PASSIVE MHD SPECTROSCOPY FOR AUGMENTING MAGNETIC RECONSTRUCTION ON SPHERICAL TOKAMAK PLASMAS

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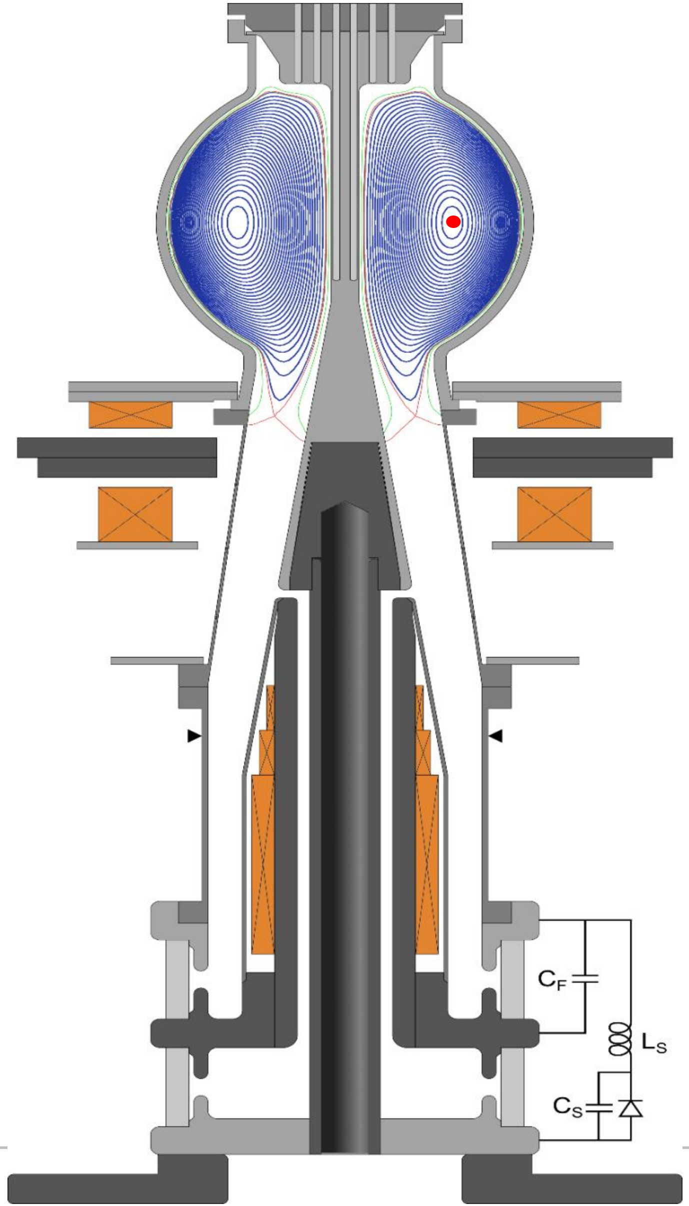
SPECTOR Experiment



- ***SPECTOR***
  - Built to allow ~3D compression tests of **SP**h**E**rical **C**ompact **TOR**oid Plasma
- Plasmas injected vertically from Marshall gun up to an Aluminum flux conserver
- Independently controlled central shaft current allows formation of spherical tokamaks

SPECTOR Experiment: Lab Flux Conserver

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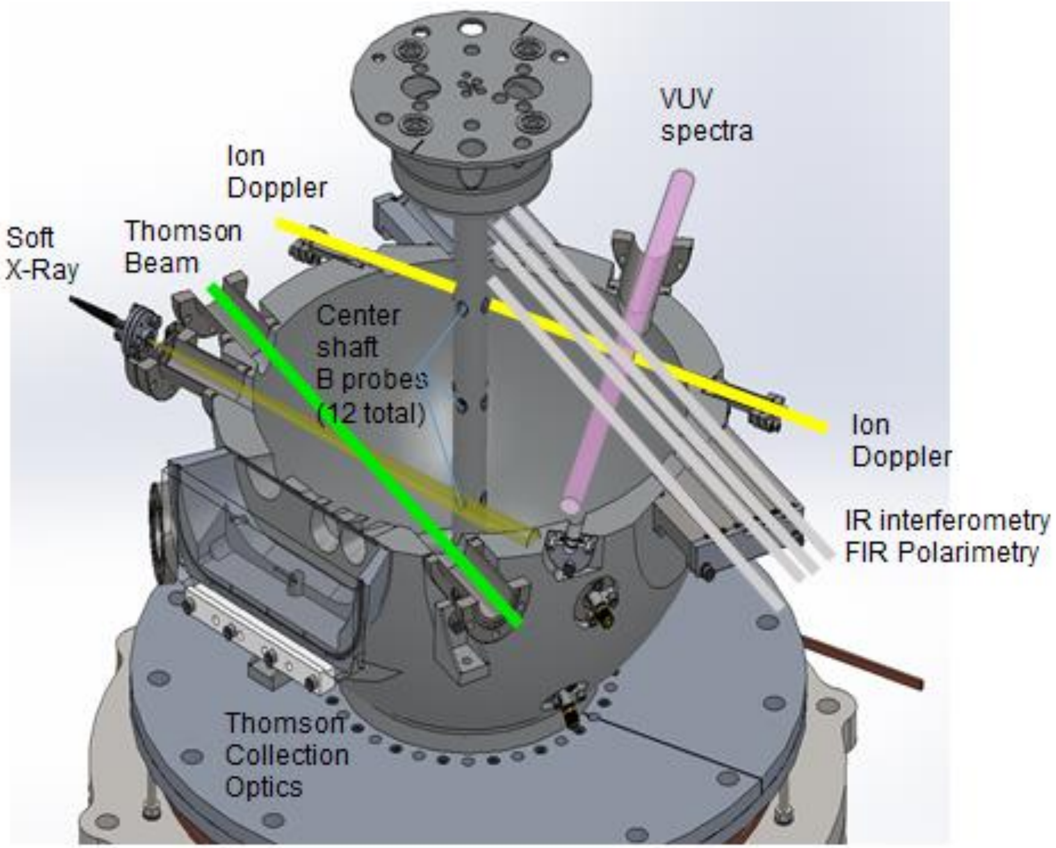
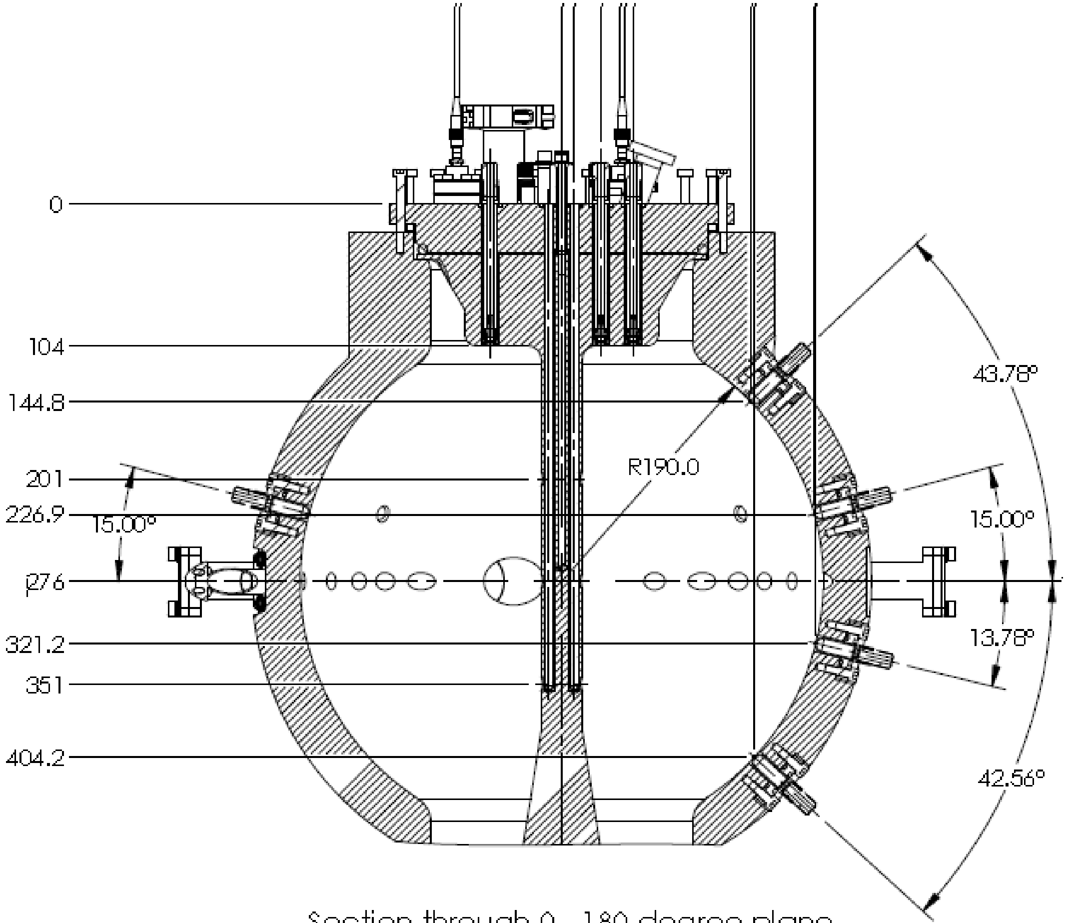
Lab Flux Conserver

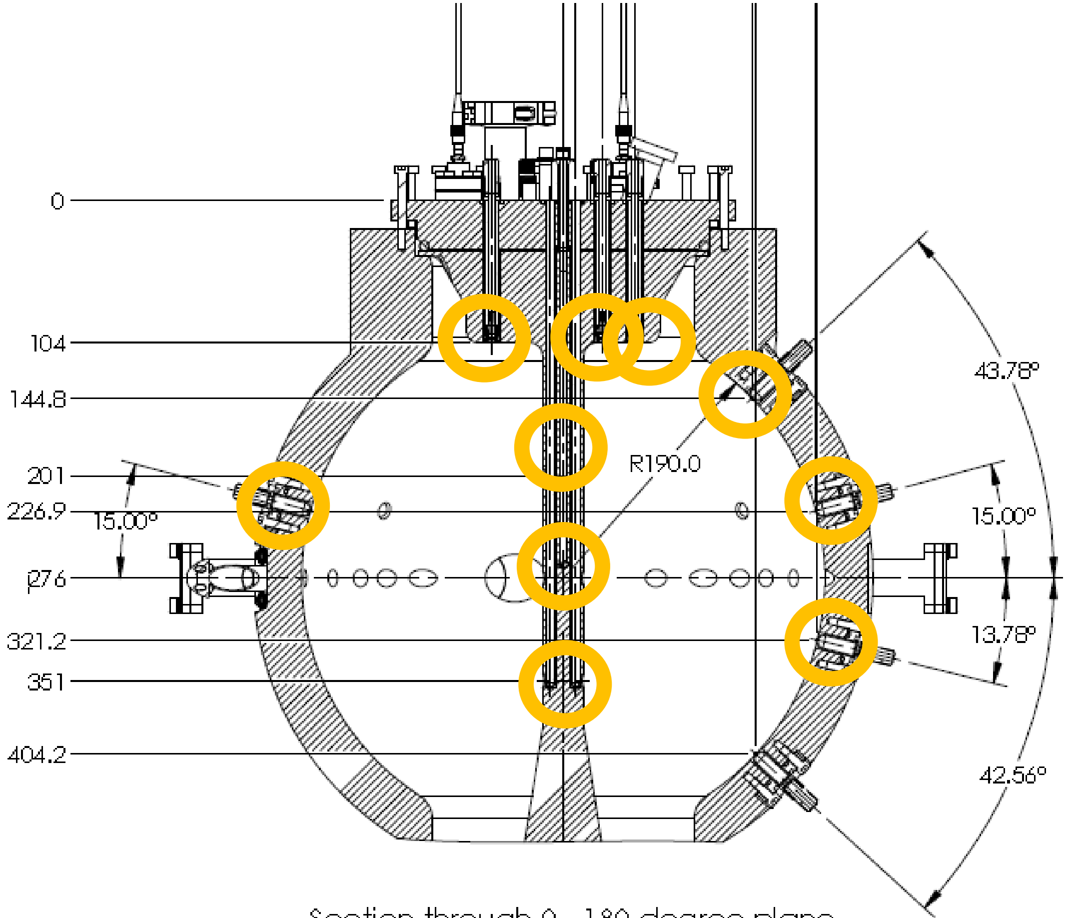




Section through 0 - 180 degree plane

- Lab version of experimental head as a substantial array of B-probes
- Enables magnetic reconstruction

