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NO1.7 - Error field identification and correction at high β_N in NSTX

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Philadelphia, PA

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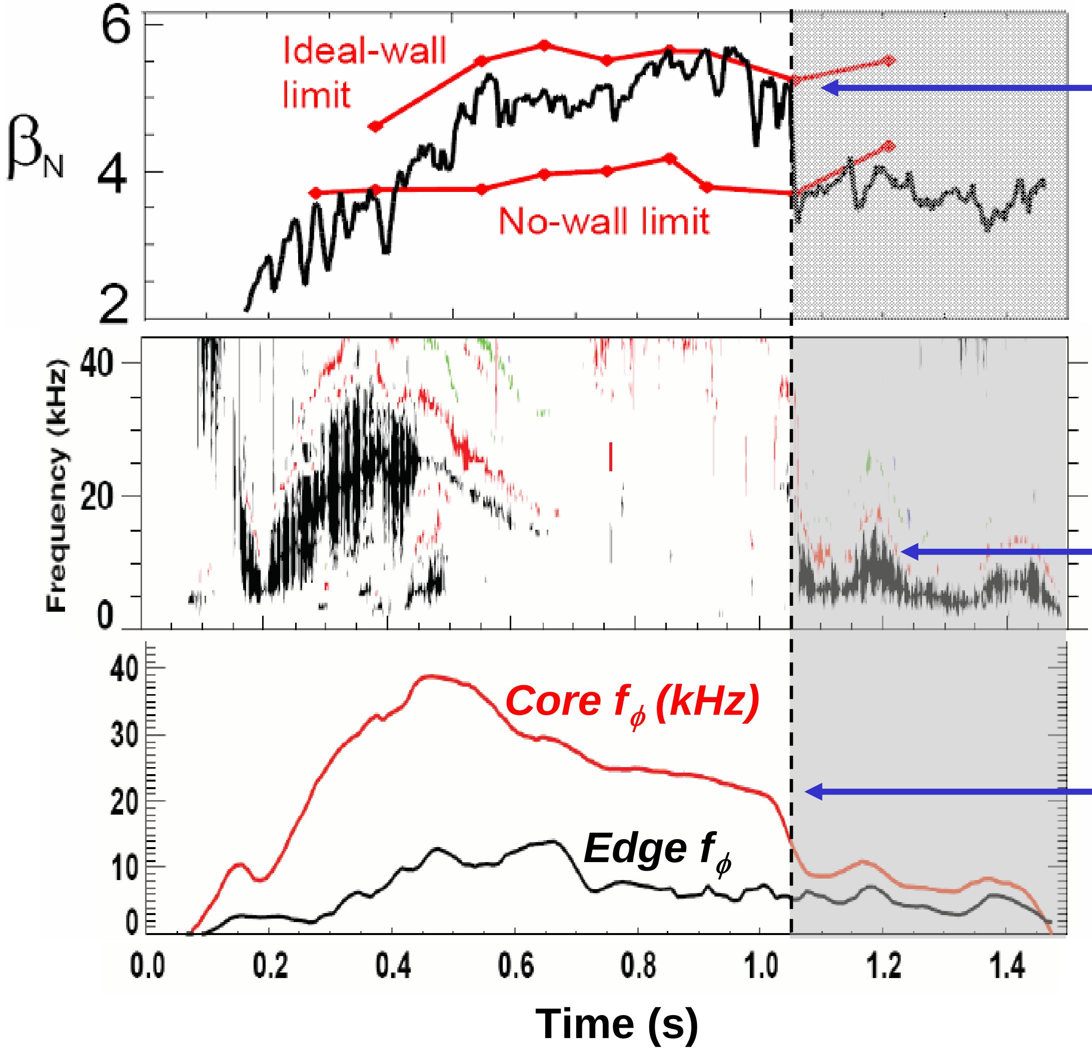
Stable operation above the ideal no-wall limit is routinely achieved without any error field correction or feedback control

NSTX

Co-injected NBI heating up to 7MW ➔ v_ϕ / v_A up to 0.5 on axis

⇒ Rotational stabilization of the n=1 RWM

Sontag, PoP **12** (2005) 056112
Sabbagh, NF **46** (2006) 635)
Reimerdes, PoP **13** (2006) 056107



MSE ⇒ repeated excursions above ideal wall limit can trigger saturated core n=1 quasi-interchange modes

