Beam Configurations

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FACET-II User Meeting

October 17th, 2023

SLAC

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

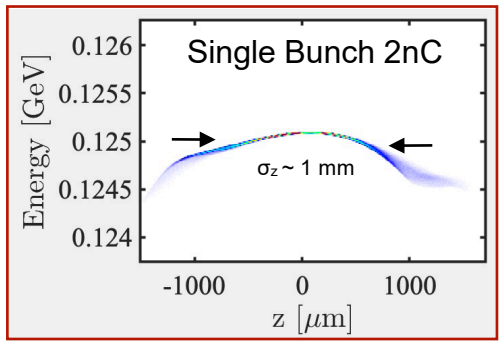
Outline

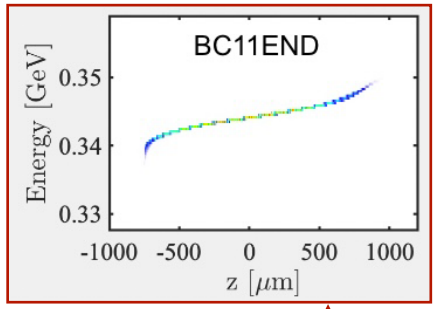
- FACET-II accelerator overview

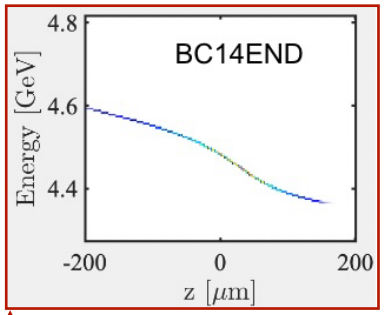
- Simulations of single bunch 2nC operation:
  - Beam parameters at IP near full compression
  - Compression tuning and collimation options
  - Impact of Laser Heater on beam parameters at IP
  - Jitter scans with laser heater on/off

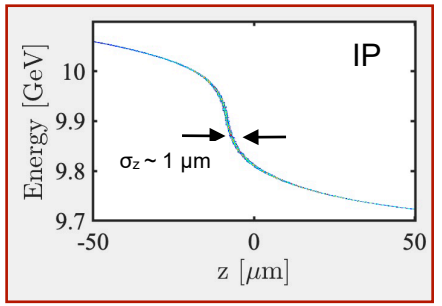
- Plans for two bunch operation

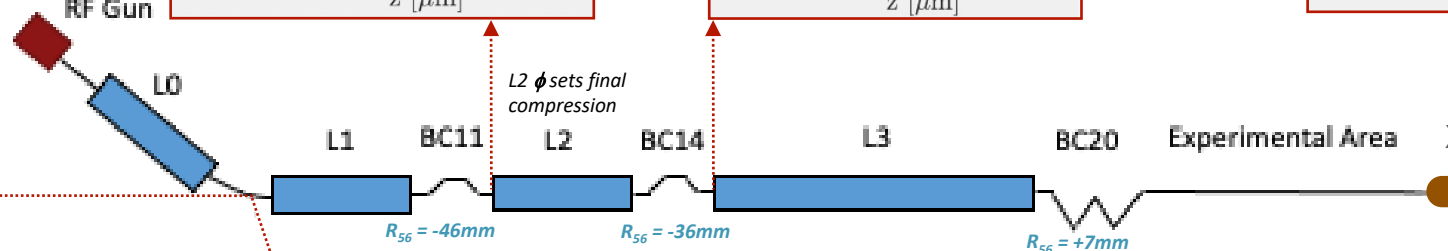
FACET-II Accelerator Overview











E = 10 GeV
Q = 0.6 – 2.0 nC
$\beta^* > 5$ cm
$\sigma_z > 0.7$ - 100 μm
$\delta_E = 0.1 – 1.4$ %
$I_{pk} = 1 – 300$ kA
$\gamma\varepsilon_x = 5$-40 mm-mrad

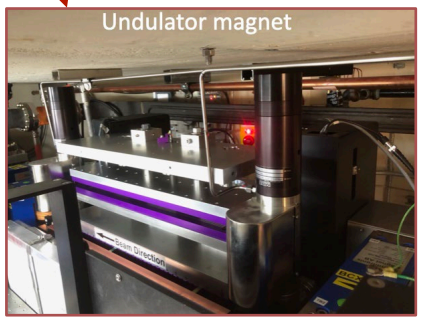
Photoinjector
Single and two bunch operation with variable charge Q = 0.6-2nC

E = 125 MeV
σ_z = 0.8 - 1 mm

E = 335 MeV
σ_z = 0.4-0.5 mm

E = 4.5 GeV
σ_z = 80-100 μm

E = 10 GeV
σ_z = 0.7-100 μm



Laser heater
Beam shaping capabilities

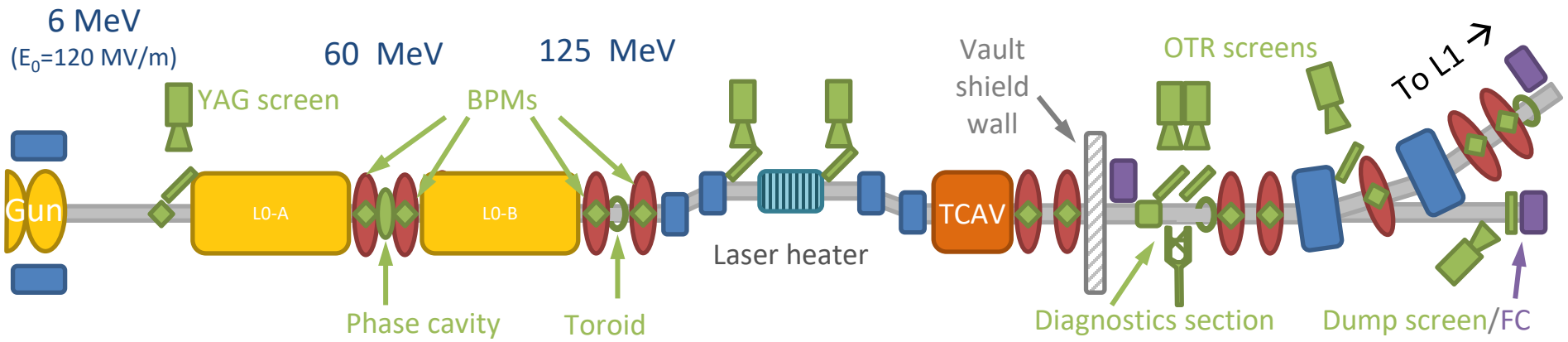
Notch and jaw collimators
Beam shaping capabilities

Main Beam Configurations

1. Single bunch, 2 nC (TDR, W-Chicane, with/without collimation/laser heater)
2. Two bunch (from cathode, 0.5 + 1.5 nC) with/without laser heater
3. Single bunch, long bunch, good transverse quality (SFQED initial experiments. *Not covered here.*)

FACET-II linac provides single and two-bunch beam configurations at IP with flexible beam shaping capabilities

Electron Injector Parameters



Parameter	Single Bunch TDR	Operation (Summer 2022)	Operation (Summer 2023)
Bunch Charge (nC)	2	2	1
Gun rf Phase (deg)	10	30	30
Cut radius on transverse laser spot [mm]	2.68	2.75	2.75
Laser pulse length (FWHM) [ps]	7.0	3.8	2.2
Gun Solenoid Int. Field Strength [kG.m]	0.38	0.39	0.39

Injector simulation infrastructure updated to streamline start-to-end modeling from gun to beam dump

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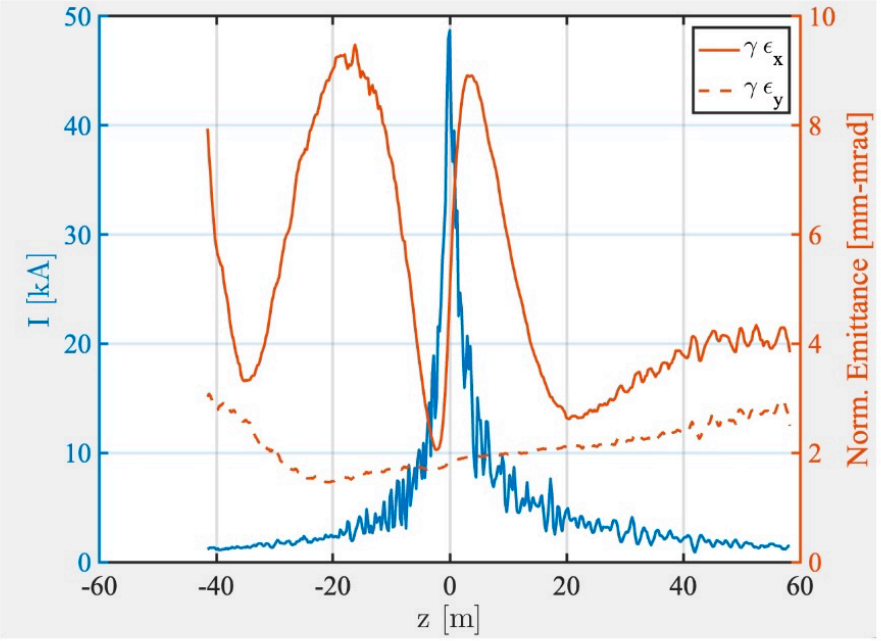
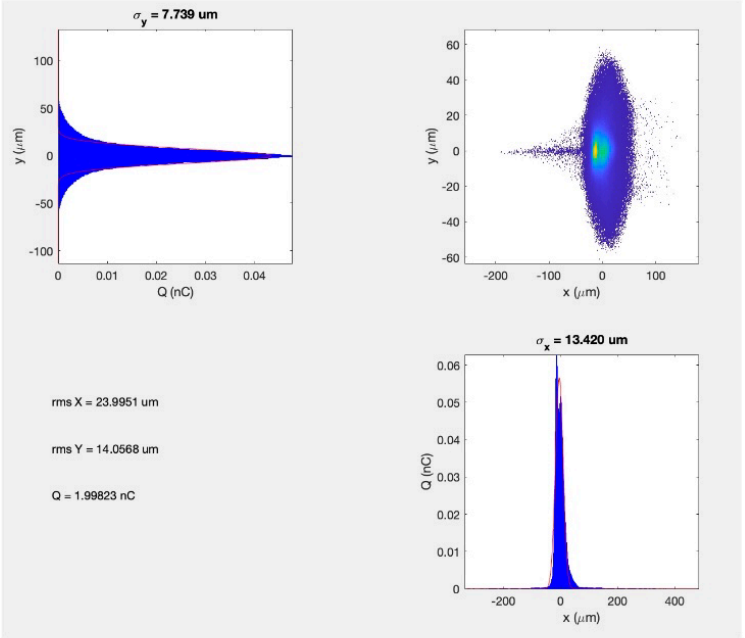
Single Bunch 2nC Beam Parameters at IP

