DESIGN STUDY OF THE CLIC POST-COLLISION BEAM LINES

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Introduction

At CLIC, the incoming beams experience very strong electromagnetic fields at the interaction point.

→ Increased angular divergence of the disrupted beam, emission of beamstrahlung photons (thus a large energy spread) and production of e^+e^- coherent pairs.

All these particles must be transported to their dump with minimal losses in the extraction line.

→ In the EUROTeV framework, a conceptual design of the CLIC post-collision line(s) was performed, based on particle tracking studies with the DIMAD code.

Details in EUROTeV-Report-2007-001 & CLIC note 704.

Contents

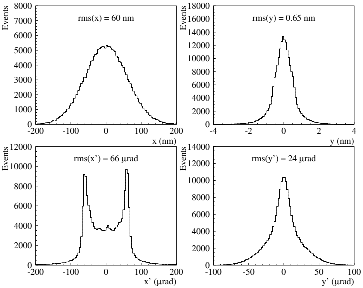
Incoming beam parameters

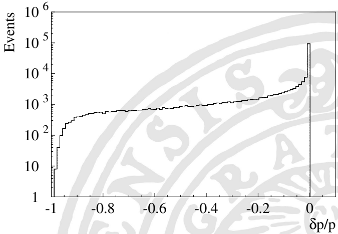
Parameter	Symbol	Value	Unit
Center-of-mass energy	E	3	TeV
Particles per bunch	N_b	2.56	10^9
Bunches per RF pulse	n	220	
Bunch spacing	Δt_b	0.267	ns
Repetition frequency	f	150	Hz
Primary beam power	P_b	20.4	MW
Horizontal normalized emittance	$(\beta\gamma)\epsilon_x$	660	nm.rad
Vertical normalized emittance	$(\beta\gamma)\epsilon_y$	10	nm.rad
Horizontal rms beam size	σ_x	60	nm
Vertical rms beam size	σ_y	0.7	nm
Rms bunch length	σ_z	30.8	μm
Peak luminosity	L	$6.5 \cdot 10^{34}$	cm^{-2} s^{-1}

Incoming beam parameters of the nominal CLIC machine [CLIC note 627].

Disrupted beam distributions

Strong beam-beam interactions lead to an emittance growth and to the apparition of low-energy tails in the disrupted beam.

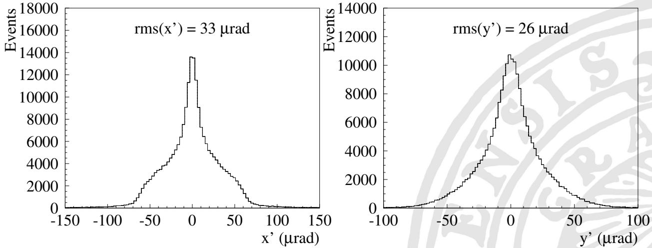




Distributions for CLIC 3 TeV

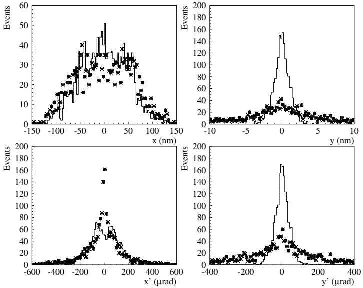
Beamstrahlung photons

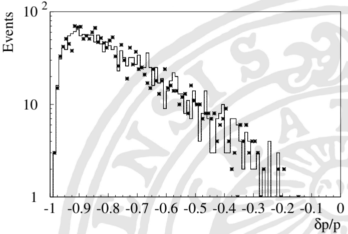
At CLIC, 1.1 beamstrahlung photons are emitted per incoming electron or positron.
The average energy loss of each incoming beam through emission of photons is $\delta_B = 16\%$.



Coherent pairs

At CLIC, one expects about 4.6×10^7 coherent pairs per bunch crossing.
The electrons and positrons of the coherent pairs carry typically about 10% of the primary beam energy.





* $\leftrightarrow$ wrong-sign charged particles

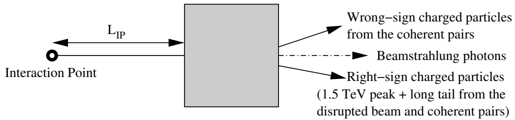
CLIC post-collision line conceptual design

The design relies on the separation by dipole magnets of the disrupted beam, the beamstrahlung photons and the particles from e^+e^- pairs with the wrong-sign charge (as compared to the outgoing beam), just downstream of the interaction point.

