H-mode Characteristics and ELM Dynamics at Near-Unity Aspect Ratio

Kathreen E. Thome
on behalf of the PEGASUS Team

University of Wisconsin-Madison

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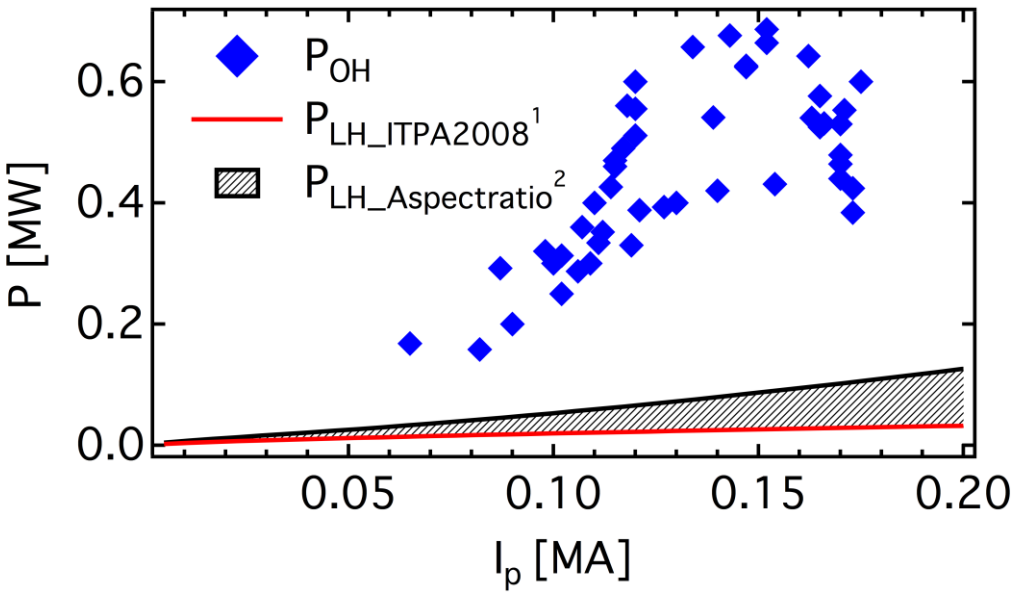
PEGASUS Toroidal Experiment

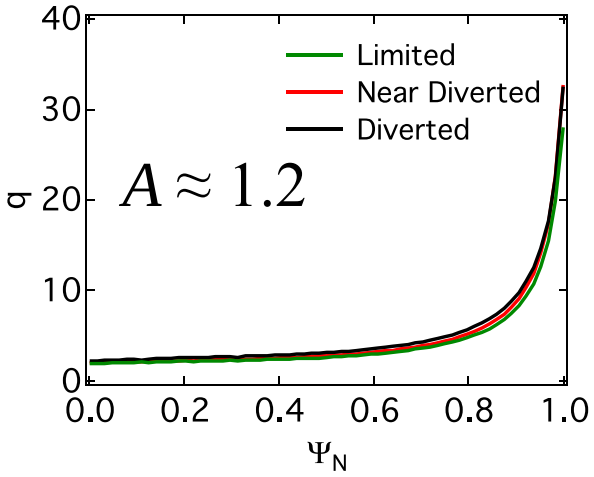
H-mode Readily Accessible at Near-Unity *A*

- $A \approx 1 \rightarrow$ low $B_T \rightarrow$ low P_{LH}

$$P_{LH} \sim n_e^{0.7} B_T^{0.7} S$$



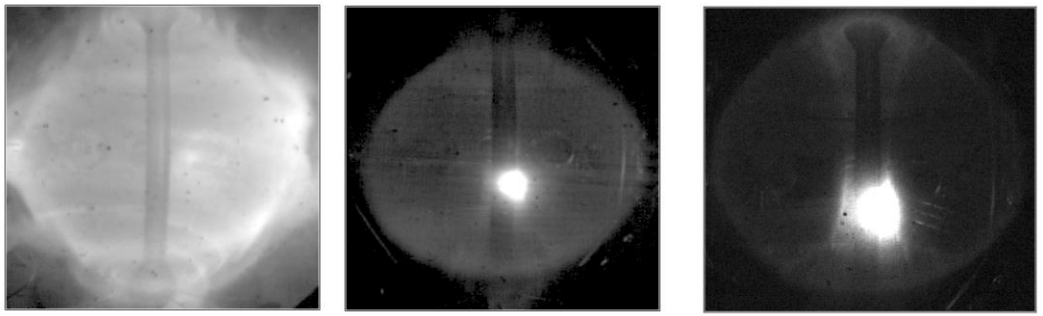
- Magnetic topology similar in limited and diverted at $A \approx 1$



