Integrated exhaust scenarios with actively controlled ELMs

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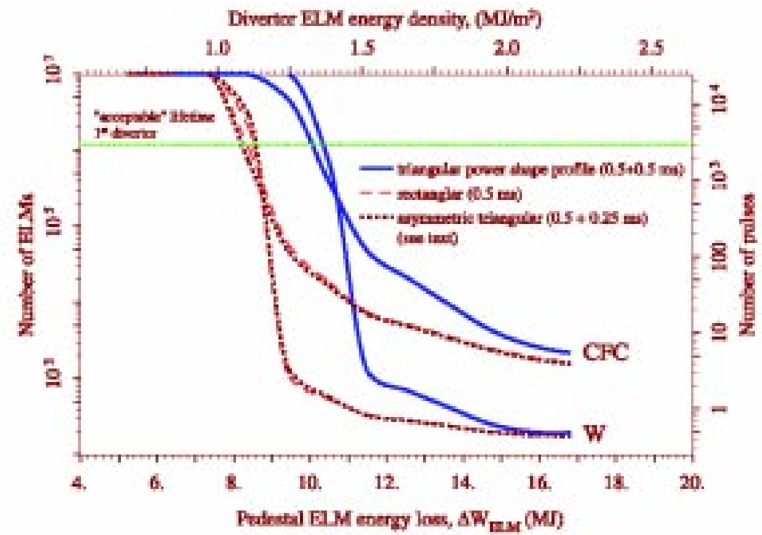
- **The aim of ELM control task**
- **Investigated trigger techniques**
- **Results from ASDEX Upgrade**
- **Application in the integrated exhaust scenario**
- **Outlook**

ASDEX Upgrade

ELM frequency control: one possible route to ELM mitigation

A. Kirk, PRL **92** (2004) 245002



F. Federici et al., PPCF **45** (2003) 1523

ELM expelling particles and energy
$\Rightarrow$ Pressure pulse (50-80% ΔW)
hit in-vessel components

Can cause severe problems for the ITER divertor
(power load density ~ V^2_{Plasma})

Polevoi et al. (NF 43 (2003) 1072):
$f_{ELM} \approx 0.5$ Hz, $\Delta W \approx 8 \times$ above limit

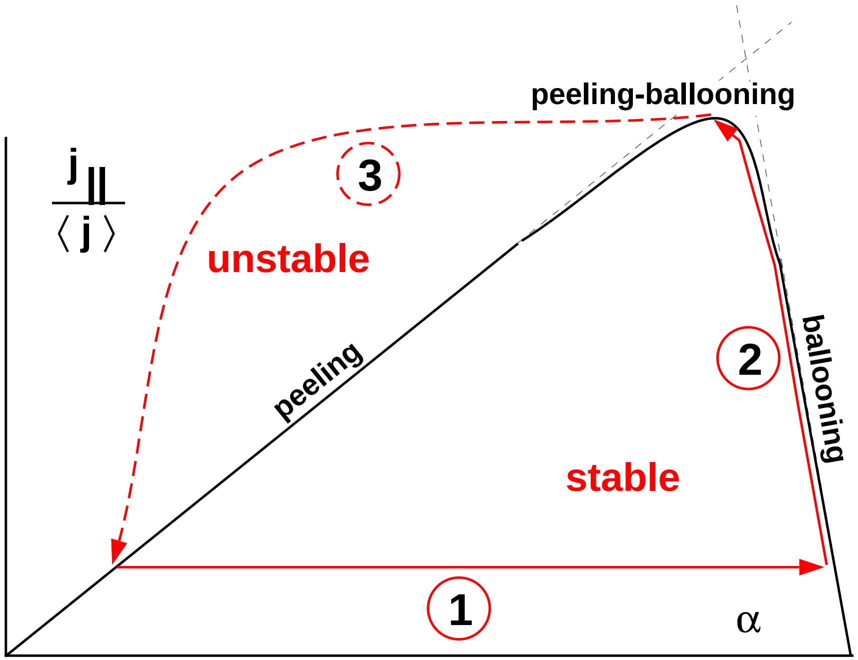
If $\langle P_{ELM} \rangle = 0.2 \times P_{heat} \Rightarrow \langle P_{ELM} \rangle \sim 1/f_{ELM}$
ameliorate via f_{ELM} enhancement
Need appropriate techniques

Approaches to control ELMs: manipulate edge p/j-profile or magn. structure

The following approaches can act on

Global & indirect (dt > dtELM)
- Ergodisation (DIII-D, equ.)
- **Vertical motion (TCV & AUG, j)**
- Current ramps (JET, j)
- ECCD, ECH (AUG, j)

Local/strong & direct (dt < dtELM)
- **Pellets (JET,AUG, p or magnetic perturbation?)**
- **Supersonic gas jet (Tore Supra, local cooling)**
- Laser blow off (KFKI, local cooling)



1. ∇p rises on transport time scale

2. ∇ clamped by high n ballooning, edge current density rises on resistive time scale

3. Medium n instability ("peeling"), p and j losses until stability recovered

How to assess the "quality" of ELM control techniques?

Main aspects of a tool when employed for ELM control with respect to operation features ("recipe development")

1) Pace making

Is external ELM control possible in a clear stable type-I ELMy H-mode regime, what is the accessible frequency range?

