# Locked Modes and Error Fields in NSTX

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MHD Experimental Task Group

NSTX Results Review

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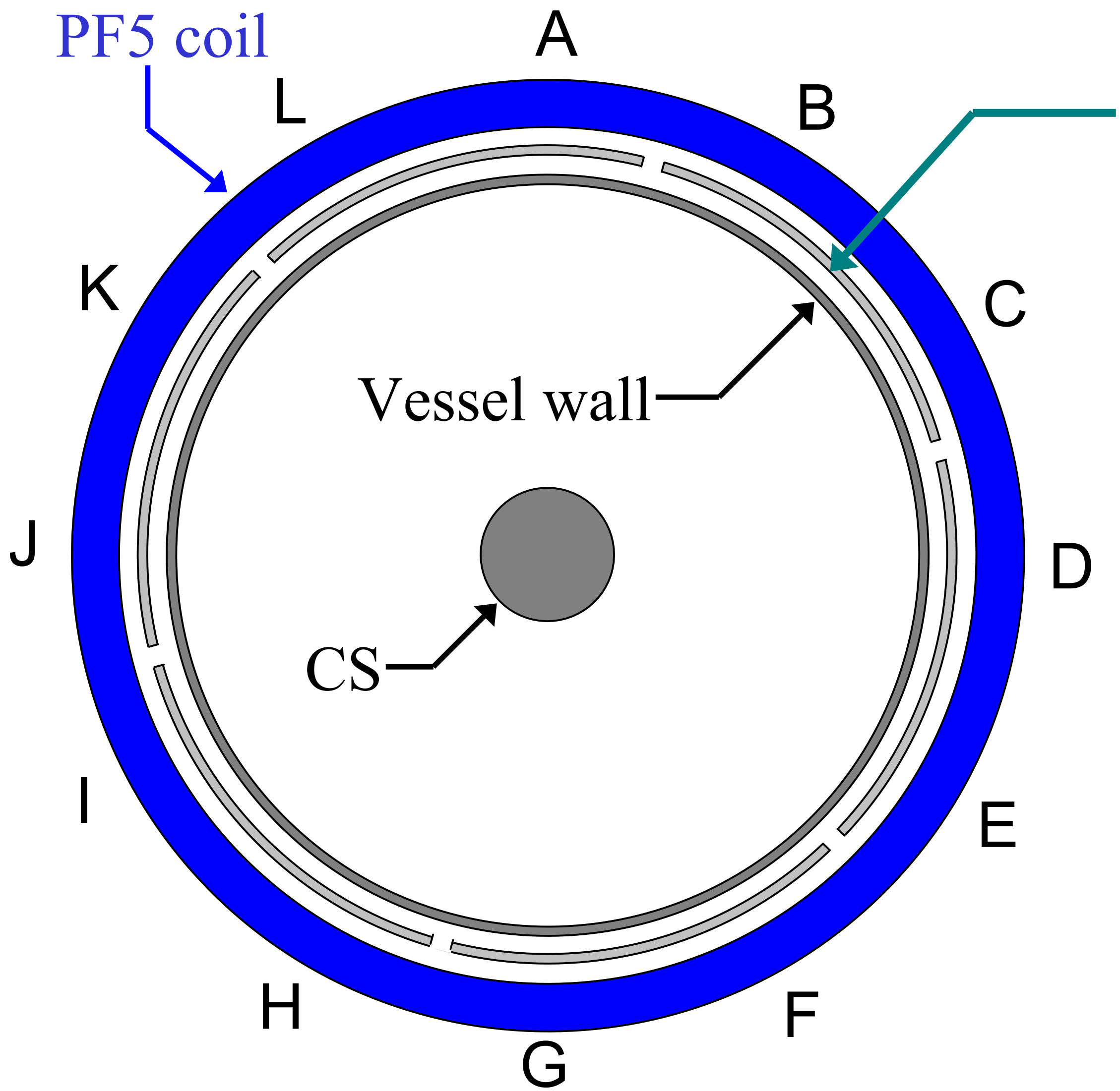
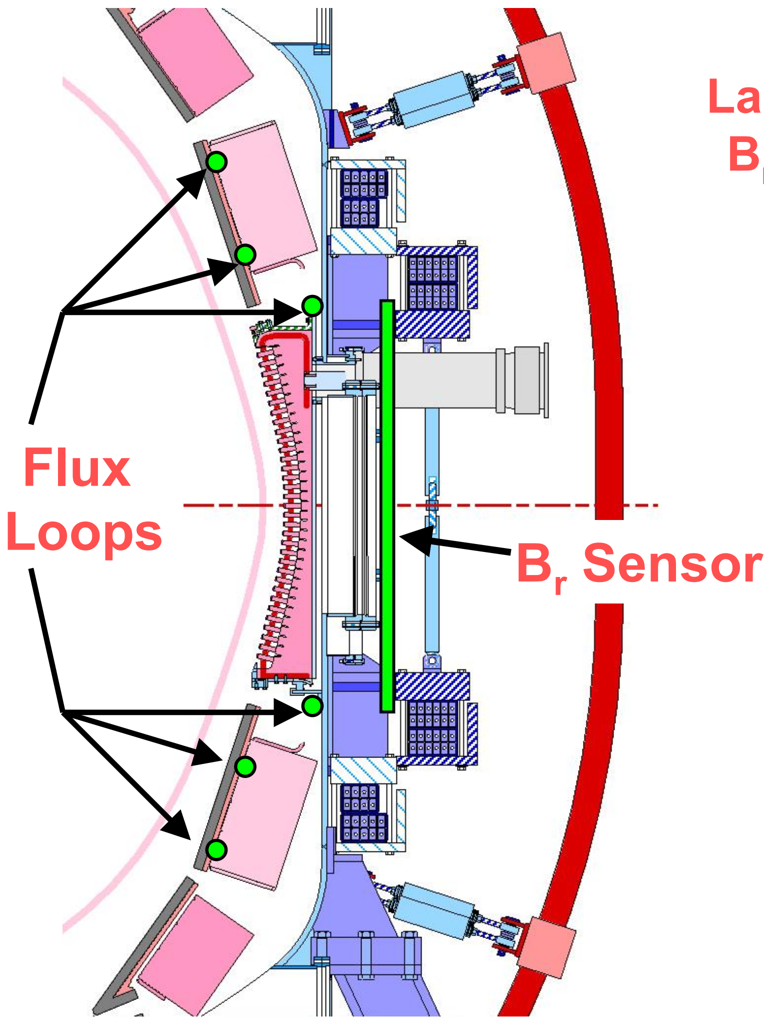
NSTX