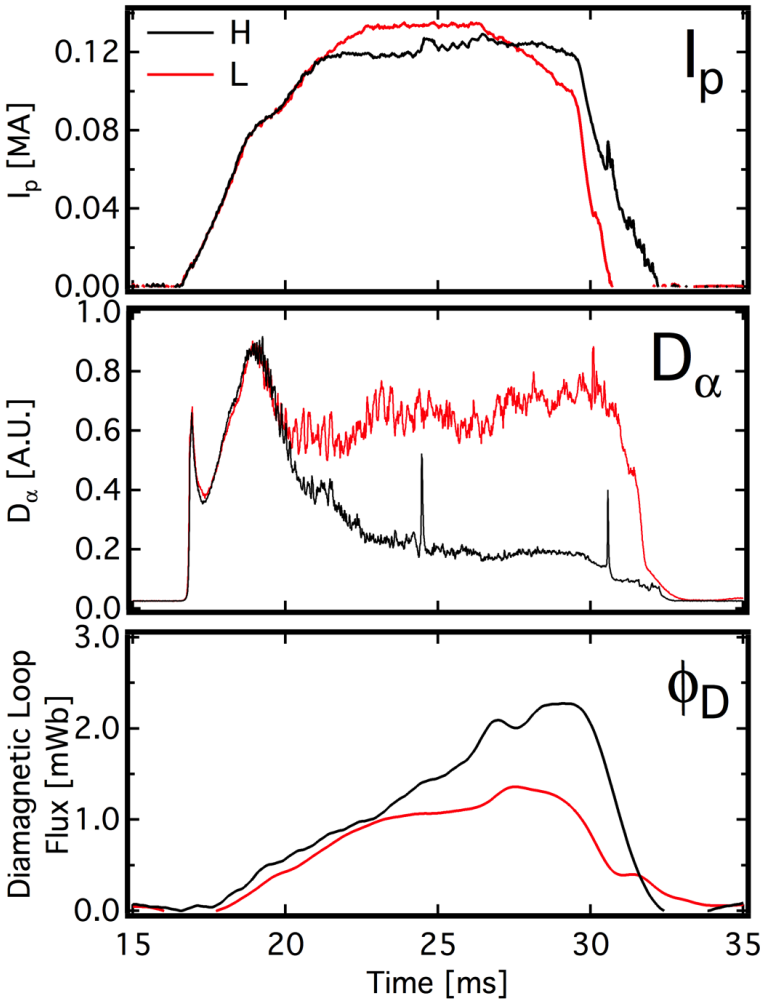
[1] *Nucl. Fusion*, **47**, S82 (2007)
[2] *Plasma Phys. Control. Fus.*, **46**, A227 (2004)

Ohmic H-mode Plasmas have Standard Signatures

Limited L **Limited H** **Near-diverted H**



- H-mode achieved via HFS fueling
- Quiescent edge
- Reduced D_α, Increased ∇D_α
- Large and small ELMs
- Bifurcation in ϕ_D
  - Transport equilibrium not attained



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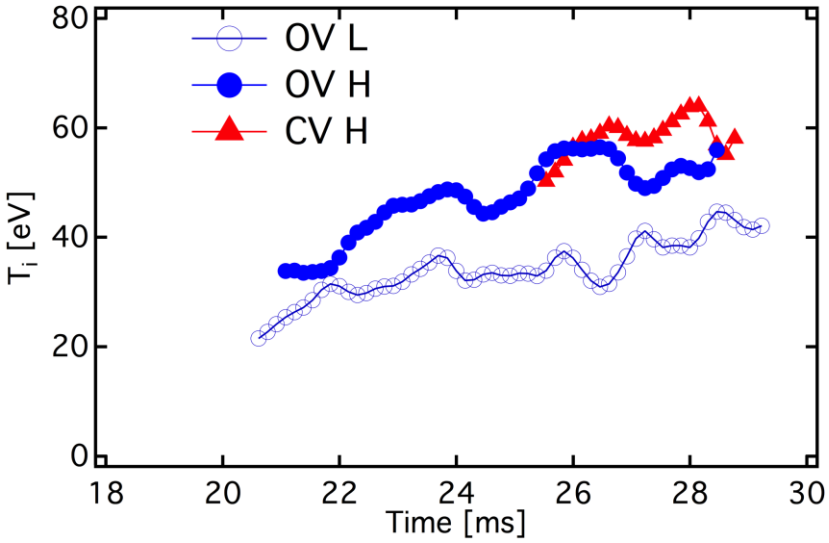
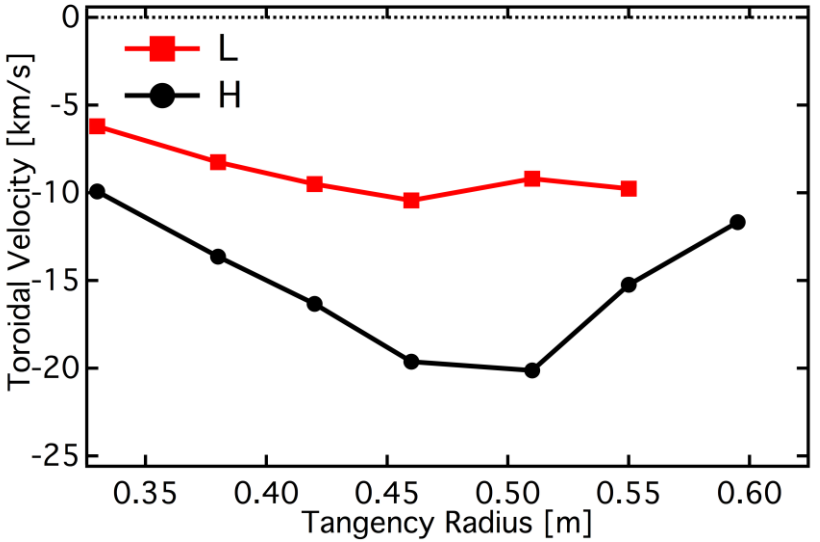
$T_i(0)$ and Edge Shear Increase in H-mode

