Edge profiles during H-mode in TCV ...

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Goal :

- measure spatial profiles of T_e and n_e near the plasma edge,
- with spatial resolution adapted to the expected gradients
- characterize profiles in terms of a set of parameters :
  - pedestal height
  - pedestal width
  - max. gradient

- provide experimental data set as input for numerical modelling
- investigate profile changes during ELM cycle

Method :

- extension of standard Thomson scattering system on TCV
- repetitive measurements during a quasi-stationary phase in ELMy H-mode
- processing of data using "coherent averaging"

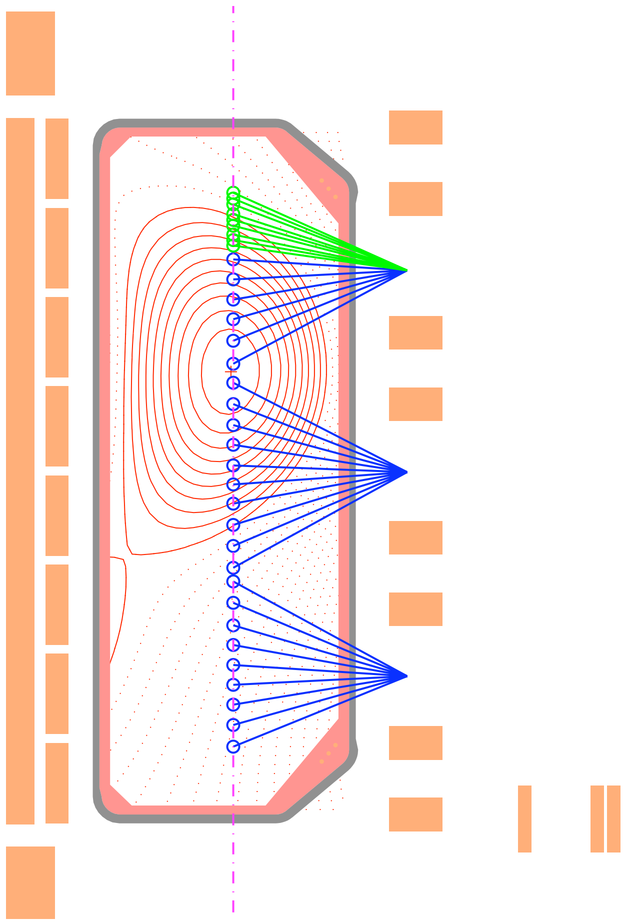
Thomson scattering system on TCV

Basic features :

- 25 spatial channels along laser beam at R=0.9m, covering full vertical extent of plasmas in TCV
- spatial resolution : ΔZ=30mm
- filter polychromators with 4 spectral channels
- repetitively pulsed Nd:YAG lasers (3 units, 20Hz each)
- sampling intervals : 50ms (standard), >1ms (burst)

Extensison :

- 9 spatial channels
- spatial resolution : ΔZ=10mm
- filter polychromators optimized for parameter range :
  - T_e : 20eV to 1keV
  - n_e : > 2. 10^{18} m^{-3}
- equipment on loan from Consorzio RFX, Padova



green : channels with improved spatial resolution (DZ ~ 10mm)

blue : channels of standard system (ΔZ ~ 30mm)

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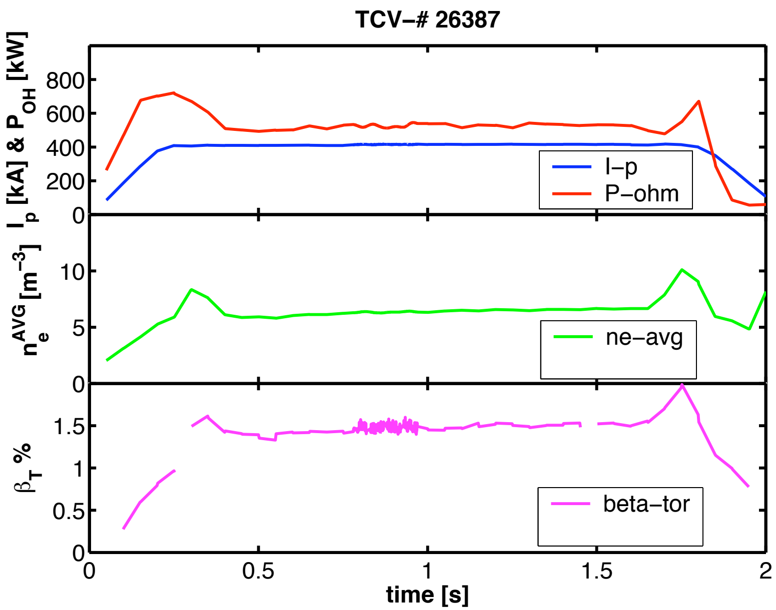
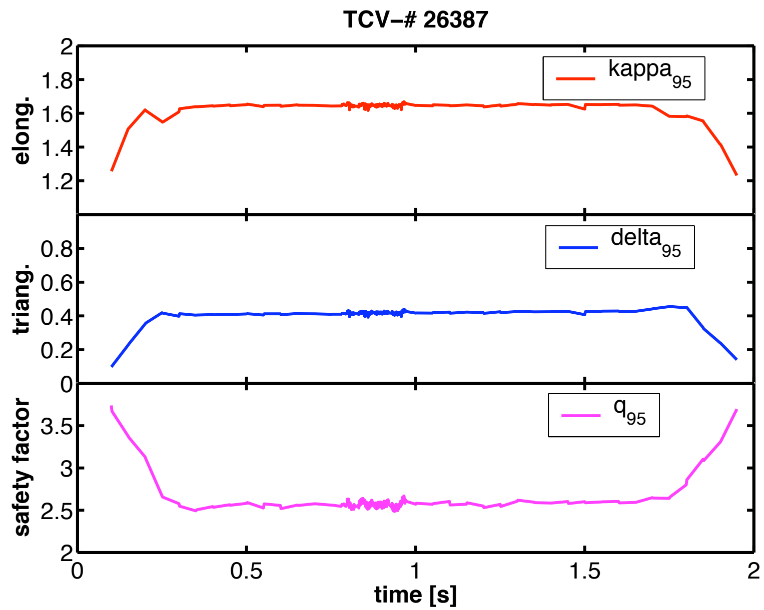
ohmic H-mode in TCV

