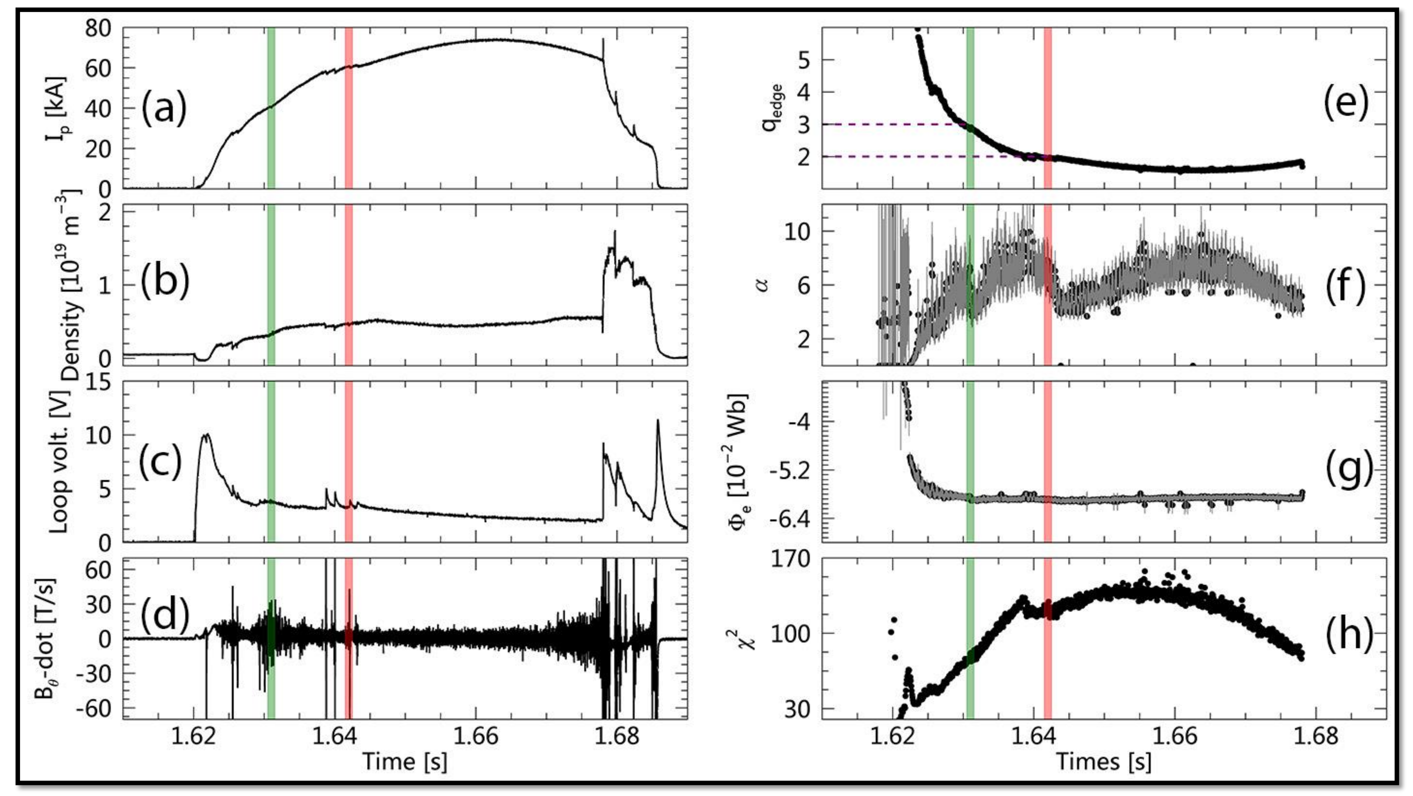


V3FIT is Used to Reconstruct 3D Equilibrium

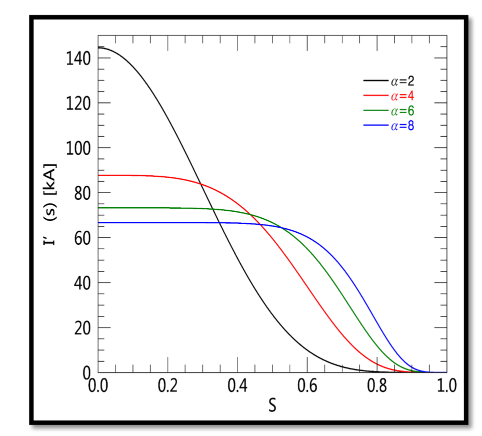
- V3FIT [1] is used for reconstructing fully 3D plasma equilibrium.
  - V3FIT computes best fitting between data signals calculated from given equilibrium model and experimental measures.
  - CTH has chosen VMEC [2] as the equilibrium solver for V3FIT.
- V3FIT utilizes measurements from magnetic diagnostics, SXR cameras and interferometer.

