INSTITUTO SUPERIOR TÉCNICO

Pre-formed channels for laser-plasma accelerators

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Outline

- *Previous work*
  - Laser-triggered disharge channels
  - Capillary discharges
  - Discharges on a capillary sequence
- *Ongoing work*
  - Discharges through a sequence of thin dielectric plates
  - Guiding & pulse collision on laser-triggered channels
  - High voltage pulser

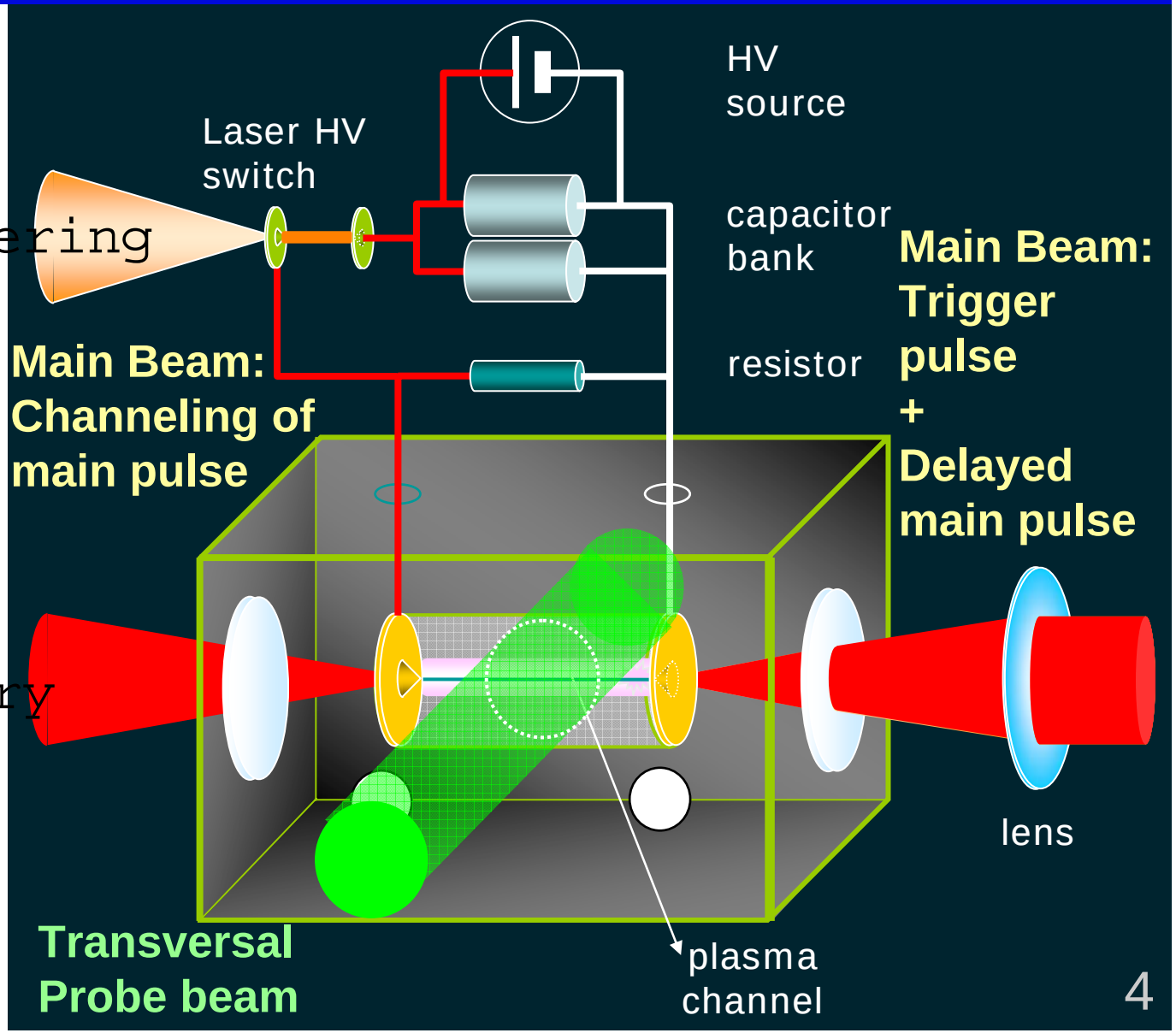
Collaborators

- *IST*
  - Laser-plasma
    - Marta Fajardo
    - João Dias
    - R. Onofrei
    - N. Lemos
    - 4 underg. stds
  - Laser
    - Gonçalo Figueira
    - L. Cardoso
    - J. Wemans
    - 2 underg. Stds
- *UCLA*
  - Chan Joshi
  - Chris Clayton
  - Ken Marsh
  - Carmen Constantin
  - F. Fang
  - J. Ralph
  - A. Pak

