Small ELM and ELM-free Operation in ARIES AT

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GENERAL ATOMICS

Small ELM and ELM-free Options in a Reactor Scenario Offer Significant Promise if They Can be Realized

- **ELM-free Scenarios:**
  - Enhanced D-alpha (EDA) Mode:
    - Observed in C-Mod
  - Quasi-H (QH) Mode:
    - Observed in DIII-D and others
  - Resonant Magnetic Perturbation (RMP) Discharges:
    - Observed in DIII-D with non-axisymmetric coils
  - Li Conditioned Discharges:
    - Observed in NSTX

- **Small ELM scenarios:**
  - Shaping:
    - Large squareness
  - Type II (“grassy”) ELMs:
    - Mostly seen in JT-60
  - Type III ELMs

Original Proposal to Study Possibility of Including Options for ELM-free and Small ELM Scenarios in ARIES

- **Take representative discharges for each regime in the respective machines and determine essential physics:**
  - Discharges from DIII-D, C-Mod, NSTX
  - Determine essential profiles and other characteristics
  - Characterize dependence of ELM type and size
- **Scale configurations to ARIES:**
  - Use profiles in ARIES configuration:
    - Density and temperature profiles from respective discharges with ARIES q profile
- **Study low to intermediate n stability of scaled configuration:**
  - Characterize ELM type and size from GATO and ELITE
- **Modified proposal to reflect recent new results:**
  - Several options can be eliminated:
    - EDA, Li Conditioning, Type II and III small ELM regimes
  - New I-mode option presents intriguing possibilities
  - ELM control by pellet pacing has shown promise in experiments

Several Options for Small ELM and ELM-free Regimes Showed Promise But are Probably Unsuitable

- **Lithium conditioning option for ELM-free regimes showed promise:**
  - Discharges range from ELMing to infrequent ELMs to ELM-free, depending on level of Li conditioning
- **Key disadvantage:**
  - **Impurity accumulation**
- **The EDA option does not appear to scale to a reactor:**
  - Limited operational range
  - Not reproduced in experiments other than C-mod
- **Shaping to control ELMs with squareness does not appear to yield sufficient control:**
  - Significant performance loss
- **Type II small ELM option does not appear to be reproducible or scalable**
- **Type III small ELM option does not appear to be scalable**

