Comparison of Measured and Simulated MSE Signals of a Tearing Mode

M.A. Makowski, M. Downes, C.T. Holcomb, R.J. Jayakumar, R. LaHaye, and D. Brennan

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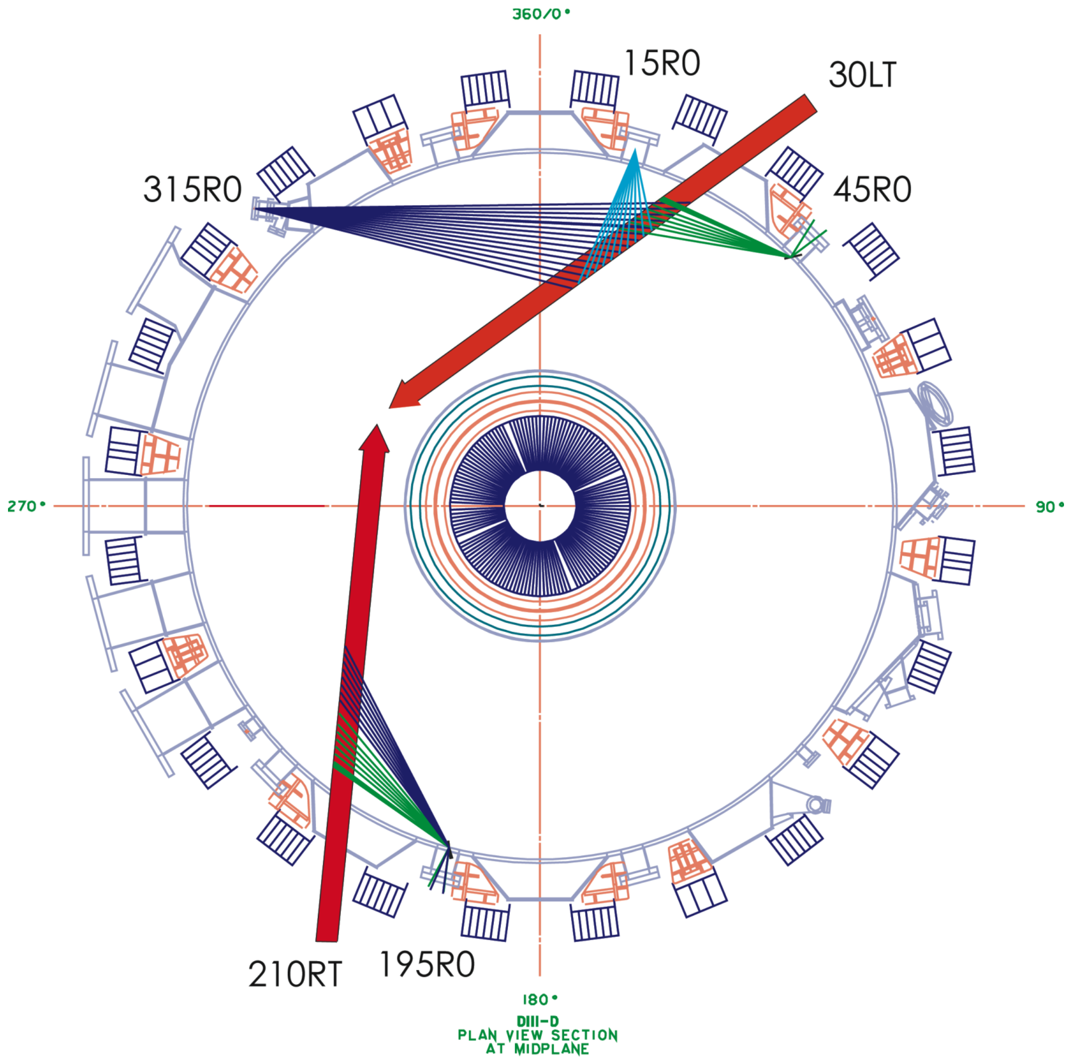
GENERAL ATOMICS

Spatial Resolution of the MSE Diagnostic Influences the Measured Pitch Angle

- The finite spatial resolution of the MSE diagnostic can modify the measured pitch angle of both the static equilibrium fields and dynamic tearing mode fields
- Effect is greatest on the radial array which has the poorest spatial resolution

- For tearing modes, the effect is more pronounced for smaller islands
- This helps explain why tearing modes are not always observed on the MSE diagnostic under many conditions when a mode is present

Each MSE array on D3D Has a Different Spatial Resolution



- **Three systems on 30lt beam**
  - 315 R0, δR ~ 50 - 120 mm
  - 15 R0, δR ~ 150 - 250 mm
  - 45 R0, δR ~ 10 - 50 mm
- **Two new systems being built on 210rt beam**
  - 195 R0 upper,
    δR ~ 10 - 50 mm
  - 195 R0 lower,
    δR ~ 40 - 70 mm
- **15 R0 array has the poorest resolution due to its radial view**

