A study of particle transport based on H_α line profiles

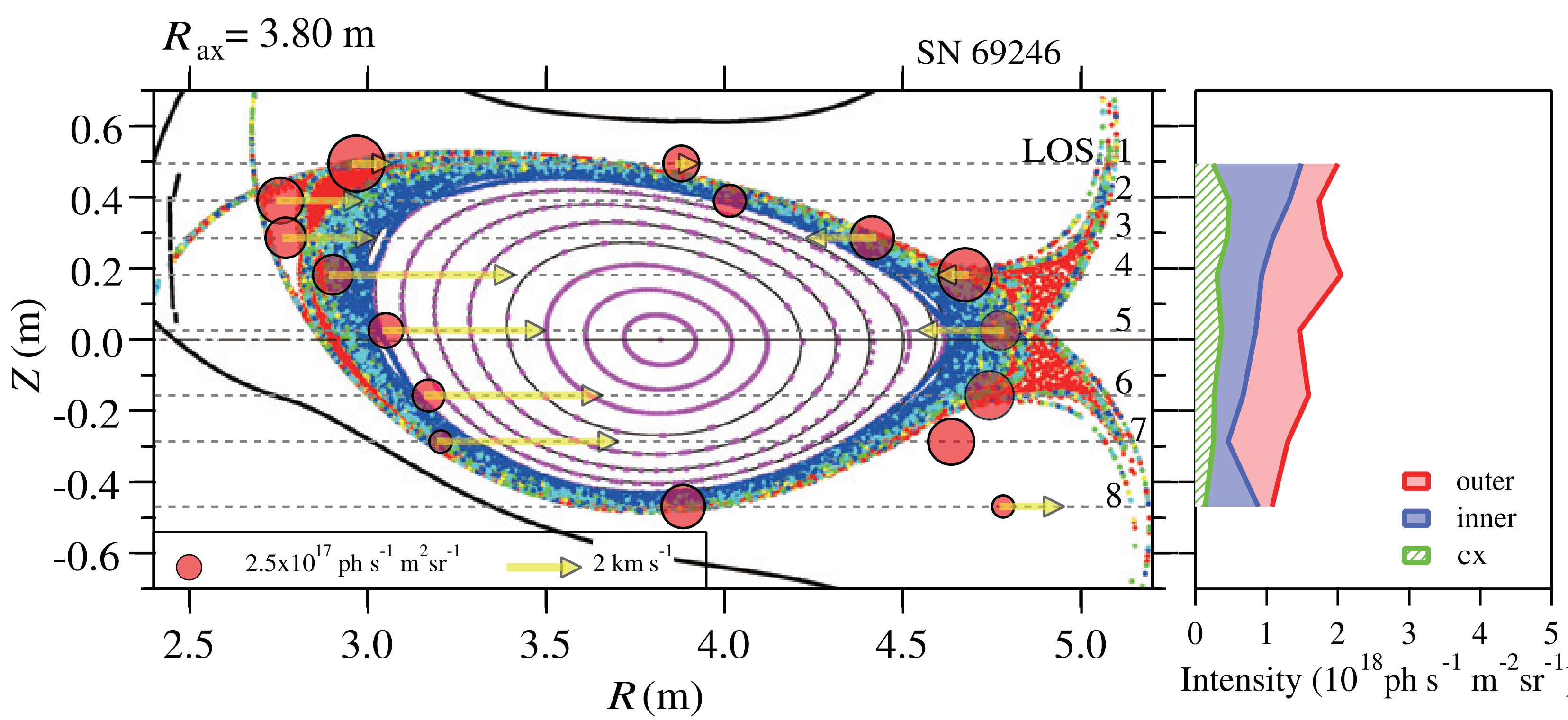
M. Goto[1], K. Sawada[2], K. Fujii[3], M. Hasuo[3], and S. Morita[1]

[1]*National Institute for Fusion Science*

[2]*Department of Applied Physics, Shinshu University*

[3]*Department of Mechanical Engineering, Kyoto University*

- dominant ionization location of hydrogen is outside LCFS, which means no direct contribution for fueling



A. Iwamae, Physics of Plasmas **17**, 090701 (2010)

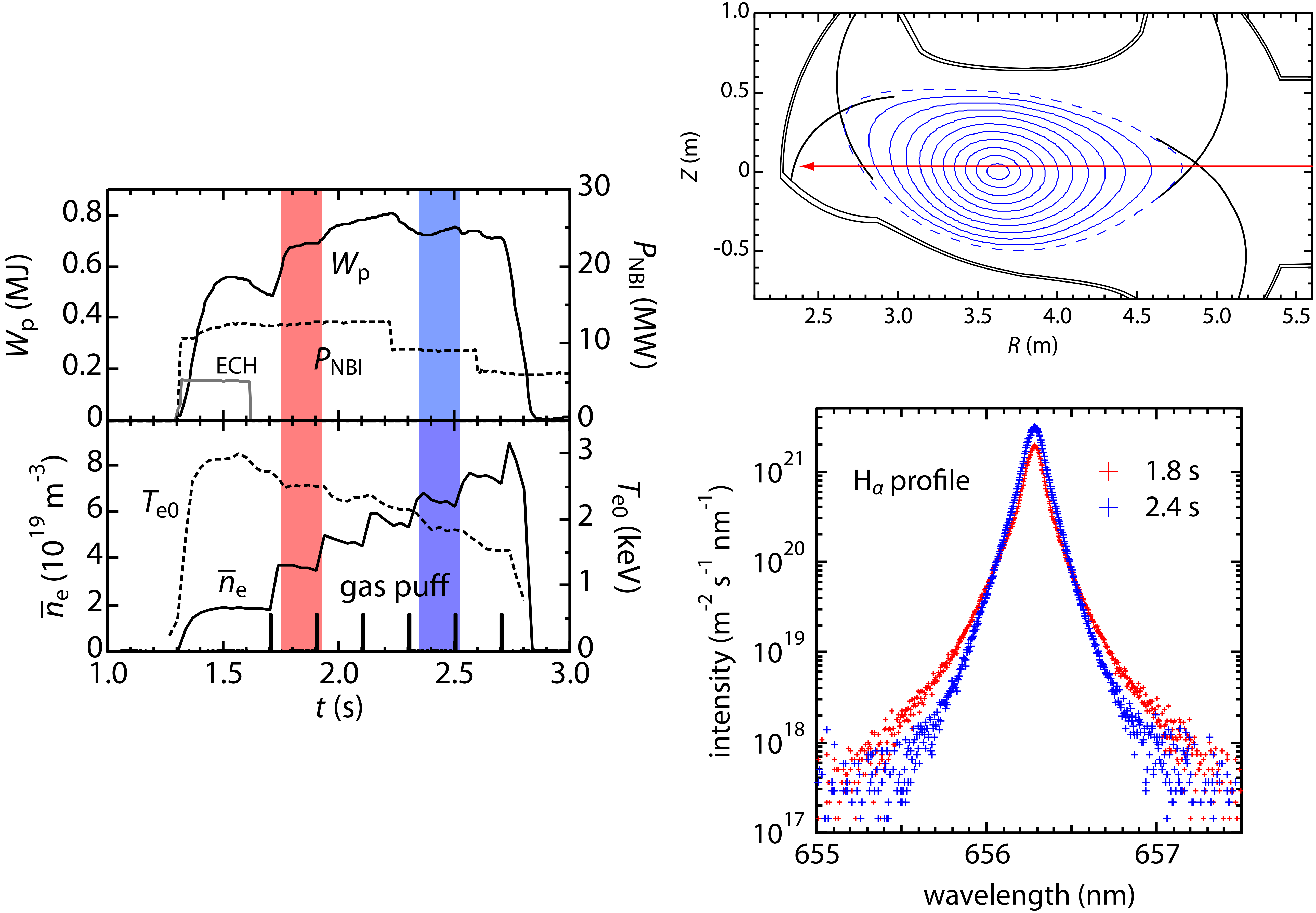
- nevertheless, n_e can be controlled by gas puff and detailed fueling mechanism is little known

- H_α line profile generally has a broad tail and is not expressed with a single Gaussian function

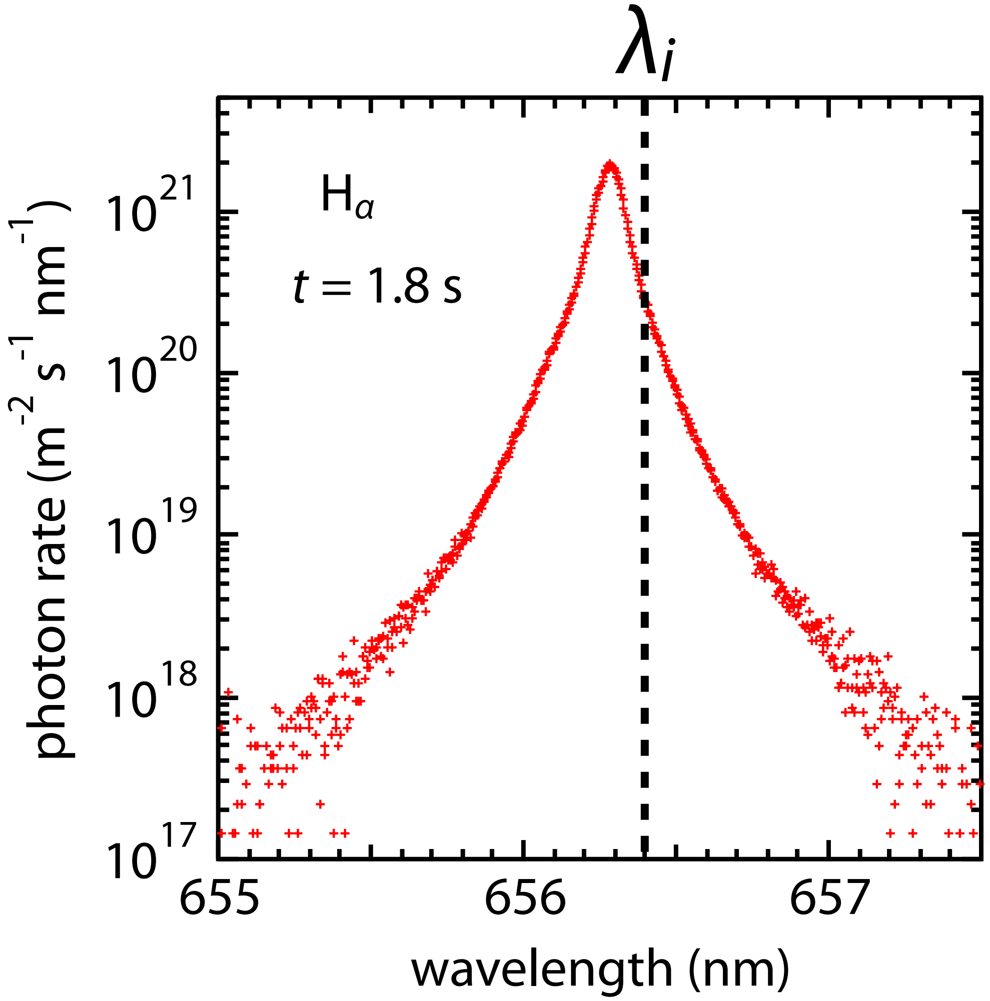
- broad component is thought to originate in CX process between cold atoms and hot protons

