Positron Beamlines and Beam Dynamics

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Overview

FACET-II positron systems design

- Existing FACET-II design includes provision for upgrading S10-S20 beamlines to accommodate resumption of e+ delivery in S20 with 1 nC beams

Design for simultaneous delivery of e- / e+ into Sector 20

- Simultaneous accleration of up to 1nC e+ & 2nC e- and delivery into S20 IP region

Start-to-end tracking simulations

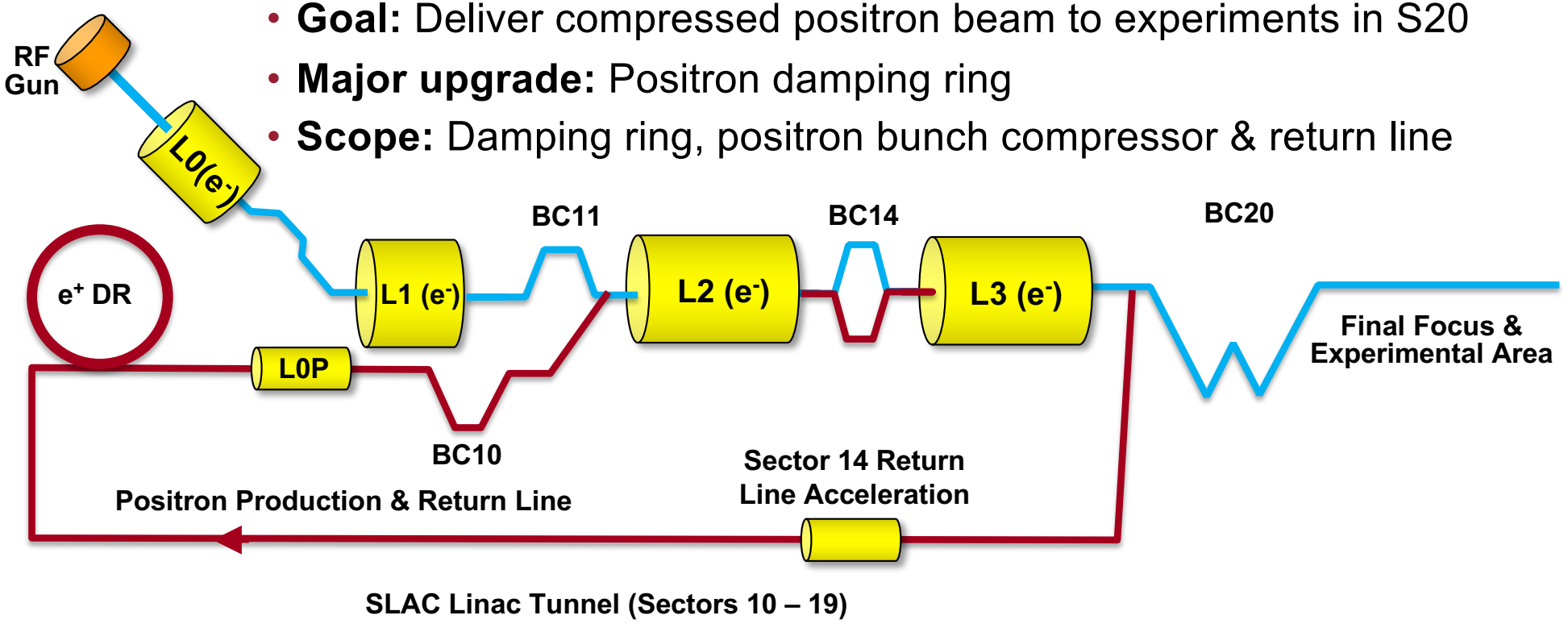
- Expected performance modeled with particle tracking, including dynamic errors

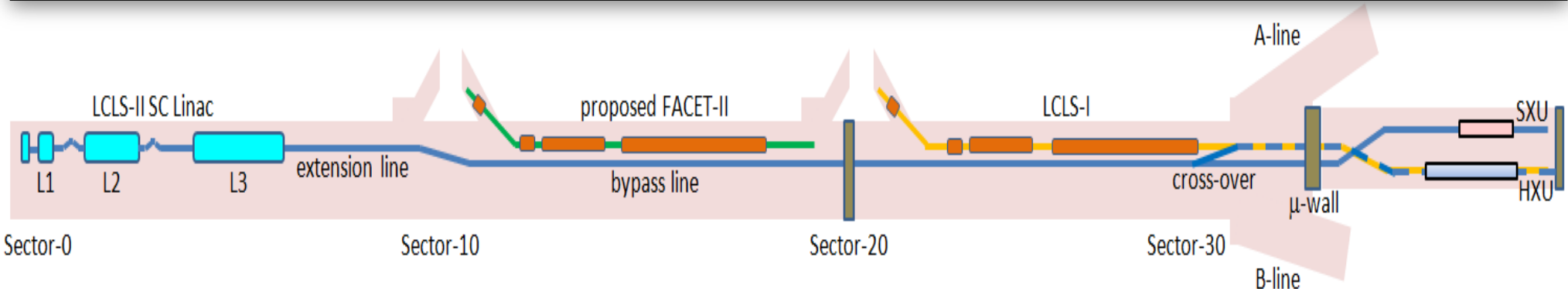
More details exist in technical design documentation:

- TDR Ch.8 : Positron Systems

FACET-II Positron Systems Overview

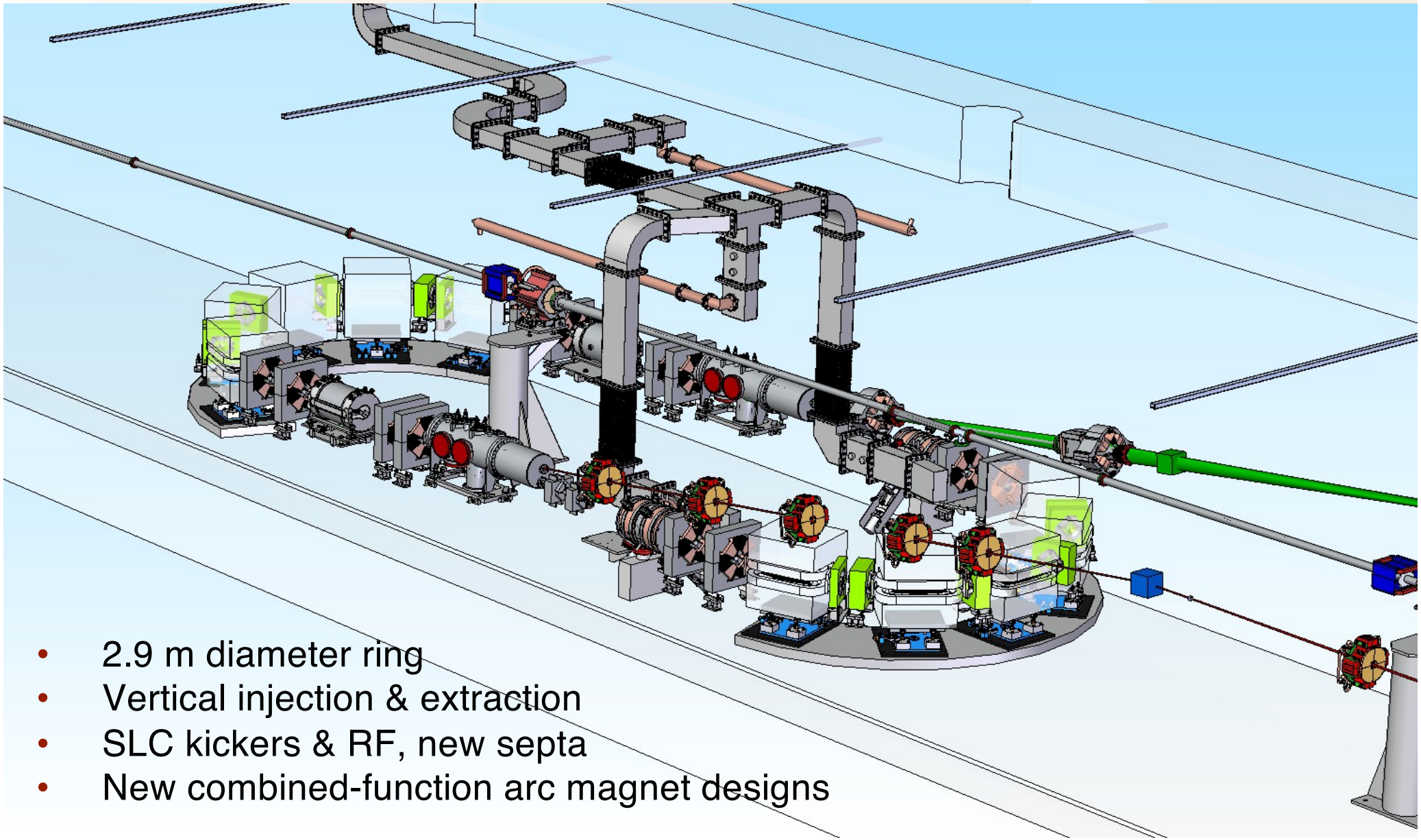
- **Goal:** Deliver compressed positron beam to experiments in S20
- **Major upgrade:** Positron damping ring
- **Scope:** Damping ring, positron bunch compressor & return line





