Stability Modeling of DIII-D Discharges with Transport Barriers

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41st Annual APS Division of Plasma Physics Meeting
Seattle, Washington
November 15 - 19, 1999

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GENERAL ATOMICS

Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.1.1.2 (Experimental)

Stability Modeling of DIII-D Discharges with Transport Barriers[1] L.L. LAO, J.R. FERRON, Y.R. LIN-LIU, E.J. STRAIT, A.D. TURNBULL, T.S. TAYLOR, General Atomics, M. MURAKAMI, Oak Ridge National Laboratory — The stability of DIII–D discharges with transport barriers is systematically studied by modeling the pressure profiles using a hyperbolic tangent representation with various radii, widths, and amplitudes. The q profiles are modeled using a spline representation with varying $q(0)$, $q_{\min}$, and $\rho_{q_{\min}}$. The equilibria are computed using the EFIT and the TOQ codes based on the parameters from a strongly shaped high triangularity DIII–D long pulse high performance discharge. Stability against the ideal low $n = 1$ and 2 modes is evaluated using the GATO code with a conducting wall at 1.5 a. The results show that the stability improves with increasing transport barrier width and radius but varies weakly with $q(0)$. When the transport barriers are L–mode like and have narrow widths in the plasma core, the stability is limited by the $n = 1$ mode. When they are H–mode like and have large widths extending toward the edge, the stability is limited by the $n = 2$ mode.

[1]Work supported by U.S. DOE Contracts DE-AC03-99ER54463 and DE-AC05-96OR22464.

☐ Prefer Oral Session
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Special instructions: DIII-D Poster Session 1, immediately following H Takahashi

Date printed: July 19, 1999

Electronic form version 1.4

MOTIVATION

- Strong local pressure gradients are often observed in discharges with internal transport barrier (ITB) which can lead to instability at low beta
- Previous stability modeling studies have been mostly discussed in terms of P(0)/ <P>
- Goals
  - — Explore stable path to configurations with both ITB and high normalized beta β_N
  - — Check sensitivity of stability limit to variations in q and ITB profiles

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OUTLINE / KEY RESULTS

- Stability limit improves with transport barrier width and radius
- Wall stabilization is crucial for ITB with large radius
- Stability limit varies weakly with q(0)
- *n* = 2 modes are more unstable in ITB with large radius and width

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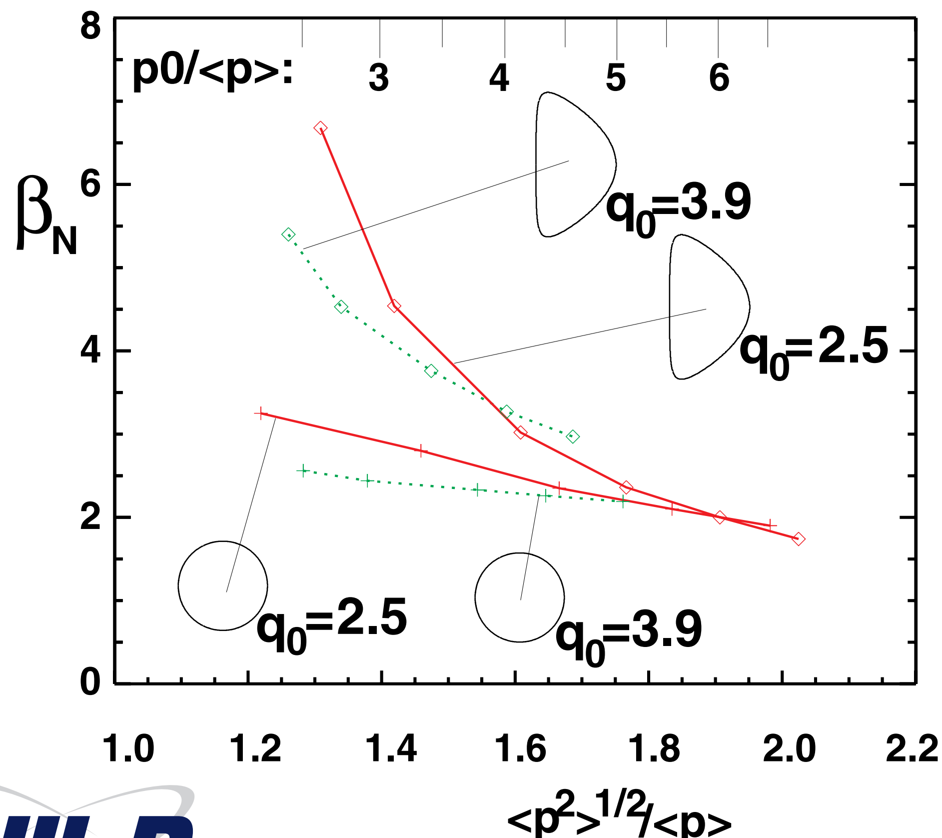
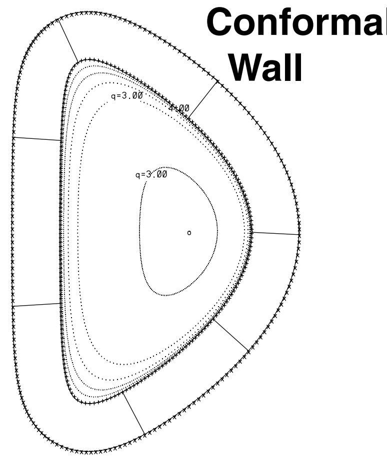
APPROACHES

- Ideal stability with a conducting wall
- Simulated equilibria with model q and pressure profiles based on spline and hyperbolic tangent representations
- Simulated equilibria with q and pressure profiles from self-consistent transport simulations

PREVIOUS STABILITY STUDY IS DISCUSSED MOSTLY IN TERMS OF P(0)/ <P>

- $P(\psi) = P_0\ (1 - \psi)^m$, $q_{95} = 5.1$, $\rho_{qmin} = 0.65$, $q_{min} = 2.1$ and 1.5
- Vary pressure profile peakedness by varying *m*





