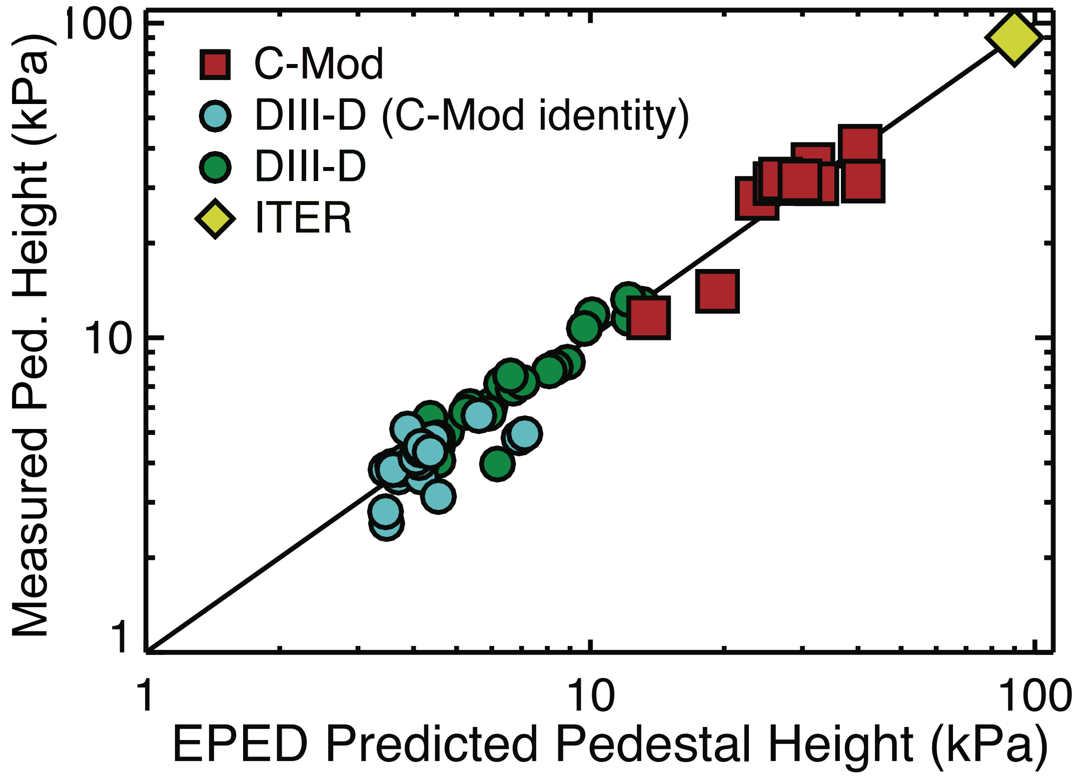
Improved Understanding of Physics Processes in Pedestal Structure, Leading to Improved Predictive Capability for ITER

by

R.J. Groebner



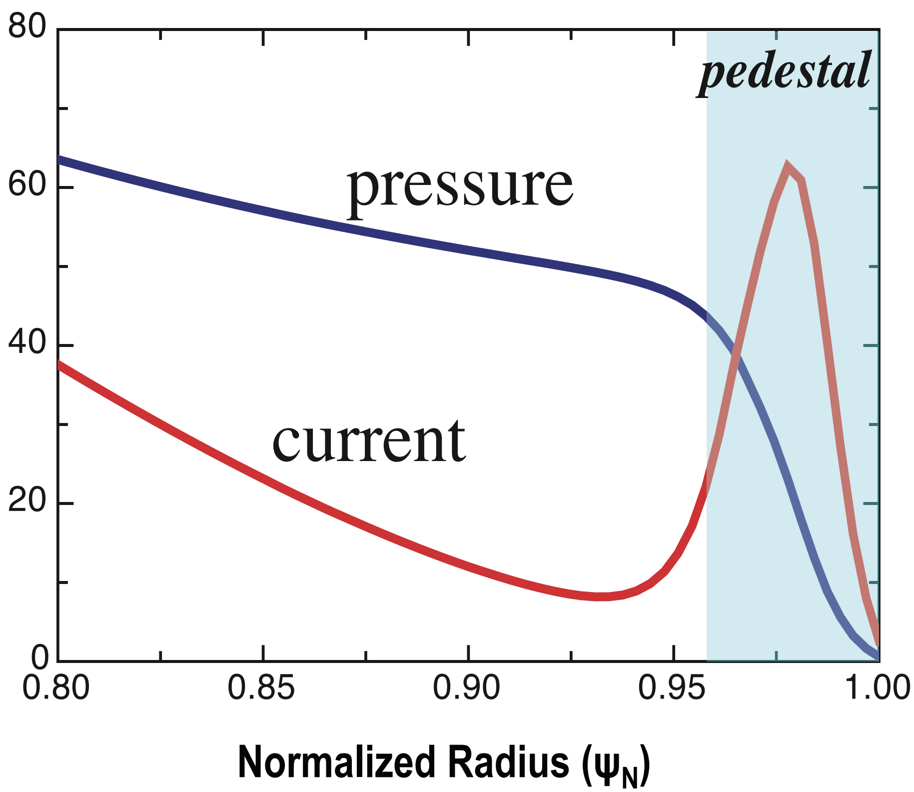
Presented at

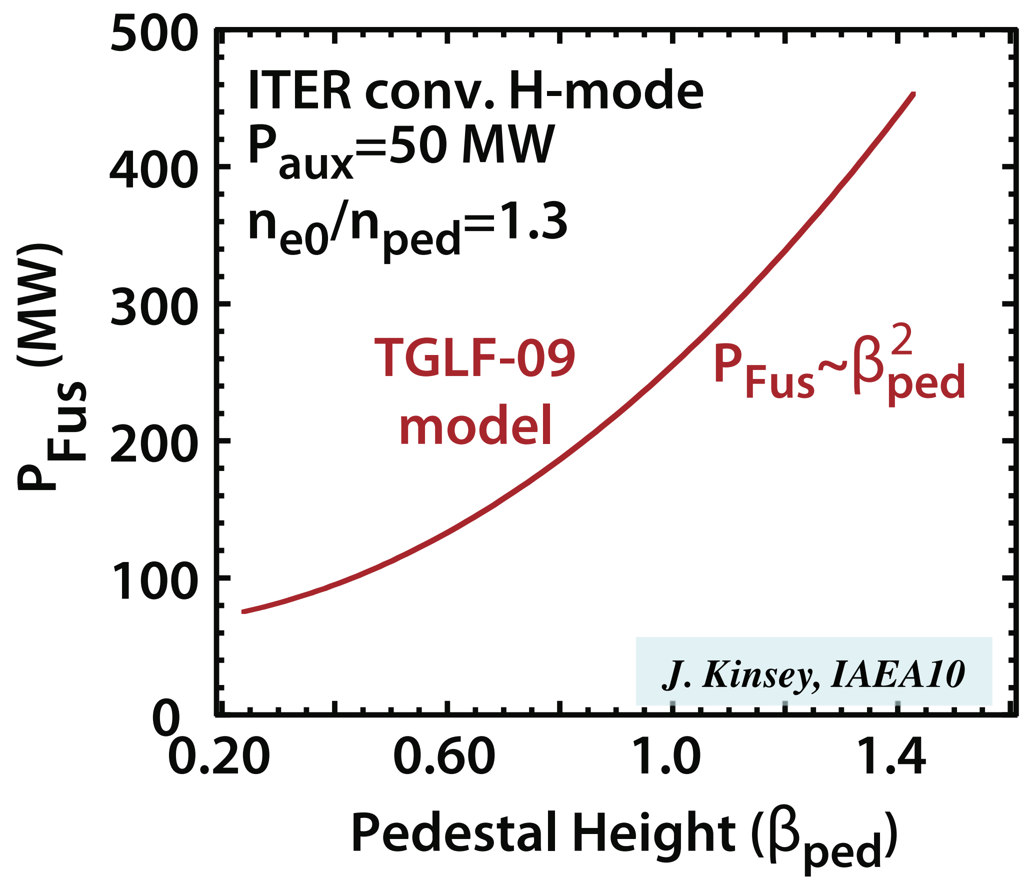
2012 IAEA Fusion Energy Conference
San Diego, California

October 8–13, 2012

Understanding the H-mode Pedestal Allows Prediction and Optimization of Fusion Power

- **High performance (H-mode) operation in tokamaks due to spontaneous formation of an edge barrier or "pedestal"**
- **Pedestal height has an enormous impact on fusion performance**





The US-DOE FY11 Joint Research Target was a US-Wide Activity to Improve Understanding of Pedestal

