Edge fast magnetic measurements during ELMs of different types in JET.

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Abstract:

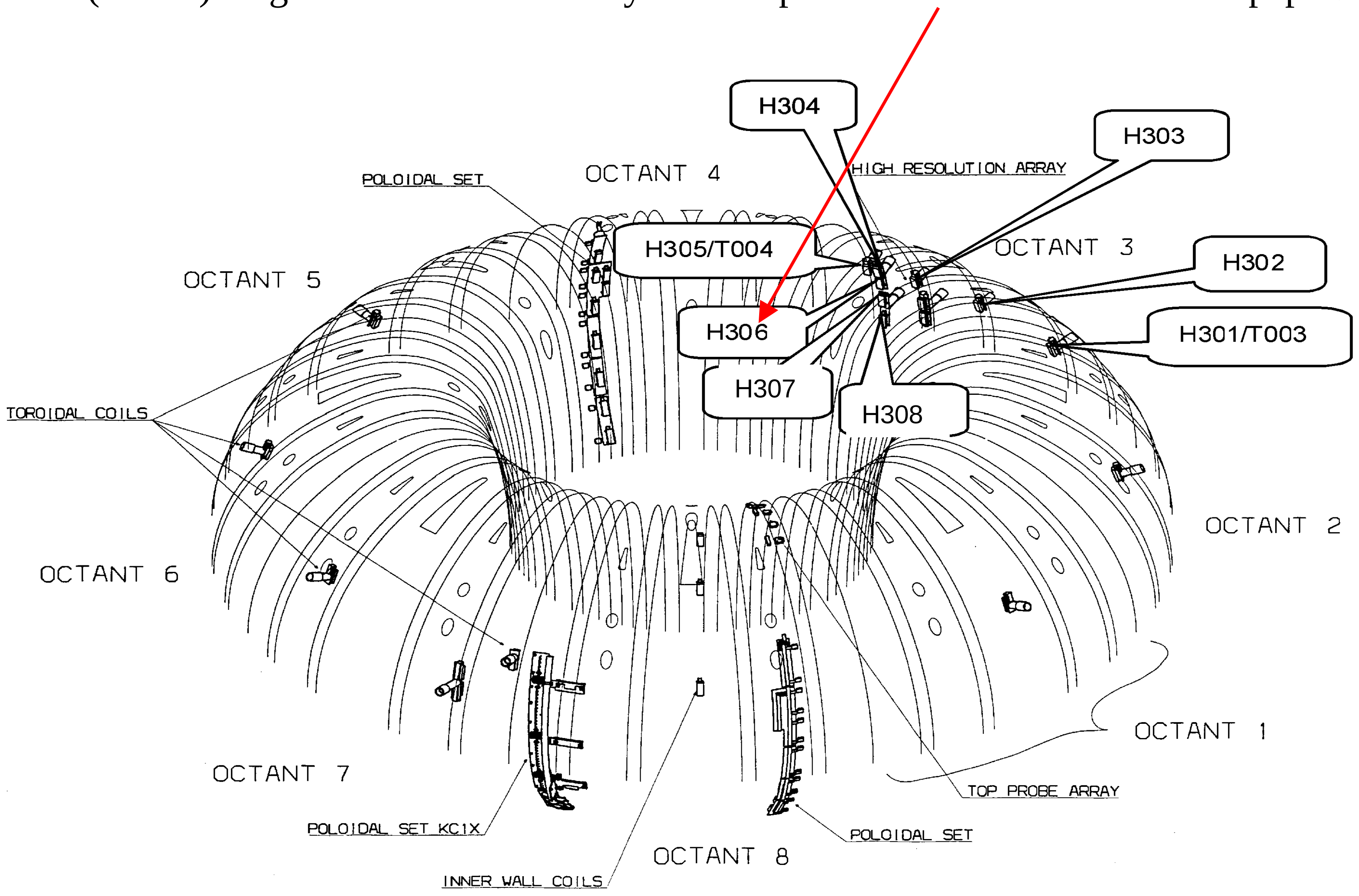
The plasma edge stability and linked with this ELMs behavior, pedestal and SOL energy and particles transport are important problems for future tokamaks. ITER operation in H-mode demands plasma regimes with high confinement at high density, but at the same time with acceptable for divertor target plates small energy losses per ELM. In present paper the fast magnetic perturbation of poloidal magnetic field edge measurements by Mirnov picfk-up coils and spectrum analysis are presented for different type of ELMs in JET. ELM time and amplitude from Mirnov coil signal were estimated in density, power and current scans.

High triangularity shots in ITER-like configuration (δ~0.5) on JET have demonstrated high confinement and high density with relatively low frequency type I ELMs and reduced losses per ELM, compared to average losses of type I ELMs at the same frequency. The broadband MHD activity (<30kHz, with main toroidal number=-8) in between type I ELMs was identified as **type II ELMs**, by analogy with the ones observed on ASDEX [Stober J. at al, 2000].

Fast magnetic signal during an **ELM type I** is correlated with rising in Da signal. The characteristic MHD time of type I ELM was estimated as ~1-2.10^{-4}s in JET for large range of plasma parameters. Magnetic perturbation amplitude decreases with the density.

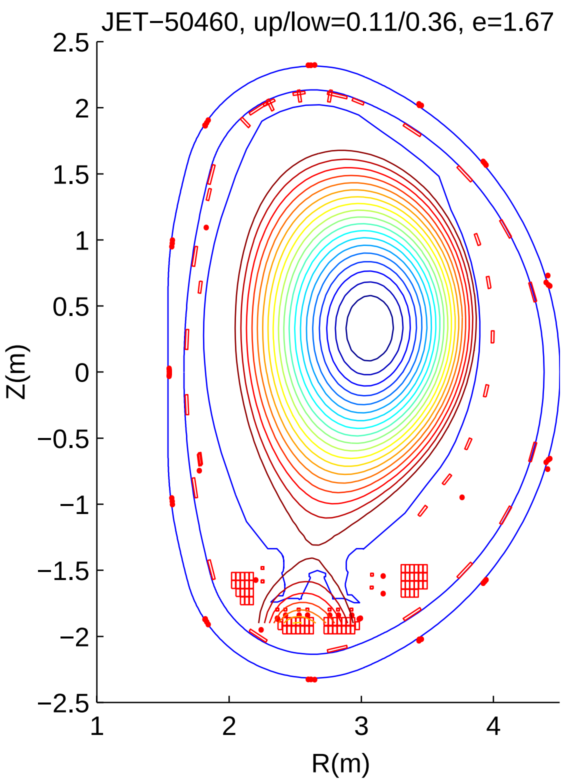
Type III ELMs activity at low density ELMy-H modes and Optimized Shear discharges demonstrate correlation between rising in Da signal and magnetic perturbation with characteristic time ~10^{-3}s and approximately 10 times lower amplitude than for type I ELMs. Type III ELMs in ELMy-H-modes at high density have no clear correlation between magnetic and Da signals, suggesting different nature of the edge instability for type III ELMs at high and low densities.

Fast (CATS) magnetic measurements by Mirnov probe **H306** were used in the paper.

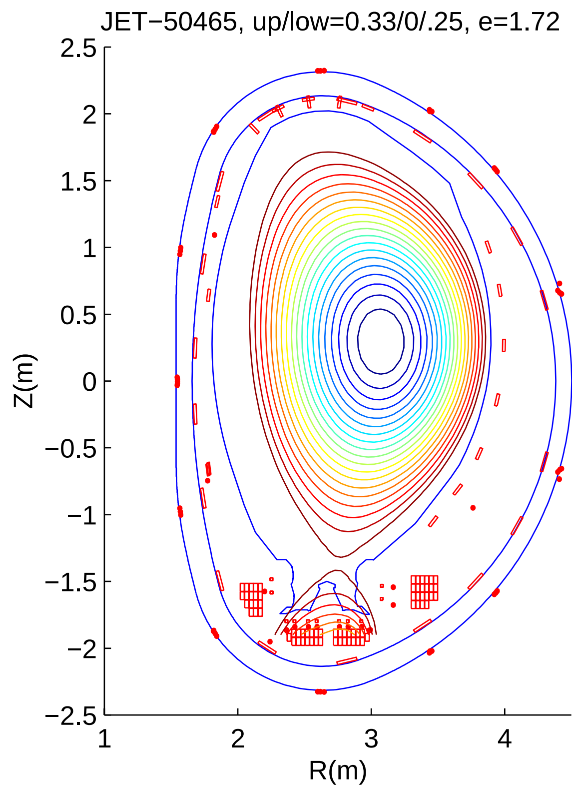


Recent triangularity scan experiments in JET 2000/2001 extended the range of δ up to the ITER - like δ~0.5 compared to JET MkII experiments *[Saibene G. et al, Nucl. Fusion 39(1999)]*

