Passive MHD Spectroscopy for Enabling Magnetic Reconstructions on Spherical Tokamak Plasmas at General Fusion

generalfusion® generalfusion®

P. O'Shea, M. Laberge, A. Mossman, M. Reynolds, and the General Fusion Team

General Fusion Inc., Burnaby, British Columbia, Canada

59th Annual Meeting of the APS Division of Plasma Physics, Milwaukee, Wisconsin, October 23–27, 2017 **UP11.00133**

INTRODUCTION

General Fusion is pursuing an MTF concept with the intent of developing an economical fusion power plant. Compression of a magnetized plasma target with a collapsing liquid metal wall addresses many of the engineering obstacles in the path of more conventional fusion concepts.

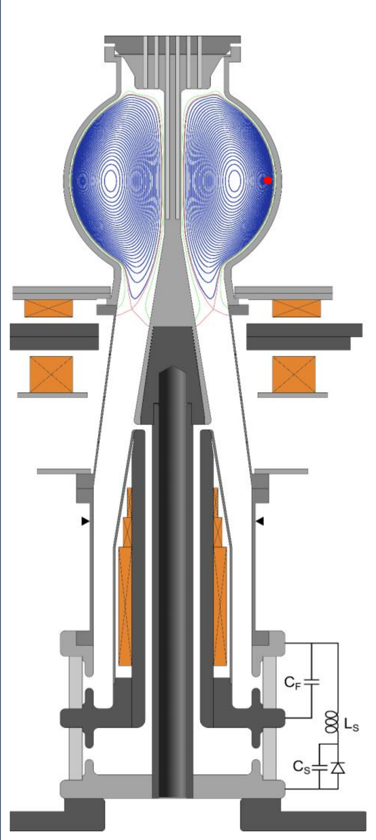
This poster discusses methods by which we diagnose the safety factor profile, q(r), in recent plasma experiments. Knowing q(r) allows us to better predict the stability of our plasmas under compression.

Abstract

Magnetic reconstructions of lab based plasma injectors at General Fusion relies heavily on edge magnetic ("Bdot") probes. On plasma experiments built for field compression (PCS) tests, the number and locations of Bdot probes is limited by mechanical constraints. Additional information about the q profiles near the core in our SPECTOR plasmas is obtained using passive MHD spectroscopy.

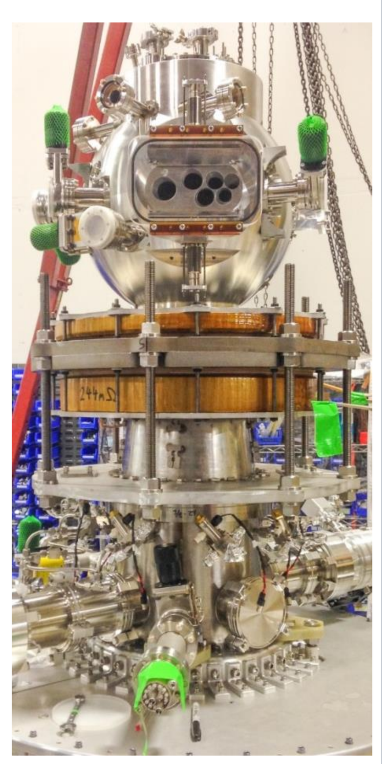
The coaxial helicity injection (CHI) formation process naturally generates hollow current profiles and reversed q shear early in each discharge. Central Ohmic heating naturally peaks the current profiles as our plasmas evolve in time, simultaneously reducing the core safety factor, q(0), and reverse shear. As the central, non-monotonic q-profile crosses rational flux surfaces, we observe transient magnetic reconnection events (MRE's) due to the double tearing mode. Modal analysis allows us to infer the q surfaces involved in each burst. The parametric dependence of the timing of MRE's allows us to estimate the continuous time evolution of the core q profile.

Combining the information about the core from MHD spectroscopy with edge magnetic probe measurements greatly enhances our certainty of the overall q profile.