Many Contributors

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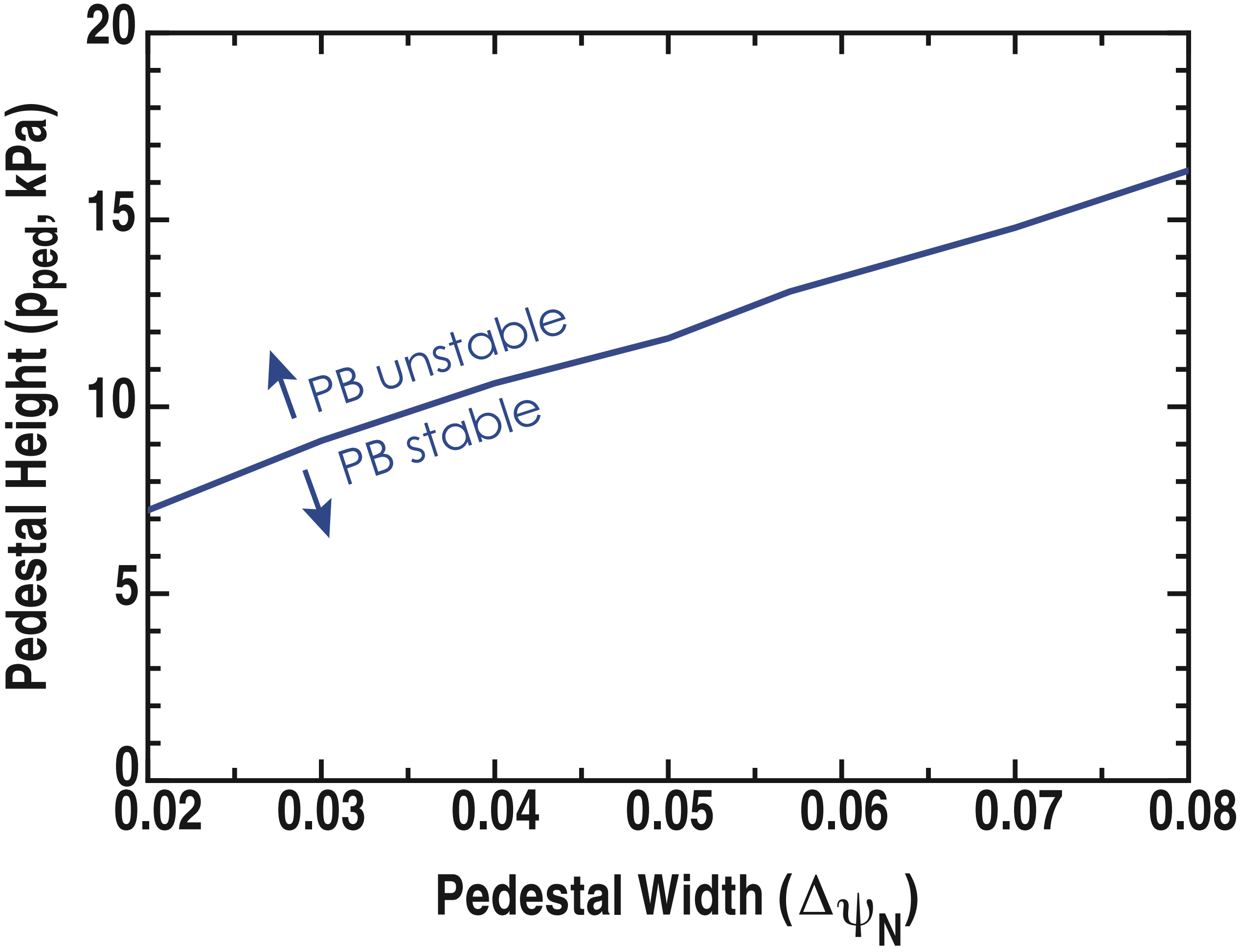
Identify physics mechanisms

Improve predictive capability

Coordination of experiment, modeling and theory

Results improve confidence that we can predict limits of pedestal pressure

Joint Research Supports a Framework for Physics of Limits to Pedestal Pressure Profile

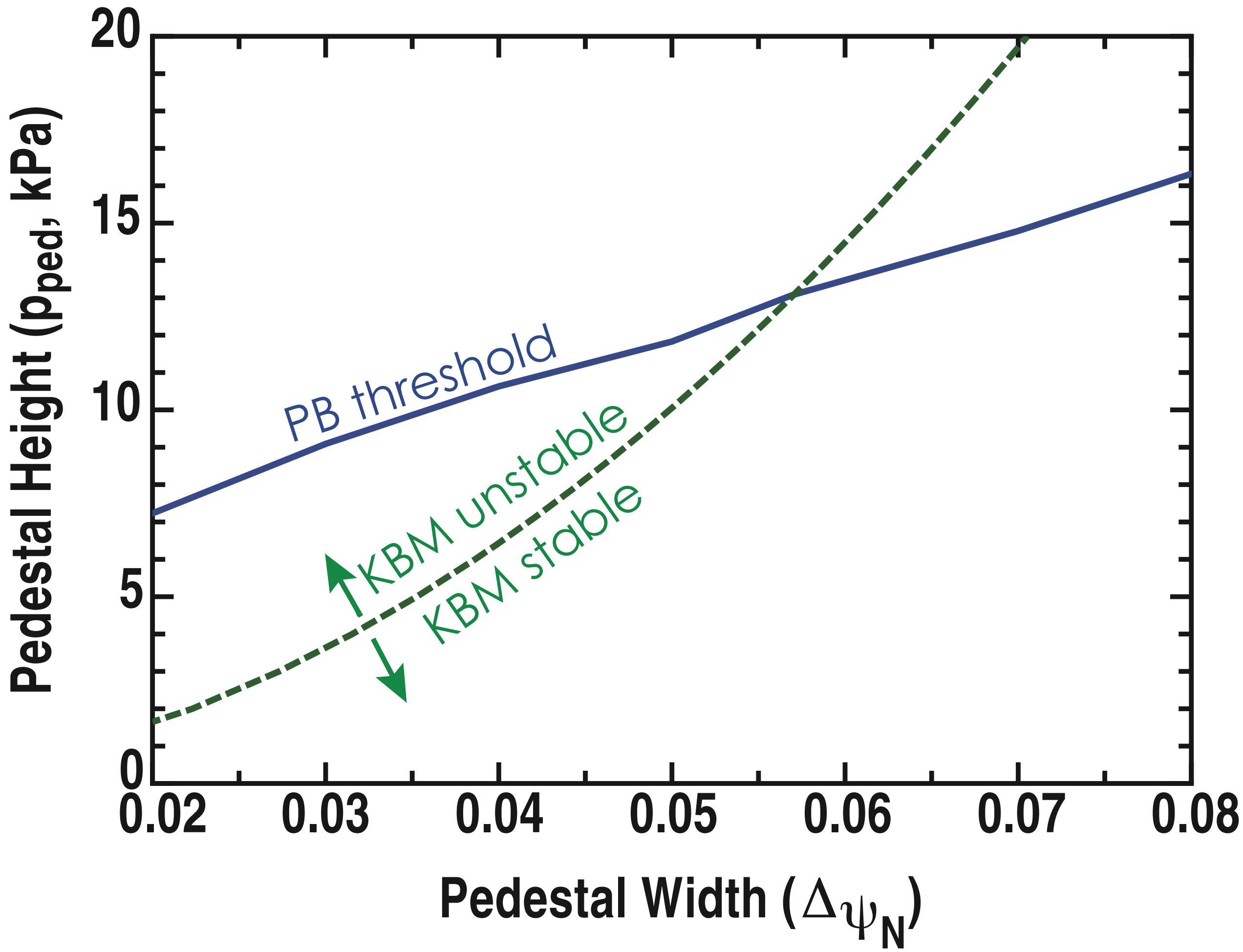


Finite-n ideal peeling-ballooning (PB) modes provide global limit to pedestal pressure

Driven by pedestal pressure gradient and current density

Have performed new tests of PB models

Kinetic Ballooning Modes Impose an Additional Limit to Pedestal Pressure Gradient

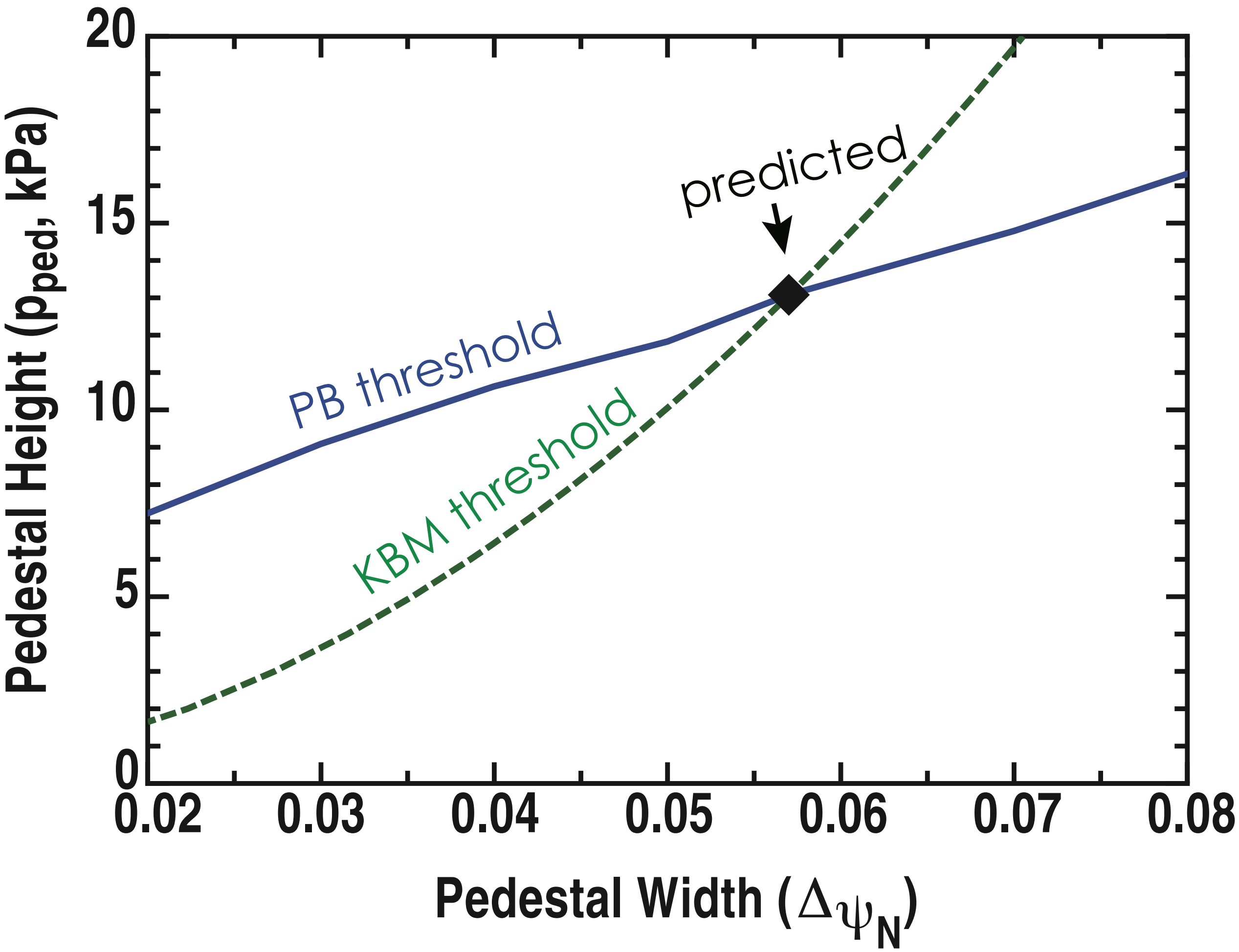


Smaller scale and more localized than PB modes

Controlled by pedestal pressure gradient and magnetic shear (current density)