Laser-triggered high-voltage discharges

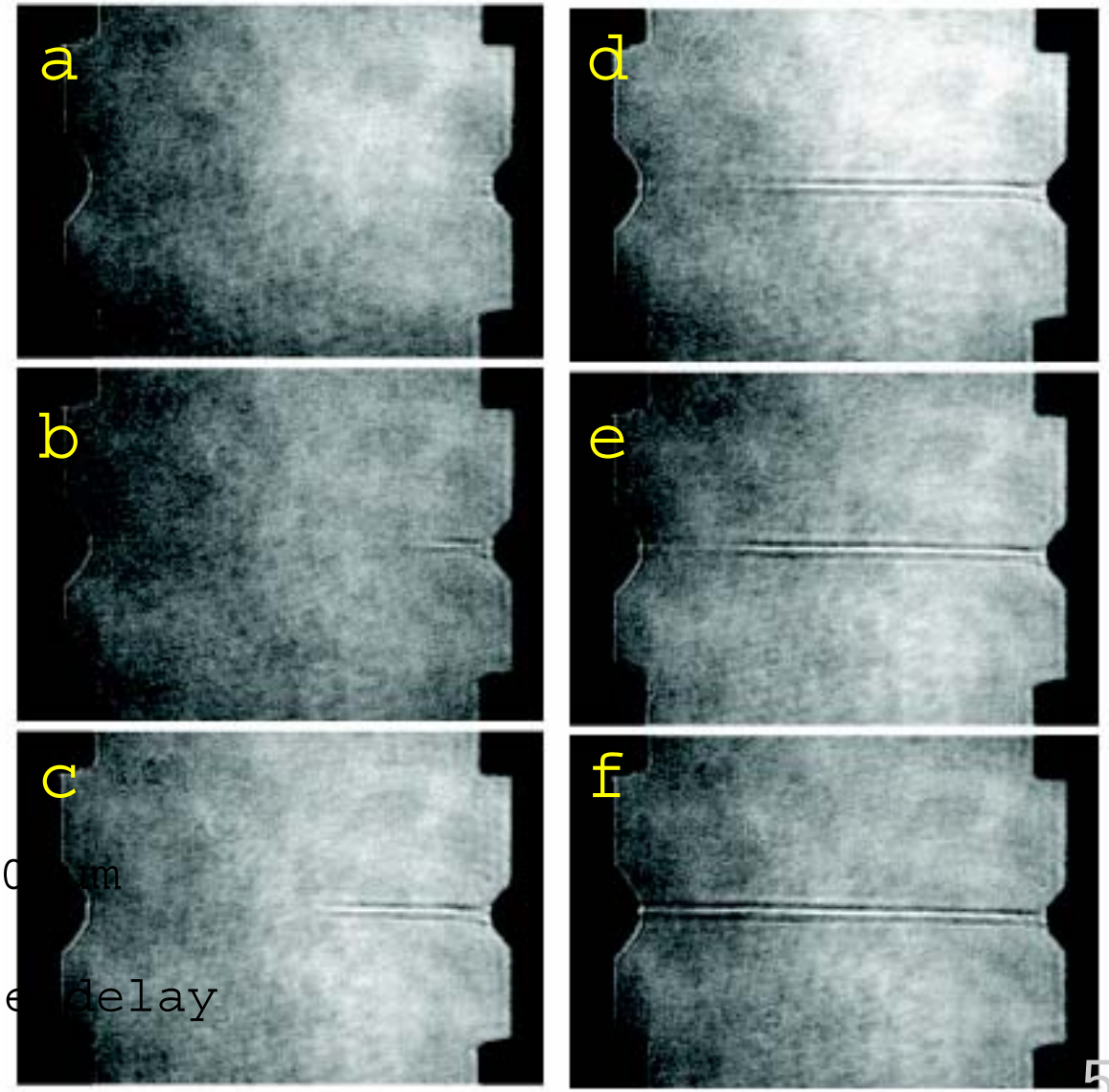
N. C. Lopes et al., Phys. Rev. E, 68, 355402 (2003)

- Laser triggering
  - No jitter
  - Sync. with laser
  - Helium 2 x ionization
  - Straight plasma line
- Open geometry
  - Makes open
  - Free expansion geometry possible
  - Transversal access to the plasma
  - Easy to change



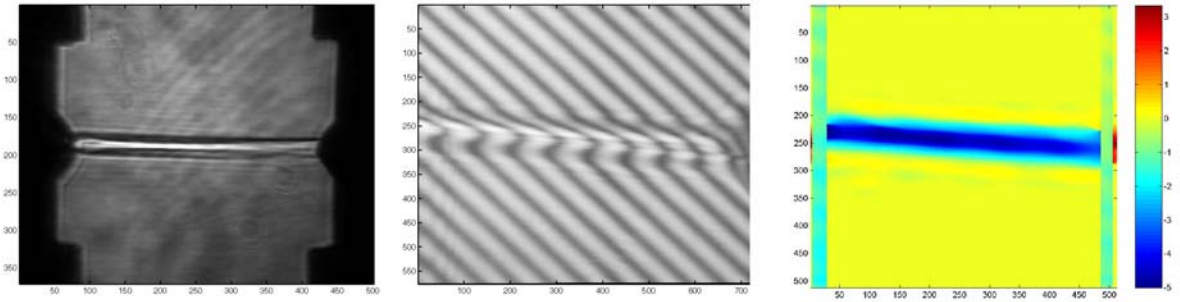
Plasma production after laser triggering

- Helium
- N_0 2.5x10^{18} cm^{-3}
- Gap 15 mm
- Trigger laser pulse
  - 1053nm
  - 800 fs
  - 0.26 J
  - 10^{-6} contrast
  - F/5 focusing
- Plasma diameter ≈150 µm
- Reproducible tunable delay