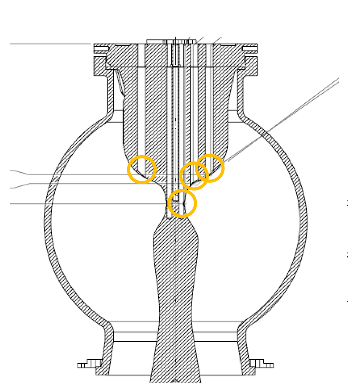
SPECTOR Cross-section & Schematic

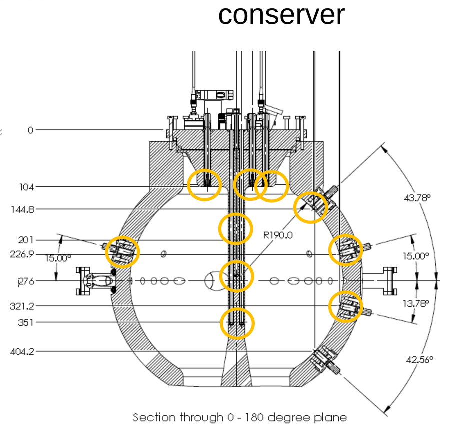
Field SPECTOR during assembly.
No instrumentation on flux conserver



Lab version SPECTOR. Note Instrumented flux conserver

Diagrams at right show that the constraints created by compression tests. B-probe coverage is severely limited in the in the ***field*** version of the SPECTOR flux conserver



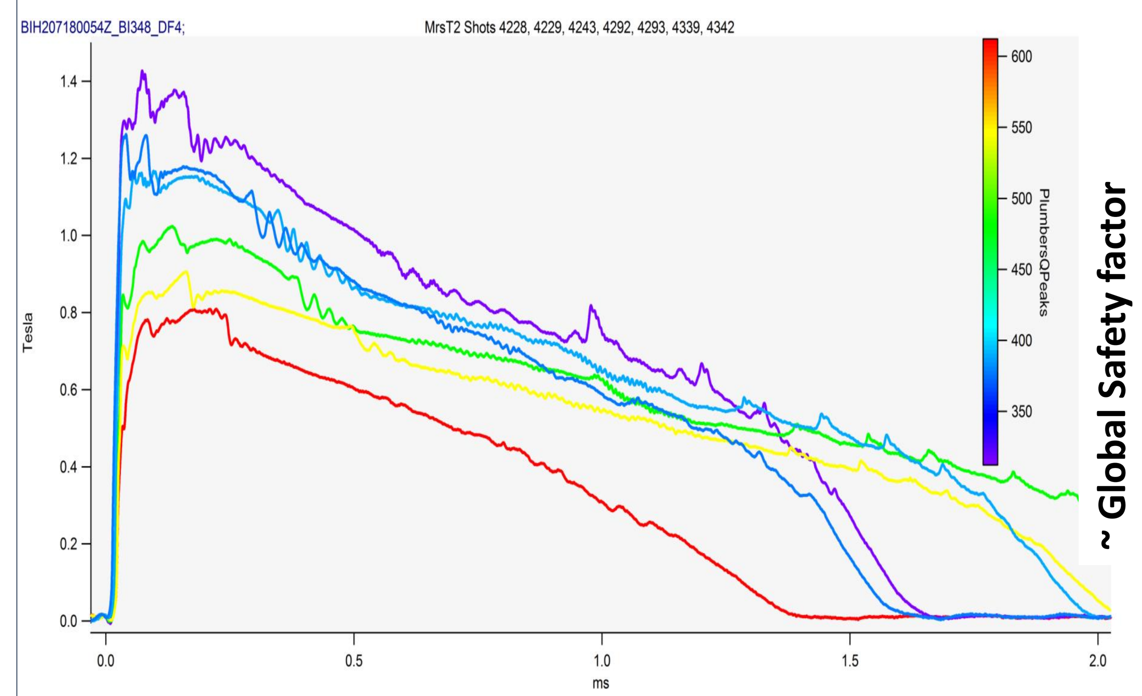


Typical Plasma Conditions

Lifetime:	1-2 ms
Species:	Deuterium, (Helium, Hydrogen)
Inner Radius:	19 cm
Density:	0.2-1.5x10^{20} m^{-3}
T_e:	100-400 eV
Magnetic Field:	1 T Poloidal, 10 T Toroidal (At inner shaft surface)

Observations of MHD Oscillations

Typical plasma discharges display a variety of transient features seen in a repeatable sequence. The timing of most features is such that onset is delayed by machine settings that increase the overall safety factor.