- Impurity $T_i(0)$ doubles
  - CV only seen in core H-mode plasmas

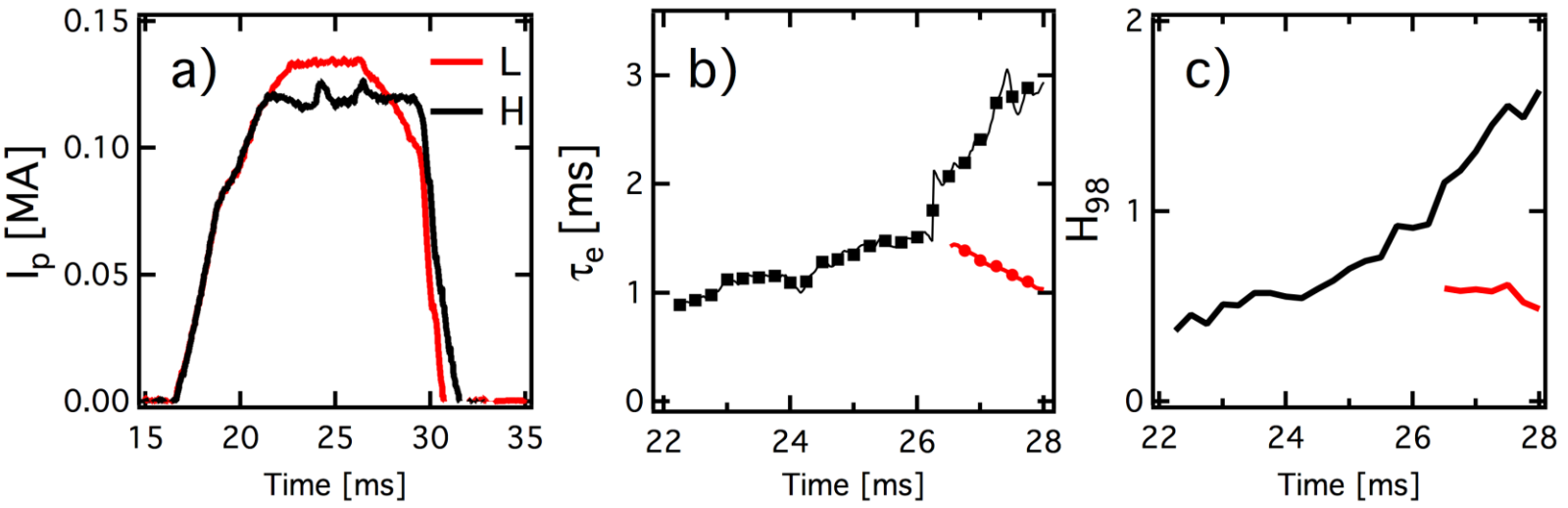


- Chordally-integrated velocity profiles show increased shear in the outer region in H-mode
  - Indirect evidence of E_r well



