E304 Plans for FY24: Gas-jet in Static fill (GiS) configuration

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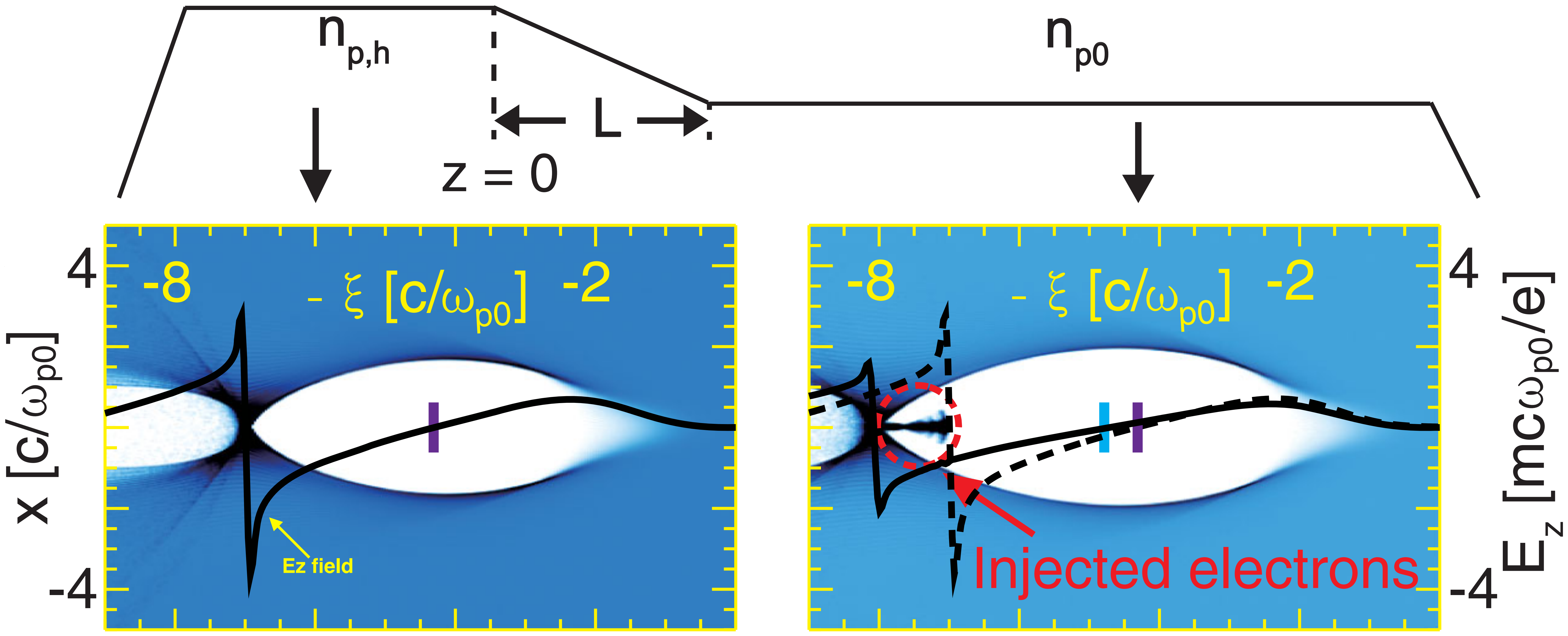
on behalf of the E300 Collaboration

Oct 18, 2023

E304 experiment

Internal generation of low-emittance, high-brightness bunches using density downramp



Xinlu Xu et al., Phys. Rev. Accel. Beams (2017)

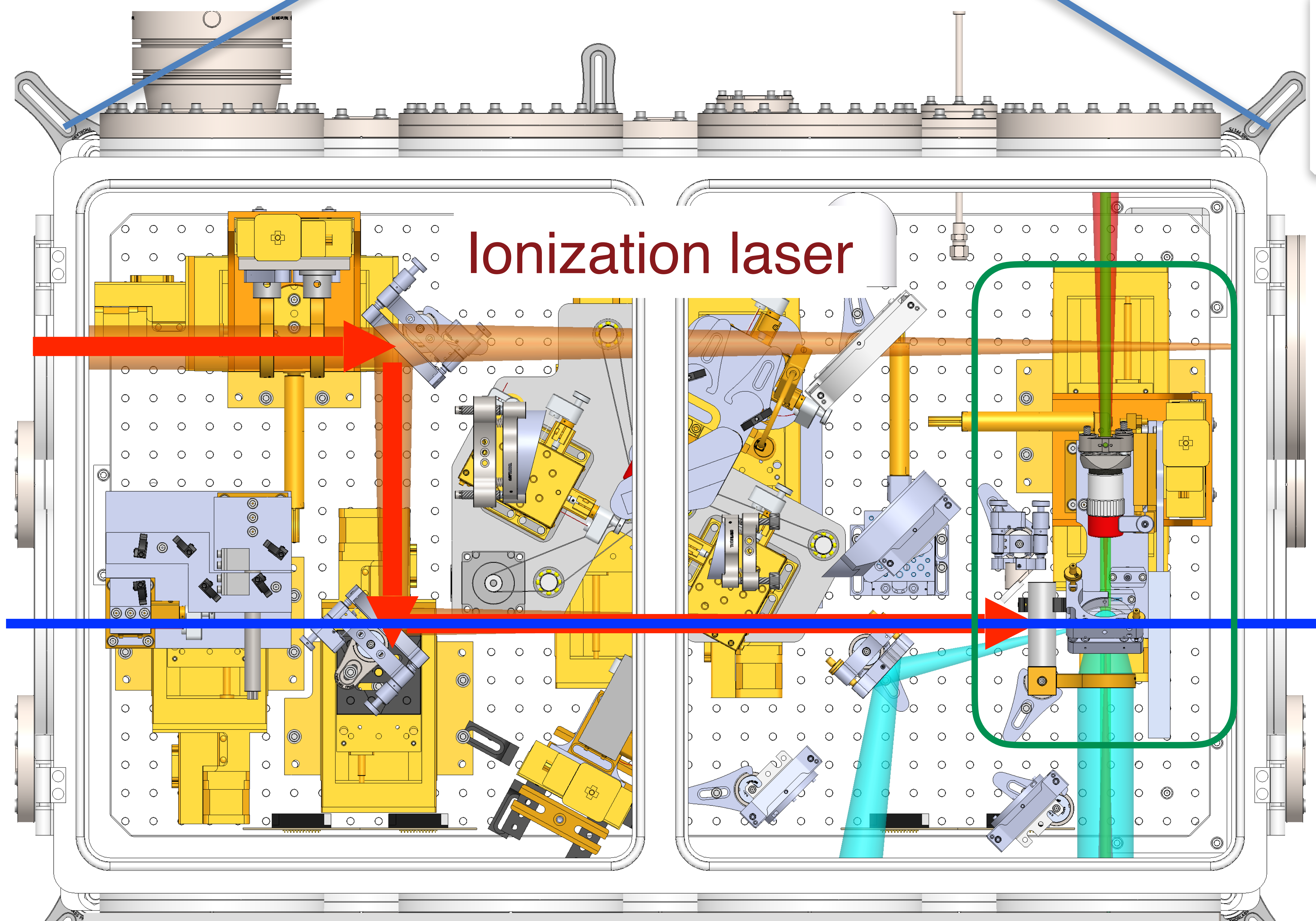
Example parameters: driver: Λ=4, σ_r=σ_z=ε_n=5.3 μm

$$\Lambda = 2I_b/I_A \quad I_A \approx 17 \text{ kA}$$

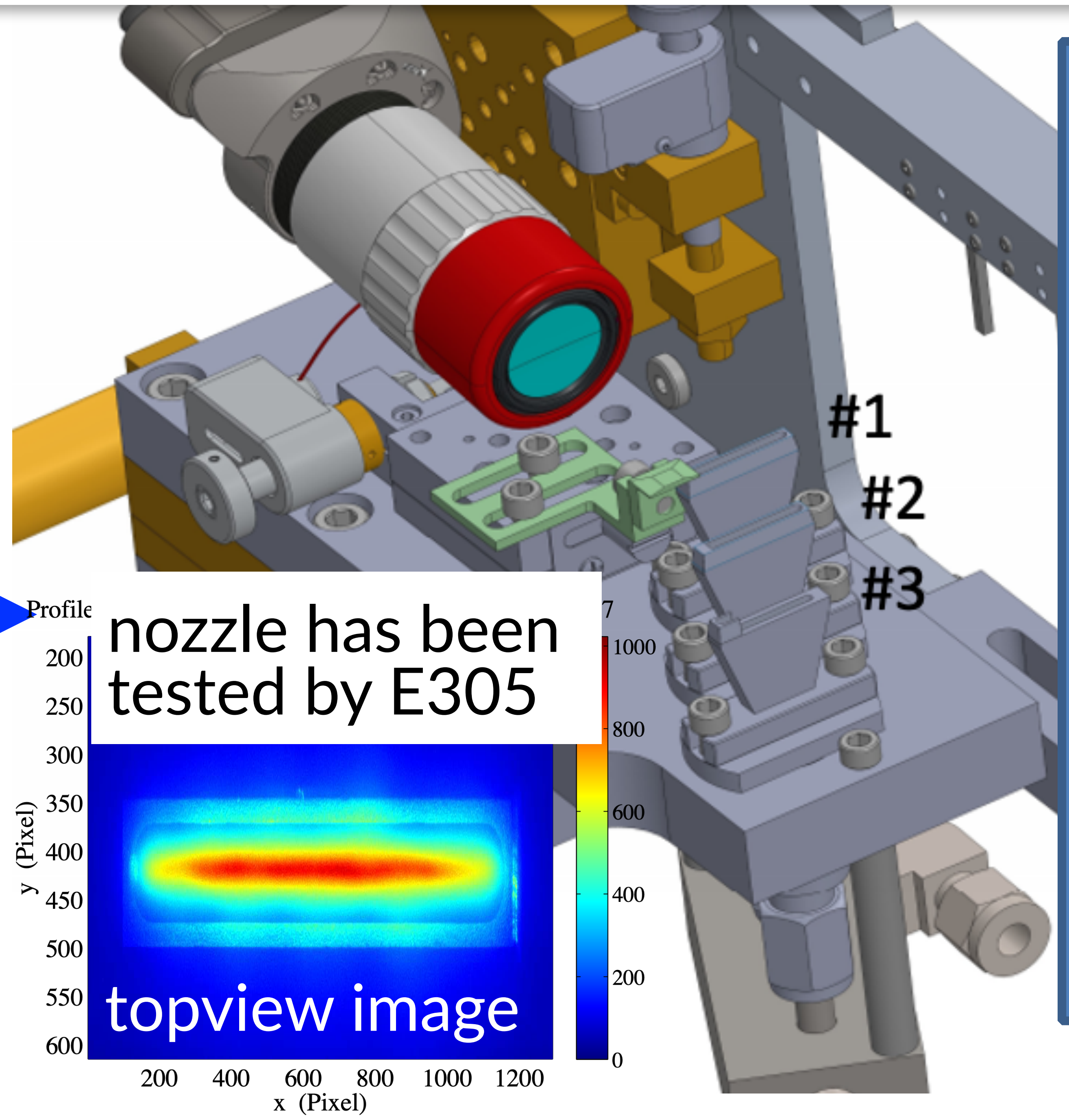
n_{ph} [cm^{-3}]	n_{p0} [cm^{-3}]	ramp [mm]	I [kA]	ε_n [nm]	B [A/m^2/rad^2]	E [MeV]	σ_E/E	Q [pC]
1.5x10^{18}	10^{18}	1.3	14	80	4E+18	620	0.15%	140

Experimental layout

UCLA



Same target assembly as E305 but different nozzles.



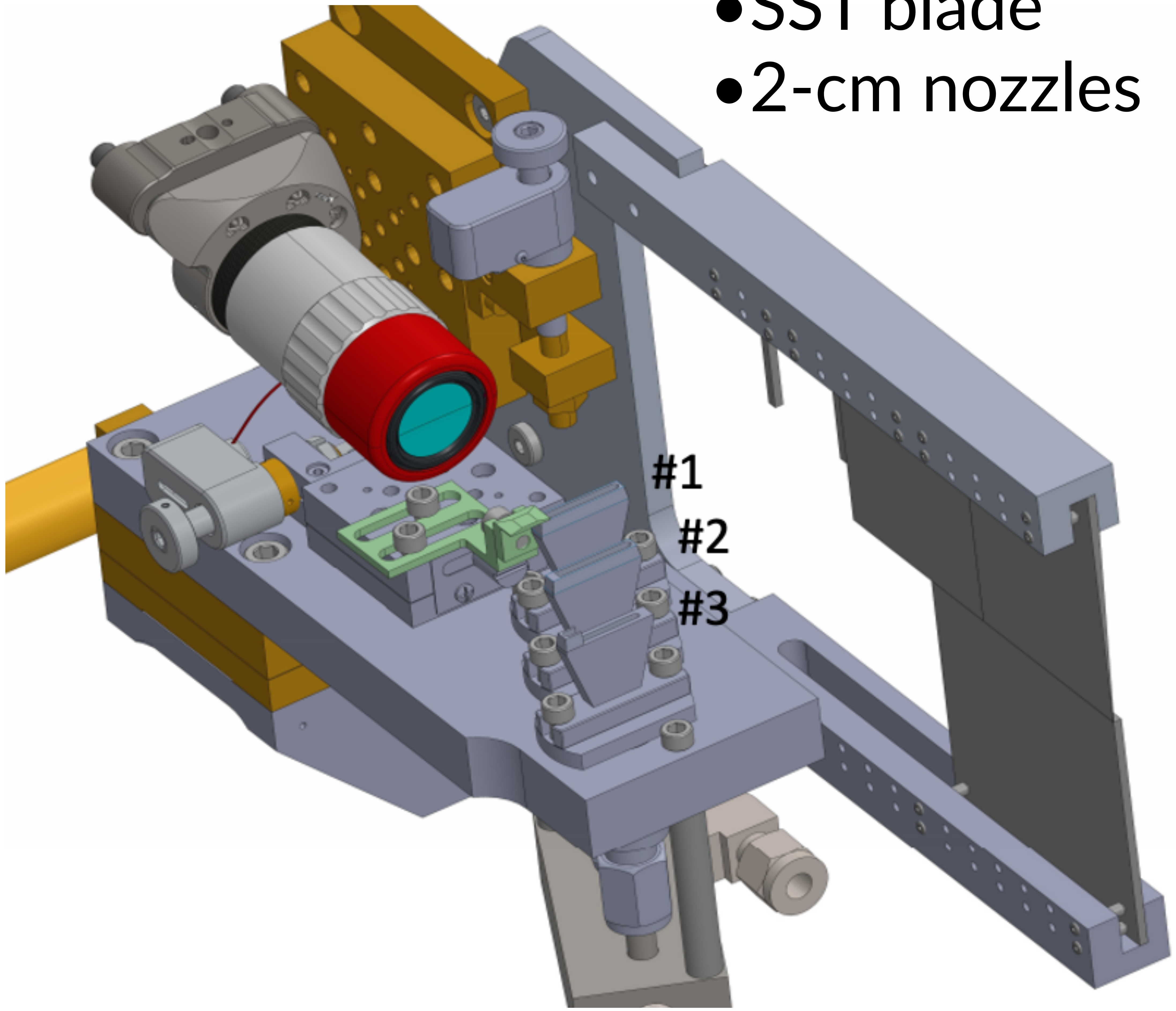
- E304 plasma source:
- 2-cm gas jets
  - Sharp downramp (~10 c/ω_p) by shock front
  - Gentle downramp (~100 c/ω_p) by structured nozzle
  - Laser ionization & beam ionization

