Optimization of LPP- and LA-DPP-EUV Light Sources

K. Nishihara[1)], A. Sunahara[2)], A. Sasaki[3)],
K. Uchino[4)], K. Teramoto[5)] and K. Hotta[5)]

[1)] Institute of Laser Engineering, Osaka University
[2)] Institute of Laser Technology,
[3)] Quantum Beam Science Directory, JAEA
[4)] Interdisciplinary of Engineering Science, Kyushu University
[5)] USHIO

Summary

Plasma conditions for high CE are almost the same for LPP and LA-DPP, although their dynamics are quite different from each other,

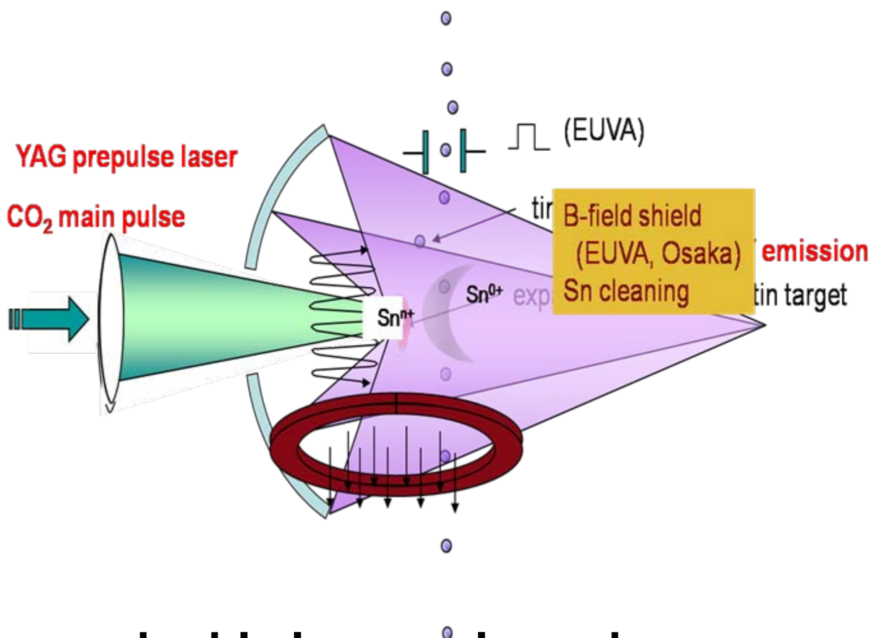
ion number density: about 5×10^{17} cm^{-3},
electron temperature: 40 eV.

CE of 4 – 6 % in LPP
spectral efficiency > 25 % in LA-DPP.

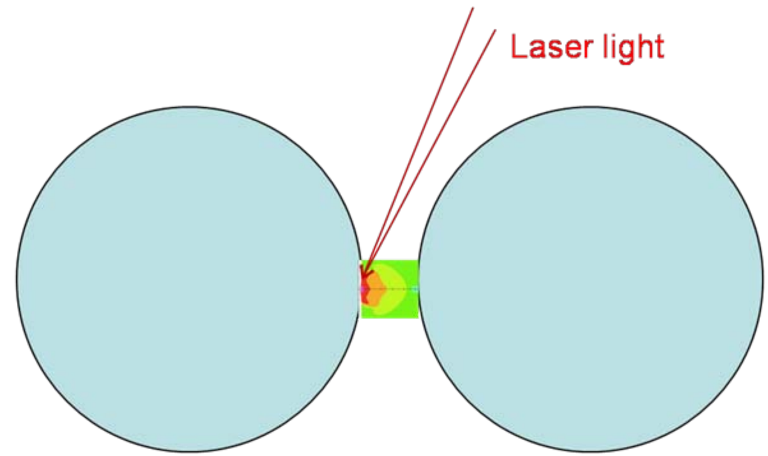
Those plasma conditions can be achieved by
double laser pulse scheme with CO_2 main laser in LPP,
laser produced and pinch plasma in LA-DPP.

Laser Thomson scattering is a useful diagnostics for plasma parameter measurement

LPP and LA-DPP



double laser pulse scheme
in LPP



laser assist DPP scheme

Theoretical Modeling of Plasma Parameters for High Efficiency EUV Light Sources

Optimum plasma conditions from power balance model (taking detail atomic processes into account)

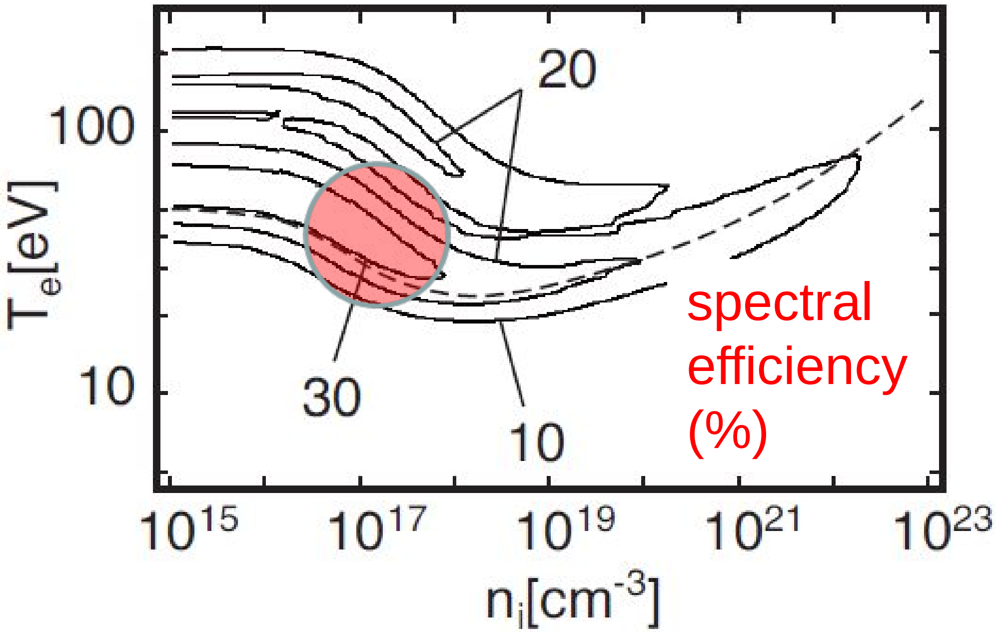
- **LPP EUV Light Source:**
  - absorbed laser intensity
    - ⇔ radiation and expansion losses, energy flux required (planar target, non-stationery expansion)
  - evaluate Conversion Efficiency