Lab Flux Conserver



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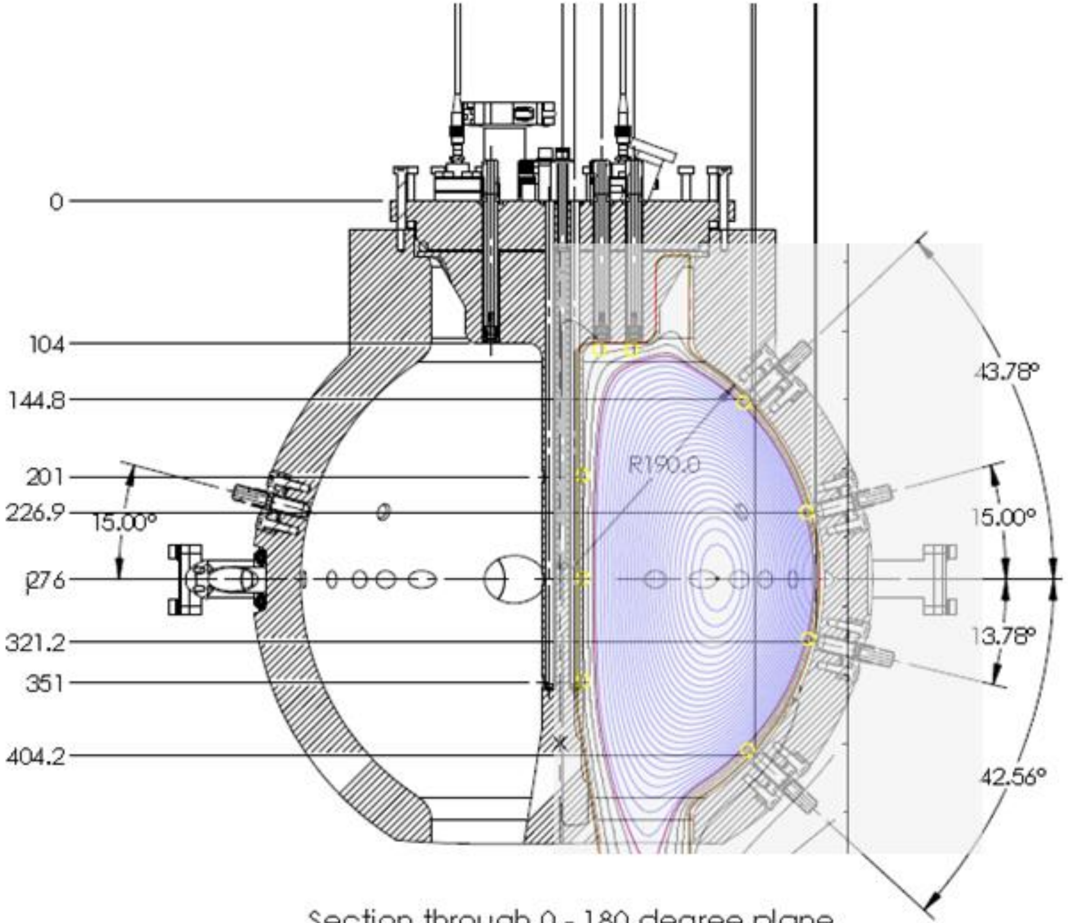

Section through 0 - 180 degree plane

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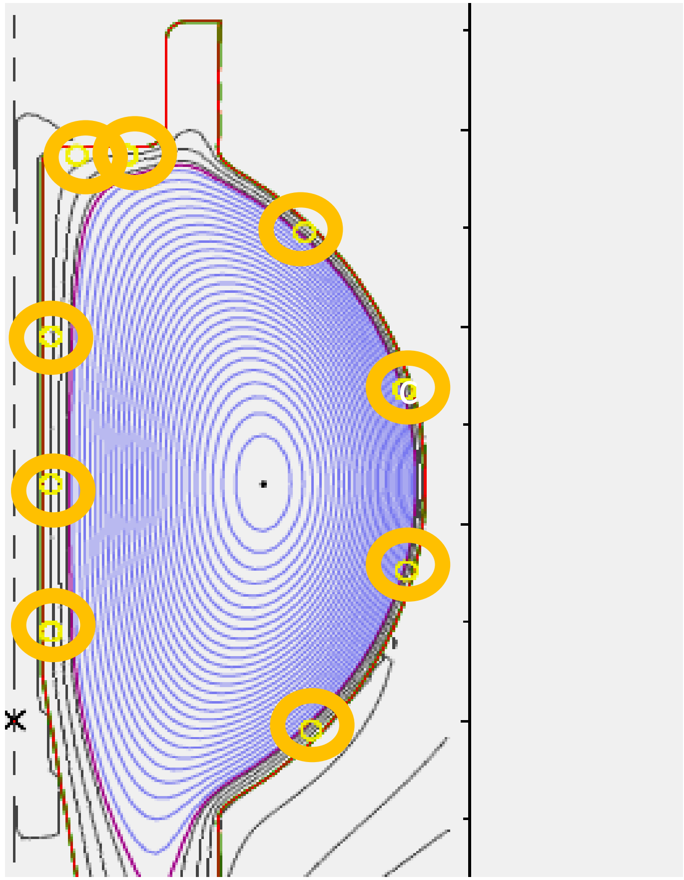
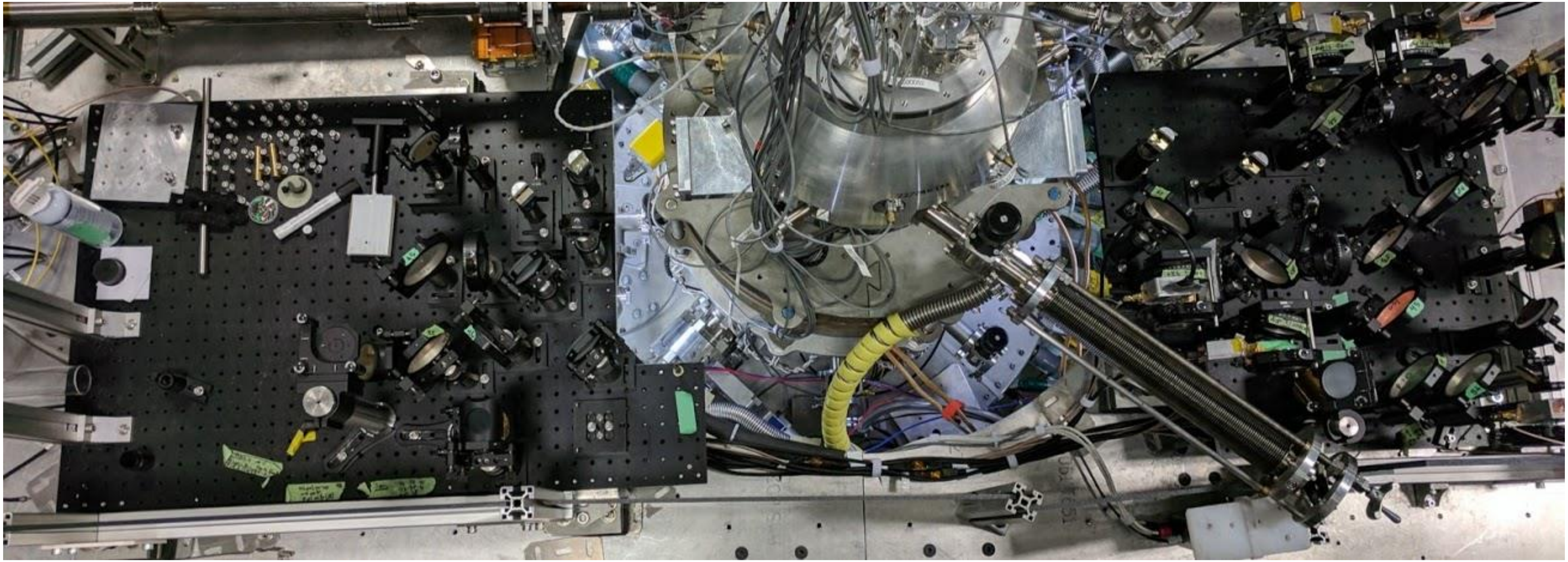


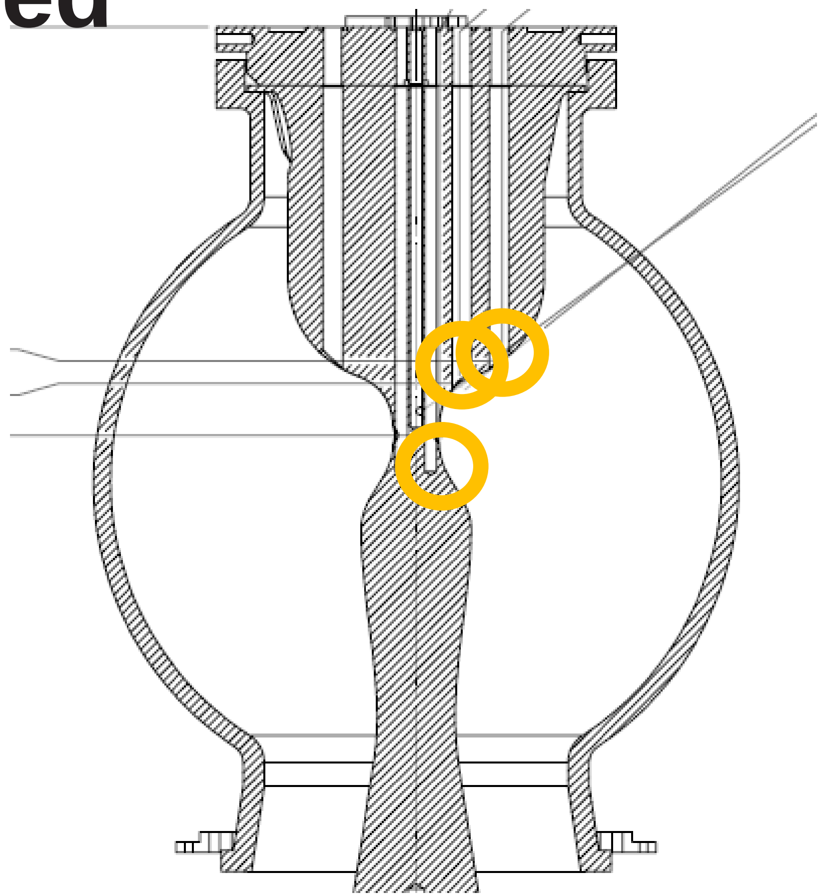
- We want to measure and control the **q-profile** of our plasmas because it is crucial for stability

Lab Version Diagnostics to aid reconstruction

- Polarimeter system (118 um laser) is under development for use on the lab version of SPECTOR



PCS Flux conserver : constrained



- Field compression version of experimental head has a limited array of B-probes
- Hinders magnetic **reconstruction**

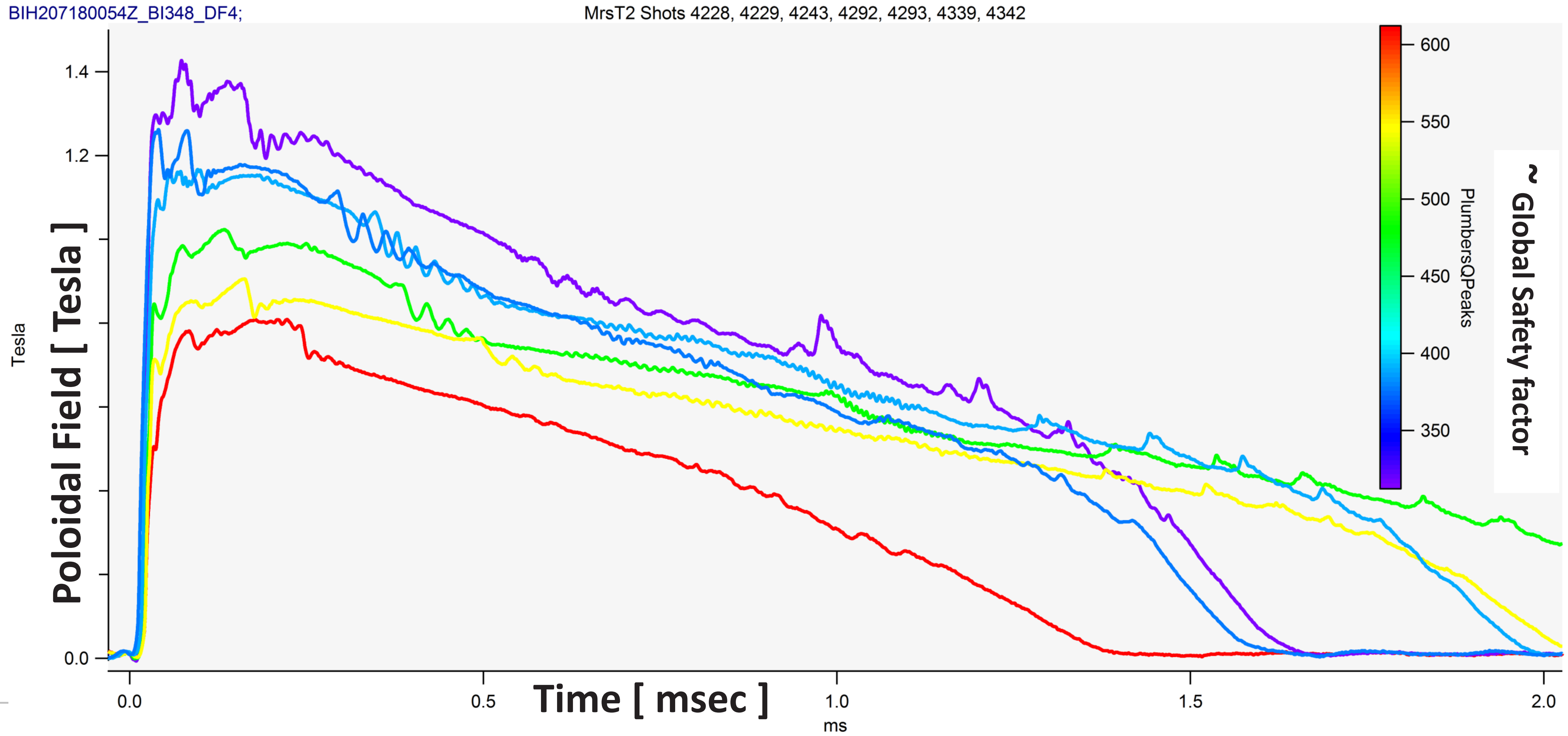
Challenge for Field Version of SPECTOR

- We have targets for q-profiles based on stability analysis
- How to do Reconstruction to know if we're near these targets ?
  - Even on the lab machine, B-probes won't tell you much about the core

