

Capillary Plasma Radiation Source in the Soft X-Ray Region

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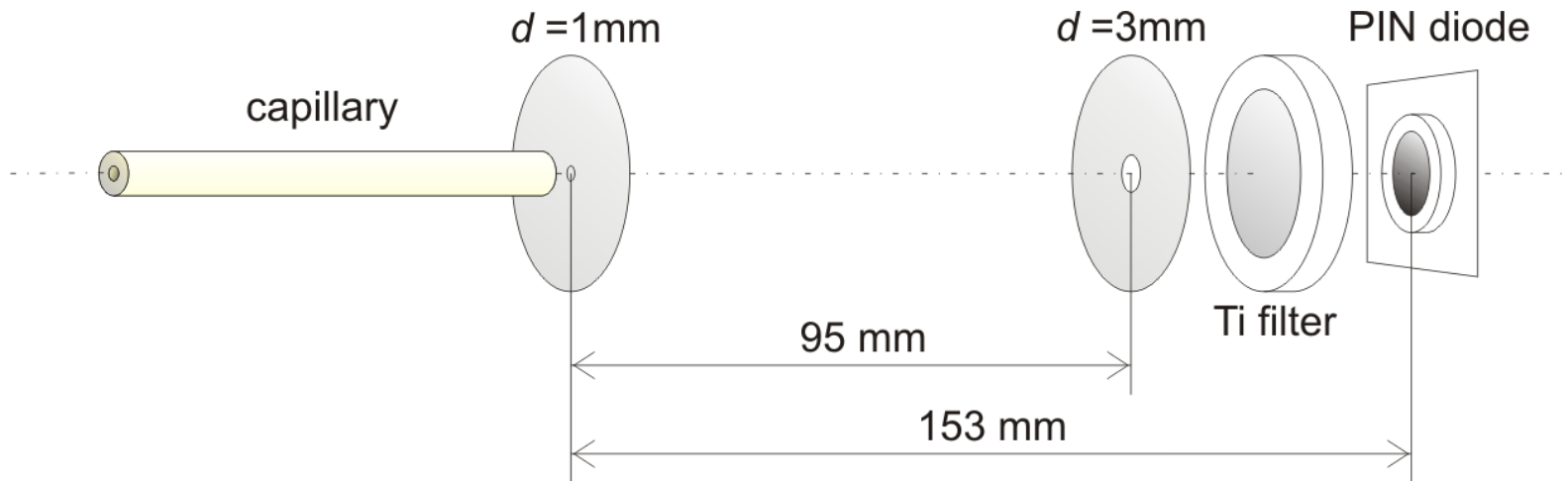
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Outline

- Modeling of nitrogen capillary plasma by Z*- code
- Comparison of measured and evaluated
 - Current profiles
 - Radiation output power profiles in ww region
- Spatial and time dependences of plasma quantities
- Ray- tracing results
- Spectra estimated by FLYCHK - code

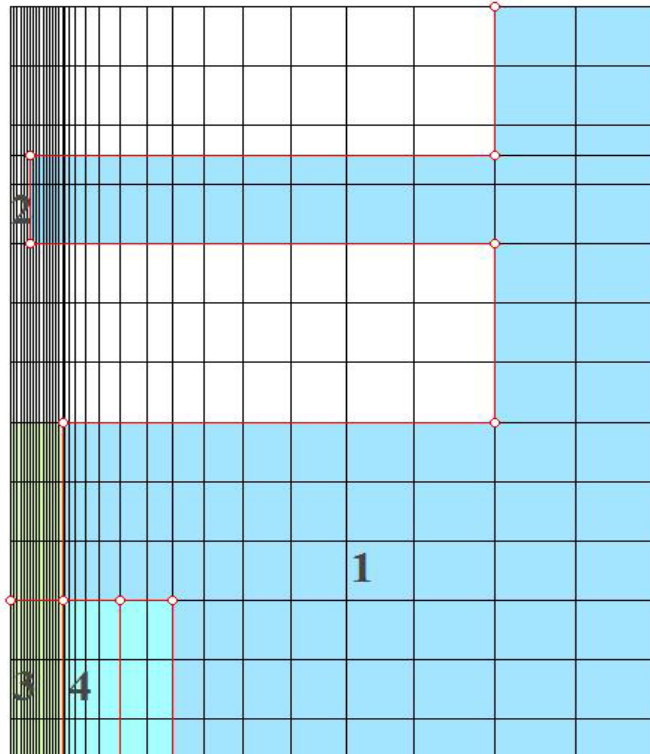
Investigated device



Capillary radius $R_0 = 0.16\text{ cm}$,
Capillary length $L = 10\text{ cm}$,
Nitrogen filling pressure $40 - 300\text{ Pa}$,
Capacitor $C = 21\text{ nF}$, charged to $U_0 = 70\text{ kV}$.

See poster S24

Z* - code modeling



Rectangular unequal differential grid in cylindrical geometry according to the experimental set up

Capillary radius $R_0 = 0.16$ cm,
Capillary length $L = 10$ cm,

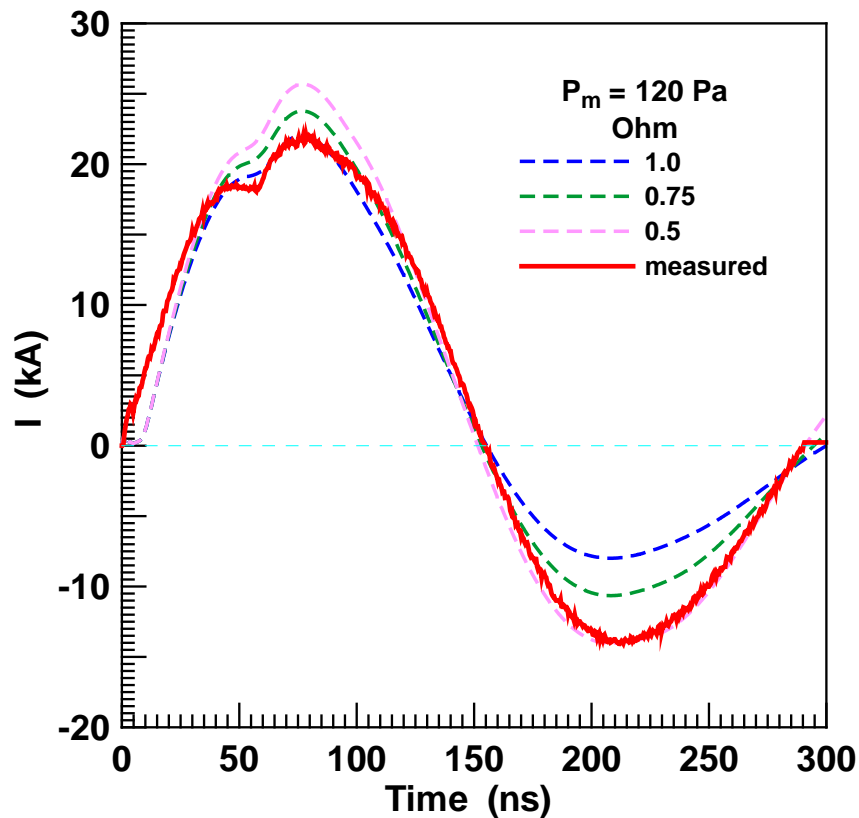
Nitrogen filling pressure 40 – 300 Pa,

Capacitor $C = 21$ nF,
Inductance $l = 50$ nH
Resistivity $R = 0.7$ Ohm
charged to $U_0 = 70$ kV.

