FACET-II Design Update

2016 FACET-II Science Workshop
October 17 - 19, 2016, SLAC National Accelerator Laboratory

Glen White

Planning for FACET-II as a Community Resource

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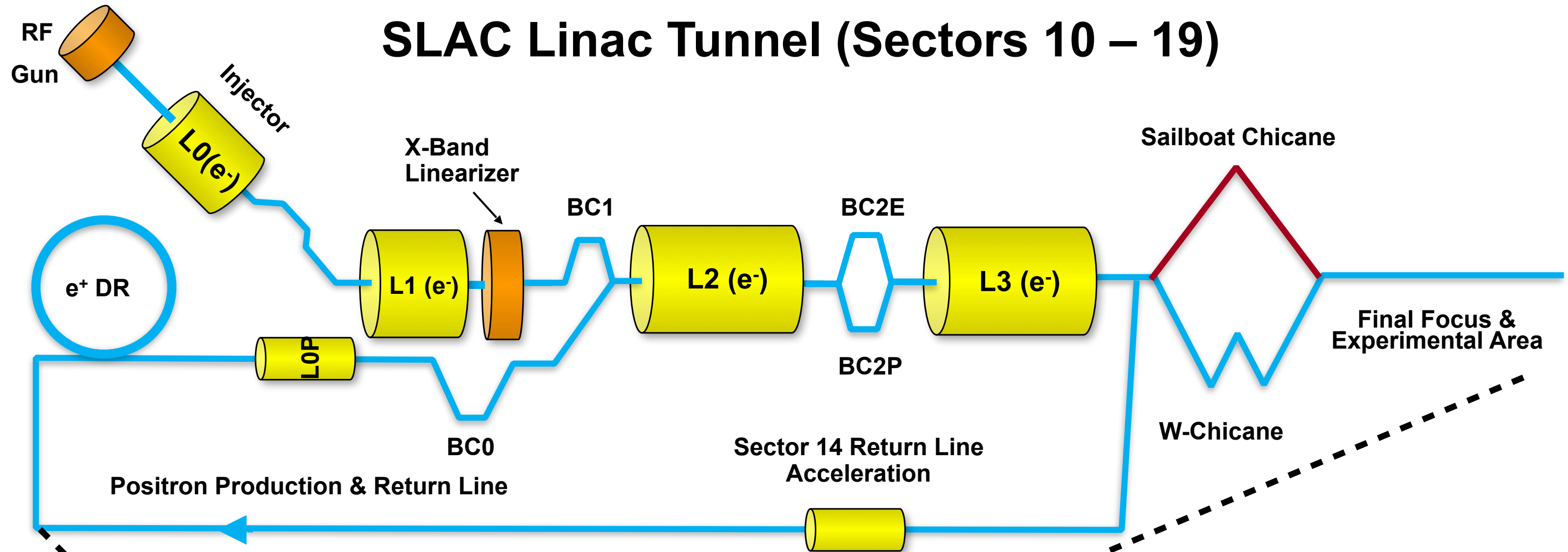
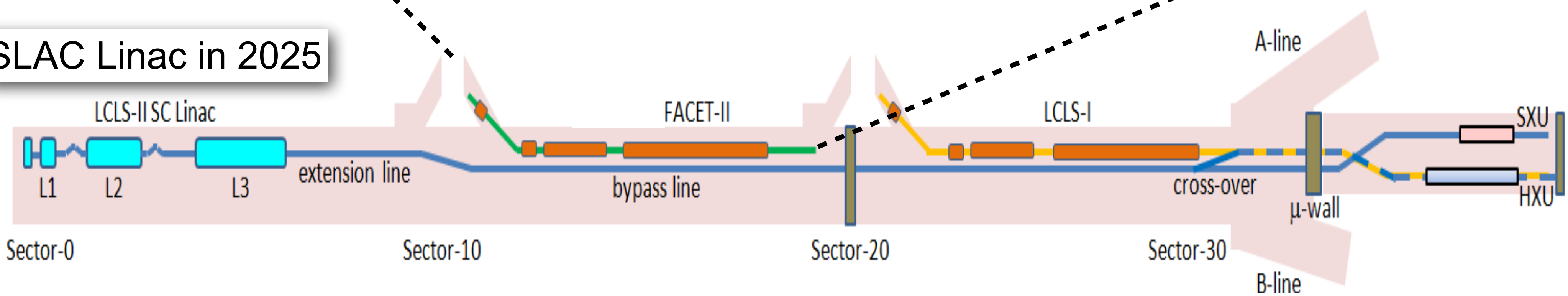
FACET-II

Photo injector
(e- beam only)
FY17-19

e+ damping ring
(e+ or e- beams)
FY19-20



SLAC Linac in 2025



FACET-I Experience

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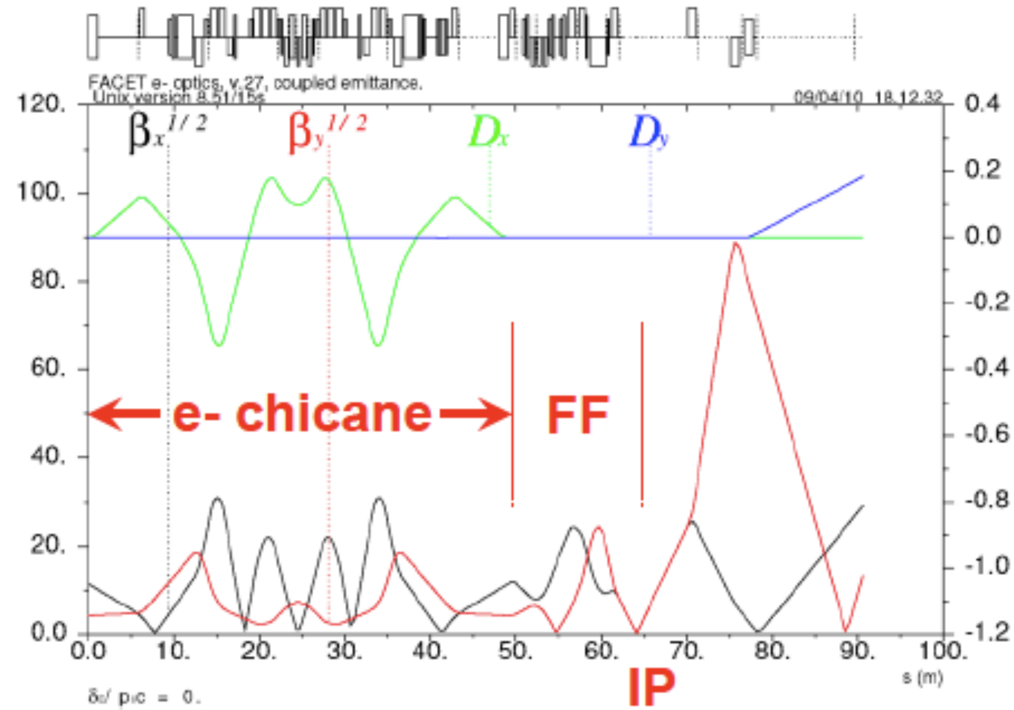
Typical requirements for FACET experiments @ 3.2 nC (20.35 GeV) e^- & e^+

- σ_x, σ_y ~ 20-30 um
- σ_z ~ 20-30 um (compressed)
  - δ_E ~ 1.4% rms
- σ_z ~ 60 um (un-compressed)
  - δ_E <1% rms



Need to control dispersion, coupling, focal waist position

- 4 sextupoles on movers
- 2 skew quadrupoles

For high energy spread:

- **chromaticity and second-order dispersion compensation by sextupoles**

FACET represented a beam dynamics challenge with simultaneous transverse and longitudinal phase space requirements and user-driven flexibility requirements

FACET-II Key Performance Parameters

Description of Scope	*Units*	*Threshold KPP*	*Objective KPP*
Beam Energy	*[GeV]*	*9*	*10*
Bunch Charge (e-/e+)	*[nC]*	*0.1/0.1*	*2/1*
Normalized Emittance in S19 (e-/e+)	*[μm-rad]*	*50/50*	*20/20*
Bunch Length (e-/e+)	*[μm]*	*100/100*	*20/20*

Threshold KPPs

- Minimum parameters against which the project's performance is measured when complete

