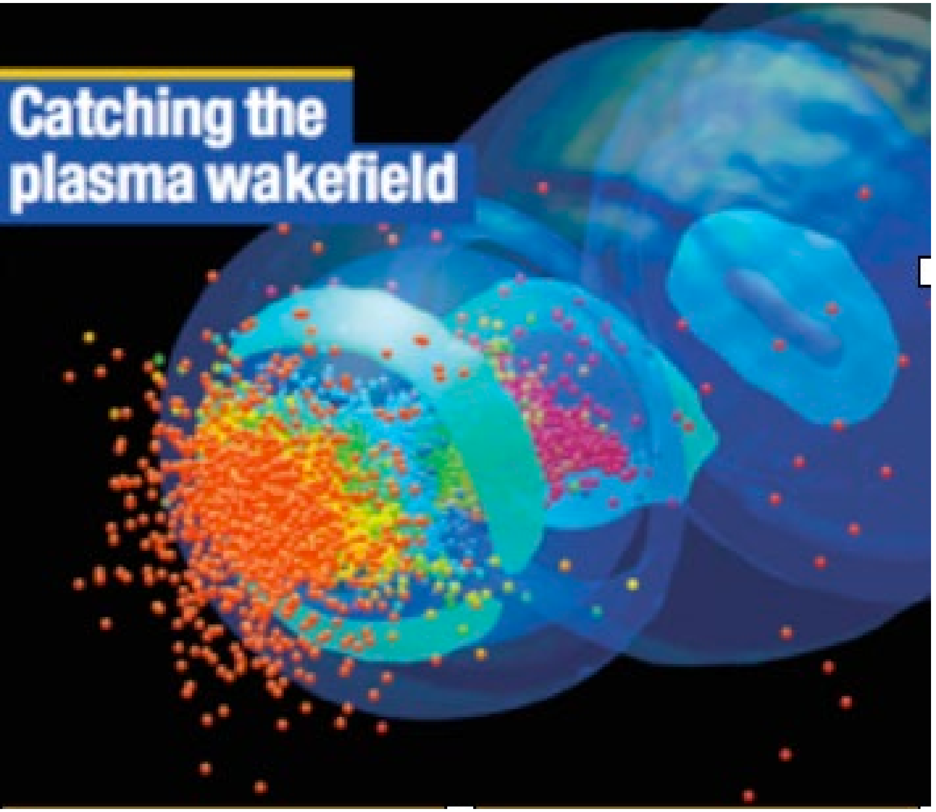

E300: Plasma Wakefield Acceleration First Results

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UCLA

Facet II Users meeting OCT 17-19th

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Plasma Wakefield Acceleration Collaboration

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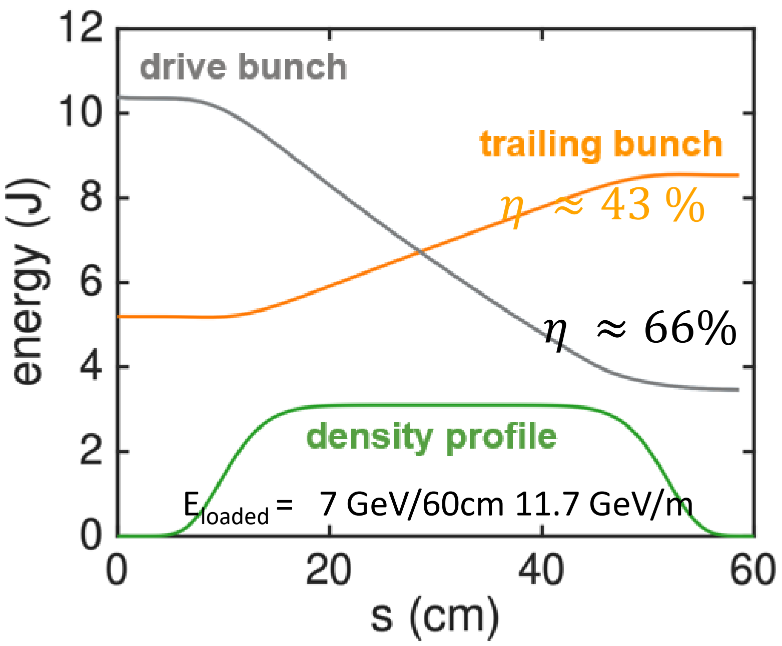
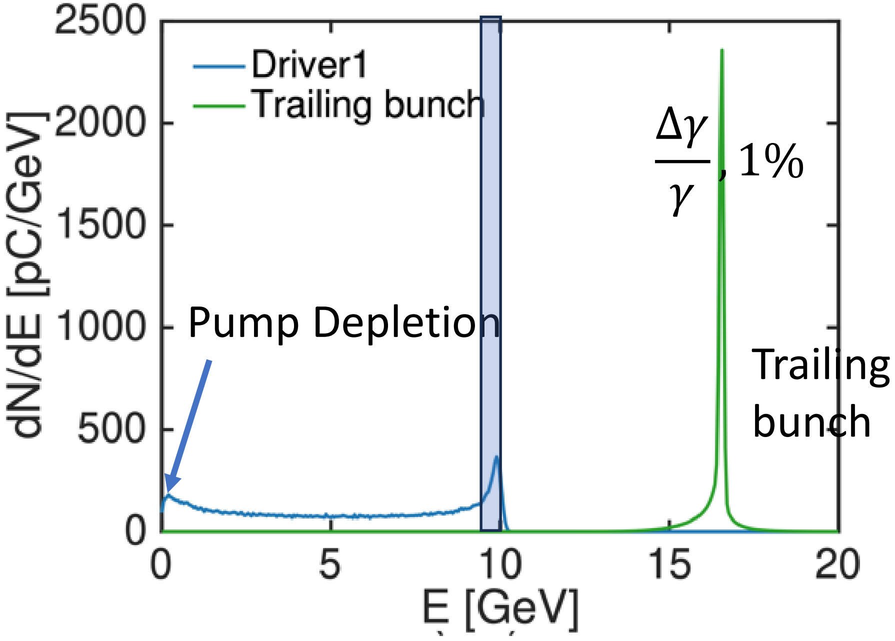
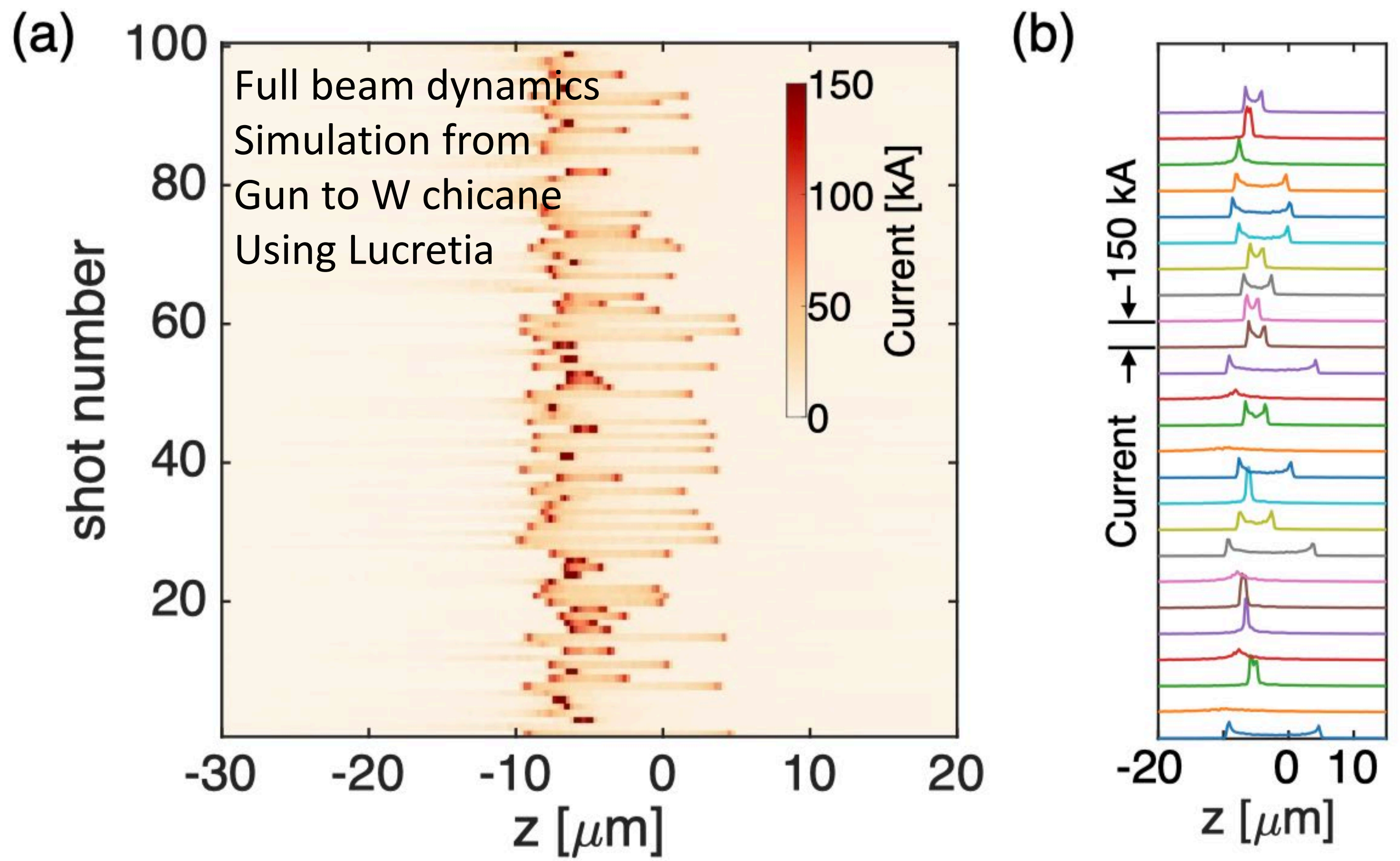
E300, Pump depleted, high-gradient, high-efficiency, low-energy spread PWFA of trailing bunch with emittance preservation





