Numerical study of Kα radiation from high density plasma by energetic charged particles

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Motivation & Outline

Motivation

In the fast ignition research,
fast electrons play an essential role in the viewpoint of energy transport.

With the use of Kα radiation,

1.) Distribution of Kα spectra gives bulk-plasma temperature information.
Fast electrons contribute to ionize the K-shell.
Cold bulk electrons mainly ionize the outer-shell bound electrons.

2.) Potentiality of sub pico-second x-ray source.

Related papers:
T. Kawamura, et al., PRE, Vol.66, 016402,(2002)
H. Nishimura, et al., JQSRT, Vol.81, pp. 327,(2003), Erratum:Vol87,pp.211,(2004)
T. Kawamura, et al., JQSRT, Vol.81, pp. 237,(2003)
IFSA2003 proceedings, pp.1022,(2003)

Outline

1.) Present status of development of the corresponding kinetics code for fast ignition research with CHCl plastic targets.

2.) Consideration of Kα radiation by energetic heavy ions.

Population kinetics modeling on Kα emission.

1s-vacant ions are created via inner-shell ionization by fast electrons.

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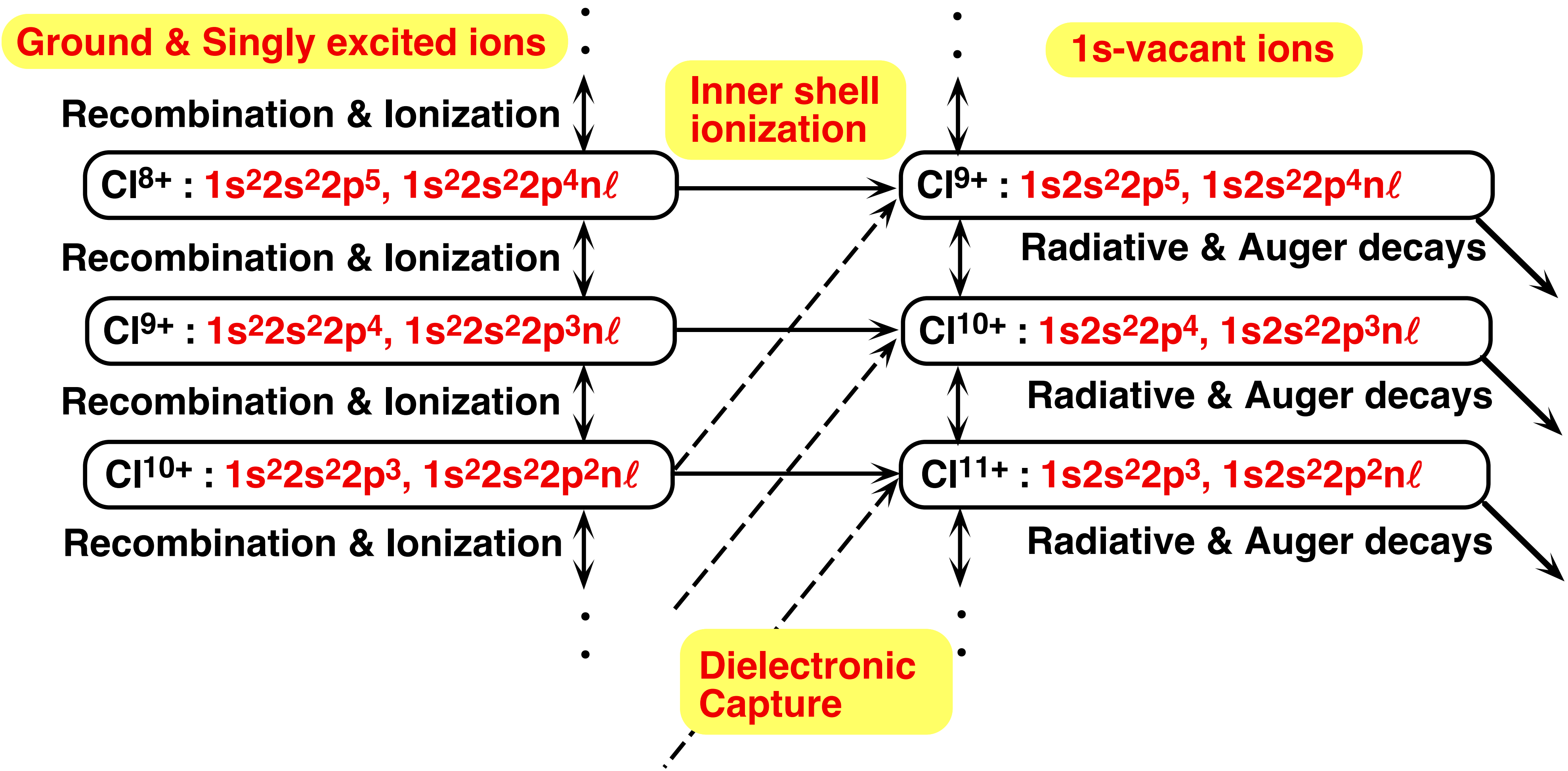

Population : P_{Gnd} & P_{Exc} >> $P_{1s\text{-}vacant}$

Transition energies and radiative decay rates for Kα lines of partially ionized chlorine atoms are calculated with GRASP-code.

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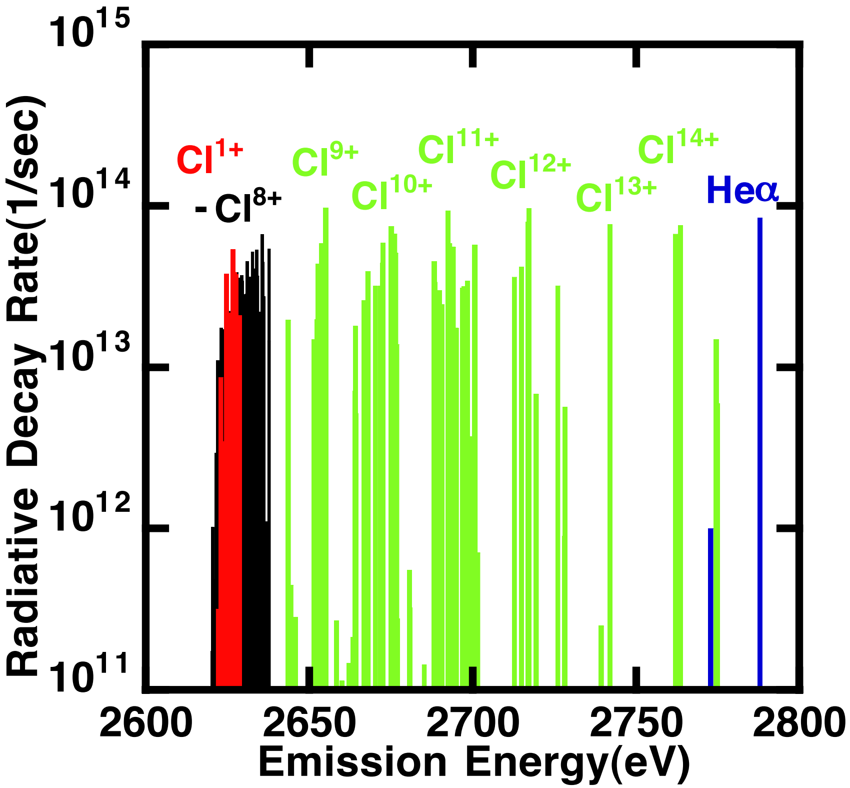

Cl^{+} : $1s^2 2s^2 2p^5 3s^2 3p^5 - 1s 2s^2 2p^6 3s^2 3p^5$

Cl^{2+} : $1s^2 2s^2 2p^5 3s^2 3p^4 - 1s 2s^2 2p^6 3s^2 3p^4$

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Cl^{8+} : $1s^2 2s^2 2p^5 - 1s 2s^2 2p^6$

Cl^{9+} : $1s^2 2s^2 2p^4 - 1s 2s^2 2p^5$

Cl^{10+} : $1s^2 2s^2 2p^3 - 1s 2s^2 2p^4$

Cl^{11+} : $1s^2 2s^2 2p^2 - 1s 2s^2 2p^3$

Cl^{12+} : $1s^2 2s^2 2p - 1s 2s^2 2p^2$

Cl^{13+} : $1s^2 2s^2 - 1s 2s^2 2p$

Cl^{14+} : $1s^2 2s - 1s 2s\ 2p$

Cl^{15+} : $1s^2 - 1s\ 2p$ (Heα)

ΔE from primary Kα (Cl^{+}) is large!!

Information of Plasma Temperature can be obtained.

Kα-lines of excited states completely overlap with those of the ground state of the next charge state.