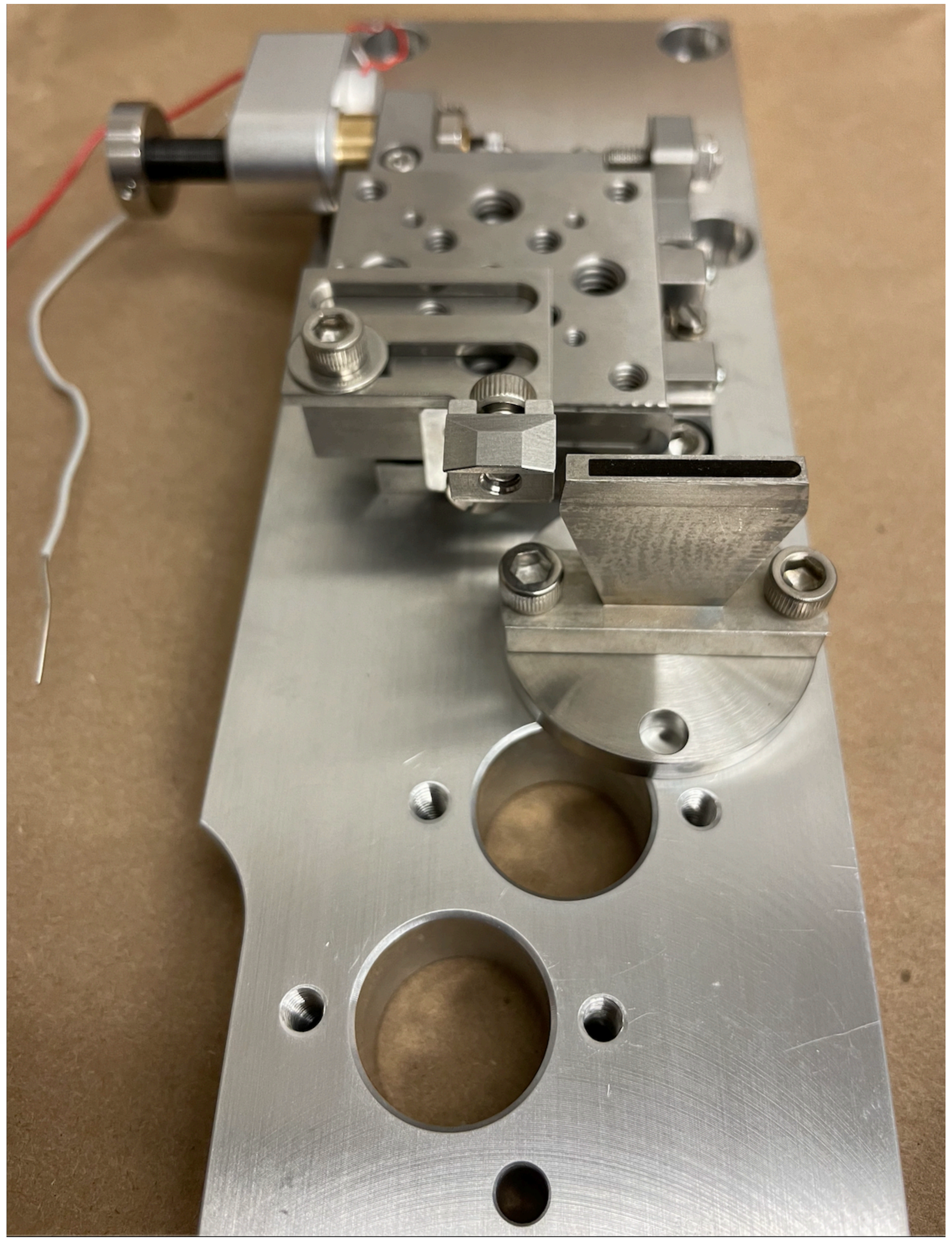
CAD drawings made by Robert Ariniello, CU

Hardware readiness

Hardwares sent to SLAC

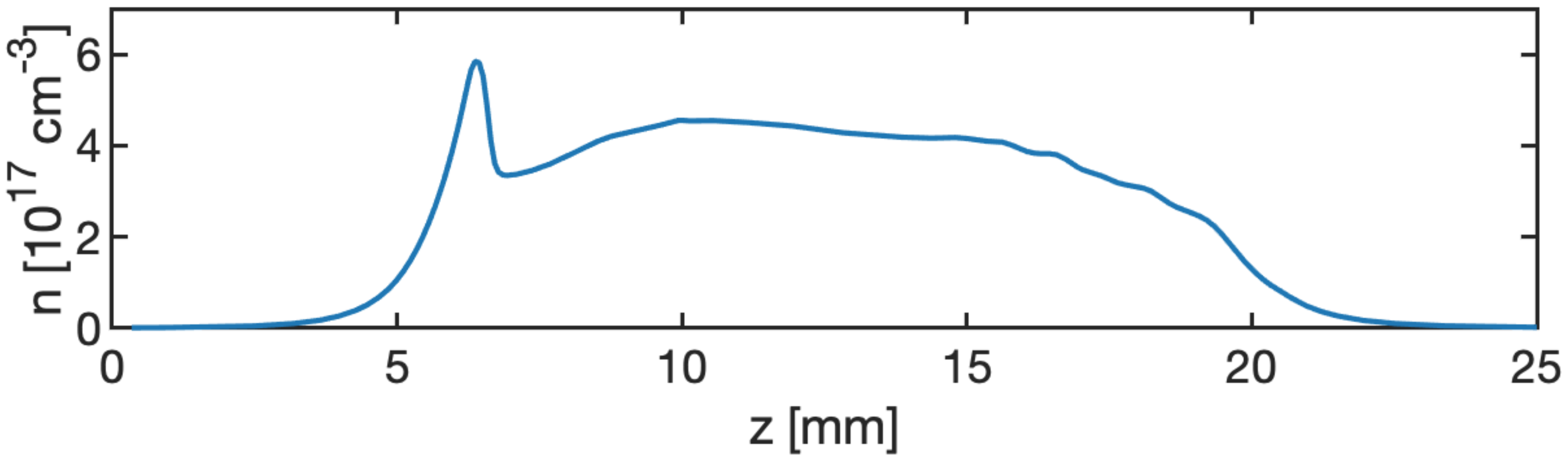
- A new plate with additional tapped holes
- a 0.5" stage for moving the blade
- SST blade
- 2-cm nozzles

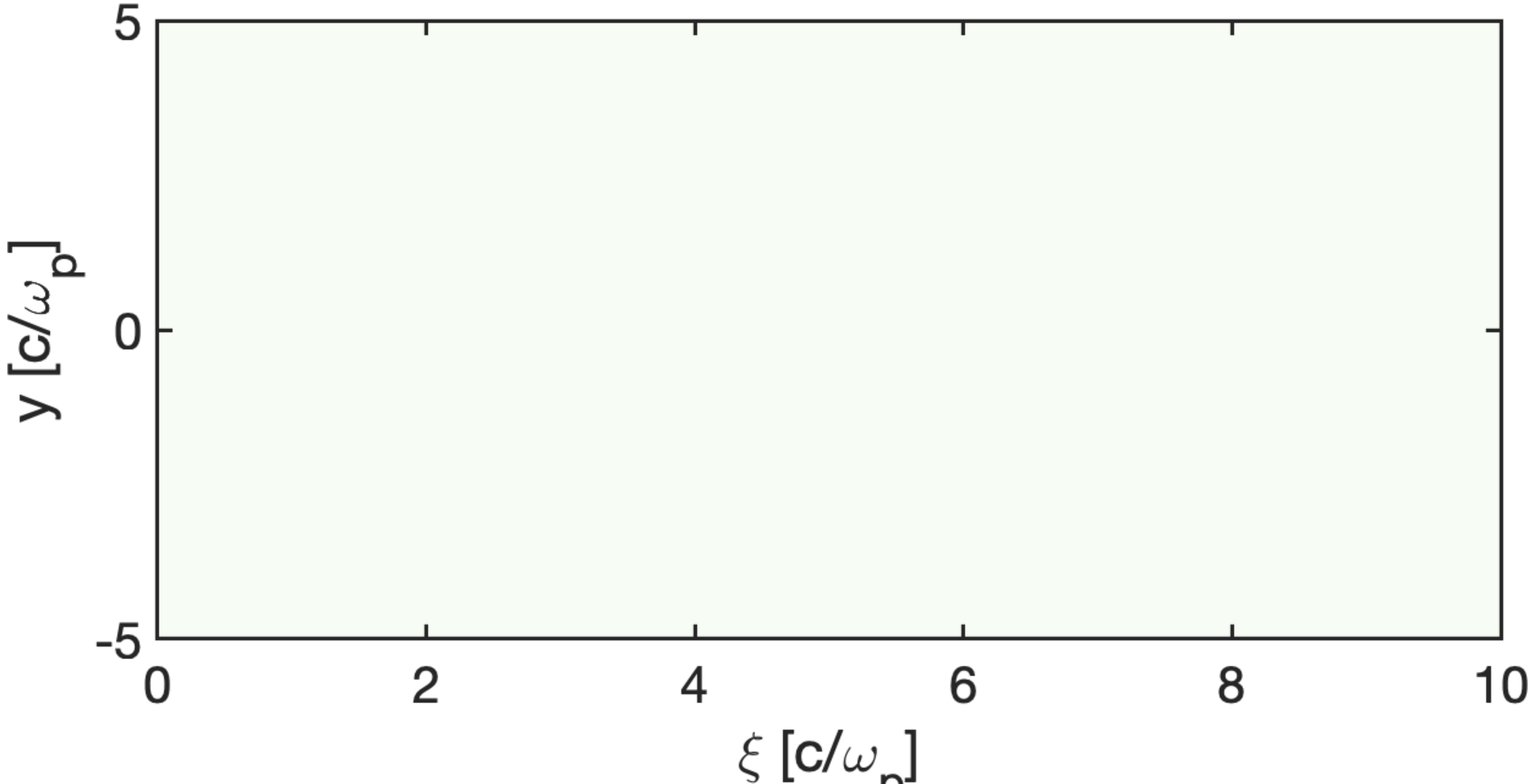




Quasi3D simulation using a simulated 2-cm nozzle density profile

density profile from fluid simulation (200psi, @4mm)



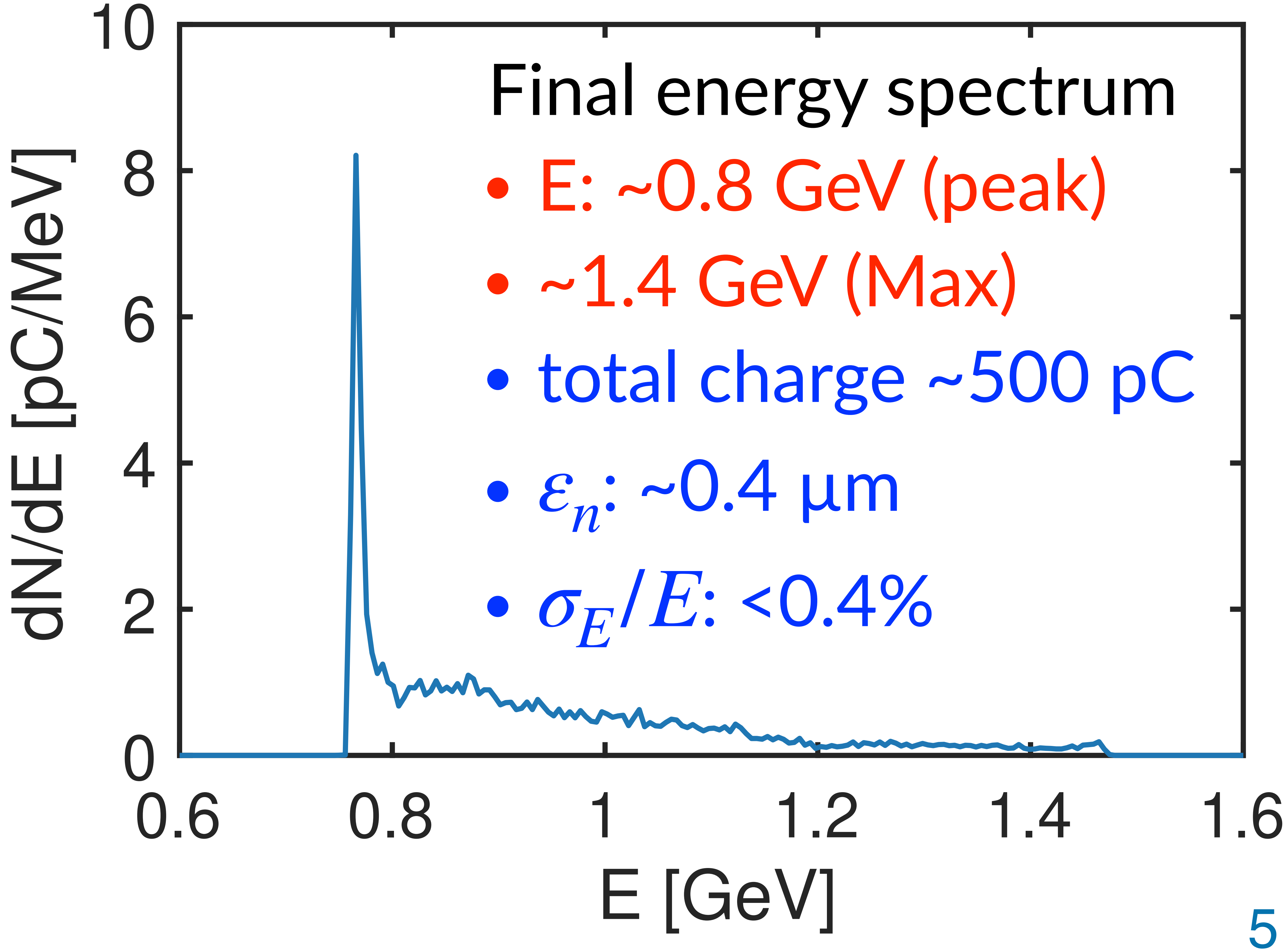


Driver parameter:

$Q = 2.0\ \mathrm{nC}$

$\sigma_r = 15\ \mu\mathrm{m}, \sigma_z = 10\ \mu\mathrm{m}$

$\Lambda = 2.8, n_b \approx 3.5\ n_p$

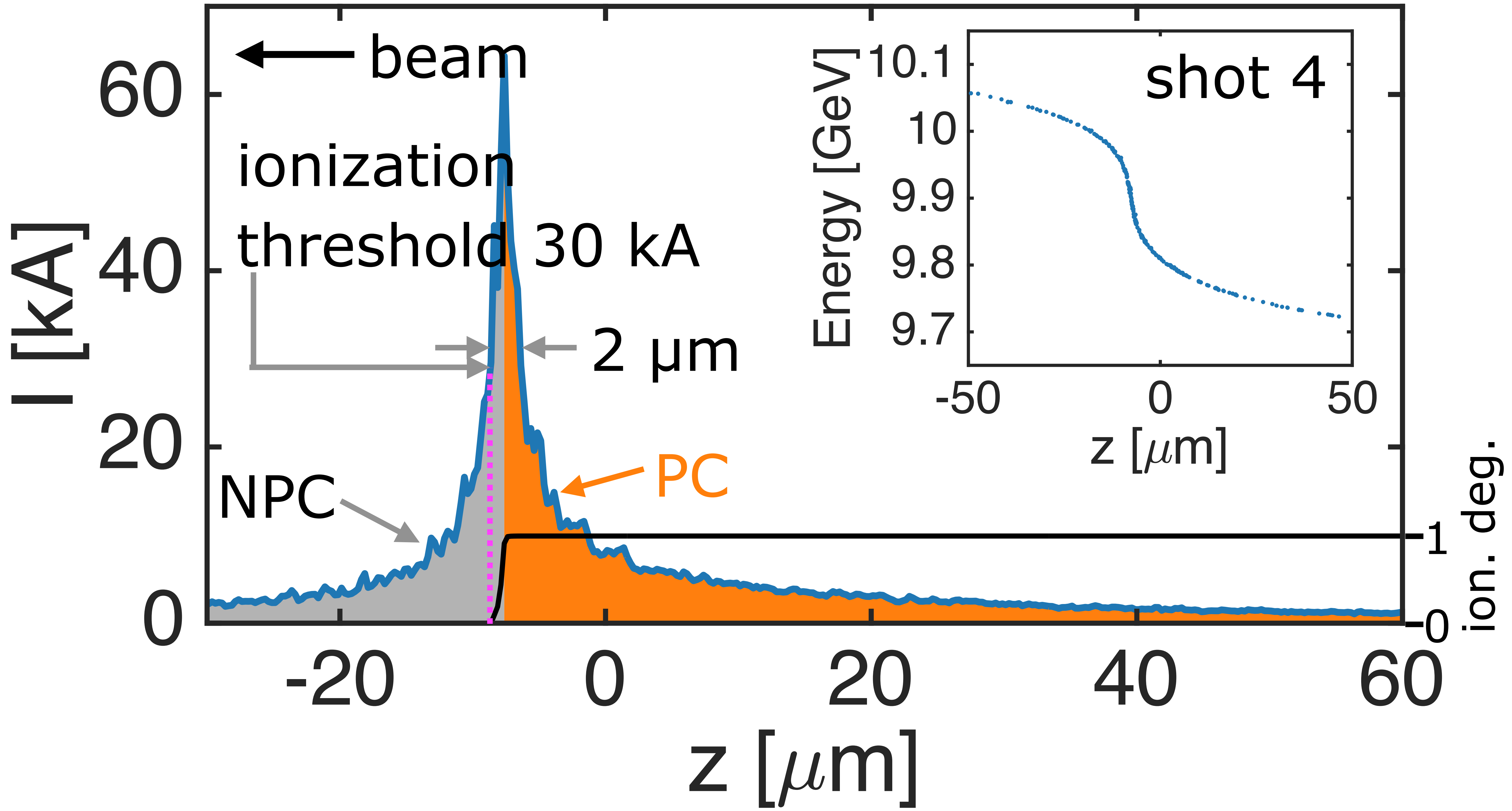


Time structured electron beam (without laser heater)

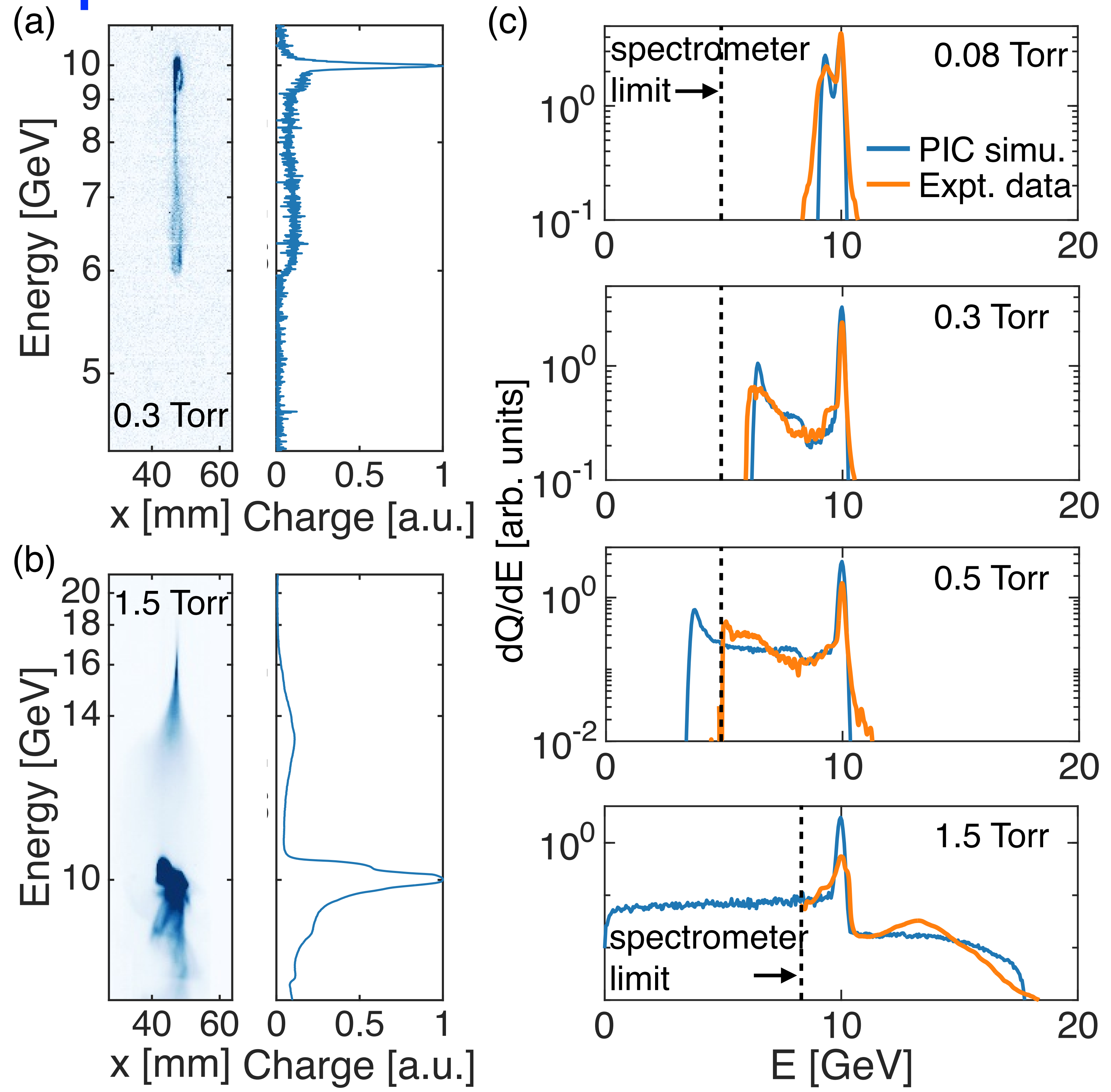
Start-to-end beamline simulation and PWFA experiments (2022 run) suggest time-structured bunches

- µm scale >50 kA current spike(s) + a longer but lower-current (<10 kA) structure
- such bunches can self-ionize meter-scale H2 plasmas and excite nonlinear wakes

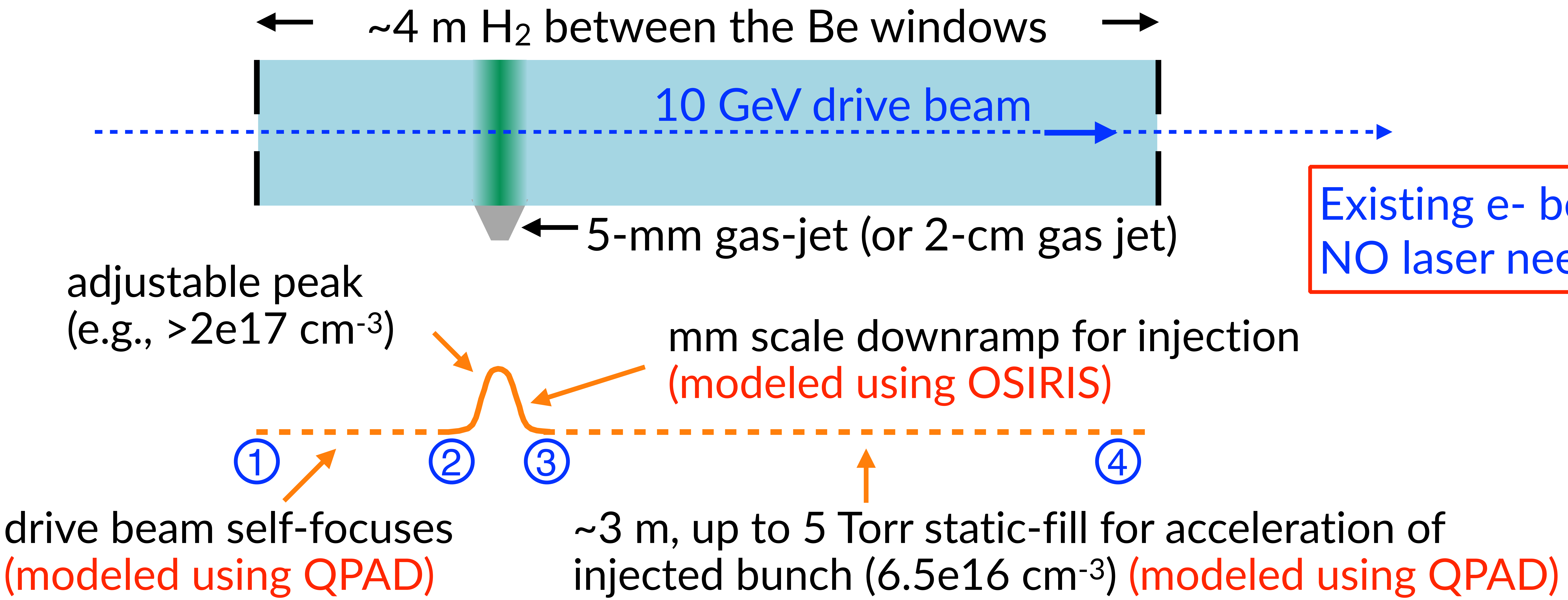
nominal current profile from beamline simulation



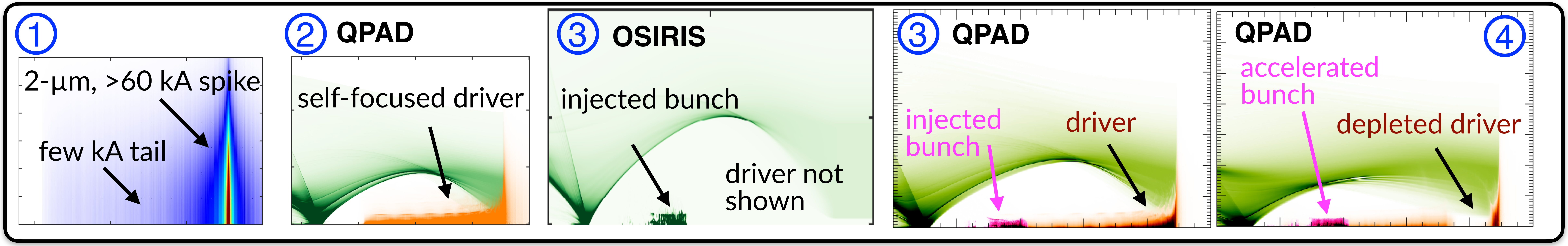
the nominal bunch reproduces experimental results



An alternative configuration: Gas-jet in Static fill (GiS)



