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Improved Resistive Wall Mode Detection on NSTX

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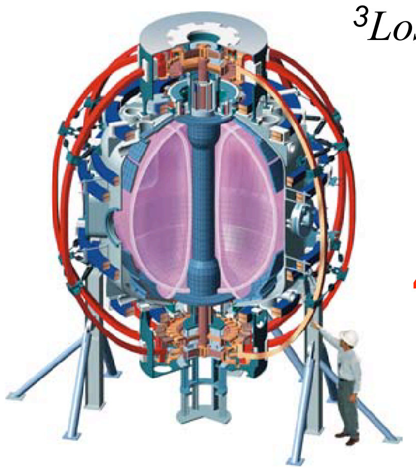

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NSTX

Upgraded RWM/Locked Mode Sensors Allow Greater Analysis & Increased Performance

- Motivation
  - RWM strongly damps rotation
  - Mode structure measurement and detection needed for physics analysis and active feedback
  - Internal sensor array gives earlier mode detection & greater spatial resolution than present external array
- Outline
  - RWM structure aids in understanding rotation damping mechanism
  - Internal sensors offer advantages over external array
  - New sensor array has been installed inside NSTX vacuum vessel
  - New array is capable of n = 1-3 mode identification

Accurate δB Measurement Will Allow for Rotation Damping Calculation

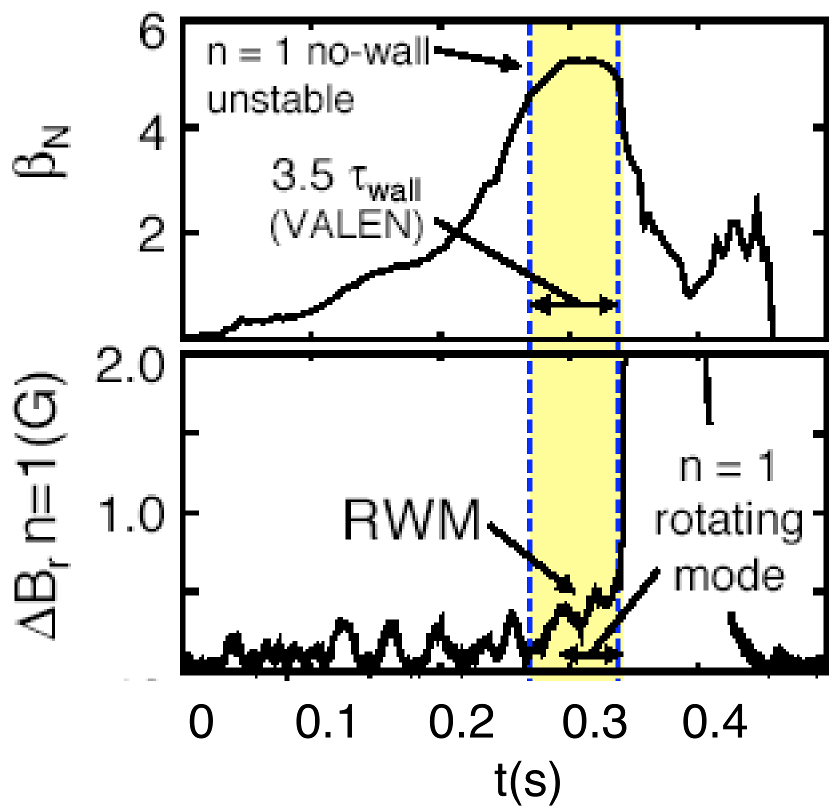
- RWM growth & locking damp rotation
  - leads to β-collapse without rotational stabilization
- Tearing modes usually present
  - does not explain onset of strong core damping when $\beta_N > \beta_{N\ no\text{-}wall}$
- Strong core damping is non-resonant
  - neoclassical viscous model with RWM provides candidate
    - damping $\propto \delta B_r^2 T_i^{0.5}$
    - detailed RWM structure needed to perform accurate calculations
- Calculations ongoing
  - tearing mode coupled with error fields first step
    - see poster LP1.013 by W. Zhu
  - RWM contribution being added

