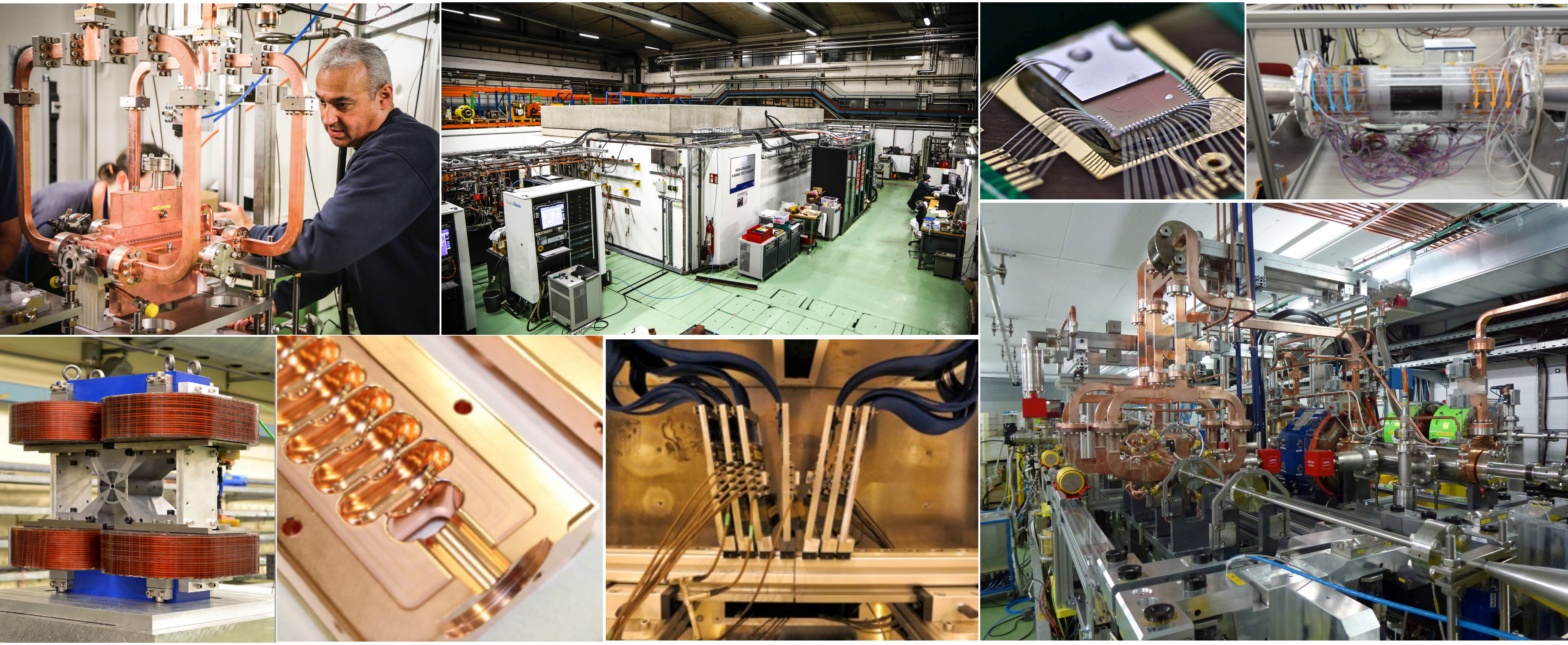
CLIC

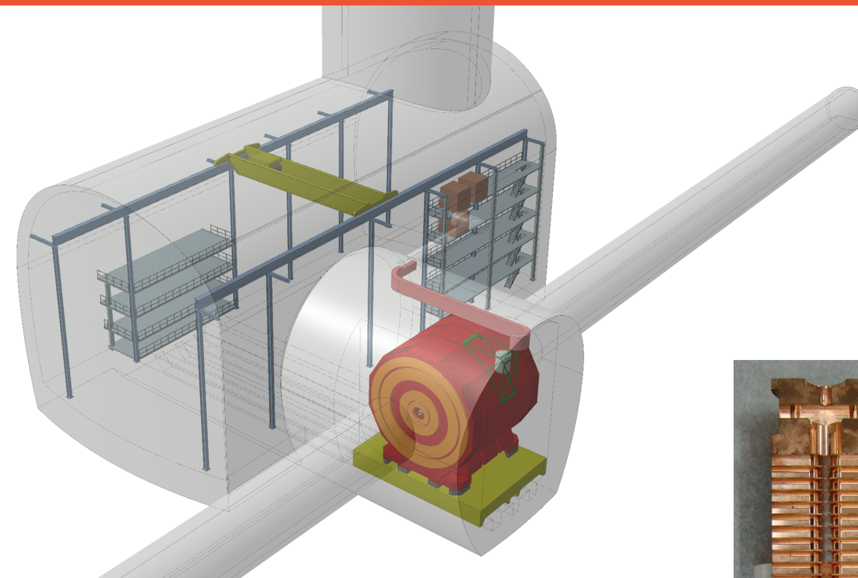


ECFA Plenary, 16 November 2018

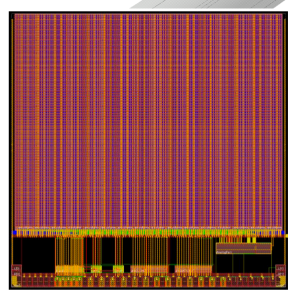
Aidan Robson, University of Glasgow & CERN
on behalf of the CLIC and CLICdp Collaborations

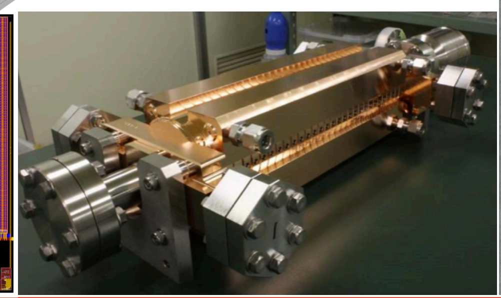
CLIC

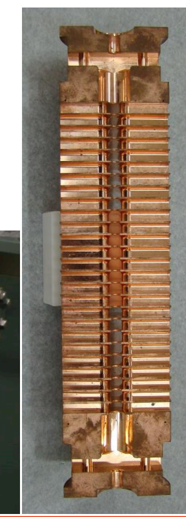
- Project overview
- Physics reach
- Detector concept and technologies
- Accelerator technologies
- Outlook



Compact Linear Collider
e^+e^- collisions up to 3TeV
http://clic.cern/







ECFA Plenary, 16 November 2018

Aidan Robson, University of Glasgow & CERN
on behalf of the CLIC and CLICdp Collaborations

