Spectroscopic studies for tungsten and hydrogen in LHD

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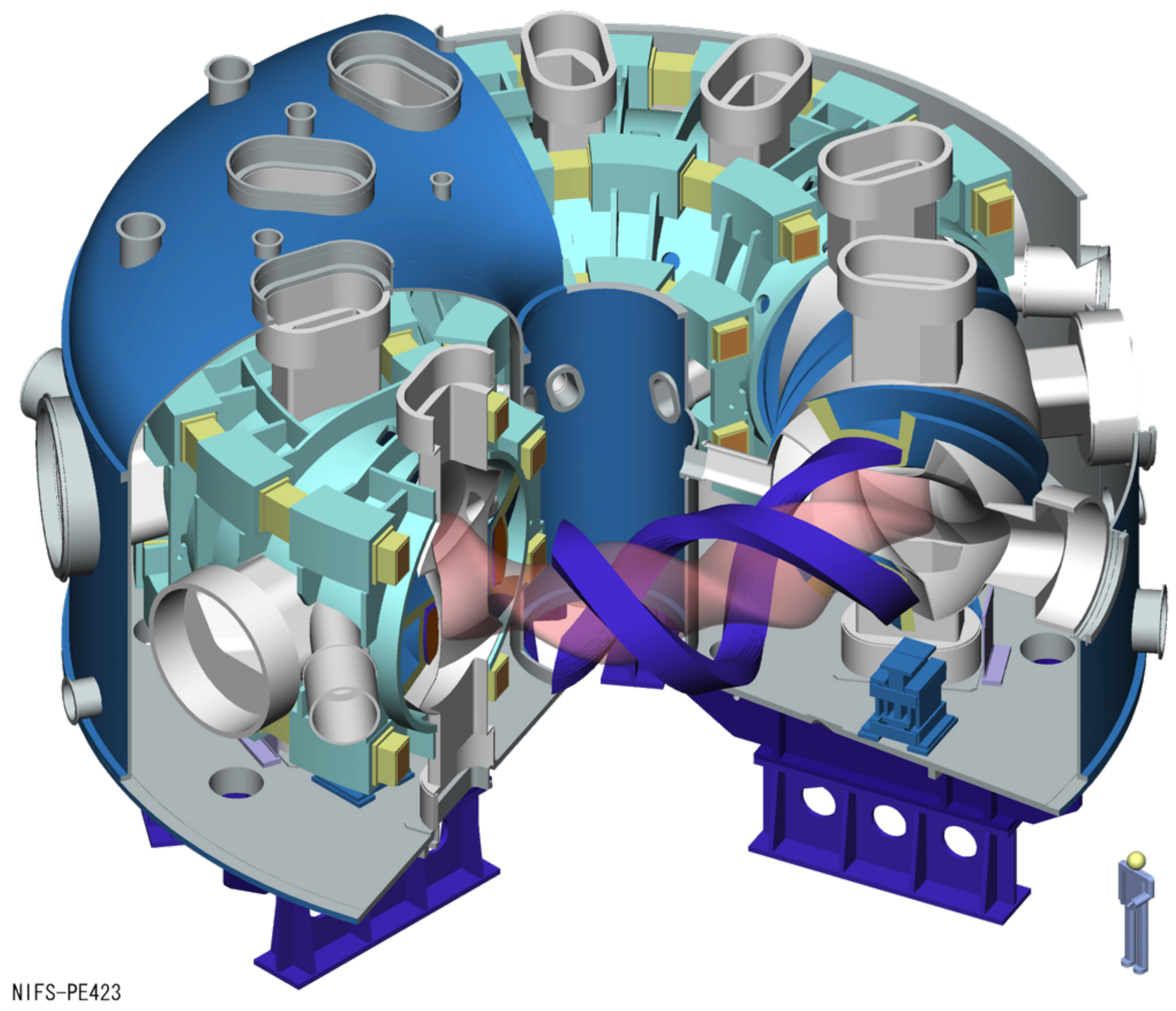
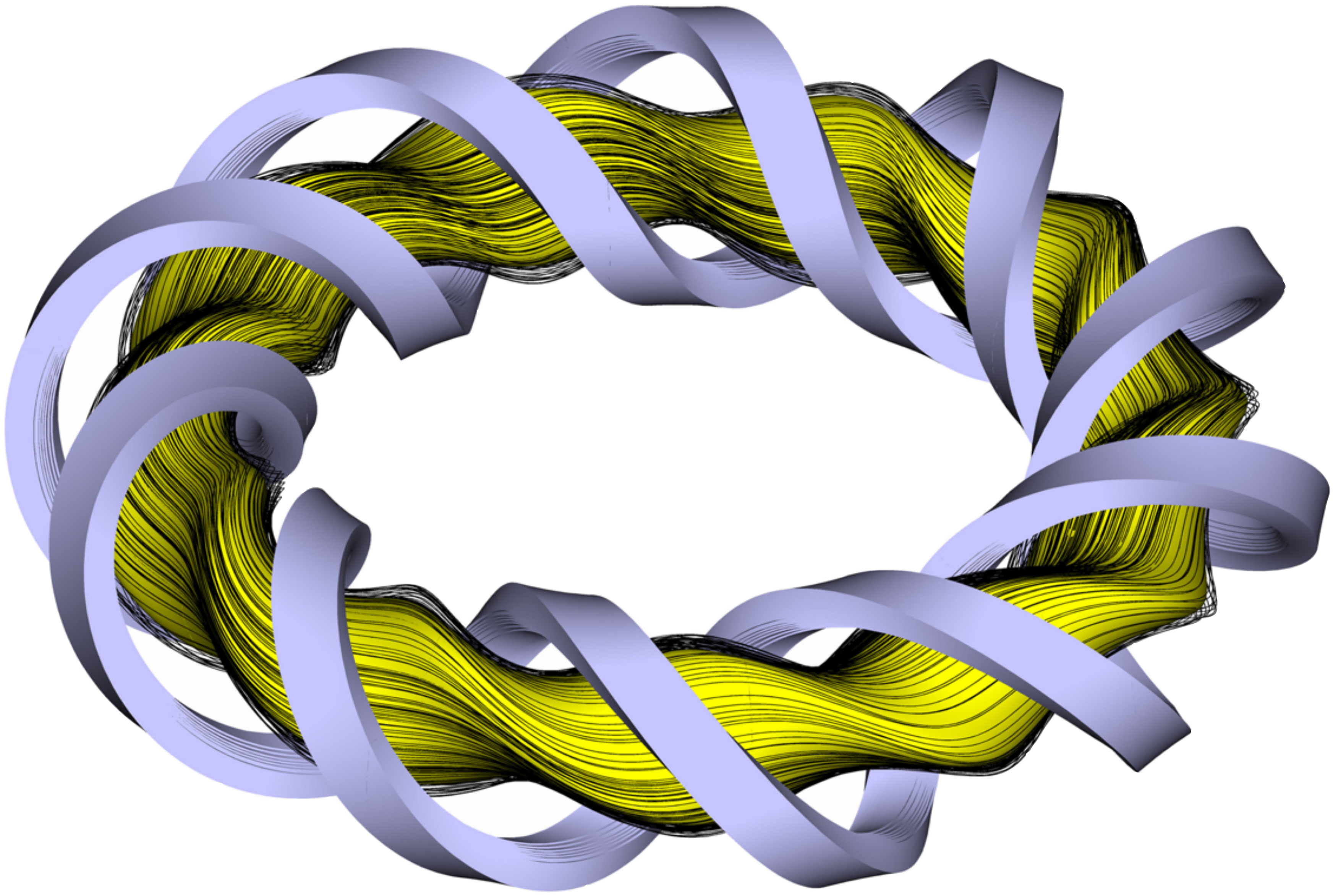
Large Helical Device (LHD)

diameter	13.5 m
weight	1500 t
major radius	3.9 m
minor radius	0.6 m
volume	30 m^3
B strength	3 T





- heliotron-type device:
  no inductive plasma current
- advantageous for steady-state operation (no disruption)

