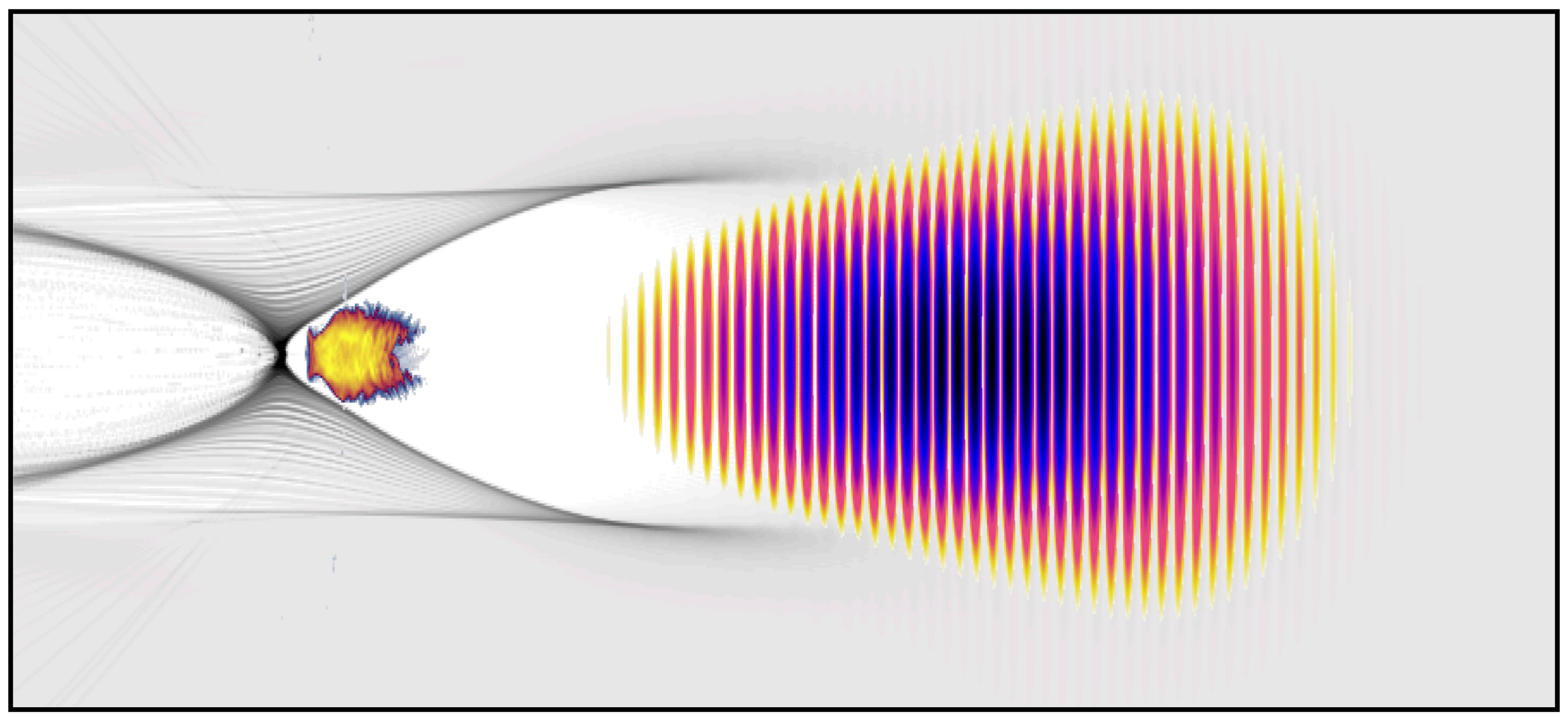
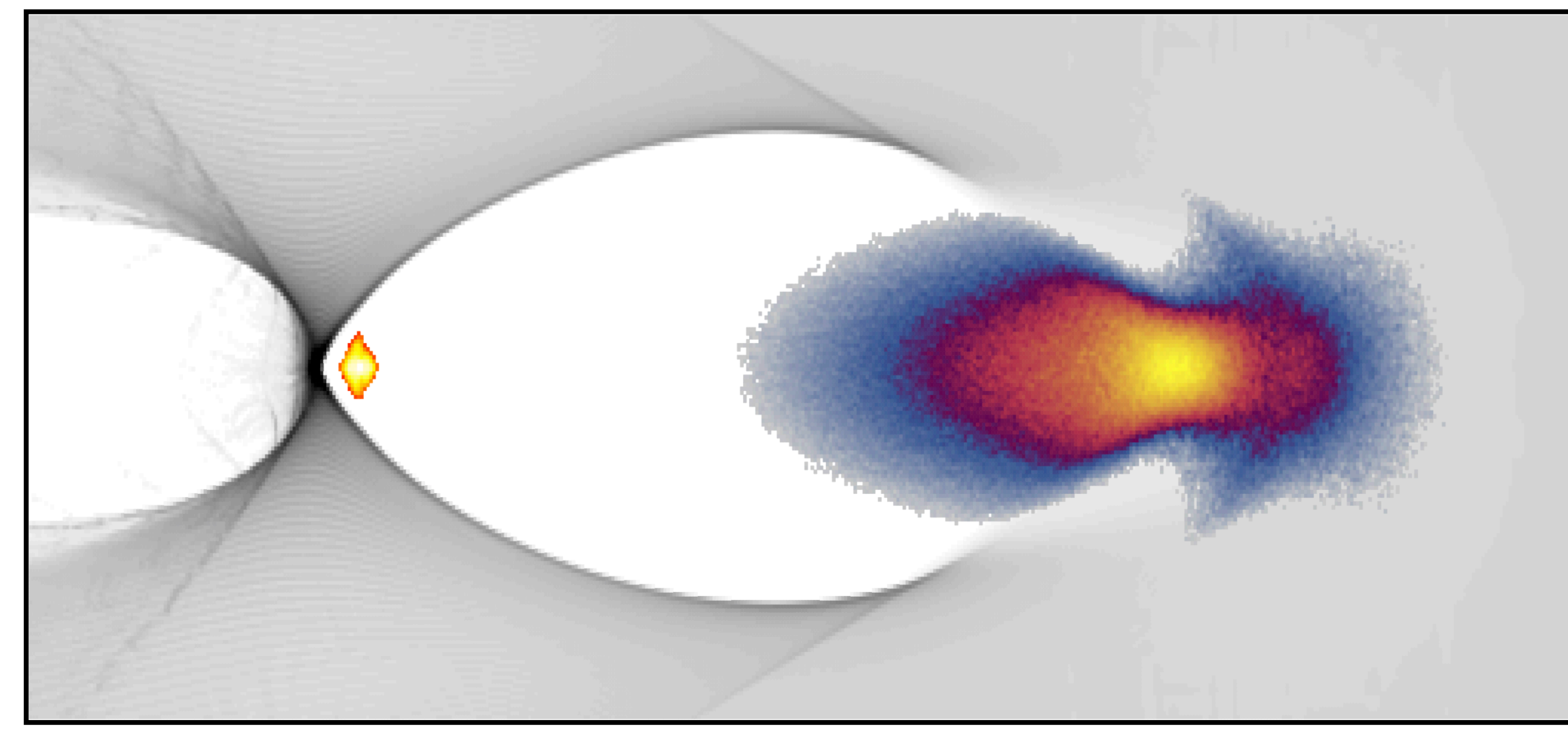
A laser-to-beam-driven plasma wakefield accelerator

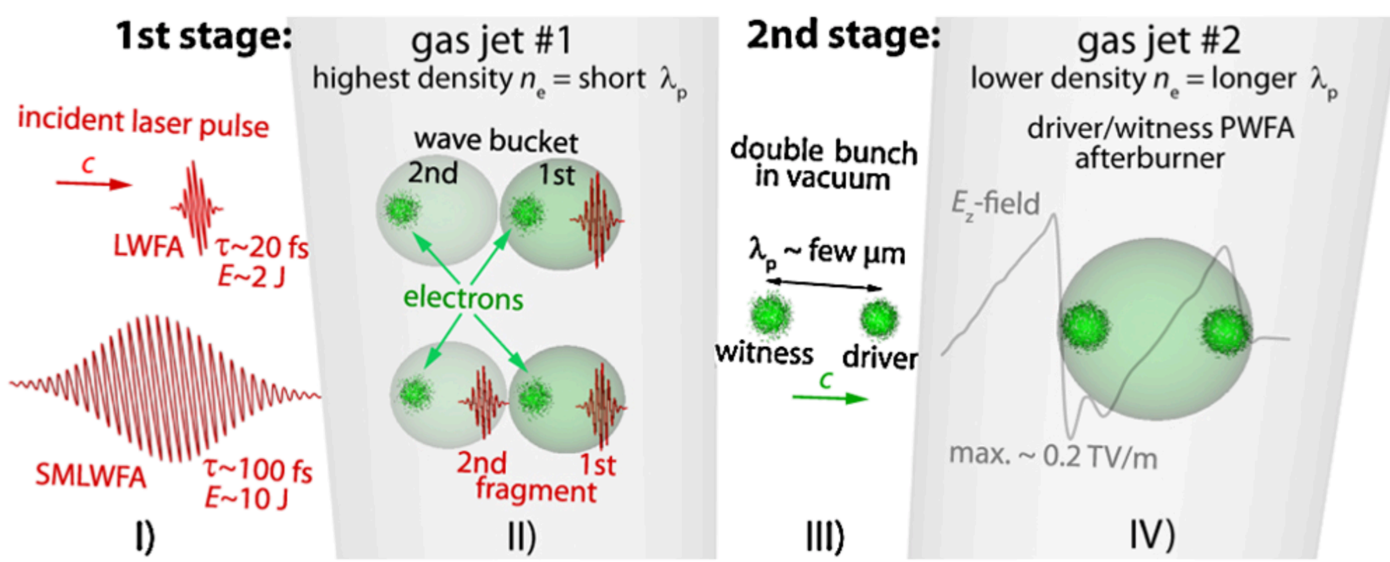




A. Martinez de la Ossa, R. W. Aßmann, M. Bussmann, J. P. Couperus, A. Debus, A. Ferran-Pousa, T. Heinemann, B. Hidding, A. Irman, A. Knetsch, T. Kurz, A. Koehler, L. Kononenko, J. Osterhoff, R. Pausch, U. Schramm

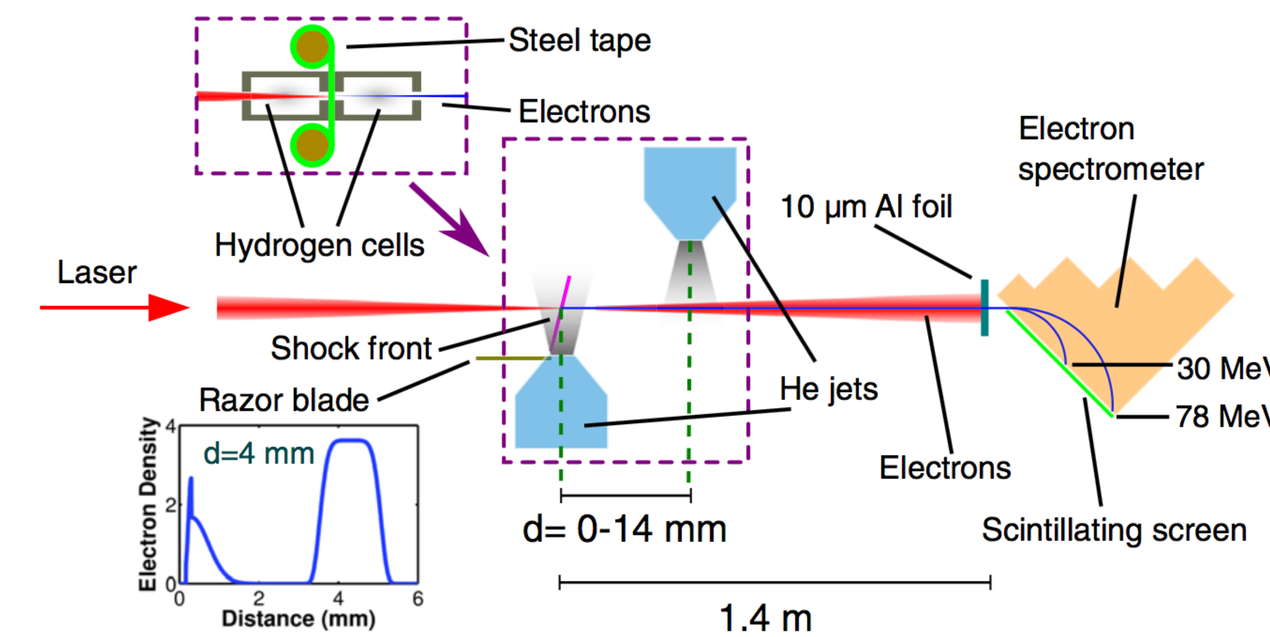
Towards Laser-driven PWFAs: ***Hybrid plasma accelerators***

Theory: Energy booster



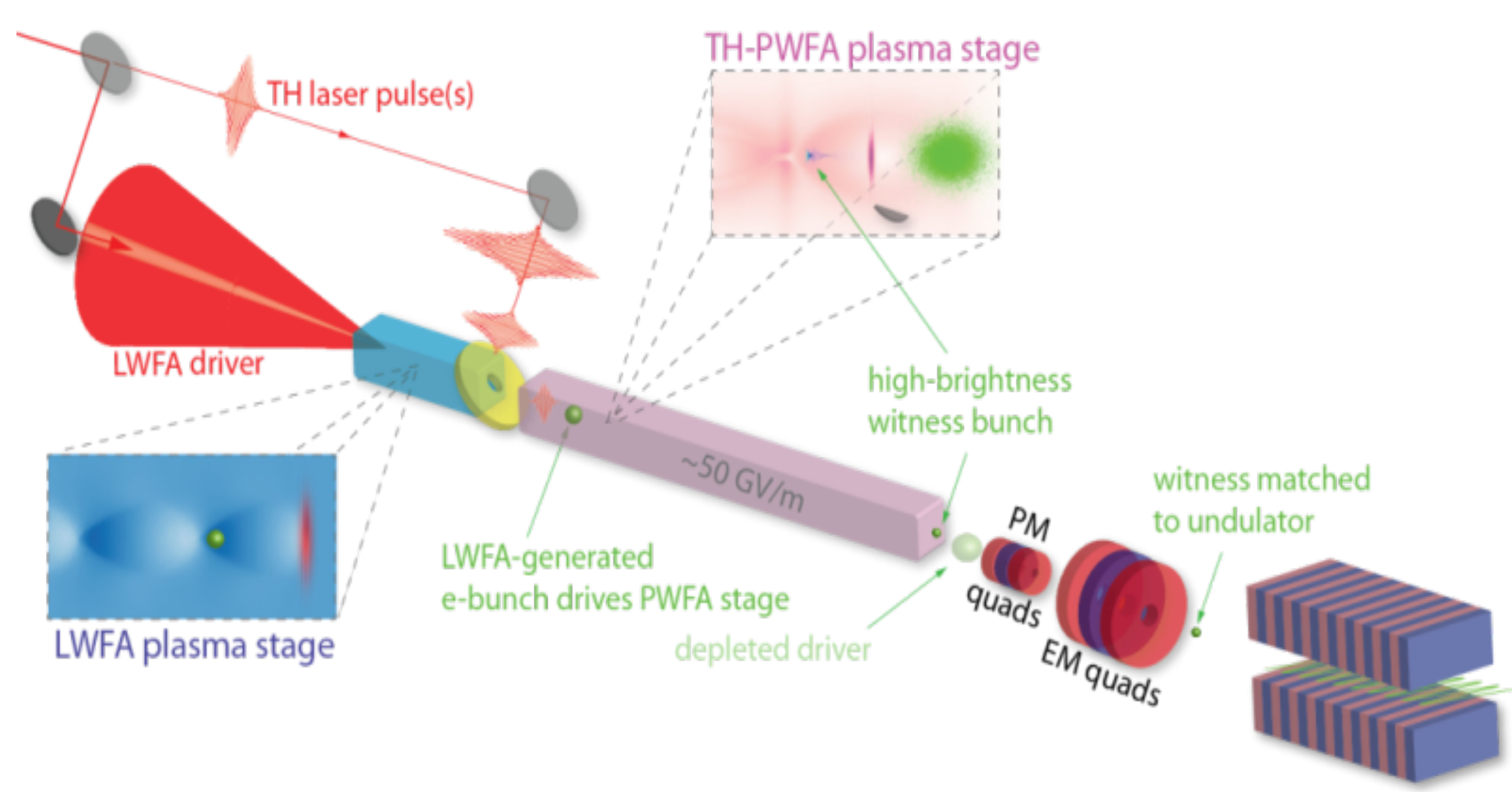
B. Hidding et al. PRL 104, 195002 (2010)

