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# Results from XP-614

## Error field identification, and
## Comparison of error field correction techniques at high $\beta_N$

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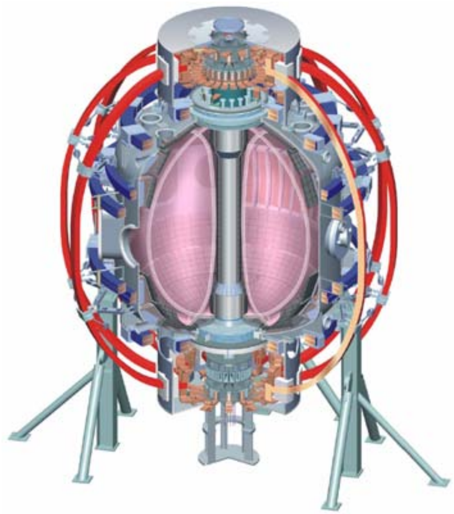
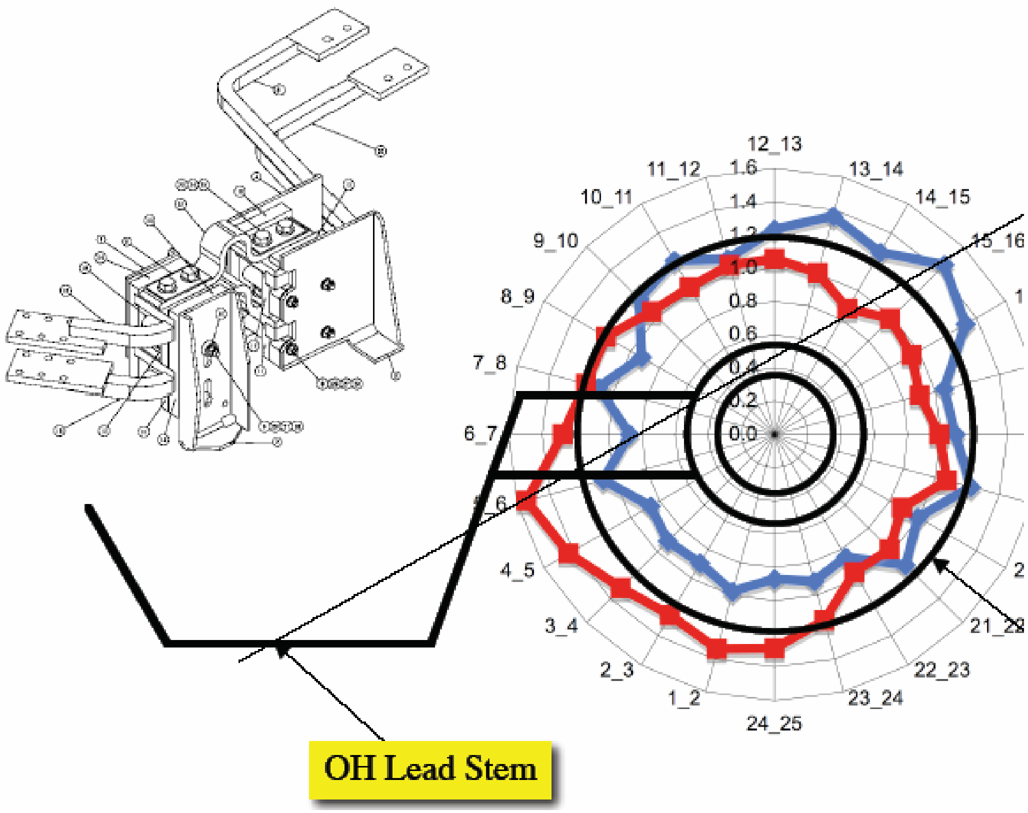
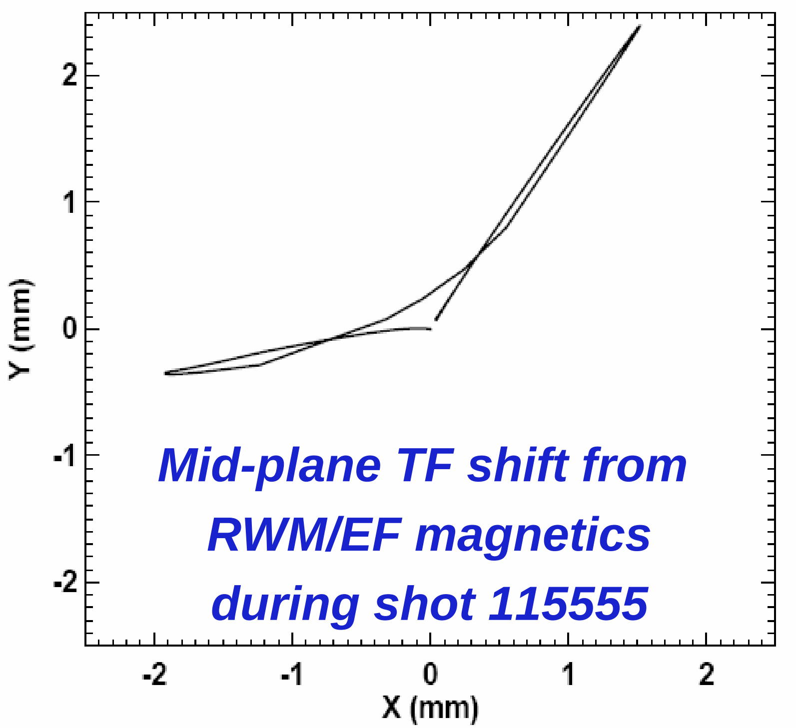
NSTX Results Review
July 26, 2006
PPPL – Princeton, NJ



## *Accumulated data strongly suggests OH/TF interaction creates error field which varies throughout shot even with constant plasma parameters*




TF flag-joint resistance variation direction consistent with direction of translation/shift inferred from magnetics

