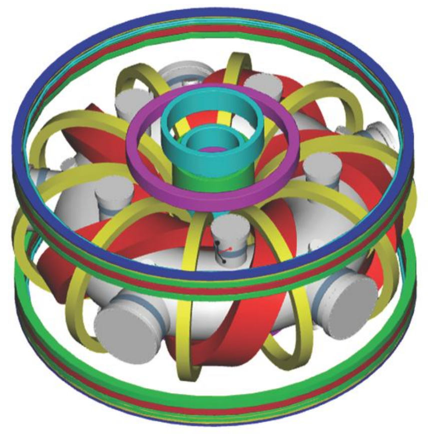
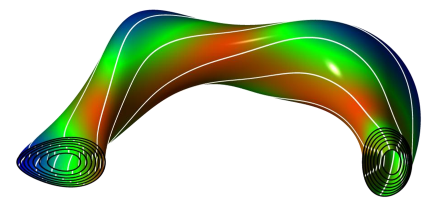
Introduction & Motivation



- Sawteeth oscillations are tied to a 1/1 MHD mode, but other important aspects and not clearly understood.
- How do sawtooth properties depend on total and vacuum transform?
- CTH has an extensive collection of internal diagnostics capable of detecting the signatures of sawtooth instabilities.
- Due to the unique nature of CTH, the vacuum and total transform can be varied.
- The size of the inversion radius and characteristics such as the rise and crash timescales are investigated as functions of the total and vacuum rotational transform.

Compact Toroidal Hybrid (CTH)



- *l* =2, 5 field-period torsatron with auxiliary toroidal field coils
- Operates as conventional torsatron with ECRH plasma generation
- Toroidal plasma current driven with an OH solenoid increases density and temperature

Parameters:

R_0 = 0.75 m, T_e ≤ 200eV, P_{input} ≤ 30 kW ECRH, B_0 ≤ 0.7 T, a_{vessel} = 0.29 m, β ≤ 0.5%, n_e ≤ 5 x 10^{19} m^{-3}, I_p ≤ 80 kA, a_{plasma} ≤ 0.2 m, Discharge duration – 0.1 s

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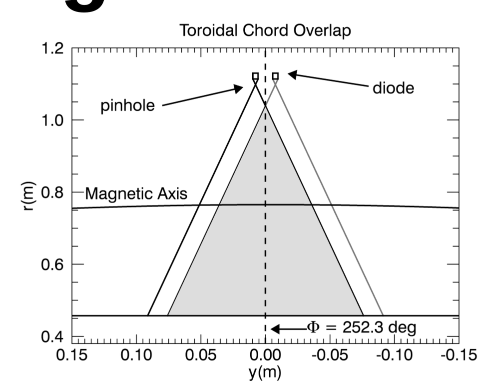
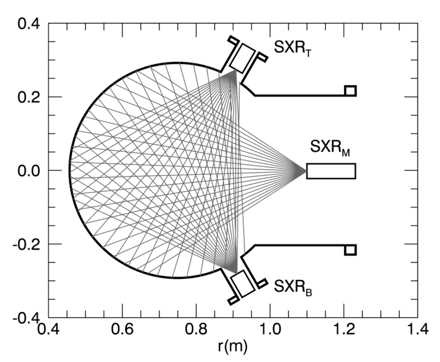
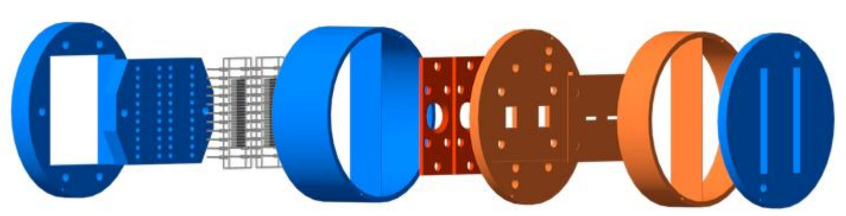
Two-Color Diagnostic on CTH