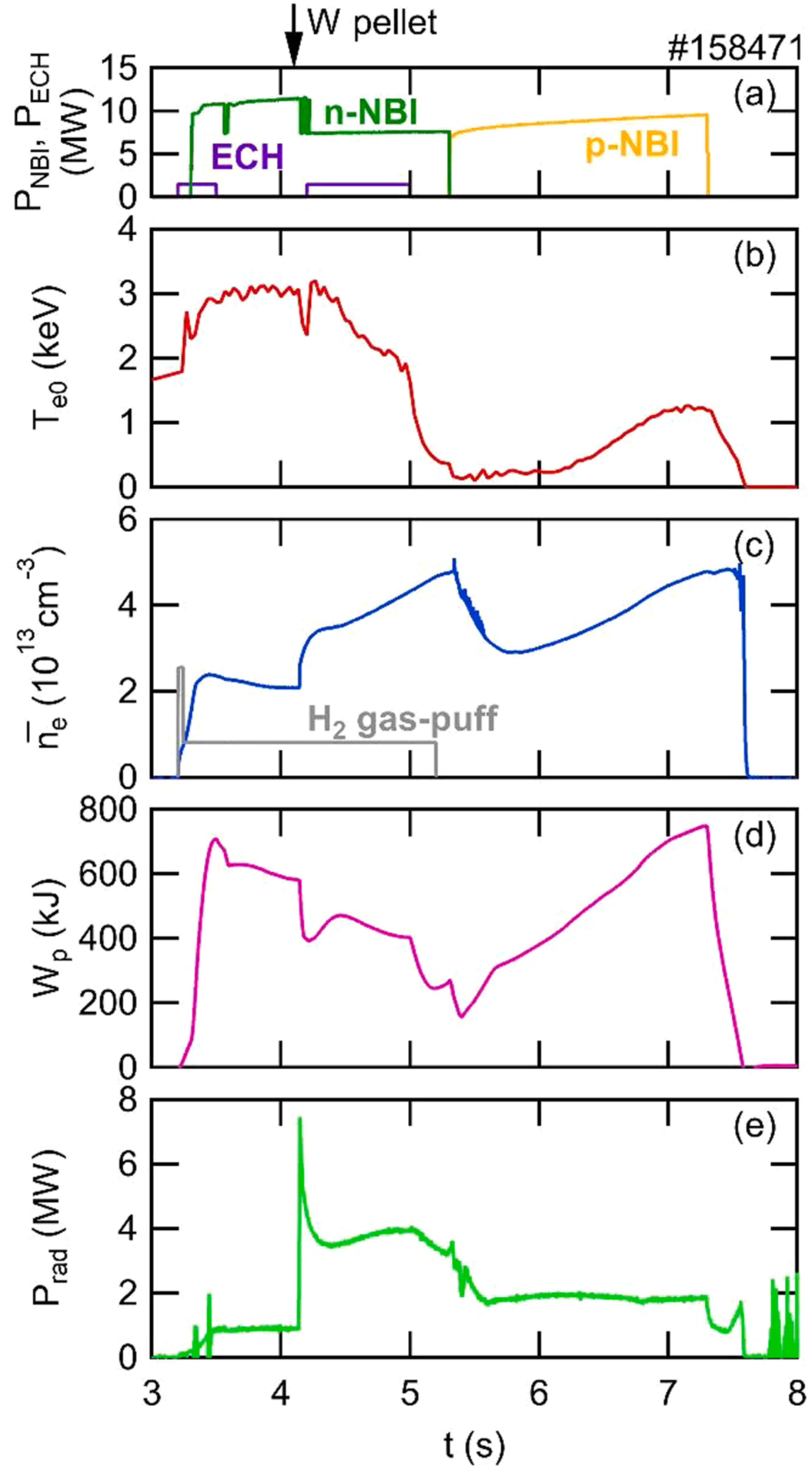
achievements

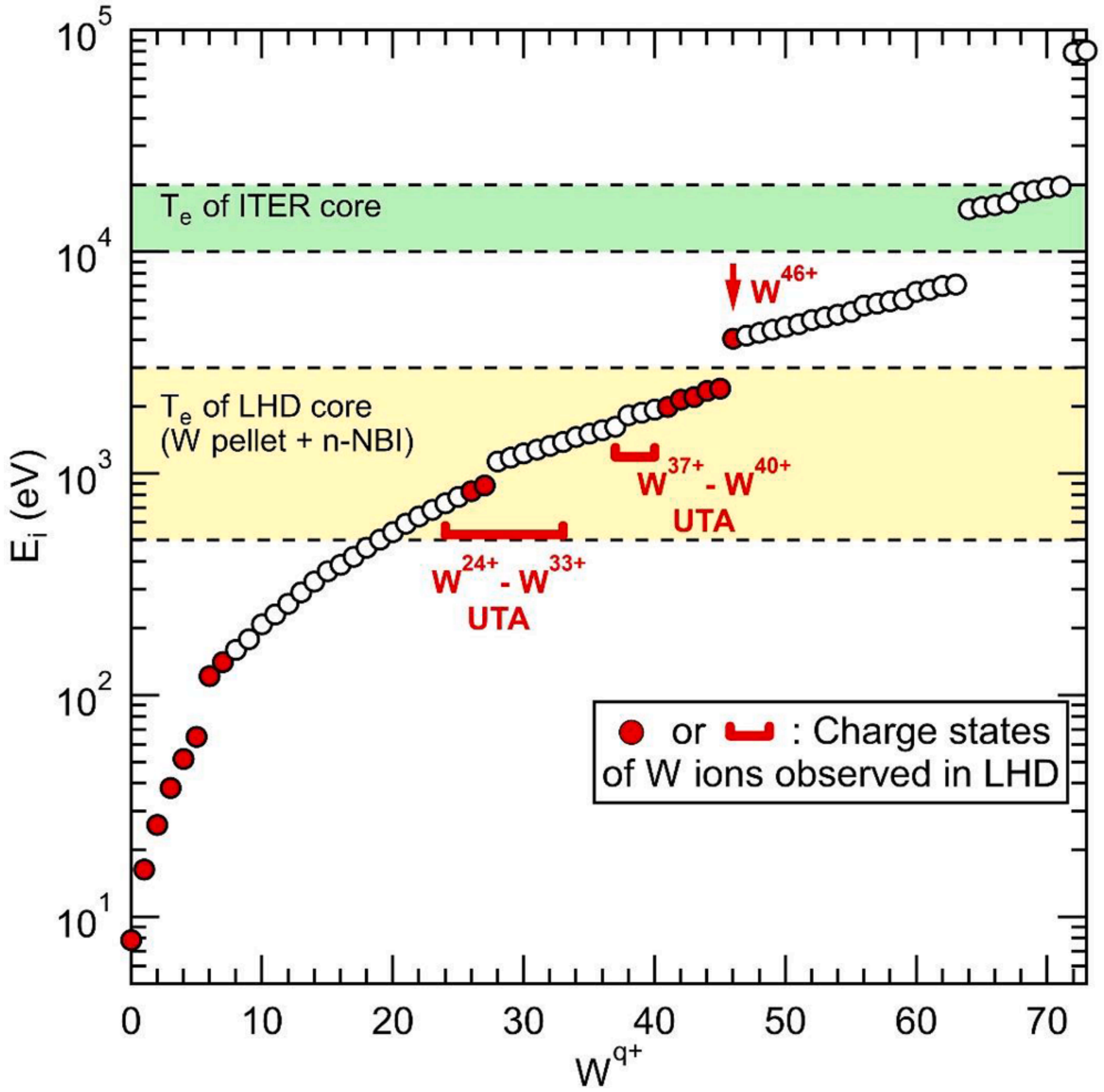
T_e	~20 keV
T_i	~10 keV
n_e	~10^{21} m^{-3}

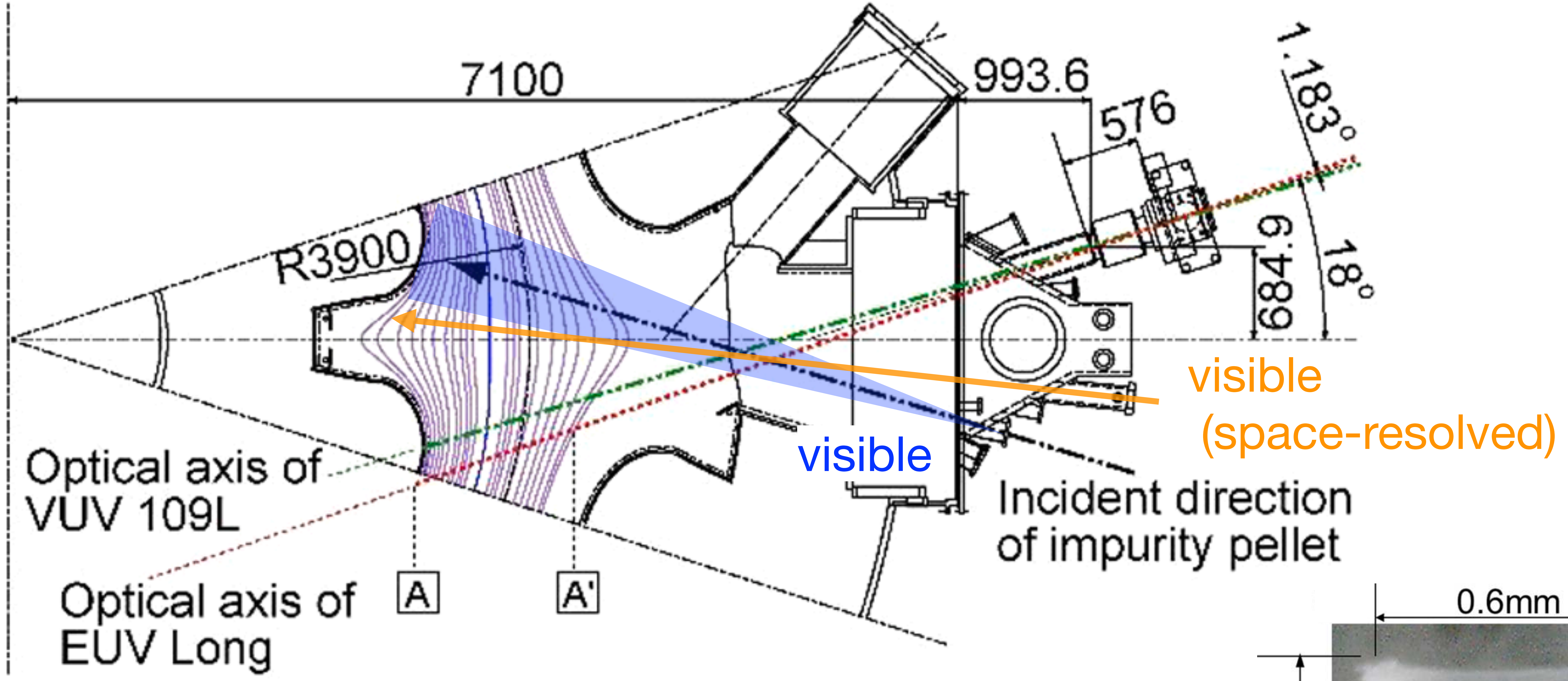

helical coil
divertor plates
helical coil

tungsten pellet injection for spectroscopic measurements

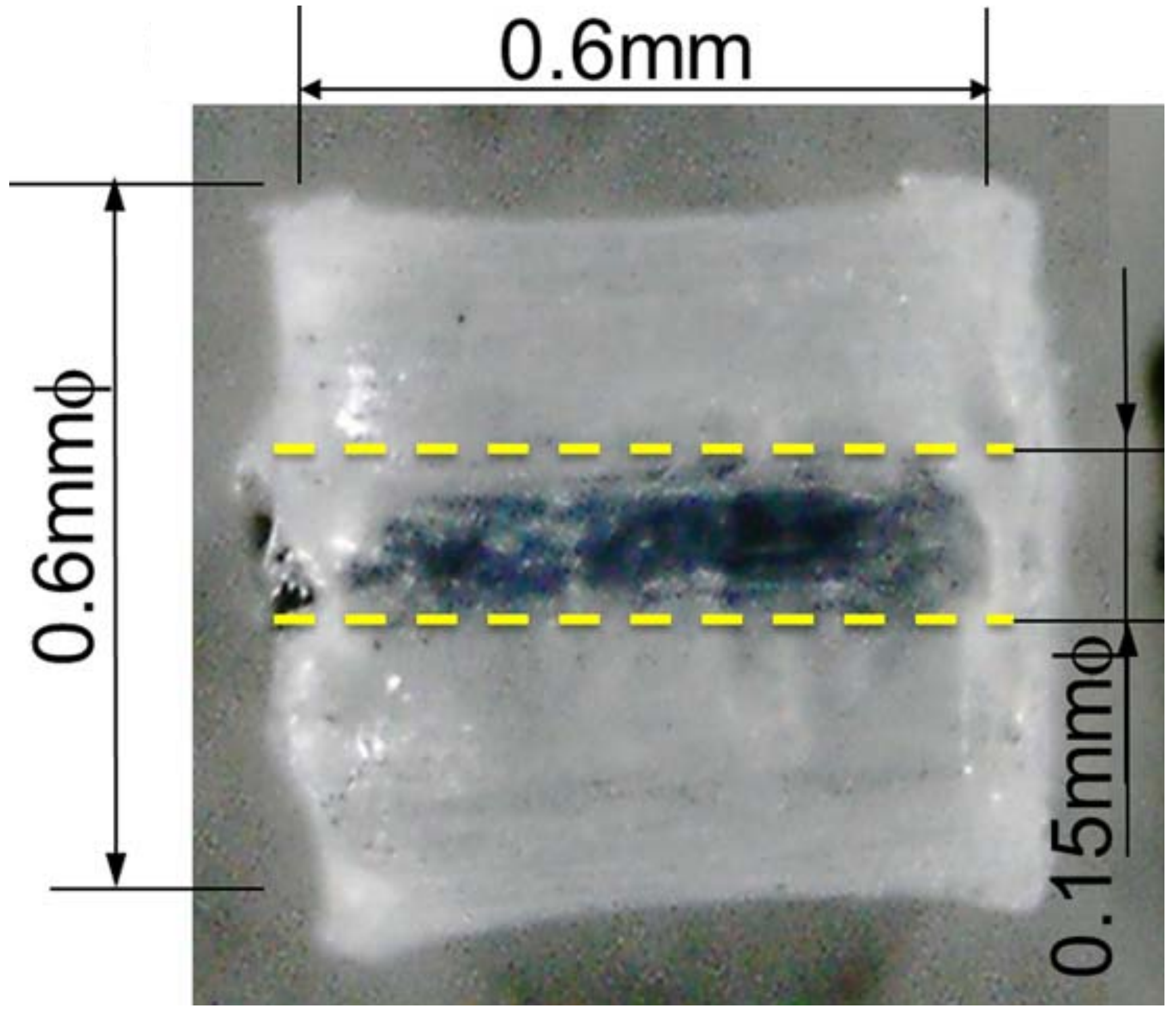
typical discharge and charge states attained in observation to date