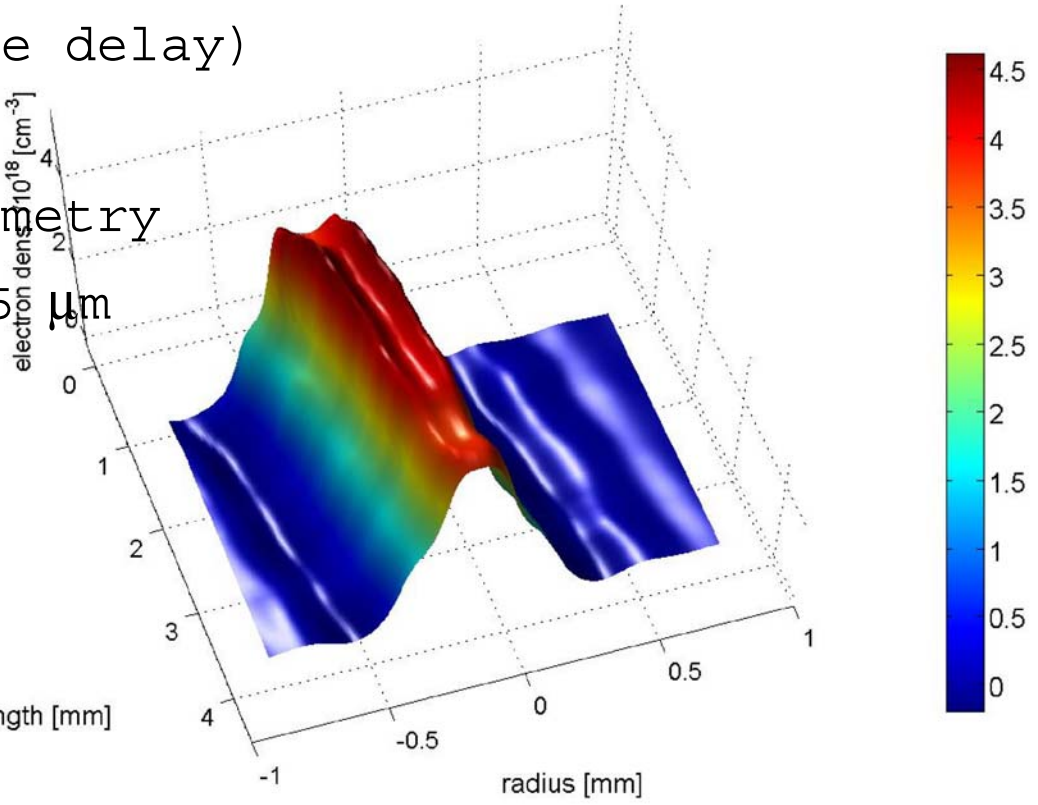


Plasma expansion and channel formation

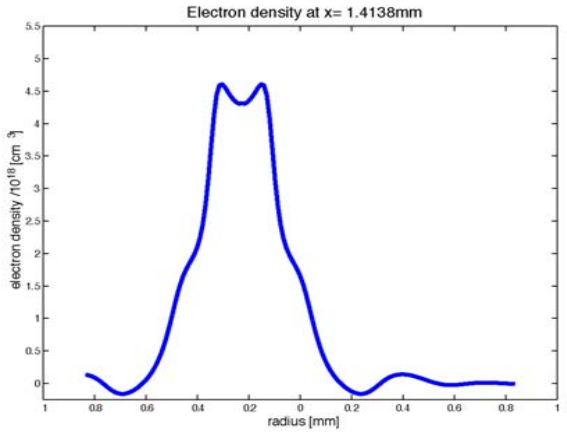
- Helium
- N_0 7.4x10^{18} cm^{-3}
- Gap 15 mm
- Pre-pulse trigg.
  (worst plasma but more delay)
- Delay 110 ns
- Perp. shear interferometry
- Prop. matched to $r_0 \approx 35$ µm



