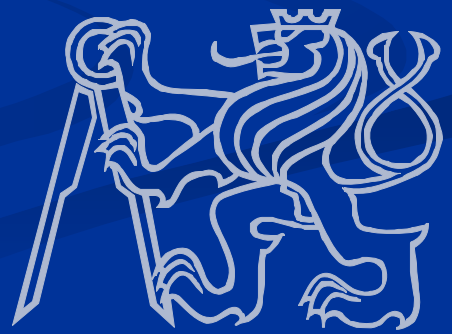
Capillary Discharge Investigations in Czech Laboratories (Achievments and Plans)

Miroslava Vrbová

Czech Technical University in Prague



LASER PLASMA RESEARCH CENTER

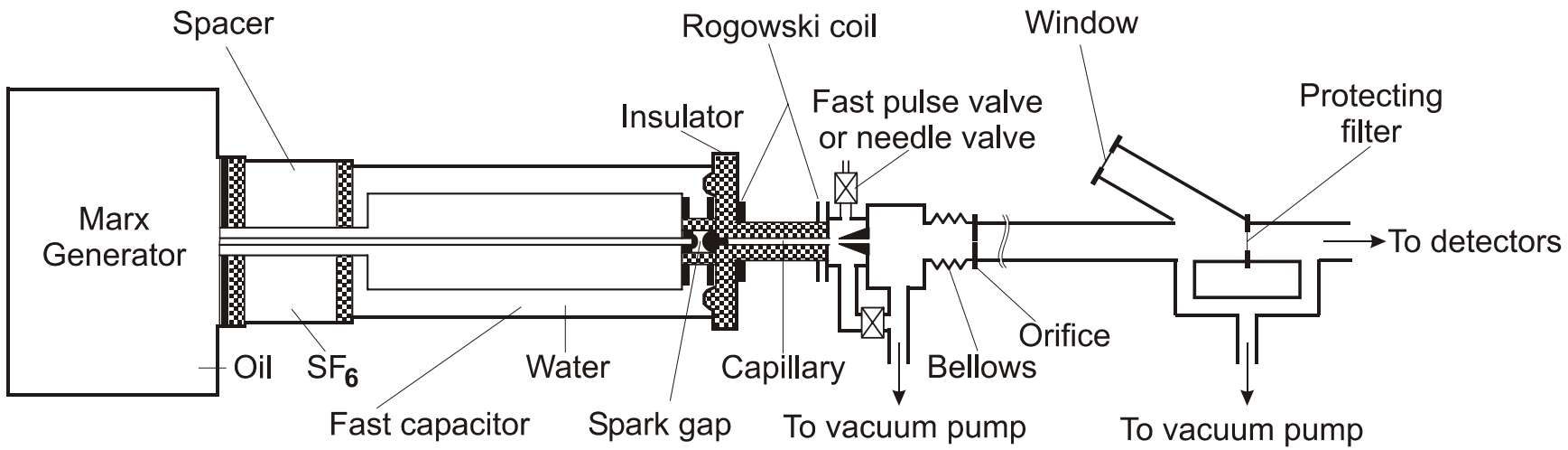
- Academy of Science of CR
  - Institute of Physics (Depts. Laser Plasma & X-Ray Lasers)
  - Institute od Plasma Physics (Dept. Pulse Plasma Systems, Laser Plasma)
- Czech Technical University in Prague
  - Faculty of Electrical Engineering (Dept. Physics)
  - Faculty of Nuclear Science and Physical Engineering (Dept. Physical Electronics)

Capillary Discharge Experiments

- CAPEX (Dept. Pulse Plasma Systems, K.Koláček)
- ABLATIVE CAPILLARY (Dept. Physical Electronics, A. Jančárek)
- NON-ABLATIVE CAPILLARY (Dept. Physical Electronics, A. Jančárek)

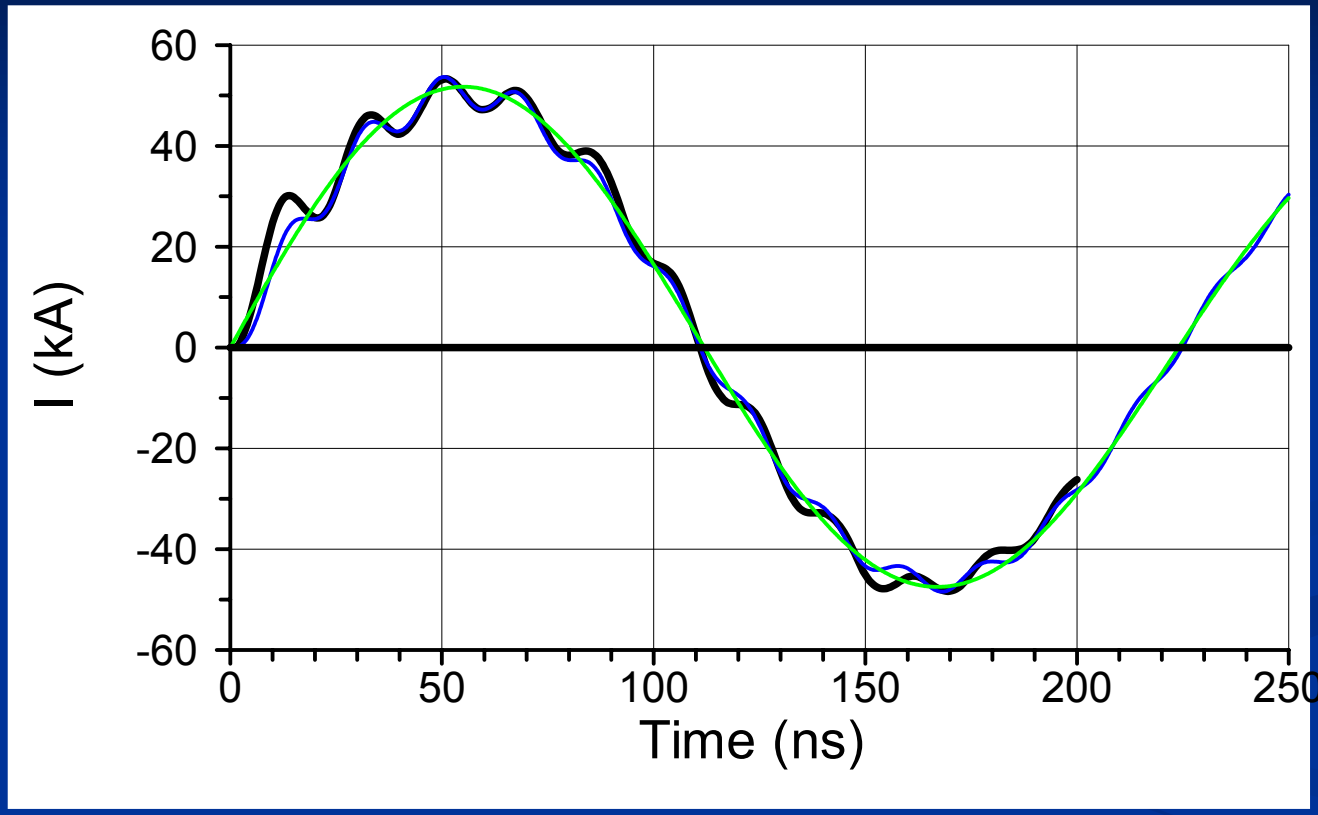
CAPEX - Argon filled capillary Institute of Plasma Physics AS CR

