Beam Dynamics study in Linear Colliders

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Drive beam - 100 A, 240 ns from 2.4 GeV to 240 MeV

Main beam – 1 A, 156 ns from 9 GeV to 1.5 TeV

12 GHz – 140 MW
Outlines

- Introduction of CLIC
- Introduction of CLIC Test Facility
- Beam-halo and tail particles generation
  - Beam Delivery System *(CLIC, ILC)*
  - Linear Accelerator *(CLIC, ILC)*
  - Drive Beam *(CLIC)*
  - CTF3 Test Beam Line
- Post Collision Line
World-wide CLIC / CTF3 collaboration

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm
24 members representing 27 institutes involving 17 funding agencies of 15 countries
Major Parameters for Linear Collider

Energy reach

\[ E_{cm} = 2 F_{\text{fill}} L_{\text{linac}} G_{RF} \]

Luminosity

\[ L = \frac{k_b N_b^2 f_{\text{rep}}}{4 \pi \sigma_x^* \sigma_y^*} \alpha \frac{\delta_B^{1/2}}{E_{cm} \epsilon_{\text{HV}}^{1/2}} \]
CLIC – Basic Features

- High acceleration gradient: > 100 MV/m
  - “Compact” collider – total length < 50 km at 3 TeV
  - Normal conducting acceleration structures at high frequency
  - Novel Two-Beam Acceleration Scheme
    - Cost effective, reliable, efficient
    - Simple tunnel, no active elements
    - Modular, easy energy upgrade in stages

Main beam – 1 A, 156 ns from 9 GeV to 1.5 TeV
100 MV/m

Drive beam - 95 A, 240 ns from 2.4 GeV to 240 MeV

4.5 m diameter
CLIC vs ILC

**ILC**
- Based on superconducting RF cavities
- Gradient 32 MV/m
- **Energy: 500 GeV, upgradeable to 1 TeV**
  (possible GigaZ factory at 90 GeV or ZZ factory at ~200 GeV is also considered)
- Detector studies focus mostly on 500 GeV

**CLIC**
- Based on 2-beam acceleration scheme
  (warm cavities)
- Gradient 100 MV/m
- **Energy: 3 TeV**, though will probably start at lower energy (~0.5 TeV)
- Detector study focuses on 3 TeV