- Despite the ability to learn from what we see on the relatively well diagnosed Lab version of Spector…
  - No two machines are perfectly identical
    - Lab version has different inner electrode
  - Machine conditions and recipe can vary
- So….we want / need to supplement the limited information we get from B-probes on the field machines with additional information

Enter “Wiggleometry” (MHD Spectroscopy)

- Most plasmas have bursts of oscillations on magnetic probes



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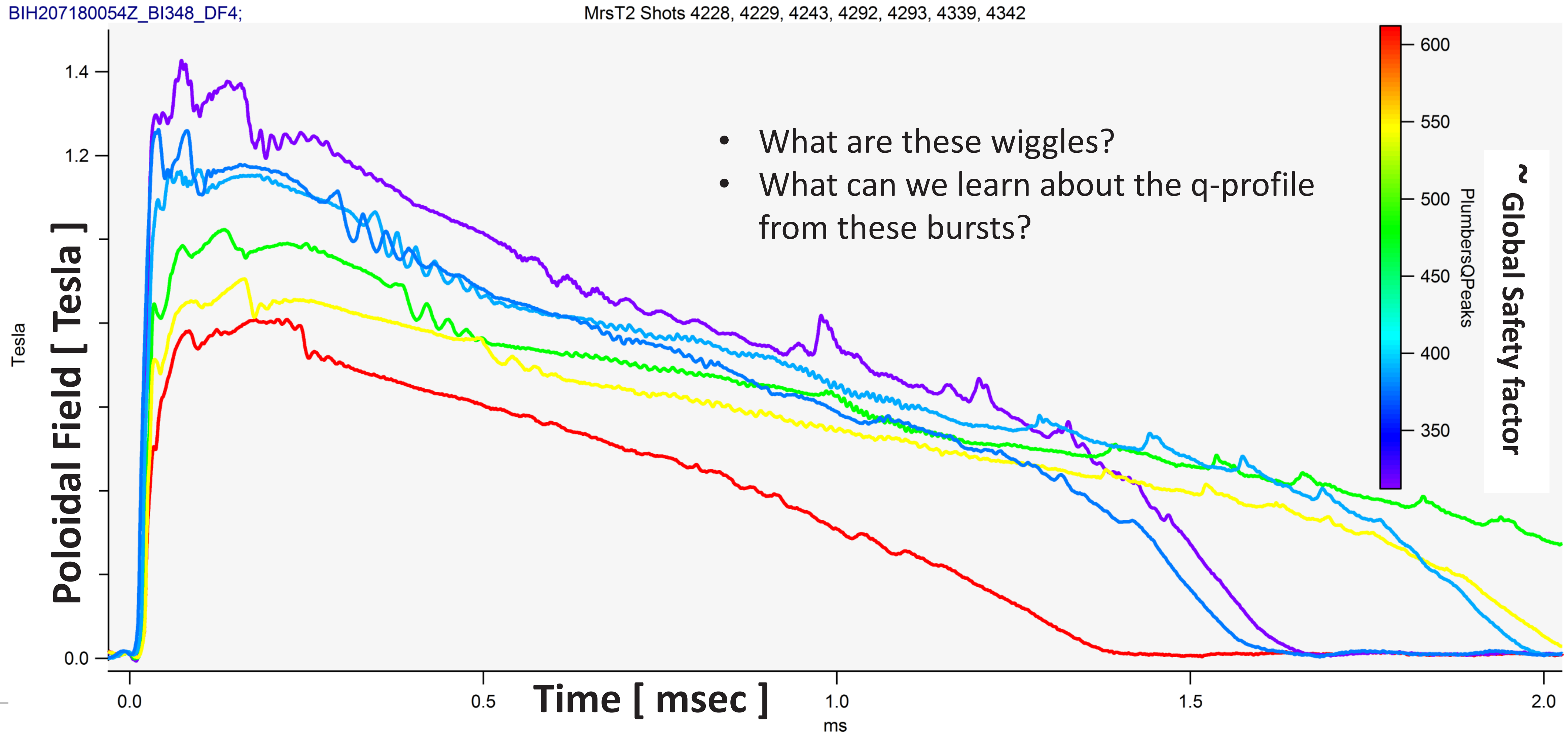
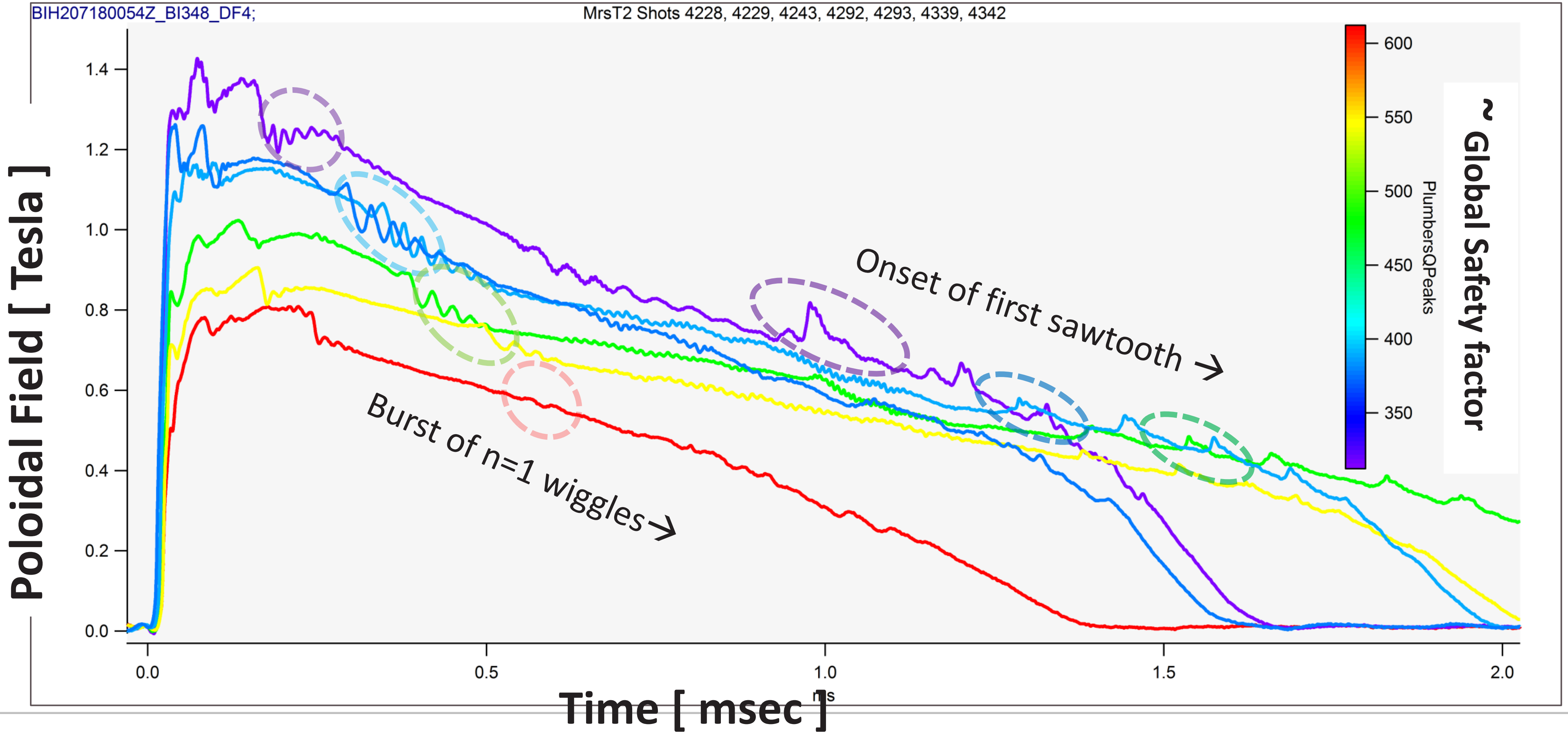


