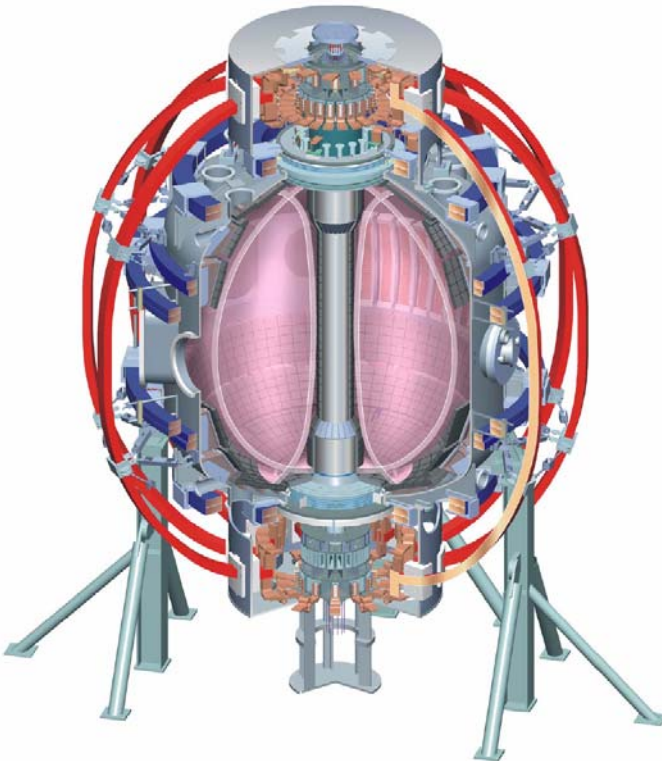


# Locked mode thresholds and EFA with applied error fields

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**NSTX Results Review  
for FY2004 Run**

**Princeton Plasma Physics Laboratory  
Princeton, NJ  
September 20-21, 2004**



Columbia U  
Comp-X  
General Atomics  
INEL  
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LANL  
LLNL  
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Nova Photonics  
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CEA, Cadarache  
IPP, Jülich  
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# Goals of XPs 415 & 455

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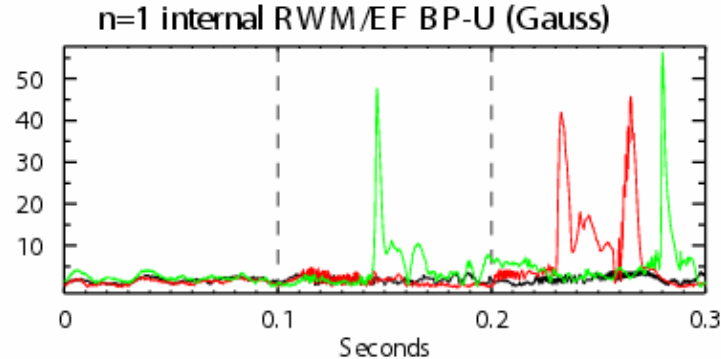
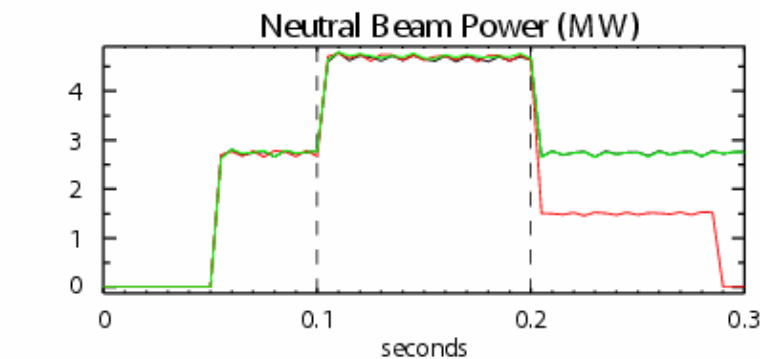
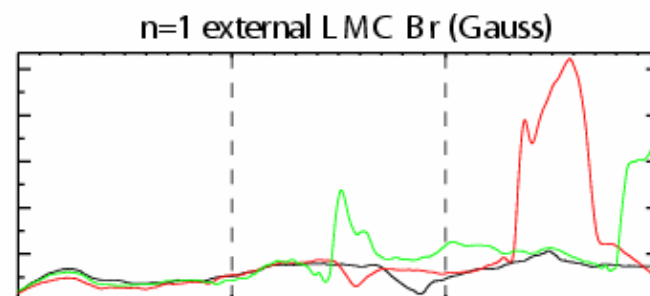
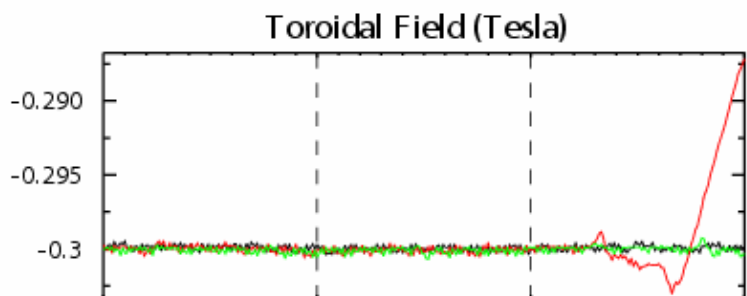
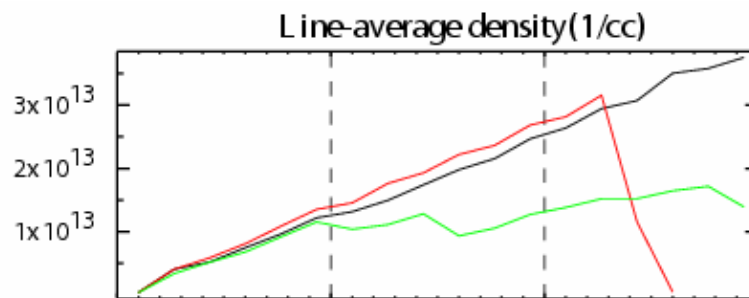
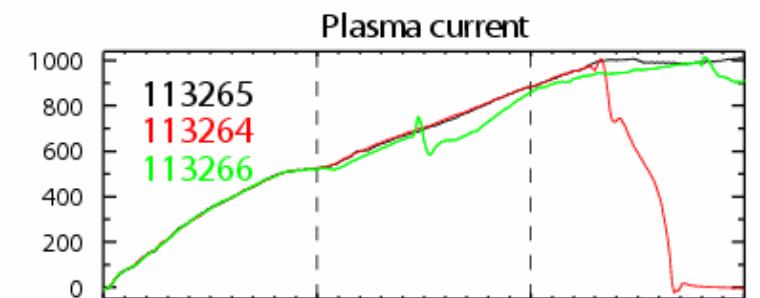