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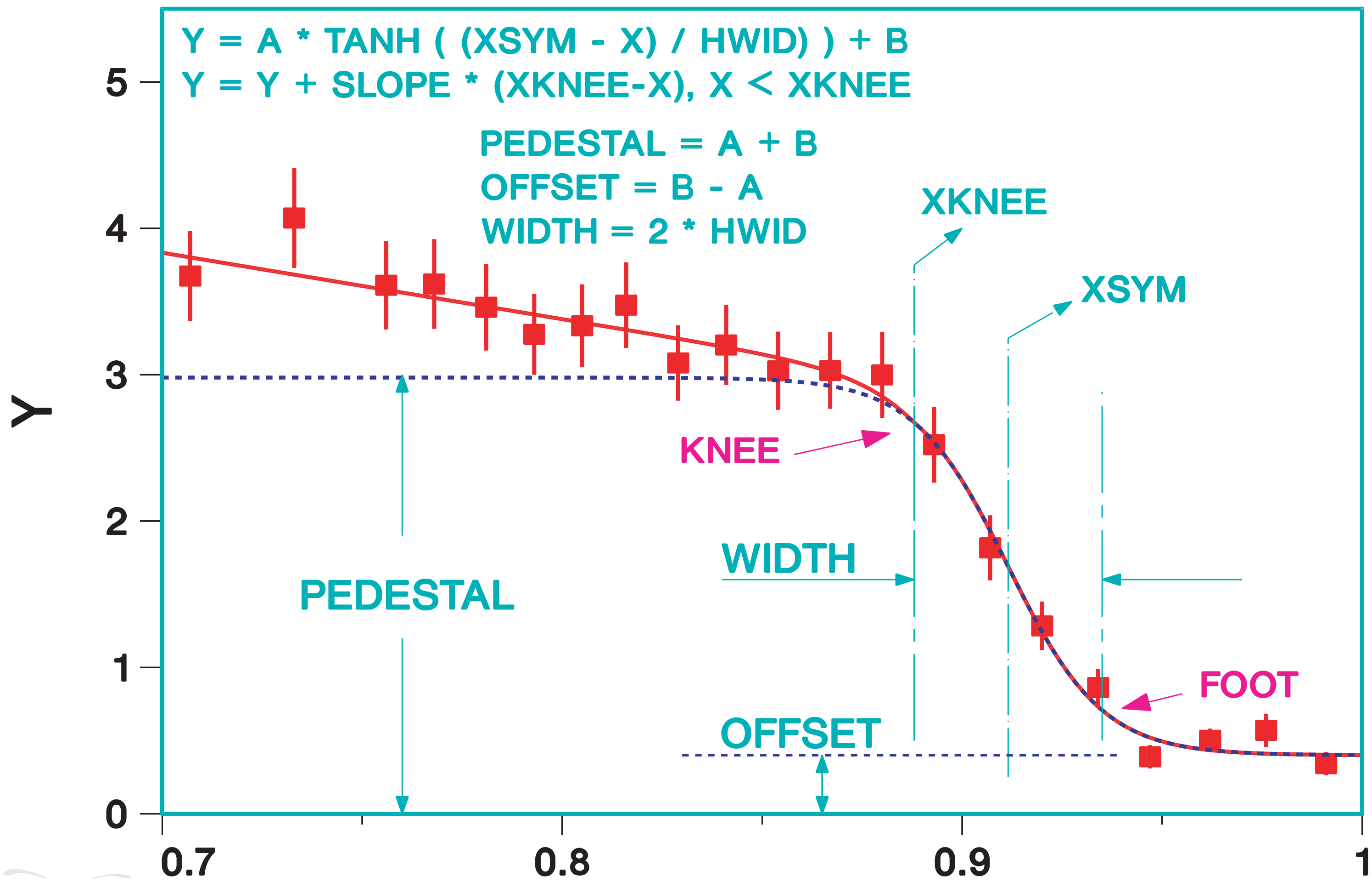
HYPERBOLIC TANGENT PROVIDES GOOD PARAMETRIZATION FOR PRESSURE PROFILES WITH TRANSPORT BARRIER

- 3 parameters amplitude, radius, and width



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ANALYSIS METHODS

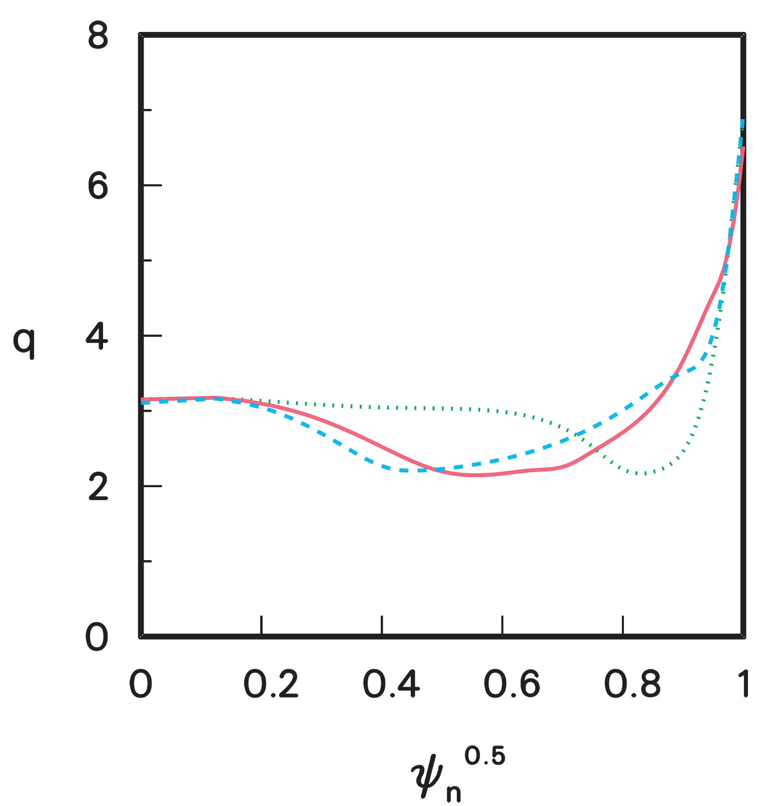
- Equilibrium
  - ToQ, EFIT
  - Up-down symmetric DND based on long pulse high performance shot 95983
  - Pressure profiles modeled using hyperbolic tangent representation with various radii, widths, and amplitudes
  - q profiles modeled using spline representation with various q(0), q_{min}, and ρ_{qmin}
  - Fixed $q_{95} \sim 5.1$
  - Single transport barrier
- Stability
  - Low *n* modes evaluated using GATO with a conducting wall at 1.5a
  - High *n* ballooning evaluated using BALOO

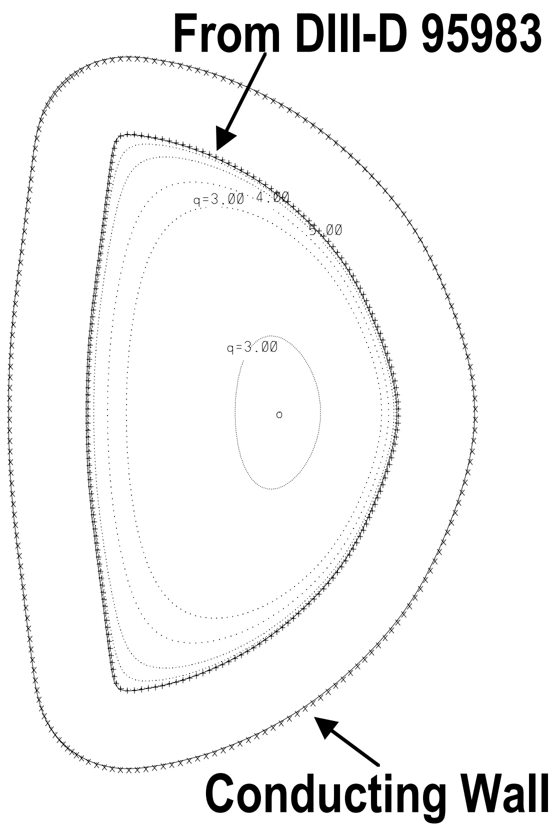
SCANS

- ITB radius ρ_{ITB}
  - Fixed shape
  - Fixed $q(0)$, q_{min}, q_{95}, $\rho_{qmin} - \rho_{ITB}$
  - Hyperbolic tangent pressure with fixed half width W_{ITB}
- ITB half width W_{ITB}
  - Fixed shape
  - Fixed $q(0)$, q_{min}, q_{95}, $\rho_{qmin} - \rho_{ITB}$
  - Fixed ρ_{ITB}
- $\rho_{qmin} - \rho_{ITB}$
  - Fixed shape
  - Fixed $q(0)$, q_{min}, q_{95}
  - Hyperbolic tangent pressure with fixed half width W_{ITB} , ρ_{ITB}
- $q(0)$, q_{min}