Technology available

Feasibility demonstrated in 2009
# Collider Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>3 TeV</th>
<th>1 TeV</th>
<th>0.5 TeV</th>
<th>ILC</th>
<th>Unit</th>
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<tr>
<td>Center of mass energy</td>
<td>$E_{cm}$</td>
<td>3000</td>
<td>1000</td>
<td>500</td>
<td>500</td>
<td>GeV</td>
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<tr>
<td>Main Linac RF Frequency</td>
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<td>12</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>GHz</td>
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<tr>
<td>Luminosity</td>
<td>$L$</td>
<td>7</td>
<td>2.25</td>
<td>2.24</td>
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<td>$10^{44} \text{ cm}^{-2} \text{ s}^{-1}$</td>
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<td>Luminosity (in 1% of energy)</td>
<td>$L_{99%}$</td>
<td>2</td>
<td>1.08</td>
<td>1.36</td>
<td></td>
<td>$10^{44} \text{ cm}^{-2} \text{ s}^{-1}$</td>
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<td>Linac repetition rate</td>
<td>$f_{rep}$</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>5</td>
<td>Hz</td>
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<tr>
<td>No. of particles / bunch</td>
<td>$N_{0}$</td>
<td>3.72</td>
<td>3.72</td>
<td>3.72</td>
<td>20</td>
<td>$10^9$</td>
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<tr>
<td>No. of bunches / pulse</td>
<td>$N_{b}$</td>
<td>312</td>
<td>312</td>
<td>312</td>
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<td>$10^9$</td>
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<tr>
<td>No. of drive beam sectors / linac</td>
<td>$N_{s}$</td>
<td>24</td>
<td>8</td>
<td>4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Overall two linac length</td>
<td>$l_{total}$</td>
<td>41.7</td>
<td>13.9</td>
<td>6.9</td>
<td>22</td>
<td>km</td>
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<tr>
<td>Proposed site length</td>
<td>$l_{2}$</td>
<td>47.9</td>
<td>20.1</td>
<td>13.2</td>
<td>31</td>
<td>km</td>
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<tr>
<td>DB Pulse length (total train)</td>
<td>$\tau_{l}$</td>
<td>139</td>
<td>46</td>
<td>23</td>
<td>-</td>
<td>$\mu$s</td>
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<td>Beam power / beam</td>
<td>$P_{b}$</td>
<td>14</td>
<td>4.6</td>
<td>4.6</td>
<td>10.8</td>
<td>MW</td>
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<tr>
<td>Wall-plug power to beam efficiency</td>
<td>$\eta_{WRF}$</td>
<td>8.7</td>
<td>6.1</td>
<td>6.1</td>
<td>9.4</td>
<td>%</td>
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<tr>
<td>Total site AC power</td>
<td>$P_{tot}$</td>
<td>322</td>
<td>~150</td>
<td>~150</td>
<td>230</td>
<td>MW</td>
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<tr>
<td>Transverse horizontal emittance</td>
<td>$\gamma_{x}$</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>8000</td>
<td>nm rad</td>
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<tr>
<td>Transverse vertical emittance</td>
<td>$\gamma_{y}$</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>nm rad</td>
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<tr>
<td>Horizontal IP beam size before pinch</td>
<td>$\sigma'_{x}$</td>
<td>40</td>
<td></td>
<td>142</td>
<td>640</td>
<td>nm</td>
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<tr>
<td>Vertical IP beam size before pinch</td>
<td>$\sigma'_{y}$</td>
<td>1</td>
<td>2</td>
<td>5.7</td>
<td></td>
<td>nm</td>
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<tr>
<td>Beamstrahlung energy loss</td>
<td>$\delta_{g}$</td>
<td>29</td>
<td>11</td>
<td>7</td>
<td>2.4</td>
<td>%</td>
</tr>
</tbody>
</table>
Demonstrate remaining CLIC feasibility issues, in particular:

- **Drive Beam generation** (fully loaded acceleration, bunch frequency multiplication)
- **CLIC accelerating structures**
- **CLIC power production structures** (PETS)
Beam-Generated Halo and Tail

- **Halo** particles contribute very little to the luminosity but may instead be a major source of *background* and radiation.
- Even if most of the halo will be stopped by collimators, the *secondary muon background* may still be significant.
- Halo and tail considerations are needed for design studies to allow to estimate and minimise any potential performance limitations from this source.
- Provides analytical estimates + package with code and interface for detailed tracking with samples and application to CLIC (+ ILC within EuroTeV)

**CLIC** : HTGEN as standard component of PLACET
Halo and Tail Sources

Particle processes:
- Beam-gas scattering (elastic, inelastic)
- Synchrotron radiation (coherent/incoherent)
- Scattering off thermal photons
- Ion/electron cloud effects
- Intrabeam scattering
- Touschek scattering

Optics related: Halo modeling
- Mismatch
- Coupling
- Dispersion
- Non-linearities

Various (equipment related, collective)
- Noise and vibration
- Dark currents
- Space charge effects close to source
- Wake fields
- Beam loading
- Spoiler scattering
Beam-Gas Scattering

\[ \sigma_{\text{Mott}} \approx \frac{2\pi Z^2 r_e^2}{\gamma^2 (1 - \cos \theta_{\text{min}})} , \theta_{\text{min}} > 10^{-6} \text{ rad} \]

\[ \sigma_{\text{Mott}} \approx \frac{4\pi Z^2 r_e^2}{\gamma^2 \theta_{\text{min}}^2} , \theta_{\text{min}} < 10^{-6} \text{ rad} \]

