Accelerator Configurations and Upgrades

FACET-II

Facility for Advanced Accelerator Experimental Tests

FACET-II DOE Operations Review

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June 14-15, 2022

SLAC NATIONAL ACCELERATOR LABORATORY

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U.S. DEPARTMENT OF ENERGY

This Talk Addresses the Following Charge Questions

3. Maintenance & Operations
   a) Are there adequate efforts and plans to efficiently operate the facilities now and through future facility upgrades, taking into consideration any potential interference with LCLS operations?
   b) Are foreseen risks to the operation assessed and the expected effectiveness of the mitigation plans in place.

5. Future Planning
   a) Are there ongoing plans to assess the potential and needs of the FACET-II facility—current and future?
   b) Are the Program Advisory Committee and Science Workshops being exploited adequately and efficiently?
   c) Is the process for identifying and prioritizing user experiments and facility upgrades effective?

Outline

Accelerator configurations designed to meet science needs of user programs

Using start-to-end tracking simulations:
3 configurations modeled

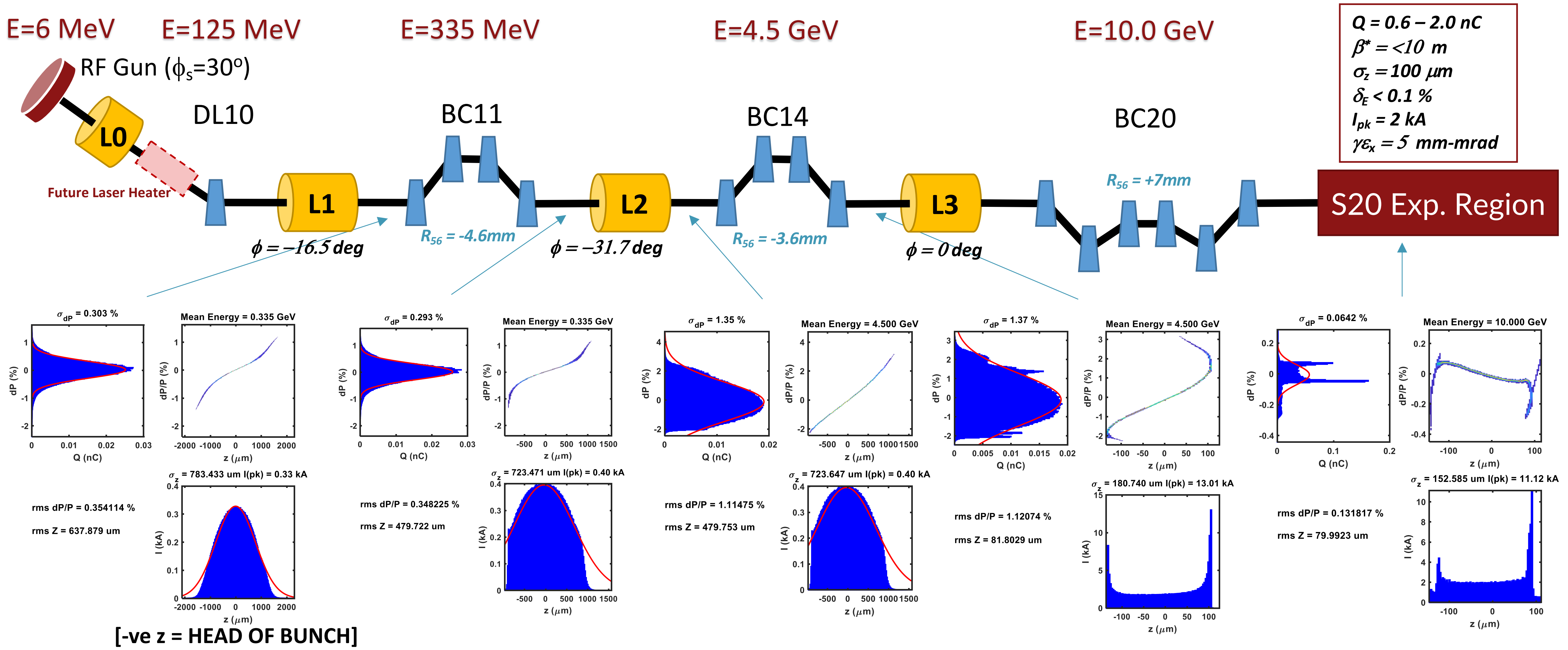
- Minimum # of configurations for ease of accelerator operations, generated with iterative consultation with high-priority experiments user community

1. "Clean" single bunch: low energy-spread, low peak-current
   - e.g. **E320 -> requires high energy for γ-boost of photons & low-backgrounds for sensitive measurements of low-energy tails of detected signals**
2. Highly compressed single bunch: high energy-spread, high peak-current (<300kA)
   - e.g. **E305 -> require v. high fields from bunch to drive instabilities in high-density plasmas, solid targets etc.**
3. 2-bunch for PWFA experiments
   - e.g. **E300 -> High peak-current drive + high-quality witness bunch tailored for optimal beam loading**