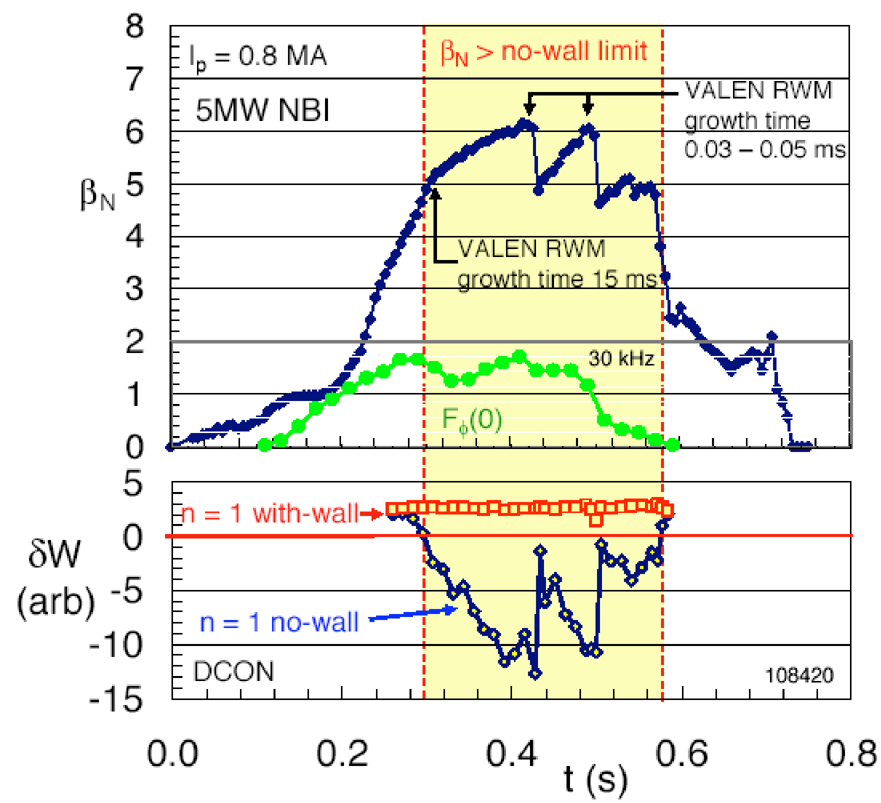
Increased Sensitivity and Mode Structure Detection with New Sensor Array

- Perturbed field measured inside conducting structure
  - present system observes mode after wall penetration
- Improved system capable of resolving up to n = 3
  - present set only measures n = 1
  - n = 2 predicted to be unstable at high-β_N
- New system has higher spatial resolution
  - new set has 12 toroidal locations above and below midplane
  - present set has 6 midplane coils each w/60 deg. toroidal coverage
- New system has fast response for feedback control
  - present set is inadequate for feedback

External Array Shows Weak n=1 signal

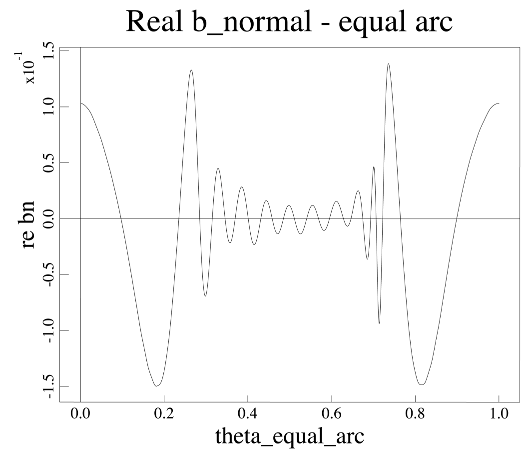
- Weak locked mode signal
- No locked mode signal - RWM?
  - internal array should distinguish