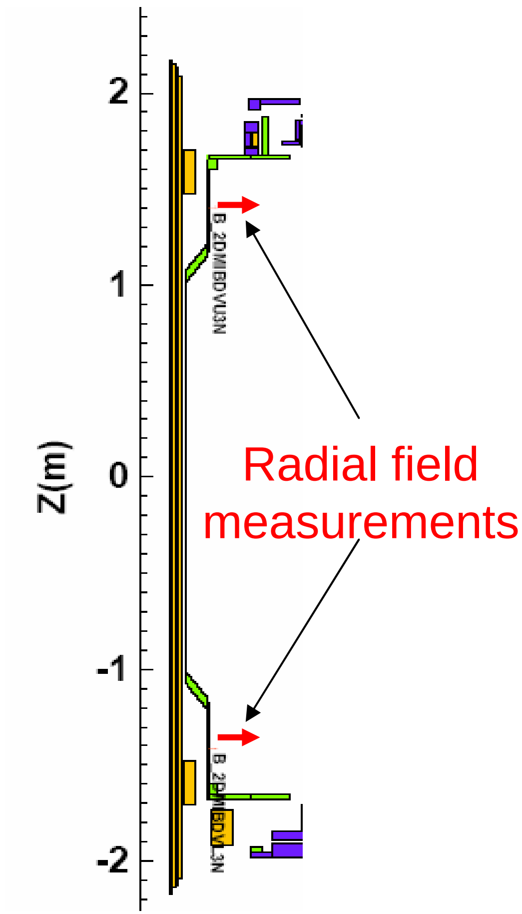
# Recent radial field measurements at ends of solenoid confirm large up/down asymmetric local error field

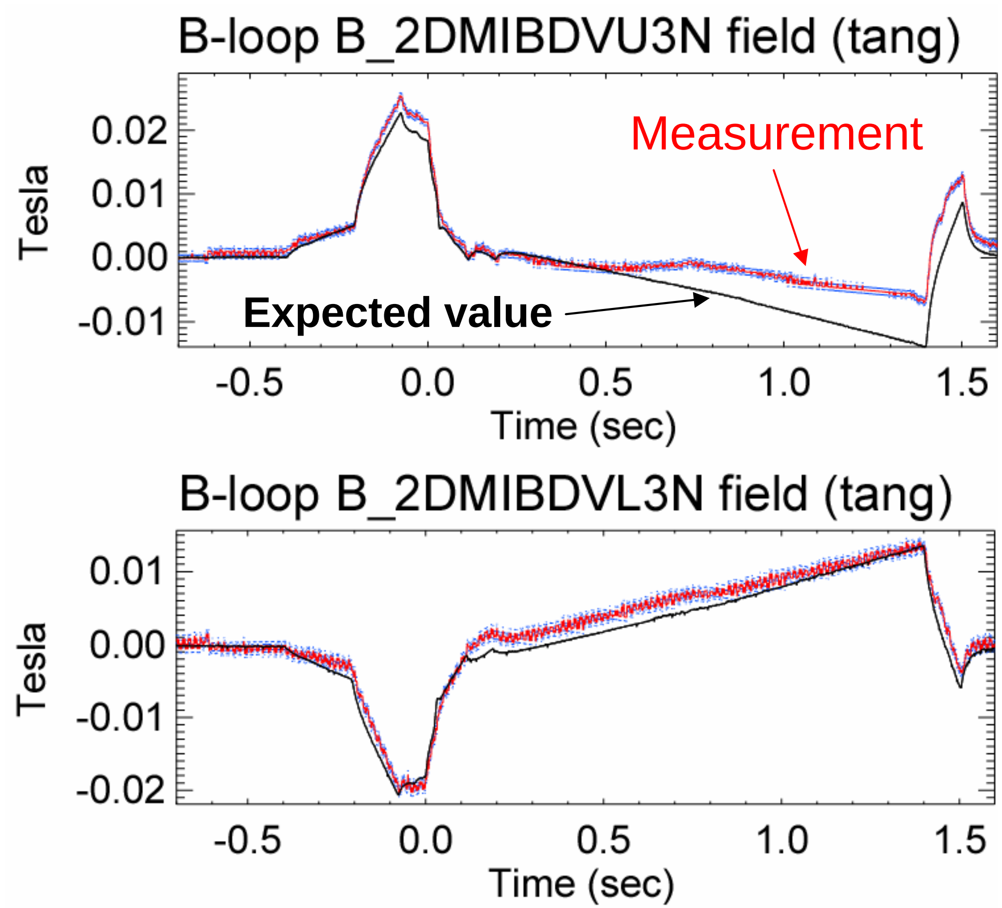
- Vacuum shot: 53kA $I_{TF}$ + OH waveform from 800kA long-pulse shot

Lower field close to expected value ⇒ small relative motion?

