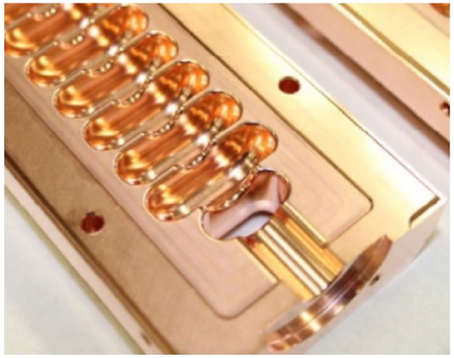
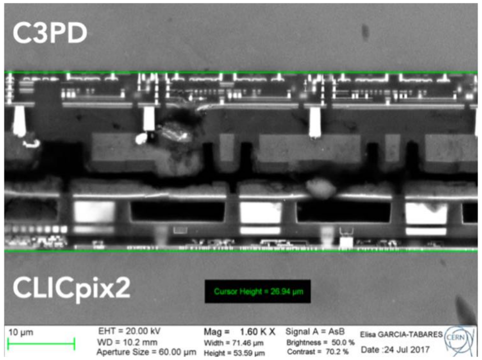
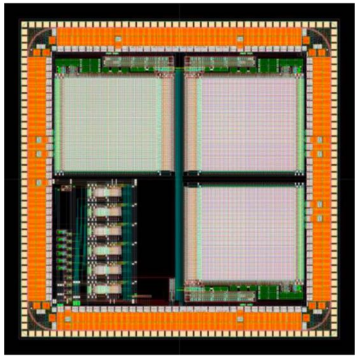
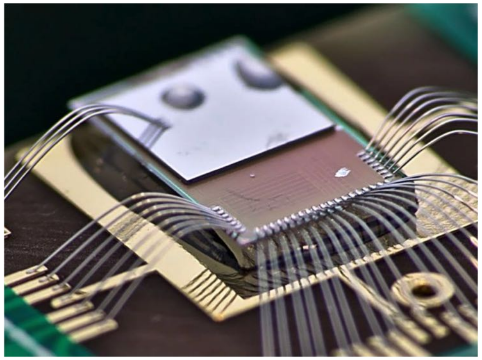
CLIC overview









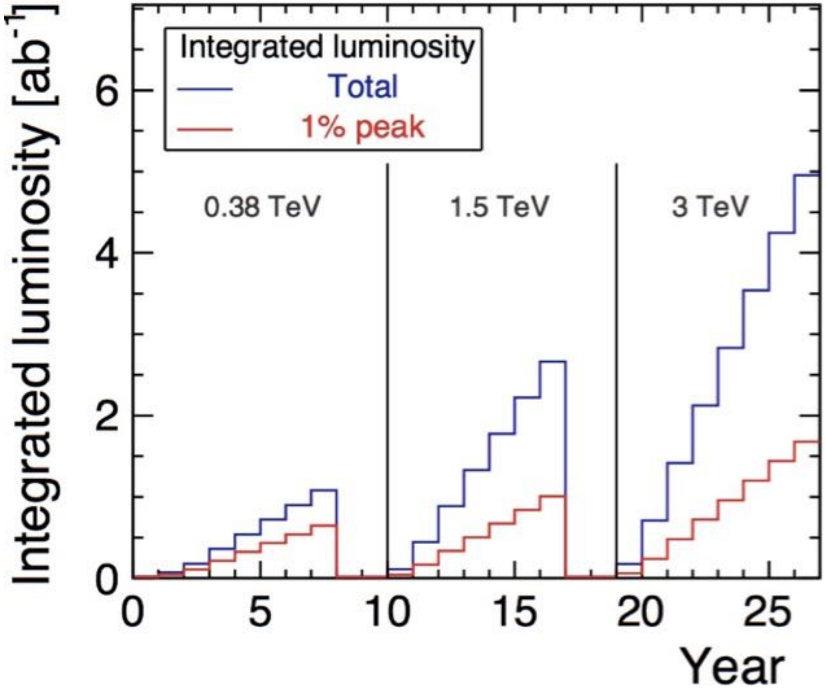
Lucie Linssen, CERN
on behalf of the CLICdp collaboration

CLIC physics and staged operation

Linear e^+e^- collider, staging scenario motivated by maximum physics output

380 GeV (350 GeV) :	precision Higgs and top physics
1.5 TeV :	BSM searches, precision Higgs, ttH, HH, top physics
3 TeV :	BSM searches, precision Higgs, HH, top physics

BSM searches: direct (up to ~1.5 TeV), indirect (>> TeV scales)



Stage	$\sqrt{s}$ [TeV]	$\mathscr{L}_{\text{int}}$ [ab^{-1}]
1	0.38 (and 0.35)	1.0
2	1.5	2.5
3	3.0	5.0

Polarised electron beam (–80%, +80%)

Ratio (50:50) at $\sqrt{s}$=380GeV ; (80:20) at $\sqrt{s}$=1.5 and 3TeV

Coherent approach for CERN future colliders (running times, luminosity performance)

1.2×10^7 sec/year   arXiv:1810.13022, Bordry et al.

CLIC collaborations

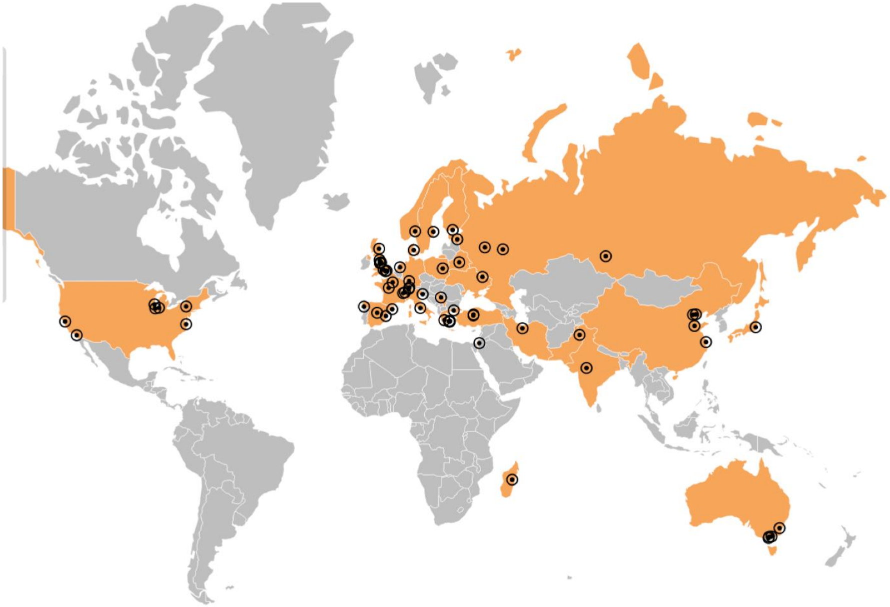
http://clic.cern/

CLIC accelerator collaboration

~60 institutes from 28 countries

CLIC accelerator studies:

- CLIC accelerator design and development
- (Construction and operation of CLIC Test Facility, CTF3)



Spokesperson: philip.burrows@physics.ox.ac.uk
CERN contact: steinar.stapnes@cern.ch

CLIC detector and physics (CLICdp)

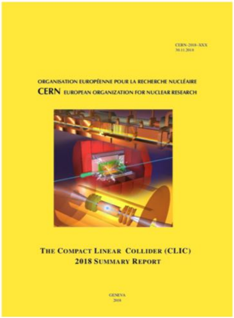
30 institutes from 18 countries

Focus of CLIC-specific studies on:

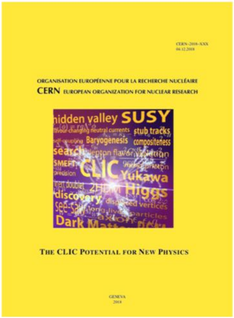
- Physics prospects & simulation studies
- Detector optimization + R&D for CLIC

Spokesperson: aidan.robson@cern.ch
CERN contact: lucie.linssen@cern.ch

CLIC overview documents

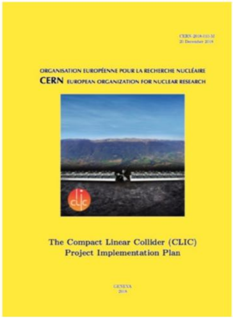

CERN-2018-XXX
30.11.2018
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
THE COMPACT LINEAR COLLIDER (CLIC)
2018 SUMMARY REPORT
GENEVA
2018

Summary

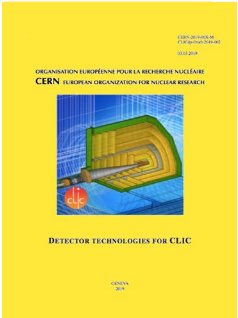

CERN-2018-XXX
04.12.2018
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

THE CLIC POTENTIAL FOR NEW PHYSICS
GENEVA
2018

Physics


ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
The Compact Linear Collider (CLIC)
Project Implementation Plan
GENEVA
2018

Accelerator


CERN-2019-00X-M
CLICdp-Draft-2019-002
03.03.2019
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
DETECTOR TECHNOLOGIES FOR CLIC
GENEVA
2019

Detector R&D

Formal European Strategy submissions

The Compact Linear e+e- Collider (CLIC): Accelerator and Detector (arXiv:1812.07987)
The Compact Linear e+e- Collider (CLIC): Physics Potential (arXiv:1812.07986)

Yellow Reports

CLIC 2018 Summary Report (CERN-2018-005-M, arXiv:1812.06018)
CLIC Project Implementation Plan (CERN-2018-010-M, arXiv:1903.08655)
The CLIC potential for new physics (CERN-2018-009-M, arXiv:1812.02093)
Detector technologies for CLIC (CERN-2019-001, arXiv:1905.02520)

Journal publications

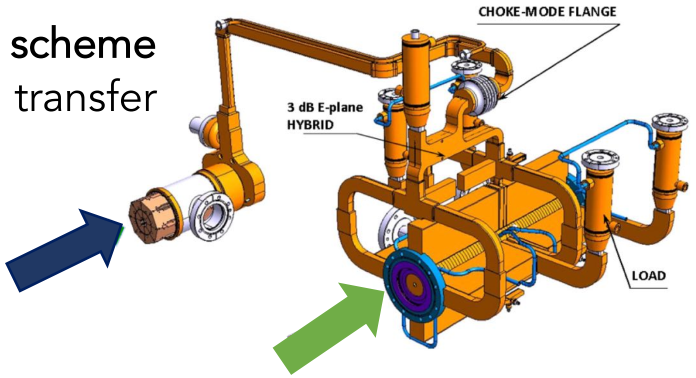
Top-quark physics at the CLIC electron-positron linear collider (Journal, arXiv:1807.02441)
Higgs physics at the CLIC electron-positron linear collider (Journal, arXiv:1608.07538)
Rescaling of analyses from this paper to latest CLIC luminosities: CDS, arXiv

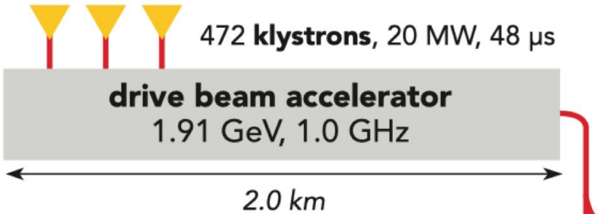
CLICdp notes

Updated CLIC luminosity staging baseline and Higgs coupling prospects (CDS,arXiv:1812.01644)
CLICdet: The post-CDR CLIC detector model (CDS)
A detector for CLIC: main parameters and performance (CDS, arXiv:1812.07337)

