The CLIC detector

From the conceptual design and requirements to the silicon pixel detector R&D activities

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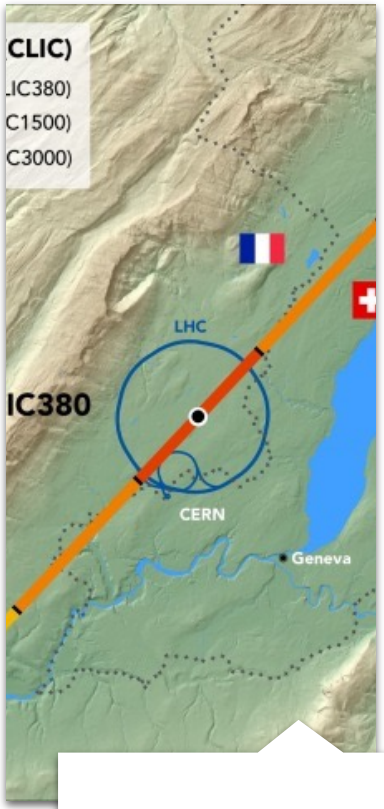
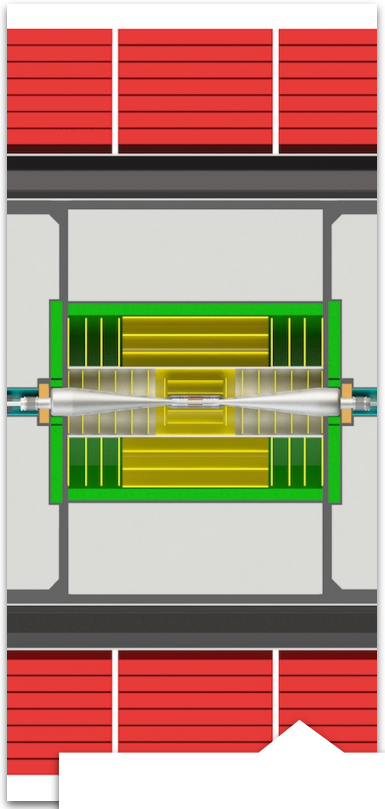
African Conference on High Energy Physics (ACHEP) **25/10/2023**

Rabat - Kenitra (Morocco) - 2023

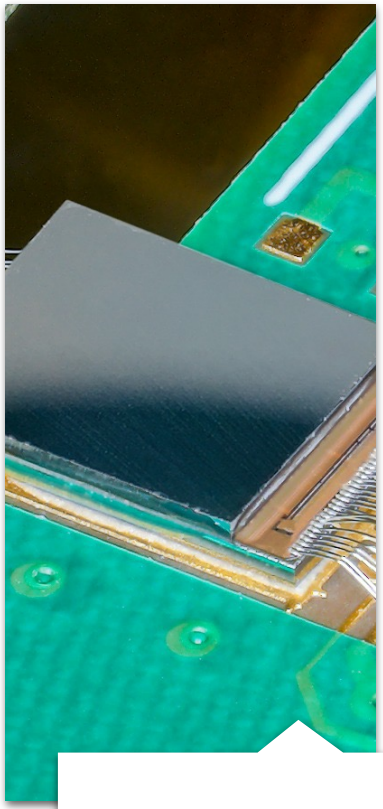
Outline



Compact Linear Collider



Detector concept



Silicon pixel R&D overview

Conclusion

Compact Linear Collider

Linear e^+e^- collider proposal for post-LHC

(Up to 50.1 km length)

Staged scenario with $\sqrt{s}$ up to 3 TeV

(380 GeV – 1.5 TeV – 3.0 TeV)