Current and slice emittance

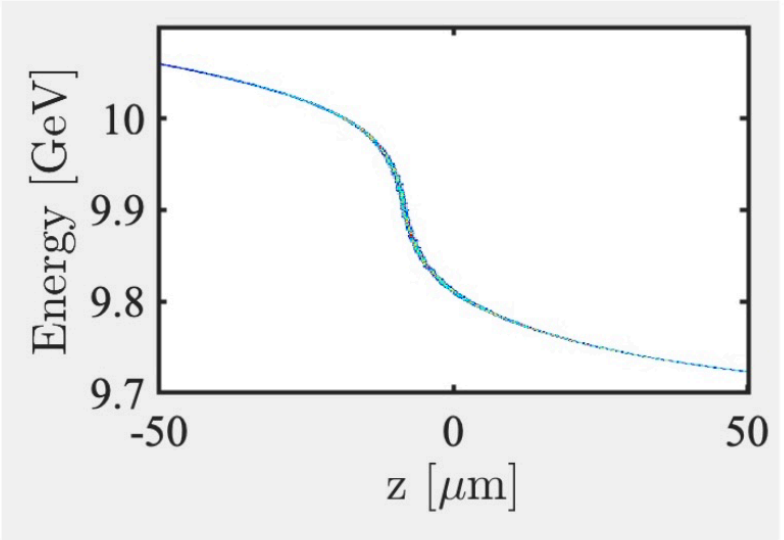


Head of the beam is on the left

Transverse Profile



Longitudinal Phase Space



CSR in BC20 increases the horizontal slice emittance and the horizontal spot size with respect to the vertical

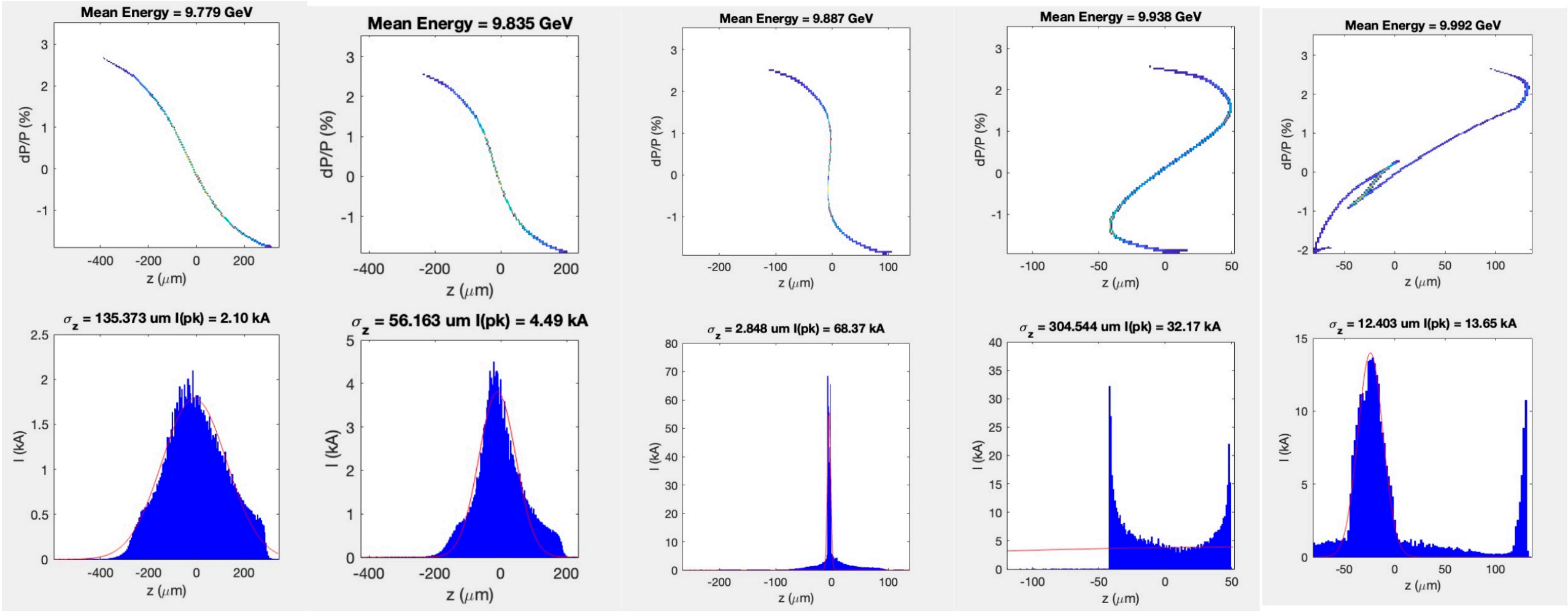
L1 phase = -20.5 deg, L2 phase = -40.05 deg
Final Focus optics are for 50cm round beta at the IP

Parameter	Value	Unit
RMS beam size, Gaussian Fit (x,y,z)	(13.4,7.7,3.3)	um
Peak current	48.7	kA
Normalized emittance 90% cut (x,y)	(5.4,1.9)	um-rad

Simulations scanning the L2 phase

Two bunch candidates?

-41.8 deg | -40.8 deg | -39.8 deg | -38.8 deg | -37.8 deg



Head of the beam is on the left

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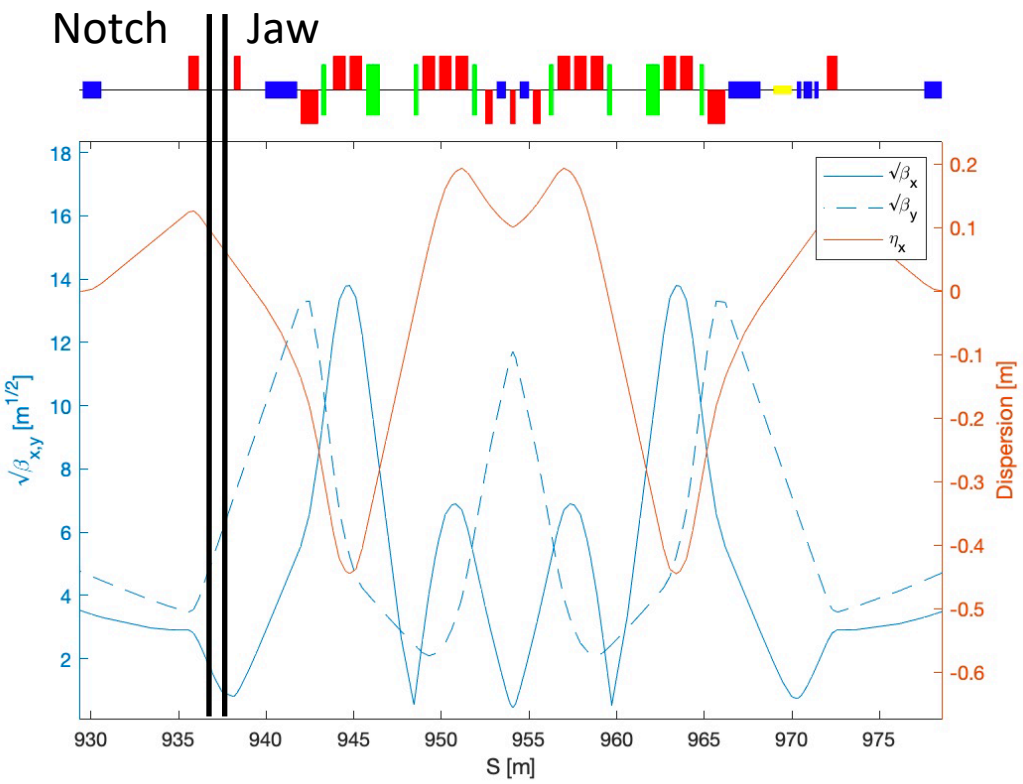
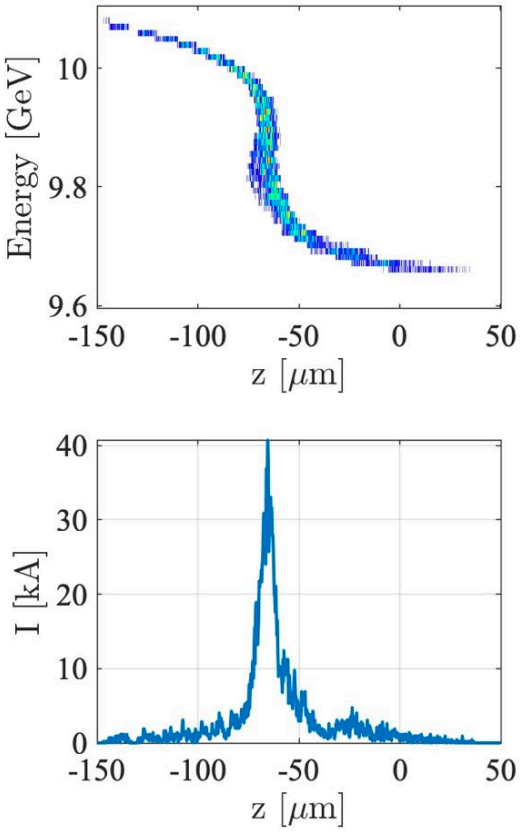
Beam shaping with Notch and Jaw Collimators in BC20