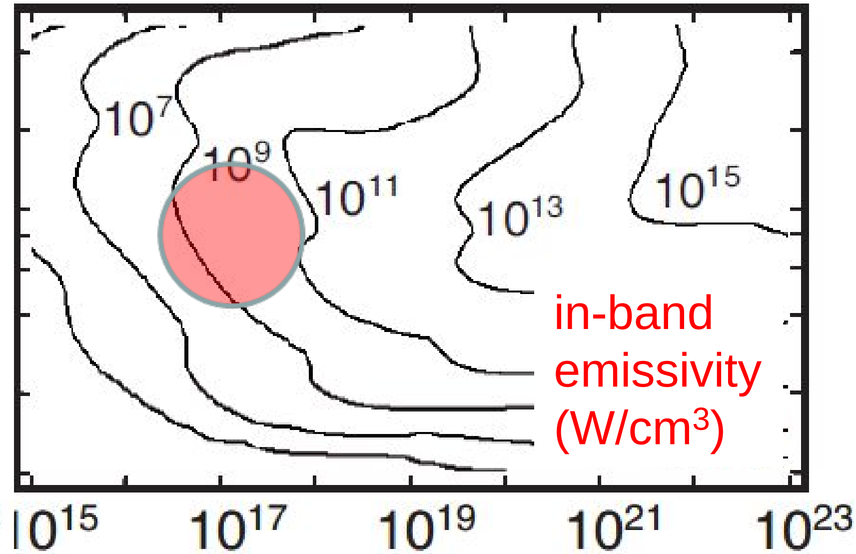
  after K. Nishihara et al PoP (2008).

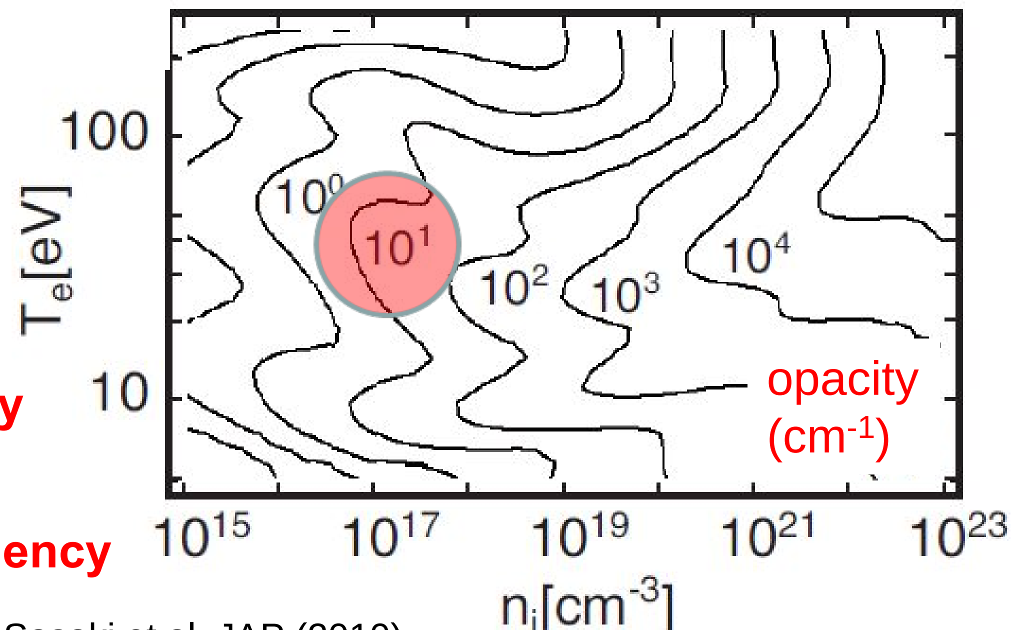
- **DPP EUV Light Source:**
  - plasma pressure ⇔ magnetic pressure,
  - radiation loss ⇔ Joule heating (cylindrical plasma, without taking pinching dynamics)
  - evaluate Spectral Efficiency

plasma condition

Optimum plasma condition expected from atomic physics for tin







Etendue ---> limit plasma size
---> opacity (∼10^1 cm^{-1})