PLASMA SHAPE IS BASED ON A DIII-D LONG PULSE HIGH PERFORMANCE DISCHARGE

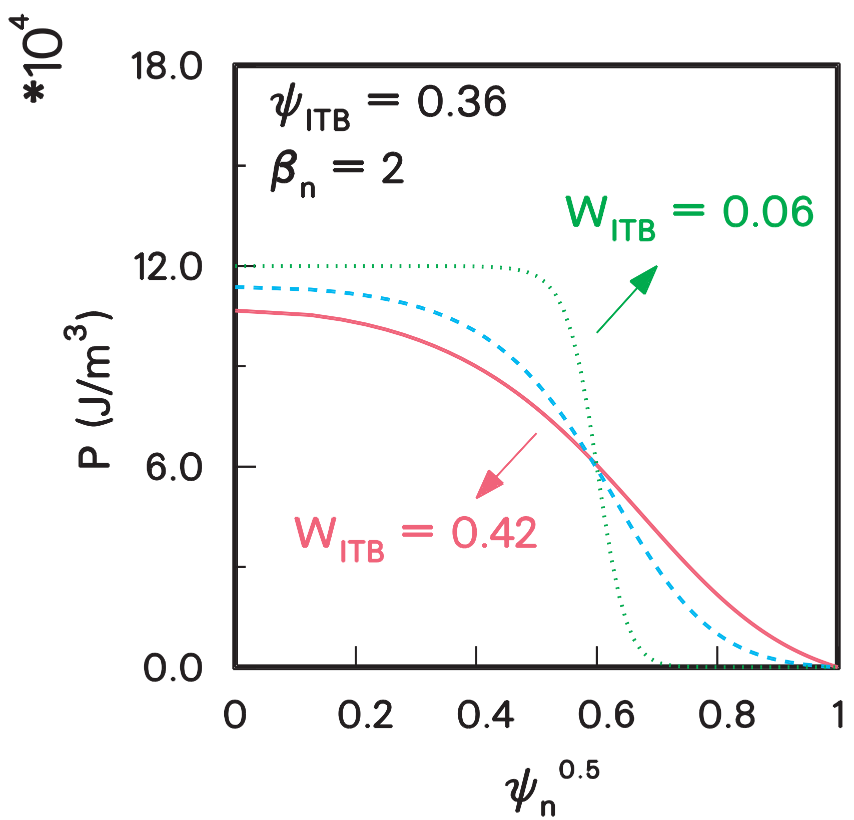
- Up-down symmetric with a conducting wall at 1.5a
- q profiles are modeled using spline representations

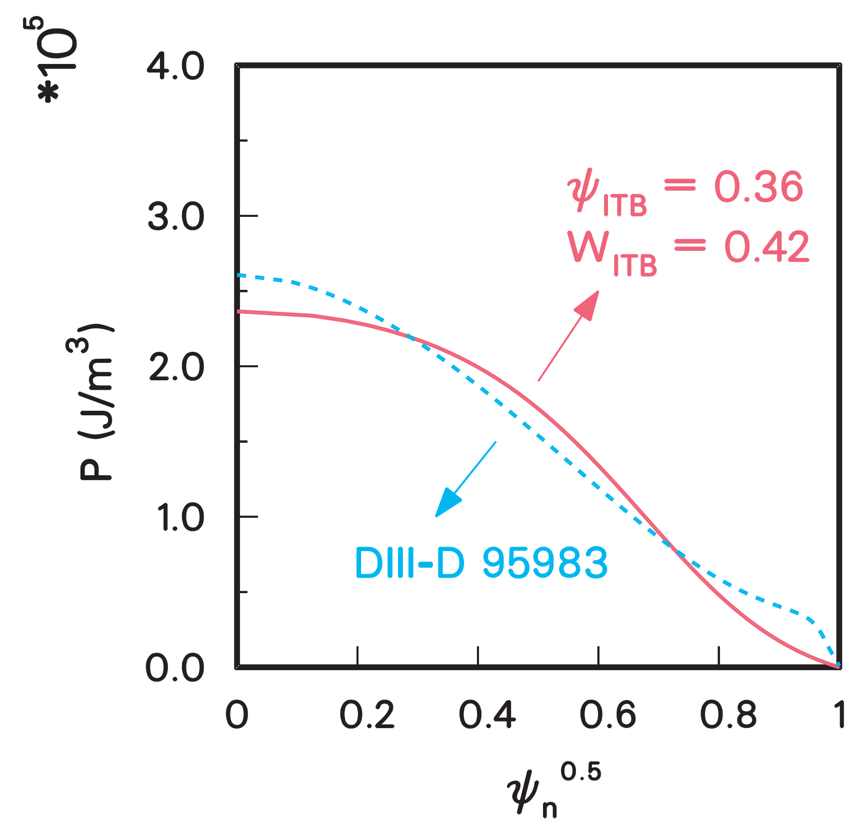




LARGEST PRESSURE GRADIENT IS REDUCED AS TRANSPORT BARRIER WIDTH IS INCREASED AT CONSTANT β

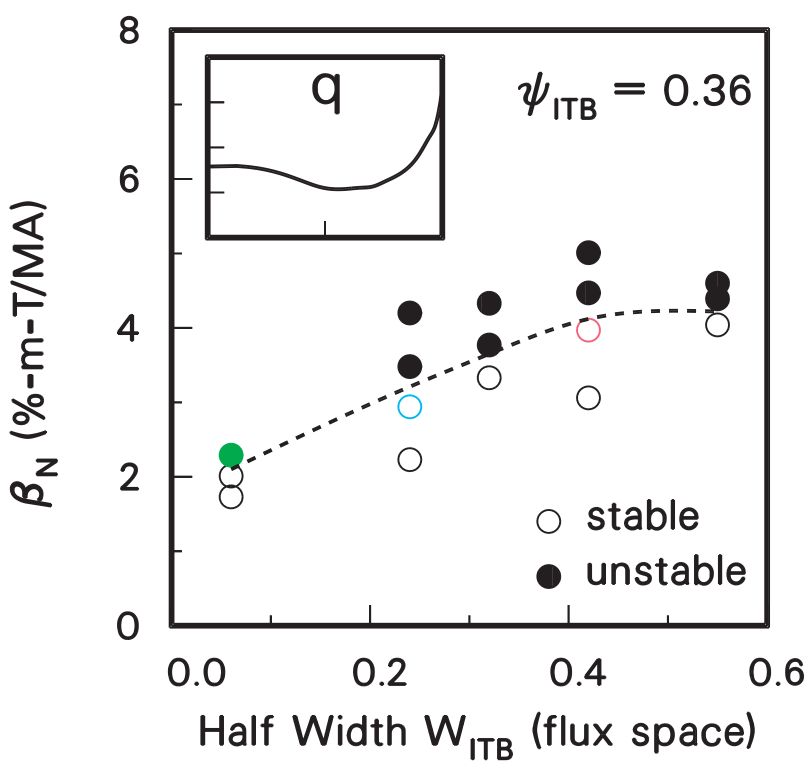
- $P(\psi) = P_0/2 \{ 1 - \mathrm{TANH}[(\psi-\psi_{ITB})/ W_{ITB}] \} - P_0/2 \{ 1 - \mathrm{TANH}[(1-\psi_{ITB})/ W_{ITB}] \}$