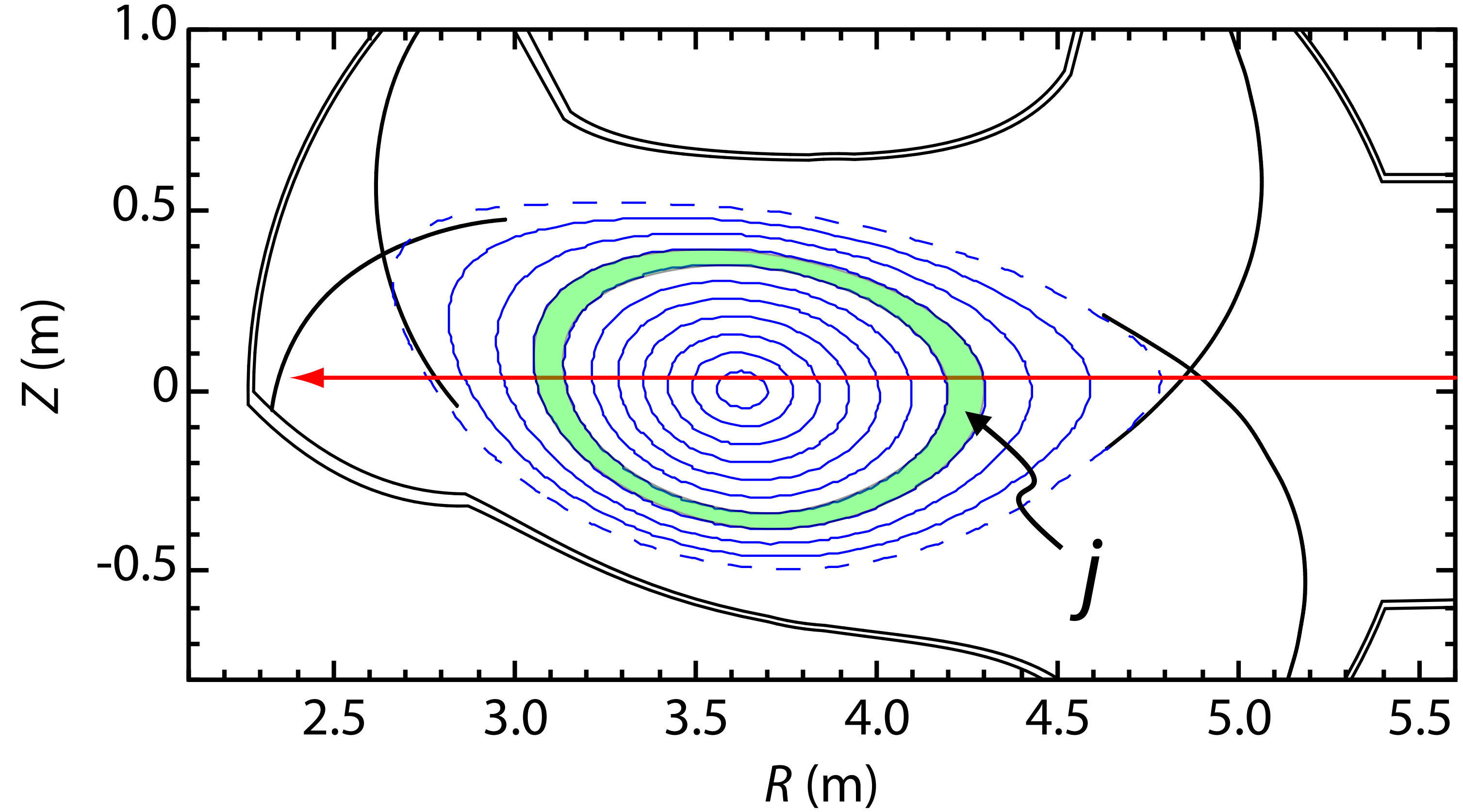
- hot atoms should have taken over VDF, or temperature, of protons in CX process

- line profile can be understood as superposition of Gaussian profiles having different width, namely, at different locations in plasma



W_p (MJ)
P_{NBI} (MW)
W_p
ECH
P_{NBI}
$\overline{n}_e$ (10^{19} m^{-3})
T_{e0} (keV)
T_{e0}
$\overline{n}_e$
gas puff
t (s)
Z (m)
R (m)
intensity (m^{-2} s^{-1} nm^{-1})
H$_\alpha$ profile
1.8 s
2.4 s
wavelength (nm)





$$I(\lambda_i) = \sum_j \eta_j \frac{1}{\sqrt{\pi} w_j} \exp\left[-\left(\frac{\lambda_i - \lambda_0}{w_j}\right)^2\right] (\Delta R)_j$$

$$I(\lambda) = \int_{R_{\min}}^{R_{\max}} \eta(R) \frac{1}{\sqrt{\pi} w(R)} \exp\left[-\left(\frac{\lambda - \lambda_0}{w(R)}\right)^2\right] \mathrm{d}R$$

$$I(\lambda) = \int_{R_{\min}}^{R_{\max}} \eta(R) \frac{1}{\sqrt{\pi} w(R)} \exp\left[-\left(\frac{\lambda - \lambda_0}{w(R)} \right)^2 \right] \mathrm{d}R$$

$$R = \begin{cases} R_{\mathrm{in}}(T) & R < R_{\mathrm{ax}} \\ R_{\mathrm{out}}(T) & R > R_{\mathrm{ax}} \end{cases}$$

$$I(\lambda) = \int_{0}^{T_0} f(T) \frac{1}{\sqrt{\pi} w(T)} \exp\left[-\left(\frac{\lambda - \lambda_0}{w(T)} \right)^2 \right] \mathrm{d}T$$

$$\left(f(T) = \eta(T) \left\{ \left| \frac{\mathrm{d}R_{\mathrm{in}}}{\mathrm{d}T} \right|_T + \left| \frac{\mathrm{d}R_{\mathrm{out}}}{\mathrm{d}T} \right|_T \right\} \right)$$

$$I(\lambda) = \int_0^{T_0} f(T) \frac{1}{\sqrt{\pi} w(T)} \exp\left[-\left(\frac{\lambda - \lambda_0}{w(T)}\right)^2\right] \mathrm{d}T$$

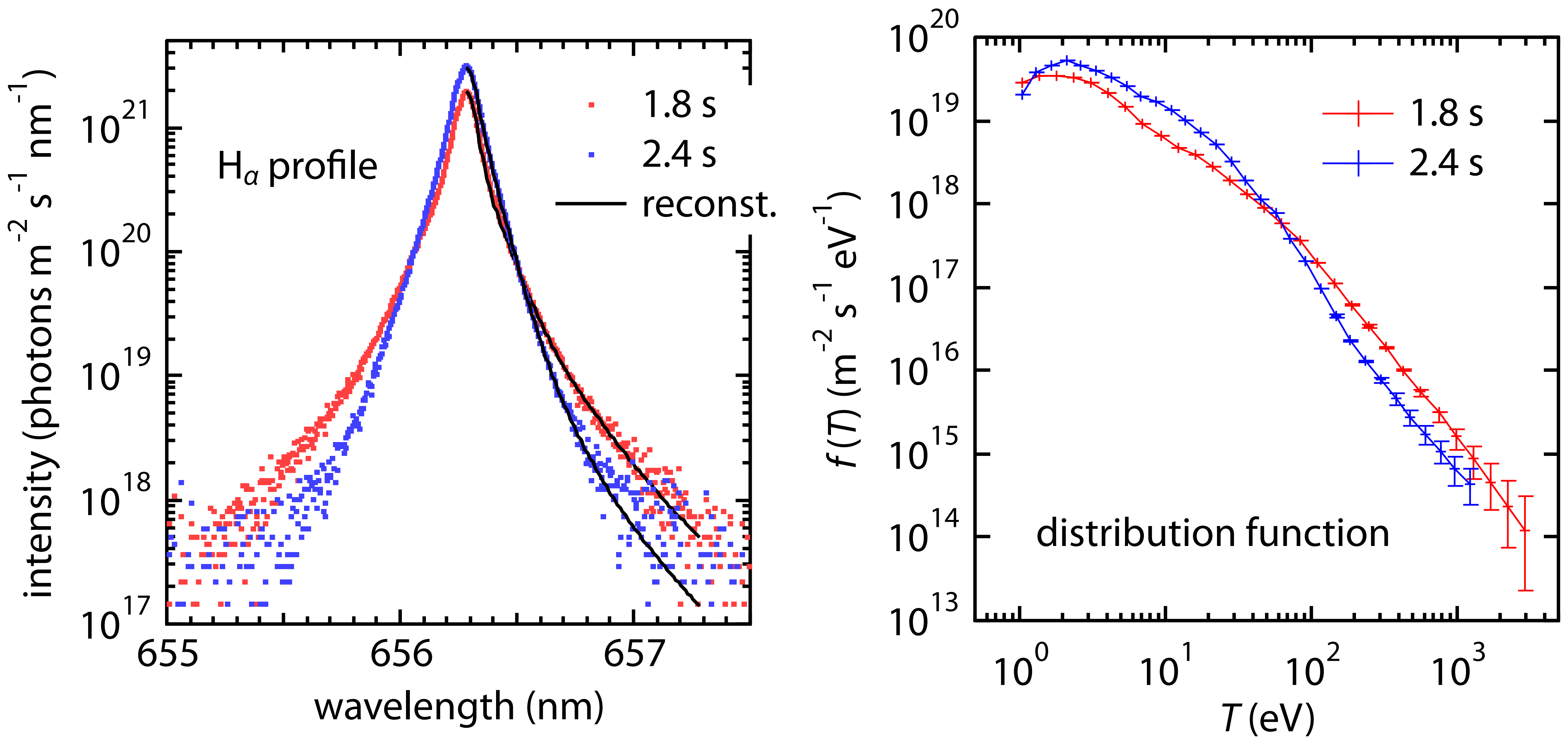
$$s = (\lambda - \lambda_0)^2$$
$$t = 1/w^2 = Mc^2/2kT\lambda_0^2$$
$$T_0 \to \infty$$