Have performed new tests of KBM models

EPED Model Combines PB and KBM Constraints to Predict Maximum Achievable Height and Width

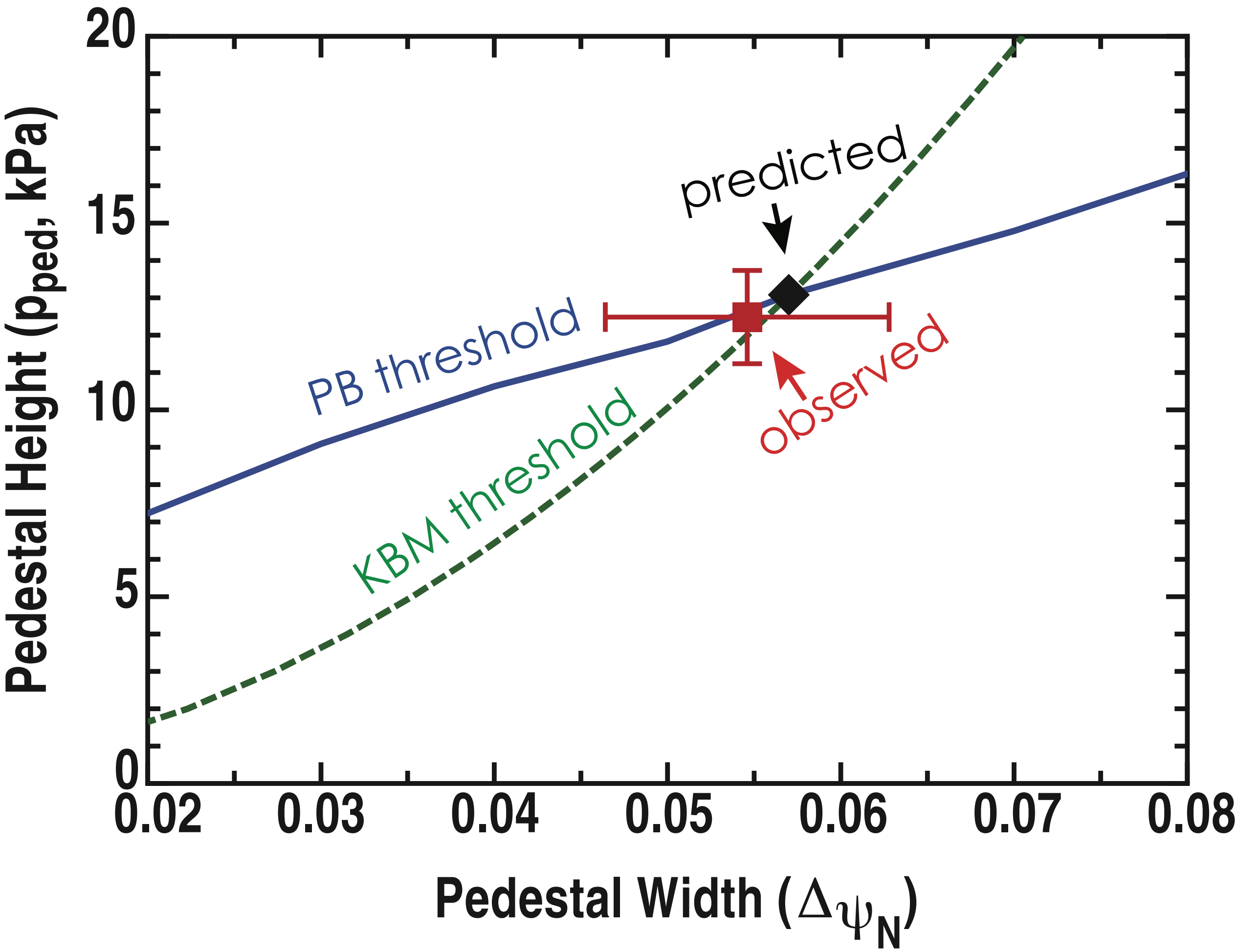


Combines models for bootstrap current, PB stability, KBM stability

Inputs: B_T, I_p, R, a, κ, δ, m_i, n_{ped}, β_{global}

Outputs: Pedestal height and width
(no free or fit parameters)

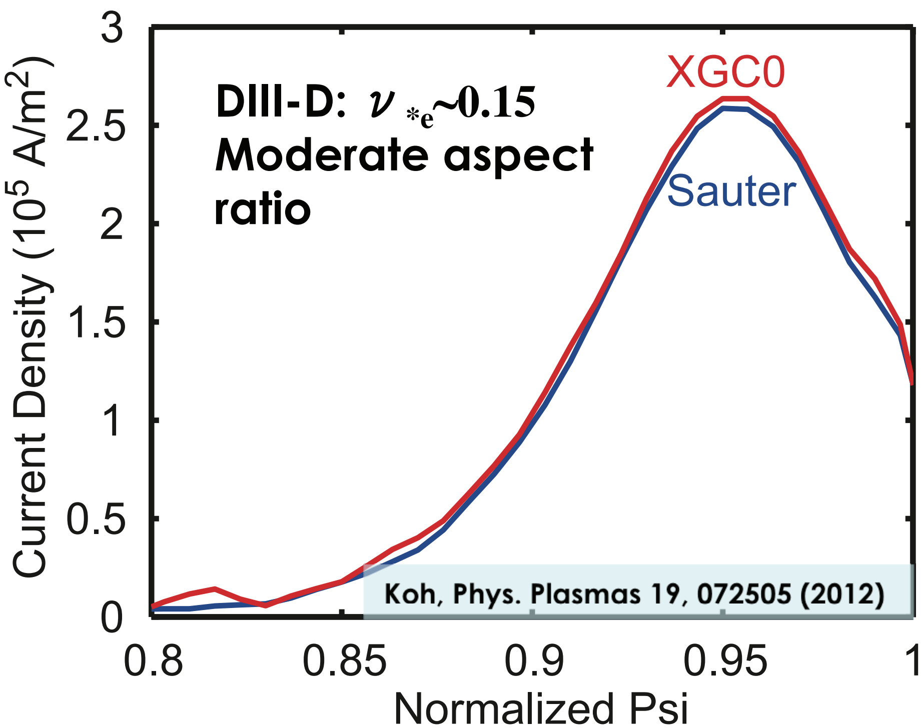
Model Predictions Agree With Observations Within ~20%

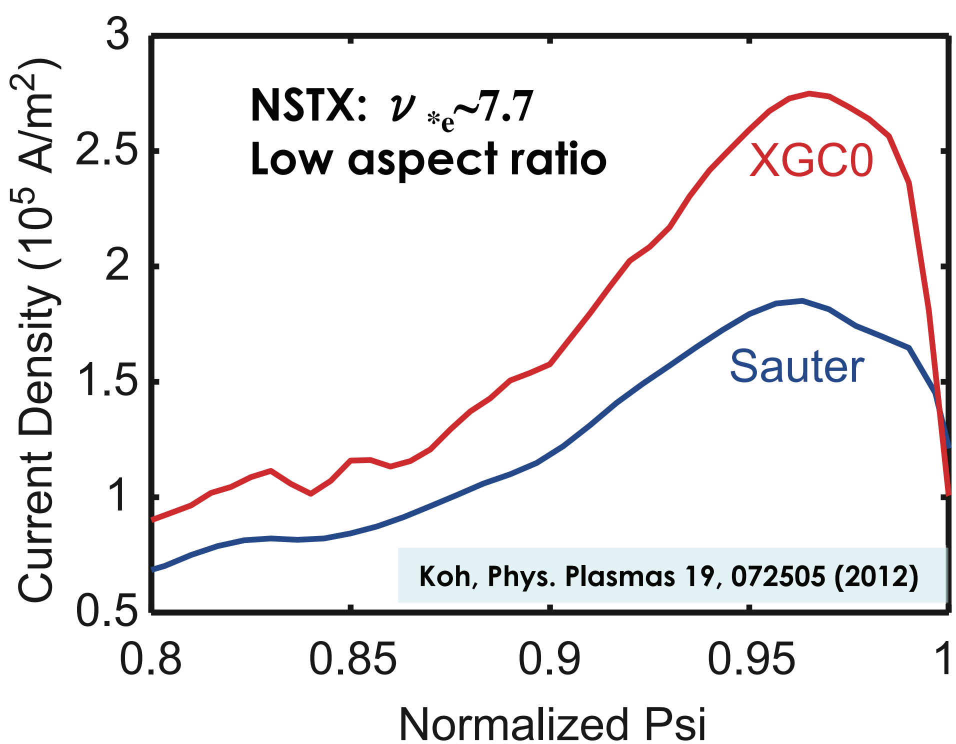


Observations typically made just before Type I ELM (edge MHD event)

Kinetic Codes for Neoclassical Bootstrap Current Have Been Used to Benchmark Simpler Models

- **NEO: ~10%–20% differences in the bootstrap current from simplified models**
- **XGC0: Agreement with Sauter model in banana-plateau regime**
  - Some differences in collisional regime
- **MIT Global Pedestal DK Code: Agreement with Sauter in banana**
  - Some disagreement in plateau [Landreman & Ernst, PPCF 2012]





