FACET-II
Laser upgrade options: >100TW, transport and quality improvement

FACET-II Science Workshop 2017

Alan Fry
October 20, 2017
Enhanced capabilities for FACET-II experimental operations

- Shorter pulse duration
- Higher pump laser energy
- Reduced beam transport losses
- Improved diagnostics

- Major upgrade for high-field QED capabilities
  - >100 TW peak power
  - Larger beam transport optics
  - Larger compressor
  - Many additional modifications

Higher peak intensity
The Laser System: 10-TW Ti:Sapphire Laser

Coherent Vitara oscillator with a Verdi pump laser: 800 nm, 20 fs pulses at 68 MHz

Quantel Nd:YAG flash lamp pump laser: 130 mJ at 532 nm

Regenerative amplifier 200 ps, 120 Hz

Preamplifier delivers 40 mJ to amplifier

Multi-Pass Amplifier delivers 600-700 mJ with Thales Saga laser integrated (2x1.8 J at 532 nm)

Periscope for laser transport
Upgrade-ready FACET laser layout

FACET-II Science Workshop, Alan Fry, 2017-10-20
What do we need to upgrade?

From Mike Litos [traumatized, but no longer on-the-hook]:
- long term (minutes to hours) pointing drift in the transport
- fast pointing jitter through the transport
- increased number and quality of diagnostics from laser room to experiment
- increased automation of laser alignment in laser room and through transport
- improved reliability & stability of intensity profile (Powerlite seemed to help)
- automation of transport lens alignment
- accurate and frequent characterization of pulse compression
- phase monitoring and correction capability (deformable mirror)
Laser System Block Diagram: current system

- Laser Oscillator
  - Stretcher
  - Regenerative Amplifier
    - Pre-Amp Amplifier
      - Power Amplifier

- Beam transport to tunnel

- Compressor
  - Beam Conditioning
    - PWFA
Laser System Block Diagram: upgrades

- Laser Oscillator
  - Stretcher
  - Regenerative Amplifier
    - Pre-Amp
    - Power Amplifier
    - Power Amp Pump 1
    - Power Amp Pump 2

- Beam transport to tunnel
  - Compressor
    - Beam Conditioning
      - PWFA
      - Reduce losses

- Regen Pump
  - Improve stability

- Pre-Amp Pump
  - Increase energy

- Reduce pulse duration

Laser System Block Diagram: diagnostics upgrades

- Laser Oscillator
  - Spectrum
  - Power
  - Energy

- Stretcher
  - Energy
  - Beam profile
  - Beam pointing

- Regenerative Amplifier
  - Energy
  - Beam profile
  - Beam pointing

- Pre-Amp Pump

- Regen Pump

- Pre-Amp Pump

- Power Amp Pump 1

- Power Amp Pump 2

- Power Amplifier

- Beam transport to tunnel
  - Pulse duration
  - Spectral phase
  - Energy
  - Beam profile
  - Beam pointing
  - Wavefront

- Compressor
- Beam Conditioning
- PWFA
<table>
<thead>
<tr>
<th>Function</th>
<th>“Spec”</th>
<th>Typical</th>
<th>Upgrade target</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regen Pump</td>
<td>20 mJ</td>
<td>20 mJ</td>
<td>20 mJ</td>
<td></td>
</tr>
<tr>
<td>Regen output</td>
<td></td>
<td></td>
<td>20 mJ</td>
<td></td>
</tr>
<tr>
<td>Pre-amp Pump</td>
<td>120 mJ</td>
<td>120 mJ</td>
<td>100 mJ</td>
<td>DPSS laser for stability</td>
</tr>
<tr>
<td>Pre-amp Output</td>
<td>35 mJ</td>
<td>35 mJ</td>
<td>30 mJ</td>
<td></td>
</tr>
<tr>
<td>Power-amp Pump</td>
<td>3.6 J</td>
<td>2.8 J</td>
<td>7 J</td>
<td>Gaia or equivalent</td>
</tr>
<tr>
<td>Power-amp output</td>
<td>1.0 J</td>
<td>0.6 J</td>
<td>1.8 J</td>
<td></td>
</tr>
<tr>
<td>Beam transport output</td>
<td>0.8 J (80%)</td>
<td>0.40 J (65%)</td>
<td>1.6 J</td>
<td>Improve optics (to 80%)</td>
</tr>
<tr>
<td>Compressor output</td>
<td>0.52 J (65%)</td>
<td>0.25 J (65%)</td>
<td>1.0 J</td>
<td></td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>40 fs</td>
<td>70 fs</td>
<td>35 fs</td>
<td>Spectral phase control</td>
</tr>
<tr>
<td>Peak Power</td>
<td>&gt;10 TW</td>
<td>3.5 TW</td>
<td>&gt;25 TW</td>
<td></td>
</tr>
</tbody>
</table>
Pulse duration upgrade: spectral phase control & monitoring

