ConformalTracking

geometry agnostic tracking library

ACAT 2019

Marko Petric

On behalf of the CLICdp collaboration

Saas-Fee, 11 March 2019

CLIC – Compact Linear Collider

- High-luminosity linear e^+e^- collider
- The only mature multi-TeV option for future lepton colliders

Current scenario:

Stage 1: 1 ab^{-1} @ $t\bar{t}$/380 GeV

Precision SM Higgs and top physics

Stage 2: 2.5 ab^{-1} @1.5 TeV:

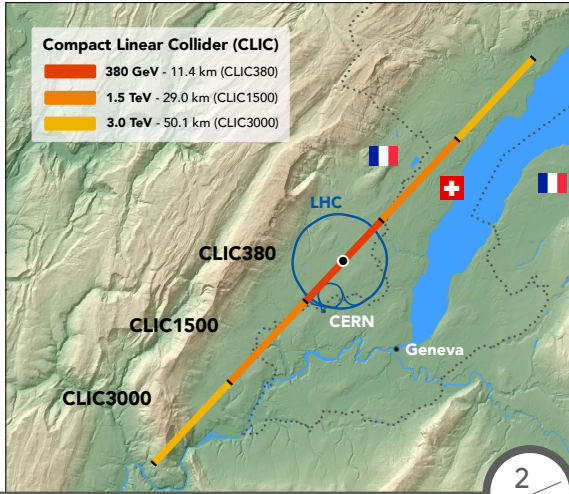
BSM, top and rare Higgs processes

Stage 3: 5 ab^{-1} @ 3 TeV :

BSM, top and rare Higgs processes

Each stage corresponds to 7-8 years

https://clic.cern



CLIC physics and tracking performance requirements

- Momentum resolution

  Higgs recoil, $H \to \mu\mu$ or ℓ from BSM

  $\frac{\sigma(p_T)}{p_T^2} \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$

- Jet energy resolution

  $W/Z/H$ di-jet separation

  $\frac{\sigma(E)}{E} \sim 3.5 - 5\%$

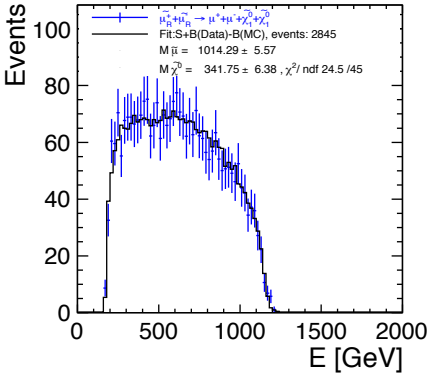
  for $E = 1000 - 50$ GeV

- Impact parameter resolution

  b/c tagging, Higgs couplings

  $\sigma_{r\phi} = \sqrt{a^2 + b^2 \cdot \mathrm{GeV}^2/(p^2 \sin^3\theta)}$

  with $a = 5\ \mu$m and $b = 15\ \mu$m



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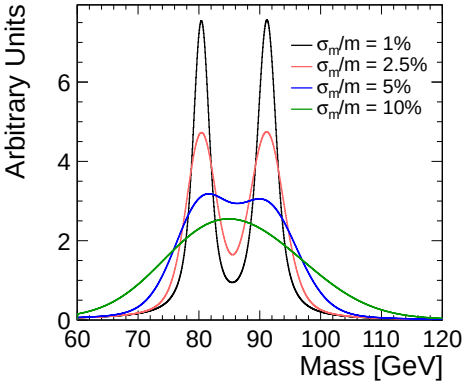

