FACET-II Start-to-End Simulations of Electron Beam

FACET-II Science Workshop, October 29, 2019

Glen White

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Overview

Start-to-end simulation of FACET-II e- beamline

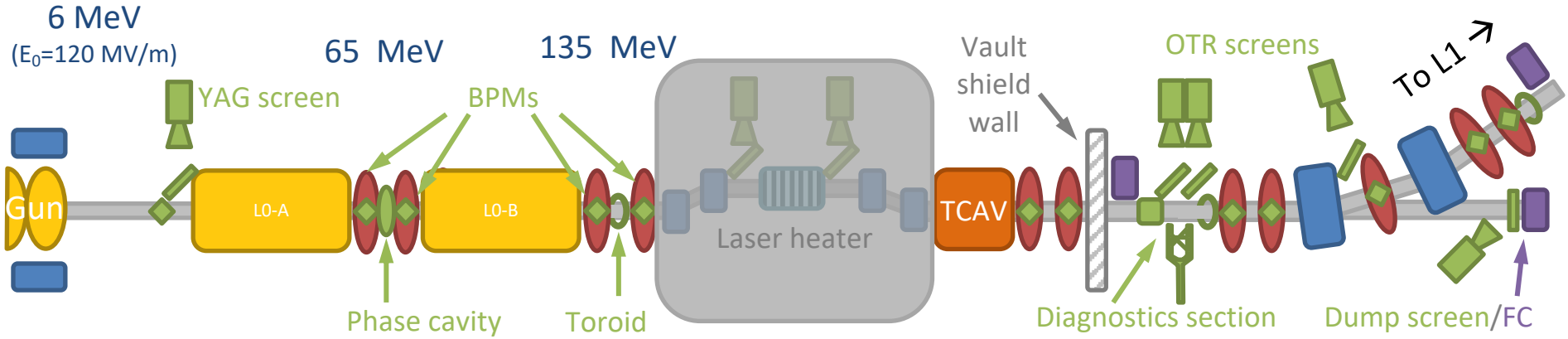
- Injector simulation gun – L1 with GPT
- Linac and bunch compressor simulation with Lucretia, including upgraded layout for Sector 20 bunch compressor and final focus system

Simulations performed with different accelerator configurations*

**All sims with updated Sector 20 layout unless otherwise stated*

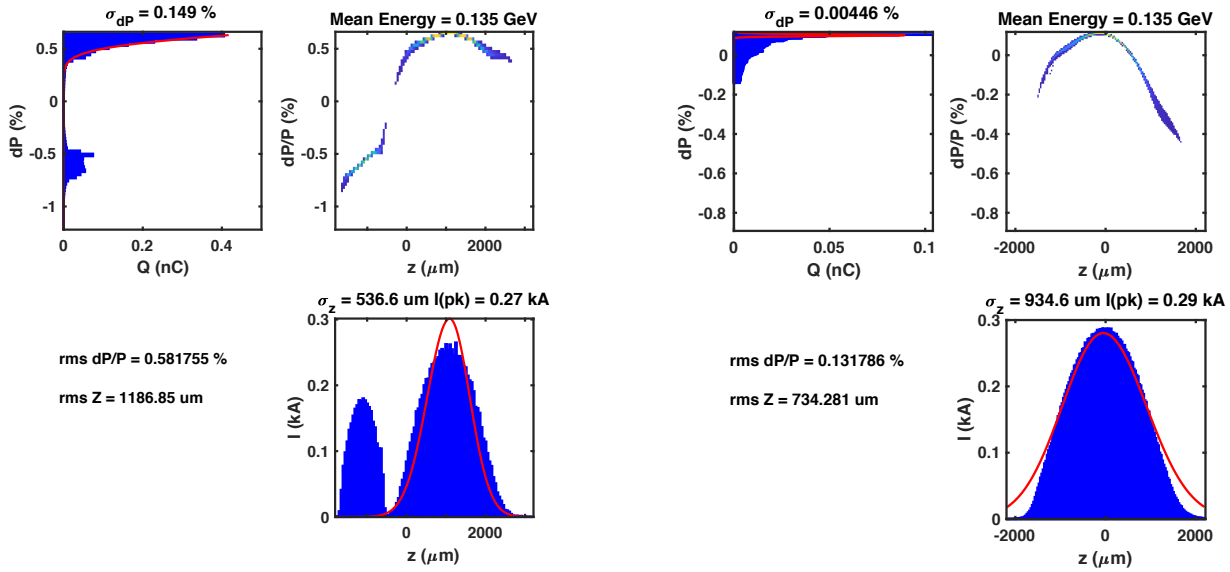
- Single bunch, 2 nC, (TDR, W-Chicane)
  I_{pk} = 72 kA
- Single bunch, high compression (using collimation & laser heater)
  I_{pk} = 50-302 kA
- Single bunch, long bunch, good transverse quality
  (SFQED initial experiments)
  I_{pk} = 3 kA
- 2 bunch (from cathode, 0.5 + 1.5 nC)
  I_{pk} = 30 / 60 kA or **10 / 20 kA** with Laser Heater

Electron Injector – Gun Parameters



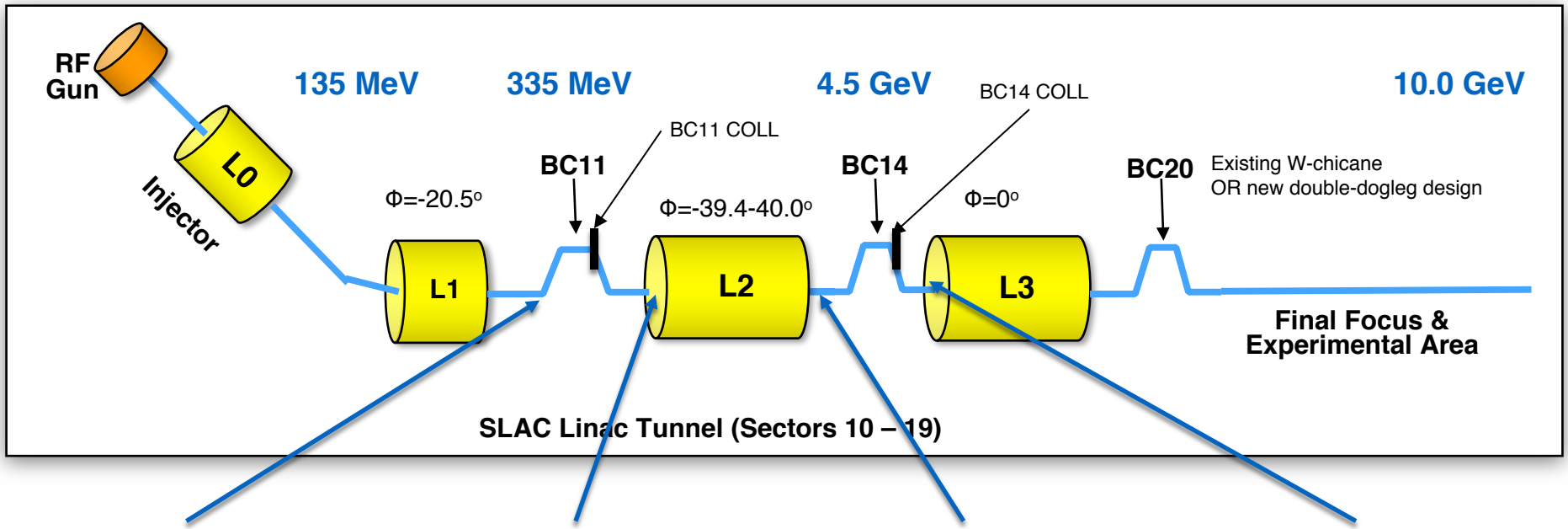
Parameter	*Single Bunch*	*2 Bunch*	
		Driver Pulse	*Witness Pulse*
Gun rf Phase (deg off zero emission)	*10*	*15*	
Laser spot Gaussian rms width pre-cut [mm]	*5.0*	*4.5*	
Cut radius on transverse laser spot [mm] (initial dist. X2 rms)	*2.68*	*2.68*	
Laser pulse length (FWHM) [ps]	*7.0*	*7.0*	*4.0*
L0-B phase w.r.t. $\delta_{E,min}$ (deg)	*0*	*-9*	
Gun Solenoid Int. Field Strength [kG.m]	*0.38*	*0.48*	