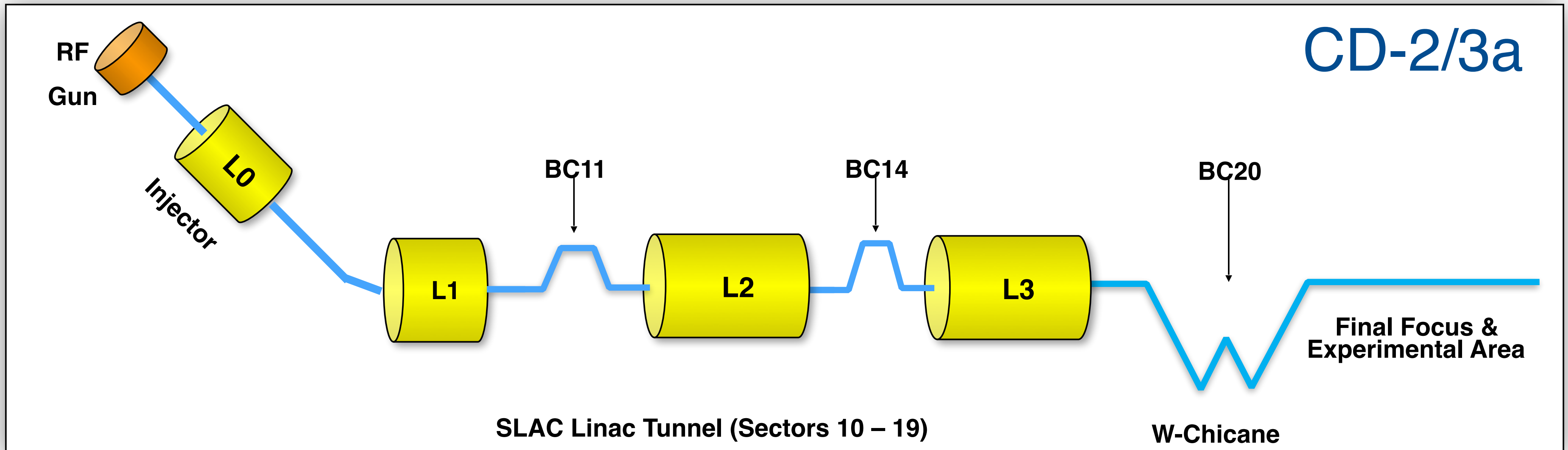
Objective KPPs

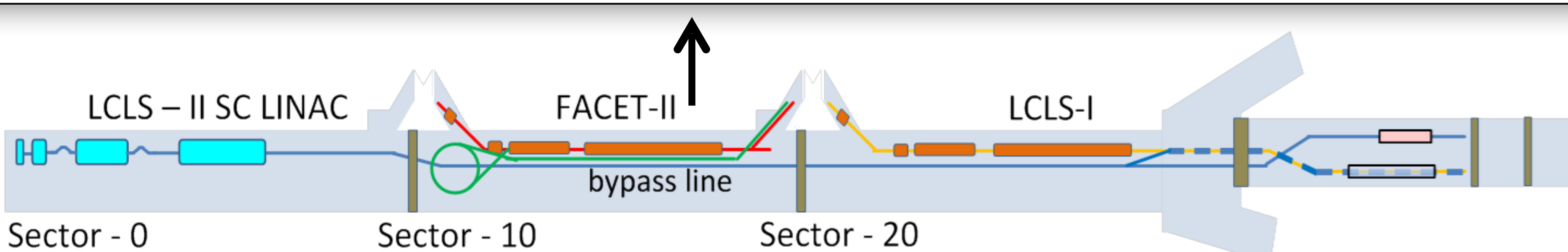
- Desired operating parameters which may be achieved during steady operation

Baseline design allows for objective key performance parameters specified by science program

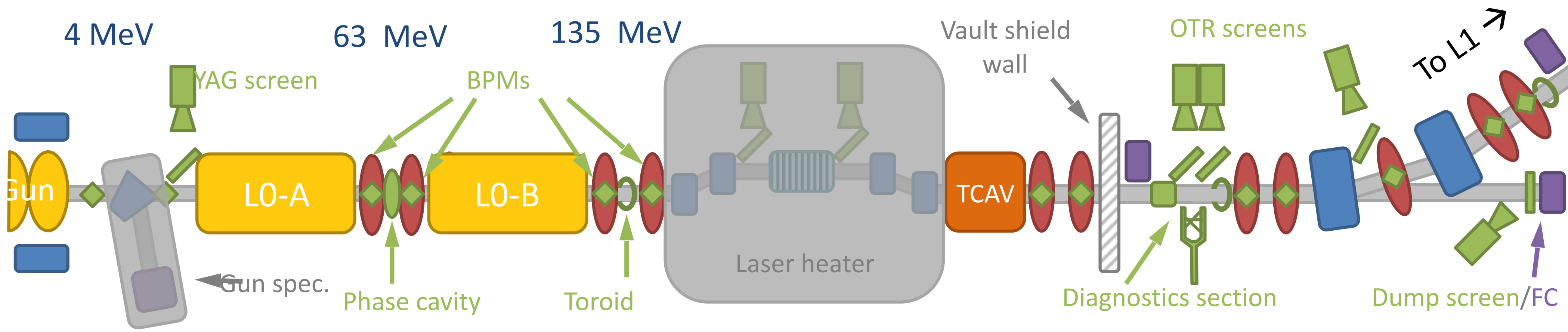
FACET-II Stage 1 FY17-19

- **Goal:** Deliver compressed electron beam from S10 to experiments in S20
- **Major upgrade:** Electron beam photoinjector in Sector 10
- **Scope:** Injector, shielding wall in S10, bunch compressors in S11 (BC11) and S14 (BC14), beam diagnostics

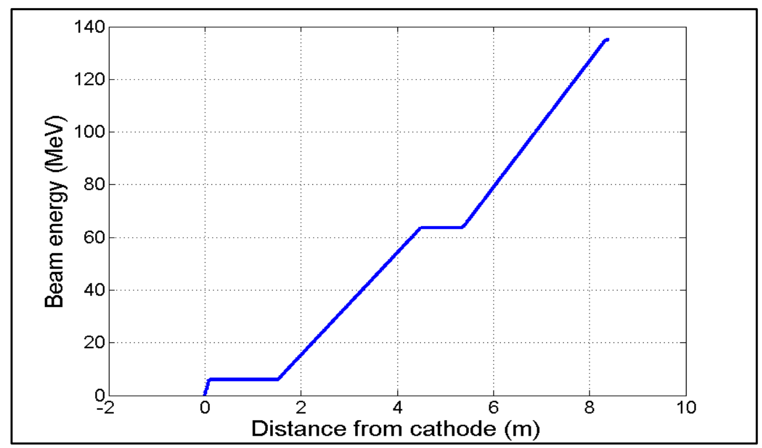




Electron Injector



- NLCTA ("Orion") RF Gun, E_0=90MV/m
- L0 accelerates to **135 MeV**
- *LH chicane – off project, space reserved*
- 35^0 bend into main linac L1 @ Sector 11
- Q < 5 nC, <300 A peak current
- Design: $\gamma\varepsilon_x$ = **3 μm-rad** @ **2 nC, 240 A**
- Emittance compensation design using IMPACT-T
- *Beam distribution from IMPACT-T simulation used to assess FACET-II performance in tracking model*

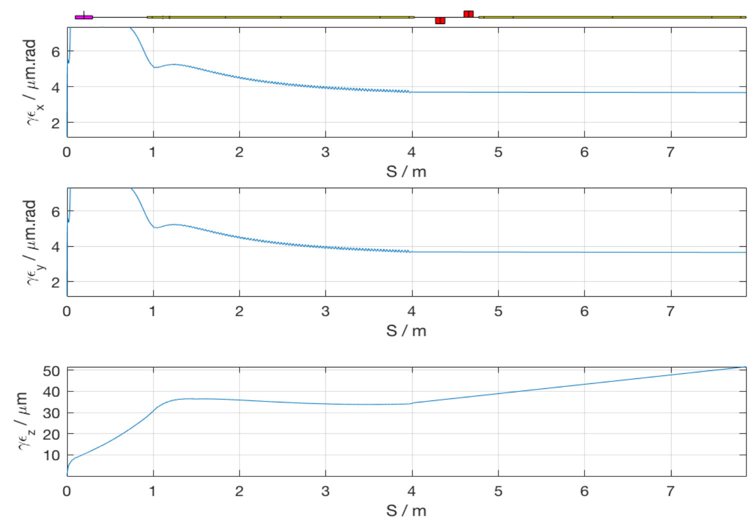


Design of the Injector Complex up to BC11 based on LCLS Sector 20 injector

Electron Injector Optimization & Simulation

Parameter	Symbol	Unit	Req.	Tracking Simulation Results			
				Orion	Orion + LH	LCLS	LCLS + LH
Peak current at injector exit	I_{pk}	kA	-	0.24	0.24	0.36	0.33
Peak current at Sector 20 IP	I_{pk}	kA	>10	70	36	95	56
Bunch length after injector (rms)	σ_z	μm	-	838	839	617	618
Bunch length at Sector 20 IP (core rms)	σ_z	μm	<20	1.8	4.3	1.5	2.8
Transverse emittance after injector (90%)	$\gamma\varepsilon_{x,y}$	μm-rad	-	2.9	2.9	3.0	3.0
Transverse emittance into Sector 19 (90%)	$\gamma\varepsilon_{x,y}$	μm-rad	<20	3.9	3.3	4.0	3.5
Tranverse beam size at Sector 20 IP (core rms)	σ_x,σ_y	μm	<20	17.7, 12.2	16.1, 11.9	17.5, 9.8	16.5, 9.9