By matching the trailing bunch to plasma profile we will show emittance preservation ofa 30-40 micron beam

Typical Single Bunch current and Longitudinal Phase Profiles
High peak current beams with time dependent structure
Large variation Generated by 0.5 % amplitude and 0.25% RF phase jitter:



What new physics can we do with a ultra-high current single bunch that we could not before?

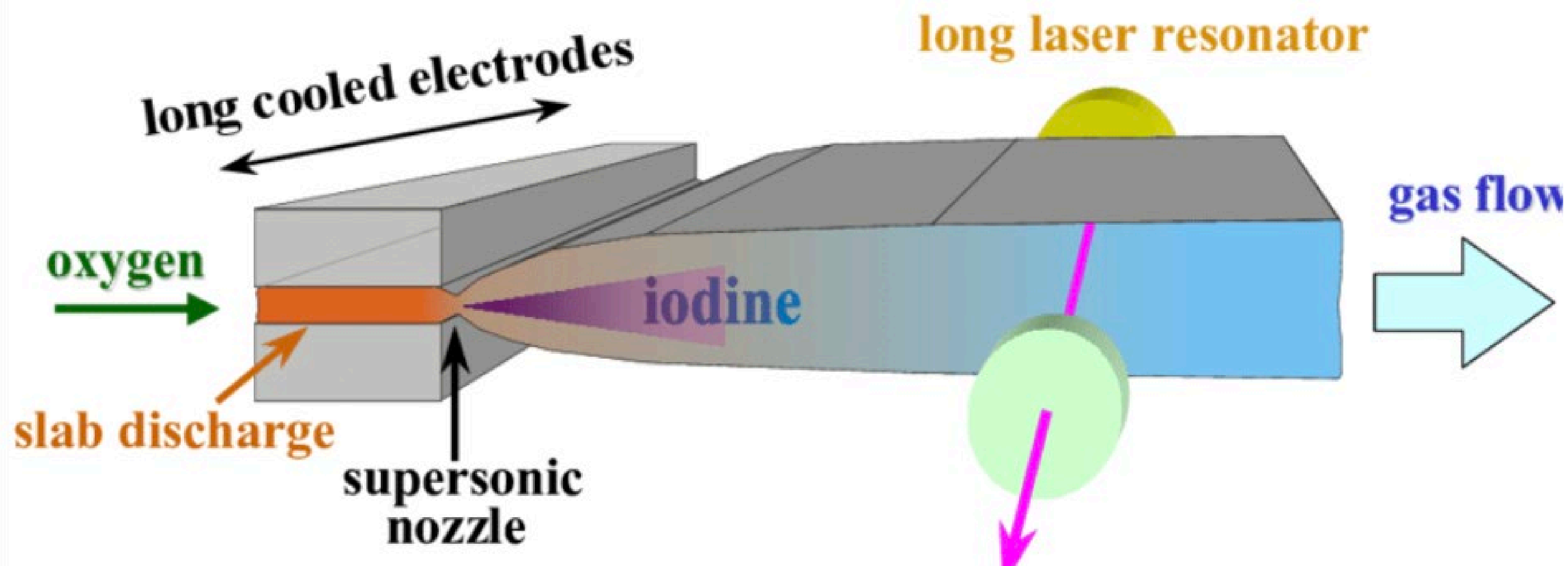
Another goal added: Meter-scale beam-ionized **hydrogen** plasma

Litos Group is looking at laser ionized meter-scale dense H_2^+ columns

Motivation: For collider application very high (10 KHz) rep. rates needed for achieving needed luminosity

Li plasmas are robust but have no diagnostic access and limited by 1 Hz (CW) and 10 Hz burst mode.
In the past we have explore self-ionized Ar plasma (Nat. Comm) . but multiple ionization can inject dark current in the wakes.
3 mm^3 H_2 volume easily be replaced by flowing the gas at Mach 5 in < 1 ms.
Drive beam in beam-ionized plasmas are self aligning to wake , reduces alignmemt issue to aligning the trailing bunch to wake

Possible to replenish the mm region of gas within < 1 ms in a burst mode using chemical laser technology



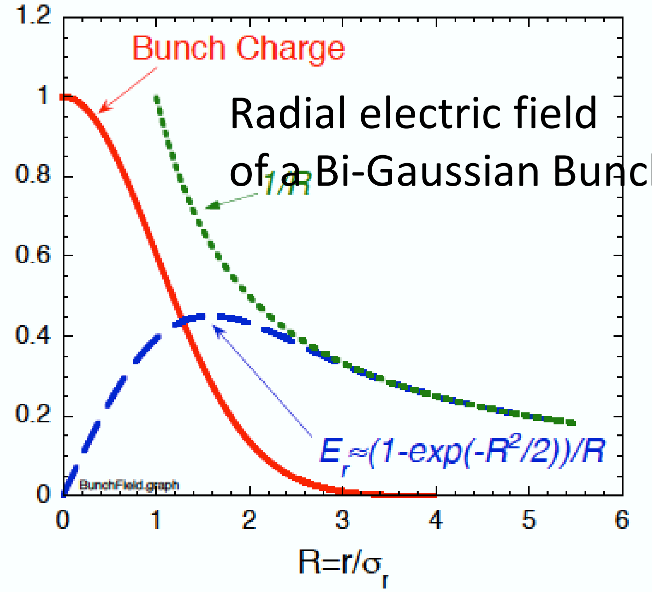
Long laminar flow gas columns in Iodine laser

Why is it difficult to produce beam ionized hydrogen?

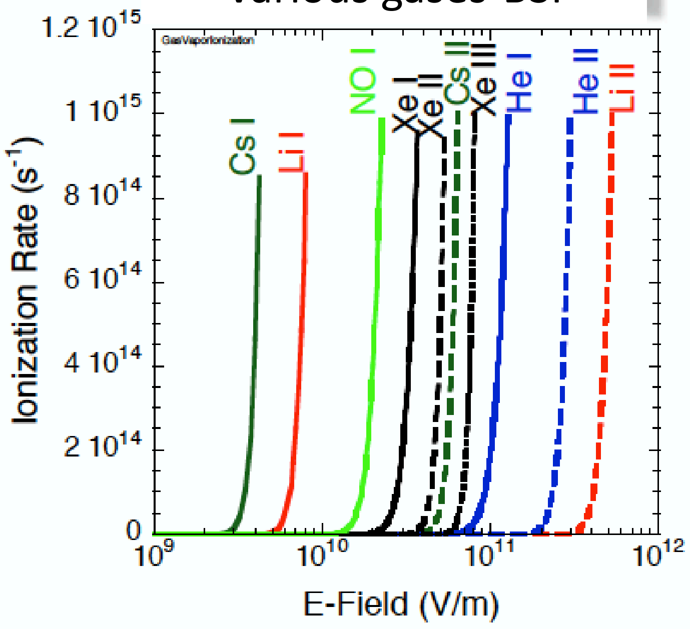
Example: Ionization by electron bunch

$$E_{r,\text{peak}}(r \approx 1.6\sigma_r) \approx 5.2 \times 10^{-10} \frac{N}{\sigma_r \sigma_z}$$

