Stationary Particle Balance Analysis at W7-AS

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W7-AS: stationary particle balance analysis

stationary particle balance: $$\frac{1}{V'}\frac{d}{dr}V'\Gamma = S_p$$

with particle flux density, Γ, $V' \simeq r$, and particle source strength, S_p, from

→ recycling fluxes and gas feed

→ NBI deposition (and pellets) for central refueling

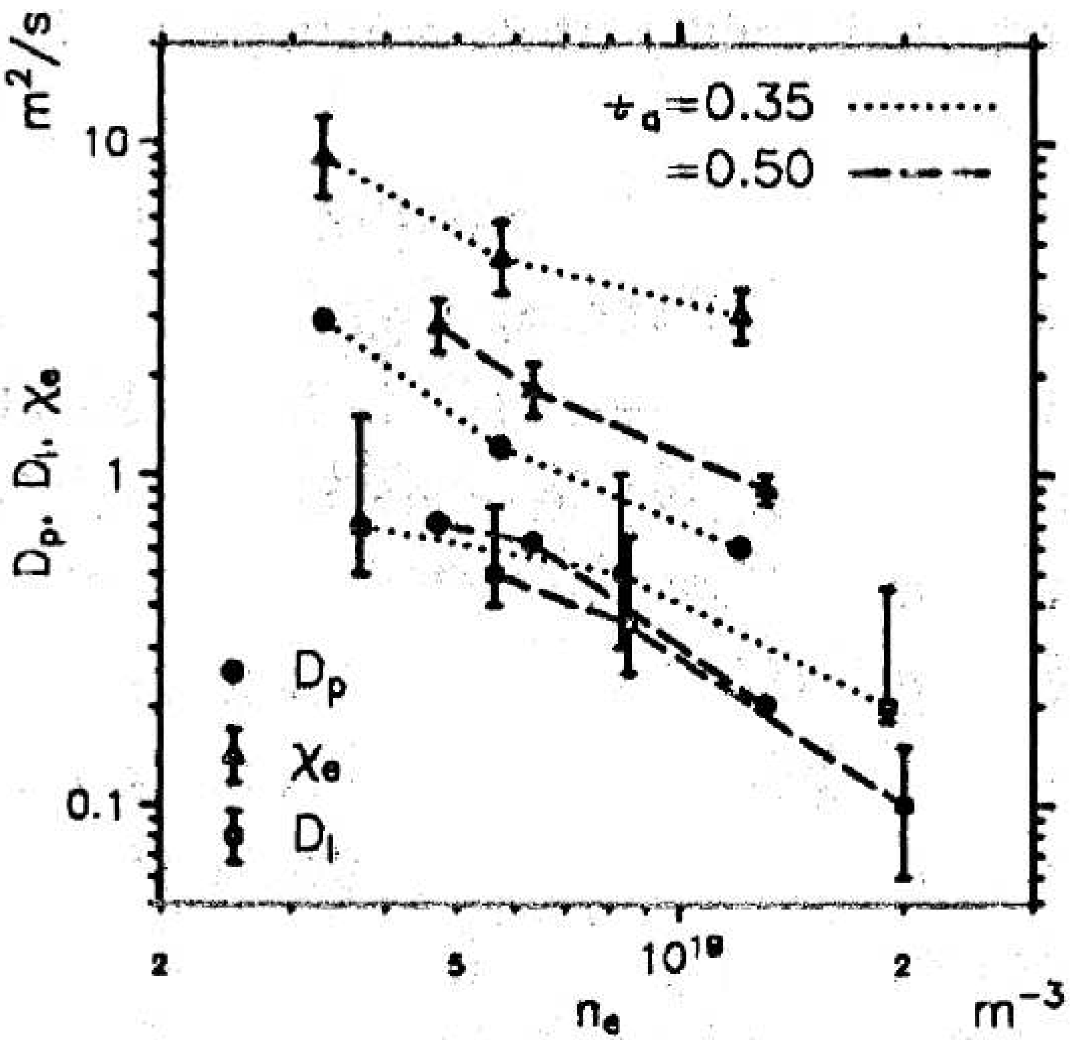
recycling fluxes: very different for low and high edge densities
(for high $n_e(a)$, see topic “edge physics”)

W7-AS: particle balances only for limiter cases (poor H_α documentation)

DEGAS code (early campaigns) and EIRENE code (later) for estimating $n_0(r)$
H_α data used in both codes to calibrate the edge neutral fluxes

in addition: convective 1D-slab modelling with boundary cond. $n_0(a),\ T_0(a)$
(Y.N. Dnestrovskii, D.P. Kostomarov, *Numerical Simulation of Plasmas, Springer-Verlag, 1986)*