Considered modifications to electron accelerator baseline design

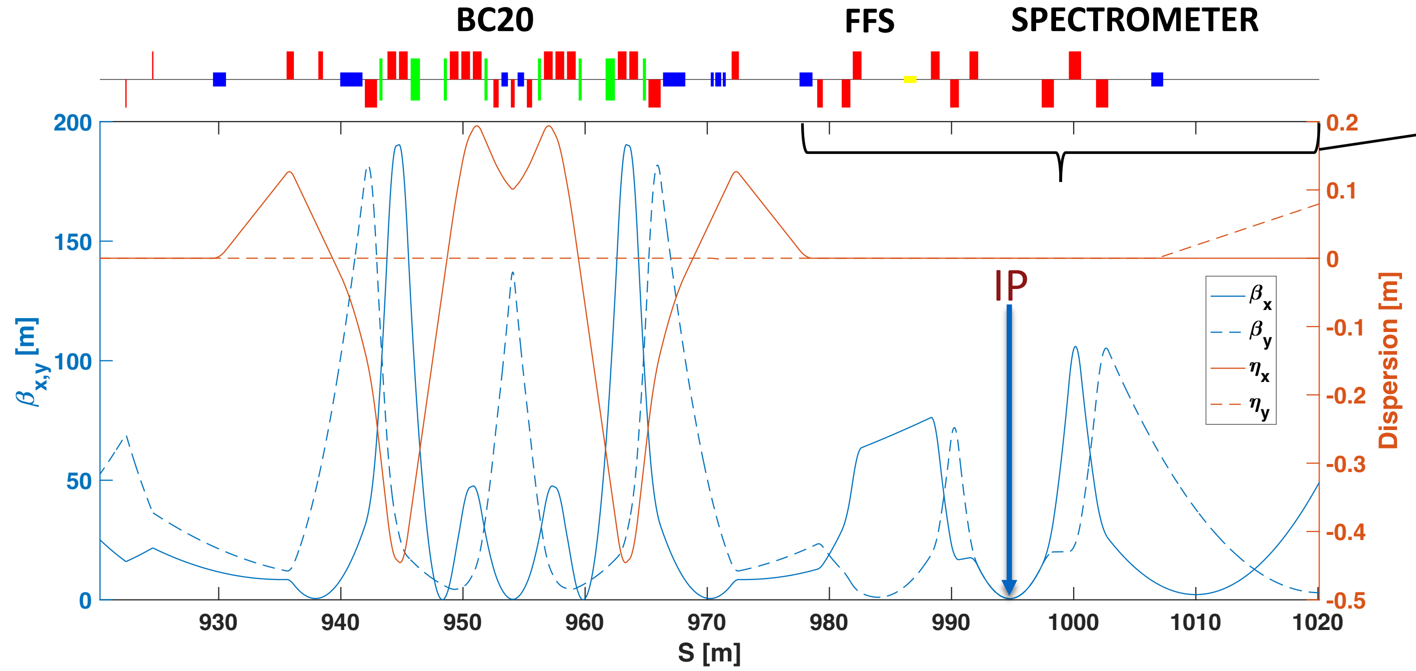
1. Can we get a notch collimator simulation that looks good to tease while we wait for two-bunch mode from gun?
2. Upgrade of final stage BC20 compression chicane?
3. Injector laser heater for increased longitudinal stability, bunch length control & μ-bunching suppression
   (Also see talk by C. Hast)

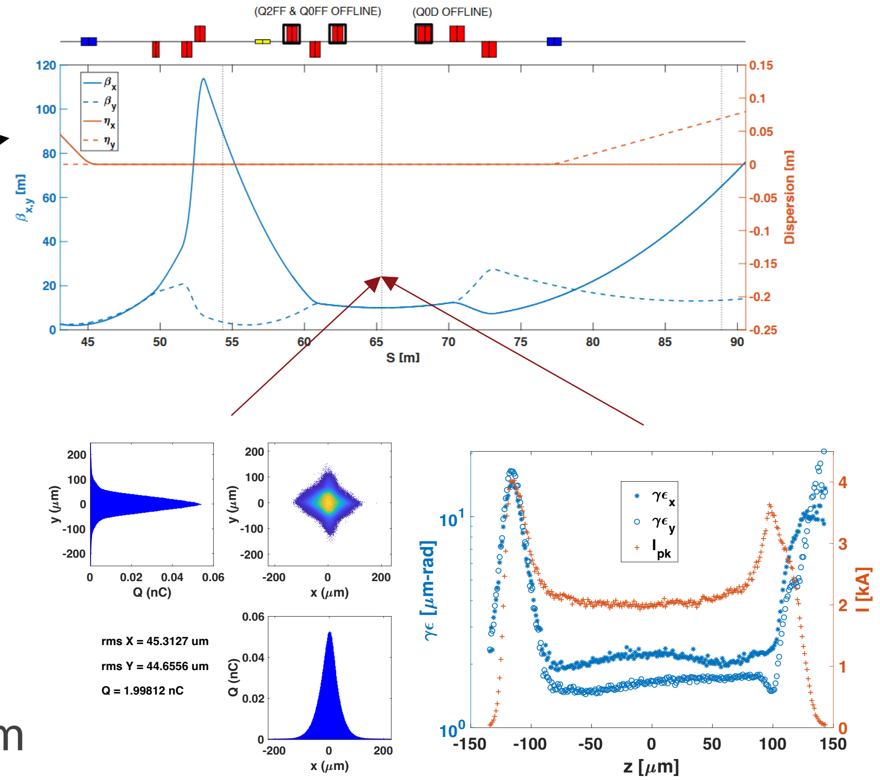
1) Single Bunch “Clean” (Low E-Spread) Configuration



