# OVERVIEW OF THE CLIC DETECTOR AND ITS PHYSICS POTENTIAL

4th International Conference on New Frontiers in Physics

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on behalf of the CLICdp Collaboration

29 August 2015

# Outline

- Introduction
- CLIC Accelerator
- CLIC Physics Programme
  - Higgs Physics
  - Top Physics
  - BSM Physics
- Detector Requirements
- CLIC Detector Concept

# CLIC Detector and Physics (CLICdp)

Light-weight collaboration structure

No engagements, on best-effort basis

With strong links to ILC

clicdp.web.cern.ch

CLICdp: 26 institutes

**Focus of CLIC-specific studies on:**

- Physics prospects and simulation studies
- Detector optimisation + R&D for CLIC

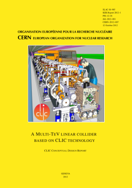
## Timeline:

2008: New start of Detector and Physics studies

- Using ILC detectors as a starting point
- Initial aim: CLIC Conceptual Design Report

2012: CLICdp was set up

2012: CLIC Conceptual Design Report published



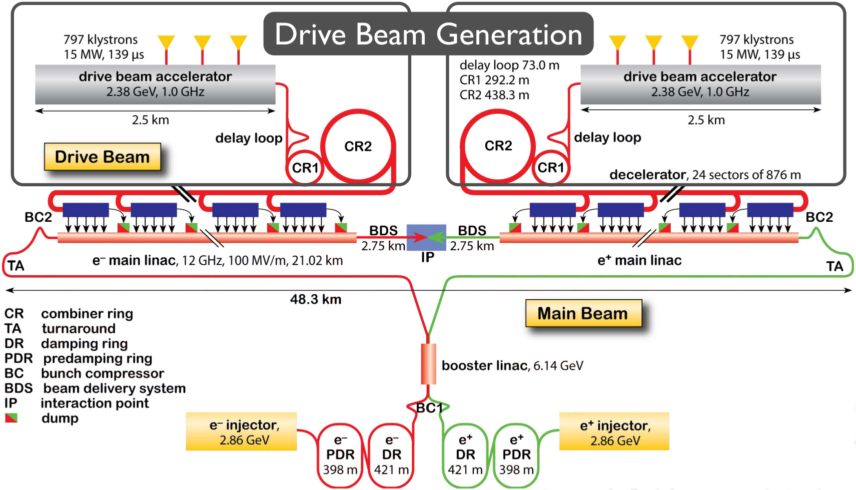



2012/2013: Input to European strategy process

2015: Developed new detector concept

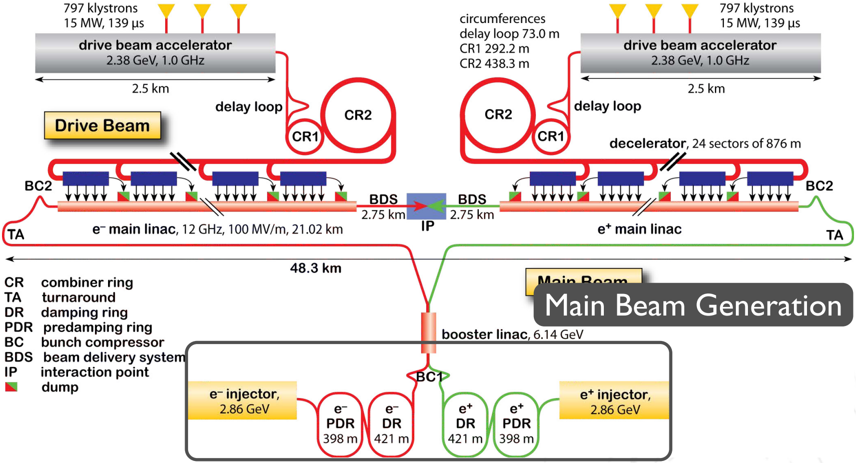
2018/19: Decision $\rightarrow$ update of European strategy