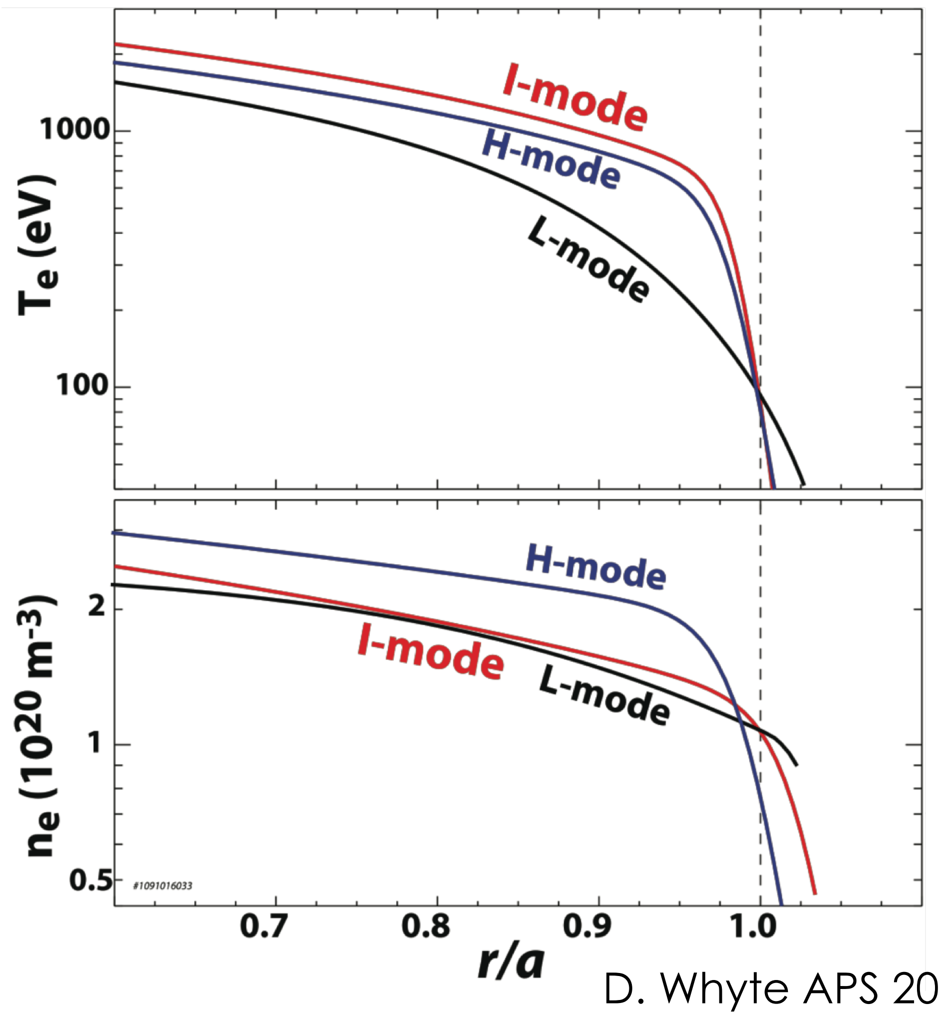
Remaining Options Still Suggest Promise

QH-mode:	Expanded limits, understanding
RMP ELM-free option:	Mechanism not yet understood
RMP induced QH-mode:	Facilitates QH-mode
Small ELMs via ELM pacing:	Small frequent pellets

- **Recently discovered I-Mode on C-Mod offers a new potential scenario if it can be scaled to a reactor:**
  - L-mode particle confinement but H-mode energy confinement
- **Recent analysis by Dennis Whyte (APS 2011):**
  - Simple scaling assumptions combined with modeling and experimental data suggest I-mode can be scaled to ITER and to a reactor:
    - Power thresholds for L-mode / I-mode and I-mode / H-mode transitions appear to allow a feasible path
    - Density scaling is favorable
    - Limited confinement degradation

I-Mode is Characterized by L-mode Density Profile and H-mode Temperature Profiles

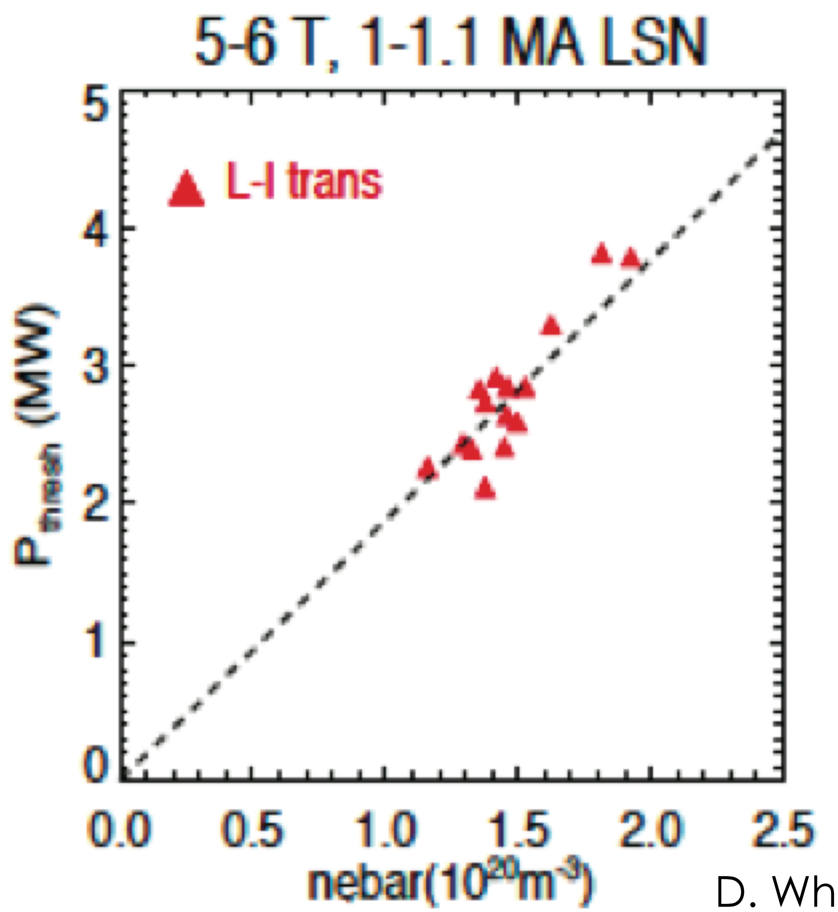
- **No steep density pedestal:**
  - L-mode particle confinement but H-mode energy confinement
- **Comparable in many ways to QH-Mode:**
  - Presence of continuous oscillation
  - Thought to be related directly to increased particle transport
- **Distinct potential advantages:**
  - Operation at low collisionality
  - Regulation of pedestal is apparently due to transport and not stability