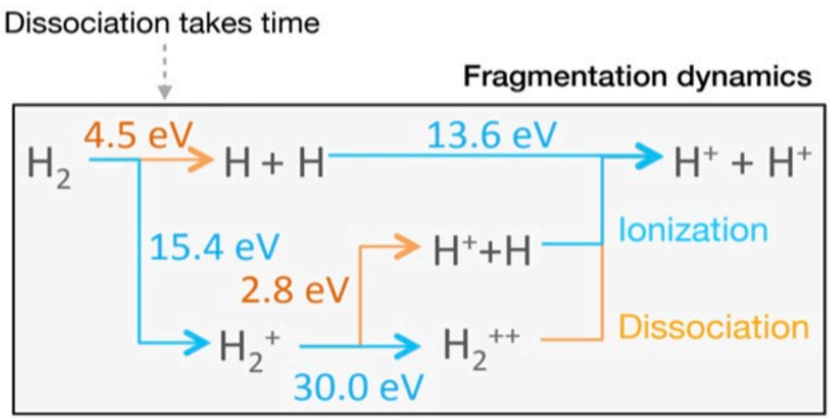
Radial electric field of a Bi-Gaussian Bunch



Ionization threshold of Various gases-BSI



Ionization pathways of H_2 molecule



Not possible to dissociate H_2 by a few fs long Laser spike

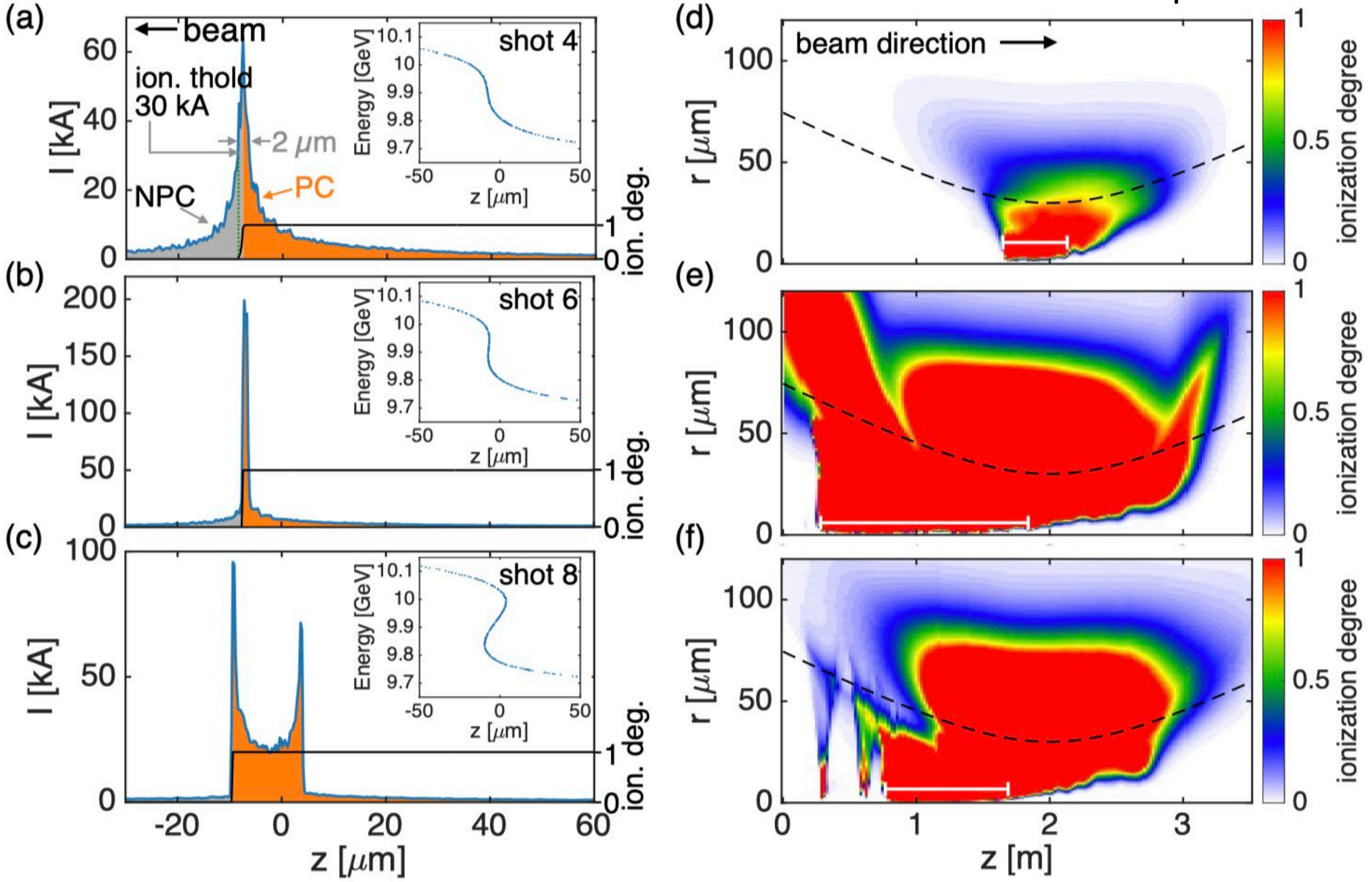
The ionization pathway follows $H_2 \rightarrow H_2^+$ (E_r >60GeV/m) GeV/m

$H_2^+ \rightarrow H_2^{++}$ (Er> 200 GeV/m)

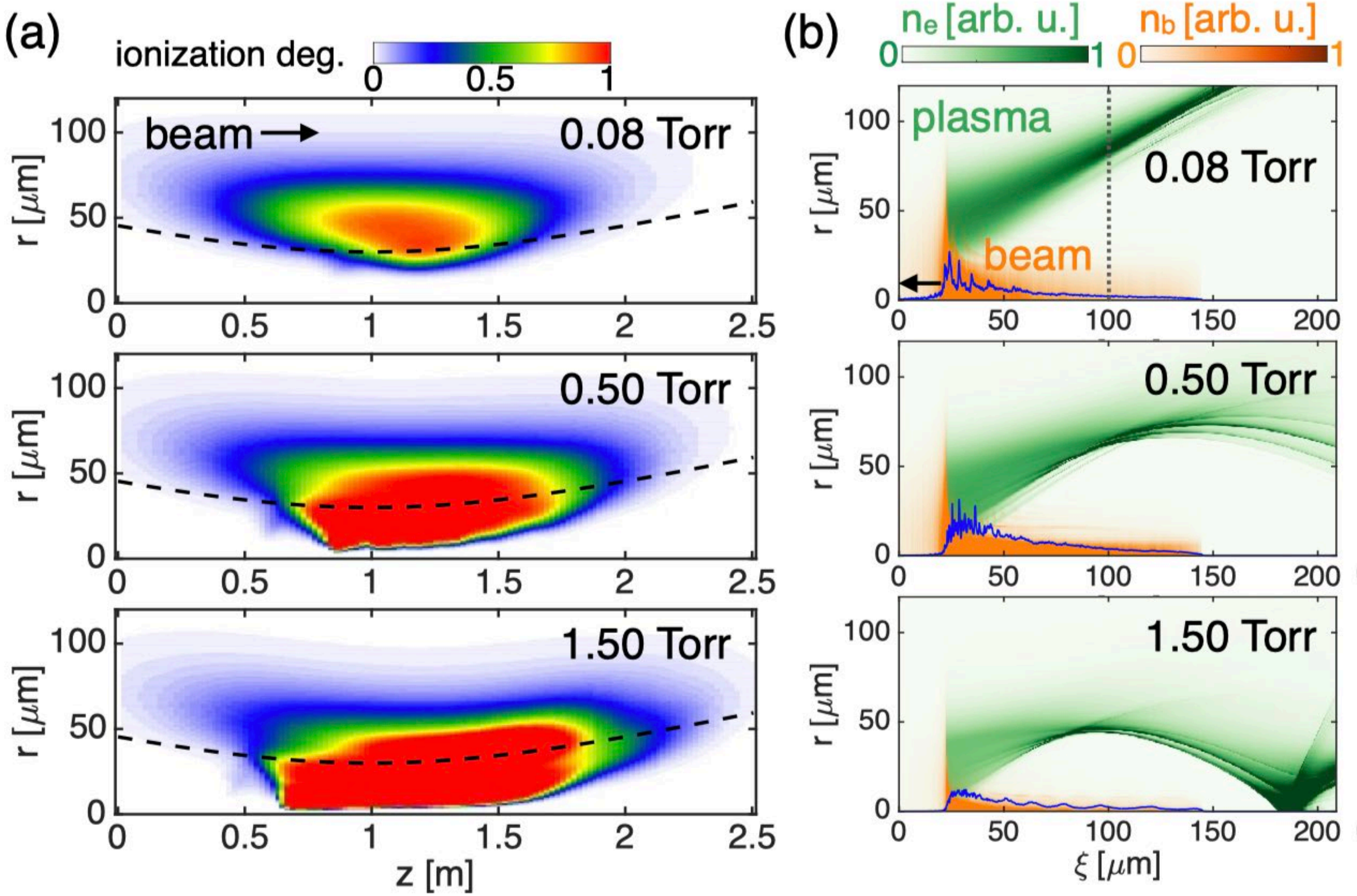
- $E_r^{\max} = 10.4 \left[\frac{\text{GV}}{\text{m}}\right] \frac{N}{10^{10}} \frac{10}{\sigma_r[\mu\text{m}]} \frac{50}{\sigma_z[\mu\text{m}]}$, $(\sigma_r)^2_{\text{matched}} = \varepsilon_n\,(c/\omega_p)\,(2/\gamma)^{1/2}$