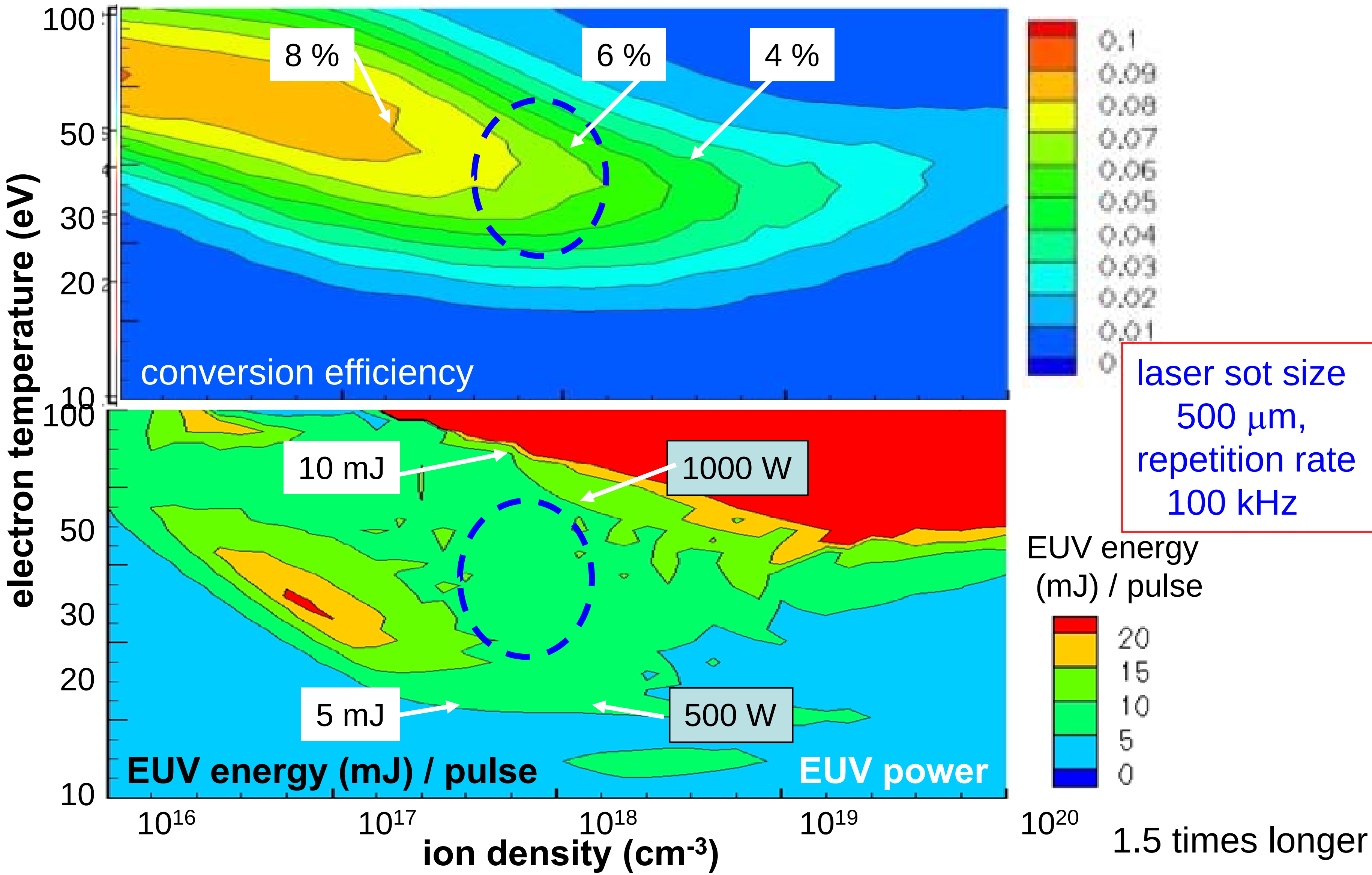
EUV power ---> in-band emissivity

High efficiency ---> spectral efficiency

After A. Sasaki et al, JAP (2010)