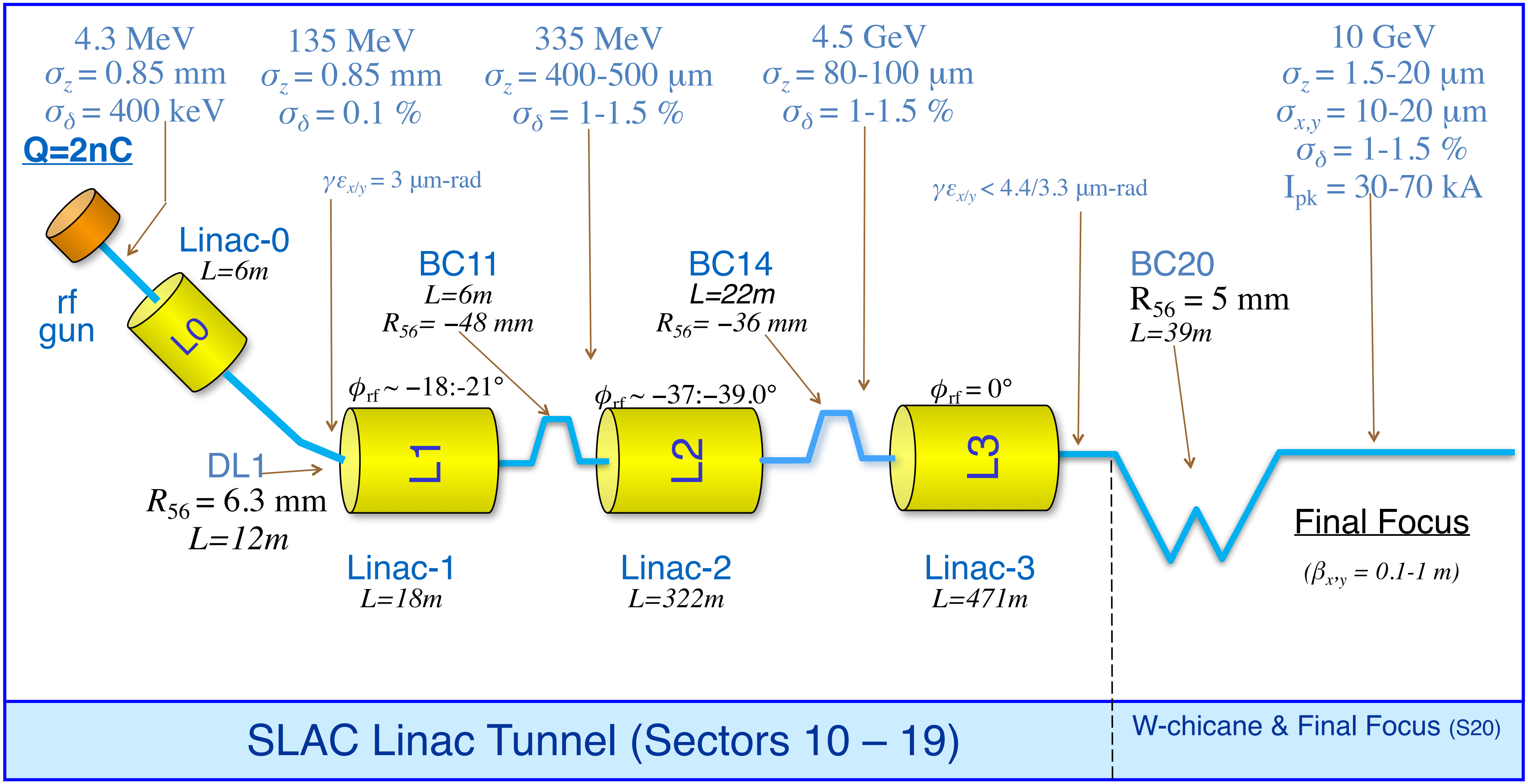
LH = “laser heater”



- ε-compensation optimization & tracking with IMPACT-T & Lucretia
- Optimize:
  - Gun Sol
  - Gun RF phase
  - Cathode-L0a drift
  - 2nd solenoid

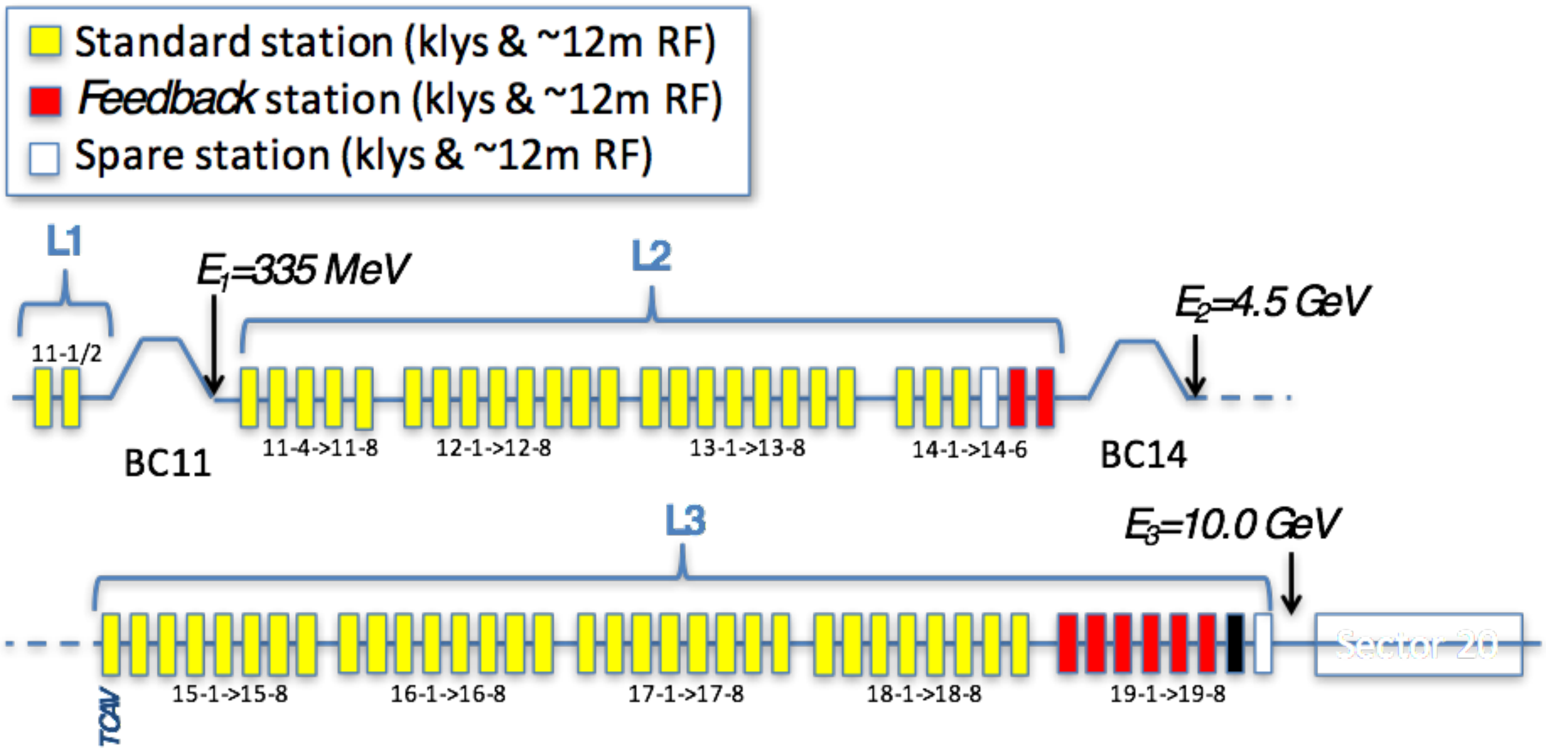
All options meet KPP requirements
Increased longitudinal brightness possible with LCLS gun

Baseline FACET-II Electron Design Parameters



Compression scheme design satisfies KPP's, flexibility to satisfy all planned experimental activities - verified with tracking simulations

Main Linac Layout & Bunch Compressors

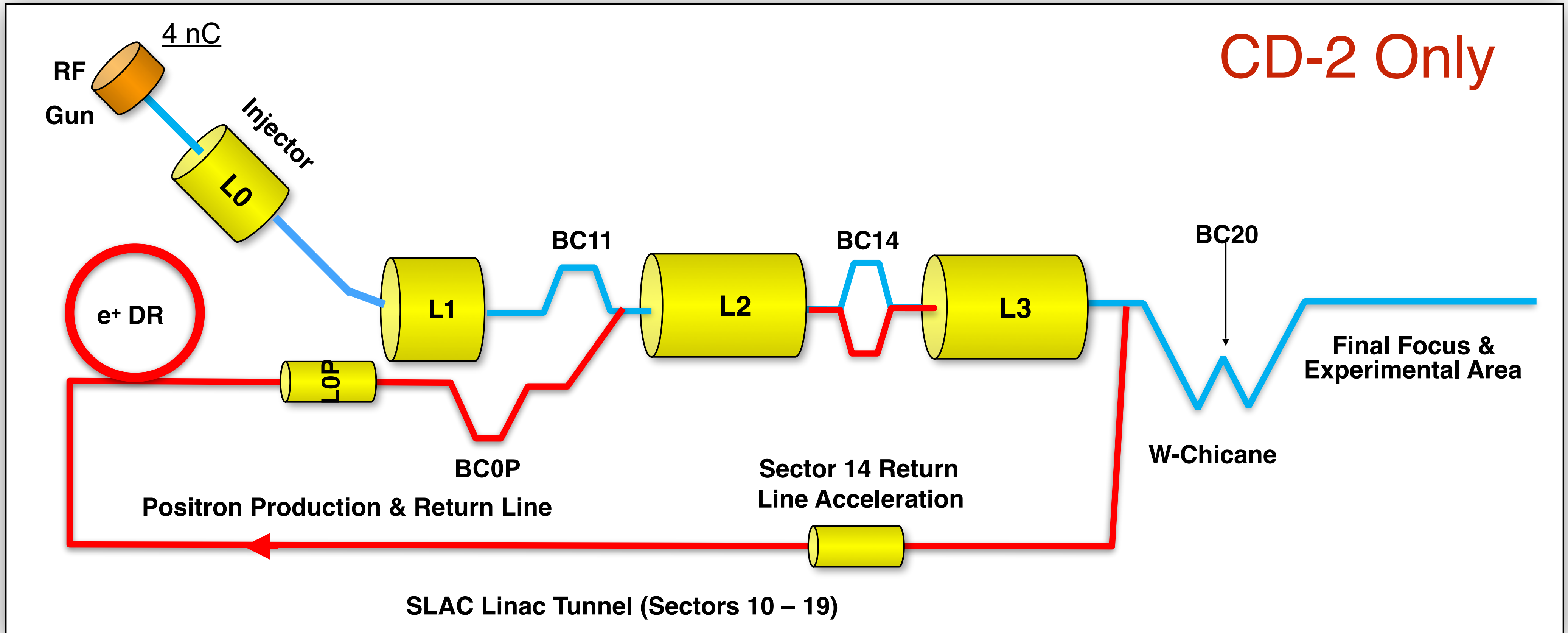


- Sector 20 operations 4.0-13.5 GeV possible (10 GeV design)
- Spare klystrons, feedback and TCAV diagnostics stations included in design