Experimental wakefields demonstration

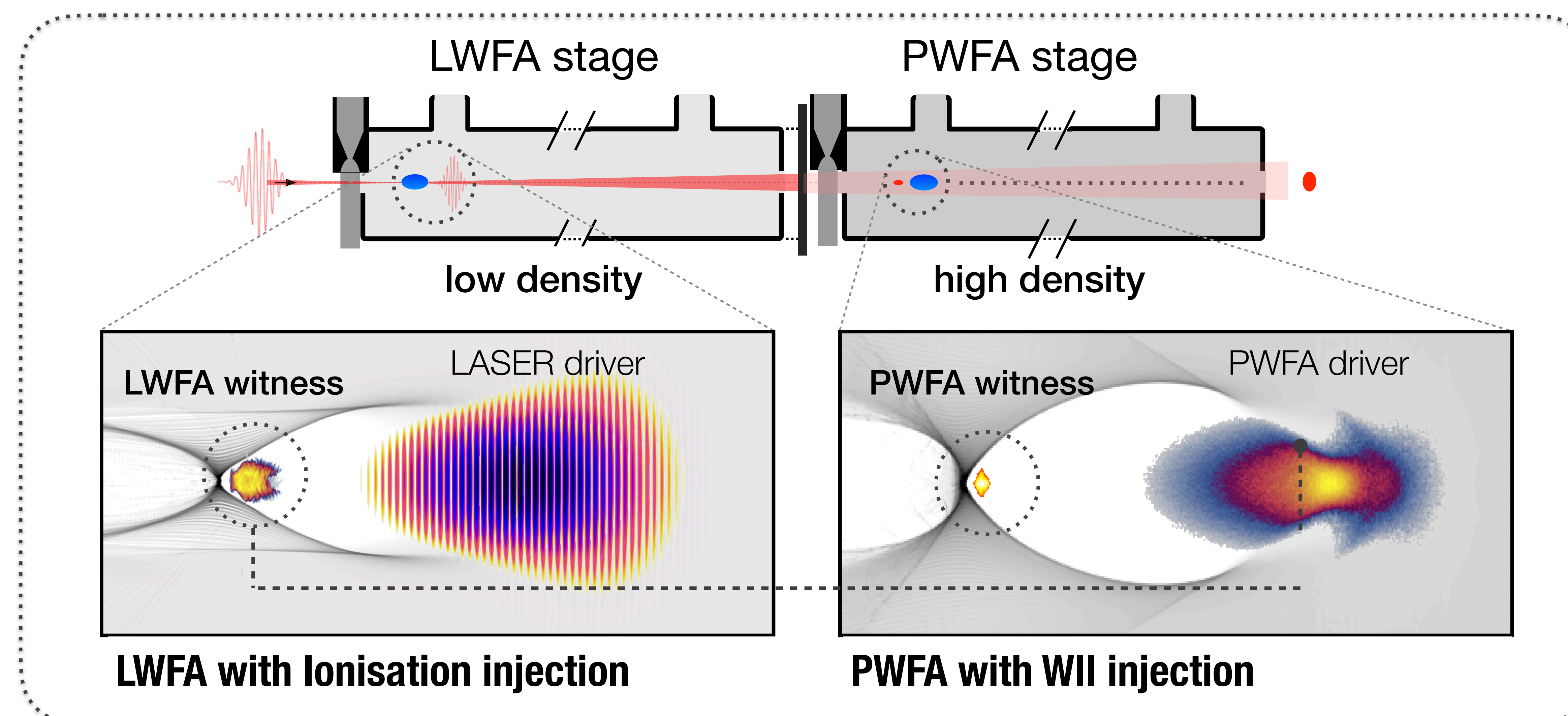


S. Chou et al., PRL 117, 144801 (2016)

Theory: **Energy and quality boosters**

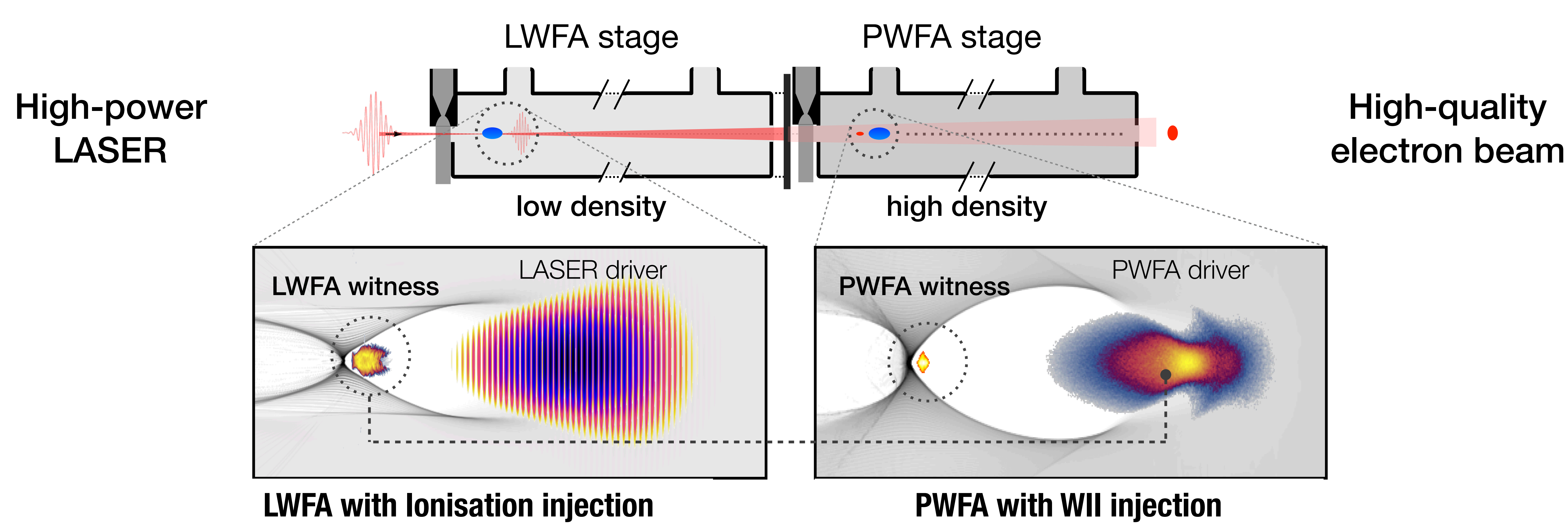


B. Hidding et al. PRL 108, 035001 (2012)



A. M. de la Ossa et al., PRL 111, 245003 (2013)

A laser-to-beam-driven plasma wakefield accelerator: **LPWFA**



Why adding PWFA stage?

- ➤ **Energy boost**: High transformer ratio in blowout regime.
- ➤ **Quality boost:** Novel injection techniques* in PWFA for the generation of low emittance beams.
- ➤ **Low energy spread**: Energy chirp balance by means of beam-loading requires high-current witness.

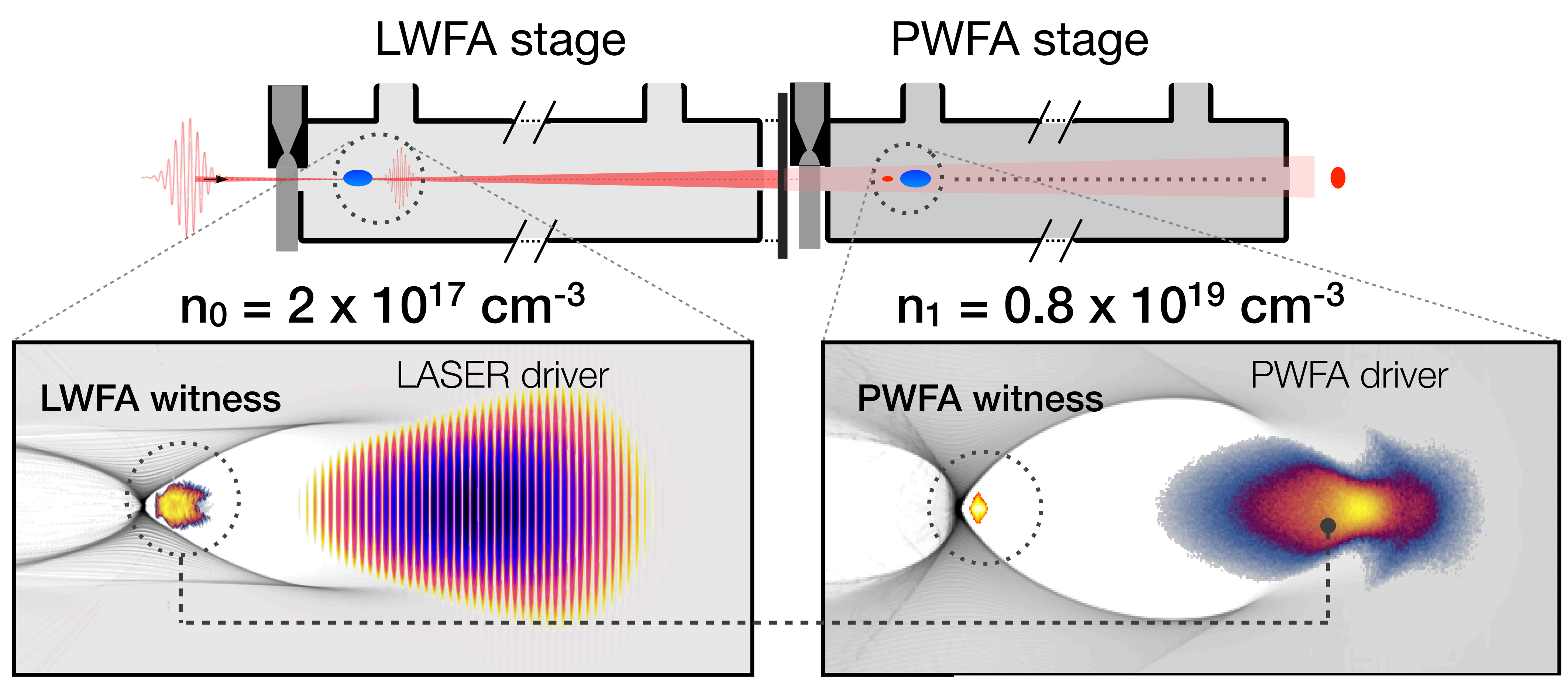
High-brightness
GeV class
electron beams
for applications demanding high-quality (e.g. FELs).

* B. Hidding et al. PRL 108, 035001 (2012).
A. M. de la Ossa et al., PRL 111, 245003 (2013).
A. M. de la Ossa et al., PRAB 20, 091301 (2017).

A laser-to-beam-driven plasma wakefield accelerator: **EuPRAXIA example**

Laser beam

$P_0 = 500$ TW
$\lambda_0 = 800$ nm
$w_0 = 41$ µm
$a_0 = 3$
$\tau = 100$ fs
Energy = 53 J



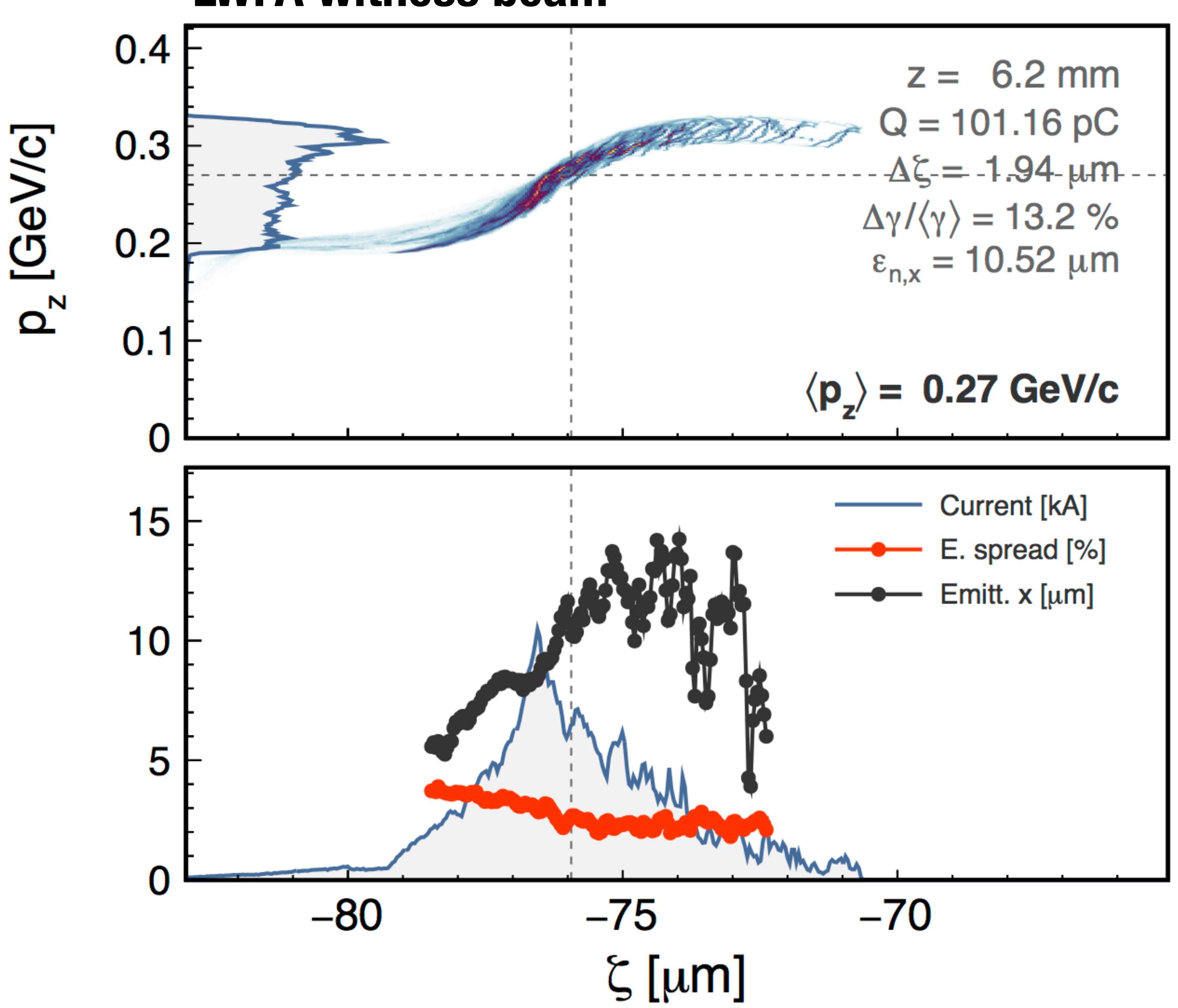
LWFA with Ionisation injection

PWFA with WII injection

Electron beam

$I_0 = 15$ kA
$\varepsilon_n = 130$ nm
$\tau = 700$ as
$\gamma mc^2 = 10$ GeV
$\Delta\gamma/\gamma = 0.1$ %
Charge = 10 pC

