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R(17-3): Identification, mitigation, and correction of intrinsic error field sources

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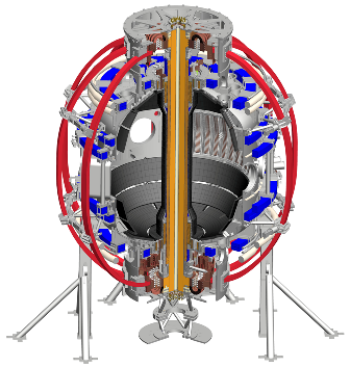
Research Milestone Status Meeting
March 31, 2017



Presentation outline

- Milestone and Recovery Project charges
- Key EFC experimental results from the FY16 NSTX-U campaign
  - Optimum flattop EFC in L-mode identified via compass scans
  - Optimum early-time EFC phase different from flattop phase
- Error field source metrology (PF5 and TF tilt)
- Vacuum error field and plasma response modeling
  - TF is the dominant error field source, even with plasma response
  - Phase of plasma-influenced TF error field is equilibrium dependent
- Future plans for the milestone (experiments, modeling)

Milestone and Recovery Project charges

- R(17-3) Milestone:

  Identify, mitigate, and develop correction strategies for intrinsic error field sources in NSTX-U

- Recovery Project charge:

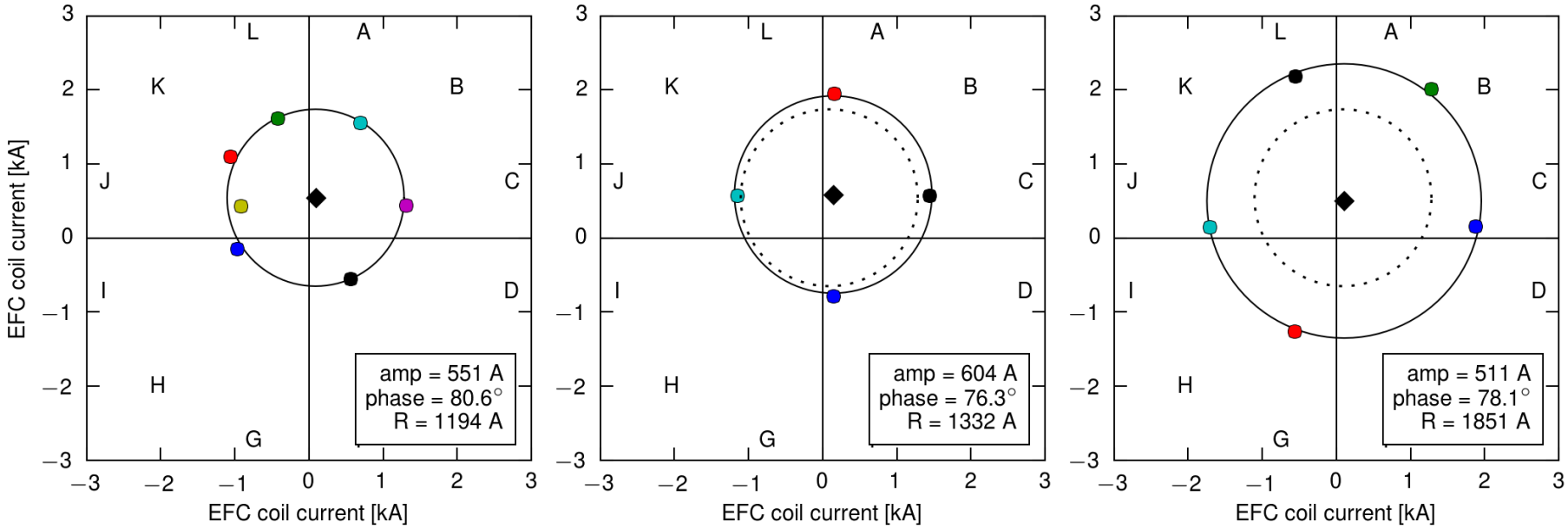
  Carry out data analysis, coil metrology, and numerical modeling of error fields to recommend a tolerance for the TF alignment upon reassembly

Optimum L-mode flattop correction: Compass scans

- Original compass scan
- Optimum amplitude: 550 A
- Optimum phase: 80°

- Higher density
- Same optimum EFC
- Rotation dominates the density scaling?