Collaborations

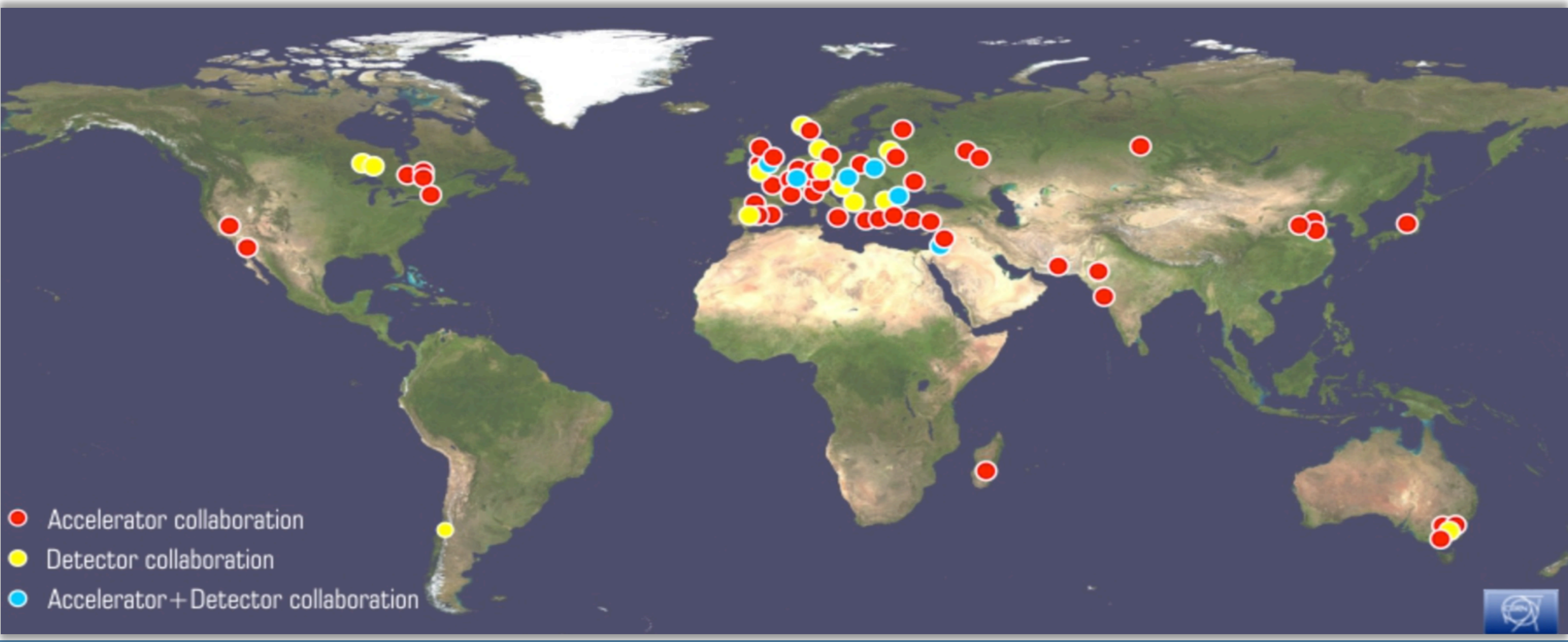
http://clic.cern/

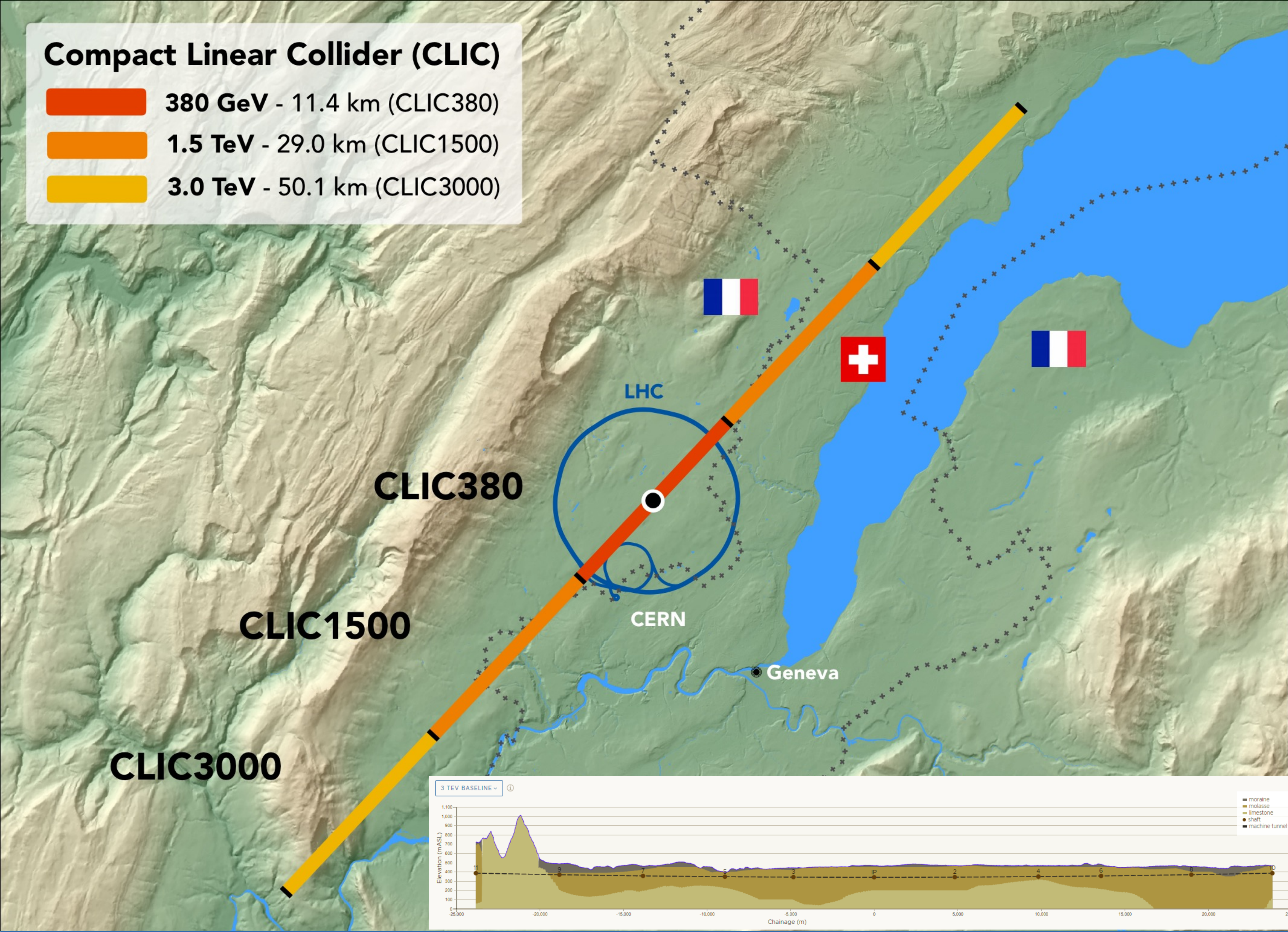
- CLIC accelerator design and development
- (Construction and operation of CTF3)

CLIC accelerator collaboration
~60 institutes from 28 countries

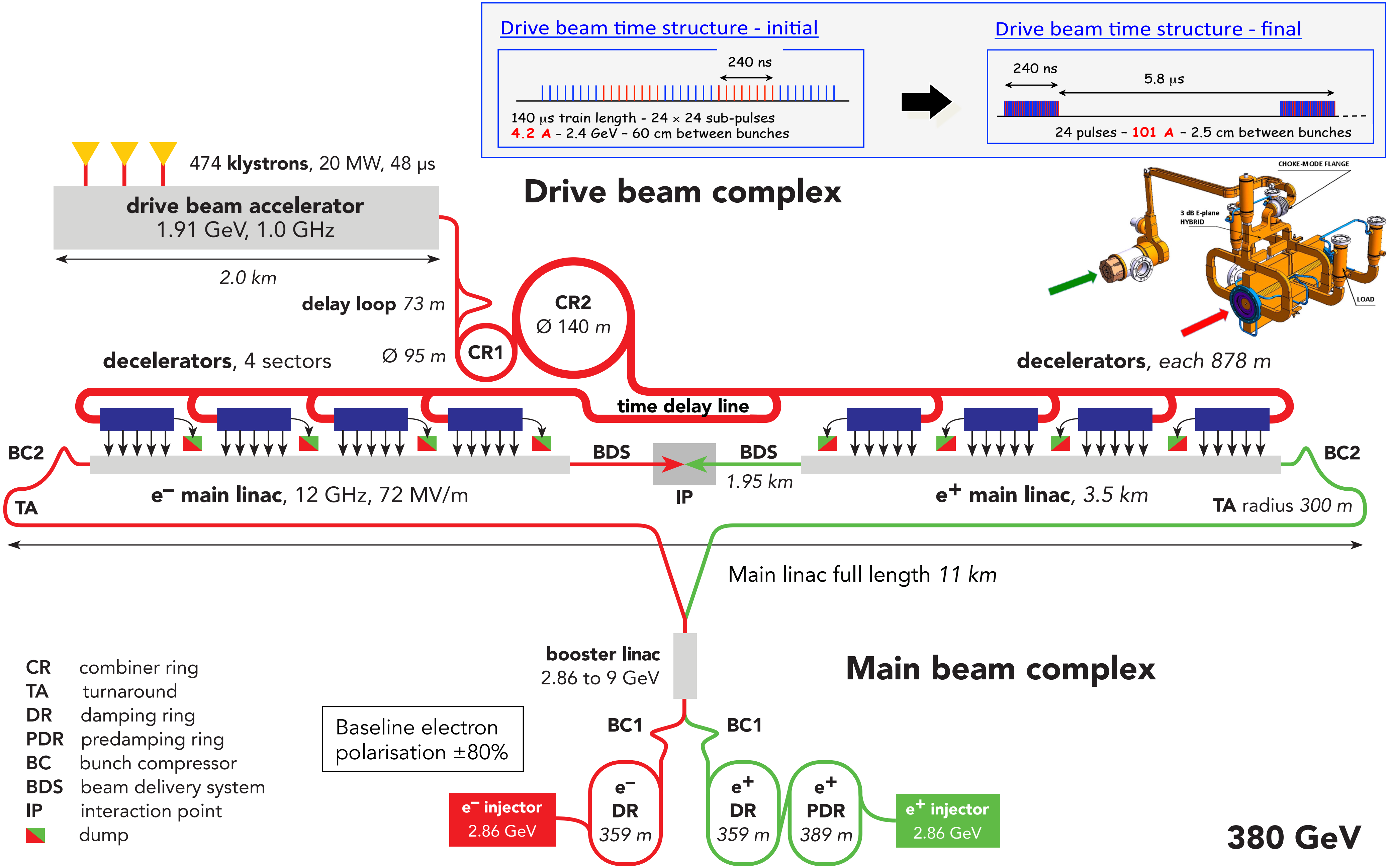
- CLIC physics prospects & simulation studies
- Detector optimization + R&D for CLIC

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

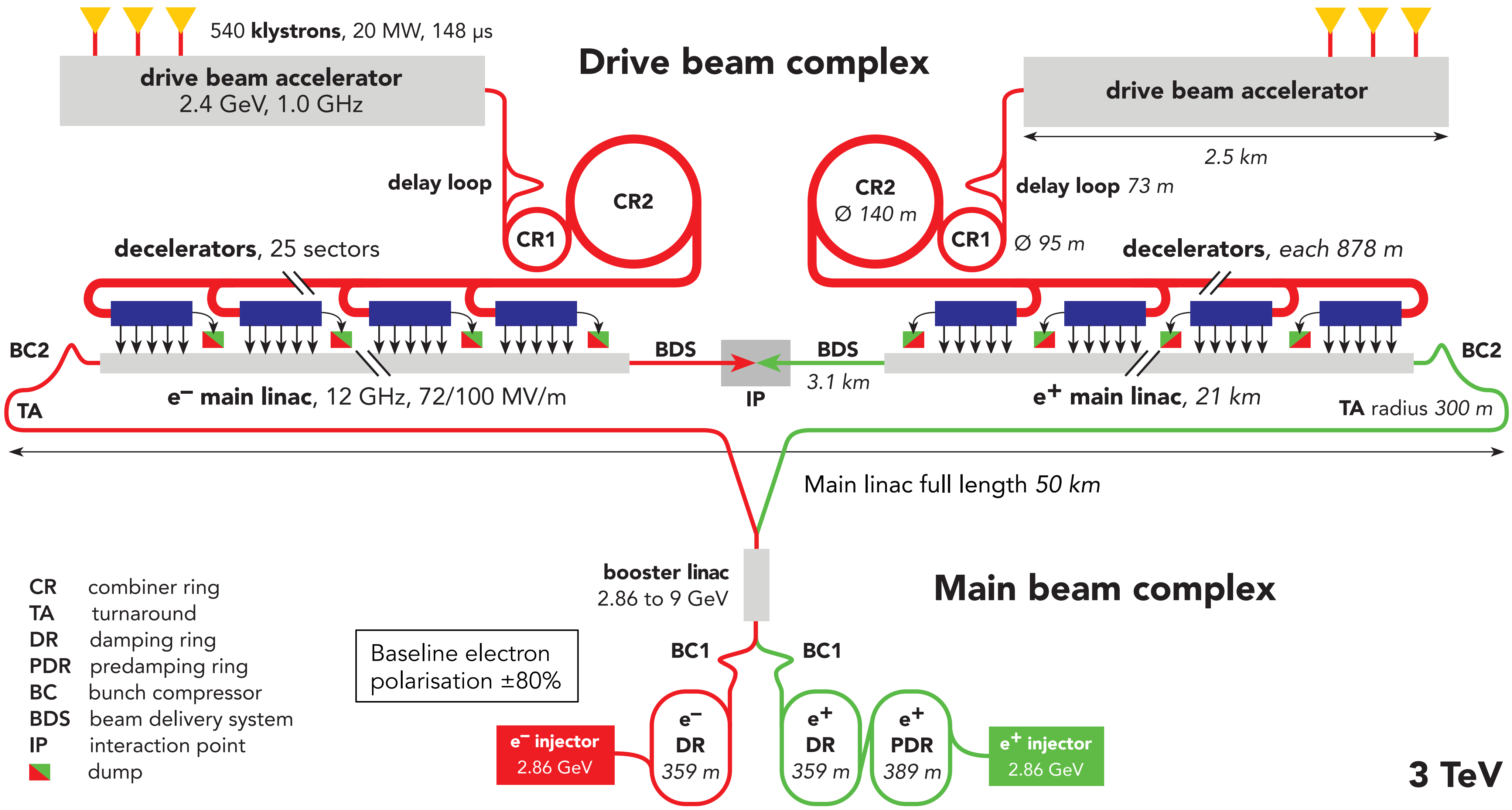



Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
3 TEV BASELINE
Elevation (mASL)
Chainage (m)
moraine
molasse
limestone
shaft
machine tunnel