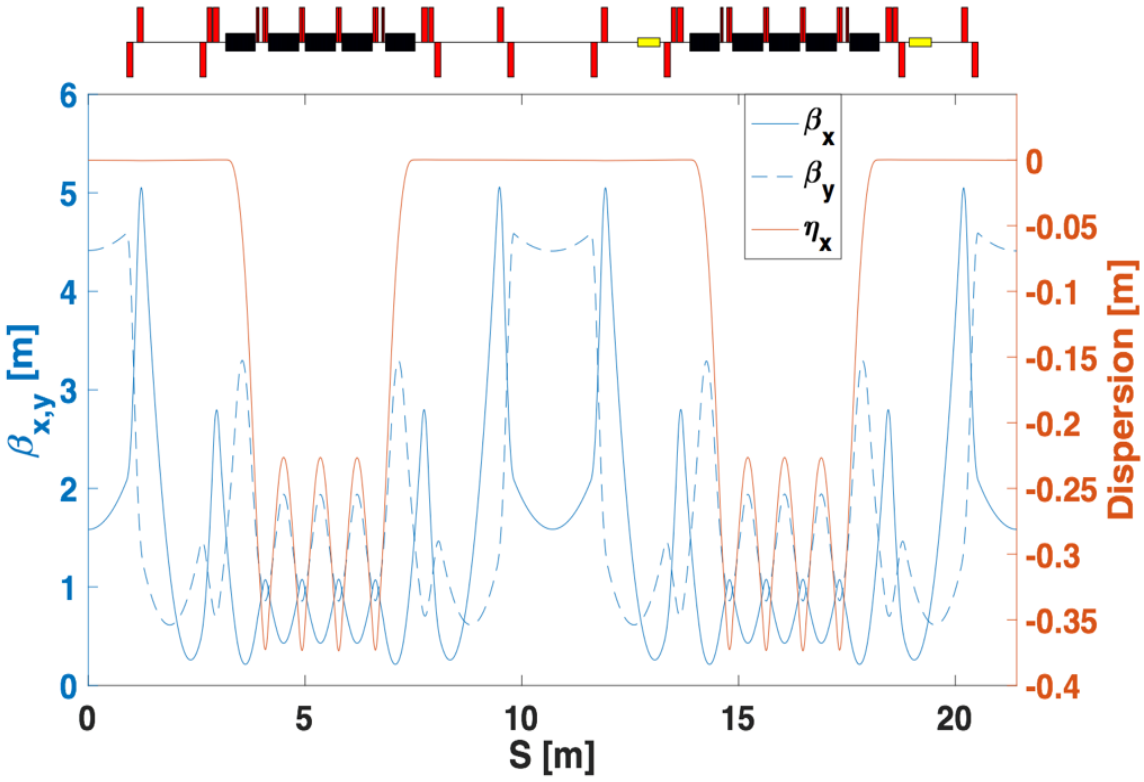
335 MeV Positron Damping Ring in Sector 10

