37th International Conference on Plasma Science

Finite Element Analysis of Ring-shaped Emission Profile in Plasma Bullet

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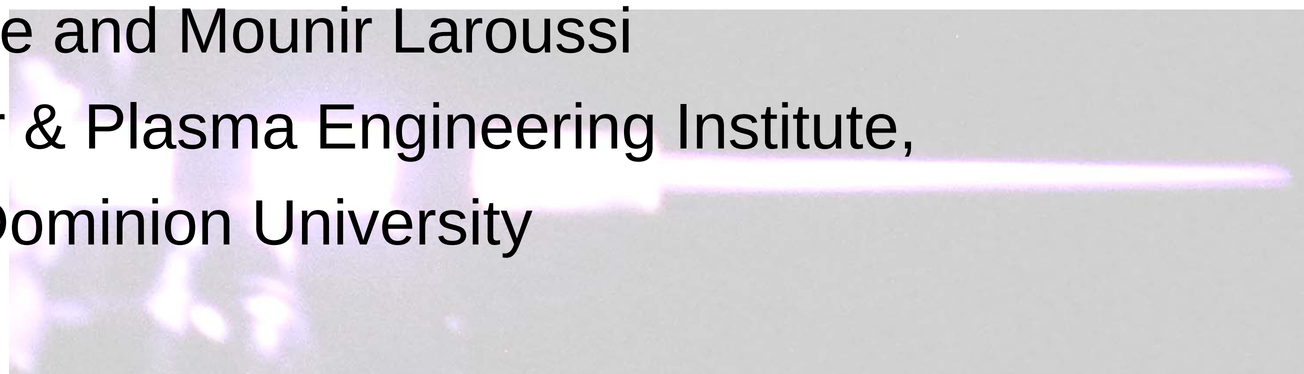
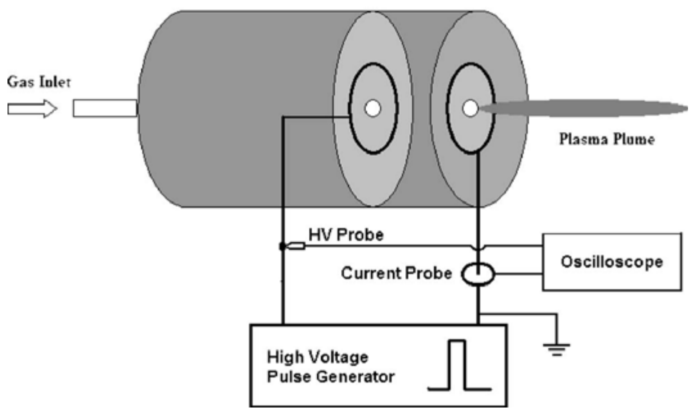
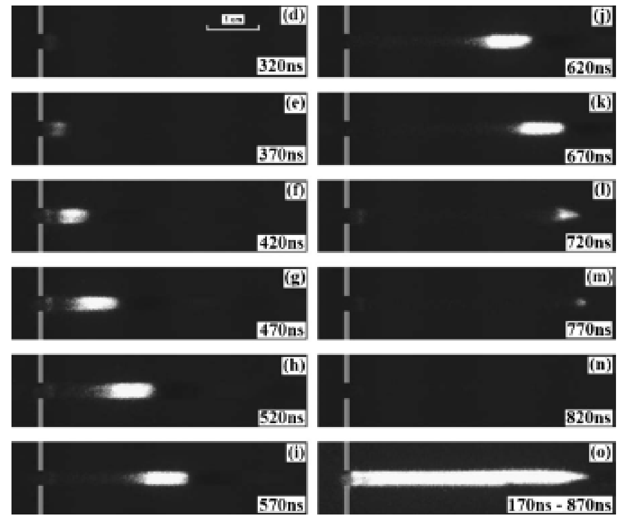


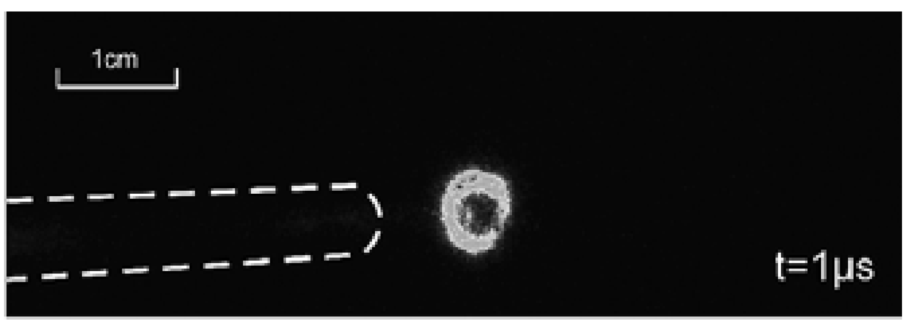
Introduction



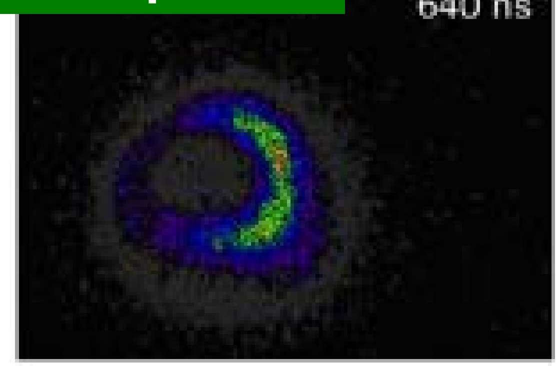
X.-P. Lu, et al., J. Appl. Phys. **100** (2006) 063302.