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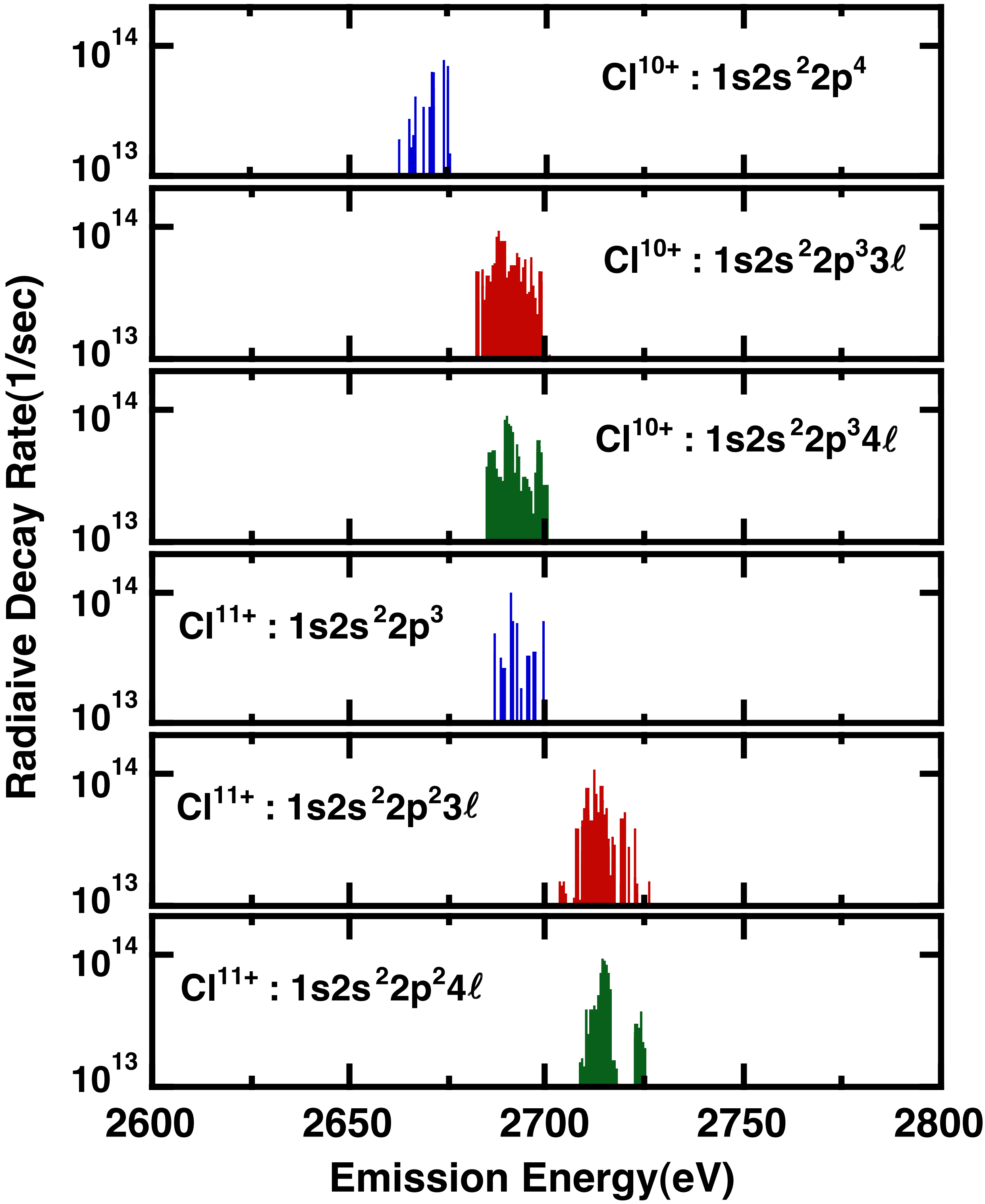
Kα transition rates are 10^{13}-10^{14} 1/sec.

Number of transitions of $1s2s^22p^Nn\ell$(n=3-4,N=1-5) are 15100.



KLL-Auger is the most dominant process of all the Auger transitions for 1s-vacant ions.

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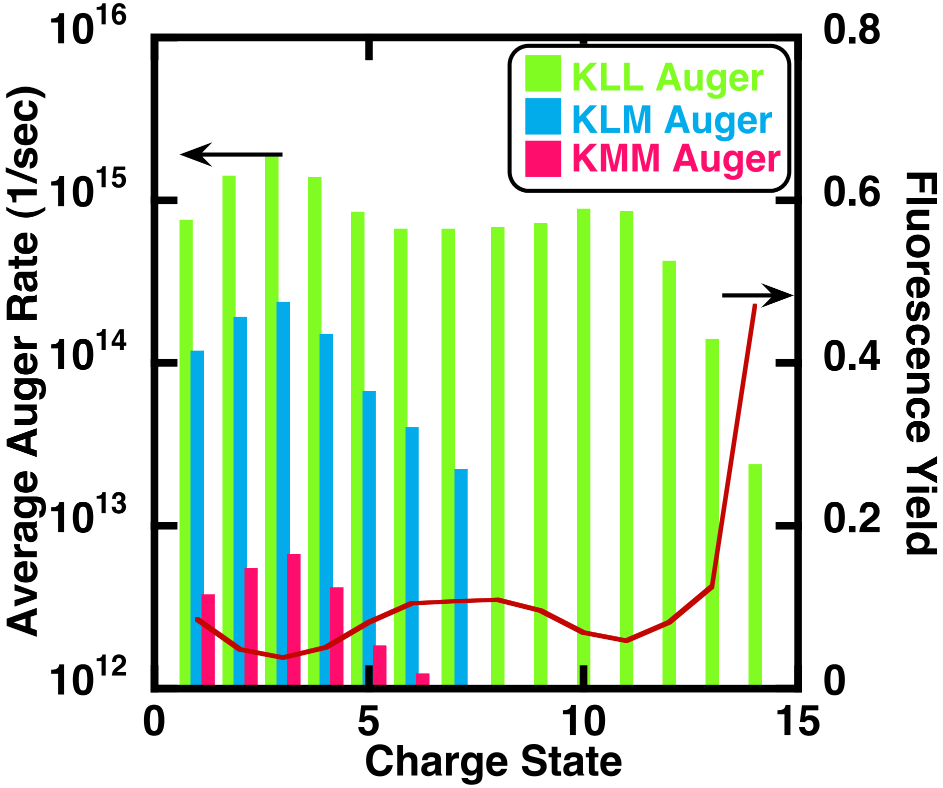
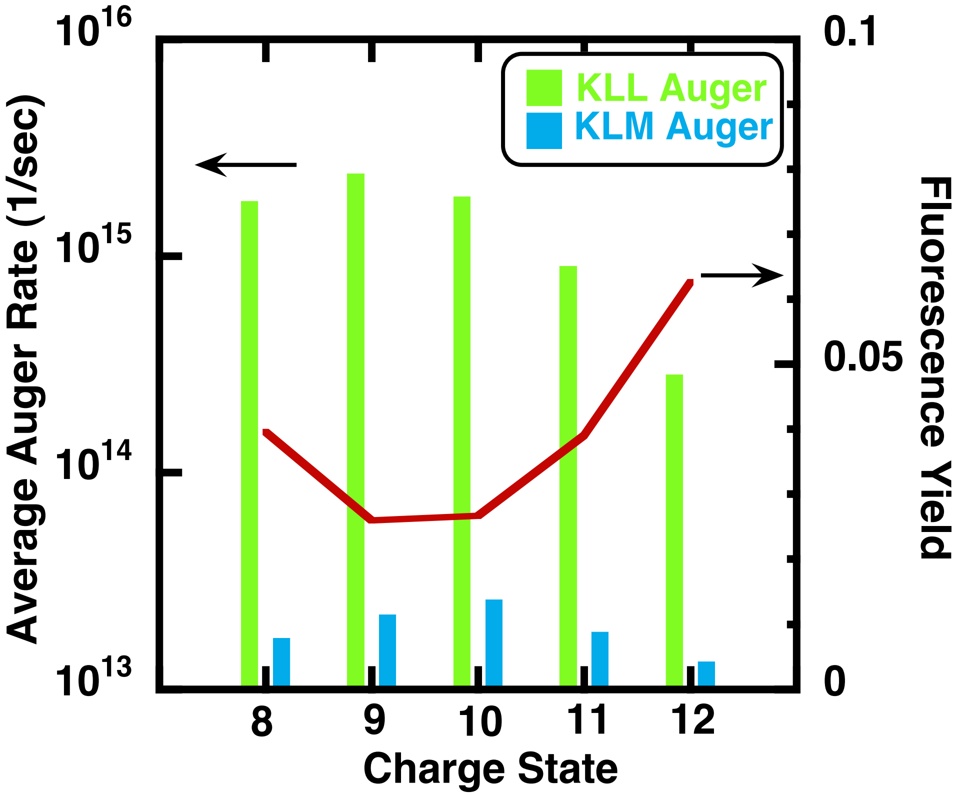
Each Auger transition is calculated by "Auger code".
S.Fritzsche, B.Fricke, Phys. Scr.T41,45(1992)

Ground states of 1s-vacant Ions



Excited states of 1s-vacant ions: $1s2s^22p^N3\ell(N=1\text{-}5,\ \ell=s,p,d)$



Average Auger rate of partially ionized Cl is about 10^{14}-10^{15} 1/sec.