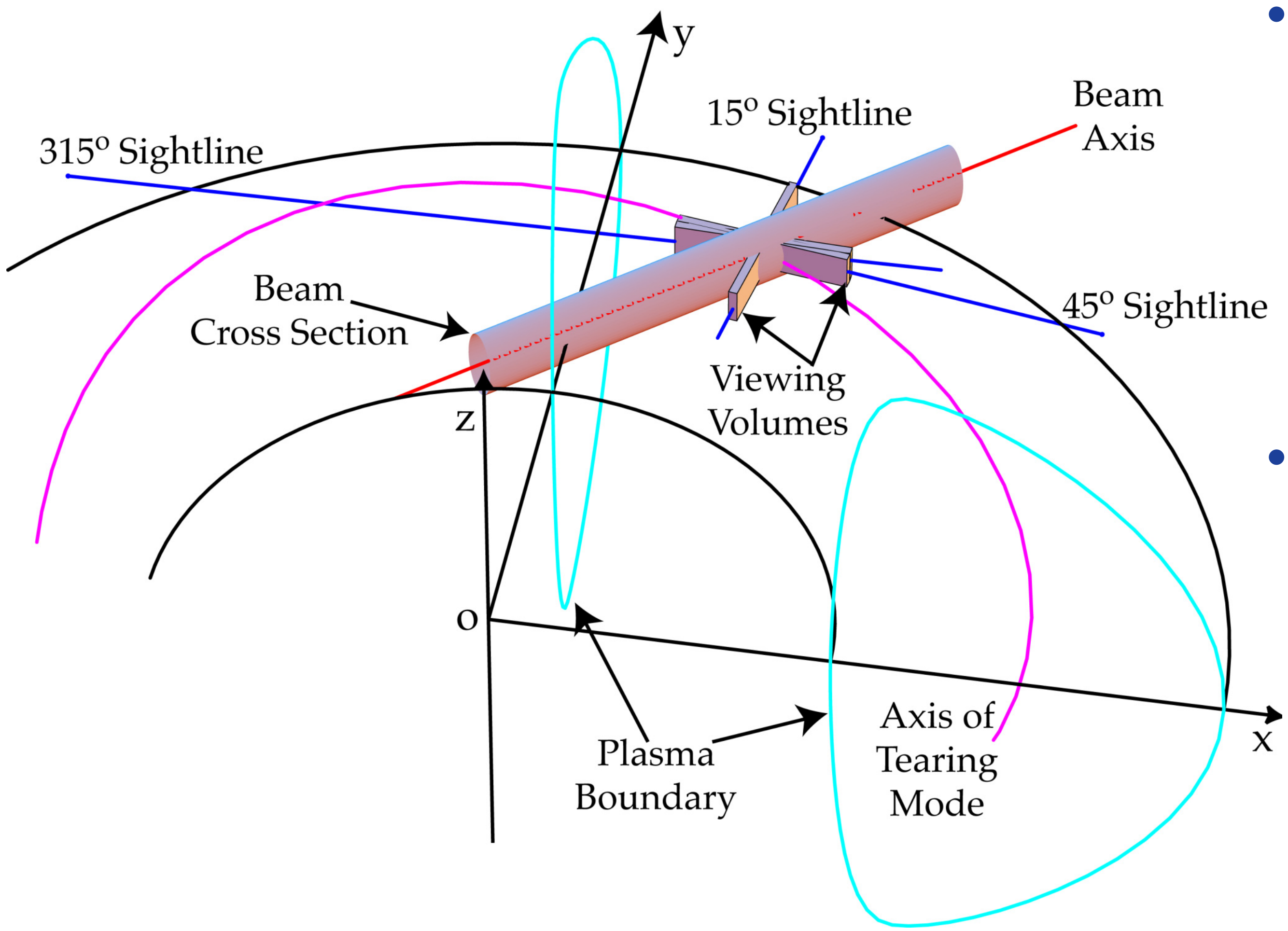
Spatial Resolution of the MSE Diagnostic Influences the Measured Pitch Angle

- **Full 3D geometry used**
  - Beam intensity, I_b
  - Sightline - defines integration volume: $d\mathbf{r}^3$
  - Magnetic field components: B_r, B_ϕ, B_z
  - Viewing coefficients: A_1, A_2, A_3, A_4
- **All quantities weighted by the spatially varying beam intensity**

$$\langle \tan\gamma_m \rangle = \frac{\int \left(\frac{A_1(\mathbf{r})B_z(\mathbf{r})}{A_2(\mathbf{r})B_\phi(\mathbf{r}) + A_3(\mathbf{r})B_R(\mathbf{r}) + A_4(\mathbf{r})B_z(\mathbf{r})} \right) I_b(\mathbf{r})\,d\mathbf{r}^3}{\int I_b(\mathbf{r})\,d\mathbf{r}^3}$$

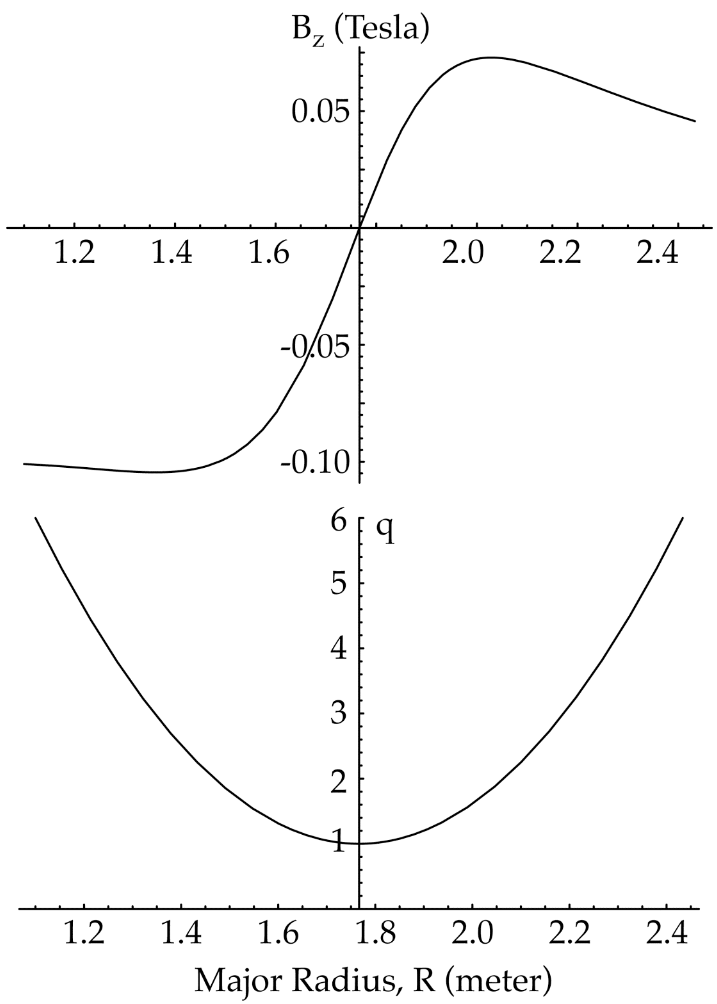
$$I_b(x,y,z) = I_0 \exp\left(-\frac{x^2}{w_x^2} - \frac{y^2}{w_y^2} - \lambda z \right)$$