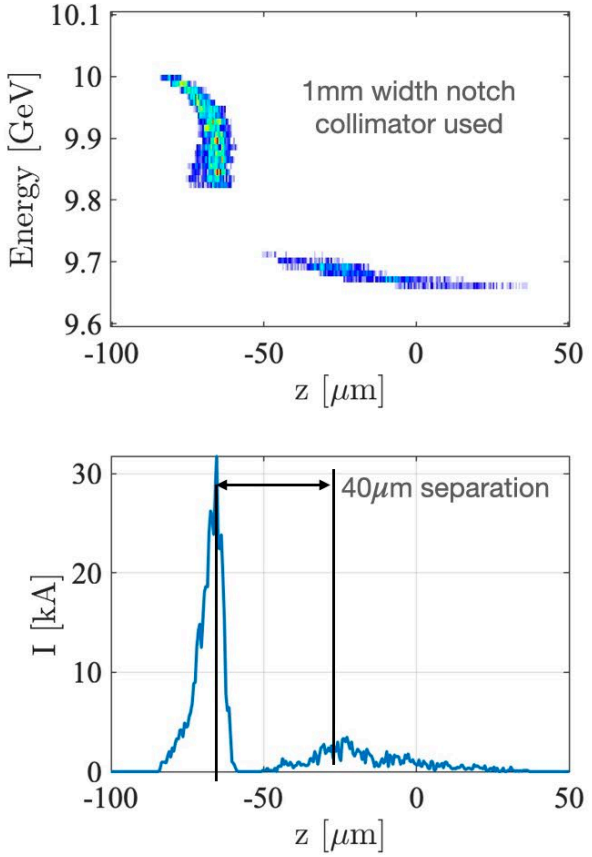
Lattice Functions in the W chicane



AT BC20END
(no collimation)



AT BC20END (notch +
jaw collimation)

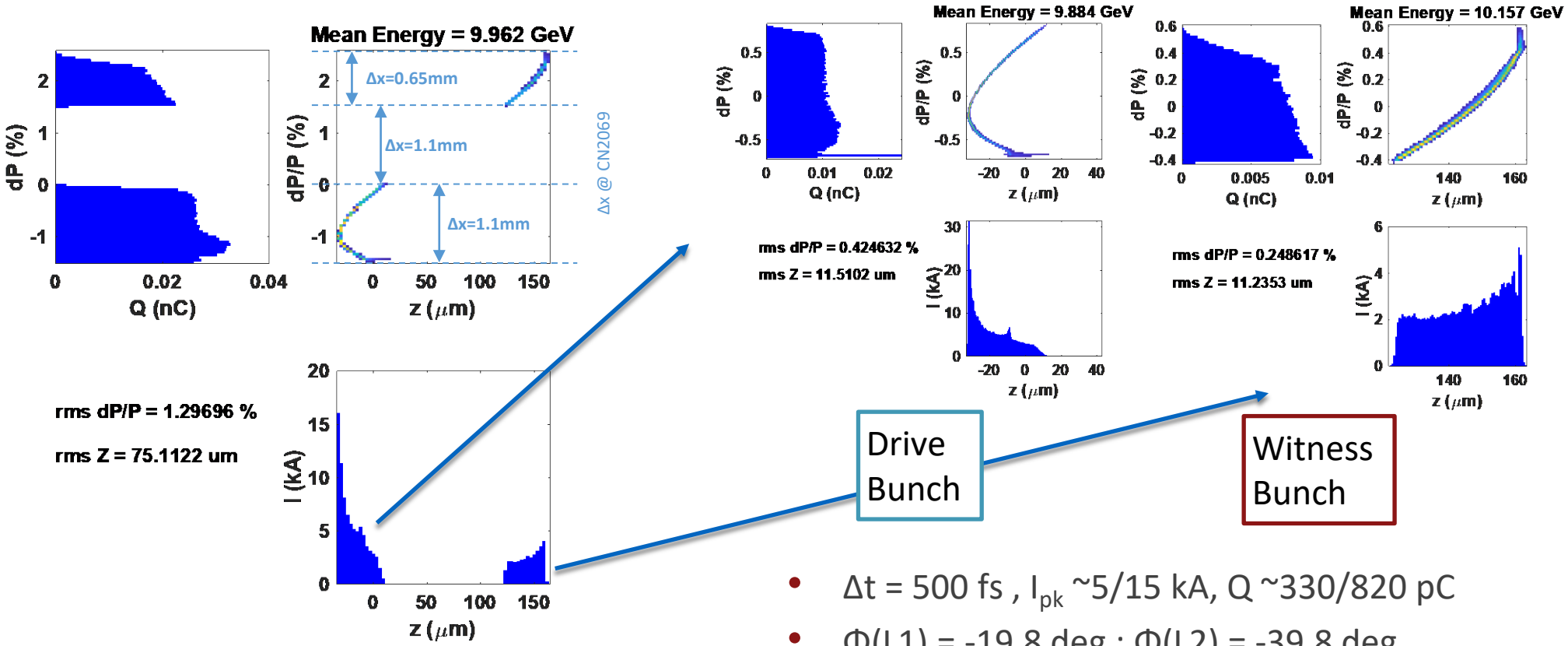


Idive/Iwitness = 10
Qdrive/Qwitness = 3.2

Qdrive = 830 pC
Qwitness = 260 pC

Notch and jaw collimation provides ability to shape beam distribution at the IP with minimal linac tuning

Alternate 2-bunch Configuration Particle Tracking

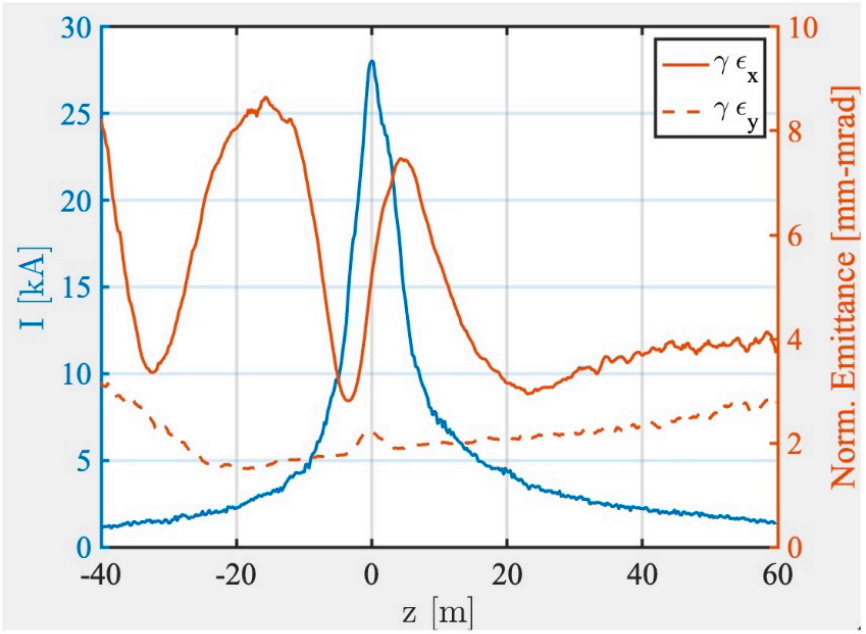


- Δt = 500 fs , I_{pk} ~5/15 kA, Q ~330/820 pC
- Φ(L1) = -19.8 deg ; Φ(L2) = -39.8 deg
- Can trade: >I_{pk} for < Δt by adjusting Φ (L1 & L2)