# CLIC Accelerator



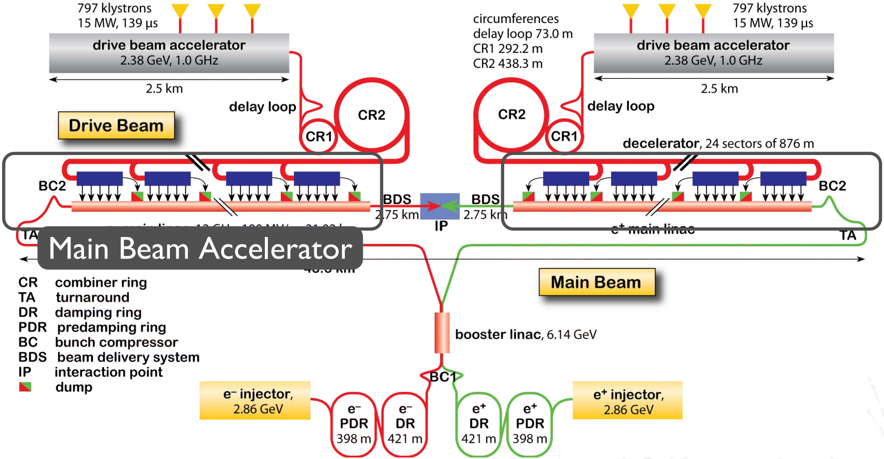

- Generation of high current (100 A) drive beam with delay loop and combiner rings

# CLIC Accelerator



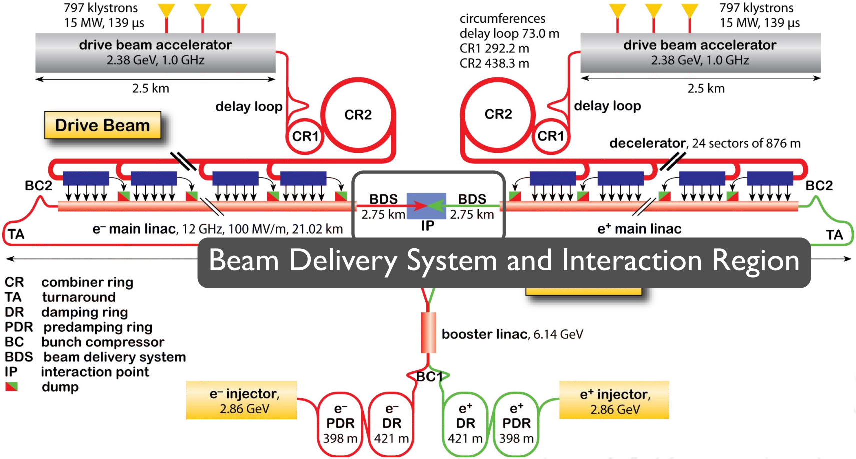

- Need small emittance main beam to achieve large luminosity
- Generation and conservation of small emittance
- Alignment and stabilisation of accelerator components

# CLIC Accelerator




- Drive beam deceleration: Power Extraction and Transfer
- Two beam acceleration: Transfer RF from drive to main beam
- Main linac gradient: Accelerating structures/Break down rate

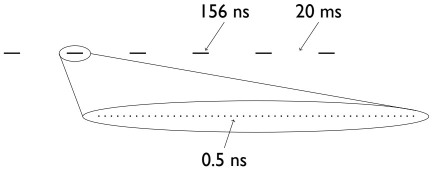
# CLIC Accelerator




- Final focus magnets
- Very stringent requirements for alignment and stabilisation