CLIC layout and power generation



CLIC layout – 3TeV



3 TeV

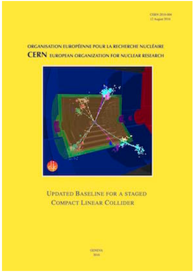
CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
(red/green square)	dump

CLIC

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
Main 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	920/20	660/20	660/20
Normalised emittance (at IP)	ϵ_x/ϵ_y	nm	950/30	—	—

CDR 2012

https://cds.cern.ch/record/1500095
https://cds.cern.ch/record/1425915
https://cds.cern.ch/record/1475225



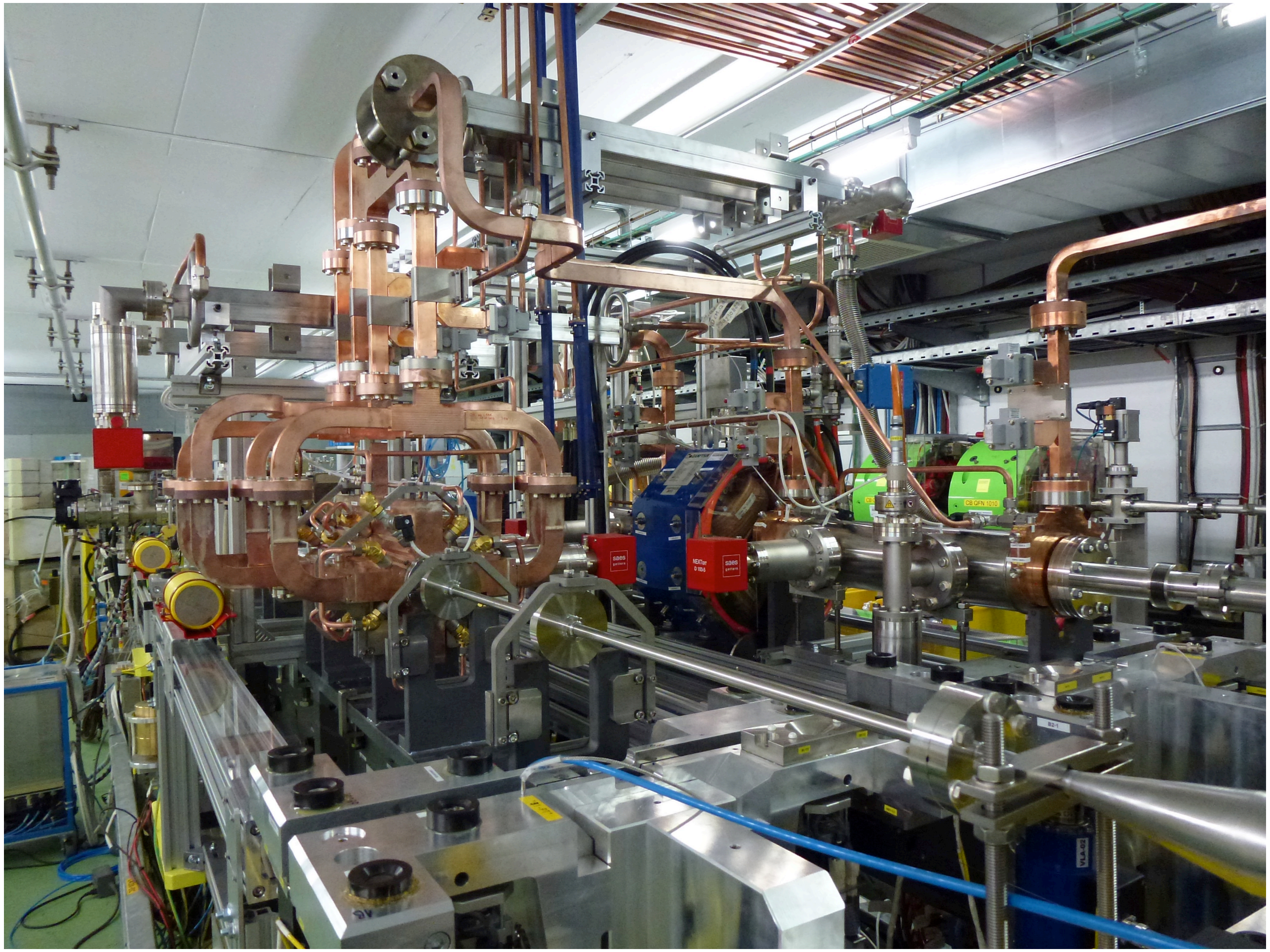
Updated Staging Baseline 2016

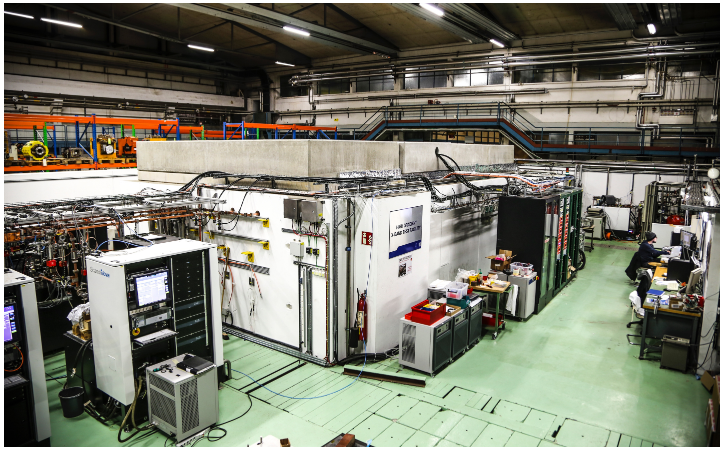
http://dx.doi.org/10.5170/CERN-2016-004

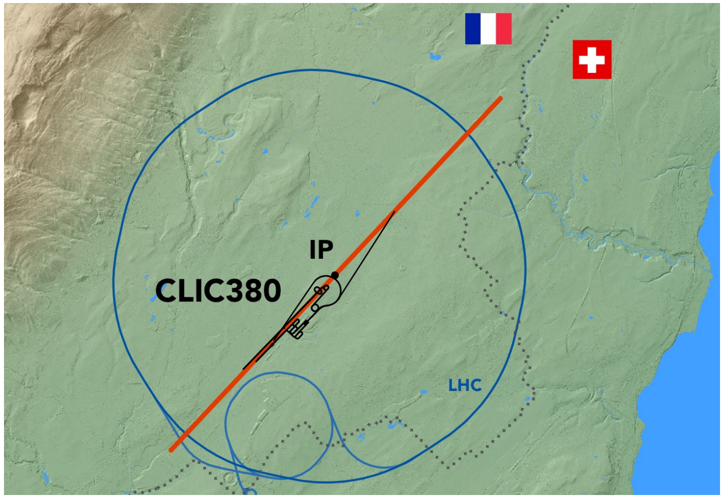
Project Implementation Plan 2018

CLIC

- Key technologies have been demonstrated
- CLIC is now a mature project, ready to be built

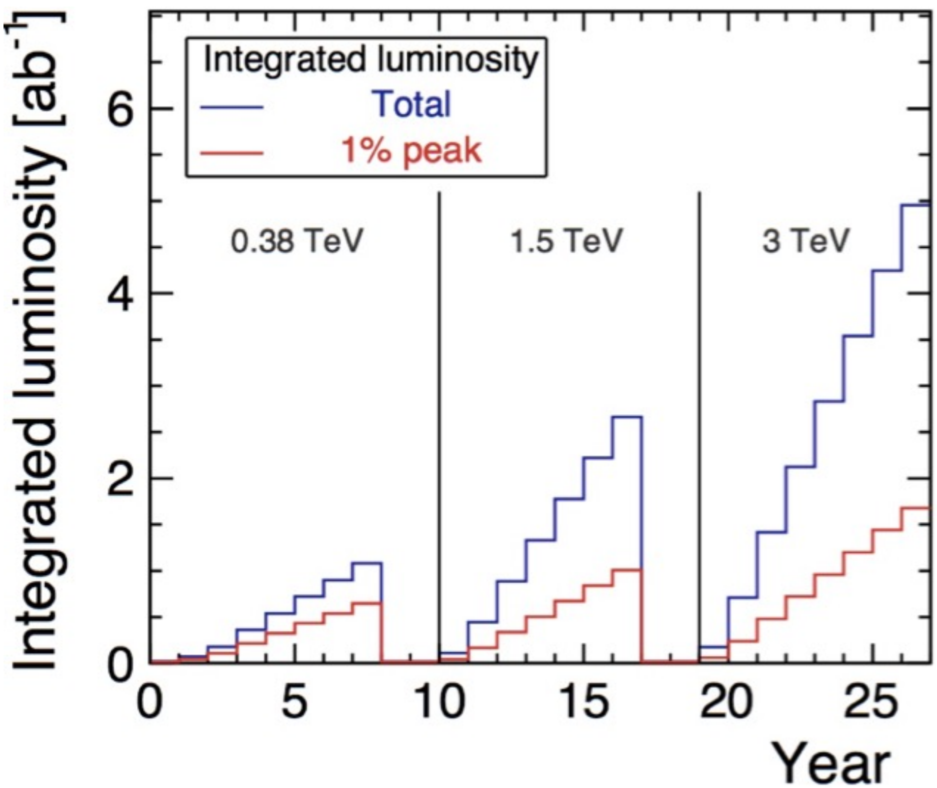






Updated CLIC Staging

New!