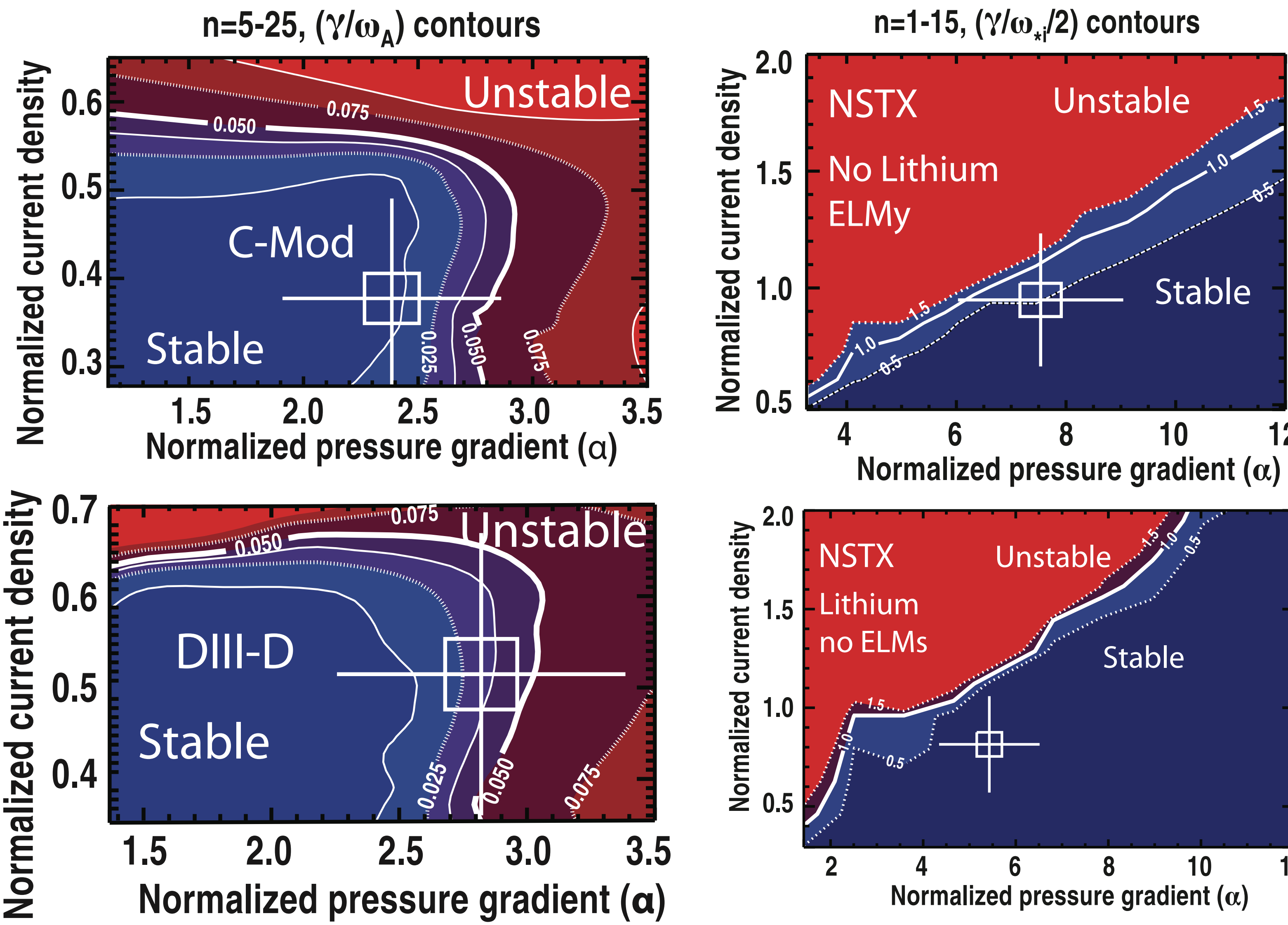
Peeling-ballooning Models Consistent with Observations of Type I ELMs in All 3 Machines

Diamagnetic effects important for C-Mod

Quantitative threshold for NSTX under study

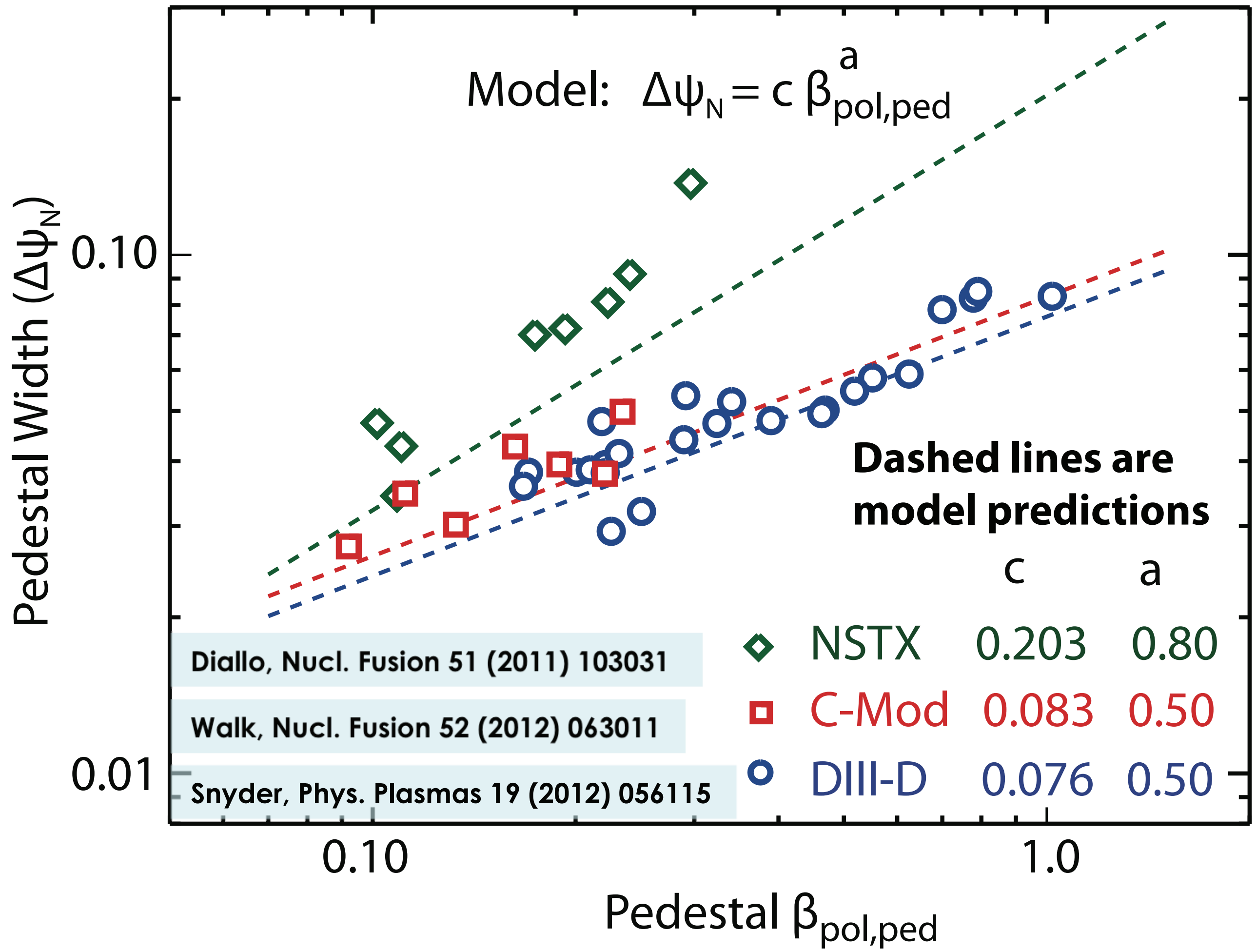
ELMs in NSTX occur at kink-peeling boundary

Predictions from ELITE, using XGC0 bootstrap current for NSTX



Data from Boyle, PPCF 53 (2011) 105011

New Version of EPED Model Predicts Width With No Adjustable Parameters



Predictions: Snyder 2012 IAEA

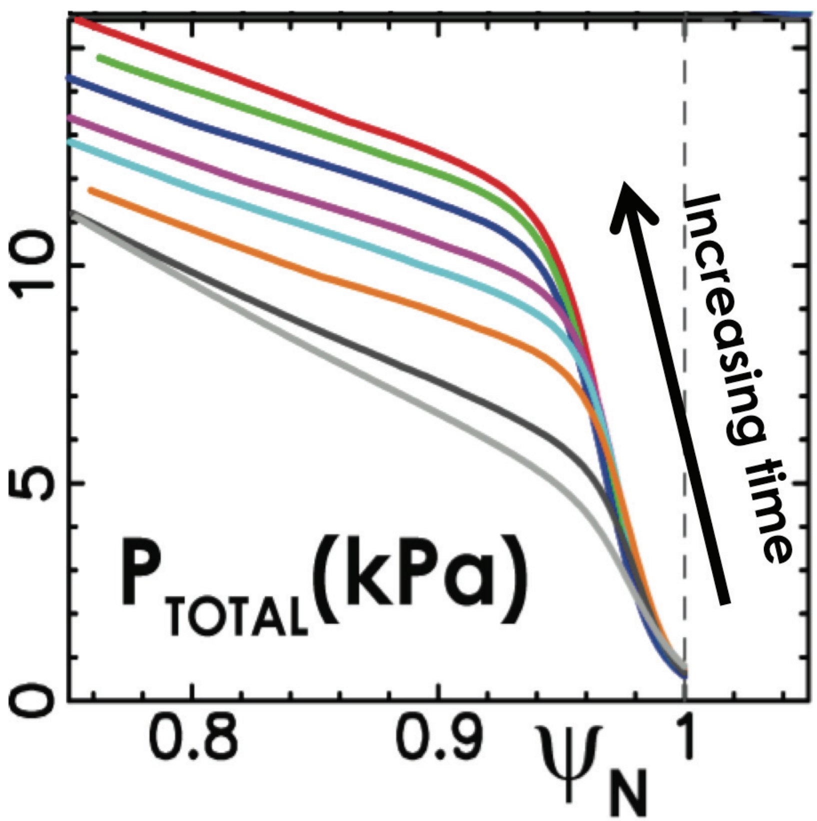
Critical gradient for KBM obtained from model of infinite-n ideal ballooning modes

