INSTITUT POLYTECHNIQUE DE PARIS

ENSTA

cnrs

Plasma Acceleration and Generation of Ion Channels at FACET-II

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on behalf of the E300 and E340 collaborations

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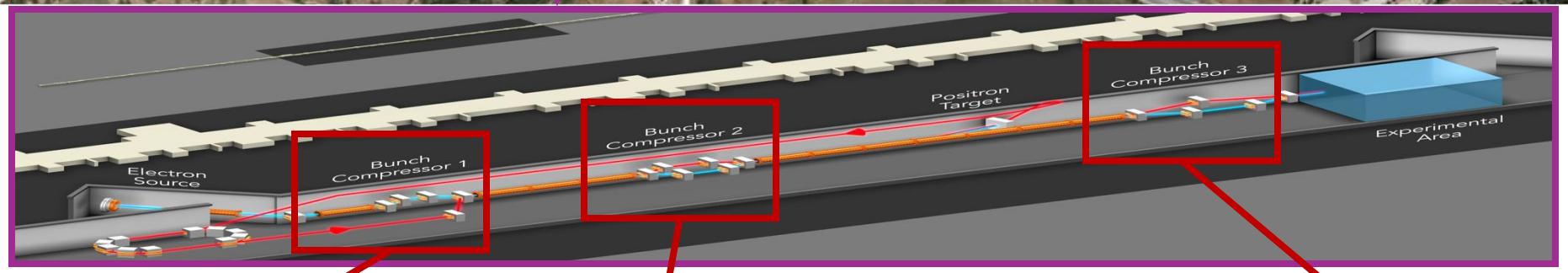
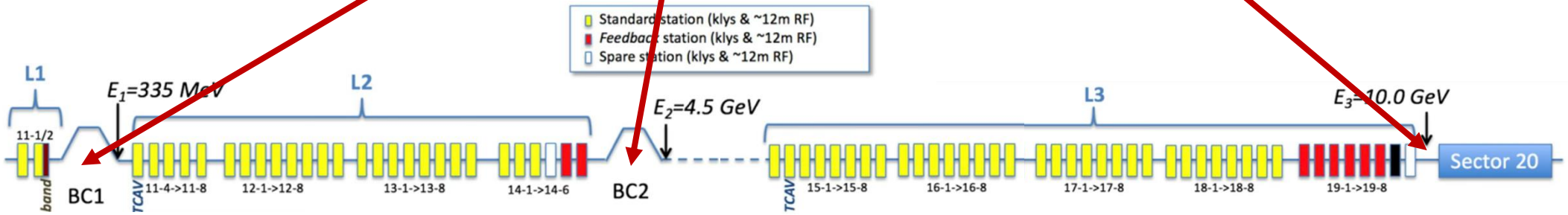
FACET-II at SLAC

Credit: SLAC

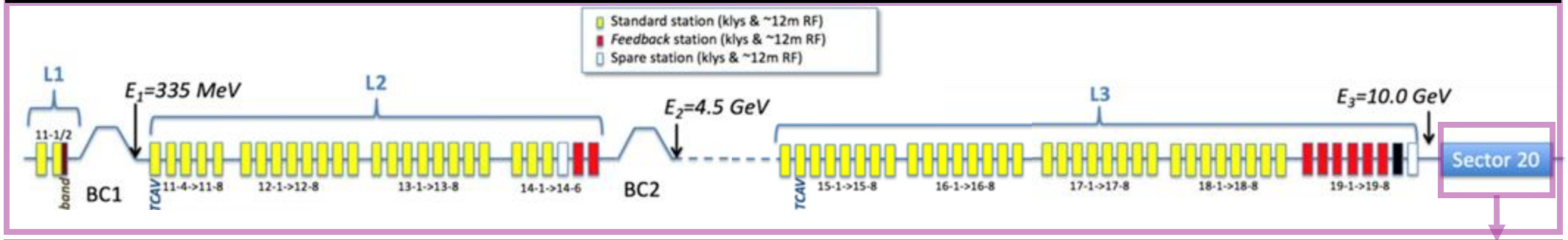


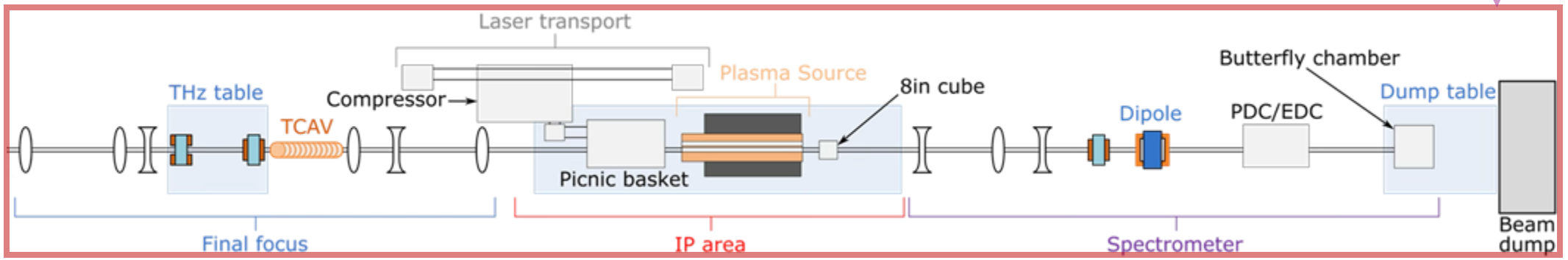


FACET-II LINAC

Credit: SLAC

- 4 LINAC sections (L0, L1, L2, L3) over 1 km accelerate electrons to 10 GeV
- L1/L2 phases and their bunch compressors BC1/BC2 manipulate the longitudinal phase space of the electrons
- Photocathode can produce 1 or 2 bunches of electrons up to 2.1 nC total charge
- O(100 kA) peak current, O(10μm) size beam at 10Hz delivered to experimental area (sector 20) for experiments

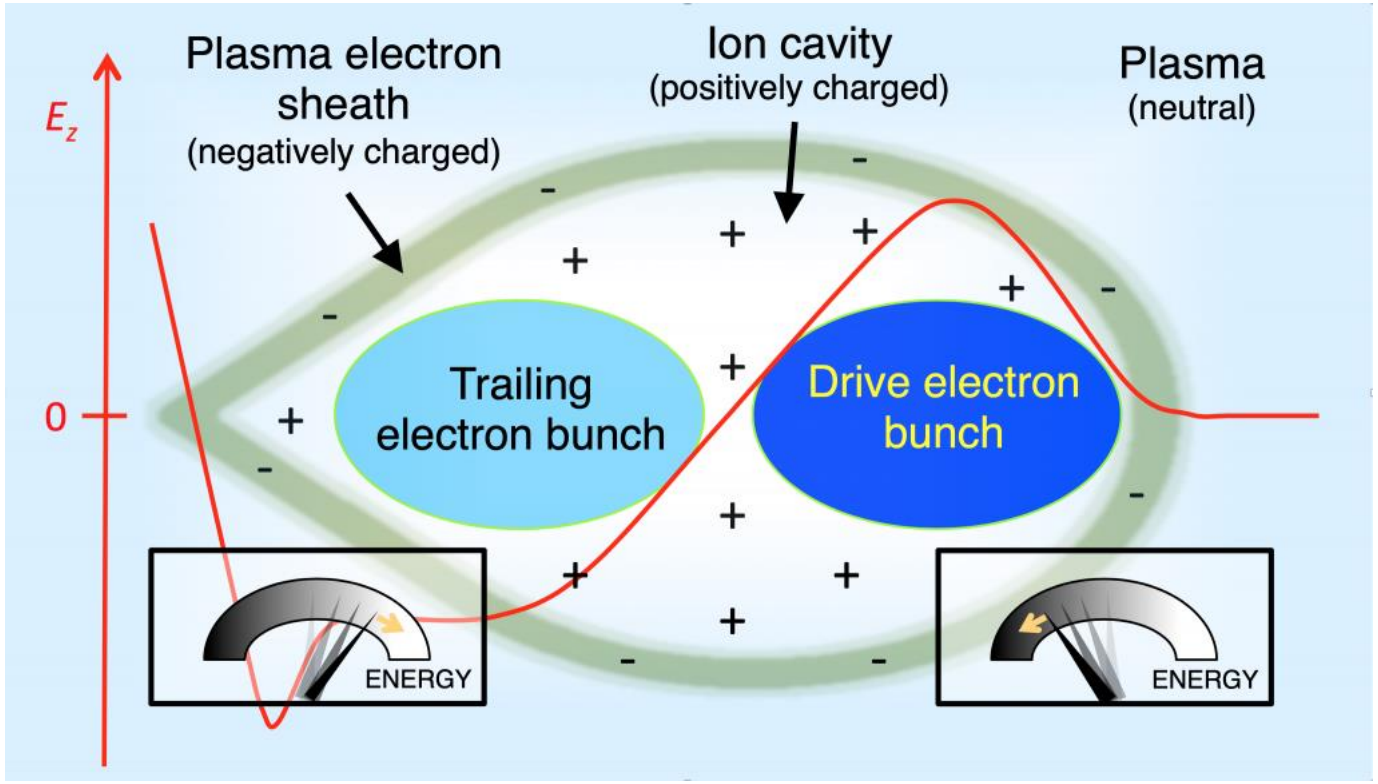




Part 1: E300
Beam-driven Plasma Acceleration

E300: Plasma Wakefield Acceleration (PWFA)

