FACET·II

Facility for Advanced Accelerator Experimental Tests

A Compact 335 MeV Positron Damping Ring Design for FACET-II

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Glen White

on behalf of FACET-II design team

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IPAC17

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Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Overview

FACET-II project

- History of FACET (2012-2016)
- Plans for FACET-II experimental program 2019+

FACET-II positron systems

- New beamlines in SLAC Linac, including damping ring

FACET-II 335 MeV positron damping ring

- Design overview and expected performance

Particle tracking

- Simulation of FACET-II delivered beam parameters

FACET Project History

Primary Goal:

- Demonstrate a single-stage high-energy plasma accelerator for electrons

Timeline:

- CD-0 2008
- CD-4 2012, Commissioning (2011)
- Experimental program (2012-2016)

A National User Facility:

- Externally reviewed experimental program
- >200 Users, 25 experiments, 8 months/year operation

Key PWFA Milestones:

- ✓Mono-energetic e- acceleration
- ✓High efficiency e^- acceleration (*Nature* **515**, Nov. 2014)
- ✓First high-gradient e^+ PWFA (*Nature* **524**, Aug. 2015)
- Demonstrate required emittance, energy spread (FY16 in preparation for *Nature*)

Premier R&D facility for PWFA: Only facility capable of e+ acceleration
Highest energy beams uniquely enable gradient > 1 GV/m

FACET-II Project Plan

Timeline:

- ✓ **Nov. 2013, FACET-II proposal, Comparative review**
- ✓ **CD-0** **Sep. 2015**
- ✓ **CD-1** **Oct. 2015** ***(ESAAB, Dec.2015)***
- ✓ CD-2/3A Sep. 2016
- • CD-3B Sep. 2017
- • CD-4 2022

Experimental program (2019-2026)

Key R&D Goals:

- Beam quality preservation, high brightness beam generation, characterization
- e^+ acceleration in e^- driven wakes
- Staging challenges with witness injector
- Generation of high flux gamma radiation

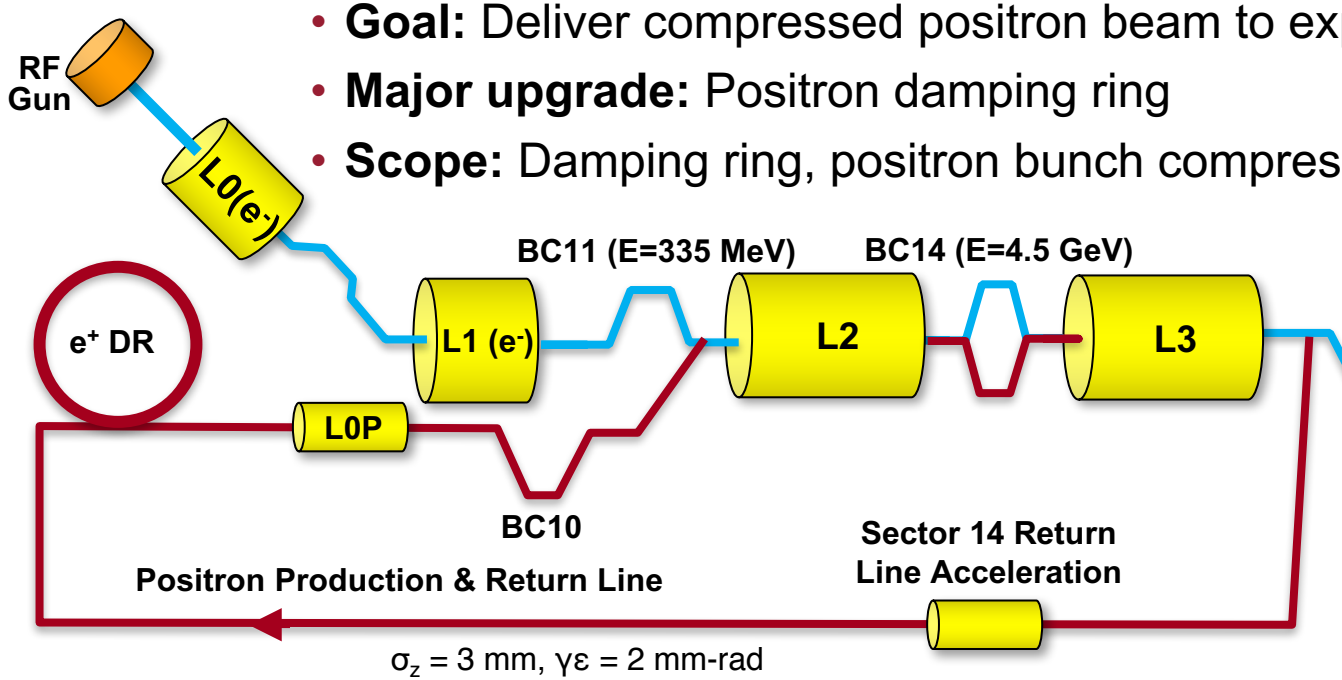
Three stages:

- Photoinjector (e- beam only) FY17-19
- e+ damping ring (e+ or e- beams) FY18-20
- "sailboat" chicane (e+ and e- beams)

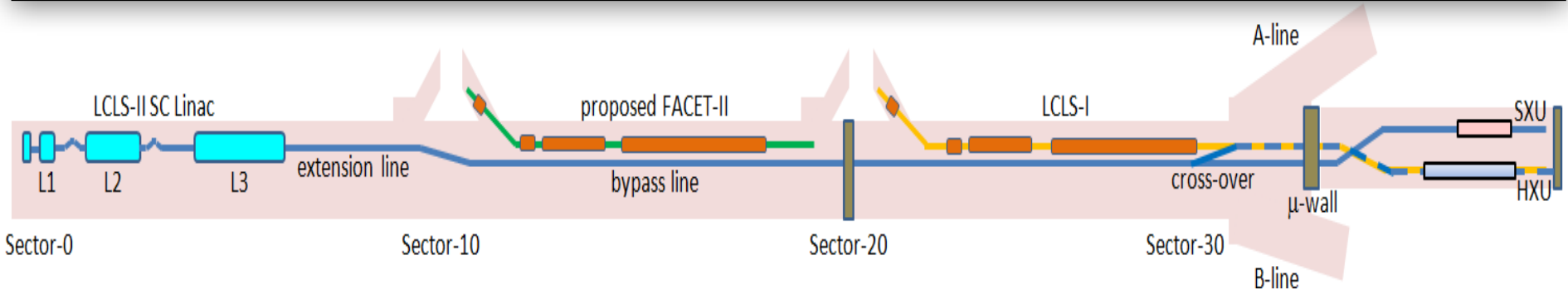
FACET-II will operate as a National User Facility with an external program advisory committee reviewing proposals and recommending priorities for the experimental program