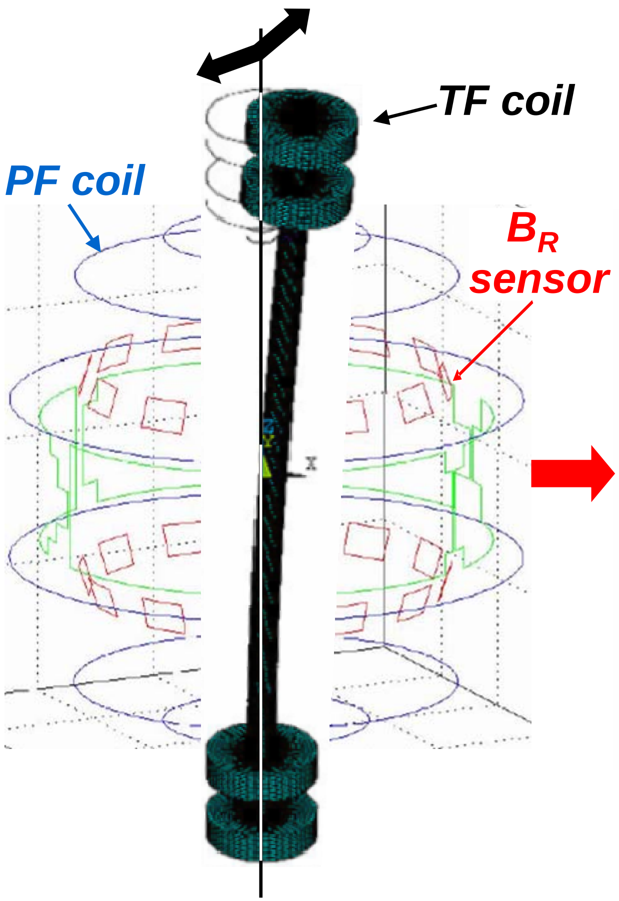
Menard, PRL **97** (2006) 095002

Central rotation is maintained until saturated core n=1 mode flattens the core rotation profile via ***Neoclassical Toroidal Viscosity***

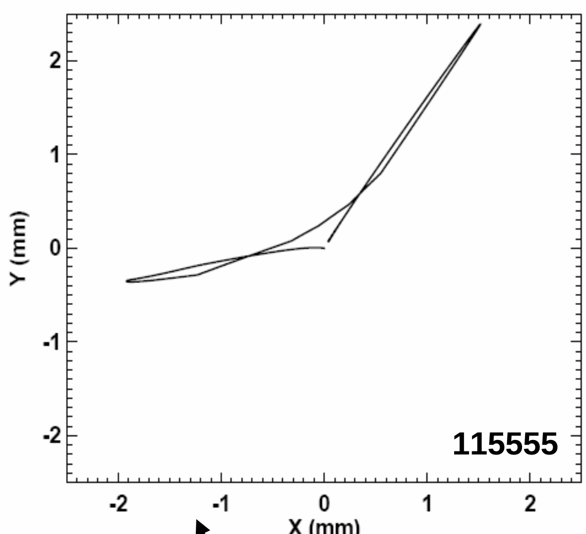
Menard, NF **45** (2005) 539
Zhu, PRL **96** (2006) 225002

Why bother with error field identification and control for NSTX?

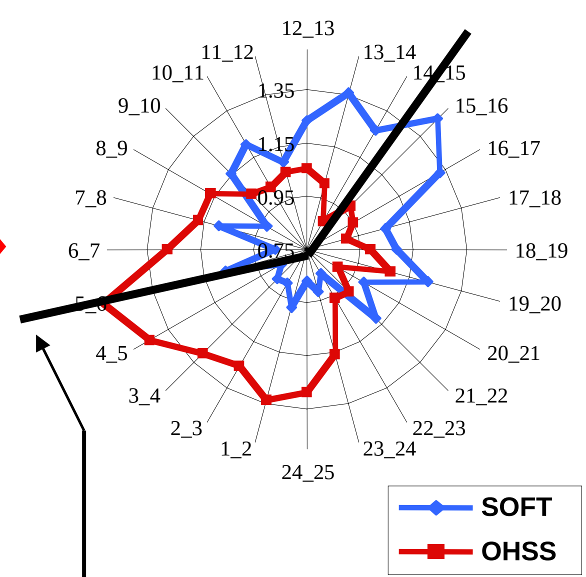
- Some scenarios with lower κ, δ exhibit Ω_ϕ and β_N collapse when $\beta_N > \beta_N$ (no-wall)
- Measure 2-3 Gauss $B_\perp^{2/1}$ EF in LM experiments… what is EF source?
- **Present picture of EF Source:** EF from/near OH leads at top of machine induces **TF coil motion relative to** B_R sensors (plates, vessel) and thus **the PF coils**



