Tunable Positron Source

CO$_2$-Laser based post-processing of ATF e$^-$ beam driven positron-electron jets

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Funding source: CU multi-year grant (ongoing)
DOE (applied)
US Patent 16,770,943
Key scientific goals

- **positron source with tunable properties - control the interaction**
  CO₂ laser-driven post-processing of ATF e-beam driven particle showers

- **tunable yet collisionless moderator**

- **NOT** aimed at production of high-energy
  *low-emittance positron beams* for collider applications

- long wavelength CO₂ laser (compared to Ti:Sapphire):
  larger plasma structures – easier to physically overlay with the showers
  slower structures for a lower plasma density – laser velocity slower for same density

- **numerous applications** benefit from a tunable positron beam
### Current positron sources

**PULSTAR NCSU Fission reactor** - positron source user-facility  
[source: https://www.ne.ncsu.edu/nrp/user-facilities/intense-positron-beam/]

**LLNL Na-22 beta plus positron source** and positron spectroscopy  
[source: https://str.llnl.gov/str/Howell.html]

**HZDR Germany - ELBE Positron (EPOS) facility**  
[source: http://positron.physik.uni-halle.de/EPOS/]

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**nuclear reactor**  
**radioactive nuclei**  
**electron linac**
Numerous positron applications

Spatial sampling of crystal electrons by in-flight annihilation of fast positrons


LLNL 2.65 MeV positron \(^{22}\text{Na}\) source – 10^5/s

...development of practical atomic-scale channeling measurements of electronic spin densities, and momentum profiles in addition to valence and bonding e\(^{-}\) density maps.
H. Chen et al.
PRL 105, 015003 (2010)
Laser shots NOT consistent!
- showers $>$ MeV electrons on converter target
- positrons NOT isolated
- positrons still divergent
- un-localized in momentum space

Maxwellian spectrum

orders-of-magnitude roll-off at high-energies
simulations of ATF-beam driven positron-electron showers

GEANT4 Acknowledgement:
J. Resta-Lopez, V. Rodin (CI) and LLNL
- Parabola with hole for re-directing the electron beam
- 3” diam parabolas with 5 mm hole available at ATF
- ATF has different parabolas with F varying between 100-250 mm. They are between 3-4” dia. But only 3” dia have holes
- Axicon pair telescope to split, expand and combine the laser beam
- Axicon pair is already in-stock at ATF
- The axicon pair cannot be used for our full power
- 2D PIC EPOCH simulations – CO2 laser-driven post-processing of ATF beam-driven showers
- Shower properties determined using GEANT4
- Initialize a long shower ~ 2.5 ps
- CO2 Laser-driven structures – can trap and slow-down positrons

<table>
<thead>
<tr>
<th>Plasma parameters</th>
<th>1TW</th>
<th>2TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>$2 \times 10^{17}$ cm$^{-3}$</td>
<td>$2 \times 10^{17}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Critical Power ($P_c$)</td>
<td>1.1 TW</td>
<td>1.1 TW</td>
</tr>
<tr>
<td>$P/P_c$</td>
<td>0.88</td>
<td>1.87</td>
</tr>
<tr>
<td>matched-$w_0$</td>
<td>32 µm</td>
<td>36 µm</td>
</tr>
<tr>
<td>$a_0$</td>
<td>1.52</td>
<td>1.95</td>
</tr>
<tr>
<td>$\lambda_b$</td>
<td>1.45 mm</td>
<td>1.45 mm</td>
</tr>
<tr>
<td>$Z_R$ (matched-$w_0$)</td>
<td>0.32 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>$\sigma_r/w_0$</td>
<td>0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Strongly Mismatched Regime of Nonlinear Laser–Plasma Acceleration: Optimization of Laser-to-Energetic Particle Efficiency
10.1109/TPS.2019.2914896

2D PIC simulation of CO2 laser driven post-processing of shower
initially use BL# 2

vacuum chamber on BL#2 – space for our spectrometers

however, need CO$_2$ laser on BL#2

can we get Ti:Sap or Nd:YAG on BL#2?
Our diagnostics

LLNL positron spectrometer


LANL gamma-ray diagnostics

Yr. 1 – *ONLY electron beam characterization of positron-electron jet* production in solid target, over the sub-ps electron beam parameter-space (spot-size, charge, current) and its interaction with laser-ionized plasma

Yr. 2 – *demonstration of spatio-temporal overlap* between a high-power CO$_2$ laser pulse within the plasma-cell along with positron-electron jets