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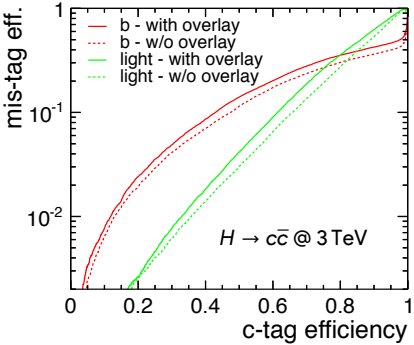
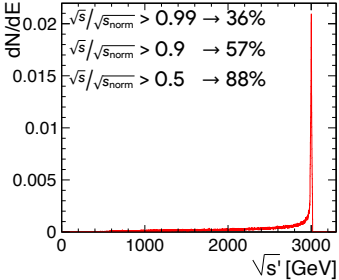
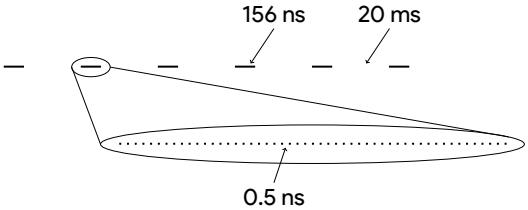


CLIC beam structure and beam-induced backgrounds

- Time stamp hits from the detectors (central det ⟺ physics event)
- Tracking timing requirements
  - 10 ns integration time
  - $10/\sqrt{12}$ ns hit resolution
- Background overlay (10 (20) beam crossings before (after) physics event)

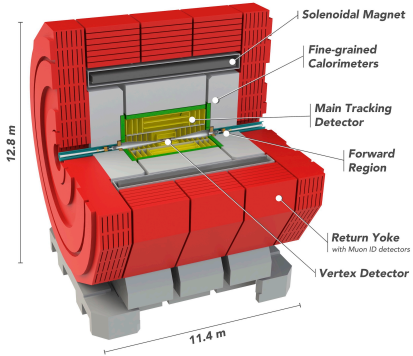




CLIC: trains at 50 Hz, 1 train = 312 bunches

- entire bunch train available for offline reconstruction
- not all bunches crossings contain a "hard" interaction

CLIC Detector Concept

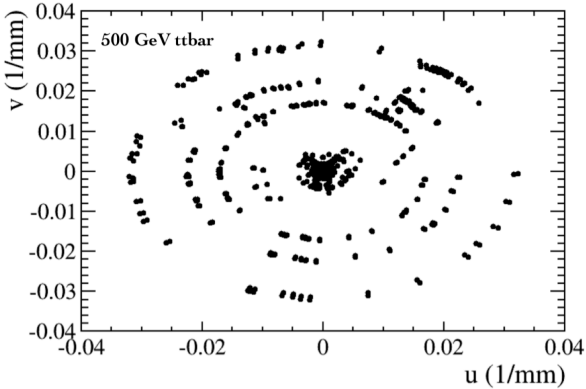


- B Field of 4 T
- Vertex: 3 double layers
  - Single-hit accuracy 3 μm
  - $0.2\%X_0$ per detection layer
  - Power pulsing → 50 mW cm^{-2}
- Si tracker: r_{max} = 1.5 m
  - single point resolution = 7 μm × 90 μm
  - detector: ~ $1\%X_0$ per layer
  - support & cables: ~ $2.5\%X_0$
- Precise timing for background rejection
  - 10 ns stamping for tracks
  - 1 ns accuracy for calo. cluster

Low-mass → small multiple scattering → ideal for conformal tracking

Tracks in Conformal Space

- Conformal map applies a geometry transform that maps circles in the x,y plane passing through the origin point into straight lines in the u,v plane



$$u = \frac{x}{x^2 + y^2}$$

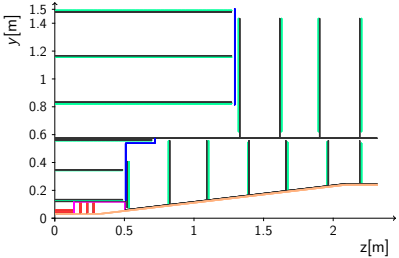
$$v = \frac{y}{x^2 + y^2}$$

- Vertex hits outside
- Tracker hits closer to (0,0)

- Pattern recognition in conformal space via cellular automaton, used to perform straight line search