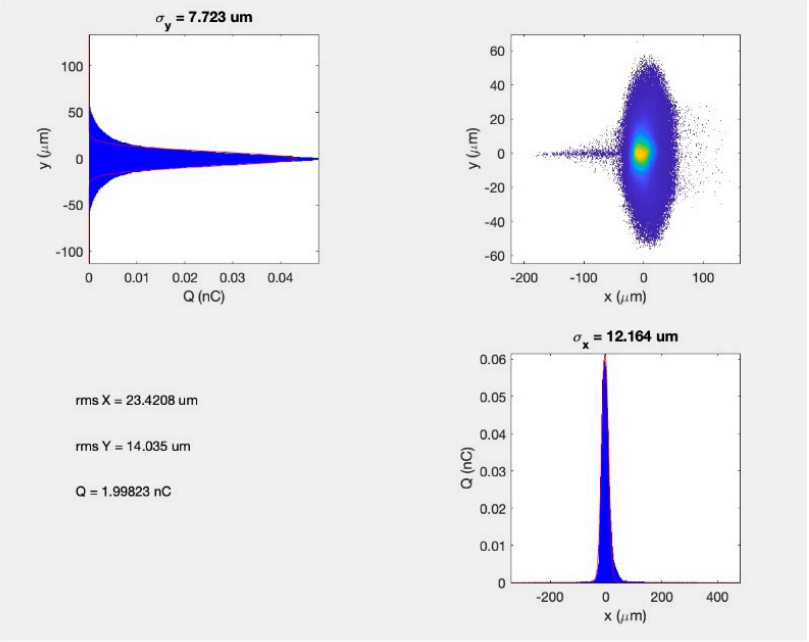
Notched configuration enables quick start of PWFA 2–bunch experiments ahead of double-pulsed injector configuration which will bring improved beam quality next year

Single Bunch 2nC Beam Parameters at IP with Laser Heater

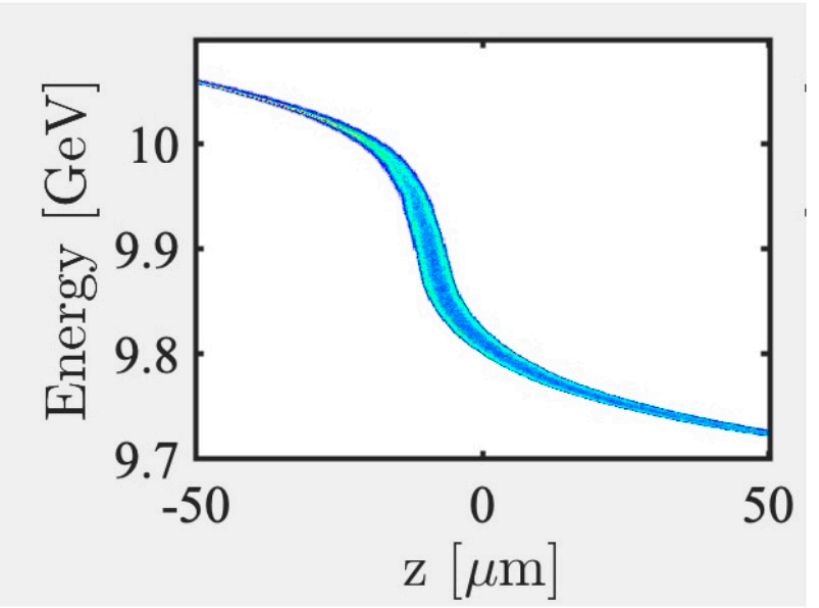
Current and slice emittance



Transverse Profile



Longitudinal Phase Space



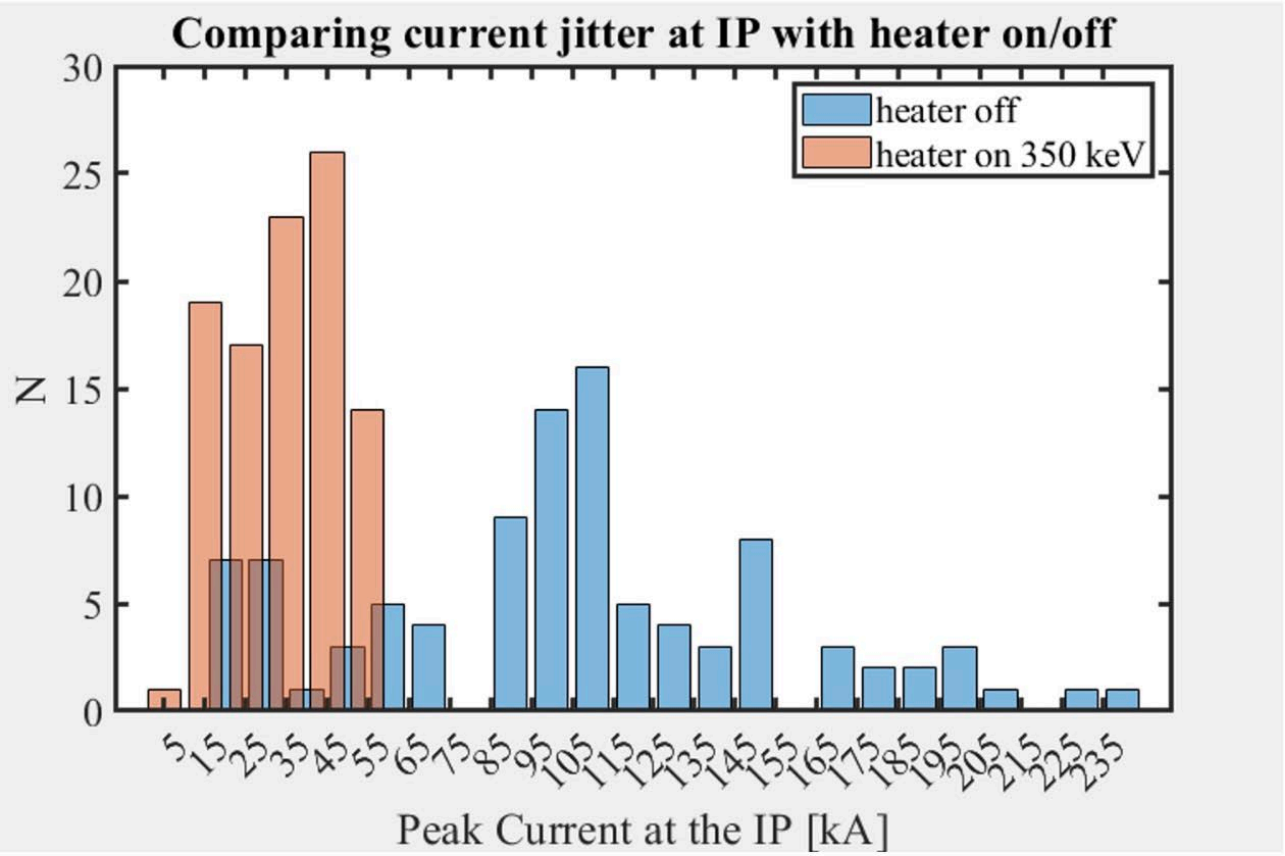
Laser heater removes some of the asymmetry in the horizontal projection and reduces the slice emittance variation in the core of the beam

L1 phase = -20.5 deg, L2 phase = -40.05 deg
Final Focus optics are for 50cm round beta at the IP
Laser heater induced energy spread = 350 keV RMS

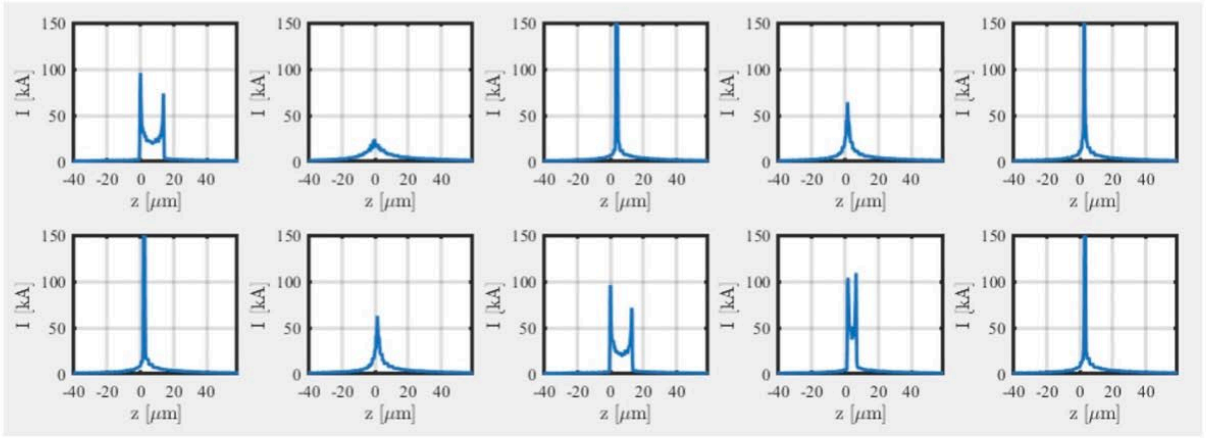
Parameter	Value	Unit
RMS beam size, Gaussian Fit (x,y,z)	(12.1,7.7,5.3)	um
Peak current	28.1	kA
Normalized emittance 90% cut (x,y)	(5.1,2.0)	um-rad

Starting point for the jitter scans is the 2nC single bunch simulation shown in the slides.
Jitter parameters are L1 and L2 RF phase (±0.25 deg) and amplitude (±0.1 %)