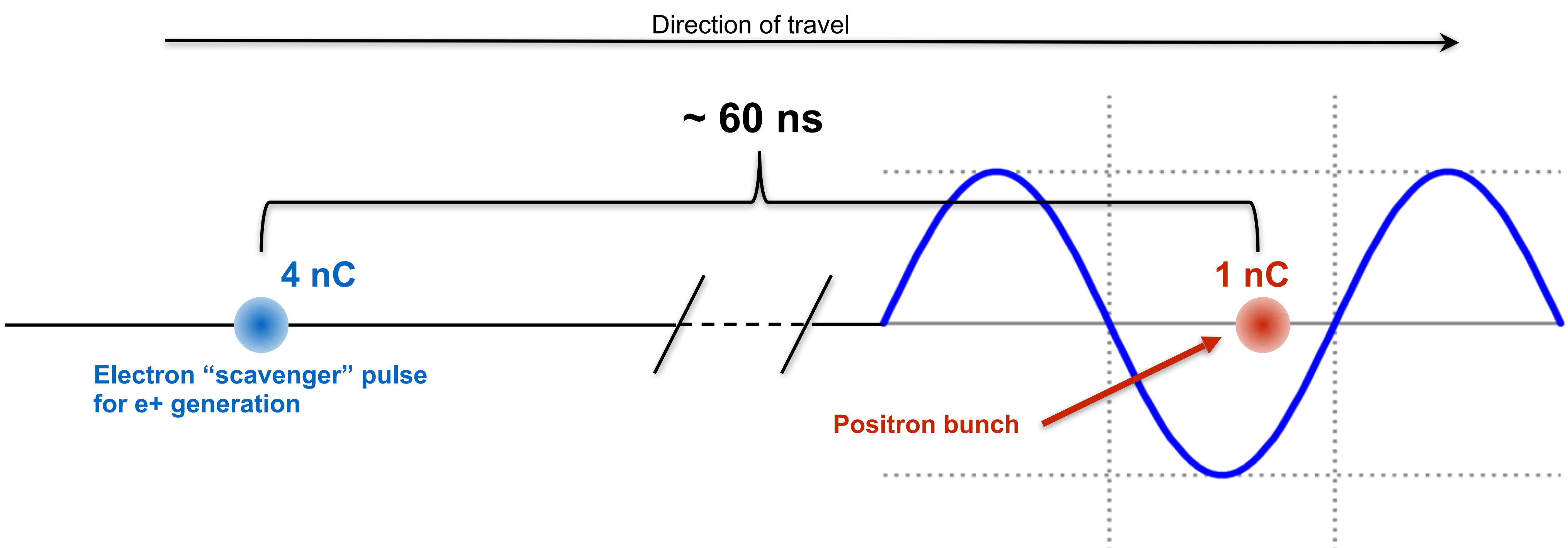
Layout of Linac Sectors 11-19 to meet required flexibility of experimental program

FACET-II Stage 2 FY17-20

- **Goal:** Deliver compressed electron beam from S10 to experiments in S20
- **Major upgrade:** Positron damping ring
- **Scope:** Damping ring, positron bunch compressor & return line



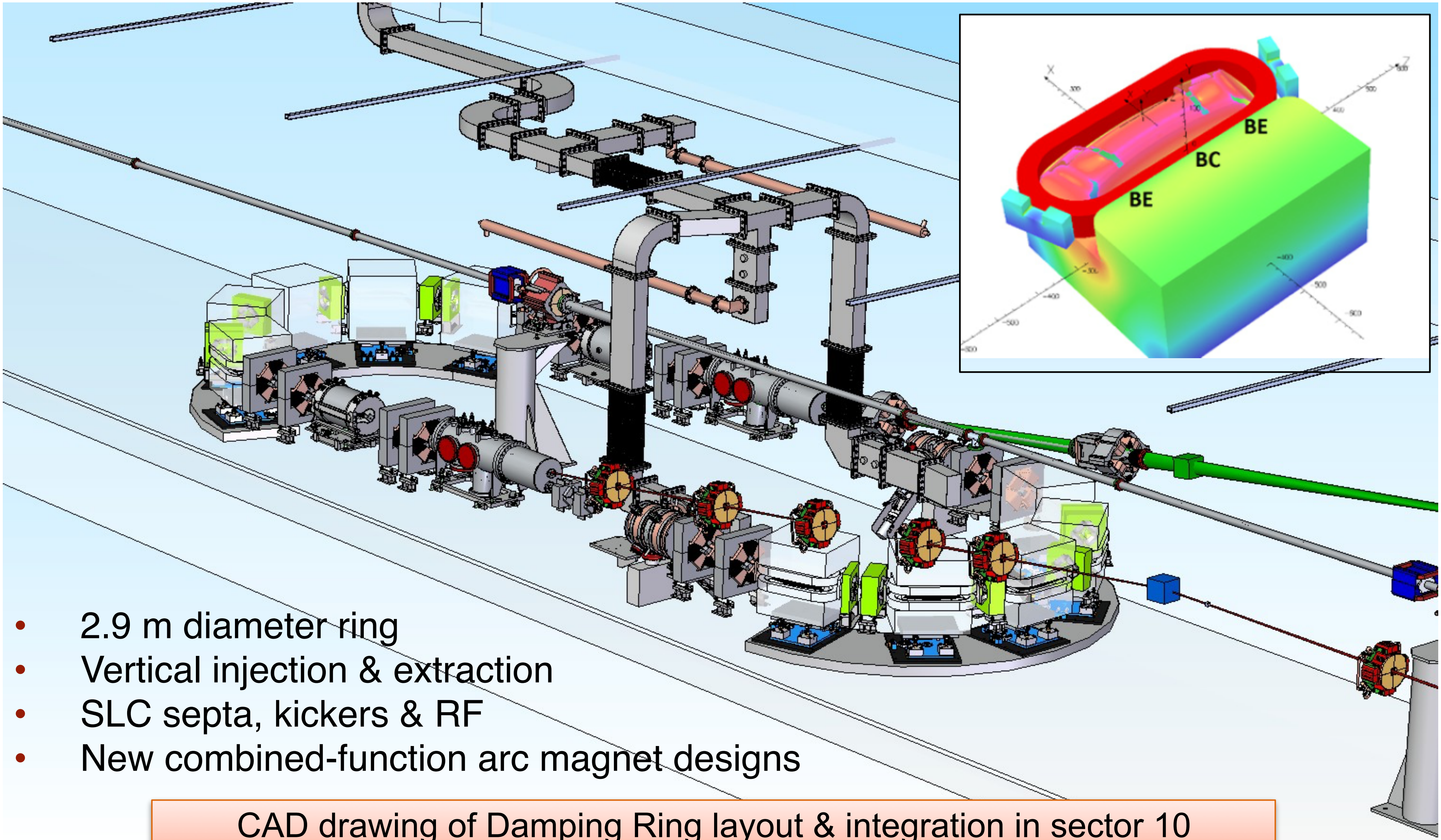
FACET-II Pulse Structure (Stage-II)



- Electron "scavenger" pulse pulled off in S19 by existing fast kicker to generate e+ bunch

Two bunches per pulse shared in L2 and L3 for Stage 2 operations

Positron Damping Ring in Sector 10



- 2.9 m diameter ring
- Vertical injection & extraction
- SLC septa, kickers & RF
- New combined-function arc magnet designs

CAD drawing of Damping Ring layout & integration in sector 10

Baseline FACET-II Positron Parameters

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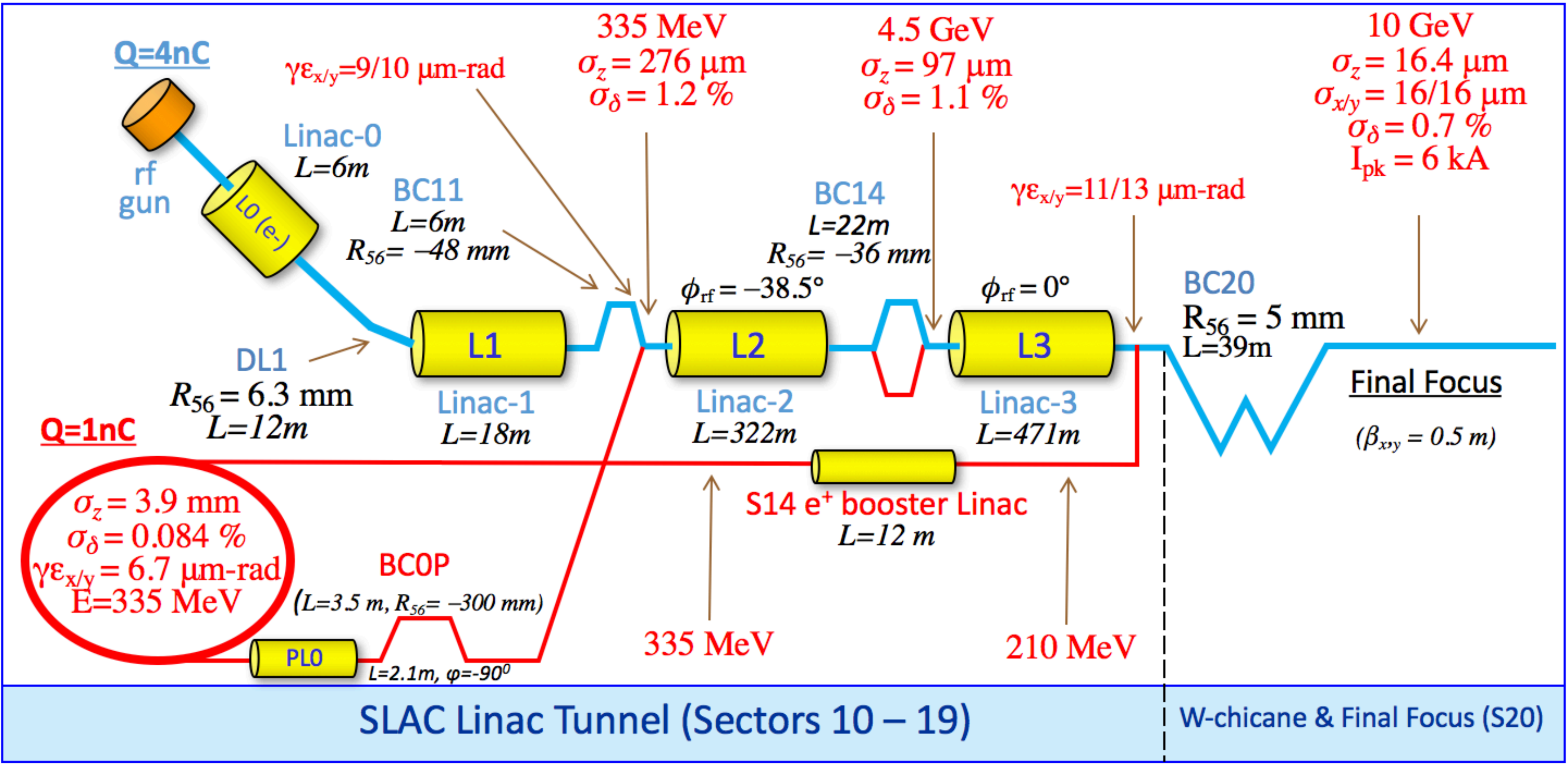