Typical plasma parameters :

series of shots with **ohmic heating** only :
constant power input : P_{ohm} 500kW
current plateau : I_p 400kA
good control of density : $n_{e\text{-}avg}$ 6.4 $10^{19} m^{-3}$

toroidal field on axis : B_T 1.44T
major radius : R_0 0.9m
minor radius : A_{min} 0.22m
majority ions : D





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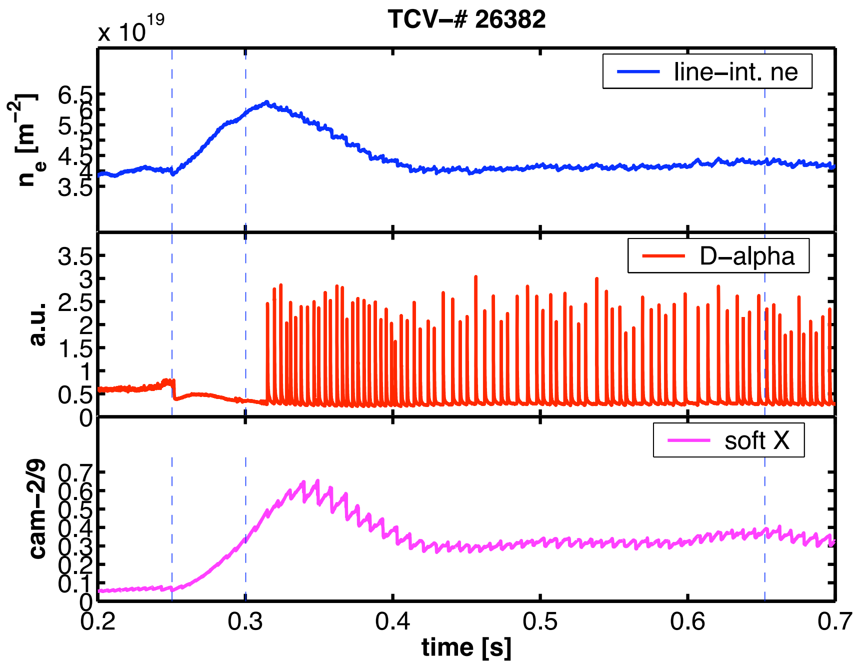
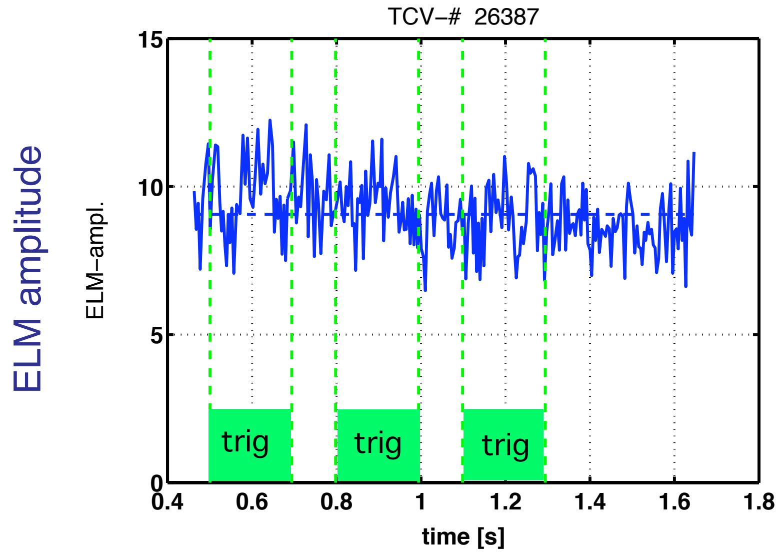
quasi-stationary phase with ELMs

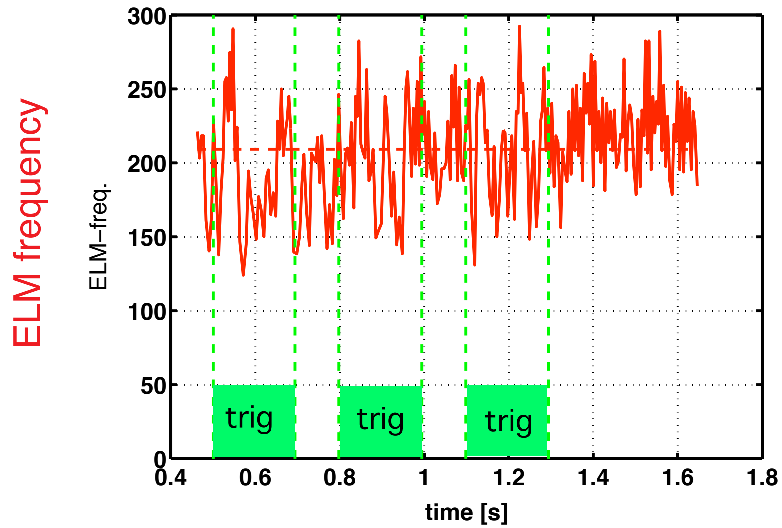
ELMy H-mode :

Scenarios have been developed on TCV which permit to obtain extended phases in ELMy H-mode with small variations in **ELM** frequency and amplitude.