Observed ring-shaped emission pattern



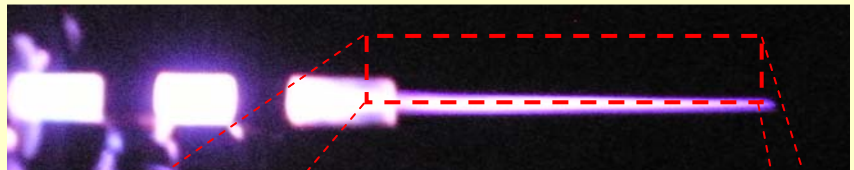
M. Teschke et al,
IEEE Trans. Plasma Sci. **33** (2005) 310.



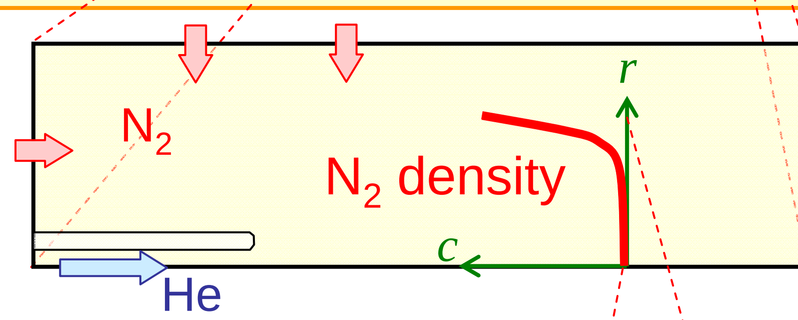
N. Merciam-Bourdet et al,
J. Phys. D **42** (2009) 055207.

Model description: the strategy

- He: 7 slpm
- 7 kV pulse excitation
- 8 kHz repetition

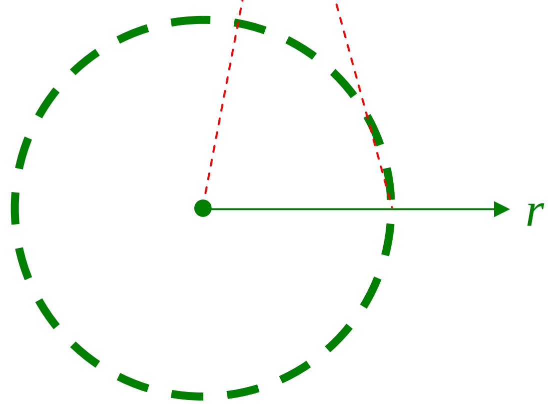


2D steady state
neutral gas flow

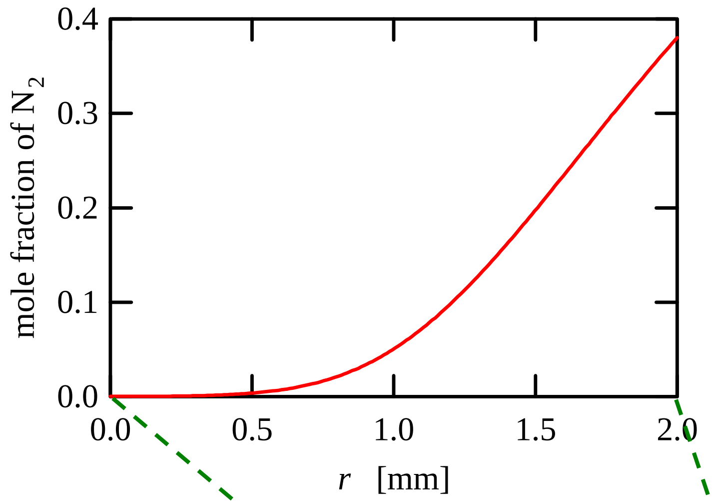


N_2 density distribution

1D plasma dynamics
in cylindrical coordinates
(cross sectional view)



