Experimental Area
Electron and Gamma Diagnostics, Differential Pumping System and Li Oven

FACET-II User Meeting 2023

Doug Storey / Associate Staff Scientist
October 17-19, 2023
Experimental area overview

  - D. Storey, C. Zhang, P. San Miguel Claveria, G. J. Cao et al., *Wakefield Generation in Hydrogen and Lithium Plasmas at FACET-II: Diagnostics and First Beam-Plasma Interaction Results* (submitted for publication)

Result of significant coordination with users to support a diverse set of experimental requirements
**Spectrometer beamline**

- **Electrons**
  - 1 GeV to >20 GeV at dump table, ~250 MeV+ at EDC chamber
- **X-rays and γ photons**
  - Gamma 1/2 screens on the dump table
  - new spectrometers under development for GDC
- **UV photons**
  - Extracted at EDC chamber, new XUV spectrometer under development
- **Positrons:**
  - 2.5 - 6 GeV in air after PDC, larger range in PDC in future

Dispersive and reimaging spectrometer enables energy resolved diagnostics for electrons, positrons, and photons
Electron diagnostics: Emittance

- **Dispersive quad scans**
  - Multi-shot measurement for $\epsilon_n(E)$ and $\beta_x(E)$

  ![DTOTR2](image1)

  - Summer 2022, compressed beam
    - Parameters across core:
      - $\epsilon_{n,x} \sim 40 \mu m$
      - $\beta_x \sim 30$ cm
      - 3% FWHM energy spread

- **Single shot emittance measurements**
  - Emittance resolution down to ~5%
  - Provides $\beta_x$ and waist location

  ![LFOV](image2)

  - Summer 2022, first H$_2$ PWFA results
    - Charge accelerated to 12.5 GeV:
      - $\epsilon_{n,x} = 1400 \mu m$
      - $\beta_x = 17.7$ cm
      - $\Delta z = 0.7$ cm (from Be window)

Development and characterization of these diagnostics is ongoing
Electron diagnostics: New online emittance diagnostic app

- Project by SULI intern Samuel Kresch
- Performs single-shot emittance analysis for saved DAQ, or live image data

Developing standardized online analysis tools to ensure consistency in data analysis
Electron diagnostics: Energy

- High resolution / in-vacuum screens
  - DTOTR1 – High resolution
    - 4.5 um spatial res. → ~0.01% rel. energy res.
  - DTOTR2 – Mid field of view
    - 30 um spatial res → ~0.05% rel. energy res.

- Large bandwidth / Large field of view
  - LFOV and CHER
    - Covers the 1 GeV to 20+ GeV range
    - LFOV uses a DRZ-Fine scintillator
    - CHER has much higher damage threshold
  - EDC_SCREEN
    - Extends measurement range to 250 MeV

DTOTR1

DTOTR2 – med resolution

LFOV – large BW – Energy depletion with H₂ PWFA
Electron diagnostics: Longitudinal diagnostics

- **XTCAV**
  - Located in the final focus and streaks in x-direction
  - Nominal longitudinal resolution down to 1um (~3fs)
  - Vertical dispersion gives LPS in single shot
  - Energy resolution: ~0.01%

- **Additional non-invasive diagnostics:**
  - S20 bunch length monitor (not yet)
  - EOS: see Claire’s upcoming talk
  - SYAG: energy distribution in BC20

Simulated XTCAV measurement

2022 - L2 compressions scans

(a) SYAG, (b) DTOTR1 and 2
Gamma diagnostics: Intensity and spectra

  - P. San Miguel Claveria, *et al.*, *Commissioning and first measurements of the initial X-ray and γ-ray detectors at FACET-II*, *Proc. of AAC’22*.

- **Gamma1**: uniform DRZ scintillator or CsI array (0.5mm pixels)
  - Provides angular profile and intensity

- **Gamma2**: DRZ scintillator behind multi-material/thickness converter
  - Information on gamma spectra

---

**GAMMA1** – Betatron radiation from PWFA (sim.) with witness bunch (a) aligned, and (b) offset

**GAMMA2**

- Raw image + filters
- Spectral response
- Fit: synch. rad spectrum with $E_c = 65$ keV

---

Gamma diagnostics commissioned and instrumental for PWFA, SFQED and more
Gamma diagnostics: Up and coming

- Compton spectrometer: single-shot gamma spectrometer
  - Range of 200 keV – 20 MeV
  - Secondary capability to resolve angle-energy double differential
- Pair spectrometer:
  - Measure gamma spectrum to 10 GeV
- More details in talk by Brian on Wed. afternoon

**New diagnostics will enable increased range and spectral sensitivity for gamma measurements**
Differential Pumping System (DPS)