Experimental setup



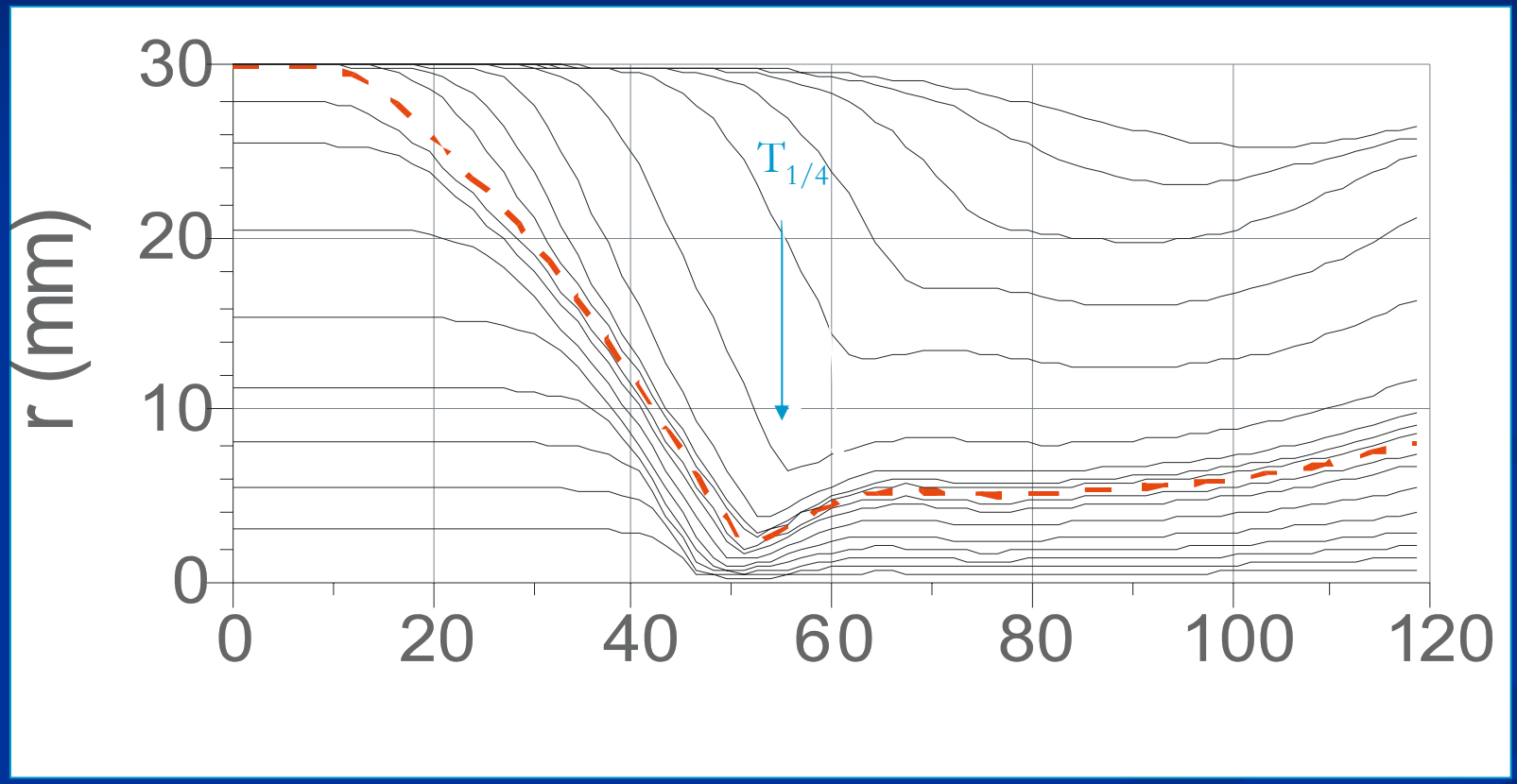
Experiment: K. Koláček et al.

Measured and fitted discharge current



$$I(t) = I_1 \sin\frac{\pi t}{2t_1} \exp\left(-\frac{t}{t_2}\right) + I_2 \frac{t_3}{t_1} \sin\frac{\pi t}{2t_3} \exp\left(-\frac{t}{t_4}\right)$$

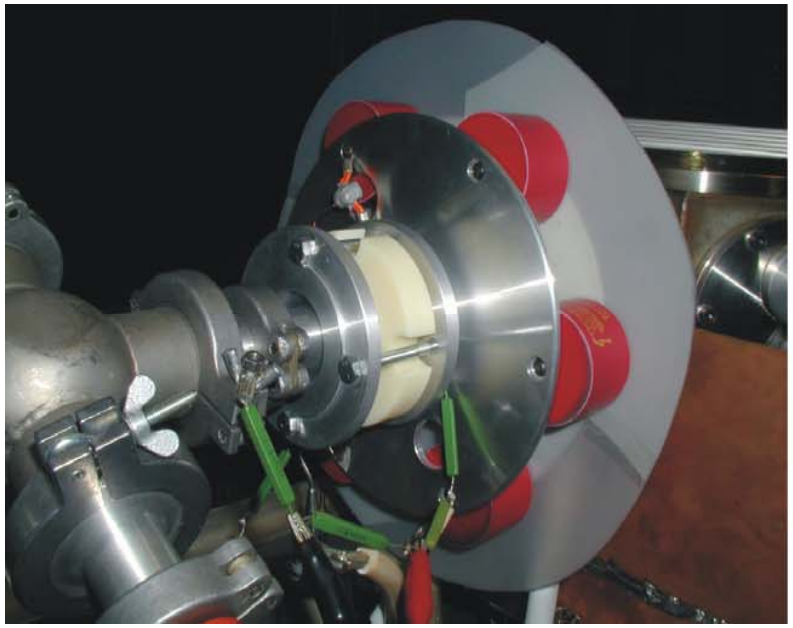
Pinching Plasma Simulations for CAPEX



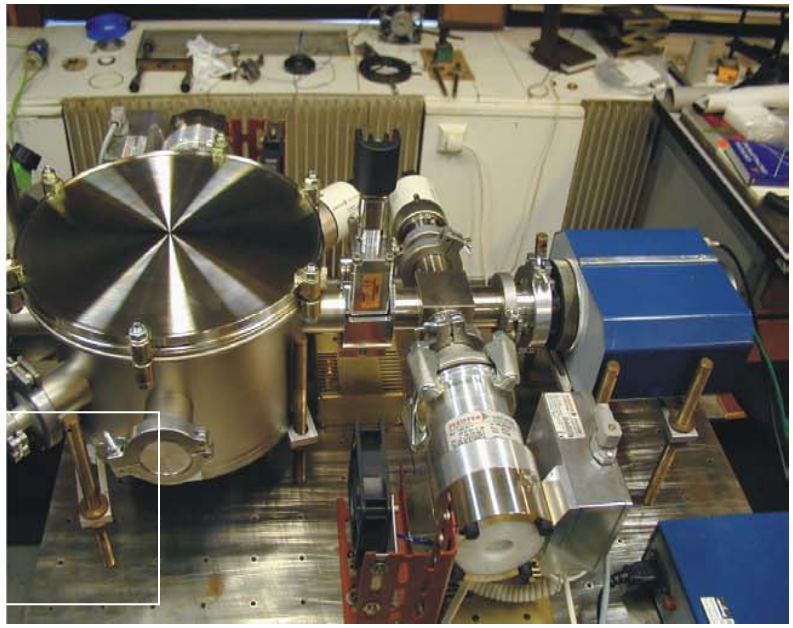
Simulations: P. Vrba, N.A. Bobrova, P.V. Sasorov