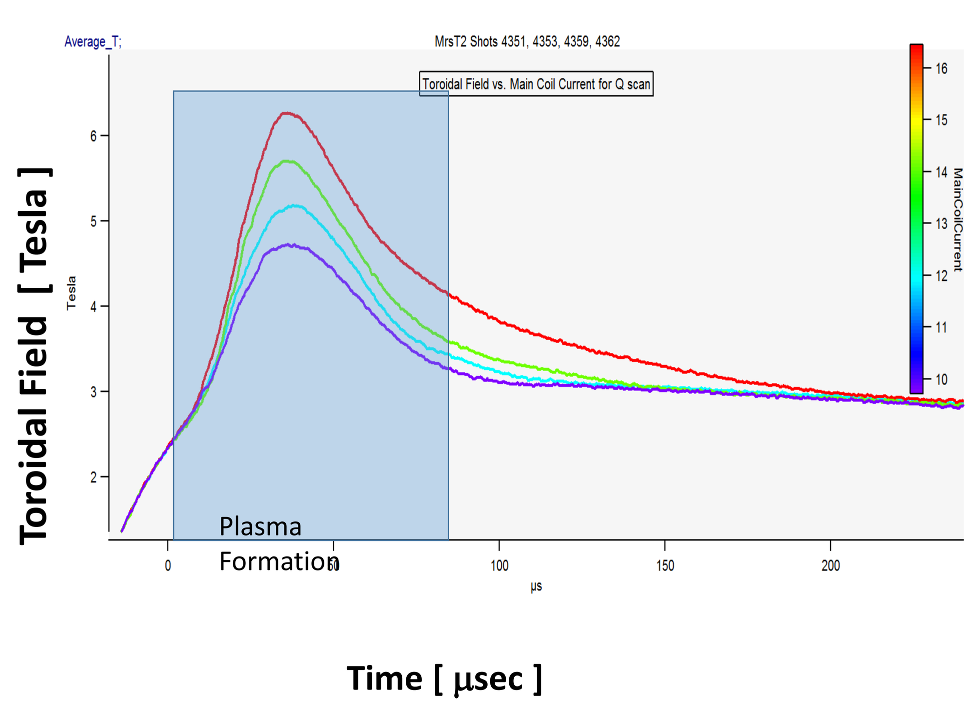


- Typical discharges end in a train of transients seen on B-probes and visible light diagnostics which are interpretted as standard tokamak Sawteeth
  - q(0) dropping below 1 due to current profile peaking, Sawtooth crash flattens current profile and for a limit cycle keeping q(0) near 1
- Before the sawtooth cycle starts, there can be a series of distinct, ~sinusoidal bursts of (usually) n=1 oscillations that come and go.
  - Discharges with higher overall safety factor have more such bursts

This is clearly MHD phenomena. If we can infer what is going on we can gain information about the evolution of the q-profile in the core.