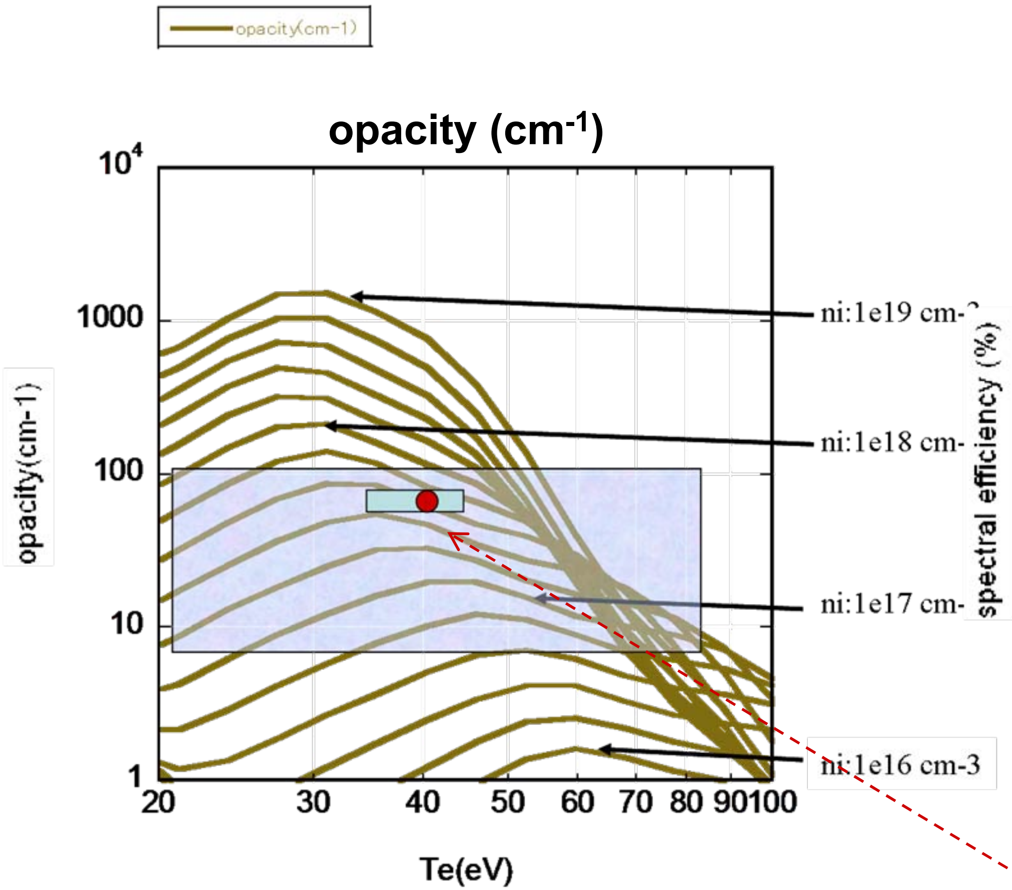
LPP plasma condition

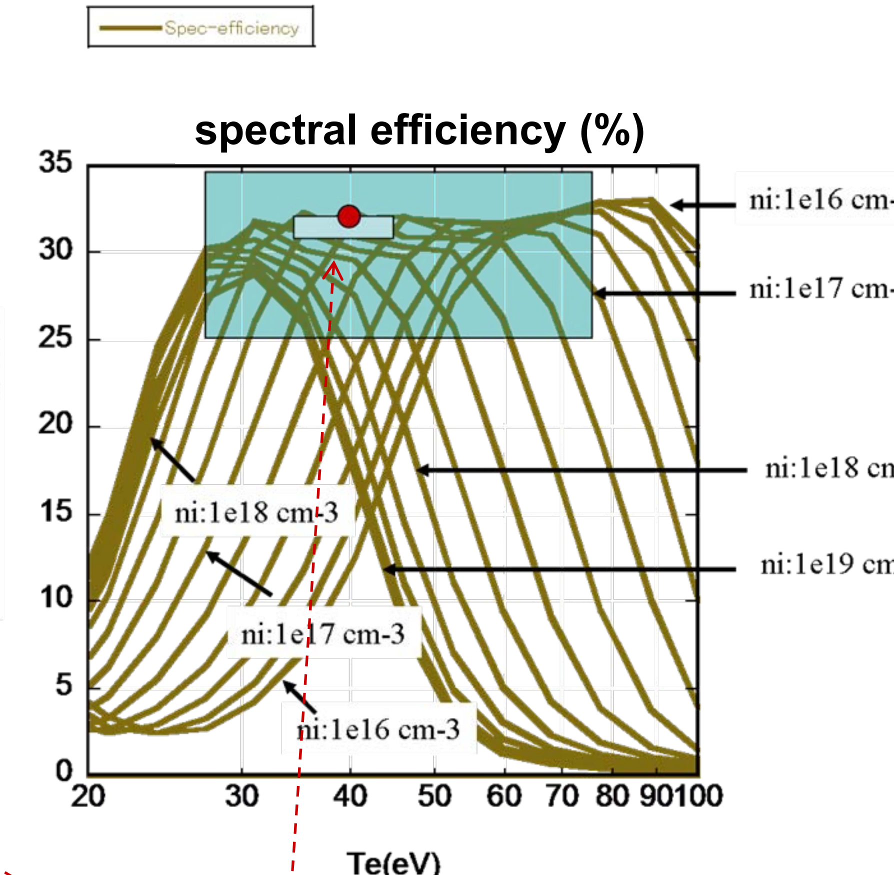
EUV power of 500 – 1000 W can be obtained at optimum conditions（required CO_2 laser power< 15 kW ）



Optimum condition：ion density 5x10^{17} – 10^{18} cm^{-3}, electron temperature 30 – 50 eV

Optimum plasma condition for LA-DPP (spectral efficiency and opacity)