Evacuated polyacetal capillary CTU in Prague

Discharge system



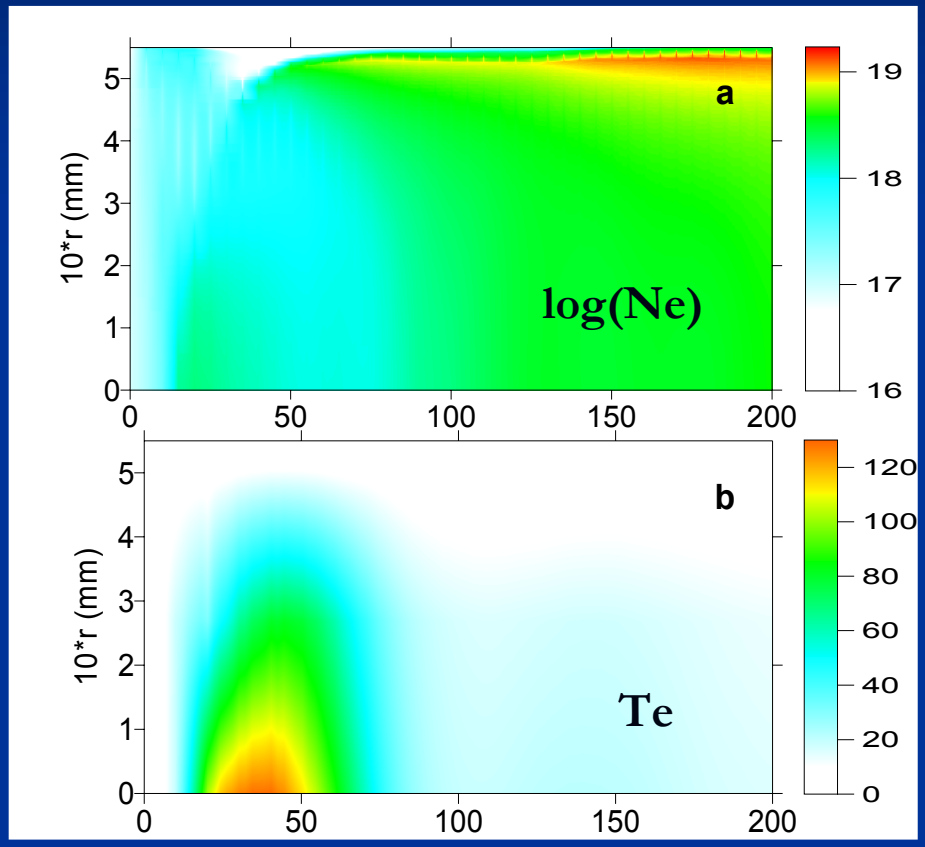
Diagnostics

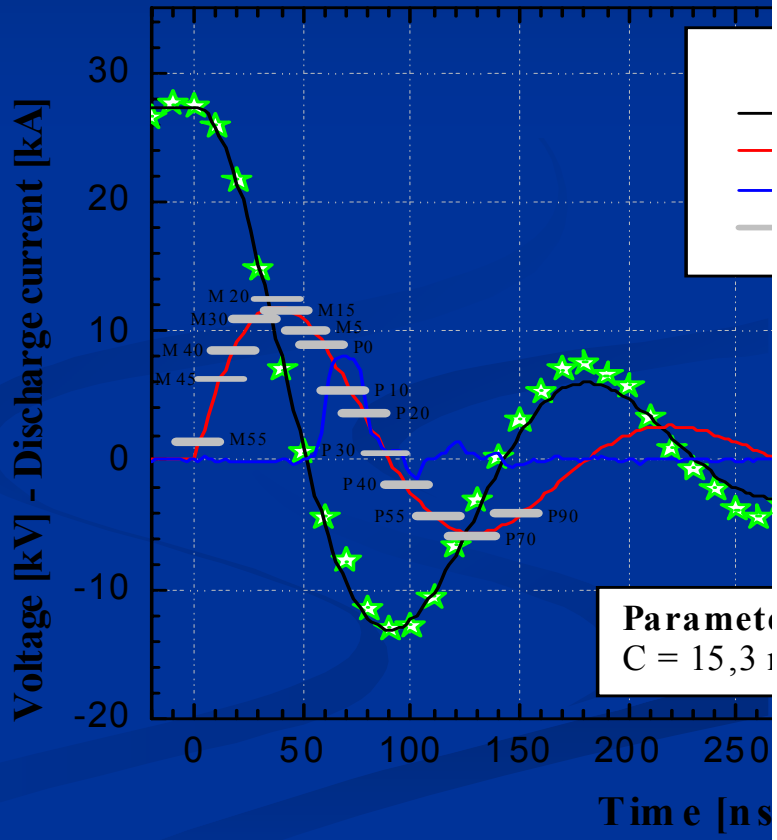


A. Jančárek et al.

$$I(t) = I_0 \sin\left(\frac{\pi t}{2t_0}\right) \exp\left(-\frac{t}{t_1}\right)$$

