Beam Induced Ionization Injection of Shaped Electron Bunches

Navid Vafaei-Najafabadi
L. Diana Amorim

Plasma Acceleration Group

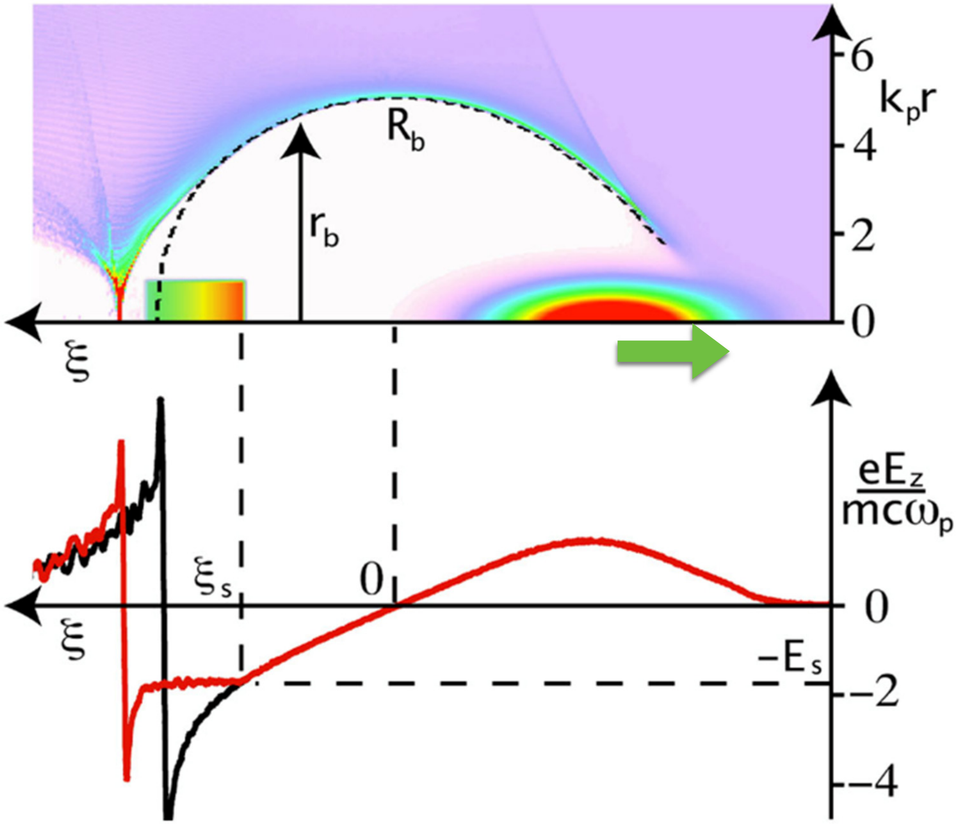
CASE
Center for Accelerator Science and Education

Stony Brook University

Synthesis

- Betatron oscillation of an unmatched beam in plasma can be leveraged to initiate ionization of impurity electrons, which are subsequently injected to form a trailing beam
- There is a direct relationship between the position of ionization and injection
- Tailoring the density of impurity on a millimeter sale can be used to shape the longitudinal profile of the injected beam on a micron scale

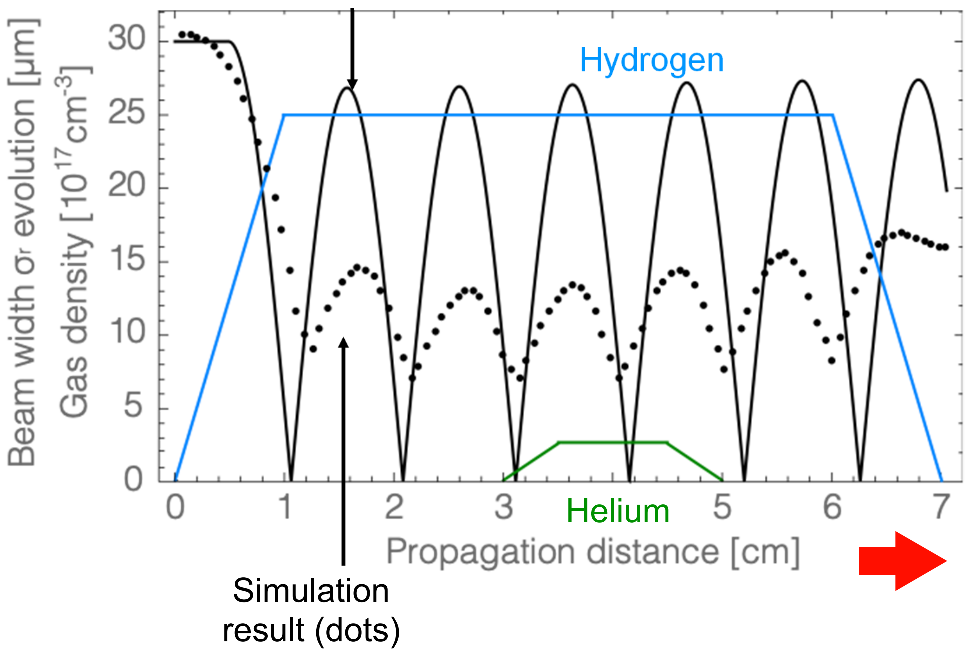
Shaped Beams Result in Ideal Beam Loading