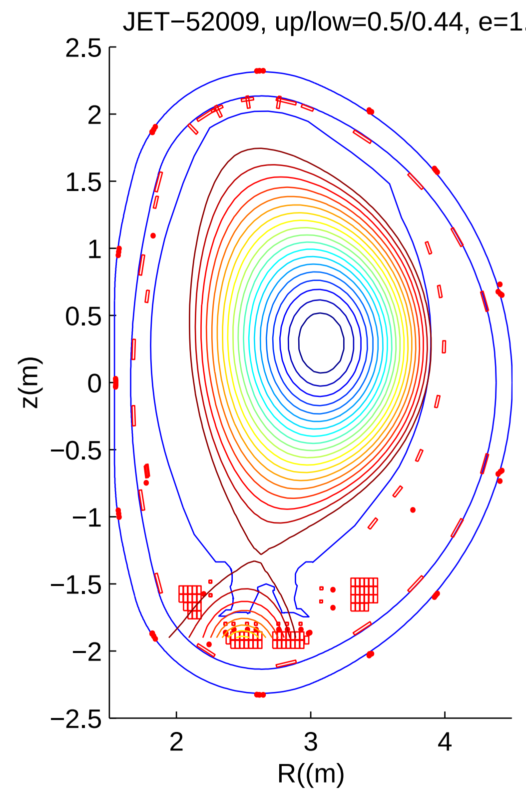
<δ>~0.23



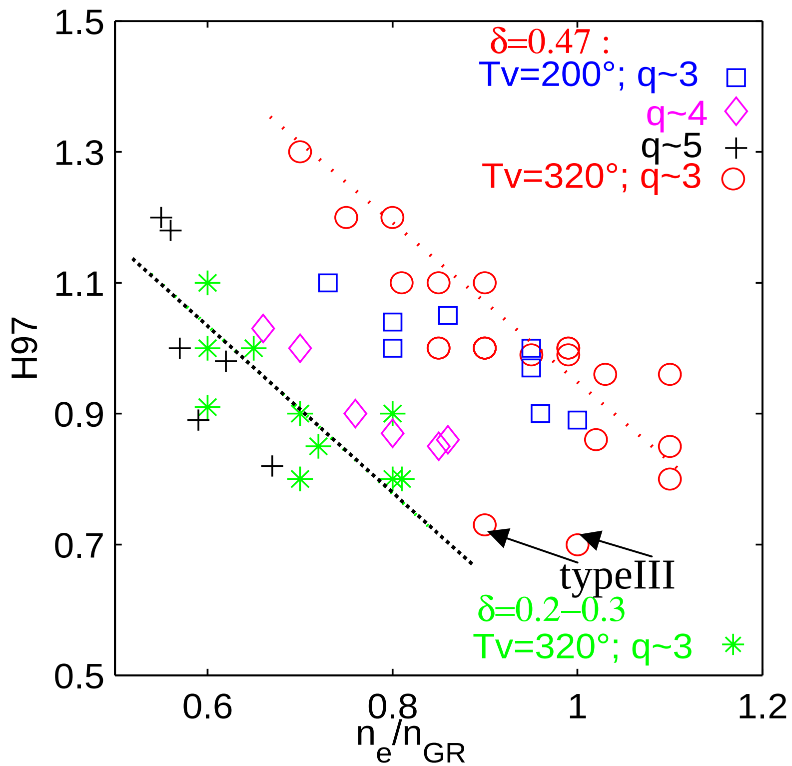
<δ>~0.29

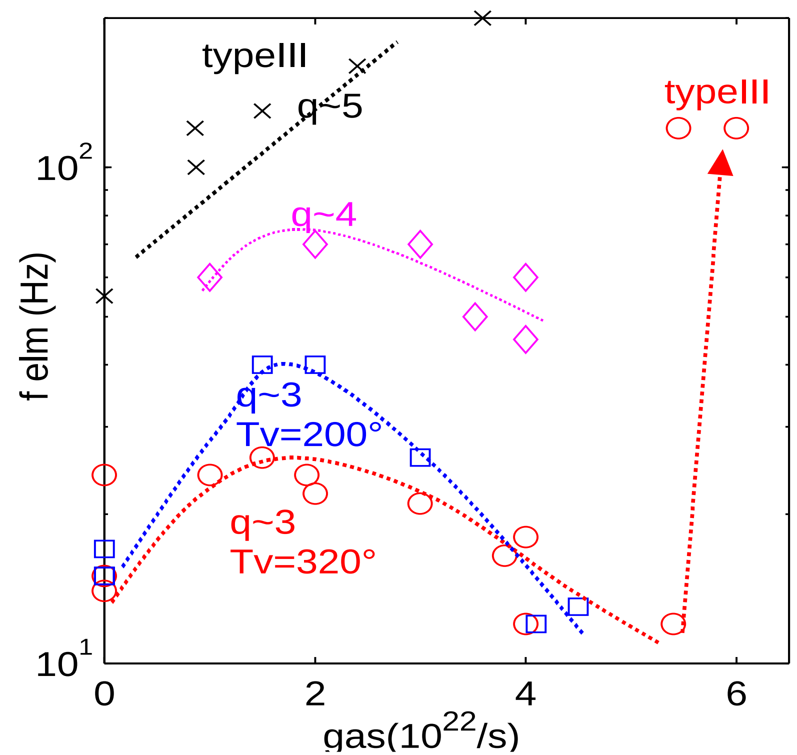


ITER-like <δ>~0.47



Bt=2.7T Ip=2.5(=2;=1.5) MA,14-15MW nbi, T vessel=320° and T vessel=200°

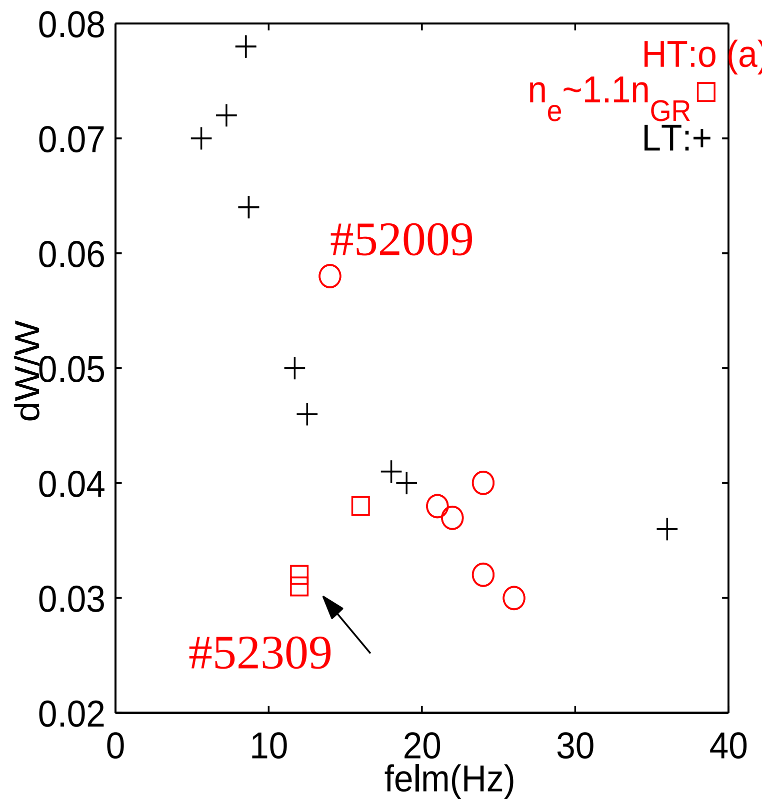


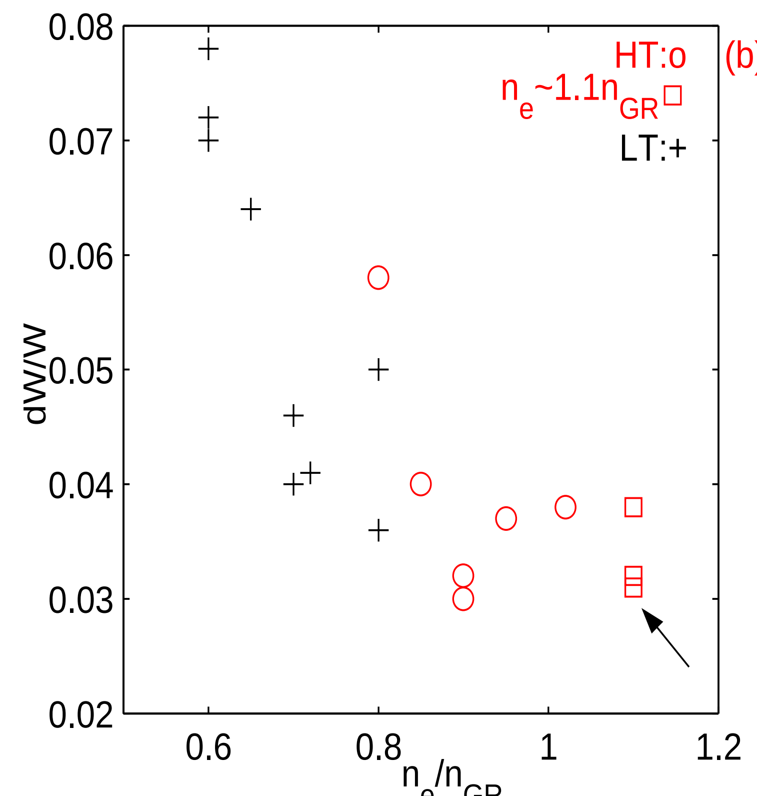


The plasma performances achieved in ITER-like triangularity configuration (δ~0.47, q_{95}=3) in JET: H_{97}=0.85 b_N~1.9, n_e~1.1n_{GR} .

The anomalous decrease of type I ELMs frequency to the values of unfuelled case (~12Hz) was observed at high gas rate at δ~0.47, q_{95}=3, but without complete disappearance of type I ELMs. Further increase of fuelling (>5 10^{22}/s) leads to type III ELMs.