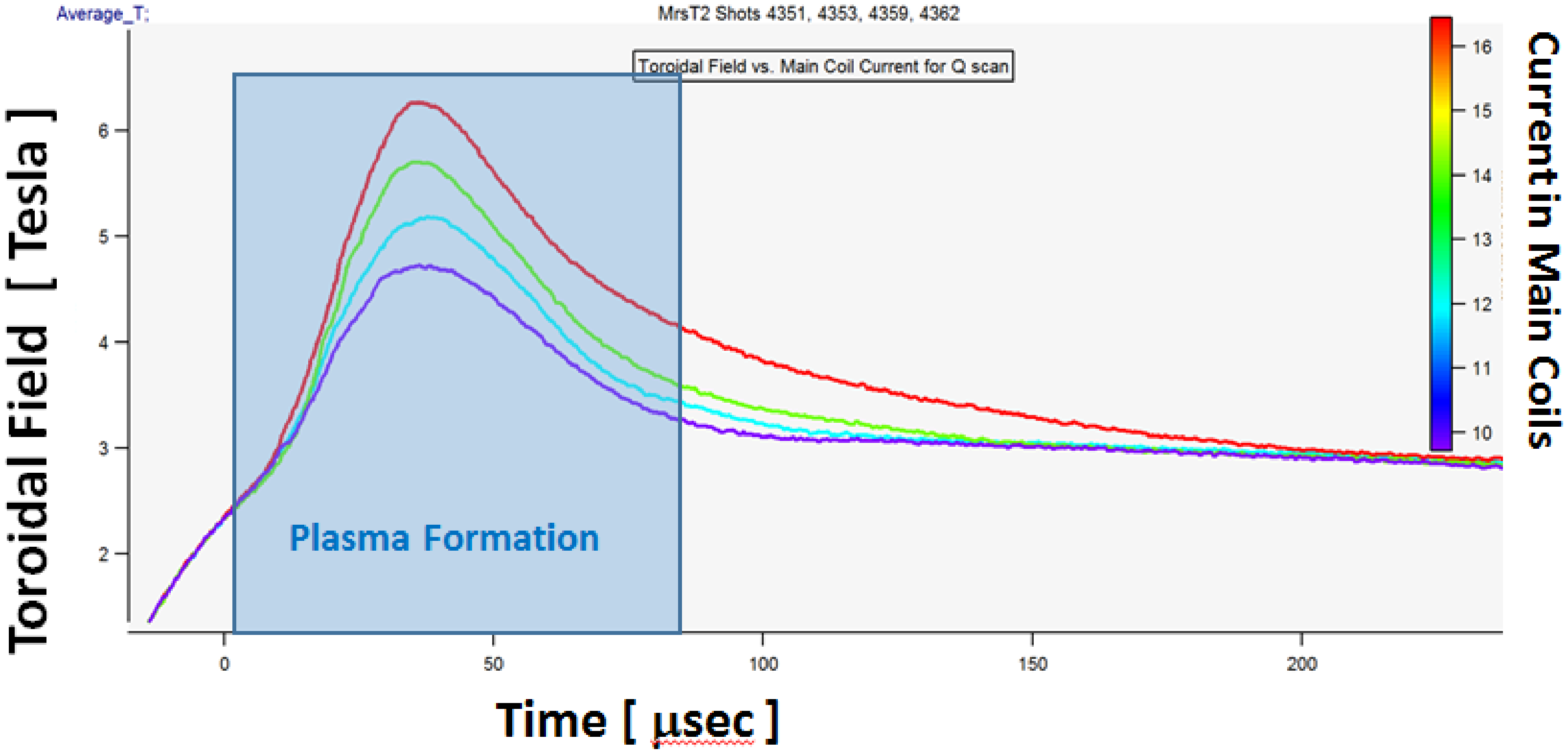
MHD Spectroscopy

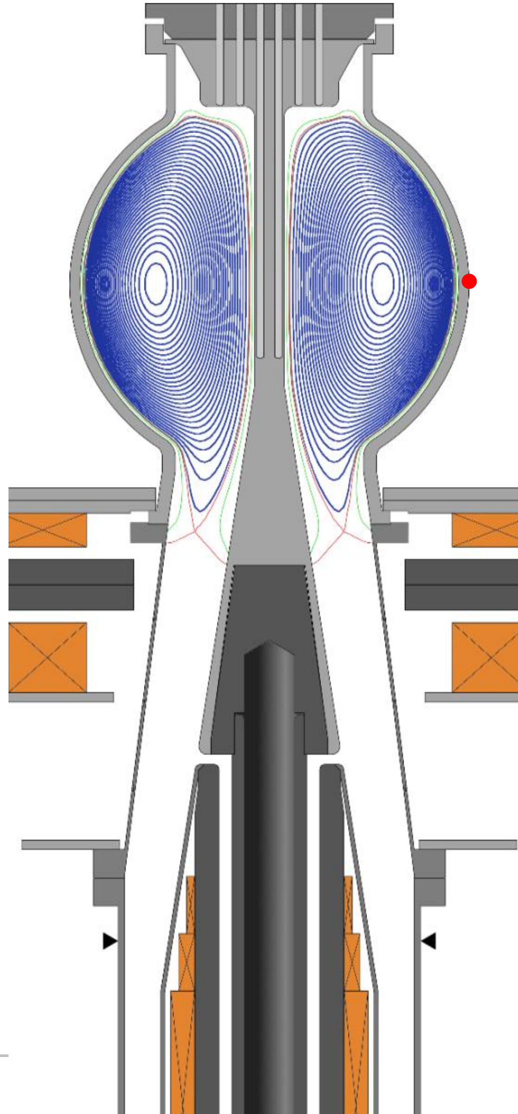
- Onset of particular wiggles are delayed in time as overall safety factor is increased from shot-shot… (eg. as we increase shaft current)



Major Dynamics / Life Cycle for our Compact Toroids

- Coaxial Helicity Injection / Marshall Gun
- After bubble-out of the CT and the formation current dies away, there is ‘excess’ toroidal field in the pot / plasma.

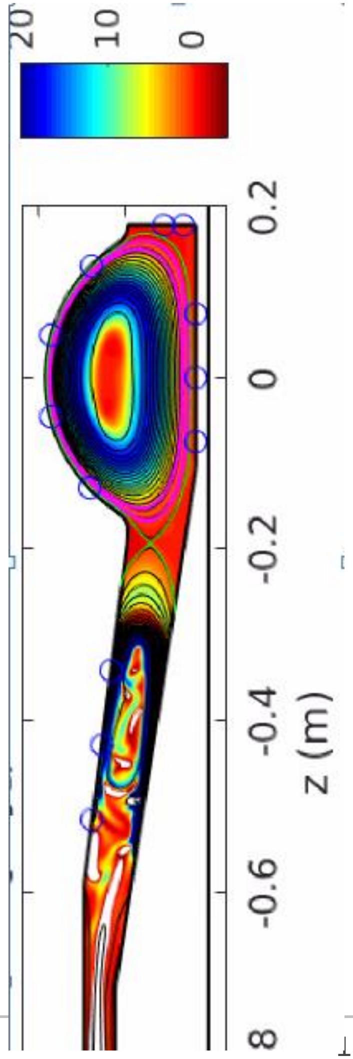




Major Dynamics / Life Cycle for our Compact Toroids

- Coaxial Helicity Injection / Marshall Gun
  - After formation ends, plasma current profile is quite hollow
  - These Plasmas have no current drive and no auxiliary heating…plasma heating after formation due to Ohmic decay of injected magnetic flux.
  - Ohmic heating will naturally evolve plasma towards a peaked current profile
  - So:
    - ***Early time : hollow current profile : reversed shear***
    - ***Late time : peaked current profile : monotonically rising q profile***

Contours of λ [1/m] from 2D MHD simulation [VAC]



2D Simulation captures basics of q-profile evolution

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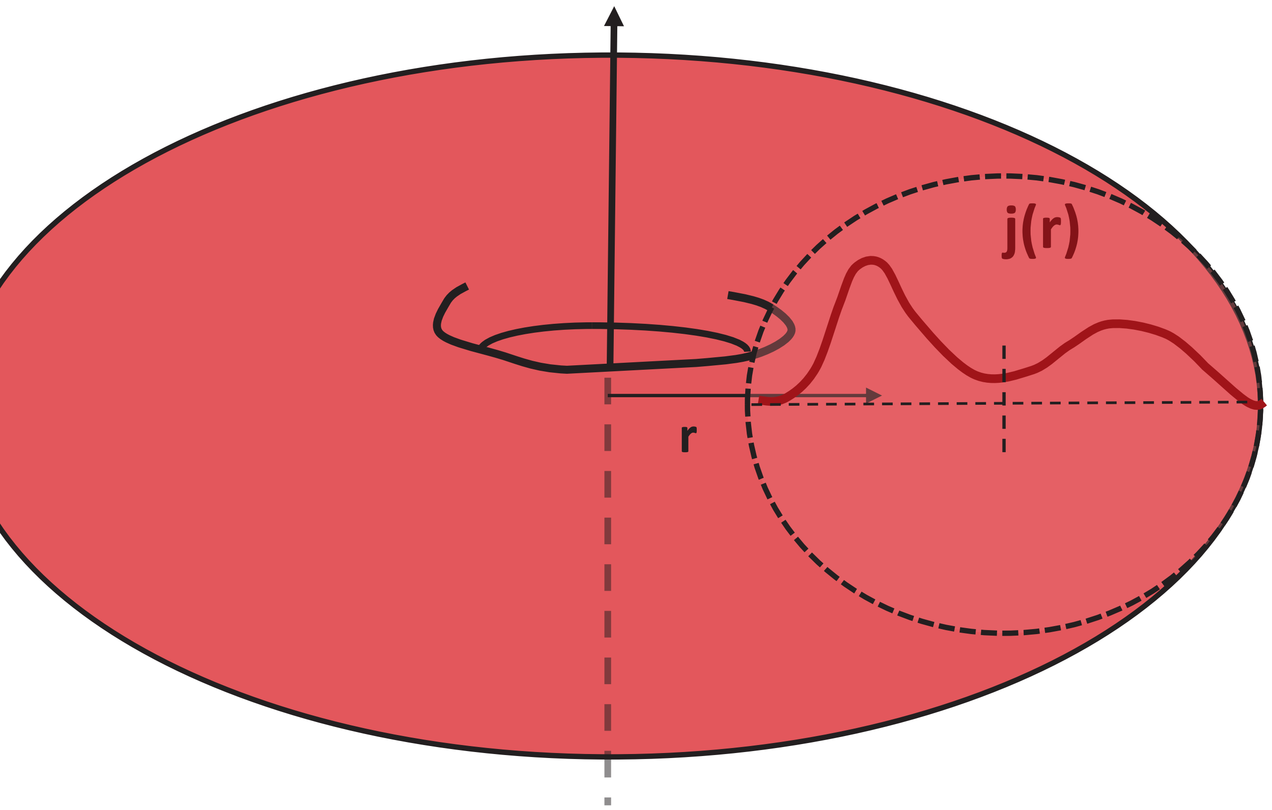
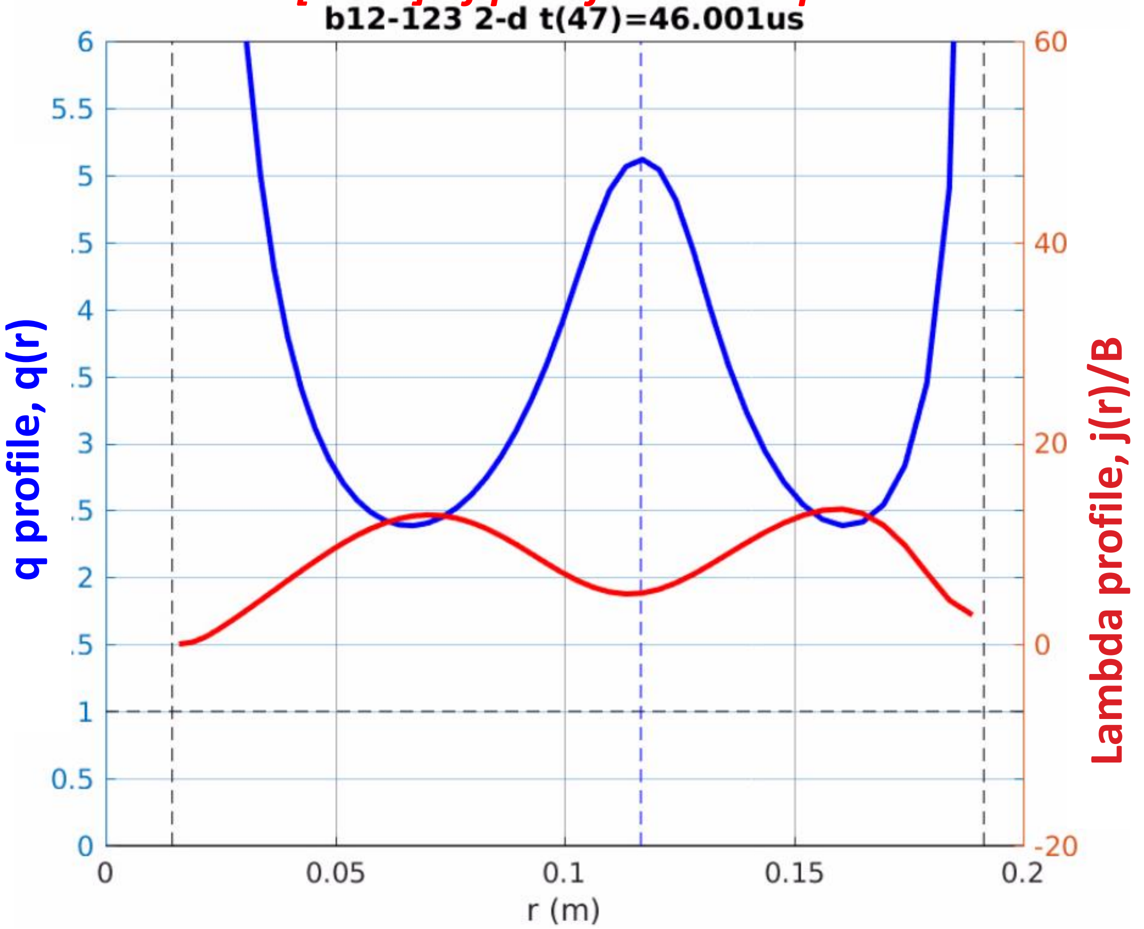
- ***Late time : peaked current profile : monotonically rising q profile***



2D MHD simulation [VAC] of post formation plasma evolution



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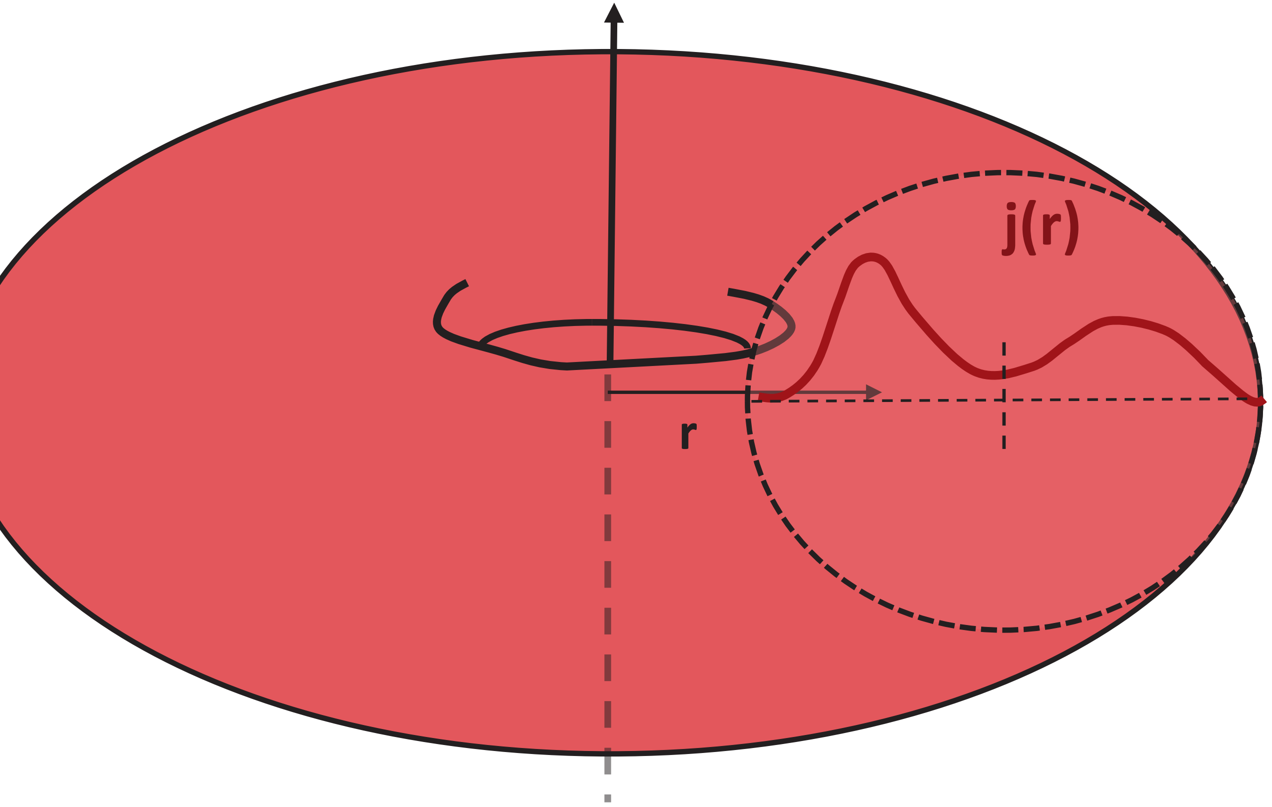