Average charge state is mostly governed by bulk electron temperature.

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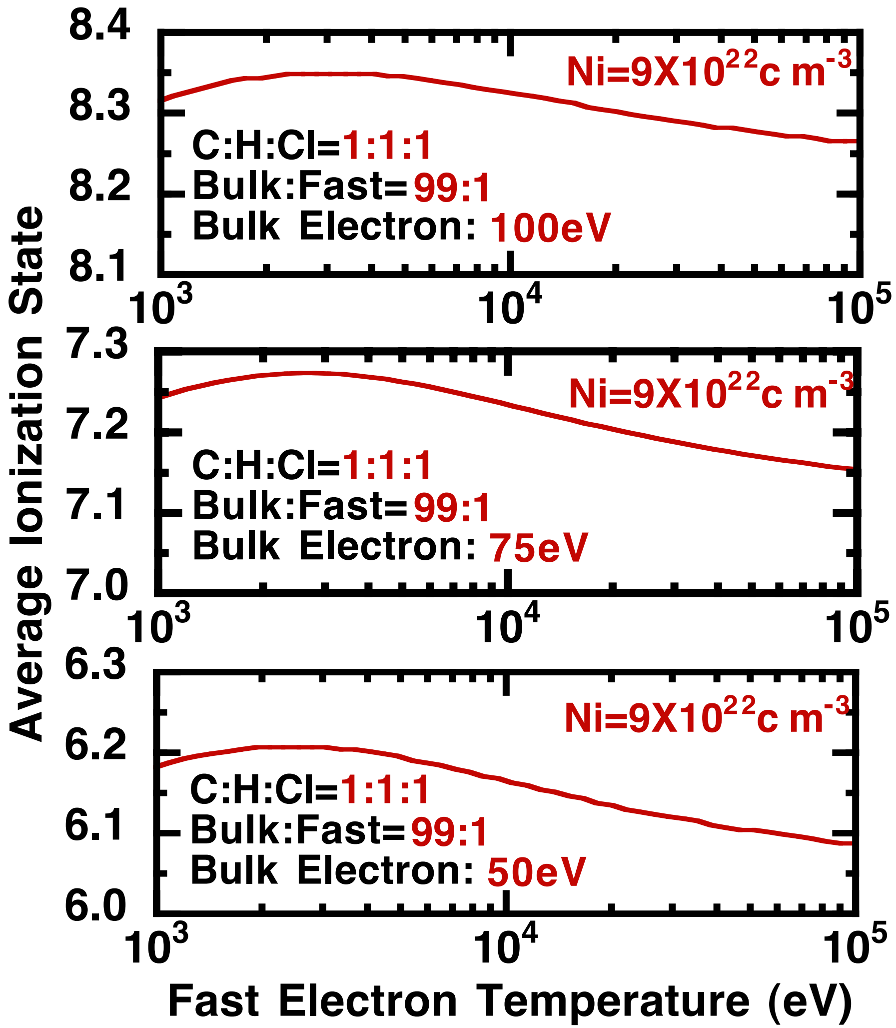
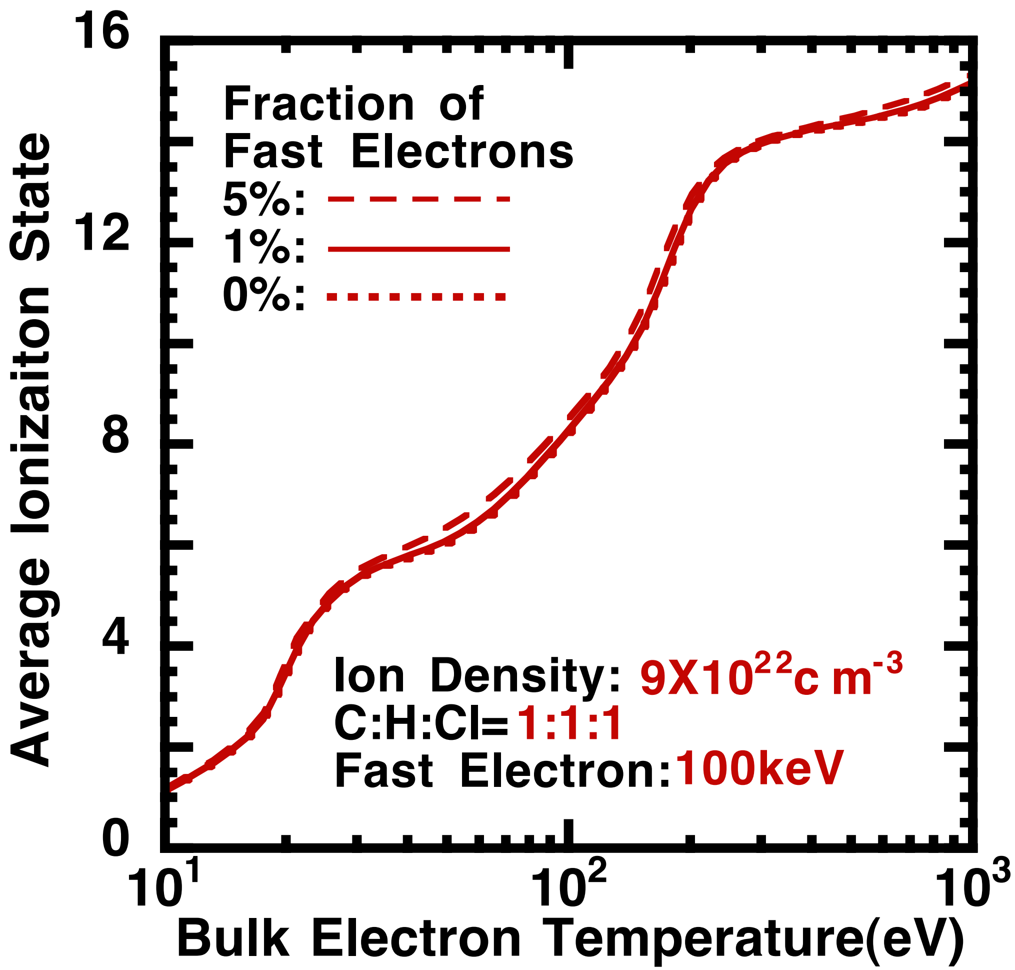
Total Ion Density : $9\times10^{22}cm^{-3}$ (C:H:Cl = 1:1:1)

Bulk e^- : Fast e^- = 99:1

No Opacity effect





Satellites of excited states $Cl^{(n-1)+}$ overlap with parent lines of ground states Cl^{n+}.

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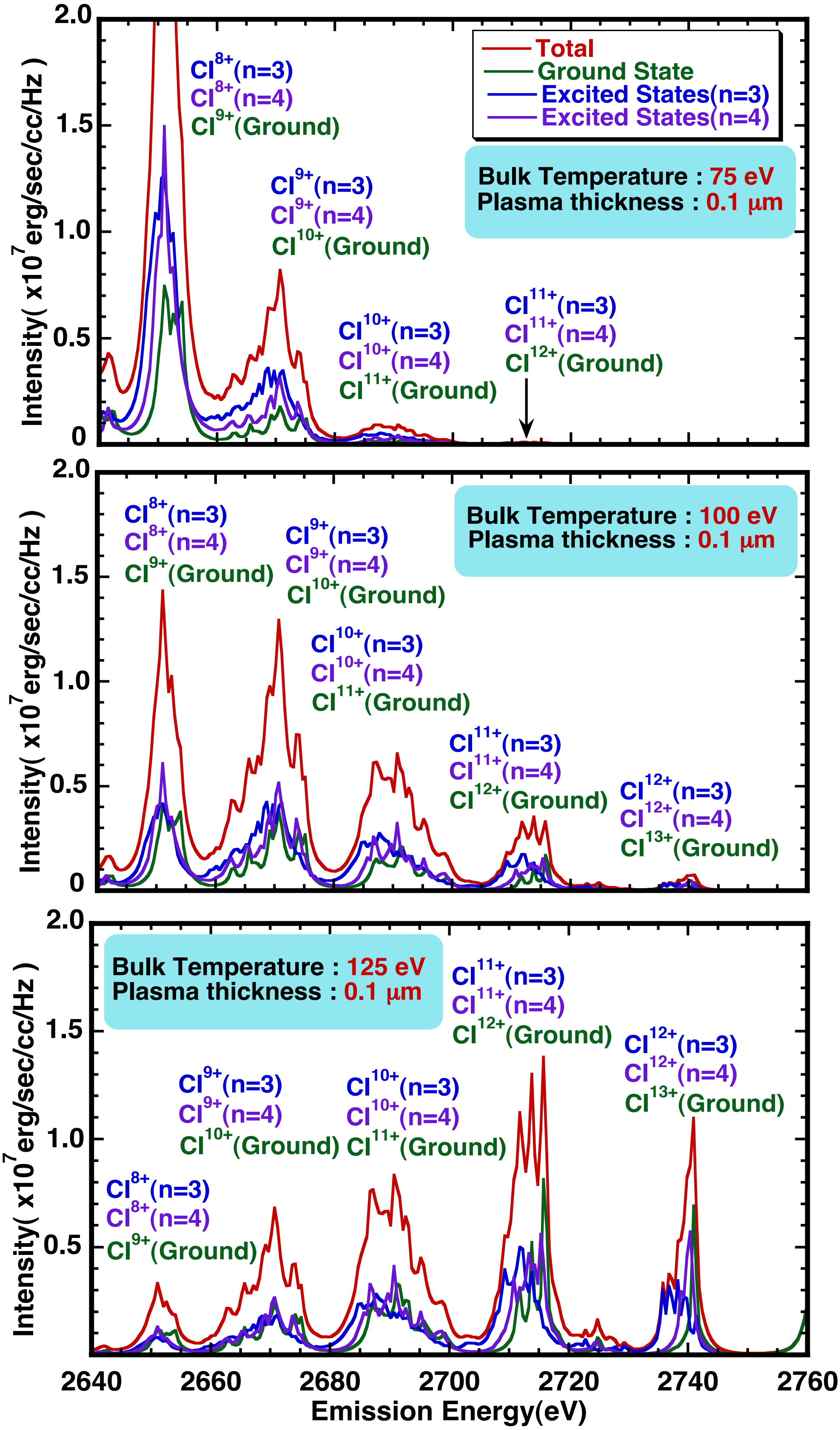
Ion Density $N_i = 9 \times 10^{22} cm^{-3}$ (C_2H_3Cl)

