H–MODE EDGE-DRIVEN INSTABILIES AS LOW–n KINK/BALLOONING MODES

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EXPERIMENTAL AND THEORETICAL EVIDENCE POINTS TO LOW–n KINK/BALLOONING MODES AS THE CAUSE OF TYPE I ELMs IN TYPICAL DIII–D DISCHARGES

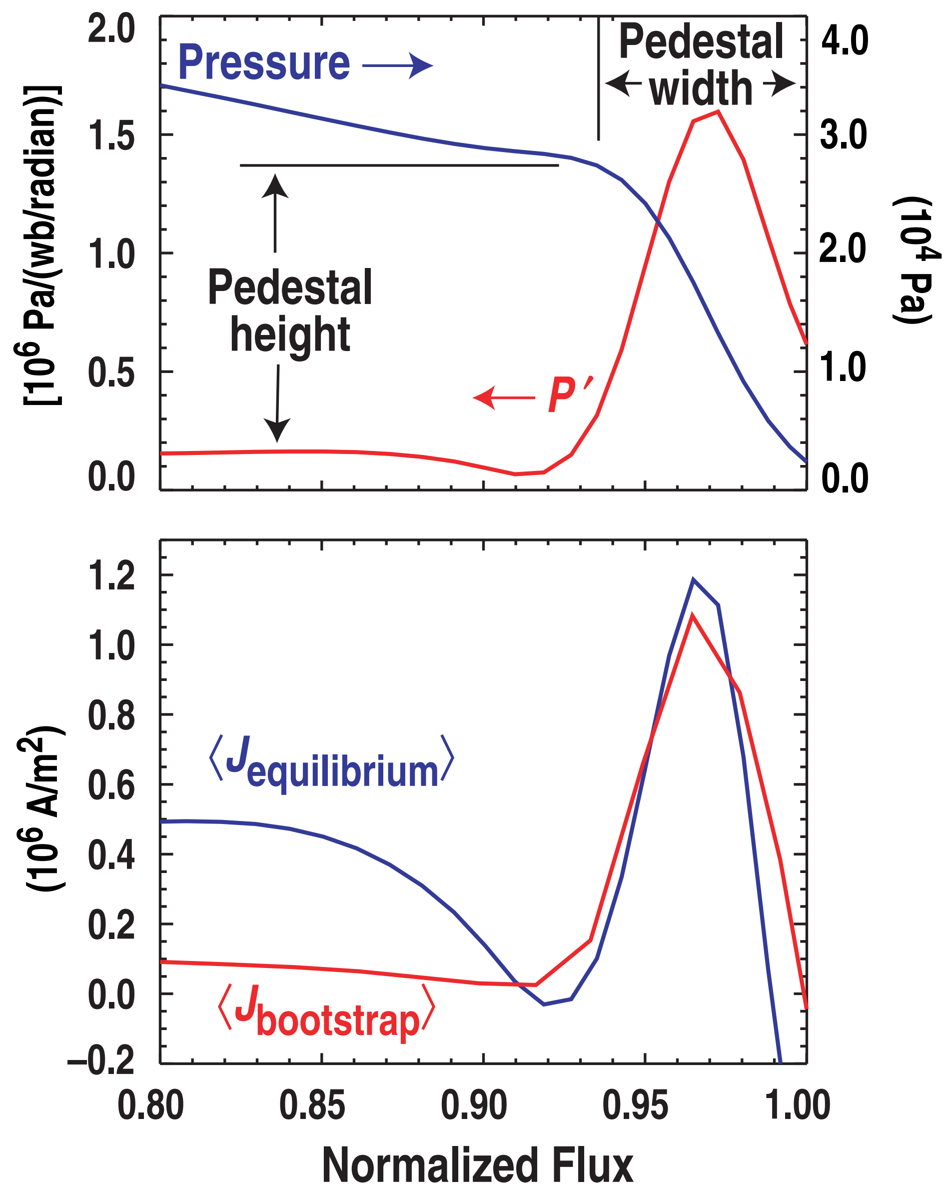
- **Physics model for edge stability threshold:**
  - Instability driven by pressure gradient and associated bootstrap current in the H–mode edge pedestal region
  - High-n ballooning mode second stability regime access aided by the bootstrap current
  - P'_{edge} increases above the ballooning mode first regime limit unitl low-n kink/ballooning mode triggered

- **Experiment: change parameters that the model predicts are keys to the edge stability physics**
  - Discharge shape: triangularity, squareness
  - Edge P': pellet injection

- **The instability character can be modified: amplitude, frequency**
  - Support for the edge stability physics model is obtained

THE H–MODE EDGE TRANSPORT BARRIER CONFIGURATION PROVIDES THE DRIVE FOR INSTABILITY

- Edge pedestal: large pressure change in a narrow region
- Free energy for edge localized modes (ELMs)
  - Large P'_{edge}
  - Bootstrap current (J_{edge})



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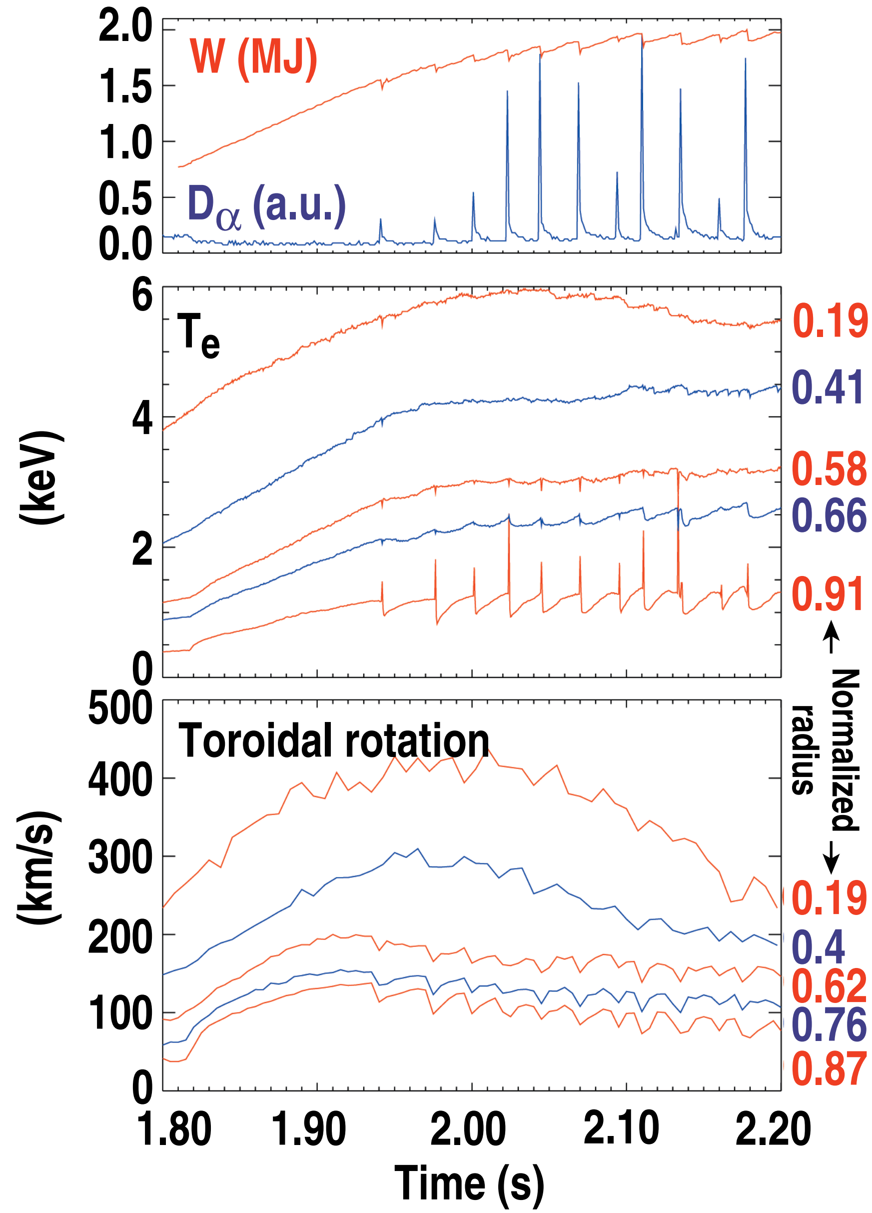
ELMs IMPACT THE DISCHARGE IN BOTH NEGATIVE AND POSITIVE WAYS