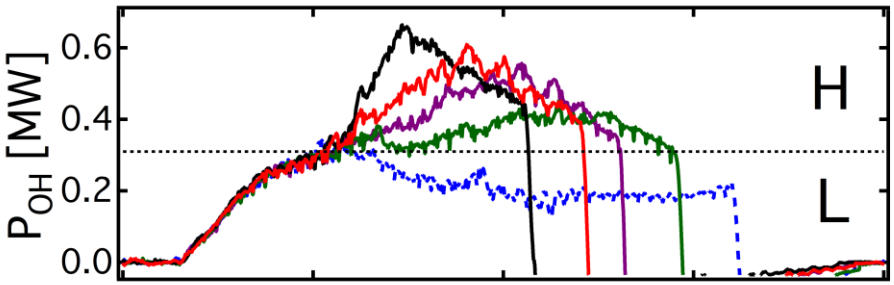
Energy Confinement Improves in H-mode

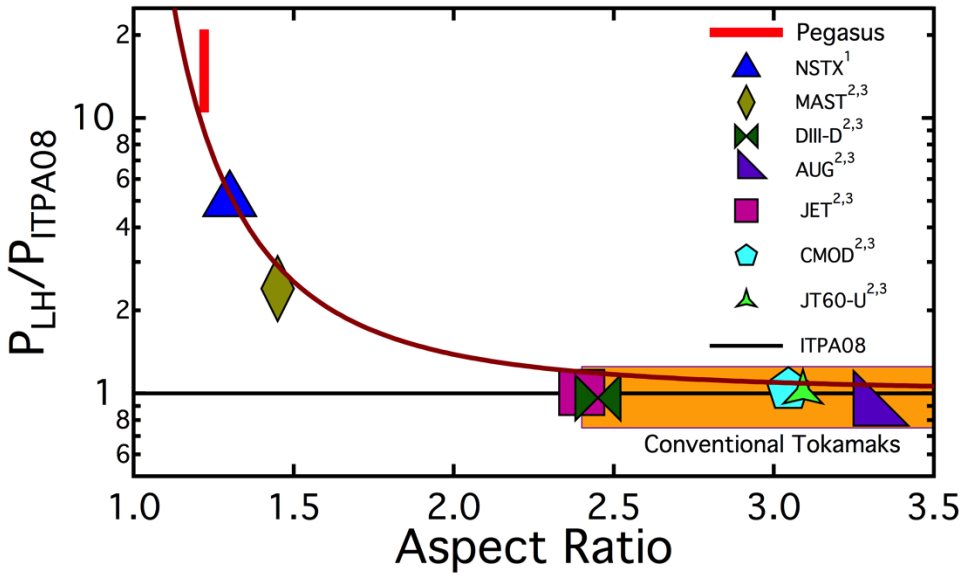
- τ_e from time-evolving magnetic reconstructions
- L-mode: $\tau_e \sim 1.5$ ms, $H_{98} \sim 0.5$
- H-mode: $\tau_e \sim 3$ ms, $H_{98} > 1$
  - Short pulse length → transport equilibrium not yet reached



P_{LH} Increasingly Diverges from Expectations as $A \rightarrow 1$

- P_{LH} studied by varying P_{OH}, n_e
  - n_e dependence observed
- PEGASUS $P_{LH}/P_{ITPA08} \approx 10$
- P_{LH}/P_{ITPA08} continues to increase as $A \rightarrow 1$