Fast Electron Temperature : 40 keV, Bulk e^-: Fast e^- = 99:1



Experimental setup on T6

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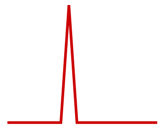
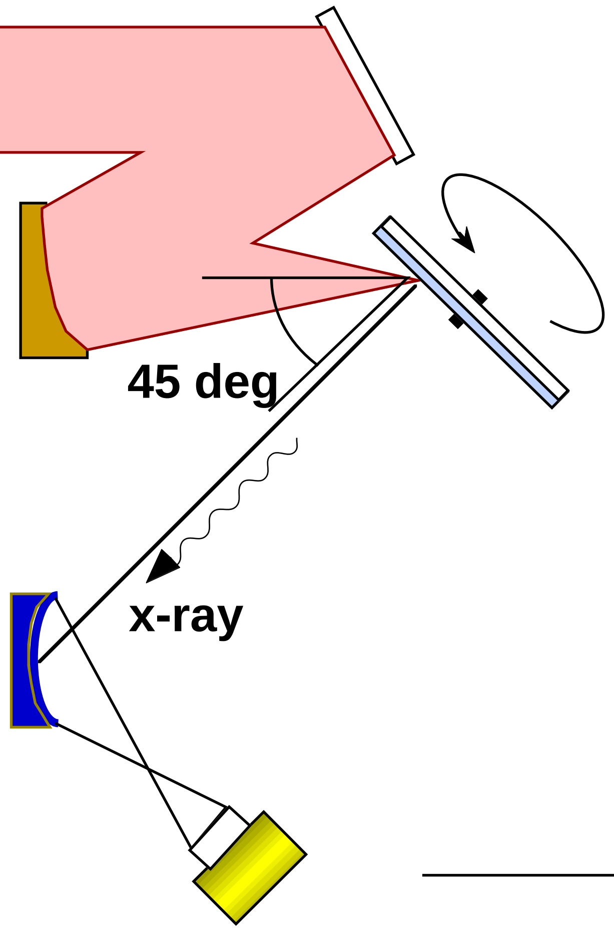




T6 laser:

@ 800 nm, ～100 mJ (on T)
132 fs, P-pol.
S= 15x21 μm @ 70%
contrast >10^{-6}
I_L=2×10^{17} W/cm^2 (T_h=50 keV)

2D curved crystal spectrograph1:

***Quartz* [10.-1], *2d*=6.6864 A**

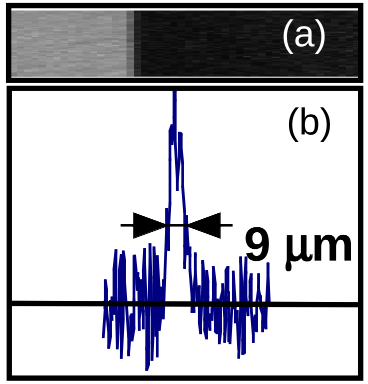
ε=2.44-2.85 keV, M= 1/8

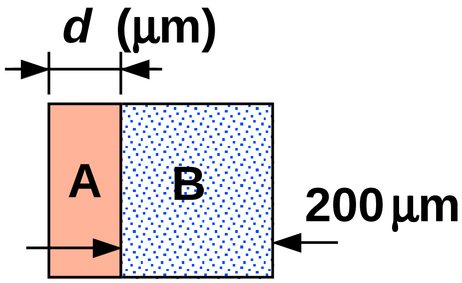
1D curved crystal spectrograph2:

PET[002], *2d*=8.742 A

ε=1.48-1.73 keV, M=1

spot-size





	A	d (μm)	B
target 1	CH	0~2	CHCl
target 2	Mg	0~2.2	Al

H.Nishimura, et al., JQSRT, Vol.81, pp.327, (2003)
Erratum : Vol.87, pp.211, (2004)

experimental result 1

The Kα lines from partially ionized plasma decease drastically with increase in thickness of over-coating, inferring energy localization.

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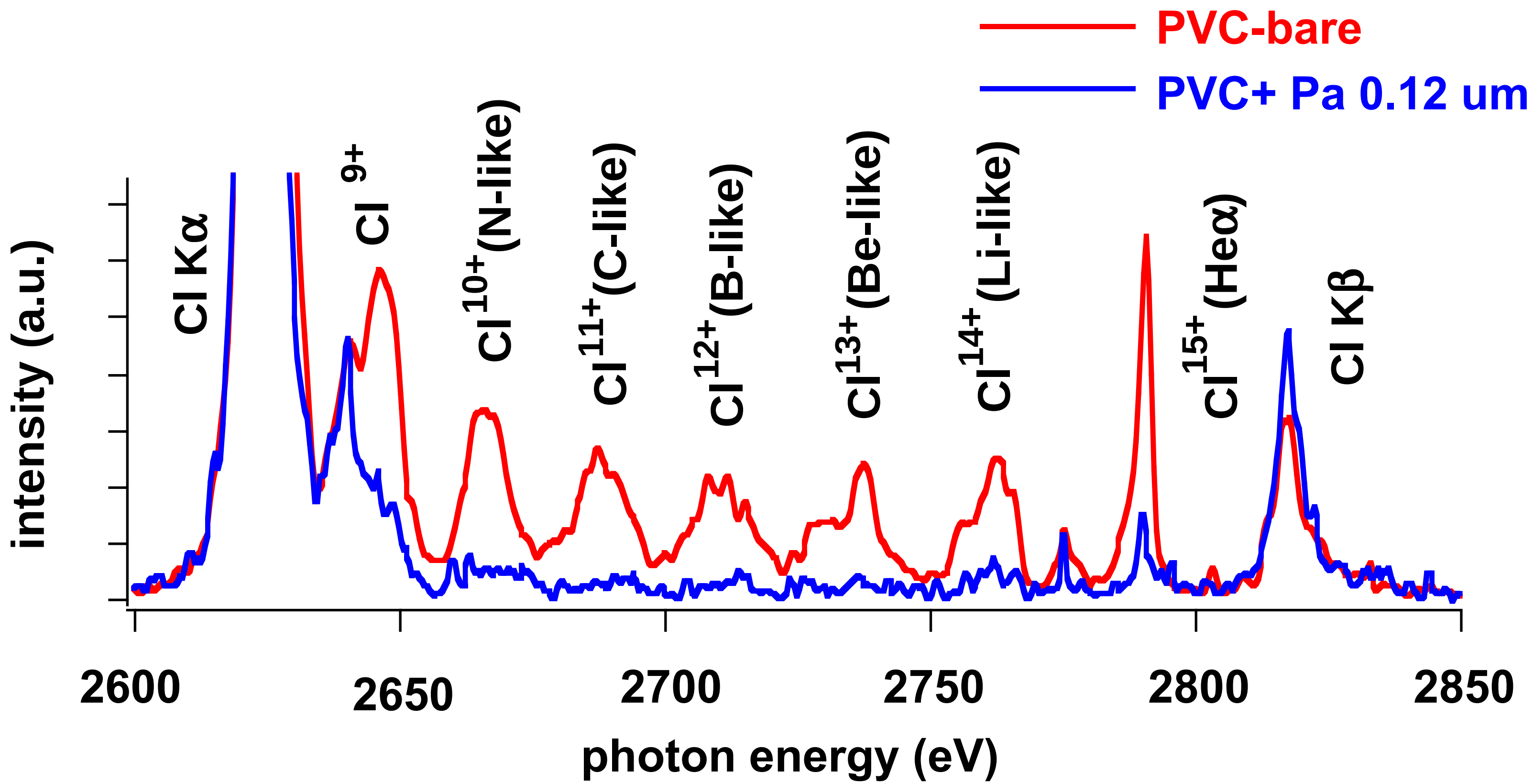

H.Nishimura, et al., JQSRT, Vol.81, pp.327, (2003)
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Time evolution of bulk electron temperature and fractional number of fast electrons are obtained from Fokker-Planck code.

