Multi-machine analysis of non-axisymmetric and rotating halo currents

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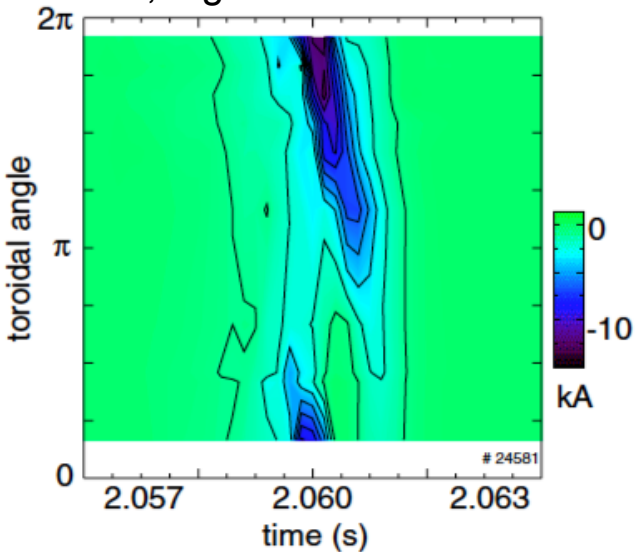
Presentation Outline

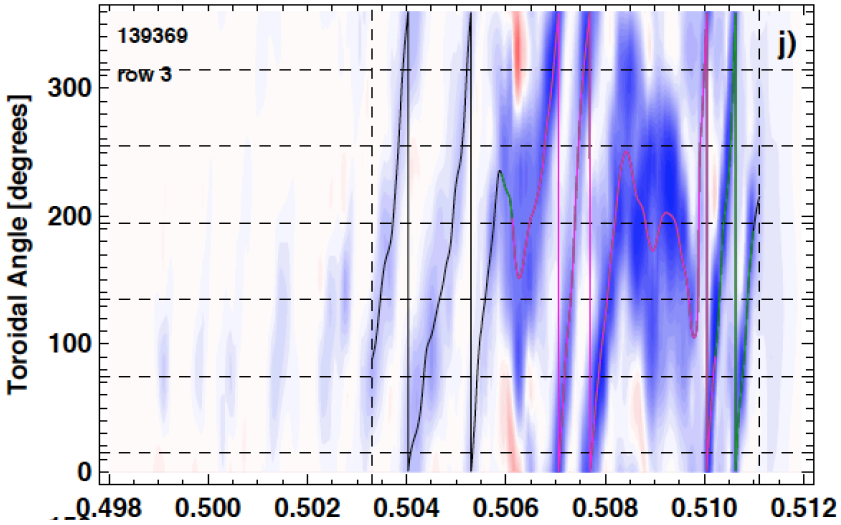
- Goal: Study halo current non-axisymmetry and rotation across many machines → use a common analytical framework
- Working to build a halo current database filled with "data units" from various machines (NSTX, DIII-D, AUG, C-Mod, etc.)
- Progress report:
  - Status of the ITPA halo current database
  - Analysis framework and representative examples
  - Preliminary statistical analysis
  - Future plans

Asymmetry and rotation observed in many machines

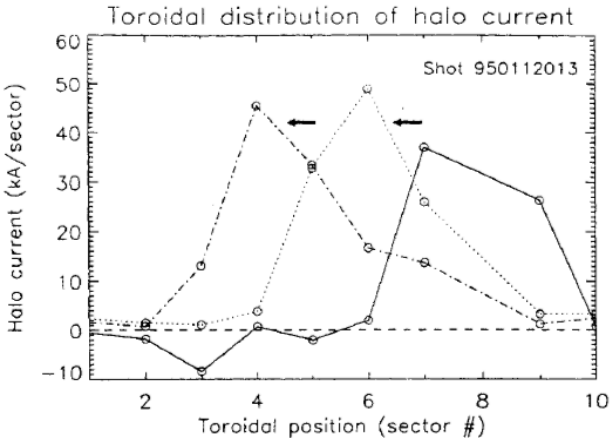
- Halo currents often exhibit non-axisymmetric structure → *n*=0 with an *n*=1 "lobe"
- Full or partial rotation of the *n*=1 lobe observed in NSTX, AUG, and C-Mod
- How do non-axisymmetry and rotation vary with machine, discharge parameters?
- What common physics drives the observed non-axisymmetry and rotation?

G. Pautasso, *Nucl. Fusion*, 2011, Fig. 15





S.P. Gerhardt, *Nucl. Fusion*, 2013

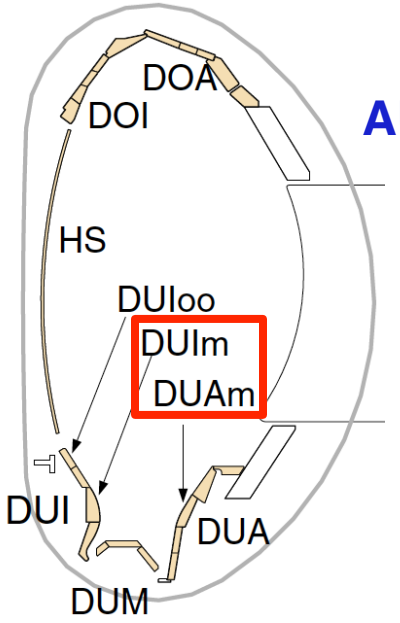


R. S. Granetz, *Nucl. Fusion*, 1996, Fig. 10

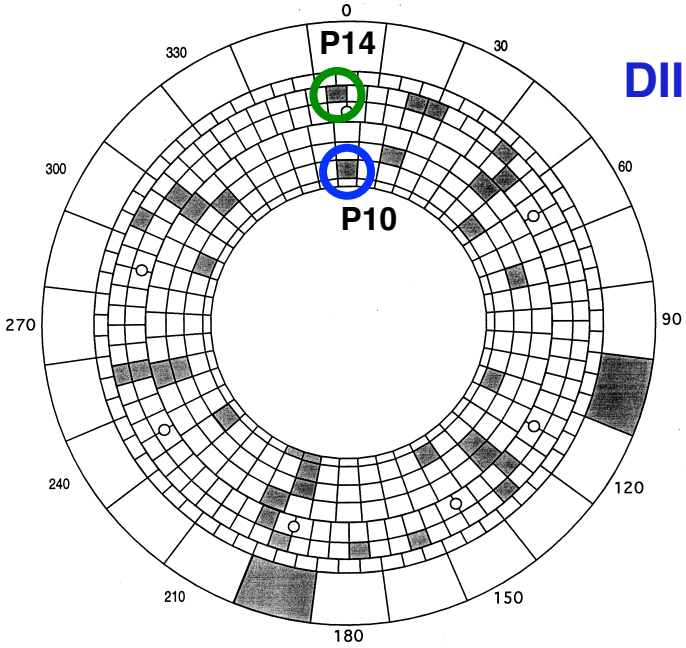
Status of the ITPA halo current database

- One “data unit” per shot (or per toroidal array per shot):
  - Equilibrium data (I_P, B_T, κ, Z_P, W_{MHD}, MGI, …)
  - Halo current data as a function of toroidal angle
  - At least four toroidal locations per sensor array
- Present contents of the database:
  - Recent NSTX shunt tile data: ~150+ shots × 2 poloidal locations
  - Recent AUG shunt tile data: ~4 shots × 2 poloidal locations
  - DIII-D TAC shunt tile data: ~60 shots × 5 poloidal locations
  - C-Mod partial rogowski data: ~1300 shots × 1 poloidal location
- Now carry out the analysis outlined in the ITPA WG specification