Expected Qualitative Behavior of Current Profile

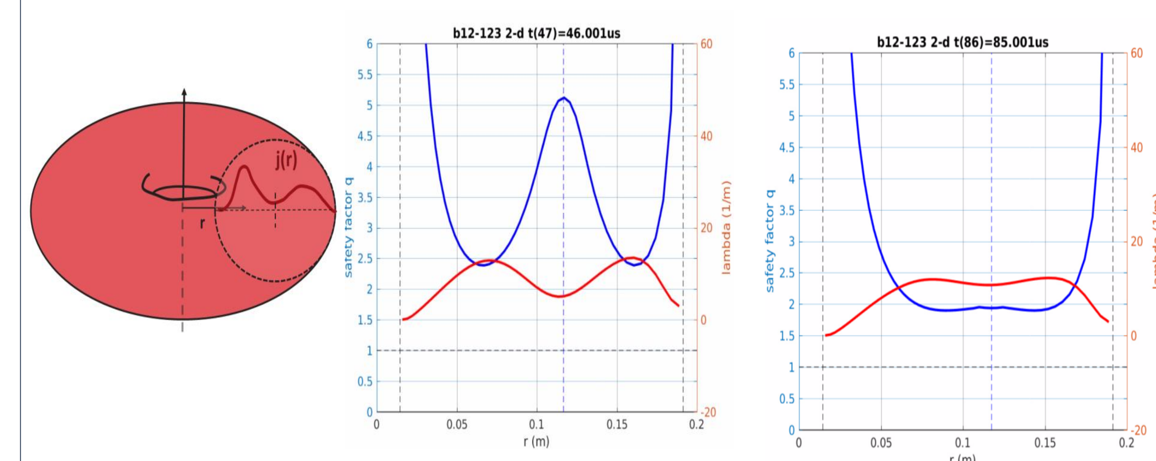
- We form these plasmas by bubbling out a CT into a flux conserving pot which has a pre-existing toroidal field created by running current through the central shaft inside the pot
  - Shaft current is strongest control we have over the overall safety factor of the CT after reconnection and relaxation.
  - Generally we run enough shaft current that the resulting plasma is a Spherical Tokamak
- After bubble-out of the CT and the formation current dies away, there is 'excess' toroidal field in the pot / plasma.



- A sheet current flows in the plasma edge as a result and until the crowbar current dies away there is a ***hollow*** plasma current distribution in the CT.
- With no auxillary heating, only Ohmic decay of the stored energy of the plasma heats the plasma. Ohmic heating will eventually give rise to ***peaked*** current profiles as the current moves towards the hot magnetic axis

Simulation Verifies Qualitative Picture of Current Evolution

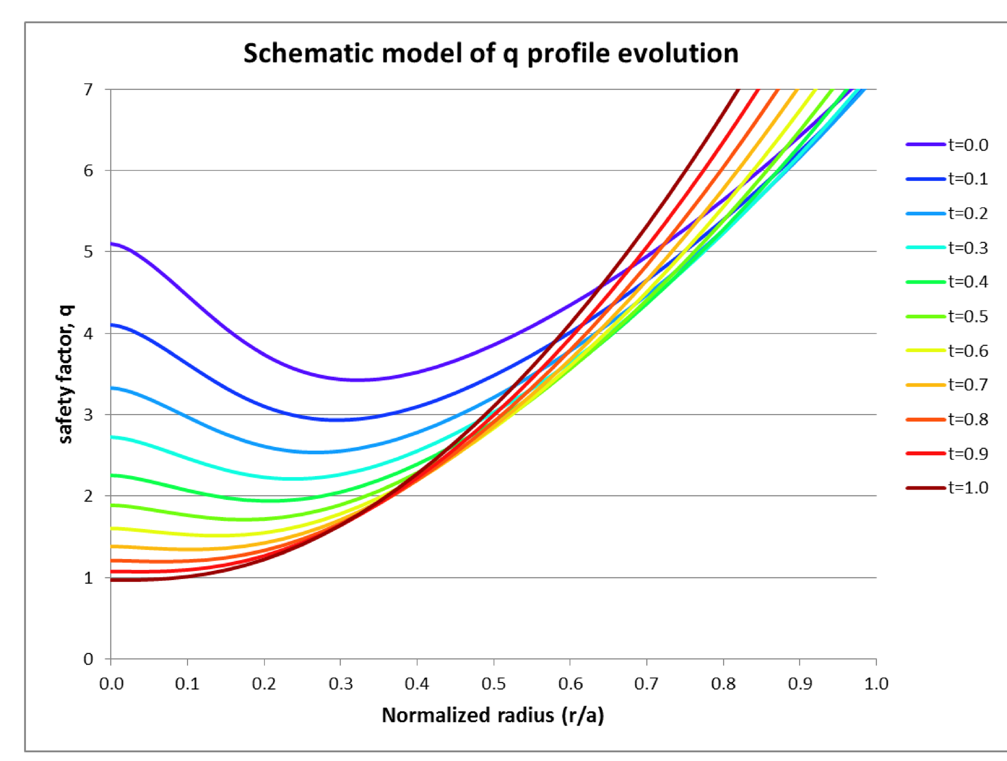
- 2D MHD simulations (VAC code) verify the picture of highly hollow current profiles early with continuous peaking thereafter:



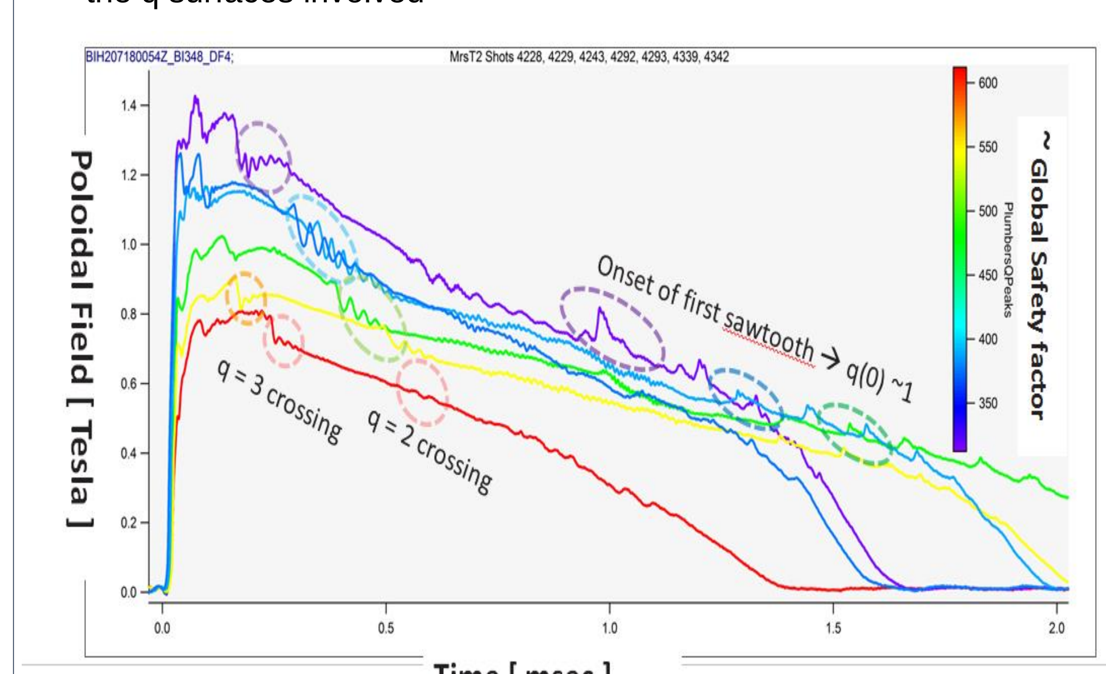
- The hollow current profiles result in safety factor profiles with reversed shear
- Early evolution of the safety factor is characterized by:
  - Decreasing central safety factor q(0)
  - Decreasing reversed shear…eventually q(r) becomes montonic
  - Increasing edge q (plasma current dies faster than shaft current)

Reversed Shear Can Give Rise To Double Tearing Mode

- Double crossing of rational flux surfaces , q = m/n , gives rise to instabilities that cause magnetic island formation

