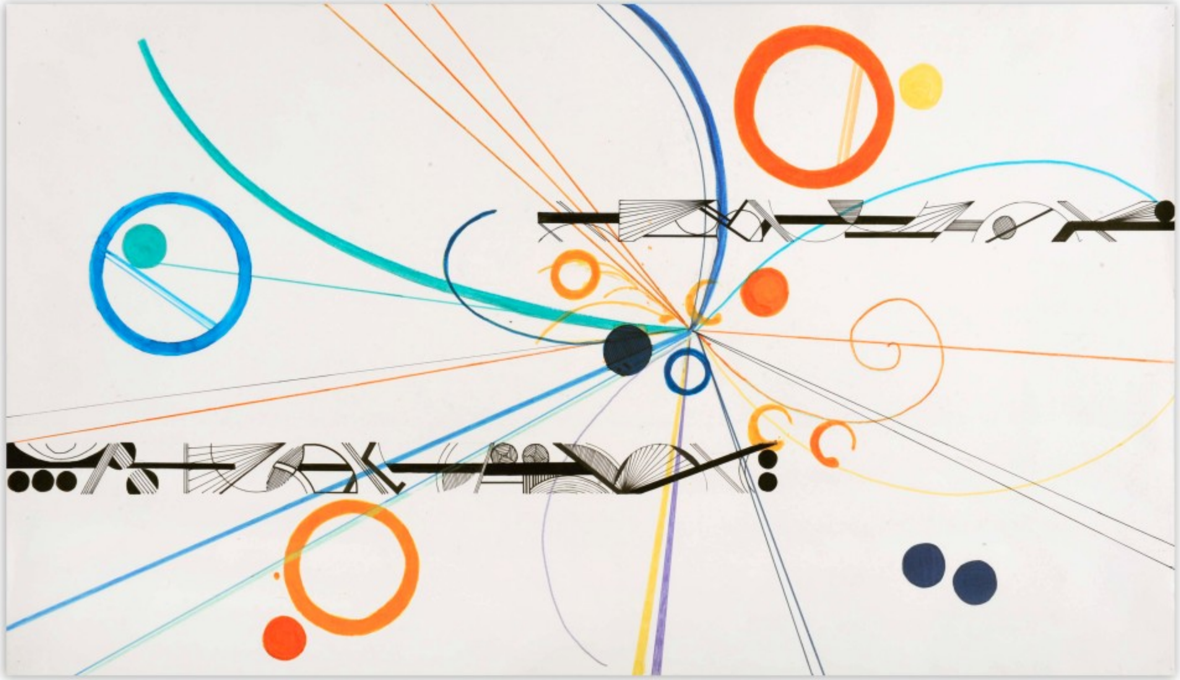

“My own visions of CLIC”, artwork by Natasha de Heney, 2010

News on physics and detectors at CLIC

Erica Brondolin
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on behalf of the CLICdp Collaboration

New Trends in High-Energy Physics
Budva, 27th September 2018

Main topics

- **Introduction**
- **CLIC accelerator**
- **CLIC detector**
- **Physics potential**
- **Summary**


“My own visions of CLIC”, artwork by Vilma Heiskaner, 2010

Introduction

CLIC accelerator

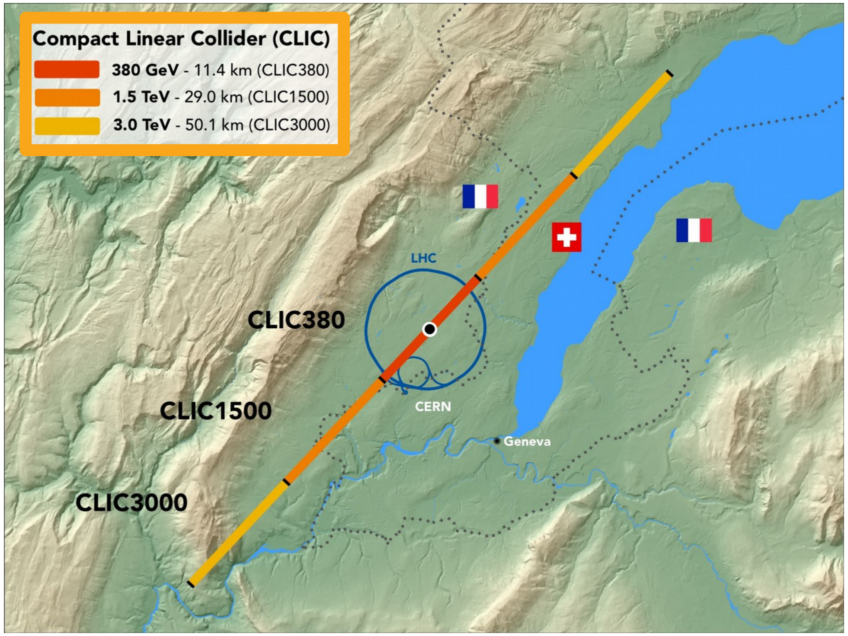
- **CLIC = Compact Linear Collider**
- High-luminosity linear e^+e^- collider
- Centre-of-mass energy from few hundred GeV up to 3 TeV
- CLIC would be implemented in several energy stages (7-8 years each)
- NEW baseline scenario:

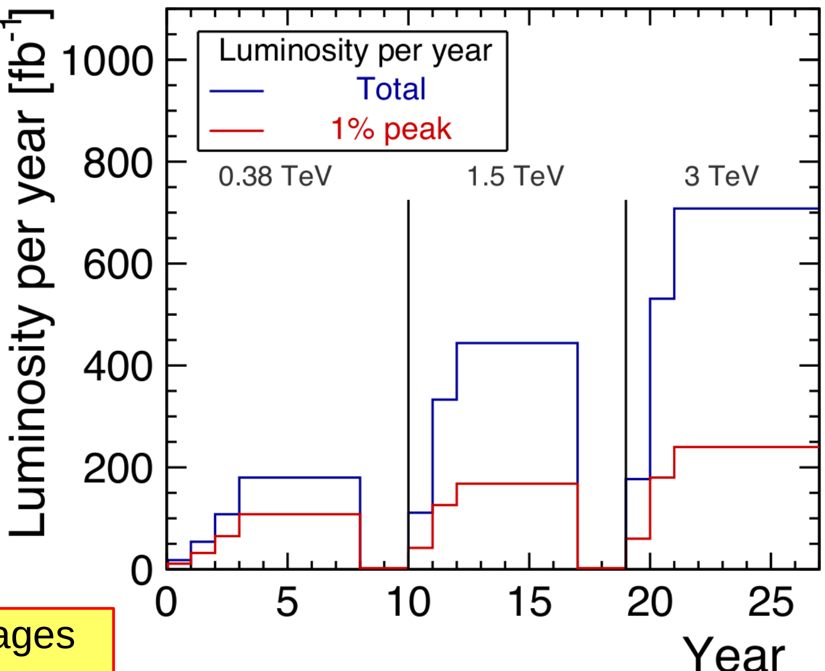
Stage	Centre-of-mass en.	L_{int} (fb^{-1})
1	380 GeV (and 350)	1000
2	1.5 TeV	2500
3	3 TeV	5000

+ 80% polarization of the e^- beam

- **Physics goals:**
  → Precision measurement of SM processes
  → Precision measurement of new physics (discovered at LHC or CLIC)
  → Search for BSM

Possibility to adapt the stages to new LHC discovery!





CLIC collaborations

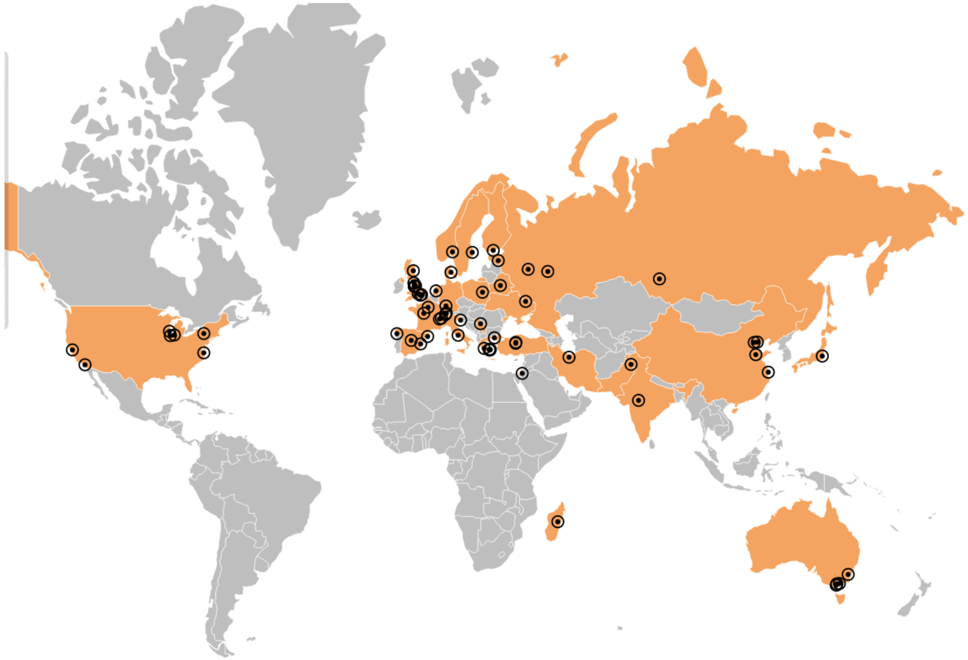
CLIC accelerator collaboration
~70 institutes from **~30 countries**

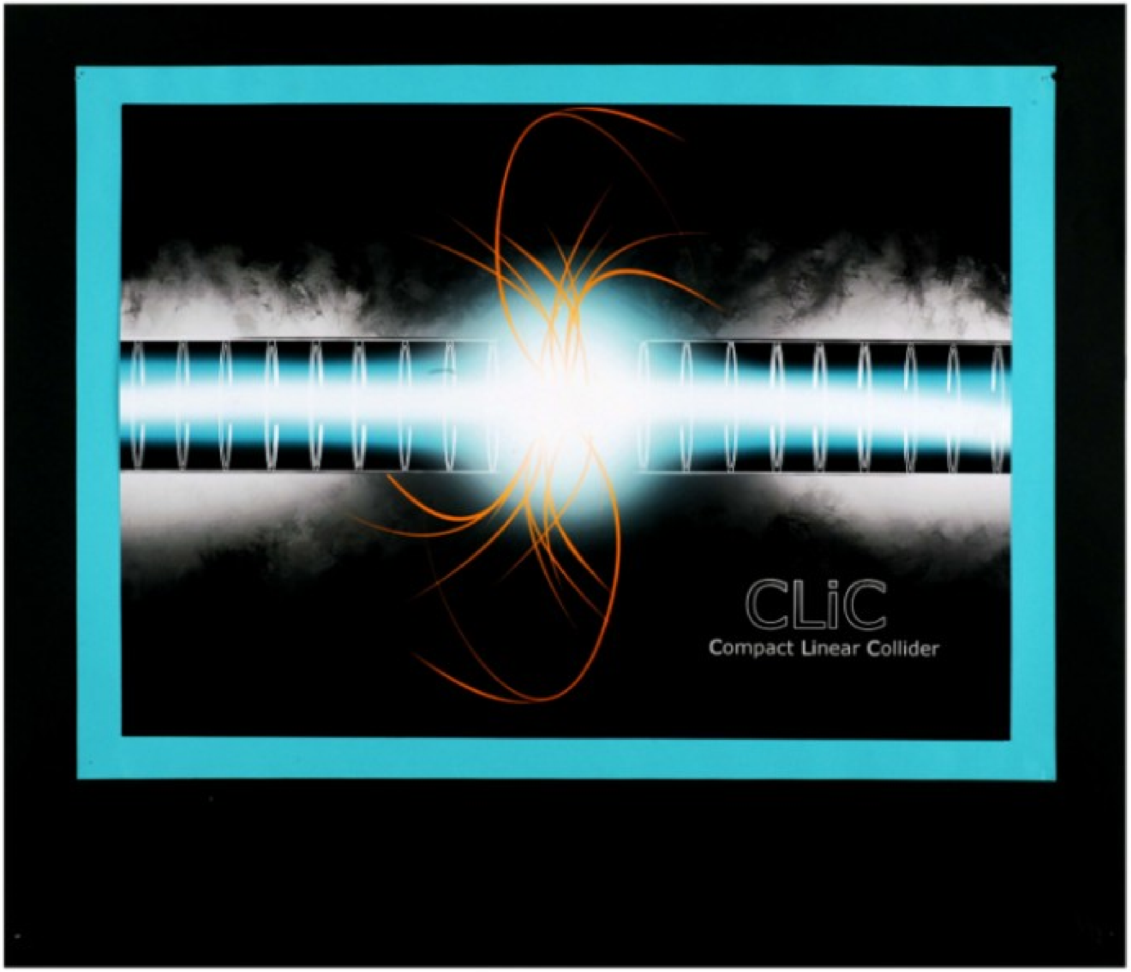
CLIC accelerator studies:
- CLIC accelerator design and development
- Construction and operation of CTF3

CLIC detector and physics (CLICdp)
~30 institutes from **18 countries**

Focus of CLIC-specific studies on:
- Physics prospects and simulation studies
- Detector optimization + R&D for CLIC