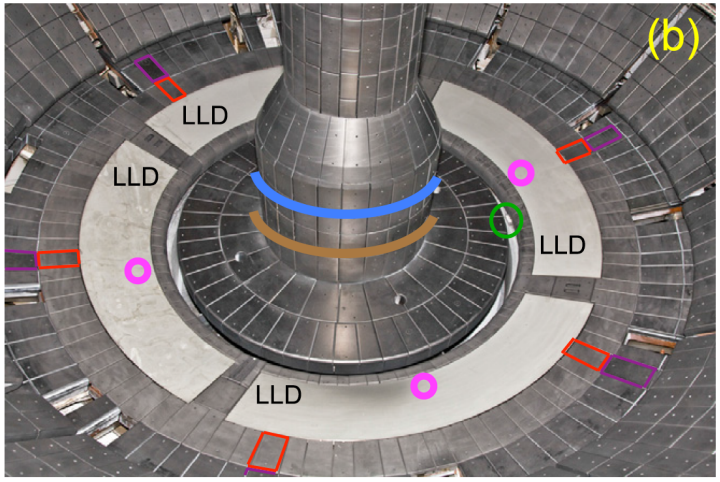
Various halo current sensor arrays



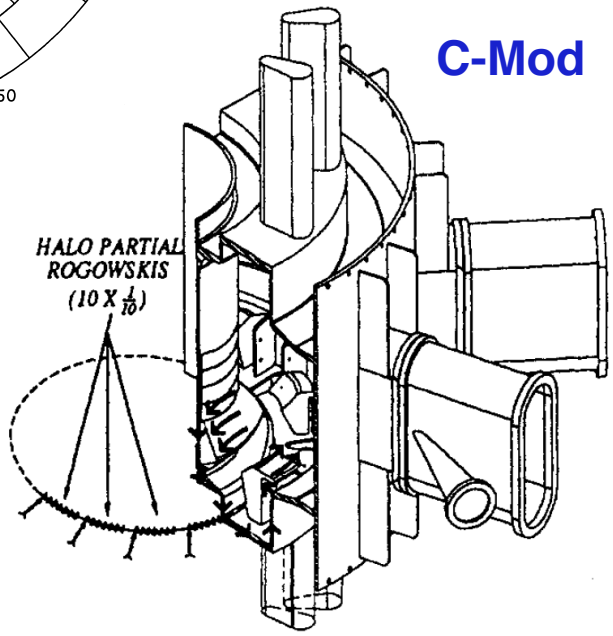
AUG



DIII-D

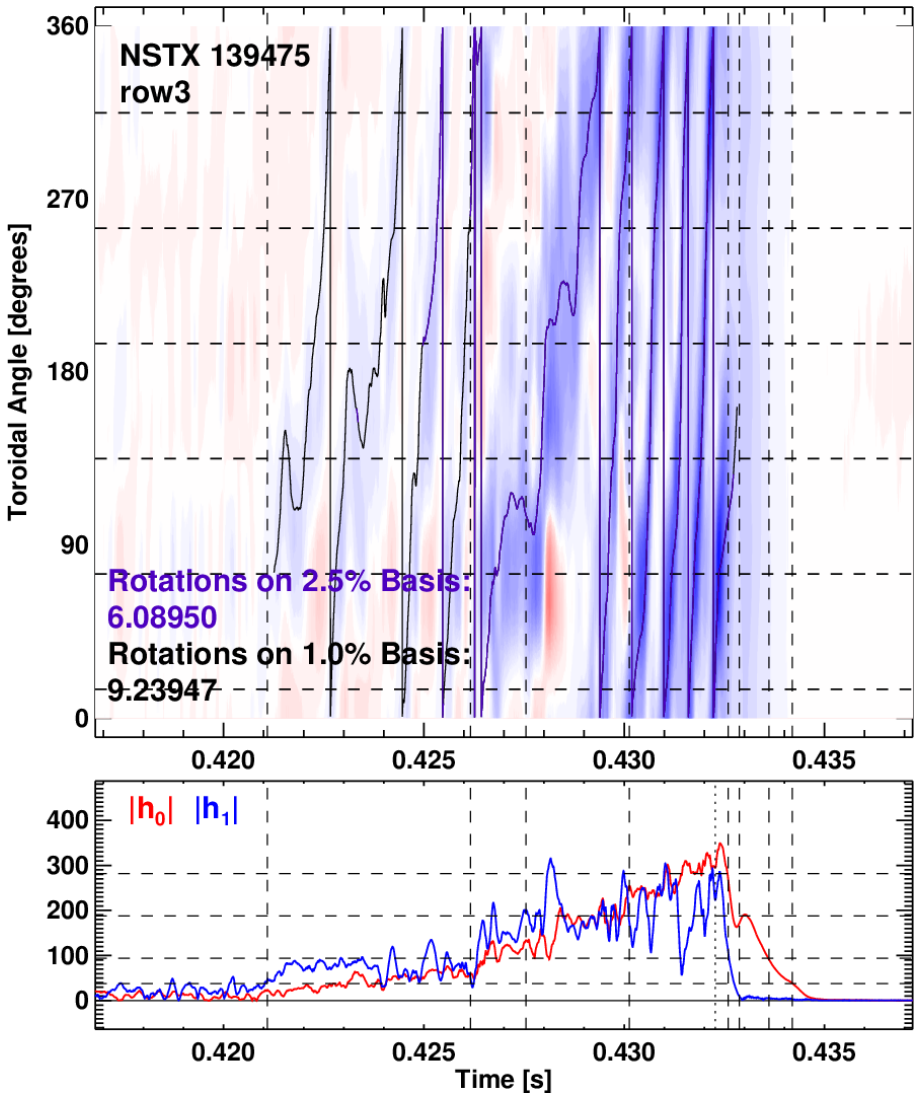


NSTX



C-Mod

Representative halo current analysis (NSTX)