D. Whyte APS 2011

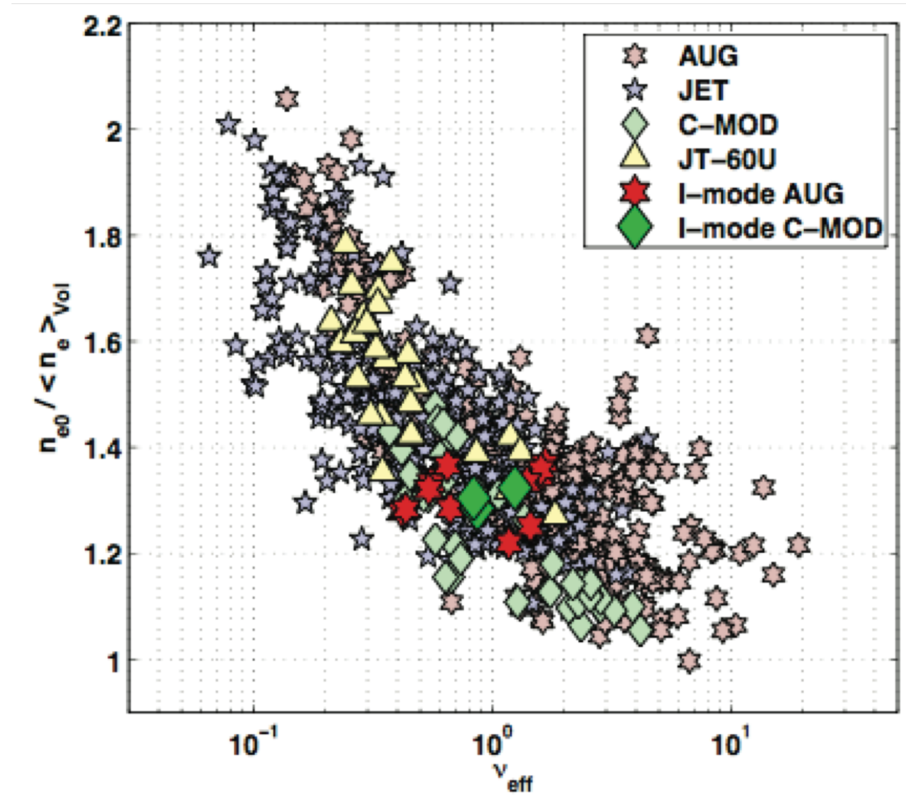
L-mode to I-Mode Transition Power Threshold Scales Proportional to Density