Low-compression, low final E-spread, good emittance preservation configuration

1) Sector 20 & Transverse Particle Tracking Results



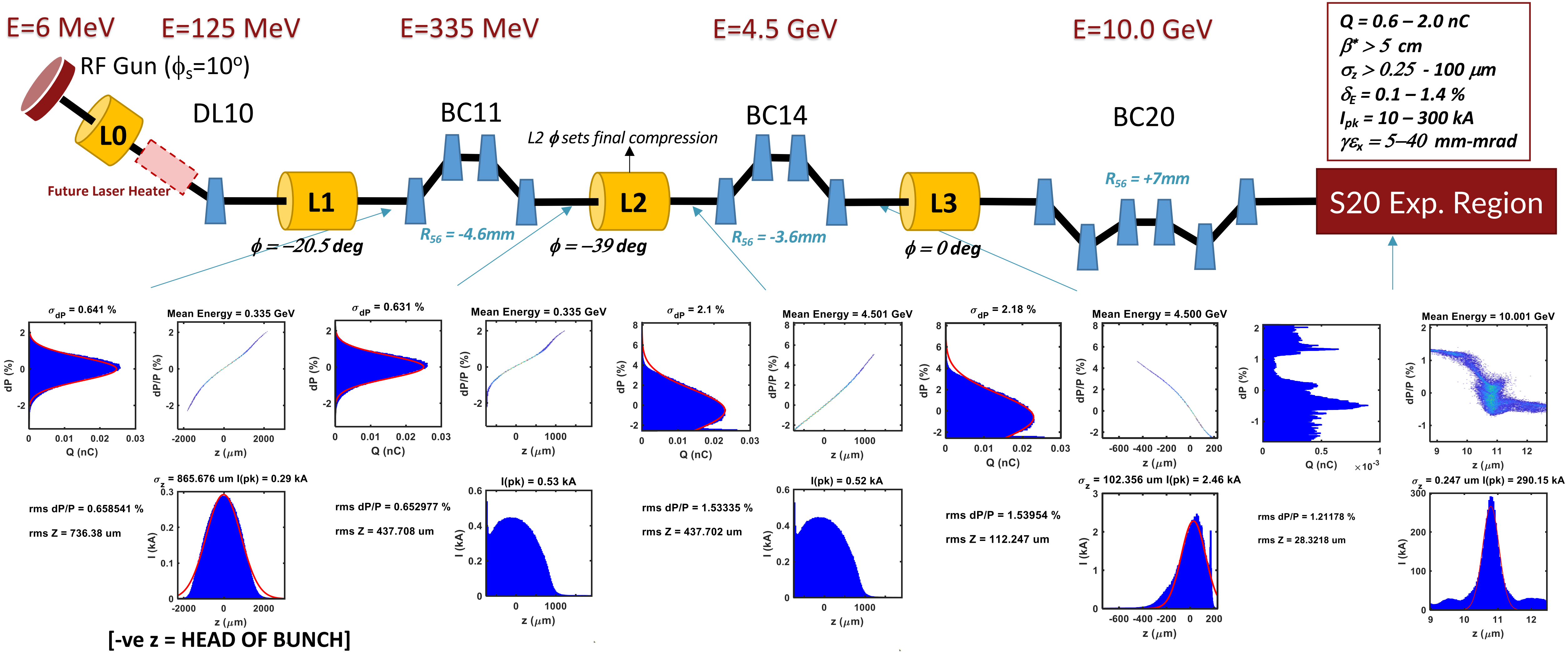


E320 Configuration with β^*=10m

- Current FACET-II Sector 20 layout, matched for R56=+7mm, β^*=50cm
- 3 families of sextupoles matched to minimize T566, & ε_x
- FFS quads (5 families of magnet) matched for round beams at IP
- R56 matching range = [-10:+10] mm
- β^* matching range > 5 cm

Sector 20 contains existing “W” chicane from FACET, new FFS & spectrometer magnets to handle round-beams

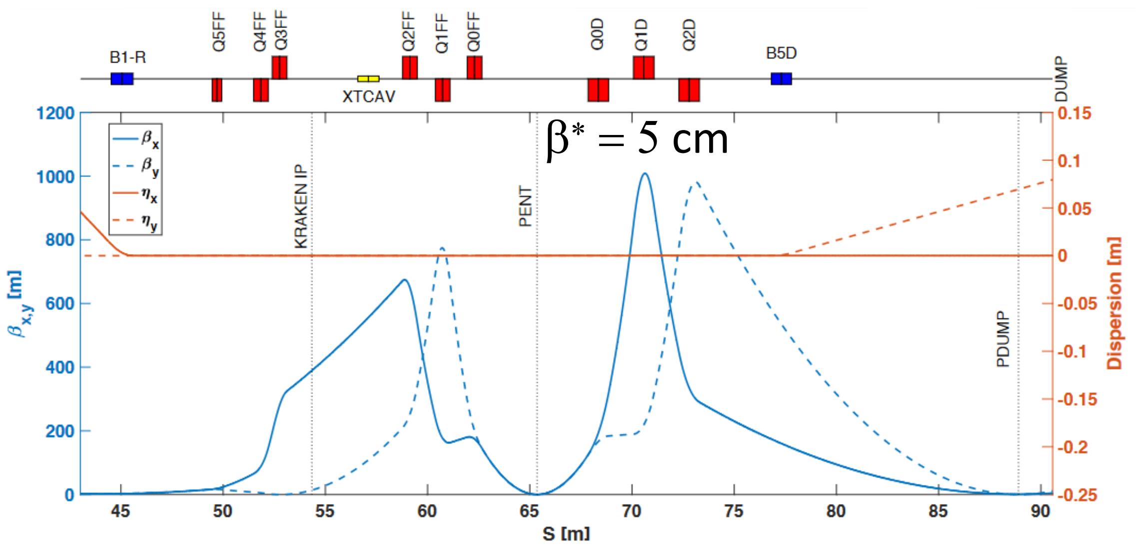
2) Single-Bunch Max-Compression Configuration

