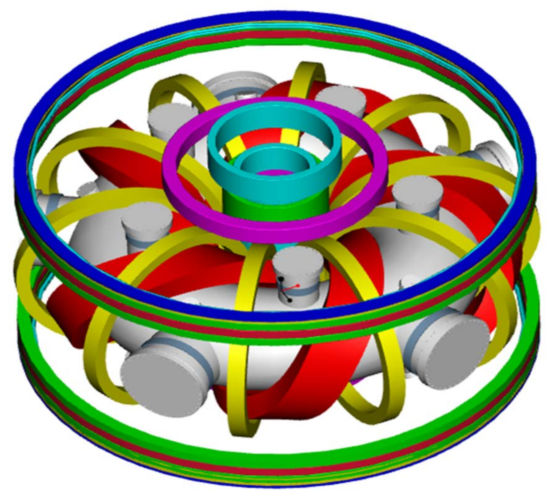
Introduction & Motivation

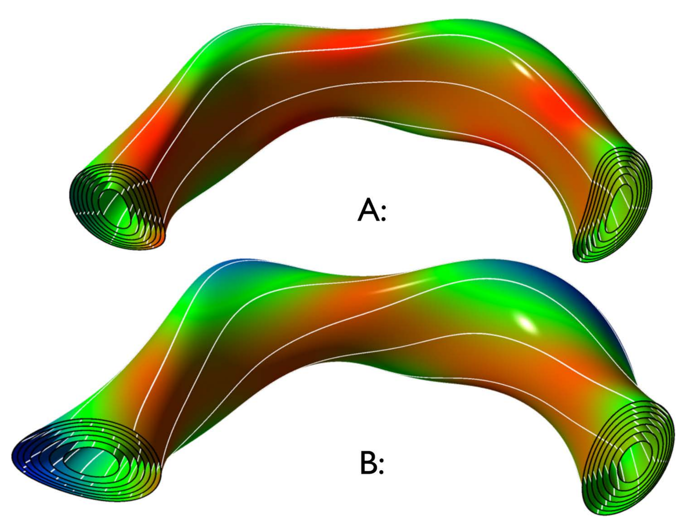
CTH is a low aspect-ratio, tokamak/stellarator hybrid with flexible magnetic configuration.

- Designed to address strong 3D shaping effects on MHD instabilities and disruptions
- Ability to drive ohmic current within pre-established ECRH stellarator plasma
- Flexible vacuum field configuration to change the amount of 3D fields applied



Helical Field coil
Toroidal Field coil
Trim Vertical Field coil
Shaping Vertical Field coil
Central Solenoid

CTH plasmas are highly non-axisymmetric with or without driven plasma current



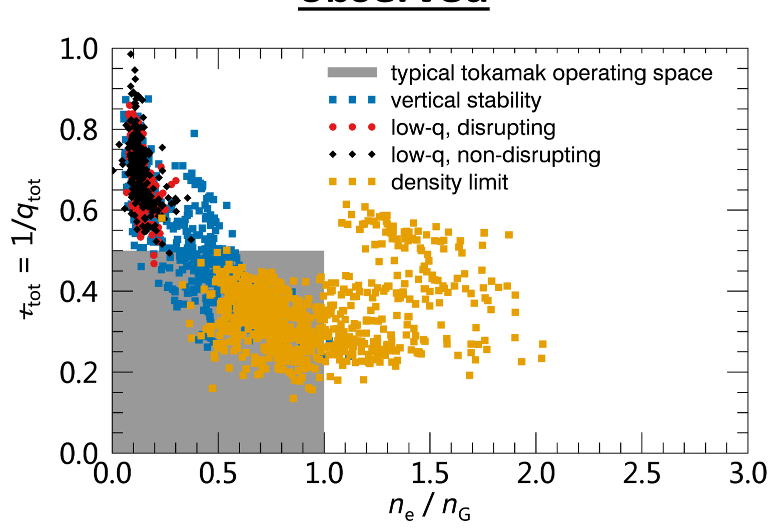
Zero current, ECRH only plasma

Plasma with driven current

3D equilibrium reconstruction is a critical tool for understanding 3D confinement and stability