Geometry is Defined Primarily by the Beam and Viewing Sightline



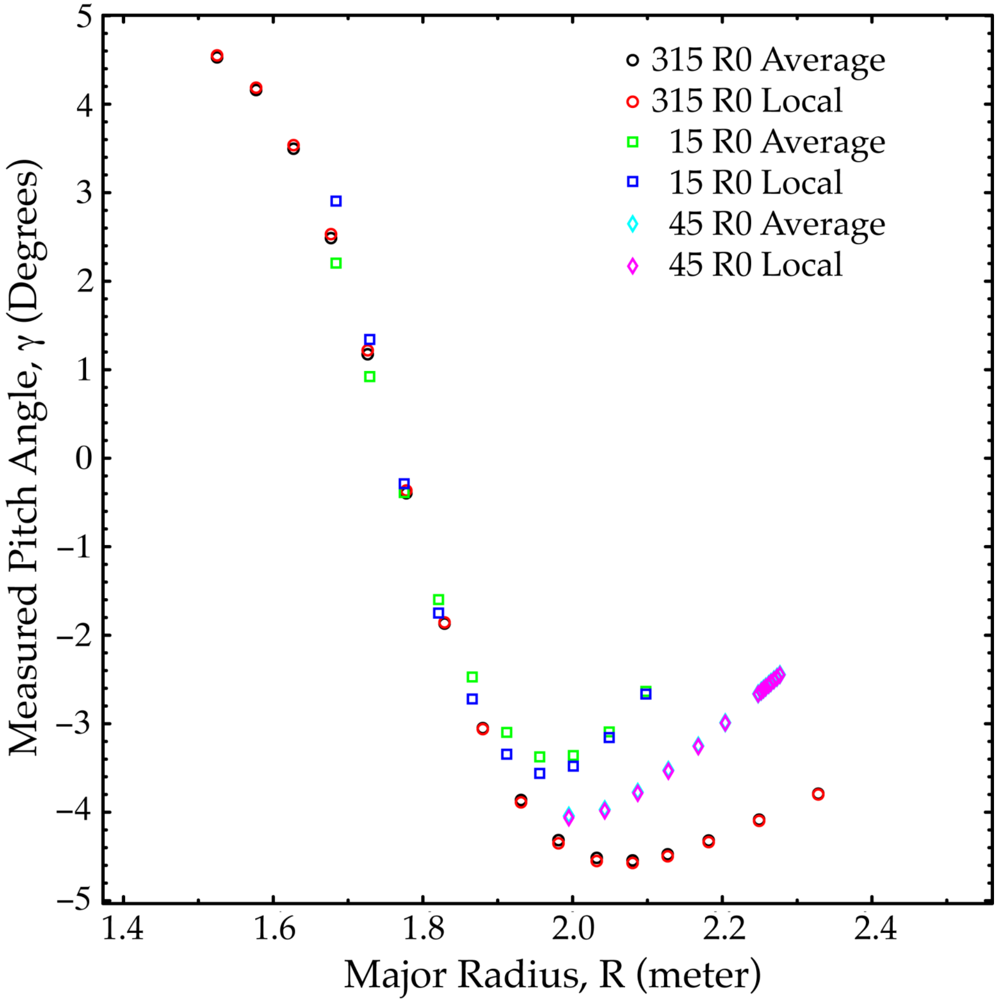
- **Integration volume is defined by**
  - The particular sightline
  - The beam profile
- **Fields depend on**
  - The equilibrium
  - The phase and radial location of the island