- Two bunches of electrons from the FACET-II LINAC are sent into the plasma
- The first bunch drives a plasma wave, and the second sees strong accelerating fields ~O(10 GV/m) in the blowout cavity
- Laser may be used for plasma pre-ionization to enhance PWFA performance

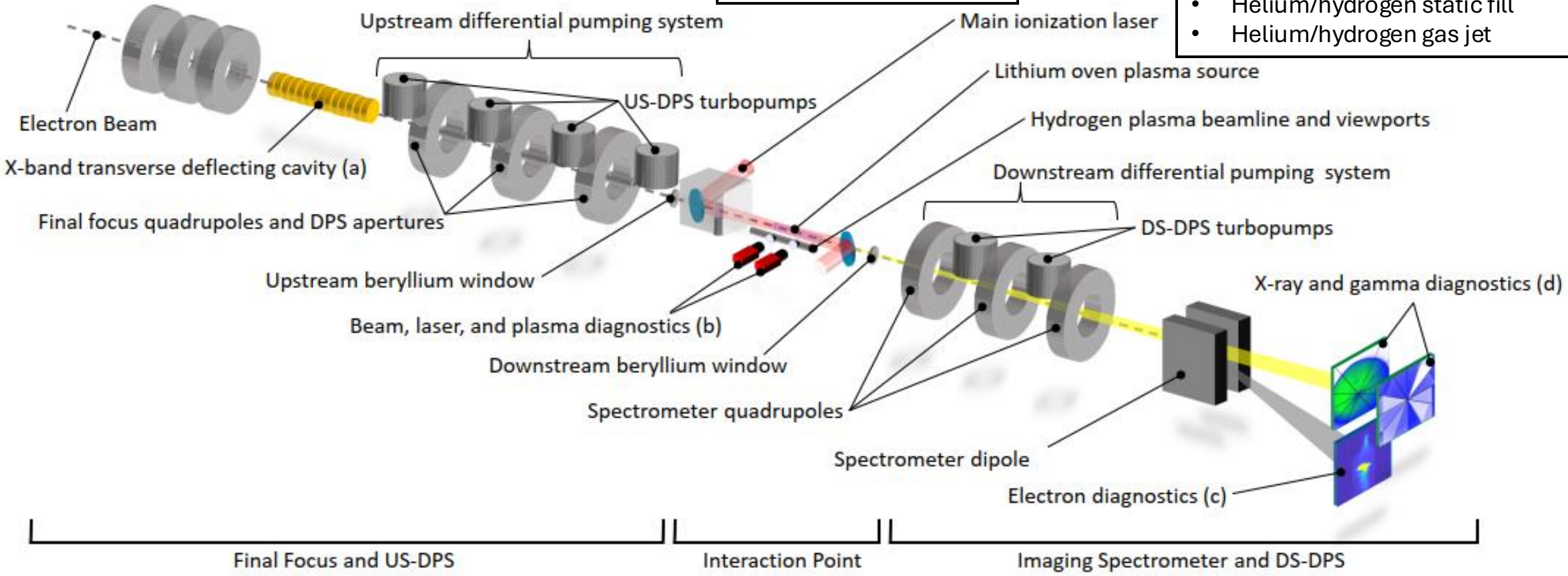


Credit: Sébastien Corde

FACET-II Experimental Area

Laser used for:
- Plasma creation
- Probe diagnostics
- Compton collisions

Variety of plasma sources:
- Lithium oven (40 cm)
- Helium/hydrogen static fill
- Helium/hydrogen gas jet

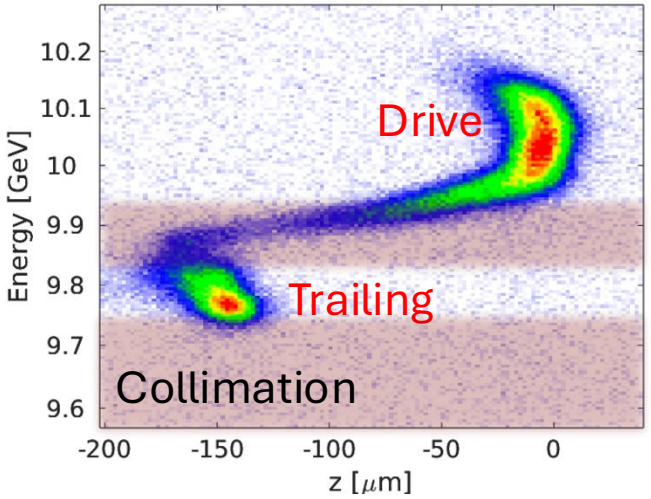


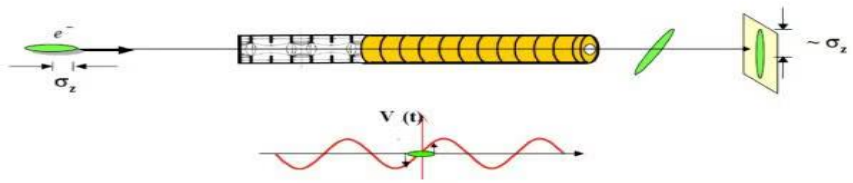
Plasma Acceleration results

Photocathode two bunch configuration:

- Driver ~1200 pC, 6-8 kA
- Trailing ~150-250 pC
- 40cm Lithium plasma, n_e = 4e16 cm^{-3}

Incoming beam : Transverse deflecting cavity measurements

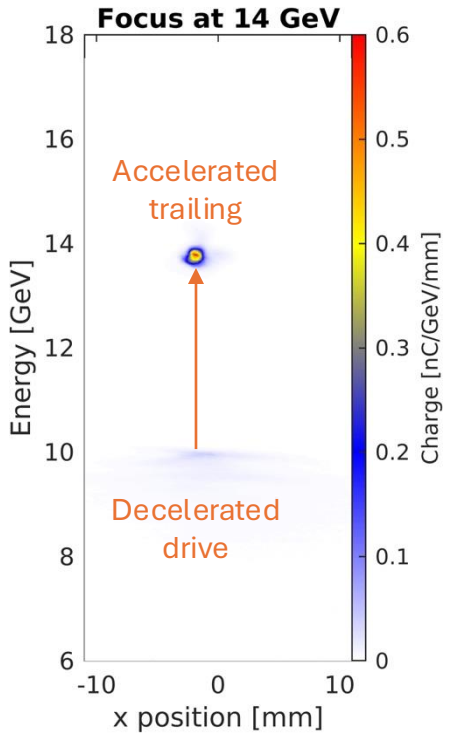


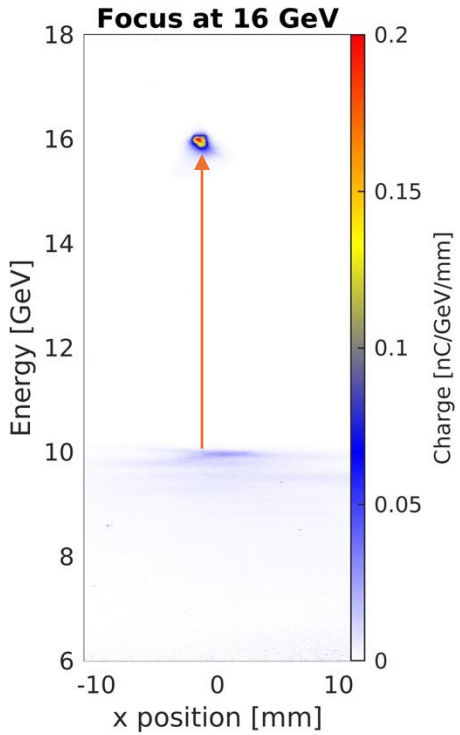


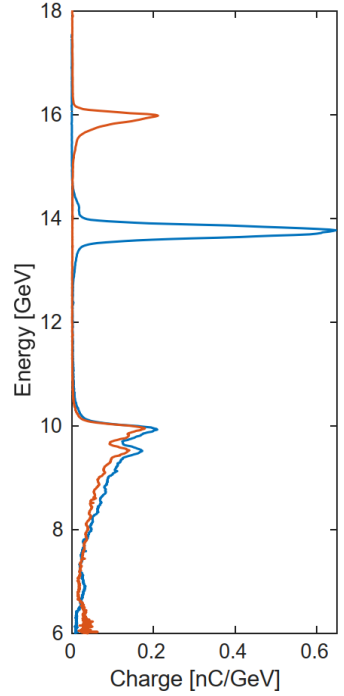
Acceleration of 4-6 GeV!