- The FACET-II beam drills holes through solid materials near the IP
  - We have ~200 µm “beam-aligned” holes in the US and DS Be windows
- DPS allows gas pressures up to 10 Torr in the IP
  - Supports gas jets and static fill for Li and H$_2$ plasmas
  - Windowless transmission for low background (not yet fully implemented)

Differential pumping system critical to allow gas delivery to IP for gas jets and plasma sources
DPS operating modes

- **Static fill:**
  - He or Ar up to 10 Torr, H\(_2\) up to 5 Torr
  - Pressure stability < 0.5% over 24 hours
    - Mass flow controller implemented by SULI intern Samara Steinfeld

- **Gas jets:**
  - Hydrogen or helium, up to 1200 psi backing pressure
  - Rates up to 10 Hz, limited by
    1) Background pressure in PB
    2) Beamline pressure (DPS limit)

<table>
<thead>
<tr>
<th>State</th>
<th>Gas:</th>
<th>Pressure:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0: High vacuum</td>
<td>none</td>
<td>High vacuum at IP</td>
</tr>
<tr>
<td>1: Li oven</td>
<td>He</td>
<td>≤ 10 Torr</td>
</tr>
<tr>
<td>2: H(_2) plasma</td>
<td>H(_2)</td>
<td>≤ 5 Torr</td>
</tr>
<tr>
<td>3: Gas jets</td>
<td>He, H(_2)</td>
<td>1200 psi, up to 10 Hz</td>
</tr>
</tbody>
</table>
Improvements to DPS

- Radiation shielding
  - >3 tons of lead and poly shielding placed around roughing pumps
    - No radiation faults since shielding added
  - Improvements to “watcher” from SULI intern Samara Steinfeld

- Purge gas added to improve H2 pumping efficiency
  - Increased static fill range from 2 Torr to 5 Torr
  - Increased rate available for gas jets

- New mass flow valve for improved static fill stability
  - Allows for remote operation, better stability

DPS is now more robust than in the previous run
Lithium plasma oven operation with DPS

- IP pressure is very robust to DPS failures
  - No single DPS failure affects the IP pressure
  - No DPS failures since lead shielding added
    - Need more experience with high-loss conditions

- Pressure stability < 0.5% of 24 hours
  - 0.5% diurnal temperature swing
  - 0.1% stability over hour time scale

- Dry-run of Li oven with DPS (no beam)
  - Operated at 5 Torr for >20 hours

Nearly ready to start testing the lithium plasma oven with beam!
Documentation on confluence

- Updated how-to pages can be found here:
  - How to perform a static fill
  - Lithium oven procedure
  - How to operate the gas jets

User-friendliness of the DPS improving with experience
Conclusions

• Comprehensive set of spectrometer diagnostics has been defined, built, and commissioned through extensive collaborations with Users

• The differential pumping system supports gas jets, static fill, and the delivery of high intensity, low emittance beams to User programs

• Improvements to robustness and usability have greatly improved performance and reliability

• Successful demonstration of the lithium oven operation supported by DPS

• Diagnostics, plasma sources, and DPS detailed here: https://arxiv.org/abs/2310.06215
Questions?
Experimental area overview

  - D. Storey, C. Zhang, P. San Miguel Claveria, G. J. Cao et al., *Wakefield Generation in Hydrogen and Lithium Plasmas at FACET-II: Diagnostics and First Beam-Plasma Interaction Results* (submitted for publication)

Developed to satisfy a diverse set of experimental requirements
Design of the upstream differential pumping system

4 x 2000 L/s turbopumps:
2 x 10,000 L/min backing pumps:

Pressure at each stage:
18 x 700mm
18 x 700mm
18 x 700mm
18 x 700mm

Apertures b/w stages:

State:  | Gas:      | Pressure:
-------|-----------|----------
0: High vacuum | none      | High vacuum at IP
1: Li oven      | He        | ≤ 5 Torr
2: H2 plasma   | H₂        | ≤ 5 Torr
3: Gas jets    | He, H₂    | 10⁻⁴ Torr background

• Four operating states that will require no hardware changes between
• Supports static fill and gas jet operation

Differential pumping system critical to allow gas delivery to IP for gas jets and plasma sources
• Tracking, profiles, and calorimetry for low energy electrons and positrons
  - PDC chamber: e+ tracking and calorimetry – 2.5-6 GeV
  - EDC chamber: e- profile monitor – 1-6 GeV
• Development driven by the E320 collaboration
Compact chicane for testing compression of plasma chirped beams

- Chicane enables extreme compression of e-beams to nm duration and coherent XUV generation
- Chicane retracts out of the beamline to restore max aperture
- Development led by E-338 collaboration
  - UV spectrometer is being installed on the EDC chamber for initial tests

Credit: C. Emma