Status of Pedestal Structure Studies on NSTX: Global Parameter Scalings

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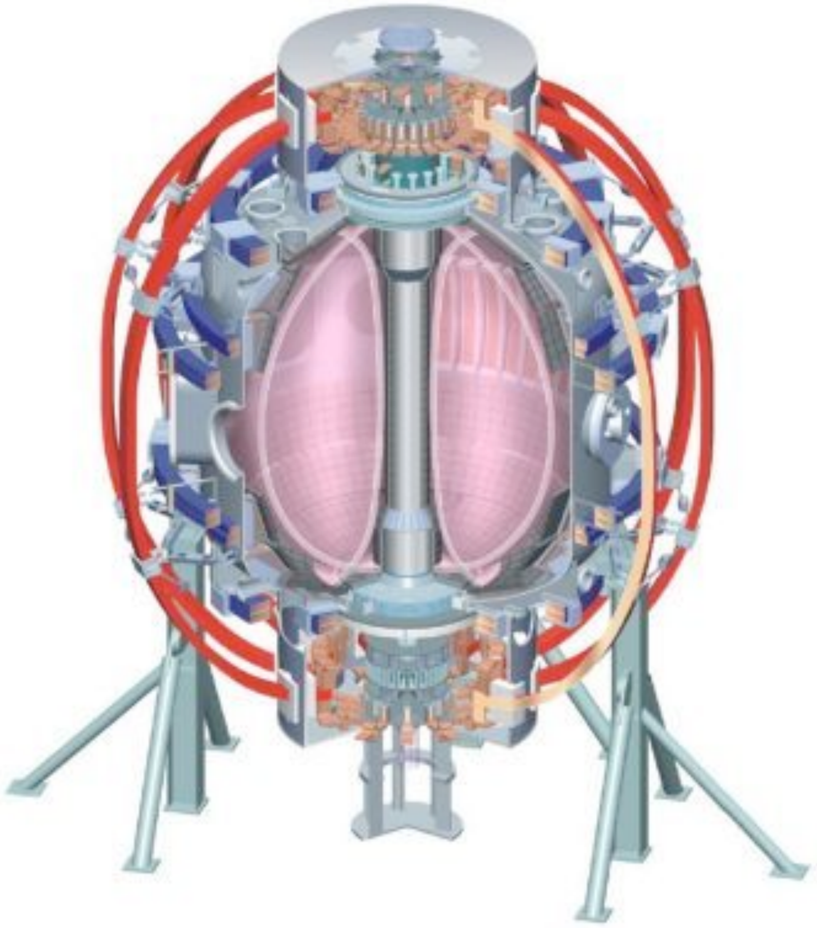

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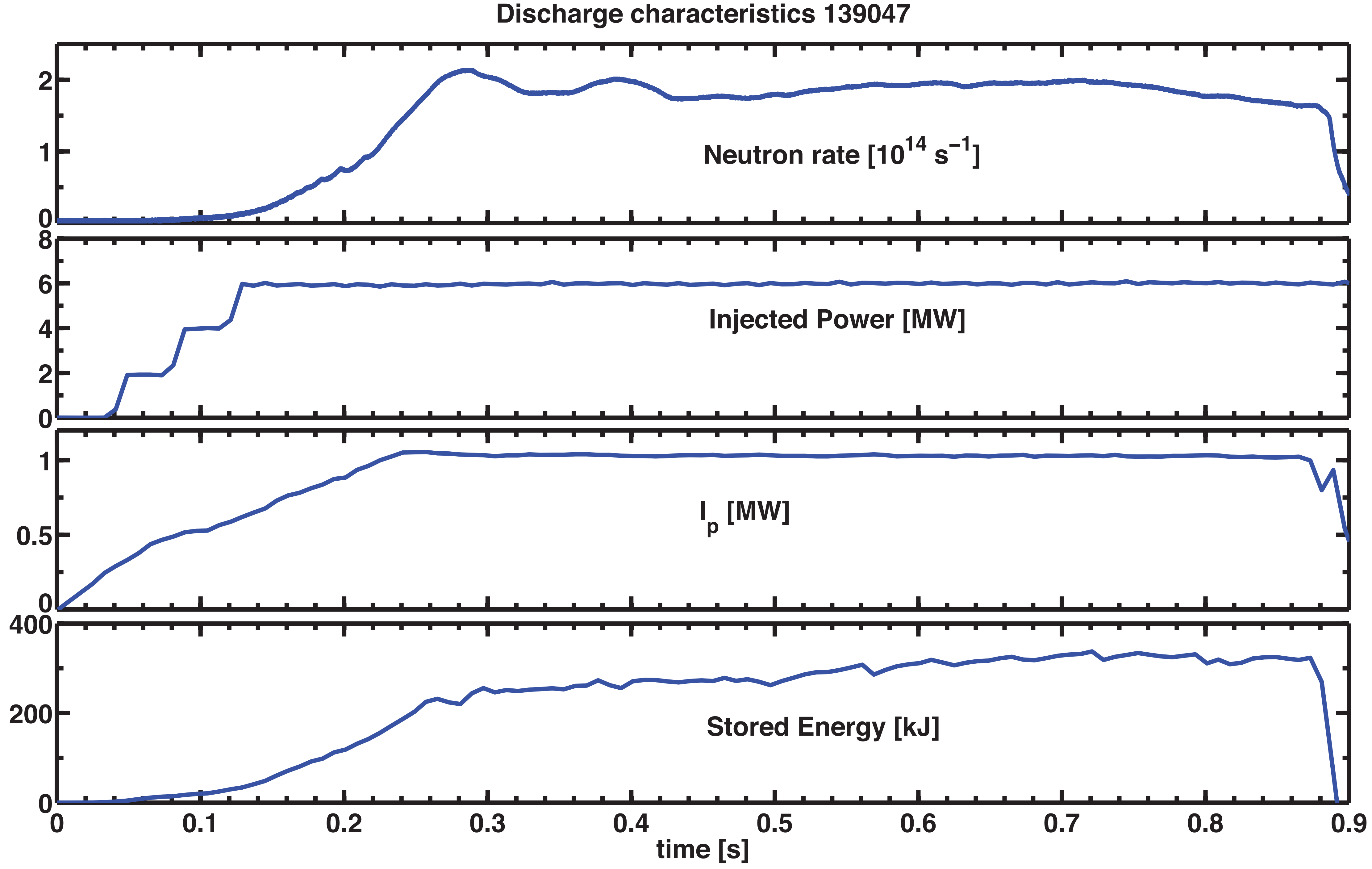
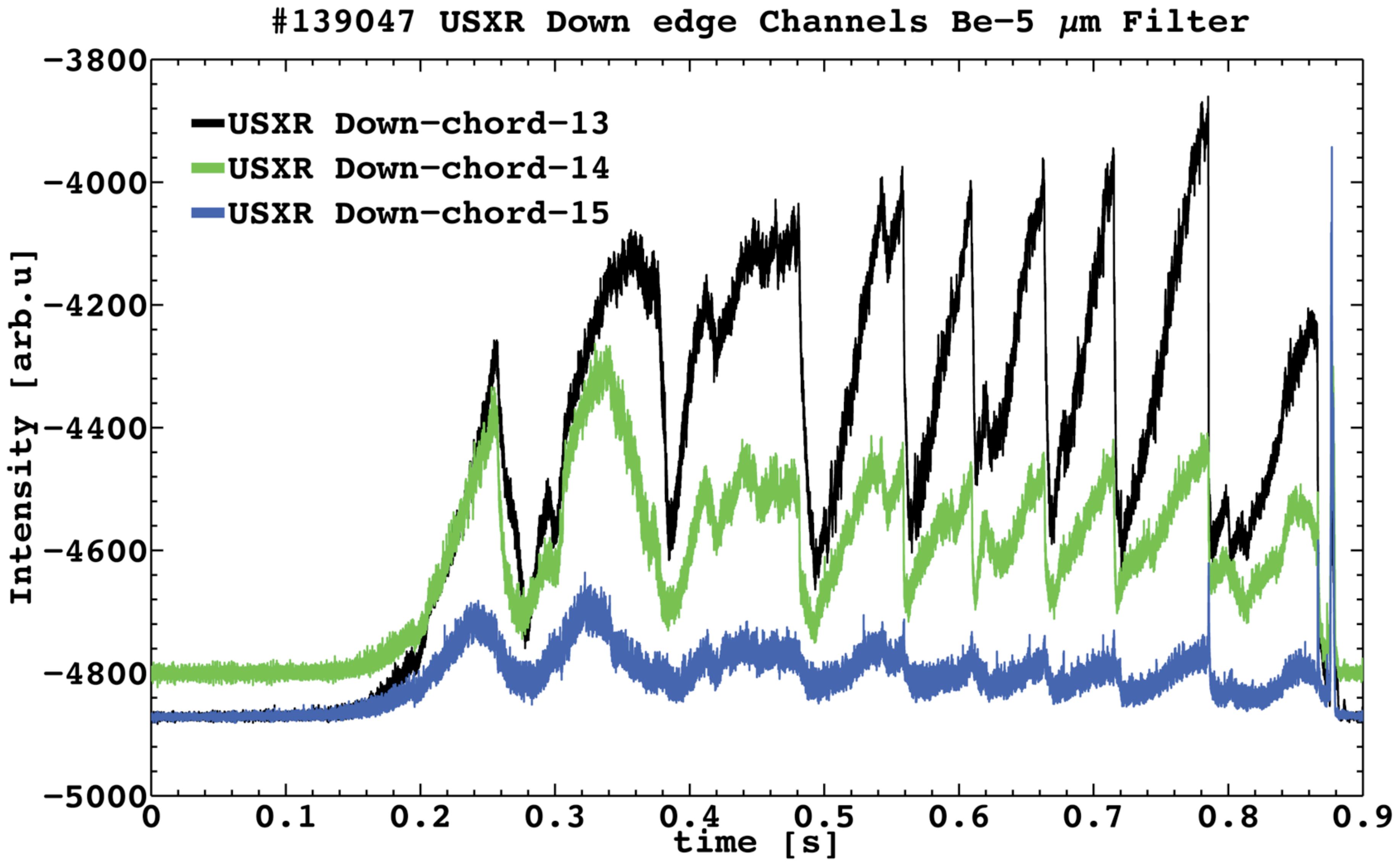
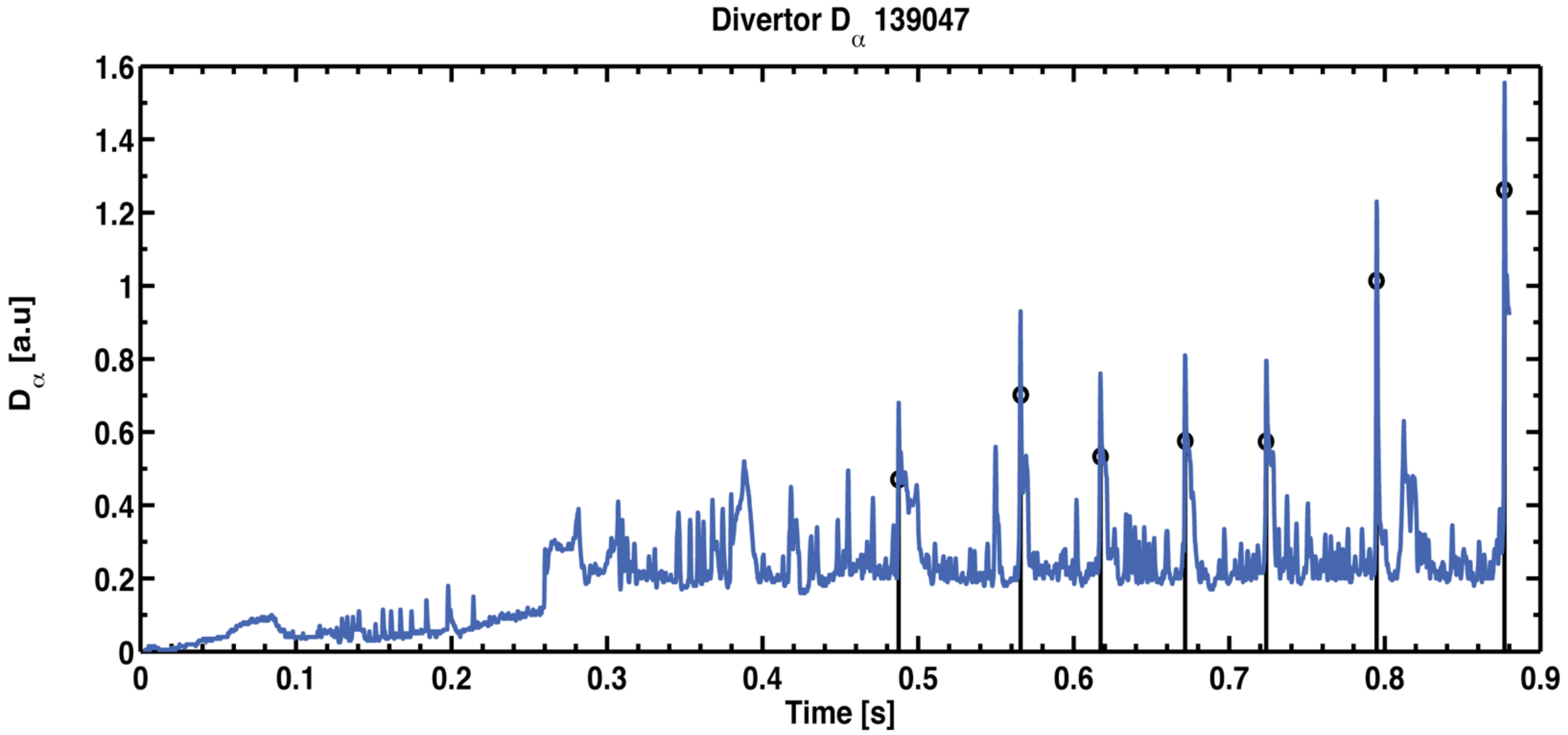
Provide and understand the pedestal structure prior to the onset of ELMs as a function of key plasma parameters

- Importance to the joint research target on pedestal structure and predictive capability and ITER.
- Investigation of key plasma parameter scalings for testing the pedestal height scaling against predictive models(e.g. EPED) in NSTX
  - Evolution of the pedestal structure during an ELM cycle
  - Is there a clear scaling of the pedestal structure with plasma current?
  - How sensitive to the shaping is the pedestal structure?
- Assess the edge fluctuations during the multiple stages on an ELM ELM cycle to ascertain the role of transport in the pedestal height saturation as well as potential mode associated with the pedestal width.