2) Impact on performance (confinement)

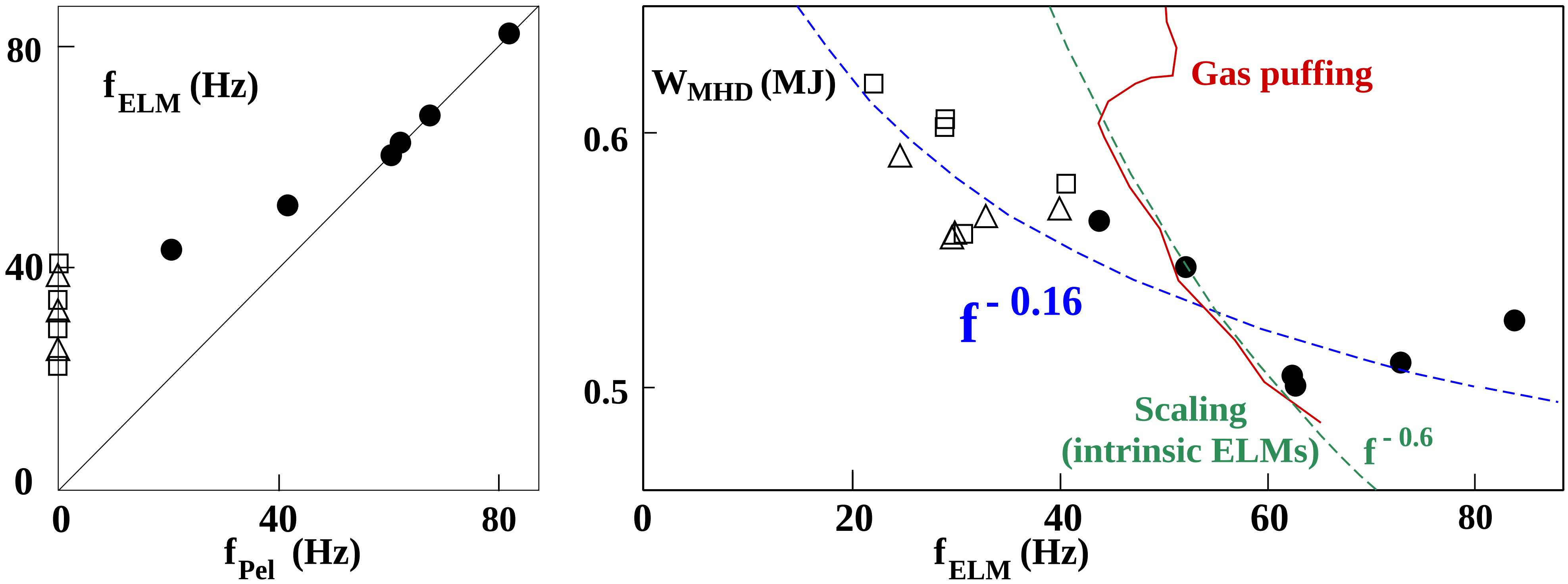
Are imposed burdens (density increase, confinement degradation) still bearable?

3) Is there really ELM mitigation?

Compare according plasmas, divertor power load

Injection of small solid D pellets: reliable ELM pace making

NF **43** (2003) 1110; **44** (2004) 665



Pace making:

$f_P \geq 1.5 \times f_0$: full control
below: mixed intr.&triggered

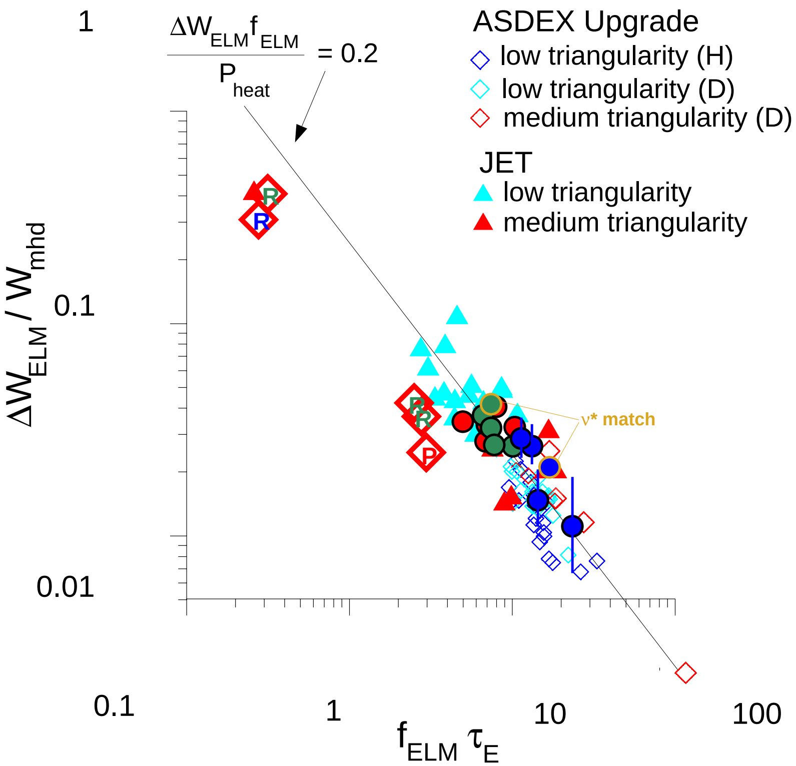
Performance:

less degradation than expected from (intrinsic) scaling, possibly due to fuelling

