Multi-pass CO$_2$ laser cavity for high repetition pulse trains

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Motivations

- Polarized positron source for International Linear Collider (ILC)

- Polarized muon beams produced through gamma conversion will compete in brightness and energy efficiency with conventional proton-based sources.

- Multi-kW $\gamma$-sources conceivable based on state-of-art CO$_2$ lasers and energy recovery linacs for rare isotope photofission, transmutation of used nuclear fuel, polarized positron sources for $e^+e^-$ colliders, etc.

- A path to compact pico- and femto-second light sources of the peak and average brightness of the order $10^{25}$ and $10^{17}$ (s mm$^2$ mrad$^2$ 0.1%)$^{-1}$ correspondingly - the orders of magnitude higher than modern light sources.
Prior art: Thomson scattering experiments in ATF

• Started as US/Japan collaboration for ILC positron source
• Record brightness and efficiency were demonstrated
• X-ray source is being used for user experiments to test applicability for material science
• Collaboration with UCLA/Italy brought equipment from ESRF

Commercially available lasers

**SOPRA (France)**

- Pressure: 5 atm
- Beam Size: 50 x 50 mm²
- Repetition Rate: 100 Hz
- Pulse Energy: 10 J
- Average Power: 1 kW
- Ionization: x-ray

**SDI (South Africa)**

- Pressure: 10 atm
- Beam Size: 13 x 13 mm²
- Repetition Rate: up to 500 Hz
- Pulse Energy: 1.5 J
- Average Power: 750 W
- Ionization: UV
Laser specs for ILC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Pulse repetition rate</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Bunches per pulse</td>
<td>100</td>
</tr>
<tr>
<td>Bunch Spacing</td>
<td>12 ns</td>
</tr>
<tr>
<td>Laser Wavelength</td>
<td>10 µm</td>
</tr>
<tr>
<td>Laser energy</td>
<td>1 J</td>
</tr>
<tr>
<td>Size at focus</td>
<td>40 µm</td>
</tr>
<tr>
<td>Laser pulse length</td>
<td>5 ps</td>
</tr>
<tr>
<td>E-beam energy</td>
<td>6 GeV</td>
</tr>
<tr>
<td>e-bunch</td>
<td>10 nC</td>
</tr>
<tr>
<td>Number of γ per electron</td>
<td>1 (per IP)</td>
</tr>
<tr>
<td>γ-beam energy</td>
<td>40 MeV</td>
</tr>
<tr>
<td>Number of lasers</td>
<td>5</td>
</tr>
<tr>
<td>e⁺ yield on target</td>
<td>2 %</td>
</tr>
<tr>
<td>e⁺ bunch</td>
<td>1 nC</td>
</tr>
</tbody>
</table>

- Requires: 15 kHz, 15 kW, picosecond, sub-terawatt CO₂ laser.

- This exceeds capabilities of laser technology by 1-2 orders of magnitude.

- Instead, we propose to reuse laser energy by circulating the pulse inside the laser amplifier cavity that incorporates Compton interaction point (IP).
Polarized positron source: the concept

- A picosecond $\text{CO}_2$ laser pulse circulates in a ring cavity

- At each pass through the cavity the laser pulse interacts with a counter-propagating electron pulse generating $\gamma$-quanta via Compton scattering

- Optical losses are compensated by intracavity amplifier

- The $\lambda$-proportional number of photons per Joule of laser energy allows for higher $\gamma$-yield (compared to solid state lasers)
Polarized positron source for ILC, CLIC, Super B

Conventional Non-Polarized Positrons:

Polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO₂ laser beam and 6 GeV e-beam produced by linac.

First tests of the laser cavity
Pulse splitting problem

Case shown:
Pulse length: 5 ps (fwhm)
Gas pressure: 7.5 atm
Branch: 10P (10.6 μm)
Amplification: 1000x
Computer simulations: multipass dynamics

- **Pressure:** 5 atm
- **Pulse energy:** 1 J
- **Pulse length:** 5 ps (fwhm)
- **Roundtrip time:** 12 ns
- **Wavelength:** 10.2 μm (R-br.)
- **Optical losses:** 5% / pass
- **Gas mixture:** 0.5 : 3 : 6.5
- **Isotopes:** \([\text{O}^{16}] : [\text{O}^{18}] = 0.8 : 1\)
Test I: Pulse injection through a holed mirror

**CO₂ amplifier**  
(double pass configuration)

- CO₂ pulse injection
- Vacuum cell
- Parabolic mirrors
- ~5mm dia. holes
- Photo diode

![Graph showing signal vs. time for different aperture diameters and their corresponding experiment and simulation results.](image)
Test II: Pulse injection using a semiconductor switch

Demonstrated:
- Multipass picosecond CO_2 laser pulse amplification and energy sustain
- Pulse injection via semiconductor switch
- Qualitative agreement between experiment and computer simulations
Summary and conclusions

- Concept of CO$_2$ laser based high-repetition rate $\gamma$-source is developed and tested
- Preferred regimes of picosecond pulse amplification in multipass cavity are determined using a newly developed simulation software
- Advantage of isotopic CO$_2$ mixture is demonstrated in computer simulations
- Qualitative agreement between proof-of-principle experiment results and computer simulations is achieved