# CLIC Accelerator

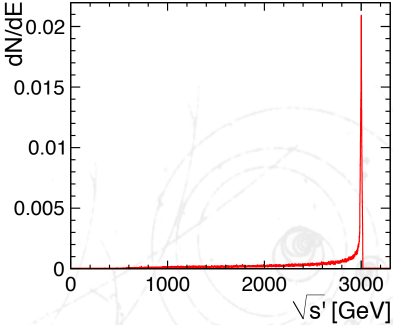
- Operated at room temperature
- Gradient: 100 MV/m
- Deflection of particles by other bunch $\rightarrow$ synchrotron radiation
- Energy loss leads to luminosity spectrum




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

Has large impact on detector requirements

| CLIC | 3 TeV |
|---|---|
| $\mathcal{L}$ [$cm^{-2}s^{-1}$] | $5.9 \times 10^{34}$ |
| Rep rate [Hz] | 50 |
| Duty cycle | 0.00078% |
| $\sigma_{x,y}$ [nm] | $45 \times 1$ |
| $\sigma_z$ [$\mu$m] | 44 |



# CLIC Energy Stages

CLIC would be implemented in several energy stages

**Current scenario:**

Stage 1: 500 $fb^{-1}$ @ 350/380 GeV

Precision SM Higgs and top physics

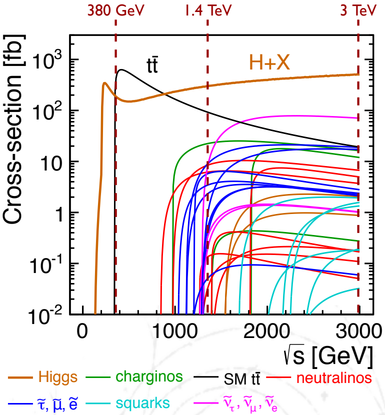
Stage 2: 1.5 $ab^{-1}$ @ 1.4 TeV:

BSM physics, rare Higgs processes

Stage 3: 2 $ab^{-1}$ @ 3 TeV :

BSM physics, rare Higgs processes

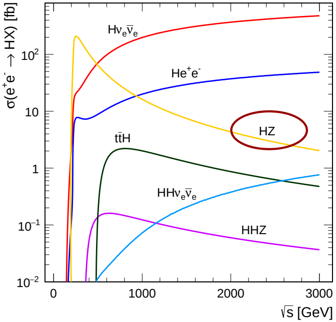
Each stage corresponds to 4-5 years

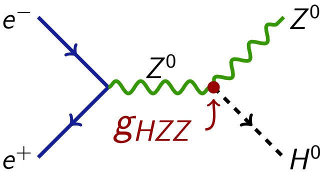



**Flexibility!**

Strategy can be adapted to possible LHC discoveries at 13 TeV!

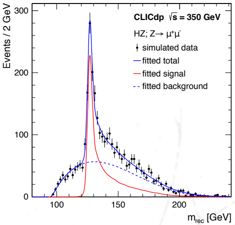
# Higgs Measurements

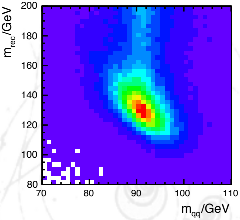



## Higgsstrahlung: $e^+e^- \to ZH$

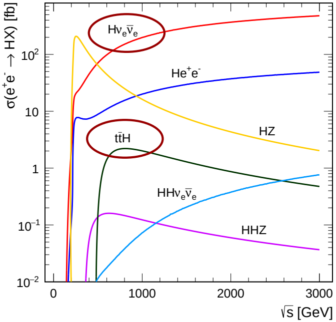
- $Z \to \ell^+\ell^-$, Higgs identified from recoil
- model-independent determination of Higgs mass and $g_{HZZ}$ (uncertainty $\sim 2\%$)
- $Z \to q\bar{q}$
- selection ensures model-independent determination of $g_{HZZ}$ (uncertainty $\sim 0.9\%$)