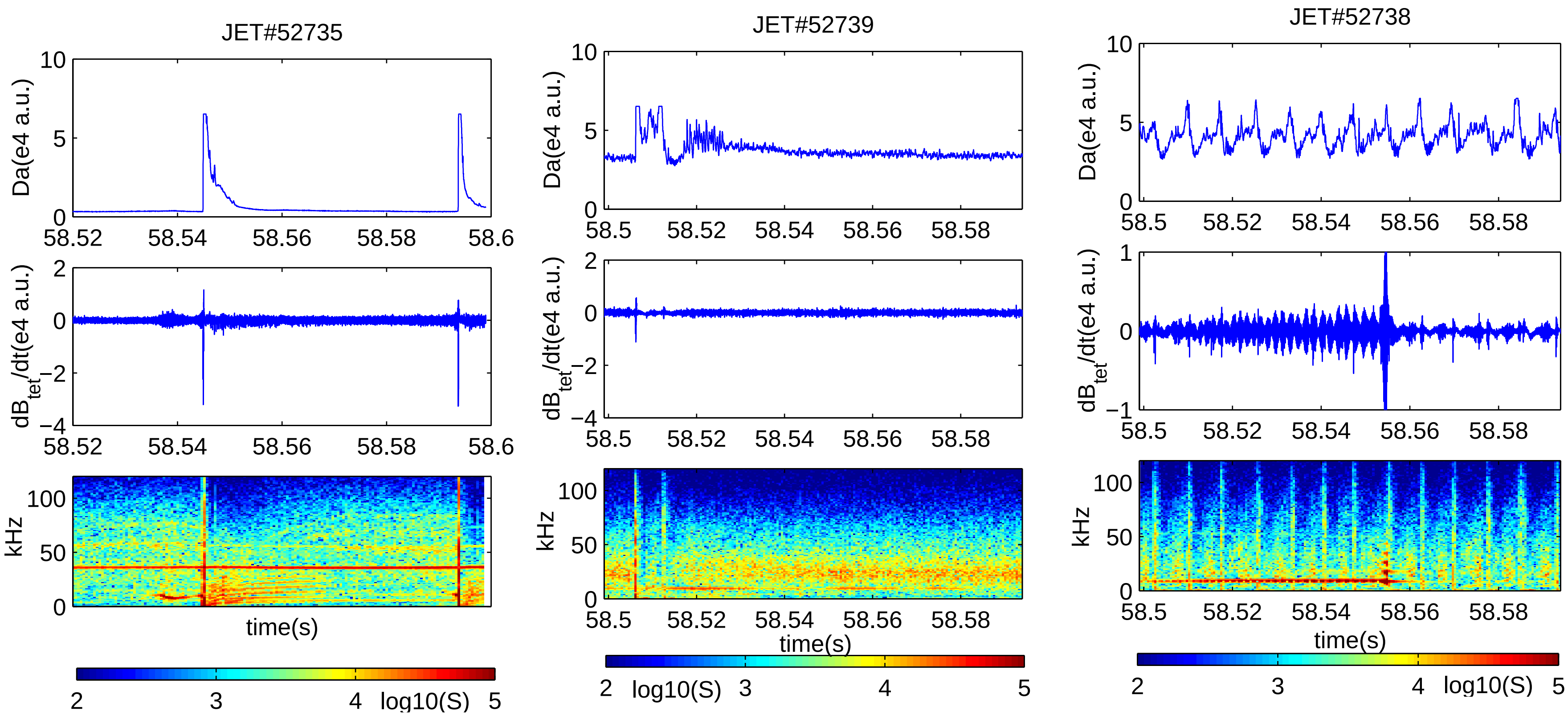
Diamagnetic energy losses per ELM: $\Delta W_{ELM}/W_{tot}$ versus ELM frequency and Greenwald number, averaged over ~10 ELMs. At low density the energy losses per ELM decrease with ELM frequency as usual,but for the shots at highest density (~1.1n_{GR}) with anomalous low frequency, the ELMs are relatively small, with $\Delta W_{ELM}/W_{tot}$ ~3% compared to 5-6% for lower density plasmas at the same f_{ELM}.





dW/W decreases with density (collisionality? *[Loarte A. et al 28th EPS, Madeira,2001])* even at the same ELM frequency.

ITER-like configuration (δu~0.5), 15MW, 2.7T/2.5MA, (high T $_{vessel}$~320C^0)



Gas=0, nped=6e19m-3, type I ELM (here “palm-tree” mode after an ELM)

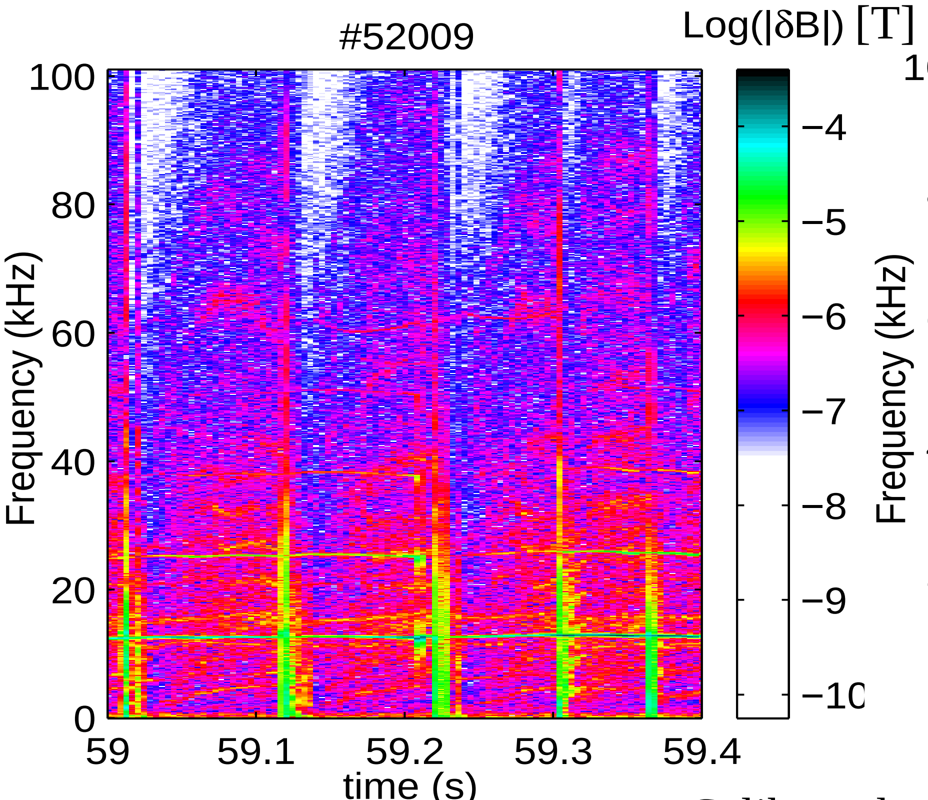
Gas=6e22/s, nped=9.3e19m-3, type I+II ELM ? (broad spectrum 0-30kHz)

Gas=5.5e22/s, nped=8.2e19m-3, type III ELM

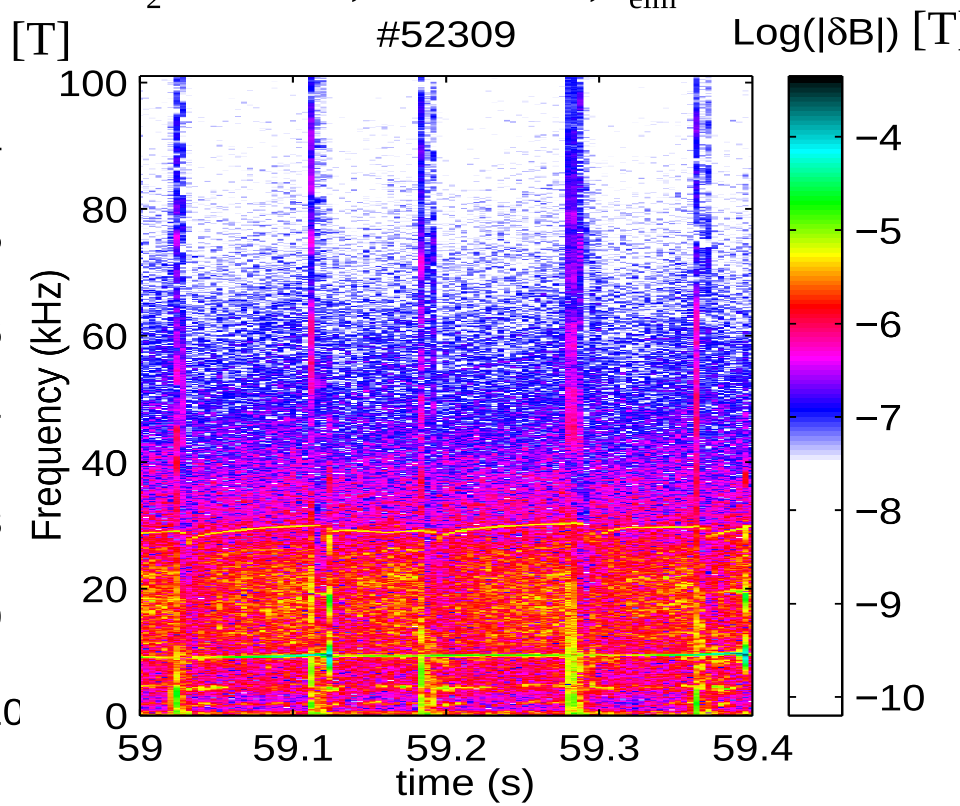
Type II ELM observed at high pedestal density (~nGR), confinement is similar to type I edge. Increased MHD during type II ~increased electron transport?

The explanation of decreased ELM frequency is linked with additional losses mechanism in between ELMs. In ITER-like triangularity scenarios the broad band 0-30kHz of magnetic fluctuations systematically appears at high density in the discharges with anomalous ELMs frequency .

