RLPI Laboratory of Relativistic Laser Plasma

# Управление длиной кильватерного ускорения оптически созданной ударной волной

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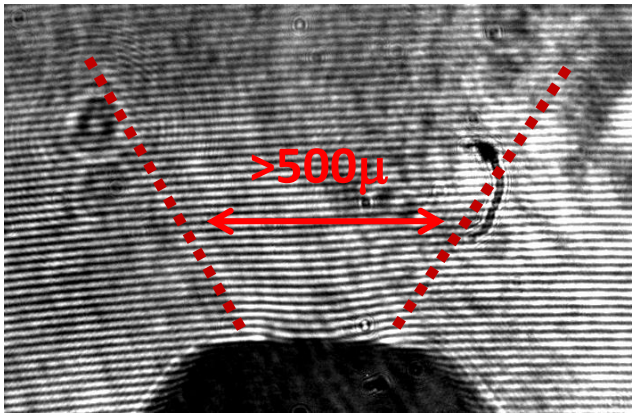
# *Outline*

*- Density profile of a gas jet, modified by a shock wave generated by an additional ns laser pulse*

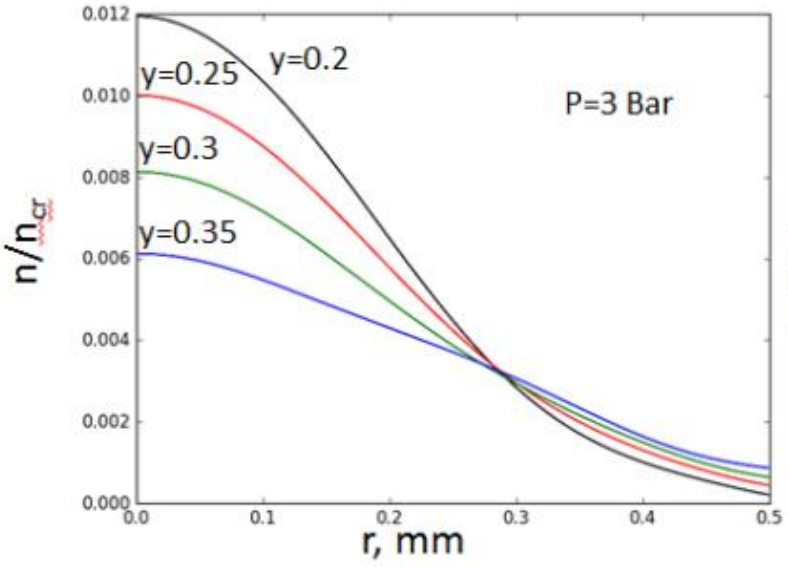
*- Electron acceleration dynamics measurements and beam quality improvement by cutting plasma channel using shock wave*

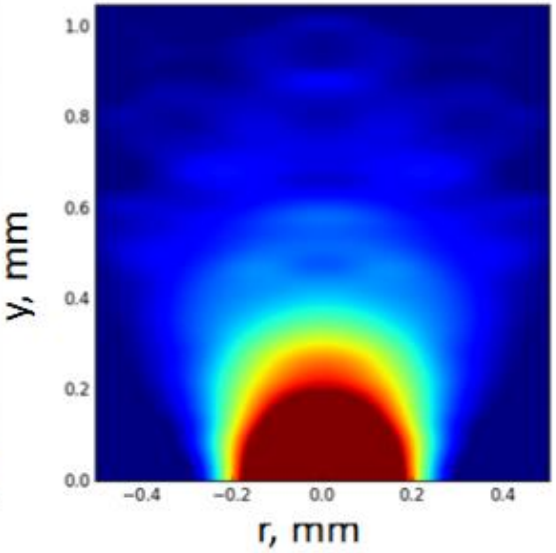
# *Gas target characterization*

**Extremely cheap design**
**Non-demanding to high vacuum pump rate**

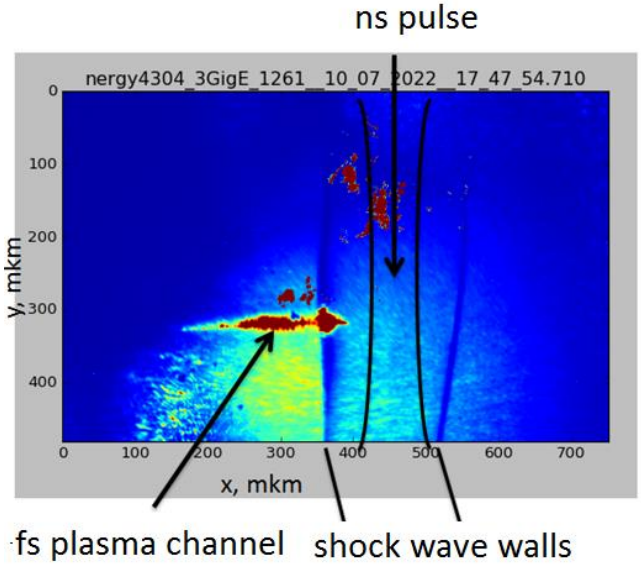


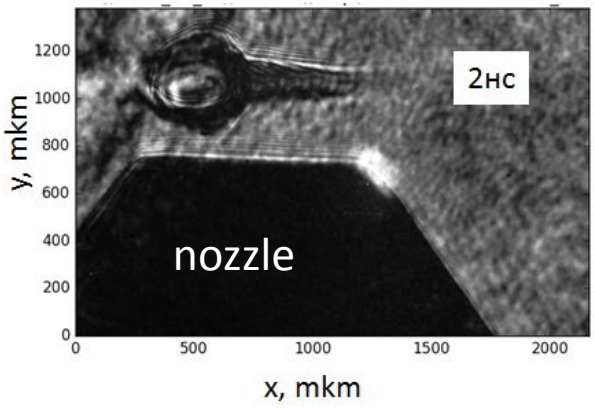

Continuous $N_2$ flow at 3-5 bar

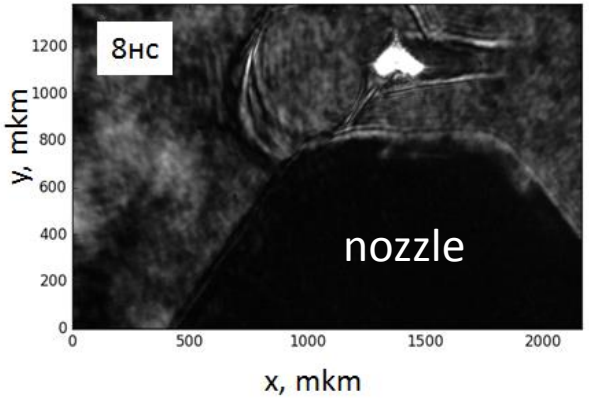


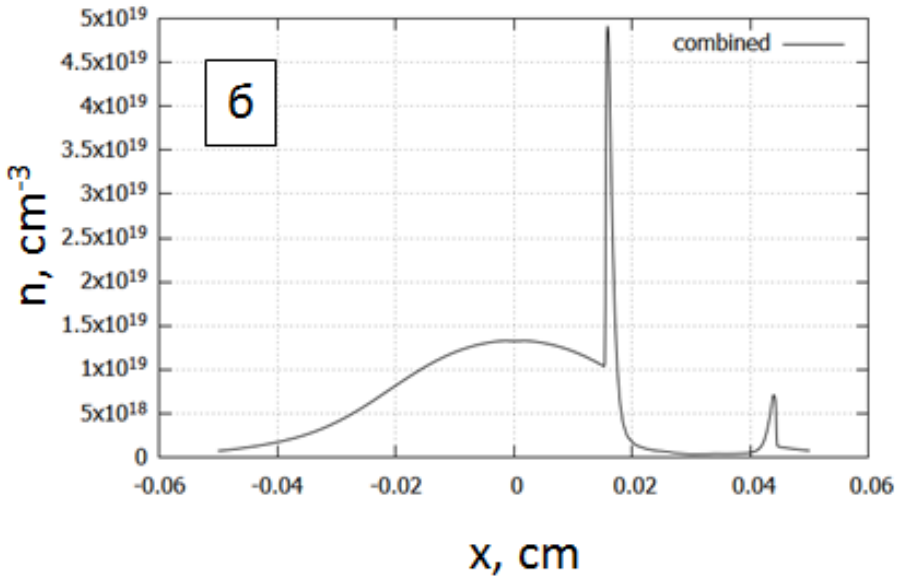



# Gas target characterization



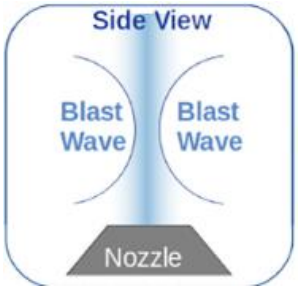



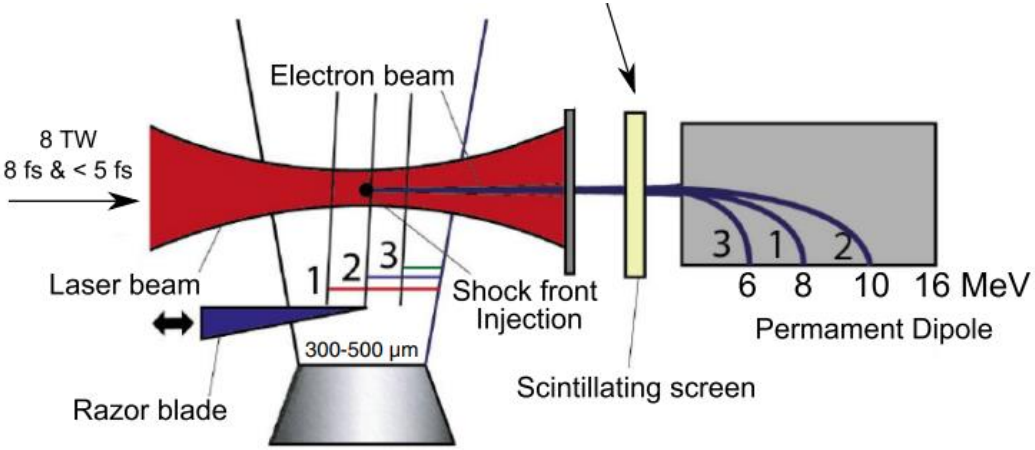

$$s(r) = \begin{cases} 5 \times \exp\left(-\left(\frac{|r - r_0|}{l_1}\right)^{1.2}\right), & r < r_0 \\ 1 + 4 \times \exp\left(-\left(\frac{|r - r_0|}{l_2}\right)^{4}\right), & r \geq r_0 \end{cases}$$

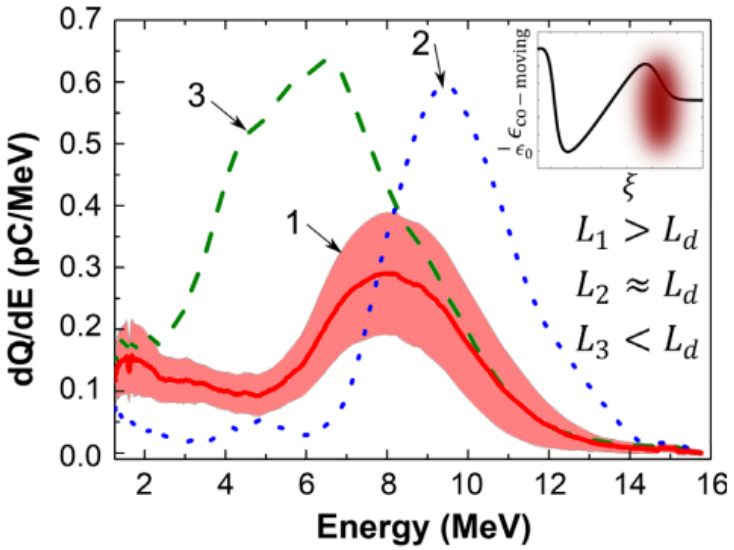
$l_1$ = 15 mkm, $l_2$ = 7 mkm for t = 2ns