Yr. 3 – demonstration of *tuning of the characteristics of positrons* by scanning over electron beam, CO2 laser and plasma properties.
# Electron Beam Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Typical Values</th>
<th>Comments</th>
<th>Requested Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>MeV</td>
<td>50-65</td>
<td>Full range is ~15-75 MeV with highest beam quality at nominal values</td>
<td>60 MeV</td>
</tr>
<tr>
<td>Bunch Charge</td>
<td>nC</td>
<td>0.1-2.0</td>
<td>Bunch length &amp; emittance vary with charge</td>
<td>1 nC</td>
</tr>
<tr>
<td>Compression</td>
<td>fs</td>
<td>Down to 100 fs (up to 1 kA peak current)</td>
<td>A magnetic bunch compressor available to compress bunch down to ~100 fs. Beam quality is variable depending on charge and amount of compression required. NOTE: Further compression options are being developed to provide bunch lengths down to the ~10 fs level</td>
<td>0.1 - 1 ps (10 fs will be highly desirable when available?)</td>
</tr>
<tr>
<td>Transverse size at IP (σ)</td>
<td>µm</td>
<td>30 – 100 (dependent on IP position)</td>
<td>It is possible to achieve transverse sizes below 10 µm with special permanent magnet optics.</td>
<td>30-50 µm Can we get the PMQ triplet setup used earlier at BNL?</td>
</tr>
<tr>
<td>Normalized Emittance</td>
<td>µm</td>
<td>1 (at 0.3 nC)</td>
<td>Variable with bunch charge</td>
<td></td>
</tr>
<tr>
<td>Rep. Rate (Hz)</td>
<td>Hz</td>
<td>1.5</td>
<td>3 Hz also available if needed</td>
<td></td>
</tr>
<tr>
<td>Trains mode</td>
<td>---</td>
<td>Single bunch</td>
<td>Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.</td>
<td></td>
</tr>
</tbody>
</table>
# CO₂ Laser Requirements

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Parameter</th>
<th>Units</th>
<th>Typical Values</th>
<th>Comments</th>
<th>Requested Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ Regenerative Amplifier Beam</strong></td>
<td>Wavelength</td>
<td>μm</td>
<td>9.2</td>
<td>Wavelength determined by mixed isotope gain media</td>
<td>9.2 μm</td>
</tr>
<tr>
<td></td>
<td>Peak Power</td>
<td>GW</td>
<td>~3</td>
<td></td>
<td>3 GW</td>
</tr>
<tr>
<td></td>
<td>Pulse Mode</td>
<td>---</td>
<td>Single</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulse Length</td>
<td>ps</td>
<td>2</td>
<td></td>
<td>2 ps</td>
</tr>
<tr>
<td></td>
<td>Pulse Energy</td>
<td>mJ</td>
<td>6</td>
<td></td>
<td>6 mJ</td>
</tr>
<tr>
<td></td>
<td>M²</td>
<td>---</td>
<td>~1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repetition Rate</td>
<td>Hz</td>
<td>1.5</td>
<td>3 Hz also available if needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polarization</td>
<td>---</td>
<td>Linear</td>
<td>Circular polarization available at slightly reduced power</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂ CPA Beam</strong></td>
<td>Wavelength</td>
<td>μm</td>
<td>9.2</td>
<td>Wavelength determined by mixed isotope gain media</td>
<td>9.2 μm</td>
</tr>
<tr>
<td></td>
<td>Peak Power</td>
<td>TW</td>
<td>2</td>
<td>~5 TW operation is planned for FY21 (requires further in-vacuum transport upgrade). A 3-year development effort to achieve &gt;10 TW and deliver to users is in progress.</td>
<td>0.5 – 2 TW</td>
</tr>
<tr>
<td></td>
<td>Pulse Mode</td>
<td>---</td>
<td>Single</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulse Energy</td>
<td>J</td>
<td>~5</td>
<td>Maximum pulse energies of &gt;10 J will become available in FY20</td>
<td>1-5 J</td>
</tr>
<tr>
<td></td>
<td>M²</td>
<td>---</td>
<td>~2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repetition Rate</td>
<td>Hz</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polarization</td>
<td>Linear</td>
<td></td>
<td>Adjustable linear polarization along with circular</td>
<td></td>
</tr>
</tbody>
</table>

*Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.*
Special Equipment Requirements and Hazards

• Electron Beam
  • plasma capillary discharge system
### Experimental Time Request

#### CY2021 Time Request

<table>
<thead>
<tr>
<th>Capability</th>
<th>Setup Hours</th>
<th>Running Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Beam Only</td>
<td>24</td>
<td>80</td>
</tr>
<tr>
<td>Laser* Only (in Laser Rooms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser(s)* + Electron Beam</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Time Estimate for Remaining Years of Experiment (including CY2021)

<table>
<thead>
<tr>
<th>Capability</th>
<th>Setup Hours</th>
<th>Running Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Beam Only</td>
<td>Good for year 1 (but pre-amp CO2 level would be very useful)</td>
<td></td>
</tr>
<tr>
<td>Laser* Only (in FEL Room)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser(s)* + Electron Beam</td>
<td>80</td>
<td>300</td>
</tr>
</tbody>
</table>

* Laser = Near-IR or LWIR (CO₂) Laser