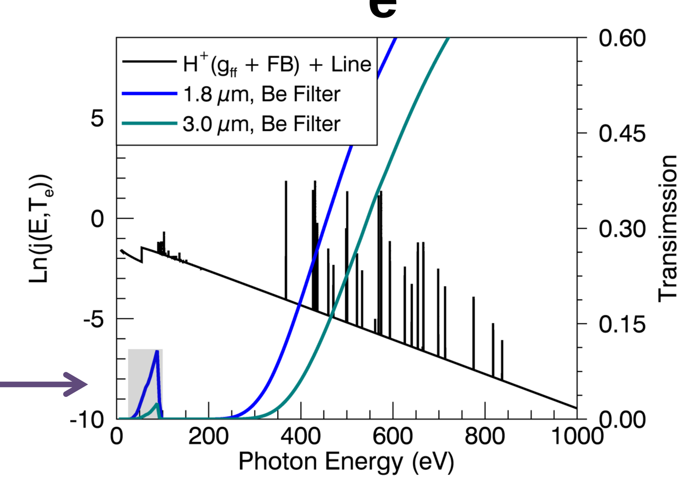




- 83% of each chord overlaps with the neighboring diode
- 2" in diameter
- Two AXUV20ELG diodes from Opto Diode Inc
- Be filters 1.8 and 3.0 microns thick
- Laser cut slits (changeable with vacuum break)
- Toroidal width of slit: 3.175mm
- Poloidal width of slit: 0.25mm

Theory of Two-Color SXR T_e

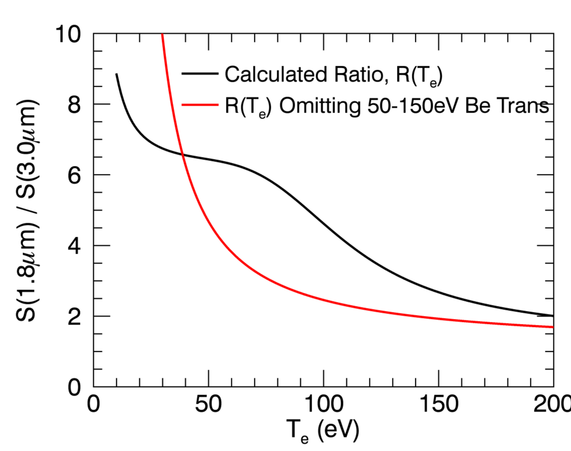
- Each filter has a different photon cut-off energy (**bold lines**) limiting the lower energy range of the bremsstrahlung radiation.
- The bremsstrahlung radiation was simulated using Atomic Data and Analysis Structure (ADAS) code[2] at: $n_e = 2*10^{19}$ m^{-3}, T_e = 100 eV.
- Due to the nature of thin Be filters, there is a low energy transmission window. This has a non-negligible effect on the electron temperature measurement.



The SXR signal for each chord with a filter of thickness t_1 is calculated using the formula:

$$SXR(t_1) = k\int_0^\infty dE \int_V j(E,T_e)A(E)T_{Be}(E,t_1)\frac{d\Omega}{4\pi}dr$$

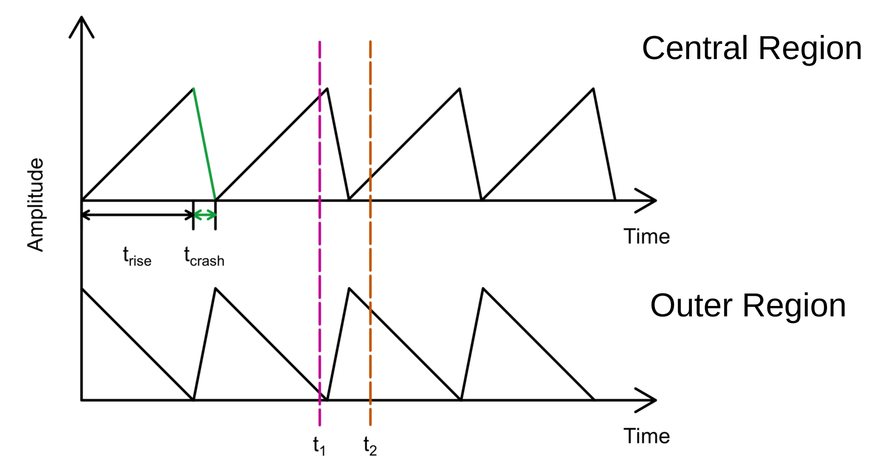
- A(E) is the absorption coefficient of the photodiode, T_{Be} is the transmission of the filter, j is the bremsstrahlung radiation.
- The temperature is determined by comparing the ratio of experimental signals to the theoretical ratio.



