Status Report on the Design of the CLIC Post-Collision Transport Line

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Introduction

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

$\rightarrow$ Increased angular divergence of the disrupted beam, emission of beamstrahlung photons (thus a larger 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.

$\rightarrow$ In 2006, a conceptual design of the (nominal) CLIC post-collision line was performed.

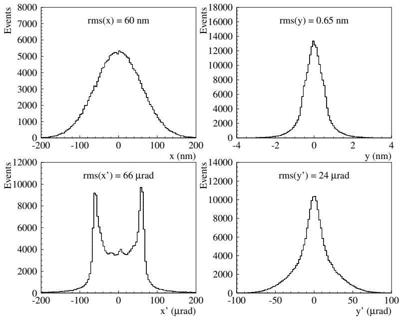
Incoming beam parameters

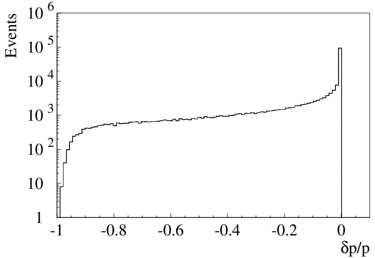
Parameter	Symbol	Value	Unit
Center-of-mass energy	E	3	TeV
Particles per bunch	N_b	2.56	10^9
Bunches per RF pulse	n	220	
Bunch spacing	Δt_b	0.267	ns
Repetition frequency	f	150	Hz
Primary beam power	P_b	20.4	MW
Horizontal normalized emittance	$(\beta\gamma)\epsilon_x$	660	nm.rad
Vertical normalized emittance	$(\beta\gamma)\epsilon_y$	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	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 the apparition of low-energy tails in the disrupted beam.

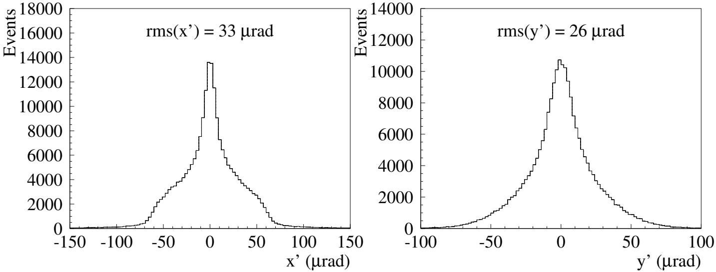




Distributions for CLIC at 3 TeV

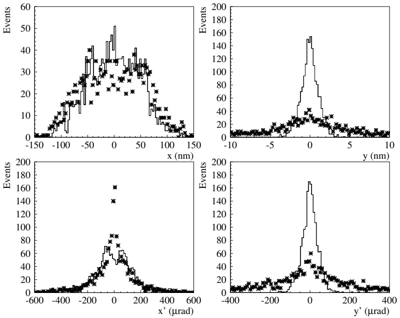
Beamstrahlung photons

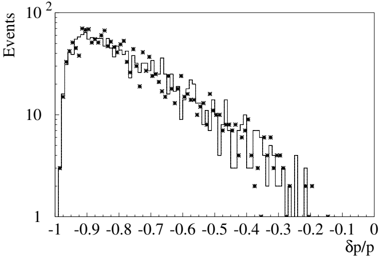
At CLIC, 1.1 beamstrahlung photons are emitted per incoming electron or positron. The average energy loss of each incoming beam through emission of photons is $\delta_B = 16\%$.



Coherent pairs

At CLIC, one expects 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.





* ↔ wrong-sign charged particles

A CLIC beam in the ILC 20 mrad extraction line??

- A detailed study of the beam losses along the ILC 20 mrad extraction line was performed, with a nominal CLIC beam (EUROTeV-Report-2006-019).
- The ILC extraction line consists of a DFDF quadruplet, two vertical chicanes (energy and polarization measurements) and a field-free region with two collimators.
- The power losses are mostly due to the low-energy tails of the disrupted beam and the coherent pairs, over-focused in the first quadrupoles of the post-collision line.
- The ILC 20 mrad extraction line is thus not adapted to the nominal CLIC beam, due to large losses (280 kW for the disrupted beam and 36 kW for the coherent pairs).
- A strong reduction of all magnetic fields allows to bring the power losses down to a reasonable level. But, the optics of the post-collision line is destroyed at the nominal energy.