W7-AS: purely diffusive modelling



purely diffusive model:

$\Gamma = -D\, n'$

rough scaling of D at outer r:

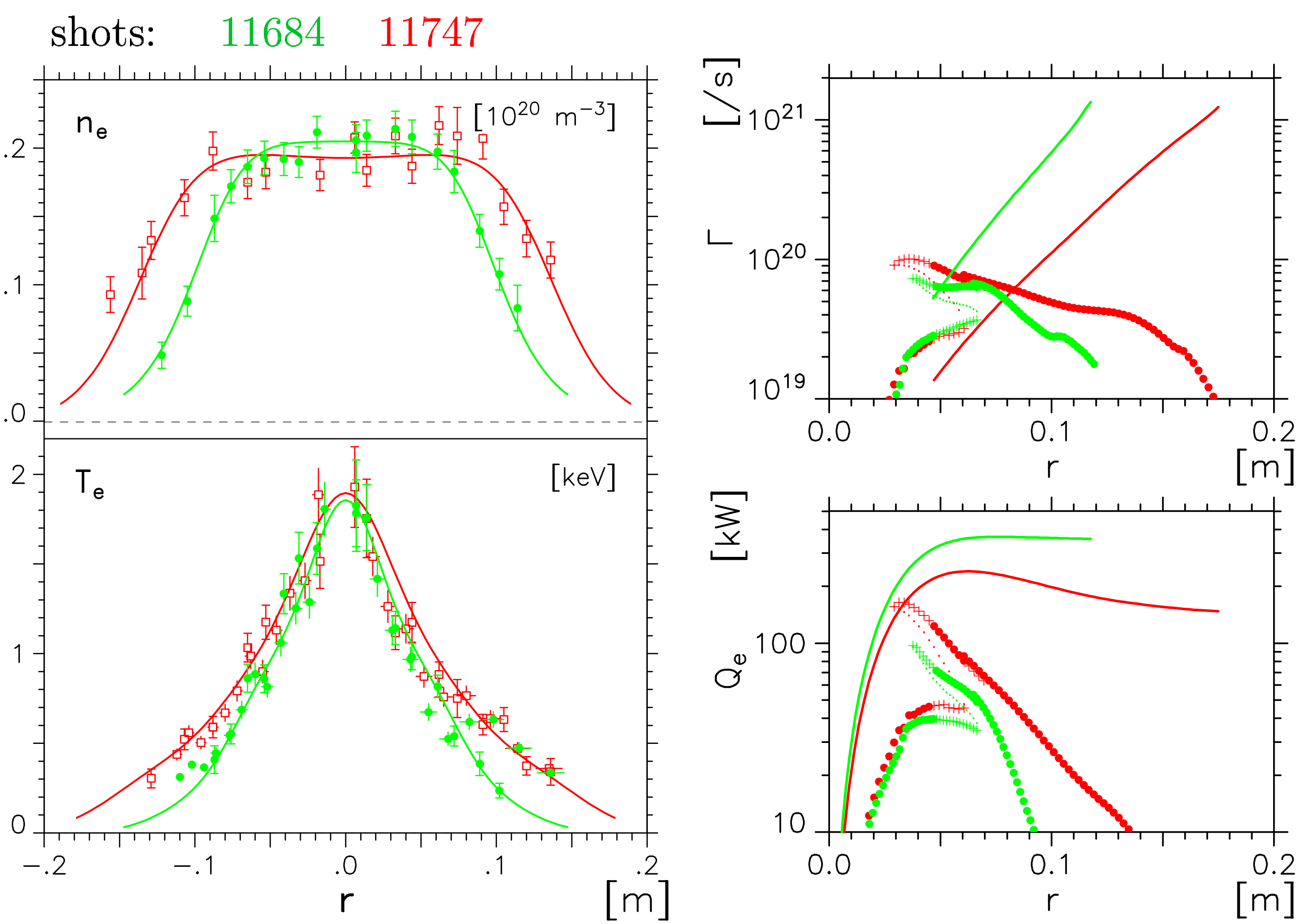
$D \propto P/n$

(also in SOL region by probes)

similar scalings for χ_e and D_I

(D_I $\rightarrow$ impurity transport)