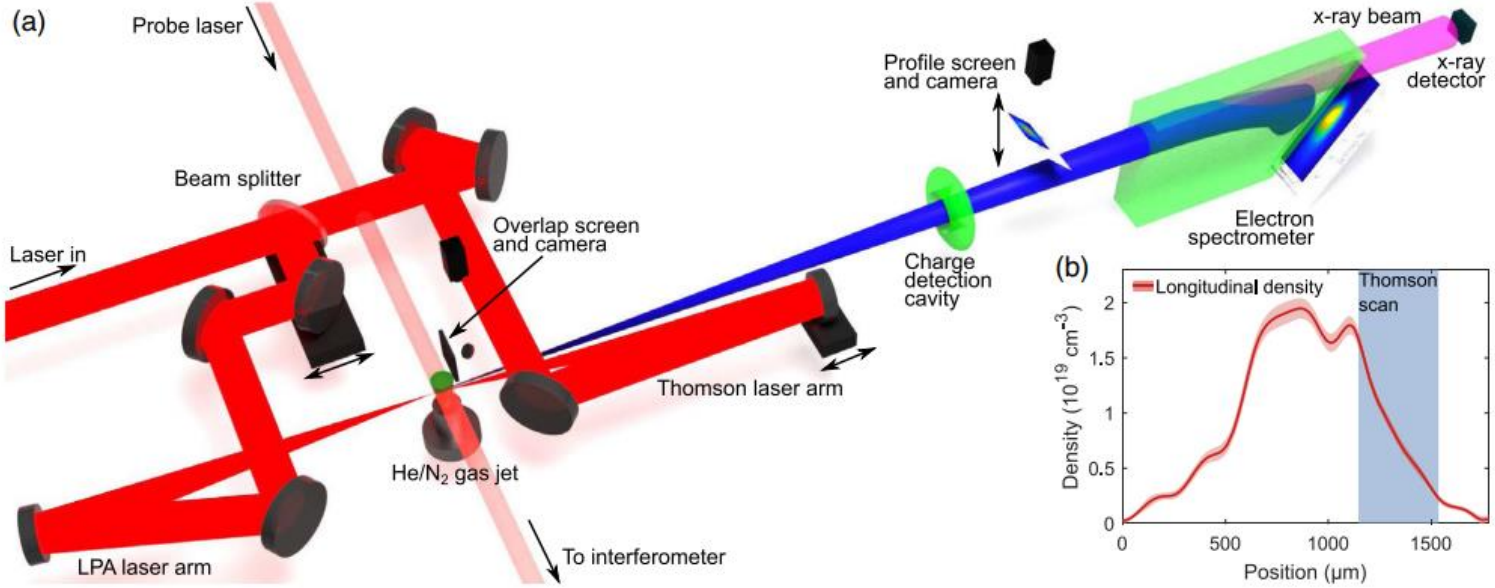

**Phys. Plasmas 28, 113102 (2021)**

# Electron beam acceleration dynamics measurements



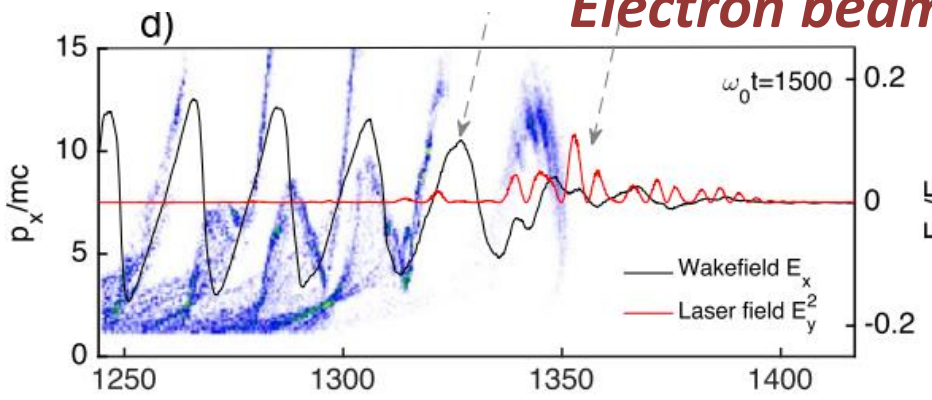




Cardenas D. E. et al. //***PRAB***. – 2020. – Т. 23. - №. 11. – С. 112803.




Bohlen S. et al. //***PRL*** – 2022. – Т. 129. – №. 24. – С. 244801.

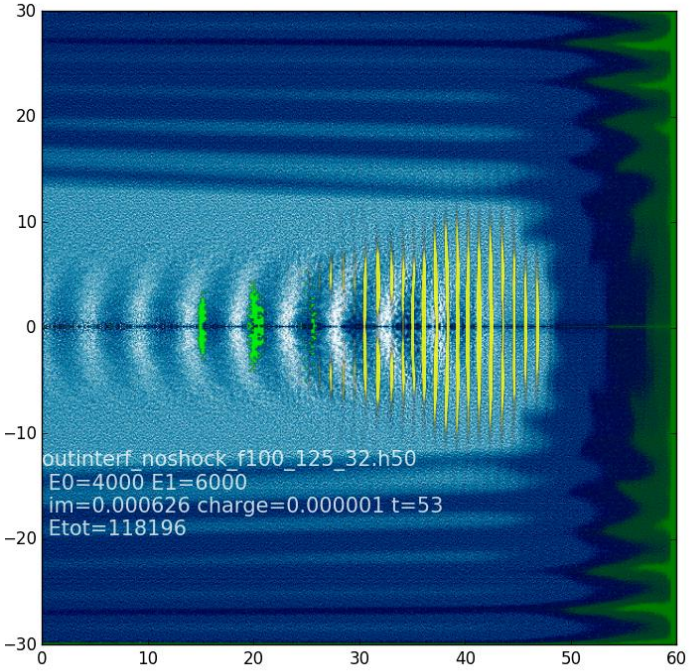
# Electron beam dephasing

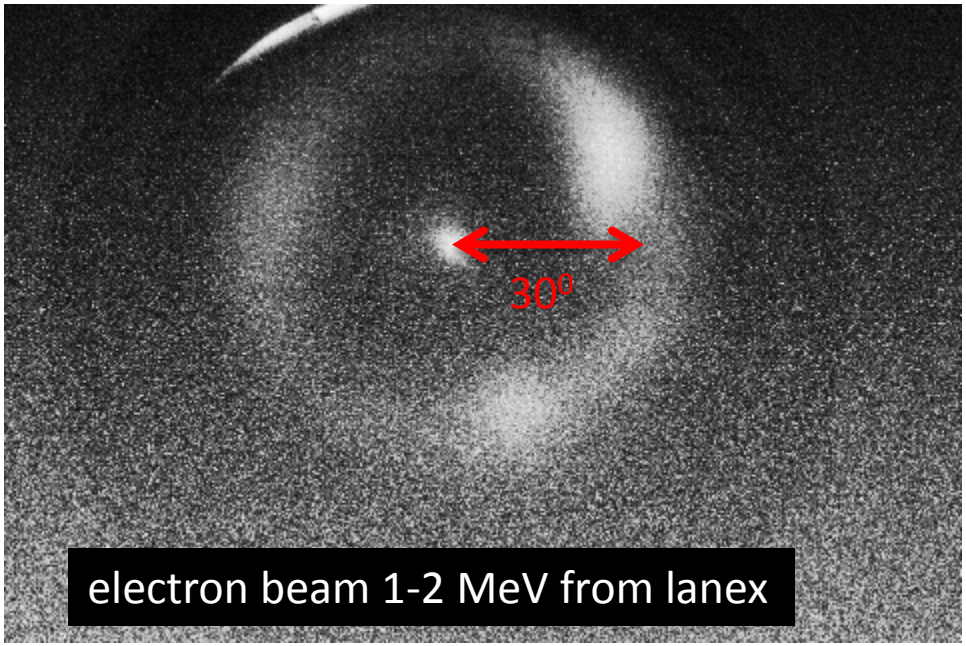



Faure J. et al. //**PPCF** – 2018. – Т. 61. – №. 1. – С. 014012.

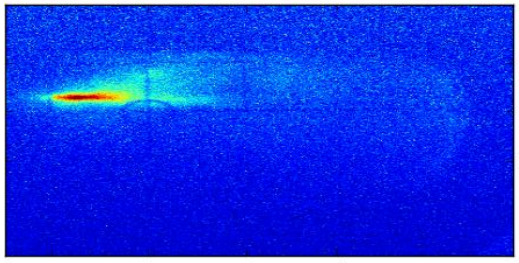
$$n \approx 0.05 n_{cr} \quad v_\phi = c\sqrt{1 - n/n_{cr}} \approx 0.975c. \quad \lambda_p = v_\phi \omega_p \approx 4.5\lambda$$

$$L_d \approx \tfrac{1}{2}\lambda_p/(1 - v_\phi/c) \approx 90\lambda \approx 20\lambda_p.$$