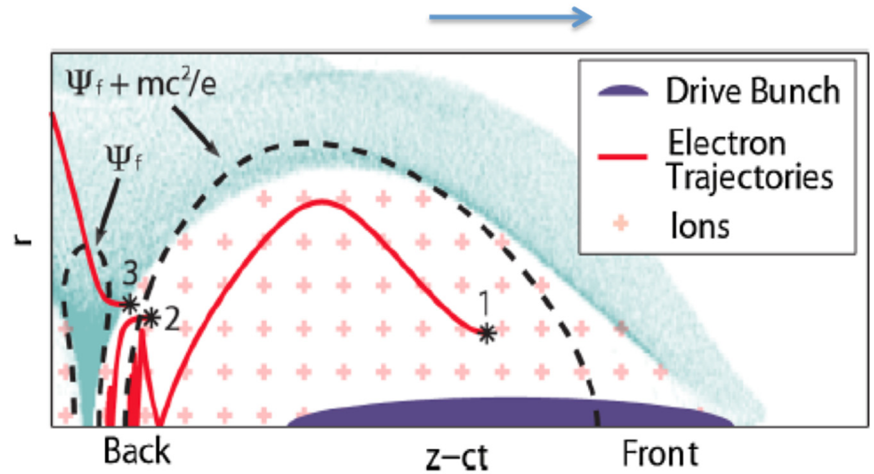


M. Tzoufras, Phys. Rev. Lett. 101, 145002 (2008)

Beam-Induced Ionization Injection

Calculated betatron oscillations





E. Oz, et al., PRL, 98, 084801 (2007)
N. Kirby, et al., PRSTAB,12, 051302(2009)

Beam emittance

$$\frac{d^2\sigma_r(z)}{dz^2} = \left(\frac{\epsilon_N^2}{\gamma^2\sigma_r^4(z)} - K^2\right)\sigma_r(z)$$

Beam energy

$$K = \omega_p/\sqrt{2\gamma}c$$

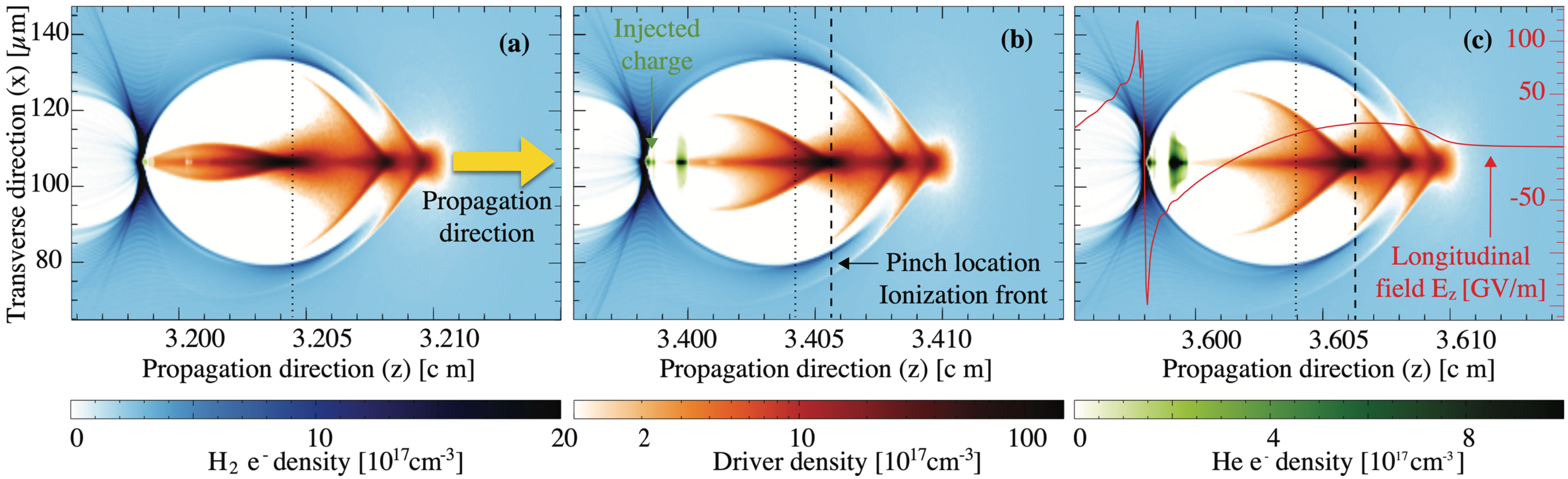
Trapping Condition: $\Delta\bar{\Psi} \leq -1$