Stage	$\sqrt{s}$ [TeV]	$\mathscr{L}_{int}$ [ab^{-1}]	increased from
1	0.38 (and 0.35)	1.0	0.5+0.1ab^{-1}
2	1.5	2.5	1.5ab^{-1}
3	3.0	5.0	3ab^{-1}

Electron polarisation enhances Higgs production at high-energy stages and provides additional observables

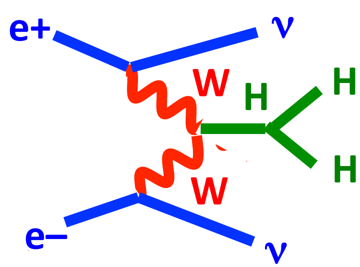
Baseline polarisation scenario adopted:
electron beam (–80%, +80%) polarised in ratio (50:50) at $\sqrt{s}$=380GeV ; (80:20) at $\sqrt{s}$=1.5 and 3TeV

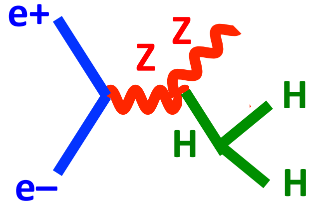
$\gamma\gamma$ collider using laser scattering also possible
Upgrades using novel accelerator techniques also possible

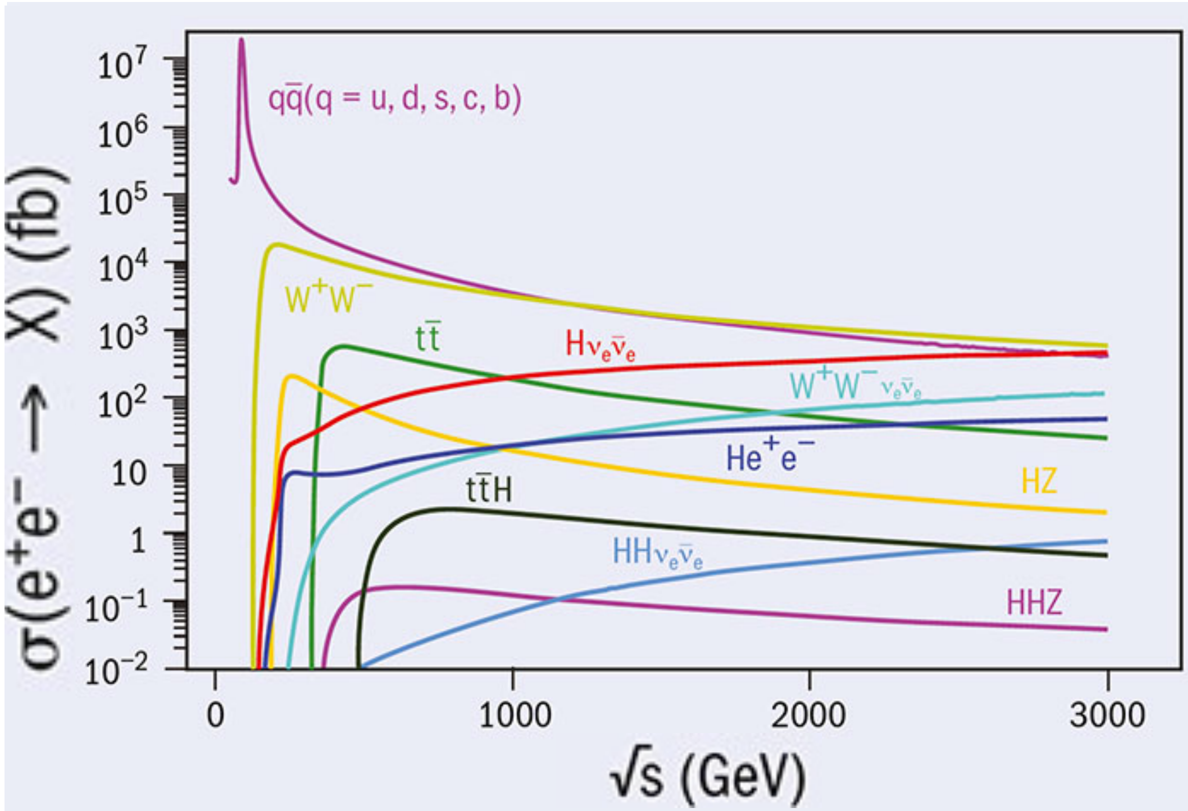
Staging and live-time assumptions following guidelines consistent with other future projects:
Machine Parameters and Projected Luminosity Performance of Proposed Future Colliders at CERN
arXiv:1810.13022, Bordry et al.

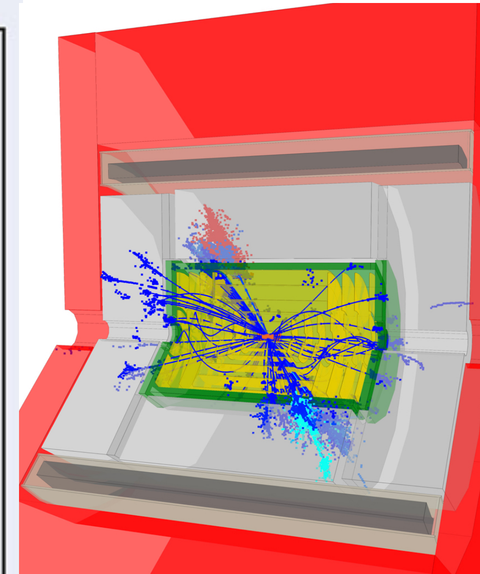
CLIC Physics

◆ Precision Higgs









tt at $\sqrt{s}$=3TeV

◆ Precision top

◆ Beyond Standard Model

Issues not addressed by SM:
- origin of the weak scale interactions
- dark matter
- origin of matter/antimatter asymmetry

Many new studies focused on discovery prospects at CLIC
Exploring the physics landscape as broadly as possible New!

Yellow Report in preparation

The CLIC Potential for New Physics

Higgs coupling sensitivity

Full GEANT-based simulation studies including beam backgrounds of many channels at all 3 stages –> global fit including correlations;

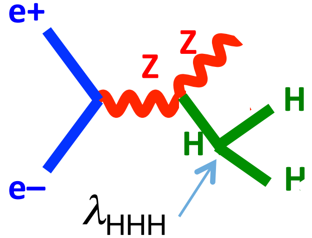
$$\sigma(ZH) \sim g^2_{HZZ}$$
$$\sigma(ZH) \times BR(H\to VV/ff) \sim g^2_{HZZ} g^2_{HVV/Hff} / \Gamma_H$$
$$\sigma(H\nu_e\bar{\nu}_e) \times BR(H\to VV/ff) \sim g^2_{HWW} g^2_{HVV/Hff} / \Gamma_H$$

Precision $\lesssim$1% for most couplings

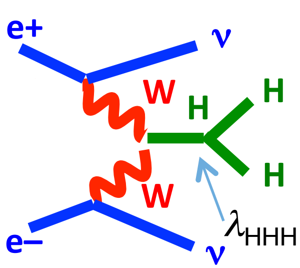
c/b/W/Z/g couplings significantly more precise than HL-LHC even after 380GeV stage

Γ_H is extracted with 4.7 – 2.5% precision

Higgs self-coupling requires high energy



complementary at 1.5TeV



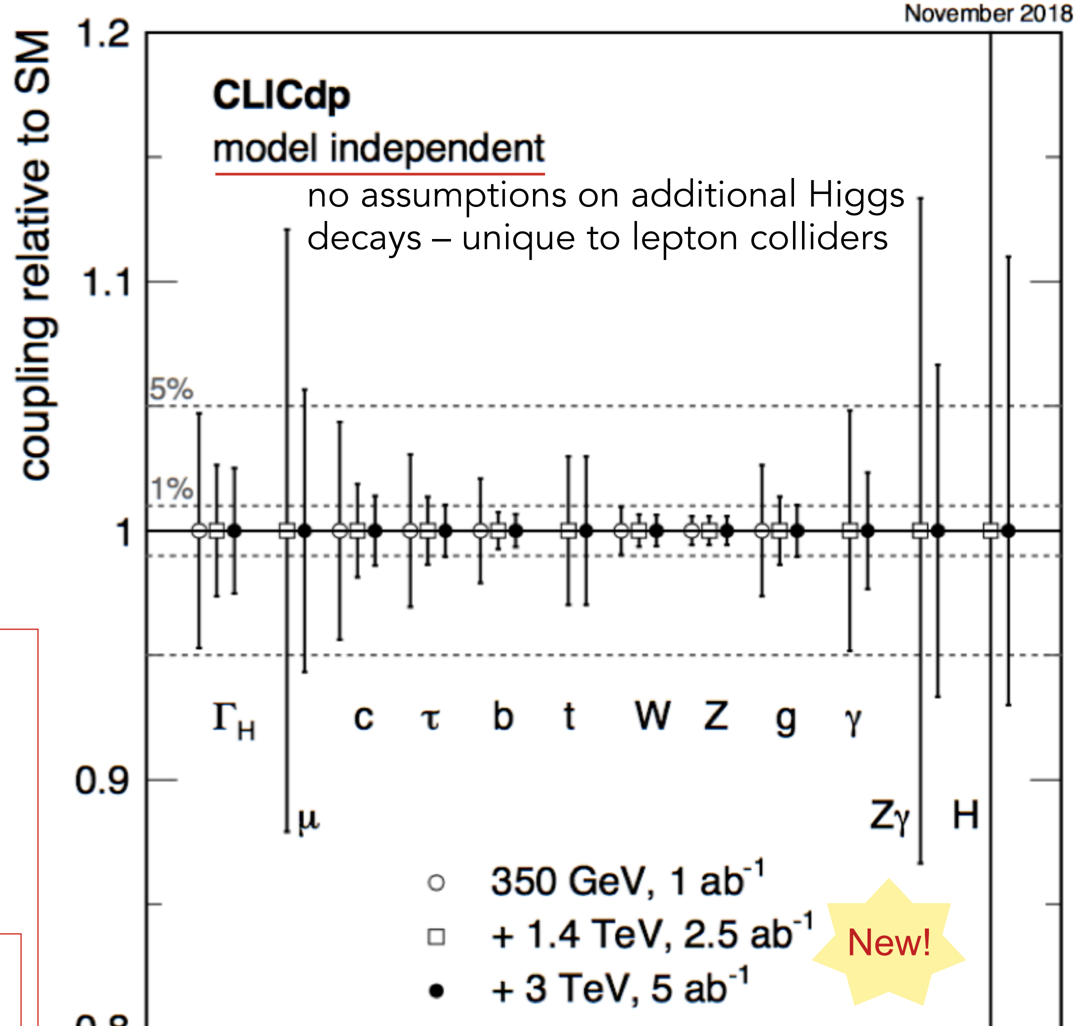
dominates at higher $\sqrt{s}$

Using M(HH) differential distribution:

$$\Delta\lambda/\lambda = {}^{+11\%}_{-7\%}$$

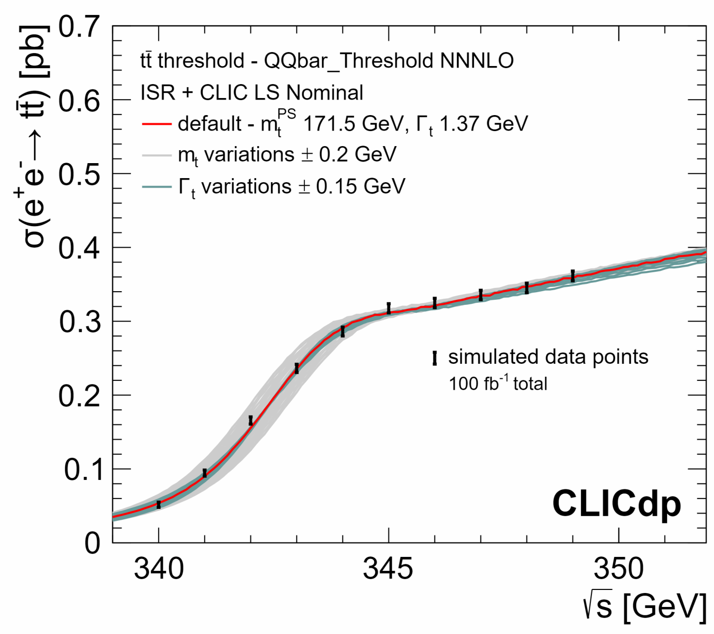
New!

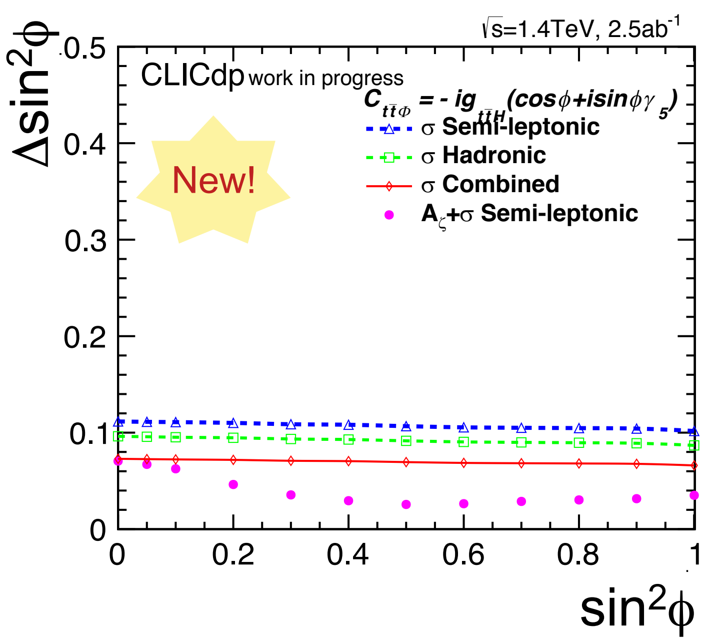
Each energy stage contributes significantly



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

Top





- Intending threshold scan around 350 GeV (10 points, ~1 year) as well as main initial-stage baseline $\sqrt{s}$=380GeV

- sensitive to top mass, width and couplings
- observe 1S 'bound state', Δm_t ~ 50 MeV

- FCNC decays
- CP properties of ttH
- cross-section and A_{FB}

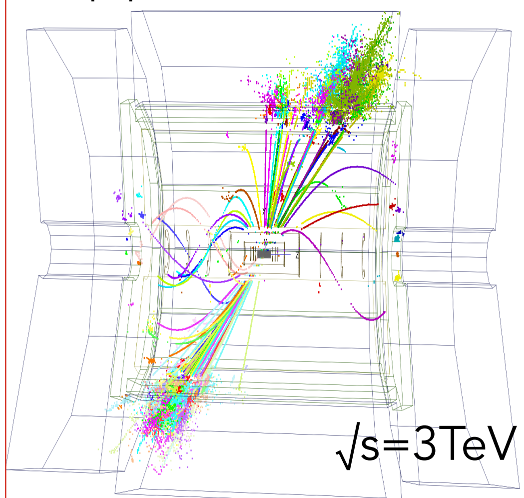
-> resolved, semi-resolved, boosted

- couplings to Z and γ
- EFT interpretation

–> initial and high-energy stages are very complementary

Polarisation provides new observables

First study of boosted top production in e^+e^-



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

Hadronic decays of high-energy top quarks do not lead to 3 separated jets

–> identify substructure

arXiv 1807.02441: Top-quark physics at the CLIC electron–positron linear collider

in journal review

EFT

Standard Model

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

Scale of new decoupled physics

Dimension-6 operators

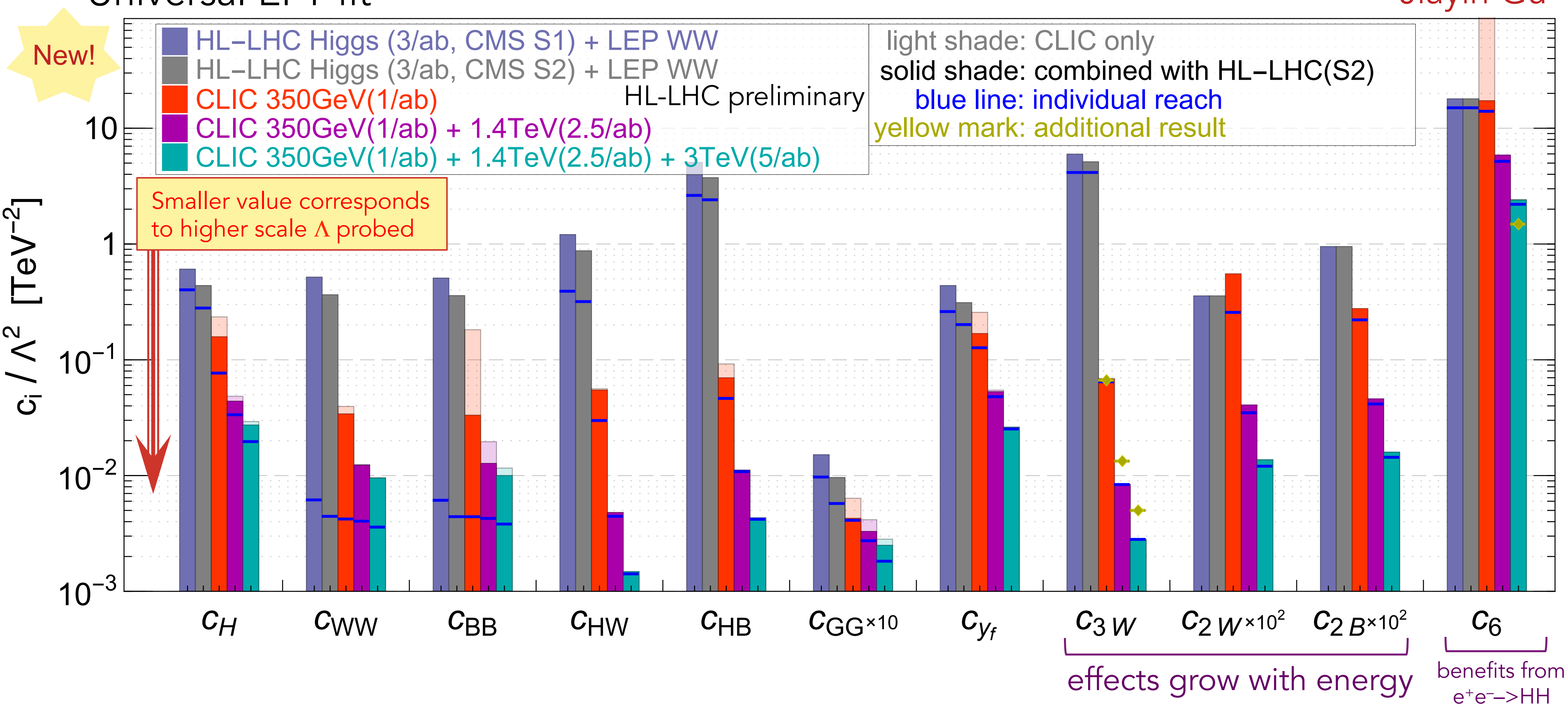
Includes CLIC Higgs, top, WW, and $e^+e^- \to f\bar{f}$ measurements