$$\mathscr{F}(s) = \int_0^{\infty} F(t) \exp(-st) \mathrm{d}t \quad \text{(Laplace transform)}$$

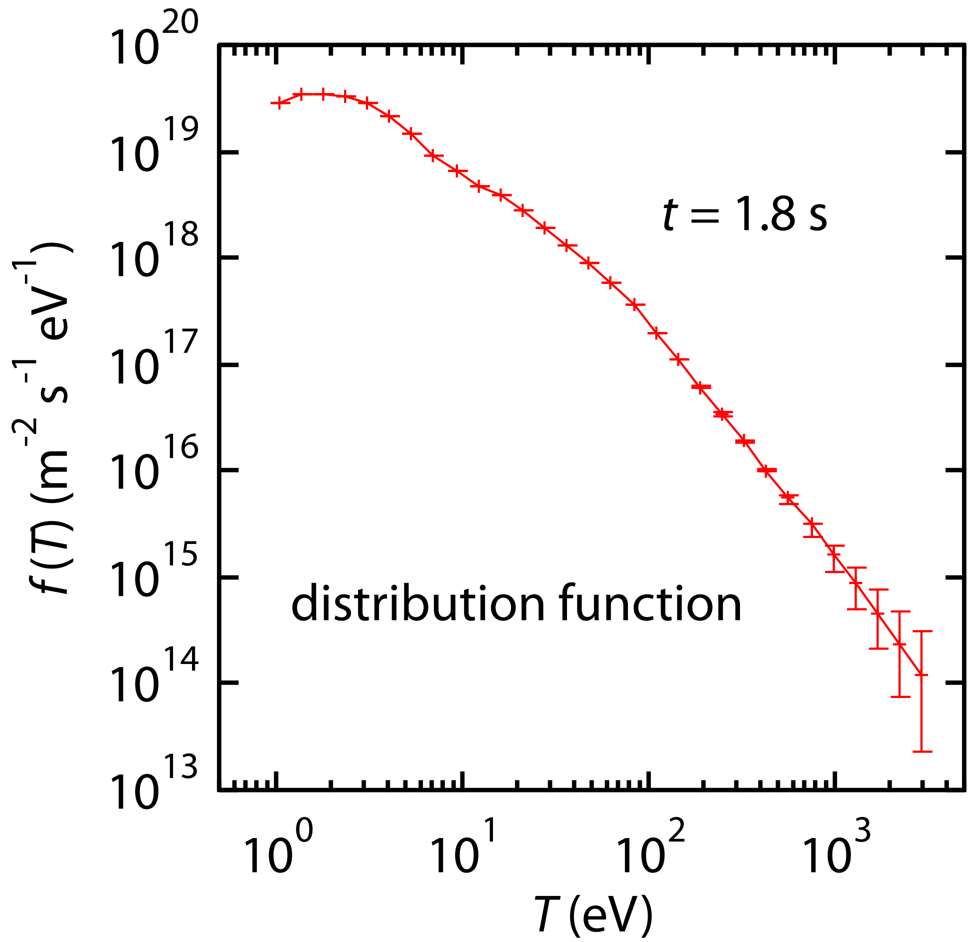
$$\left(F(t) = f(T) \frac{1}{\sqrt{\pi} w(T)} \frac{\mathrm{d}T}{\mathrm{d}t}\right)$$

$F(t)$ and then $f(T)$ are obtained by numerical inversion of the Laplace transform

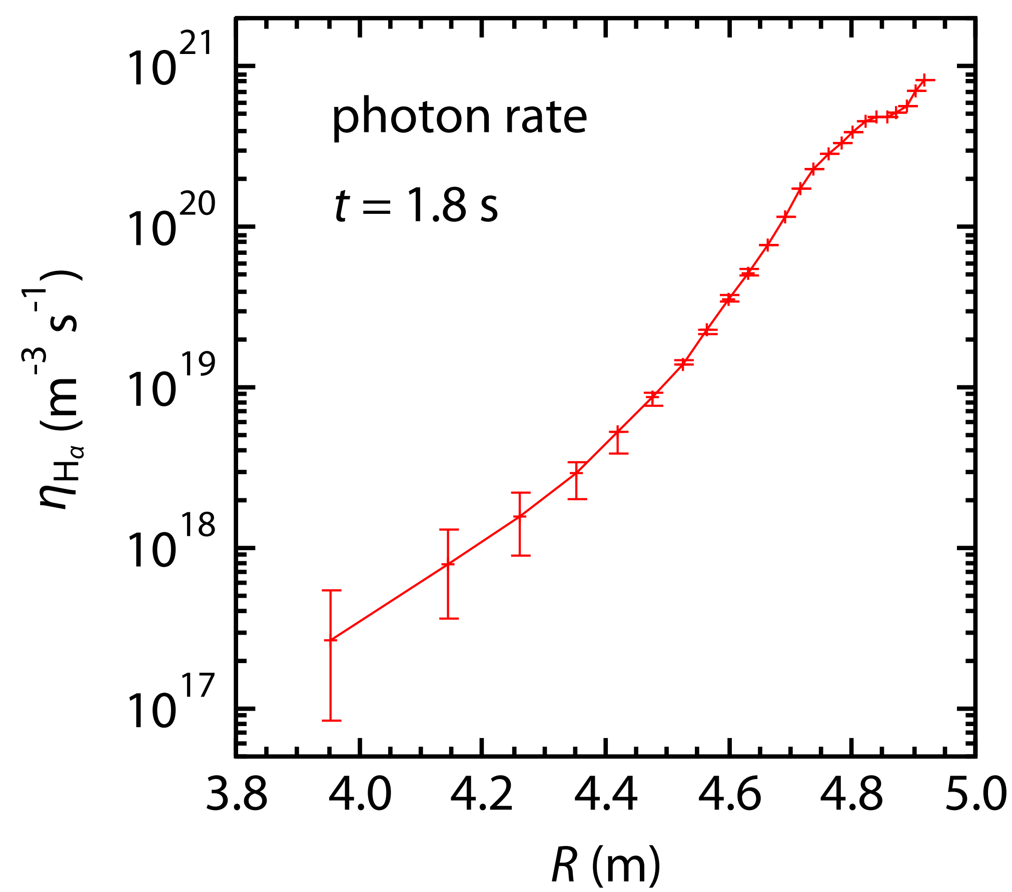
(R. E. Bellman *et al.*, *Numerical Inversion of the Laplace Transform*, 1966)

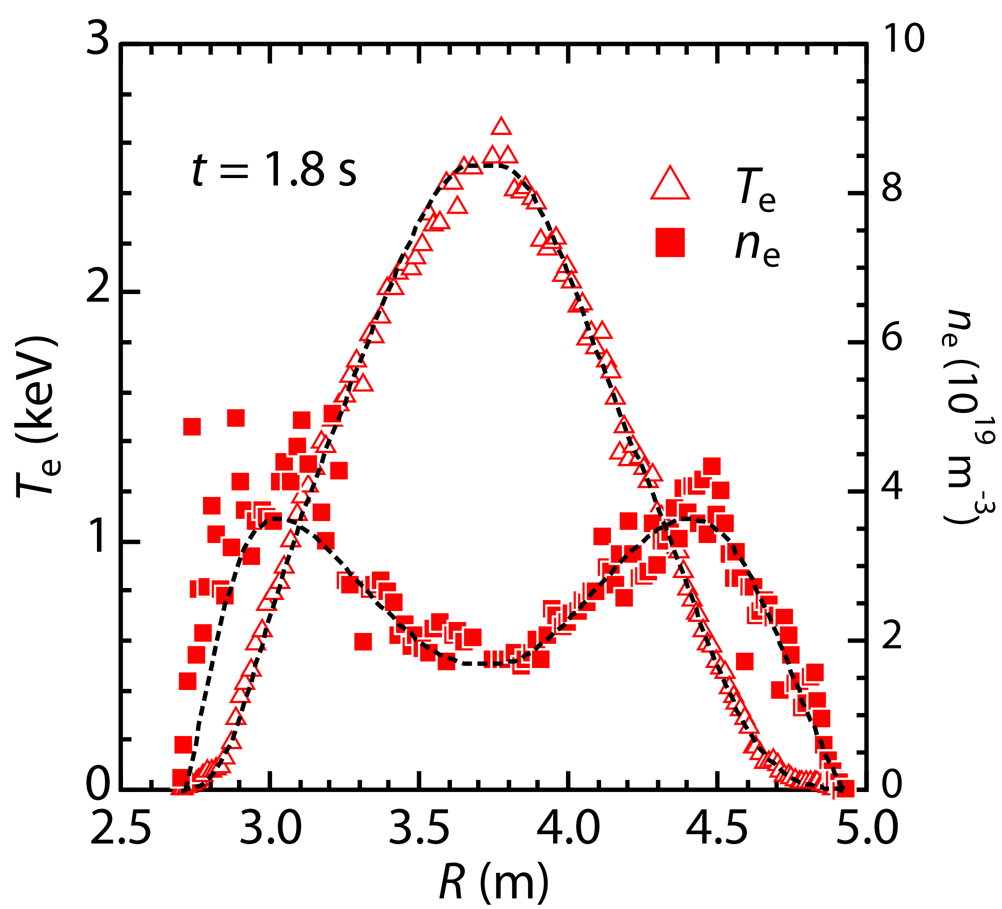


H$_\alpha$ profile
1.8 s
2.4 s
reconst.
intensity (photons m^{-2} s^{-1} nm^{-1})
wavelength (nm)
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
655
656
657
distribution function
1.8 s
2.4 s
$f(T)$ (m^{-2} s^{-1} eV^{-1})
T (eV)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^0
10^1
10^2
10^3