W7-AS: stat. particle balances for pure ECRH



limiters:

inward shifted

outward shifted

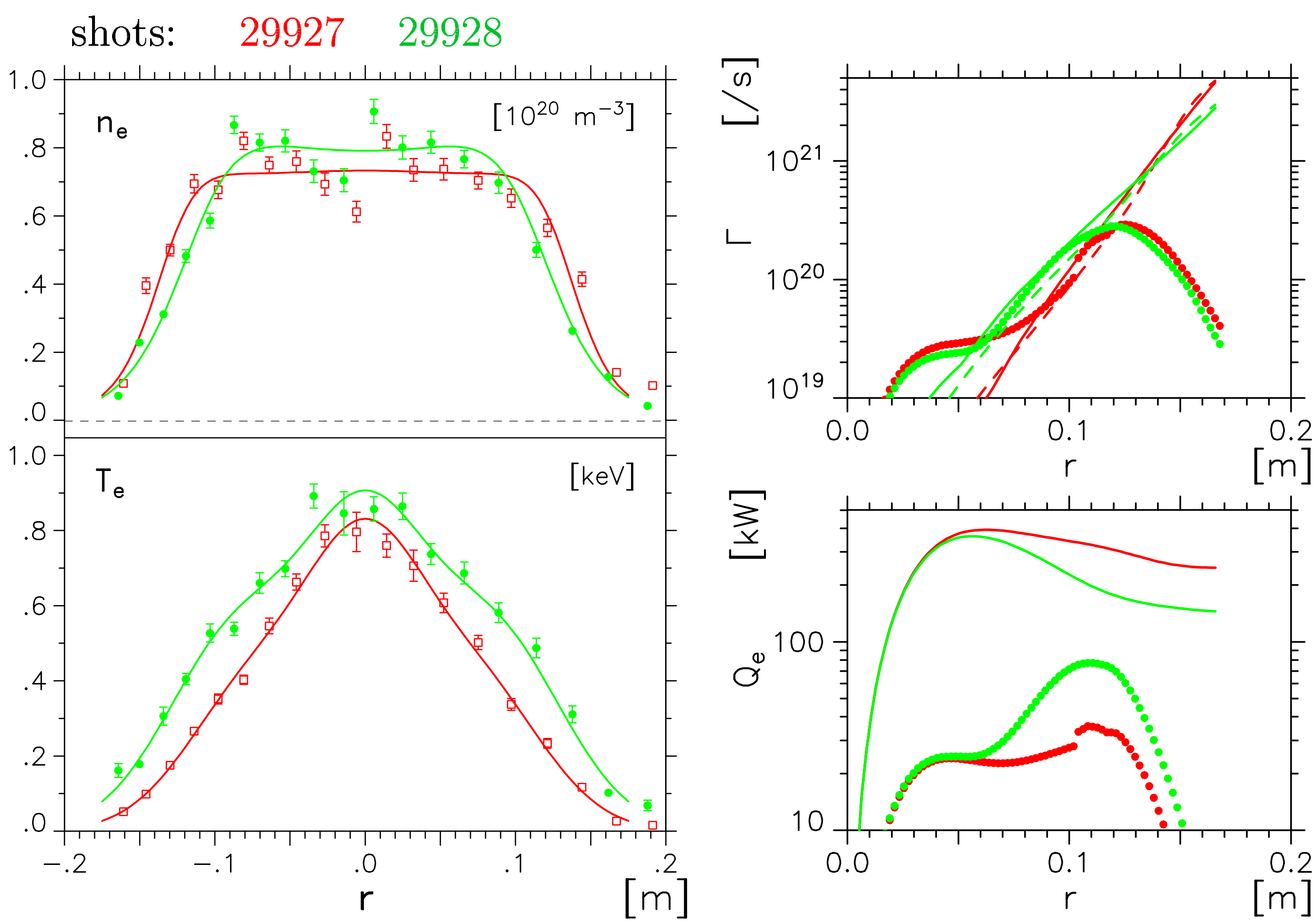
$P_{\text{ECRH}} \simeq 350$ kW

O1-mode; 70 GHz

DEGAS simulation

neoclassical fluxes from DKES: ● ●

W7-AS: stat. particle balances for pure ECRH



$\iota(a) = 0.345$

$\iota(a) = 0.340$

$P_{\mathrm{ECRH}} \simeq 500$ kW

X2-mode; 140 GHz

EIRENE simul.

conv. model

$T_0(a)$ (eV):