[1] J.D. Hanson, S.P. Hirshman, S.F. Knowlton, L.L. Lao, E.A. Lazarus, and J.M. Shields, Nucl. Fusion 49, 075031 (2009)
[2] S.P. Hirshman and D.K. Lee, Comput. Phys. Commun. 39, 161 (1986)

Whole Shot Reconstruction with Magnetic Diagnostics

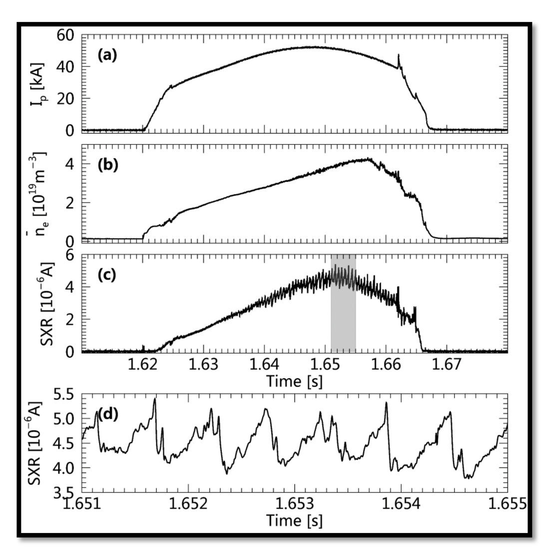


- The current profile parametrization is based on a single fitting parameter α: $I'(s) = I_o(1 - s^{\alpha})^6$
- Hesitations are observed in the rise of plasma current.
- MHD oscillations observed by B_θ-dot coils
- Edge safety factor goes through integer values
- Sudden narrowing of current profile.
- Using magnetics alone does not give accurate estimation of internal current profile.

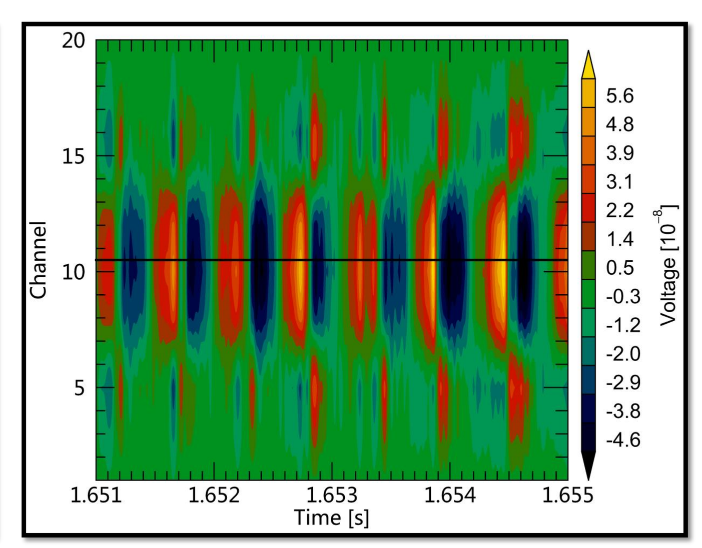


Measured Sawtooth Inversion Radius Applied to Reconstruction

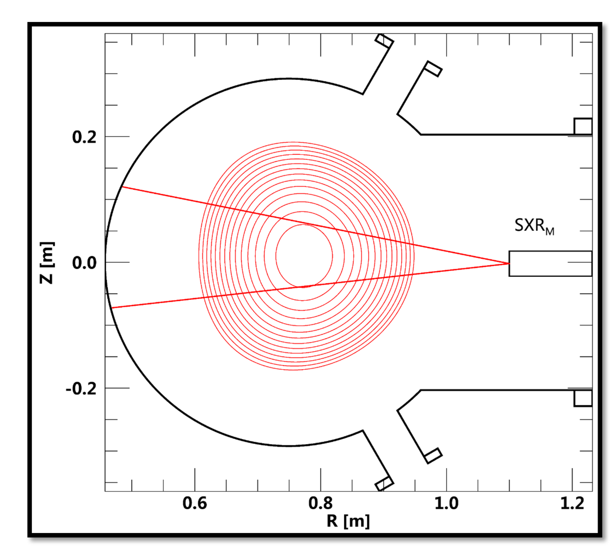
Sawteeth are observed in CTH plasmas with sufficient density