Anode part of the grid

- 1 – blue - outer electrode,
- 2 – outer orifice,
- 3 – yellow – inner part of capillary,
- 4 – green - capillary wall (dielectric)

Measured and evaluated current profiles



Charging voltage $U_0 = 70 \text{ kV}$ (used)

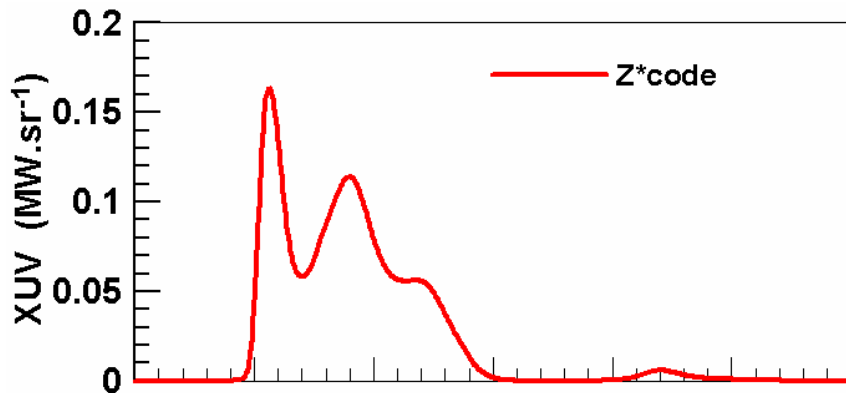
Capacitor $C = 21 \text{ nF}$ (used)

Parasitic inductance $l = 50 \text{ nH}$ (estimated)

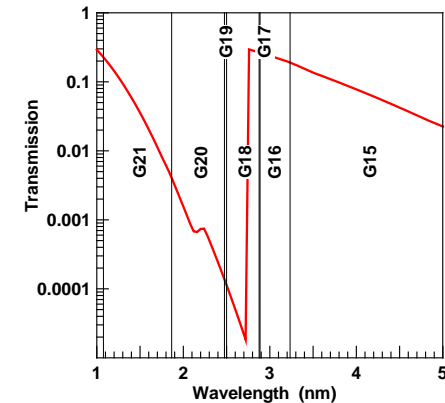
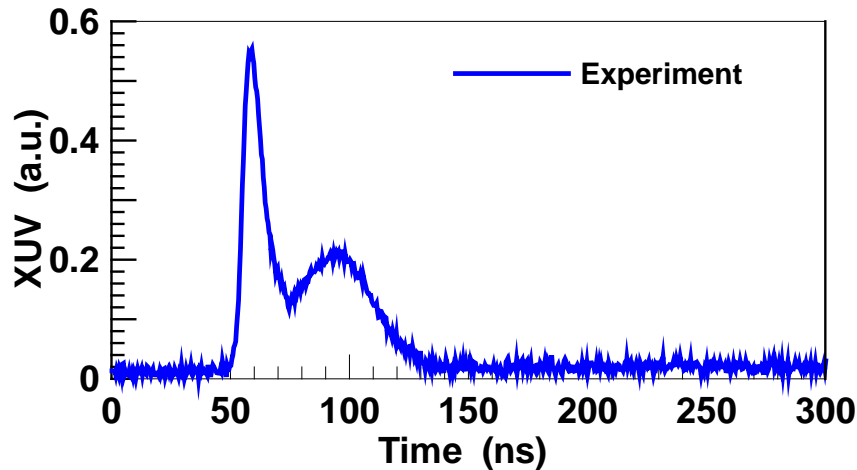
Parasitic resistivity $R = 0.75 \text{ Ohm}$ (fitted)

Evaluated and measured output power profiles

pressure $P = 100$ Pa, voltage $U_0 = 70$ kV



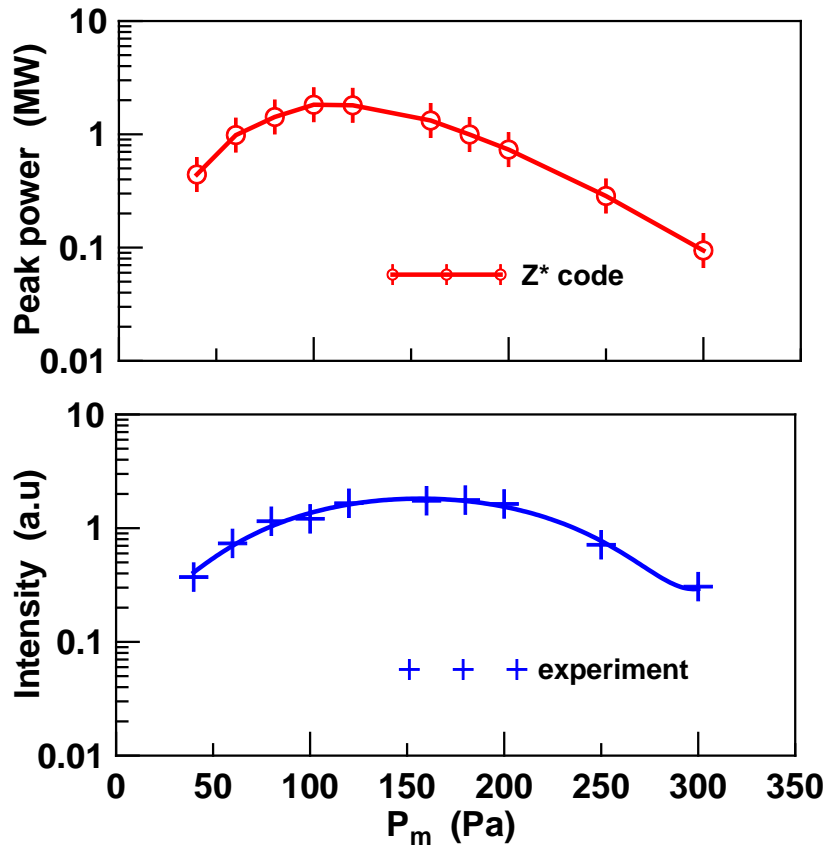
Evaluated output power
in the spectral range
2.8766 – 2.8867 nm



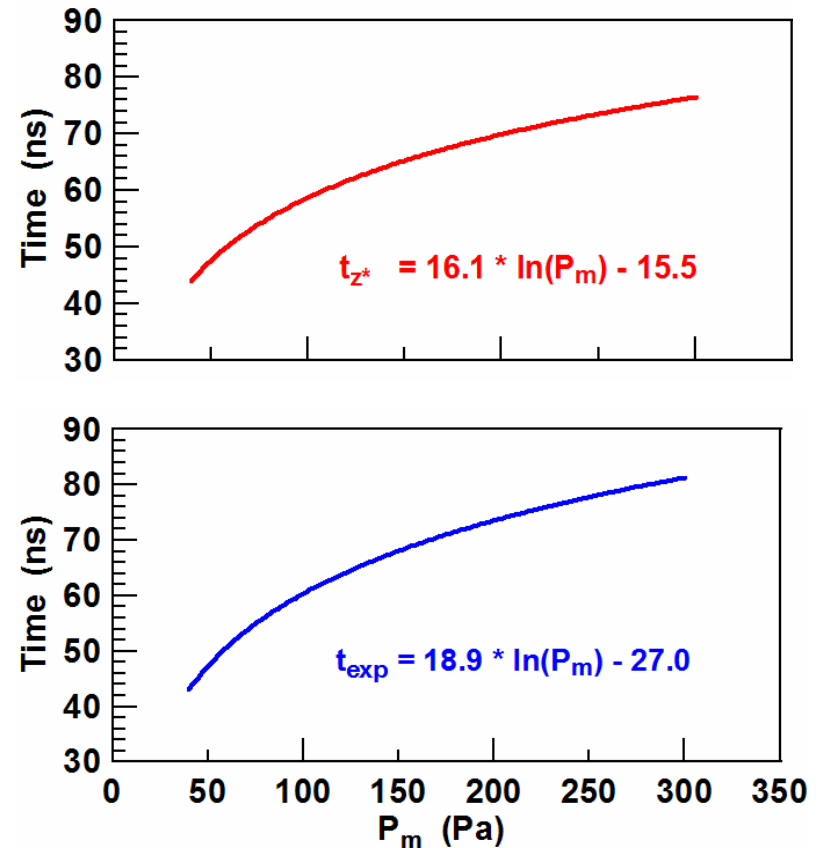
Measured output power passing
through Titanium foil