**Upper field significantly different ⇒ 50-70G local EF**

**This data not included in shift/tilt model yet…**

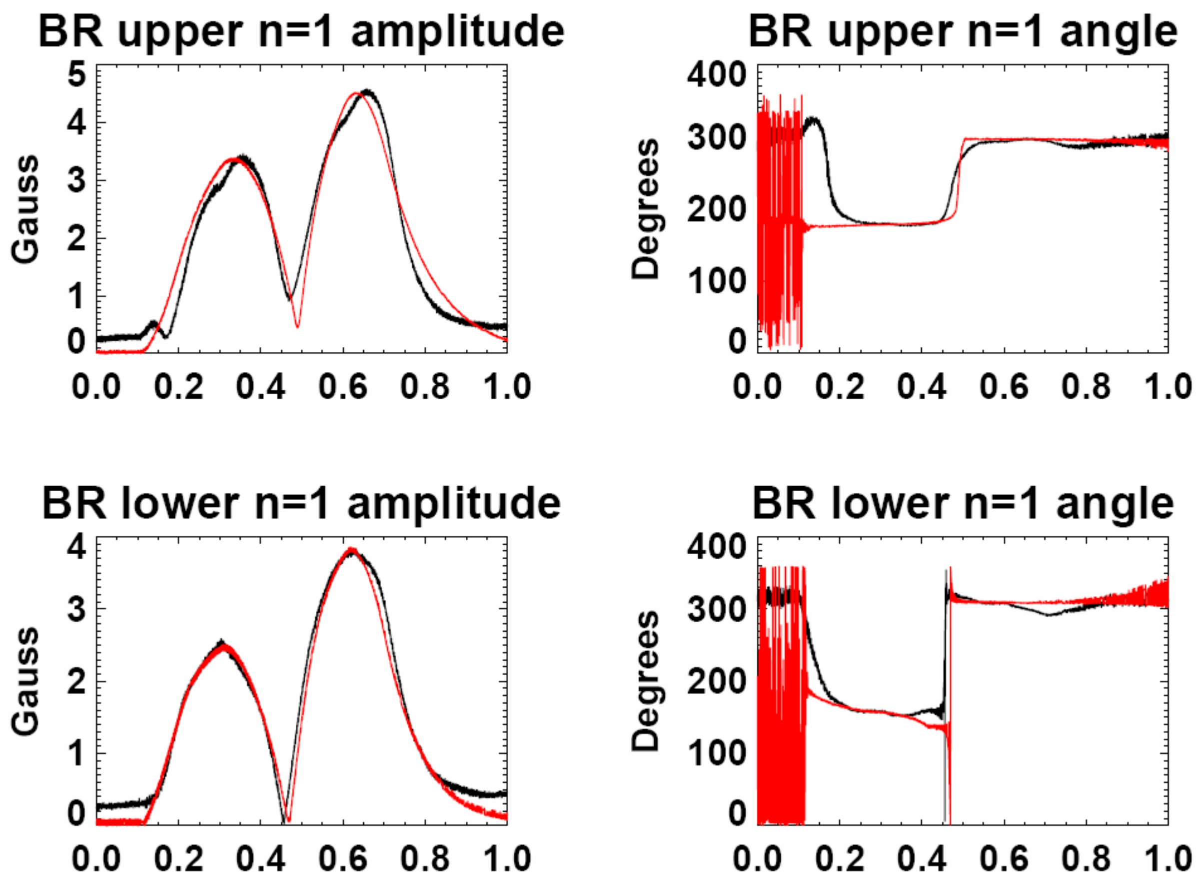


# Accurate modeling of n=1 $B_R$ error field from OH+TF requires inclusion of time lag and polarity dependence

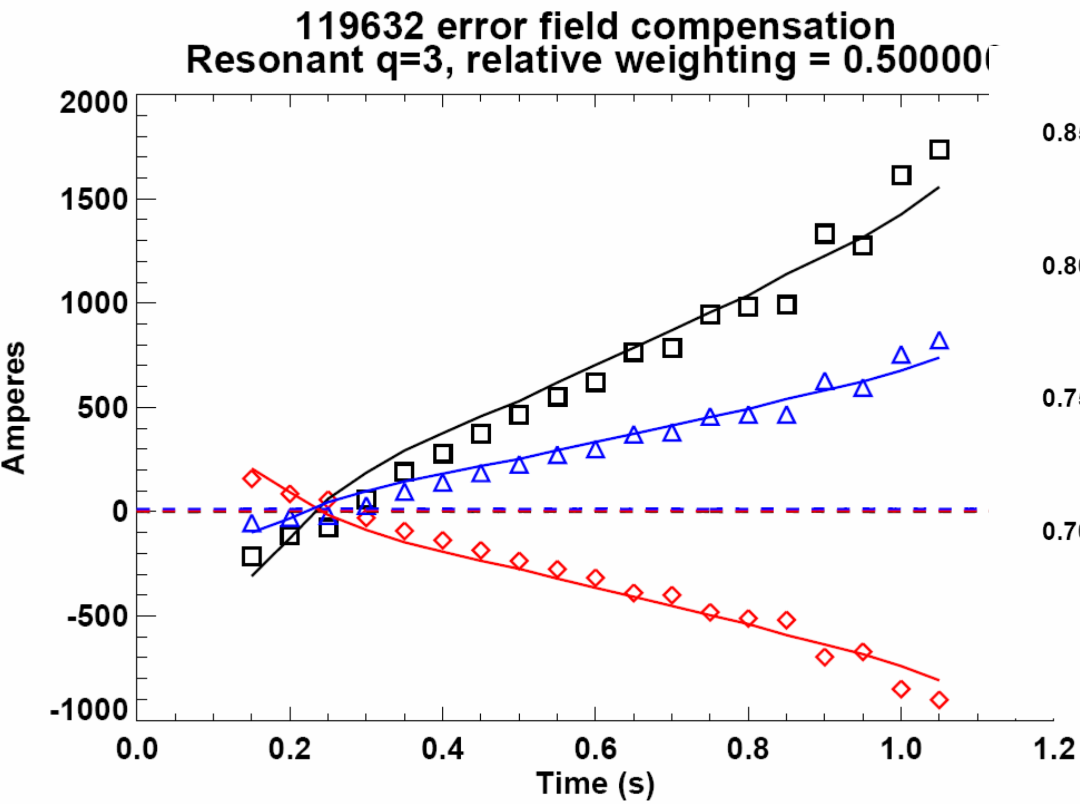
- **Developed TF model allowing both shift and tilt**
- Multiple filter time-constants needed to capture time lags
- **Accurate prediction of EF at sensor → hope for predicting EF in plasma**

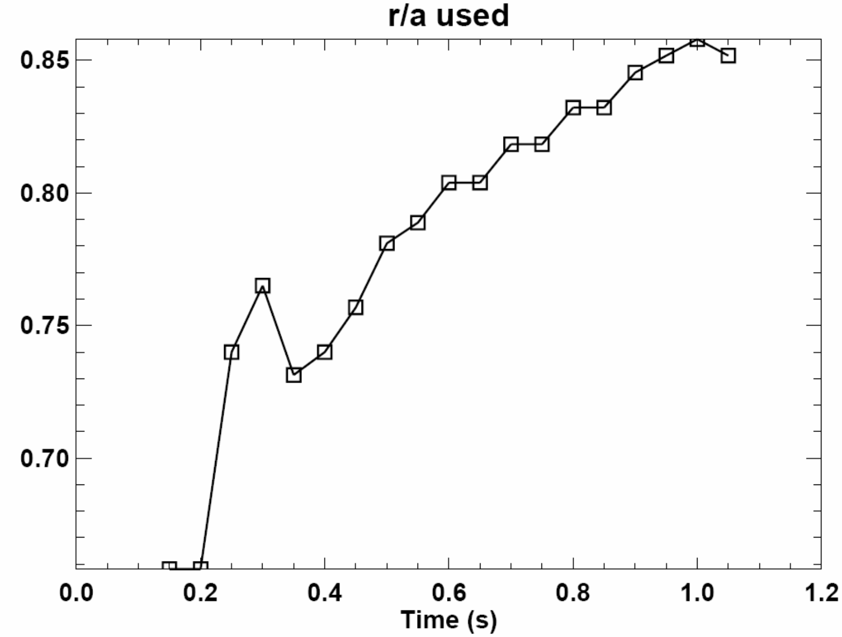
***Measured***
***& Simulated***
***error field***
***at sensors***



# Methodology for predictive EFC for OHxTF:

- Developed PCS algorithm to minimize EF (empirical rotation damping) at q=3 surface by weighting m=0 against m=2 components of EF
- Allow for rectification and time-lag
- Track q=3 radius during shot → **MAY NOT WORK for different q evolution**




