Beam Configurations

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FACET-II User Meeting
October 17th, 2023
SLAC
Outline

• FACET-II accelerator overview

• Simulations of single bunch 2nC operation:
  • Beam parameters at IP near full compression
  • Compression tuning and collimation options
  • Impact of Laser Heater on beam parameters at IP
  • Jitter scans with laser heater on/off

• Plans for two bunch operation
FACET-II Accelerator Overview

Photoinjector
Single and two bunch operation with variable charge $Q = 0.6-2nC$

Main Beam Configurations
1. Single bunch, 2 nC
   (TDR, W-Chicane, with/without collimation/laser heater)
2. Two bunch (from cathode, 0.5 + 1.5 nC) with/without laser heater
3. Single bunch, long bunch, good transverse quality (SFQED initial experiments. Not covered here.)
Electron Injector Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Single Bunch TDR</th>
<th>Operation (Summer 2022)</th>
<th>Operation (Summer 2023)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch Charge (nC)</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Gun rf Phase (deg)</td>
<td>10</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Cut radius on transverse laser spot [mm]</td>
<td>2.68</td>
<td>2.75</td>
<td>2.75</td>
</tr>
<tr>
<td>Laser pulse length (FWHM) [ps]</td>
<td>7.0</td>
<td>3.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Gun Solenoid Int. Field Strength [kG.m]</td>
<td>0.38</td>
<td>0.39</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Injector simulation infrastructure updated to streamline start-to-end modeling from gun to beam dump
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Single Bunch 2nC Beam Parameters at IP

Current and slice emittance

Transverse Profile

Longitudinal Phase Space

Head of the beam is on the left

CSR in BC20 increases the horizontal slice emittance and the horizontal spot size with respect to the vertical

L1 phase = -20.5 deg, L2 phase = -40.05 deg

Final Focus optics are for 50cm round beta at the IP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS beam size, Gaussian Fit (x,y,z)</td>
<td>(13.4,7.7,3.3)</td>
<td>um</td>
</tr>
<tr>
<td>Peak current</td>
<td>48.7</td>
<td>kA</td>
</tr>
<tr>
<td>Normalized emittance 90% cut (x,y)</td>
<td>(5.4,1.9)</td>
<td>um-rad</td>
</tr>
</tbody>
</table>
Simulations scanning the L2 phase

-41.8 deg

-40.8 deg

-39.8 deg

-38.8 deg

-37.8 deg

Head of the beam is on the left
Beam shaping with Notch and Jaw Collimators in BC20

Lattice Functions in the W chicane

Notch and jaw collimation provides ability to shape beam distribution at the IP with minimal linac tuning
Alternate 2-bunch Configuration Particle Tracking

- $\Delta t = 500$ fs, $I_{pk} \sim 5/15$ kA, $Q \sim 330/820$ pC
- $\Phi(L1) = -19.8$ deg; $\Phi(L2) = -39.8$ deg
- Can trade: $>I_{pk}$ for $<\Delta t$ by adjusting $\Phi (L1 \& L2)$

Notched configuration enables quick start of PWFA 2–bunch experiments ahead of double-pulsed injector configuration which will bring improved beam quality next year.
Single Bunch 2nC Beam Parameters at IP with Laser Heater

Current and slice emittance

Transverse Profile

Longitudinal Phase Space

Laser heater removes some of the asymmetry in the horizontal projection and reduces the slice emittance variation in the core of the beam.

L1 phase = -20.5 deg, L2 phase = -40.05 deg
Final Focus optics are for 50cm round beta at the IP
Laser heater induced energy spread = 350 keV RMS

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<td>RMS beam size, Gaussian Fit (x,y,z)</td>
<td>(12.1,7.7,5.3)</td>
<td>um</td>
</tr>
<tr>
<td>Peak current</td>
<td>28.1</td>
<td>kA</td>
</tr>
<tr>
<td>Normalized emittance 90% cut (x,y)</td>
<td>(5.1,2.0)</td>
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Jitter scans - single bunch current variation with LH on/off at 350 keV

The laser heater reduces fluctuations of the peak current at the IP.
Jitter data used to understand PWFA interaction

- Participating charge and energy are loss in PWFA sensitive current profile

- Simulations used to quantitatively understand charge participation in ionization and capture of particles.