SLAC



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

Positron Damping Ring Design Overview



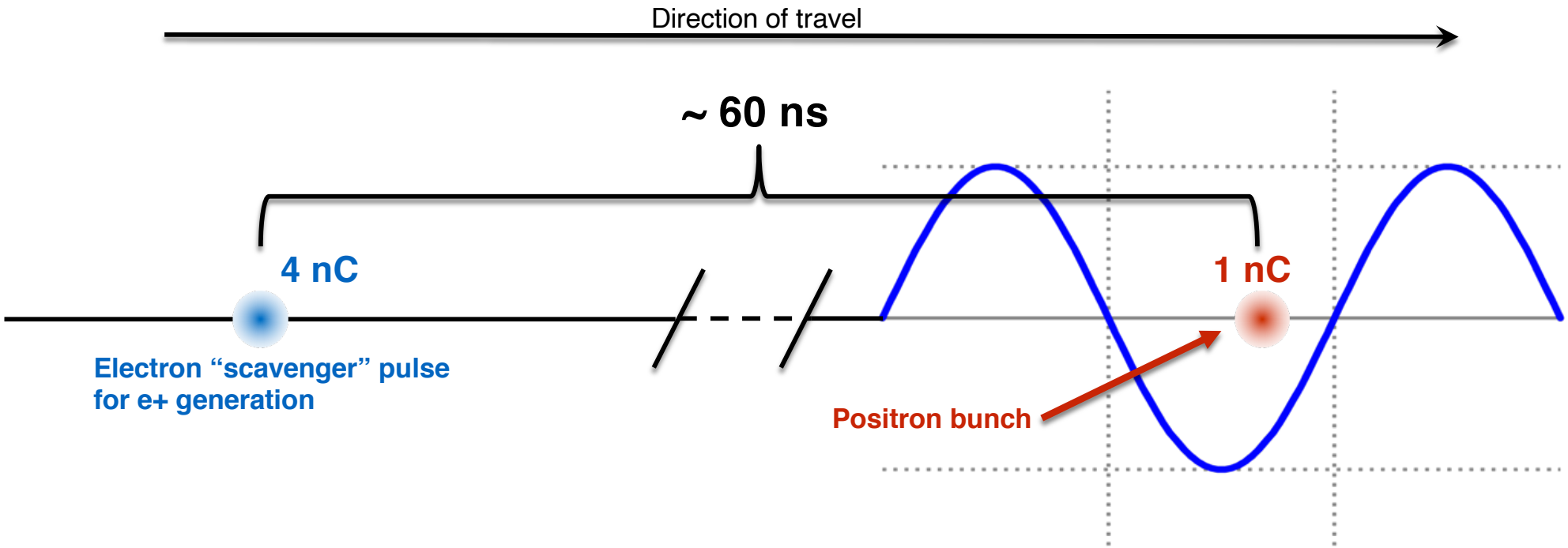
Parameter	Value
Energy, E [MeV]	335.0
Bunch Charge, Q [nC]	1.0
Beam Current, I [mA]	14.0
Circumference, C [m]	21.41
Arc Bend Radius, ρ [m^{-1}]	0.78
RF Energy Acceptance, A [%]	2.9-4.1
Tune, ν_a, ν_b	4.588, 2.570
Emittance, $\gamma\epsilon_{a,b}$ [μm-rad]	5.5-5.8
Bunch length, σ_z [mm]	3.0-3.9
Energy spread, σ_δ [%]	0.048-0.062
Mom. compaction, α_p	0.0525
Damping partition, J_x, J_y, J_z	2.15,1.0,0.85
Damping time, τ_a, τ_b, τ_c [ms]	16.9, 36.4, 43.0
Natural Chromaticity, ξ_{a0}, ξ_{b0}	-6.5, -4.4
Chromaticity, ξ_a, ξ_b	+1, +1
Syn. Energy loss / turn, U_0 [keV]	1.362
RF voltage, V_{RF} [MV]	1.1-2.2
RF frequency, f_{RF} [MHz]	714.0
Harmonic Number [n]	51
Synchrotron Tune	0.037 (521.9 kHZ, 26.8 turns)

1 nC @ 5 Hz

- σ_z = 3.9 mm, σ_δ = 0.062 %
- $\gamma\varepsilon_t$ = 5.5 μm-rad (fully coupled, defined by IBS)

DR e+ performance estimates including IBS

FACET-II Positron Operations Pulse Structure

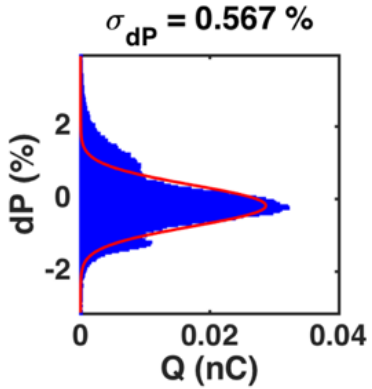


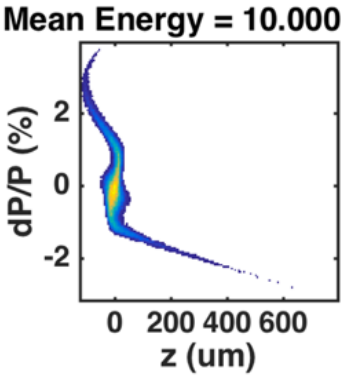
- Electron "scavenger" pulse pulled off in S19 by existing fast kicker to generate e+ bunch

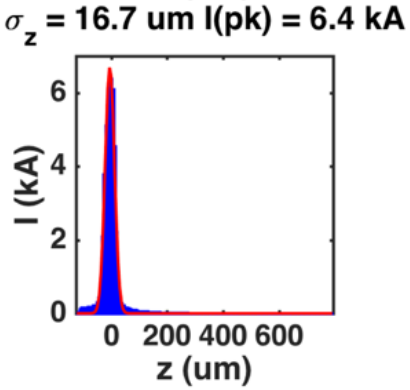
Two bunches per pulse shared in L2 and L3 for positron operations