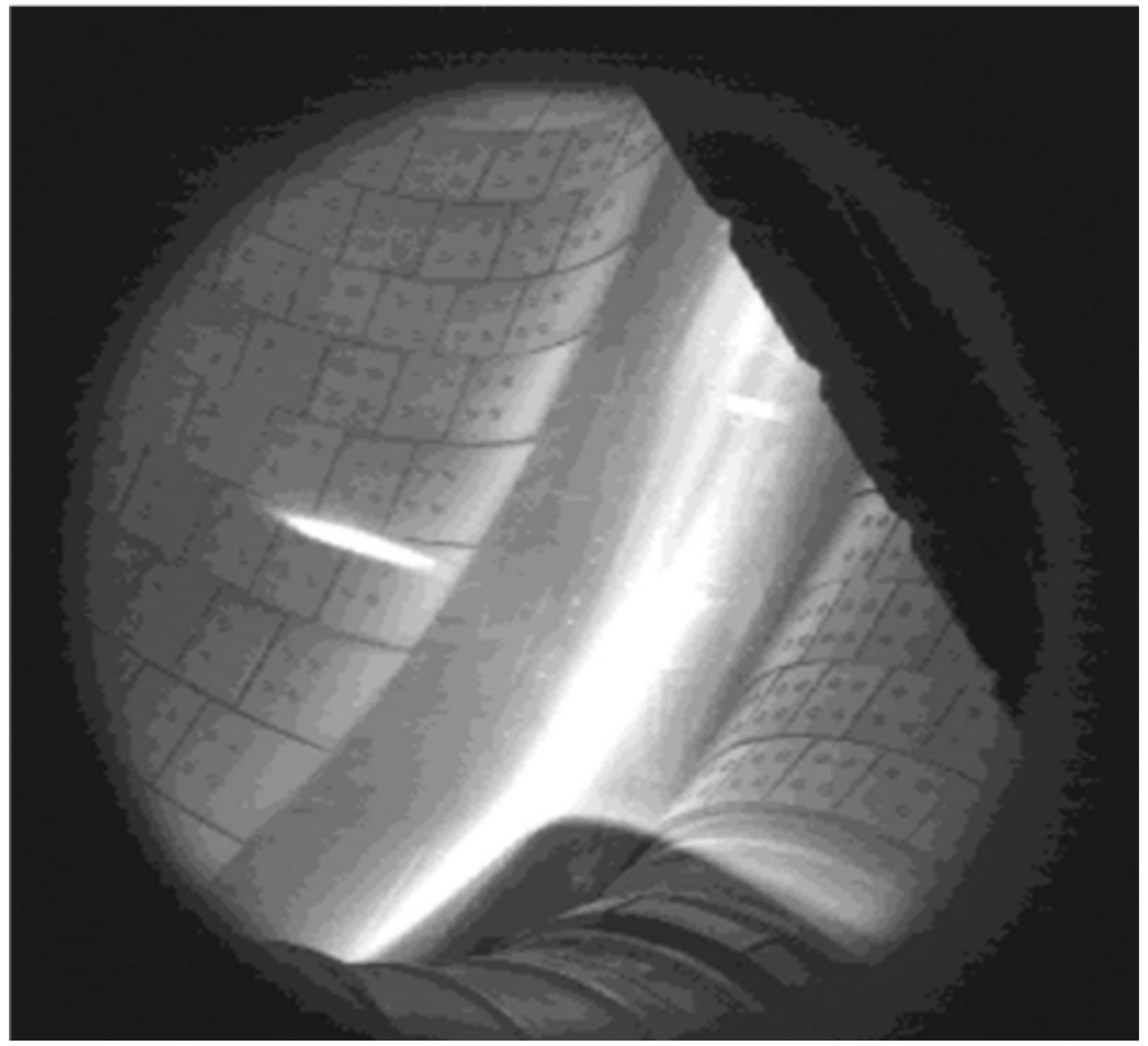
φ0.15mm tungsten wire
in polyethylene tube