- ELM perturbations inhibit internal barrier formation
  - Core momentum density decreases after ELMs begin
- Other detrimental effects:
  - Divertor heat pulses
  - Neoclassical tearing mode seed islands
- Pedestal height is correlated with confinement
  - "Stiff" transport models
- ELMs help control electron and impurity densities
- These are "Type I" ELMs



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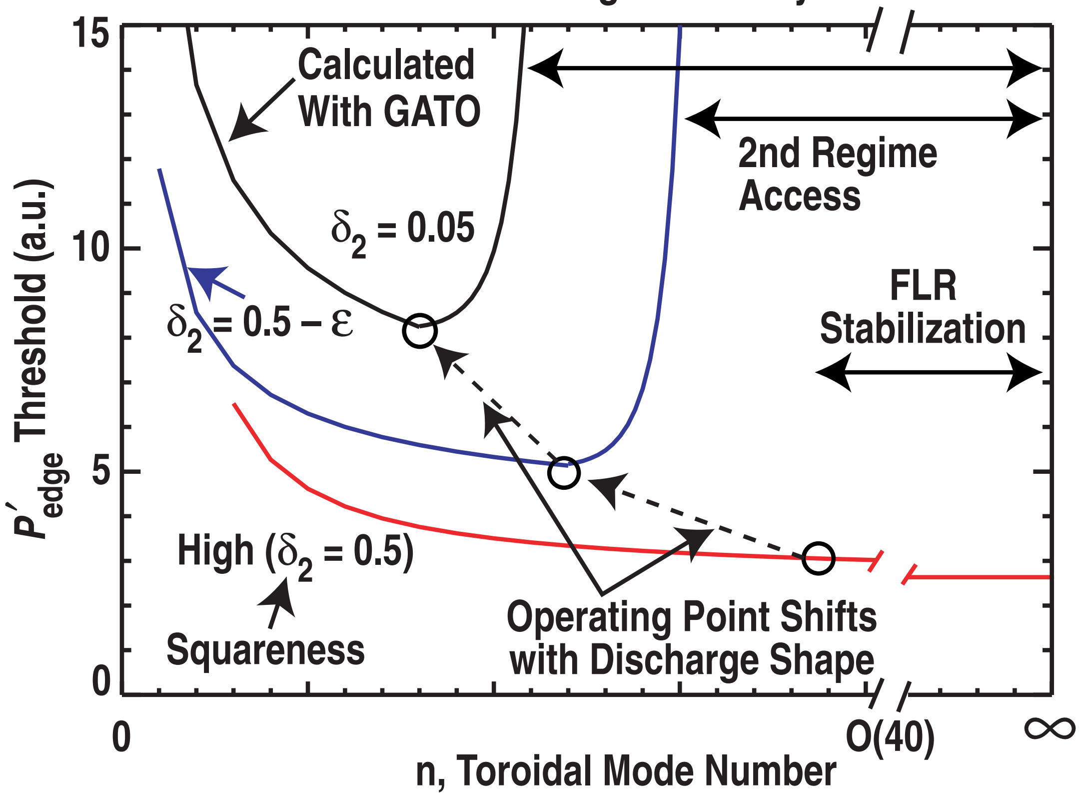
THEORY AND EXPERIMENT EXHIBIT THE FEATURES OF A MODEL OF TYPE I ELMs AS LOW-n CURRENT/PRESSURE DRIVEN INSTABILITIES

- ELM is the highest n–mode without 2nd regime access
- High squareness: no 2nd regime access
- Shape changes toward easier 2nd regime access (squareness, triangularity)⇒
  - — Higher P'_{edge} (factor 2–3)
  - — Larger ELM amplitude
  - — Factor 100 lower frequency
  - — Infer lower n
  - — Theory: n_{2nd} decreases
  - — Theory: P'_{edge} threshold decreases with n

