Operational Status of CESR-c

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CESR-c Operation since 2003
12 s.c. wigglers since mid-2004

1.5-6 GeV beam energy
Presently 2.085 GeV

768 m circumference

24 bunches/beam
60 mA/beam

The electron and positron beams are separated by means of electrostatic separators.

The optical distortions introduced by this “pretzel” orbit are corrected using the lattice design flexibility afforded by 180 quadrupole and sextupole magnets.
CESR as a Charm Factory

Physics Motivation

Unprecedented statistical precision for decays of charm-quark bound states

Increase world data sample by two orders of magnitude

CESR provides unique opportunities

1) Decades of design and operating experience with the CESR storage ring and injectors

2) CLEO state-of-the-art detector technology

3) Threshold production kinematics

Success contingent on meeting major accelerator physics challenges

Design and operation of first wiggler-dominated storage ring
Severe consequences for lowering beam energy:

- Emittance \( (\varepsilon_h \propto E^2) \)
- Energy spread
- Damping time \( (\tau \propto E^{-3}) \) and injection rate
- Beam-beam kicks and tune shifts
- Single-bunch instability thresholds
- Intra-bunch scattering

Twelve 2.1-Tesla 130-cm-long superferric wiggler magnets to restore damping

- Emittance: \( 30 \rightarrow 220 \text{ nm-rad} \)
- Damping time: \( 570 \rightarrow 55 \text{ ms} \)
- Energy spread: \( 2 \times 10^{-4} \rightarrow 8 \times 10^{-4} \)

Need flexible lattice design capability

Vertical tune shift 0.1 per wiggler!
8-pole Superconducting Wiggler Magnets

8 poles (4 x 20 cm, 2 x 15 cm, 2 x 10 cm)
Central poles: 660 turns, 95 kA
End poles: 352 turns, 51 kA (trim adjust)

In-house design & construction 2001-2004
Installation complete August, 2004

Beam-based characterization of wiggler nonlinearities accurately modeled for three-wiggler cluster in-situ. Analytic wiggler field model uses Taylor mapping for fast tracking simulation.
## Commissioning Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>8/2002</td>
<td>First wiggler installed</td>
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<tr>
<td>9/2002</td>
<td>Machine studies verify wiggler properties</td>
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<tr>
<td>10-12/2002</td>
<td>Engineering run 90 mA, 1x10^{31}</td>
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<tr>
<td>7/2003</td>
<td>New vertex chamber in CLEO</td>
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<tr>
<td>8/2003</td>
<td>Five more wiggler magnets</td>
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<tr>
<td>11/2003-4/2004</td>
<td>First Physics run 110 mA, 3x10^{31}, (3x world sample of ψ(3s))</td>
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<tr>
<td>4-6/2004</td>
<td>Complete installation of 12 wigglers</td>
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<tr>
<td>8-9/2004</td>
<td>Install fast luminosity monitor</td>
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<tr>
<td>9/2004-3/2005</td>
<td>Production run at 3770 MeV, 160 mA, 6x10^{31}, (ψ(3s) X 4)</td>
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<td>8-9/2005</td>
<td>D_s scan</td>
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<tr>
<td>12/2005-1/2006</td>
<td>D_s Production (4170 MeV)</td>
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<tr>
<td>1-2/2006</td>
<td>Install new solenoid compensation magnets</td>
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<tr>
<td>3-4/2006</td>
<td>D_s Production (3X), 120 mA, 7x10^{31}, injection into collision</td>
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Developments since PAC 2005

- New IR Optics
- Electron injection into collision
- BBI included in lattice design
- Constraint on e+e- symmetry
- New diagnostic tools