CLIC complex, 380 GeV

Two-beam acceleration scheme
power extraction and transfer



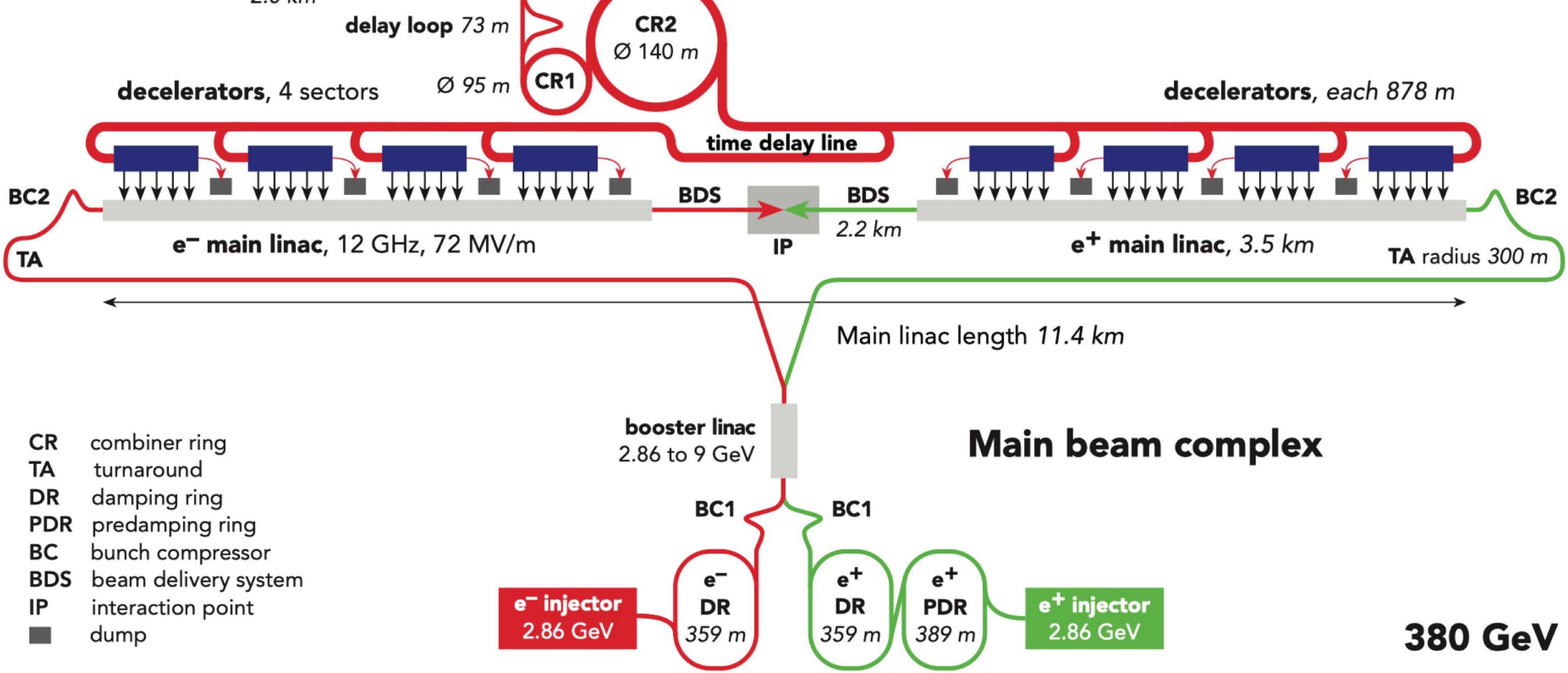


472 **klystrons**, 20 MW, 48 μs

drive beam accelerator
1.91 GeV, 1.0 GHz

2.0 km

Drive beam complex



delay loop *73 m*

CR2
Ø *140 m*

Ø *95 m* **CR1**

decelerators, 4 sectors

decelerators, *each 878 m*

time delay line

BC2 **BDS** **BDS** **BC2**

TA **e⁻ main linac**, 12 GHz, 72 MV/m

IP

2.2 km

e⁺ main linac, *3.5 km*

TA radius *300 m*

Main linac length *11.4 km*

booster linac
2.86 to 9 GeV

Main beam complex

BC1 **BC1**

e⁻ injector
2.86 GeV

e⁻
DR
359 m

e⁺
DR
359 m

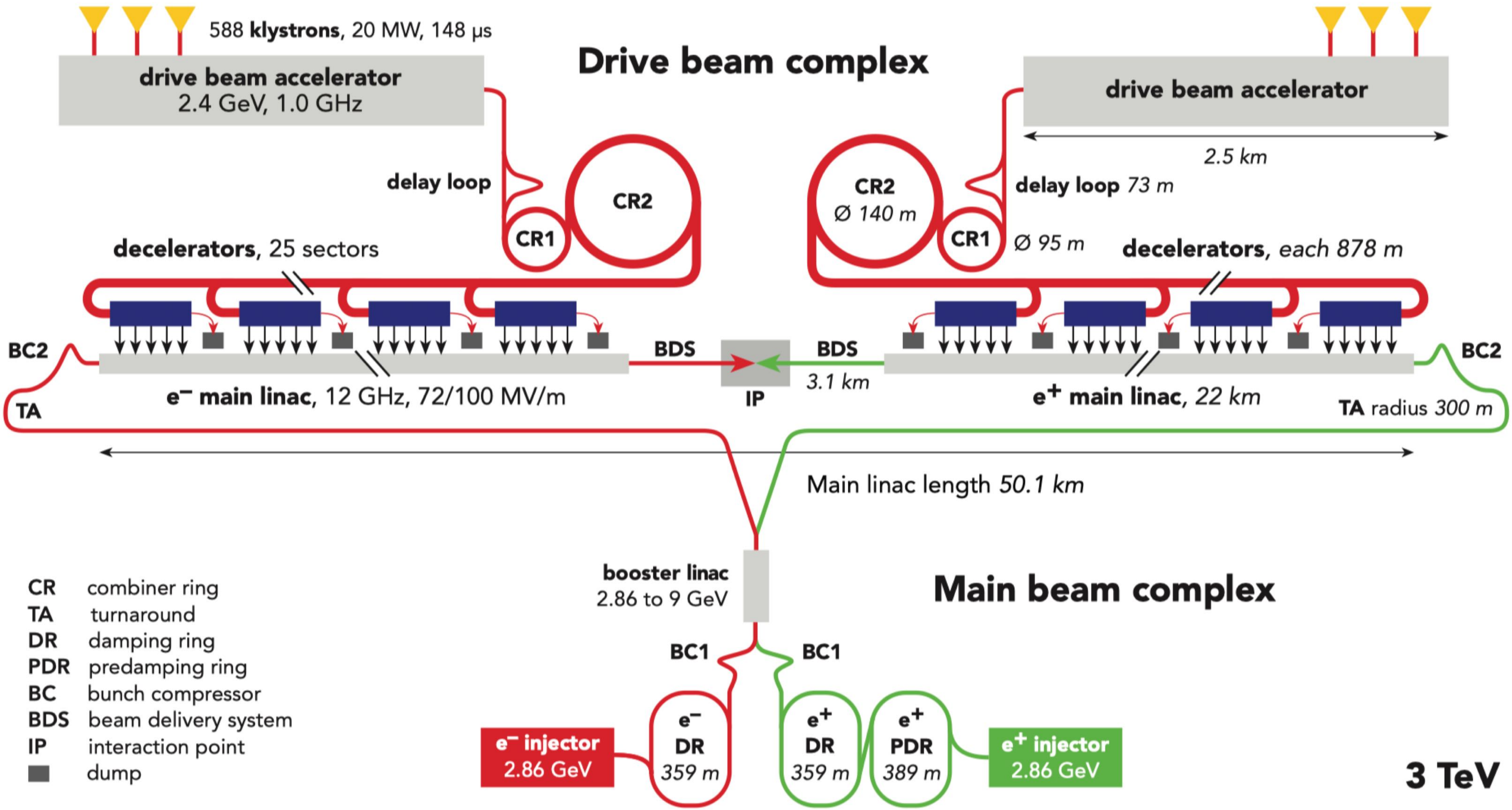
e⁺
PDR
389 m

e⁺ injector
2.86 GeV

CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
■	dump

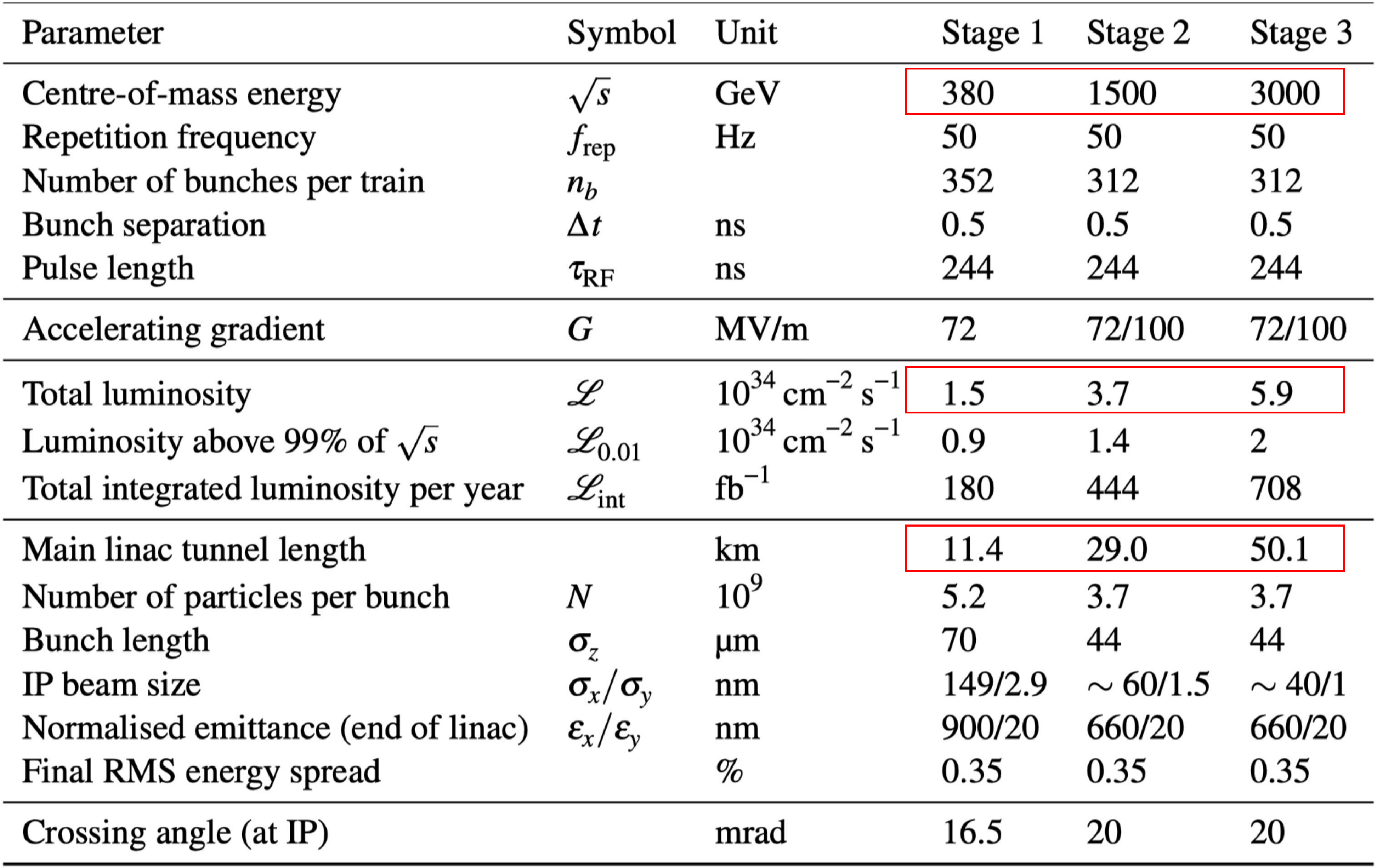
380 GeV

CLIC complex, 3 TeV



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
■	dump

overview of CLIC parameters

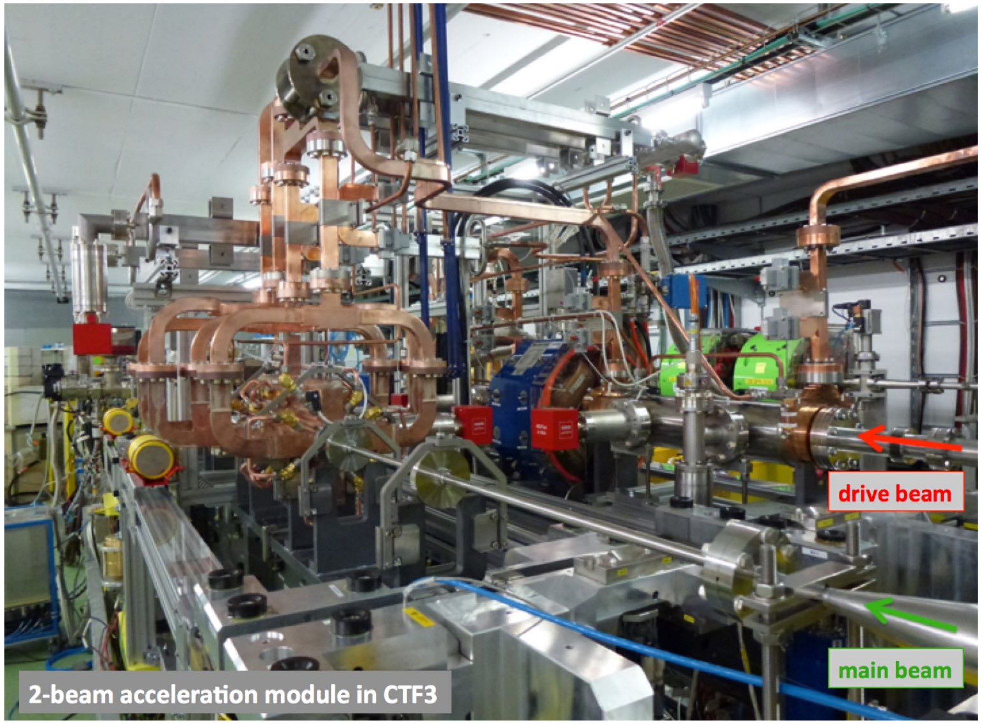


Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	$10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	$10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$	0.9	1.4	2
Total integrated luminosity per year	$\mathscr{L}_{\text{int}}$	fb^{-1}	180	444	708
Main linac tunnel length		km	11.4	29.0	50.1
Number of particles per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	μm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	900/20	660/20	660/20
Final RMS energy spread		%	0.35	0.35	0.35
Crossing angle (at IP)		mrad	16.5	20	20

arXiv:1812.06018

readiness of CLIC technology

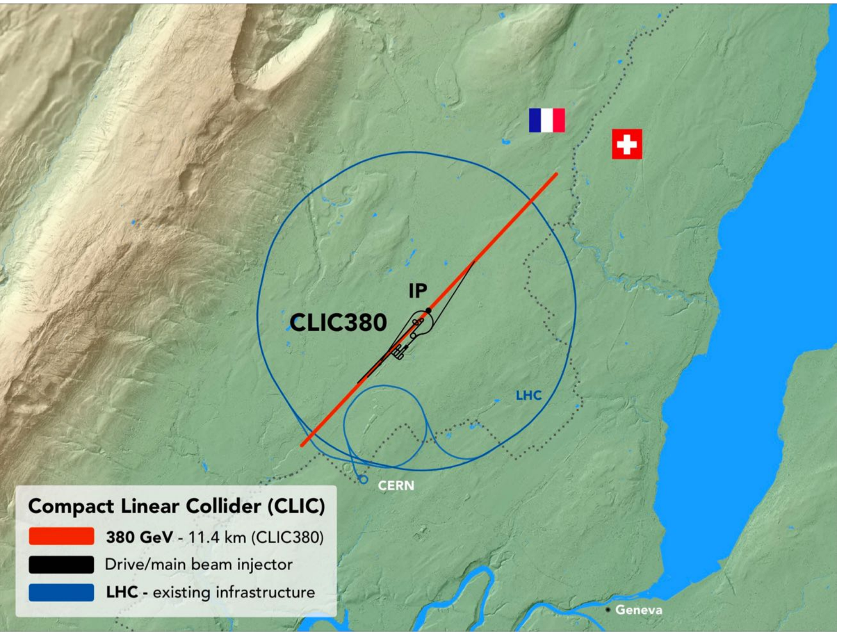
Many years of development, within a large international collaboration:
Simulations, large diversity of hardware tests, system tests with beam at many labs…



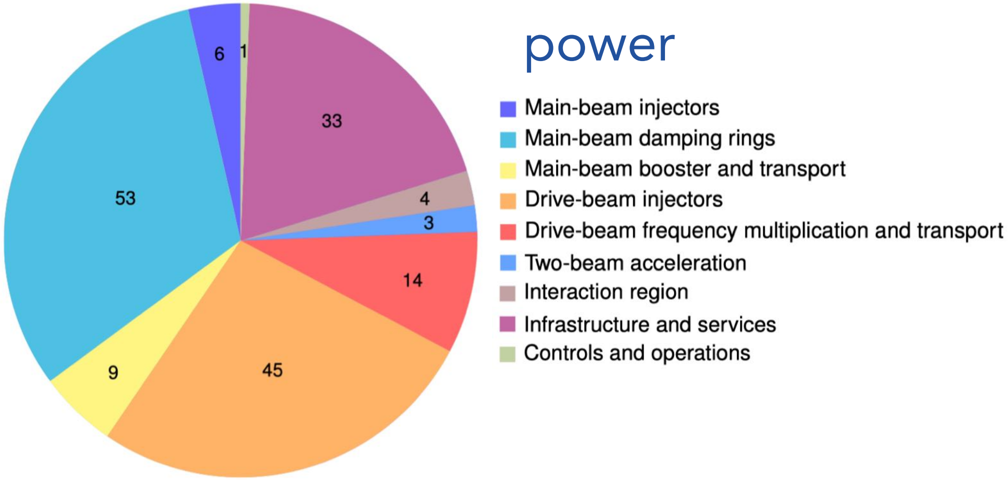
E.g. CTF3 successfully demonstrated:

- ✓ drive beam generation
- ✓ RF power extraction
- ✓ two-beam acceleration up to a gradient of 145 MeV/m

civil engineering, power, cost



Main 380 GeV surface infrastructures fit on CERN-owned land



Collision energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	168	25	9
1500	364	38	13
3000	589	46	17

Currently only optimized for 380 GeV
Further savings possible
1.5 TeV and 3 TeV power *not yet optimized*

cost of accelerator complex

CLIC 380 GeV drive-beam based : 5890^{+1470}_{-1270} MCHF

1st upgrade to 1.5 TeV → add ~5100 MCHF
2nd upgrade to 3 TeV → add another ~7300 MCHF

arXiv:1812.06018

CLIC technology applications

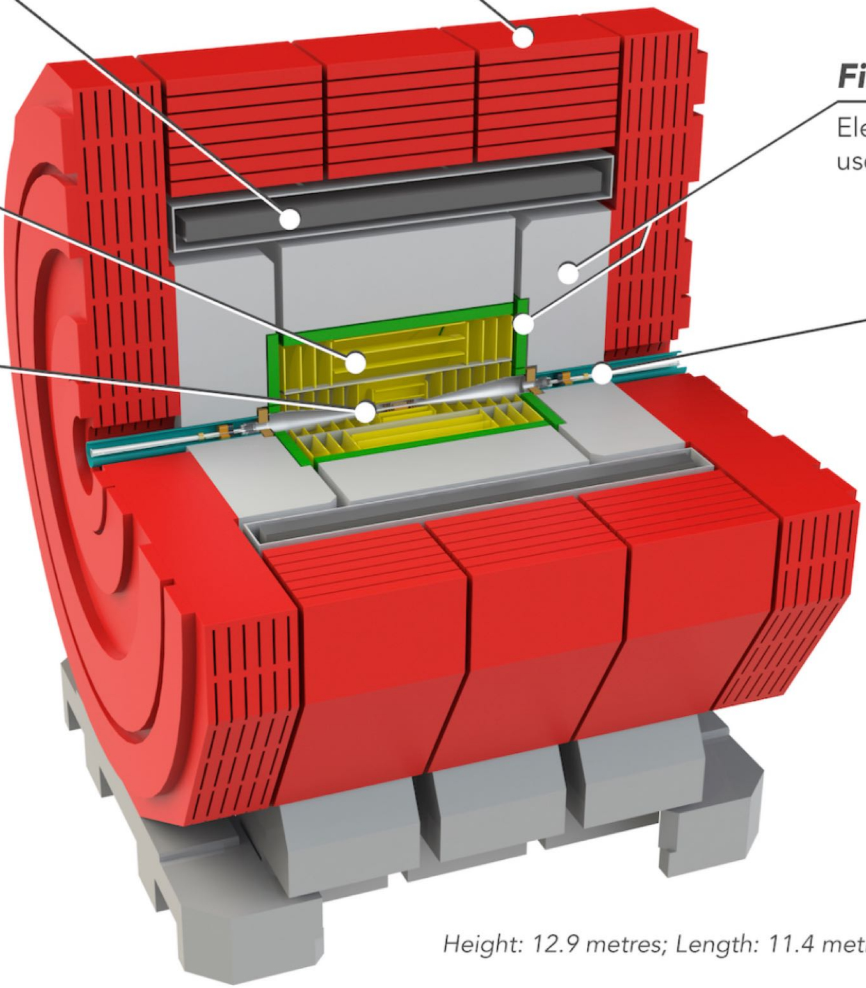
Collaboration with many facilities
Photon sources, medical applications
Lots of experience being built up