*6 coefficients*

*+ $\tau_{LPF}$ = 95ms*

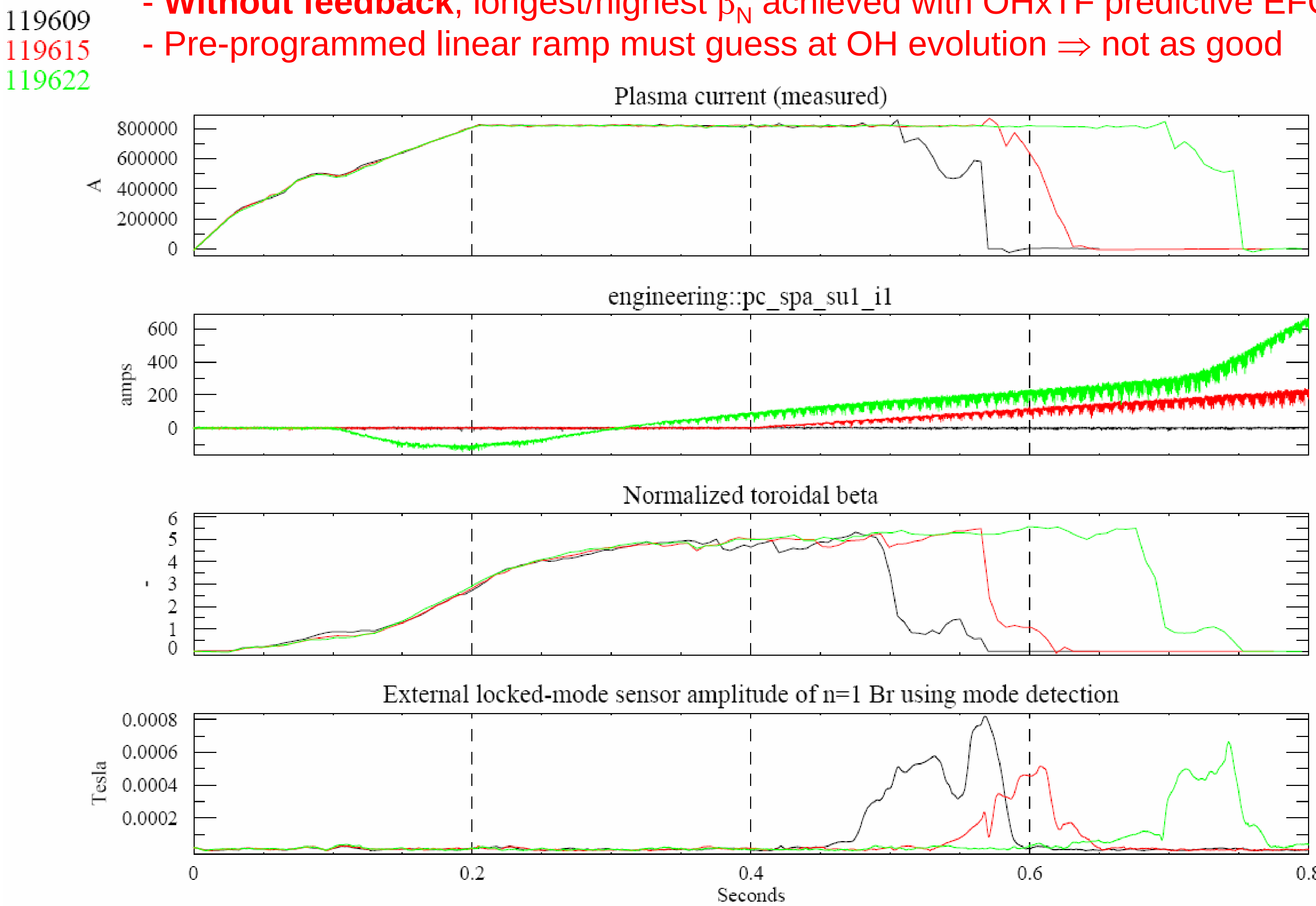
**SPA 1: s=1.11, a=0.534A/kA$^2$**

**SPA 2: s=-0.620, a=-0.234A/kA$^2$**

**SPA 3: s=0.483, a=0.297A/kA$^2$**

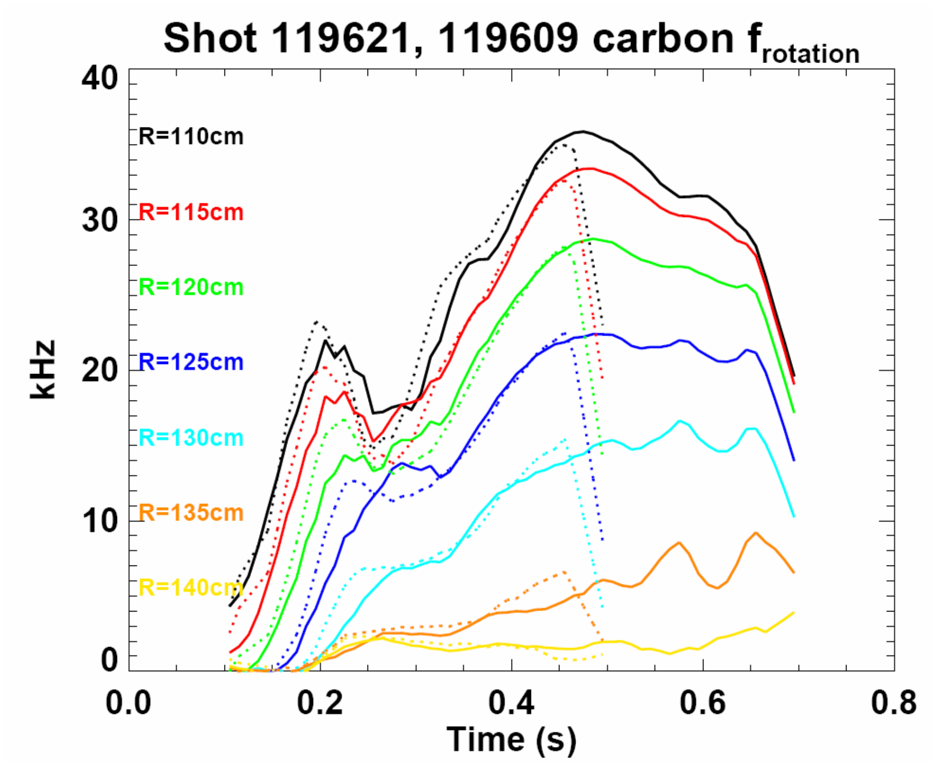
# Tracking OH waveform better than simple SPA pre-programming