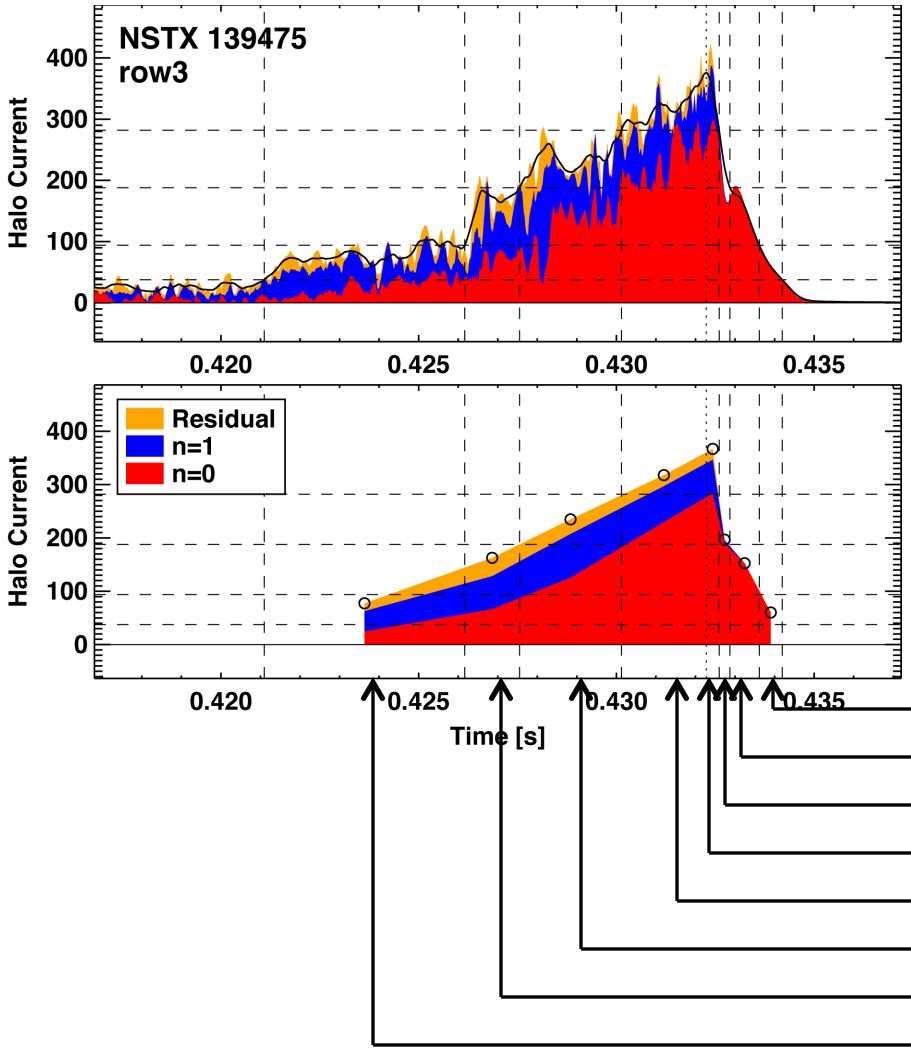
- Fit n=0,1 profile to each toroidal array at each time point:

$$I_h(\phi) = h_0 + h_1 \sin(\phi - h_2)$$

- Amplitude of each component tracked by h_0, h_1
- The n=1 phase is tracked by h_2

- Total rotation calculated by integrating h_2 in time
- Rotation is only "counted" when the n=1 contribution is at least 1% (or 2.5%) of the peak RMS halo current value

Representative halo current analysis (NSTX)



$$\mathrm{RMS}\{I_h\}^2 = \frac{1}{N_\phi}\sum_i I_h^2(\phi_i)$$

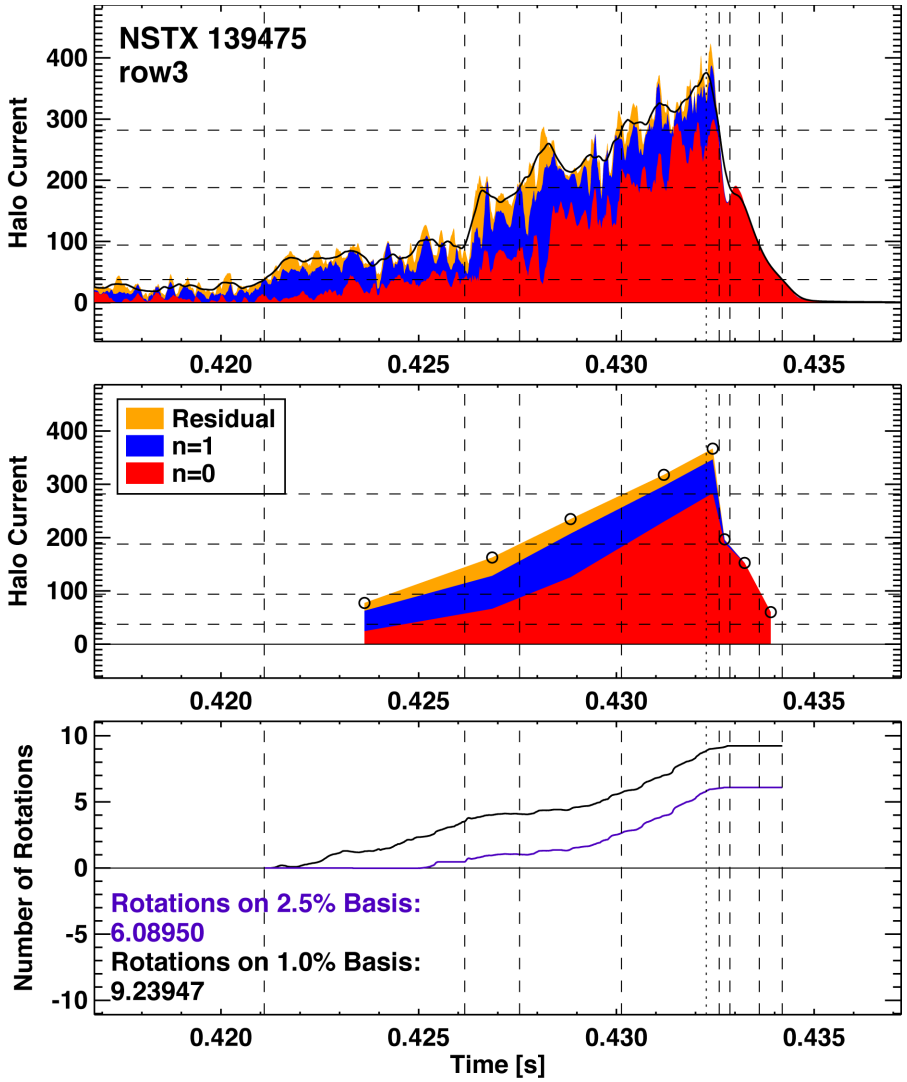
$$= h_0^2 + \frac{1}{2}h_1^2 + \mathrm{Residual}$$

$$n=1 \text{ fraction} \equiv \frac{h_1^2/2}{\mathrm{RMS}\{I_h\}^2}$$

- Interval 8: 25–10%
- Interval 7: 50–25%
- Interval 6: 75–50%
- Interval 5: 100–75%
- Interval 4: 75–100%
- Interval 3: 50–75%
- Interval 2: 25–50%
- Interval 1: 10–25%

$$\frac{\mathrm{RMS}\{I_h\}}{\max\{\mathrm{RMS}\{I_h\}\}}$$

Representative halo current analysis (NSTX)