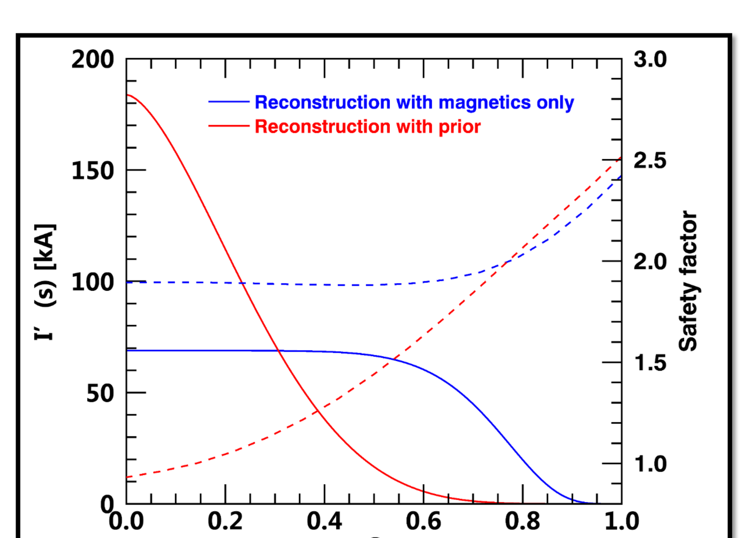
Bi-orthogonal Decomposition shows the structure of sawteeth and is used to identify the inversion channels



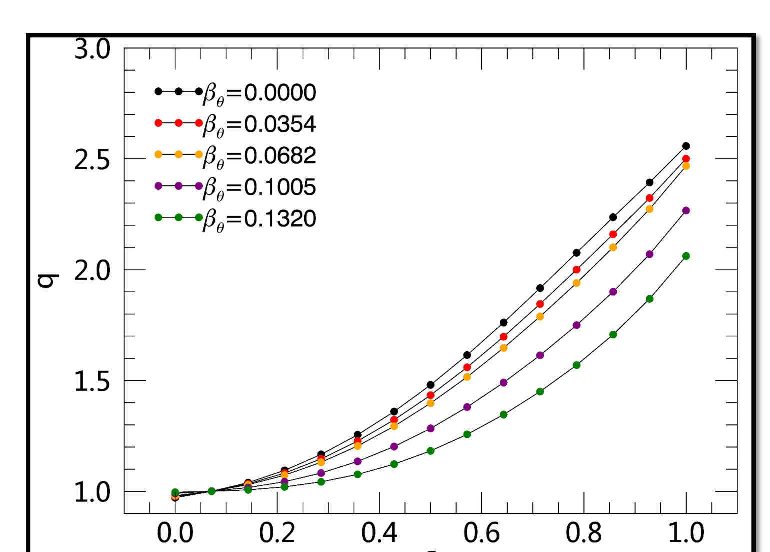
Inversion channels are projected on the equilibrium surface to identify the inversion surface.



- Inversion channel calculated using BD is consistent with the result using cross-correlation analysis.



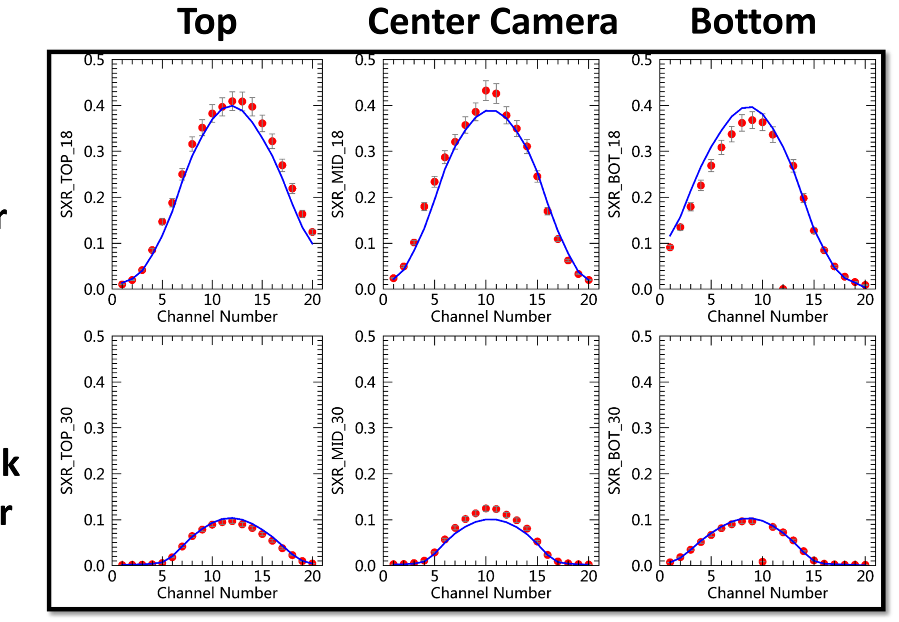
- Reconstruction using inversion information results a much more peaked current profile ($\alpha = 1.7 \pm 0.14$).
- Reconstruction of the same discharge with magnetics alone yields $\alpha = 7.5 \pm 4.6$.
- The resulting q-profile is flatter at minimum value of 0.9.

