E-320: Probing Strong-field QED at FACET-II

FACET-II PAC Meeting
October 28, 2020

Sebastian Meuren
(for the E-320 collaboration)
E-320: general objective & context

- **Mission**: probe the regime $a_0 \gg 1, \chi \gtrsim 1$ for the first time (qualitative difference to E-144: $a_0 \lesssim 1, \chi \lesssim 1$)
- **Laser** (baseline aim): 0.6 J energy (Strehl 0.7), 35 fs, 2.0 μm FWHM spot: $a_0 \approx 10$ ($I \approx 2 \times 10^{20}$ W/cm²)
- **Electrons**: 13 GeV, collide at 28.07°: $\chi \approx 1.4$ (2nC, Gaussian: $\sigma_x = 24$ μm, $\sigma_y = 30$ μm, flattop: $L_z = 250$ μm)
E-320: initial milestones

- **2021 (spring)**: calibrate detectors, measure backgrounds, access perturbative regime: $a_0 \lesssim 1$ ($\sim 10^{18} \text{W/cm}^2$)
- **2021 (summer)**: observe the transition to nonperturbative laser-electron interactions: $a_0 \gtrsim 5$ ($\gtrsim 10^{19} \text{W/cm}^2$)

- **2021 (winter)**: quantum radiation reaction (electrons emitting $n \gtrsim 5$ photons)
- **2021 (winter)**: QED vacuum breakdown: $a_0 \gtrsim 10$ ($\gtrsim 2 \times 10^{20} \text{W/cm}^2$)

- **2022 (spring)**: LCFA breakdown requires Compton / pair spectrometer
  (Naranjo & Rosenzweig)

Detector response: Mir-Ali Hessami & Storey
E-320: overview

Main contributors: IP: Nielsen & Salgado/Zepf; FACET IP coordination: Ariniello; IP diagnostics: Chen & Ekerfelt; New beamline: Storey; PCAL: Salgado/Zepf; DT detectors: Storey & San Miguel Claveria
Coordination: Gerstmayr, Meuren, Reis, Yakimenko

- OAP alignment laser & focus diagnostic
- Laser-electron overlap (space & time)
- Electron & gamma detection: dump table (shared diagnostic)
- “Low-energy” electrons: detector in EDC chamber
- Single positron detection: rudimentary tracking capability, Cherenkov calorimeter (PCAL)

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E-320: IP – fully ready by 11/25

High-intensity laser focus
- 1st OAP alignment: two steering mirrors or via OAP tip/tilt + e-beam translation
- Diagnostic: prism + microscope objective, separately retractable, xyz motorized

Alignment Targets
- Separate assembly
- Fully motorized (xyz)
- Beam/laser spatial overlap: Ce:YAG screen/needle
- Pinhole for alternative OAP alignment

OAP alignment proof of principle
- Laser focusability test: FWHM spot only $\leq 18\%$ larger than diffraction limit (deformable mirror)
- Significant improvement in Strehl ratio expected with $\lambda/10$ OAPs (arrival 11/25)

Common OAP base plate
- Height adjustment (manual or stepper + belt)
- Currently manufactured (ready: 10/30, arrival: 11/16)
- Possibility for interferometric alignment, facilitates shot-to-shot diagnostic of the laser focus quality

Measurement/Analysis: Chen & Isele
E-320: positron detection: ready by 12/11

- Challenge: measure $\lesssim 1$ positron/shot: dedicated new detector area
- Combine calorimeter & tracking: best possible background rejection
- Energy range 2.5-5.7 GeV (adjustable via dipole 1-2.3, 2-4.5, 3.0-6.8)
- Cherenkov calorimeter calibrated (ELBE), ready for shipment to SLAC

PCAL design: Salgado/Zepf
(with input from Aarhus & Stanford)
Original PDC/EDC background simulations: Cavanagh/Sarri
Update: Watt
E-320: electron & gamma detectors

New Beamline: PDC & EDC
Dump Table

Quantum beamstrahlung (mostly single emissions)

Emission of multiple photons (quantum radiation reaction)
Stochastic emission (finite lifetime)

Breakdown of the LCFA at small photon energies

- Spectrum: 160 keV – 23 MeV
- 1% energy resolution ≥ 1 MeV

Tamburini

Mir-Ali Hessami & Storey

Sebastian Meuren (for the E-320 collaboration)

Baby Compton: Naranjo/Rosenzweig (funding via DARPA & DOE Stewardship)
New Beamline (PDC & EDC): Storey
Dump Table: Storey & San Miguel Claveria
E-320: future science program