$$\bar{\Psi} = \frac{e}{mc^2}(\phi - v_\phi A_z)$$

Pseudo potential

Phase velocity

“Pinch” Feature



Ionization front identified by the moving dashed line

	σ_z	σ_r	Emittance	Energy	Charge
e- beam	30μm	30μm	120mm.mrad	20.35GeV	3.2nC

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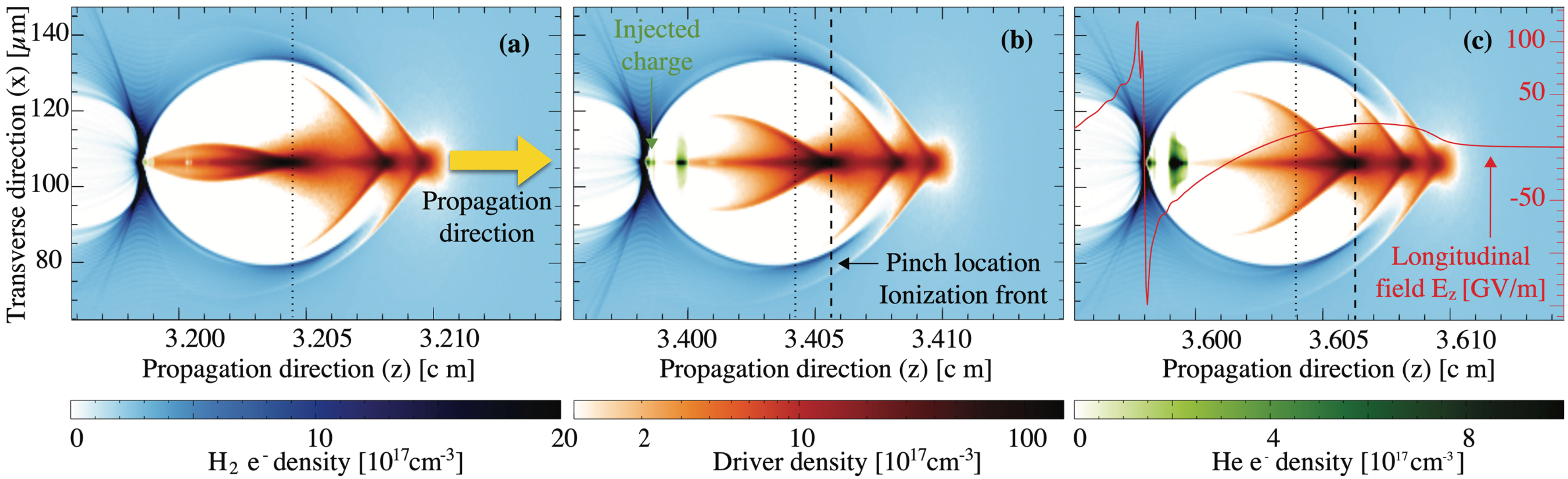
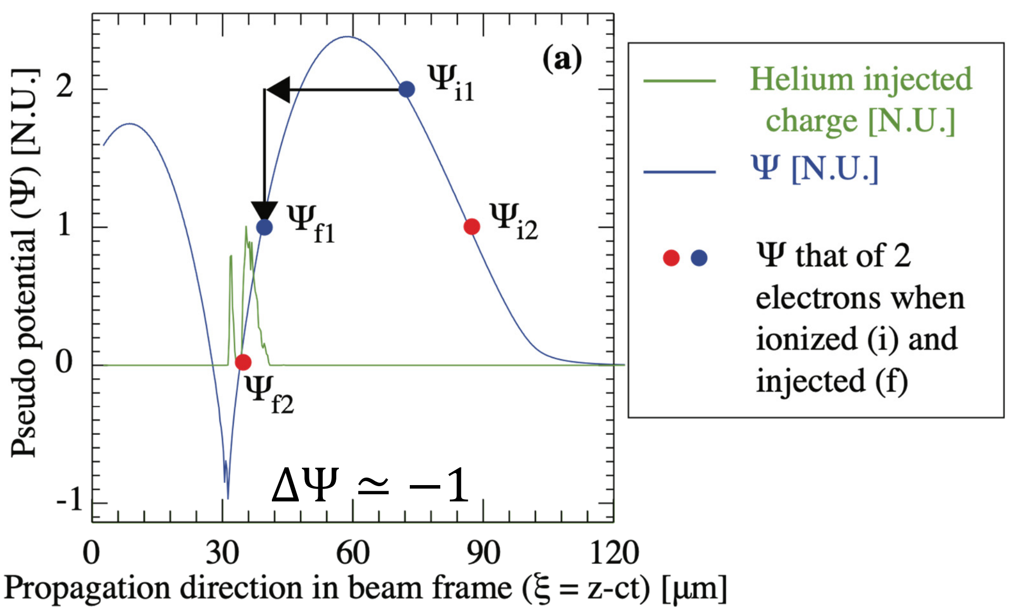
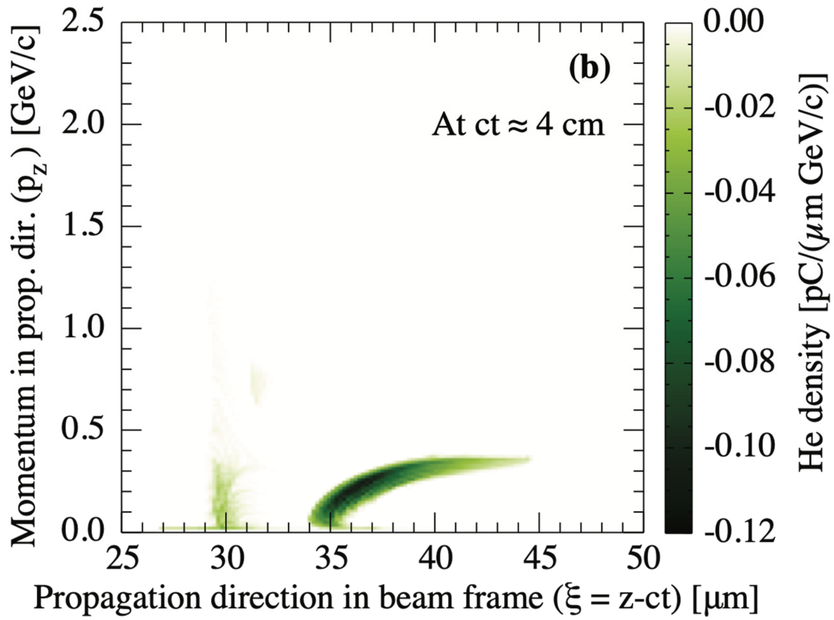
One-to-One Mapping Between Ionization and Injection Allows Bunch Shaping