D_2=0, δ=0.47, n/nGR~0.8, f_{elm}~14Hz



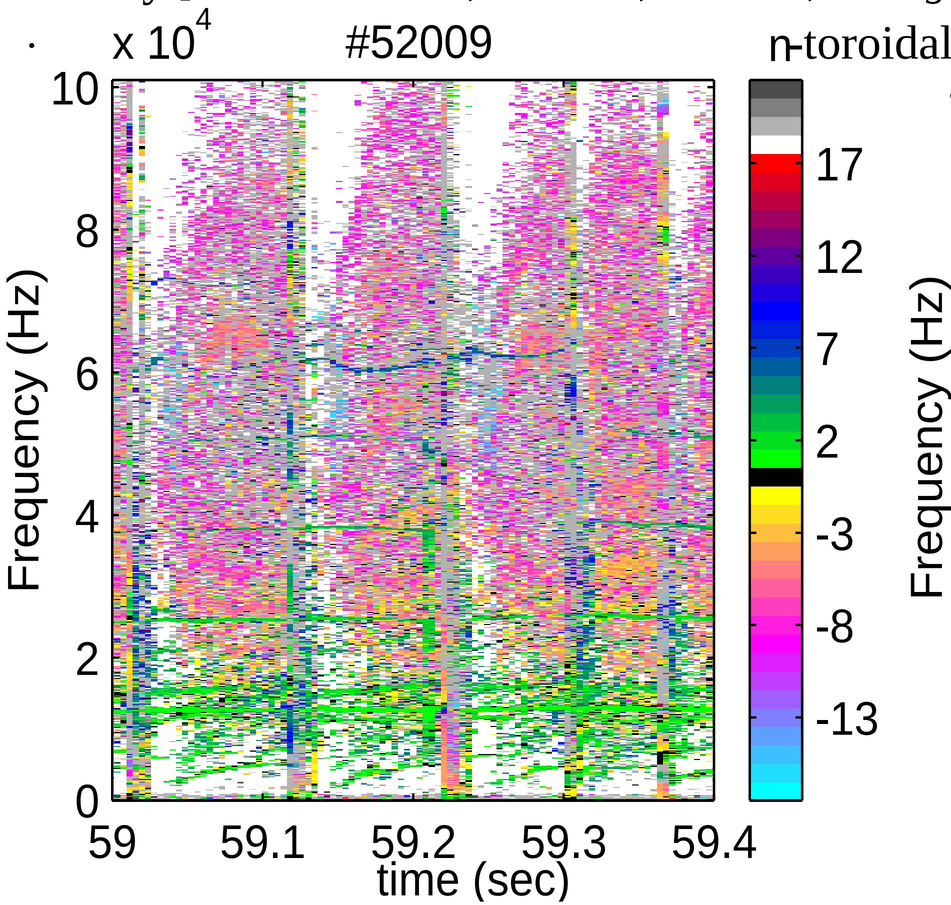
D_2=5.4e22/s, n/nGR~1.1, f_{elm}~12Hz

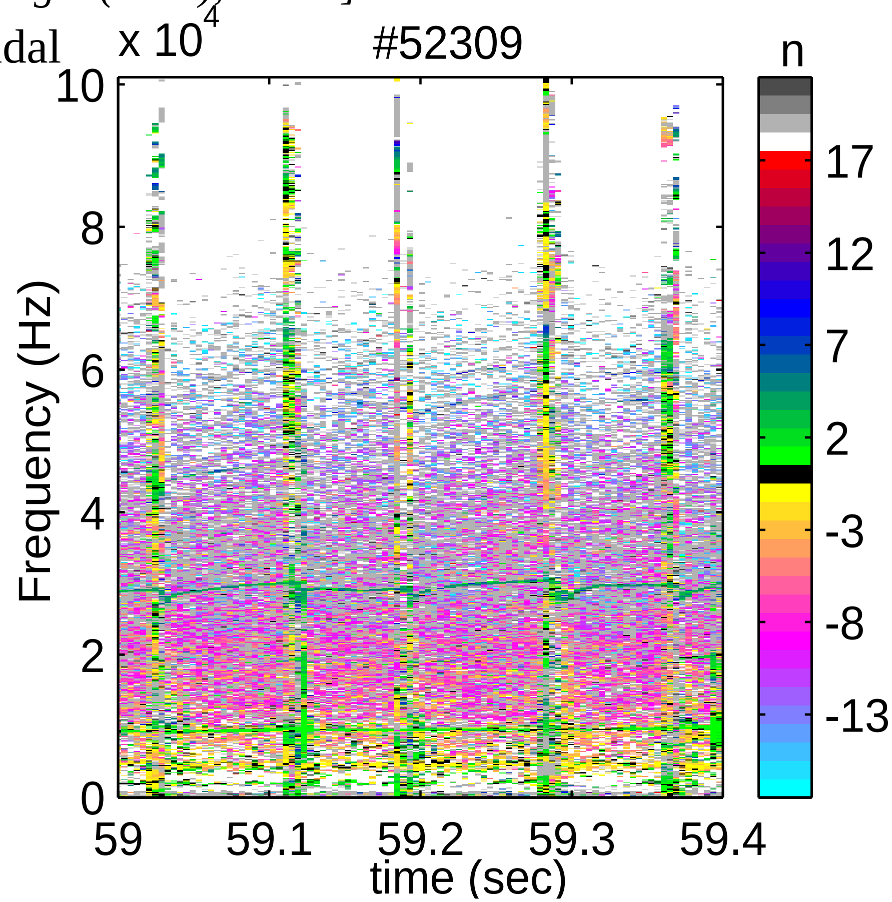


Calibrated spectrums.

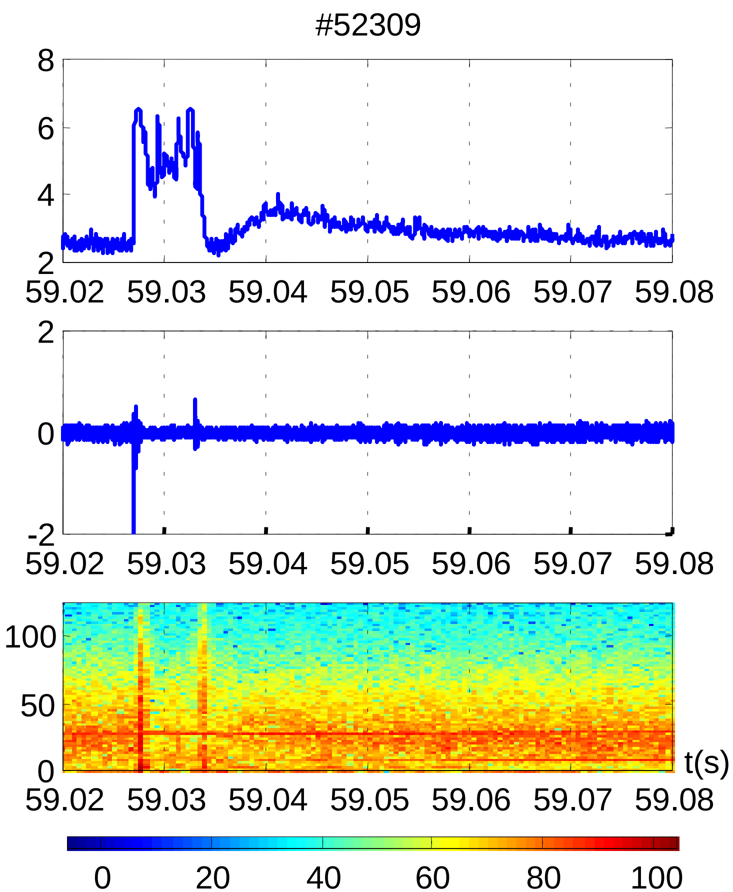
high frequencies >50kHz are suppressed

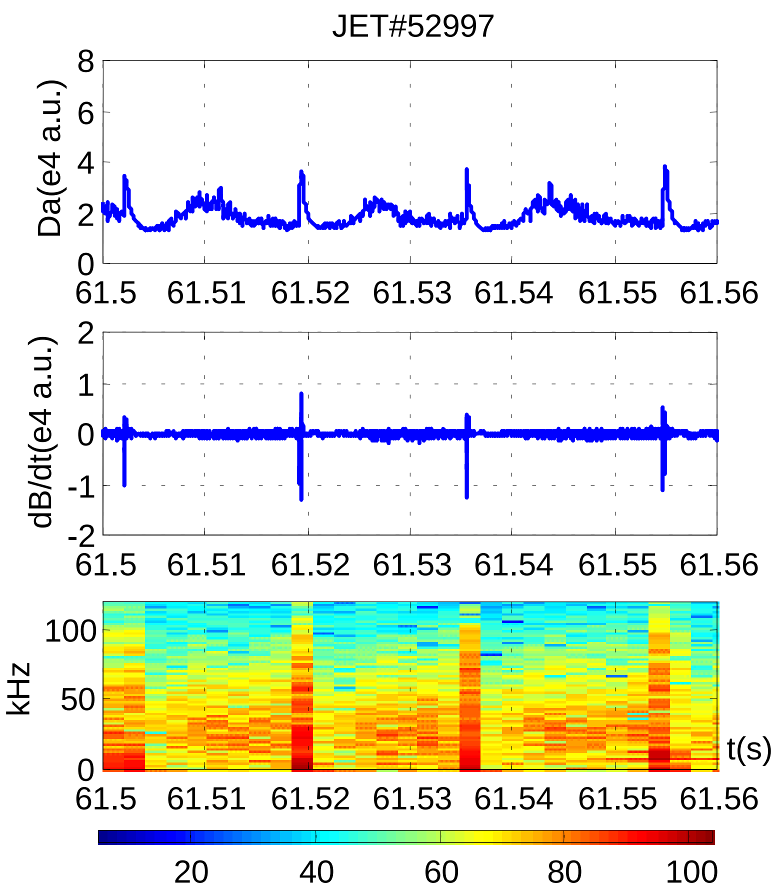
The time-correlation analysis of signals from toroidally separated pick -up coils permitted the identification of the main toroidal number n=-8. These MHD activity in high density, high triangularity discharges were associated with so-called type II ELMs by analogy with one observed also in ASDEX-U.The type II ELMs or grassy ELMs regimes provides high pedestal pressure comparable with type I regime and good confinement even at high density *[Saibene G. et al, 28th EPS, Madeira, Portugal (2001), OT.28]*.