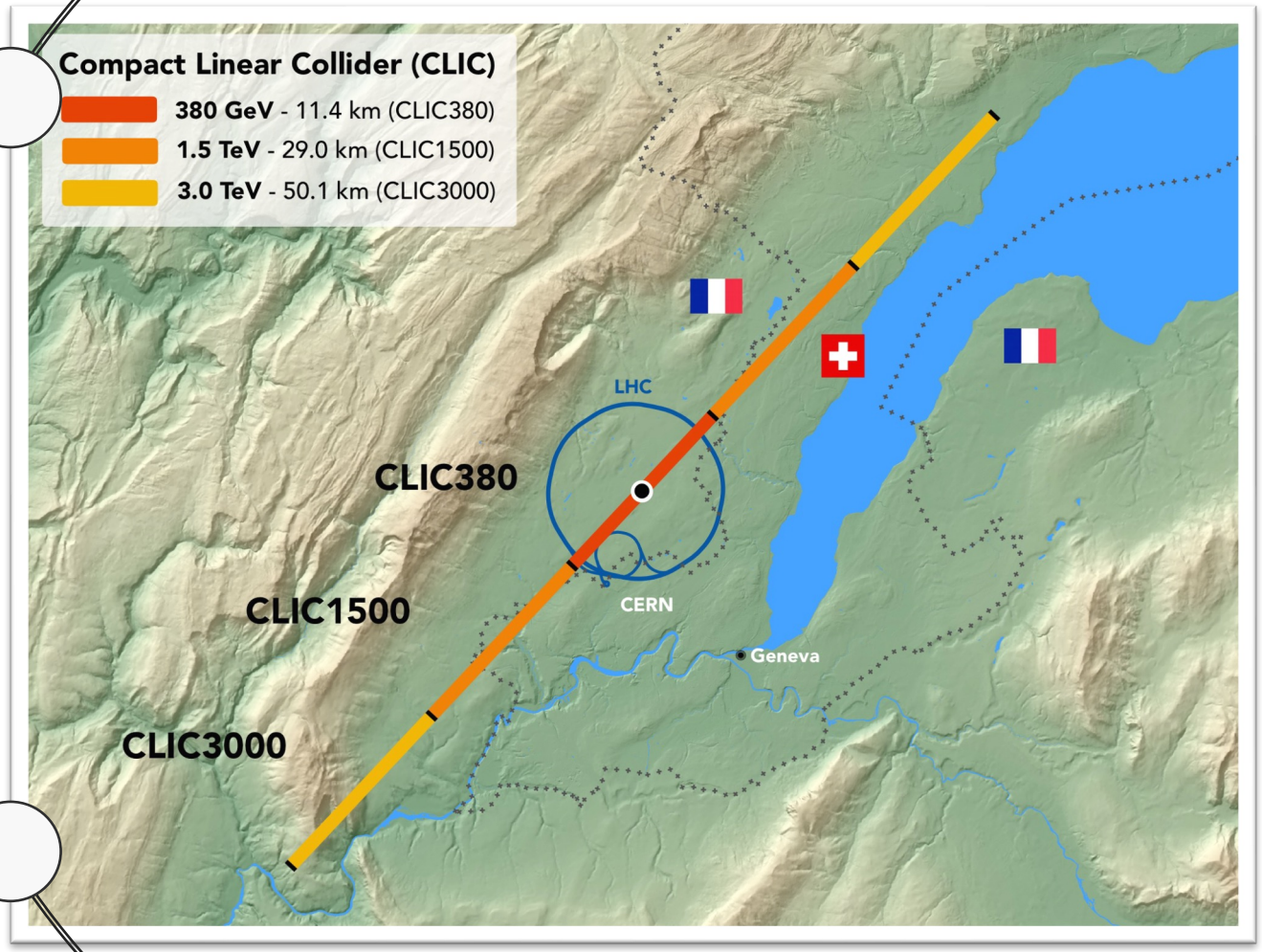
Two-beam RF acceleration scheme

Drive-beam complex + Main beam complex

(156 ns bunch trains and 50 Hz duty cycle)

Precision and discovery physics at the TeV scale

Extensive Higgs physics and beyond



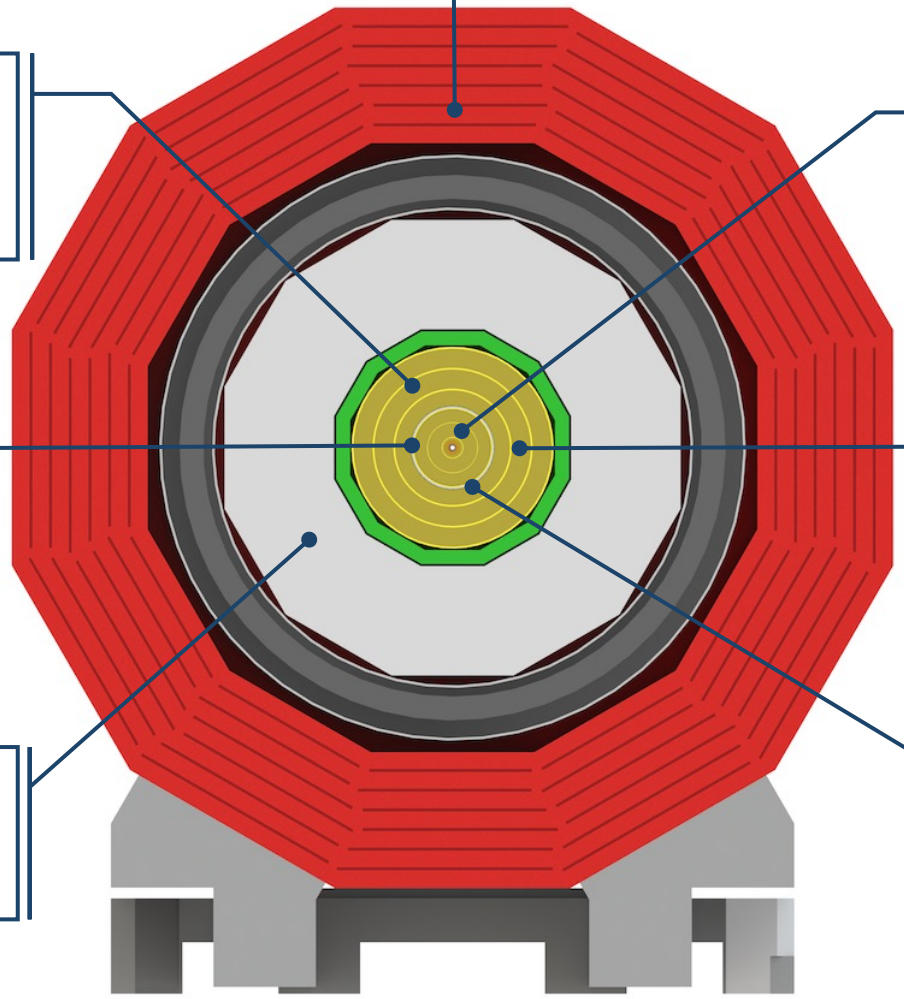
CLIC 2018 Summary Report – CERN 2018-005

Detector requirements

Driving force: precision physics

High track-momentum resolution for high-p_T tracks
$\sigma_{p_T^2}/p_T^2 \leq 2 \times 10^{-5}\,\mathrm{GeV}^{-1}$

High impact-parameter resolution
$\sigma_{d_0}^2 = (5\ \mu\mathrm{m})^2 + (15\ \mu\mathrm{m\ GeV})^2/(p^2 \sin^3\theta)$



High beam-induced background rates
(Maximum 8.8 Hits$[1/\mathrm{mm}^2/\mathrm{train}]$