- **XP 415 - Parametric dependence of low-density locked-mode threshold**
  - Find locking threshold vs. density and  $B_T$
  - Compare external to internal sensor signature
  - Measure rotation profile during locked phase
  
- **XP 455 - Error-field studies using tearing modes and mode control coils**
  - Try to modify locking during  $I_p$  ramp with RWM coils
    - Vary coil current amplitude and polarity
    - Determine threshold density vs. applied B-field
  - Extend results into flat-top (started)
    - Extend coil current pulse and scan coil current amplitude

# XP415: $I_p$ ramp-up LM threshold near $\bar{n}_e = 1.2 \times 10^{19} \text{ m}^{-3}$



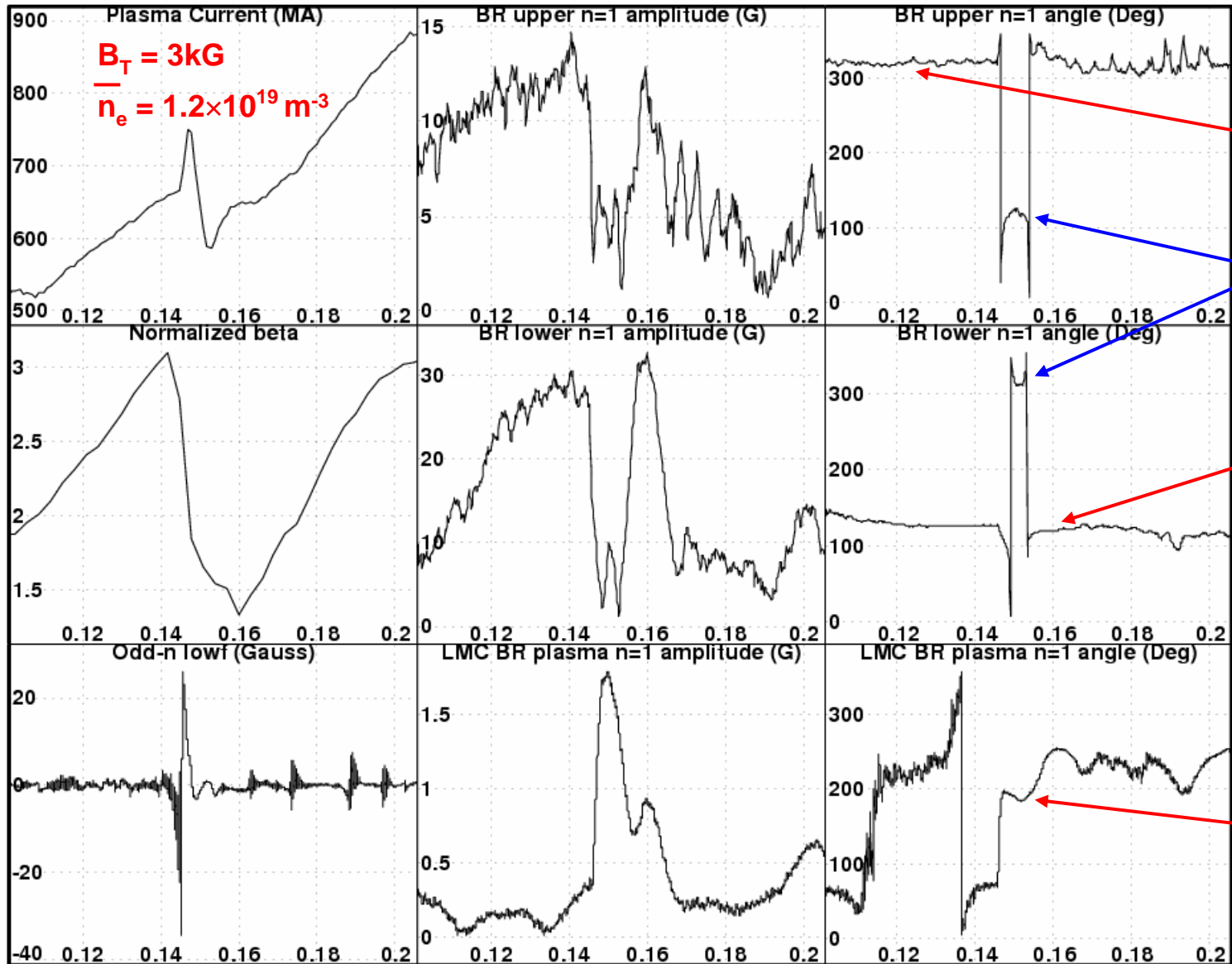
- Had to avoid early H-mode to get mode to lock at 3kG
- Rotating mode locks later w/o sufficient NBI