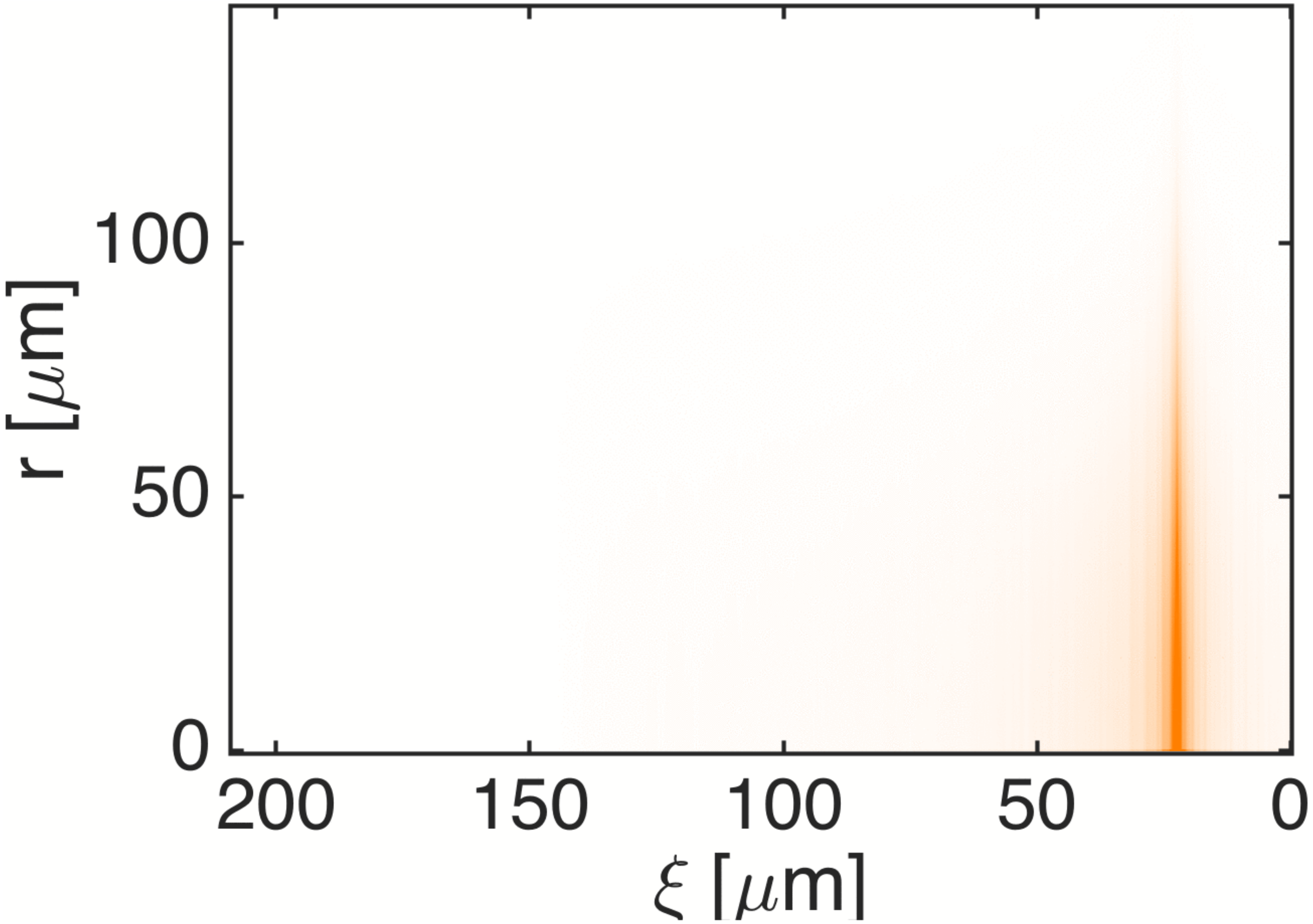
Existing e- beam
NO laser needed

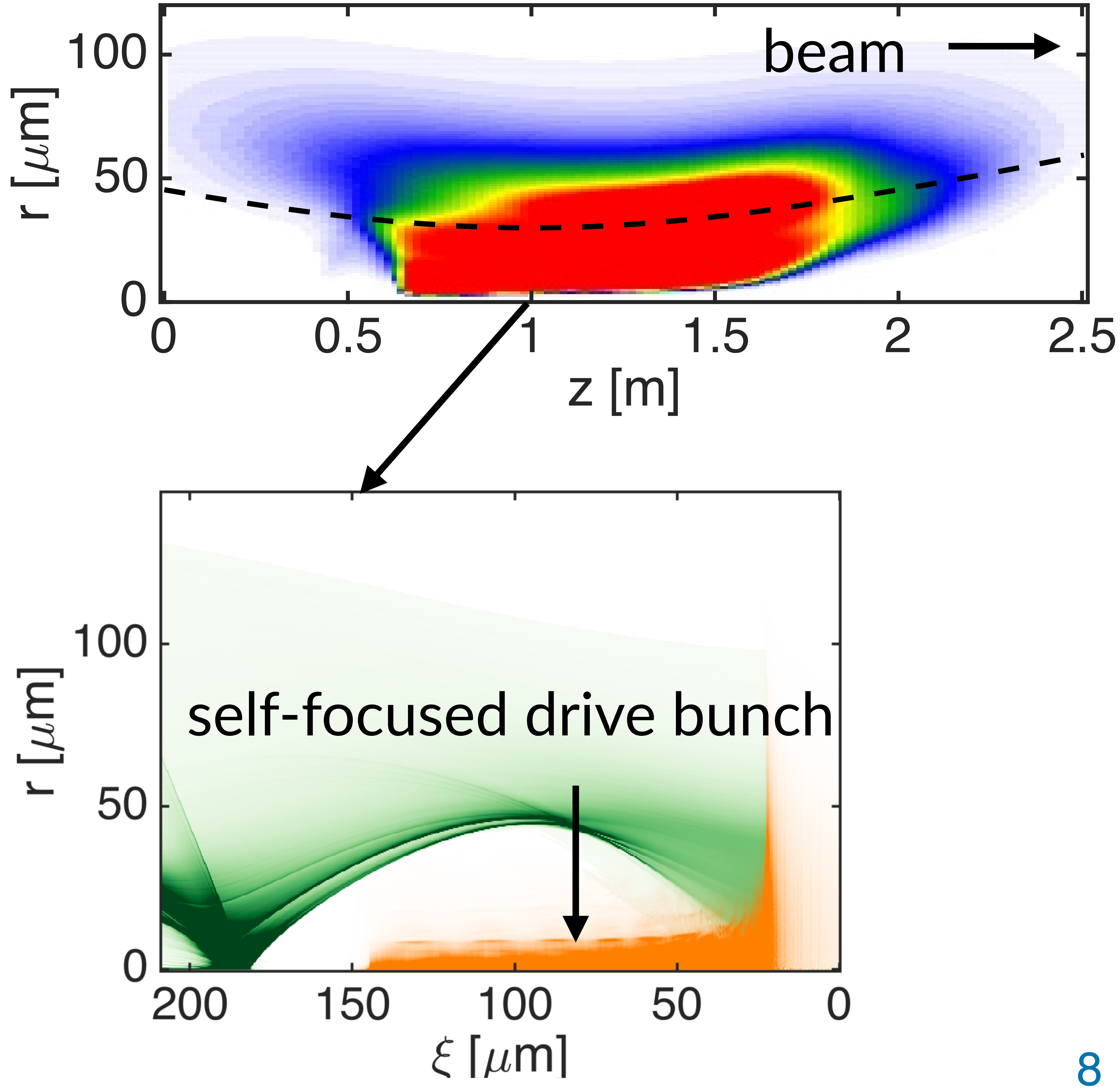


Step I: QPAD simulation of self-focusing of the driver

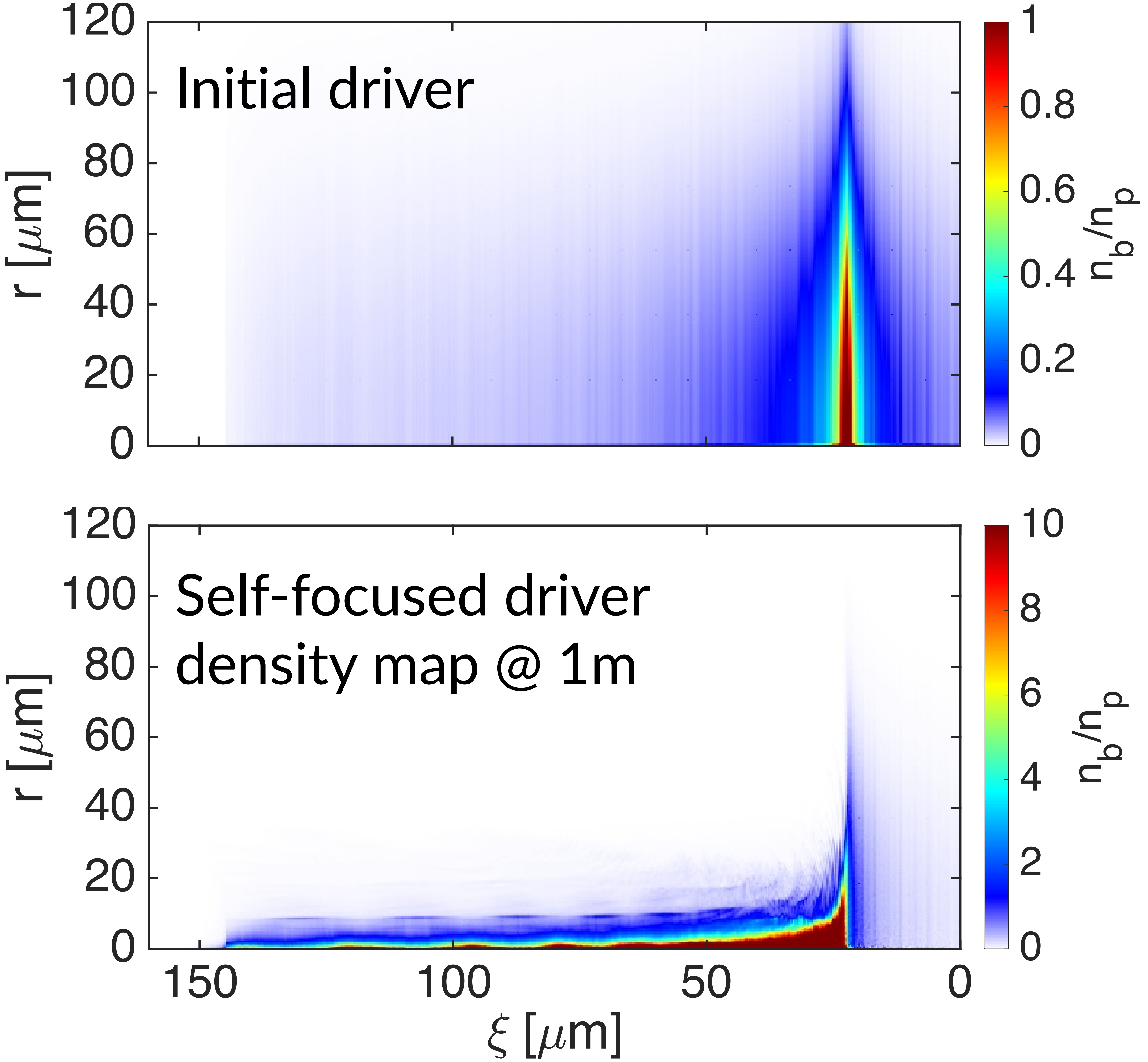
Beam ionization of H_2 and self-focusing

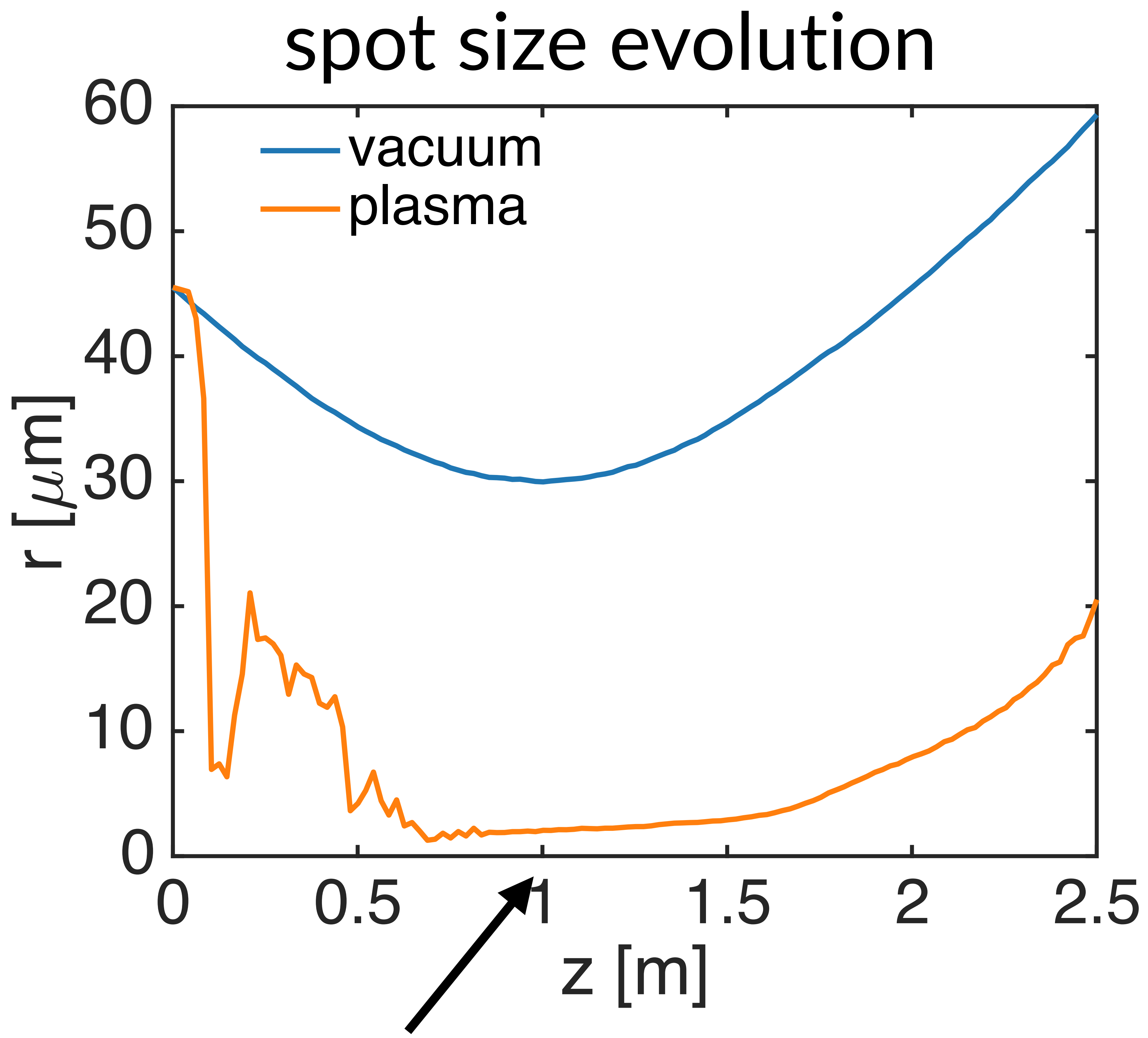
- 1.5 Torr static fill (**n_e~5e16 cm^{-3}**)
- atomic hydrogen with 15.4 eV IP, ADK model
- "nominal" driver





