ELI ERIC, ELI Beamlines
CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING

# *Capillary Discharge Applications at ELI-Beams and CTU Groups*

Alexandr Jancarek, Michal Nevrkla,
Ladislav Pina and Alexander Molodozhentsev

EuPRAXIA Doctoral Network

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- Research team – introduction

- L2-DUHA laser

- Capillary Discharge
- H, He/N2 capillary sources for LPA
- Ar capillary discharge for APL

- Ne-like Argon 46.9nm laser
- He-like Nitrogen 2.88 nm incoherent source
- H-like Nitrogen recombination source driver

**Scientists**

**As. prof. L. Pína, DrSc. Leader of the XUV photonics group**

**N. Bobrova, DrSc., A. Jančárek*, PhD., M. Nevrkla*, PhD., prof. M. Vrbová, PhD., Ing. P. Vrba, PhD., Bc. R. Míka Havlíková**

**A. Molodozhentsev, PhD. Leader of the Luis group**

**S. Maity, PhD., P. Sasorov, PhD., P. Zimmermann, PhD.**

**T. J. Green, PhD. Leader of L2 laser group**

**G.M Grittani, PhD. Leader of ELBA group**

**CTU and ELI PhD. students**

**MSc. M. Miceski, Ing. S. Niekrasz, Ing. J. Šišma, Ing. F. Vitha, MSc. A. Whitehead**


# Laser-Plasma-Accelerator-Based Compact Free Electron Laser PROGRAM at ELI Beamlines

Alexander Molodozhentsev

ELI ERIC / ELI Beamlines, Czech Republic

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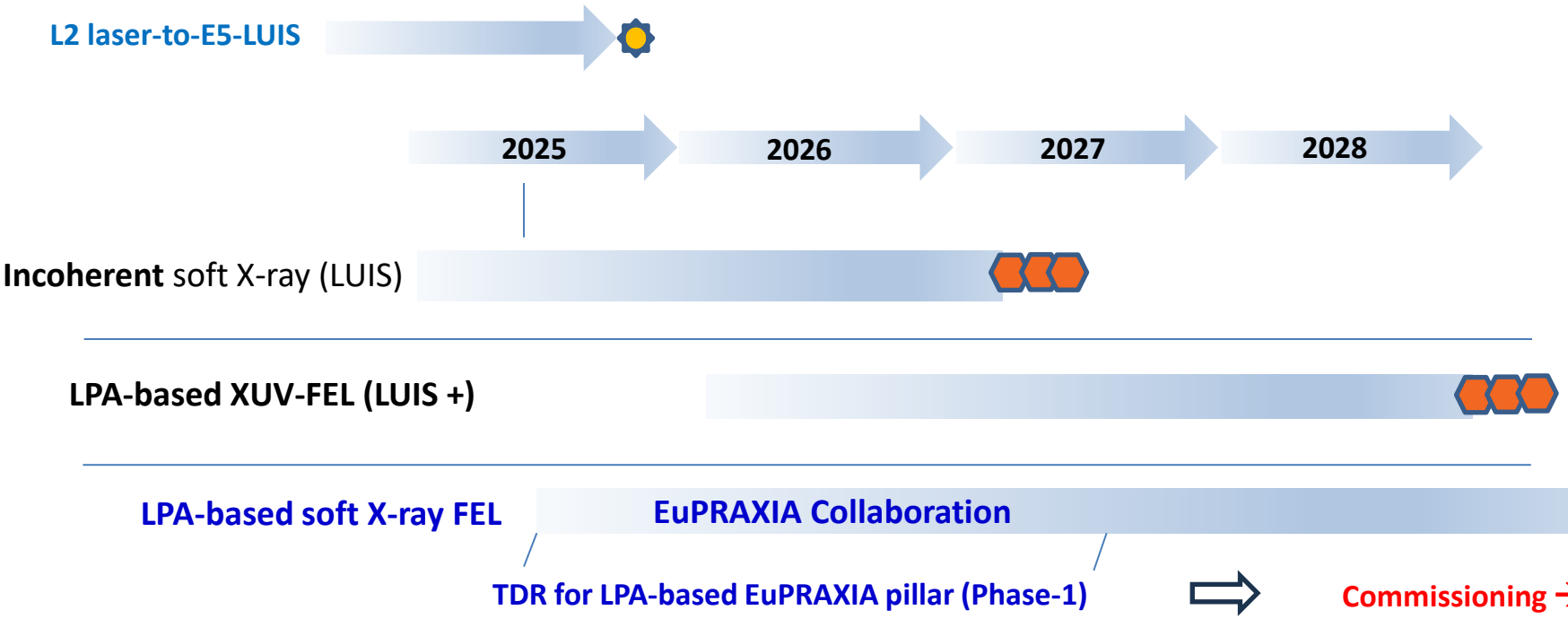
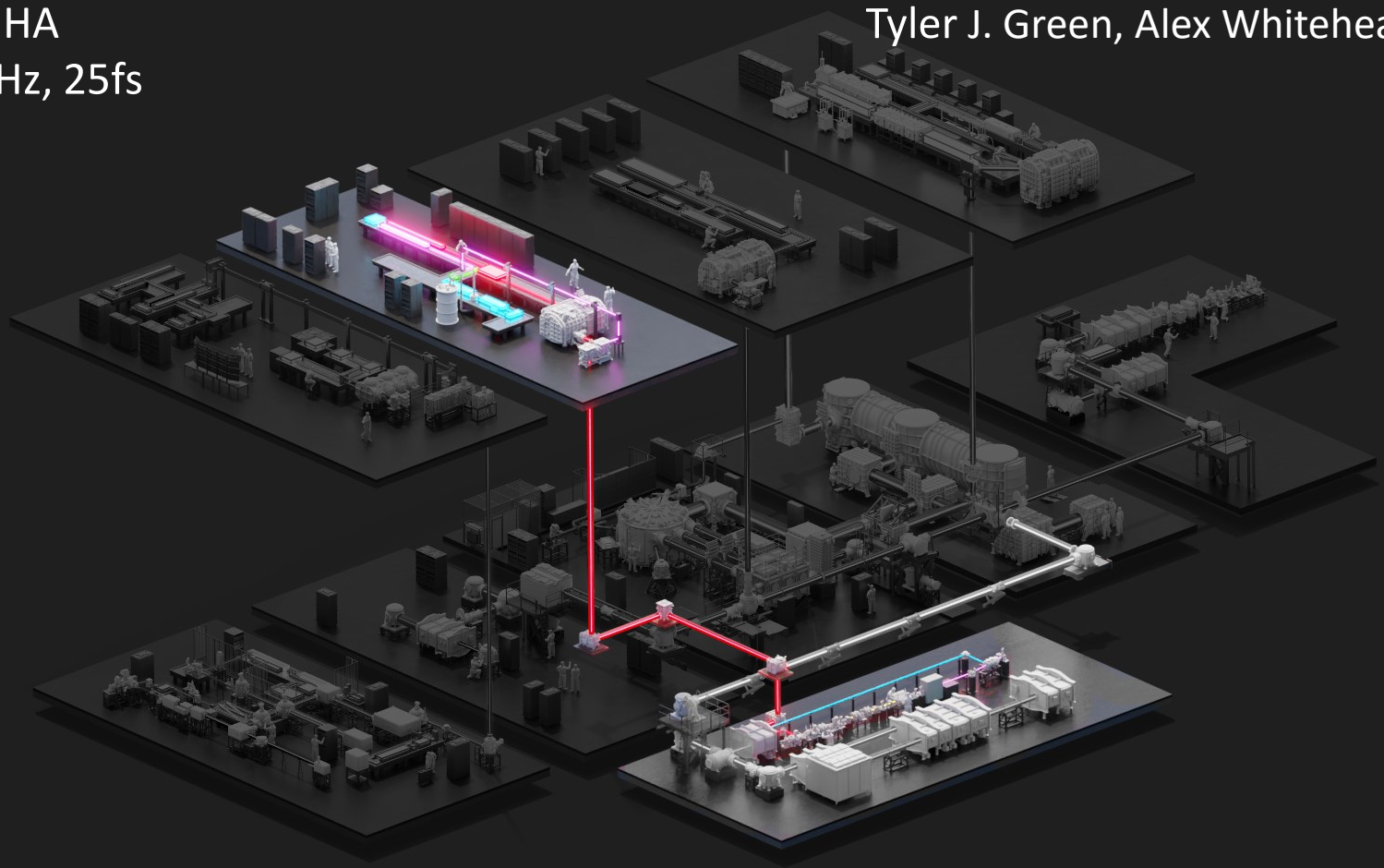
# PLASMA ACCELERATOR BASED FREE ELECTRON LASER PROGRAM AT ELI ERIC (ELI Beamlines)