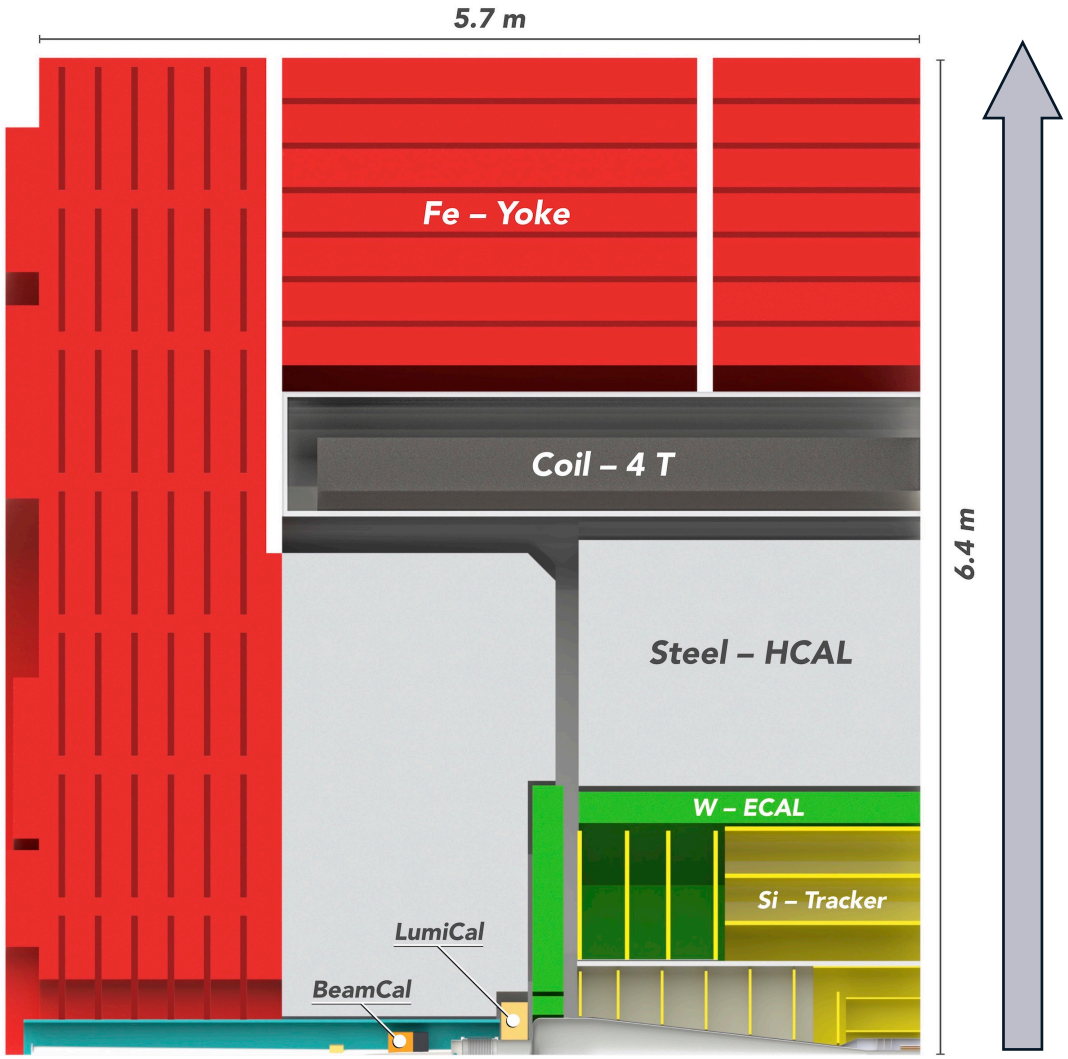
Low radiation hardness requirements
(Up to $6{\times}10^{10}\ \mathrm{n_{eq}}/\mathrm{cm}^2/\mathrm{yr}$)

High jet-energy resolution for light-quark jets
$\sigma_E/E \leq 3.5\%\ (100\ \mathrm{GeV} \leq E \leq 1\ \mathrm{TeV})$

Low polar angle coverage
($\sim$10 mrad)
for e^- and γ to assist background rejection

Detector Technologies for CLIC – CERN 2019-001

Detector concept: CLICdet



Trigger-less readout
- Thanks to short train duration and low duty cycle

Return yoke (iron) with muon detectors
- Magnetic field confinement and muon identification

Solenoid magnet
- Magnetic field B = 4T

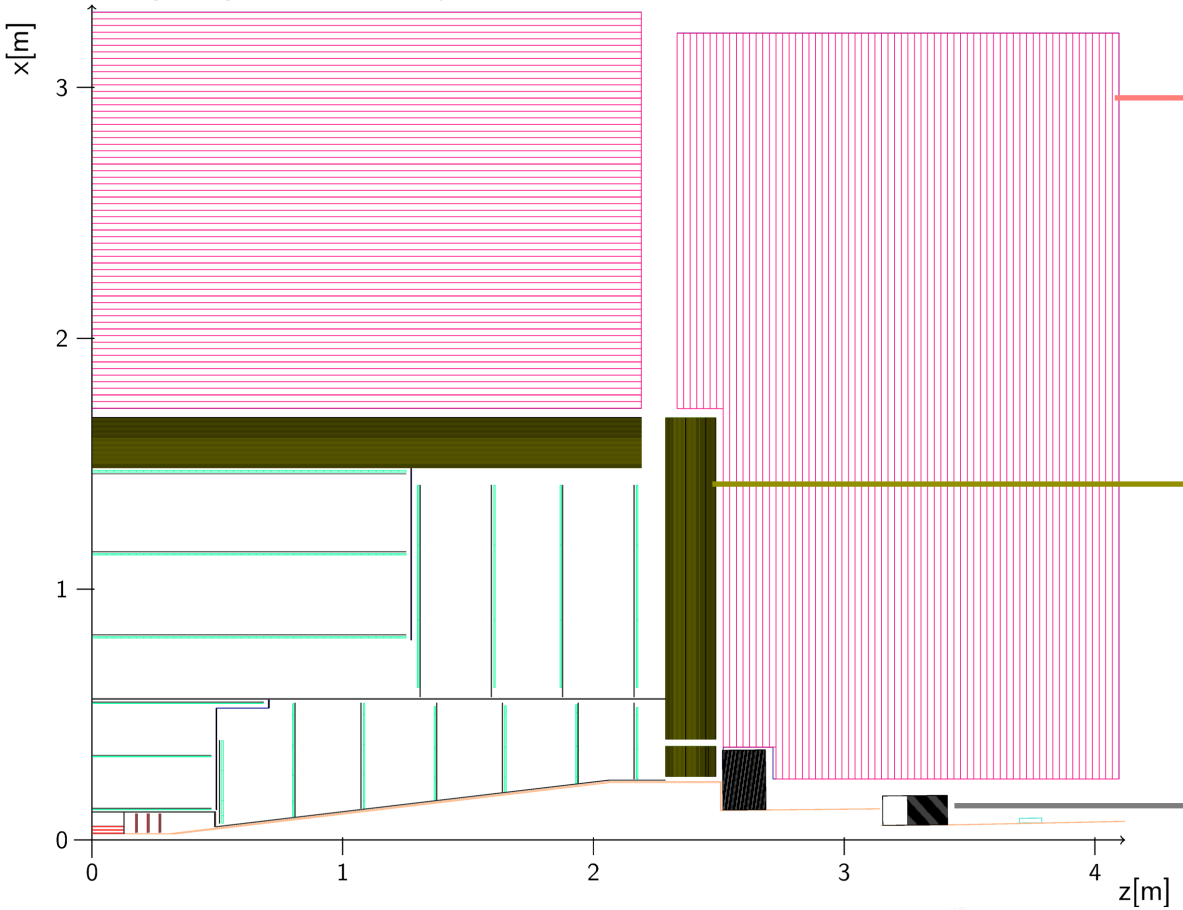
Highly granular calorimetry
- Optimised for Particle Flow Analysis