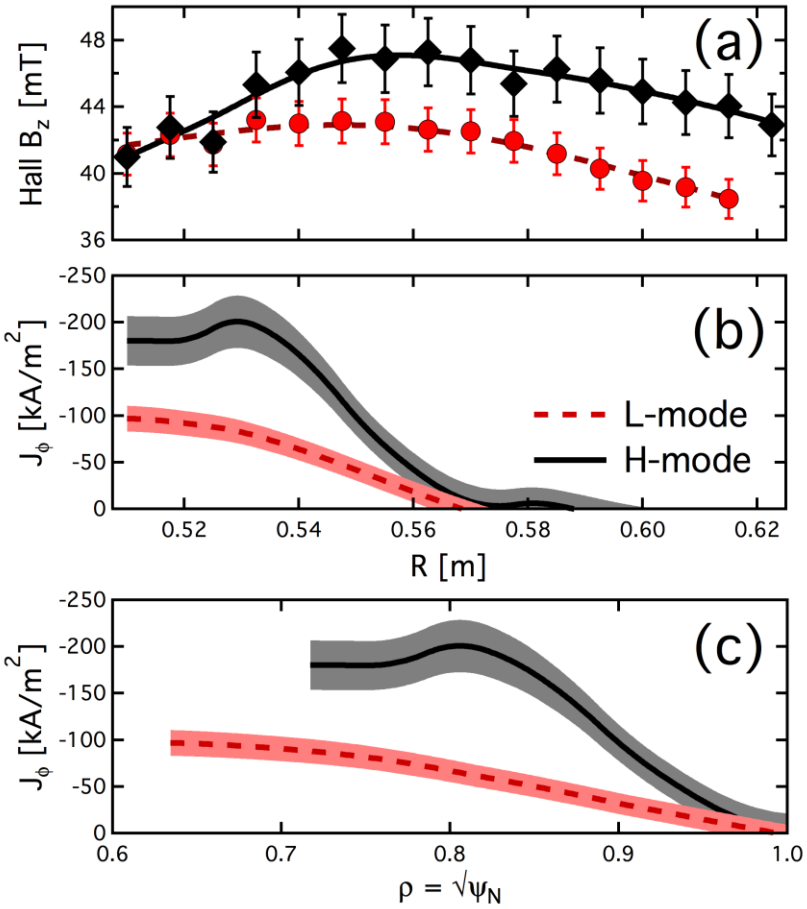


[1] *Nucl. Fusion*, **50**, 064010 (2010)
[2] *Journal of Physics: Conference Series*, **123**, 012033 (2008)
[3] Tokamaks, 4th ed. (2011), p 630

Current Pedestal Measured with High Time and Space Resolution

- $J_\phi(R,t)$ from Hall Probe B_z measurements[1,2]

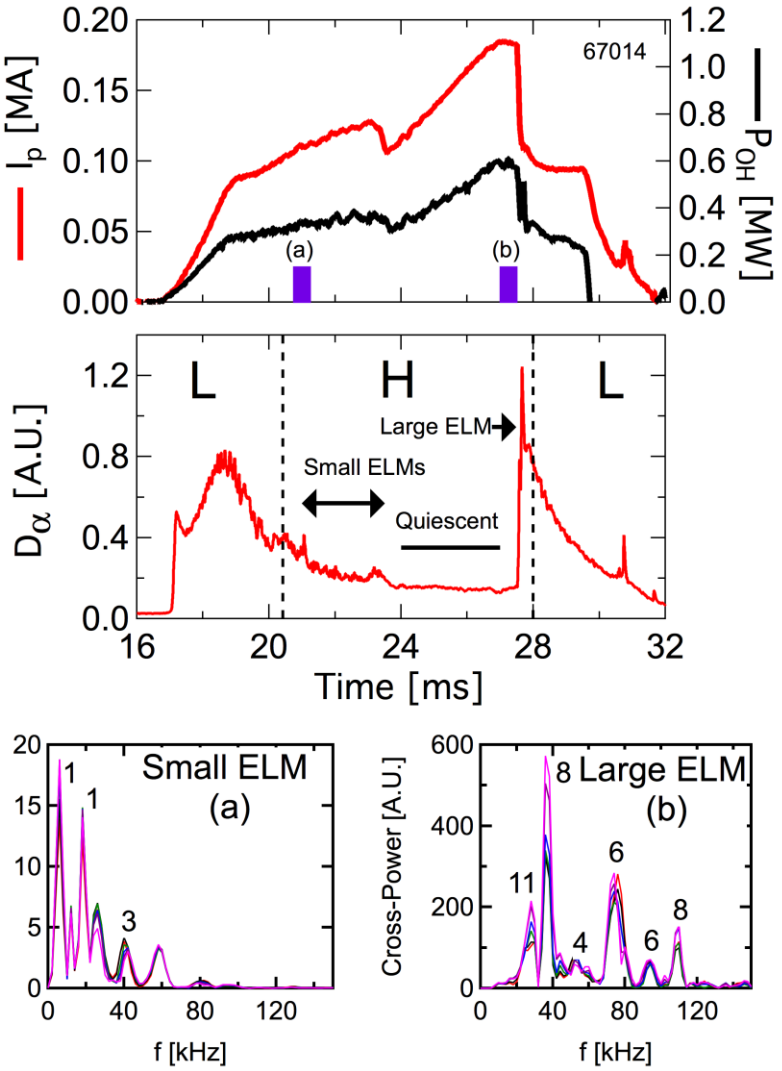
- Clear current pedestal observed
  - H scale length ~ 2 cm
  - L scale length ~ 4 cm



[1] *Rev. Sci. Instrum.*, **81**, 10E105 (2010)
[2] *Phys. Rev. Lett.*, **107**, 035003 (2011)