20 40

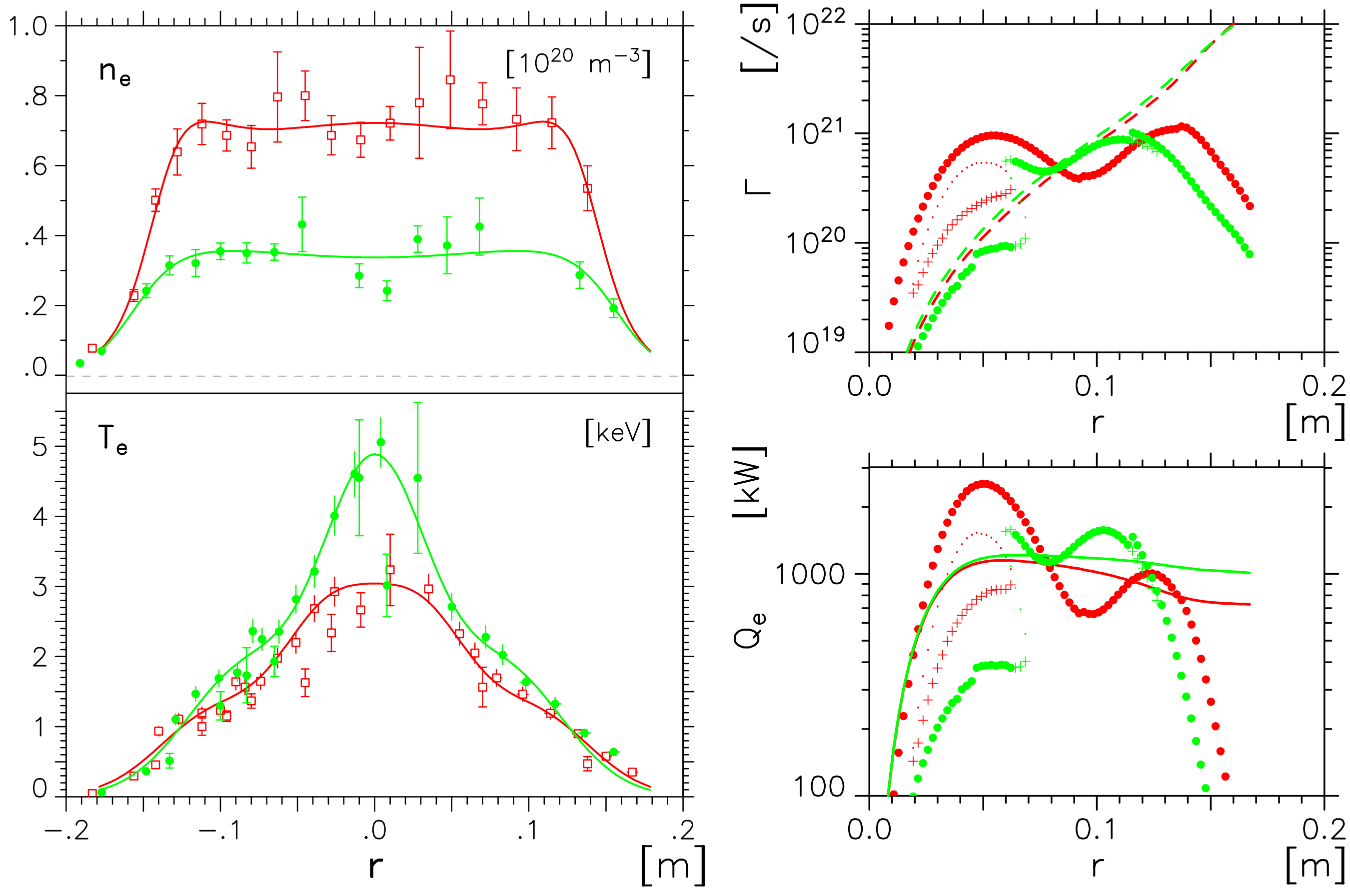
$n_0(a)$ (10^{14} m^{-3}):

