# Time Evolution of H-mode Pedestal Characteristics in Type I ELM Discharges on DIII-D

by
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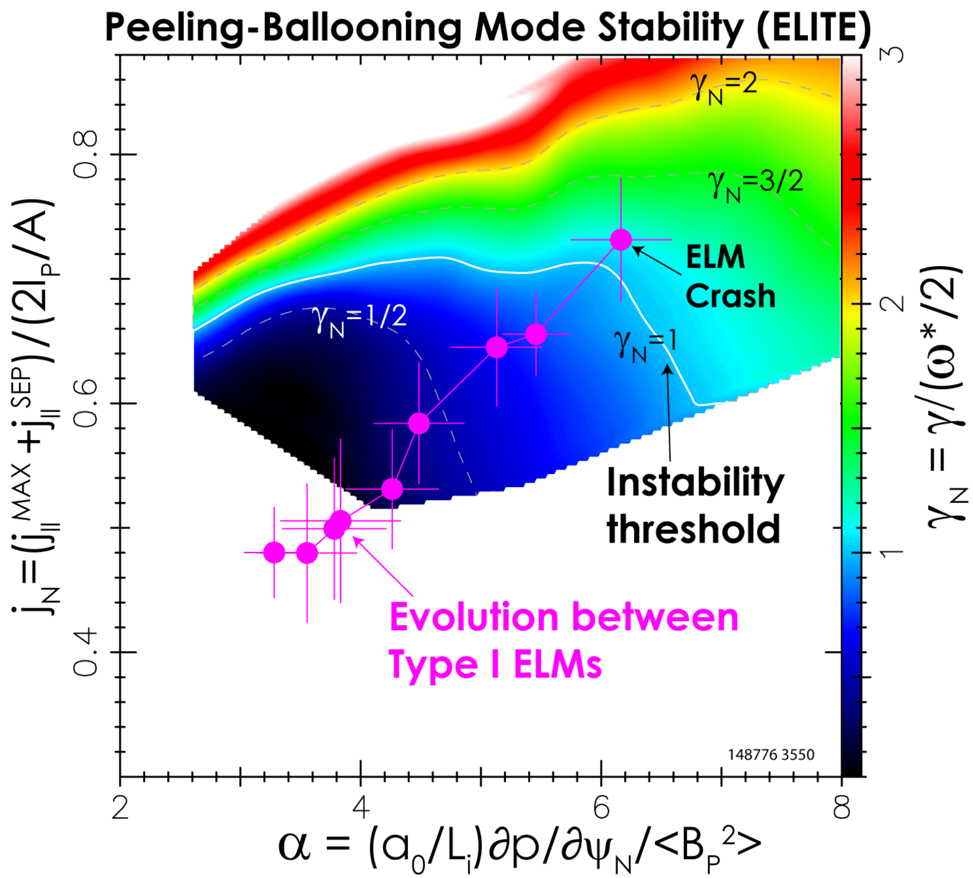


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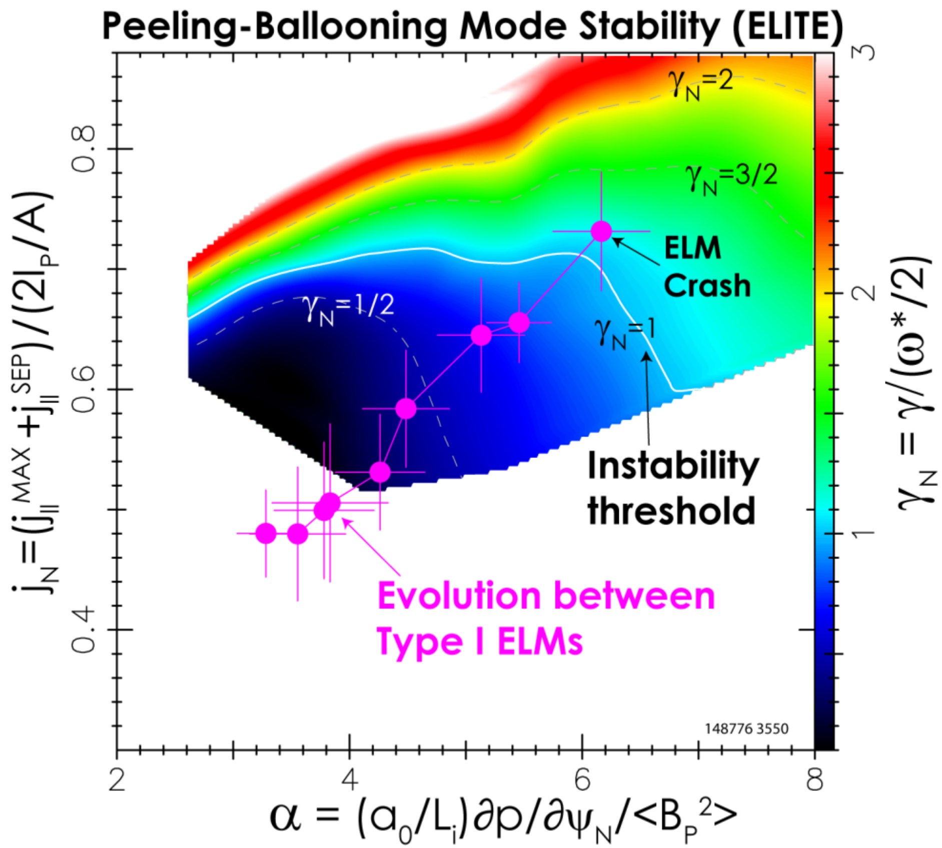
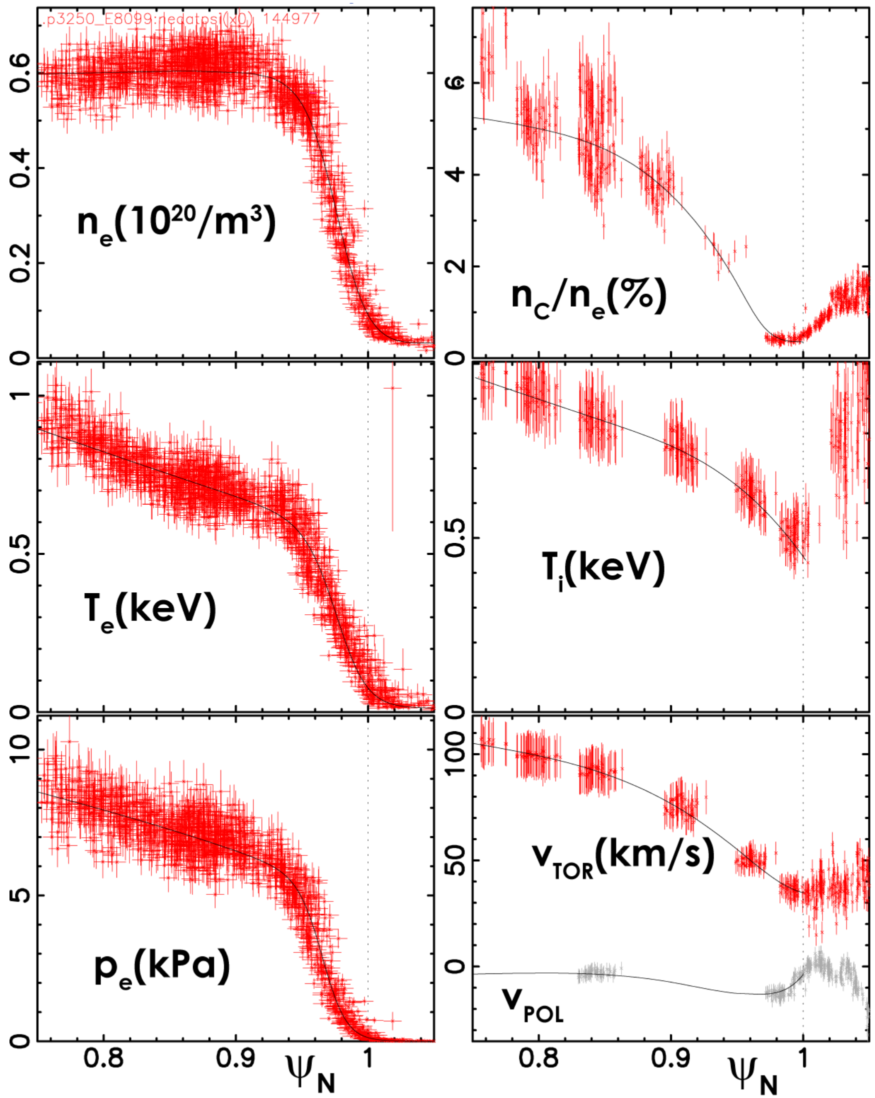
# Summary