Full silicon vertex and tracking detector
- Fine pitch and ultra-low mass vertex detector

Forward luminometers
- LumiCal and BeamCal calorimeters

Electromagnetic and hadronic calorimeters

High granularity



Hadronic Calorimeter

- Steel absorber plates
- Scintillator tiles
- $30\times30\ mm^2$ tile size
- $7.5\ \lambda_I$ total thickness
- 60 layers

Electromagnetic Calorimeter

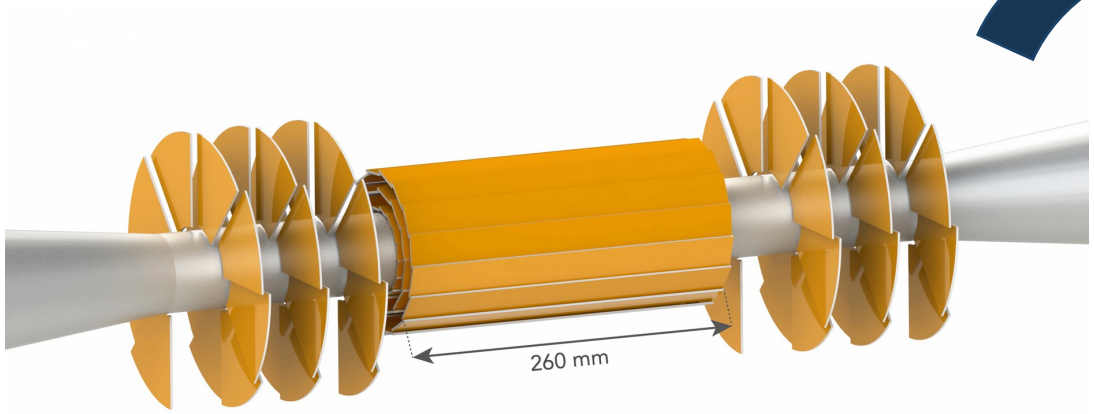
- Sampling calo
- Silicon-Tungsten
- $5\times5\ mm^2$ cell size
- $1\ \lambda_I$ total thickness
- 40 layers

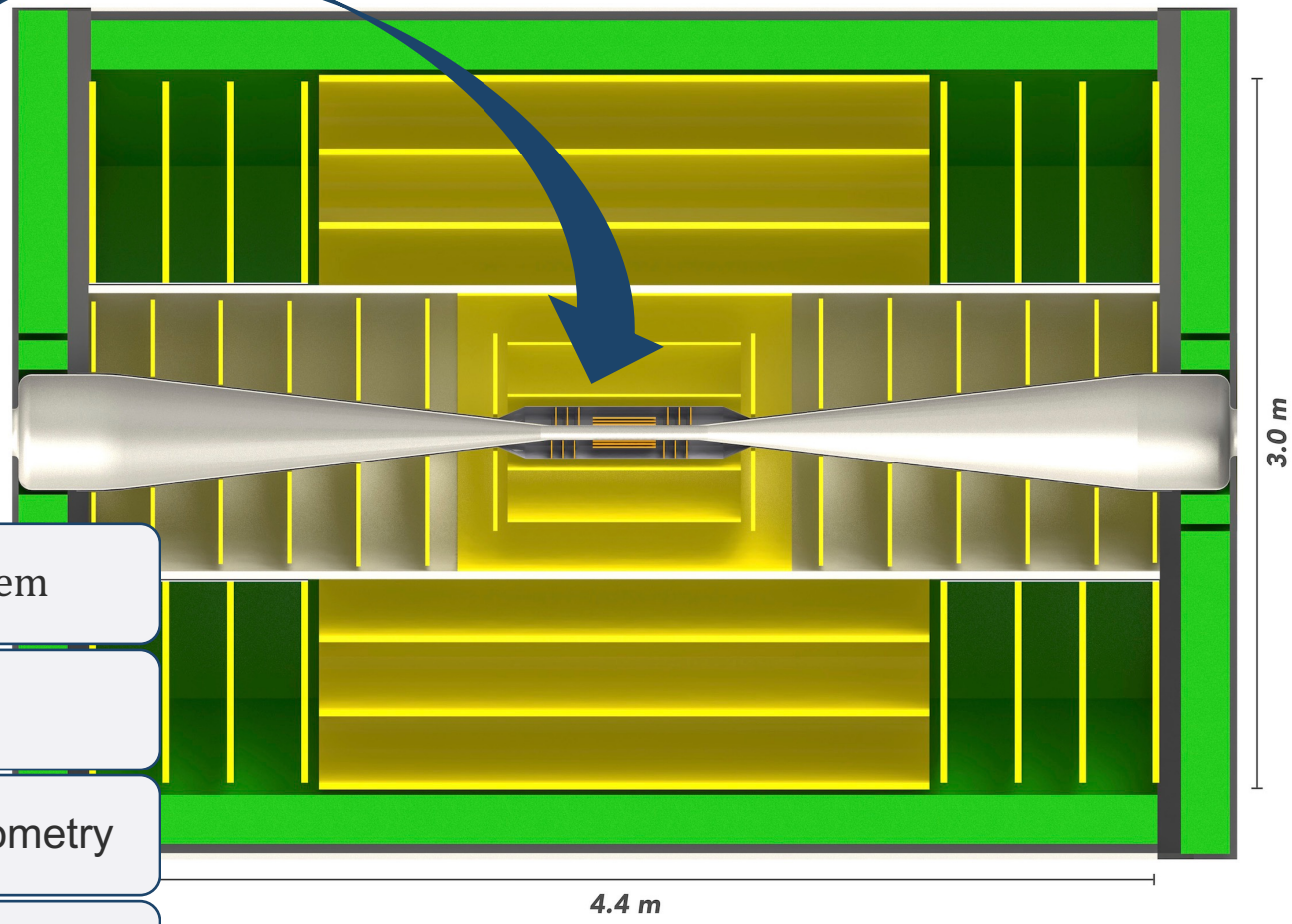
Forward Calorimeters

- LumiCal, BeamCal
- Luminometers
- Silicon-Tungsten
- $5\times5\ mm^2$ cell size
- 40 layers