5.0 2.5

neoclassical fluxes from DKES: ● ●

W7-AS: stat. particle balances for pure ECRH

shots: 42754 42757



CERC discharges

$P_{ECRH} \simeq 1200$ kW

X2-mode; 140 GHz

convective model

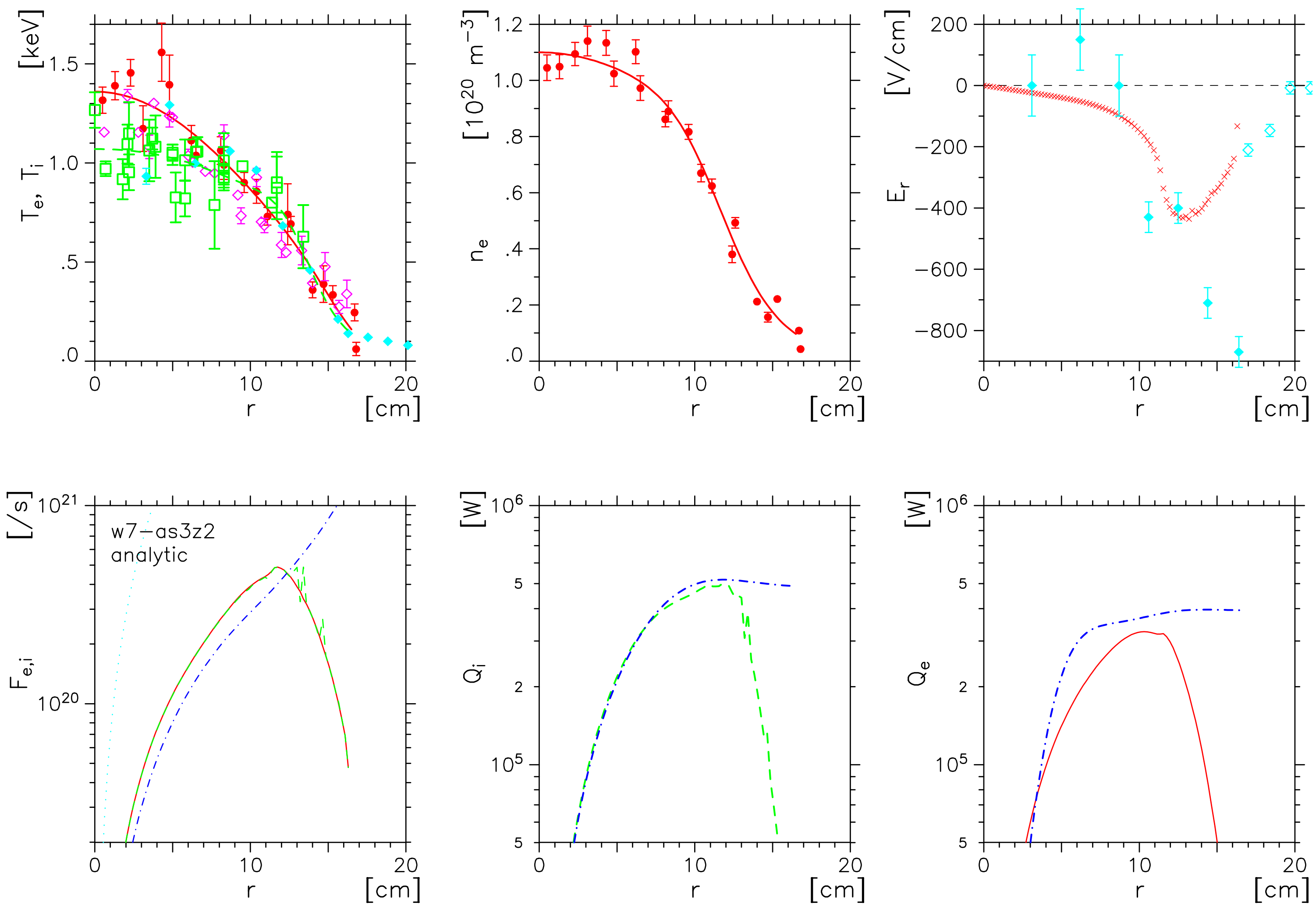
$T_0(a) \simeq 70$ eV

$n_0(a) \simeq 7.5 \cdot 10^{14}$ m^{-3}

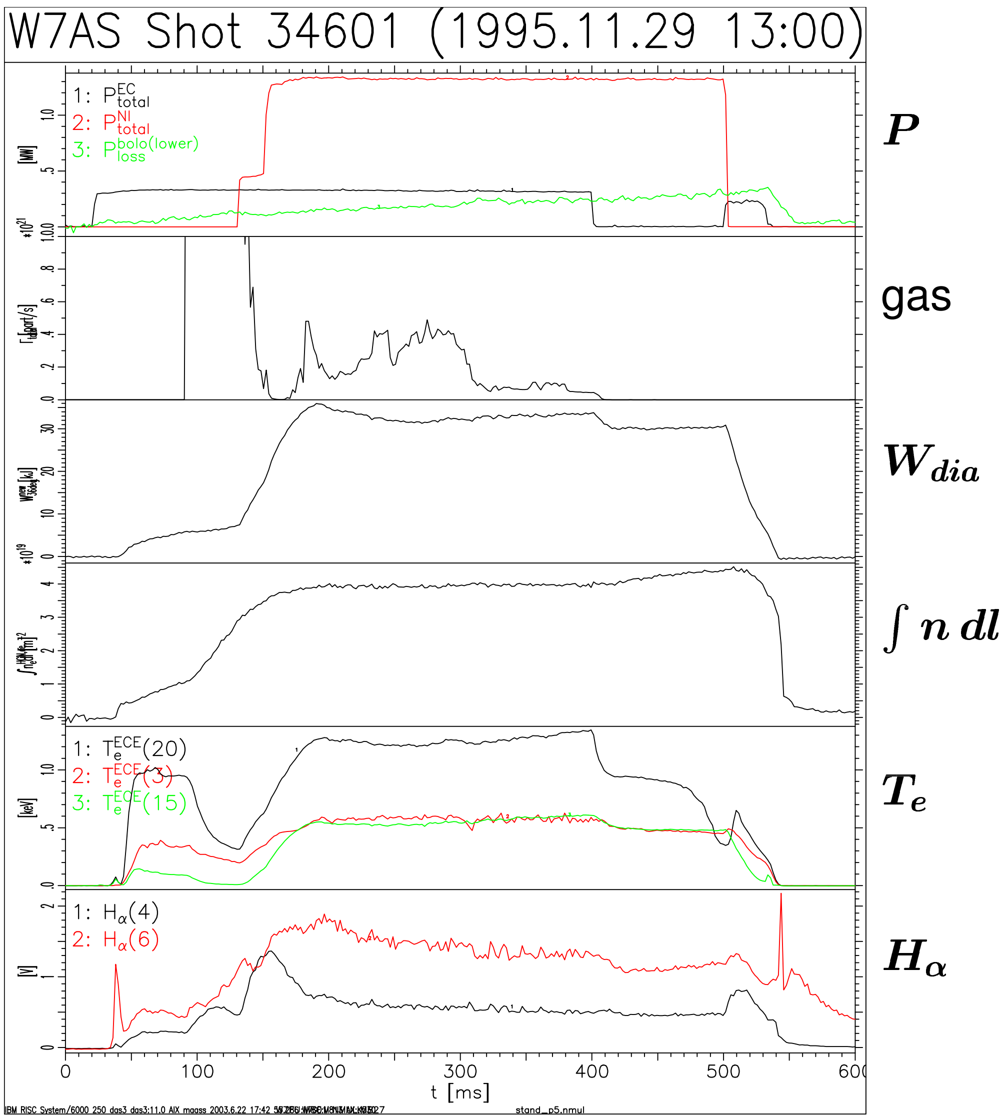
