FACET-II
Facility for Advanced Accelerator Experimental Tests

Upgrade Options

S20 chicane + Linearizer and Laser heater

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Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Overview

- Experimental requirements
- Performance with existing layout
- Upgrade options
  - **Sector 20 optics** upgrade options
    - Final bunch compressor
      - Double-dogleg
      - Emittance compensated compressor design
    - Final focus and spectrometer quadrupoles
  - **Laser heater** in e- injector
  - **X-band "linearizer"** LCAV structure in L1
- Performance estimates with upgrade optics from start-to-end tracking

Experimental requirements

KPP's will be met for existing layout, some experiments however benefit from increased levels of beam compression (peak current / small bunch length) and/or improved beam quality (emittance):

SFQED (E-320)

- e.g. "$\sigma_z = 10\mu m$, $I_{pk} = 20kA$, $\delta_E \sim 0.5\%$" will benefit from linearizer

Beam filamentation (E-305)

- Gas target specs also befit from linearizer. Solid target needs high peak current, S20 upgrade required.

TeV/m plasma wakefield acceleration (E-317)

Attosecond strong-field physics (E-318)

Advanced diagnostics (E-326,327,328,329)

- Extending beyond TCAV measurement resolution

Furthering design efforts towards ultimate compressor

Many experimental proposals "pushed" goals will benefit and/or require proposed upgrades

Existing Layout
3-stage Bunch Compressor SLAC S10 – S20

Existing design good to meet KPP's

- ε = 20 um-rad, σ_z < 20 um, Q=2 nC

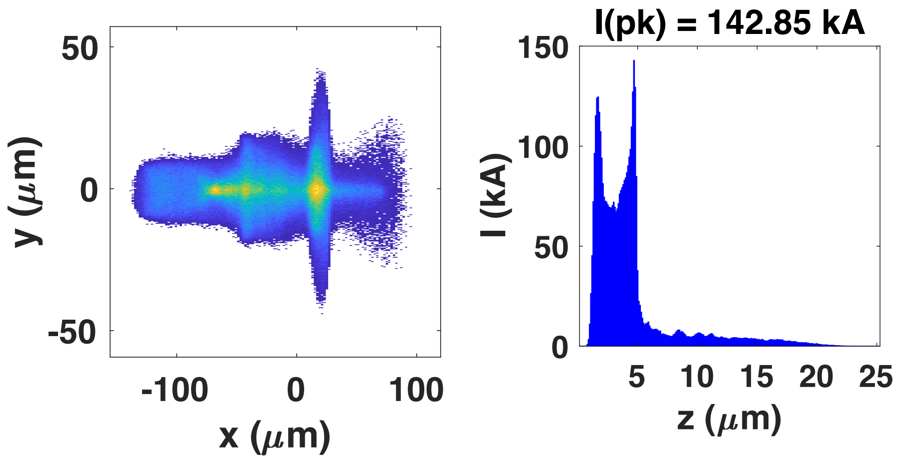
Making full use of low-emittance rf photo injector

- Expect capability for σ_z < 1 um @ ε(in L3) < 5 um-rad (I_{pk} up to 300kA)
- Greatly exceed current state-of-the-art

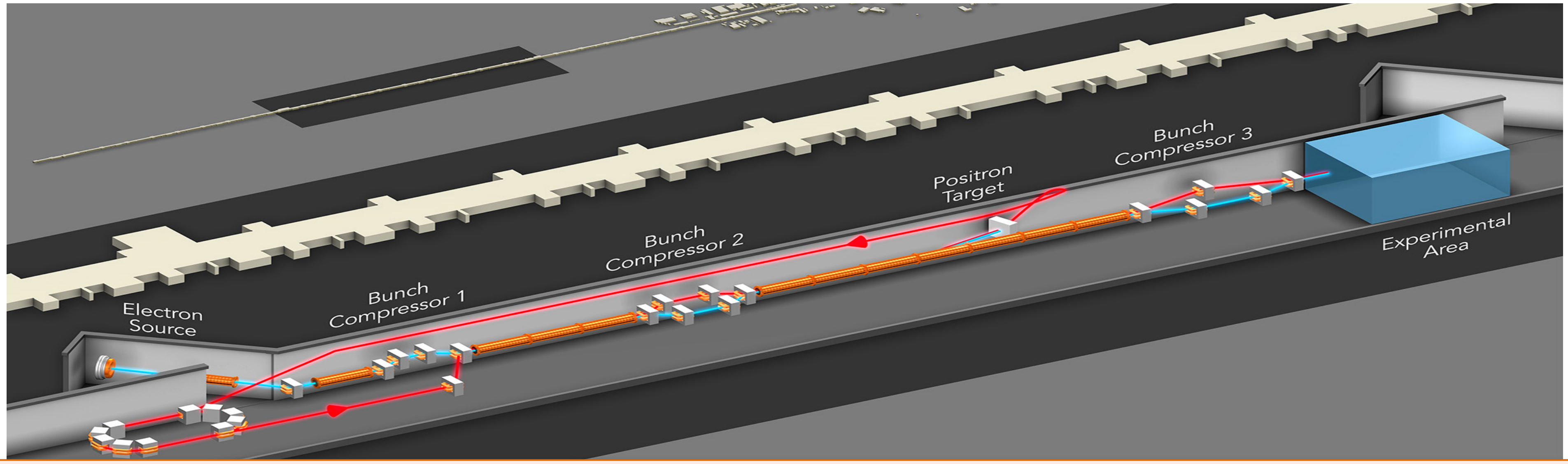
Limitations of existing system to fully exploit this possibility

- Linearity of compression & fine-control of longitudinal phase
- Emittance & longitudinal compression degradation in final compressor

