Impurity radiation to control pedestal temperature: how to meet the constraints for an integrated scenario?

Presented by P. Monier-Garbet,

Thanks to all the contributors to this work

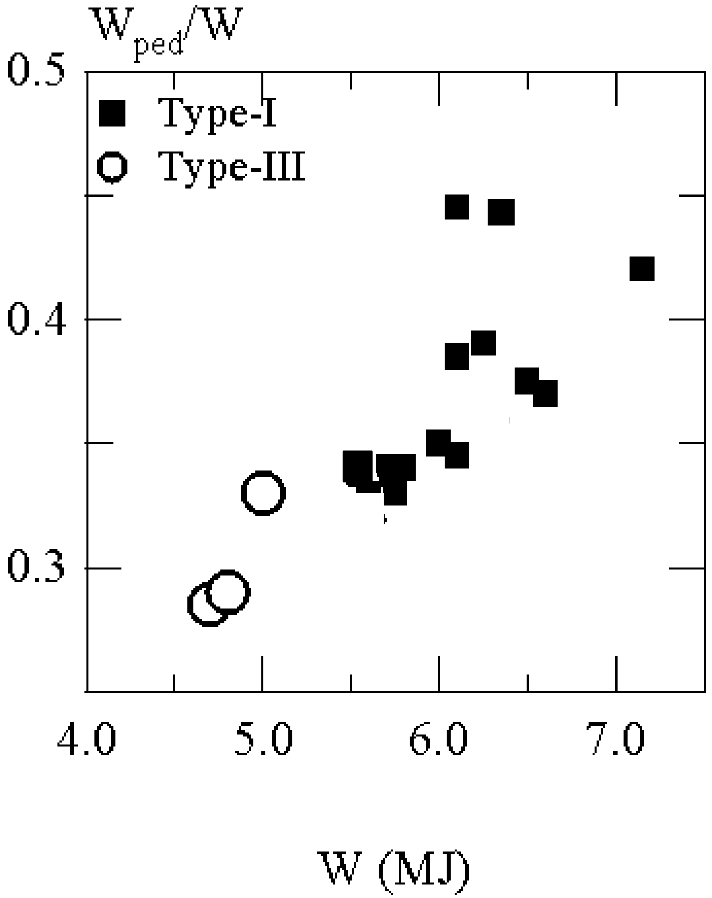
2. Introduction: what are the requirements?

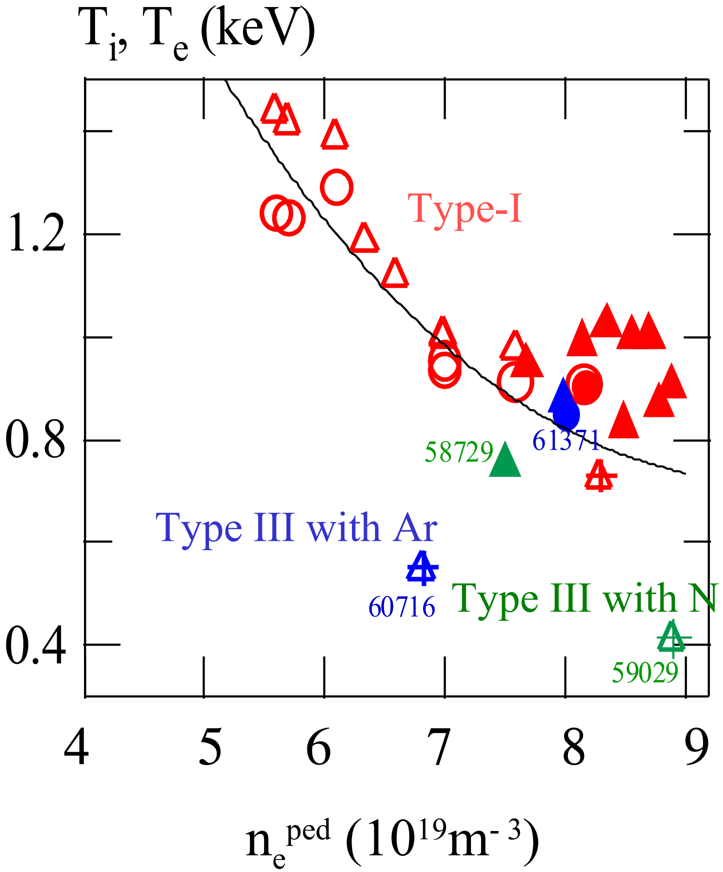
2. Control of the pedestal temperature with impurity radiation?

3. Conclusion: integration?

In standard H-mode, high energy content requires:

- high W_{ped}: decreasing W_{ped} = decreasing W (profile stiffness)
- P close to Typ-I ELM value





ELM control is needed. How?

1) confinement marginally affected: maintain ∇P ~ at ballooning threshold

ELM suppression

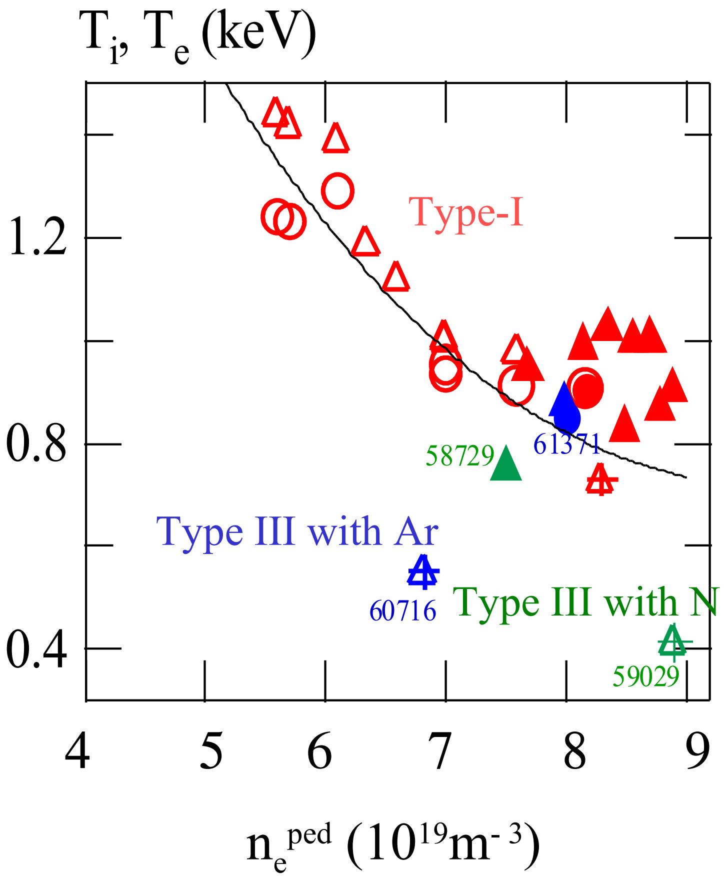
- ergodisation of plasma edge

-harmonic oscillations

ELM frequency control

- pellet pace making: (convective ELMs?)

