

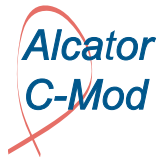
# Characterization of the Pedestal in Alcator C-Mod ELMing H-Modes and Comparison to the EPED Model

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Transport Task Force Workshop 2012, Annapolis, MD



## Dedicated ELMing H-mode study on Alcator C-Mod, spanning broad range of plasma parameters

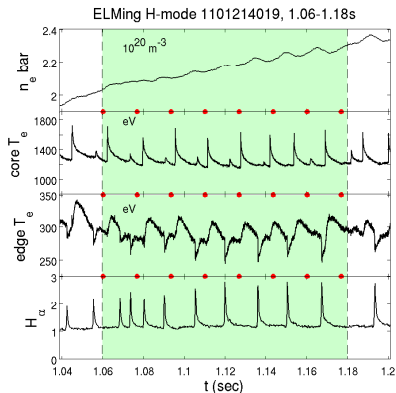
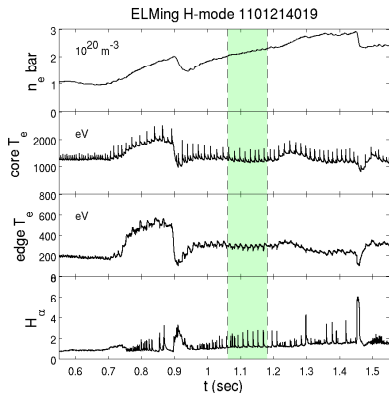
- H-mode pedestal scaled across plasma current (400-1100kA), magnetic field (3.5-8T), plasma shaping
- Pedestal scalings consistent with  $\nabla p_{ped} \propto I_p^2$ , similar to previous EDA H-mode studies on C-Mod
- Pedestal width shows strong scaling with  $\beta_{p,ped}$  consistent with KBM, weak/no scaling with other parameters

## Pedestal structure compared to predictions from most recent iteration of EPED model

- ELM-synced pedestal heights show good correlation to EPED model predictions
- Correlation to width predictions difficult due to robust pedestal width on C-Mod

Data shown in JR Walk *et al.*, accepted to *Nuc. Fus.* (2012)

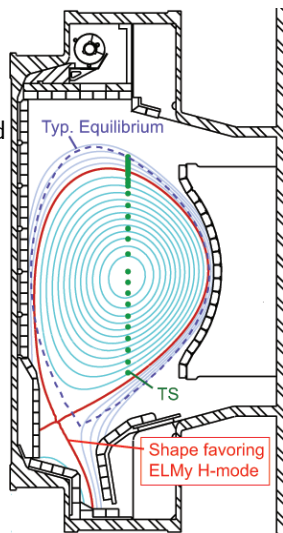
# ELMing H-Modes on C-Mod



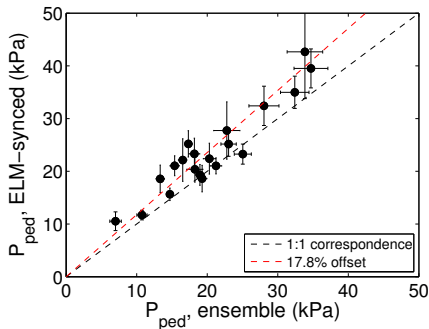
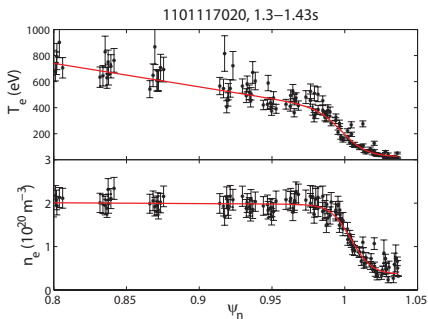
- ELMing H-modes identified by  $H_\alpha$  radiation, ECE  $T_e$  (traces at 40% and 98% poloidal flux shown), fluctuation measurements, divertor heat loading
- Select periods of slowly-varying  $\bar{n}_e$ , consistent frequency/amplitude ELMs for study

# High-Resolution Edge Diagnostics Available for Pedestal Studies on C-Mod

- Pedestal density and temperature measurements taken with high-resolution Thomson Scattering diagnostic -  $\sim 1\text{mm}$  spot sizes mapped to outboard midplane
- Two 30Hz Nd:YAG lasers fired out of phase gives 60Hz frame rate
- Additional  $T_e$  data taken from ECE diagnostics; high time resolution and  $\sim 1\text{cm}$  spot sizes track edge  $T_e$  evolution, but cannot resolve pedestal structure
- Note altered equilibrium conducive to ELMing operation, with low upper triangularity and elongation