ELMy discharges are obtained with constant shaping parameters

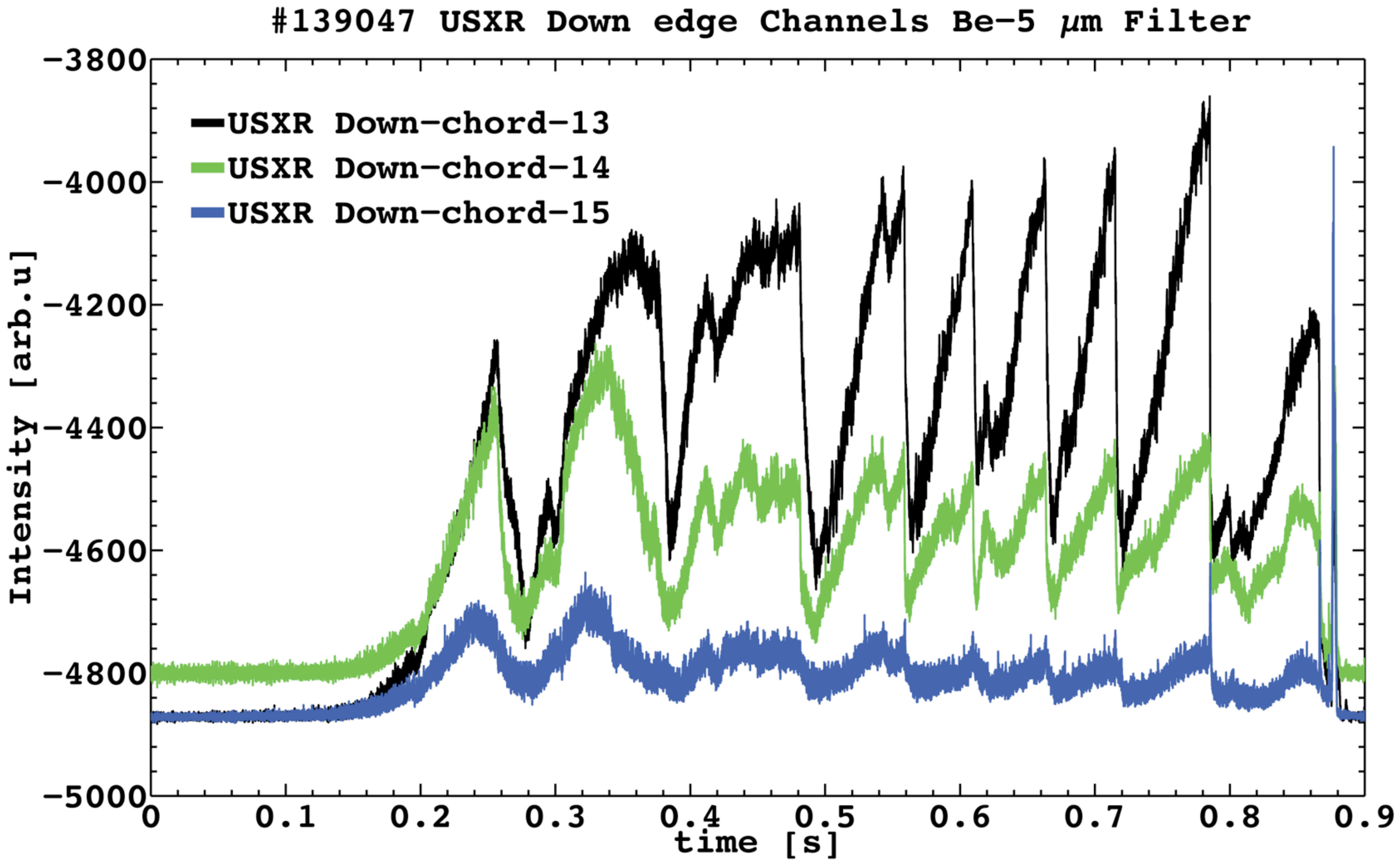

Discharge characteristics 139047

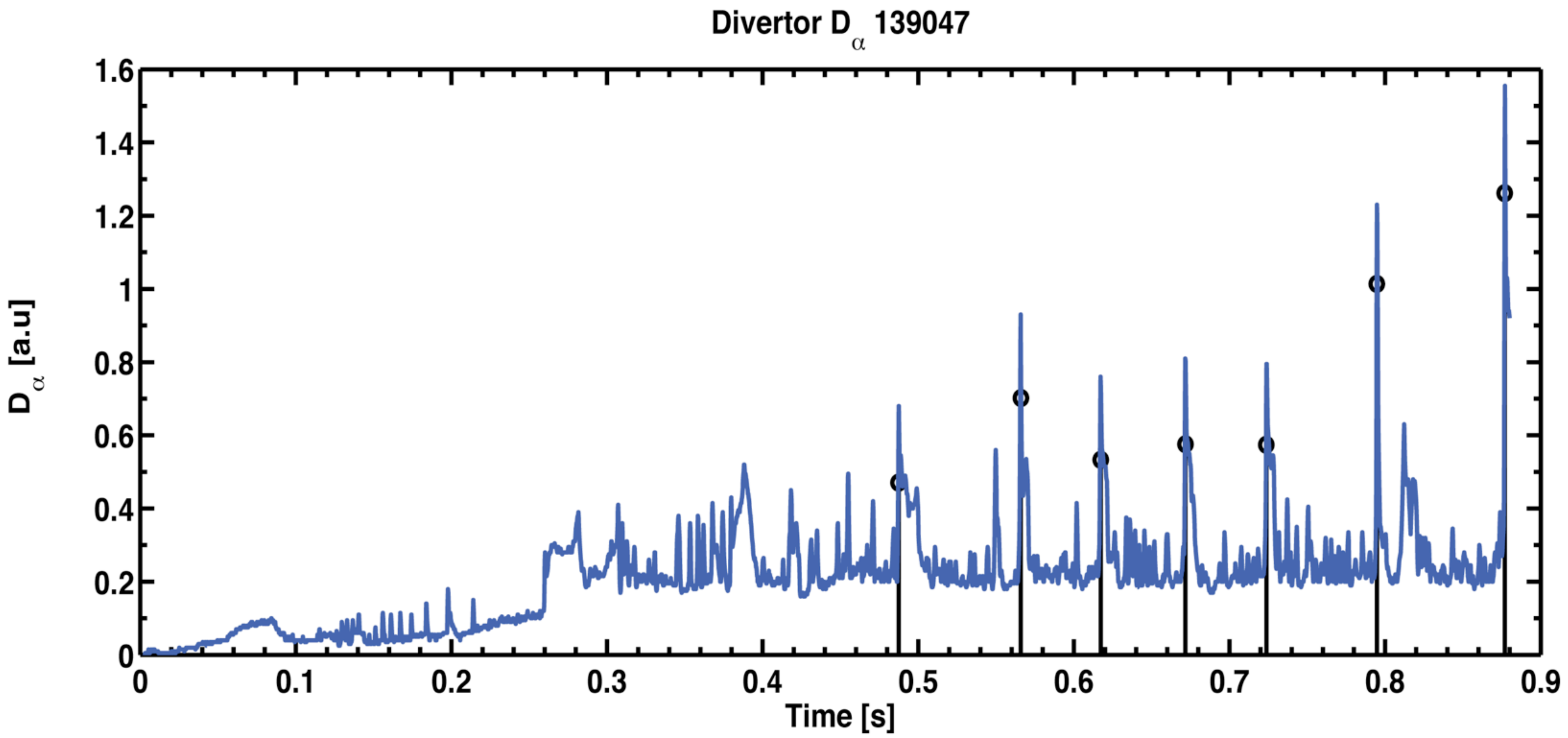

#139047 USXR Down edge Channels Be−5 μm Filter

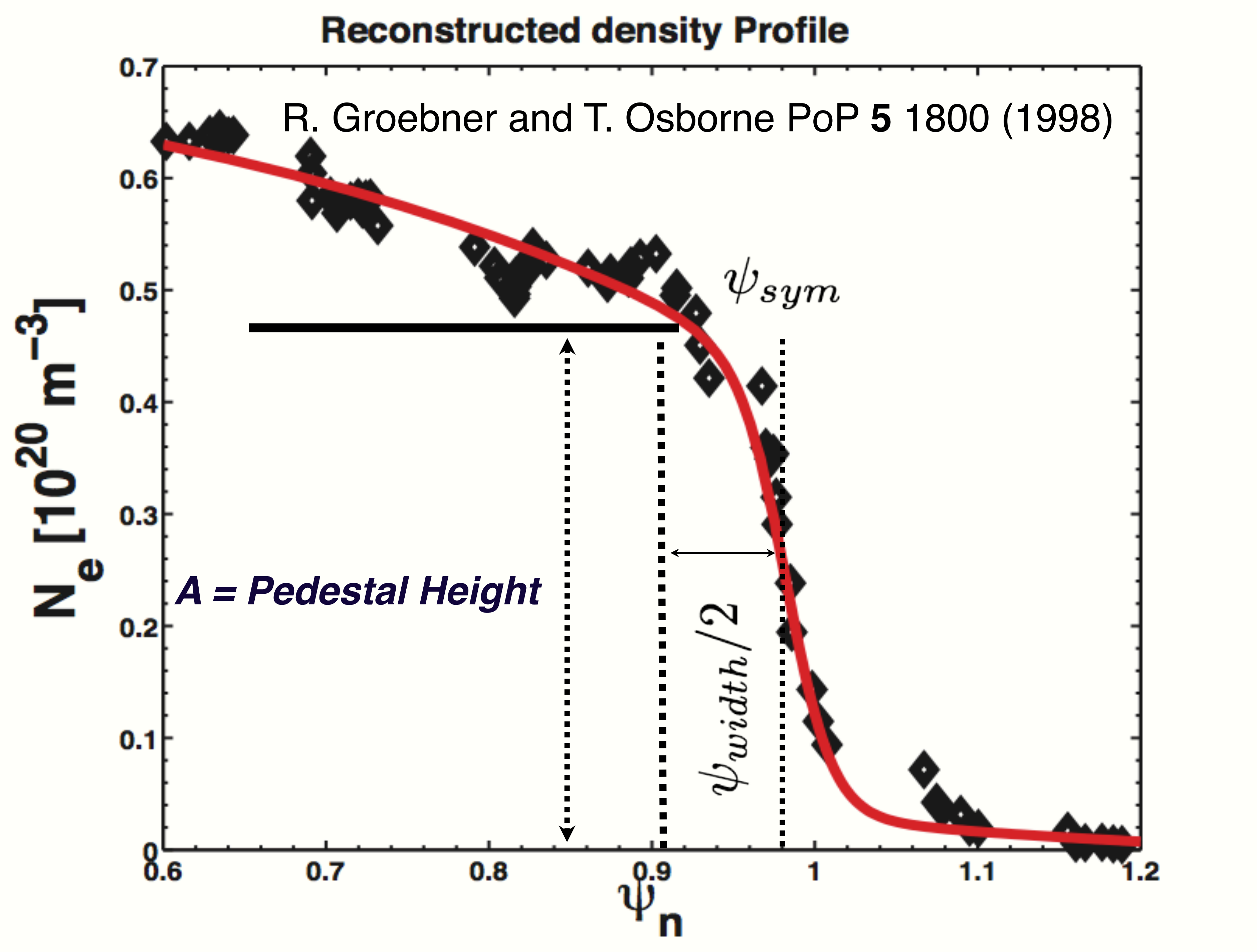

Divertor D$_\alpha$ 139047

Signatures of ELMs are simultaneously tracked/observed on the Dalpha, theUSXR signals, and the total stored energy. These large events are comparable to type I ELMs

Composite radial profiles of key plasma parameters are parametrized using tanh function fits for systematic determination of the pedestal height and width



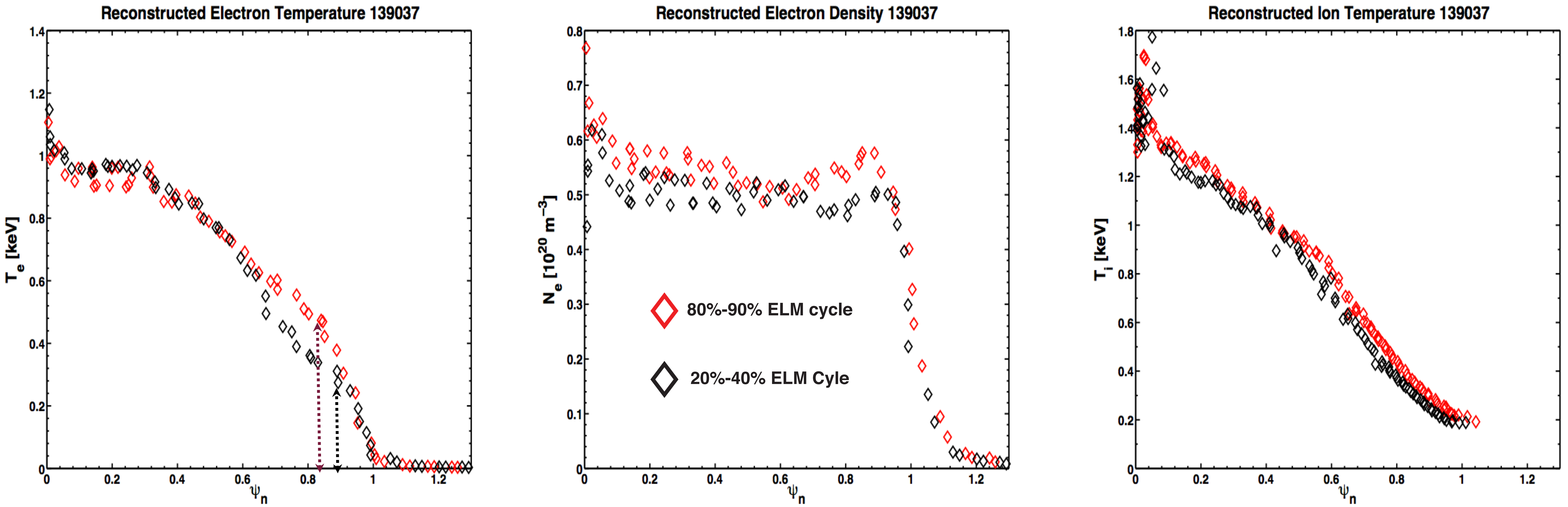




$$N_e(\psi) = A\tanh\left(\frac{\psi_{sym}-\psi}{\psi_{width}}\right) + offset$$

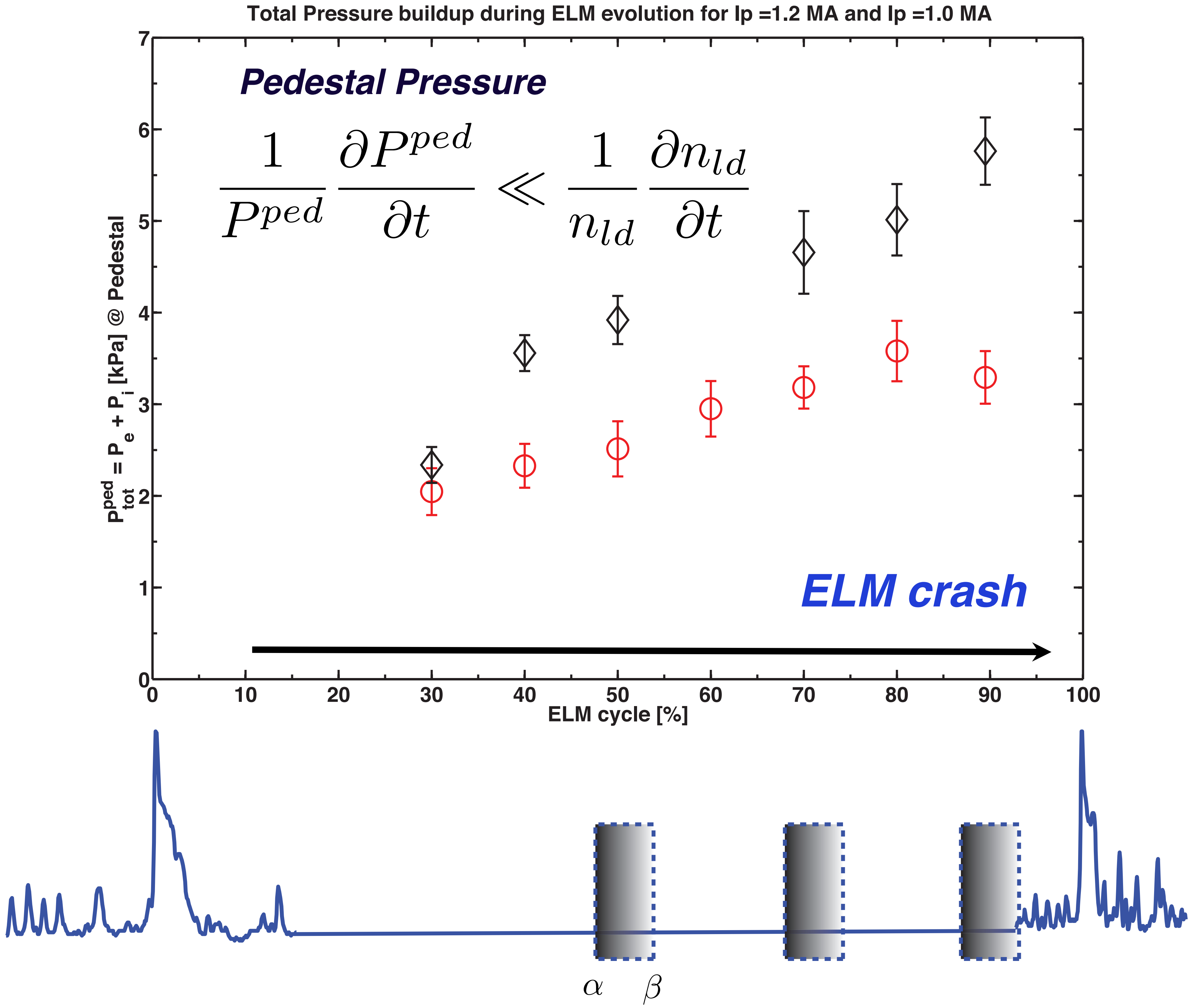
- Edge radial profiles of electron density and temperature are systematically fitted using tanh function.
- Success of this approach is judged based on the fit lines to the data.
- The error on the fit parameter is determined from the deviation of the scattered data.
- Ion profiles are typically spline fitted as there is typically no clear pedestal.

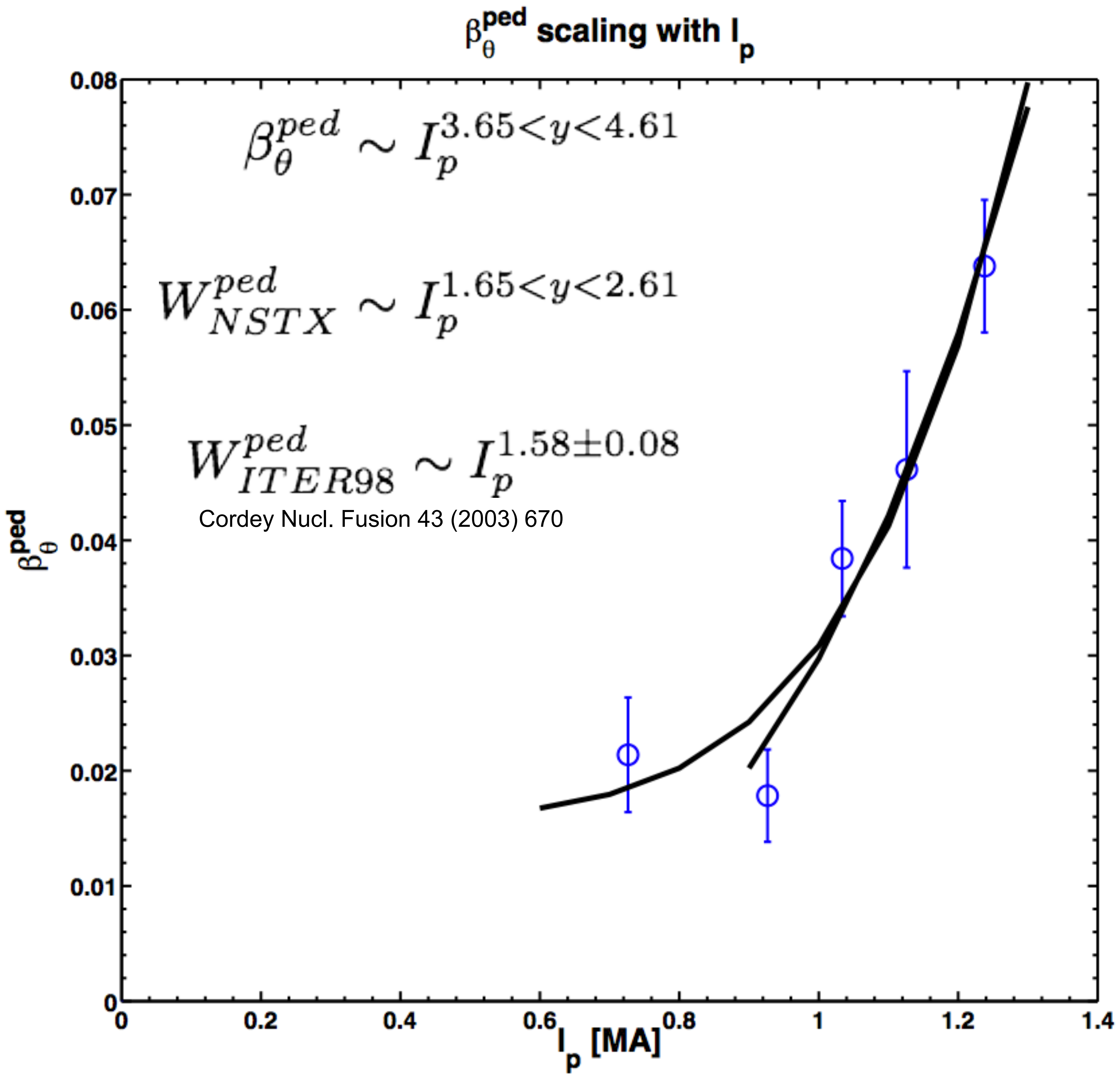
Edge Profiles before and after an ELM indicates minimal increase in gradient



- The electron temperature gradient before and after the ELM appears to be minimally affected.
- The temperature profile shows evidence of a “localized” depletion of the top of the pedestal with minimal change in its gradient leading to an increase of the pedestal temperature width.