$$\mathrm{RMS}\{I_h\}^2 = \frac{1}{N_\phi}\sum_i I_h^2(\phi_i)$$

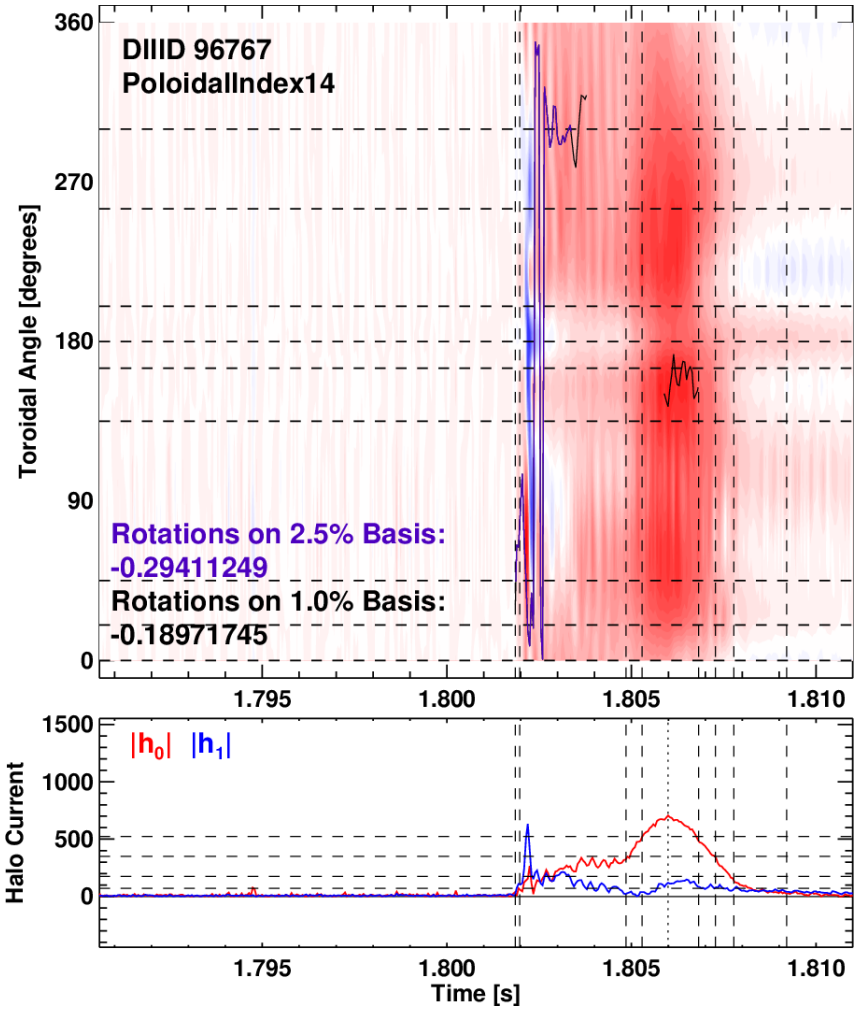
$$= h_0^2 + \frac{1}{2}h_1^2 + \mathrm{Residual}$$

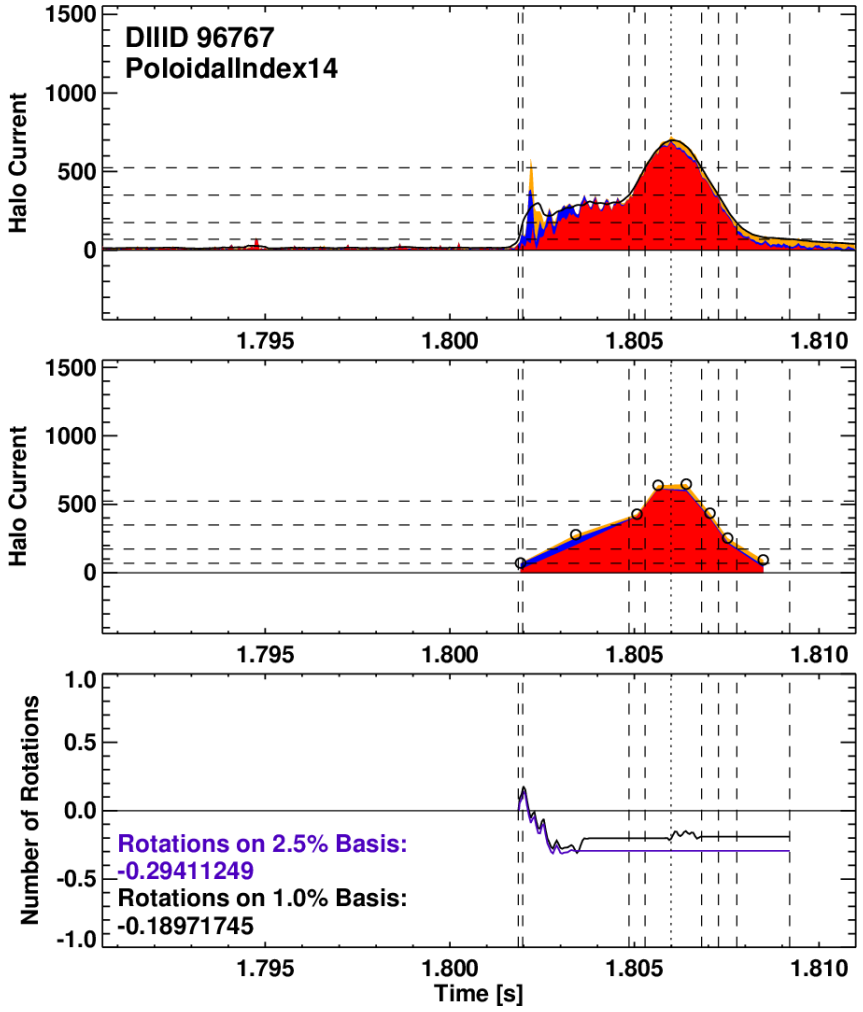
$$n=1 \text{ fraction} \equiv \frac{h_1^2/2}{\mathrm{RMS}\{I_h\}^2}$$

Rotation counted when:

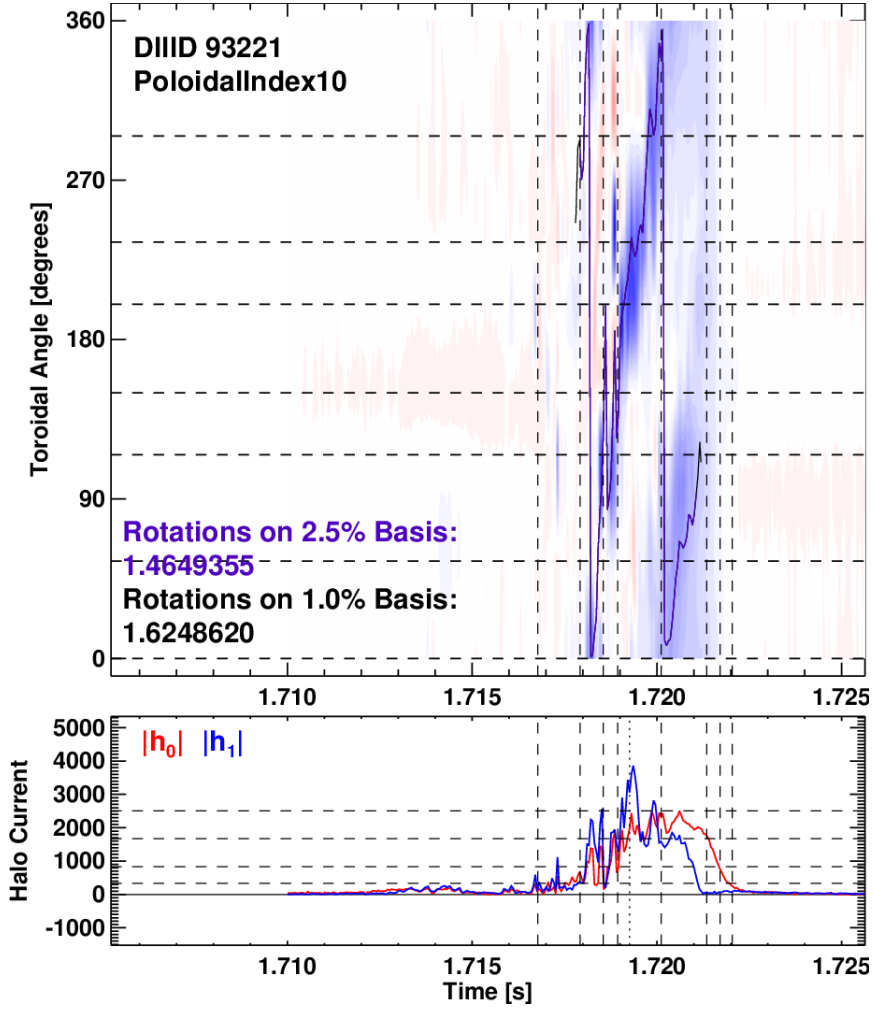
$$\frac{h_1^2/2}{\max\left\{\mathrm{RMS}\{I_h\}^2\right\}} > \text{Basis \%}$$