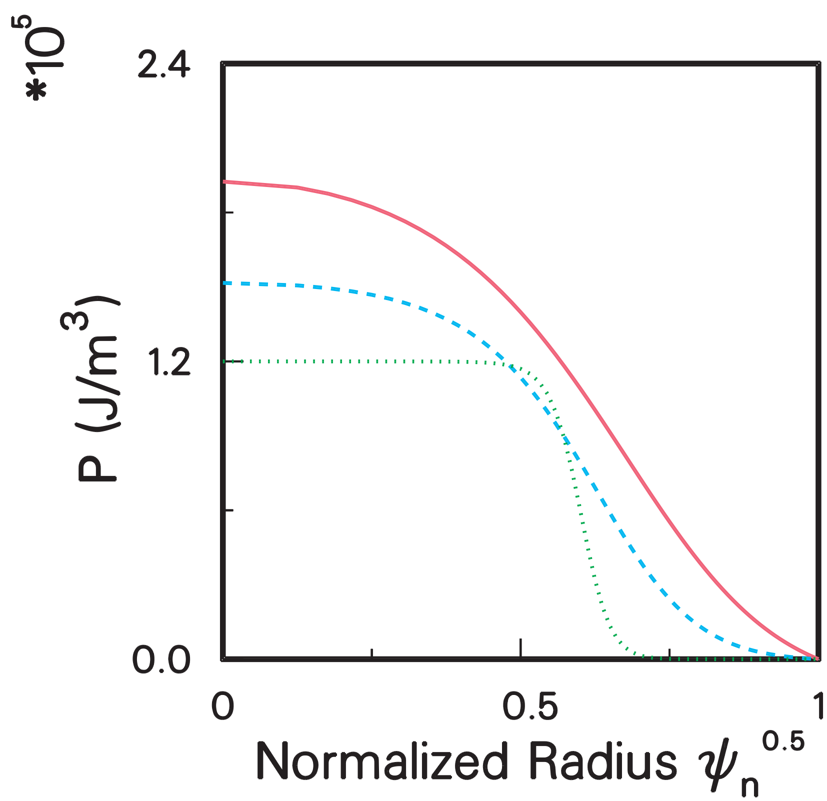




STABILITY LIMIT IMPROVES WITH INTERNAL TRANSPORT BARRIER WIDTH

- fixed shape DND, $q_{95} = 5.1$, $q(0) = 3.2$, $q_{min} = 2.2$
- ideal n = 1 with wall at 1.5a, $\psi_{qmin}^{0.5} - \psi_{ITB}^{0.5} = 0.05$
- stability improves due to geometric effect, closer to wall, and stronger shear





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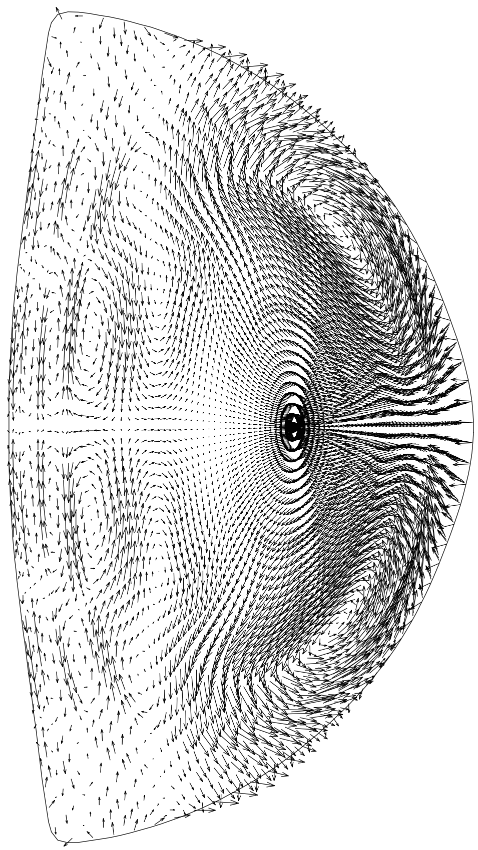
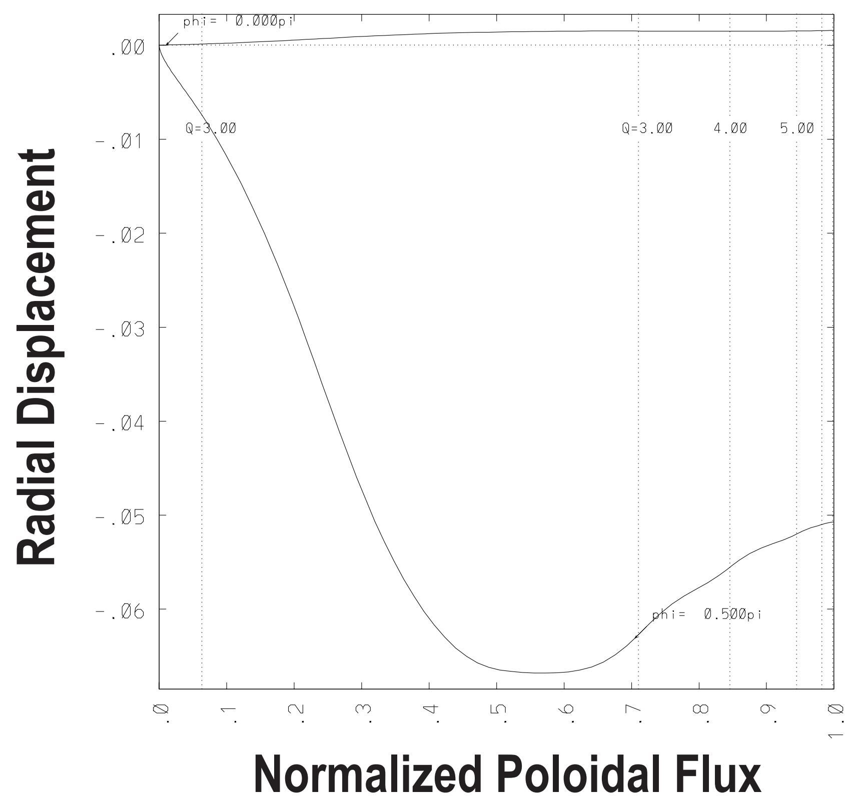
THE n = 1 UNSTABLE MODE HAS A GLOBAL RADIAL STRUCTURE

- $\beta_N = 4.3$, $W_{ITB} = 0.24$, $\psi_{ITB} = 0.36$, $q(0) = 3.2$, $q_{min} = 2.2$, $q_{95} = 5.1$, $\psi_{qmin} = 0.42$
- Computed using GATO with a conducting wall at 1.5a