See academic training W. Wuensch
https://indico.cern.ch/event/668151/

One example: **SwissFEL**
- 104 C-band structures, 5.7 GHz, 2 m long
- Beam up to 6 GeV at 100 Hz
- Similar μm-level tolerances
- Length ⇔ 800 CLIC structures

CLIC detector

The CLIC detector model



Solenoidal Magnet
Superconducting magnet,
magnetic field of 4 tesla

Return Yoke
Iron return yoke with
detectors for muon ID

Tracking Detector
Silicon pixel detector,
outer radius 1.5 metres

Fine-grained Calorimeters
Electromagnetic and hadronic calorimeters
used for particle flow analysis

Forward Region
Electromagnetic calorimeters
for luminosity measurement and
extended angular coverage

Vertex Detector
Ultra-low mass silicon pixel
detector, inner radius
31 millimetres

Tracking detector
Material: 1–2% X_0 / layer
Single-point resolution: 7 micrometres

Vertex detector
25 micrometre pixels
Material: 0.2% X_0 / layer
Single-point resolution: 3 micrometres
Forced air-flow cooling

Electromagnetic calorimeter
40 layers (silicon sensors, tungsten plates)
Material: 22 X_0 + 1 λ_I

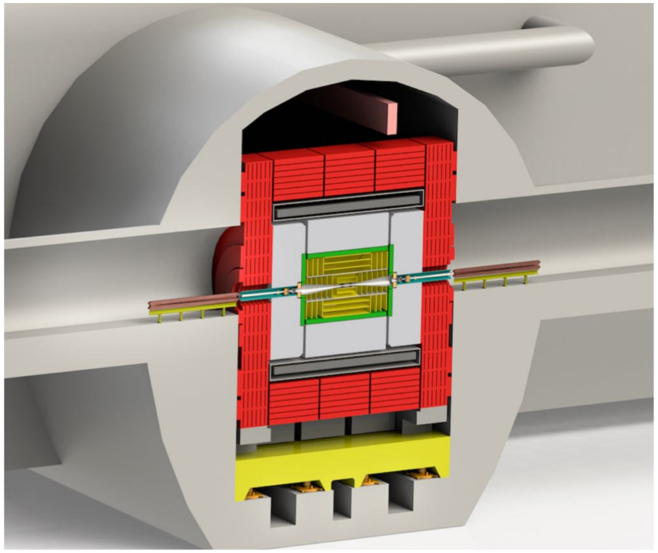
Hadronic calorimeter
60 layers (plastic scintillators, steel plates)
Material: 7.5 λ_I

Learn more about the CLIC detector at clic.cern

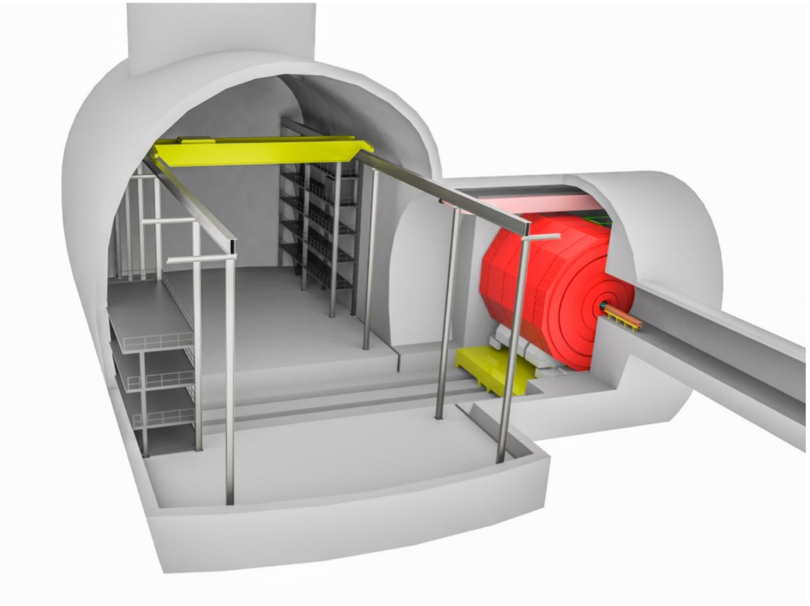
Height: 12.9 metres; Length: 11.4 metres; Weight: 8100 tonnes

CLICdp June 2019

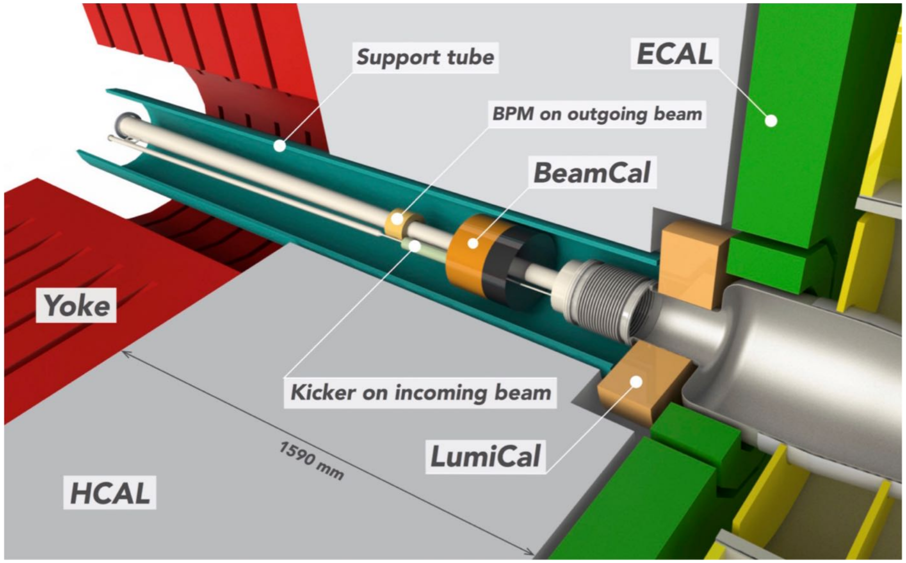
forward region and MDI



Last focusing elements in accelerator tunnel, L*=6 m. Detector kept short along beam line.



Service cavern (left), experimental cavern (right)



Forward detector region comprising beam feedback system and forward calorimeters:

- LumiCal (39 > θ >134 mrad)
- BeamCal (10 > θ > 46 mrad)

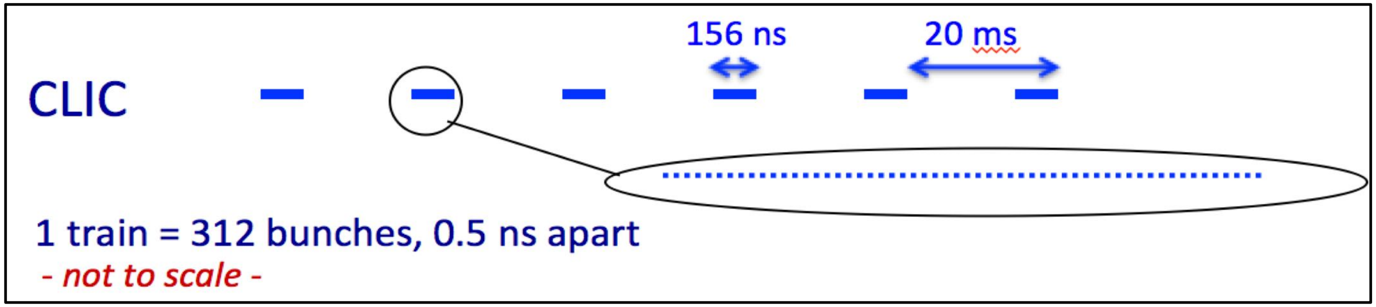
⟸ *FCAL collaboration*

Luminosity measurement down to *few* 0.1%
Forward coverage for electrons/photons

impact of beam conditions on detector

Beam in bunch trains @ 50 Hz

Very small, high-current particle bunches => **beamstrahlung**



1 train = 312 bunches, 0.5 ns apart

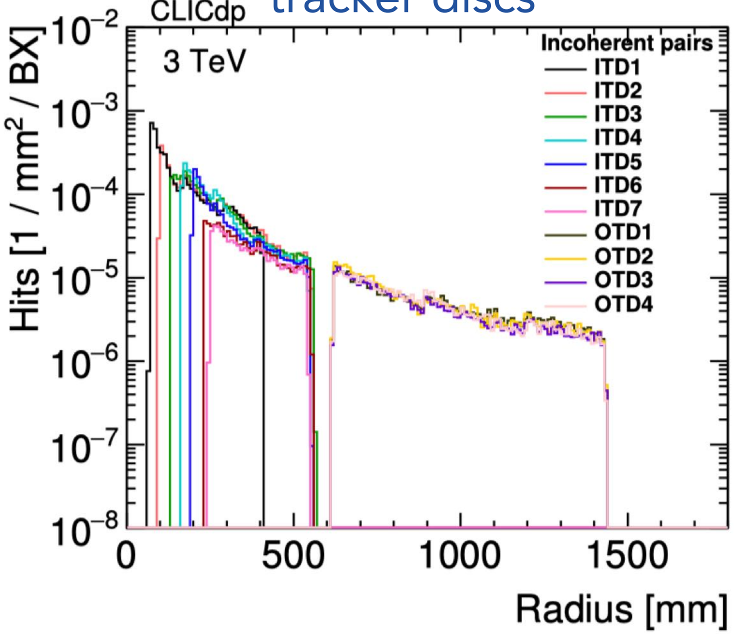
- not to scale -

Triggerless readout, once per full (156 ns) bunch train
Power pulsing foreseen for all subdetectors

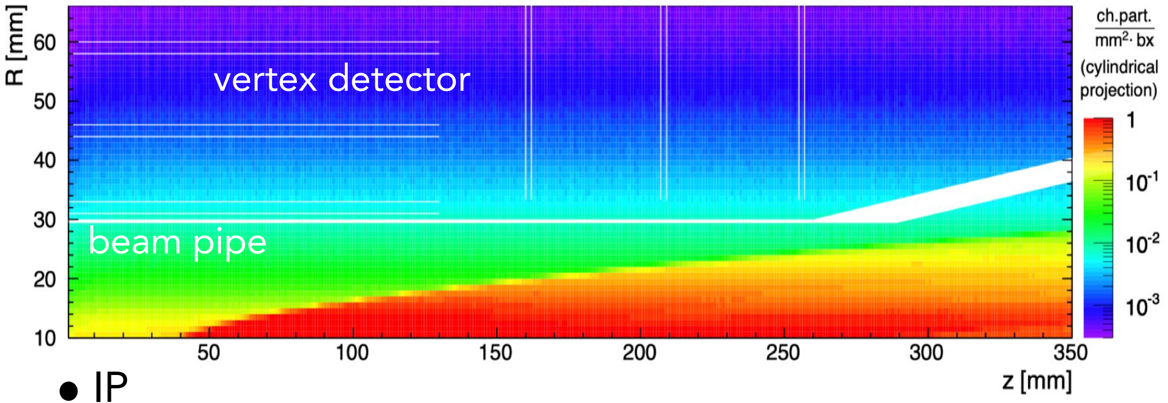
Expect at most one hard e^+e^- collision per bunch train
=> **detector occupancies** dominated by beamstrahlung

Detector designed to achieve occupancies below 3-4%

tracker discs



3 TeV



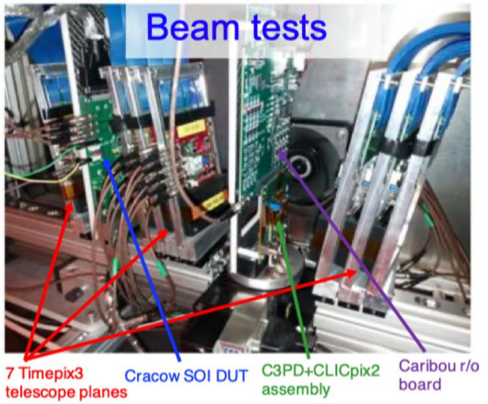
arXiv:1812.07337

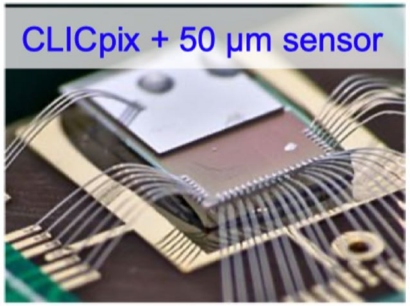
Max. vertex pixel size 25*25 μm^2
Max. tracker cells size depends on location:
max 0.05 mm^2 – 0.5 mm^2

CLIC silicon pixel-detector R&D

Sensor + readout technologies

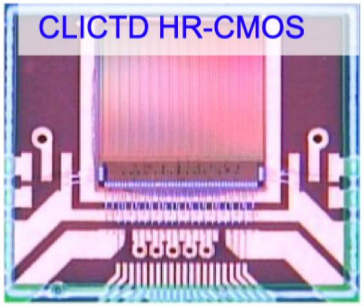
Sensor + readout technology	Currently studied for
Bump-bonded Hybrid planar sensors	Vertex
Capacitively coupled HV-CMOS sensors	Vertex
Monolithic HV-CMOS sensors	Tracker
Monolithic HR-CMOS sensor	Tracker
Monolithic SOI sensors	Vertex, Tracker


Beam tests


CLICpix + 50 μm sensor

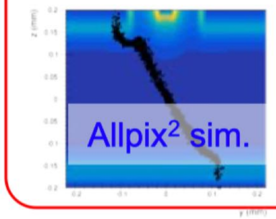

C3PD+CLICpix2 glue ass.

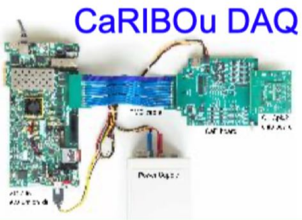

ATLASPIX HV-CMOS


CLICTD HR-CMOS

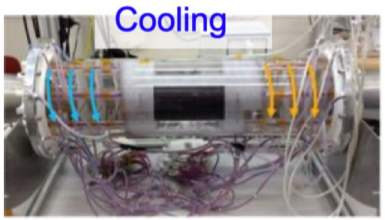

Cracow SOI

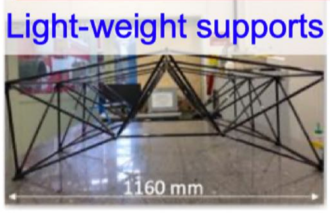
Simulation/Characterisation

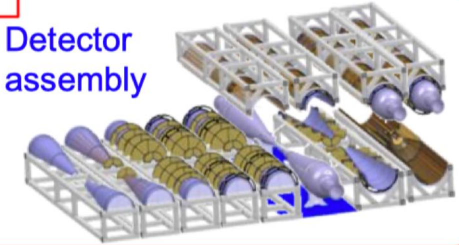

Allpix^2 sim.