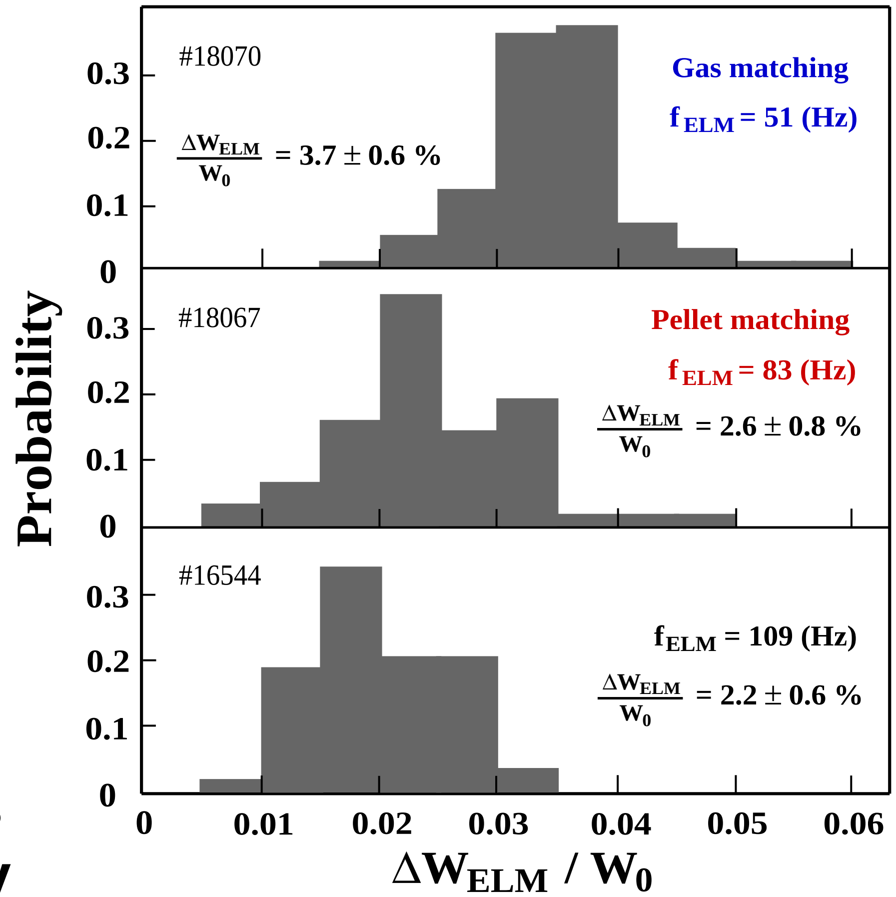
ASDEX Upgrade

Injection of small solid D pellets: ELM energy content reduction

All discharges analysed show ELMs in accordance with fixed power loss scaling



Matched plasma: higher f_{ELM} results in reduced averaged and maximum ELM loss

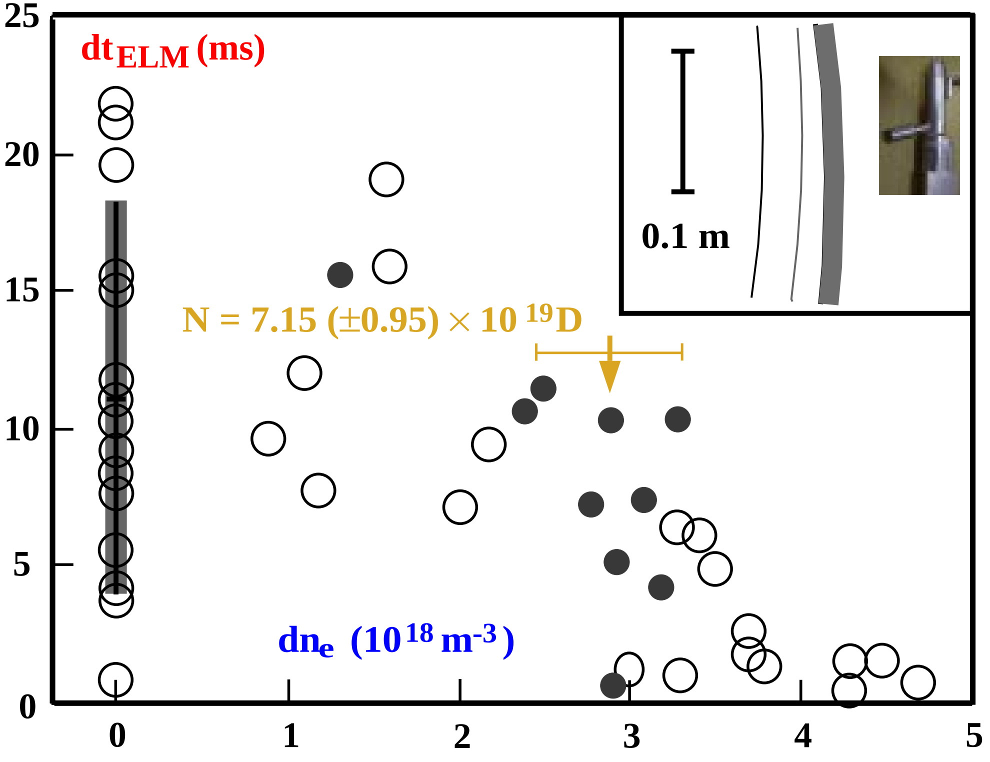


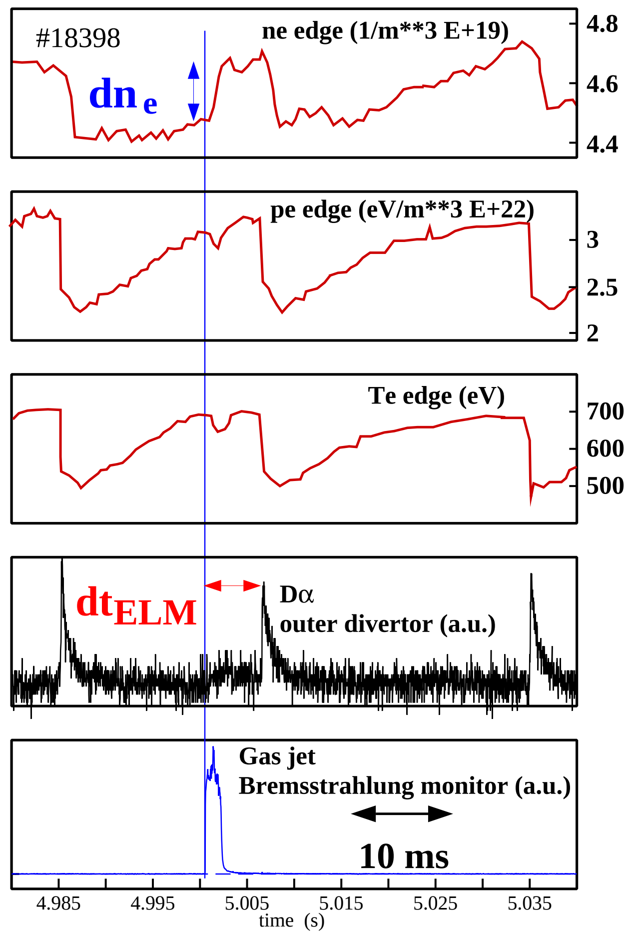
ELM mitigation:

triggered ELM (distribution) behaves like intrinsic one at **same frequency**

Injection of supersonic D gas jet: no instant ELM trigger

Gas jet causes density ⇑ and temperature ⇓ at pedestal top ⇒
"premature" pressure rise, next ELM slightly earlier
⇒ pure fuelling effect, not suitable for ELM control