Optimum plasma

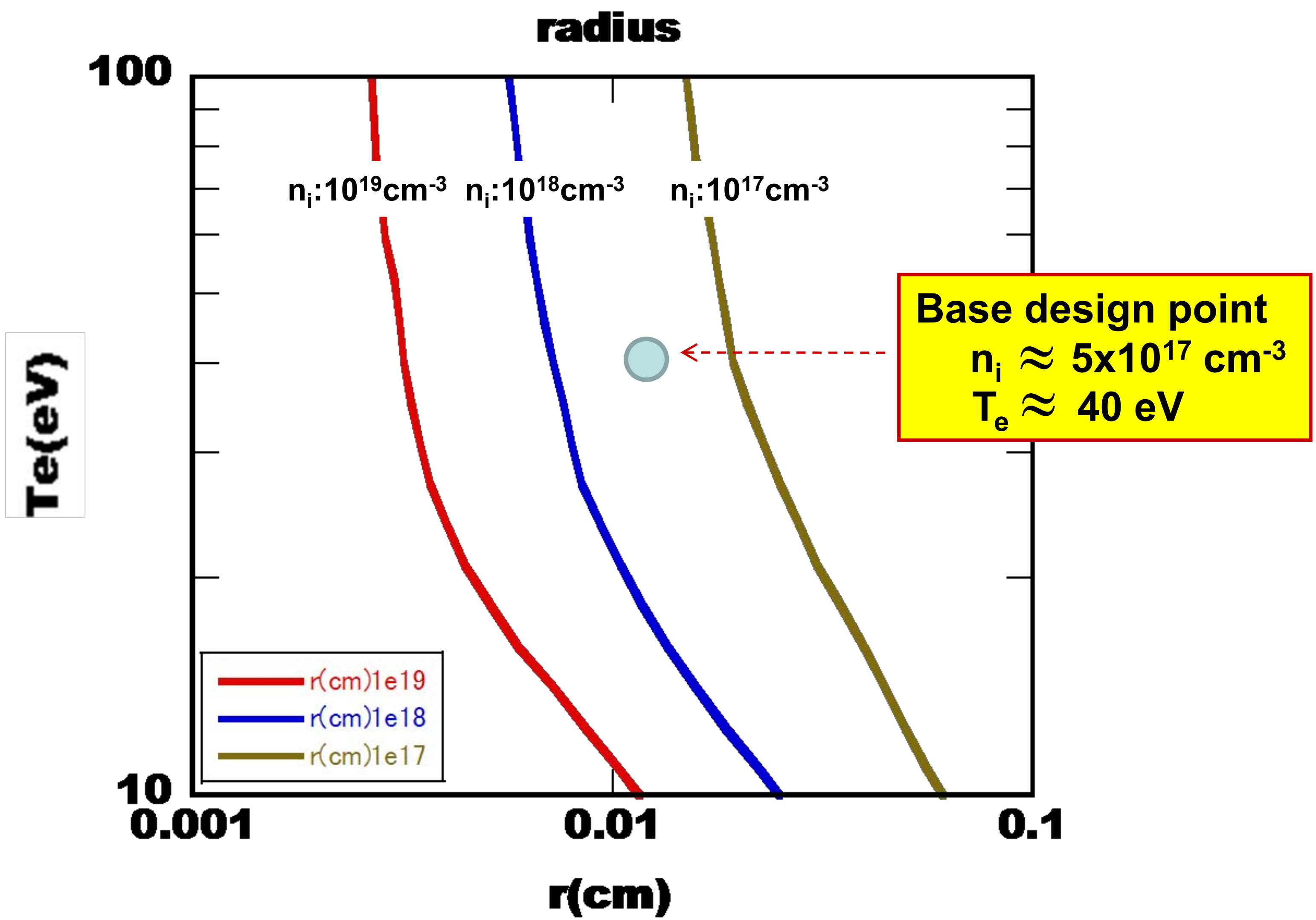
- **r x** $\sigma \approx 1$
- **high spectral efficiency**
  where pinch plasma radius: r
  opacity: σ

base design
$n_i \approx 5\times10^{17}$ **cm**$^{-3}$
$T_e \approx$ **40 eV**

LA-DPP plasma condition

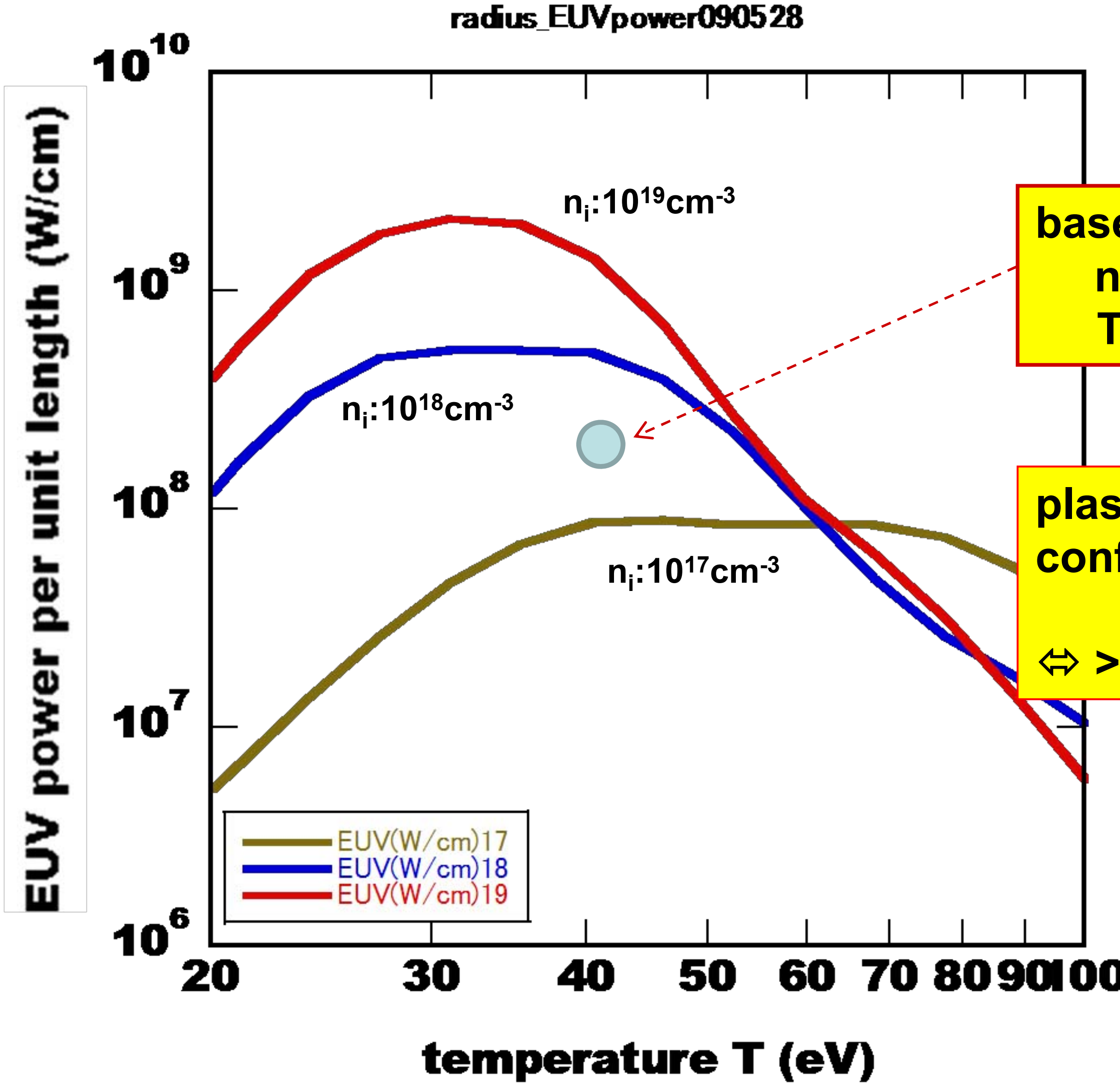
Proper opacity of pinched plasma can be achieved in temperature of 30 – 50 eV, ion density of 2 – 8 x 10^{17} cm^{-3}