Common R&D effort within the CALICE and FCAL collaborations

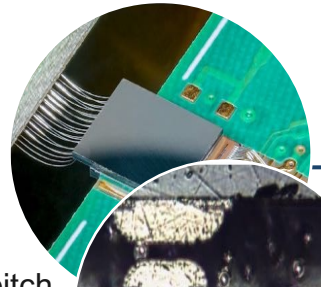
Vertex and tracking detector





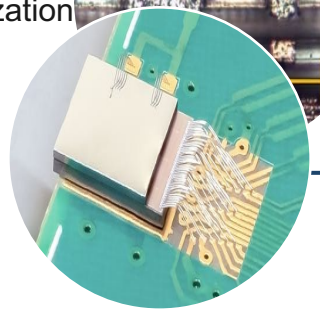
Cell size $(25\times25)\mu m^2$	Fine-pitch vertex system
Cell size $(0.050\times1-10)\ mm^2$	All silicon tracker
Allows air-flow cooling	Forward vertex spiral geometry
Background suppression	Nanosecond precision hit timing

Silicon pixel detector R&D overview



CLICpix2
+
C3PD

Fine-pitch
Hybridization



CLICpix2
+
planar

Hybrid Pixel Detectors

Detectors Development Tools

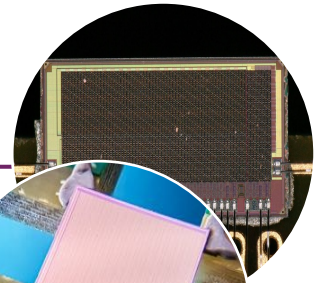
Caribou

Allpix Squared

Corryvreckan

Monolithic CMOS Detectors

H2M



CLICTD

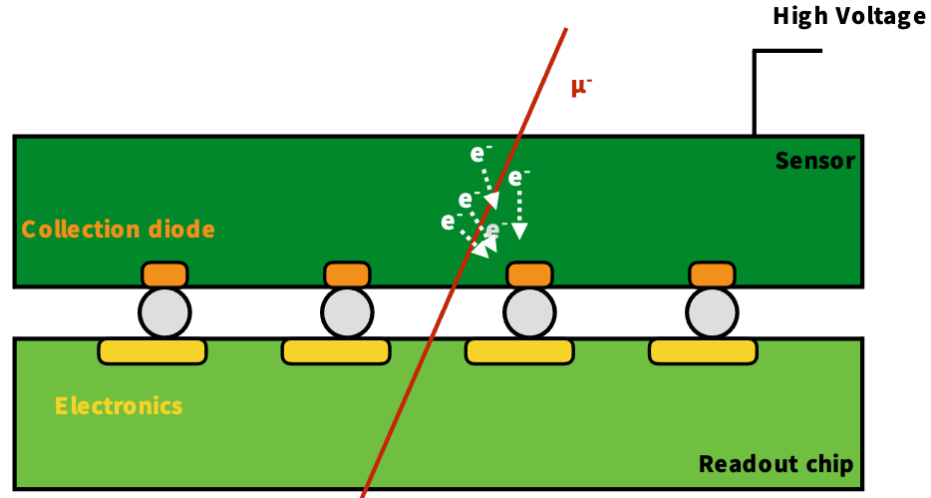
ATLASpix3

Various collaborative frameworks (CLICdp, CERN EP R&D, DRD 3/7, AIDAinnova, …)

Focus on conceptual studies and technology demonstrators

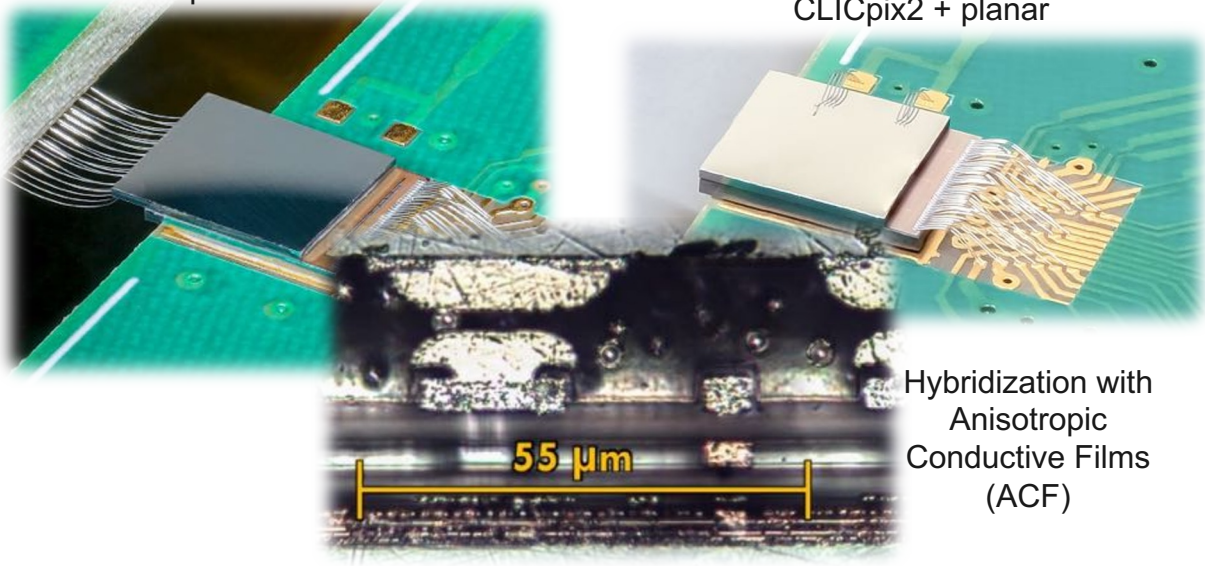
Hybrid pixel detectors

- **Target applications for CLIC**
  - Vertex detectors and timing layers
- **Separated sensor and readout ASIC**
- **Many new sensor concepts under investigation:**
  - Thin sensors with large fill factor
  - Active / passive CMOS sensors
  - Enhanced lateral drift (ELAD) for optimal position resolution
  - Charge amplification (LGAD) for picosecond timing
- **Improve interconnect technologies:**
  - Fine-pitch bump bonding
  - Bonding with Anisotropic Conductive Adhesives (ACA)
- **Challenges:**
  - Material budget
  - Interconnect: costs and target minimum pitch