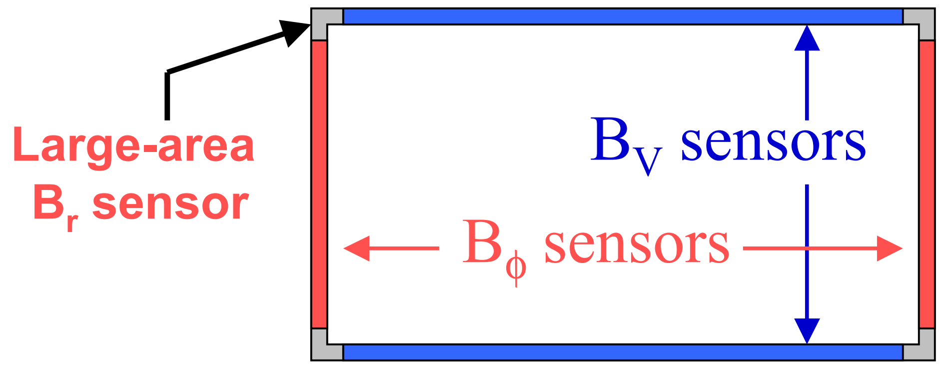
# Measurement of low-frequency n=1 modes




- **6 large $B_r$ sensors**
- Opposing sensors are differenced in analog, then integrated
  - MDS+ tree archives uncompensated $\delta B_r$
    - J/K-D/E, A/L-F/G, B/C-H/I
  - Remaining calibration done in software (IDL)
- $B_r$ sensors are mounted on PF5 coils
  - PF5 generates large apparent $\delta B_r$ caused by:
    - Sensor misalignment
    - PF5 non-circularity

# Nulling vacuum $B_r$ requires several additional sensors




- Each $B_r$ sensor has 2 $B_v$ and $B_\phi$ sensors for misalignment correction
  - Signals summed for spatial averaging
- Flux loops
  - Wall loops used for $B_r$ gain correction
  - Flux loop voltages used as source terms for modeling circulating eddy currents in passive plates and wall
- Flux loops essential to modeling vacuum response

($B_R$ sensors designed by E. Fredrickson)