TF coil shift at mid-plane
inferred from B_R sensors
during OH+TF vacuum shot



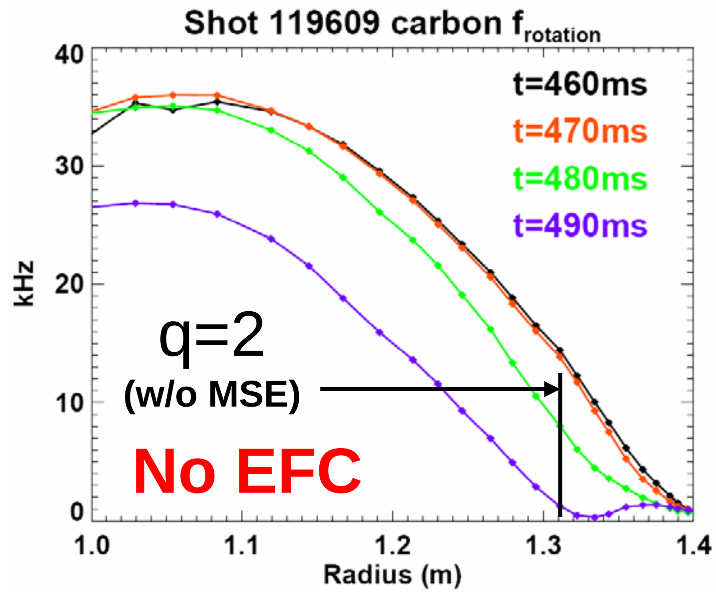
Normalized TF bottom joint voltage drop from OH+TF test

