DESIGN STUDY OF THE CLIC POST-COLLISION BEAM LINE

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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.

First design: EUROTeV-Report-2007-001 (January 2007).
Update: EUROTeV-Report-2008-021 (May 2008).

Contents

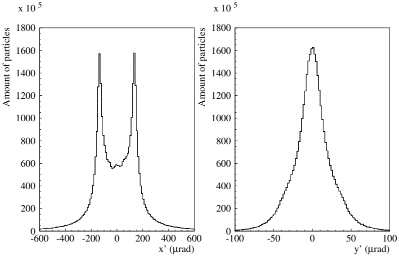
Incoming beam parameters

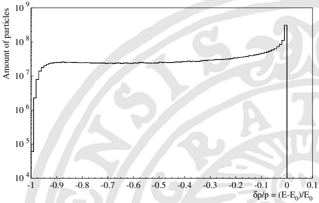
Parameter	Symbol	Value	Unit
Center-of-mass energy	E	3	TeV
Acceleration frequency	f_{RF}	12	GHz
Acceleration gradient	g_{ACC}	100	MV/m
Particles per bunch	N_b	3.72	10^9
Bunches per RF pulse	n	312	
Bunch spacing	Δt_b	0.5	ns
Repetition frequency	f	50	Hz
Primary beam power	P_b	14	MW
Horizontal normalized emittance	$(\beta\gamma)\epsilon_x$	660	nm.rad
Vertical normalized emittance	$(\beta\gamma)\epsilon_y$	20	nm.rad
Horizontal rms beam size	σ_x^*	40	nm
Vertical rms beam size	σ_y^*	1	nm
Rms bunch length	σ_z^*	45	μm
Peak luminosity	L	$5.9 \cdot 10^{34}$	cm^{-2} s^{-1}

New incoming beam parameters of the nominal CLIC machine.

Disrupted beam distributions

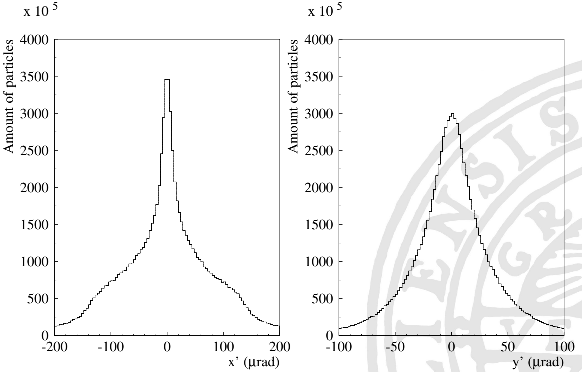
Strong beam-beam interactions lead to an emittance growth and to the apparition of low-energy tails in the disrupted beam.





Beamstrahlung photons

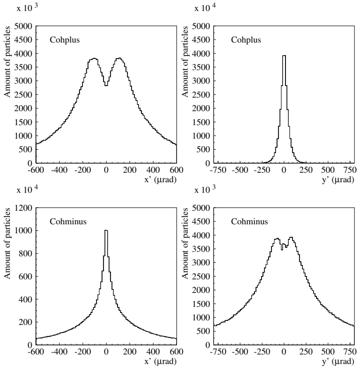
At CLIC, 2.2 beamstrahlung photons are emitted per incoming electron or positron.
The average energy loss of each incoming beam through emission of photons is $\delta_B = 29\%$.

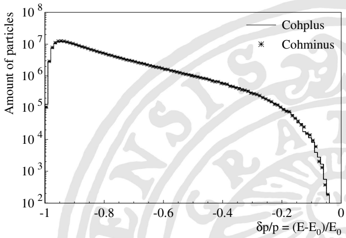


Coherent pairs

At CLIC, one expects about 5 × 10^8 coherent pairs per bunch crossing.

The electrons and positrons of the coherent pairs carry typically about 10% of the primary beam energy.



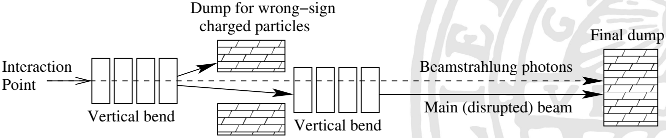


* ↔ wrong-sign charged particles

CLIC post-collision line conceptual design

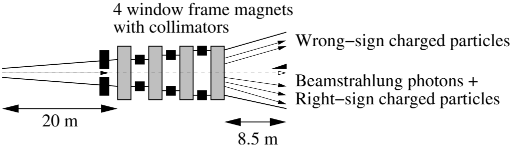
The design relies on the separation by dipole magnets of the disrupted beam, the beamstrahlung photons and the particles from e^+e^- pairs with the wrong-sign charge. It is followed by a transport to the dump in dedicated lines:

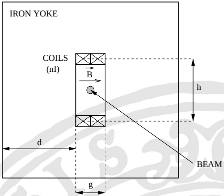
- a short one for the wrong-sign charged particles of the coherent pairs, to prevent the transverse beam size from increasing too much.
- a much longer one for the disrupted beam and the beamstrahlung photons, to avoid a too small spot size for the undisrupted beam at the dump window.