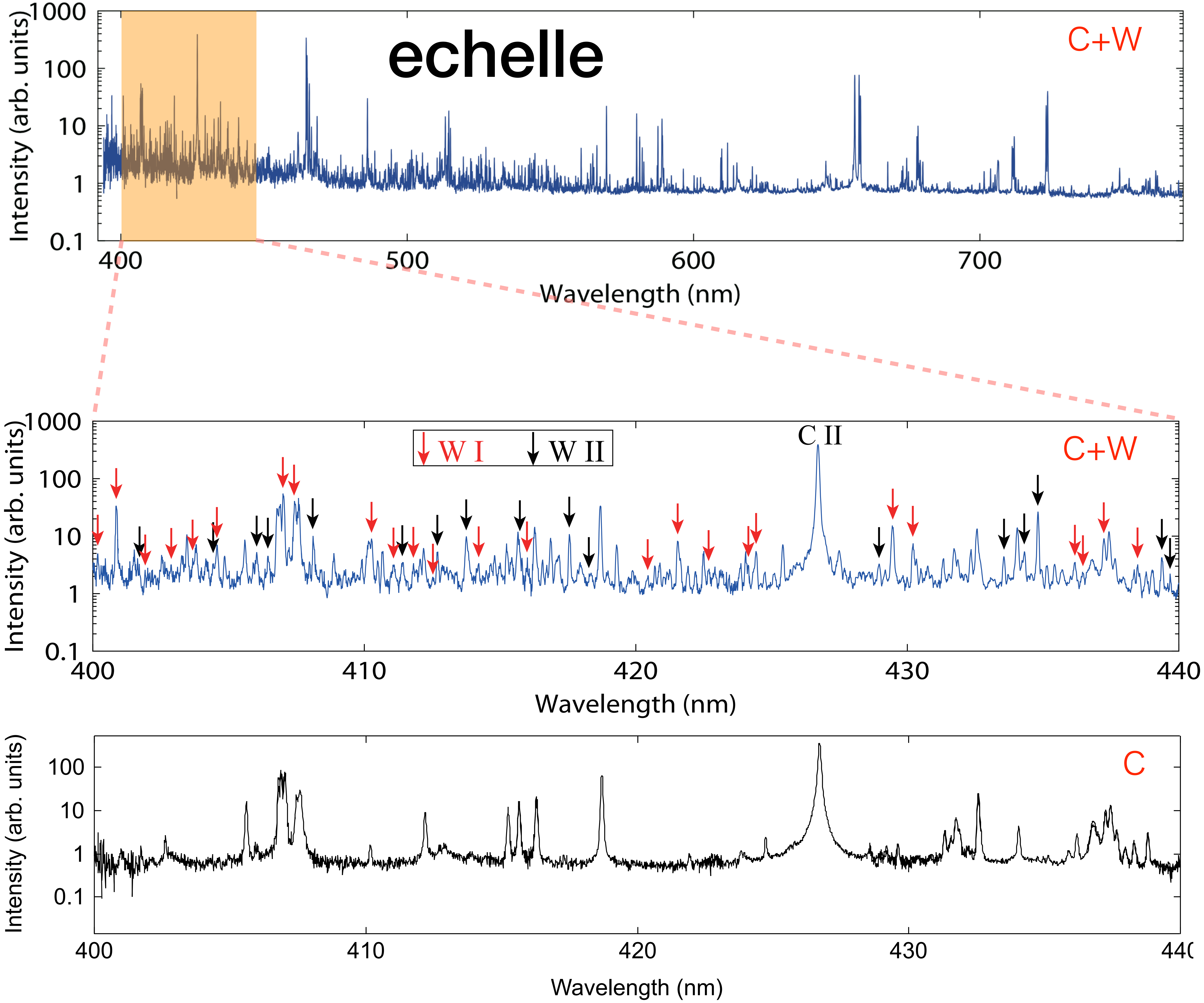


spectrum observed for the ablation cloud

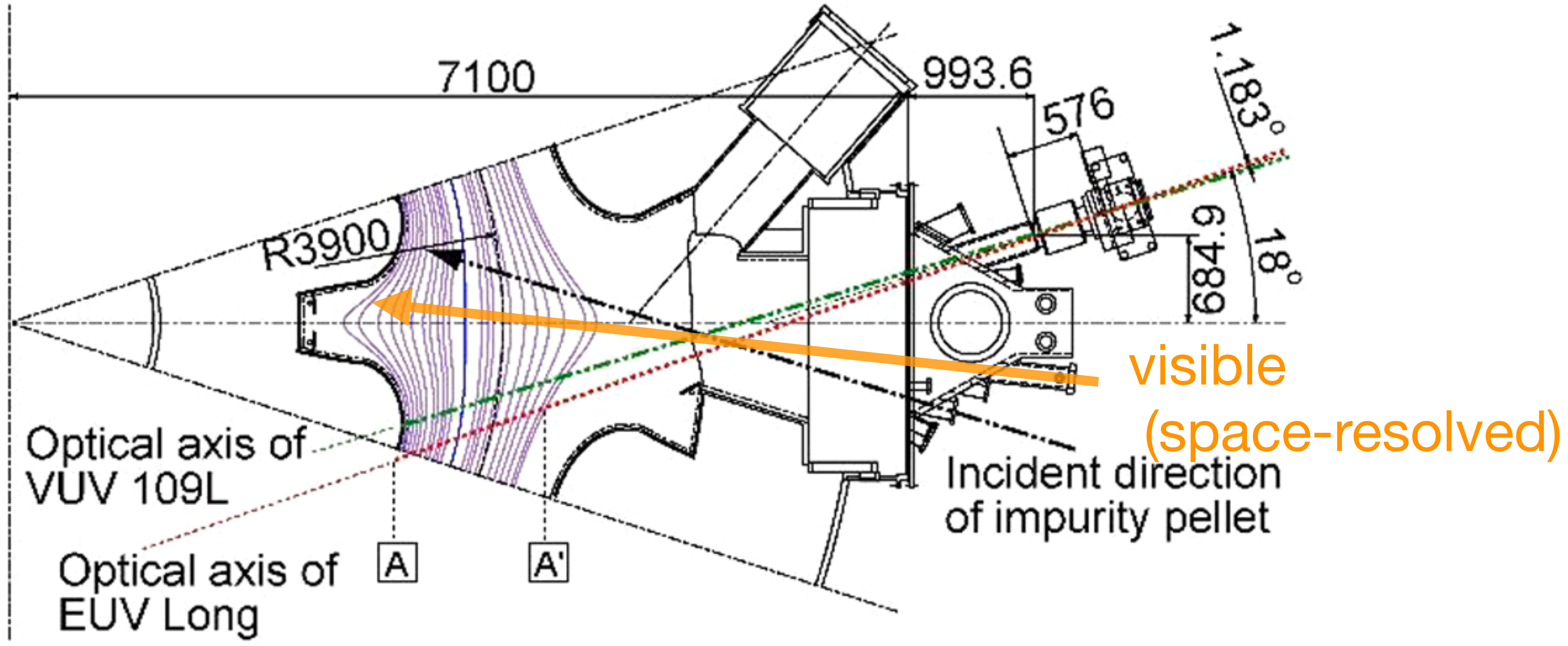
T_e ~1 eV

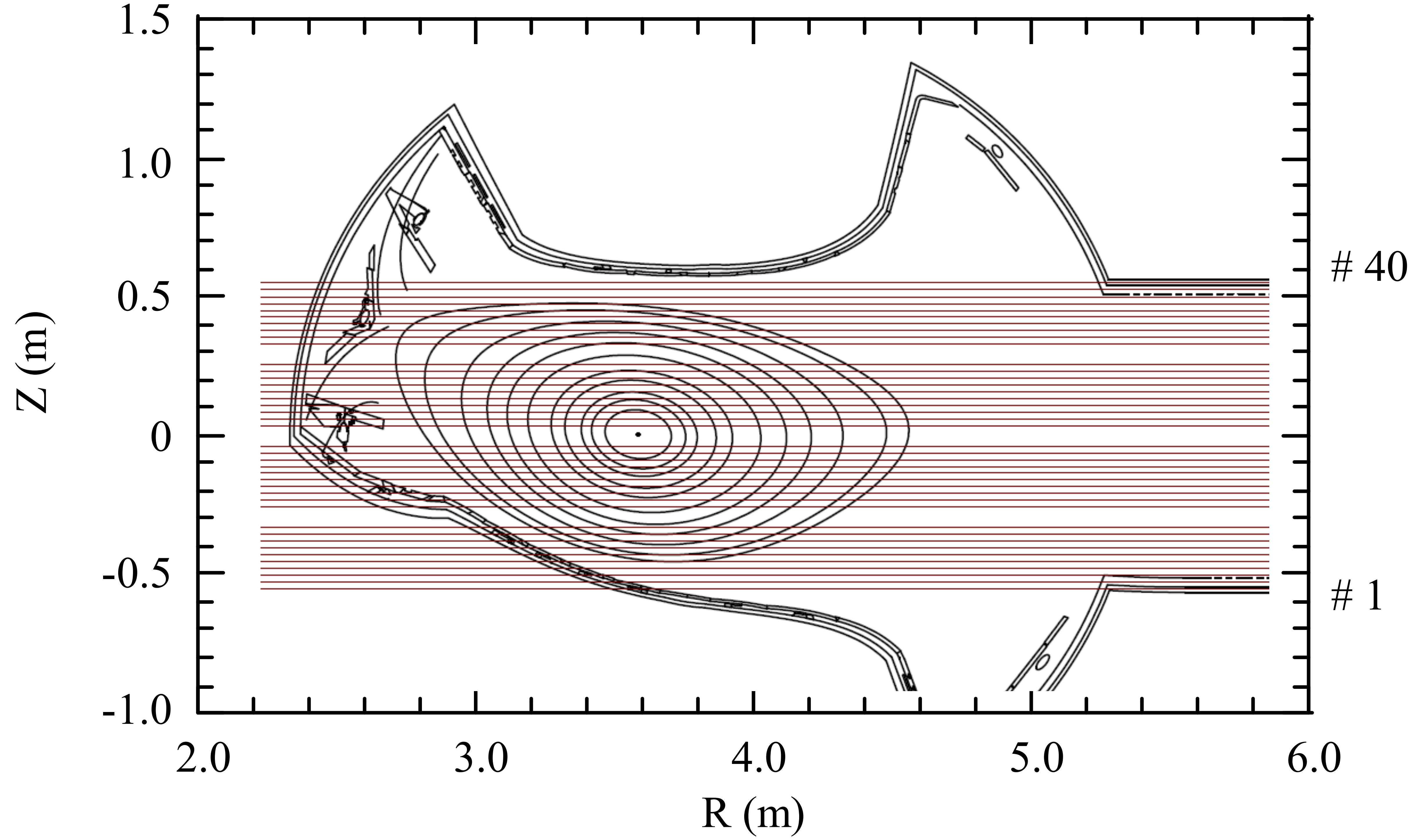
n_e ~10^{23} m^{-3}

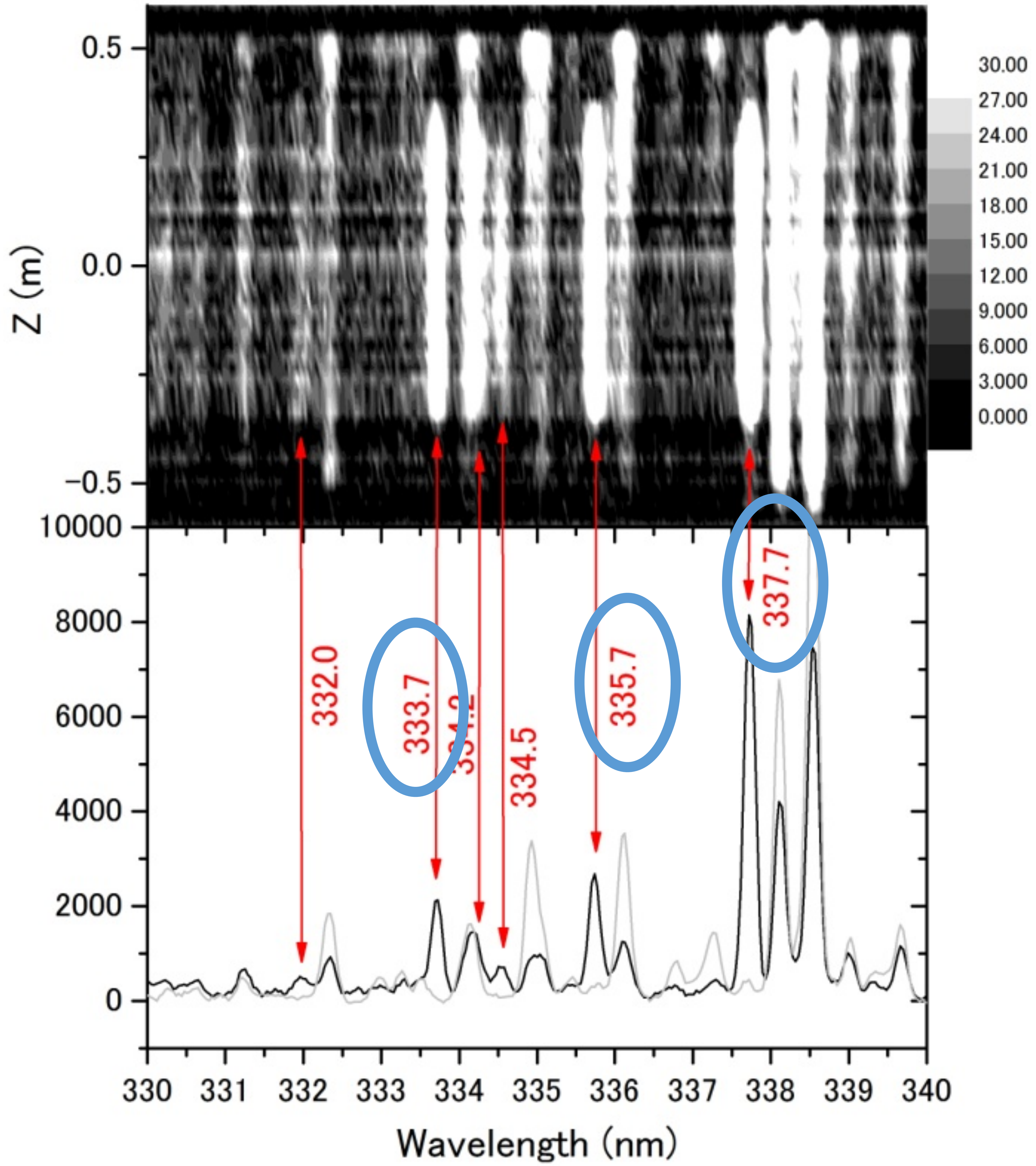




space-resolved visible measurement



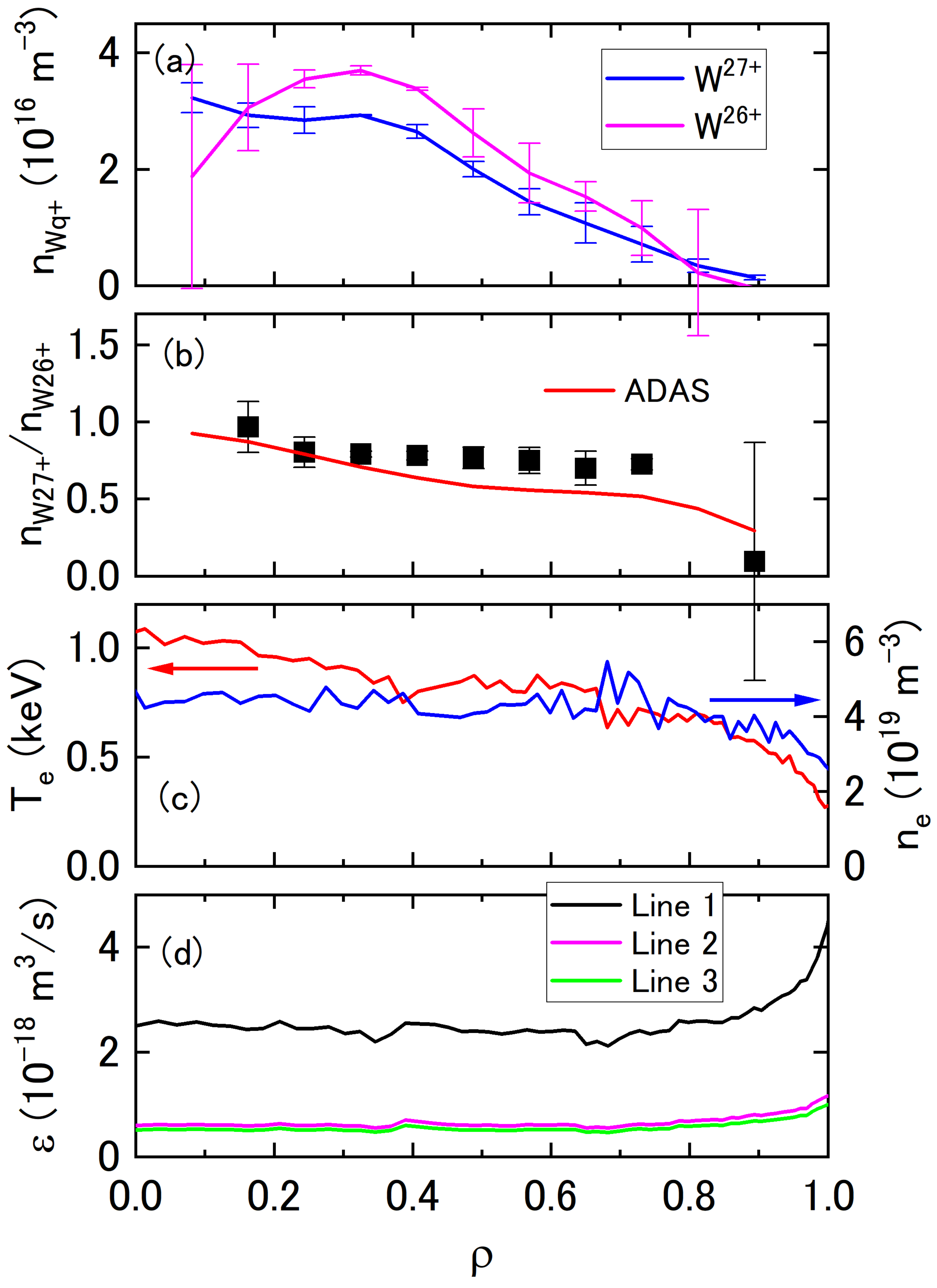




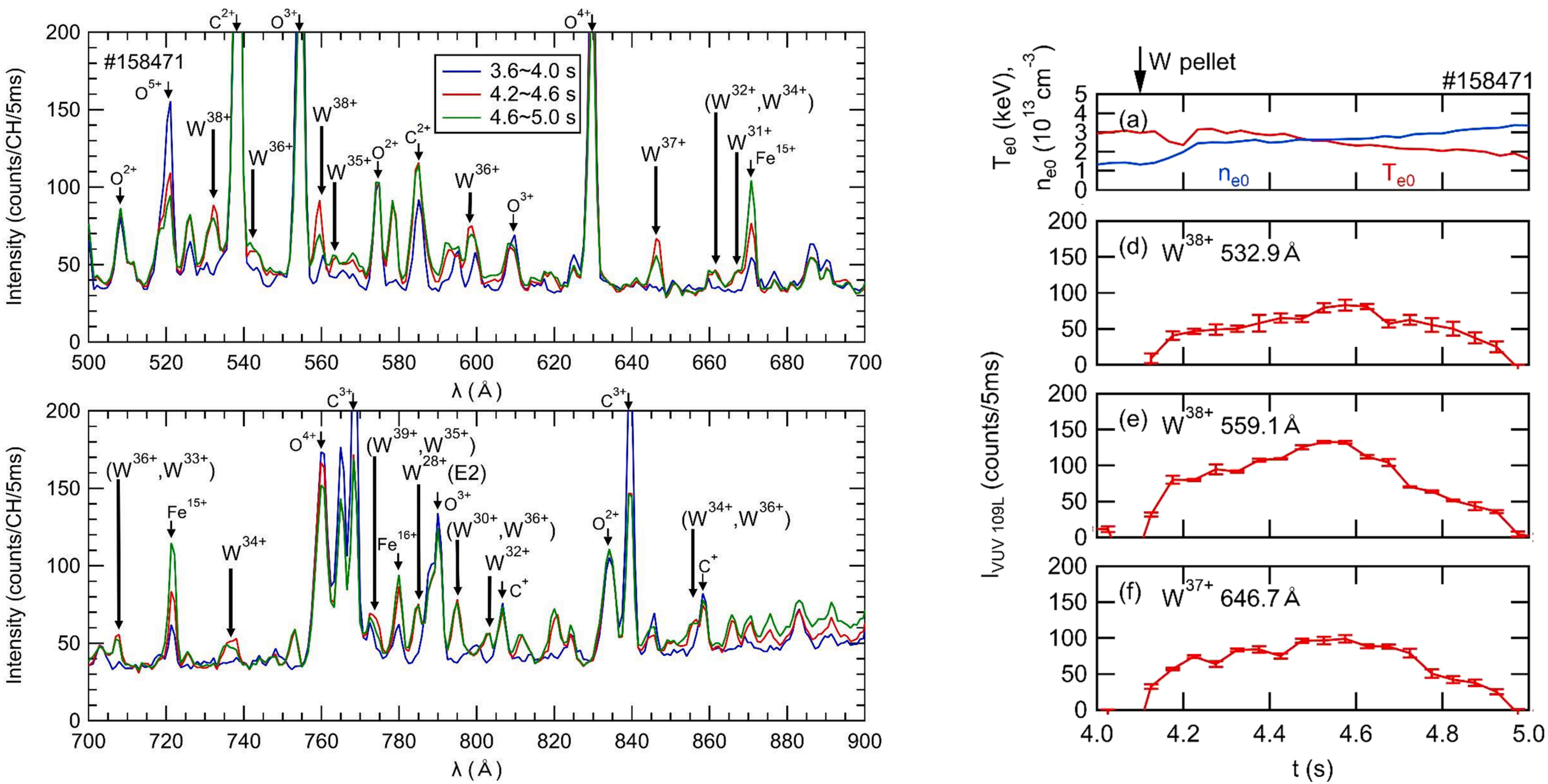