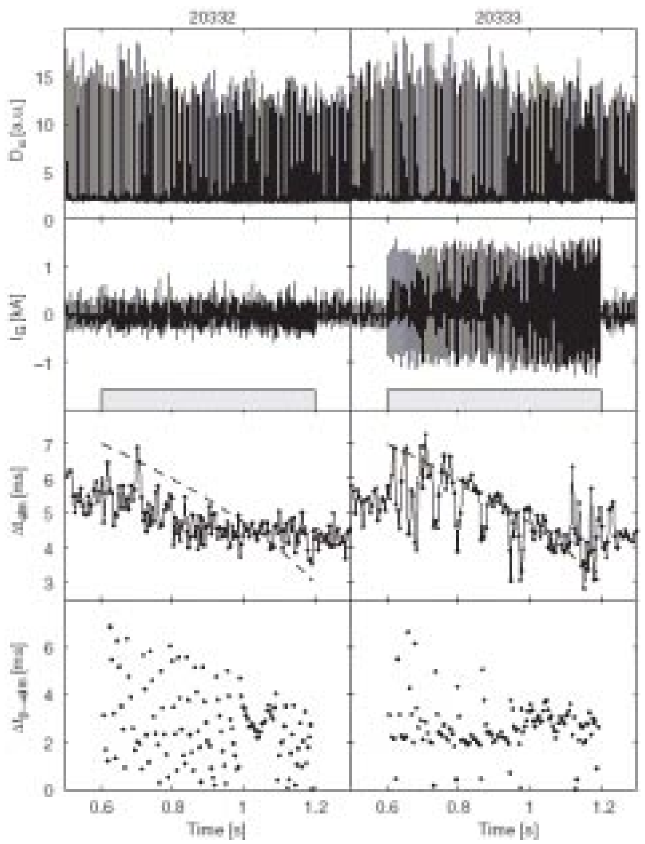




1 ms response time ⇒ 50 Hz rate ≅ 5 E21 D/s
same Γ by gas bleeding ⇒ fELM 80 - 120 Hz

"Magnetic triggering": useful in type-III and type-I ELM plasmas

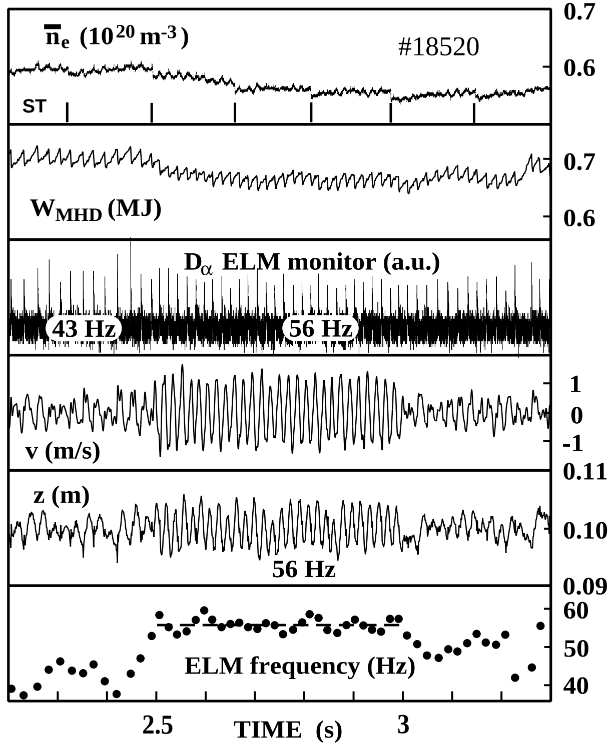
TCV : type-III ELMs



A. Degeling et al., PPCF **45** (2003) 1637

Idea & Experts

AUG : type-I ELMs



❶ f_D/f_{ELM} = 0.75 - 1.8

❷ $W_{MHD} \sim f_{ELM}^{-0.22\pm0.06}$

❸ ELMs on scaling

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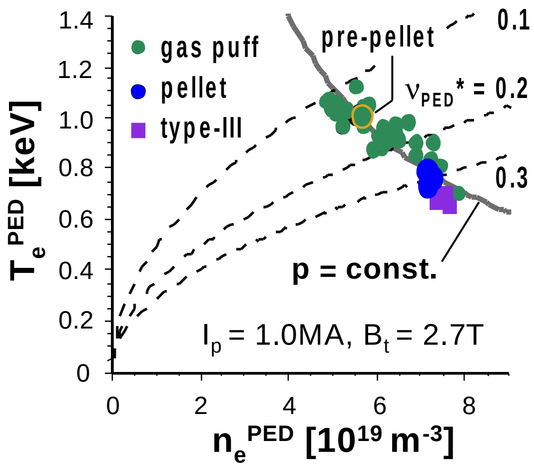
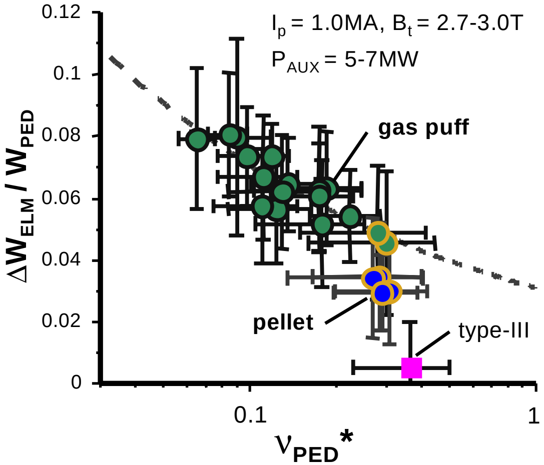
Investigation of ELM physics by comparison of intrinsic and triggered ELMs