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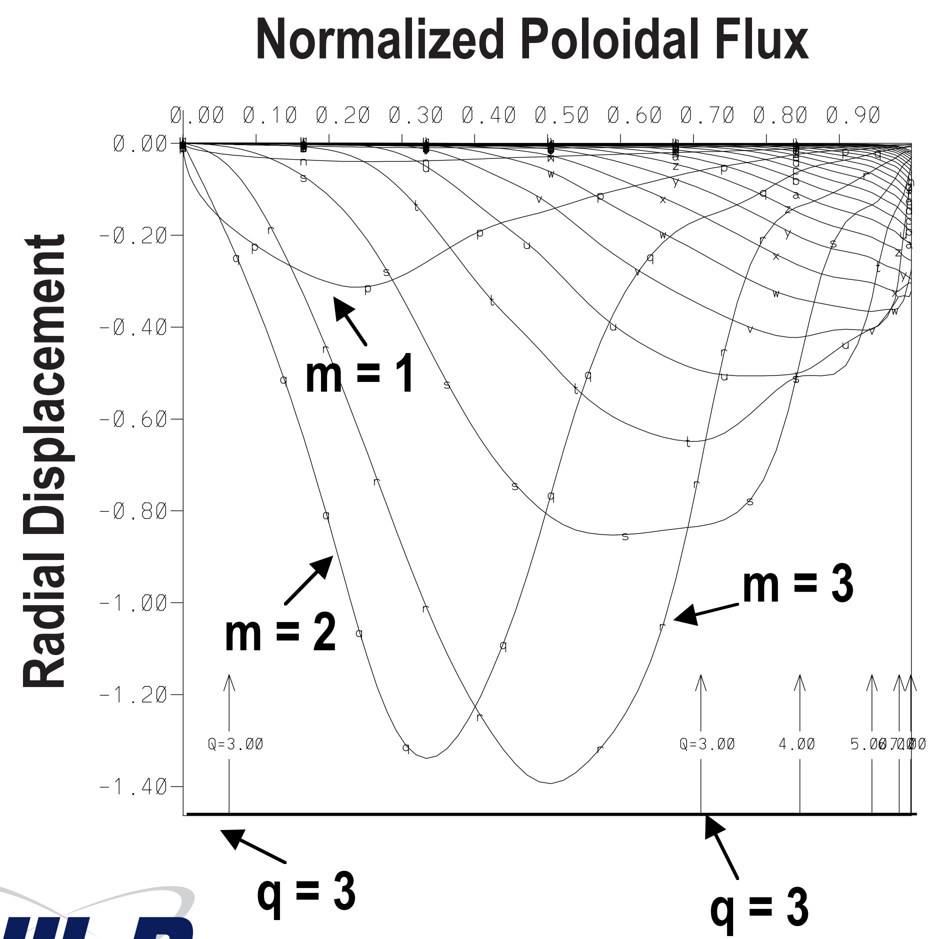
THE n = 1 UNSTABLE MODE HAS AN INFERNAL MODE STRUCTURE

- $\beta_N = 4.3$, $W_{ITB} = 0.24$, $\psi_{ITB} = 0.36$, $q(0) = 3.2$, $q_{min} = 2.2$, $q_{95} = 5.1$, $\psi_{qmin} = 0.423$
- Computed using GATO with a conducting wall at 1.5a



- Large m = 1, 2 components although no q = 1 and 2 surfaces

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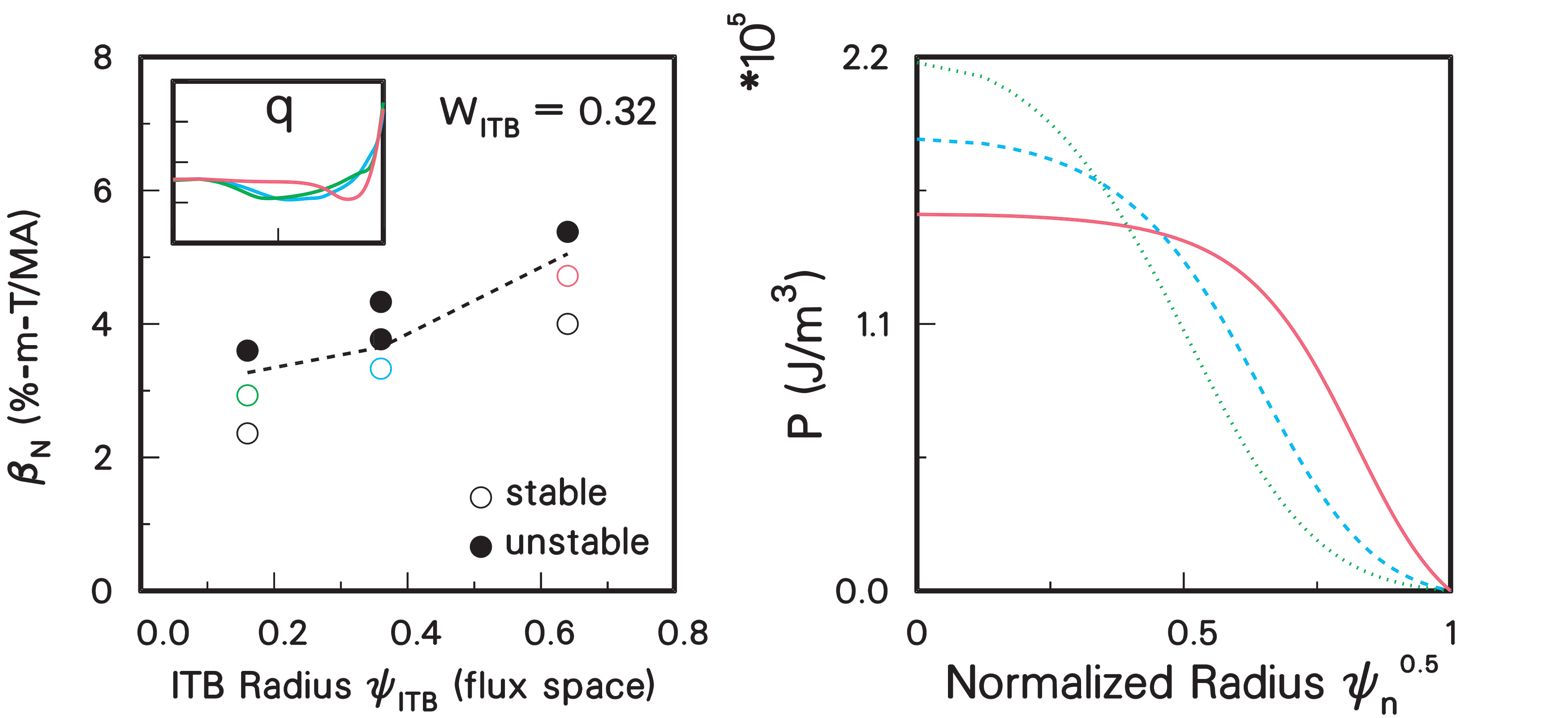
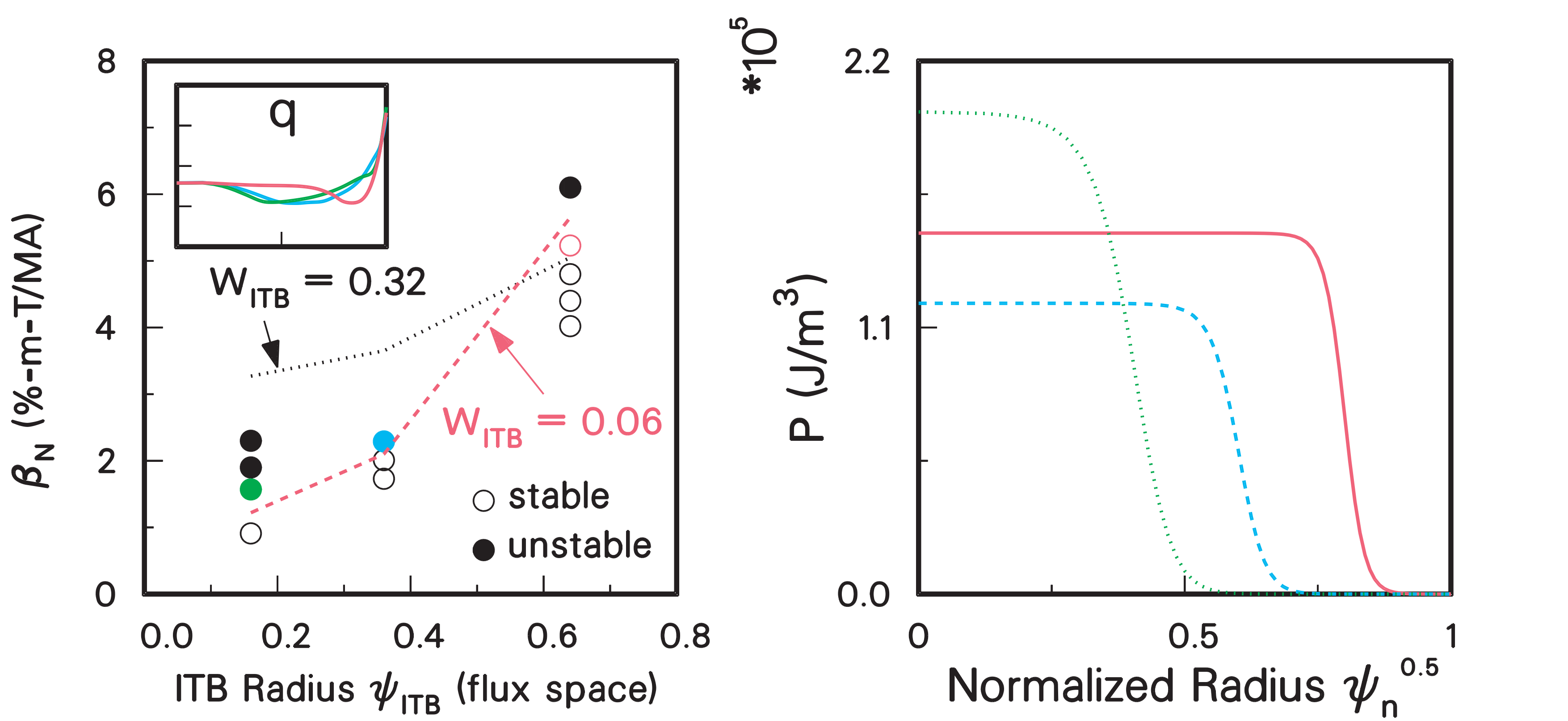
STABILITY LIMIT IMPROVES WITH INTERNAL TRANSPORT BARRIER RADIUS