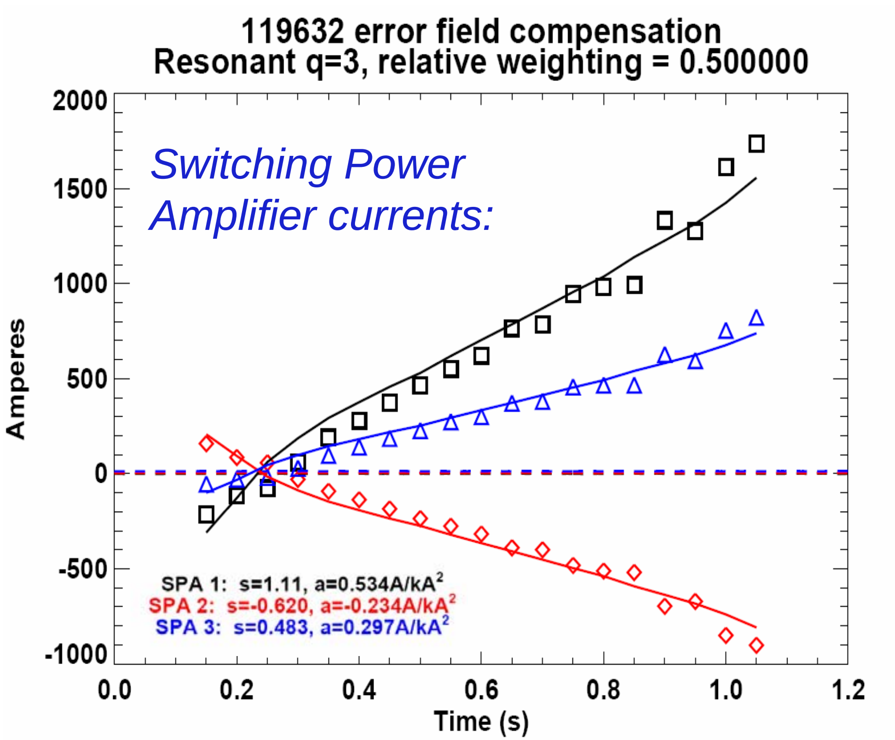


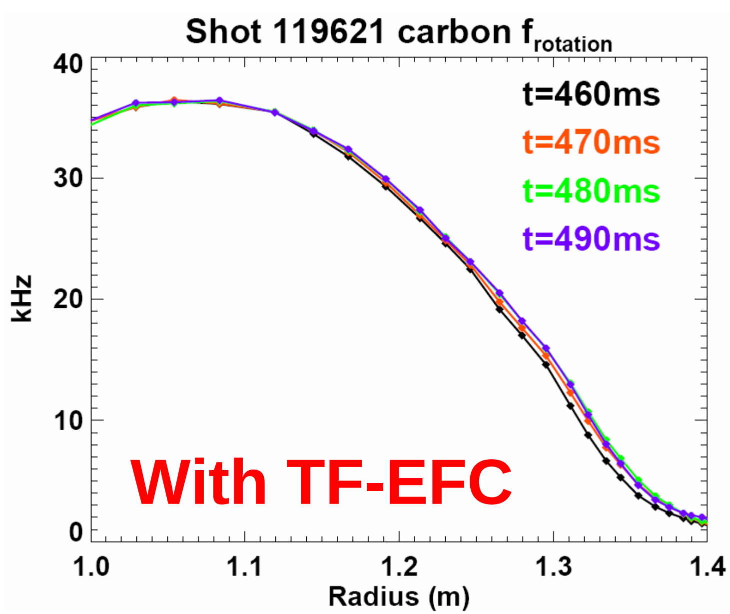
TF flag-joint voltage variation direction consistent with magnetics

Methodology for real-time TF error field correction (TF-EFC)

- Use real-time $I_{OH} \times I_{TF}$, incorporate observed rectification and time-lag of EF
- Empirically minimize rotation damping near q=2-3 for 100-200ms of reference shot
  - Extrapolate in time, balance m=2 against m=0 ***(non-resonant!)*** of EF from moving TF
  - Correction coefficients must be altered for different q(ρ,t), startup, shape, etc.