Simple Cylindrical Plasma Equilibrium is Used



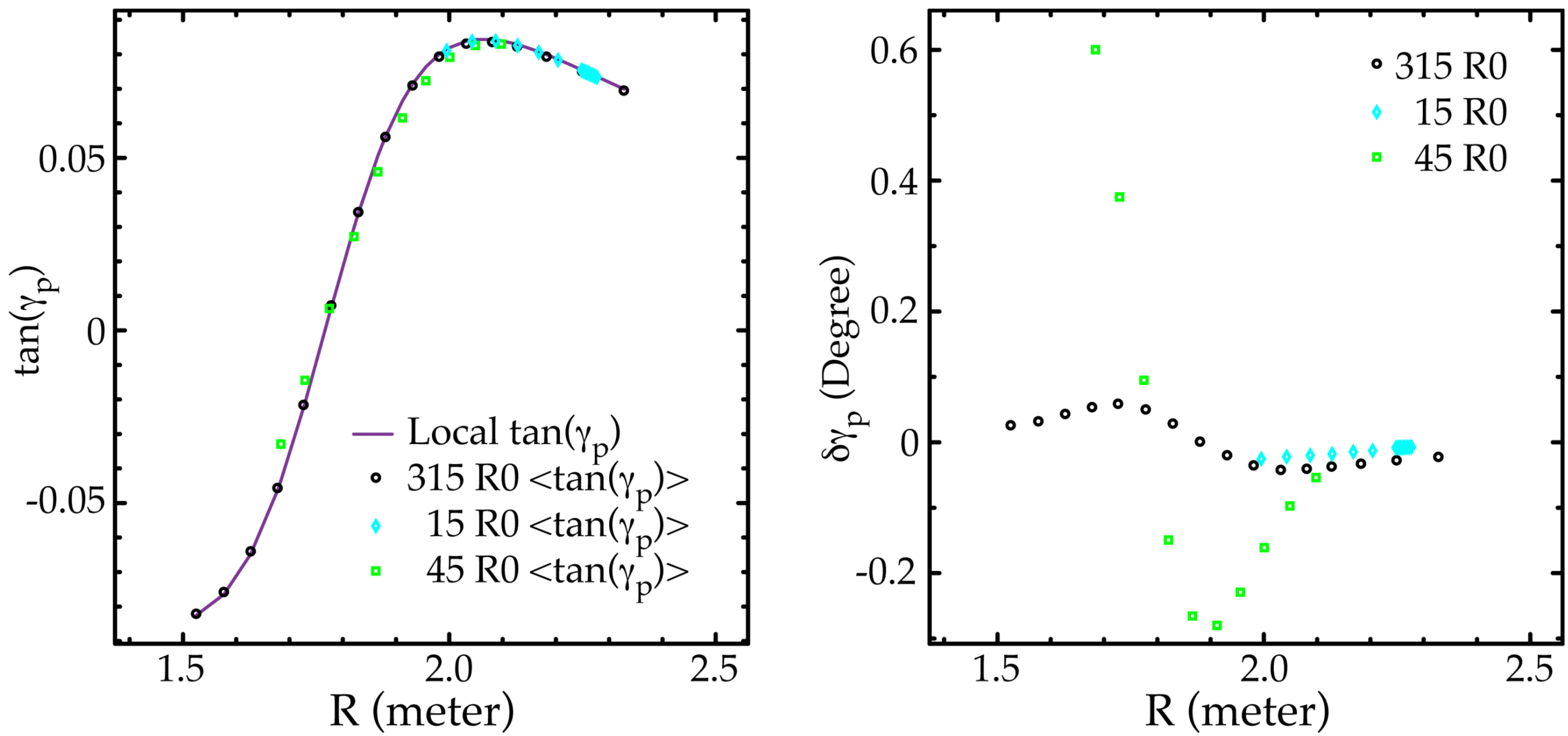
- **Currently, use a cylindrical plasma equilibrium**
  - Will eventually upgrade to handle arbitrary EFIT equilibria
- **Even this simple model is sufficient to demonstrate the issue**
- **Parameters:**
  - a = 0.67 m
  - R0 = 1.76 m
  - $B_{\phi 0}$ = 1.0 T
  - q_{lim} = 6

Effect of Spatial Averaging Is Most Pronounced on Array with Poorest Resolution



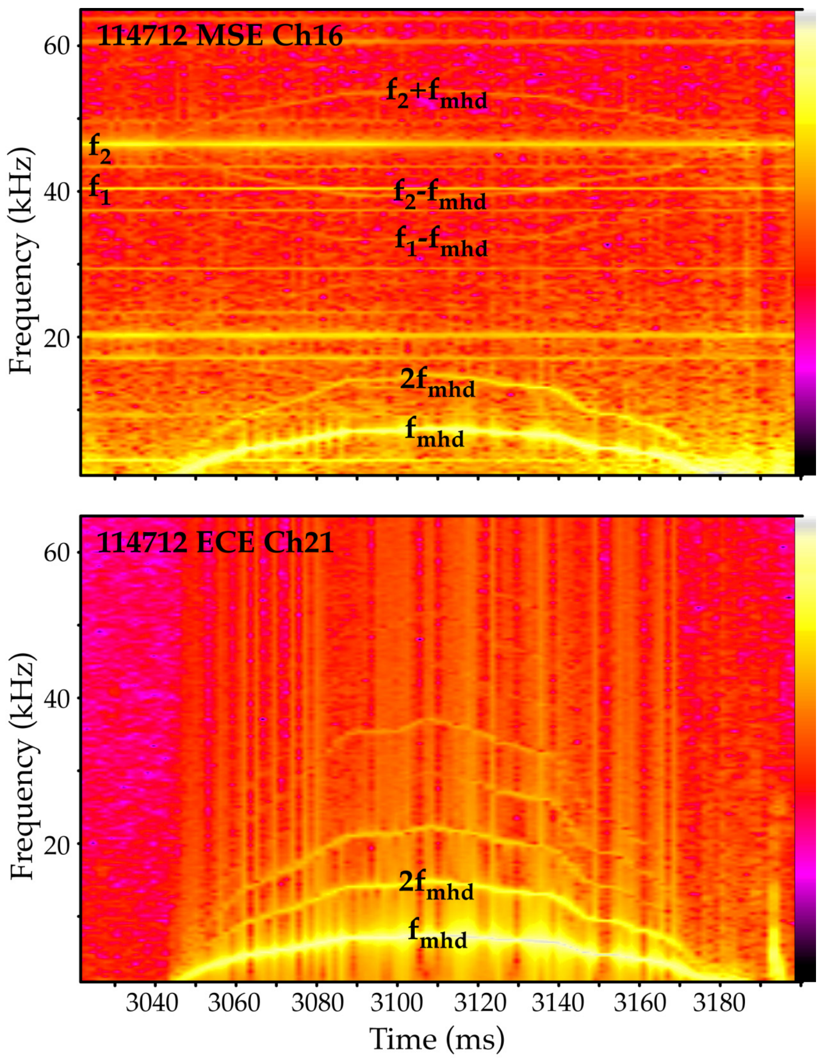
- **The 15 R0 array has the poorest spatial resolution and the largest difference between the local and average values of the measured pitch angle**
- **The 45 R0 array shows virtually no difference**
- **The sign of the difference for the 15 R0 array changes across the axis**
- **The difference will cause a systematic error in the calculation of the q-profile**