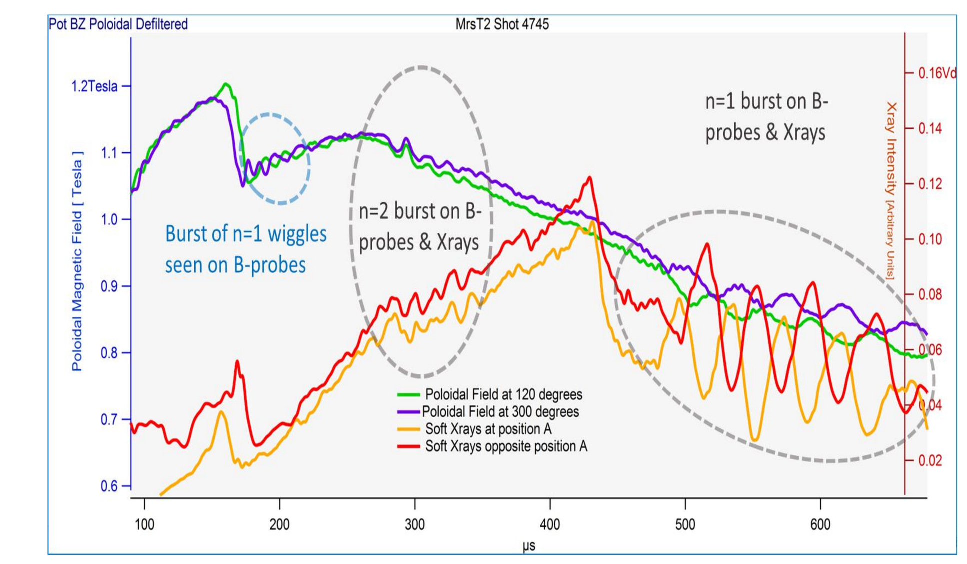


- Oscillations arise as plasma rotates island structure in front of B-probes.
- Most sinusoidal bursts of wiggles are (verified) n=1 modes corresponding to crossings of q = 3 , then q = 2 as current peaks
- Less frequently we observe a brief (verified) n=2 oscillation in between n=1 modes. These correspond to crossings of q = 5/2 or (at lower overall safety factor only) q = 3/2
- Poloidal mode number can not be directly verified but assuming continuous evolution towards sawteeth (q =1 phenomenon) identifies the q surfaces involved



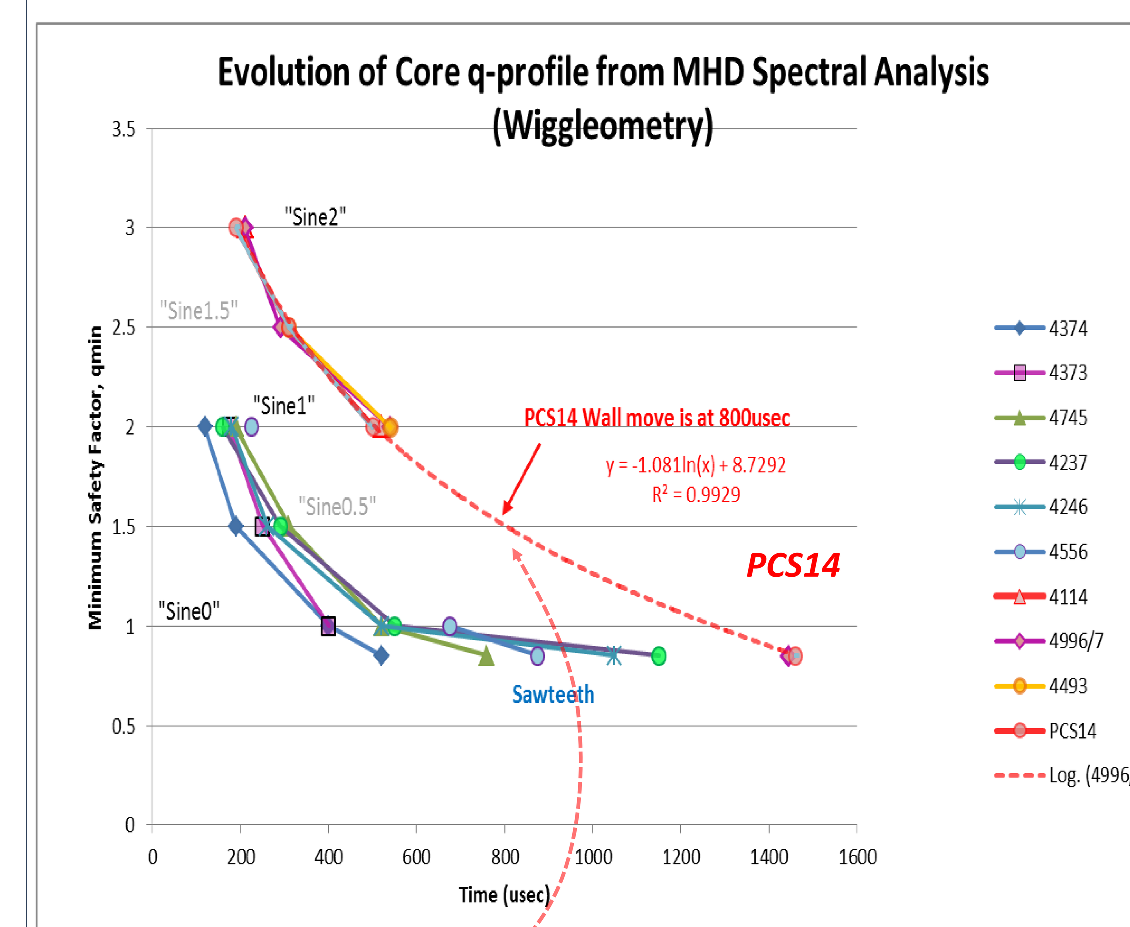
- Oscillations go away in a given shot when there are no double crossings of rational flux surfaces
  - Can happen briefly between values of q = 3 and q = 2
  - Oscillations will cease altogether once reversed shear washes out