- Simulation was done in the region near target surface. -

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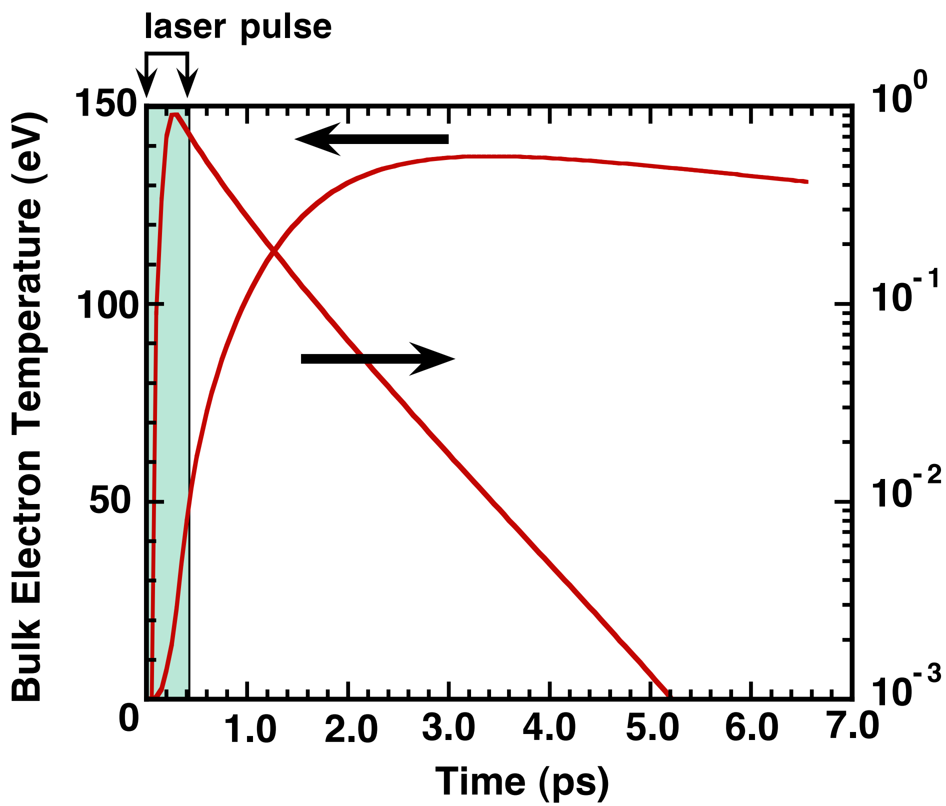
Neglecting advection term in the F-P equation.

→ Local deposition near target surface.
Heat transport in the axial direction is inhibited.



Assumptions:

Ion density(C_2H_3Cl) : Solid density

Fast electron temperature : 50 keV

Incident laser energy absorption : 15%

Result:

Bulk electron temperature : 140 eV

Life-time of fast electron : several ps

Time dependent properties of Kα radiation combined with Fokker-Planck code are obtained.

- Simulation was done in the region near target surface. -

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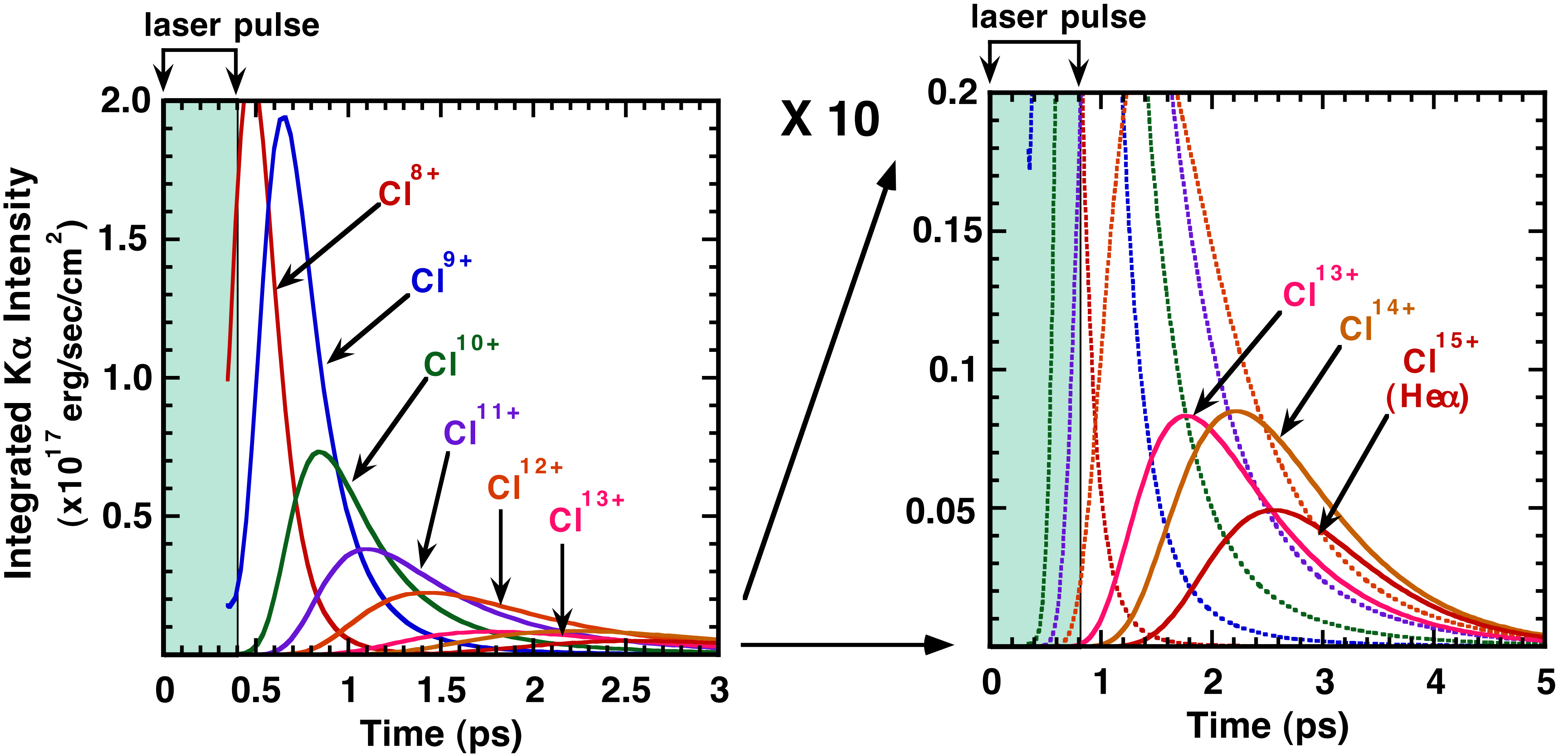
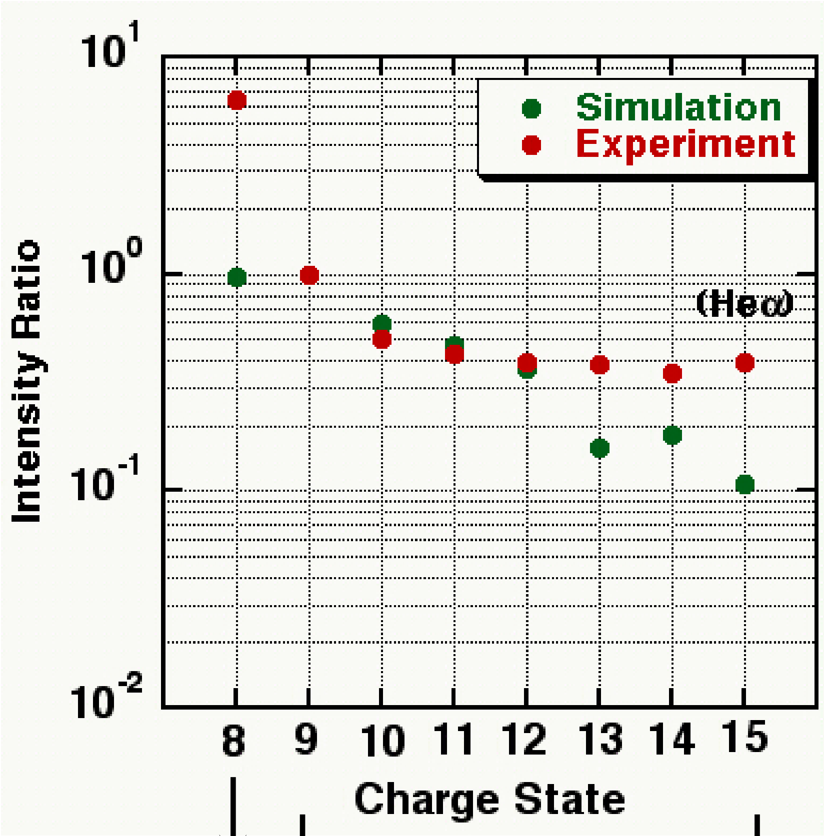


Comparison between simulation and experiment is made in the framework of intensity ratio for time-integrated data.