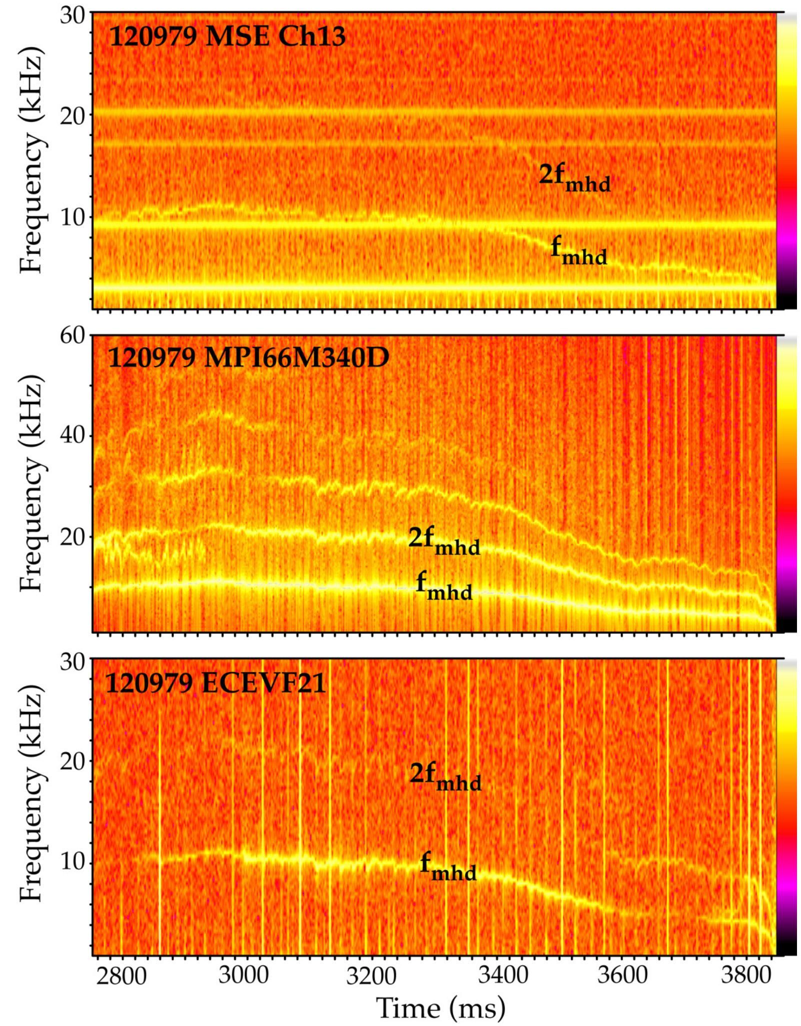
Corrections to the Plasma Pitch Angle Are as Large as 0.5°



$$\tan\gamma_p = \frac{B_\theta}{B_\phi} \approx \frac{B_z}{B_\phi} \text{ on the midplane}$$

Tearing Modes Are Observed with the Fast MSE Data Acquisition System





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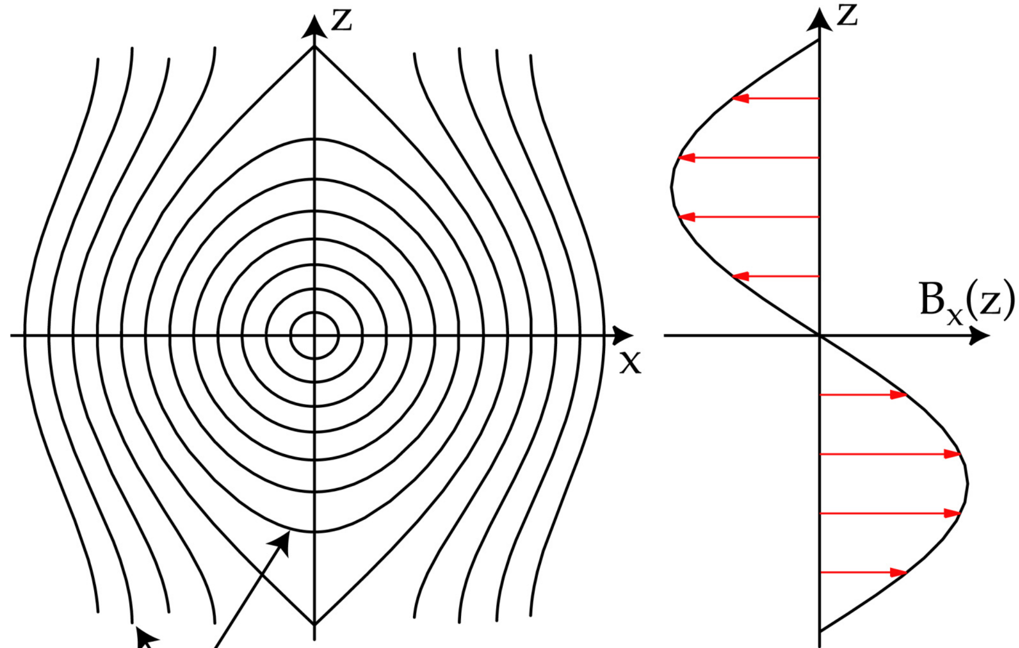
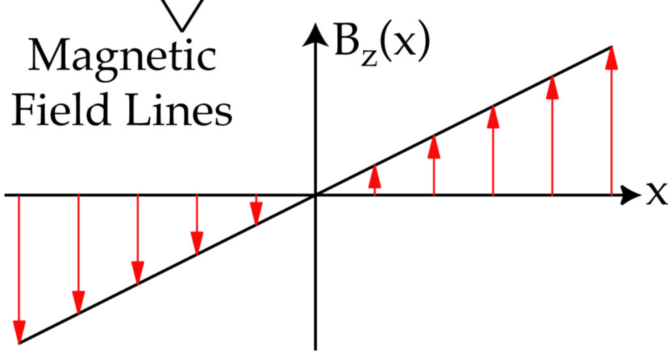
Slab Model of Tearing Mode Island Contains Essential Features of the Physics