(4 GeV acceleration)/(40 cm plasma) = **10 GeV/m**

Credit: Doug Storey







$\Delta E = 3.8$ GeV
$\sigma_E = 0.76\ \%$
$\eta_{tot} = 6\ \%$
$Q_w = 180$ pC

$\Delta E = 6$ GeV
$\sigma_E = 0.69\ \%$
$\eta_{tot} = 3\ \%$
$Q_w = 60$ pC

Credit: Clément Vovard

PWFA repeatibility

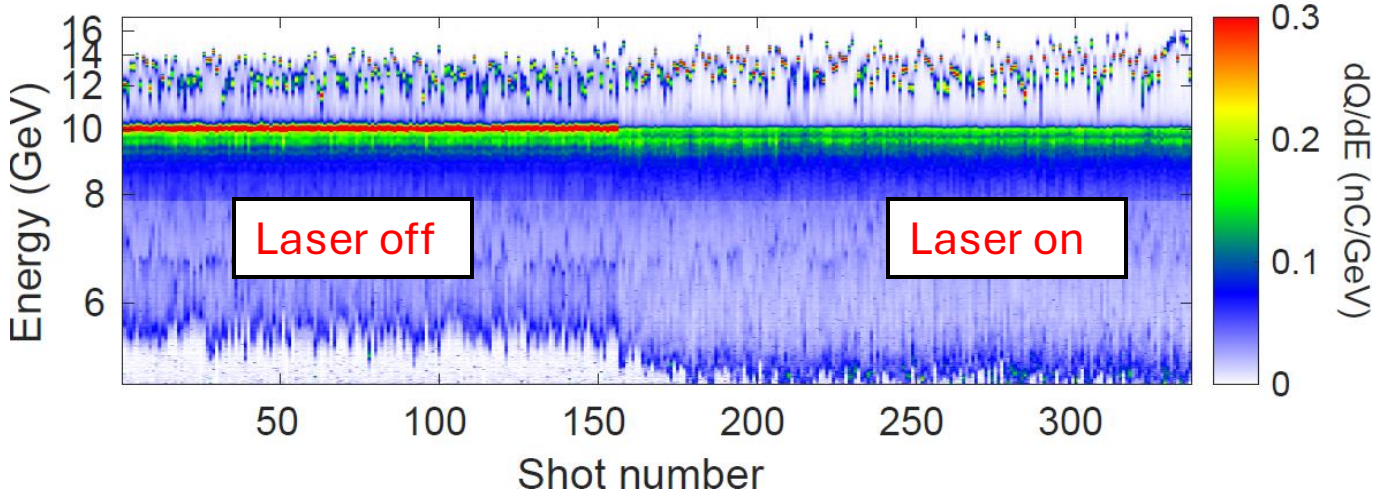
Laser on = laser pre-ionization of plasma
Laser off = beam ionization of plasma

Imaging Quadrupoles

Top 50% of shots

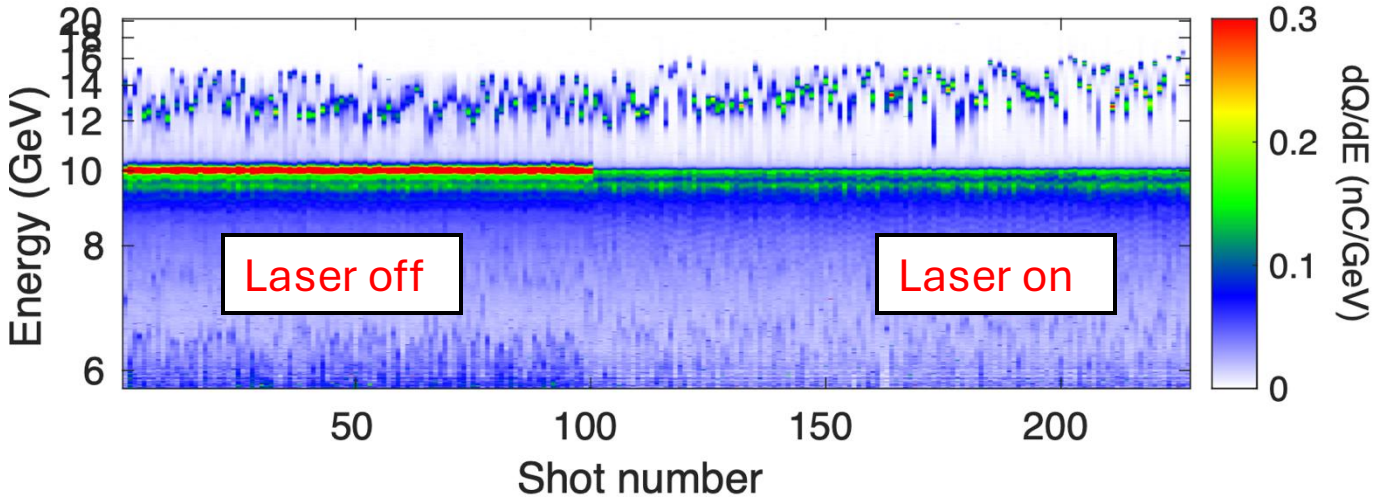
Top 10% of shots

14 GeV



$\Delta E = 4.13 \pm 0.47\ GeV$
$Q_w = 133 \pm 18\ pC$
$\sigma_E = 0.82 \pm 0.21\ \%$
$\eta_{tot} = 4.3 \pm 0.4\ \%$

16 GeV

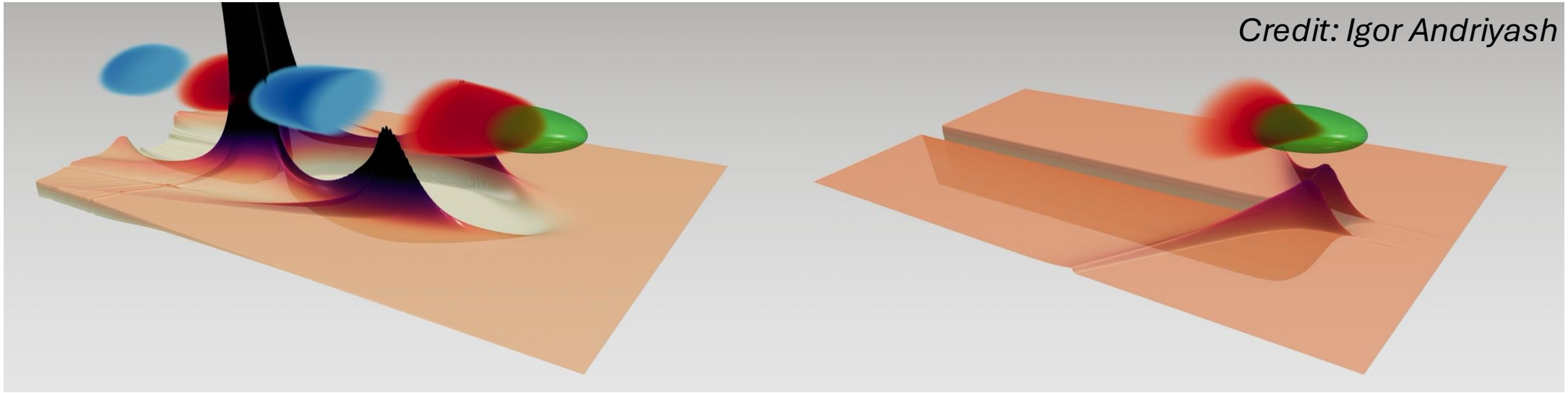


$\Delta E = 4.85 \pm 0.76\ GeV$
$Q_w = 95 \pm 35\ pC$
$\sigma_E = 1.34 \pm 0.37\ \%$
$\eta_{tot} = 4.0 \pm 1.1\ \%$

Section 2: E340
Control and probing of plasma accelerators and wakeless mode

Plasma acceleration

Wakeless



Credit: Igor Andriyash

- Electron beam ionizes gas and drives plasma wave
- Multiple **plasma oscillation periods** formed
- Driver loses energy and the charge in the back is **accelerated**

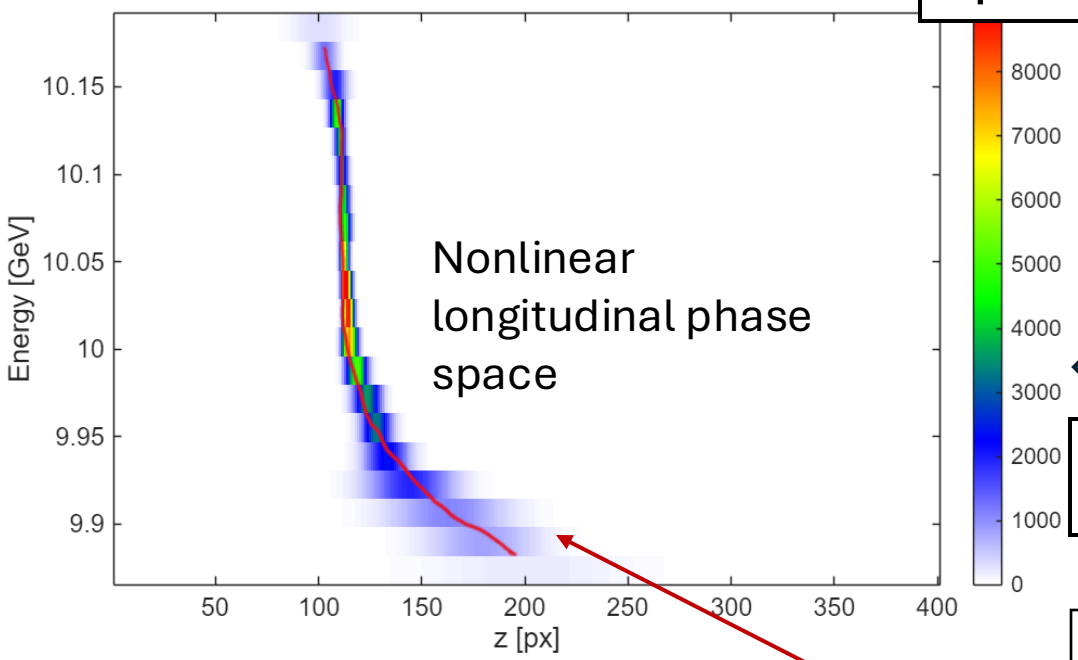
- Electron bunch only ionizes **narrow plasma channel**
- Electrons are ejected and don't come back to the axis – **straight ion channel is formed**
- Driver loses energy **without acceleration** in trailing