Strongly benefits from high-energy running

–> will appear in 'The CLIC Potential for New Physics' Yellow Report

Universal EFT fit

Jiayin Gu



Standard Model

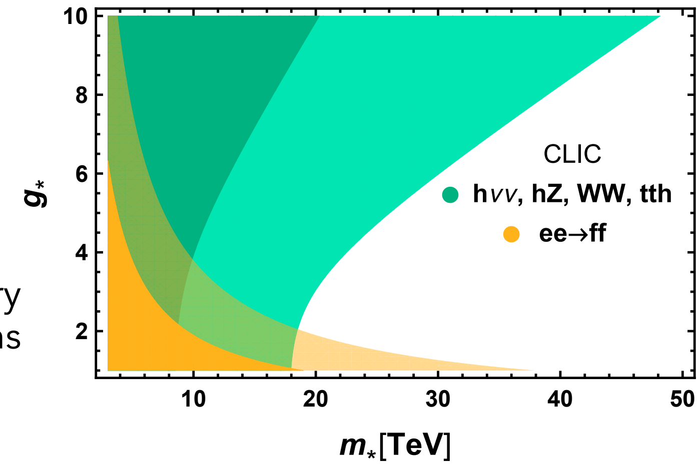
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$$

Scale of new decoupled physics

Dimension-6 operators

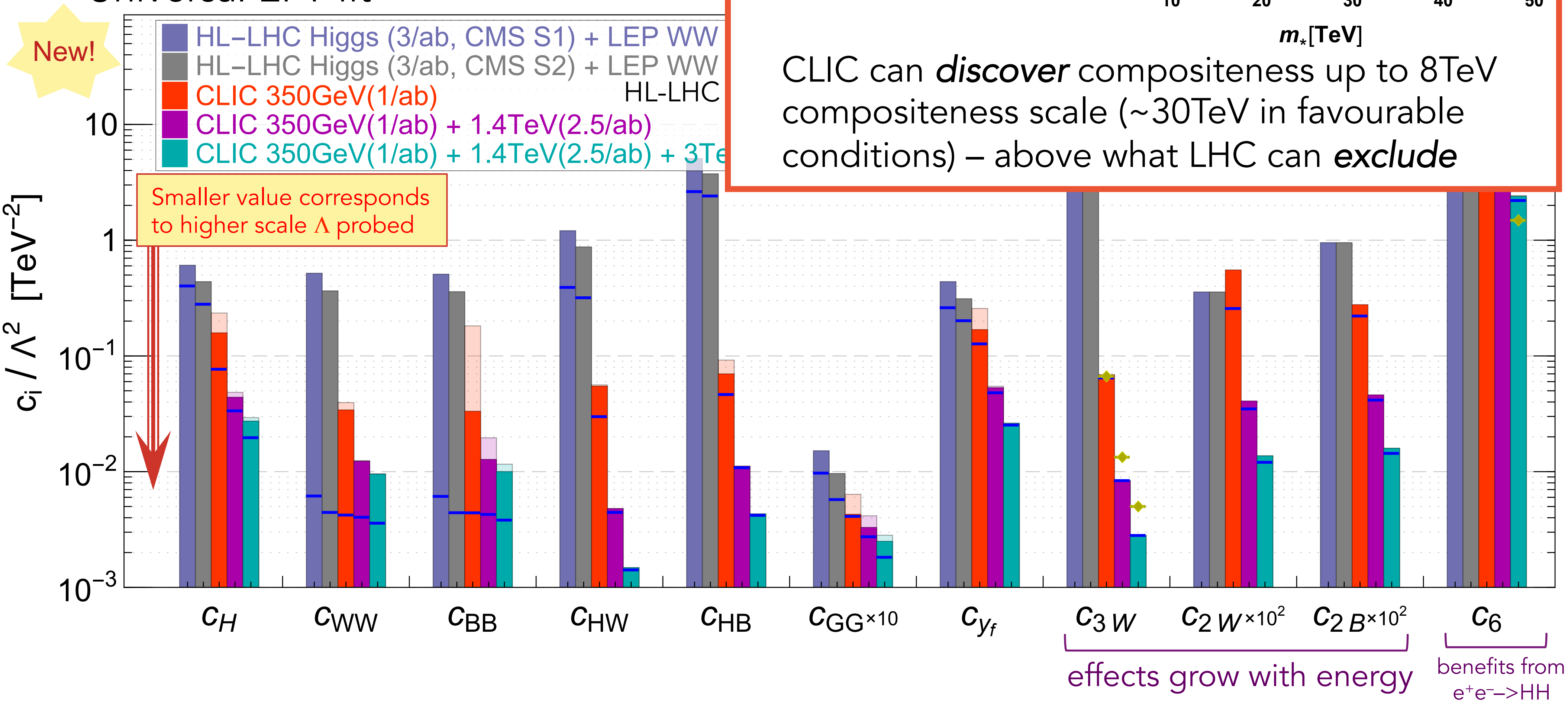
Can interpret in concrete BSM scenarios e.g. Higgs & top-quark compositeness

5-σ discovery regions



CLIC can ***discover*** compositeness up to 8TeV compositeness scale (~30TeV in favourable conditions) – above what LHC can ***exclude***

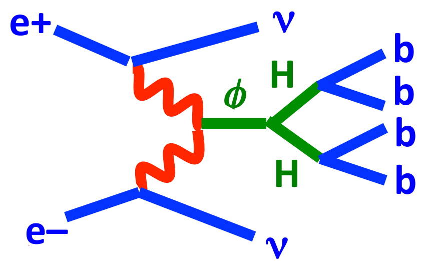
Universal EFT fit



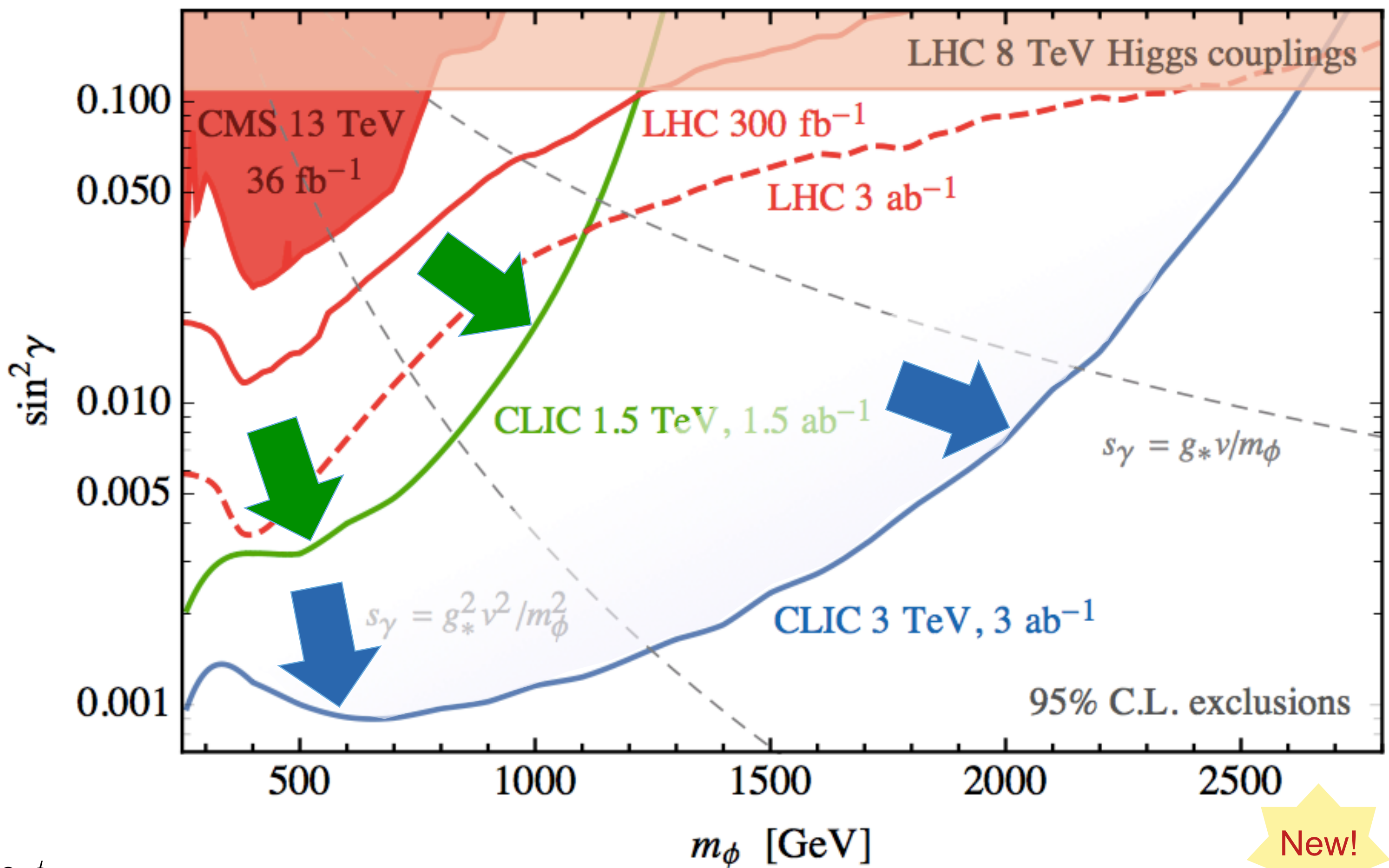
Higgs + heavy singlet

Direct search for real scalar singlet ϕ : new physics weakly coupled to SM

arXiv: 1807.04743 – Buttazzo, Redigolo, Sala, Tesi



(To be updated for new luminosities)



New!

$$h = h_0 \cos\gamma + S \sin\gamma$$

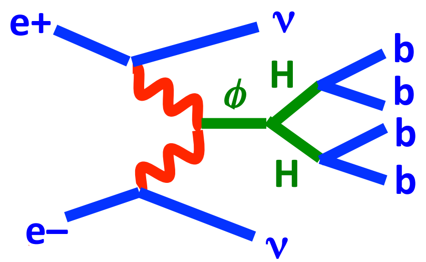
$$\phi = S \cos\gamma - h_0 \sin\gamma$$