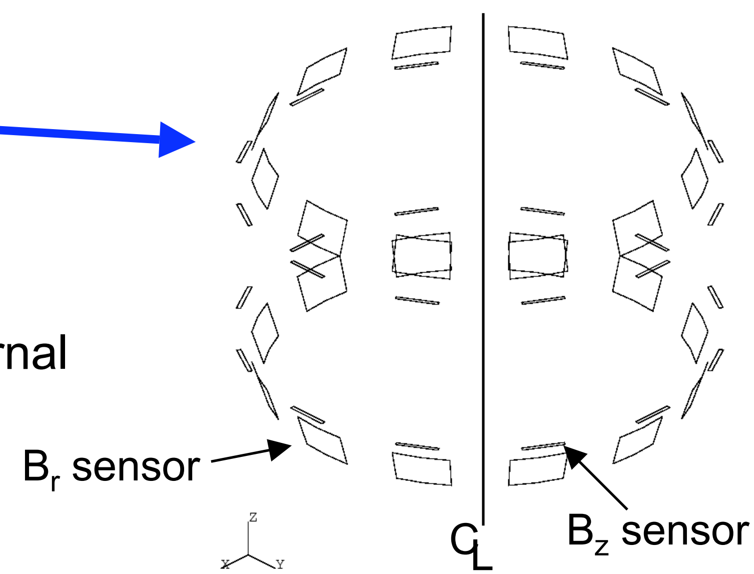


New Sensors Modeled with VALEN 3D and DCON Computed Mode Structure

- DCON gives ideal mode structure
  - computed from shot 108420
    - I_p = 0.8 MA, β_N = 6, β_t = 18%,
  - perturbations strongest at outboard midplane
    - due to ballooning character at high-β
  - eigenfunctions provide input to circuit model



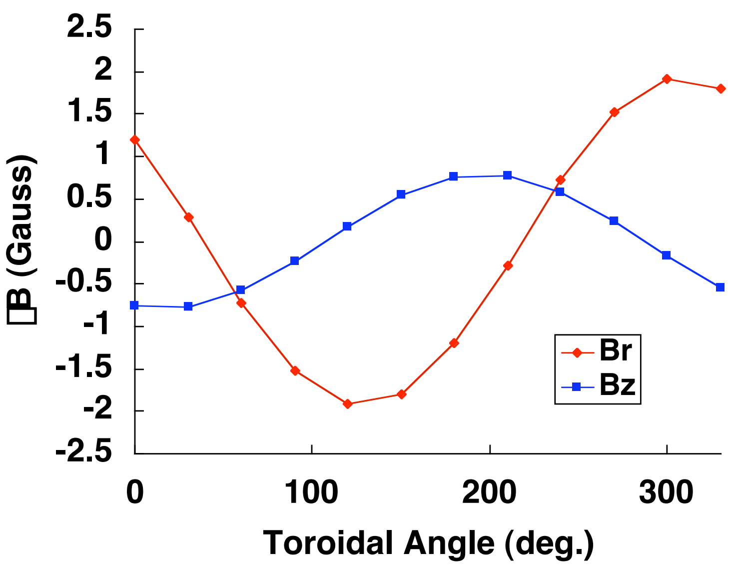
- VALEN simulates sensor array
  - existing n=1 data used for calibration
    - assume locked, slowly growing mode
    - compare predicted to measured external flux



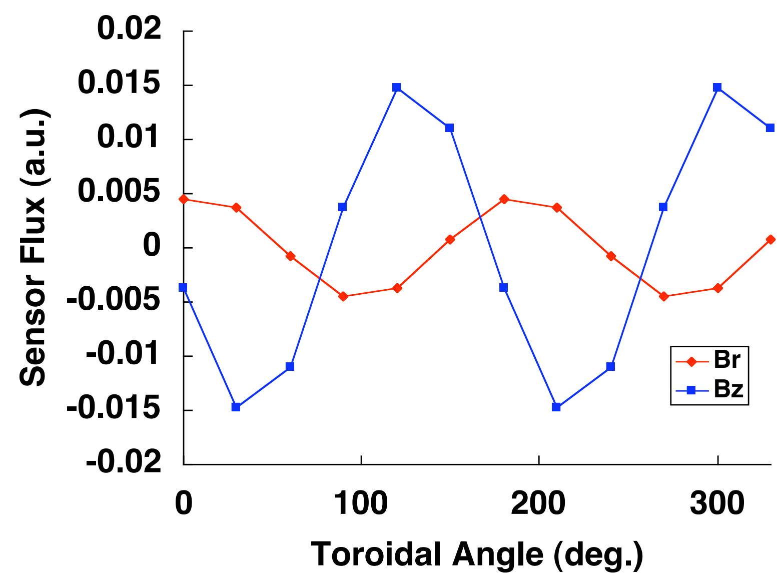
Internal Sensors Have Greater Spatial Resolution & Detect Larger Field Perturbation