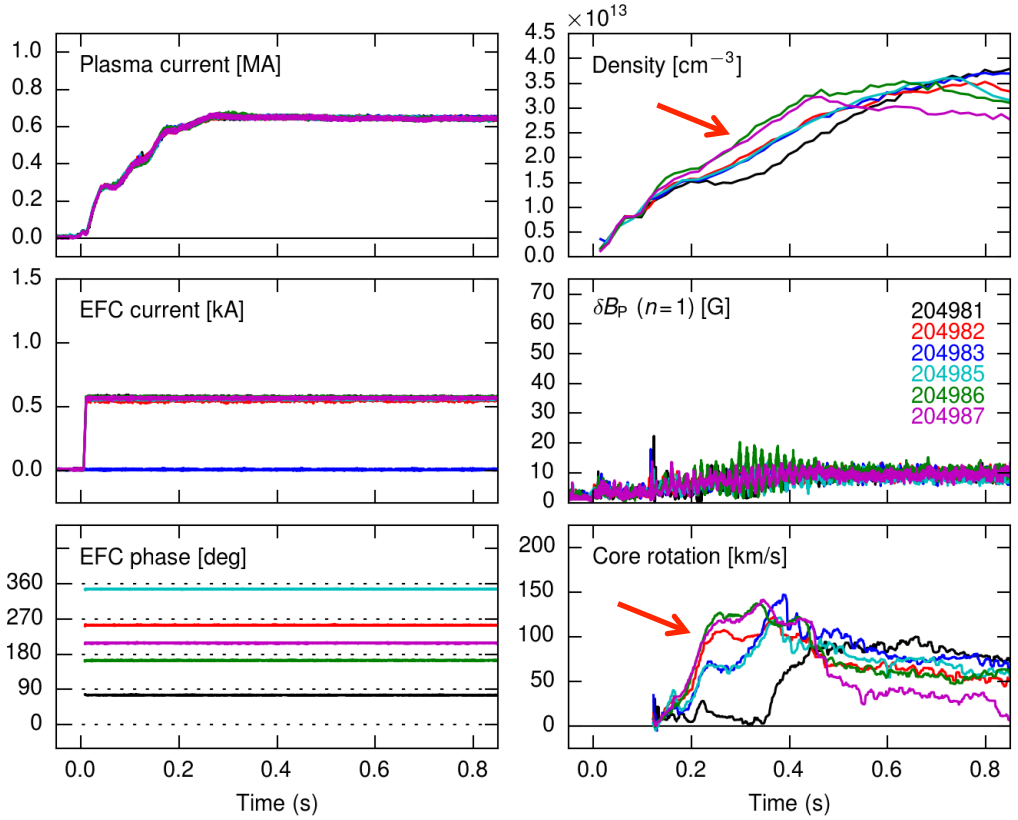
- Different OH flux state
- Same optimum EFC
- Eliminates the OH as a major error field source



All three compass scans give the same optimum correction

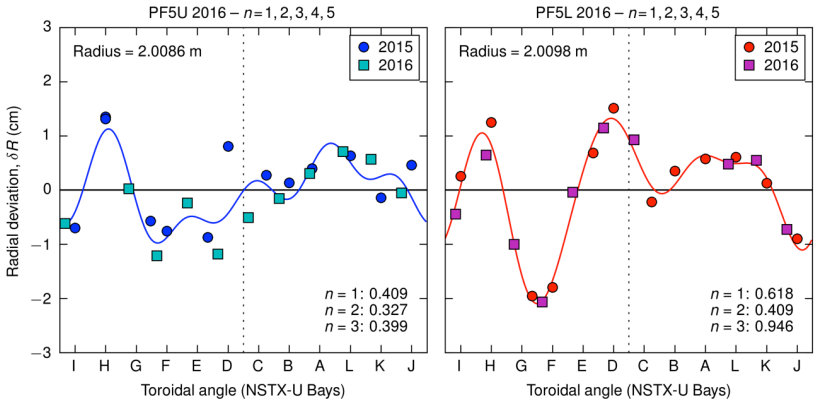
Optimum early-time phase is different from flattop