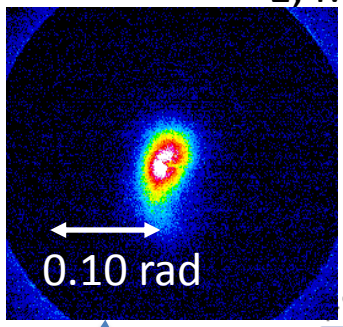


# Experimental setup

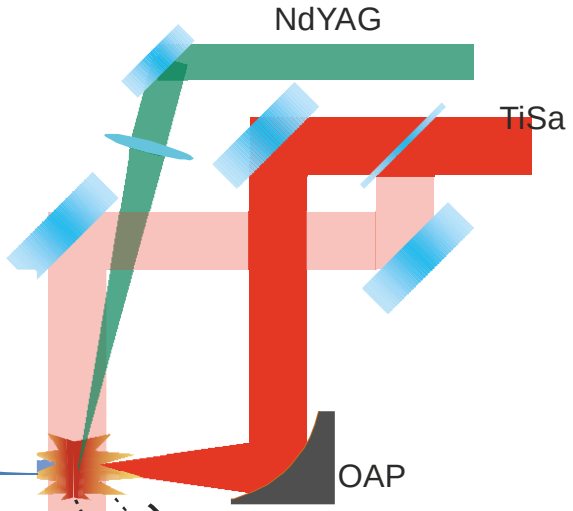


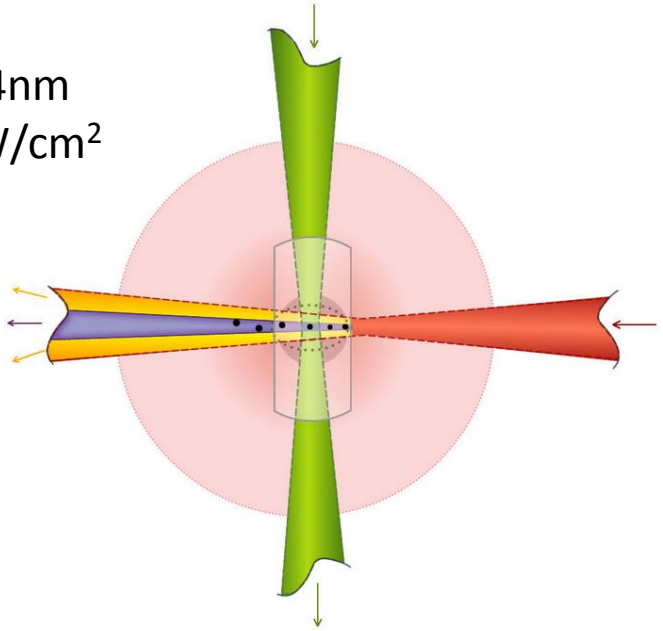

**NdYAG**: 100mJ, 10ns, 1064nm
**TiSa:** 50mJ, 50 fs, 5x10$^{18}$ W/cm$^2$

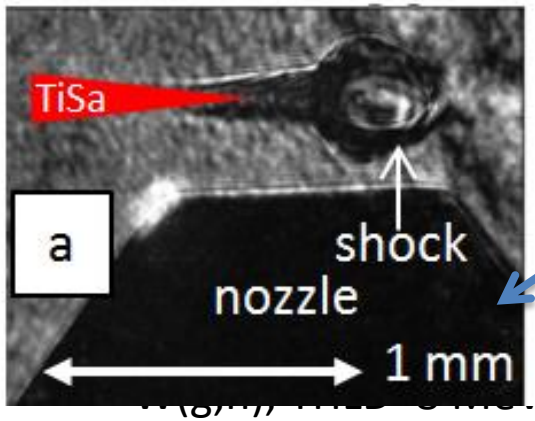


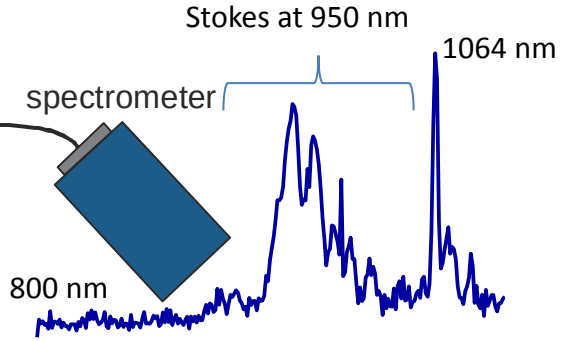


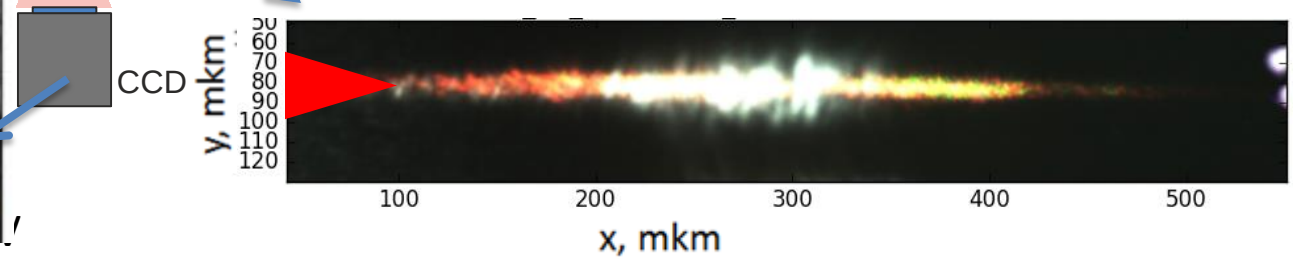




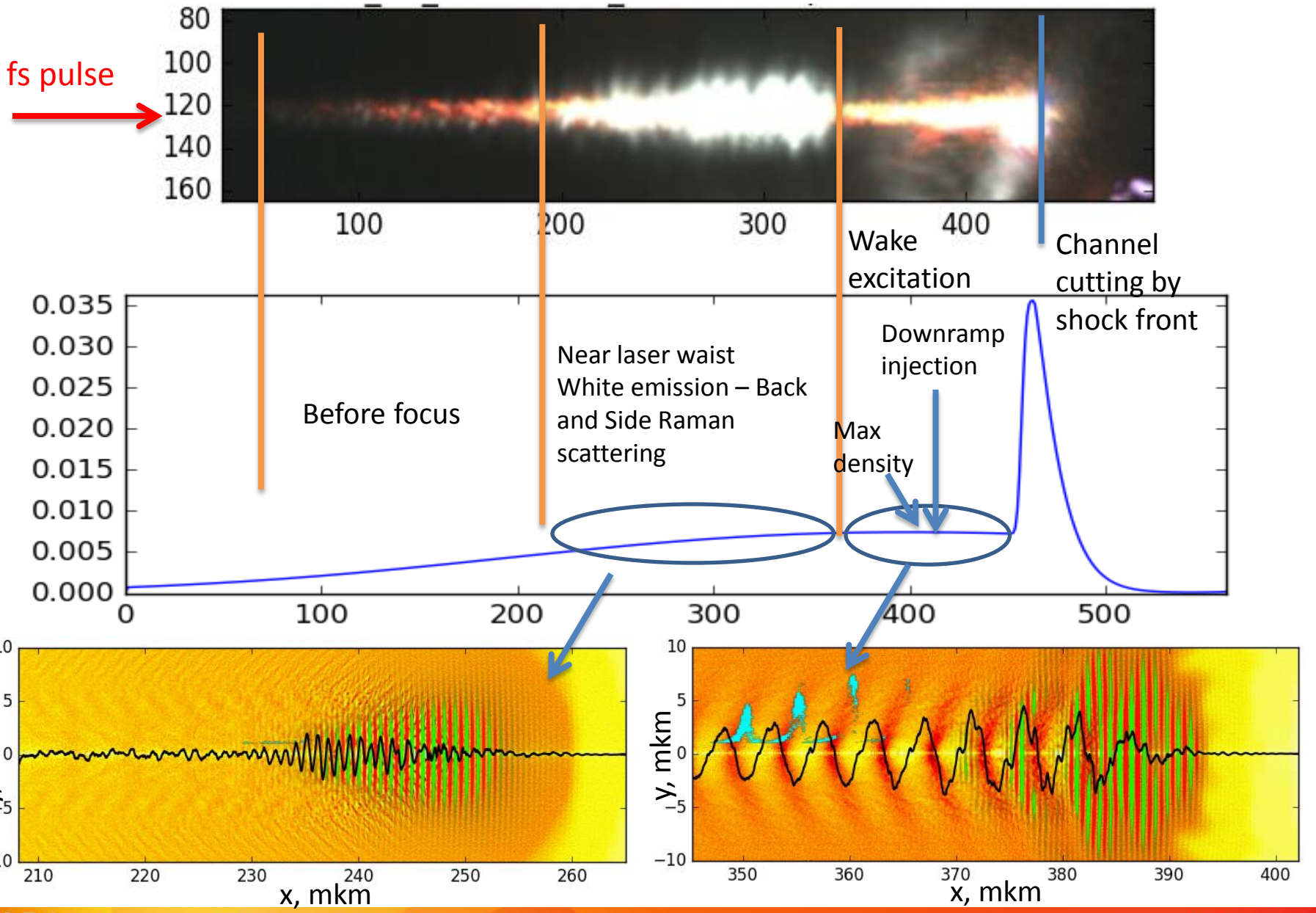