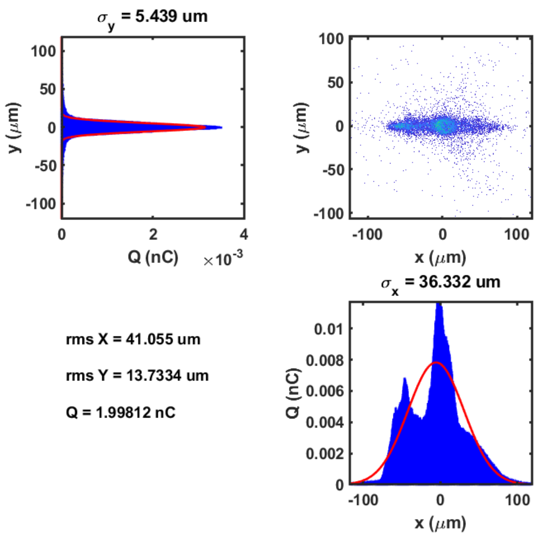


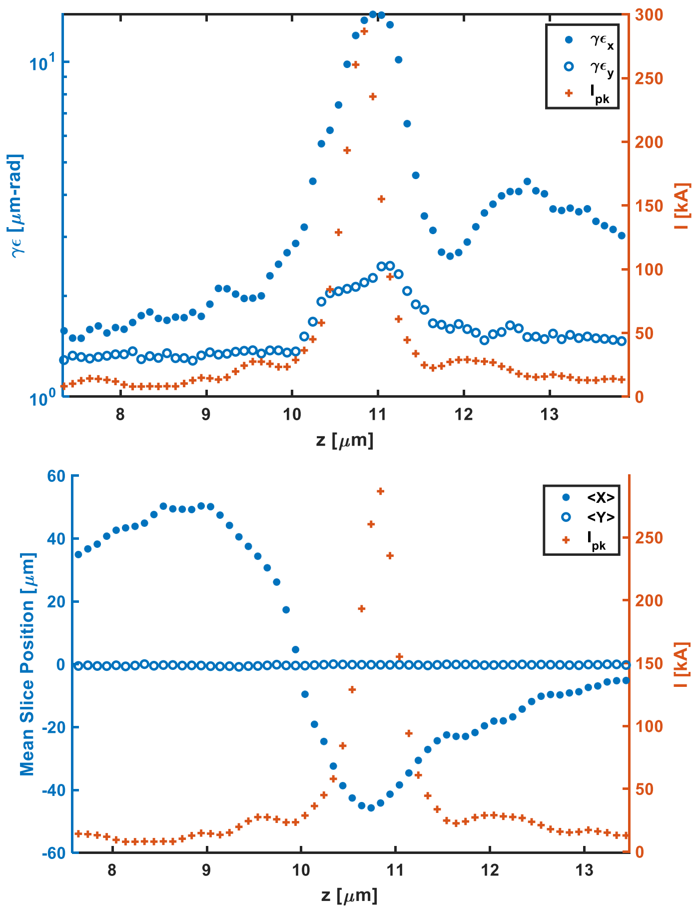
Q = 0.6 – 2.0 nC
$\beta^* > 5$ cm
$\sigma_z > 0.25$ - 100 μm
δ_E = 0.1 – 1.4 %
I_{pk} = 10 – 300 kA
$\gamma\epsilon_x$ = 5–40 mm-mrad

Over-compress bunch in BC14 for high-energy-spread, high-peak current requirements in S20

2) Transverse Particle Distribution @ IP (Max Compression)