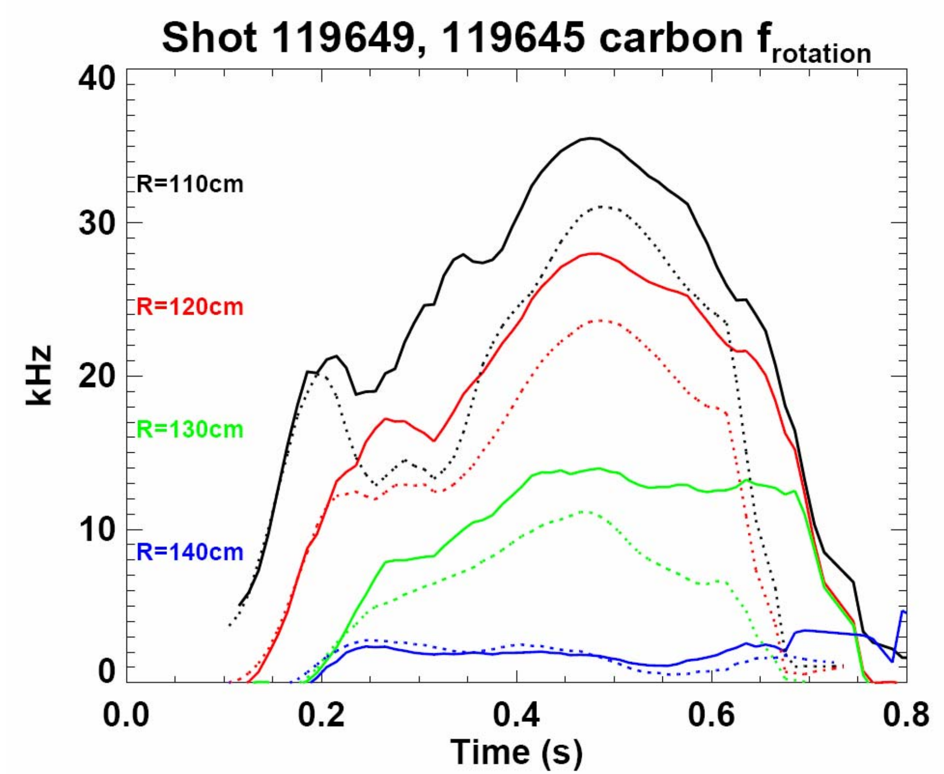
- **Without feedback**, longest/highest $\beta_N$ achieved with OHxTF predictive EFC
- Pre-programmed linear ramp must guess at OH evolution $\Rightarrow$ not as good



# EFC helps to sustain rotation

- Scan of EFC amplitude finds that optimal proportionality value (119649) results in higher rotation and beta than shot with non-optimal value (119645)