Design of the extraction magnets

The first magnetic elements of the CLIC post-collision line are four dipoles, spaced by 1.5 m, each with a field of 1 T and a length of 4 m (bending angle: 0.8 mrad at 1.5 TeV).

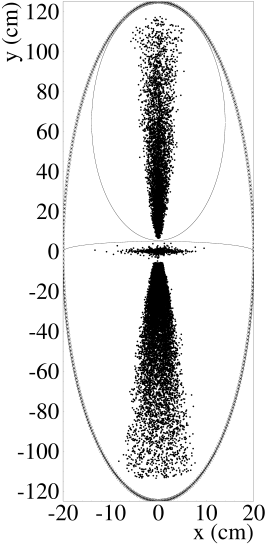




Magnet Name	s_{start} (m)	X_{pipe} (cm)	Y_{pipe} (cm)	g (cm)	h (cm)	nI (kA.turns)	$d+g/2$ (cm)
Mag1	20.0	15	25	16.7	41.9	132.9	20.7
Mag2	25.5	20	60	23.0	76.9	183.0	34.1
Mag3	31.0	25	95	28.8	111.9	229.1	47.3
Mag4	36.5	30	130	34.4	146.9	273.7	60.4

Between two magnets, a 90 cm long collimator absorbs the particles with $\delta p/p < -0.95$.

Physical separation of the beams

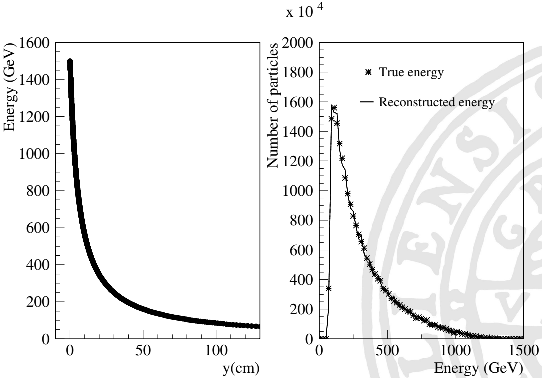


- The wrong-sign charged particles of the e^+e^- pairs are separated from other outgoing beams 8.5 m downstream of the fourth magnet ($D_y = 6$ cm).
- A 5 mm thick wall is inserted to physically separate the beams.
- The disrupted beam, the beamstrahlung photons and the right-sign charged particles of the e^+e^- pairs are transported further.

Collection and analysis of the coherent pairs

Beam power on dump for the wrong-sign charged particles of the coherent pairs = 172 kW.

An early measurement of the beam profiles allows to derive the energy spectrum of the e^+e^- coherent pairs, before the beam becomes too large.

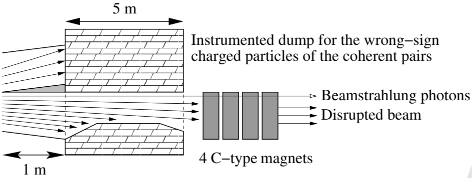


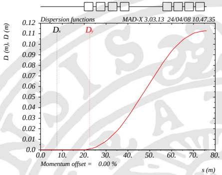
Transport of the main outgoing beam (1)

The (undisrupted) beam size at the exit window must be large to avoid a too large thermal stress:

$\Longrightarrow$ Long distance between the IP and the dump.

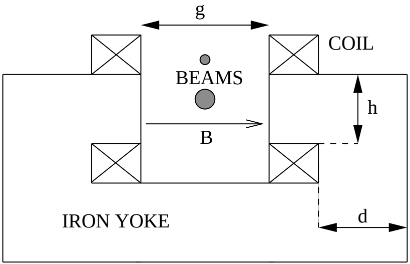
$\Longrightarrow$ Four magnets to have $D'_y = 0$ after the chicane.





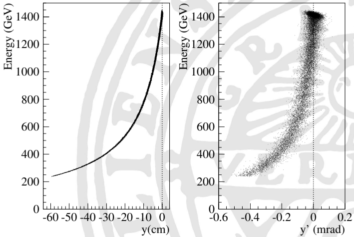
The charged particles with $\delta < -0.84$ are absorbed in the dump of the wrong-sign charged particles of the coherent pairs: loss free transport through the four magnets.

Transport of the main outgoing beam (2)



Parameter	Value
L	4 m
B	0.973 T
g	45 cm
h	64 cm
nI	360 kA.turns
X_{coil}	30 cm
Y_{coil}	36 cm
$d + X_{coil} + g/2$	93.5 cm

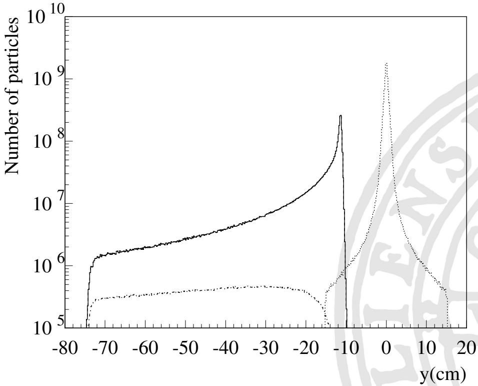
After the chicane, the high energy peak has $D'_y = 0$ and travels parallel to the beamstrahlung photons. Low-energy particles still have a small negative y'.