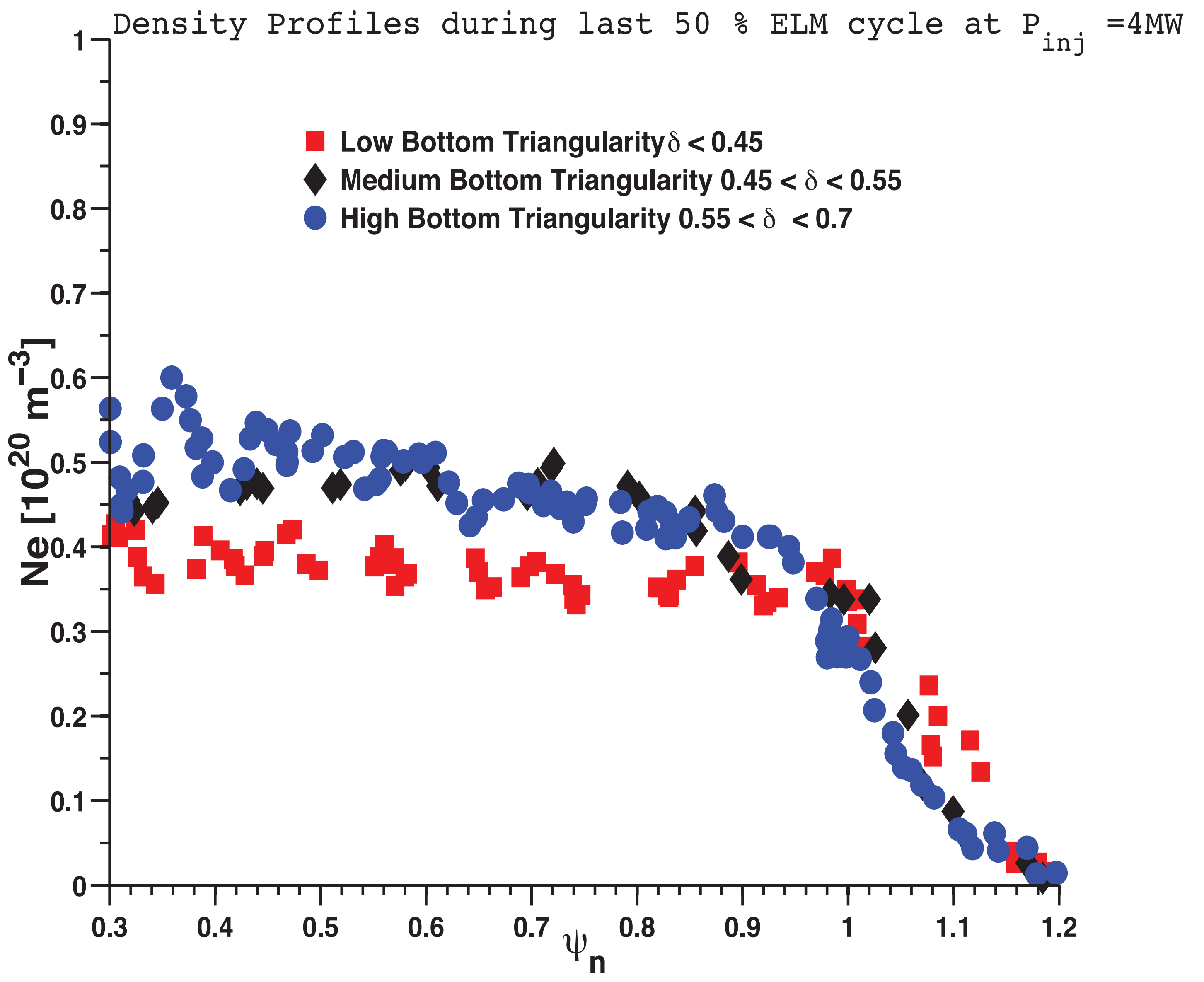
Pedestal height builds up during an ELM cycle and the pedestal poloidal beta scales with plasma current

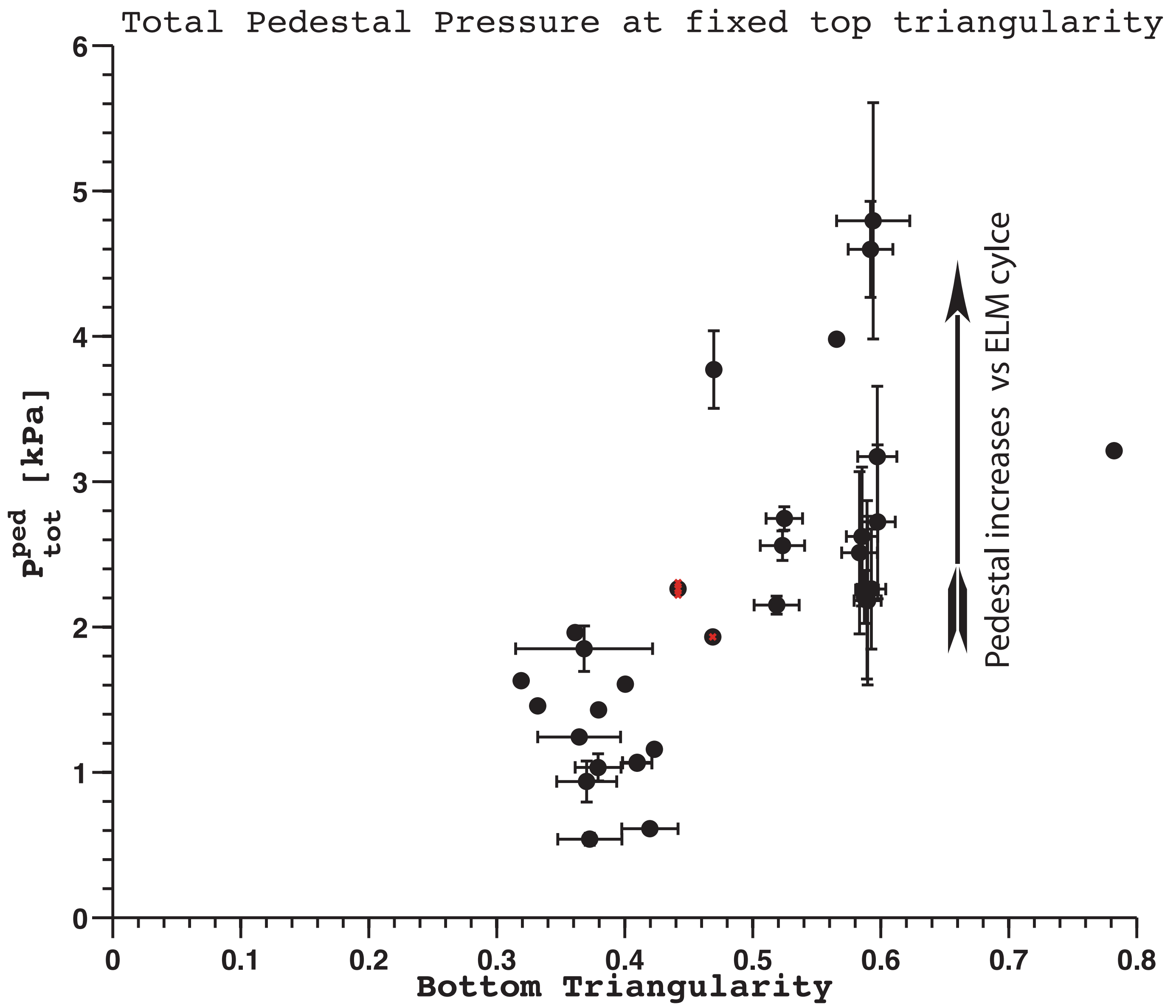


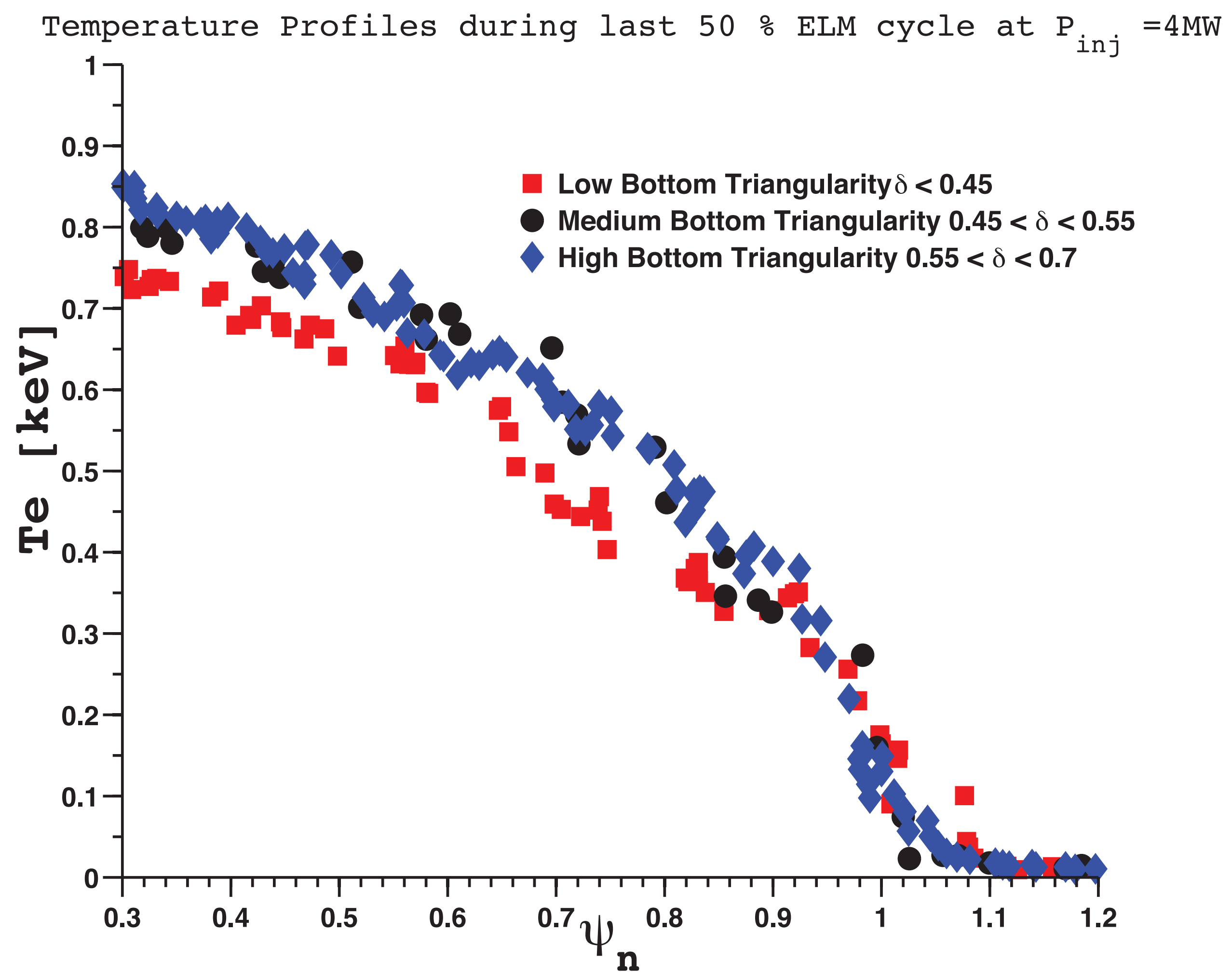


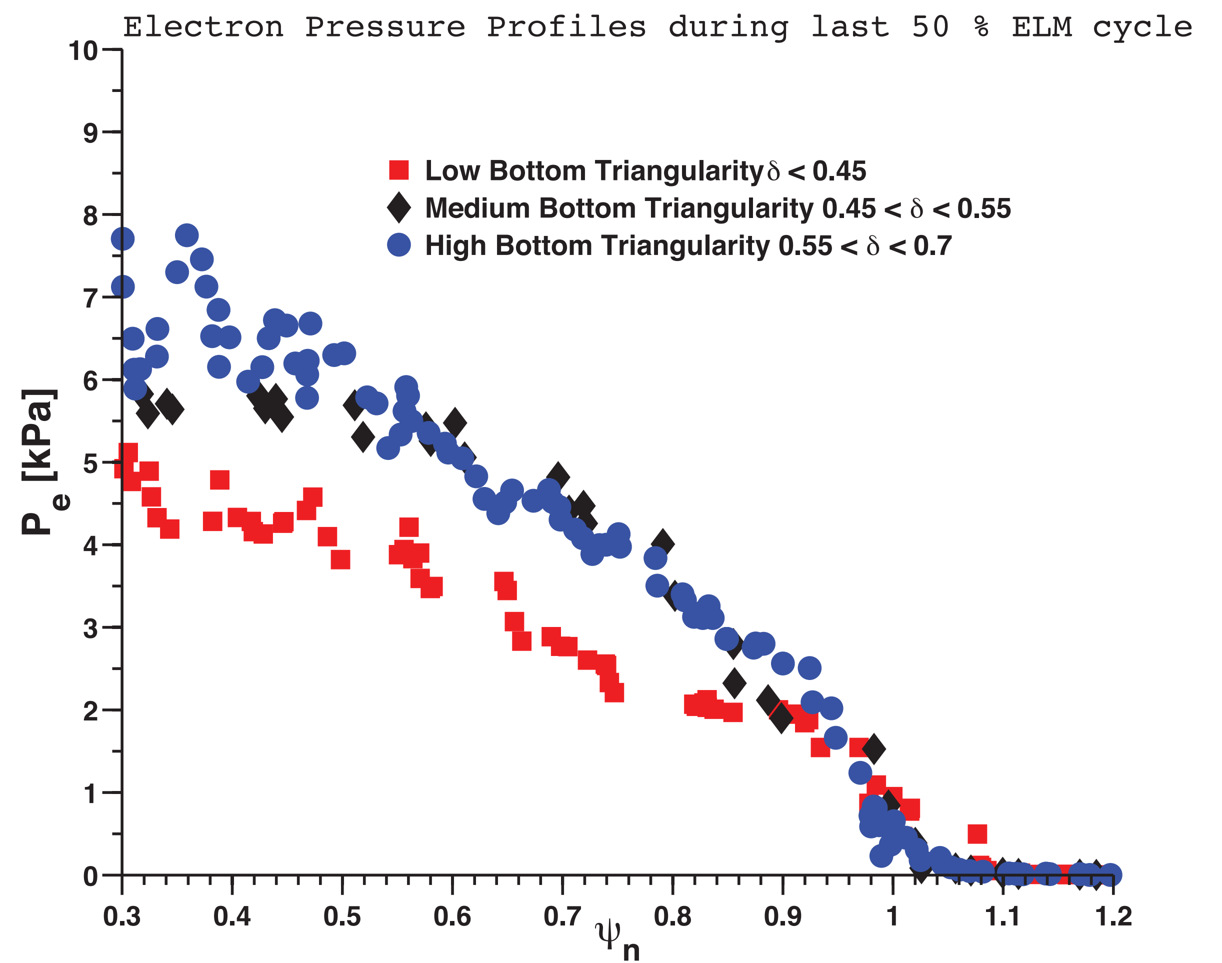
- Pedestal pressure increases with a variation by a factor ~ 3 before the ELM crash showing **no consistent saturation at high plasma current.** Particle transport could be a an important factor the saturation.
- Strong Ip scaling with the pedestal poloidal beta consistent with ITER98 scaling.

Effects of Triangularity of the Pedestal height at constant input power.


Density Profiles during last 50 % ELM cycle at P_{inj} =4MW

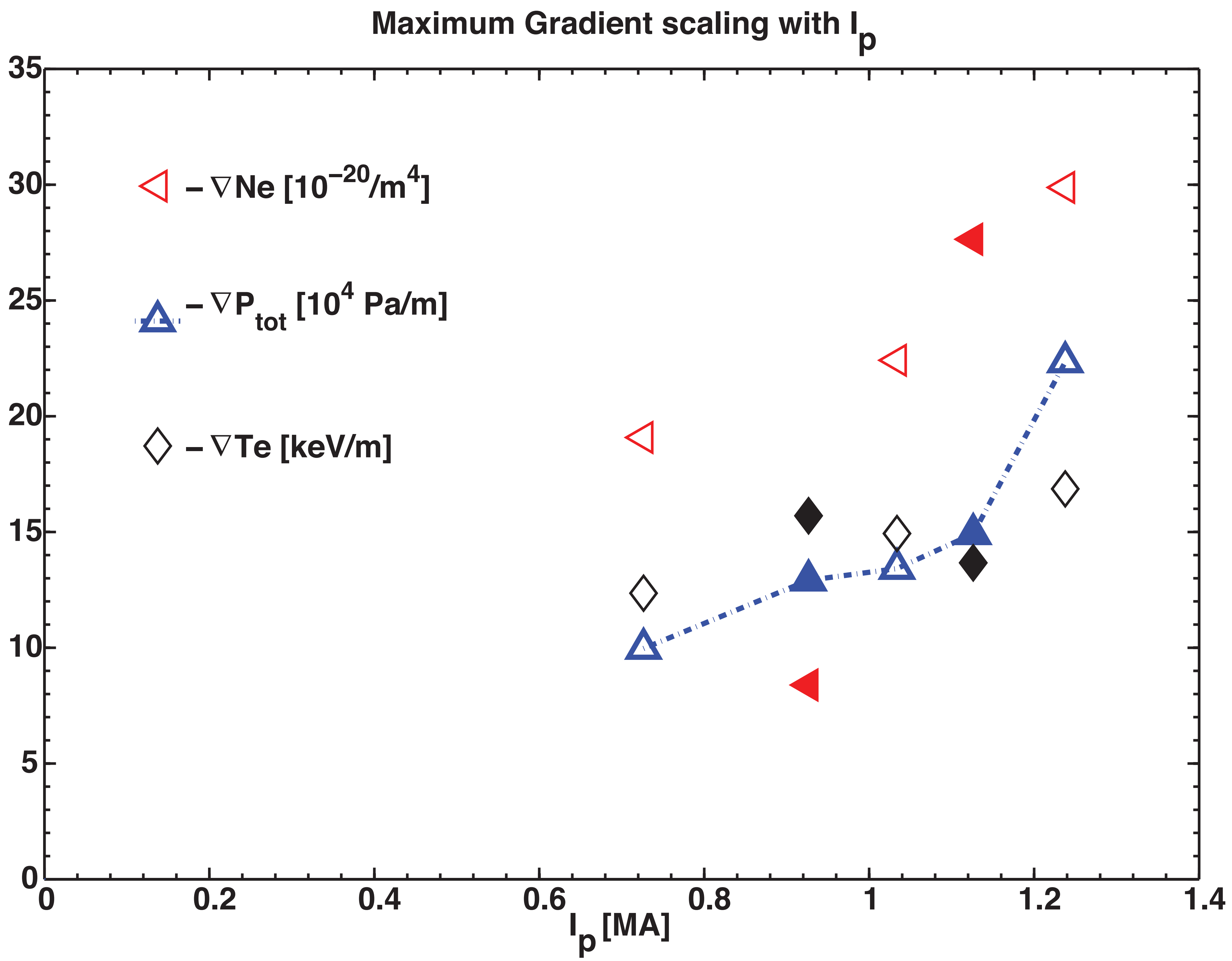

Total Pedestal Pressure at fixed top triangularity

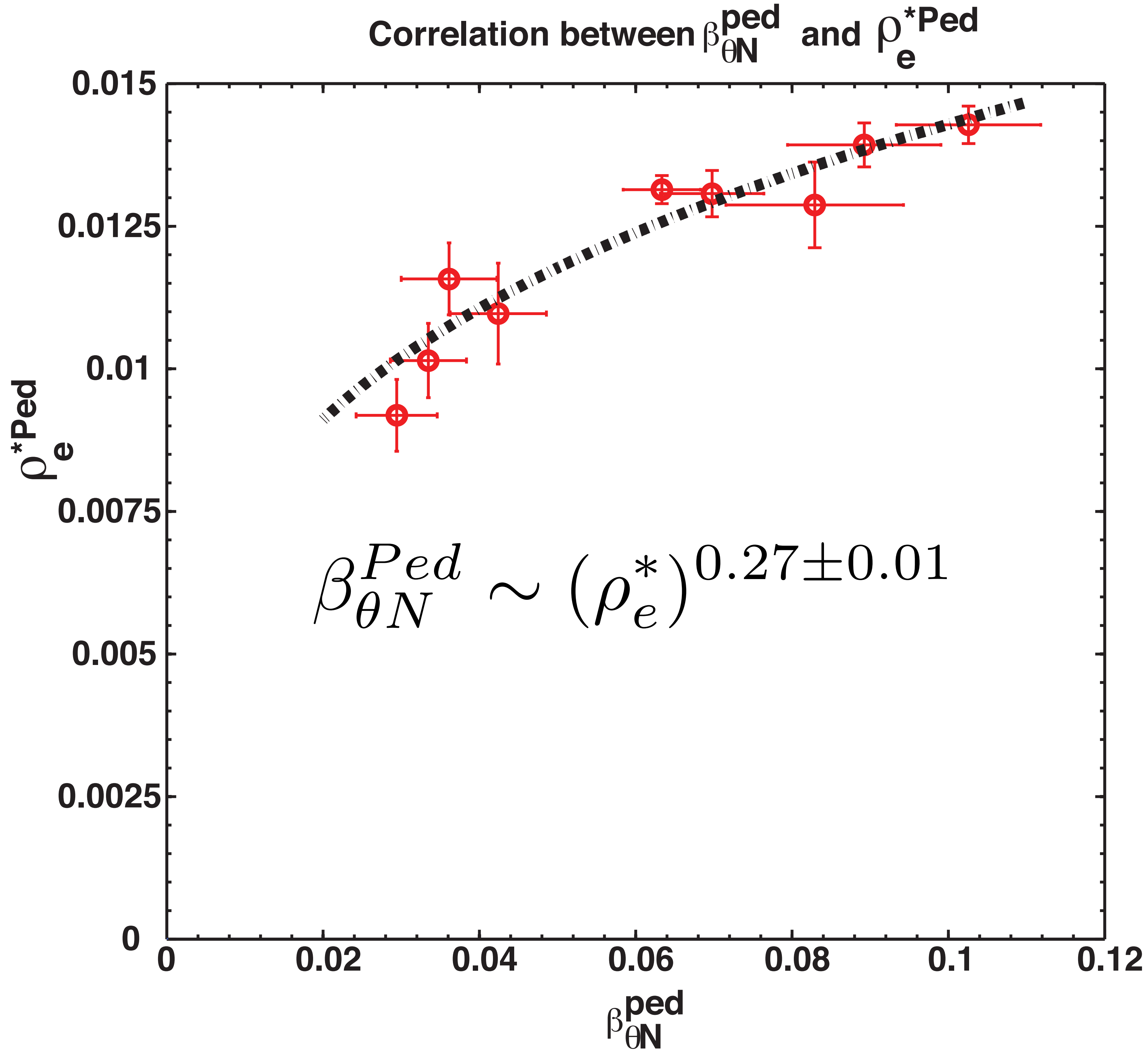

Temperature Profiles during last 50 % ELM cycle at P_{inj} =4MW


Electron Pressure Profiles during last 50 % ELM cycle

- Using the bottom triangularity as a proxy for the shape parameter and keeping all other parameter constant
- Small increase in the density and temperature pedestals
- Clear increase of the pedestal height with bottom triangularity.