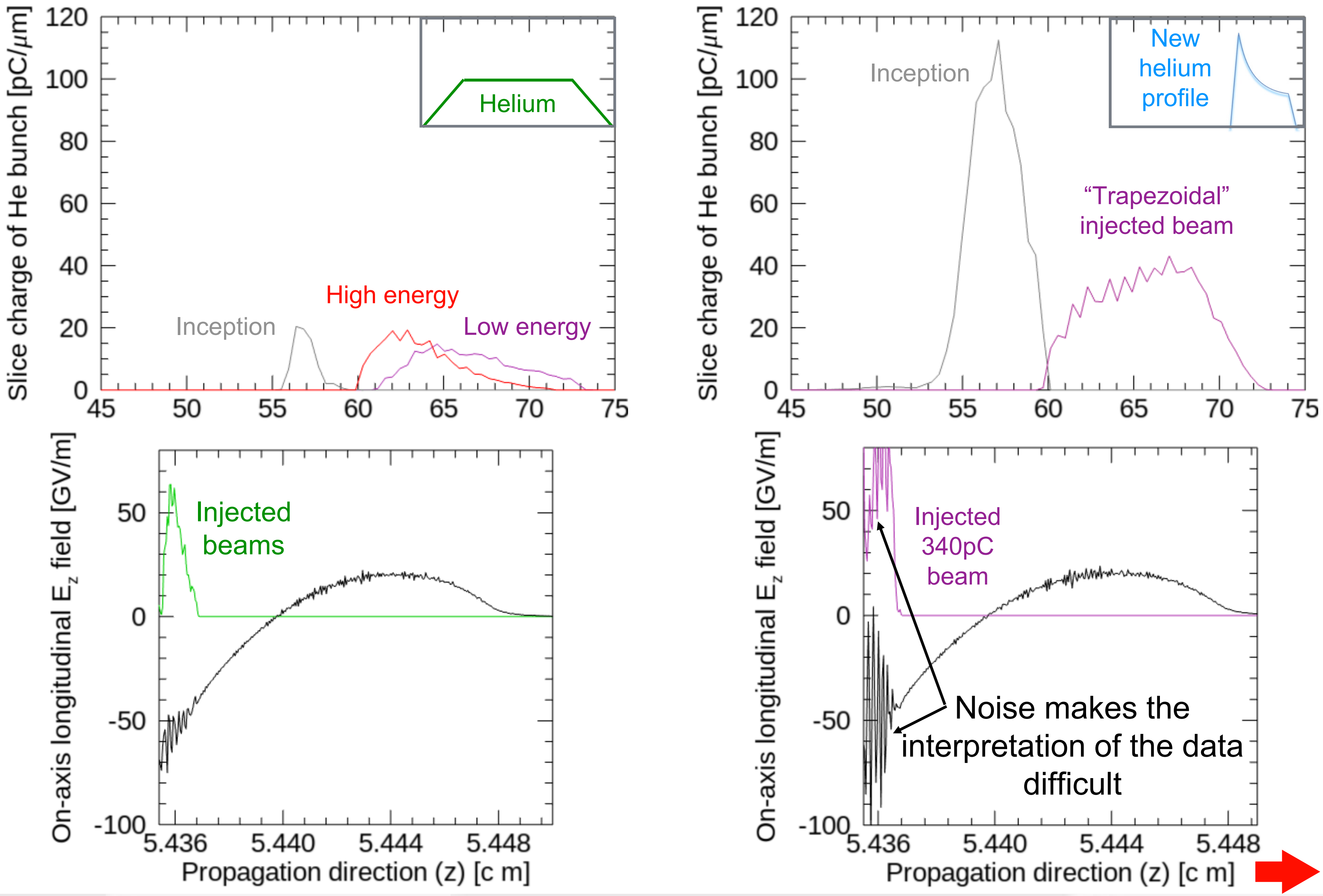




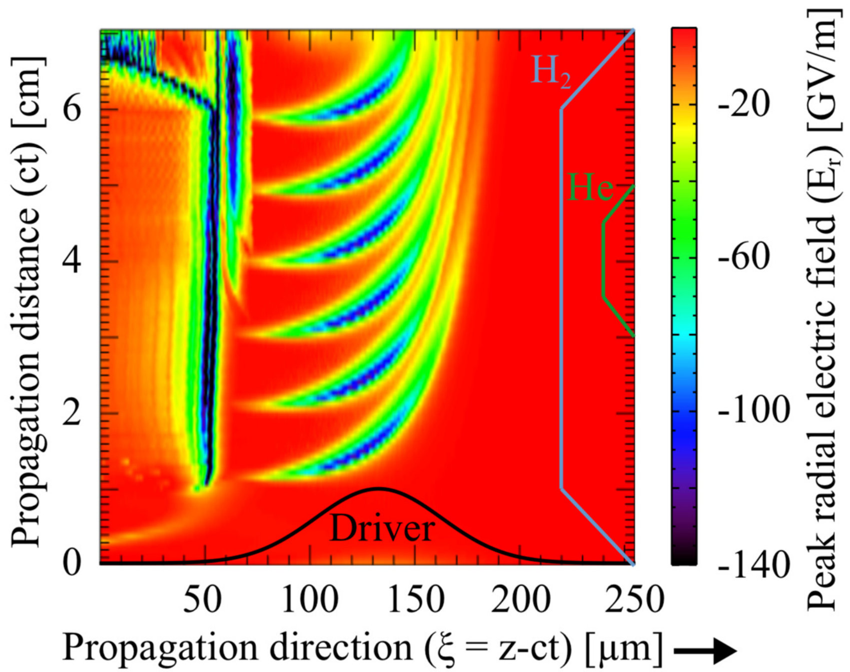


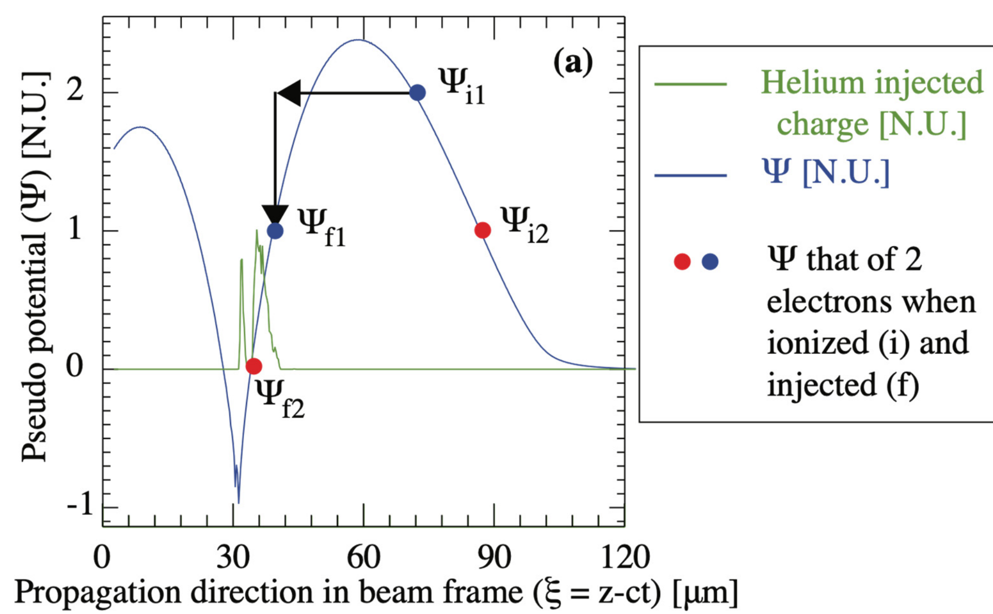
By controlling the concentration of impurity at each pinching location we can control the final beam density profile

Beam Profiles Injected with Different Density Profiles