identified to be M1 lines

q+	IP (keV)	Wavelength (nm)	Transition
26+	0.7844	333.748(9)	$4f^2\ ^3F_4 \rightarrow {}^3F_3$
		335.758(11)	$4f^2\ ^3F_4 \rightarrow {}^1G_4$
27+	0.8334	337.743(26)	$4f\ ^2F_{7/2} \rightarrow {}^2F_{5/2}$

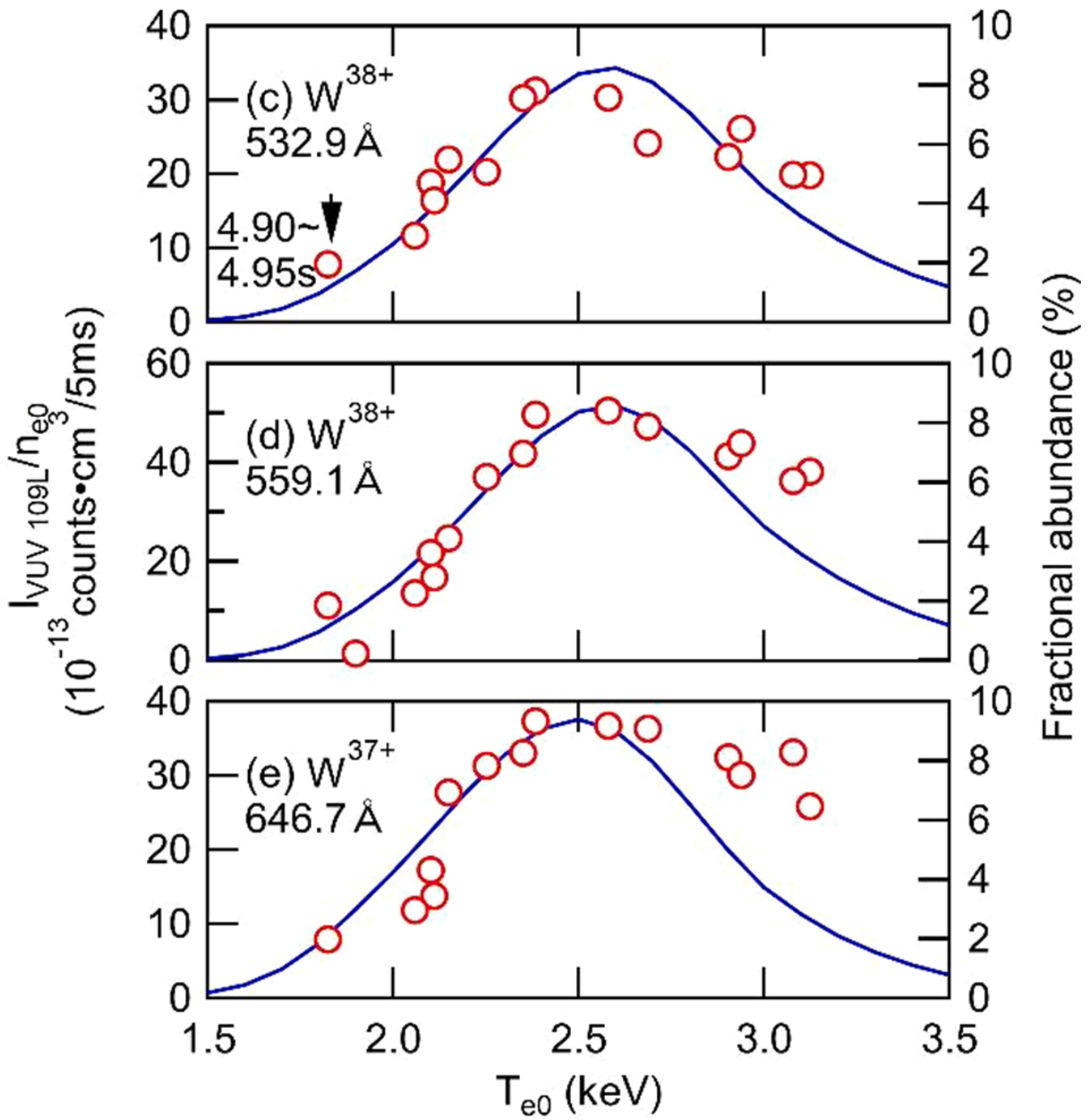
ionization balance is a good approximation when fractional abundance is considered