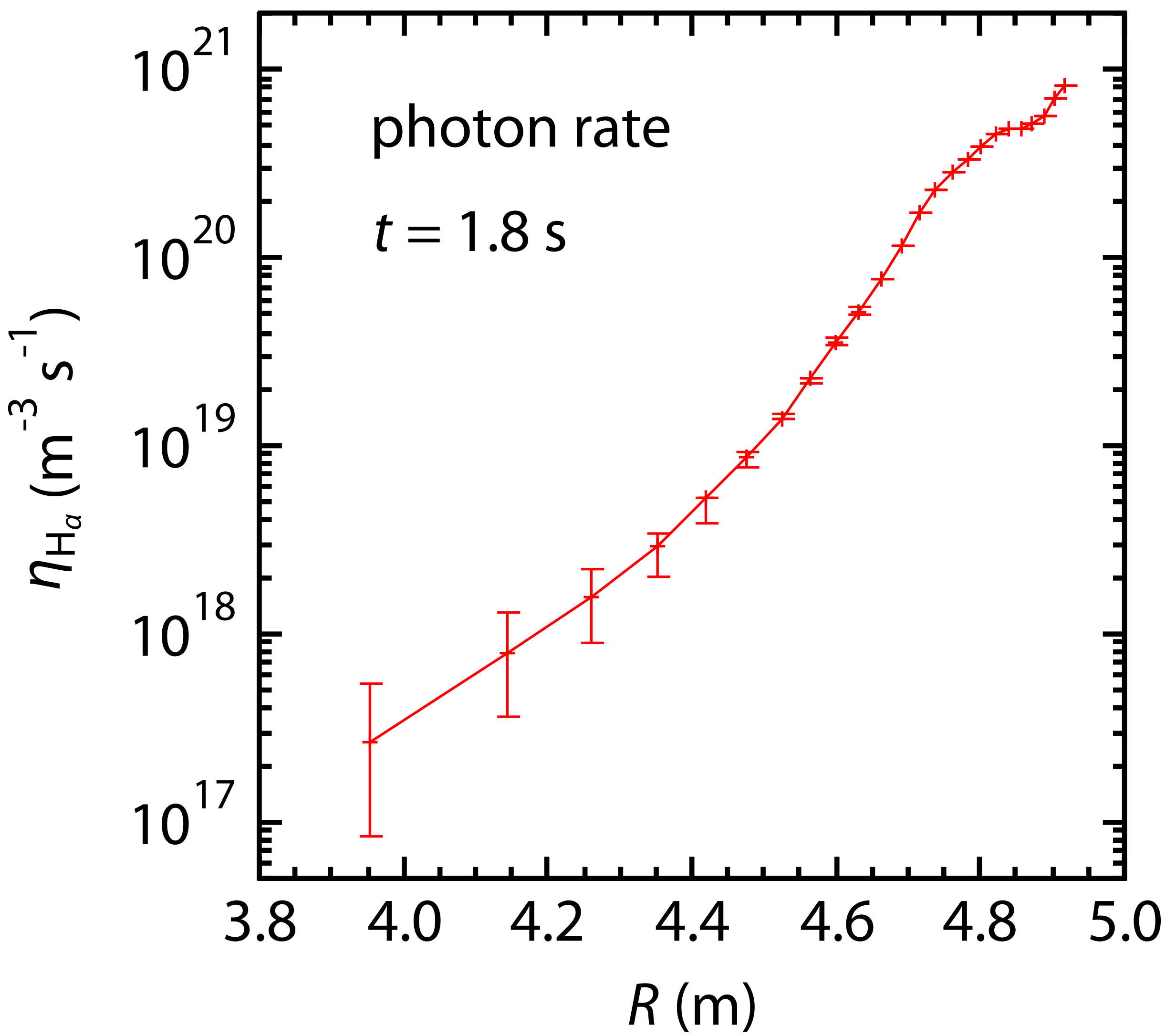
$$\eta(R) = f(T) \Bigg/ \left\{ \left| \frac{\mathrm{d}R_{\mathrm{in}}}{\mathrm{d}T_{\mathrm{e}}} \right|_T + \left| \frac{\mathrm{d}R_{\mathrm{out}}}{\mathrm{d}T_{\mathrm{e}}} \right|_T \right\}$$

