ITC12, Toki, Japan, December 2001

First island divertor experiments on the W7-AS stellarator

P. Grigull for the W7-AS Team

Max-Planck-Institut für Plasmaphysik, EURATOM Ass., D85748 Garching, Germany

Outline:
1. **Motivation**
2. **Divertor geometry in W7-AS**
3. **Major aims of the programme**
4. **Plasma performance at high density**
5. **Divertor regimes**
6. **Operational ranges**
7. **Summary**

Motivation

- ***Stellarators will need divertors*** **for plasma exhaust.**

- **Solutions have to be compatible with stellarator con-figurations.**

- **Utilize flux diversion by magnetic islands at the edge**
----> ***Island divertor***

- **W7-X: study of the reactor potential of this concept.**

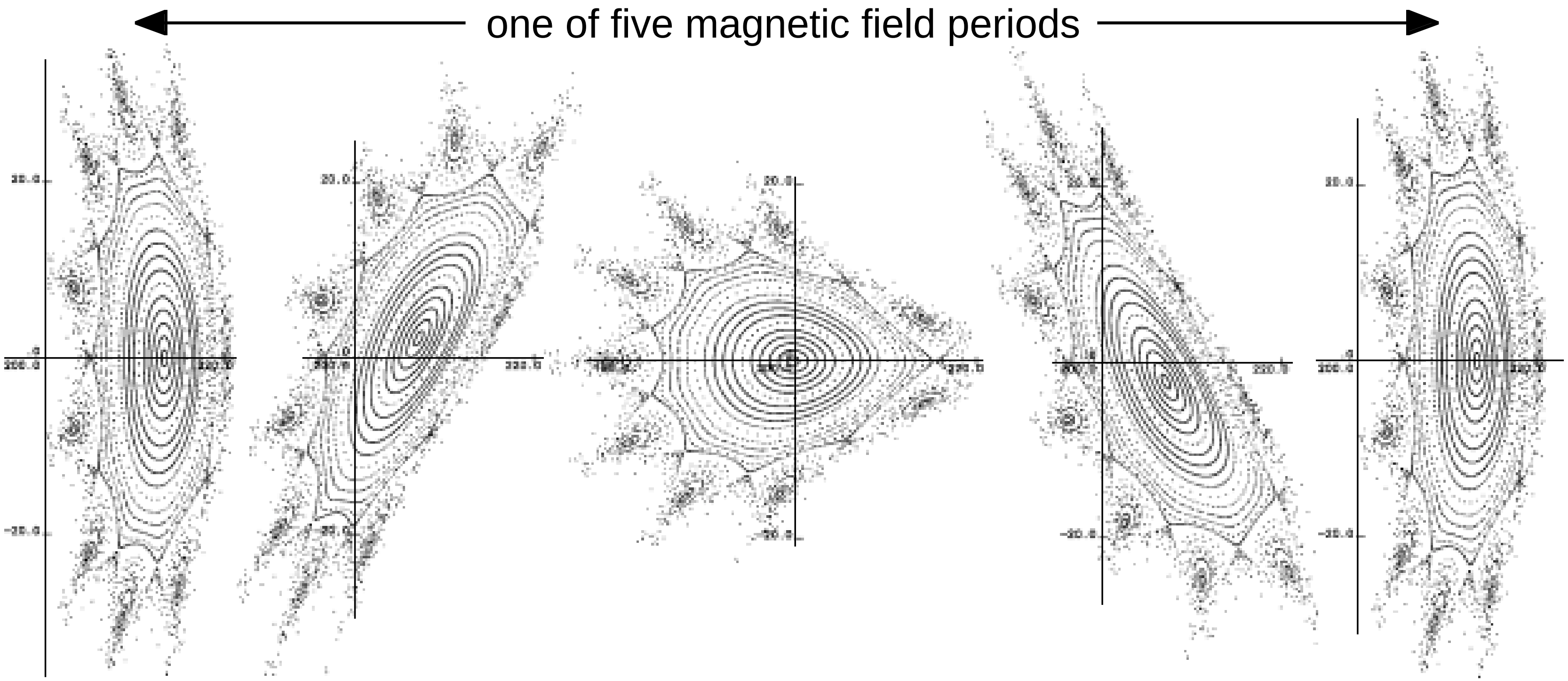
- **W7-AS can be operated with similar edge structure, divertor studies can provide preparatory information.**

Major studies have been started in March 2001

Divertor geometry in 7-AS: boundary islands

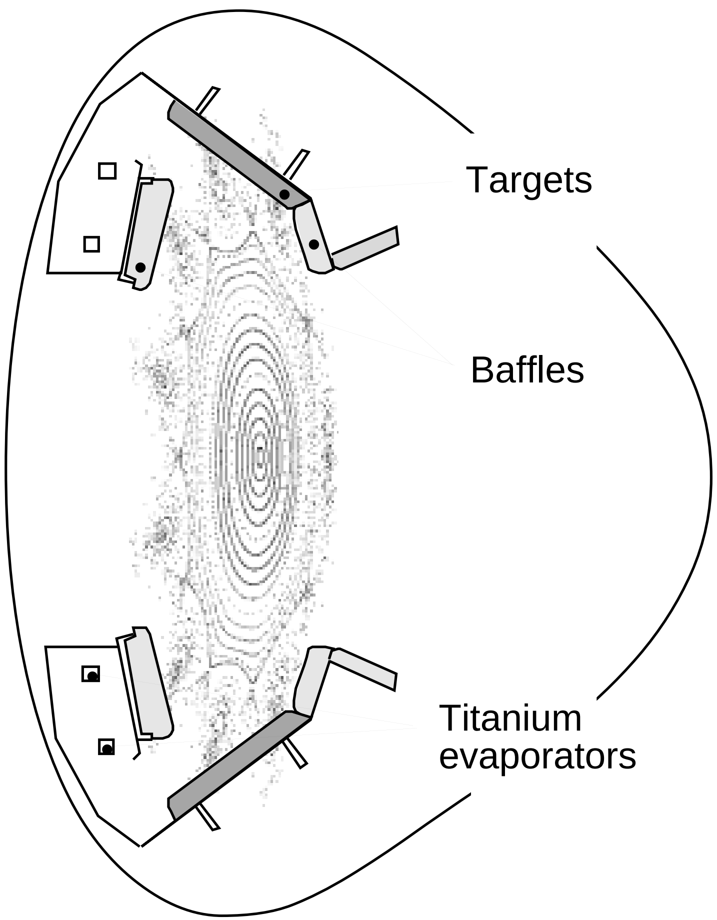
R = 2 m, $a \leq$ 0.16 m, $B \leq$ 2.5 T, non-planar coils, five field periods

- **can be operated with large magnetic islands at the edge**
- **rad. position can be varied by adjusting the rot. transform**
- **rad. width can be varied by special control coils**

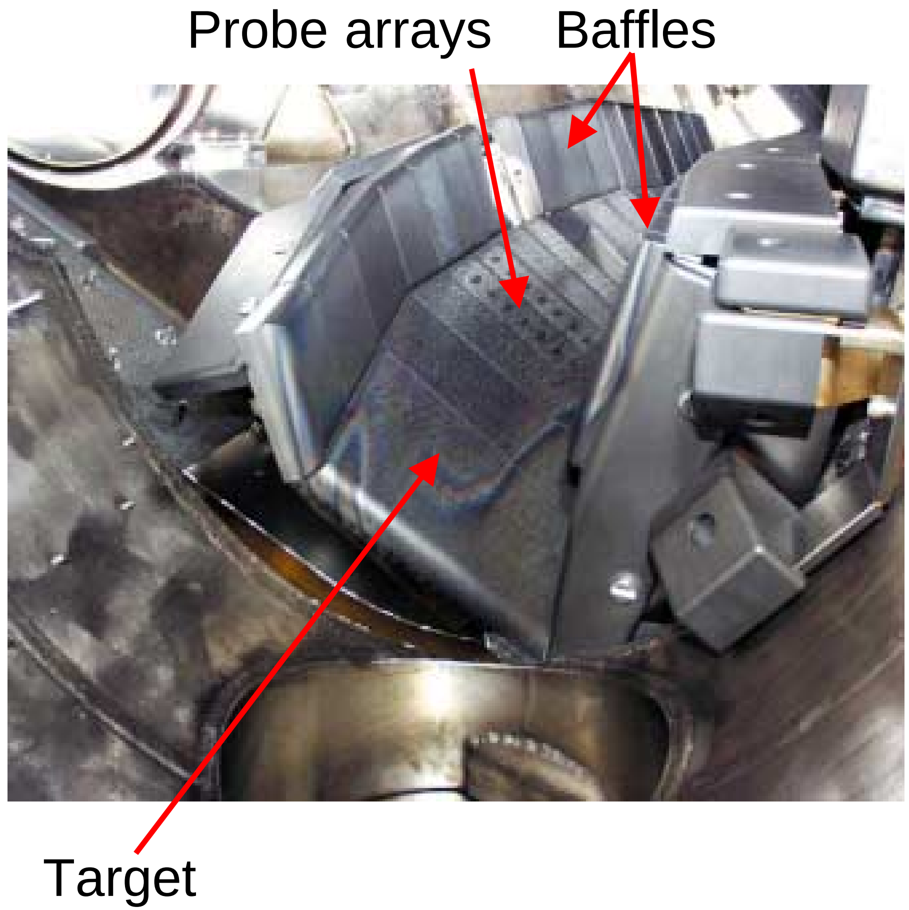


Divertor geometry in W7-AS

Ten divertor modules



Bottom divertor



Major aims of the programme

To answer the questions:

First experiments

- ***Effects of the new divertors on the plasma performance?***
- ***Cold divertor plasmas without too strong cooling of the core ?***
- ***Controlled? Compatible with active particle pumping?***
- ***Compatible with improved confinement scenarios (e.g. ELMy H-mode)?***

Data shall be used to validate the EMC3-EIRENE code.

