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High-β Error Field Detection (1515) and Dynamic Error Field Correction (1516)

Clayton E. Myers

S. P. Gerhardt, J.-K. Park, and J. E. Menard

XP 1515, 1516
MS TSG Review
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XP Goals and Allocations

- XP 1515: High-beta *n*=1,2,3 error field detection
  - Goal: Assess *n*=1,2,3 error fields at high-β → detect not correct
  - Allocation: 0.5 run day (non-XMP CCE) → ~12 shots
- XP 1516: Dynamic error field correction (DEFC)
  - Goal: Optimize DEFC observer (miu) and PID controller
  - Allocation: 1.0 run days (non-XMP CCE) → ~24 shots

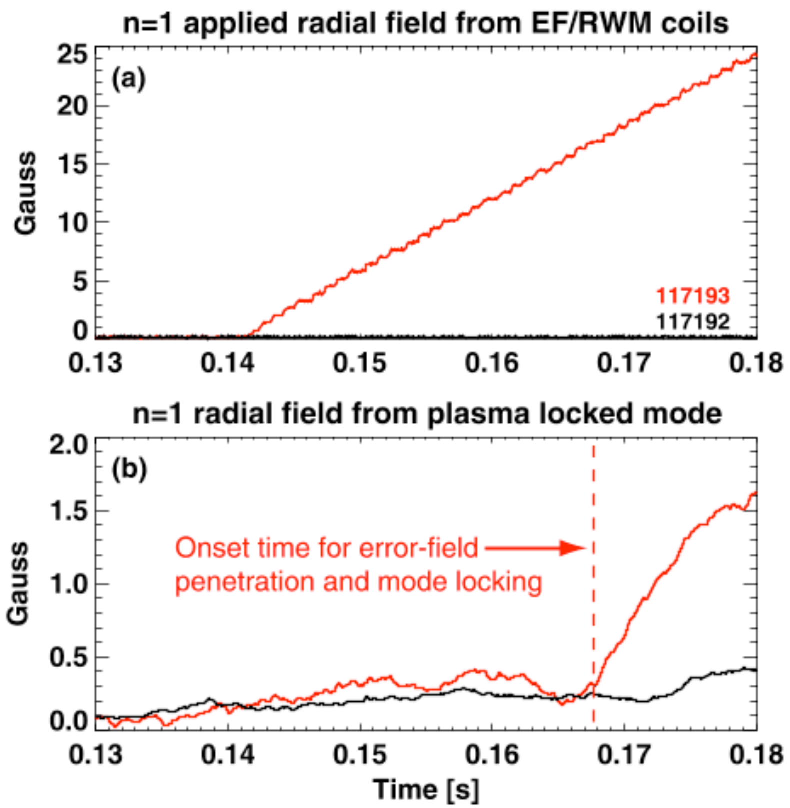
Diagnostic & target plasma requirements

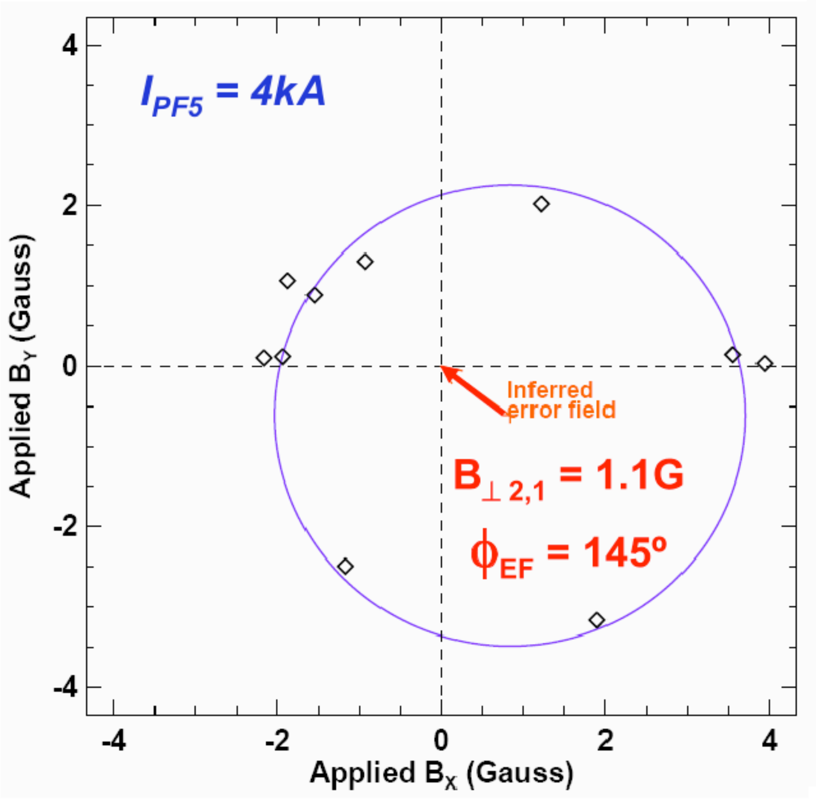
- Diagnostics:
  - RWM/EF sensors (locked modes)
  - CHERS (rotation)
  - Disruptions
- Target plasmas:
  - H-mode discharges above the no-wall limit
  - Need CHERS as fast as it will go → NB1 only (?)
- Hardware requirements:
  - NSTX-U fiducial shot
  - RWM coils + SPAs

XP 1515: High-β Error Field Detection

Step 1: *n*=1 compass scan (4 shots)

- Ramp applied *n*=1 amplitude at fixed phase → look for locked mode
- Four points to fill out the circle → identifies intrinsic *n*=1 error field