- pedestal impurity radiation



2) degraded confinement

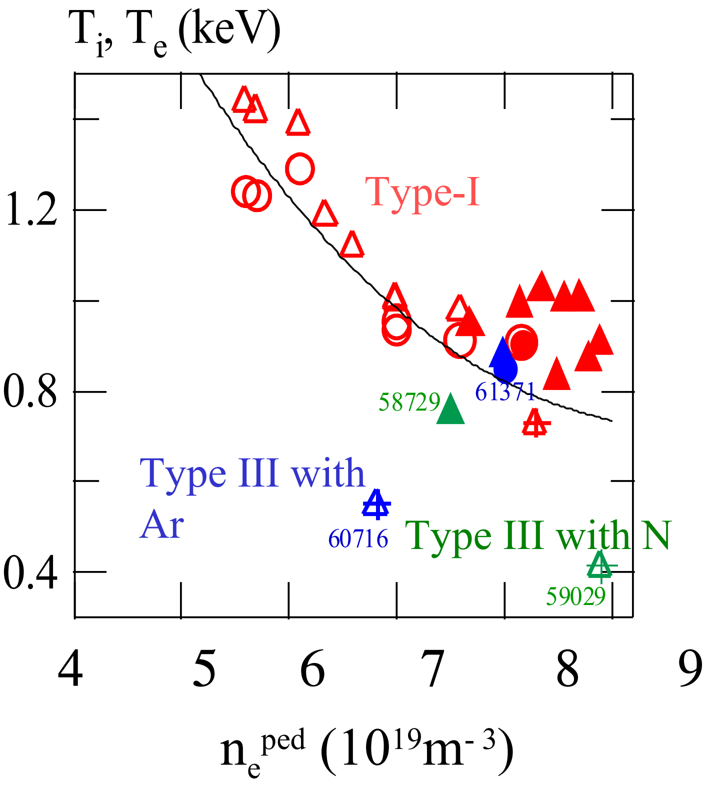
decrease ∇P further, and :

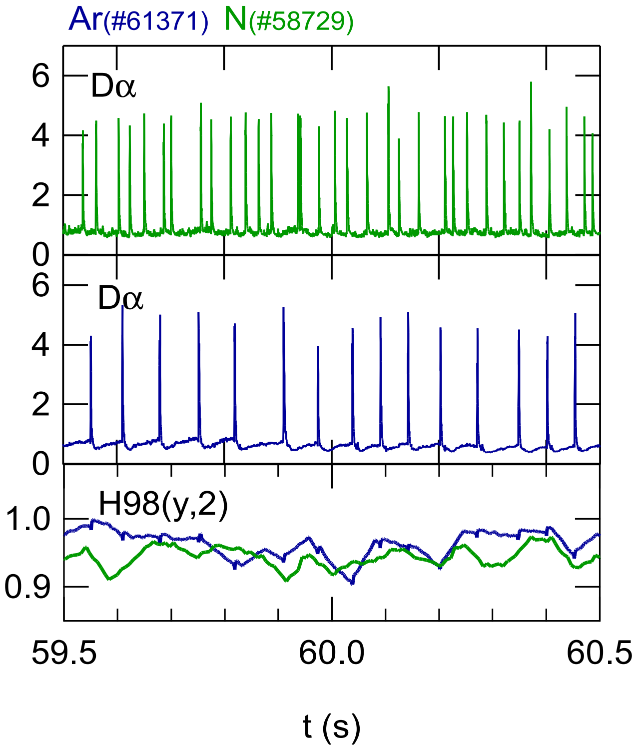
find a scenario with high W and low W_{ped}

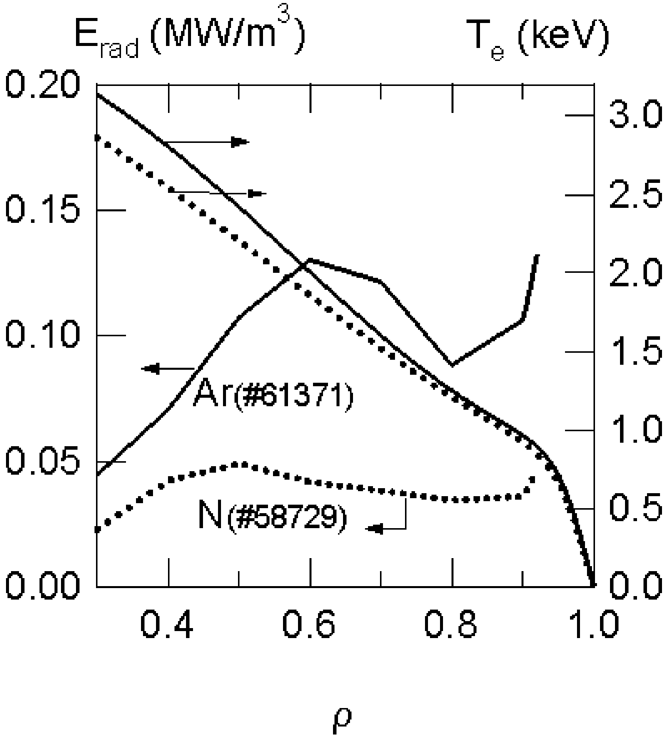
increase I_p to recover W

→scenario with Type III ELMs at high I_p

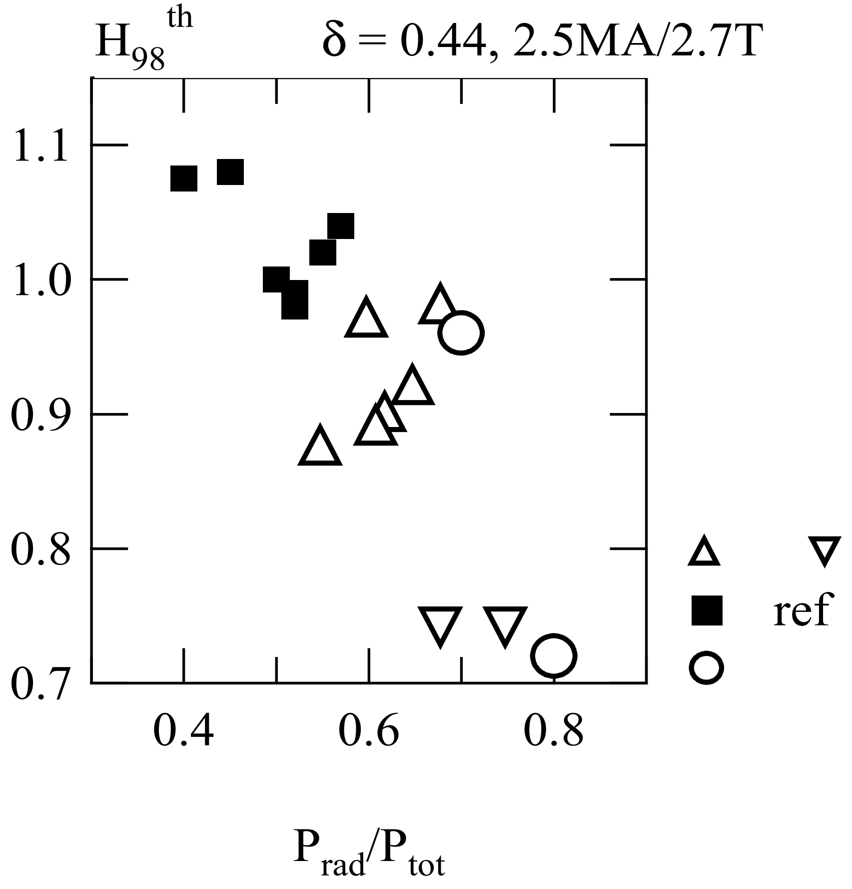
1) confinement ~not affected: control the Type I ELM frequency with pedestal radiation *(alternatively, use radiation to maintain T_e^{ped} just below threshold for Type I ELMs ?)*