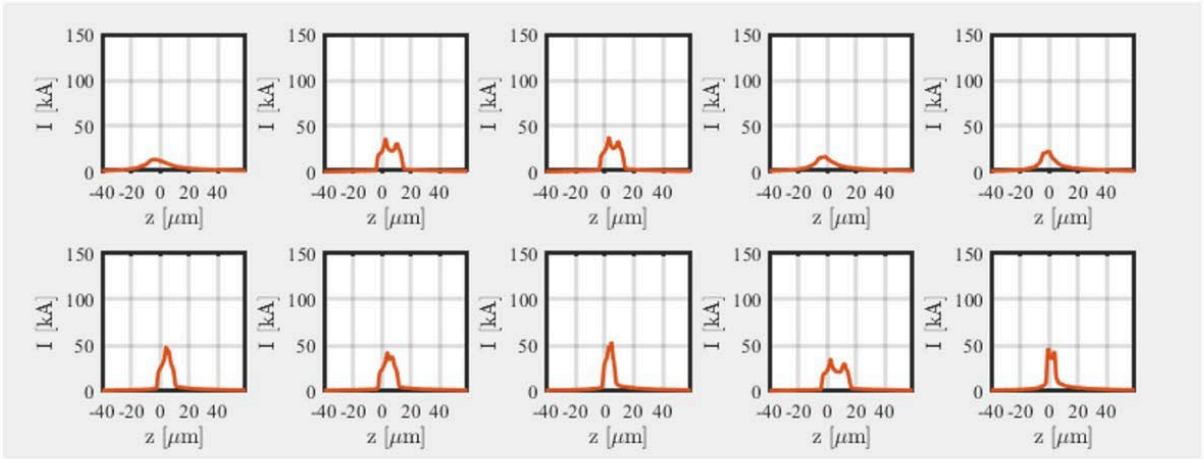
Jitter scans - single bunch current variation with LH on/off at 350 keV



Current profile examples heater off

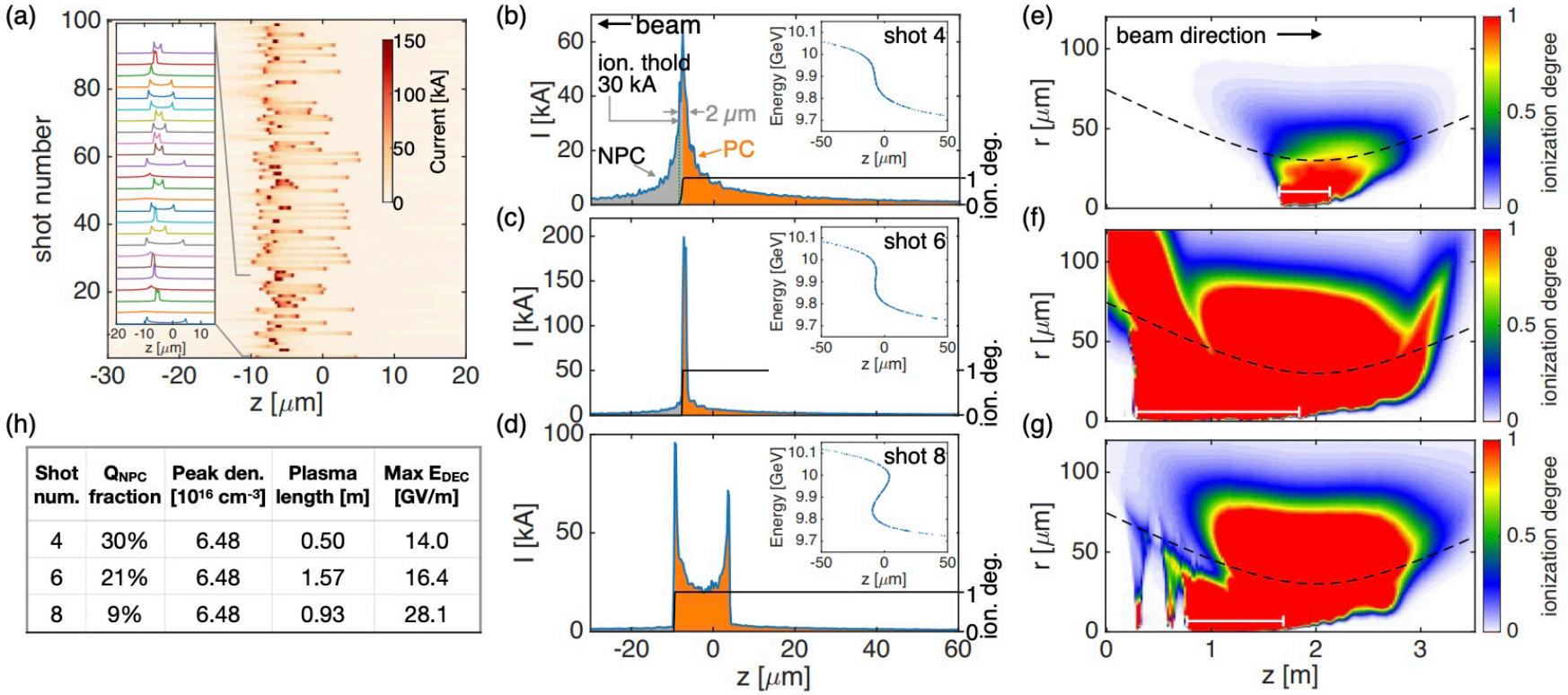


Current profile examples heater on



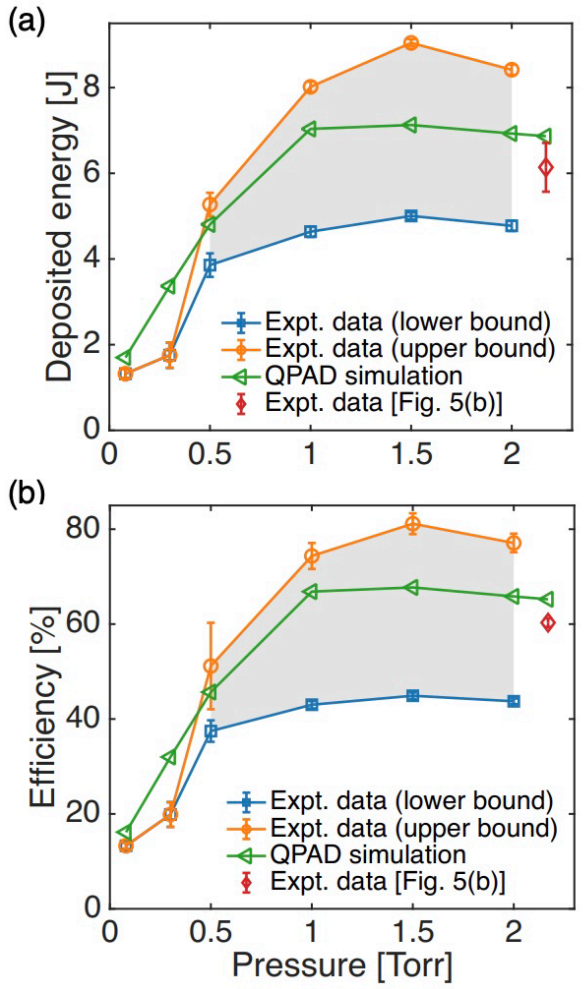
The laser heater reduces fluctuations of the peak current at the IP

Jitter data used to understand PWFA interaction



(h)

Shot num.	Q_{NPC} fraction	Peak den. [10^{16} cm^{-3}]	Plasma length [m]	Max E_{DEC} [GV/m]
4	30%	6.48	0.50	14.0
6	21%	6.48	1.57	16.4
8	9%	6.48	0.93	28.1

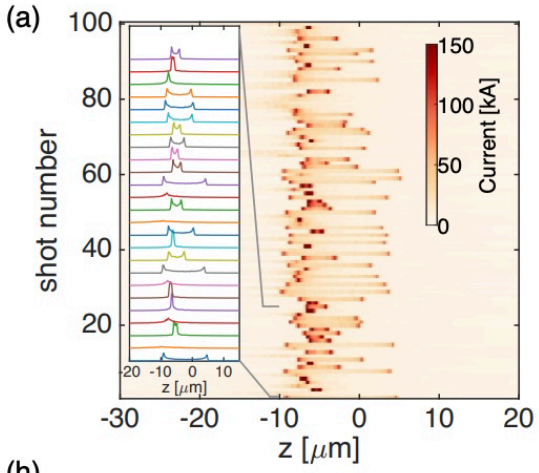


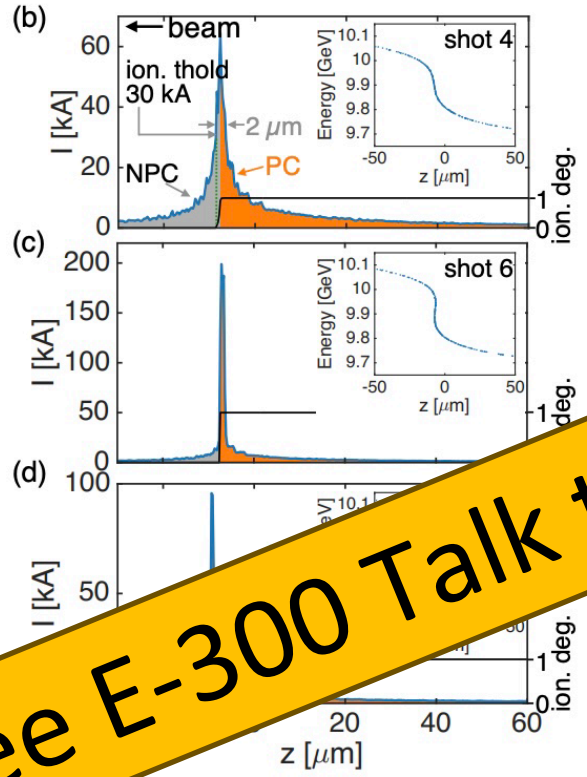
- Participating charge and energy are loss in PWFA sensitive current profile