Predictions in good agreement with C-Mod and DIII-D data

Predictions show aspect ratio dependence

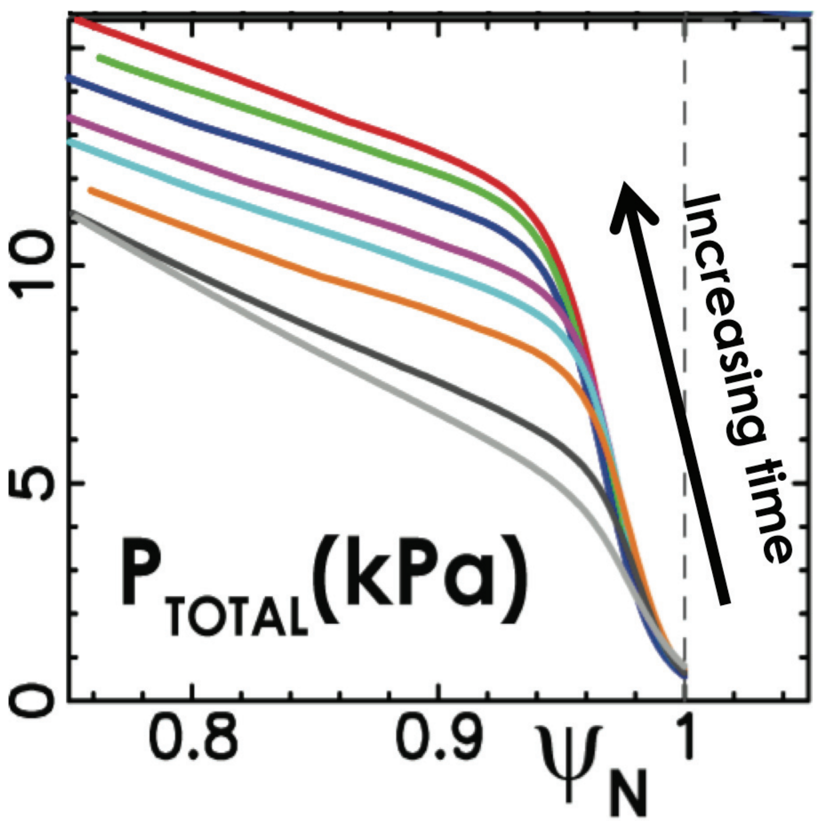
Extension of model to low aspect ratio is work in progress

Pedestal Growth Between ELMS Provides Additional Test of EPED Model and KBM Physics

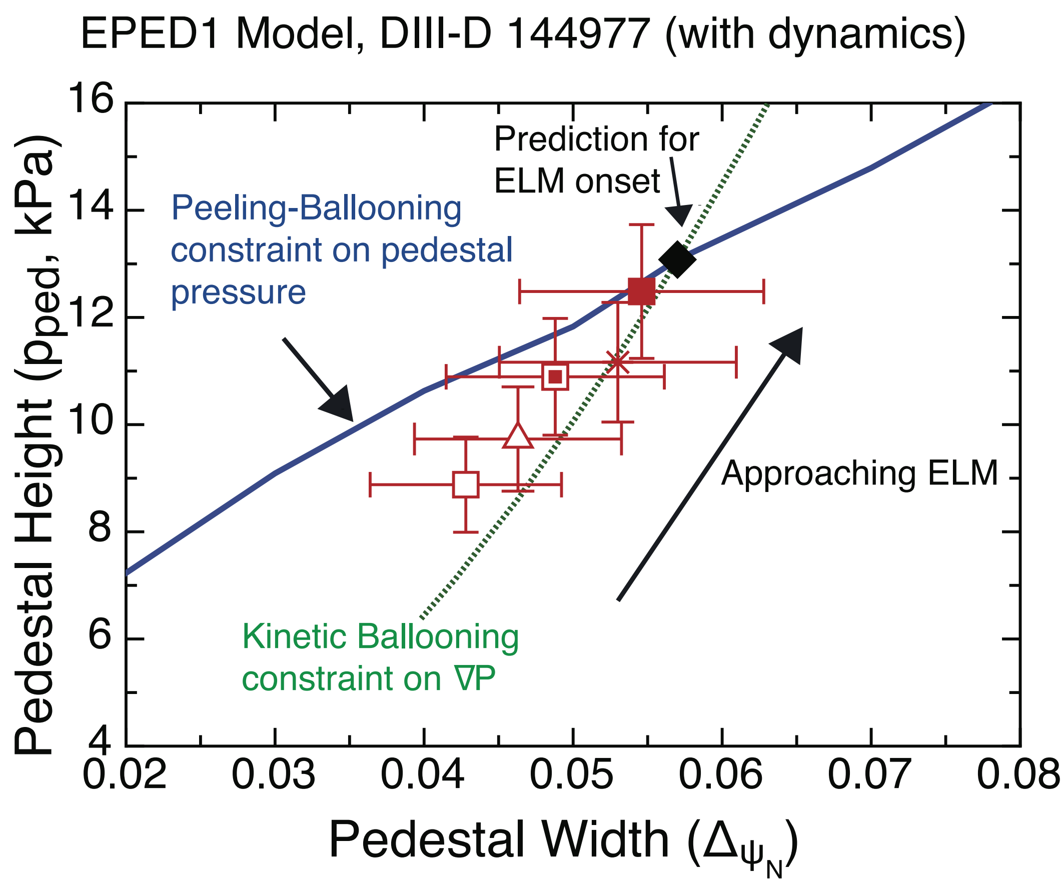


T.H. Osborne, 2011 H-Mode Workshop

KBM Model Predicts ∇P Evolution Observed Between ELMs

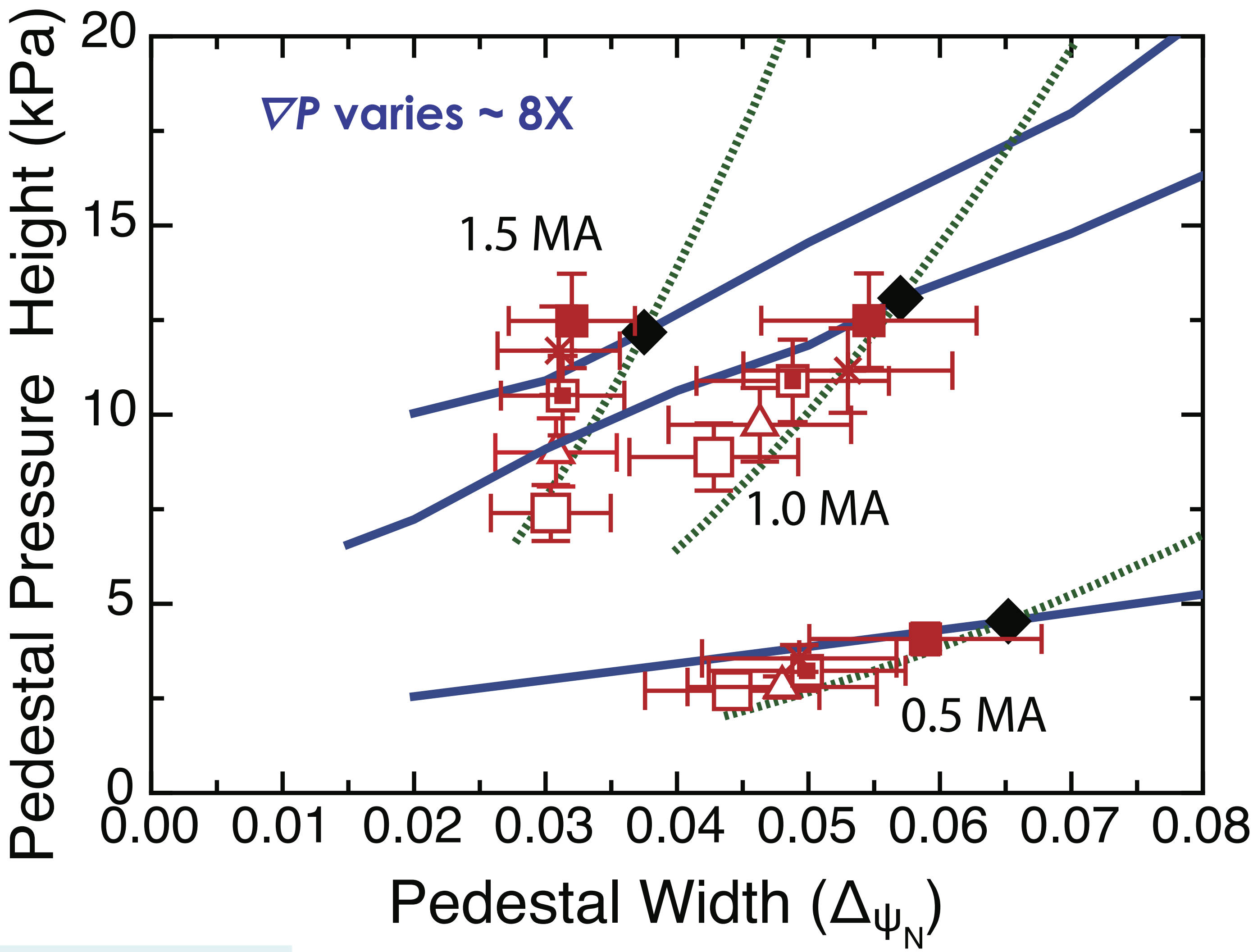


T.H. Osborne, 2011 H-Mode Workshop



P.B. Snyder, Phys Plasmas 19, 056115 (2012)

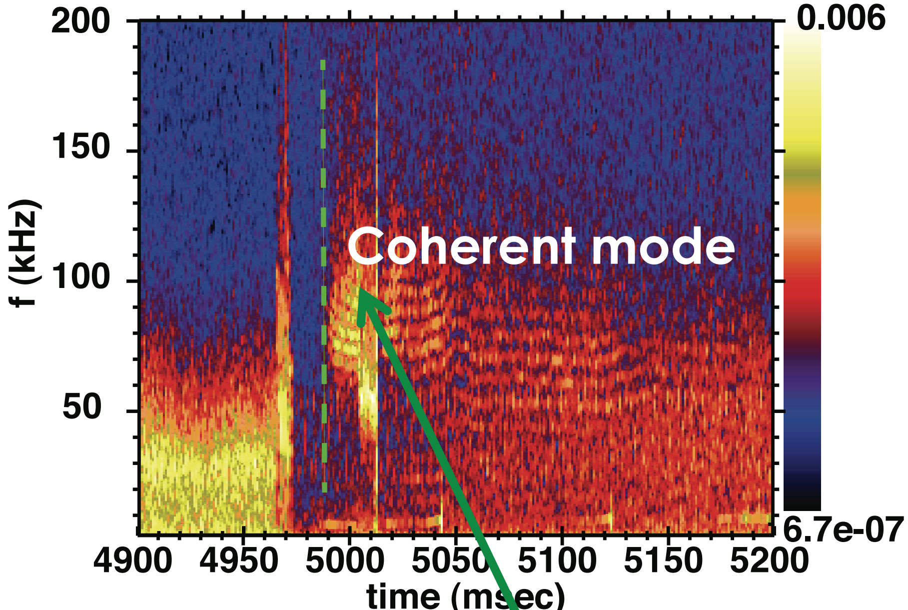
EPED Model Predicts ∇P Observed During Pedestal Buildup for a Range of Plasma Currents

