Simulation of Laserwire in BDS

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Laser-Wire MiniWorkshop
Lausanne
LWS as CLIC diagnostic

Beam emittance diagnostics:

• needed by physics experiments
• evaluate performance
• commissioning lattice – “emittance bumps”

LWS is non-destructive (small total cross section)

• relative number of electrons intersecting laser beam
• transverse density scan if small enough laser width
• does not directly measure beam angles

Concerns about background and statistical noise
Thomson scatter

In electron rest frame, photon is upshifted by $\gamma_0$, so $\nu' \approx \gamma_0 \nu_0$

(or $2 \gamma_0$ if originally antiparallel)

If photon energy is still less than electron rest mass, nearly elastic collision, with scattering angle distribution (in rest frame)

$$\frac{d\sigma}{d\Omega} \propto 1 + \cos^2 \theta$$

Photons which are nearly backscattered then get upshifted by another factor of $2 \gamma_0$ when go back to lab frame

Scattered frequencies as high as $2 \gamma_0^2 \times$ initial frequency

- with angles $< 1 / \gamma_0$ (much smaller deflection for electrons)
- still a small fraction of electron energy
Compton Scatter

Define $\xi = h\nu' / m_e c^2$, where $\nu'$ is the laser frequency in the electron rest frame – key parameter for behavior.

When $\xi > 1$, can’t ignore energy exchange in electron rest frame.

Net result:

- the photon can acquire most of the electron’s energy
- final electron energy is at least $m_e^2 c^4 / 2 h\nu_0$, so final $\gamma > \gamma_0 / 2 \xi$
- typical angle of photon, maximum angle of electron

$$\sim \xi / \gamma_0 \approx h\nu_0 / m_e c^2$$

electrons with largest angle have energy $\sim \gamma_0 m_e c^2 / \xi$
Scaling for LWS signal

Main demands for LWS: large signal, good resolution

electron beam params: $\varepsilon_X, \varepsilon_Y, \sigma_X, \sigma_Y, \tau_B$, charge -- only control size

laser: peak power $P_L$, $\sigma_L$, $\tau_L$, $\lambda$

look at measuring Y profile:

need $\lambda < \sigma_L < \sigma_Y$ and $\sigma_Y / \sigma_X > \lambda / 2 \pi \sigma_L = \text{angle of laser cone}$

number of scatters $\propto N_e P_L (\lambda / \sigma_Y) [\tau_L / (\tau_L^2 + \tau_B^2)^{1/2}] (\lambda / E_B)$

take as large $\lambda, \tau_L$ as acceptable

want large $\xi = h\nu'/m_ec^2 = 5 E_B[\text{TeV}] / \lambda[\mu\text{m}]$

For higher energies, need more laser power for same signal.
CLIC parameters:

electrons: 0.67 nC per bunch

20 µ spot size, 20 x 680 nm normalized emittance

energy 1.5 TeV, typical angle 0.3 – 11 nrad

laser: 0.25 µ wavelength, 5 µ width, 1 mJ per pulse

0.12 ps matches 35 µm bunch length

scatter params: \( \frac{h \nu_0}{m_e c^2} \approx 10^{-5} \quad \xi_0 \approx 30 \)

diagnostics: gas detector, signal is from low energy electrons

A) strong sextupoles at 20 + 40 m; B) long 100 gauss dipole field

roughly \textbf{3000} scattering events per pulse
The diagrams illustrate the energy flux and number of particles in relation to angular steps for photon and electron interactions. The energy flux is plotted against angular (in radians) and the number of particles is plotted against the same angular steps. The diagrams are labeled with the number of QED steps and show distinct peaks and valleys that indicate the behavior of these interactions at different energy flux levels. The data suggest a significant difference in the energy flux between photon and electron interactions, with the photon interactions showing a more pronounced peak at certain angular steps.
CLIC – using sextupoles

degraded electrons (using sextupoles)

- Energy (left)
- Photon Energy (left)
- Number (right)
- Photon Number (right)
CLIC – using dipoles
note: beampipe is straight
degraded electrons (using dipoles)
CLIC Results

Degraded electrons can be swept out of the beam by magnetic fields.

Short Sextupoles:

peak has 15% of scattered electrons, but less peaked in energy

feasibility will depend on detection method, lattice design

Long Dipoles:

simple design works well

signal is similar to secondaries produced by lost TeV particles

Background estimate, 1 TeV particle / meter hitting pipe – reasonable?

Measure photons? Harder to separate from halo and SR
CLIC Simulations

GEANT4 results, for GeV deposited in detector

- with 1 halo electron hitting beampipe per meter (very clean beam).
- corr to time-average of 3.7 mW per meter, for CLIC timing

<table>
<thead>
<tr>
<th>System</th>
<th>Signal</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>sextupoles, shielded Pb detector</td>
<td>65</td>
<td>120</td>
</tr>
<tr>
<td>sextupoles, shielded gas detector</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>dipole, unshielded gas detector</td>
<td>0.78</td>
<td>0.05</td>
</tr>
<tr>
<td>dipole, 500 GeV beam</td>
<td>1.8</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Noise caused by spray of secondaries from (mostly local?) losses

For sextupoles, have large bending angles, maybe can separate signal from background based on direction.
graph obtained from G. Blair
## Laser Parameters

Design parameters compared with currently available lasers:

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Nd:YAG</th>
<th>Ti:Sapphire</th>
</tr>
</thead>
<tbody>
<tr>
<td>wavelength</td>
<td>250 nm</td>
<td>266 nm</td>
<td>800 nm</td>
</tr>
<tr>
<td>bunch length (FWHM)</td>
<td>150 fs</td>
<td>3 ns</td>
<td>50 fs</td>
</tr>
<tr>
<td>energy per pulse</td>
<td>1 mJ</td>
<td>200 mJ</td>
<td>0.7 mJ</td>
</tr>
<tr>
<td>rep rate</td>
<td>100 Hz</td>
<td>10 Hz</td>
<td>1 kHz</td>
</tr>
<tr>
<td>energy fluct</td>
<td>?</td>
<td>8 %</td>
<td>1 %</td>
</tr>
<tr>
<td>peak power</td>
<td>5 GW</td>
<td>0.05 GW</td>
<td>1 GW after triple?</td>
</tr>
<tr>
<td>eff. overlap energy</td>
<td>1 mJ (by def)</td>
<td>0.1 mJ*</td>
<td>0.2 mJ</td>
</tr>
</tbody>
</table>

*enhanced by overlap with multiple bunches in pulse train*
Simulation Goals:

For further research and GEANT4 simulations:

- collimation and other noise reduction
- optimize detector design for degraded electrons
- fit more carefully into beam delivery system (BDS) design
- look into enlarging beam cross-section, if necessary
- study sources of background: characterize beam halo, losses
- second look at photons