- **Slab model of a tearing mode is used in the calculations**
- **Model incorporates a modulating B_x and B_z**
- **Model captures essential features of the tearing mode**

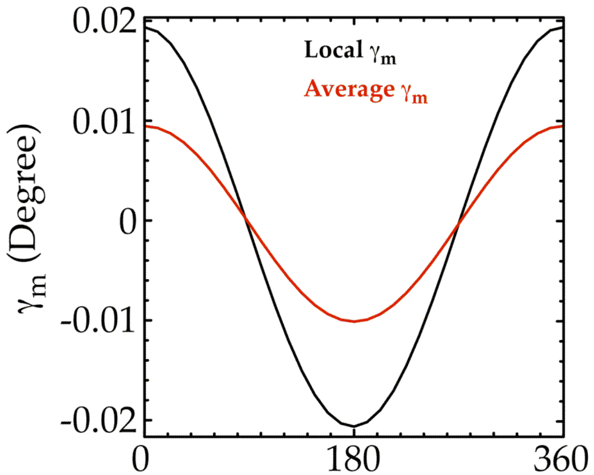


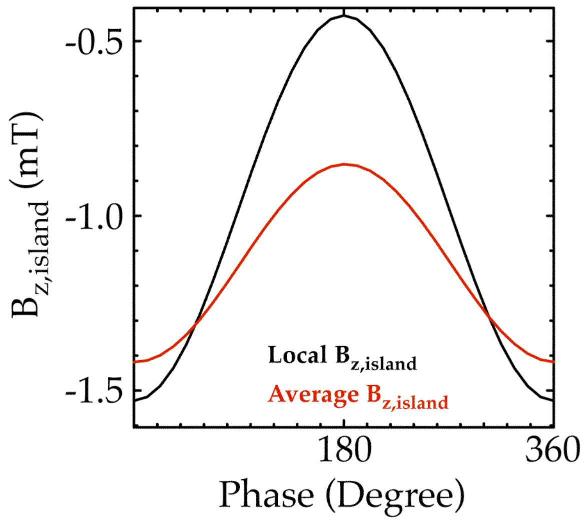
$$B_{x,island}(x,z) = B_{x1}(x)\sin(k_z z - \Omega t)$$

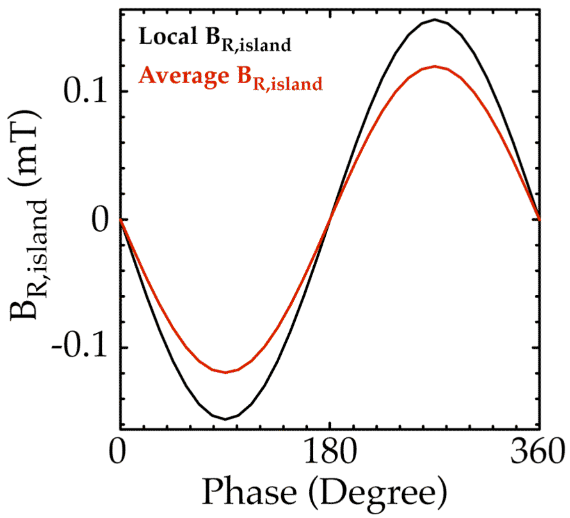
$$B_{z,island}(x,z) = B'_{z1}x + \frac{1}{k_z}B'_{x1}(x)\cos(k_z z - \Omega t)$$