6D Particle tracking to IP with 2D CSR

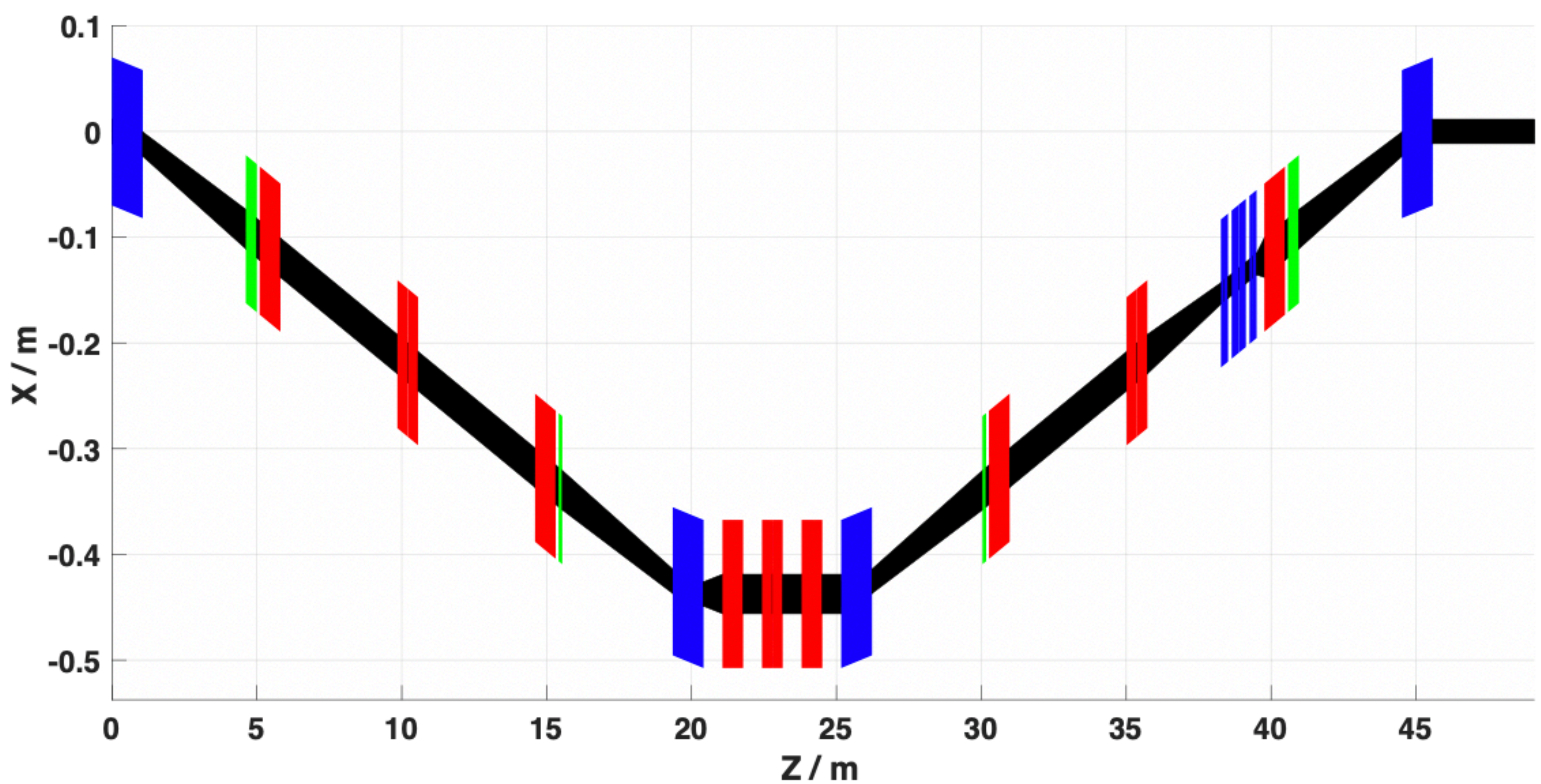


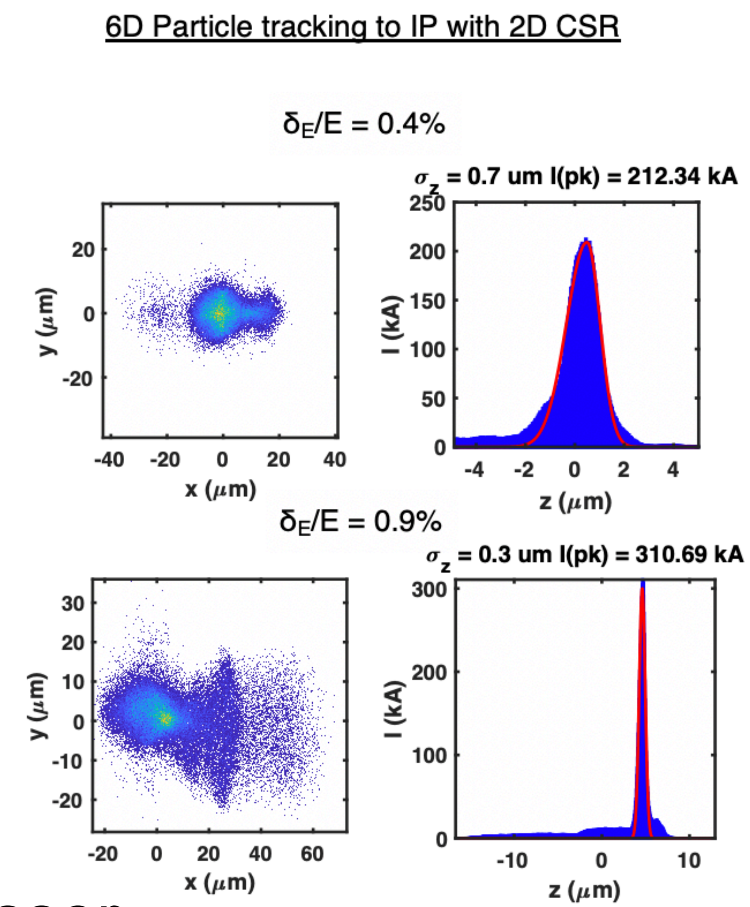
W-chicane limits I_{pk} ~<100kA, with $\Delta\varepsilon$ ~ 40 um-rad