It is then followed by a transport to the dump through dedicated extraction lines:

- a short one for the wrong-sign charged particles of the coherent pairs, to prevent the transverse beam size from increasing too much.
- a much longer one for the disrupted beam and the beamstrahlung photons, to avoid a too small spot size for the undisrupted beam at the dump window.

Design of the extraction magnets



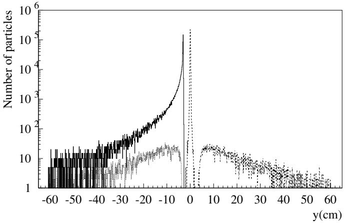
For 1.5 TeV particles, the vertical deviation must be 10 times larger than the worse photon cone size at the last dipole exit [$rms^{\gamma}(y')$ = 80 μrad, with an offset at the IP].

$$BL_D^2 - 8L_D - 8L_{IP} = 0 \Longrightarrow L_D = \frac{4}{B}\left(1 + \sqrt{1 + L_{IP}B/2}\right)$$

With $B = 1$ T and $L_{IP} = 16$ m, one gets L_D =16 m. The bending angle of 3.2 mrad is provided by four 4 m long (compact) window-frame magnets.

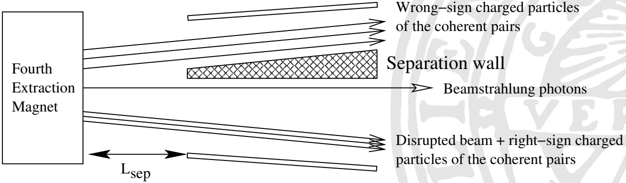
Two 20 cm long collimators are installed between the dipoles to stop charged particles with $\delta < -0.95$.

Physical separation of the beams



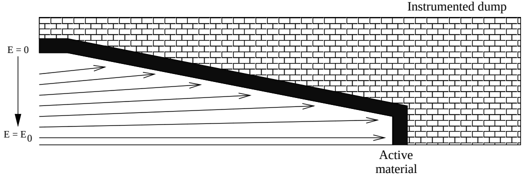
Vertical beam profiles at the exit of the fourth extraction magnet (35 m from the IP).

The wrong-sign charged particles of the e^+e^- pairs are separated from other outgoing beams 3 m downstream ($D_y = 4$ cm).

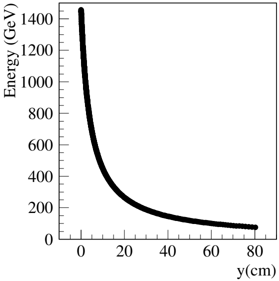


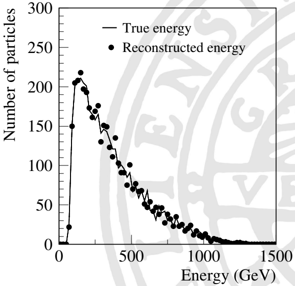
Collection and analysis of the coherent pairs

Beam power to dump = 40 kW



An early measurement of the beam profiles allows to measure the energy spectrum of the coherent pairs, before the beam becomes too large.

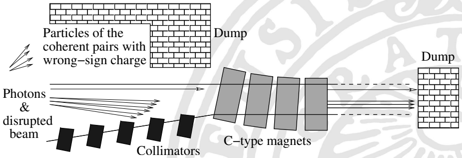




Transport of the main outgoing beam

- The (undisrupted) beam size at the exit window must be large (1 mm^2) to avoid a too large thermal stress $\Longrightarrow$ long distance between the IP and the dump.
- The dump window can neither be too thick (to avoid showers) nor have a too large cross section (small mechanical stress) $\Longrightarrow$ reasonable size for the pipe of the outgoing beam.

Additional magnets to have $D'_y = 0$ after the chicane and at the dump.

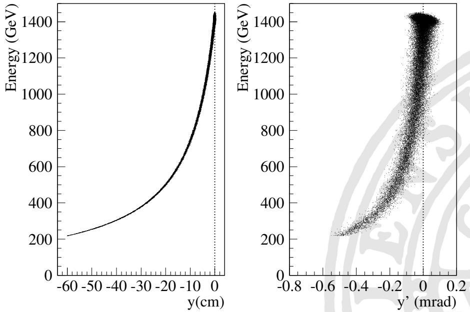


Charged particles with $\delta < -0.85$ are absorbed in five 1 m long collimators. Loss free transport through four C-type magnets.

Beam transport after the vertical chicane

At the chicane exit, the high-energy peak is parallel to the beamstrahlung photons ($D'_y = 0$).

Low-energy particles still have a small negative y', which may lead to beam losses.



