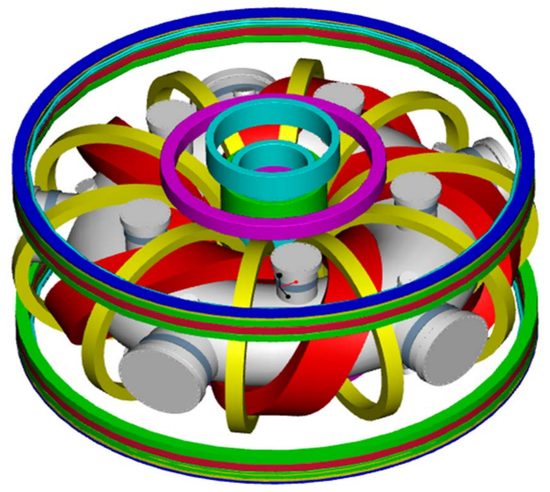
Compact Toroidal Hybrid Experiment

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

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

$$\iota_{tot} = \iota_{current} + \iota_{external}$$

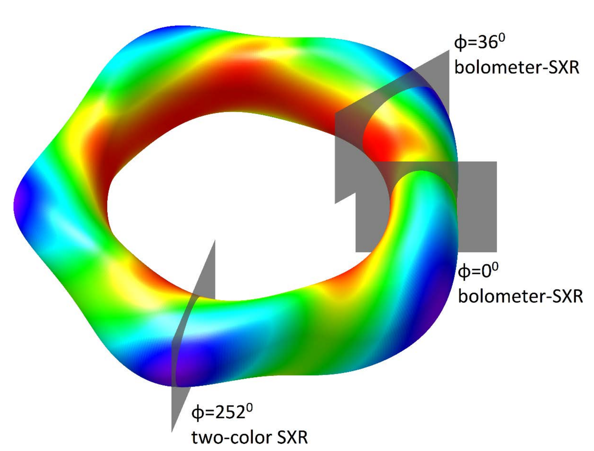


Helical Field coil
Toroidal Field coil
Trim Vertical Field coil
Shaping Vertical Field coil
Central Solenoid

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

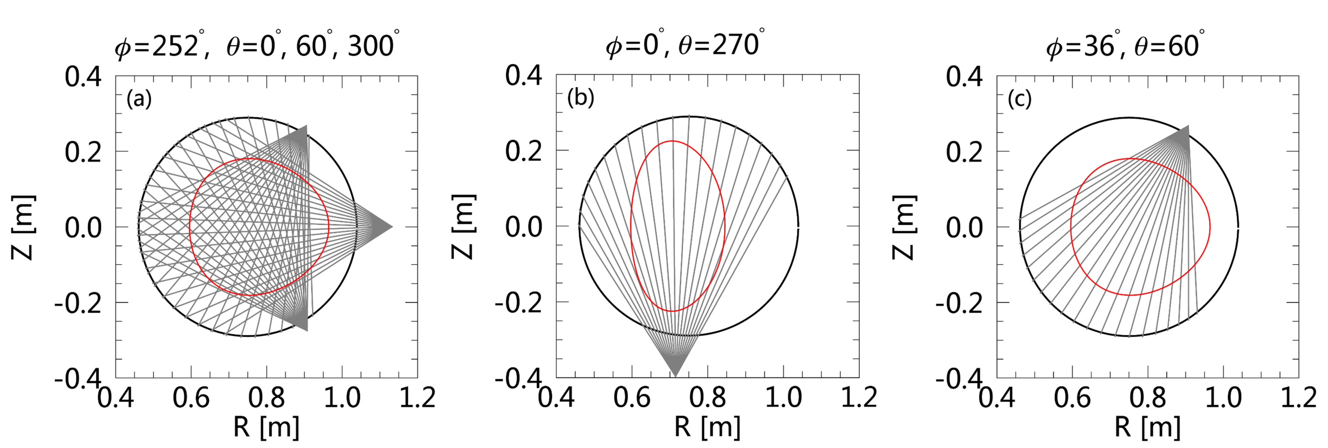
- V3FIT[1], which uses VMEC[2] as the equilibrium solver, is used to reconstruct CTH plasmas
- V3FIT optimizes the plasma parameters to achieve the best agreement between modeled signals and experimental measurements
- V3FIT on CTH presently uses magnetic diagnostics, SXR measurements for fitting