Model description: 2-D steady state gas flow



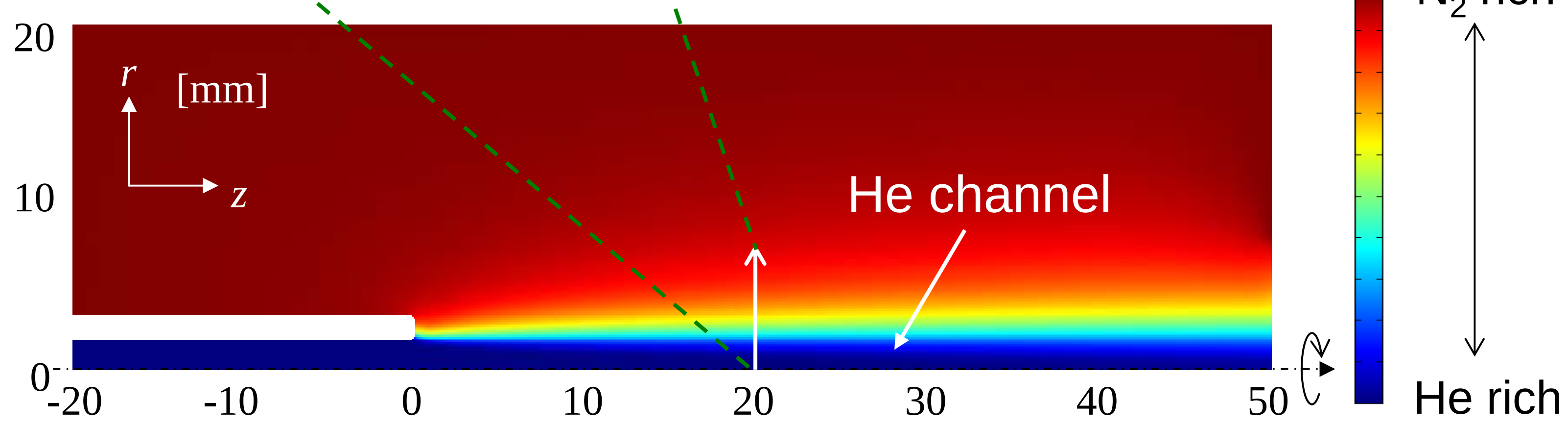
le N-S equation

: total mass continuity

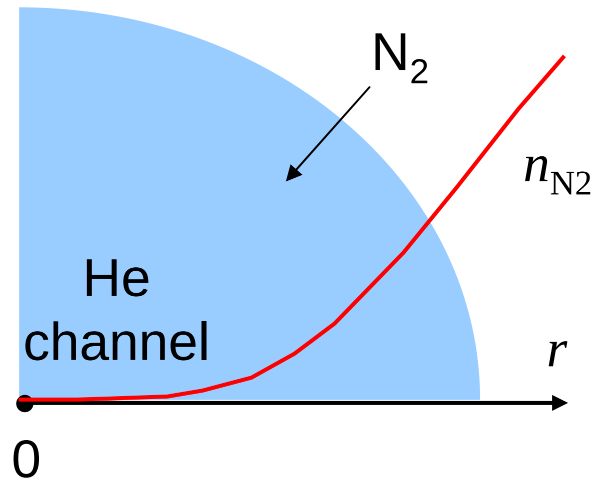
: continuity for N_2

: total momentum continuity

Mole fraction of air



Model description: 1-D plasma dynamics



- species: e, He^*, He_2^*, He^+, He_2^+, N_2^*, N_2^+
- rate coefficients: from local Boltzmann equation (local field and N_2 concentration)
- pressure: 1 atm
- temperature: 300 K
- solver: COMSOL and Matlab

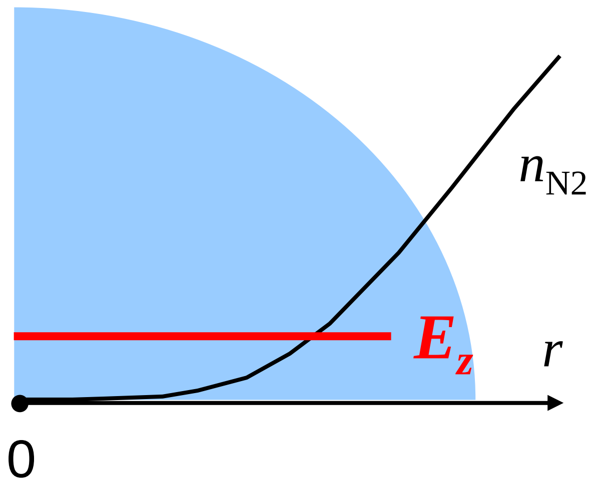
Fluid model with local field approximation

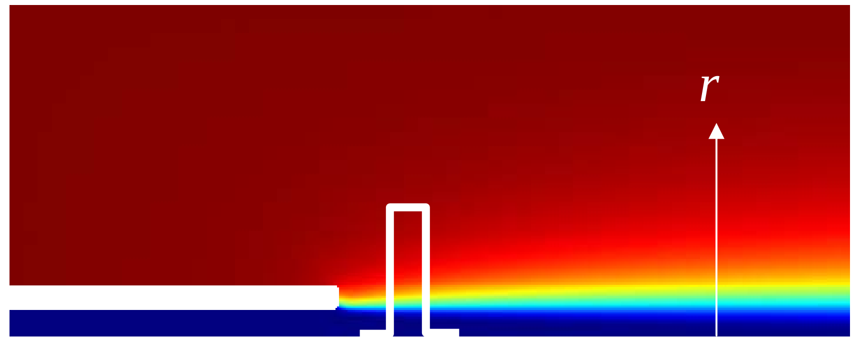
$$\frac{\partial n_i}{\partial t} + \frac{1}{r}\frac{\partial (r\Gamma_i)}{\partial r} = S_i$$ (mass continuity)

$$\Gamma_i = \mathrm{sgn}(q_i)\, n_i \mu_i E_r - D_i \frac{\partial n_i}{\partial r}$$ (drift-diffusion)