http://clic.cern

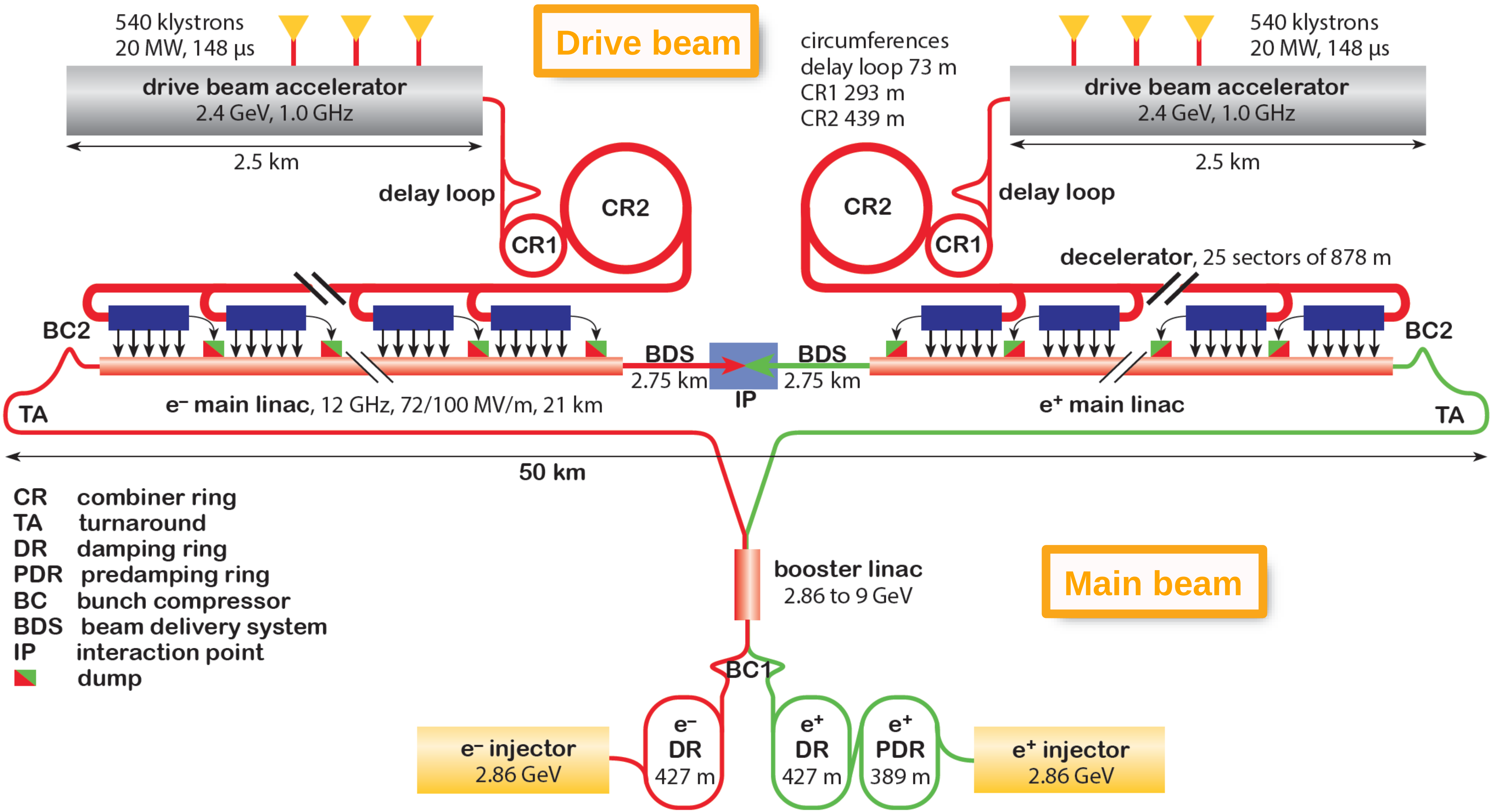




“My own visions of CLIC”, artwork by Alexander Duncan, 2010

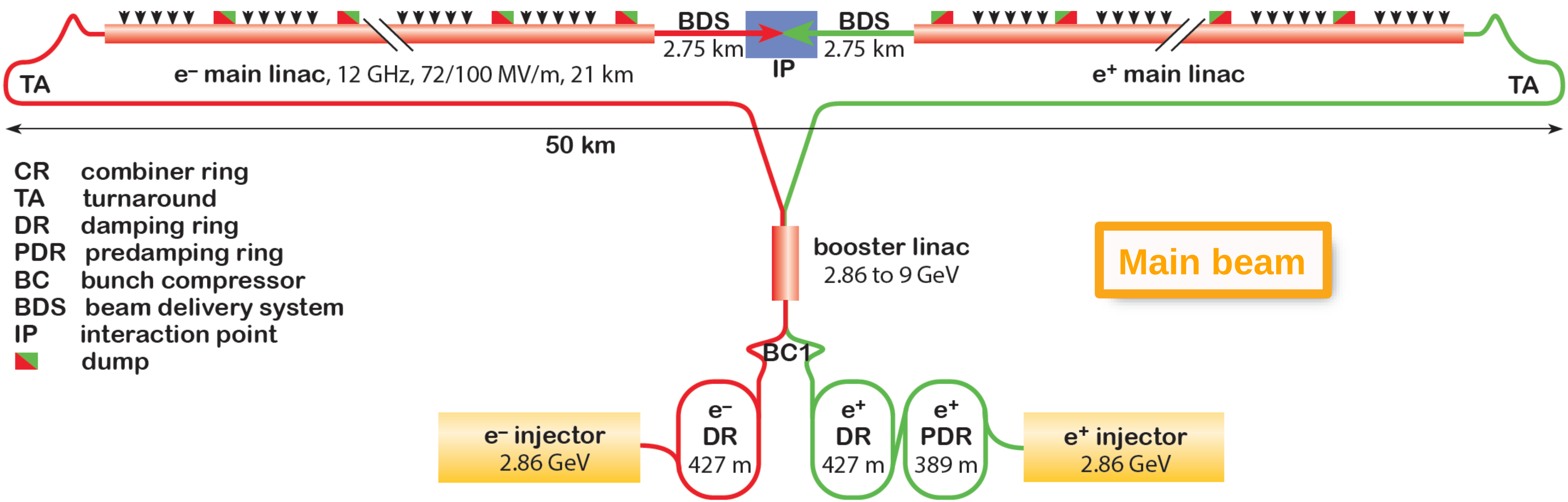
CLIC accelerator

CLIC layout at 3 TeV



+/-80% polarised **unpolarised**

CLIC layout at 3 TeV

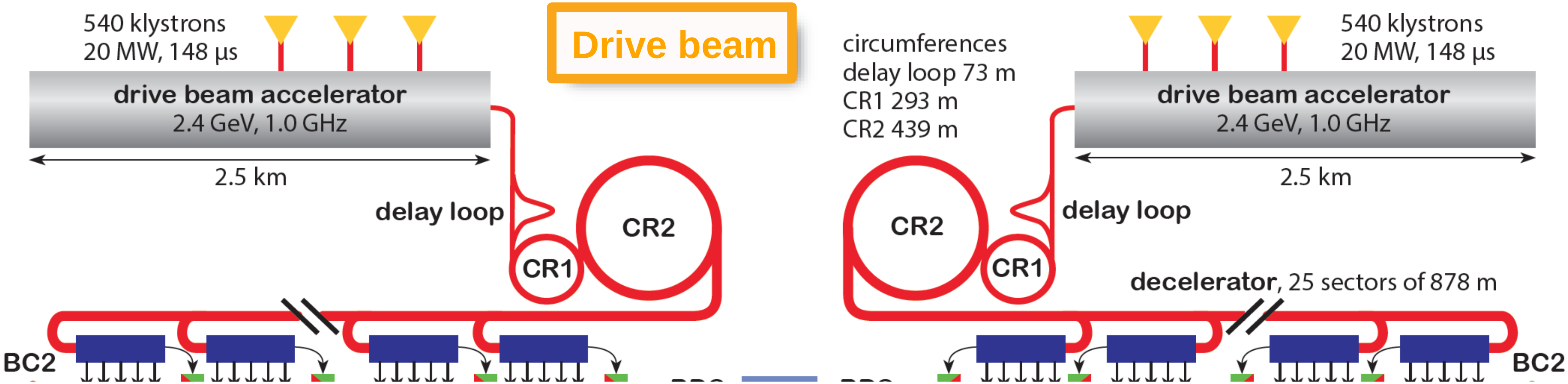


+/-80% polarised unpolarised

CLIC layout at 3 TeV

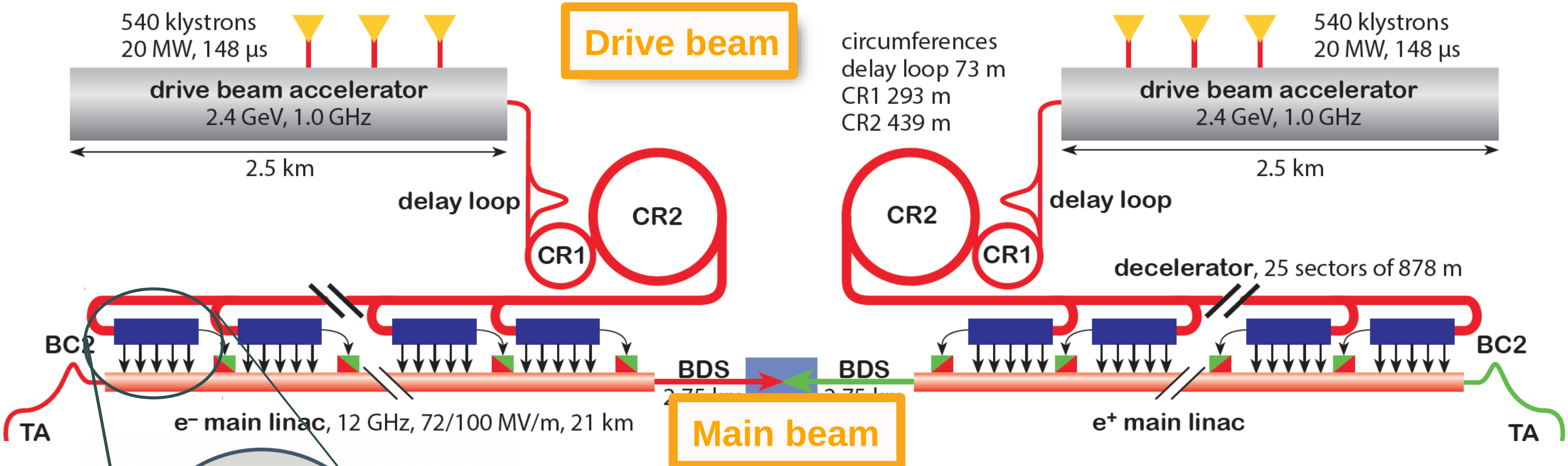
High centre-of-mass energy requires high-gradient acceleration

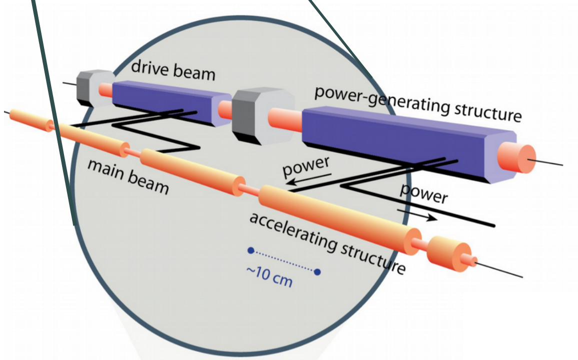
→ CLIC uses a Two-beam acceleration scheme at 12 GHz, gradient of 100 MV/m

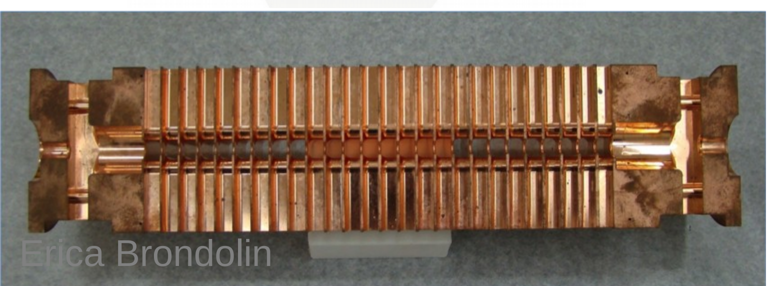


CLIC layout at 3 TeV

RF power source using “Two-beam technique”





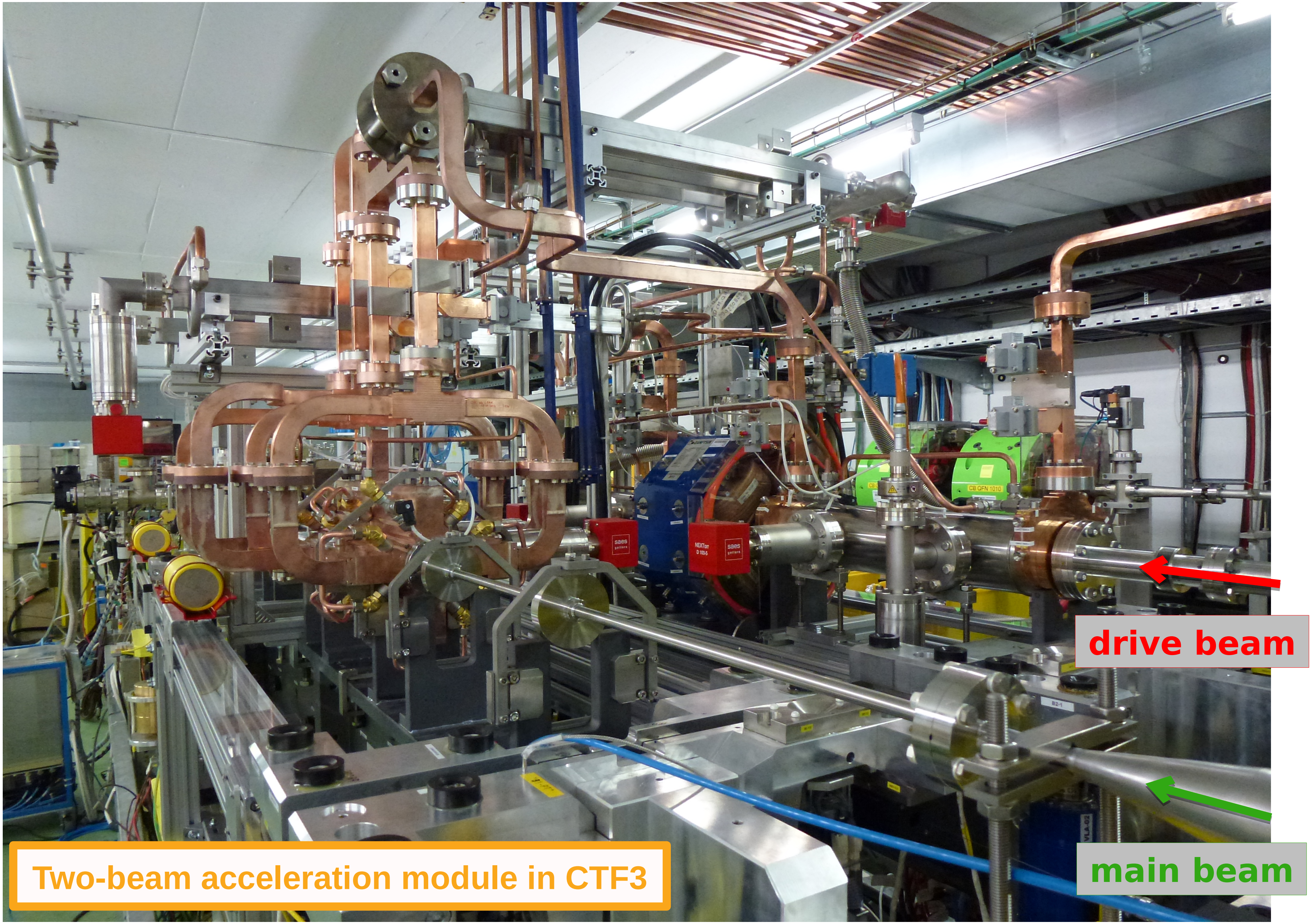


→ **Drive beam**: 12 GHz bunch structure, high current (100 A), low energy (2.4 GeV -240 MeV), klystron acceleration

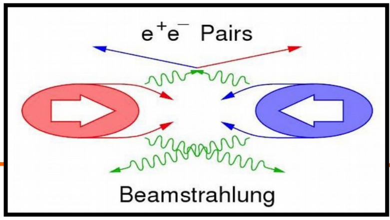
→ **Main beam for physics**: lower current (1.2 A), high energy (9 GeV-1.5 TeV), accelerated by the RF cavities powered by the deceleration of the drive beam in special RF structures (PETS)

- Two beam technique demonstrated at CERN, CLIC CTF3 test facility

Two-beam setup



Beam-induced backgrounds



CLIC achieves high luminosities by using extremely small beam sizes

→ 3 TeV CLIC bunch size: $\sigma_{x,y,z}$ = {40 nm, 1 nm, 44 μm}

(at LHC $\sigma_{T,z}$ = {16.7 μm, 7.55 cm})

→ very high EM-fields → beam-beam interactions

Main backgrounds:

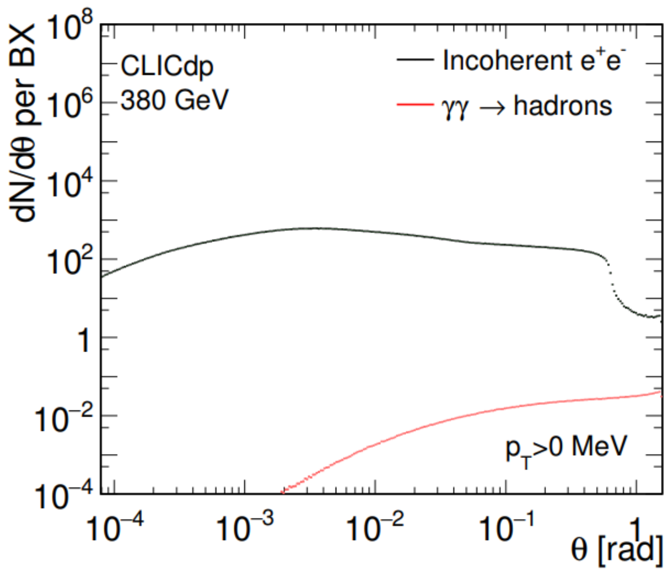
- **Incoherent e^+e^- pairs**
  - → High occupancy
  - → Mostly in the forward region
  - → Impact on detector granularity and design
- **γγ → hadrons**
  - → High energy deposits
  - → Impact on detector granularity, design and physics measurement

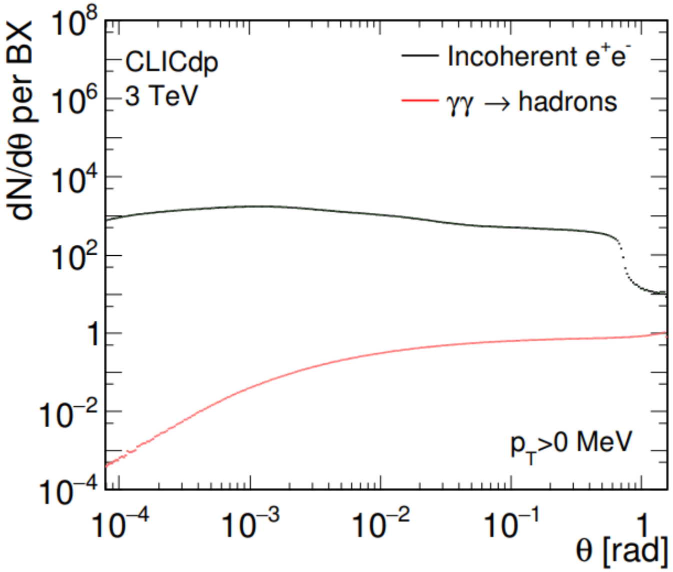
Detector acceptance starts at 10 mrad

Effect is dependent on √s

→ Background particles

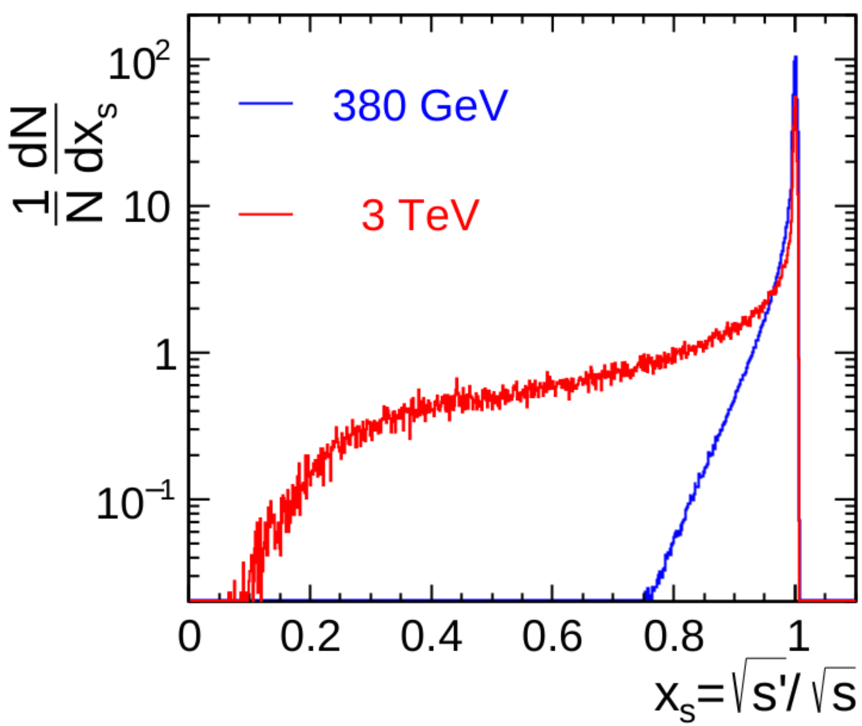
→ Reduces √s





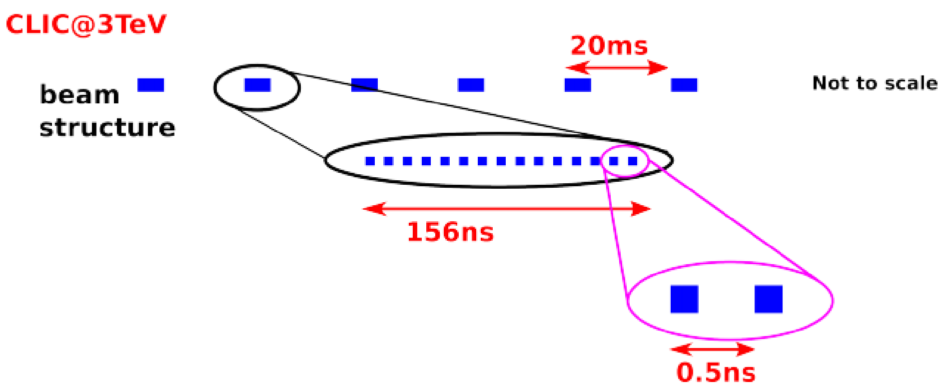
Beam at CLIC

Luminosity spectrum



- Due to beamstrahlung, important energy losses right at the interaction point
- Collision energy is reduced by the amount lost in beamstrahlung before collision

Bunch separation



- Bunch separation and background suppression drives timing requirement of detector:

  < 10 ns hit time-stamping in tracking

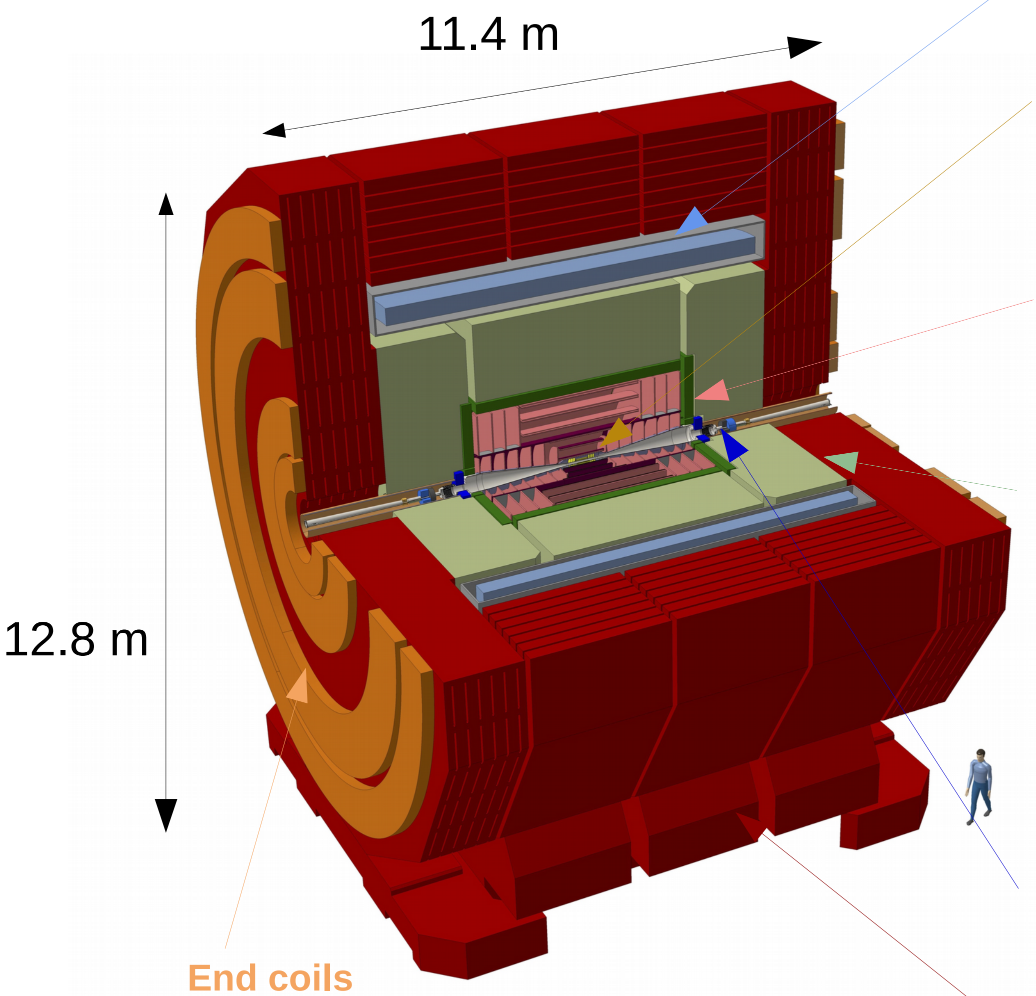
  < 1 ns accuracy for calorimeter hits


“My own visions of CLIC”, artwork by Lukas Molketin, 2010

CLIC detector

CLIC detector concept

Designed for Particle Flow Analysis (PFA) and optimised for CLIC environment



Superconducting solenoid with 4T magnetic field

Vertex detector

- 3 double layers with 25 × 25 μm^2 pixels
- Extremely accurate (σ < 3 μm) and light (< 0.2 % X_0 per layer)

Silicon Tracker

- Tracker composed of large pixels/strips
- Outer R ~ 1.5 m
- < 10 ns hit time-stamping in tracking

Fine grained calorimeters

Si-W ECAL

- 40 layers → 22 X_0 and 1 λ_I
- 5 × 5 mm^2 silicon cell size (~ 2500 m^2)
- < 1 ns accuracy for calorimeter hits

Scint-Fe HCAL

- 60 layers → 7.5 λ_I
- 30 × 30 mm^2 scintillator cell size (~ 9000 m^2)
- < 1 ns accuracy for calorimeter hits

