

Spectroscopic studies for tungsten and hydrogen in LHD

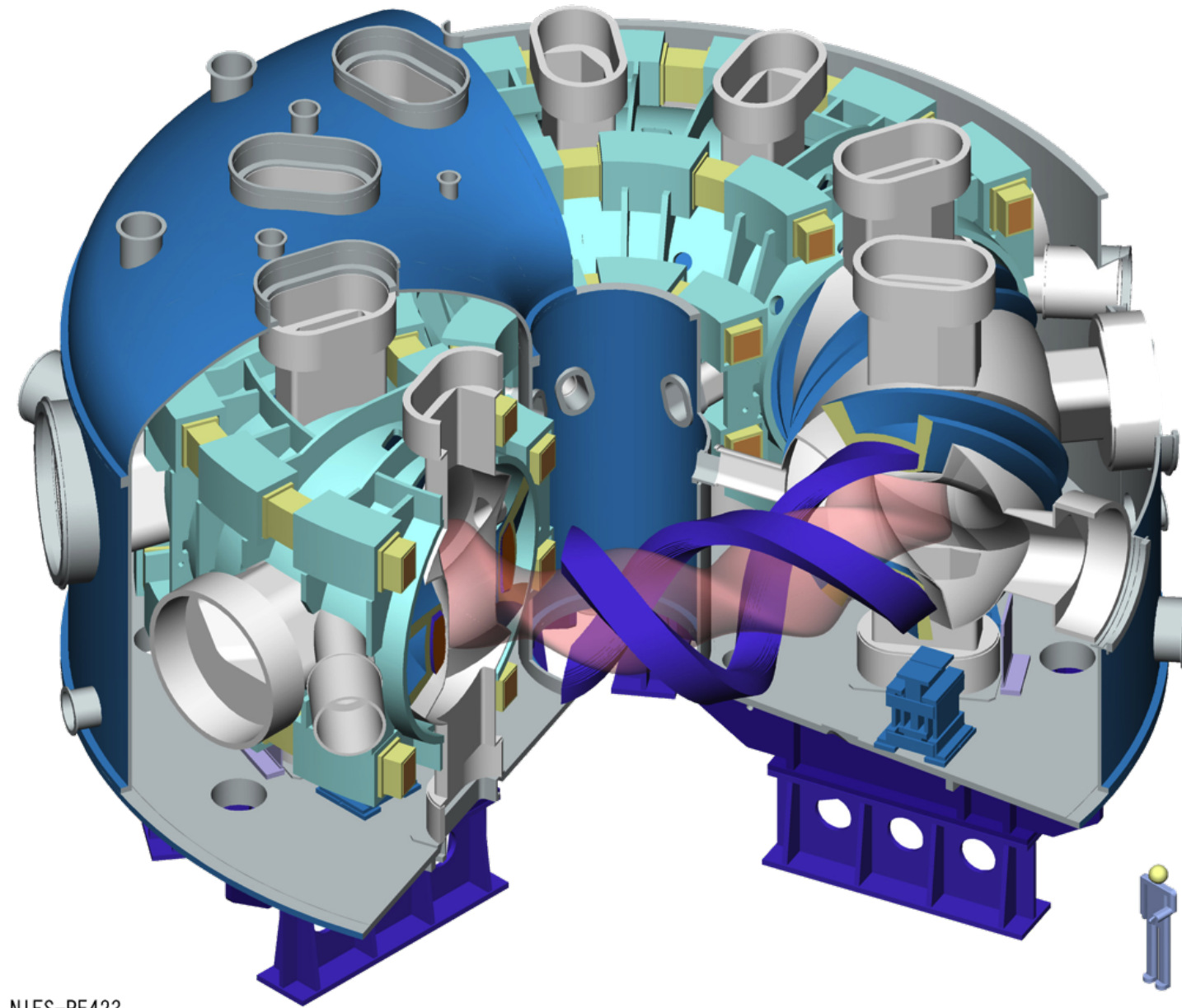
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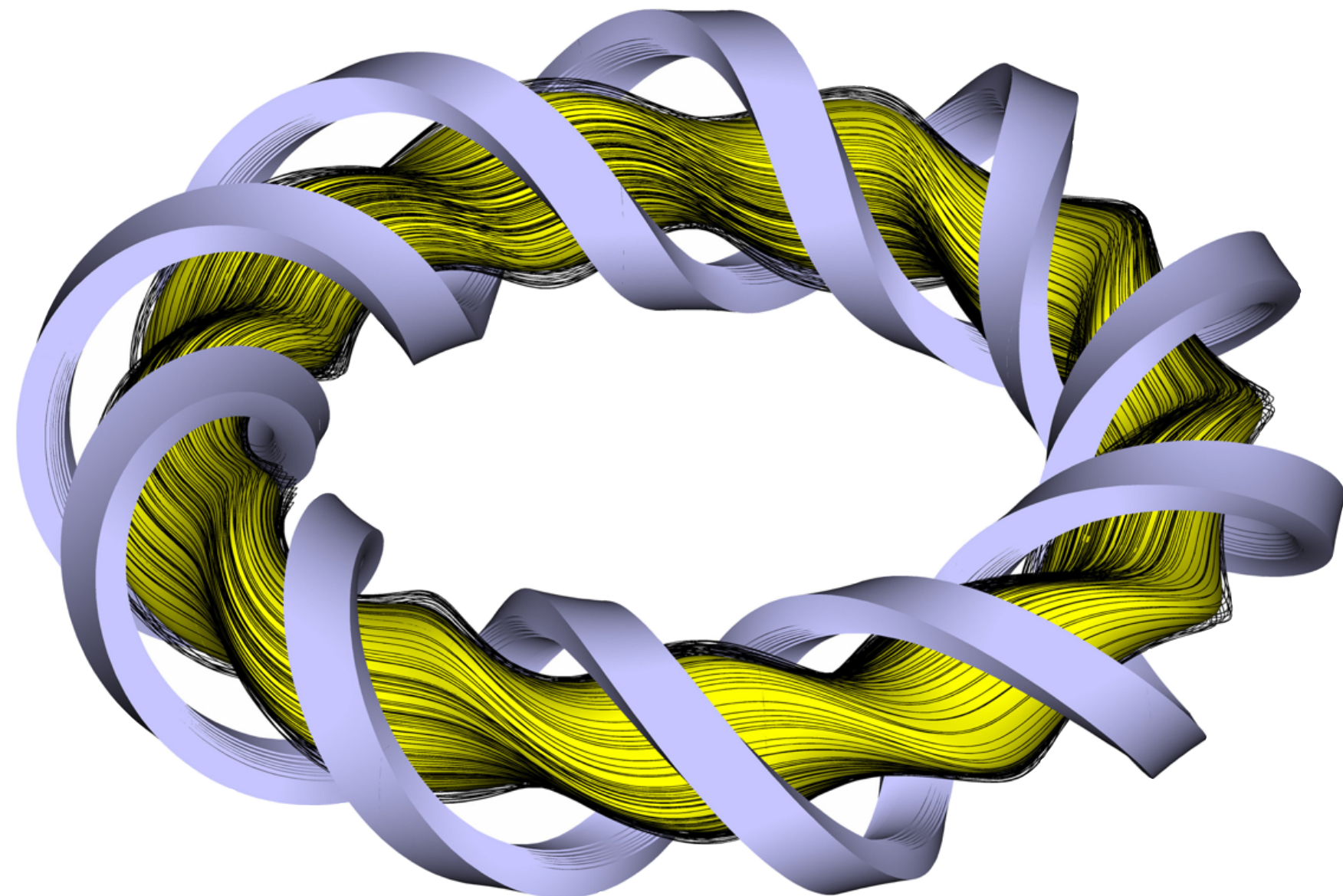
Large Helical Device (LHD)

An aerial photograph of the Large Helical Device (LHD) tokamak reactor. The device is a large, complex, cylindrical structure with a central column and a toroidal ring. It is surrounded by a dense network of pipes, walkways, and support structures. The facility is a large, industrial building with a high ceiling and concrete walls. The lighting is bright, and the overall scene is one of a sophisticated scientific instrument.