relation between plasma radius and temperature



LA-DPP plasma condition

EUV power > 100 mJ / pulse can be possible in the range temperature: 30 – 50 eV, ion density: 2 – 8 x 10^{17} cm^{-3}



base design point
$n_i \approx 5 \times 10^{17}$ cm^{-3}
$T_e \approx 40$ eV

plasma length: 1mm
confinement time: 20 ns

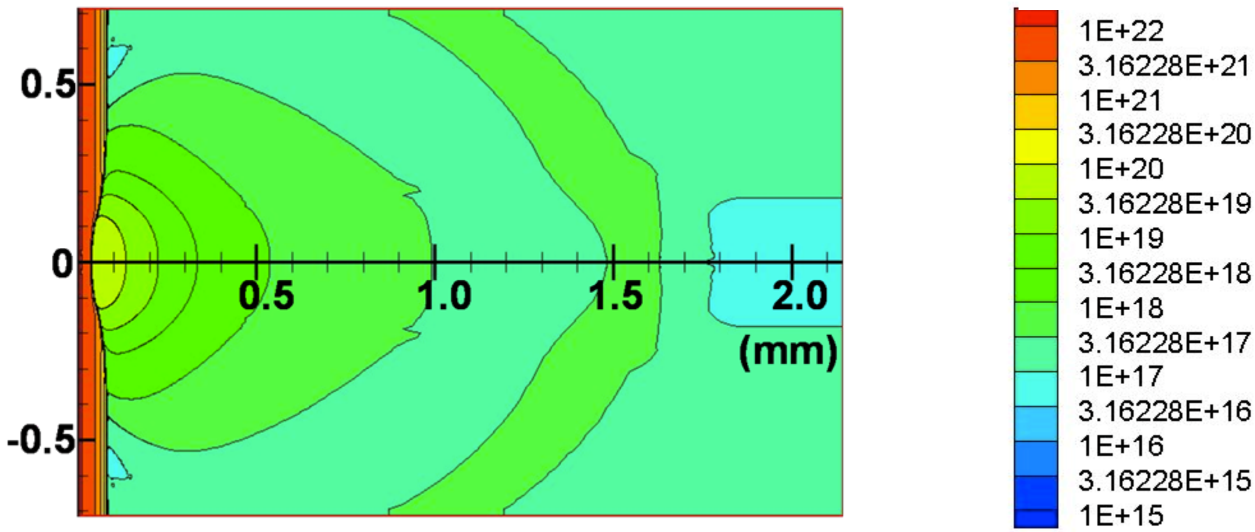
⇔ > 100 mJ / pulse

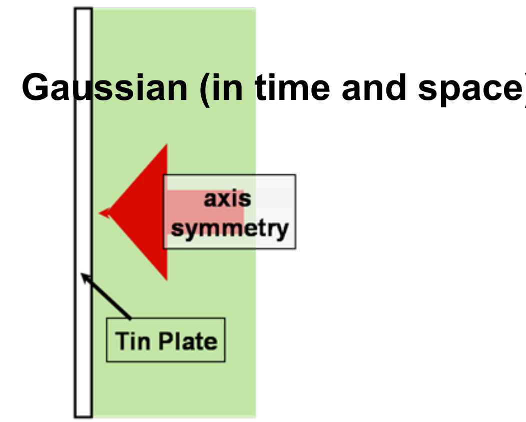
LA-DPP
plasma expansion

Laser produced plasma provides high density plasma for LA-DPP (2d hydro agrees well with experiments)

Electron density at 70 ns

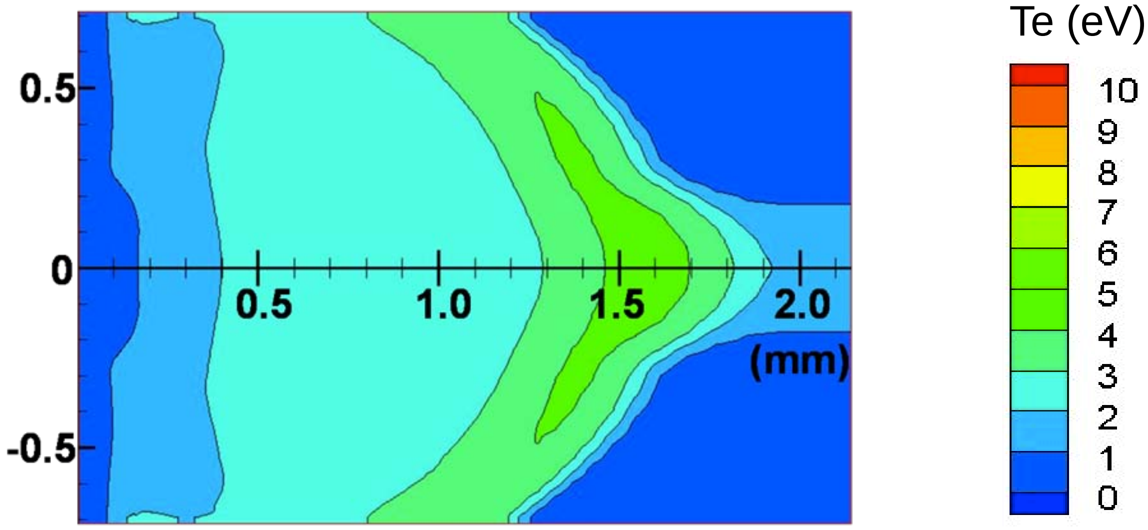
ne (cm^{-3})