Existing layout meets KPP requirements but doesn't fully utilize full potential of new high-quality, electron injector

Improve final compression quality: New BC20 configuration

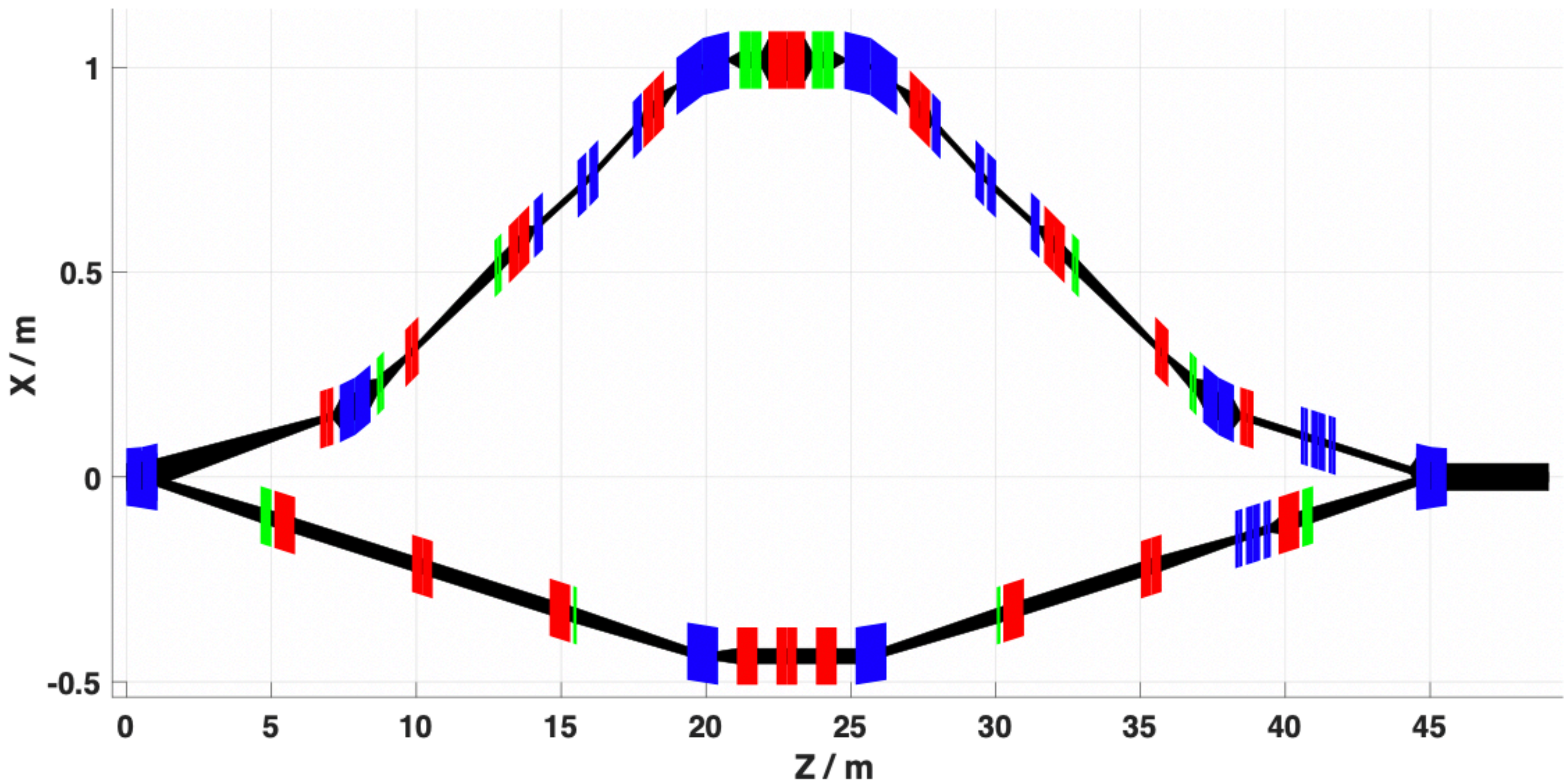


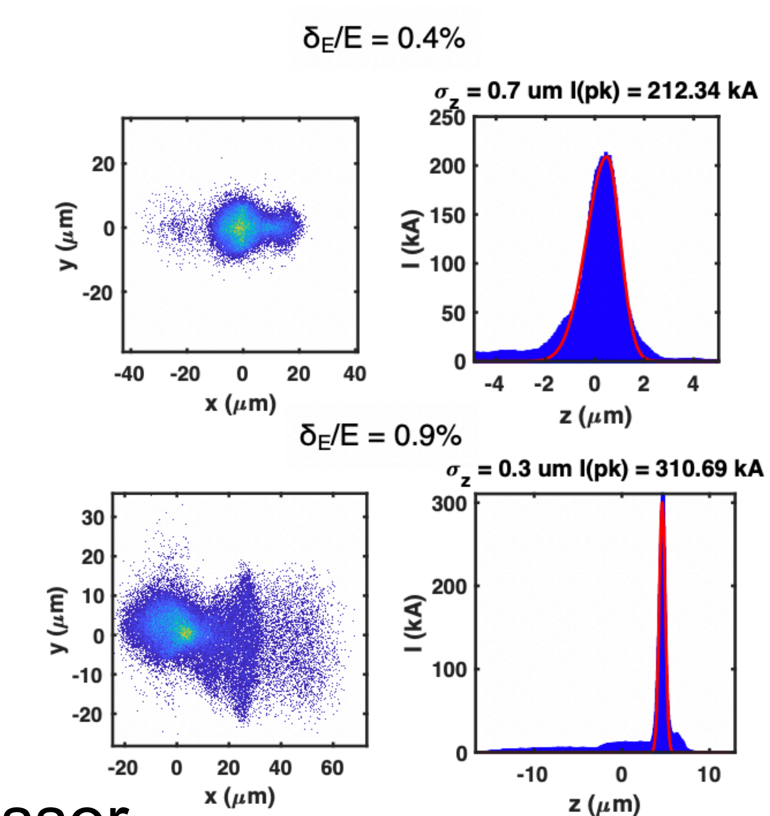


- Proposed upgrade : "double-dogleg" style BC20 compressor
- Reduced integrated bending & optimized optics mitigates CSR degradation
  - I_{pk} ~200 kA with $\Delta\varepsilon_x$ = 23 μm-rad *(low espread)* ***requires linearizer***