Self-focused beam from the QPAD simulation





beam parameters evaluated here

σ_r : 30 —> 3 μm

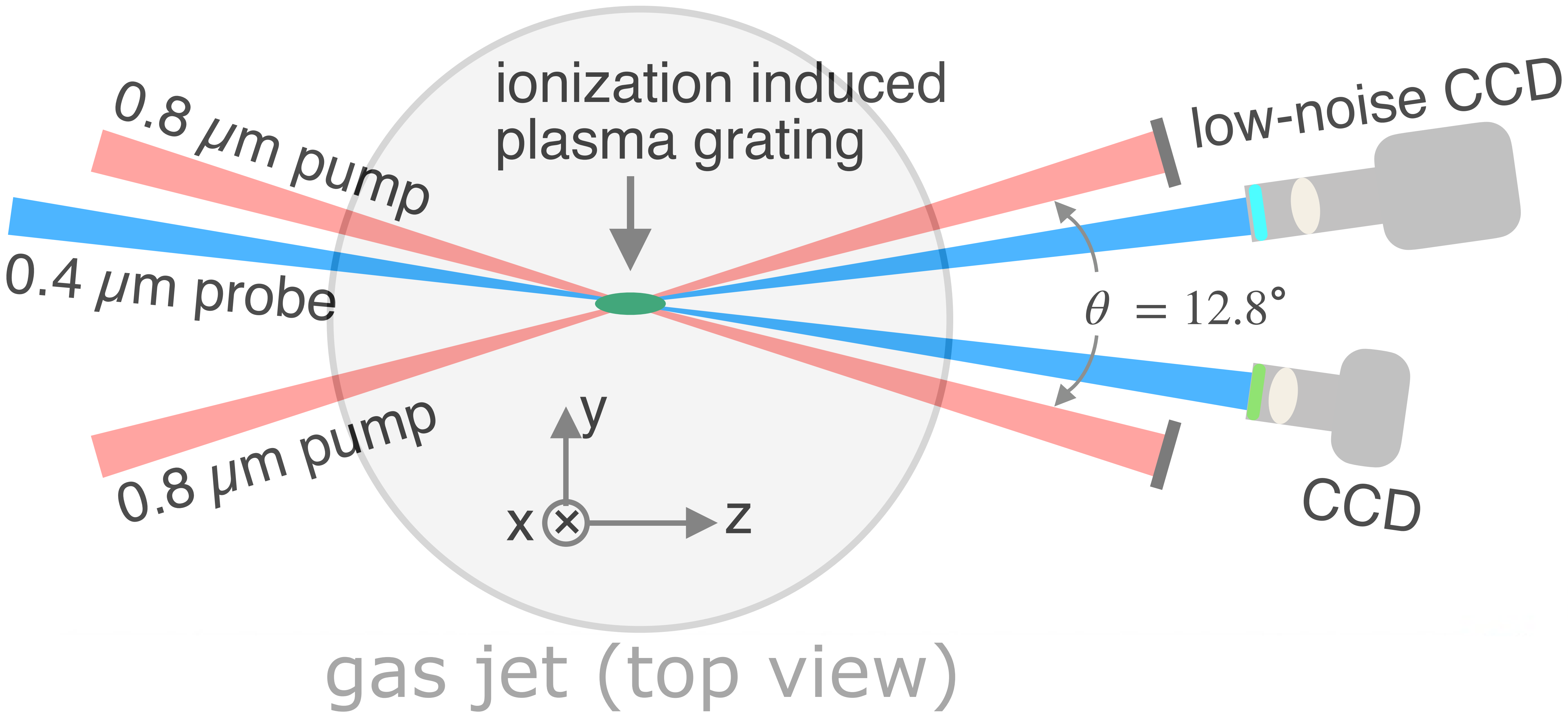
n_b increases by 100 times

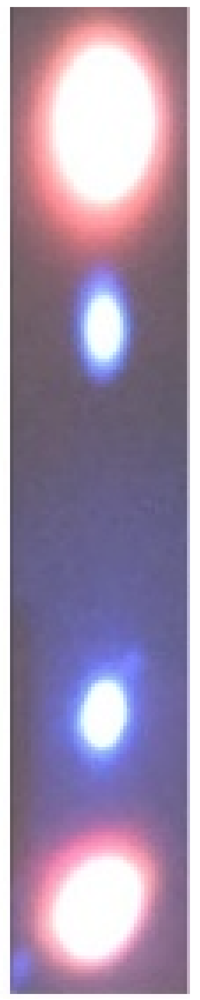
put gas jet here to inject electrons

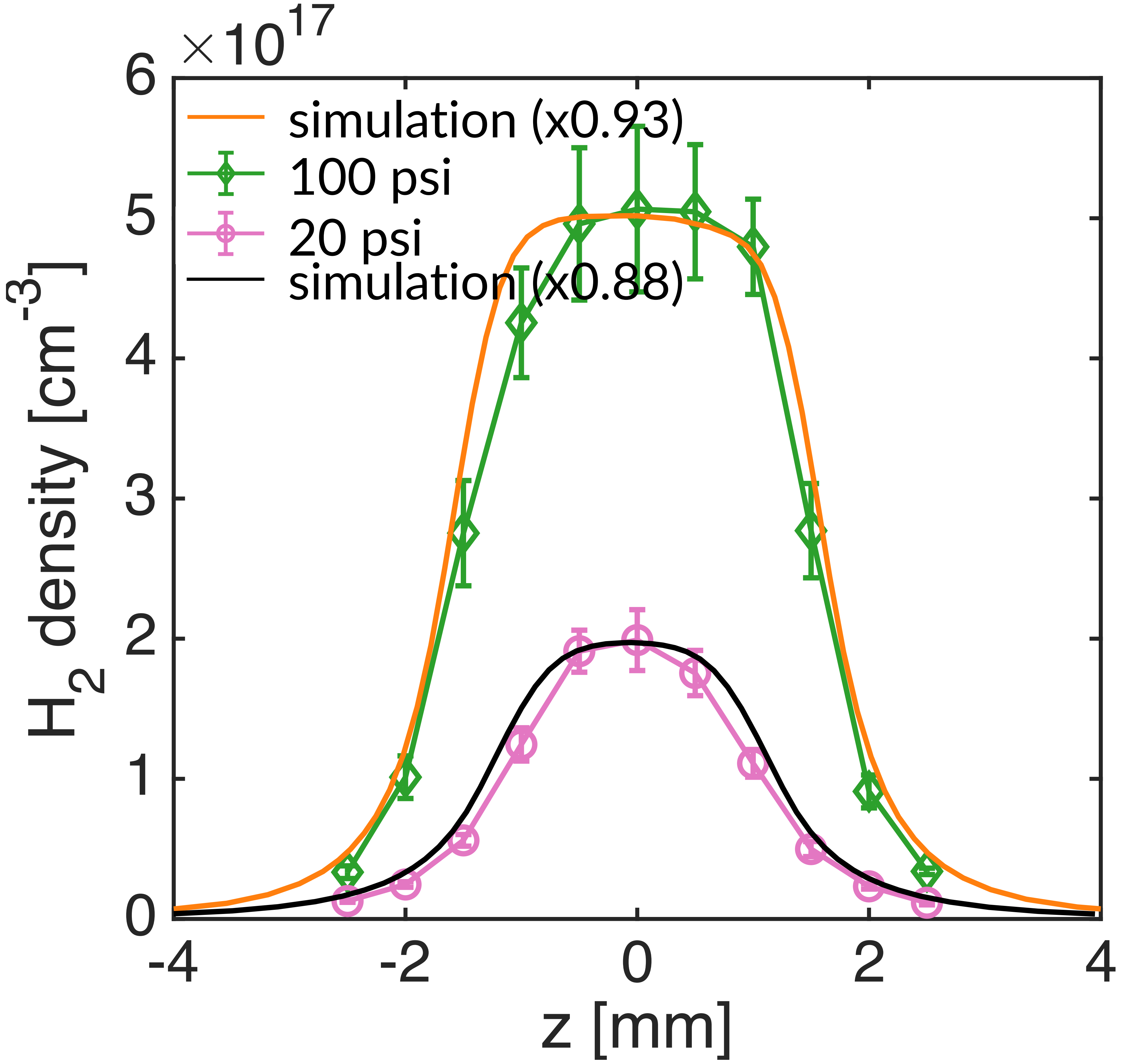
Low-density gas jet had been characterized using IPG

We need a low-density (~10^{17} cm^{-3}) gas jet to make a density bump in the static fill gas

- Difficult to characterize using interferometer (or wavefront sensor)
- We have developed a new method to measure density down to 10^{15} cm^{-3}
- It's based on ionization induced plasma grating (IPG)

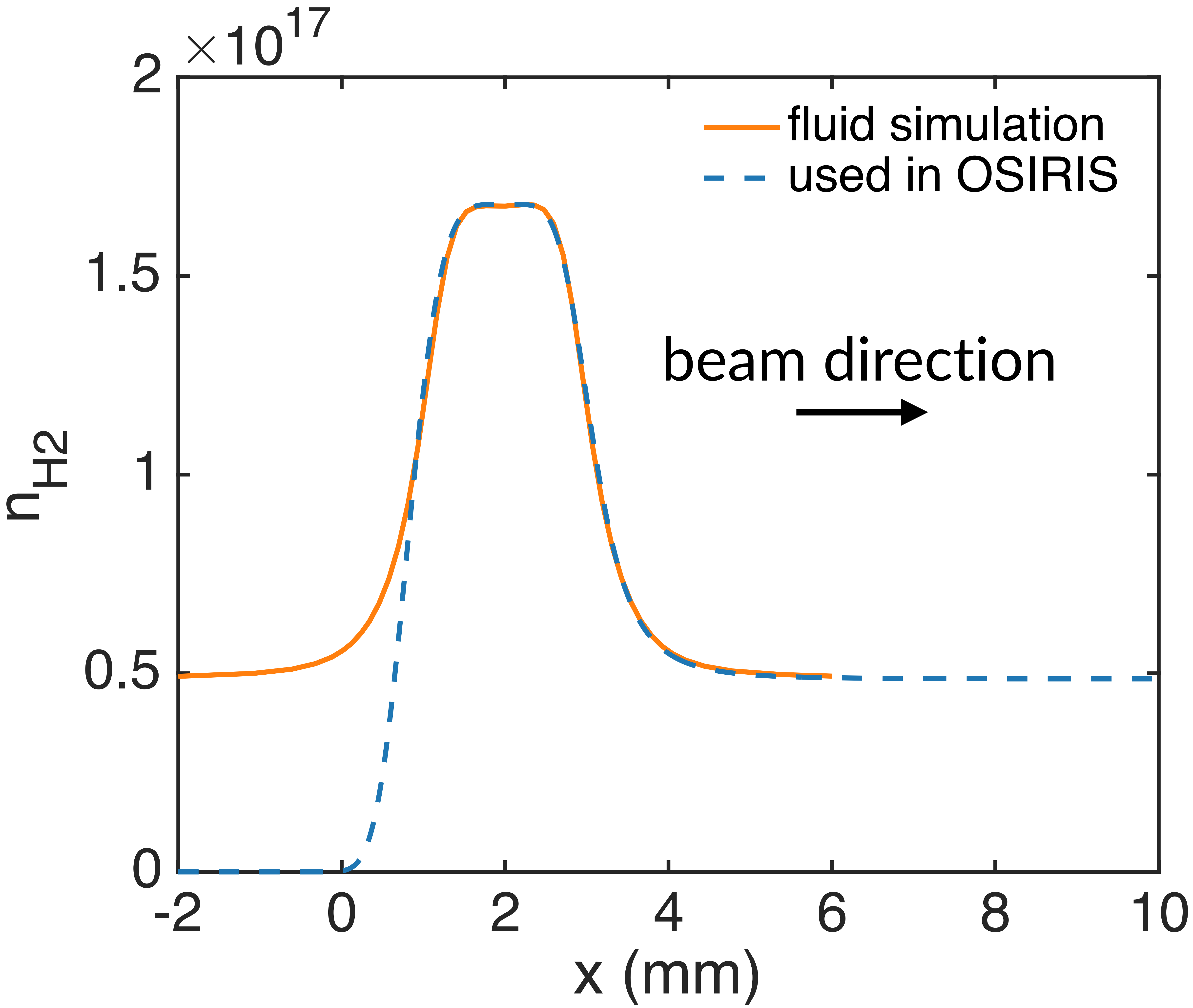






C. Zhang et al. PPCF 63, 095011 (2021)

Density profile from fluid simulations

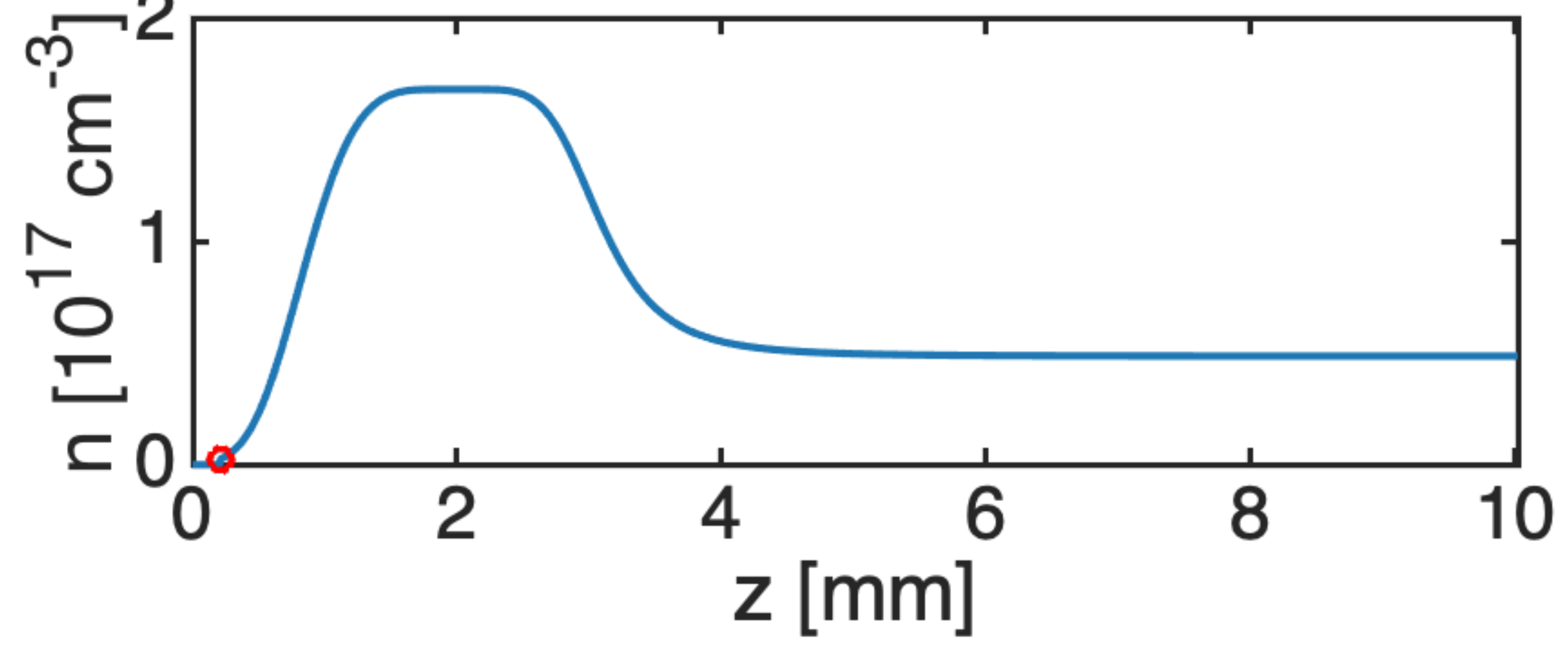


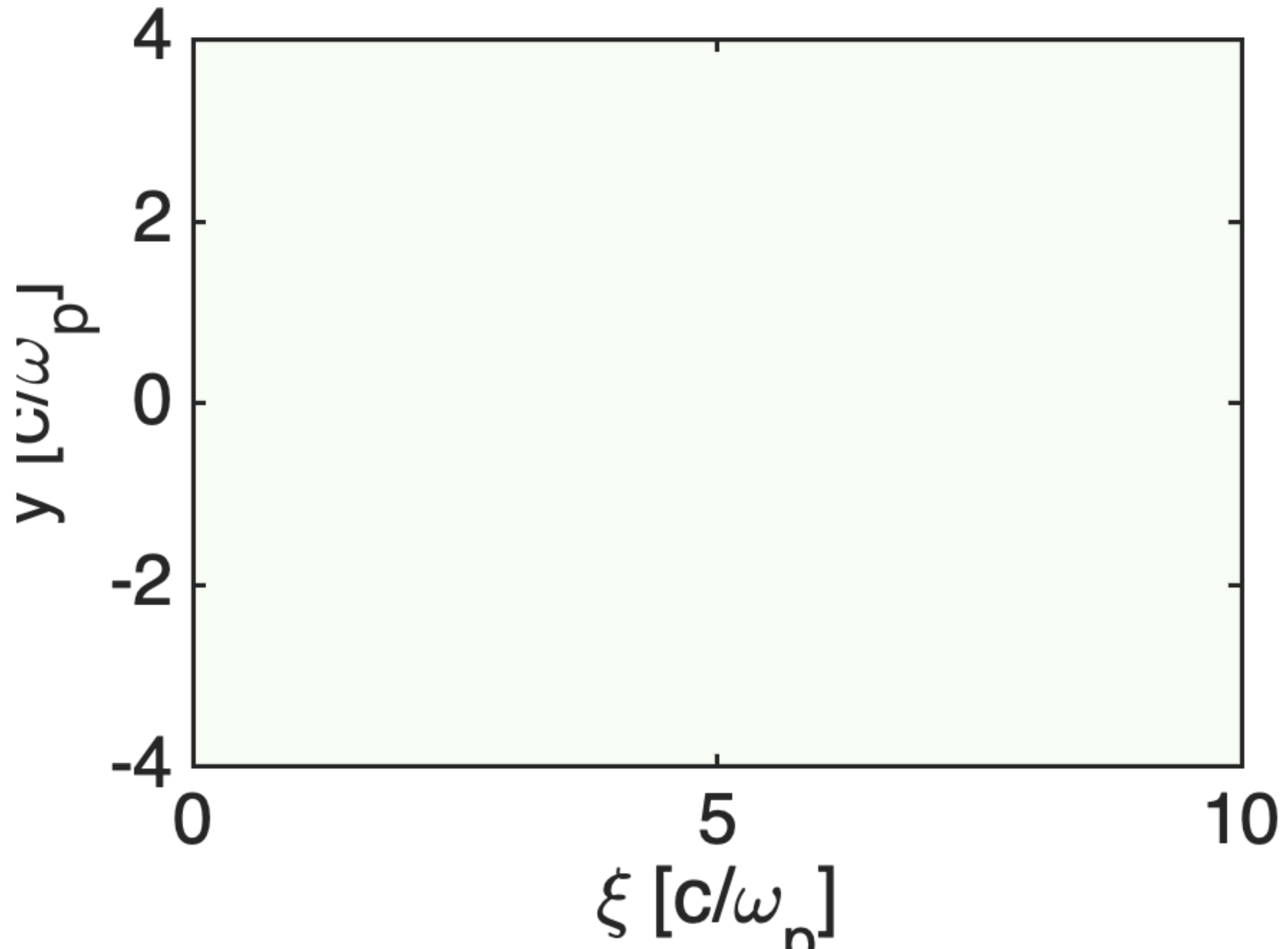
- 1.5 Torr static fill (**n_{e0}~5e16 cm^{-3}**)
- 5-mm dia. round nozzle
  - Backing pressure 10 psi
  - Mach number ~5
- Density downramp
  - Peak density @2 mm: **1.7e17 cm^{-3}**
  - **Ramp length: 1 mm**
  - **Density ratio n_{peak}/n_{e0} ~ 3.5**
- Density ratio is tunable by changing backing pressure