Electron temperature at 70 ns

Te (eV)



Pulse Energy :10mJ

Pulse Duration :9ns

150μmφ(FWHM)

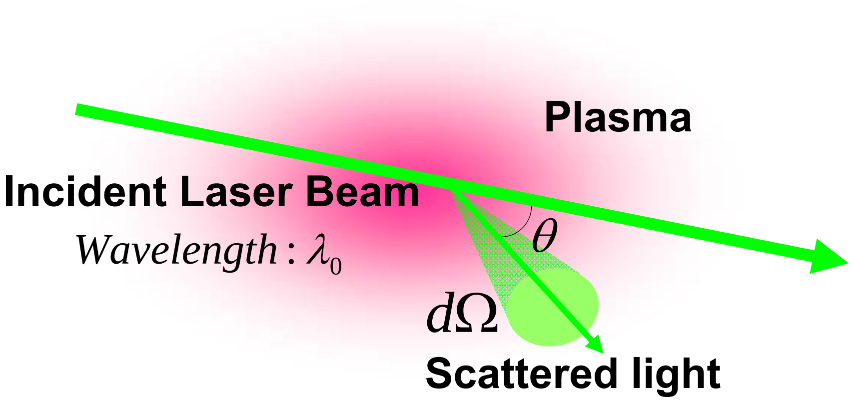
1.06μm wavelength Laser

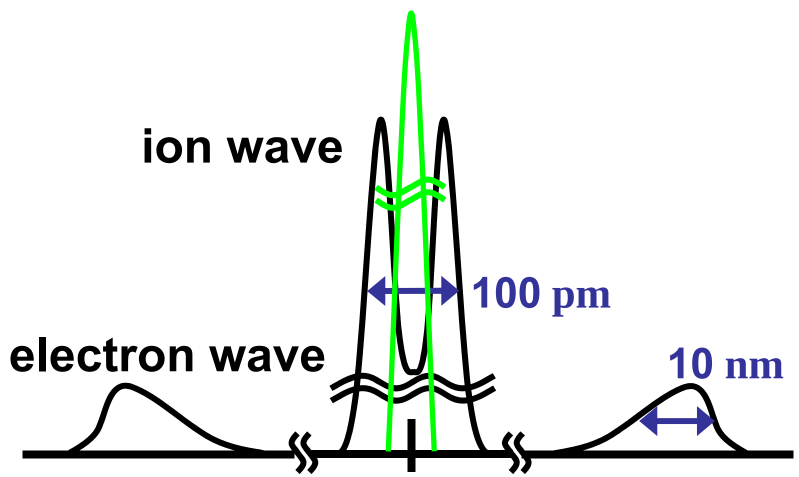
Laser Thomson scattering can be a useful plasma diagnostics