Summary of main results

Access to a new regime with NBI at very high density (up to $n_e \approx 3.5 \times 10^{20}\ m^{-3}$) with improved confinement:

- **τ_E steeply increases with density,**
- **τ_p and τ_{imp} decrease with increasing density ($\tau_{imp} \approx \tau_E$ at highest density)**

→ **Density control already without Ti-gettering,**

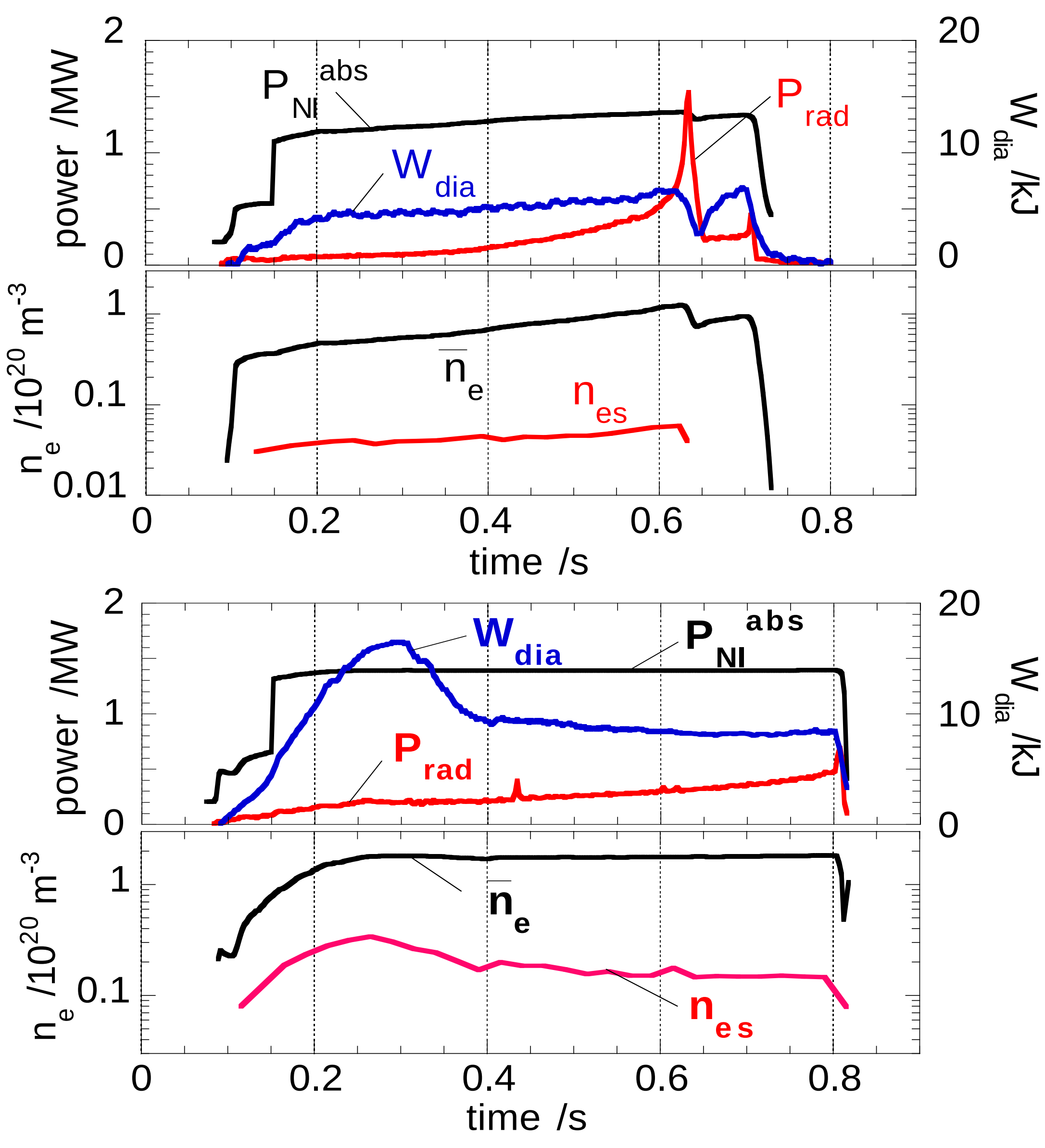
→ **quasi-steady state operation also including partial detachment,**

→ **radiatiation always peaked at the edge.**

Record value of <ß> ≈ 3.1% achieved (at B = 1.25 T)

Plasma heating by HF (EBW 140 GHz) successfully demonstrated.

Plasma performance at high density: trans. to stationarity



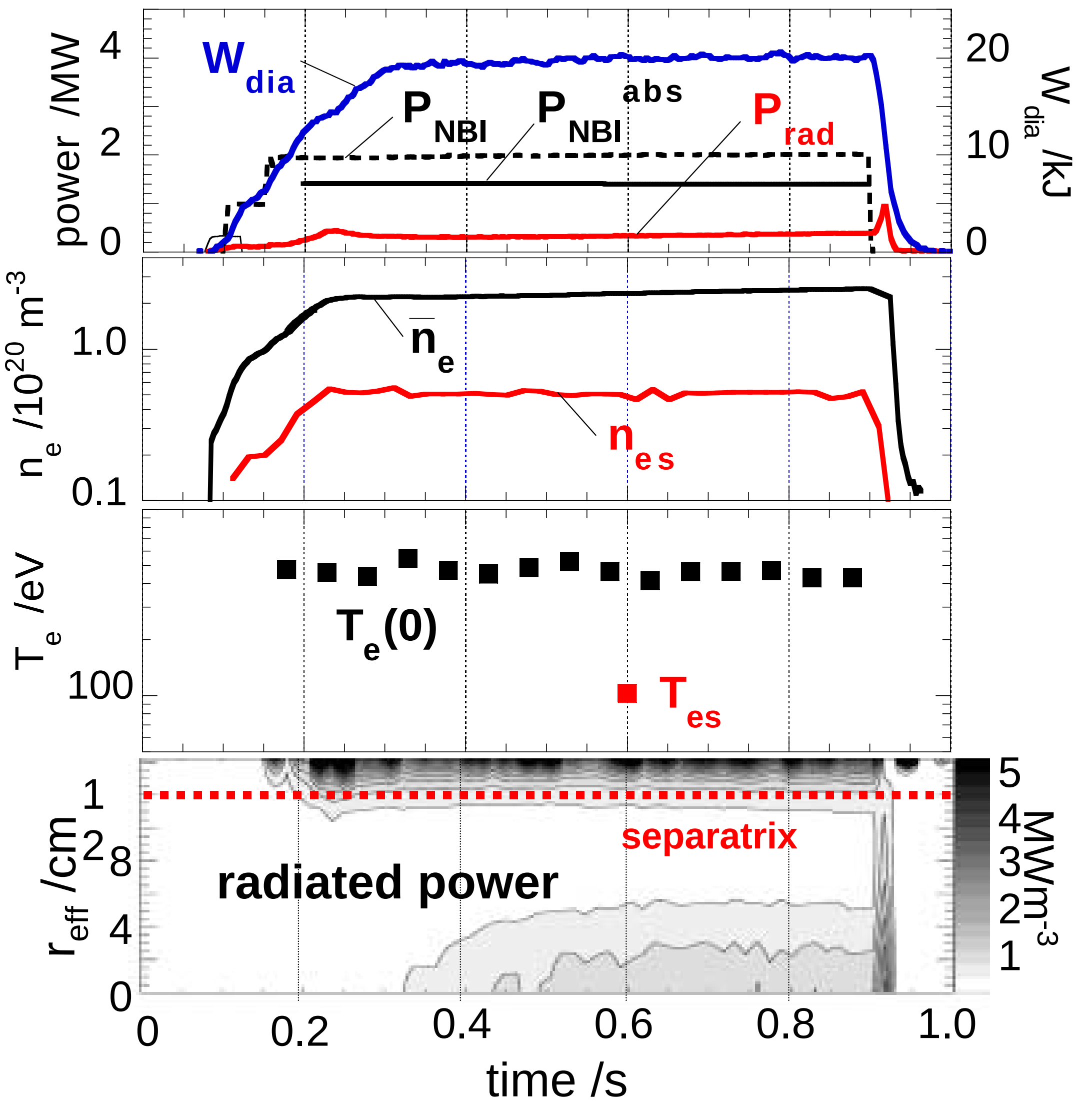
$n_e < 1.8\ 10^{20}\ m^{-3}$

normal confinement (NC)

unstationary

- **stored energy < 10 kJ,**
- **radiation increasing with time,**
- **extremely small edge density**

Plasma performance at high density: access to stationarity



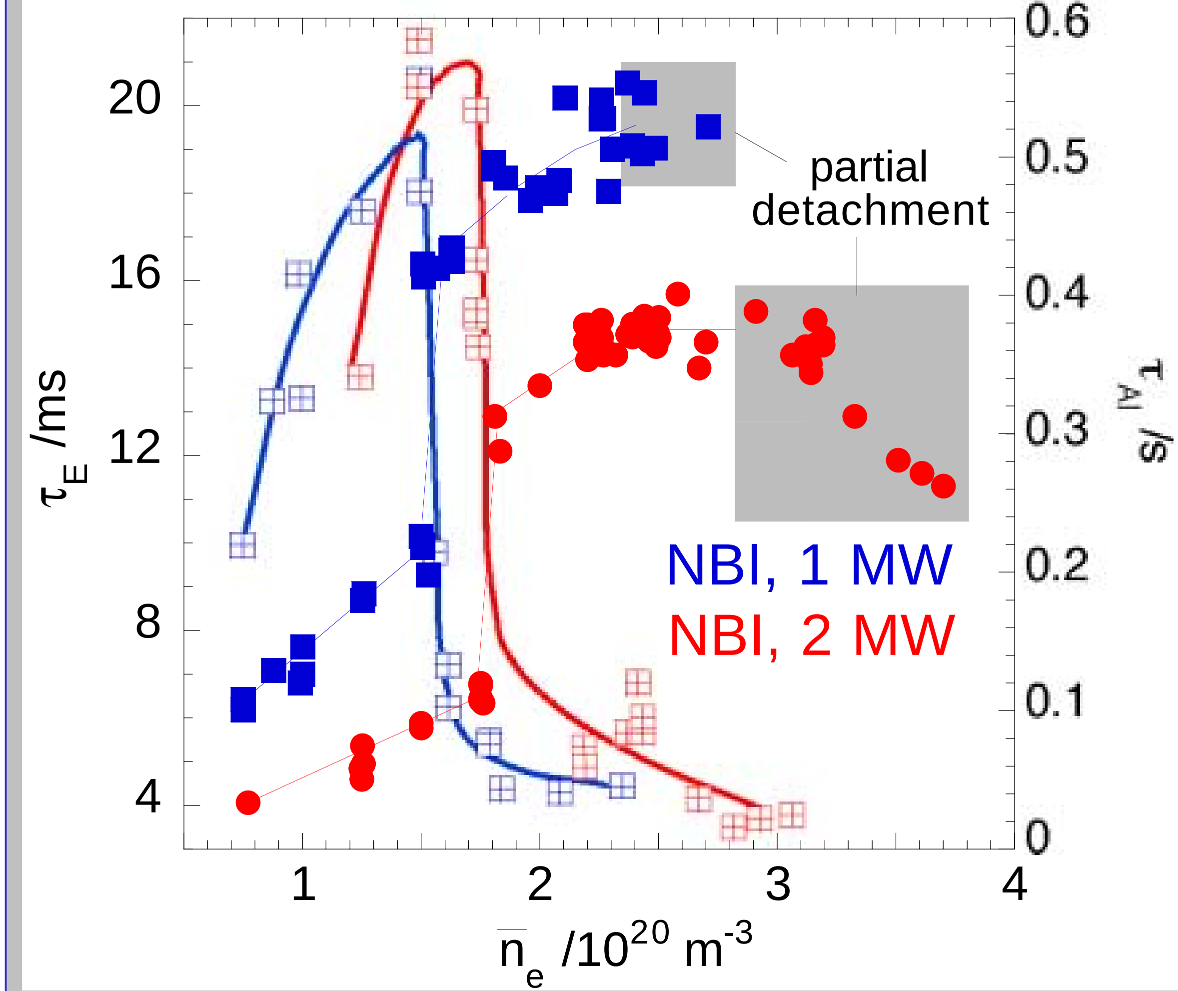
$n_e > 1.8\ 10^{20}$ m^{-3}

improved confinement (IC)