Type II ELMs in ITER-like for different plasma current and vessel temperature(Pnbi~15MW).



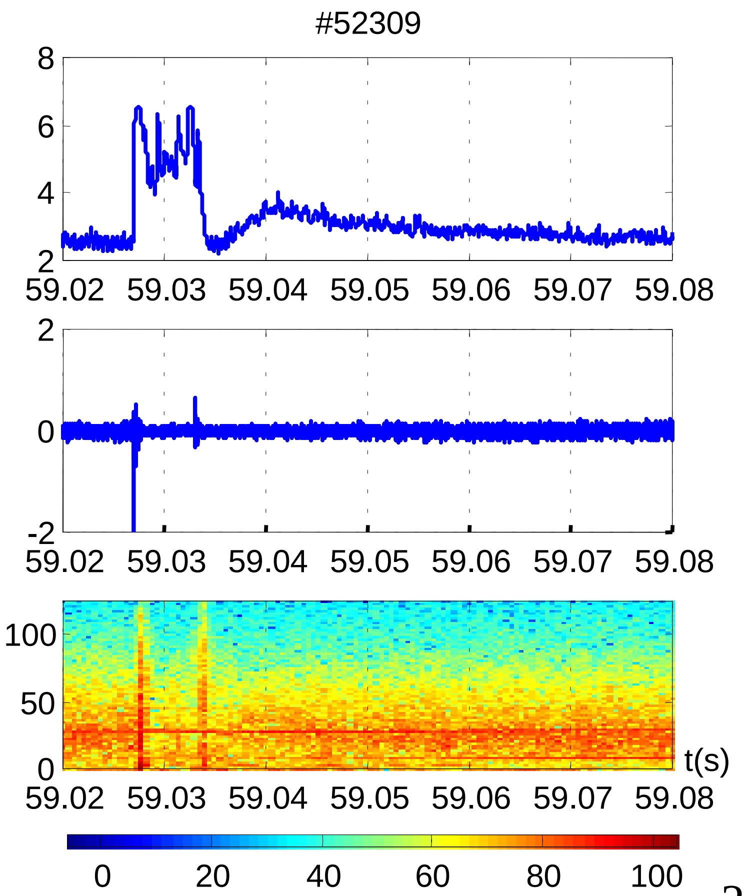


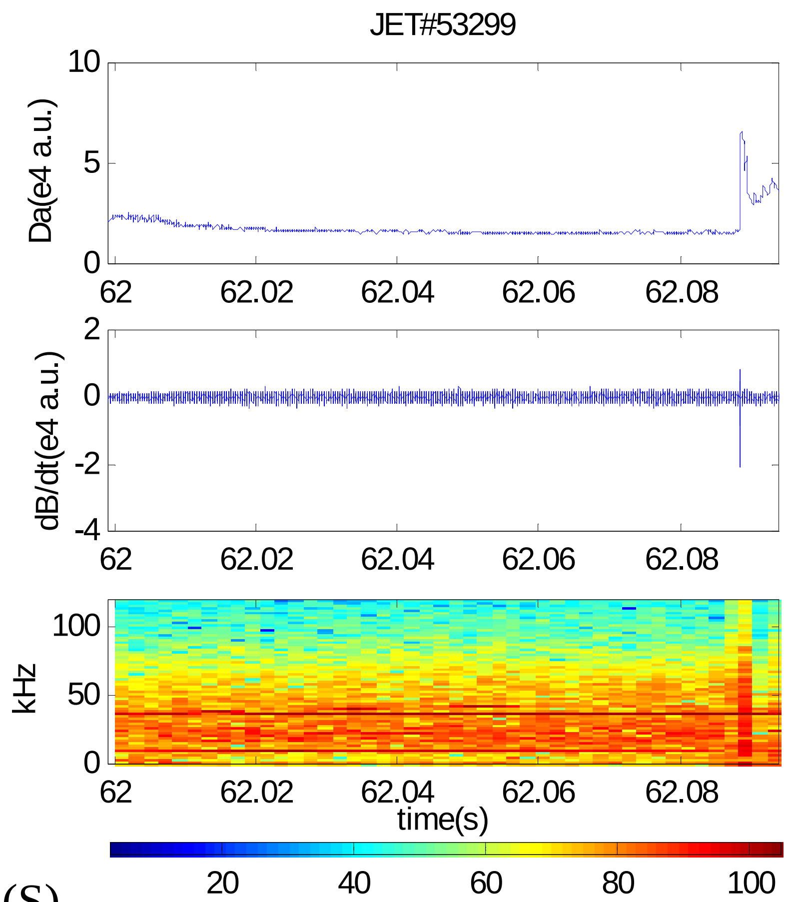
20log10(S)

2.5MA/2.7T, Tv=320C^0
up/low=0.52/0.44,
nped=9.3e19m-3'
felm~12Hz (type I+II)

2MA/2.7T, Tv=200C^0
up/low=0.52/0.44,
nped=6.6e19m-3,
felm~40Hz (type I+II)

Type II ELMs in ITER-like for different vessel temperature(Pnbi~15MW).Gas~4e22/s.



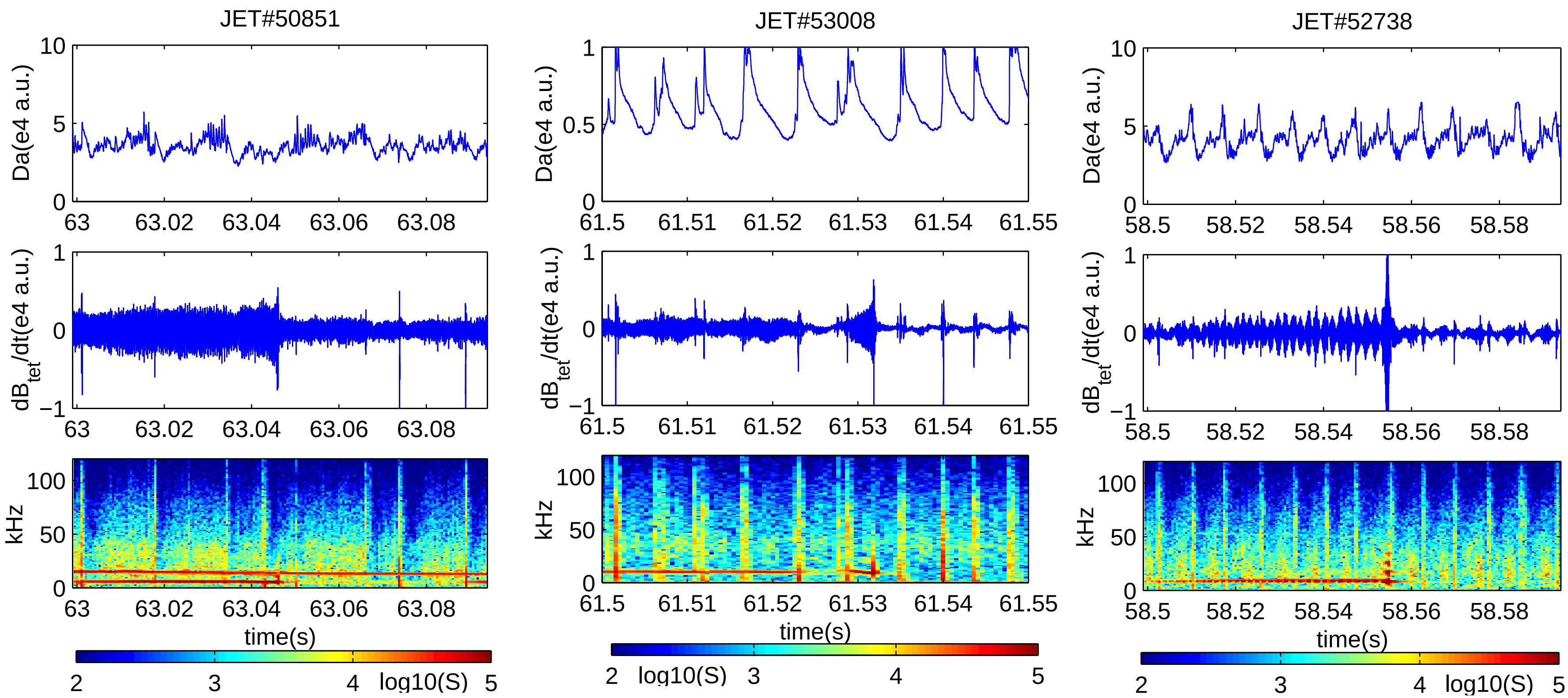


20log10(S)

2.5MA/2.7T, Tv=320C^0
up/low=0.52/0.44,
n_{ped}=9.3e19m-3'
felm~12Hz (type I+II)

2.5MA/2.7T, Tv=200C^0
up/low=0.52/0.44,
n_{ped}=9.e19m-3,
felm~12Hz (type I+II)

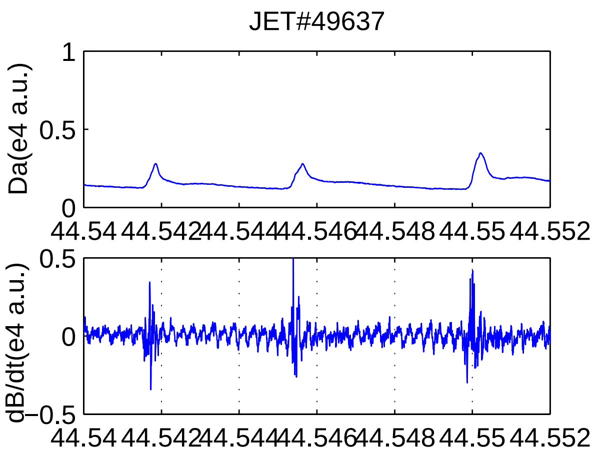
Characteristic type III ELMs spectrum (Pnbi~15MW).