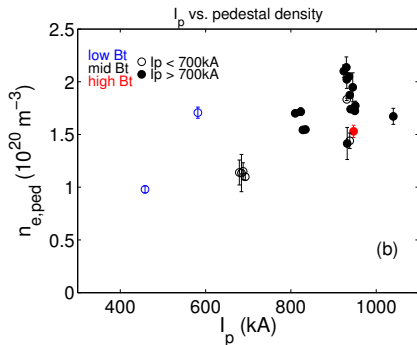
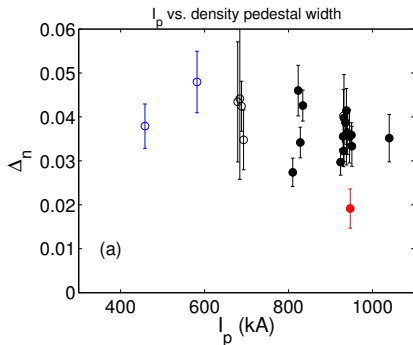
# Pedestal Profile Modeled from Thomson Scattering Data



- TS data from ELMing period collated into single **ensemble averaged** pedestal for fitting
- Shots with suitable data prepared with **ELM-synchronized** data - only data from last 20% of ELM cycle used
- ELM-synced pedestal pressure on average **17.8% higher** than ensemble average

# Experimental Scalings Agree with Range of ETB Phenomena

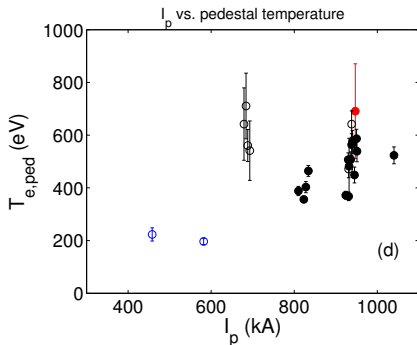
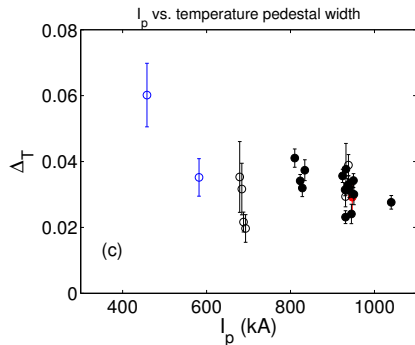
Density, Temperature, pressure pedestal height, pedestal widths  $\Delta_n$ ,  $\Delta_T$ , model width  $\Delta_\psi = \frac{1}{2} (\Delta_n + \Delta_T)$  scaled against  $I_p$  from 400-1100kA



Linear density dependence  $n_{e,ped} \propto I_p$ , previously observed in EDA H-modes; however, less stiff than in EDA case

# Experimental Scalings Agree with Range of ETB Phenomena

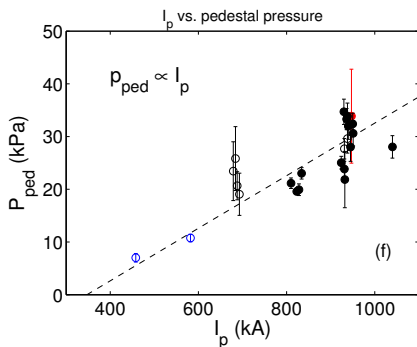
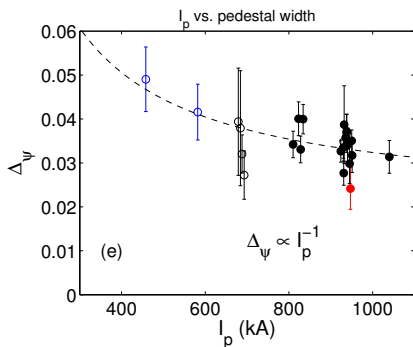
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No clear scaling of  $T_{e,ped}$  with  $I_p$ , low current 5.4T shots (open black circles) attain high pedestal temperatures