**Current schedule aiming … → User operation**

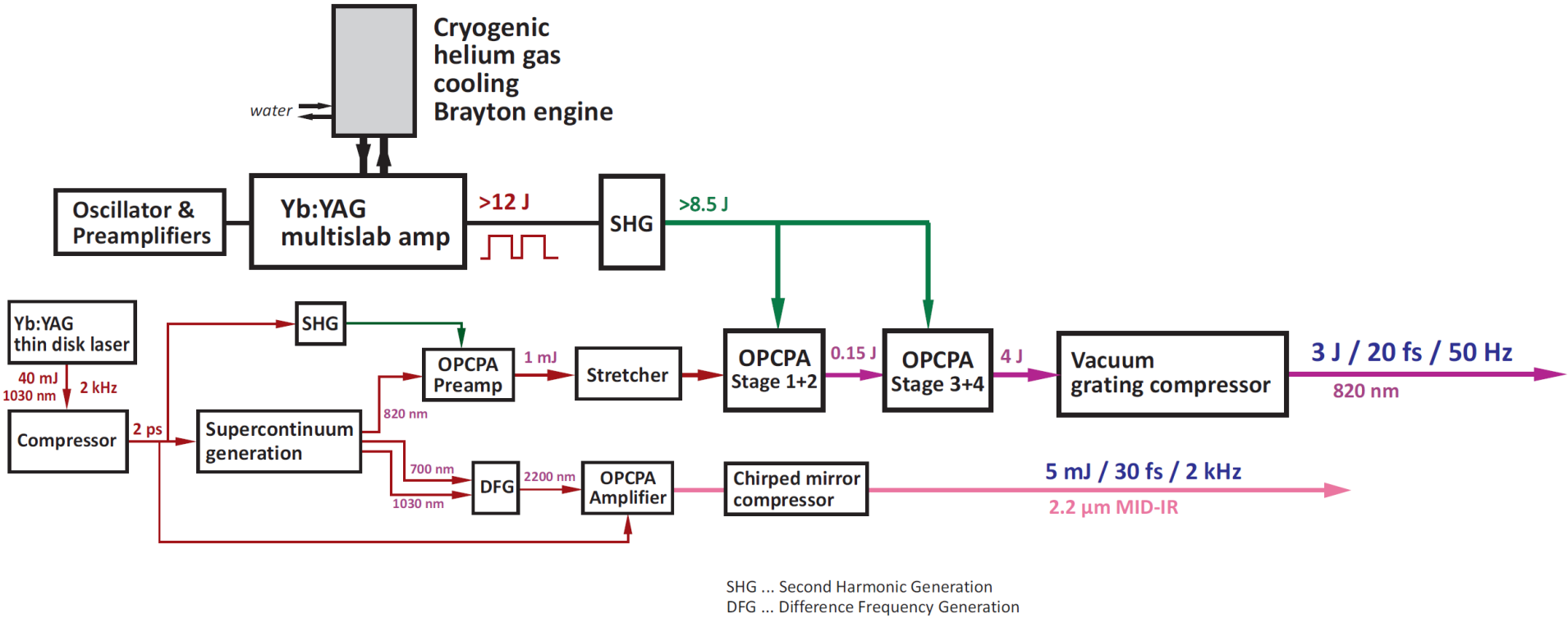


L2-DUHA
3J, 20Hz, 25fs

Tyler J. Green, Alex Whitehead



# L2-DUHA 100TW, 20Hz (under development)



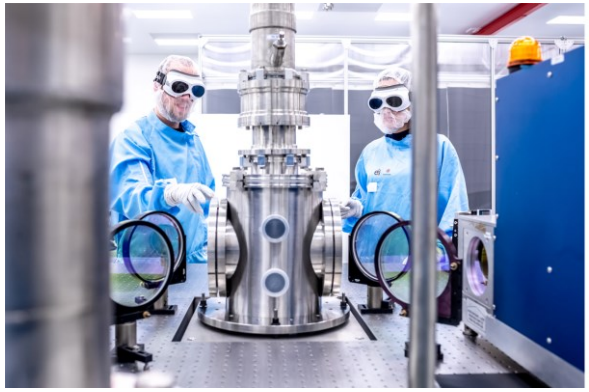

SHG ... Second Harmonic Generation
DFG ... Difference Frequency Generation

Intended as dedicated driver for LWFA. Focus on repetition rate with goal of 100Hz and peak power of 200TW

# L2-DUHA 100TW, 20Hz (under development)

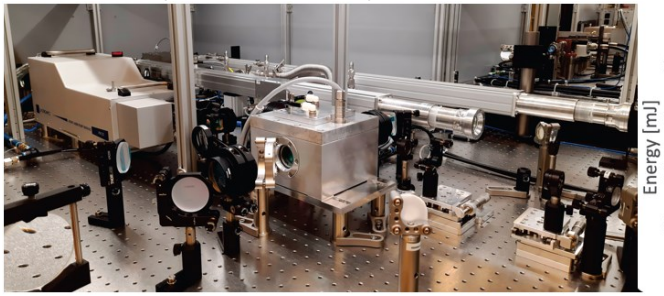
Pump laser amplification based on cryogenically cooled Yb:YAG multi-slab technology.

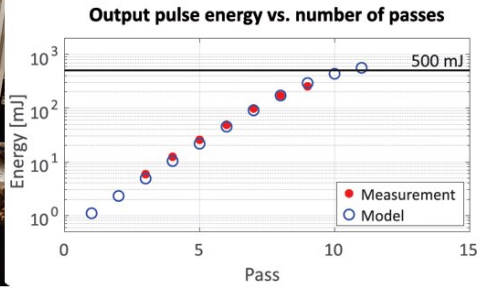
**10J demonstrated** from the system and the multipass amplifier is being upgraded in L2-DUHA project.



Cryogenic cooling demonstrated to 120K

Booster amplifier operating at 250mJ and cryo running at 120K. Amplification in main amplifier underway

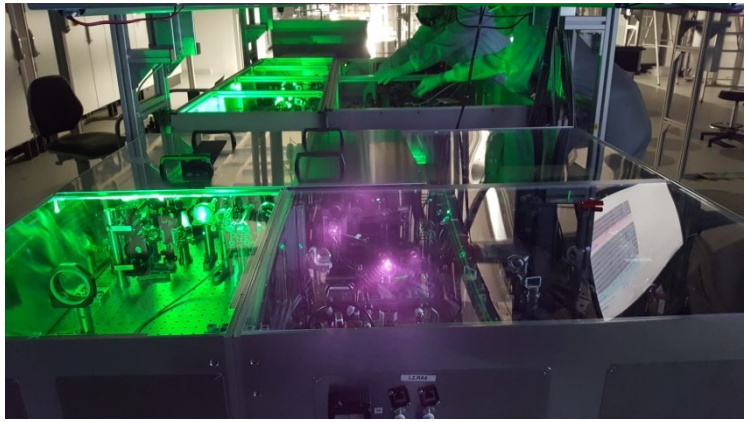


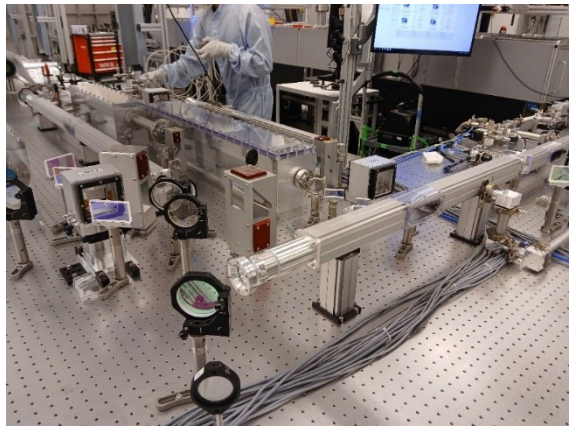


# L2-DUHA 100TW, 20Hz (under development)

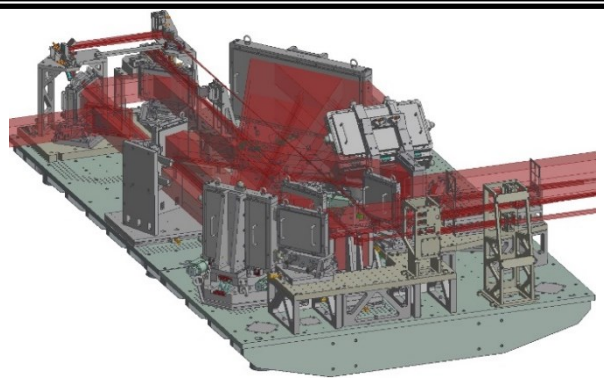
Short pulse amplifier is combination of picosecond and nanosecond OPCPA pumped by DPSSL

High energy OPCPA pre-aligned and alignment and synchronization of pump and signal pulses underway



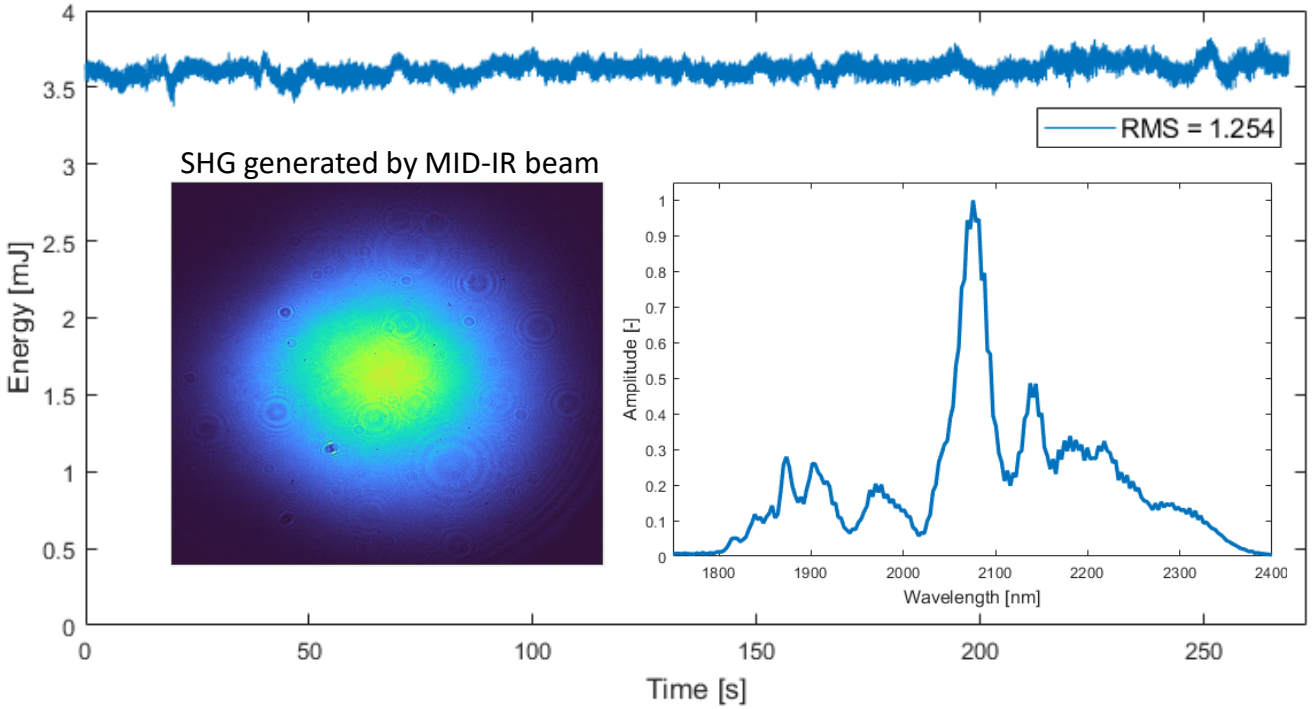


200 TW compressor is installed and connected to beam transport to experimental hall. Currently being populated with optics



# Mid IR OPCPA

- Achieved 3.6 mJ
- Spectrum spaning from 1800 nm to 2400 nm
- SHG generated by mid-IR beam has Gaussian shape