- Improved diagnostics allow tracking of pedestal evolution between ELMs
- Peeling-ballooning mode instability drive builds continuously during inter-ELM period reaching the stability limit at ELM crash
- Pedestal evolution is generally consistent with KBM constraint in the EPEP1.0 model
- The pedestal can evolve to higher pressure at higher collisionality possibly due to effects of $\nu_{*e}$ on stability




Computed with ELITE Code

# High Spatial and Temporal Resolution TS and CER Systems Allow Between ELM Pedestal Evolution Studies




- In 2011, 10 additional TS spatial points (D. Eldon, B. Bray) in pedestal + improved temporal resolution (2x50 Hz + 4x20 Hz lasers)
- In 2012 improvements in TS calibration, analysis techniques, … (B. Bray, T. Carlstrom, TS Team). Improvements in CER analysis
- At low ELM frequency ($\tau_{ELM}$≥100 ms) can follow time evolution over a single inter-ELM period

# Pedestal Current Density Profile Computed from Neoclassical Models Using Kinetic Profiles

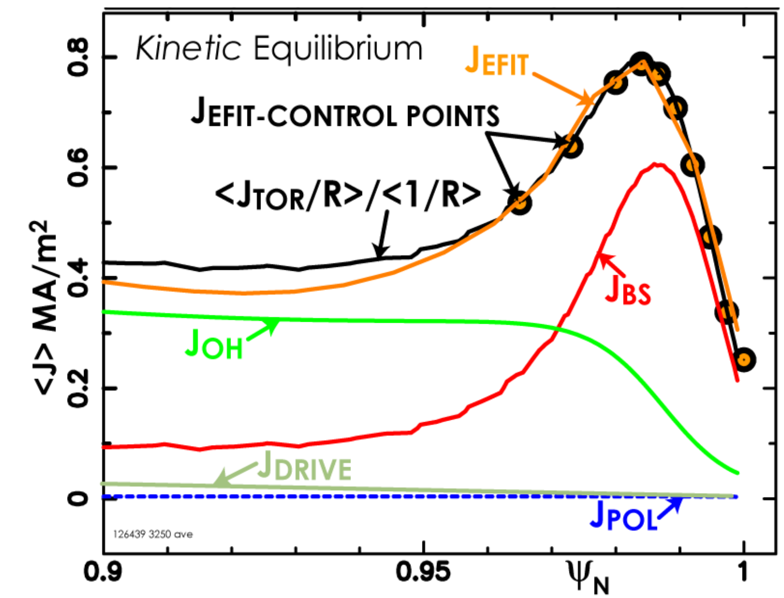
- $j_{PED} = j_{BS} + j_{DRIVE} + j_{OH}$ computed from kinetic profiles
- $j_{BS}$ dominates $j_{PED.}$ Computed from NC models (Sauter, XGC0)

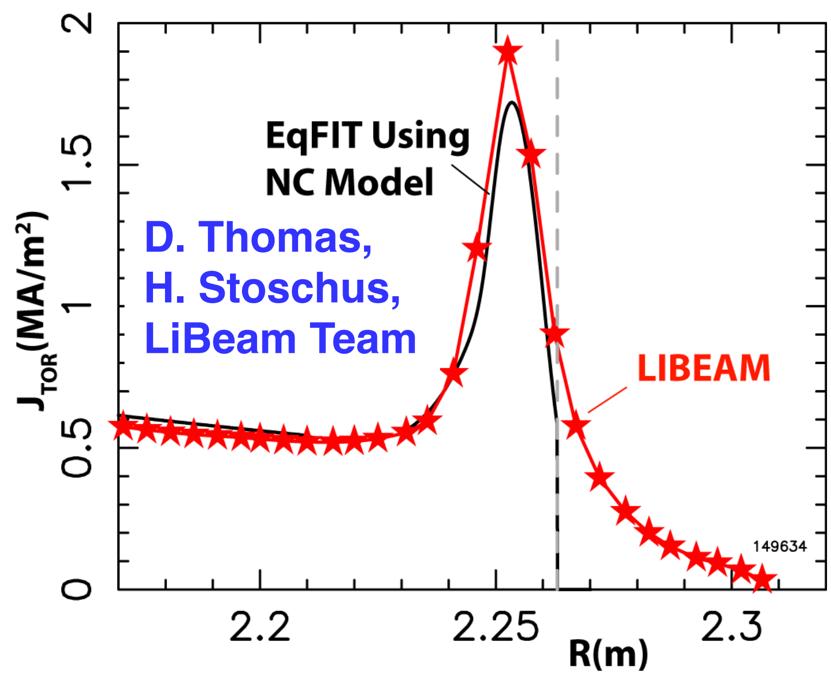
  $$J_{BS} \approx -\mathrm{L}(f_T, Z, \nu_{*e}) \partial P/\partial \psi$$