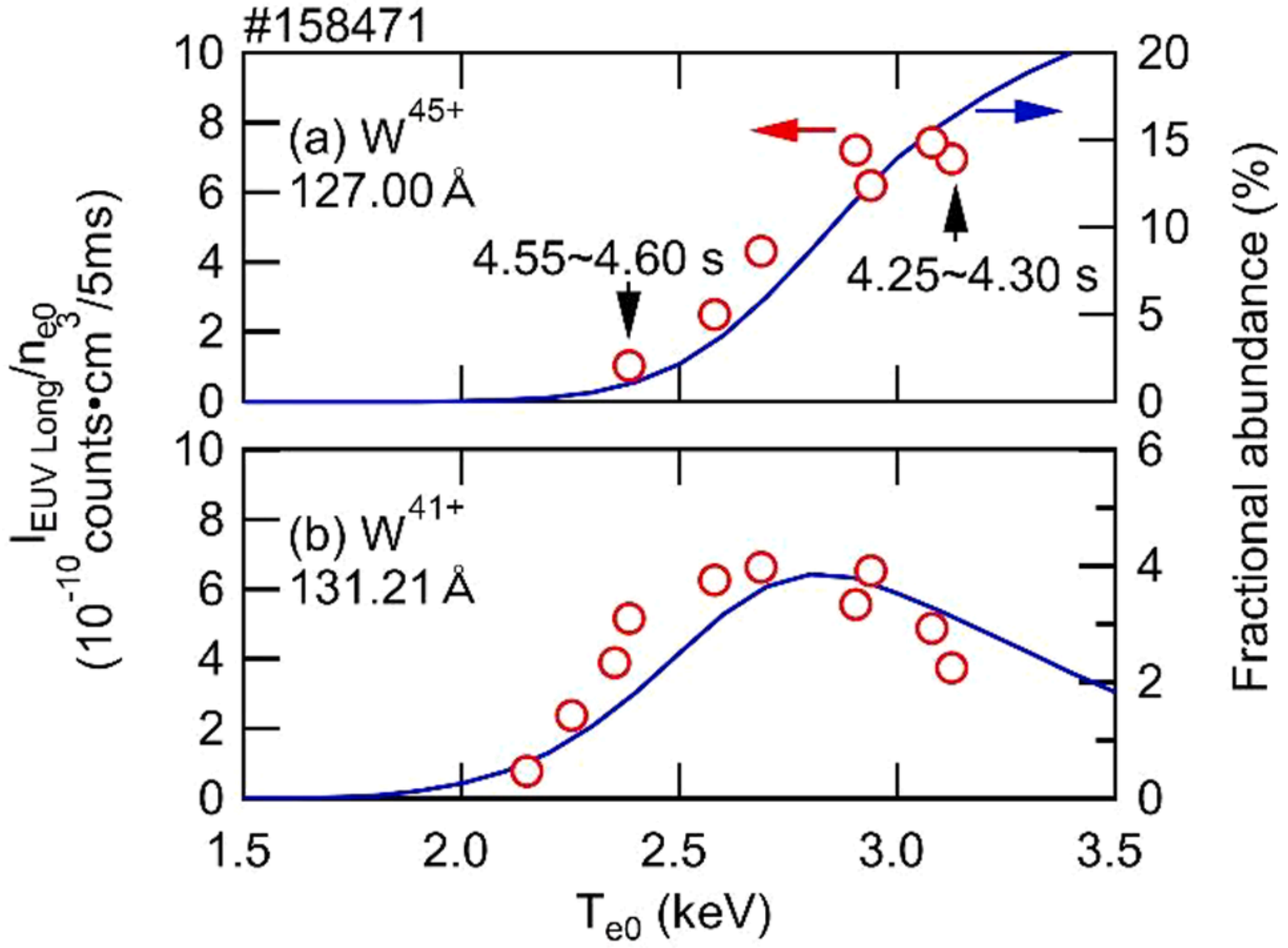


M1 lines in VUV and their temporal behaviors



VUV lines also suggest ionization balance

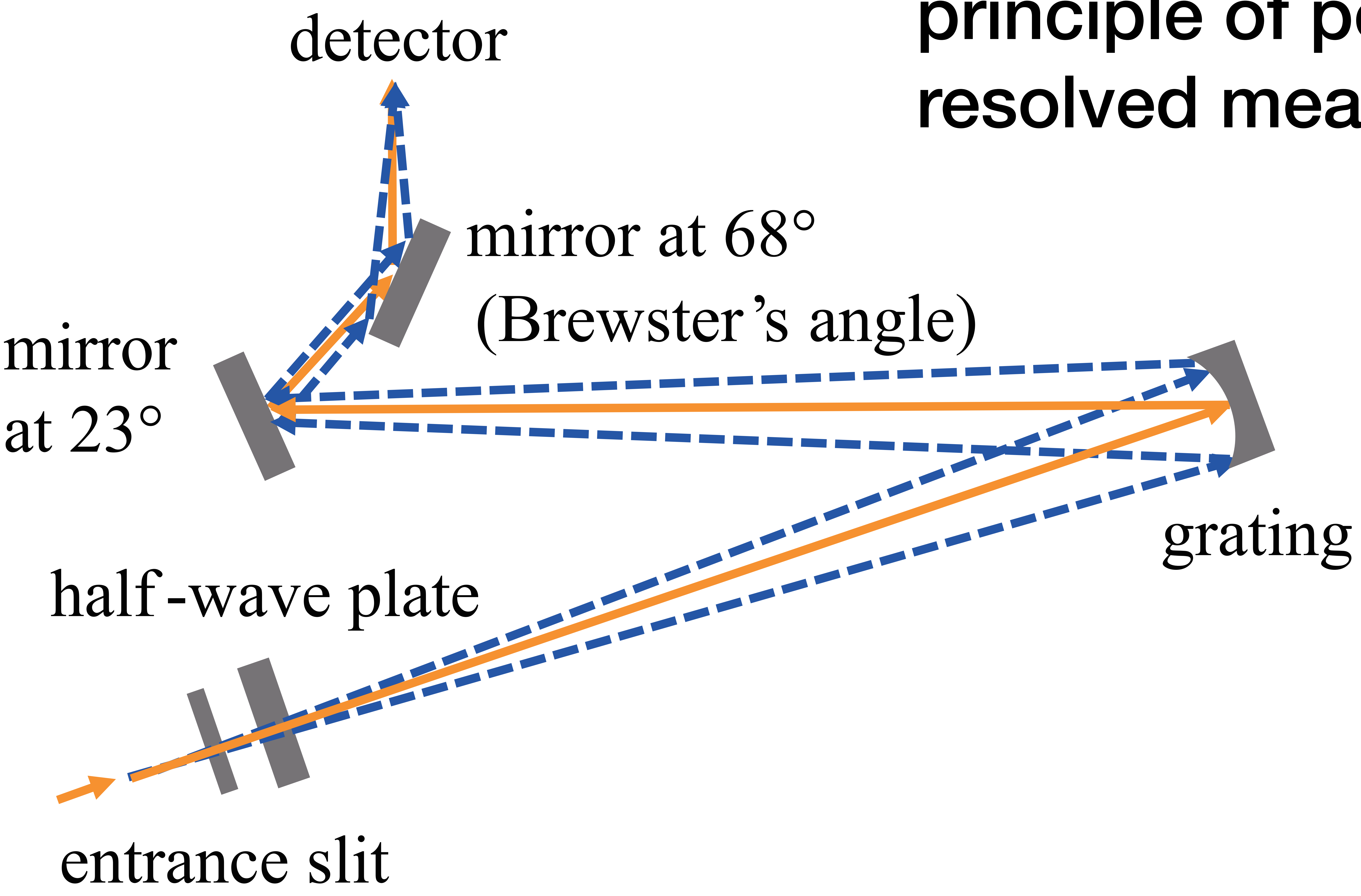


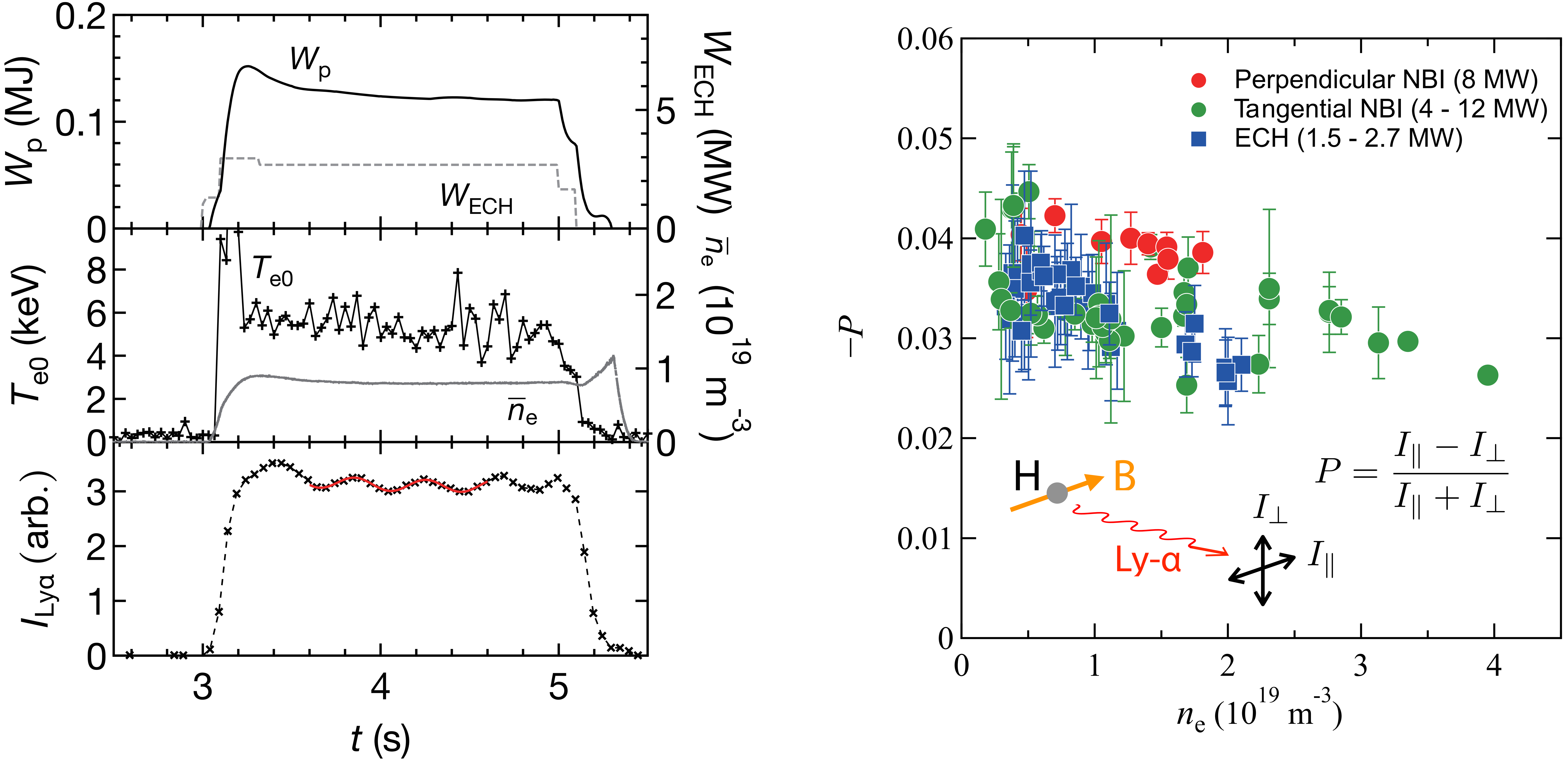


- The pellet injection is a standard method for the impurity-relating studies in LHD.
- We have established a technique of providing tungsten ions adequate for spectroscopic measurements without causing a plasma collapse.
- A number of emission lines of tungsten ions from visible to EUV have been successfully observed and they are being used for the impurity transport study and for the atomic data evaluation study.
- Special interest is focused on the M1 lines which should be useful for accessing the core plasma region with visible or VUV observation systems.