Forward calorimeters

- very forward electron tagging and luminosity measurements

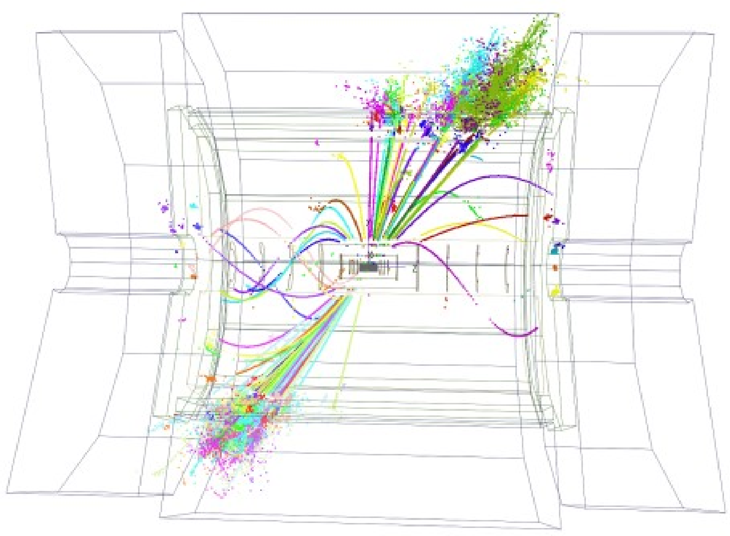
Return yoke & muon chambers

- Used mainly for muon ID

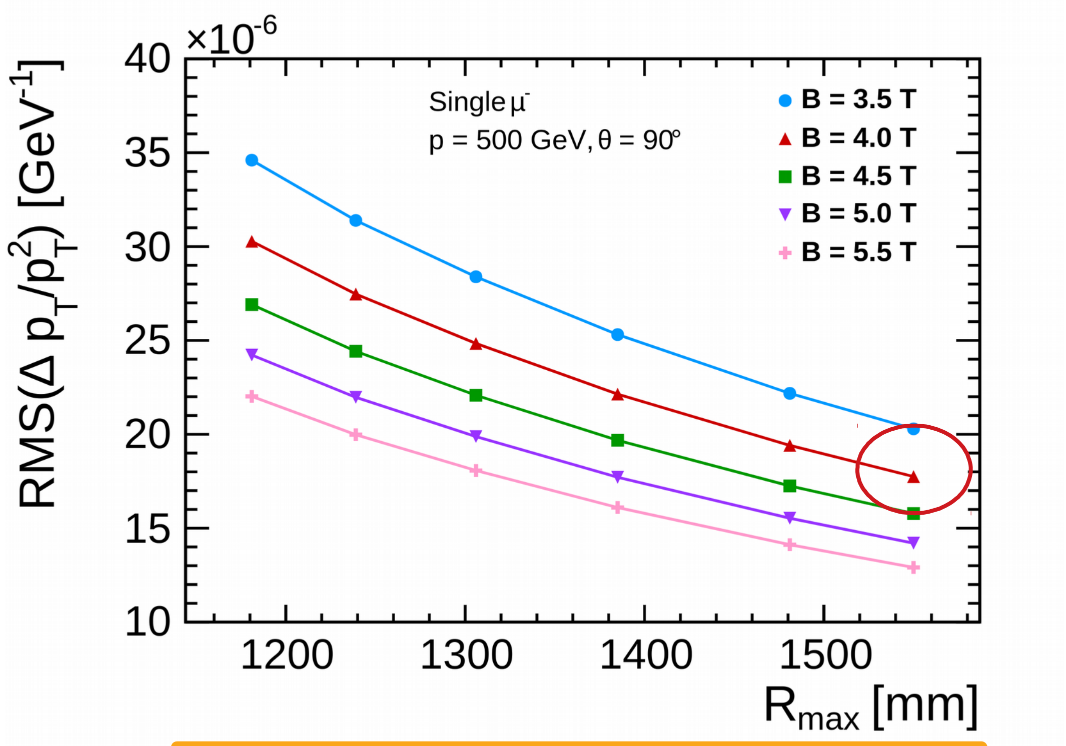
More details in: CLICdp-Note-2017-001

Full det simulation and optimization

- Full Geant4 detector simulation including overlay of beam-induced backgrounds
- Full reconstruction chain including:
  reconstruction of tracks and clusters → particle flow objects → jets → flavor tagging
- Optimization of CLIC detector model in full detector simulations
  → Ensure that detector performance meets requirements



Example: $e^+e^- \rightarrow t\bar{t}$ @ 3 TeV

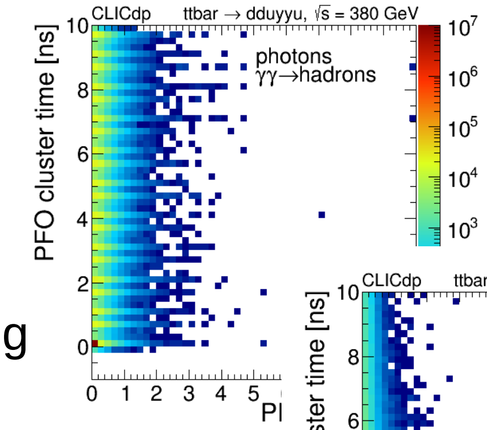


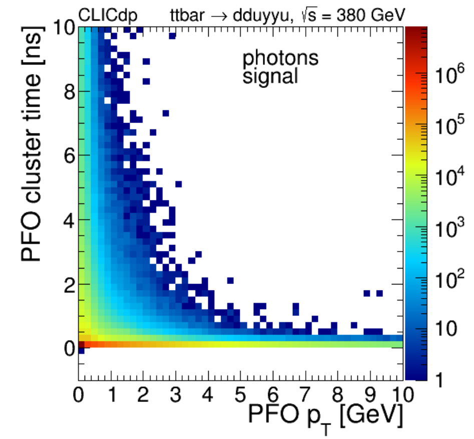
Example: Tracker radius and B-Field ↔ momentum resolution

Beam-induced background rejection

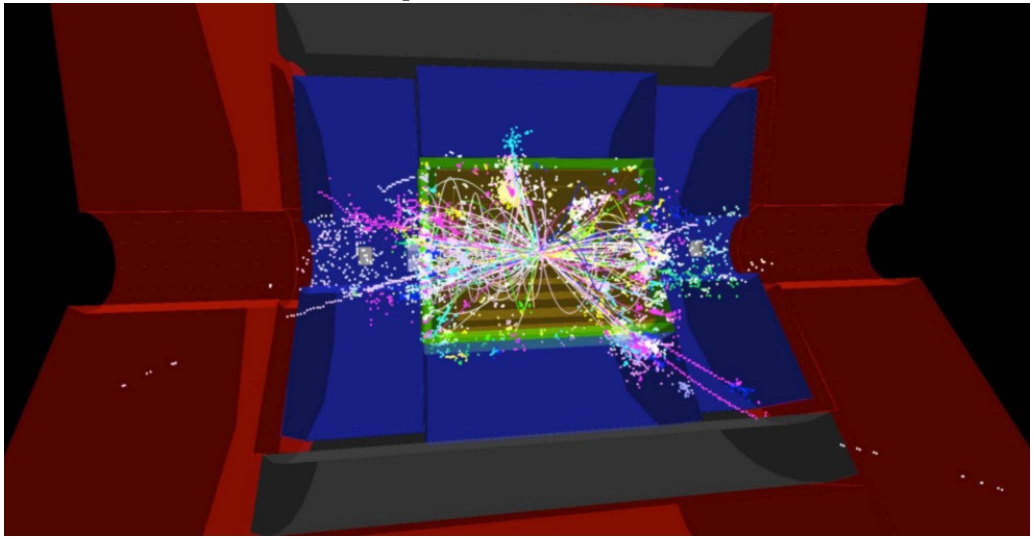
Beam-induced background from γγ → hadrons can be efficiently suppressed by applying p_t vs. time selections on individually reconstructed particles

- Identify time of physics event in the full bunch train
- Cluster time obtained by combining sub-detectors hit timing information and correct for time-of-flight
- Accept reconstructed particles depending on particle type, cluster time, and p_T
- Selection cuts reduce background from 1.2 TeV to 100 GeV @ 3 TeV!

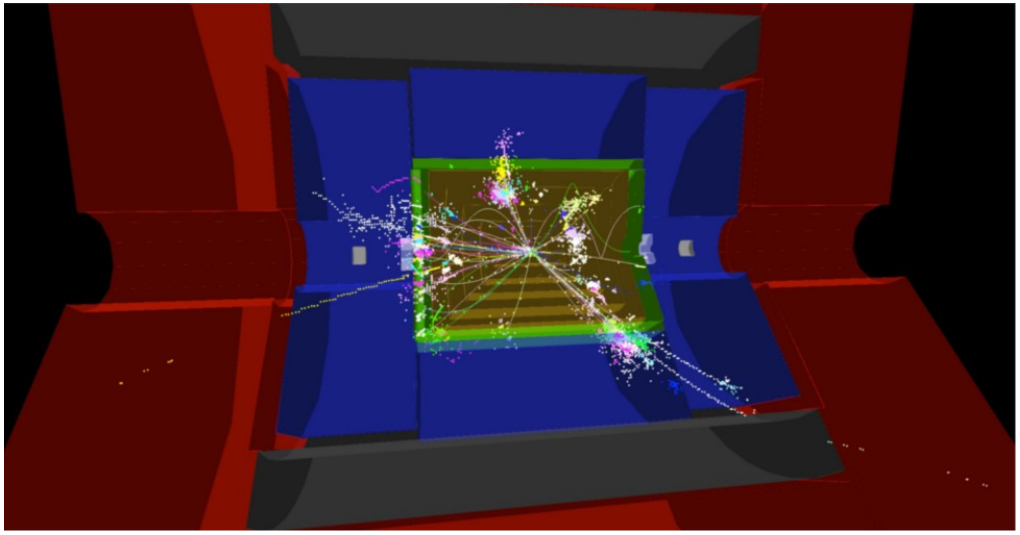




Before the pt vs. time selections



After the pt vs. time selections



Example: e+e− → ttH → Wb Wb H → qqb τνb bb at 1.4 TeV

Detector requirements & performance

Momentum resolution

(e.g. H → $\mu^+\mu^-$, leptons from BSM processes)

$$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$$

above 100 GeV

Energy resolution for light-quark jets

(e.g. W/Z/h di-jet mass separation)

$$\frac{\sigma_E}{E} \sim 3.5 - 5\ \%$$

for E = 1 TeV – 50 GeV

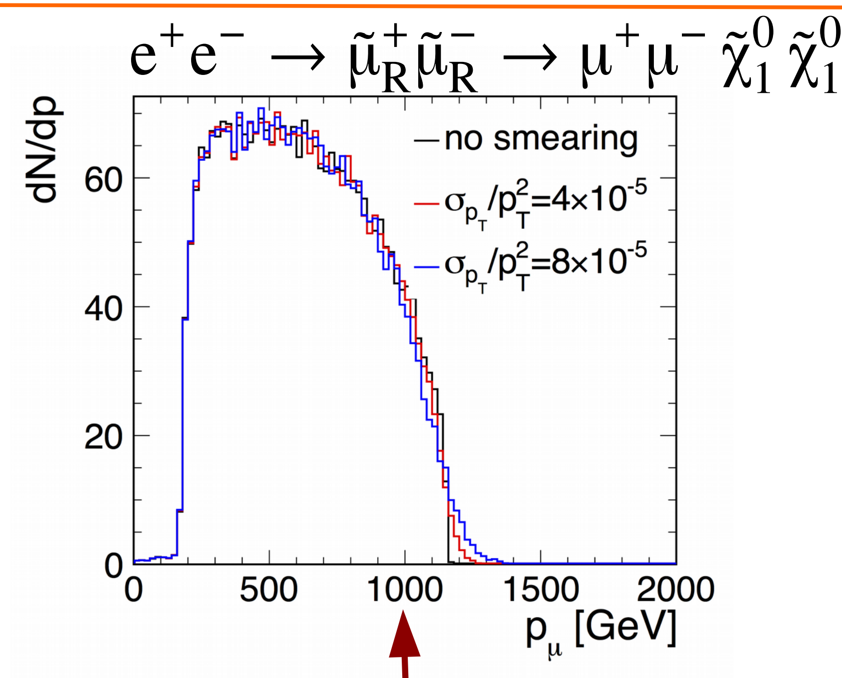
Impact parameter resolution

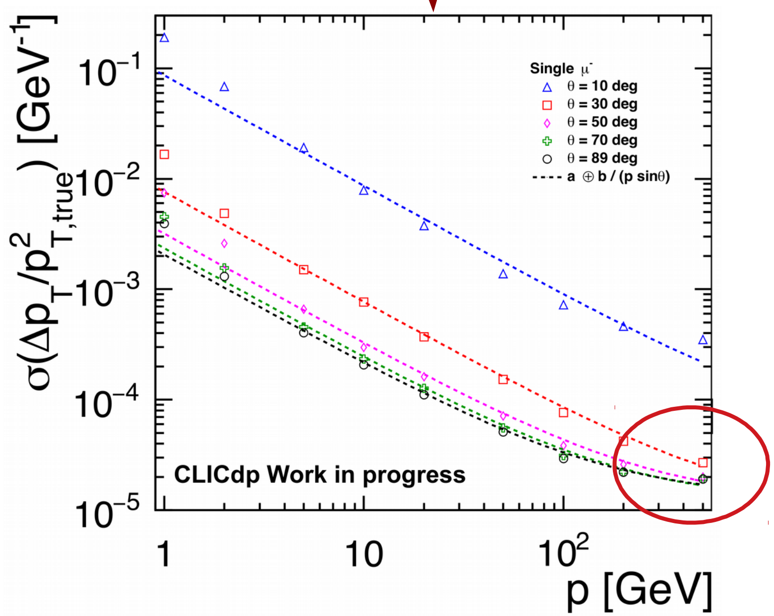
(e.g. b/c tagging, Higgs couplings)

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$

Lepton identification efficiency > 95 %

Very forward electron tagging





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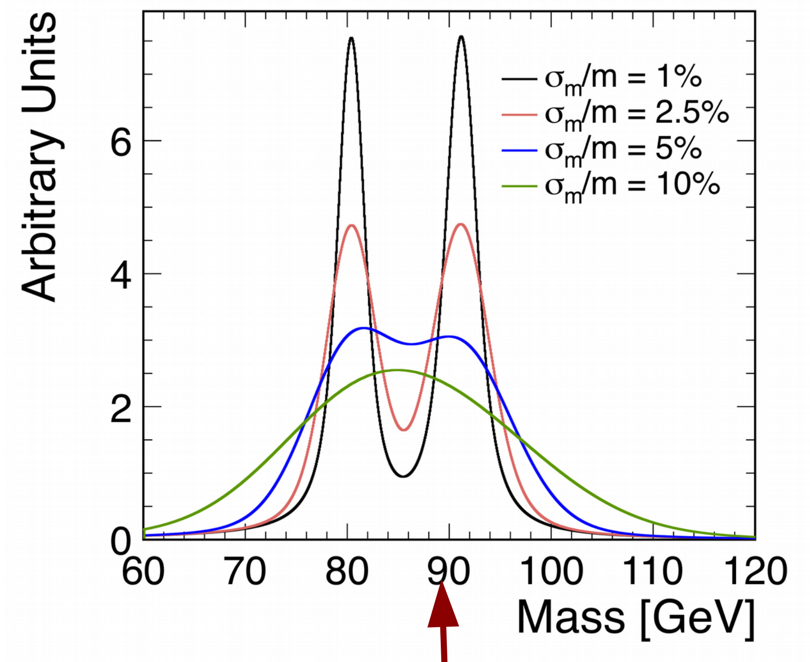

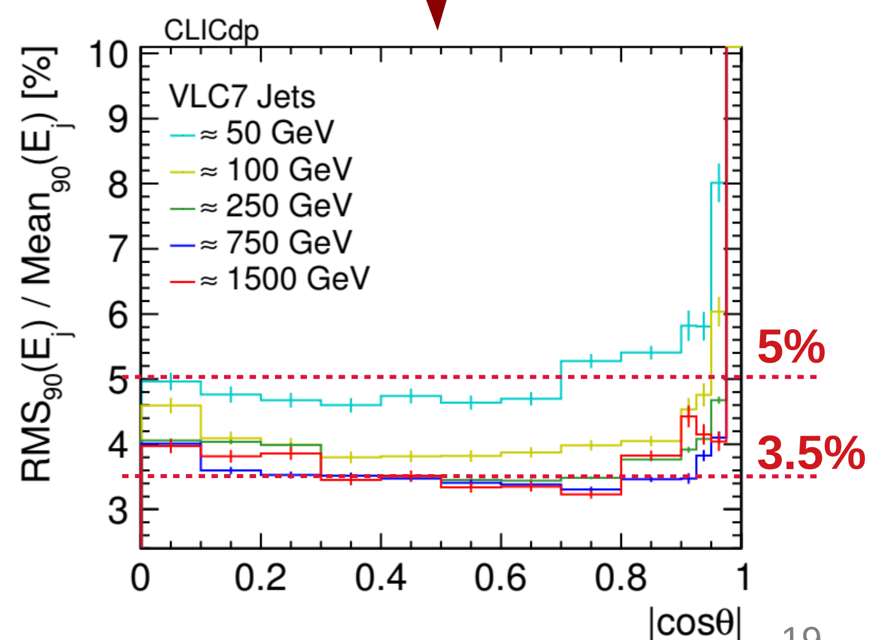

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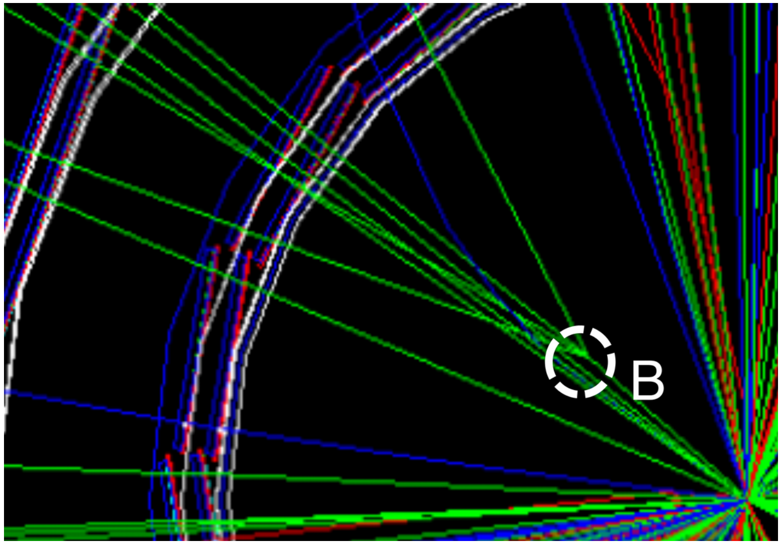
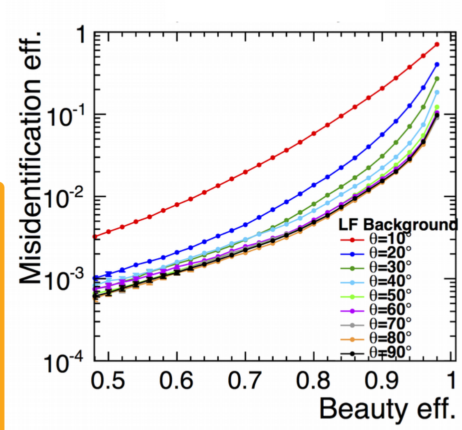
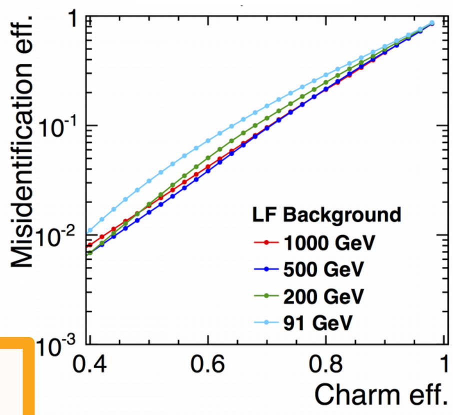