# Toroidal phase data from sensors offers clues into EF



NSTX RWM/EF BR n=1 Modes 113266



$\phi_{\text{ENG}} = 310^\circ$

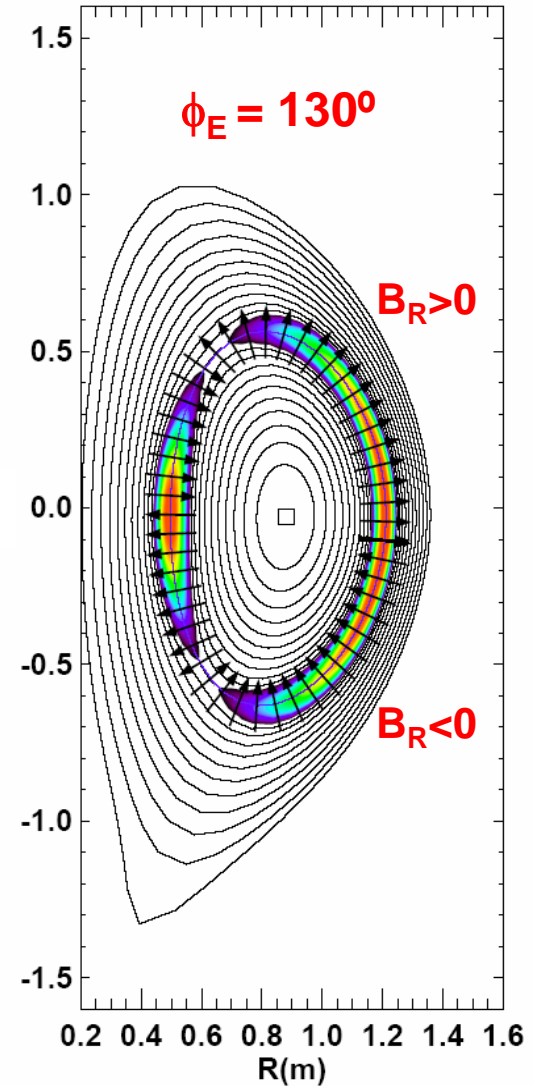
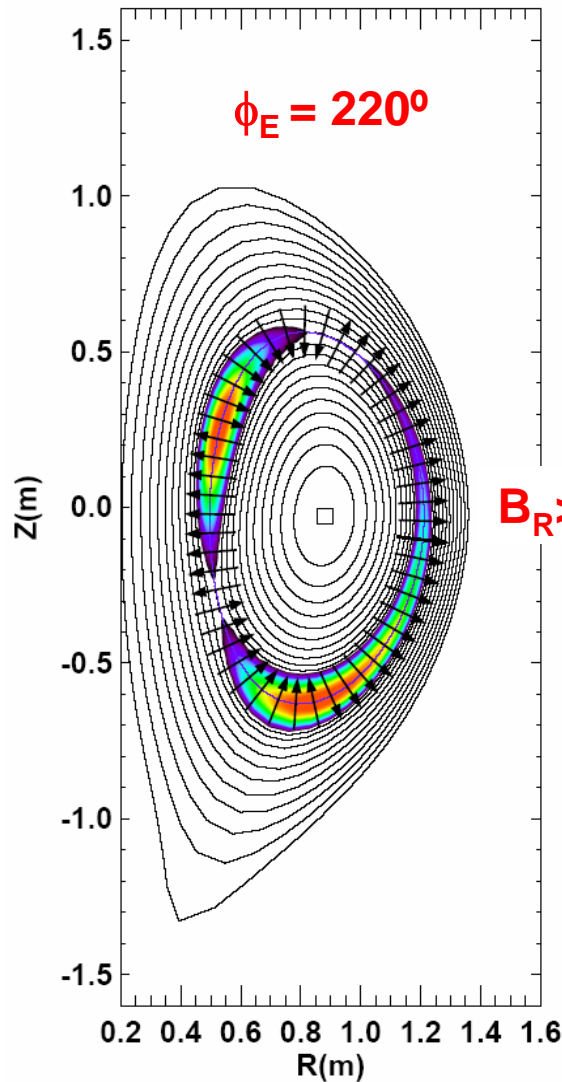
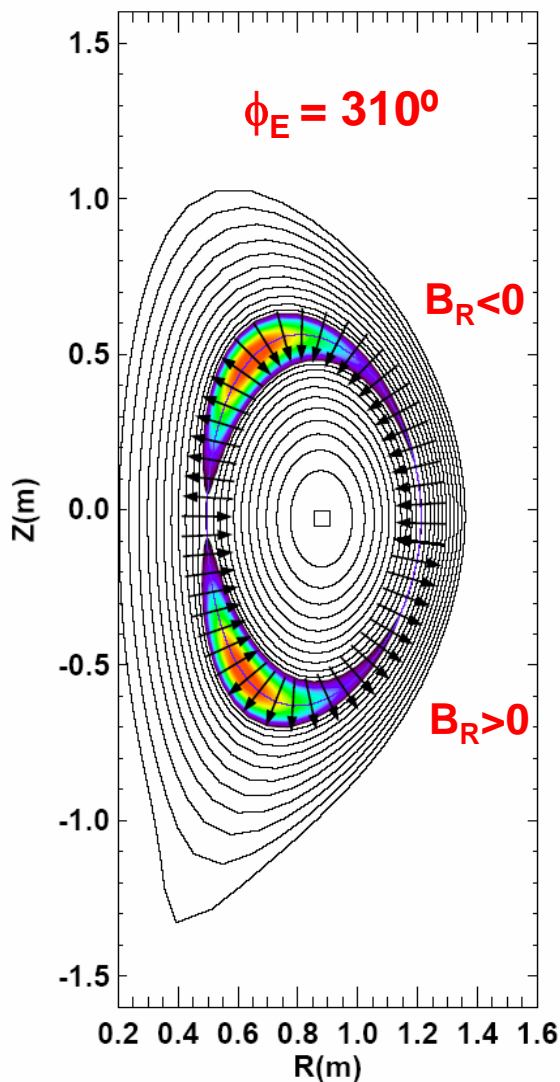
Locked  
phase