FACET-II Positron Systems Overview

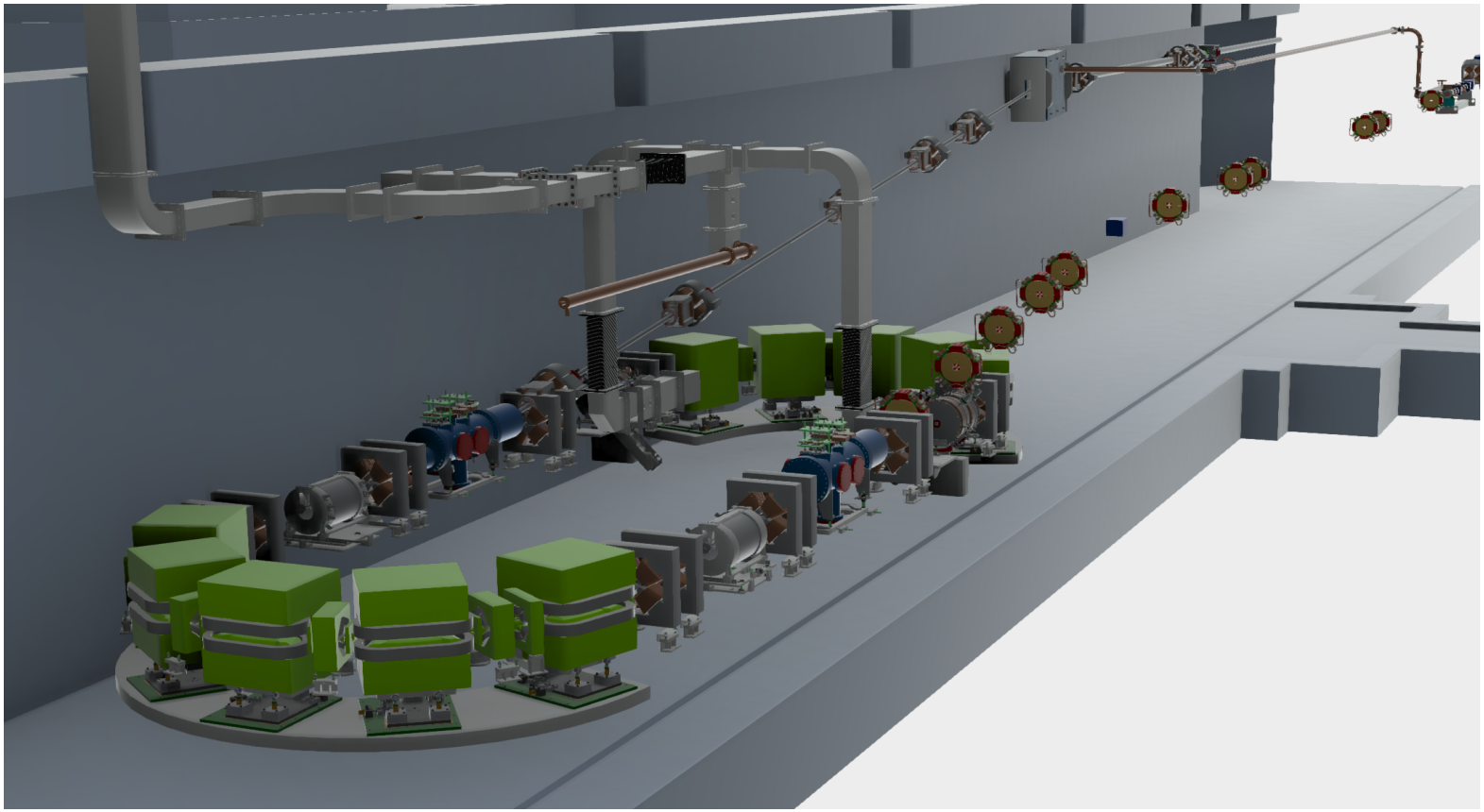
- **Goal:** Deliver compressed positron beam to experiments in S20
- **Major upgrade:** Positron damping ring
- **Scope:** Damping ring, positron bunch compressor & return line



Q = 2/1 nC (e-/e+)
E = 10 GeV
$\sigma_z < 20$ µm
$I_{pk} > 5$ kA
$\gamma\varepsilon_{x,y} < 20$ µm-rad



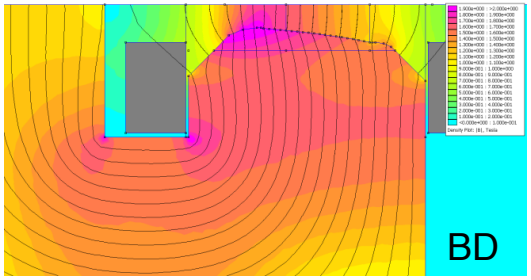
335 MeV Positron Damping Ring in Sector 10



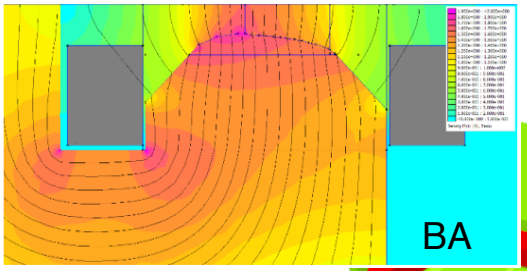
- 2.9 m diameter ring
- Vertical injection & extraction
- SLC kickers & RF, new septa
- New combined-function arc magnet designs