- Uncorrected spectral dispersion can be measured (FROG, SPIDER, D-Scan, etc.) and controlled (Dazzler, SLM, DM, etc.) with commercial devices.
- Anticipate routine operation at **35 fs FWHM**
Pump laser upgrade: higher energy

Example pump lasers from Thales
(other suppliers have comparable products)

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Energy @ 532nm [J]</th>
<th>Rep Rate [Hz]</th>
<th>Est. Ti:S compressed energy [J]</th>
<th>Est. peak power [TW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaia-I</td>
<td>7.5</td>
<td>5</td>
<td>1</td>
<td>25</td>
</tr>
</tbody>
</table>

0.6m x 1.1m - fits on existing tables (barely)
Beam transport upgrade: improved optics

- Beam transport has relatively high losses (35%), uncorrected dispersion, possibly some spectral clipping
- Replacement of optics should increase transmission to 80% and reduce spectral phase and amplitude degradation

~28 m of laser transport to Compressor in FACET tunnel
FACET-II opportunities

\[ \omega = 1.55 \text{eV}, \eta = 17, Y = 3 \quad \text{strong-field Compton scattering, rad. reaction} \]

\[ \omega = 4.8 \text{eV}, \eta << 1, \Psi = 0 \quad \text{Pair production} \]

\[ \omega = 1.55 \text{eV}, \eta << 1, Y = 0, \text{circ pol.} \quad \text{Vacuum birefringence} \]

\[ \omega = 1.55, \eta = 17, Y = 1.6 \]

\[ \omega = 1.55, \eta = 17, Y = 0.4 \]
100TW upgrade: creative space utilization (and many other upgrades)

- Higher energy pump laser (possibly at reduced rep-rate)
  - Possibly additional space needed in laser lab
- Larger Ti:sapphire amplifier crystal and beam optics
- Increased stretching to reduce nonlinear effects in amplifier and beam transport
- Increased beam size through beam transport and compressor
- Increased grating size and separation in larger compressor tank
- Possible need to suppress pre-pulses
- High quality parabolic focusing and recollimating optics on hexapod manipulators to achieve highest beam quality
- Deformable mirror and wavefront sensor for high intensity beam at focus
- ….
Pump laser upgrade: toward 100TW

Example pump lasers from Thales
(other suppliers have comparable products)

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<th>Est. peak power [TW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaia-HP</td>
<td>16</td>
<td>5</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td>Atlas 25</td>
<td>25</td>
<td>0.1</td>
<td>3</td>
<td>85</td>
</tr>
<tr>
<td>Atlas 50</td>
<td>50</td>
<td>0.016</td>
<td>6</td>
<td>170</td>
</tr>
</tbody>
</table>
Pump laser upgrade challenge: space

- Gaia-HP laser head is 1m x 2.7m
  - Must be mounted stably, close to power amplifier, with access for maintenance and service
- Power supply and cooling unit are 0.5m x 1.5m together
  - Must be located within ~3m of laser head
- May need to expand room, e.g. into entrance to S20 building
Compressor upgrade: larger optics for 100TW class operation

- Increase beam diameter to ~10cm
- Increase grating width to ~30cm
- Increase grating separation by ~2-3x
- Compressor enclosure footprint increases by 3-5x
Beam delivery upgrade: deformable mirror & wavefront sensor

After amplification, a deformable mirror in combination with a wavefront sensor corrects the distortions produced in the laser chain and sent to the compressor. The spot on sample is optimized afterwards using a second feedback loop that corrects the distortion introduced by the compressor and focusing optics in the experimental chamber.

<table>
<thead>
<tr>
<th>Before correction</th>
<th>After correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.576 um RMS distortion</td>
<td>22 nm RMS distortion</td>
</tr>
<tr>
<td>2.502 um P-V</td>
<td>100 nm P-V</td>
</tr>
</tbody>
</table>
FACET-II Laser: Conclusions

- FACET-II ionization laser system can be upgraded at moderate cost to achieve >25TW at 5Hz
  - Spectral phase control
  - Higher energy pump laser
  - Improved beam transport optics
  - Improved diagnostics
- 100TW class upgrade for nonlinear QED is possible at higher cost with multiple upgrades throughout the laser, beam transport, and delivery systems
- Design and operations support provided by experienced LCLS Laser Science & Technology Division
Laser Support Team

LCLS Laser Science and Technology Division (Alan Fry, Division Director)

• Lasers In Accelerators Department (Steve Edstrom, Department Head)
  - Sasha Gilevich, Laser Engineer
  - Philippe Hering, Laser Physicist
  - Alan Miahnahri, Opto-mechanical Engineer
  - Wayne Polzin, Laser Engineer
  - Sharon Vetter, Laser Engineer
  - Marc Welch, Laser Engineer

• Lasers in LCLS Science Department (Joe Robinson, Department Head)
  - 8 Laser Scientists
Experimental Setup

1.2 m

5.2 m

2.4 m

FACET tunnel

FACET laser room

Penetration 20-11 to FACET tunnel

~28 m of laser transport to Compressor in FACET tunnel