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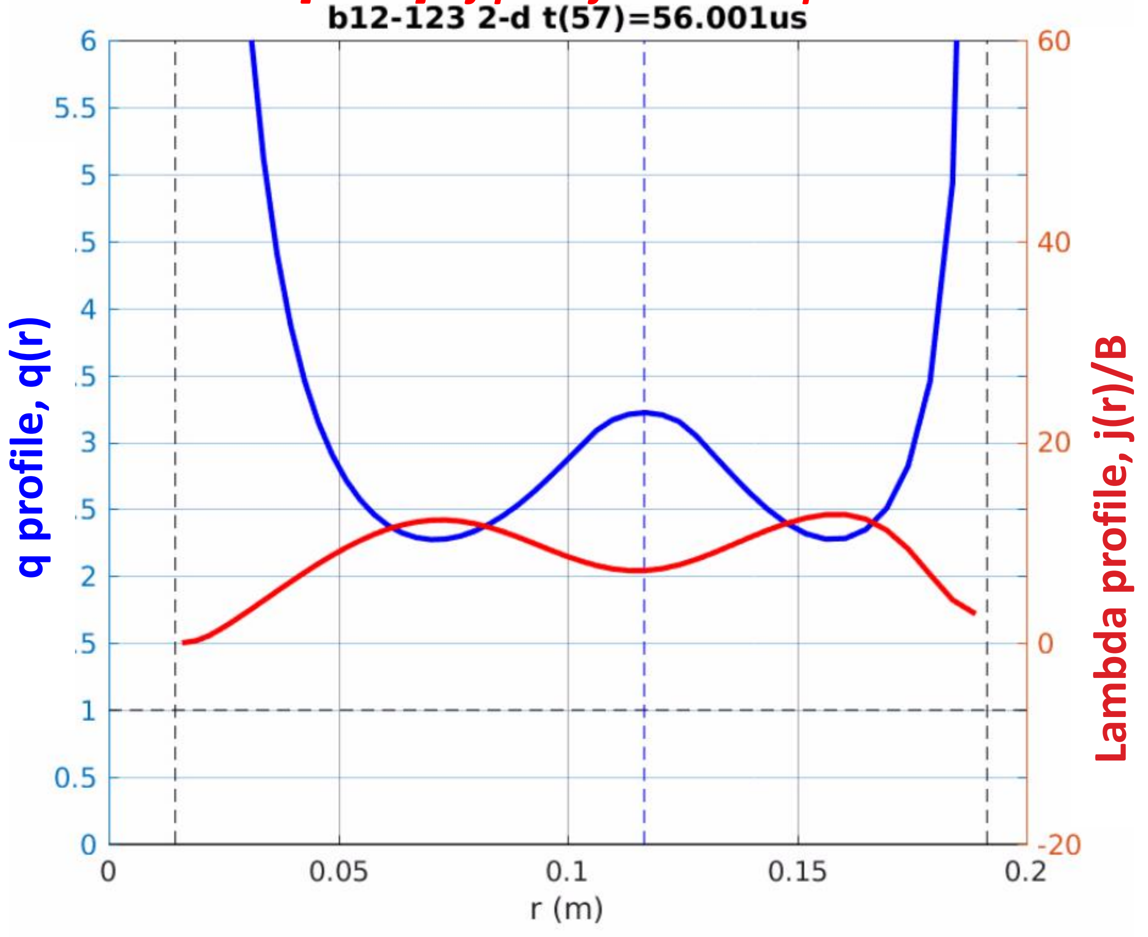

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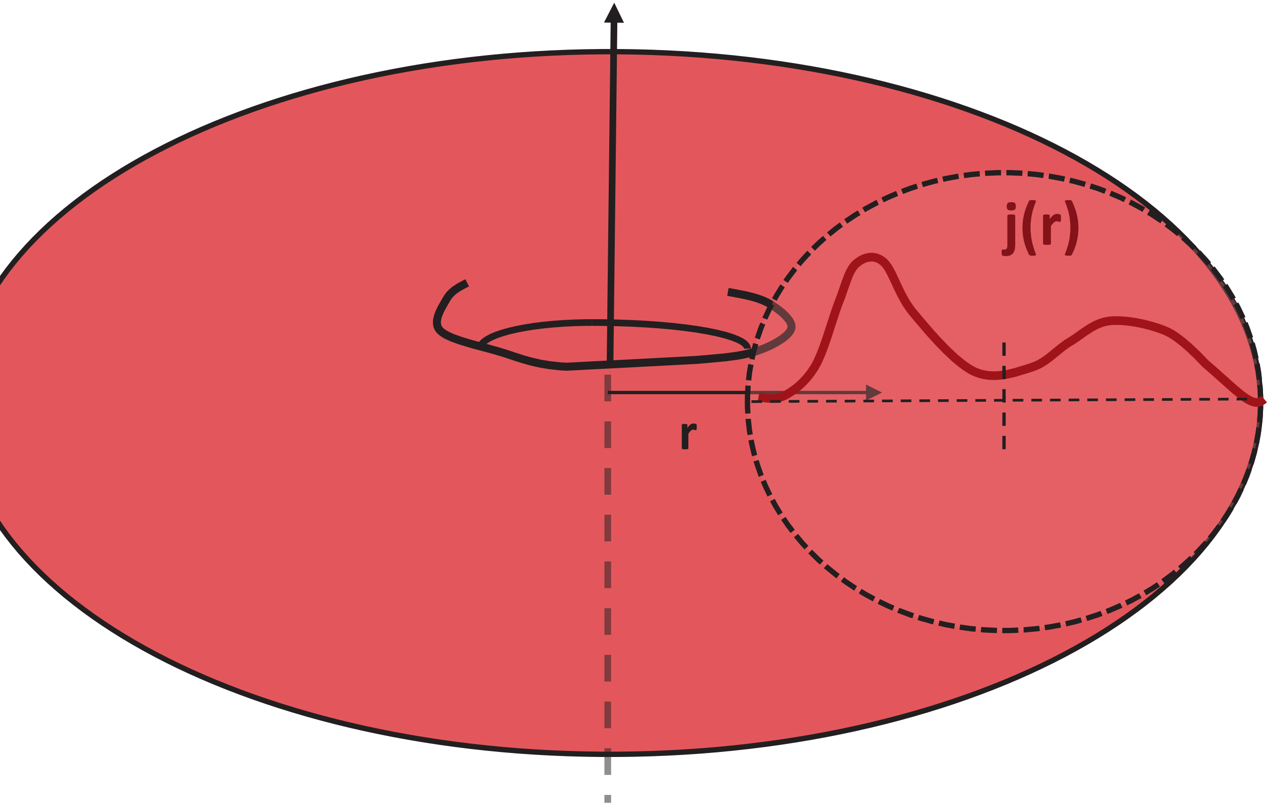