In addition, **magnetic perturbations** have been used to control and synchronize the ELMs (see intervals labeled “trig”)







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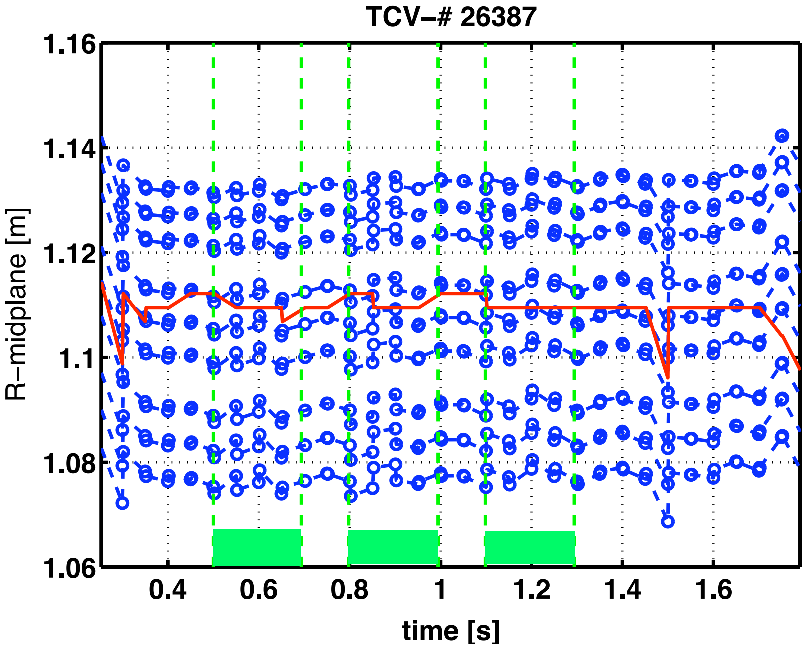
mapping of local TS measurements

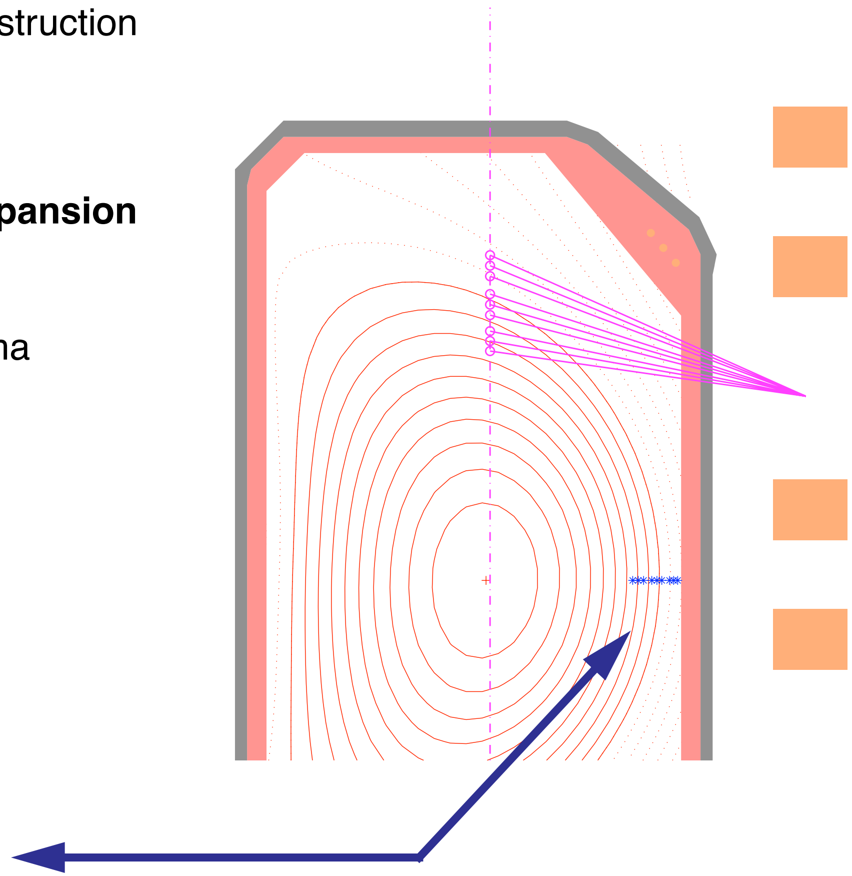
Mapping onto equatorial plane :

- using flux surface geometry from equilibrium reconstruction based on magnetic measurements
- assuming n_e and T_e constant on flux surfaces

- effective spatial resolution improved due to **flux expansion** in the area of the TS observation volumes

- **spatial sweeps** due to vertical motion of the plasma





effect of magnetic ELM triggering

Effect of **periodic current pulses** applied to internal coils :