quasi steady-state

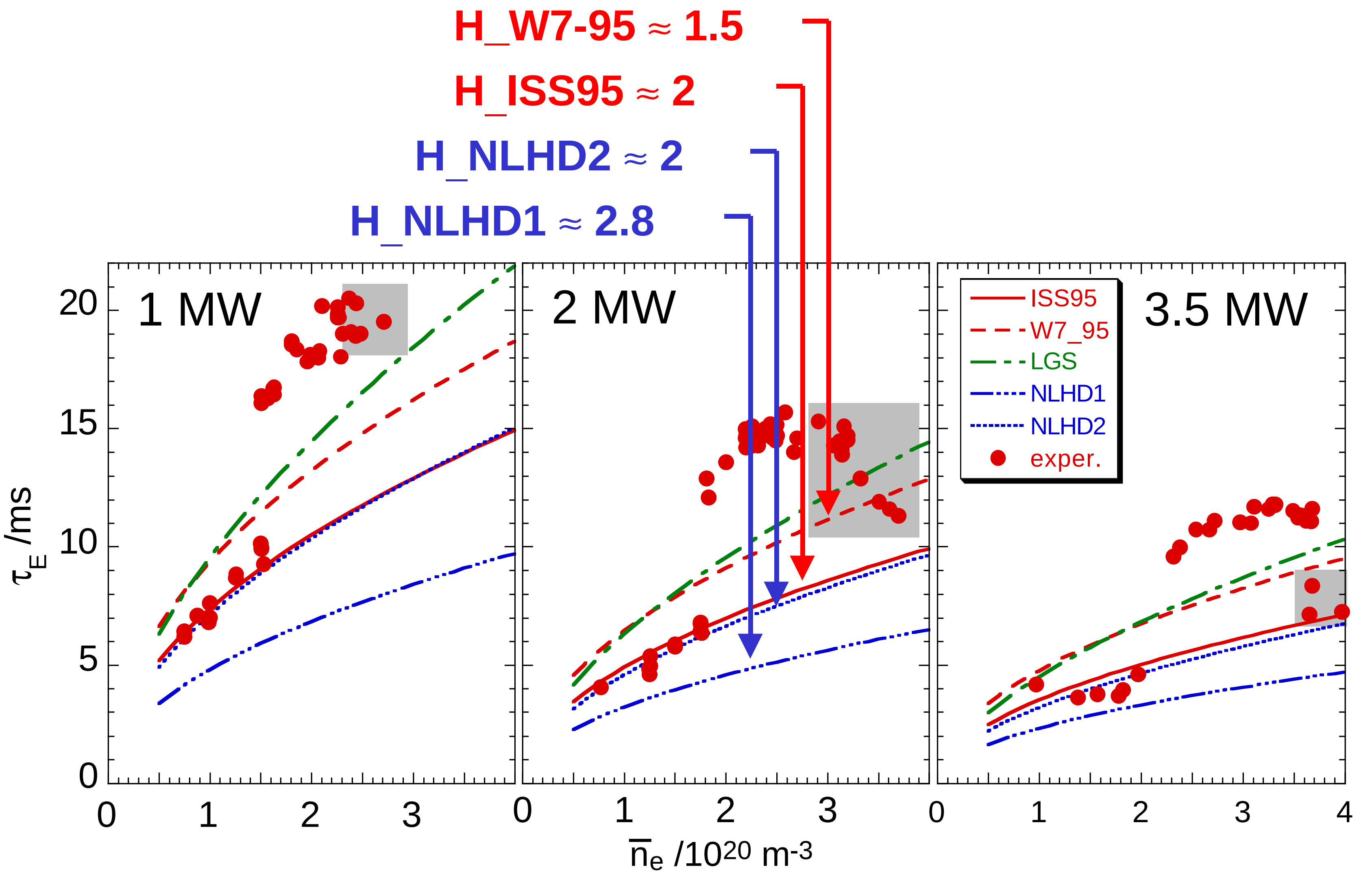
- **stored energy ≈ 20 kJ**
- **$T_e(0) \approx 500$ eV, $\nu^* \approx 0.3$**
- **edge density ≈ $5\ 10^{19}$ m^{-3}**
- **edge temperature ≈100 eV**
- **radiation edge-dominated**

Plasma performance at high density: improved confinement



- **IC: steep increase (´jump´) of τ_E,**
- **low to moderate τ_E degradation at partial detachment**
- **steep drop of τ_{imp}**

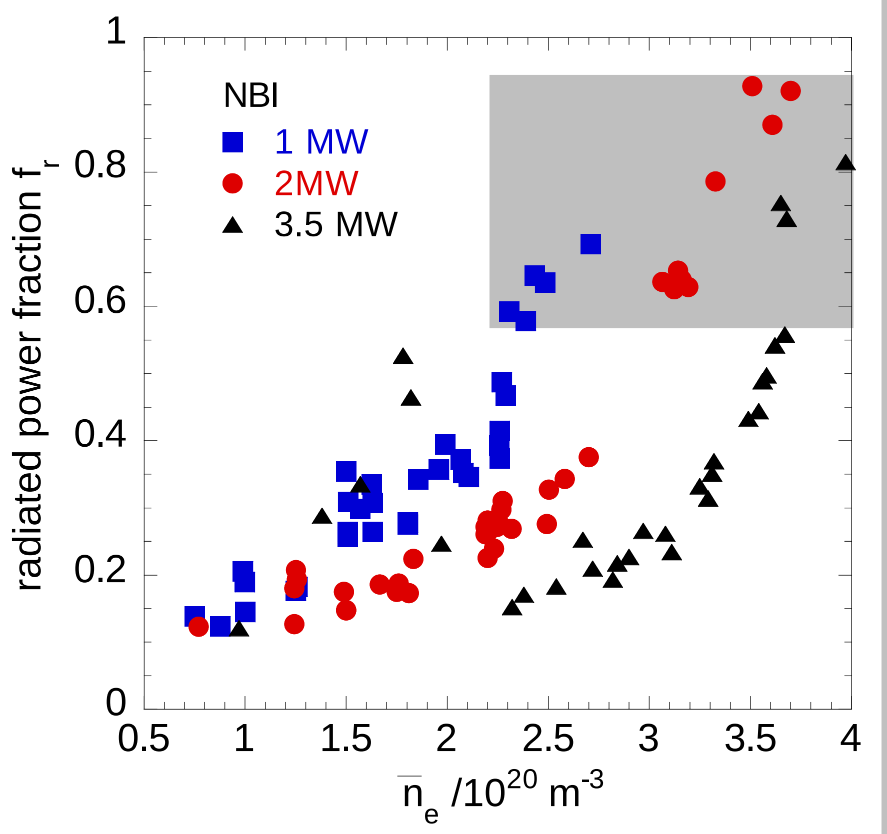
Plasma performance at high density: improved confinement