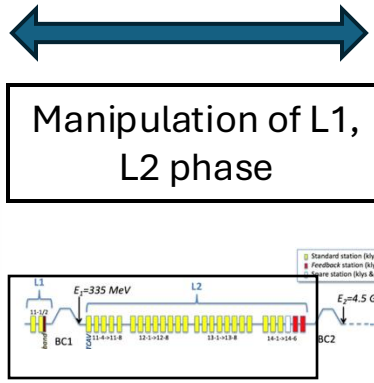
The transition between the two regimes could open promising paths for positron acceleration

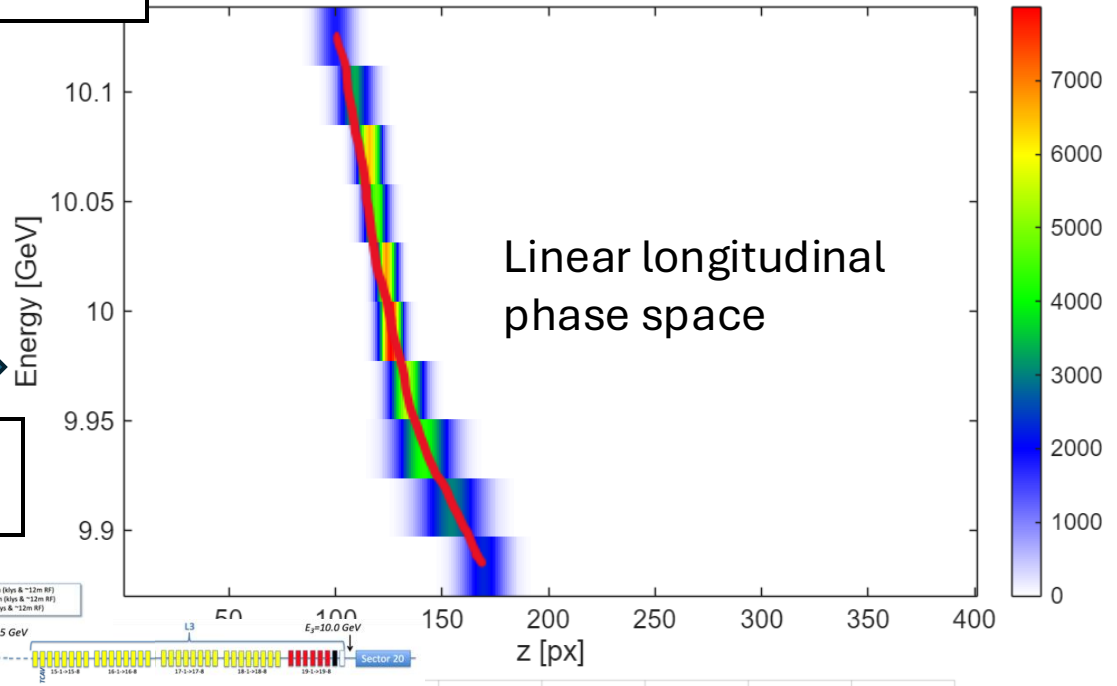
Plasma acceleration

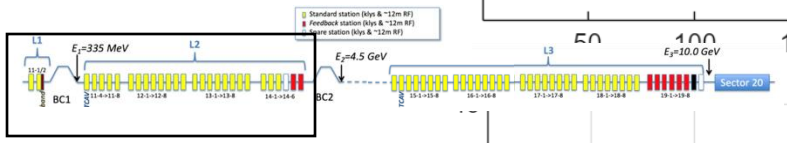
Longitudinal phase space reconstruction

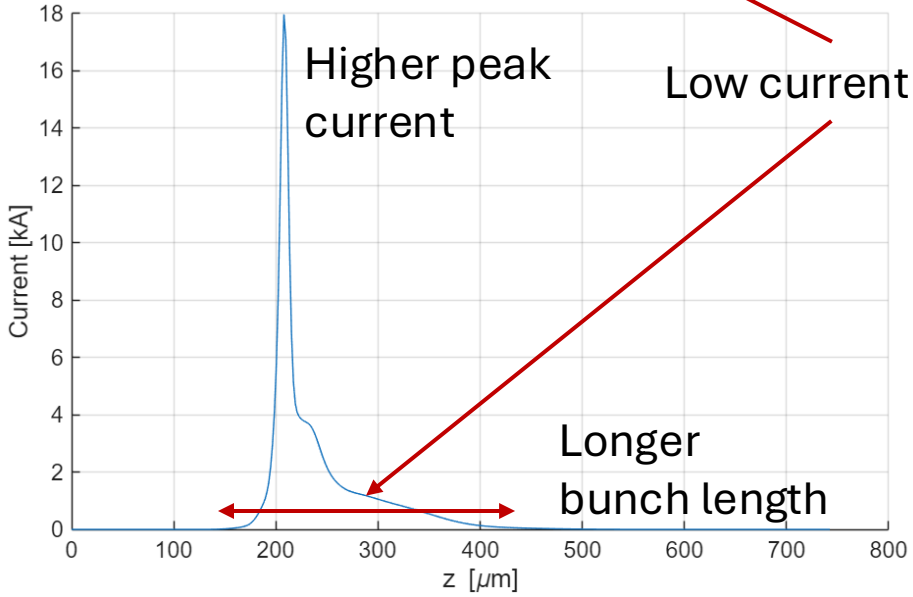
Wakeless







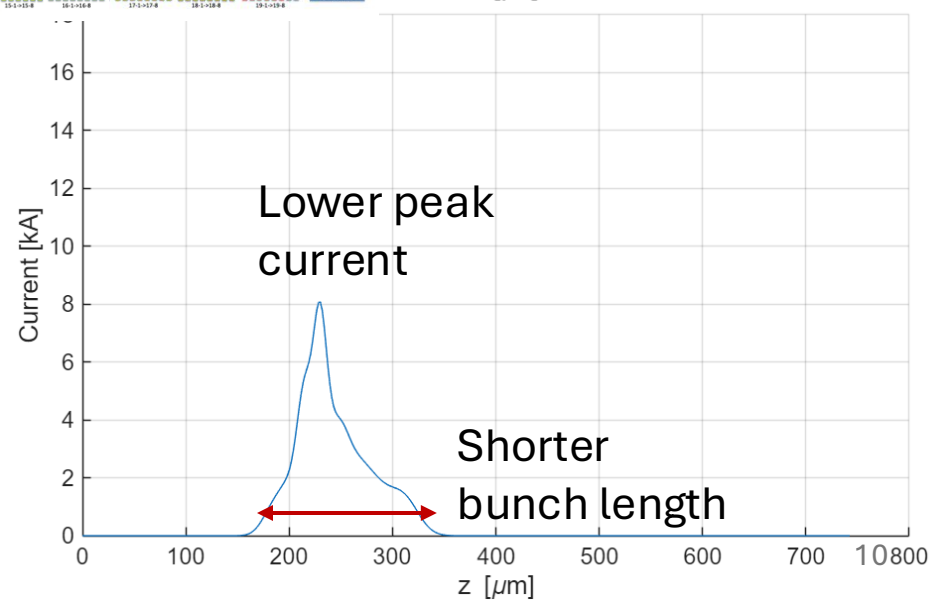