  - I_{pk} ~300 kA with $\Delta\varepsilon_x$ = 40 μm-rad *(high espread)*

Proposed upgrades to BC20 partially mitigates CSR emittance growth and generates high peak current electron beams

New BC20 configuration compatible with e+ upgrade option





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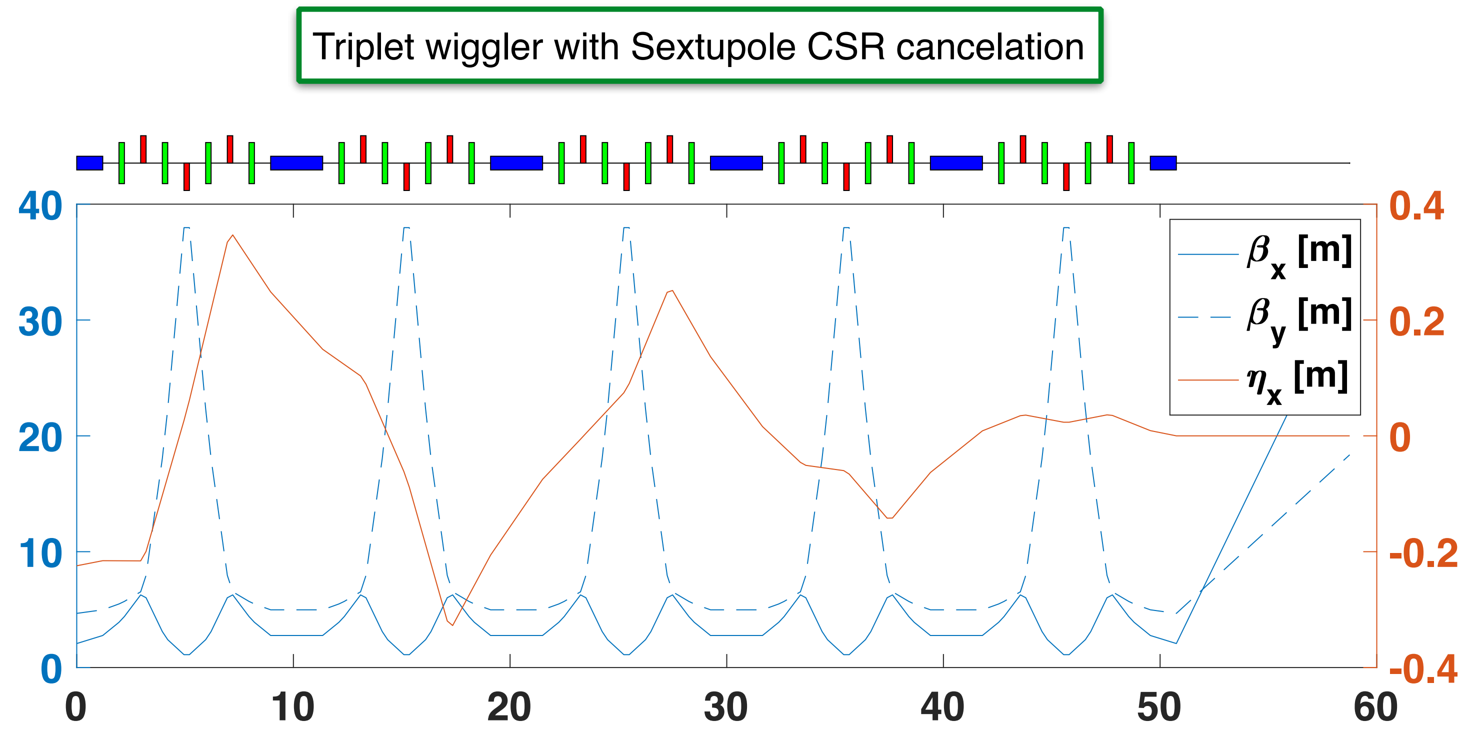
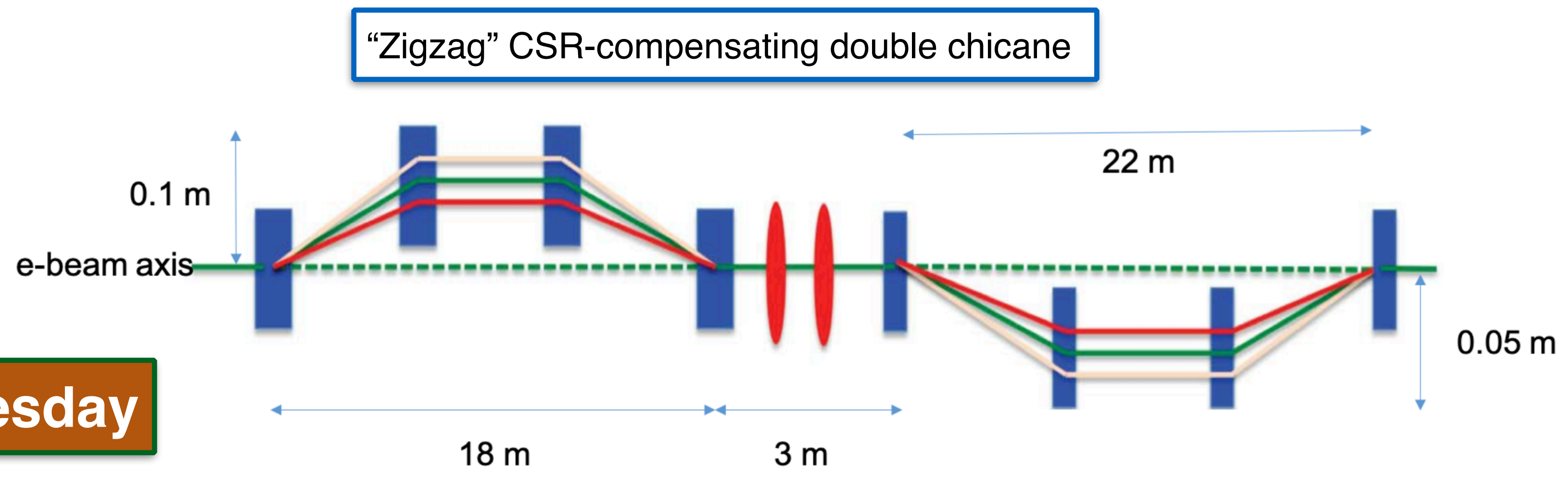
- *Provision for e+ arm to synchronize e- / e+ delivery into S20*