Schematic of Ideal MHD Edge Instability Thresholds



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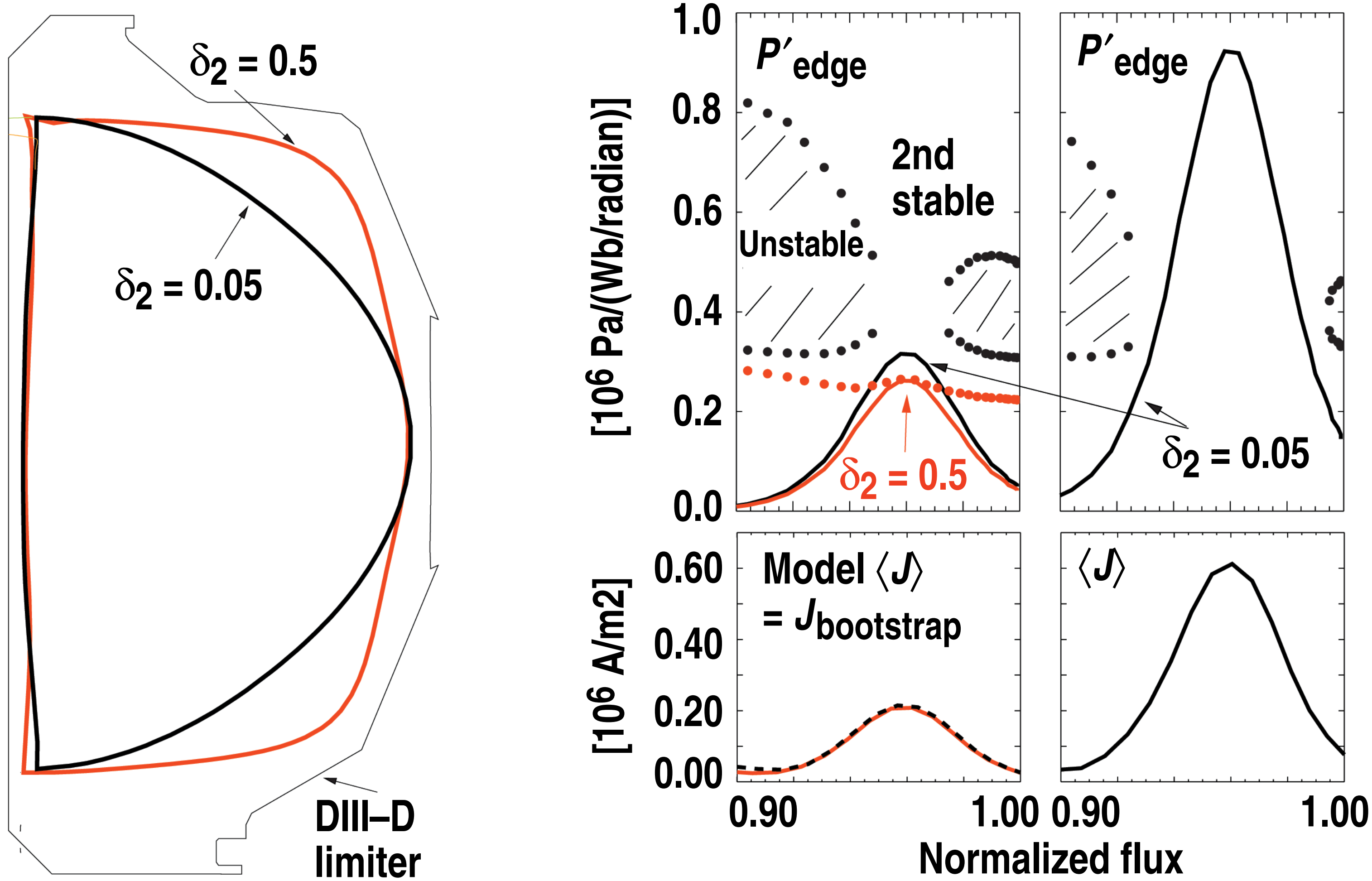
HIGH SQUARENESS SHAPES ARE NOT EXPECTED TO HAVE SECOND STABLE REGIME ACCESS

- Low poloidal field at the "corners" weights the bad curvature regions



- δ_2 = squareness ($R(\theta) = R_0 + a\cos(\theta + \sin^{-1}\delta\sin\theta)$, $Z(\theta) = \kappa a \sin(\theta + \delta_2 \sin 2\theta)$)

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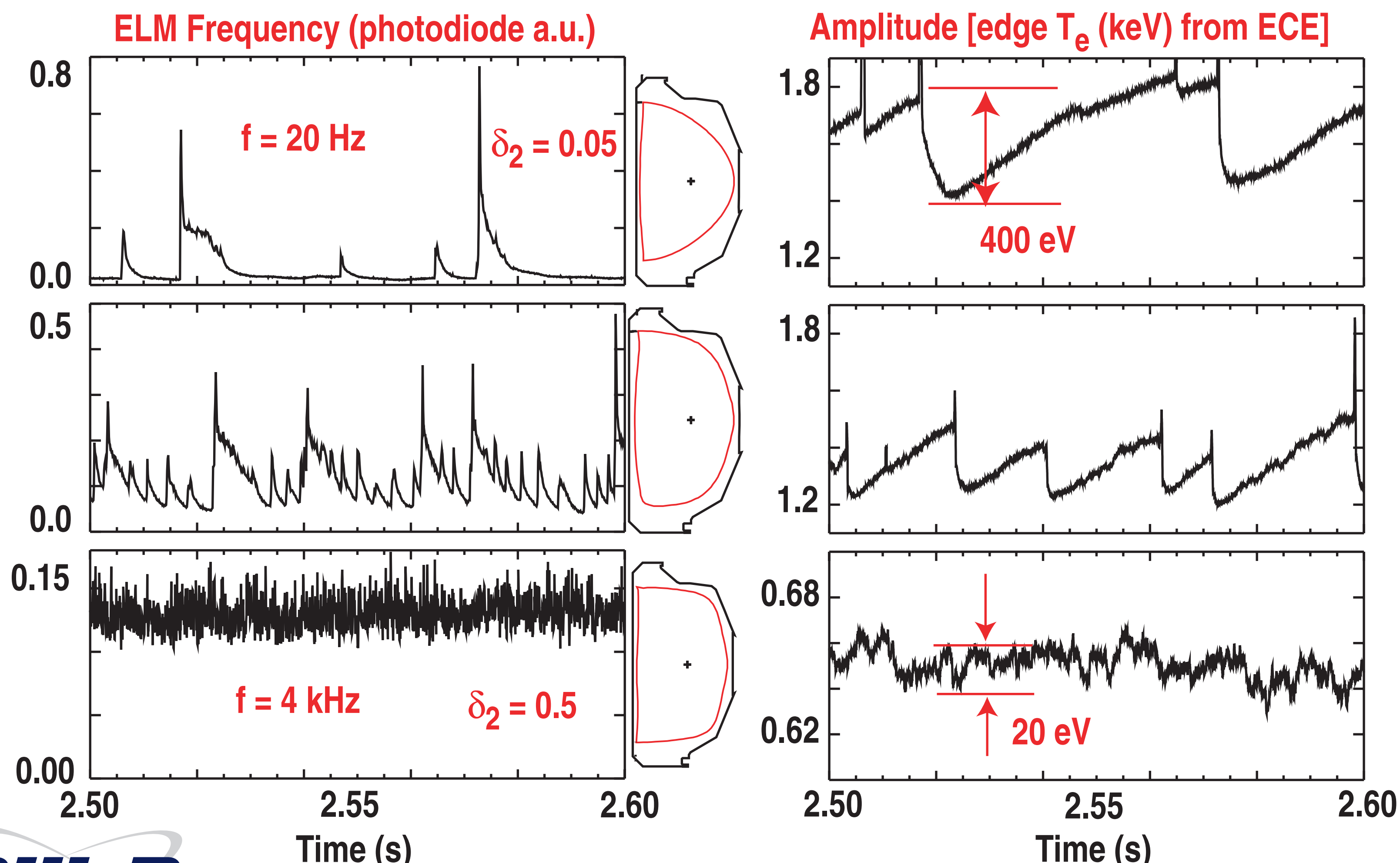
CHANGE IN BALLOONING 2nd REGIME ACCESSIBILITY IS INDICATED BY CHANGES IN ELM FREQUENCY AND AMPLITUDE

- At sufficiently high squareness:
  - ELM frequency increases a factor of 10
  - T_e perturbations are not measurable
- Abrupt: only a small shape change required