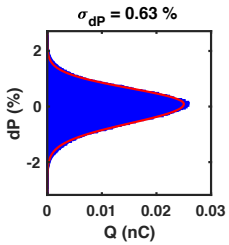
Beam Parameters @ L1

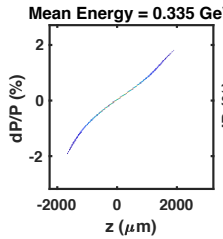


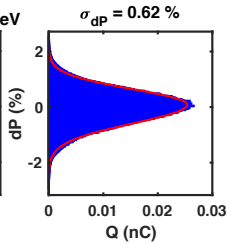
Parameter	FACET-II TDR	Double-Pulse Option	
		Driver Pulse	Witness Pulse
Bunch Charge [nC]	2.0	1.6	0.5
Transverse Emittance (90%) [μm-rad]	3.0	3.1	2.3
Peak Current [A]	290	270	180
Bunch Length (rms) [μm]	736	608	277
Bunch separation [mm] (peak-peak)	--	2.18	

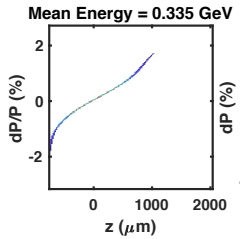
Linac Bunch Compression – Single Bunch

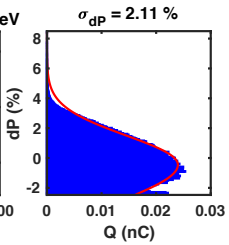


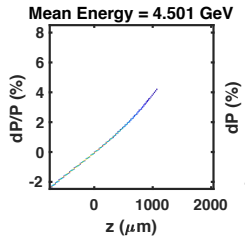


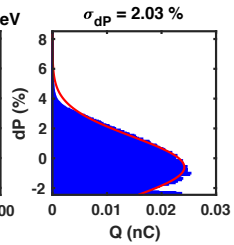


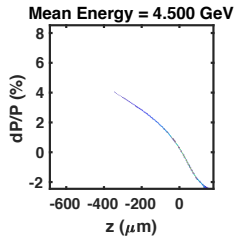






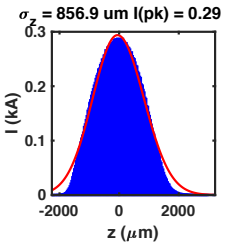






rms dP/P = 0.65298 %

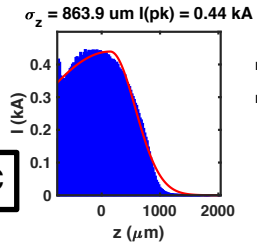
rms Z = 735.642 um



2.0 nC

rms dP/P = 0.646992 %

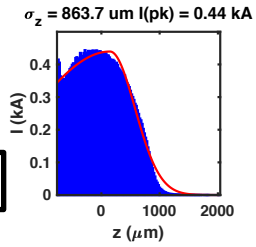