Dominant contribution of the density gradient in the critical pressure gradient and weak correlation of the ρ_e^* with normalized beta poloidal

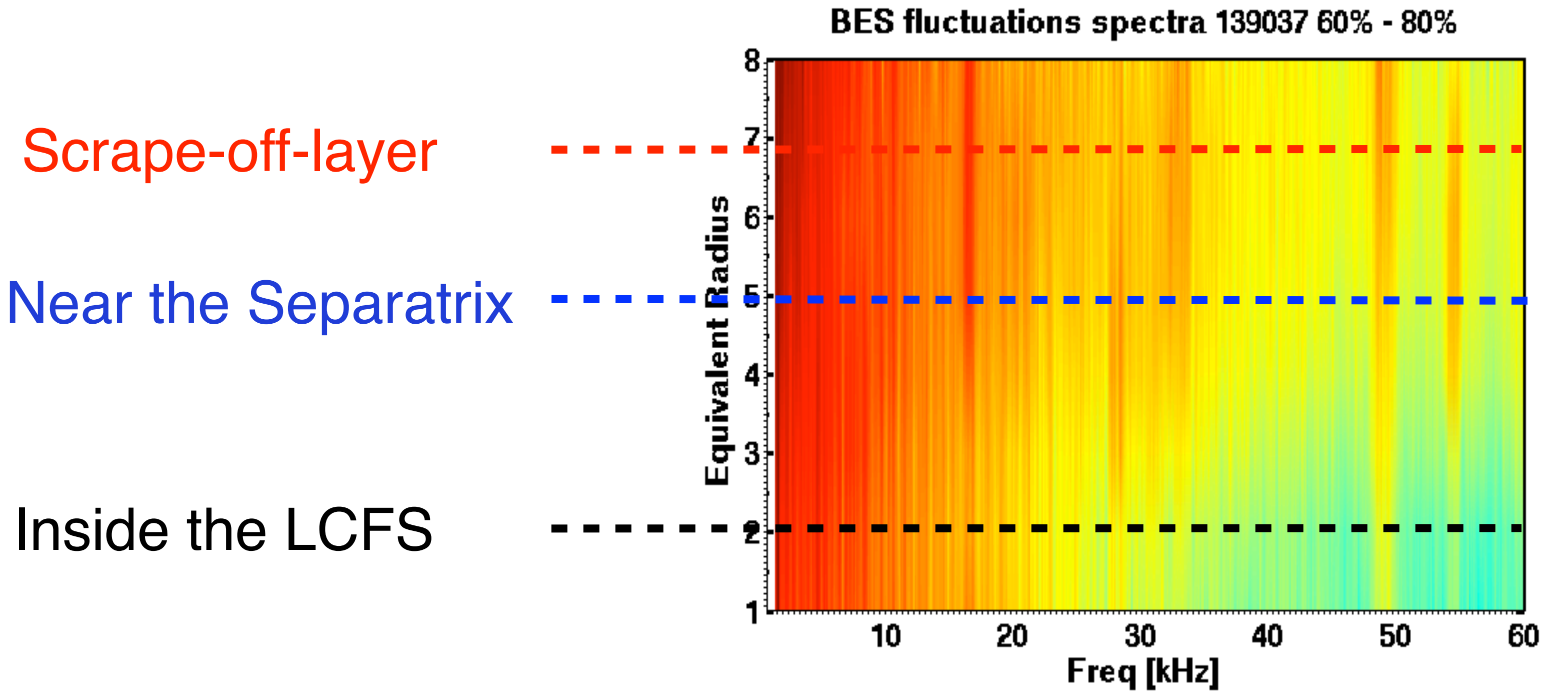


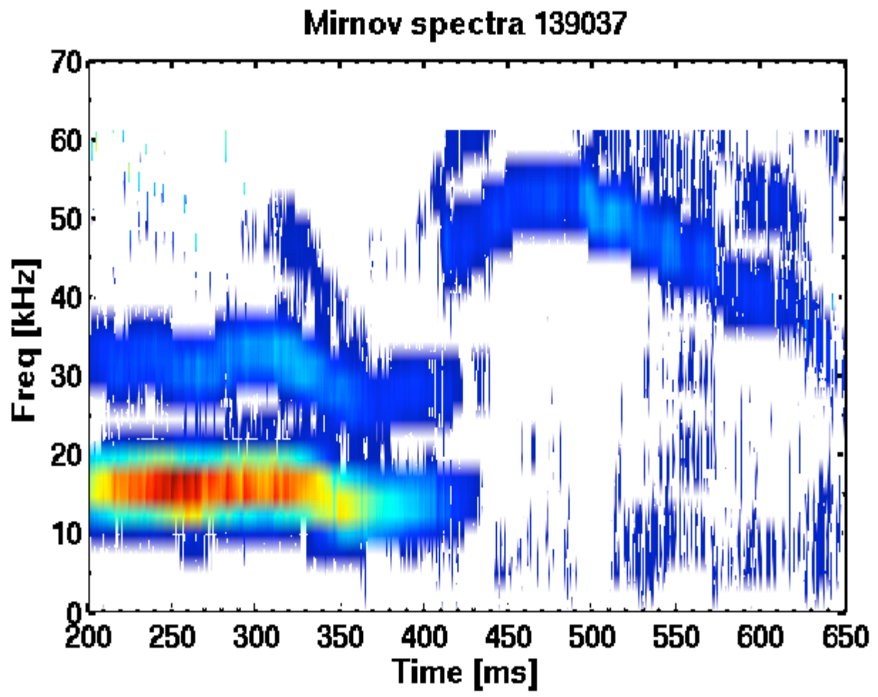


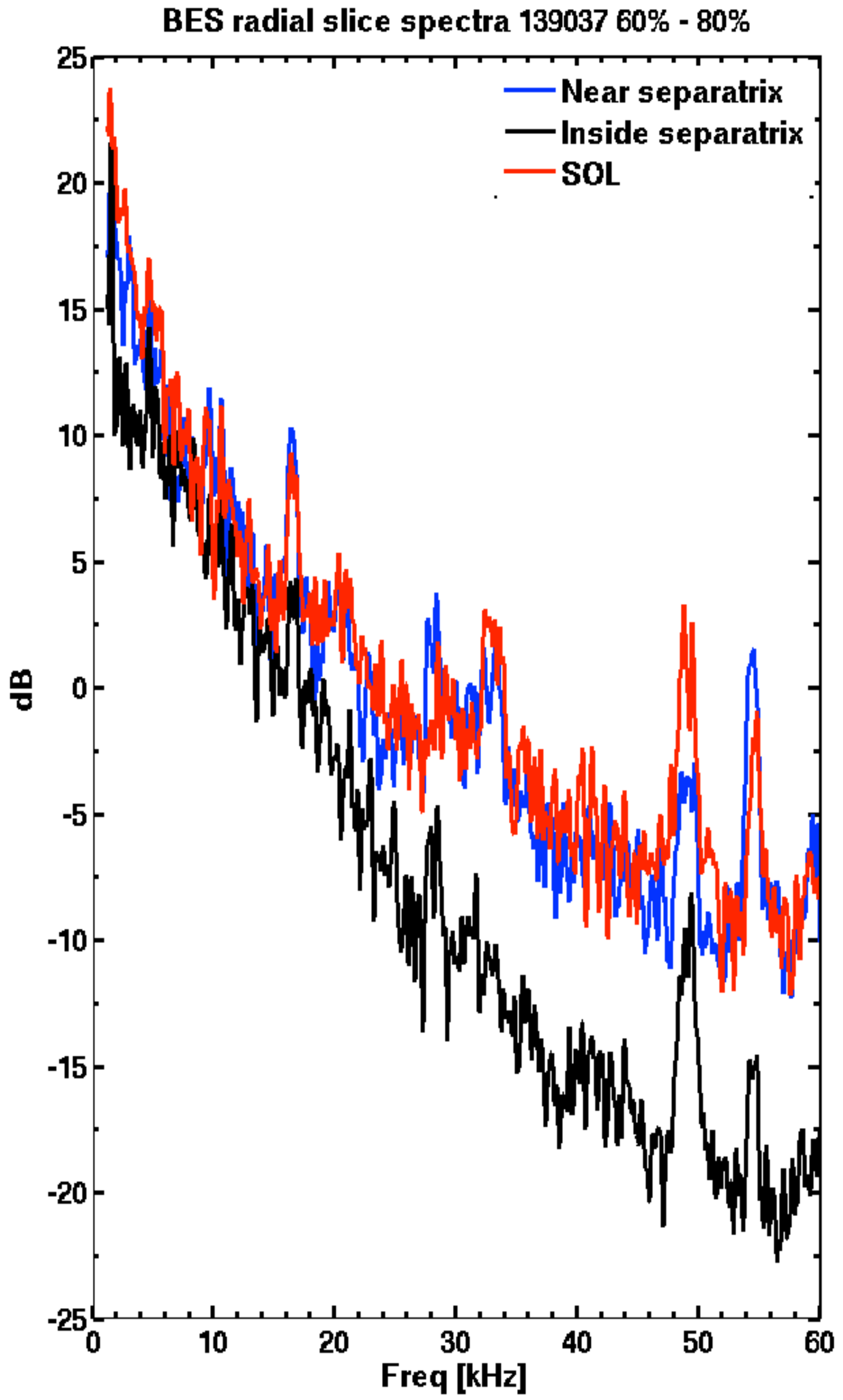
The pressure gradient scales with Ip at constant toroidal field and the density gradient increases much faster than temperature gradient.

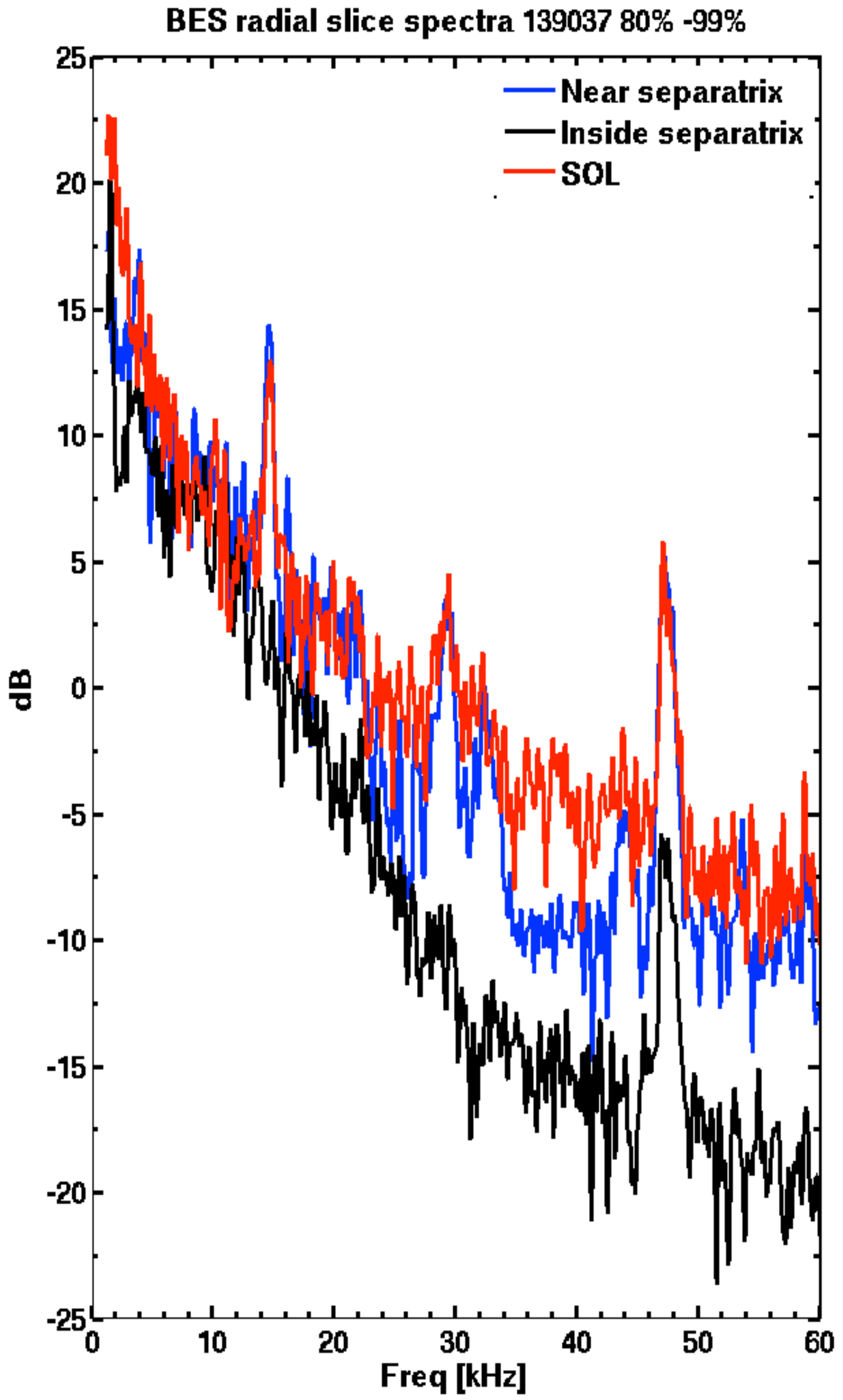
Correlation between the normalized poloidal beta with ρ_e^* evaluated at electron pedestal temperature is weaker than similar scaling in MAST.

Inter-ELM fluctuations from BES indicate generic changes in fluctuations spectra during the ELM cycle but a decoupling of the intrinsic MHD activities is difficult


BES fluctuations spectra 139037 60% - 80%

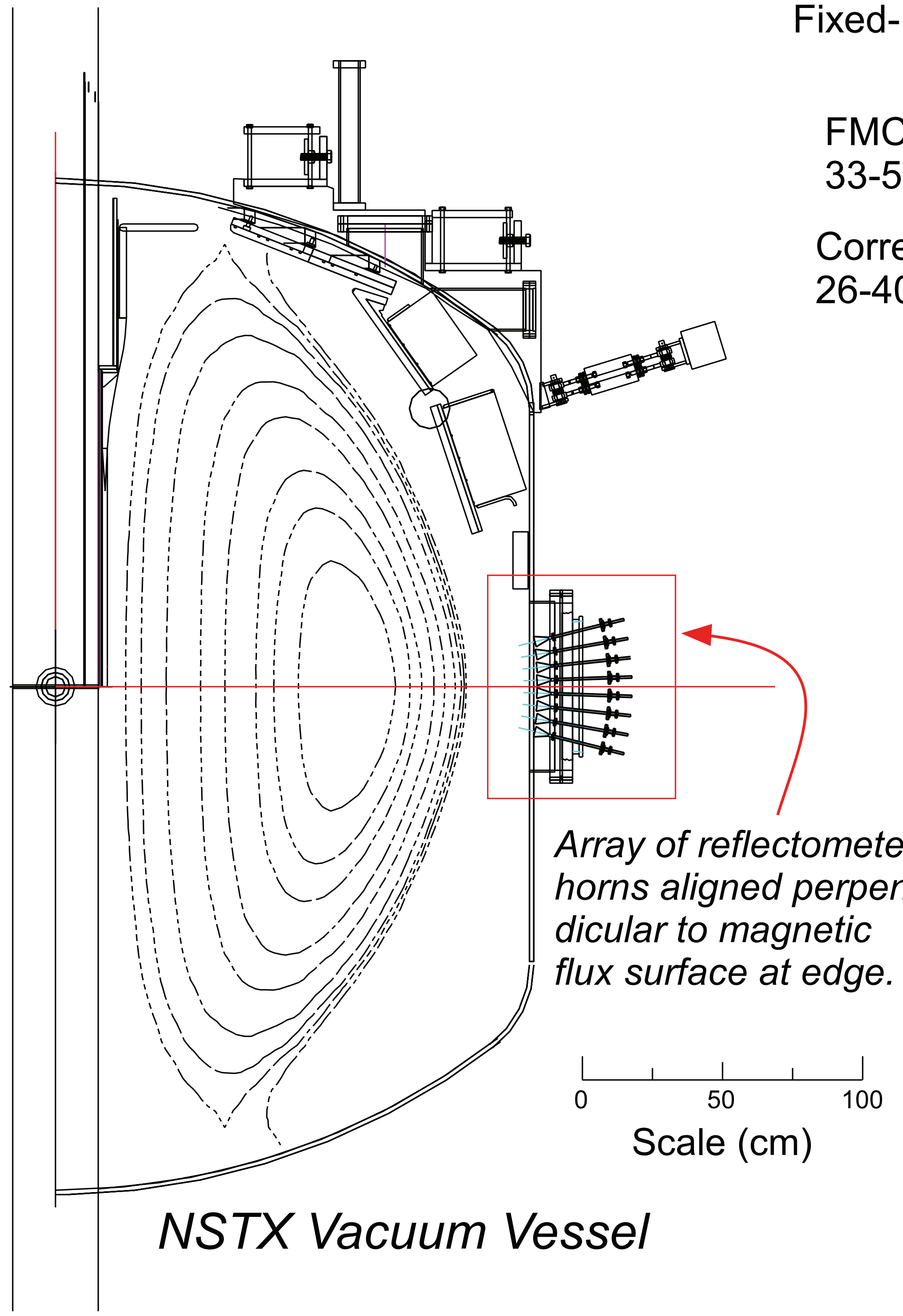

Mirnov spectra 139037

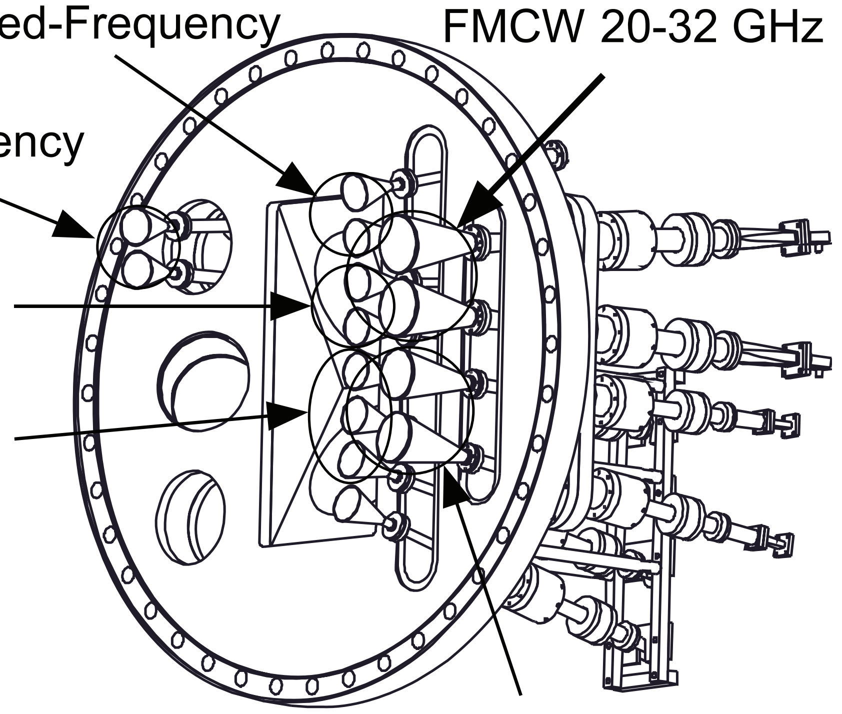

BES radial slice spectra 139037 60% - 80%


BES radial slice spectra 139037 80% -99%

Inter-ELM density fluctuation through BES enables the localization of fluctuation peaks detected on Mirnov coils but no clear signature of modes correlated with the pedestal structure.