- V3FIT[1], which uses VMEC[2] as the equilibrium solver, is used to reconstruct CTH plasmas
- V3FIT optimizes the plasma parameters to achieve the best agreement between modeled signals and experimental measurements
- V3FIT is capable of utilizing many types of diagnostics including: magnetic diagnostics, SXR measurements, interferometer signals, Thomson scattering measurements

CTH operational space and three types of disruptions observed



References

[1] J.D. Hanson et al., Nucl. Fusion, 2009
[2] S.P. Hirshman et al., Comput. Phys. Commun. 1986
[3] J. Christiansen and J. Taylor, Nuclear Fusion 22, 111 (1982)
[4] M. Greenwald et al., Nucl. Fusion, 1988

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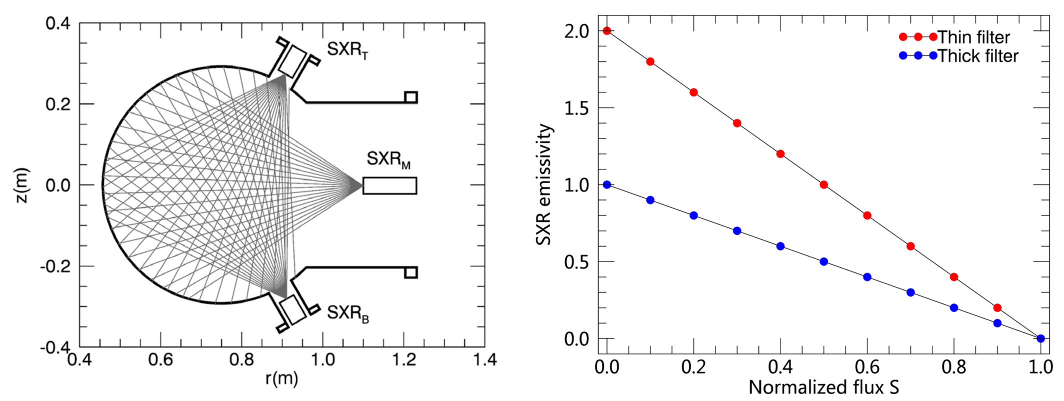
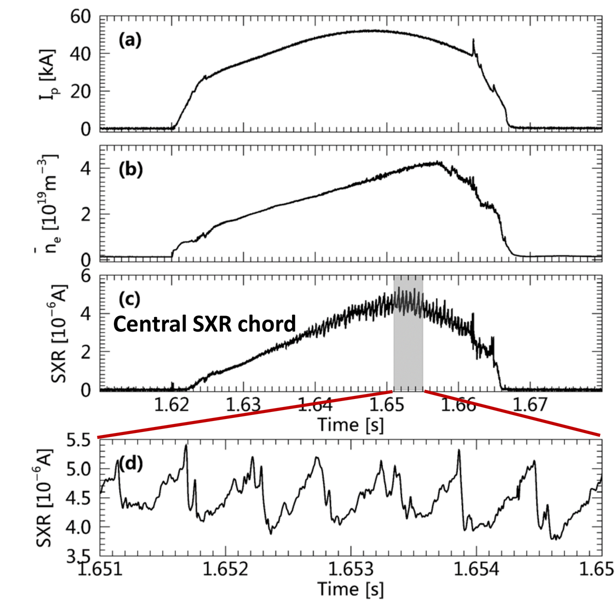
Determination of Current and q Profiles Using SXR Emissivity Measurements