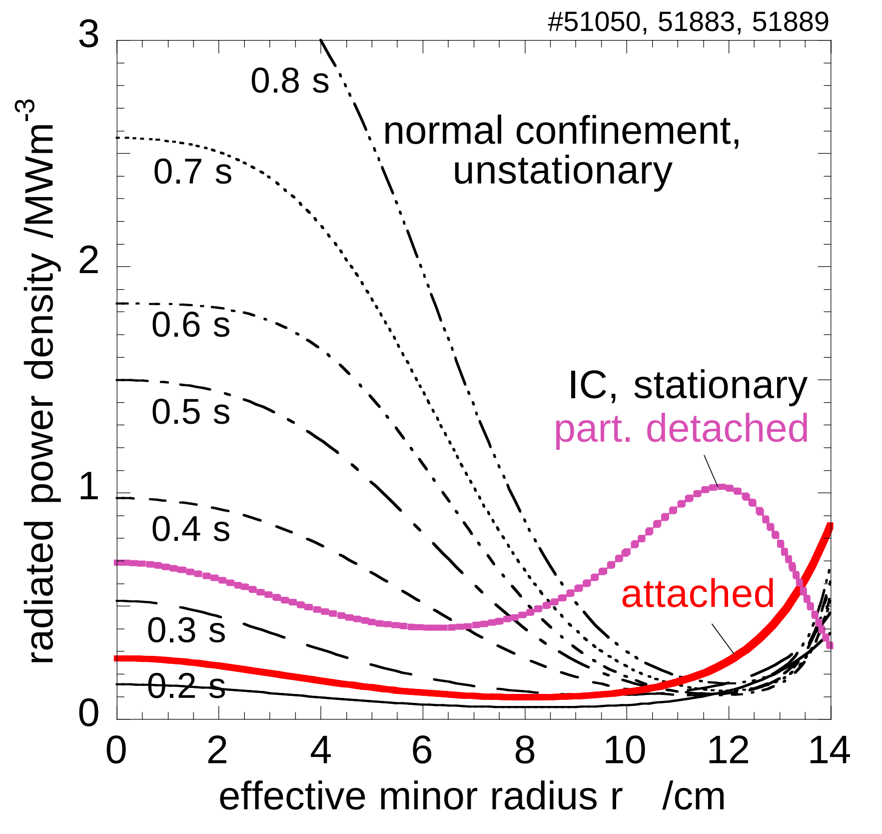


Plasma performance at high density: plasma radiation

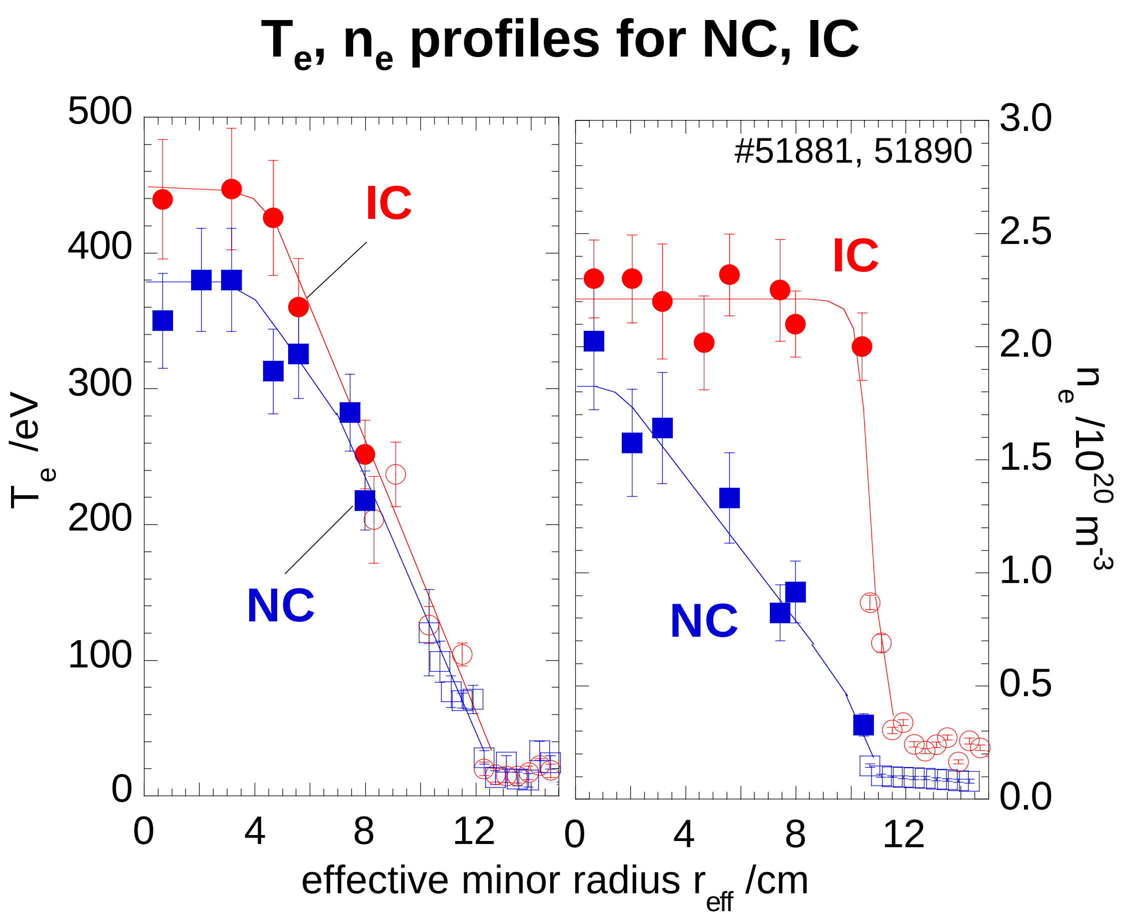
- **radiated power fraction low to moderate in attached regimes,**
- **up to 90% at detachment**

- **NC: core-dominated radiation, unstationary**
- **IC: edge-dominated radiation, stationary**





Plasma performance at high density: core parameters



NC ---> IC:

- **T_e profiles unchanged,**
- **n_e profiles broadened.**

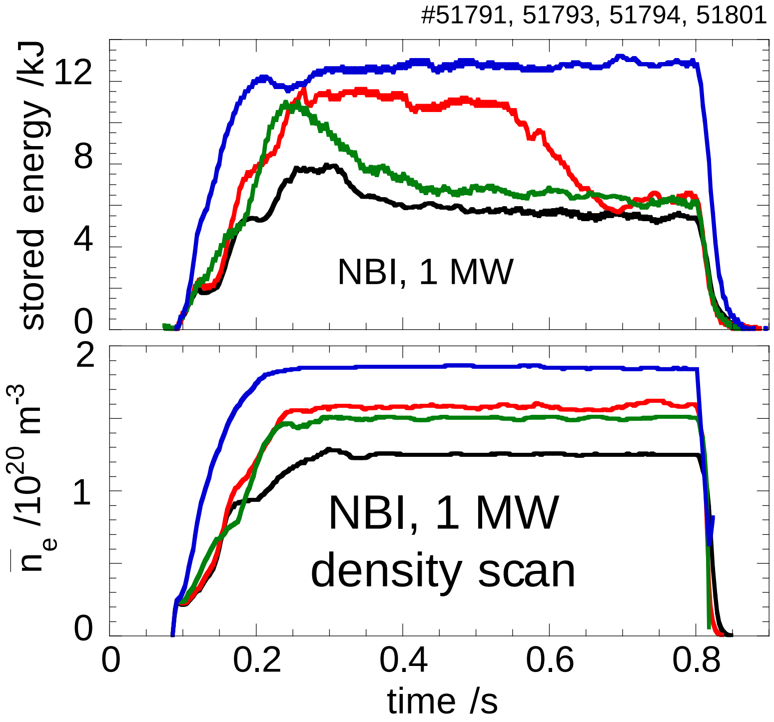
SITAR analysis of Al emission:

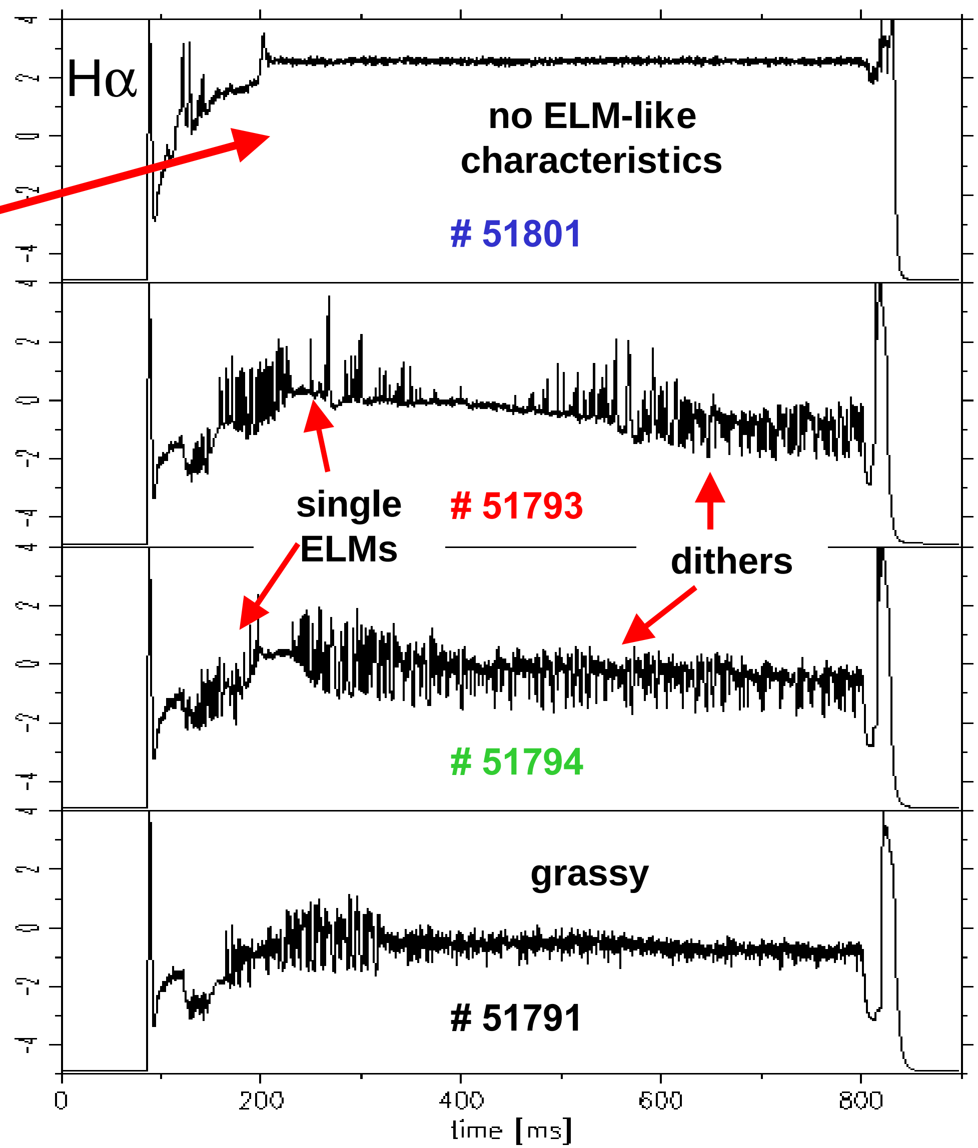
- **marginal change of diffusion coefficients,**
- **reduction of v_{in} at the edge by a factor of 4 - 5.**

Plasma performance at high density: H-mode?