Beam-Beam Collisions: $\chi \geq 10$ already for 3 TeV CLIC

Beamstrahlung Mitigation: Short-Bunch Paradigm
- plasma lens: transverse size $\leq \mu$m
- 90° collisions: interaction time $\leq 6$ fs

Laboratory Astrophysics: Understanding Magnetars
$\chi \geq 2$: onset of QED cascades

Photon-Photon Collider (gamma/optical):
2nd IP $\rightarrow$ Vacuum Birefringence
- 12.9 keV x-ray + 100 PW $\leftrightarrow$ 6 GeV $\gamma$ + 100 TW

Quantum Coherence in Extreme Conditions
- Use two-color laser with phase control
- Coherent $e^-e^+$ re-collisions

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### Laser upgrade: 100 TW scale to start probing \( \chi \gg 1 \)

<table>
<thead>
<tr>
<th>Energy [J]</th>
<th>Duration [fs]</th>
<th>Power [TW]</th>
<th>Diameter [mm]</th>
<th>Optics</th>
<th>OAP [\mu m]</th>
<th>Spot [\mu m]</th>
<th>Strehl</th>
<th>Intensity [W/cm²]</th>
<th>( a_0 )</th>
<th>( \chi )</th>
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<tbody>
<tr>
<td>Existing laser</td>
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<tr>
<td>0.30</td>
<td>50</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td>0.4</td>
<td>4.7 × 10¹⁹</td>
<td>4.7</td>
<td>0.68</td>
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<tr>
<td>0.44</td>
<td>40</td>
<td>10</td>
<td>40</td>
<td>3”</td>
<td>2.0</td>
<td>2.00 (1.67)</td>
<td>0.6</td>
<td>1.3 × 10²⁰</td>
<td>7.8</td>
<td>1.1</td>
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<td>0.60</td>
<td>35</td>
<td>16</td>
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<td></td>
<td></td>
<td></td>
<td>0.7</td>
<td>2.3 × 10²⁰</td>
<td>10</td>
<td>1.5</td>
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<td>Desired upgrade</td>
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<tr>
<td>1.28</td>
<td>35</td>
<td>34</td>
<td>60</td>
<td>4”</td>
<td>1.8</td>
<td>1.85 (1.48)</td>
<td>0.6</td>
<td>5.0 × 10²⁰</td>
<td>15</td>
<td>2.2</td>
</tr>
<tr>
<td>4.0</td>
<td>35</td>
<td>107</td>
<td>100</td>
<td>6”</td>
<td>1.9</td>
<td>1.94 (1.55)</td>
<td>0.7</td>
<td>1.7 × 10²¹</td>
<td>28</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- **Energy**: Total energy after compressor
- **Duration**: Gaussian temporal profile, intensity FWHM
- **Power**: Intensity FWHM (limit given by Airy disk)
- **Diameter**: Flattop, diameter before OAP

### Beamline upgrade: introduce 2\(^{nd}\) IP for photon-photon collider

- Compton backscattering: 13 GeV + 3\(^{rd}\) harmonic → 6 GeV gamma photons, polarization control
- Requires a dogleg / chicane to deflect main beam
- Access to a new level of control, rich new physics program, e.g., vacuum dichroism/birefringence

### Detector upgrades

- Pair spectrometer (access to full gamma spectrum)
- Silicon tracking detectors (positron energy spectrum)
E-320 is ready for tests & installation

- IP assembly
  - Almost everything in hand
  - OAP coating (ARO): 11/25
  - OAP mount (Thorlabs): 11/16
  - Baseplate (Jena): 11/16
  - POC: Gerstmayr/Reis/SM

- Positron calorimeter
  - Manufactured in Jena
  - Calibrated at ELBE
  - DAQ integration started
  - Ready to be shipped
  - POC: Salgado/Zepf

- New beamline (PDC/EDC)
  - Passed safety review
  - In production (MDC): 12/11
  - Installation: January 2021
  - POC: Storey

- Baby Compton
  - Designed by UCLA, currently in production
  - Installation:
    - POC: Naranjo/Rosenzweig

- Deformable mirror
  - Successfully tested
  - (\(\lambda/1\) OAP): spot size
  - \(\leq 18\%\) beyond DL
  - POC: Chen/O’Shea

- Experimental review
  - Started in August 2020
  - POC: Gerstmayr/SM & Clarke

- Fiber laser
  - Single-mode fiber laser 785nm, >50mW (in hand)
  - OAP interferometer
  - POC: Chen/Gerstmayr/Reis

- Radiation safety review
  - Analysis: 9-page document
  - Submitted in April 2020
  - POC: Chen/SM & Clarke

E-XYZ & FACET: thank you for the collaborative spirit
Thank you for your attention
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