Step II: Downramp injection modeled using Osiris quasi-3D

UCLA

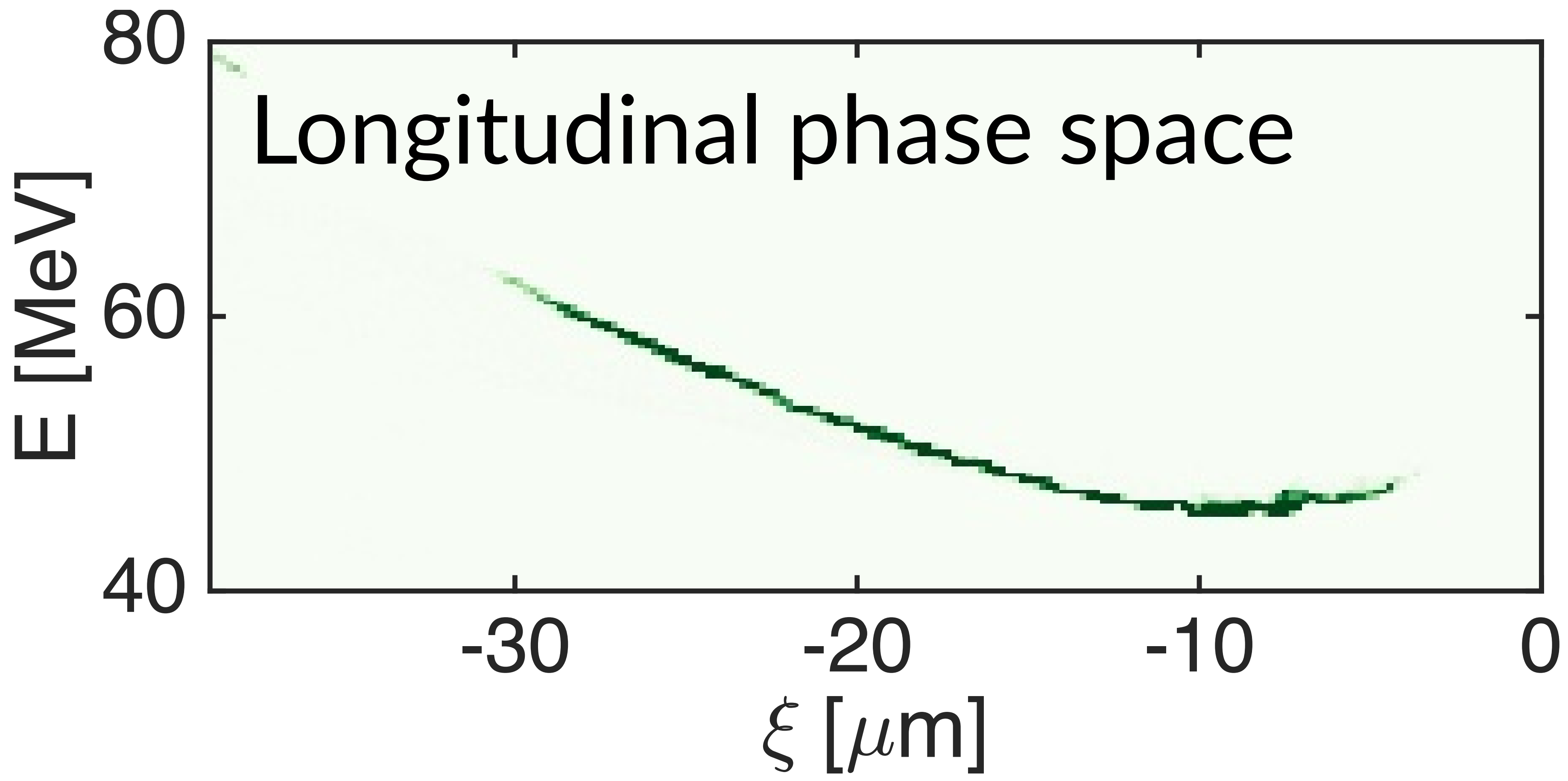
Injection process

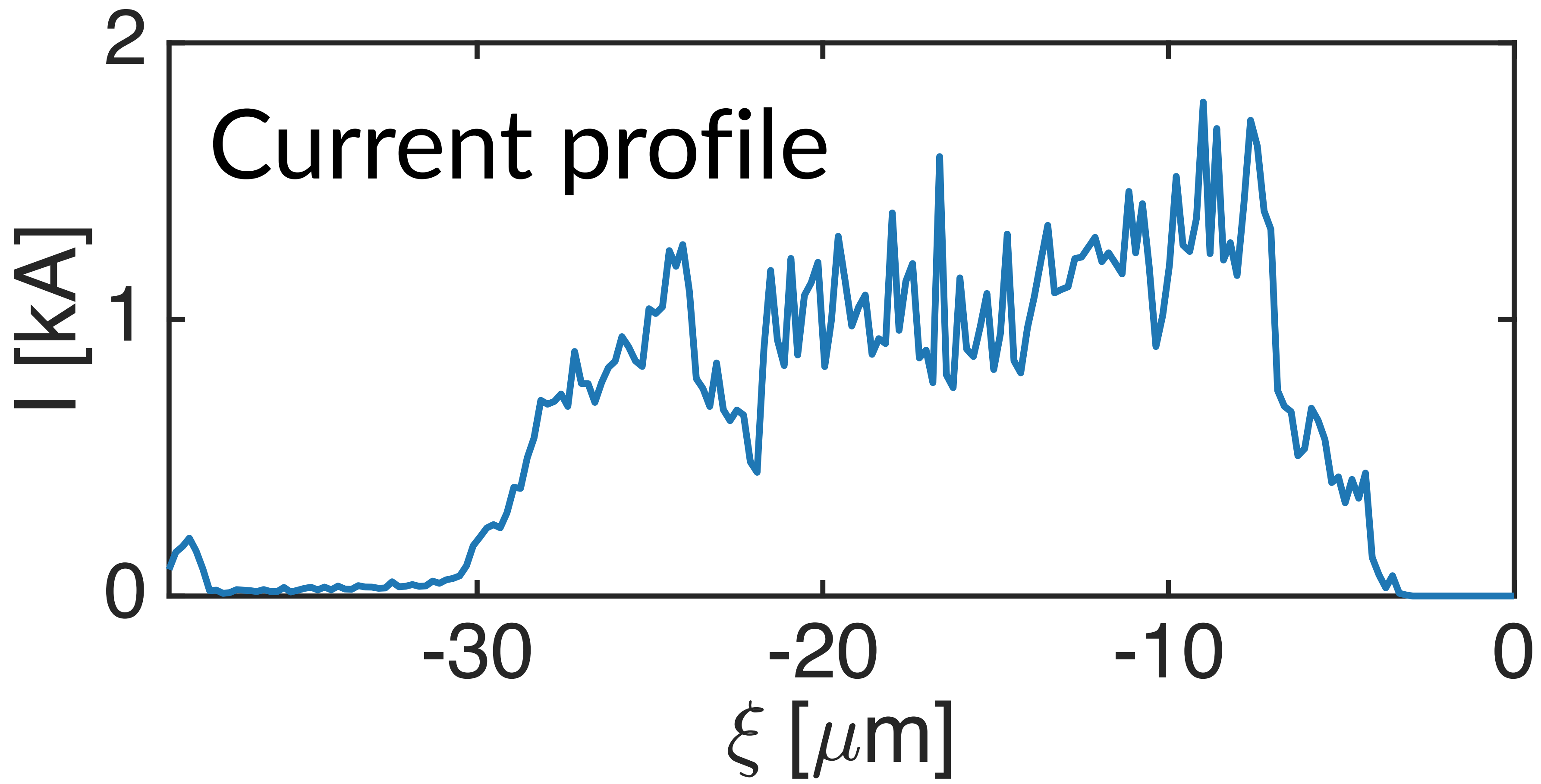




Bunch parameters@z=10 mm:

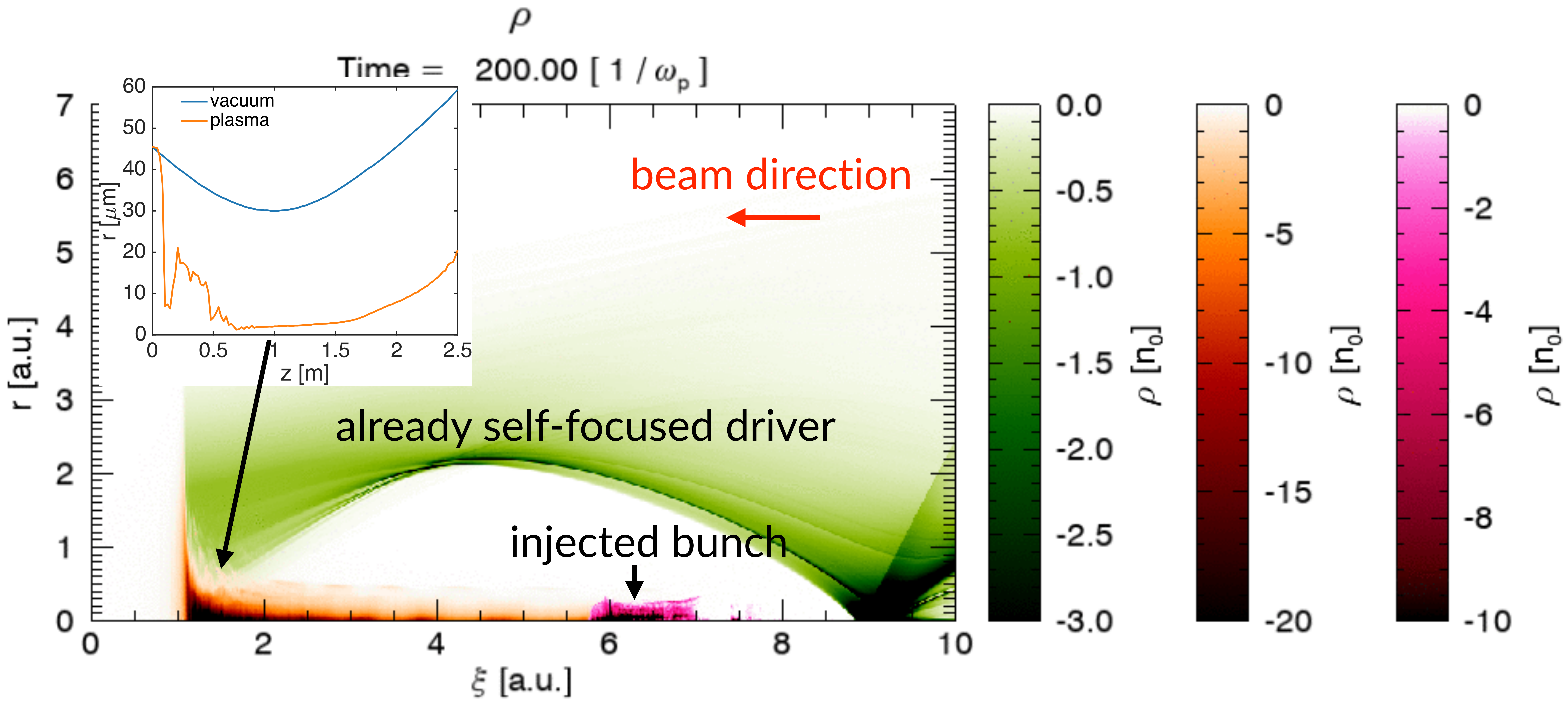
- slice and normalized emittance: ~0.5 μm
- peak current: ~1 kA, total charge 83 pC





Step III: Acceleration of the injected bunch modeled using QPAD

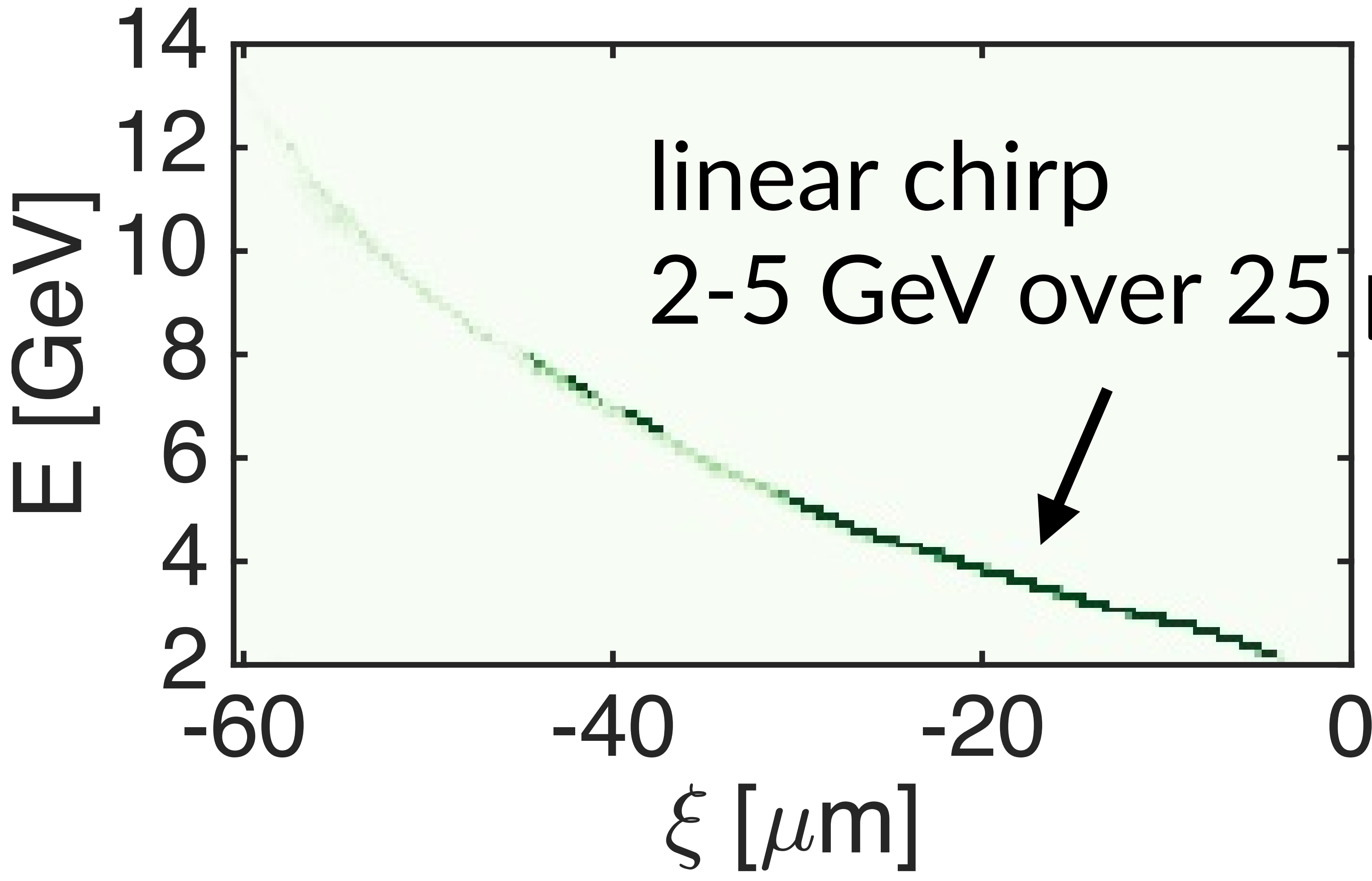
- Import the downramp injected bunch into the 2nd QPAD simulation
- Reload the self-focused driver