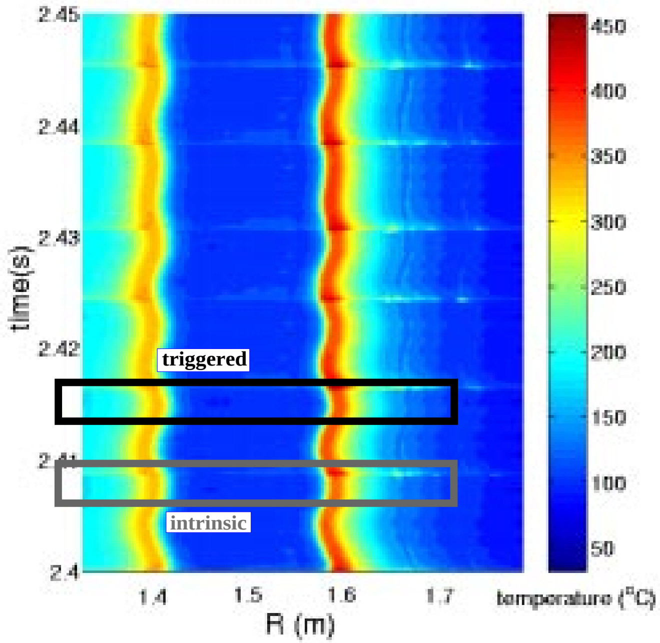
Strong correlation between plasma parameters and fELM released
⇒ fELM becomes "free" parameter

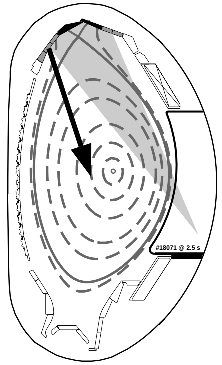


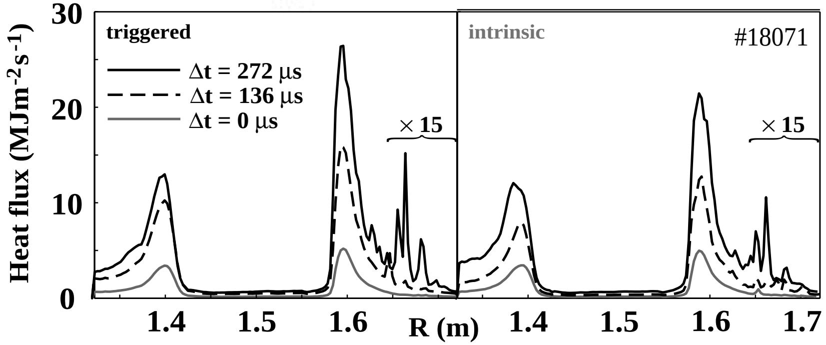


No significant difference in the ELM dynamics (structure) with respect to temporal or spatial resolution once the ELM is triggered

for identical fELM

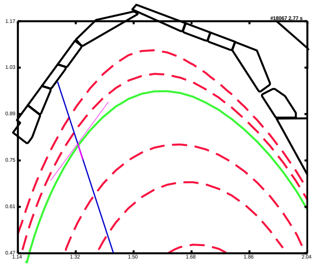


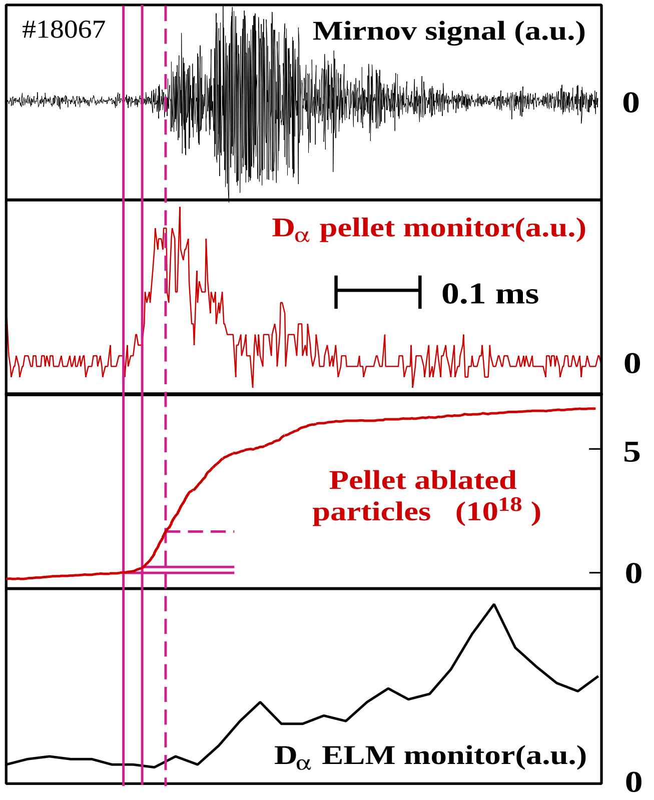




Thermography: same heat load pattern
also:
Mirnov: same temporal evolution of mode activity
Reflectometry: same turbulence at edge (resolves gas impact)