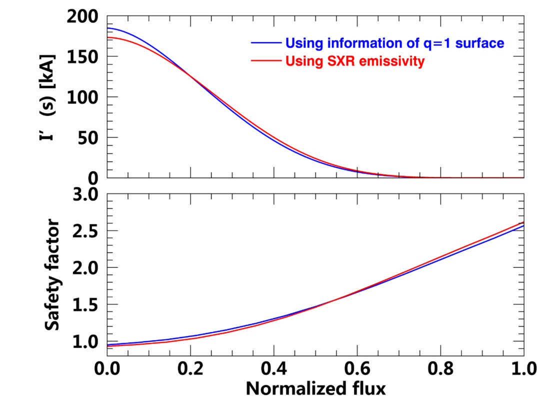
- Determination of current and transform profiles is crucial for understanding the 3D MHD instability and disruption mechanisms in Compact Toroidal Hybrid (CTH)
- Current distribution can be completely determined purely from geometric information of magnetic flux surfaces [3]
- SXR data has been used to infer current and q profiles in JET, PEGASUS, DIII-D
- Flux surfaces are reconstructed within V3FIT using SXR emissivity measurements, assuming SXR emission to be constant on flux surfaces



- Total of SXR 120 signals used in V3FIT
- Raw measurements are deconvoluted, filtered and averaged over 1 ms
- V3FIT initialized with two ten-segment linear emissivity profiles
- SXR inputs are treated as line-integrated signals

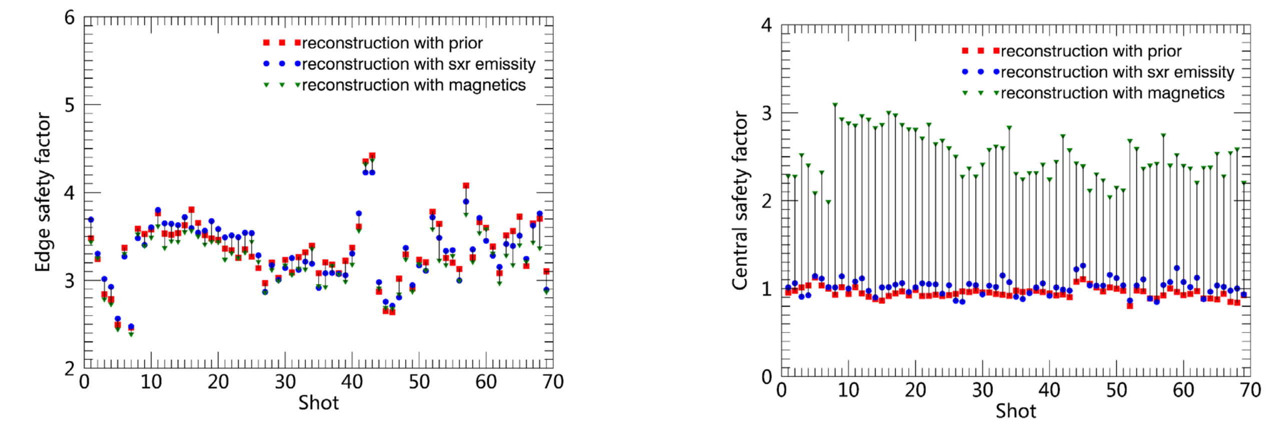
Reconstructing sawtoothing plasma with SXR data





- Reconstructed current and q profile consistent with that using the prior constraint of inversion radius (q=1)

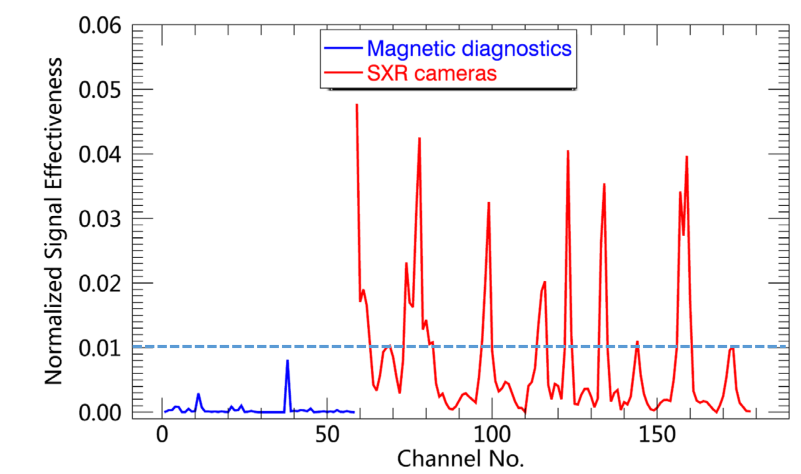
Internal inputs improve reconstruction of plasma core