$\phi_{\text{ENG}} = 120^\circ$

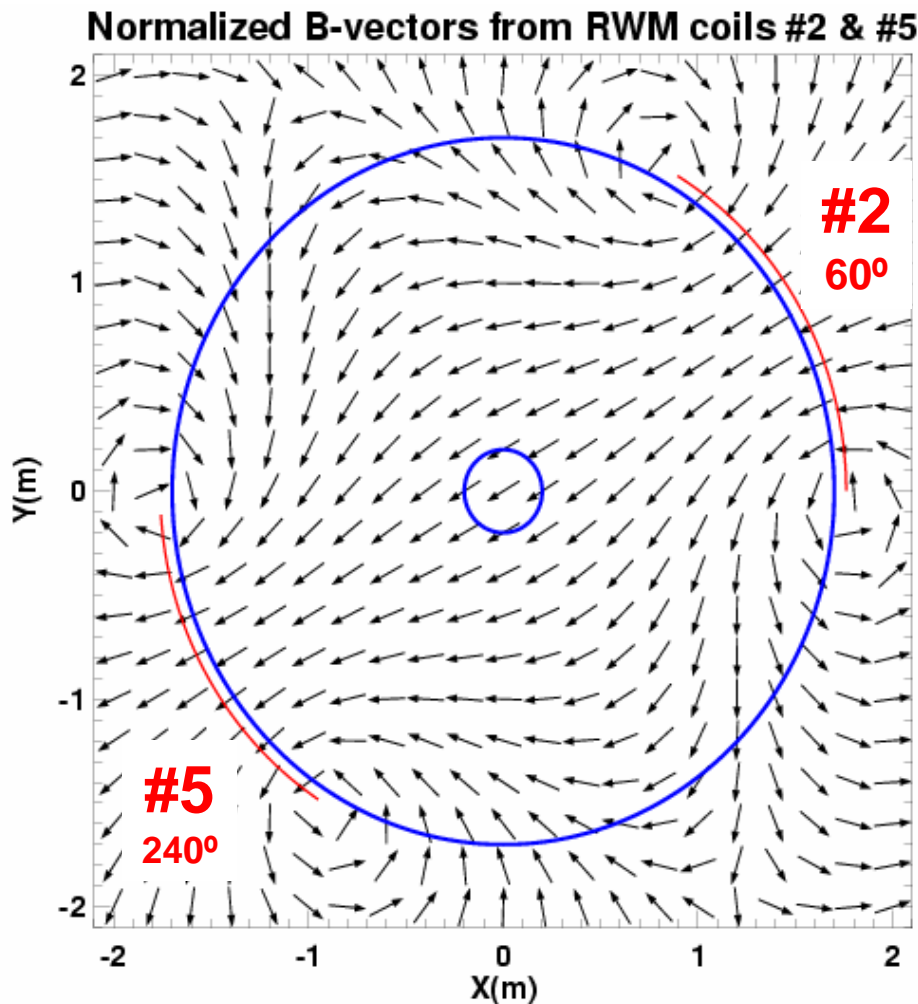
$\phi_{\text{ENG}} =$   
 $200\text{-}250^\circ$

(Bays G,H)

Data suggests island locked with O-point near  $Z=0$ ,  $\phi_{\text{ENG}} \approx 130^\circ \Rightarrow$  apply  $\pm B_R$  at  $\phi_{\text{ENG}} \approx 240^\circ$  (H/I)