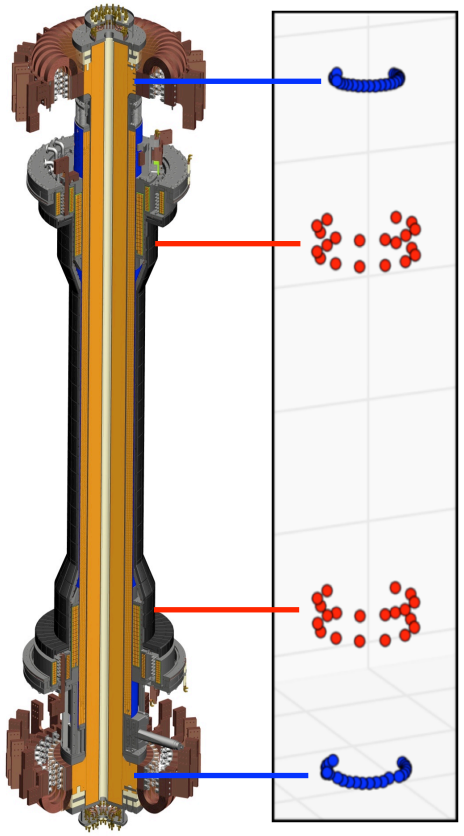
- Apply static n = 1 early in time → scan the phase
- Optimum flattop phase of 80° is *counter-productive*
- Phase asymmetry is visible in the density and the core rotation
- Sets the stage for vacuum and plasma response modeling of the EF sources

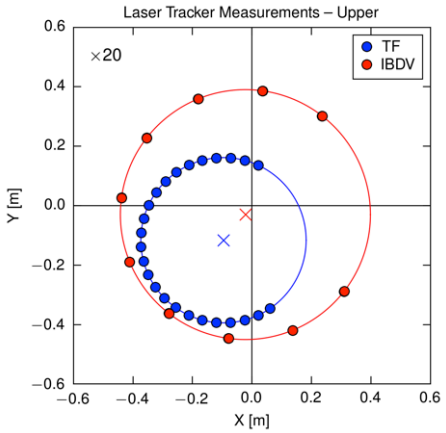


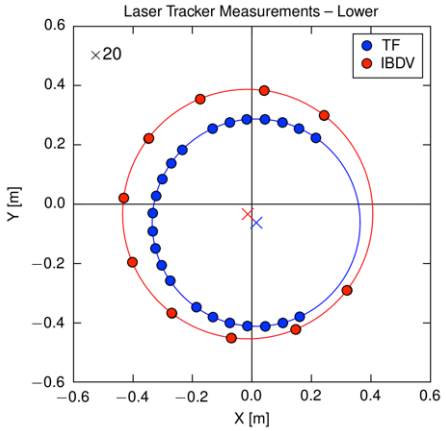
Coil metrology conducted on both PF5 and TF rod

- Combine metrology techniques: ruler, ROMER arm, laser tracker
- PF5 n = 1 amplitude and phase:
  - δR ~ 6 mm at ϕ = 16°
- TF rod shift and tilt:
  - Shift = 4.9 mm at ϕ = 246°
  - Tilt = 1.2 mrad at ϕ = 206° (6 mm)