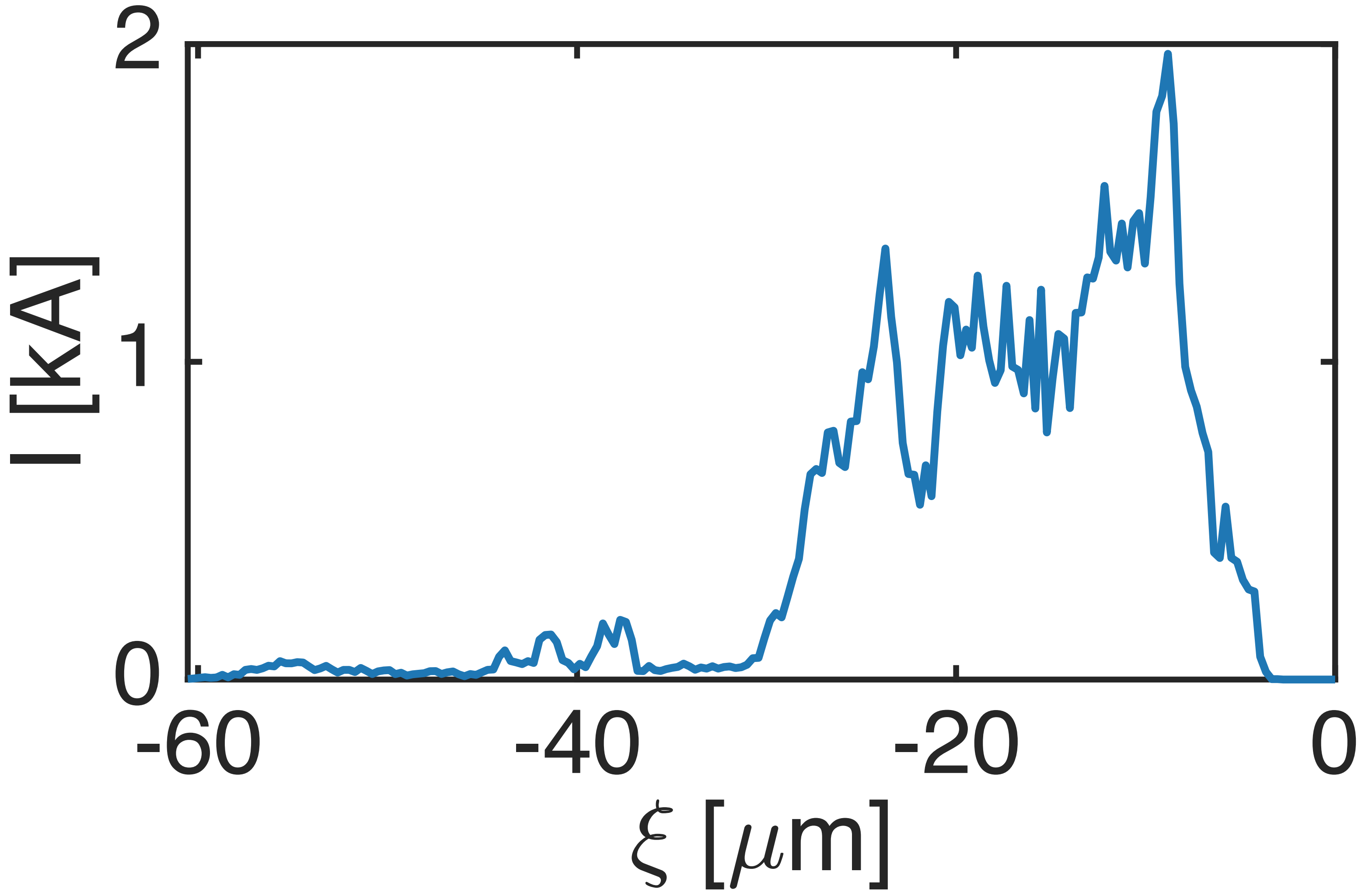
Final parameters of the electron bunch

UCLA

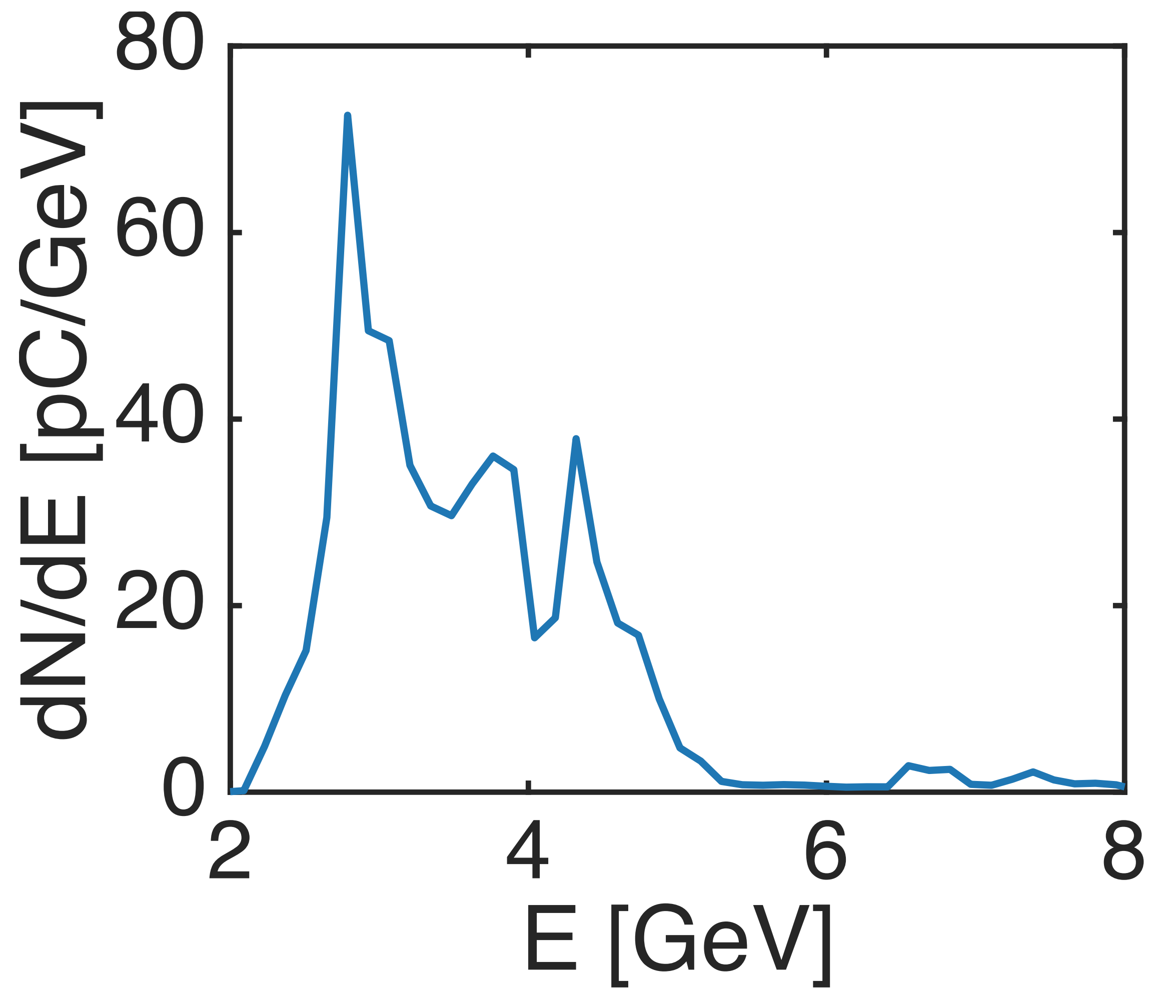
Longitudinal phase space and current profile of the injected bunch



linear chirp
2-5 GeV over 25 μm (1.7%/μm)

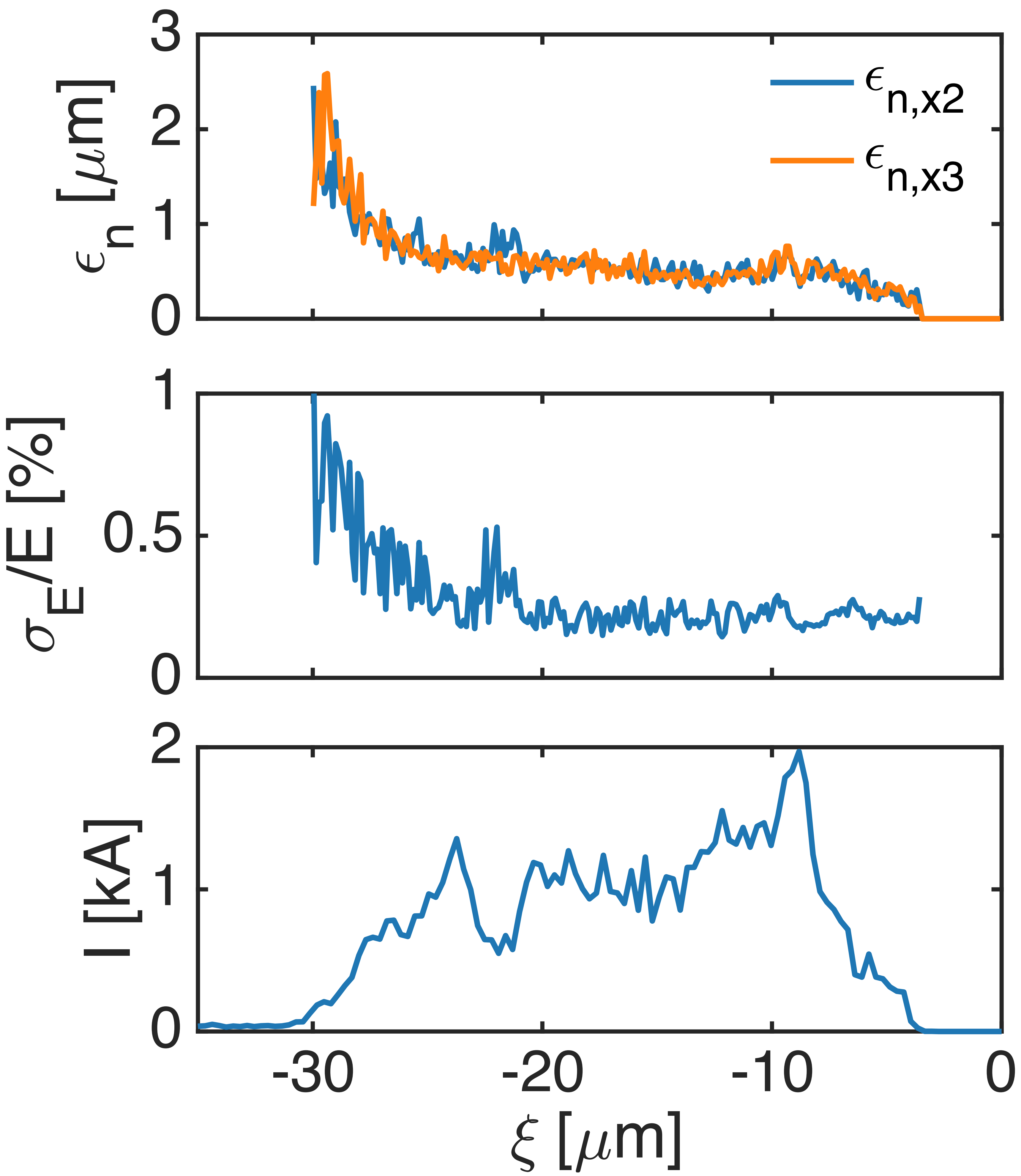


Energy spectrum



Slice beam parameters:

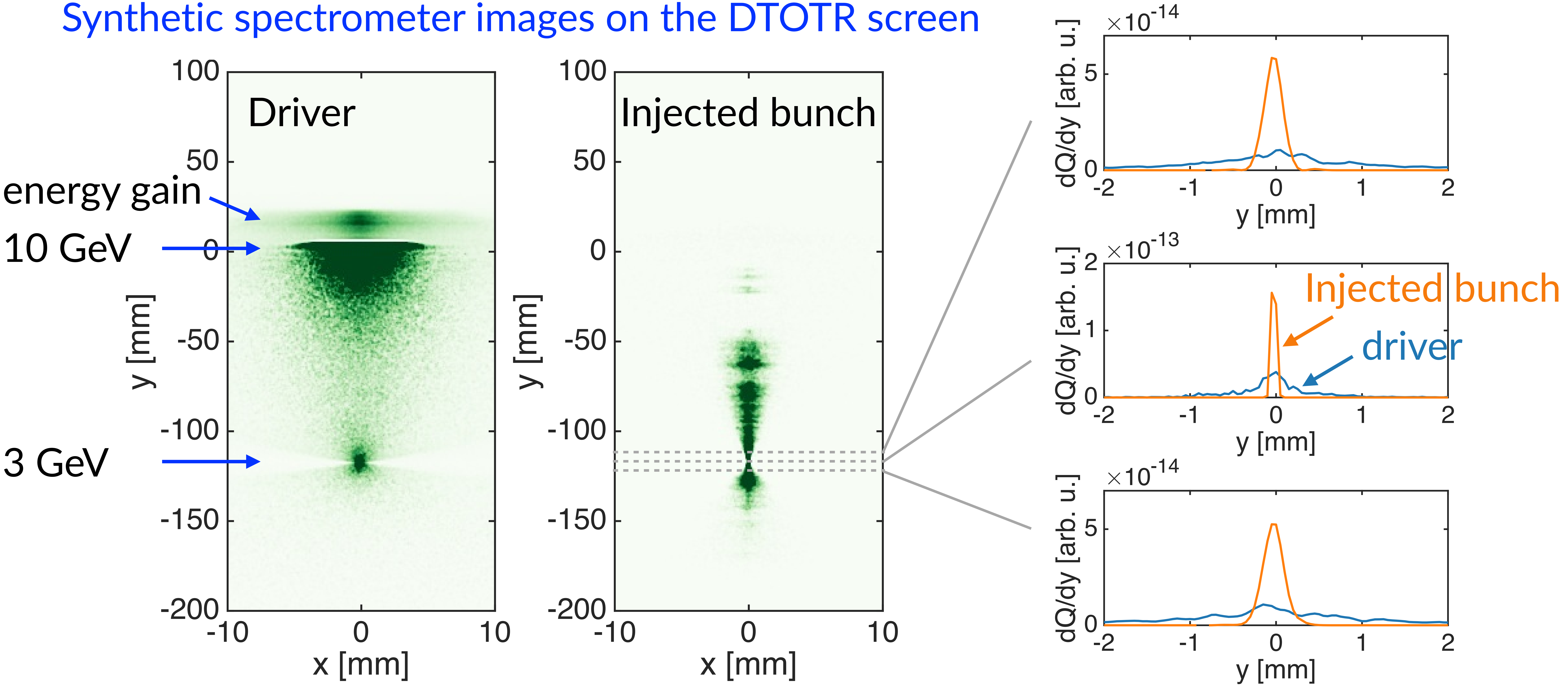
- ε_n: ~0.7 μm, σ_E/E: ~0.2%, I: ~1 kA



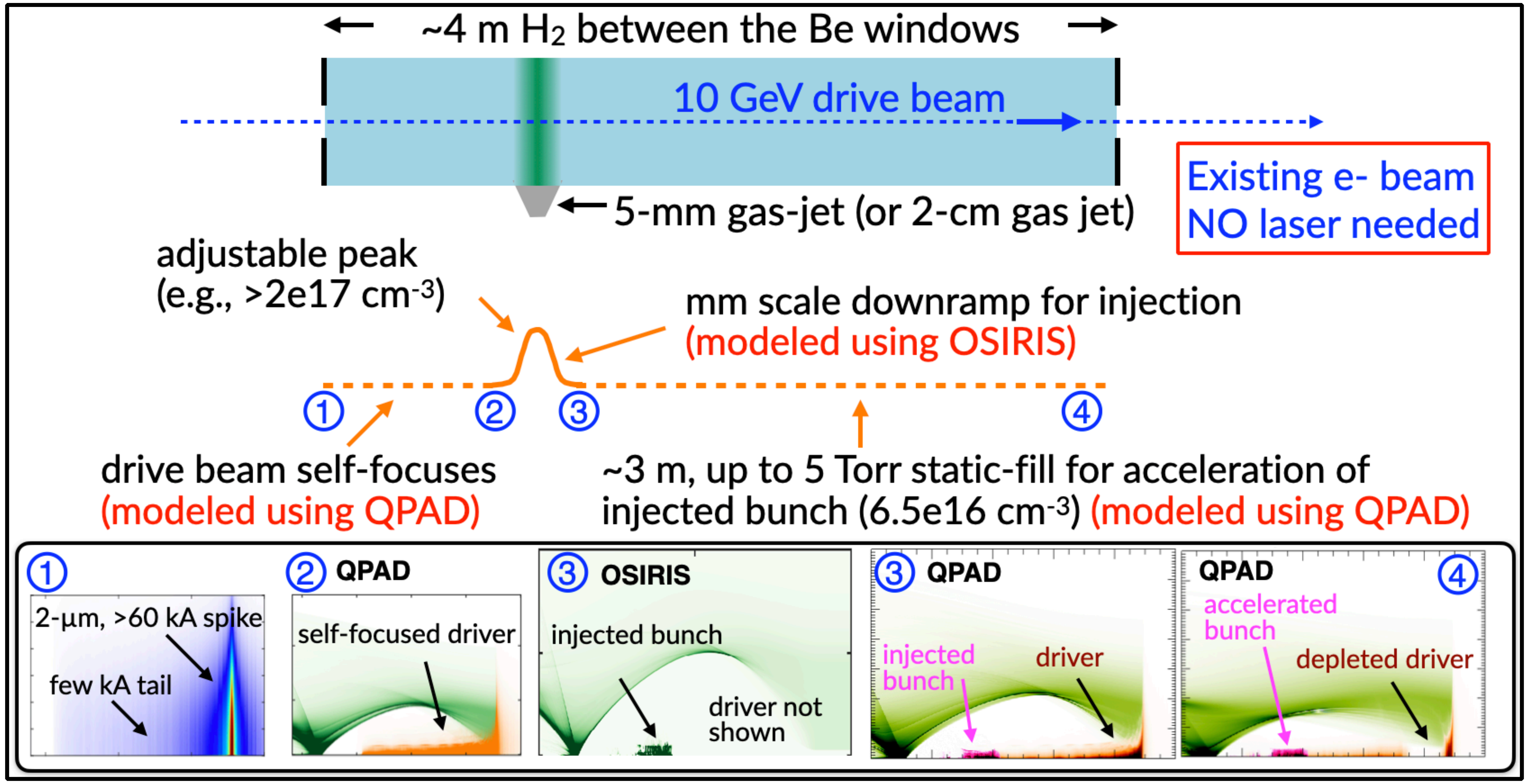
Distinguish the injected bunch from the decelerated driver electrons

The injected bunch has a much smaller emittance (0.7 µm vs 20 µm of the driver)

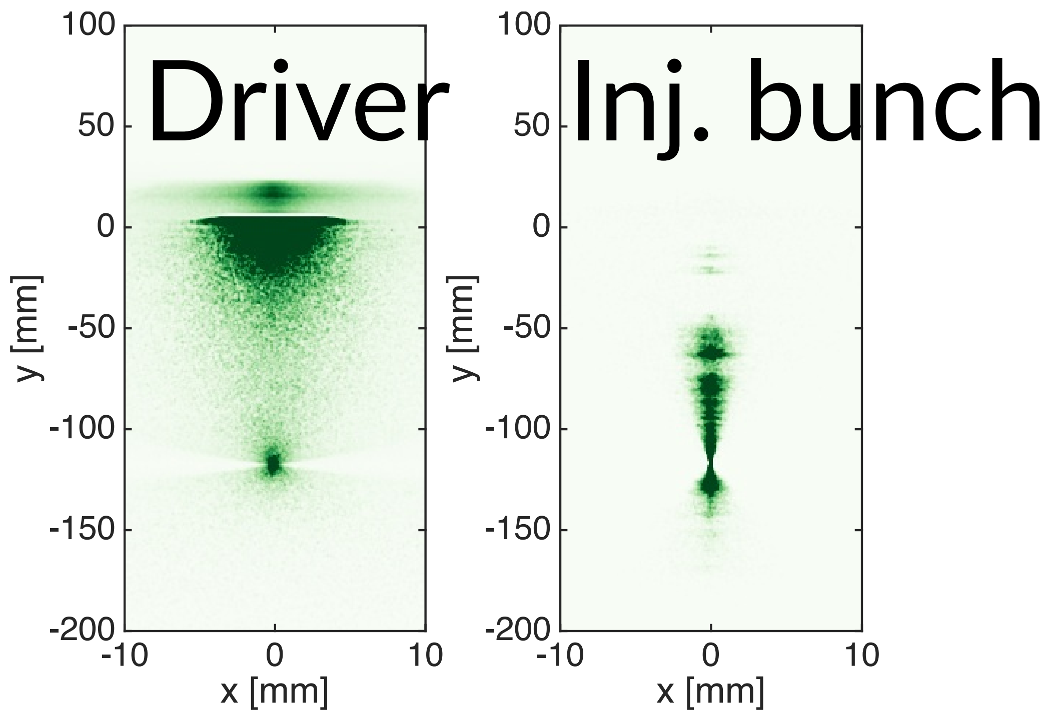
Synthetic spectrometer images on the DTOTR screen

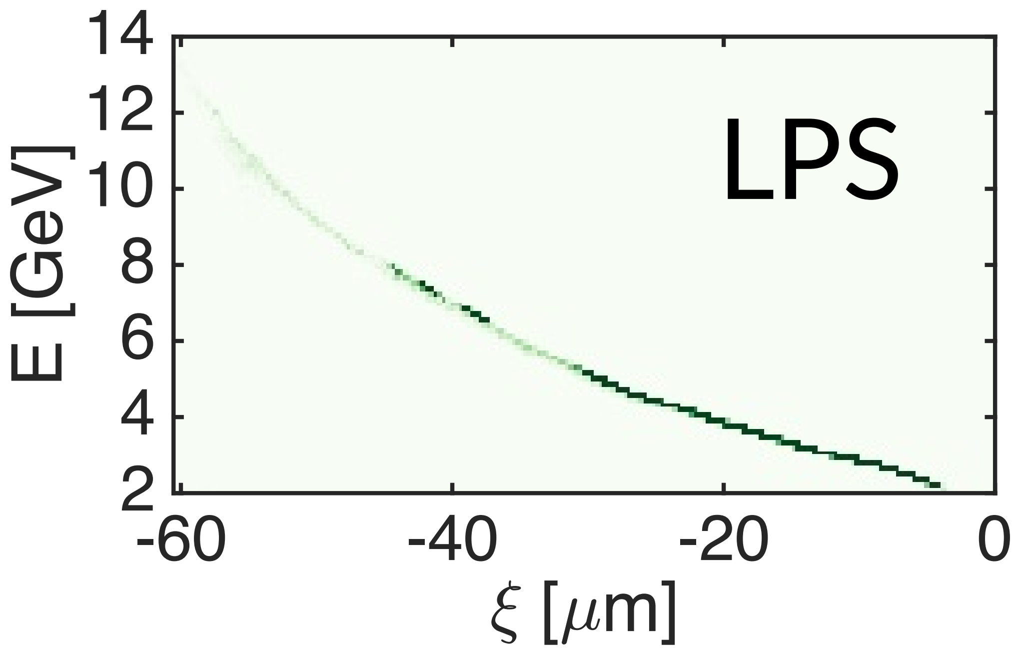


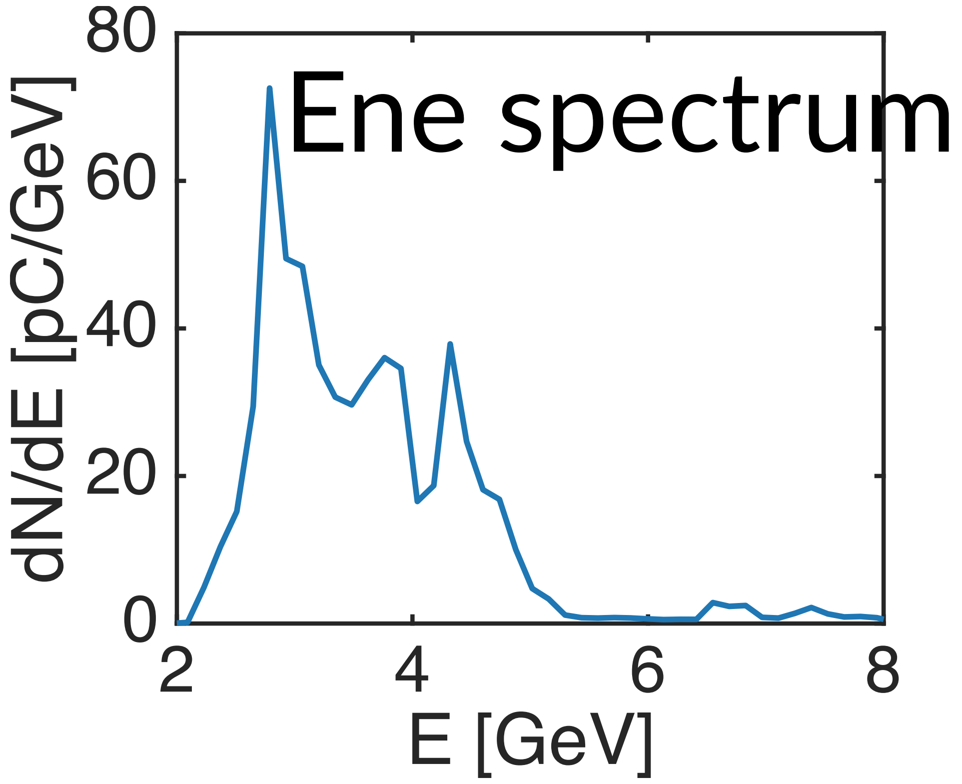
Summary: E304 Gas-jet in Static fill (GiS) configuration

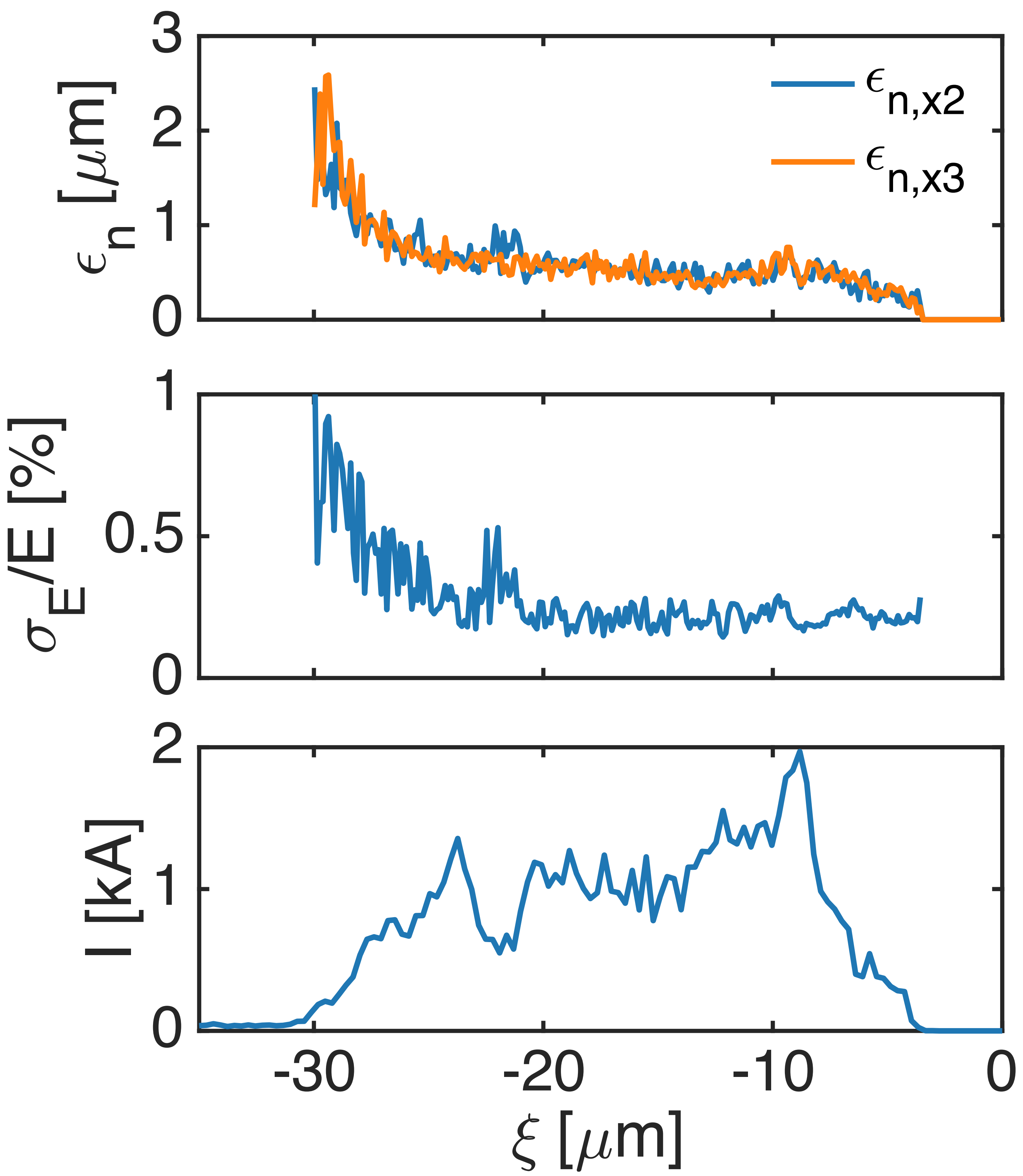


- **Setup**: Ready to go
- **Outcome**: multi-GeV high-brightness e- bunch
- ε_n: 0.7 µm, σ_E/E: 0.2%, I: ~1 kA









Collaborations

UCLA — C. Joshi, K. Marsh, W. B. Mori, Y. Wu, Z. Nie

SLAC — X. Xu, M. Hogan, FACET-II staff

loa — Sebastien Corde’s group

Mike Litos’ group

Thank you for your attention

Questions?