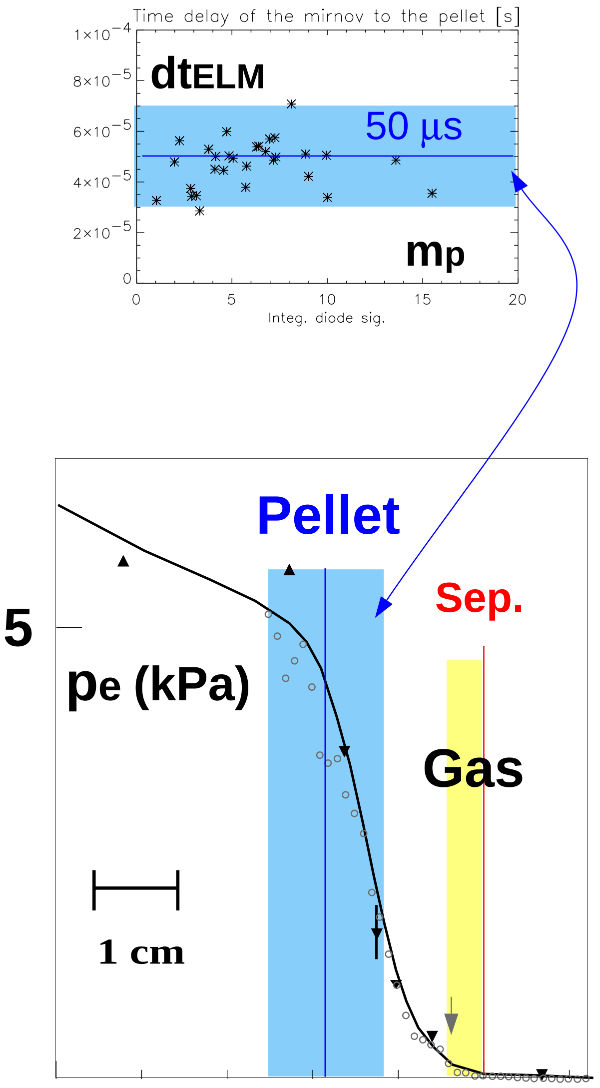
The "external" trigger as a perturbation probing the local stability