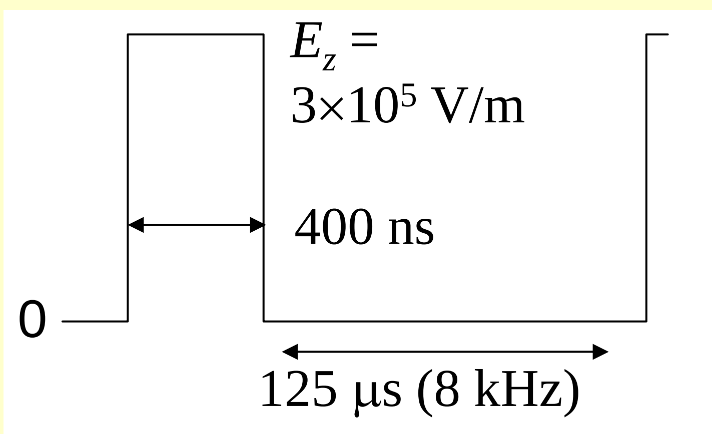
$$\varepsilon_0 \frac{1}{r}\frac{\partial (rE_r)}{\partial r} = \sum_i q_i n_i$$ (Poisson's eq. in r-direction)

Model description: 1-D plasma dynamics -2





Given electric field (not self-consistent!)