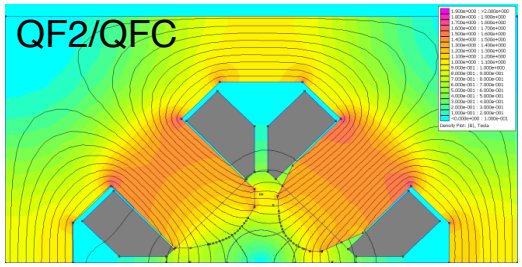
DR Arc Magnet Design and Modeling

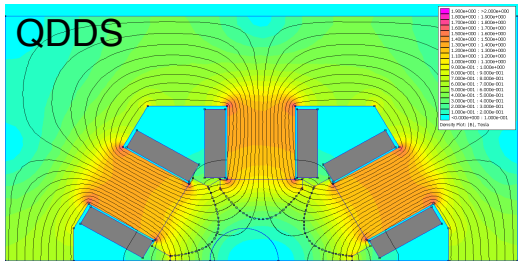
- 3D magnet design of arc with Opera



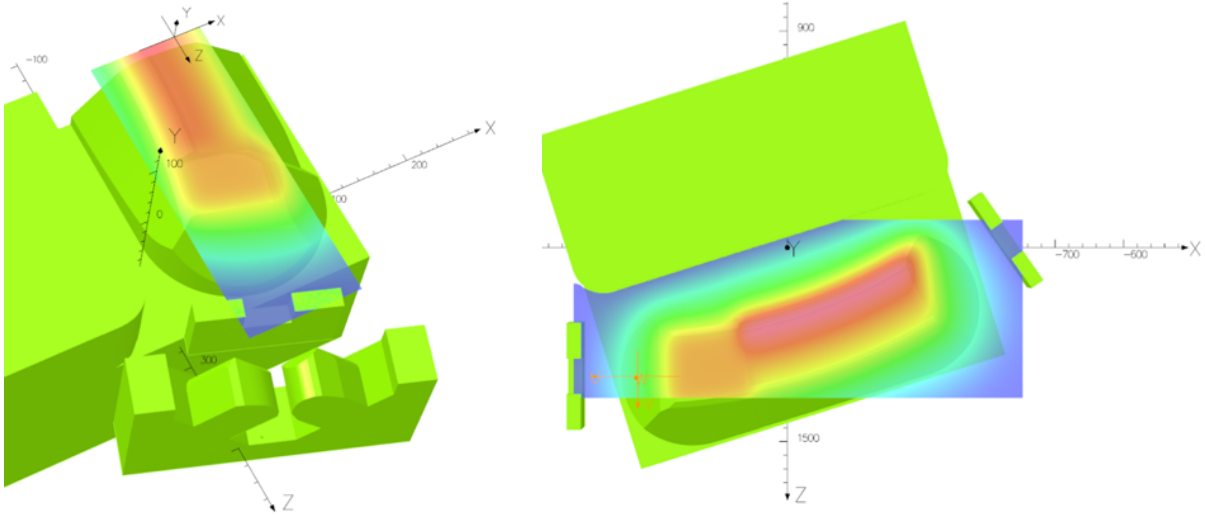
B_0 = 1.44 T (B_{max} = 1.8-2.1T)