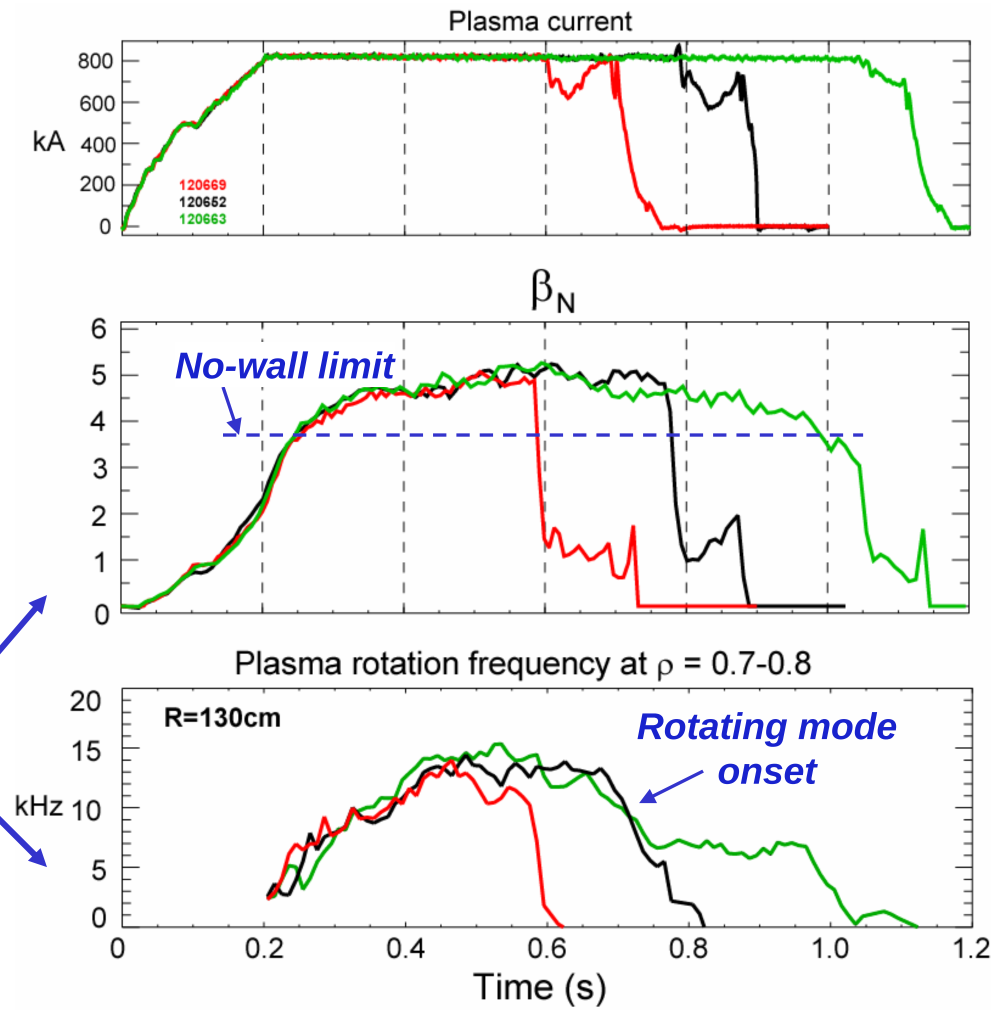



# Compared feedback driven by mode-ID from BP sensors to predictive error field correction (PEFC) from OHxTF

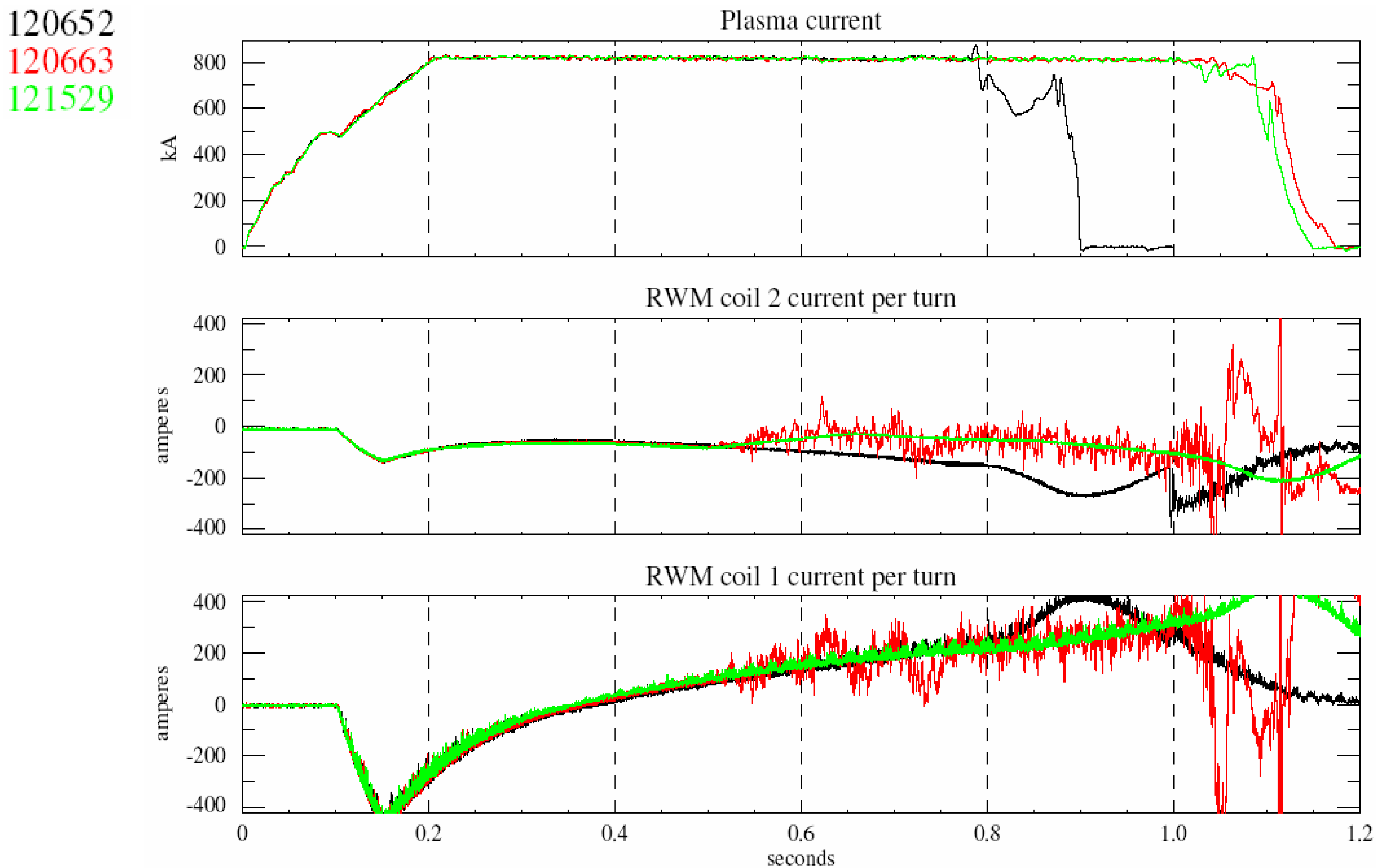
- **<u>COMMISSIONED in FY2006:</u>**
  - **Real-time sensor compensation**
  - **Mode ID algorithm for BP & BR**
  - **Combined PEFC + mode-ID driven feedback + pre-programmed $I_{SPA}$**
- **XP614 scanned phase angle**
  - **150 degrees optimal for BPU**
- **Scanned feedback gain**
  - **0.7 optimal – need to rescan at optimal gain value**
- **COMBINATION of two EFC techniques works best**

Can sustain high $\beta_N$ during rotation drop from saturated n=1 core mode

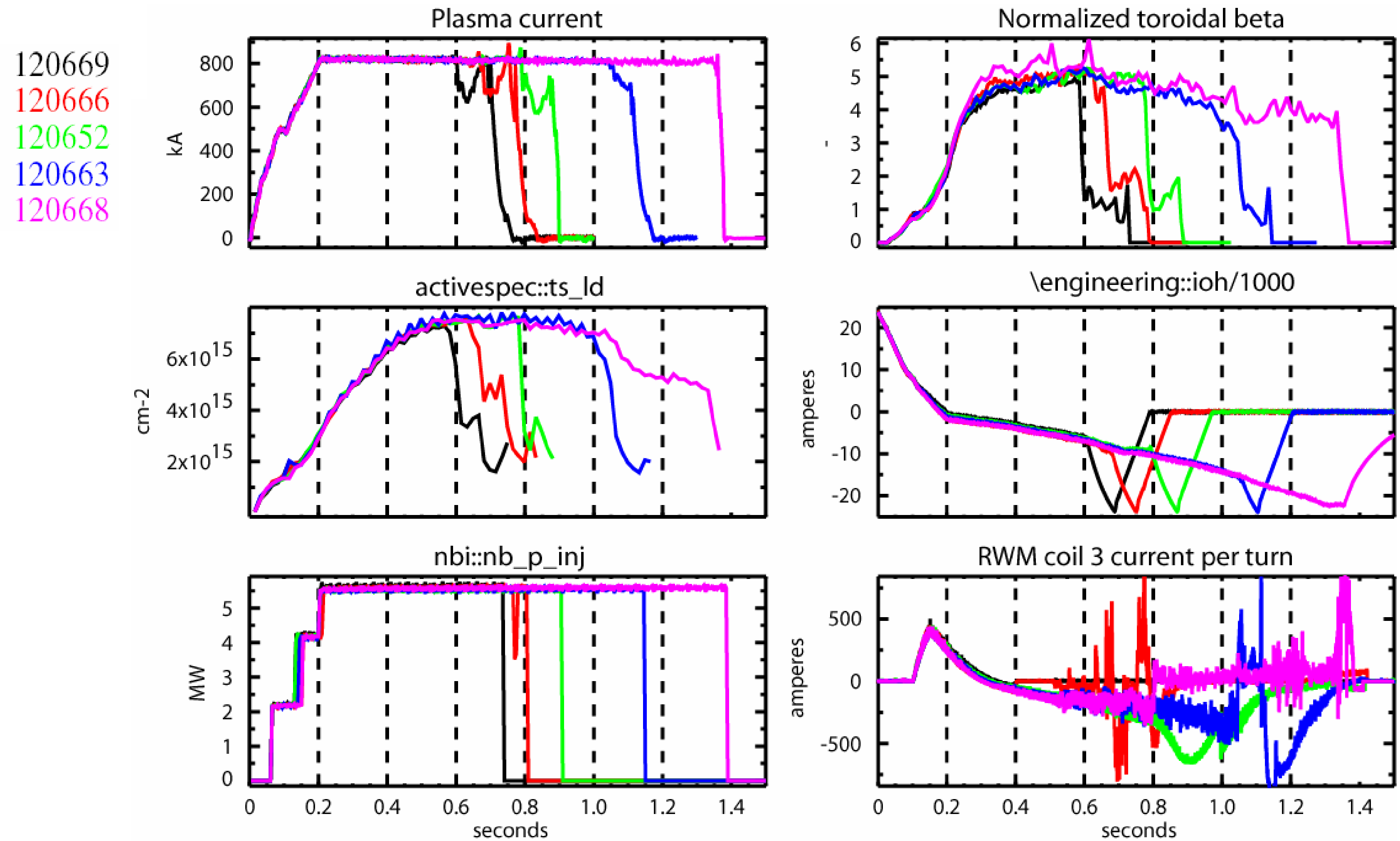
- **No error field control during high $\beta_N$ phase**
- **Predictive correction of known error fields**
- **Predictive correction + active feedback**