CaRIBOu DAQ

Detector integration


Cooling

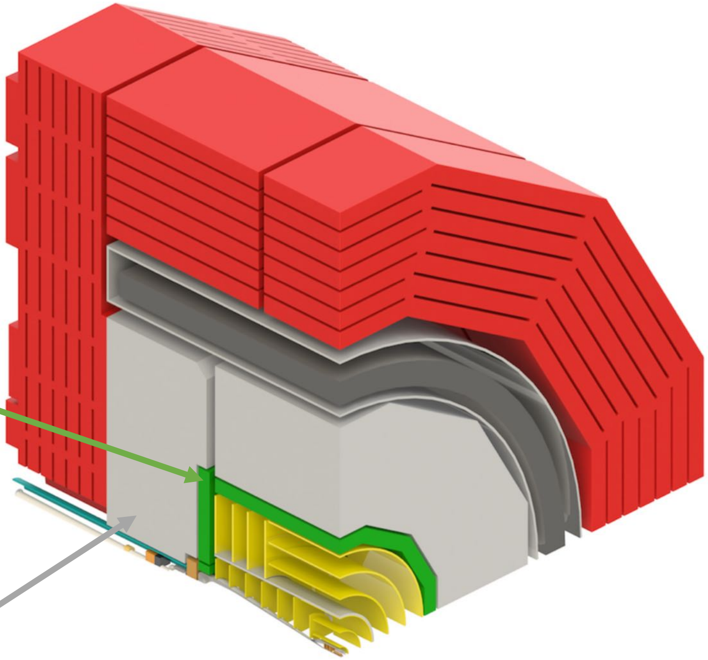

Light-weight supports


Detector assembly

- Challenging requirements lead to extensive detector R&D program
- ~10 institutes active in vertex/tracker R&D
- Collaboration with ATLAS, STREAM, ALICE, LHCb, Mu3e, AIDA-2020

Focus on conceptual studies + technology demonstrators

high-granularity calorimetry



Electromagnetic calorimeter: Silicon – tungsten
- 2 mm tungsten plates, 500 μm silicon sensors
- 40 layers, 22 X_0 or 1 λ_I, 5×5 mm^2 cells
- ~2500 m^2 silicon, 100 million channels

Hadronic calorimeter: Scintillator – steel
- 19 mm steel plates, 3 mm plastic scintillators + SiPM
- 60 layers, 7.5 λ_I, 30×30 mm^2 cells
- ~9000 m^2 scintillator, 10 million channels

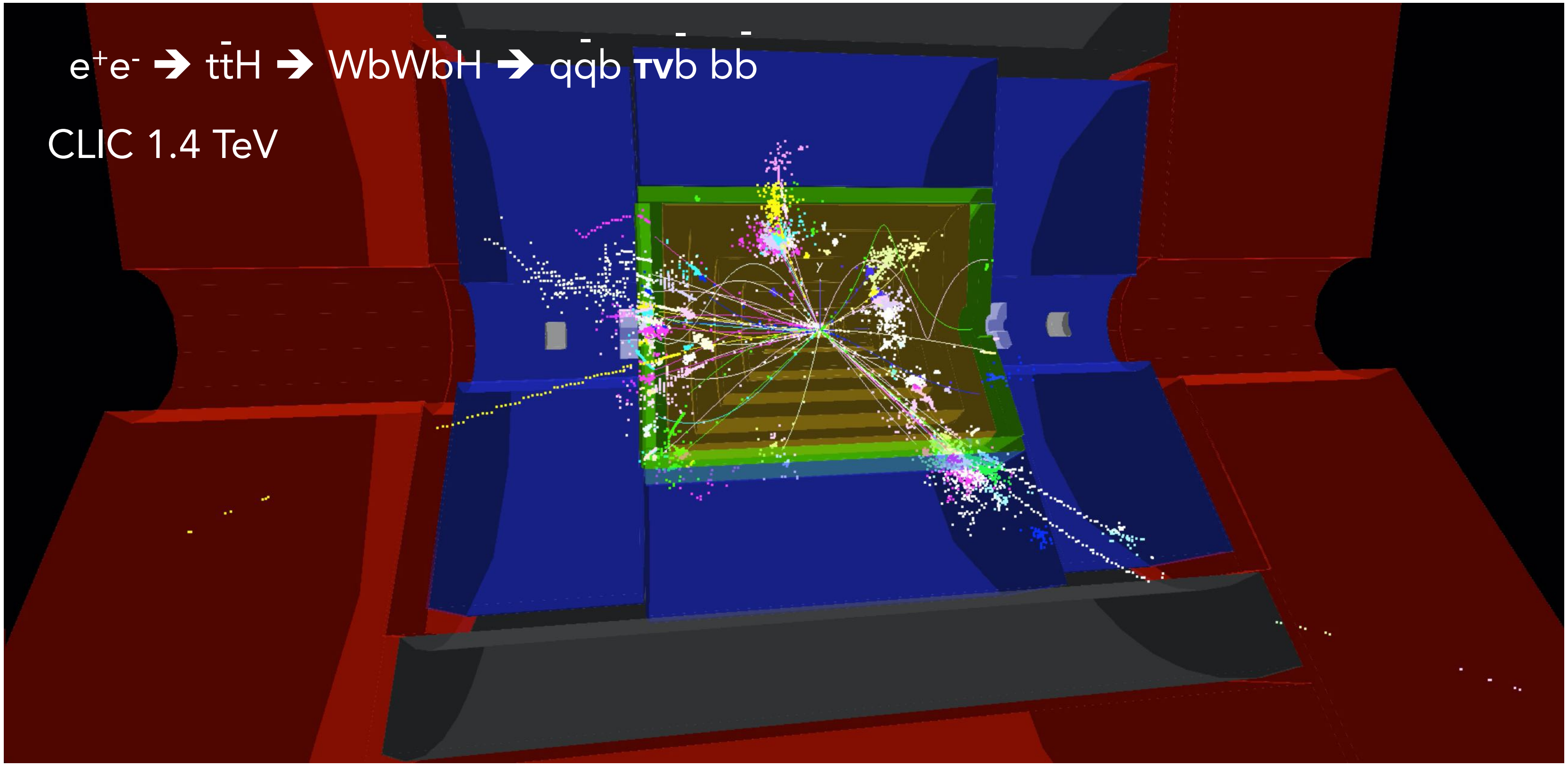
⇧

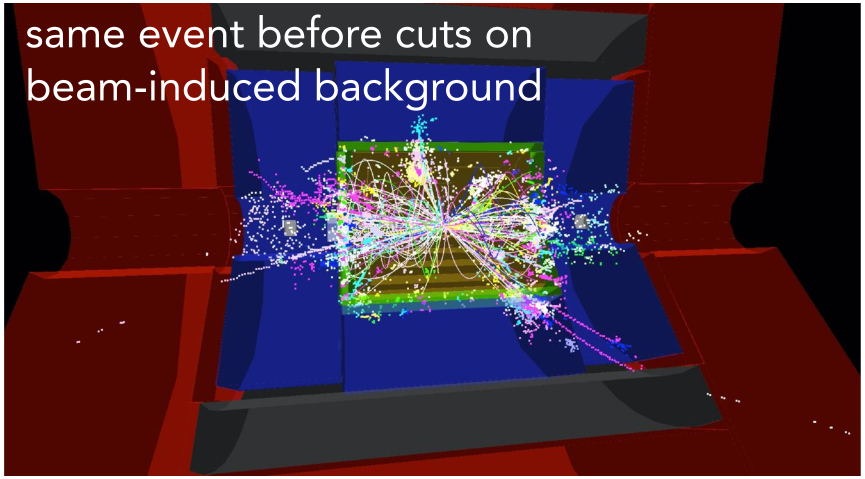
Developed by CALICE collaboration

Technology choices similar to CMS HGCal upgrade project

CALICE SiPM+scint HCAL protoype

background suppression





Highly granular calorimetry + precise hit timing

↓

Very effective in suppressing backgrounds **for fully reconstructed particles**

↓

General trend for **e^+e^-** and **pp** colliders

physics at CLIC

Measurement of SM particles with high precision:
in particular **Higgs boson** and **top quark**

BSM sensitivity through:

– **probing SM Effective Field Theories** with unprecedented precision

– **direct and indirect BSM searches** that significantly extend reach of HL-LHC, including new particles in challenging non-standard signatures

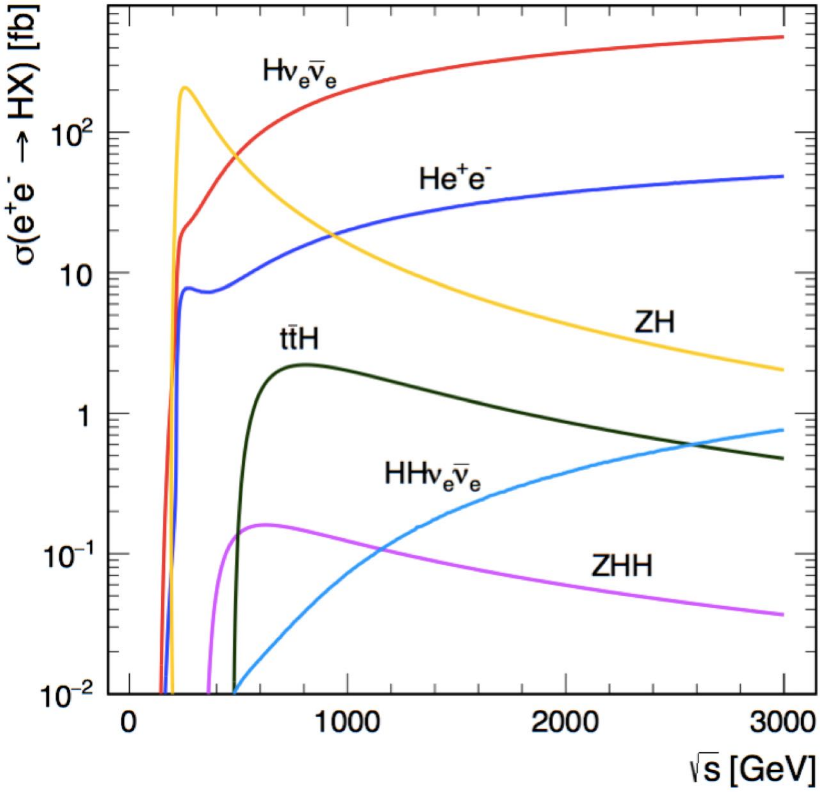
Higgs coupling sensitivity

Full Geant4 simulation/reconstruction (including beam backgrounds) at all 3 stages → global fit including correlations

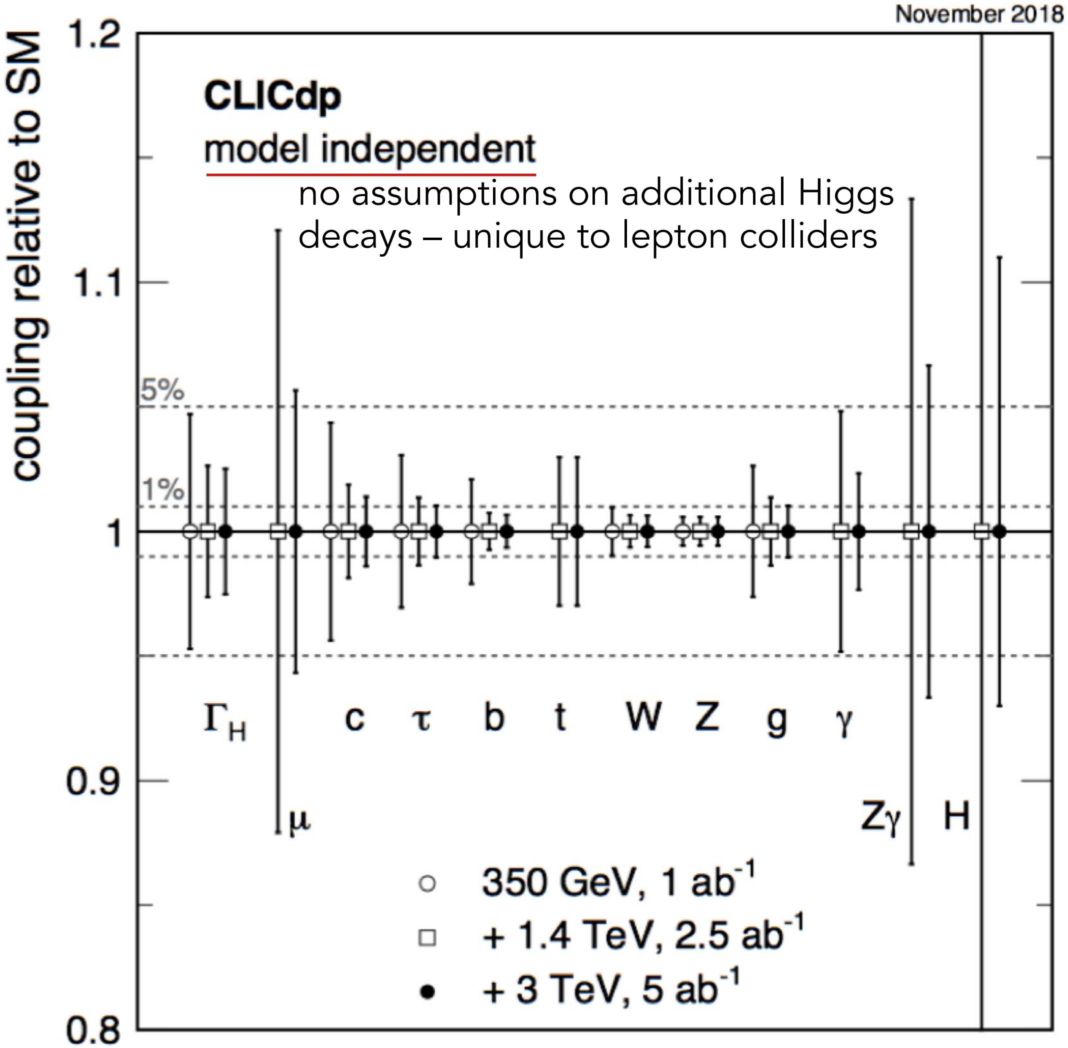
Precision <1% for most couplings

c/b/W/Z/g couplings significantly more precise than HL-LHC even after 380 GeV stage

Γ_H is extracted with 4.7 – 2.5% precision



Each energy stage contributes significantly

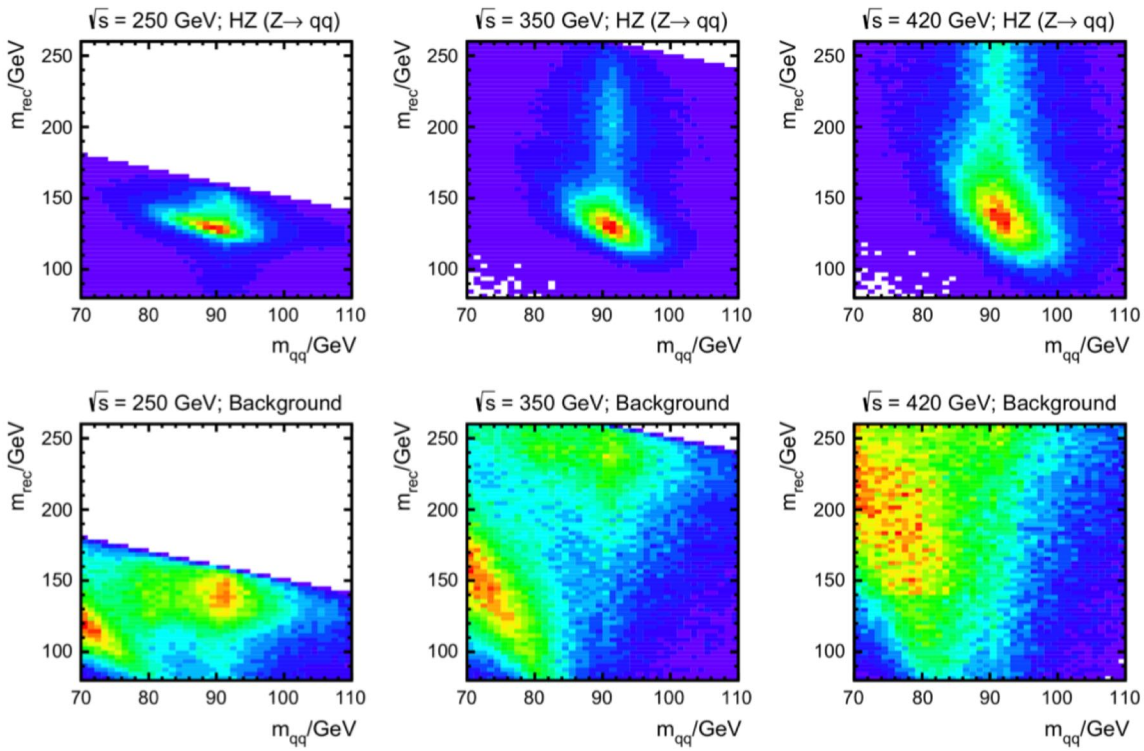


no assumptions on additional Higgs decays – unique to lepton colliders

Based on Eur. Phys. J. C 77 475 (2017) updated to ESPPU luminosity scenario

Choice of 380 GeV for first CLIC stage

$\sqrt{s}$ = 250 GeV: **$\sqrt{s}$ = 350 GeV:** **$\sqrt{s}$ = 420 GeV:**

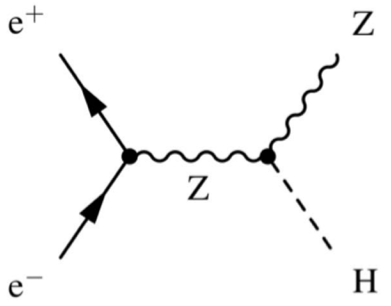


$\sqrt{s}$ [GeV]:	L_{int} [fb^{-1}]:	σ(ZH) [fb]	Δσ(ZH)
250	1000	136	±2.58%
350	1000	93	±1.27%
420	1000	68	±1.86%