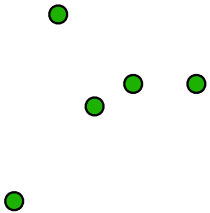
Pattern recognition – full chain

Build tracks	Vertex barrel	Standard cuts
Extend tracks	Vertex endcap	Standard cuts
Build tracks	Vertex b + e	Standard cuts
Build tracks	Vertex b + e	Looser cuts (angle x 5)
Build tracks	Vertex b + e	Looser cuts (angle x 10)
Build tracks	Vertex b + e	Looser cuts (angle x 10; χ^2 x 20)
Extend tracks	Tracker collection	Looser cuts (angle x 10; χ^2 x 20)
Build tracks	All collections	Displaced cuts

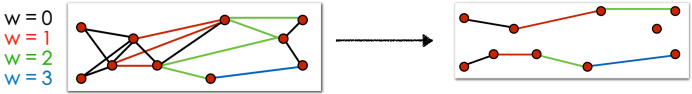


- Chain is fully configurable (boost::spirit)
- Pattern recognition geometry-agnostic
- Based only on the hit position in global space
- Without constraint on the hit position in subdetectors

Build tracks in vertex barrel



- Pattern search starts in vertex barrel
- Hit used as seed to look for neighbors with 2D tree
  - hits not outside the search cone
  - hits not too far from the seed hit
- Seed cells created and extended to virtual hits
- Cellular tracks are vectors of cells
  - each cell has a weight
  - each subsequent link increments the weight by 1
  - create valid tracks starting from higher weight
  - if more paths available, branch the track



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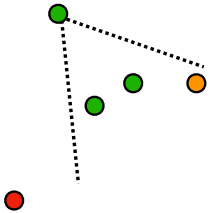

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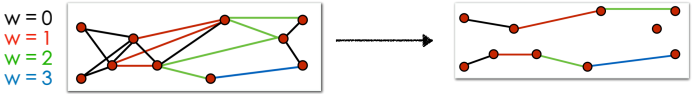

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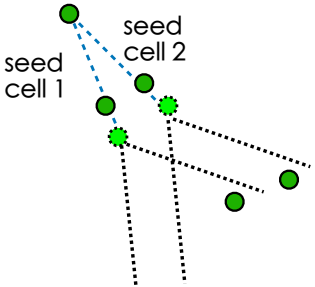

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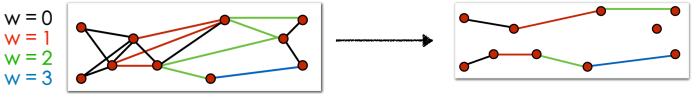

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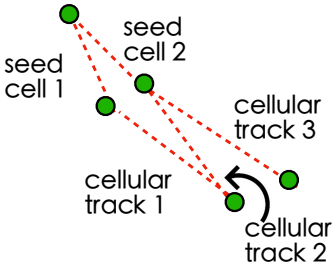

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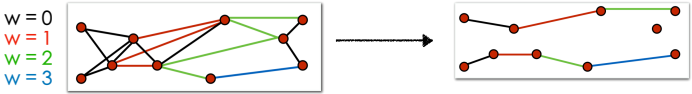

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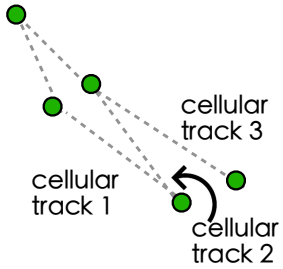
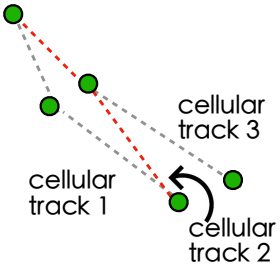


- For all cellular tracks starting from seed hit:
  - linear regression (u,v) → χ^2/ndf
  - linear regression (s,z) → χ^2/ndf
    - s: arc segment along the helix
  - remove hits progressively to refit and compare χ^2
- Best track is one with lowest χ^2
  - similar χ^2 are kept
  - clones (overlapping hits ≥ 2) are skimmed
  - longest usually preferred if χ^2 not too large
- Hits are marked as used and the search continues with the unused ones in the collection