- fixed shape DND, $q_{95} = 5.1$, $q(0) = 3.2$, $q_{min} = 2.2$
- ideal n = 1 with wall at 1.5a, $\psi_{qmin}^{0.5} - \psi_{ITB}^{0.5} = 0.05$
- stability improves mainly due to geometric effects



STABILITY LIMIT IMPROVES WITH INTERNAL TRANSPORT BARRIER RADIUS

- fixed shape DND, $q_{95} = 5.1$, $q(0) = 3.2$, $q_{min} = 2.2$
- ideal n = 1 with wall at 1.5a, $\psi_{qmin}^{0.5} - \psi_{ITB}^{0.5} = 0.05$
- stability improves due to geometric effect, closer to wall, and stronger shear



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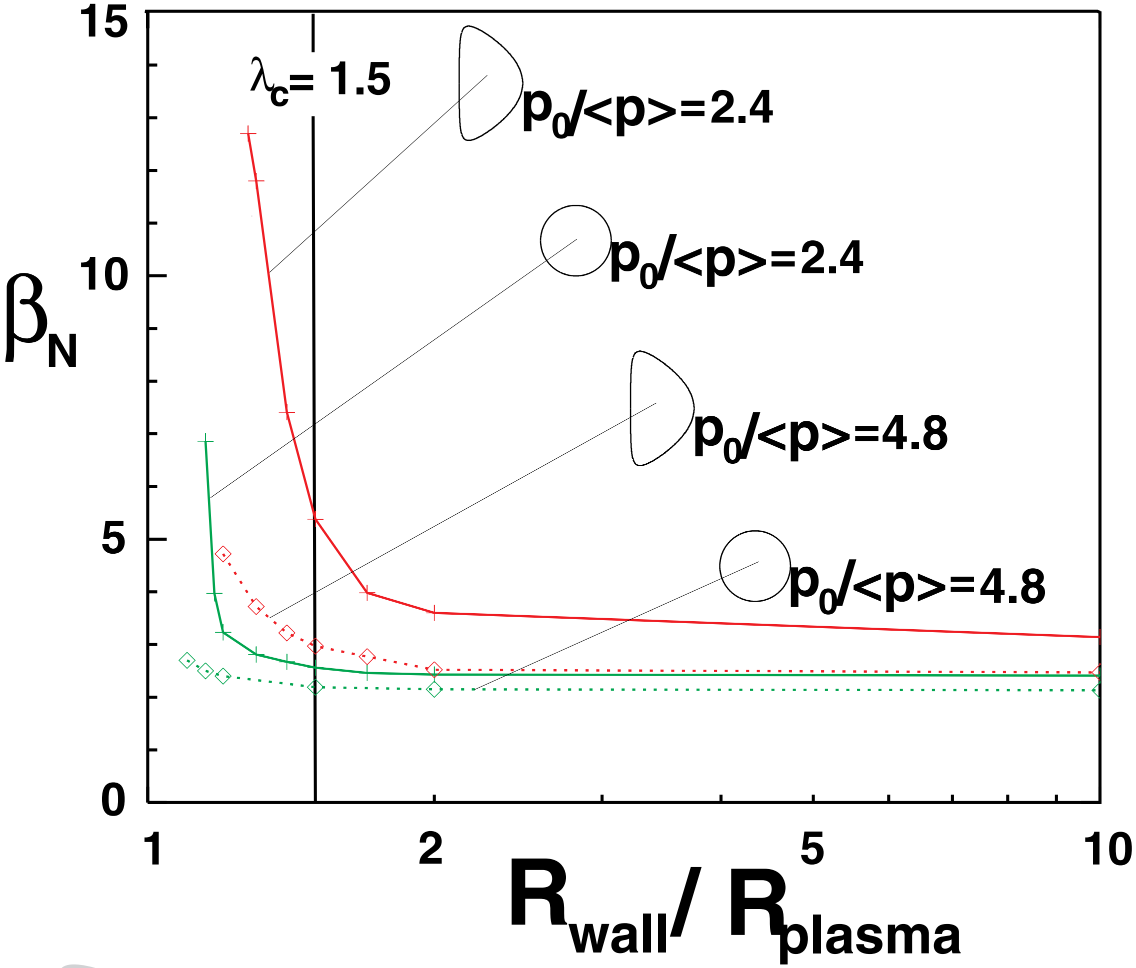
PREVIOUS STABILITY STUDY SHOWS THAT WALL STABILIZATION IS CRUCIAL