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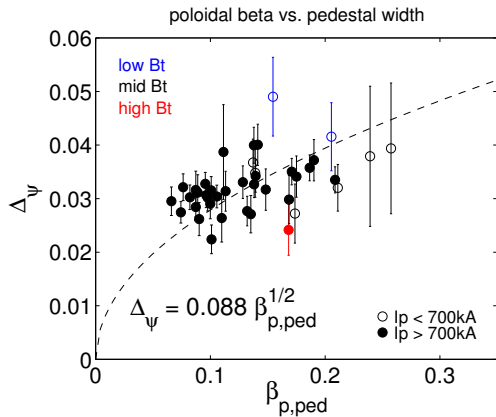
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Pedestal pressure  $p_{ped} \propto I_p$ ,  $\Delta_\psi \propto I_p^{-1}$ ; combined,  $\nabla p_{ped} \propto I_p^2$ , matching broader ETB studies [J.W. Hughes *et al.*, *Nuc. Fus.* **47** (2007)]



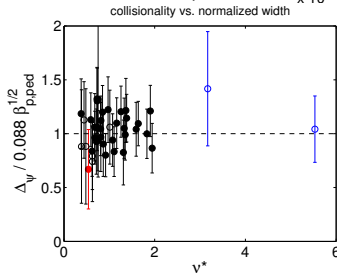
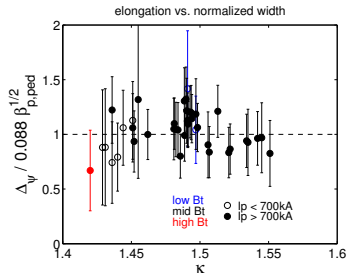
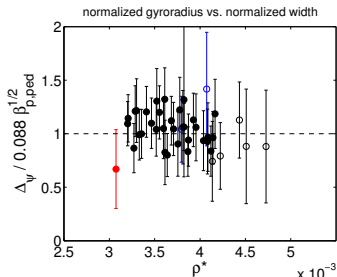
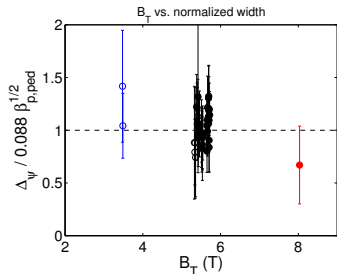
# Dominant Pedestal Width Scaling $\Delta\psi \propto \beta_{p,ped}^{1/2}$



- Dominant width scaling  $\Delta\psi \propto \beta_{p,ped}^{1/2}$  from kinetic-ballooning theory [P. Snyder *et al.*, *Phys. Plas.* **16** (2009)]
- Fitted scale factor from ensemble-averaged data  $\langle c \rangle = 0.088$
- Secondary width scalings found by normalizing width to  $\beta_{p,ped}$  dependence, norm. width =  $\Delta\psi / 0.088 \beta_{p,ped}^{1/2}$

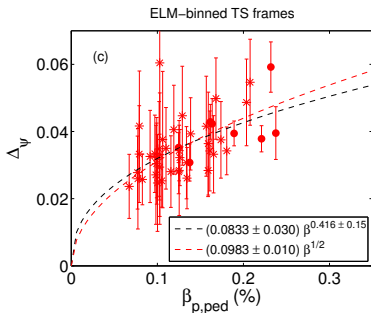
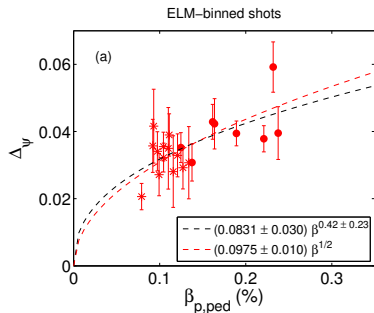
# No Strong Width Scaling with Other Factors

Normalized width shows no major scalings with  $\rho^*$ ,  $\kappa$ ,  $\nu^*$ ; cannot exclude scaling with  $B_T$  with existing data



# New ELM-Synced Data Extend $\beta_{p,ped}$ Range

New ELM-synced data doubles observed  $\beta_{p,ped}$  range on C-Mod from previous experiment [P. Snyder *et al.*, *Nucl. Fus.* **49**, 085035 (2009)]. Using data synchronized to last 20% of ELM cycle:

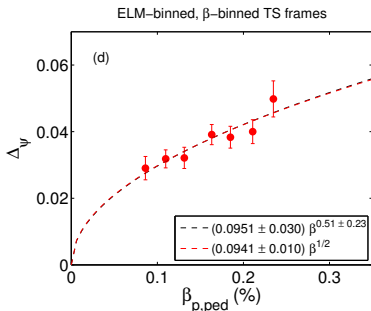
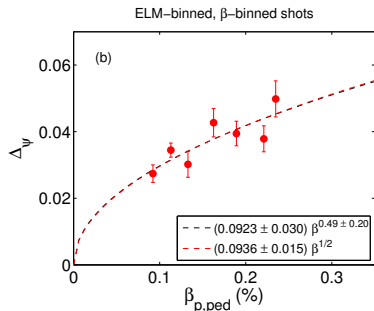


Fitting results consistent with previously observed scalings on C-Mod, DIII-D, JET; **robust predictive capability** for EPED model across broad range of pedestal parameters

see also talks by JW Hughes, PB Snyder 4/11/12

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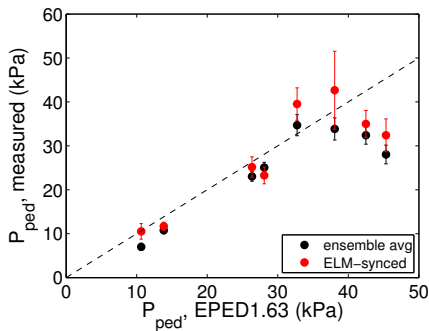
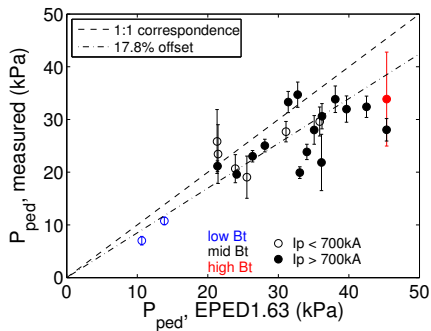
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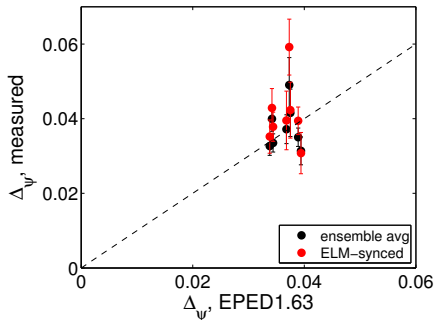
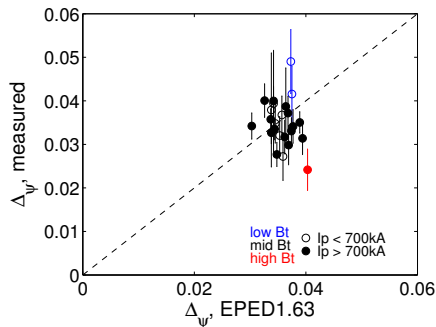
see also talks by JW Hughes, PB Snyder 4/11/12

# EPED Model Predictions Show Good Correlation to ELM-Synced Pedestal Heights



- ELM-synced pressure pedestal height gives correlation of  $0.989 \pm 0.15$  to prediction
- Ensemble-averaged pressure pedestal lower than prediction ( $0.84 \pm 0.15$ ), corrected by 17.8% offset from ELM-synced data
- Ensemble-averaged pedestal only acceptably matched to prediction below  $p_{ped} \sim 35$  kPa

# Robust Pedestal Width Reflected in EPED Predictions



- $\Delta_{\psi}$  robust within 2-5% of normalized poloidal flux across parameter range
- No improvement with ELM syncing; width correlated to  $1.01 \pm 0.20$ , within  $\sim 20\%$  error in EPED predictions

## ELMing H-modes show good correlation to broad range of ETB phenomena

- Experimental scaling of pressure pedestal shows  $\nabla p \propto I_p^2$ ,  $n_{e,ped} \propto I_p$  consistent with previously observed pedestal phenomena
- Strong width scaling with pedestal poloidal beta, weak/no scaling with other parameters found over extended range in  $\beta_{p,ped}$  - scaling of  $\Delta\psi \propto \beta_{p,ped}^{1/2}$  consistent with kinetic-ballooning theory, previous cross-machine studies

## EPED model provides robust predictions of pedestal structure on C-Mod

- Very good correlation between predicted pressure pedestal height and observations using data synchronized to ELM cycle peaks
- Robust pedestal width on C-Mod reproduced by EPED model predictions

Data presented in JR Walk *et al.*, accepted to *Nuclear Fusion* (2012)