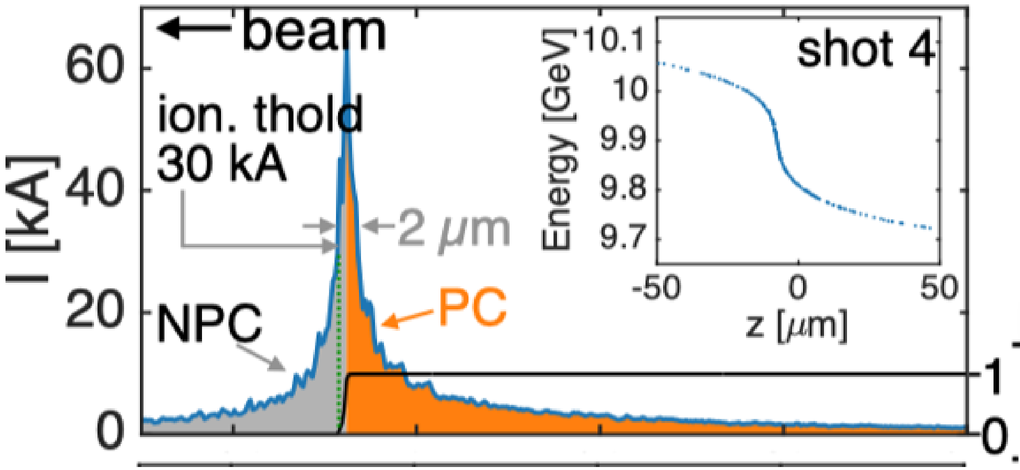
Shot to shot jitter produces large variations in H_2^+ plasma profiles (QPAD simulations)

Ion density 30-50 um after the current spike



Plasmas and wakes produced by nominal beam profile in QPAD simulations at different gas pressures



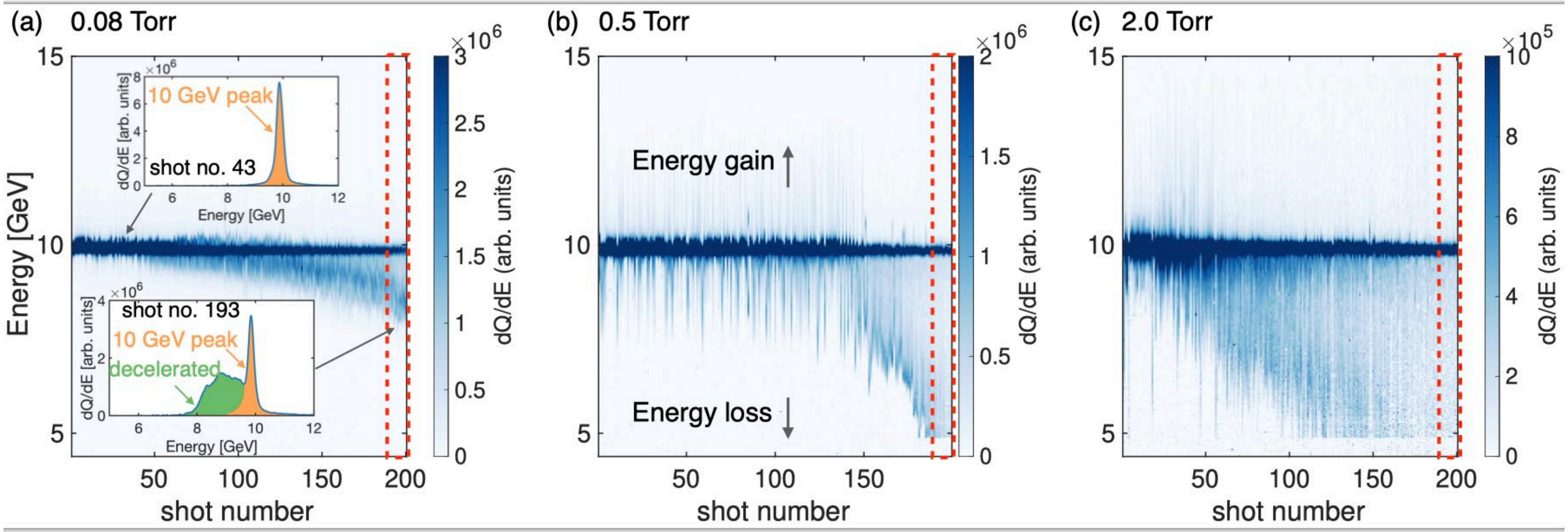


NPC is non-participating charge I(t) , 30 KA

0.08 Torr   Only deceleration
0.5   Torr   Onset of acceleration
1.5   Torr   Pump depletion and energy gain

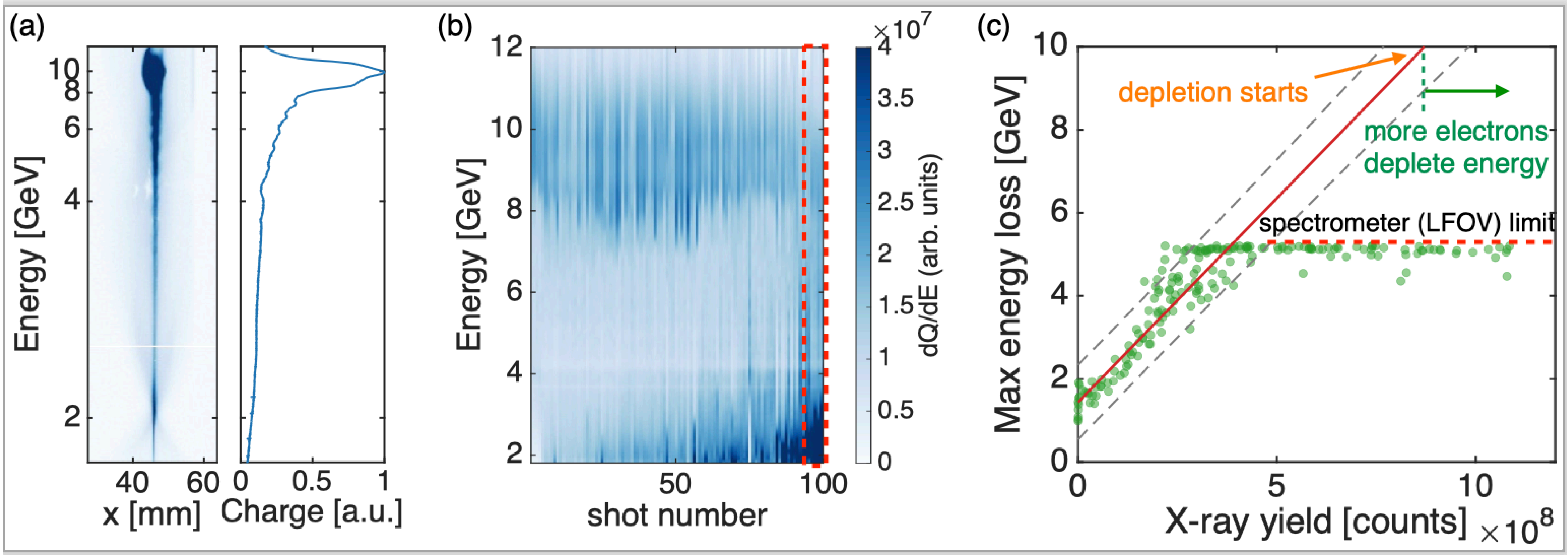
Experimental results of beam spectrum after plasma

(remember that the beam current profile is expected to fluctuate giving a whole range of variation of energy loss/gain of beam slices due to changes to plasma length and peak decelerating gradient)