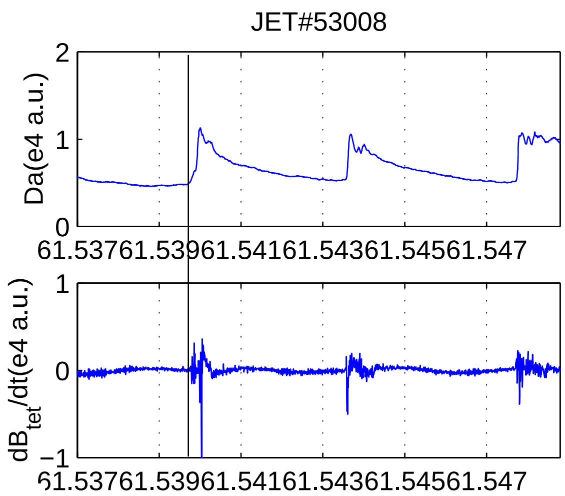
(high T $_{vessel}$~320C^0)
2.4MA/2.4T,
up/low=0.38/0.28,
nped=6.44e19m-3'
felm~70Hz (type III)

(low T $_{vessel}$~200C^0)
1.5MA/2.7T,
up/low=0.52/0.44,
nped=3.e19m-3,
felm~200Hz (type III)

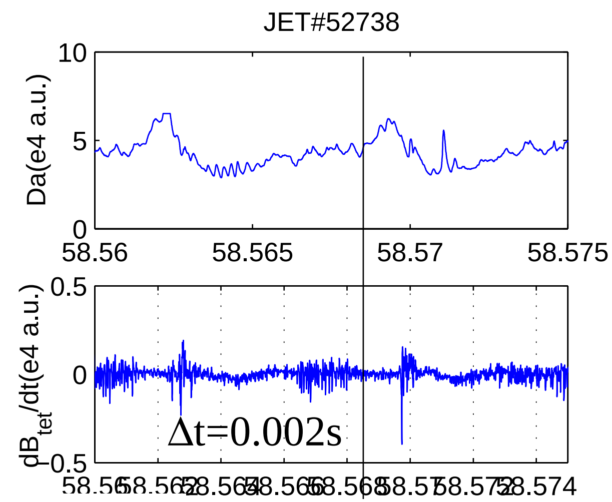
(high T $_{vessel}$~320C^0)
2.5MA/2.7T,
up/low=0.52/0.44,
nped=8.2.e19m-3,
felm~125Hz (type III)



OS, 2. 2MA/2.6T,
nped=2.e19m-3,
felm~200Hz (type III)



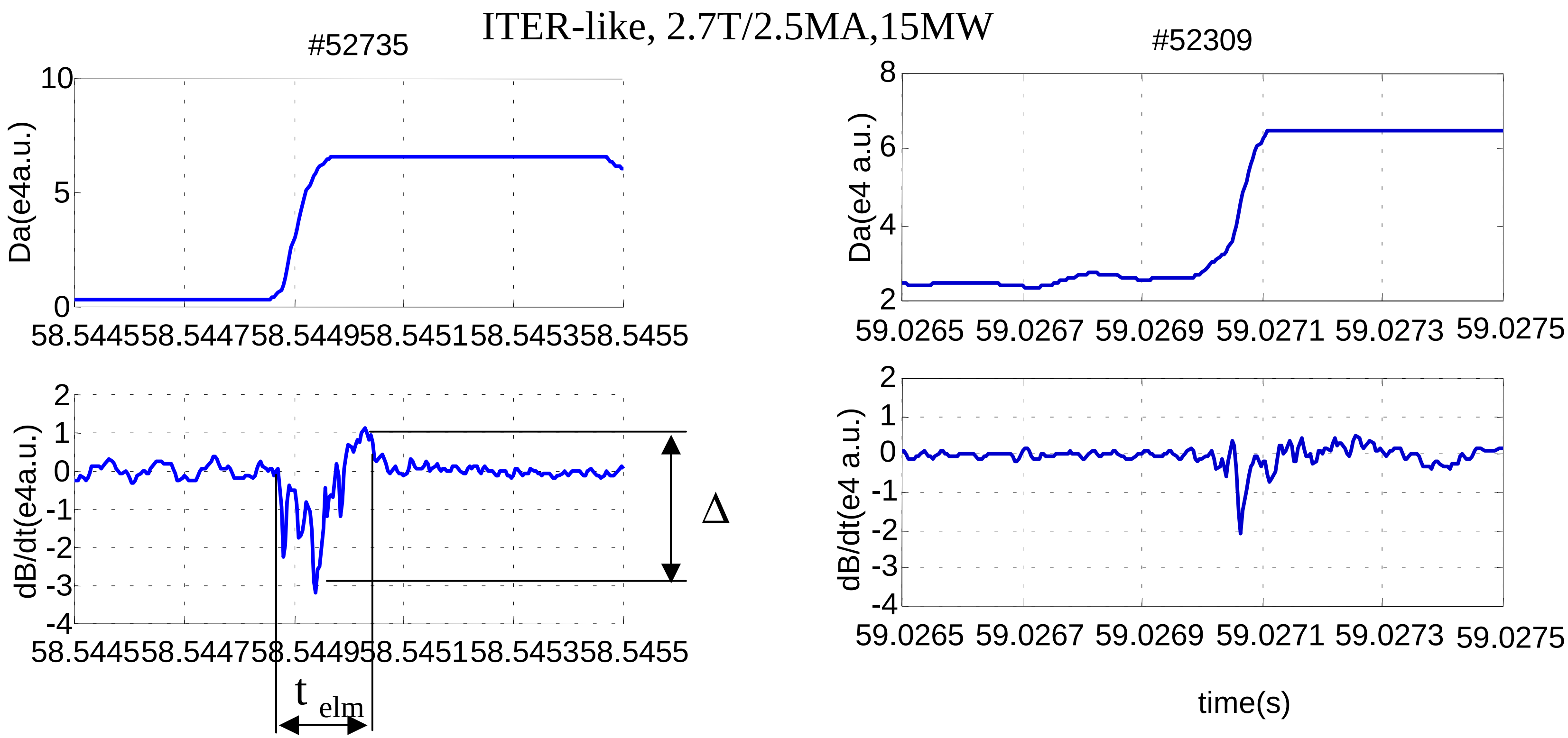
1.5MA/2.7T,
nped=3.e19m-3,
felm~200Hz (type III)



2.5MA/2.7T
nped=8.2.e19m-3,
felm~125Hz (type III)

High and low density **type III** elms have different characteristics on magnetics.
Type III ELMs activity at low density in OS and ELMy-H mode demonstrated correlation between Da signal and magnetic perturbation with characteristic time ~10^{-3}s and approximately 10 times lower amplitude than for type I ELMs. Type III ELMs at high density have no clear correlation between magnetic and Da signals, suggesting different nature of the edge instability for type III ELMs at high and low densities.

Magnetic perturbation dB_θ/dt measured by Mirnov pick-up coil of type I ELM (CATS data)