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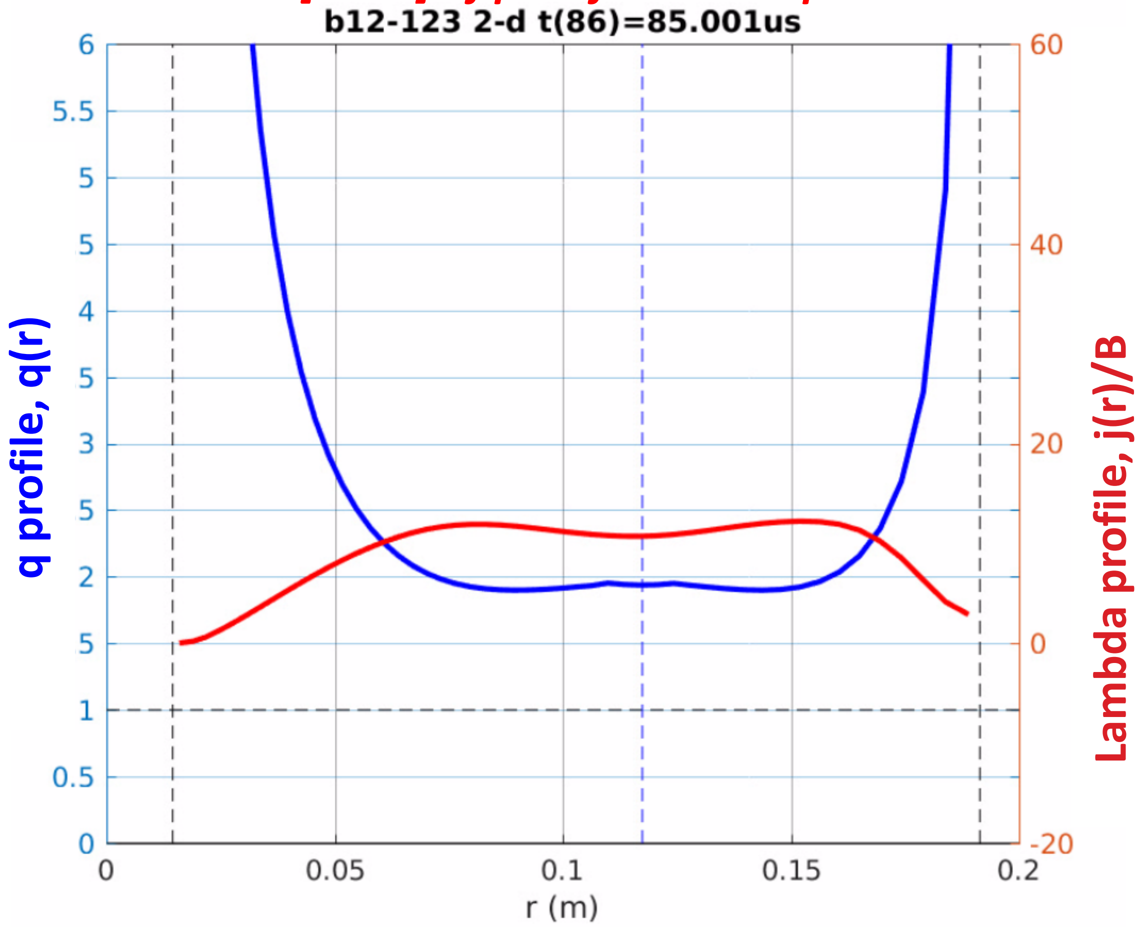
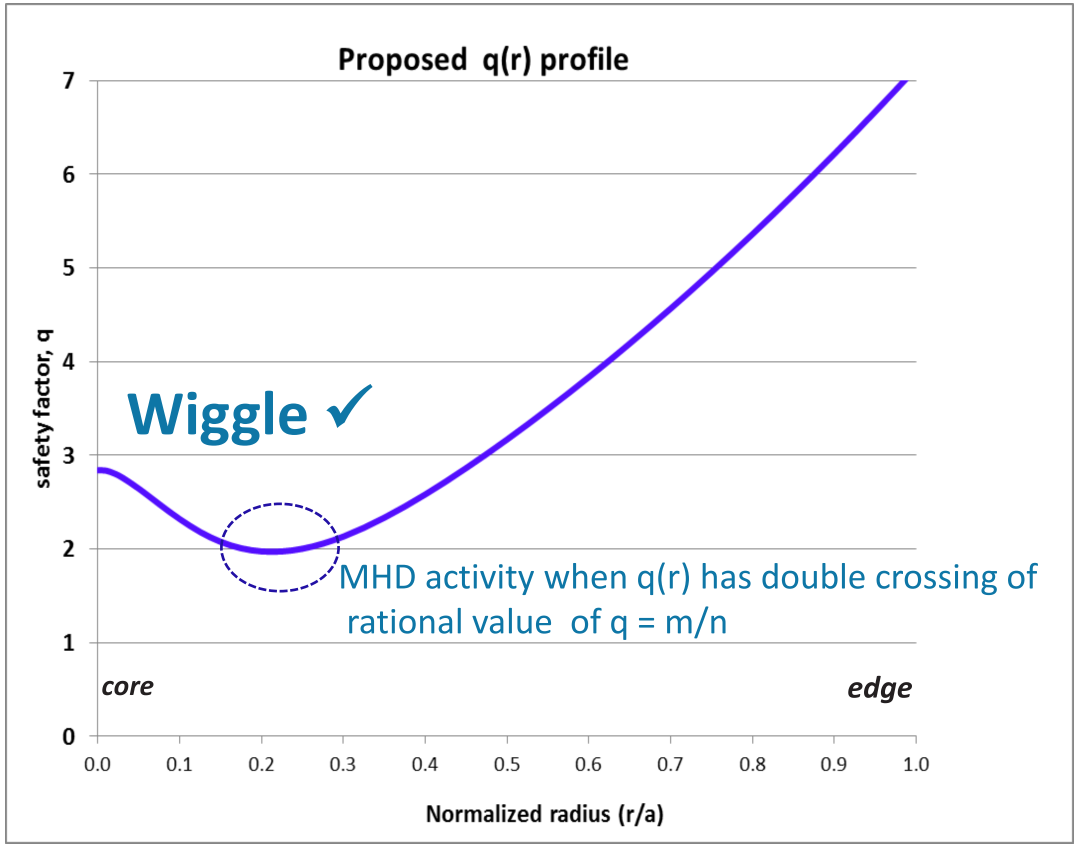
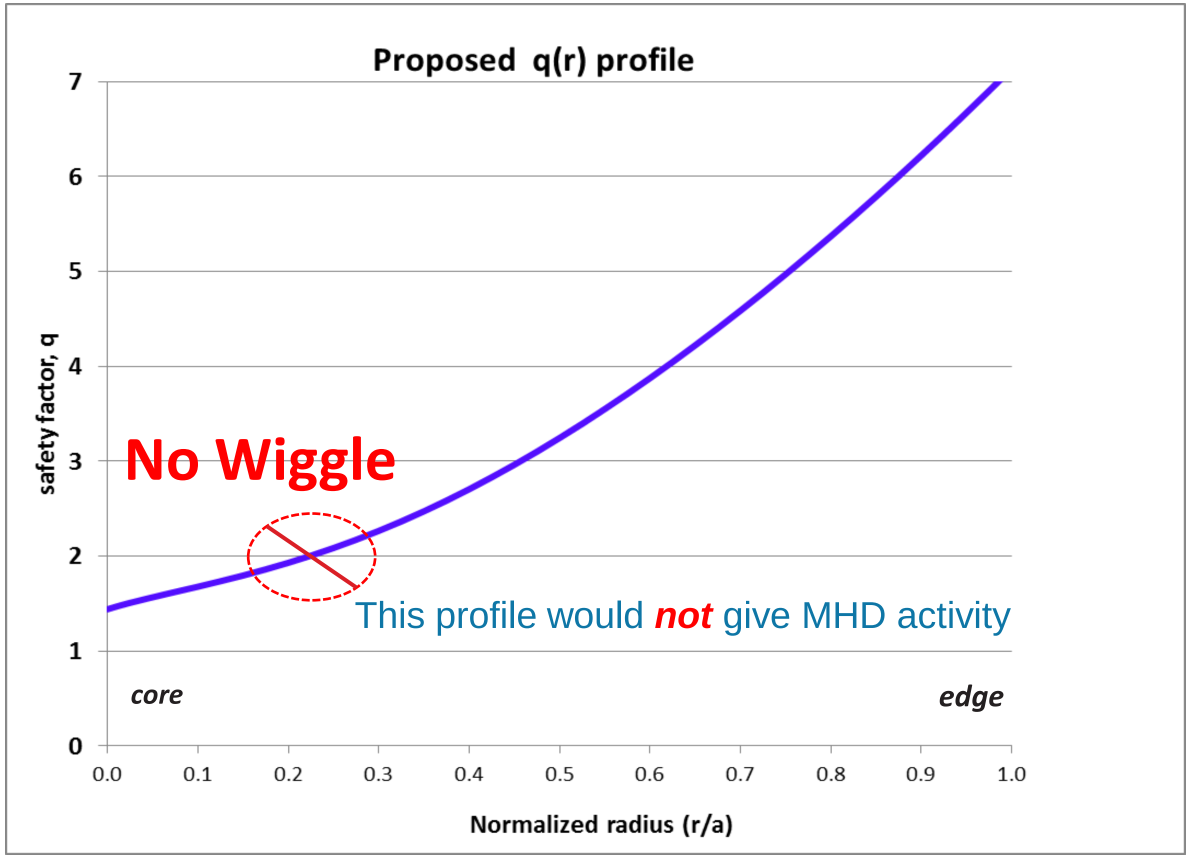


Reversed shear can give rise to double tearing mode*

* B. Carreras, H.R. Hicks and B.V. Waddell, **Tearing-mode activity for hollow current profiles** 1979 Nucl. Fusion 19 583.

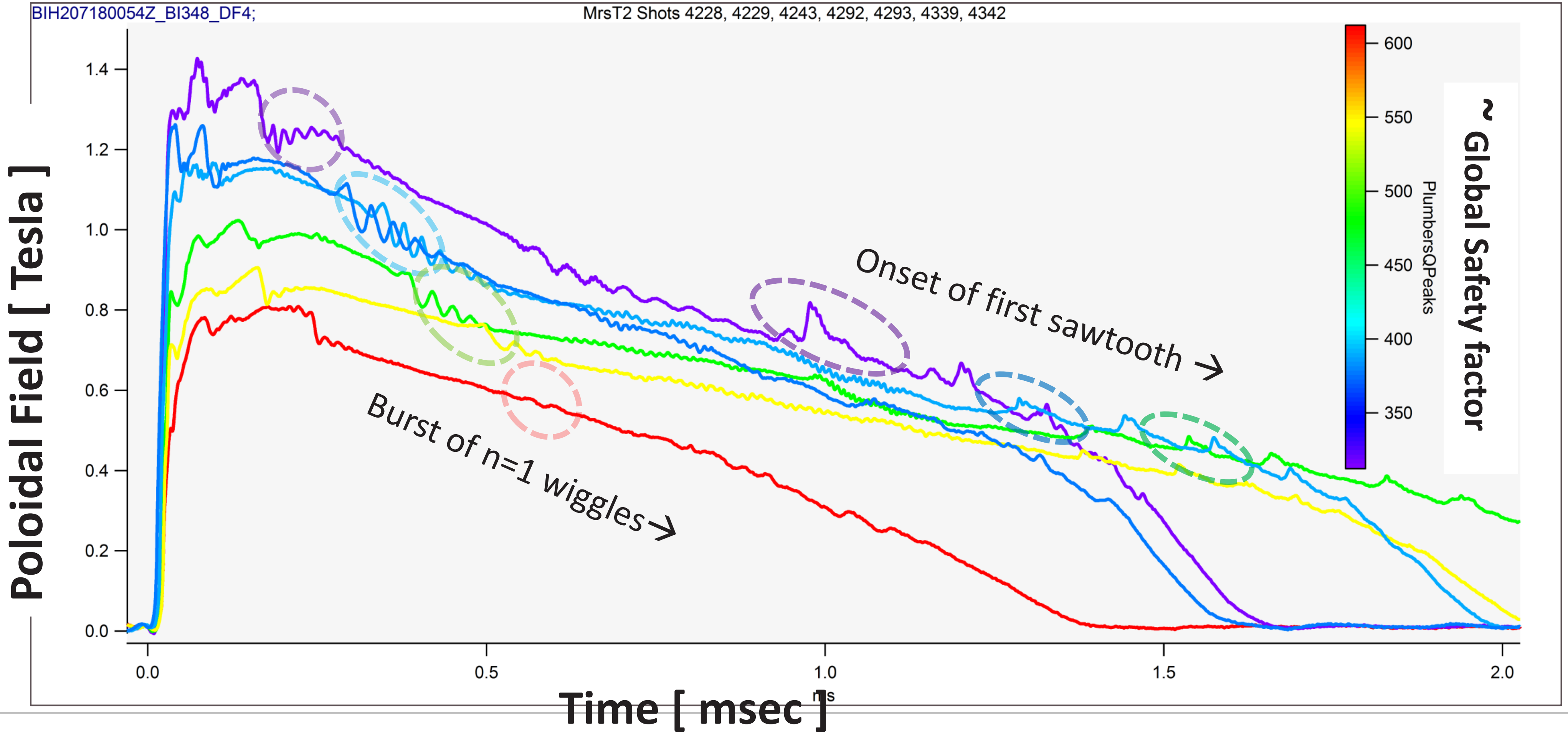




- Double crossing of rational flux surfaces excites instability, magnetic islands forms. As plasma rotates by B-probes we see a wiggle until the conditions enabling the instability end

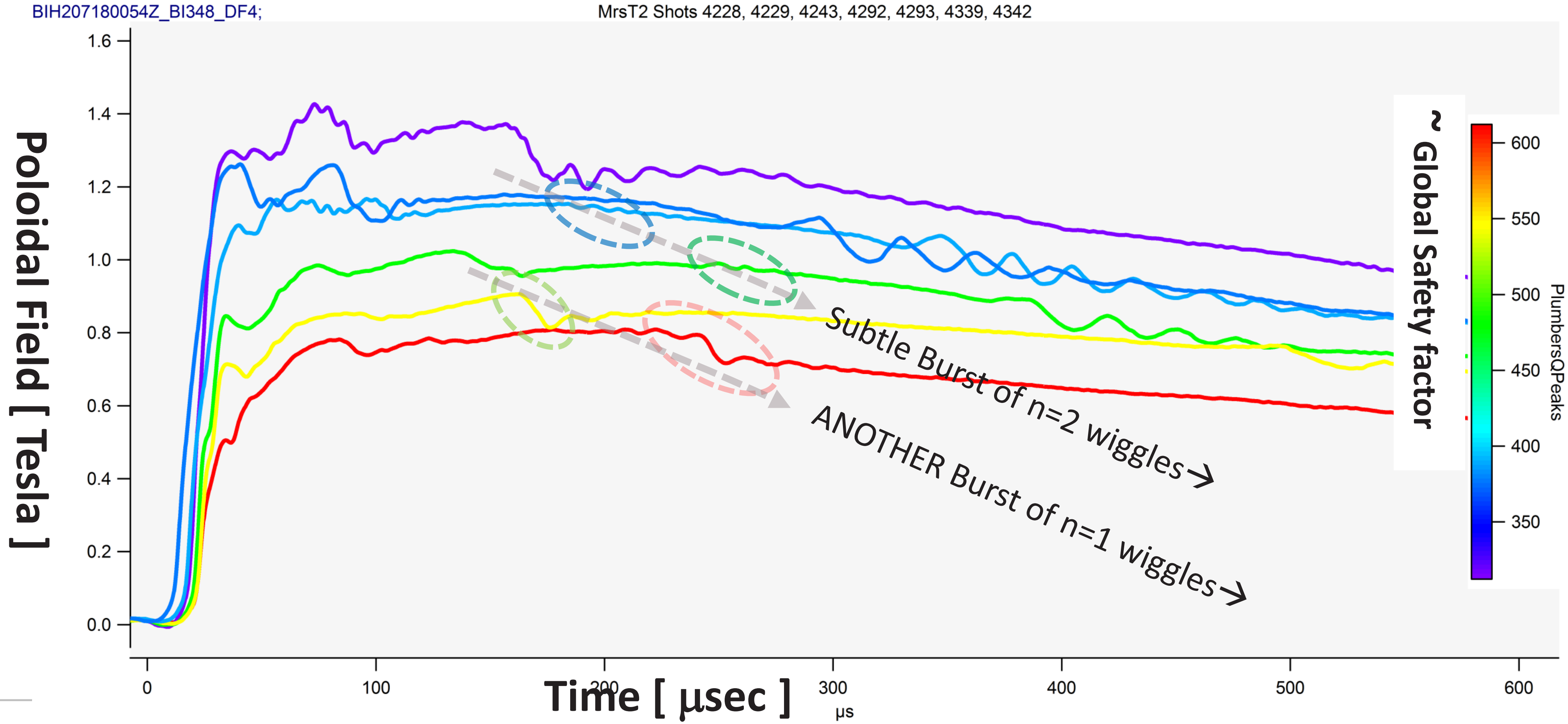
MHD Spectroscopy

- Onset of particular wiggles are delayed in time as overall safety factor is increased from shot-shot… (eg. as we increase shaft current)