CLICpix2 + C3PD

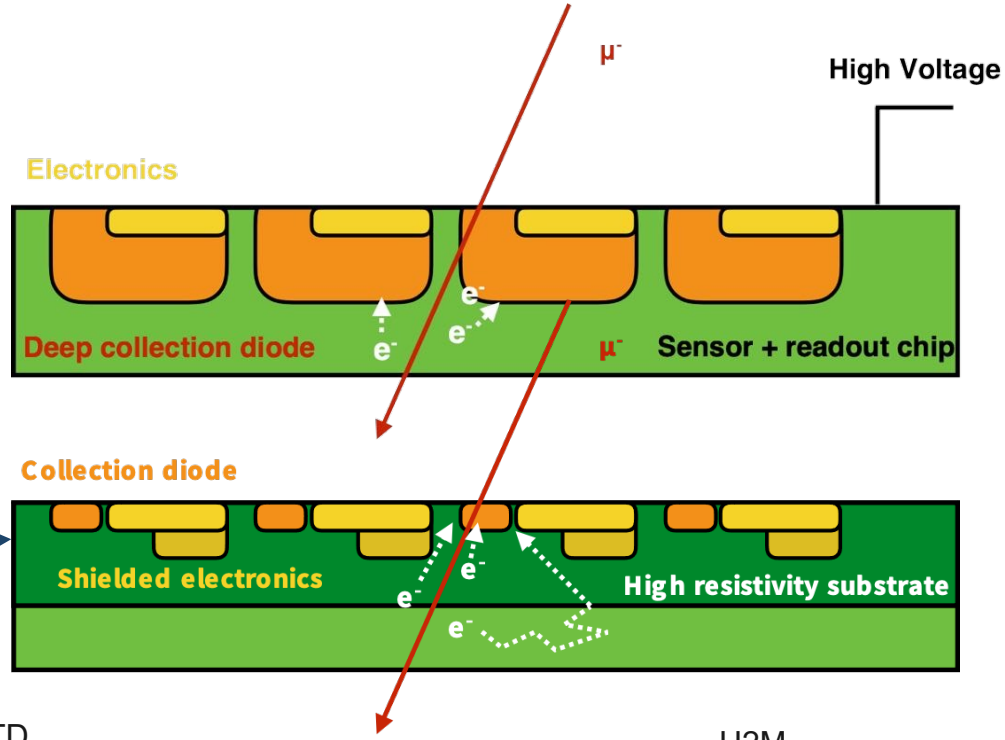
CLICpix2 + planar

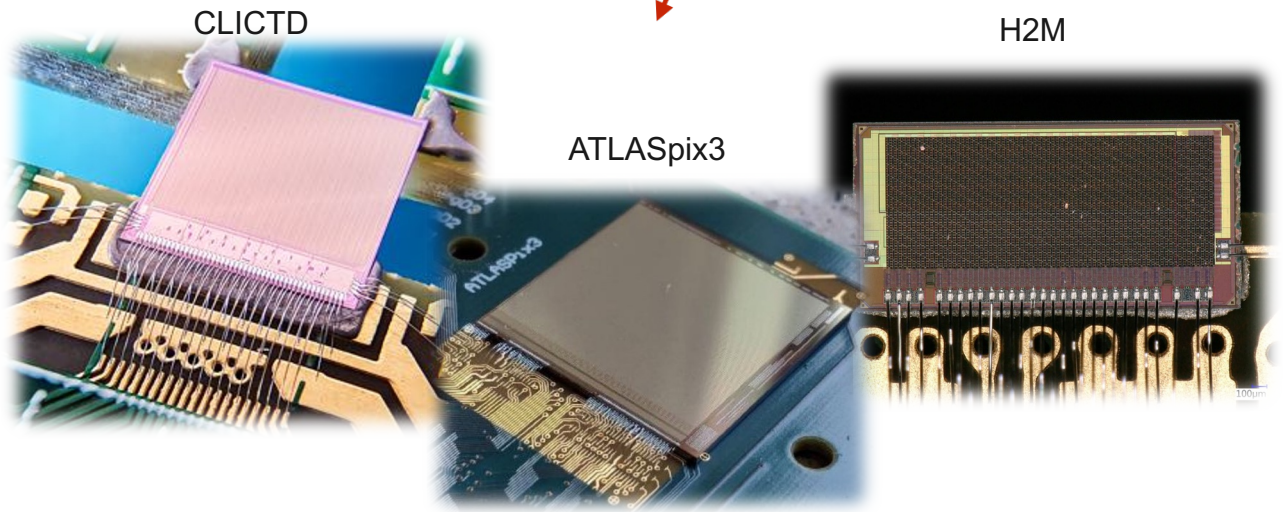


Hybridization with Anisotropic Conductive Films (ACF)

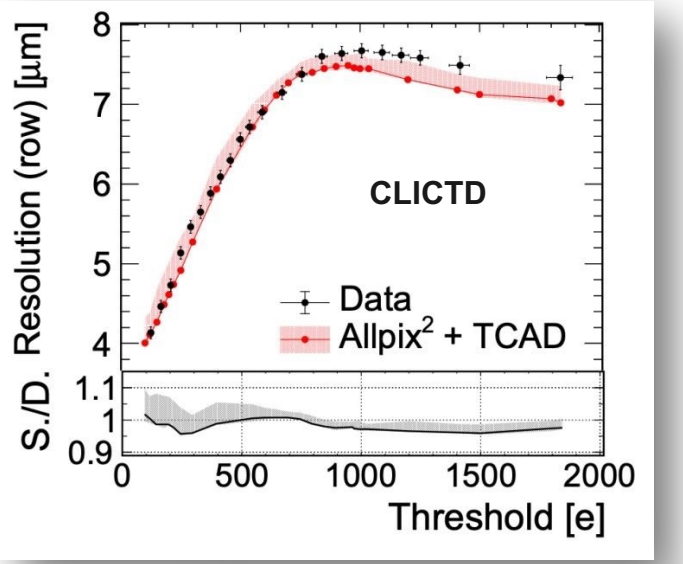
Monolithic CMOS detectors

- **Target applications for CLIC**
  - Vertex and trackers of all Higgs factory detectors
- **Fully integrated sensor and readout ASIC**
- **Multiple investigated concepts:**
  - Large-collection electrode High-Voltage (HV-CMOS)
  - Small-collection-electrode (low Capacitance, high SNR, low power)
- **No interconnect technology needed**
  - No bonding thus simplified construction
- **Trend towards smaller feature sizes**
  - 180 nm → 65 nm for improved performance
- **Challenges:**
  - Complex non-uniform sensor structures
  - Interplay of sensor and readout
  - Limited access to proprietary information