- Combined uncertainty $\sim 0.8\%$

# Higgs Measurements

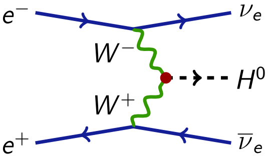


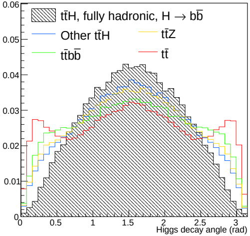

### *WW* Fusion: $e^+e^- \to H\nu_e\overline{\nu}_e$

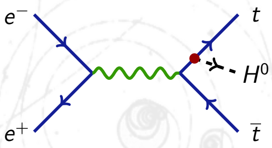
- $\sigma \propto \log s$ dominant > 450 GeV
- 3 TeV access to $H \to c\overline{c}$ and rare Higgs decays like $H \to \mu^+\mu^-$
- Model independent Higgs width

### $t\bar{t}H$ Production: $e^+e^- \to t\bar{t}H$

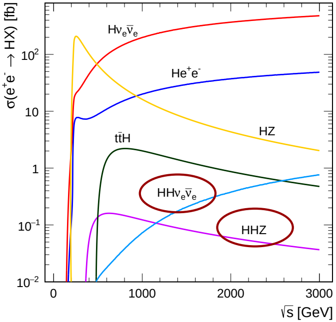
- Sensitive to top Yukawa coupling
- Peaks 800 GeV measured @1.4 TeV



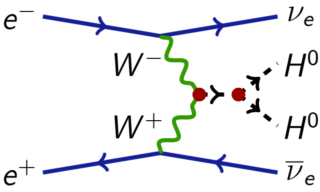



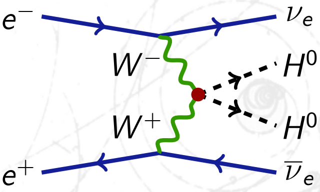
# Higgs Measurements




## Double Higgs production

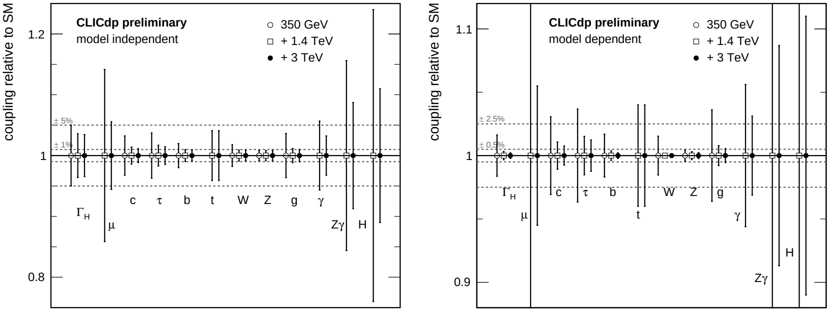
- $e^+e^- \to ZHH$ max. @600 GeV
- $e^+e^- \to HH\nu_e\overline{\nu}_e$
- Only 225 (1200) $HH\nu_e\overline{\nu}_e$ events at 1.4 (3) TeV
- High luminosity and high energy crucial
- Sensitive to Higgs self-coupling and the quartic coupling
- quartic coupling $g_{HHWW}$ ($\sim$ 3%) and self-coupling $\lambda$ ($\sim$ 12%)



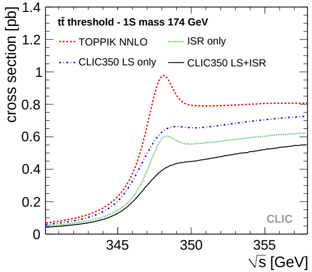
# Higgs Measurements Summary

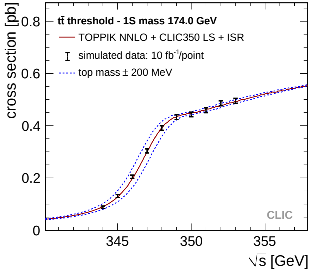
Lepton collider allows to measure Higgs properties with high precision