H-mode signatures during transition to IC,

IC: - only small spin-up,
- no evidence for ETB



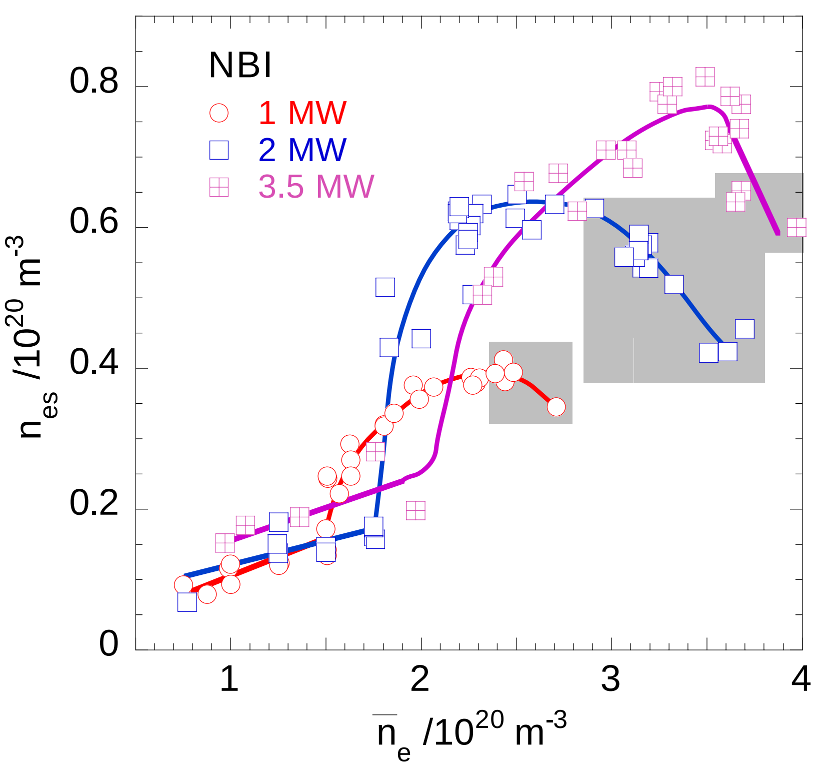


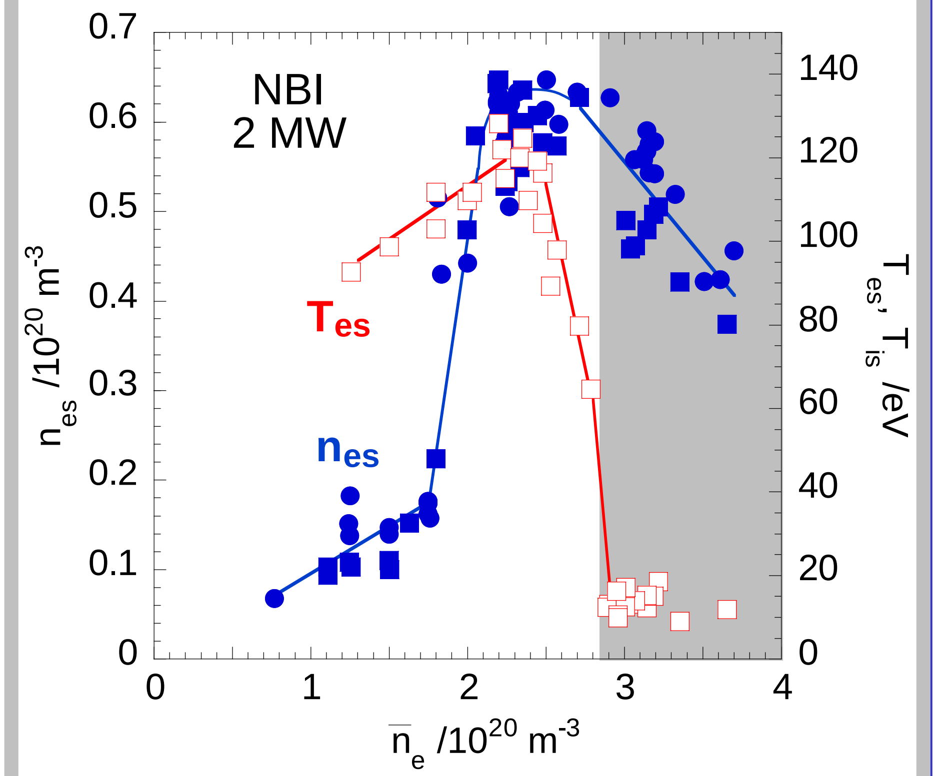
Plasma performance at high density: edge parameters

NC ---> IC---> detachment:

- **edge density n_{es} increases steeply**
- **drops at detachment**

- **edge temperatures T_{es} and, hence, upstream pressures drop already prior to detachment**