Electron density

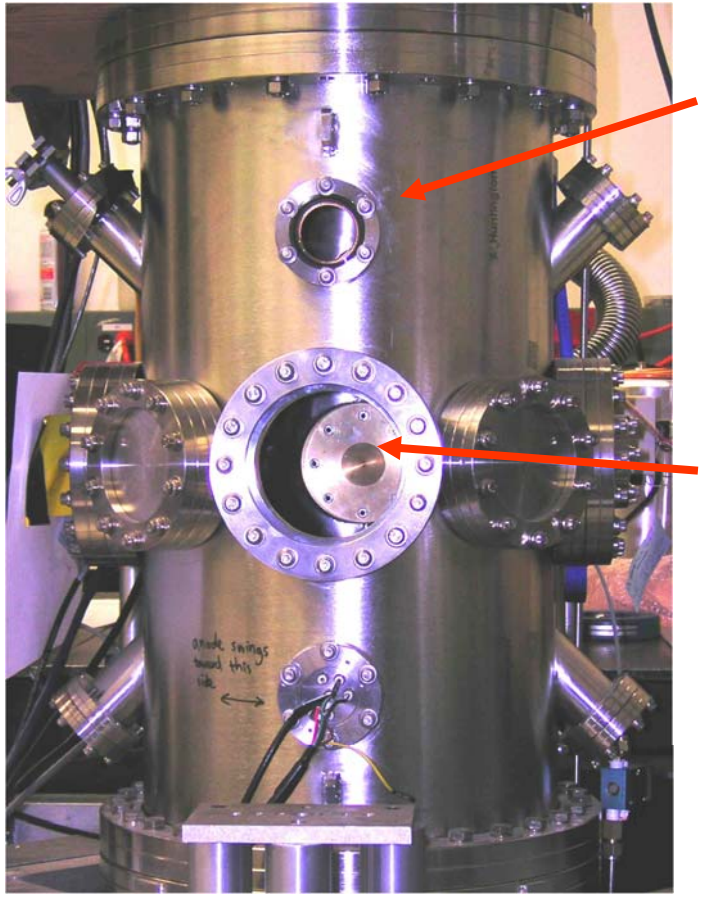


Electron density lineout



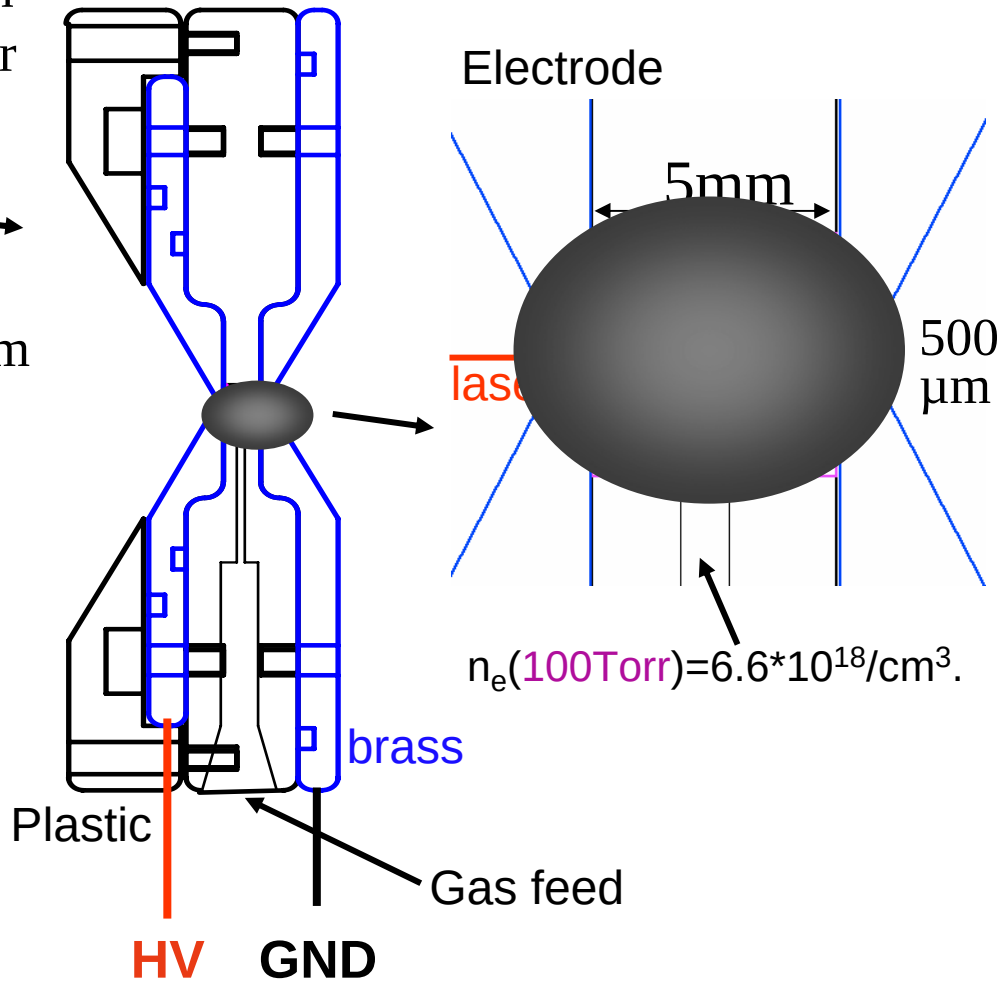
UCLA

Plasma source 1: D 500 um capillary discharge



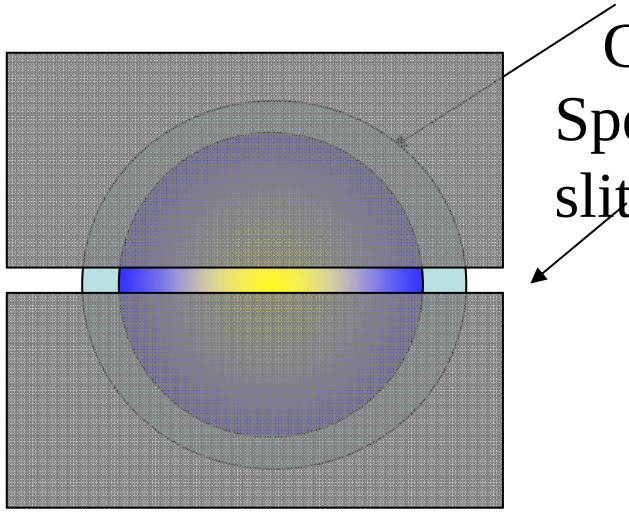
Vacuum chamber

D 500 µm capillary

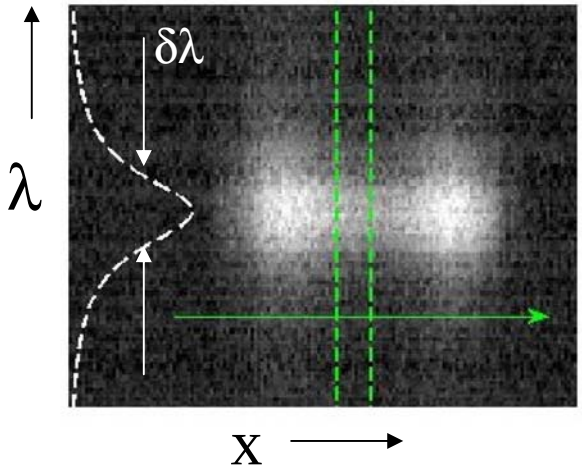


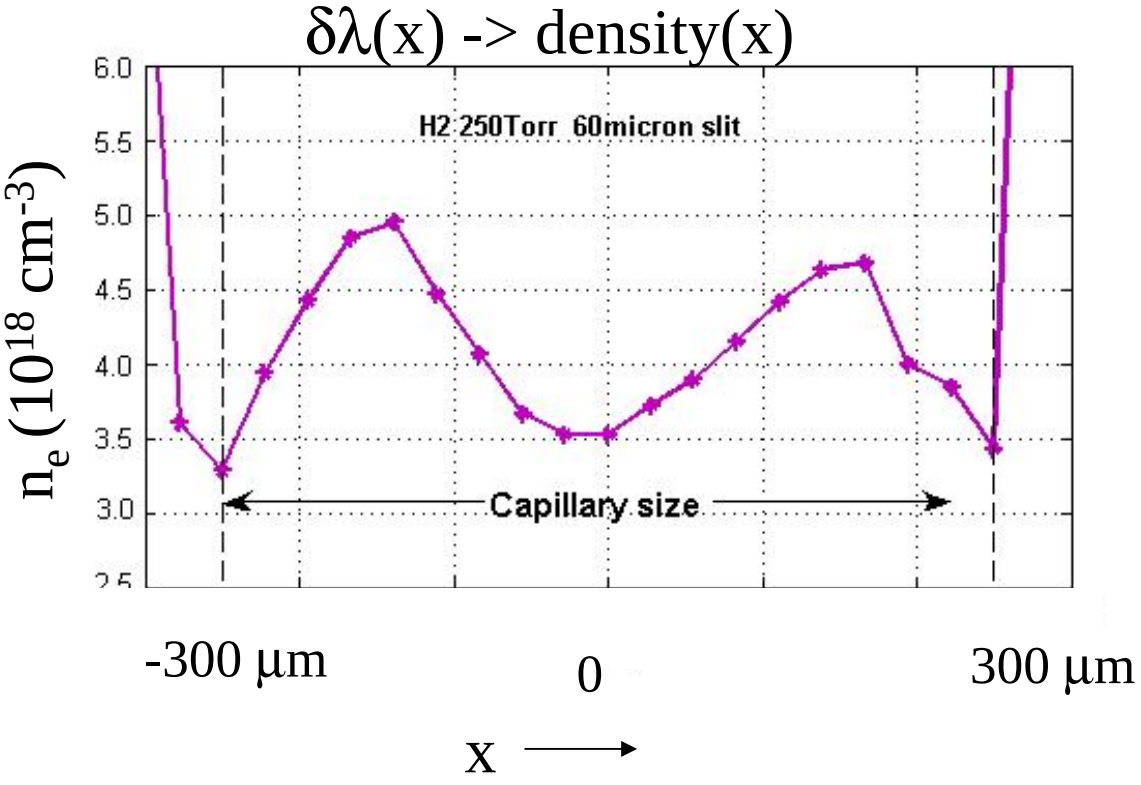
+ High-voltage pulser (thyratron based) for the capillary discharge, vacuum pumps, diagnostics

Measuring plasma density (H_α Stark broadening)