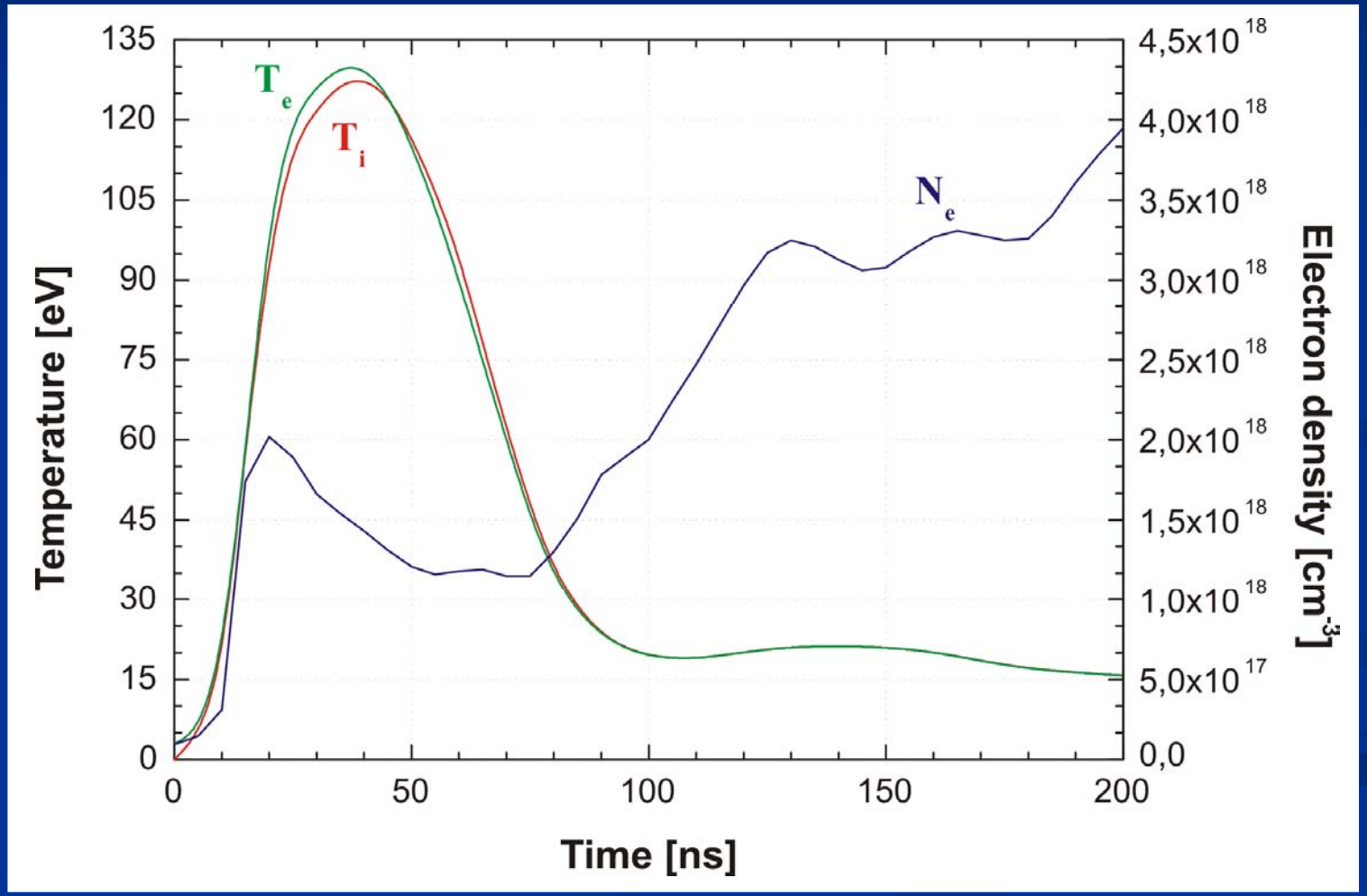
Evacuated polyacetal capillary



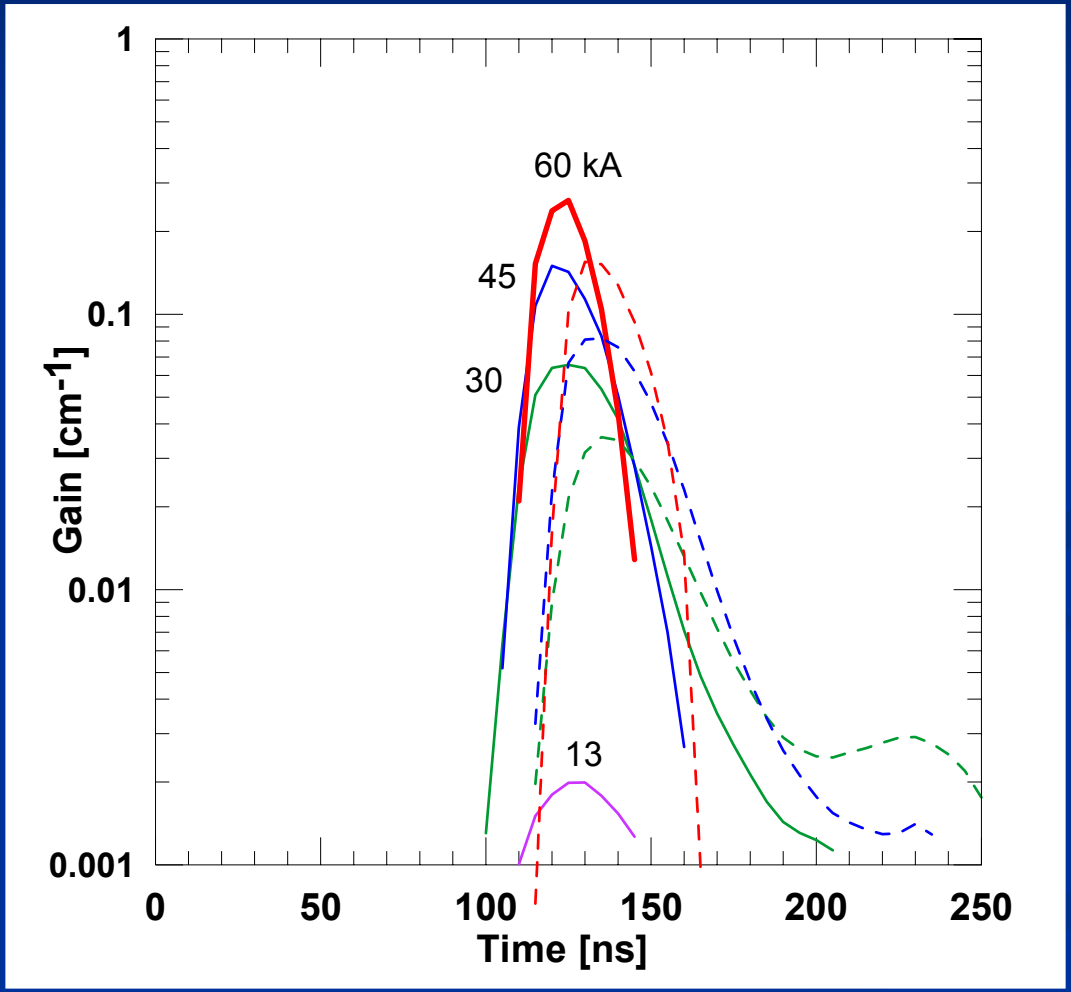


Simulations: P. Vrba, N.A. Bobrova, P.V. Sasorov

Time dependences of axial values of electron temperature and density



Evaluated gain factor



$$G = \sigma \{N_2 - (g_2/g_1) N_1\}$$

- Negligible gain for the peak current of 13 kA
- To get measurable gain remarkable increase of the peak current is required.

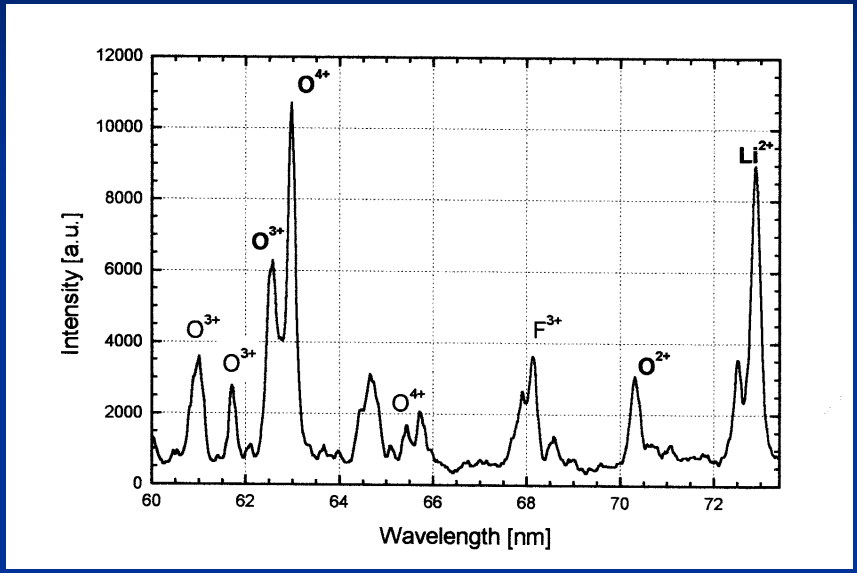
THERORETICAL CONTRIBUTIONS
(INTERNATIONAL COOPERATION)

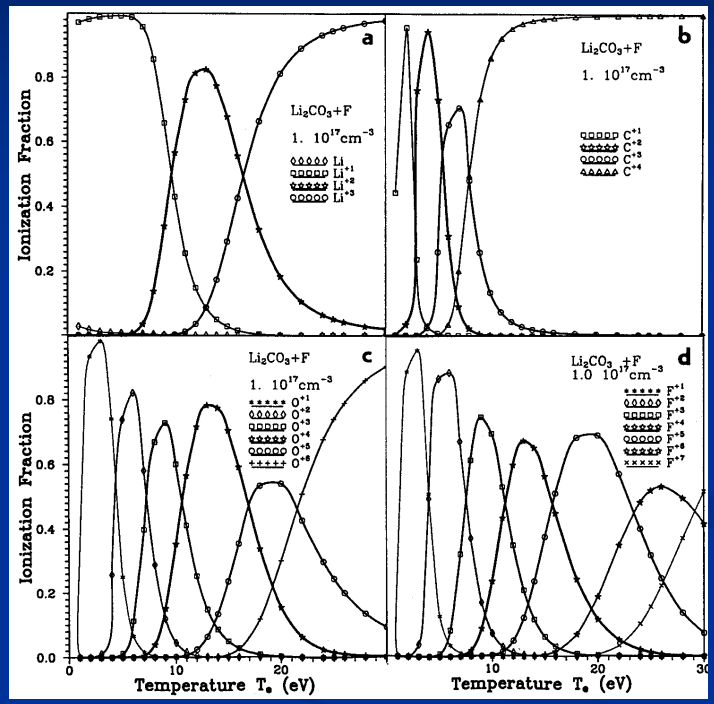
- Estimation of the Electron Temperature in **Li_2CO_3** Ablative Capillary (Austrian – Czech- Russian)
- **Xenon** Capillary Discharge as a Source of Soft X-Ray (French-Czech-Russian)
- Pinching Discharge in **Nitrogen Filled** Capillary (Czech- Russian)
- Z-Pinch in Argon Filled Capillary (Czech- Russian-Japanese)

Cooperation - Projects

- 1998, 1999 – KONTAKT (Czech-Austrian- TU Graz)
- 1999-2001 – GAČR (IPP , FNSPE)
- 2000-2004 – Laser Plasma Research Center (IP, IPP,
- 2000-2007 – INGO Program (Reserch in the frame of International Center for Dense and Magnetized Plasma)
- 2002-2004 – KONTAKT (Capillary Discharge Optimization, Czech-Japan
- _____
- Long term cooperation between IPP and FNSPE
- Long term cooperation with ITEP (N. Bobrova, P. Sasorov)
- Informal cooperation with GREMI (C.Cachoncinle, O.Saroukh –student exchange)
- Prepared cooperation with Universita d´Aquila (G.Tomassetti)

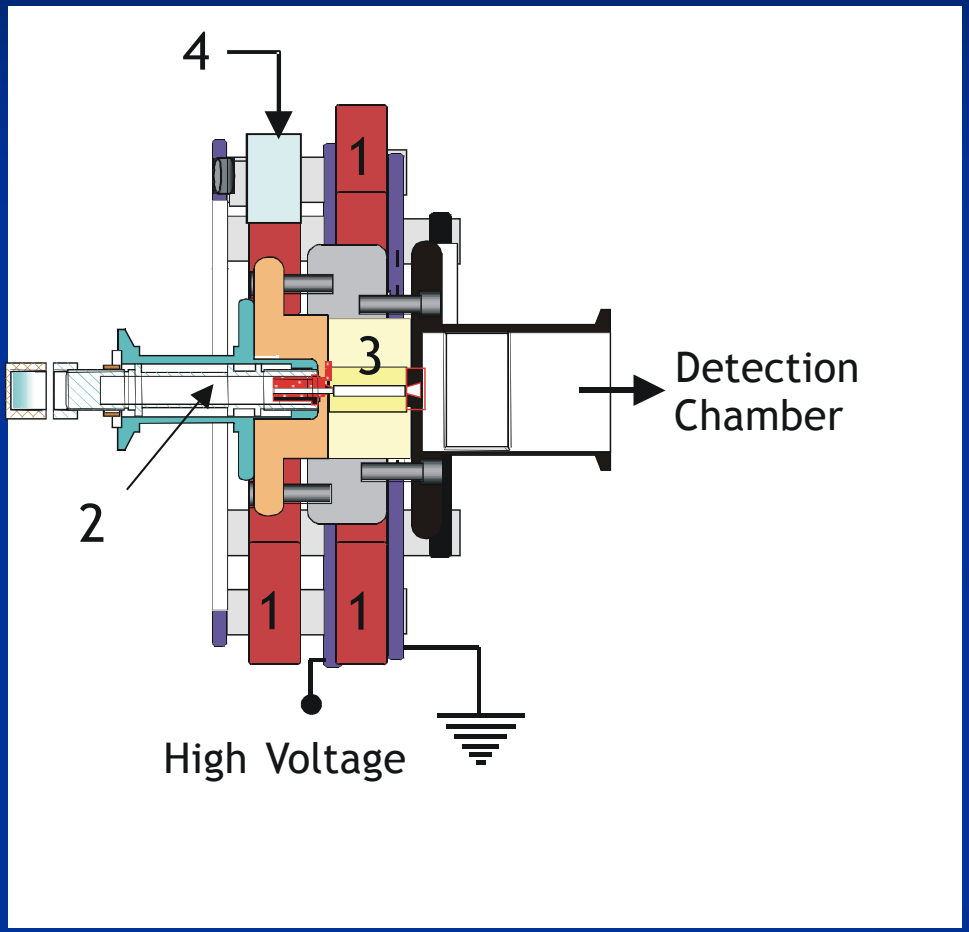
Cooperation with TU Graz





- Li2CO3 capillary discharge
- records at various delay times with gating interval 5 ns
- oxygen, lithium and fluorine ions identified