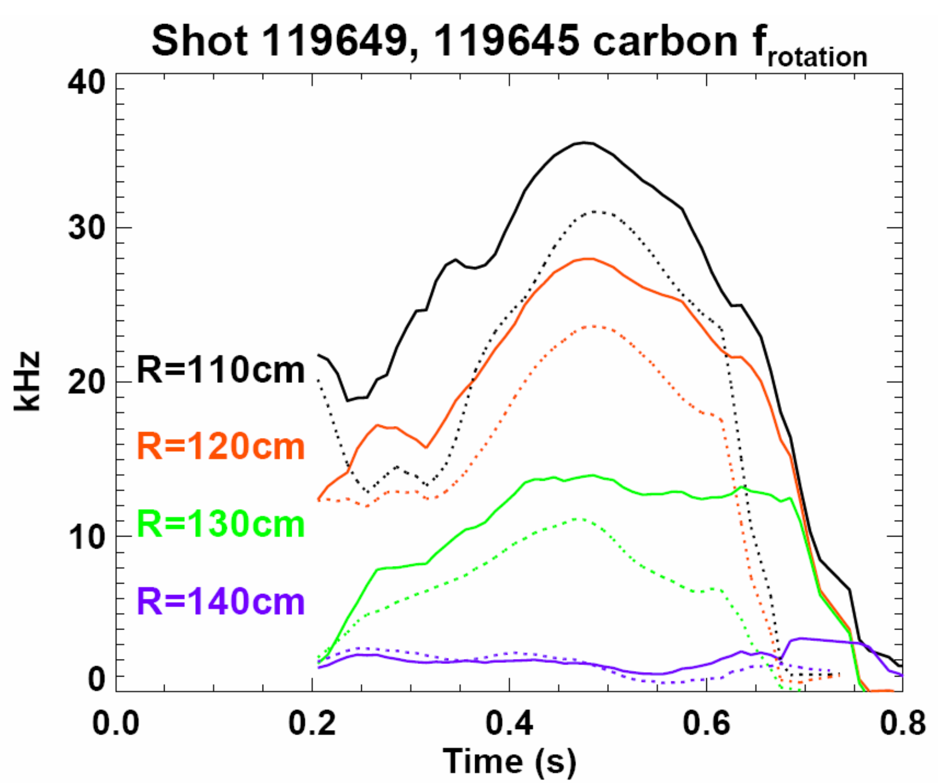




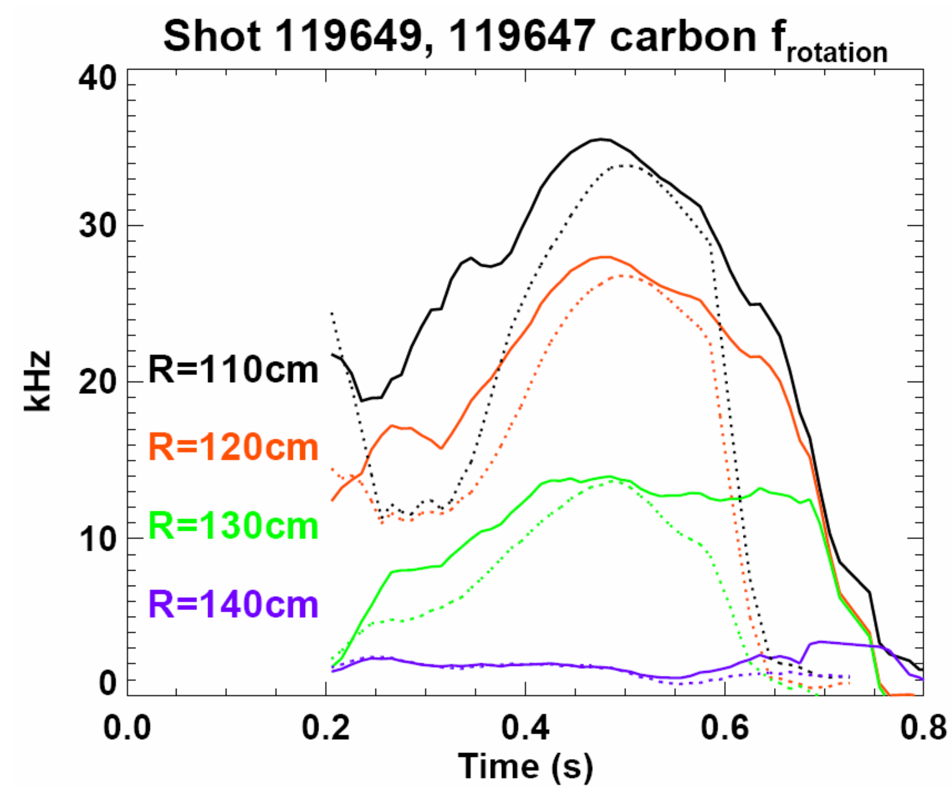
Rotation sustainment is a sensitive function of TF-EFC gain

Solid: Optimized TF-EFC gains

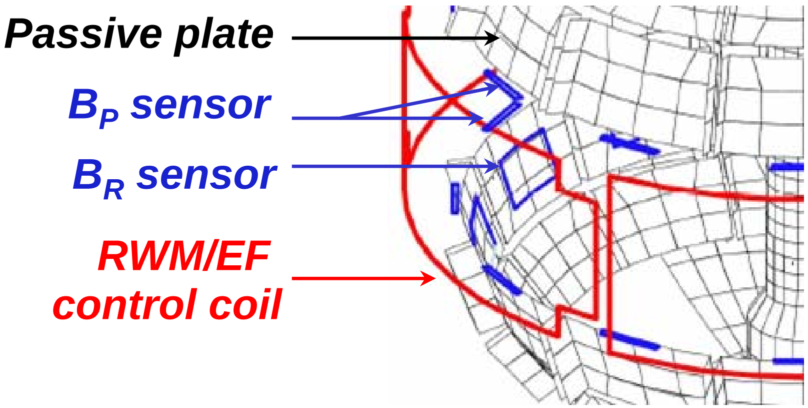
Dashed: Proportional gain *increased 20%* above optimum