- A toroidal array of 6 B-probes and polarity inferred from other diagnostics allows the identification of the toroidal mode number, ***n***, of the oscillations (wiggles)

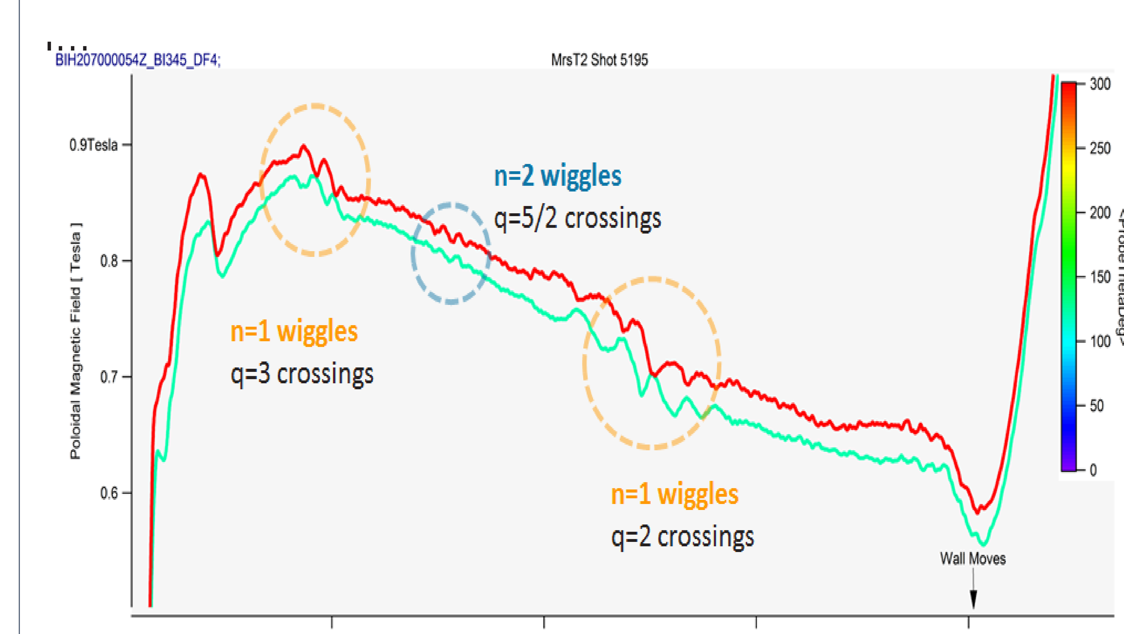


Time History Of Different Wiggles Tells The Story Of Core q

- Can identify particular q-crossings from shot to shot.
  - Since core-q is dropping versus time, it makes sense that a wiggle associated with a given value of q will take longer to appear for a shot with higher overall safety factor (eg with higher shaft current)



- The absence of an n=2 oscillation near 800 μsec of these shots implies that reversed shear is gone by that time



CONCLUSION

- Despite the fact that our PCS-14 shot had very little coverage from B-probes (due to mechanical constraints of doing field compression tests), this analysis tells us that at the time of wall move for that shot (800 μsec) , the central q profile was flat and very near q(0) = 3/2
- This is a very valuable piece of information that we can use to further advance our understanding of the stability of CTs under compression.