Collaboration with GREMI Orleans

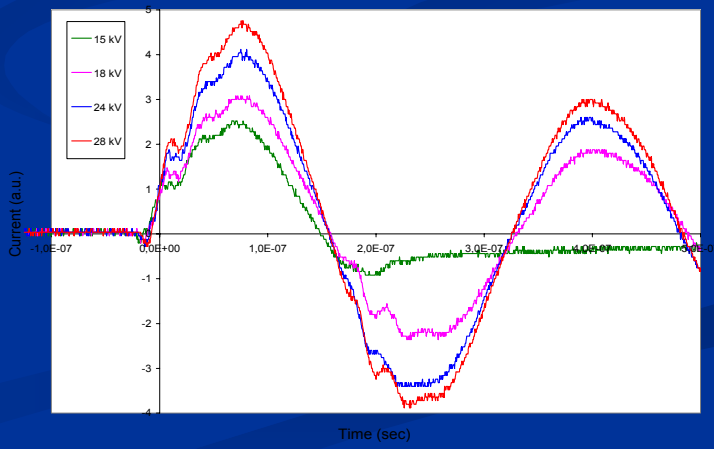


Goal of the experiment:

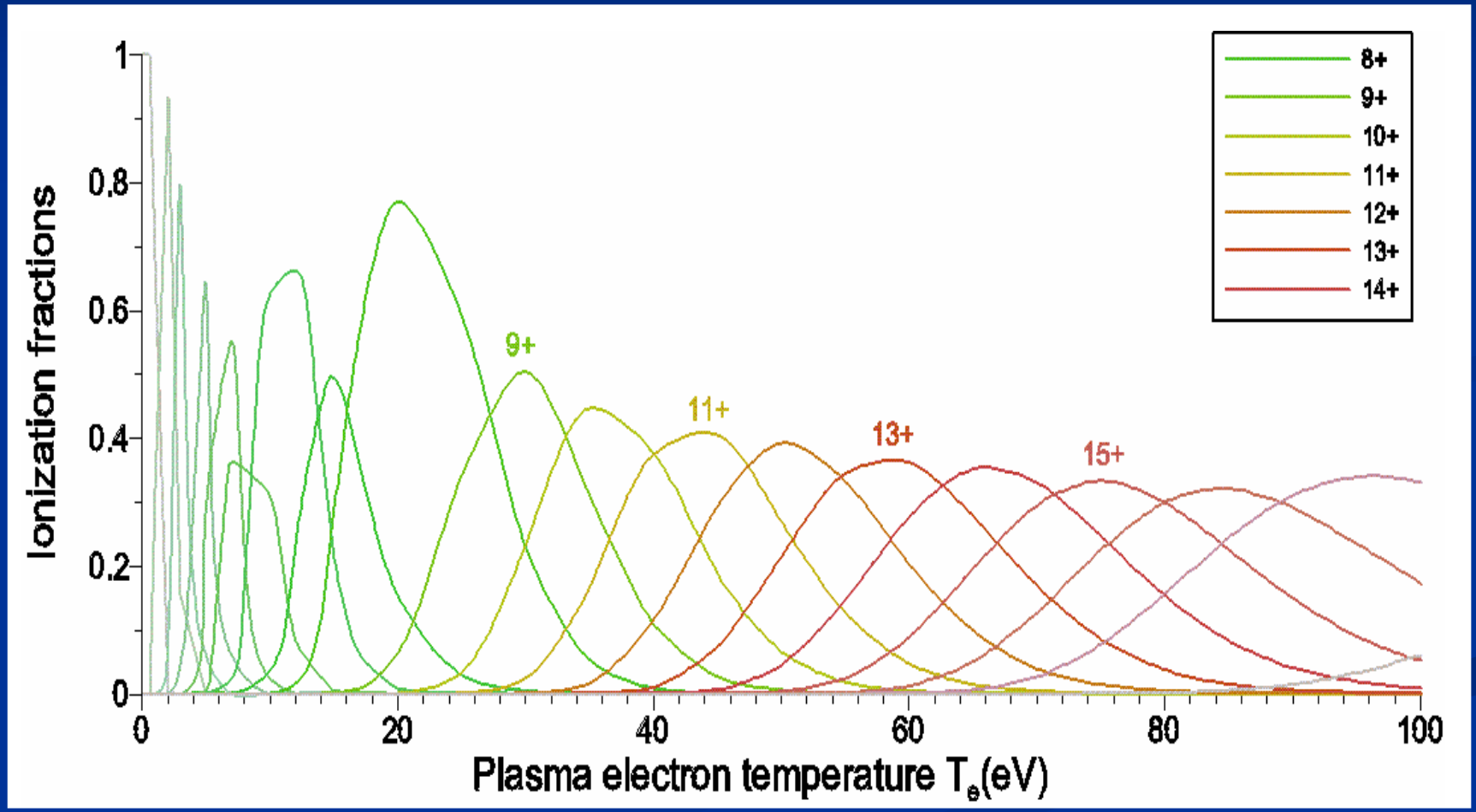
- High brightness source of radiation (λ =13 nm)

Goal of the simulations:

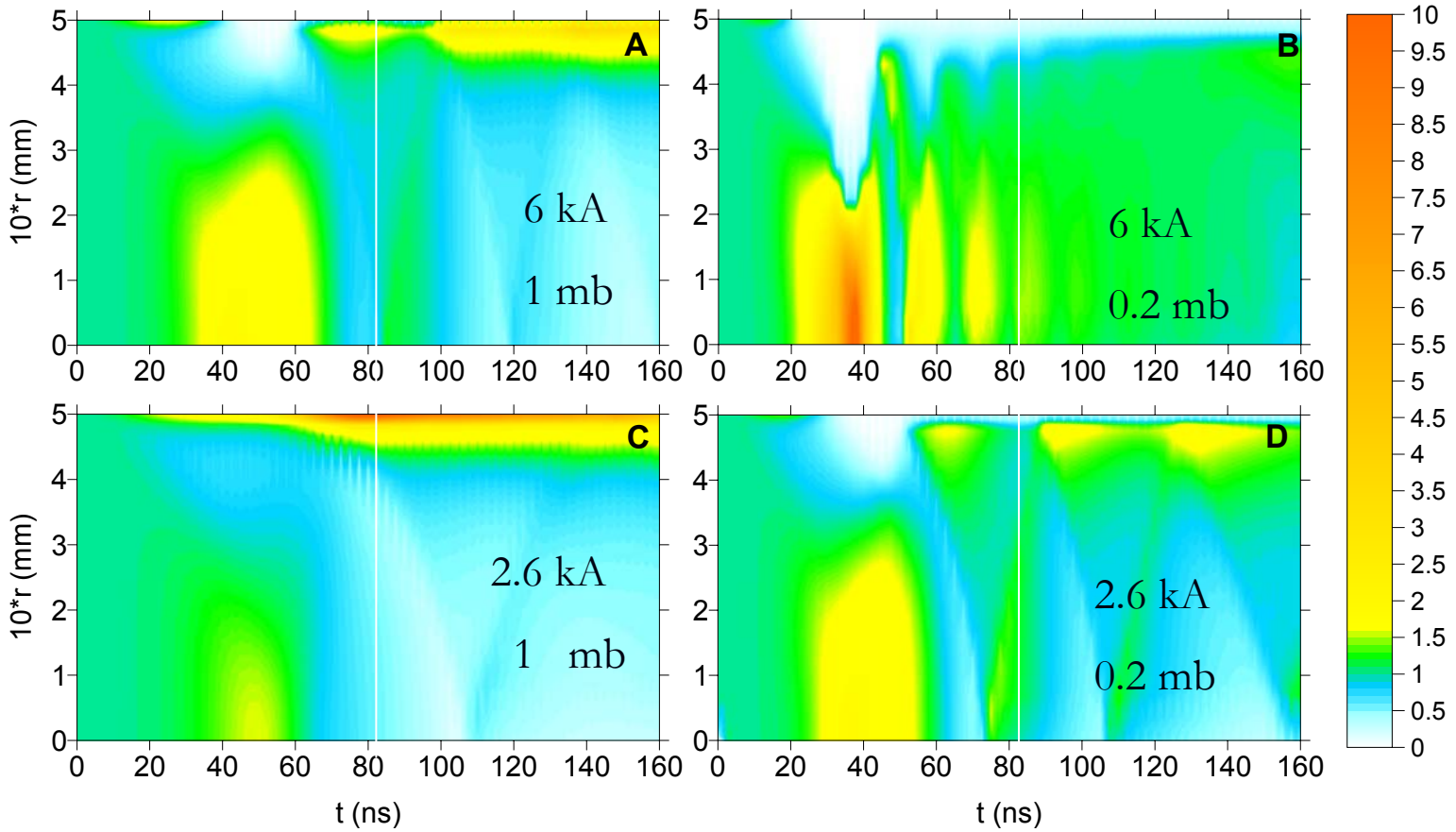
- Dependence of plasma properties on pressure (gradient)