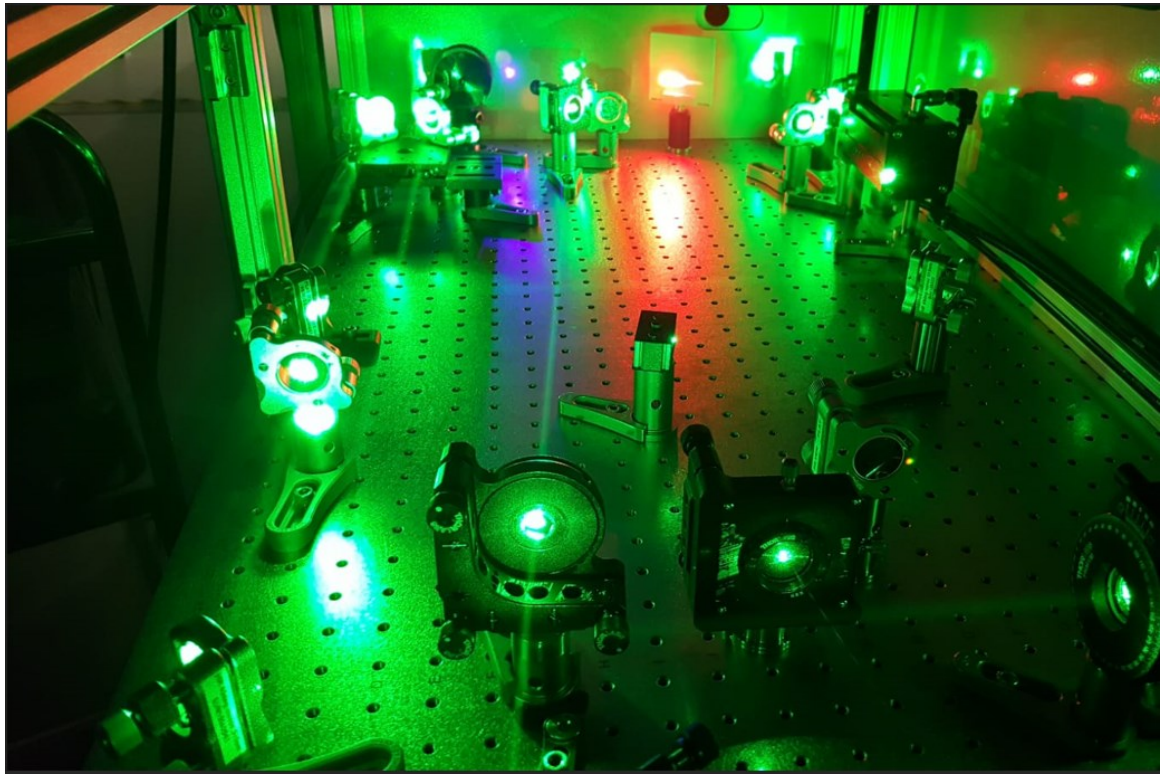
# Broadband Front end

Current status:

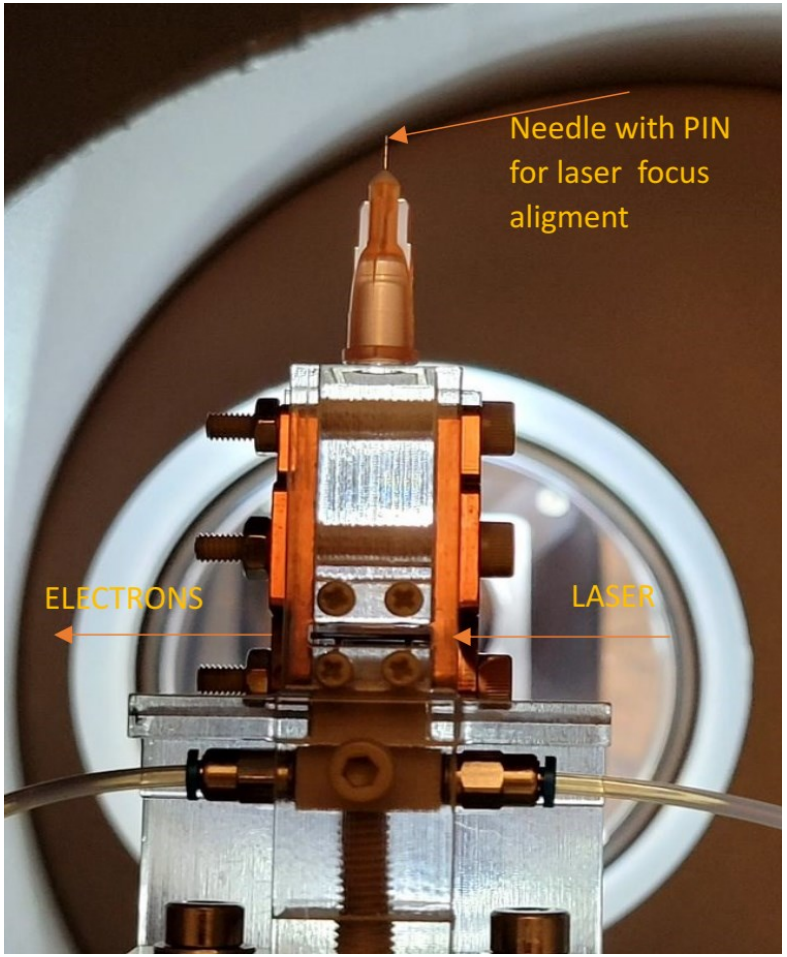
- Stable pump laser source
- Broadband generation using SC
- Amplification of near IR beam to > 2 mJ
- Mid IR generation using DFG
- Amplification of mid IR to ≈ 3.6 mJ

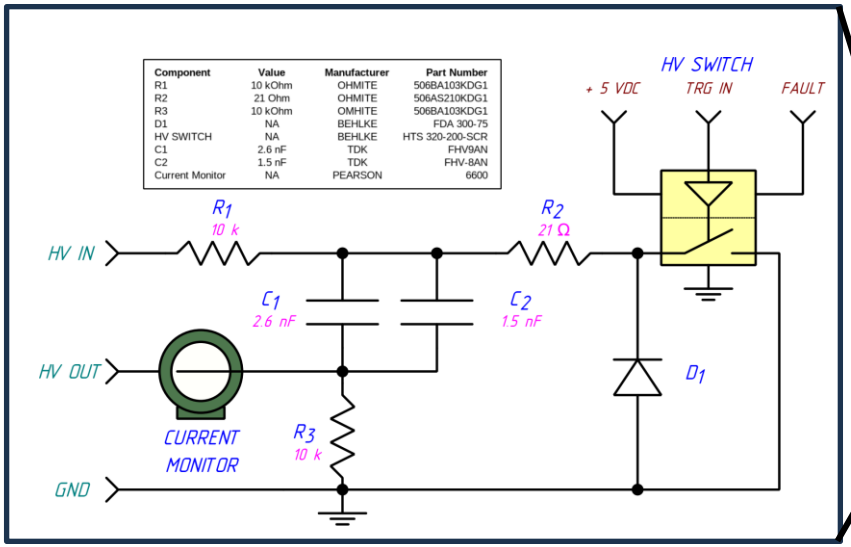
To be done:

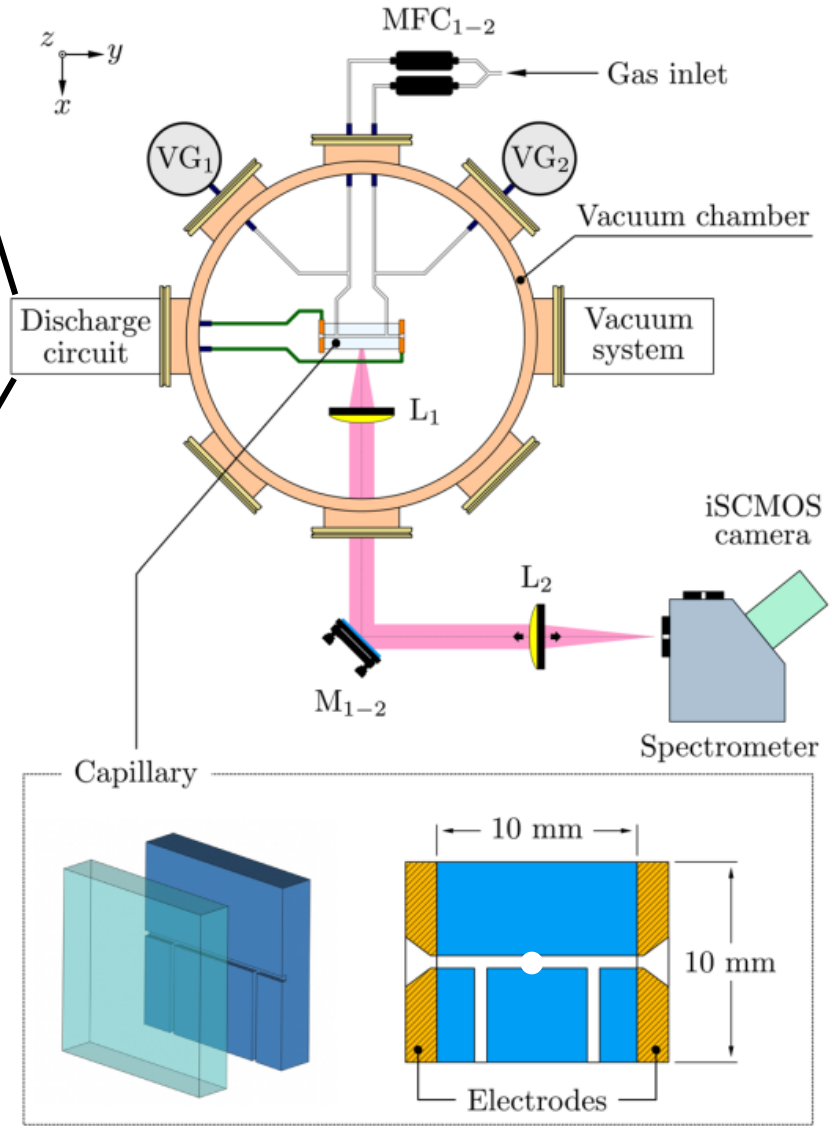
- Beam profile optimization and stretching of near IR beam
- Amplification of mid IR to 5 mJ and complete < 30 fs compression