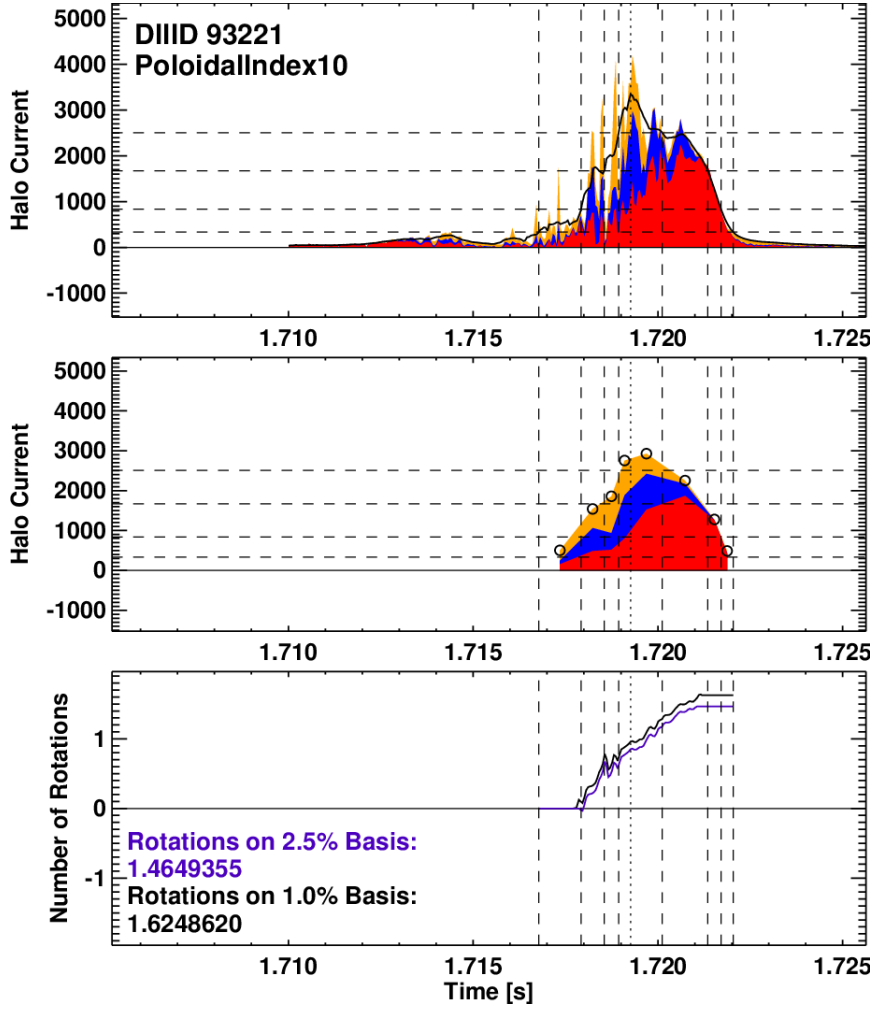
Representative DIII-D Example (I)