Build tracks in vertex barrel



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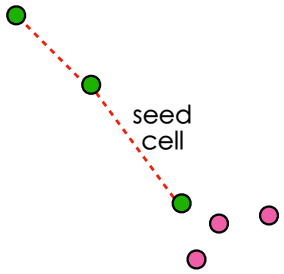
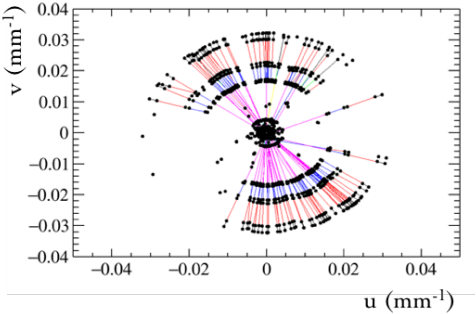
Extend tracks in vertex endcap



- Extended tracks from vertex barrel into the endcaps, starting from seed cell between the last two hits of the track
- Pick candidates to which to extend based on nearest neighbor search
- Each hit candidate is progressively added to the track. Based on a re-fit the hit is accepted / rejected based on its χ^2

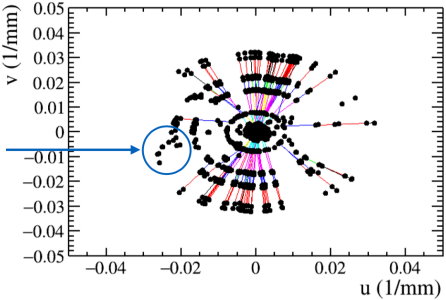
Build tracks with leftover vertex hits and extend in tracker

- After all possible extensions done, try to build new tracks from leftover hits
  - standard cuts
  - looser angle cuts
  - looser χ^2 cuts
- Extend all tracks made in the vertex (barrel, endcap, combined) to all the tracker hit collections



Displaced tracks in conformal space

- Conformal mapping turns circles through the origin into straight lines
  - Quadratic term to include displaced tracks, but eventually χ^2 breaks down

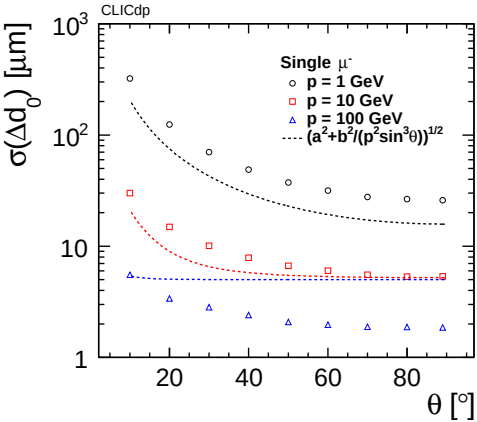


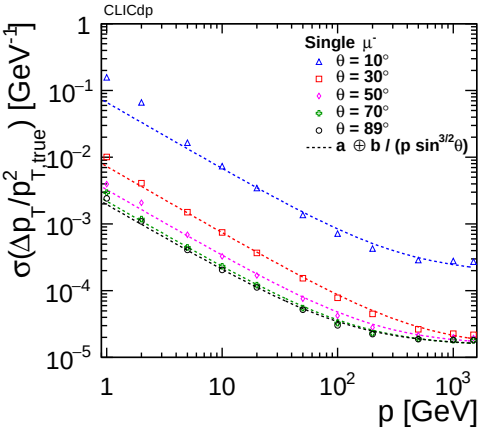
- Major strategy change
  - broader search angle than for prompt tracks
  - minimum 5 hits for tracks
  - start searching from tracker towards vertex
- Most time consuming segment of search

Fitting the tracks

- Work done in Marlin (LC Framework) and LCIO EDM
- Based DD4hep/DDRec surface extension
- Kalman Filter track fit performed with KalTest
  - independent from the pattern recognition
  - DDKalTest: interface to DD4hep surfaces
- Helix prefix with 3 hits gives track state
  - first, middle, last
- Initialise fit with prefit parameters
- Kalman filter
  - hits added one by one
  - acceptance/rejected based on a χ^2 cut