- Reconstructions done with three methods: using magnetic data only; using prior knowledge of the q=1 surface and magnetic data; using SXR and magnetic data
- Reconstructed edge q values are consistent for all reconstructions
- Reconstructed central q values are within 15% of reconstructions using SXR data and the inversion information

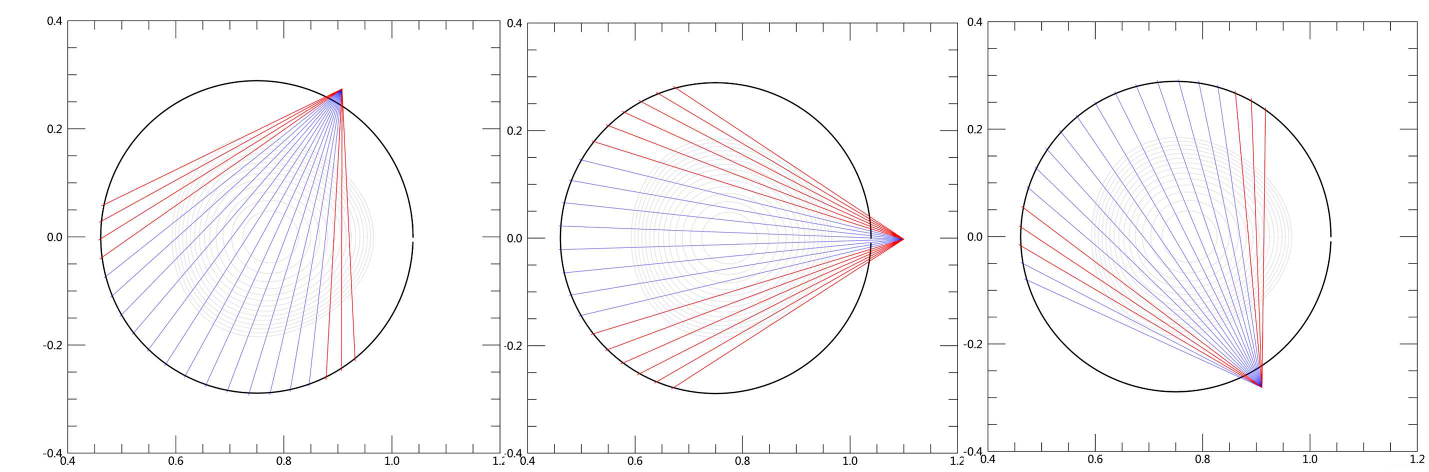
V3FIT Signal effectiveness

- Signal effectiveness is a dimensionless, normalized ratio of the fractional reduction in the reconstructed parameter variance to the fractional reduction in the signal variance
- It essentially tells which measurements are more effective in determining specific plasma parameter



- Current profile parameterization:
  - $J = J_0(1 - S^{\alpha})^6$
- Signal effectiveness with respect to α calculated for all magnetic and SXR channels
- Averaged over 144 different plasmas