Upcoming detailed CLICdet performance report

“My own visions of CLIC”, artwork by Sean Steed, 2010

Physics potential

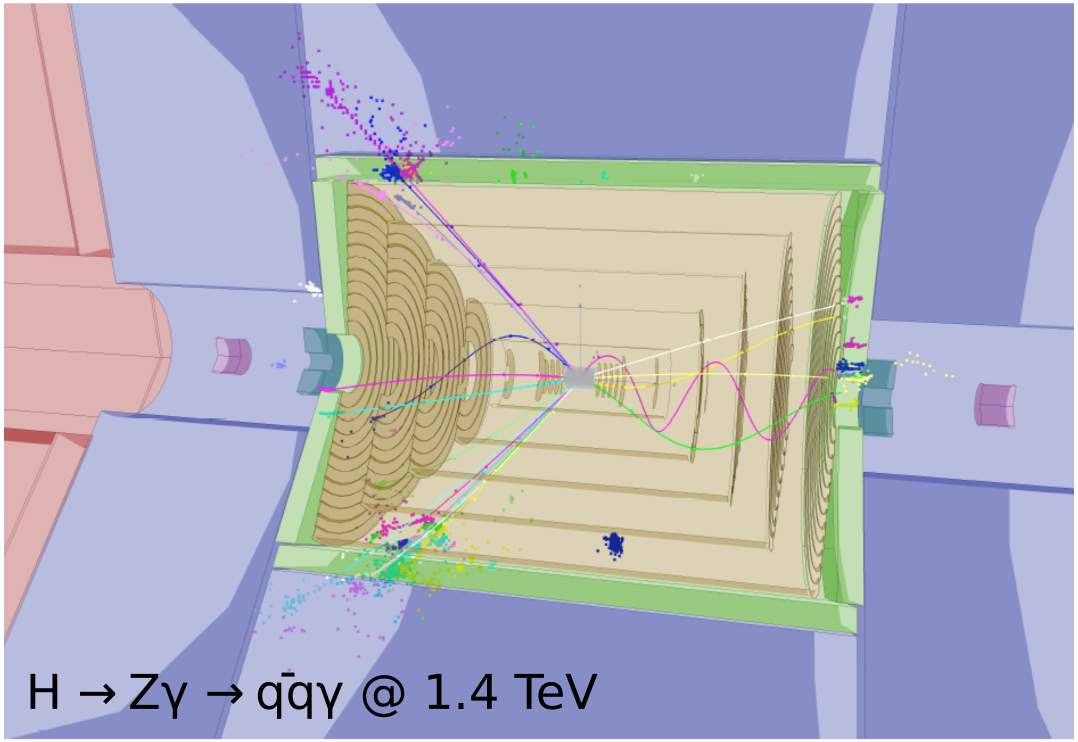
Main physics topics

- **Higgs boson**
- **Top quark**
- **BSM (direct and indirect)**

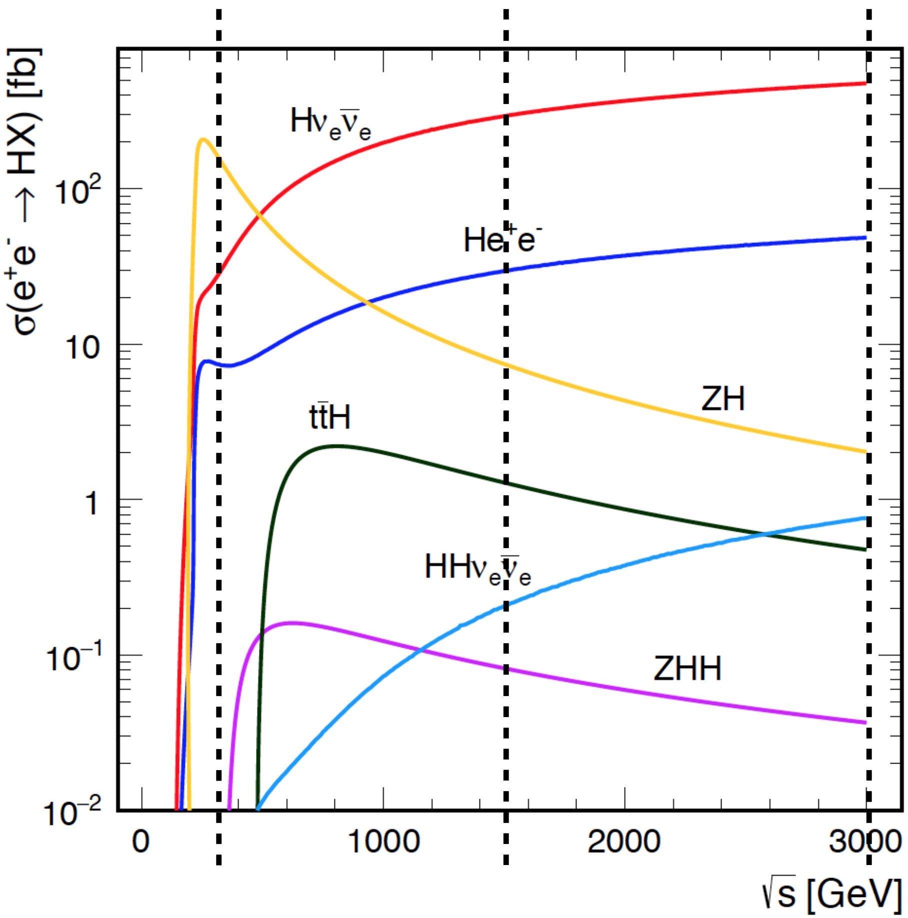
- What can we learn by studying the Higgs boson and the top quark in collisions?
- Which precision measurements can hint to new physics at very high scales?
- Can CLIC make direct observations although the LHC has found nothing so far?

Stage	Centre-of-mass en.	L_{int} (fb^{-1})
1	380 GeV (and 350)	1000
2	1.5 TeV	2500
3	3 TeV	5000

All results are produced with new scenario, if not indicated otherwise

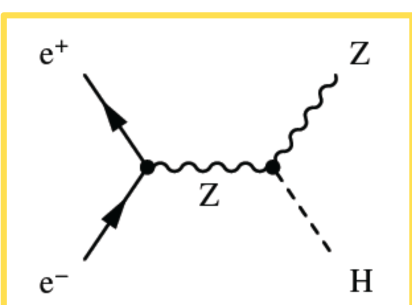


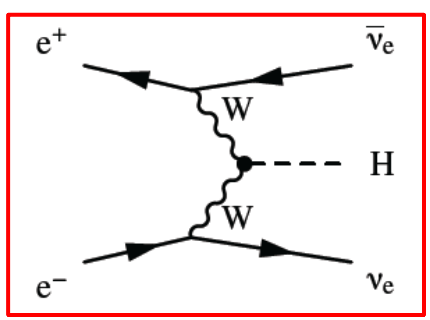
Higgs physics at CLIC

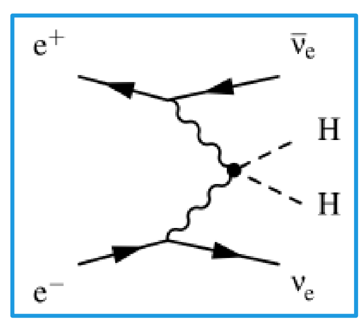


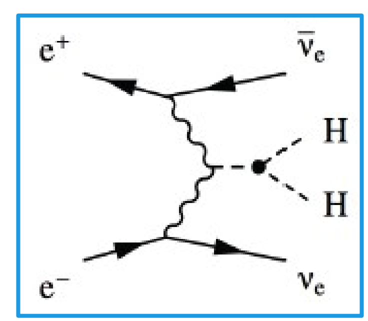
All Higgs studies summarised in the following paper: Eur. Phys. J. C 77 (2017) 475

- Higgsstrahlung: **$e^+e^- \to$ ZH**
  - → $\sigma \sim 1/s$, dominant up to ~ 450 GeV
  - → Higgs identification from recoil
- WW fusion: **$e^+e^- \to H\nu_e\bar{\nu}_e$**
  - → $\sigma \sim \log(s)$, dominant above ~ 450 GeV
  - → Large statistics at high energy
- **$e^+e^- \to HH\nu_e\bar{\nu}_e$**
  - → Allow simultaneous extraction of triple Higgs coupling, λ, and HHWW quadratic coupling
  - → Benefits from high-energy operation
  - → **Rarer decays more available at higher energy**





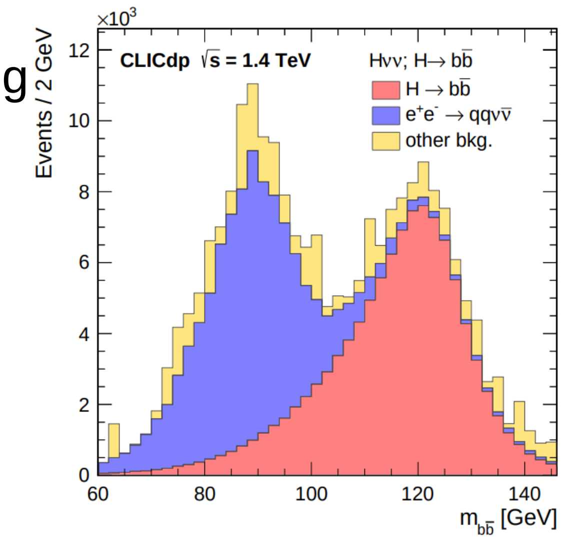




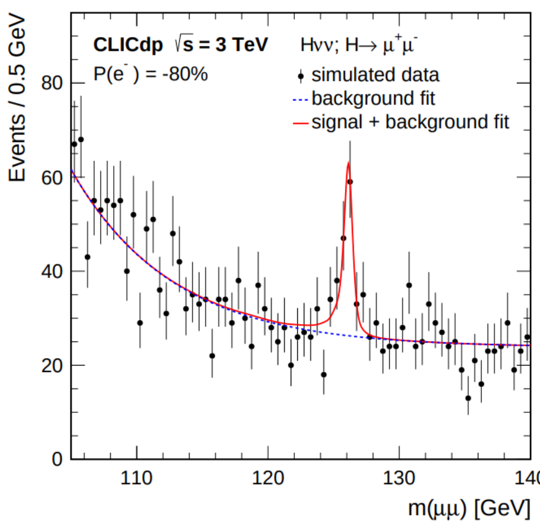
Selected Higgs analysis

- Old staging scenario
- H → $b\bar{b}$ requires good flavour tagging and jet energy resolution
- H → $\mu^+\mu^-$ visible thanks to excellent momentum resolution

H → $b\bar{b}$



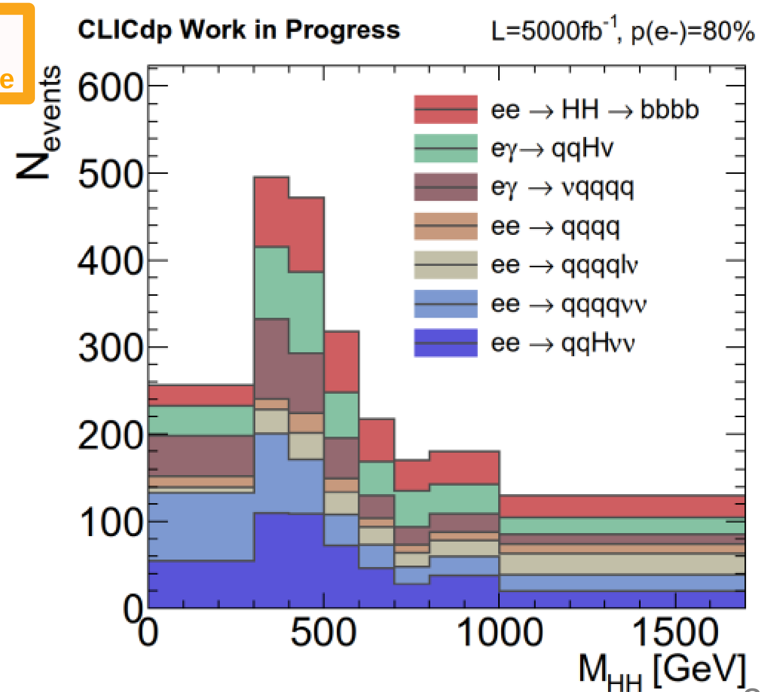
H → $\mu^+\mu^-$



- NEW staging scenario
- Small cross-section of double Higgs production requires highest energy and large luminosities
- $HH\nu_e\bar{\nu}_e$ scales by 1.8 (0.2) for -80% (+80%) e^- polarisation
- With updated running scenario, combining 1.5 TeV and 3 TeV

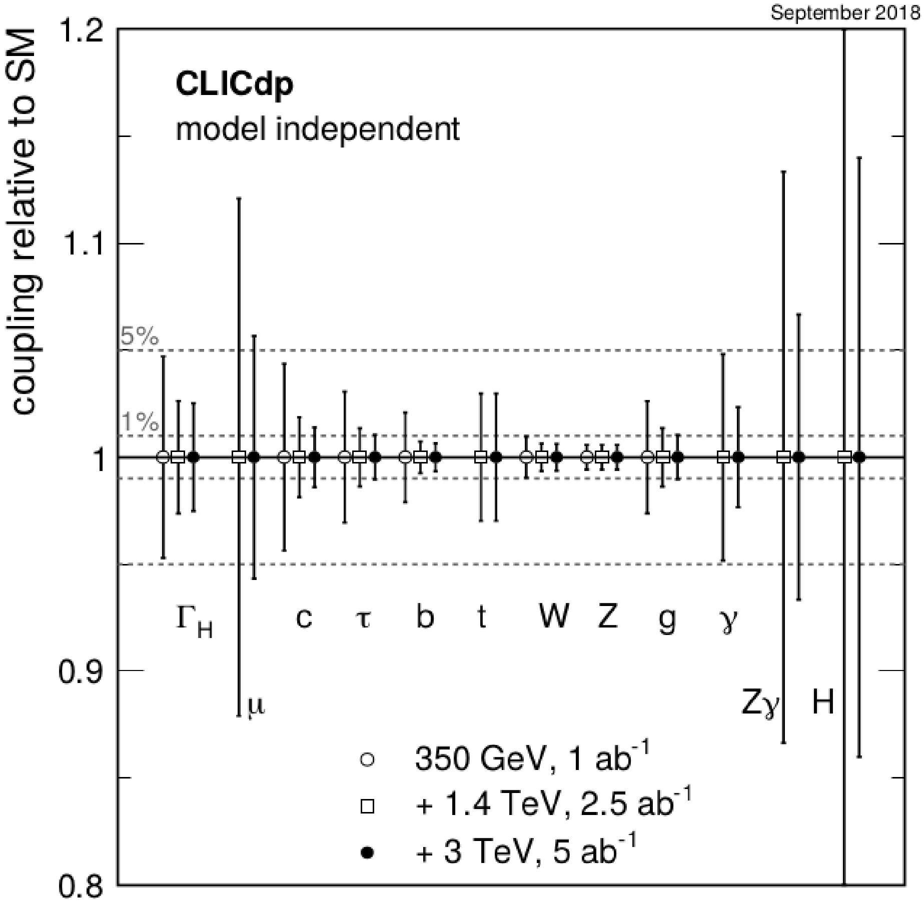
  → $\Delta g_{HHH}/g_{HHH} \approx 10\%$ reachable

$e^+e^- \rightarrow HH\nu_e\bar{\nu}_e$



Higgs physics at CLIC

Fully model-independent analysis:
Free parameters Γ_H and ten Higgs couplings
No assumption on invisible Higgs decays

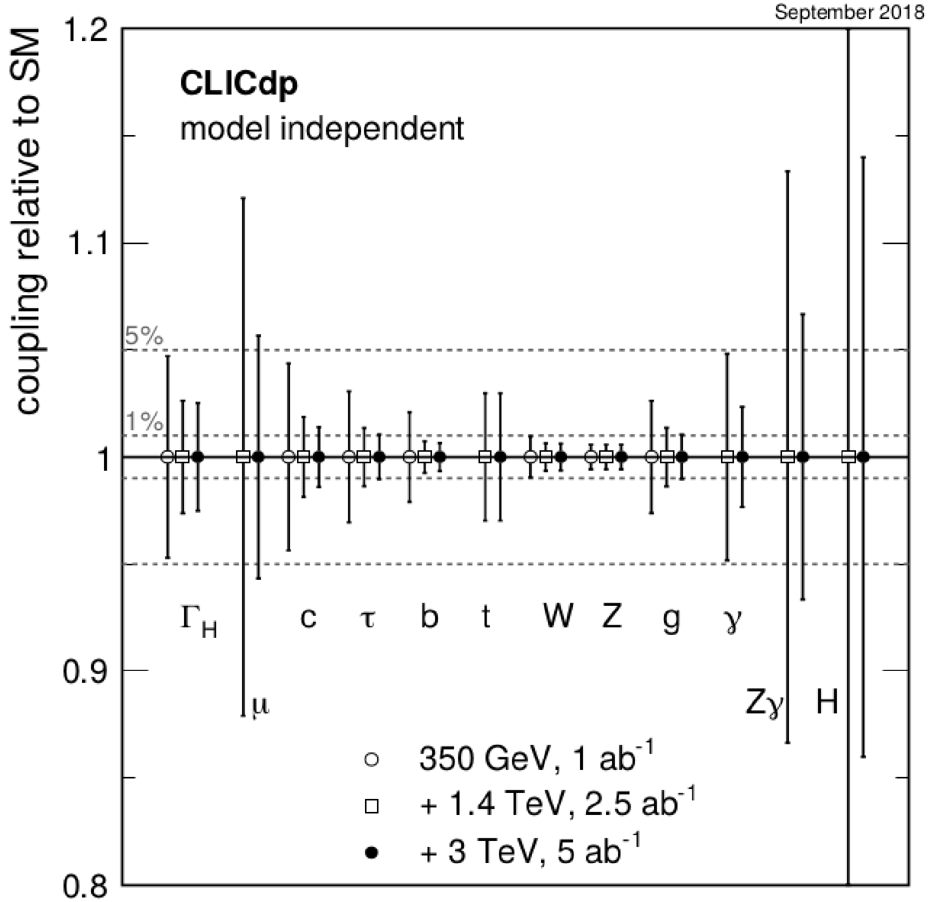


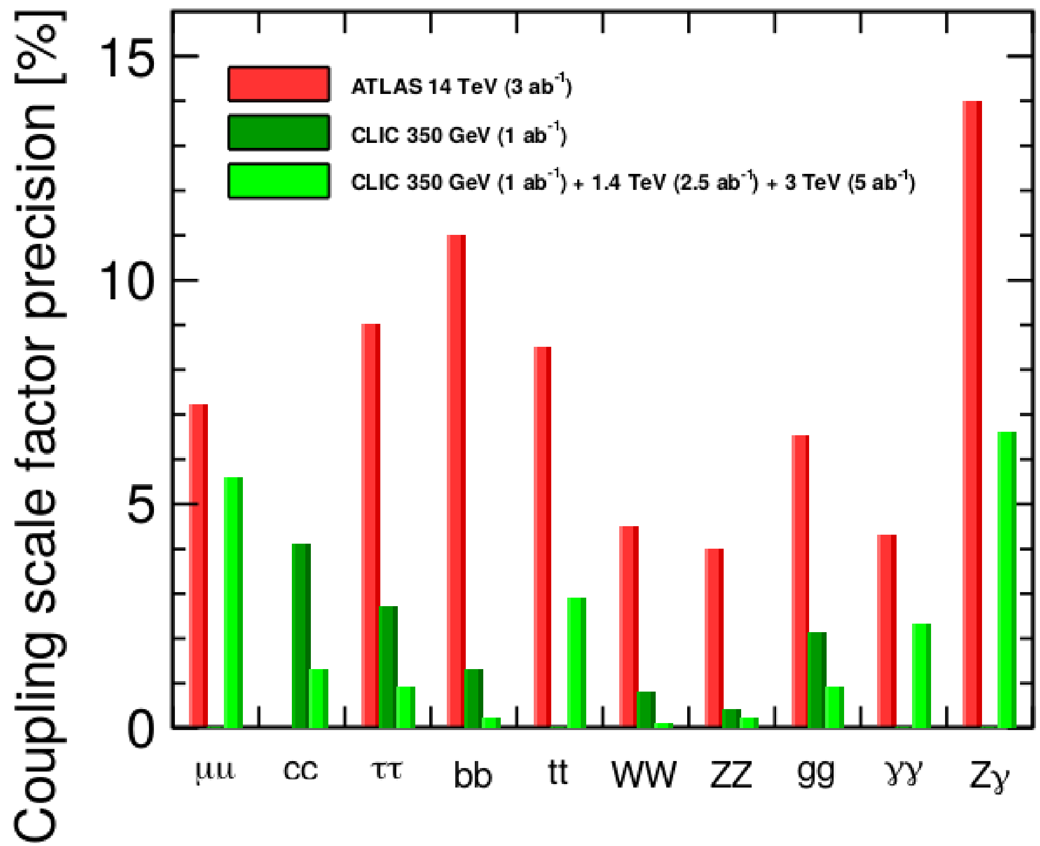
High precision measurements:
- Couplings with sub-1% level (at 1% for rare decays)
- The Higgs width is extracted with 4.7 – 2.5% precision

Higgs physics at CLIC

Fully model-independent analysis:
Free parameters Γ_H and ten Higgs couplings
No assumption on invisible Higgs decays