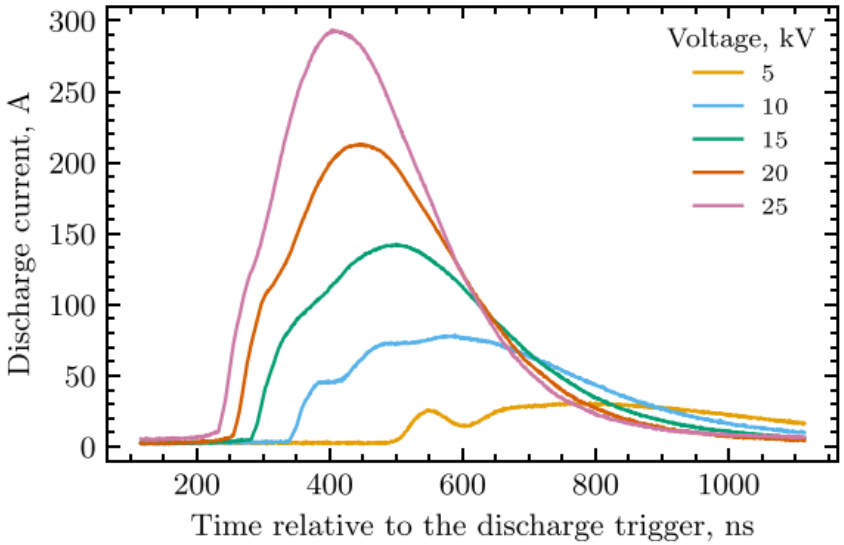


# Capillary discharge for LPA
# ELI Luis lab test bench

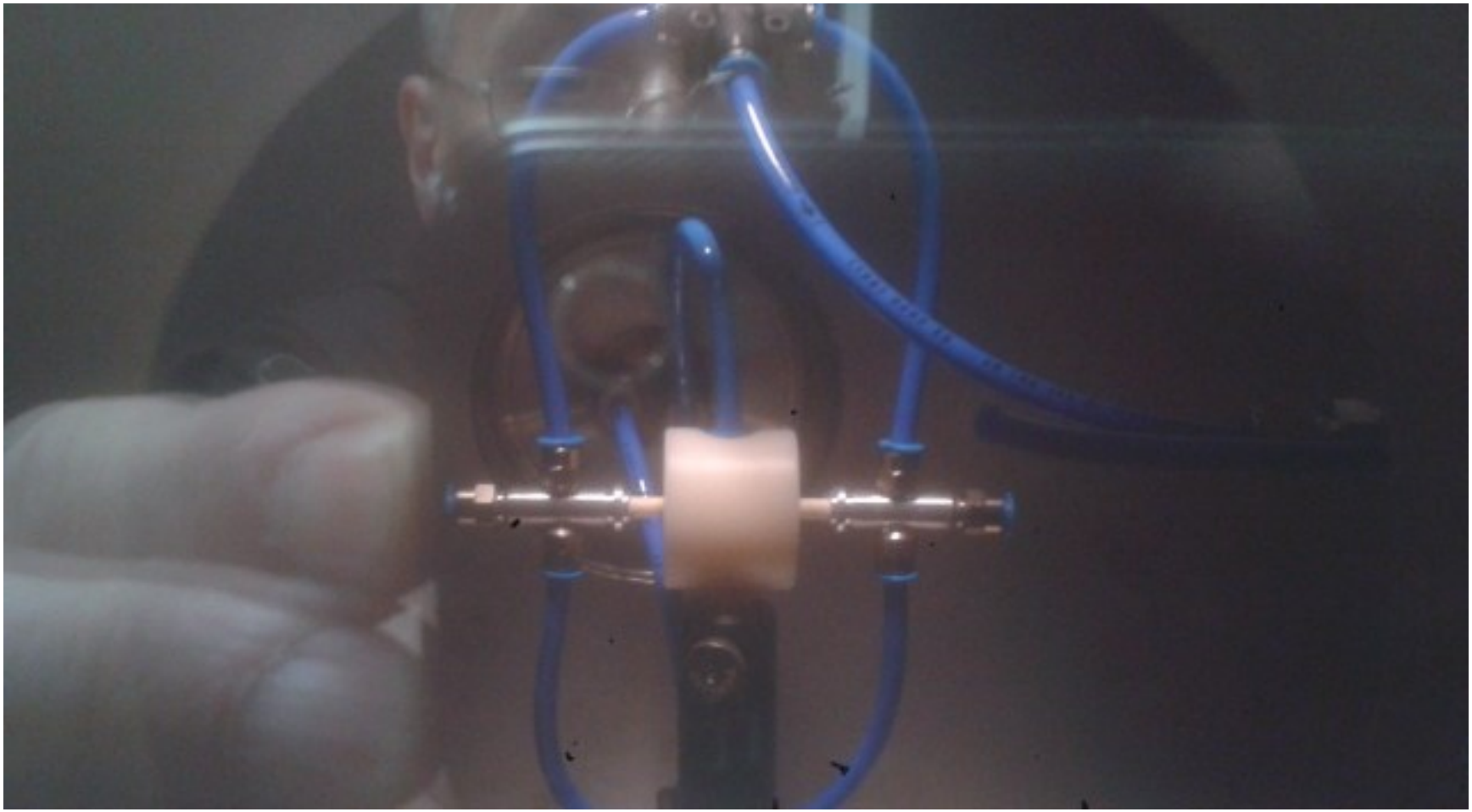



Component | Value | Manufacturer | Part Number
R1 | 10 kOhm | OHMITE | 506BA103KDG1
R2 | 21 Ohm | OHMITE | 506AS210KDG1
R3 | 10 kOhm | OHMITE | 506BA103KDG1
D1 | NA | BEHLKE | FDA 300-75
HV SWITCH | NA | BEHLKE | HTS 320-200-SCR
C1 | 2.6 nF | TDK | FHV9AN
C2 | 1.5 nF | TDK | FHV-8AN
Current Monitor | NA | PEARSON | 6600
HV SWITCH
+ 5 VDC
TRG IN
FAULT
R1
10 k
R2
21 Ω
HV IN
C1
2.6 nF
C2
1.5 nF
HV OUT
D1
CURRENT
MONITOR
R3
10 k
GND


MFC1−2
Gas inlet
z
y
x
VG1
VG2
Vacuum chamber
Discharge circuit
Vacuum system
L1
iSCMOS camera
L2
M1−2
Spectrometer
Capillary
10 mm
10 mm
Electrodes


Discharge current, A
300
250
200
150
100
50
0
200
400
600
800
1000
Time relative to the discharge trigger, ns
Voltage, kV
5
10
15
20
25

# Active Plasma Lens
# CTU test benches

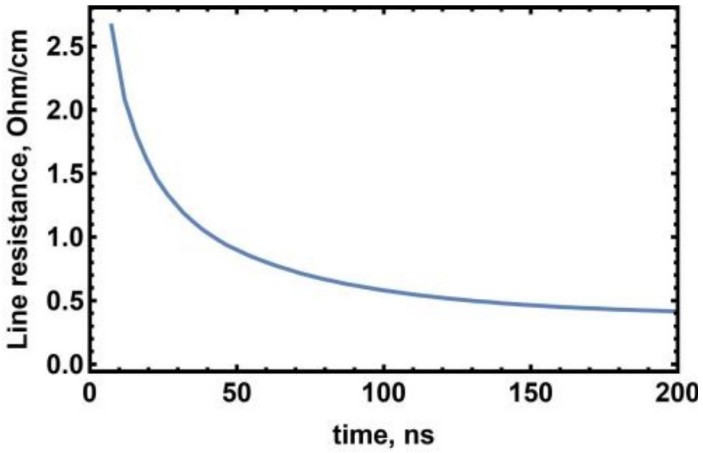


APL discharge in alumina/sapphire capillary

**$I_{max}$ = 800 A** **$T_{1/2}$ = 400 ns**

**diameter = 2 mm** **length = 7 cm**

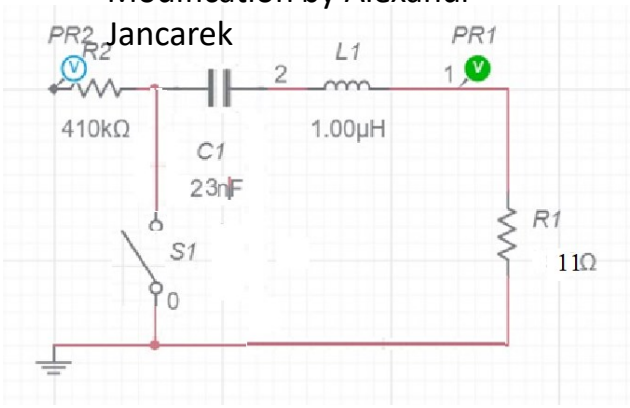
**Ar; 30 mbar**

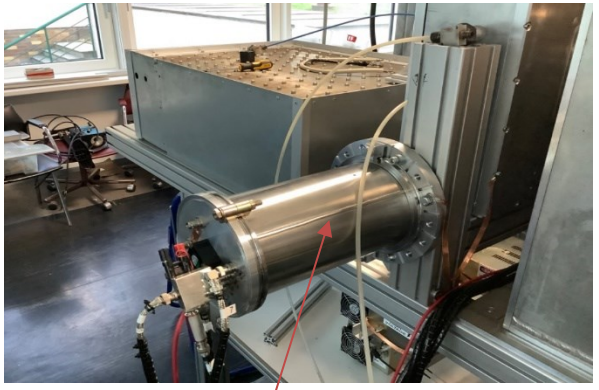



Pavel Sasorov, Alexander Molodozhentsev

Michal Nevrkla, Thyratron 52TR50 (S1) test bench

Modification by Alexandr Jancarek

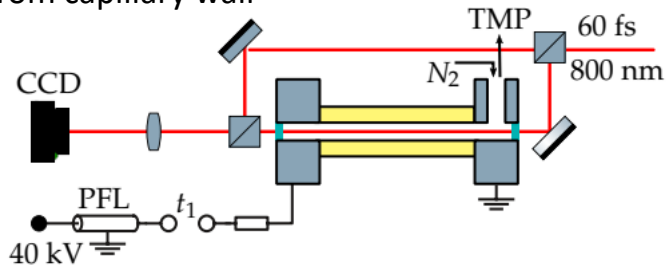


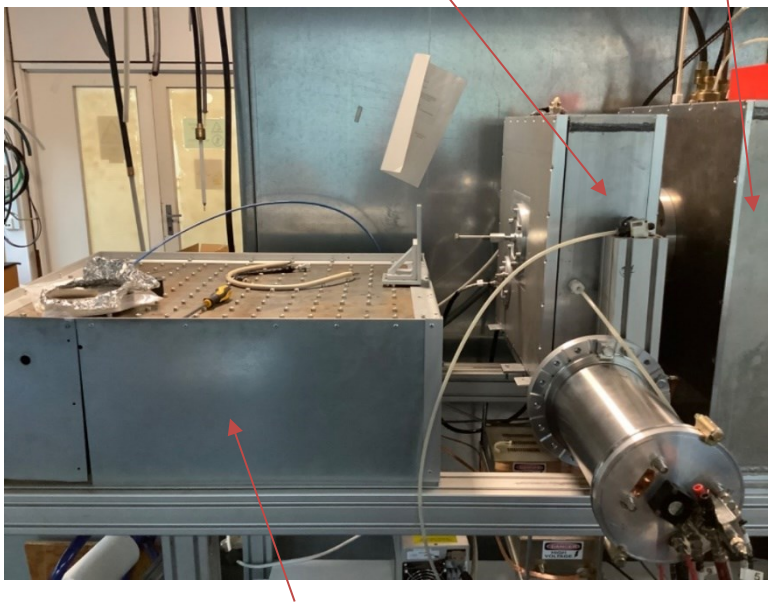
Thyratron circuit

CTU capillary discharge test bench

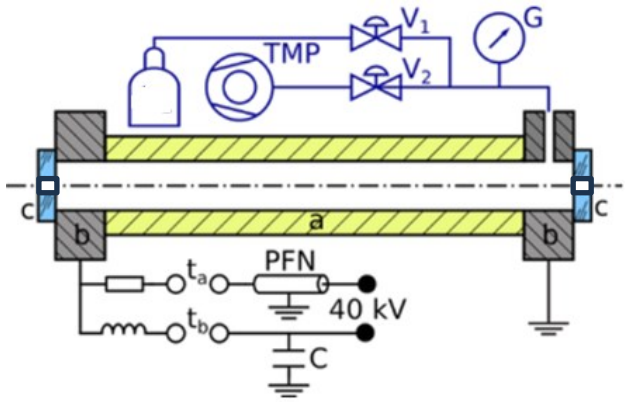
Developed to test the role (by interferometry and spectroscopy) of preionisation on capillary discharge with special shape of current to reduce ablation from capillary wall