Most effective SXR channels are from the edge with enough signal strength

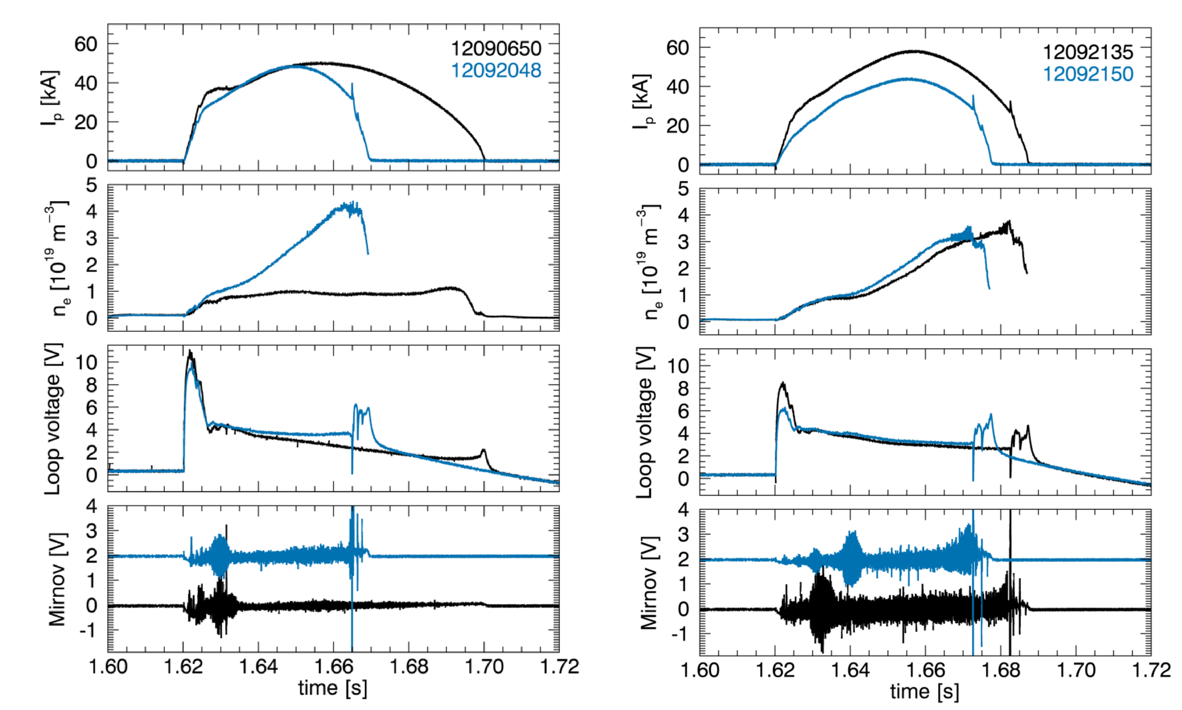


Suppression of Density Limit Disruptions in CTH

Empirical Greenwald density limit

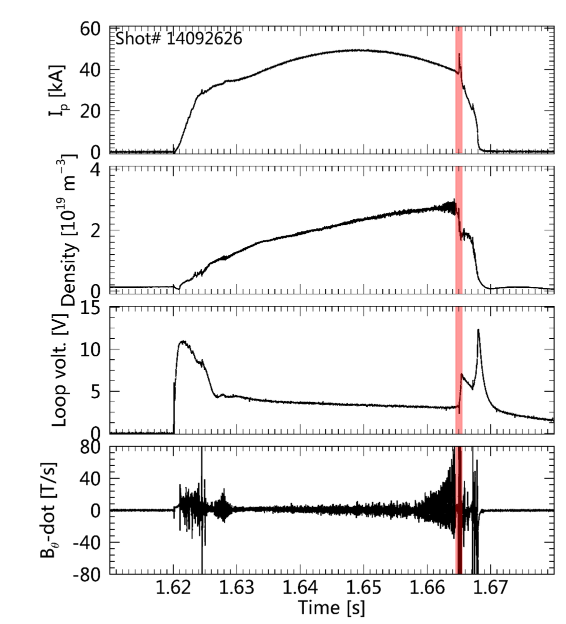
- Operating density limit for all tokamaks: $n_G \equiv \frac{I_P}{\pi a^2}$ [4]
- Density limit associated with MHD instability
  - Edge cooling of dense edge plasma initiates narrowing of plasma current profile which becomes MHD unstable to tearing modes
- Disruptions observed in CTH with sufficiently high densities