# Calibration steps for locked mode sensors

## (for deducing plasma-induced $\delta B_r$)

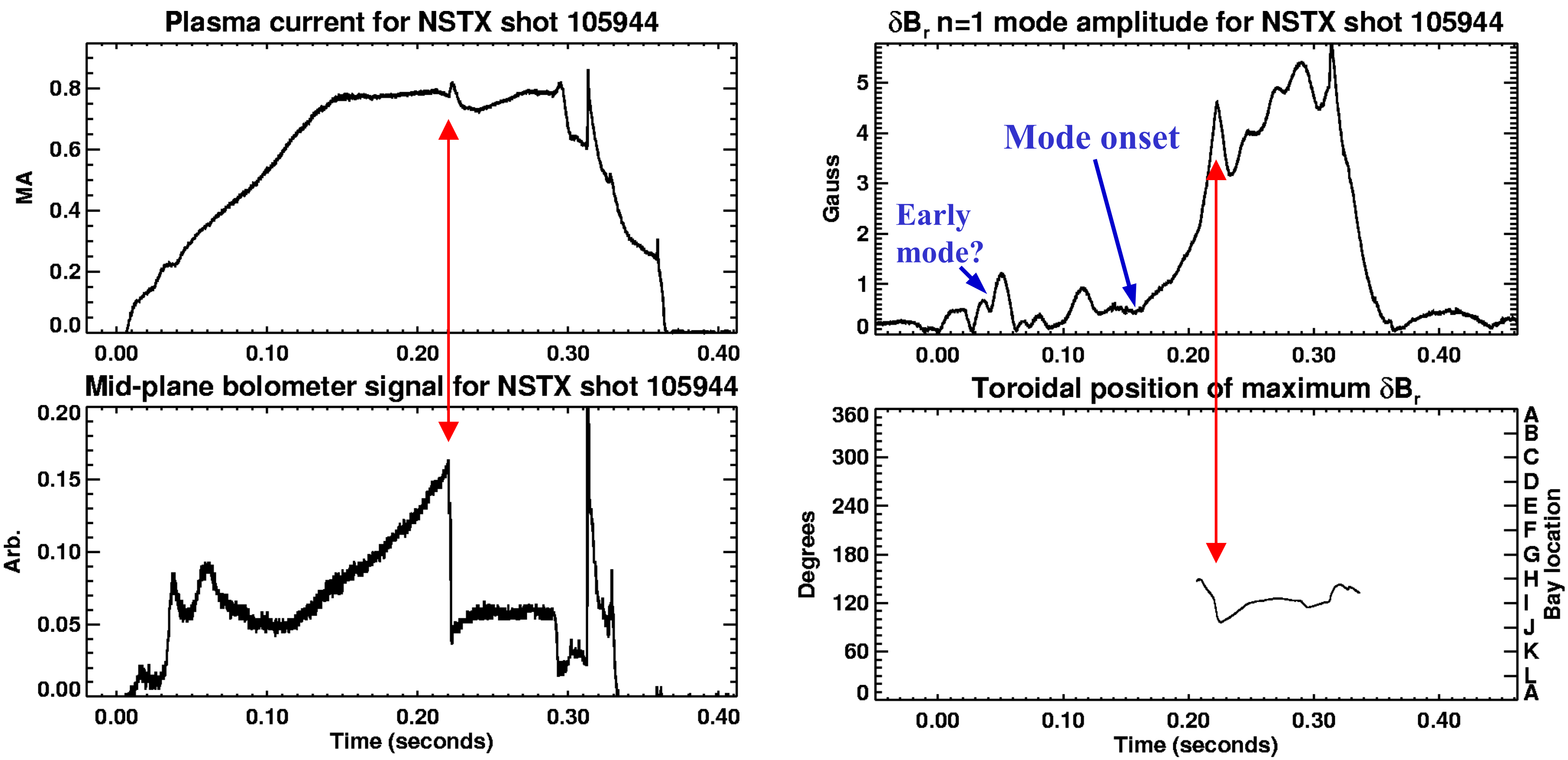
1. Calibrate VF and TF compensation sensors using PF3U/L, and TF
2. Correct for sensor misalignment with respect to TF
3. Correct for sensor misalignment with respect to VF from PF3U/L
4. Correct for sensor gain differences using $B_r$ from wall flux loops
5. Subtract remaining static $\delta B_r$ using coil currents
6. Subtract PF-induced $\delta B_r$ using low-pass filtered loop voltages

   ***Plate and wall 3D circulating eddy-currents $\Rightarrow$ 2-6 Gauss error fields***
7. Subtract TF-induced $\delta B_r$ using low-pass filtered $dB_T/dt$ at sensors
8. Subtract any remaining TF pickup due to alignment changes
9. Subtract non-linear filtered $I_{OH}$ x $I_{TF}$ term, sometimes unipolar

   ***Indicative of TF coil movement due to torque near CS, up to 6 Gauss error***
10. Remove PF5 supply switching noise with band-pass filter

# Ohmic shots: often early and prolonged locking

- “Reconnection event” collapse occurs near t=220ms
- Mode growth starts near t=160ms
- Mode persists for 100ms after collapse event