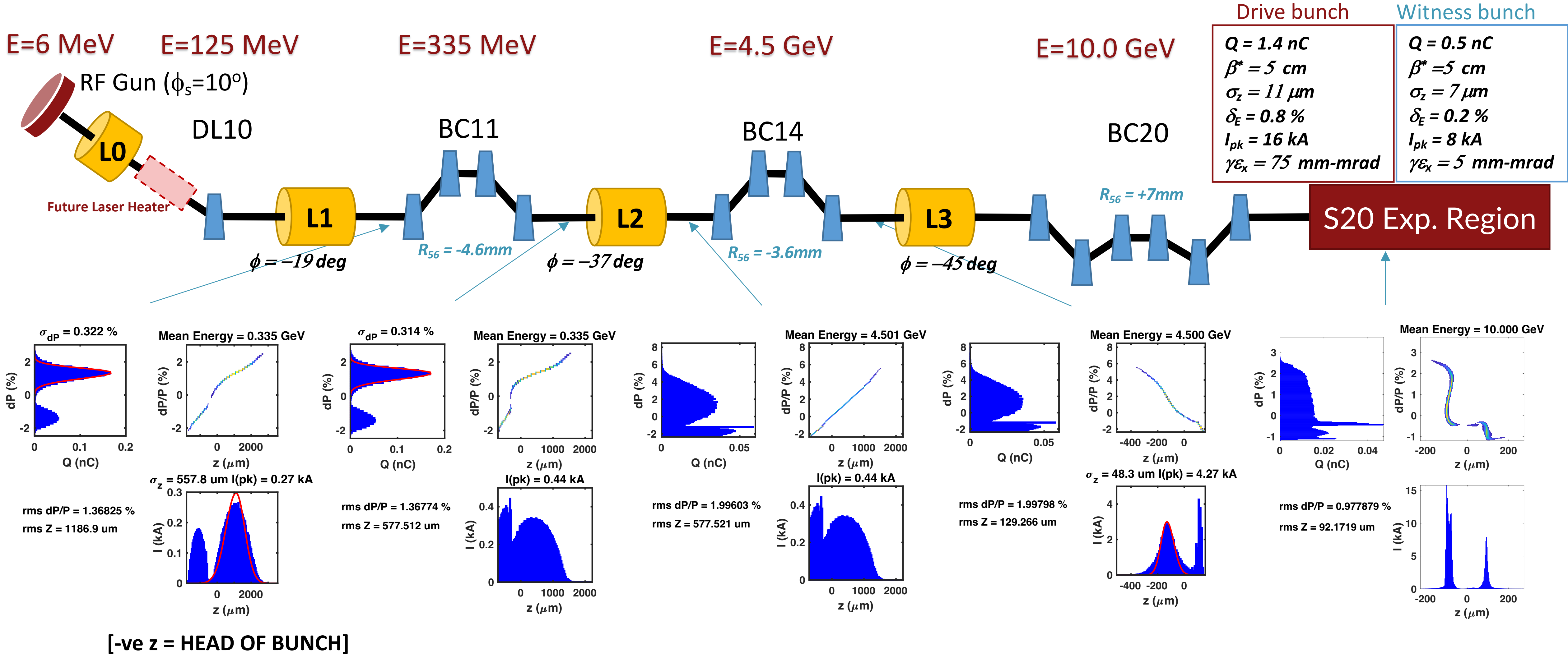




- Horizontal emittance varies ~5-40 mm-mrad for bunch lengths 100 -> 0.25 um due to CSR effects in BC20
- CSR generates longitudinal position-dependent kicks according to charge as beam traverses BC20

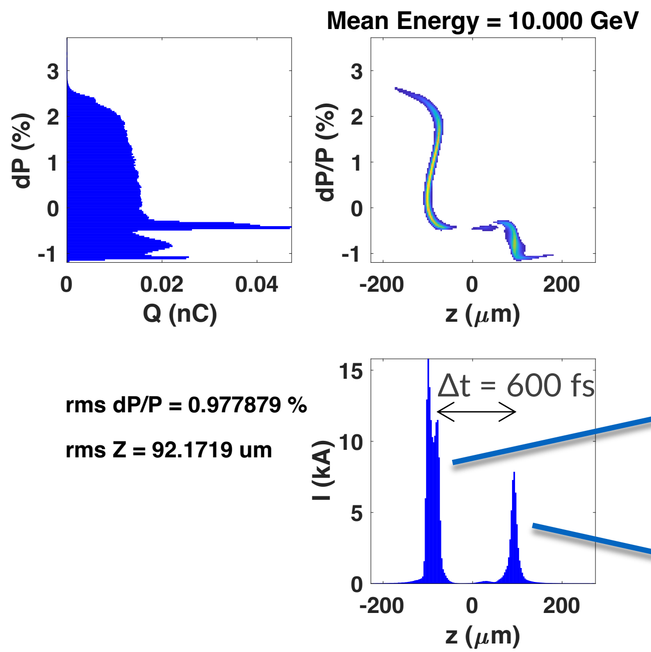
Bunch compression : bend-plane emittance growth tradeoff due to CSR effects
Communication with experimental groups to understand optimal configuration in each case

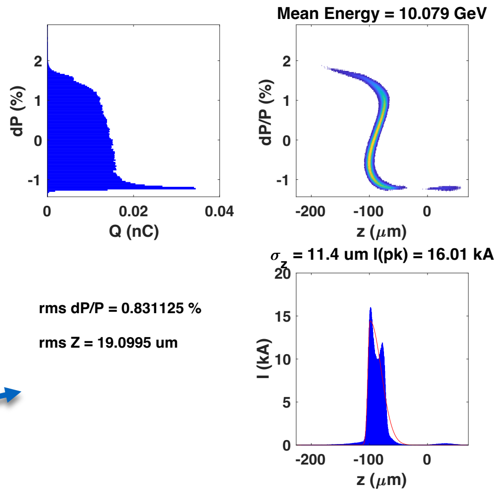
3) Two-Bunch Configuration

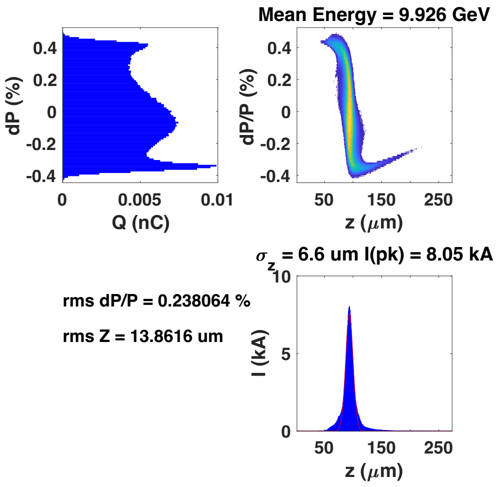


Double-pulsed laser on RF Gun generates drive+witness pulse with 3:1 charge ratio, 2:1 I_{pk}

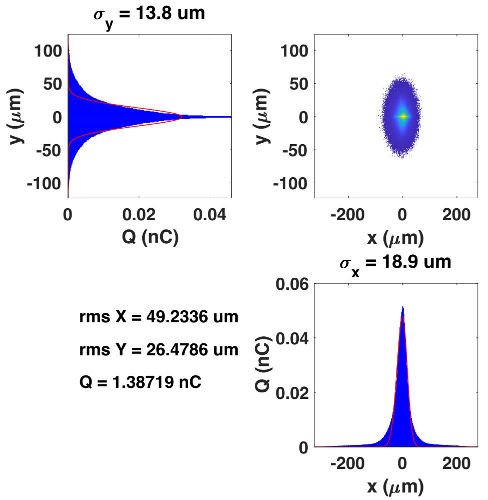
3) Two-Bunch Particle Distributions @ IP