Density limit disruptions observed in CTH



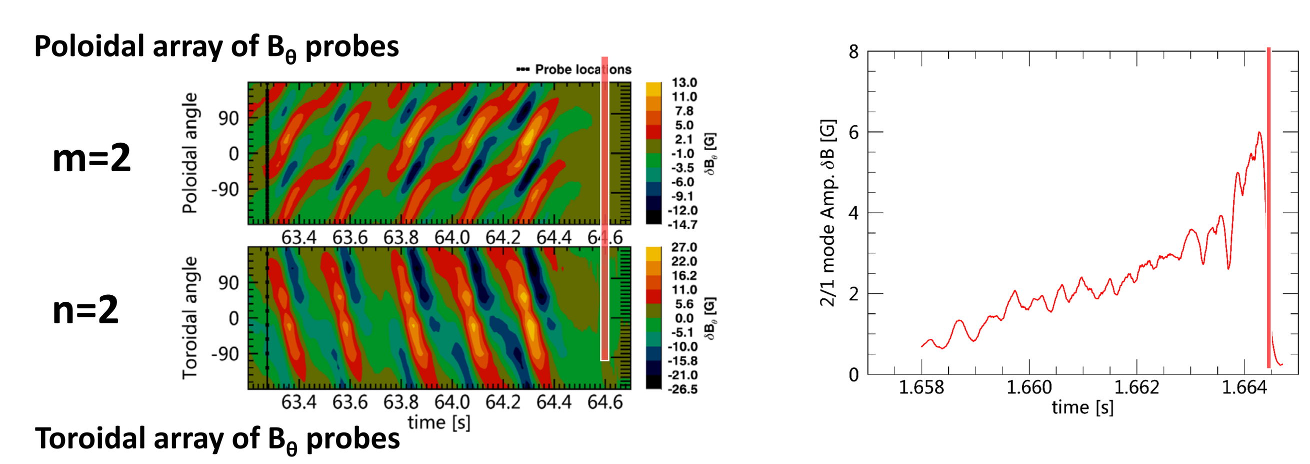
- Two discharges with similar vacuum transform (ι_{vac} = 0.05)
- Blue discharge disrupted with ramping density
- Black discharge did not disrupt with lower density

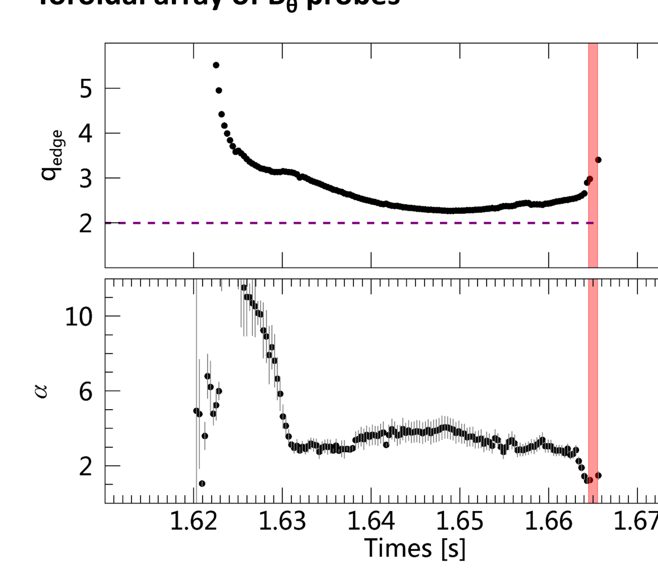
- Similar transform ι_{vac} = 0.07
- Different loop voltage settings
- Disruption correlates with plasma current and density
- Disruption depends on plasma current and density, not the evolution of the discharge



- Phenomenology of hybrid discharge terminations similar to tokamak disruptions:
  - Current spike followed by rapid decay
  - Increasing density
  - Negative loop voltage spike
  - Strong coherent MHD precursor

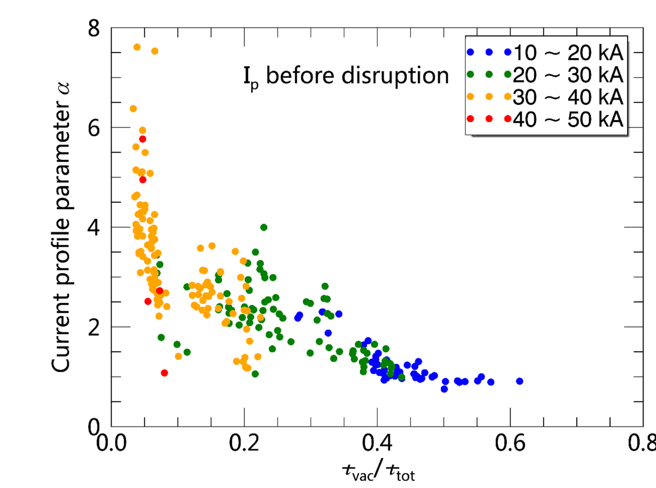
Growing m/n=2/1 tearing mode locks prior to disruption