γ is mixing angle of SM-like Higgs (m_h=125GeV), and singlet-like state ϕ

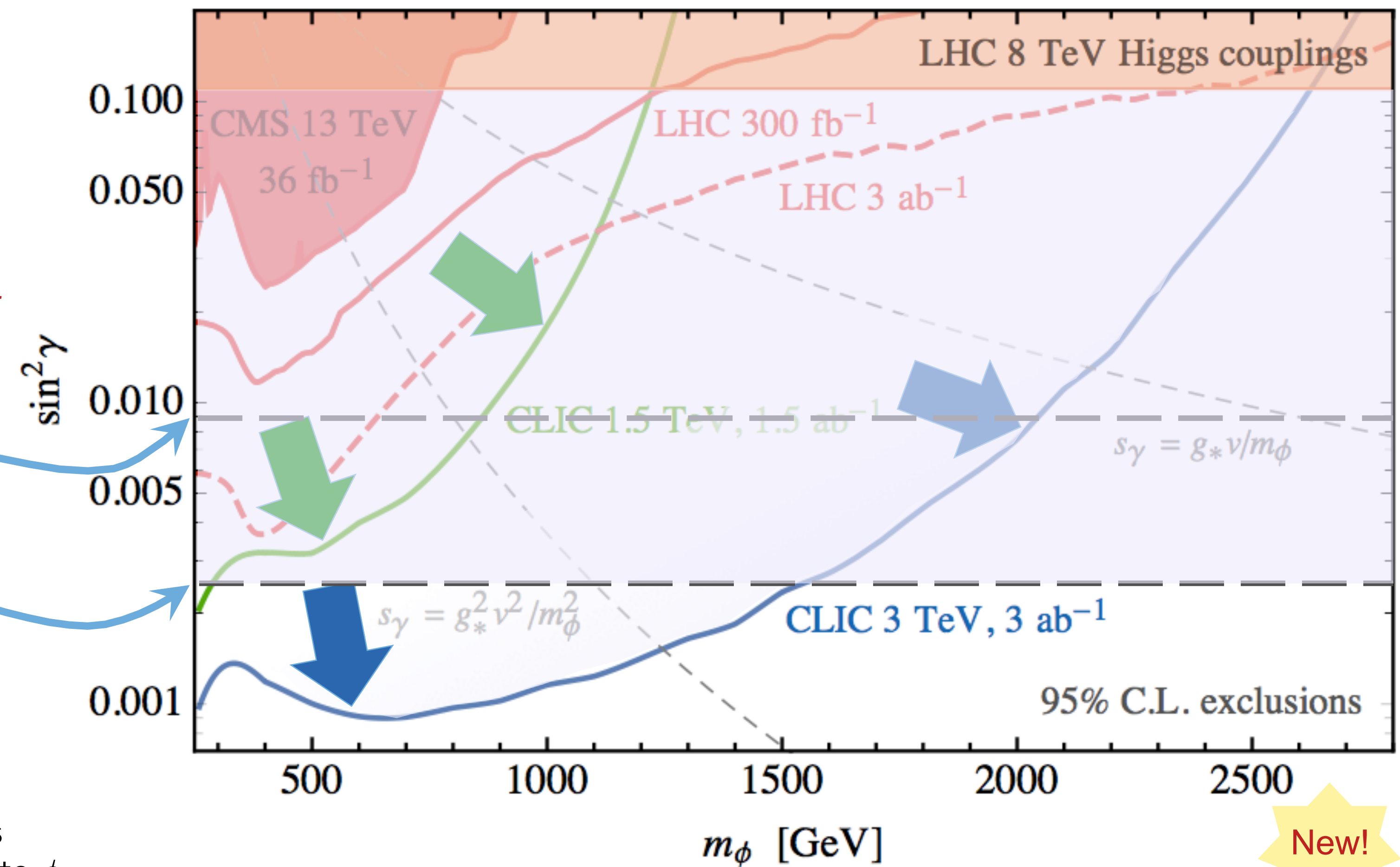
Higgs + heavy singlet

Direct search for real scalar singlet ϕ: new physics weakly coupled to SM

arXiv: 1807.04743 – Buttazzo, Redigolo, Sala, Tesi



(To be updated for new luminosities)



New!

Indirect search

very complimentary:

arXiv: 1608.07538 + Roloff

Higgs couplings give:

$\sin^2\gamma$<0.9% 95% CL (380GeV)

$\sin^2\gamma$<0.24% 95% CL (380GeV+1.5TeV+3TeV)

$$h = h_0 \cos\gamma + S \sin\gamma$$

$$\phi = S\cos\gamma - h_0 \sin\gamma$$

γ is mixing angle of SM-like Higgs (m_h=125GeV), and singlet-like state ϕ

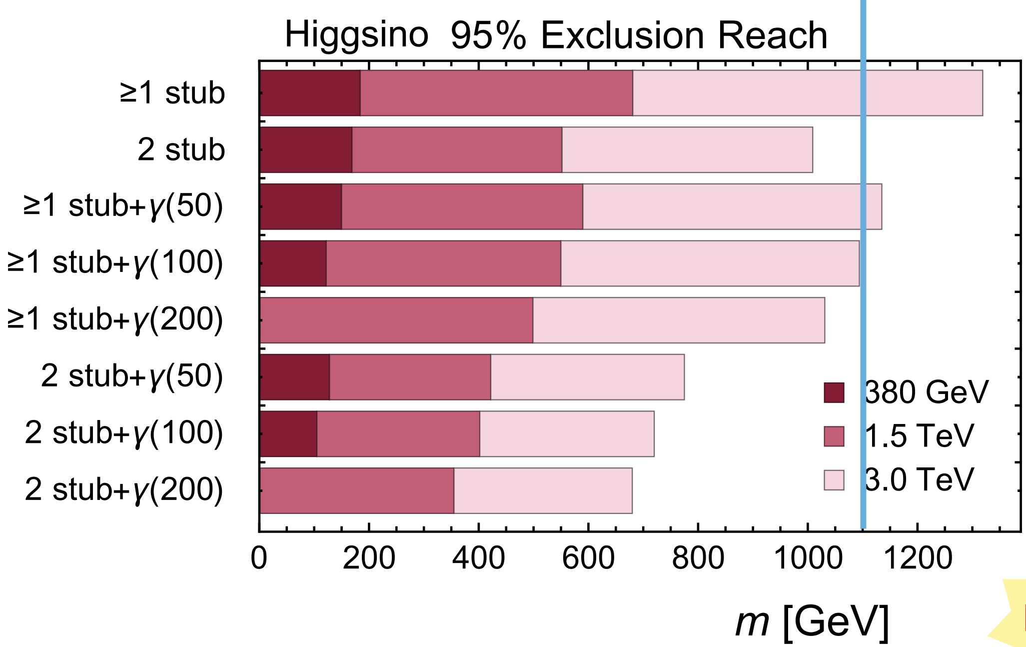
Dark matter

Higgsino:

WIMP dark matter candidate, connected to weak scale naturalness, and gauge coupling unification

When other superpartners decoupled:
$\chi^{\pm}$ slightly heavier than χ^0
$\chi^{\pm} \to \pi^{\pm}\chi^0$ **leaving 'charged stub' in detector**

reach Higgsino mass of 1.1TeV, required for DM relic mass density – even with some level of background



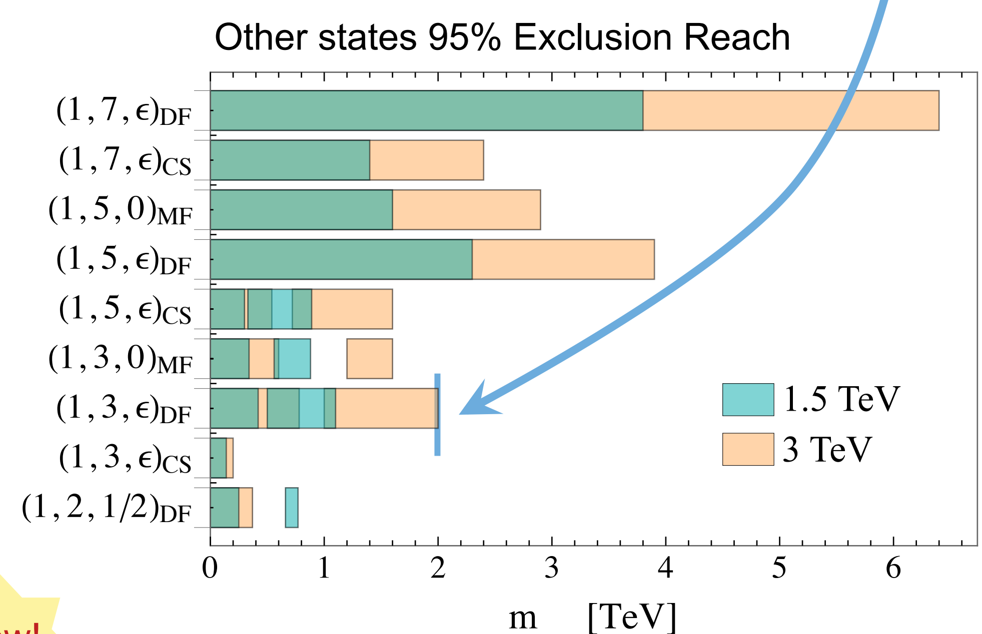
Electroweak precision tests:

arXiv: 1810.10993 - Di Luzio, Gröber, Panico

Precision measurements of $d\sigma/d(\cos\theta)$ in $e^+e^- \to f\bar{f}$ sensitive to new states –> exclude mass ranges

diverse experimentally

e.g. for *n*=3 Dirac fermion, *m*=2TeV saturates DM relic mass density: can be excluded by CLIC



New!