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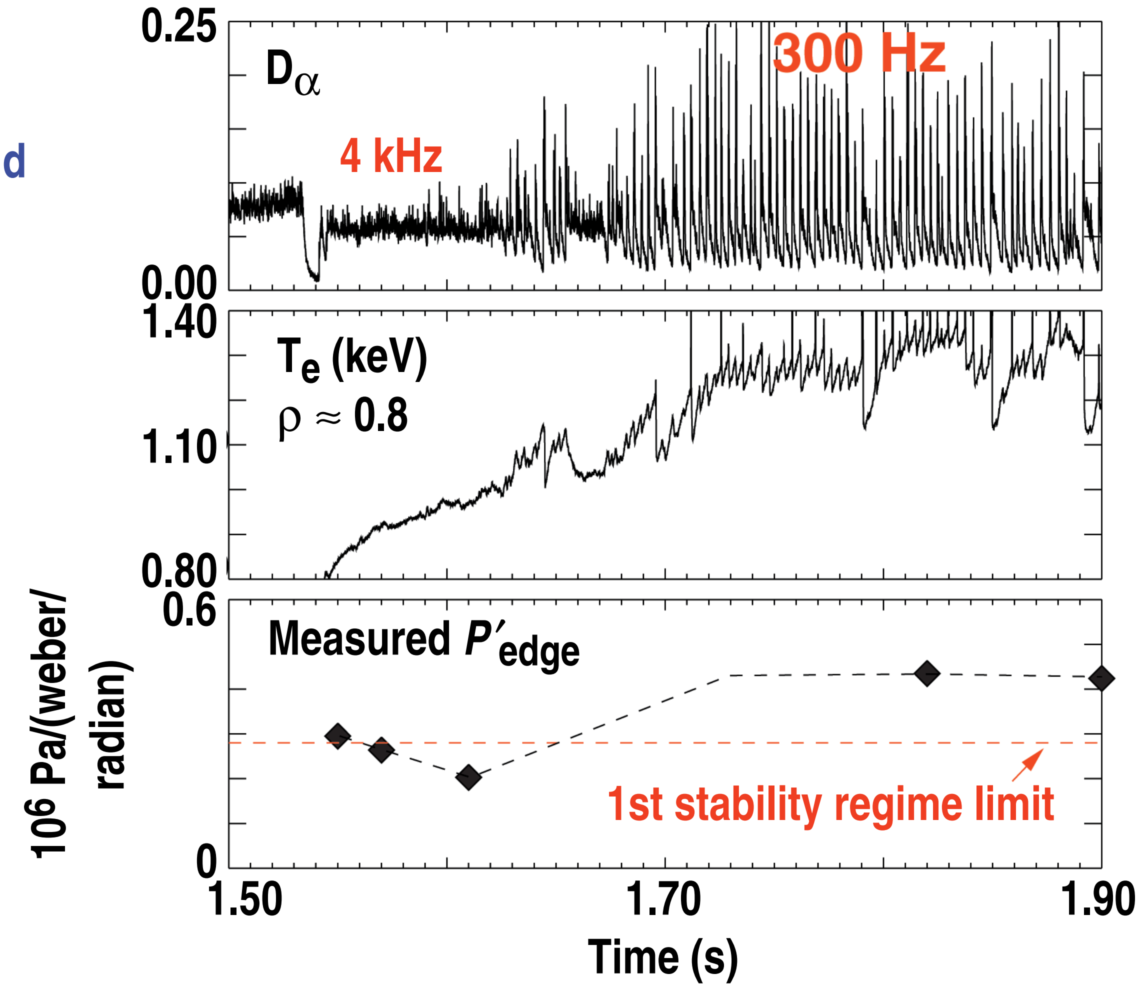
SHIFT IN 2nd STABLE REGIME ACCESS OBSERVED AT CONSTANT DISCHARGE SHAPE

- *J* evolution after H–mode transition
- Shape marginal for second regime access
- Changes to note:
  - ELM frequency
  - T_e perturbation
  - Pressure gradient



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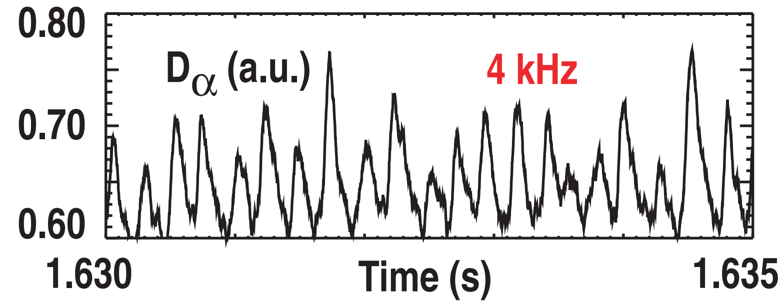
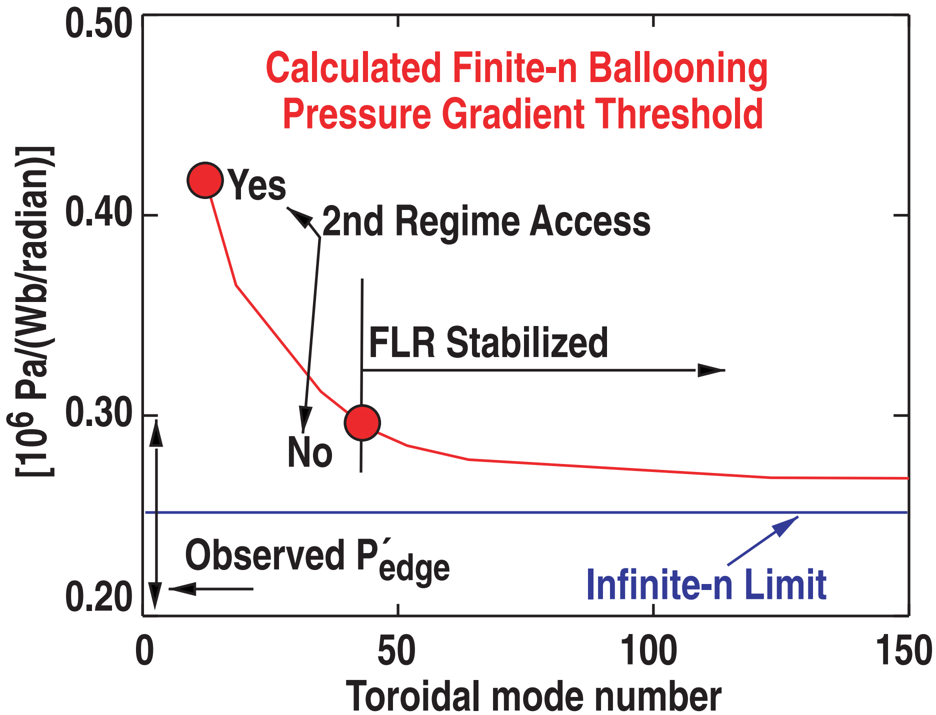
WITH NO 2nd REGIME ACCESS, OBSERVED ELMs SHOULD HAVE THE LARGEST n WITHOUT FINITE LARMOR RADIUS STABILIZATION

- FLR averaging stabilizes modes with $k_{\perp}\rho_i > 0.5$
- High squareness, without second regime access:
  - Small, but still discrete, ELMs
- Finite-n corrections to infinite-n theory give the P'_{edge} threshold at intermediate n values
- BALMSC code (M.S. Chu, M.S. Chance)