Multiple SXR cameras installed in different toroidal and poloidal locations



- Ten pinhole-type SXR/bolometer cameras, 200 channels total
- Three two-color SXR cameras, two bolometer/SXR system
- 160 SXR measurements used in V3FIT

Position and chordal views of all SXR cameras



- 7 SXR cameras installed at the half period of CTH (ϕ=36° and ϕ=252°), where the plasma is more circular
- 1 camera installed at the full period of CTH (ϕ=0°), where the plasma is most vertically elongated

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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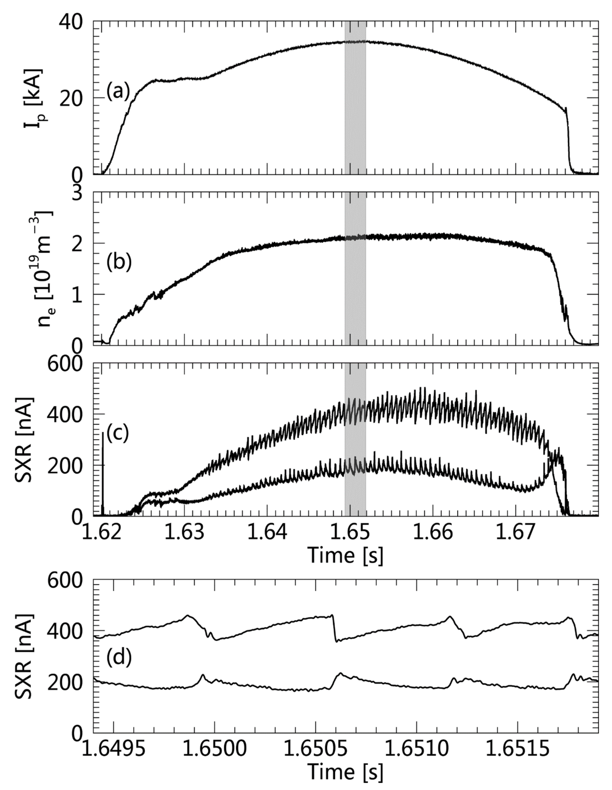
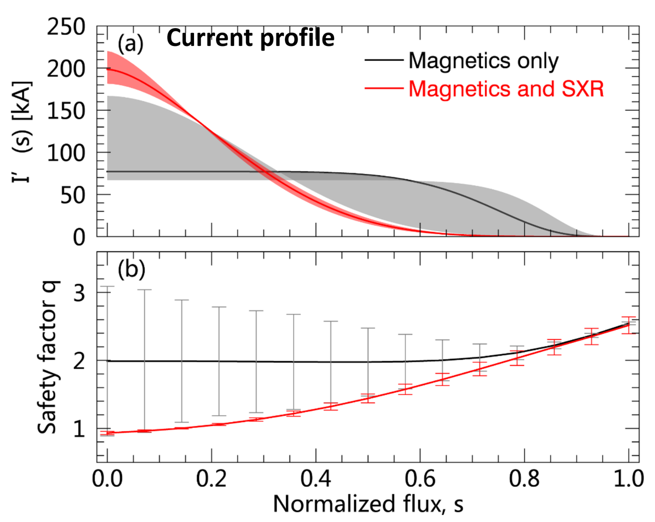
Determination of Current and q Profiles Using SXR Emissivity Measurements

- Current distribution can be determined from geometric information of magnetic flux surfaces [3]
- Flux surfaces reconstructed using 160 SXR measurements, assuming SXR emission to be constant on flux surfaces
- SXR inputs are treated as line-integrated signals
- Emissivity profiles are reconstructed in V3FIT from SXR cameras employing identical filters.