rms Z = 438.556 um



1.6-2.0 nC

rms dP/P = 1.47258 %

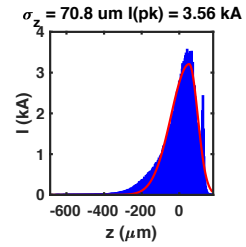
rms Z = 438.557 um



1.6-2.0 nC

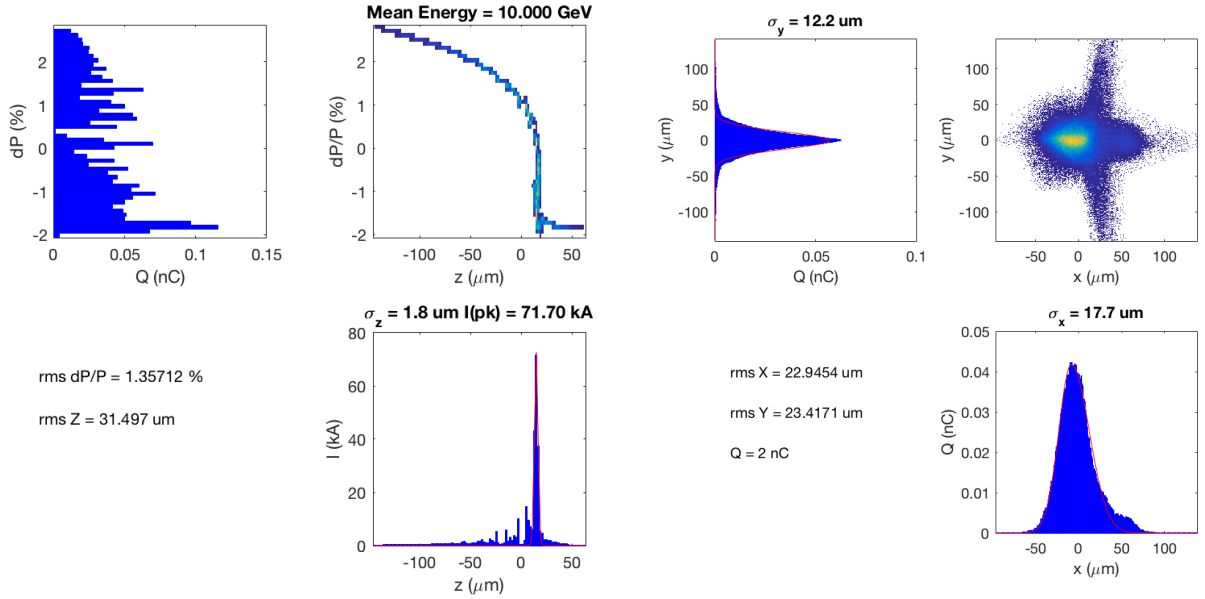
rms dP/P = 1.47818 %

rms Z = 90.216 um



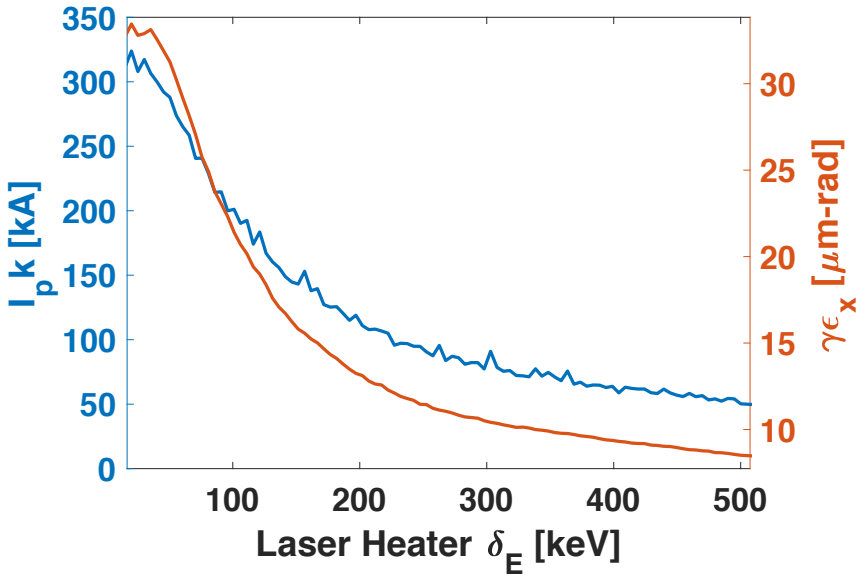
1.3-2.0 nC

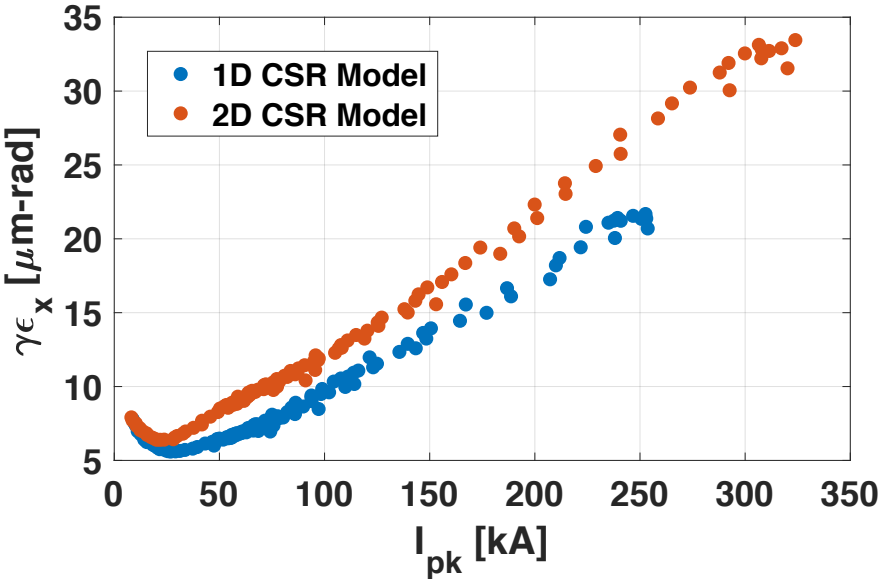
Beam @ Sector 20 IP (PENT) – Single Bunch (TDR)



- 1D CSR model only
- β^*=50cm
  - Chromatic effects challenging with large energy spread

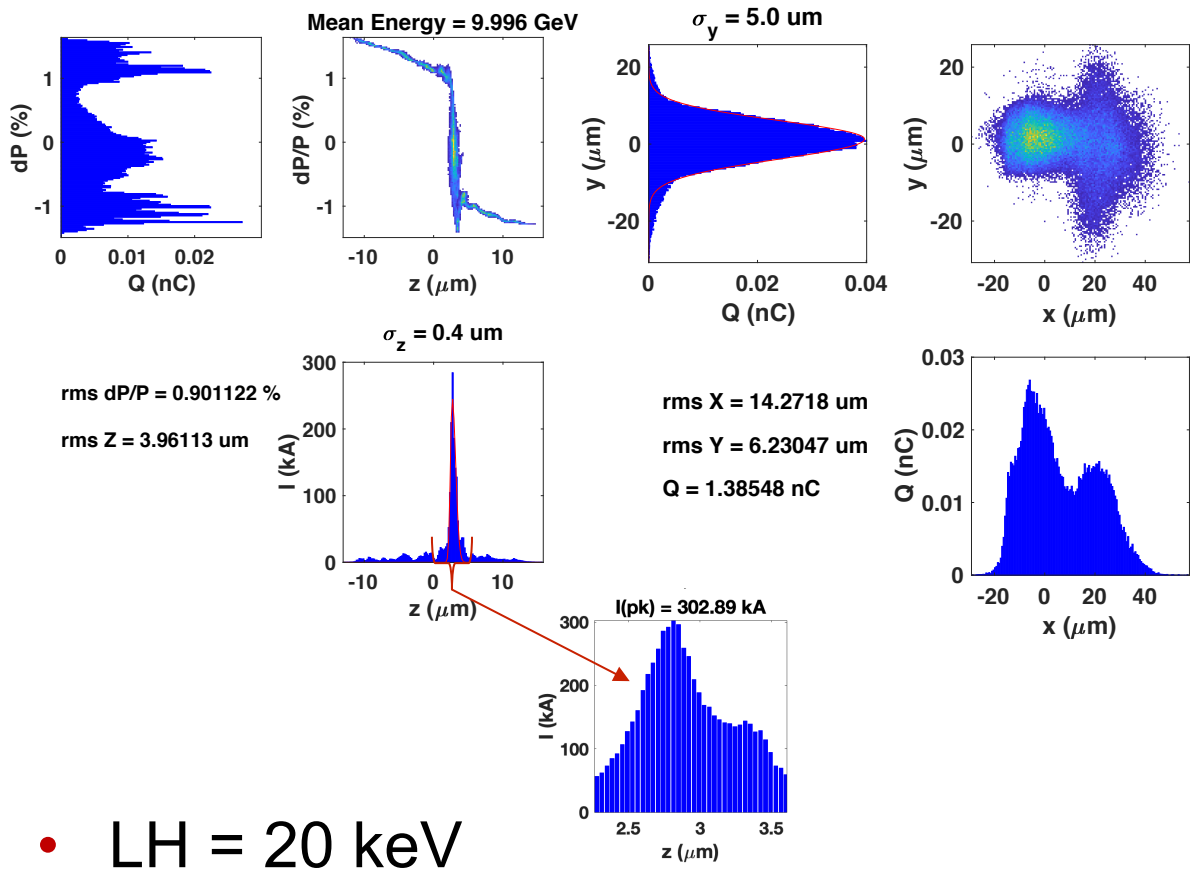
Electron Injector Laser Heater & CSR



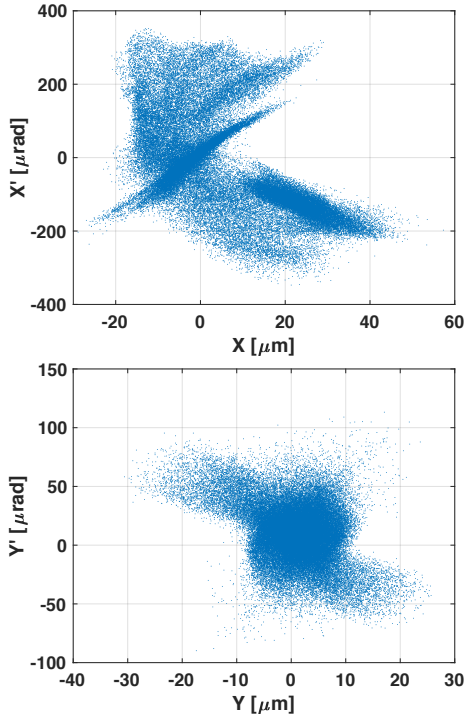


- Laser heater in electron injector : control Sector 20 bunch length (peak current) with minimal Linac re-tuning
  - Also surpresses micro-bunching in Linac
- For I_{pk} > 10 kA, need 2D CSR model

Beam @ Sector 20 IP (PENT) – Single Bunch (+ LH,COLL)