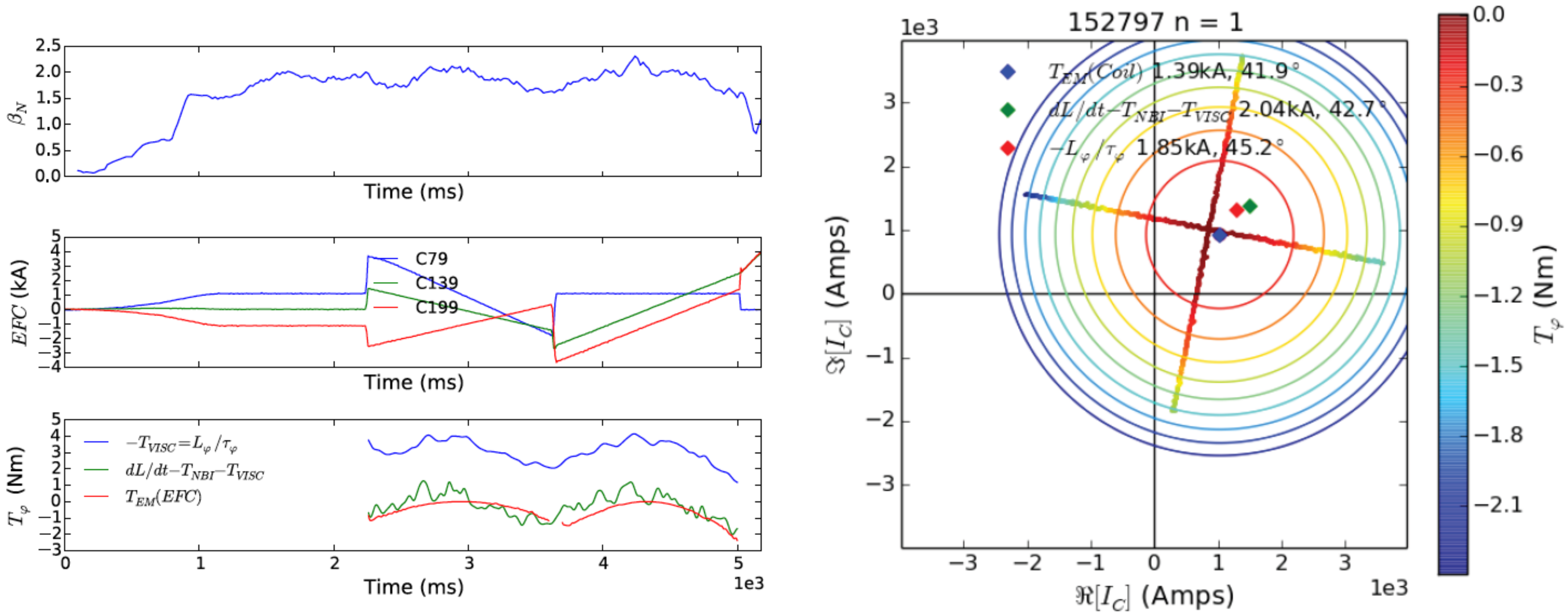




Menard et al., *NF* **50**, 045008 (2010)

Step 2: *n*=1 amplitude and/or phase sweep (2 shots)

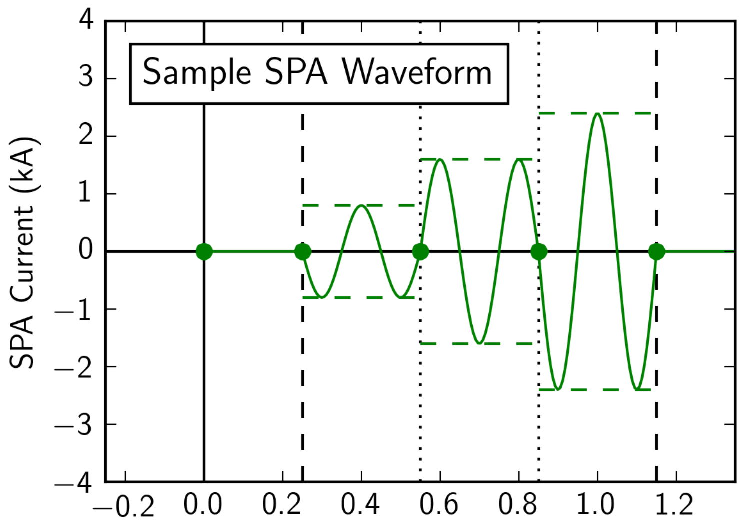
- Try to use DIII-D technique of ramping amplitude through zero at fixed phase
- Need to fill out two axes in complex phase space (see below)
- Only takes one shot in DIII-D → at least two in NSTX-U (need ~1s flattop?)
- Could alternatively scan phase at fixed amplitude (traveling wave)



N. C. Logan, Ph.D. Thesis, Princeton University (2015)

Steps 3 & 4: *n*=2,3 amplitude (or phase) sweep (5 shots)

- 6 SPA setup allows *n*=2,3 perturbations in same XP
- For *n*=2 (3 shots):
  - Amplitude modulation with 5 Hz phase sweep on top (three amplitudes per shot, 300 ms flattop per amplitude)
  - Run same shot positive and negative
  - Select three refined amplitudes for third shot
  - [Or try amplitude sweep as with *n*=1]
- For *n*=3 (2 shots):
  - Three amplitudes per shot
  - No phase sweep possible
  - Simply flip sign in second shot