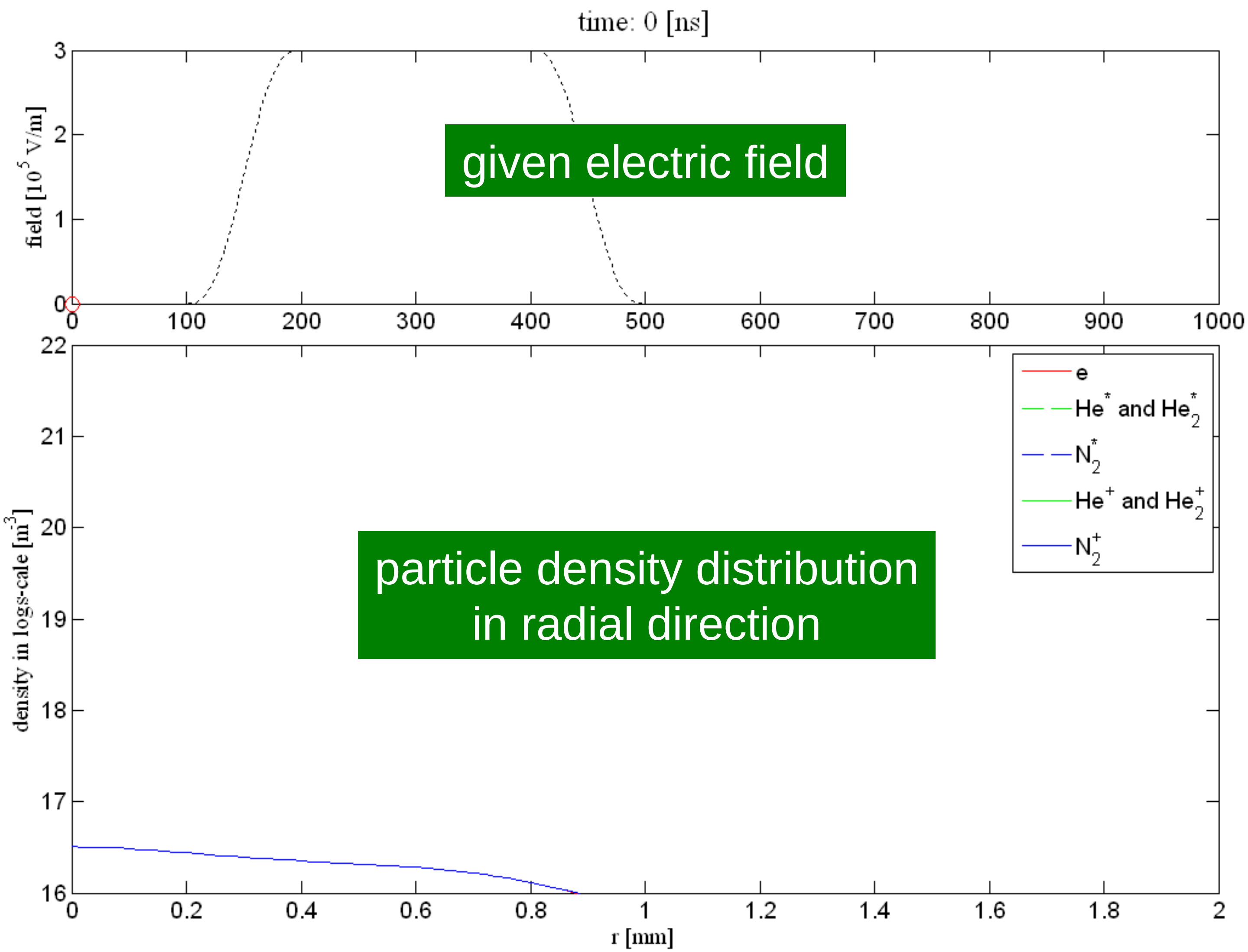


$$|\mathbf{E}| = \sqrt{|E_r|^2 + |E_z|^2}$$

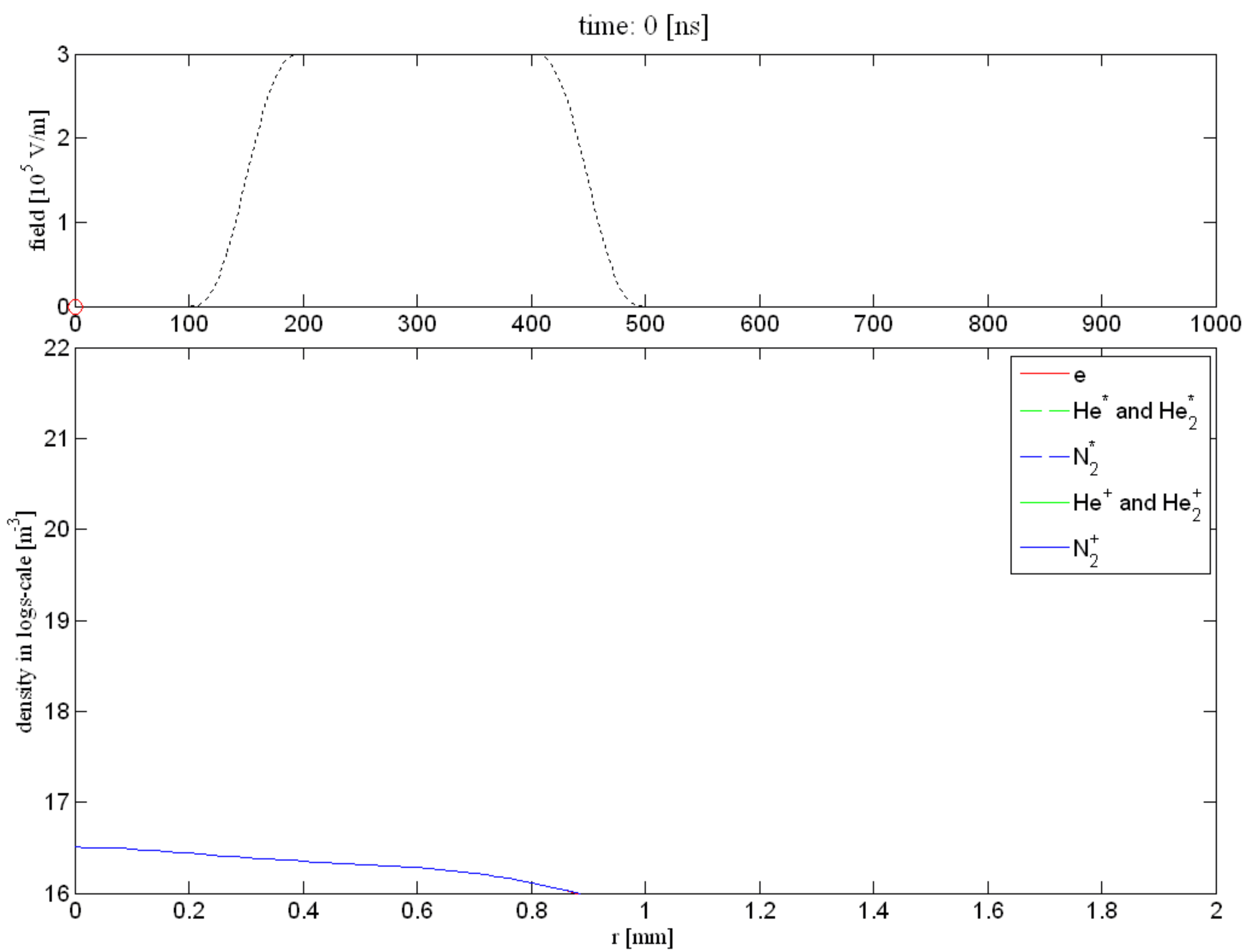
Poisson's eq. given

reaction rate: $k = f\left(|\mathbf{E}|\right)$

Results: plasma dynamics (*z* = 20 mm)