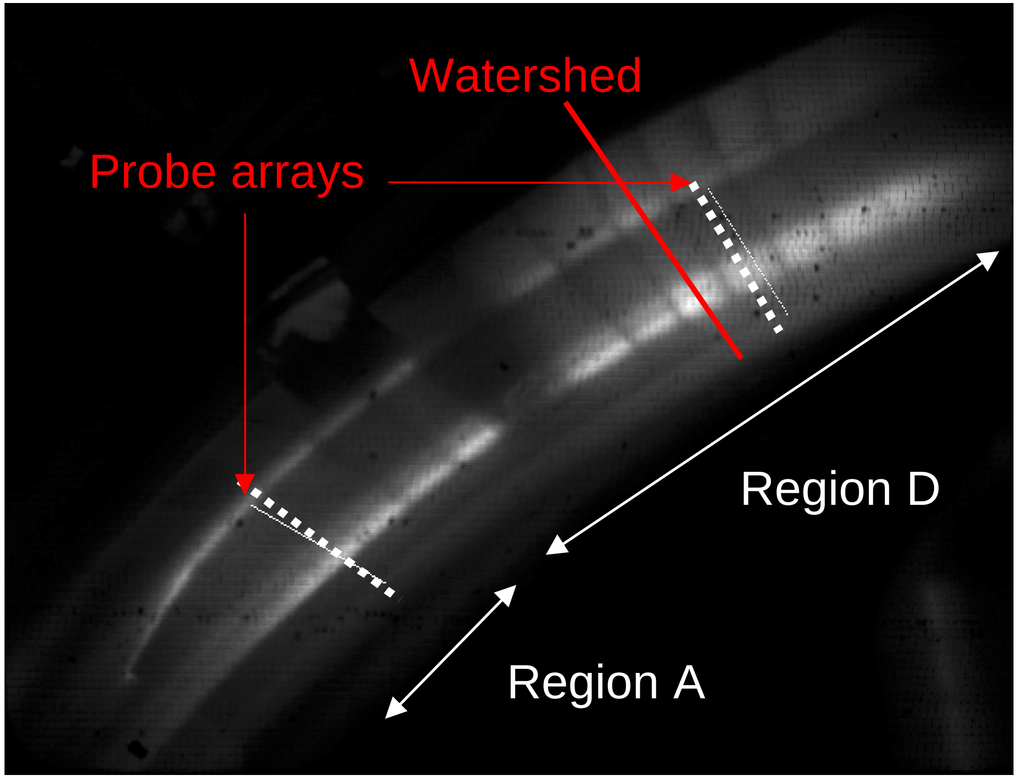




Divertor plasma regimes

The plasma-target interaction concentrates mainly at helical stripes

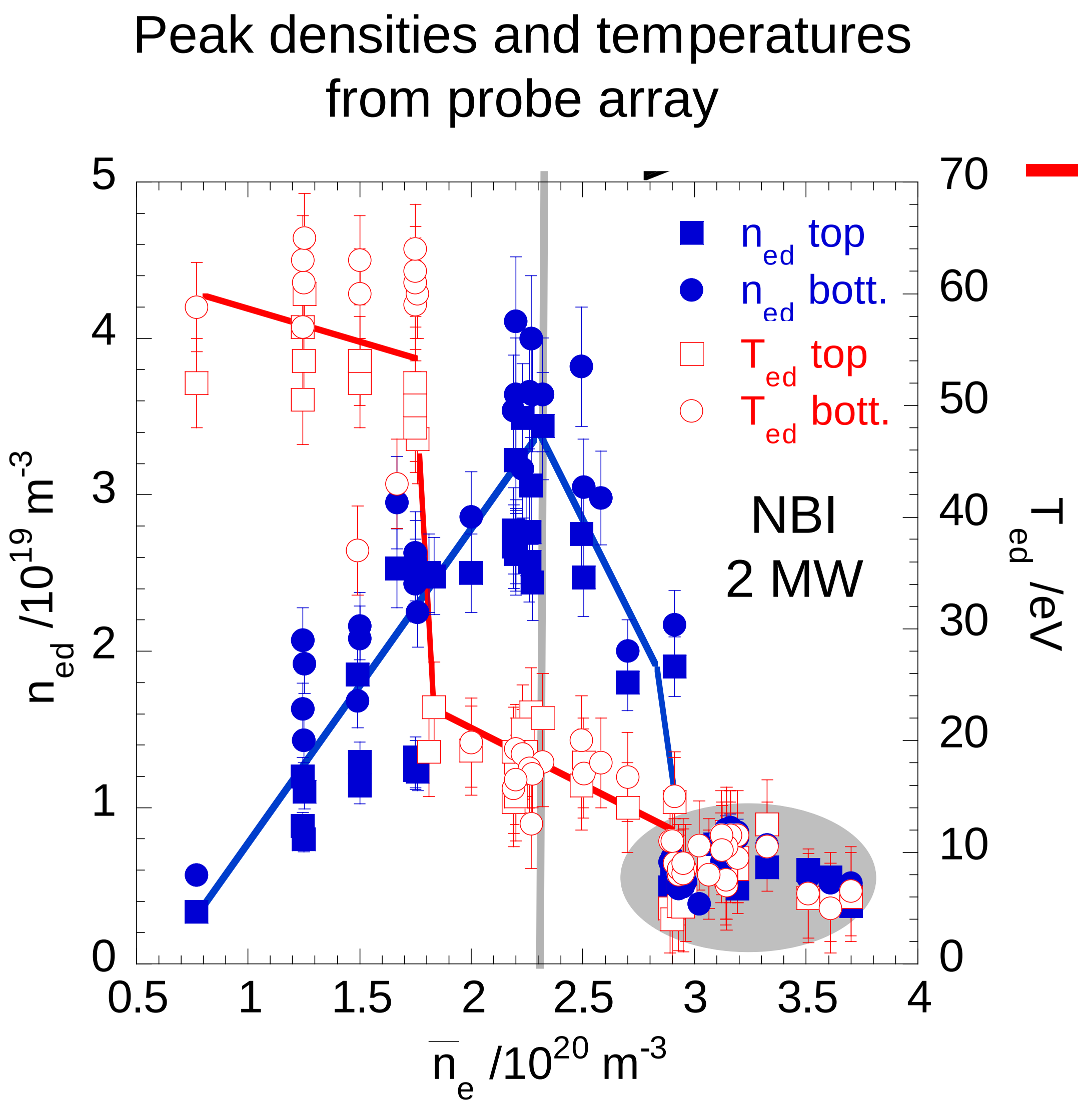
Hα traces

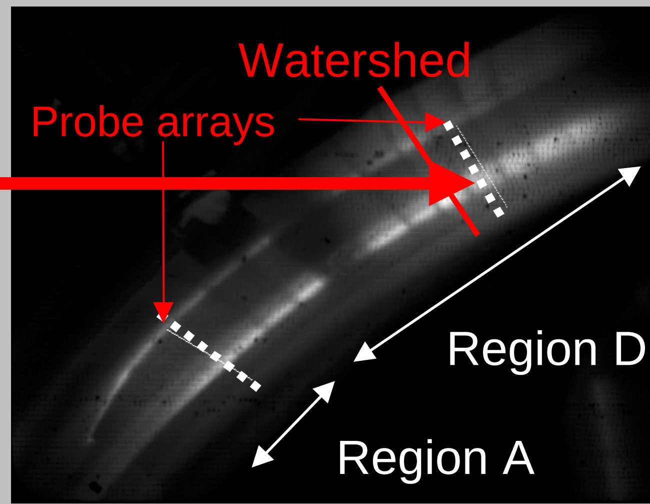


Region D:
rollover and detachment
of energy and particle flux at high density

Region A:
attached spots even at highest density

Divertor plasma regimes: downstream parameters





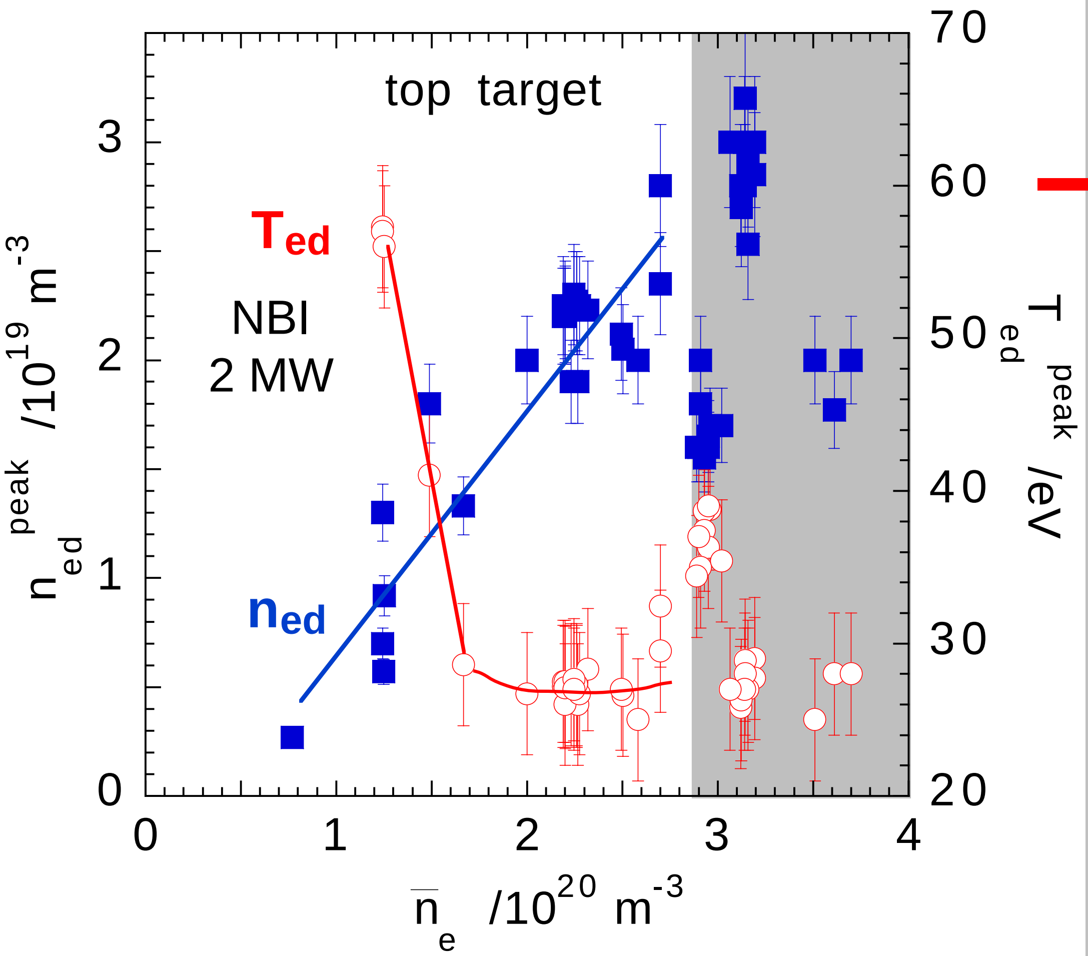
Region D:

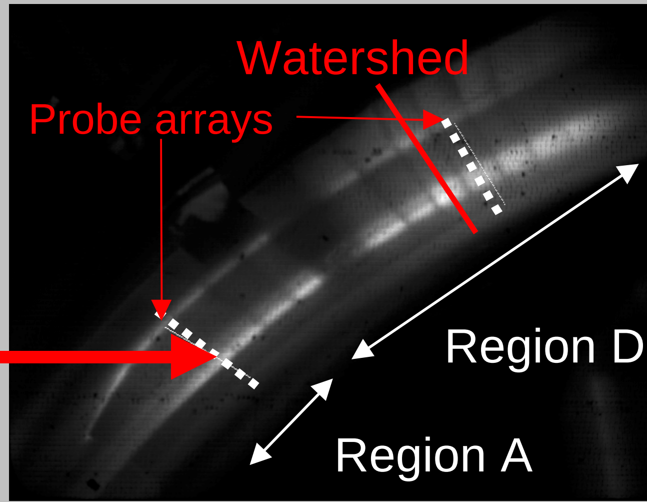
-rollover up to detachment of n_{ed}, Γ_{pd} (confirmed by 2D H_α data)

- T_{ed} > 2 eV at detachment (from H_α/H_γ)

Divertor regimes: downstream parameters

Peak densities and temperatures from probe array





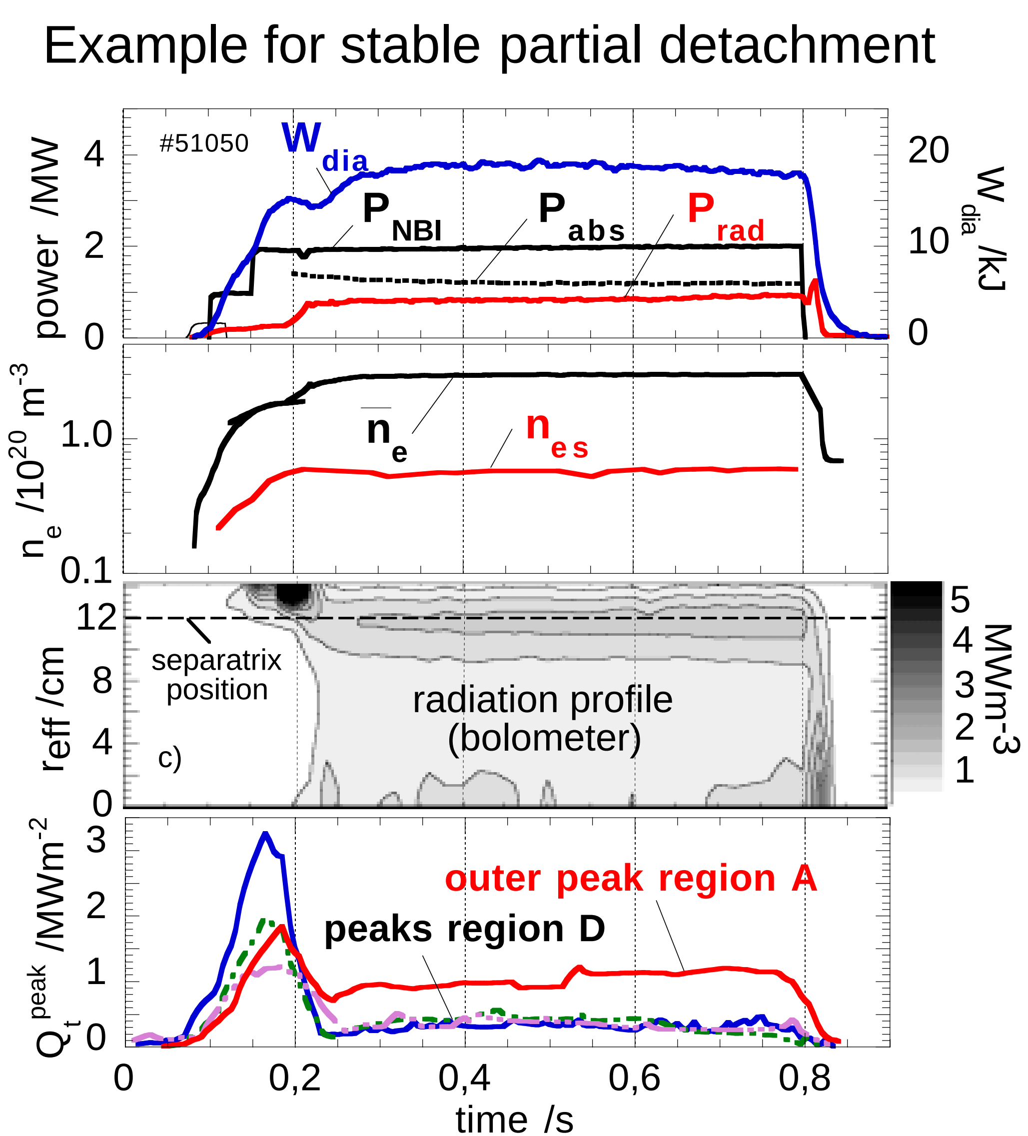
Region A:

- **Downstream peak T_{ed} stays above 20 eV**

  ---> attached spot

- **inconsistent with low T_{es}**
  ---> inhomogeneous T_{es}?