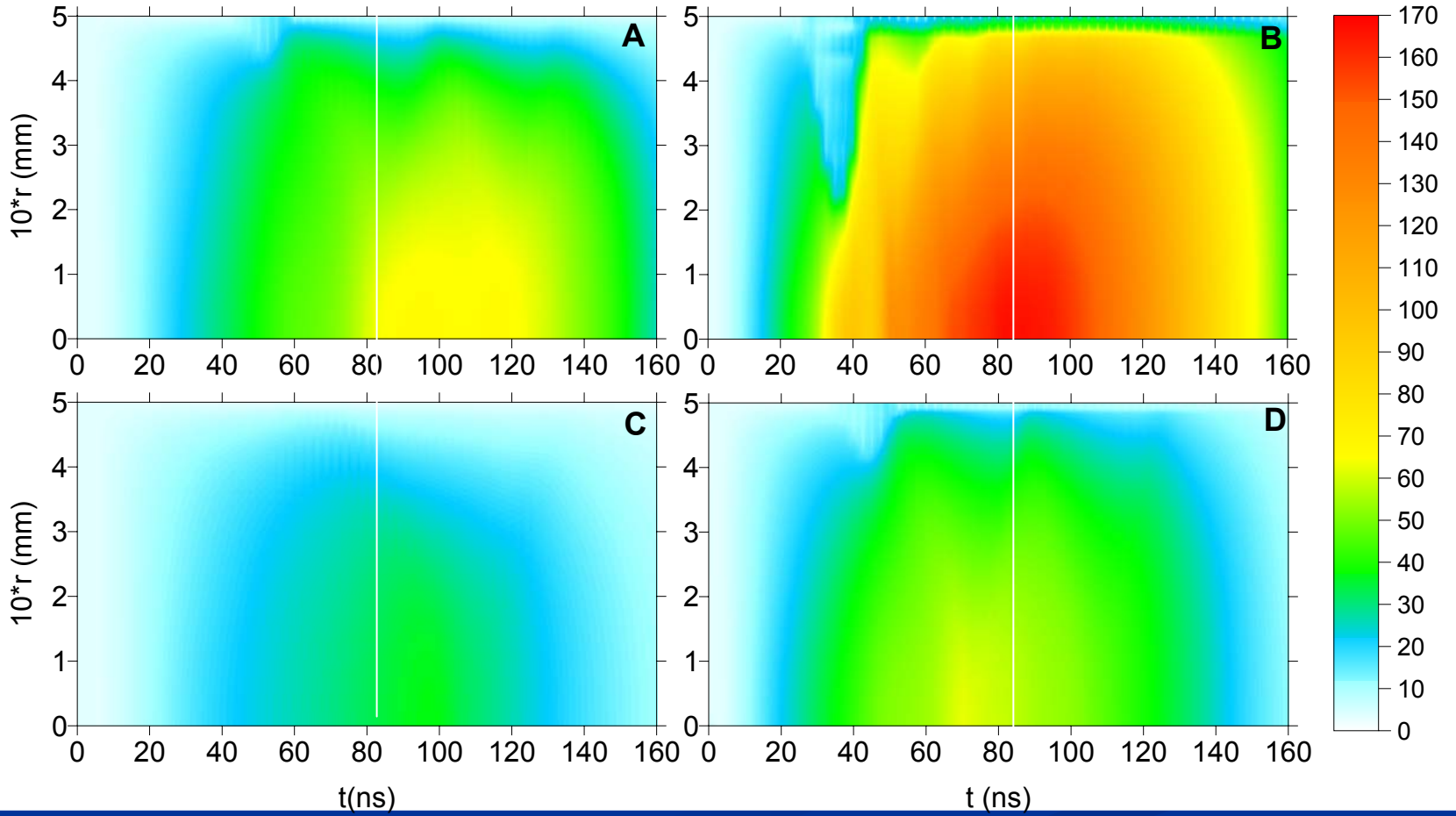
Ionization state of Xe vs plasma electron temperature



Xe plasma dynamics (multiple reflections)

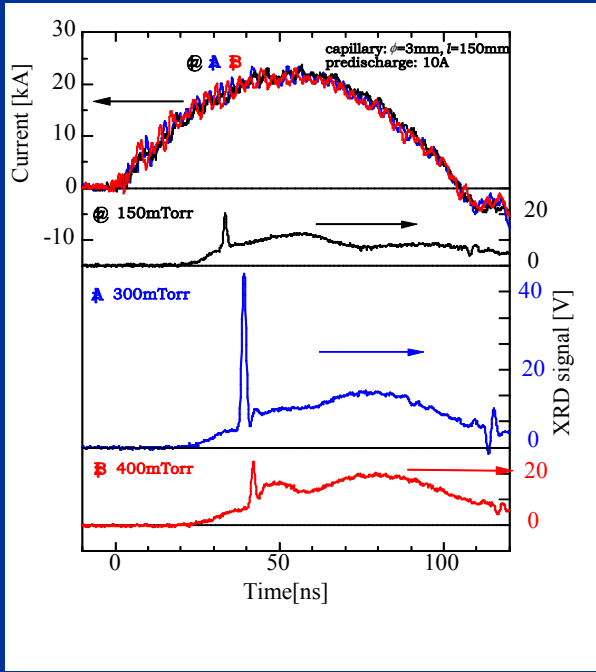


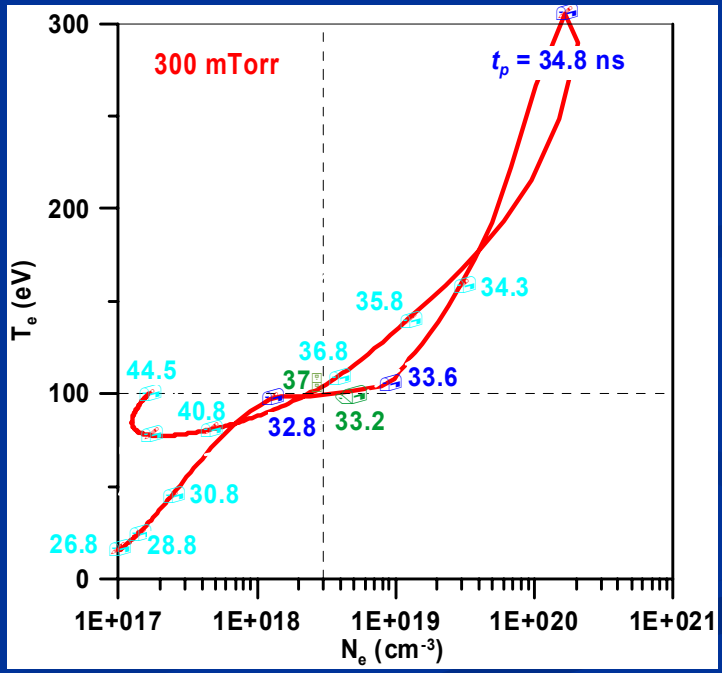
The space-time dependences of electron temperature T_e