H_α line

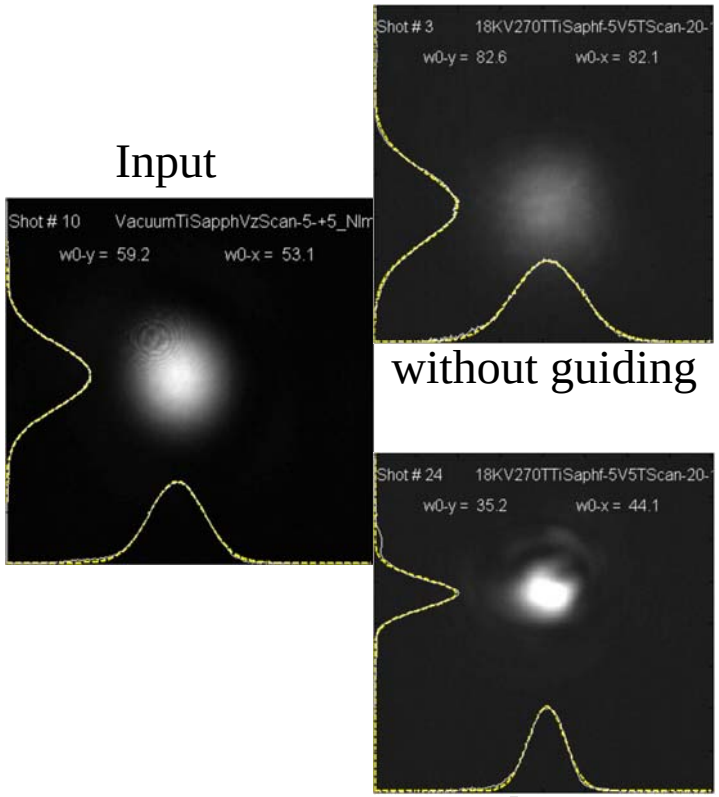




Low intensity laser guiding in single capillary

Output at 3 mm away from exit

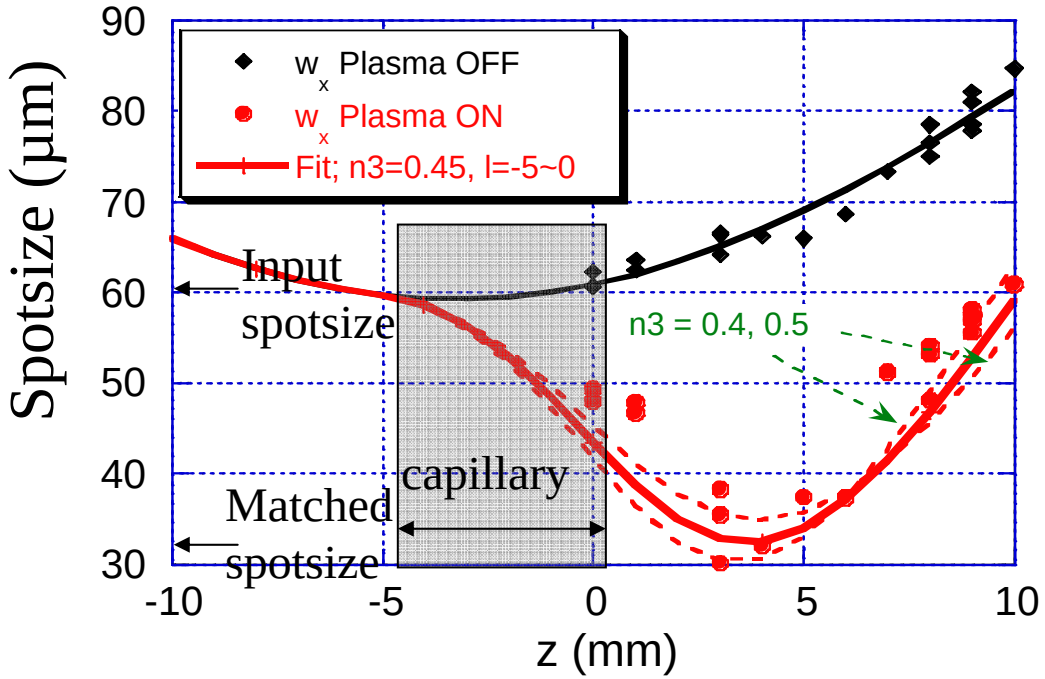
Input



without guiding

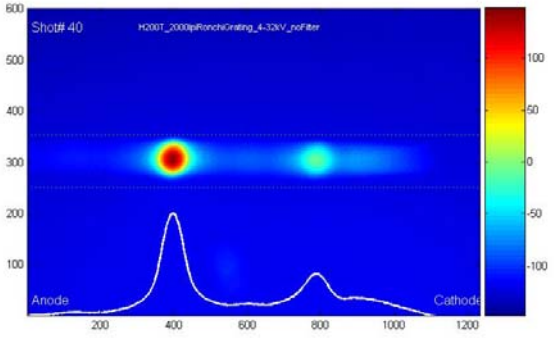
with guiding

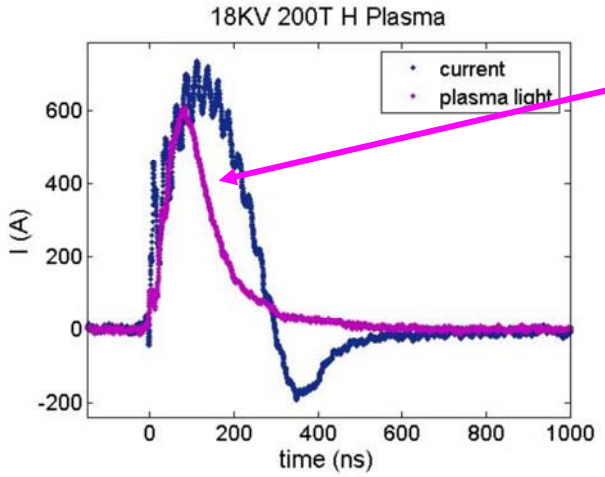
Experimental data and fit for propagation of Gaussian beam w/wo guiding



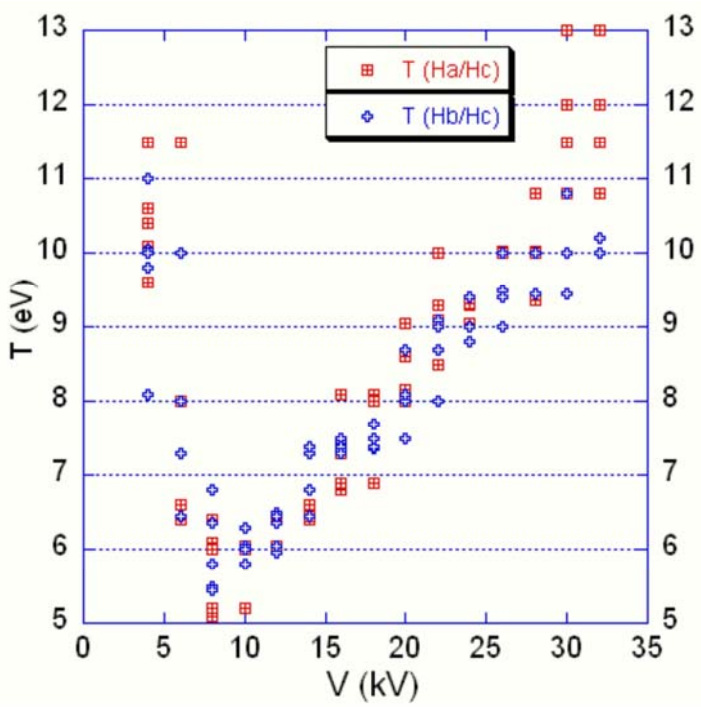
We got n3 (density at 100μm subtract density on axis) about $0.5*10^{18}/cm^3$ at about 220 torr, which agrees our results from Stark broadening.