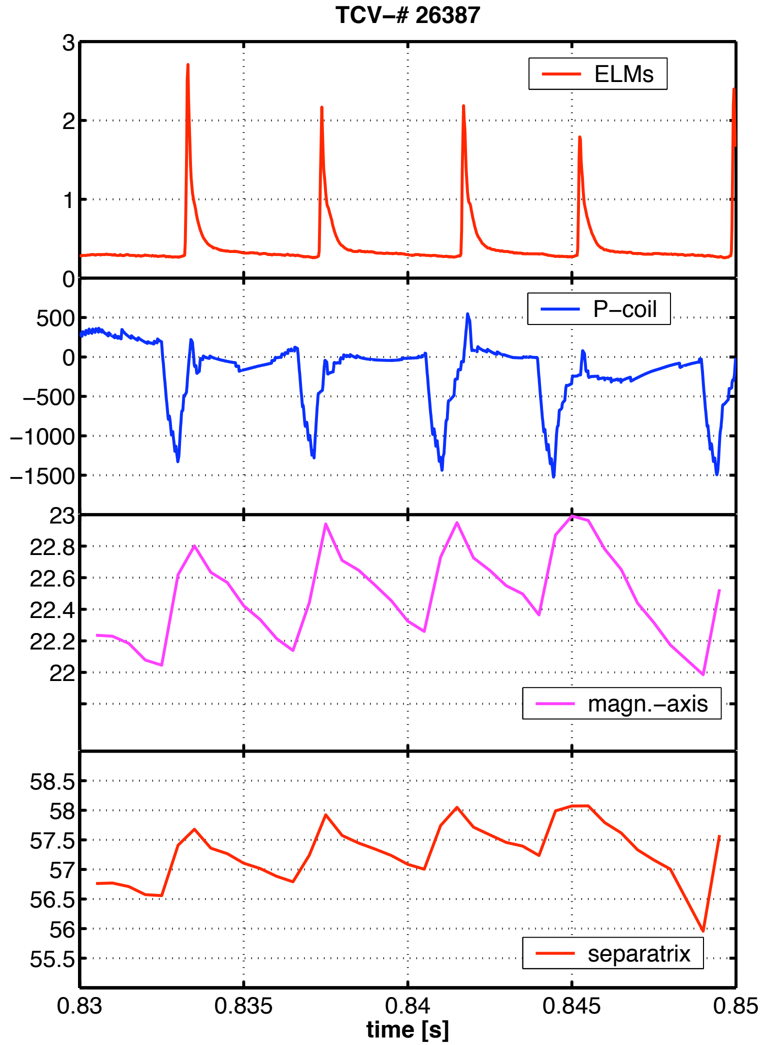
- contribute to the triggering and synchronization of the ELMs
- induce local current density near the edge
- cause small vertical displacements of the separatrix position

sequence of ELMs

current pulses on internal coils

Z displacement of magnetic axis (cm)

Z displacement of separatrix (cm)



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representation of edge profiles

the modified TANH function

$$F = a(5) - a(1) \cdot \tanh X - a(1) \cdot a(4) \cdot \frac{(X \cdot e^{-X})}{e^{X} + e^{-X}}$$

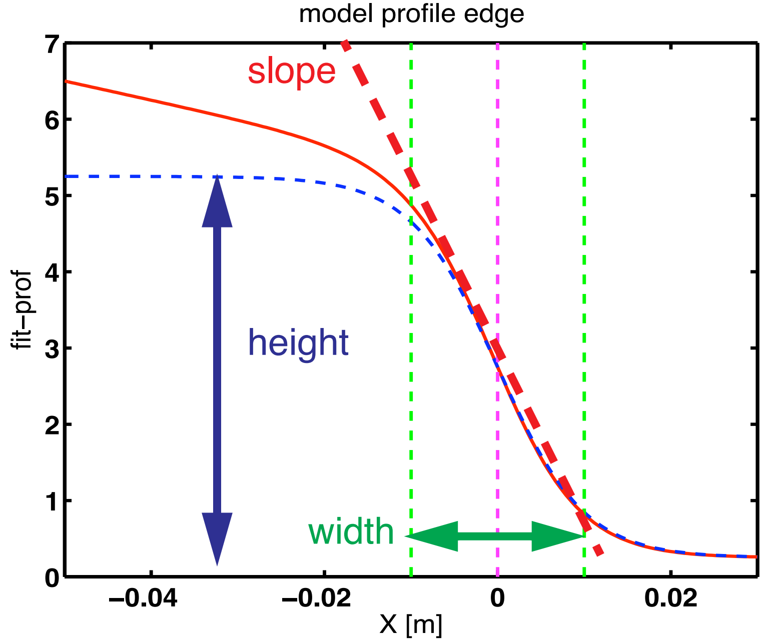
using normalized spatial coordinates :

R = radius on midplane

$$X = \frac{(R - a(2))}{a(3)}$$

function parameters :

- pedestal height : a(1) + a(5)
- pedestal width : 2 a(3)
- slope : a(1) / a(3)



see also refs. :

R.J. Groebner, T.H. Osborne
PoP 5(5), 1800-1806, 1998
A. Kallenbach, R. Dux et al.
Nucl. Fusion 43, 573-578, 2003