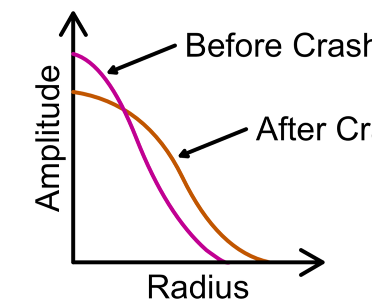
Initial estimate of impurity radiation effects

- If a impurity content of 1.25% is assumed, this gives a Z_{eff} of 1.5
  - Line radiation accounts for 14% (1.8 µm filter) and 21% (3.0 µm filter) of the total signal.
  - This is an overestimate of impurity radiation effects because of the ionization balance calculation used to find the ionization states.
  - The free-bound contribution transforms the theoretical ratio that a given signal ratio of 2.0 to 10 results in a estimated temperature of ~30 eV. This plot is not shown.
  - Estimated temperatures from Spitzer resistivity and a SXR spectrometer show that the plasma temperature is much higher than 30 eV. It is on order of ~150 eV.
  - Impurity ion transport, the effective residence time were neglected and are needed to have an accurate representation of the impurities.
  - A Thomson scattering diagnostic is under development to give an accurate value of the temperature.

Sawtooth Instability in CTH

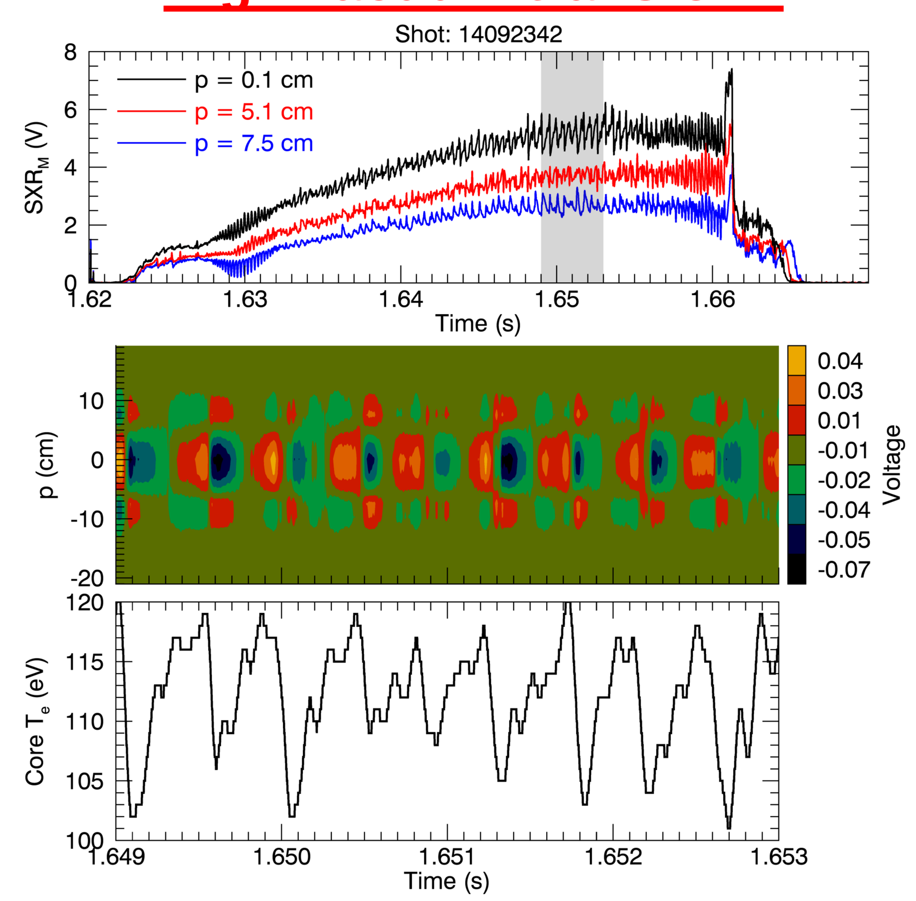


- The core of the plasma is heated ohmically, peaking the plasma current and temperature therefore letting q drop below unity.
- A m = 1, n = 1 MHD mode then grows until the core confinement is lost and expels the energy to the outer regions.