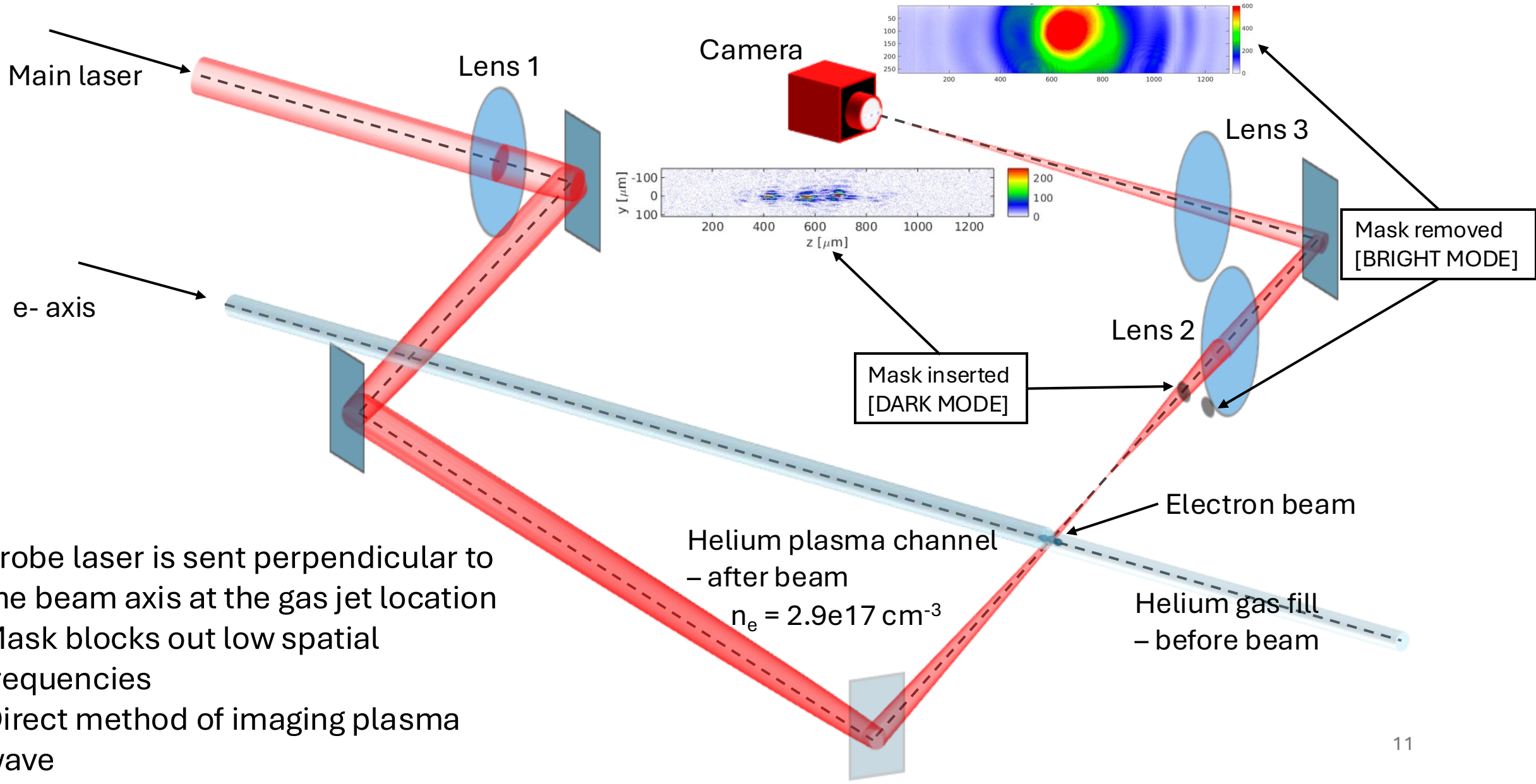
Front

Back

Beam direction



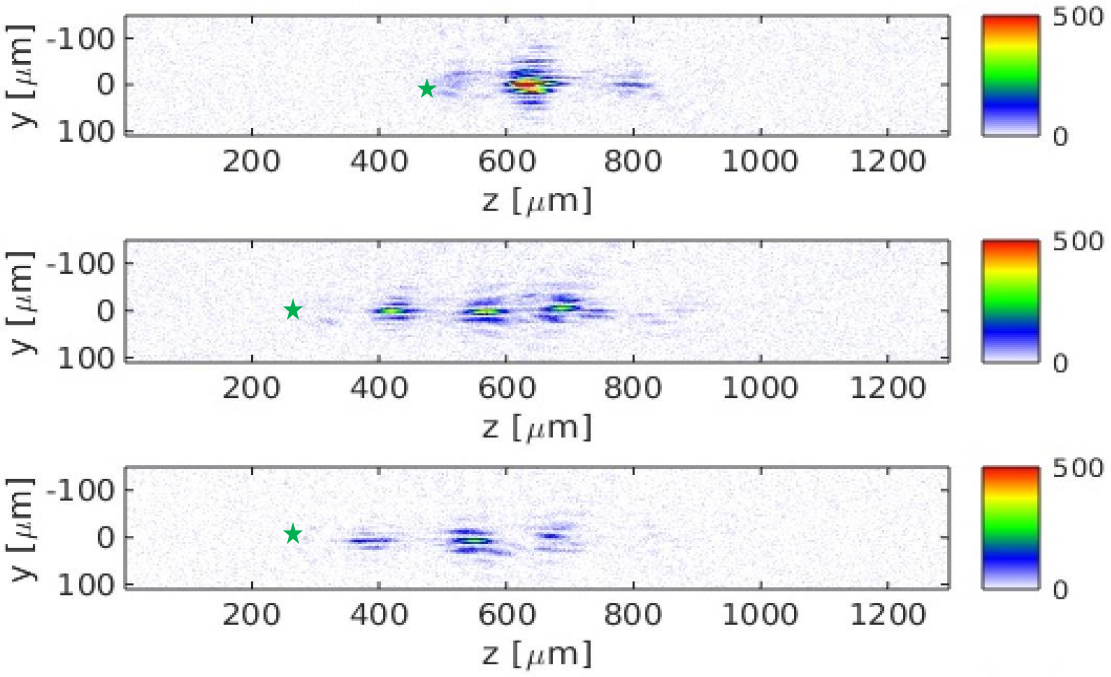
E340: Dark-field shadowgraphy at SLAC



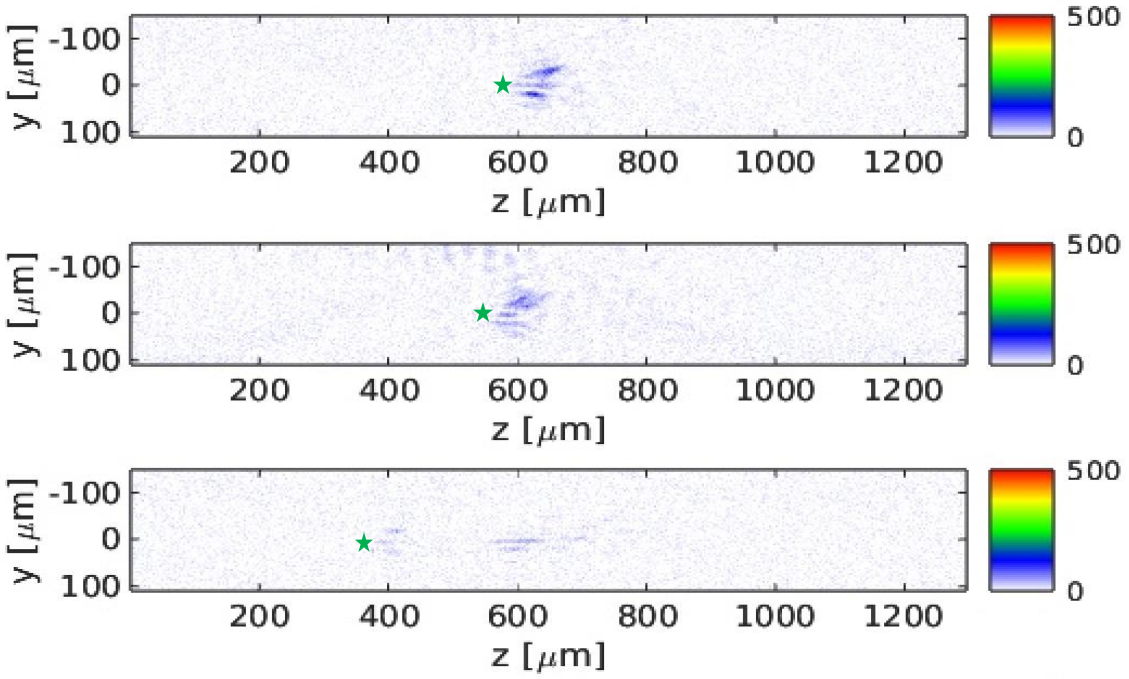
- Probe laser is sent perpendicular to the beam axis at the gas jet location
- Mask blocks out low spatial frequencies
- Direct method of imaging plasma wave