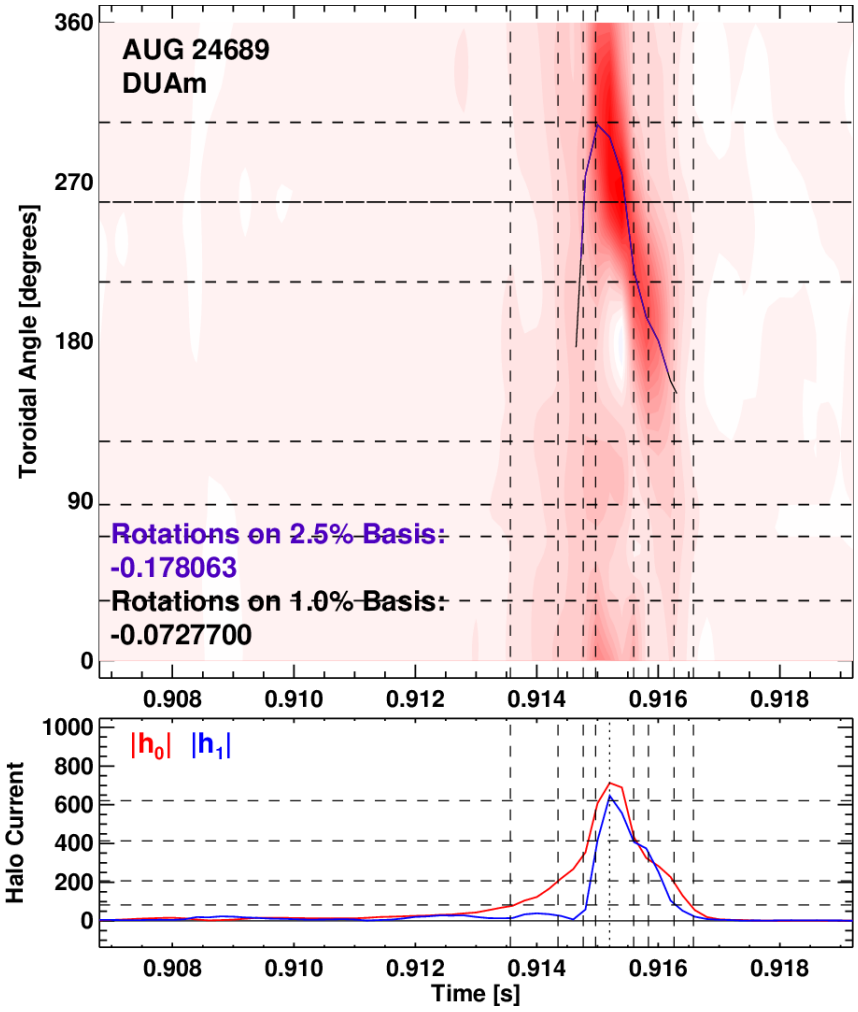


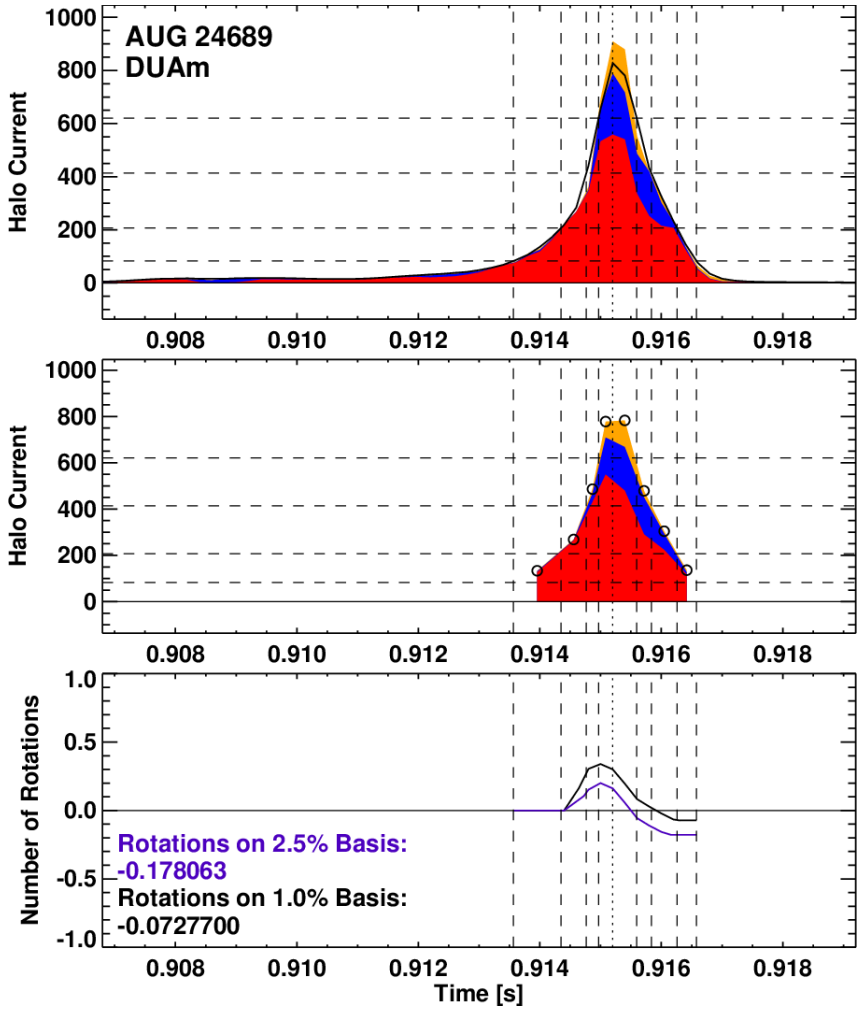
Representative DIII-D Example (II)