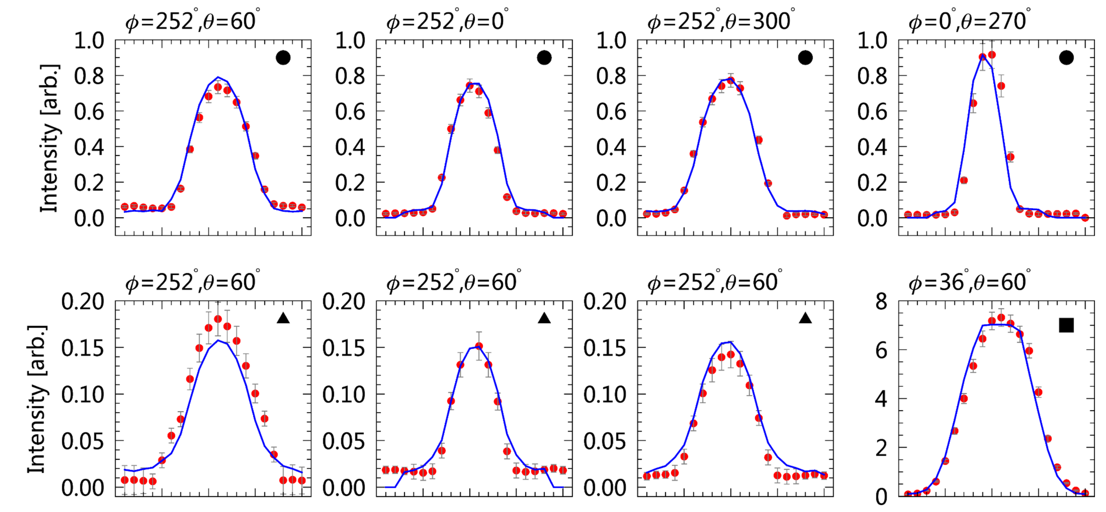
SXR measurements helps to reconstruct sawtoothing plasma





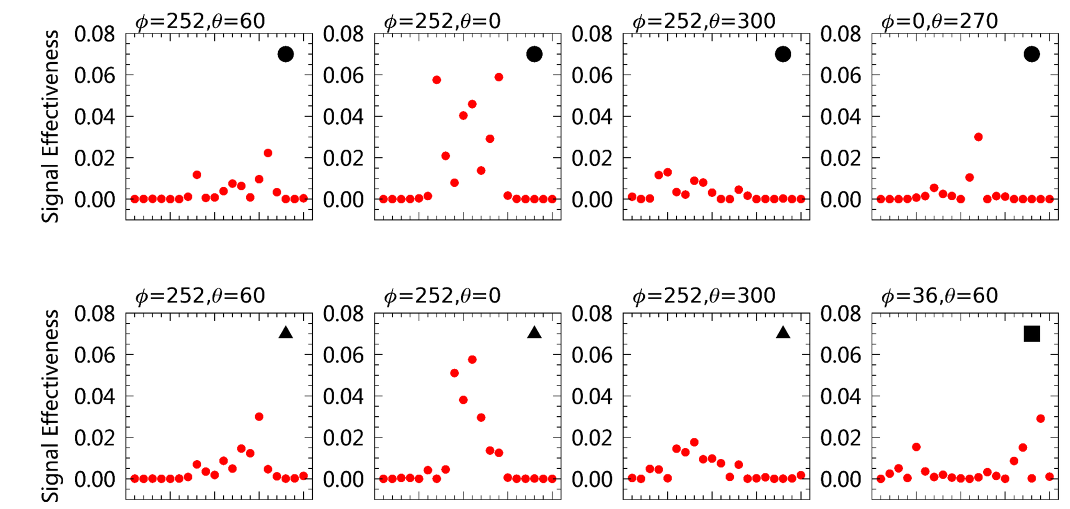
- Clear sawteeth and inversion of the phase (q=1 surface) from SXR measurements
- Reconstructions with only magnetic diagnostics yield inaccurate results
  - Resulting central q far from 1
  - Large fitting uncertainties in both current and q profiles
- Inclusion of SXR data results more accurate reconstruction
  - Reconstructed central q close to 1
  - A substantially more peaked current profile
  - Lower uncertainties in both current and q profiles