Proposed upgrades to BC20 partially mitigates CSR emittance growth and generates high peak current electron beams

Emittance-compensated compressor design options

- Currently evaluating emittance-compensated bunch compressor designs
- Length compatible with BC20, considered for future installation options
- Promise of max bunch compression (I_{pk}>200 kA) with minimal or no emittance degradation





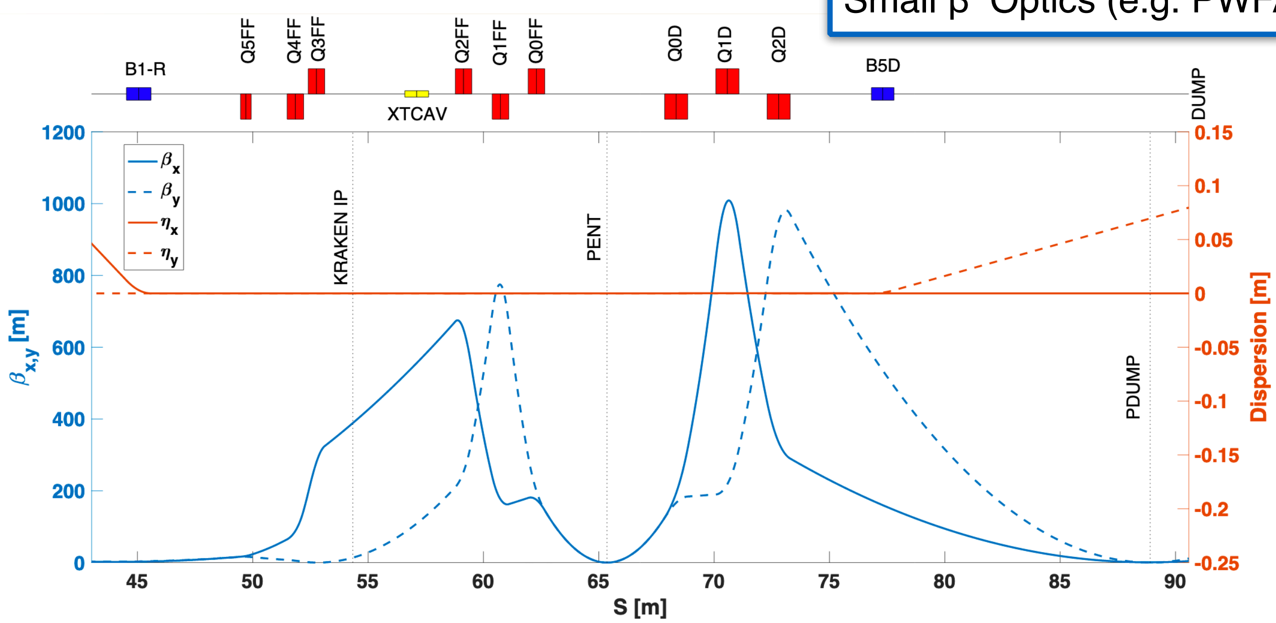
See talk by Yichao Jing on Tuesday

Evaluating emittance-compensation designs for BC20

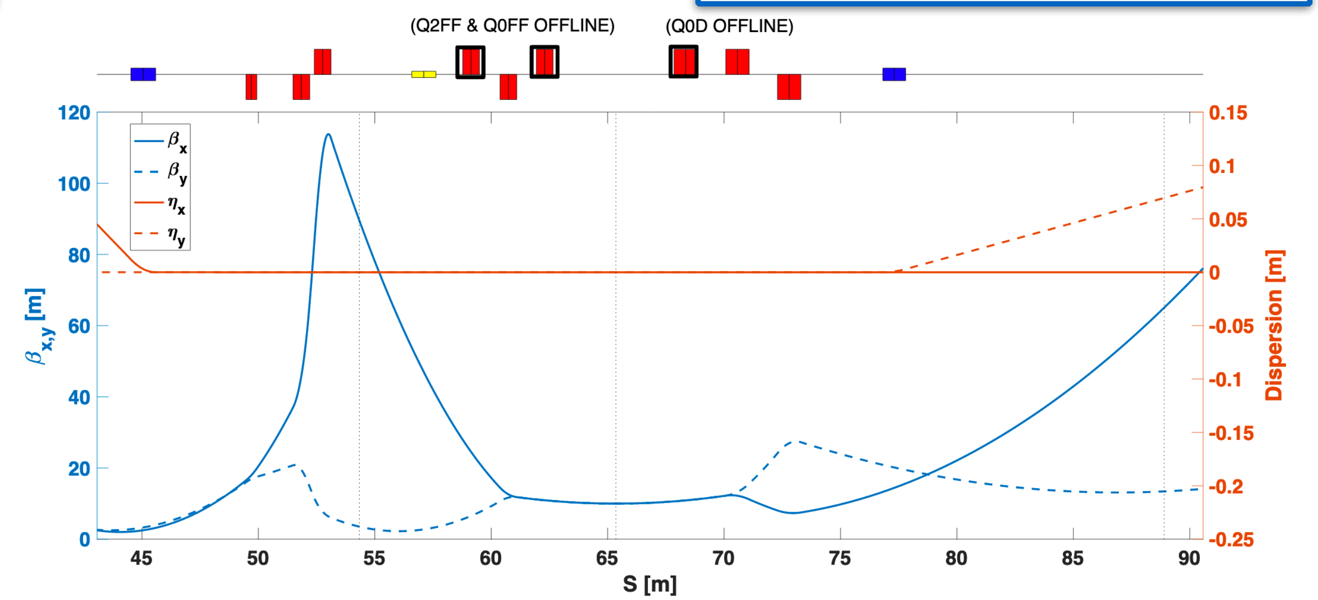
Sector 20 final focus and spectrometer magnets

See https://www.slac.stanford.edu/~whitegr/F2_S2E/ for more optics configuration options

Small β* Optics (e.g. PWFA)