Hadronic Z decays provide the best sensitivity at 350 GeV

Optimisation study for the first CLIC stage (together with top physics):

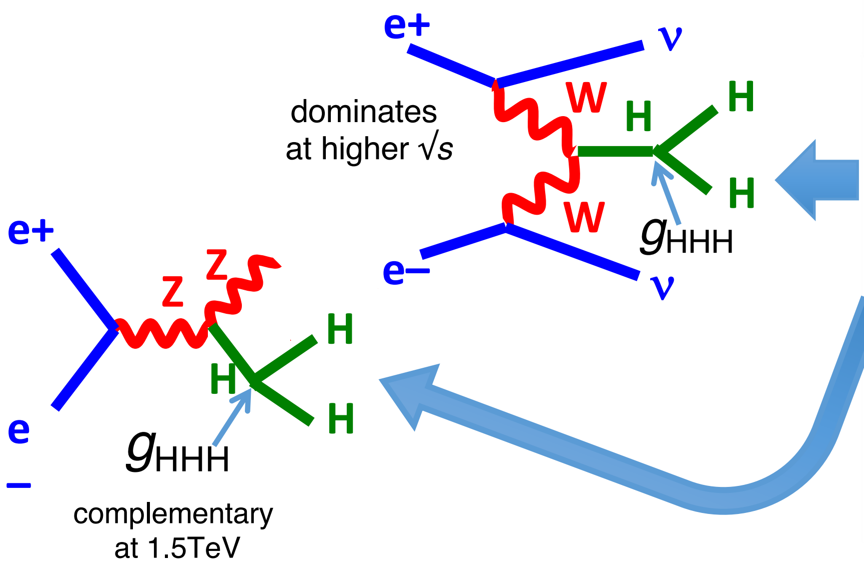
- At 250 GeV the background is more signal-like
- At 420 GeV the cross section is lower and the jet energy resolution is worse



Eur. Phys. J. C 76, 72 (2016)

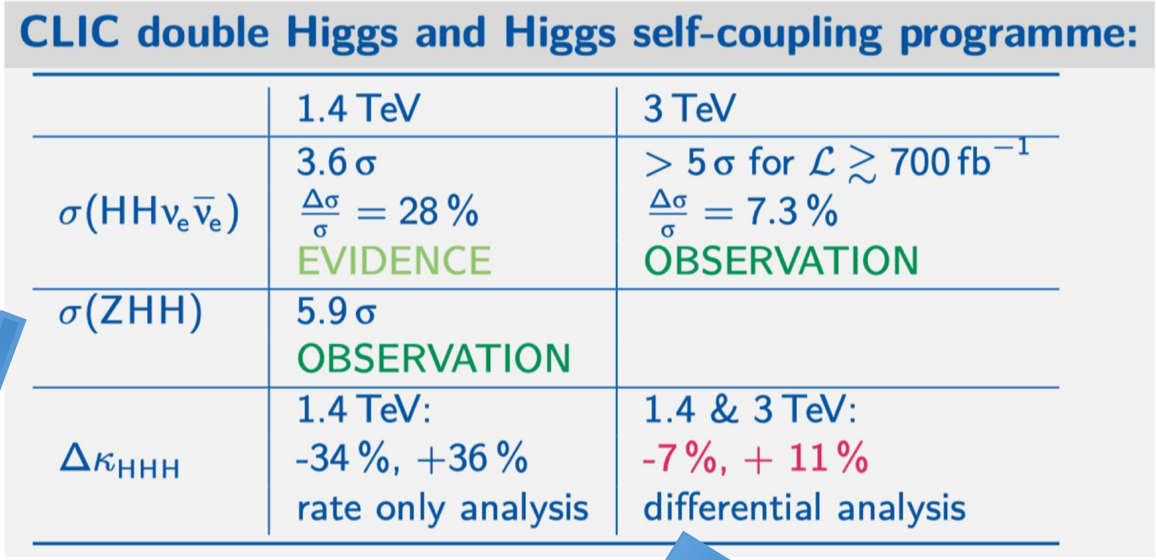
Higgs self-coupling

Higgs self-coupling requires high energy



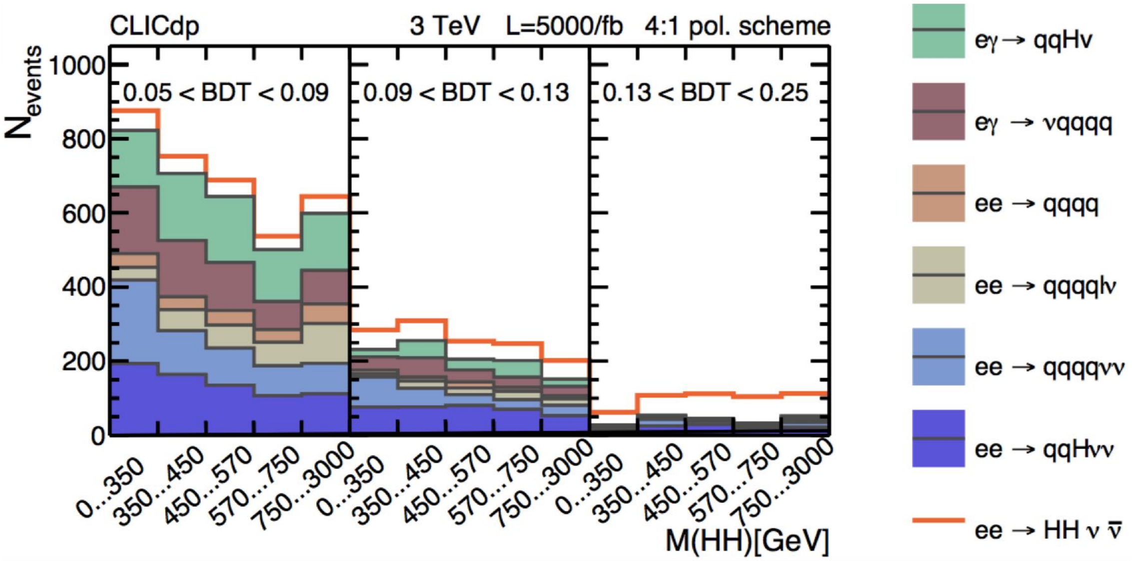
dominates at higher √s

complementary at 1.5TeV



CLIC double Higgs and Higgs self-coupling programme:

	1.4 TeV	3 TeV
$\sigma(HH\nu_e\bar{\nu}_e)$	$3.6\,\sigma$ $\frac{\Delta\sigma}{\sigma} = 28\,\%$ EVIDENCE	$> 5\,\sigma$ for $\mathcal{L} \gtrsim 700\,\text{fb}^{-1}$ $\frac{\Delta\sigma}{\sigma} = 7.3\,\%$ OBSERVATION
$\sigma(ZHH)$	$5.9\,\sigma$ OBSERVATION	
$\Delta\kappa_{HHH}$	1.4 TeV: -34 %, +36 % rate only analysis	1.4 & 3 TeV: -7 %, + 11 % differential analysis



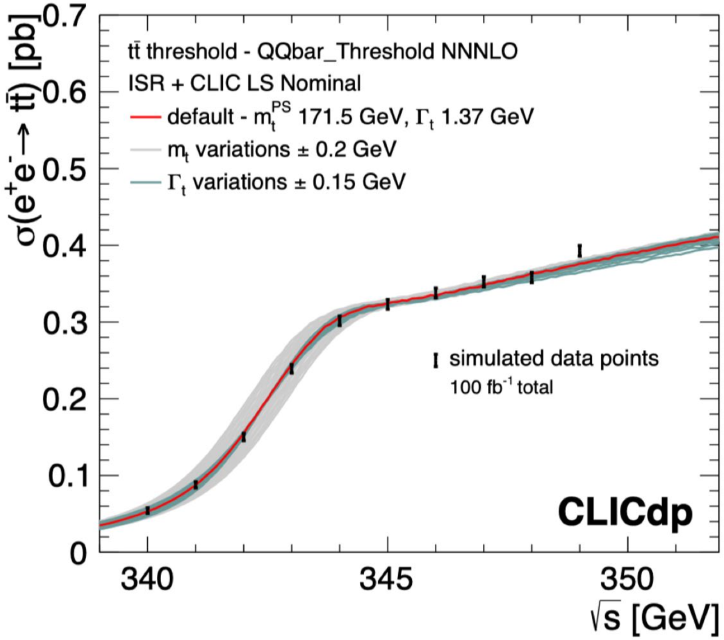
Template fit at 3TeV using two variables: *M*(HH) differential distribution and BDT score

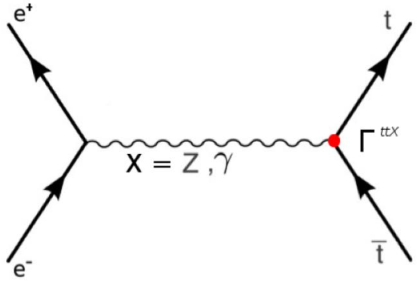
Gives unrivalled sensitivity to Higgs self-coupling:

$$\boxed{\Delta g_{HHH}/g_{HHH} = {}^{+11\%}_{-7\%}}$$

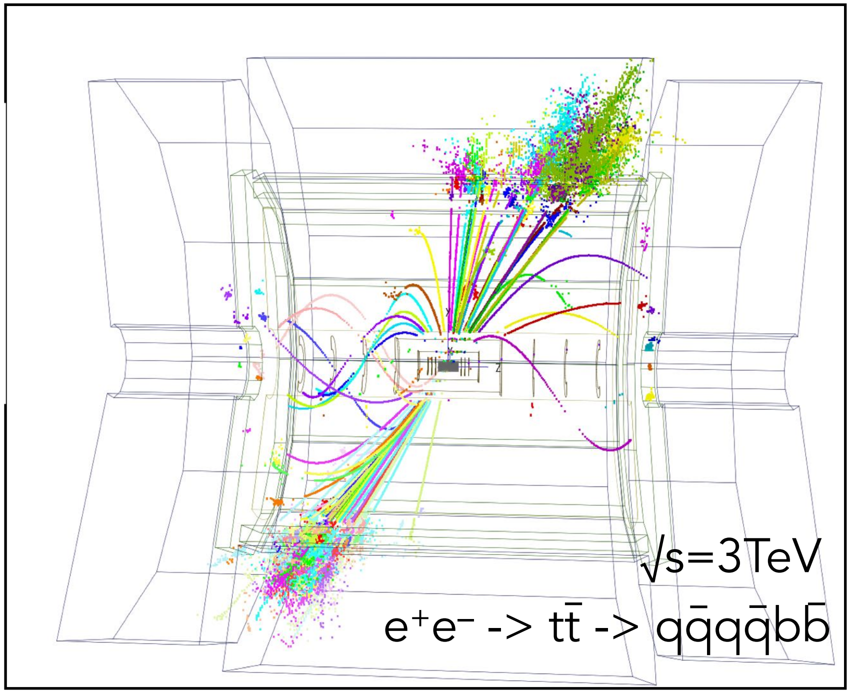
arXiv:1901.05897

top quark physics at CLIC





$e^+e^- \to tt \to WbWb$



$\sqrt{s}$=3TeV

$e^+e^- \to t\bar{t} \to q\bar{q}q\bar{q}b\bar{b}$

Top mass from threshold scan around 350 GeV (100 fb^{-1})

observe 1S 'bound state', Δm_t ~ 50–75 MeV

$e^+e^- \to tt$ at all CLIC energies

→ complementarity

- coupling to Z and γ
- forward-backward asymmetry
- EFT interpretation

also:
- FCNC top decays
- ttH incl. CP analysis

First e^+e^- study of boosted top production, using jet substructure in reconstruction

Journal, arXiv:1807.02441

EFT

Standard Model

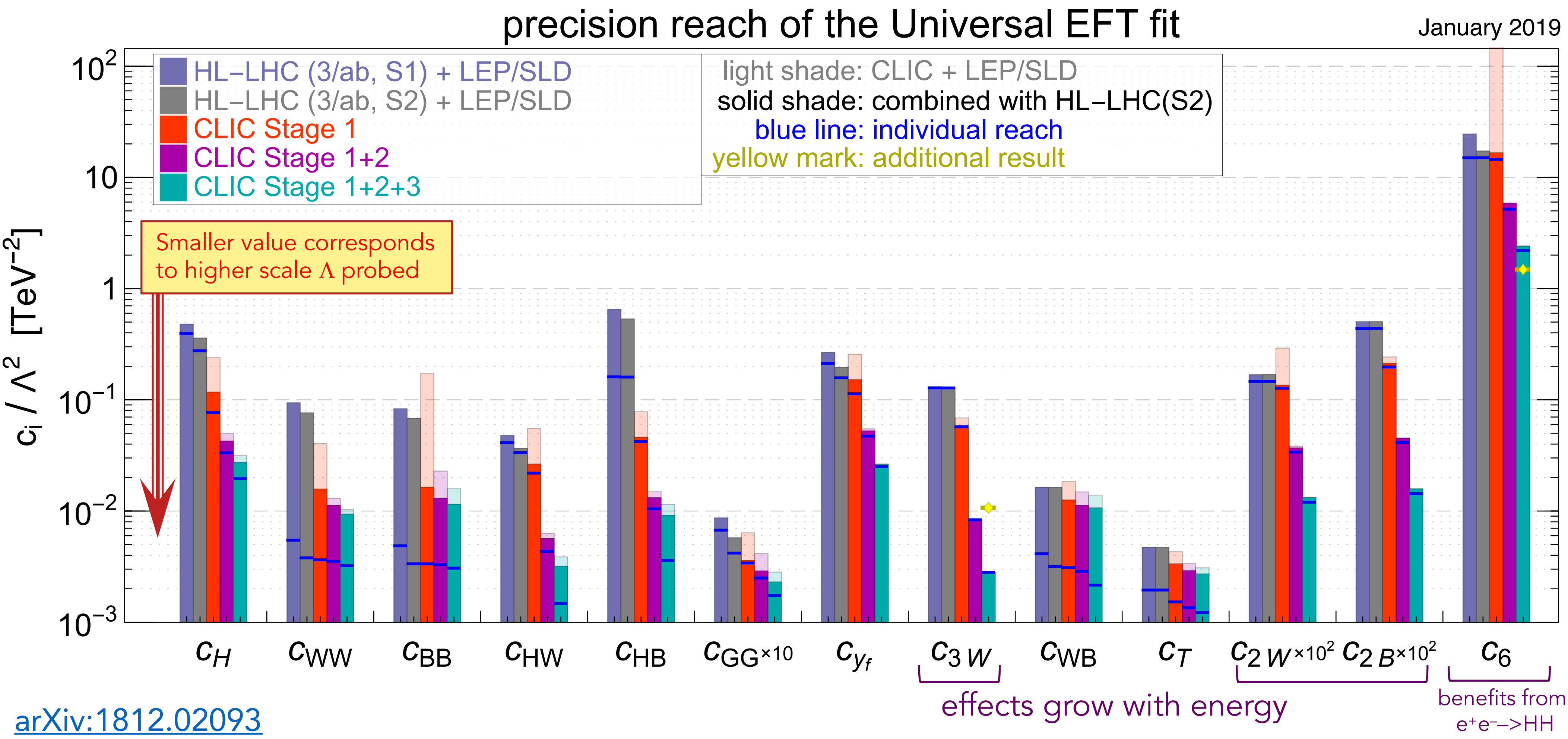
$$\mathcal{L}_{\text{SMEFT}} = \boxed{\mathcal{L}_{\text{SM}}} + \sum_i \frac{c_i}{\boxed{\Lambda}^2}\boxed{\mathcal{O}_i}$$

Scale of new decoupled physics

Dimension-6 operators

Include CLIC Higgs, top, WW, and $e^+e^- \to f\bar{f}$ measurements in global fit to constrain dimension-6 EFT operators

Strongly benefits from high-energy running



arXiv:1812.02093

Higgs factories => how to work together?