Compression scheme designed to satisfy objective KPP, verified with tracking simulations

Monte Carlo Simulation Including Errors

KPP Parameter	Electron Bunch		Positron Bunch	
	Design Req.	Simulation	Design Req.	Simulation
ε_x (μm-rad) [S19]	<20	4.4 +/- 0.5	<20	10.7 +/- 0.7
ε_y (μm-rad) [S19]	<20	3.3 +/- 0.1	<20	13.0 +/- 1.2
σ_z (μm) [IP]	<20	3.1 +/- 1.5	<20	16.5 +/- 0.2
I_{pk} (kA) [IP]	>10	64 +/- 16	>5	5.8 +/- 0.2

A MC simulation including all known error sources was performed – KPP Design parameters are met with expected error tolerances

Configuration for 2-Bunch (e-) Experiments:

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Request:

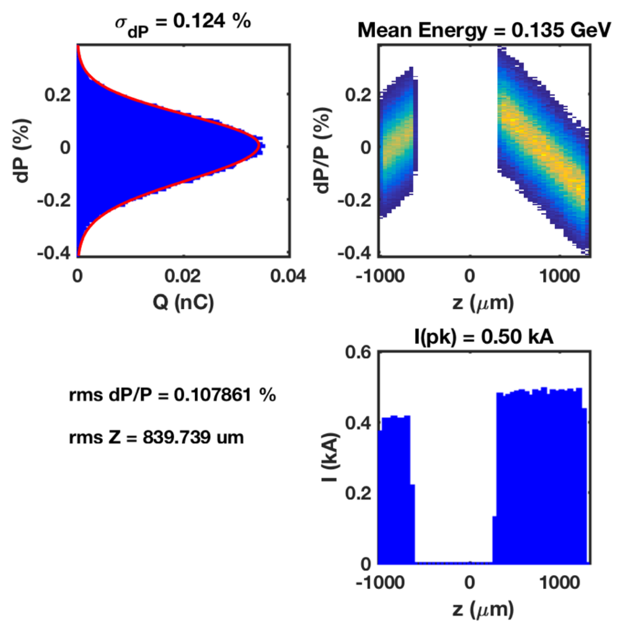
- 2 Bunches: Drive + Witness, Δt = 250 fs [~75 μm]

- Drive Bunch:
  - Q = 1.6 nC
  - I_{pk} > 15 kA
  - $\gamma\varepsilon_{x,y}$ < 10 μm-rad

- Witness Bunch:
  - Q = 0.5 nC
  - I_{pk} > 7.5 kA
  - $\gamma\varepsilon_{x,y}$ < 10 μm-rad

- I_{pk} Drive:Witness = 2:1

Longitudinal Bunch Profile Definition @ Laser Heater

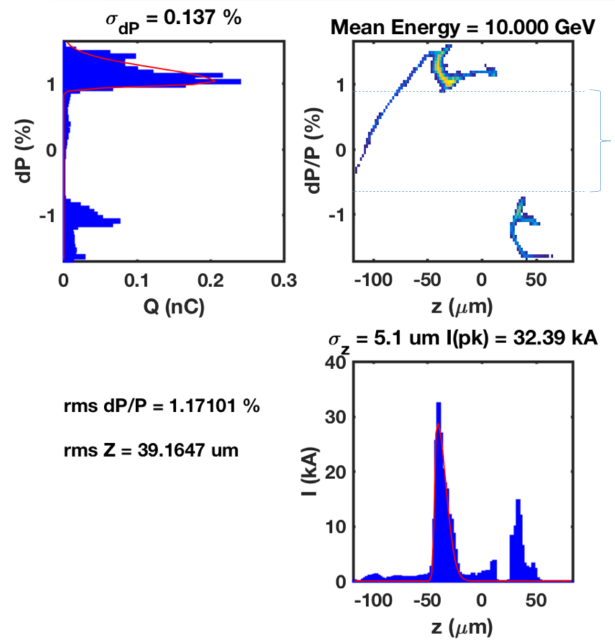


Initial $\gamma\varepsilon_{x,y}$ = 3.2 μm-rad

Property	Drive Bunch	Witness Bunch
Q / nC	1.6	0.5
δ_E / E (% uncorrel.)	0.08	0.08
Shape	Top-hat, ramp	Top-hat, ramp
Ramp Time / μs	10	10
L / mm	1.0	0.375
<Ez> r_{correl}	-0.45	0.4
dz / mm	1.62	

Highlighted boxes are optimized values

Particle Tracking @ E200 IP



S20 Notch Collimator (100 pC)

Parameter @ IP	No COLL		S20 Notch COLL	
	Drive	Witness	Drive	Witness
Q / nC	1.6	0.5	1.5	0.5
δ_E / E (% rms)	0.24	0.24	0.16	0.25
I_{pk} / kA	32	16	34	16
$\gamma\varepsilon_y$ / μm-rad	3.4	3.2	3.3	3.2
$\gamma\varepsilon_x$ / μm-rad	6.4	7.8	5.6	7.8
$\gamma\varepsilon_x$ / μm-rad (90%)	5.7	6.1	5.1	6.1

Linac RF Phase Settings

L1 φ = -18.0^0

L2 φ = -38.0^0

Δt @ IP = 250 fs

BC11 & BC14 unchanged

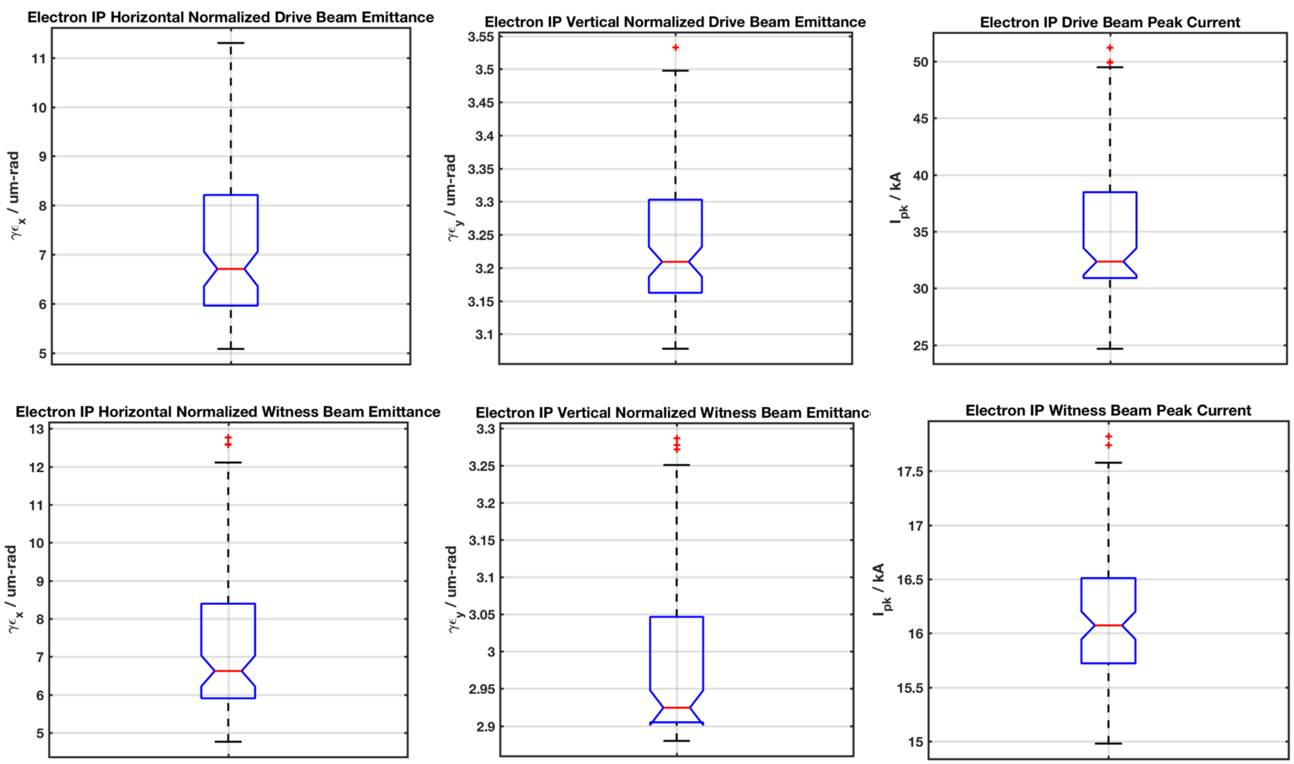
Dynamic Errors (100 Monte Carlo Seeds)