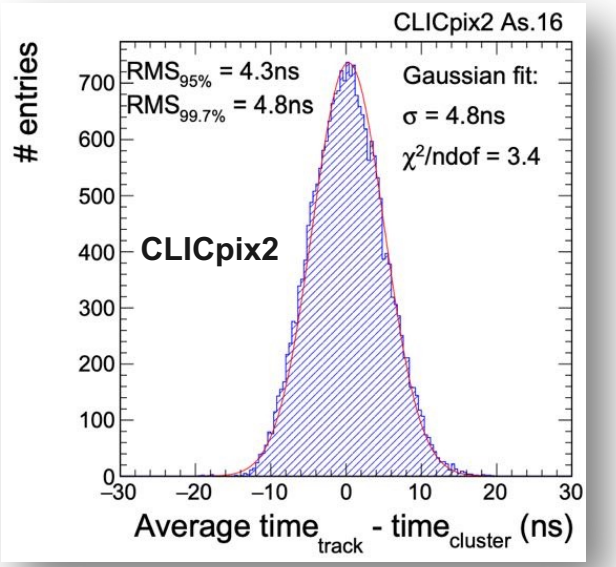


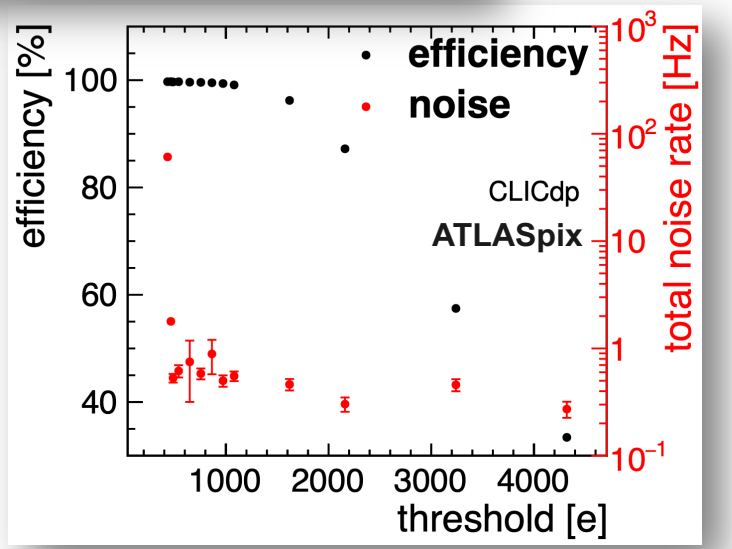
Performance studies

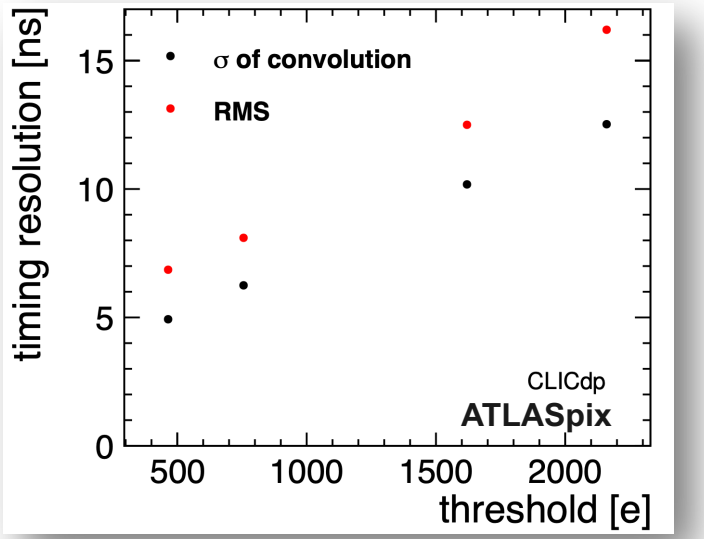


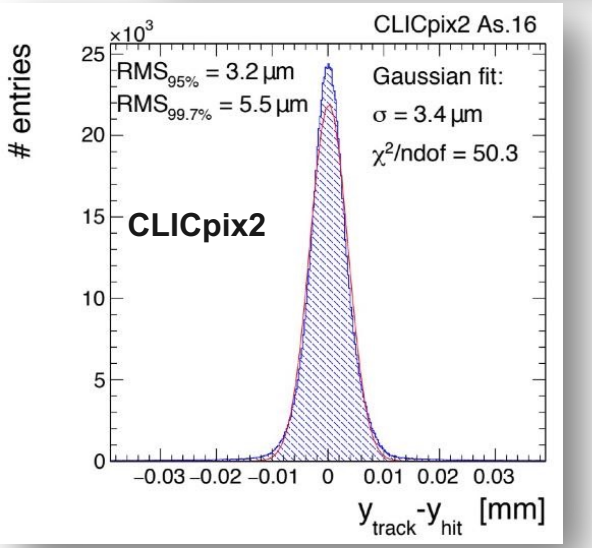
Individual vertex/tracker requirements achieved

Combination of low material budget and high measurement precision remains challenging