Experimental shadowgram snapshots

Plasma acceleration

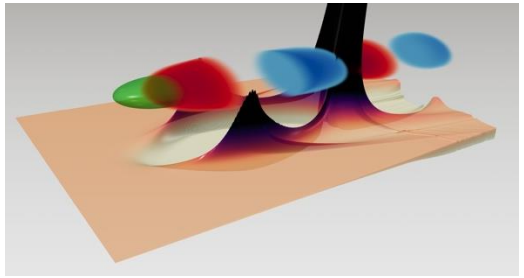


Wakeless



★ = electron beam front

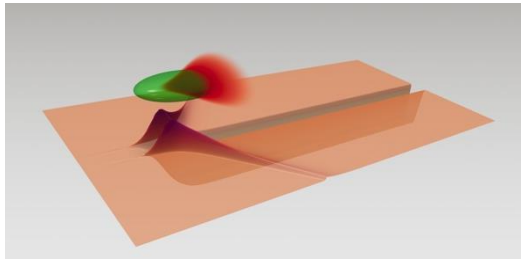
Multiple oscillations behind driver



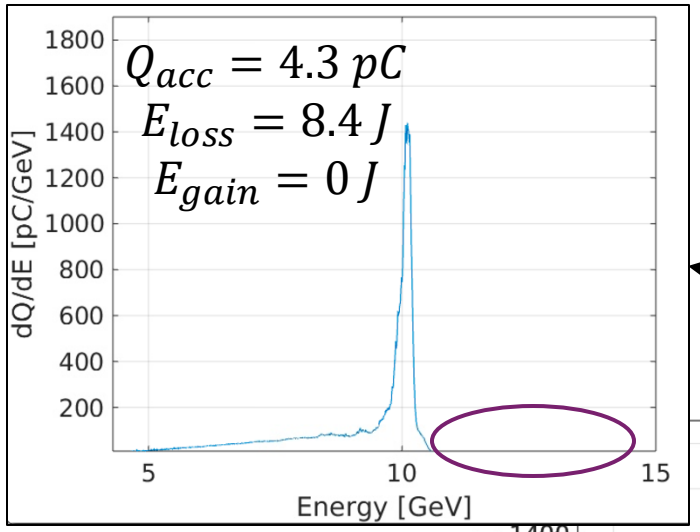
Front ← Back

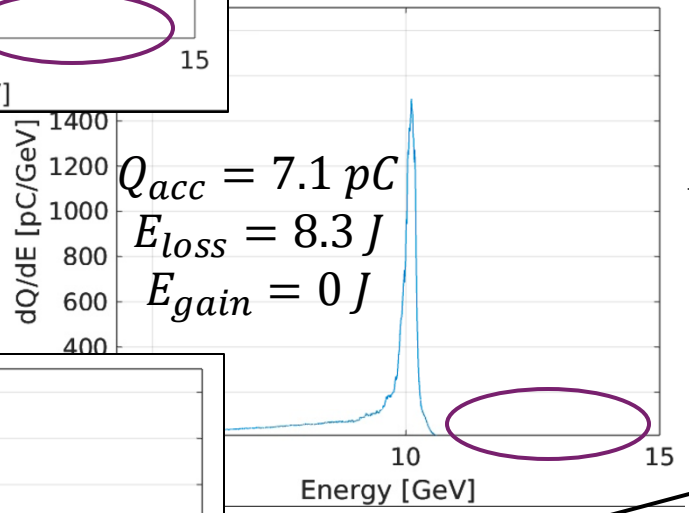
Beam direction

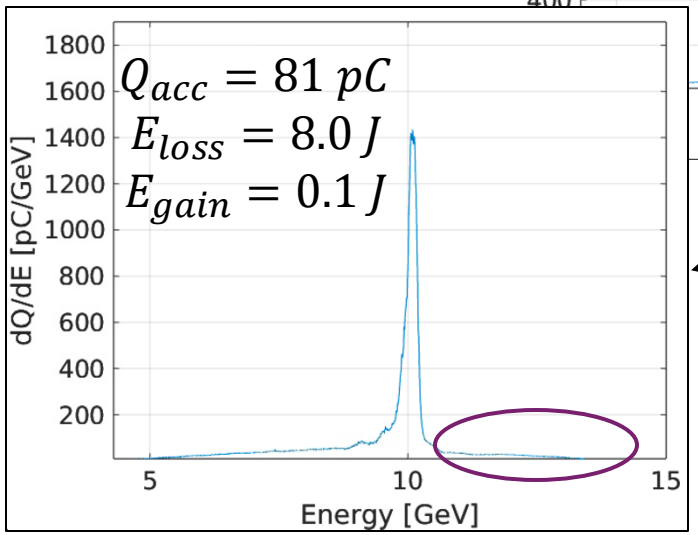
No oscillations behind driver



Shadowgrams vs electron spectra

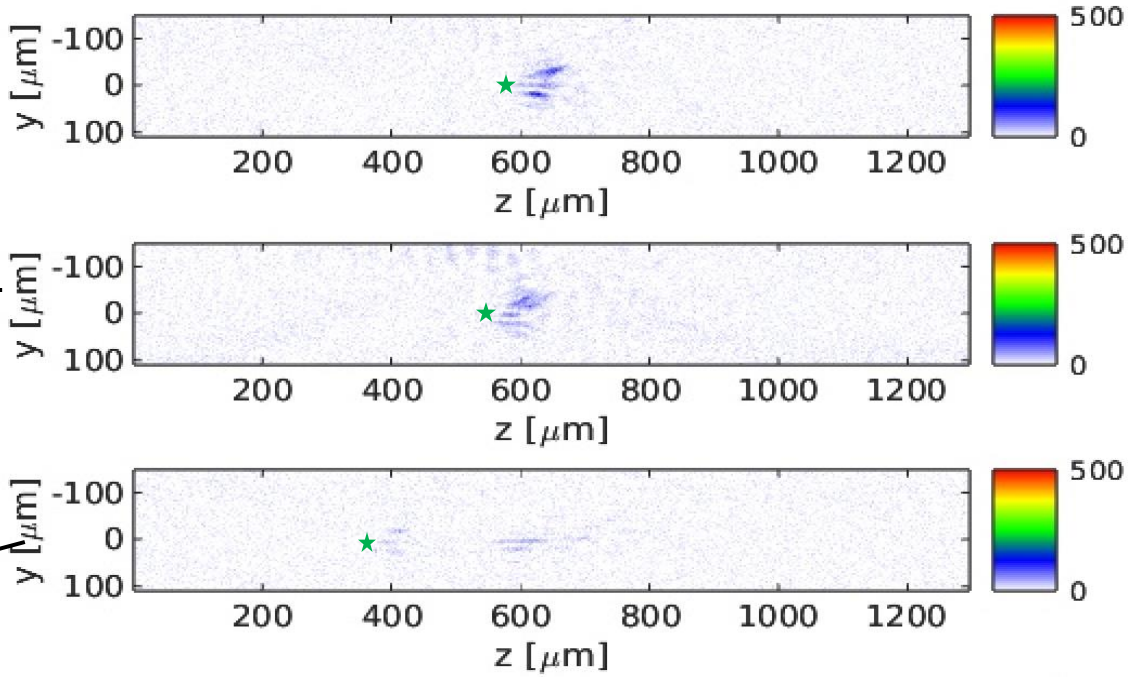






Little to no acceleration

Wakeless



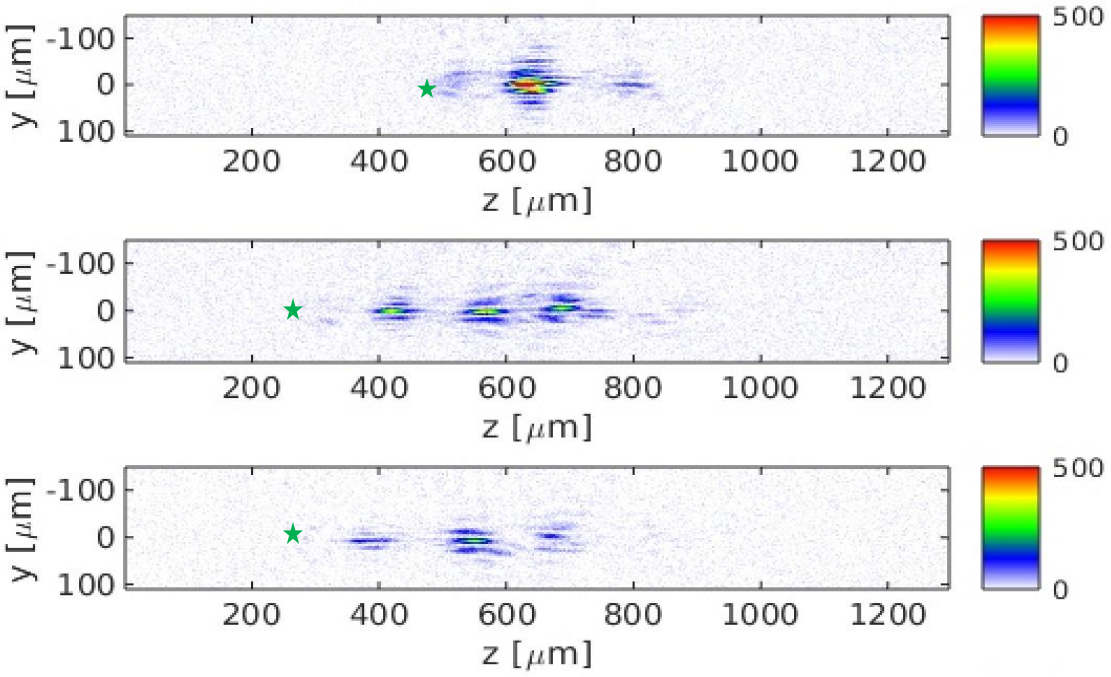
★ = electron beam front

Front Back

Beam direction

Shadowgrams vs electron spectra

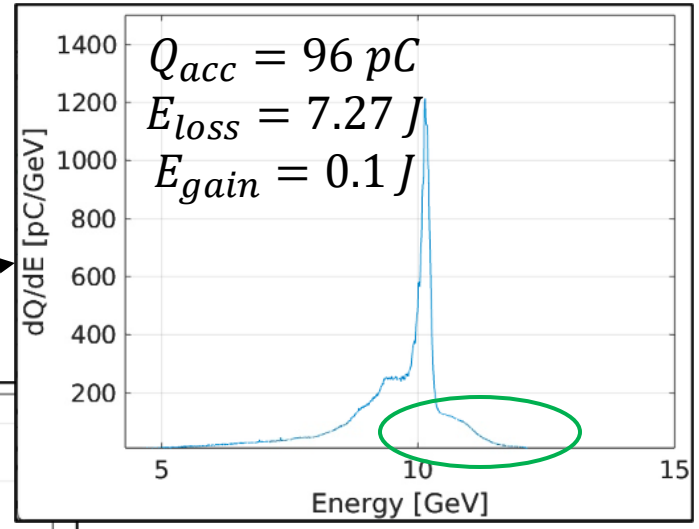
Plasma acceleration

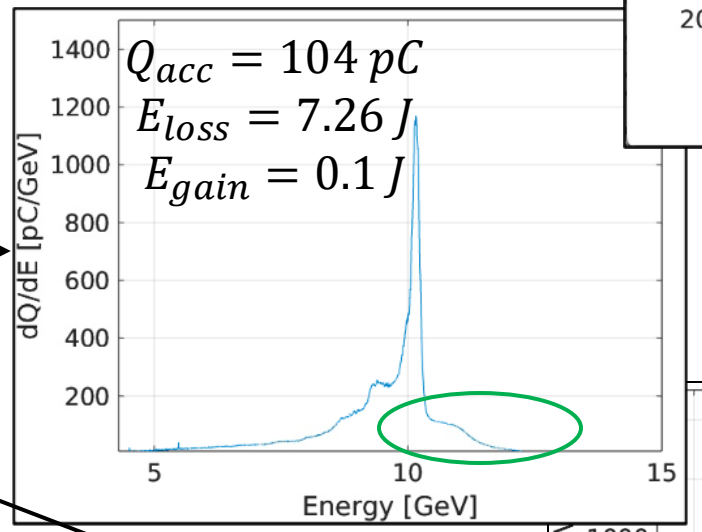


Front Back

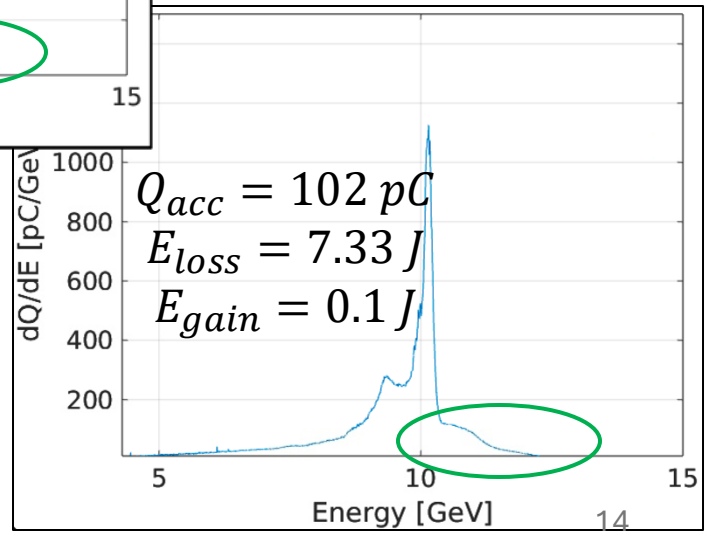