High-quality IP beam (e.g. SFQED)



Existing FFS designed for 20 GeV, flat (100:1) emittance beams

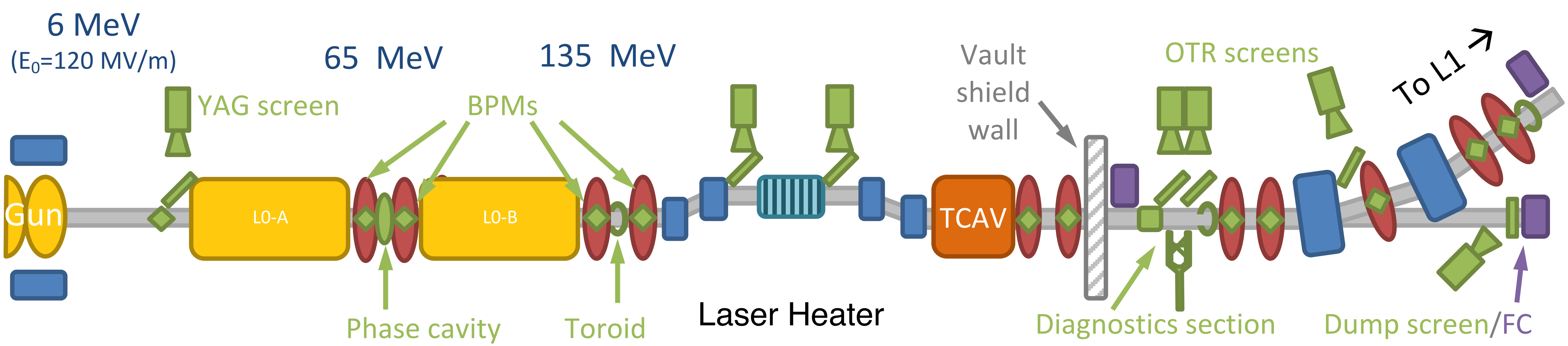
Re-designed FFS for 10 GeV, round emittance beams

- Permits β* < 15cm & allows flexibility for different experimental requirements
- XTCAV relocation & rotation allows for LPS diagnostics
  - e.g. E-327

Re-designed spectrometer allows for clean beam propagation with reduced β* optics and high-resolution LPS diagnostics

Re-designed FFS & dump optics to cater specifically for round-beam configuration from photo-injector

Laser heater



Chicane included in injector installation

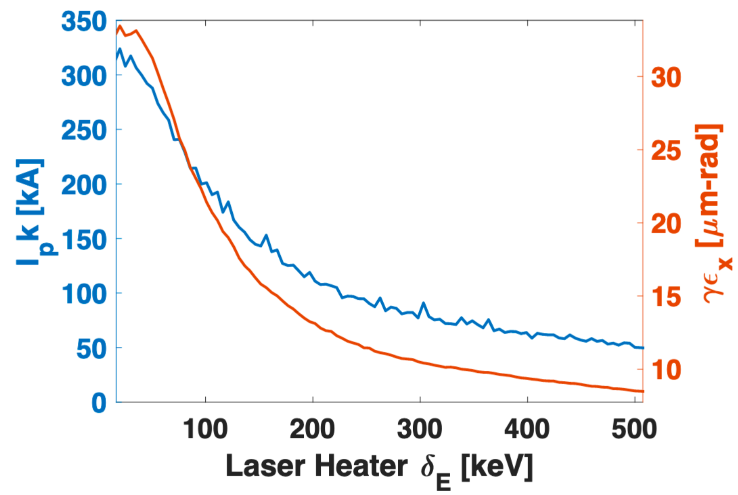
Requires addition of undulator & IR laser transport, alignment system