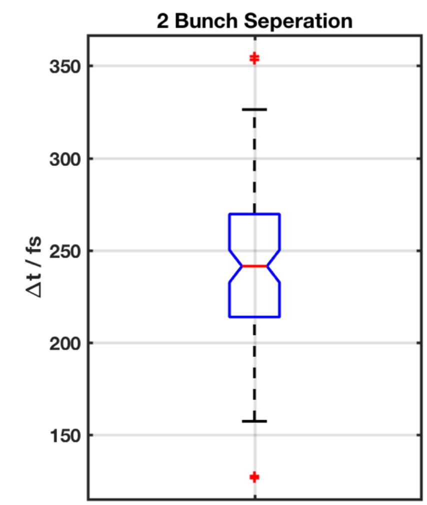
Property	Value
Source Charge Fluctuation	*1% (e-) 2% (e+)*
Source Position Fluctuation	*0.05 $\sigma_{x/y}$*
Initial Electron Laser Timing	*200 fs*
L1X Phase Jitter	*0.25 degX*
L1S Phase Jitter	*0.1 degS*
L2 Phase Jitter	*0.25 degS*
L3 Phase Jitter	*0.25 degS*
L0P Phase Jitter	*0.1 degS*
L1X Amplitude Jitter	*0.25 %*
L1S Amplitude Jitter	*0.1 %*
L2, L3, L0P Amplitude Jitter	*0.25 %*
BC0 Magnet Strength Jitter	*1e-5 dB/B*
BC1 Magnet Strength Jitter	*1e-5 dB/B*
BC2 Magnet Strength Jitter	*1e-4 dB/B*
BC3 Magnet Strength Jitter	*1e-4 dB/B*
Magnet Vibration (x/y)	*1.5 / 0.5 um*
Magnet Vib. (PEC) (x/y)	*0.4 / 0.2 um*

No Collimation

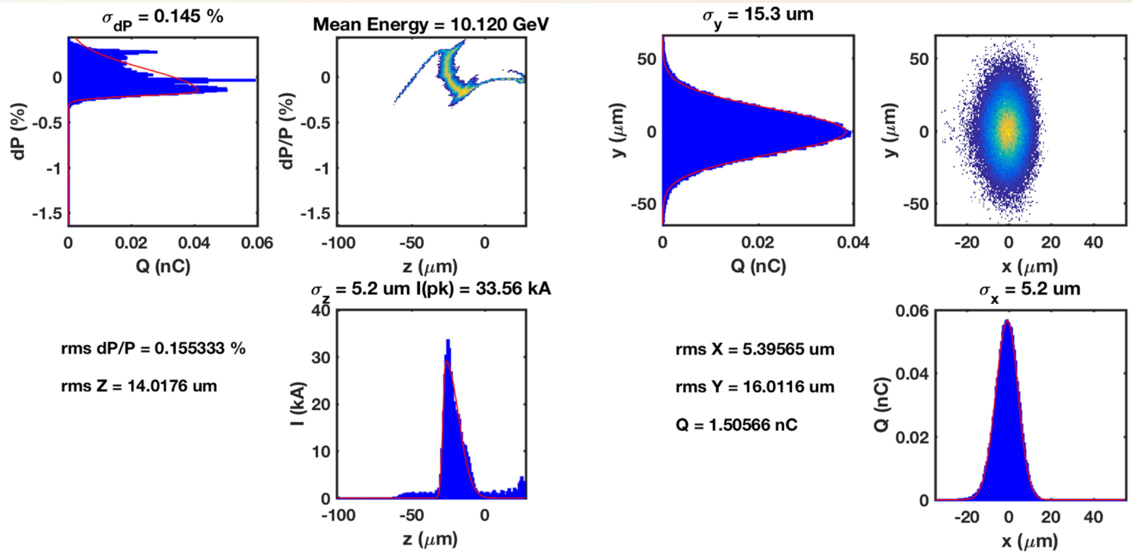
Parameter @ IP	Drive Bunch	Witness Bunch
ε_x (μm-rad) (90%)	7.2 +/- 1.6	7.4 +/- 2.0
ε_y (μm-rad) (90%)	3.2 +/- 0.1	3.0 +/- 0.1
Δt (fs)	243 +/- 45	
I_{pk} (kA)	35.5 +/- 6.6	16.1 +/- 0.6

Dynamic Errors (100 Monte Carlo Seeds)