  L increase with $f_T$, decrease with $\nu_{*e}$

  $$\nu_{*e} \sim q Z_{eff} n/T^2$$

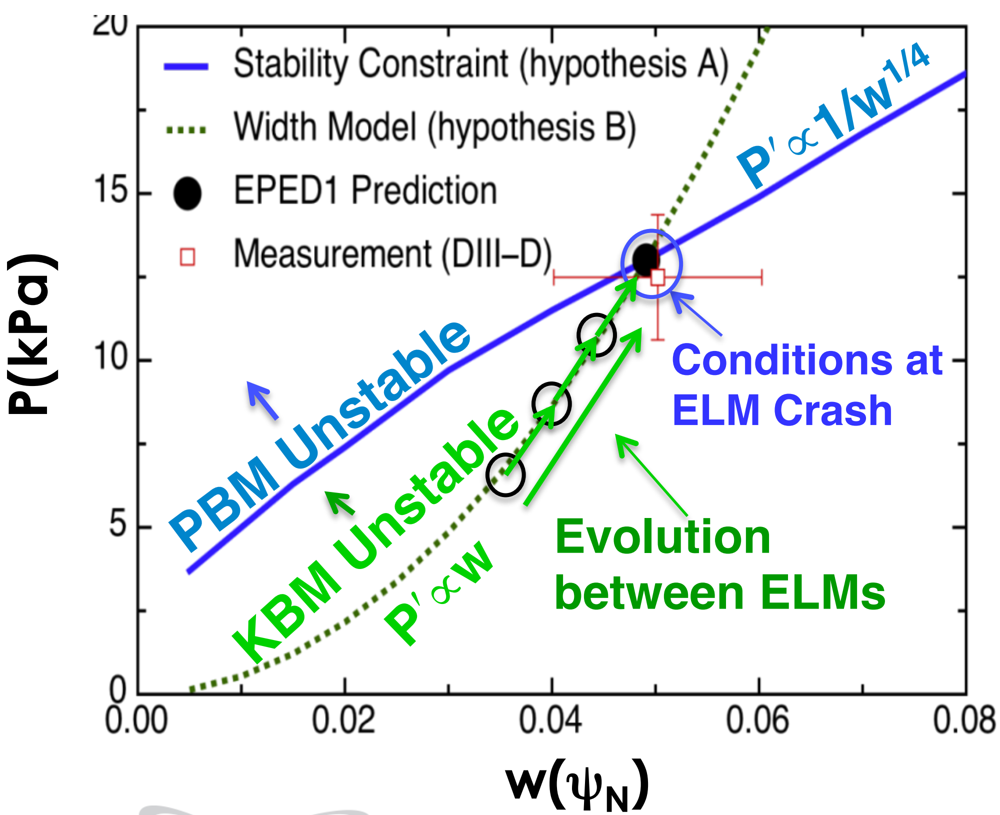
- $j_{DRIVE}$ from NUBEAM
- $j_{OH}$ assumed fully relaxed. Transients at ELM dissipate quickly (<~10ms).
- EFIT j matched to $j_{PED}$ in pedestal and MSE in core
- Recent improvements in the LiBeam system should soon allow direct measurement of $j_{PED}$



# Pedestal Evolution Under the EPED Model[1] Set by Edge Stability Constraints

- **In EPED model kinetic ballooning mode, KBM, provides pedestal transport constraint while peeling ballooning mode, PBM, provides ELM stability limit**
  - KBM expected to survive $V'_{ExB}$ and produce strong transport and so act as a limit on p′
  - EPED1.0 model predicts $p^{PED}$ at ELM within 20% over a range of tokamak sizes and discharge conditions as the intersection between the KBM and PBM limits




- **EPED1.0:** Empirical fit to a constant KBM p′ scaling coefficient, $c_\alpha$

  $w(\psi_N)=0.076(\beta_{Pol}^{PED})^{1/2} \Rightarrow$

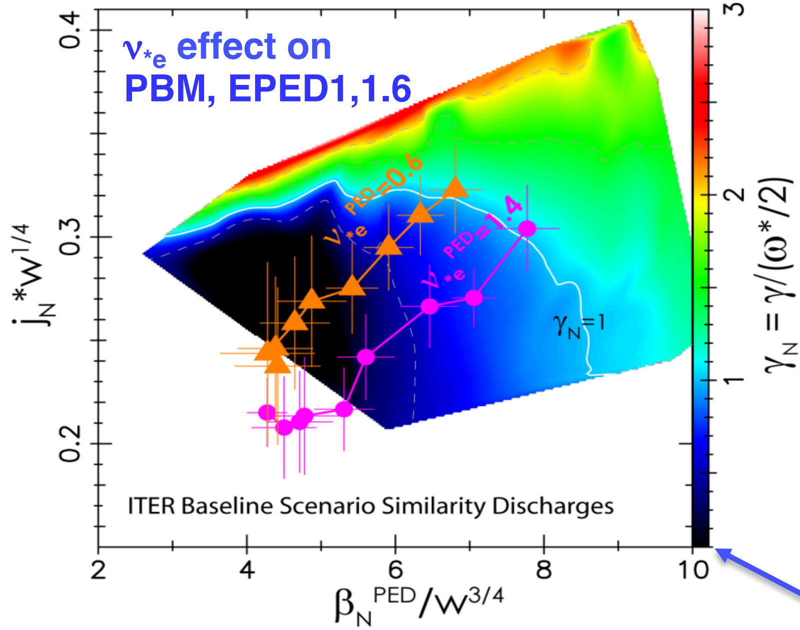
  $\alpha = a_0/L_i \; 1/\langle B_P^2\rangle \; \partial p/\partial \psi_N = c_\alpha w$