Transport of the main outgoing beam (3)

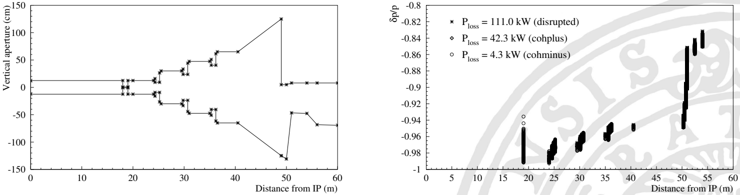
The main dump is placed at the end of the post-collision line, 150 m downstream of the interaction point.

An accurate analysis of the final transverse beam profiles allows to derive information on the e^+e^- collisions.



Beam losses along the post-collision line

All charged particles with $\delta > -0.84$ and beamstrahlung photons reach the final dump. The low-energy tails are lost in either collimators or the intermediate dump, due to (mostly vertical) aperture restrictions.



DIMAD and BDSIM results are in excellent agreement. Back-scattered particles are now under study using the GEANT4 interface to BDSIM.

Constraints for the CLIC exit window

- The exit window between the accelerator vacuum and the dump must withstand a power of 14 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 150 m from the interaction point, the transverse area of the undisrupted beam is 3 mm^2 (2.5 mm^2 if failure of magnetic elements).
- For a bunch train: $\Delta T_{inst} = \left(\frac{dE}{\rho dx}\right) \times \frac{n\,N_b}{2\pi C \sigma^2_{beam}}$.
- Cyclic thermal stress: $\sigma_c = \alpha E \Delta T_{inst}$.
- Equilibrium: $T_0 - T_{edge} \simeq \left(\frac{dE}{dx}\right) \times \frac{n\,N_b\,f}{4\pi k} \ln\left(1 + \frac{R^2}{2\sigma^2_{beam}}\right)$ assuming a round window...
- Mechanical stress: $\sigma_s \propto \Delta P \times \text{Area}/\text{Thickness}^2$

Material selection for the exit window

- The CLIC window has a large cross section, it must be thick 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.

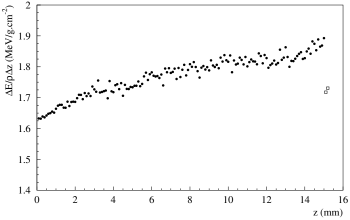
At the LHC, a large diameter carbon-carbon composite window was designed, the SIGRABOND 1501G grade from SGL was selected.

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 but Aluminium is preferable at CLIC to rapidly transport away the heat.

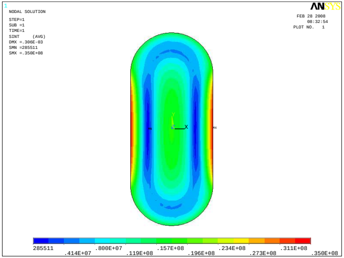
$\longrightarrow$ Design a similar exit window for CLIC.

Simulation results

FLUKA → energy deposition by a 1.5 TeV e^- beam in a 15 mm C-C window and a 0.2 mm Aluminium foil.



Material	C-C	Al
ρ (g/cm^3)	1.5	2.7
C (J/g K)	0.53	0.90
k (W/K cm)	0.24	2.37
E (GPa)	70	70
α (K^{-1})	$7 \cdot 10^{-6}$	$2.3 \cdot 10^{-5}$
ΔT_{inst} (K)	3.0	1.7
ΔT_{eq} (K)	76	14
σ_c (MPa)	1.5	2.7



ANSYS simulations → the maximal mechanical stress in the C-C window is 35 MPa (near the lateral edges, 10 times less than the tensile strength), displacement of 0.3 mm at the centre.

What to measure and how?

The post-collision line should be used to measure the quality of the e^+e^- collisions and monitor beam-beam offsets during the machine tuning. See V. Ziemann's EUROTeV-Report-2008-016.

- Measurement of the energy spectrum and flux of the wrong-sign charged particles of the coherent pairs at the intermediate dump.
- Monitor the low-energy tails, using reverse-biased PIN diodes in the collimators sandwiched between the window frame magnets.
- Monitor the temperature dependent refractive index of the water in the dump with an interferometer, and derive the vertical beam profile.
- Beamstrahlung monitor: detect the high-energy muons produced by the beamstrahlung photons in the main dump and derive the corresponding flux.

Summary and outlooks

- A conceptual design of the CLIC post-collision beam line(s) is available.
- It accomodates the recent changes of CLIC beam parameters, it has been shortened by 100 m and simplified (large quadrupoles were removed).

Future studies for the CLIC post-collision line, in and beyond EUROTeV:

- BDSIM particle tracking: losses in the collimators, back-scattered photons at the IP, etc (R. Appleby).
- More detailed studies of post-collision diagnostics, implementation of the beam instrumentation, dump and magnet design, etc (K. Elsener).

Article to be submitted to PRST-AB soon...