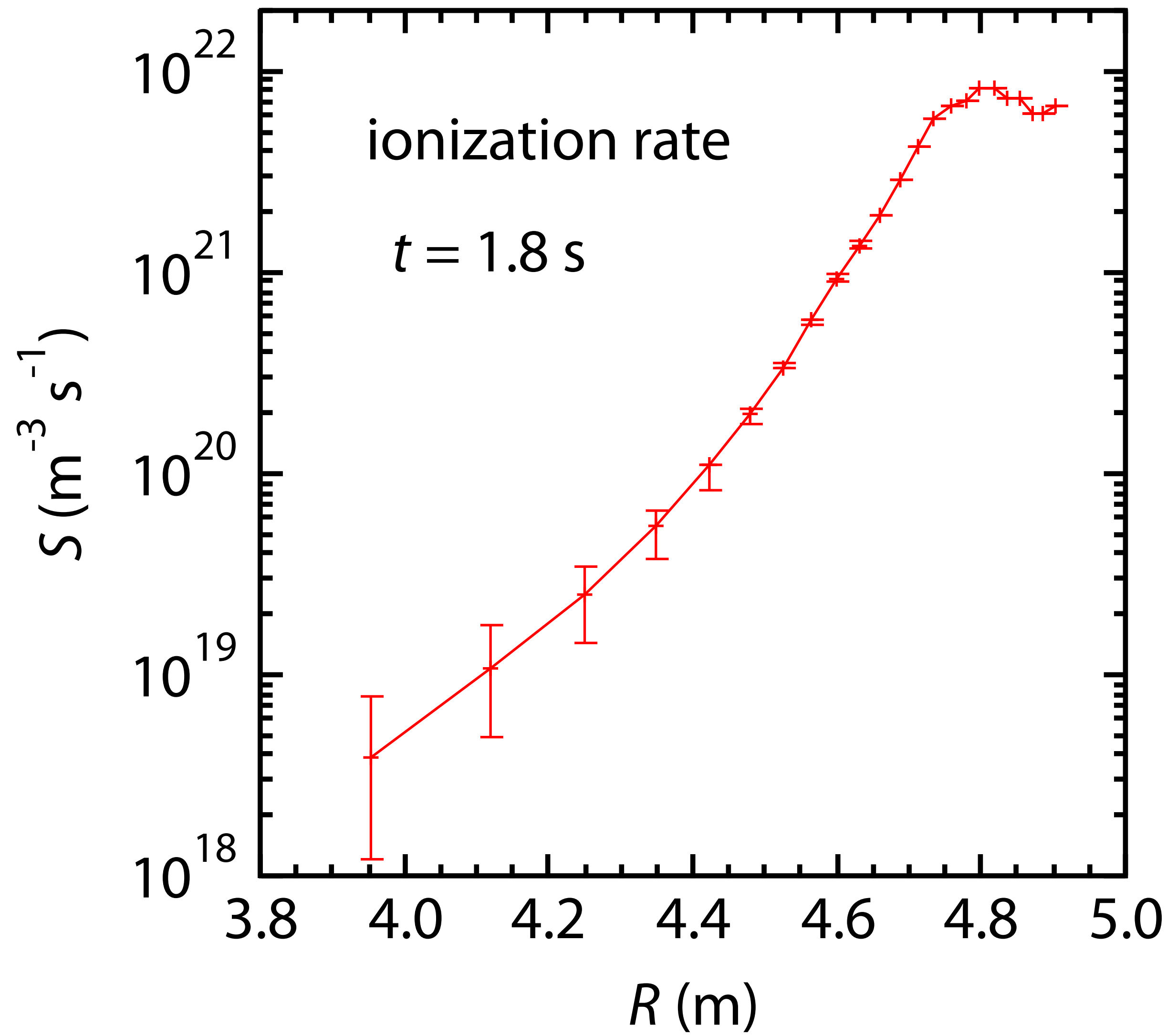




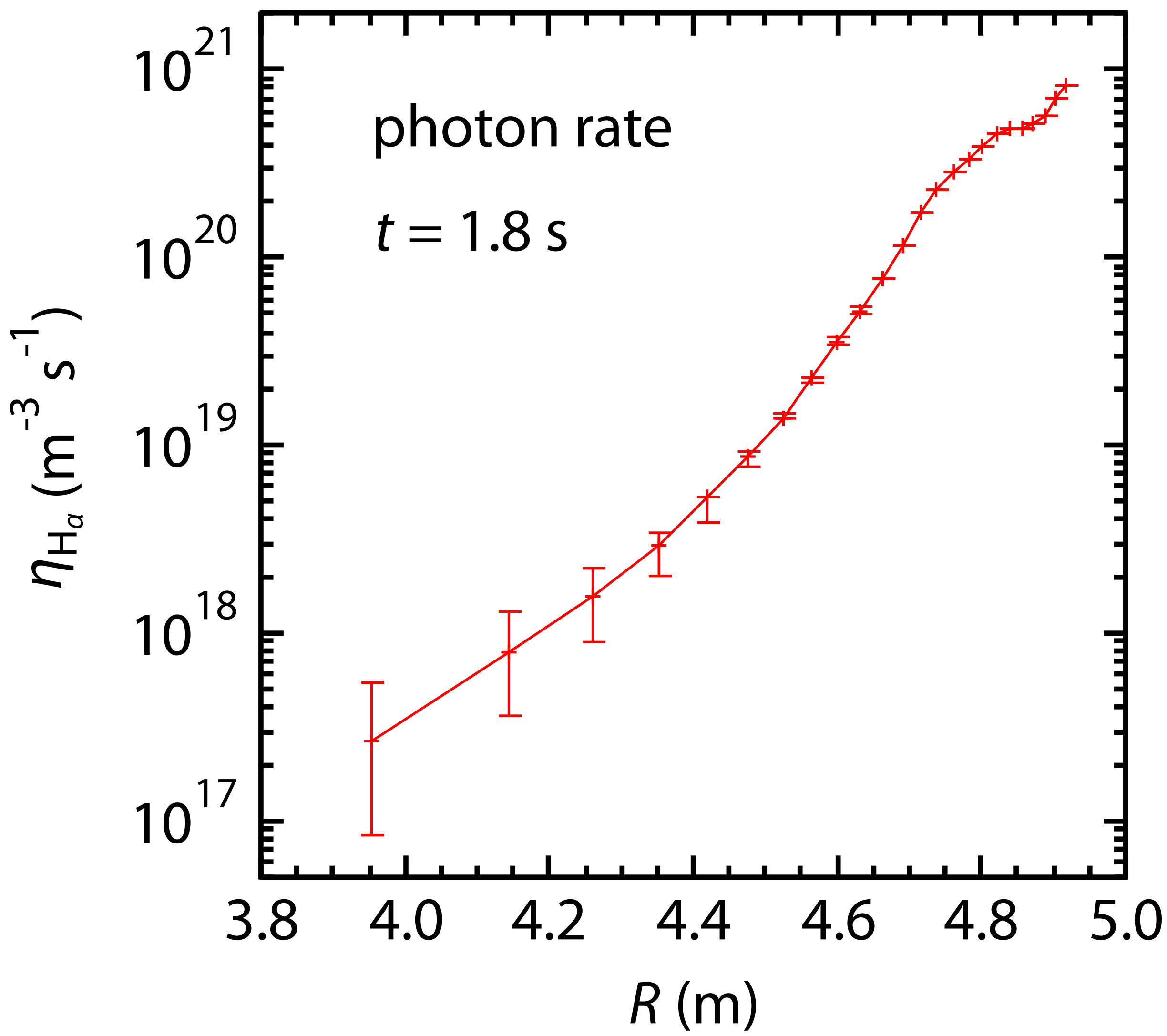
under assumption of $T_i = T_e$

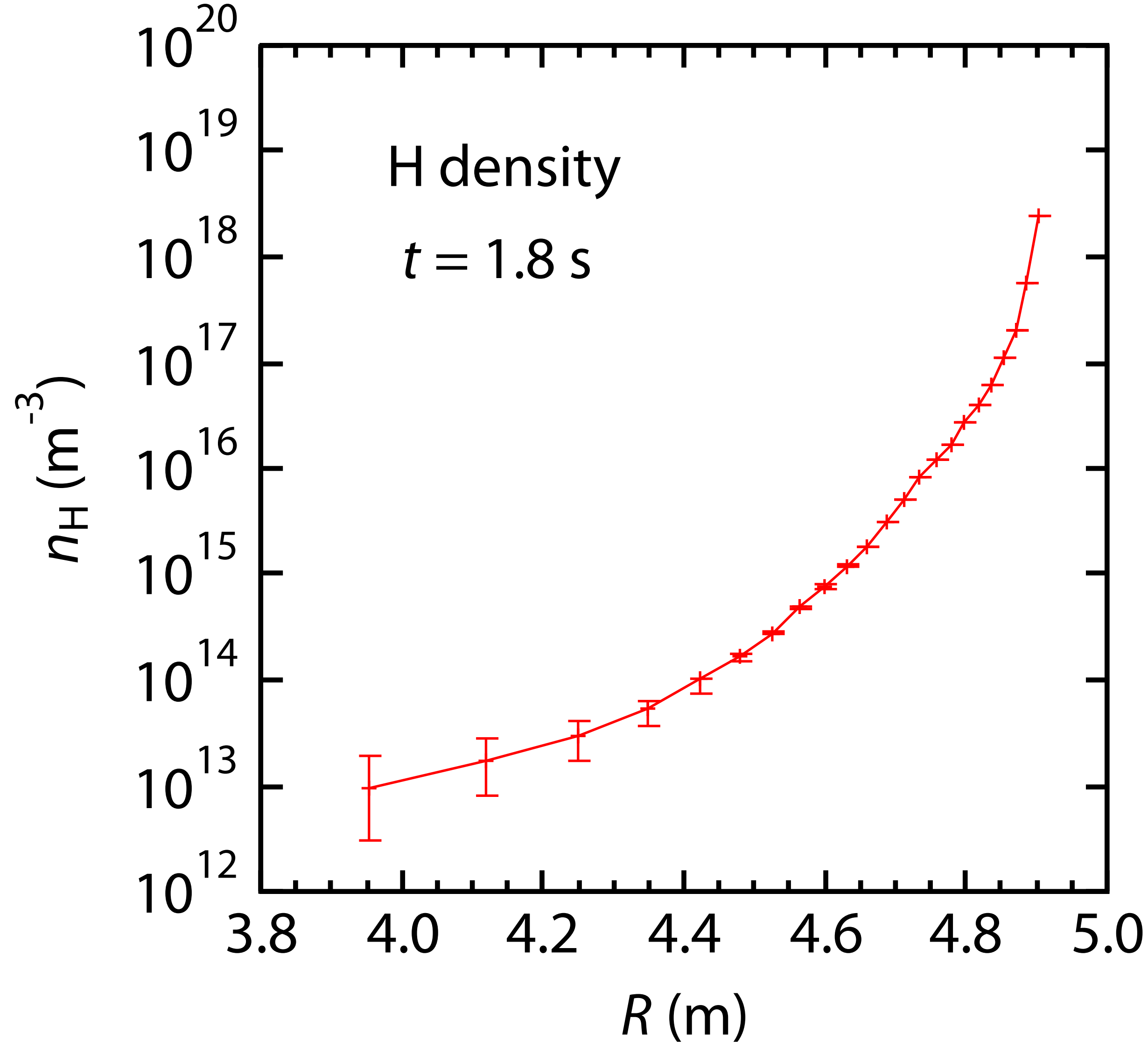
$$\begin{cases} S = S_{CR} n_e n_H \\ \eta = A(3,2) R_1(3) n_e n_H \end{cases} \Rightarrow S = \eta \frac{S_{CR}}{A(3,2) R_1(3)}$$