neoclassical fluxes from DKES: ● ●

W7-AS: neoclassical transport analysis

shot 34609 absorbed power: 830 kW NBI, 330 kW ECRH



W7-AS: “ECRH pump-out”



shot 34601: time traces

$t = 0.35$ s: transport analysis

$t = 0.40$ s: ECRH switched off

$t = 0.45$ s: ECE profile

$t = 0.49$ s: ECE with cut-off

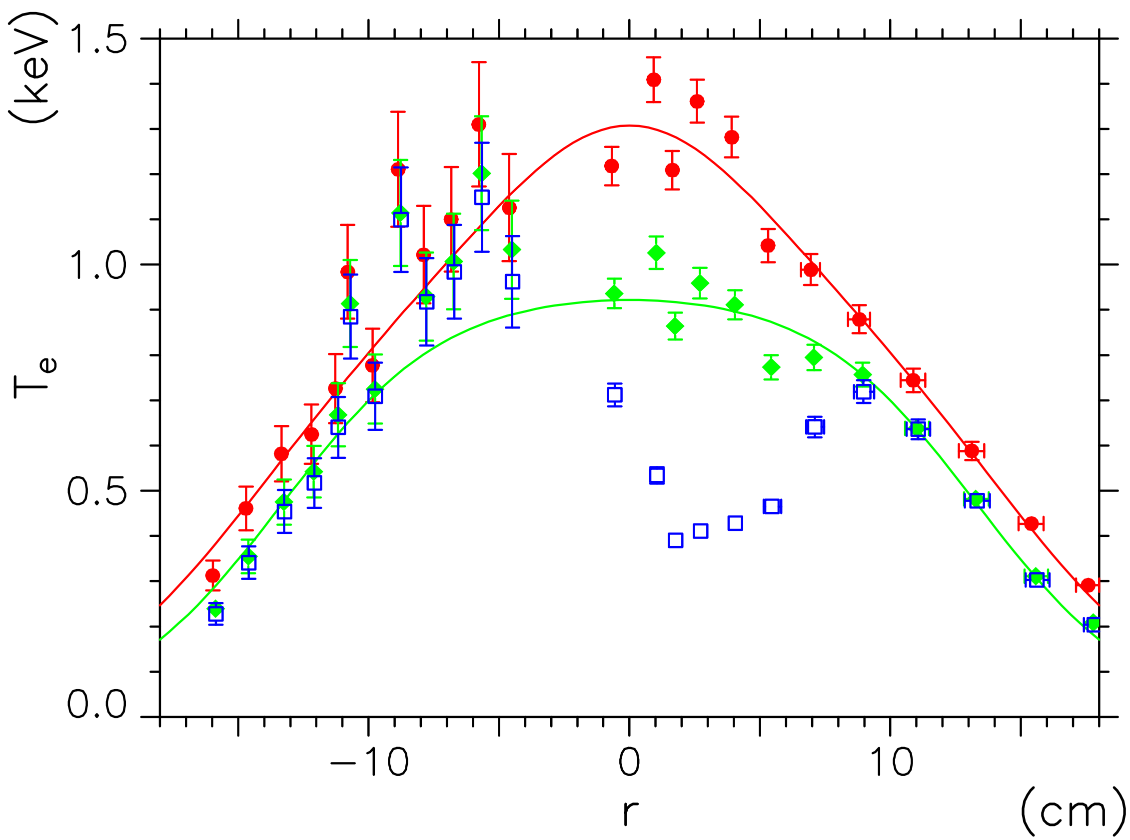
after ECRH switched off:

1. recycling reduced (H_α)
2. no gas feed
3. density control lost

$\rightarrow$ particle transport reduced

W7-AS: "ECRH pump-out"

shot 34601: $n_e(0)$ close to cut-off



ECE profiles:

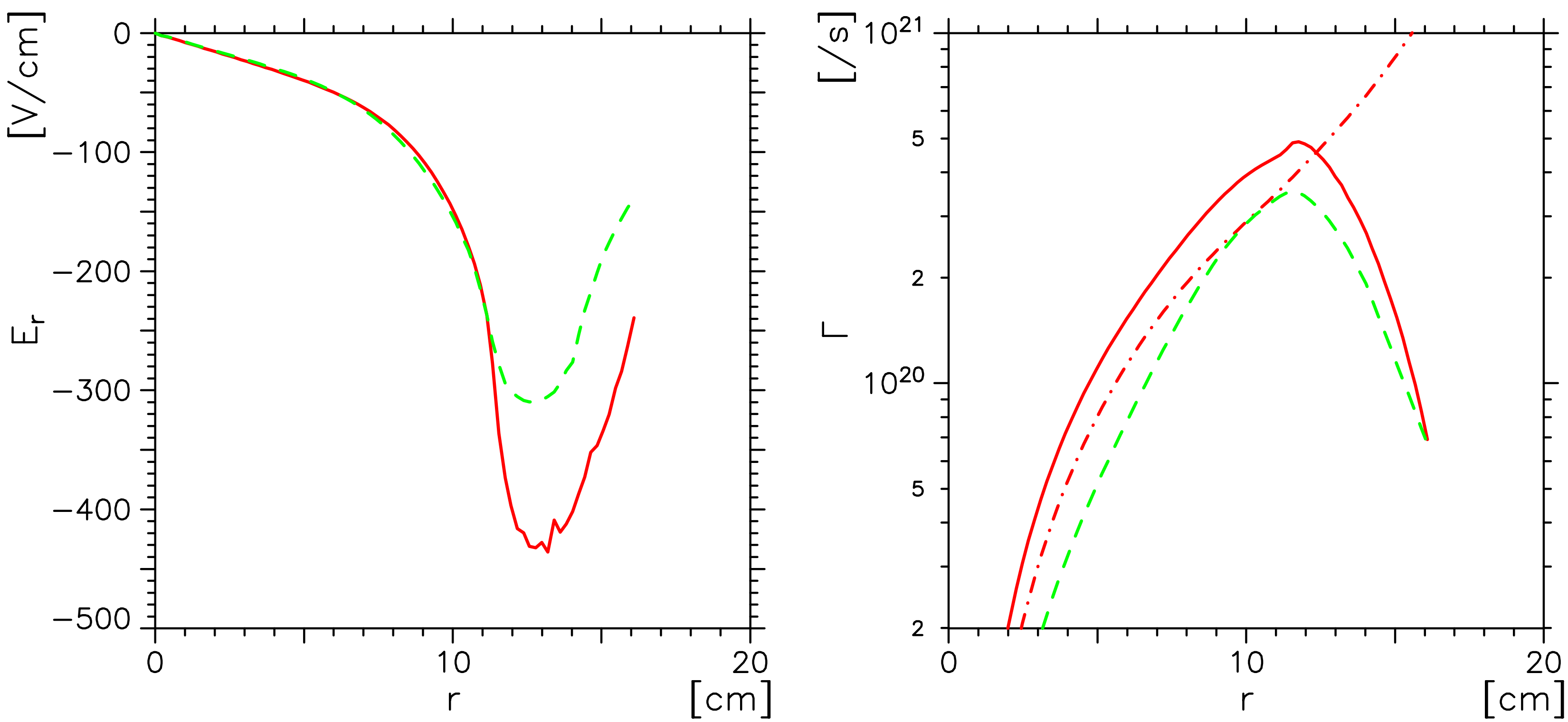
$t = 0.35$ s: with ECRH

$t = 0.45$ s: w/o ECRH

$t = 0.49$ s: cut-off

W7-AS: "ECRH pump-out" - ambipolar fluxes

shot 34601: $t = 0.35$ s and $t = 0.45$ s



density increase: $\dot{N}_{r<10\ \mathrm{cm}} \simeq 4.4\ 10^{19}$ /s

NBI particle source for $r < 10$ cm: $\simeq 3\ 10^{20}$ /s

difference of particle fluxes at $t = 0.35$ and $t = 0.45$ s $\simeq \dot{N}_{r<10\ \mathrm{cm}}$