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

$$T_e \quad \sim 20 \text{ keV}$$

$$T_i \quad \sim 10 \text{ keV}$$

$$n_e \quad \sim 10^{21} \text{ m}^{-3}$$



helical coil

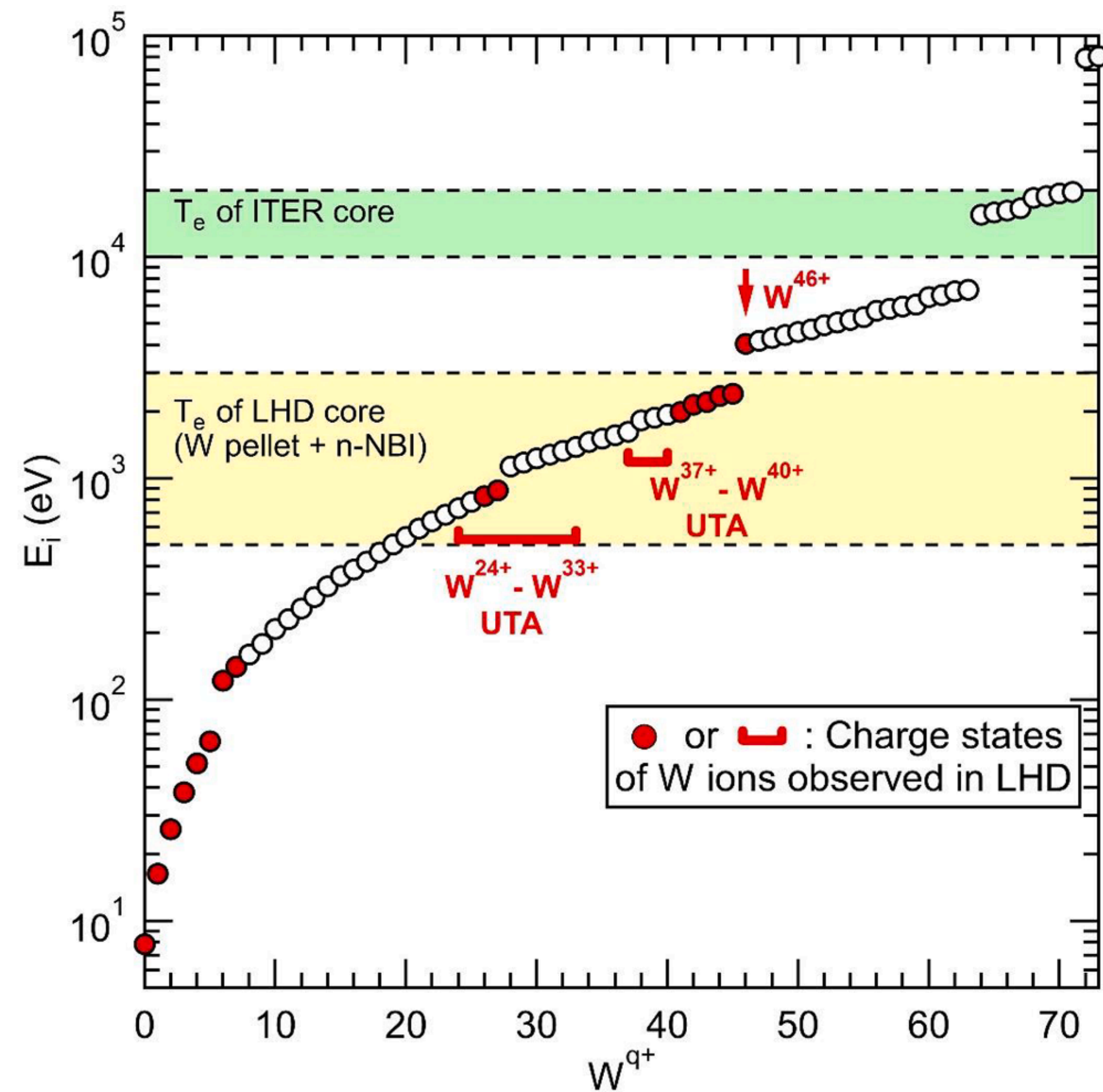
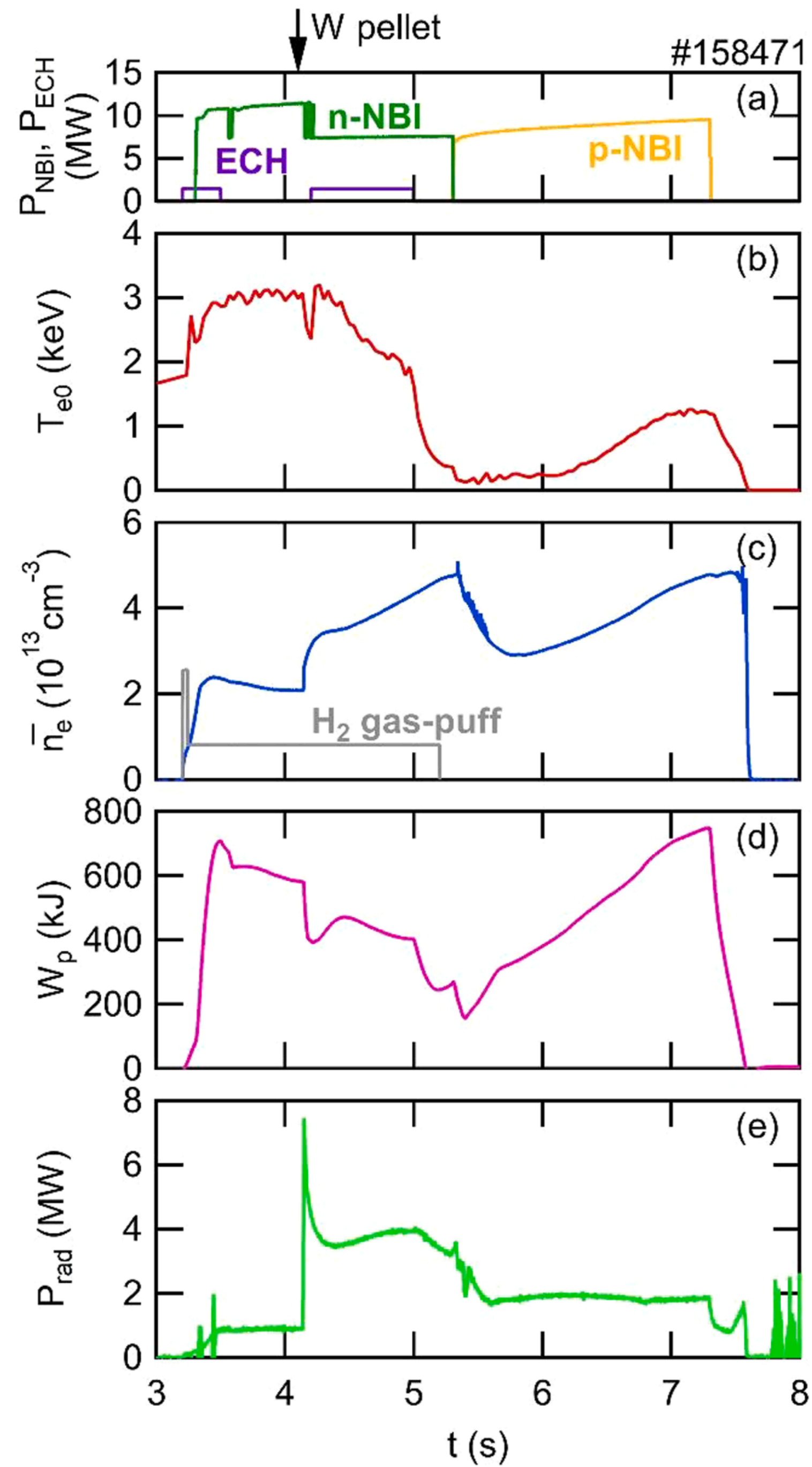
The image shows the interior of a tokamak reactor, characterized by its complex, curved metallic structure. The walls are composed of numerous small, rectangular tiles, each with a grid of small holes. These tiles are arranged in a helical pattern, following the curvature of the vessel. The lighting is dramatic, with bright highlights reflecting off the metallic surfaces and deep shadows in the recessed areas. The overall appearance is one of high precision and advanced engineering.

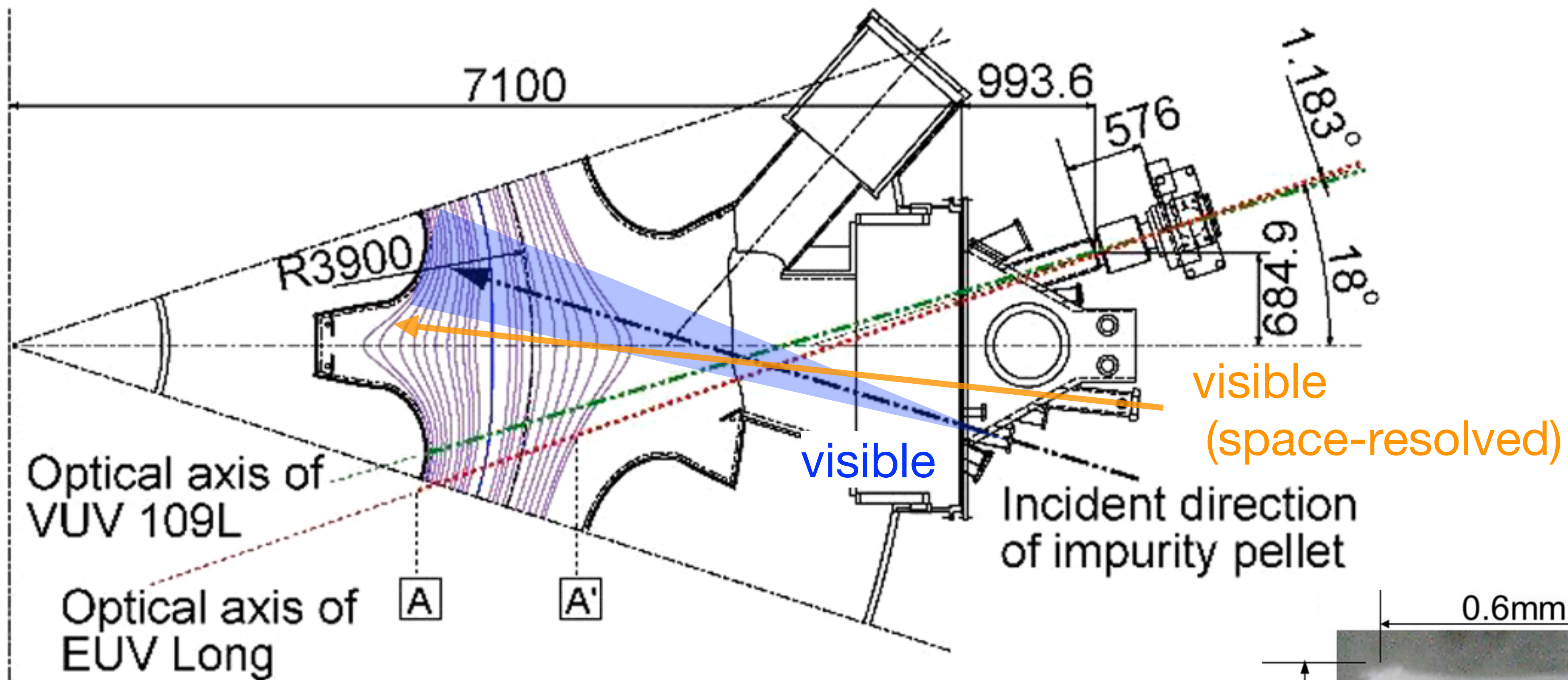
divertor plates

helical coil

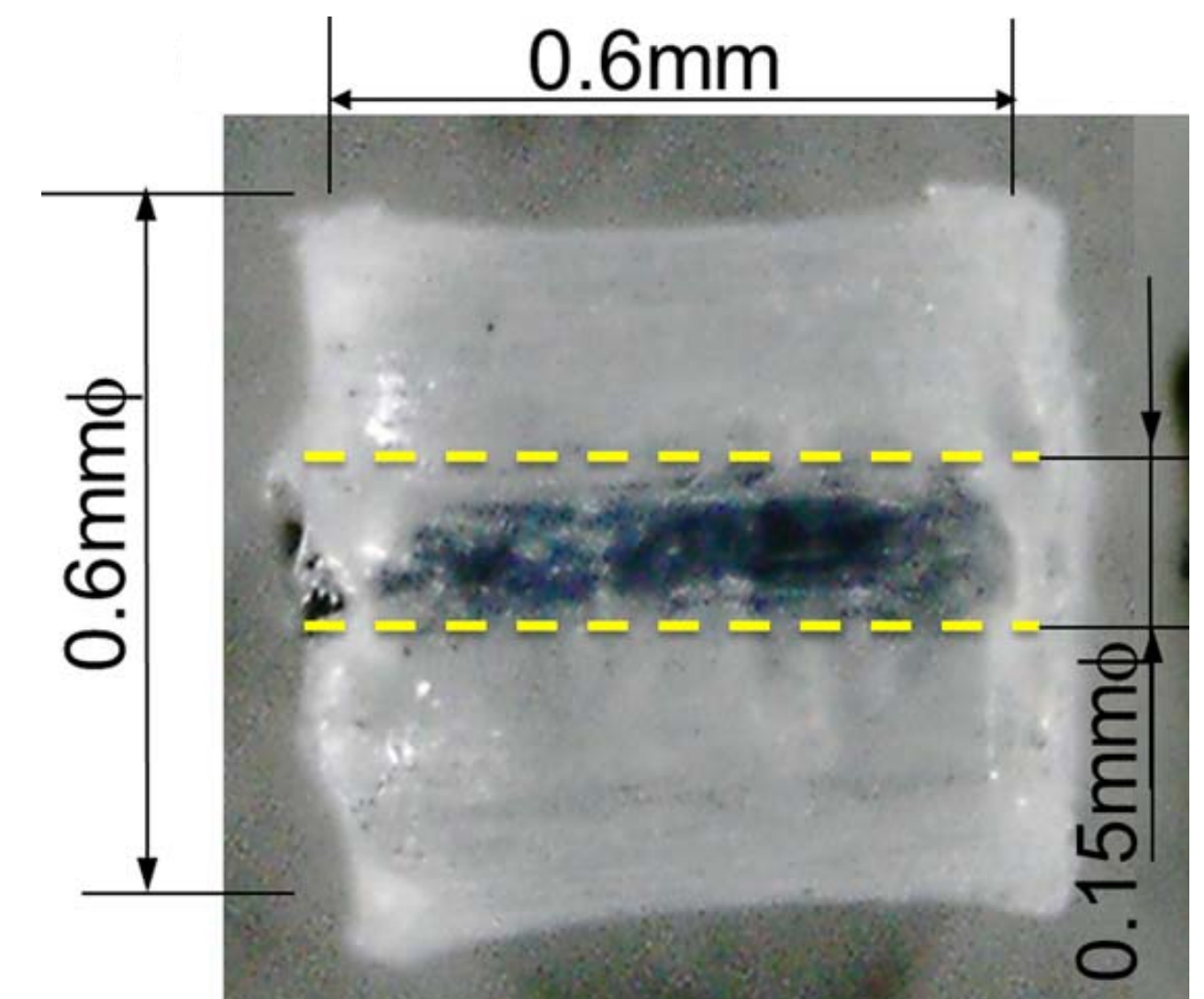
**tungsten pellet injection for
spectroscopic measurements**