★ = electron beam front

Beam direction





Visible acceleration



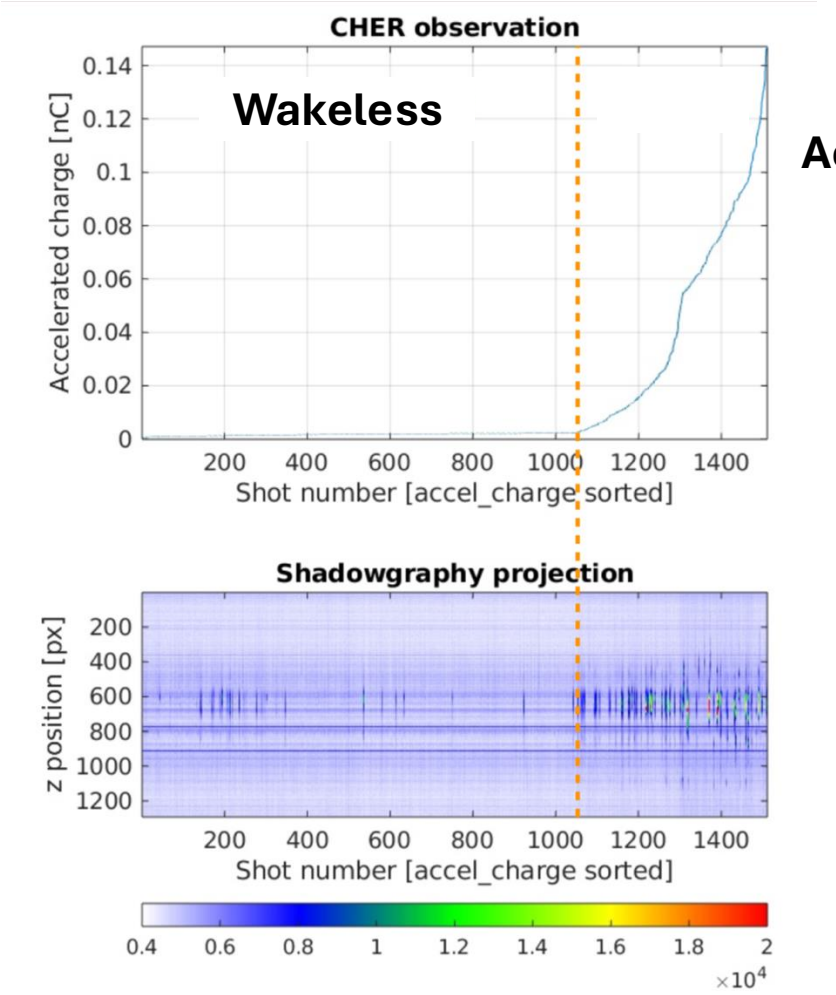
Electron spectrum

In this dataset, shot-to-shot fluctuations resulted in a variation in peak currents that lead to a mixture of Plasma acceleration and wakeless shots.

More charge accelerated

↕

Stronger shadowgraphy trace



Plasma Acceleration

Conclusions

E300:

- O(10 GeV/m) acceleration observed for 150-250 pC witness bunch
- Sub 1% energy spread of accelerated bunch
- 5-6% total efficiency observed

E340:

- First demonstration of dark-field shadowgraphy images at an accelerator facilty
- Plasma acceleration and wakeless transition observed by changing longitudinal phase space

Many thanks to our collaborators

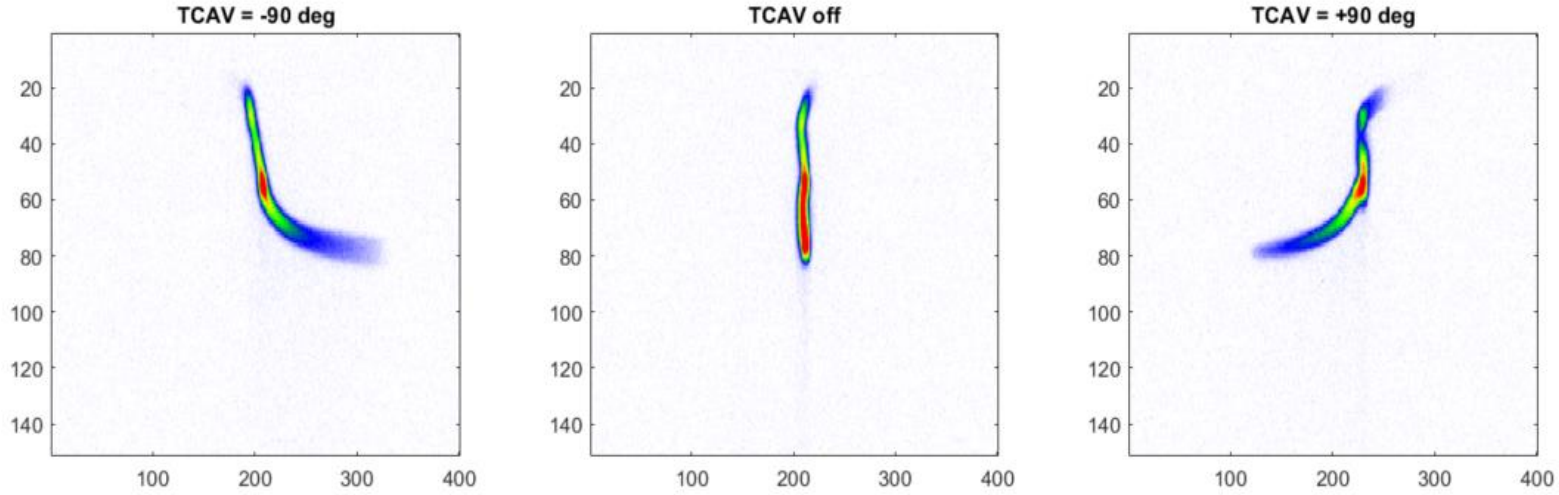
Thank you

Questions?