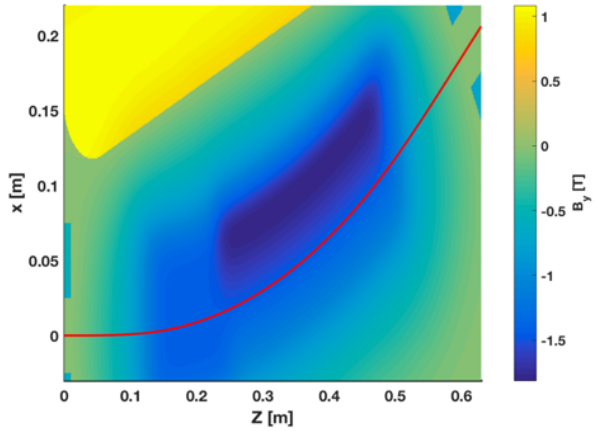




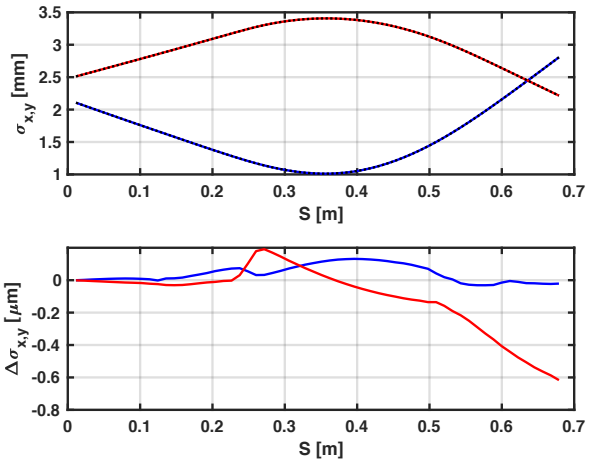


Arc Dipoles – BA & BD



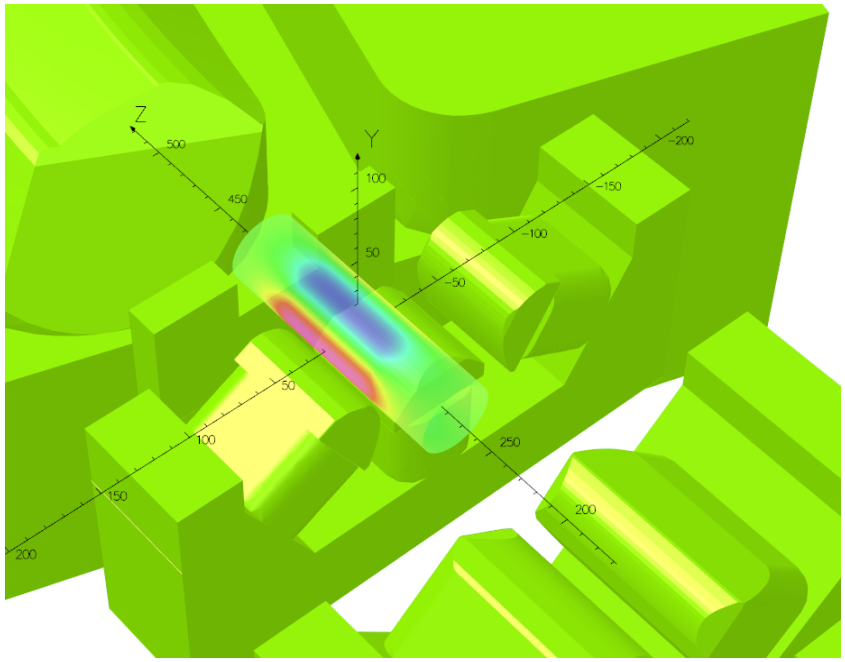


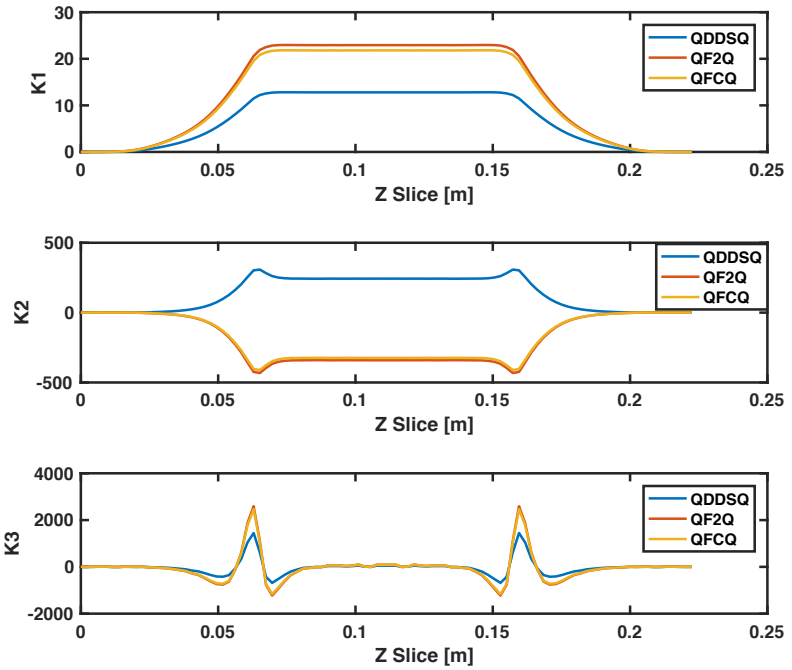
- 10 mm slices through 60 cm bend magnets
- Test particles distributed across physical aperture : evaluate at each slice location