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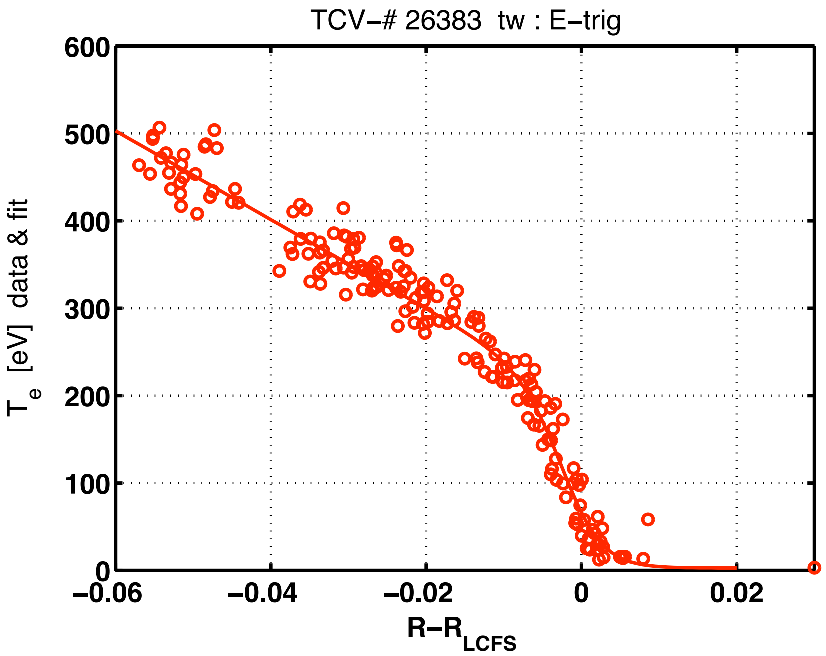
profiles during ELMy H-mode phase

Time-averaged profiles : during quasi-stationary phase

small vertical displacements of separatrix location
lead to improved spatial coverage after mapping of the data points onto the plasma midplane

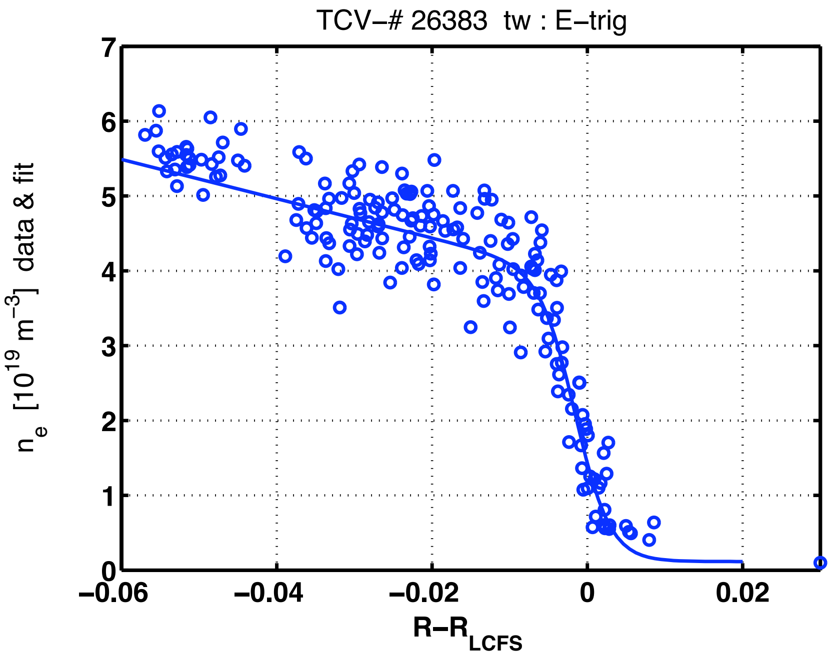
electron temperature T_e



pedestal height : 210 ev
pedestal width : 1.1 cm

max. grad. : 190 eV/cm

electron density n_e



pedestal height : 4.1 10^{19} m^{-3}
pedestal width : 0.9 cm

max. grad. : 4.5 10^{19} m^{-3}/cm

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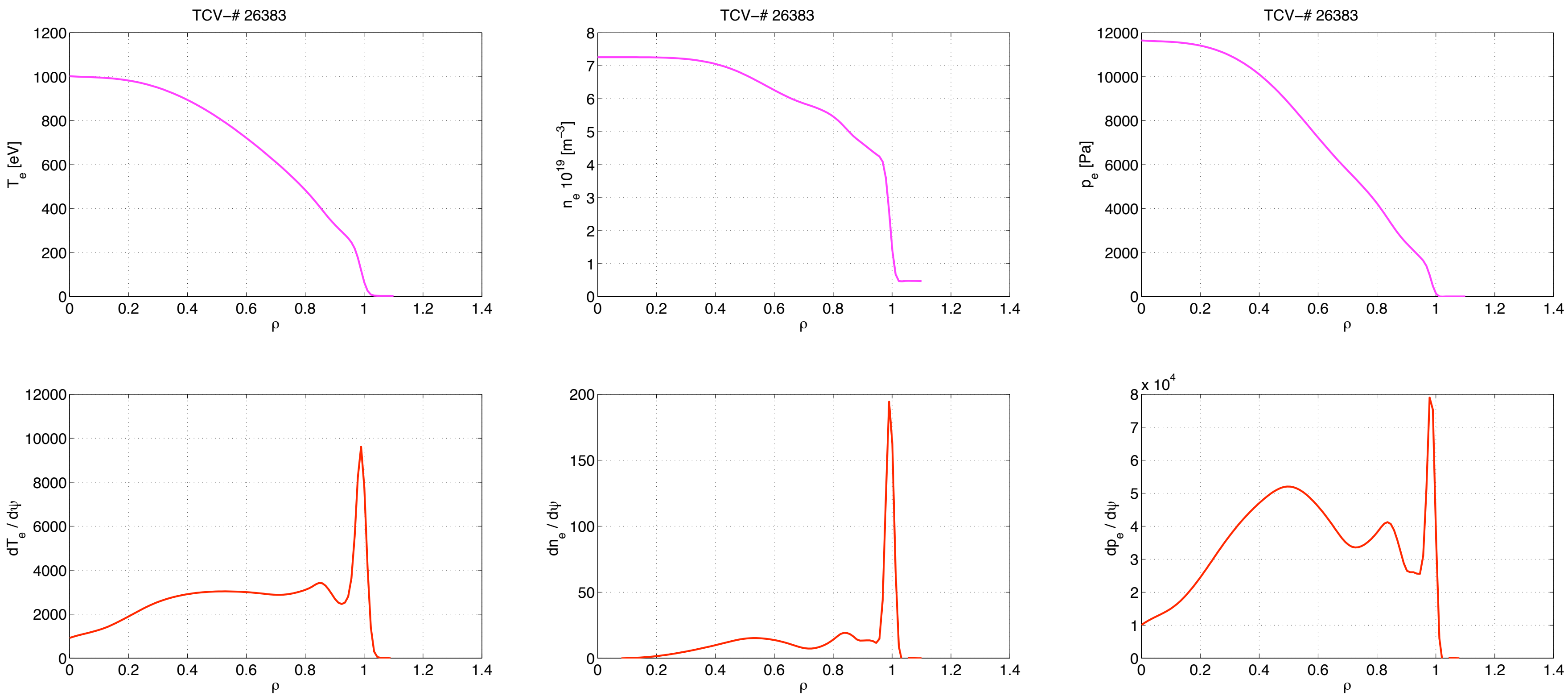
complete profiles