Plasma accelerated spectra reveal details of incoming beam consistent with simulation results
Jitter data used to understand PWFA interaction

- Participating charge and energy are loss in PWFA sensitive current profile
- Simulations used to quantitatively understand charge participation in ionization and capture of particles.

Plasma accelerated spectra reveal details of incoming beam consistent with simulation results

See E-300 Talk this afternoon
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• Plans for two bunch operation
Hardware is in hand and ready for installation
Expected two-bunch beam parameters at IP, LH off

**Current and slice emittance**

- 166 um separation
- \( \gamma \epsilon_x \) and \( \gamma \epsilon_y \)

**Transverse Profile**

- \( \sigma_y = 9.886 \) um
- \( \sigma_y' = 20.947 \) um
- \( \text{rms } X = 35.6018 \) um
- \( \text{rms } Y = 41.992 \) um
- \( Q = 1.00910 \) nC

**Longitudinal Phase Space**

- Energy [GeV]

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Head of the beam is on the left

**Witness beam energy set to 10 GeV in the final focus**

L1 phase = -23 deg, L2 phase = -42.5 deg

Final Focus optics are for 50cm round beta at the IP

<table>
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<tr>
<th>Parameter</th>
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<th>Unit</th>
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<tbody>
<tr>
<td>RMS beam size, Gaussian Fit</td>
<td>20.6, 9.5, 3.9</td>
<td>24.3, 5.4, 6.4</td>
<td>um</td>
</tr>
<tr>
<td>(x,y,z)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak current</td>
<td>43.7</td>
<td>20.4</td>
<td>kA</td>
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<tr>
<td>Normalized emittance 90% cut (x,y)</td>
<td>24.8, 20.5</td>
<td>27.35</td>
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Expected two-bunch beam parameters at IP, LH on

Current and slice emittance

- 166 um separation
- $\gamma \epsilon_x$ vs $\gamma \epsilon_y$

Transverse Profile

- $\sigma_y = 0.010$ um
- $\sigma_x = 22.214$ um
- rms X = 35.6739 um
- rms Y = 42.2669 um
- $Q = 1.96819 \times 10^5$

Longitudinal Phase Space

- Energy [GeV]
- $z [\mu m]$

Head of the beam is on the left

Witness beam energy set to 10 GeV in the final focus

Note that 3.5 mJ is the max LH energy we have measured going into the LH undulator

L1 phase = -23 deg, L2 phase = -42.5 deg

Final Focus optics are for 50cm round beta at the IP

LH energy = 3.5 mJ, LH pulse length = 9 ps FWHM

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<tr>
<td>RMS beam size, Gaussian Fit (x,y,z)</td>
<td>21.9,9.6, 4.7</td>
<td>23.5,5.5, 5.0</td>
<td>um</td>
</tr>
<tr>
<td>Peak current</td>
<td>28.4</td>
<td>14.4</td>
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<td>Normalized emittance 90% cut (x,y)</td>
<td>27.7,22.6</td>
<td>25.7,37</td>
<td>um-rad</td>
</tr>
</tbody>
</table>
Drive/Witness beam parameters at IP with LH on/off

Drive

Witness

LH off

LH off

Drive

Witness

LH on

LH on

I [kA]

Norm. Emittance [mm-mrad]

z [um]
Summary

• FACET-II offers flexible single bunch and (soon-to-come) two bunch configurations with beam shaping capabilities to serve the user community.

• Start-to-end simulations set expectation for beam parameters at the IP including shot-to-shot variation due to linac jitter.

  - Example beam distributions and lattice configurations are available here.

• Recently commissioned upgrades like the laser heater can improve the beam stability at the IP.

• These linac jitter simulations will inform PWFA simulations.

• Two-bunch UV pulse stacker hardware in hand; planned install during winter down.

  - Other options in the meantime

Accelerator configurations designed to meet the need of the FACET-II science program.