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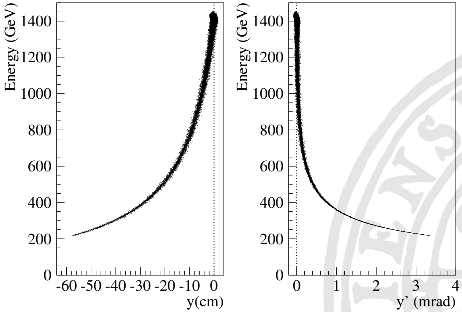
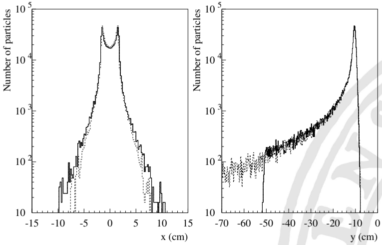
Implementation of a refocusing region

To bend back the low-energy tail, use 16 quadrupoles (length of 2 m, pole-field of 1 T and aperture radius of 70 cm). As these are large quadrupoles, they must be installed at least 150 m away from the IP.



Transport to the dump

- The refocusing region allows flexibility in the design of the last post-collision line section and of the exit window, since the rms size of the disrupted beam decreases with the distance to the dump.
- In our design, the dump is 247 m away from the IP.



The transport of the photons remains loss free from the IP to the dump, where $\sigma_x(\gamma) = 8.2$ mm and $\sigma_y(\gamma) = 6.5$ mm.

Constraints for the CLIC exit window

- The exit window between the accelerator vacuum and the dump must withstand a power of 20 MW.
- The outgoing beam is widened by e^+e^- collisions, but the exit window must also withstand the energy density of the undisrupted beam.
- At 250 m from the interaction point, the transverse size of the undisrupted beam is 2.2 mm $\times$ 3.3 mm (2.1 mm $\times$ 1.9 mm if failure of magnetic elements).

For a circular window with a centered round beam:

- Mechanical (static) stress: $\sigma_s = 0.49\,\Delta P\,\frac{R^2}{d^2}$.
- Cyclic thermal stress: $\sigma_c = \frac{1}{2}\alpha E\,\Delta T_{inst}$.
- For a bunch train: $\Delta T_{inst} = \left(\frac{dE}{\rho dx}\right) \times \frac{n\,N_b}{2\pi C\sigma_{beam}^2}$.
- Equilibrium: $T_0 = T_{edge} + \left(\frac{dE}{dx}\right) \times \frac{n\,N_b\,f}{4\pi k}\ln\left(1 + \frac{R^2}{2\sigma_{beam}^2}\right)$.

Material selection for the exit window

- The CLIC window has a large cross section, so it must be thick in order to withstand the mechanical pressure.
- In order to avoid electromagnetic showering in the window, it must have a large radiation length: use low-Z materials.
- Low elastic modulus and thermal expansion coefficient to keep σ_C at a reasonable level.

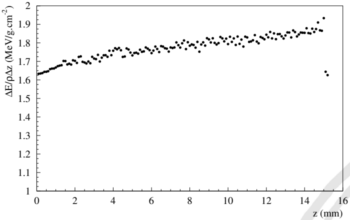
At the LHC, a large diameter carbon-carbon composite window was designed, the SIGRABOND 1501G grade from SGL was selected.

The composite is quite porous: a thin leak-tight foil on the high pressure side is needed to hold vacuum... Stainless steel was chosen at the LHC.

$\longrightarrow$ Design a similar exit window for CLIC.

Simulations for a round exit window

Energy deposition and temperature increase by a 1.5 TeV undisrupted e^- beam in a 15 mm thick C-C window and a 0.2 mm thin foil ($R = 25$ cm):



Material	ρ (g/cm^3)	C (J/g K)	k (W/K cm)	ΔT_{inst} (K)	ΔT_{eq} (K)
C-C	1.50	0.53	0.24	1.1	103.5
Steel 316	7.80	0.50	0.16	1.0	639.8
Aluminium	2.70	0.90	2.37	0.6	17.4
Titanium	4.54	0.53	0.22	1.0	314.2
Copper	8.96	0.38	3.90	1.3	32.8

More realistic ANSYS simulations are being performed...

Summary and outlooks

- A conceptual design of the CLIC post-collision beam line(s) is now available.
- It was tested with position and angular offsets at the IP, all extra losses occur in the collimators.
- Simulations of the CLIC exit window are being performed to validate a design based on a C-C composite thick window + a thin leak-tight foil.

Future studies for the CLIC post-collision line:

- Test the design of the lattice and of the exit window with new CLIC parameters.
- BDSIM particle tracking: losses in the collimators, back-scattered particles at the IP, etc.
- Implementation of beam instrumentation, how do we measure the luminosity and other beam properties?