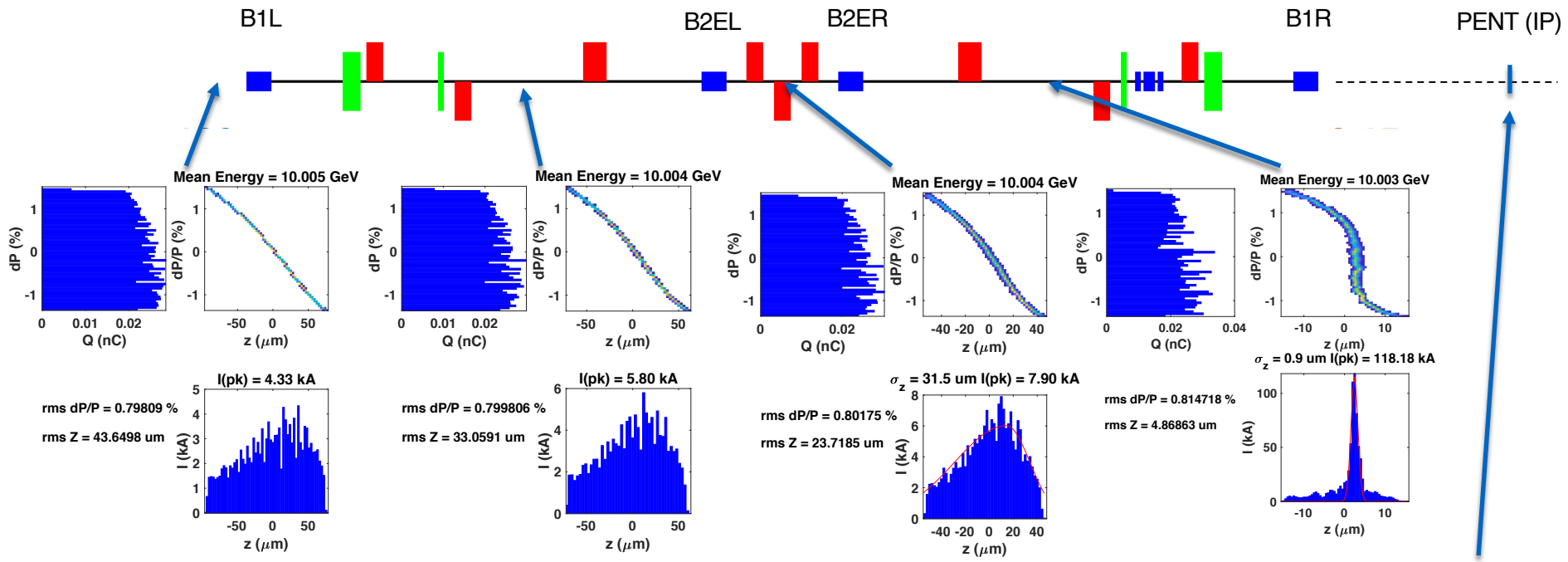


$\beta^* = 10$ cm



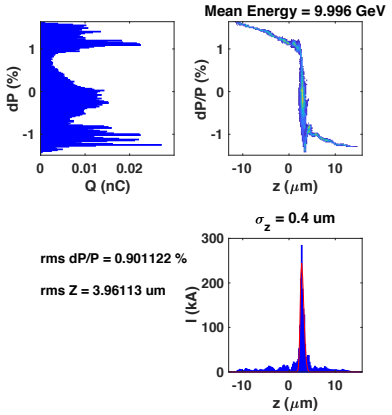
- LH = 20 keV
- $\gamma\varepsilon_{x,y}$ = 33 , 2.8 μm-rad
- Non-trivial correlations in phase-space

Compression Profile Through BC20

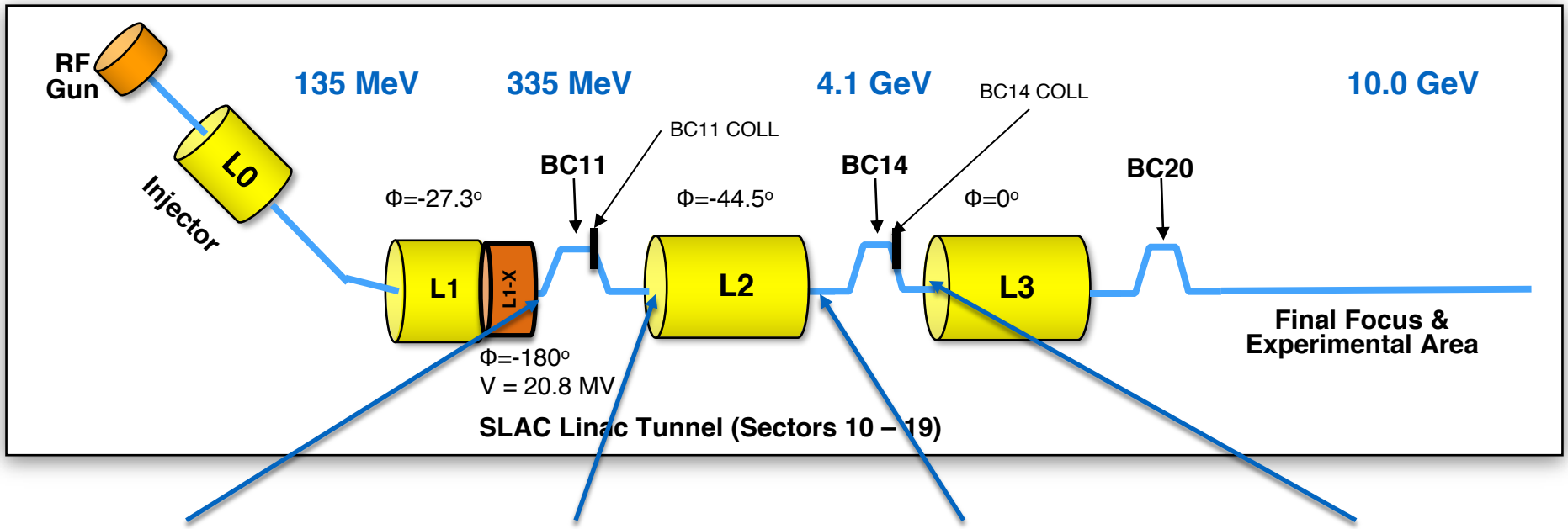


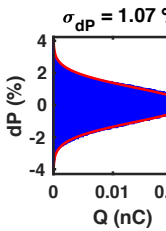
Bunch parameters after named element from tracked macro particles

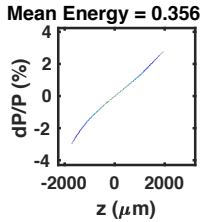
	BEGBC20	B1L	B2EL	B2ER	B1R	IP
$\gamma\varepsilon_x$ (μm-rad)	2.4	3.3	3.1	4.0	13.7	32.8
I_{pk} (kA)	4.3	5.8	7.9	118.2	262.8	302.9
σ_z (μm)	43.6	33.1	23.7	4.9	0.4	0.4

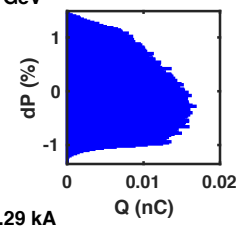


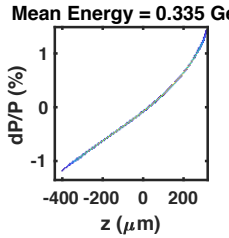
Linac Bunch Compression – Single Bunch + L1X Linearizer (Low Energy Spread Configuration)