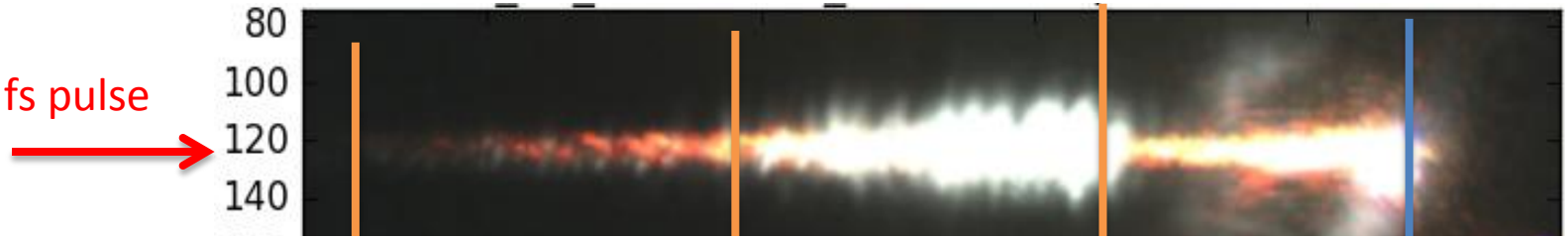



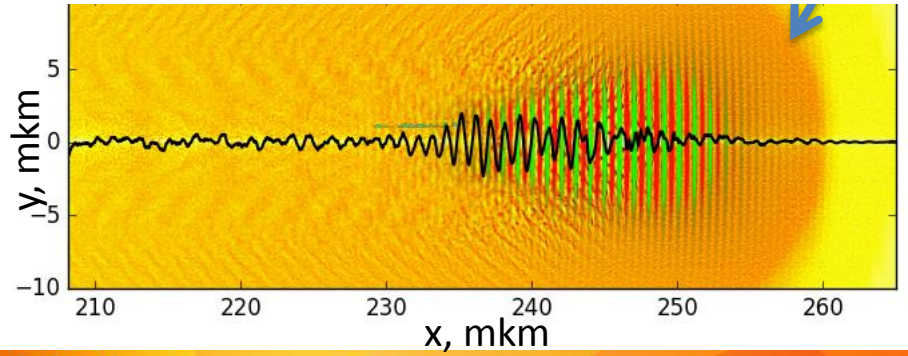
# Plasma channel optical emission

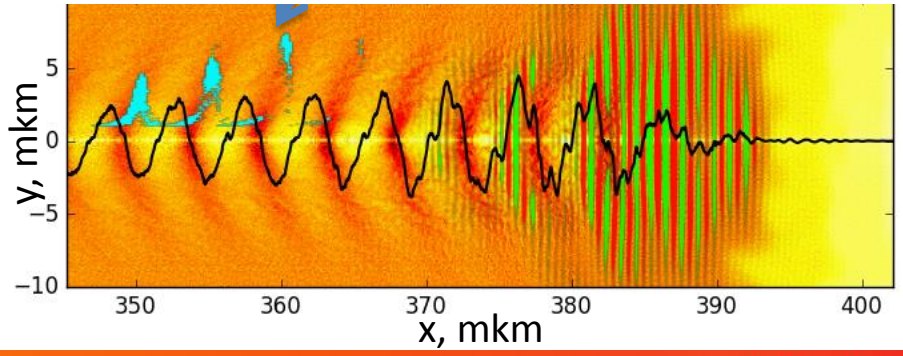


# Plasma channel optical emission

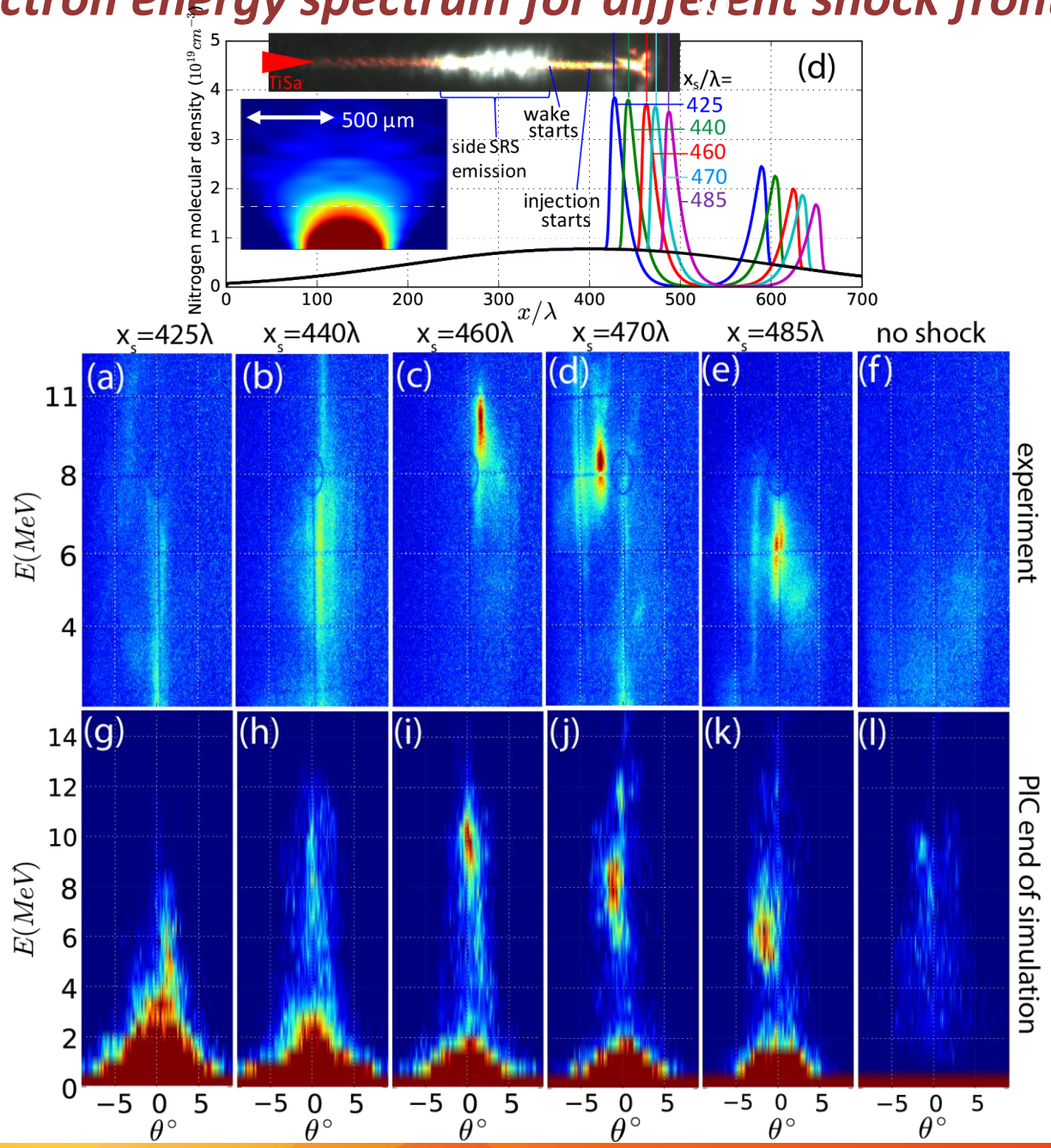




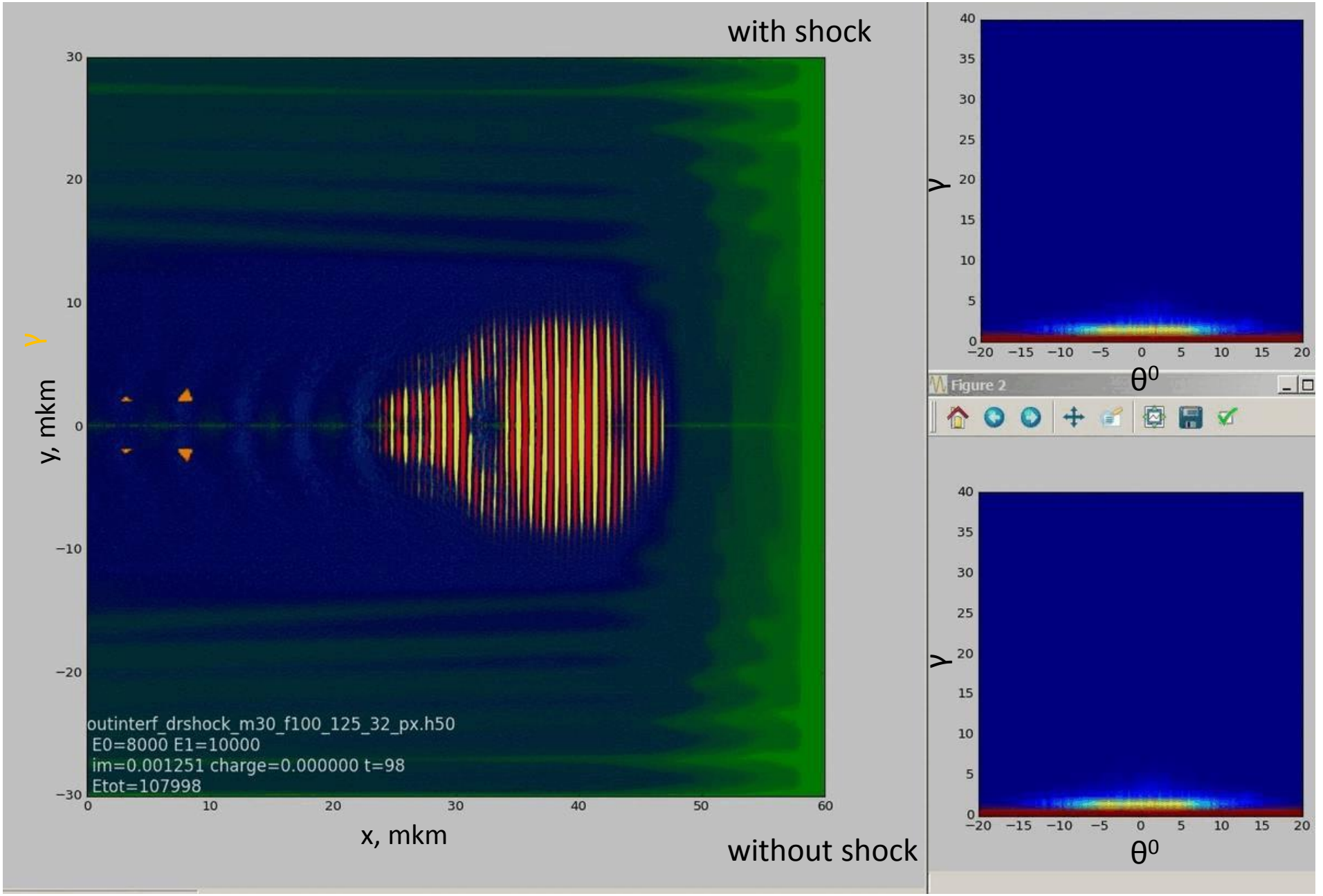


# Electron energy spectrum for different shock front positions

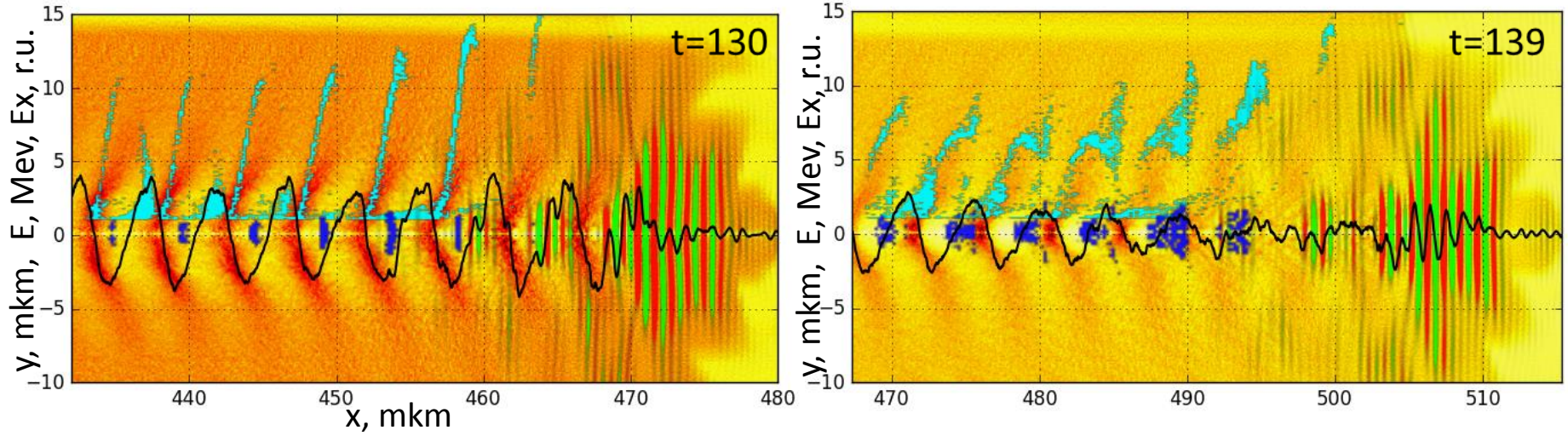