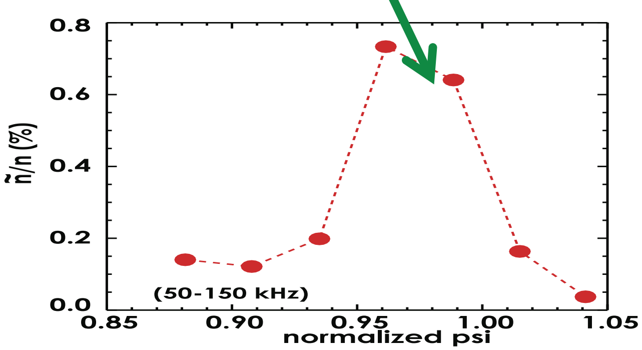


T.H. Osborne, 2011 H-Mode Workshop

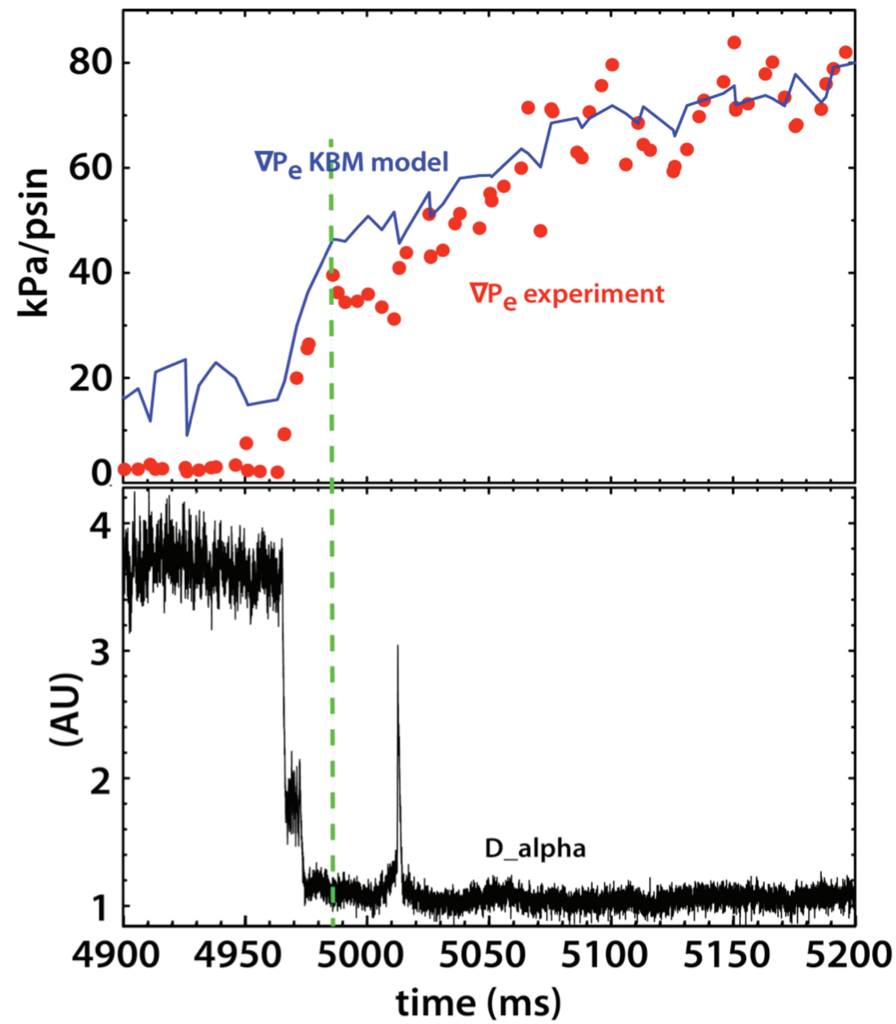
Onset of Density Fluctuations Correlated With Slowing of Pedestal Evolution

Coherent mode localized to pedestal





Pressure gradient quickly reaches KBM threshold



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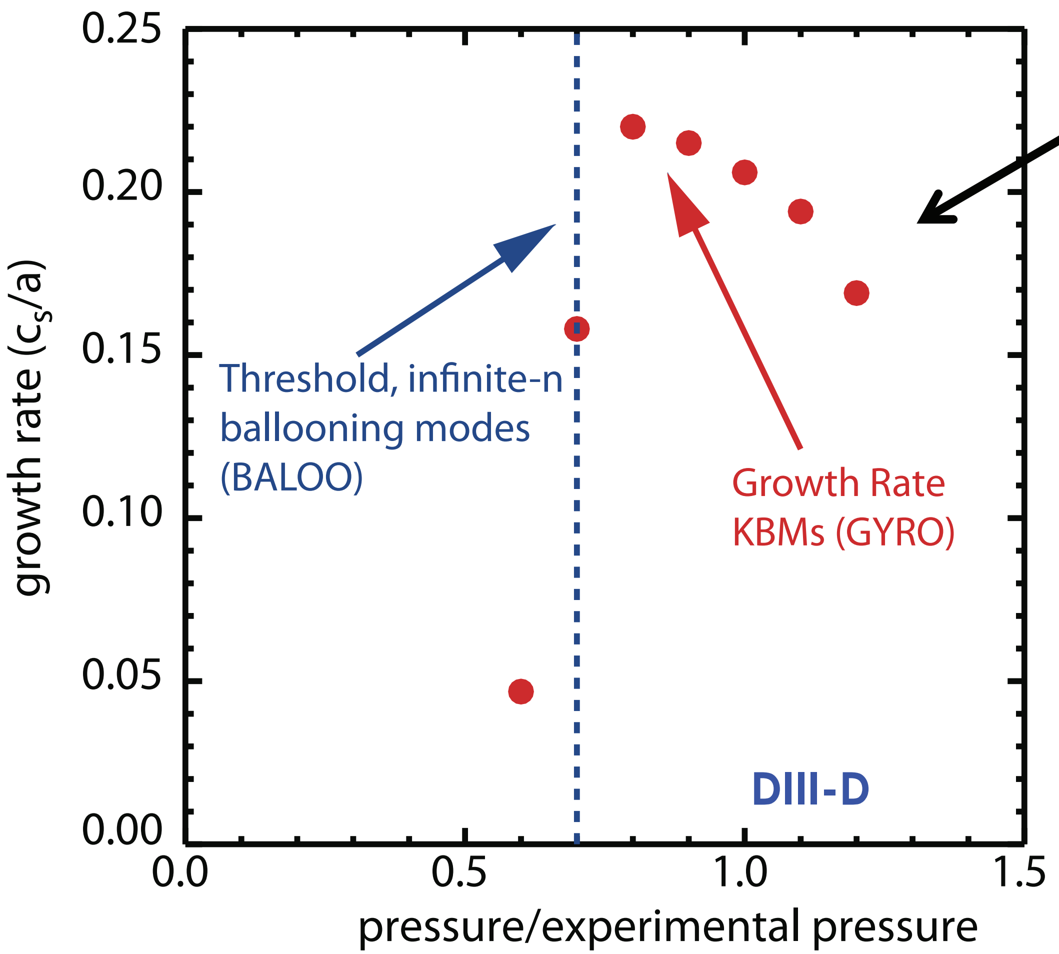
KBM Modes Predicted for Realistic Experimental Conditions



GYRO simulations find KBM threshold ~ same as for infinite-n ideal ballooning modes

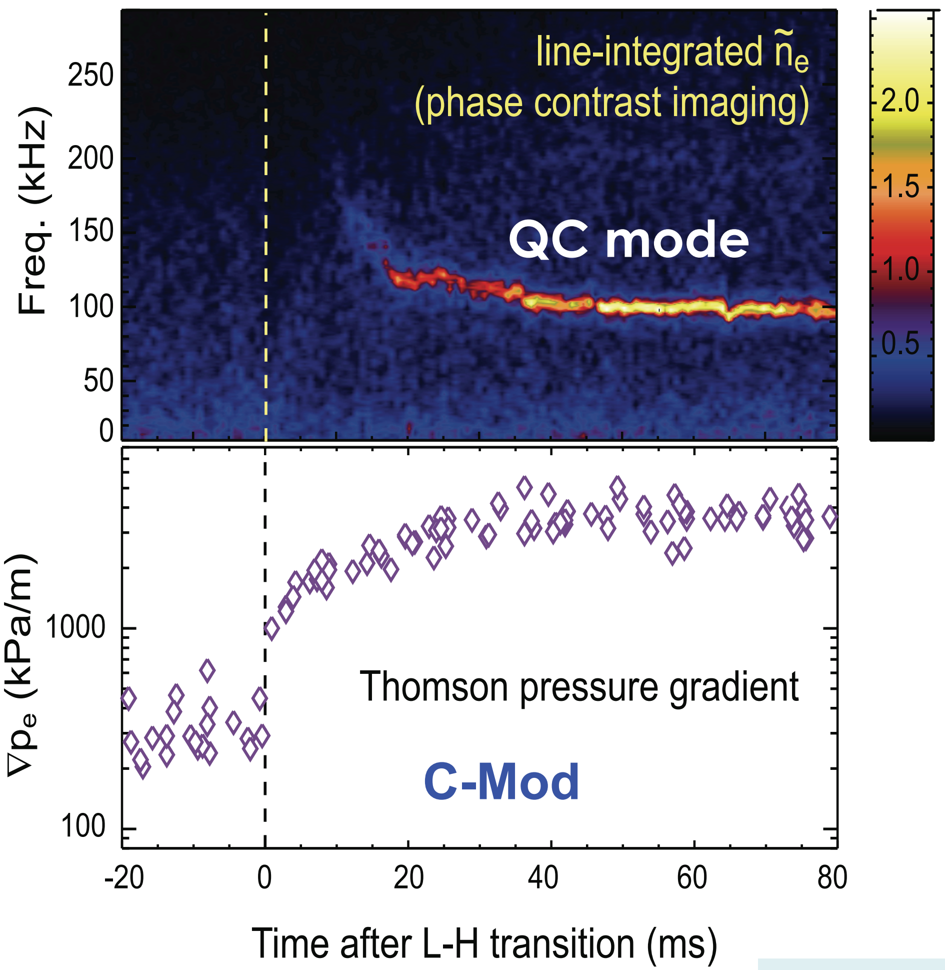
E. Wang, Nucl. Fusion 52 (2012)