Slice model generated and evaluated from particle tracking in GPT using 3D Opera field calculations

DR Magnet Model – Arc Quad-Sextupoles

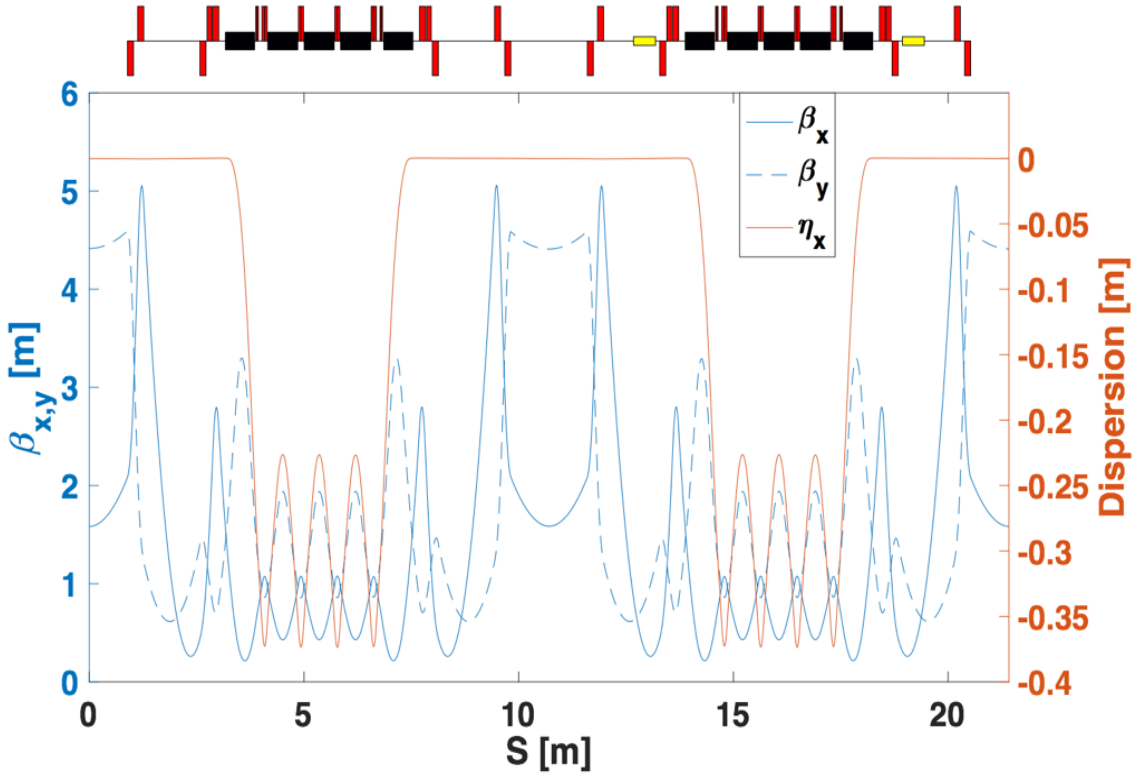




- Two mechanical types of combined function quad/sext magnet
  - QDDS & QFC/QF2
- 3 mm slices from fits to 3D Opera fields