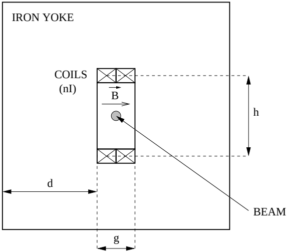
Conceptual design of the CLIC post-collision line

The proposed design of the CLIC post-collision line is based on the separation by dipole magnets of the disrupted beam, the beamstrahlung photons and the particles of the coherent pairs that have 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 long one for the disrupted beam and the beamstrahlung photons, to avoid a too small spot size for the undisrupted beam at the dump window.

Constraints for the design of the extraction magnets



We use compact window-frame magnets:

Ampere's law: $nI = \oint \mathbf{H} \cdot d\mathbf{s} \simeq \frac{B}{\mu_0} g$

For the magnetic flux to return through the yoke: $d \geq h \times \frac{B}{2B_{max}}$.

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

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

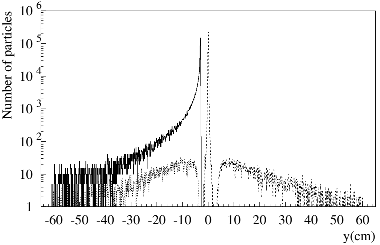
With $B = 1$ T and $L_{IP} = 16$ m, one gets L_D =16 m. The bending angle of 3.2 mrad is provided by four 4 m long magnets.

Extraction magnets and collimators

Extraction Magnet	g (cm)	h (cm)	nI (kA.turns)	$2d+g$ (cm)
1	13.7	36.9	109.0	35.4
2	18.7	71.9	148.8	61.0
3	23.0	106.9	183.0	85.9
4	27.0	141.9	214.8	110.5

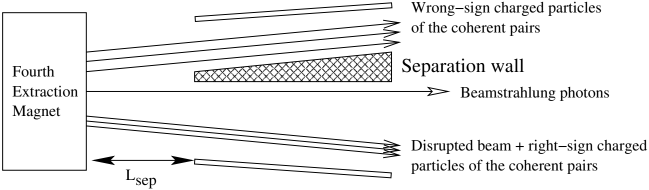
In order to avoid power losses in the magnets, two 20 cm long collimators are installed between the dipoles, and stop charged particles with $\delta < -0.95$.

Collimator	Y_c (cm)	Beam losses (kW)
1-2 (a)	7.8	0.04 and 0.02
1-2 (b)	8.0	0.05 and 0.02
2-3 (a)	22.2	0.15 and 0.05
2-3 (b)	21.7	0.16 and 0.04
3-4 (a)	38.8	0.37 and 0.11
3-4 (b)	37.4	0.34 and 0.10



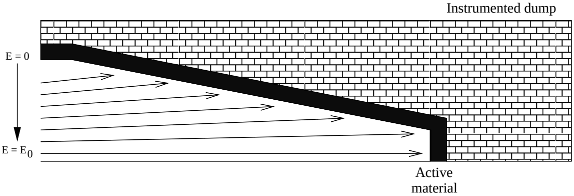
Vertical beam profiles at the exit of the fourth extraction magnet (35 m from the IP).

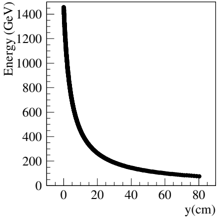
The wrong-sign charged particles of the coherent pairs are separated from the other outgoing beams 3 m downstream ($D_y = 4$ cm).

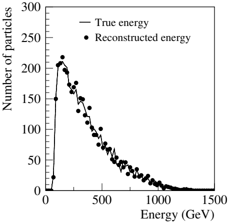


Collection and analysis of the coherent pairs

Beam power to dump = 40 kW





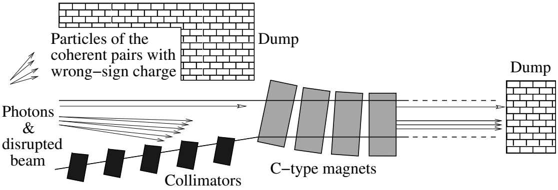


An early measurement of the beam profiles allows to measure the energy spectrum of the coherent pairs, before the beam becomes too large.