Measuring the Plasma Temperature using the $I_{H\text{-}\alpha}/I_c$ and $I_{H\text{-}\beta}/I_c$ ratios





Temperature measured at t ≈ 0+100 ns



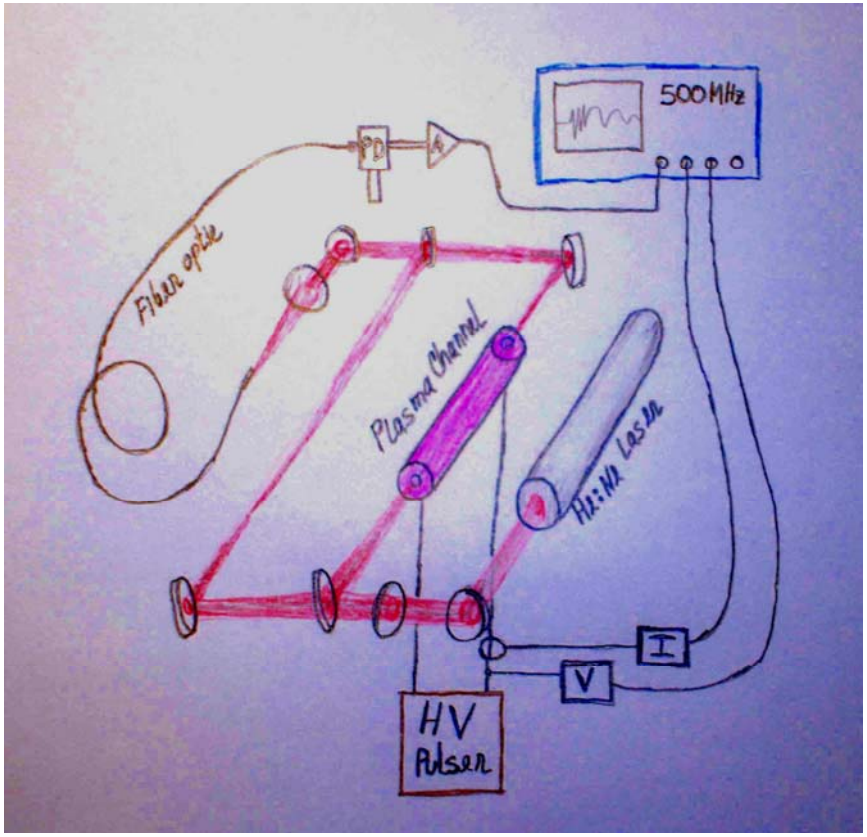
$$\frac{I_l}{I_c} = \frac{3^{3/2}\pi^3 (137a_0)^2 f \; g \exp\left[(E_\infty - E_l)/(KT)\right]}{2\lambda\Delta\lambda\, g_i \left\{ (g_{ff}/2)(KT/E_H)\exp\left[E_H/(n'^2 KT)\right] + \sum_n (g_{fb}/n^3)\exp\left[E_H/(n^2 KT)\right] \right\}}$$

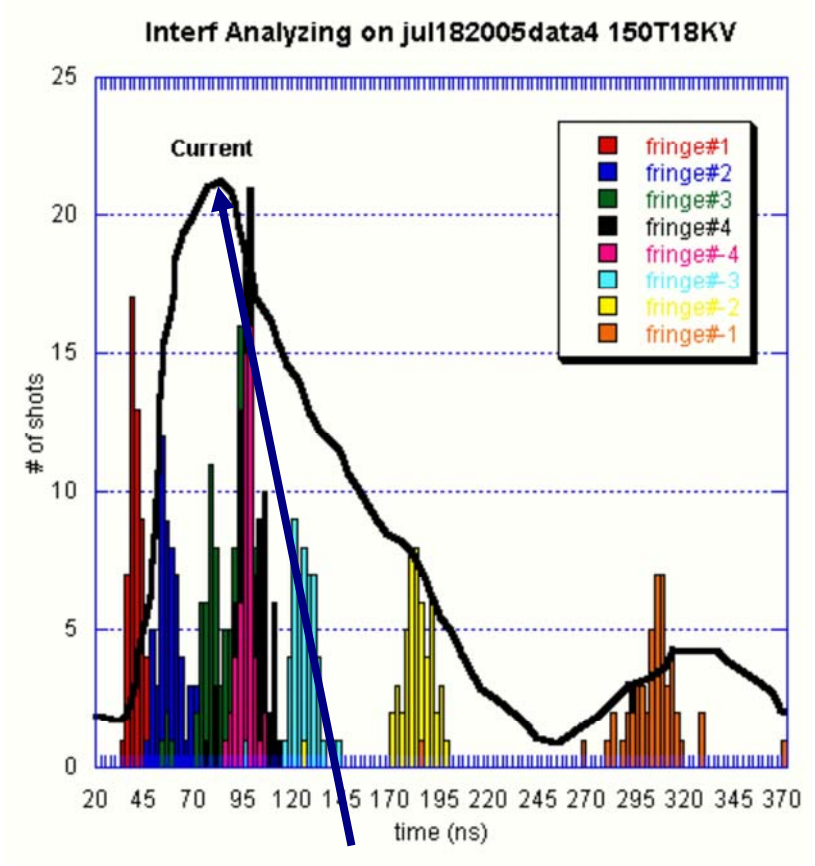
Line

Free-Free

Free-Bound

Measuring the electron density (time resolved)





$n_{e\,max} \approx (7.1 \pm 0.8) \times 10^{18}\ cm^{-3}$

$$\Delta N = \frac{L}{\lambda_0}\left[1-\left(1-\frac{\omega_p^{\,2}}{\omega^2}\right)^{1/2}\right] \quad \rightarrow \quad n = 3.528\frac{\Delta N}{L_{[mm]}}\left(\times 10^{18} cm^{-3}\right)$$