LWFA witness beam

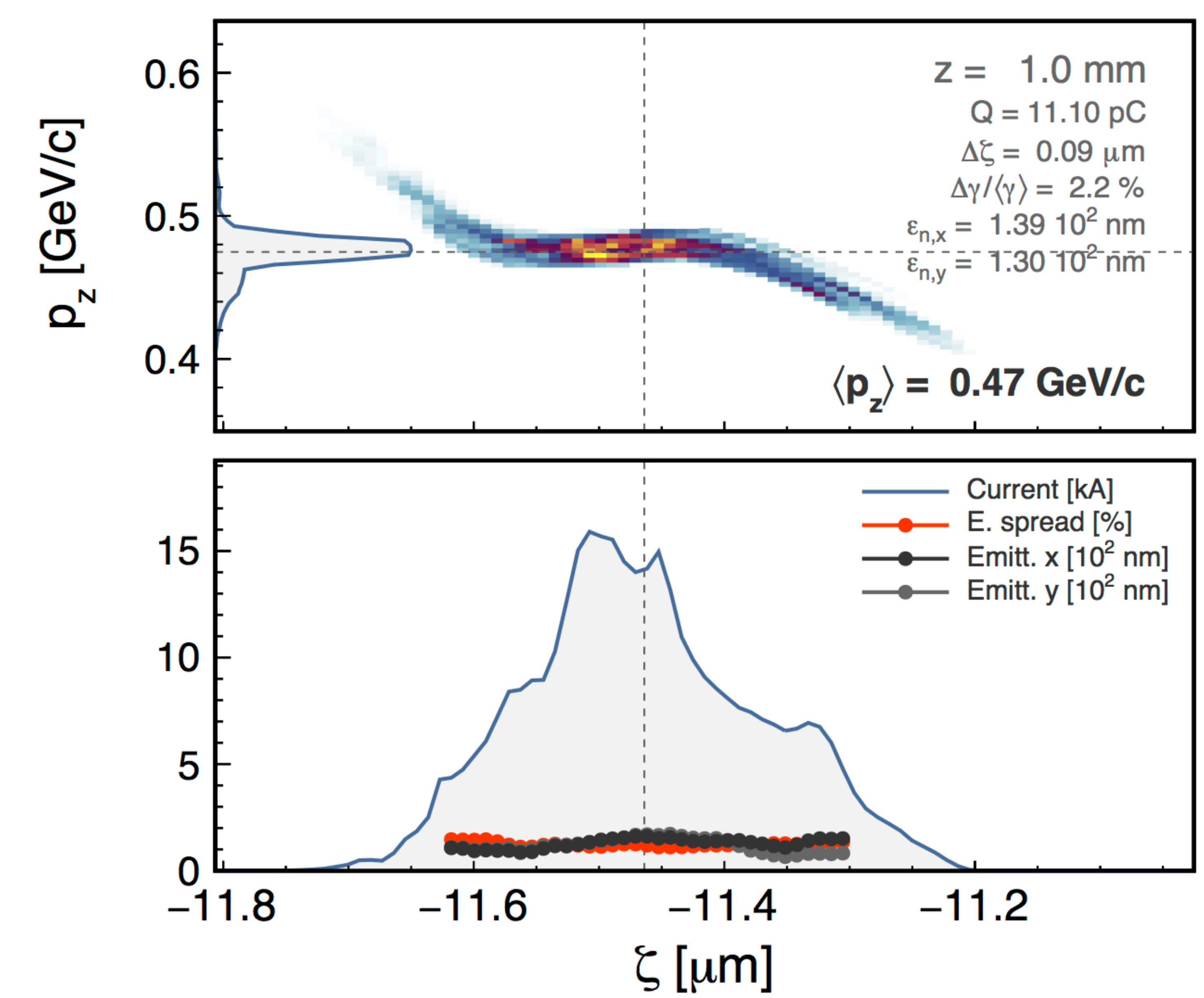


Energy doubling $\Delta\gamma_{\mathrm{w}} = R\,\gamma_{\mathrm{d}}$

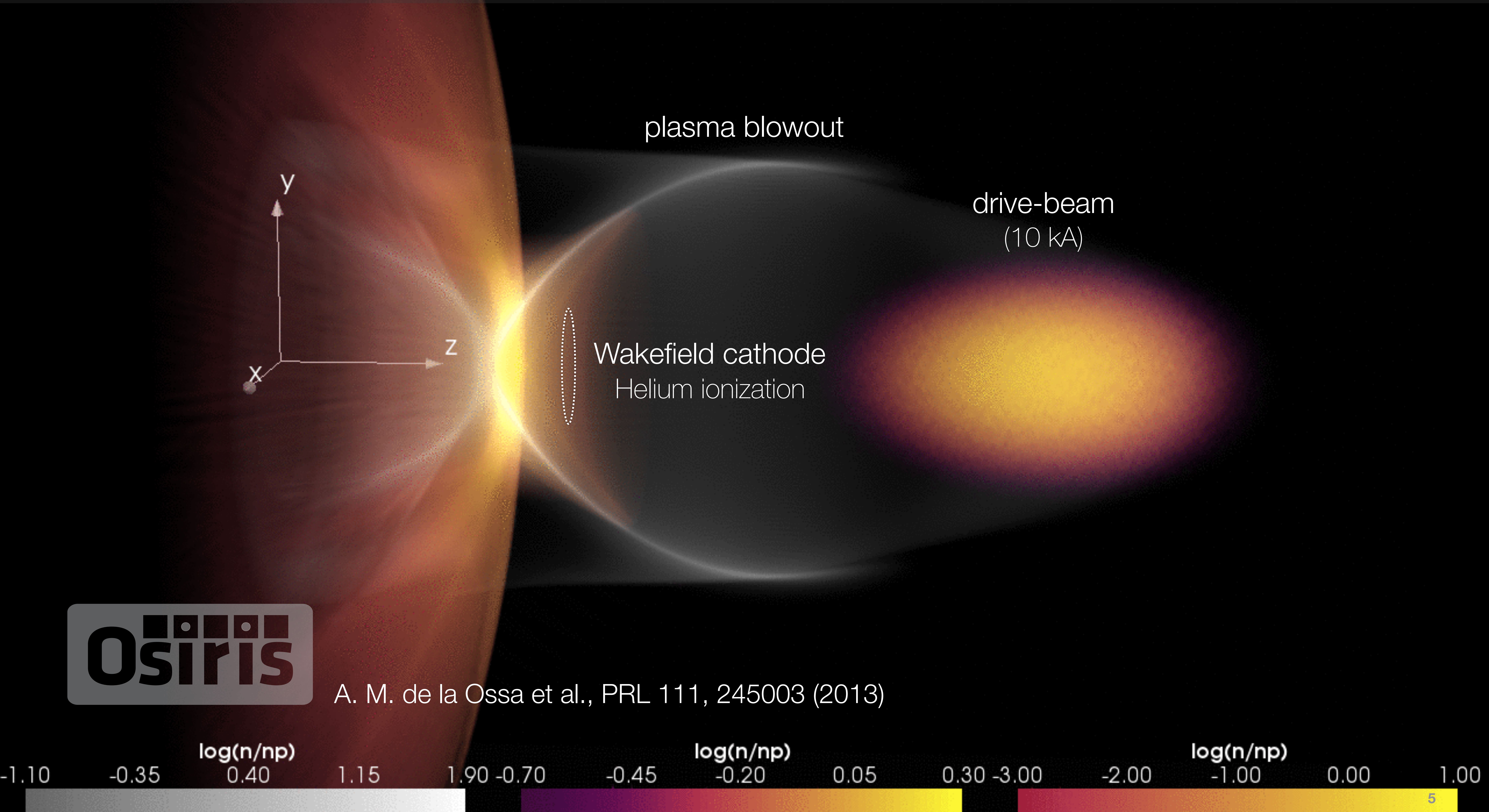
Brightness booster $B \propto \frac{I_b}{\epsilon_n^2}$

x 10000

PWFA witness beam

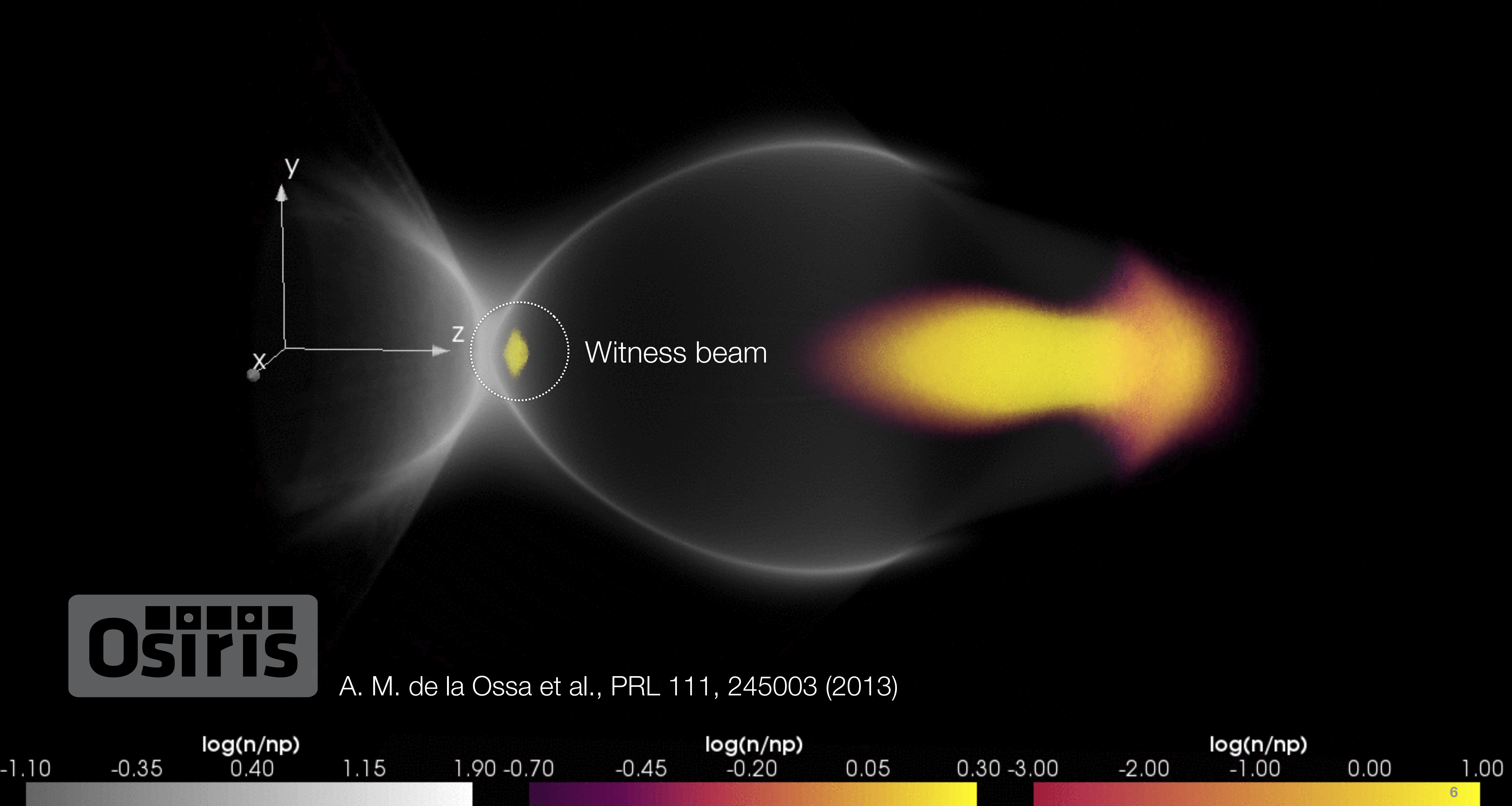


PWFA stage with WII injection (OSIRIS 3D)



A. M. de la Ossa et al., PRL 111, 245003 (2013)

PWFA stage with WII injection (OSIRIS 3D)



A. M. de la Ossa et al., PRL 111, 245003 (2013)

PWFA with WII injection: **Self-Similar Staging**

PWFA with WII injection

Requirements:

- **High-current drivers (GeV class):**
  Needs a strong blowout regime for trapping.
- **Appropriate dopant species:**
  Ionisation is triggered by the wakefields only.

Features:

- **Short and high-quality witness:**
  Low-emittance witness ➜ $\varepsilon_n \approx 0.1/k_p$
- **High-energy witness:**
  Energy-per-electron can double/triple the driver
  High transformer ratio: $\Delta E_{wit} = R\, E_{dri}$
- **High-current and low energy spread witness:**
  High-current witness is needed for beam-loading at high transformer ratio.

Self-Similar Staging

Witness beams from WII injection
can drive WII injection
in a higher density plasma

⇩

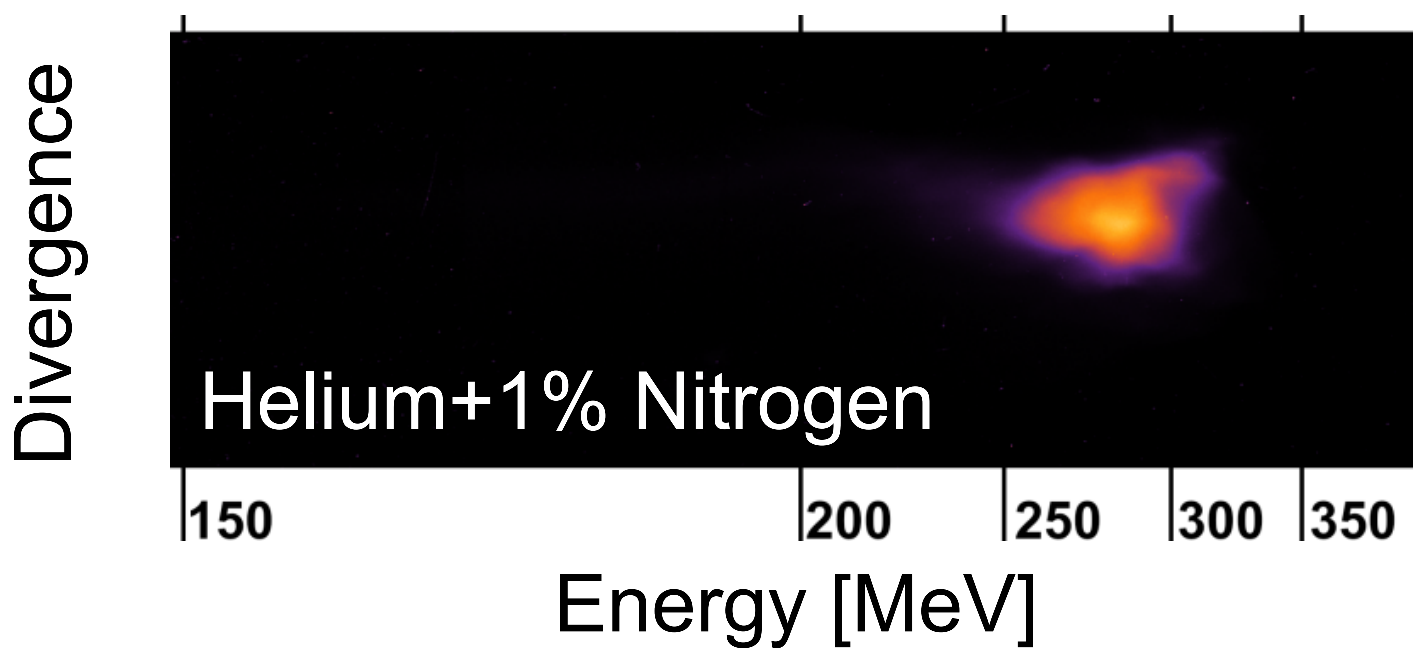
Energy doubling and
order of magnitude reduction of
length and emittance in each stage.