Nevrkla et al.: *Appl. Sci.* **2021**, *11*(21), 10253

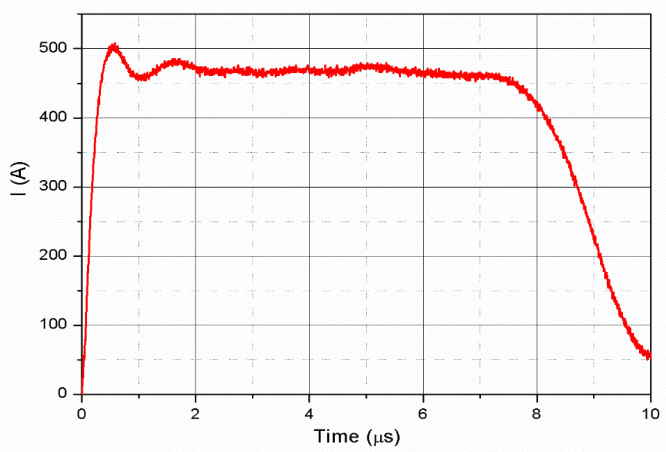



Preionisation circuit

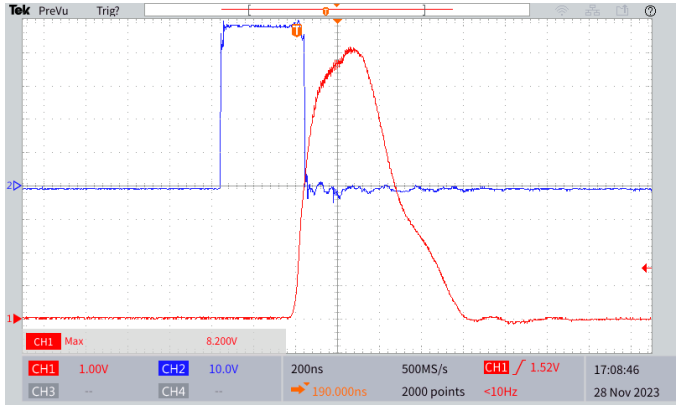



Possible design of APL circuit

FJFI CVUT discharge test bench modified for circuit design of APL



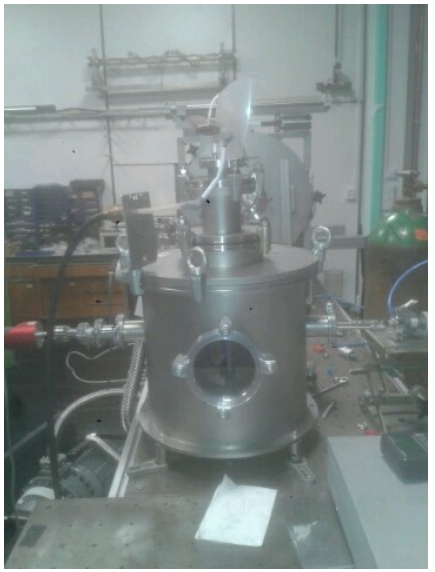

Preionisation current max.

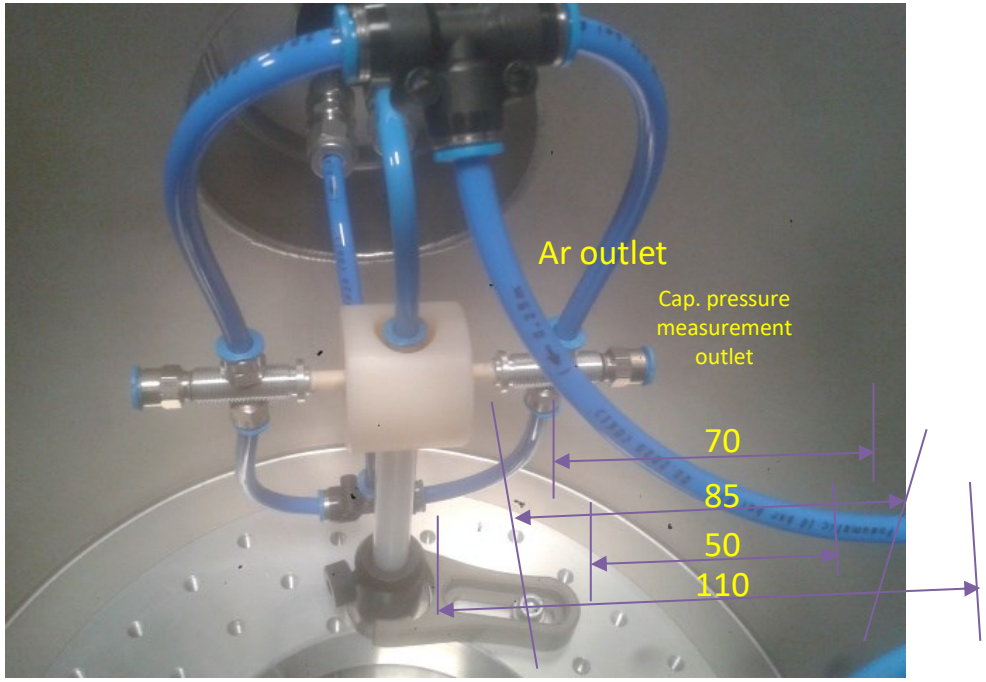



R1 11.5Ohm; C1 23nF; V 16 kV; I 820A

Thyratron circuit modified and tested by AJ and will be used for APL tests with electron beam

FJFI CVUT gas/vacuum test bench to prepare APL for LUIS experiment in E5



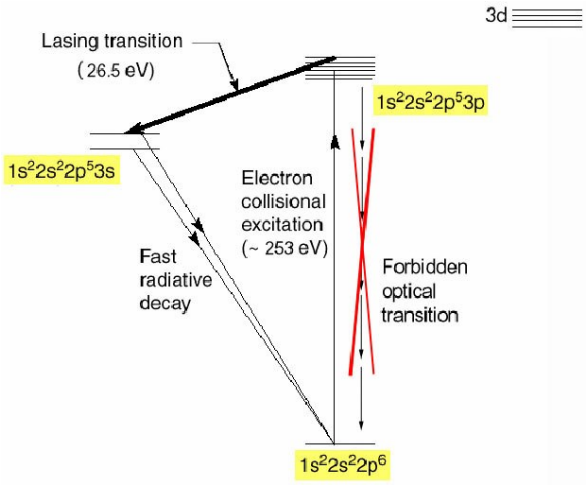



Ar inlet

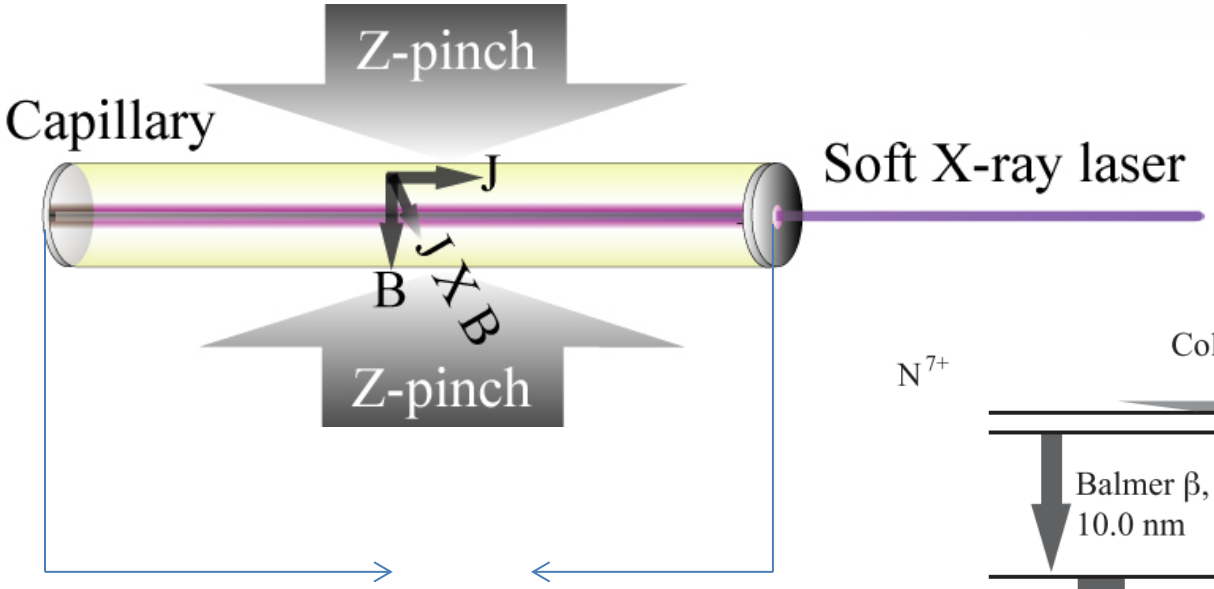
Alumina capillary for APL ϕ 2mm L 70mm Tubes ϕ 6x1mm