Pressure dependences evaluated and measured

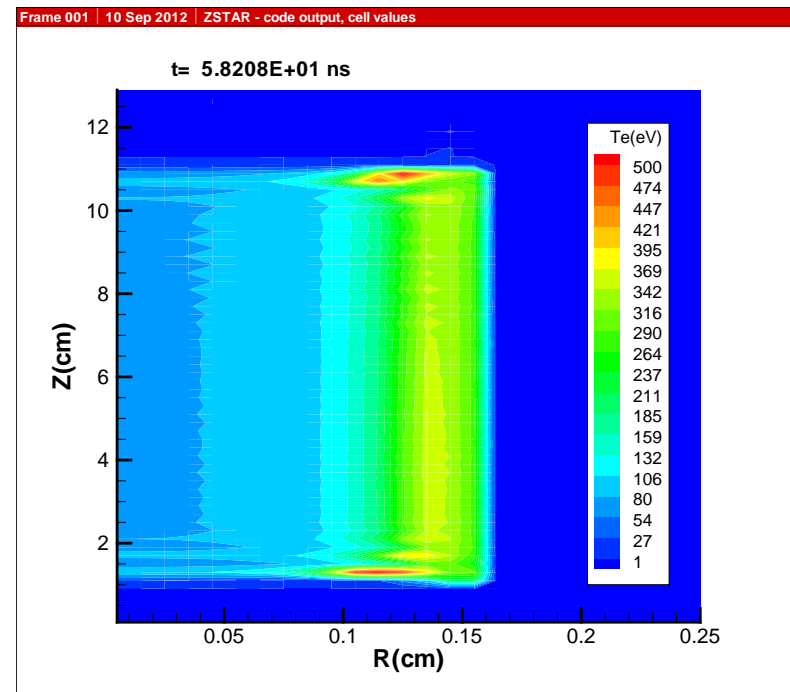
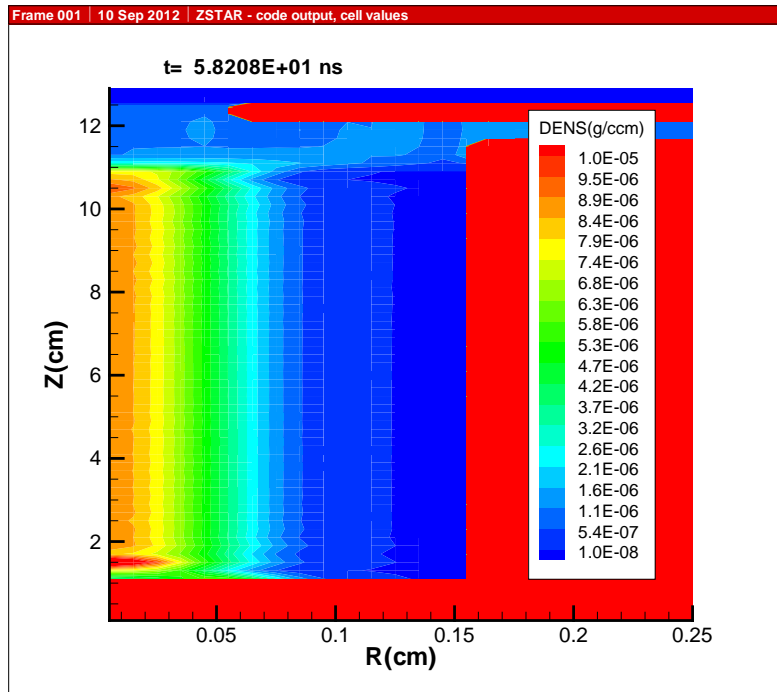
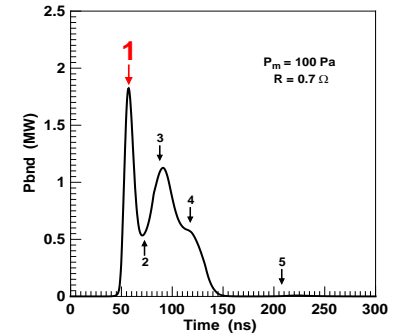
Peak values of emitted power



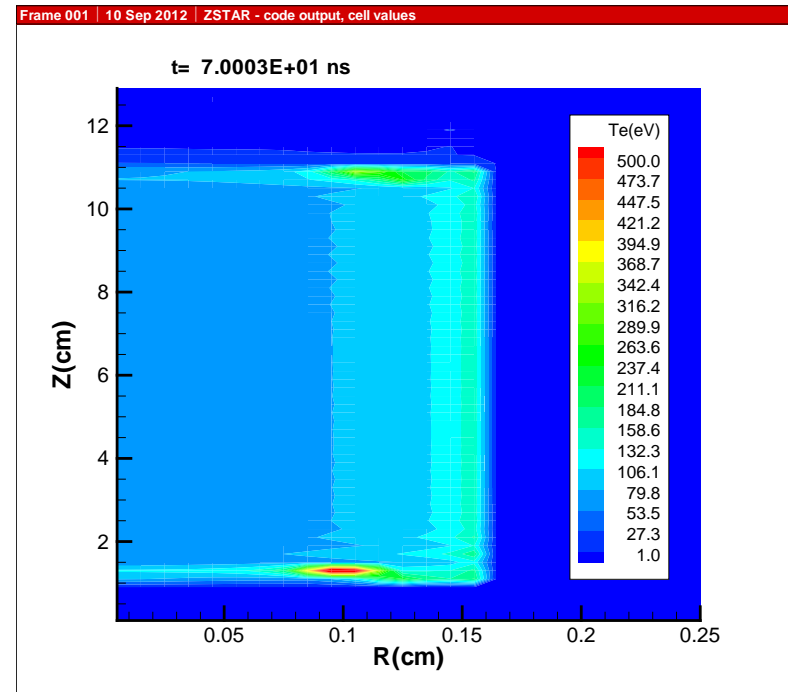
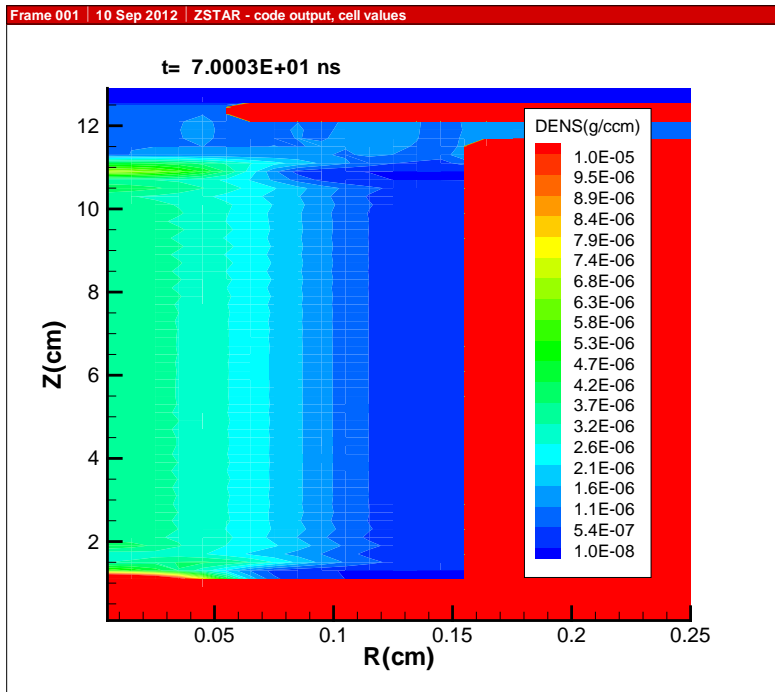
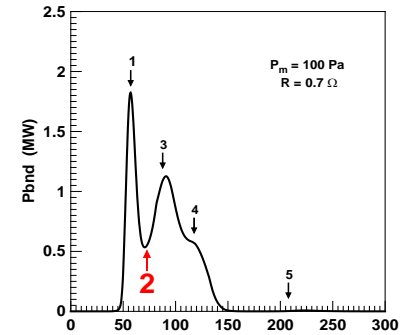
Time delays