# PIC simulation of dephasing reduction

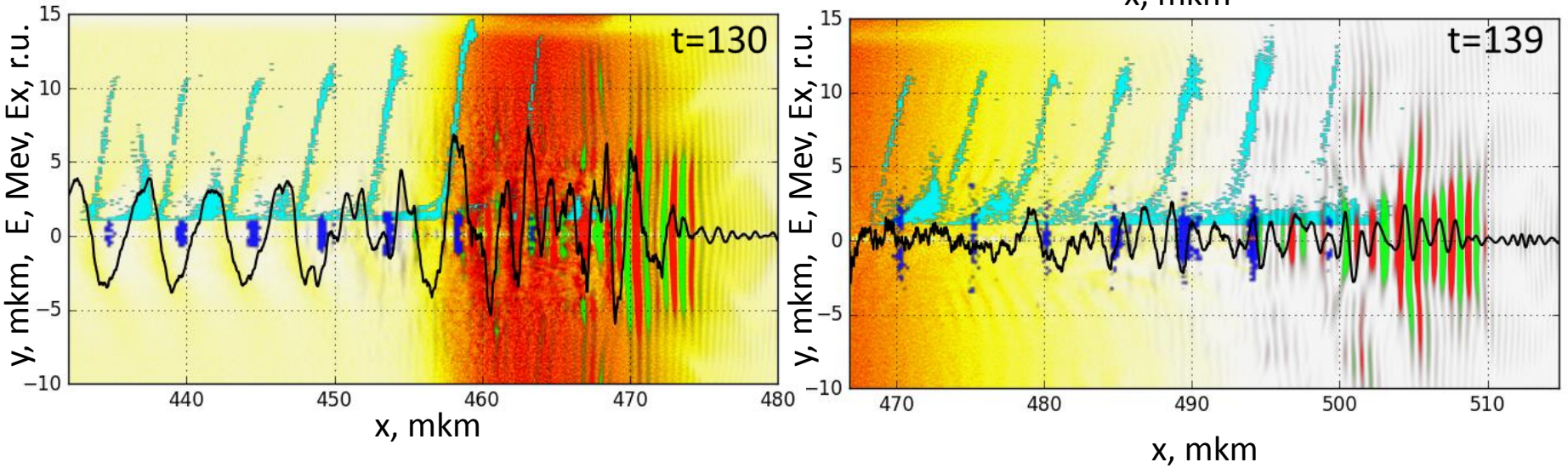


# PIC simulation of dephasing reduction

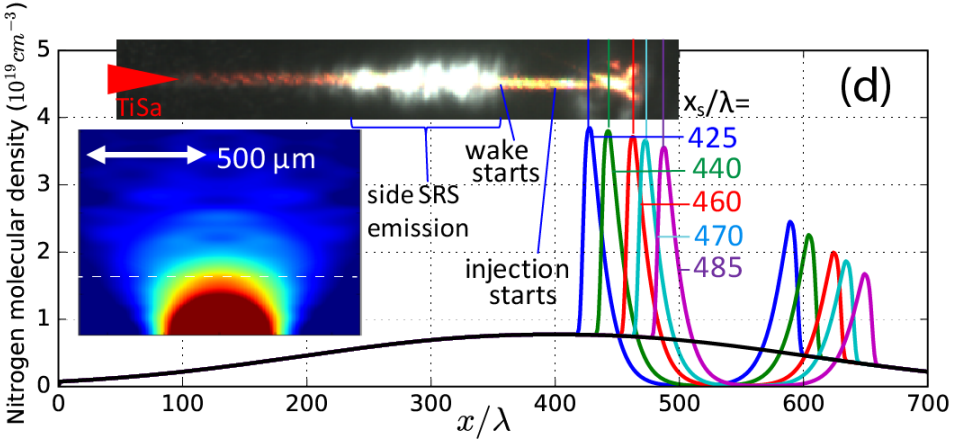
without shock

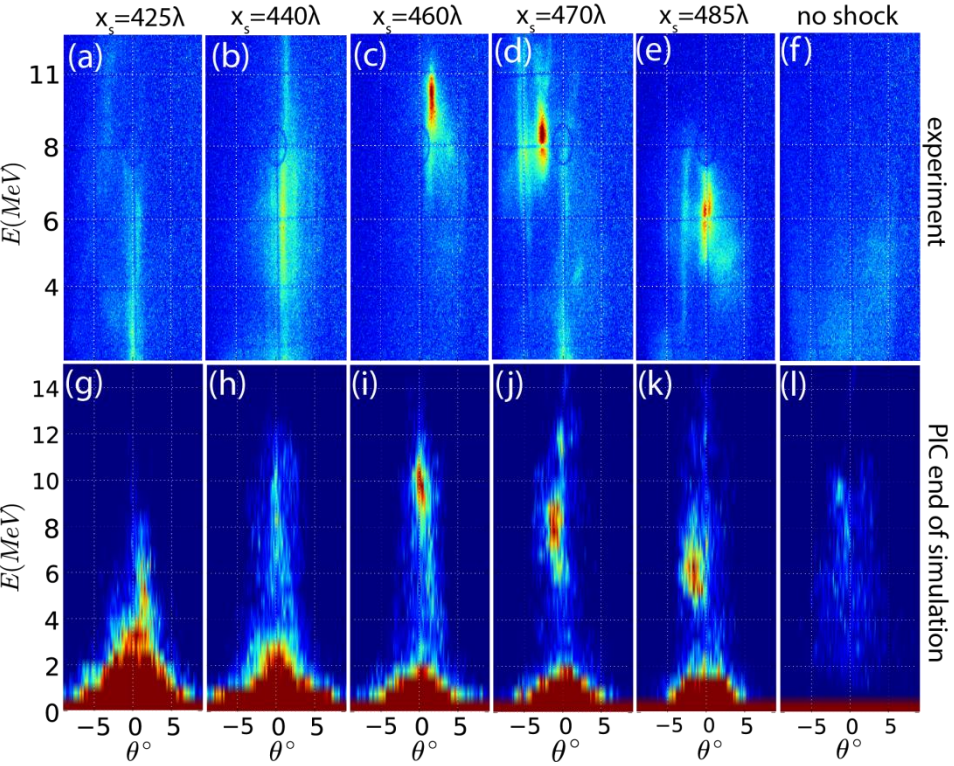


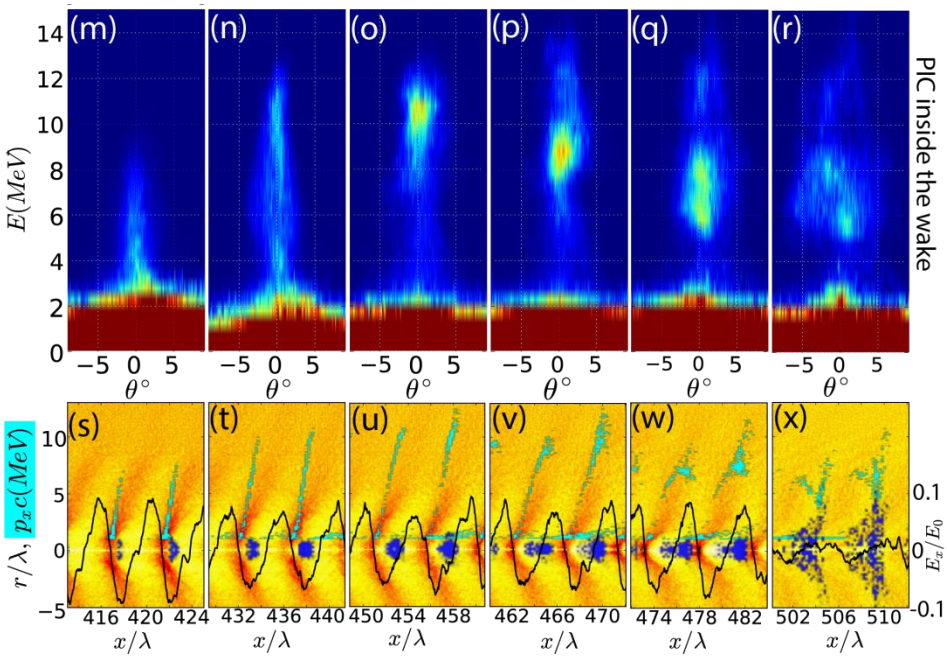

with shock



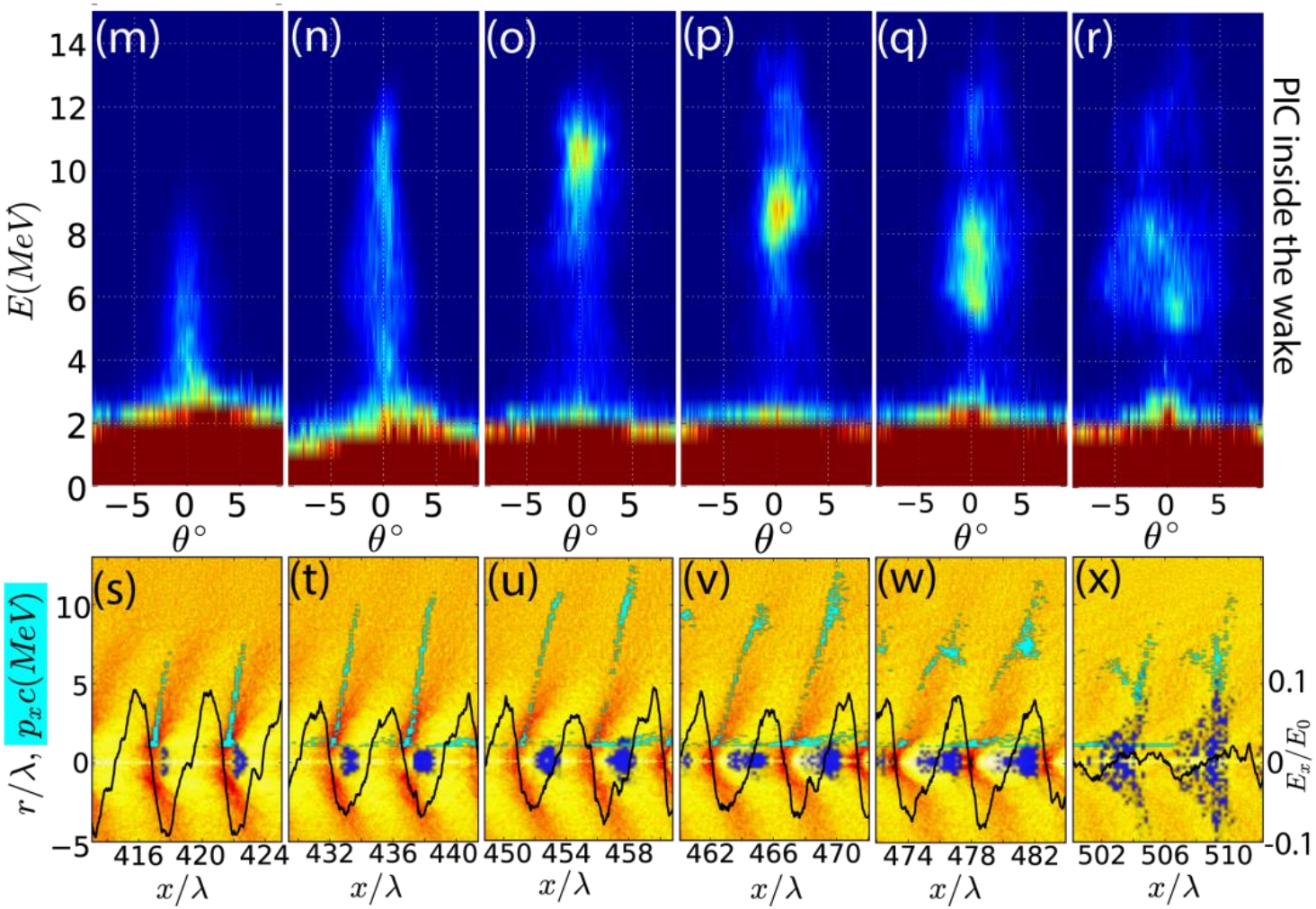
# Electron energy spectrum for different shock front positions