- Model independent extraction only at lepton colliders
- Due to model independent measurement of $g_{HZZ}$
- Many couplings measured with $\sim$ 1% precision
- Higgs width extracted with 5-3.5% precision
- Model dependent fits can achieve precision below 1%, strongly dependent on fit assumptions

# Top Pair Production Threshold

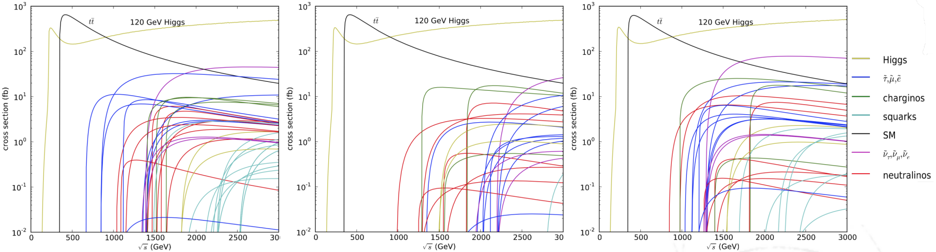



- Measure $t\bar{t}$ production at different $E_{\mathrm{cms}}$ around threshold
- Cross section distorted by ISR and Luminosity Spectrum
- Combined with selection efficiency and background contamination
- Precision on $1S$ mass: $\sim$ 50 MeV
- Theoretical uncertainty $\sim$ 10 MeV when transforming the measured $1S$ mass to the $\overline{\mathrm{MS}}$ mass scheme
- Precision at the LHC limited to about 500 MeV

# Prospects for BSM Physics at CLIC

- Direct searches via pair-production up to kinematic limit $\sqrt{s}/2$
- Precision measurement of new particle masses and couplings




**CDR Model I, 3 TeV:**
- Squarks
- Heavy Higgs

**CDR Model II, 3 TeV:**
- Smuons, selectrons
- Gauginos

**CDR Model III, 1.4 TeV:**
- Smuons, selectrons
- Staus
- Gauginos

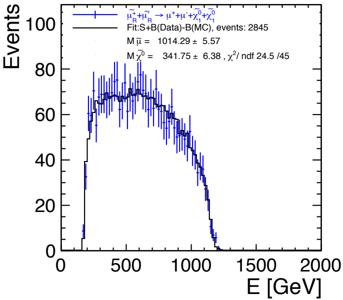
- In general $\mathcal{O}(1\%)$ precision on masses and cross-sections
- Wider applicability: classify spin and quantum numbers

# Prospects for BSM Physics at CLIC

## Sleptons and Gauginos

- Slepton signature very clean: leptons and missing energy

  $e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$
- Endpoint of spectra $\to$ mass
- Slepton mass precision $< 1\%$ for sleptons below 1 TeV

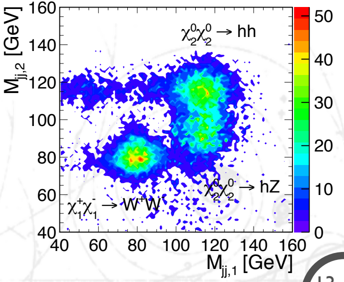



- Chargino and neutralino $\to$ 4 jets and $E_{\text{Miss}}$

  $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$

  $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 h^+h^-$

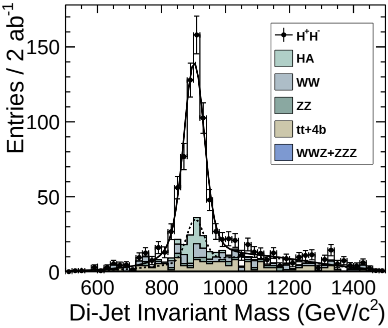
  $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 Zh$
- Gaugino mass precision $1 - 1.5\%$