Cold Kα emission (Cl^{+} - Cl^{8+})

Hot Kα emission (Cl^{9+} - Cl^{15+})

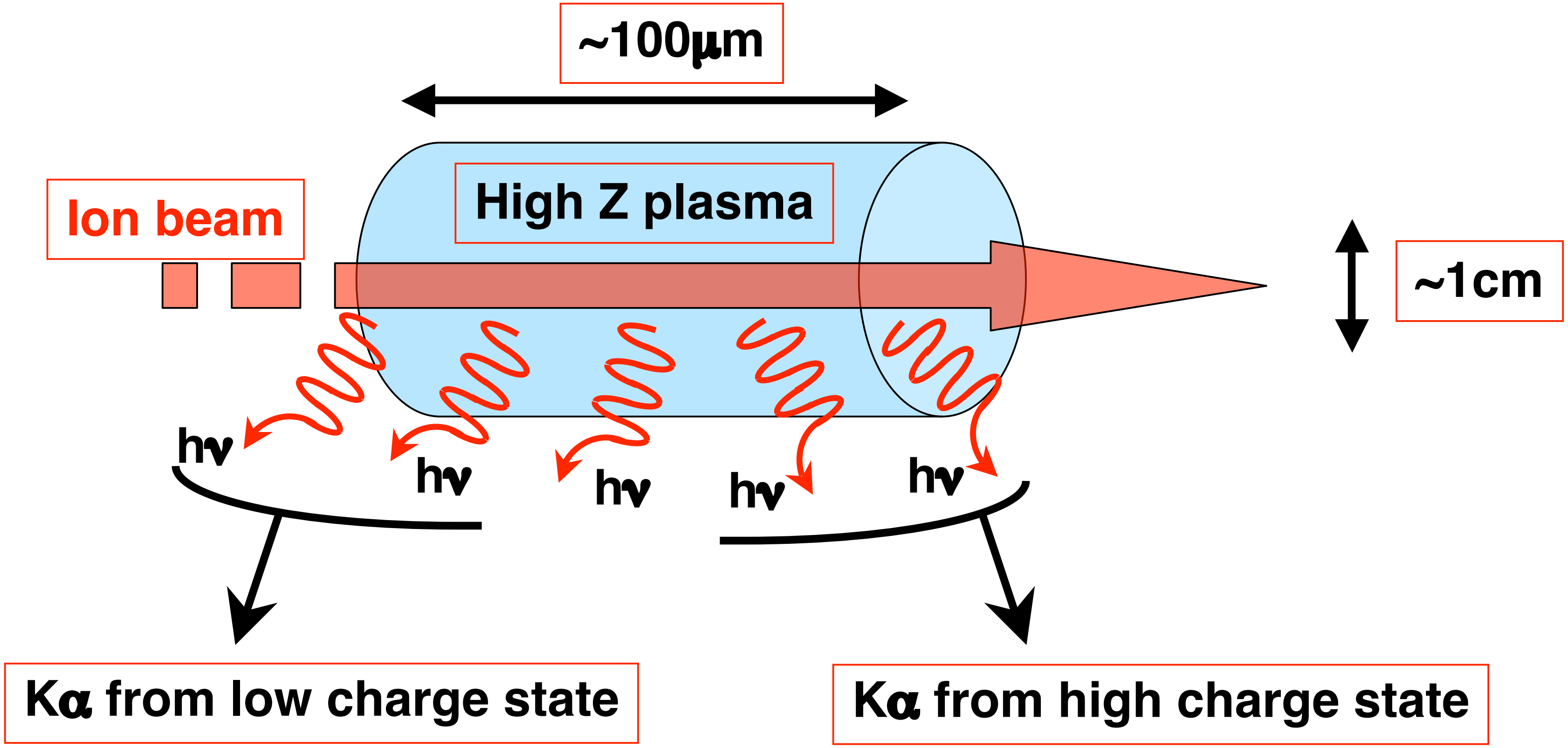
Because of unresolved properties;

1.) Intensities of Cl^{+} - Cl^{8+} are grouped together as cold Kα emissions.

2.) Intensities of excited states Cl^{n+} are grouped together with that of ground state $Cl^{(n+1)+}$.

Hot Kα emissions show good agreement between simulation and experiment results.

Consideration of Kα-radiation by ion beams for plasma diagnosis. With spatial resolved observation of Kα-radiation, plasma heating process can be understood clearer than the traditional way of "TOF".



Spatial resolved diagnosis of heating process is possible.

For chlorine plasmas, ion energy of more than few tens MeV is necessary to occur the K-shell ionization.

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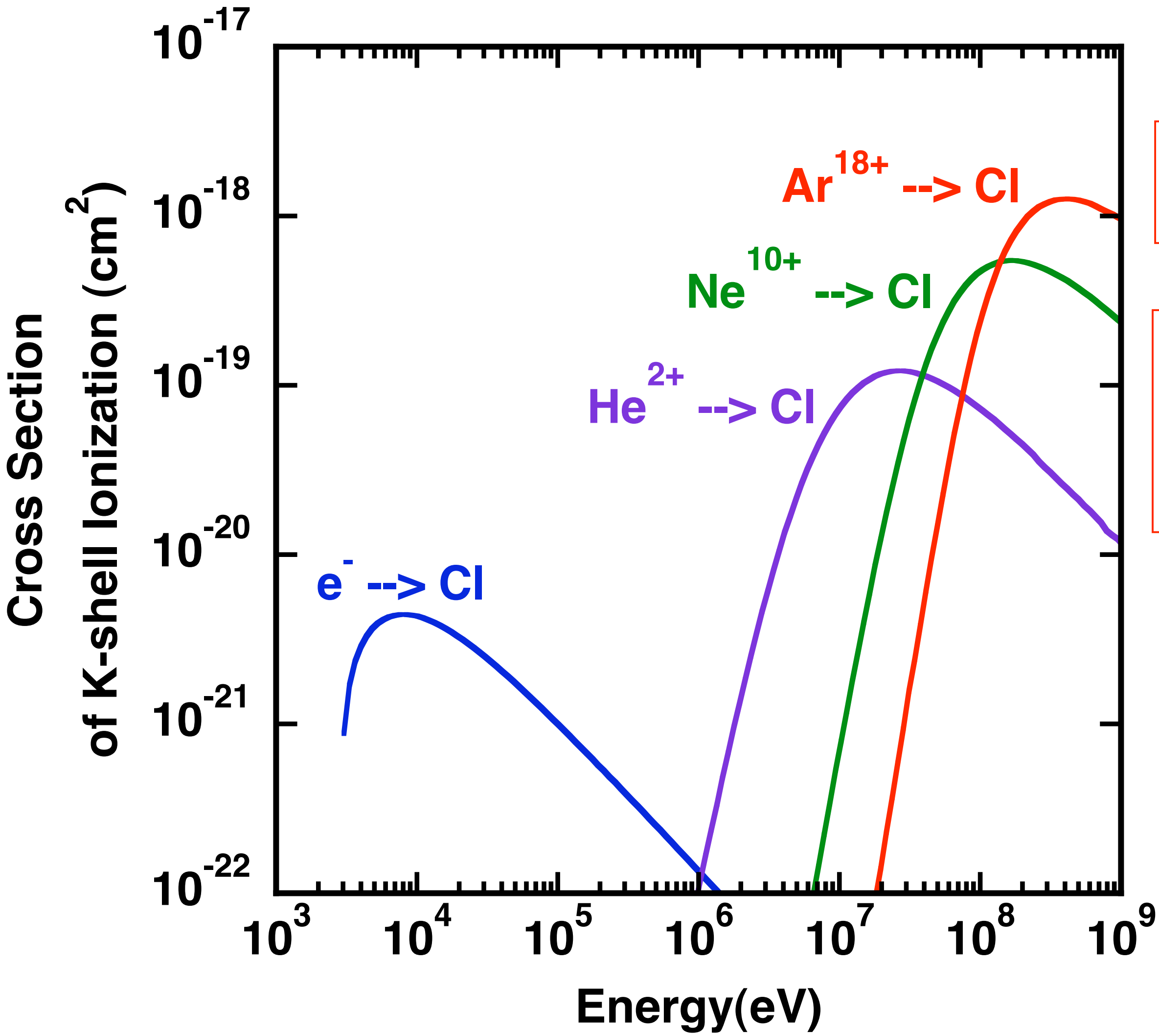

Ion impact K-shell ionization:
ADNDT, Vol.20, pp.503,(1977)

Electron impact ionization:
J. Phys. B: Atom. Molec. Phys., Vol.11, pp.541,(1978), and related papers.