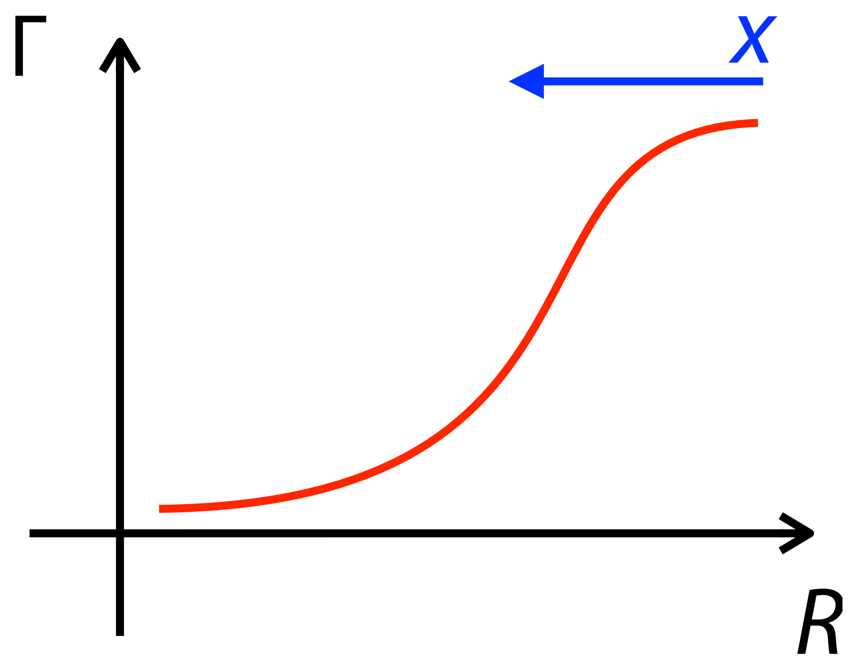




$$n_{\mathrm{H}} = \frac{\eta}{A(3,2)R_1(3)n_e}$$

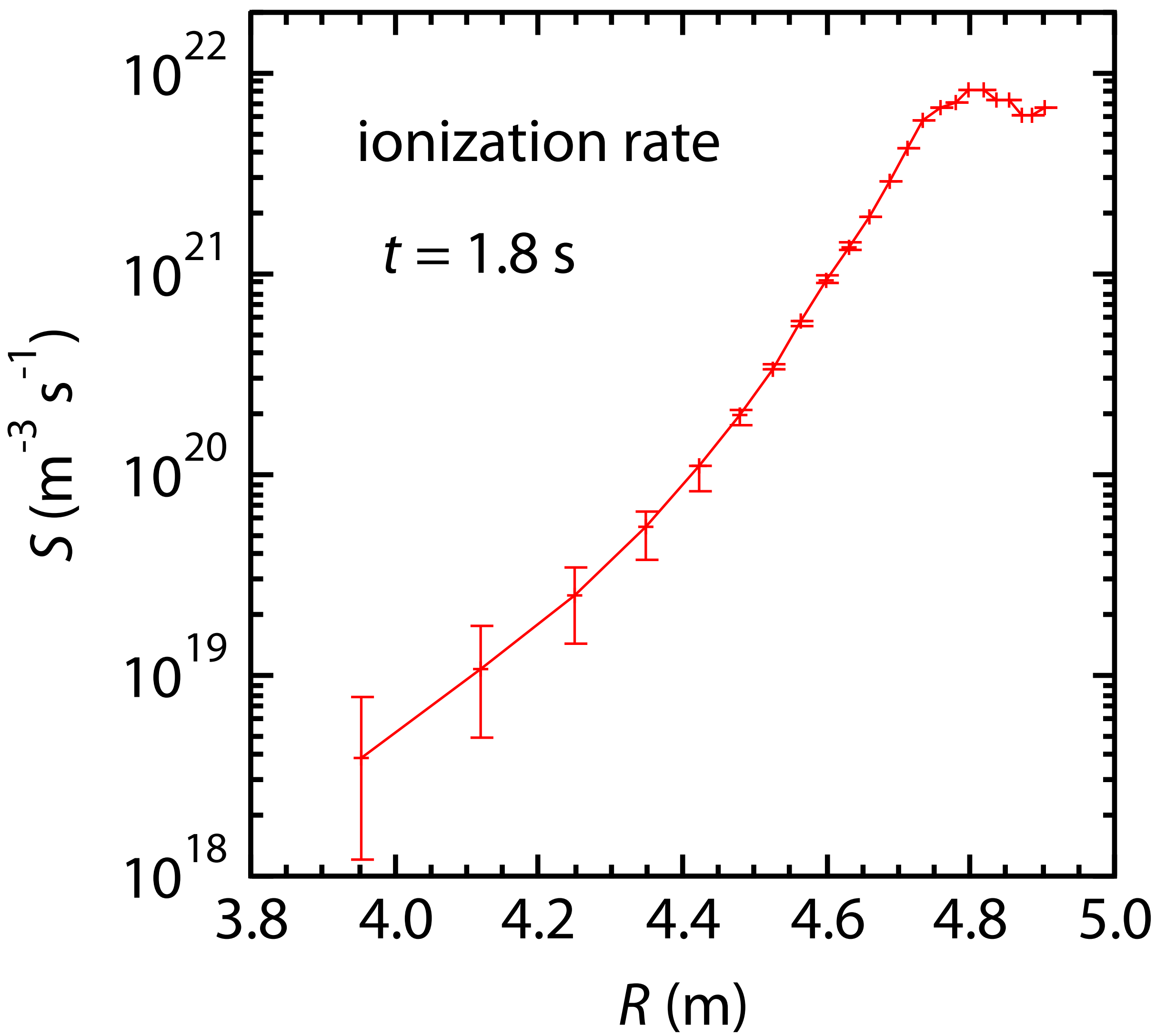


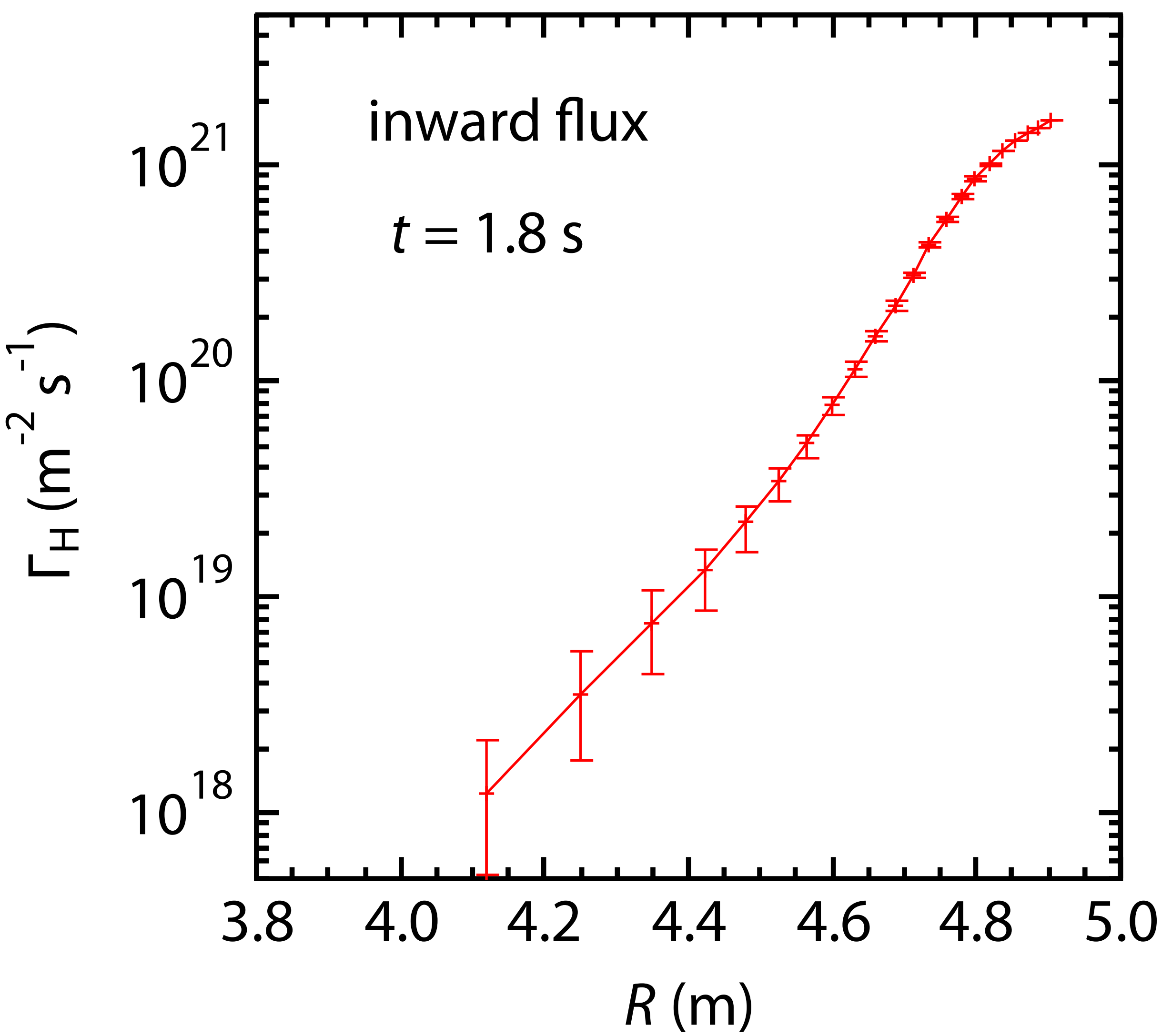


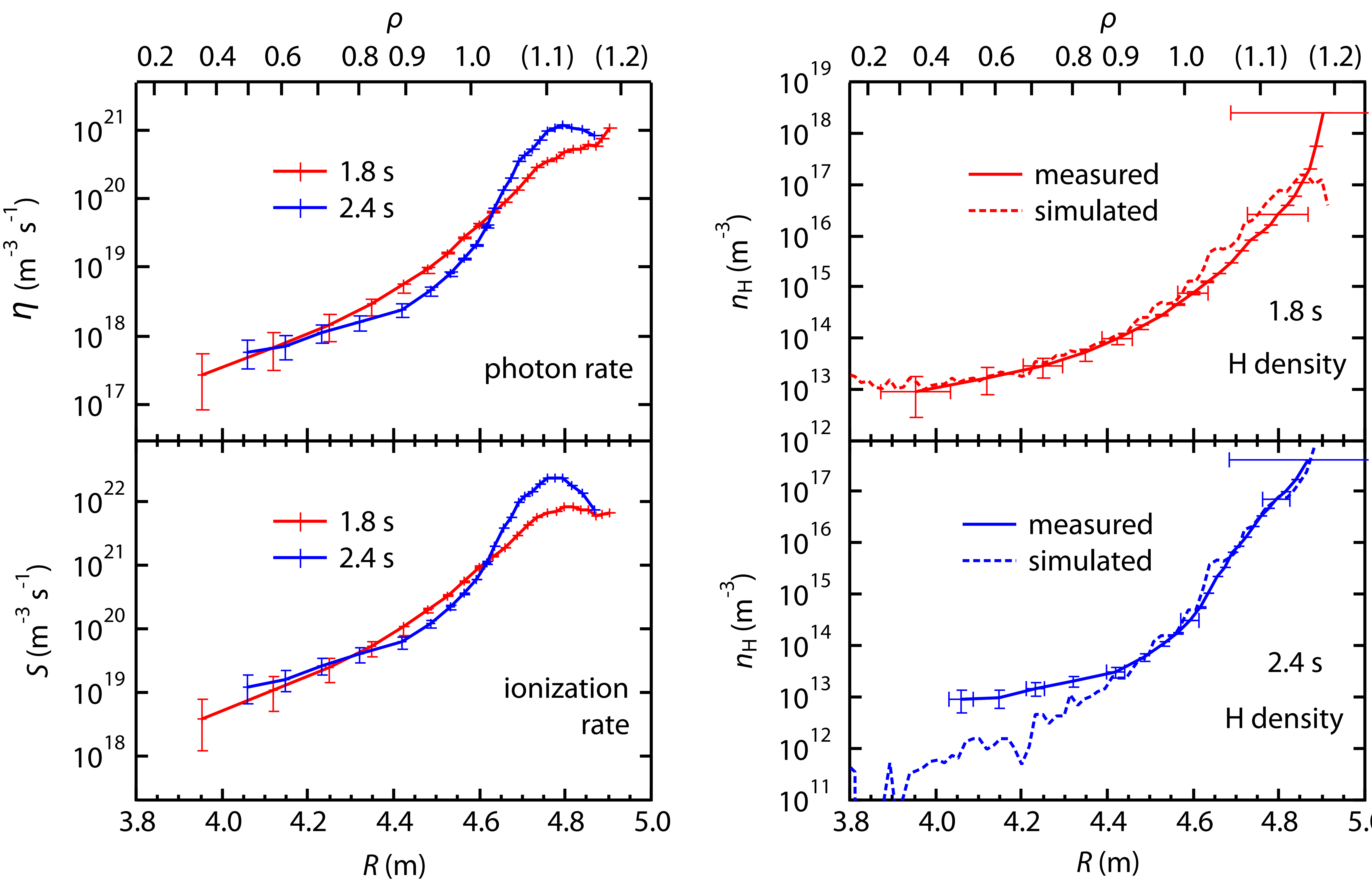


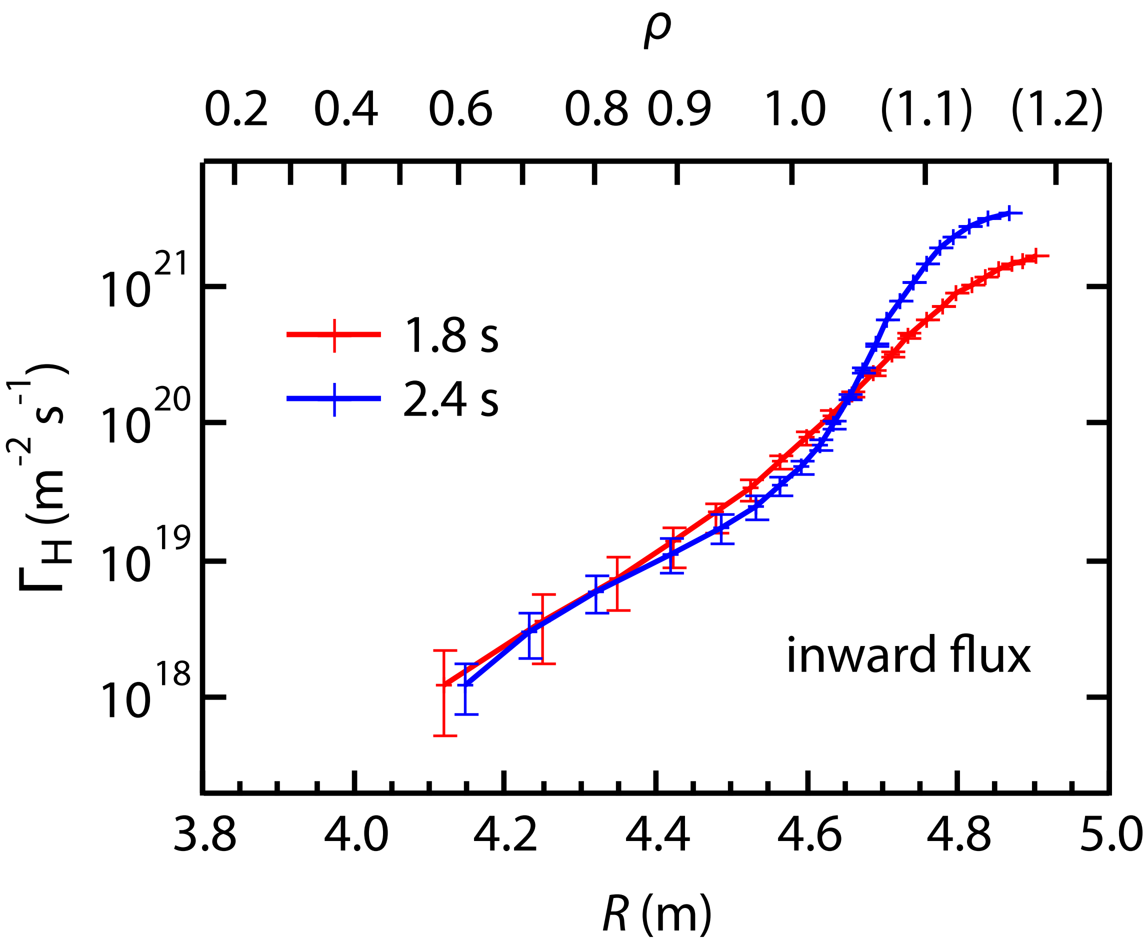