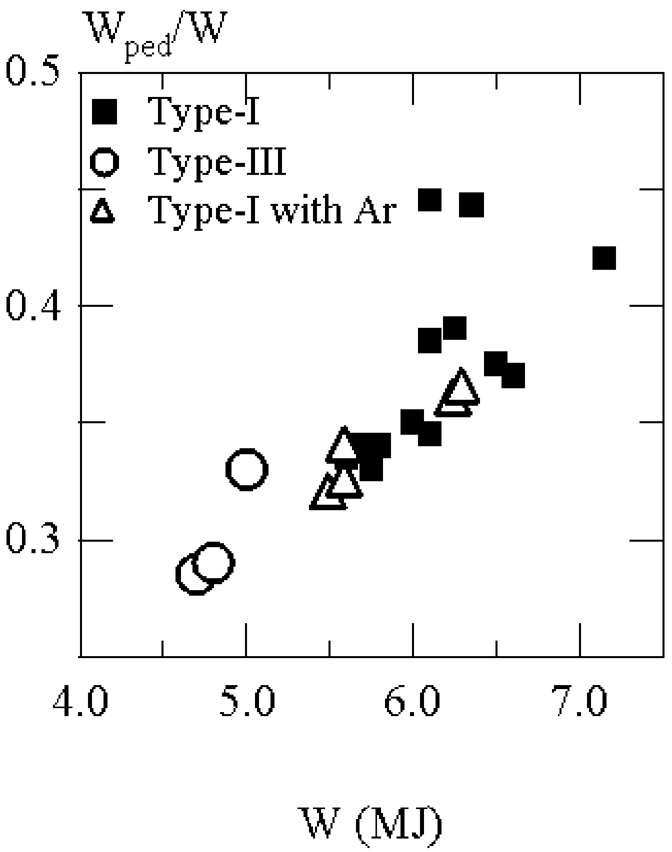




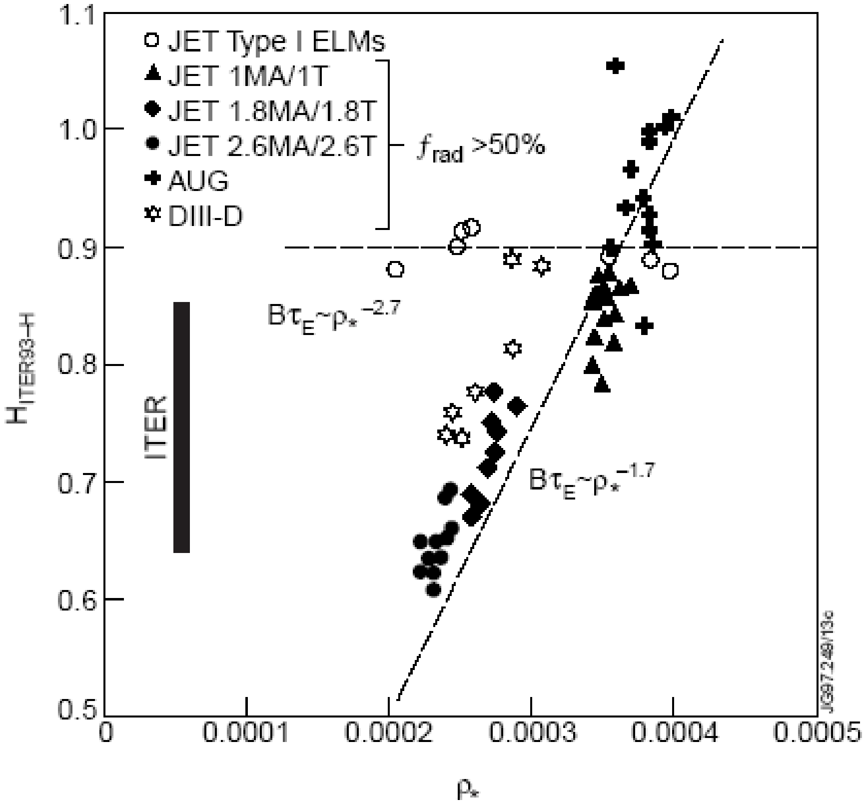


Pedestal radiation reduces W_{ped} and total stored energy (W)





Degradation / gyro-Bohm ITERH93-P scaling is observed at low ρ*

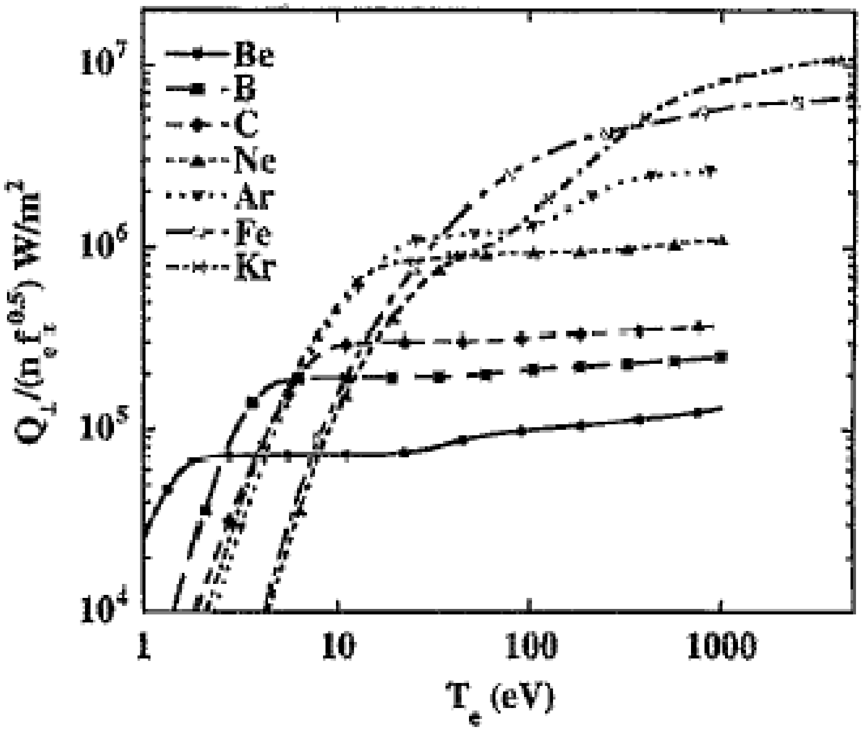


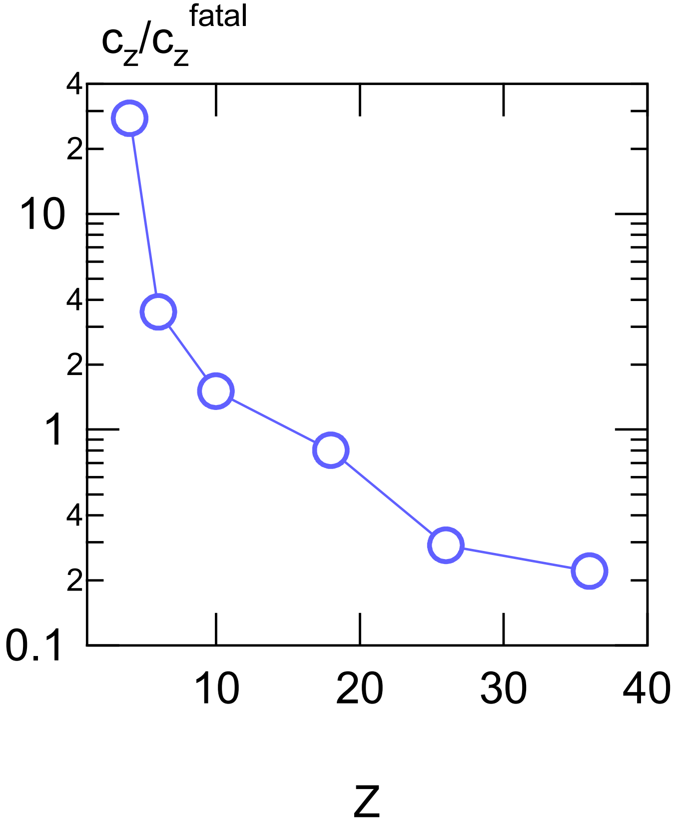
G.F. Matthews et al., NF **39** (1999) 19 - 40.