Reflectometry to probe density fluctuations at the top of the pedestal during the multiple stages of an ELM cycle





$$\varphi \sim 4\pi/\lambda_0 \int_{R_{ant}}^{R_c} \sqrt{(1 - n_e/n_c)}\mathrm{d}l$$

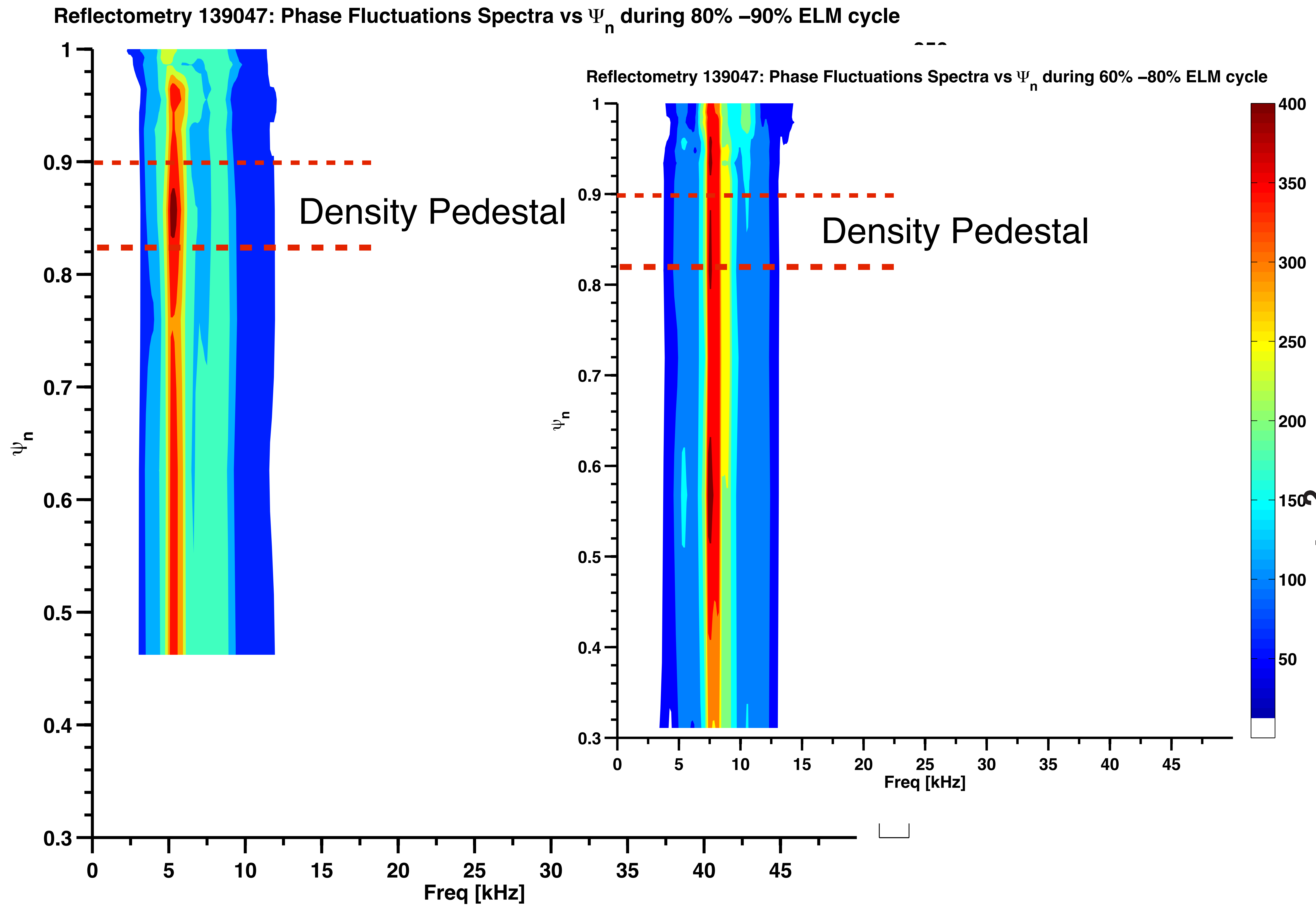
$$\delta\varphi = \varphi - <\varphi>$$

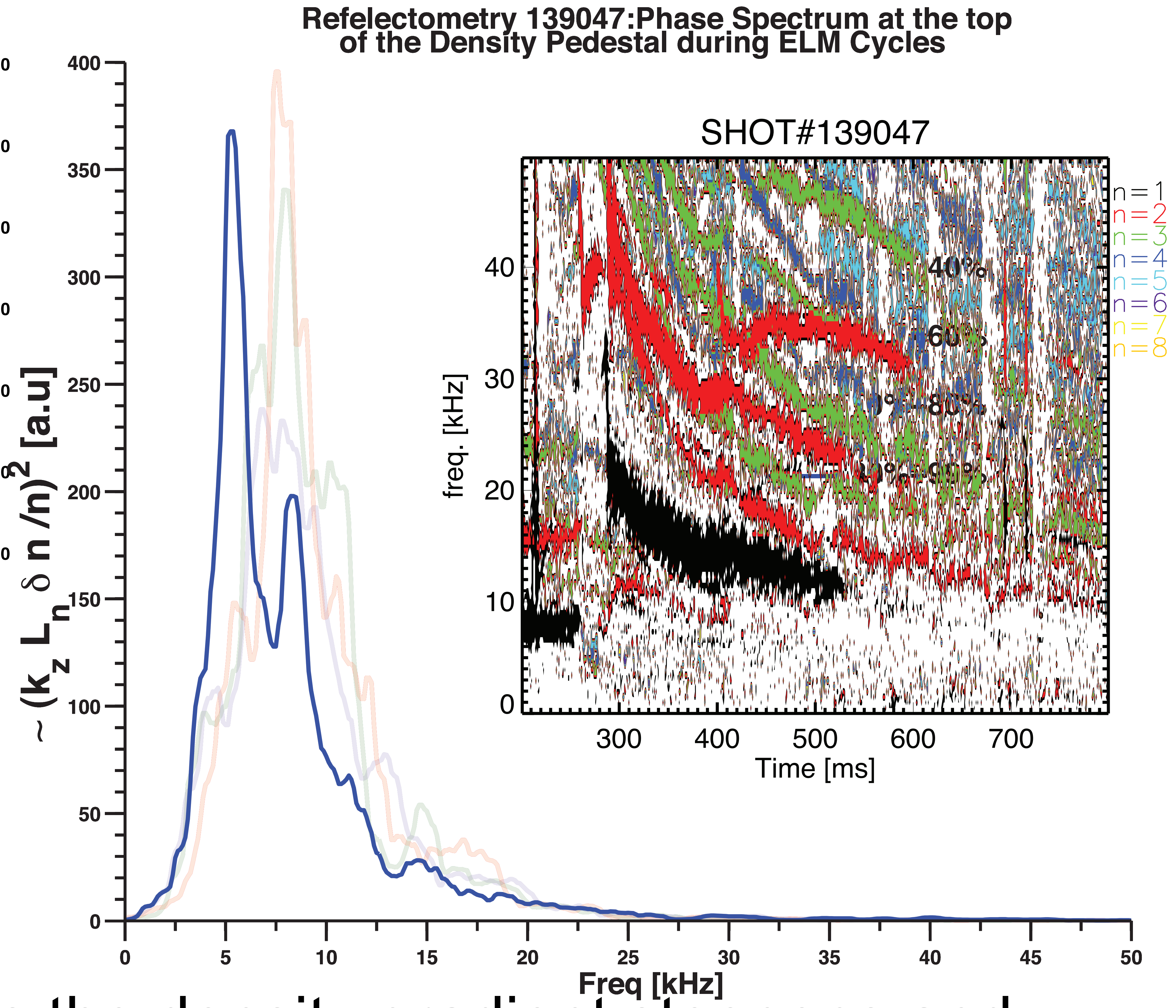
$$\delta\varphi \sim k_0 L_n \frac{\delta n_e}{n_e}, k_z L_n < 1$$

$$\delta\varphi \sim k_0 \sqrt{\frac{L_n}{k_z}} \frac{\delta n_e}{n_e}, k_z L_n > 1$$

- Phase excursion originates from deviation of the cutoff radial position or from the change in electron density.
- Phase fluctuations provide direct access to density fluctuation near the edge of the plasma during the ELM cycle

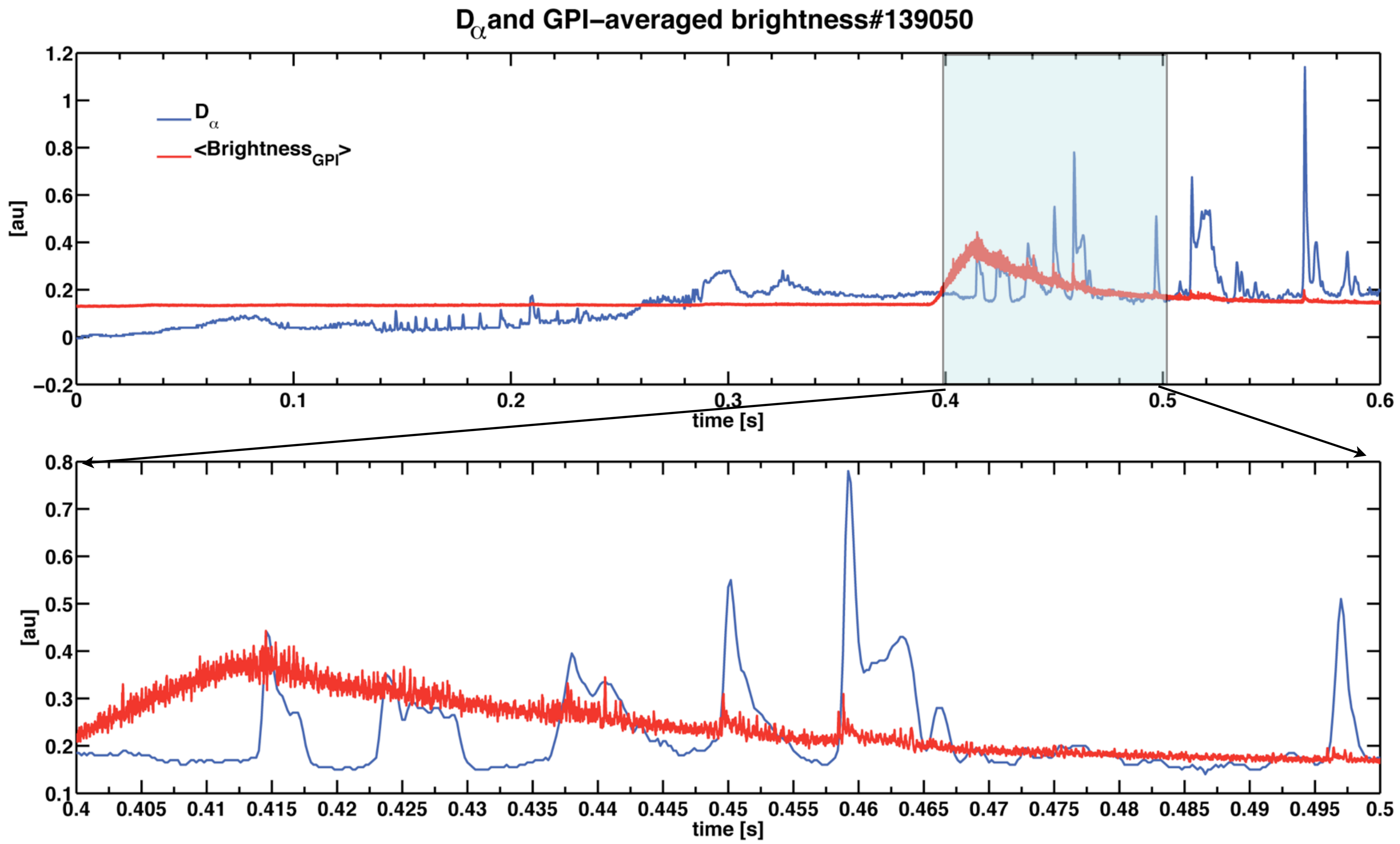
Mapping the reflectometer signals to normalized flux coordinates allow for better targeting of density fluctuation at the pedestal top

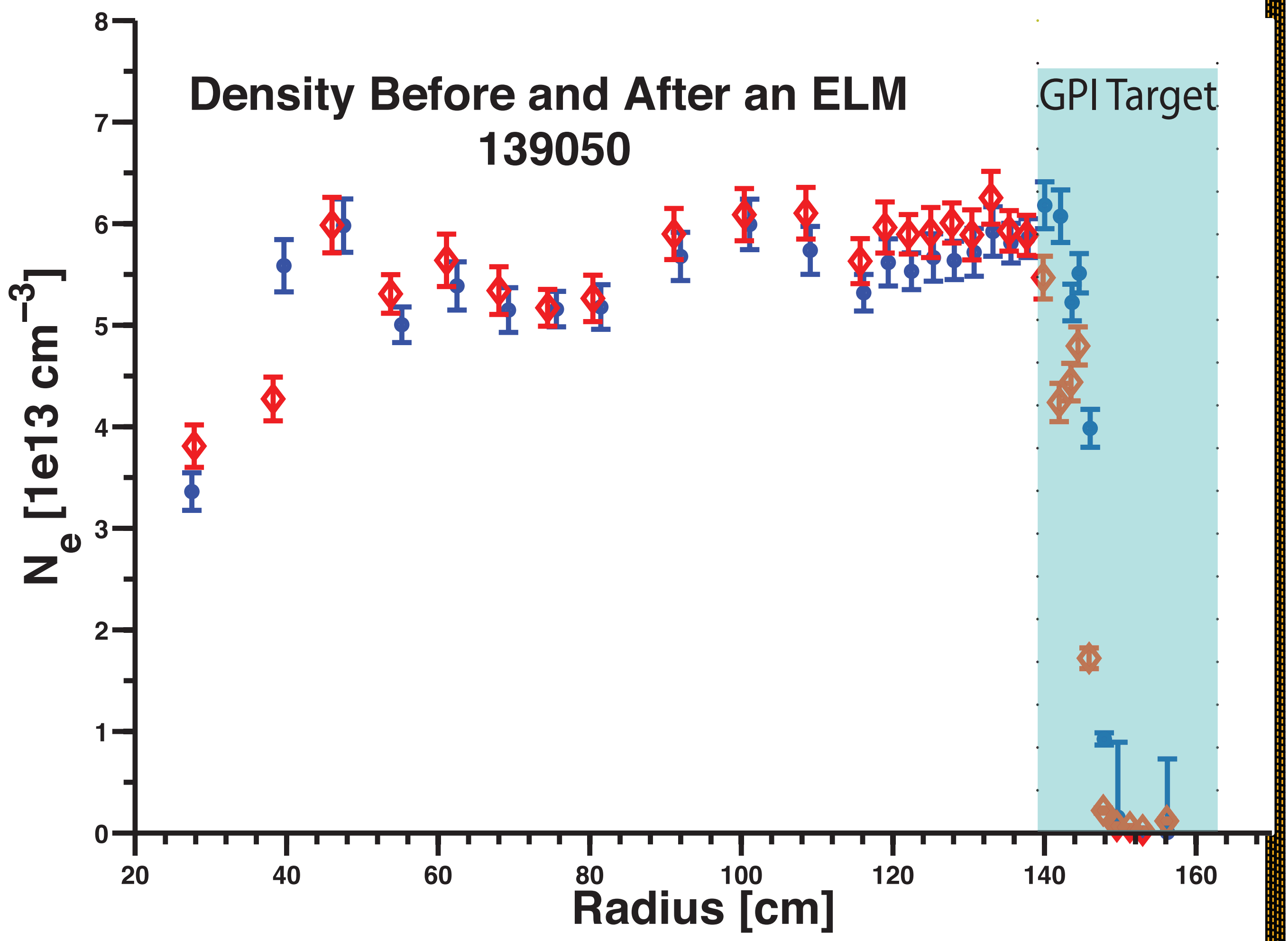


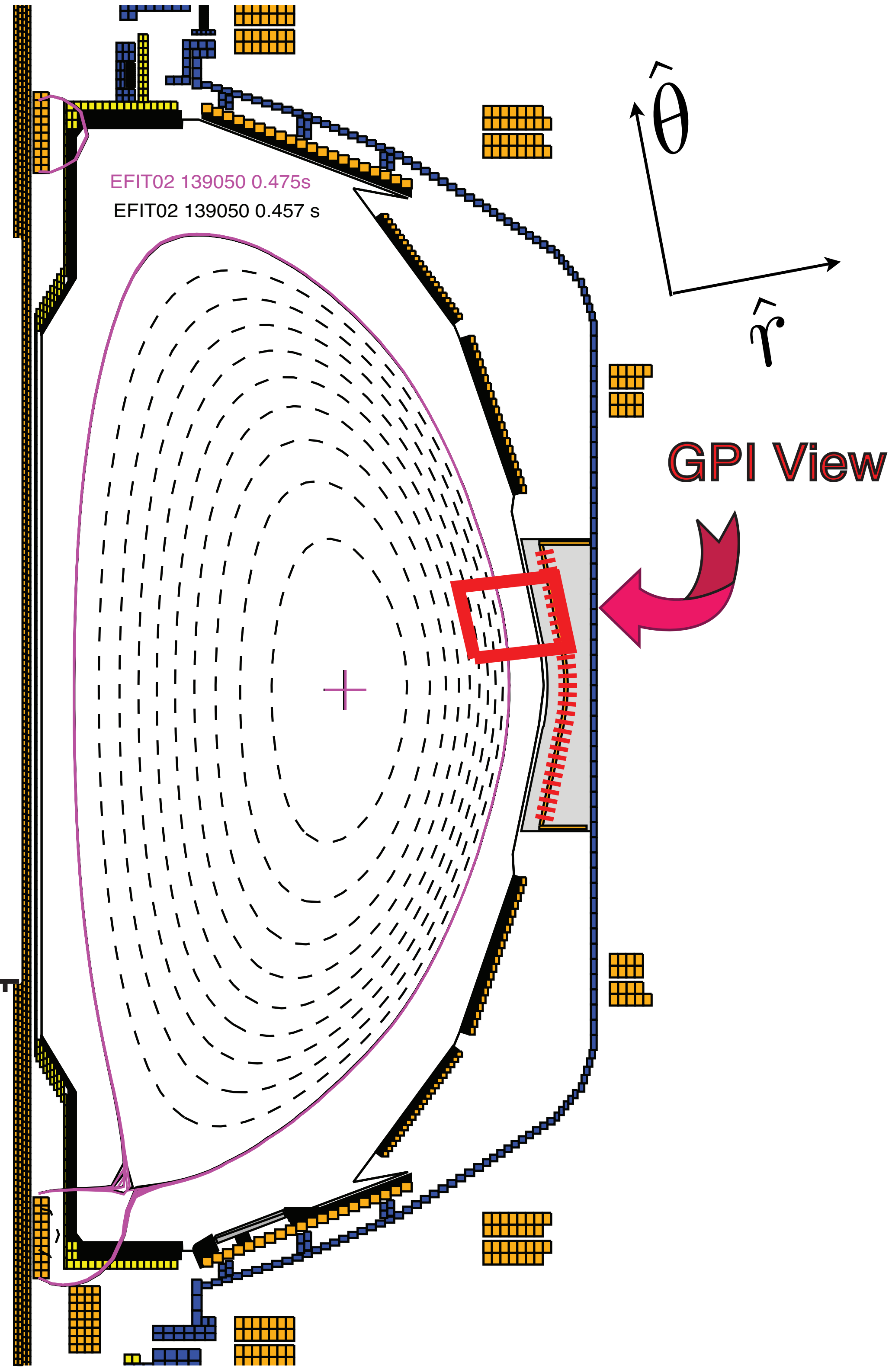


- Density fluctuations span a smaller region as the density gradient steepens and peak at the top pedestal.
- Observation of low frequency electrostatic mode competition during an ELM cycle.