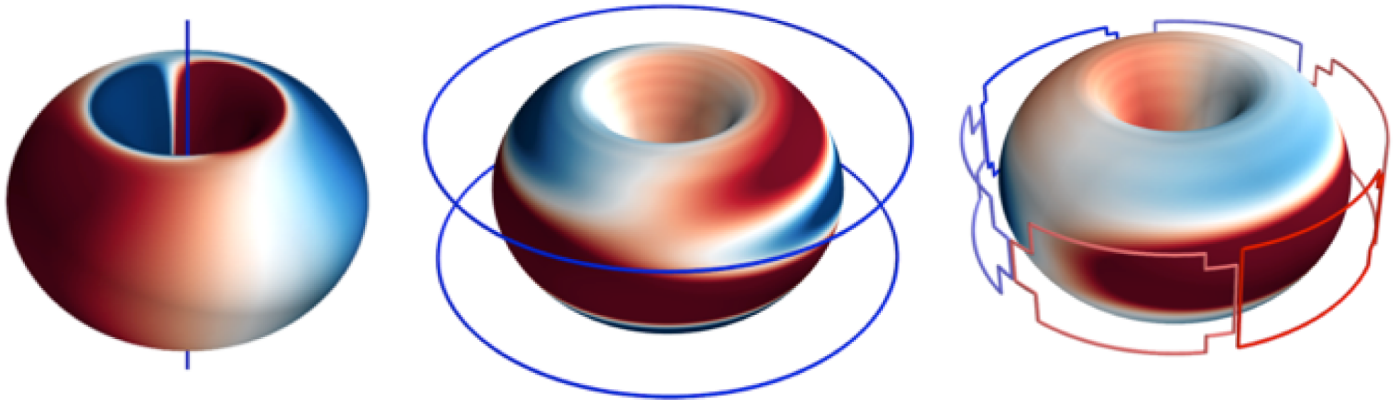


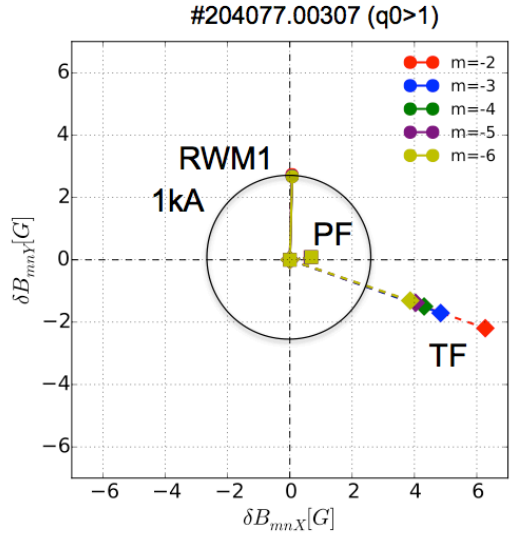


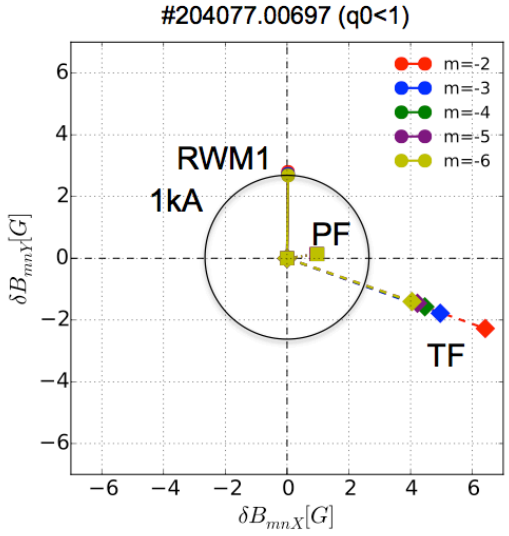




IPEC vacuum field calculations → TF 2/1 is large!