Dashed: Proportional gain *decreased 20%* below optimum

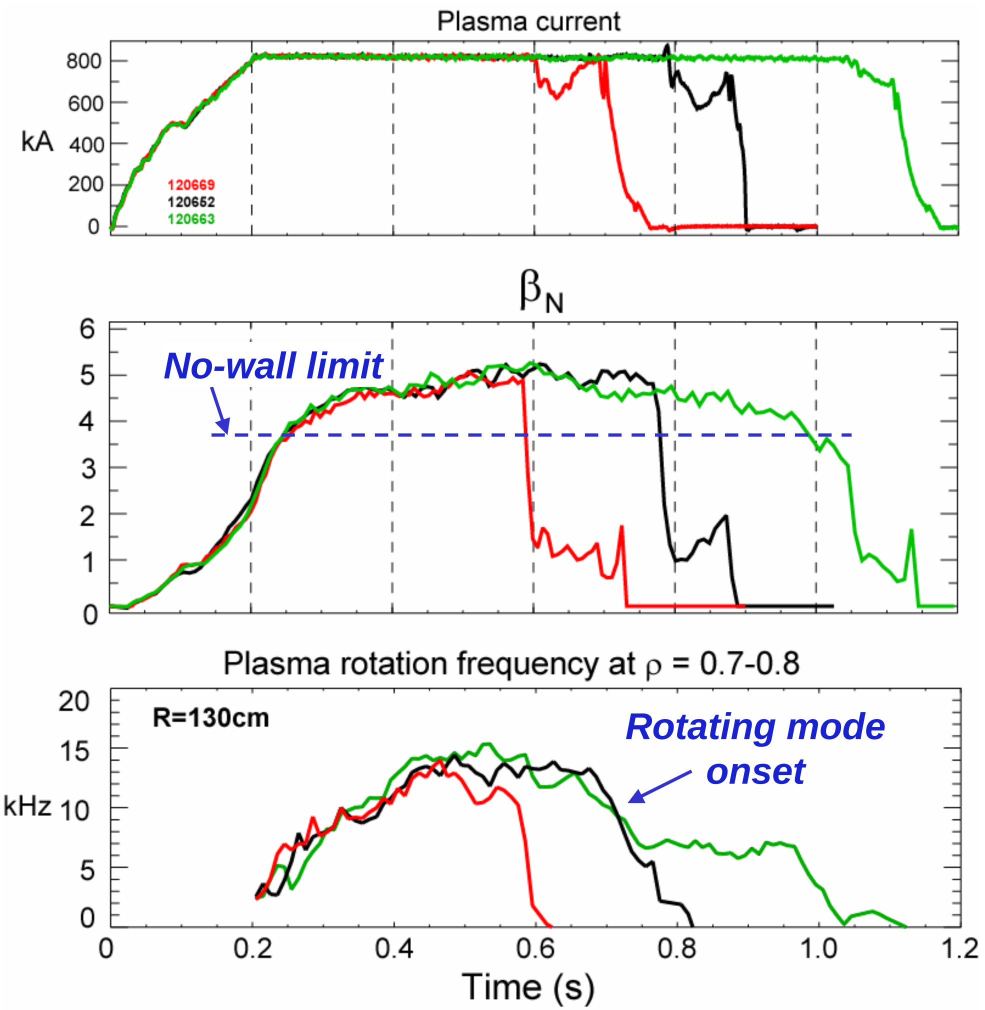


Combination of TF error field correction and n=1 feedback driven by B_P sensors optimizes plasma performance