Ω = rotation angular frequency

Spatial Averaging Reduces the Amplitude of All Quantities



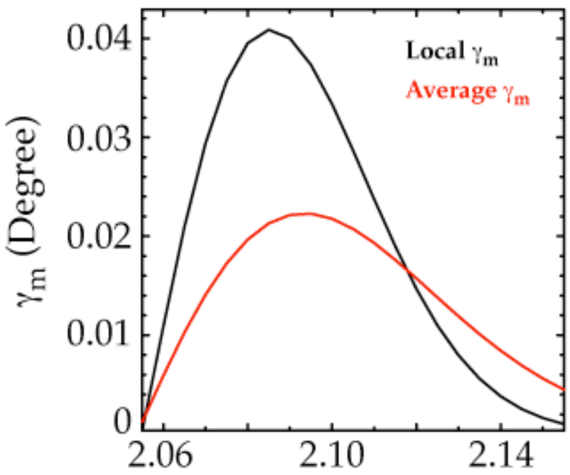


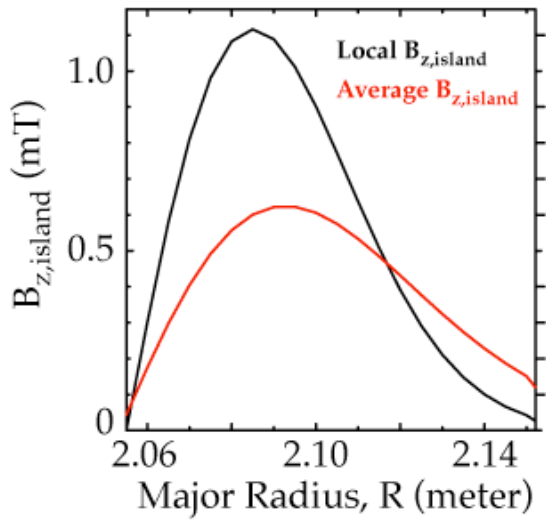


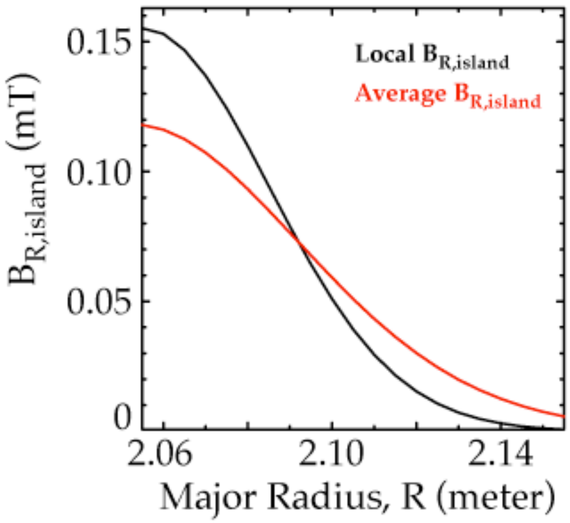
- Phase scan at a point radially displaced 1 cm from the center of the island

- Here, island full width is 6 cm
- B_z has the largest amplitude
- Phase of γ_m tracks that of B_z
- B_R makes a negligible contribution to the pitch angle
- No B_ϕ in slab model

Spatial Averaging Smears the Mode Structure







- **Amplitude reduction is array dependent**
  - 315° Array: 50%
  - 45° Array: 10%
  - 15° Array: 75%

- **Spatial averaging reduces the detected amplitude of the field, in this case by a factor of ~ 2**
- **Spatial averaging also smears the radial structure of the mode**
- **γ_m tracks the spatially averaged value of B_z**

The Pitch Angle Fluctuation Results Entirely from δB_z

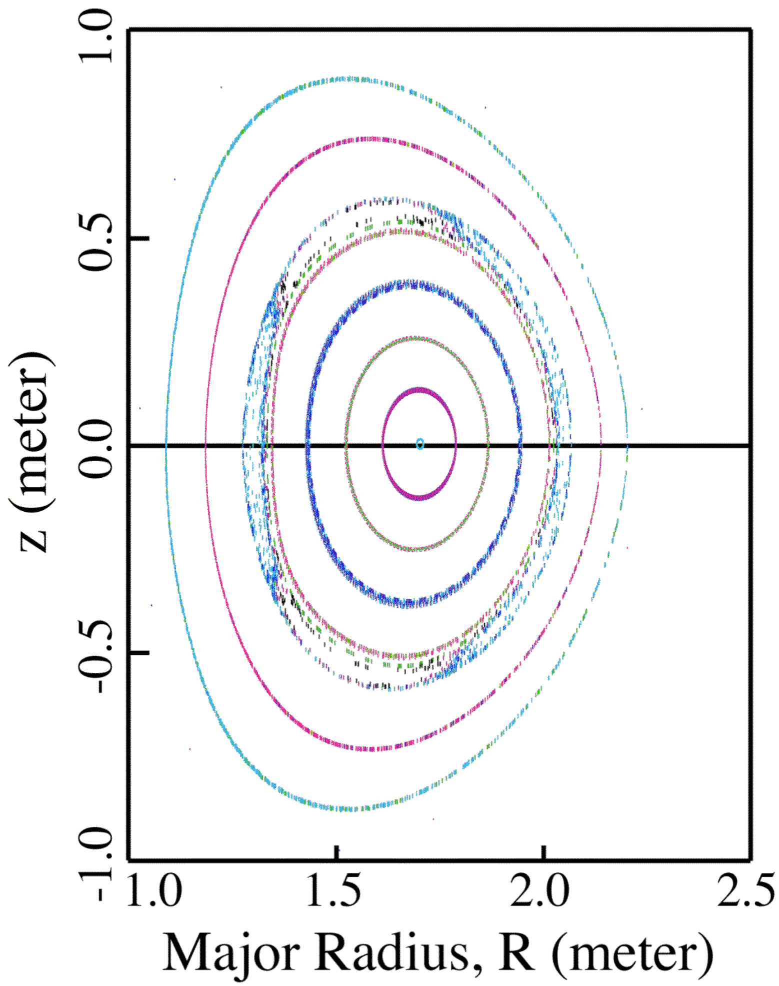
- The pitch angle fluctuation results predominantly from δB_z
- Since $\delta B_\phi \sim \delta B_z$, $\delta B_\phi / B_\phi << \delta B_z / B_z$
- Also, the contribution from δB_R is small both because $\delta B_R << \delta B_z$ and because this factor is multiplied by $\tan(\gamma_m) \sim 0.1$

$$\delta\gamma_m = \frac{1}{2}\sin 2\gamma_m \left[\frac{\delta B_z}{B_z}\left(1 - \frac{A_4}{A_1}\tan\gamma_m\right) - \frac{\delta B_\phi}{B_\phi} - \frac{A_3}{A_1}\frac{\delta B_R}{B_z}\tan\gamma_m \right]$$

$$\left\langle \frac{\delta\gamma_m}{\gamma_m} \right\rangle \approx \left\langle \frac{\delta B_z}{B_z} \right\rangle$$