Maximum energy loss of 5 GeV set by the dispersion of the dipole magnet

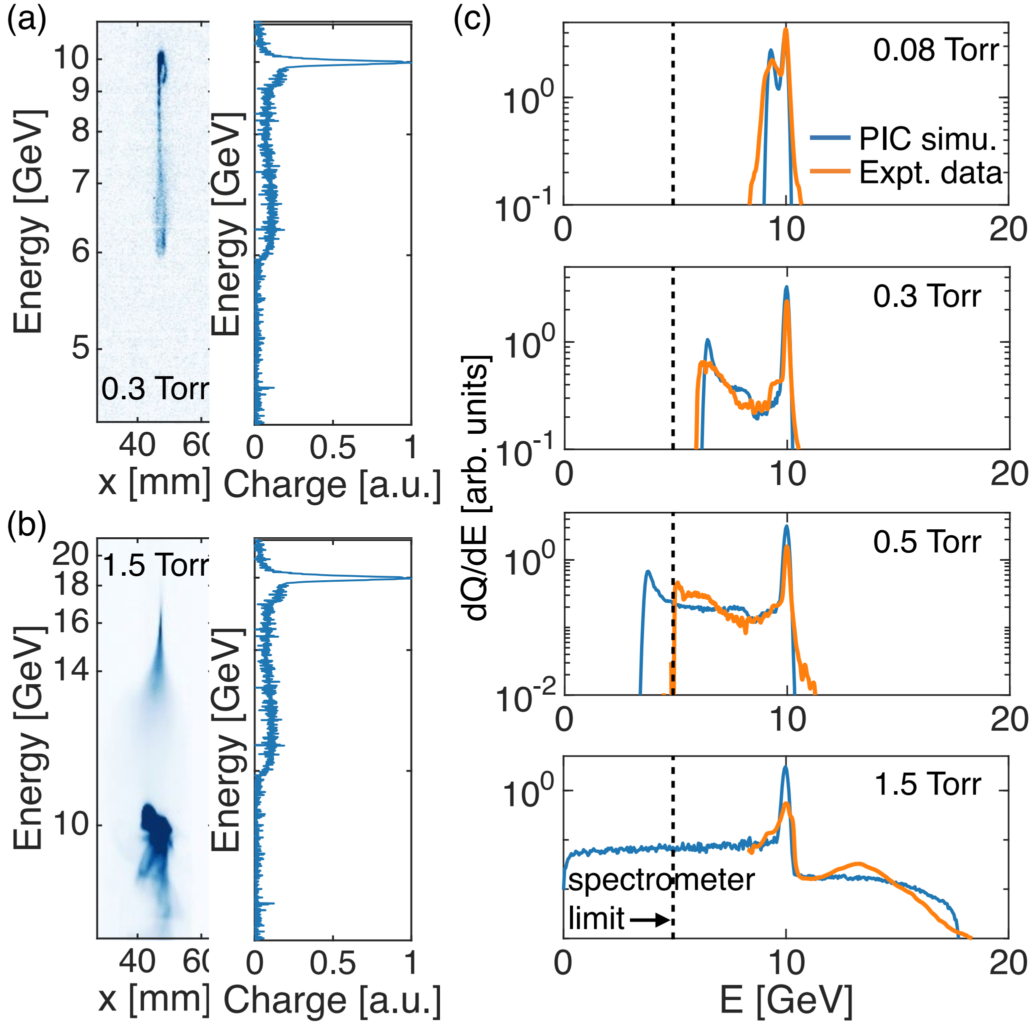
Direct and indirect evidence of near complete energy depletion of some electrons



Direct evidence on energy spectrometer by making dipole dispersion smaller

Indirect evidence by extrapolating correlation
Between Betatron X-ray yield and energy loss

Comparison between changes to beam spectrum with H_2 pressure in simulations and experiment



Onset of energy loss

Double valued energy loss giving an enhanced charge peak at Highest energy loss

Cut-off observed in experimental spectrum due to limited field of view of the screen

Clear evidence of energy gain up to 7-8 GeV , continuous spectrum
In all spectra the NPC is clearly seen as a peak at 10 GeV

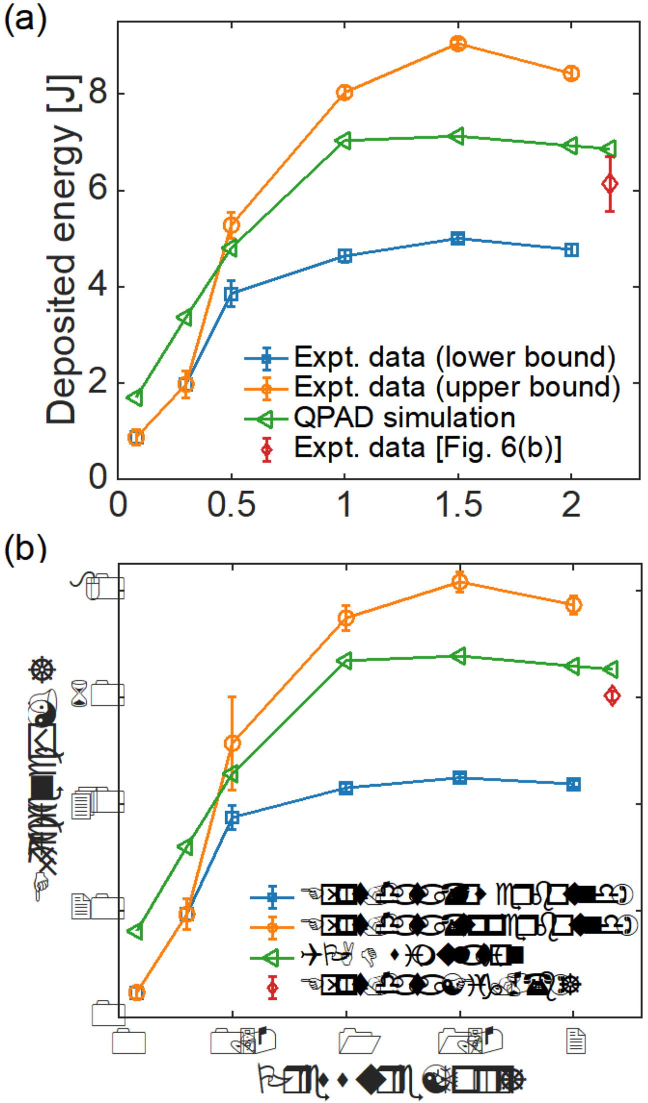
Total energy deposited by the beam into plasma (wake) and energy transfer efficiency from beam to wake

Assume energy expended in ionizing the gas is negligible

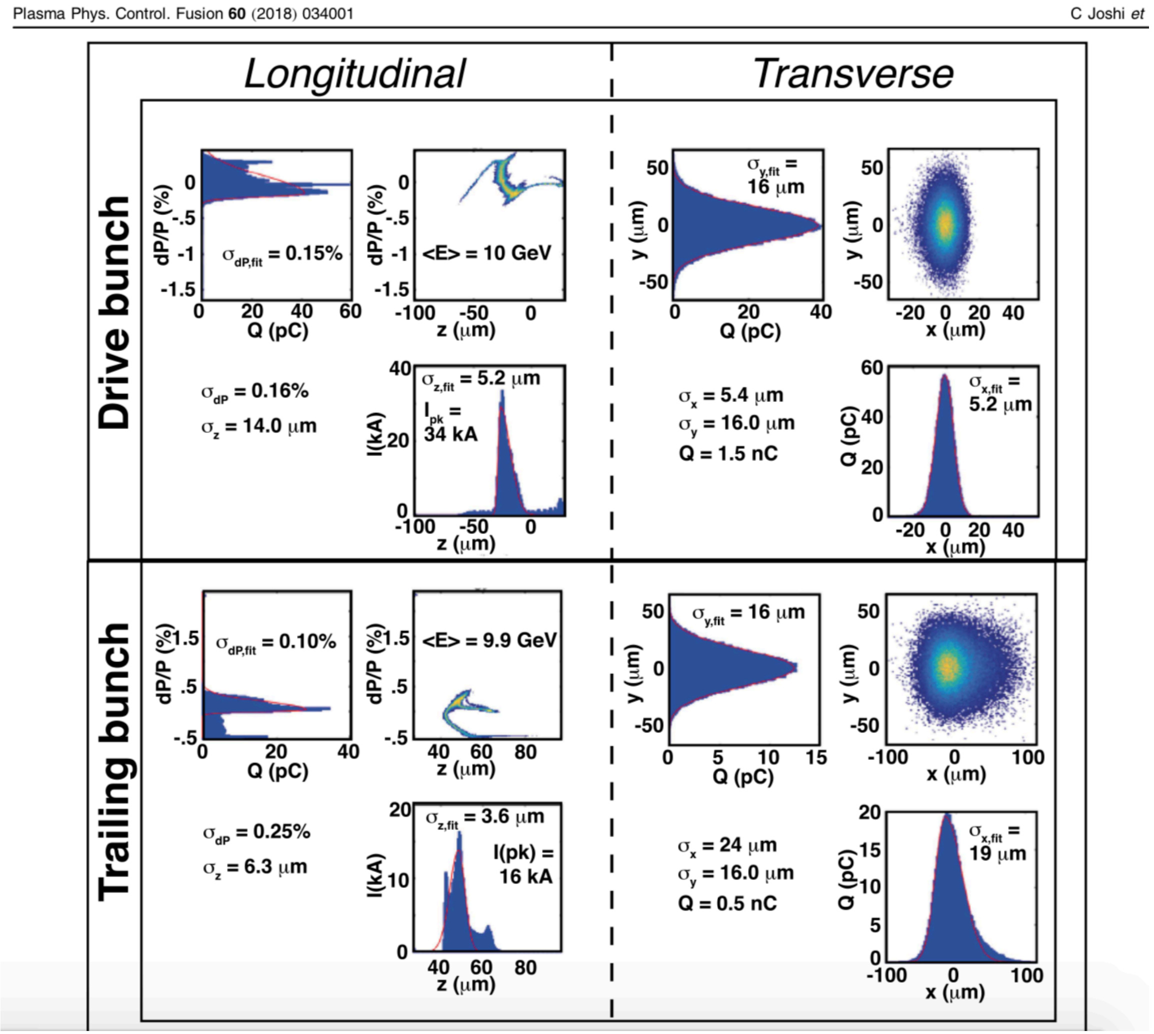
Assume energy emitted in visible and X-ray radiation is negligible