Electron density n_e

Electron Temperature T_e,
Ion temperature T_i

Charge state Z





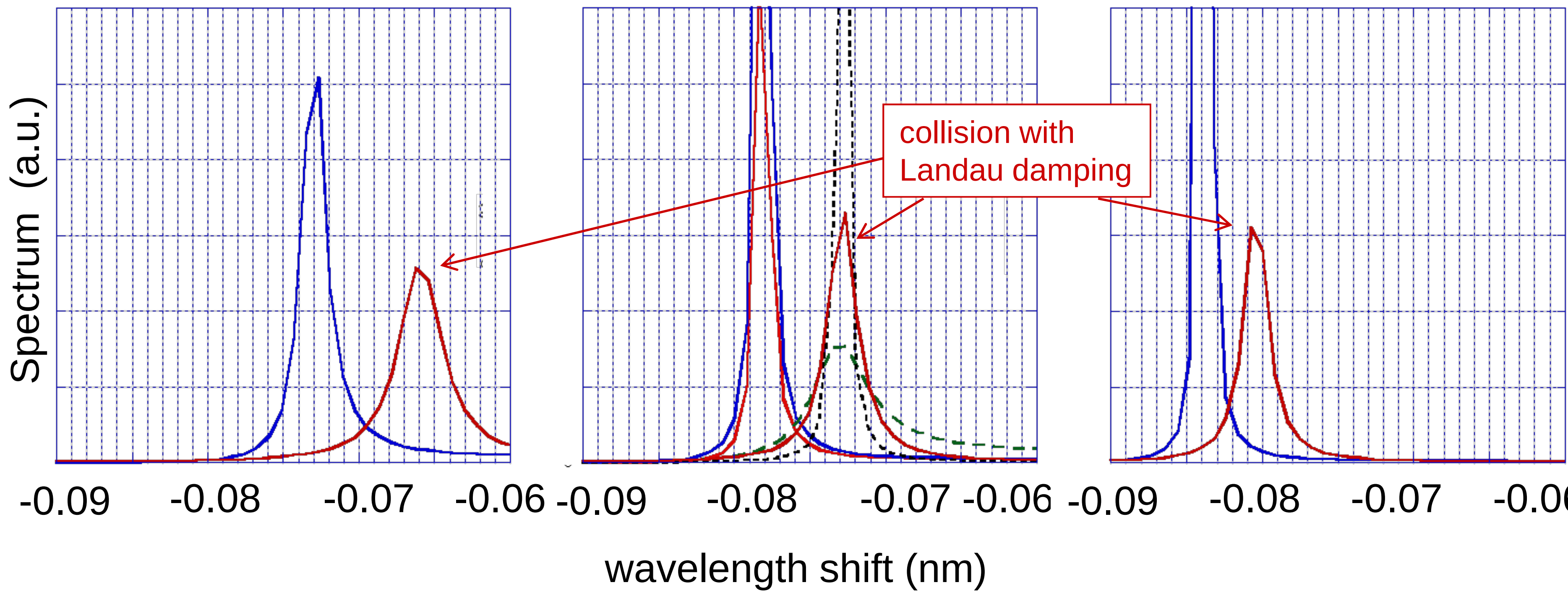
・10 pm required resolution

Model spectrum agrees well with laser plasma experiments at Kyushu Univ.

diagnostics 1

Electron temperature dependence of Thomson spectrum
Peak shift provides electron temperature as expected

large dependence of peak wavelength on electron temperature



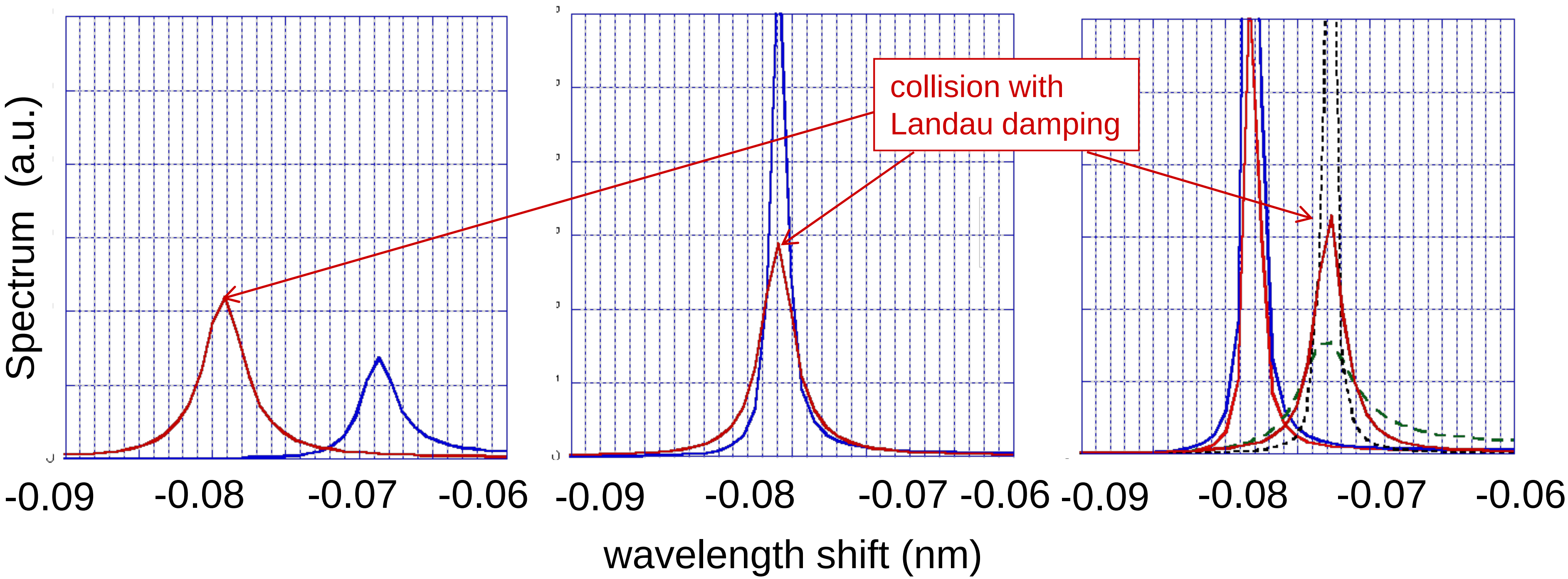
n_e: 5.92x10^{18} cm^{-3}
n_i: 1.581x10^{17} cm^{-3}
T_e: 20 eV
Z: 11.84

n_e: 7.24x10^{18} cm^{-3}
n_i: 1.581x10^{17} cm^{-3}
T_e: 28.28 eV
Z: 14.48

n_e: 8.84x10^{18} cm^{-3}
n_i: 1.581x10^{17} cm^{-3}
T_e: 40 eV
Z: 17.68

Plasma parameters can be obtained from Thomson Spectrum with absolute value of scattered light intensity

Dependence of spectrum width and intensity on electron density



n_e: 8.538×10^{17} cm^{-3}
n_i: 5×10^{16} cm^{-3}
T_e: 28.28 eV
Z: 17.08

n_e: 2.492×10^{18} cm^{-3}
n_i: 1.581×10^{17} cm^{-3}
T_e: 28.28 eV
Z: 15.76

n_e: 7.24×10^{18} cm^{-3}
n_e: 5×10^{17} cm^{-3}
T_e: 28.28 eV
Z: 14.48