$$\frac{d\Gamma}{dx} = -S$$

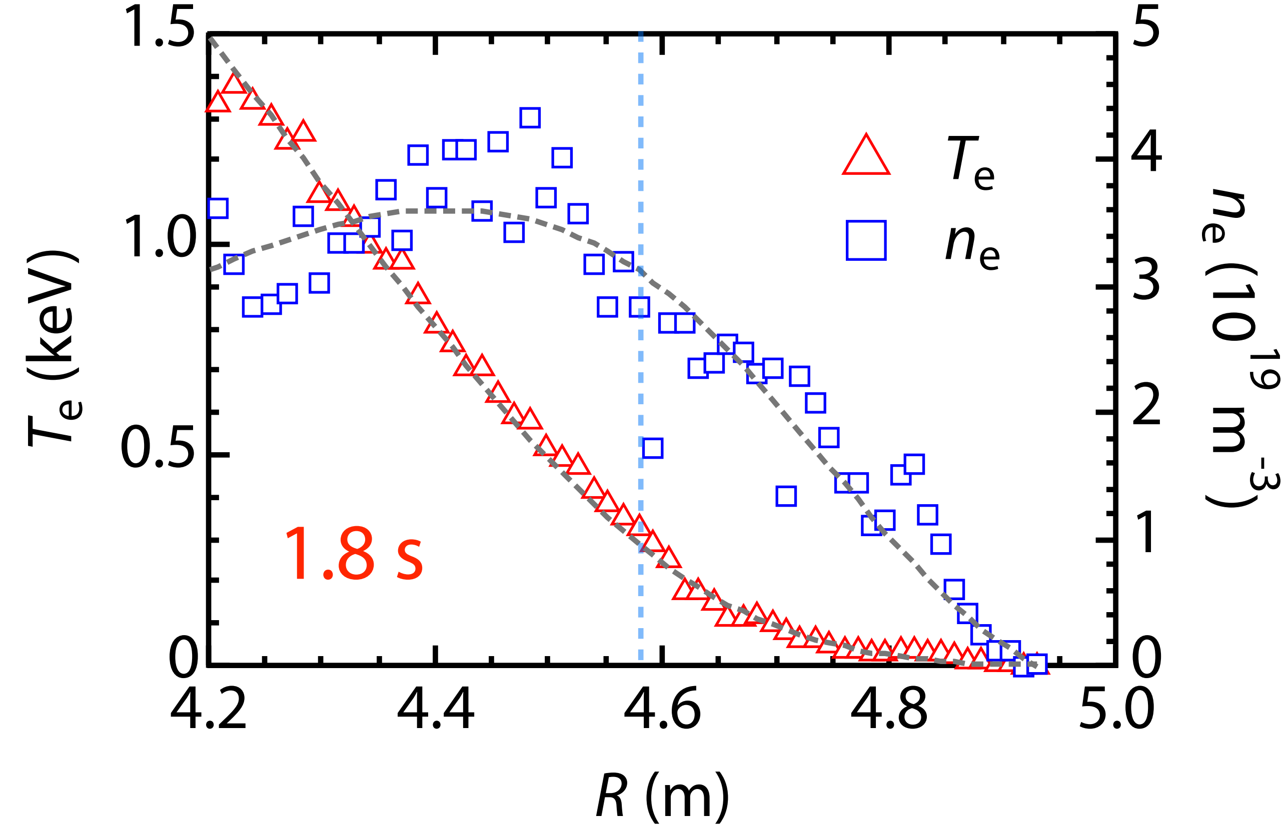
$$\Gamma(R) = \int_{R_{ax}}^{R} S \, dR$$






ρ
0.2 0.4 0.6 0.8 0.9 1.0 (1.1) (1.2)
η (m^-3 s^-1)
1.8 s
2.4 s
photon rate
S (m^-3 s^-1)
ionization rate
R (m)
n_H (m^-3)
measured
simulated
1.8 s
H density
2.4 s
H density