Experimental measurements (red) and modeled signals (blue) match well



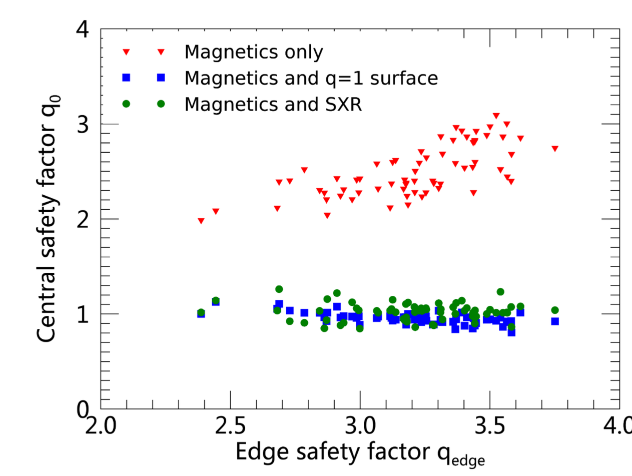
- Reasonable profile fitting supports the assumption that SXR emissivity may be taken to be a constant on a flux surface for CTH plasmas

Signal Effectiveness: a measure of how effective one diagnostic is in determining a specific plasma parameter



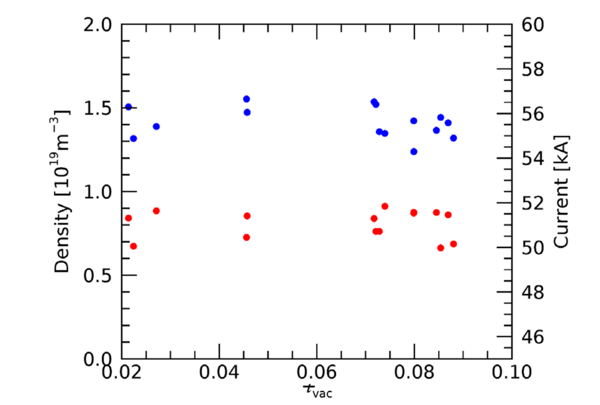
- The most effective SXR chords found to be those spanning the strong gradients in the signal level.
- The central cameras have the most effective chords
- Camera at the full period of CTH (ϕ=0°) is less sensitive compared to cameras at the half period (ϕ=36° and ϕ=252°)

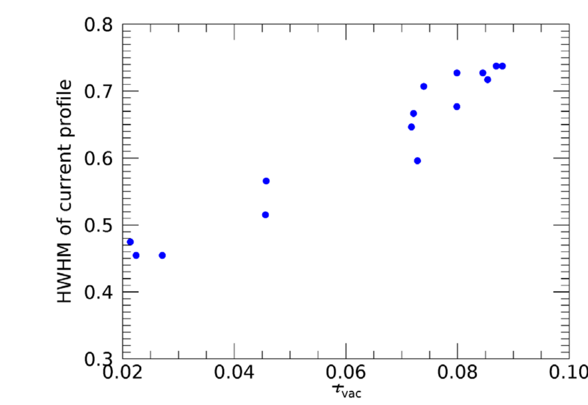
SXR measurements of internal emission improve reconstruction of plasma core



- Three reconstructing methods: using magnetic data only; using the q=1 surface constraint; using both SXR and magnetic data
- Edge q(a) are similar for all reconstructions: external magnetics measure the total current accurately
- Central q from either reconstruction using SXR data or the inversion information agree to within 15% or less, confirming peakedness of current profile relative to fitting with magnetics alone.