- L-I transition power threshold



D. Whyte APS 2011

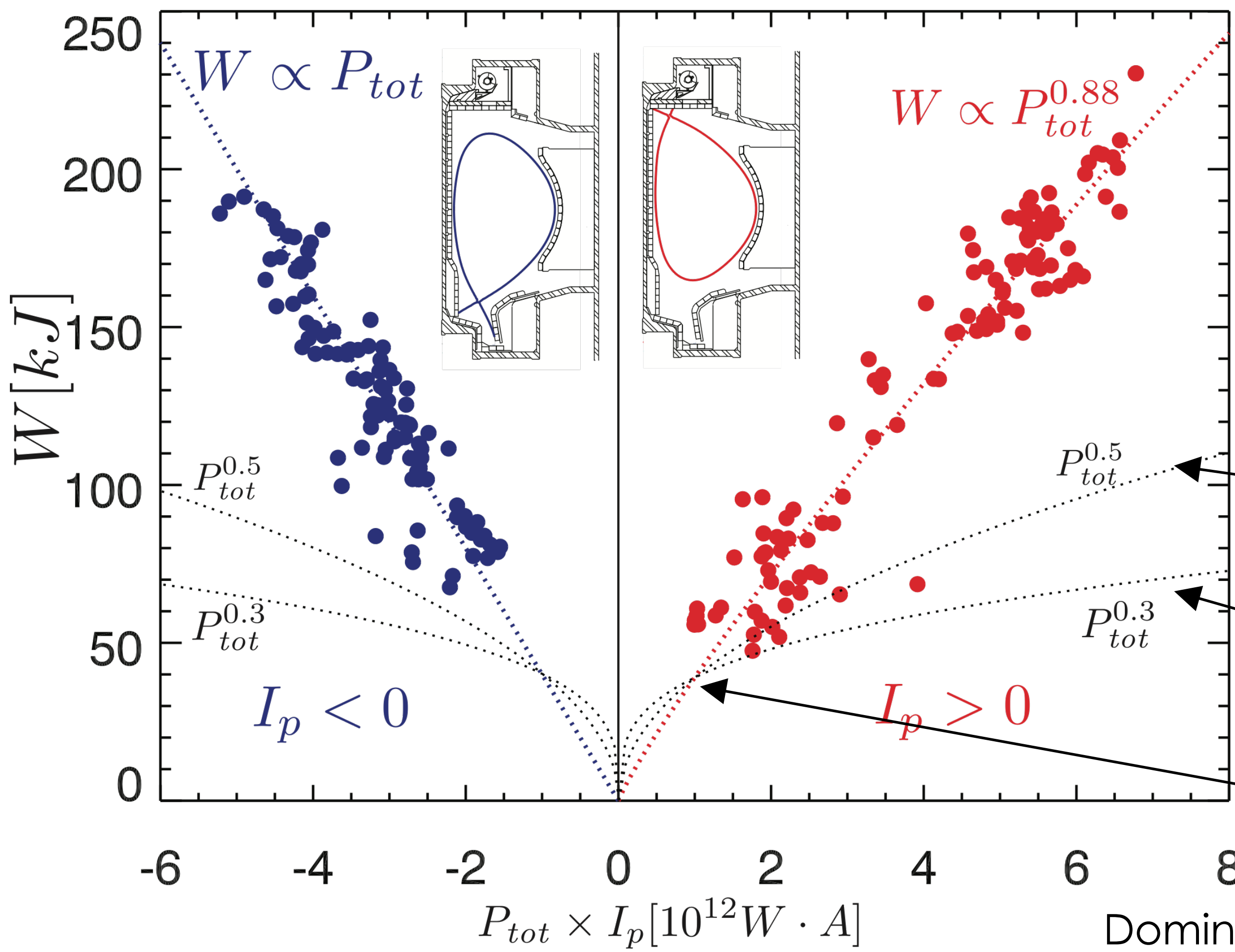
- Density profile peakedness is similar to L-mode