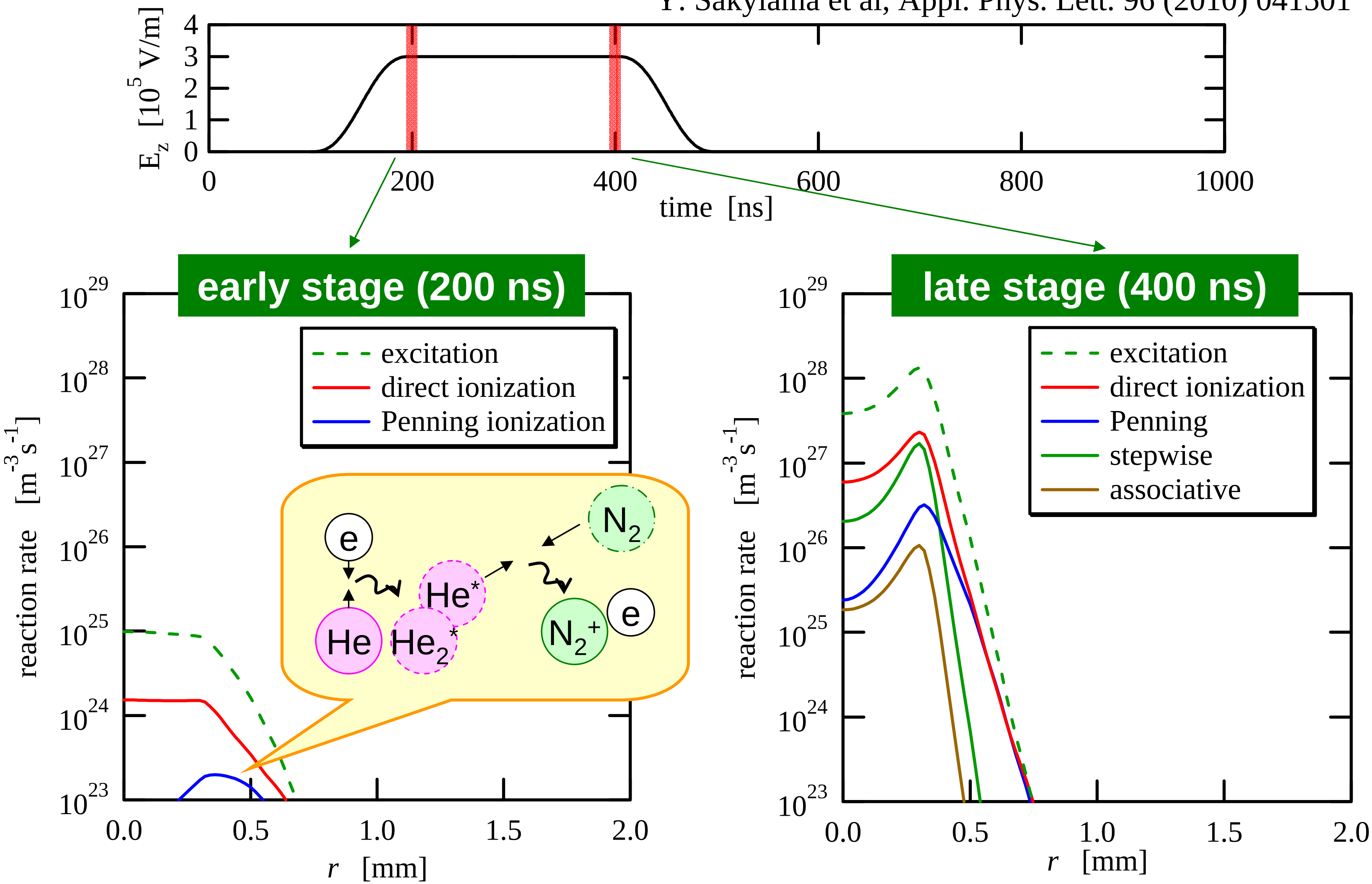


Results: plasma dynamics (*z* = 20 mm)

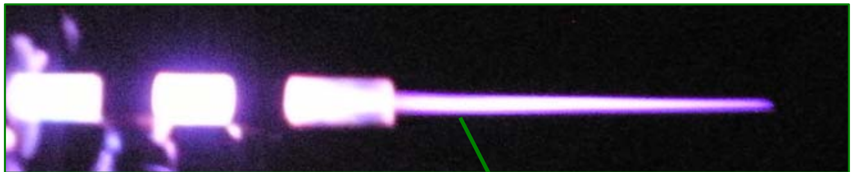


Results: ionization mechanisms (z = 20 mm)