Relating The Position of Pinch and Injection





$$\xi_p(ct)[\mu\text{m}] = -1527.9 + 682.9ct[cm] - 69.7ct[cm]^2$$

$$\xi_f(\xi_p)[\mu\text{m}] \approx \xi_{f0} - (\xi_p - \xi_{p0})\frac{\Delta\xi_f}{\Delta\xi_p} = 71.2 - 0.3(\xi_p[\mu\text{m}] - 100)$$

Particle tracking was used to connect the position of pinch and the final position of electrons

Future Work

Control the pinch trajectory, e.g. optimizing energy spread

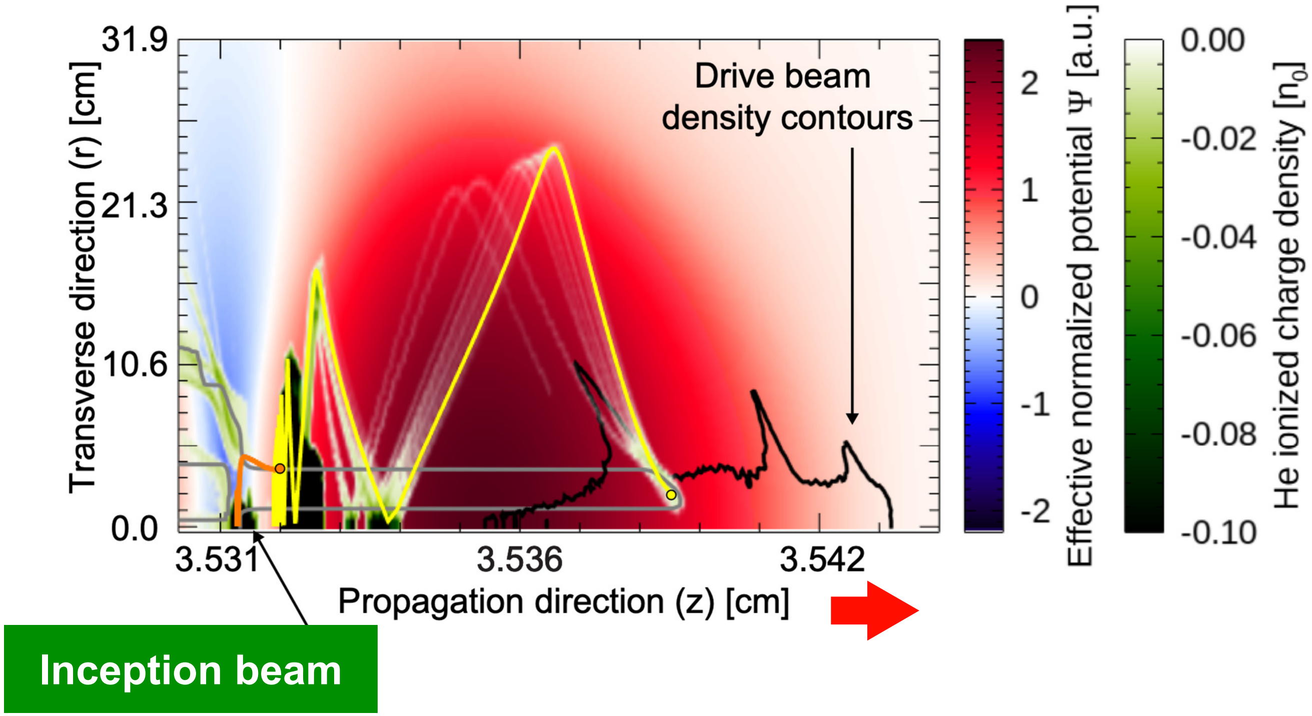
Better Understand the relation between the injected and ionized electrons