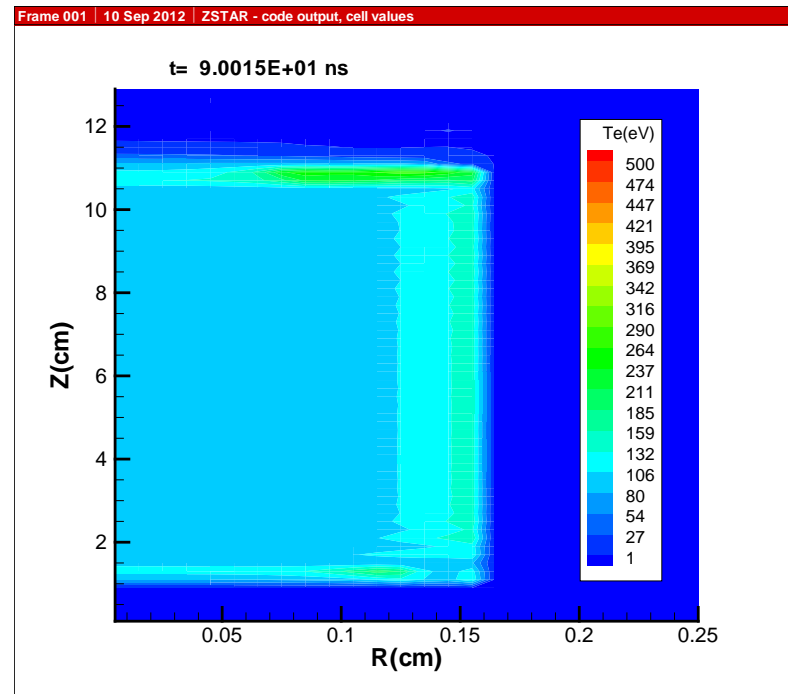
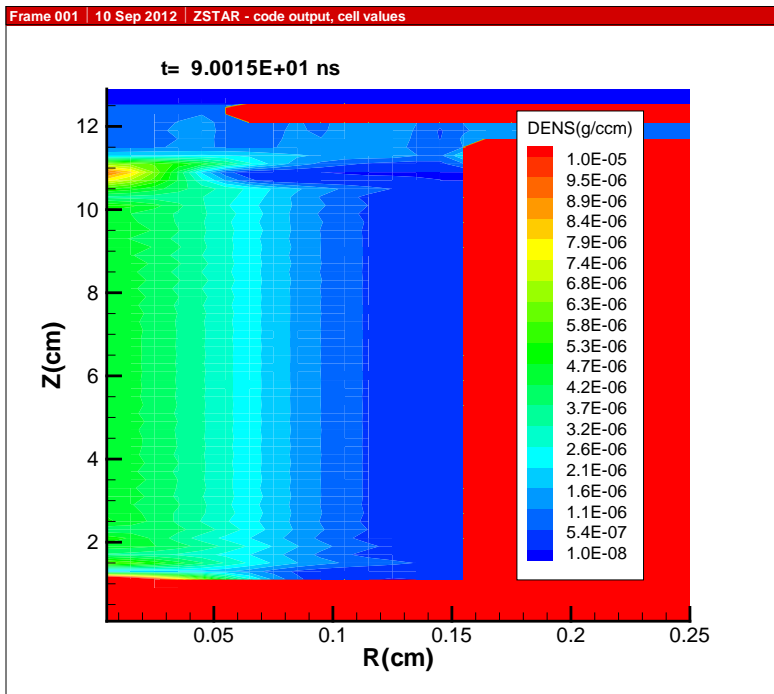
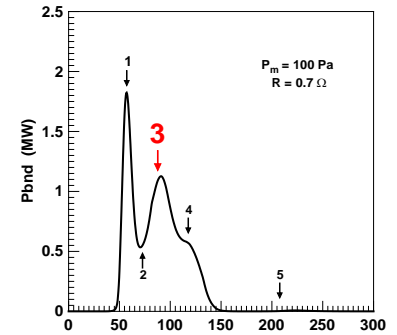
Plasma density and temperature at $t = 58$ ns