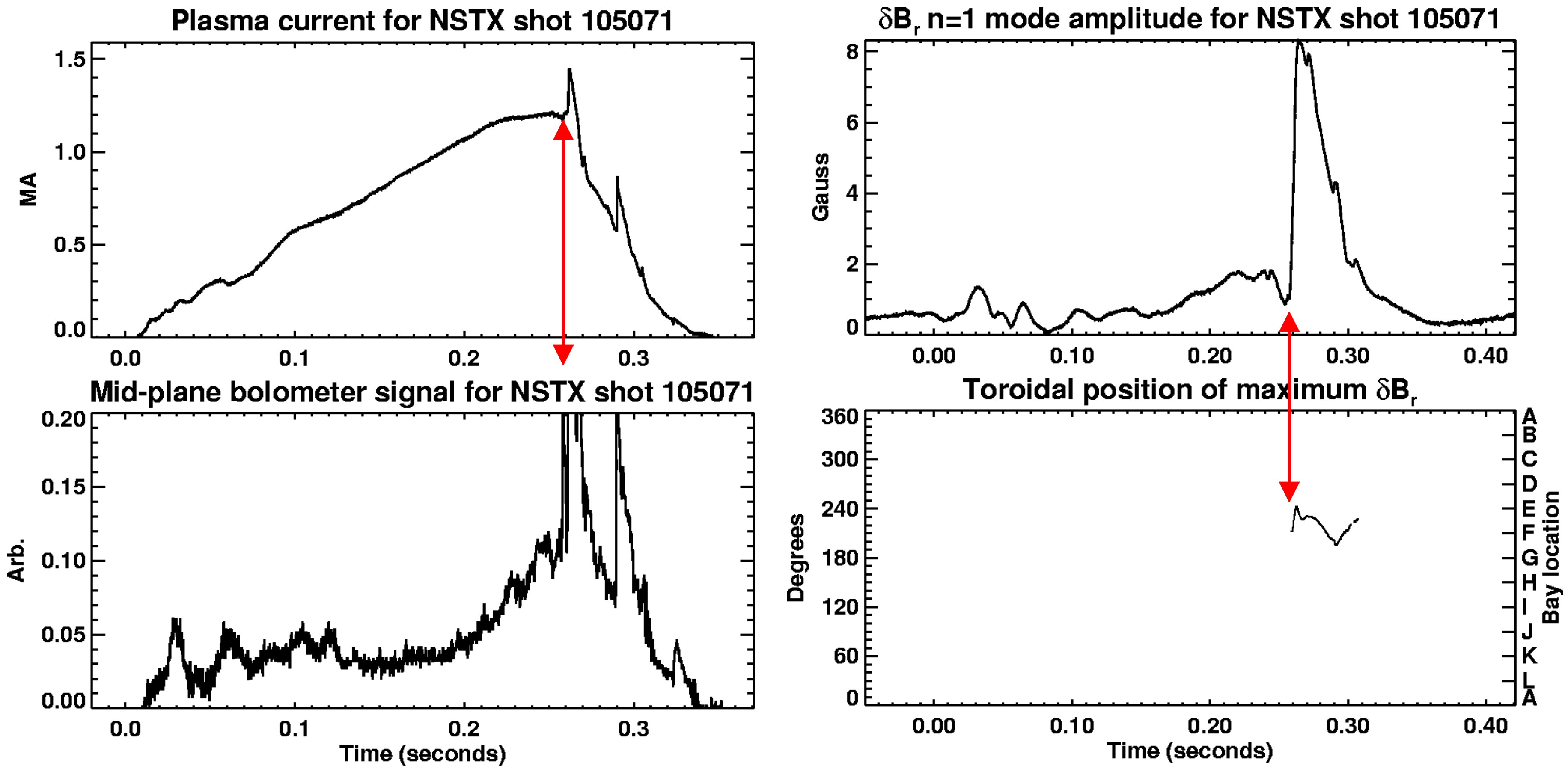


# Most NBI heated shots quiescent until internal modes are driven unstable

$I_P$=1.2MA

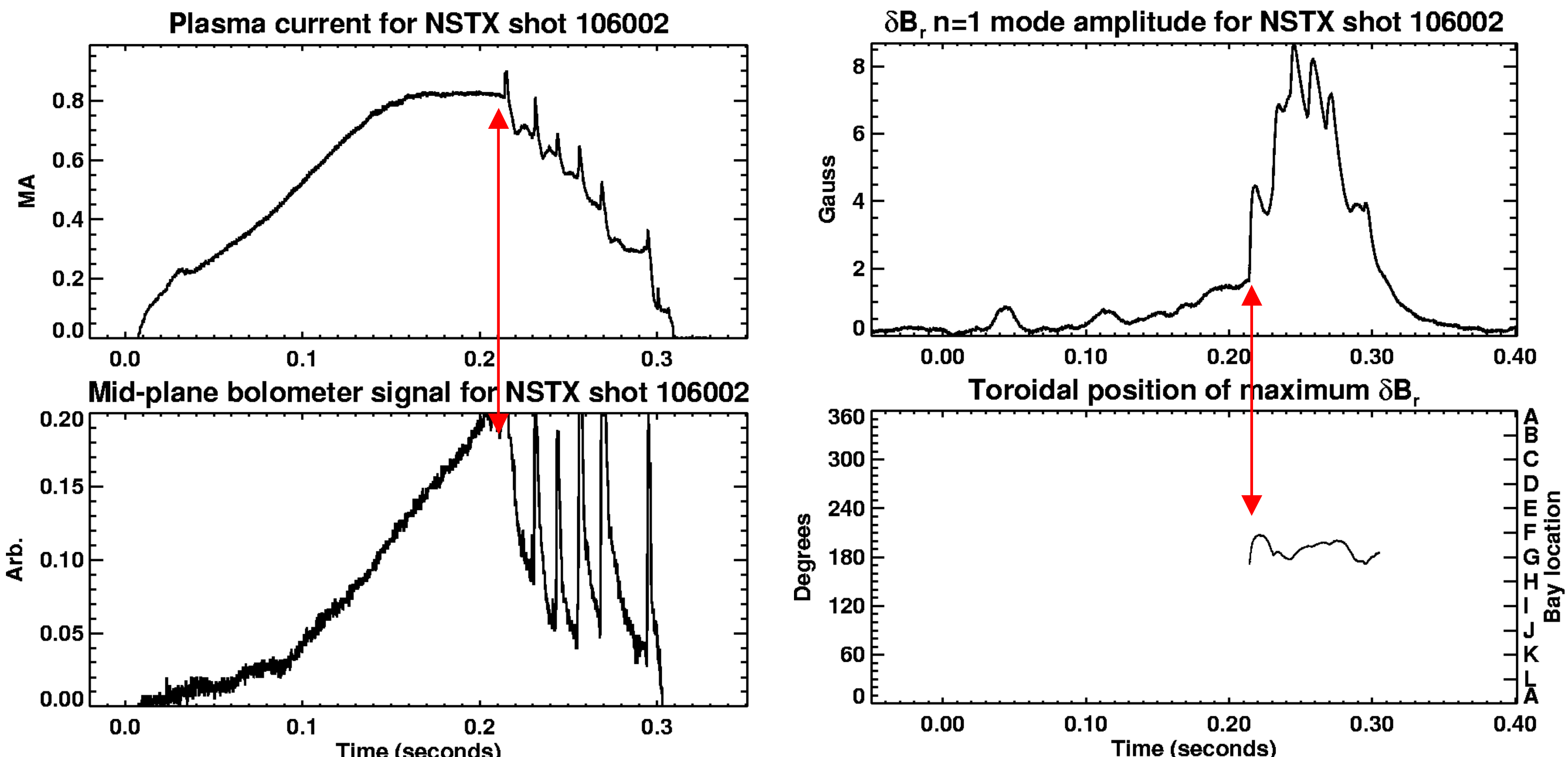
$\beta_t = 17\%,\ \beta_N = 3$

- No obvious early mode onset time
- n=1 mode locks near Bays E-G