The CLICdp collaboration currently pursues several activities and provides infrastructures which are **available/extendable for collaboration on Higgs factories in general**.
Most prominent examples listed below

- Broad collaborative **silicon pixel R&D effort** (hybrid, monolithic), includes **supporting tools**:
  - Beam telescope and DAQ framework
  - Generic Caribou readout system for pixel-detector prototypes TWEPP proc 2019
  - Allpix2 simulation framework arXiv:1806.05813, arXiv:2002.12602
  - Corryvreckon analysis framework arXiv:1912.00856

Contact persons:
dominik.dannheim@cern.ch (CERN), mathieu.benoit@cern.ch (Brookhaven)

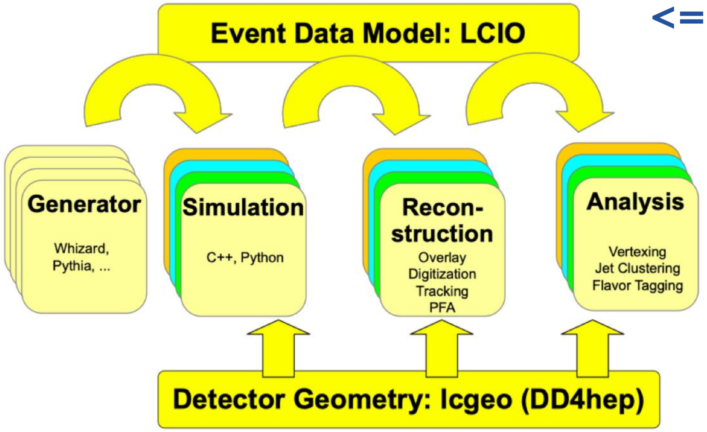
arXiv:1905.02520

Software and analysis tools:

- Complete software for full simulation/reconstruction (ilCSoft => Key4hep)
- Support for physics studies (including, e.g., generators, beam-induced bkg overlay)
- Grid production tool iLCDirac

See next slide

simulation/reconstruction SW



Event Data Model: LCIO

Generator
Whizard,
Pythia, ...

Simulation
C++, Python

Recon-struction
Overlay
Digitization
Tracking
PFA

Analysis
Vertexing
Jet Clustering
Flavor Tagging

Detector Geometry: lcgeo (DD4hep)

<= Generic SW diagram for detector optimisation and physics studies

Now	Future
iLCSoft	Key4hep
Marlin framework	GAUDI framework
LCIO event data model	EDM4hep/PODIO event data model
*+!~ available to many	*+?# available to all

Detector	Collider	SW name	SW status	SW future
ILD	ILC	iLCSoft	Full sim/reco	Key4hep
SiD	ILC	iLCSoft	Full sim/reco	
CLICdet	CLIC	iLCSoft	Full sim/reco	
CLD	FCC-ee	iLCSoft	Full sim/reco	
IDEA	FCC-ee	FCC-SW	Fast sim/reco	
IDEA	CEPC	FCC-SW	Fast sim/reco	
CEPCbaseline	CEPC	iLCSoft branch-off	Full sim/reco	

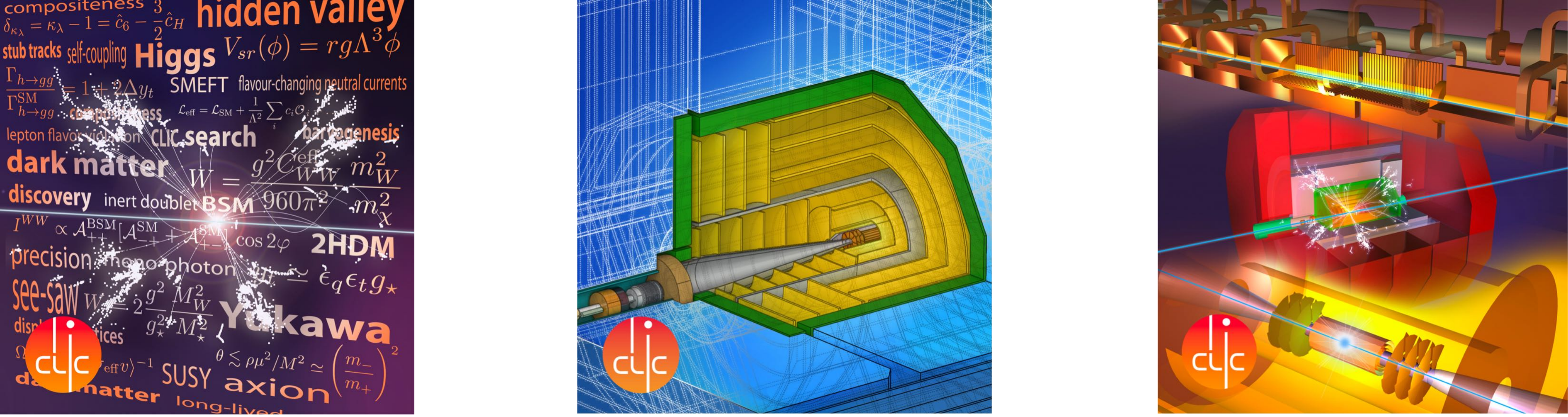
Recommendation:

use iLCSoft now

and

join Key4hep development

Contact: frank.gaede@desy.de (DESY, iLCSoft/Key4hep), andre.philippe.sailer@cern.ch (CERN, iLCSoft/Key4hep/iLCDirac), paolo.giacomelli@bo.infn.it (Bologna, FCC-SW/Key4hep), manqi.ruan@ihep.ac.cn (IHEP, CEPC), philipp.roloff@cern.ch (CERN, physics studies iLCSoft/Key4hep), jenny.list@desy.de (DESY, physics studies iLCSoft/Key4hep)



CLIC is a very attractive post-LHC facility for CERN

Unprecedented, diverse and guaranteed excellent physics reach

thanks to lepton collider precision AND multi-TeV collisions

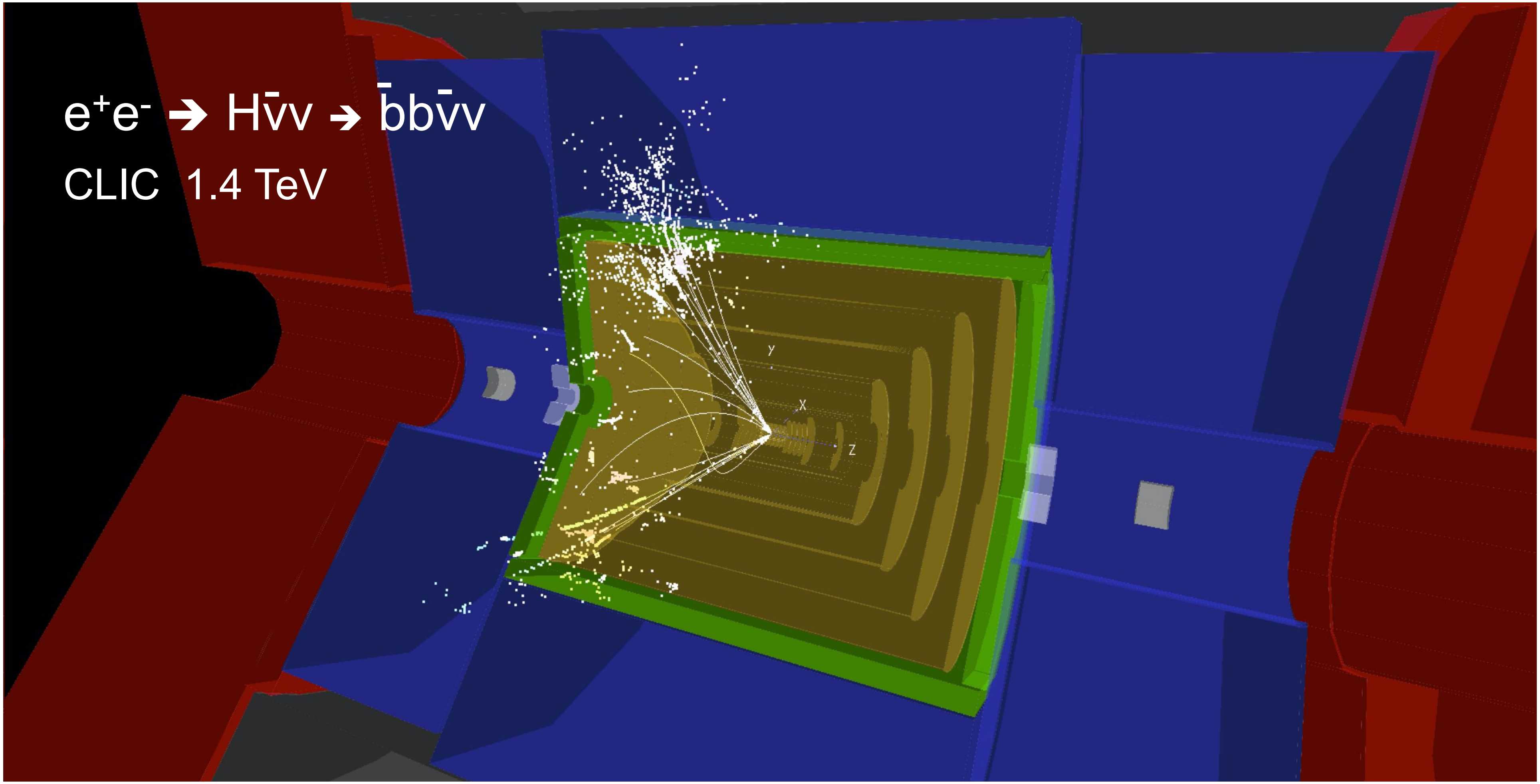
Demonstrated accelerator technologies

Feasible timescale, "affordable" cost

US colleagues are most welcome to join the broad e^+e^- community for physics studies, detector design and detector R&D.

Independently of the future e^+e^- collider facility, we recommend to use existing tools and join common developments.

THANK YOU !



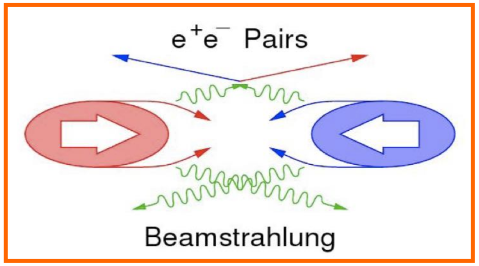
$e^+e^- \rightarrow H\bar{\nu}\nu \rightarrow \bar{b}b\bar{\nu}\nu$

CLIC 1.4 TeV

H → $b\bar{b}$ (58% BR): selection efficiency ~40% (1.4 TeV), ~50% (380 GeV)

reserve slides

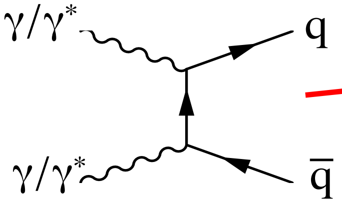
beam-induced backgrounds at CLIC



Beam-beam background at IP:

- Small beams => very high E-fields
  - **Beamstrahlung**
  - **Pair-background**
    - High occupancies
  - **γγ to hadrons**
    - Energy deposits

Simplified picture:
Design issue (small cell sizes)

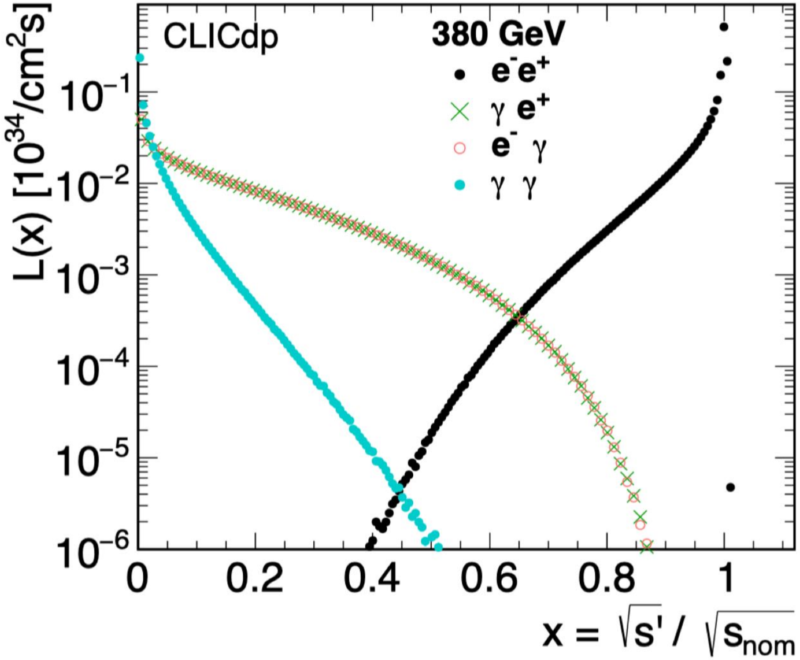


Impacts on the physics
Needs suppression in data

Beamstrahlung ➔ important energy losses right at the interaction point

Most physics processes are studied well above production threshold => profit from full spectrum

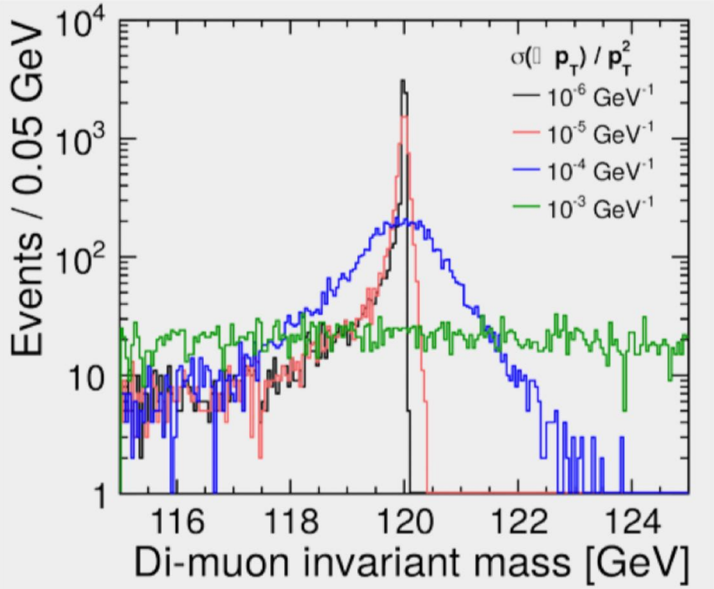
Luminosity spectrum can be measured in situ using large-angle Bhabha scattering events, to 5% accuracy at 3 TeV
Eur.Phys.J. C74 (2014) no.4, 2833



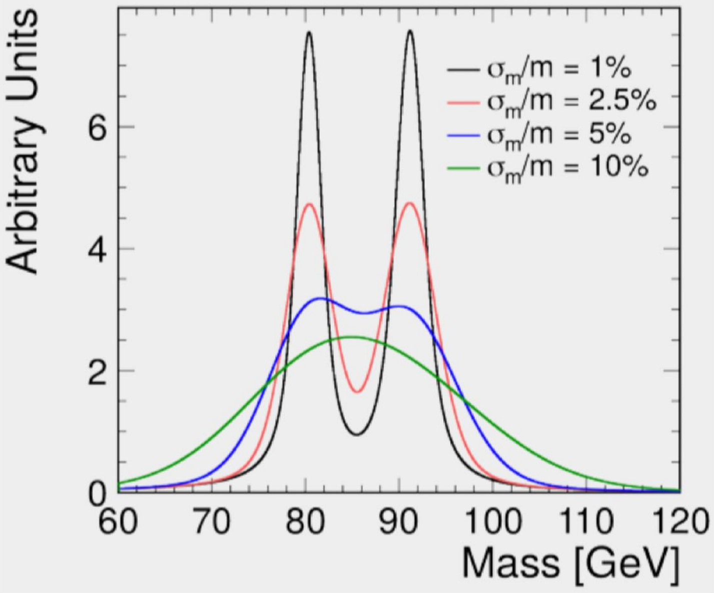
arXiv:1812.06018

detector performance requirements

- Momentum resolution
  - Higgs recoil mass, Higgs coupling to muons
  - **$\sigma_{p_T}/p_T \sim 2 \times 10^{-5}$ GeV^{-1}** above 100 GeV