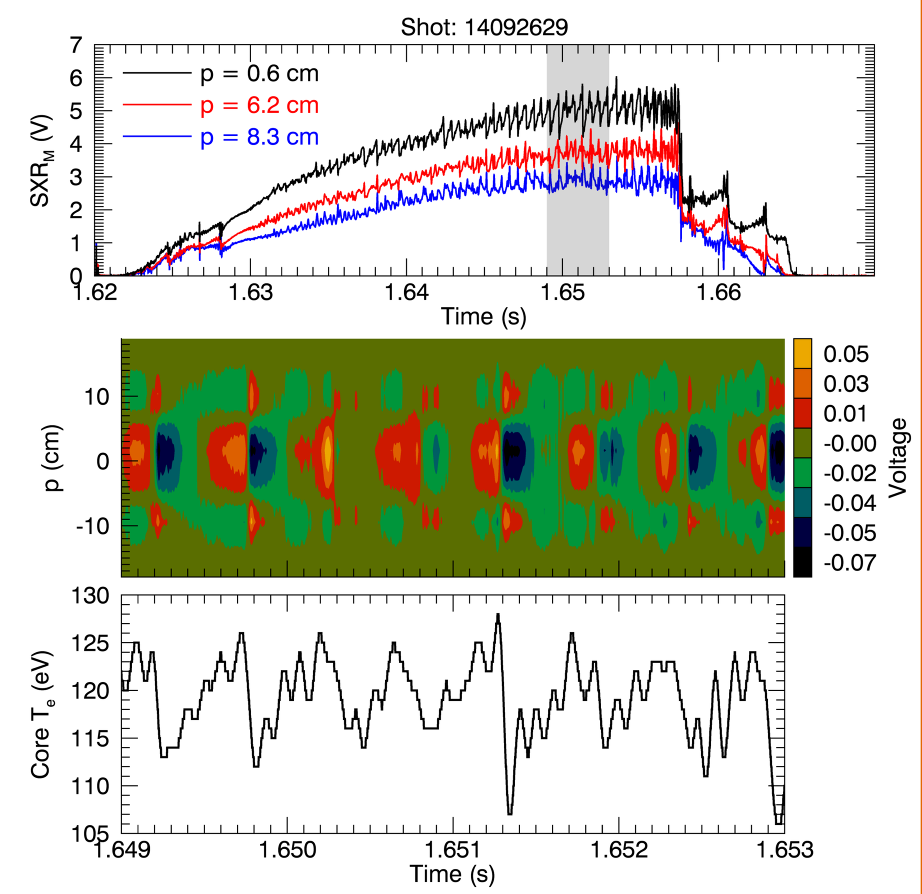


- Schematic of current density and electron temperature profiles
- They peak during the ramp and flatten after a crash.