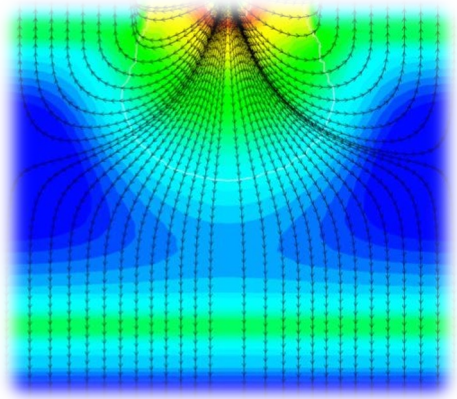




Detectors development tools

Detector Simulation

Allpix Squared framework



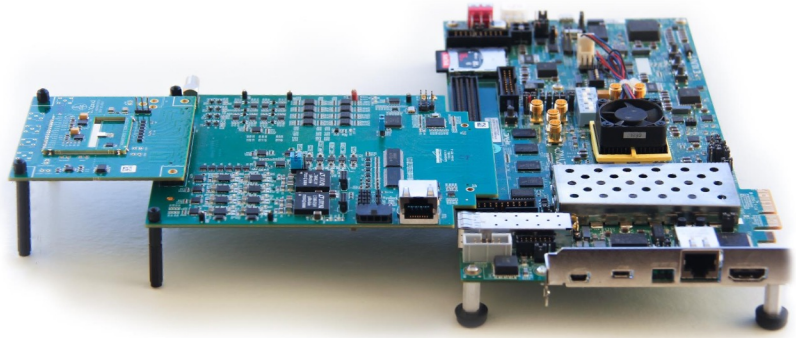
Modular simulation toolkit

Combines finite-element (3D TCAD) and Monte Carlo simulation

Targets many applications HEP and beyond

DAQ Test-System

Caribou system



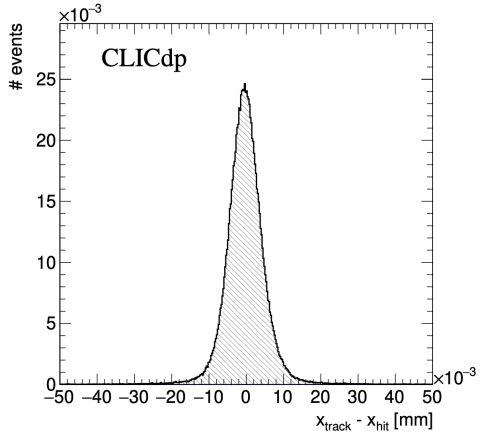
Versatile SoC-based DAQ system

Provides unified hardware, firmware and software platform to wide user base in HEP community

Keeps user focus on detector integration and characterization

Test-Beam Analysis

Corryvreckan framework



Modular data reconstruction framework

Highly flexible and configurable reconstruction and analysis workflow

Wide user base in HEP (CLICdp, ALICE, CMS, ATLAS, LHCb, Mu3e, …)

Conclusions

- **Stringent requirement for CLIC detector subsystems**
  - Precision physics needs
  - Environmental conditions

- **Optimized detector concept with different technology choices is proposed**

- **Diverse detector technology R&D programme is pursued:**
  - Broad silicon R&D profiting from advancements in semiconductor industry
  - Targetting both Vertex/Tracker

- **Fulfilling all CLIC detector requirements simultaneously remains challenging**

- **Further progress requires:**
  - Integrated focused efforts
  - Combining optimization and physics exploration
  - Broadening technology R&D and detector-integration studies

- **Final words:**
  - CLIC offers a strongly proven feasability and a large physics potential (see Jan Klamka's talk)

Thank you

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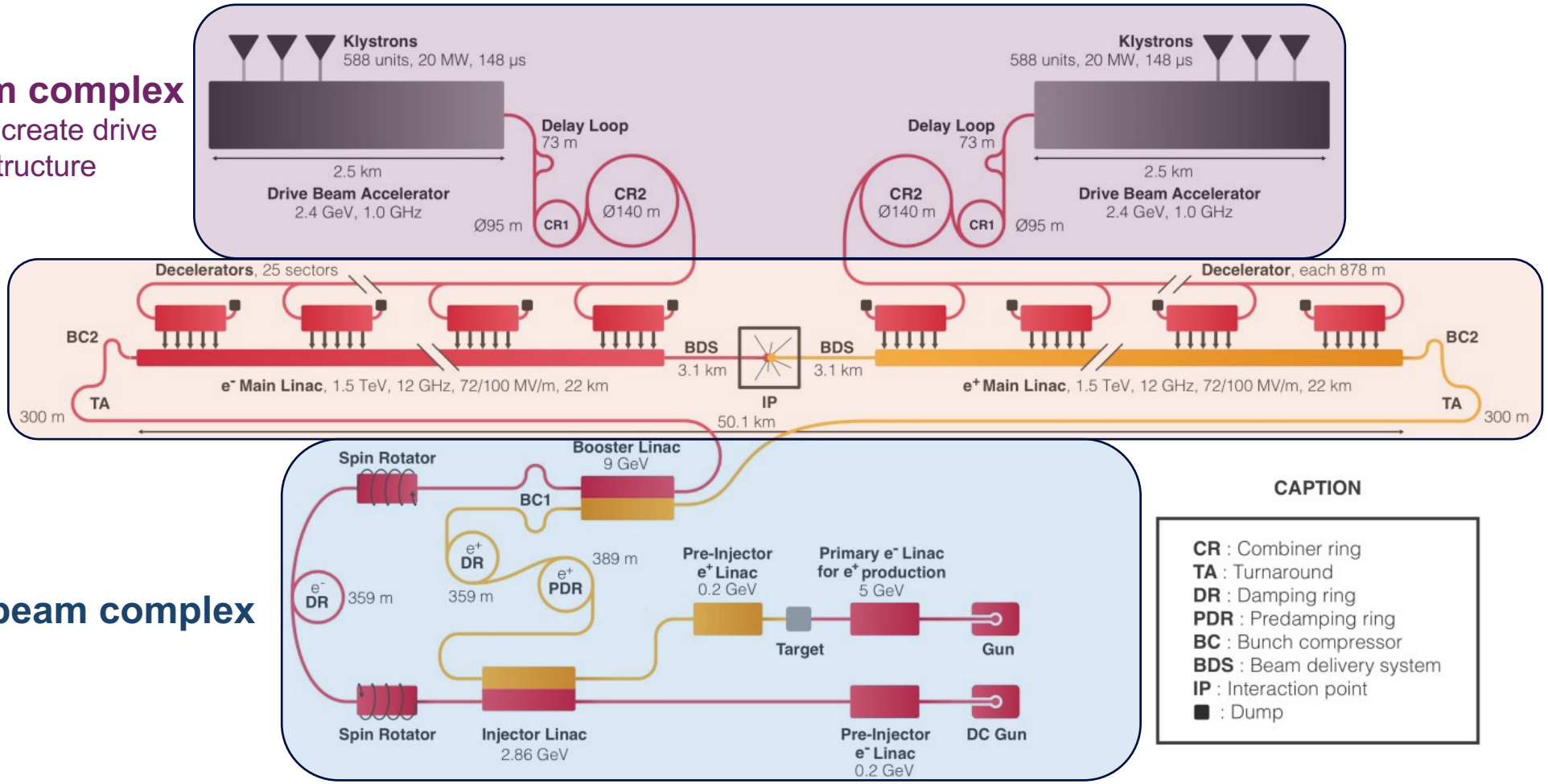
Accelerator layout at 3 TeV

Drive beam complex
Delay loops create drive beam structure

Main beam complex



Two-beam RF acceleration scheme

CLIC Project Implementation Plan – CERN 2018-010

3 TeV