Start-to-End Tracking
Positron Longitudinal & Transverse Phase Space at IP

β^*=50cm

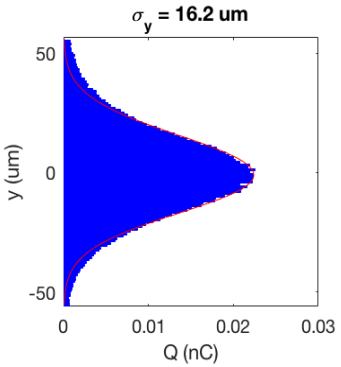


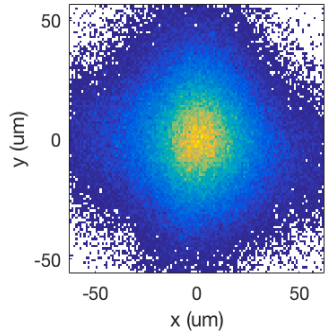




rms dP/P = 0.832536 %

rms Z = 37.4579 um

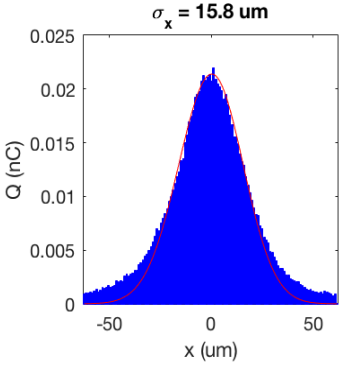




rms X = 20.7197 um

rms Y = 18.5521 um

Q = 0.999995 nC

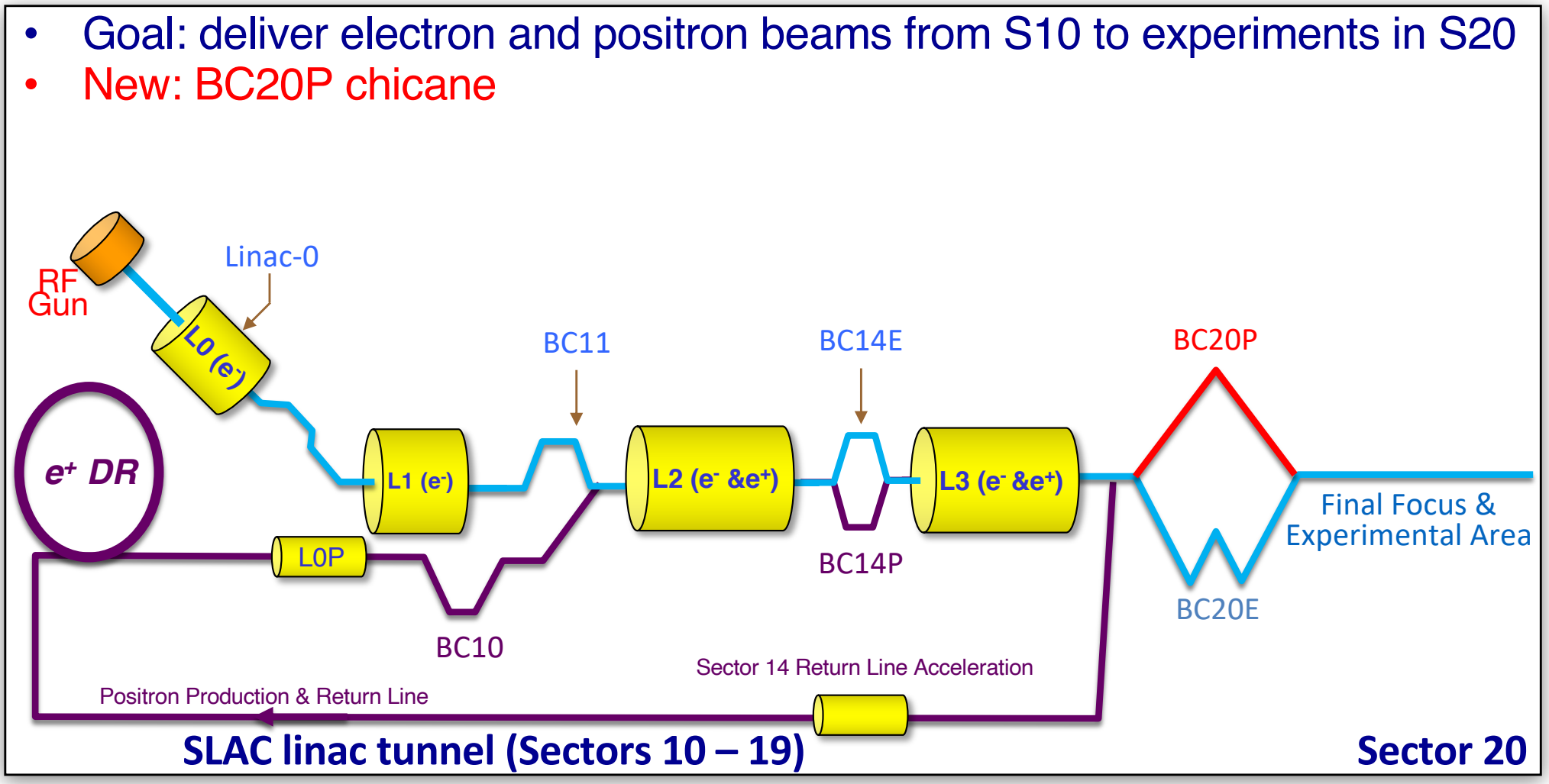


$\gamma\varepsilon_{x,y}$ ~ 10 μm-rad

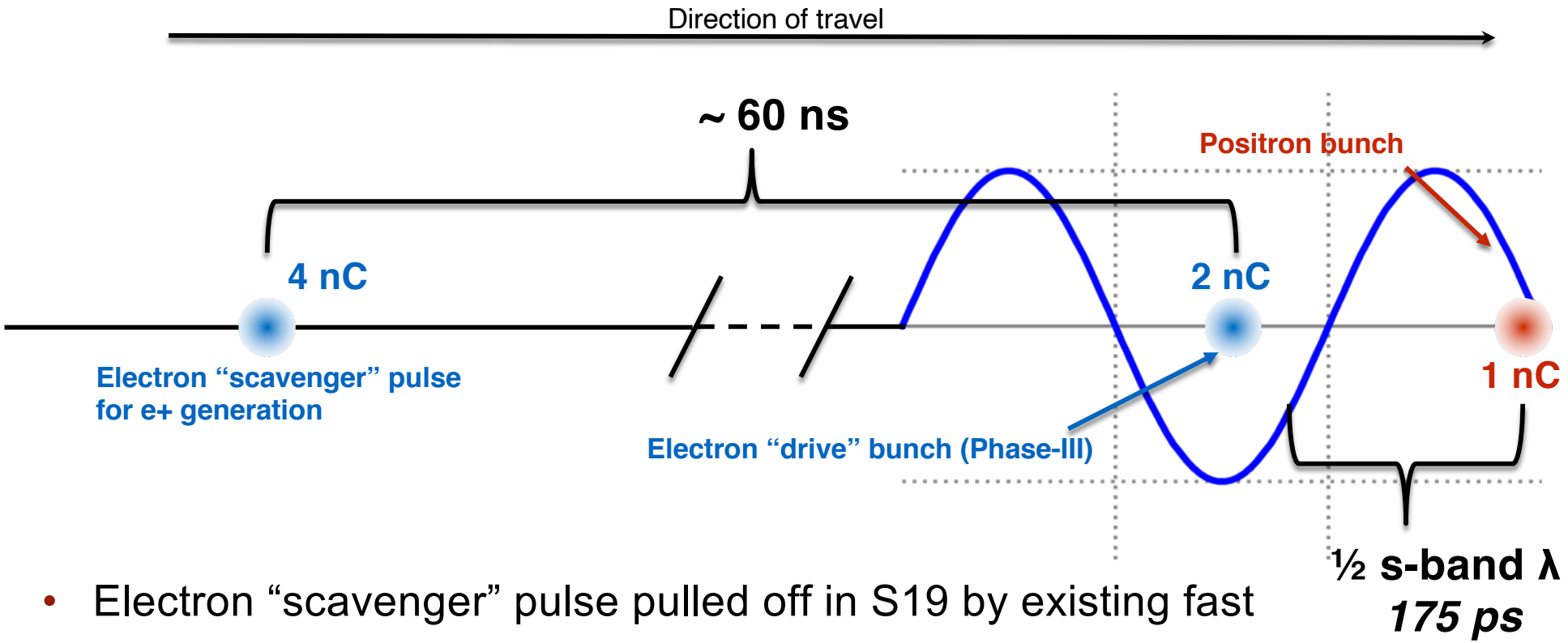
Design core bunch length **<20um** for both electrons and positrons achieved. Meets typical plasma expt. requirements for **$\sigma_{x,y}$ < 20 μm**

FACET-II Stage III

- Goal: deliver electron and positron beams from S10 to experiments in S20
- New: BC20P chicane



FACET-II Pulse Structure



- Electron "scavenger" pulse pulled off in S19 by existing fast kicker to generate e+ bunch
- For Phase III: Path length difference in BC3E/BC3P system places e+ witness bunch behind e- drive bunch