Large (Type I) and Small (Type III) ELMs are Seen

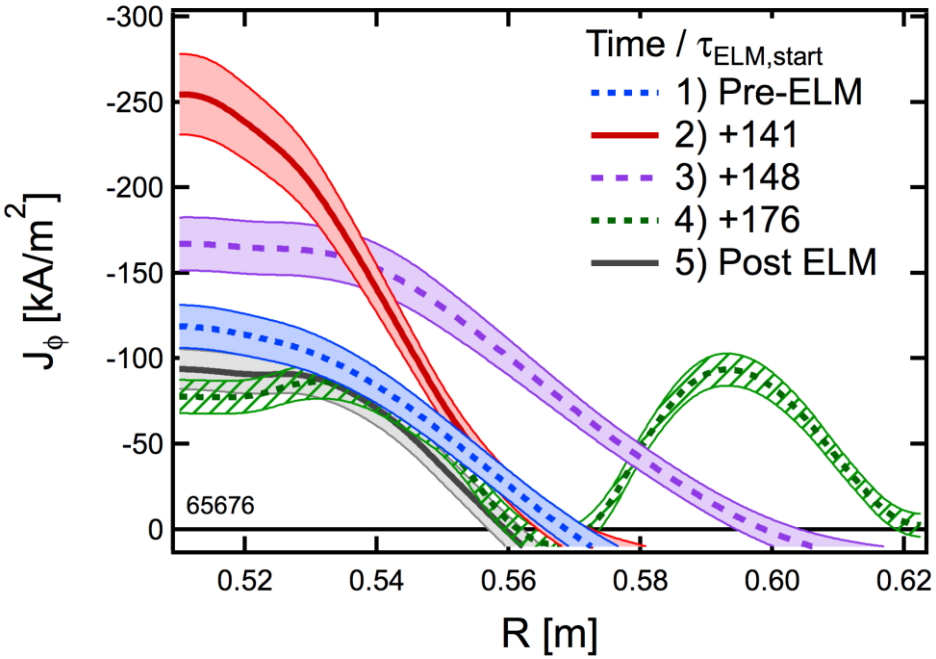
- STs magnetic structure opposite of ATs
  - Large ("Type I"): intermediate-n
    - Infrequent, violent, $P_{OH} >> P_{LH}$
  - Small ("Type III"): low-n
    - Common, less perturbing, $P_{OH} \sim P_{LH}$
- Simultaneously unstable modes
  - Dominant n = 8 grows continuously
  - Non-dominant components fluctuate prior to crash