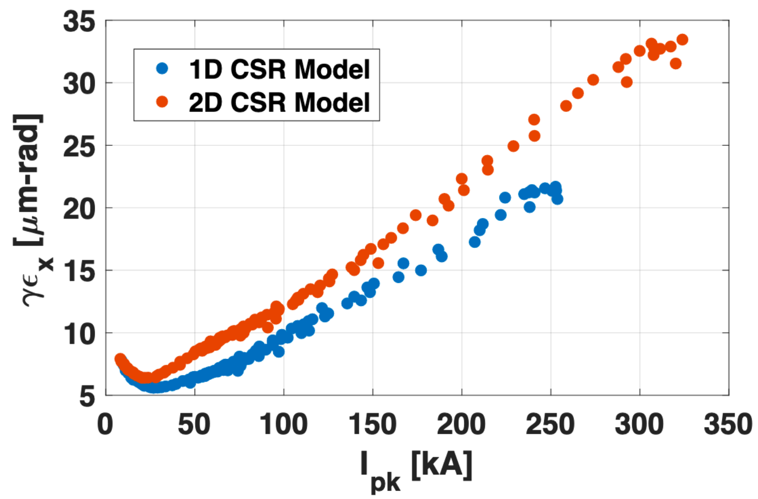
Increases incoherent slice energy spread of electron beam

- Orthogonal control of final bunch length
- Suppression of micro-bunching
- Mitigation of longitudinal jitter effects from linac rf

Laser heater upgrade option preserved in design: allows for bunch length control, micro-bunching suppression and rf jitter reduction

Laser heater allows control of final bunch length and micro-bunching suppression





Orthogonal control of final bunch length with selection of laser heater power

- Flexibility for experiments
- Benchmarking of new CSR physics modeling tools
- Relative bunch length jitter reduces with LH power
  - $\Delta\sigma_z$ ~ 3μm @ full compression e.g. 500 keV LH -> X6 reduction in $\Delta\sigma/\sigma$

https://doi.org/10.1038/s41598-020-61764-y

Suppression of micro bunching
Example: 50 keV energy spread @ laser heater

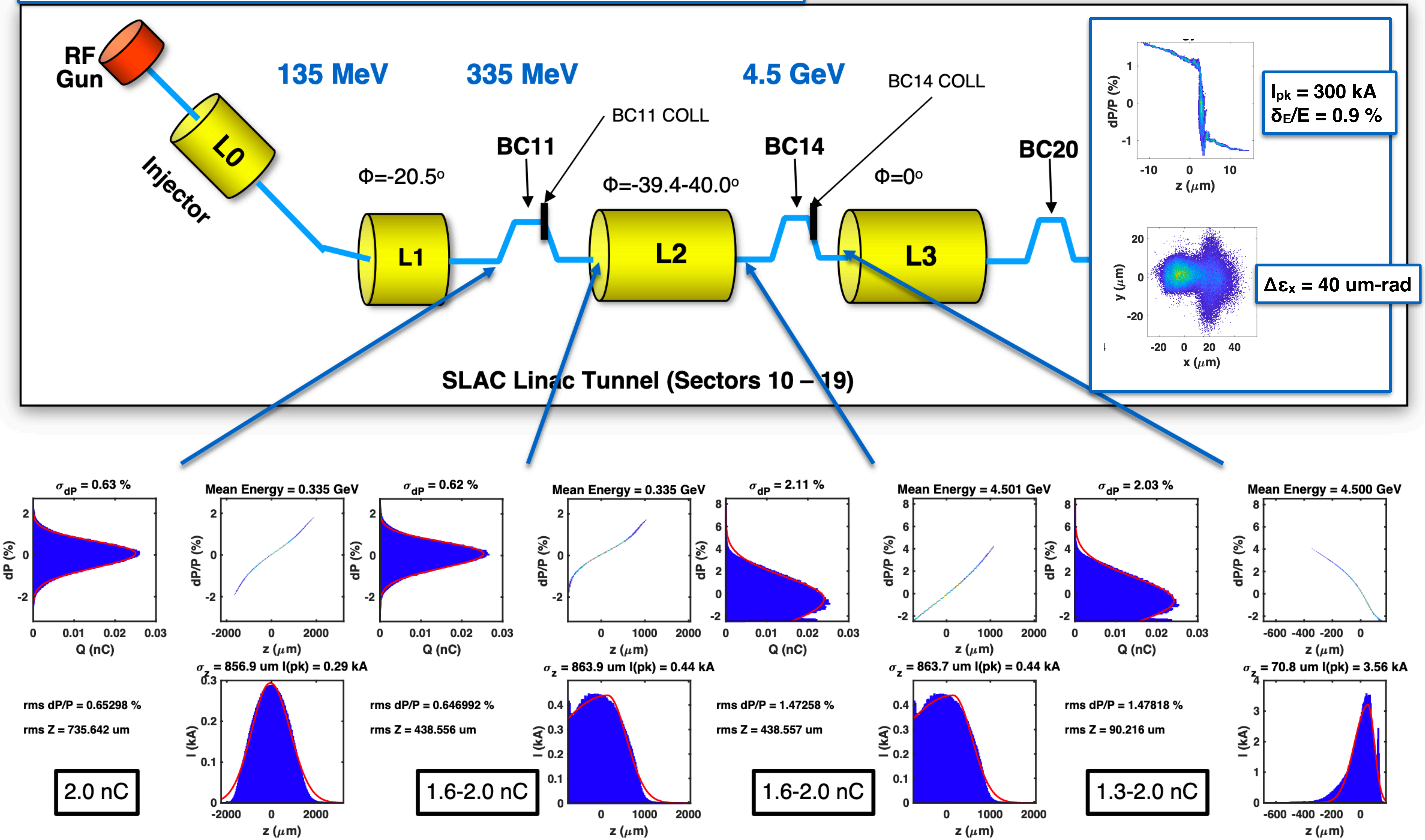
$$\lambda_c = \left(\frac{2\pi R_{56}}{1 + h_1 R_{56}}\right).(\delta_E/E)$$