# Two external mode control coils used for mode locking & error field studies



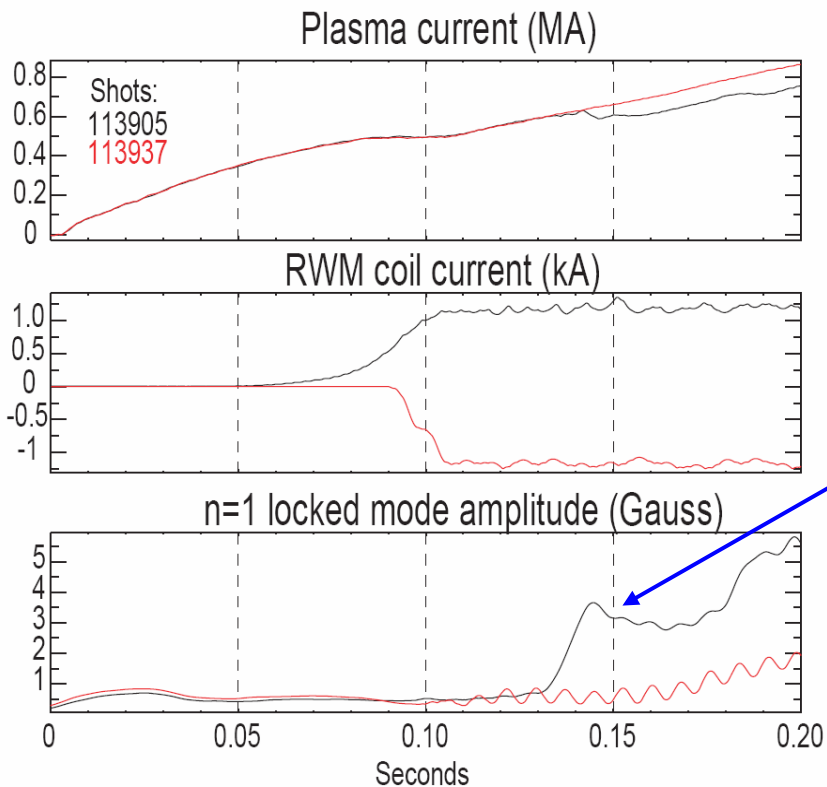
- $1\text{kA } I_{\text{RWM}} \Rightarrow 10\text{G}$  of  $n=1$  radial field @ external  $B_R$  sensors
- $n=3$  amplitude similar @ ext. sensors, but w/ much faster radial fall-off into plasma

# Mode locking threshold during $I_p$ ramp depends on sign of applied external field



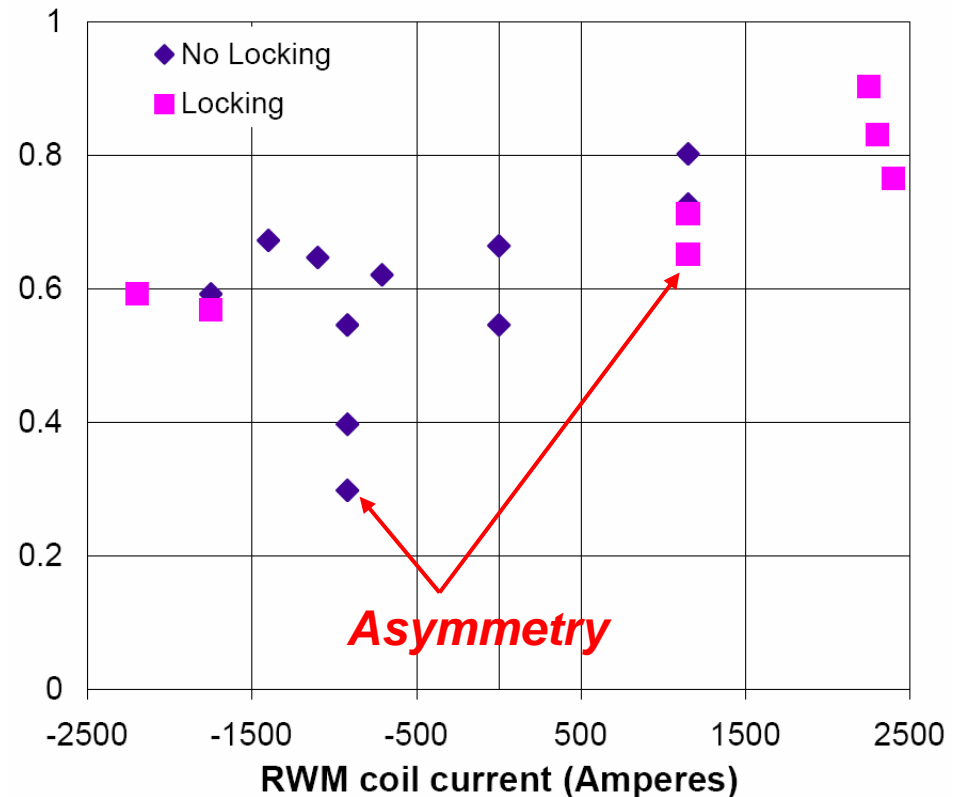
→ residual error field during  $I_p$  ramp