polarization of hydrogen Ly-α and plasma anisotropy

principle of polarization resolved measurement



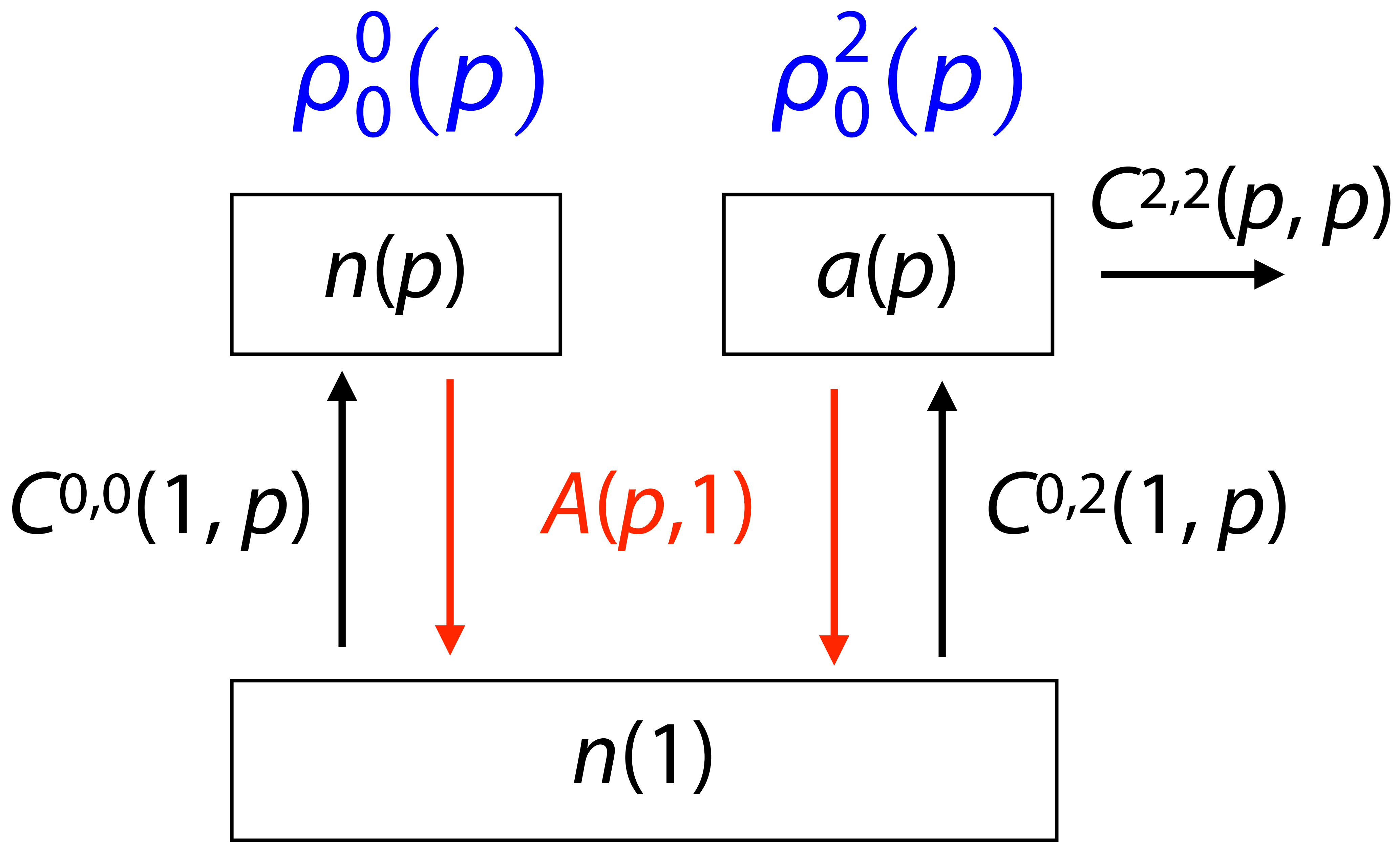


0.2
0.1
0
W_p (MJ)
W_p
W_{ECH}
W_{ECH} (MW)
5
0
8
6
4
2
0
T_{e0} (keV)
T_{e0}
$\bar{n}_e$
$\bar{n}_e$ (10^{19} m^{-3})
2
1
0
3
2
1
0
$I_{Ly\alpha}$ (arb.)
3
4
5
t (s)
0.06
0.05
0.04
0.03
0.02
0.01
0
$-P$
Perpendicular NBI (8 MW)
Tangential NBI (4 - 12 MW)
ECH (1.5 - 2.7 MW)
H
B
Ly-α
$I_\perp$
$I_\parallel$
$P = \frac{I_\parallel - I_\perp}{I_\parallel + I_\perp}$
0
1
2
3
4
n_e (10^{19} m^{-3})

population-alignment CR model

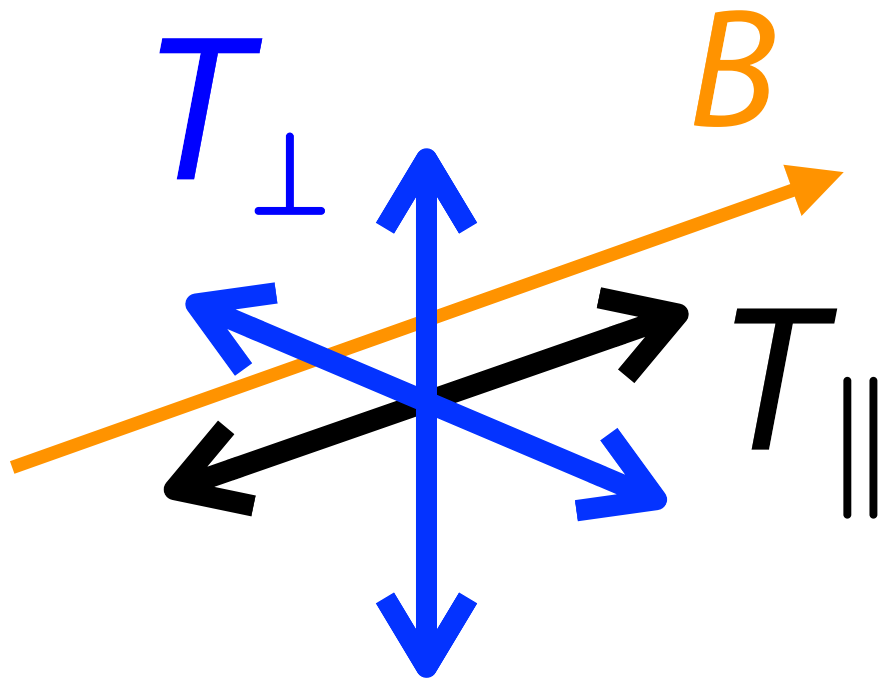
$$\rho(p) = \underbrace{\rho_0^0(p)T_0^{(0)}(p)}_{\text{population}} + \underbrace{\rho_0^2(p)T_0^{(2)}(p)}_{\text{alignment}}$$