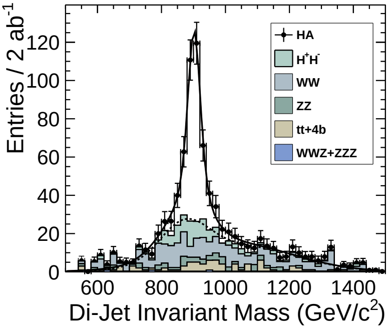


# Prospects for BSM Physics at CLIC

## Heavy Higgs Bosons

- Degenerate in mass $\rightarrow$ complex final state, heavy flavour jets
  $e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$
  $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$
- Separation requires heavy-flavour tagging (benchmark for detector optimisation)
- Precision of 0.3% on heavy Higgs masses

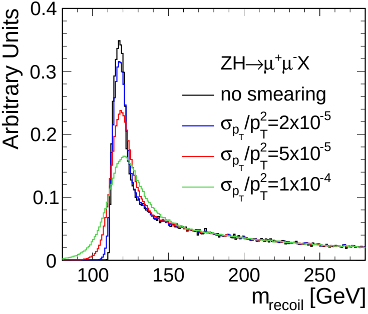


# From Physics Aims to Detector Needs

- **Momentum resolution:**

  Higgs recoil, $H \to \mu\mu$ or $\ell$ from BSM
  $\frac{\sigma(p_T)}{p_T^2} \sim 2 \times 10^{-5}$ GeV$^2$




- 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
  $\sigma_{r\phi} = \sqrt{a^2 + b^2 \cdot \text{GeV}/(p^2 \sin^3\theta)}$
  with $a = 5\ \mu$m and $b = 15\ \mu$m

- Angular coverage

  lepton identification, very forward electron tagging

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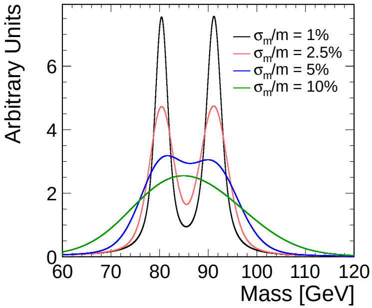

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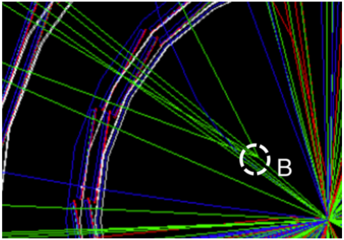


- Angular coverage

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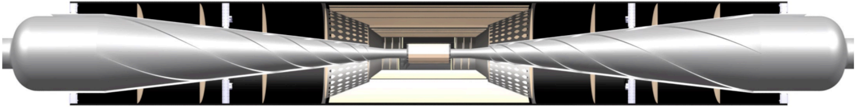
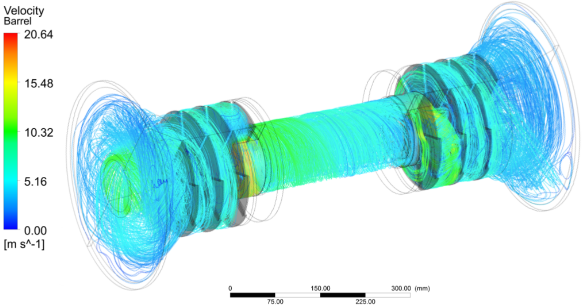
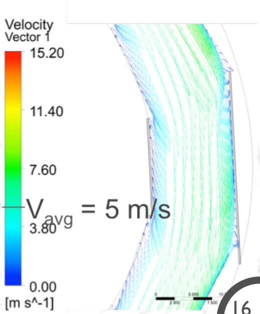
# Vertex R&D

- 3 $\mu$m point accuracy $\rightarrow$ 25 $\times$ 25 $\mu m^2$ pixels and 10 ns timing
- Low material budget $\rightarrow$ $0.2\% X_0$ per detection layer
- Low-power design, power pulsing $\rightarrow$ 50 mW cm$^{-2}$