All the energy lost by the drive electron charge that follows the ionization front goes in forming the wake

At the highest pressure of 2.1 torr a few percent of the energy is extracted by the accelerating charge



E300 : Second Year Plan Can FACET II provide 2 Bunch Configuration?



Drive Beam: E = 10.0 GeV,

N =1.0 x 10^{10} (1.6 nC),

β_x = 70.0 cm, $\alpha_{x,y}$ = 4.2, 1.6 β_y = 70.0 cm,

β^*_x < 2-7 cm, β^*_y <08 cm+ σ_z < 5.2 μm+

$\sigma_{z,r.m.s.}$ < 14.0μm+

εNx = 3.4 μm, εNy = 3.0 μm

I_{peak}=34 KA

Trailing Beam: E = 9.9 GeV,

N <2-014 x 0/ 8 '/ -4 nC(+

β =5.0 cm, α = 0,

β* = 5.0 cm, s = 0 cm, σ_z = 3.6 μm ,

$\sigma_{z,r.m.s.}$ < 6.3 μm+

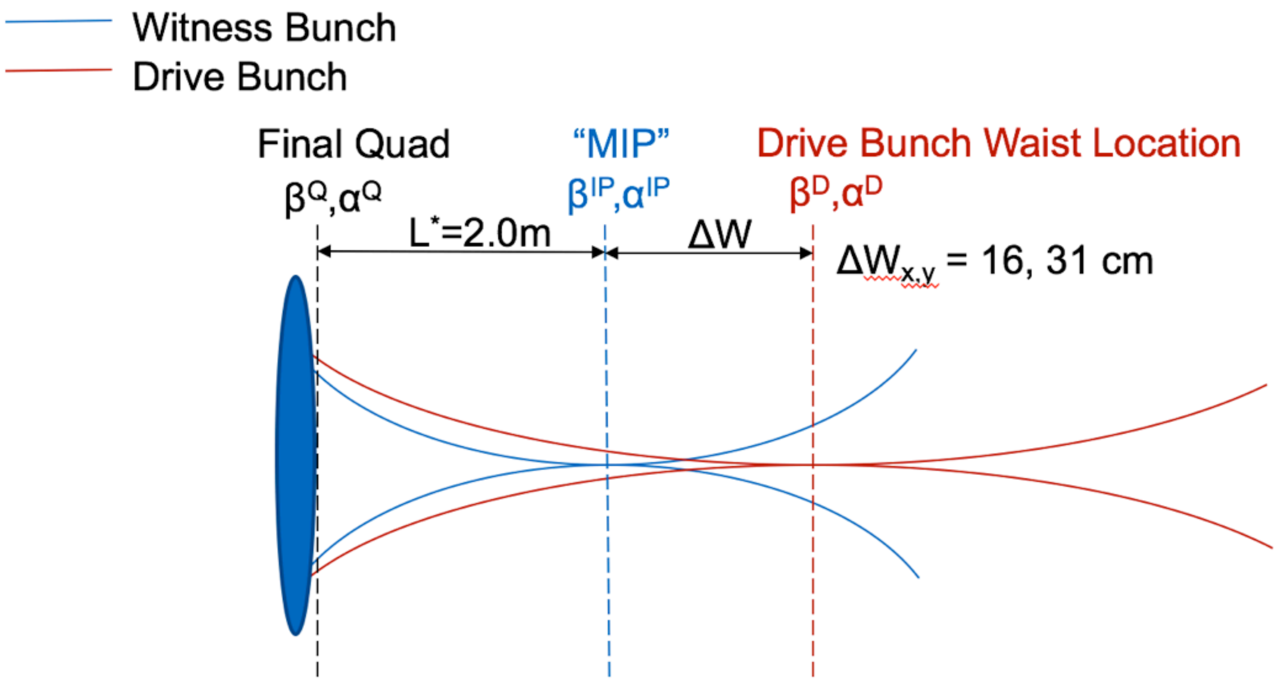
I_{peak}=16KA

εN = 3.15 μm

Bunch Separation: 150 μm

Final focus and IP

(for a 30um emittance we very unlikely will ionize He in the ramps)



	α^Q [x,y]	β^Q [x,y]	α^{IP} [x,y]	β^{IP} [x,y]	α^D [x,y]	β^D [x,y]
Witness	40, 40	80, 80 m	0.0, 0.0	5.0, 5.0 cm	-3.1, -5.8	53, 185 cm
Drive	59, 12	127, 27 m	4.2, 1.6	70, 70 cm	0.0, 0.0	3.7, 19 cm

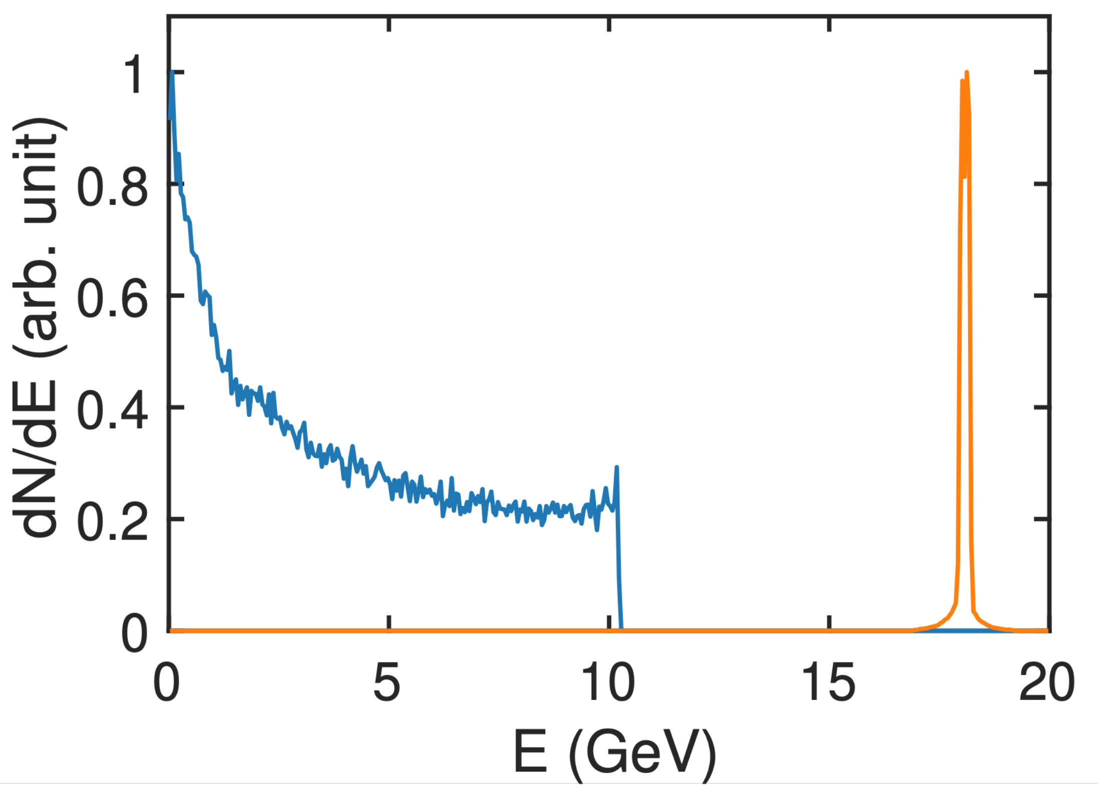
Figure 3.1: Final Focus at FACET II experimental area. Courtesy of Glenn White (SLAC).