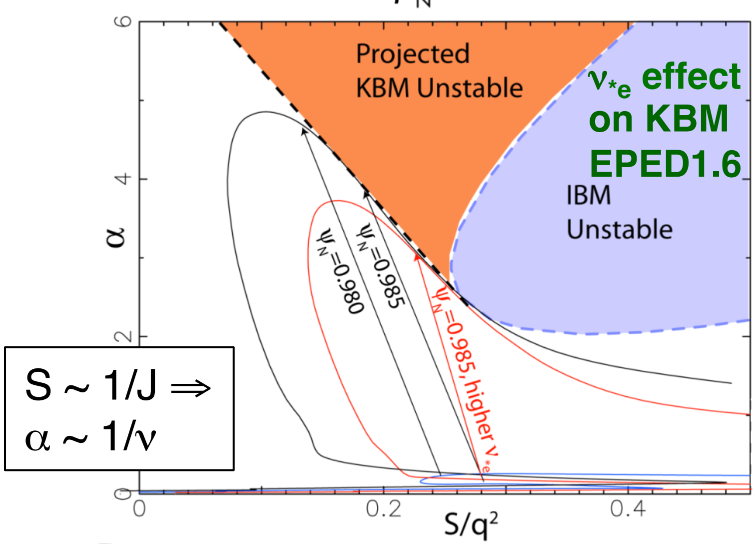
- **EPED1.6[1]:** Parametric dependence of $c_\alpha$ derived using n=∞ ideal ballooning mode to estimate KBM limit

  $\alpha = c_\alpha(\nu_{*e},\ldots)w$

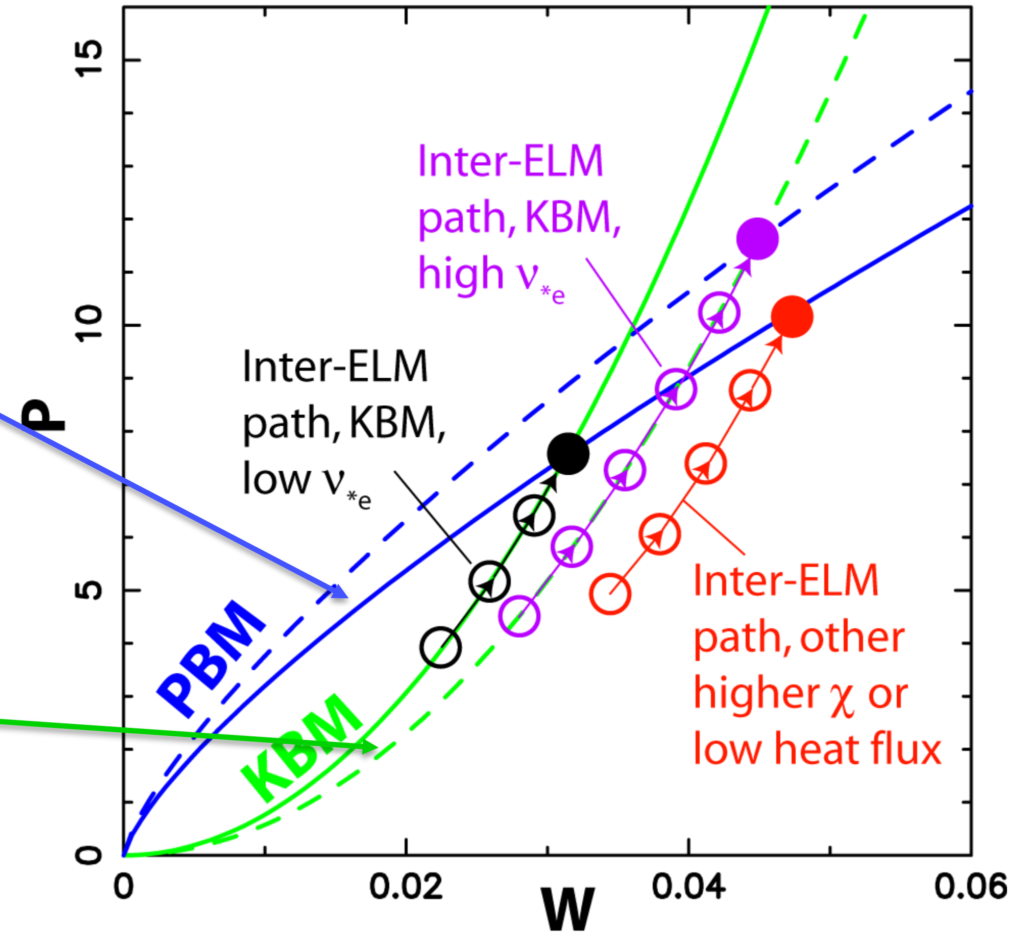
[1]P.B. Snyder, Nucl. Fusion 51 (2011)