Current profile found to broaden with increasing external vacuum transform





- Group of discharges with similar density and current but varying external vacuum transform
- HWHM of reconstructed current profile increases with vacuum transform

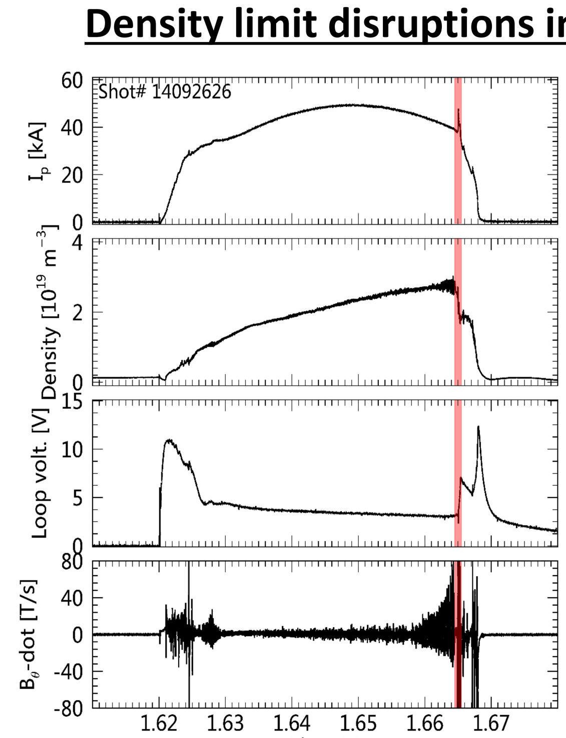
- Addition of 3D shaping fields suppresses internal MHD instabilities, reducing the current gradient
- Change of trapped electron fraction in the toroidal magnetic ripples modifies the neoclassic resistivity

Density Limit Disruptions in CTH

Empirical Greenwald density limit

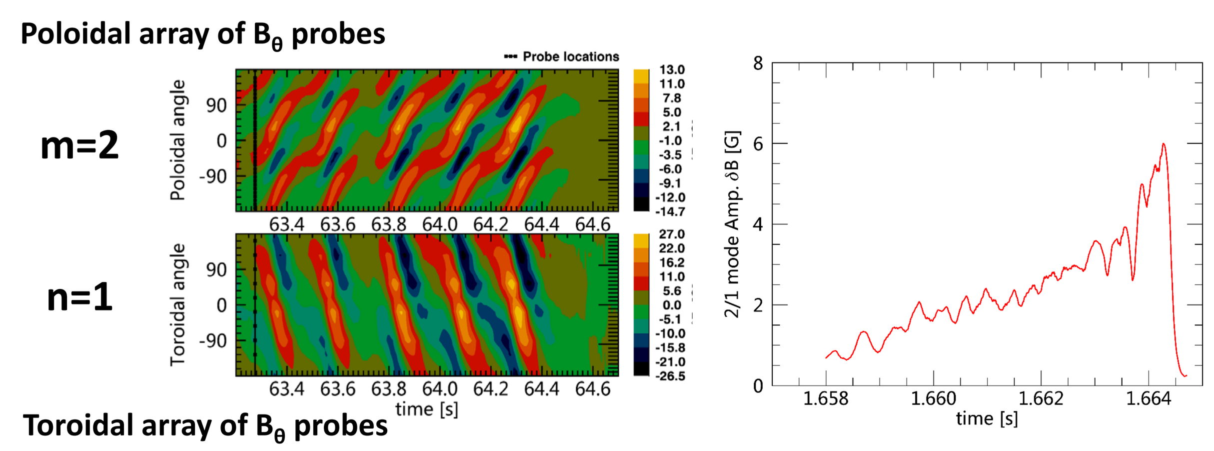
- Operating density limit for all tokamaks: $n_G \equiv \frac{I_P}{\pi a^2}$ [4]
- Density limit associated with MHD instability
  - Edge cooling of dense edge plasma by radiation or density-driven turbulence initiates narrowing of plasma current profile which becomes MHD unstable to tearing modes