Z~Kr minimizes the impurity concentration required to control W_{ped} in ITER

D. Post, et al., Phys. Plasma, 2 (1995) 2328-2336.

$$\begin{cases} Q_{¿} = -\kappa \dfrac{\partial T_e}{\partial r} \\ \dfrac{\partial Q_{¿}}{\partial r} = -n_e n_Z L_Z(T_e) \end{cases} \Rightarrow \quad Q_{¿}^2 \approx 2 n_e^2 c_z \kappa \int_0^{T_e} L_Z(T_e)\, \mathrm{d}T_e$$



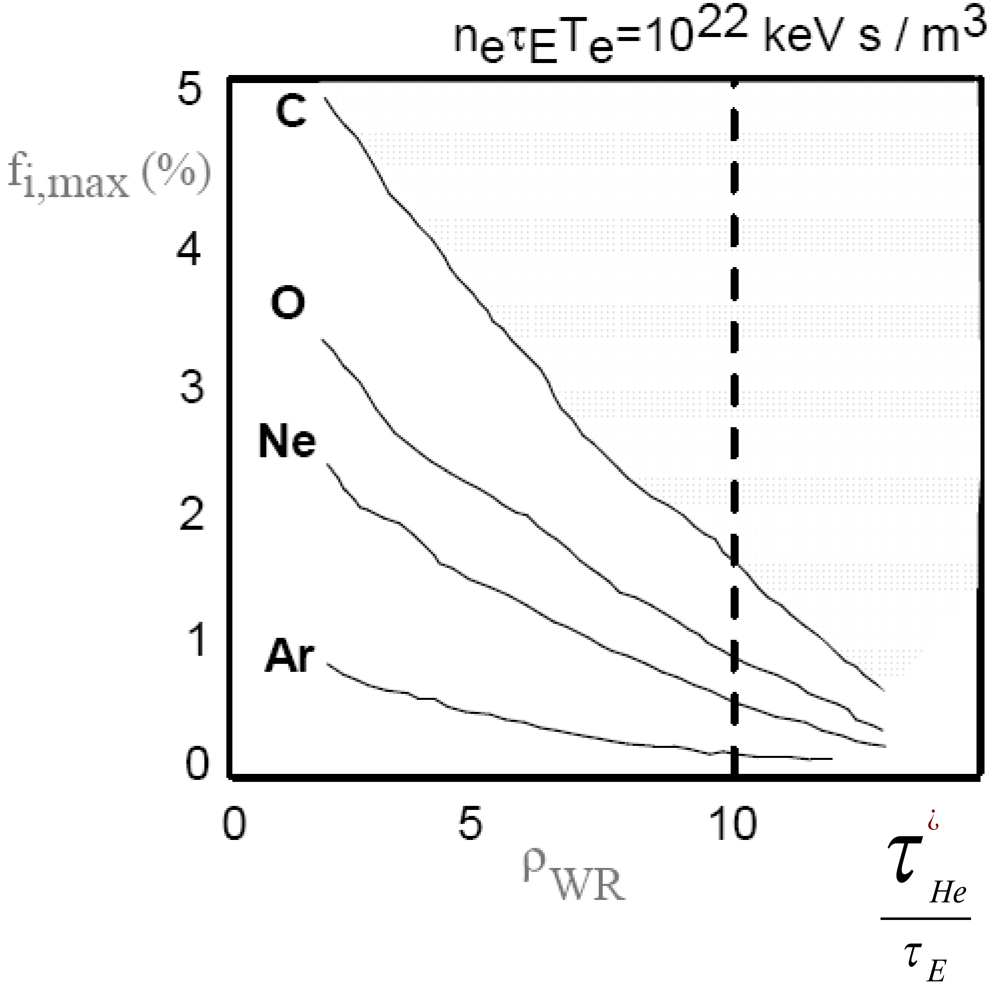


$Q_{¿} = 0.1\,\mathrm{MW/m^2}$

$n_e = 0.8 \times 10^{20}\, m^{-3}$

$\kappa = 2 \times 10^{20}\, m^{-1} s^{-1}$

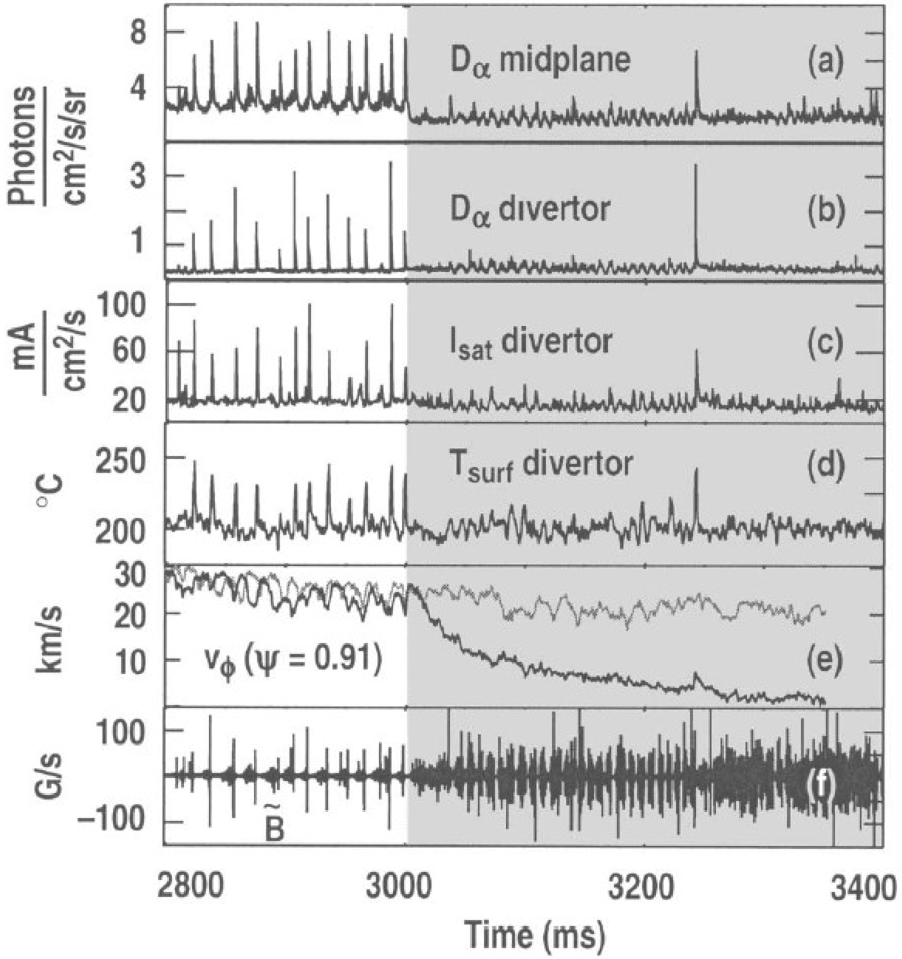
Low edge τ_p (as ~ provided by Type I ELMs) is needed to control impurity accumulation in the core.

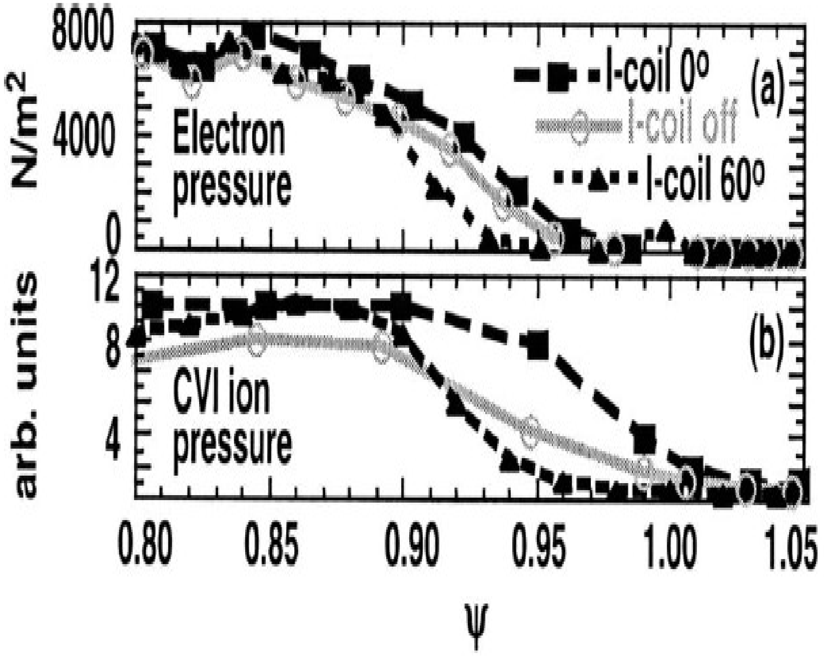


Maximum impurity concentration for steady-state solution depends on τ^*_{He}/τ_E

U. Samm et al., JNM 241-243 (1997) 827-832.

Pedestal CVI ion pressure increases in ELM suppression experiments with ergodic coils in DIII-D