Work out the noise issue/ cross check with other codes

Understand the issues impacting the injected beam quality

Optimize this process for FACET II drive beam

Inception beam results from the BIII by the beams produced via BIII of the drive beam



Pinched drive beam ionizes and injects helium electrons (yellow) into trailing beams

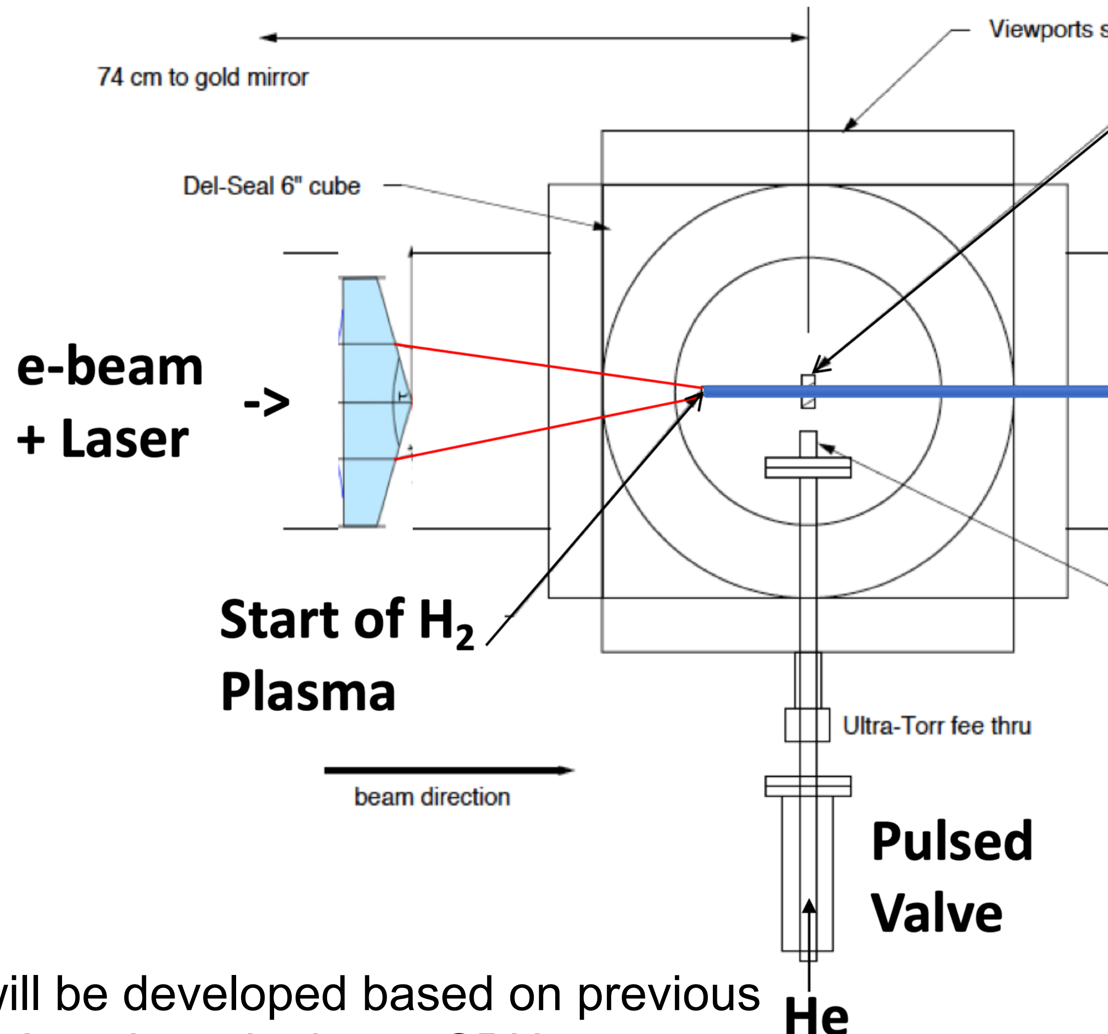
Trailing beams can further ionize helium (away from the propagation axis) and inject the inception beam (orange)