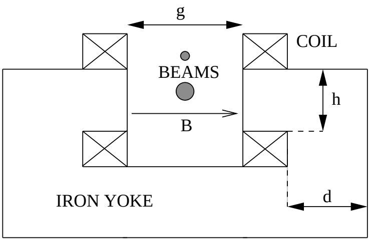
Constraints for the transport of the disrupted beam

- The (undisrupted) beam spot size on the dump 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 thick (to avoid showers) nor have a 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.



C-type magnets and collimators



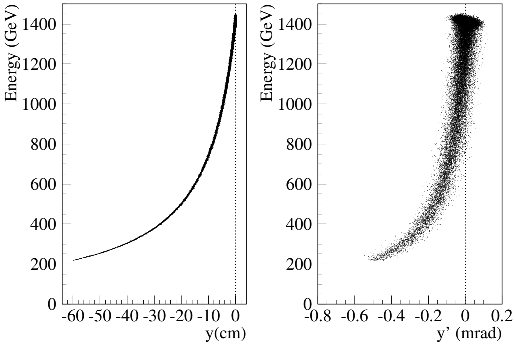
- $B = 0.973$ T (synchrotron radiation losses)
- $g = 20$ cm, $nI = 160$ kA.turns
- $d \geq \frac{B}{B_{max}}(h + 0.5g)$
- with $h = 65$ cm, $d \geq 43$ cm
- the minimum horizontal dimension is 126 cm.

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

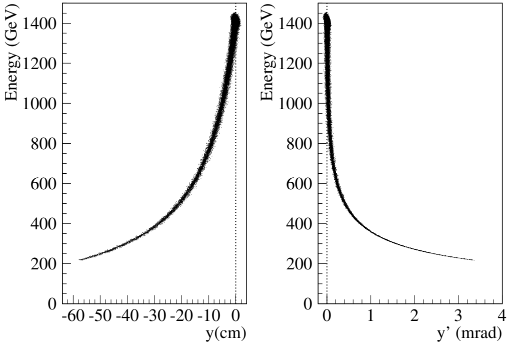
Collimator	Y_c (cm)	P_{loss} (kW)
Coll-C1	48.0	6.97
Coll-C2	43.5	7.18
Coll-C3	42.1	7.45
Coll-C4	41.5	7.93
Coll-C5	41.0	8.60

Beam transport after the vertical chicane

At the chicane exit, the high-energy peak is parallel to the beamstrahlung photons ($D'_y = 0$) but the low-energy particles still have a small negative y', which may lead to beam losses.

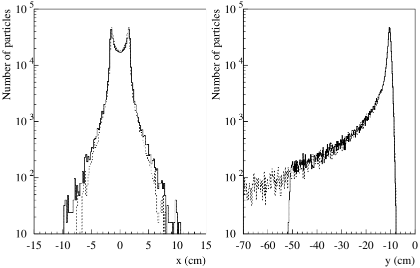


To bend back the low-energy tail, 16 quadrupoles are used (length of 2 m, pole-field of 1 T and aperture radius of 70 cm). As these are large quadrupoles, they must be installed at least 150 m away from the IP.



Transport to the dump

- The presence of the refocusing region allows flexibility in the design of the last post-collision line section and the exit window, as 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.

Conclusion and outlooks

- A conceptual design of the CLIC post-collision line is now available. It is based on the separation of the different components of the outgoing beam by a vertical chicane and their transport through dedicated lines.
- Our design was based on DIMAD particle trackings and it was performed in the case of ideal e^+e^- collisions.
- Small vertical offsets in position and angle were also introduced at the IP. The performance of the CLIC post-collision line is not affected and additional power losses occur only in the collimators.
- More details in EUROTeV-Report-2007-001 (in review).

OUTLOOKS: careful design of the dump window, more detailed simulations with BDSIM, integration into the CLIC complex, etc.