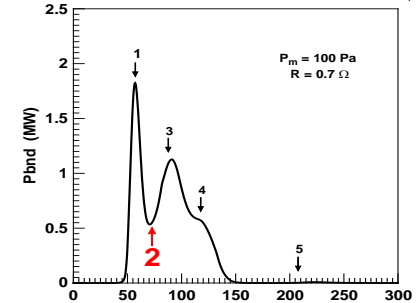
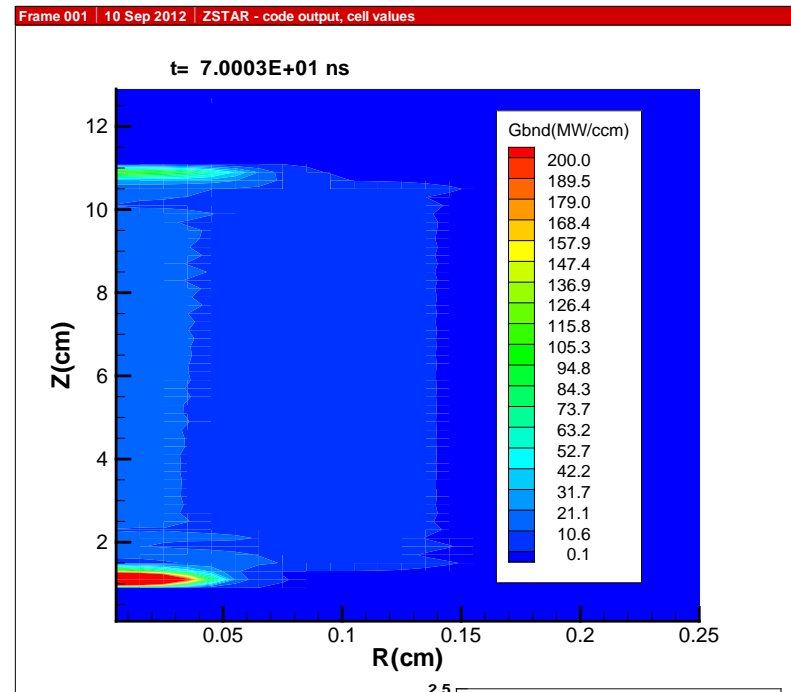
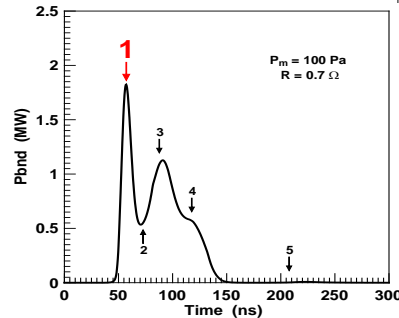
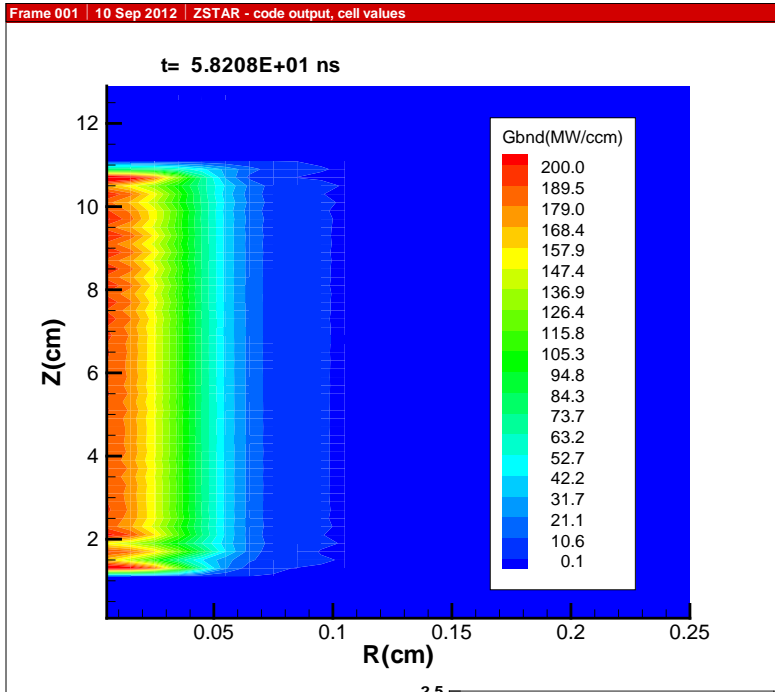
Plasma density and temperature at $t = 70$ ns



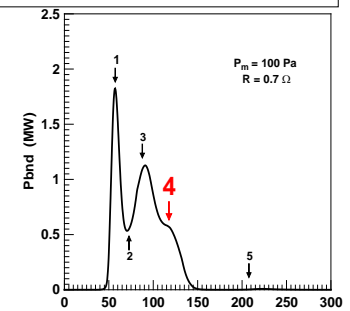
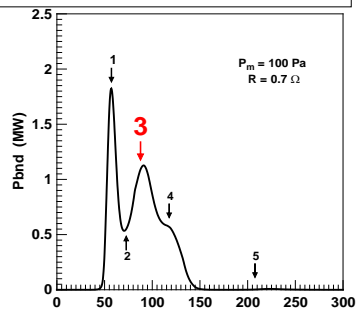
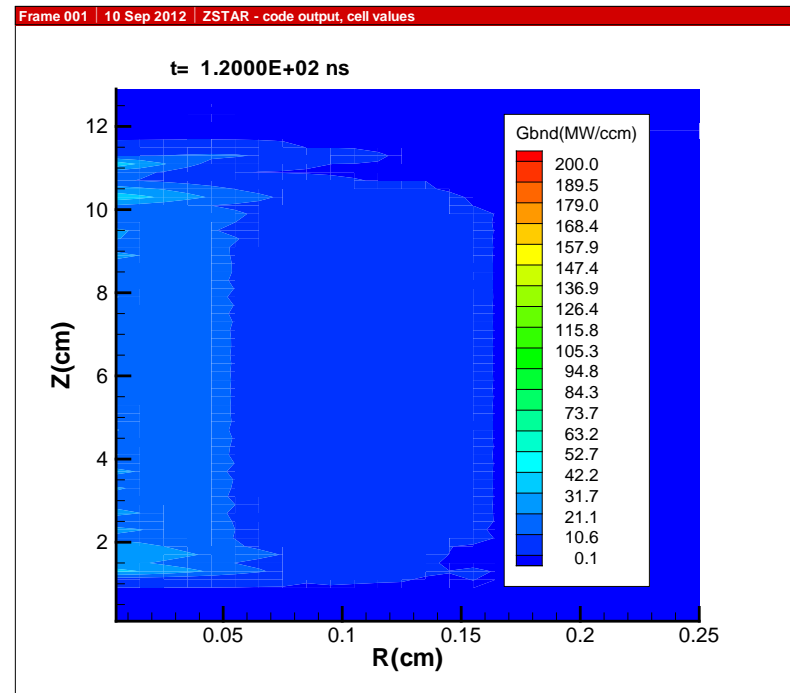
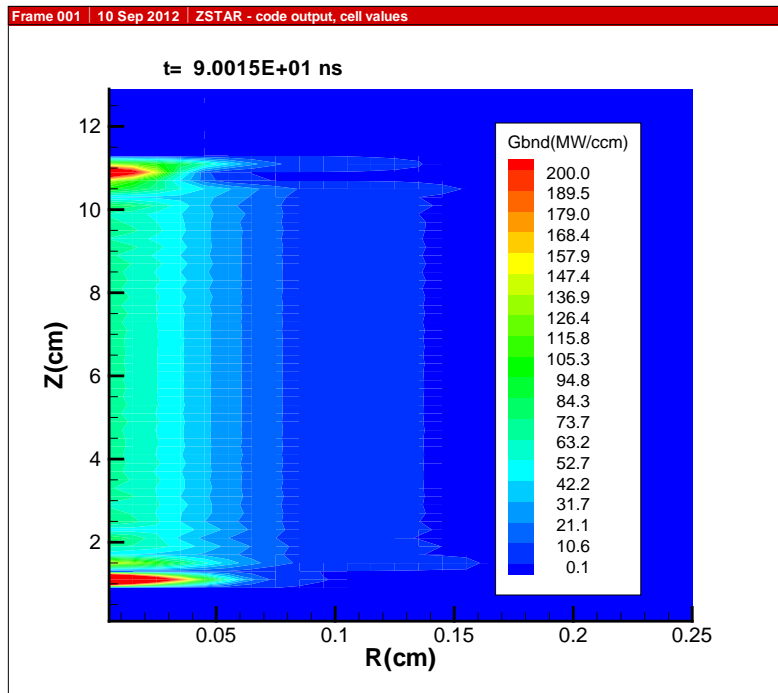
Plasma density and temperature at $t = 90$ ns