Model-dependent analysis:
Γ_H constrained by the SM expectations
No invisible Higgs decays

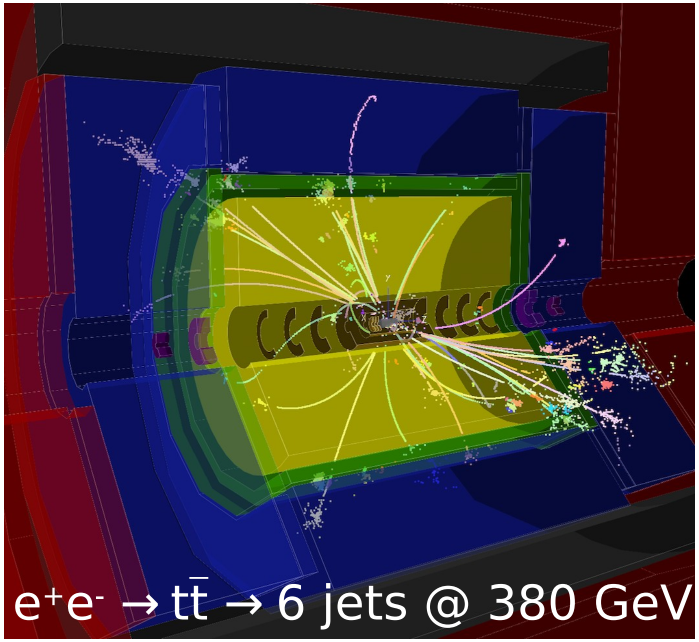




High precision measurements:
- Already the first CLIC stage significantly better than HL-LHC for several couplings
- The full program enhances the precision further
- μμ, γγ and Zγ would benefit from HL-LHC + CLIC combination

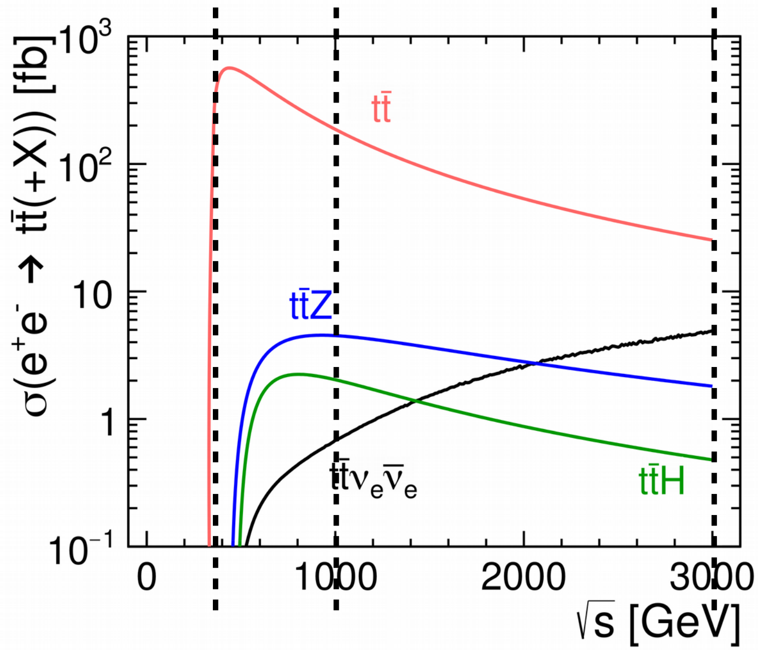
Top-quark physics at CLIC

All Higgs studies summarised in the following paper (using old staging scenario): https://arxiv.org/abs/1807.02441



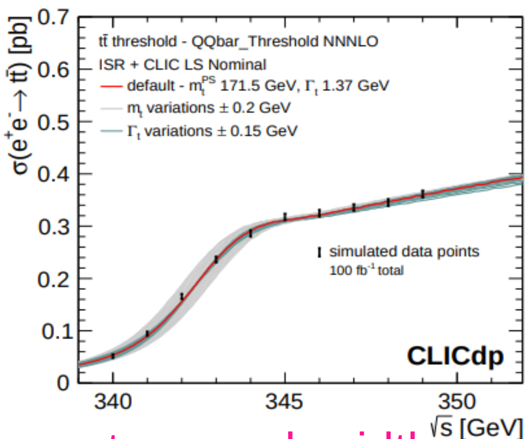
Studies at different stages:

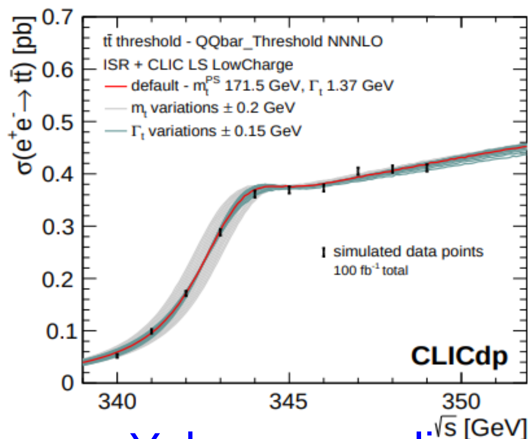
- 350 GeV and 380 GeV:
  - **$e^+e^- \rightarrow t\bar{t}$:** Production threshold at $\sqrt{s} \sim 2m_{top}$
    Large event sample at 380 GeV
  - Threshold scan around 350 GeV
  - Top-quark mass from radiative events or direct reconstruction of the top quark
  - Flavour-changing neutral current top-quark decays
- 1.4 TeV and 3 TeV:
  - **$e^+e^- \rightarrow t\bar{t}H$:** Maximum near 800 GeV
  - **$e^+e^- \rightarrow t\bar{t}\nu_e\bar{\nu}_e$ (Vector Boson Fusion):**
    Benefits from highest energies
  - Vector boson fusion production of top pairs
  - Top Yukawa coupling
- Kinematic studies of top-pair production at all stages



Top threshold scan @ 350 GeV

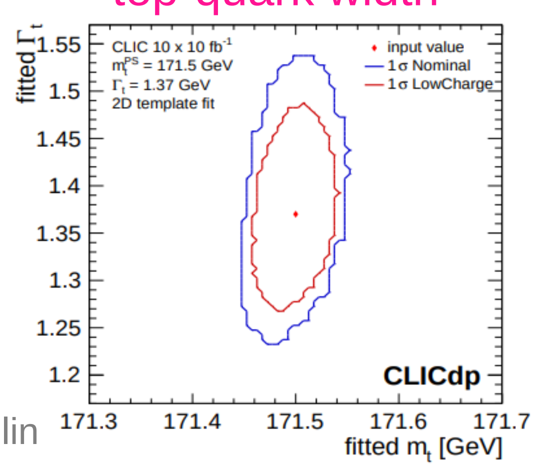
- Well-defined 1S top mass can be measured
- $\sigma_{e+e- \to t\bar{t}}$ around threshold is sensitive to 1s top-quark mass, width and other model parameters
- Energy scan: 10 points with 10 fb^{-1} from 340 GeV to 349 GeV
- Expected uncertainty on the top-mass $\boldsymbol{\sigma_{mtop}}$ **≈ 50 MeV** (dominated by theoretical uncertainties)
- Precision at the HL-LHC limited to several hundred MeV

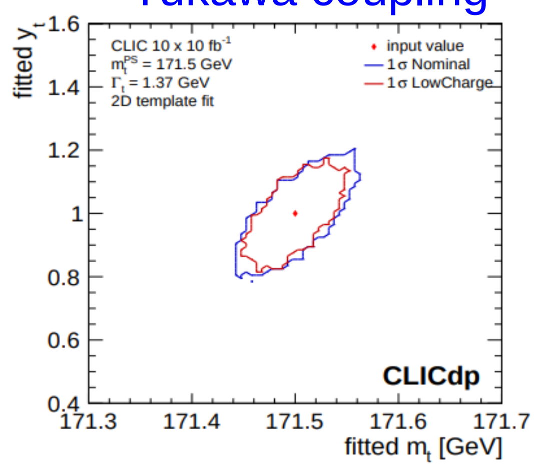




top-quark width

Yukawa coupling

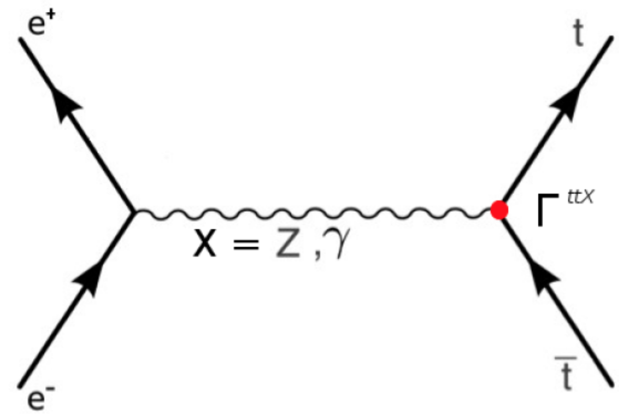


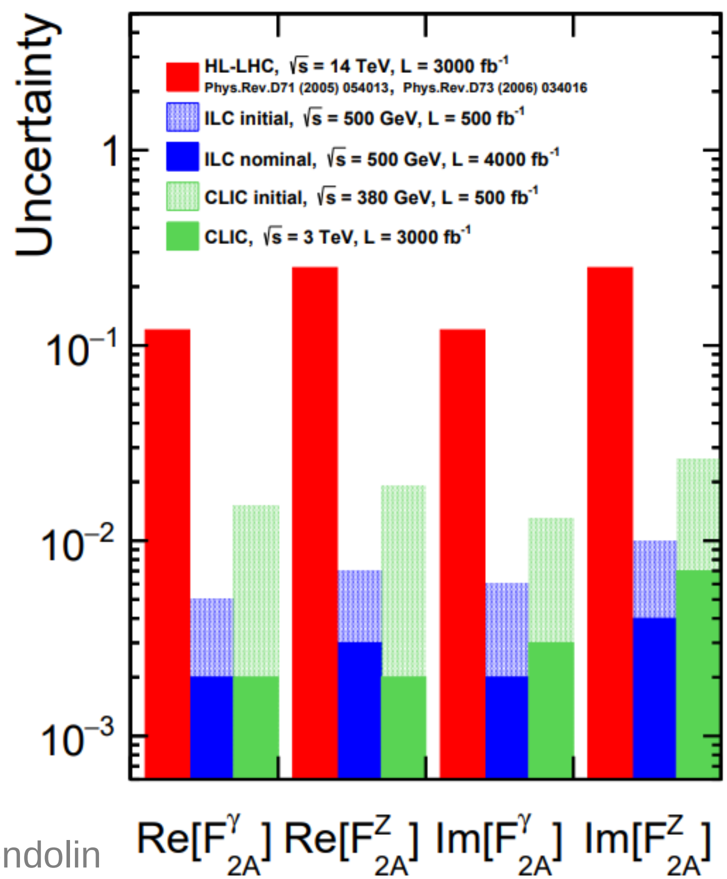


→ Dedicated luminosity spectra (low bunch charge) also reduces uncertainties on the extracted top-quark width and Yukawa coupling

Top-quark coupling to Z and γ

- **Top quark pairs are produced via Z/γ**
  → New physics would modify the ttV vertex
- At a linear collider the **γ and Z form factors** can be disentangled *using beam polarization* by measuring:
  → production cross section
  → forward-backward asymmetry
  → helicity angle distribution (in leptonic decays)



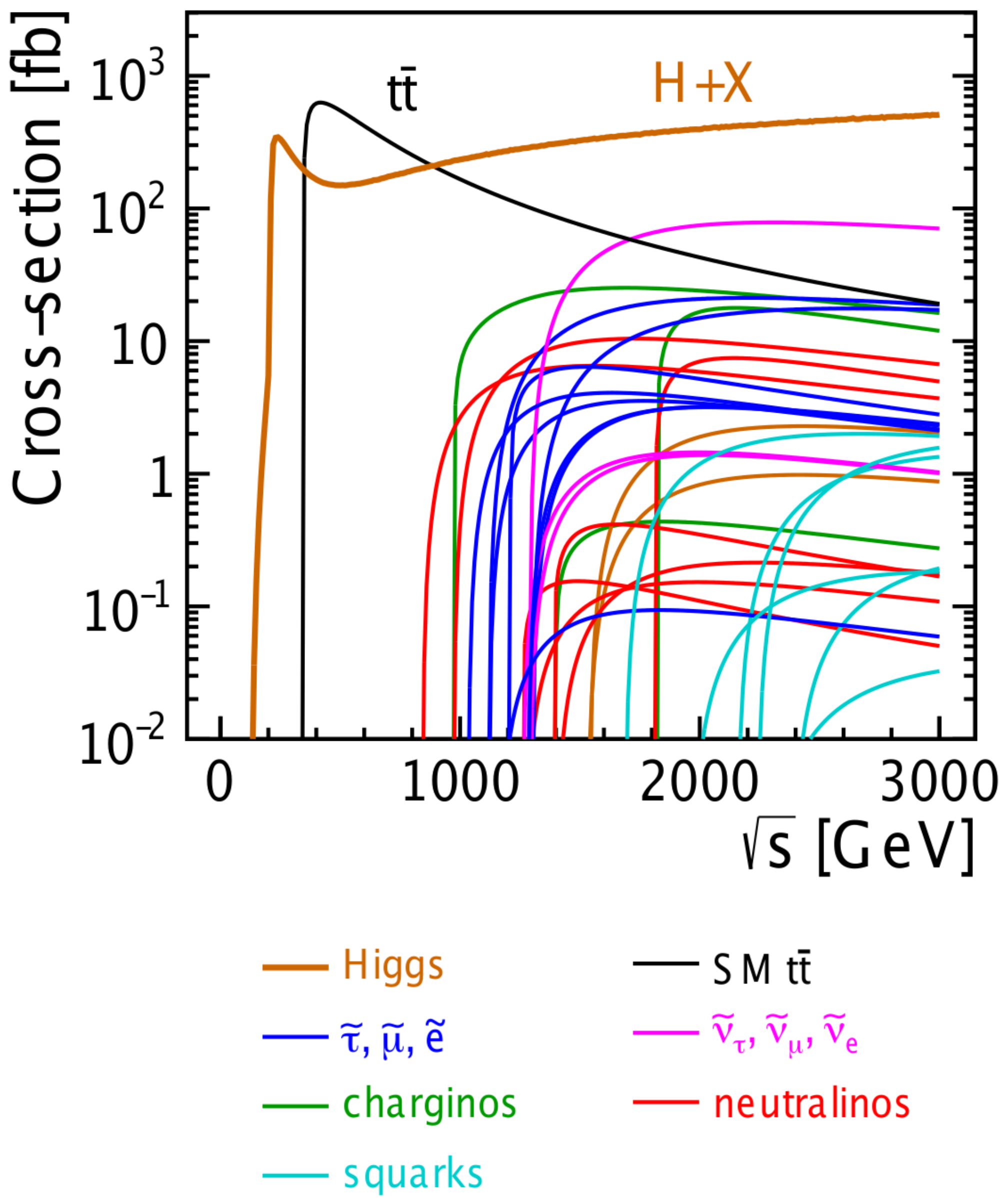


- Expected precision at HL-LHC, ILC (500 GeV) and CLIC (380 GeV / 3 TeV)

- **ILC:** e^- and e^+ polarized (80% / 30%)
- **CLIC:** e^- polarized (80%)

- Already the first CLIC stage significantly better than HL-LHC
- Result obtained with old staging scenario

Beyond Standard Model at CLIC



- CLIC operating at high energy provides significant discovery potential for BSM physics → **Comprehensive BSM report under work**
- **Direct searches** of new particles:

  → Direct searches can find particles up to 1.5 TeV

  → Possible observation of the new phenomena thanks to the low background (no QCD)

  → Precision measurements of new particle properties (also for the ones discovered in (HL-)LHC)
- **Indirect searches** of new physics:

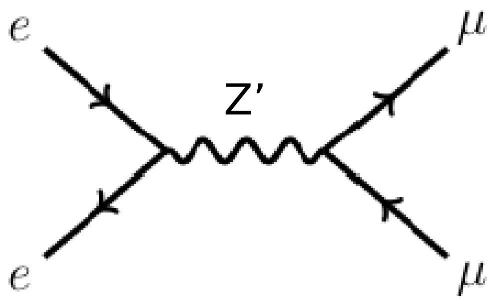
  → Precision measurements of sensitive observables reveal a signs of new physics, comparing to the SM expectations

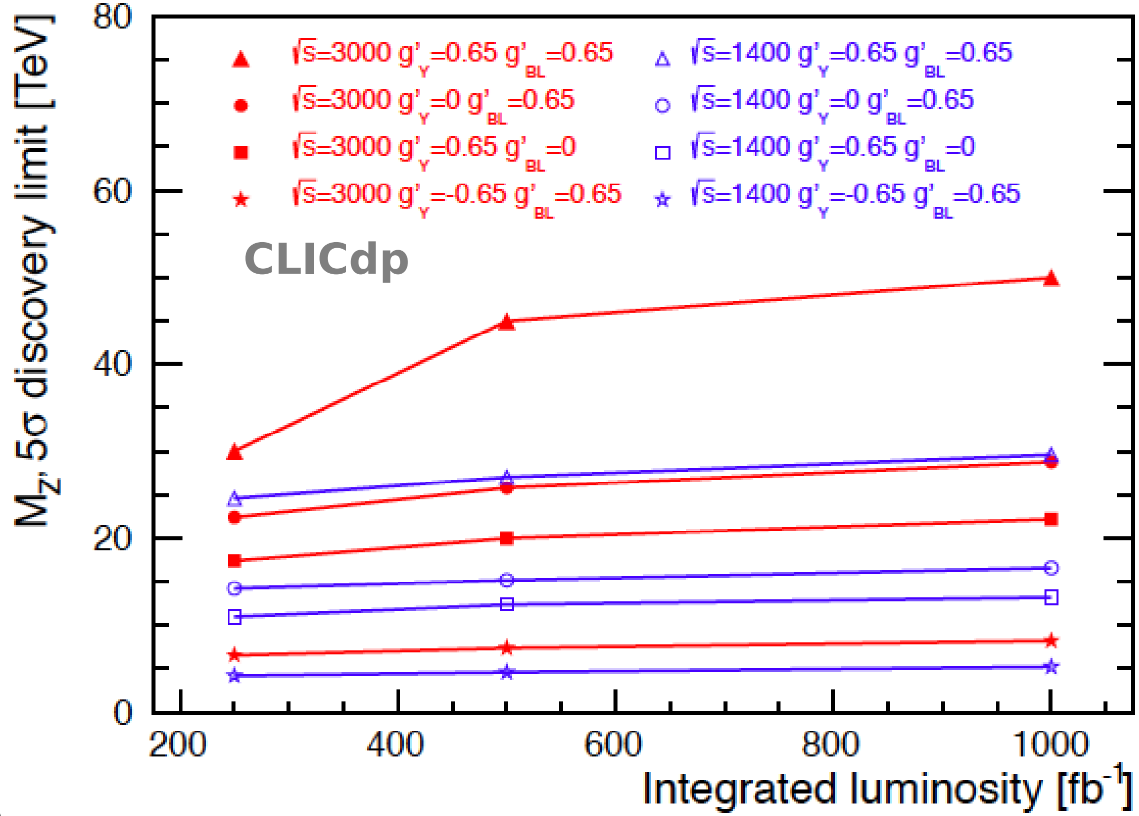
  → The reach is higher – several tens of TeV

Beyond Standard Model at CLIC

Example of indirect measurement:

$Z' \rightarrow \mu^+\mu^-$





- **Observables:**
  - → Total $e^+e^- \rightarrow \mu^+\mu^-$ cross section
  - → Forward-backward asymmetry
  - → Left-right asymmetry (with ±80% e^- polarisation)