# Under EPED Pedestal Pressure at the ELM Should Increase with Increasing Pedestal Collisionality




- **Effect of $\nu_{*e}$ is through reduction of $j_{BS}$ for a given p′**



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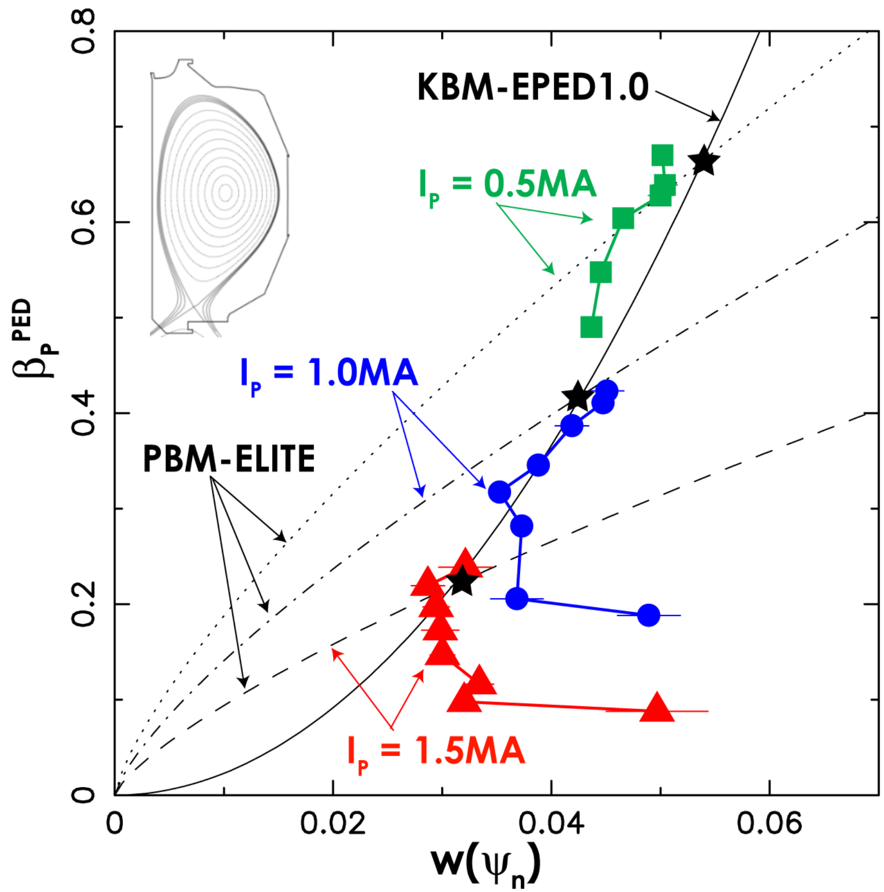
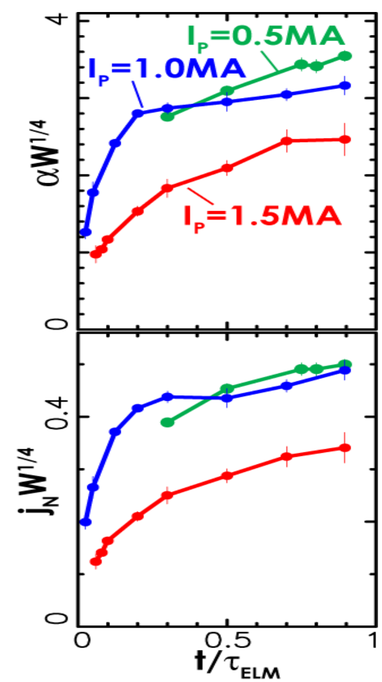
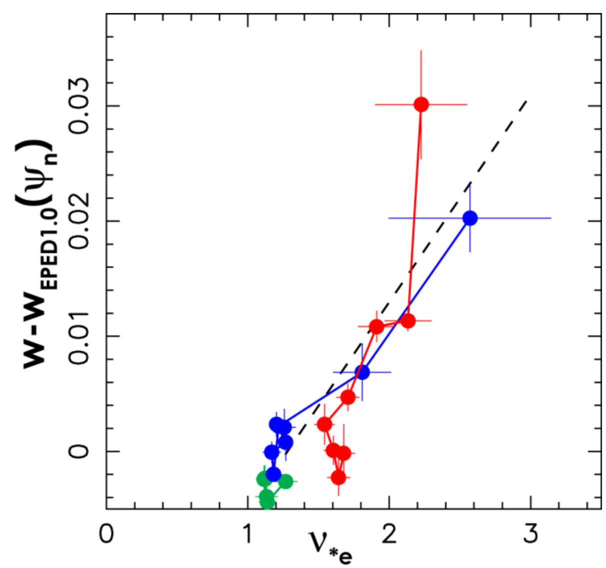
# Pressure Profile Evolution from $I_P$ Scan Experiment in General Agreement with EPED1.0 Model Predictions

- **In all cases ELMs occur at pressures close to EPED1.0 model predictions.**
- **Inter-ELM evolution consistent with KBM constraint except possibly at early times**
- **Correlation of $w$-$w_{EPED1}$ with $\nu_{*e}$ suggests $w$ may track KBM even early in EFP**



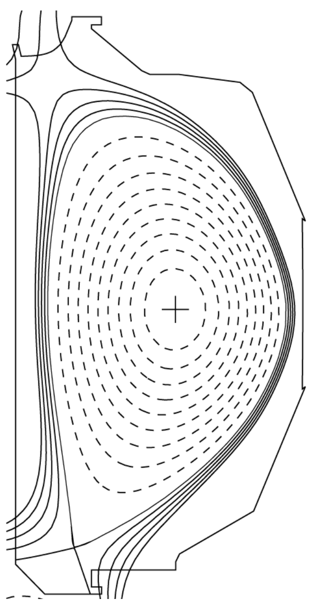

| $I_P$ | $B_T$ | $q_{95}$ | $N_e$ | $P_{HEAT}$ | $P/P_{LH}$ | $\tau_{ELM}$ |
|---|---|---|---|---|---|---|
| 1.5 | 2.1 | 3.5 | 0.8 | 2.2 | 1.0 | 230 |
| 1.0 | 2.1 | 5.1 | 0.6 | 2.2 | 1.2 | 140 |
| 0.5 | 2.1 | 10.6 | 0.2 | 2.2 | 2.1 | 70 |