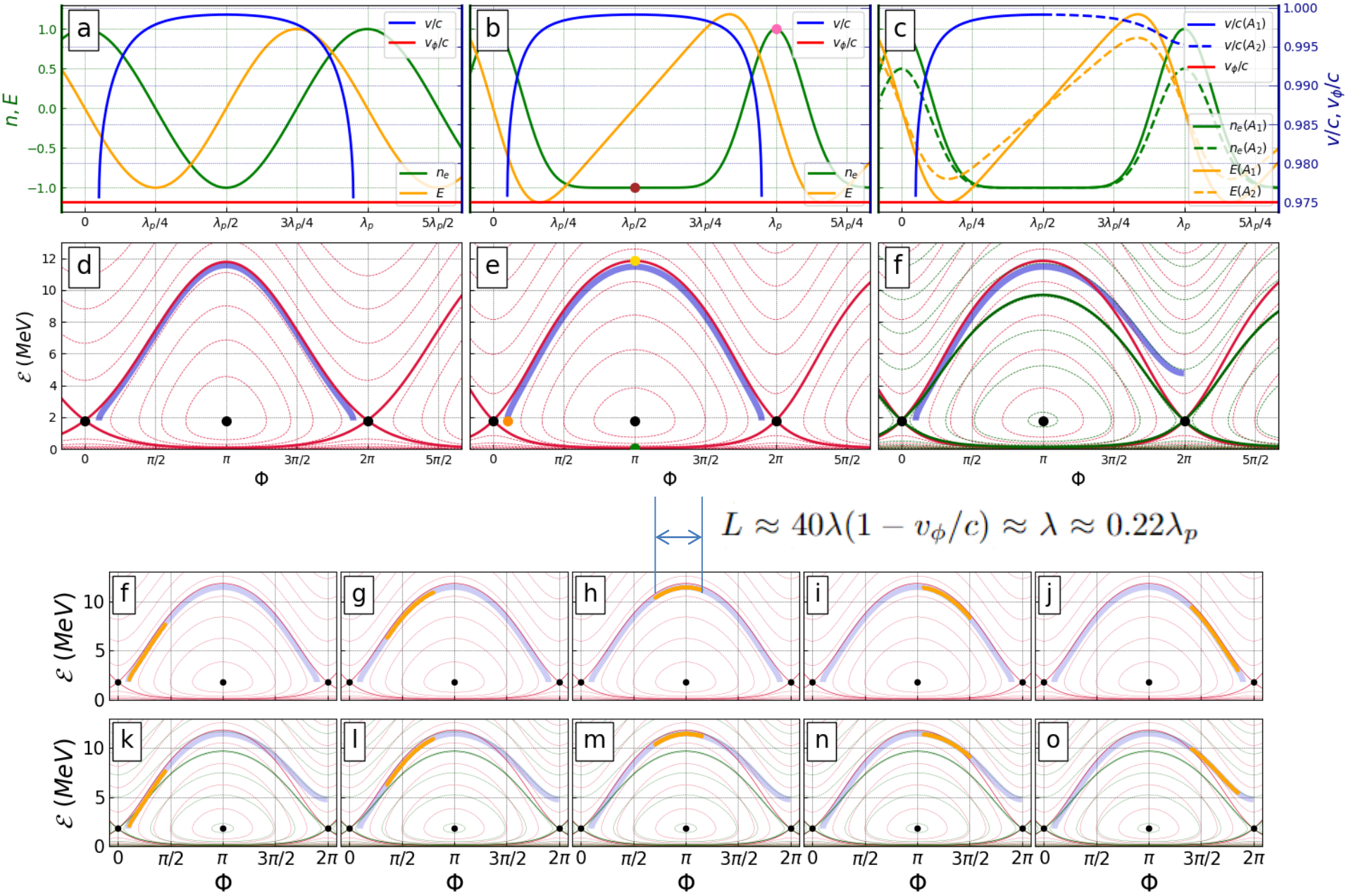



# Electron energy spectrum for different shock front positions

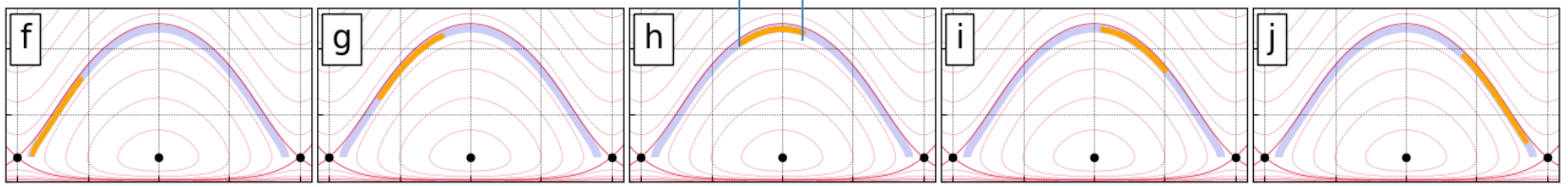


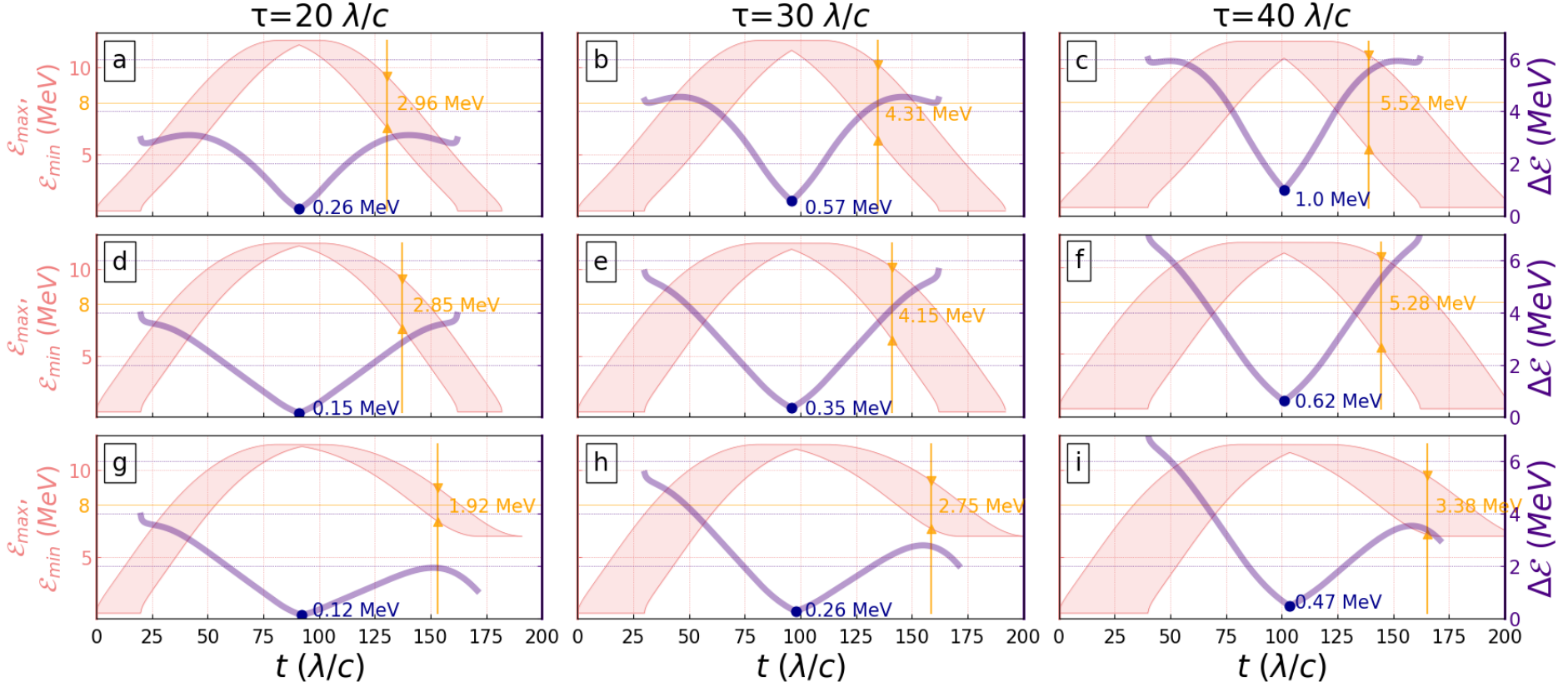
# Electron bunch in phase space



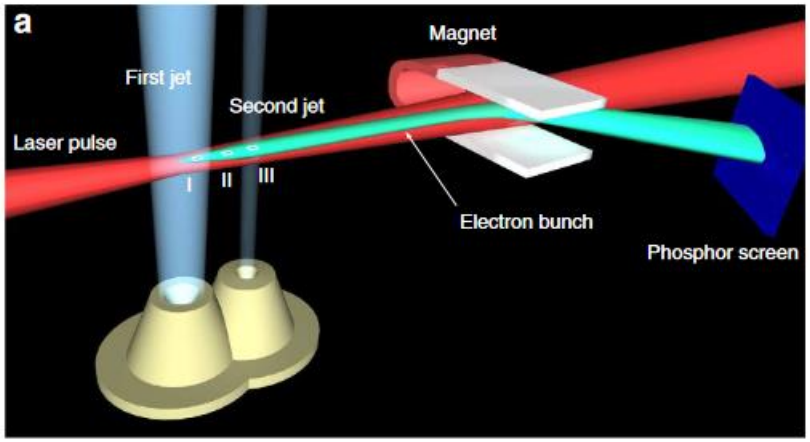
# Electron bunch in phase space

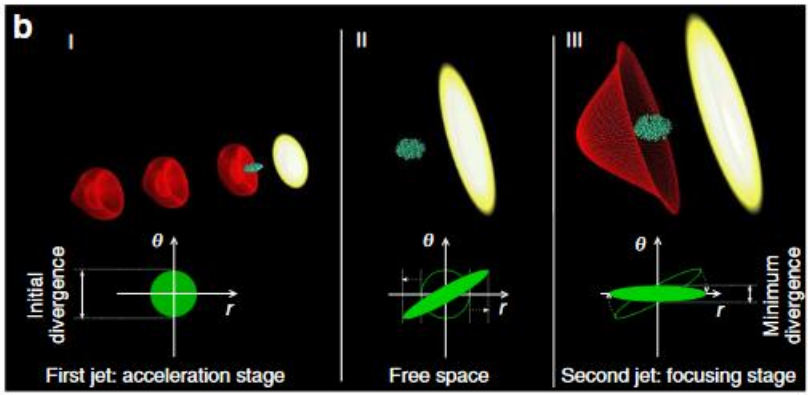
$$L \approx 40\lambda(1 - v_\phi/c) \approx \lambda \approx 0.22\lambda_p$$



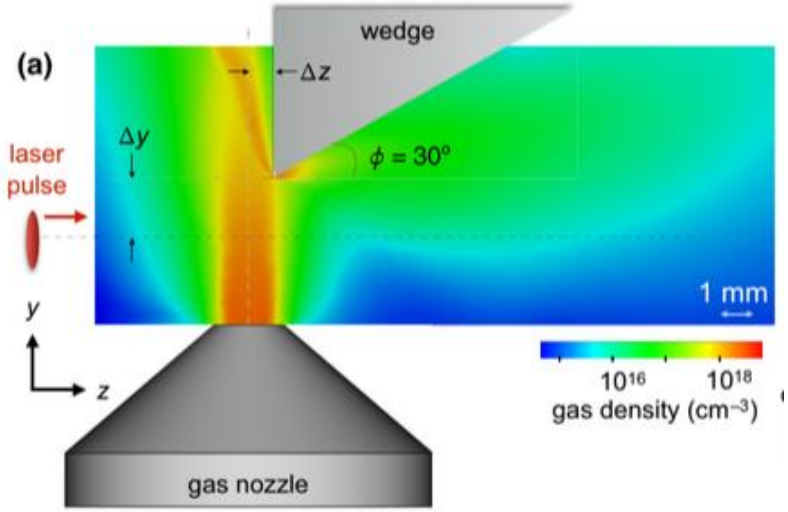



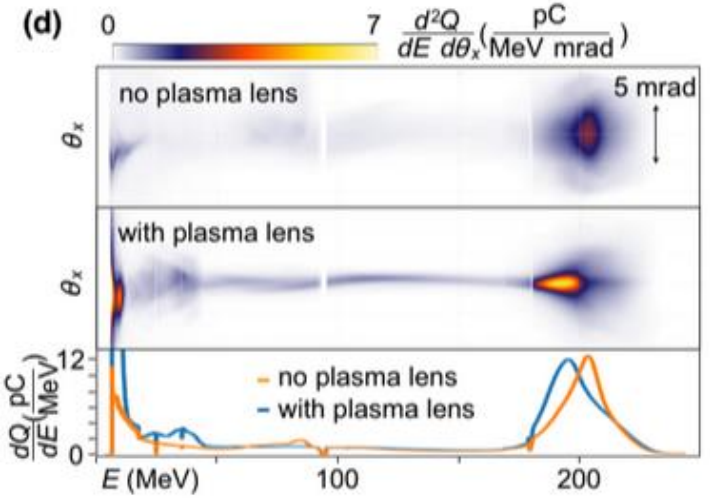
# Plasma lens



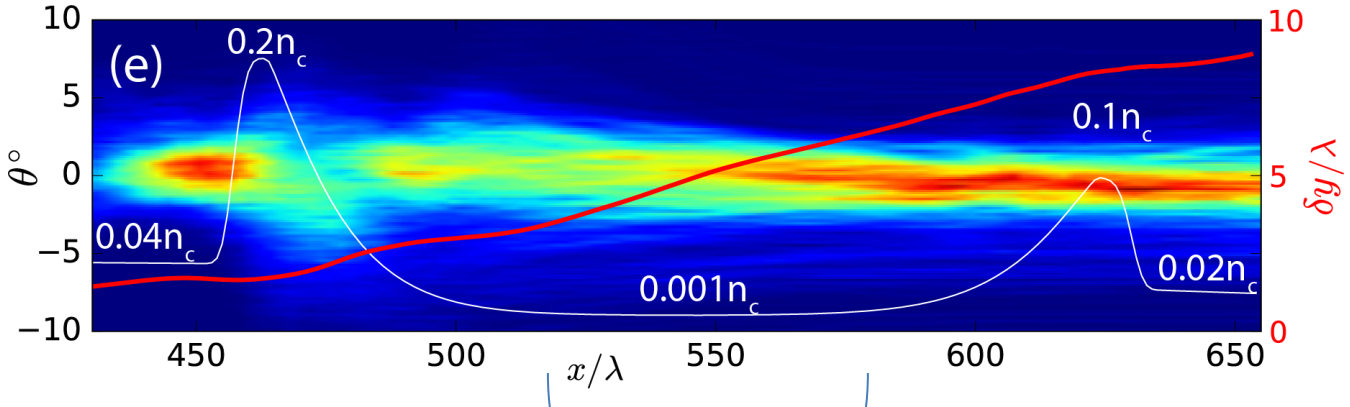

Thaury C. et al. Demonstration of relativistic electron beam focusing by a laser-plasma lens //**Nature communications**. – 2015. – Т. 6. – №. 1. – С. 6860.