# Time-averaged SPA currents from feedback equivalent to un-averaged feedback → correcting RFA from stable RWM



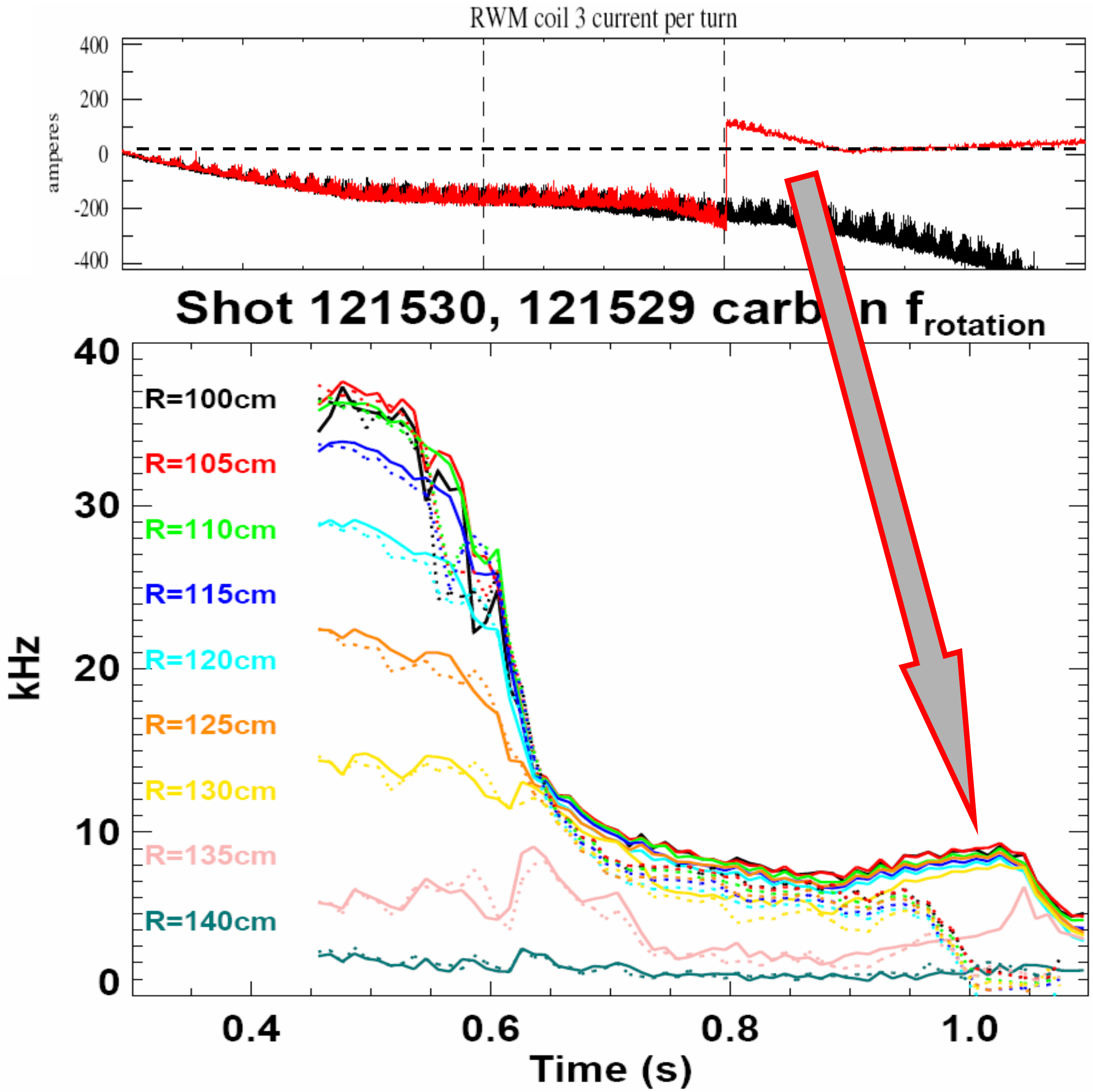
# Mode-ID feedback alone not robust early → OHxTF needed early, but Turning OHxTF correction *OFF* late gave best performance




- OHxTF t=0.1-0.4s, no sensor-based feedback
- OHxTF t=0.1-0.4s, feedback on after t=0.5s
- OHxTF t=0.1-end of shot, no feedback
- OHxTF t=0.1-end, feedback on after t=0.5s
- OHxTF t=0.1-0.8s, feedback on after t=0.5s