\[ \theta_{\text{min}} = \sqrt{\frac{\varepsilon}{\beta}} \]

\[ \sigma_{\text{Brem}} = \frac{A}{N_A X_0} \left( -\frac{4}{3} \ln k_{\text{min}} - \frac{5}{6} + \frac{4}{3} k_{\text{min}} - \frac{k_{\text{min}}^2}{2} \right) \]

where, \[ X_0 = \frac{716.4A}{Z(Z+1) \ln(287\sqrt{Z})} \text{ [g/cm}^2\text{]} \]

\[ \lambda_{\text{int}} = \frac{1}{n.N_{\text{bunch}} \sigma} \]

\[ S = P \cdot l \]

\[ p = n \cdot k_B \cdot T \]
Beam Delivery System (BDS)

Collimation System

- Reduce the background by removing particles at large betatron amplitudes (Halo) or energy Offsets.
- The choice of the collimator apertures should guarantee good cleaning efficiency of Halo.
- To avoid wakefields that might degrade the orbit stability.

Final Focus System

- Need to provide a very strong focusing.
- Reduces the transverse sizes of the beam at the IP sufficiently to provide the required luminosity
- The correction of chromatic and geometric aberrations.

BDS Purpose: Reduce the beam sizes to nanometer sizes to produce the luminosity
Equation of Motion

\[ x''(s) - k(s)x(s) = 0 \quad \text{Hills equation} \]

\[ x(s) = \sqrt{\varepsilon} \sqrt{\beta(s)} \cdot \cos(\psi(s) + \phi) \quad \text{General solution} \]

(1) \quad x(s) = \sqrt{\varepsilon} \sqrt{\beta(s)} \cos(\psi(s) + \phi)

(2) \quad x'(s) = -\frac{\sqrt{\varepsilon}}{\sqrt{\beta(s)}} \left\{ \alpha(s) \cos(\psi(s) + \phi) + \sin(\psi(s) + \phi) \right\}

\[ \varepsilon = \gamma(s) x^2(s) + 2\alpha(s)x(s)x'(s) + \beta(s)x'(s)^2 \]

Twiss Parameters

\[ \alpha(s) = \frac{-1}{2} \beta'(s) \]
\[ \gamma(s) = \frac{1 + \alpha(s)^2}{\beta(s)} \]

Dispersion Function

\[ x'' + x\left(\frac{1}{\rho^2} - k\right) = \frac{\Delta p}{p} \cdot \frac{1}{\rho} \]

general solution:

\[ x(s) = x_h(s) + x_i(s) \]

Phase Advance:

\[ \psi(s) = \int_0^s \frac{ds}{\beta(s)} \]

Tune:

\[ Q_y = \frac{1}{2\pi} \int \frac{ds}{\beta(s)} \]

Chromaticity:

\[ \xi = \frac{-1}{4\pi} \int K(s) \beta(s) \, ds \]
### CLIC BDS Optics

#### Entrance Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_x$</td>
<td>64.171 m</td>
</tr>
<tr>
<td>$\alpha_x$</td>
<td>-1.95133</td>
</tr>
<tr>
<td>$\beta_y$</td>
<td>18.2438 m</td>
</tr>
<tr>
<td>$\alpha_y$</td>
<td>0.605865</td>
</tr>
<tr>
<td>$\beta_x^*$</td>
<td>7 mm</td>
</tr>
<tr>
<td>$\alpha_x^*$</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_y^*$</td>
<td>90 $\mu$m</td>
</tr>
<tr>
<td>$\alpha_y^*$</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Energy:** 1.5 TeV
- **$\gamma_{\varepsilon_x}$:** 680 nm
- **$\gamma_{\varepsilon_y}$:** 10 nm

![Diagram of CLIC BDS Optics](image)

- $\beta_x = 7$ mm and $\beta_y = 0.09$ mm
- $\gamma_{\varepsilon_x} = 680$ nm
- $\gamma_{\varepsilon_y} = 10$ nm
Simulation : Model of the Beam