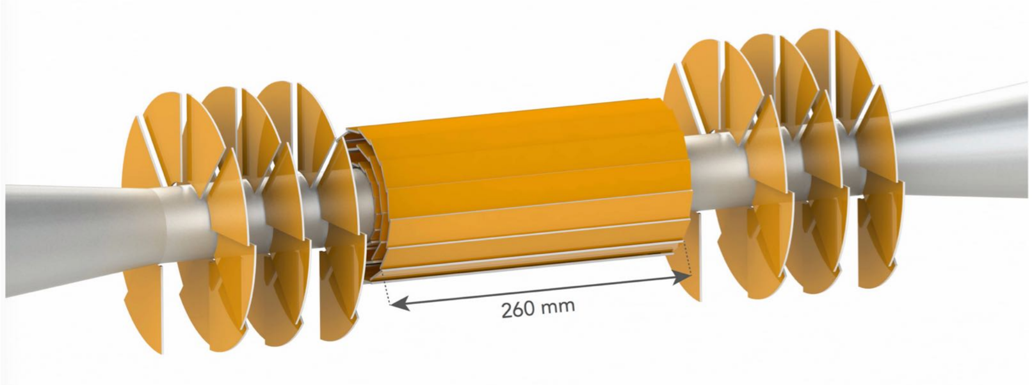
- Impact parameter resolution
  - c/b-tagging, Higgs branching ratios
  - **$\sigma_{r\phi} \sim a \oplus b / (p[\text{GeV}] \sin^{3/2}\theta)$ µm** with a = 5 µm, b = 15 µm
- Jet energy resolution
  - Separation of W/Z/H di-jets
  - **$\sigma_E/E \sim 5\% - 3.5\%$** for jets at 50 GeV – 1000 GeV



- Angular coverage
  - Very forward electron and photon tagging
  - Down to θ = 10 mrad (η = 5.3)

vertex and tracking detectors

Vertex detector



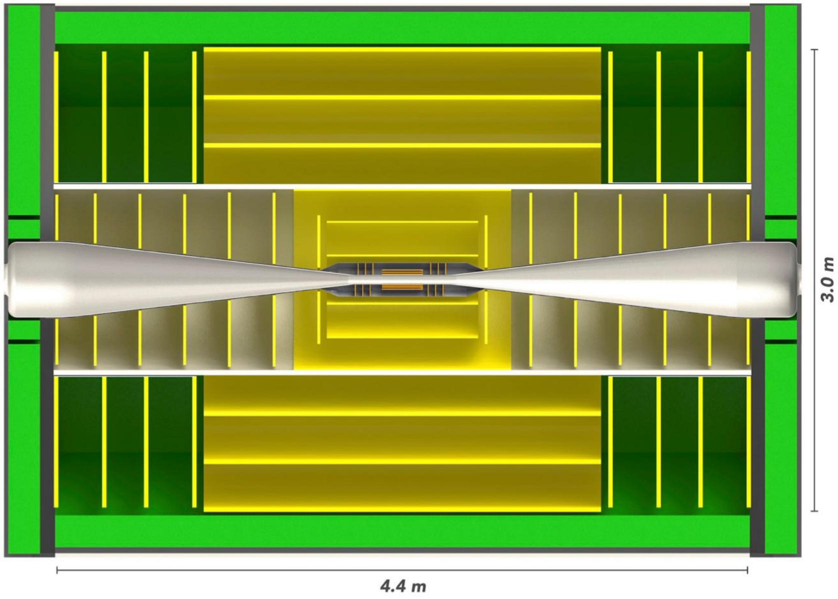
Requirements:

low mass: 0.2%X_0 per layer
low power: 50 mW/cm^2 for air cooling
single point resolution: 3 μm
hit time resolution: ~5 ns

Implementation and R&D:

silicon-based (pixels, hybrid or monolithic)
3 double layers
spiraling petals to facilitate air cooling
power pulsing

Tracker



Requirements:

low mass: 1-2%X_0 per layer
single point resolution: 7 μm
hit time resolution: ~5 ns

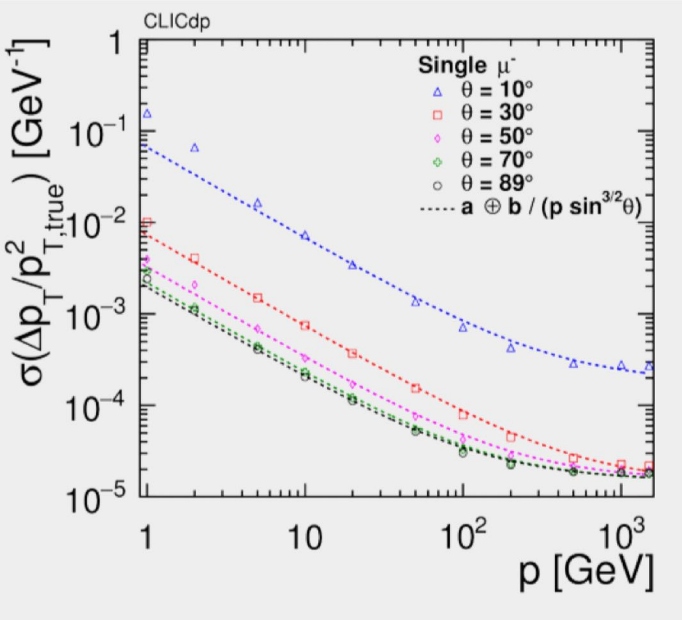
Implementation and R&D:

silicon-based (pixels, monolithic)
power pulsing
water cooling (below atm. pressure)

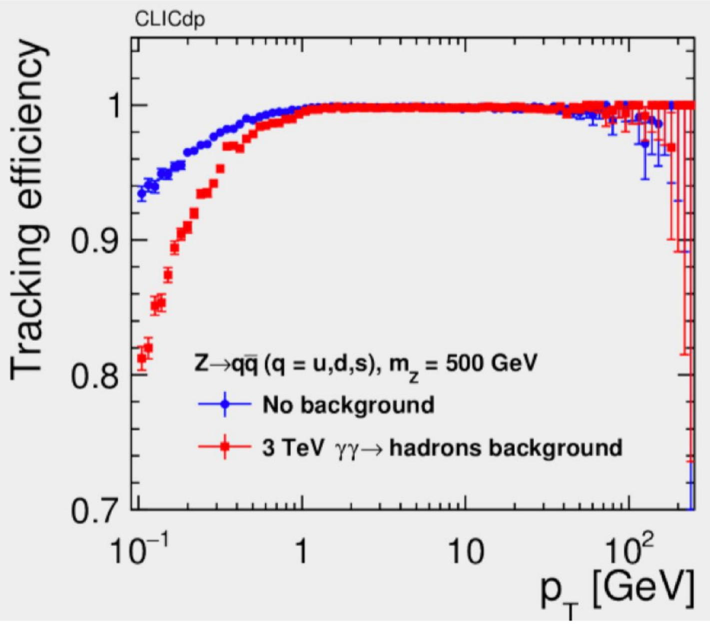
tracking performance

Detector description (*in DD4hep*), detector simulation (*in Geant4*) and reconstruction implemented in **iLCSoft framework**

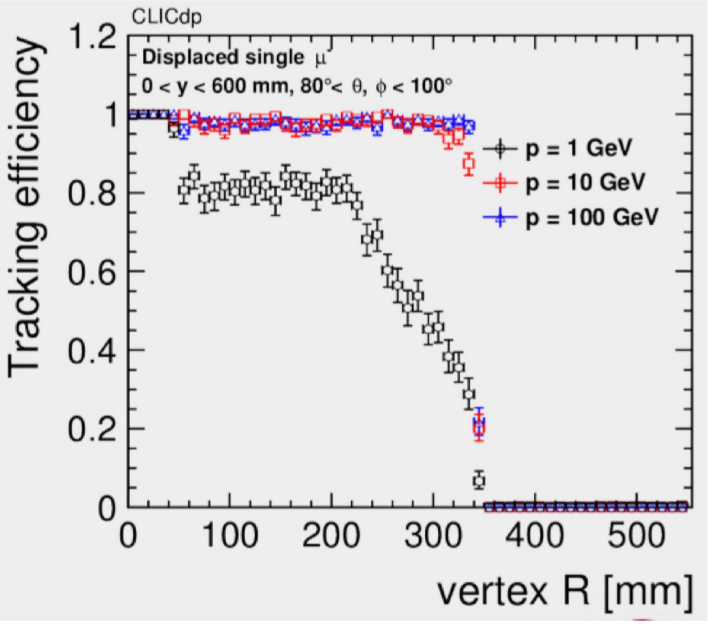
Tracking based on **conformal tracking** and **Kalman-filter based fit**



Track momentum resolution for single particles
2×10^{-5} dp_T/p_T^2 achieved for high-momentum tracks



Tracking efficiency within light quark jets
With and without background



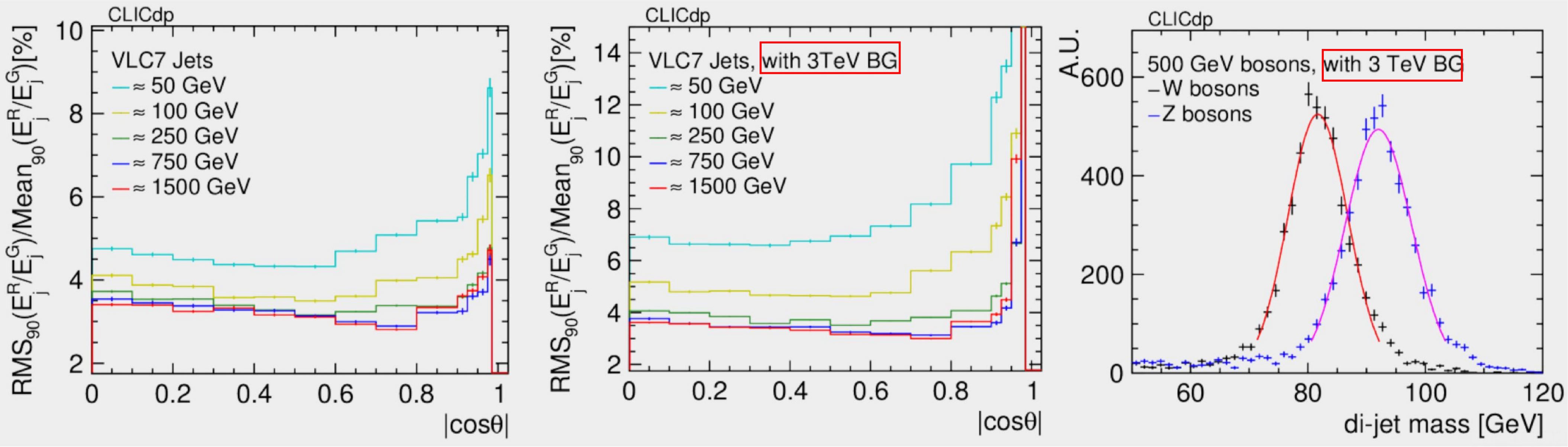
Tracking efficiency for displaced tracks
(min 4 hits required)

arXiv:1812.07337

PFA, jet energy reconstruction

PandoraPFA particle flow analysis used for jet energy reconstruction and particle ID. Combined with **jet clustering optimized for e^+e^-** (**VLC** Valencia algorithm)

- Jet energy resolution from $Z/\gamma^* \rightarrow qq$, compare reconstruction with MC truth
  - → Objective of 3.5-5% jet energy resolution achieved for high-E jets in most of angular range
  - → Impact from 3 TeV backgrounds largest for low-energy jets, resolution 6-8%
- W/Z mass separation in 2-jet events: 2σ separation with VLC7 jets, including 3 TeV bkg

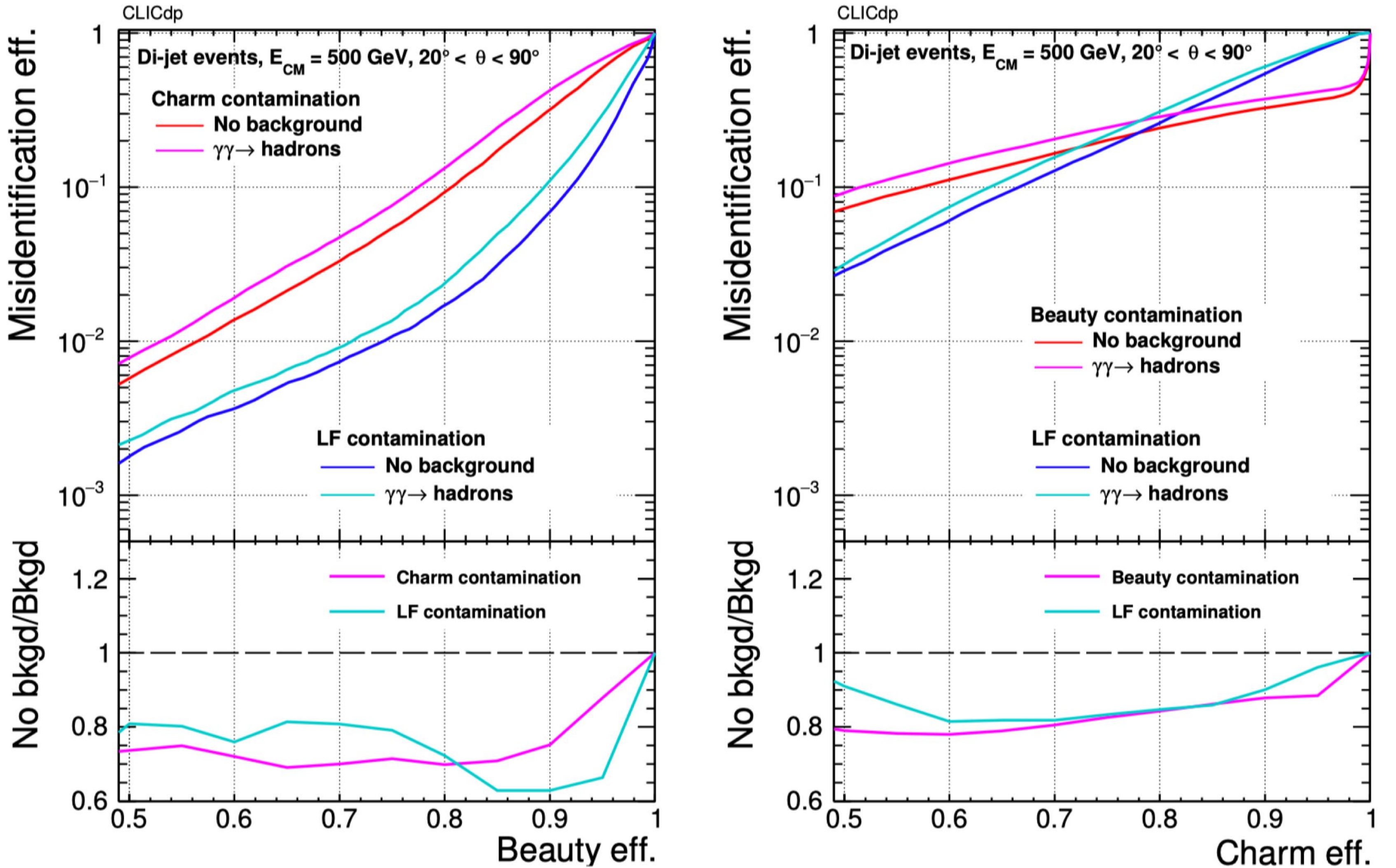


arXiv:1812.07337

flavour tagging performance

LCFIplus package used for flavour tagging

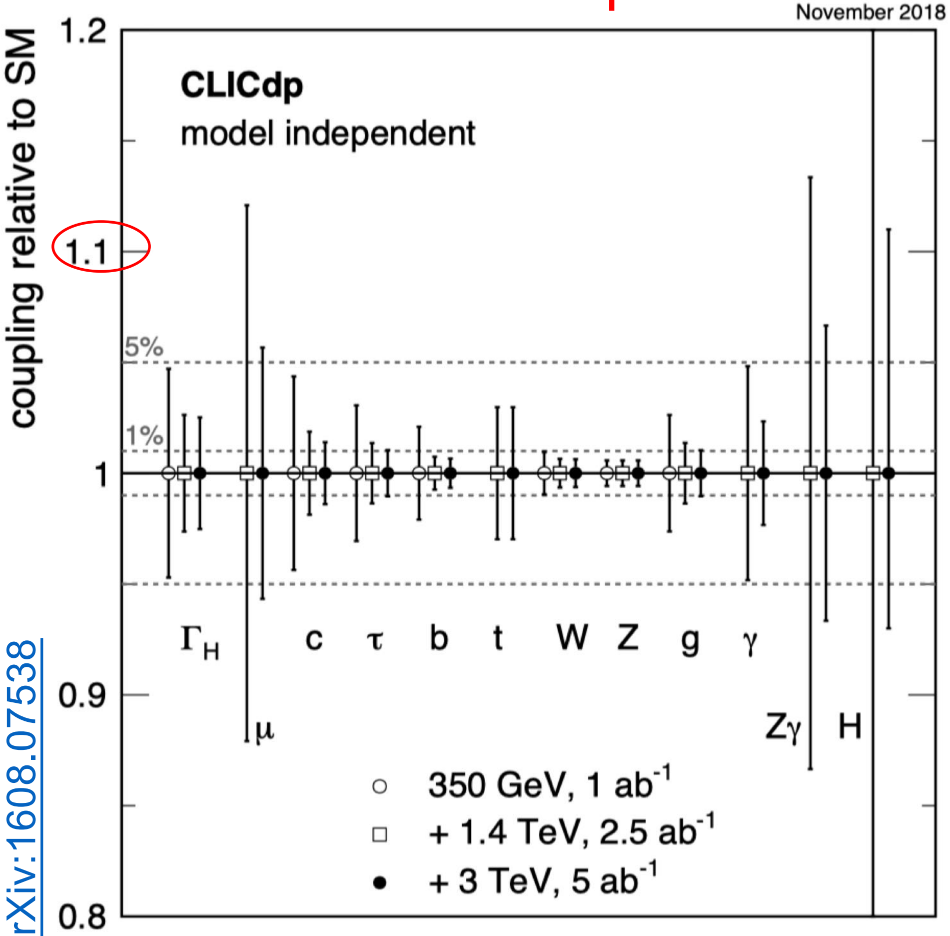
Studied in 500 GeV di-jet events, with and without $\gamma\gamma \rightarrow \mathrm{hadrons}$ background (3TeV equivalent)