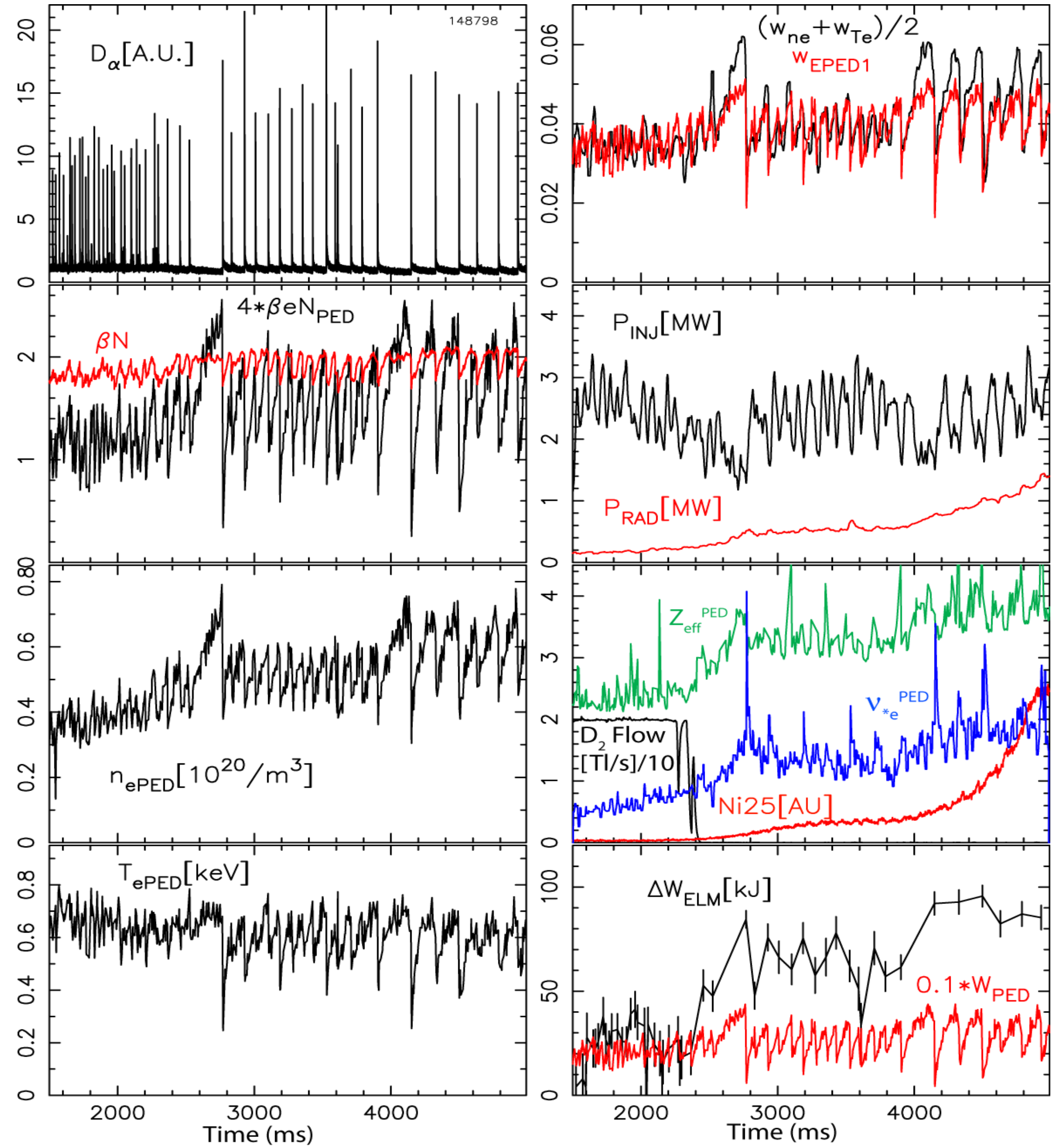


# A Range of Pedestal Pressures are Obtained in ITER Baseline Scenario Similarity Discharges

- **Pedestal pressure increase associated with wider ETB and higher $n_e^{PED}$**
- **ETB width > EPED1 scaling late in inter-ELM period at low $f_{ELM}$**
- **At low $f_{ELM}$**
  - Higher $\nu_{*e}$, $Z_{eff}$
  - larger $\Delta W_{ELM}$ despite higher $\nu_{*e}$
  - High Z impurity accumulation






- **ITER Baseline**
- **ITER Shape**
- **$I_P$=1.2 MA, $B_T$=1.6 T**
- **$q_{95}$ = 3.1**
- **1.6 < $\beta_N$ < 2.2, $\beta_N$ feedback**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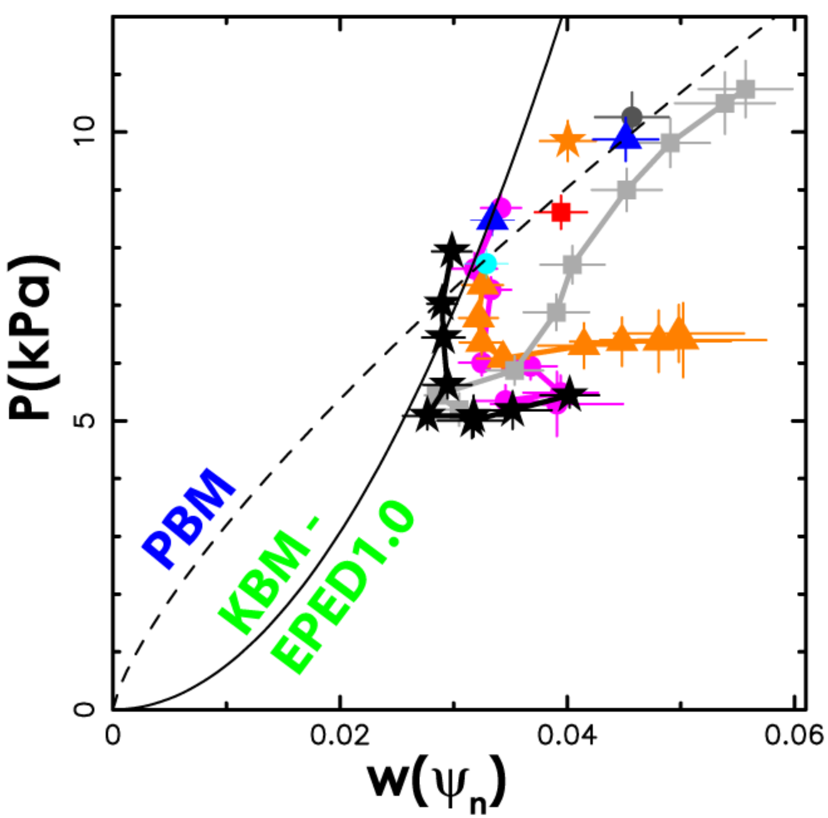
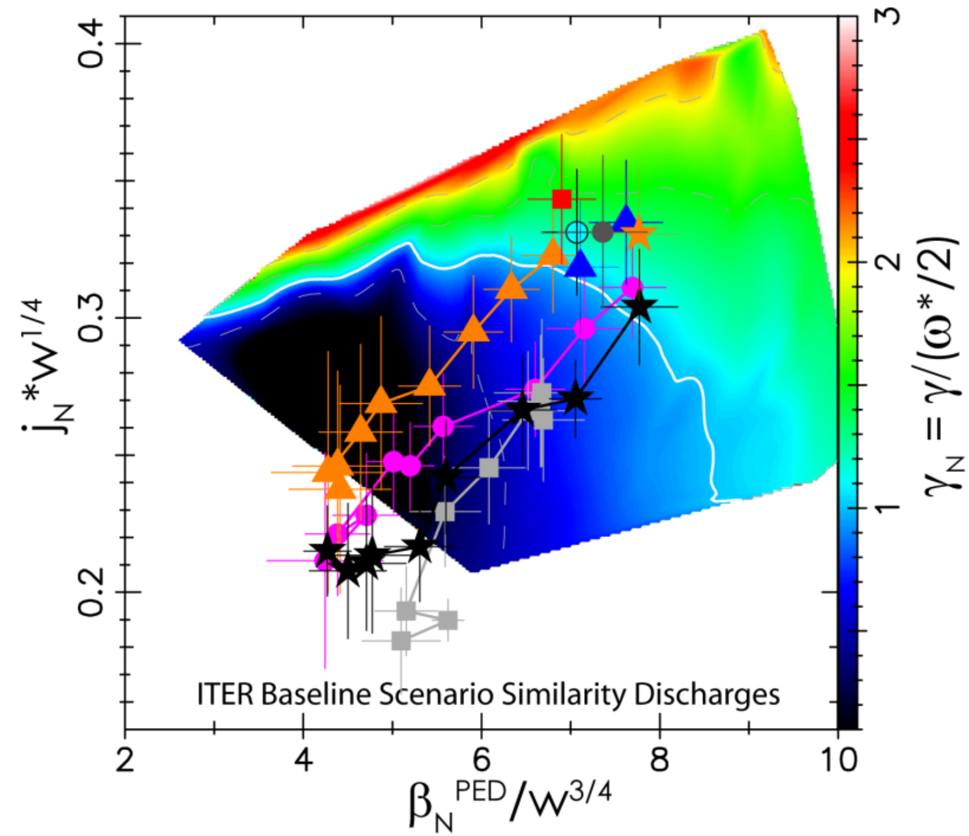
# ITER Baseline Cases that Reach High $P^{PED}$ Exceed the EPED1.0 KBM Width Scaling