- Estimate of $\delta\gamma_m$ from above equation is consistent with value derived from the calculated spatial average
- The above result implies that the detected fluctuation amplitude is small, being of the order of ~ 0.1°

NIMROD Results Confirm Conclusions Obtained with the Slab Model



- NIMROD used to simulate a 2/1 tearing mode
- $\delta B_z \sim \delta B_\phi >> \delta B_R$
- Moderate size island with a full width of ~ 3 cm
- Spatial structure of the mode is complex
- δB_z will give the predominant contribution to the pitch angle fluctuation as

$$\frac{\delta B_z}{B_z} >> \frac{\delta B_\phi}{B_\phi}, \frac{\delta B_R}{B_R}$$

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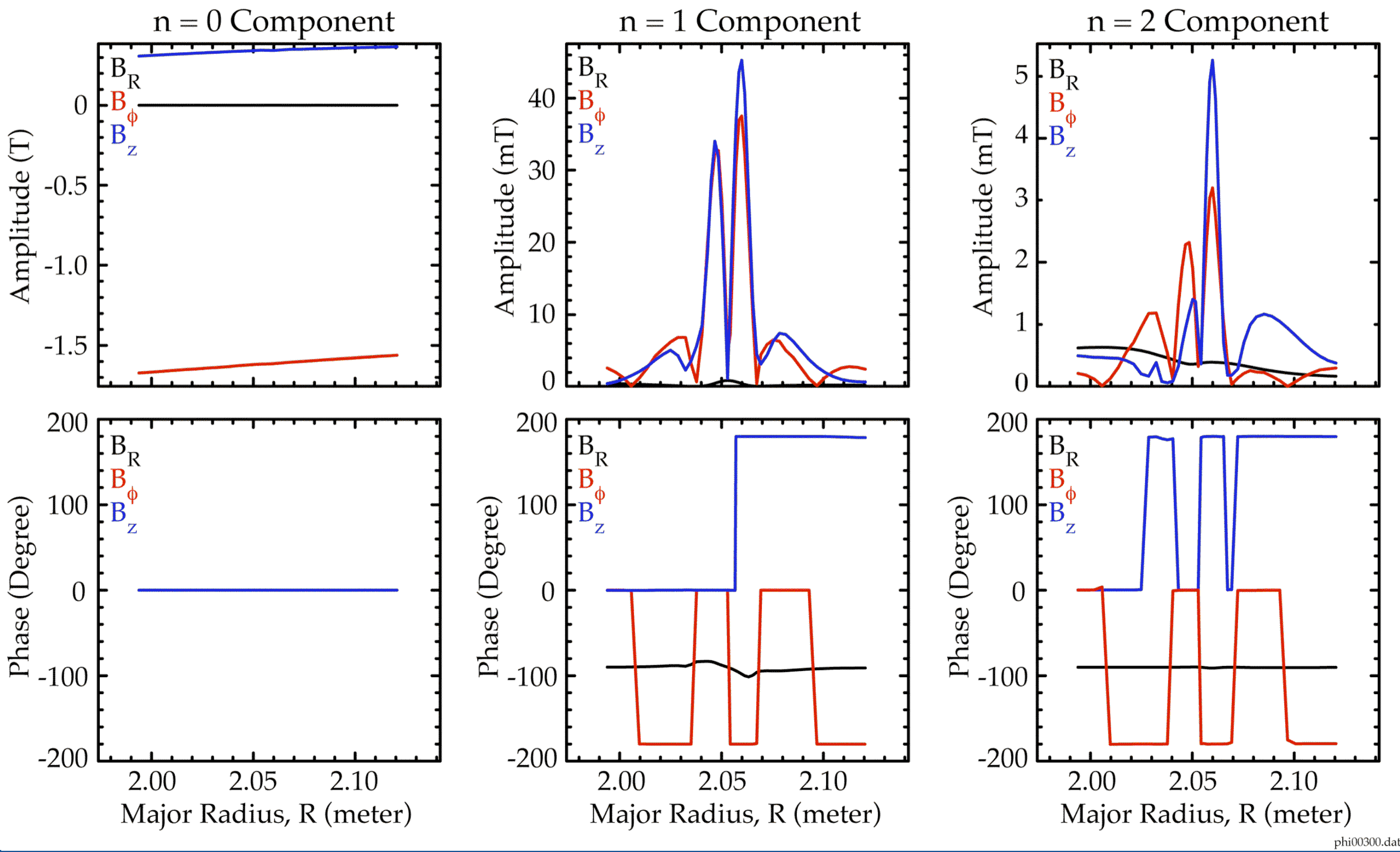
NIMROD Simulation Reveals Detailed Structure of the Tearing Mode



Conclusions

- **Effect of spatial averaging of the equilibrium fields is important**
  - Plan to implement a correction in EFIT
- **Effect is most significant on the radial channels**

- **Effect of spatial averaging of island fields is also important, particularly for small islands**
  - Observed island mode structure is smeared
  - Inferred amplitude is reduced significantly
  - Is array dependent with the 15 array having the greatest reduction in amplitude
- **Only δB_z contributes significantly to the measured fluctuation in pitch angle**
- **Estimate that typically $\delta B_z \sim 0.1°$**

Spatial Average of the Equilibrium Fields

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Spatial Average of the Tearing Mode Fields

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