- With a close wall β_N is substantially increased

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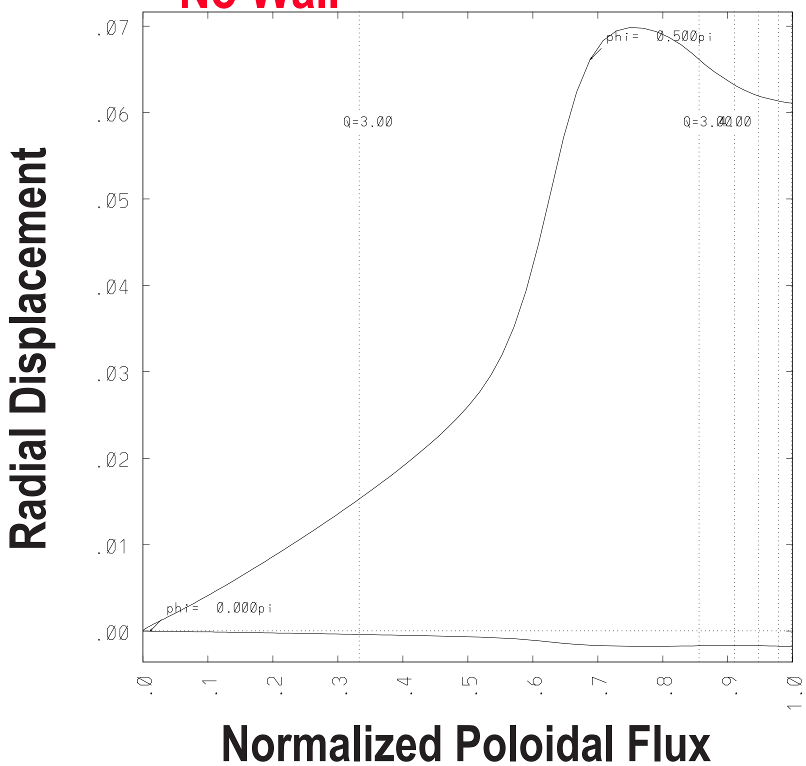
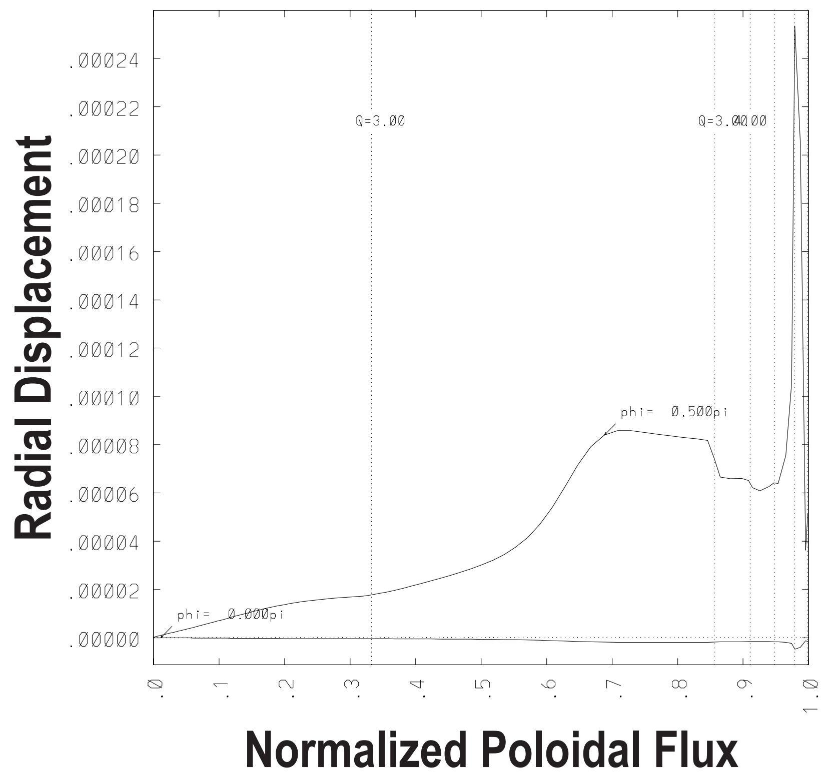
WALL STABILIZATION IS CRUCIAL FOR STABILITY

- β_N = 5.2, W_{ITB} = 0.06, ψ_{ITB} = 0.36, q(0) = 3.2, q_{min} = 2.2, q_{95} = 5.1
- Computed using GATO with a conducting wall at 1.5a