Pressure in capillary 30 mbar, in chamber 10 to -2 mbar

# Capillary discharge XUV source

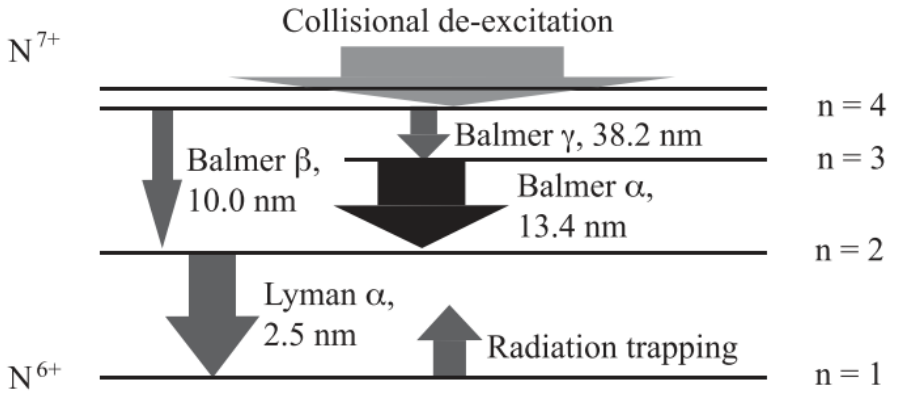



Direct collisional pumping




HV pulse

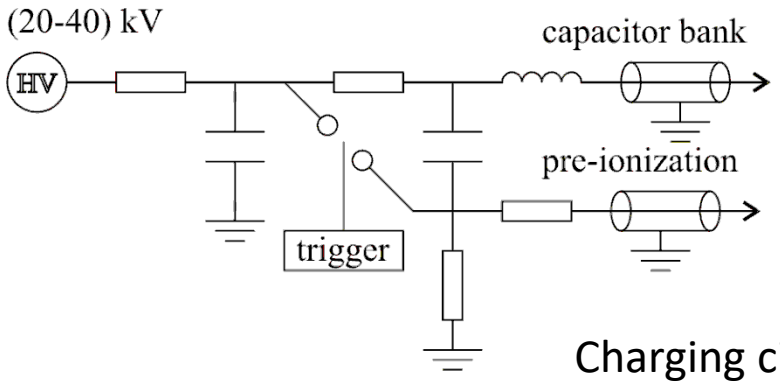
Recombination pumping



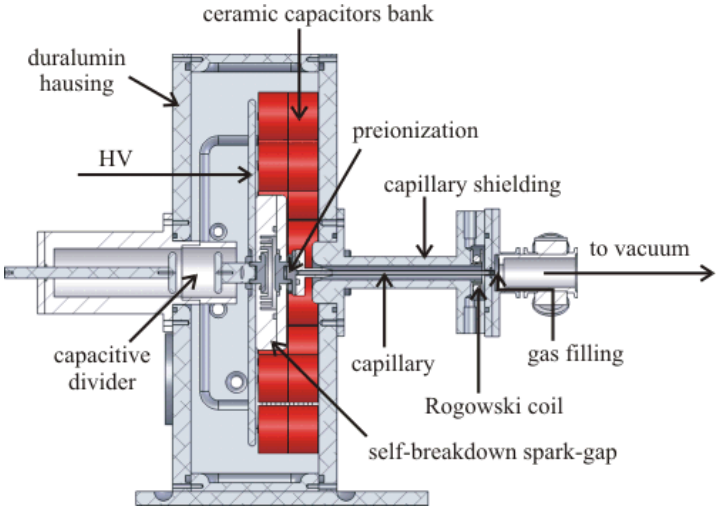

Argon, Nitrogen 0.01-10mbar or solid material vapours

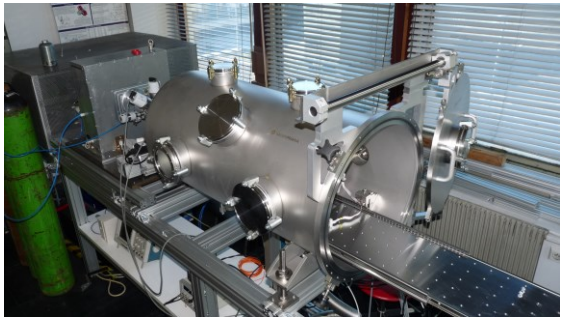
Hotta et al.

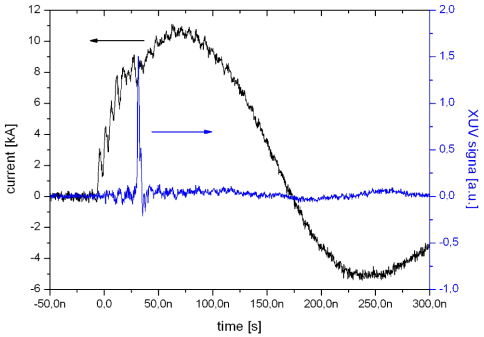
# Discharge Apparatus for Ne-like Ar 46.9 nm laser




Charging circuit

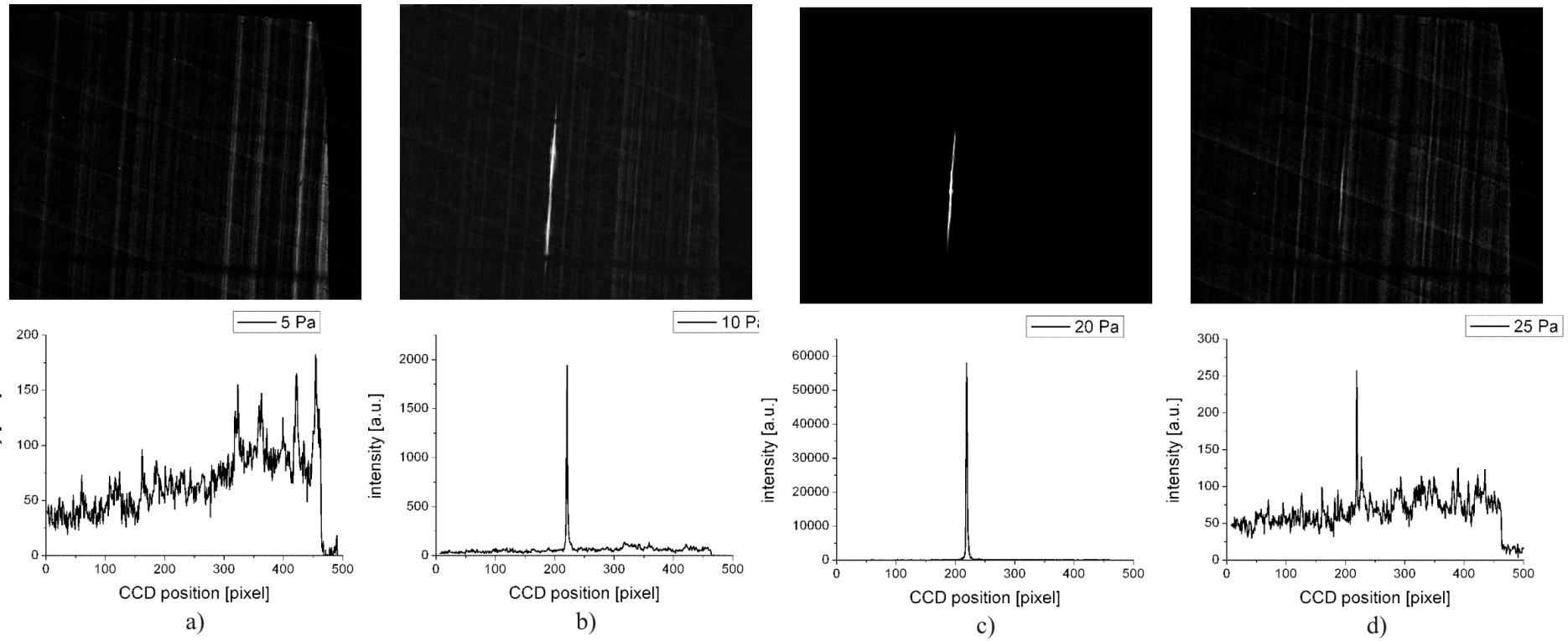




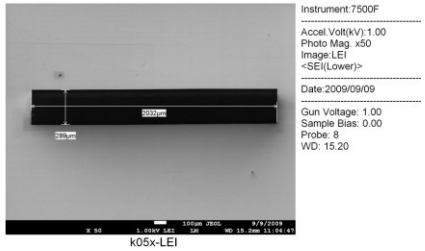

- Ceramic capacitors (1.25 ÷ 31 nF).
- Al2O3 capillary, 3.2mm dia., 9-20cm long
- Low inductance -> high dI/dt.
- Pulse-charged: 1x Marx + coil.
- RL Rogowski coil.
- Bursts up to 5Hz

# Argon spectra 30 ÷ 80 nm

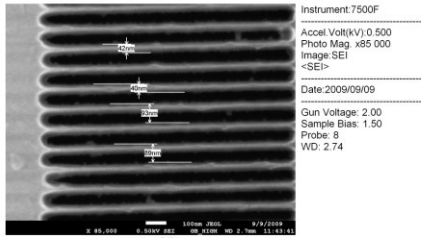



- Time integrated spectra current 12kA laser line 46.9nm
- 300 G/mm blazed grazing incidence reflective  grating spectrometer

# Application



k05x-LEI

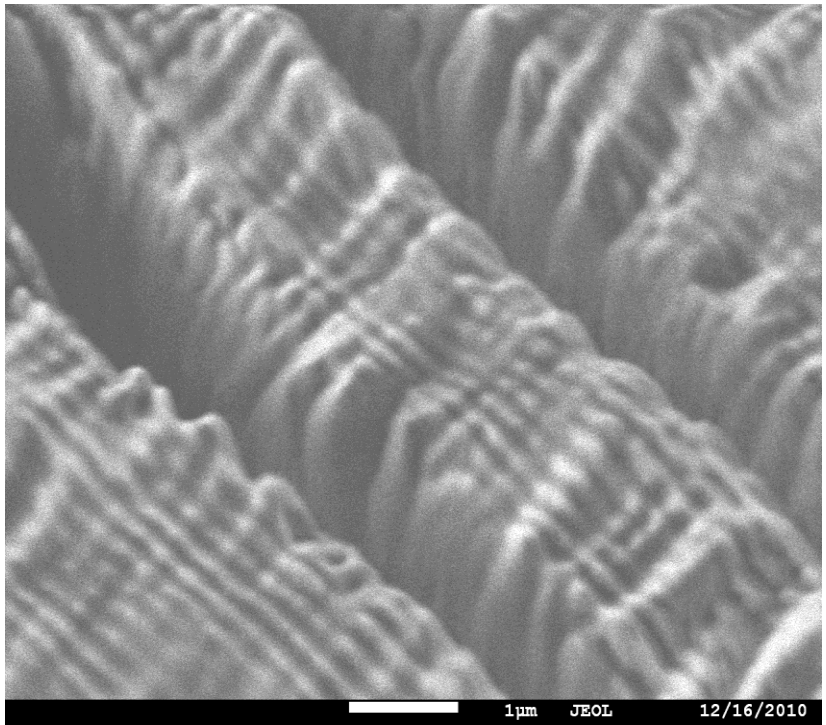


85kx-SEI

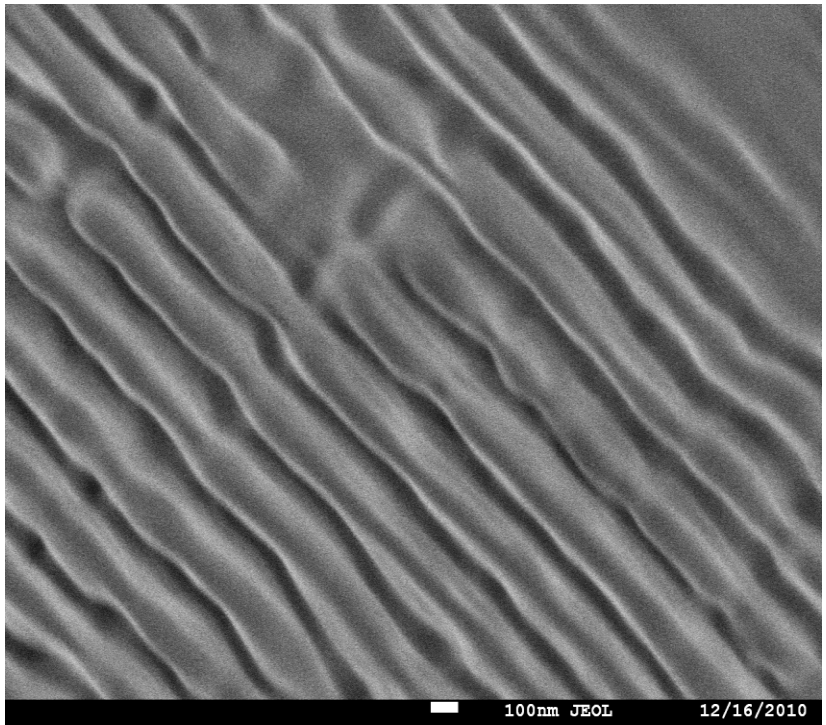
Transmitting
SiNx grating
2 x 0.3mm
10 000lp/mm