Y. Sakyiama et al, Appl. Phys. Lett. 96 (2010) 041501

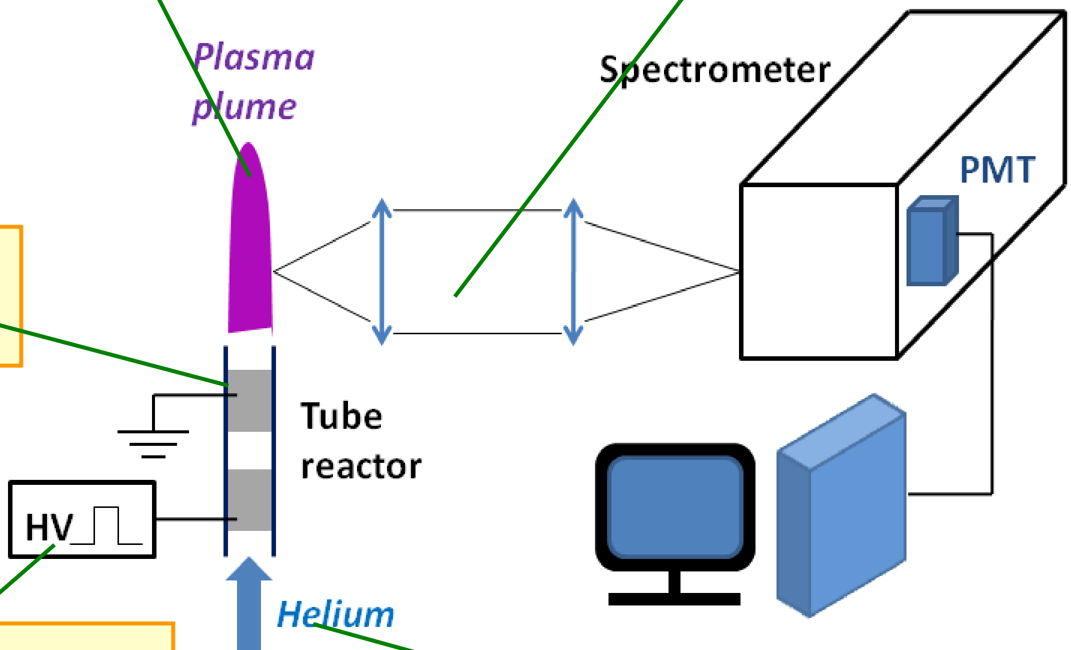


Experiments: time and spatially-resolved OES



Time resolution: 1 ns

Spatial resolution: ~50 μm



inner diameter: 3 mm

amplitude : 7 kV

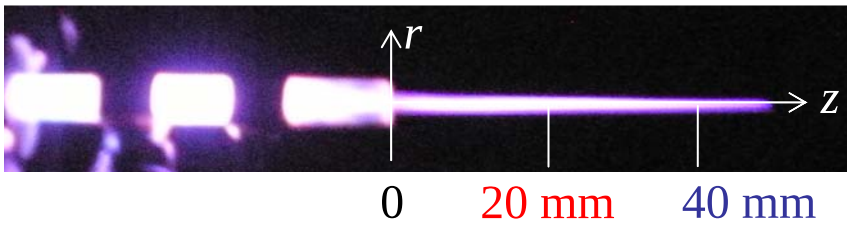
pulse width : 2 μs

repetition rate : 8 kHz

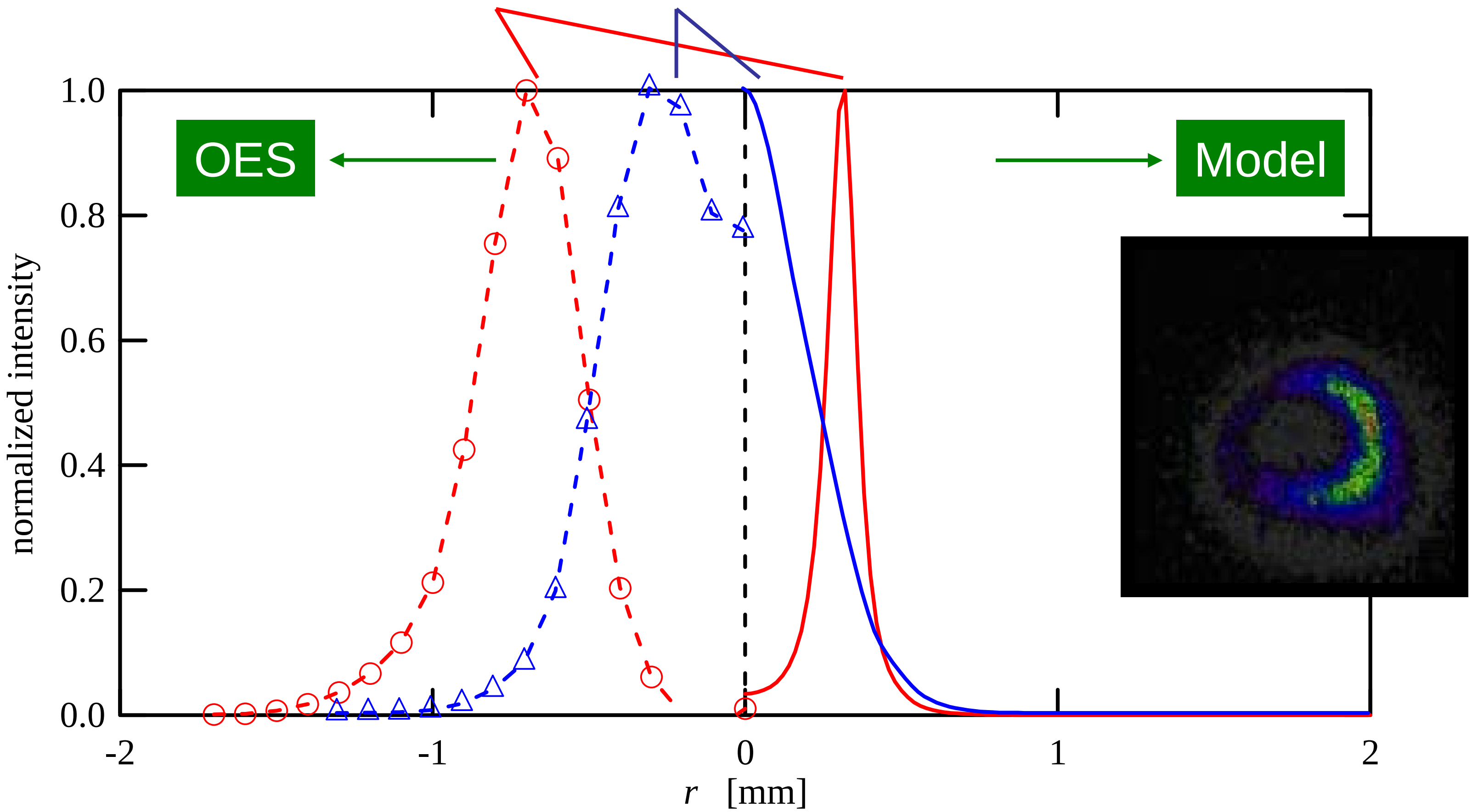
Helium flow: 7 slpm

Results: N_2 SPS profile in radial direction

Y. Sakyiama et al, Appl. Phys. Lett. 96 (2010) 041501

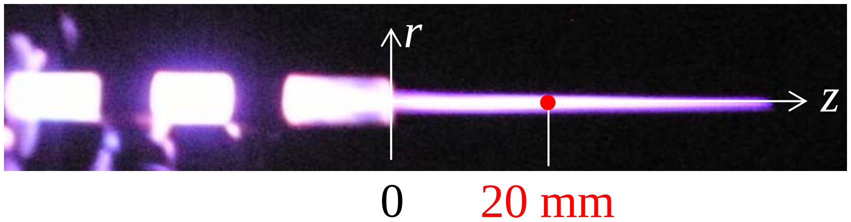


integration time for OES:
100 ms (800 bullets)