Typical 2/1 locked mode signatures during  $I_p$  ramp w/ RWM coil current on



Density threshold vs. RWM coil current:

$$\bar{n}_e(20) \times q_{95}^{0.8} \text{ (DIII-D scaling)}$$



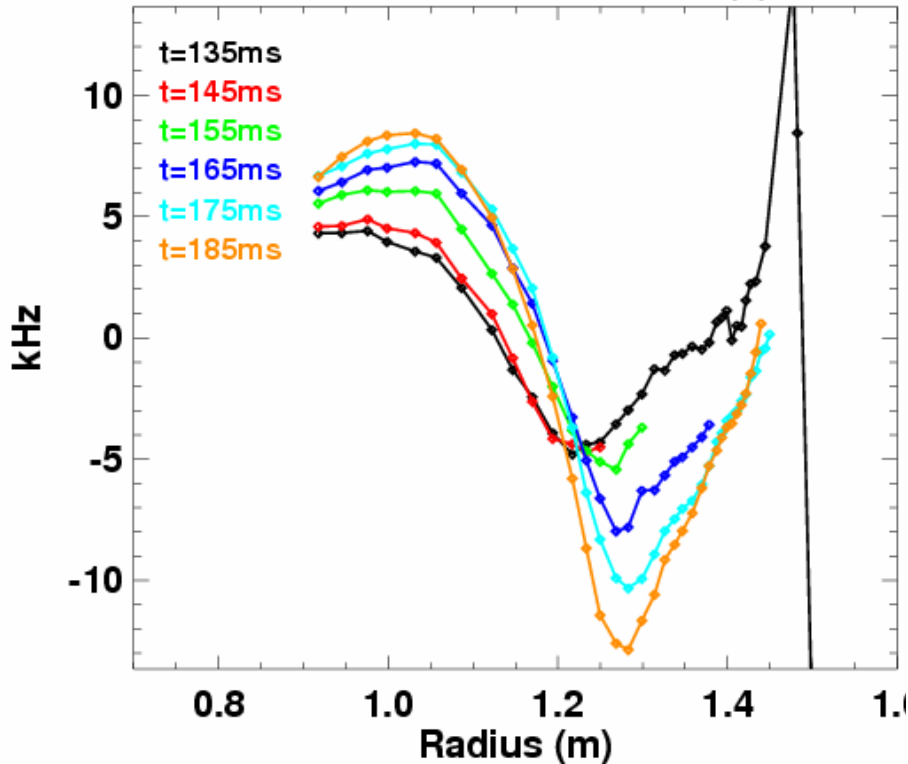
# Rotation evolution also depends on sign of $I_{RWM}$



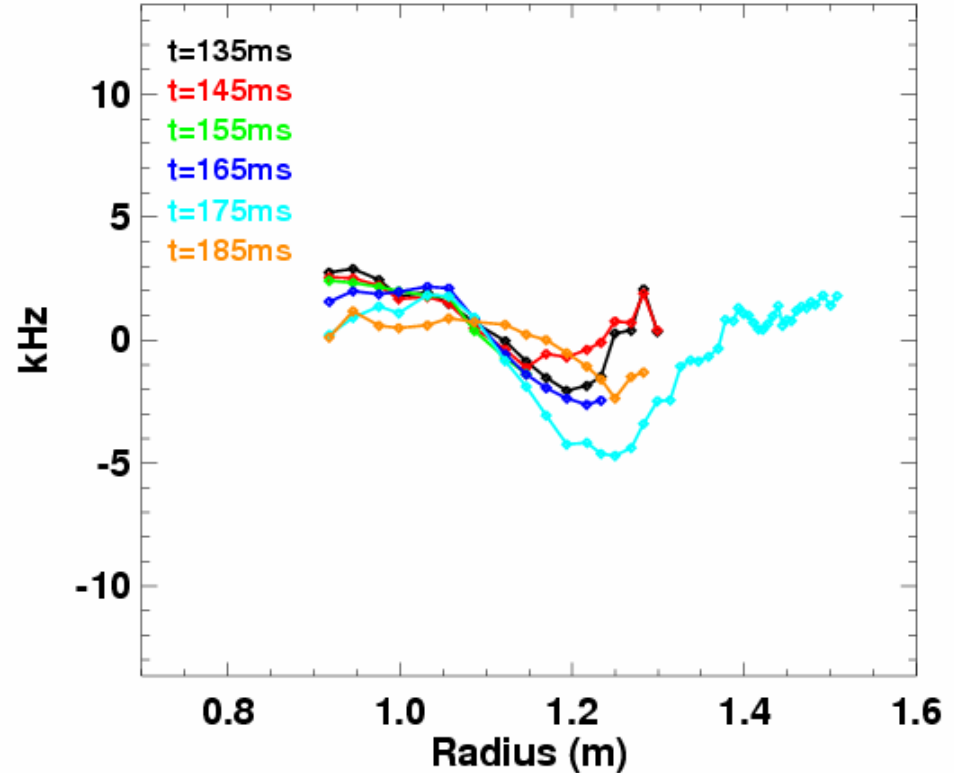
$I_{RWM2} = -1.2\text{kA}$   
mode not locked