If a lattice is linear then particle representation:

$$\sum \equiv \begin{bmatrix}
\sigma'_{x,i} \sigma_{x,i} & \sigma'_{x,i} \sigma_{x,i} & \sigma'_{x,i} \sigma_{y,i} & \sigma'_{x,i} \sigma_{y,i} \\
\sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{y,i} & \sigma'_{y,i} \sigma_{y,i} \\
\sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{y,i} & \sigma'_{y,i} \sigma_{y,i} \\
\sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{x,i} & \sigma'_{y,i} \sigma_{y,i} & \sigma'_{y,i} \sigma_{y,i}
\end{bmatrix}$$

Beam Matrix of pulse representation:

$$\sum \equiv \begin{bmatrix}
\sum_{xx} & \sum_{xx'} & \sum_{xy} & \sum_{xy'} \\
\sum_{x'x} & \sum_{x'x'} & \sum_{x'y} & \sum_{x'y'} \\
\sum_{yx} & \sum_{yx'} & \sum_{yy} & \sum_{yy'} \\
\sum{y'x} & \sum{y'x'} & \sum{y'y} & \sum{y'y'}
\end{bmatrix}$$

Models of the Elements: Quadrupoles, Drifts, BPMs, Dipoles, RF, Dec. Structures
Beam Tracking in BDS (1)

Beam-Entrance Profile in BDS
Beam Tracking in BDS (2)

Beam Profile at IP
Beam Tracking in BDS (3)

Collimations region

Final Focus

Halo—particles with large betatron amplitudes or with large energy off-sets

Total no. of elements  637
No. of slices  31
No. of macroparticles 100
Energy  1496 GeV
Charge  4 nC
Emitt. along x-axis 680 μrad
Emitt. Along y-axis  10 μrad
Normal temperature
Residual gas N₂
Lattice with no collimators

Large beta + alignment errors resulting in dispersion

Longitudinal coordinate
Beam Tracking in BDS (4)

Constant pressure

- Halo > 102μm = 30%
- Halo > 1 mm = ~ 3%
- Halo > 10 mm = ~ 0.5%

Diagram showing octupole octupole collimator+collimator+ spoilers with percentages 3.1% and 10%.
Halo Estimation using Collimation Depth

Only 17% of halo particles are outside the window in case of final quad is super conducting final magnet. 25 $\sigma_x$ and 80 $\sigma_y$.

Only 4.5% particles are outside the selected window in case of final quad is permanent magnet. 400 $\sigma_x$ and 1000 $\sigma_y$.

Bremsstrahlung ➔ energy loss

$\frac{dp}{p} [%]$
Integrated over the Linac, the probability for Mott scattering is then $1.16 \times 10^{-3}$.

The total probability for the 2.75 km long BDS is $6.02 \times 10^{-5}$.

For the sum of LINAC and BDS we get a scattering probability of $1.2 \times 10^{-3}$.

The probability for inelastic scattering with a fractional energy loss $K_{\text{min}} > 0.01$ is much smaller, about $2.1 \times 10^{-13}$ m both in the LINAC and BDS.

Summing up over the full length, we get a probability for inelastic scattering for the combined LINAC and BDS system of $5 \times 10^{-9}$.

A fraction of about $2 \times 10^{-4}$ of all particles will have large amplitudes and hit the spoilers in the BDS.

With $1.24 \times 10^{12}$ particles per train, this would translate into a flux of $2.4 \times 10^{8}$ particles per train impacting on the spoiler.

At 1.5 TeV, we expect that a fraction of about $9 \times 10^{-4}$ of these particles produce secondary muons, resulting in a flux of about $2 \times 10^{-5}$ muons per train.
The probability for elastic scattering at the beginning of the LINAC is about 50 times higher.

The elastic scattering probability in whole LINAC is $9 \times 10^{-3}$.