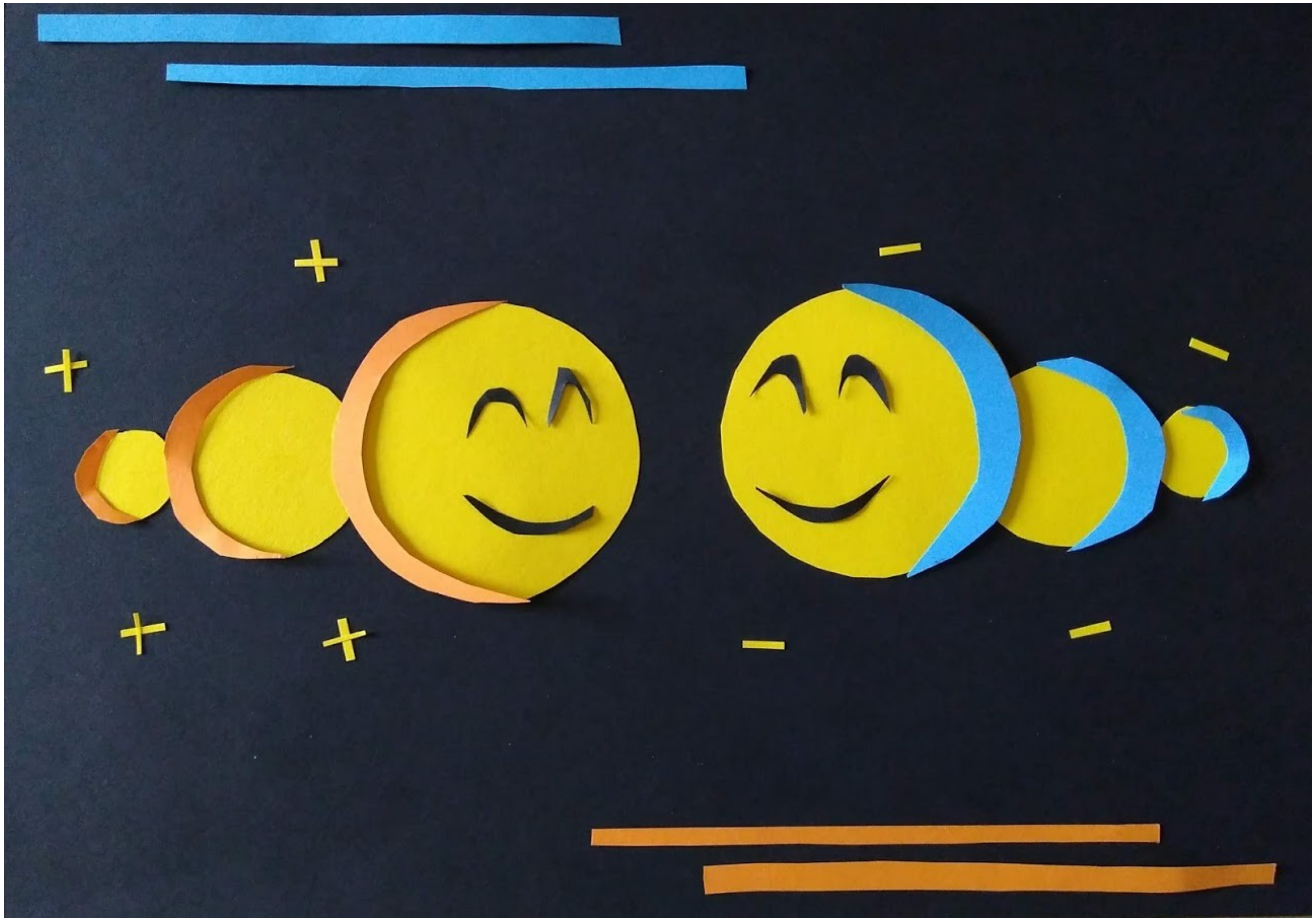
- **If LHC discovers Z' (e.g. for $M_{Z'}$=5 TeV)**

→ CLIC precision measurement of effective couplings

otherwise:

→ CLIC discovery reach up to tens of TeV (depending on the couplings)

More details in: **arXiv:1208.1148**



“My own visions of CLIC”, collage by Erica Brondolin, 2018

Conclusions

Summary

- **CLIC is e^+e^- collider from a few hundred GeV up to 3 TeV**
- **CLIC is a mature international project**
- **The accelerator technical challenges have been solved**
- **CLIC environment and physics goals lead to challenging requirements for**

  → **detector**: Strong R&D programme on ultra-light vertex and tracking detectors & fine-grained calorimeters

  → **software**: Full detector simulation and reconstruction already in place, which allows not only detailed analysis but also studies for detector optimization
- **CLIC is a precision machine with a unique physics potential**

  Energy-staging → optimal for physics:

  380 GeV: Optimised for high precision measurements of Higgs boson and top quark

  1.5, 3 TeV: Best sensitivity for BSM searches, rare Higgs processes and decays

  → High physics potential already at the first stage, possible start from 2035

- **A statement about CLIC as a future option for CERN is expected from the 2019-2020 update to European Strategy of Particle Physics → stay tuned!**

Thank you for the attention!

Bibliography and sources

- CLIC Conceptual Design Report: http://clicdp.web.cern.ch/content/conceptual-design-report
- CLIC accelerator and artworks: http://clic-study.web.cern.ch
- CLICdet: The post-CDR CLIC detector model: https://cds.cern.ch/record/2254048
- Higgs physics at the CLIC electron–positron linear collider: https://arxiv.org/abs/1608.07538
- Projections for measurements of Higgs boson signal strengths and coupling parameters with the ATLAS detector at a HL-LHC: https://cds.cern.ch/record/1956710
- Top-Quark Physics at the CLIC Electron-Positron Linear Collider: https://arxiv.org/abs/1807.02441
- Physics performances for Z' searches at 3 TeV and 1.5 TeV CLIC: https://arxiv.org/abs/1208.1148
- Academic Training Lecture about CLIC: https://indico.cern.ch/event/668147/
- Luminosity spectrum reconstruction at linear colliders: Eur.Phys.J. C74 (2014) no.4, 2833

CLIC timeline

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, Drive Beam Facility and other system verifications, 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

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

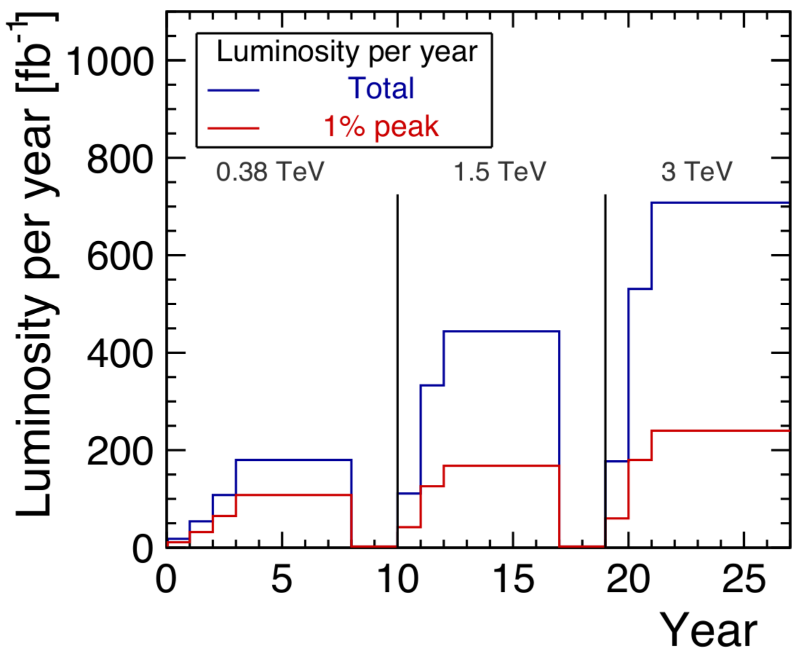
Old/new stage scenarios

- **NEW** baseline scenario:

Stage	Centre-of-mass en.	L_{int} (fb^{-1})
1	380 GeV (and 350)	1000
2	1.5 TeV	2500
3	3 TeV	5000

+ 80% polarization of the e^- beam

- 1 year = 1.2 x 10^7 seconds
- 27 years

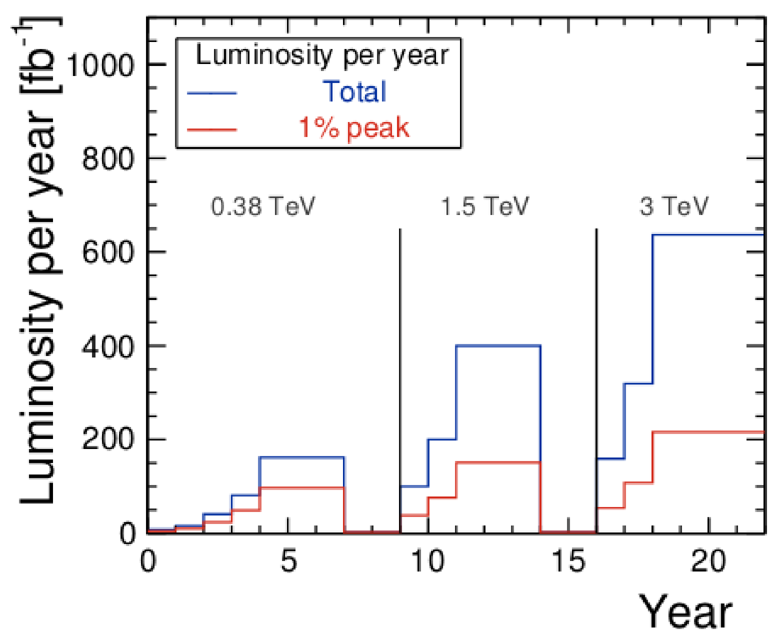


- **OLD** baseline scenario:

Stage	Centre-of-mass en.	L_{int} (fb^{-1})
1	380 GeV 350 GeV	500 100
2	1.5 TeV	1500
3	3 TeV	3000

+ no polarization of the beam assumed as baseline

- 1 year = 1.2 x 10^7 seconds
- 22 years



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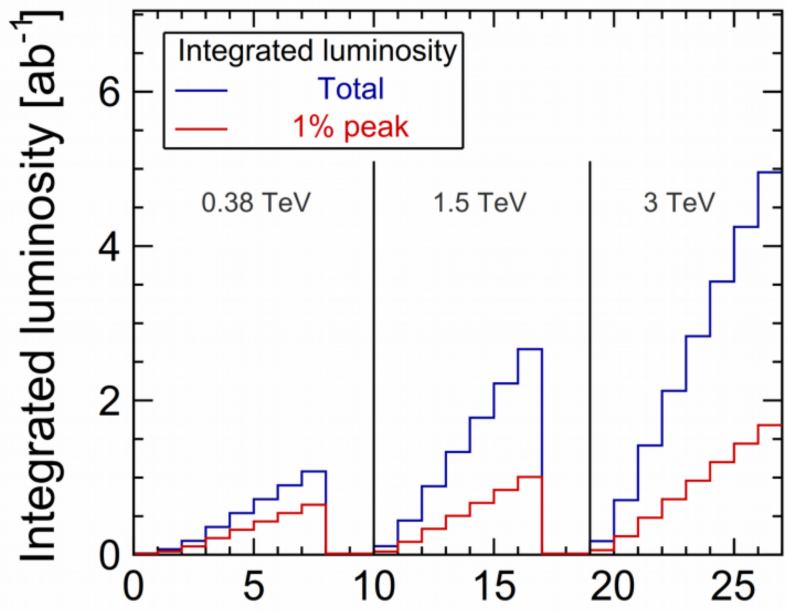

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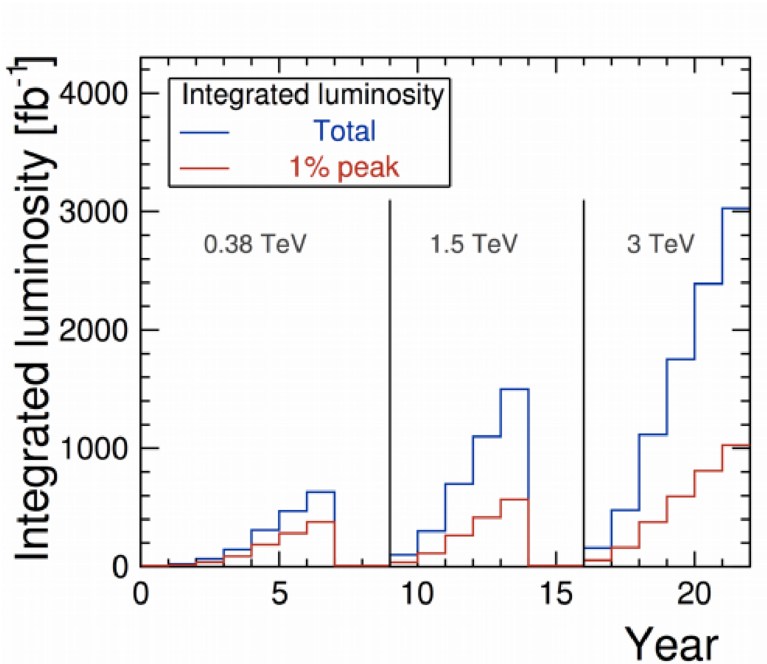


Impact of polarization

- Polarization in NEW scenario:

  - 380 GeV: 0.5 ab^{-1} with -80% and 0.5 ab^{-1} with +80%

  - 1.4 TeV: 2 ab^{-1} with -80% and 0.5 ab^{-1} with +80%

  - 3 TeV: 4 ab^{-1} with -80% and 1 ab^{-1} with +80%
- Higgsstrahlung at first stage: precision almost independent of electron beam polarisation
- $H\nu_e\bar{\nu}_e$ and $HH\nu_e\bar{\nu}_e$: cross section scales by 1.8 (0.2) for -80% (+80%) electron beam polarisation

  → The Higgs program prefers the -80% configuration at high energy

  (equivalent to reduction of run time due)
- The BSM sensitivity of two fermion production: benefits from some fraction with +80%, examples:

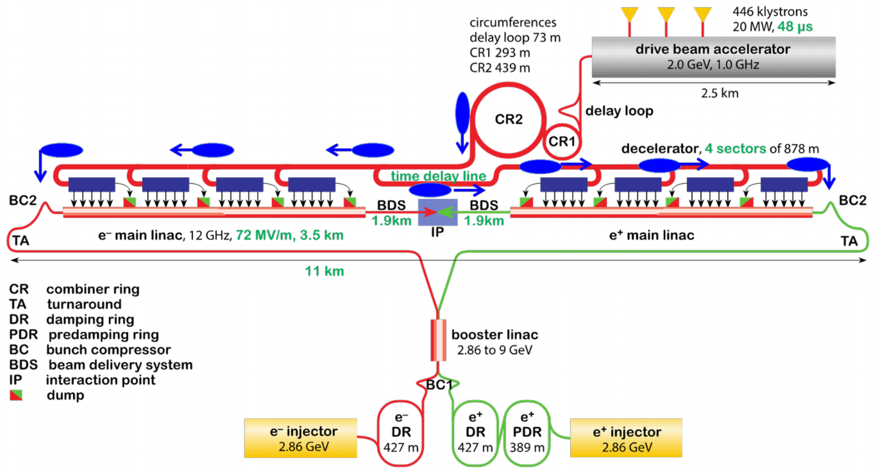
  1) e+e−→ tt (less than 50% with +80% acceptable)

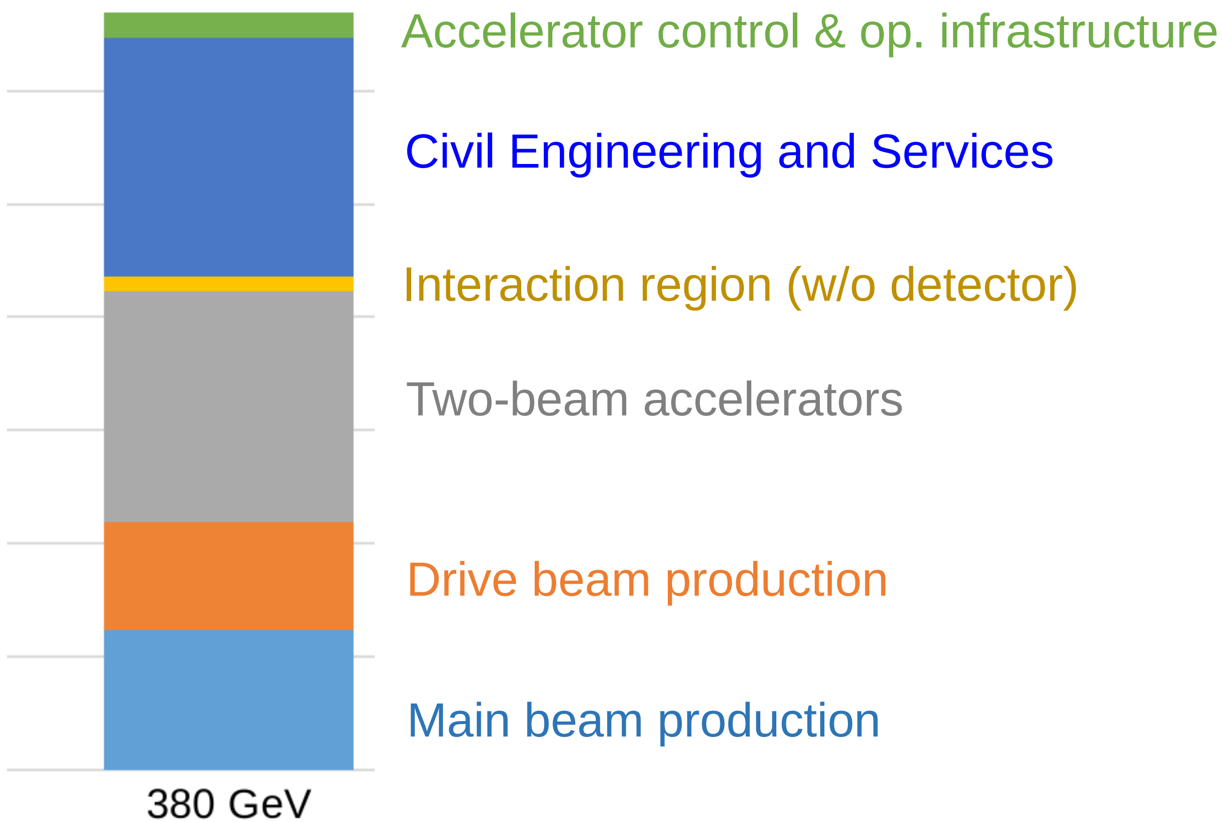
  2) Z' from e+e- → μ+μ− (systematics limited already with 1 ab−1)

  → Also at high energy some faction of data with +80% is desired
- Collecting 80% (70%) of the luminosity with -80% electron beam polarisation at high energy corresponds to 48% (32%) more run time for double Higgs production and rare decays
- If new physics is discovered: polarisation might be useful to constrain the underlying theory

CLIC costs and power

- Ongoing: detailed bottom-up estimate of cost and power
- Current estimate: O(6 GCHF) for 380 GeV stage, power O(200 MW)
- Considerable savings compared to CERN-2016-004 identified (2016 numbers were extrapolated from 500 GeV CLIC (CDR 2012) - 6.7 GCHF)