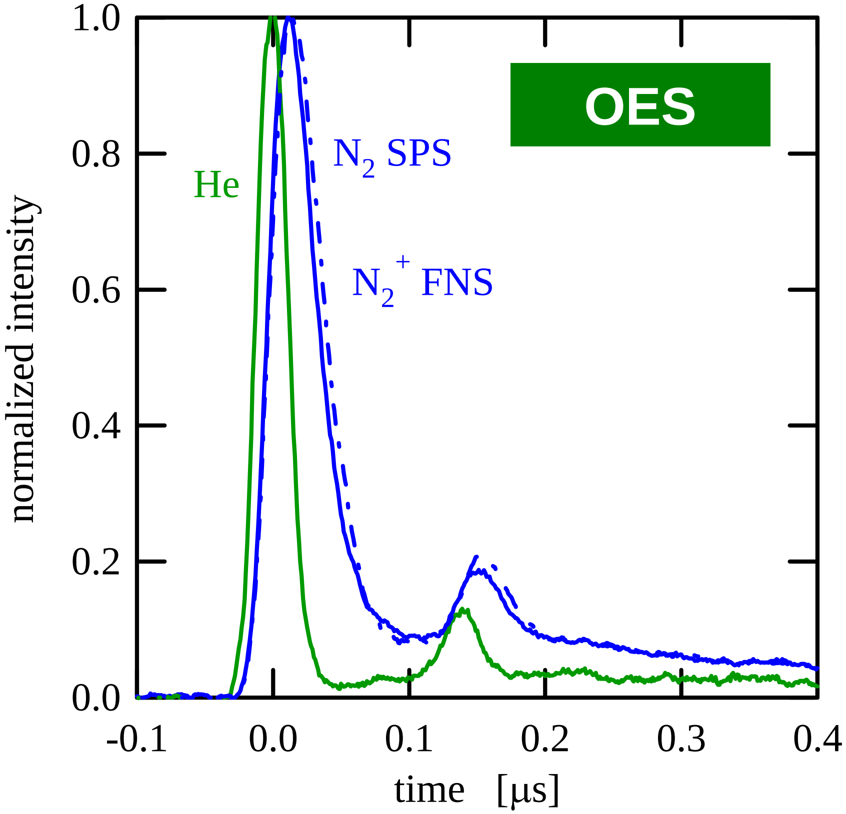


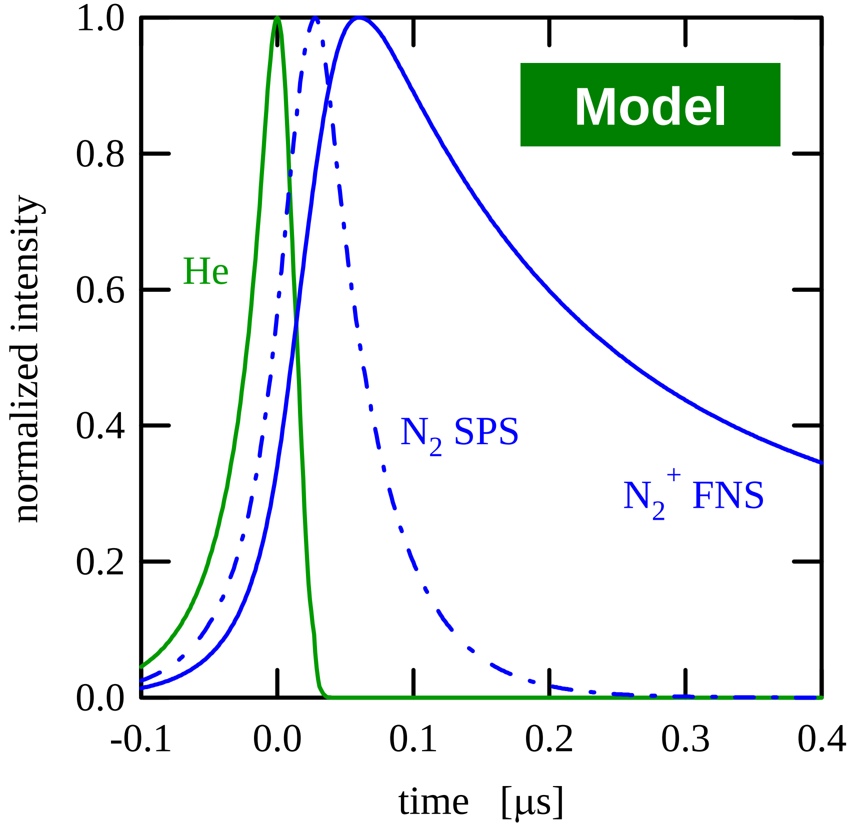
Results: time-development of emission profile

Y. Sakyiama et al, Appl. Phys. Lett. 96 (2010) 041501



N_2 ($C^3\Pi_u$): SPS at 337.1 nm
N_2^+ ($B^2\Sigma_u^+$): FNS at 391.2 nm
He: 706.5 nm





Concluding Remarks

1. We have developed a one-way coupling model between neutral gas flow and plasmas for modeling of the plasma bullet.

2. The ring-shaped profile is initiated by Penning ionization between helium metastables and background nitrogen at the early stage.

3. The diameter of the ring decreases as the bullet propagates due to quenching by air. This agrees with our OES measurement.