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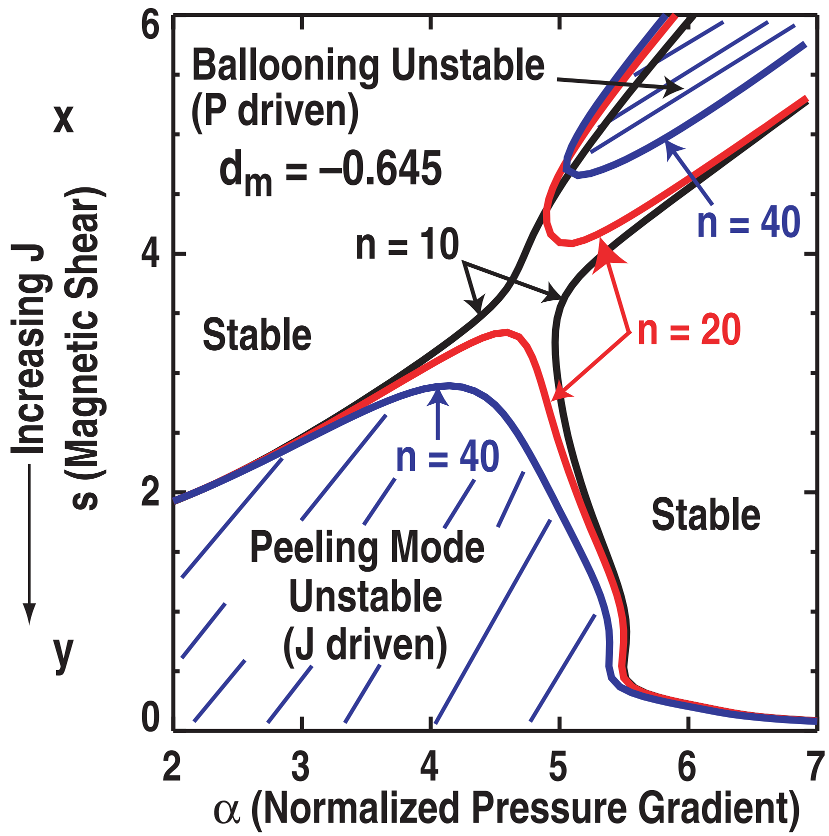
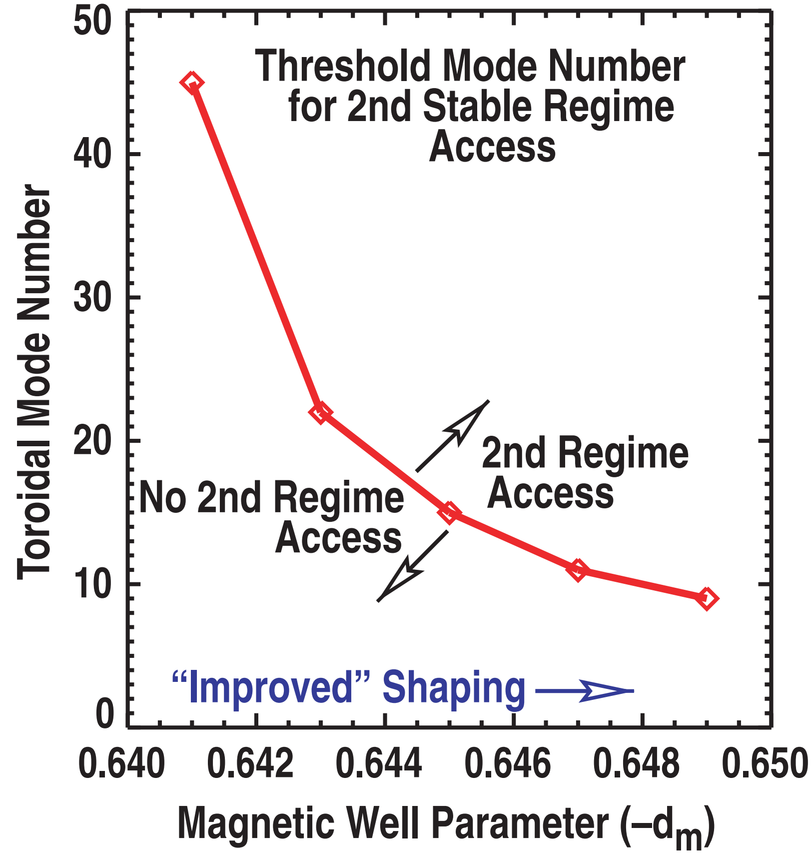
INTERMEDIATE-n MODES CAN HAVE A 2nd REGIME OF STABILITY

- Evaluated for high aspect ratio, shifted circle equilibria
- Magnetic well parameter (d_m) models the expected effect of shape changes
- Minimum value of n with 2nd regime access should depend on discharge shape





- Results of H.R. Wilson, R.L. Miller, Phys. Plasmas 6, 873 (1999) extended by P. Snyder

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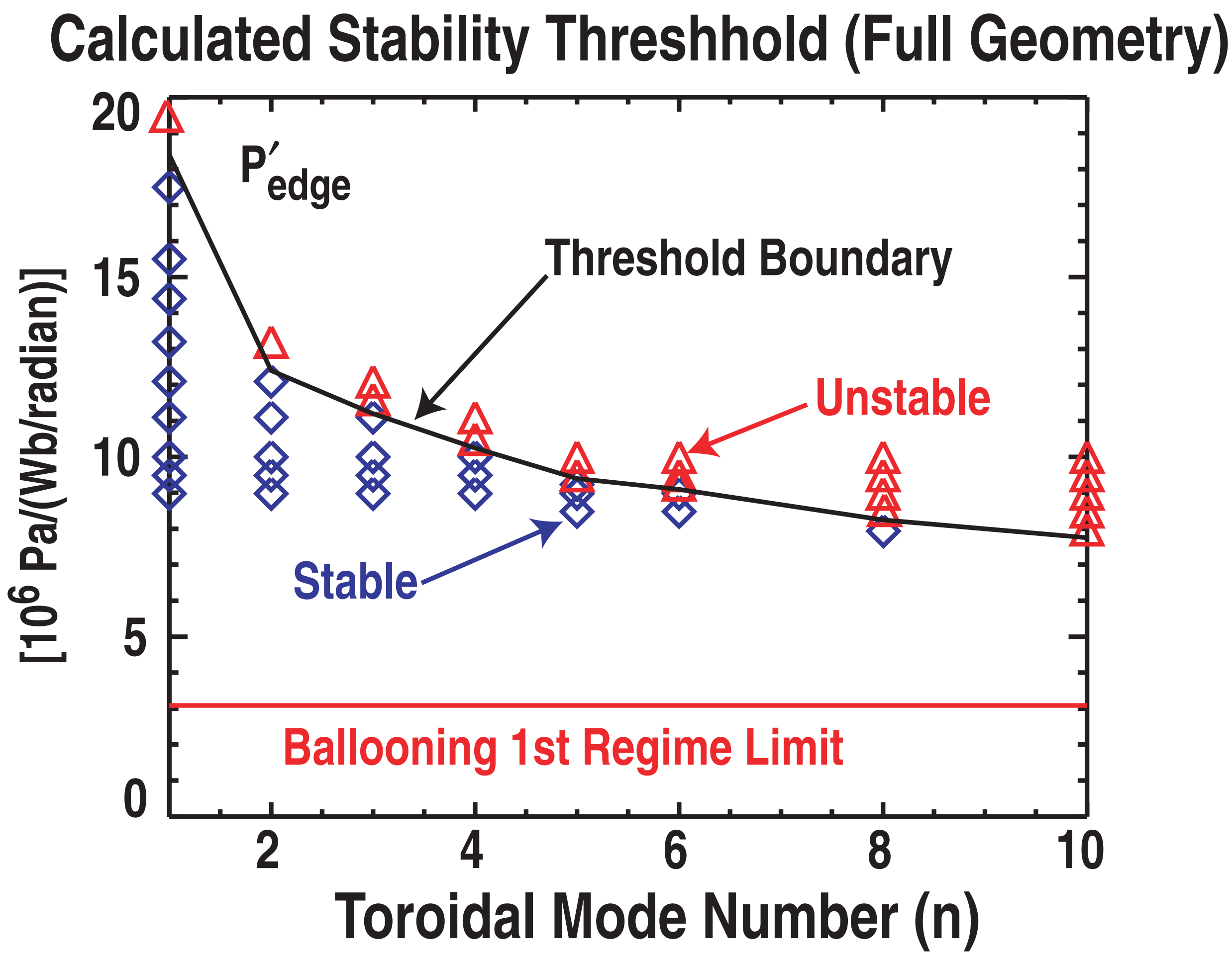
MODE WITH THE LARGEST n WITHOUT 2nd STABLE REGIME ACCESS WILL HAVE THE LOWEST P'_{edge} STABILTY THRESHOLD