Power density emitted in the 2.8766 – 2.8867 nm spectral band at 58 and 70 ns



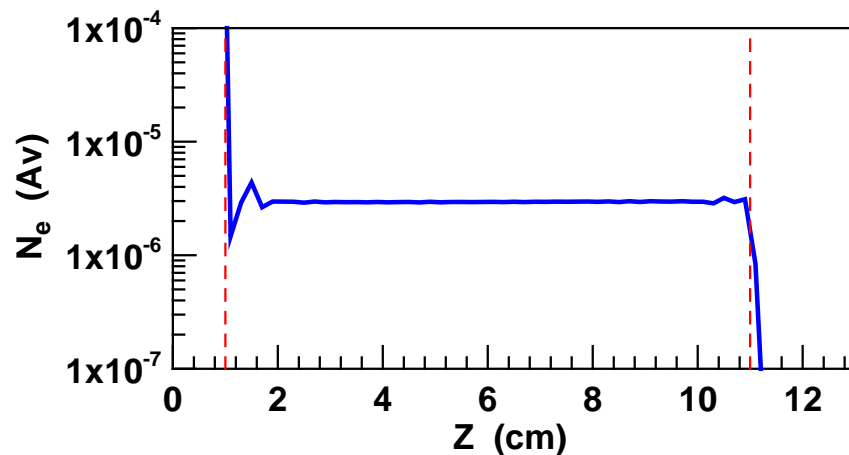
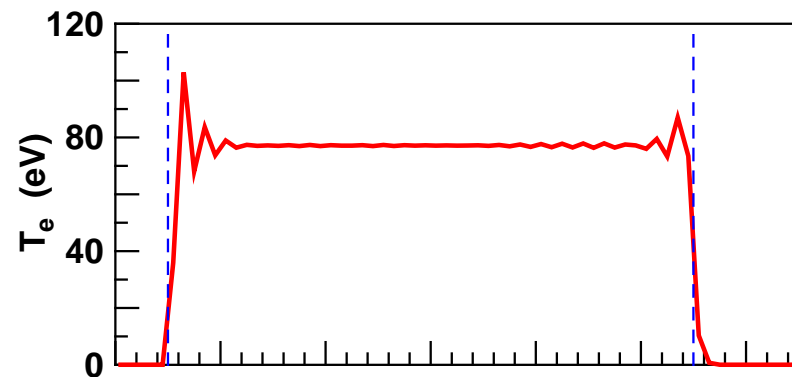
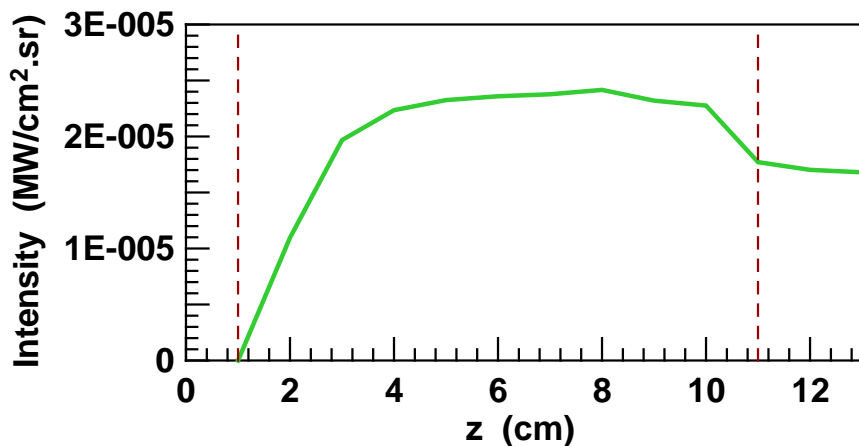
Power density emitted in the 2.8766 – 2.8867 nm spectral band at 90 and 120 ns



Ray tracing along capillary axis

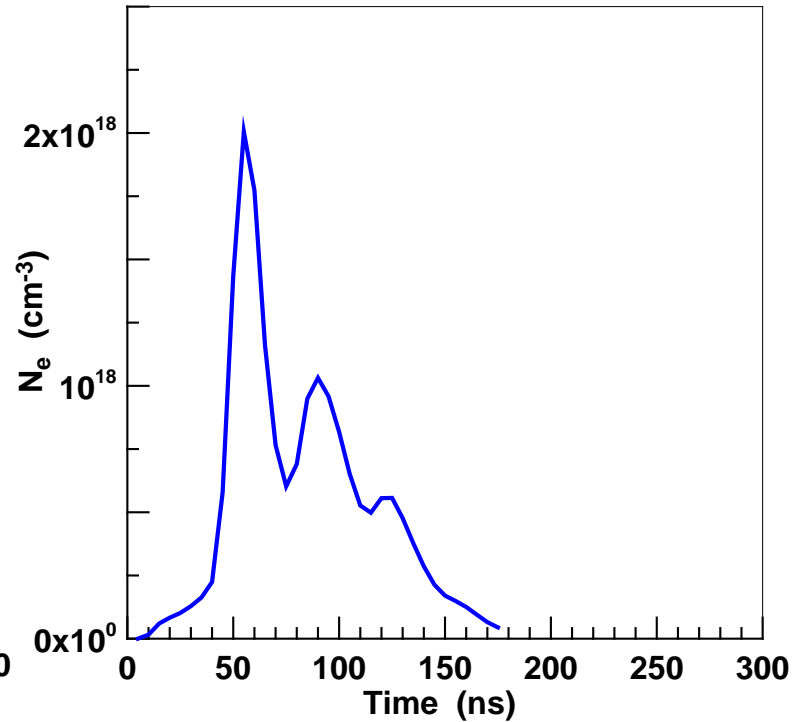
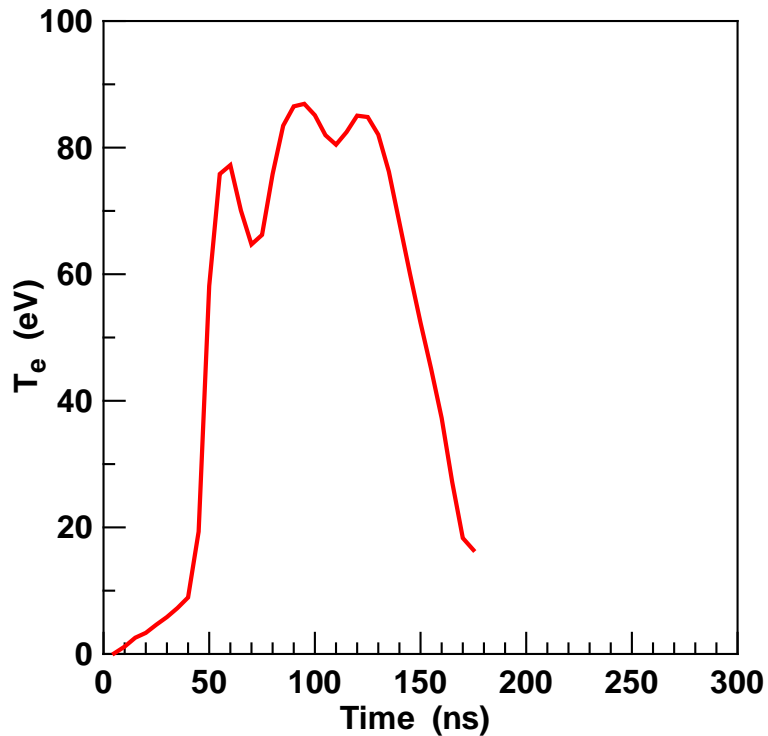
pressure $P = 100$ Pa, voltage $U_0 = 70$ kV, time $t = 60$ ns