Combining data from TS measurements in core & edge :

profiles and derivatives in normalized poloidal flux coordinates

temperature **density** **pressure**



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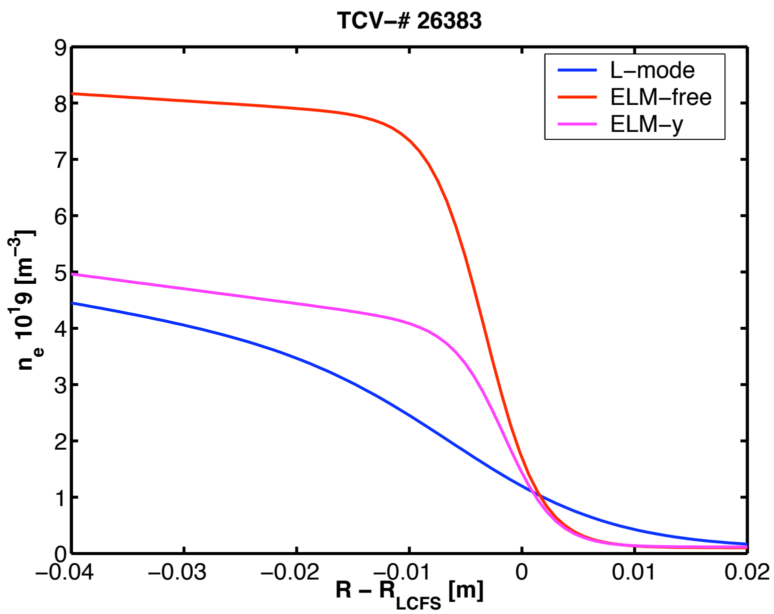
evolution of profiles

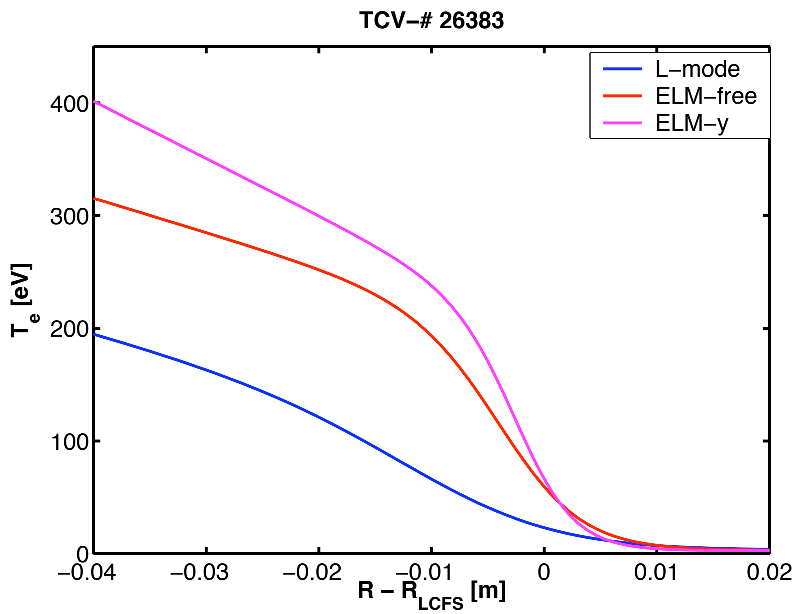
Characteristic changes in edge profiles during a TCV shot : L-mode & H-mode

the same fit function (tanh) has been used in all cases

density :



temperature :



- smooth profiles during L-mode
- formation of large pedestal during ELM-free phase, large gradients near the edge
- decrease of n_e and rise of T_e in ELMy H-mode phase, strong gradients remain

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profile changes due to ELM

Analysis of individual measurements :