No Wall



Wall at 1.5a



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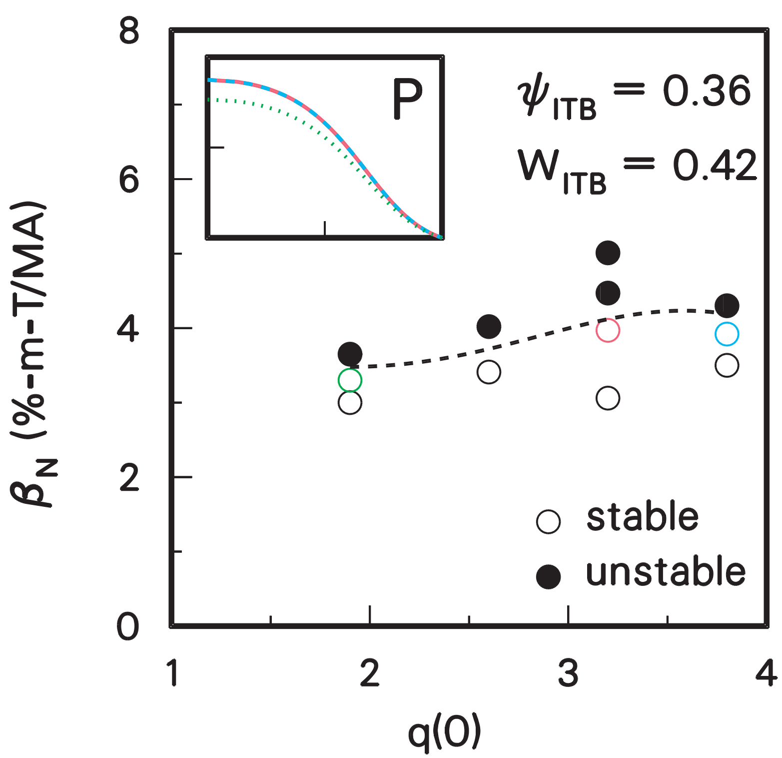
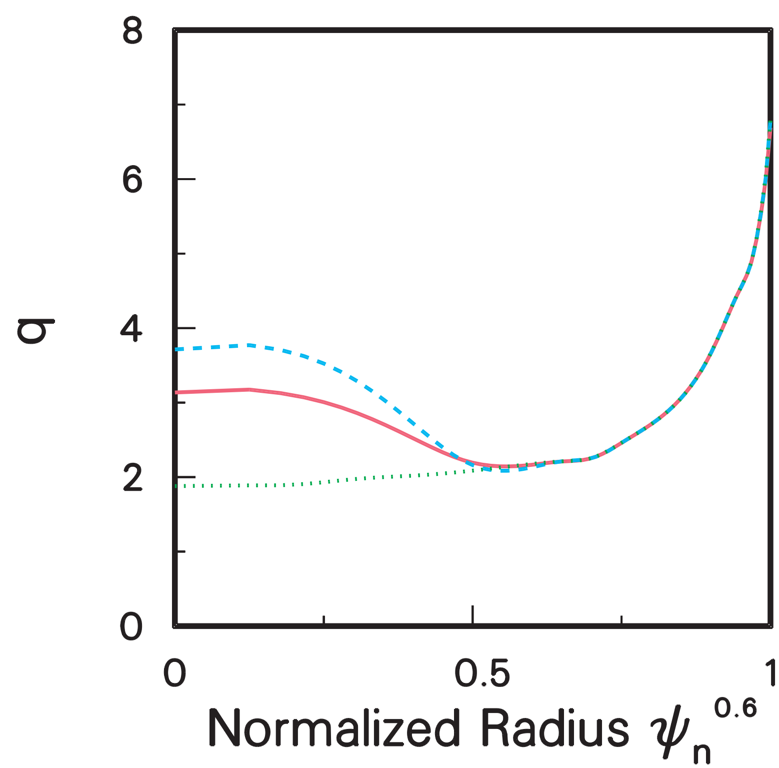
STABILITY LIMIT VARIES WEAKLY WITH q(0)

- fixed shape DND, $q_{95} = 5.1$, $q_{min} = 2.2$
- hyperbolic tangent pressure representation
- ideal n = 1, wall at 1.5a





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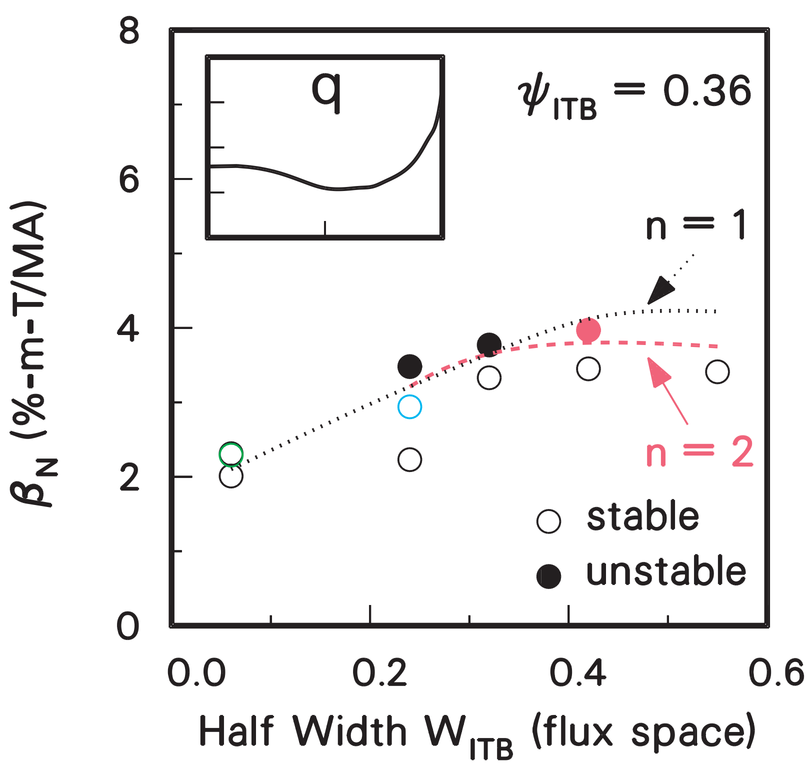
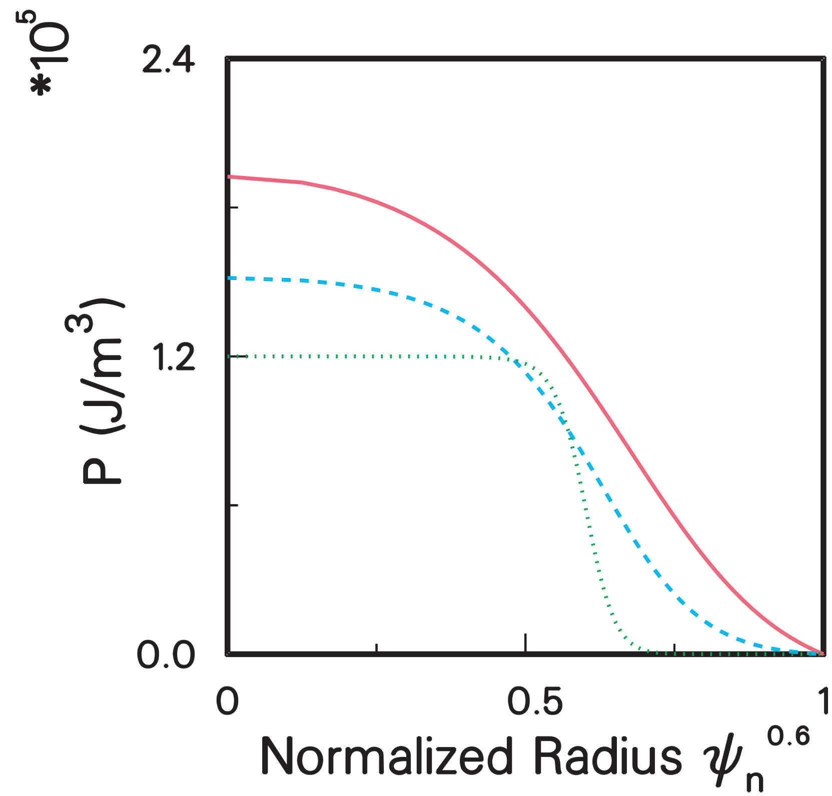
n = 2 MODES ARE MORE UNSTABLE IN ITB WITH LARGE WIDTH

- fixed shape DND, $q_{95} = 5.1$, $q(0) = 3.2$, $q_{min} = 2.2$
- ideal n = 2, wall at 1.5a
- wall stabilization is less effective against n = 2 modes





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SUMMARY

- Hyperbolic tangent function provides an useful representation to systematic study the effects of Internal transport barrier (ITB) width and radius on MHD stability
- Stability limit improves with transport barrier width and radius
- Wall stabilization is crucial for ITB with large radius
- Stability limit varies weakly with q(0)
- n=2 modes are more unstable in ITB with large radius and width
- Future work
  - More sophisticated pressure models, hyperbolic tangent + linear
  - Higher n modes, edge stability
  - Shaping, squareness, outboard bump