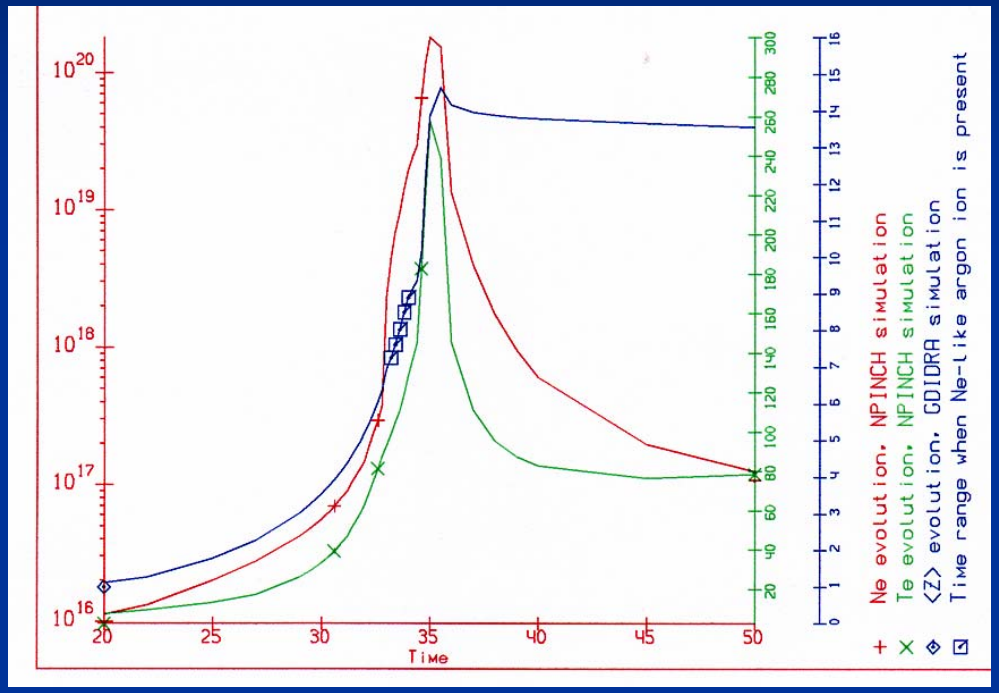
Collaboration with TIT Tokio

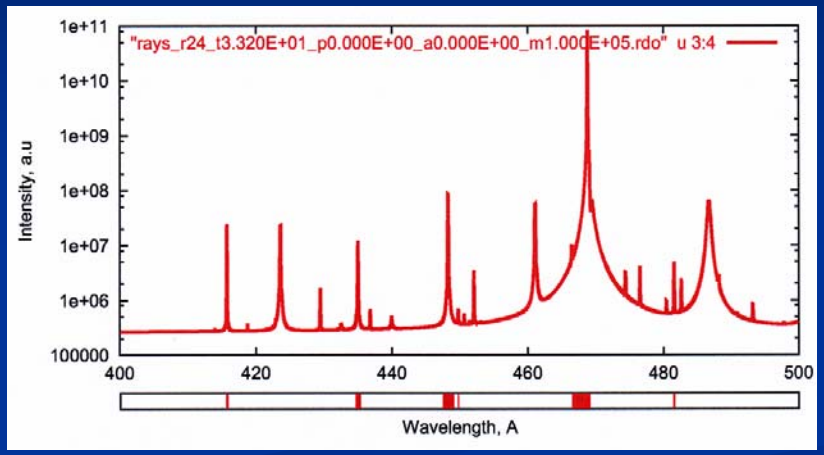
- Argon filled capillary discharge for EUV laser pumping (P. VRBA, N. A. BOBROVA, K. HORIOKA, E. HOTTA, P. V. SASOROV, A. STEPANOV, M. VRBOVA)