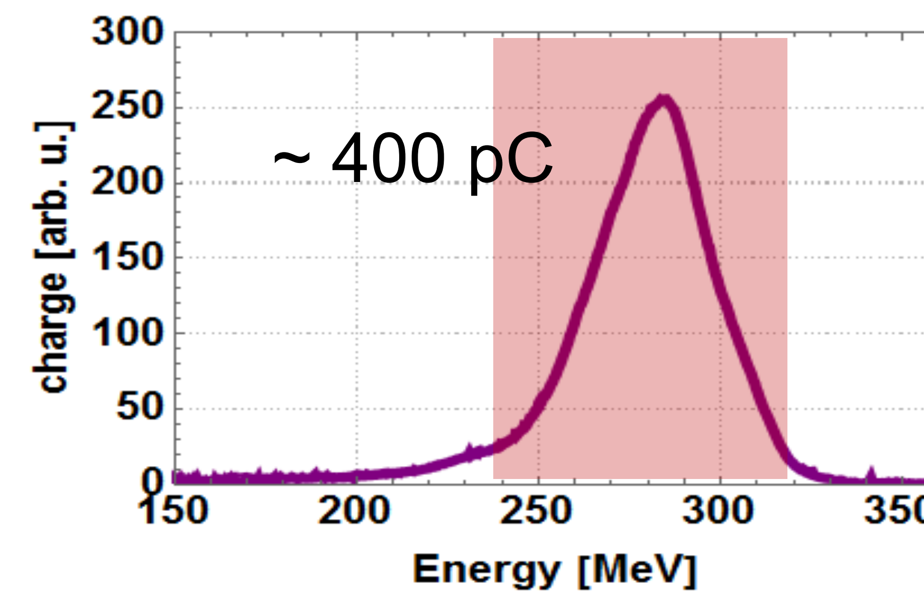
Can LWFA beams drive PWFA with WII injection?

A. Martinez de la Ossa *et al.*, Phys. Plasmas 22, 093107 (2015)

Towards Laser-driven PWFA: ***Proof-of-concept*** **experiment at HZDR**

LWFA with ionization injection





Laser: 2.8 J, 28 fs, 20 μm (on target)

Peak energy: ~ 283 MeV
Energy spread: ~ 40 MeV (14%)
More stable: charge, pointing, energy
Estimated peak current: ~ 30 kA

J. Couperus et al., Nature Communications 8, 487 (2017)

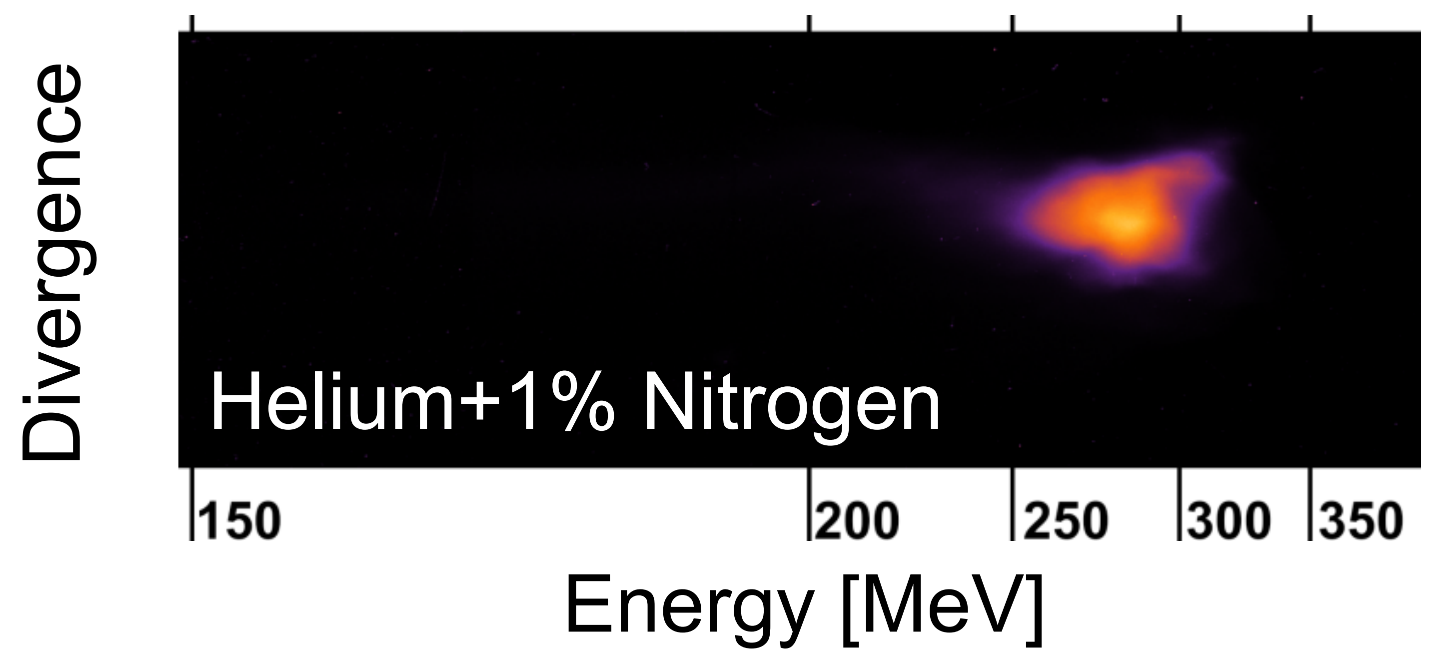
Demonstration of a beam loaded nanocoulomb-class laser wakefield accelerator
J. Couperus et al., Nature Communications 8, 487 (2017)

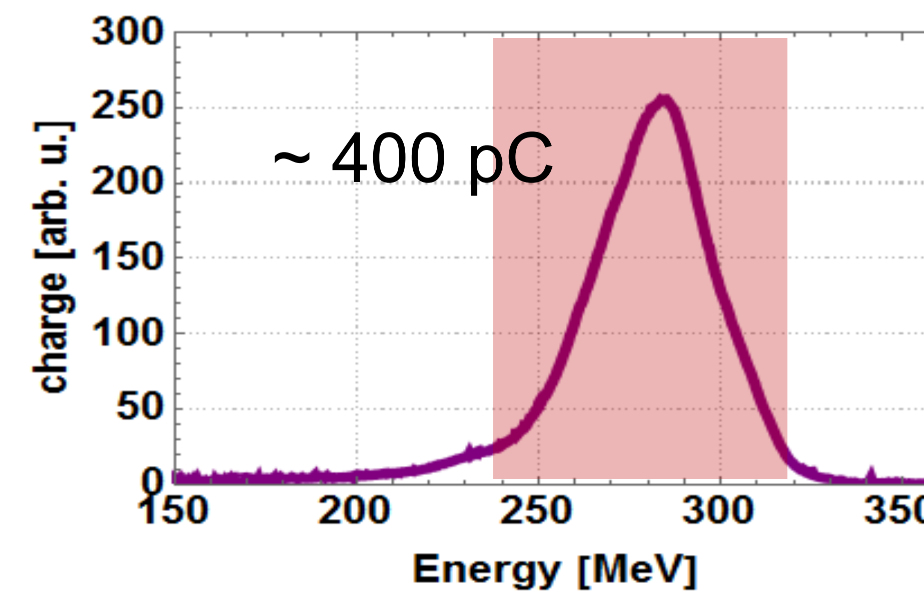
"Ionization injection enables loading of ~0.5 nC within a mono-energetic peak"

> 30 kA peak current electron beams with low energy spread

Towards Laser-driven PWFA: ***Proof-of-concept* experiment at HZDR**

HZDR LWFA with ionization injection





Laser: 2.8 J, 28 fs, 20 μm (on target)

Peak energy: ~ 283 MeV
Energy spread: ~ 40 MeV (14%)
More stable: charge, pointing, energy
Estimated peak current: ~ 30 kA

J. Couperus et al., Nature Communications 8, 487 (2017)

Proof of concept experiment at Dresden

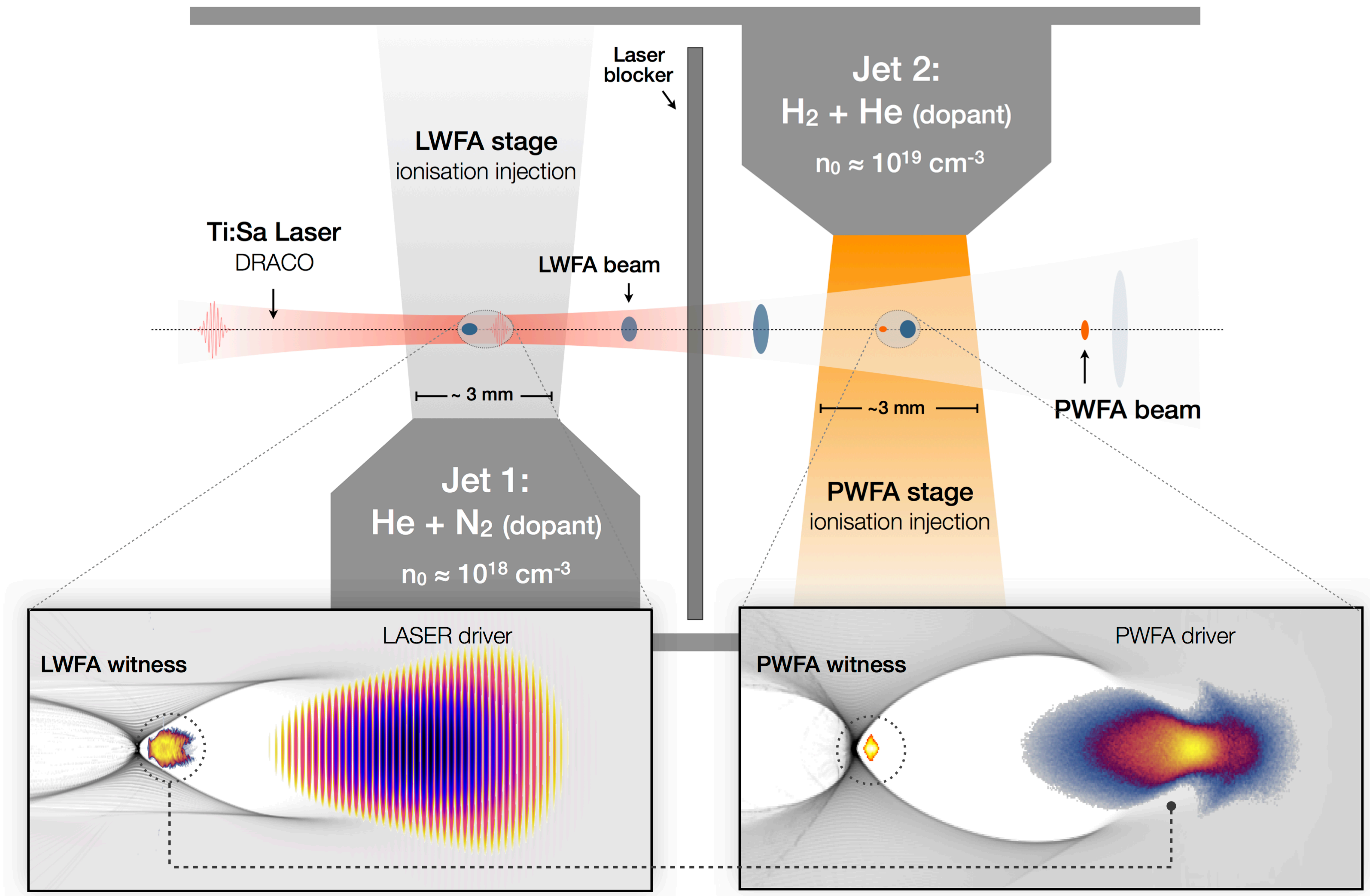
- ➤ Demonstration of injection and acceleration in a PWFA stage driven by a LWFA beam.

LPWFA

A. Irman, J. Couperus, T. Kurz, T. Heinemann, A. Koehler, A. Debus, R. Pausch, M. Bussmann, A. M. de la Ossa, J. Osterhoff, B. Hidding, R. Aßmann, U. Schramm.

University of Strathclyde Glasgow | UHH | DESY | HZDR Helmholtz Zentrum Dresden Rossendorf | EuPRAXIA