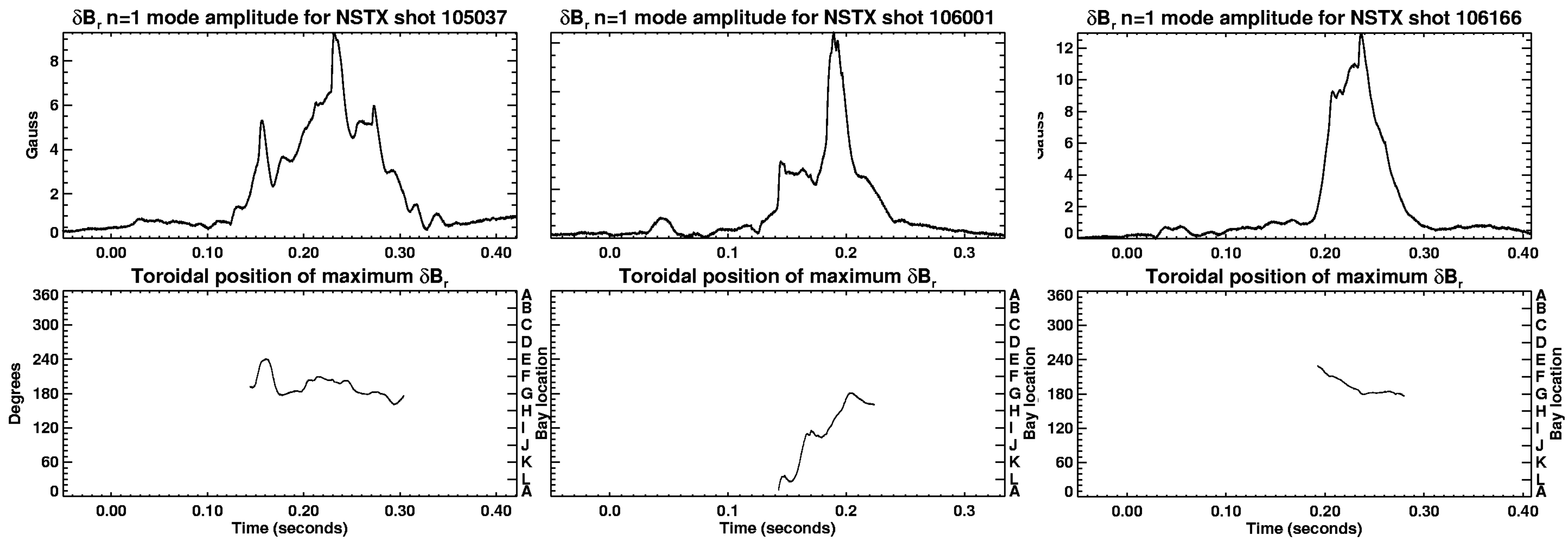


# Multiple IRE's exhibit successive locking

- Again, no obvious early onset time
- Each IRE-driven mode locks near Bay G

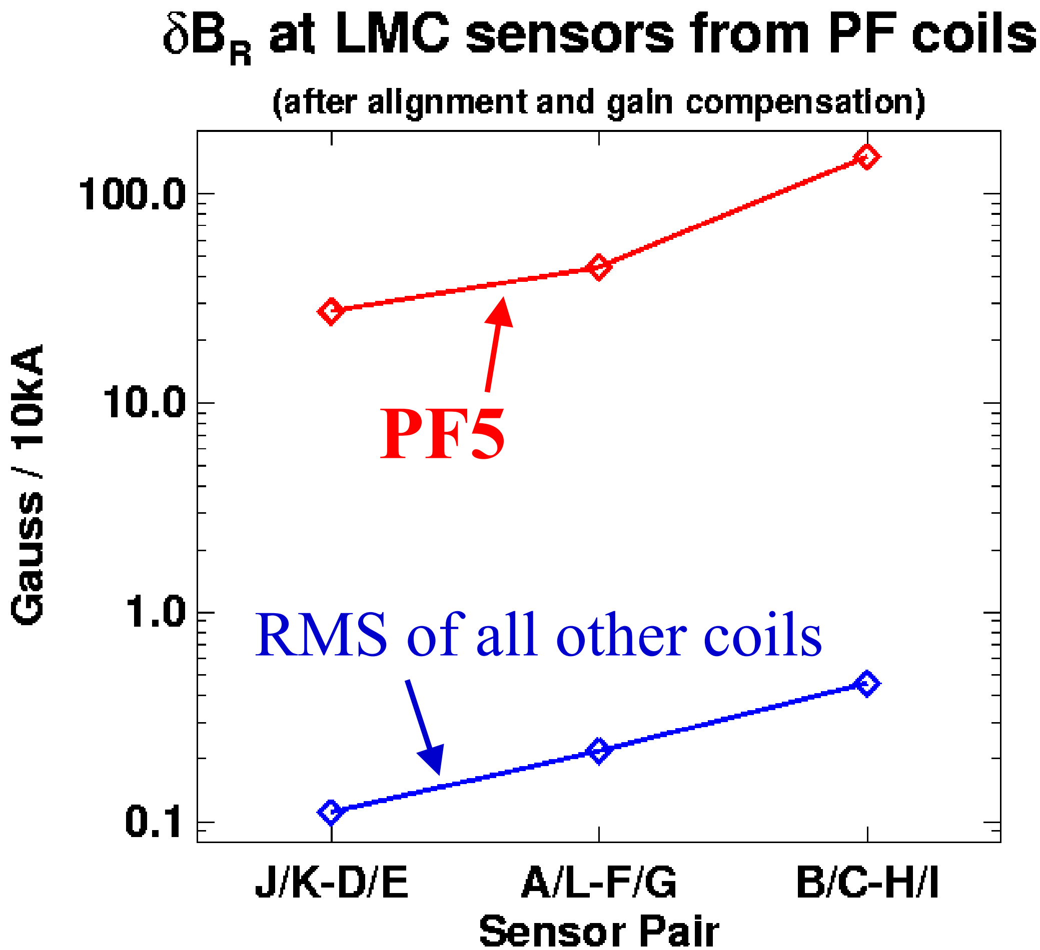


# Rotation dynamics of modes (a few examples)



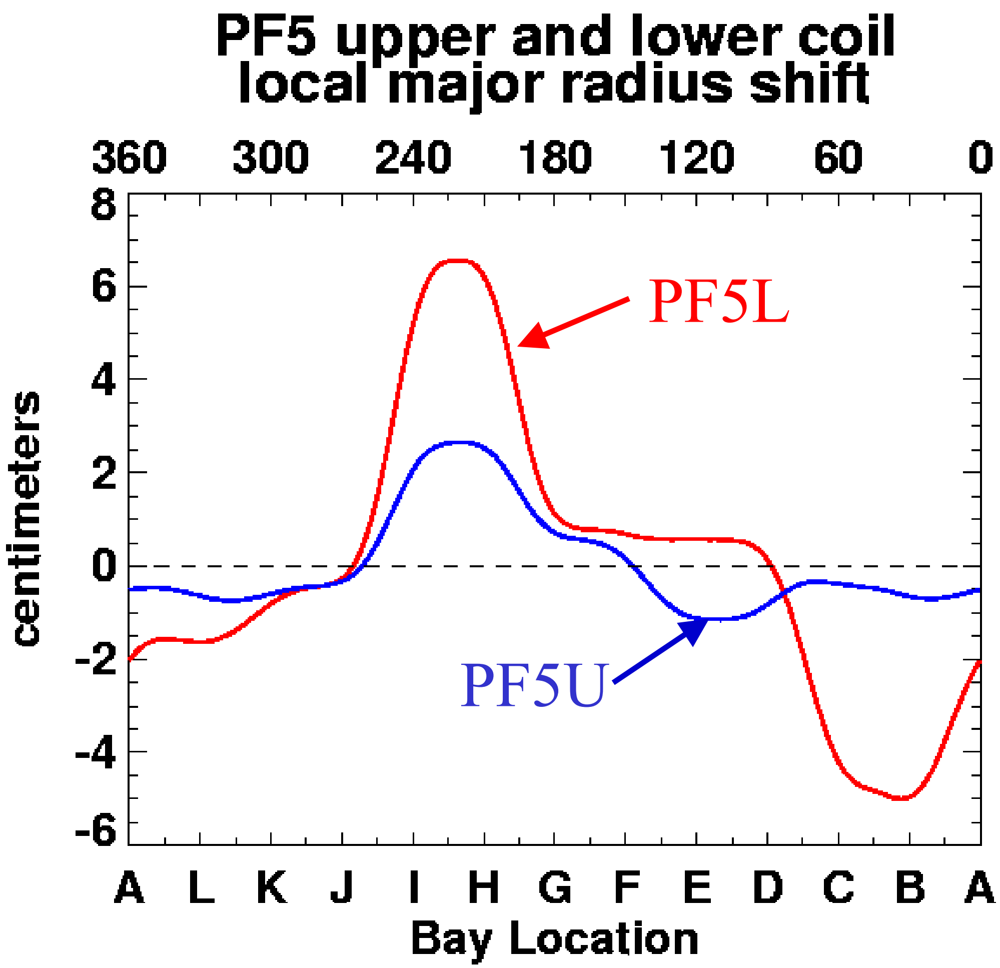

- Ohmic shot
  - Position jittery, but essentially static
  - **Long mode duration of 150 ms**
- NBI Shot (Kink-XP)
  - **Co-rotation**
  - ½ revolution
  - **10 cm outboard gap**
- NBI Shot (RWM-XP)
  - **Weak counter rotation**
  - **2 cm outboard gap**