- B_r perturbation ~4x larger at internal location than external
  - Maximum external n=1 B_r signal is 0.47 Gauss
- Calculated mode structure from NSTX shot 108420
  - No external n = 2 B data for calibration

Internal n=1 B

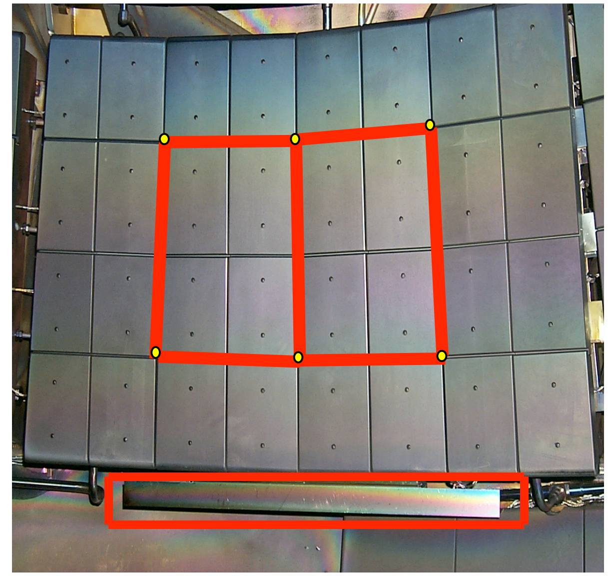


Internal n=2 $_{norm}$

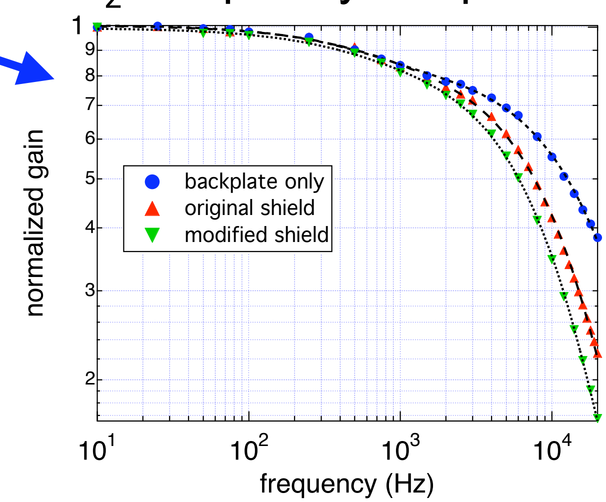


Internal Sensor Array Installed

- Toroidally symmetric B_z and B_r arrays at 12 locations
  - upper and lower arrays □ 48 sensors total
- B_r behind carbon tiles on primary passive plates
- B_z mounted on midplane side of plates
- Adequate frequency response
  - RWM rotates slowly
    - □ ~ 1/□$_{wall}$
  - B_r sensors are much lower inductance
- Instrumentation currently being commissioned