Towards Laser-driven PWFA: ***Proof-of-concept* experiment at HZDR**



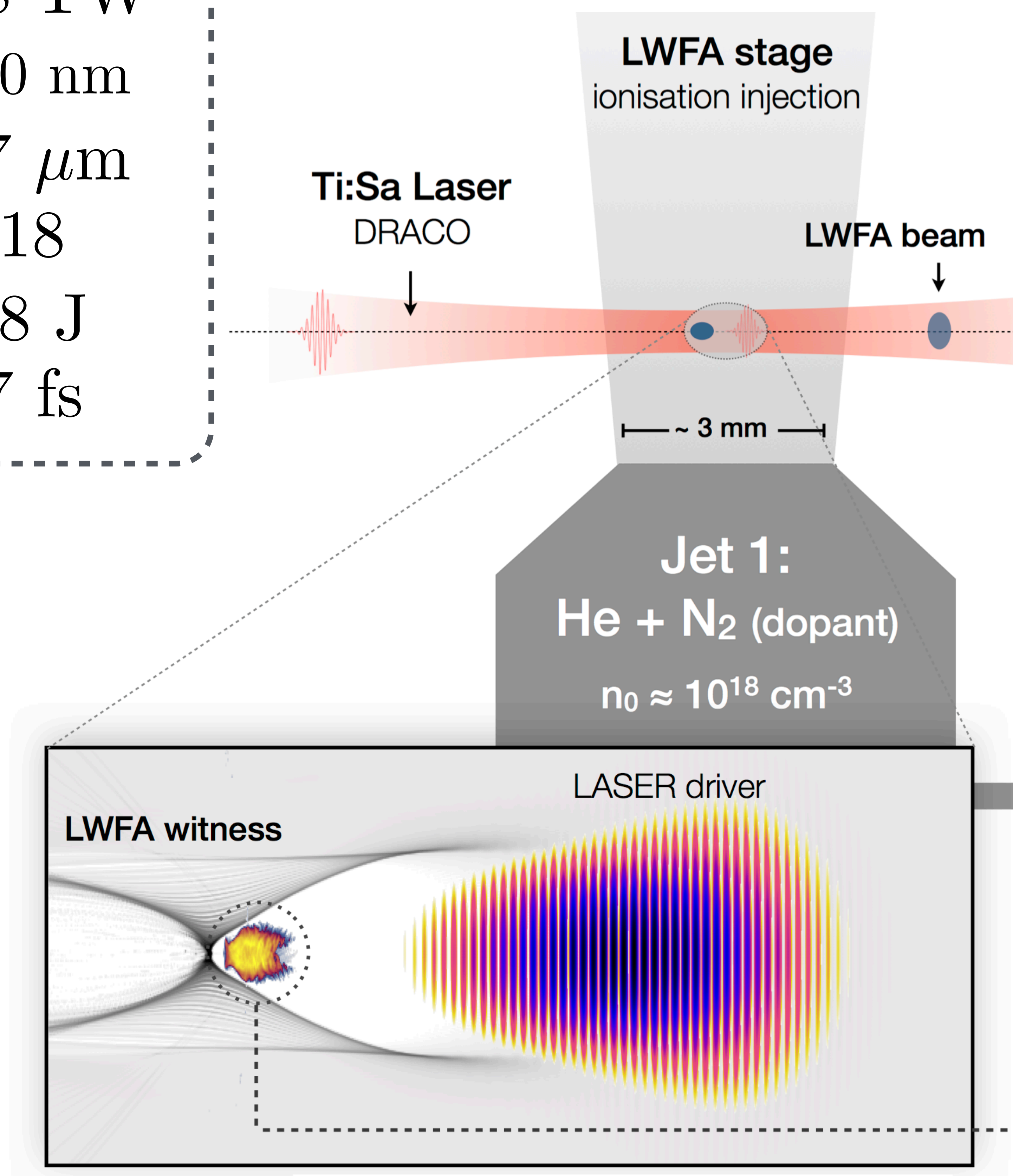
LWFA with Ionisation injection

PWFA with WII injection

LWFA beams from ionization injection: A 3D simulation for HZDR

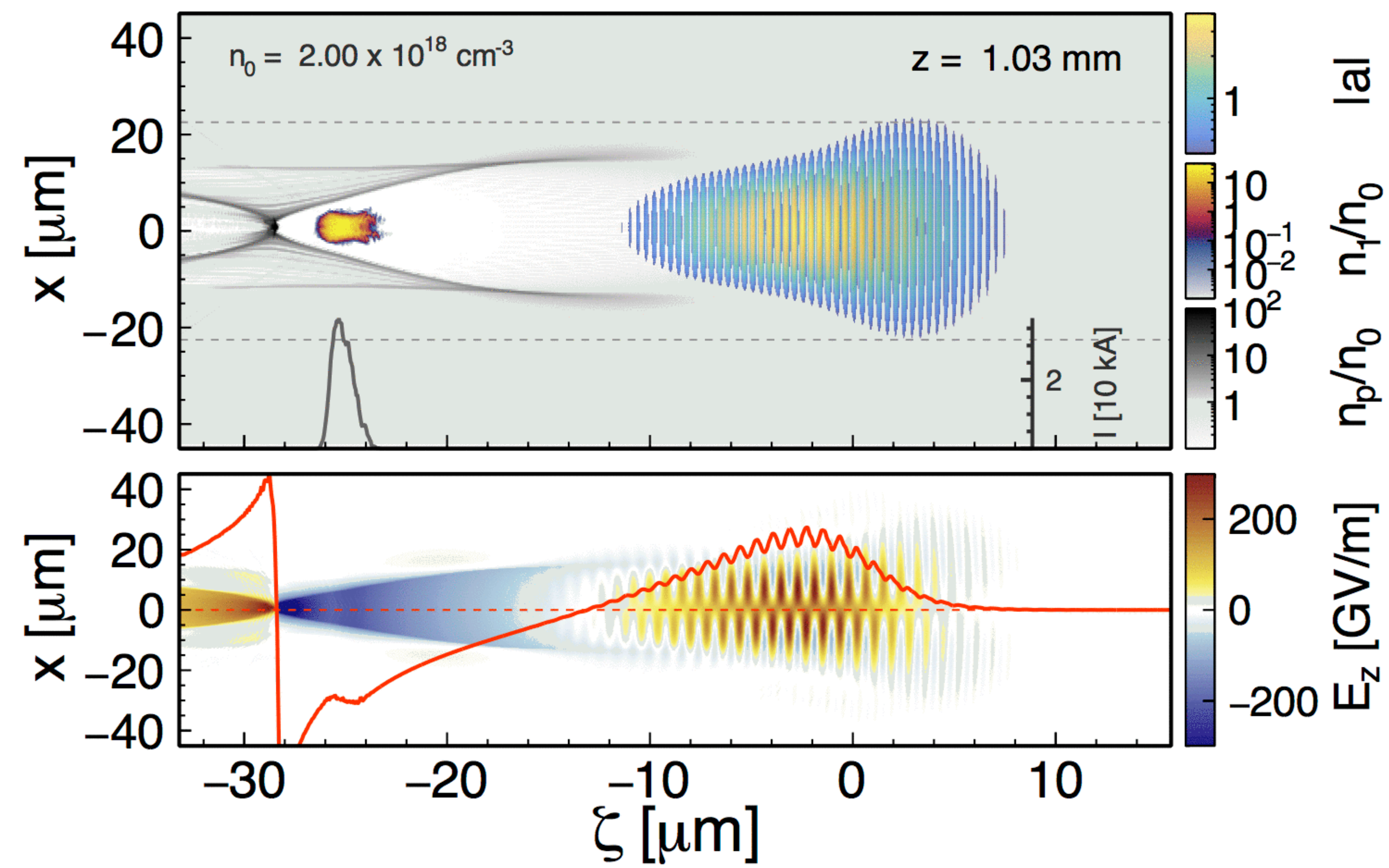
DRACO laser

$P_0 = 98$ TW
$\lambda_0 = 800$ nm
$w_0 = 17\ \mu m$
$a_0 = 3.18$
$\mathcal{E} = 2.8$ J
$\tau = 27$ fs

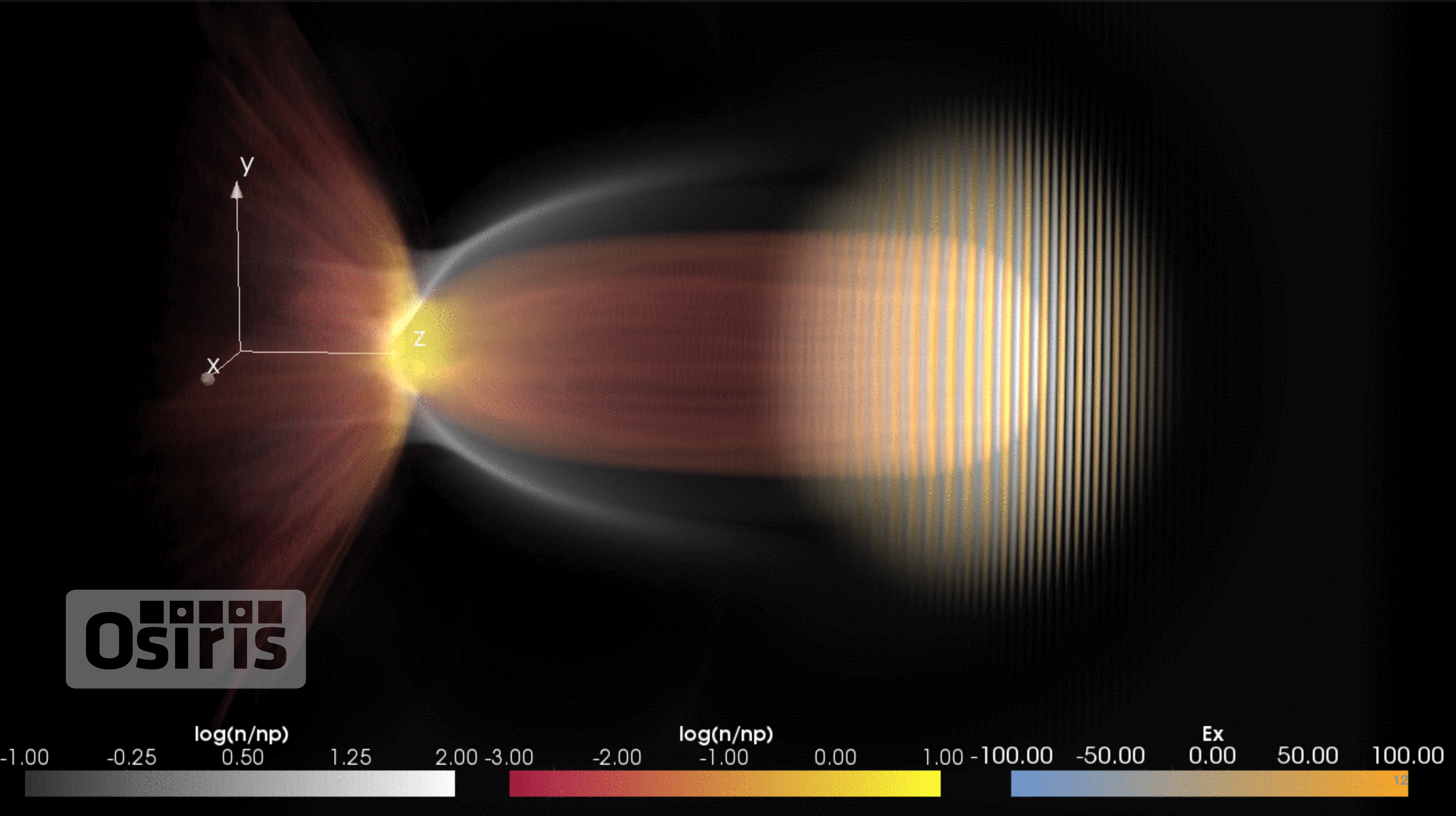


LWFA with Ionisation injection

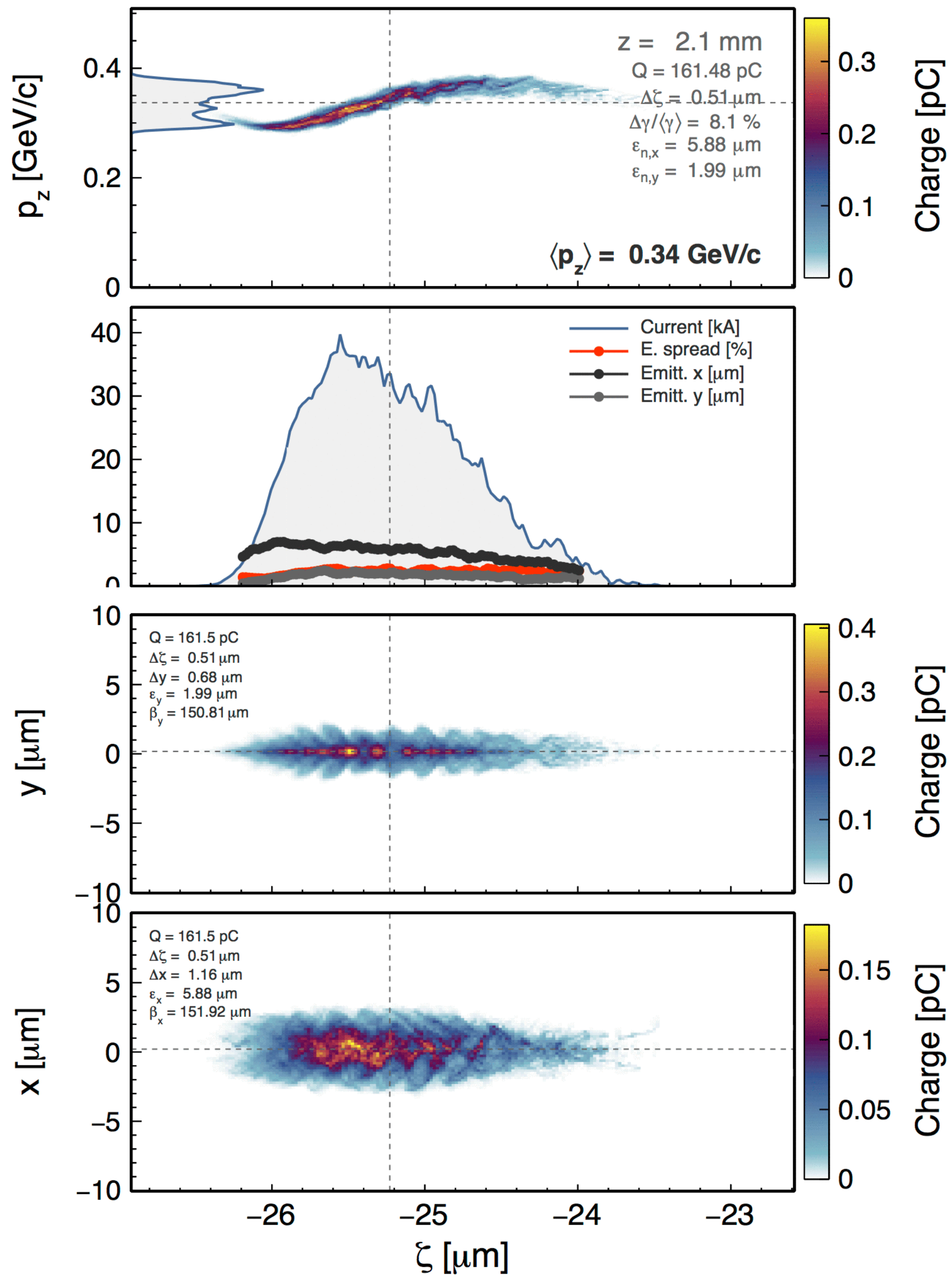
3D PIC simulation (OSIRIS)