typical discharge and charge states attained in observation to date





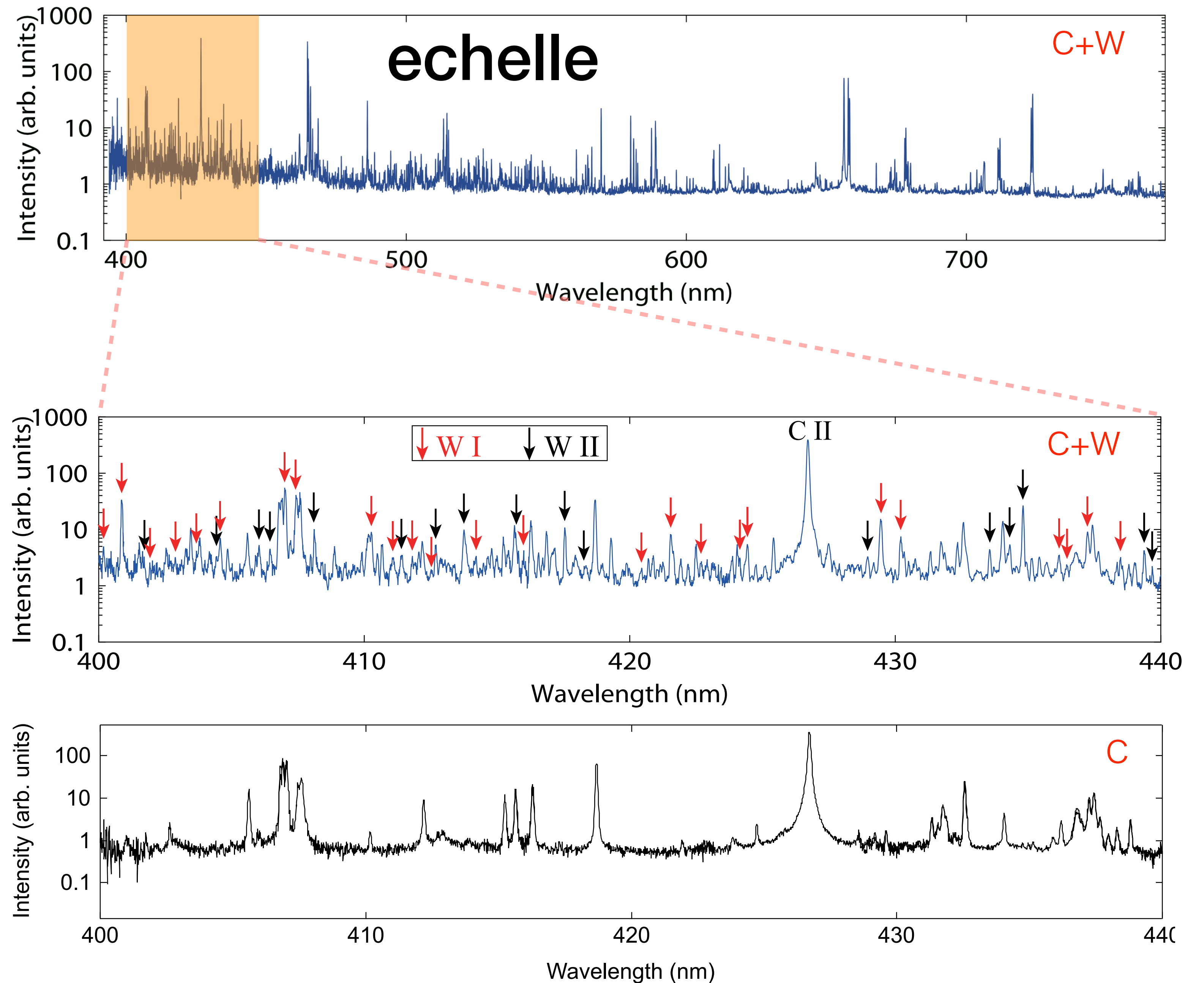
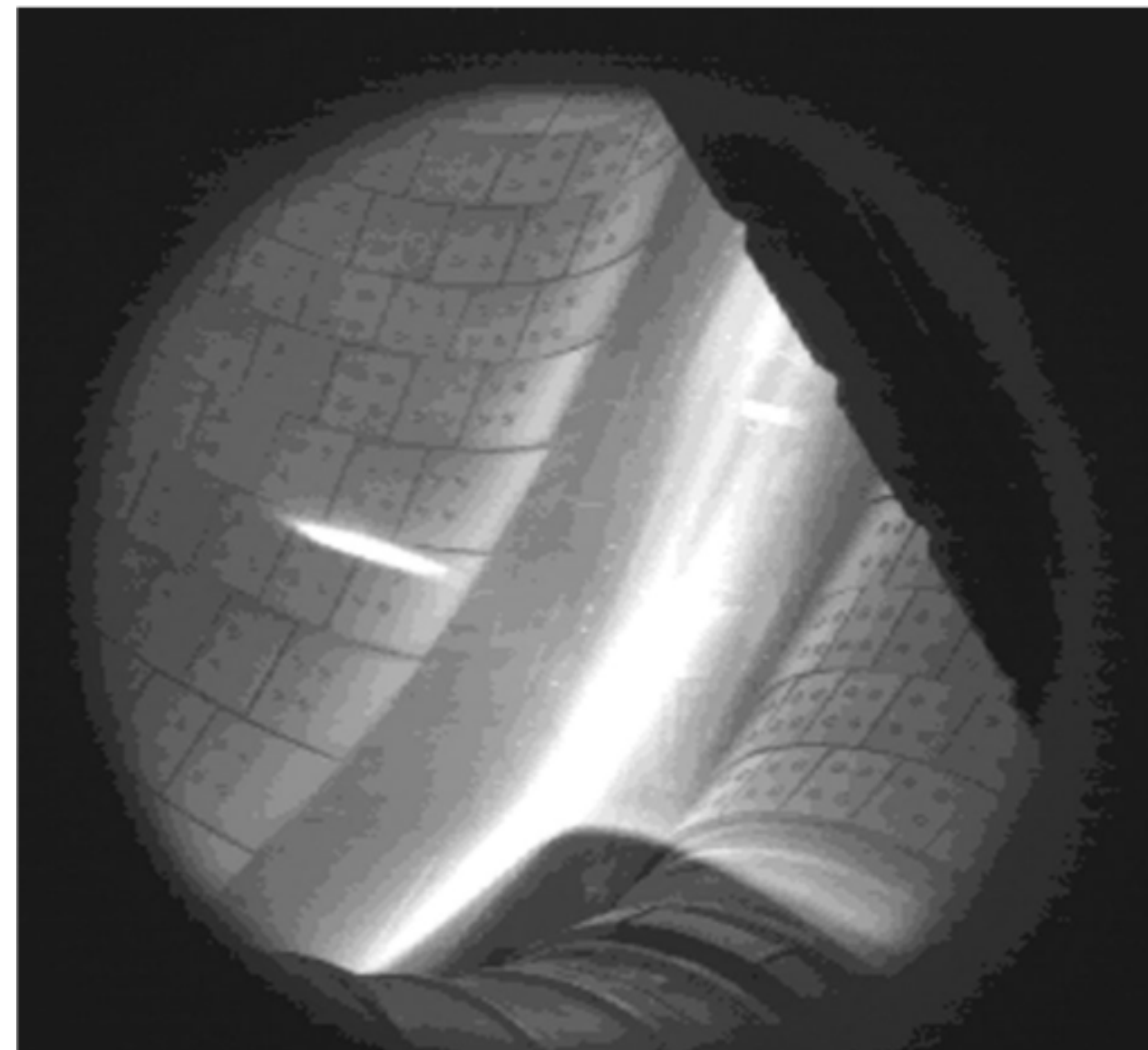
$\phi 0.15\text{mm}$ tungsten wire
in polyethylene tube