UCLA

Plasma source 2:
D 300 μm, length 6 mm - 10 mm - …

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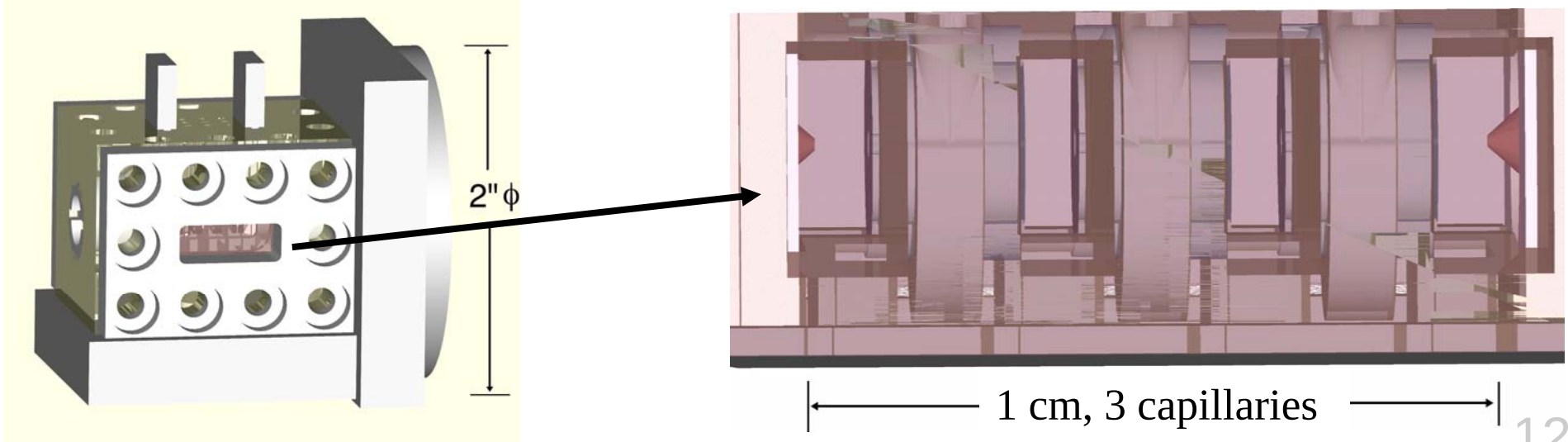
Why

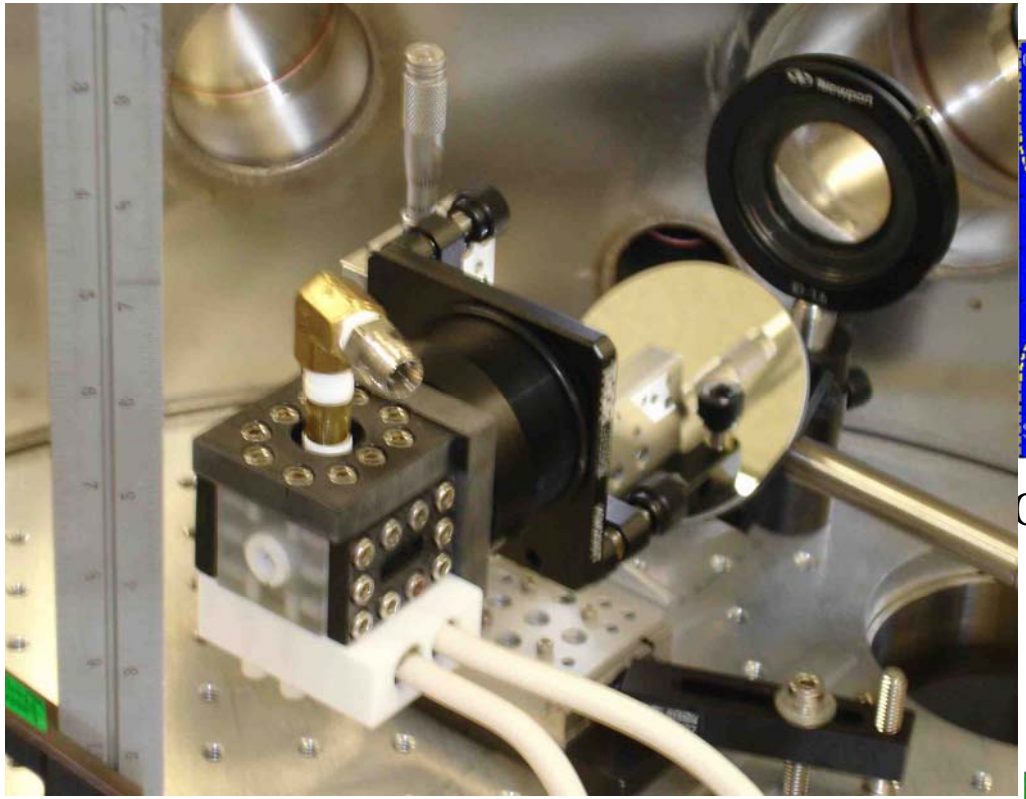
- increase and change channel length
- decrease filling time and and gas leak to the vacuum system
- use of high and lower plasma density
- include transversal plasma diagnostics
- setup inside vacuum chamber

How

- use a sequence of capillaries aligned inside a gas cell

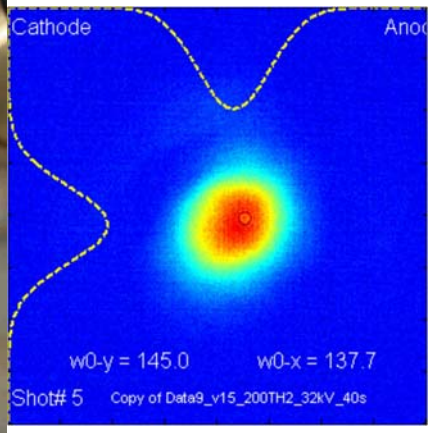


Guiding in multiple capillary discharges

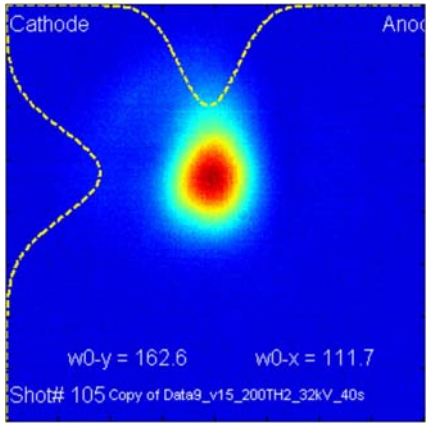


Channeling device at vacuum chamber,
rep. rate 1 sh. / 5-20 s
(vacuum limited, depending on pressure),
lifetime > 100 000 shots (so far)