Sliced model of combined function quad/sextupoles included in model

Positron Damping Ring Design Overview

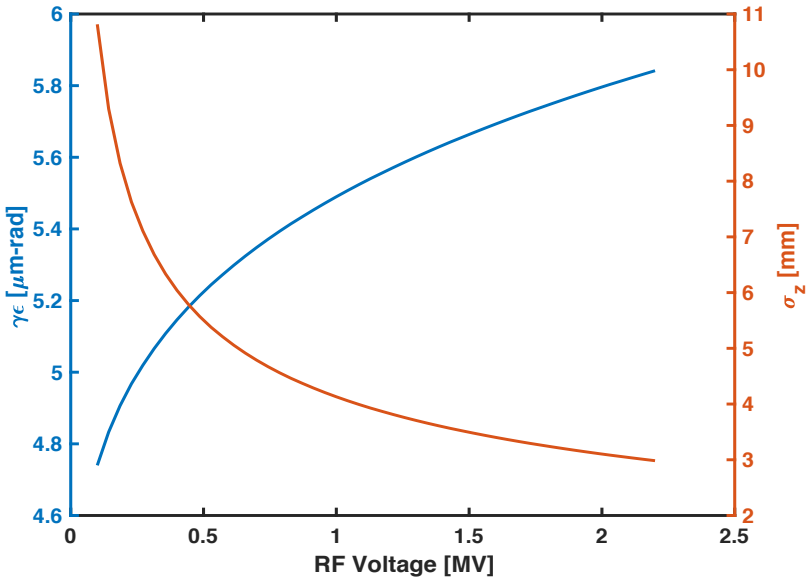


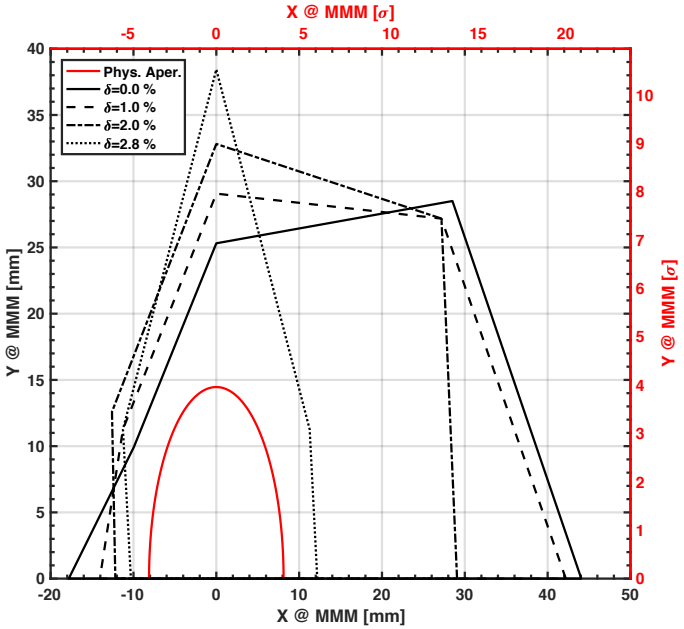
Parameter	Value
Energy, E [MeV]	335.0
Bunch Charge, Q [nC]	1.0
Beam Current, I [mA]	14.0
Circumference, C [m]	21.41
Arc Bend Radius, ρ [m^{-1}]	0.78
RF Energy Acceptance, A [%]	2.9
Tune, $\boldsymbol{\nu_a, \nu_b}$	4.588, 2.570
Emittance, $\boldsymbol{\gamma\epsilon_{a,b}}$ [μm-rad]	5.5
Bunch length, $\boldsymbol{\sigma_z}$ [mm]	3.9
Energy spread, $\boldsymbol{\sigma_\delta}$ [%]	0.062
Mom. compaction, α_p	0.0525
Damping partition, J_x, J_y, J_z	2.15,1.0,0.85
Damping time, $\boldsymbol{\tau_a, \tau_b, \tau_c}$ [ms]	16.9, 36.4, 43.0
Natural Chromaticity, $\boldsymbol{\xi_{a0}, \xi_{b0}}$	-6.5, -4.4
Chromaticity, $\boldsymbol{\xi_a, \xi_b}$	+1, +1
Syn. Energy loss / turn, U_0 [keV]	1.362
RF voltage, V_{RF} [MV]	1.1
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 %
- $\gamma\varepsilon_t$ = 2 mm-rad -> 5.5 μm-rad (fully coupled)