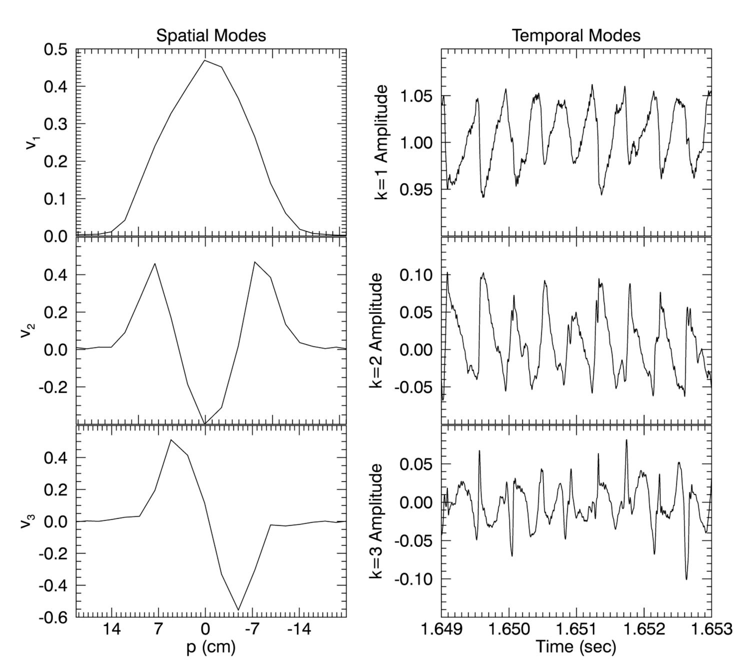
High vacuum transform

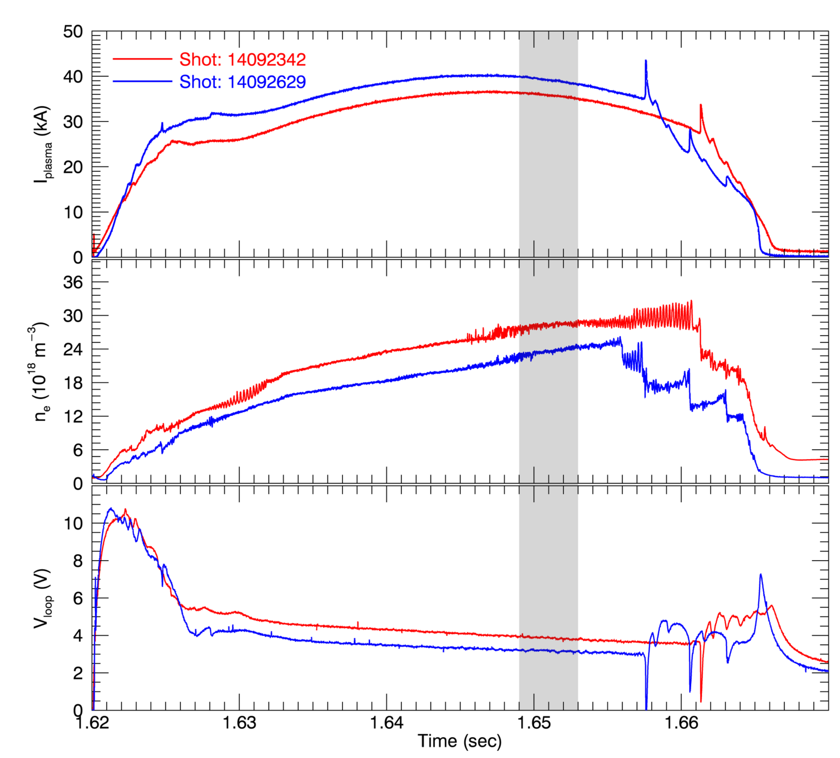


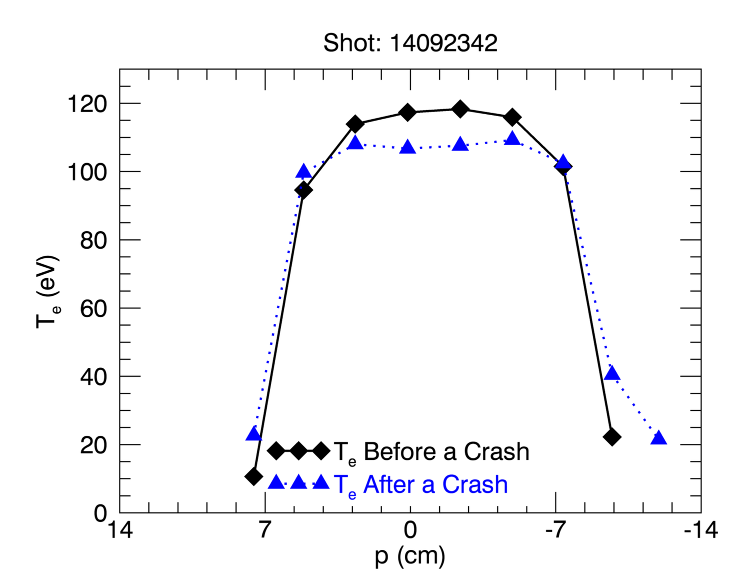
Low vacuum transform



Singular value decomposition used to extract modes and inversion radius

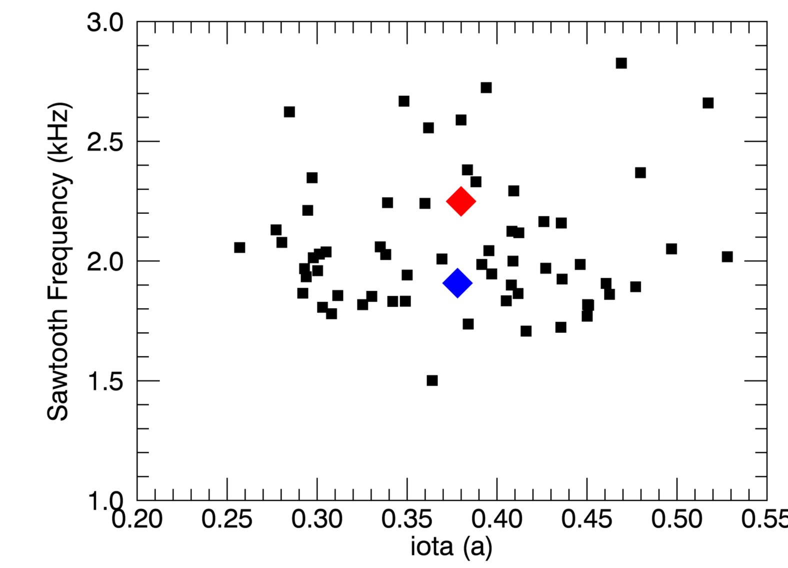


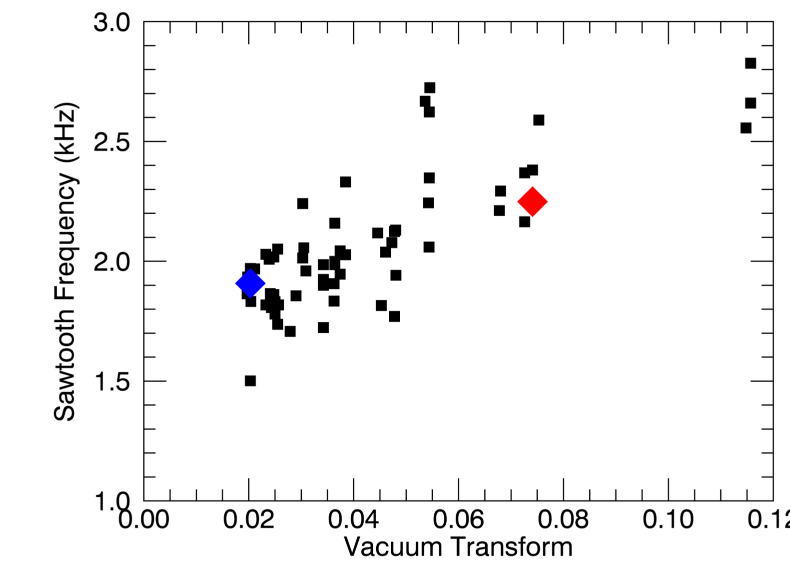