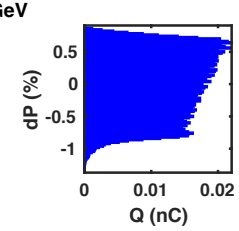


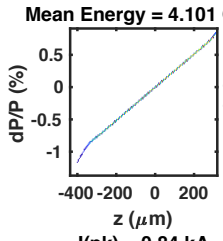


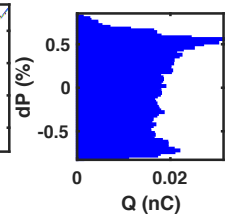


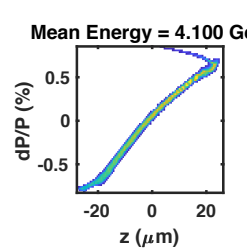




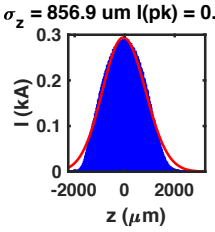






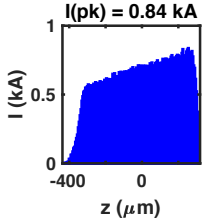


rms dP/P = 1.02357 %
rms Z = 735.641 um



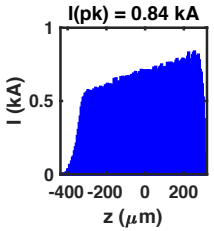
2.0 nC

rms dP/P = 0.626277 %
rms Z = 188.222 um



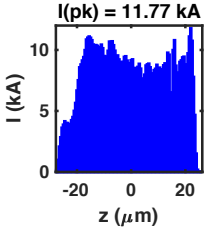
1.8 nC

rms dP/P = 0.48595 %
rms Z = 188.222 um



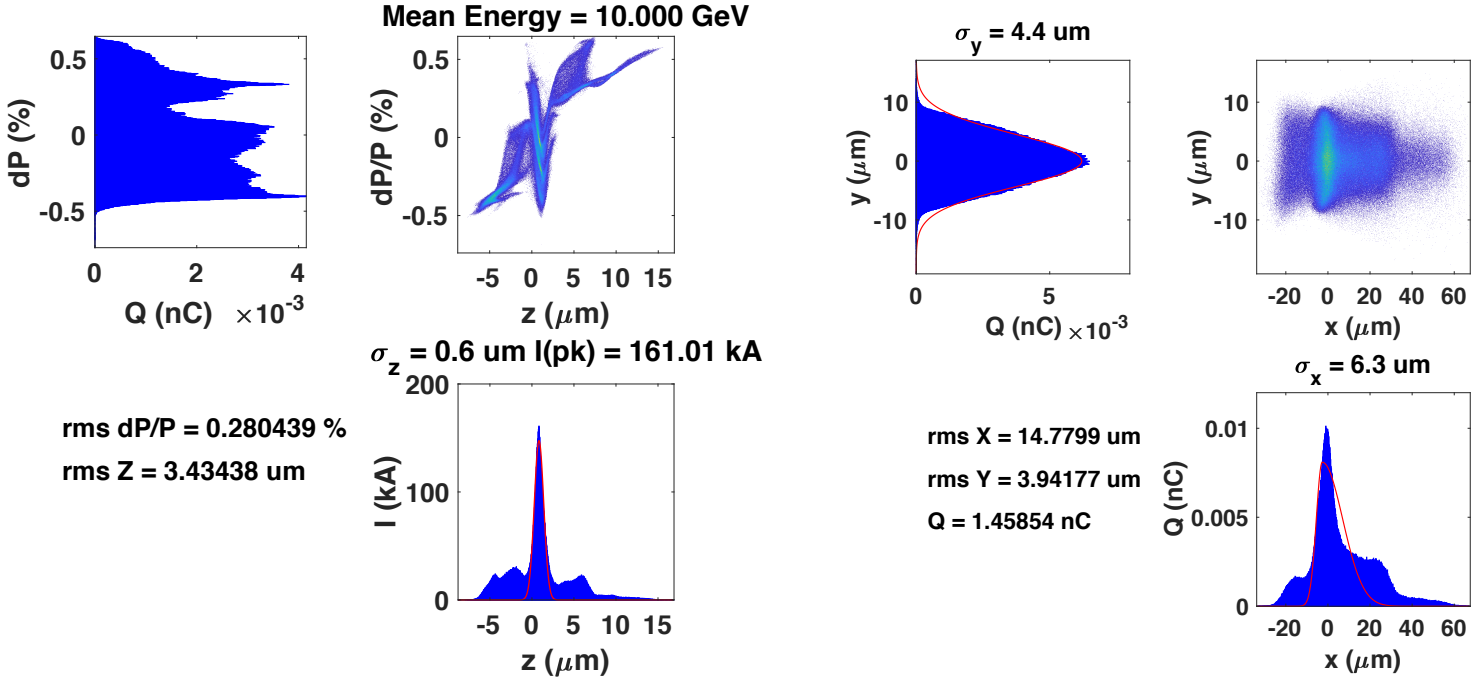
1.5 nC

rms dP/P = 0.446251 %
rms Z = 13.7287 um



1.5 nC

Beam @ Sector 20 IP (PENT) – Single Bunch (+L1X & COLL) (Low Energy Spread Configuration)



rms dP/P = 0.280439 %

rms Z = 3.43438 um

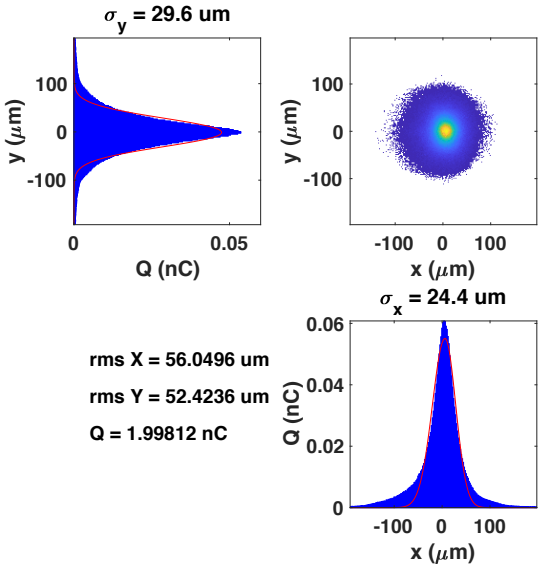
rms X = 14.7799 um

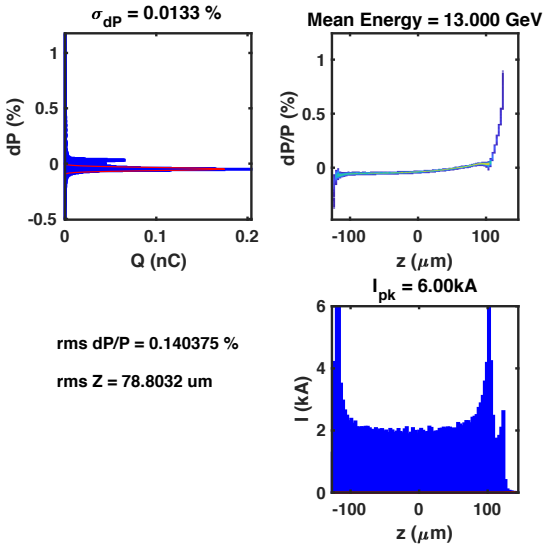
rms Y = 3.94177 um

Q = 1.45854 nC

- L1X Enables high I_{pk} (>100kA) with low energy spread (<0.3%)
- $\gamma\varepsilon_{x,y}$ = 37, 2.5 μm-rad