First jet: LWFA with Ionisation injection OSIRIS 3D with DRACO-laser

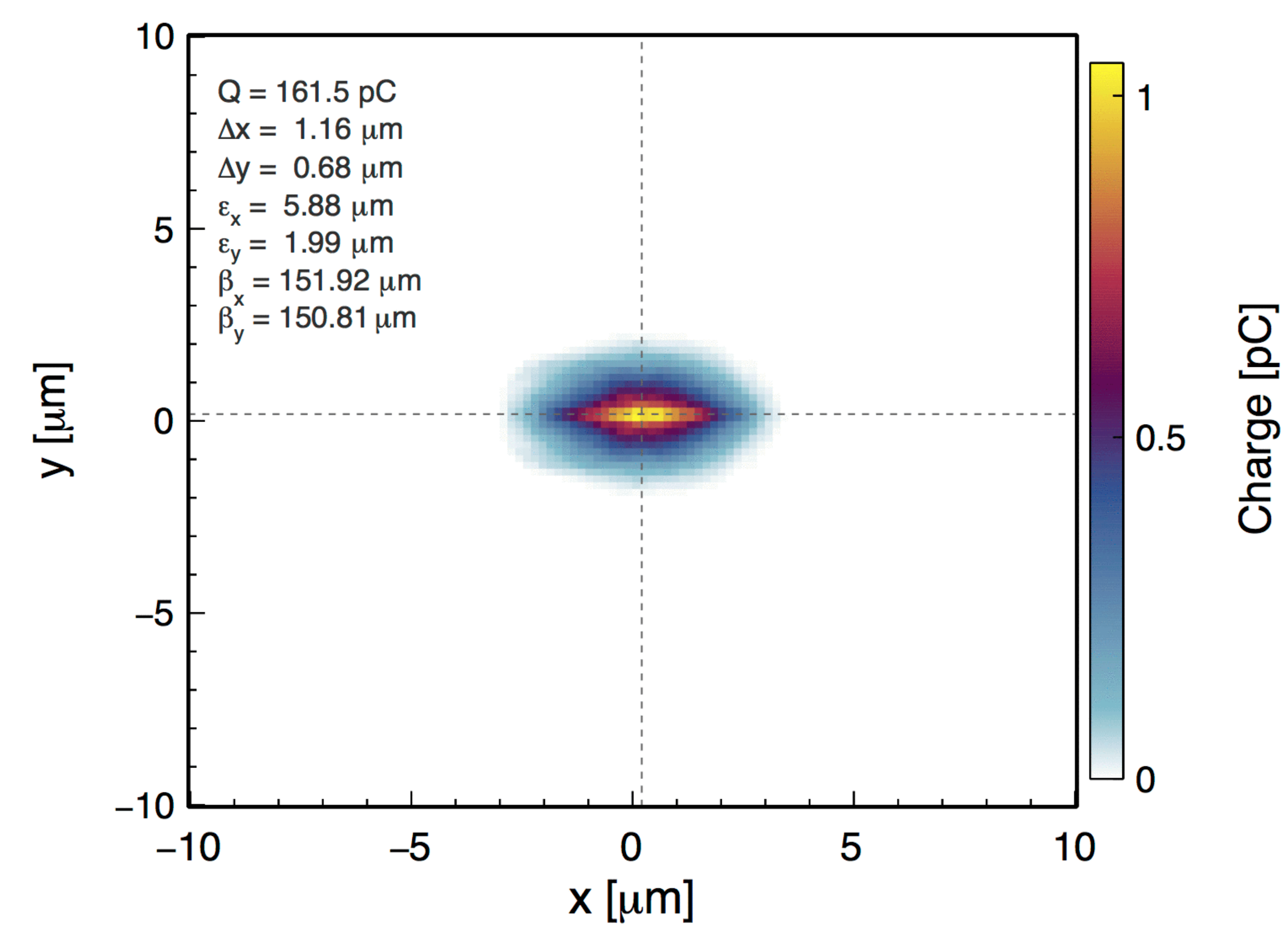


LWFA beams from ionization injection: OSIRIS 3D with HZDR parameters



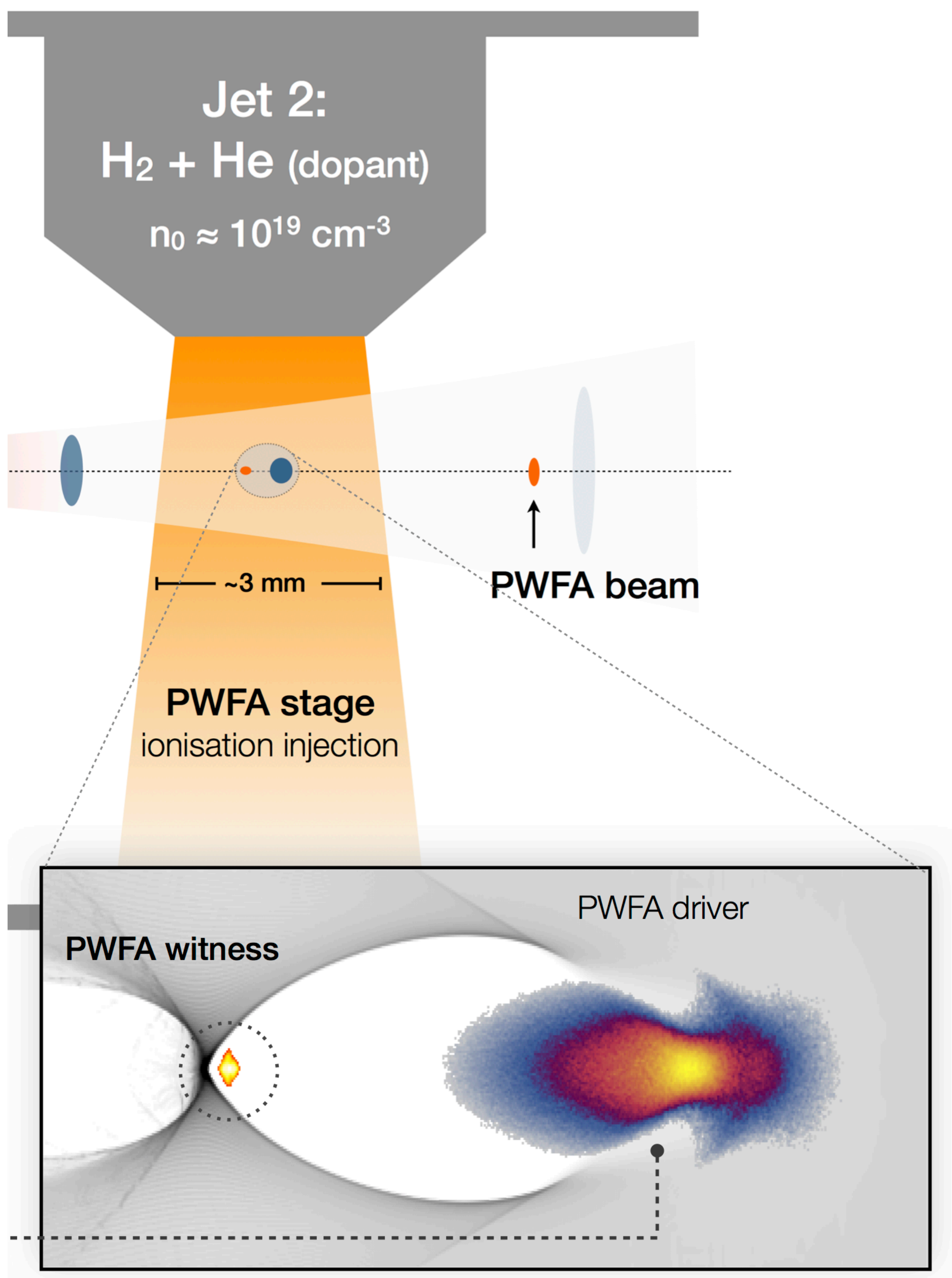
Witness bunch LWFA (after 1.8 mm)

- Energy: **340 MeV**
- Energy spread: **10%**
- Charge: **162 pC**
- Current: **35 kA**
- Length (rms): **0.5 μm** (~4 fs fwhm)
- Norm. emittance: **6 μm**

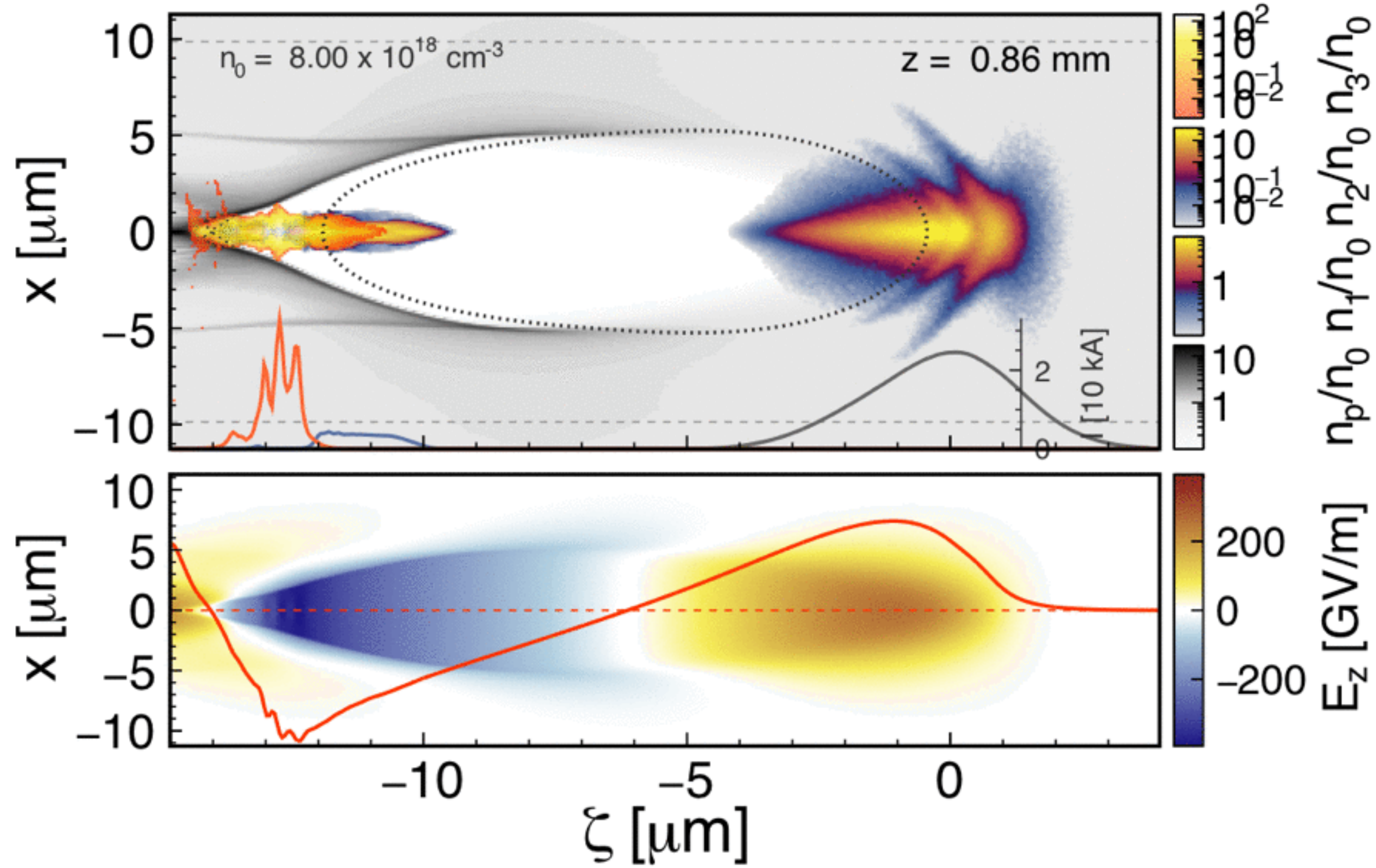


Laser-to-beam-driven WFA: **PWFA with HZDR-type drive-beam**

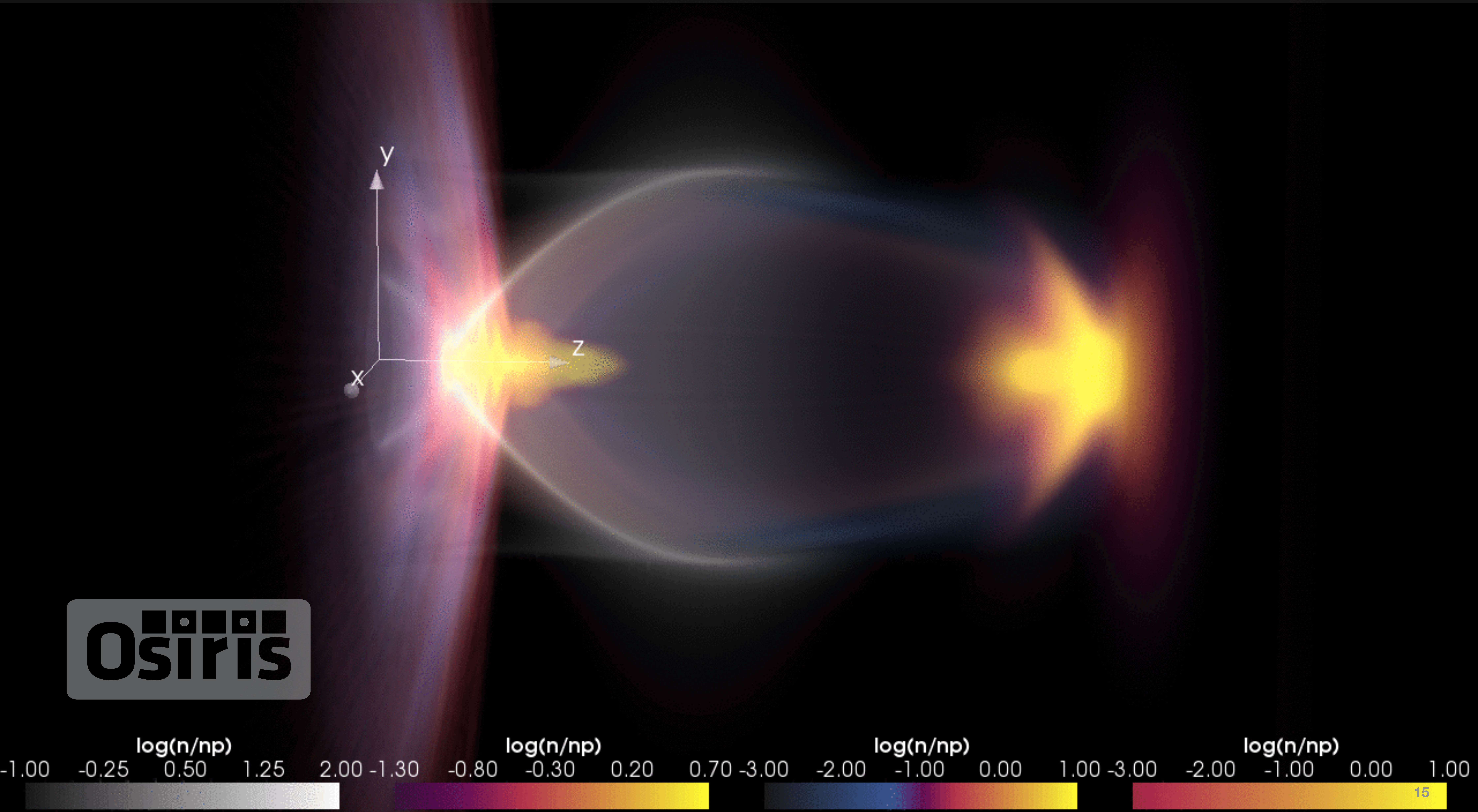
Second jet: PWFA with Ionisation injection



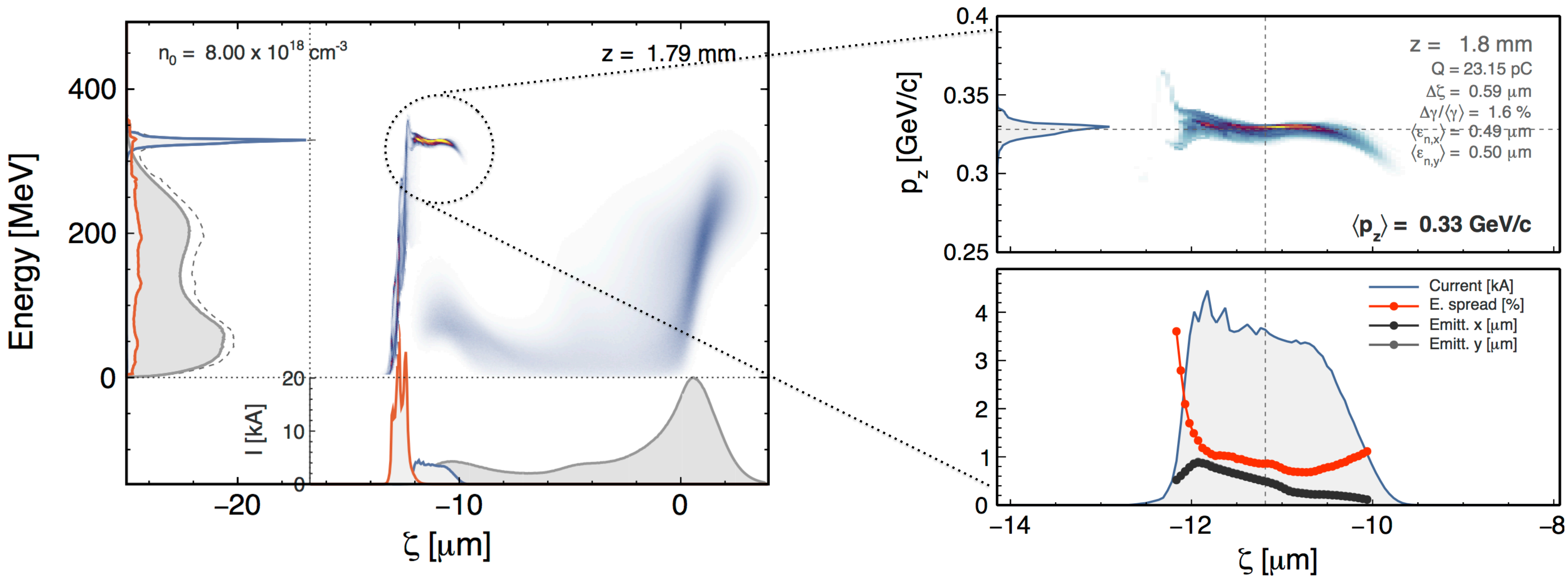
3D PIC simulation (OSIRIS)



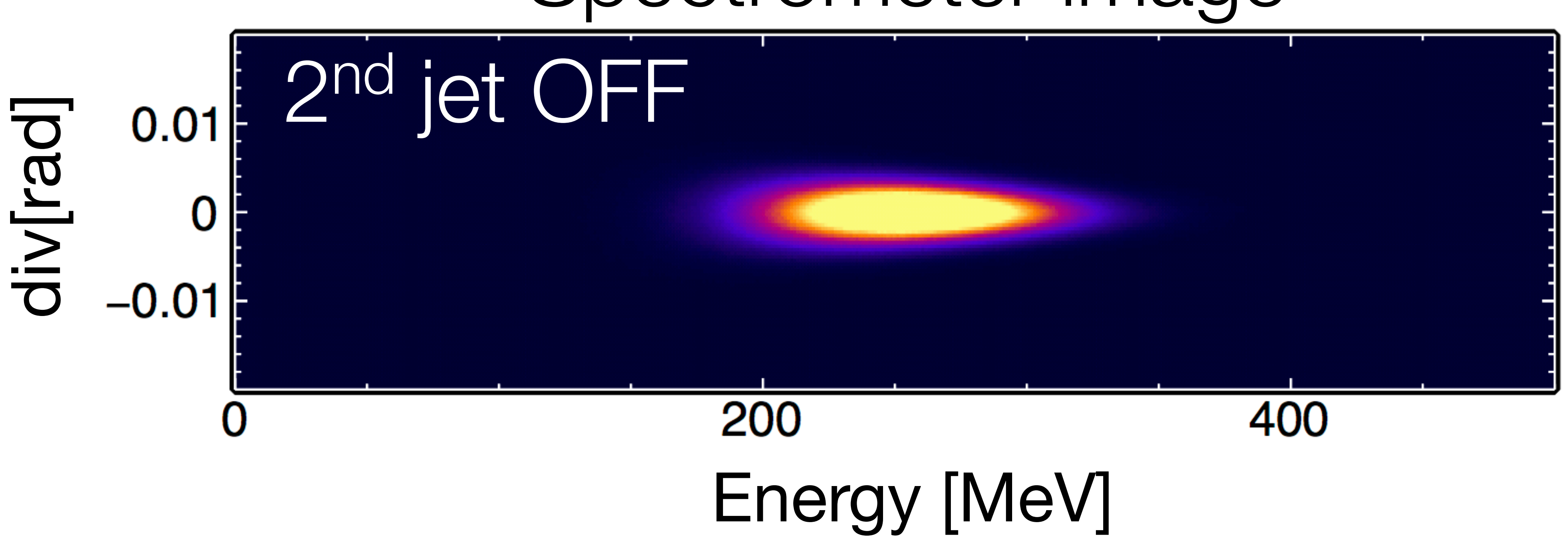
Second jet: PWFA with Ionisation injection (HZDR-type driver)