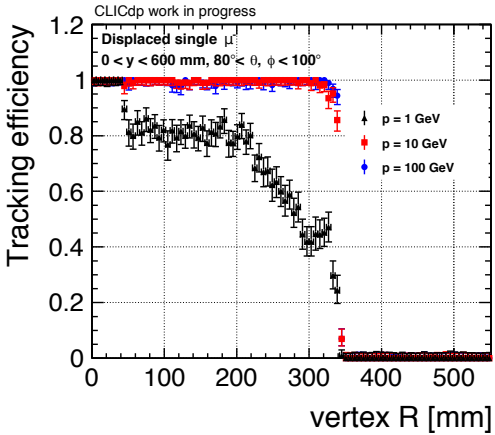
Performance d_0 and p_T resolution for single μ

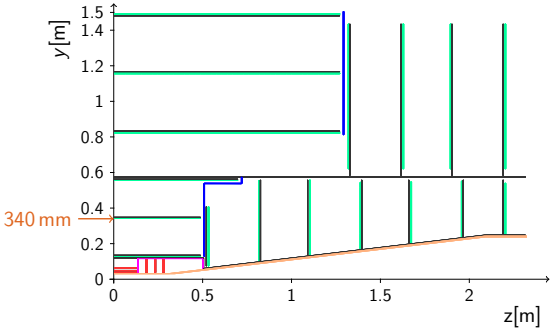




- In good agreement with target values of required performance

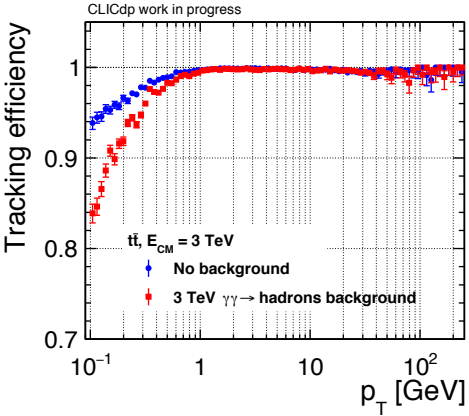
Efficiency for displaced single μ

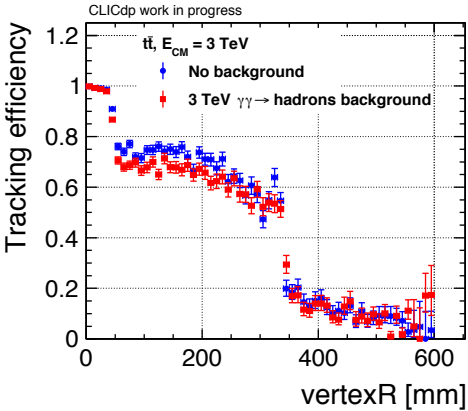




- Track generated uniformly along y axis with given opening angle

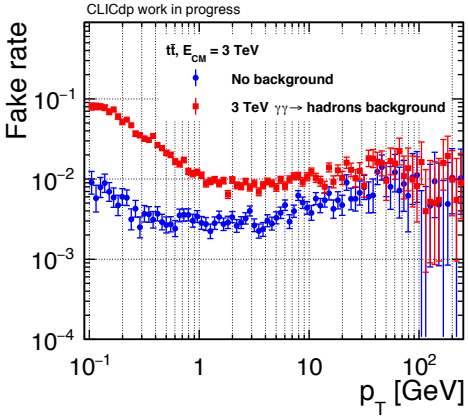
Efficiency for *tt*-bar @ 3 TeV

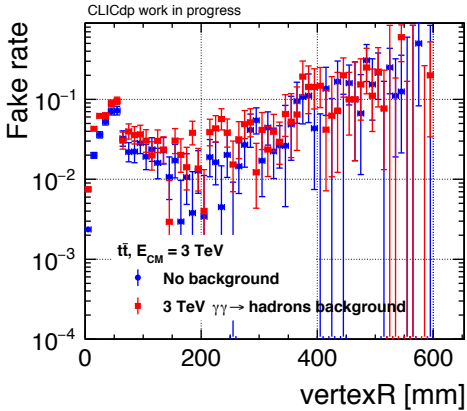




- Efficiency = pure reconstructed particles / reconstructable
  - pure = purity > 75% (hits belong to associated MC particles / total hits)
  - reconstructable = stable, $p_T > 0.1$ GeV, unique hits ≥ 4