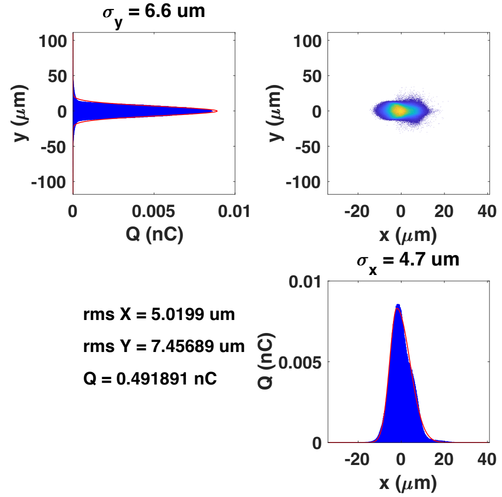




Drive Bunch



Witness Bunch



γε = 73 x 35 μm-rad

β* longitudinal waist offset due to energy difference

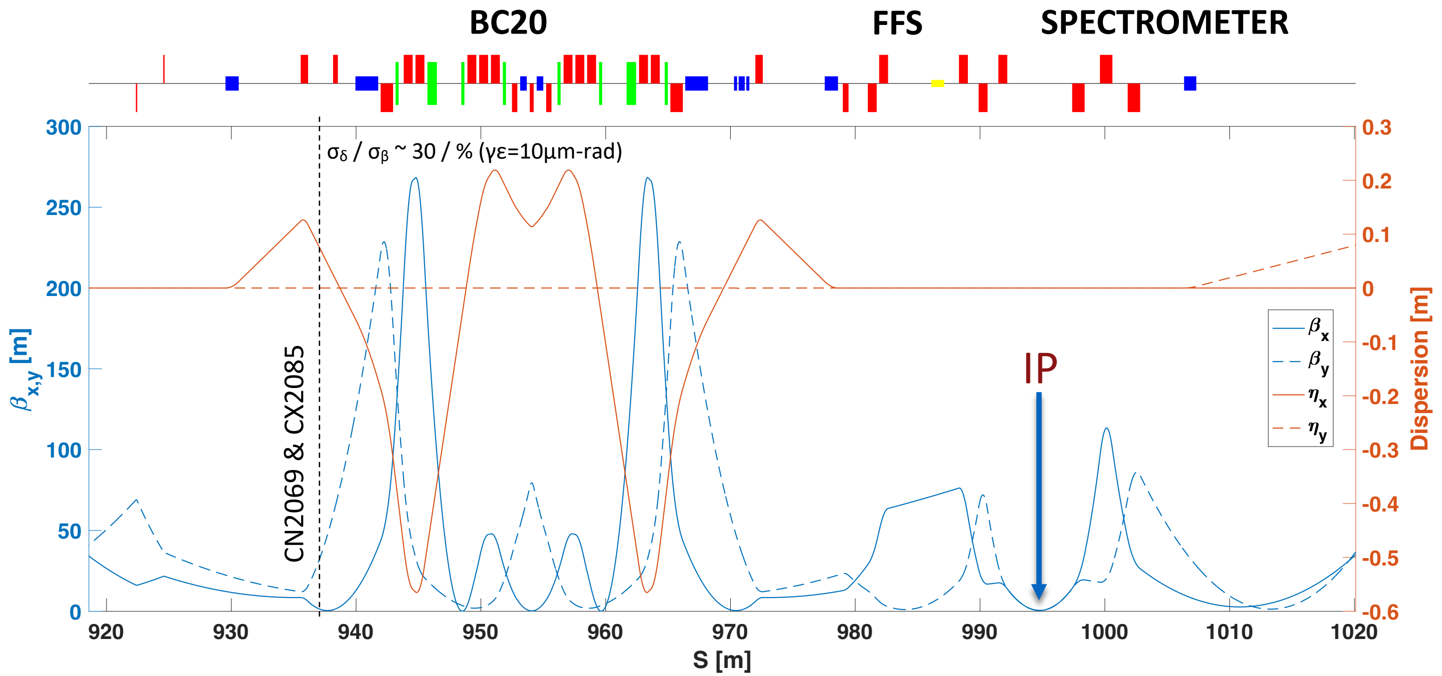
$\Delta W_{x,y}$ = 22.8, 17.3 cm

γε = 4.5 x 2.6 μm-rad

- Can make use of BC20 “notch” collimator to help separate bunches
- 150 MeV energy difference between drive & witness generates different beam dynamics
- Trade-offs exist e.g. bunch spacing vs. transverse quality: iterating with experimental groups to optimize

High-quality witness bunch generated, driven by higher charge drive beam at requisite longitudinal spacing

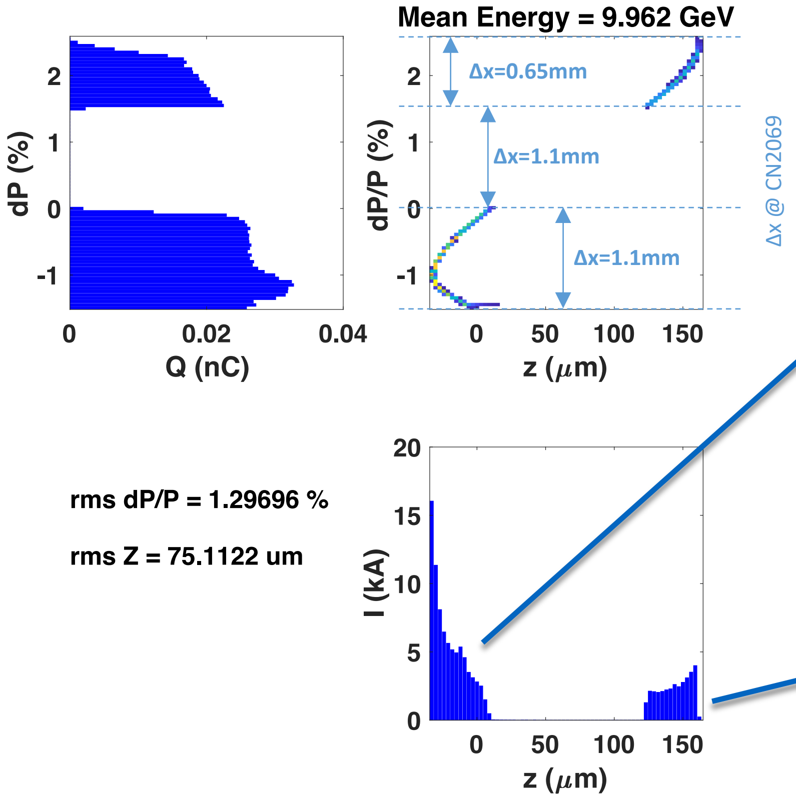
Alternate 2-Bunch Setup using BC20 Notch & Jaw Collimators