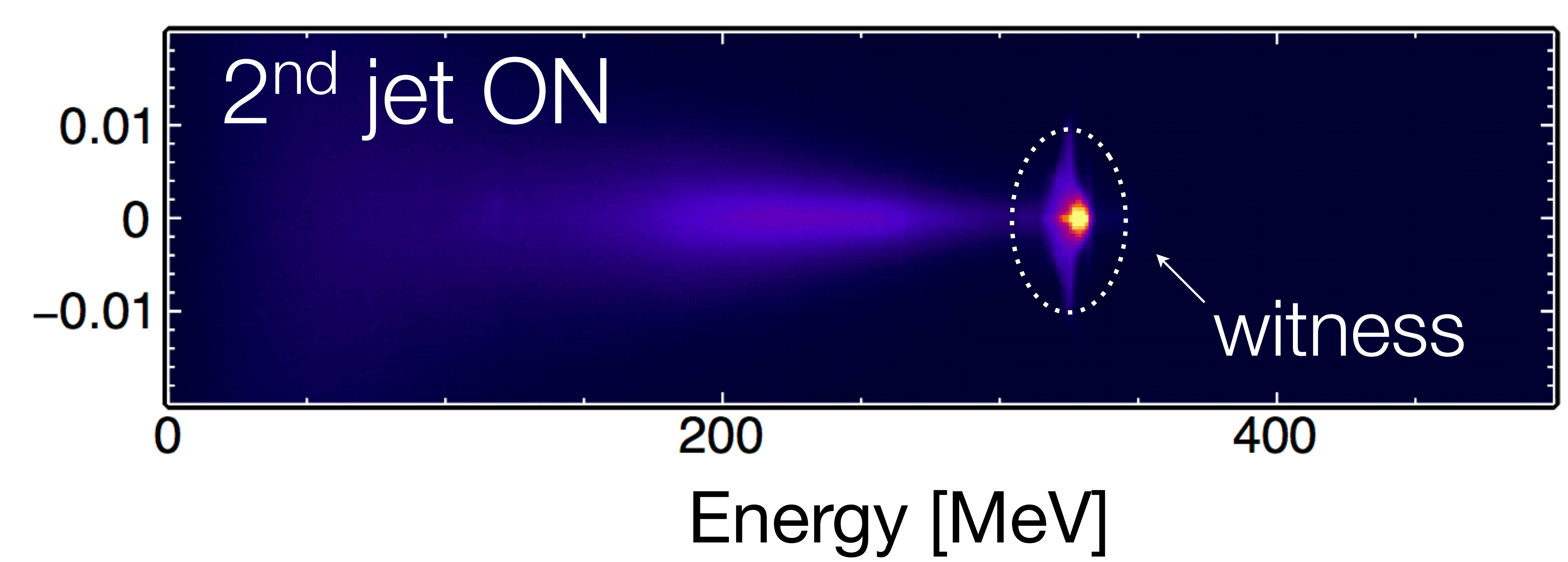


Laser-to-beam-driven WFA: **PWFA simulation with HZDR beam**

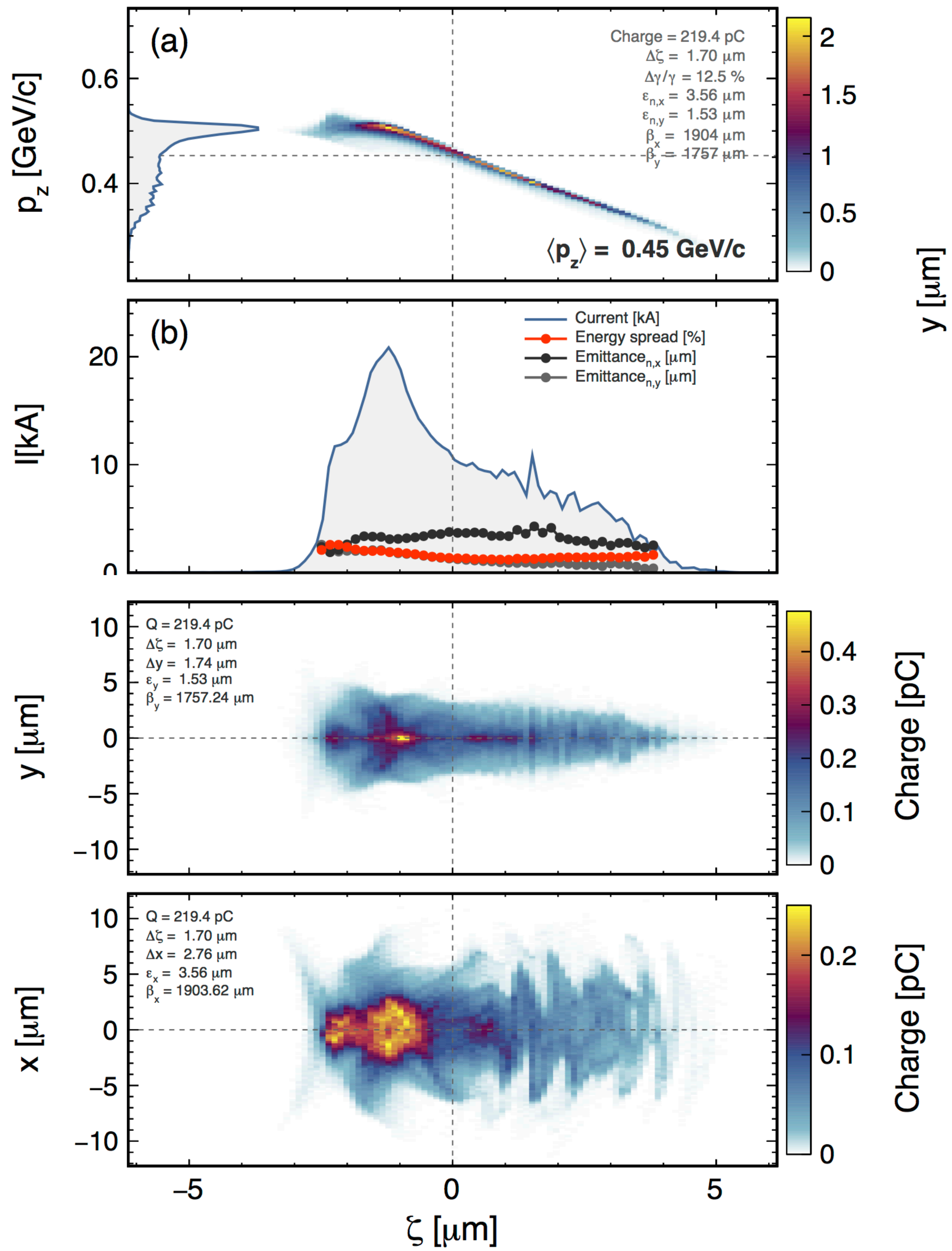


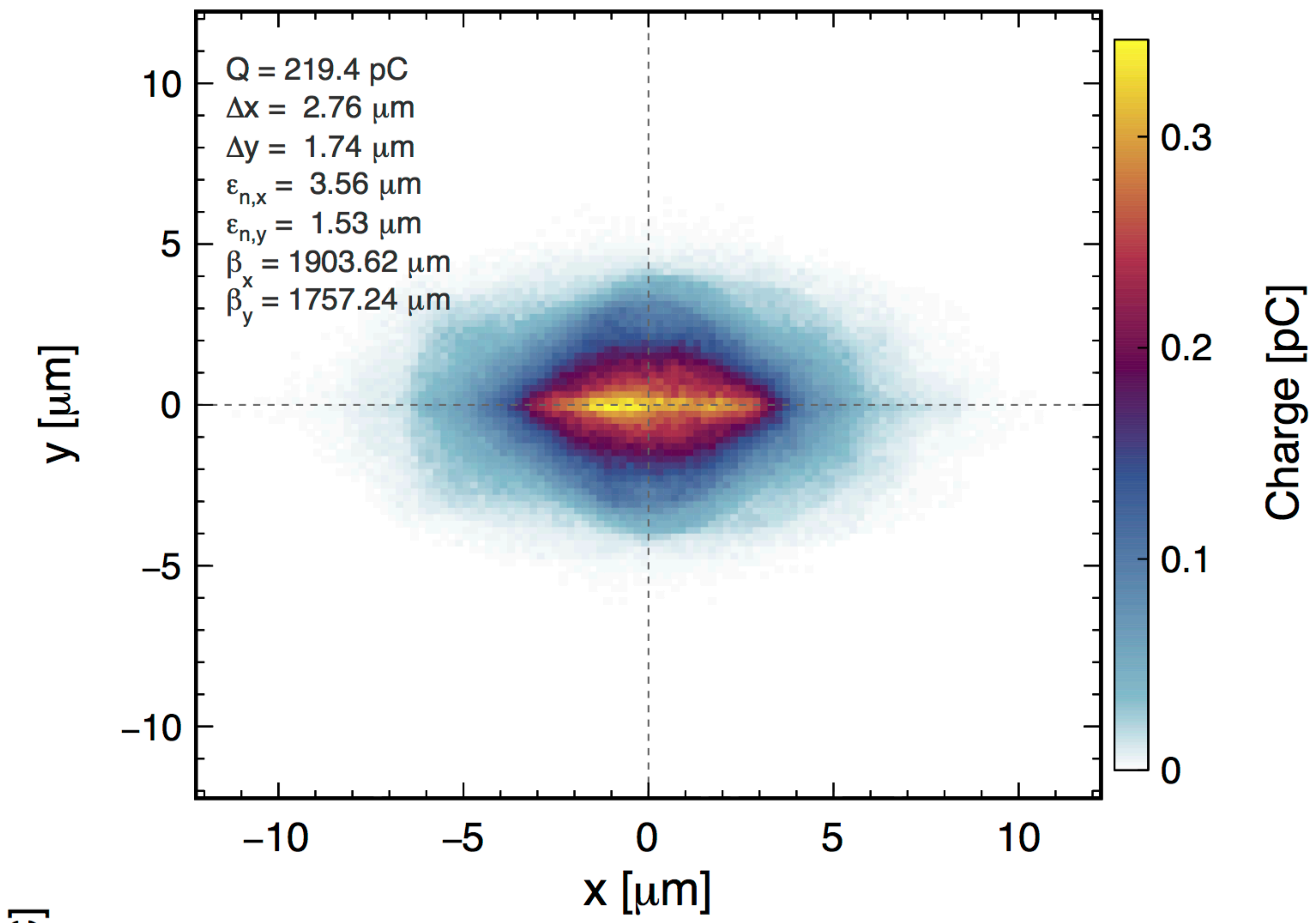
"Spectrometer image"





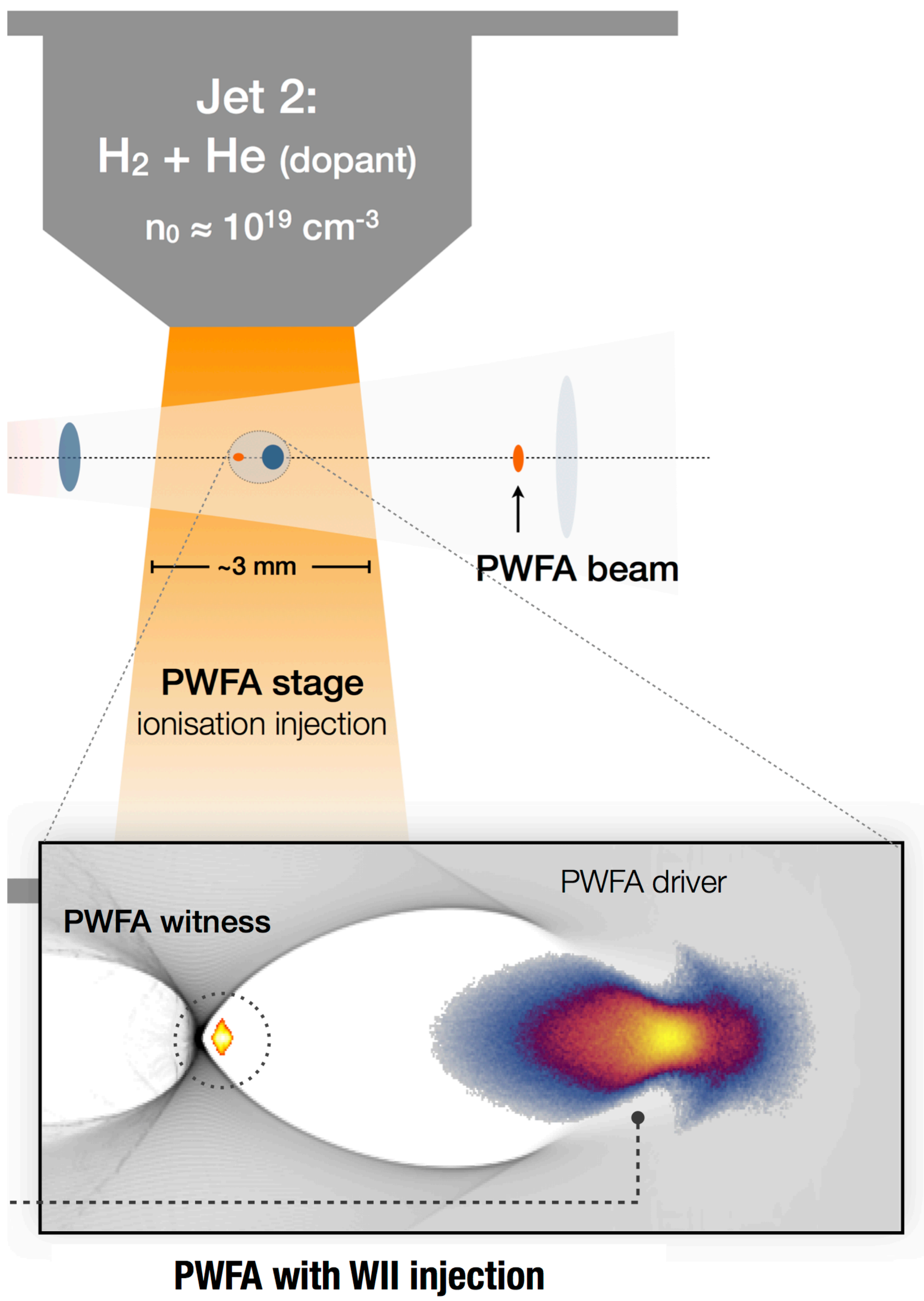
LWFA beams from ionization injection: **PIConGPU simulation (HZDR)**