- Calculated P'_{edge} threshhold decreases with toroidal mode number
- Fixed, medium squareness (δ_2 = 0.05) shape, wall radius = 1.5α, GATO code



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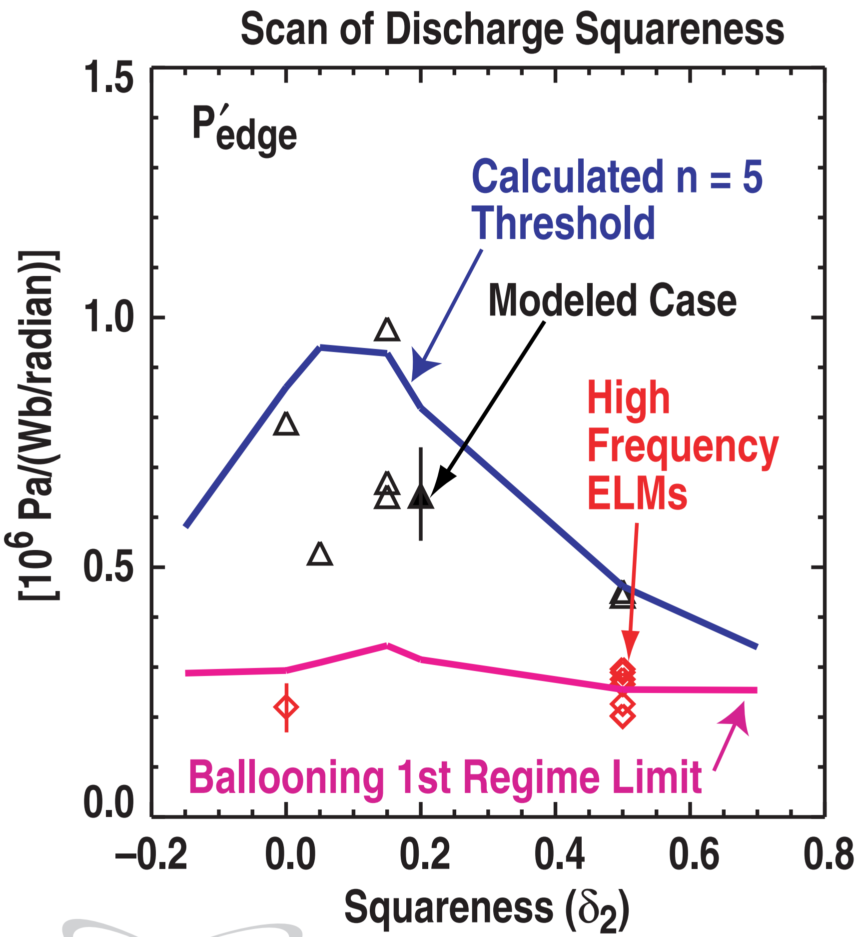
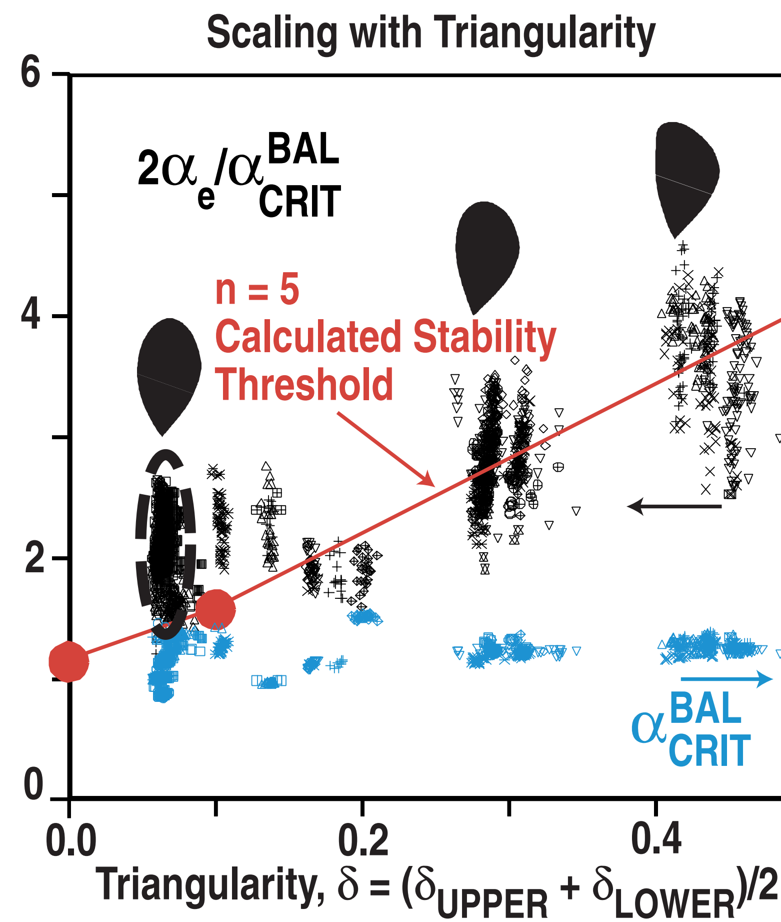
MEASURED P'_{edge} SCALES WITH DISCHARGE SHAPE LIKE THE PREDICTED THRESHOLD FOR n = 5 IDEAL, KINK/BALLOONING MODES

- Squareness scan shows quantitative agreement within 40% for similar pedestal width
- Pedestal pressure also increases with triangularity