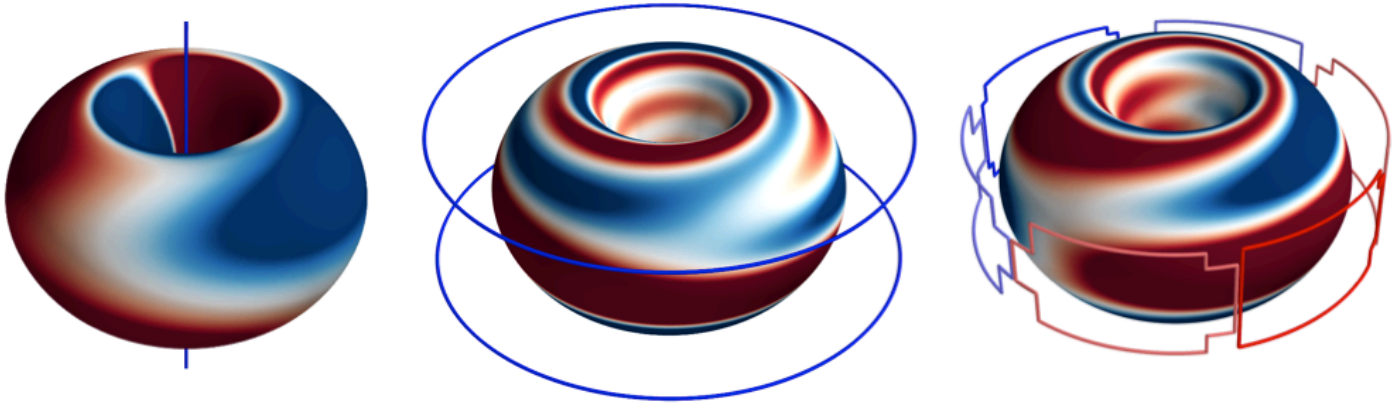


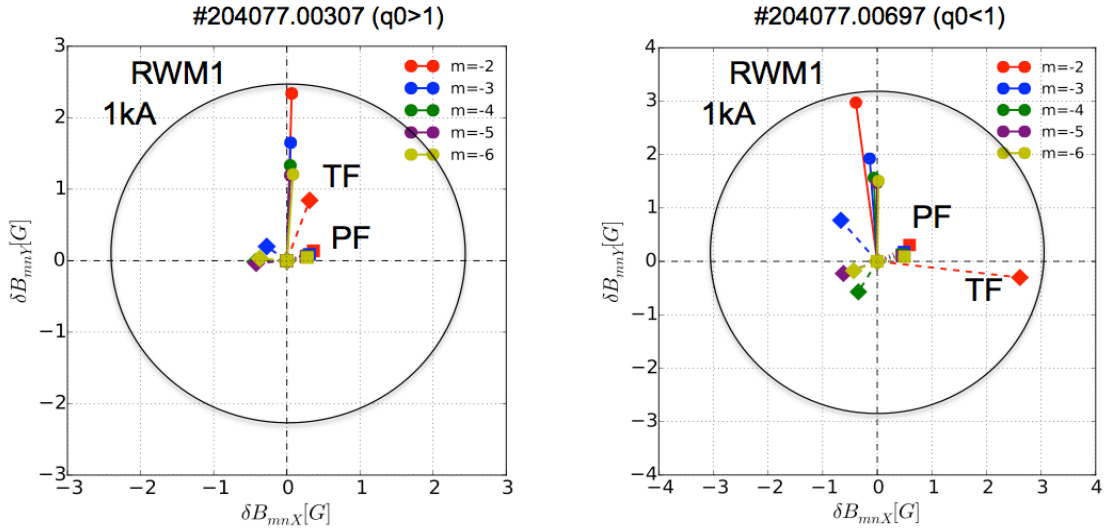


2/1 fields (Δ'):

- RWM ~ 3 G
- PF5 ~ 1 G
- TF ~ 7 G

IPEC plasma response → TF reduced, still dominant





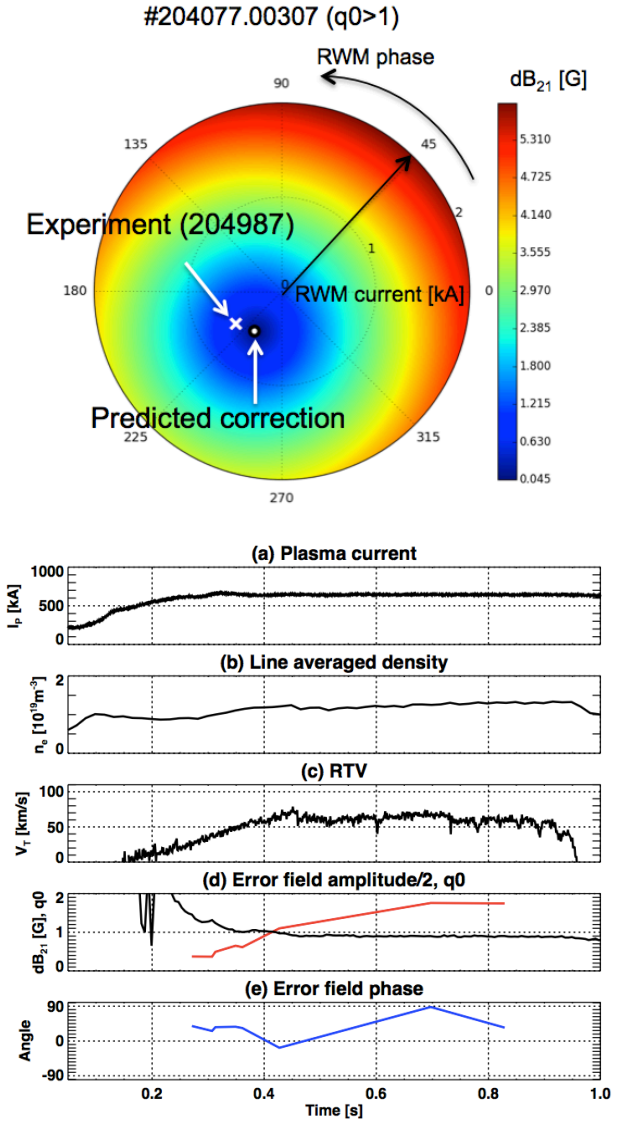
2/1 fields (Δ'):