Pre-ionized vs. beam-ionized plasma (realistic ramps)
no helium ramps: Get a net efficiency of > 30% w pump depletion

Final energy spectrum:

pre-ionized plasma

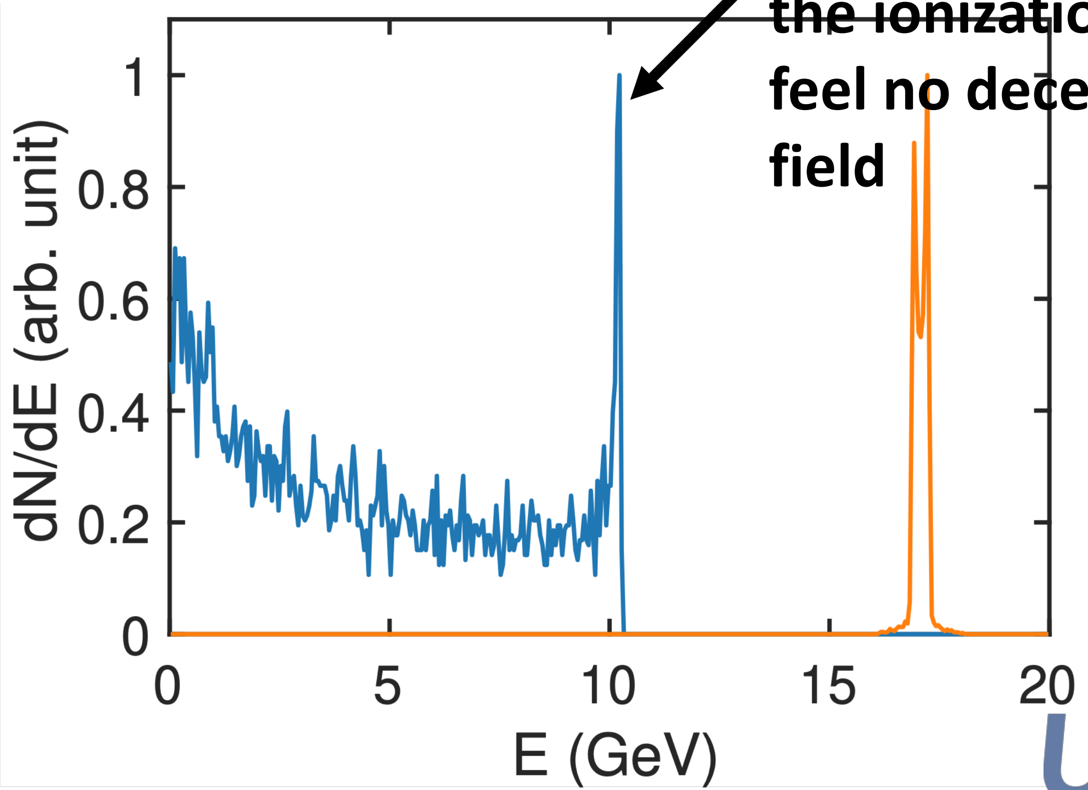
E_f=18 GeV, ΔE/E=0.9%



beam-ionized plasma

E_f=17 GeV, ΔE/E=1.0 %

Electrons ahead of the ionization front feel no decelerating field



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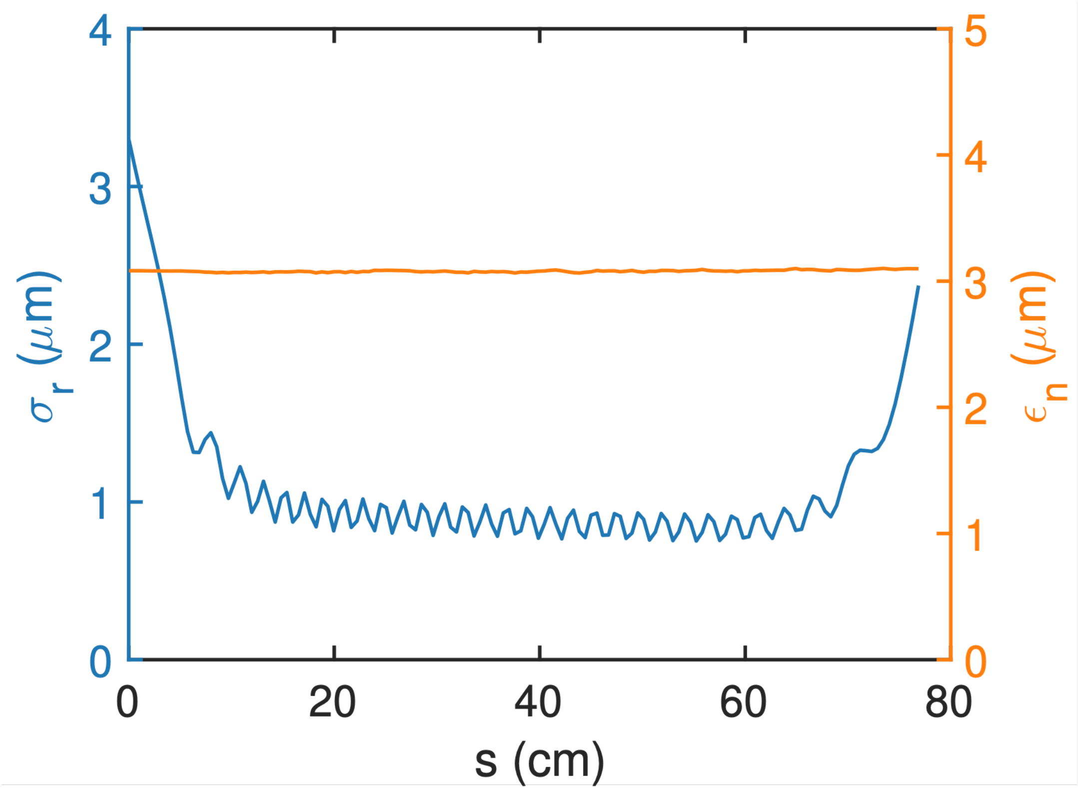
E300 Plans for year 3: Beam matching and emittance preservation (realistic ramps)

Beam size and emittance evolution:

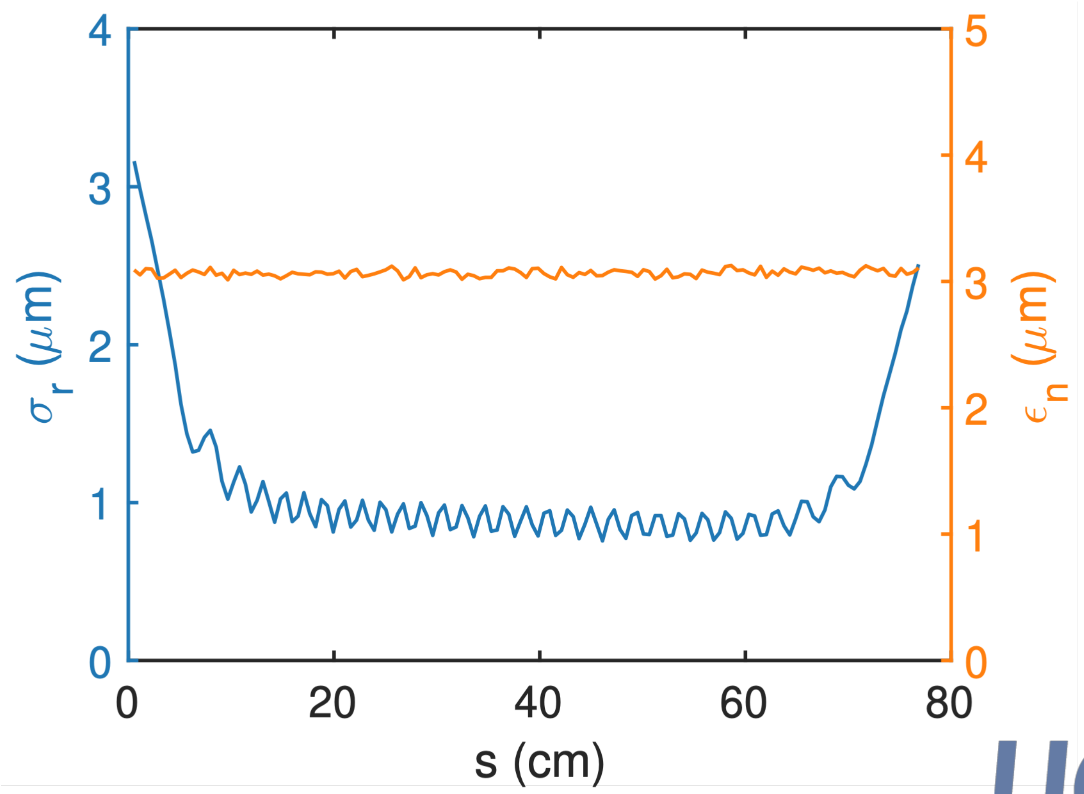
pre-ionized plasma

negligible emittance growth



beam-ionized plasma

negligible emittance growth



Suppose we have only the single bunch set-up : Create a second bunch via downramp injection into the wake