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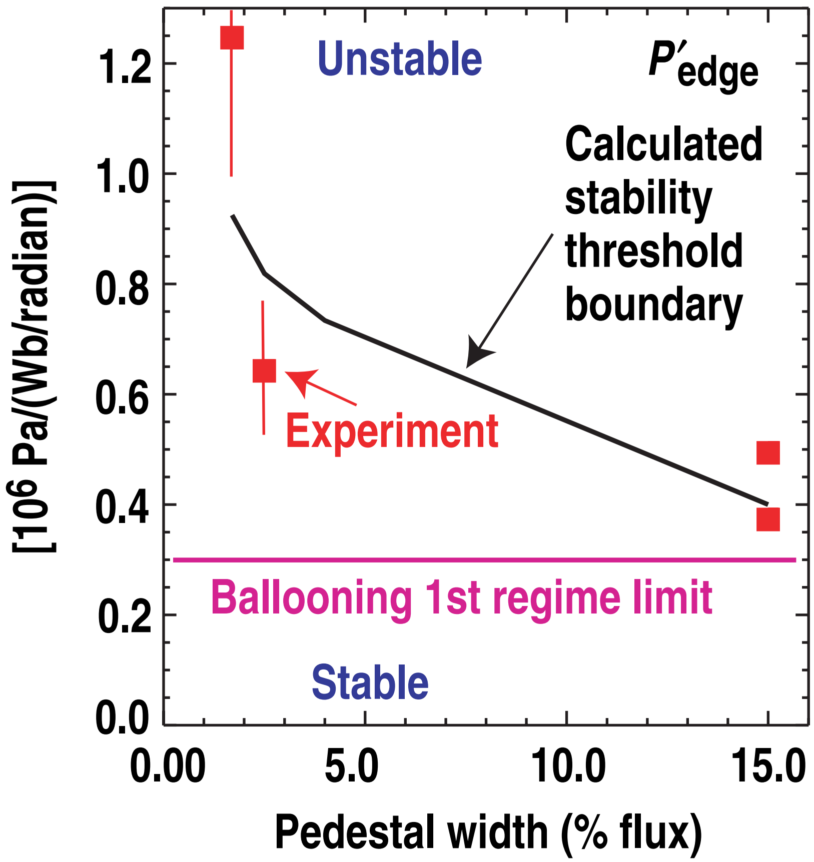
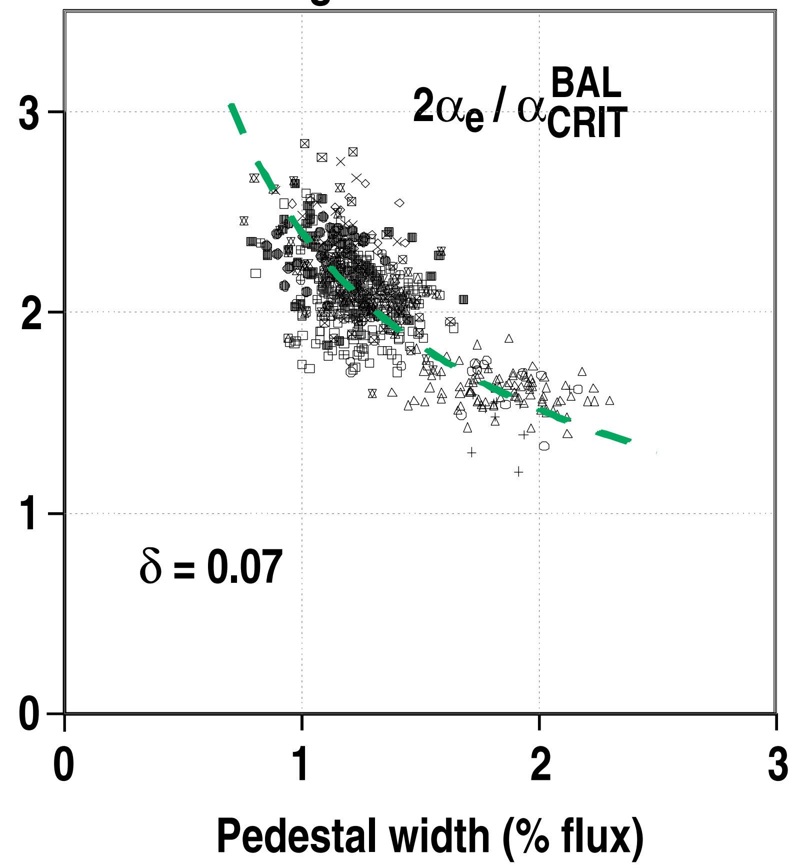
THE P'_{edge} STABILITY THRESHOLD IS REDUCED AS THE PEDESTAL WIDTH INCREASES

- Results from averaging of P' and J profiles by a long wavelength (low n) mode
- P'_{edge} threshold is reduced to close to ballooning 1st regime limit