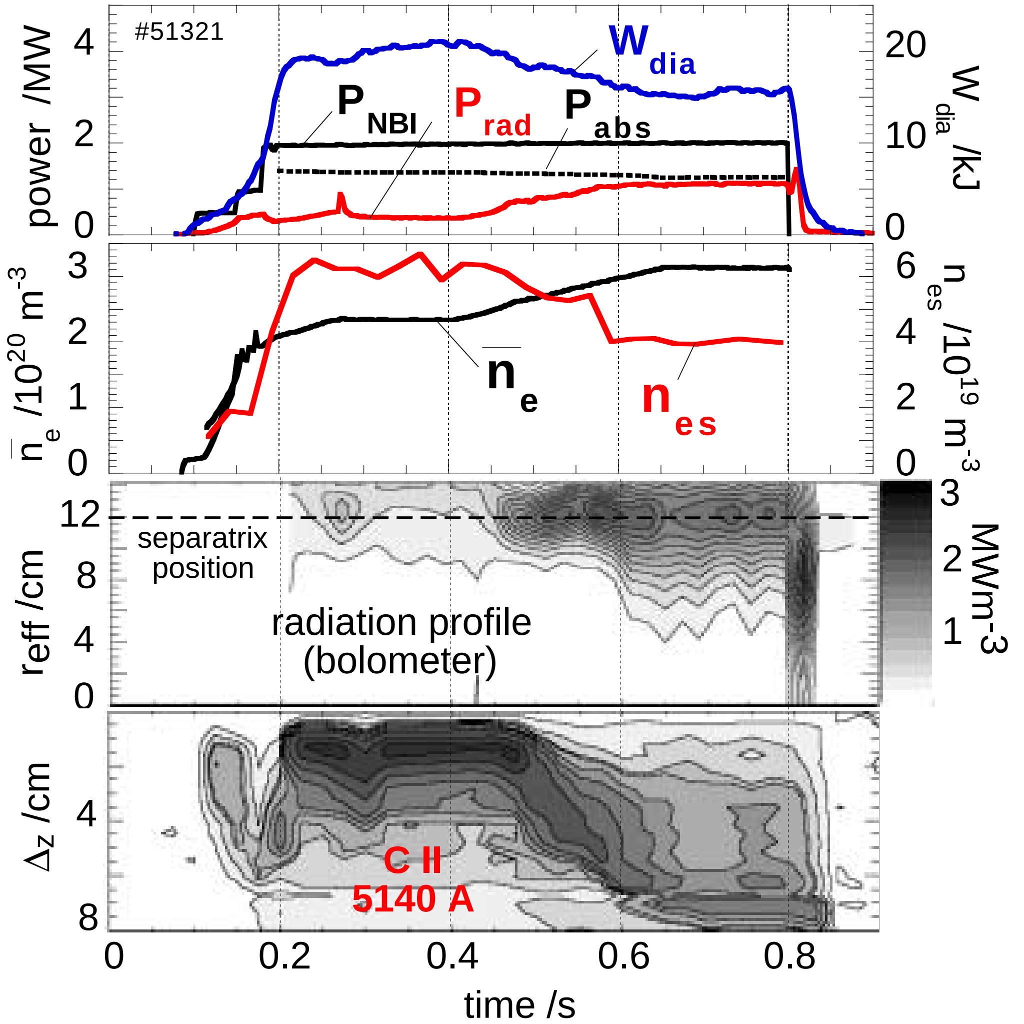
Divertor regimes: stable partial detachment



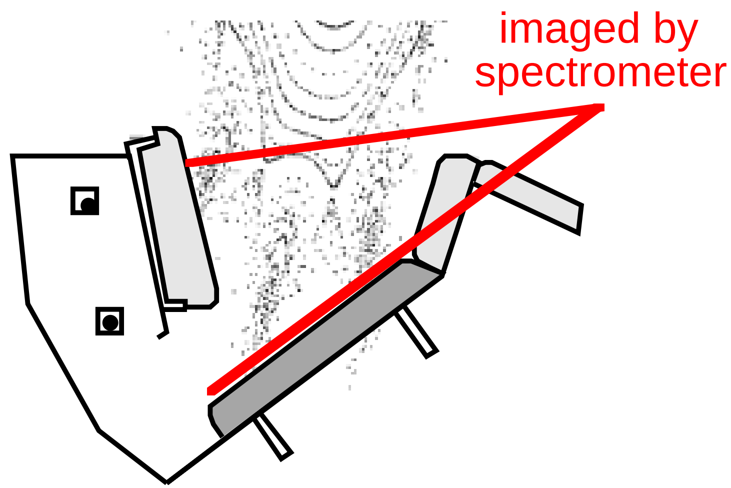
- $\overline{n}_e$ = 3 10^{20} m^{-3}
- $T_e(0)$ = 400 eV,
- T_{es} = 20 eV (?)
- radiated power fraction up to 80%
- radiation peaked at the separatrix position
- outer peak in region A attached

Divertor regimes: controlled transition to part. detachment

Controlled transition to ‚stronger‘ partial detachment



- radiated power fraction ≈ 85%
- edge radiation dominated,
- peak of C II radiation shifts in controlled way towards the x-points.

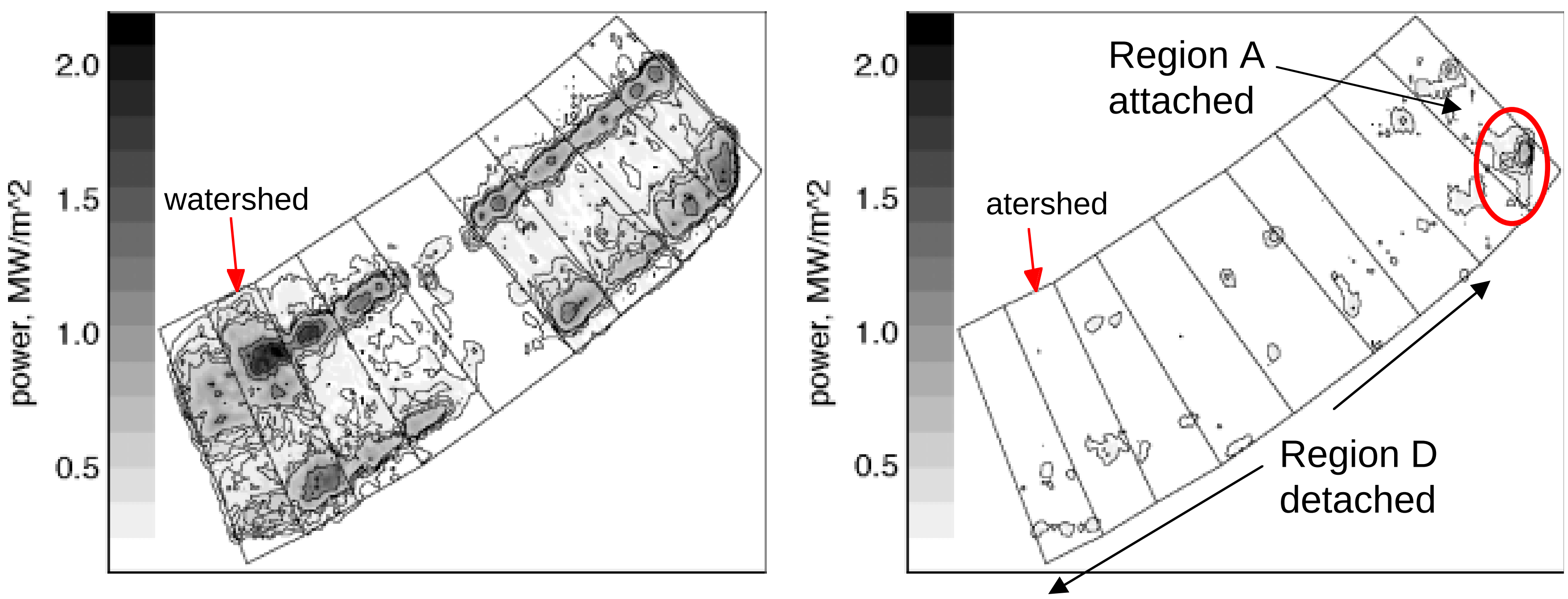


Divertor regimes: reduction of thermal load

Thermal load patterns on target, discharge #51321
(3D calculation from thermography)