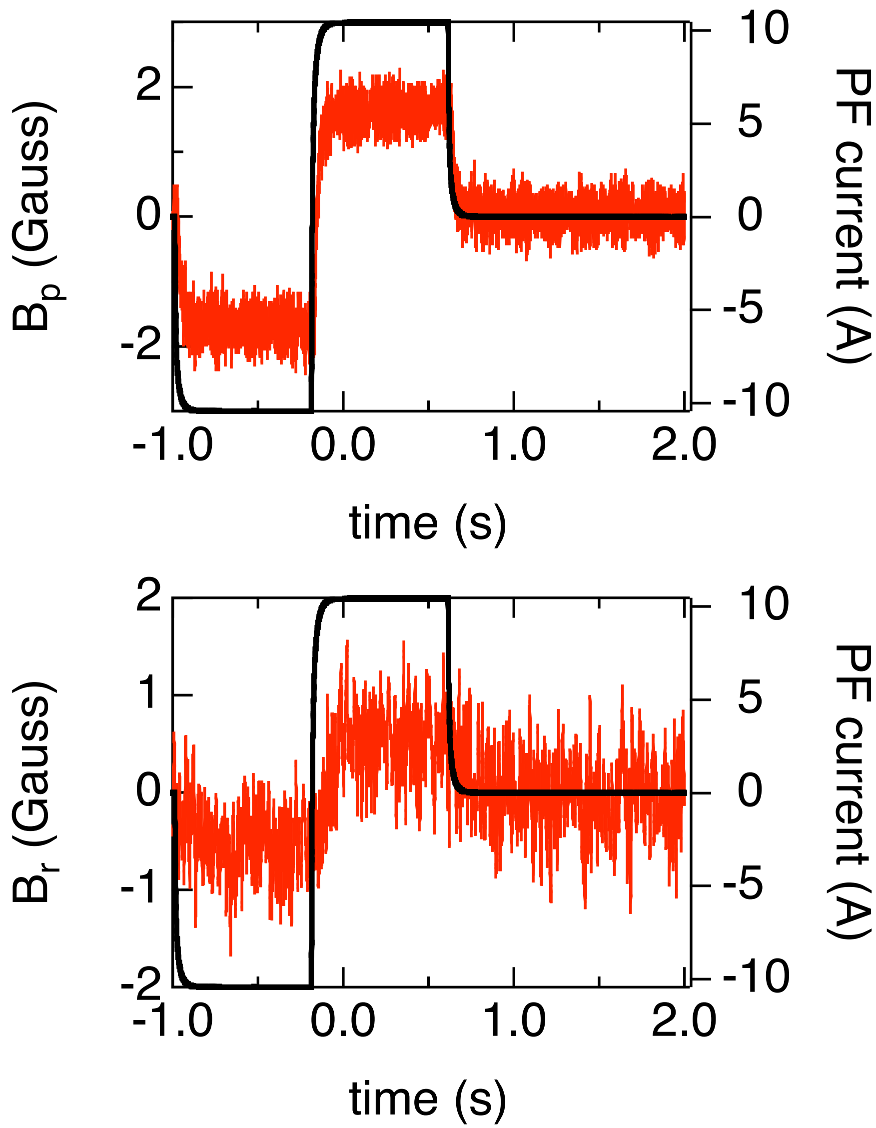


B_z Frequency Response



Sensors Capable of < 1G mode Detection

- Initial sensor tests show good sensitivity
  - limited by sensor area
- noise due to wall/plate eddy currents must be subtracted
  - fields-only shots for calibration
  - noise level of ~ 0.3 Gauss achieved with external sensors
    - utilized local B_z and B_{ϕ} compensation sensors
    - compensation not available with internal sensors
- plasma signal must also be subtracted
  - n = 0 motion