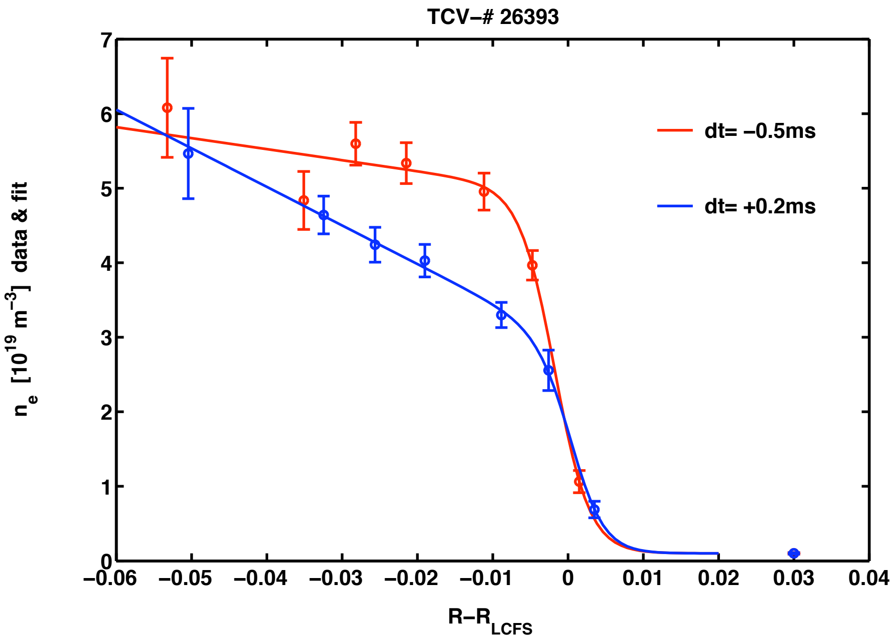
Comparions of profiles measured immediately **before** (-0.5ms) and **after** (+0.2ms) an **ELM** :

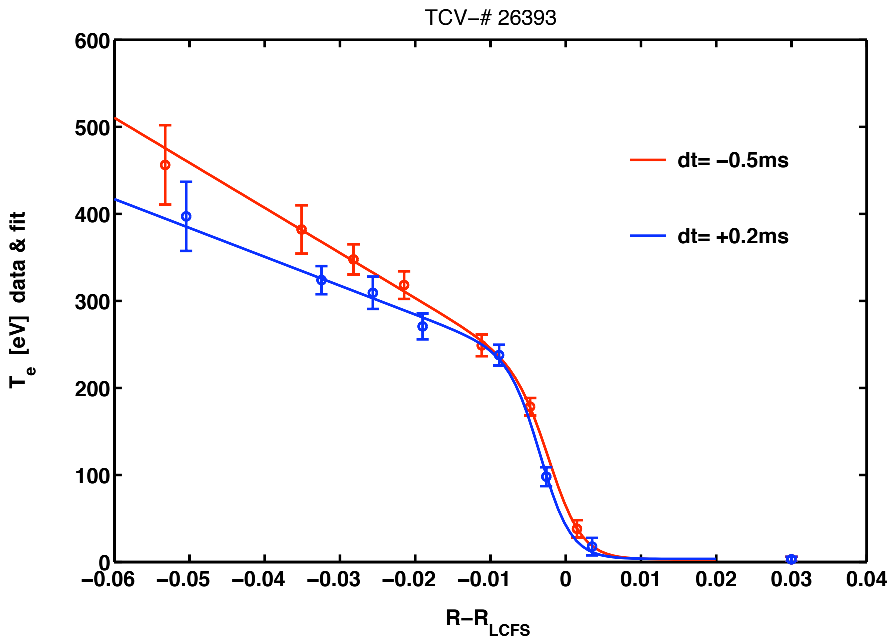
Observation :

Occurance of an ELM affects profiles of density and temperature to a different degree :

density :
collapse of pedestal height

temperature :
smaller effect





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variation during ELM cycle (1)

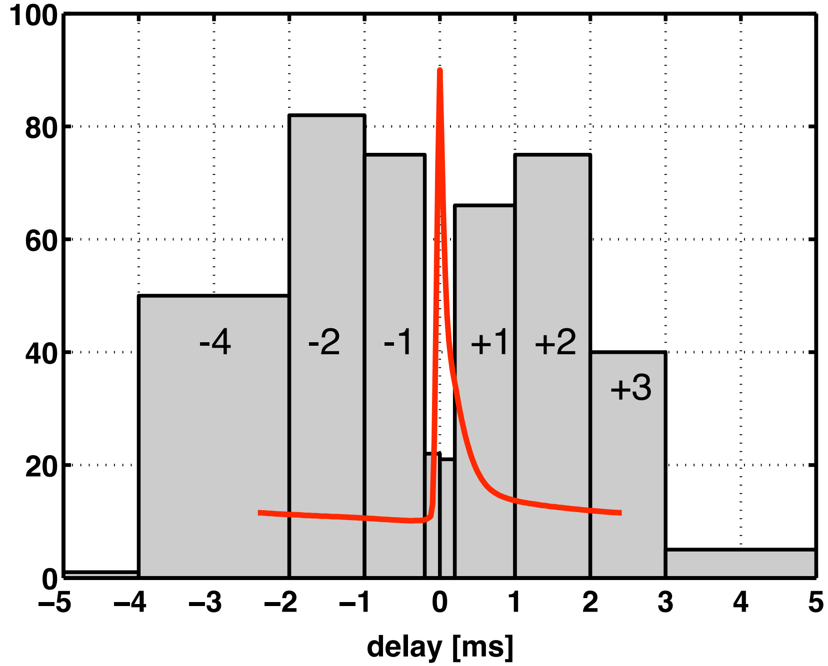
Coherent averaging :

- collection of data from quasi-stationary time intervals of several reproducible shots
- measurements at fixed repetition rate provide "random sampling" during the ELM cycle
- grouping of the data into "bins" according to their time delay with respect to the ELM spike