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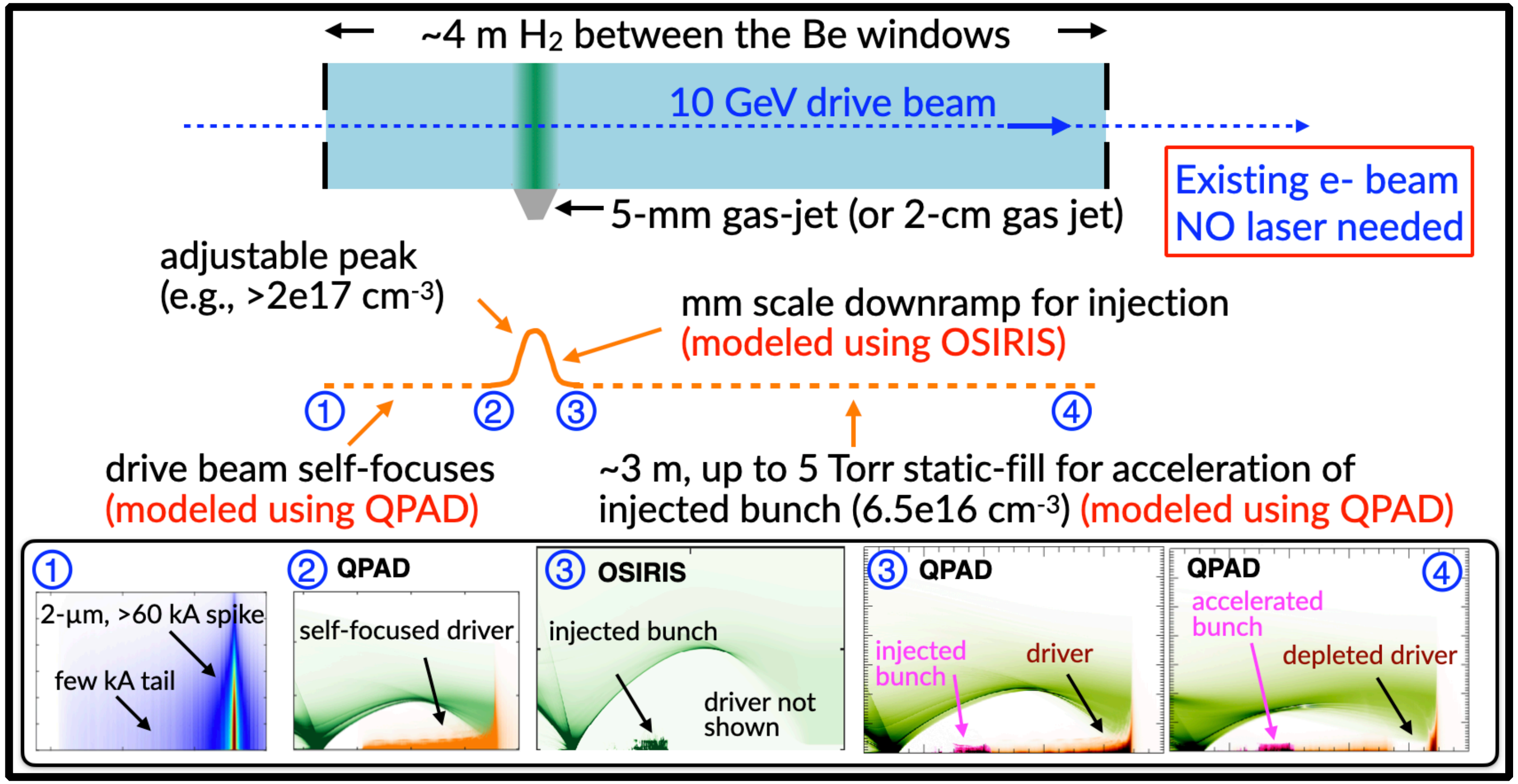
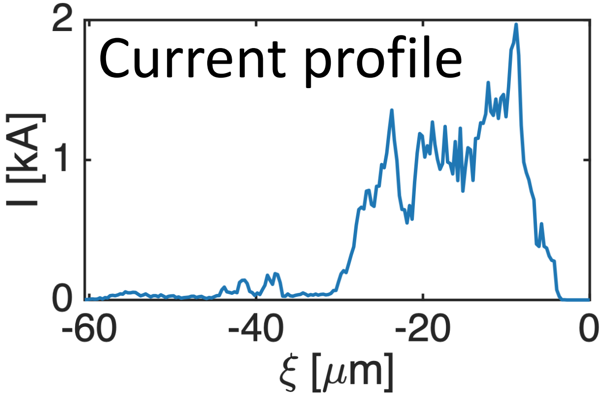
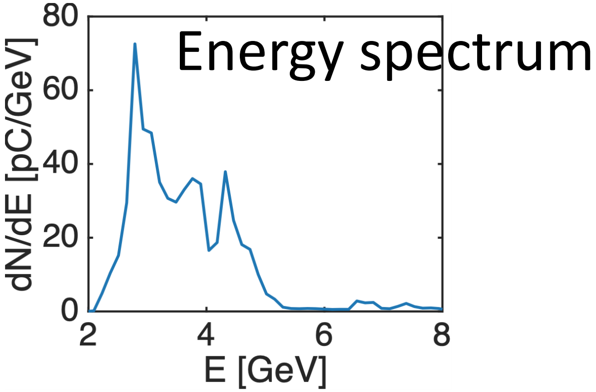
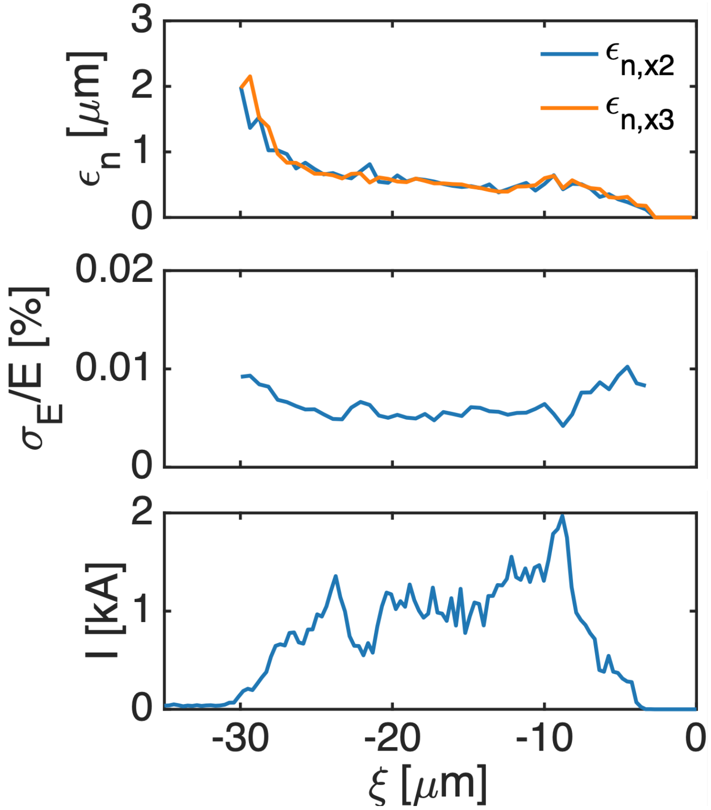


- **Setup**: Ready to go
- **Outcome**: multi-GeV high-brightness e- bunch

- ε_n: 0.7 μm, σ_E/E: 0.01%, I: ~1 kA







E 300 Publications submitted to Journal Publications

1) Wakefield Generation in Hydrogen and Lithium Plasmas at FACET-II: Diagnostics and First Beam-Plasma Interaction Results

- D. Storey et al submitted to Physical Review Accelerators and Beams

2) Generation of meter-scale hydrogen plasmas and efficient pump-limited wake field excitation using 10 GeV electron bunches

- C. Zhang et al , submitted to Plasma Physics and Controlled Fusion

3)Perspectives on Positron Arm of a Plasma-based Linear Collider: Accomplishments and Formidable Challenges
Chandrashekhar Joshi, Warren B. Mori and Mark J. Hogan: Under preparation

4) Commissioning and first measurements of the initial X-ray and γ -ray detectors at FACET-II
, P. San Miguel Claveria et. al, AAC 2022 Conference Proceedings IEEE (2023)

- Thank you for your attention