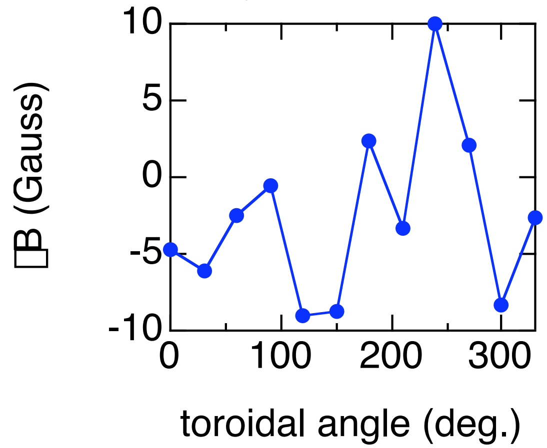


New Sensors Provide Robust Mode Detection for n = 1-3

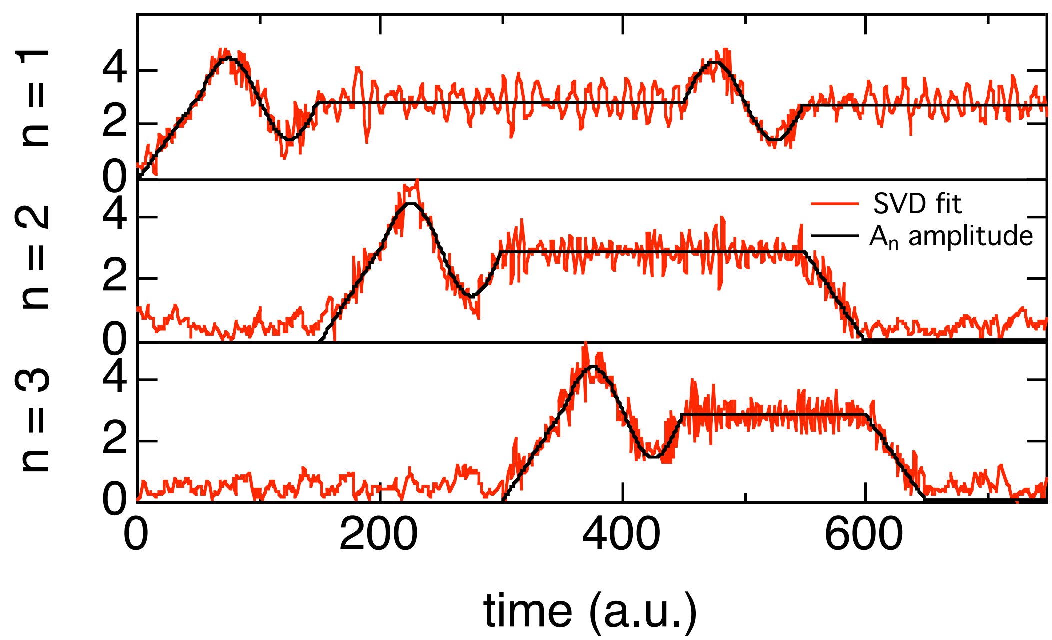
- Noisy signals input to SVD mode detection algorithm
  - signal at each sensor location given by: $S(\phi) = \sum_{n=1,2,3} A_n \sin(\phi + \delta_n)$
    - ϕ is toroidal location of sensor
  - Random Gaussian noise added to each signal
  - Modes readily distinguishable

Raw Signals - 1 Gauss noise

$A_{1\text{-}3}$ = 3 Gauss



SVD Results - 1 Gauss noise



NSTX Ready for Further RWM Studies

- Upgraded sensors necessary for further RWM studies
- Internal B_p & B_r sensor arrays installed in NSTX
  - allows for earlier mode detection
  - gives greater spatial resolution
  - up to n = 3 mode ID possible
- SVD mode detection algorithm provides n = 1-3 identification
- Future work
  - calibrate background subtraction using full field shots
  - use measured mode structure in rotation damping calculations

support slides follow

SVD Analysis Gives Mode Amplitudes and Phases

- SVD fit of signals to solve overdetermined matrix equation:

$$\overleftrightarrow{A}\vec{x} = \vec{b} \quad \text{where} \quad \vec{x} = \begin{bmatrix} A_1 \cos\phi_1 \\ A_1 \sin\phi_1 \\ A_2 \cos\phi_2 \\ A_2 \sin\phi_2 \\ A_3 \cos\phi_3 \\ A_3 \sin\phi_3 \end{bmatrix}$$

$\overleftrightarrow{A} =$ coefficient matrix determined by sensor toroidal locations

$\vec{b} =$ vector of measured signal pair sums and differences

-pairs are grouped with 2 x 180 deg. separation + 4 x 90 deg. separation