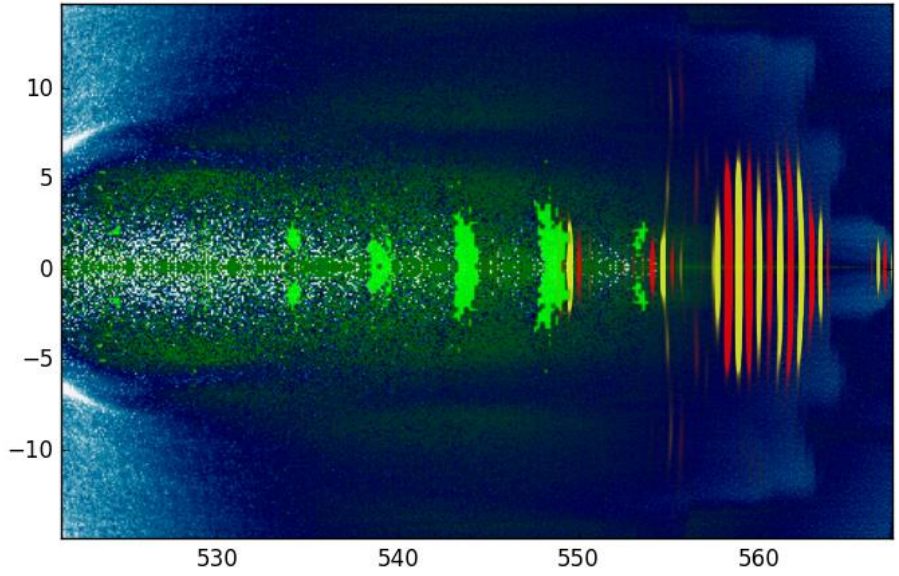


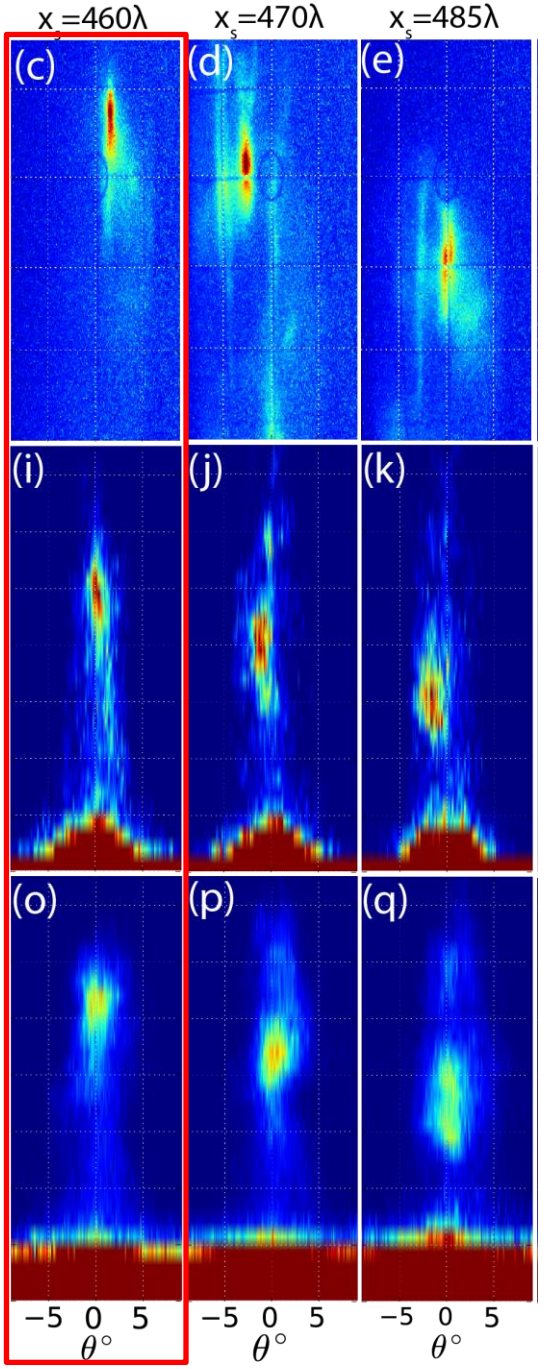




Chang Y. Y. et al. Reduction of the electron-beam divergence of laser wakefield accelerators by integrated plasma lenses //**Physical Review Applied**. – 2023. – Т. 20. – №. 6. – С. L061001.

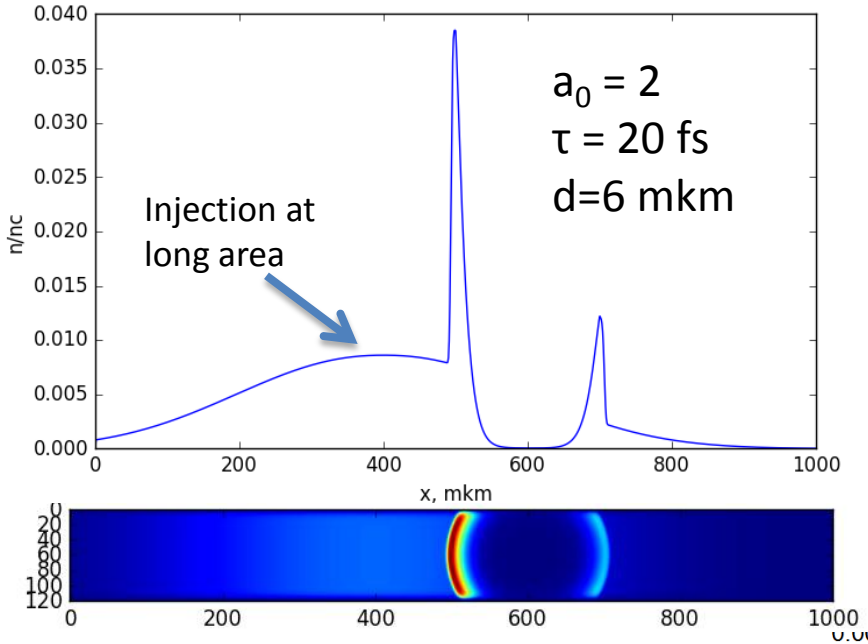
# Plasma lens

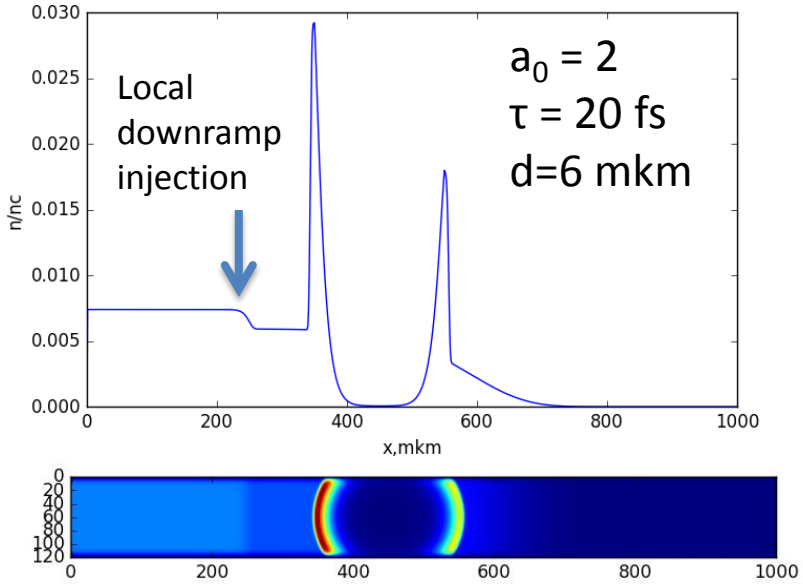

(e)
0.2n_c
0.1n_c
0.04n_c
0.001n_c
0.02n_c
θ°
δy/λ
x/λ
10
5
0
−5
−10
450
500
550
600
650