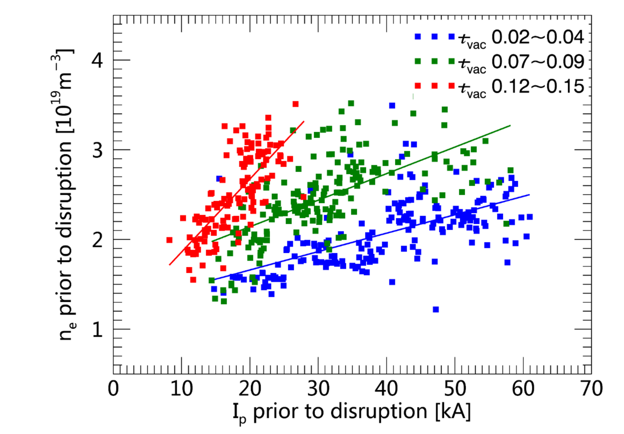


- q=2 surface moving towards plasma core before disruption
- Sudden peaking of current profile (decreasing of parameter α) just prior to disruption

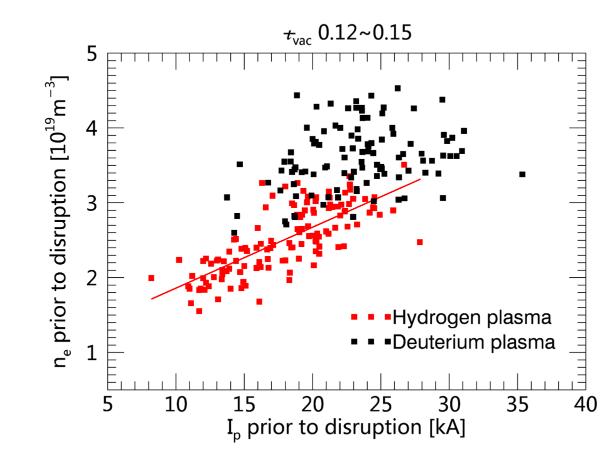
Density limit disruptions modified by applied 3D fields



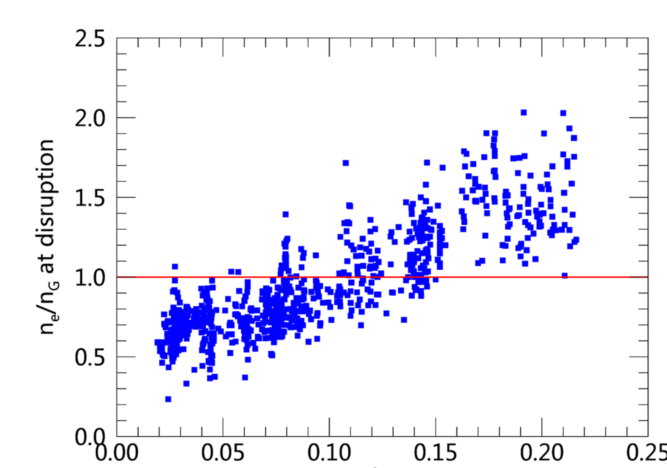
- Ensemble of disrupting plasmas with varying vacuum transforms
- Reconstructions of current profile performed just before disruption
- Current profile narrows to a greater extent as the external transform is raised



- For a given current, higher densities are achieved with addition of vacuum transform



- Operation with deuterium extends achievable plasma currents and densities to higher values



- Greenwald limits calculated using toroidally averaged poloidal cross-section areas
- Normalized density limit increases by a factor of nearly 4 as the vacuum transform is raised