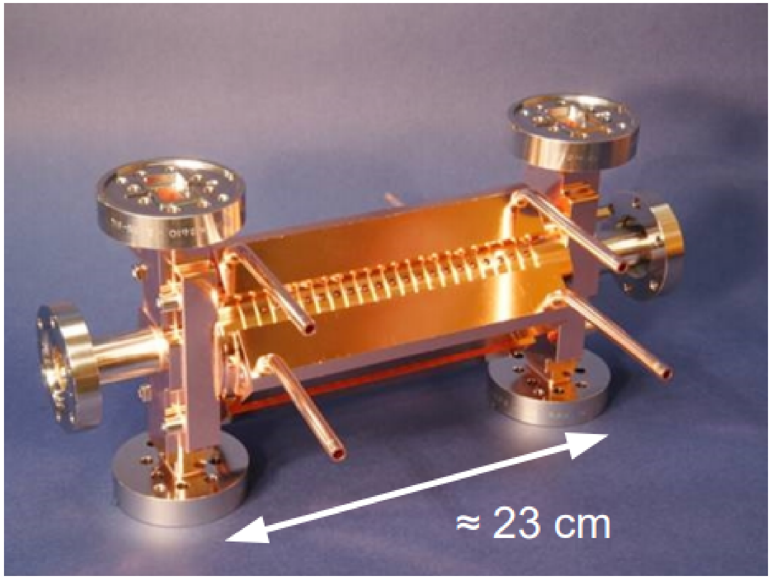


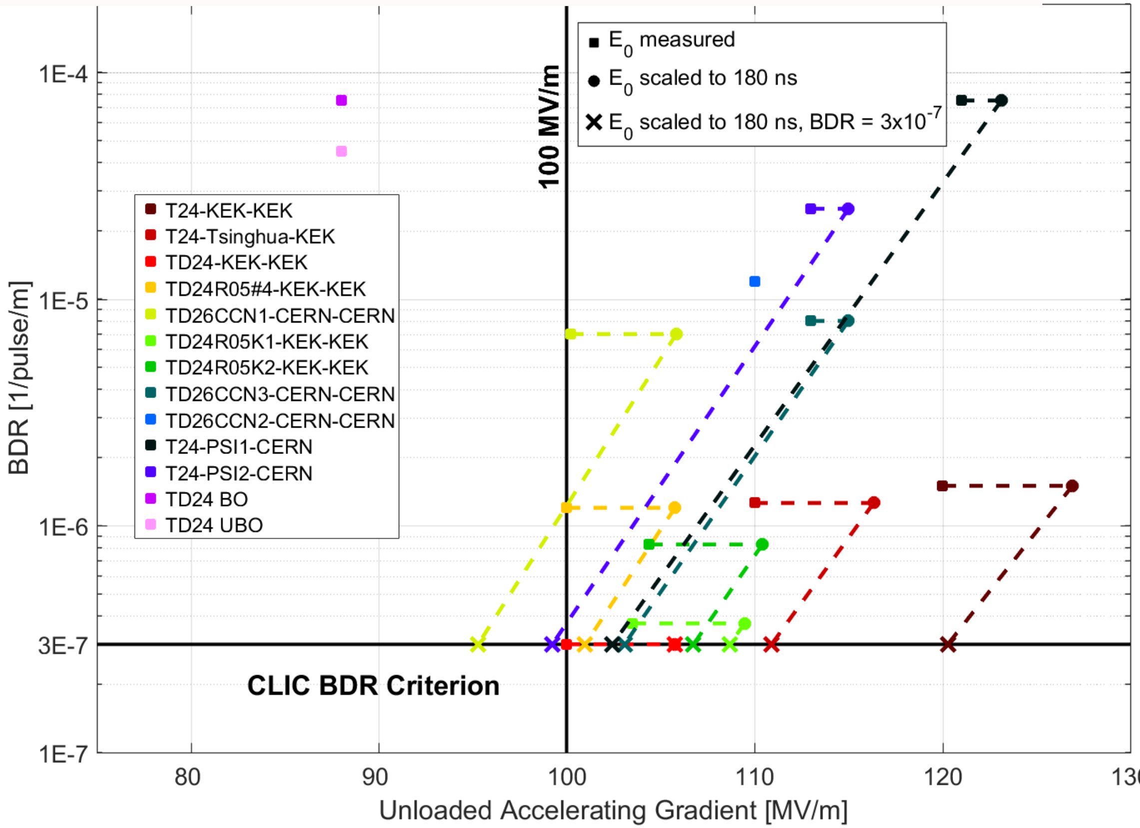


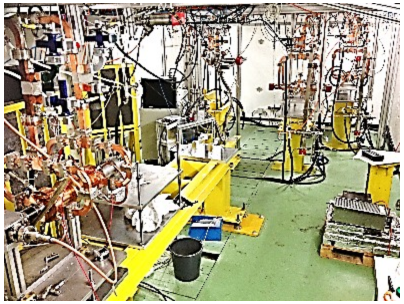
CLIC accelerating structures

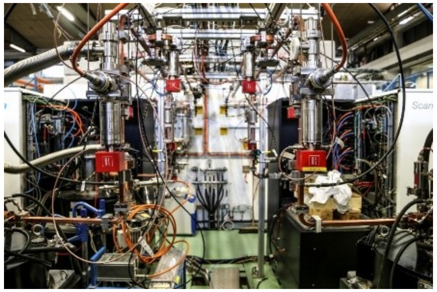
Achieved 100 MV/m gradient in main-beam RF cavities

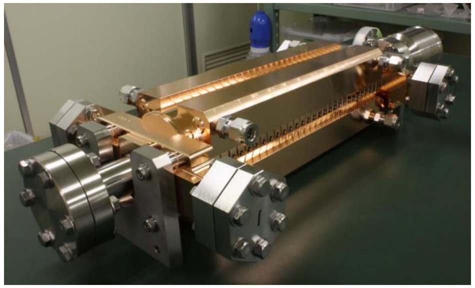
- R&D around the world
- Feasibility study using Break Down Rate (BDR)
- Shorter pulses allow higher gradient







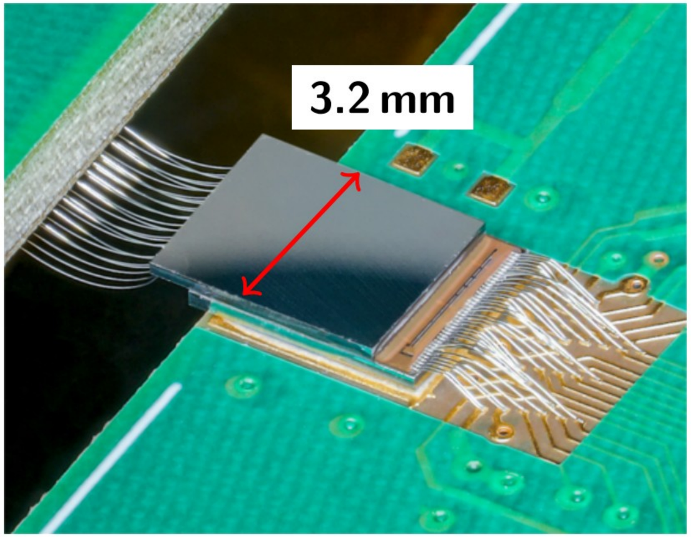




R&D in CLICdp (examples)

Vertex & Tracker

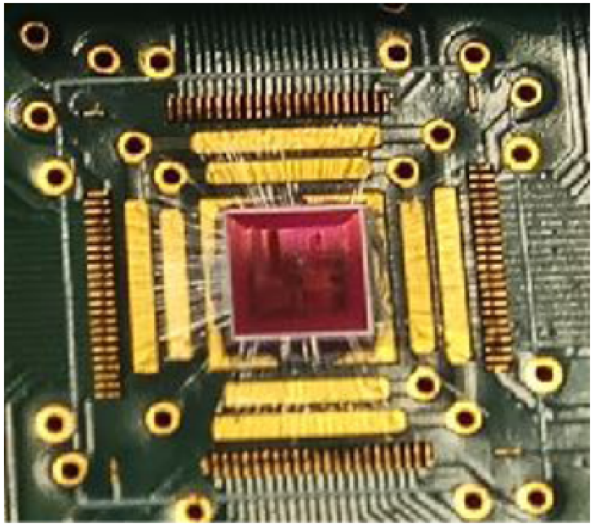
CLICpix2 + C3PD glue assembly



hybrid ←

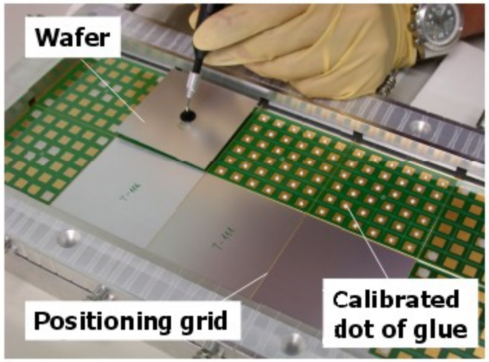
monolithic →

Cracow SOI test chip

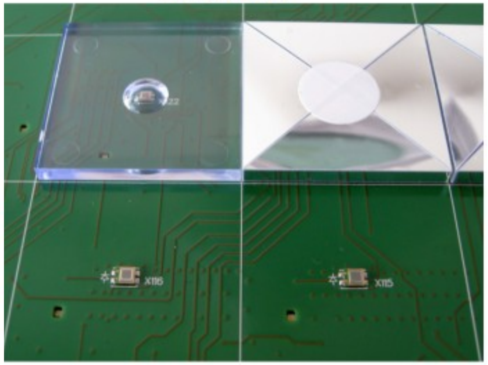


Calorimetry

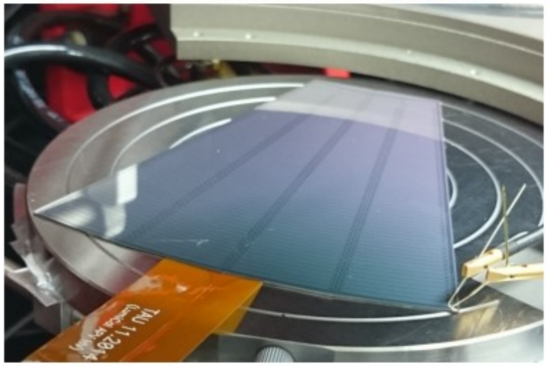
CALICE silicon PIN diodes
$1 \times 1\,\mathrm{cm}^2$ in 6×6 matrices



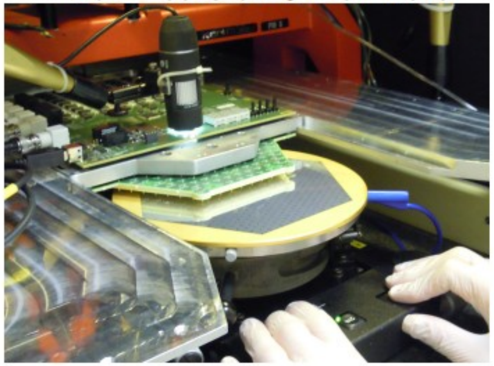
CALICE scint. tiles + SiPMs
$3 \times 3\,\mathrm{cm}^2$



LumiCal silicon sensor petal
1.8 mm wide strips, diff. lengths



CMS HGCal silicon diodes
$\sim 1\,\mathrm{cm}^2$ cells on 8-inch wafer



Beam at CLIC

Luminosity spectrum

Fraction $\sqrt{s'}/\sqrt{s}$	380 GeV	3 TeV
> 0.99	63%	36%
> 0.9	91%	57%
> 0.8	98%	69%
> 0.7	99.5%	77%
> 0.5	≈100%	89%

- Due to beamstrahlung, important energy losses right at the interaction point
- Collision energy is reduced by the amount lost in beamstrahlung before collision
- Most physics processes are studied well above production threshold

  → Can profit from almost full luminosity

Bunch separation

Property $\sqrt{s}$	380 GeV	1.5/3 TeV
Train repetition rate	50 Hz	50 Hz
Bunches / train	356	312
Train duration	178 ns	156 ns
Bunch separation	0.5 ns	0.5 ns
Duty cycle	0.00089%	0.00078 %

- Bunch separation drives timing requirement of detector:

  < 10 ns hit time-stamping in tracking

  < 1 ns accuracy for calorimeter hits
- Low duty cycle:

  Possibility of power pulsing of detectors

Flavour Changing Neutral Current

- FCNC top-quark decays are strongly suppressed in SM (CKM+GIM)
- **Signatures**: $t \to c\gamma$, $t \to cH$, $t \to c$ + missing energy
- top decaying to charm, where the charm tagging capability at CLIC can be exploited
- **Results**: 95% C.L. limits (500 fb^{-1} @ 380 GeV)

$$BR(t \to c\gamma) < 4.7 \times 10^{-5}$$

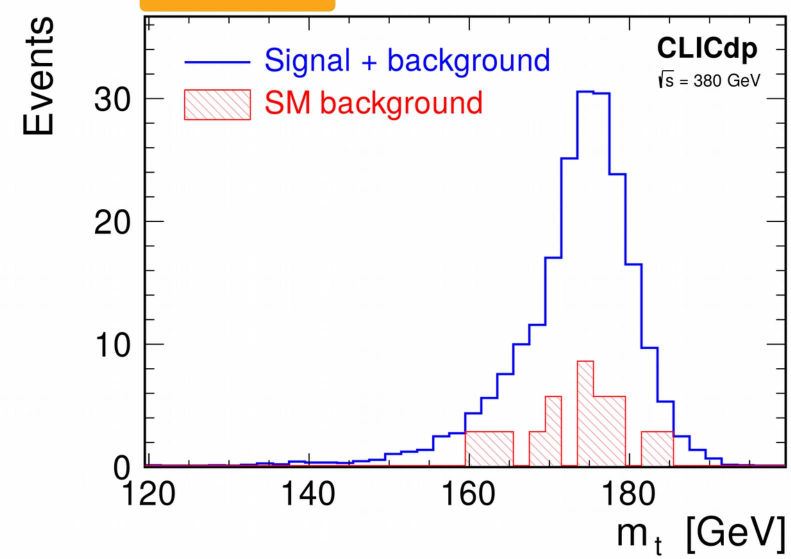
CMS@HL-LHC[1]: $BR(t \to c\gamma) < 7.4 \times 10^{-5}$

$$BR(t \to cH)\times BR(H \to bb) < 1.2 \times 10^{-4}$$

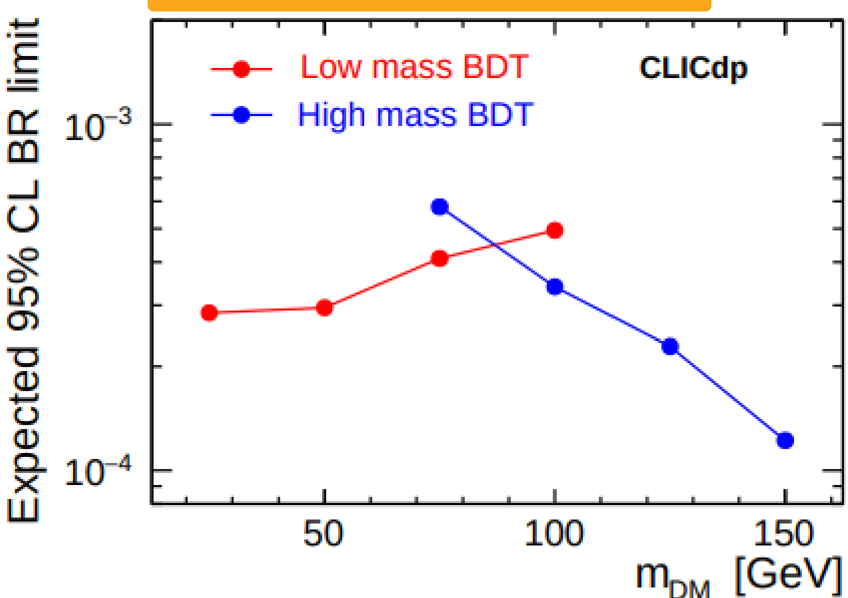
ATLAS@HL-LHC[2]: $BR(t \to cH) < 2 \times 10^{-4}$

$$BR(t \to c + \text{missing energy})(*): 1.2 - 4.1 \times 10^{-4}$$

$t \to c\gamma$



$t \to c$ + missing energy



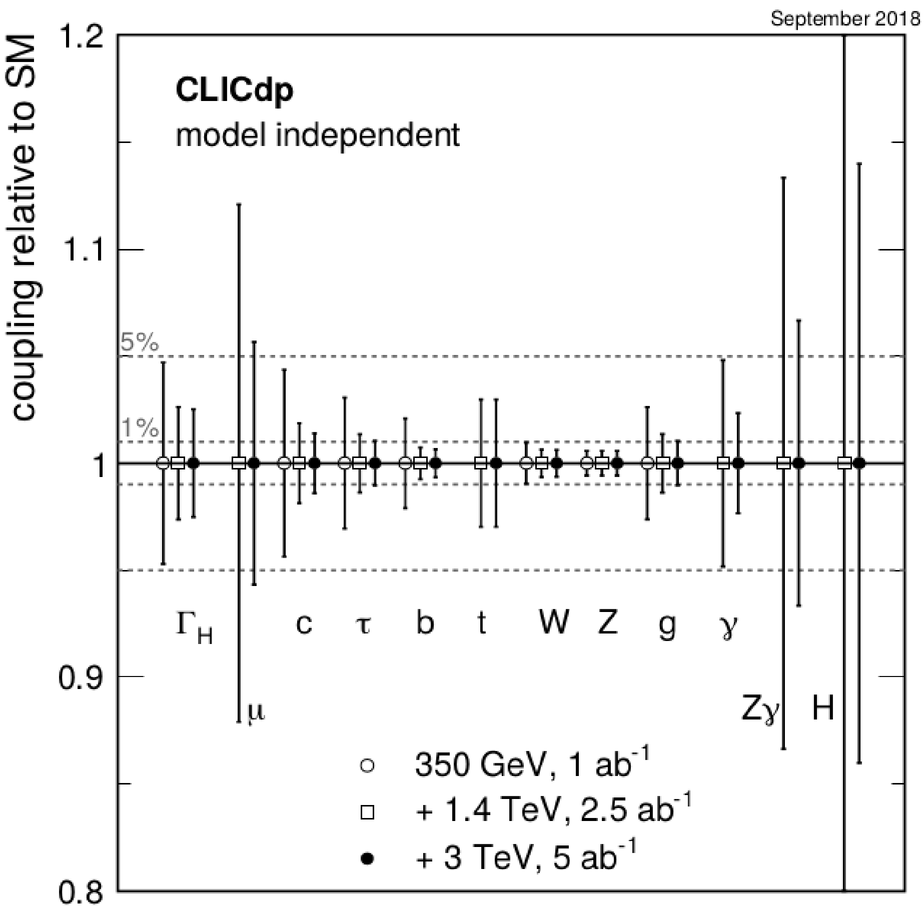
(*) depends on invisible mass, BDTs trained for different masses

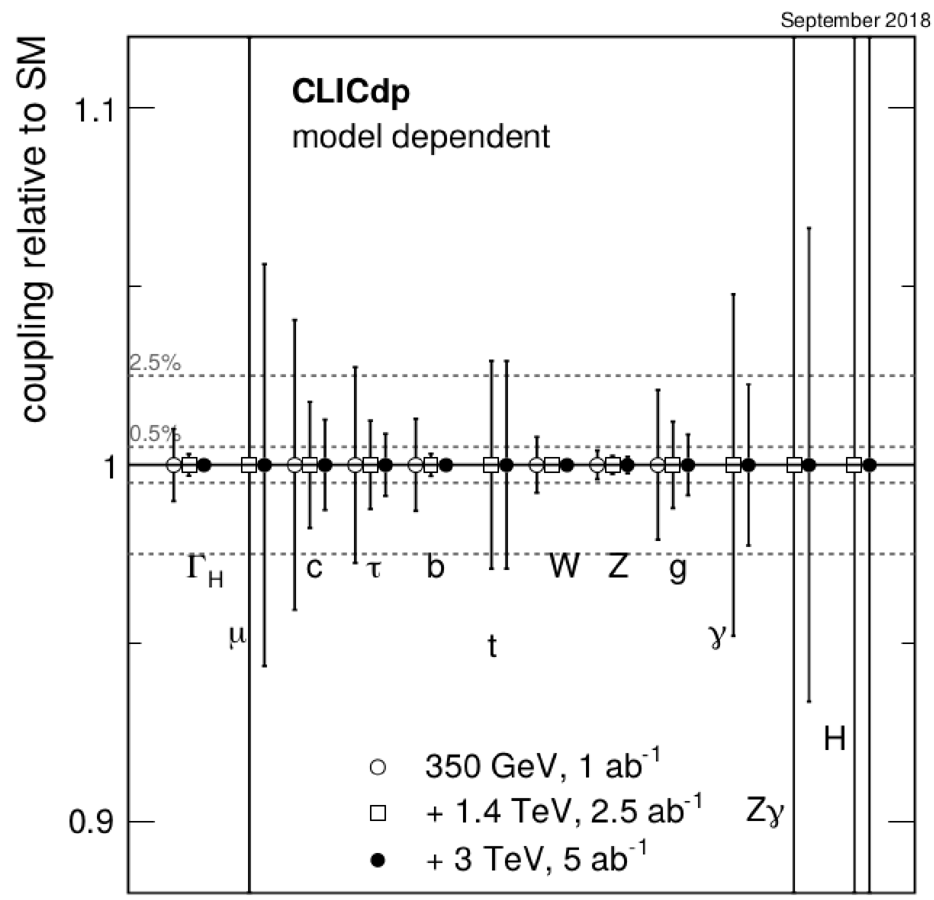
[1] https://cds.cern.ch/record/2293646
[2] https://cds.cern.ch/record/2209126

Higgs physics at CLIC

Fully model-independent analysis:
Free parameters Γ_H and ten Higgs couplings
No assumption on invisible Higgs decays

Model-dependent analysis:
Γ_H constrained by the SM expectations
No invisible Higgs decays