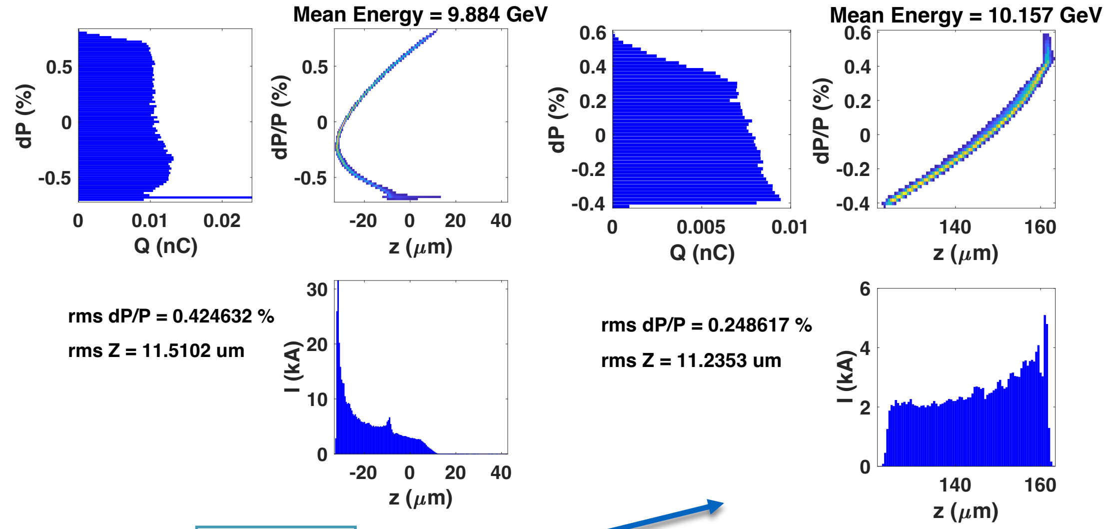


- Whilst we commission double-bunch injector setup, use tested notched 2-bunch setup from FACET-I experience
- Compared with FACET-I, smaller head-tail energy spread: re-configure for larger R56 in BC20
  - Optics re-matched for R56=+10 mm
  - Adjust L1 & L2 rf phases to fine-tune 2-bunch results
- Use notch & jaw collimators as indicated to generate 2-bunch profile

Option to use FACET-I mechanism for 2-bunch operations with modifications to BC20 optics

Alternate 2-bunch Configuration Particle Tracking





Drive Bunch

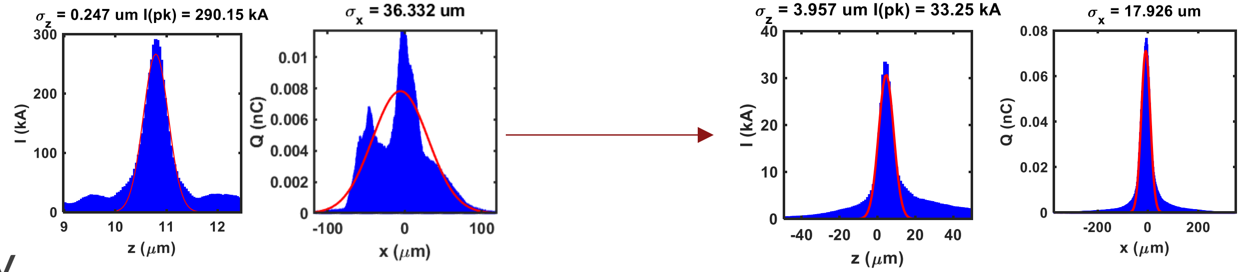
Witness Bunch

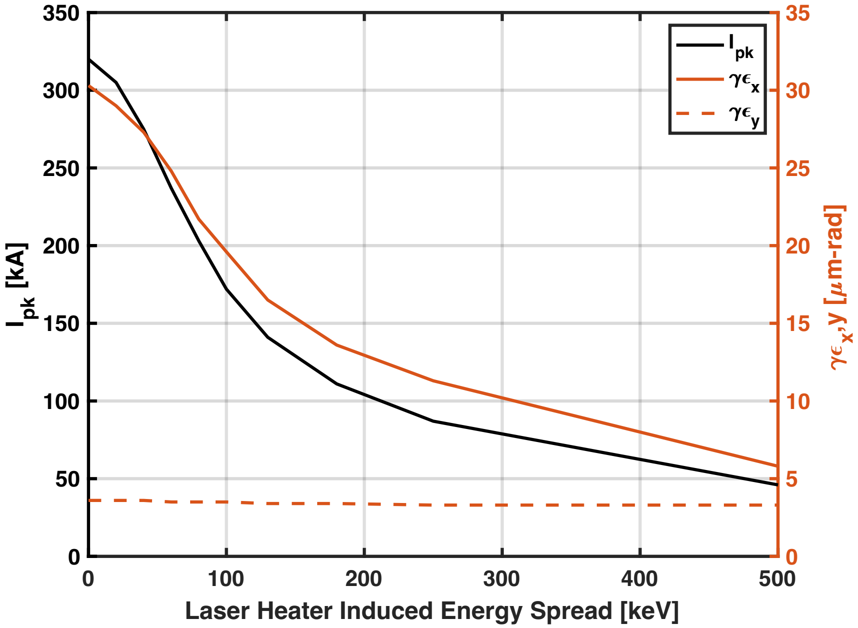
- Δt = 500 fs , I_{pk} ~5/15 kA, Q ~330/820 pC
- Φ(L1) = -19.8 deg ; Φ(L2) = -39.8 deg
- Can trade: >I_{pk} for < Δt by adjusting Φ (L1&L2)