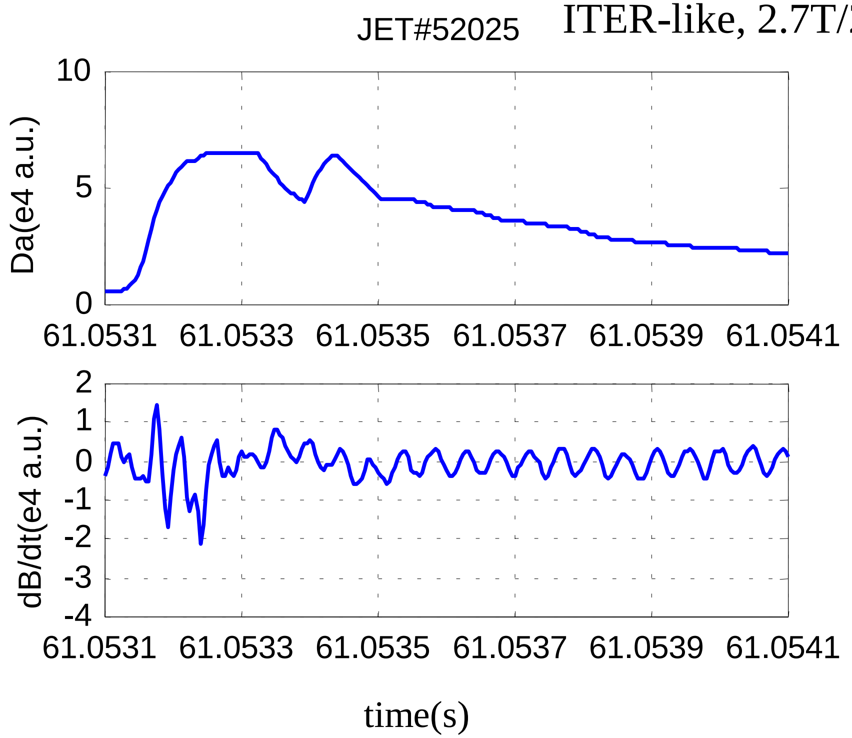


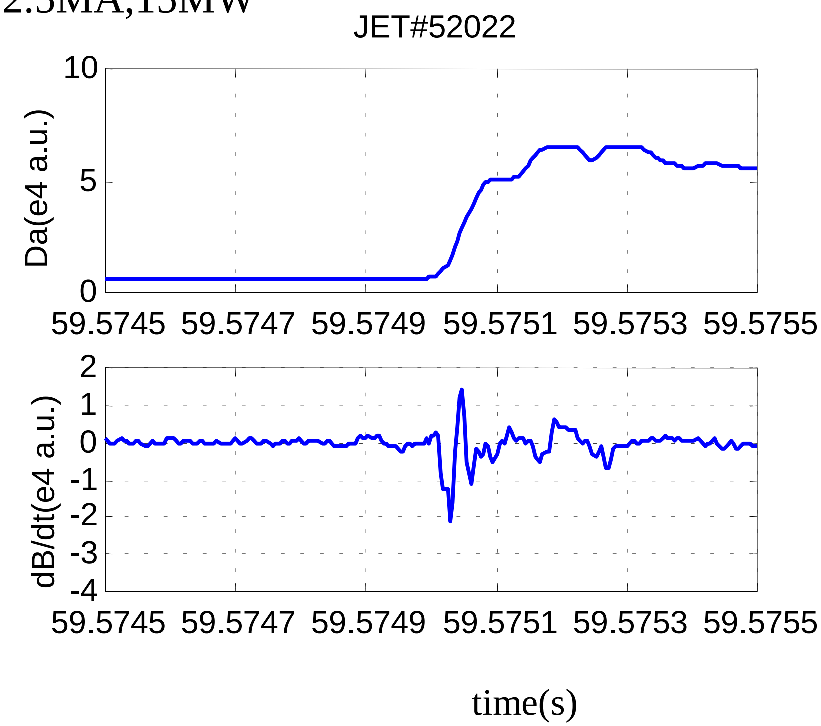
$n_{ped}=0.6\ 10^{20}m^{-3}$
$t_{elm} \sim 2.10^{-4}s$
$\Delta(dB/dt) \sim 4$ (e4 a.u.)

$n_{ped}=0.93 10^{20}m^{-3}$
$t_{elm} \sim 1.5 10^{-4}s$
$\Delta(dB/dt) \sim 2$ (e4 a.u.)

t_{elm} doesn't depend on the density, dB_θ/dt amplitude decreases

ITER-like, 2.7T/2.5MA,15MW

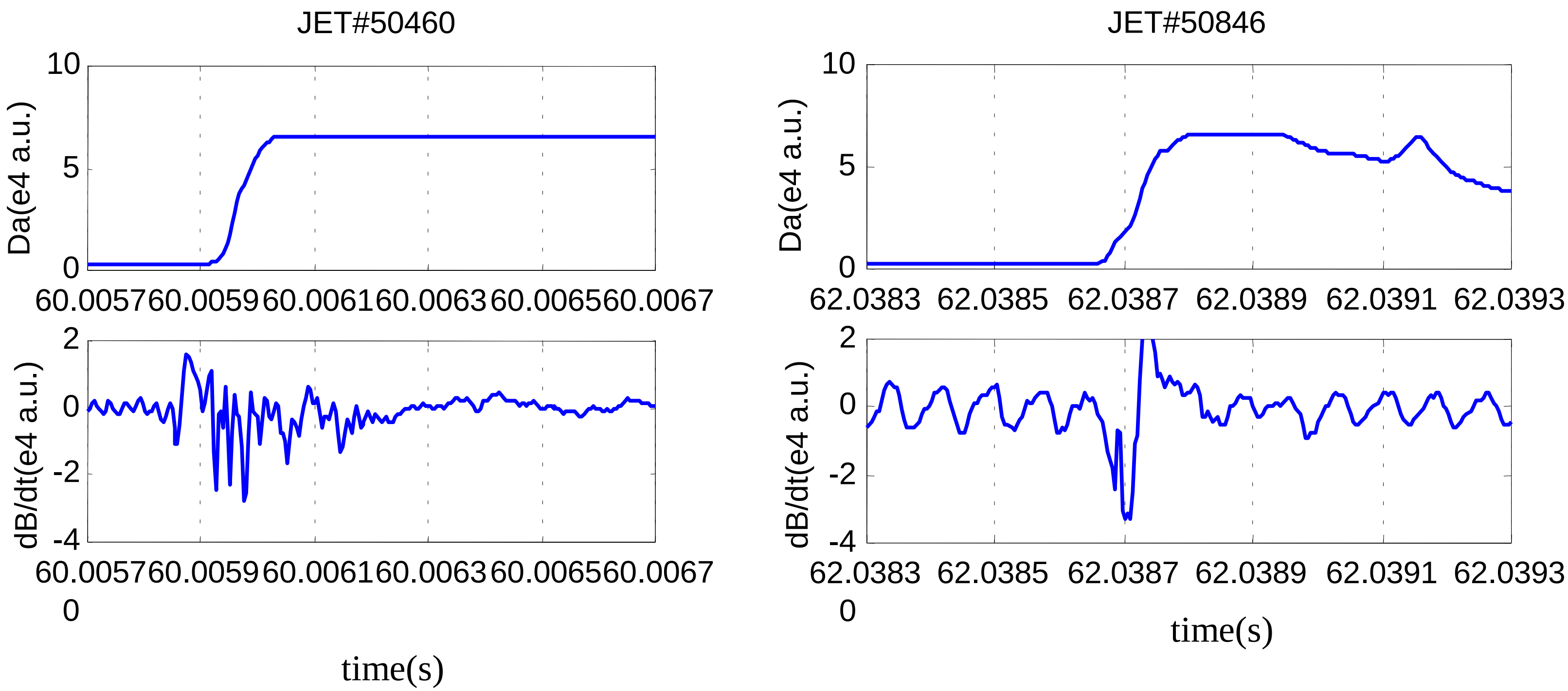




n_{ped}=0.7 10^{20} m^{-3}
t_{elm} ~2.10^{-4} s
Δ(dB/dt)~3 (e4 a.u.)

n_{ped}=0.73 10^{20} m^{-3}
t_{elm} ~1.5$10^{-4}$ s
Δ(dB/dt)~3 (e4 a.u.)

t_{elm} and dB/dt amplitude are~ the same for the same n_{ped}



n_{ped}=0.4 $10^{20}m^{-3}$
t_{elm} ~2.5$10^{-4}$s
Δ(dB/dt)~4.5 (e4 a.u.)

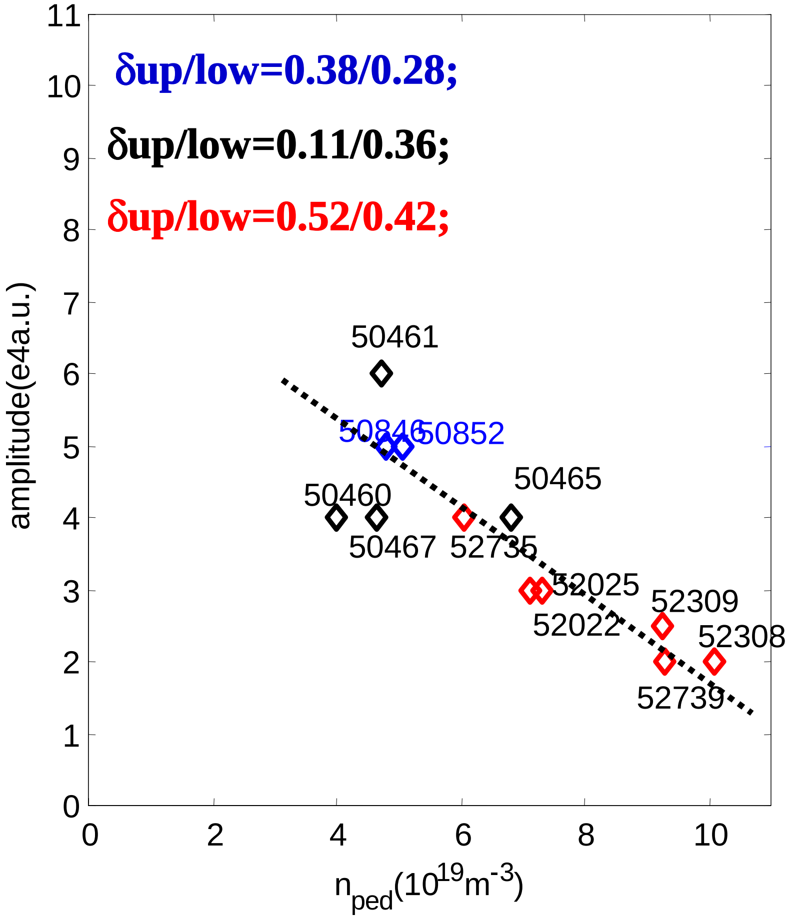
δ_{up}=0.11

n_{ped}=0.48 $10^{20}m^{-3}$
t_{elm} ~2.10^{-4}s
Δ(dB/dt)~5 (e4 a.u.)