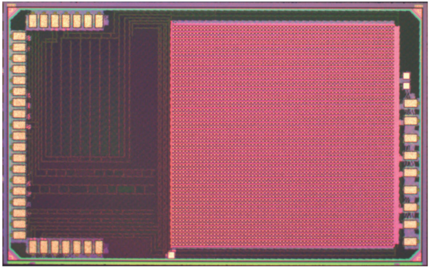



- Air cooling

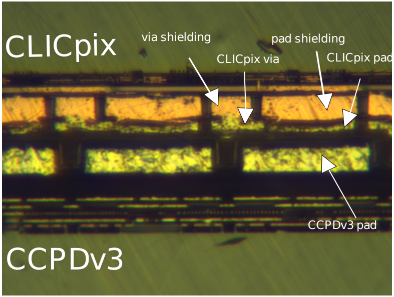


# Vertex R&D

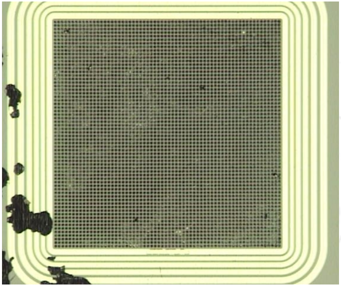
- CLICpix first pixel chip in 65 nm technology
  - Collaboration with LHC upgrades (RD53)
- Two lines of utilization studied:



1. Capacitively coupled to active sensor

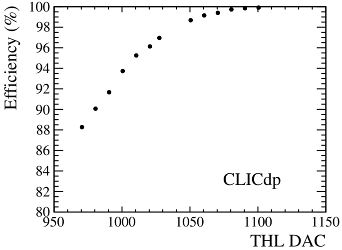


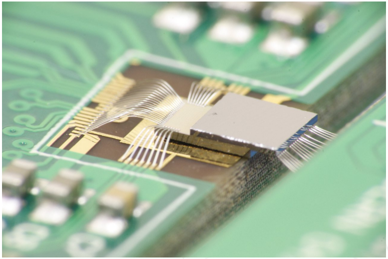

2. Bump bonded to planar sensor



# Vertex R&D

- Option 1:
  - HV-CMOS active sensor with two-stage amplifier in each pixel
  - Capacitively coupled to readout



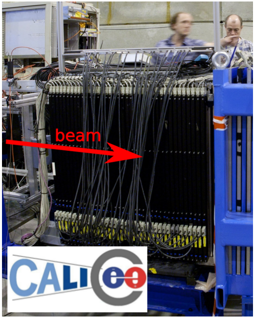



  - 99.9% hit efficiency achieved in beam
- Option 2:
  - Successfully bump bonded and tested in beam two weeks ago
  - Successfully operated device → results at future conferences

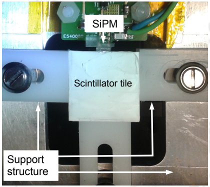
# Calorimetry R&D

- R&D in CALICE collaboration
- Jet energy resolution goal 3.5% above 100 GeV $\rightarrow$ high-granularity sampling calorimeters
  $\rightarrow$ readout cell size of few $cm^2$
- CALICE test beam experiments + analysis:
  - Electromagnetic/Hadronic calorimeters with: scintillator, silicon or gas
  - W and Fe as absorbers
  - Analogue and digital readout
    Example: Scintillator tiles+SiPM

CALICE test beam experiments



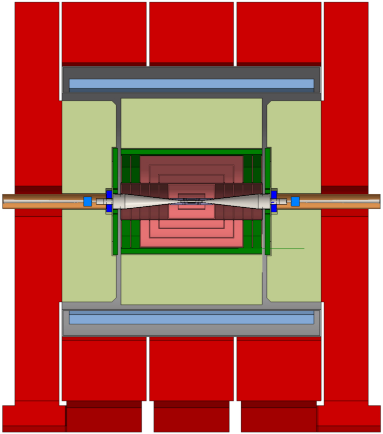

Scintillator (20mm$\times$20mm)