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

BC20P Chicane

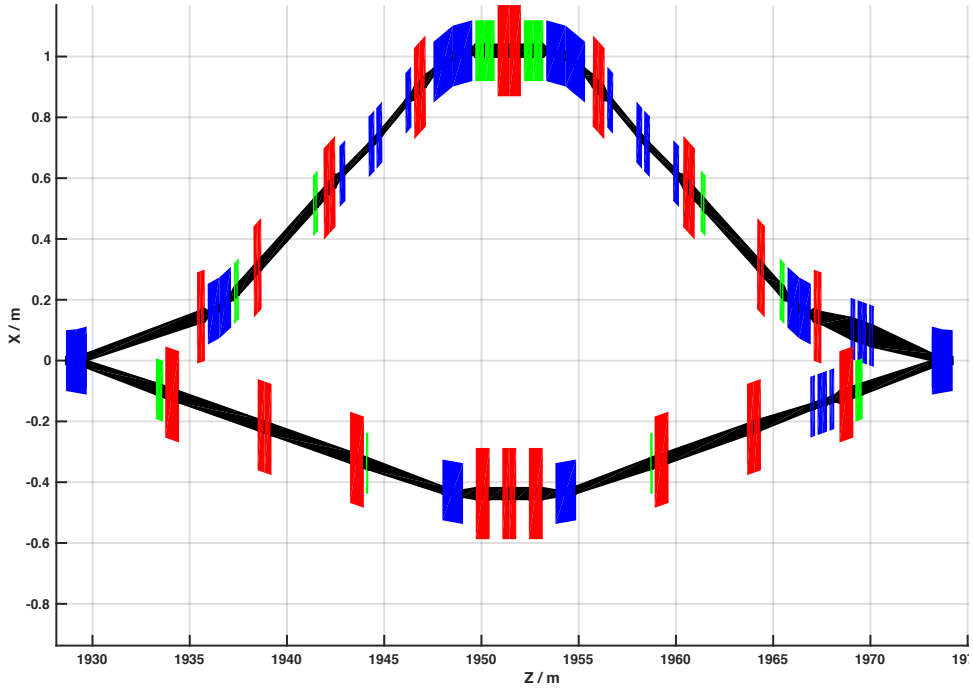
Coarse and fine adjustment controls:

Δz 0 - 500 μm

- Infrequently used- re-tuning required after adjustment
- B3 Δθ = 18.6 mrad (for 500 μm)
- Move Q5, S3E/L to orbit (54 mm)
- Correct angle with Q5 Δx=-21 mm

Δz +/- 100 μm

- Continuously adjustable with minimal impact on other delivered beam parameters
- 2 X 4-bend chicanes
- θ = 6.45 mrad (0 - 9.14) = +/- 100 μm



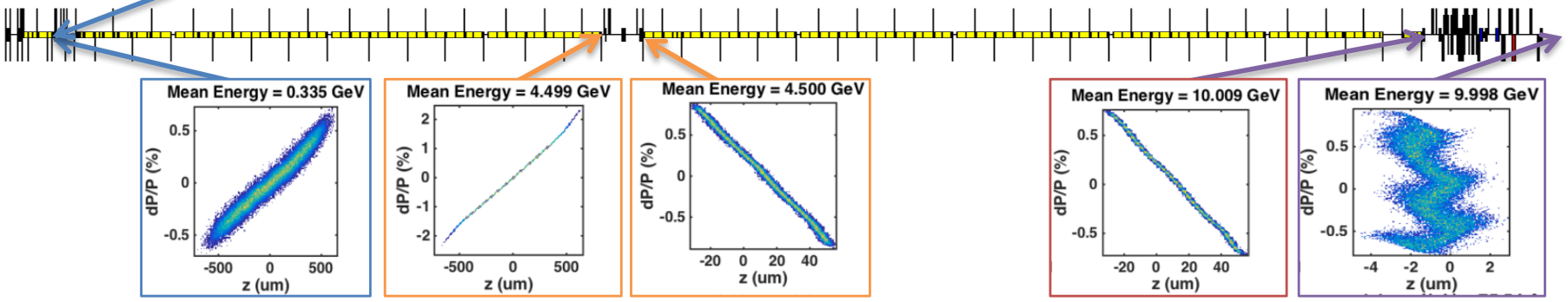
BC20P Functionality

- Path length difference BC20P-BC20E puts e-/e+ into same z location after chicane
- BC20P also serves same functions as BC20E for e+ beam
- BC20P provides relative z offset adjustment

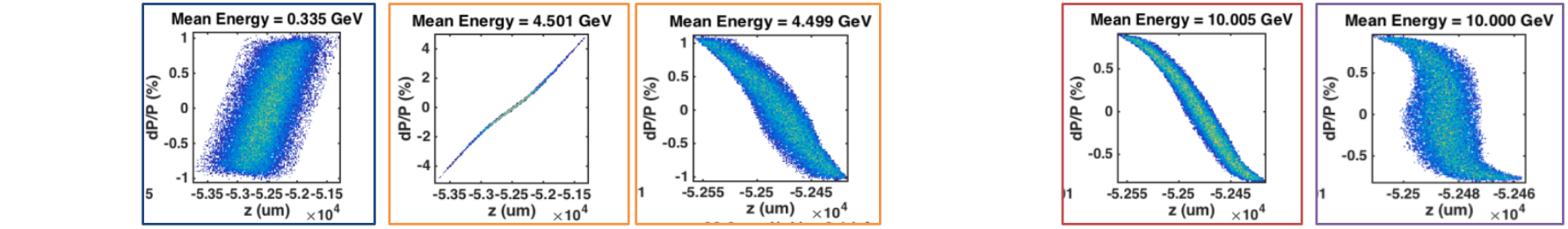
Example Bunch Compression Configuration with Collimation in BC10, BC11, BC14