Double-null divertor



Single-null divertor



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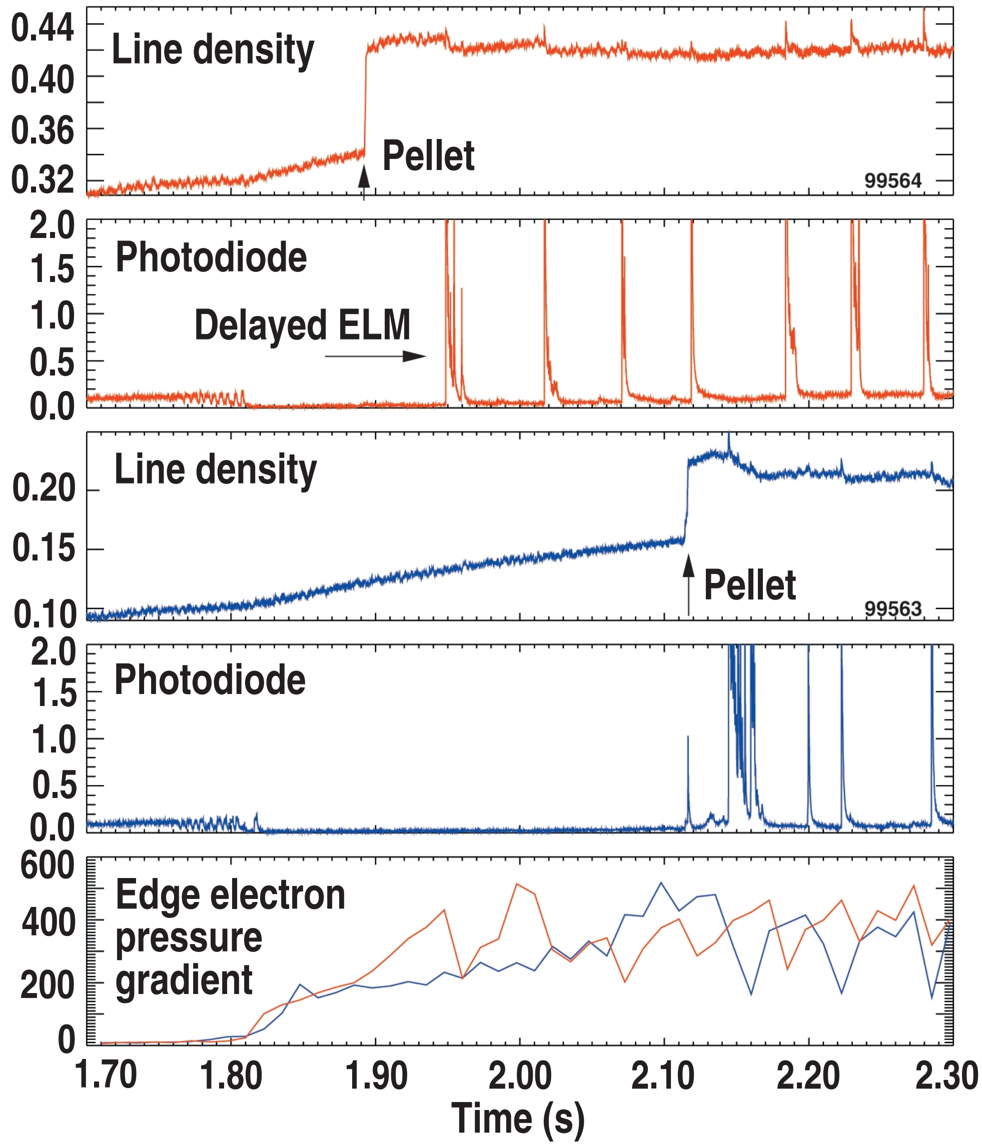
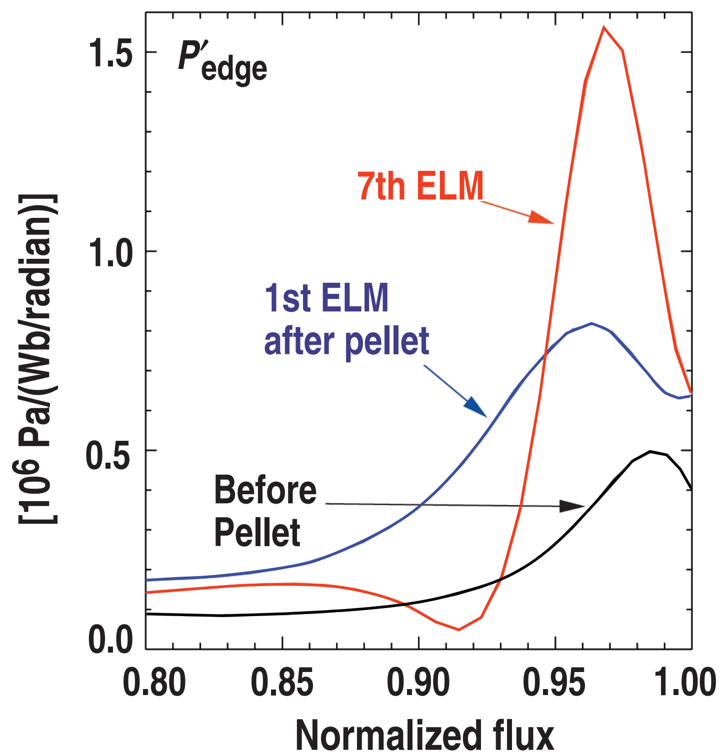
ELMing PHASE CAN BE INITIATED BY INJECTING A DEUTERIUM PELLET TO INCREASE P'_{edge}



- Time for the edge pressure gradient to build to the ELM threshold ⇒ delay between pellet and first ELM
- Threshold = function (width)



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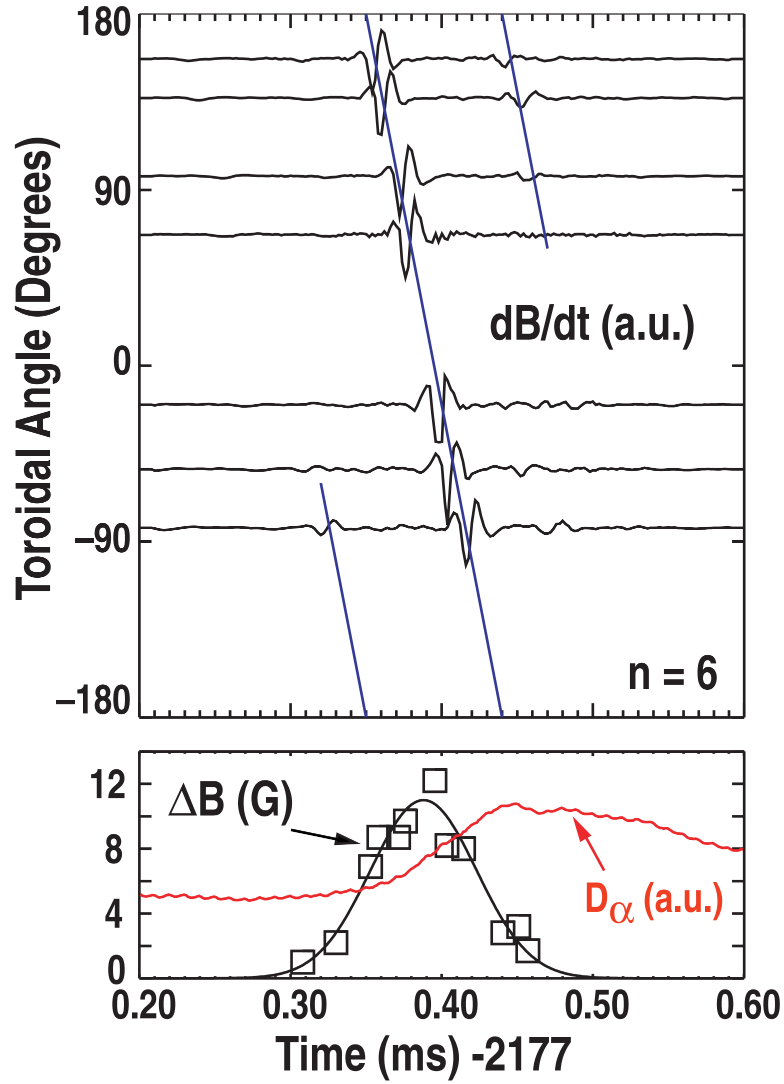
MEASURED MAGNETIC FLUCTUATIONS ACCOMPANYING TYPE I ELMs HAVE SHOWN IDEAL INSTABILITIES WITH $2 \leq n \leq 9$

- Rapid growth rate indicates an ideal MHD instability
- Clear mode number measurement is relatively rare
- Infer mode number changes from changes in amplitude and frequency



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THE BEST MATCH OF THE DISTINGUISHING FEATURES IN BOTH EXPERIMENT AND THEORY IS TO LOW–n MODES

- ELM character responds to a change in second stability regime accessibility. Demonstrates the character of ELMs generated by high–n modes
  - With second regime access: low frequency, large amplitude ELMs
  - Without second regime access: high frequency, small amplitude ELMs
- With second stability regime access: measured P'_{edge} and calculated low–n stability threshold well above infinite–n limit
- Observed P'_{edge} scales with shape (squareness and triangularity)
  - Similar to scaling of calculated low–n threshold
  - Little change with shape in calculated infinite–n threshold
- Observed and calculated dependence of P'_{edge} threshold on pedestal width
  - Low–n mode averages the profile over a large radial region
  - Infinite–n mode depends on local parameters