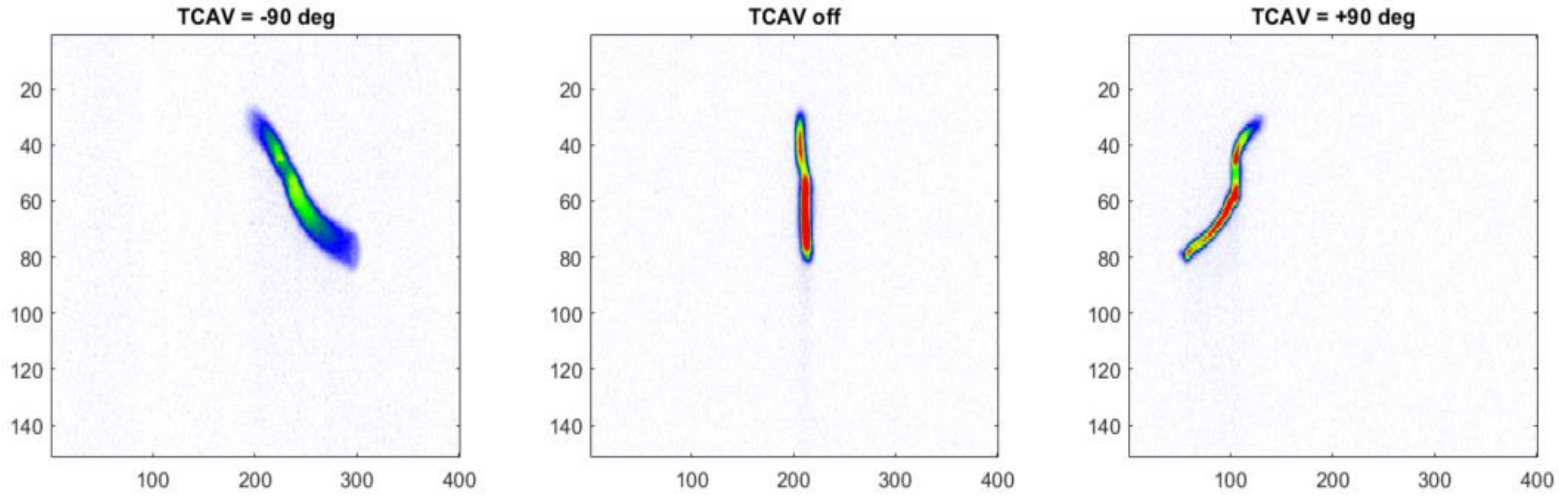
Backup

Longitudinal phase space reconstruction

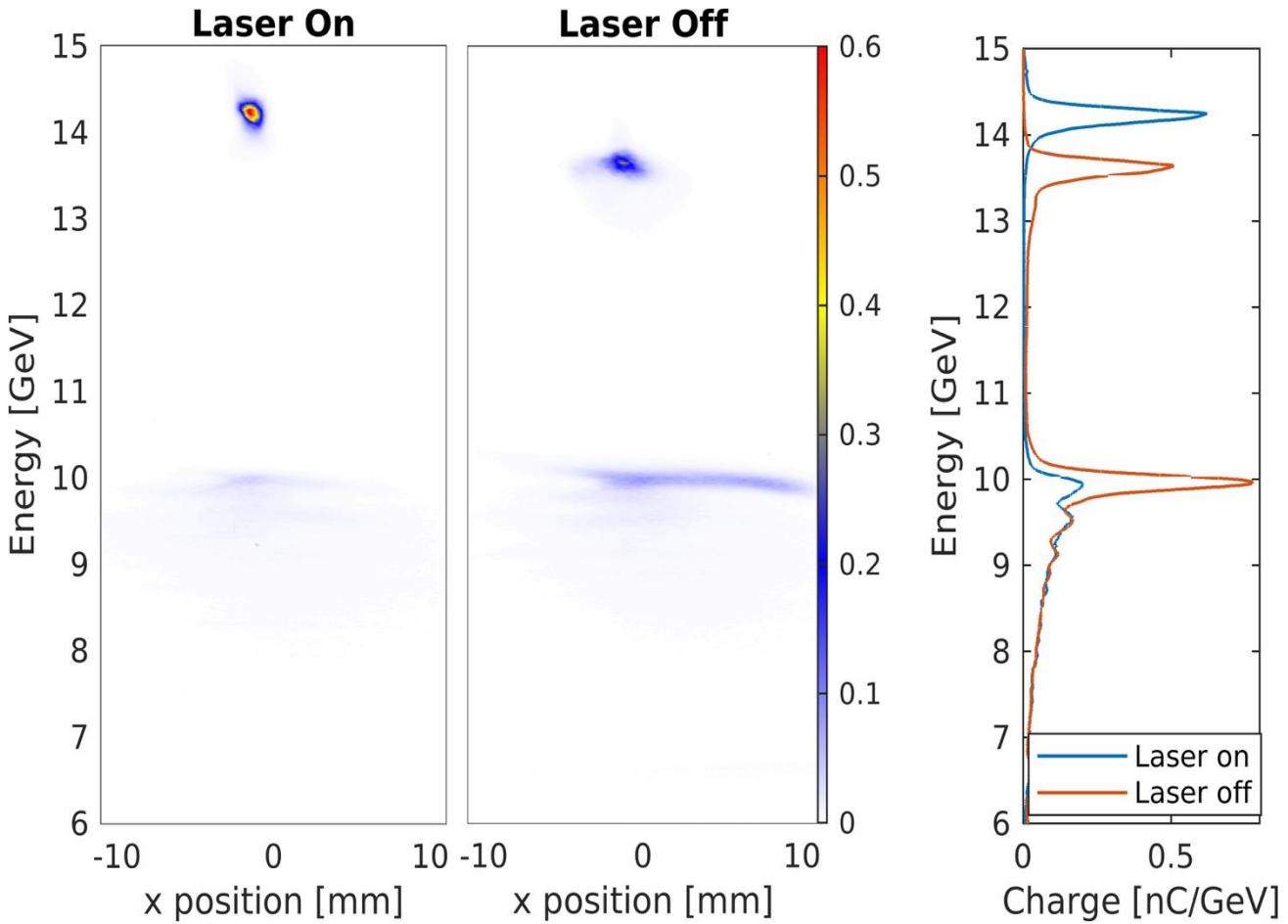
PWFA



Wakeless



Impact of laser pre-ionization



	Laser Ionized	Beam Ionized
Energy gain, ΔE_w	(4.0 ± 0.2) GeV	(3.7 ± 0.2) GeV
Field uniformity, $\sigma_{E_w}/\Delta E$	(2.3 ± 0.2) %	(3.4 ± 0.6) %
Total efficiency, η_{tot}	**(5.5 ± 0.5) %**	**(4.6 ± 0.3) %**
Witness charge capture, Q_w	(68 ± 6) %	(64 ± 4) %

Credit: Doug Storey

Figure of merit

How to determine “best” shots?

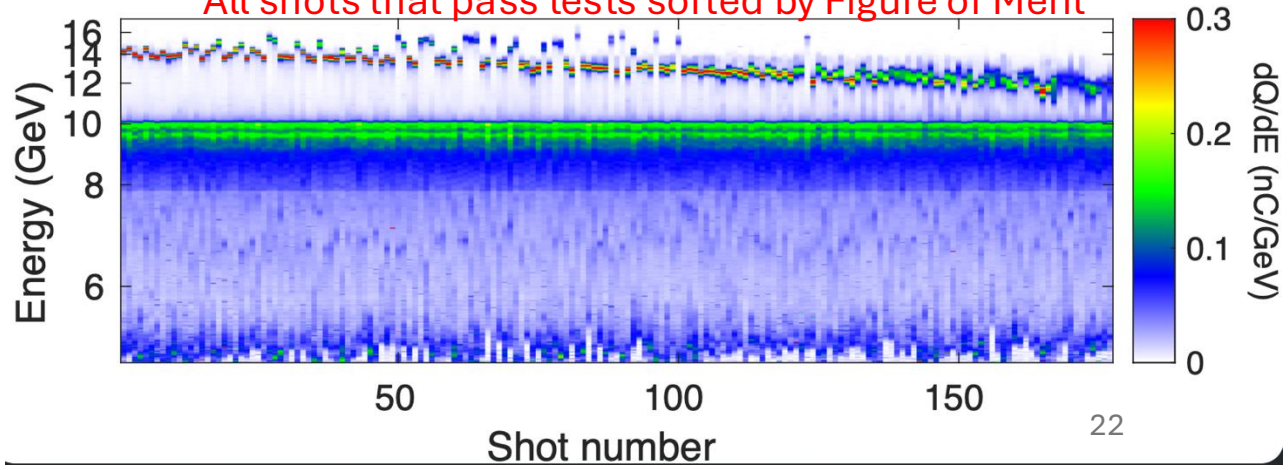
1) Examples of tests to filter shots with no acceleration:

- Max dQ/dE above 10.5 GeV ≥ 50 pC (minimum threshold for accelerated peak)
- total charge accelerated above 10.5 GeV ≥ 10 pC (removes hot pixels)
- RMS (E_{RMS}) and mean energy (⟨E⟩) of charge above 10.5 GeV satisfy $1.5\ E_{RMS} <$ ⟨E⟩ - 10.5 GeV
- Full list: https://confluence.slac.stanford.edu/spaces/FACET/pages/623415042/PWFA+analysis+CHER+pre-processing

2) Define figure of merit on remaining shots:

- $$\Omega = \frac{\left(\frac{\sigma_{E_W}}{\Delta E_W}\right)}{\eta_{tot}\left(\frac{\Delta E_W}{10\ \mathrm{GeV}}\right)}$$

All shots that pass tests sorted by Figure of Merit



FACET-II at SLAC

Credit: SLAC