In the calculation, ion energies are set so that the maximum cross sections can be obtained with the energy-spread of 0.1 %, 1%, and 10%.

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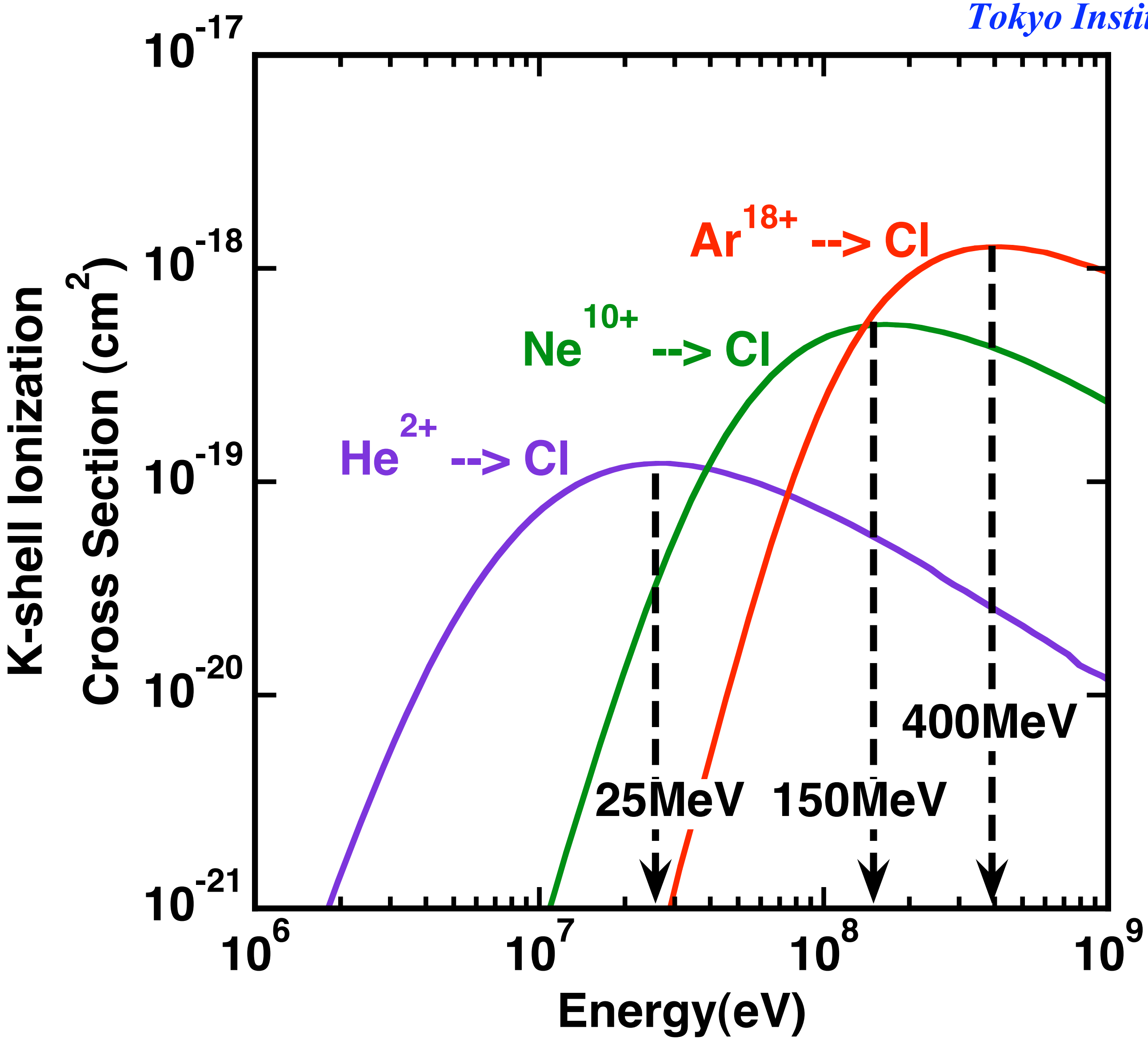

For chlorine plasmas, temperature diagnosis by Kα-radiation with ion beams is suitable for electron temperature Te < 100 eV .

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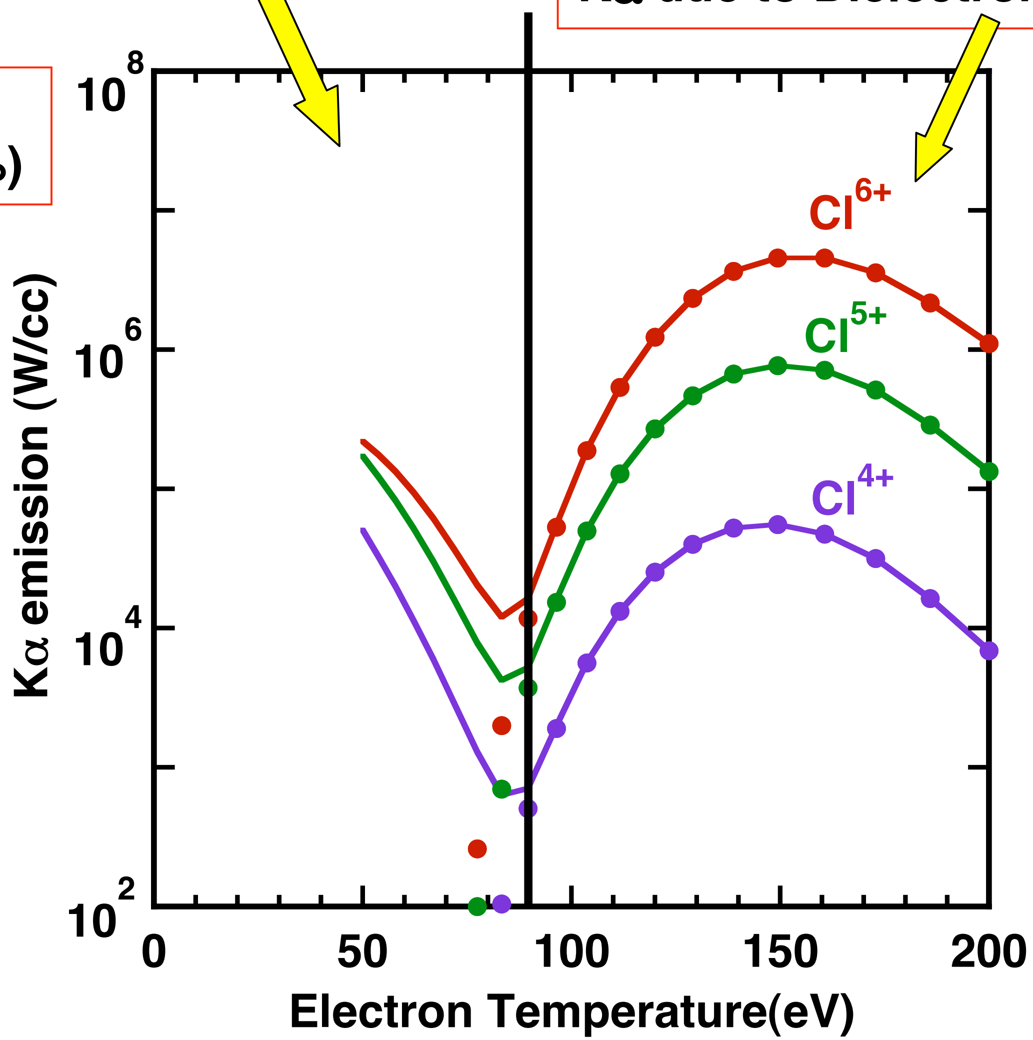
Kα due to the K-shell Ionization by He^{2+} Impact

Kα due to Dielectronic Capture

He^{2+} current : 1 kA/cm^2
Enegry : 25 MeV (±0.1%)