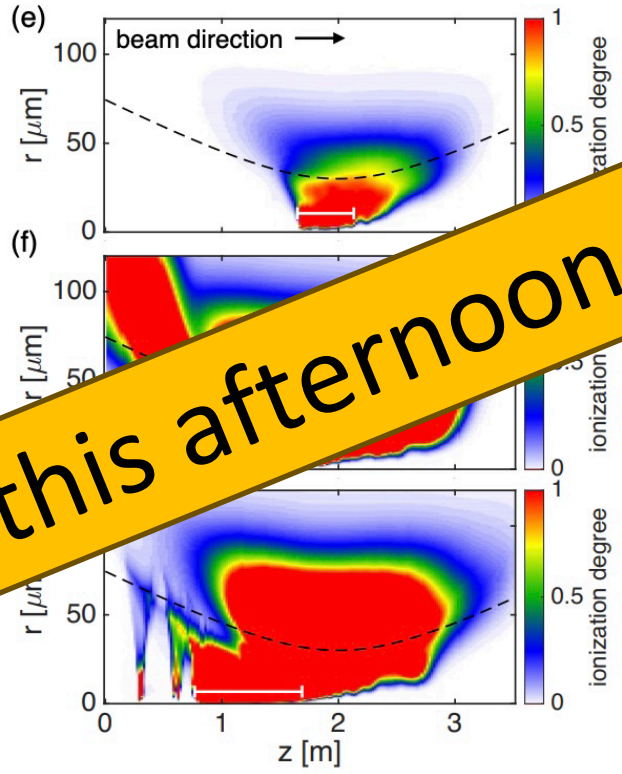
- Simulations used to quantitatively understand charge participation in ionization and capture of particles.

Plasma accelerated spectra reveal details of incoming beam consistent with simulation results

Jitter data used to understand PWFA interaction

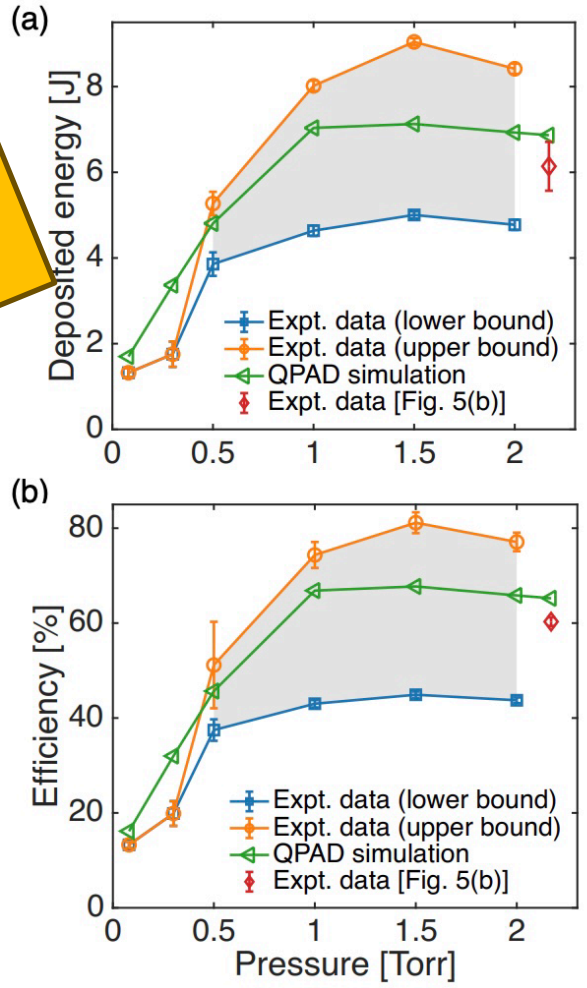






(h)

Shot num.	Q_{NPC} fraction	Peak den. [10^{16} cm^{-3}]	Plasma length [m]	Max E_{DEC} [GV/m]
4	30%	6.48	0.50	14.0
6	21%	6.48	1.57	16.4
8	9%	6.48	0.93	28



See E-300 Talk this afternoon

- Participating charge [illegible]ergy are loss in PWFA sensitive current profile

- Simulations used to quantitatively understand charge participation in ionization and capture of particles.

Plasma accelerated spectra reveal details of incoming beam consistent with simulation results

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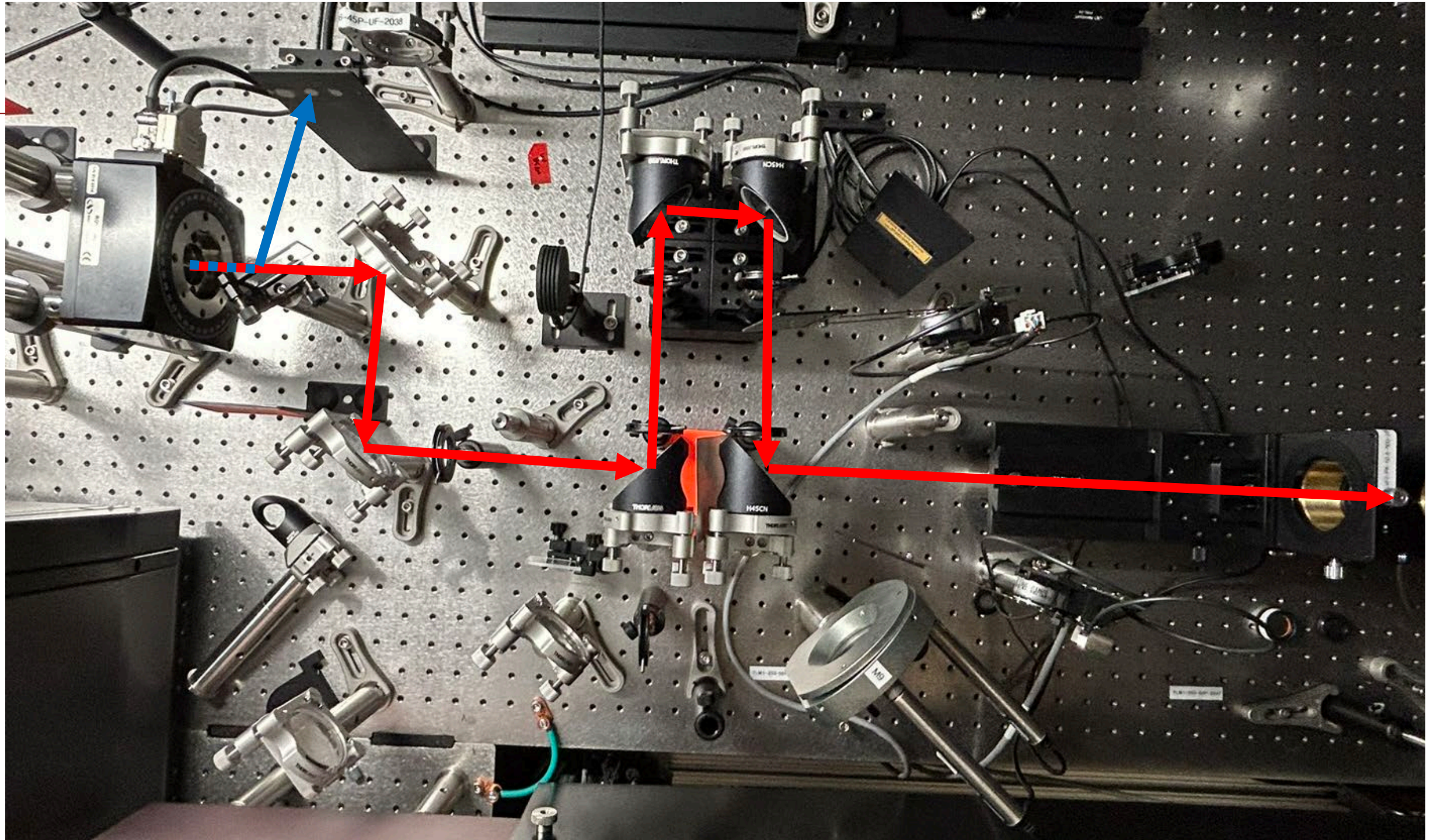
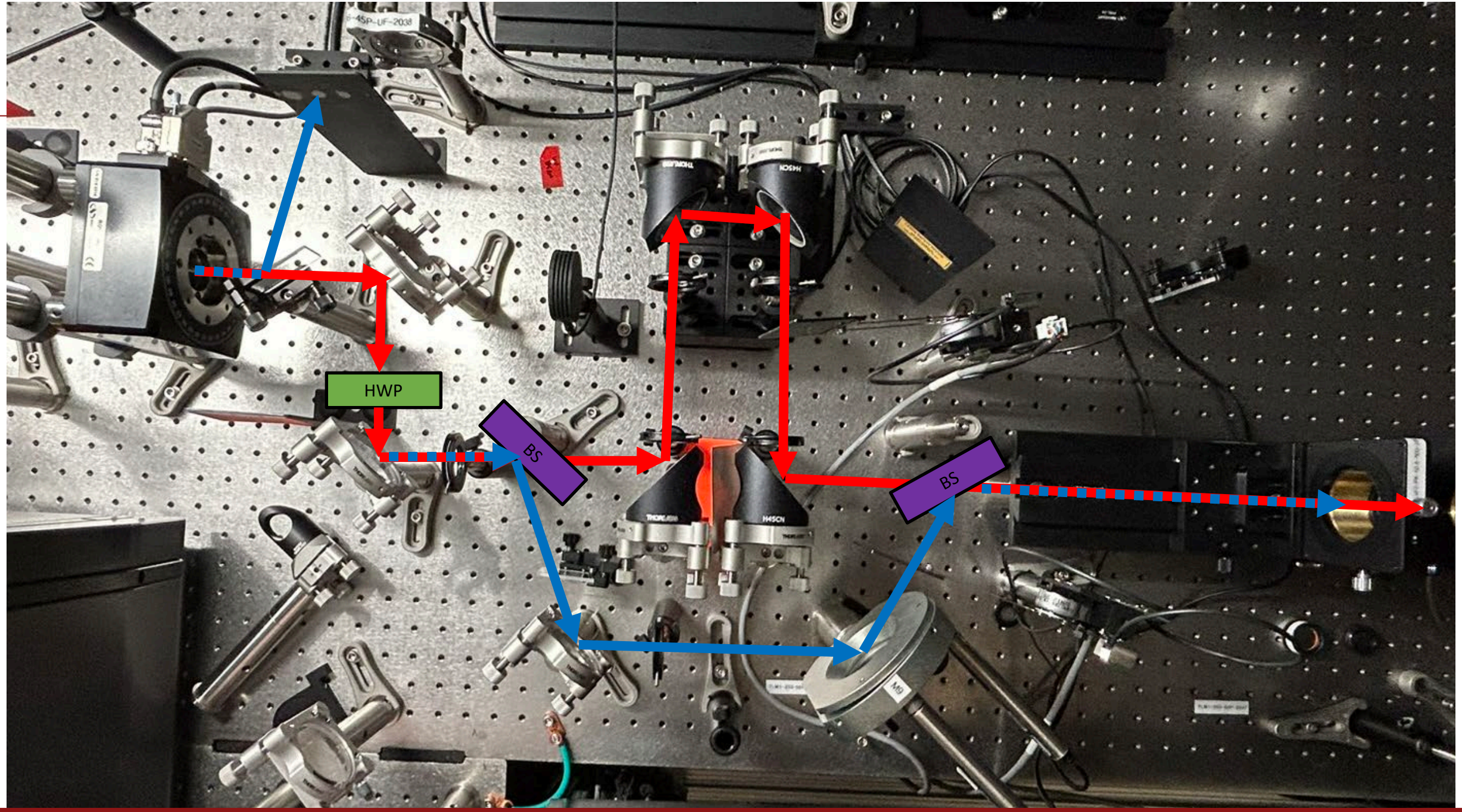
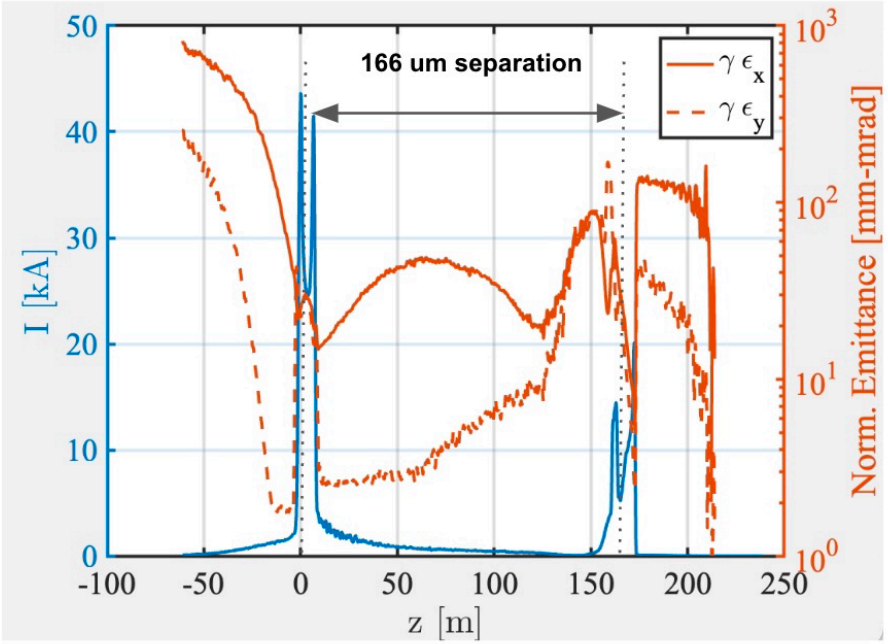