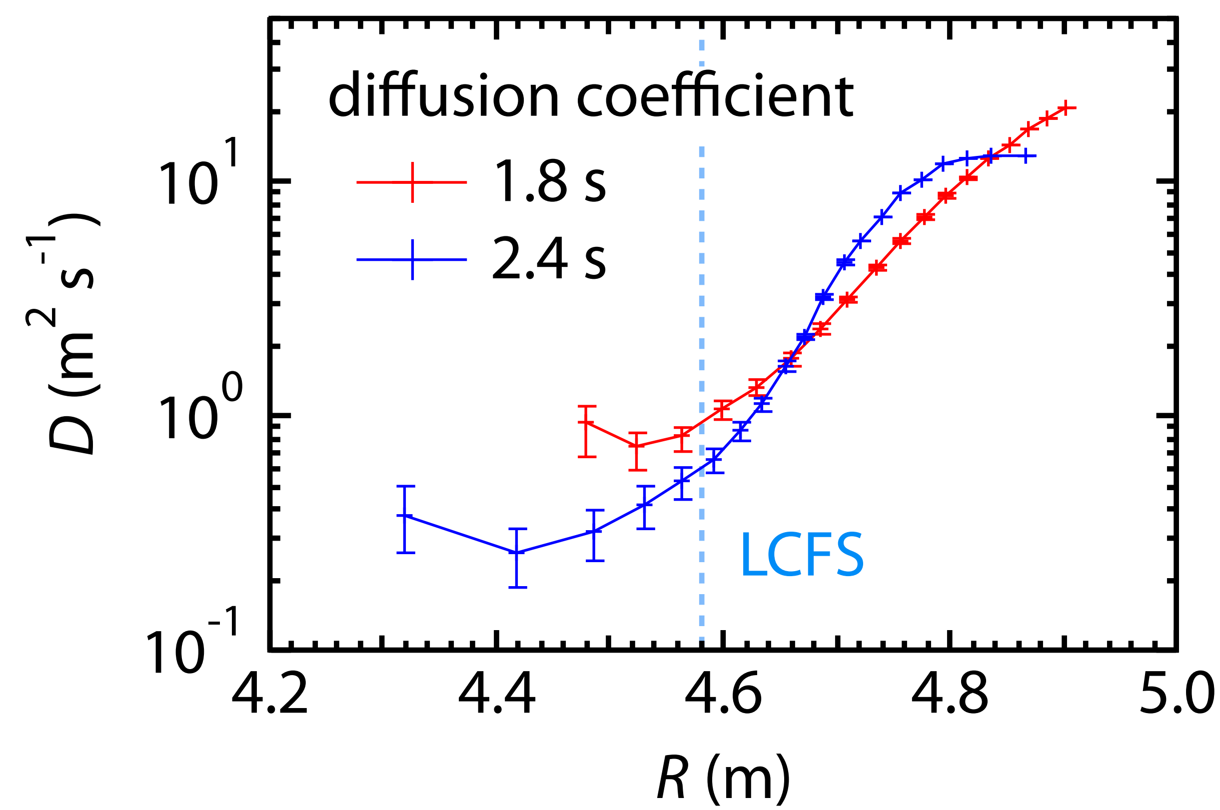


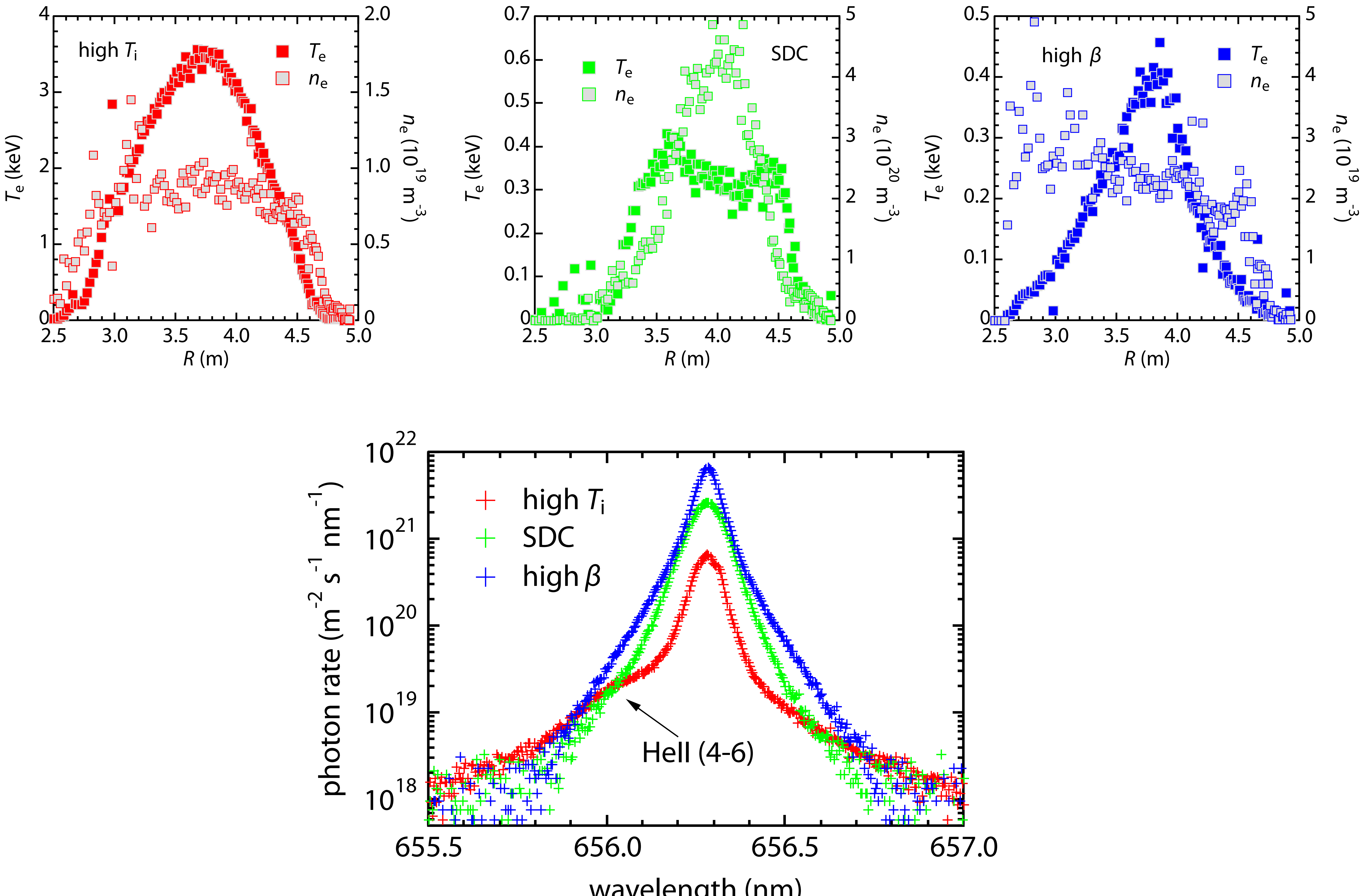
- if transport is subject to diffusion

$$\Gamma_e = -D\frac{dn_e}{dR}$$

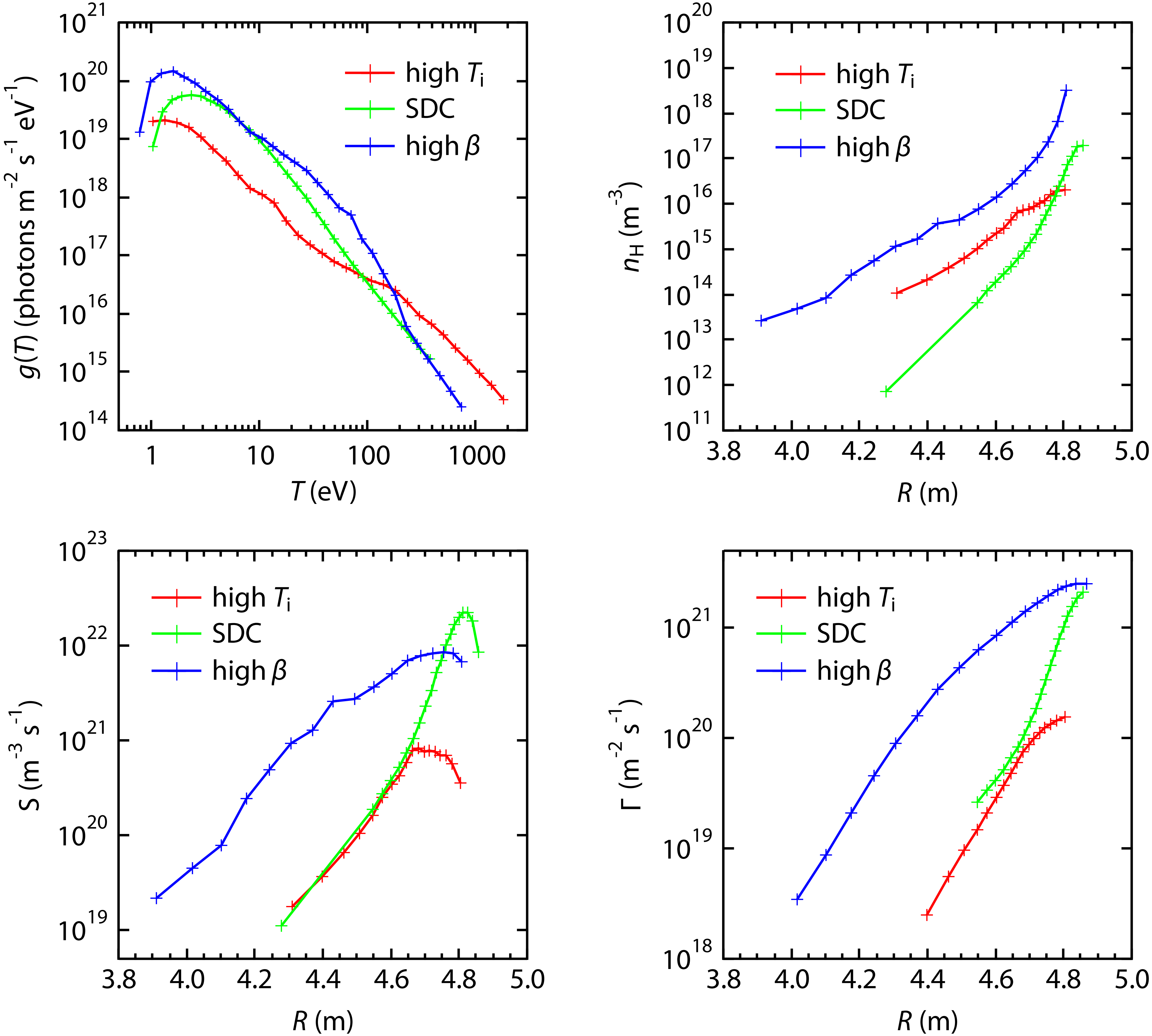
- the plasma is approximately in steady state

$$\Gamma_e = -\Gamma_H$$





high T_i
T_e
n_e
T_e (keV)
n_e (10^{19} m^{-3})
R (m)
SDC
n_e (10^{20} m^{-3})
high β
photon rate (m^{-2} s^{-1} nm^{-1})
wavelength (nm)
HeII (4-6)



high T_i
SDC
high β
$g(T)$ (photons m^{-2} s^{-1} eV^{-1})
T (eV)
n_H (m^{-3})
R (m)
S (m^{-3} s^{-1})
R (m)
Γ (m^{-2} s^{-1})
R (m)

- distribution function with respect to atom temperature is derived from a single H_α spectrum

- radial profiles of particle source function, neutral density, and inward atom flux are determined

- results for various kinds of discharges are well understood intuitively

- Monte-Carlo simulation gives consistency with measurement