Large ELM $J_{edge}(R,t)$ Dynamics Measured Throughout Single ELM Cycle

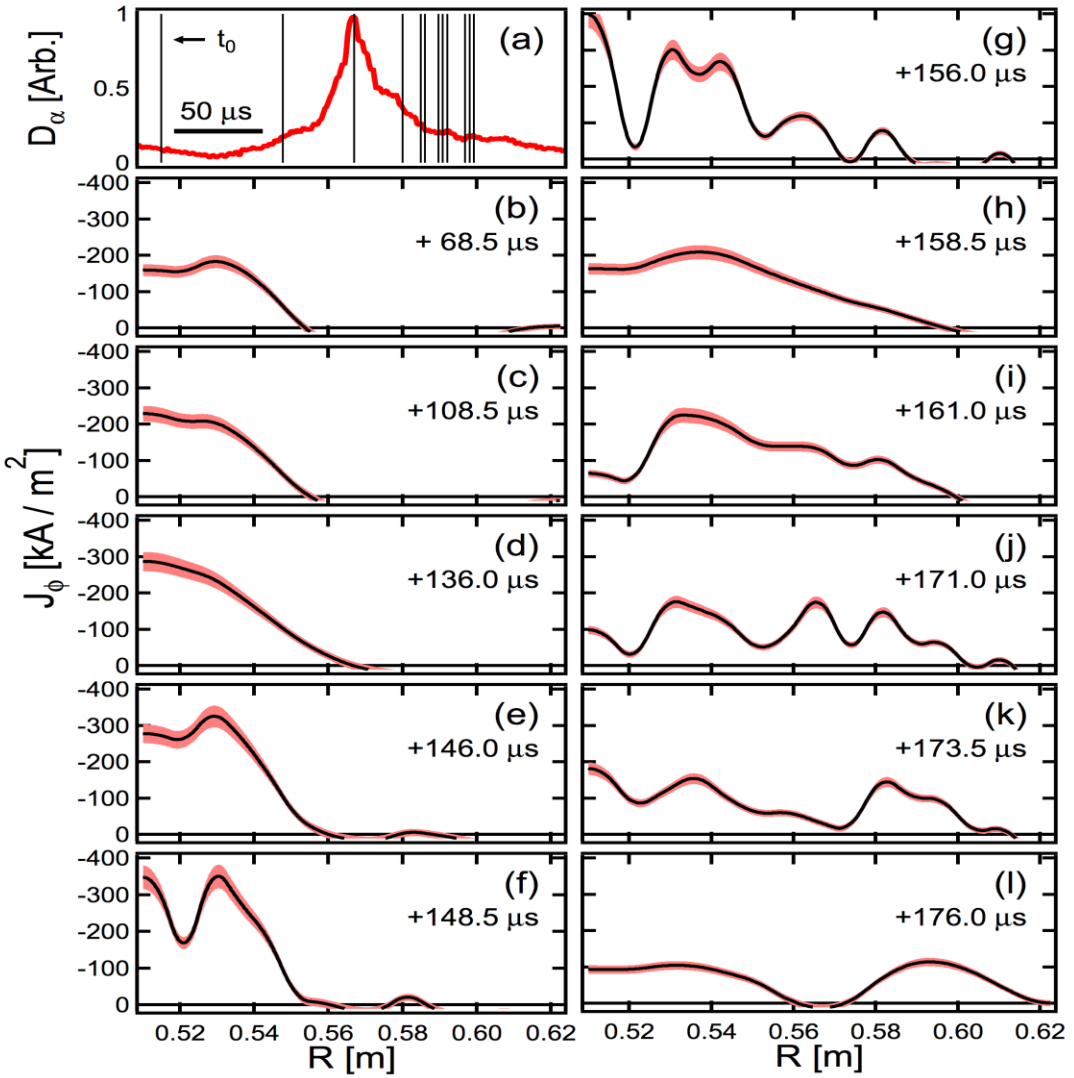
- Complex $J_{edge}(R,t)$ evolution

1) Modest but steep pedestal
2) Rapid buildup until crash
3) Collapse with wider pedestal gradient
4) Current-hole filament ejection
5) Recovery: lower than pre-ELM pedestal



Closer Inspection of J_{edge} Reveals Complex Dynamic Behavior

- Current profile evolution through ELM cycle shows complex multimodal behavior
- Opportunities for detailed comparisons to nonlinear MHD simulations
  - E.g. NIMROD, JOREK, BOUT++



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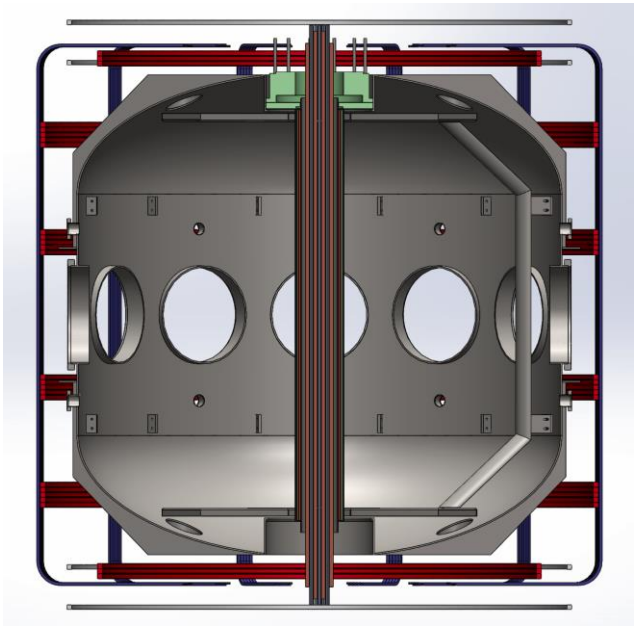
PEGASUS-U Will Provide Access to Nonlinear ELM Studies and H-mode Physics

- H-mode readily accessible at A ≈ 1
  - Initial PEGASUS results constrained by short pulse and limited V-s
- PEGASUS-U will have 6x V-s, 4x pulse length (0.1 s)
  - p(R,t), J(R,t), v_{Π}(R,t) through ELM cycles
  - ELM modification and mitigation
    - J_{edge} injection, C-pellet pacing
  - Neoclassical physics tests



PEGASUS-U: new centerstack, divertor coils

Conclusions: A ~ 1 Operation Enables Studies of AT Physics

- H-mode achieved in plasma with simple diagnostic access
  - Standard characteristics: Pedestal; low D_α; increased τ_e; $H_{98} \geq 1$; etc.
  - $J_{edge}(R,t)$ dynamics measured through ELM cycle
- Features unique to low-*A* emerging
  - Strong P_{LH} threshold scaling with *A*
  - Relative mode numbers at low-*A* opposite that of high-*A*
- Overall, complements experiments on larger fusion facilities
  - Detailed measurements can elucidate more limited results on larger facilities

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For more details, please see the Wednesday afternoon poster session:
PP8.00091: Initiatives in Non-Solenoidal Startup and H-mode Physics at Near-Unity *A*
PP8.00097: Probe Measurements in the H-mode Pedestal Region in the Pegasus Toroidal Experiment