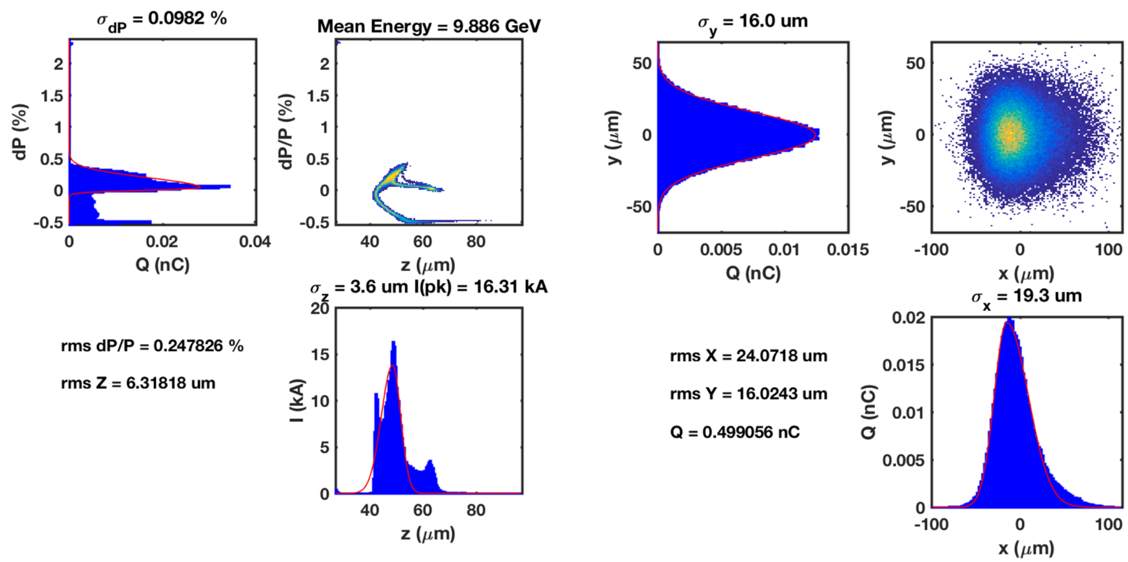




Tracked Particles @ S20 IP with Collimation



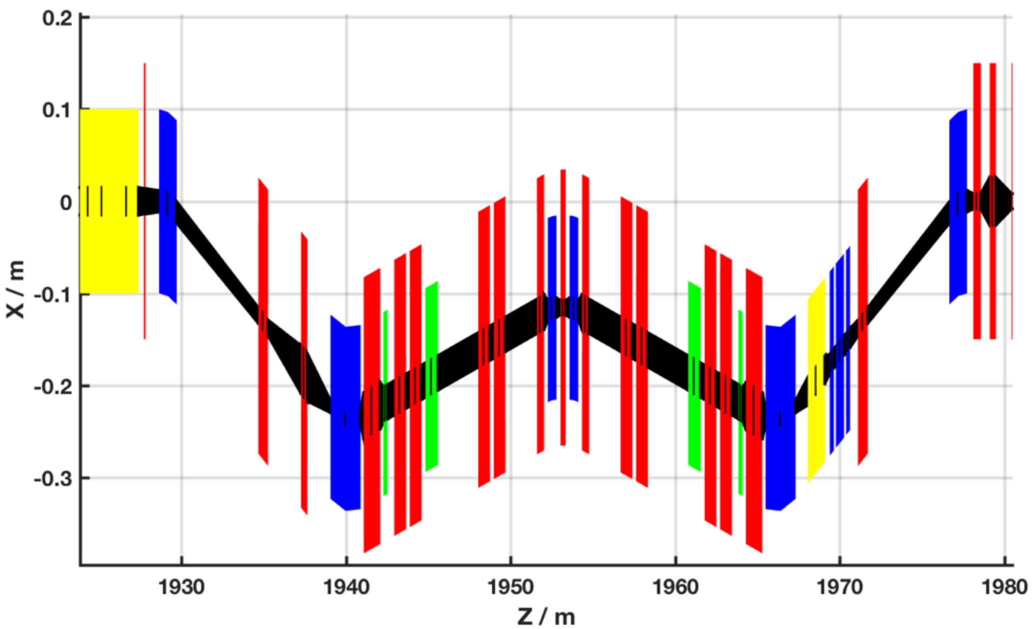
Drive Beam

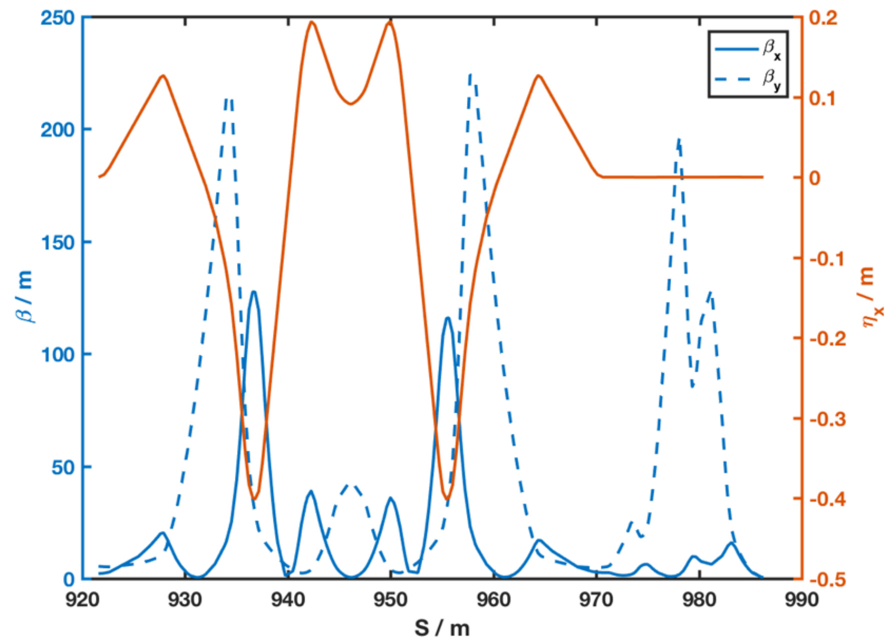


Witness Beam

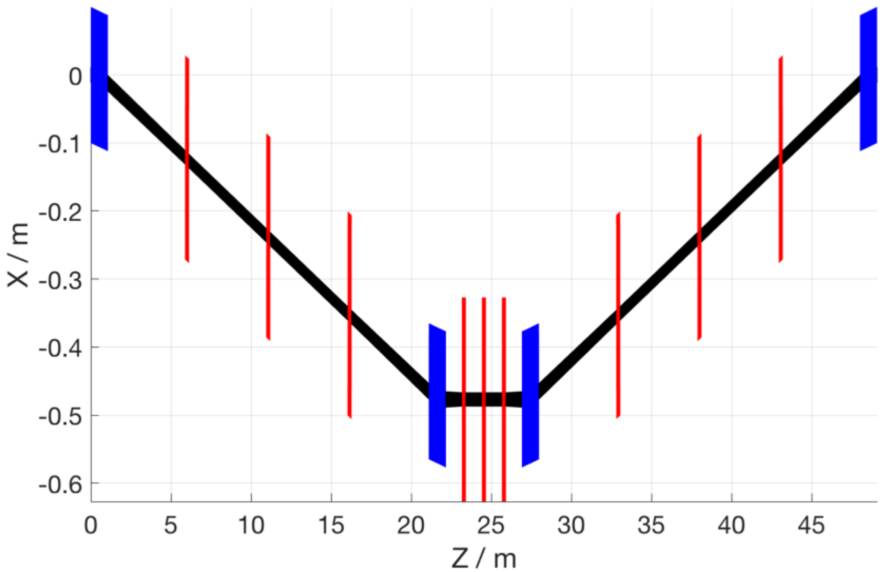
This is Great! But wait, THERE IS MORE…

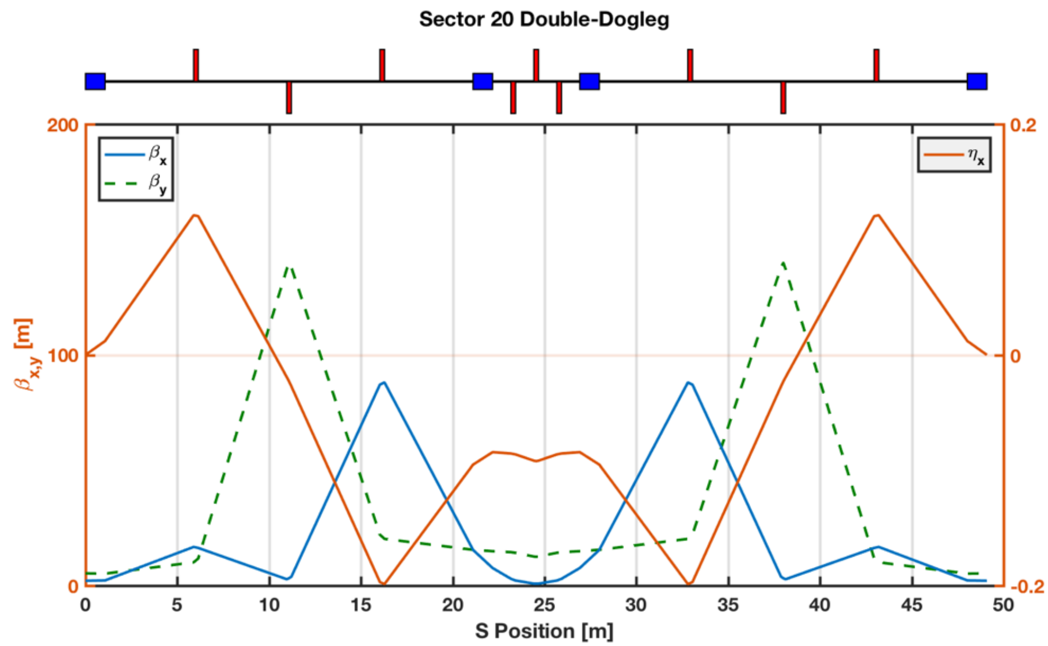
Current S20 BC20E (W) Chicane @ r56=+5mm





New BC20E Layout Option





CSR emittance growth properties should be better, fewer magnets, simpler lattice, lower beta functions

R56 = +4.15 mm (adjustable)

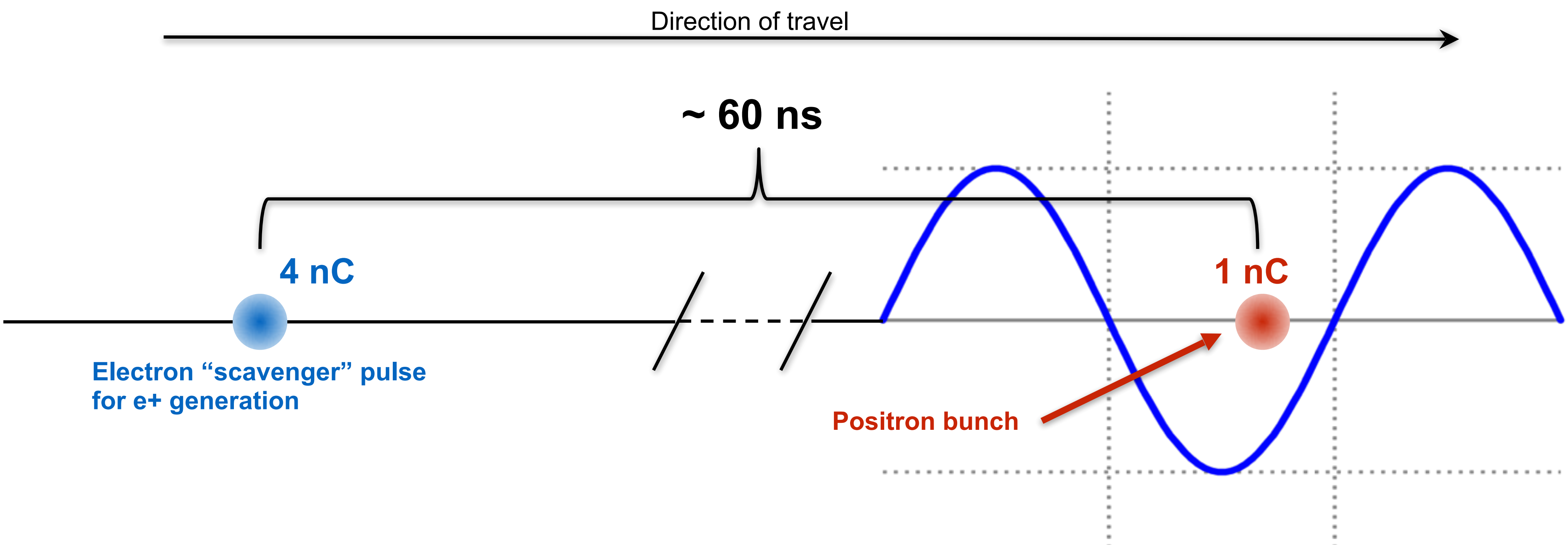
ΔS = 49.088 m ; Δz = 49.0773 m (Δz == Current S20 W-chicane) (Δs = +4.3mm)

- NOT compatible with current e+ sailboat (need 5.24cm path length difference BC20E-BC20P)

9 Quadrupoles & 4 bends

Possibility to reduce Δz enough to move XTCAV to common line after BC1-R?

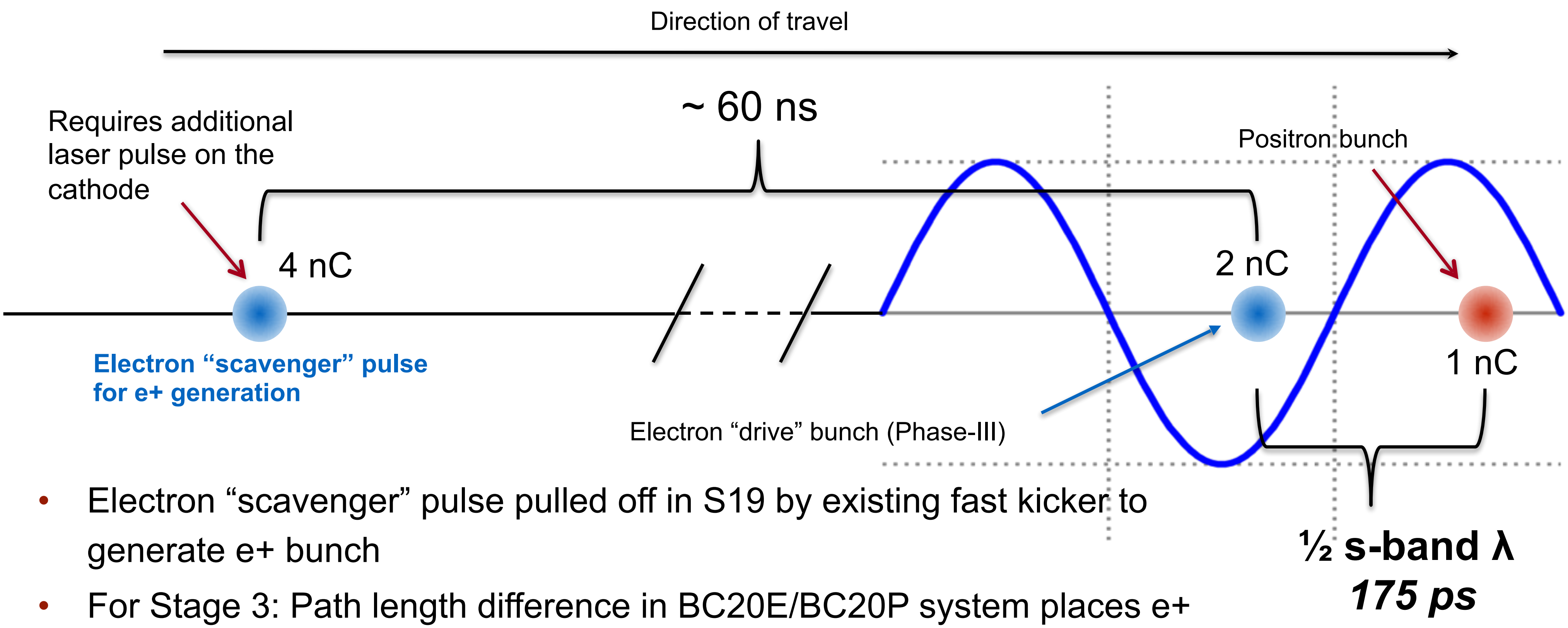
FACET-II Pulse Structure (Stage-II)