Density limit disruptions in CTH similar to those in tokamaks

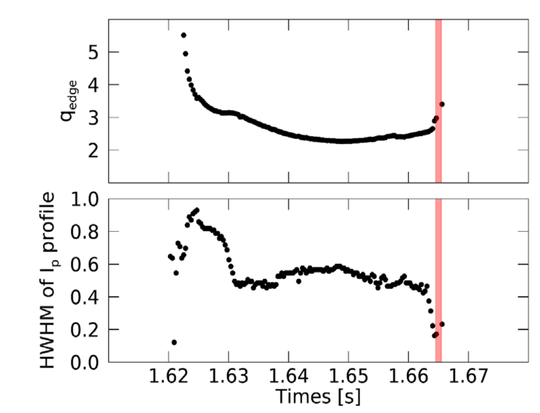


- Phenomenology of hybrid discharge terminations similar to tokamak disruptions:
  - Current spike followed by rapid decay
  - Increasing density
  - Negative loop voltage spike
  - Strong coherent MHD precursor

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

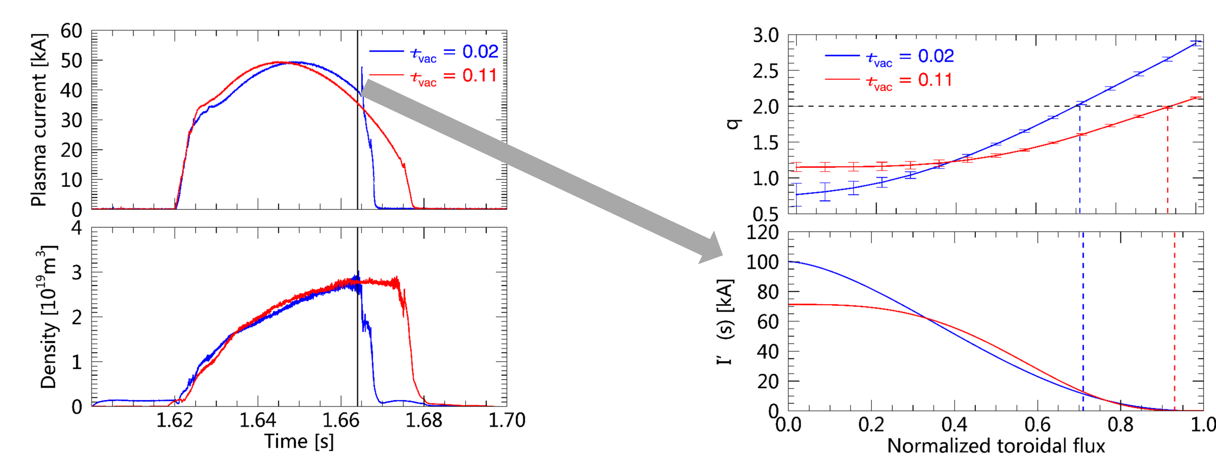


Narrowing of current profile before disruption



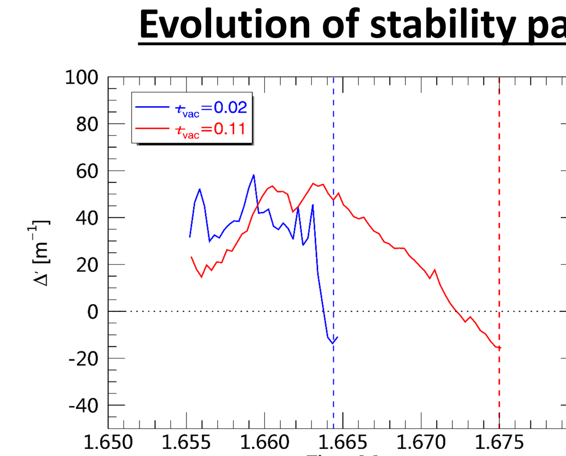
- Sequential reconstructions done using both SXR and magnetic data
- *q*=2 surface moving towards plasma core before disruption
- Sudden peaking of current profile just prior to disruption