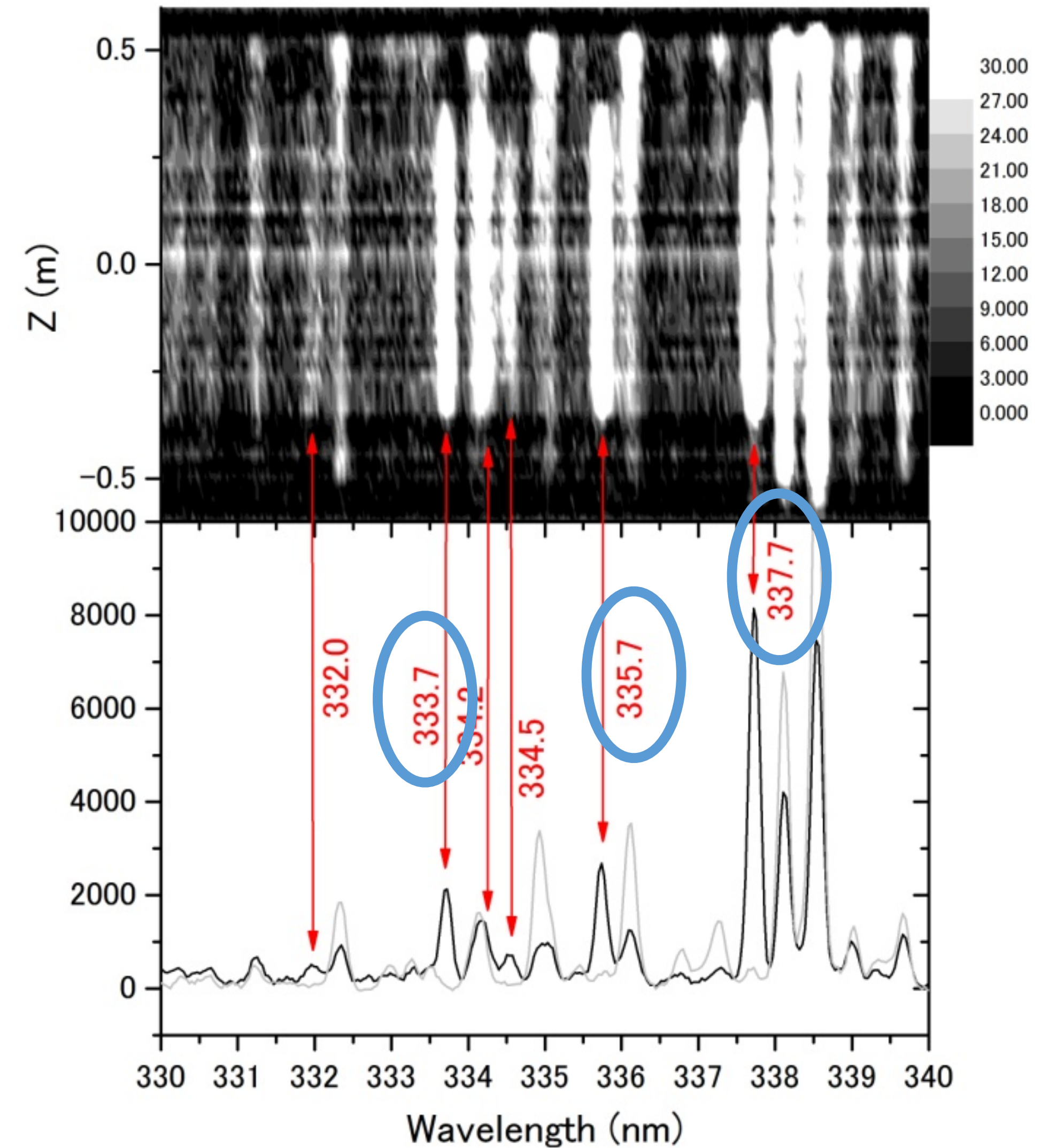
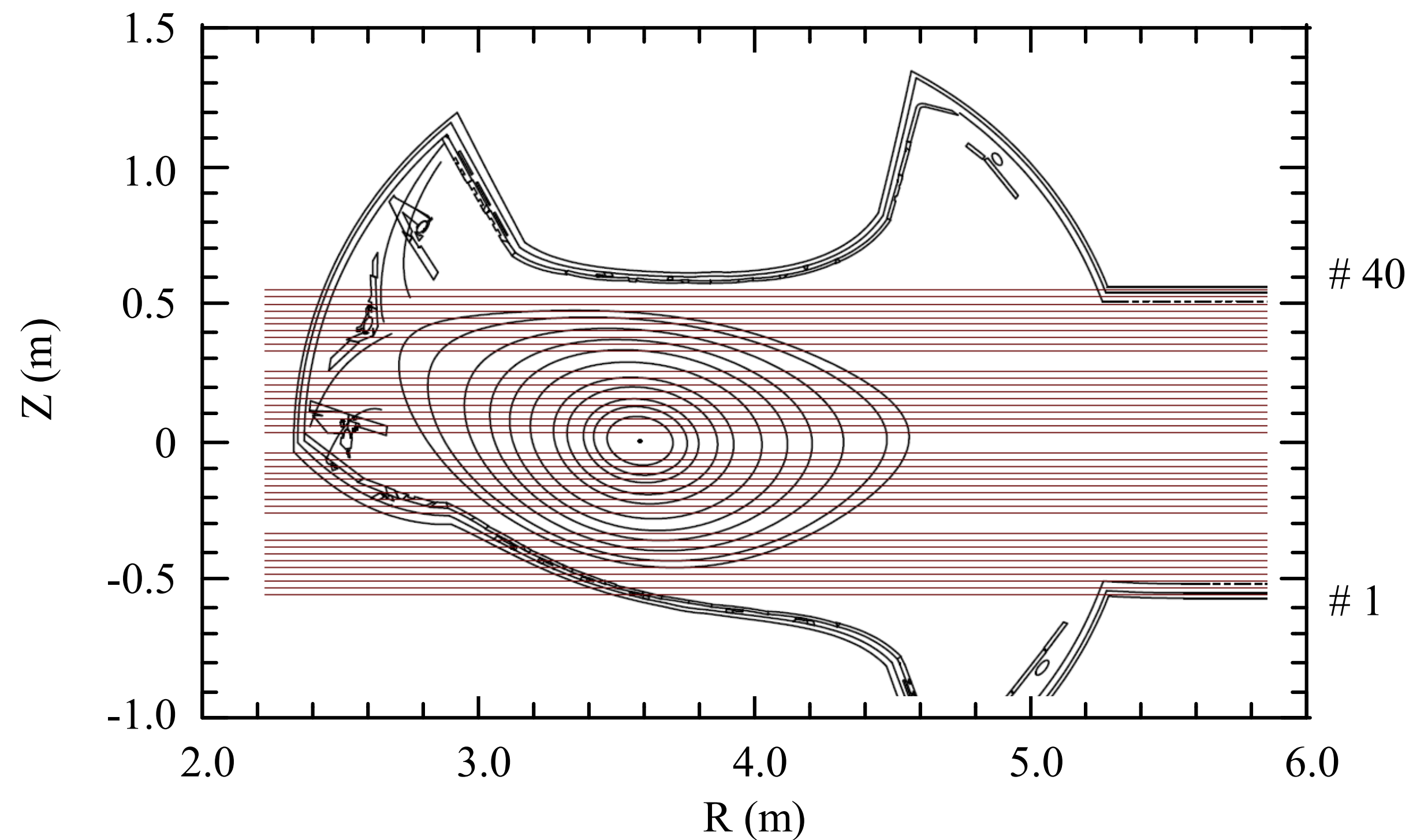
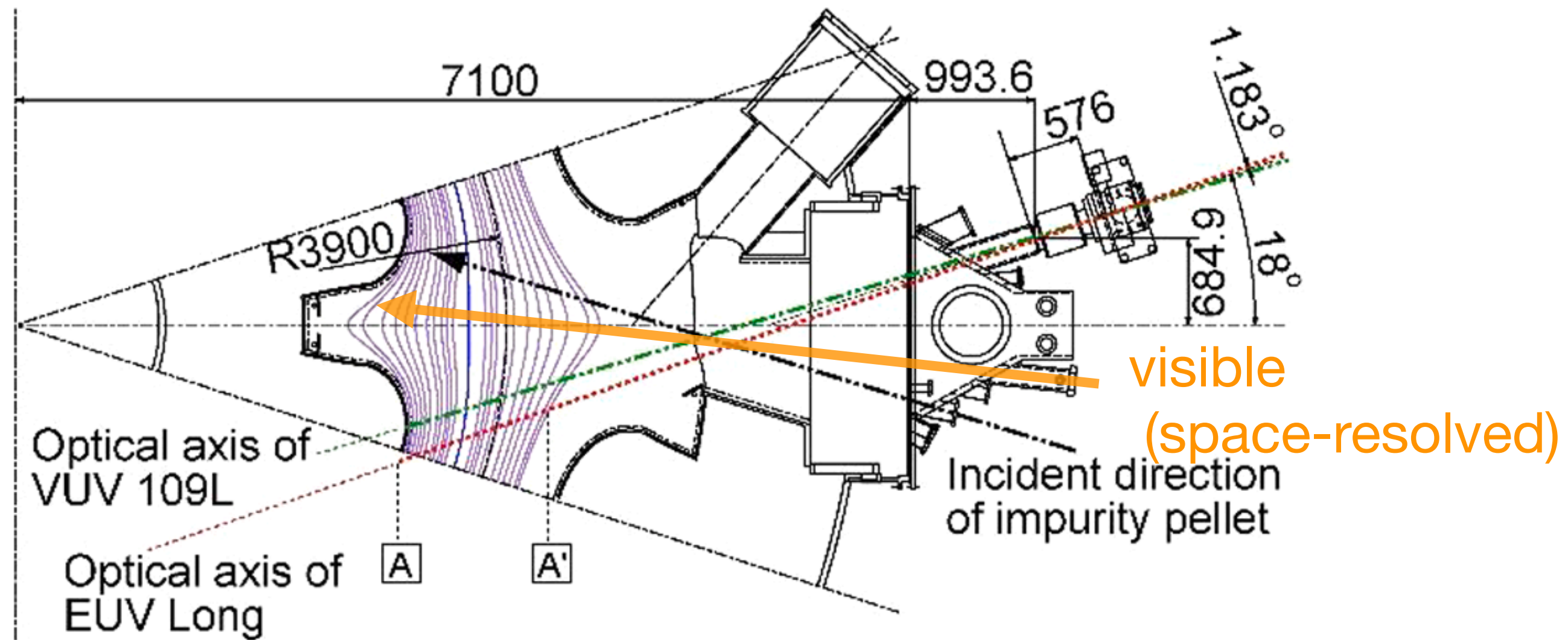
spectrum observed for the ablation cloud