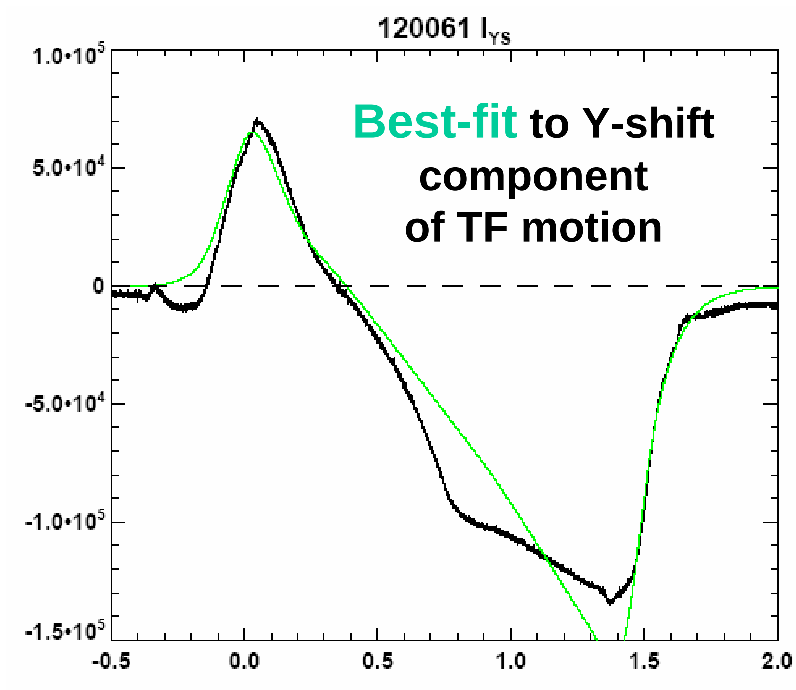
→ **120663 & 120668 imply late OHxTF is not optimized, and may be due to non-linearity of OHxTF field late in shot**

# All SPA current off after t=900ms → increased rotation

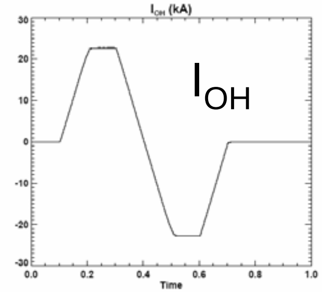


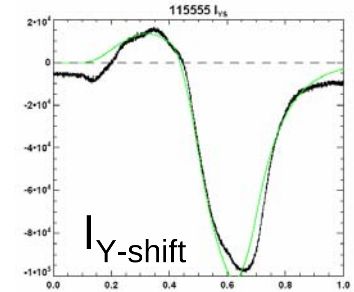
# Find OHxTF correction is needed early in shot, but hinders performance late in shot – why?

- Measured OHxTF error field (black) has “break-in-slope” near 800ms which present PCS algorithm (green) cannot match - **leading to degraded compensation late in shot?**




- Algorithm was designed using “short pulse” waveforms which can be fit much better.



# Upper radial error field increases non-linearly with OHxTF current product ➔ threshold effect?

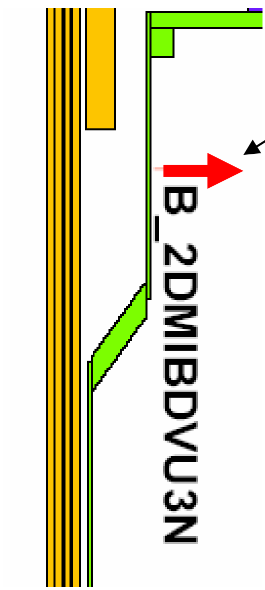
**Note change in slope of deviation from expected value**

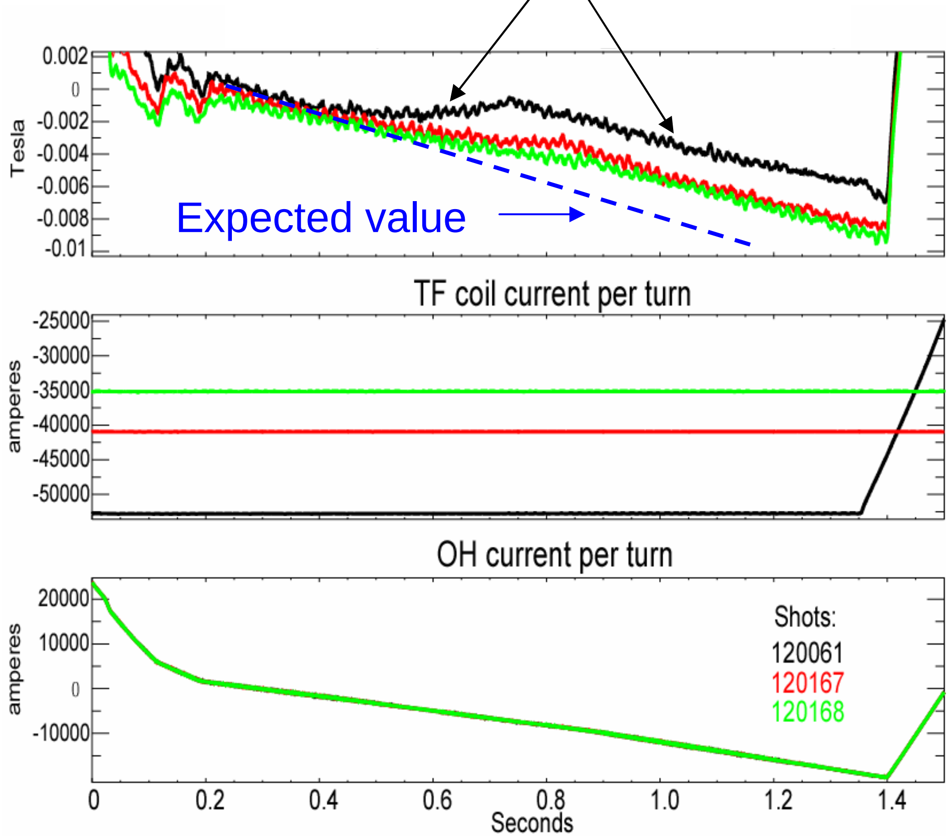
→ **OHxTF force interacting with TF/OH thermal expansion?**

→ **VERY** difficult to model for predictive EF correction

Slope changes at t=0.7-0.9s

Upper radial field measurement



# Summary

- Latest EF hypothesis:  Field from OH lead loop pushes on TF bundle, bundle tilts/bends, causes n=1 EF in main chamber

- Developed predictive OHxTF EFC model in PCS – increased discharge duration in otherwise disruptive target

- Implemented real-time mode-ID and feedback, optimized phase and gain, compared/added to PEFC
  - **Doubled flat-top duration of target discharge**
  - **Time-averaged currents give same response → RFA correction**

- PEFC likely failing at end of shot due to non-linear TF motion
  - PEFC algorithm also q-profile dependent, and marginal to start with…
  - RFA also beta-dependent – likely a combination of both effects