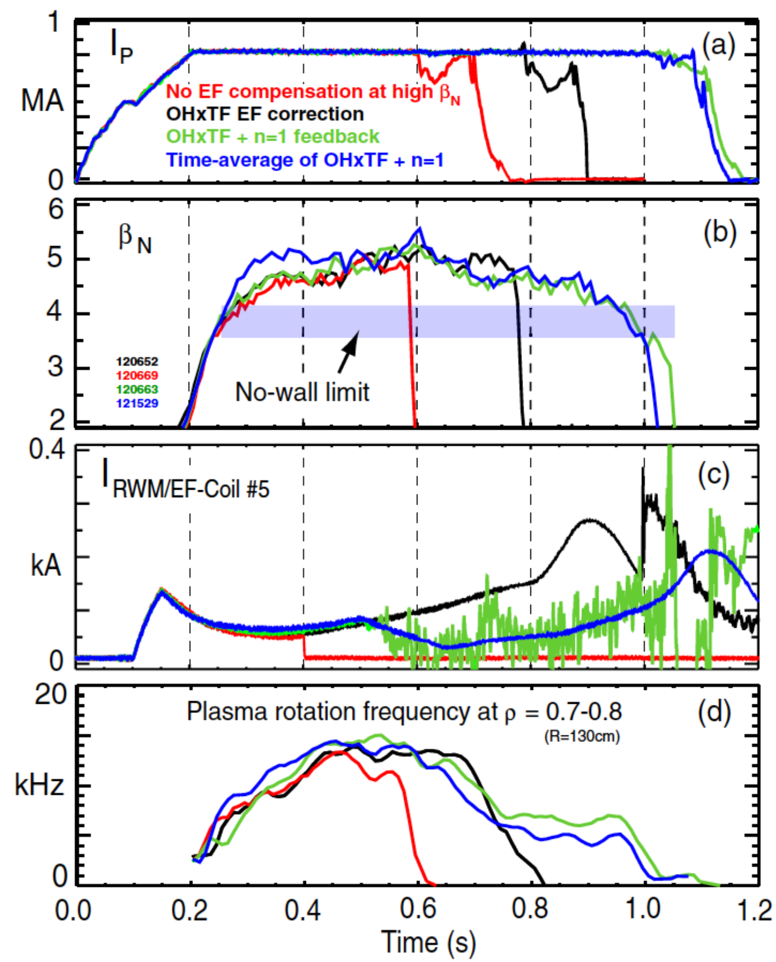
XP 1515 Synthesized Shot Plan

• Step 1: *n*=1 compass scan (locking)	4 shots
• Step 2: *n*=1 amplitude sweep (rotation)	2 shots
• Step 3: *n*=2 amplitude modulation/phase sweep	3 shots
• Step 4: *n*=3 amplitude modulation	2 shots
• Step 5: Fire shot at best combined settings	1 shot
Total:	12 shots

XP 1516: Dynamic Error Field Correction

Dynamic Error Field Correction in NSTX

- Previous results
  - Longest NSTX discharges achieved with real time *n*=1 EF correction
  - Standard tool for NSTX operation
- This XP: Optimization of PID dynamic error field correction
  - The mode ID upgrade (miu) algorithm corrects for static and AC pickup on the RWM/EF sensors
  - Tune the sensors, phases, and gains in the miu-based PID feedback algorithm
  - Utilize low pass filter (already available in PCS) to isolate the effect of DEFC from fast RWM control



J. E. Menard, et al., *NF* **50**, 045008 (2010)

Real-time sensor compensations for "Mode ID"

- Sensors should measure the *n*=1 field from the plasma only.
  - Need to "compensate" the i^{th} sensor B_i for other sources of field
  - With proper compensations, vacuum shots produce no signal
- ~~Three~~ Two compensations now in real-time system

Static
Present From Beginning

$$C_{i,static} = \sum_{j=0}^{NumCoils-1} p_j I_j$$

960 Coefficients

~~***OHxTF***~~
~~***New For 2010***~~

~~$f_i = LPF\left(I_{OH} \times I_{TF}; \tau_{OHxTF,i}\right)$~~

~~$f_i = \frac{f_i}{1+\beta_i f_i}$~~

~~**if** $f_i > 0$ **then** $C_{OH\times TF,i} = r_{p,i} f_i$~~

~~**if** $f_i < 0$ **then** $C_{OH\times TF,i_i} = r_{n,i} f_i$~~

~~***96 Coefficients***~~

AC Compensation For
Fluctuating RWM Coil Currents
New For 2010

$$C_{AC,i}(t) = \sum_{j=0}^{5} \sum_{k=0}^{k_{max}} p_{i,j,k} LPF\left(\frac{dI_{RWM,j}(t)}{dt}; \tau_{AC,i,k}\right)$$