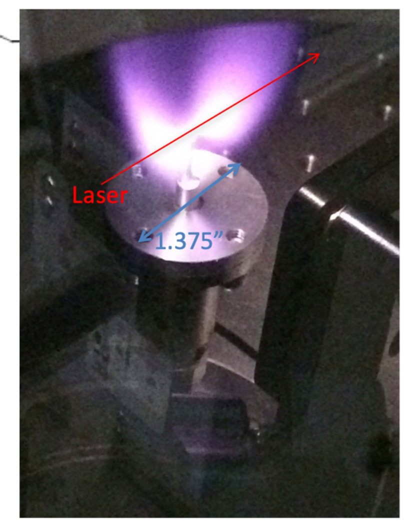
He 100% ionization contour
"Inception" e- trajectory
High energy e- trajectory

FACET II Experiments

Parameter	Symbol	Unit	Nominal	Range
Final electron energy	E_f	GeV	10.0	4.0 – 13.7
Initial electron bunch charge	Q_0	nC	2	2 – 5
Final electron bunch charge	Q_f	nC	0.7	0.7 - 5
Pulse repetition rate	f_{rep}	Hz	30	1 - 30
Number of electron bunches per RF pulse	N_b	-	1	1 - 2
Electron transverse core beam size (x/y, rms)	σ_x/σ_y	μm	6/6	6-20/6-10
Final electron peak current	I_{pk}	kA	76	10-100
Final electron bunch length (rms)	σ_z	μm	1	1 - 20

Leveraging FACET II's Meter-Long Hydrogen Plasma Roadmap





Helium jet will be developed based on previous work at UCLA and continuing at SBU

FACET Collaboration

N. Vafaei-Najafabadi

C.E. Clayton, K.A. Marsh, W. An, W. Lu, F. Tsung, W.B. Mori, C.Joshi

S. Corde, A. Doche

E. Adli

J. Allen, C.I. Clarke, J.P. Delahaye, R.J. England, S. Gessner, S.Z. Green, N. Lipkowitz, G. White, J. Yocky , M.J. Hogan, V. Yakimenko

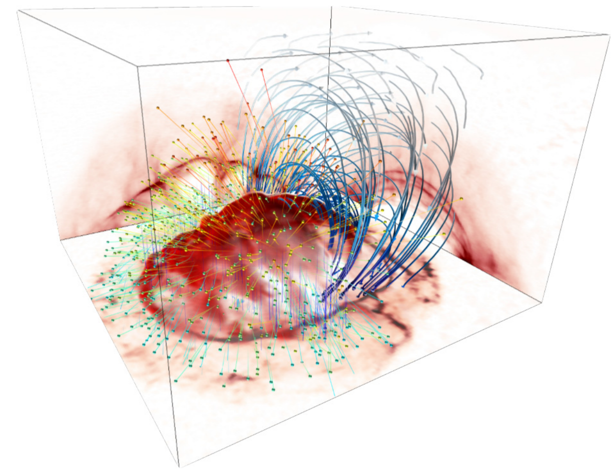
M. Litos

OSIRIS simulations were done in **CORI**@NERSC and **SEAWULF**@SBU

Osiris 4.0

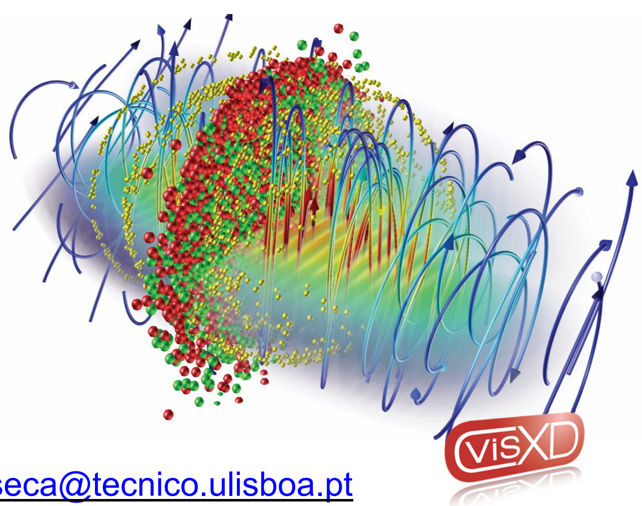
osiris framework

- Massivelly Parallel, Fully Relativistic Particle-in-Cell (PIC) Code
- Visualization and Data Analysis Infrastructure
- Developed by the osiris.consortium
  ⇒ UCLA + IST



TÉCNICO LISBOA

UCLA



Ricardo Fonseca: ricardo.fonseca@tecnico.ulisboa.pt
Frank Tsung: tsung@physics.ucla.edu

http://epp.tecnico.ulisboa.pt/
http://plasmasim.physics.ucla.edu/

code features

- Scalability to ~ 1.6 M cores
- SIMD hardware optimized
- Parallel I/O
- Dynamic Load Balancing
- QED module
- Particle merging
- GPGPU support
- Xeon Phi support

The End