- RWM ~ 2-3 G
- PF5 ~ 0.5 G
- TF ~ 1-3 G

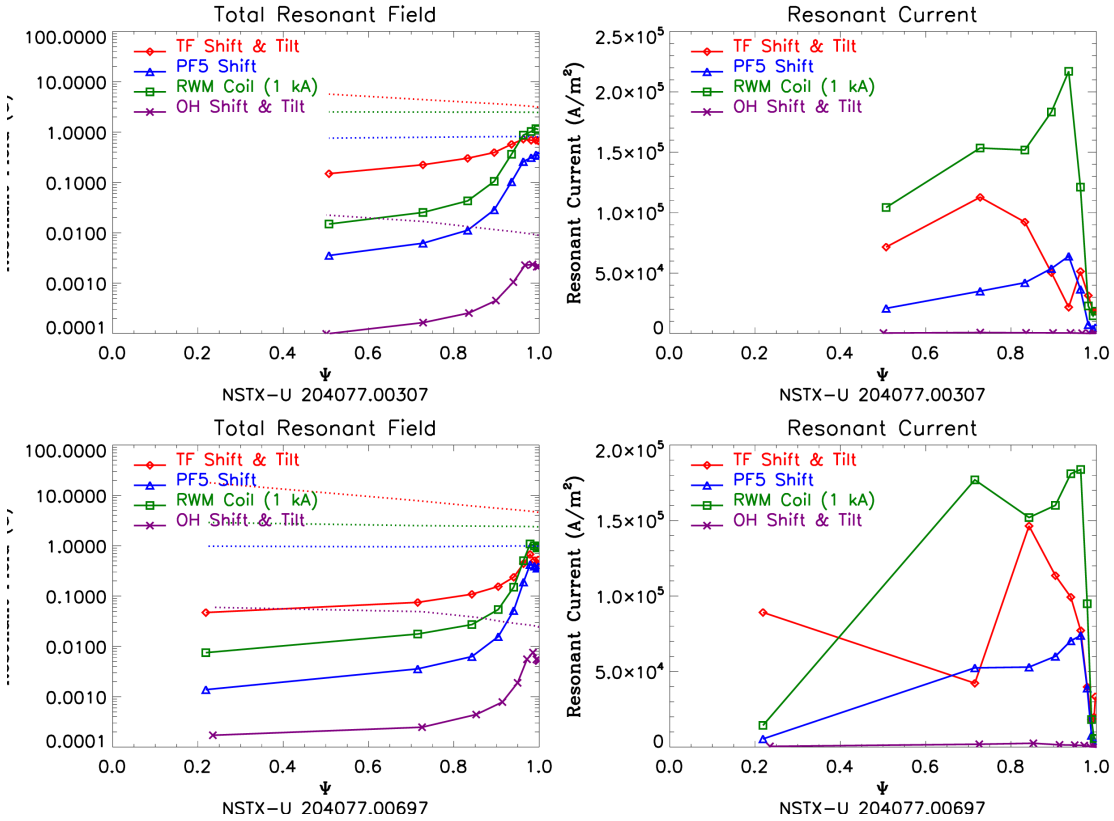
TF phase rotates

Compare to experiments → good early-time matching

- IPEC plasma response calculations agree with early-time error field correction (phase and amplitude)
- The TF is the dominant EF source in this calculation
- No such agreement in the flattop (equilibrium-dependent phase and amplitude)
- Difficult to model the linear response in these plasmas given that $q_0 < 1$