1008 Coefficients

Final Field For Plasma Mode Identification

$$B_{i,plasma} = B_i - C_{i,static} - \cancel{C_{i,OH\times TF}} - C_{i,AC}$$

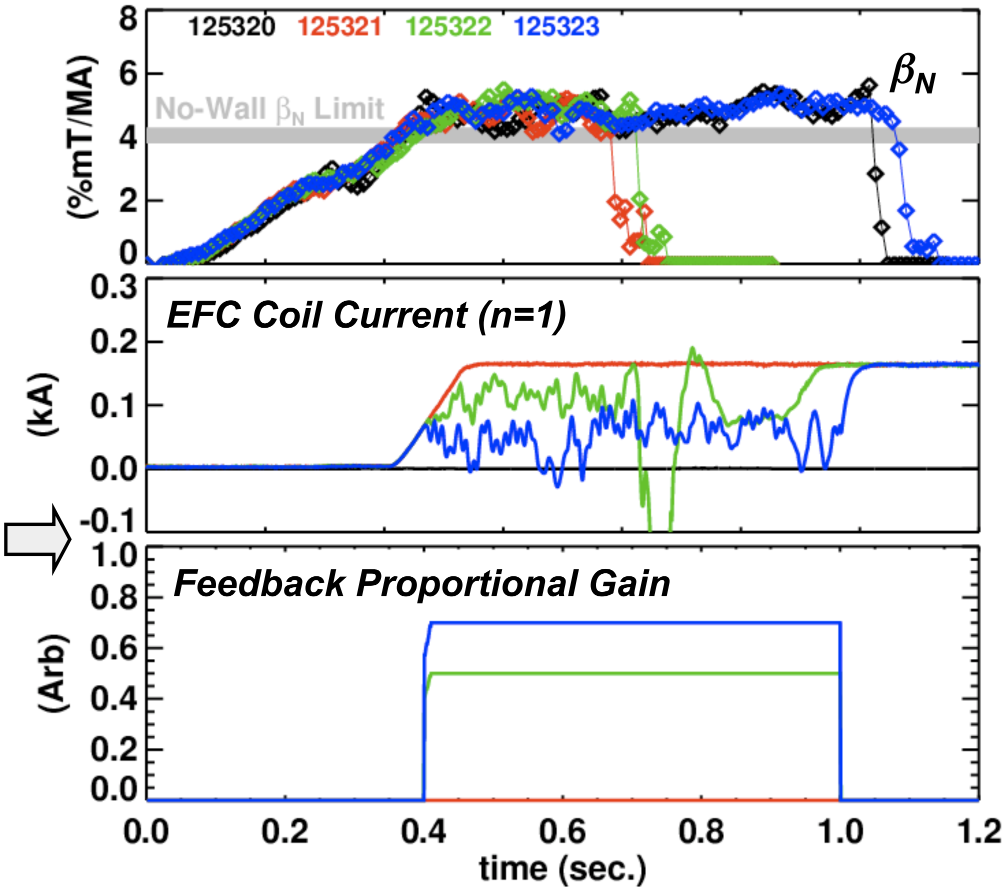
remaining compensation: vessel eddy currents via loop voltages

DEFC tuning prescription (Menard et al.)