SFQED Configuration – Low Energy Spread, High Energy

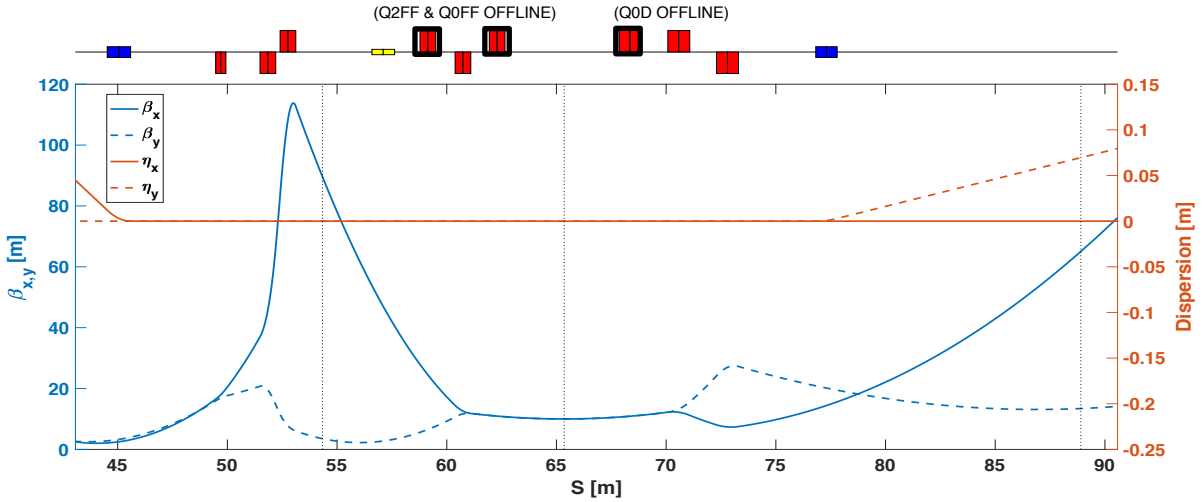




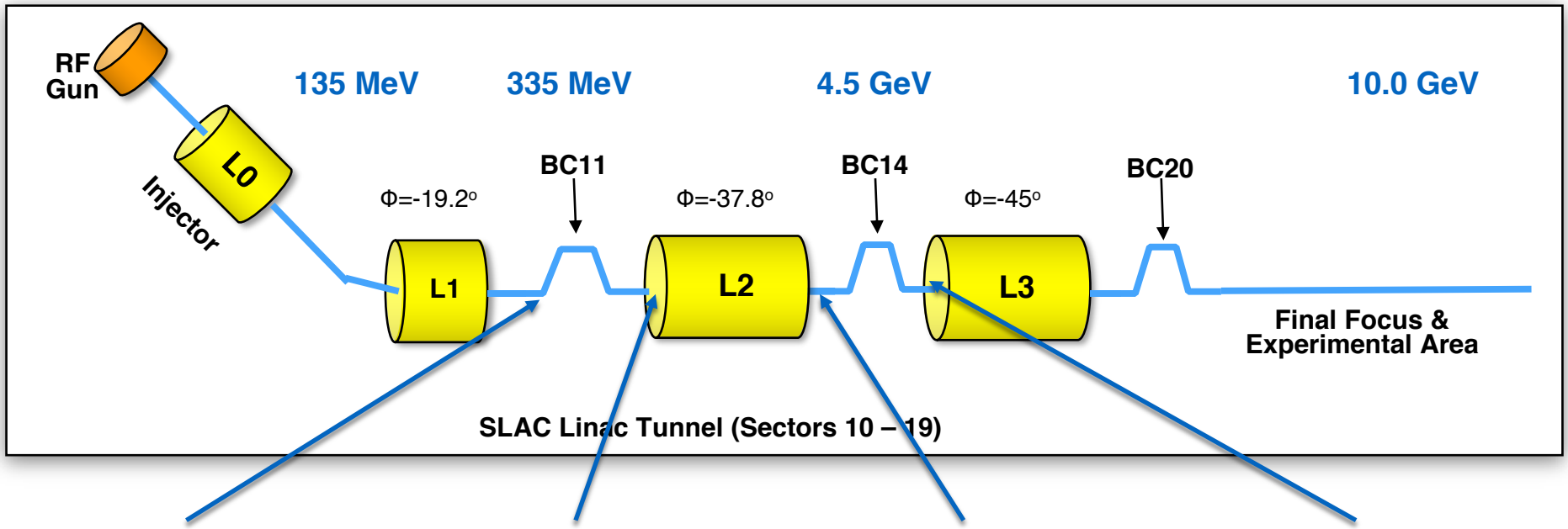
Particle tracking:

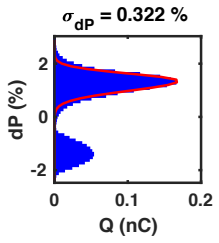
- $\gamma\varepsilon_{x,y}$ = 4 μm-rad
- σ_z = 250 μm full width
  - (79 μm rms)
- $\sigma_{x,y}$ ~ 25 μm (core)
- Q=2 nC (N_e=1.25E10)

- $\beta^*_{x,y}$ = 10m

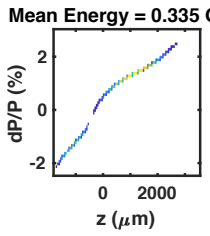


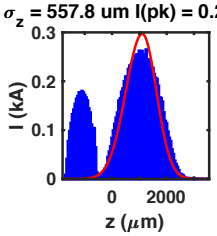
Linac Bunch Compression – 2 Bunch Configuration

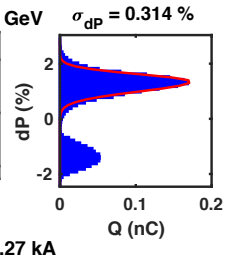




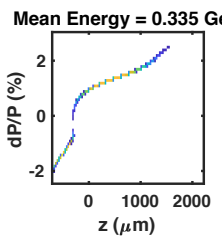
rms dP/P = 1.36825 %
rms Z = 1186.9 um

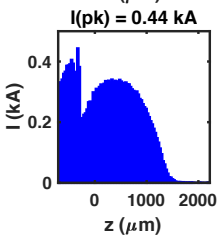


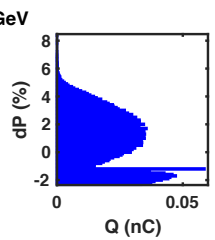




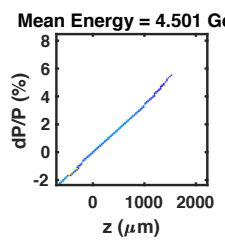
rms dP/P = 1.36774 %
rms Z = 577.512 um

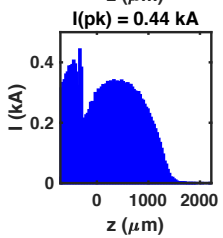


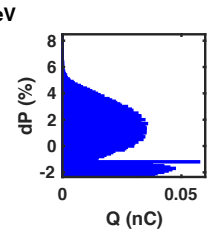




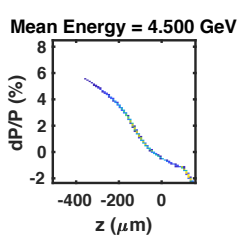
rms dP/P = 1.99603 %
rms Z = 577.521 um

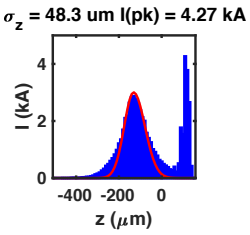






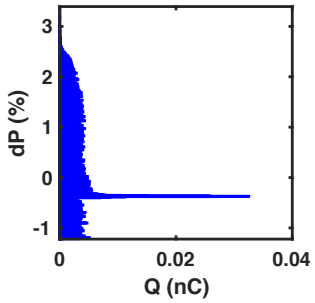
rms dP/P = 1.99798 %
rms Z = 129.266 um

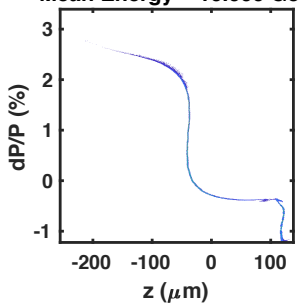




Beam @ Sector 20 IP (PENT) – 2 Bunch (Longitudinal)