BC11 Chicane bend exit

e- & e+ z/δ phase space



σ_z (um) / I_{pk} (kA)	287 / 0.4	287 / 0.4	24 / 3.4		24 / 3.8	1 / 76
δ_E (%) / Q (nC)	0.3 / 1.2	0.9 / 1.2	0.5 / 0.7		0.4 / 0.7	0.4 / 0.7



σ_z (um)/ I_{pk}(kA)	350 / 0.4	350 / 0.4	29 / 3.1		29 / 3.1	7.4 / 12.1
δ_E (%) / Q (nC)	0.5 / 1.2	1.2 / 1.2	0.6 / 0.6		0.5 / 0.6	0.5 / 0.6

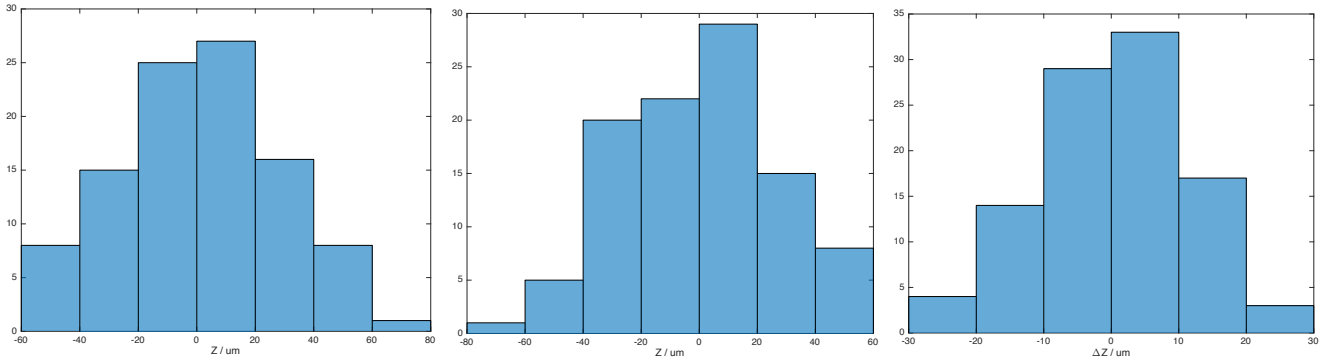
Tracked longitudinal phase space from BC11, simultaneously for electrons and positrons

Start-to-End Monte Carlo Tracking Simulation + Errors

Property	Value
Source Charge Fluctuation	1% (e-) 2% (e+)
Source Position Fluctuation	0.05 sigma (e-) 0.2 sigma (e+)
Initial Electron Laser Timing Error	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 Amplitude Jitter	0.25 %
L3 Amplitude Jitter	0.25 %
L0P Amplitude Jitter	0.25 %
BC10 Magnet Strength Jitter	1e-5 dB/B
BC1 Magnet Strength Jitter	1e-4 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

IP Parameter	Electron Bunch		Positron Bunch	
	Required	Simulated	Required	Simulated
σ_x (um)	< 20	7.9 +/- 3.1	< 20	13.7 +/ 5.4
σ_y (um)	< 20	7.6 +/- 1.9	< 20	7.4 +/- 0.3
σ_z (um)	< 20	3.5 +/- 2.2	< 20	7.4 +/- 0.9
I_{pk} (kA)	>15	37 +/- 20	> 5	11.7 +/- 1.8

e^-/e^+ rms IP Waist Position Jitter: 27 μm (11 μm relative)



Particle tracking performed with modelled error sources

Conclusion

Positrons can be restored to Sector 20 by utilizing existing S19 positron source with a 4 nC electron driver pulse

- New BC14 chicane section
- 335 MeV booster Linac in return line
- New compact DR in Sector 10
- New beamlines to extract beam from return line into DR, extract beam from DR and extract,compress & inject into BC11

Simultaneous e- e+ delivery (dz +/- 600 μm) made possible by adding BC20P beamline component

- Allows for up to ~ 10 / 70 kA in Sector 20 (e-/e+) with 700pC charge per bunch
- Up to 1 nC e+ bunch possible with reduced peak current (~6-7 kA)