Only a fraction of these will hit spoilers or the beam pipe.

The probability integrated over LINAC with angles exceeding 30 times the beam vertical divergence is $10^{-5}$.

Integrated probability over BDS is $5 \times 10^{-7}$.

The probability for inelastic scattering with a fractional energy loss $k_{\text{min}} > 0.01$ is small, $1.8 \times 10^{-12}/\text{m}$ in the LINAC and rather similar, $1.0 \times 10^{-12}/\text{m}$ in the BDS.

Sum of LINAC and BDS inelastic scattering of $2.3 \times 10^{-8}$.

The probability of thermal scattering is still much smaller, about $9 \times 10^{-11}$ for the BDS and completely negligible for the LINAC.

The beam-gas scattering from the LINAC and BDS combined results in a fraction of $10^{-4}$ of the particles impacting on the spoilers.

For the nominal intensity of $2 \times 10^{10}$ particles per bunch and 2820 bunches, we expect that $6 \times 10^9$ particles hit the spoilers at each train crossing.

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$e_{N,y,\text{initial}}$</td>
<td>nm</td>
<td>20.0</td>
</tr>
<tr>
<td>$\beta y$</td>
<td>m</td>
<td>100</td>
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<tr>
<td>Residual gas (BDS)</td>
<td></td>
<td>N2</td>
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<tr>
<td>Residual gas (LINAC)</td>
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<td>He</td>
</tr>
<tr>
<td>Temperature (BDS)</td>
<td>K</td>
<td>300</td>
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<td>Temperature (LINAC)</td>
<td>K</td>
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<tr>
<td>Pressure (BDS)</td>
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<td>50</td>
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<tr>
<td>Pressure (LINAC)</td>
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<tr>
<td>$k_{\text{min}}$</td>
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<td>0.01</td>
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### Table of Gas Properties

<table>
<thead>
<tr>
<th>Location</th>
<th>$E_{\text{GeV}}$</th>
<th>Gas</th>
<th>$\rho$ $\text{m}^{-3}$</th>
<th>$\sigma_{\text{el}}$ $\text{Barn}$</th>
<th>$P$ $\text{m}^{-1}$</th>
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<tr>
<td>LINAC</td>
<td>5</td>
<td>He</td>
<td>$4.8 \times 10^{16}$</td>
<td>$2.0 \times 10^6$</td>
<td>$9.9 \times 10^{-6}$</td>
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<tr>
<td>LINAC</td>
<td>250</td>
<td>He</td>
<td>$4.8 \times 10^{16}$</td>
<td>$3.8 \times 10^4$</td>
<td>$1.8 \times 10^{-7}$</td>
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<tr>
<td>BDS</td>
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<td>N2</td>
<td>$1.6 \times 10^{15}$</td>
<td>$4.6 \times 10^{-5}$</td>
<td>$1.5 \times 10^{-7}$</td>
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</table>
Analytical Estimates and Simulations for ILC BDS

Horizontal (top) and vertical (bottom) beam positions as function of the longitudinal coordinate $s$ in the BDS