Remarks on transient transport analysis

1D particle balance eq. with the particle flux, Γ, and source term, S

$$\frac{\partial}{\partial t} n(r,t) + \frac{1}{V'} \frac{\partial}{\partial r} V' \Gamma = S(r,t),$$

particle flux with *diffusive* and *convective* contributions,

$$\Gamma(r,t) = -D(r,t) \frac{\partial}{\partial r} n(r,t) + V(r,t) n(r,t)$$

linearisation with respect to small (transient) variations of n, S, D and V

Taylor expansion starting from the stationary particle balance at $t = t_0$

$$-\frac{1}{V'} \frac{\partial}{\partial r} V' \Big\{ D_0(r) \frac{\partial}{\partial r} n_0(r) - V_0(r) n_0(r) \Big\} = S_0(r)$$

With $\delta n = n(r,t) - n_0(r)$, $\delta D = D(r,t) - D_0(r)$, ... (1st order in δ)

$$\frac{\partial}{\partial t} \delta n - \frac{1}{V'} \frac{\partial}{\partial r} V' \Big\{ \delta D \, n_0' + D_0 \frac{\partial \delta n}{\partial r} - \delta V \, n_0 - V_0 \, \delta n \Big\} = \delta S.$$

δD and δV are separated in *implicit* and in *explicit* time dependence

Remarks on transient transport analysis (2)

implicit contributions: $\delta D^{\rm im} = \delta D(r, n, n')$ and $\delta V^{\rm im} = \delta V(r, n, n')$

explicit contributions: $\delta D^{\rm ex}(r,t) = \delta D - \delta D^{\rm im}$ and $\delta V^{\rm ex}(r,t) = \delta V - \delta V^{\rm im}$

explicit time dependent $\rightarrow$ *effective* source strength, δS^*:

$$\delta S^*(r,t) = \delta S(r,t) + \frac{1}{V'}\frac{\partial}{\partial r} V'\{\delta D^{\rm ex}(r,t)\, n_0' - \delta V^{\rm ex}(r,t)\, n_0\}.$$

implicit coefficients in *1st* order:

$$\delta D^{\rm im} = \frac{\partial D}{\partial n}\delta n + \frac{\partial D}{\partial n'}\frac{\partial \delta n}{\partial r} \qquad \text{and} \qquad \delta V^{\rm im} = \frac{\partial V}{\partial n}\delta n + \frac{\partial V}{\partial n'}\frac{\partial \delta n}{\partial r}$$

$$\frac{\partial}{\partial t}\delta n - \frac{1}{V'}\frac{\partial}{\partial r} V' \left\{ D^* \frac{\partial \delta n}{\partial r} - V^* \delta n \right\} = \delta S^*$$

with *effective* transport coefficients defined by

$$D^*(r) = D_0 + \frac{\partial D}{\partial n'} n_0' - \frac{\partial V}{\partial n'} n_0 \qquad \text{and} \qquad V^*(r) = V_0 + \frac{\partial V}{\partial n} n_0 - \frac{\partial D}{\partial n} n_0'$$

Remarks on transient transport analysis (3)

transient particle balance analysis: only $\delta S^*(r,t)$, $D^*(r)$ and $V^*(r)$

$\longrightarrow$ this is the maximum information

implicit modelling: 6 unknowns in 2 eqs. $\longrightarrow$ additional assumptions ???

example: purely diffusive ansatz, $V = 0$, and D_0 from stationary balance

$$\frac{\partial \ln D}{\partial \ln n'} = \frac{D^*}{D_0} - 1 \qquad \text{and} \qquad \frac{\partial \ln D}{\partial \ln n} = -\frac{V^*}{D_0}\frac{n_0}{n_0'}$$

ansatz: $D \propto 1/n$, *implicit* particle flux is given by

$$\Gamma^{\mathrm{im}} = -D_0 \frac{\partial \delta n}{\partial r} + D_0 \frac{n_0'}{n_0} \delta n,$$

$\longrightarrow$ convective term in transient analysis even for purely diffusive transport

$\longrightarrow$ ansatz $D \propto 1/n$ leads to an “inward pinch”