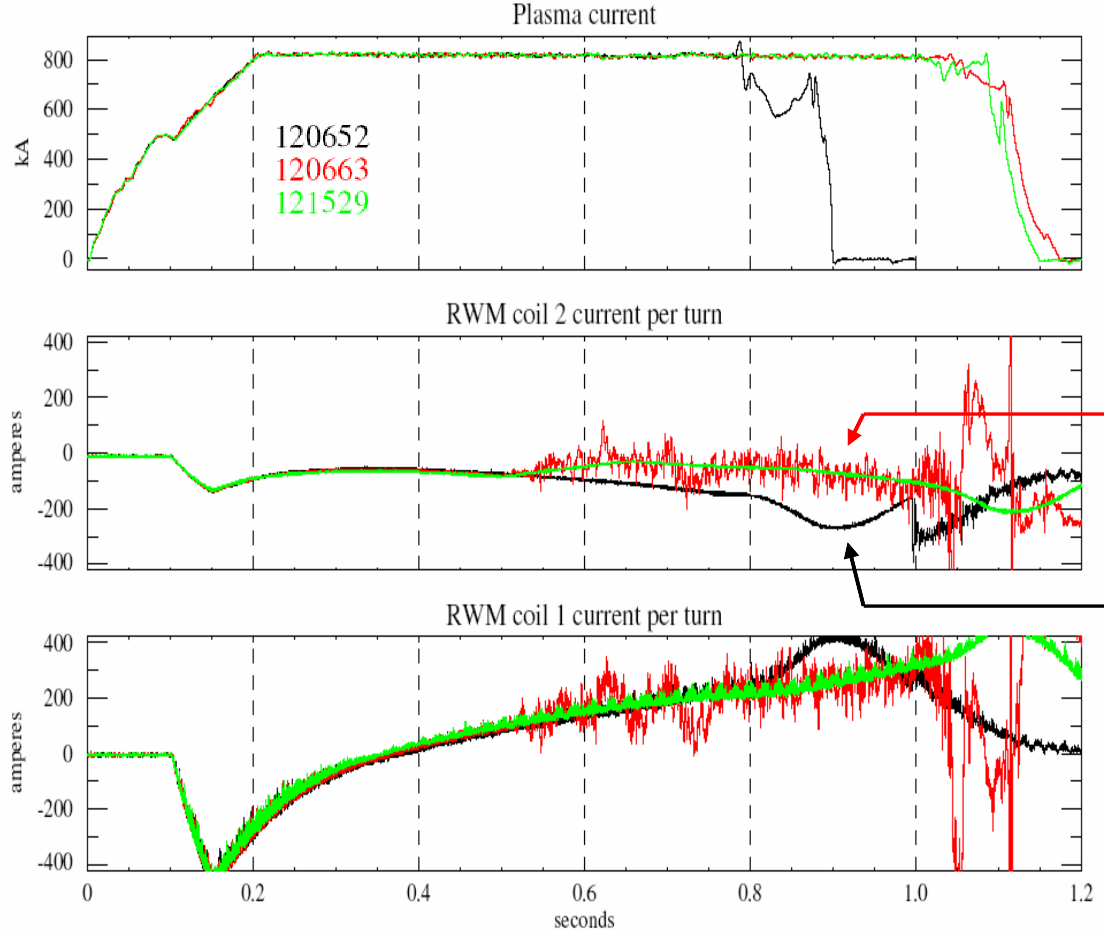
- Mode detection
  - Linear compensation: PF, TF, OH
  - Assume n=1 thru 2 modes present
- RWM/EF coil current driven by:
  - Pre-programmed (braking, spectr.)
  - Correction of OHxTF EF
  - Feedback on n=1 component of B_P
- Feedback control optimization:
  - Scan phase of n=1 B_P wrt coil B_R
  - Scan proportional gain (0.7 optimal)

- **No error field control during high β_N phase**
- **TF-EFC**
- **TF-EFC + active n=1 B_P feedback**



Plasma performance from time-averaged SPA currents from feedback equivalent to non-time-averaged currents

- **TF-EFC**
- **TF-EFC + active n=1 B_P feedback**
- **TF-EFC + time-averaged active n=1 B_P feedback**



- β_N, rotation (not shown) similar with and w/o time-averaging of coil currents
  - Green shot EFC currents ***pre-programmed*** ⇒
  - n=1 RWM is stable
  - Stabilized by sustained Ω_ϕ
- Feedback on n=1 B_P changes EFC amplitude and phase relative to TF-EFC alone
  - TF EF model known to lose accuracy late in shot
  - Modification of RFA (and hence EFC) from β variation also possible

Summary

- OH lead-area EF tilts TF bundle several mm → n=1 EF in vessel

- TF-EFC yields 50% increase in duration above no-wall limit

- Implemented real-time low-f mode-ID and n=1 B_P feedback
- Optimized phase and gain, compared and added to TF-EFC
  - **n=1 feedback alone not (yet) robust**
  - **n=1 feedback + TF-EFC doubles flat-top duration above no-wall limit**
  - Time-averaged control currents give same response → RFA suppression

- Future work:
  - Attempt to reduce OH error field and/or better constrain TF motion
  - Incorporate non-linear TF motion to improve TF-EFC late in discharge
  - Incorporate up + down and B_R + B_P sensors for improved mode-ID
  - Study full plasma response to EF with DCON/IPEC **(J. Park – QP1.29)**

Backup Slides

Radial field measurements at ends of solenoid imply TF tilts and is approximately fixed at bottom of machine

- **Vacuum shot: OH waveform from 800kA discharge (constant TF)**
- **Upper field significantly different than expected ⇒ 50-70G local EF**
- **Field at bottom close to expected value → small relative motion**