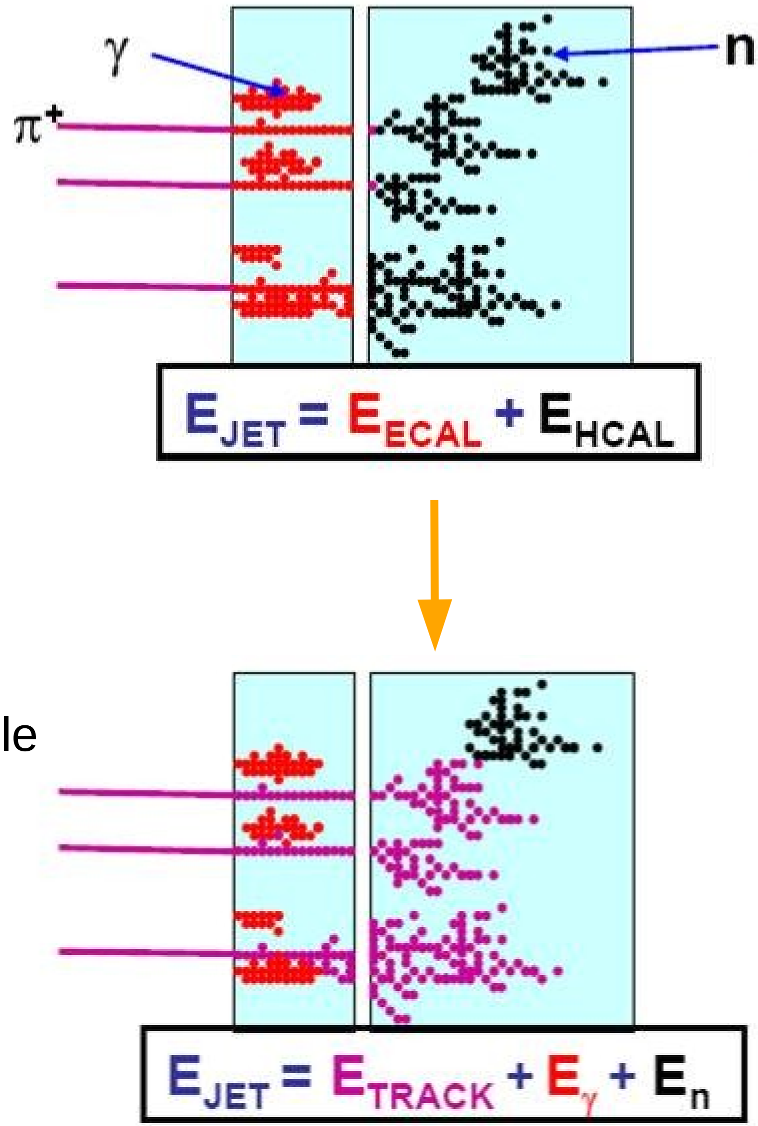
The Particle Flow approach

Main idea of Particle Flow approach:

- **Average jet composition:** → Use the best information
  60% charged particles → tracker
  30% photons → ECAL
  10% neutral hadrons → HCAL

- **Hardware:**
  Resolve energy deposits from different particles
  → High granularity calorimeters

- **Software:**
  Associate energy deposits to the correct individual particle
  → Sophisticated reconstruction software

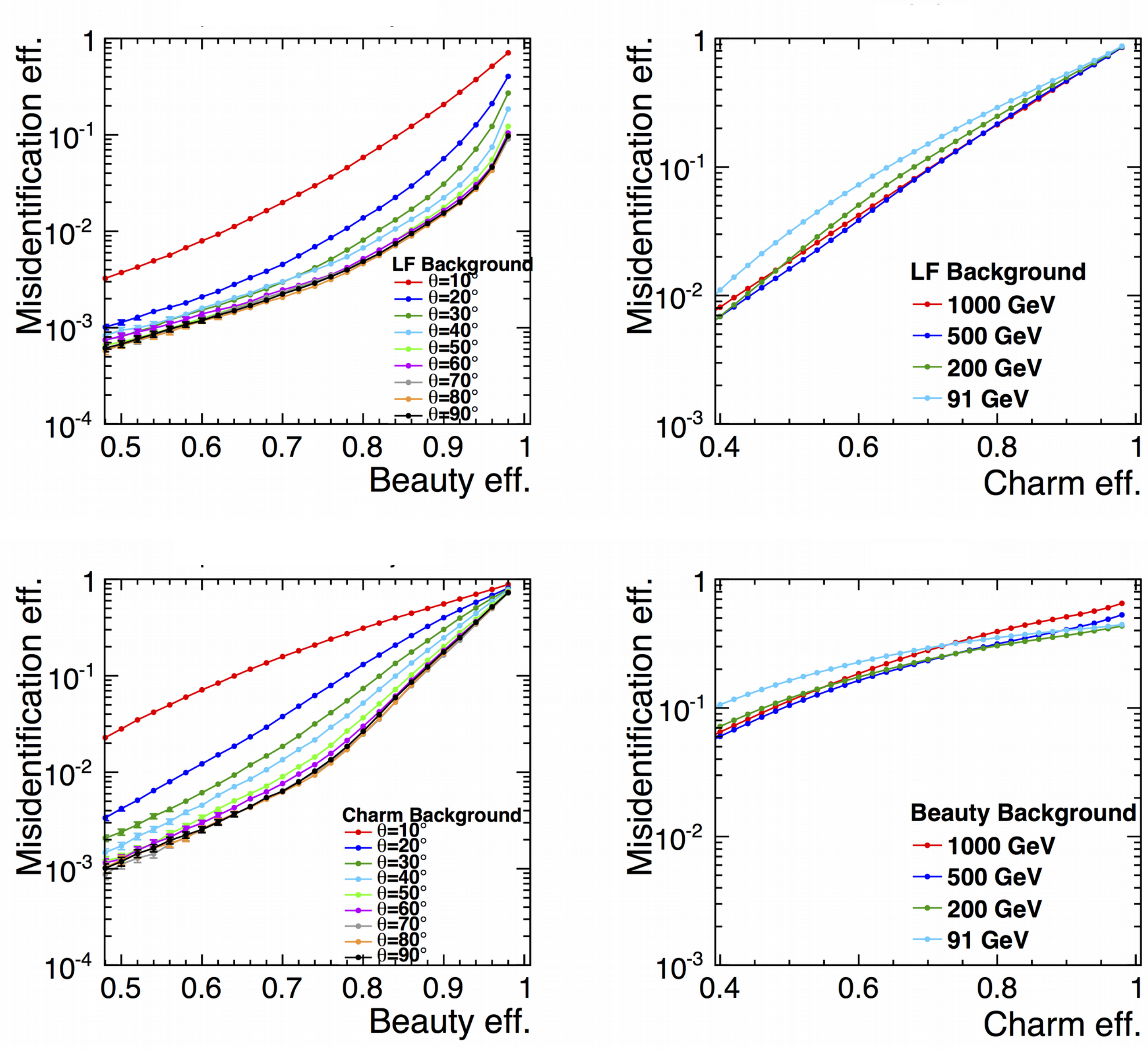


Flavour tagging at CLIC

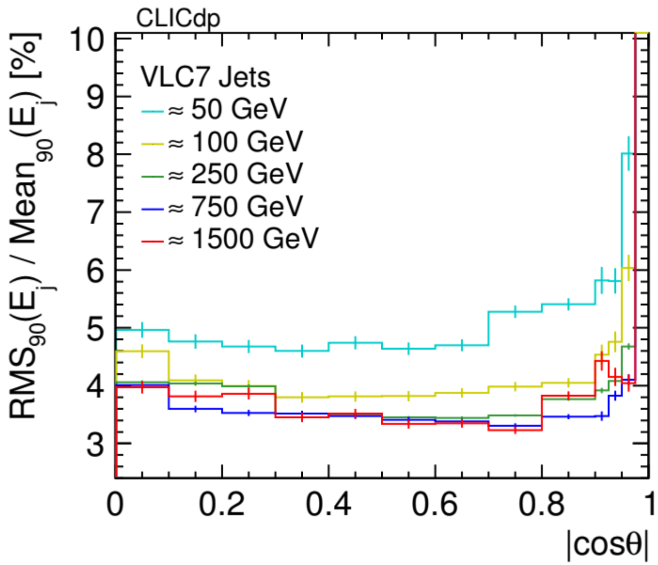
b- and c-tagging in $e^+e^- \rightarrow qq$ events

- Vertex finder reconstructs primary and secondary vertices

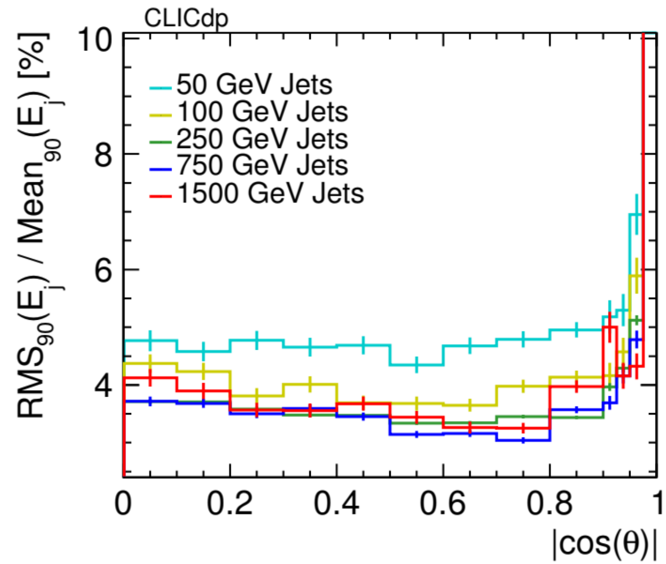
- Jet reconstruction using jet clustering algorithm



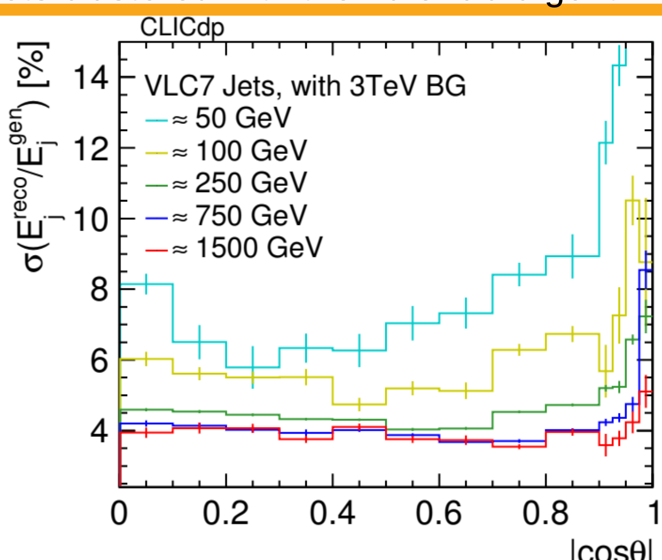
Jet resolution at CLIC



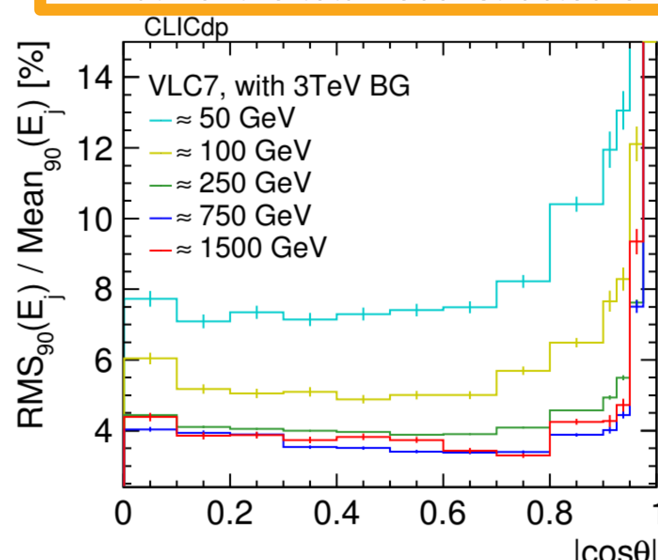
Jet energy resolution computed using jets clustered with the Valencia algorithm



Jet energy resolution computed using the width of the total reconstructed energy



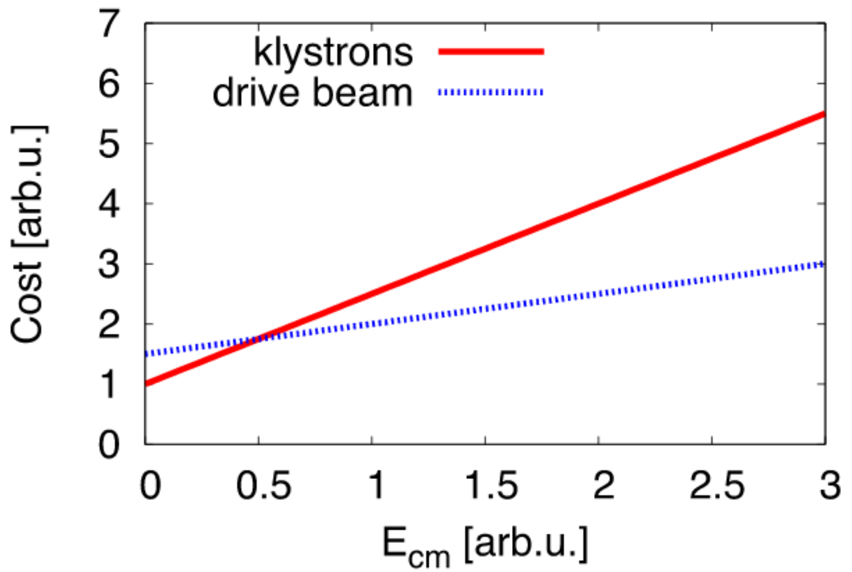
Jet energy resolution including 3 TeV background using double sided Crystal Ball fit



Jet energy resolution including 3 TeV background

High Accelerating Gradient Challenge

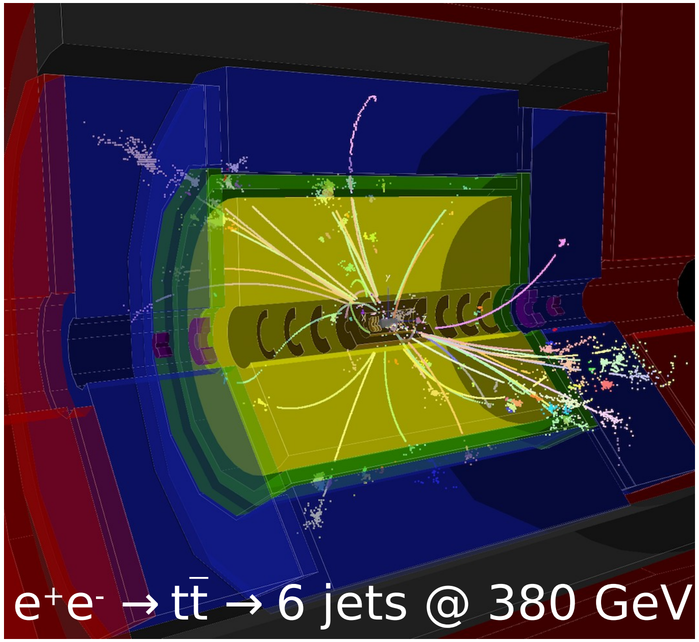
- State of the art superconducting cavities can provide 35 MV/m but require costly cryogenics installation
- Widely used accelerator power sources - klystrons - cannot efficiently provide pulses at required frequency (12 GHz), pulse duration (152 ns)
- Required 9.2 TW peak RF power, 244 ns pulse length repeated at 50 Hz would need 35 000 klystrons to provide enough power - unfeasible and cost ineffective
- Klystrons can be used to give power to classical low frequency cavities and accelerate a so-called drive beam
- This beam with low energy (2.4 GeV) and high current (100 A) is used as a power source for high frequency RF cavities
- Drive beam is thus decelerated in special Power Extraction and Transfer Structures (PETS) to only 10% of its initial energy

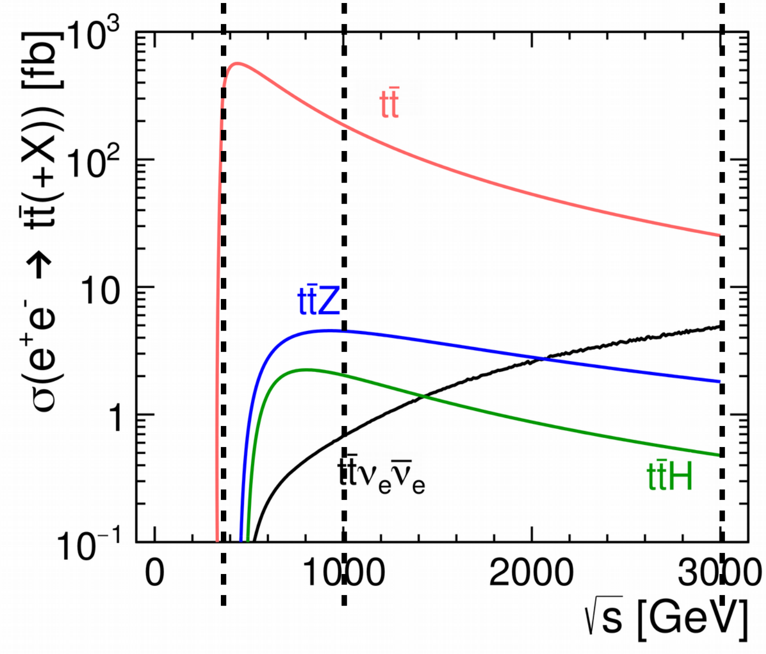


Top-quark physics at CLIC

Motivations:

- Top quark is the heaviest known particle
- Yukawa coupling to Higgs boson y_t~1 → key to understanding Electroweak Symmetry Breaking
- Top quark decays before hadronising → test ground of QCD
- Large loop contribution to many precision measurements
- Sensitive to many BSM scenarios a window to BSM
- So far top quark only measured at hadron colliders



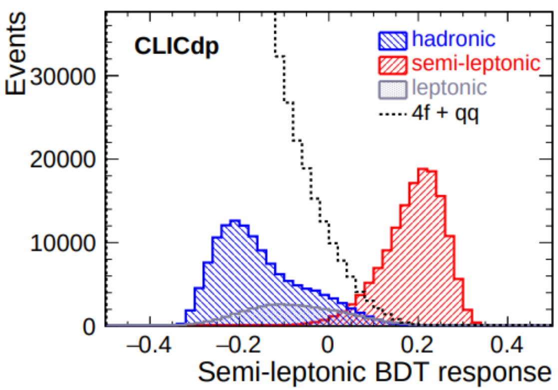


Flavour Changing Neutral Current

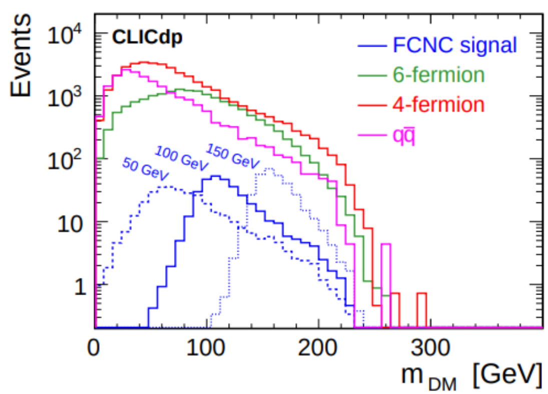
Analysis procedure:

- event classification and pre-selection
  (based on flavour tagging, lepton and photon identification, global event properties and jet clustering results)
- kinematic fit (for signal and background hypothesis)
- final selection based on multivariate analysis (BDT)

Event classification for $t \to cH$

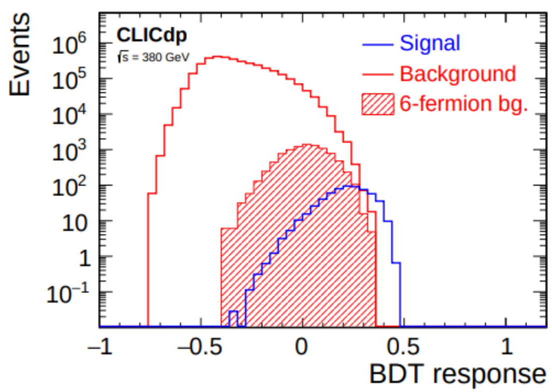


Reconstructed missing mass for $t \to c + \not{E}$

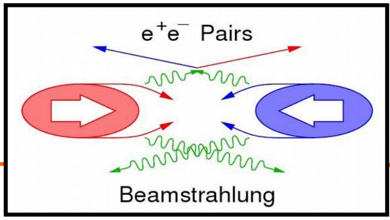


for BR

BDT response distribution for $t \to c\gamma$



Beam-induced backgrounds



CLIC achieves high luminosities by using extremely small beam sizes

→ 3 TeV CLIC bunch size: $\sigma_{x,y,z}$ = {40 nm, 1 nm, 44 μm}

(at LHC $\sigma_{T,z}$ = {16.7 μm, 7.55 cm})

→ very high EM-fields → beam-beam interactions

Main backgrounds:

- **Incoherent e^+e^- pairs**
  - → High occupancy
  - → Mostly in the forward region
  - → Impact on detector granularity and design
- **γγ → hadrons**
  - → High energy deposits
  - → Impact on detector granularity, design and physics measurement

Detector acceptance starts at 10 mrad

Effect is dependent on √s

→ Background particles

→ Reduces √s