- As in the $I_p$ scan width contracts in early part of inter-ELM period (<20%)
- Lower *w* shots track up the EPED1.0 KBM limit and ELM at the PBM limit
- Cases reaching high $P^{PED}$ exceed the EPED1.0 KBM scaling but still generally agree with predicted PBM threshold





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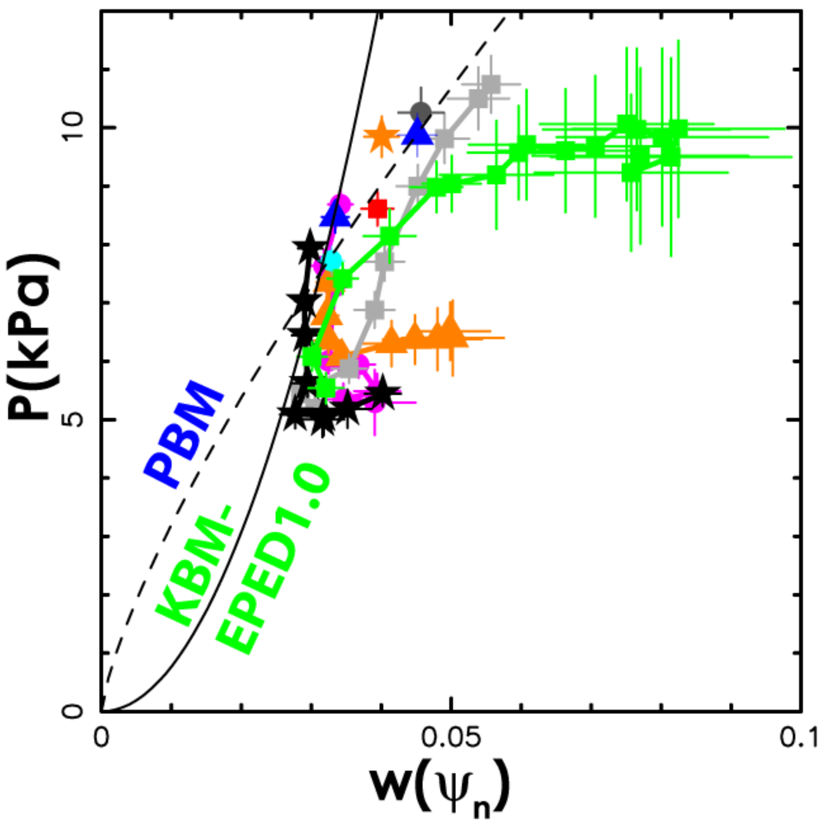
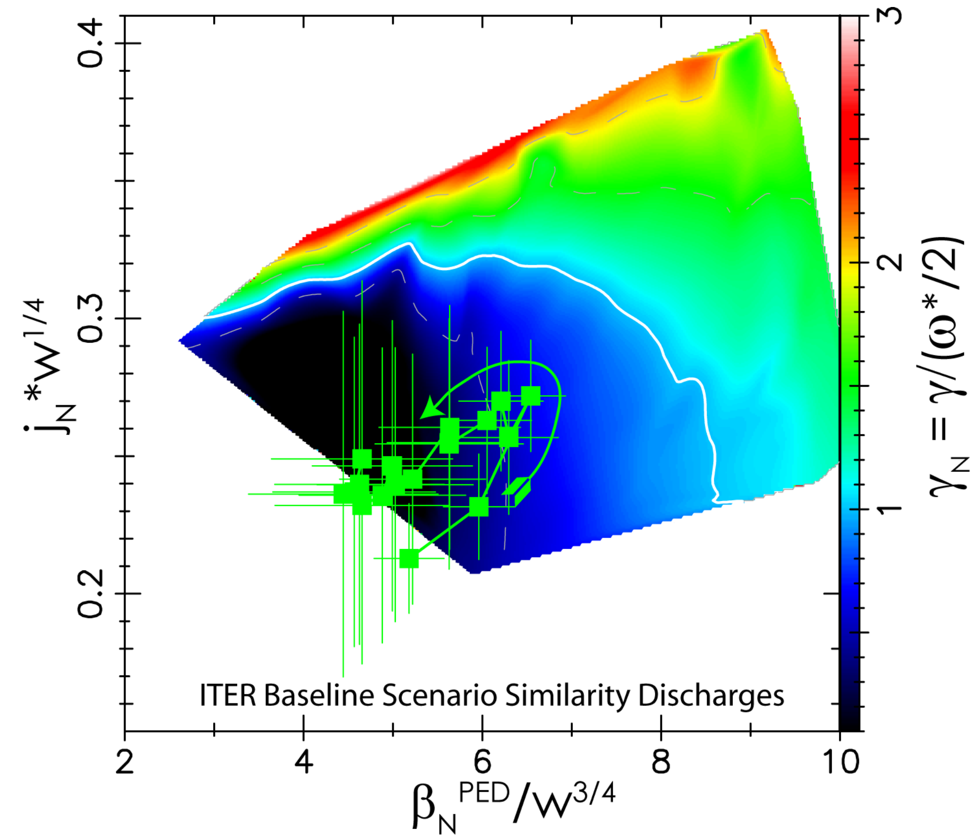
# ITER Baseline Discharge at $\beta_N$=1.6 Goes ELM Free, Reaching Very Large Width