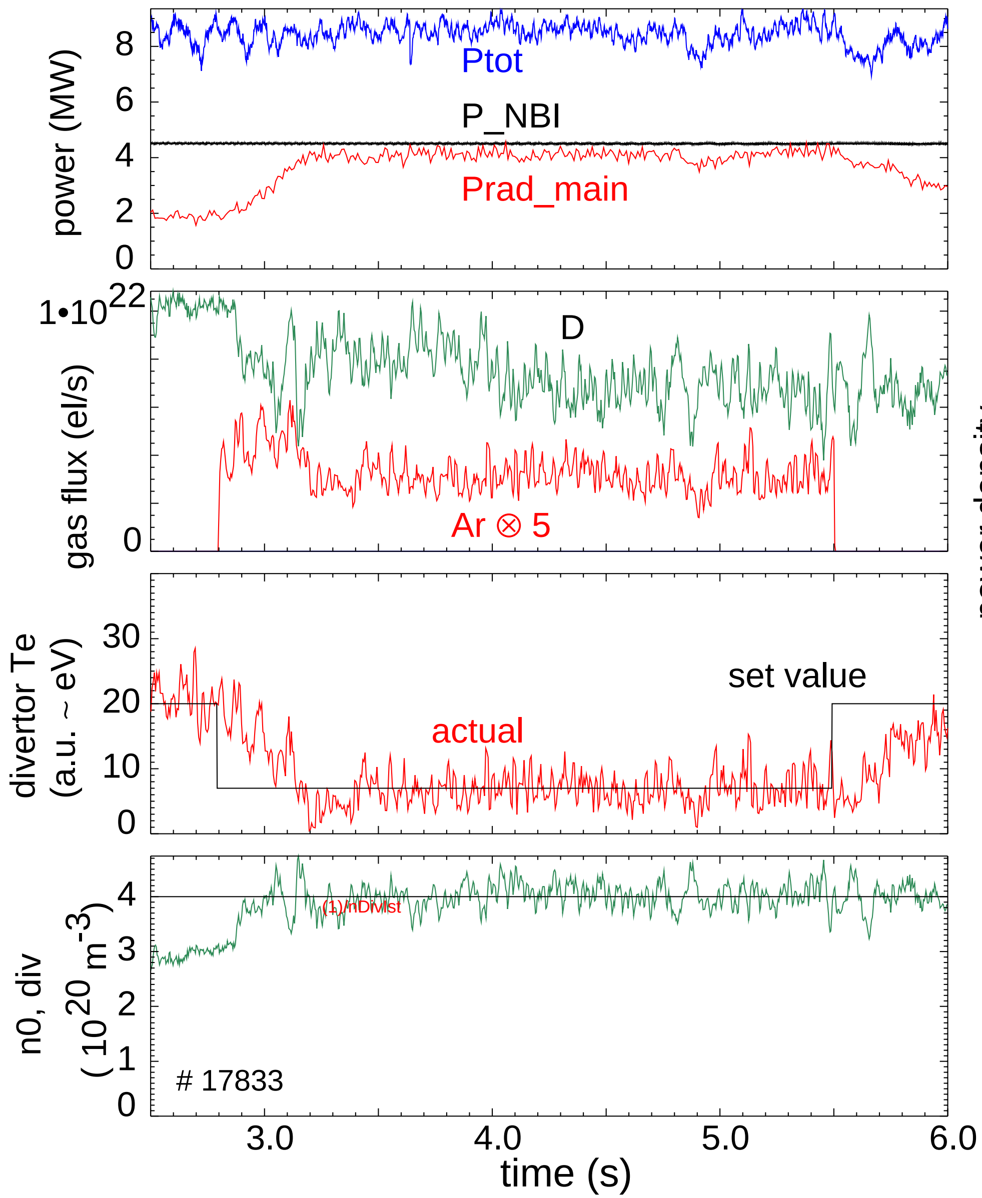


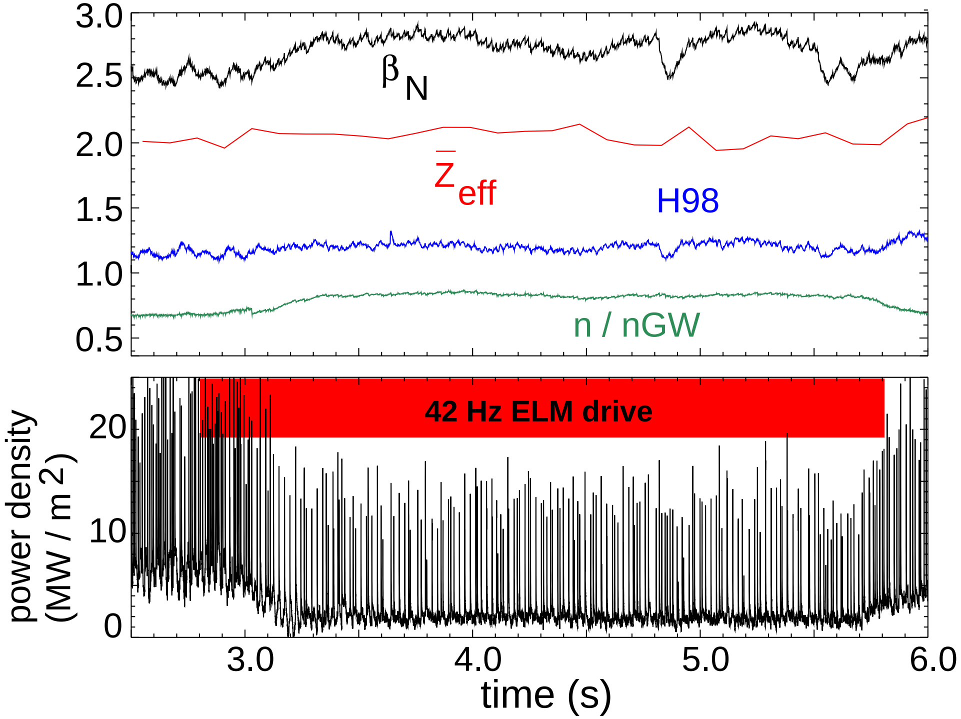
ELM trigger time: location inside barrier region

- not depending on pellet features (prompt ELM)
- best correlation with pen. depths
- seems to depend on local parameters (not yet resolved)

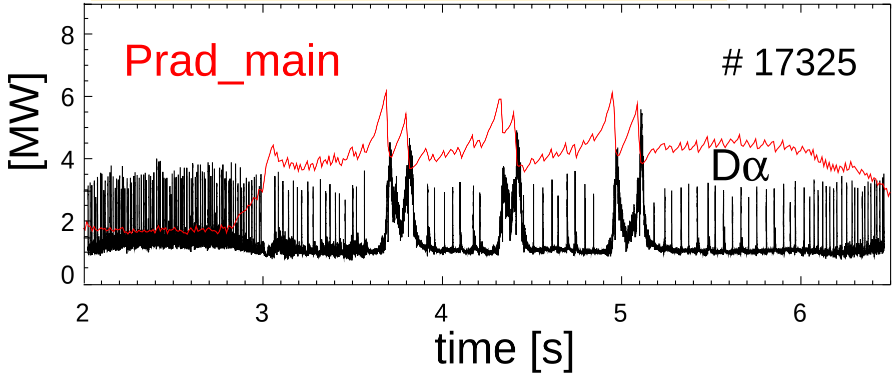


Integrated exhaust scenario, controlling: inter-ELM & ELM power, particle removal rate





reference without pellets:



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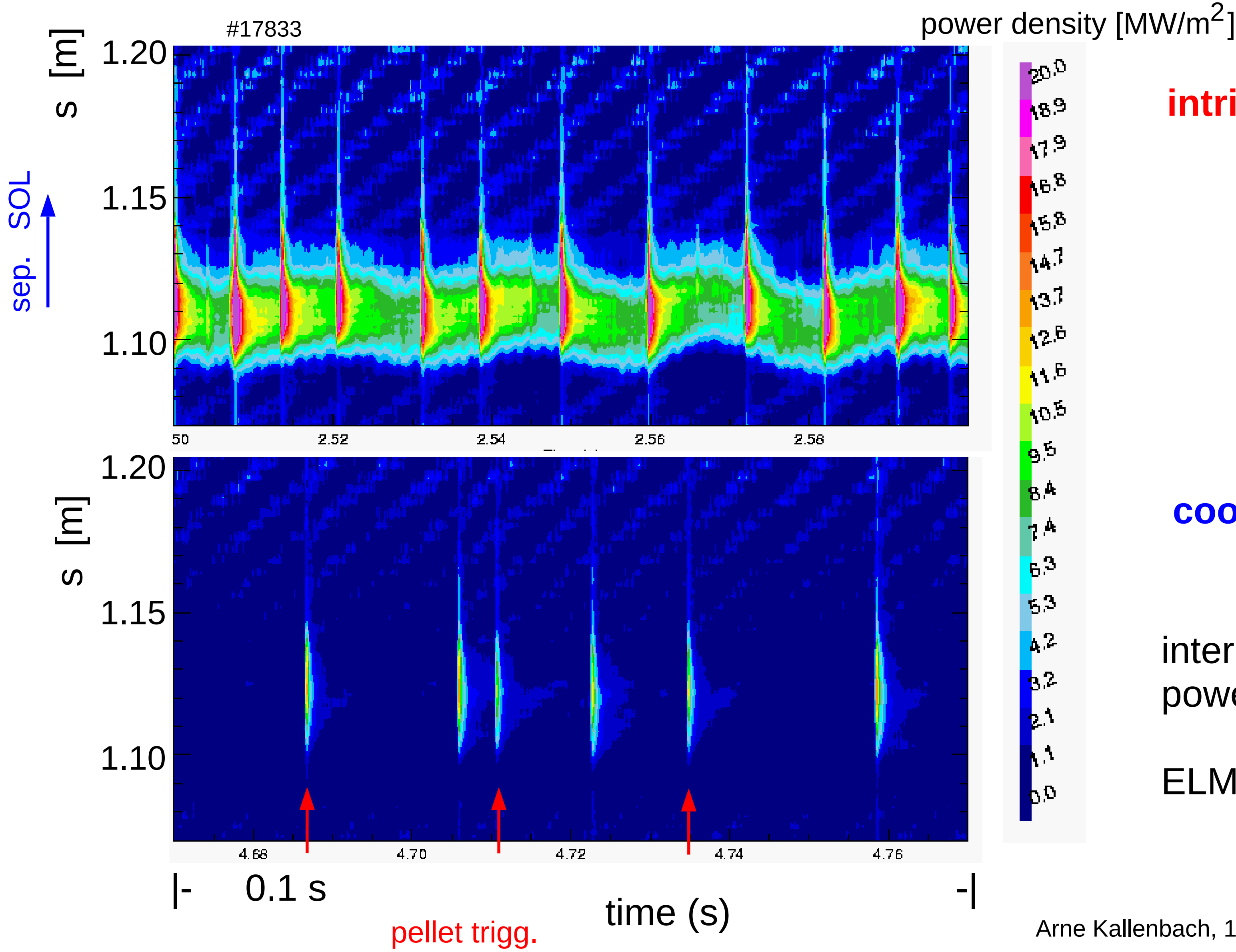
Integrated exhaust scenario: outer target heat flux from thermography