Transverse beam profiles at BDS entrance
## CLIC Drive Beam Tracking (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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</thead>
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<tr>
<td>Drive beam sector length</td>
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</tr>
<tr>
<td>numb. of part. per bunch</td>
<td>$10^9$</td>
<td>52.5</td>
</tr>
<tr>
<td>numb. of bunches per train</td>
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<td>2928</td>
</tr>
<tr>
<td>mean initial beam energy</td>
<td>GeV</td>
<td>2.40</td>
</tr>
<tr>
<td>mean final beam energy</td>
<td>GeV</td>
<td>0.40</td>
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<tr>
<td>$\varepsilon_{N,y,\text{initial}}$</td>
<td>mm</td>
<td>150.0</td>
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<tr>
<td>$\varepsilon_{N,y,\text{final}}$</td>
<td>mm</td>
<td>334</td>
</tr>
<tr>
<td>Residual gas mixture</td>
<td></td>
<td>40% H2O, 40% H2, 20% (CO, N2, CO2)</td>
</tr>
<tr>
<td>Temperature</td>
<td>K</td>
<td>300</td>
</tr>
<tr>
<td>Pressure</td>
<td>nTorr</td>
<td>10</td>
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<tr>
<td>Beam divergence</td>
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<tr>
<td>$K_{\text{min}}$</td>
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<td>0.01</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>$\rho$ [$m^{-3}$]</th>
<th>$P_{\text{init}}$ [$m^{-1}$]</th>
<th>$P_{\text{final}}$ [$m^{-1}$]</th>
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<tbody>
<tr>
<td>Mott</td>
<td>$3.22\times10^{14}$</td>
<td>$7.96\times10^{-12}$</td>
<td>$4.21\times10^{-11}$</td>
</tr>
<tr>
<td>Brems.</td>
<td>$3.22\times10^{14}$</td>
<td>$1.11\times10^{-13}$</td>
<td>$1.11\times10^{-13}$</td>
</tr>
<tr>
<td>Comp.</td>
<td>$5.45\times10^{14}$</td>
<td>$3.63\times10^{-14}$</td>
<td>$3.63\times10^{-14}$</td>
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</tbody>
</table>
CLIC Drive Beam Tracking (2)

Mott scattering

- Same pressure
- Higher energy

Bremsstrahlung

- Smaller angles important
Energy spread caused by Compton scattering stays below 0.25%.

Total scattering probability integrated over the whole decelerator is $7.69 \times 10^{-9}$.

Effect of ionization of residual gas shows that the ionization level stays below 3%. So no need of model extension.

The total number of intra beam scattering events per unit time scales with $1/\beta^4$ and increases with particle density which shows that intra beam as well as Touschek become more relevant with low energy beams and small beam size.

Sliced beam model and particle beam model.

Particle is considered to be lost if amplitude exceeds the aperture of element.

Small fraction of $10^{-7}$ particles is lost.
Test Beam Line (CTF3)

Lattice units for Simulation
16 of FODO cells PETS (Coupler as drift) Quadrupole BPM
Maximum beam energy = 0.150 GeV
Lorentz factor ($\gamma$) = 293.543
Velocity ($\beta$) = 0.999994
Normalized emittance $\varepsilon_N = \varepsilon_{x,y,N} = 150$ mrad
Geometric emittance $\varepsilon = \varepsilon_N / (\beta \gamma) = 0.511001$ mrad
Beta Functions $\beta_x = 0.827, \quad \beta_y = 4.72 m$

$$\theta_{\min} = \sqrt{\varepsilon / \beta}$$
$$\theta_x = \sqrt{(\varepsilon_x / \beta_x)} = 0.786 mrad$$
$$\theta_y = \sqrt{(\varepsilon_y / \beta_y)} = 0.329 mrad$$
Drive Beam Halo: CTF3-TBL

<table>
<thead>
<tr>
<th>Location</th>
<th>E (GeV)</th>
<th>Gas</th>
<th>$\sigma_{el}$ (Barn)</th>
<th>$\sigma_{in}$ (Barn)</th>
<th>$P_{el}$ (m$^{-1}$)</th>
<th>$P_{in}$ (m$^{-1}$)</th>
<th>$\Theta_{min}$ (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTF3-TBL</td>
<td>0.150</td>
<td>$N_2$</td>
<td>5242</td>
<td>5.5117</td>
<td>3.37e-10</td>
<td>1.77e-13</td>
<td>329</td>
</tr>
</tbody>
</table>
Radiated photons have rather broad energy spectrum and around 20 times large angle than scattered electrons.
Drive Beam Halo: CTF3-TBL Tracking

Steady State power extraction efficiency = \( \frac{E_{\text{in}}}{E_{\text{out}}} \)

Beam core deceleration

HTGEN+PLACET application to low energy CLIC drive beam, started potential for benchmarking - CTF3
Halo Flux Estimate: CTF3-TBL