Gas-Puff Imaging as a tool to extract velocity fluctuations near the top of the pedestal during an ELM cycle







GPI brightness profile coincides with the region of largest density gradient providing velocity fluctuation information at edge of the plasma.

Assuming the advection of the GPI brightness the velocity fluctuations can be determined.

Using the transformation of the brightness I to advected coordinate $(\hat{\xi}, \hat{\eta})$

$$\tau \mapsto t$$

$$\xi \mapsto r$$

$$\eta \mapsto r(1 \pm t\tfrac{\partial V_0}{\partial r})$$

$$\widehat{\theta} \times \widehat{r} = \widehat{\varphi}$$

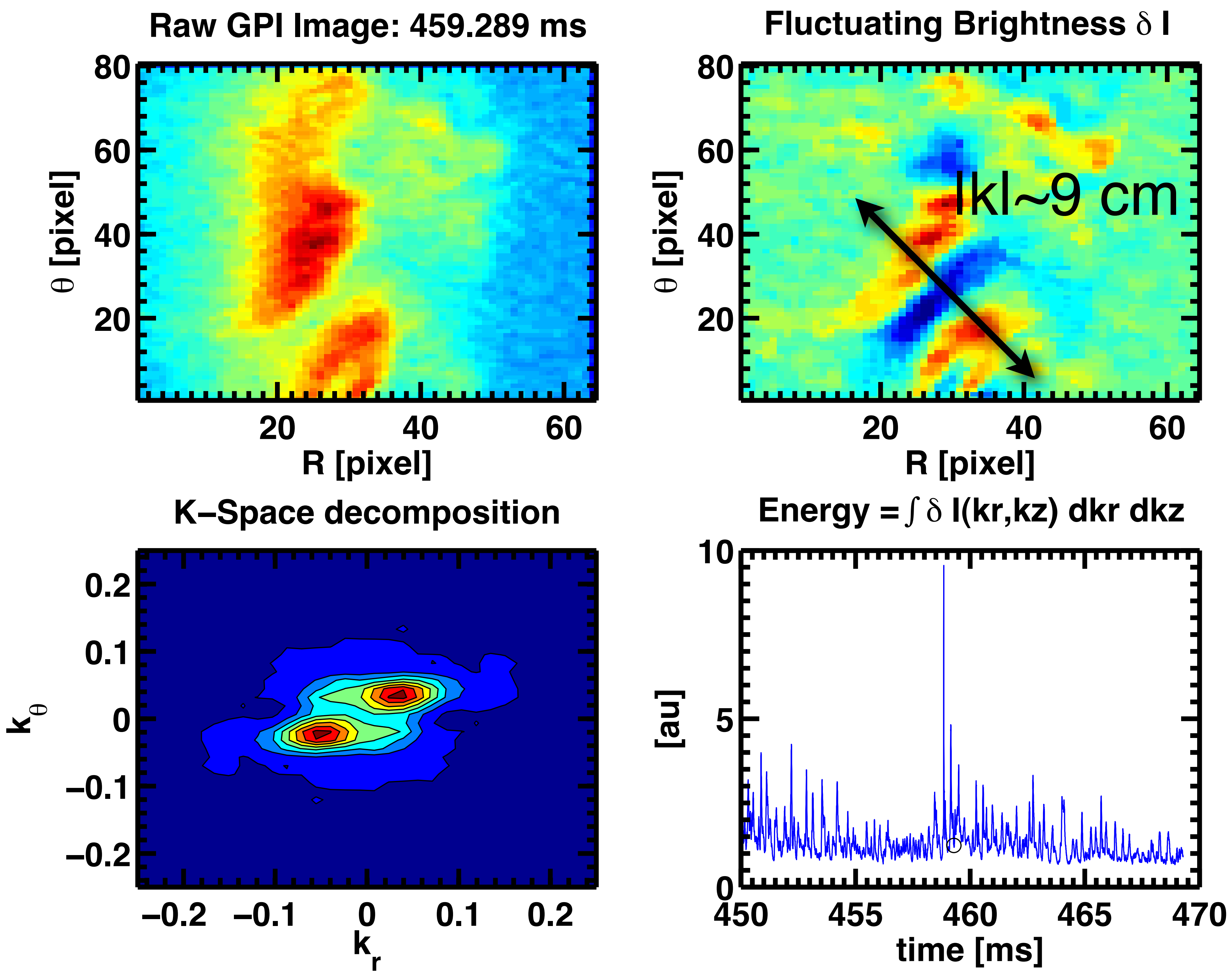
The solution of the advected diffusion equation can be written as:

$$I(\xi,\eta,\tau) = \tfrac{1}{(2\pi)^2} \int \int dk_\xi dk_\eta \widehat{I}_{\mathbf{k}}(\tau) e^{i(k_\xi \xi + k_\eta \eta)}$$

$$\frac{d\widehat{I}_{\mathbf{k}}}{d\tau} = \mu \underbrace{\left[(k_\xi \pm \frac{\partial V_0}{\partial r} k_\eta)^2 + k_\eta^2 \right]}_{\mathbf{k}^2} \widehat{I}_{\mathbf{k}}$$

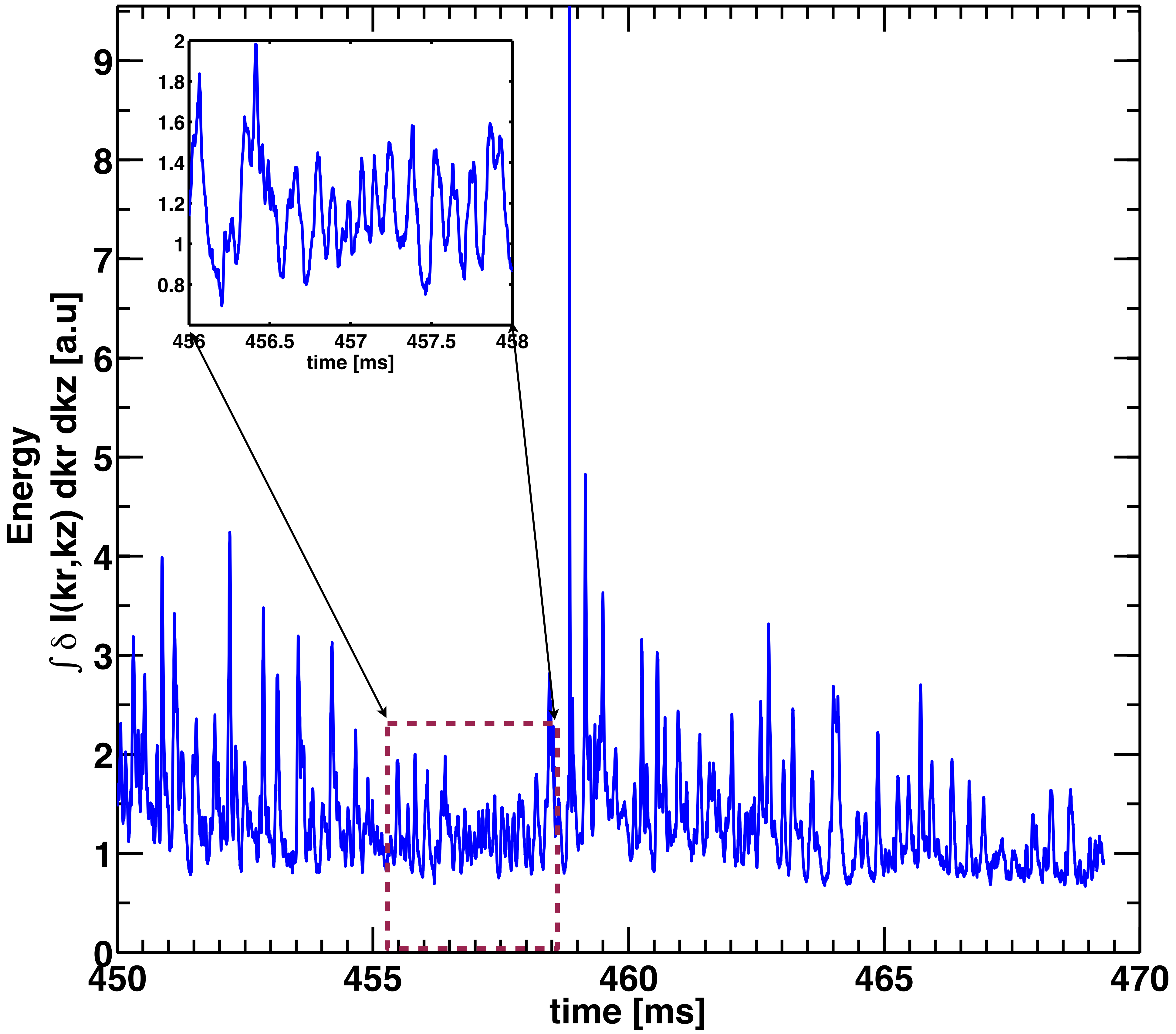
Assuming or invoking an oscillatory flow of the type $\frac{\partial V_0}{\partial r} rcos(\omega\tau)$

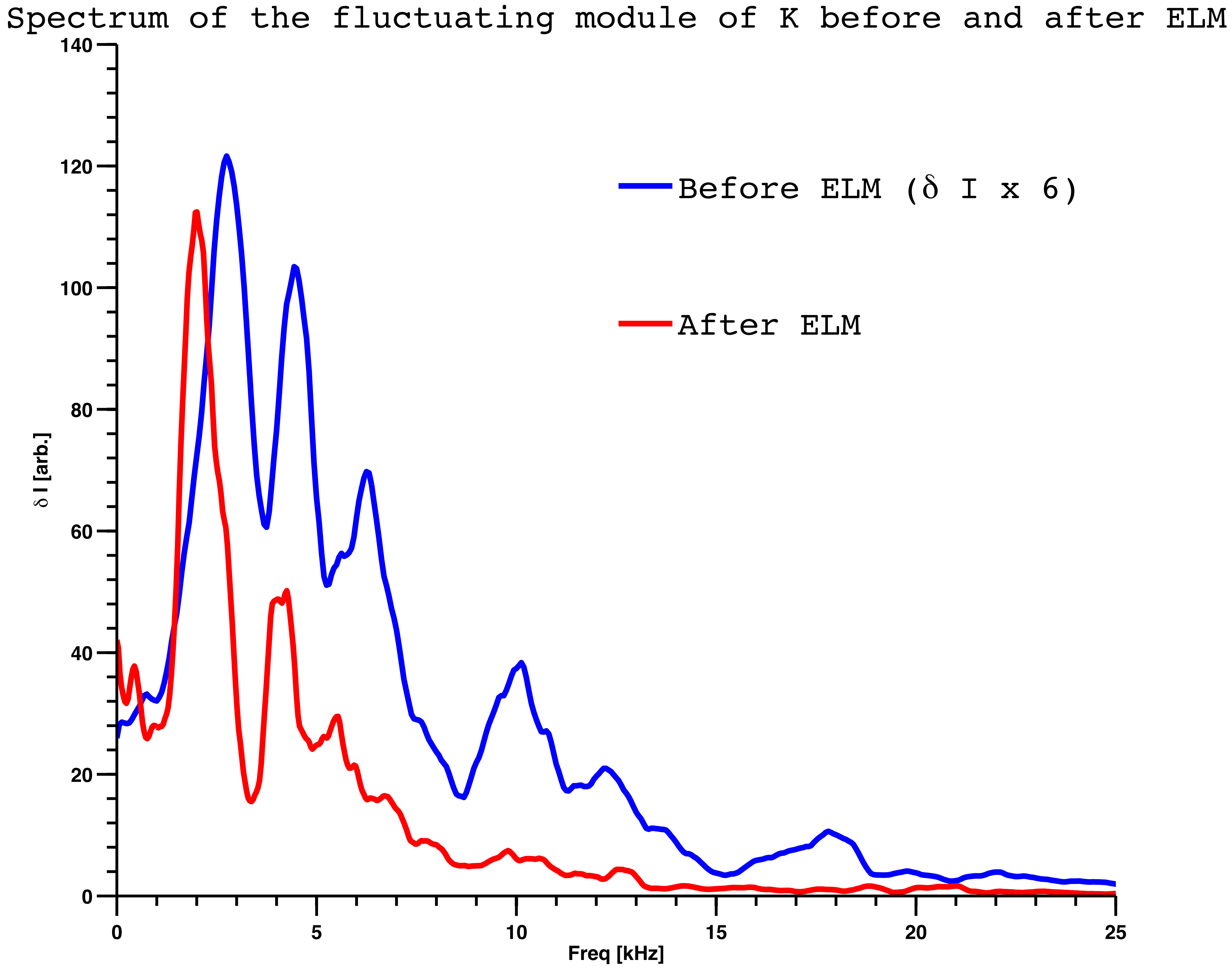
$$\mathbf{k} = \sqrt{(k_\xi \pm \tfrac{\partial V_0}{\partial r} k_\eta \tau \sin(\omega\tau)/(\omega\tau))^2 + k_\eta^2}$$



Oscillatory velocity fluctuations pave the way for fluctuation-induced particle transport at the edge of the plasma analysis.

Evolution of mod k before and after an ELM




Spectrum of the fluctuating module of K before and after ELM

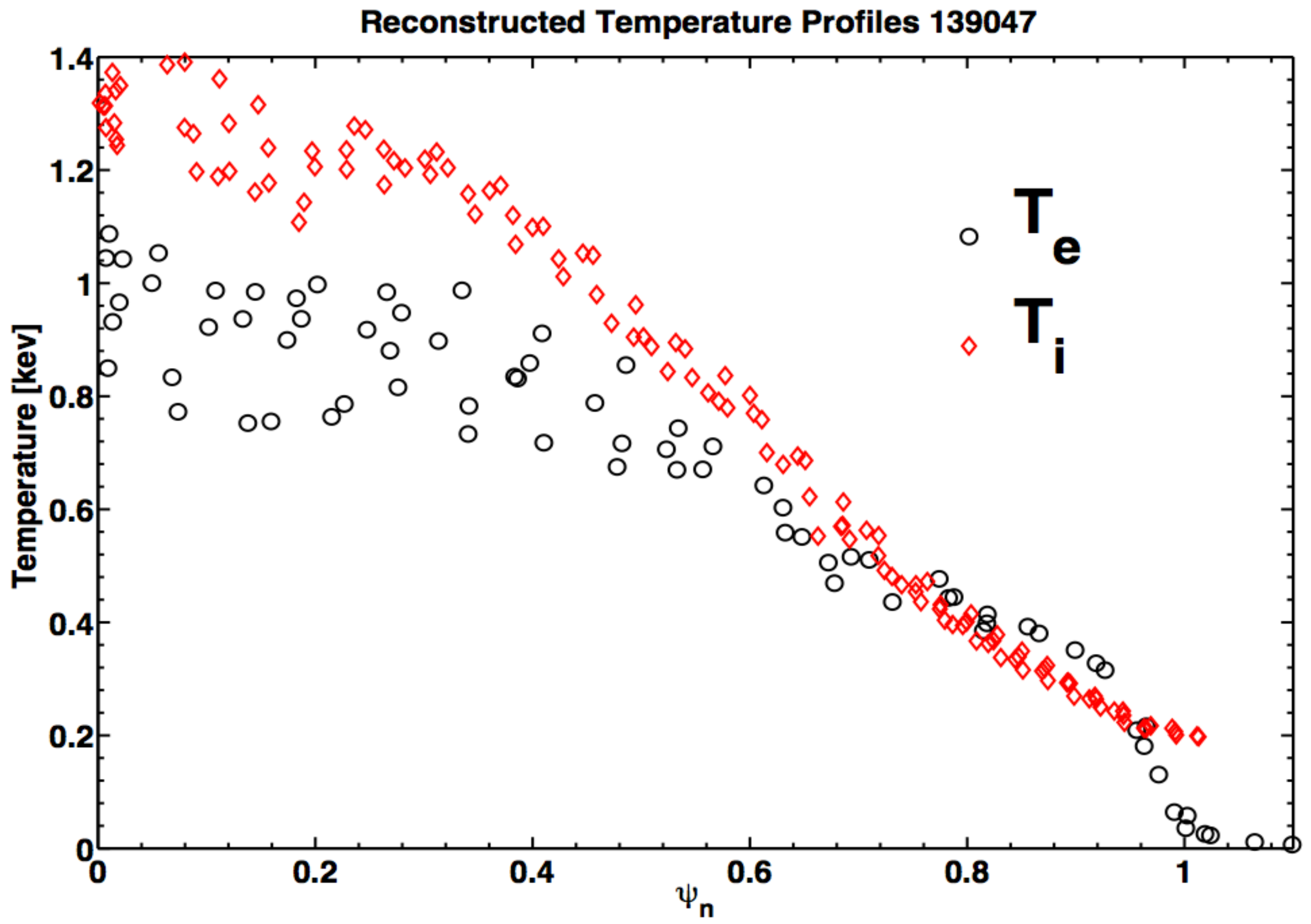
Clear intensification of GPI brightness fluctuations and decrease of the frequency at fixed edge toroidal velocity after ELM crash: this is consistent with the widening of the pedestal width after an ELM crash