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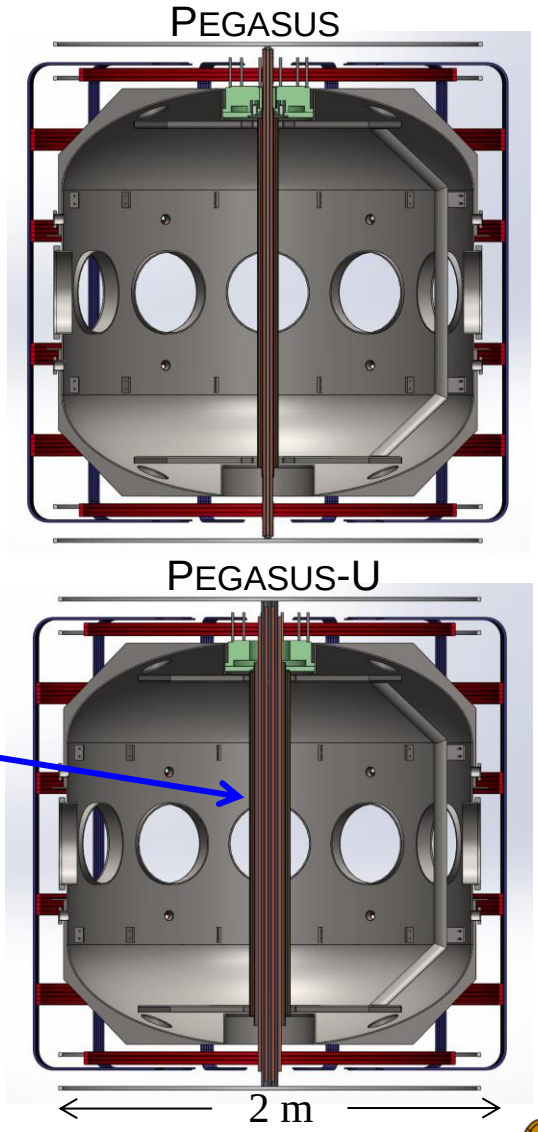
BACKUP SLIDES

PEGASUS-U Initiative: Advancing Non-Solenoidal Startup and AT Physics

- Mission
  - Physics and technology of LHI
  - Nonlinear ELM dynamics, H-mode physics
  - Tokamak stability limits: A~1 high β_T regime

- Facility enhancements
  - New centerstack assembly
    - B_T increases 5x
    - $\otimes t_{pulse}$ ~ 100 msec
    - V-sec increases 6x (PPPL)
    - Improved separatrix operation
  - NSTX-U relevant LHI injector arrays
  - Diagnostics: multipoint TS; CHERS via DNB



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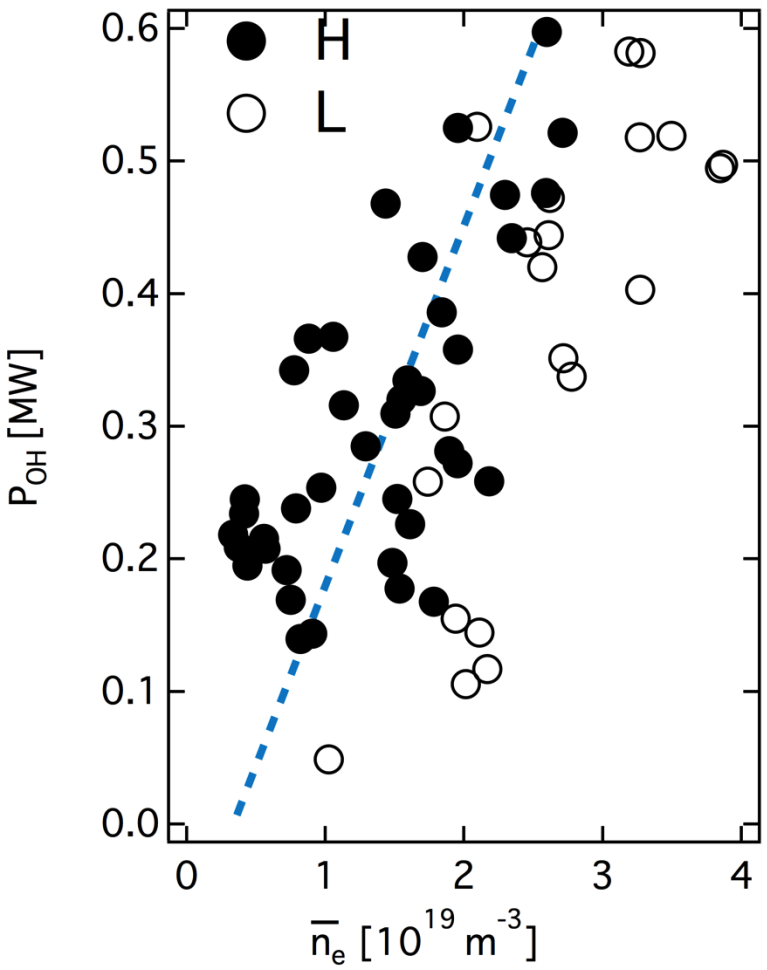
Limited P_{LH} Follows Standard n_e Dependence



- P_{OH} = 0.1-0.6 MW
  - Density dependence
    - No observed $n_e$min
  - Much greater than scaling predictions