Pre-programmed n=1 EF correction requires a priori estimate of intrinsic EF
Detect plasma response → **EF correction using *only feedback on RFA***

RFA Suppression Algorithm

- **Use discharge with rotationally stabilized RWM.**
- **Deliberately apply n=1 EF in order to reduce rotation, destabilize an RWM.**
- **Find feedback phase that reduces the applied n=1 currents (B_P sensors).**
  - **Direct coil-sensor pickup is removed.**
- **Increase the gain until currents are nearly nulled and plasma stability is restored.**



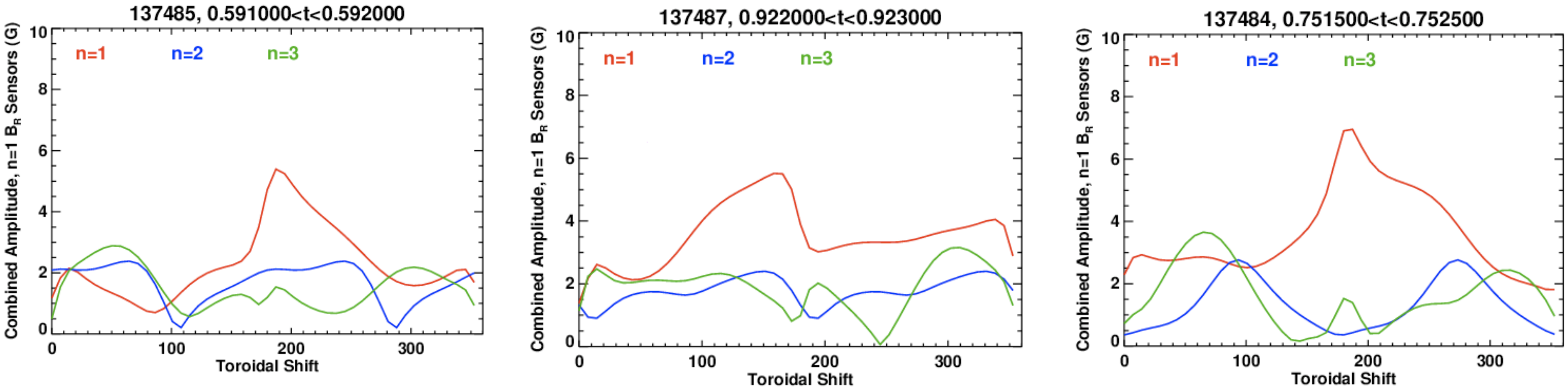
→ *Use same gain/phase settings to suppress RFA from intrinsic EF* ***and*** *any unstable RWMs*

XP Preparation

- Prove that RWM/EF sensor compensation is working
- Early decision point:
  - Use intrinsic or deliberate n=1 error field for DEFC tuning?
- Will tune DEFC with two independent observers: the B_P and B_R RWM/EF sensors:
  - Should get preliminary gain and phase scan from XMP 121 (6 SPA RWM control checkout)
  - For each sensor set, need "optimum spatial phase" → see next slide
- Parameters to scan per observer (B_P,B_R):
  - Feedback gain
  - Feedback phase
  - Low pass filter (LPF) time constant = [off, 20 ms, 40 ms]?

Determining the upper/lower spatial phase difference

- Find time in discharge when there is likely to be a dominant n=1 mode.
  - Just after an n=1 mode stops rotating and locks to the wall.
  - Large RWM.
- Find spatial phase that maximizes the n=1 amplitude.
- For B_P sensors, spatial phase of 150-180° is the clear winner.
- Appears to be an optimum for B_R sensors around 180° as well.
  - XP-802 used 0° B_R spatial phase for feedback, while off-line analysis presently uses 250°.



Use this spatial phase (180°) when generating the mode-ID matrix for realtime control

XP 1516 Synthesized Shot Plan

- Run shots with three settings per shot (~250 ms duration?)

- Step 1: B_P obs. = 2 gains × 4 phases × 3 tLPF — 8 shots
- Step 2: B_R obs. = 2 gains × 4 phases × 3 tLPF — 8 shots
- Step 3a: Test against intrinsic EF if deliberate EF used — 4 shots
- Step 3b: Run with B_P+B_R feedback for comparison
- Step 5: Apply traveling wave of various frequencies to test suppression via DEFC — 4 shots

Total: 24 shots