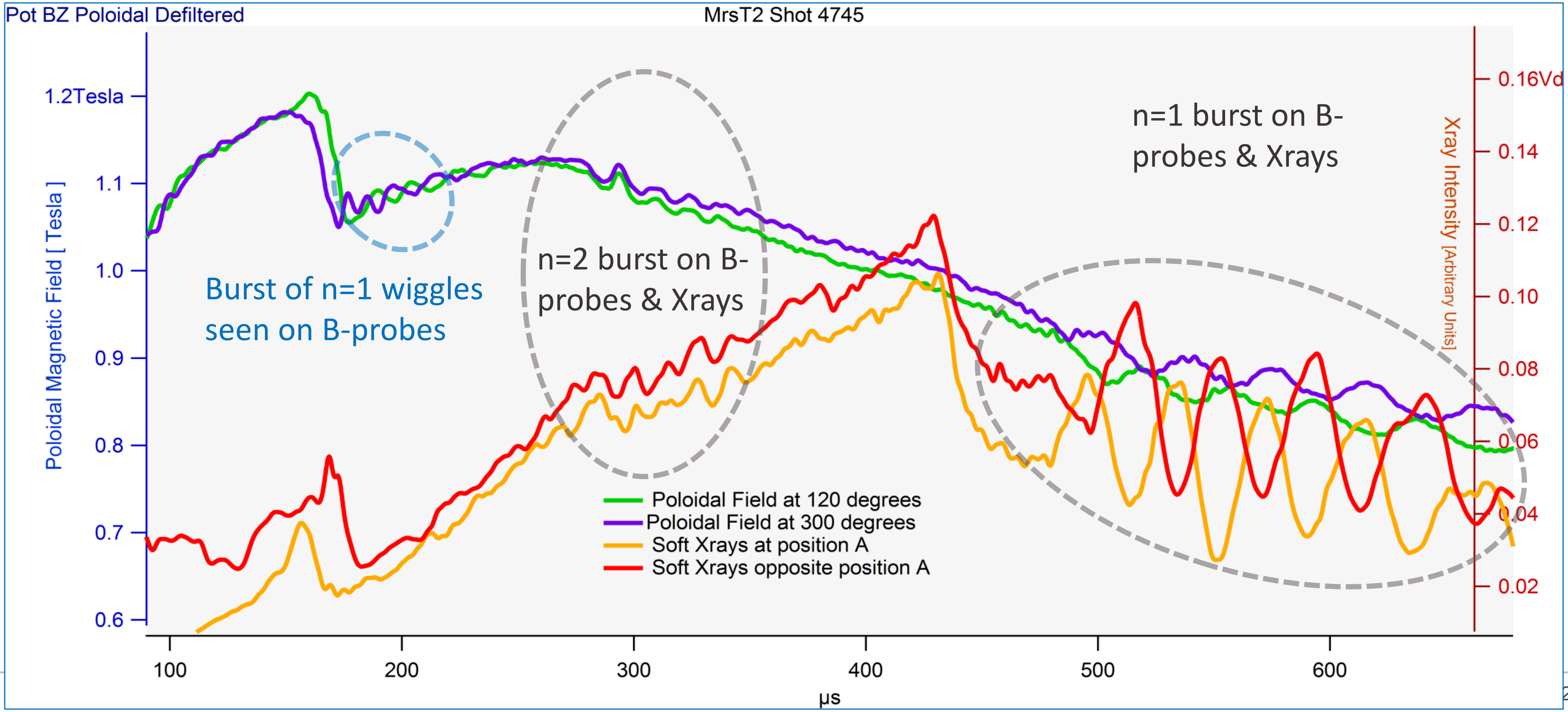
MHD Spectroscopy

- Onset of identifiable wiggles are delayed in time as overall safety factor is increased shot-shot. Even more features visible when you zoom in



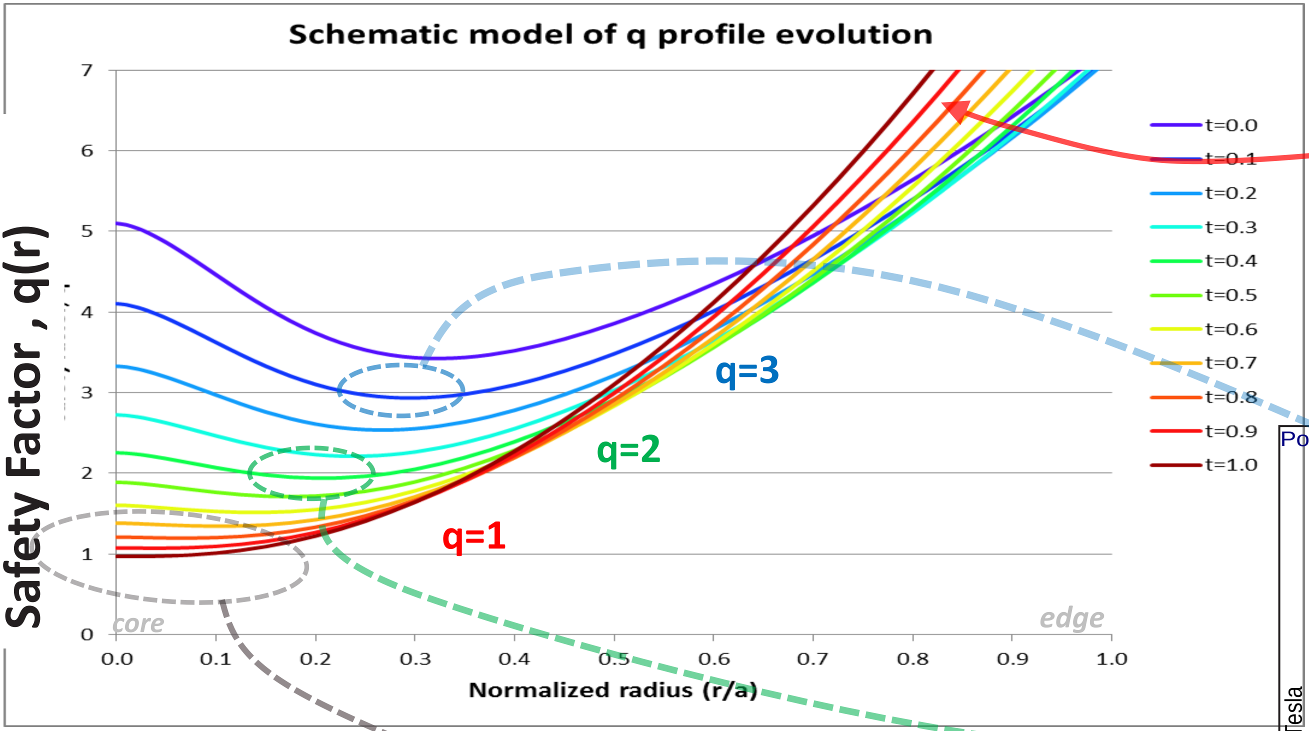
MHD Spectroscopy

- Wiggles verified to be due to rotation of helical structures seen on other diagnostics. An array of 6 B-probes can ID toroidal mode number, ***n***

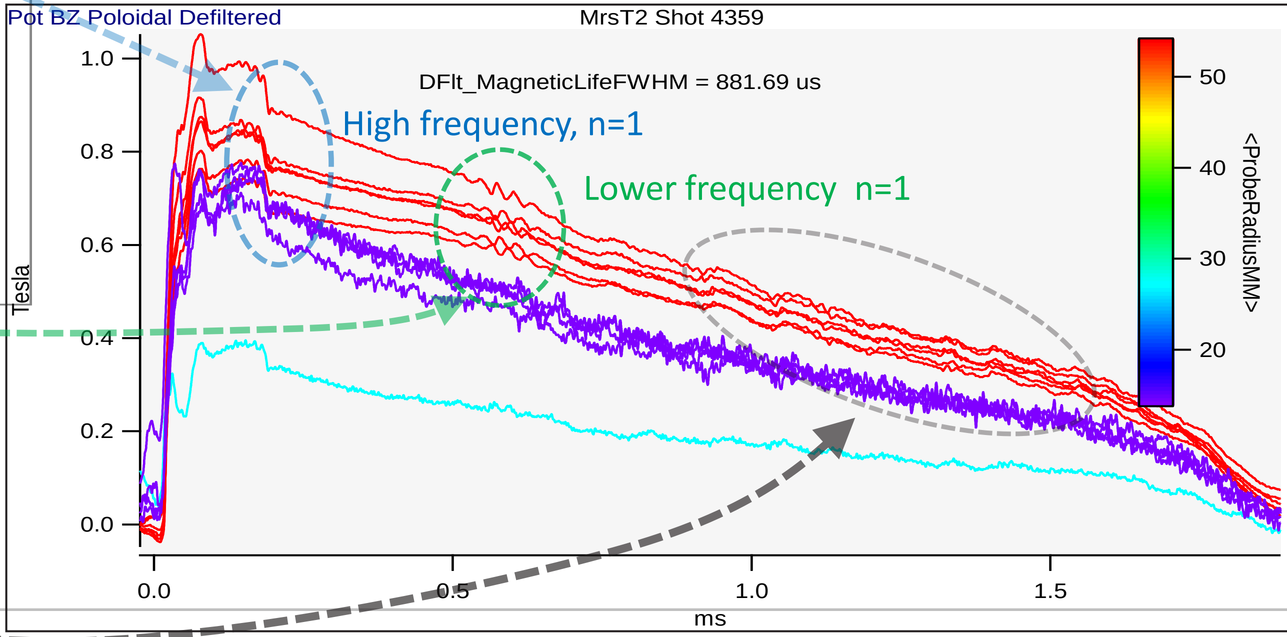


Example of what our q-model says during real shots: Highish-Q

- At higher safety factor we saw repeatable appearance of n=1 wiggles early and then later another distinct n=1 later. Both are delayed as overall safety factor is increased
- Our interpretation is that this is because the core q(r) is falling through q=3 and then q=2



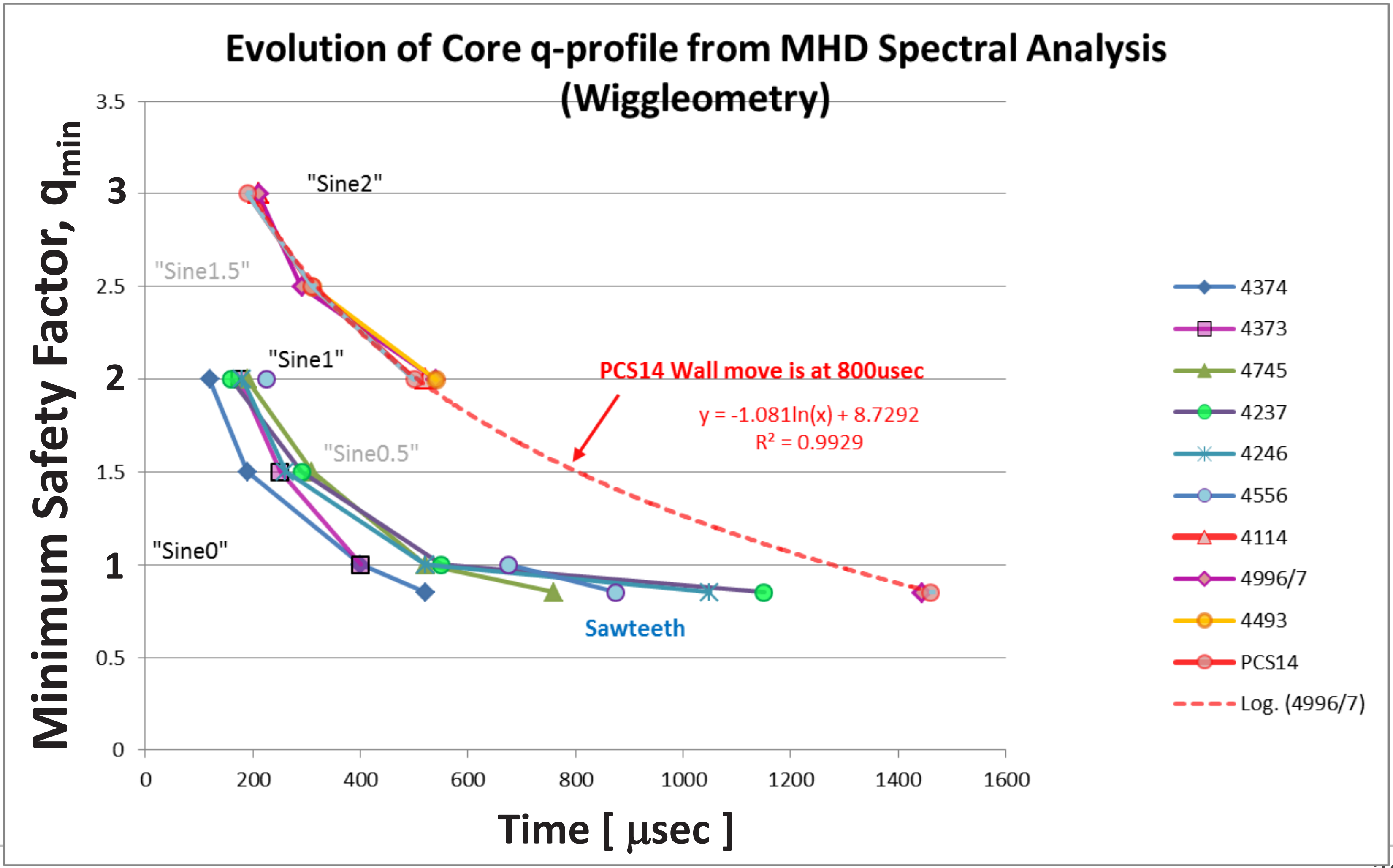
- Edge *q* has to increase with time because shaft current dies slower than plasma current…but in the core it can fall as plasma 'de-hollows'