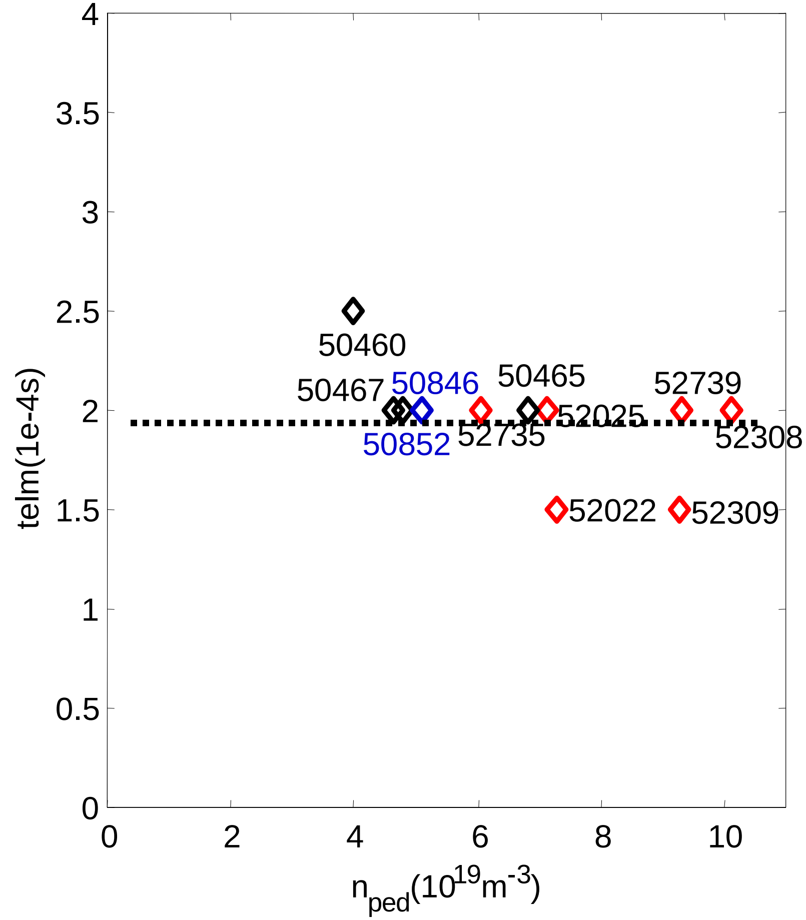
δ_{up}=0.28

No triangularity dependence if nped is the same

Magnetic perturbation amplitude Δ(dB/dt) decreases with pedestal density

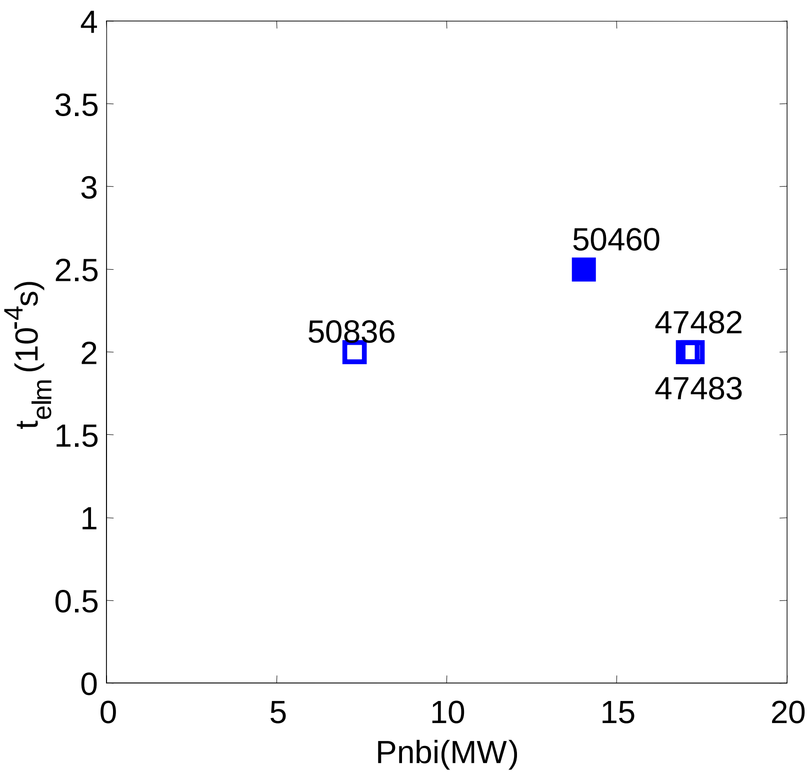


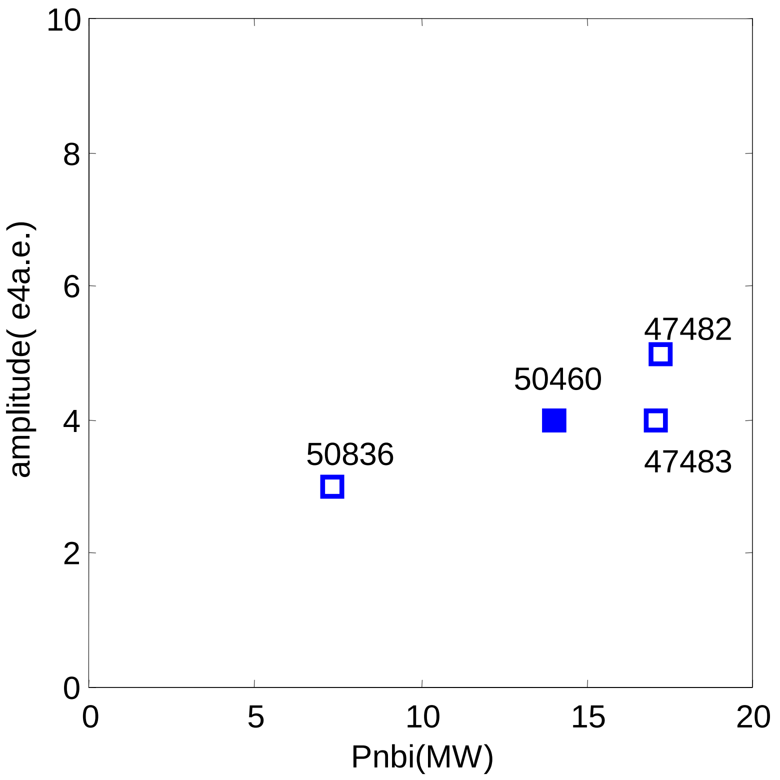
ELM precursor duration t_{elm}~constant with density (and triangularity)



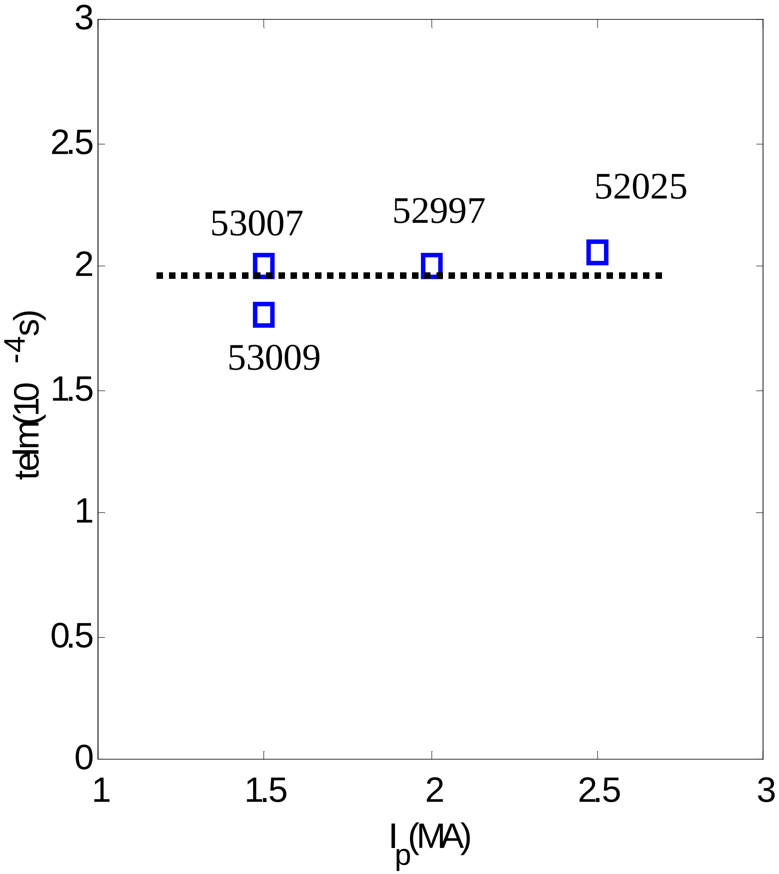
~14-15MW, 2.4,2.7T/2.5MA pulses

Weak power dependence of magnetic perturbation amplitude Δ(dB/dt); ELM duration ~constant for the same pedestal density (n ped~3.7-4.5e19m-3). All pulses 1.9MA/2T except #50460 (2.5MA/2.4T).





No q dependence for ELM duration t_{elm}.
All pulses: 2.7T, ~15MW



Characteristic time scales compare to ELM time in JET:

t_{elm}~ 2.10^{-4} s, elm rising time ~ 10^{-4} s

electron parallel time:
$\tau_{//}^{e}$ ~$L_{//}/V_{Te}$~ $\pi Rq/V_{Te}$~2.10^{-6} s (for 1keV, q=3)

ion parallel time (here only convection, at high density + collisions):
$\tau_{//}^{i}$ ~$L_{//}/c_s$~ $\pi Rq/V_{Ti}$~10^{-4} s (for 1keV)
compatible with t_{elm}

<u>electrons can be stochastic</u>: $t_{elm}/ \tau_{//}^{e}$ ~10^2

Conclusions:

1. ELMs frequency decrease at high pedestal density (~nGR) was observed in ITER-like triangularity configuration at high (320°) and low (200°) vessel temperatures.

2. Energy losses per ELM decreases with density.

3. The broadband MHD activity (<30kHz, with main toroidal number=-8) appears in high density (nGR~1.1) high triangularity discharges (δ~0.5) in between type I ELMs.

4. Type I ELM duration in JET is 1.5-2.10^{-4} s~ approximately constant with density, q, power. Magnetic perturbation amplitude decreases (~ linearly) with density increase, which can explain reduced energy losses per ELM at high density.

5. Type III ELMs activity at low density demonstrated correlation between Da signal and magnetic perturbation with characteristic time ~10^{-3}s and approximately 10 times lower amplitude than for type I ELMs. Type III ELMs at high density have no clear correlation between magnetic and Da signals.