$$T_e \sim 1 \text{ eV}$$

$$n_e \sim 10^{23} \text{ m}^{-3}$$



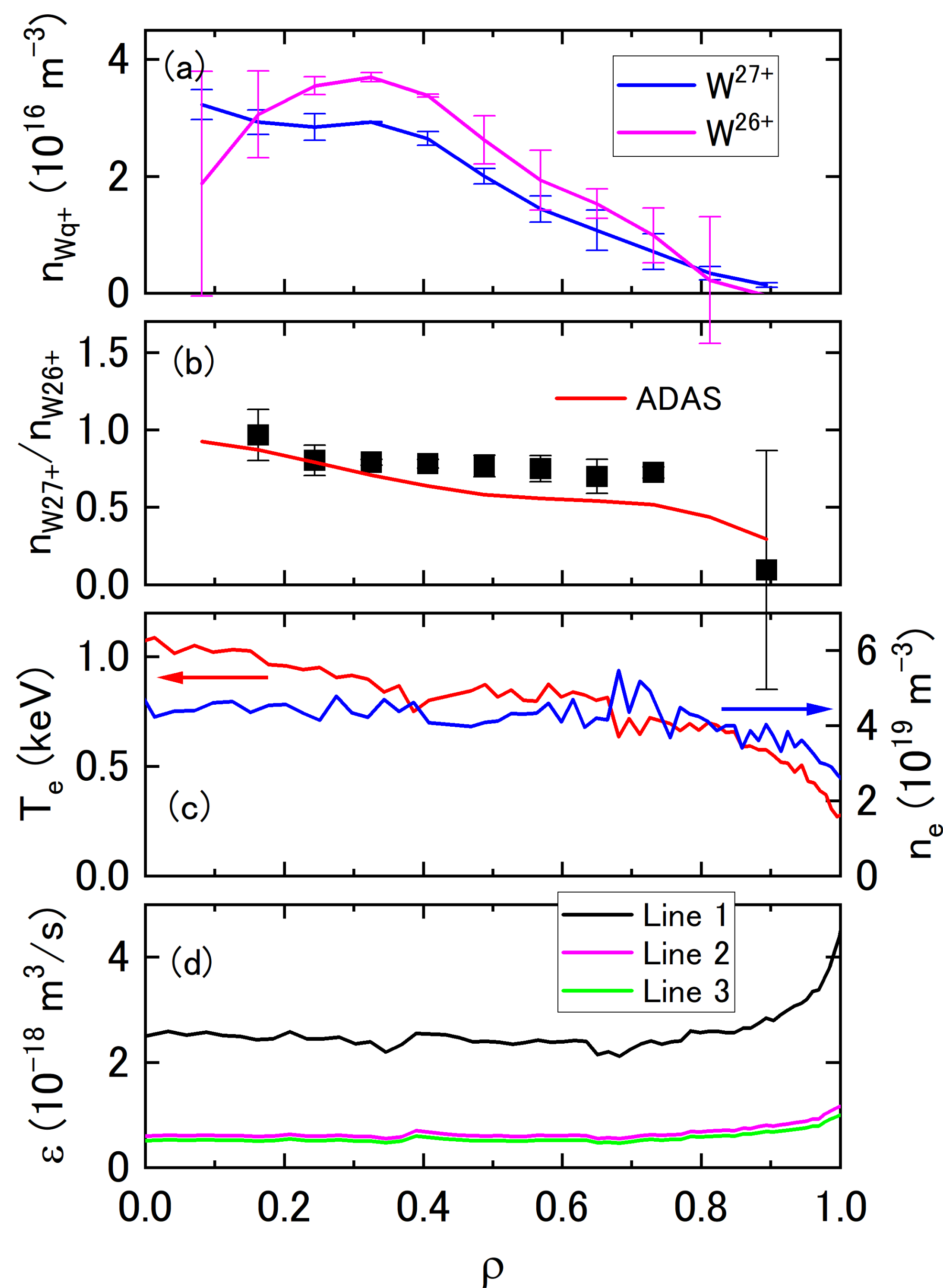
space-resolved visible measurement



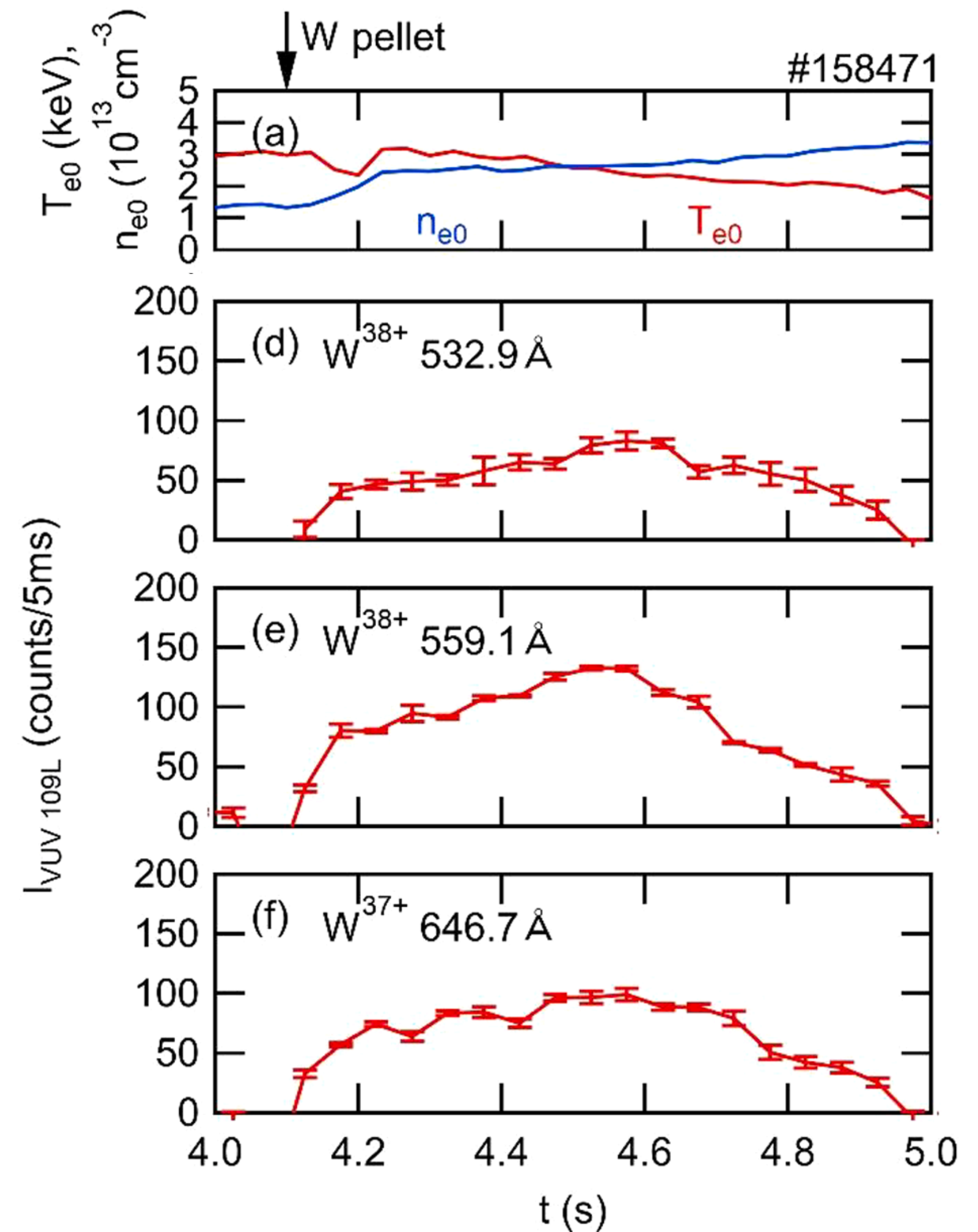
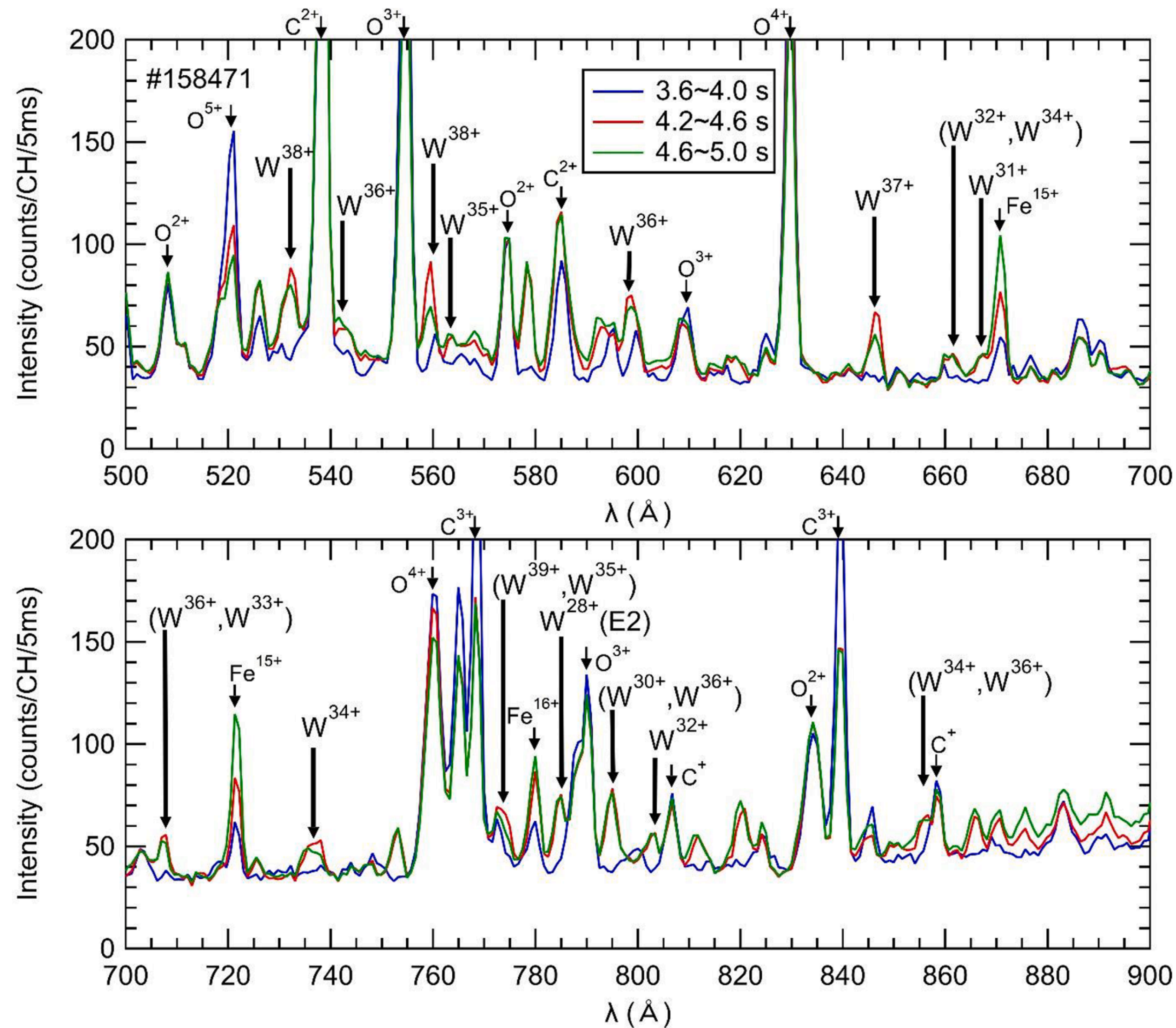
identified to be M1 lines

<i>q</i> +	IP (keV)	Wavelength (nm)	Transition
26+	0.7844	333.748(9)	4f ² ³ F ₄ → ³ F ₃
		335.758(11)	4f ² ³ F ₄ → ¹ G ₄
27+	0.8334	337.743(26)	4f ² F _{7/2} → ² F _{5/2}

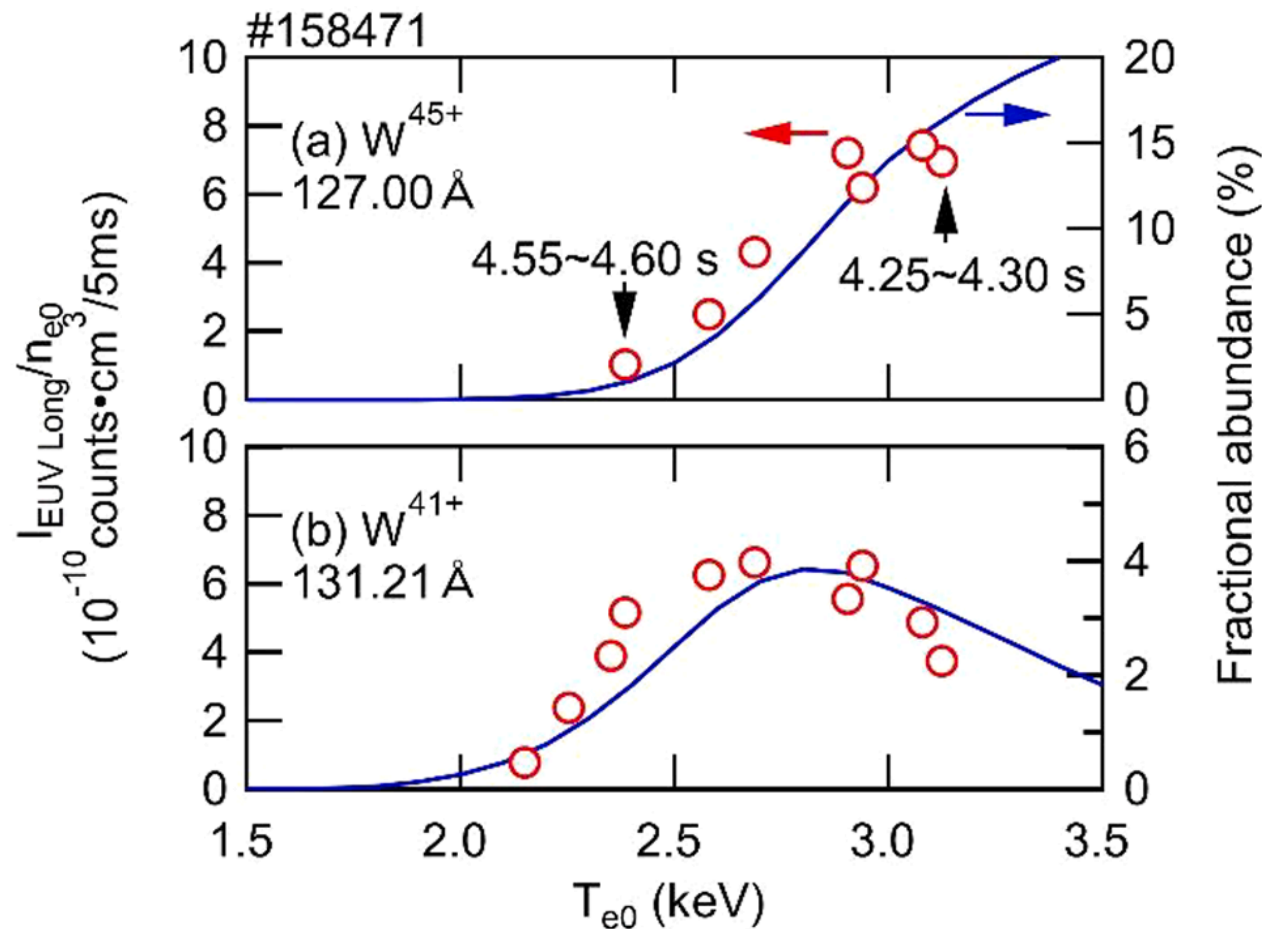
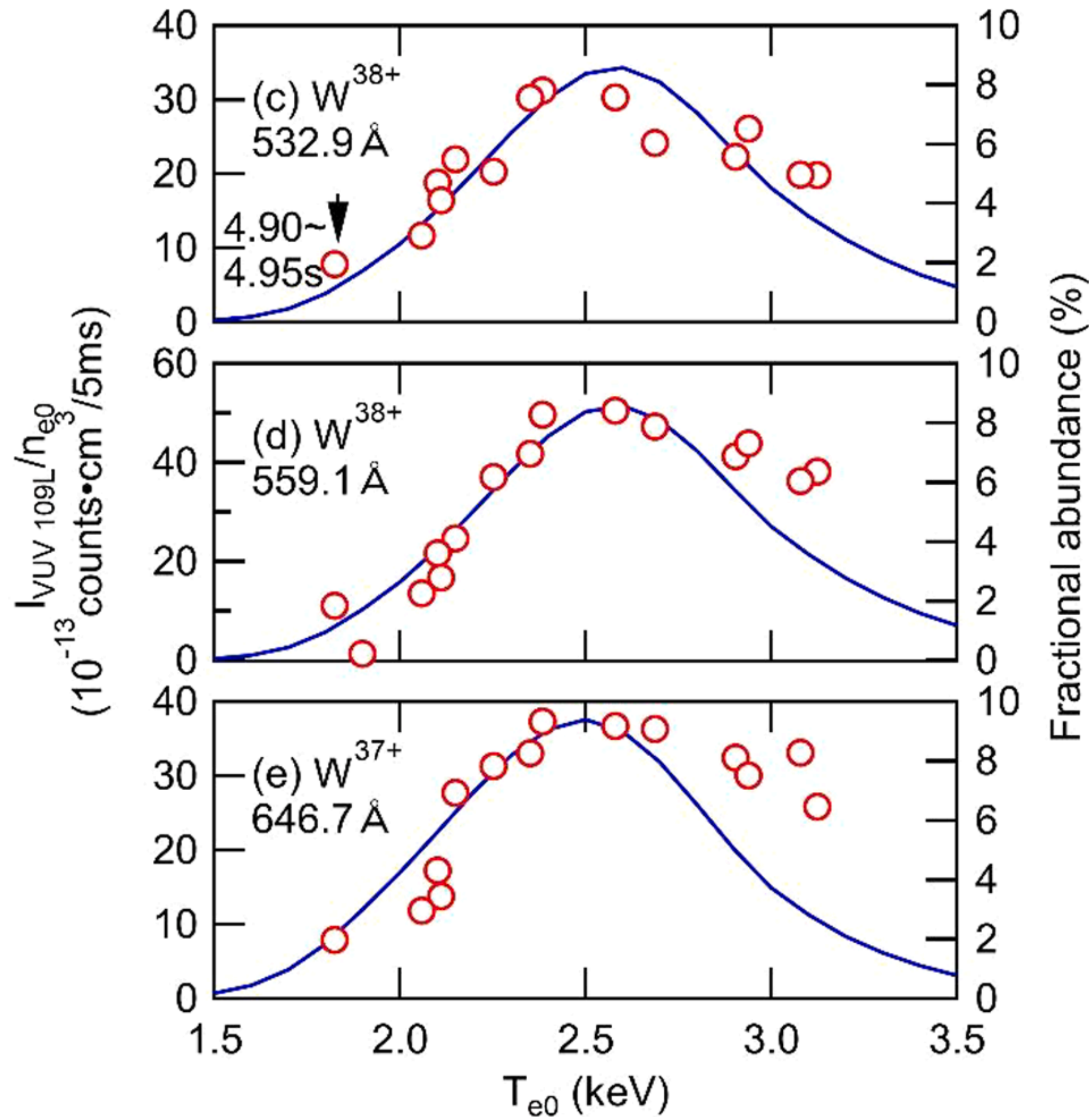
ionization balance is a good approximation when fractional abundance is considered