Evaluated intensity in the spectral band 17 ($\lambda = 2.8766 - 2.886$ nm)

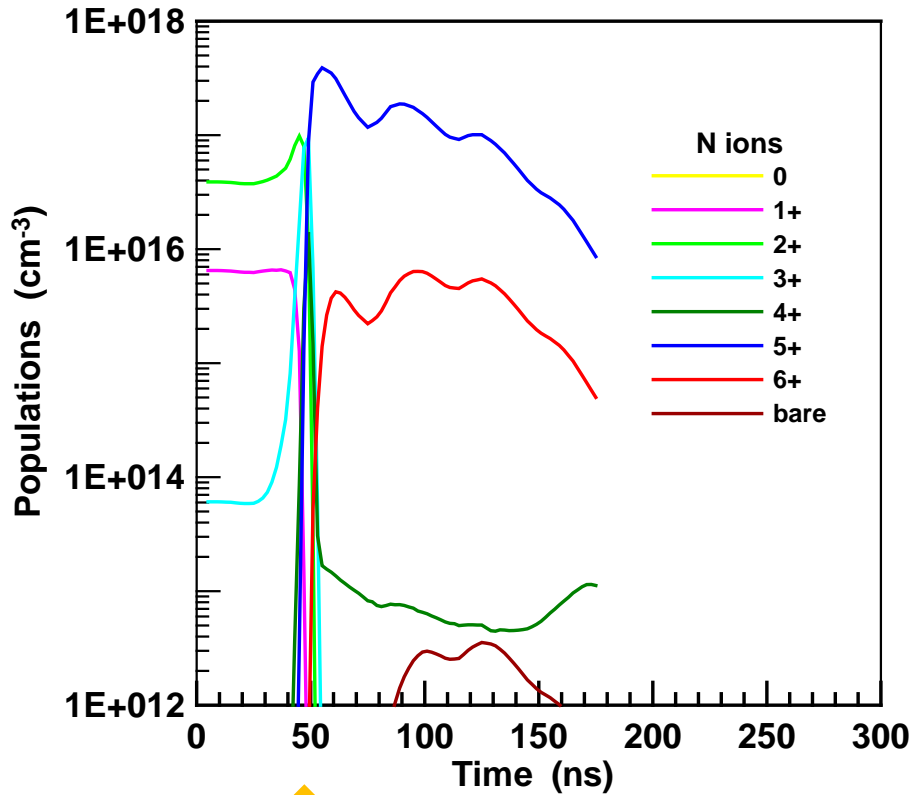


Time dependences of electron temperature and density in capillary center ($r = 0$ cm, $z = 6$ cm)

Pressure 100 Pa



Ion kinetics evaluated according to FLY code

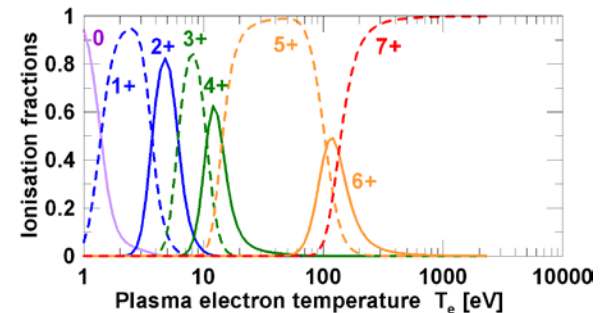


Pinch time

Time dependences of T_e and Ne in capillary center used as input data

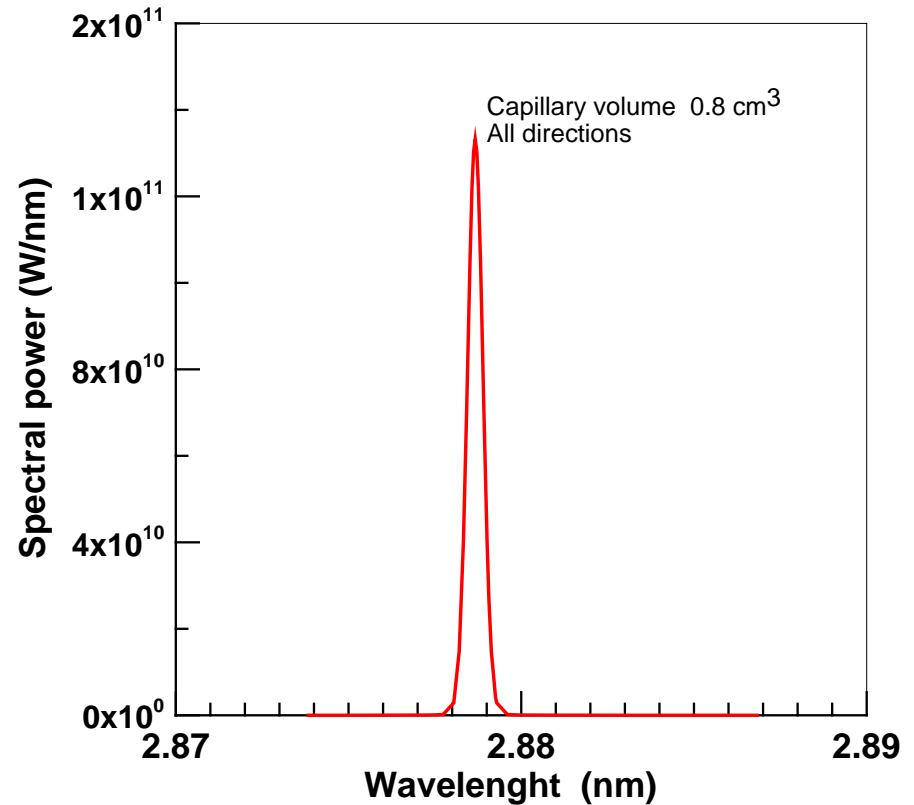
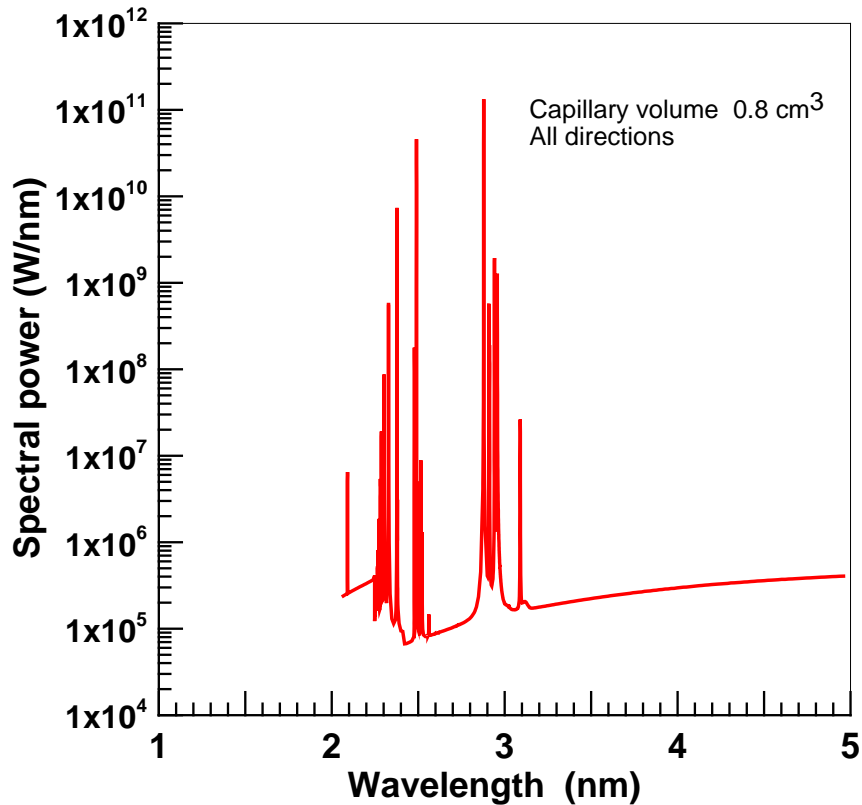
Quick change of ionization state at pinch time