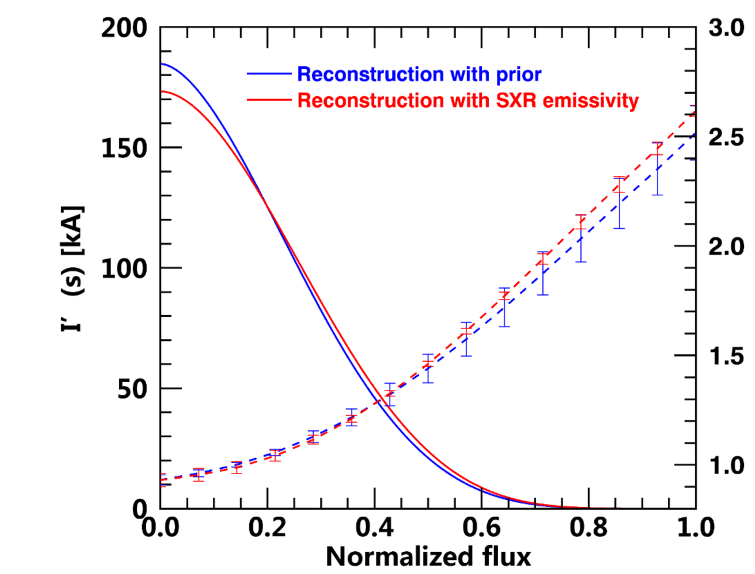


- The pressure has limited effect on the reconstructed q-profile for a low-beta plasma configuration.

Reconstruction of the Same Sawtooth Discharge with SXR Emission

- SXR emissivity is assumed to be constant on flux surfaces.
- Flux surface geometry is fitted by V3FIT using multiply chordal SXR emission.
- SXR data acquired from three 20-channel cameras with 2 different filters.



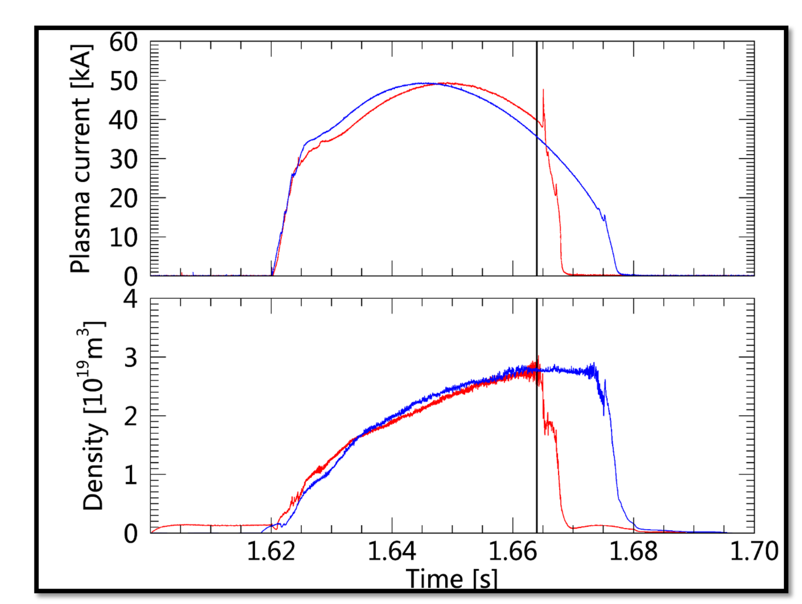


- Reconstruction without sawtooth inversion still finds q=1 surface near the magnetic axis.
- Reconstructed current profile is more peaked compared to the one from magnetics alone.
- Similar q and current profiles obtained as the reconstruction using inversion information.