Angioni, et al., PPCF 2009

C-mod Data Shows That Confinement Degradation in I-mode is Not a Serious Issue

- Stored energy increases almost linearly with the heating power



Scaling is mostly from P_{tot} but with some I_p variation

Renormalized L-mode scaling

Renormalized H-mode scaling

Normalization point

Dominguez PhD Thesis

Access to I-mode Appears Feasible on ITER

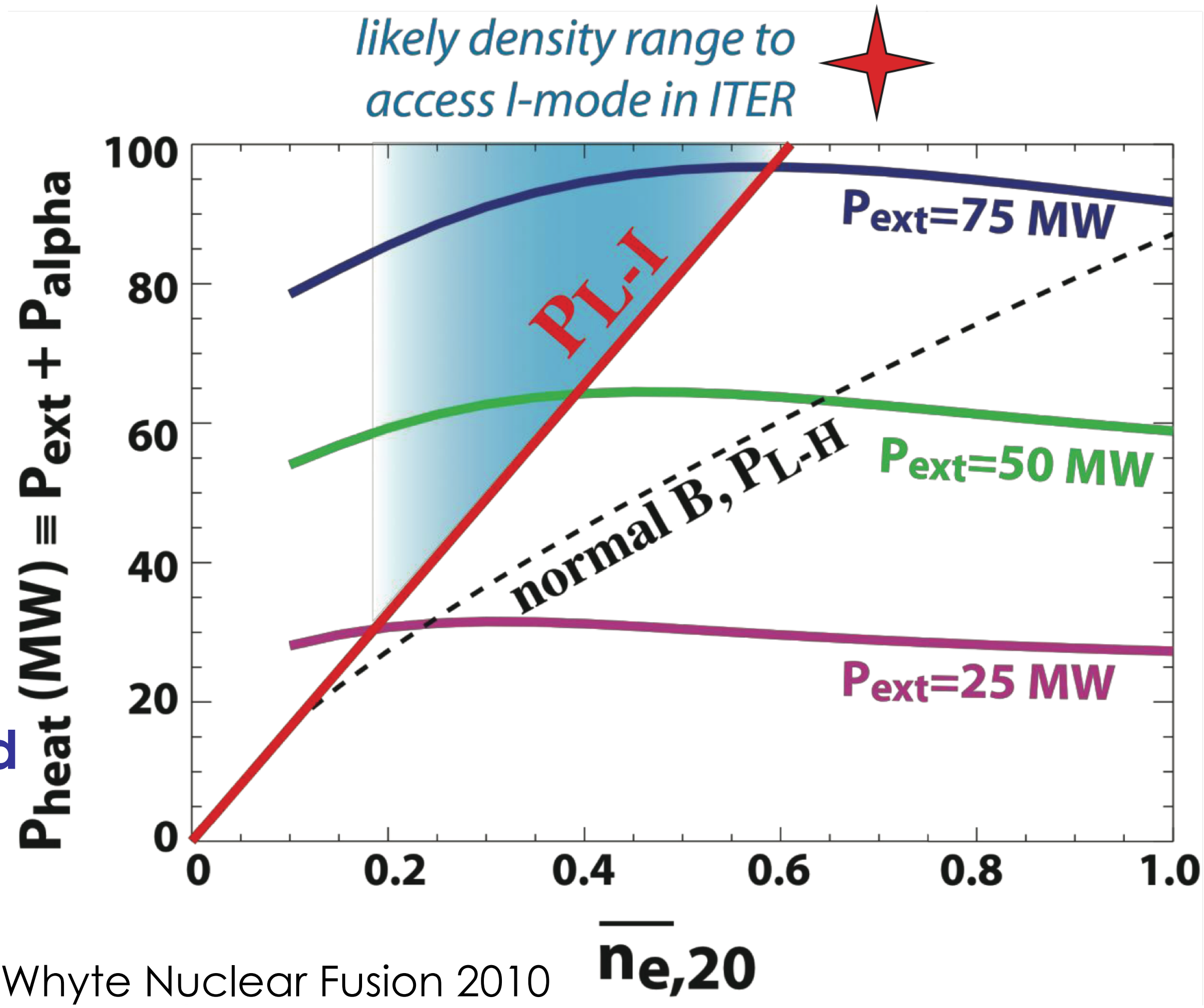
- **Scaling using n_e and relative cross sections**