arXiv:1812.07337

combined CLIC Higgs coupling results

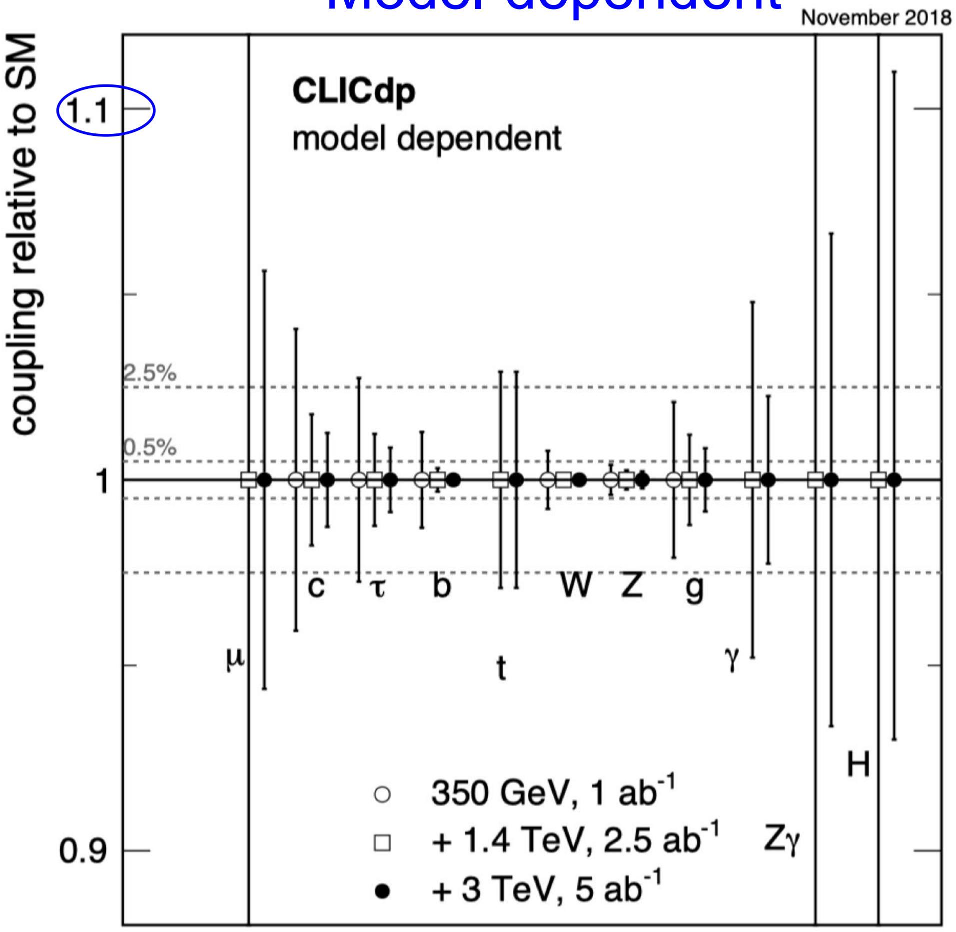
Model-independent



Higgs width is a free parameter, allows for additional non-SM decays

arXiv:1608.07538

Model-dependent



LHC-like fit, assuming SM decays only. Fit to deviations from SM BR's

Scaled from: Eur. Phys. J. C 77 475 (2017)

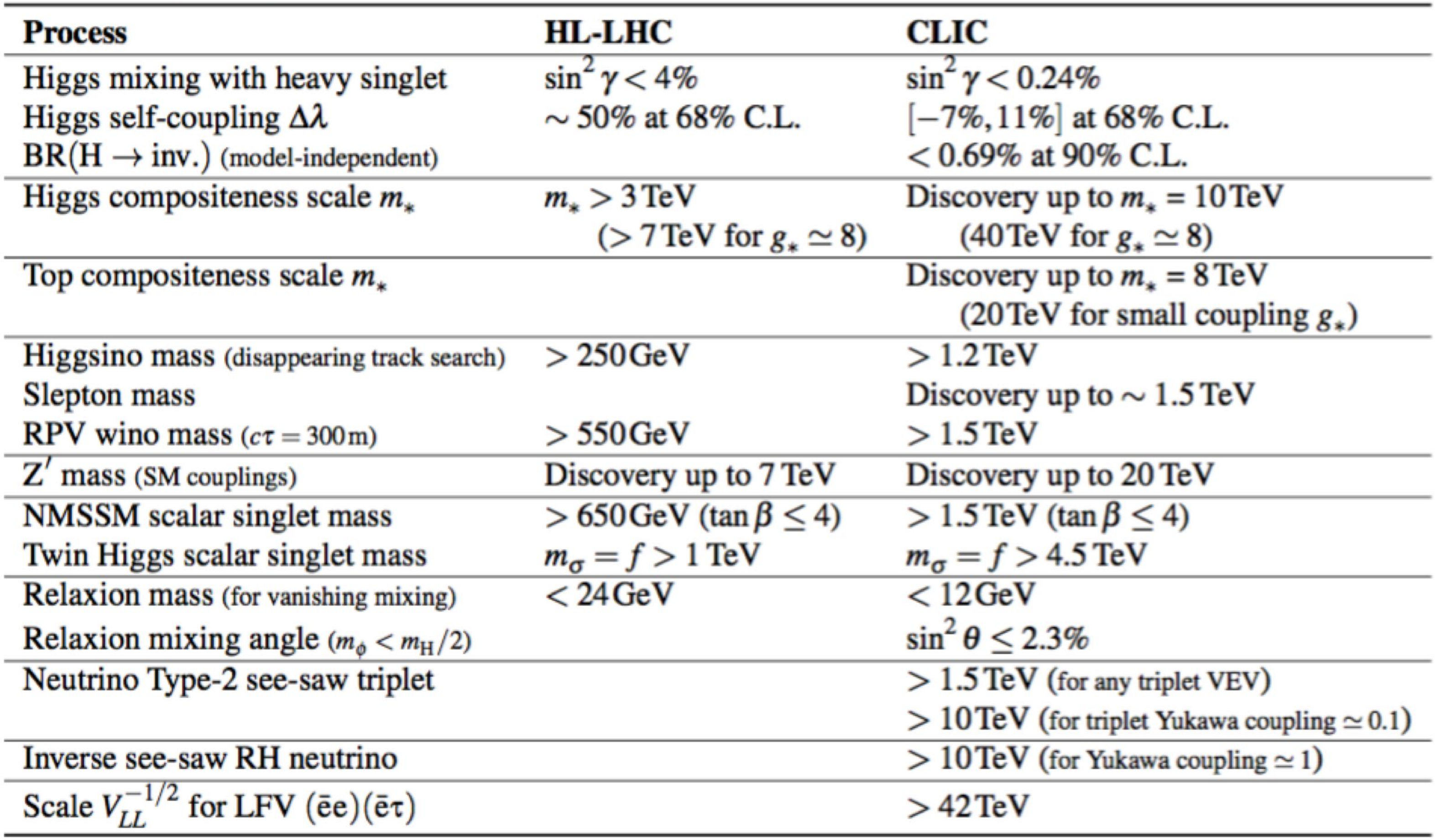
Full CLIC program, ~7 yrs of running at each stage:

- Model-independent: down to ±1% for most couplings, ultimately limited by g_{HZZ} ±0.6%
- Model-dependent: ±1% down to ± few ‰ for most couplings
- Accuracy on Higgs width: ±2.5% (MI)

New physics reach

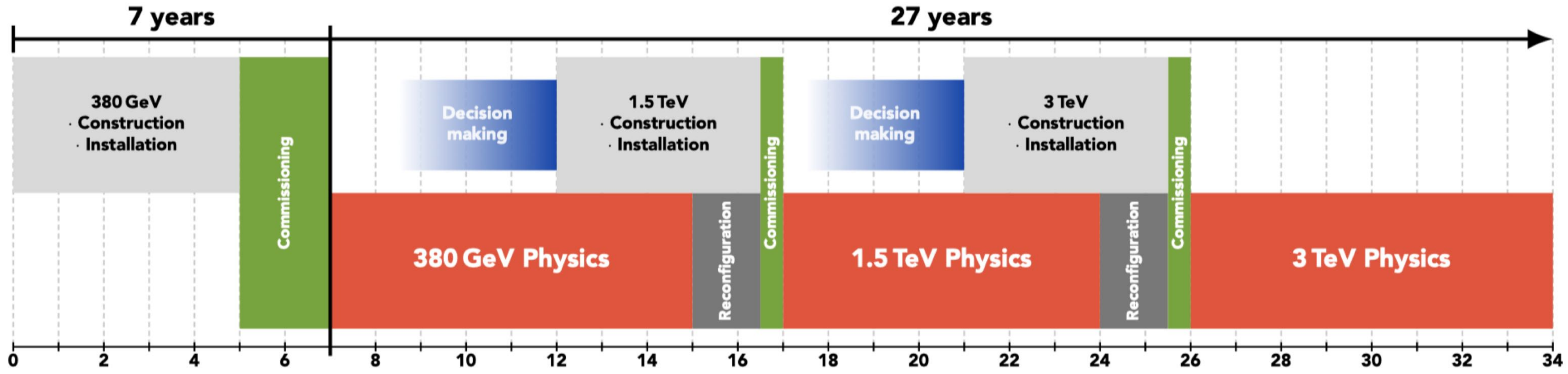
The precision measurements and searches can be interpreted in a wide range of model frameworks

Indicative CLIC reach for new physics. Sensitivities are given for the full CLIC programme covering the three centre-of-mass stages. All limits are at 95% C.L. unless stated otherwise. Details on many of these examples are given in The CLIC Potential for New Physics: https://arxiv.org/abs/1812.07986



Process	**HL-LHC**	**CLIC**
Higgs mixing with heavy singlet	$\sin^2\gamma < 4\%$	$\sin^2\gamma < 0.24\%$
Higgs self-coupling $\Delta\lambda$	$\sim 50\%$ at 68% C.L.	$[-7\%, 11\%]$ at 68% C.L.
BR(H → inv.) (model-independent)		$< 0.69\%$ at 90% C.L.
Higgs compositeness scale m_*	$m_* > 3\,\text{TeV}$ $(> 7\,\text{TeV for } g_* \simeq 8)$	Discovery up to $m_* = 10\,\text{TeV}$ $(40\,\text{TeV for } g_* \simeq 8)$
Top compositeness scale m_*		Discovery up to $m_* = 8\,\text{TeV}$ (20 TeV for small coupling g_*)
Higgsino mass (disappearing track search)	$> 250\,\text{GeV}$	$> 1.2\,\text{TeV}$
Slepton mass		Discovery up to $\sim 1.5\,\text{TeV}$
RPV wino mass ($c\tau = 300\,\text{m}$)	$> 550\,\text{GeV}$	$> 1.5\,\text{TeV}$
Z' mass (SM couplings)	Discovery up to 7 TeV	Discovery up to 20 TeV
NMSSM scalar singlet mass	$> 650\,\text{GeV}$ ($\tan\beta \leq 4$)	$> 1.5\,\text{TeV}$ ($\tan\beta \leq 4$)
Twin Higgs scalar singlet mass	$m_\sigma = f > 1\,\text{TeV}$	$m_\sigma = f > 4.5\,\text{TeV}$
Relaxion mass (for vanishing mixing)	$< 24\,\text{GeV}$	$< 12\,\text{GeV}$
Relaxion mixing angle ($m_\phi < m_H/2$)		$\sin^2\theta \leq 2.3\%$
Neutrino Type-2 see-saw triplet		$> 1.5\,\text{TeV}$ (for any triplet VEV) $> 10\,\text{TeV}$ (for triplet Yukawa coupling $\simeq 0.1$)
Inverse see-saw RH neutrino		$> 10\,\text{TeV}$ (for Yukawa coupling $\simeq 1$)
Scale $V_{LL}^{-1/2}$ for LFV $(\bar{e}e)(\bar{e}\tau)$		$> 42\,\text{TeV}$

CLIC time line



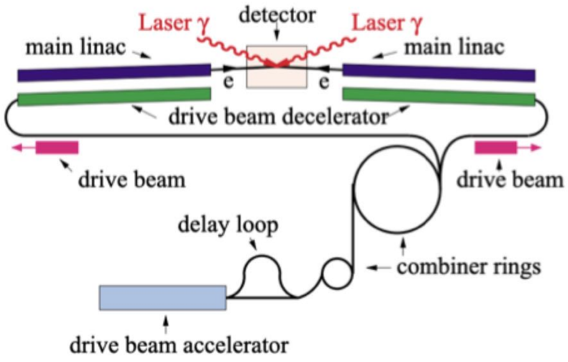
Technology-driven schedule, from start of construction.

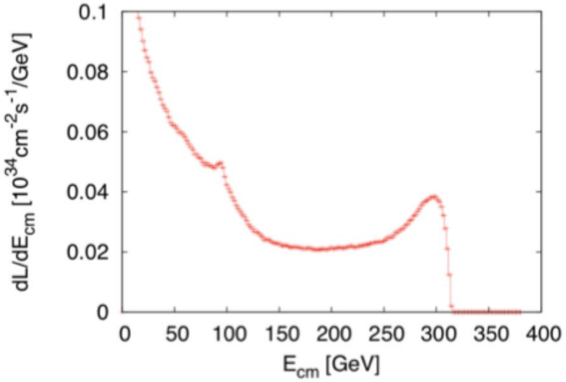
After an *in principle go ahead*, min. 5 years are needed before construction can start.

=> First beams could be available by 2035

Z-pole and gamma-gamma options

- Operating the fully installed 380 GeV CLIC accelerator complex but at the Z-pole results in a luminosity of about L = 2.3 x 10^{32} $cm^{-2}s^{-1}$
- On the other hand, an initial installation of just the linac needed for Z-pole energy factory, and an appropriately adapted beam delivery system, would result in a luminosity of L = 0.36 × 1034 cm−2s−1 for 50 Hz operation.
- In gamma-gamma mode, the electrons in both beams are focused at the IP and an intense laser pulse can be used to back-scatter photons from each beam and make them interact. The electron polarisation is important for this process and 80% can be expected. Although detailed studies of the interaction region configuration have not yet been performed, a first order an idea the performance can be obtained, including the luminosity spectrum.





CERN-ACC-2019-0051 ; CLIC-Note-1143
http://cds.cern.ch/record/2687090