t = 0.35 s, attached

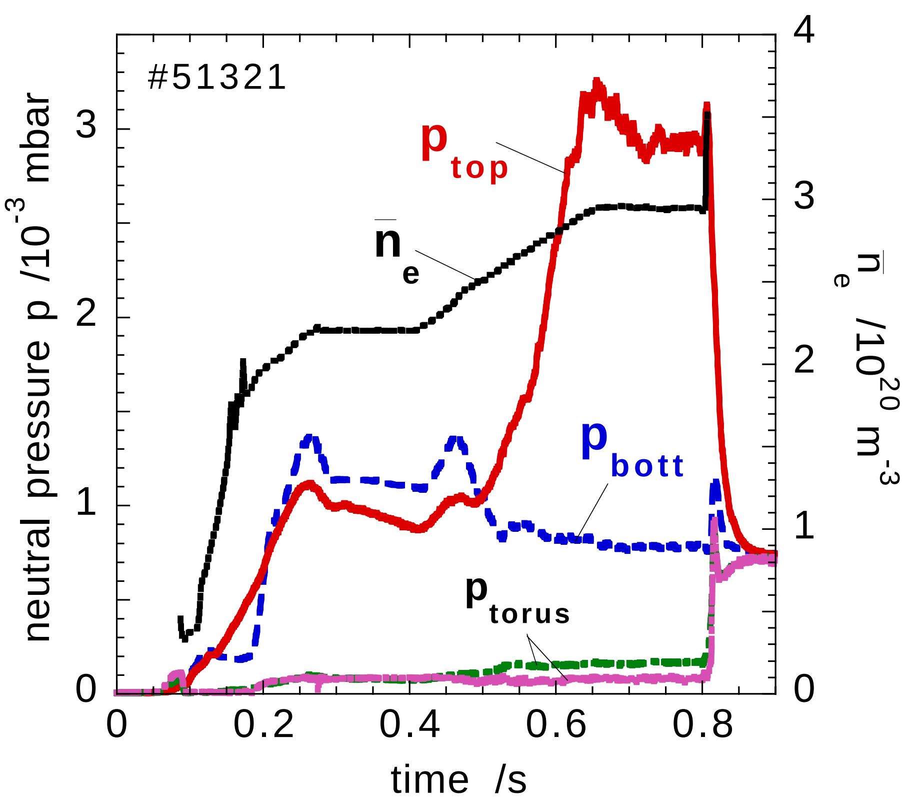
t = 0.65 s,partially detached

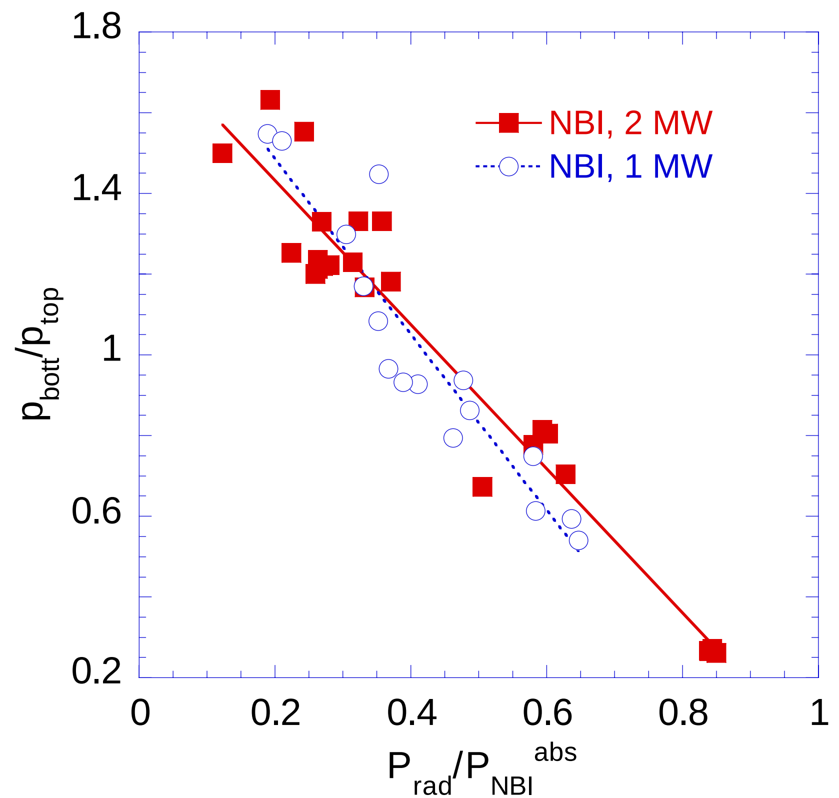


Divertor regimes: asymmetries

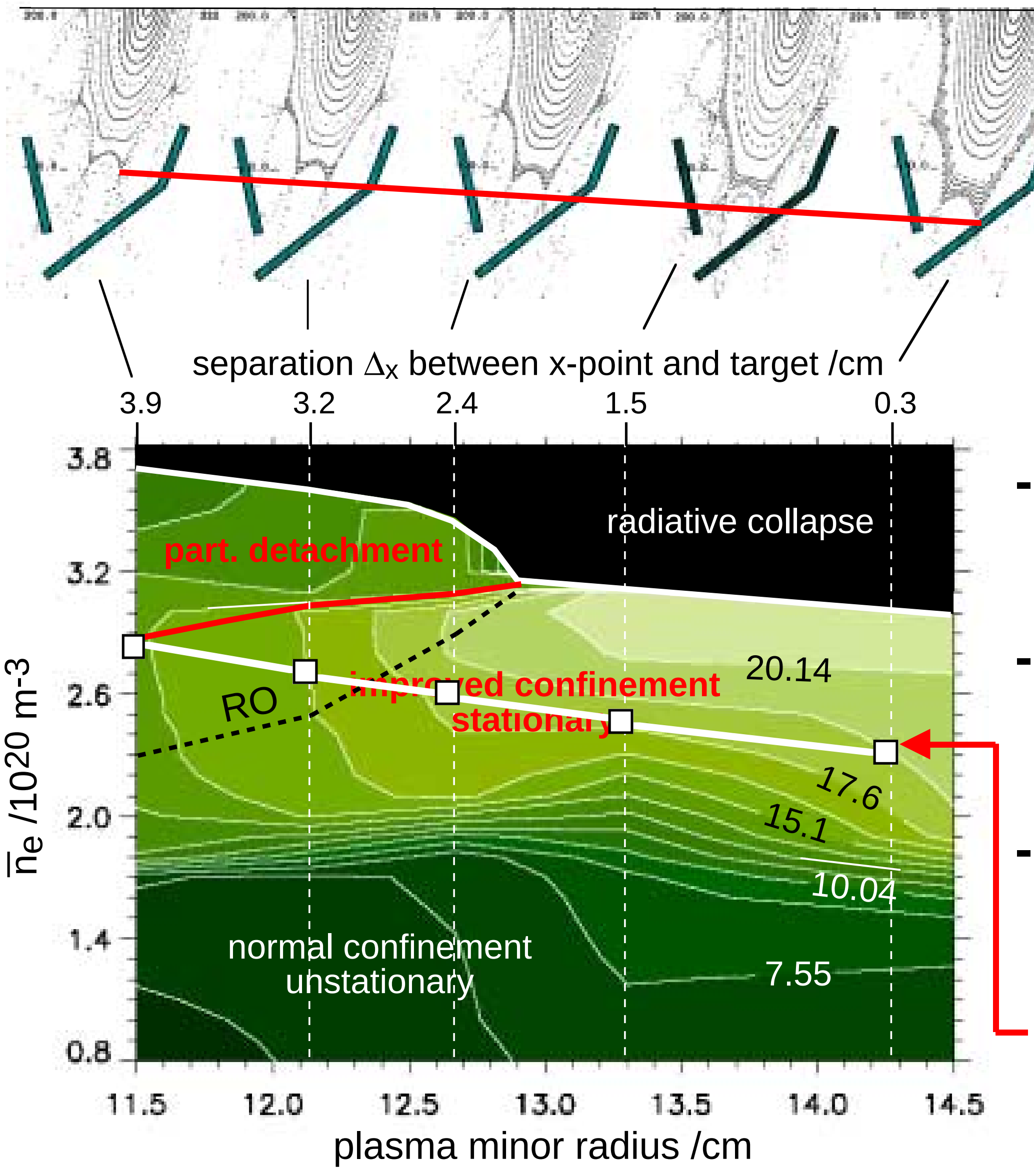
Neutral pressures inside divertor subvolume show strong up/down asymmetry.

- Asymmetry may even invert,
- radiated power fraction is an ordering parameter





Operational ranges and density limit



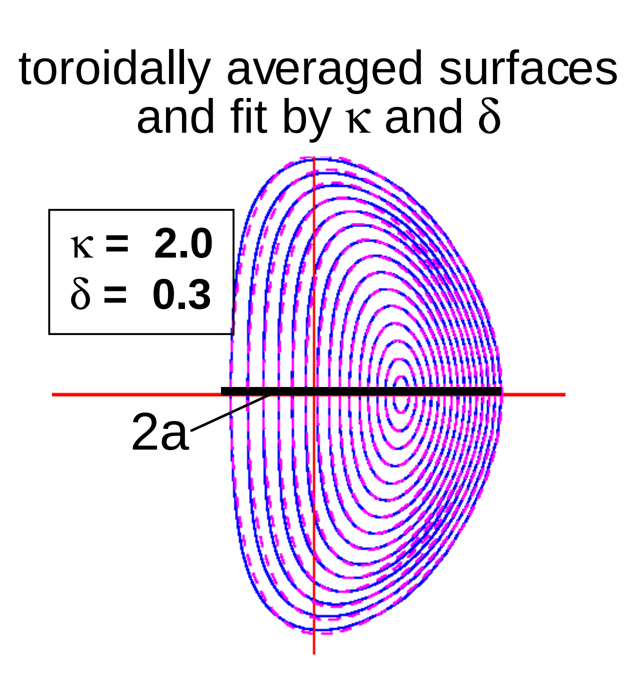
Variation of a_{pl} and Δ_x by control coil currents

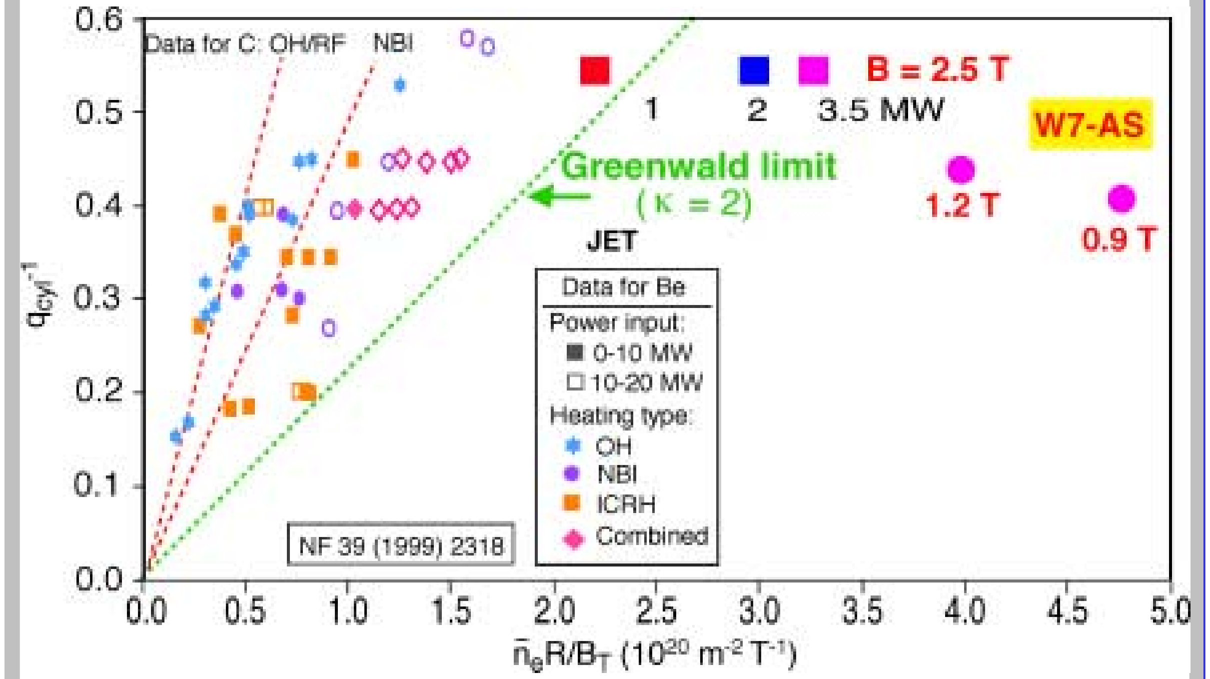
NBI, 2 MW:

- **Access to IC independent of Δ_x,**
- **partial detachment at $\Delta_x \geq 2.4$ cm**
- **partial detachment extends accessible density range**

density limit SUDO et al.

Operational ranges and density limit





$$\frac{1}{q_c} = 2\frac{RI_{eq}}{5a^2B}/[1+\kappa^2(1+2\delta^2-1.2\delta^3)]$$

$$\bar{n}_G = \kappa\bar{J} = I_{eq}/\pi a^2$$

Summary

- Access to a new NBI, high-density regime (up to $n_e \approx 3.5x\ 10^{20}\ m^{-3}$) with high τ_E and low τ_p and τ_{imp}
- Full density control already without Ti-gettering,
- Quasi-steady state operation also including partial detachment,
- Edge-dominated radiation, radiated power fractions are low to moderate in attached and high (up to 90%) in detached regimes
- Detachment is partial: it does not extend over the full target area, and the particle and energy fluxes stay finite (T_{ed} > 2 eV)
- Improved confinement in all separatrix-bounded configurations,
- Stable part. detachment restricts to configurations with larger distance between x-points and targets (divertor configurations).