$I_{RWM2} = +1.2\text{kA}$   
mode locked and  
rotation clamped near 0

Shot 113937 carbon  $f_{\text{rotation}}$

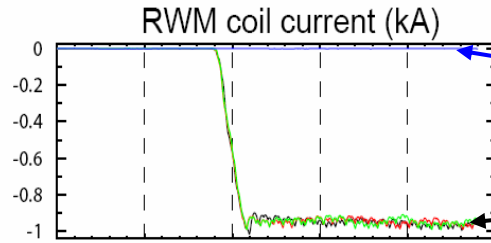
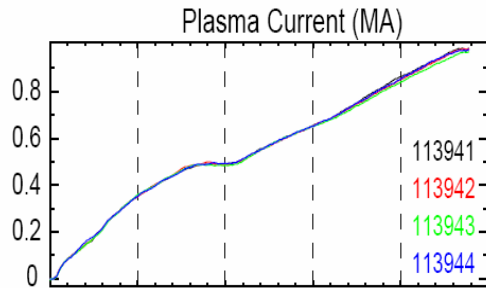


Shot 113905 carbon  $f_{\text{rotation}}$



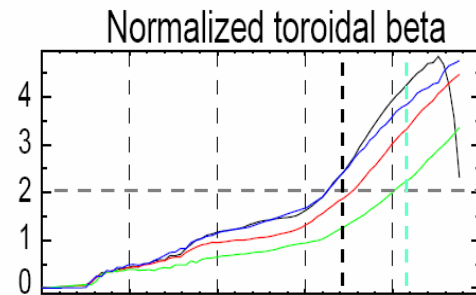
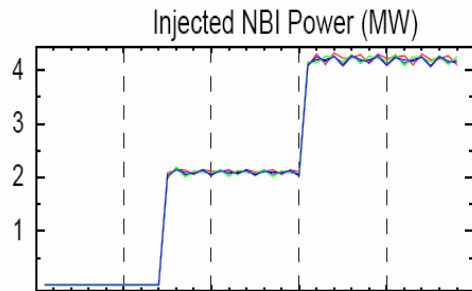


# Locked-mode shots also demonstrate error field amplification (EFA) dependence on $\beta_N$ at low- $n_e$

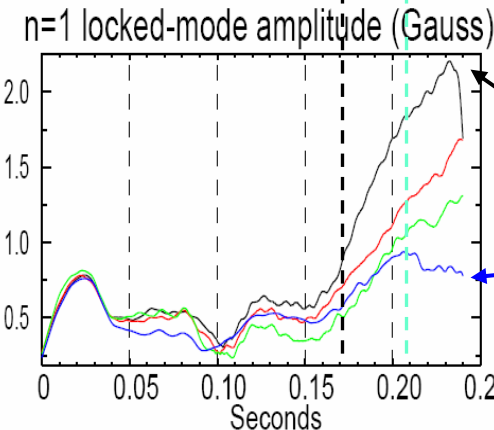
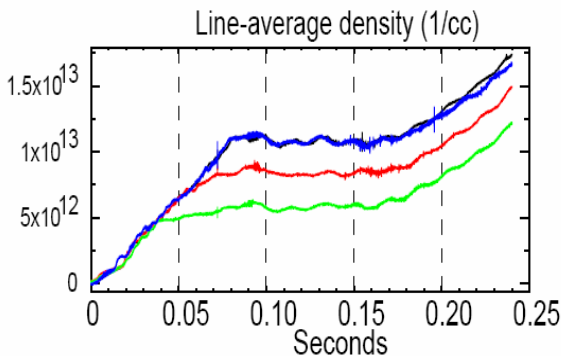


• Blue shot has  $I_{RWM} = 0$

• Others use  $I_{RWM}$  that doesn't cause locking at  $t=140\text{ms}$



•  $n_e$  scan yields  $\beta$  scan after 2<sup>nd</sup> source fires  
– NBI waveforms fixed