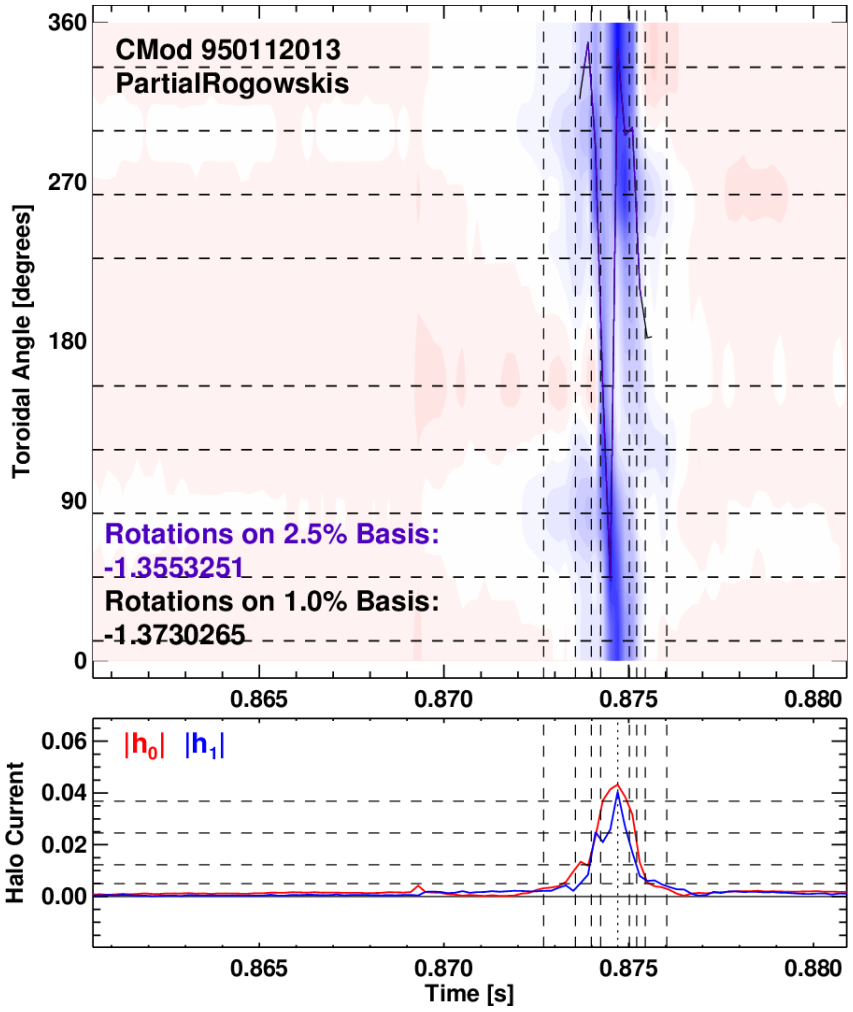


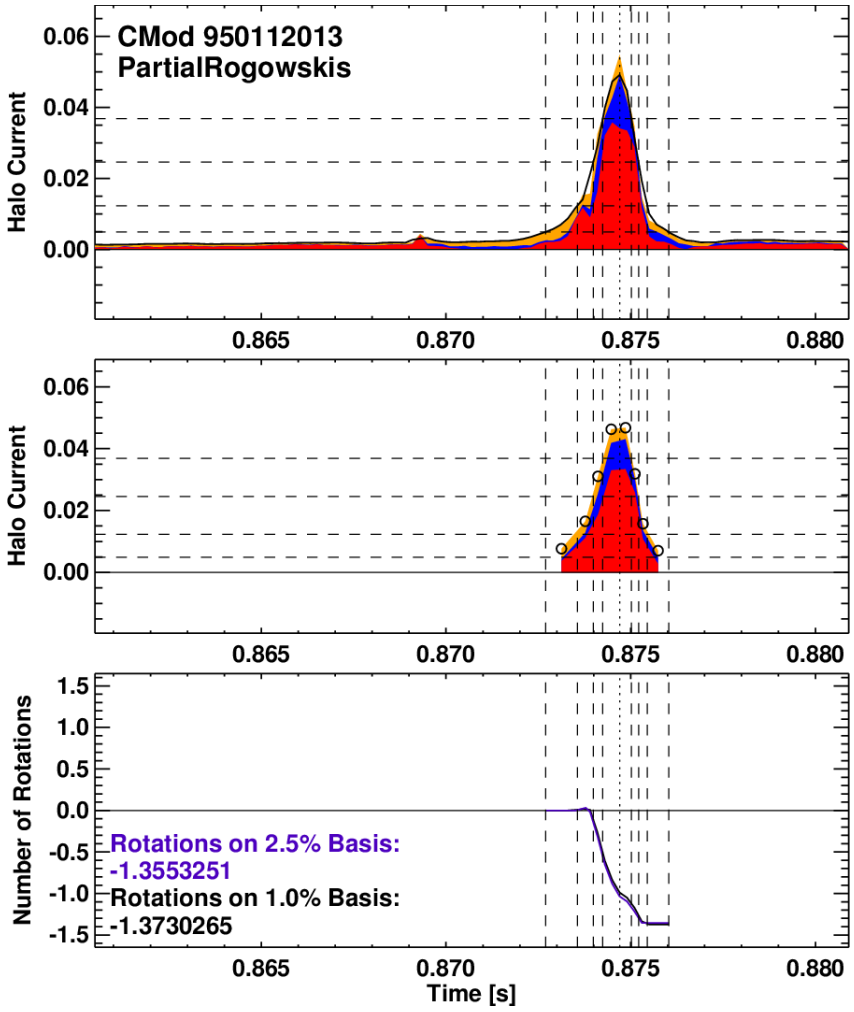
Representative AUG Example



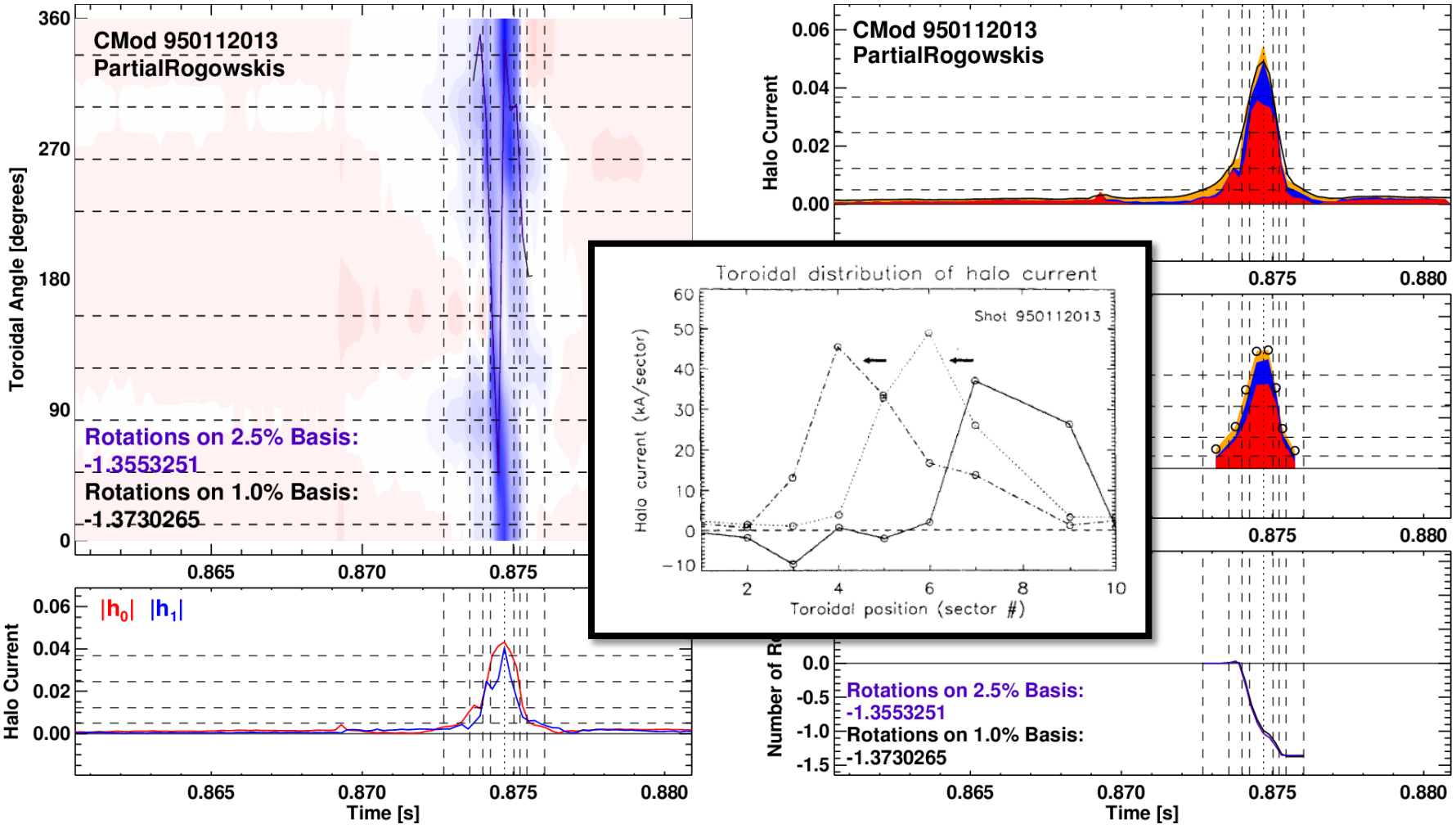


C-Mod Example (first for this WG)





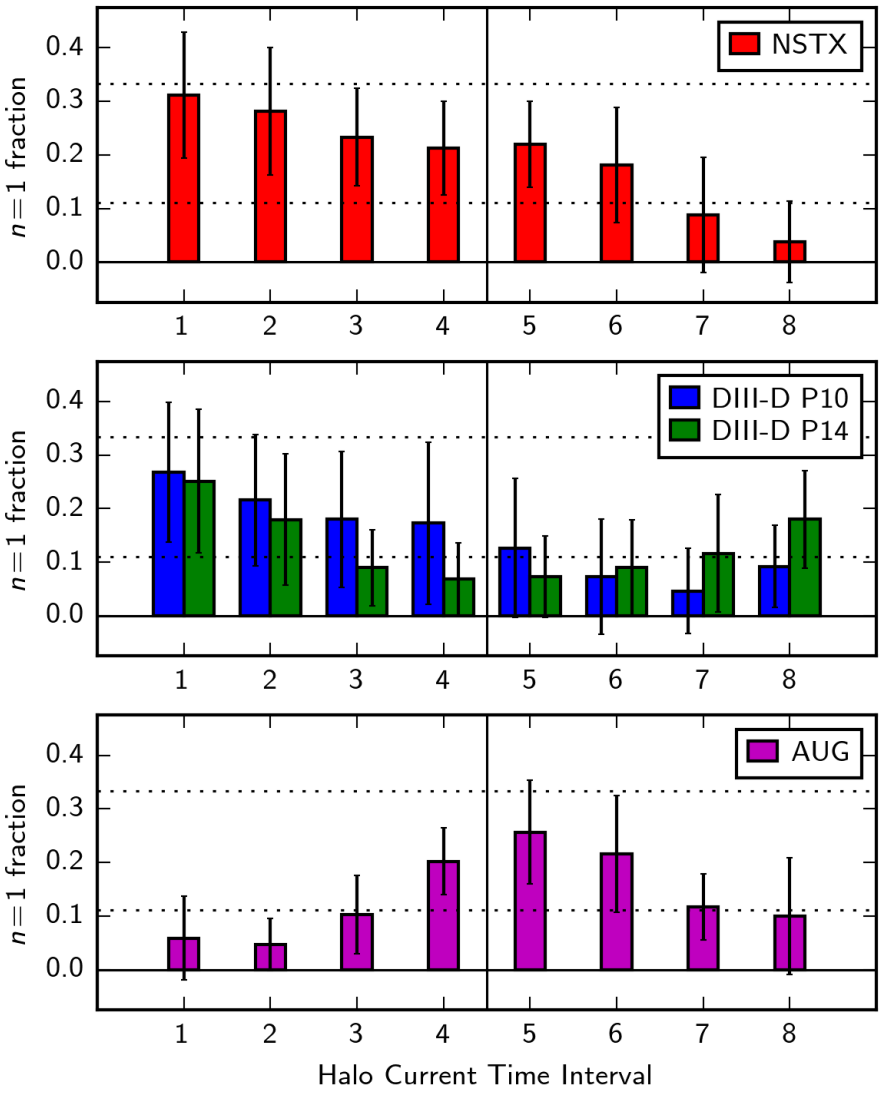
C-Mod Example (first for this WG)