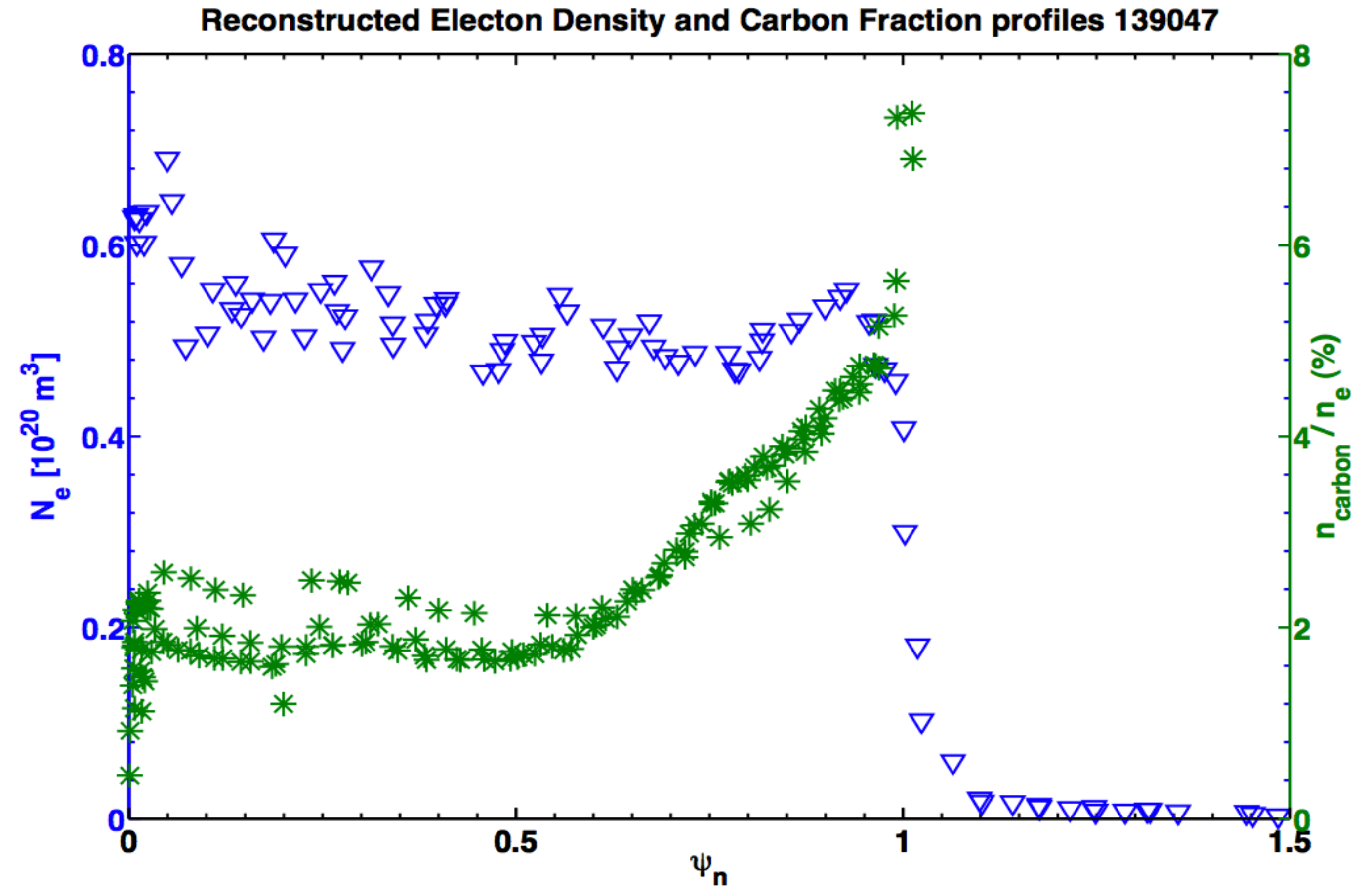
Summary and future directions

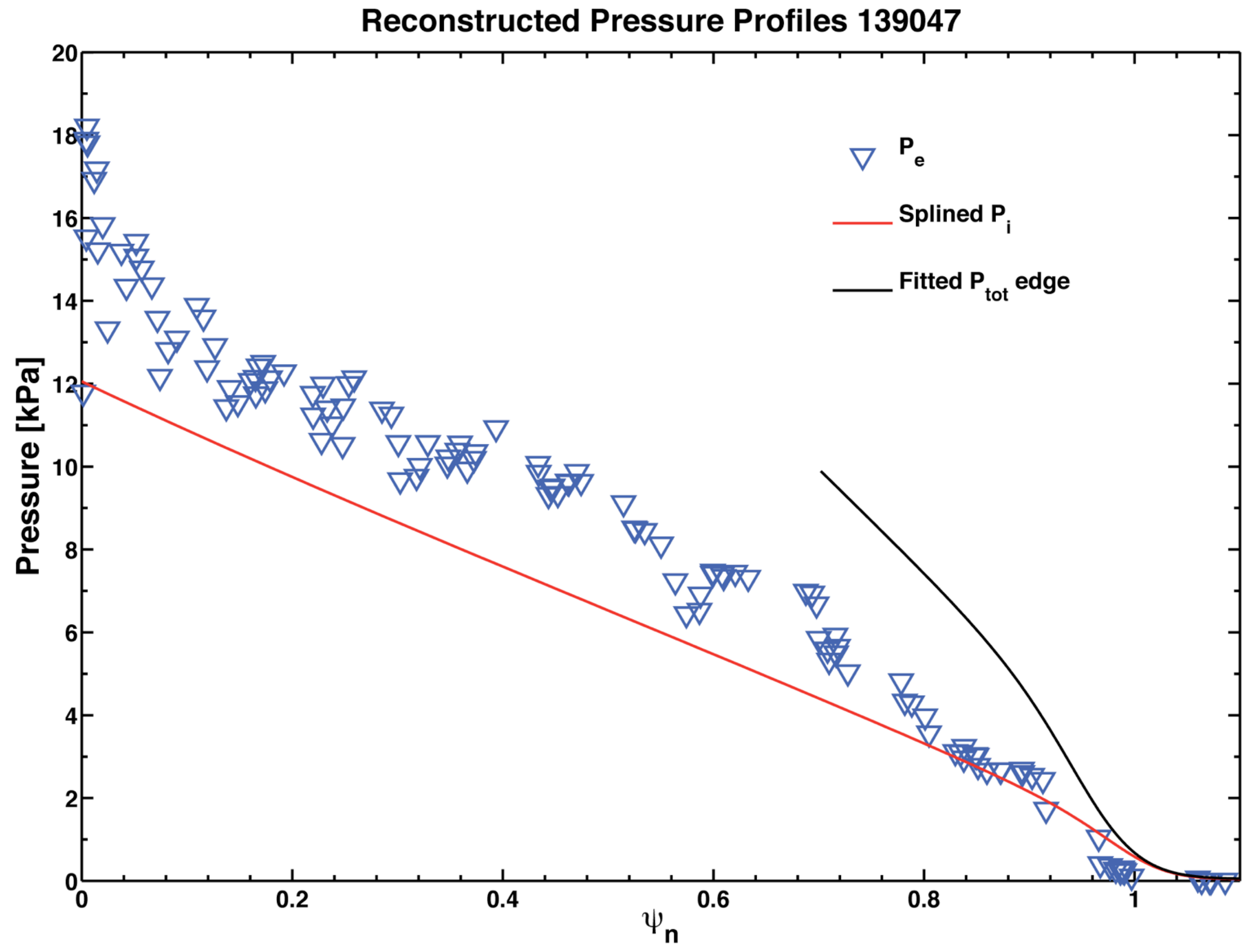
- Observation of a clear Ip scaling with pedestal height consistent with ITER98 scalings.
- Obtained a scaling of the pedestal height with triangularity.
- Demonstration of the pedestal pressure buildup during an ELM cycle with no clear saturation suggesting that transport is a key ingredient.
- Evidence of weak correlation between rhos and the normalized poloidal beta can be translated to a minimal link between pedestal height and width
- Inter-ELM fluctuations analysis applied to density and velocity can help unfold the fluctuation-induced particle transport at various stages of the ELM dynamic.
  - Stability analysis are slated to be performed (ELITE, PEST).
  - The role transport in pedestal structure during the multiple stages of the ELM.
  - Additional Thomson scattering resolution to improve the pedestal region measurements.

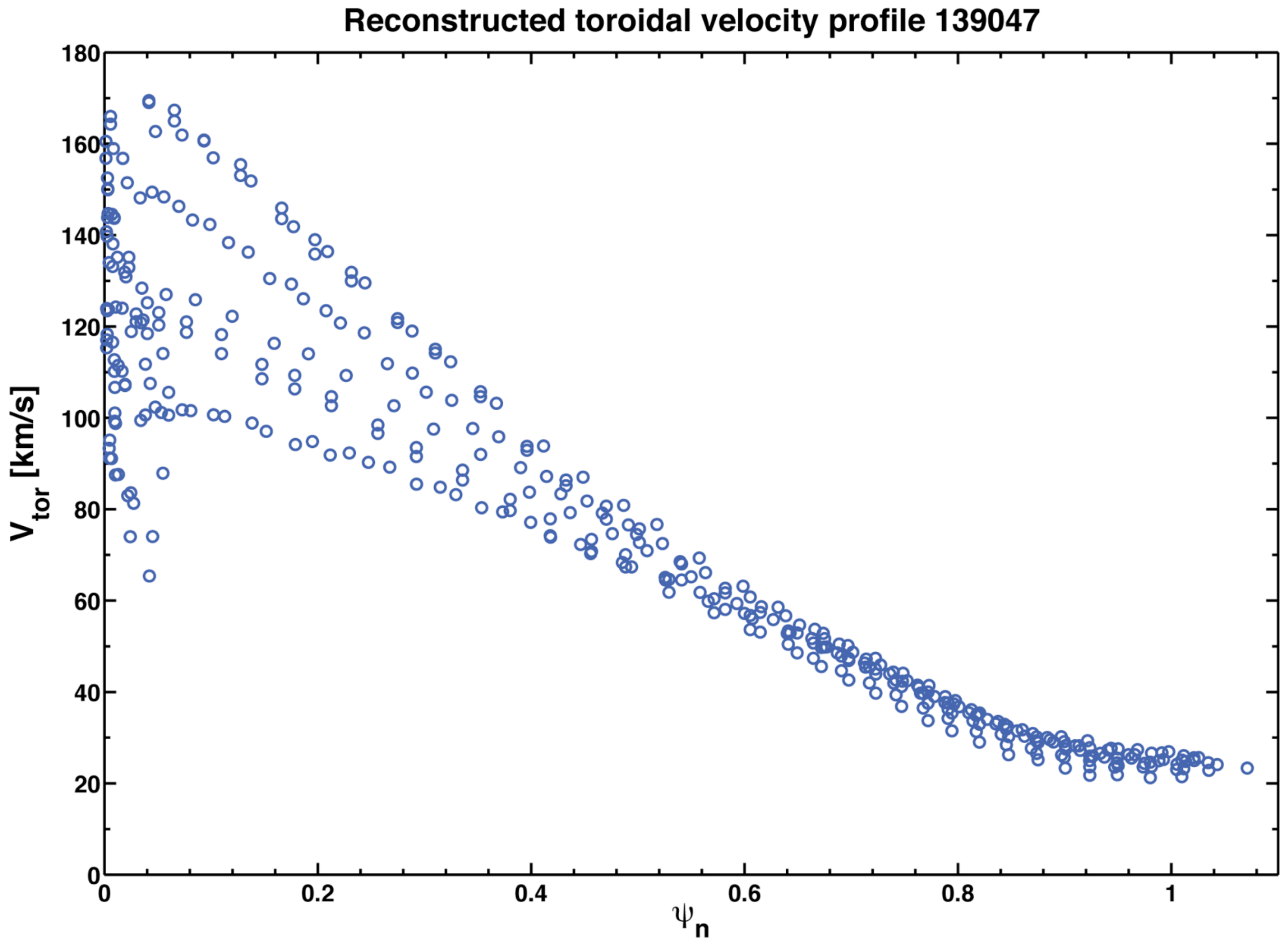
Backup

Reconstruction of key plasma parameters during inter-ELM phase using conditionally sampled radial profiles enhances the gradient region