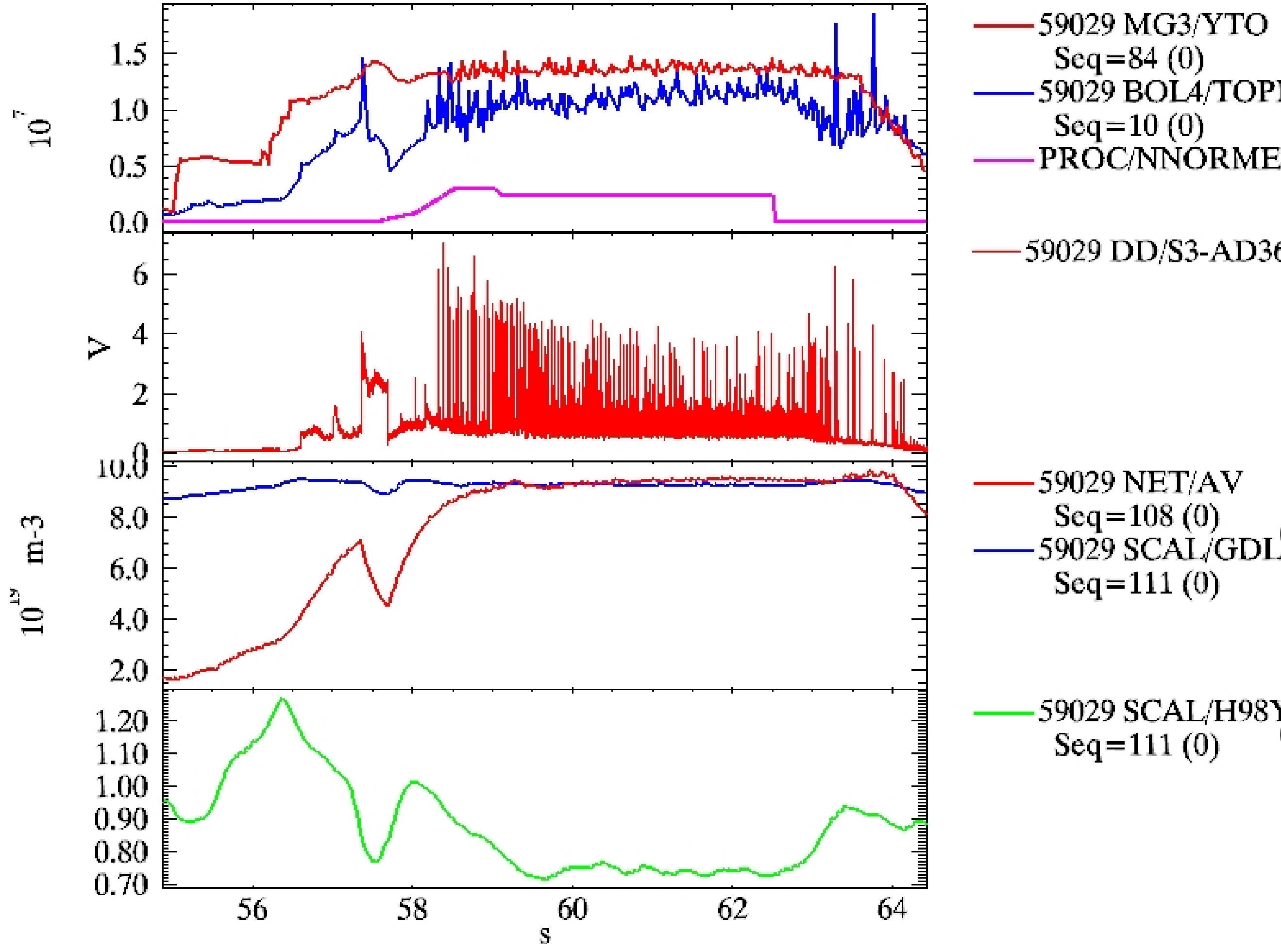


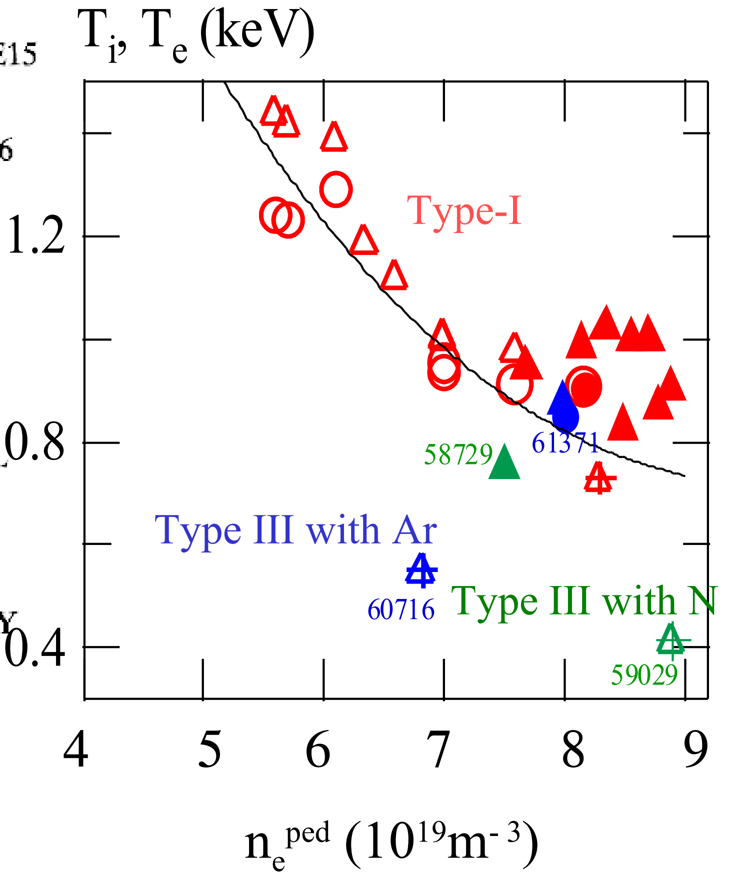


T. Evans, R. Moyer, P.R. Thomas et al., Phys. Rev. Lett. **92** (2004) 235003.

2) use radiation to produce Type III-ELM regime

HT3 configuration, 2.5MA/2.0T (q_{95}=2.6) **N seeding**

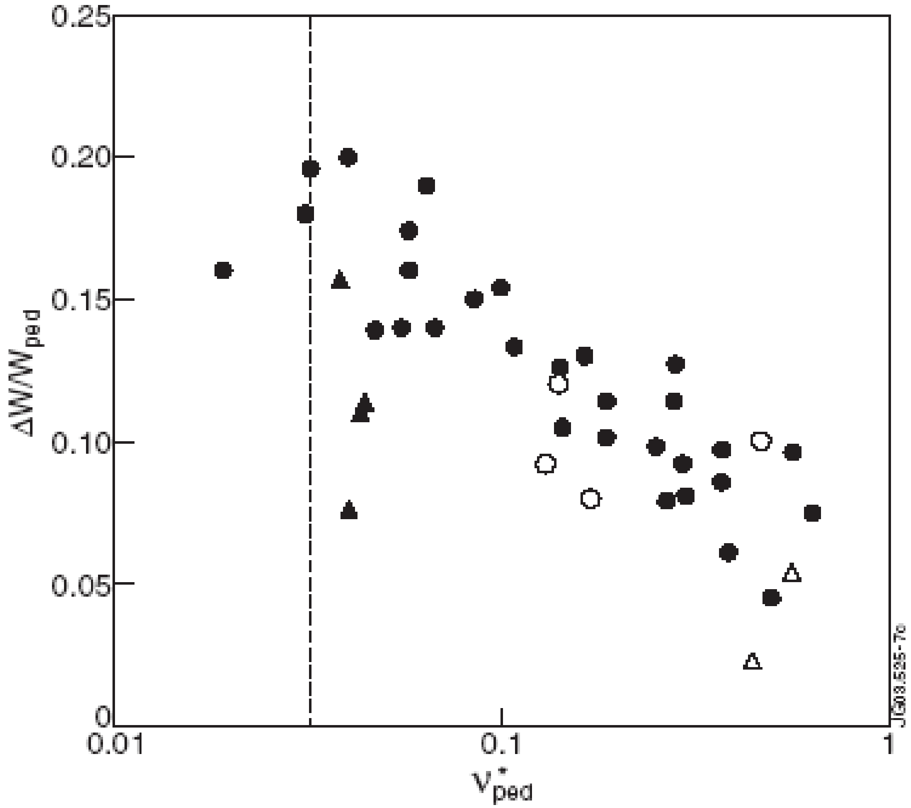




Remaining issues include:

- Type III ELM regime at low ν?
- Core dilution (will high Ip help?)
- Is edge τ_p low enough?

- In case of hybrid scenario: is type III regime compatible with hybrid scenario?



Conclusion:

- Impurity radiation may be used as a tool to control W_{ped}.
- Additional requirements for integrated scenario include:

→maintain low edge τ_p for particle removal

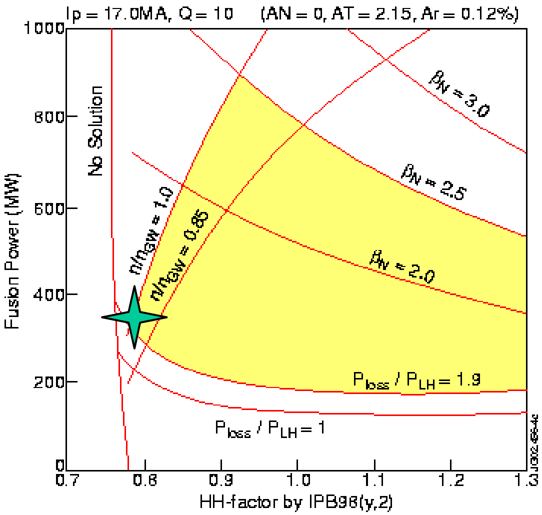
→If W_{ped} significantly decreased, then need to recover stored energy:

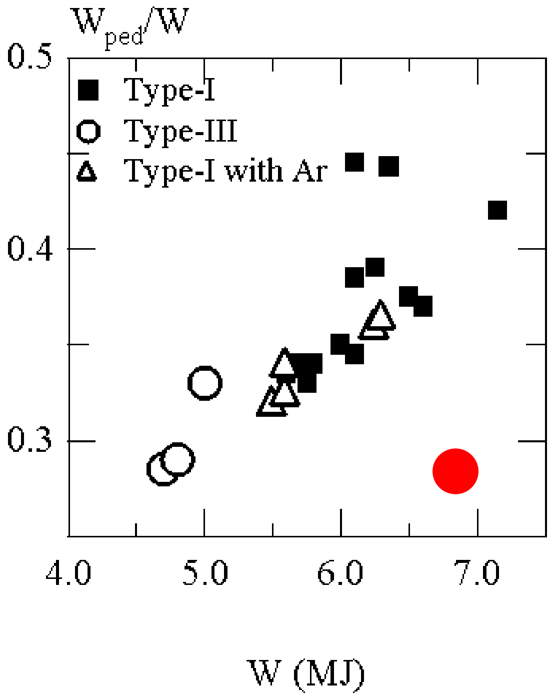
break profile stiffness : how?

Recover W by other means (experiments planned in 2006 at JET):

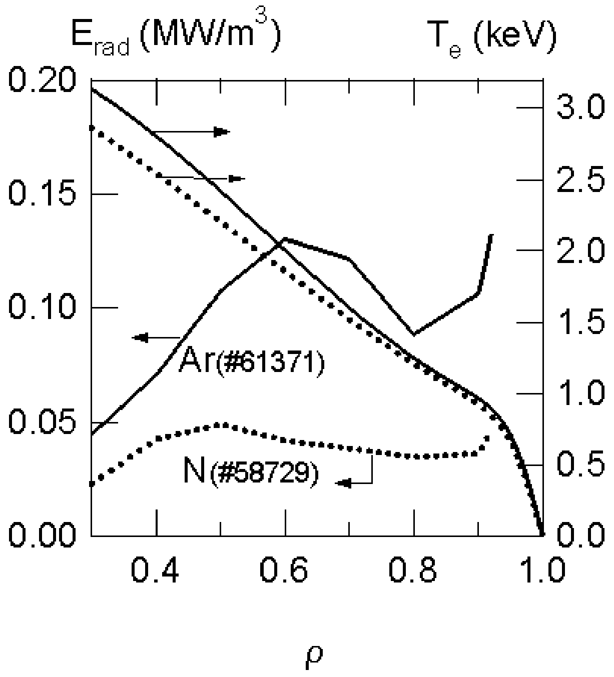
Type III H-mode → needs 17MA in ITER

Hybrid scenario ?





→use radiation to maintain T_e^{ped} just below threshold for Type I ELMs ?



1) Determine what impurity level is required depending on:

    choice of impurity species

    Local/edge injection

2) consequences on core performances

Dilution

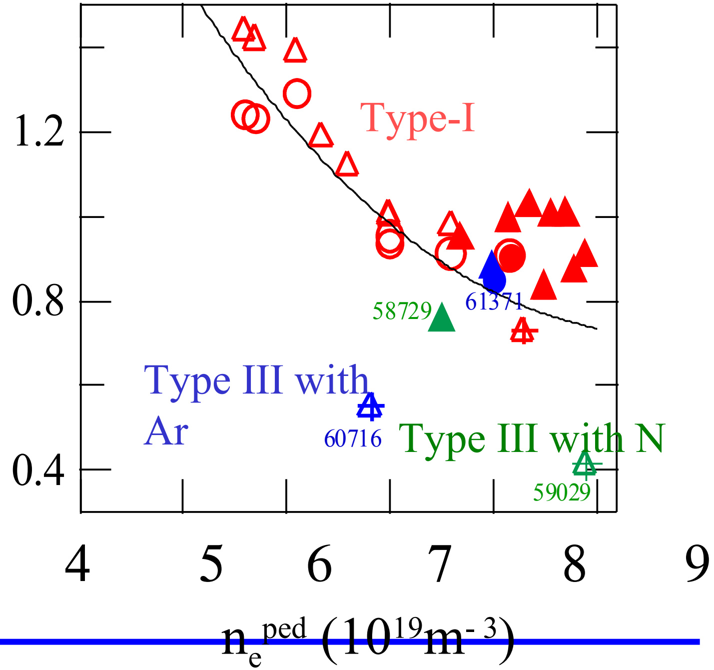
Energy content

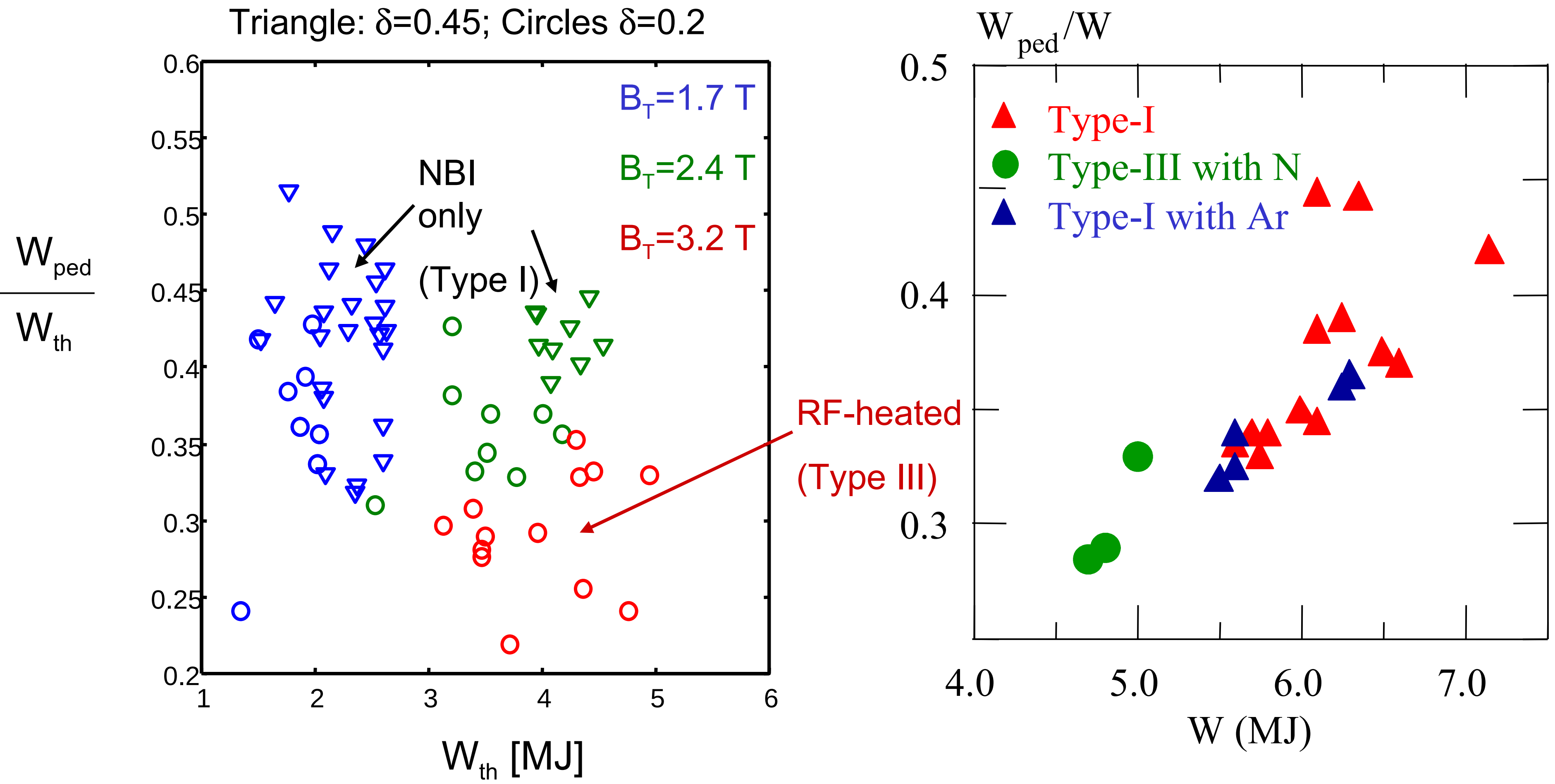
Impurity accumulation:

  non steady-state once ELMs are removed

  how to get low edge τ_p?

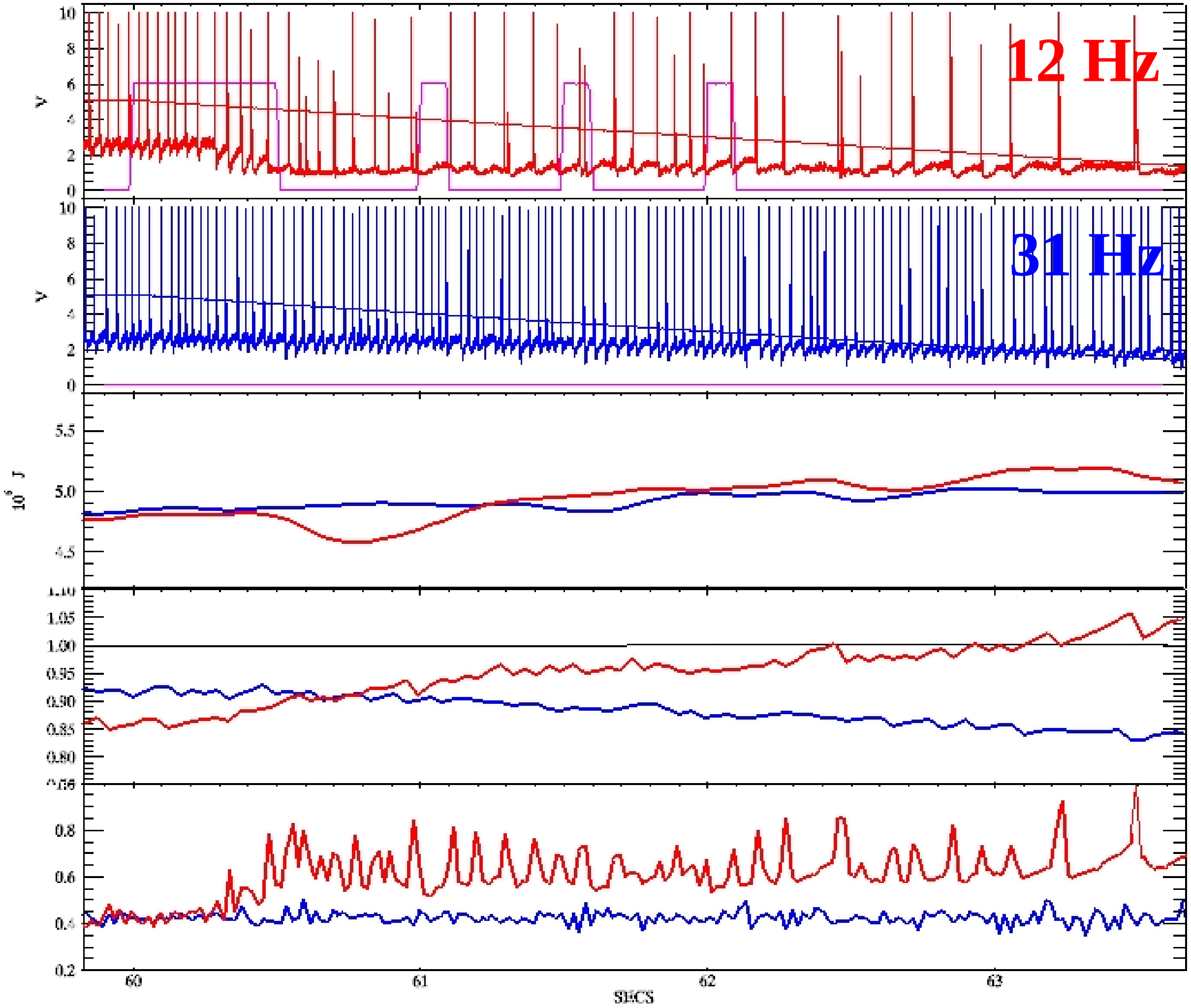
  high pumping efficiency required




Triangle: δ=0.45; Circles δ=0.2
W_{ped} / W_{th}
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
1
2
3
4
5
6
W_{th} [MJ]
B_T=1.7 T
B_T=2.4 T
B_T=3.2 T
NBI only (Type I)
RF-heated (Type III)
W_{ped}/W
0.5
0.4
0.3
4.0
5.0
6.0
7.0
W (MJ)
▲ Type-I
● Type-III with N
▲ Type-I with Ar

f_{ELM} decreases with Ar seeding : - effect of collisionality (Z_{eff} ↗) ? - signature of Type I ELMs (P_{sep} ↘)

#53548 with Ar #53549 without Ar



- EHT configuration (d »0.40) with septum
- 2.3MA, 2.4T, P_{tot} =16MW

same W_{dia} despite decreased P_{sep}.