Ablation (dry etching)
of PMMA by Ar 46.9nm
laser, 10mJ/cm2 100 pulses
via transmitting grating

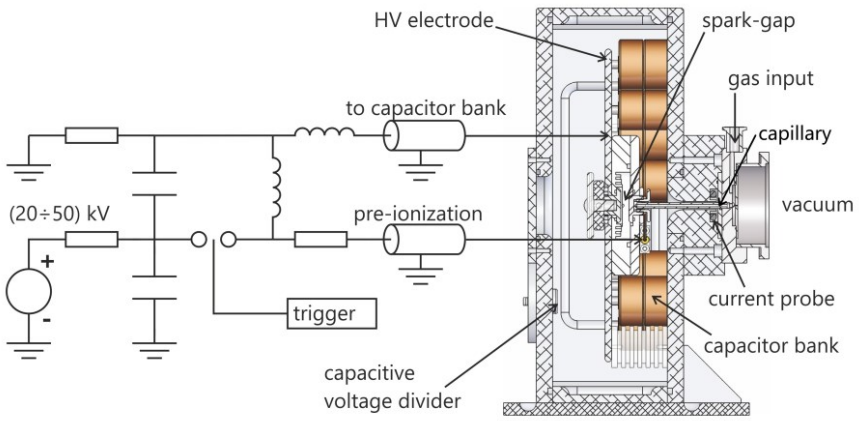
Direct image of mask



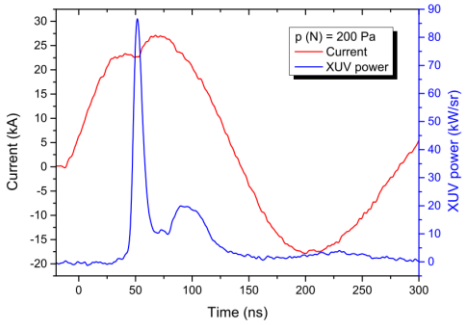

Interference image

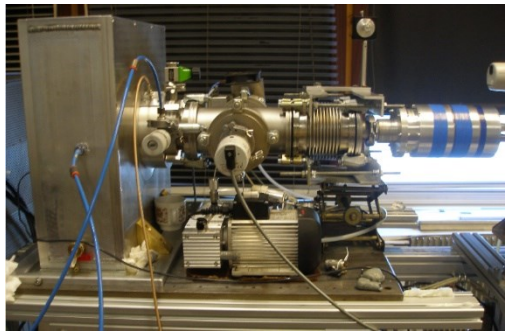


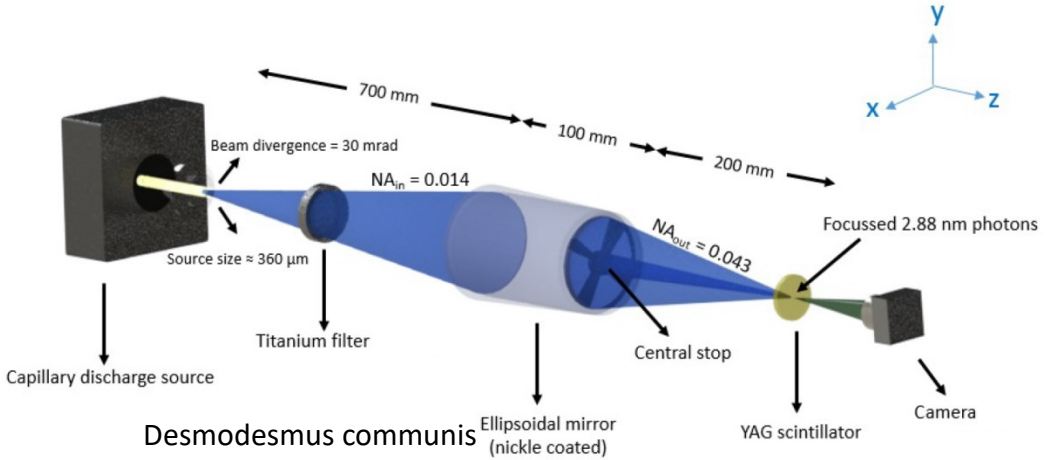
# Incoherent N5+ capillary source 2.88 nm for SXR full-field microscope



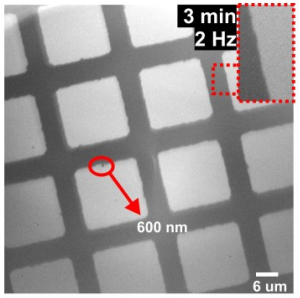

- Capillary
  - Alumina
  - Lenght 10 cm
  - Diam. 3,2 mm
- Capacity 21 nF
- HV 50 – 80 kV
- Output to vacuum
- dia 1 mm