- **Lowest $\beta_N$=1.6 ITER baseline shot goes ELM free and returns to L-mode due to high radiation from accumulated high Z impurities**
- **Width grows to 8% of minor radius greatly exceeding $w_{EPED1.0}$ but moves away from PBM boundary and so does not reach high $P^{PED}$**





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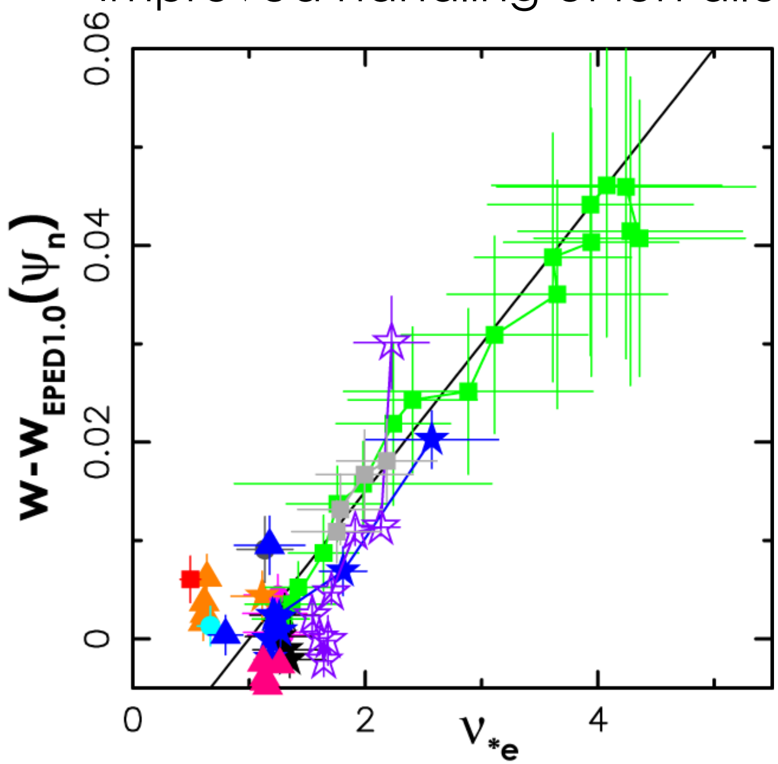
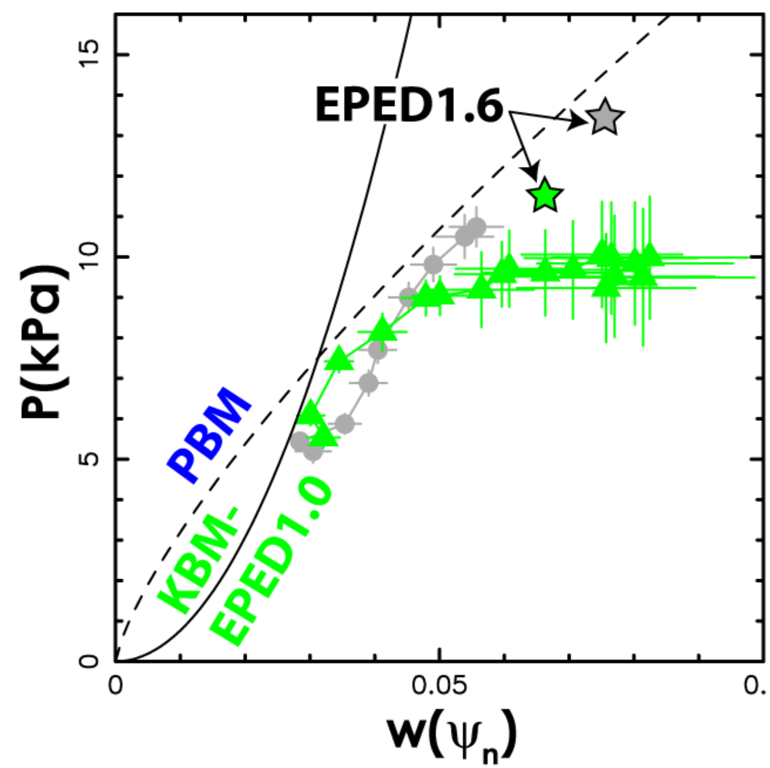
# Correlation of Large Widths with Collisionality Possibly Due to $\nu_{*e}$ Destabilizing Effect on KBM

- **w - $w_{EPED1.0}$ increases with $\nu_{*e}$**
  - Consistent with what would be expected for the effect of reduced $j_{BS}$ at higher $\nu_{*e}$ on KBM stability
- **EPED1.6 predicts substantially higher pressure but exceeds measured values**
  - Improved handling of ion dilution needed in EPED





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# Summary, Conclusion

- **Improvements in pedestal profile measurements have allowed detailed studies of the pedestal evolution between Type I ELMs**
- **The EPED model, combining PBM and KBM stability limits to determine the pedestal pressure at the ELM is supported by results of pedestal evolution studies**
- **At increased collisionality PBM threshold is increase in peeling limited regime and KBM limit is reduced also allowing higher $P^{PED}$ at the ELM stability limit**
  - This may provide a path to improved performance
  - Large pedestal also associated with large ELMs