M1 lines in VUV and their temporal behaviors



VUV lines also suggest ionization balance



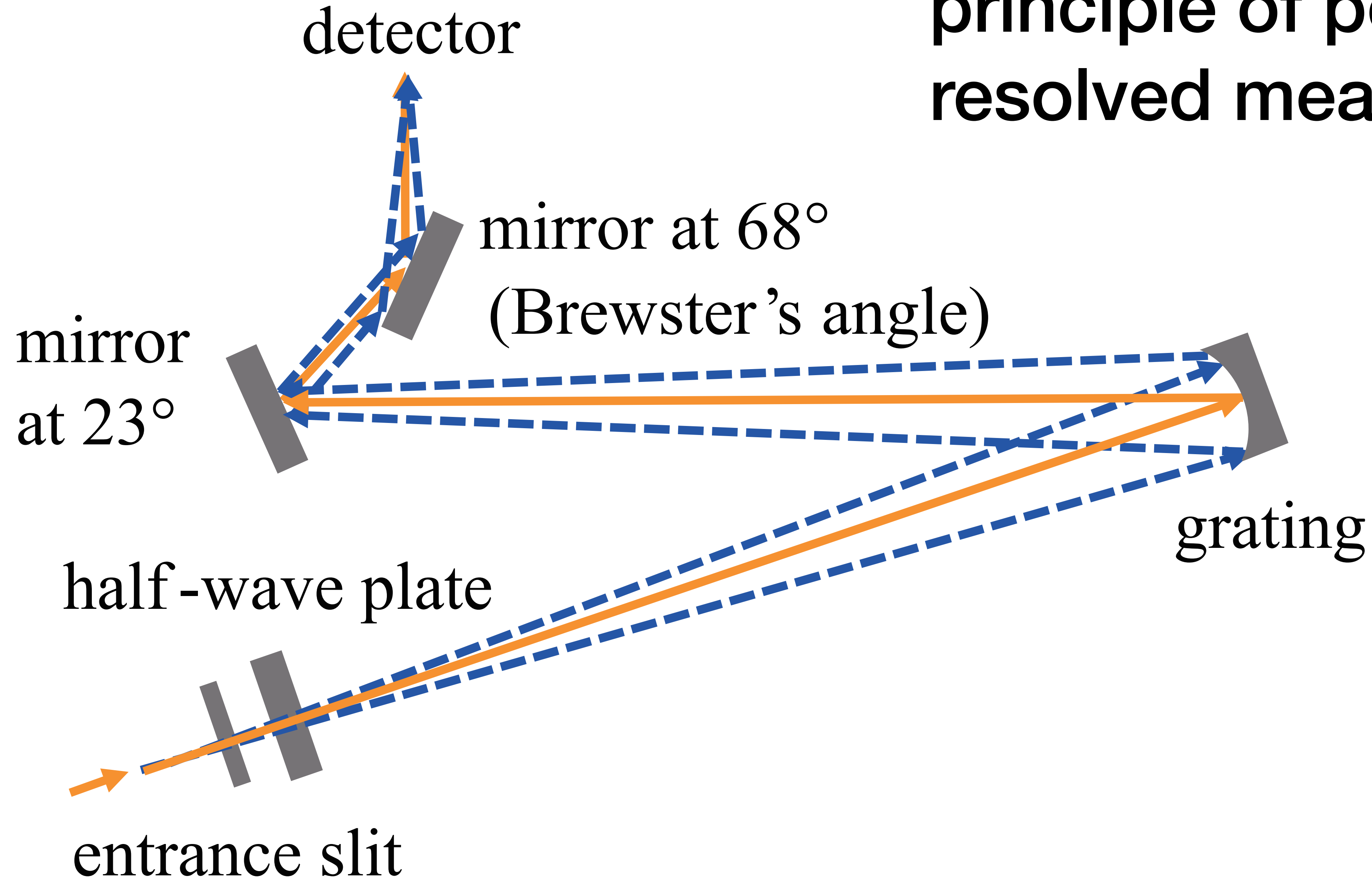
- The pellet injection is a standard method for the impurity-relating studies in LHD.
- We have established a technique of providing tungsten ions adequate for spectroscopic measurements without causing a plasma collapse.
- A number of emission lines of tungsten ions from visible to EUV have been successfully observed

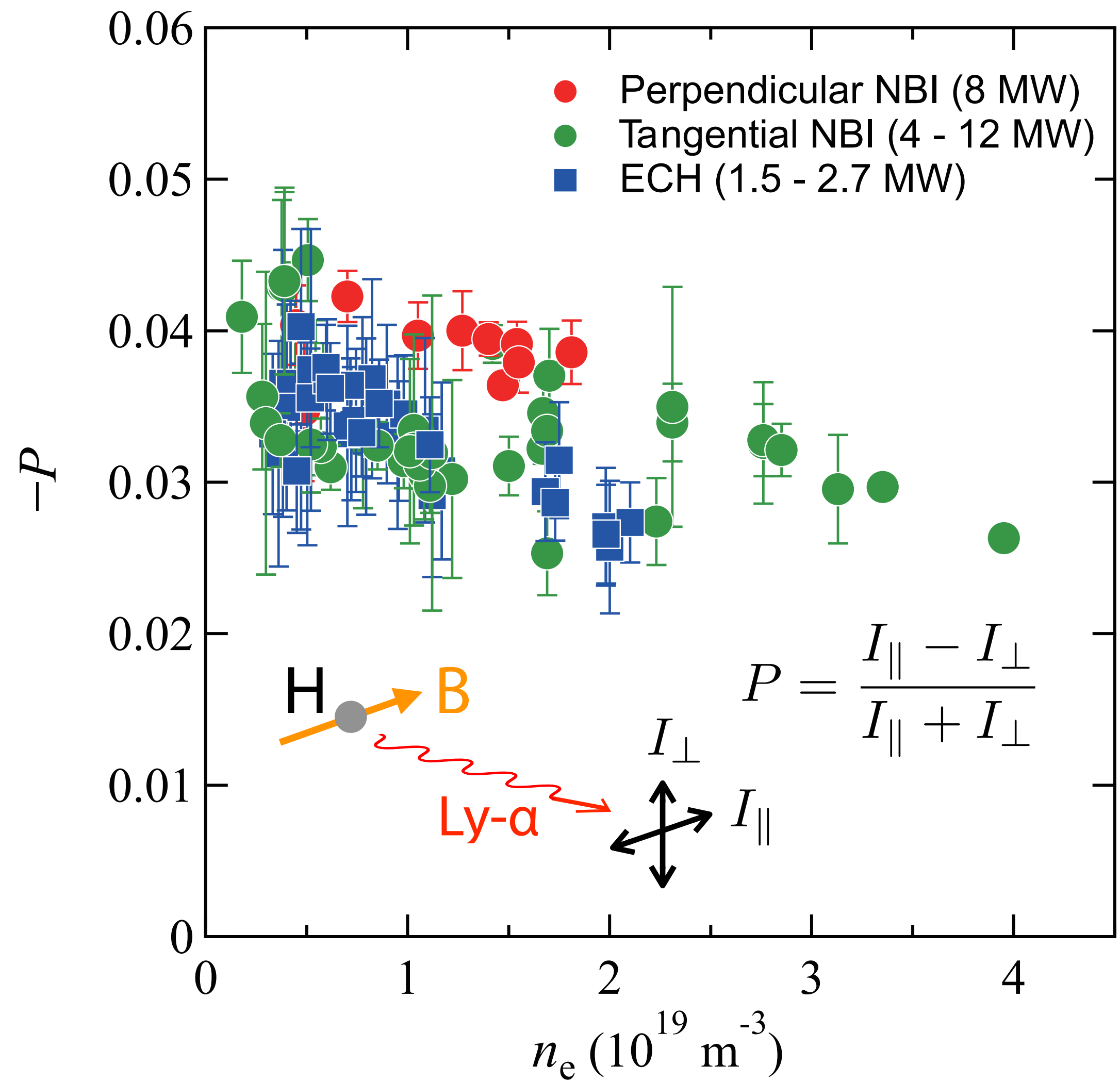
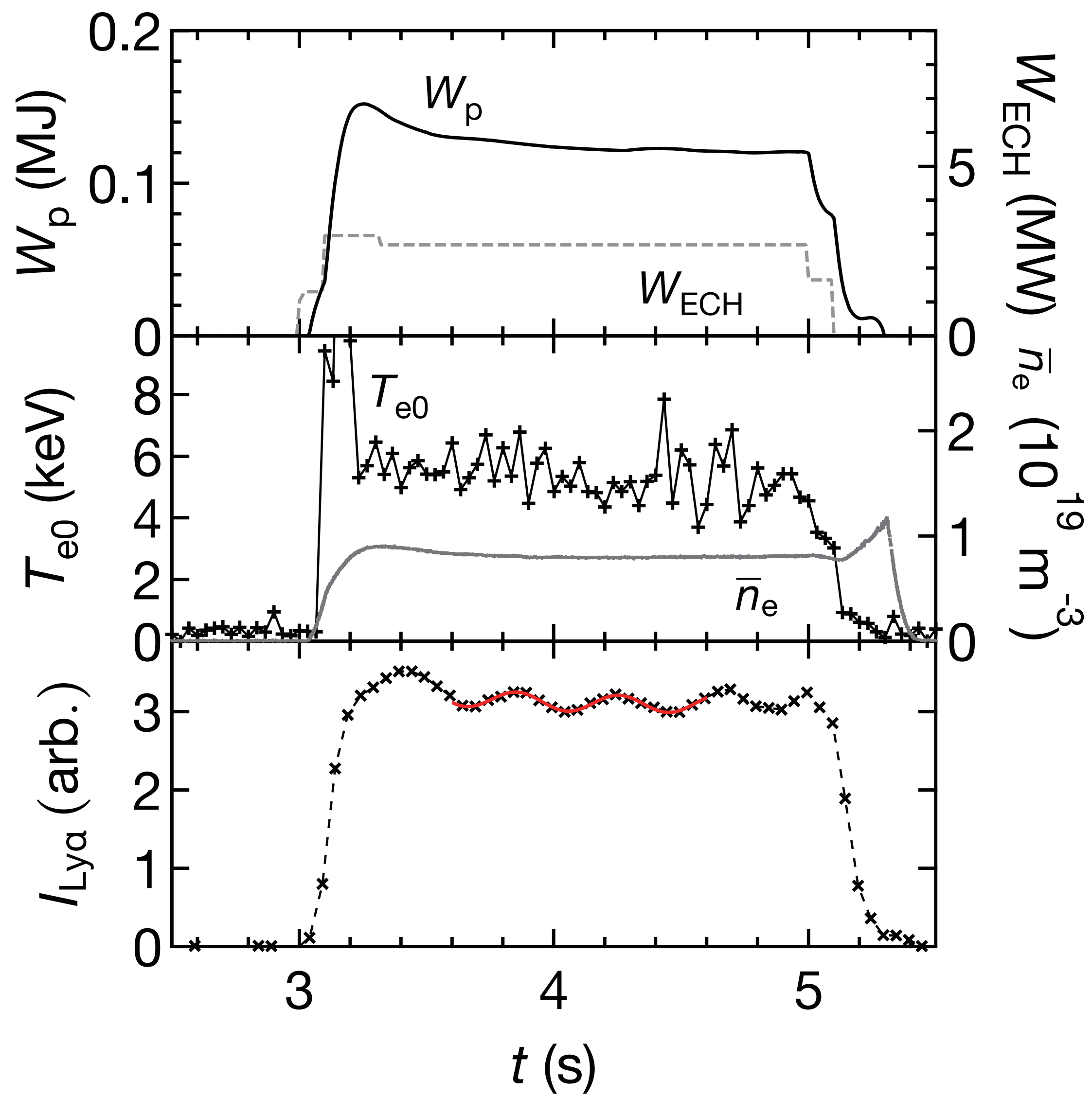
and they are being used for the impurity transport study and for the atomic data evaluation study.