Global EM simulations with GEM predict KBM in two discharges near Type I ELM threshold

W. Wan Phys. Rev. Lett. (2012)

Onset of Density Fluctuations Correlated With Slowing of Pedestal Evolution in EDA Discharge

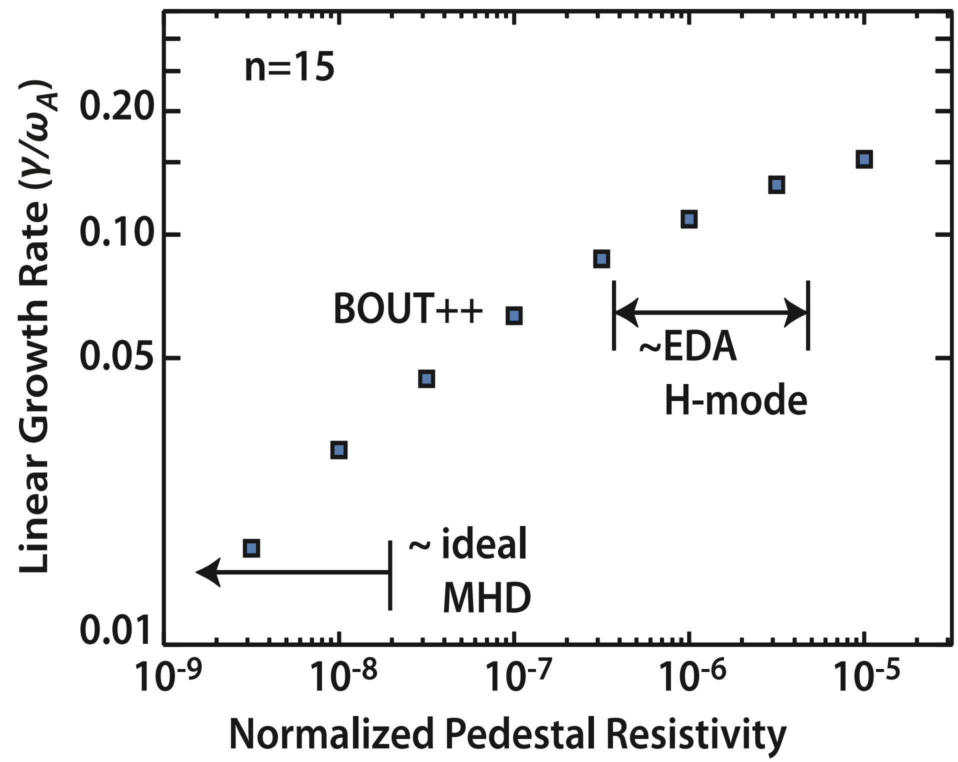
∇P_e saturation correlated with strength of QC mode



BOUT++ simulations of EDA H-mode:

Discharge is ideally stable

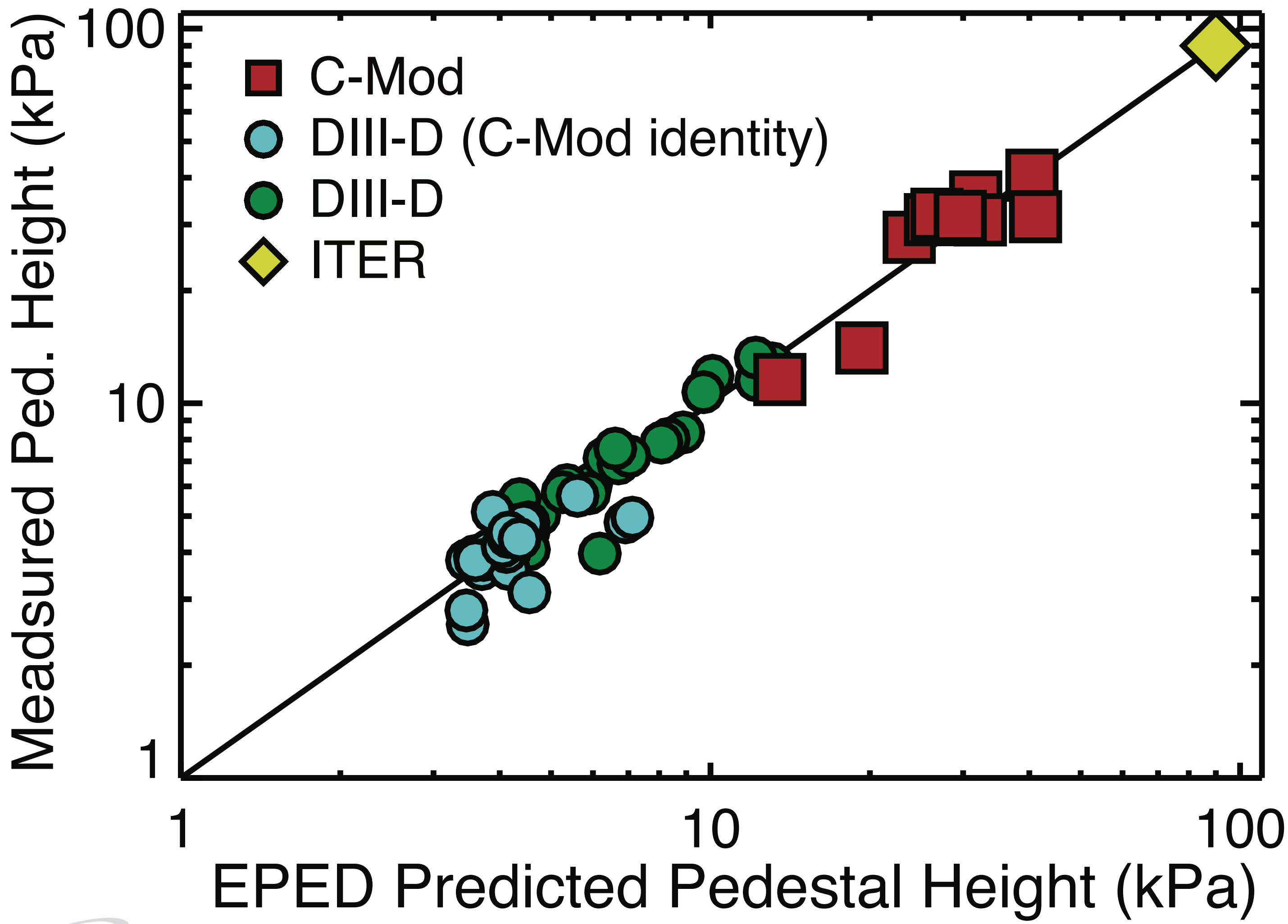
Linear growth rate increases with resistivity



Hughes 2012 IAEA

EPED Model Predicts Pedestal Height/Width to ~20% Accuracy for Medium Aspect Ratio Tokamaks

C-Mod data increase maximum pressure for benchmarking by ~ 2X



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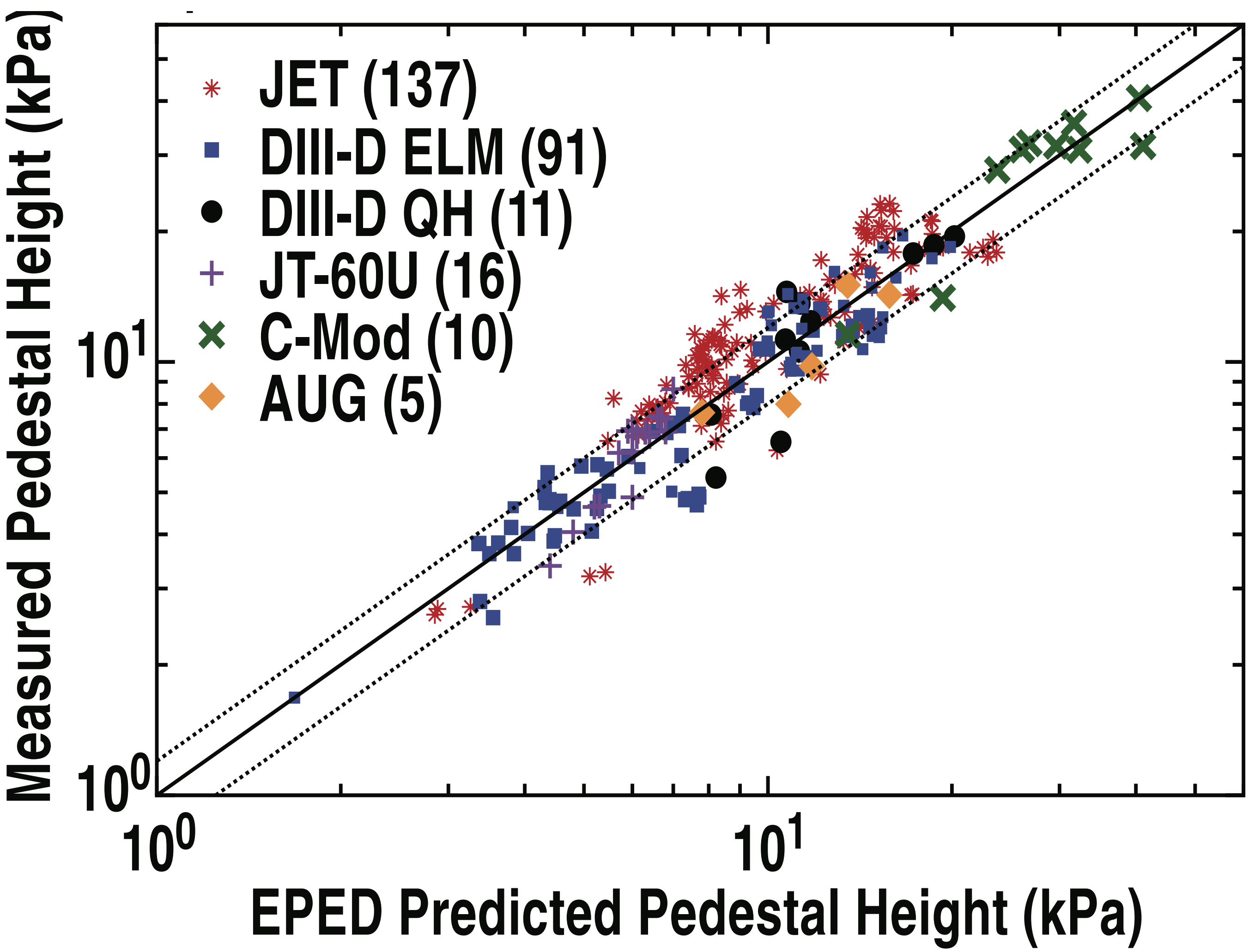
RJ Groebner/IAEA/October 2012