# PF5 dominates $\delta B_r$ pickup after compensation

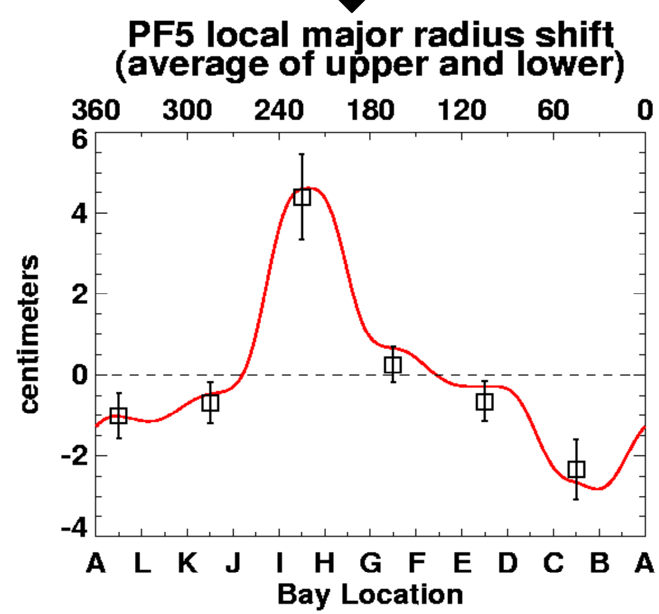



- ***Align with PF3U/L*** $\Rightarrow$ pickup from all other non-PF5 coils is small
- PF5 pickup is 2 orders of magnitude larger
  - Sensors in near-field
  - Coils are not circular
  - $\delta B_r$ = 30-150 Gauss measured at sensor

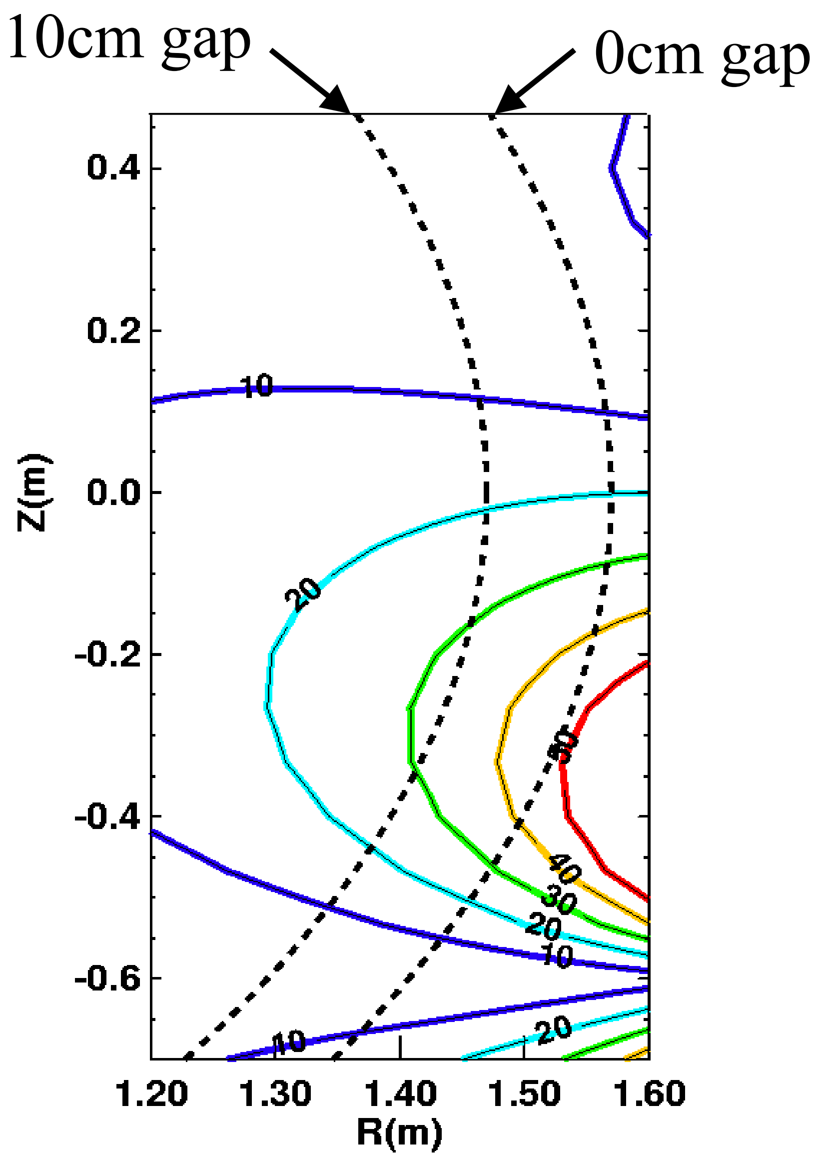
# PF5-U/L coil shape inferred from $\delta B_r$ and $B_V$