- $\text{electrons/bunch} = 1.4575 \times 10^{10}$
- $\text{Probability} = 3.37 \times 10^{-10} / \text{m}$
- $\text{Probability in CLIC TBL Drive beam} = 7.41 \times 10^{-9}$
- $\text{Halo/bunch} = 1.08 \times 10^2$
Halo Acceleration in Linac (1)

LINAC Beamline

- Full Tracking
- Temperature 300 K
- Pressure 10 ntorr
- Scattering angle 10 nrad
- Residual Gas

- Standard PLACET lattice
- Total no. of elements 54068
  - No. of Quad. 1324
  - No. of BPMs 1324
- No. of slices 31
- No. of macroparticles 100
- Linac injection energy 9.0 GeV
- Charge 4 nC
- Emitt. along x-axis 680 nrad
- Emitt. Along y-axis 10 nrad

Energy of the halo particles is increasing almost linearly during passing through the accelerating structures of the LINAC.
Halo Acceleration in Linac (2)
CLIC Post Collision Line

Benchmarking study between DIMAD and PLACET codes with 20 mrad post collision line
Overview (1)

• **Comparison between two contemporary codes: DIMAD and PLACET.**
• **CLIC post collision line for benchmarking purpose.**
• **We consider current 20mrad extraction line of CLIC**
• **Tracking performed using**
  • 4-particles tracking with different energy deviation.
  • 1K particles
  • Heavily disrupted post collision electrons beam
• Lattice conversion from DIMAD→MAD-X→PLACET format
• Rotation of beam axes from horizontal to vertical is performed by tilt option inside the sector bend at right angle.
• Few wrong units are corrected:
  • Modification in extraction line lattice
    - Aperture sizes are corrected
    - Removal of aperture constraints from drifts
    - Implementation of aperture constraints on four collimators as well.
• Disrupted beam as DIMAD input
• Tracking performed with PLACET from IP to dump.
Transportation of spent beams and the beamsstrahlung photons from the interaction point to their dumps, with as small losses as possible.
# Extraction Line Lattice

Table 1: First set of four magnets, starting 20 m from the interaction point.

<table>
<thead>
<tr>
<th></th>
<th>Magnet 1</th>
<th>Magnet 2</th>
<th>Magnet 3</th>
<th>Magnet 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>4.000</td>
<td>4.000</td>
<td>4.000</td>
<td>4.000</td>
</tr>
<tr>
<td>Width (m)</td>
<td>0.414</td>
<td>0.682</td>
<td>0.946</td>
<td>1.208</td>
</tr>
<tr>
<td>Height (m)</td>
<td>0.833</td>
<td>1.451</td>
<td>2.065</td>
<td>2.677</td>
</tr>
<tr>
<td>Gap width (m)</td>
<td>0.167</td>
<td>0.230</td>
<td>0.288</td>
<td>0.344</td>
</tr>
<tr>
<td>Gap height (m)</td>
<td>0.260</td>
<td>0.610</td>
<td>0.960</td>
<td>1.310</td>
</tr>
</tbody>
</table>

Table 2: Second set of four magnets, just after the intermediate dump.

<table>
<thead>
<tr>
<th></th>
<th>Magnet 5</th>
<th>Magnet 6</th>
<th>Magnet 7</th>
<th>Magnet 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>4.000</td>
<td>4.000</td>
<td>4.000</td>
<td>4.000</td>
</tr>
<tr>
<td>Width (m)</td>
<td>1.870</td>
<td>1.870</td>
<td>1.870</td>
<td>1.870</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.510</td>
<td>1.510</td>
<td>1.510</td>
<td>1.510</td>
</tr>
<tr>
<td>Gap width (m)</td>
<td>0.450</td>
<td>0.450</td>
<td>0.450</td>
<td>0.450</td>
</tr>
<tr>
<td>Gap height (m)</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