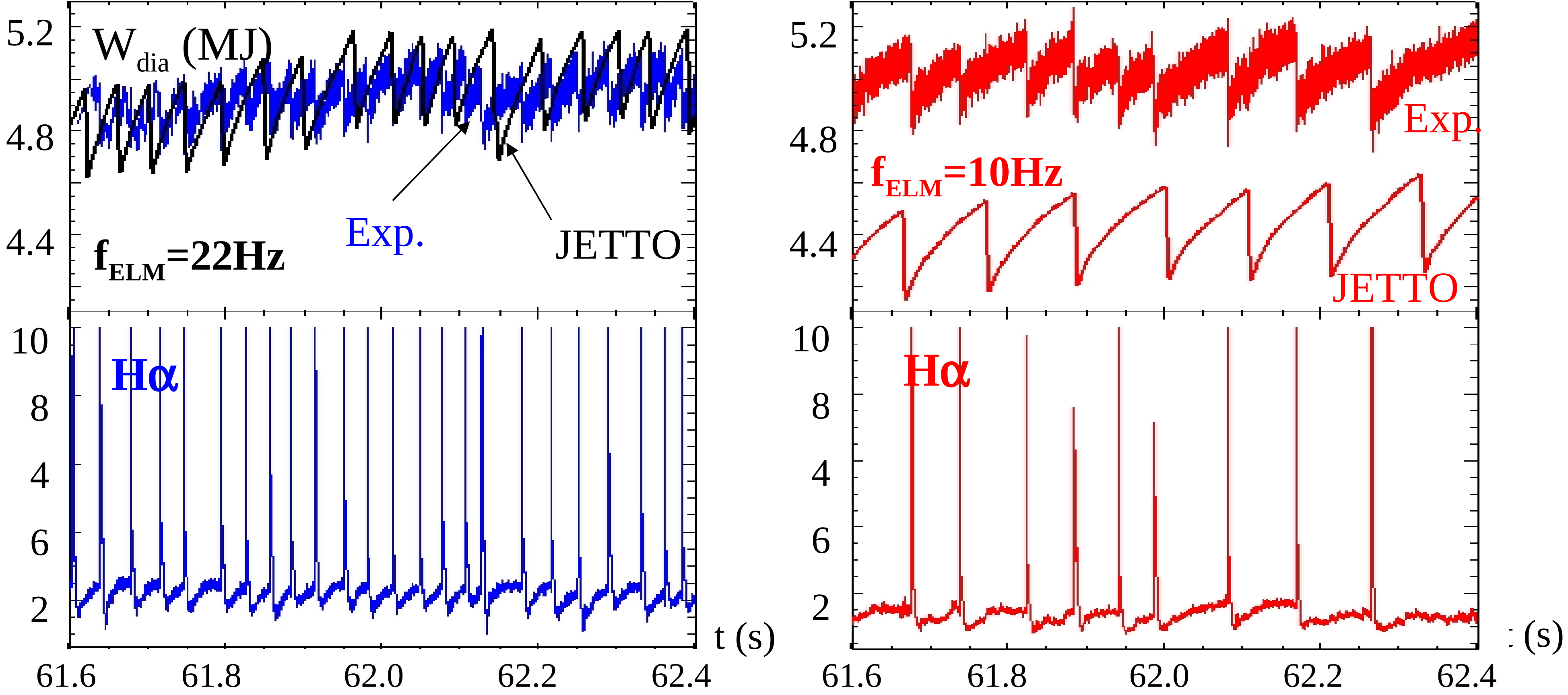
n_e/n_{Gr}

P_{rad}/P_{tot}

Simple Model for ELMs used in JETTO :

When α reaches α_{crit}, the particle diffusion in the edge is increased.

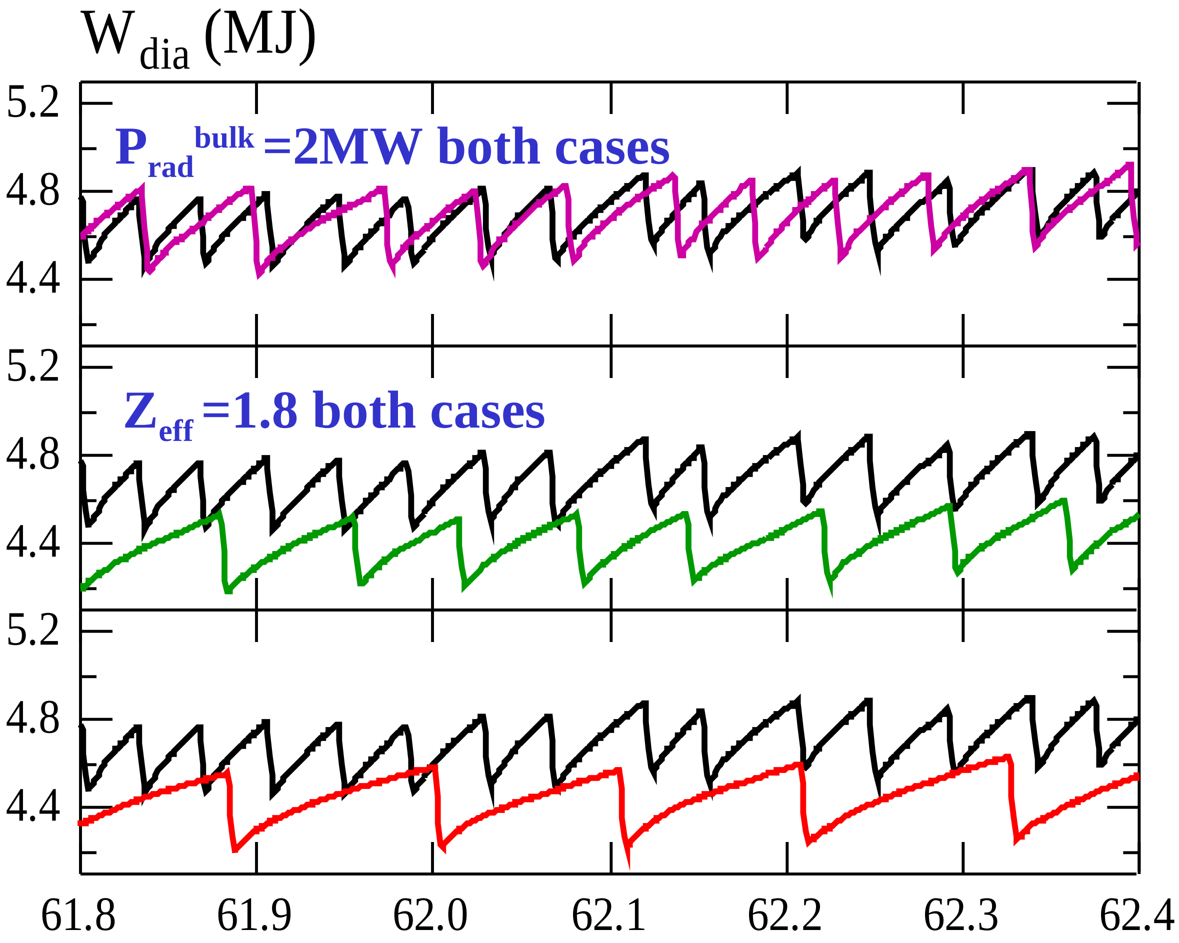
➡ Exp. decrease of f_{ELM} with Ar seeding well reproduced with this model.



#53549 without Ar, Z_{eff}=1.8, P_{rad}^{bulk}=2MW

#53548 with Ar, Z_{eff}=2.2, P_{rad}^{bulk}=6MW

The decrease of f_{ELM} is mainly due to increase of P_{rad}^{bulk} (weak effect of change in collisionality).



Effect of change in Z_{eff}

Z_{eff} =1.8

Z_{eff} =2.2, f_{ELM} x 0.80

Effect of change in P_{rad}^{bulk}

P_{rad}^{bulk} = 2MW

P_{rad}^{bulk} = 6MW, f_{ELM} x 0.54

Combination of both effects

CX and transport effects increase the radiation capability → Decrease c/cfatal that is required