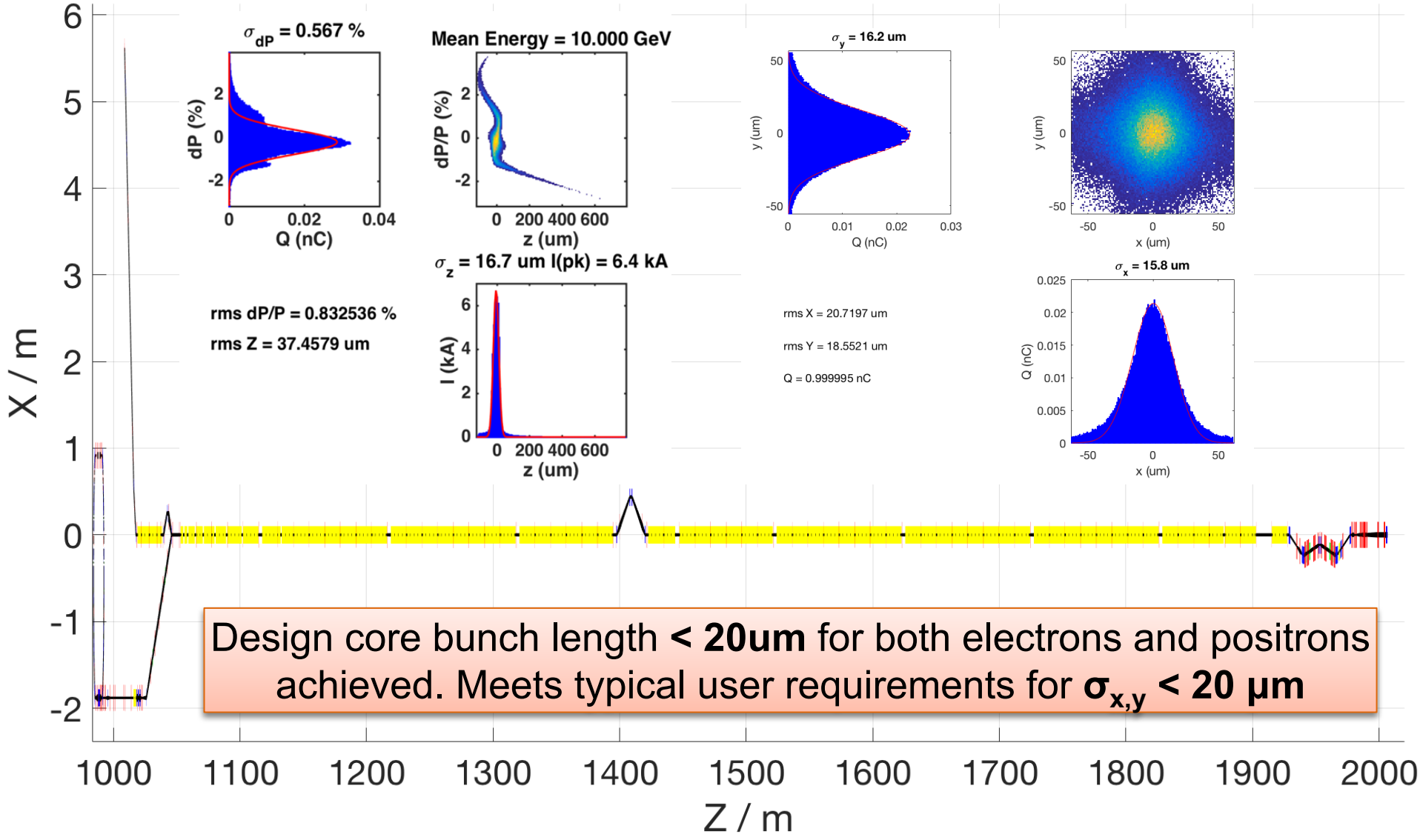
DR Beam Dynamics





- BMAD IBS calculation – using Bjorken & Mtingwa's formula with full coupling.
- Dynamic aperture from particle tracking (PTC)
  - 100k turns (~20% of damping time)
  - Dynamic aperture larger than physical aperture up to max RF energy acceptance of ring
- Instability thresholds OK < 1.25 nC, error tolerance sufficient

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



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

Conclusion

FACET-II facility designed to continue advanced acceleration R&D program started by FACET at SLAC 2019-2026

- Accelerator design to deliver high peak current, low emittance electron and positron bunches using central 1/3 of SLC Linac

Continuation of positron program requires construction of new 335 MeV damping ring inside SLC tunnel at Sector 10

- Restricted space requires unusually compact ring design
- User requirements drive unusual ring parameters: high 6D brightness required, fully coupled transverse emittance
- Detailed 3D modeling of ring arcs performed and ring parameters calculated
  - *Codes used: Opera, LEGO, BMAD, AT, GPT*
- Start-to-end tracking simulations indicate user requirements can be met
  - *Code used: Lucretia*