$$S_{ITER} / S_{C\,mod} \sim 9$$

$$P_{heat} \sim n_e \left(S_{ITER} / S_{C\,mod} \right)$$

- **Alpha power in ITER calculated from simulation using C-mod profiles**

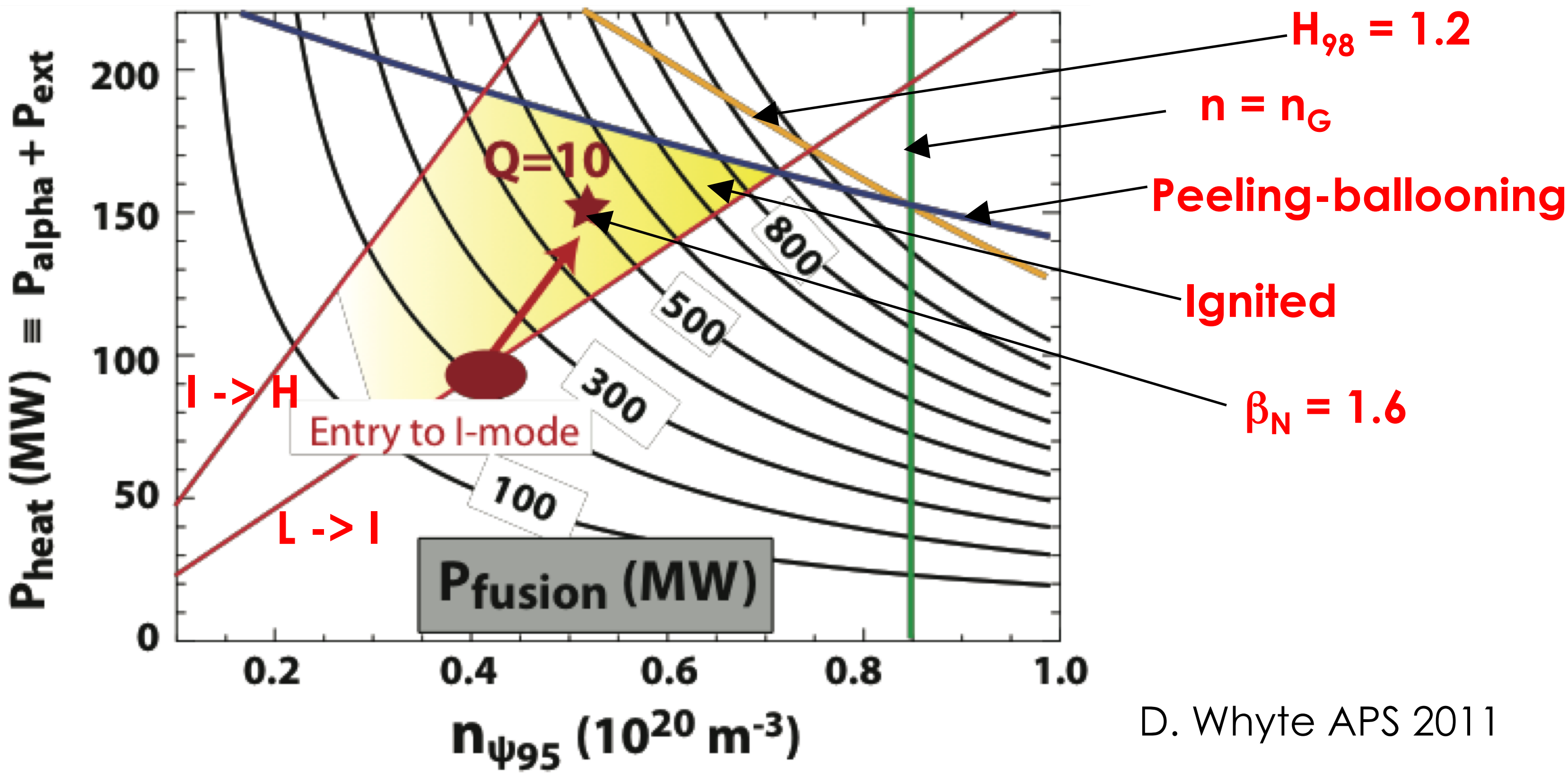
$$P_{heat} = P_{ext} + P_{alpha}$$



D. Whyte Nuclear Fusion 2010

I-mode Can be Accessed on ITER at Low Heating Power from Low Density

- Desired fusion power can be reached by increasing density with heating power after the I-mode transition



D. Whyte APS 2011

- Recent experiments in C-mod confirmed that after a low density L-I transition, ne could be increased 25% while remaining in I-mode

Key Issues: How do the Small ELM and ELM-free Regimes Scale to ARIES ACT 1

- **ARIES β_N ~ 5 but all present discharges have much lower β_N:**
  - High β_N will make the modes much larger with same pedestal:
    - How does pedestal width and height really scale if these operating modes are reproduced in an ARIES scale reactor?
    - Experimentally ELM losses are proportional to energy contained in the pedestal
- **ARIES has high internal q with flat low shear profile:**
  - How does this affect coupling of edge pedestal stability to core:
    - Likely to increase mode width
- **What is role of nearby wall:**
  - Coupling to wall will be quite different at high β_N with high bootstrap fraction:
    - Unstable edge modes are generally much more global at high β_N