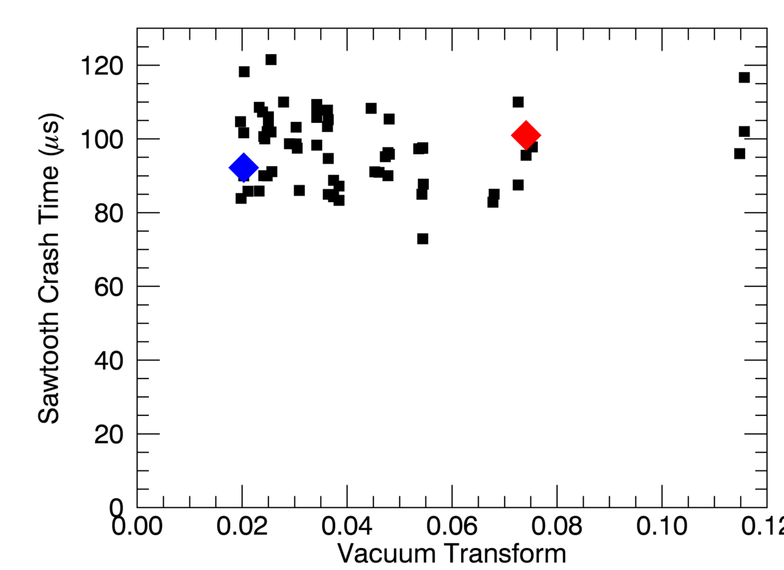
- Calculated values of the electron temperature profile during the peak of a sawtooth oscillation (diamonds).
- The profile right after the crash (blue triangles) shows a decrease in core temperature of ~10 eV and an increase in the profile width.