Compressor	δ_E/E	h_1 (m^{-1})	$\lvert R_{56} \rvert$	λ_c (μm)
BC11	1.9E-05	8.8	0.046	3.9 -> 84
BC14	9E-06	33.5	0.036	1.9 -> 77
BC20	4.8E-05	177.3	0.005	7.4 -> 8.2

Laser heater a useful tool for experimental flexibility and studying physics of extreme compression

Particle tracking: upgraded Sector 20 optics with max bunch compression

See https://www.slac.stanford.edu/~whitegr/F2_S2E/ for more performance studies



X-band linearizer
> Enables high I_{pk} @ low energy spread <

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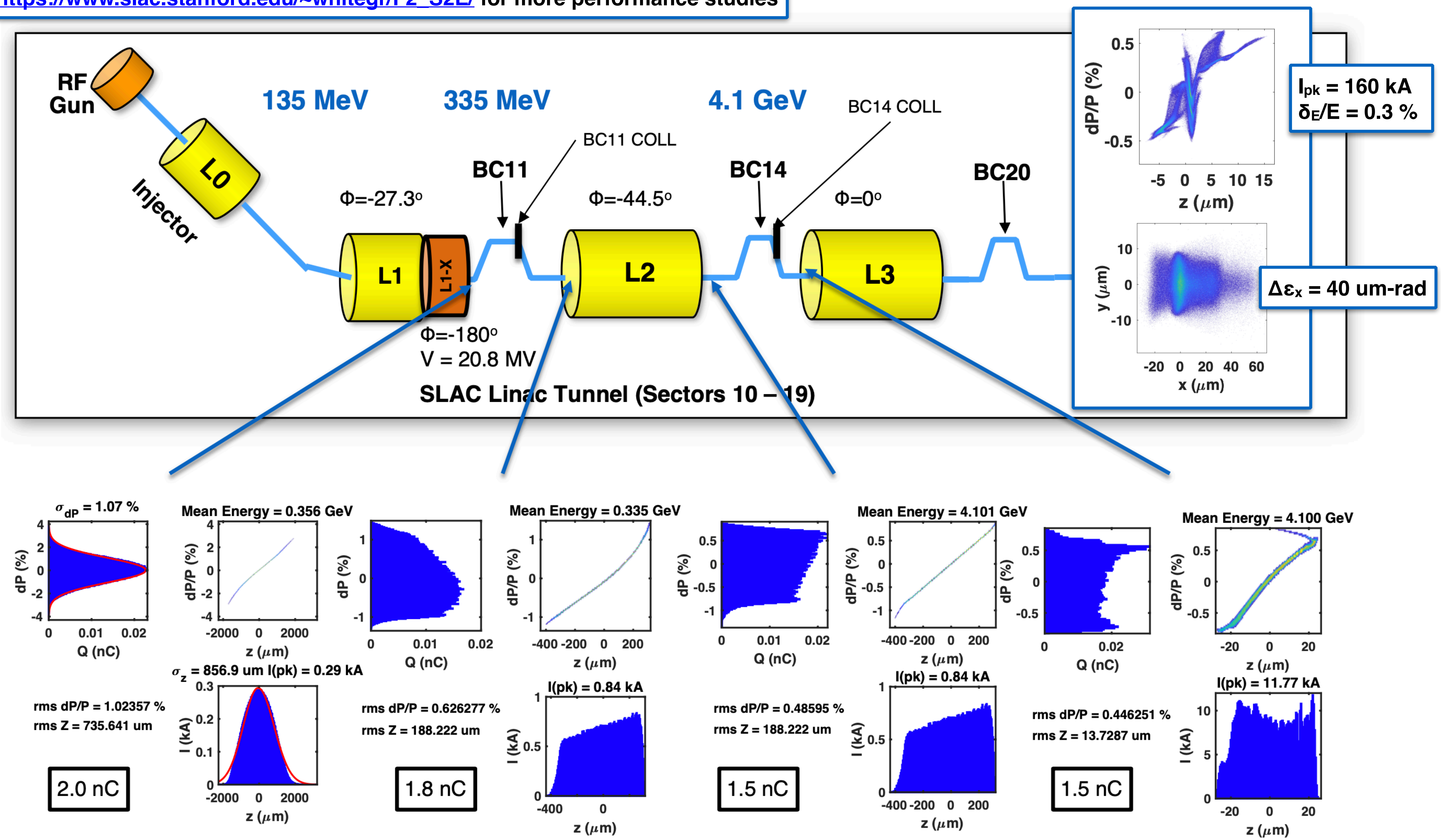

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Summary

Existing layout allows KPP's and planned experimental program

- **Limits exist to full compression potential granted by low-emittance electron injector**

Considered upgrades allow an enhanced experimental program by providing:

- Up to 300 kA peak current max compression at 0.9% energy spread with upgraded BC20
- Small spot size focusing (β @IP 15->5 cm) and optimized diagnostics setup with upgraded FFS & spectrometer in Sector 20
- Up to 160 kA peak current max compression at 0.3% energy spread with x-band linearizer
- Orthogonal control of compression, micro-bunching & jitter suppression with laser heater

Design study currently in progress for emittance-compensated BC20 to provide high peak current with high-quality transverse phase-space