spherical coordinate representation of density matrix



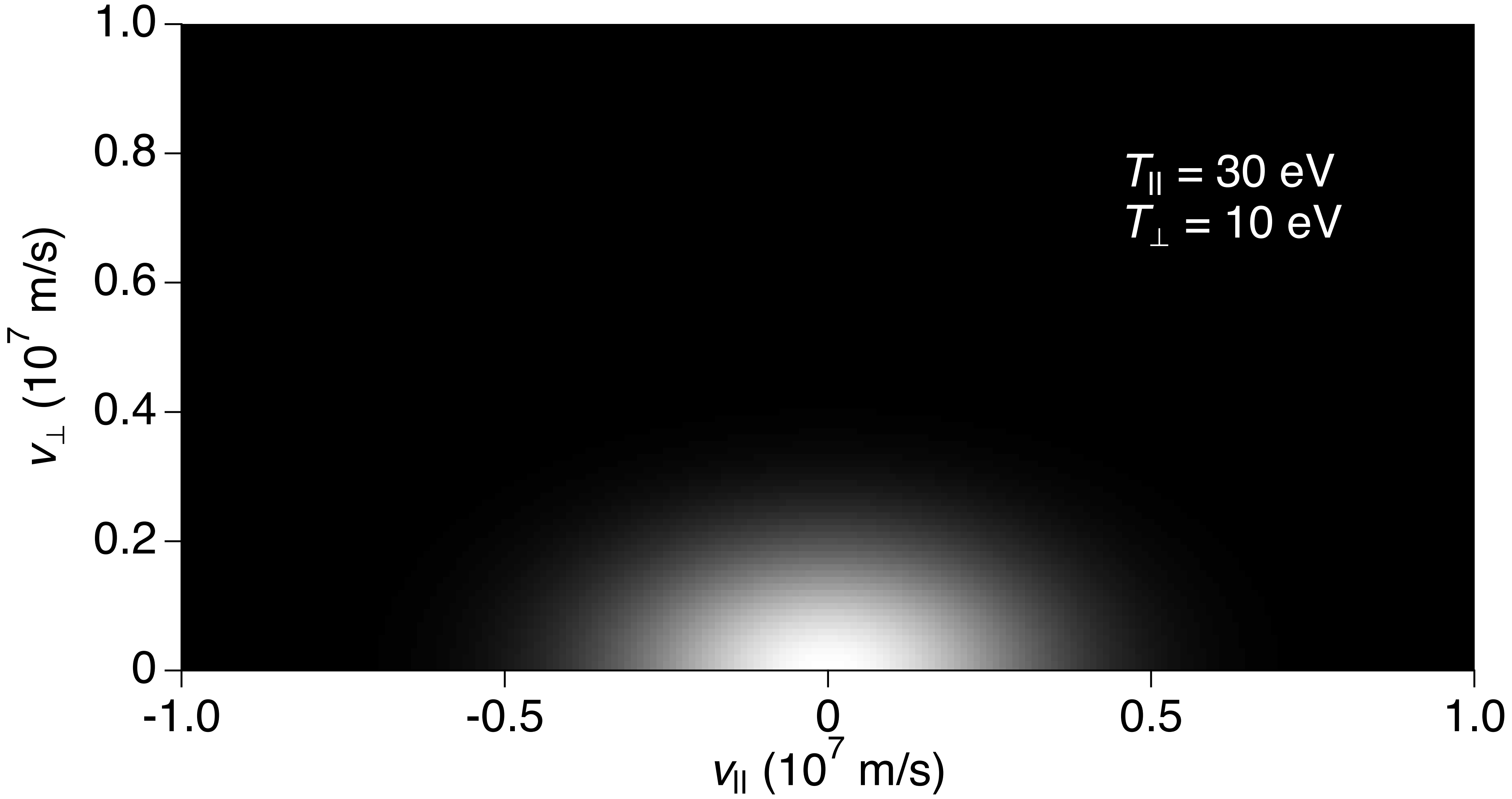
$$\frac{a(p)}{n(p)} \to P$$

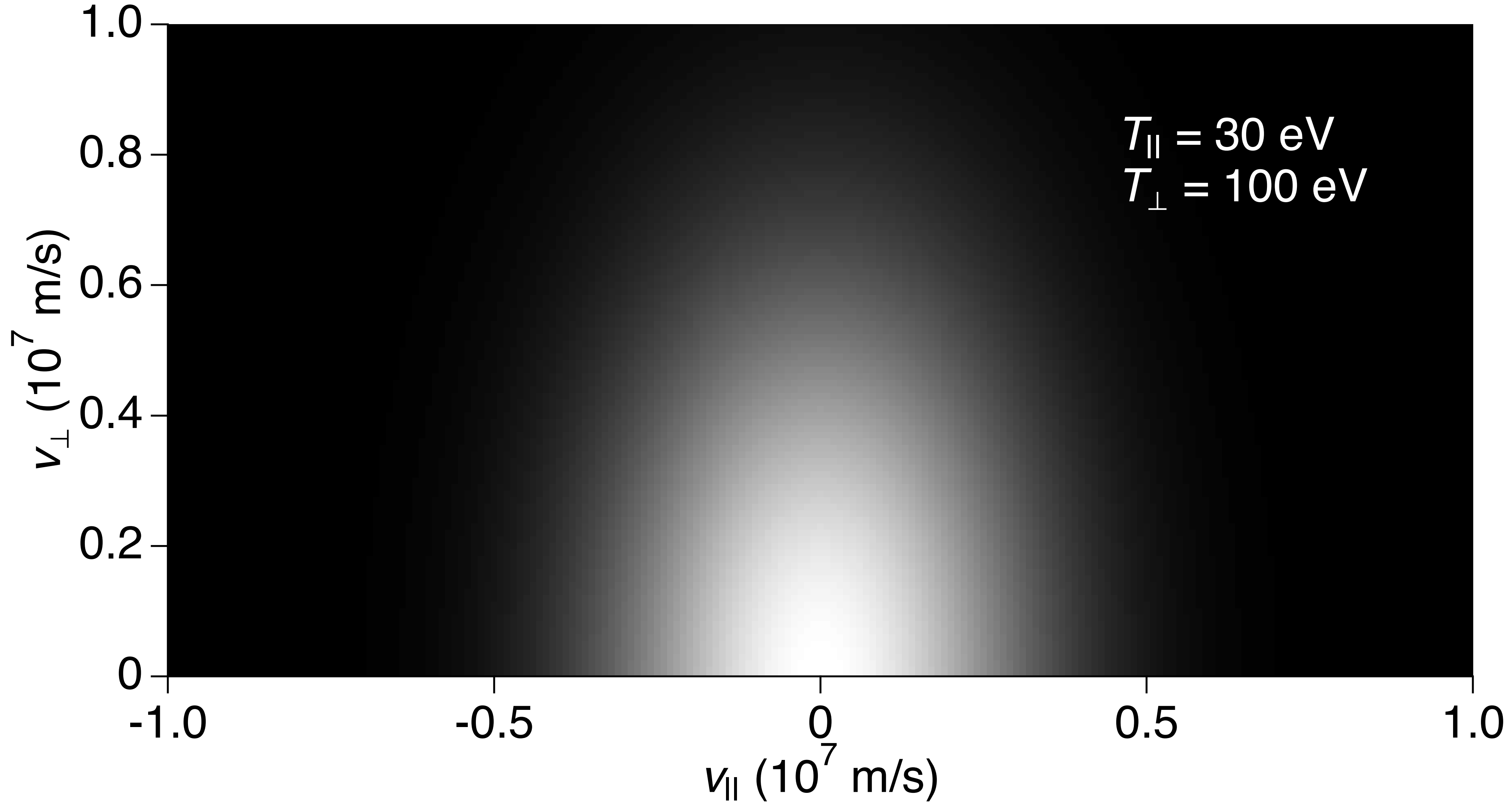
velocity distribution function



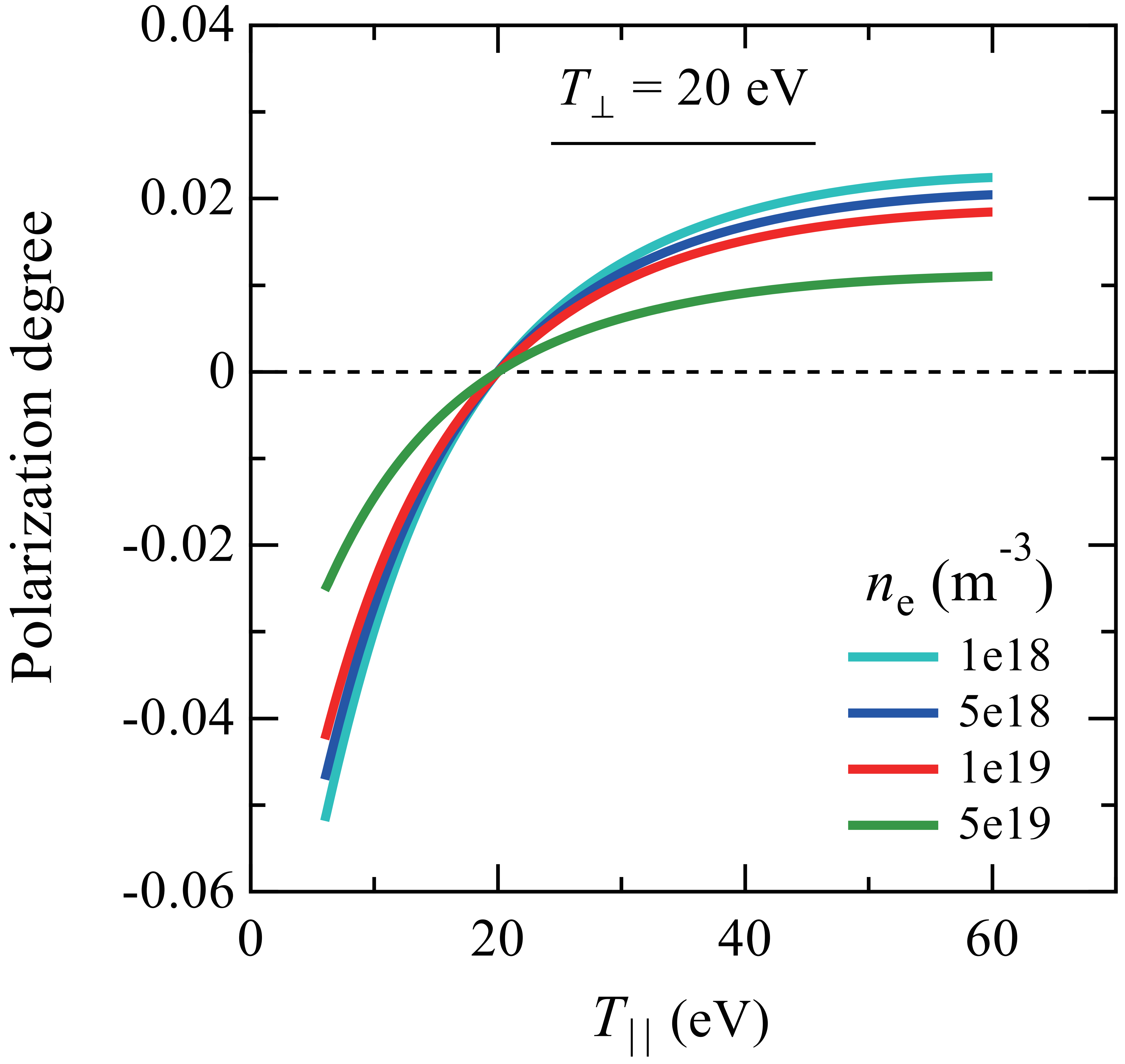
$$f(v,\theta) = 2\pi\left(\frac{m}{2\pi k}\right)^{3/2}\left(\frac{1}{T_\perp^2 T_\parallel}\right)^{1/2}\exp\left[-\frac{mv^2}{2k}\left(\frac{\sin^2\theta}{T_\perp}+\frac{\cos^2\theta}{T_\parallel}\right)\right]$$

$$v_\parallel = v\cos\theta,\ \ v_\perp = v\sin\theta$$

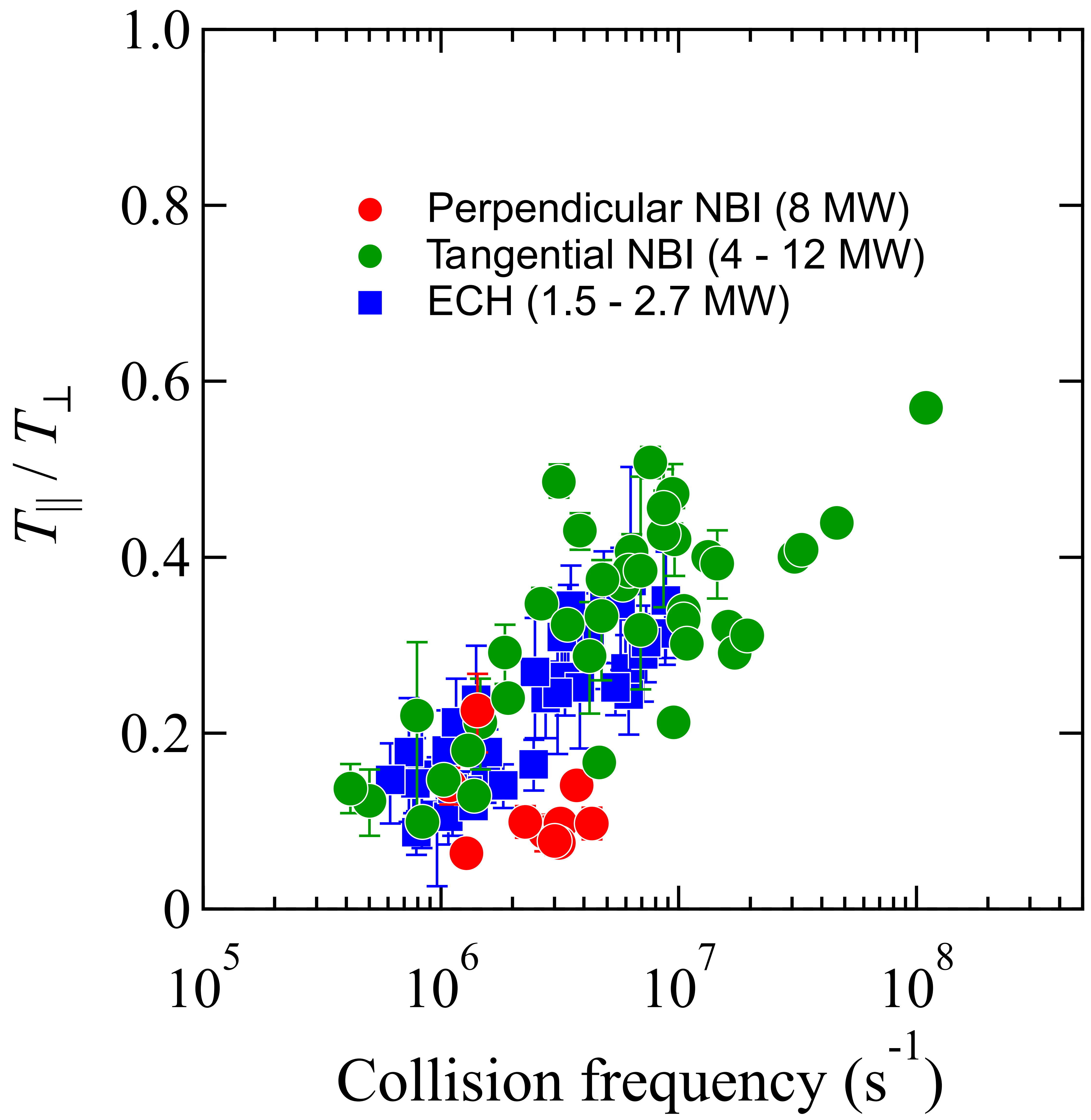




simulation results with PACR model



anisotropy in terms of $T_{\parallel}/T_{\perp}$ derived from P



- Polarization of the hydrogen Lyman-α line is detected in the Large Helical Device.
- A simple simulation model is constructed in the framework of PACR model.
- With the help of the simulation model, the anisotropy in EVDF in terms of $T_\parallel/T_\perp$ is evaluated.
- $T_\parallel/T_\perp$ shows a tendency to decrease and deviate from unity with decreasing electron-electron collision frequency.
- This result qualitatively agrees with an intuitive understanding of the anisotropic EVDF in the plasma boundary.