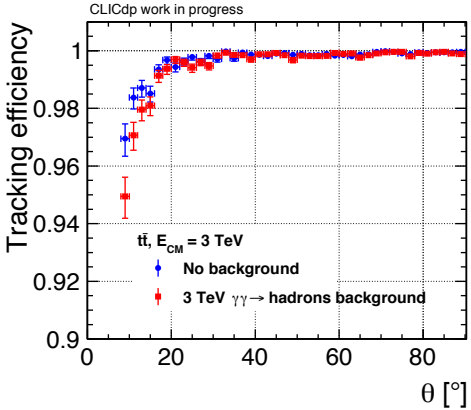
Fake rate for *tt*-bar @ 3 TeV

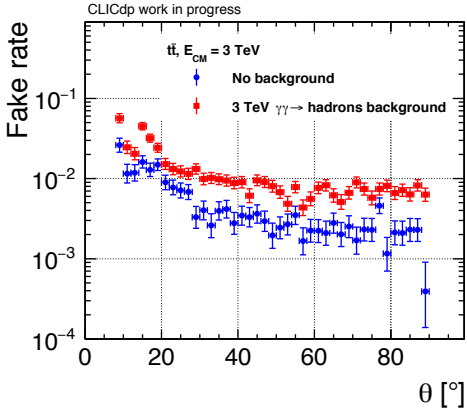




- Fake rate = impure reconstructed particles / reconstructed
  - fake = purity < 75% (hits belong to associated MC particles / total hits)

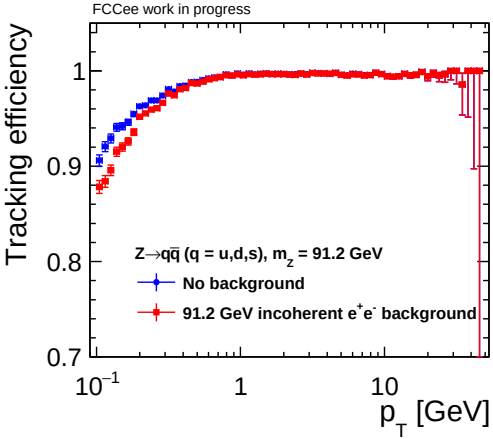
Efficiency and fake rate for *tt*-bar @ 3 TeV





- More performance plots https://cds.cern.ch/record/2649437

Works also with different geometry - FCCee



- Z bosons at rest decaying into light quarks
- background from e^+e^- pairs

- Works also with different detectors e.g. FCCee CLD
- using DD4hep Detector description
- Smaller magnetic field 4T→ 2T
- Larger tracker 1.5m→ 2.15m
- smaller beam-pipe 29mm→ 15mm
- adapting pattern recognition parameters

Summary

- ConformalTracking provides robust solution for pattern recognition
- Works in single particle as well as complex events
- Can cope successfully with beam induced backgrounds
- Perform well with displaced tracks
- Successfully handle different detector geometries
- github.com/iLCSoft/ConformalTracking/

BACKUP

CLIC and the European Strategy

- Formal European Strategy submissions
  - CLIC: Accelerator and Detector (arXiv:1812.07987)
  - CLIC: Physics Potential (arXiv:1812.07986)
- Yellow Reports
  - CLIC 2018 Summary Report (CERN-2018-005-M)
  - CLIC Project Implementation Plan (CERN-2018-010-M)
  - The CLIC potential for new physics (CERN-2018-009-M)
- Journal publications
  - Top-quark physics at the CLIC linear collider (arXiv:1807.02441)
  - Higgs physics at the CLIC electron-positron linear collider (arXiv:1608.07538)
- https://clic.cern/european-strategy

CLIC and the European Strategy

2013 – 2019

Development Phase
Development of a project plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 – 2025

Preparation Phase
Finalisation of implementation parameters, preparation for industrial procurement, pre-series and system optimisation studies, technical proposal of the experiment, site authorisation

2026 – 2034

Construction Phase
Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2020
Update of the European Strategy for Particle Physics

2026
Ready for construction

2035
First collisions