M9



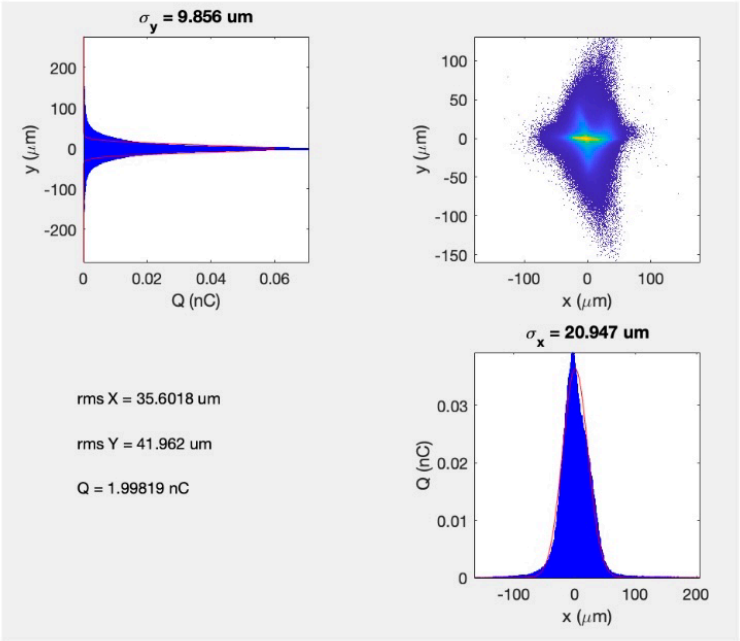
Hardware is in hand and ready for installation

Expected two-bunch beam parameters at IP, LH off

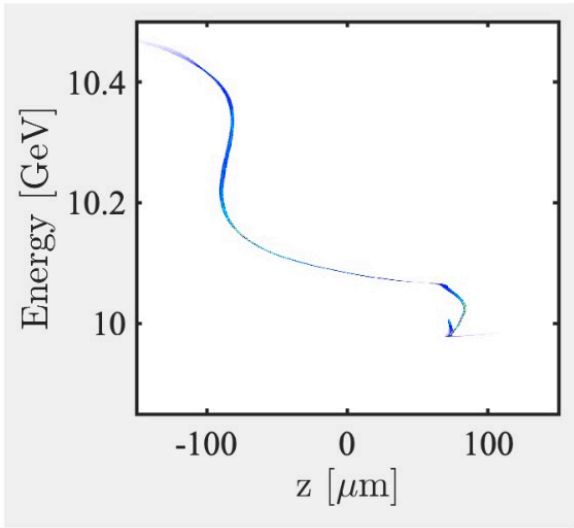
Current and slice emittance



Transverse Profile



Longitudinal Phase Space



Head of the beam is on the left

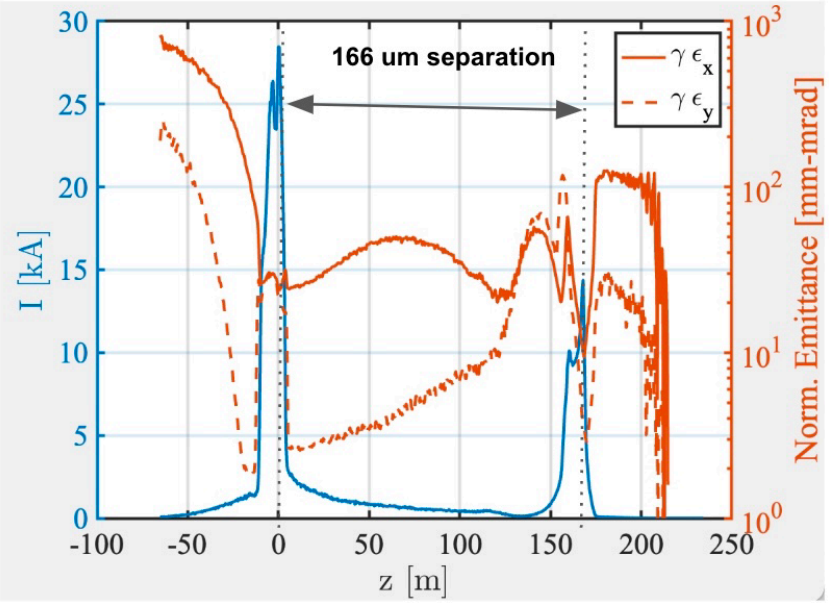
Witness beam energy set to 10 GeV in the final focus

L1 phase = -23 deg, L2 phase = -42.5 deg
Final Focus optics are for 50cm round beta at the IP

Parameter	Drive	Wit	Unit
RMS beam size, Gaussian Fit (x,y,z)	20.6,9.5, 3.9	24.3,5.4, 6.4	um
Peak current	43.7	20.4	kA
Normalized emittance 90% cut (x,y)	24.8,20.5	27,35	um-rad