Preliminary low intensity guiding

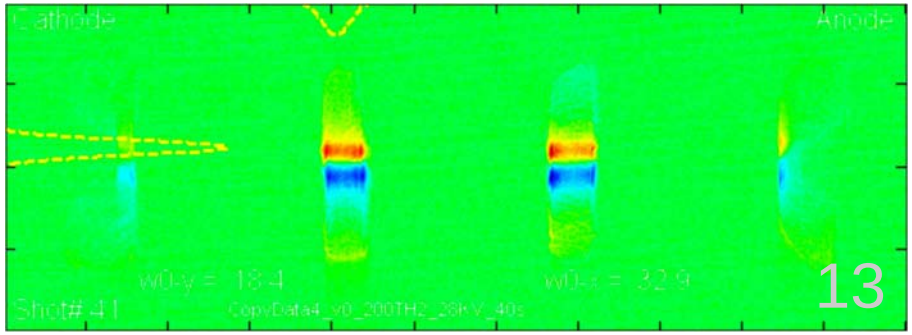


Output without guiding



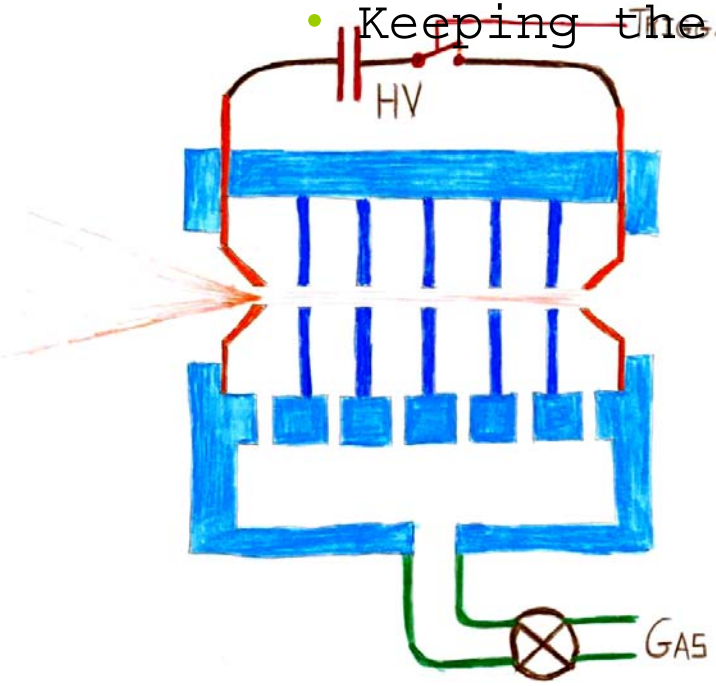
Output with guiding

side view Schlieren with background subtraction



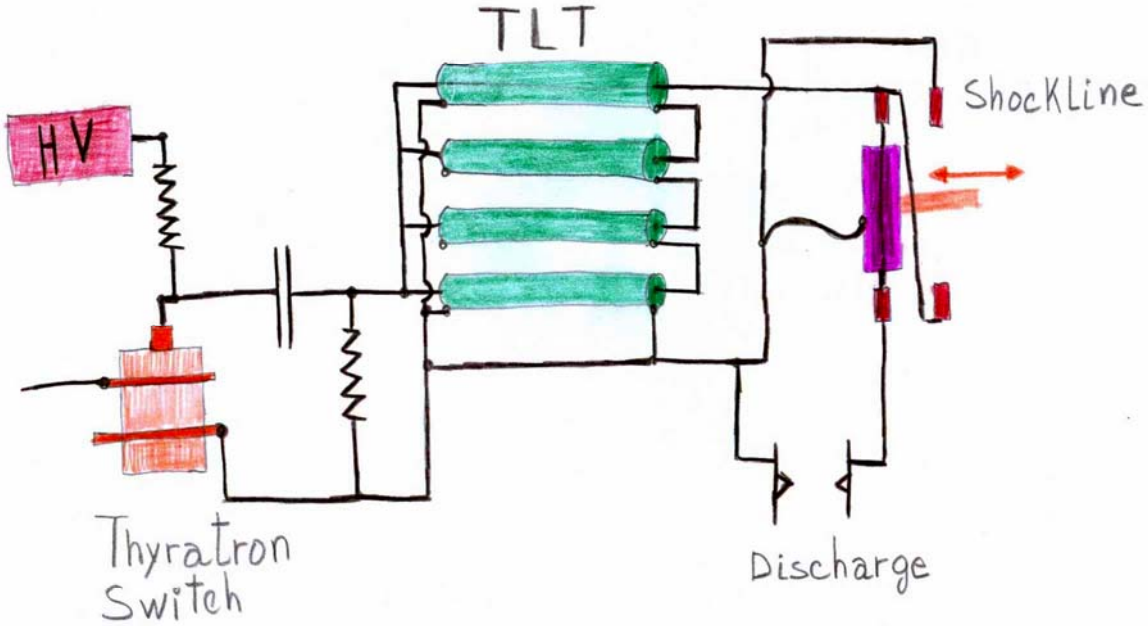
Discharge trough a sequence of thin plates

- Why
  - Radial plasma expansion
  - No laser triggering
  - Fast gas filling
  - Different density regions
- How
  - Reduce the capillary length to about the capillary diameter
  - Keeping the gaps



- Length 2 cm
- Gaps 2.5 mm
- Plate tickness 0.25 mm
- Hole diameters 0.3 mm
- Voltage 20 - 80 KV

High-voltage pulser



- Thyratron Switch 0-30 KV, 0-5KA
- Transmission Line Transformer 2 x 4 (input Z 6 Ohm, output Z 100 ohm)
- Shockline for ns rise time
- Pulse duration 50-100 ns
- Trigger sync. with laser

IST laser system

Oscillator Mira+Verdi 10

100 fs, 2 nJ @ 1053 nm

Offner grating stretcher

$\Delta\lambda$ ~ 15 nm, t_p ~ 0.9 ns

Ti:sapphire regen. amplifier

$\Delta\lambda$ ~ 9.5 nm, E = 4 mJ

2x passed Ø 16 mm Nd:phosphate rod amplifer

$\Delta\lambda$ ~ 7 nm, E = 1.5 J

2x passed Ø 45 mm Nd:phosphate rod amplifer

$\Delta\lambda$ ~ 6 nm, E = 9 J

Yb:Glass Reg. Amp.

$\Delta\lambda$ ~ 8 nm, E = 50 J

Vacuum grating compressor

$\Delta\lambda$ ~ 6 nm, E = 6 J

Compressor

E = 30 mJ, t_p=200 fs

P=0.15 TW

Target

E = 6 J, t_p=300 fs

P=20 TW

Conclusion

- Laser-triggered channels on free space
  - Characterization and guiding
- Channels in a sequence of capillaries
  - Ready for high-power guiding (1 cm dephasing length)
  - Characterization at lower densities
- Channels in a sequence of thin plates
  - Characterization after July 06
- Support at IST
  - High-voltage pulser
  - 20 TW Laser system