- Coll. 1: $Y = 0.184$ m
- Coll. 2: $Y = 0.476$ m
- Coll. 3: $X = Y = 0.809$ m
Optics

\[ \beta(s) = \beta^* + \frac{s^2}{\beta^*} \]

*In case when there is no quadrupole, only 2 sets of 4 bending magnets*
Switched off SR
No need of particle-matter interactions
Single particle trajectory
Four particles with transverse components \((x = 0, \, x_p = 0, \, y = 0, \, y_p = 0)\) at IP
Energy deviation of each \((\delta = 0, \, \delta = -0.3333, \, \delta = -0.80000, \, \delta = 0.93333)\)
Ideal Beam with Off Momentum Particles

Transverse coordinates:
\[ X,= Y =,XP =,YP = 0, , \text{while } E \neq 0 \]

With One bending magnet

With two bending magnets
Disrupted Beam: Transverse Distributions
Disrupted Beam: Energy vs Offsets/Angles

We start tracking the disrupted beam 200K particles and after loss through the extraction line, ended up with 181 K
Disrupted Beam: Energy Histogram
ACCELERATOR:: CLIC-2500

{ energy  = 2500. ;
  particles = 0.4 ;
  emitt_x = 0.58 ;
  emitt_y = 0.01 ;
  beta_x = 8.0 ;
  beta_y = 0.1 ;
  sigma_z = 30. ;
  dist_z = 0 ;
  espread = 0.0 ;
  which_espread = 0;
  offset_x = 0 ;
  offset_y = 0. ;
  waist_x = 0 ;
  waist_y = 0 ;
  angle_x = 0 ;
  angle_y = 0 ;
  angle_phi = 0 ;
  trav_focus = 0 ;
}

PARAMETERS::

CLIC_standard_compton

{ 
  n_x=64 ;
  n_y=64 ;
  n_z=36 ;
  n_t=8 ;
  cut_x=3.0*sigma_x.1 ;
  cut_y=6.0*sigma_y.1 ;
  cut_z=3.0*sigma_z.1 ;
  n_m=40000 ;
  force_symmetric=1; 
  integration_method=2 ;
  do_eloss = 1 ;
  do_espread = 1 ;
  do_isr = 1 ;
  store_beam=1 ;
  electron_ratio=0.1 ;
  do_photons=1 ;
  photon_ratio=0.1 ;
  store_photons=1 ;
  do_pairs=0 ;
}

track_pairs=1; grids=7 ;
pair_ratio = 1.0;
pair_ecut = 0.005 ;
beam_size=1;
do_compt = 1;
compt_x_min=0.01;
compt_emax=800;
do_hadrons=1;
store_hadrons = 1 ;
hadron_ratio=1000. ;
do_jets=1 ;
store_jets=1 ;
jet_ptmin=3.2 ;
jet_ratio=10000. ;
jet_log=1;
do_lumi=1 ;
um_lumi=10000 ;
lumi_p=0.0001 ;
}
Jets Production at CLIC
Conclusion

- Analytical estimation of scattering probability of beam-generated halo in:
  - Beam delivery system and LINAC of CLIC
  - Beam delivery system and LINAC of ILC
  - CLIC drive beam
  - CLIC Test Facility 3 drive beam

- Performed a detailed benchmarking study of two particle tracking codes, DIMAD and PLACET using 20mrad post collision line.

- Beam-Beam interaction (study going on......)
Beam-Halo Collimation

- Beam halo: damping ring, linac, final focus aberrations etc
- The beam halo can result in electromagnetic showers and SR reaching the detector (+ muon background).
- Halo removed by physically intercepting the particles using mechanical spoilers + thick absorbers to remove the debris.
- Thick absorbers then become a source of muons – should be within tolerable levels at the detector.
- IR layout and mainly final doublet dominate.
Lattice with low Dispersion: BDS

Lost particles = 4%)}
Transverse Phase Space: Exit of BDS

Horizontal

Vertical