- PF5L error field dominates
  - Coil is effectively shifted
  - Also somewhat elliptical
  - Introduces n=1 and n=3
- Good agreement with PF5 vertical field at $B_V$ sensors

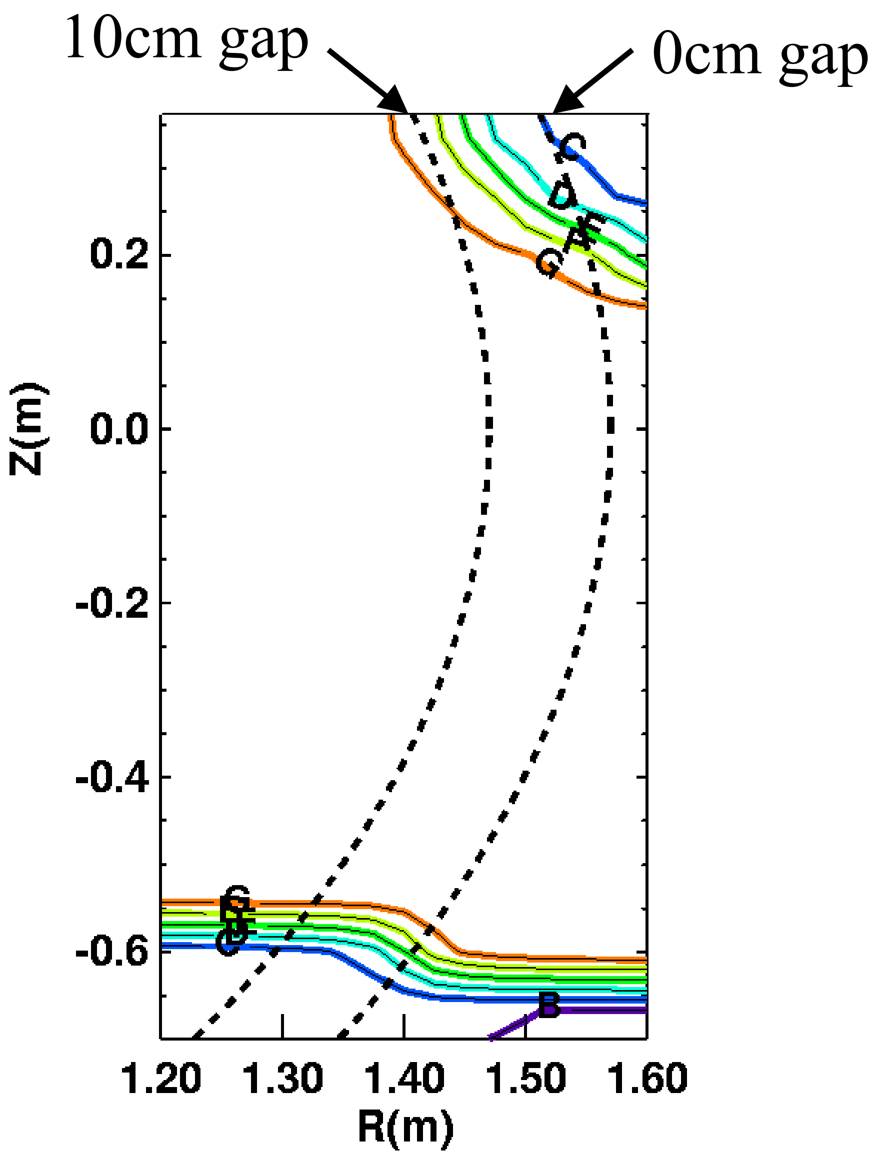


# n=1 error field contours from PF5 at 10kA




- Error field is localized to lower PF5 coil
- 30-50 Gauss n=1 error field for typical PF5 current and 0cm gap
- 20-30 Gauss peak error field for 10cm gap

# Expected locking position from PF5 error field




- Dominant expected locking position also localized to lower vessel
- Locking near Bays G or H predicted for modes near lower outboard mid-plane
- Nearly all modes should lock between C through H

# Summary

- Locked-mode detectors calibrated to ~ 1-2 Gauss level
  - Plasma n=1 mode amplitudes > 2 Gauss are obvious
  - Inferences about smaller mode amplitudes require some care
- High-current NSTX plasmas routinely show locking behavior
  - Many 400-600kA HHFW target shots are relatively quiet
- Infer from data that NBI-driven plasma rotation/shear likely suppresses locking activity (compare to HHFW, ohmic)
- Modes most often lock then decay near Bays G or H

  $\Rightarrow$ **Consistent with significant PF5 induced error field**
- Likely difficult to take advantage of wall stabilization without fixing PF5 coils and/or adding correction/feedback coils.
  - Shifting PF5L and forcing it to be more circular would be helpful