Lab setup

# New CLIC Detector Concept

- R&D + MC analysis $\rightarrow$ new detector concept
- New concept and simulation SW chain being developed



- B Field of 4 T
- Vertex detector: 3 double layers
- Silicon tracker: $r = 1.5$ m
- ECal (silicon + W) with 25 layers ($23X_0$)
- HCal (analog + Fe) with 60 layers ($7.5\lambda$)
- Precise timing for background
  - 10 ns stamping for tracks
  - 1 ns accuracy for calo. cluster

# Summary and Conclusions

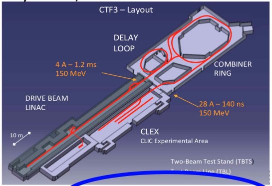
- Well-established physics programme
- Higgs physics:
  - model independent measurements
  - precision measurements and rare decays (high statistics)
  - top Yukawa coupling and Higgs self-coupling
- BSM physics
  - direct searches possible up to the kinematic limit
  - mass measurements of BSM particles up to %-level precision
- Precision top physics
- Very active R&D programme ongoing
- The CLIC technology has been demonstrated in large scale-tests
  - No show stoppers identified
  - CLIC is an available option for CERN after the LHC

# BACKUP

# CLIC Strategy and Objectives

### 2013-18 Development Phase

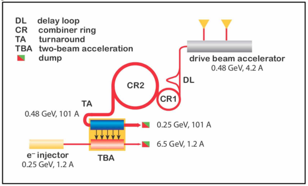
Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.




### 4-5 year Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

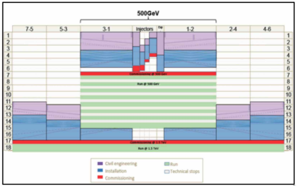
Prepare detailed Technical Proposals for the detector-systems.




### Construction Phase

Stage 1 construction of CLIC, in parallel with detector construction.

Preparation for implementation of further stages.




### 2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

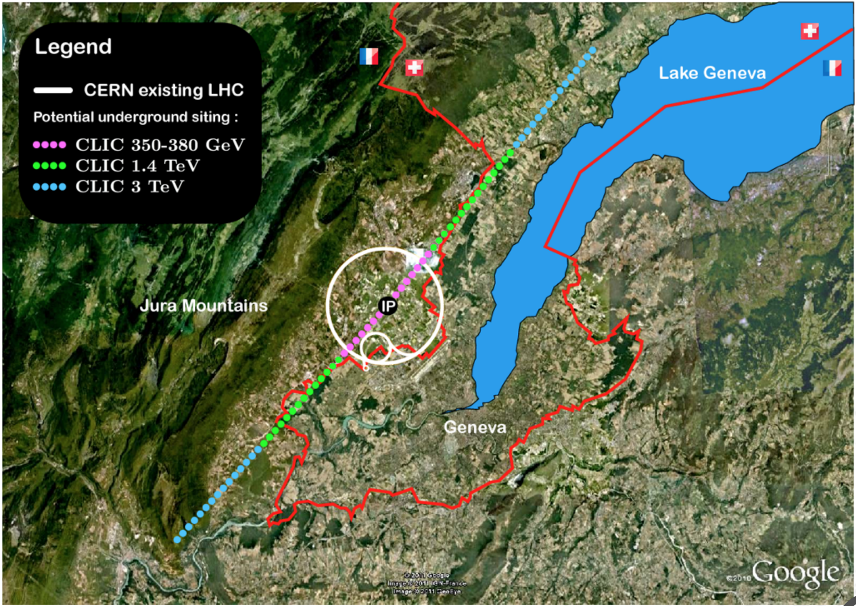
### 2024-25 Construction Start

Ready for full construction and main tunnel excavation.

### Commissioning

Becoming ready for data-taking as the LHC programme reaches completion.

# CLIC Layout


Legend
CERN existing LHC
Potential underground siting :
CLIC 350-380 GeV
CLIC 1.4 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva
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