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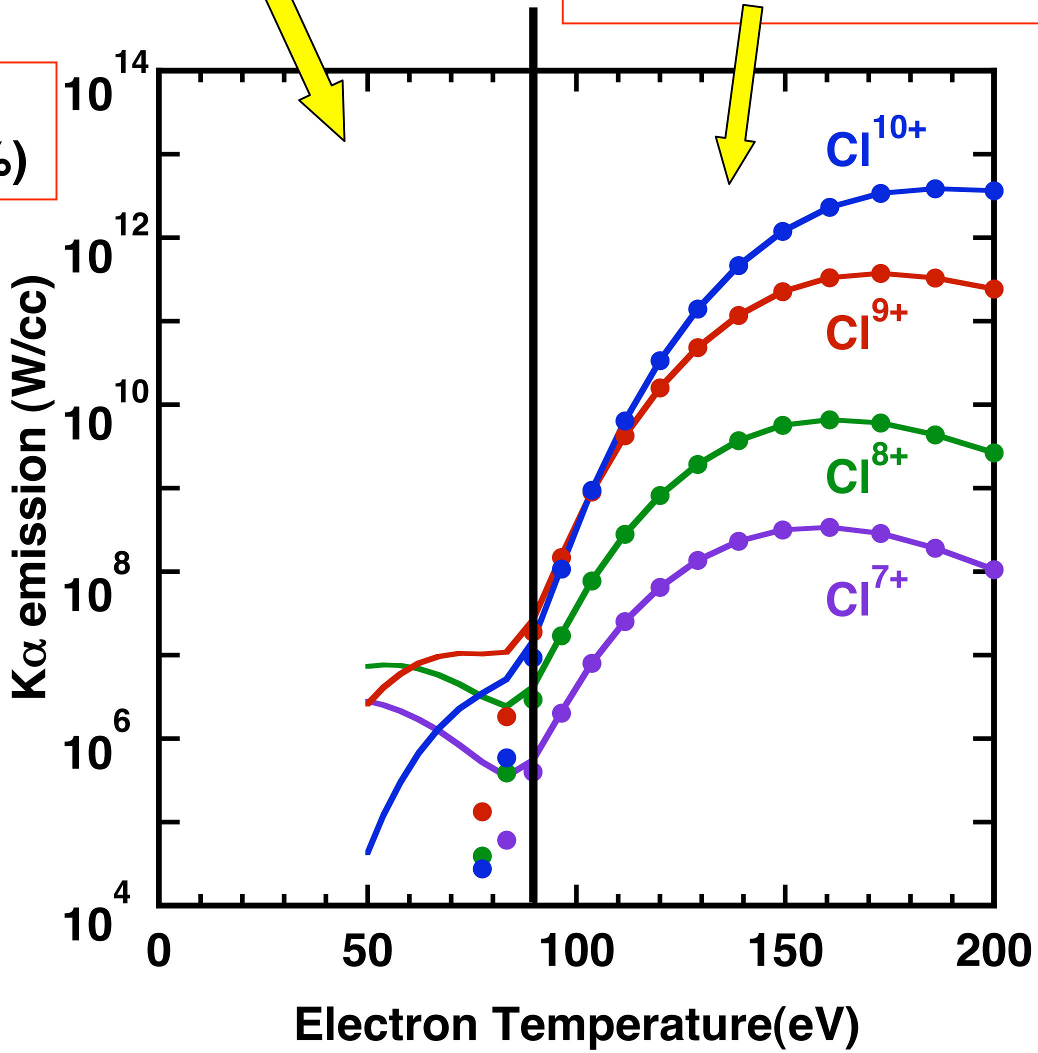

Emission density of Kα-radiations is very small in comparison with that by fast electrons generated by sub-ps laser pulses.

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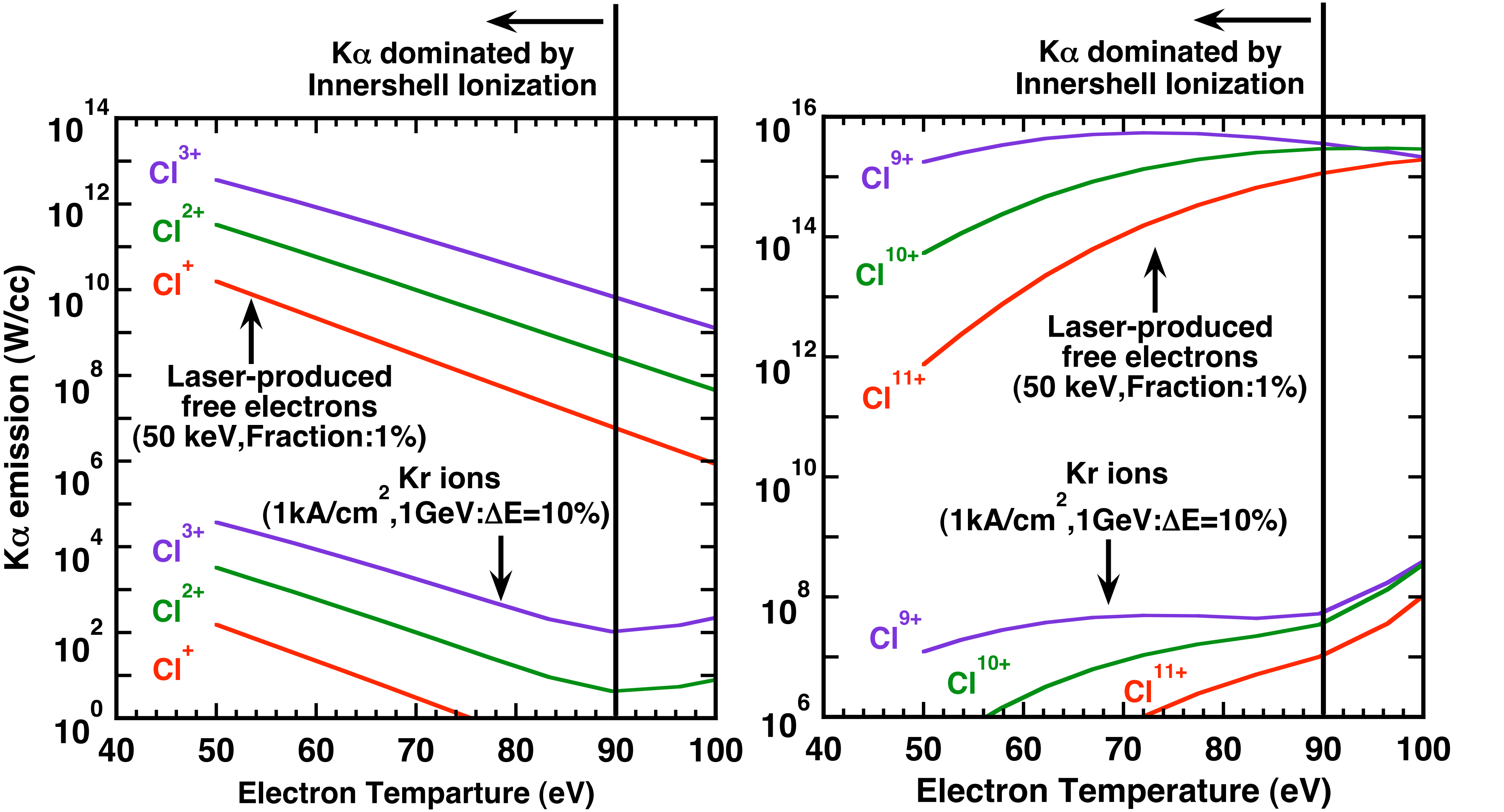
Kα-radiation by ion beams is about 10^{-8} of that by LPP-scheme.



To get the same order of Kα-radiation by LPP-scheme, the difference of Kα yield must be covered by a large plasma.

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Kα-radiation by energetic heavy ions scheme:

1.) Ionization cross-section: 10~100 times larger than energetic electrons'.

2.) Ion beam density : ~10^{12} cm^{-3} at 1 kA/cm^2 with He^{2+} beams.
(cf.) Energetic electrons by laser-produced plasma scheme: ~ 10^{21} cm^{-3}

Resultant plasma volume to get Kα-radiation by Ion beams:

1.) Ion beam cross section : ~1cm^2
2.) Ion Stopping range : ~100 μm

--> 10^{-2} cm^3

on the assumption that plasma is heated up uniformly.

(cf.) With LPP-scheme :

1.) e^- beam cross section ~ laser spot size : ~ < 100 μm^2
2.) heated depth (in the T6-experiments) : ~ < 0.1 μm

--> 10^{-11} cm^3

There may be potentiality to get Kα-radiation by ion beams.

Summary & Plans

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Summary

1.) Present status of development of the corresponding kinetics code for fast ignition research with CHCl plastic targets.

Population kinetics and spectral synthesis codes of Kα-emission of partially ionized Cl atoms has been developed.

--> Comparing with experimental results,
a plasma temperature of 100~150 eV on the target surface is deduced,
and showing the potentiality for the generation of sub-ps x-ray.

2.) Consideration of Kα radiation by energetic heavy ions.

Kα radiation by high intense, energetic (~MeV, or GeV) heavy ion beams may be useful for the diagnosis of heated plasma.

Plans

1.) Code development for fast ignition:
--> Code extension to cover polarized x-ray for the diagnosis of velocity distribution function (in progress now).

2.) Consideration of Kα radiation by intense heavy ion beams
--> To proceed it further for purpose of plasma diagnostics.