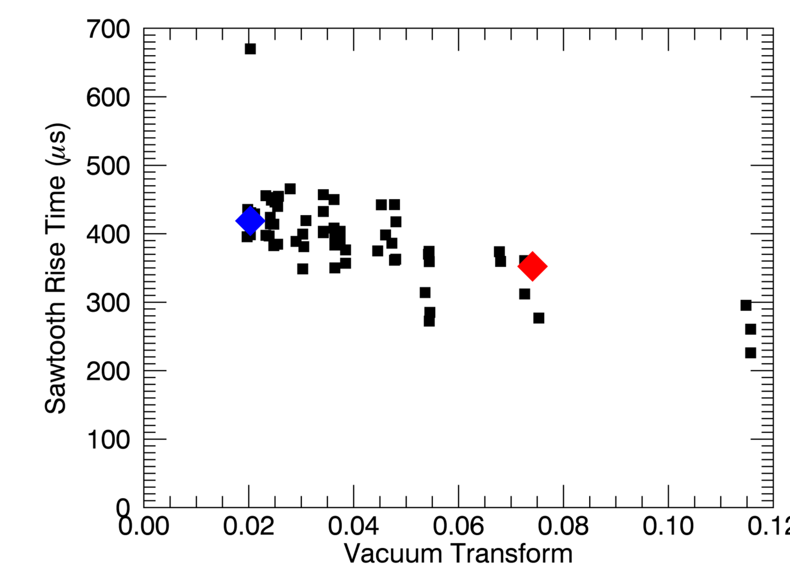
Vacuum Transform and Sawteeth



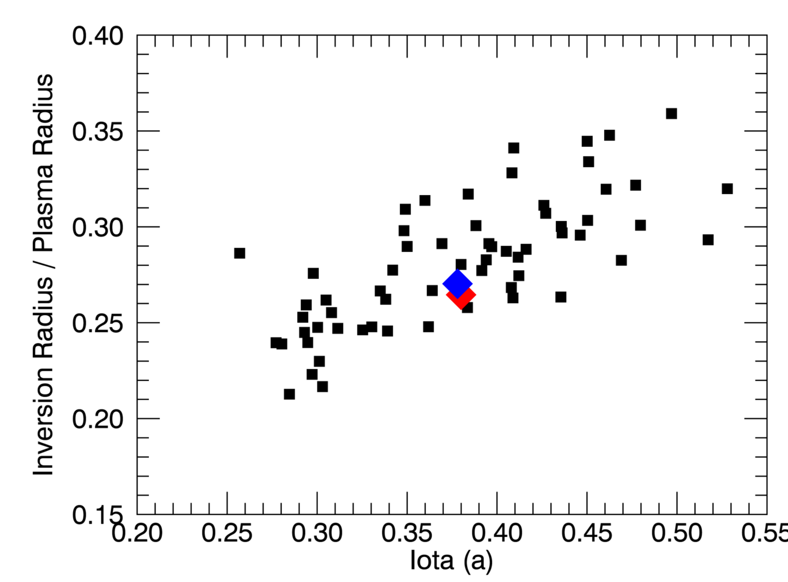


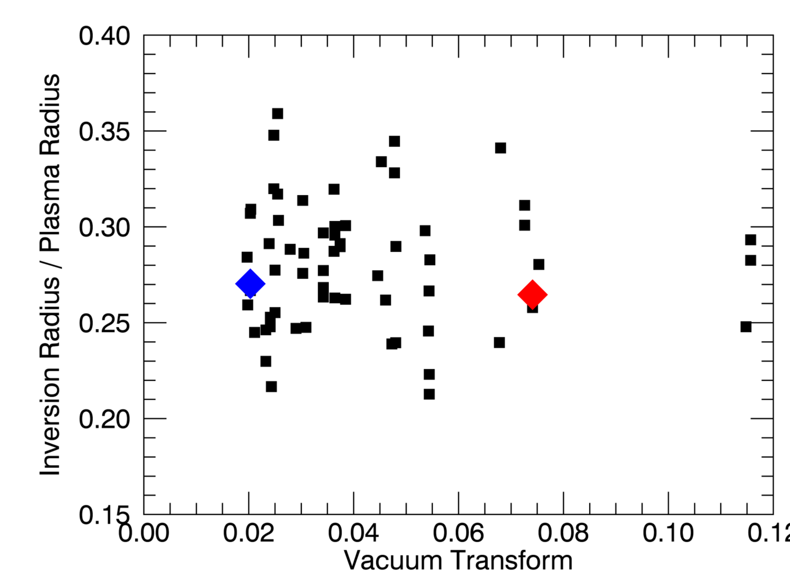
- The sawtooting frequency appears to be independent of the total edge transform during a discharge, but dependent on the vacuum transform of the stellarator equilibrium applied before the discharge.
- The sawtooth rise time increases with the vacuum transform, while the crash time does not.

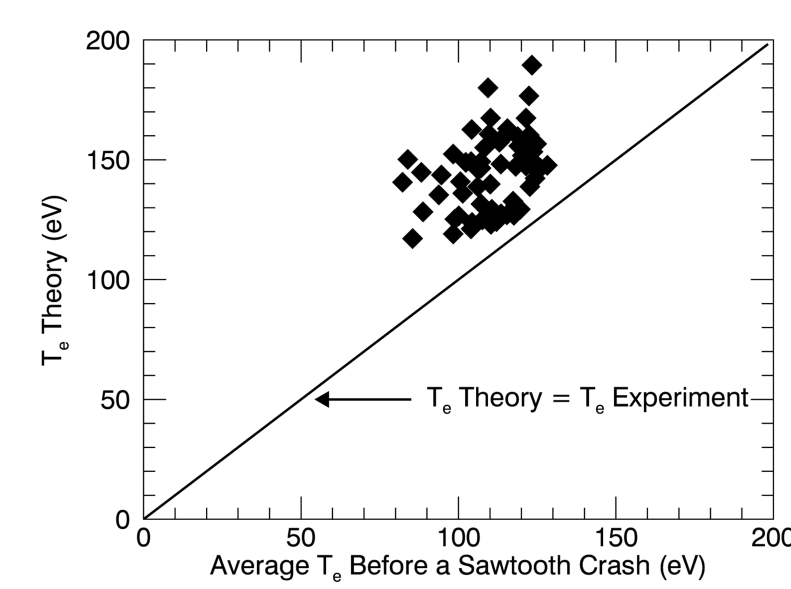




Sawtooth inversion radius scales with total edge transform







A temperature requirement for the onset of sawteeth with a q = 1 surface in the plasma interior is given by[1]:

$$1 = \frac{4\pi B_z}{\mu_0 V}\eta$$

- Using, B_z = 0.5T, ln(Λ) = 15, Z_{eff} = 1.5, and the loop voltage from the experiment gives an estimated temperature using Spitzer resistivity.
- The loop voltage was assumed to be constant across the plasma.
- This x-axis is the electron temperature in the core of the plasma before a sawtooth crash from the two-color diagnostic.

Future Work

- Investigate the effects of impurity radiation on the two-color measurement.
- Explore sawtoothing discharges at greater vacuum transform.
- Use tomography to examine the shape and structure of the sawteeth.

1. G. Jahns, M. Soler, B. Waddell, J. Callen, and H. Hicks,, Nuclear Fusion, 18, 609 (1978)
2. H. P Summers, The ADAS user manual, version 2.6, 2004, see www.adas.ac.uk