Passive suppression from external applied vacuum transform



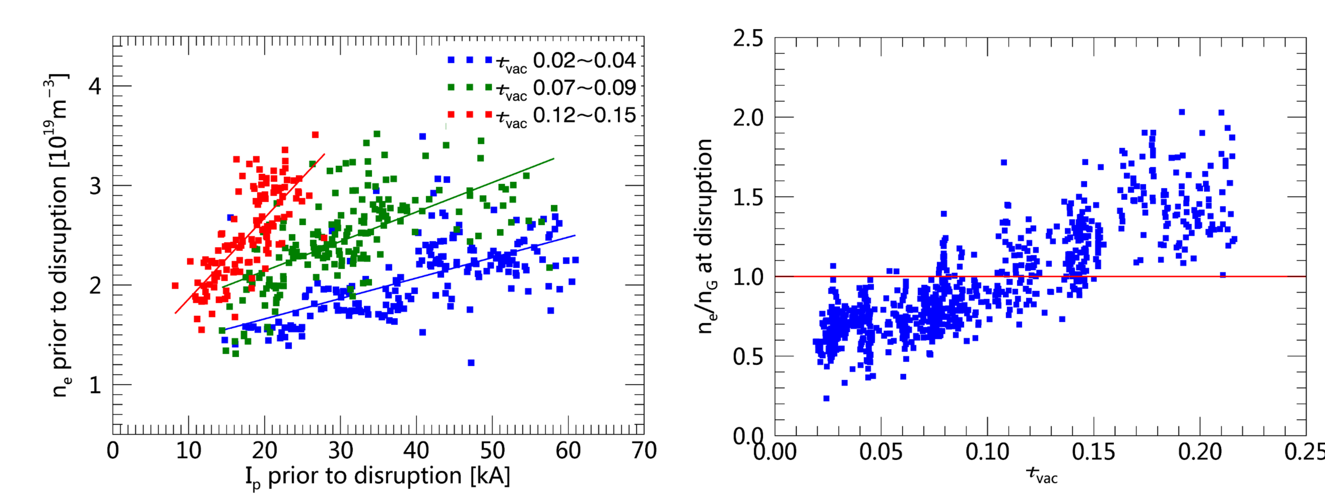
- Two discharges with similar density and current but different vacuum field configuration
- Addition of vacuum transform flattens both the current and q profile, decreasing the current gradient where q=2

Evolution of stability parameter Δ′ towards disruption

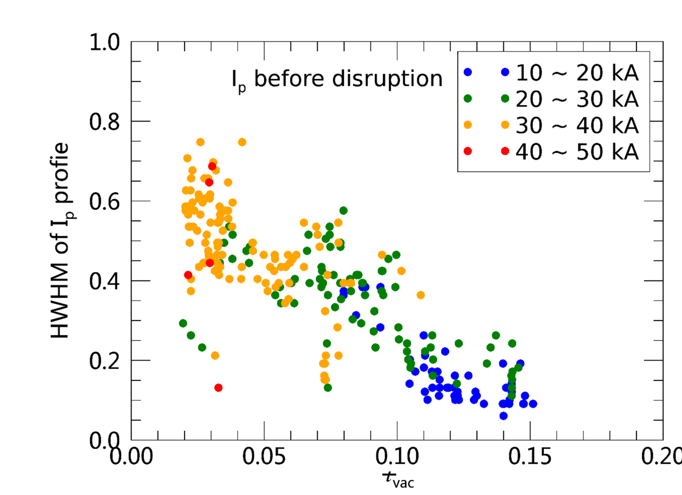


- Δ′ decreases below zero before disruption
- Addition of external vacuum transform elevates the value of Δ′, providing a stabilization effect

Modified density limit behavior with external vacuum transform



- Densities and currents recorded before disruption
- For a given current, higher densities are achieved with addition of vacuum transform
- 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



- 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
- Plasma disrupts at lower current with increasing external vacuum transform