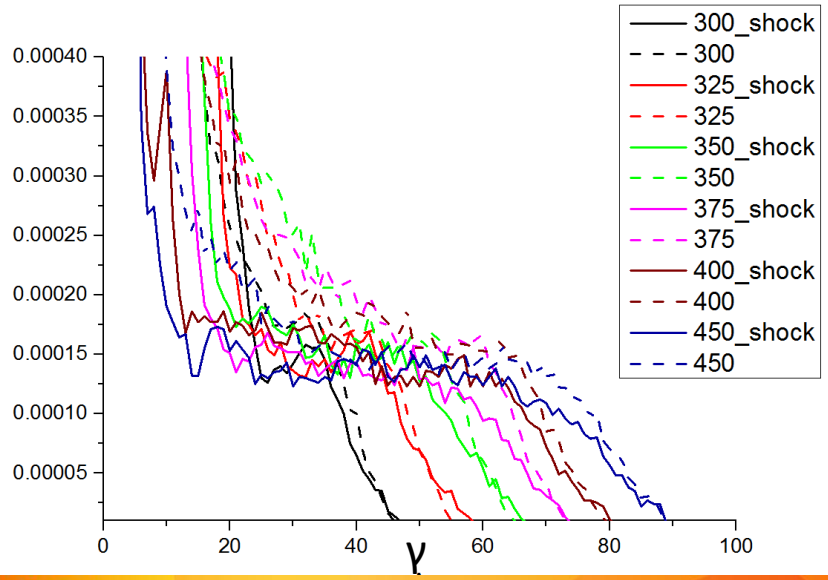

10
5
0
−5
−10
530
540
550
560

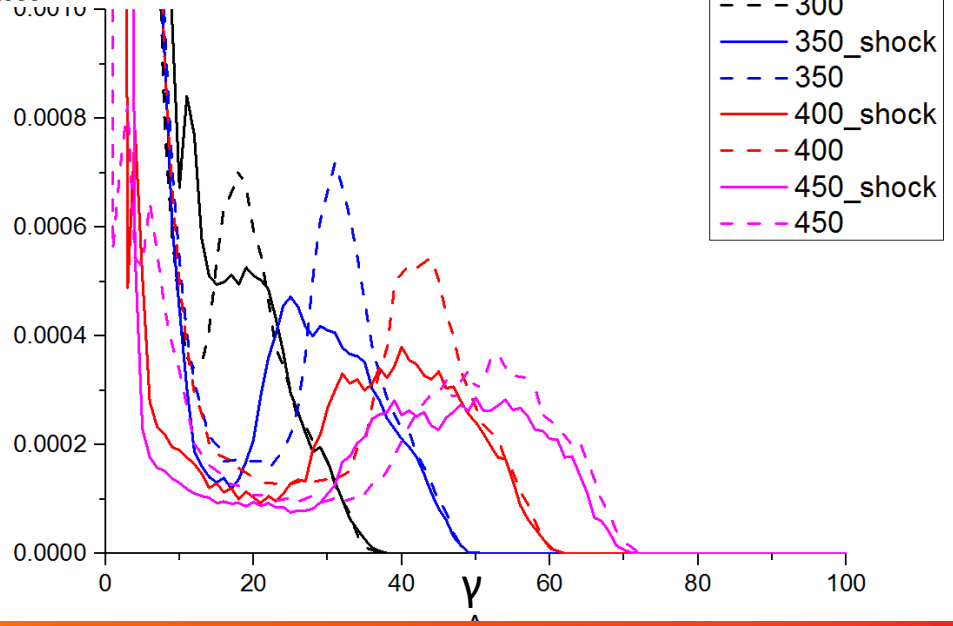

x_s=460λ
x_s=470λ
x_s=485λ
(c)
(d)
(e)
(i)
(j)
(k)
(o)
(p)
(q)
−5 0 5
θ°

# Electron beam acceleration dynamics measurements

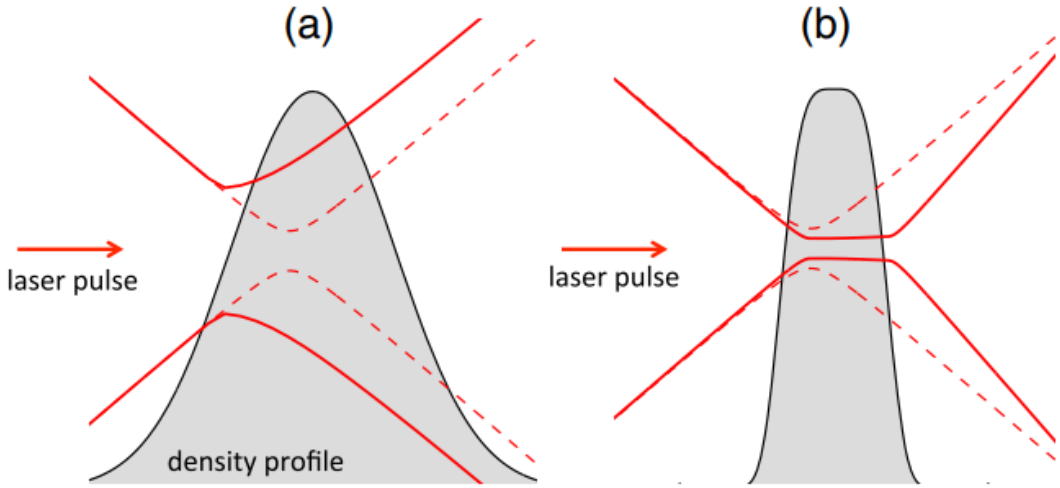


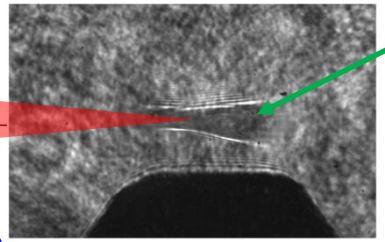
# Reduction of defocusing

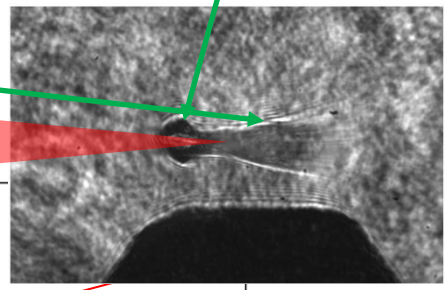



Gustas D. et al. //*PRAB* – 2018. – Т. 21. – №. 1. – С. 013401.

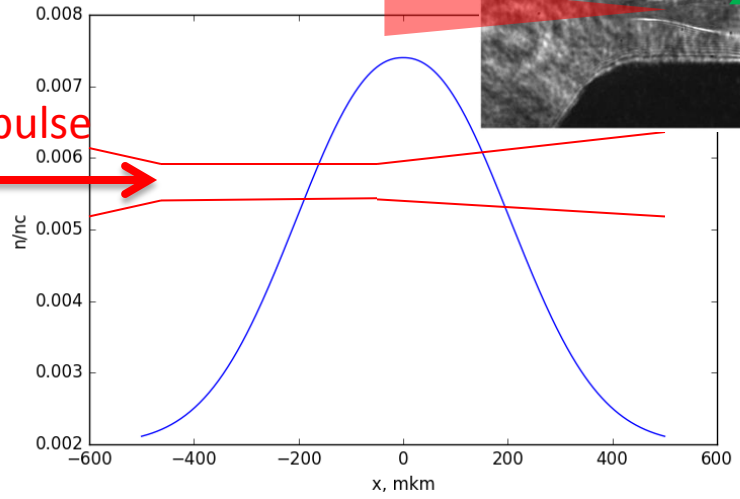
Cylindrical shock wave

Ionization of gas by fs radiation

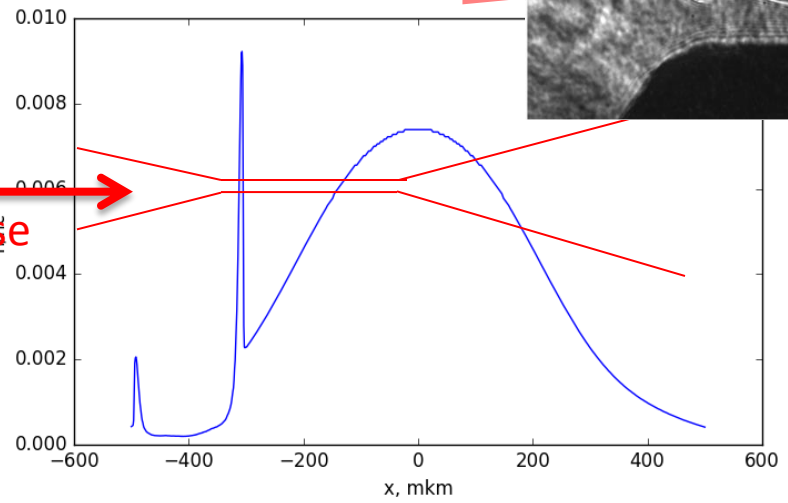




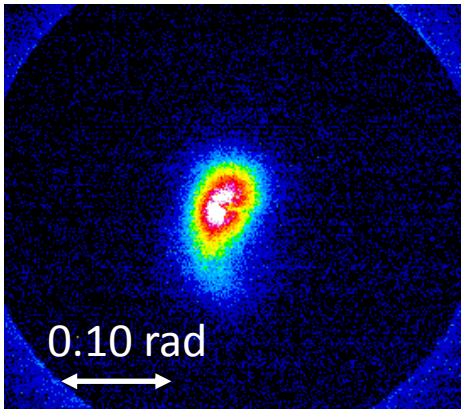
fs pulse

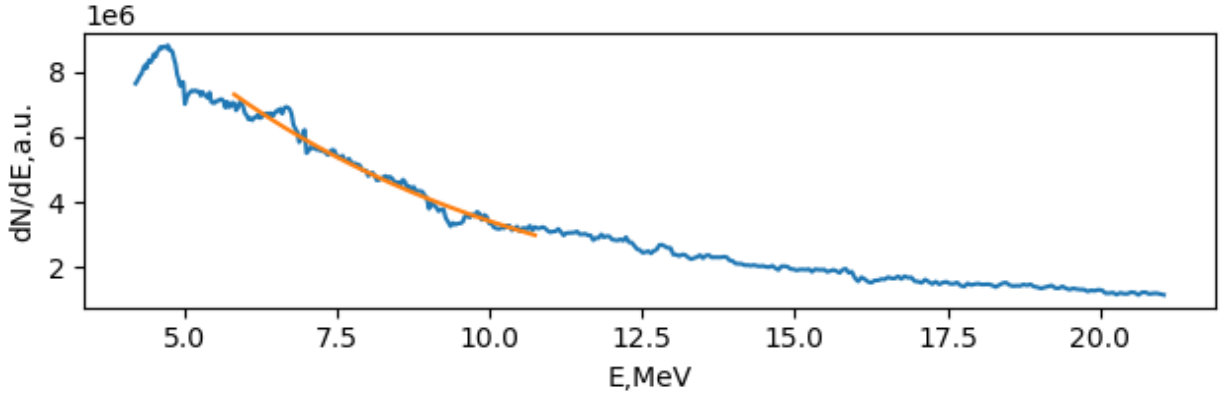


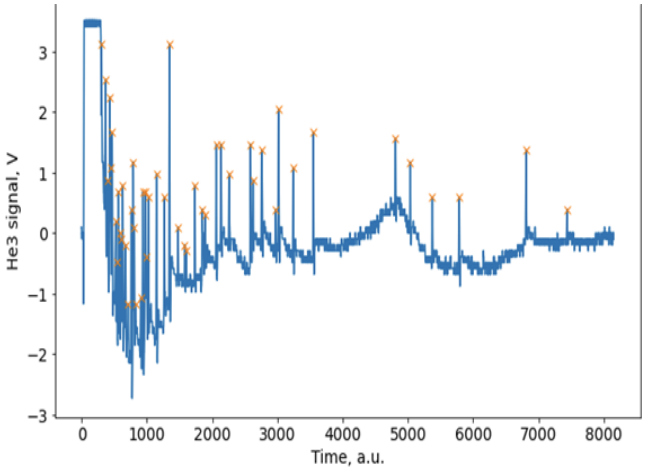

fs pulse



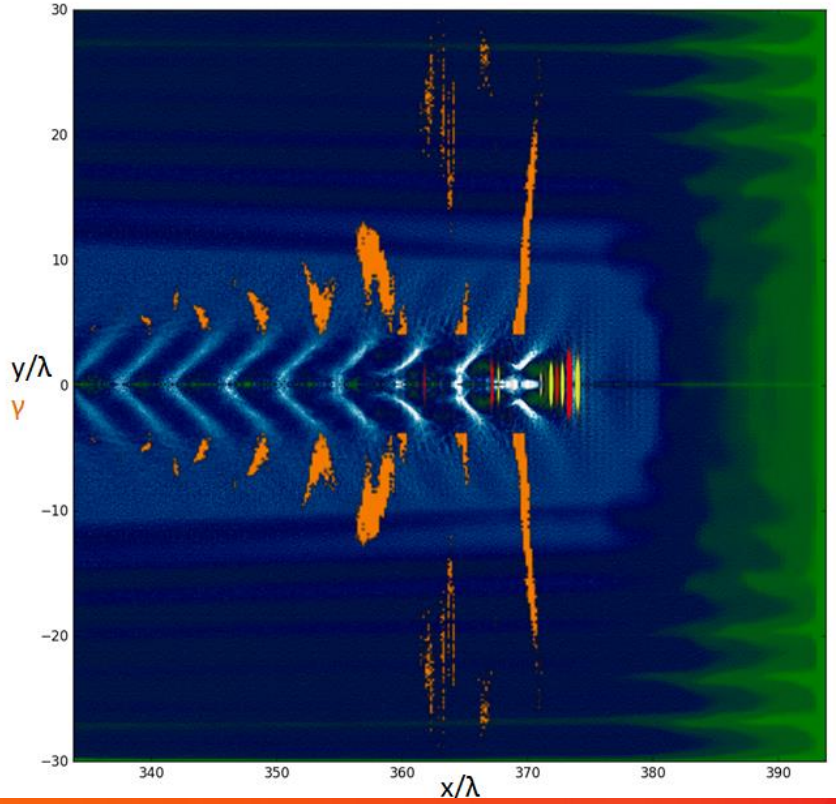
# Electron beam parameters




**8x10$^5$ neutrons / (shot × J )**




**4x10$^4$ neutrons / shot**

**&**

**up to 10 pC >8MeV**

**(up to 2 pC >8MeV without shock)**

# Conclusions

- Channel cutting by a shock wave can be used to measure the spatial dynamics of electron acceleration and for reduction of the electron bunch dephasing in the plasma wave. This is demonstrated for SM-LWFA
- Using this technique, a quasi-monochromatic (8-11 MeV) beam with a charge of 2 pC was obtained in SM-LWFA
- Reduction of defocusing allowed to experimentally obtain the well collimated electron bunch with charge up to 10pC (>8 MeV energy range)
- Neutron source of $10^6$ neutrons / (shot × J ) was obtained
- Results are easily scalable to kHz level. Wide range of applications (non-demanding to bunch energy spread), including ultrafast neutron source, X-rays, radiography are available.

***Thank you for attention***

# Electron beam dephasing