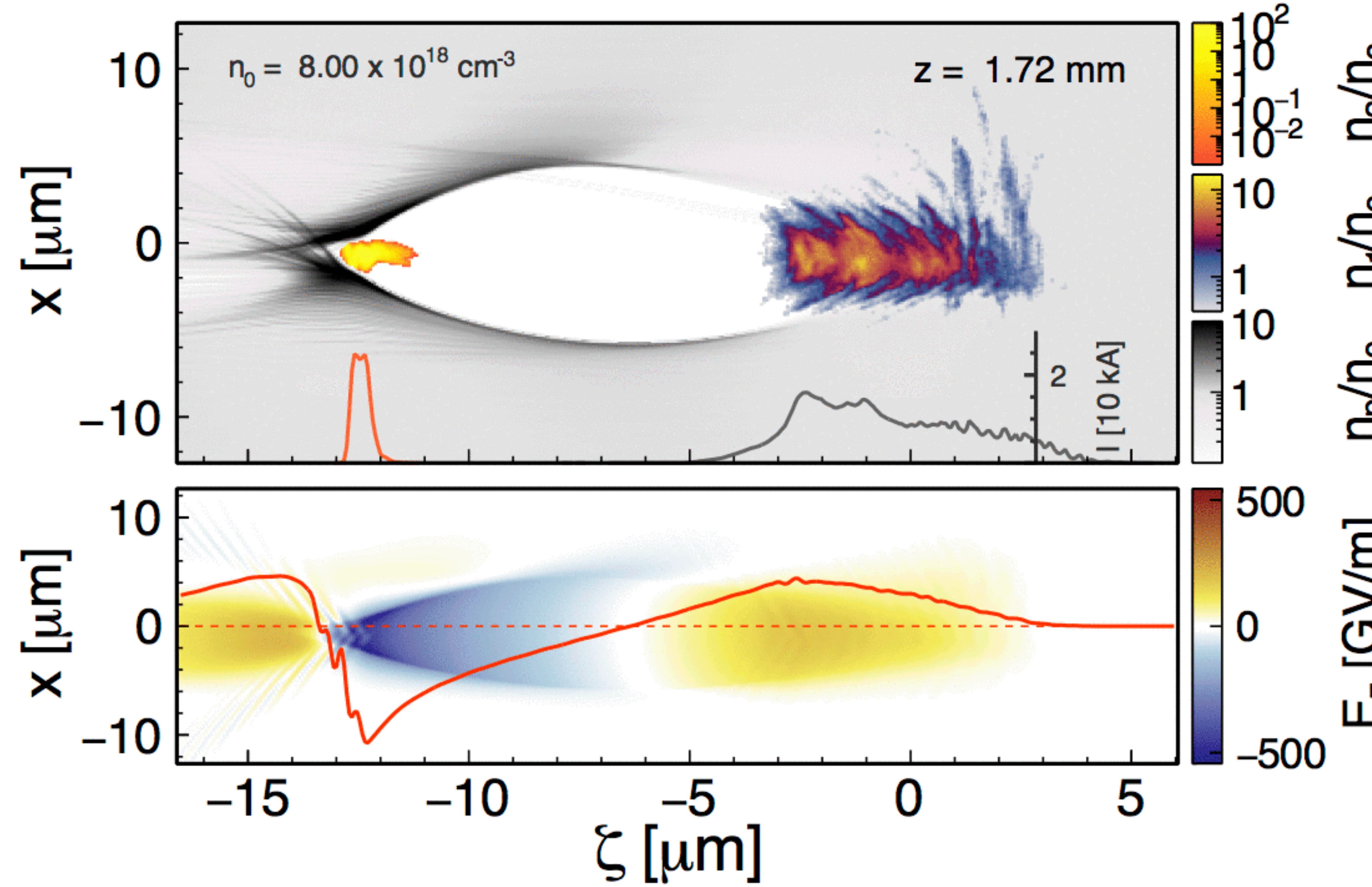


PIConGPU

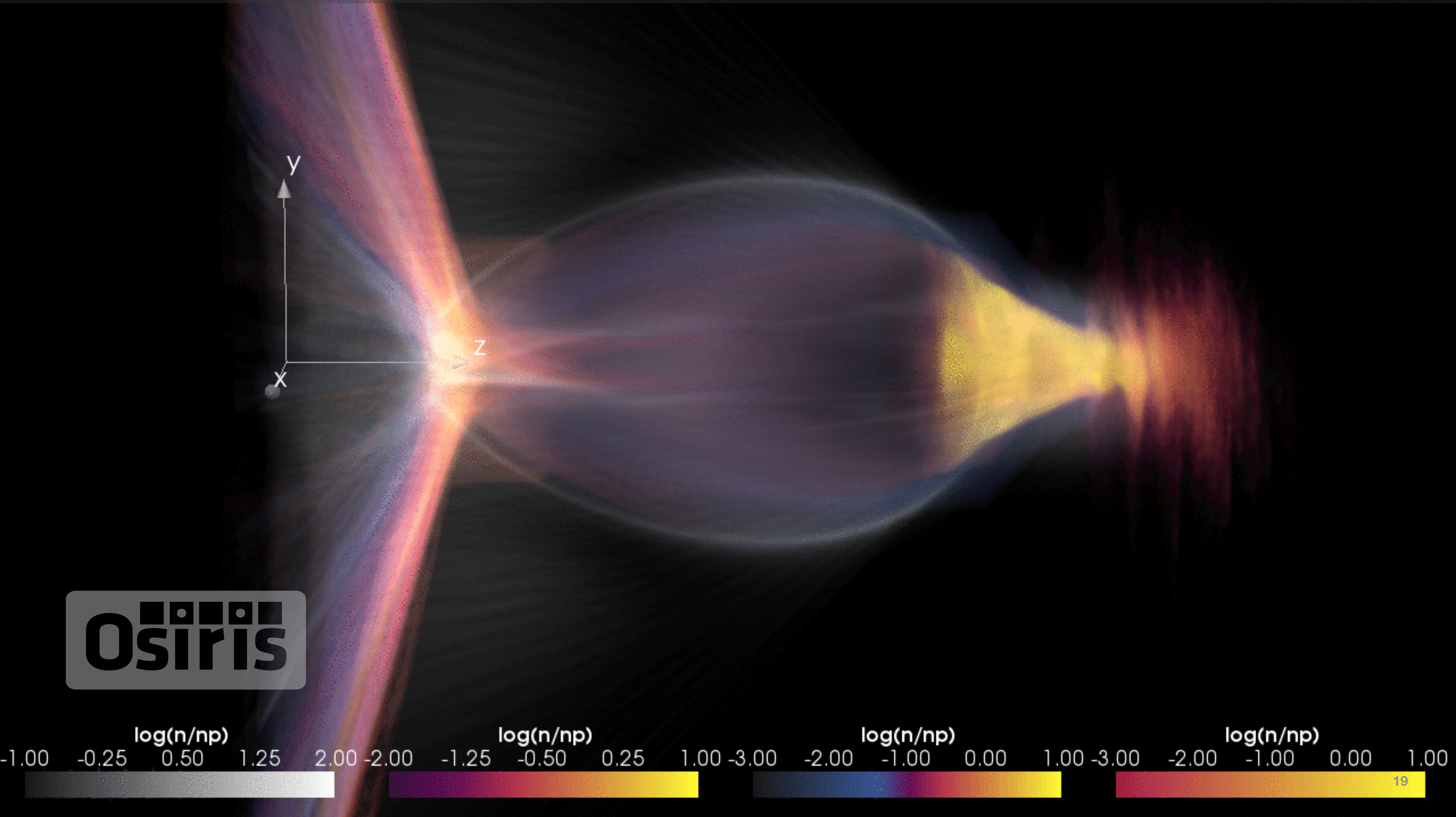
Second jet: PWFA with Ionisation injection



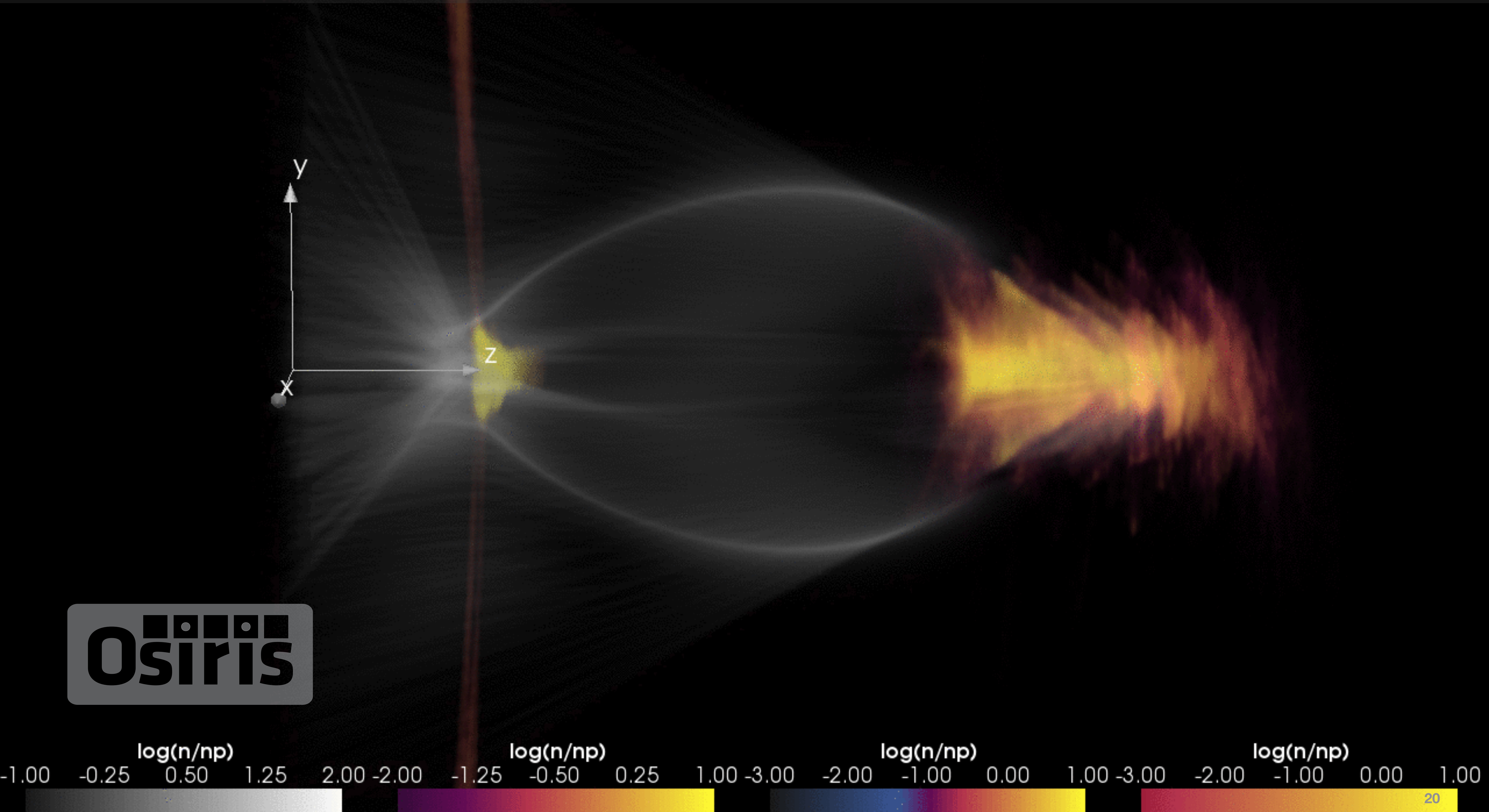
3D PIC simulation (OSIRIS)



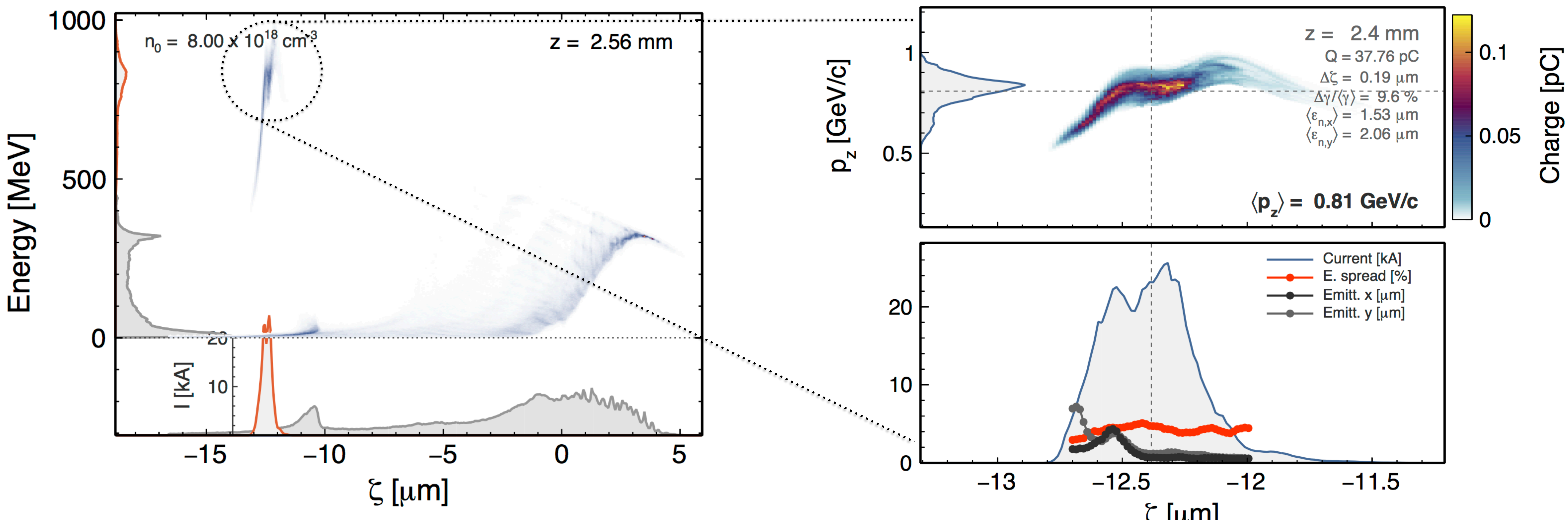
Second jet: PWFA with Ionisation injection (start-to-end)



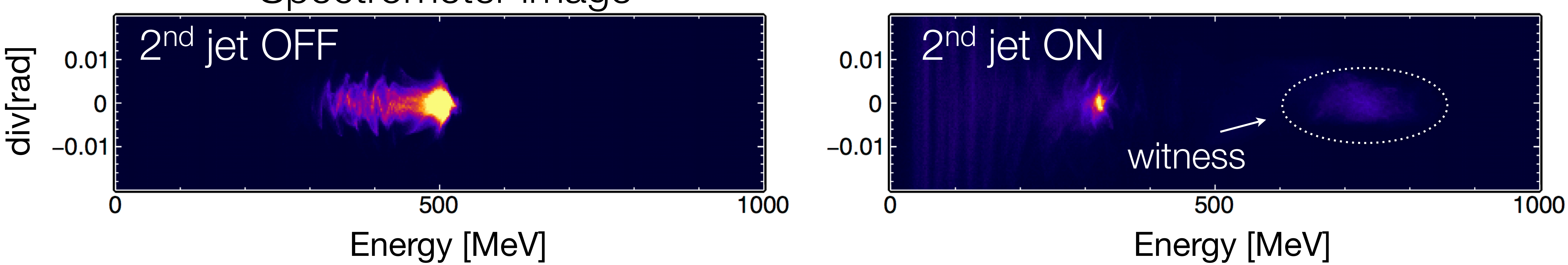
Second jet: PWFA with Ionisation injection (start-to-end)



Laser-to-beam-driven WFA: **PWFA simulation with PIConGPU beam**



"Spectrometer image"



Laser-to-beam-driven WFA: **Summary**

Conceptual design for a laser-to-beam driven plasma accelerator:
For the production of multi-GeV, high-brightness, FEL capable beams.

Preliminary working point achieved by means of PIC simulations:
Energy and brightness booster: 2 x energy, 10000 x brightness.

Proof-of-concept experiment at HZDR (LPWFA experiment):
Injection of electron beams in a PWFA driven by electron beams from LWFA.

Preliminary start-to-end simulations for the LPWFA experiment:
Energy doubling of low-emittance beams in the PWFA stage.

Thank you