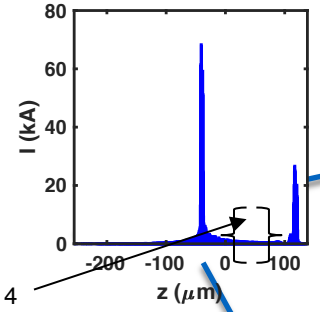
IP Beam Parameters Controllable with Laser Heater and S20 Matching





rms dP/P = 0.999983 %

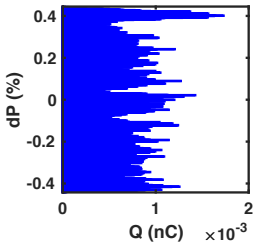
rms Z = 78.2258 μm



Collimation in BC11 & BC14
can remove inter-pulse charge
(at cost of 100pC drive bunch charge loss)

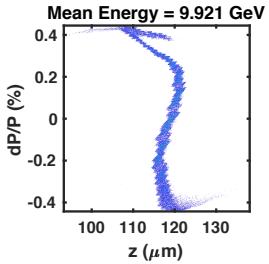
Δz = 150 μm

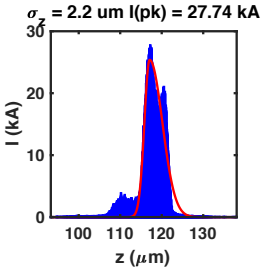
(Δt=500 fs) (peak-peak)

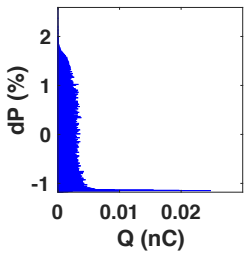


rms dP/P = 0.263753 %

rms Z = 3.24795 μm

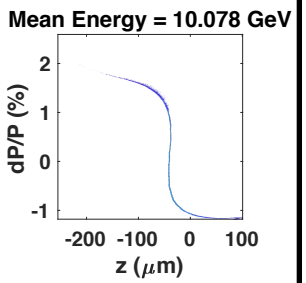


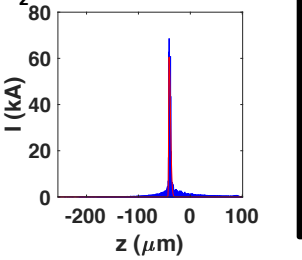


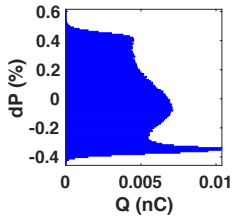


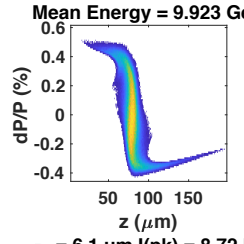
rms dP/P = 0.83708 %

rms Z = 31.4419 μm



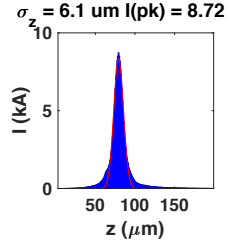




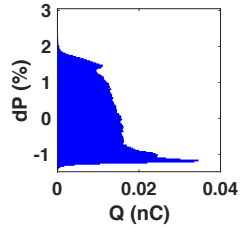


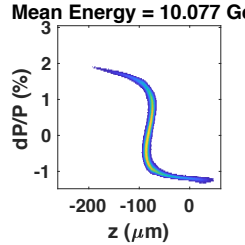
rms dP/P = 0.241981 %

rms Z = 13.7802 um



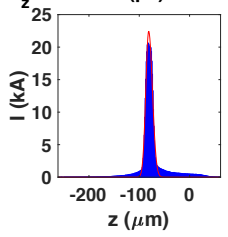
+ Laser Heater, Mean Energy Match





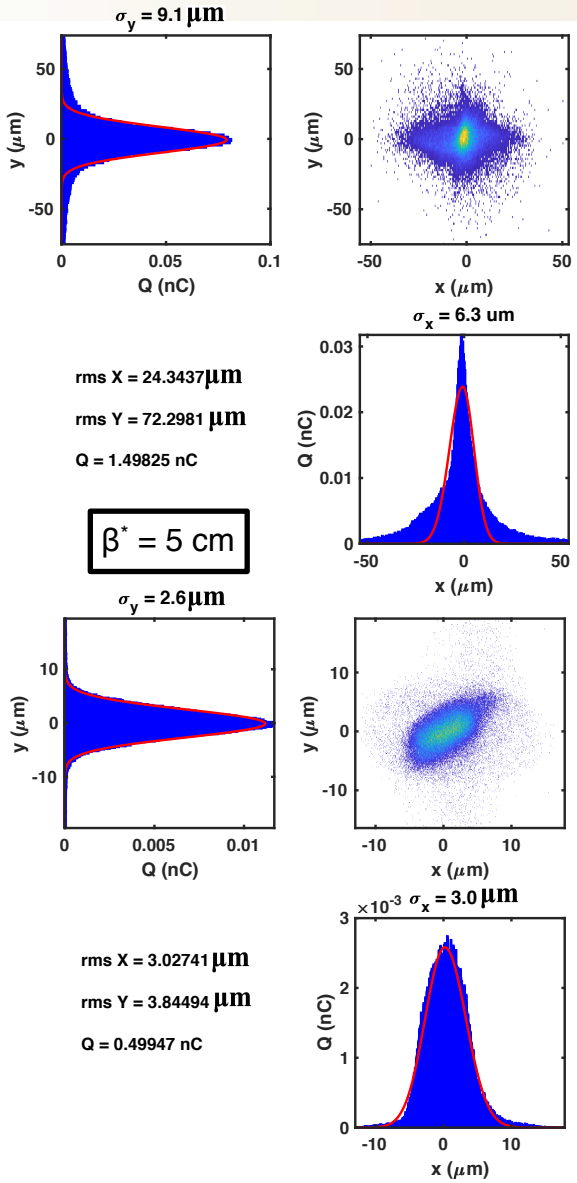
rms dP/P = 0.86249 %

rms Z = 25.9227 um



Beam @ Sector 20 IP (PENT) – 2 Bunch (Transverse)