- Variants of **"Sawtooth"** phenomena seen late in most shots are all due to q(0) ≤1 effects

Quantitative time history of q min

- Study the comings and goings of the various modes as a function of time and machine settings. Can unambiguously ID the q values associated with each
  - All discharges end in Sawteeth q~1
  - The q=1.5 mode goes away at higher overall safety factor because reversed shear is gone late in discharge



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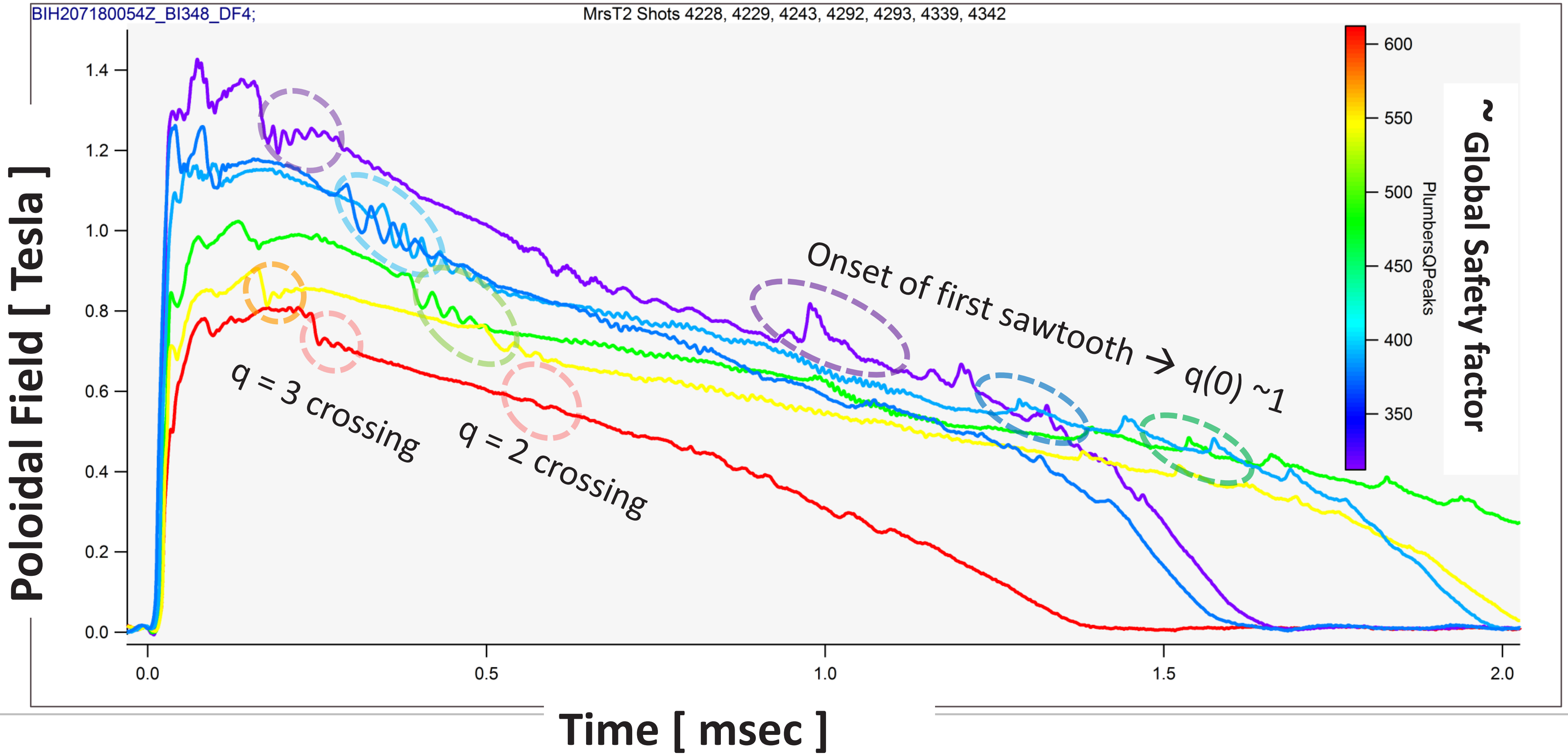
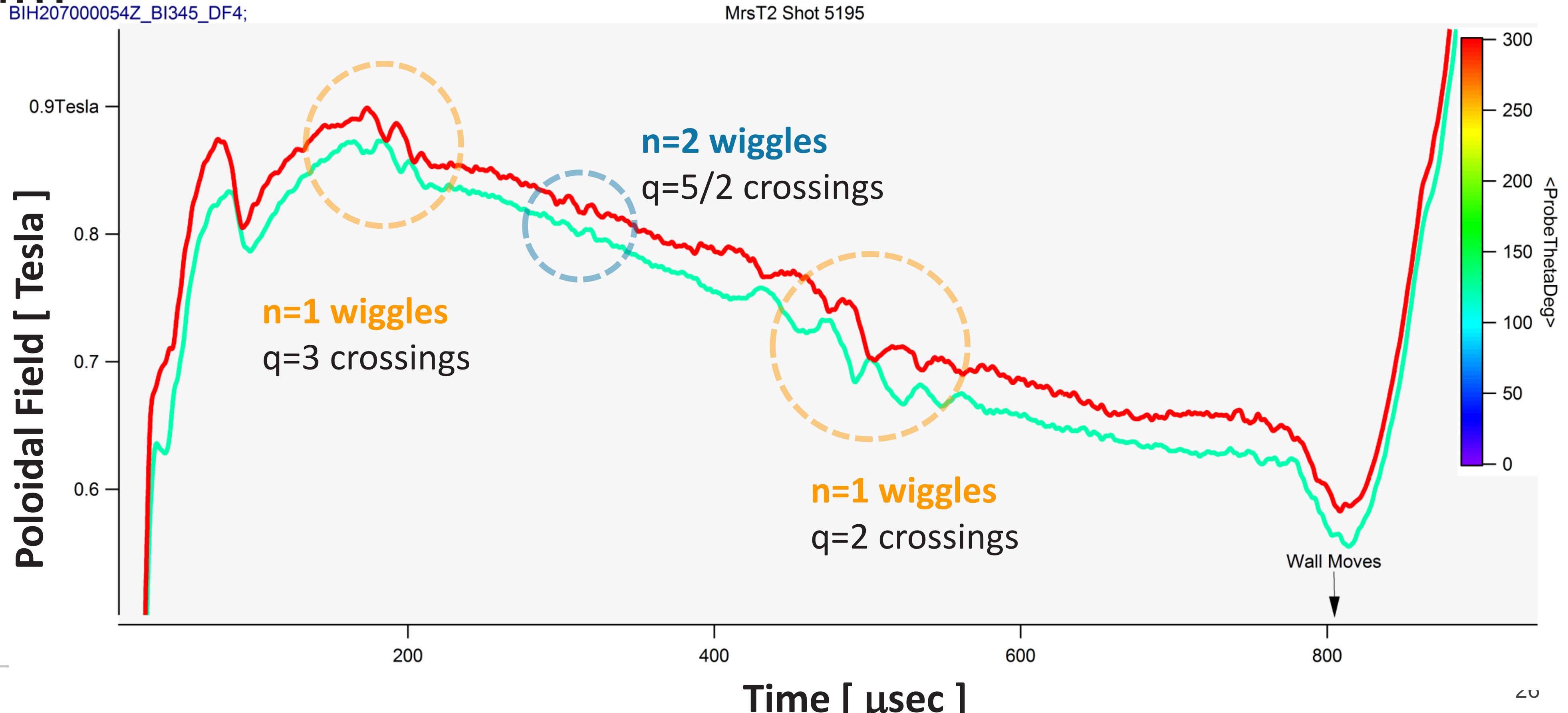


Inferences about q-profile during PCS 14 test

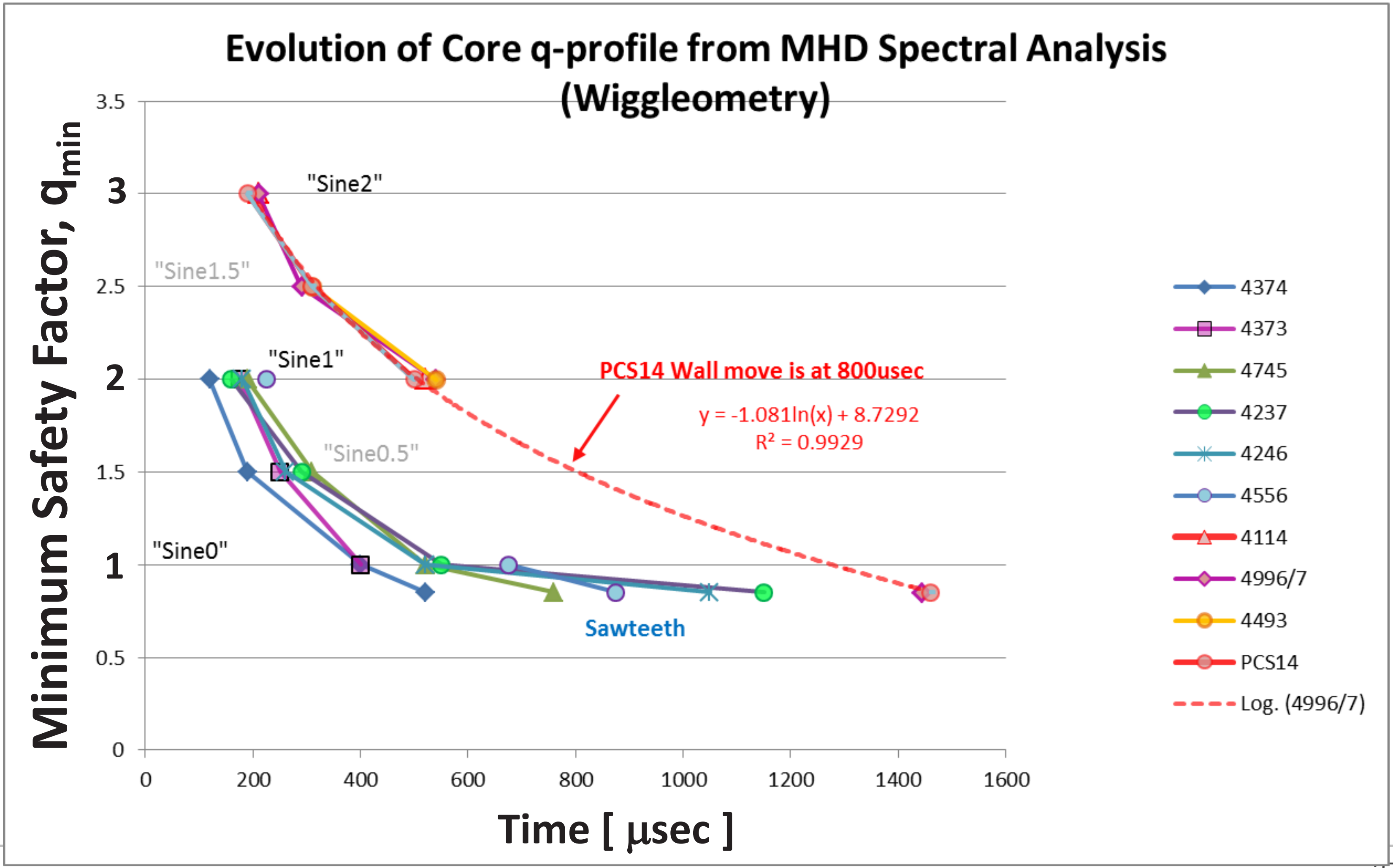
- Can clearly see 3 bursts of MHD from q=3, q=5/2, & q=2 crossings
- From similar shots leading up to the compression shot we also know approximately when the reversed shear disappears and when sawteeth begin…



We were able to infer central q-profile for PCS 14

- Study the comings and goings of the various modes as a function of time and machine settings. Can unambiguously ID the q values associated with each

  - At the time the wall began moving on PCS 14, we infer that central q-profile had just become monotonic and central value was very near q(0) = 3/2



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