- 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





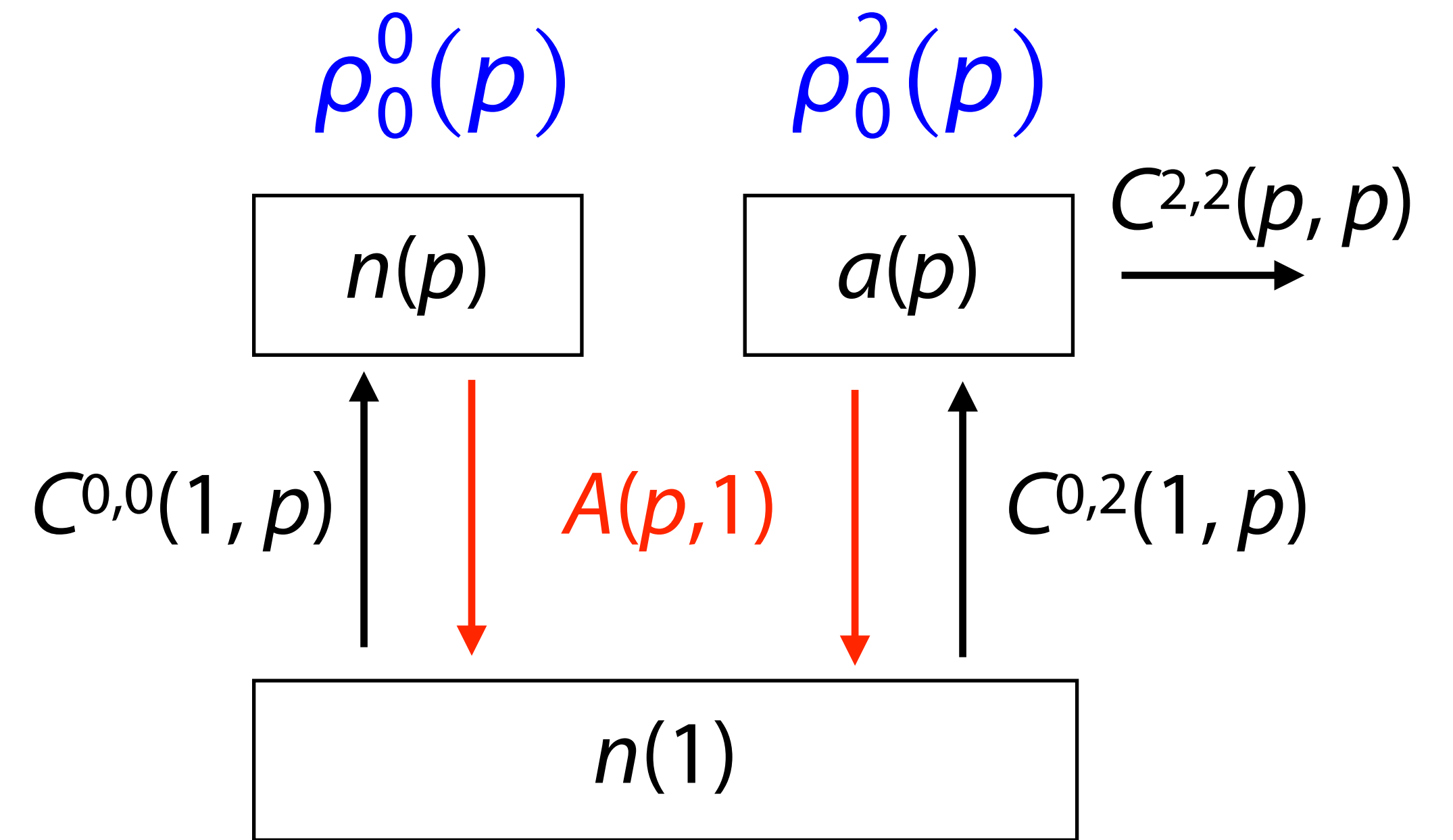
population-alignment CR model

$$\rho(p) = \rho_0^0(p) T_0^{(0)}(p) + \rho_0^2(p) T_0^{(2)}(p)$$

population

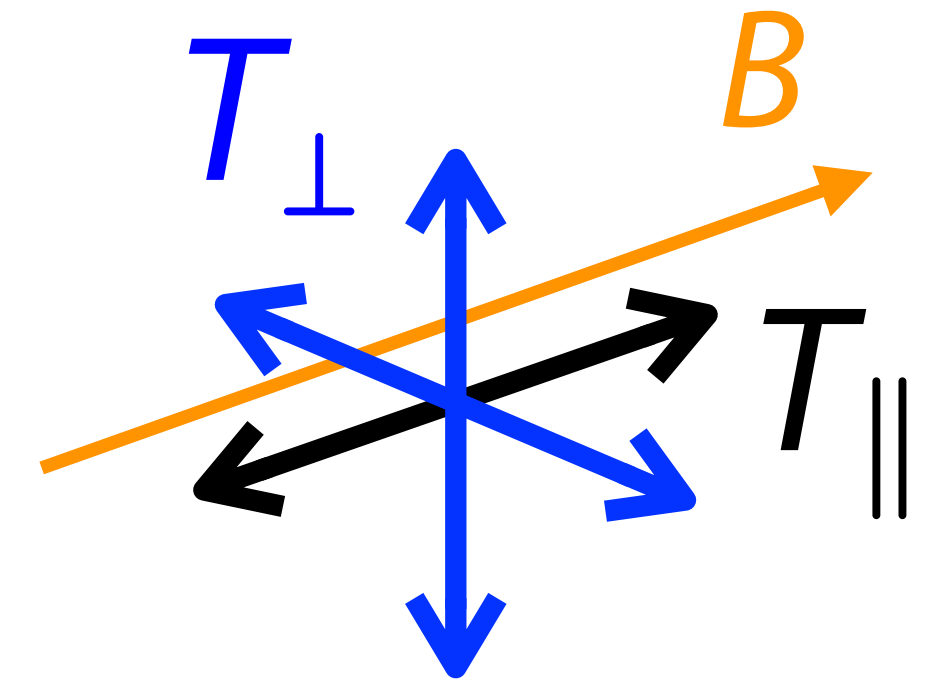
alignment

spherical coordinate
representation of
density matrix



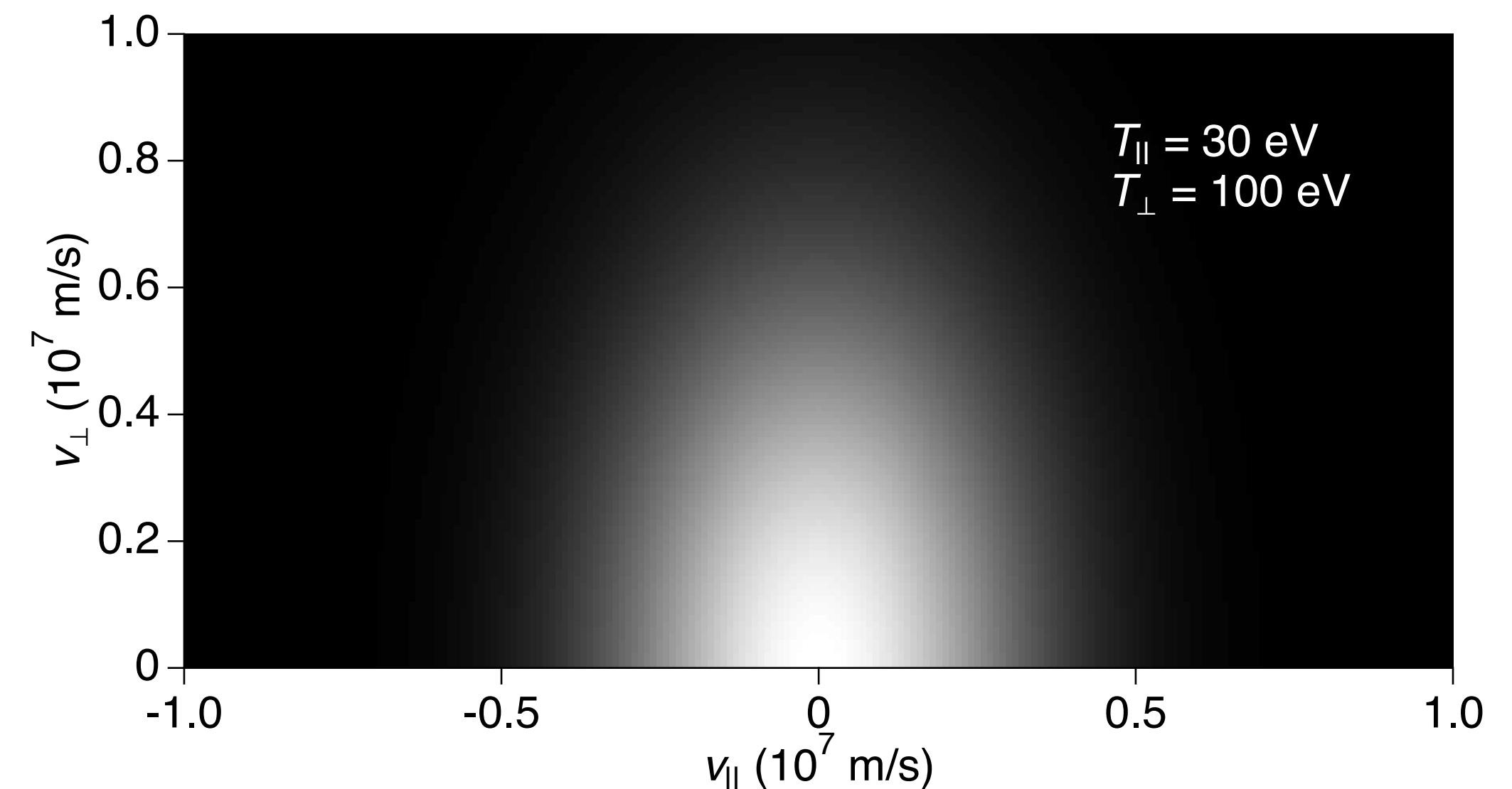
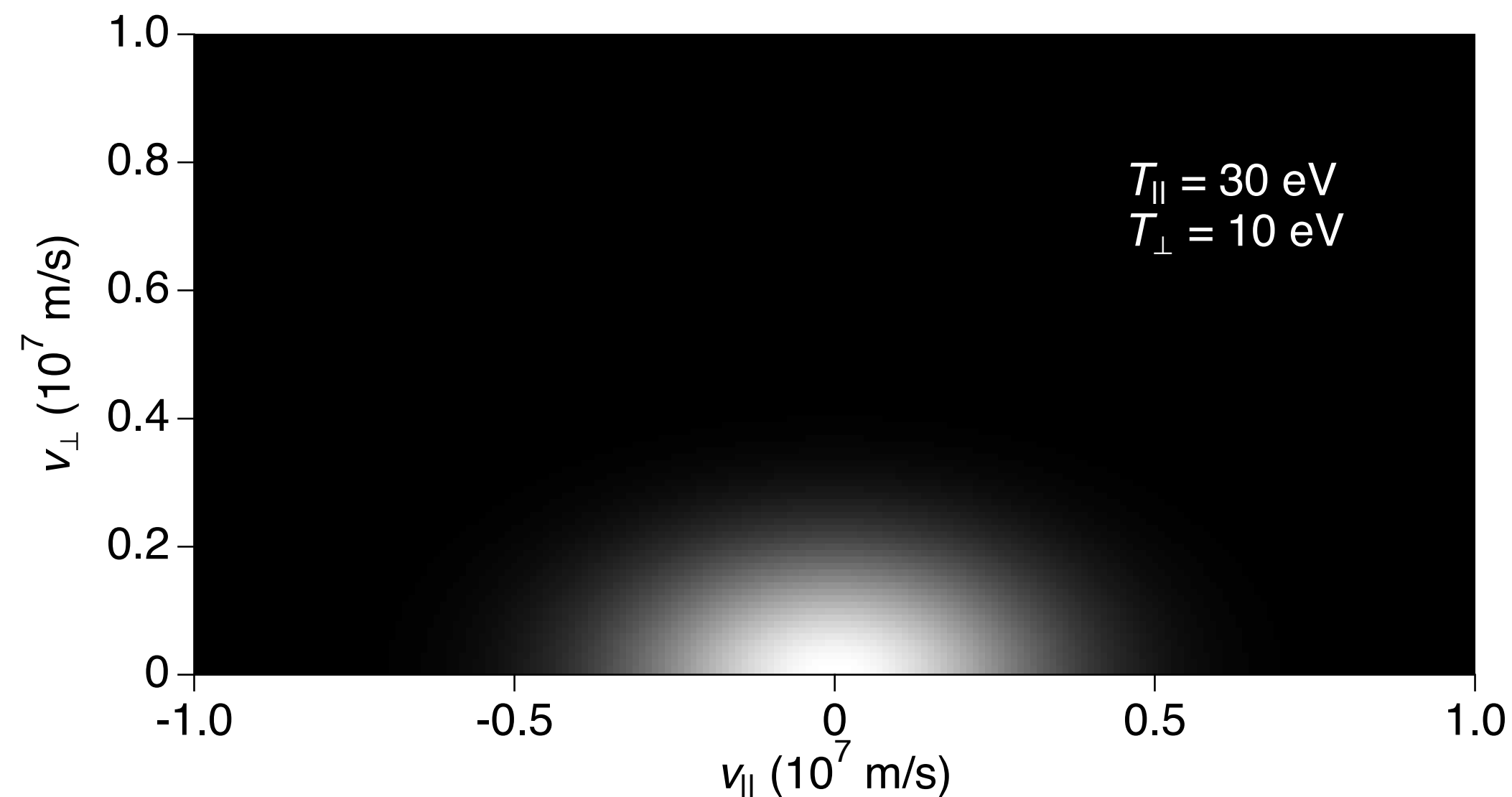
$$\frac{a(p)}{n(p)} \rightarrow p$$