Distribution of "bins" with respect to "typical" ELM

Criteria for the selection of the "bins"

1. time scale of expected profile changes
2. distribution of samples within time interval
3. statistics, number of samples per interval

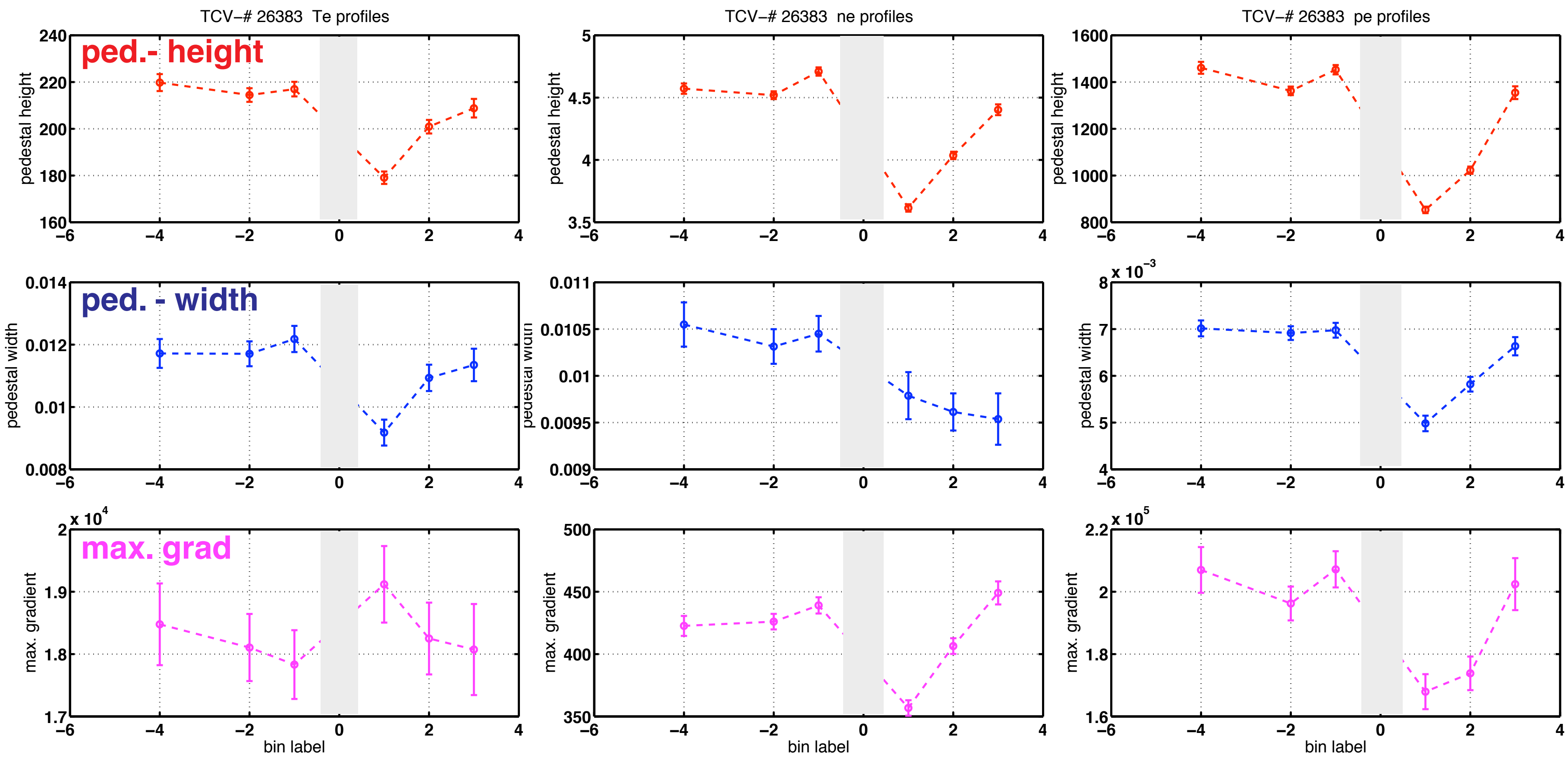


variation during ELM cycle (2)

Change in profile parameters : pedestal height pedestal width max. gradient

using on profile fits by mod-tanh function and “coherent averaging”
time window ± 0.2ms around the ELM excluded, data in this interval not reproducible

temperature **density** **pressure**



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summary

Instrumentation :

- Thomson scattering diagnostic on TCV upgraded by adding channels with higher spatial resolution in the edge region
- ΔZ = 10mm adequate to resolve gradient zone of temperature and density profiles, when advantage is taken of the local flux expansion
- system adapted for measurements at low temperatures (> 10 eV) and densities (> 5 10^{18} m^{-3}).

Scenarios :

- fast sweeping of separatrix location helps to obtain better spatial sampling
- "coherent averaging" as a means to reconstruct time evolution during ELM cycle requires quasi-stationary ELMy H-mode phases with regular ELMs
- random sampling has permitted to follow time evolution during typical ELM cycle even with a diagnostic of inherently low sampling rate (20Hz Thomson scattering)

Analysis :

- mapping onto reference coordinates (mid-plane) relies on accuracy of the equilibrium reconstruction
- modified TANH function with 5 free parameters gives good description of edge profiles
- characteristic change in parameters observed at L-H transition & before and after ELM
- measured gradients represent a lower limit due to given spatial resolution of the instrument
- the same method (TS) can be used for measurements of core and edge profiles (consistency).
- results can be linked to measurements in the SOL obtained from other diagnostics (Langmuir probes).