IP Beam Parameters Controllable with Laser Heater and S20 Matching



Drive Bunch

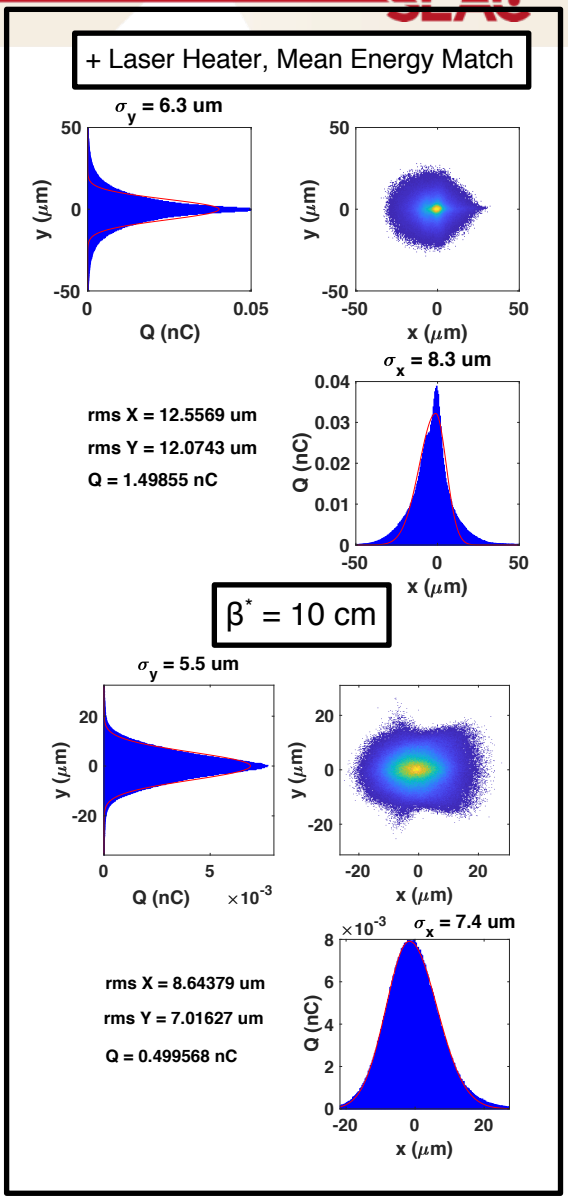
<- $\gamma\varepsilon_{x,y}$ (90%) = 20.6, 37.1 μm-rad

$\gamma\varepsilon_{x,y}$ (90%) = 20.6, 37.1 μm-rad ->

Witness Bunch

<- $\gamma\varepsilon_{x,y}$ (90%) = 3.2, 2.6 μm-rad

$\gamma\varepsilon_{x,y}$ (90%) = 5.9, 3.1 μm-rad ->



IP Waist Locations for Drive and Witness Bunch

Witness Bunch

Drive Bunch

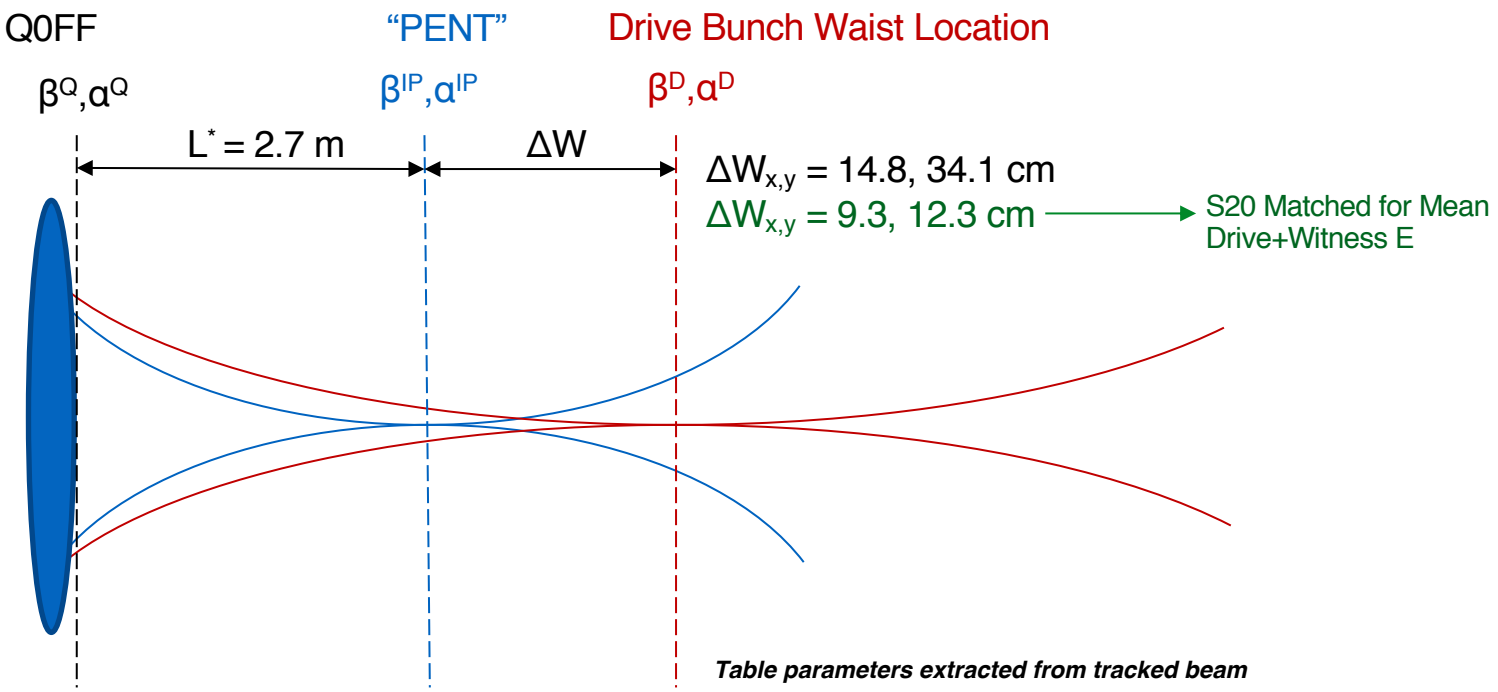


Table parameters extracted from tracked beam

	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	54, 56	148, 148 m	0.1, 0.7	5.0, 7.0 cm	-2.9, -6.4	46, 203 cm
Drive	32, 19	91, 59 m	1.7, 2.2	33, 33 cm	0.0, 0.0	8.9, 16 cm
Witness	44, 20	114, 51 m	-1.6, -1.0	20, 25 cm	0.5, 0.9	7.5, 23 cm
Drive	23, 17	64, 46 m	0.5, 0.0	15, 15 cm	0.0, 0.0	12, 16 cm

S20 Matched for Mean Drive+Witness E

Summary Table

Configuration	I_{pk} [kA]	σ_z^* [μm]	σ_x^* [μm]	σ_y^* [μm]	$\gamma\varepsilon_x$ [μm-rad]	$\gamma\varepsilon_y$ [μm-rad]	Q [nC]	δ_E/E (%)
2 bunch (Witness, Drive)	28, 68	3.2, 2.2	3.0, 6.3	2.6, 9.1	3, 21	2.6, 12	0.5,1.5	0.3, 0.8
2 bunch (W, D) + LH	15, 34	3.7, 3.4	4.1, 12.9	3.7, 8.2	4, 26	4.3, 12	0.5, 1.5	0.3, 0.8
Single Bunch, TDR	72	1.8	17.7	12.2	12	6	2.0	1.4
Single Bunch + COLL + LH	302	0.4	14.3	5.0	33	3	1.4	0.9
Single Bunch + L1X + COLL + LH	161	0.6	4.6	4.4	37	3	1.5	0.3
Single Bunch, 13 GeV, + COLL (long bunch)	4.2	97	1.9	2.2	3	3	1.9	0.03

$\gamma\varepsilon$ is normalized, "90% emittance", $\sigma_{x,y,z}$ is Gaussian width of fit to core of distribution

- Tracked particles at various locations stored on start-to-end tracking results web page: ***http://www.slac.stanford.edu/~whitegr/F2_S2E***

Extra Slides

Bunch Compression in S20 FFS

- CSR in BC20 generates high-order z-r' correlations in bunch
- Z-motion in FFS depends on transverse momentum
  - i.e. dz = L/2 (px^2 + py^2) for each element
- In max compression configuration, enough to influence final peak current
  - Core σ_z ~ 500 -> 300 nm