velocity distribution function

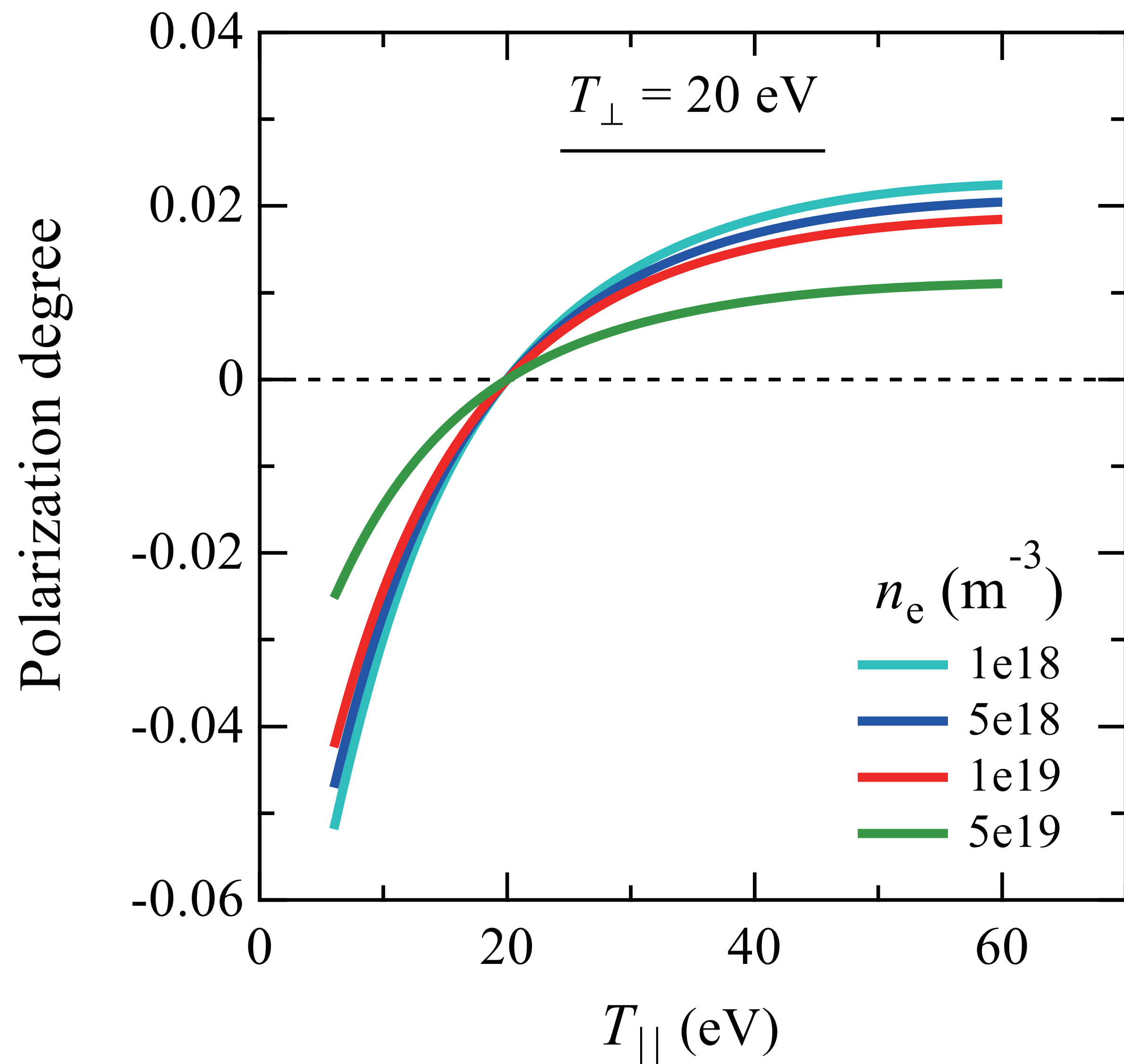


$$f(v, \theta) = 2\pi \left(\frac{m}{2\pi k} \right)^{3/2} \left(\frac{1}{T_{\perp}^2 T_{\parallel}} \right)^{1/2} \exp \left[-\frac{mv^2}{2k} \left(\frac{\sin^2 \theta}{T_{\perp}} + \frac{\cos^2 \theta}{T_{\parallel}} \right) \right]$$

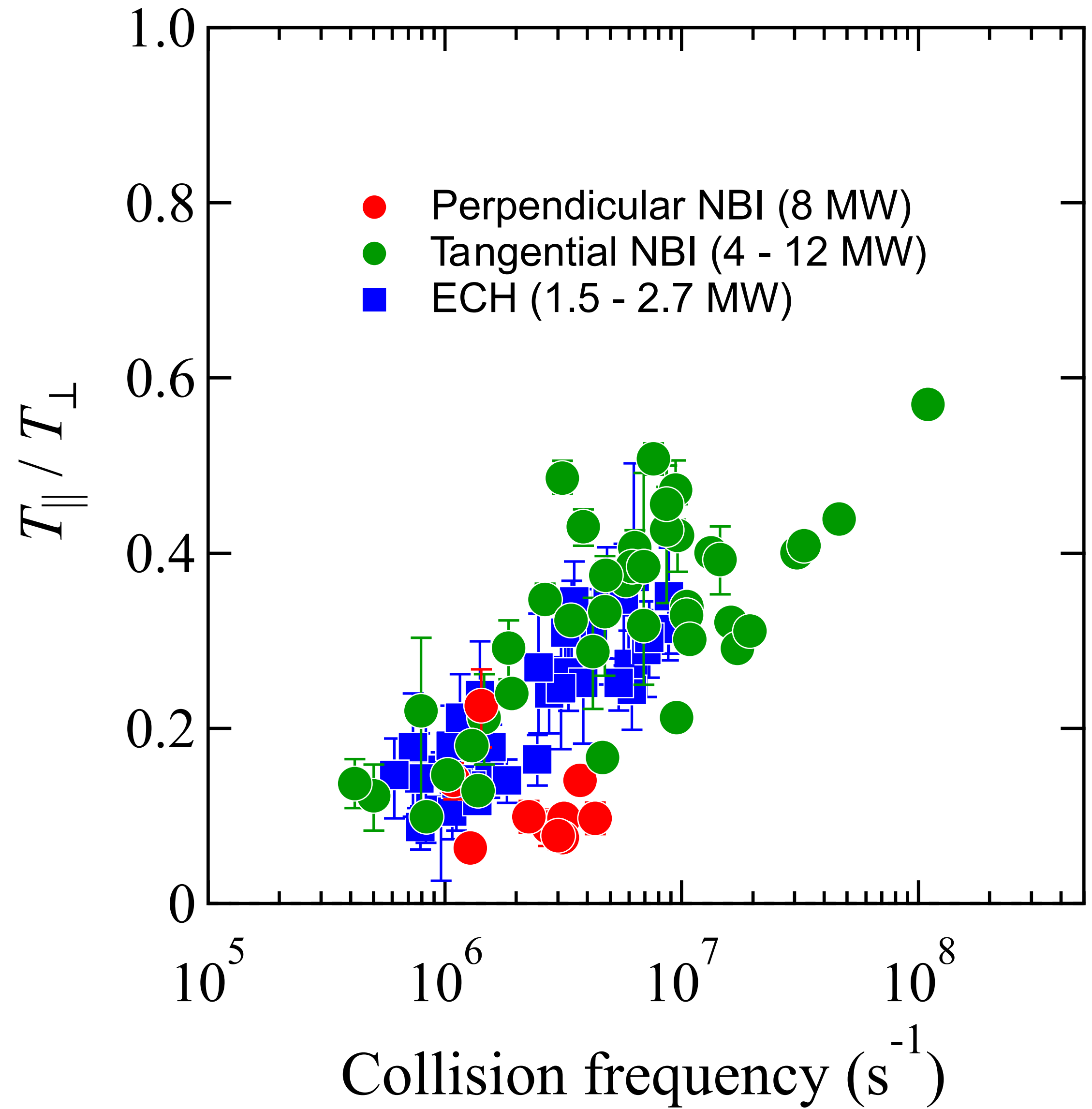
$$v_{\parallel} = v \cos \theta, \quad v_{\perp} = v \sin \theta$$



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.