Prevailing He-like ions after the pinch



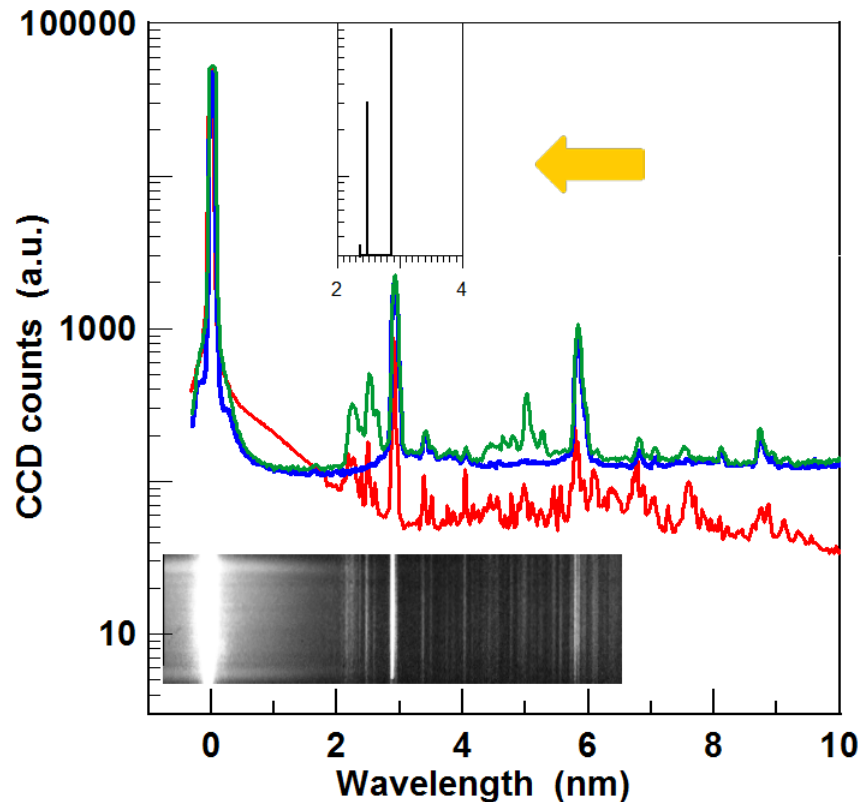
Instantaneous spectra at $t = 56$ ns

evaluated according to FLYCHK code



See poster S23

Spectra measured and evaluated



Diffraction patterns as registered by CCD camera

- 200 μm aperture without filter
- 400 μm aperture and Cr filter
- 400 μm aperture and Ti filter

← Evaluated spectral lines of helium-like nitrogen (small embedded graph).

See poster S38

Conclusions

- Both, calculated and measured current profiles were near to dumped sinus with the peak value ~ 23 kA and the half period ~ 150 ns.
- Output power at $\lambda = 2,88$ nm dominates other spectral lines emitted in ww spectral range
- Time dependences of the power in the line have pulse profiles with two remarkable peaks in the wide range of pressures.
- The highest peak value ~ 1.8 MW at pressure ~ 100 Pa was evaluated.
- The estimated energy 5.5 mJ.sr^{-1} ($\sim 10^{14}$ photons.sr $^{-1}$) corresponds properly to observed experimental value
- Pinching nitrogen capillary discharge as a source of monochromatic radiation in water window region is promising source for biological object imaging.

Acknowledgement

This work was supported by grants on the projects:

- GACR P102/12/2043 „Pulse Source of Soft X- Rays for Biomedical Applications“
- MEYSF CR Project LA 08024 „Research in the Frame of Dense and Magnetized Plasma Center“
- MEYS ESF Project CZ.1.07/2.3.00/20.0092 „Research Team Advancement at FBME CTU in Prague“

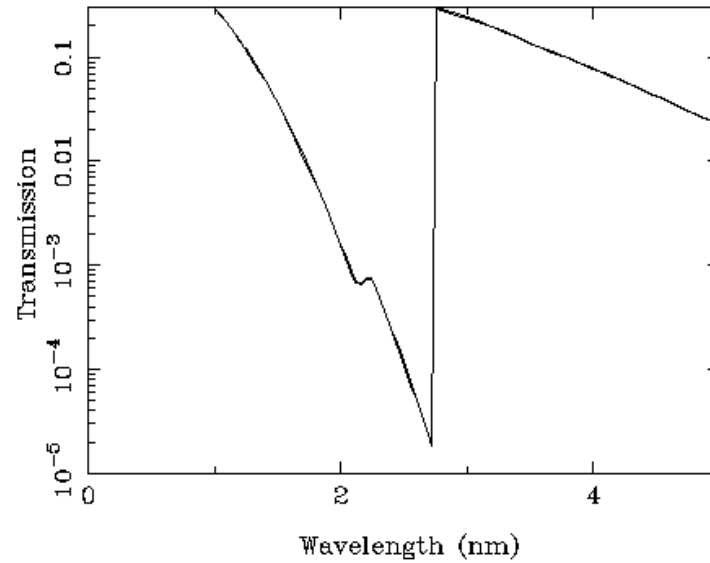
Thank you very much for your attention



Wavelengths of band boundaries and wavelengths of line emission inside the bands

Group	Lower limit λ_1 [nm]	Upper limit λ_2 [nm]	Group width $\Delta\lambda$ [nm]	NVI spectr. line λ [nm]	NVII spectr. line λ [nm]	Filter edge λ [nm]
15	3.2340976	4.999888	1.7658			
16	2.8867111	3.2340976	0.3473			
17	2.8766645	2.8867111	0.0100	2.87870		
18	2.4996823	2.8766645	0.3770			2.72-2.76
19	2.4747353	2.4996823	0.0249	2.48980	2.47846	
20	1.865158	2.4747353	0.6096			
21	1.0763119	1.865158	0.7884			

Ti Density=4.54 Thickness=0.8 microns



	Wavelength (nm)		$g_k A_{ki}$	T Filter transmissivity	Relative intensity observed
	2.0905		1.607 e+12		1.1 e +9 . n_{hy}
N VII	2.09106	1s-3p	0.803 e+12	0.7 e-3	0.5 e +9 . n_{hy}
	2.47792		6.020 e+12		0.6 e +9 . n_{hy}
N VII	2.47846	1s-2p	3.008 e+12	1.0 e-4	0.3 e +9 . n_{hy}
N VI	2.48980	1s ² -1s3p	1.547 e+12	1.0 e-4	1,5 e +8 . n_{he}
N VI	2.87870	1s ² -1s2p	5.427 e+12	0,26	1.4 e+12 . n_{he}