Expected two-bunch beam parameters at IP, LH on

Current and slice emittance



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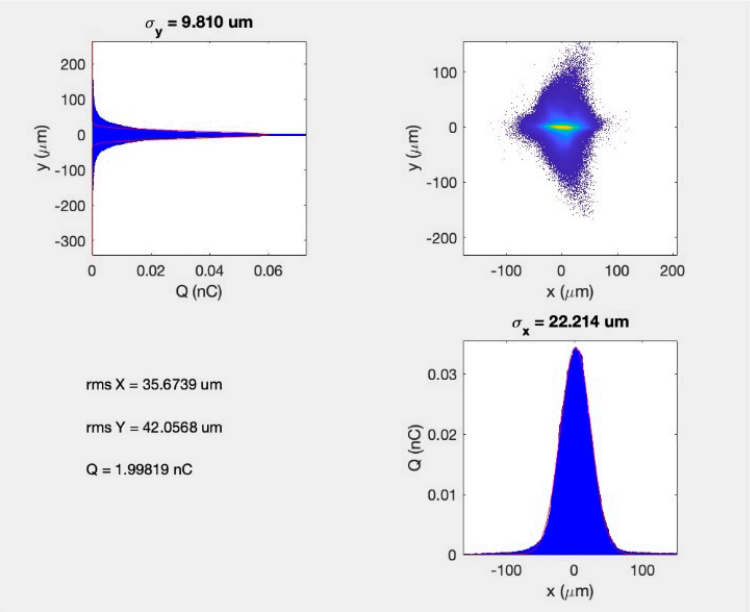
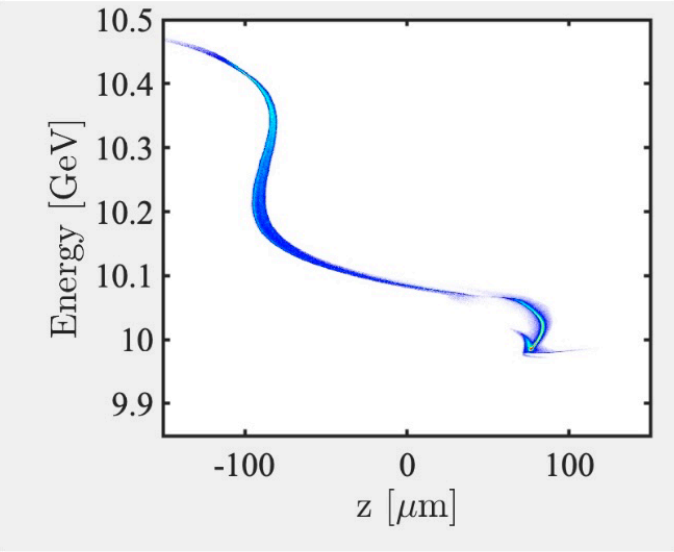


Longitudinal Phase Space



Head of the beam is on the left

Witness beam energy set to 10 GeV in the final focus

Note that 3.5 mJ is the max LH energy we have measured going into the LH undulator

L1 phase = -23 deg, L2 phase = -42.5 deg

Final Focus optics are for 50cm round beta at the IP

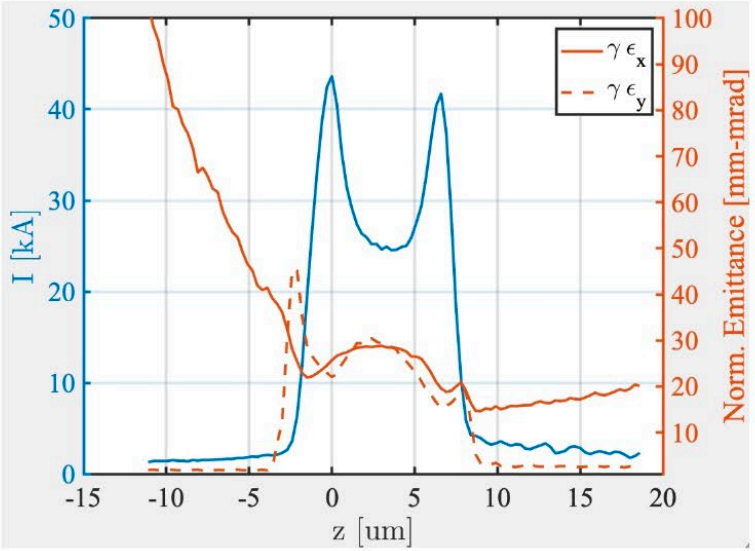
LH energy = 3.5 mJ, LH pulse length = 9 ps FWHM

Parameter	Drive	Wit	Unit
RMS beam size, Gaussian Fit (x,y,z)	21.9,9.6, 4.7	23.5,5.5, 5.0	um
Peak current	28.4	14.4	kA
Normalized emittance 90% cut (x,y)	27.7,22.6	25.7,37	um-rad

Drive/Witness beam parameters at IP with LH on/off

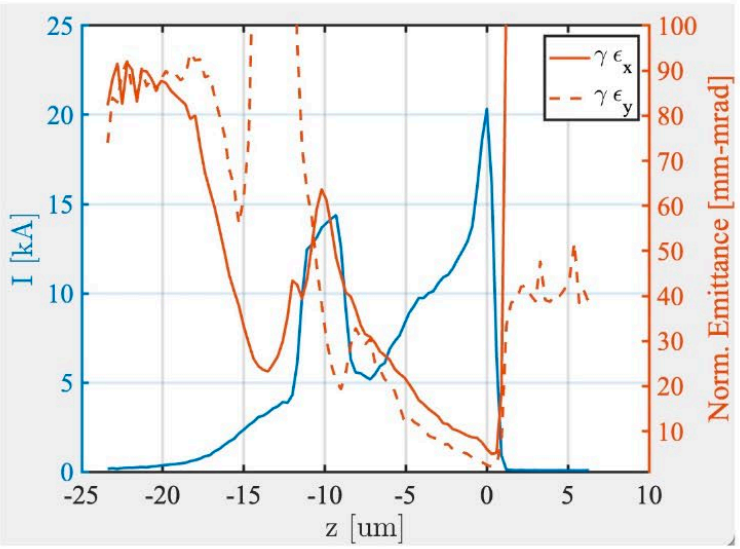
Drive

LH off



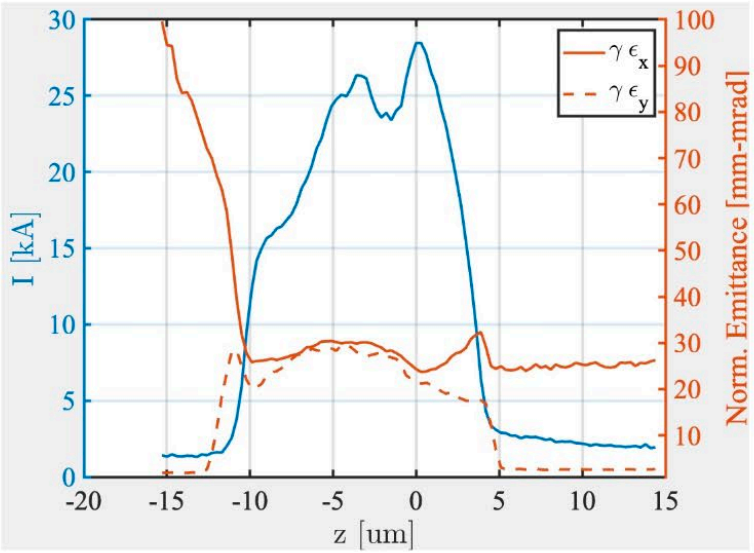
Witness

LH off



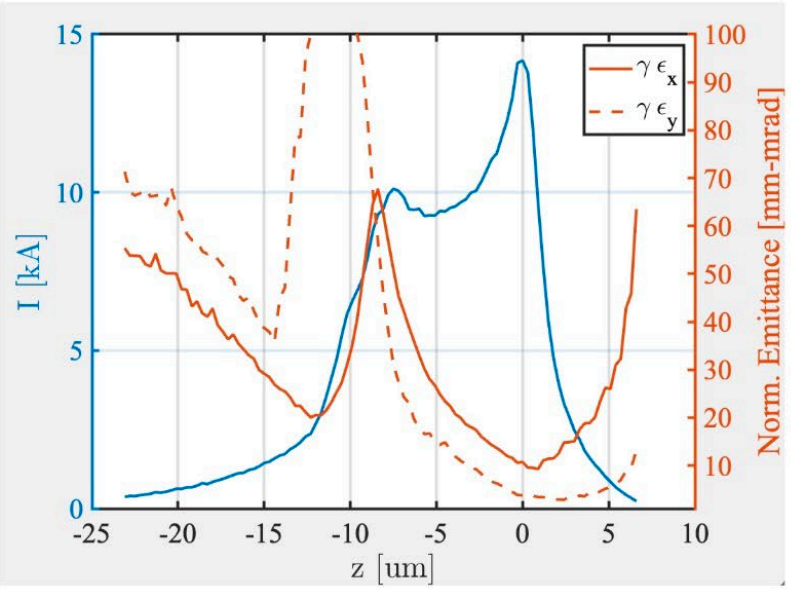
Drive

LH on



Witness

LH on



Summary

- FACET-II offers flexible single bunch and (soon-to-come) two bunch configurations with beam shaping capabilities to serve the user community.
- Start-to-end simulations set expectation for beam parameters at the IP including shot-to-shot variation due to linac jitter.
  - Example beam distributions and lattice configurations are available here
- Recently commissioned upgrades like the laser heater can improve the beam stability at the IP.
- These linac jitter simulations will inform PWFA simulations
- Two-bunch UV pulse stacker hardware in hand; planned install during winter down
  - Other options in the meantime

Accelerator configurations designed to meet the need of the FACET-II science program