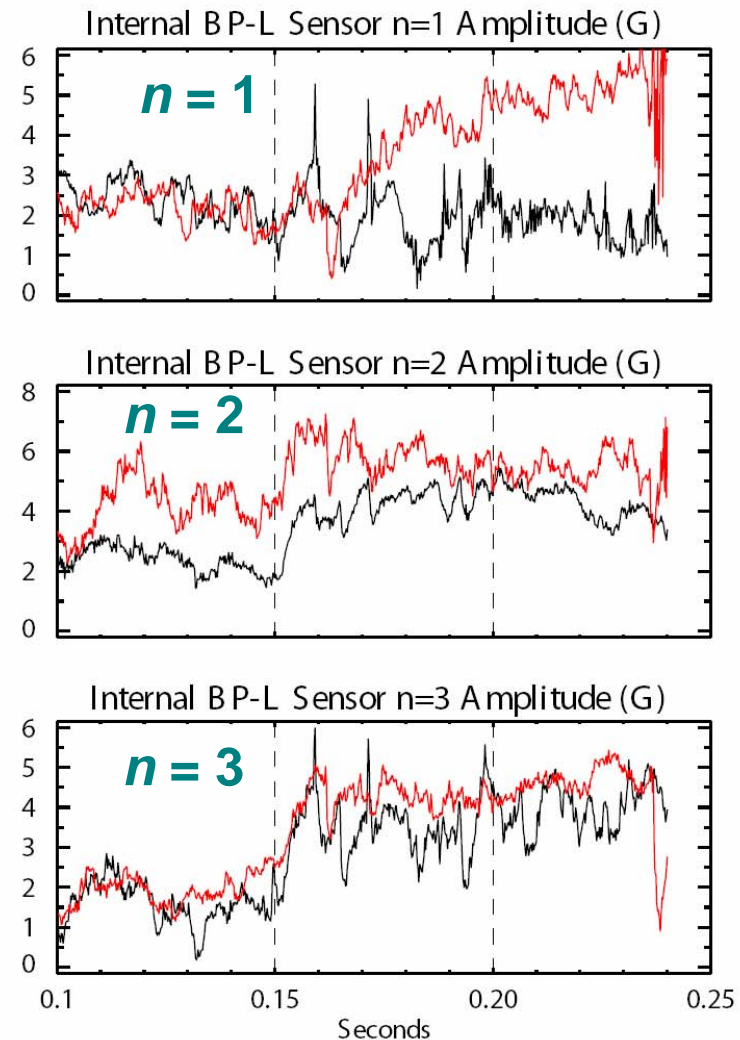
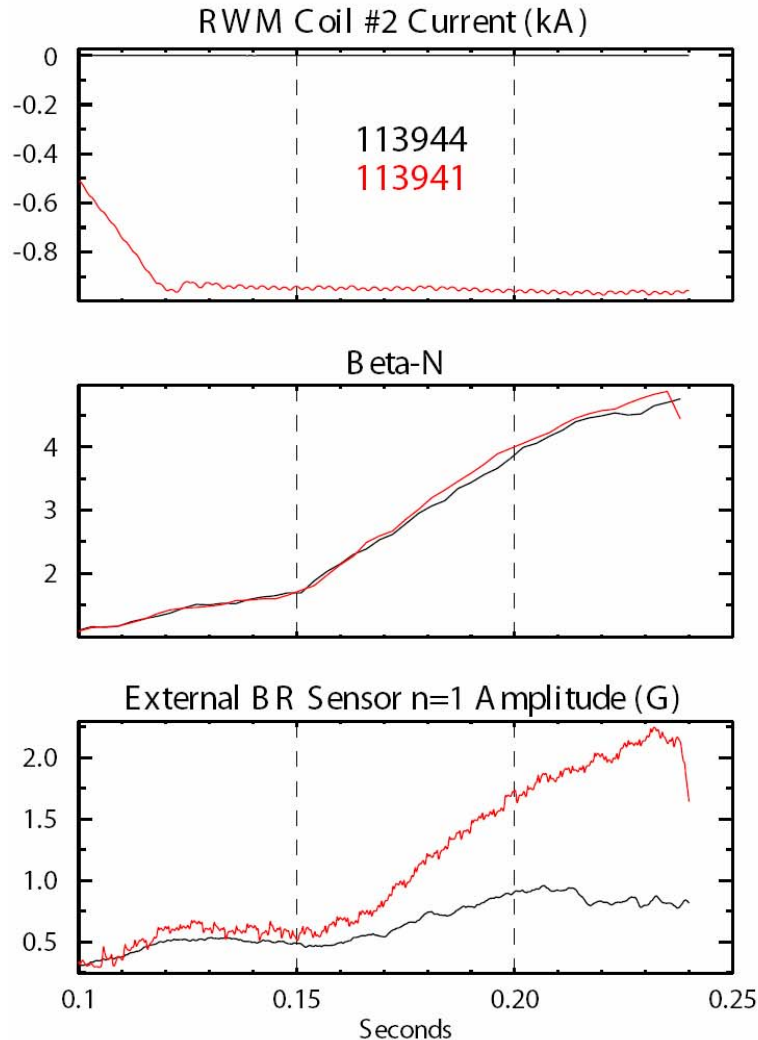
• Plasma amplifies field when  $\beta_N >$  approx. 2

$I_{RWM} = 0$  shot has smallest LM signal  $\rightarrow$  smaller residual error field later in shot?

# Internal sensors find only n=1 EFA



- n=1 EFA factor  $\approx 2-3$  at maximum  $\beta_N$
- n=2 and n=3 EFA weak or absent



# Summary of results from XP 415

## Parametric dependence of low-density locked-mode threshold



- $B_T$  scan with 1MA PF1B LSN and early NBI:
  - Ramp-up locked mode stable at 140ms for all fields tried (3-4.5kG) when plasma achieved early H-mode @ 100ms
    - True even with reduce density prior to transition
  - With density very low prior to normal transition, H-mode transition could be avoided and locked-mode excited at 3kG
    - Did not test  $B_T$  scaling in this condition (due to 3kG limit)
- Locking of rotating mode @ 200ms sensitive to  $P_{NBI}$ 
  - Need 2MW or above to keep mode from locking
  - Likely evidence of rotation (torque) threshold
    - Have CHERS data, not in MDS+ yet

# Summary of results from XP 455

## Error-field studies using tearing modes and mode control coils



- Started from LM target developed in XP415
  - Toroidal position of installed coils chosen based on toroidal phase of locked-modes during  $I_p$  ramp-up (prior to XP455)
    - a.k.a. educated guess from external LM sensors
- Locking density threshold depends on sign of  $I_{RWM}$ 
  - Sign of current consistent with correcting transient EF
    - Possible shift of plate and/or vessel conductor magnetic center
- Error field amplification measured at higher  $\beta_N$ 
  - Later during  $I_p$  ramp, toroidal phase of error field changes, and “corrective” RWM field apparently becomes error field.
  - External & internal sensors measure 2-3 $\times$   $n=1$  amplification
    - Little or no internal  $n=2$  or  $n=3$  amplification of applied EF observed