intrinsic phase

cooled phase

inter-ELM
power detachment

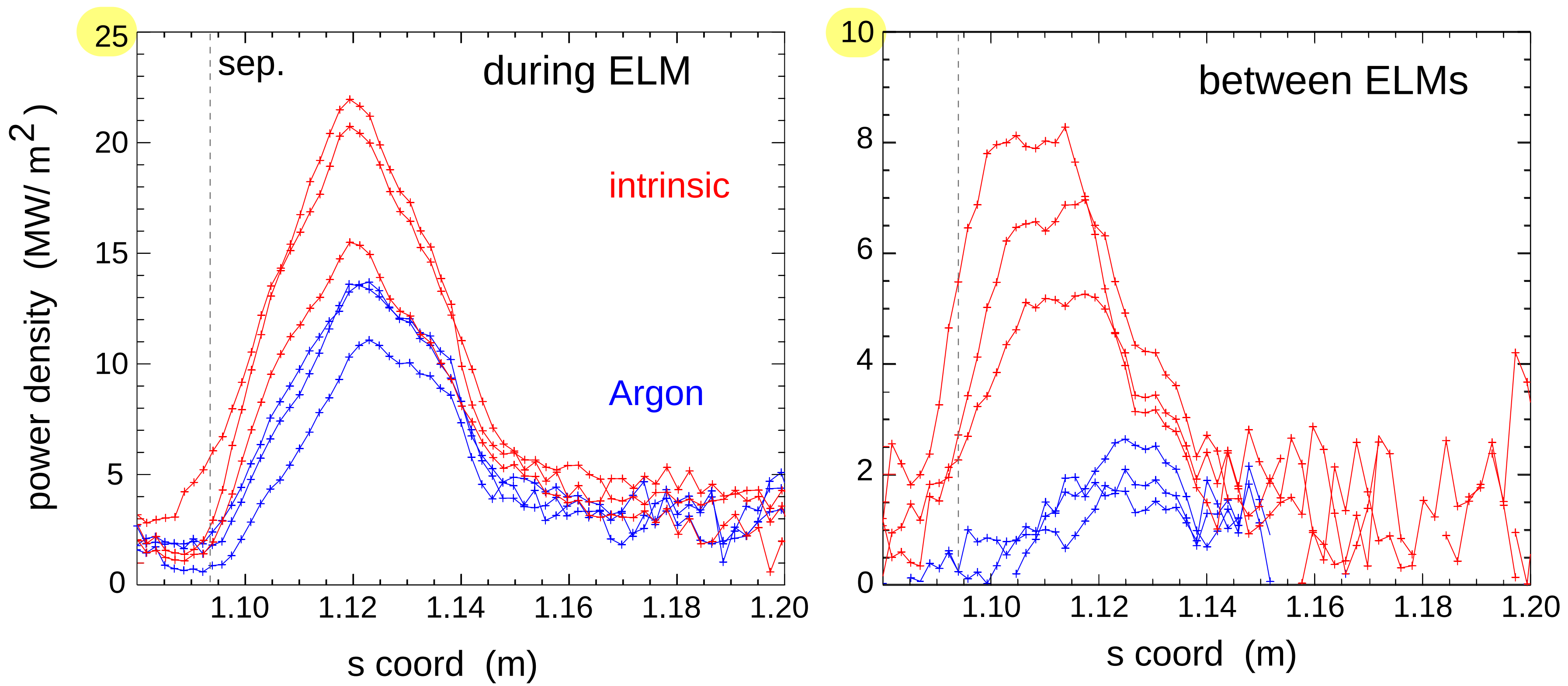
ELM power reduced

Arne Kallenbach, 16th PSI, 2004, O-27

Mitigation of inter- and intra-ELM impact: Argon seeding reduces divertor power load

IR thermography viewing outer divertor target power load:

Ar seeding reduces f_{ELM} 108 → 60 Hz
but reduced both the intra- and inter-ELM power flux
(P_{rad}⇑; ν*⇑ @ n⇑,T⇓ in pedestal)



Summary & Outlook

External ELM pace making can enhance f_{ELM} and reduce P_{ELM}

f_{ELM} becomes "free" parameter; small impact in performance

Different methods available, "probing" the ELM physics

Application in integrated exhaust scenario using an "extrinsic" radiator reduces both inter and intra ELM divertor power flux

Makes operation with full high-Z wall feasible

Detailed investigation of ELM physics

Pellet tool becomes more simple with increasing R
Pace making might even come as "bonus" with fuelling