Diagnosics of Interaction Point Properties and Bunch-by-Bunch Tune Measurements in CESR, G.W. Codner et al, Beam Instrumentation Workshop 2006
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<tbody>
<tr>
<td>$\mathcal{L}$ ($10^{30}$ cm$^{-2}$ s$^{-1}$)</td>
<td>300</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>$I_{\text{beam}}$ (mA)</td>
<td>180</td>
<td>75</td>
<td>65</td>
</tr>
<tr>
<td>Nr Bunches</td>
<td>45</td>
<td>40</td>
<td>24</td>
</tr>
<tr>
<td>$\varepsilon_H$ (nm-rad)</td>
<td>220</td>
<td>135</td>
<td>120</td>
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<tr>
<td>$\xi_V$</td>
<td>0.04</td>
<td>0.024</td>
<td>0.029</td>
</tr>
<tr>
<td>$\beta_V$ (cm)</td>
<td>1.0</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$\sigma_E/E$ ($10^{-4}$)</td>
<td>0.81</td>
<td>0.85</td>
<td>0.81</td>
</tr>
<tr>
<td>$\tau_{H,V}$ (ms)</td>
<td>55</td>
<td>50</td>
<td>55</td>
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**New IR Compensation Scheme 2006**

Skew-quadrupole compensation of CLEO detector solenoid was implemented in 2001 and used for 5.3 GeV operation.

Full CESR luminosity modeling in early 2005 indicated that the energy-dependence of compensation is more important at CESR-c energy due to larger energy spread.

Two-solenoid solution was DAΦNE-inspired, but optics design was complicated by existing permanent and s.c. quadrupoles.

Improved Tune Plane Footprint

New solenoid compensation reduces strength of synchro-betatron resonance

improved ease of machine tuning

Nominal Solenoid Compensation

Solenoid strength reduced 20%
Residual coupling compensated using IR skew quads

Horizontal Tune (kHz)
Topping Off: Reliability & Duty Cycle

Ability to inject and collide in similar optics avoids fill-to-fill thermal cycling
Tune excursions from BBI much reduced (less hysterisis!)
Turn-around times reduced from 4 to less than 2 minutes.

March 26, 2005

April 8, 2006
These recent improvements in IP optics, tune plane footprint and duty cycle re-emphasize the importance of finding a way to compensate optical distortions arising from the beam-beam interaction.

Horizontal crossing positions for electron train 1 bunch 1

**Beam-beam kicks**

- Positrons: 8 trains of 3 bunches
- Electron Orbit
- Positron Orbit
- Interaction Point
Present stored-current limit: 2.5 mA in 8x3 operation in collision, but higher if the beams are separated at the IP.

Limit on a single electron bunch into 8x3 positrons is 8 mA.

As a result, much effort has been put into modeling the beam-beam interaction both at the IP and at the parasitic crossings.

Some improvement has been obtained already by including consideration of the long-range BBI in the lattice design. Nonetheless, the distortion of the beta function is substantial, even when the tunes are held constant during filling.

Until now, operational compensation of the BBI effects has consisted of global tune corrections. We have recently developed an optics correction algorithm based on locally closed beta bumps using eight quadrupole magnets around each set of crossings. Initial results from machine studies in April, including compensation of the BBI at the main IP, are encouraging.
Near-term Improvement Plans

Machine Studies Projects July-September 2006

- Lattice design development, e.g. pretzel optimization
- Tune IP BBI compensation (empirical coefficients)
- Tune local parasitic crossing compensation
- Improve e- injection efficiency
- Sextupole tuning to avoid resonances
- Study alternative working points
- Develop run-time tuning aids
- Improve hardware reliability through diagnostic tools
- Injector tuning
During the past year, CESR-c operation has been improved by:

- new IR optics; new solenoids built and installed
- lattice design optimization including new IR and BBI effects
- establishing a top-off mode for electron injection into collision

Bunch-by-bunch and turn-by-turn diagnostic tools have been commissioned.

Development of BBI compensation algorithms is underway.

CESR/CLEO continues to be major contributor to the active field of charm spectroscopy. Discovery of new bound states of charmed quarks, precision measurements of form factors, and many first-time observations coincide with increasing precision of lattice QCD phenomenology. CLEO presently dominates the world sample of $\psi(3770)$ and $D_s$ threshold data and is on track to increase former by a factor of two and latter by a factor of four. The foreseen program also includes tripling the world sample of $\psi(3686)$ decays by the time of its completion in April, 2008.