Ion kinetics and spectra evaluation





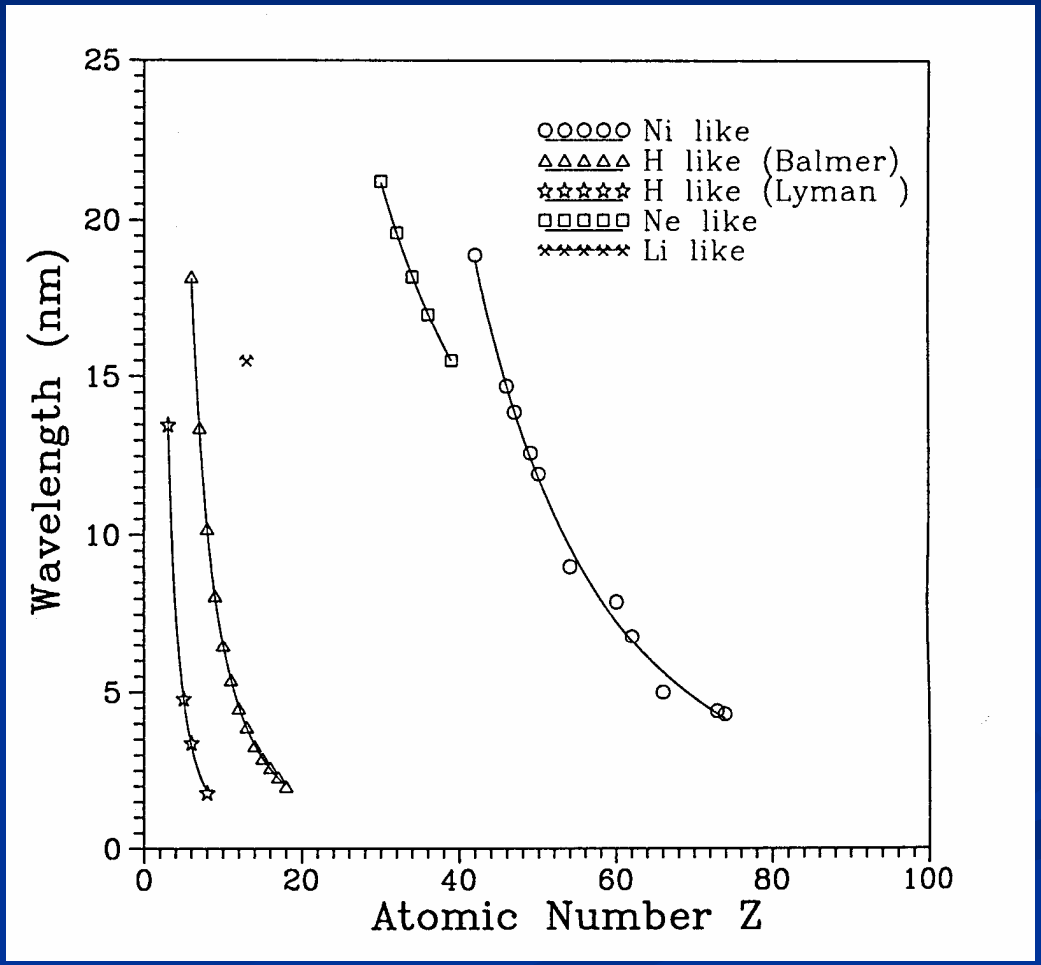
Validity of the model prooved

Lasing wavelength

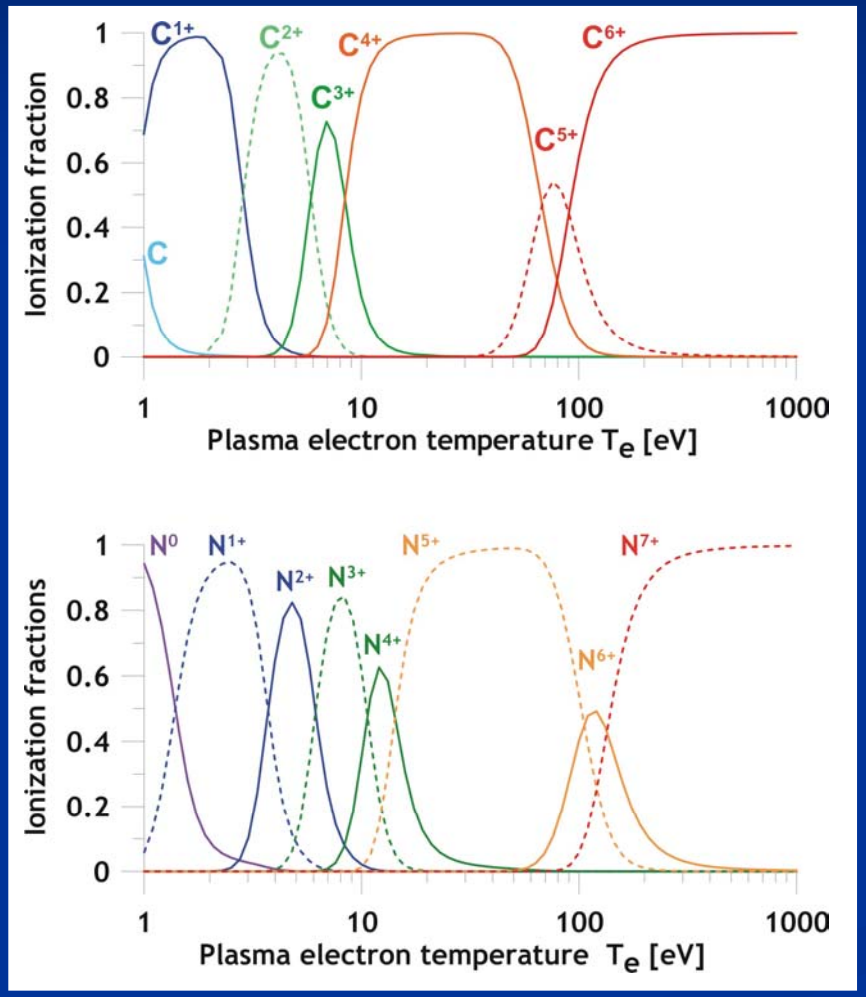
Argon: 46.9 nm

Carbon: 18.2 nm

Nitrogen: 13.4 nm

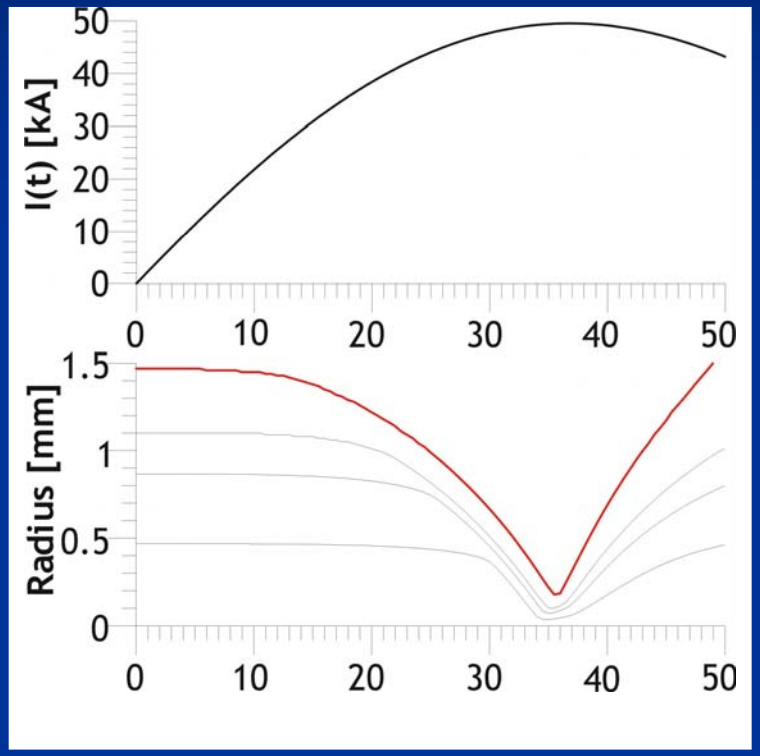


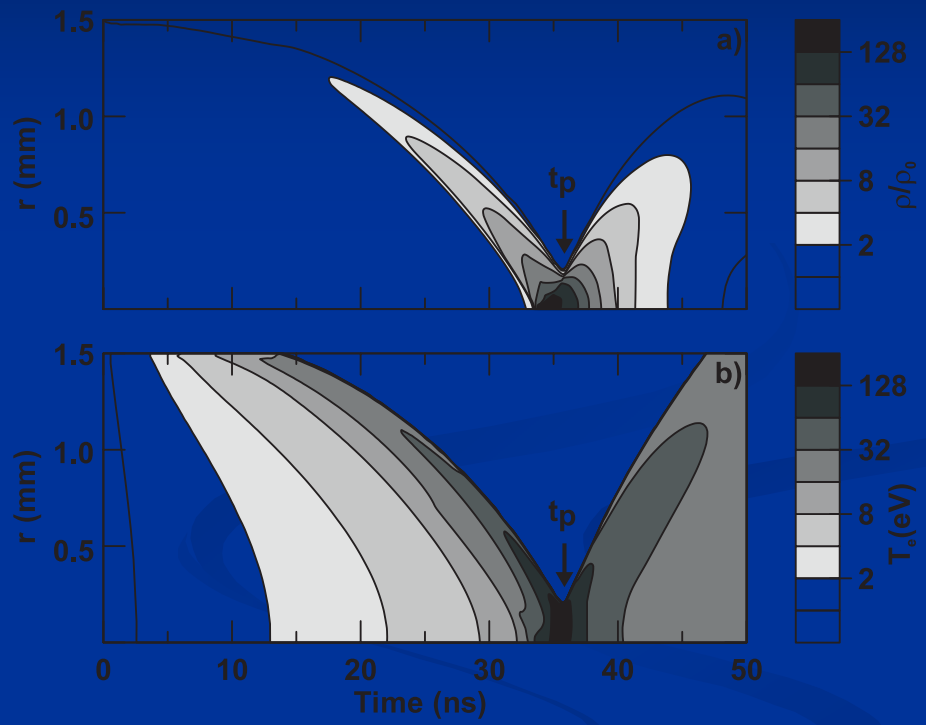
Nitrogen filled capillary recombination pumping



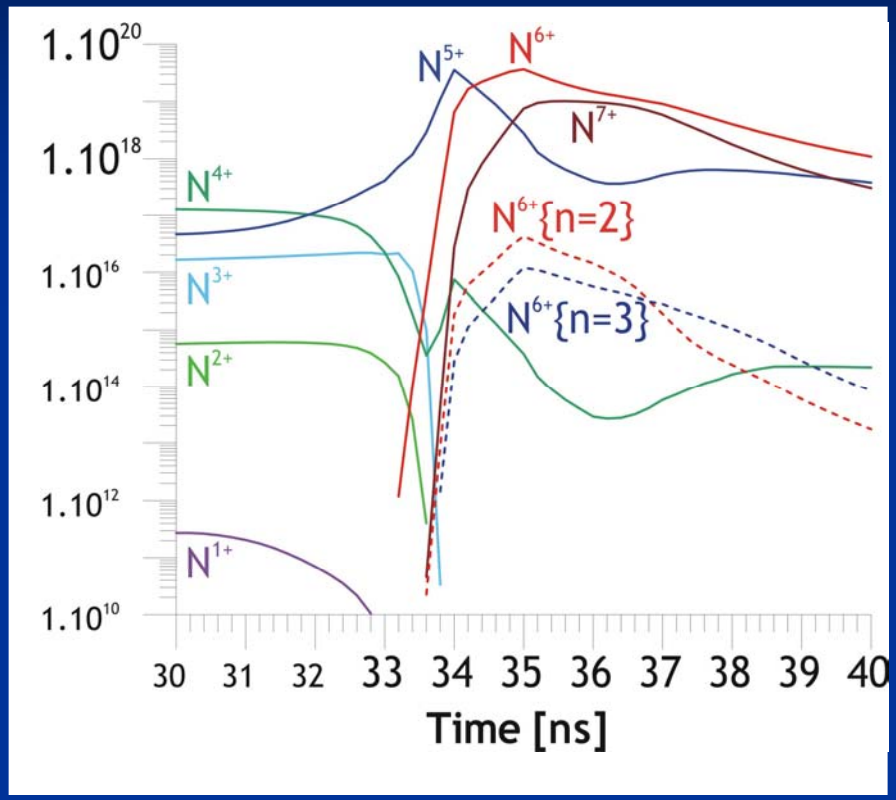
- Laser transition – Balmer α line
- Lasing wavelength – 13.5 nm
- Pumping scheme
  1. Heating during the pinch
  2. Fully ionized nitrogen atoms produced
  3. Quick plasma cooling during the pinch decay
  4. Three body recombination in under-cooled plasma

Pinch evolution in non-ablating nitrogen filled capillary





Theoretical Analysis



Experiment suggested

I_{max}= 50 kA, $T_{1/4}$= 40 ns

OUR GOALS

- To develop a method of optimization of pinching discharge in non-ablating capillaries
- To realize EUV laser recombination pumping during pinch decay
- To get lasing at the wavelength of 13 nm

Cooperation expected (planned)

- Tokio Institute of Technology (Japan)
  - further progam shoud be agreed
- University of Aquila (Italy)
  - nitrogen pinch modelling,
  - experiments with nitrogen filled capillary prepared
- Troitsk Institute for Innovation (Russia)
  - modelling of EUV radiation spectra
- Institute of Theoretical Physics (Russia)
  - MHD code improving

Conclusion

Any coment,

suggestion

idea

for future cooperative activities are highly appreciated.