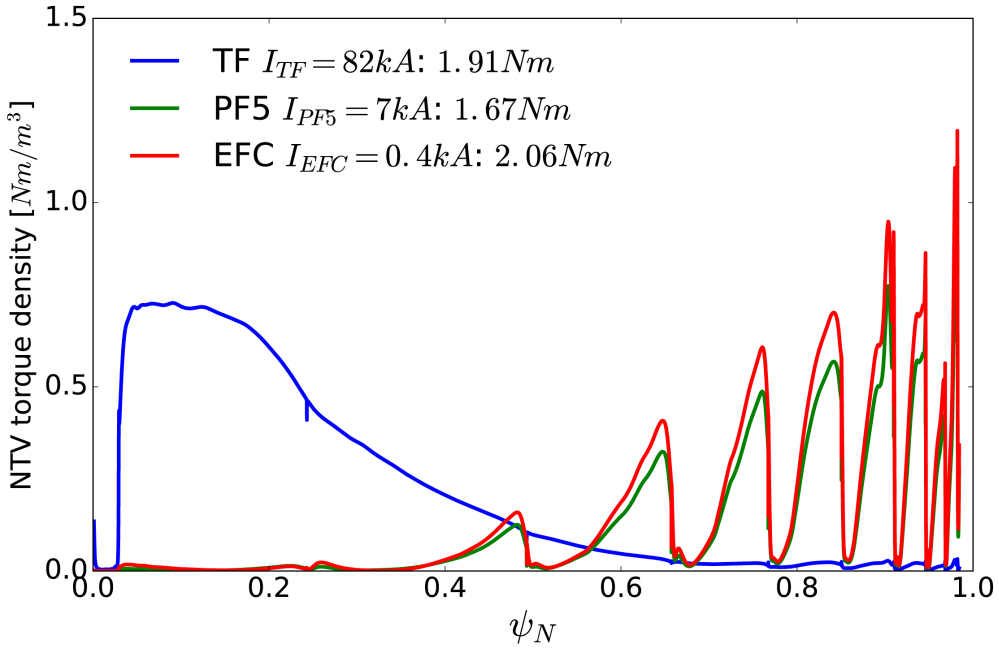
M3D-C1 finds TF is dominant drive of resonant response in resistive MHD model



- M3D-C1 resistive MHD plasma response calculations (L-mode) find TF (shift) is dominant drive
- C1's resonant currents agree with IPEC's Δ'
- Need to reduce the TF EF by (at least) 2× to be below the *n*=1 locking threshold w/o external correction (in L-mode)
- Stricter requirements likely for H-mode

IPEC NTV calculations → TF NTV strong in H-mode

- L-mode: NTV unimportant, resonant correction dominates
- H-mode: Resonant correction unimportant, NTV dominates
- TF NTV is difficult to correct with EFC (RWM) coils [right]
- Need to reduce TF EF by (at least) 3× to reduce TF NTV by 10×



Summary and future work

- Recommended tolerance for TF EF:
  - At least 2× reduction for resonant fields (L-mode), 3× for NTV (H-mode)
  - To ensure safety margin, recommend 5× mechanical reduction (≤ 1 mm)
- Future work (experimental):
  - Work with engineers to develop reinstallation strategy (metrology, etc.)
  - Magnetic sensor instrumentation during coil validation testing? → directly measure the error fields → coil shape model validation, etc.
- Future work (modeling):
  - M3D-C1 response calculations will explore the effect of beam torque on tearing drive to help interpret observations of NB2 unlocking the q=2 surface
  - IPEC/GPEC modeling with RWM + NCC coils to see if both resonant and non-resonant field effects from TF are correctable
  - M3D-C1 resistive MHD calculation of plasma response to RWM + NCC
  - IPEC/GPEC comparison study with recent COMPASS HFS coil studies for ITER projection