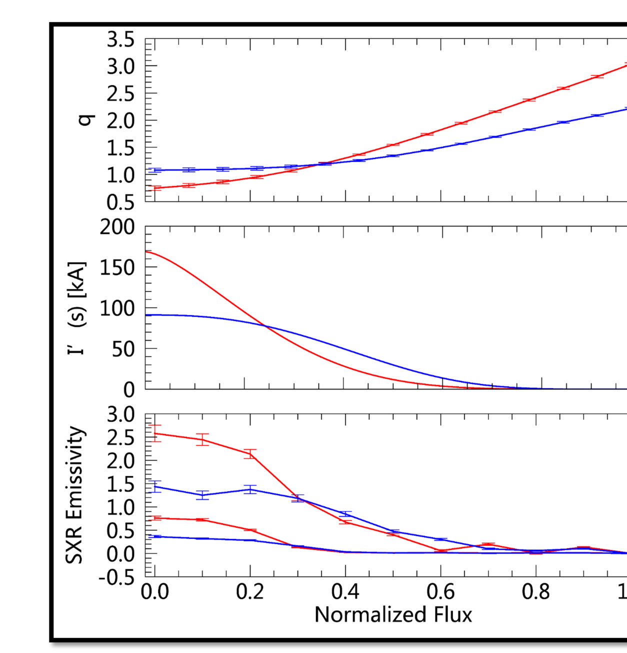
Density limit disruption suppression in CTH

Density limit disruptions observed in CTH by ramping density with edge fueling

Red: low vacuum transform (0.02)
Blue: high vacuum transform (0.11)

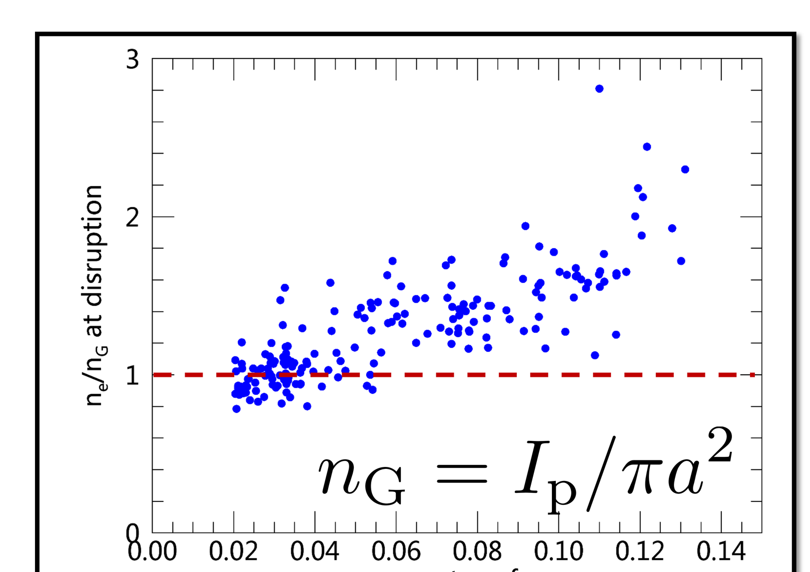


Reconstructions of the two discharges at the same time slice

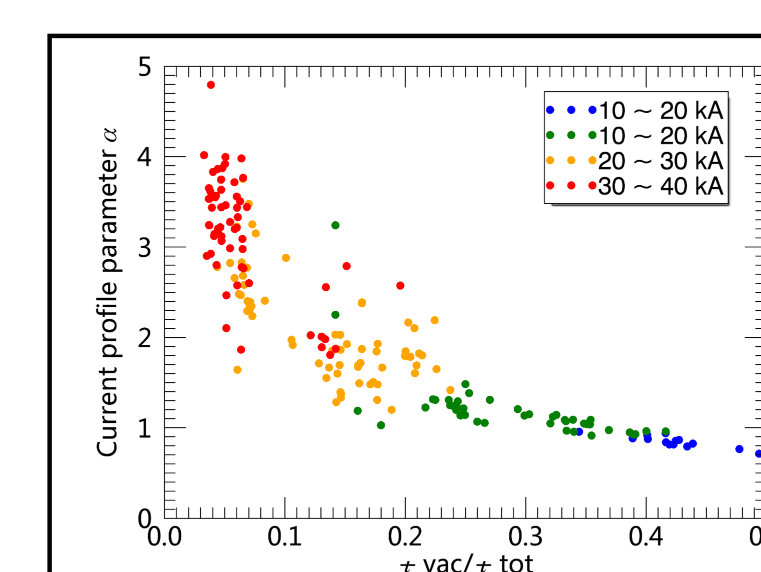


- Addition of vacuum transform found to flatten both current and transform profiles, leading to a more stable regime.

Collection of 190 density limit disruption discharges with varying vacuum transform



- Density at disruption exceeds Greenwald limit as vacuum transform is increased



- High density plasmas tends to disrupt with more peaked current profile with increasing 3D fields