Non-axisymmetry (n=1) vs. time interval

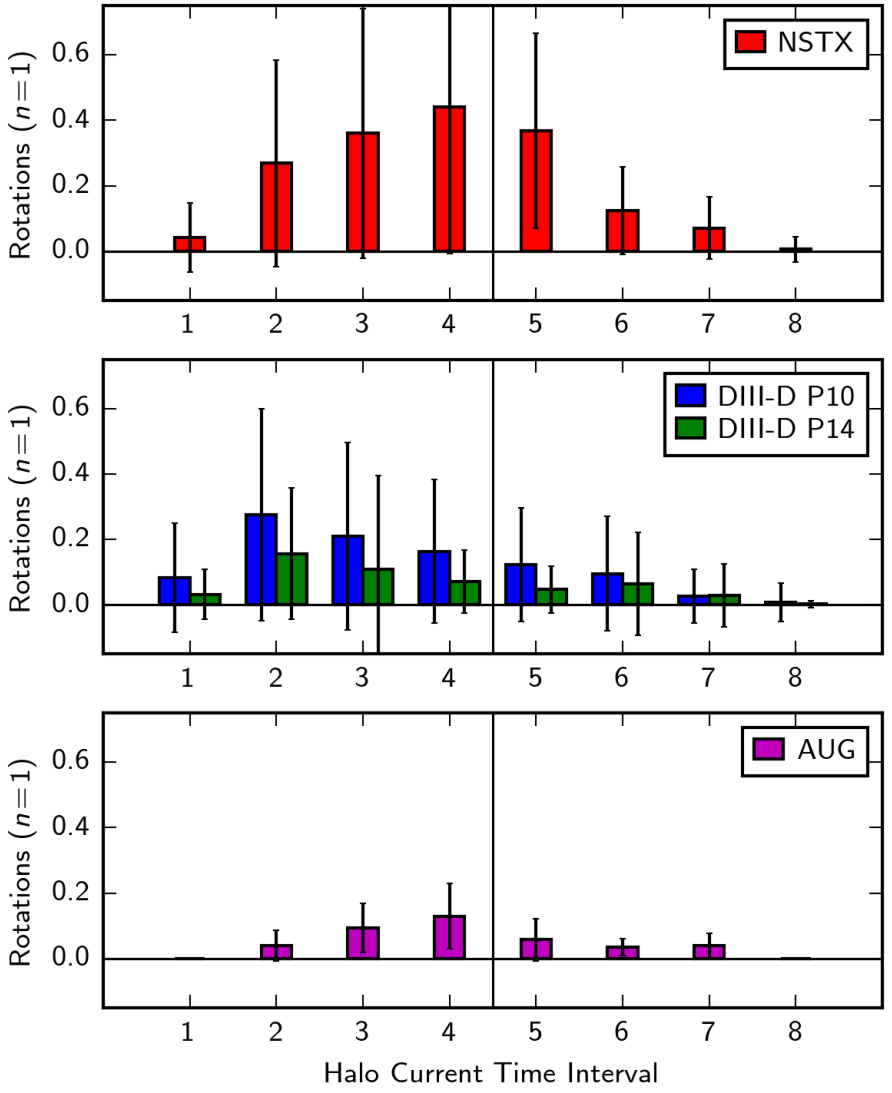
$$n=1 \text{ fraction} \equiv \frac{h_1^2/2}{\text{RMS}\{I_h\}^2}$$

- NSTX non-axisymmetric from the start, symmetrizes *after* the peak of the pulse
- DIII-D has high axisymmetry *during* the peak of the pulse
- DIII-D axisymmetry depends on the poloidal location!
- AUG is *least* symmetric at the peak of the pulse

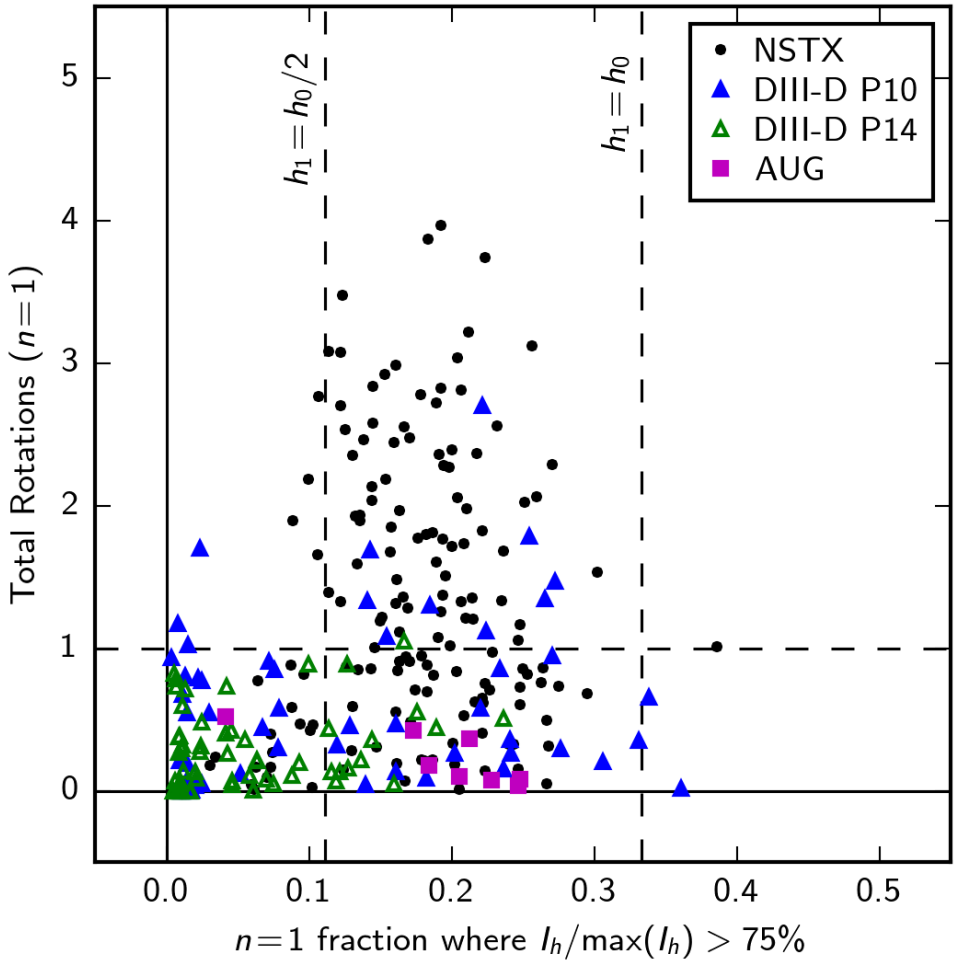


Rotation (*n*=1) vs. time interval

- NSTX has highest rotation in this database
- NSTX rotation peaks near halo current maximum
- DIII-D rotates more before the maximum than after
- DIII-D has very little rotation outboard (P14) but more rotation inboard (P10)
- AUG has low rotation, but the temporal profile is similar to NSTX



Combined non-axisymmetry and rotation



- Summarize the previous two bar graphs in one scatter plot
- Average the *n*=1 fraction over intervals 4 and 5 (peak)
- Largely reflects the findings of the two previous bar graphs
- Note the strong inboard/outboard asymmetry in the two DIII-D poloidal arrays (P10/P14)

Future plans

- Analysis w.r.t. the equilibrium data:
  - Equilibrium data (I_P, B_T, κ, Z_P, W_{MHD}, MGI, …)
  - Current quench times, edge safety factor, vertical position, etc.
- Fold in the new contributions:
  - Statistical analysis of the C-Mod data
  - More shots from AUG → coming soon
  - Contributions from JET?
- Continue to work toward satisfying the ITPA WG specification doc:
  - "Windowed cosine power fits" rather than just simple n=0/n=1
  - Analyze locked vs. rotating cases independently
  - Comparison with proposed scaling laws