- Electron "scavenger" pulse pulled off in S19 by existing fast kicker to generate e+ bunch

Two bunches per pulse shared in L2 and L3 for Stage 2 operations

FACET-II Pulse Structure (Stage III)



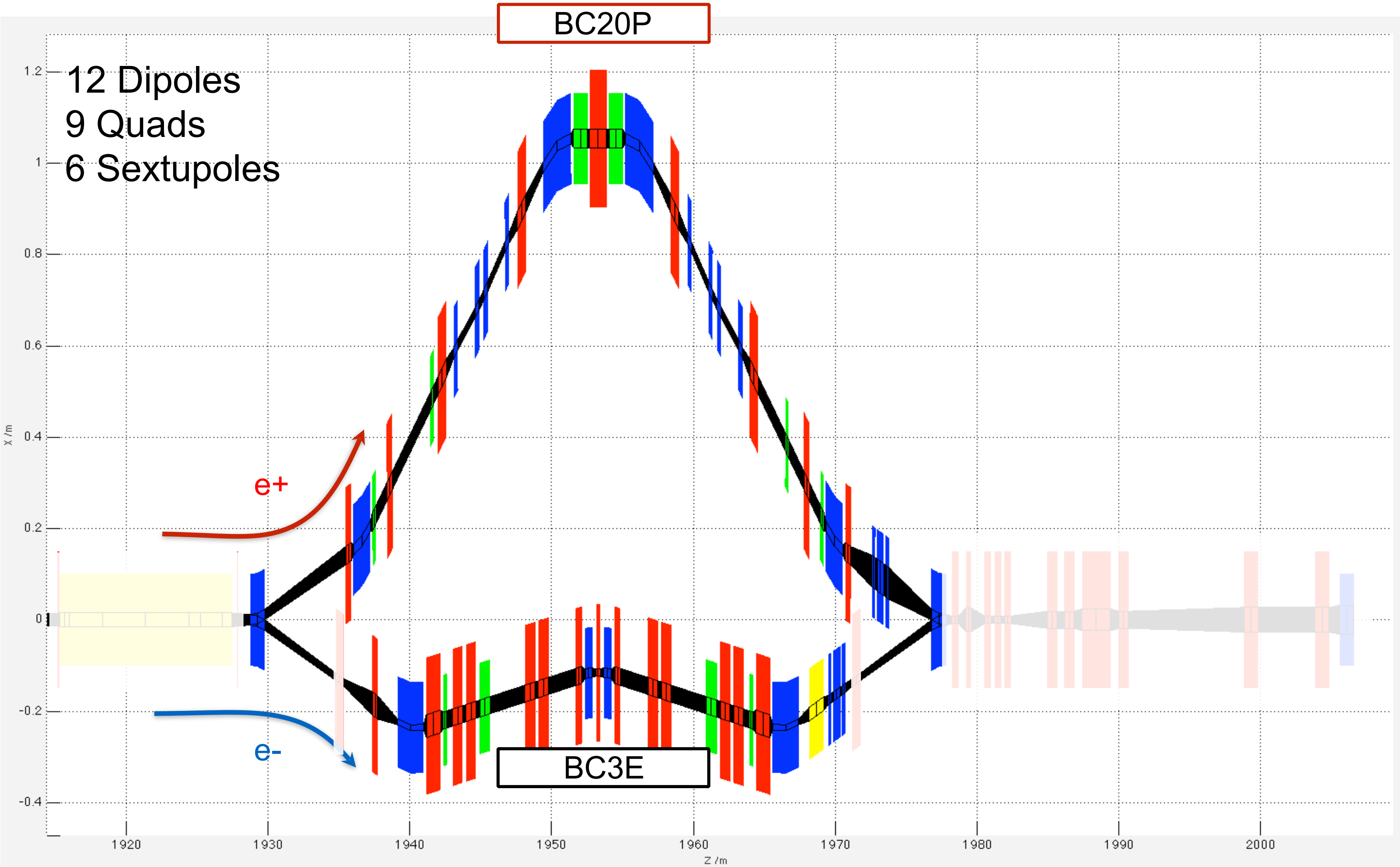
- Electron "scavenger" pulse pulled off in S19 by existing fast kicker to generate e+ bunch
- For Stage 3: Path length difference in BC20E/BC20P system places e+ witness bunch ~200 μm behind e- drive bunch

Sailboat chicane design goals:

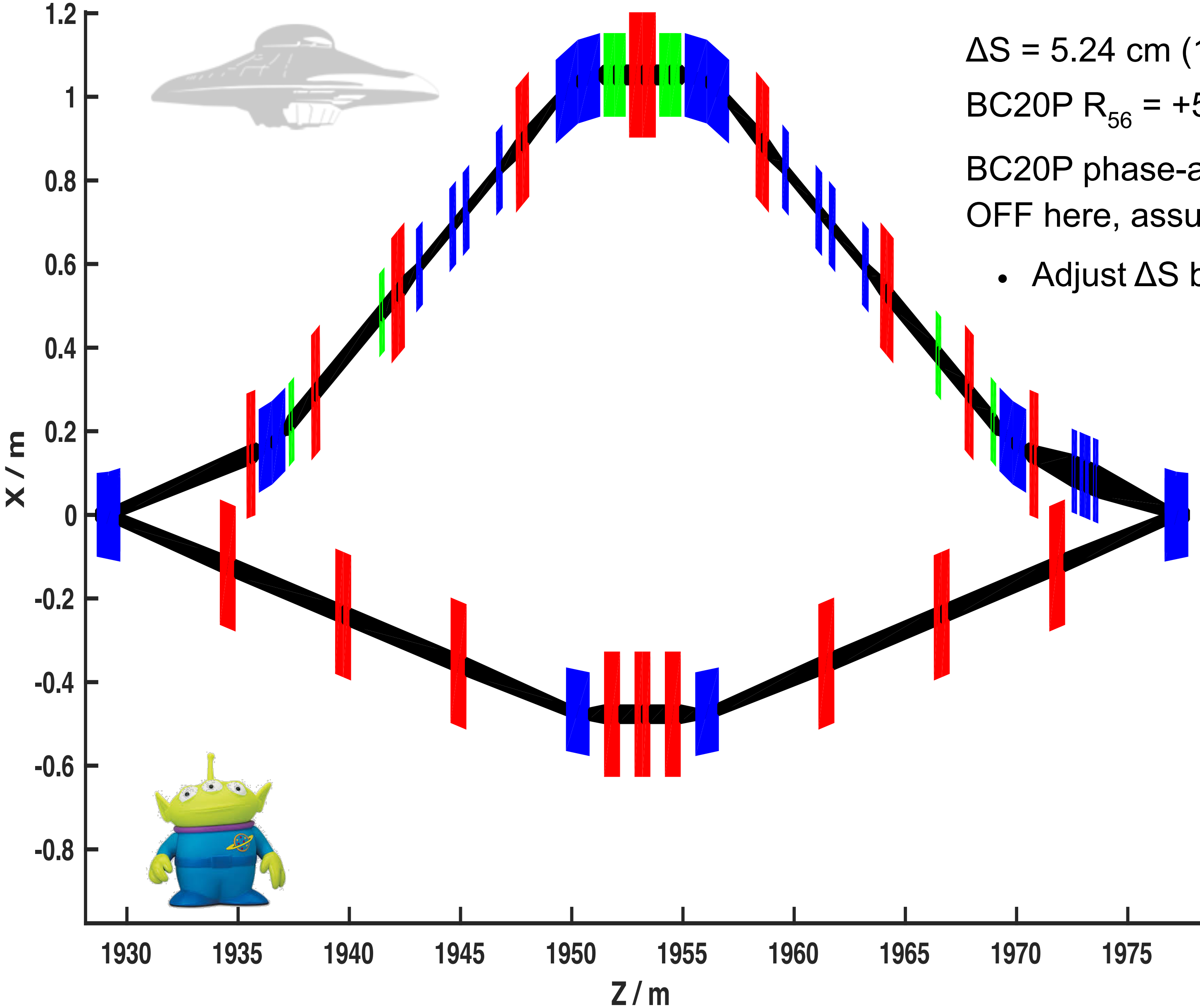
- 5.27 cm (175 ps) path length difference
- Simultaneous focusing solutions for e- and e+

Three bunches per pulse shared in L2 and L3 for Phase-III operations

Sector 20 Sailboat Chicane Overview



BC20P “Flying Saucer” Chicane



ΔS = 5.24 cm (175 ps)

BC20P R_{56} = +5 mm

BC20P phase-adjust chicanes switched OFF here, assumed not used

- Adjust ΔS by changing E_e vs. E_p