Reconstructed Temperature Profiles 139047

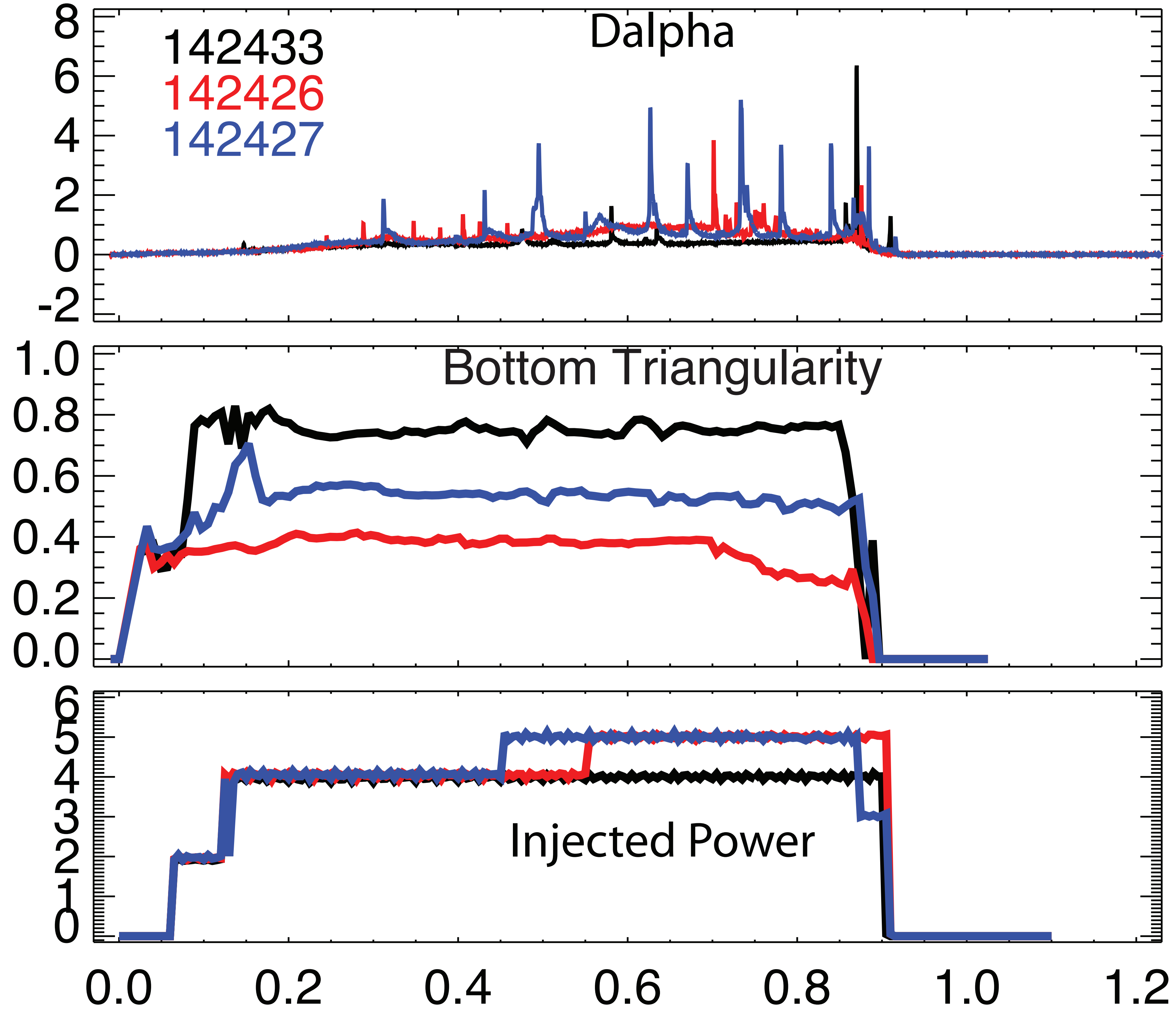

Reconstructed Electon Density and Carbon Fraction profiles 139047

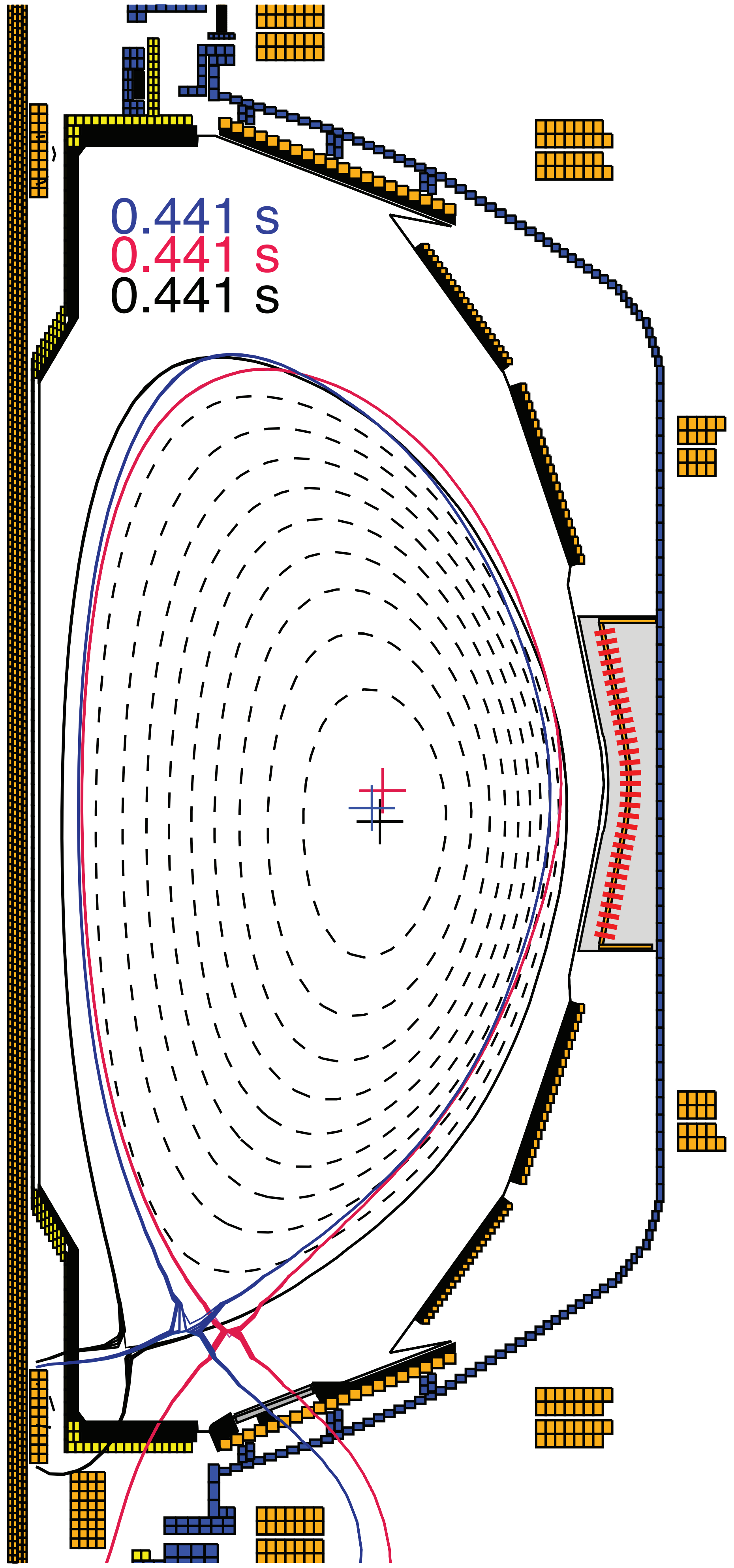

Reconstructed Pressure Profiles 139047


Reconstructed toroidal velocity profile 139047

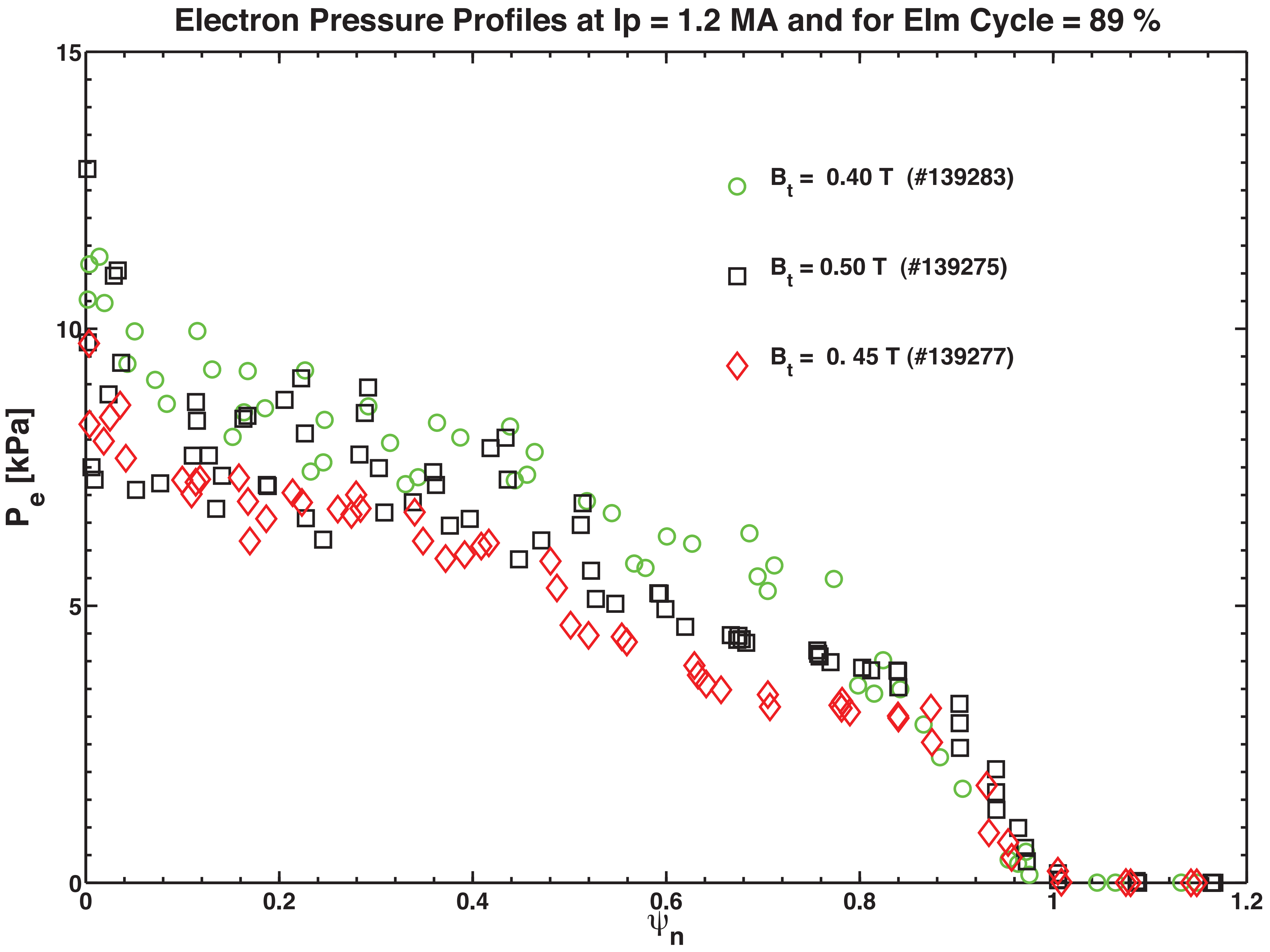
- The reconstruction assumes the same physics at the onset of each ELM, which in this case is the peeling-ballooning instability.
- The low data scattering at the edge indicates that the conditionally sampling procedure is an adequate approach for that region.
- For the investigation of the scaling with Ip, systematic errors can be neglected.

Characteristic discharges



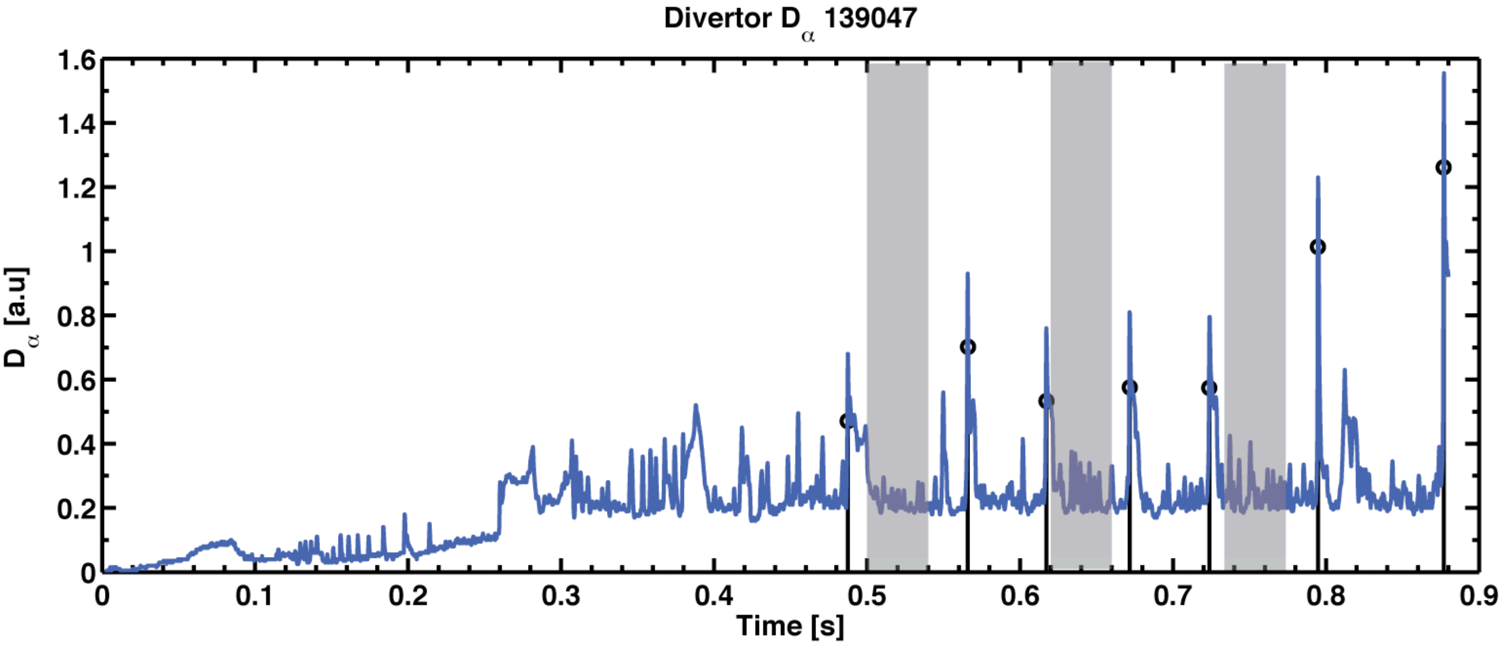


Scaling of the pedestal structure with toroidal field

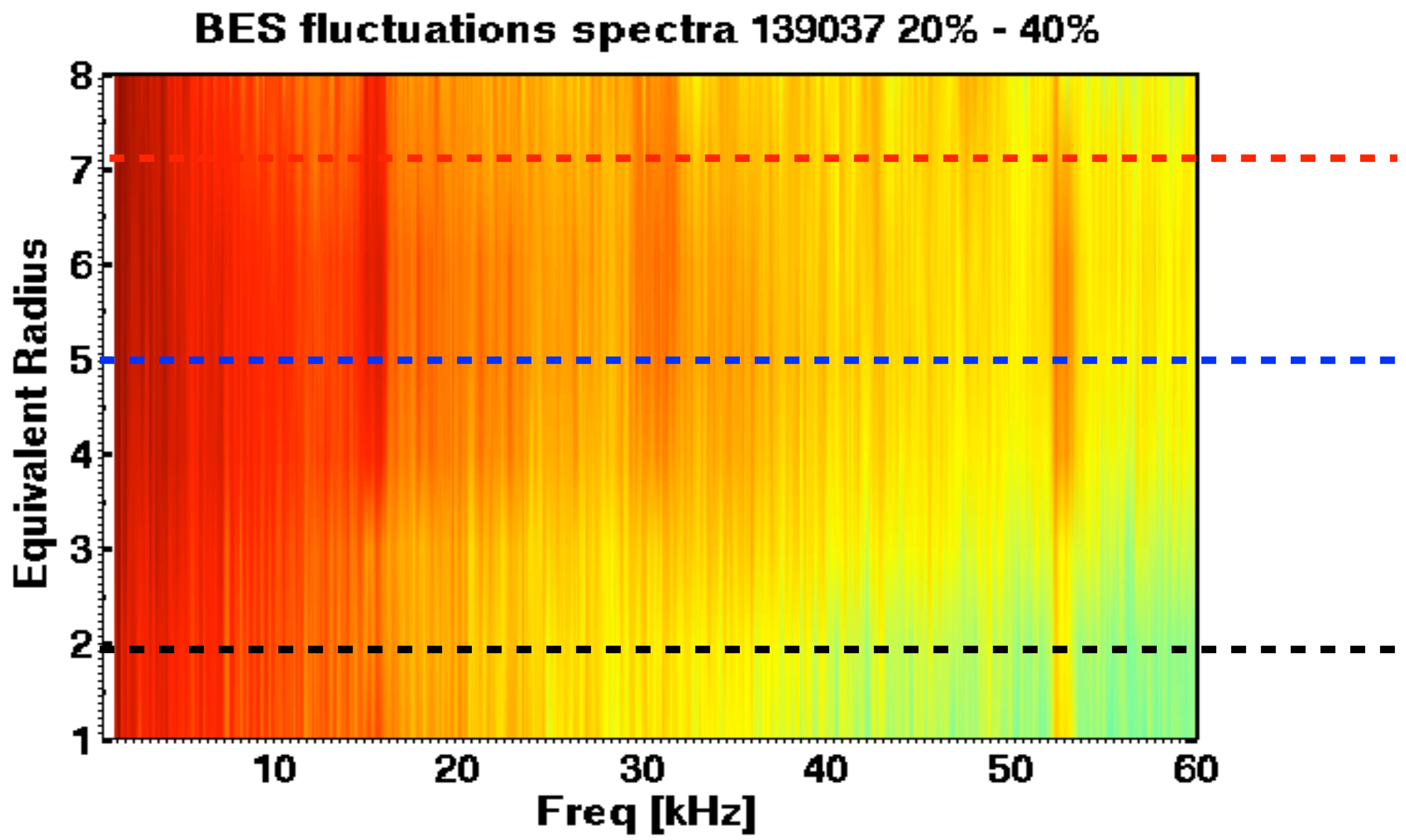


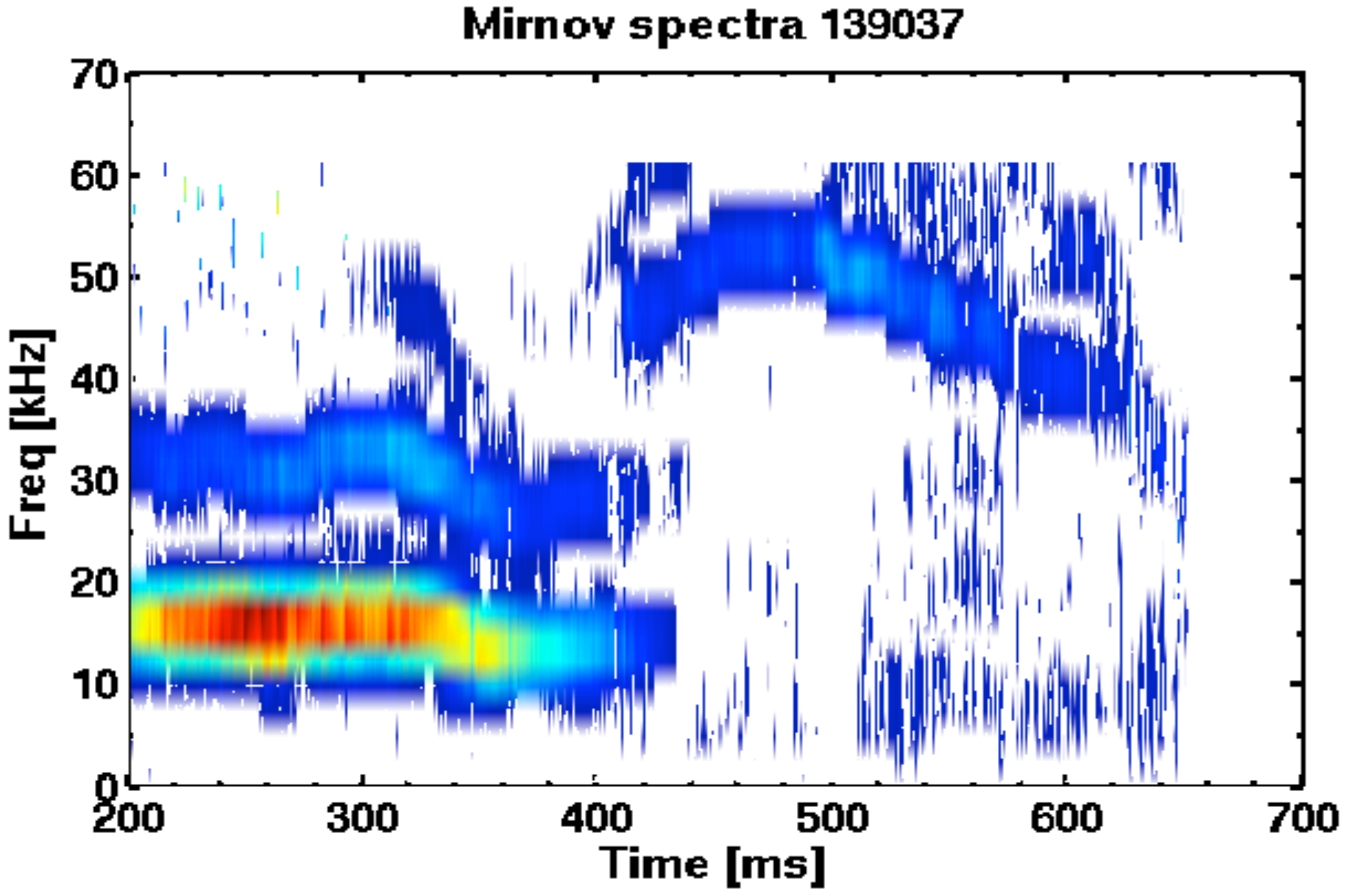
- –We performed a toroidal field scan at high plasma current to be close to the stability limit.
- –We observe no clear scaling of the pedestal height with magnetic field.
- –The electron pressure gradient increases with toroidal field suggesting potential correlation with the pedestal width.

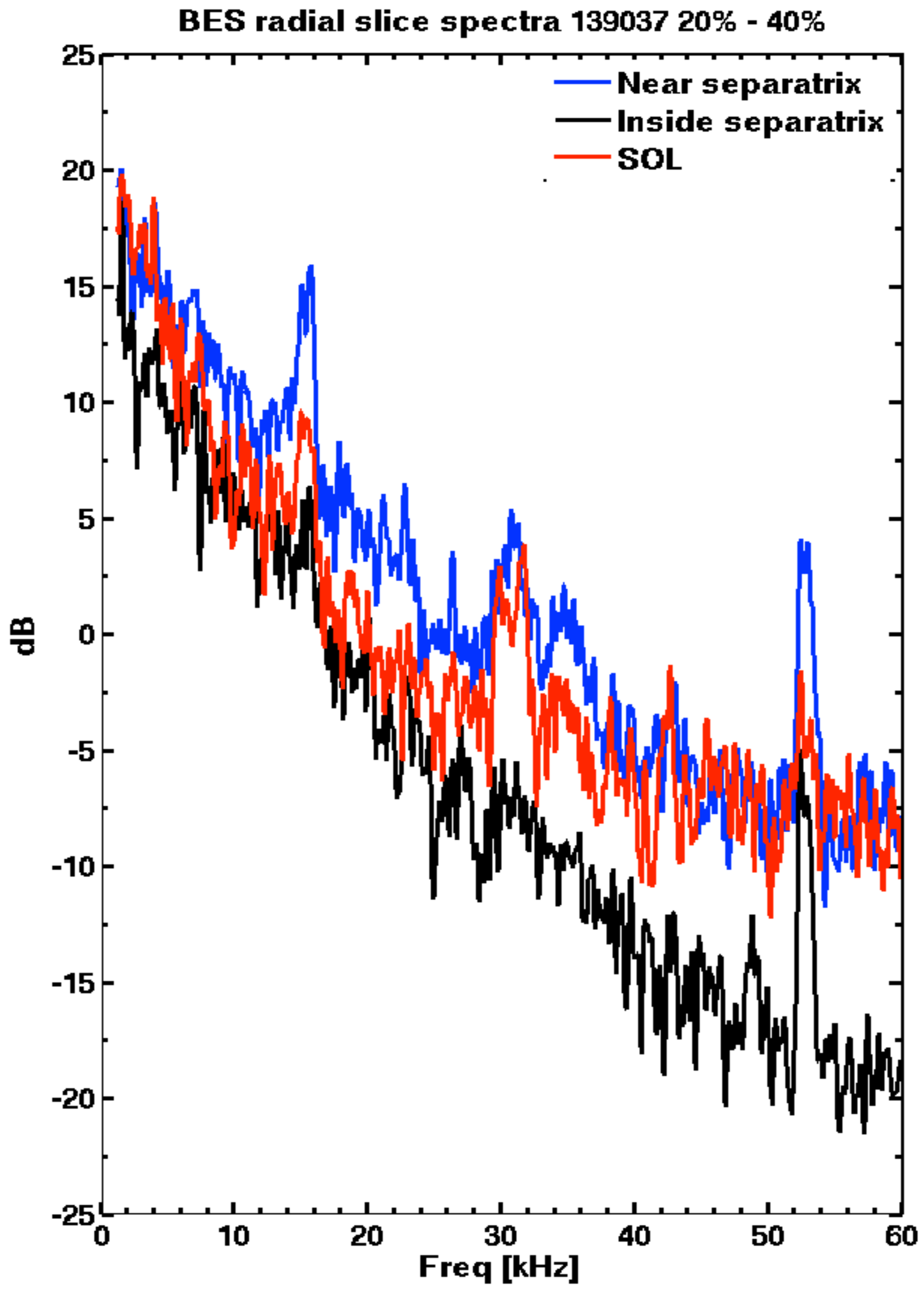
Preliminary Investigation of Inter-ELM fluctuations in search of an obvious mode: BES indicates generic changes in fluctuations spectra during the ELM cycle


Divertor D_α 139047

- Can low-k density fluctuations correlated with an ELM cycle be detected?
- A projection of the time window (depending on ELM cycle) in Fourier domain enables a systematic assessment of fluctuation spectra during an ELM cycle.


BES fluctuations spectra 139037 20% - 40%


Mirnov spectra 139037


BES radial slice spectra 139037 20% - 40%