Notched configuration enables quick start of PWFA 2–bunch experiments ahead of double-pulsed injector configuration which will bring improved beam quality at a later date

Laser Heater

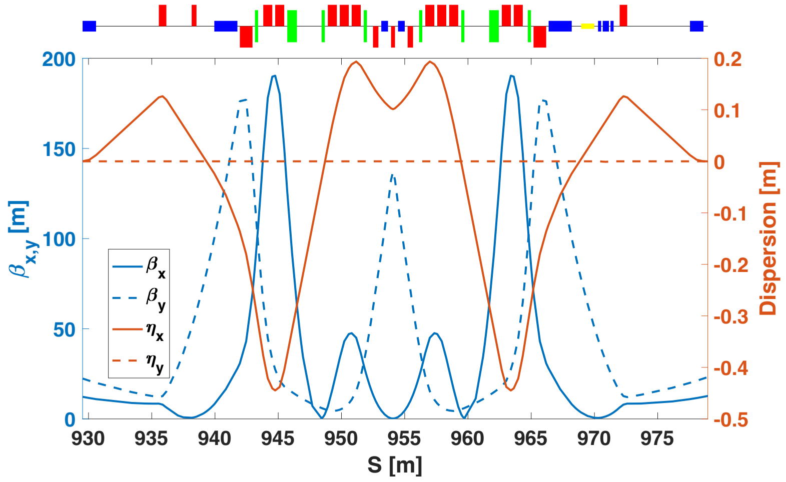
- Laser heater used to increase incoherent energy spread in injector
- Consider 0->500 keV heating
- Enables orthogonal control of final energy spread
  - Minimizes accelerator tuning for different final bunch lengths
- Provides trade-off between final peak current and horizontal emittance
- Final beam profiles become more Gaussian
- Suppresses micro-bunching and coherent emission by putting a cap on max peak current possible

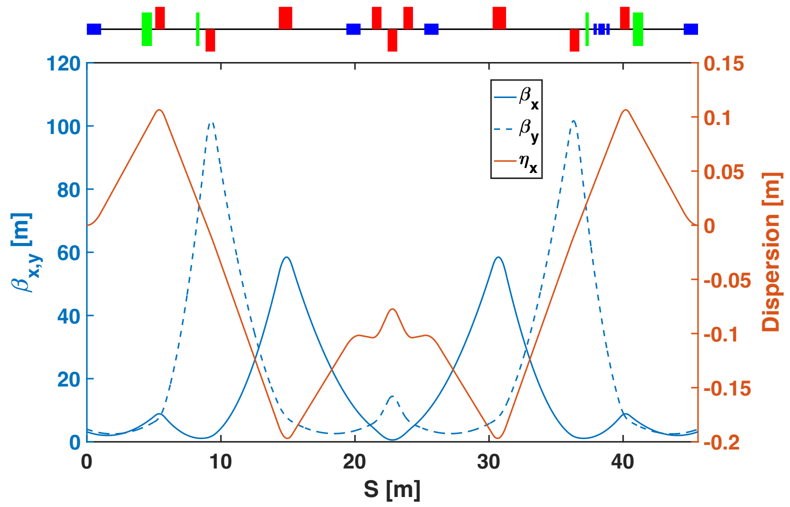




Injector laser heater can be used for bunch length control and μ-bunching suppression
See talk by C. Hast on installation plan and details

BC20 Chicane Upgrade





- New BC20E layout, re-using subset of existing magnets
  - uses reduced magnet count => easier operations
  - lower chromatic aberrations, better beam quality / lower losses @ high energy spread
  - compression range R56 = 0 -> 5mm
    OK for FACET-II parameters
    NB: no 2-bunch notch operation option
  - 3.5m shorter z length -> more FFS space

	W-Chicane	New BC20E
R56	-10 - +10 mm	0 - +5 mm
Magnet count	18 quads 6 bends 6 sextupoles	9 quads 4 bends 4 sextupoles
z length	49.1 m	45.6 m
β(max) @ R56=5mm	190 m	100 m
ε_x @ δ_E = 1.2 % **Sextupoles OFF** **Sextupoles Opt.**	 400 um-rad 15 um-rad	 60 um-rad 15 um-rad

New BC20 designed and installation plan ready, install possible during next long LCLS downtime
Expected to ease operational complexity and provide more space for upstream S20 experiments

Summary

- 3 primary accelerator configurations studied: developed in co-ordination with user community to meet their needs
  - 3-stage Linac compression with variable 3rd stage compression & real-time configurable FFS
    1. Low Espread, high beam quality
    2. Single pulse, high-compression (tunable)
    3. Double-pulse for drive-witness bunch configuration used by plasma acceleration programs
       - Either double-pulsed from RF gun or "notched" using BC20 collimators
- Performance assessed using start-to-end tracking simulations
  - Lucretia tracking model now also used in online operations
  - Same tools used and benchmarked against FACET-I operations in the past
- Upgrades considered for improved performance
  - Laser heater chicane in injector for bunch length control and μ-bunching suppression
  - BC20 upgrade using fewer quadrupole and bending magnets for easier operational management

Accelerator configurations designed to meet all user needs & verified using start-to-end tracking model

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Questions?

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