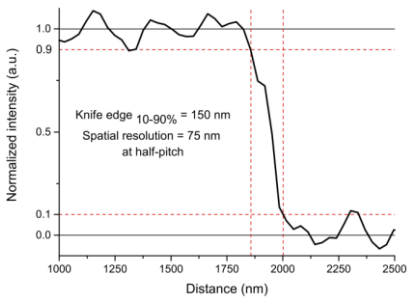


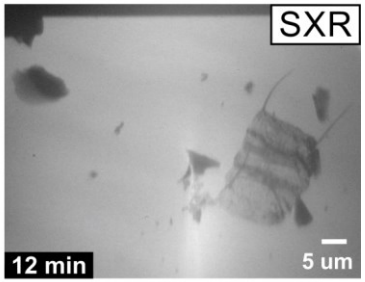



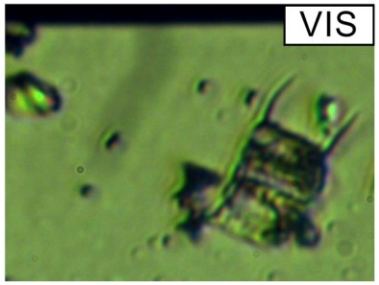



Desmodesmus communis



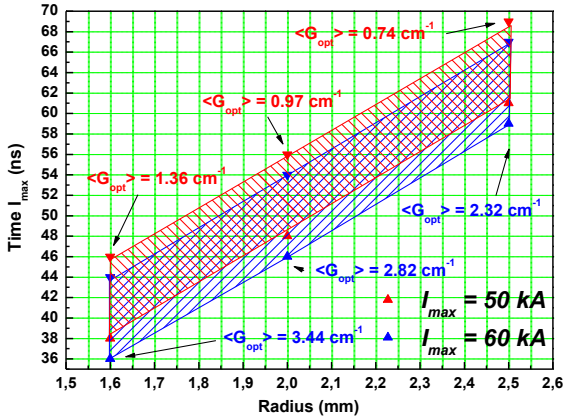



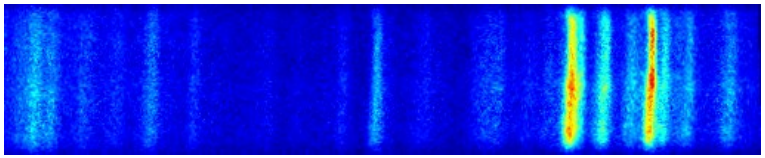
Gain limited by wall ablation

# CTU measurement of time-integrated spectra of N with capillary ϕ4mm

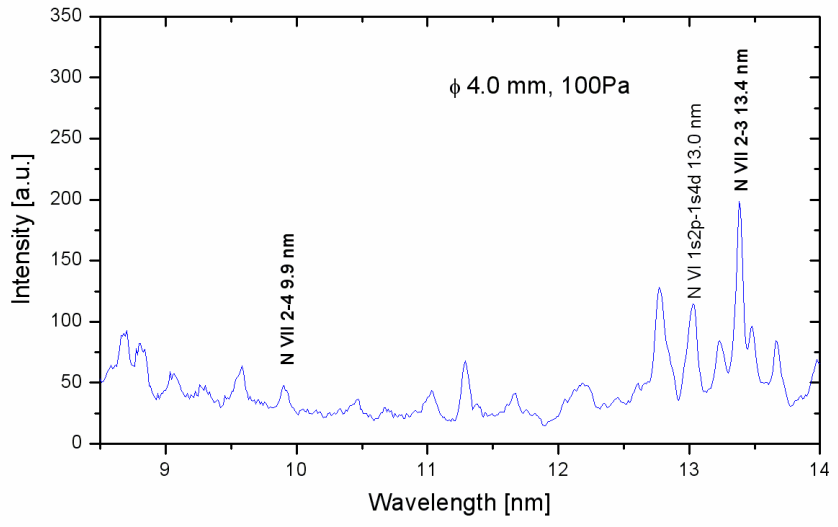


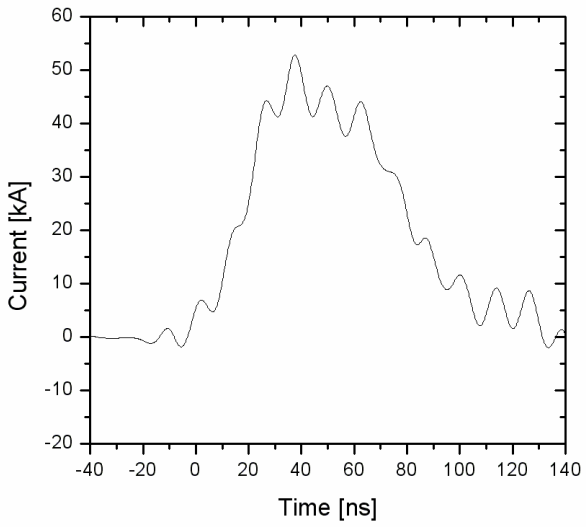

spectrum images for pressure in the range 80-550 Pa

$B_\alpha$

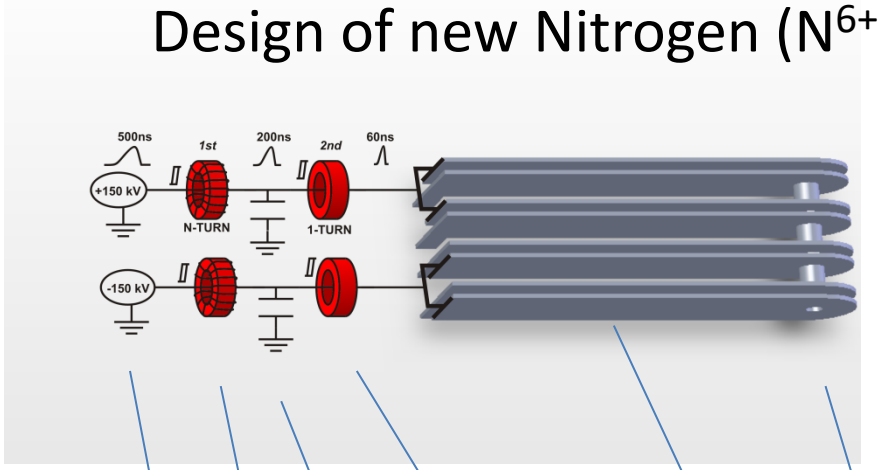


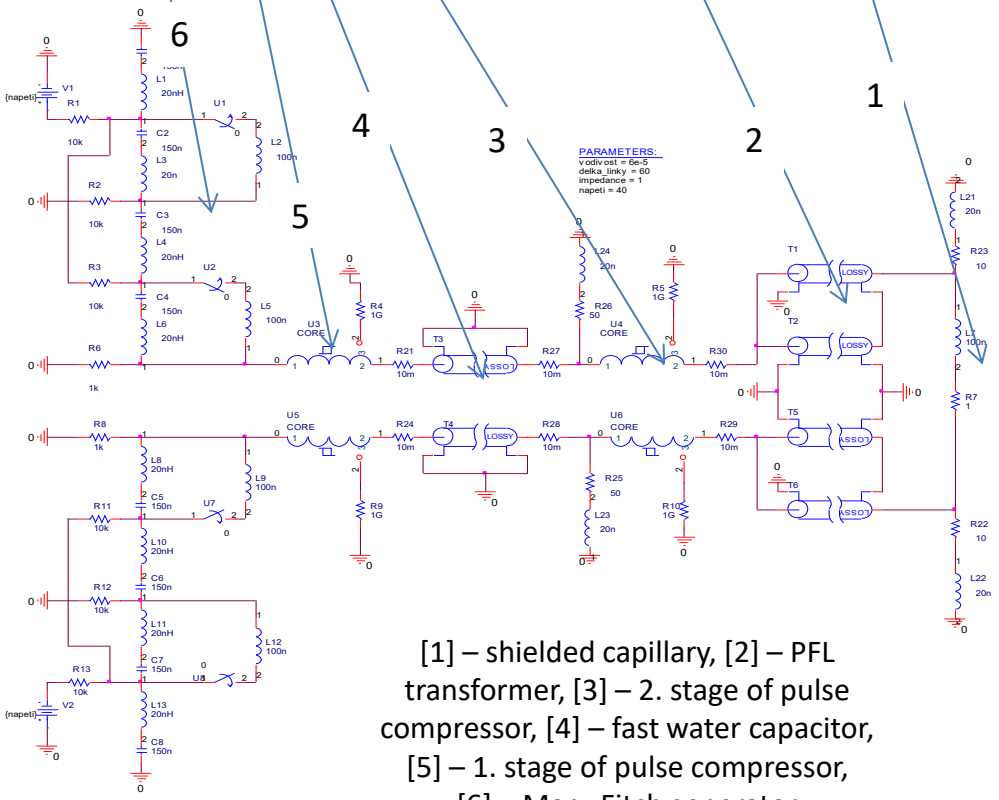
100 Pa = 760 mTorr



# Design of new Nitrogen ($N^{6+}$) capillary discharge source

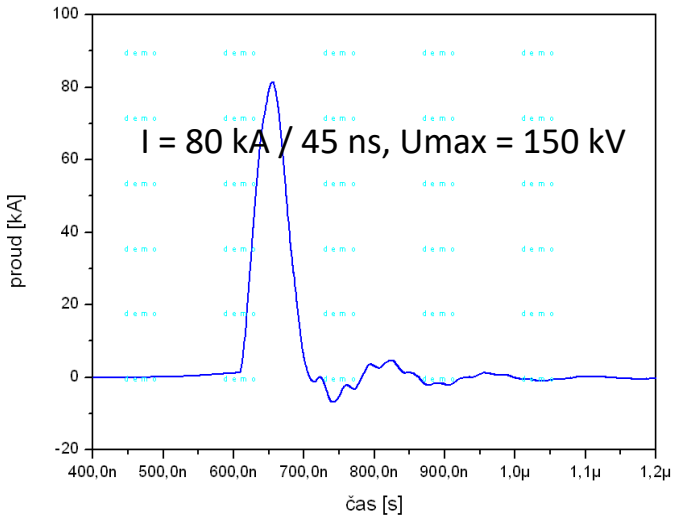


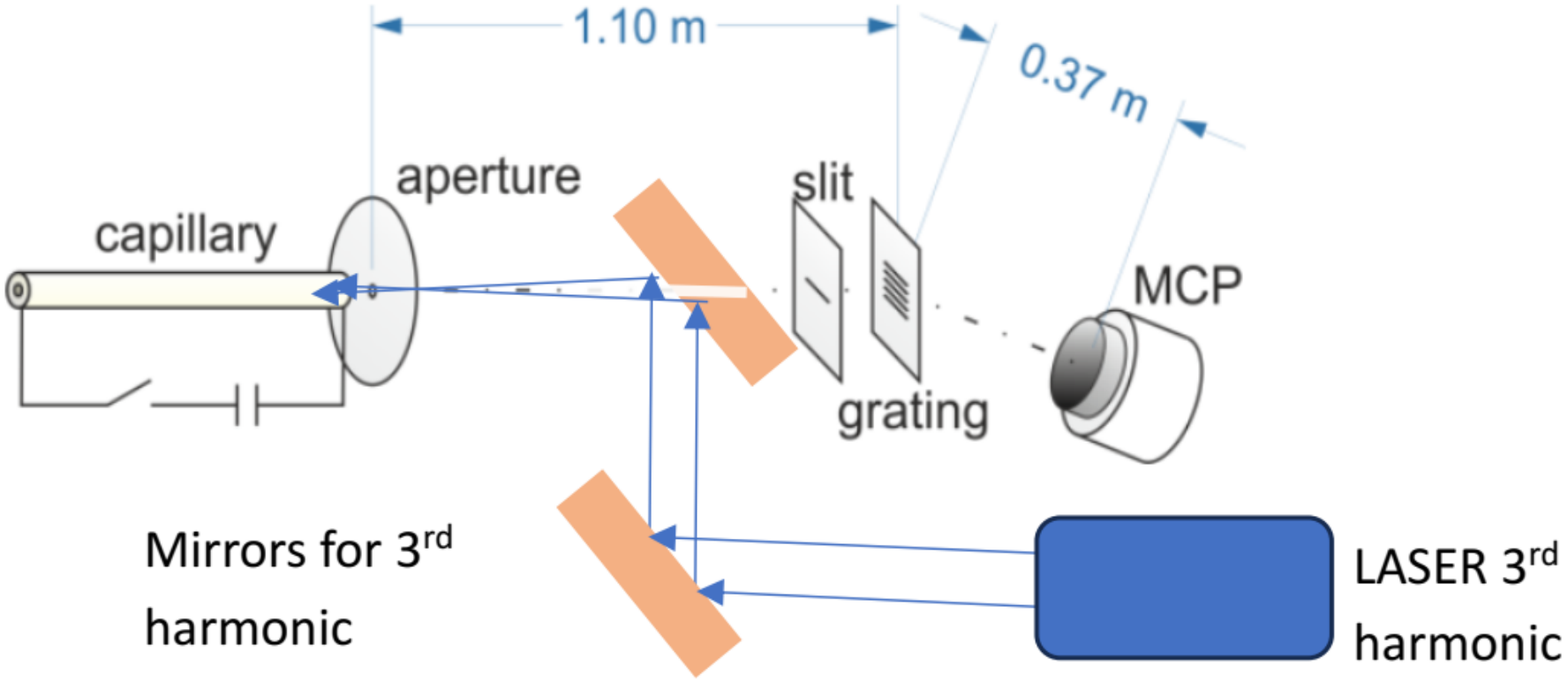

[1] – shielded capillary, [2] – PFL transformer, [3] – 2. stage of pulse compressor, [4] – fast water capacitor, [5] – 1. stage of pulse compressor, [6] – Marx-Fitch generator

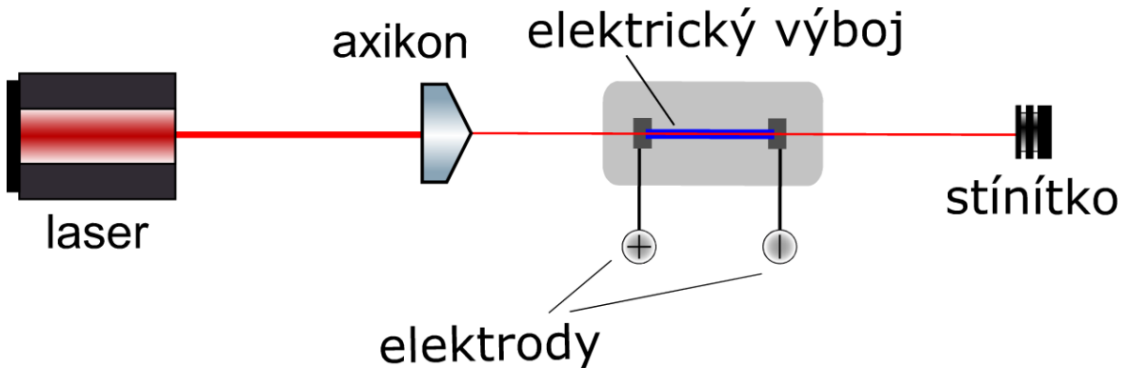
Requirements:

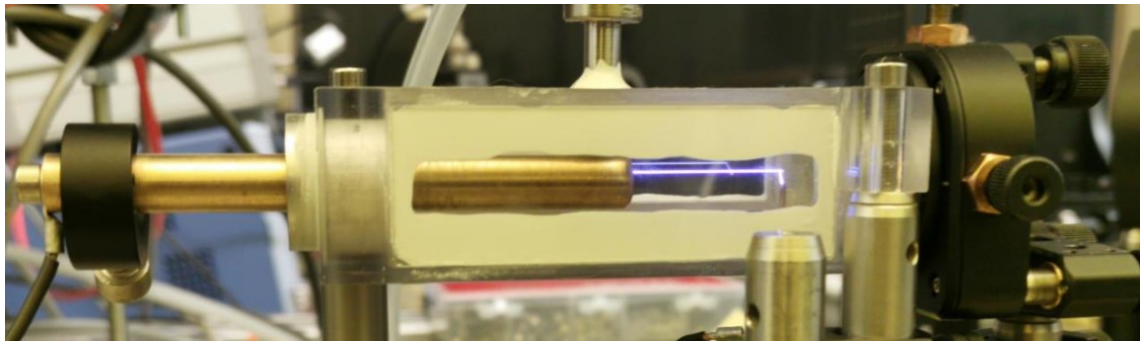
1. Lowest voltage ☺
2. Lower EMI noise
3. Water window and 13.4nm range
4. *GL* > 15
5. ***T*e > 140 eV for** >50% of N7+ ions
   ***T*e < 60 eV in less than 5 ns**.
6. How to avoid wall ablation?



# Hybrid discharge & ps laser pumping of 13.4nm recombination N6+ laser to decrease ablation effect





A plasma channel of various shape created by an electrical discharge switched by fs laser in the center of the gas cell to avoid wall ablation or for fs laser pulse guiding

THANK YOU for ATENTION