EPED Model Has Been Tested on an International Tokamak Database

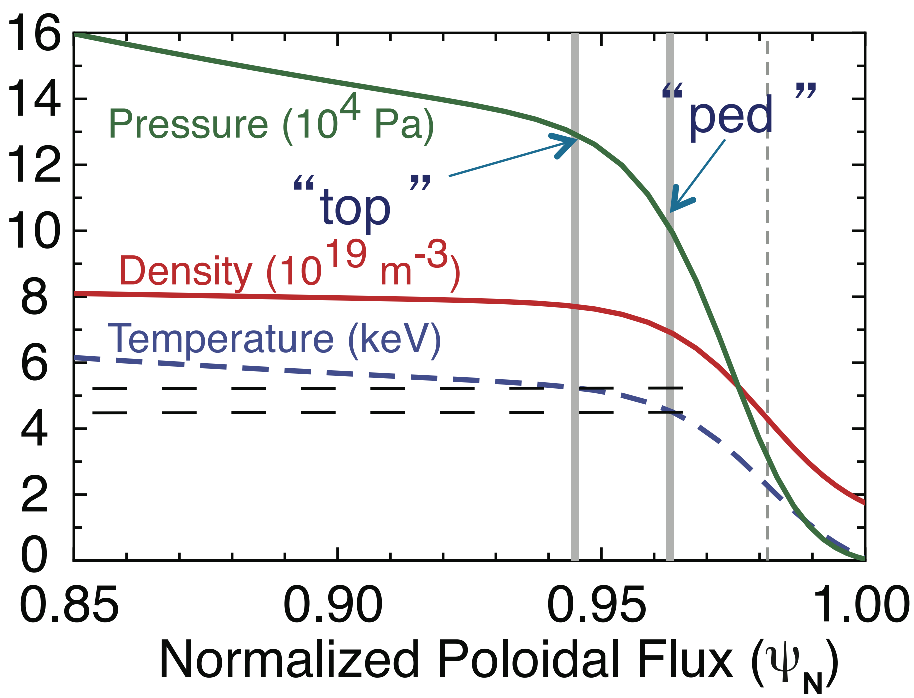
Comparison of model to 270 cases on 5 tokamaks



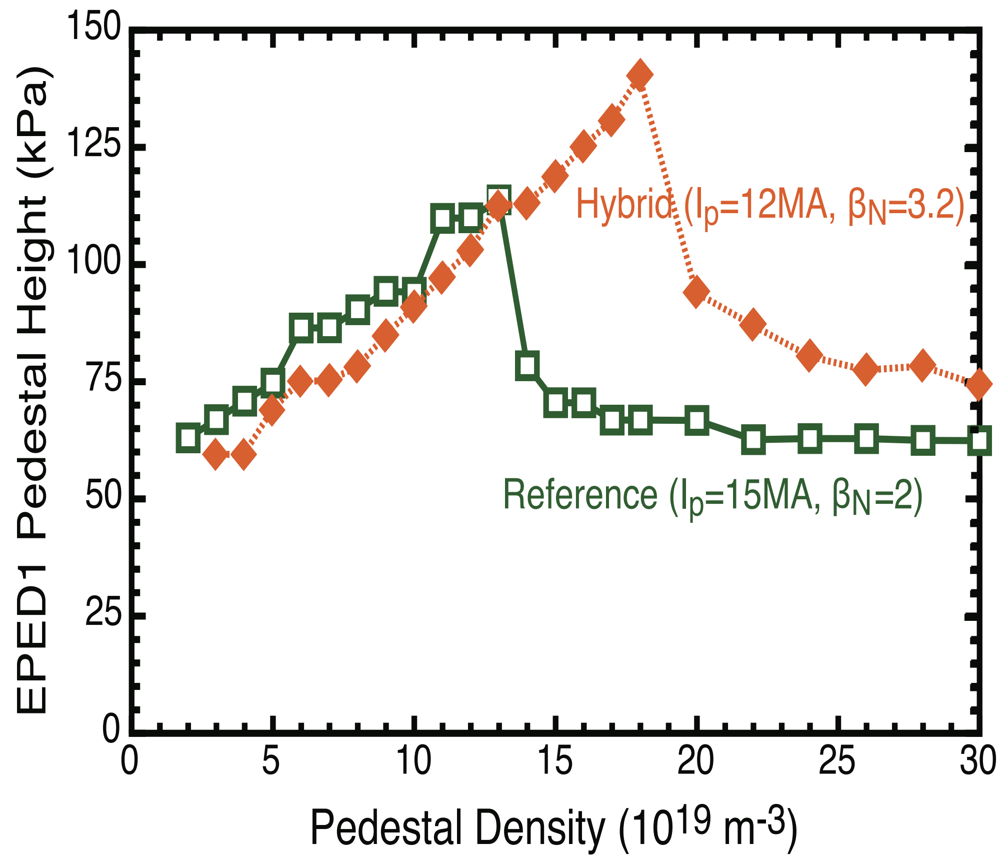
ITER Pedestal Predictions and Optimizations are Made With EPED Model

For ITER baseline, full model predicts (n_{ped} ~ $7x10^{19}$ m^{-3}):

- **Pedestal height of $\beta_{N,ped}$ ~ 0.6**
- **Width ~4.4 cm**
- **T_{ped} ~ 4.5 keV**



Model predicts that ITER pedestal optimizes at higher density



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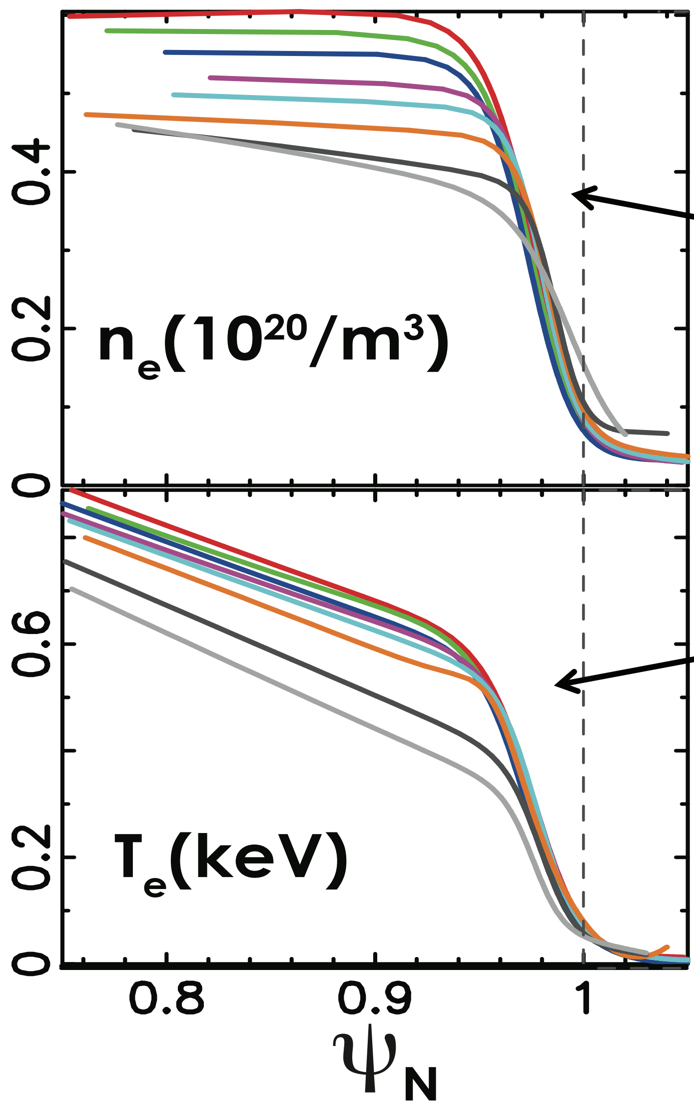
Full Predictive Capability Requires Understanding of Density and Temperature



Several models for individual profiles were studied

Density profile
- Neoclassical transport
- Paleclassical transport
- Pinch
- Neutral fueling

Electron temperature profile
- Electron temperature gradient turb
- Paleoclassical transport

Preliminary conclusion: several processes likely to be operative in pedestal profile formation

Results From Joint Research Target Activity Support a Framework for How the Pressure Pedestal Works

- **Limits to pedestal pressure profile are controlled by peeling-ballooning stability and kinetic ballooning modes**

- **These physics processes combined in EPED model, which predicts pressure pedestal height in existing machines to ~20% accuracy**

- **Good confidence that we can predict and optimize pedestal in ITER**

- **For ITER baseline discharge at n_{ped} ~ 7×10^{19} m^{-3}, prediction is T_{ped} ~ 4.5 keV**
  - Higher pedestal density is predicted to provide improved performance