DF=Dirac Fermion, MF=Majorana Fermion, CS=Complex Scalar
SU(3)xSU(2)xU(1) representation; different *n*-tuplet multiplicities

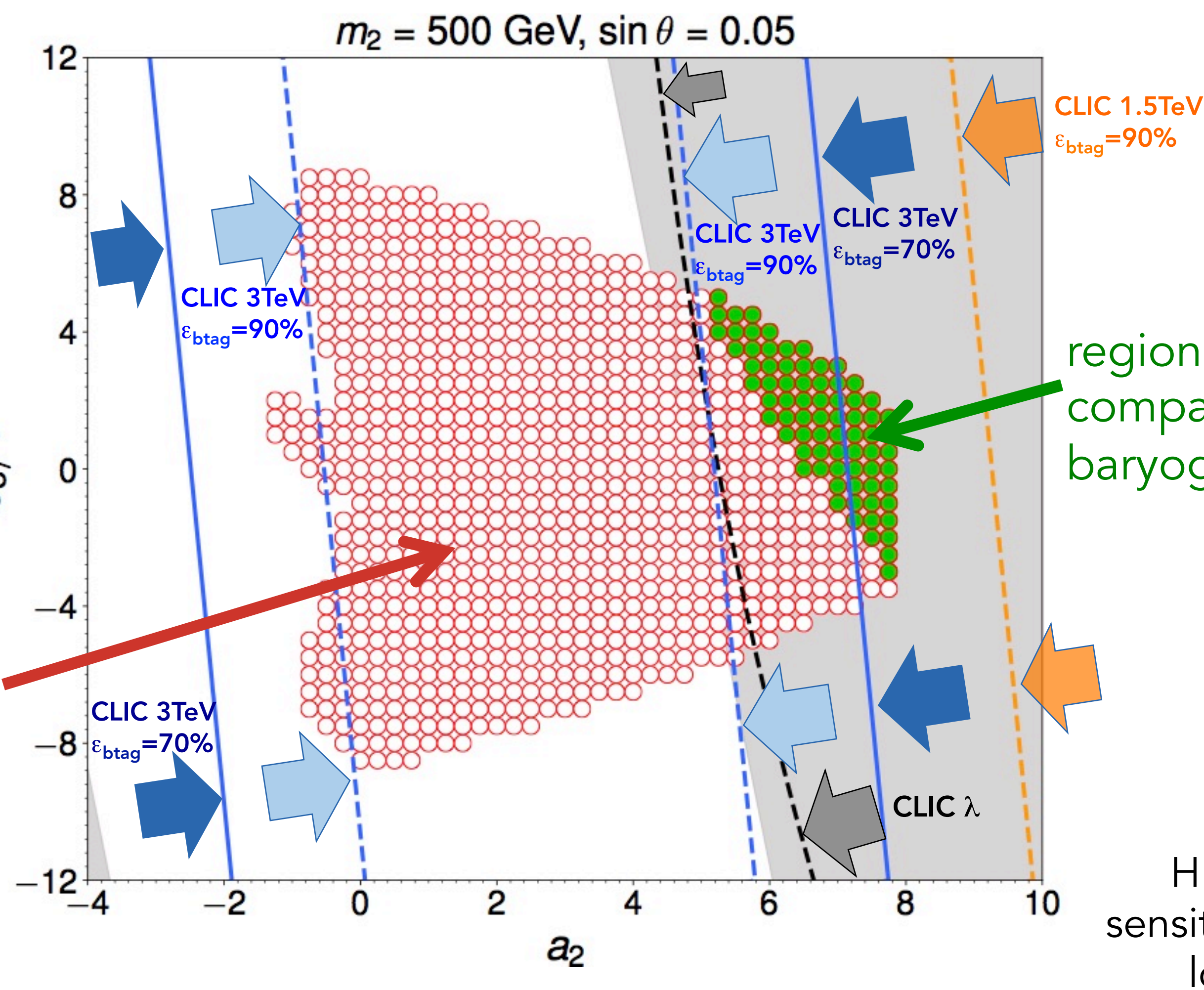
Baryogenesis

arXiv:1807.04284 No, Spannowsky

New!

A potential barrier between the symmetric vacuum and the vacuum after EW symmetry breaking, gives a first-order phase transition: a necessary condition for baryogenesis

Explored in the Higgs+singlet model.
CLIC resonant di-Higgs searches
CLIC Higgs self-coupling λ

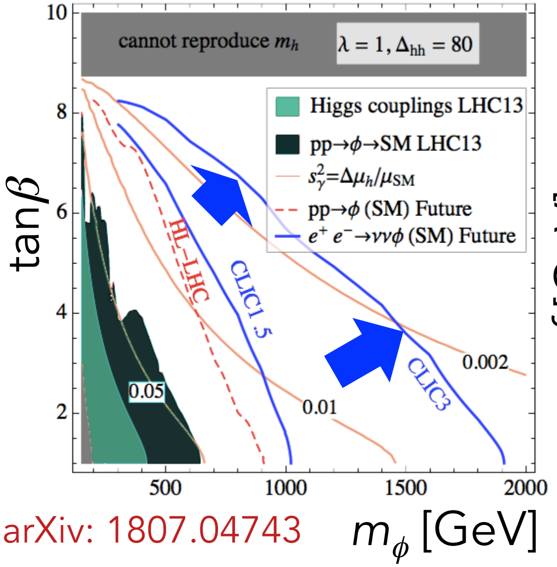


a_2 and b_3/v are parameters of the temperature-dependent effective potential; m_2 and θ are the singlet mass and mixing

well-constrained by
CLIC Higgs self-coupling (black)
and CLIC resonant di-Higgs
searches at 1.5TeV and 3 TeV

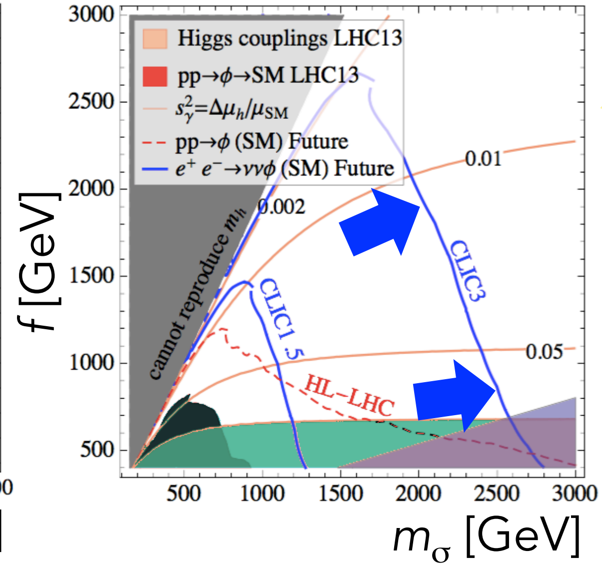
HL-LHC not sensitive at this low mixing sinθ=0.05

Interpretations and full programme



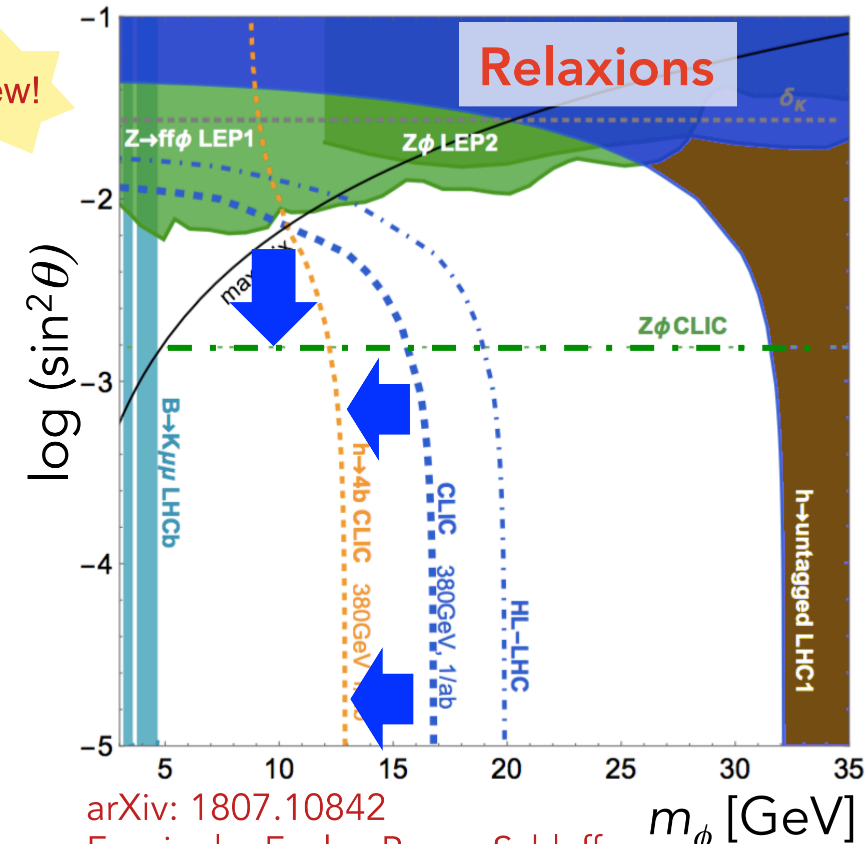
arXiv: 1807.04743

Higgs + singlet as **NMSSM**



Higgs + singlet as **Twin Higgs** model

New!



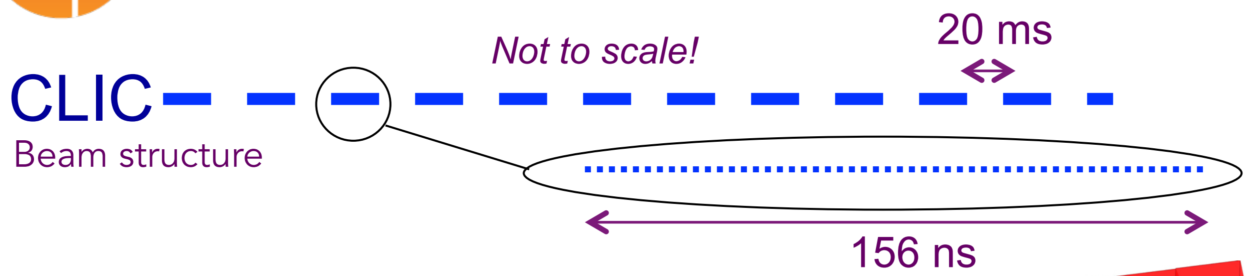
arXiv: 1807.10842
Frugiuele, Fuchs, Perez, Schlaffer

- Precision Higgs couplings and self-coupling
- Precision electroweak and top-quark analysis
- Sensitivity to BSM effects in the SMEFT
- Higgs and top compositeness
- Baryogenesis
- Direct discoveries of new particles
- Extra Higgs boson searches
- Dark matter searches
- Lepton and flavour violation
- Neutrino properties
- Hidden sector searches
- Exotic Higgs boson decays

Many more studies in forthcoming CERN Yellow Report (250 pages)

The CLIC Potential for New Physics

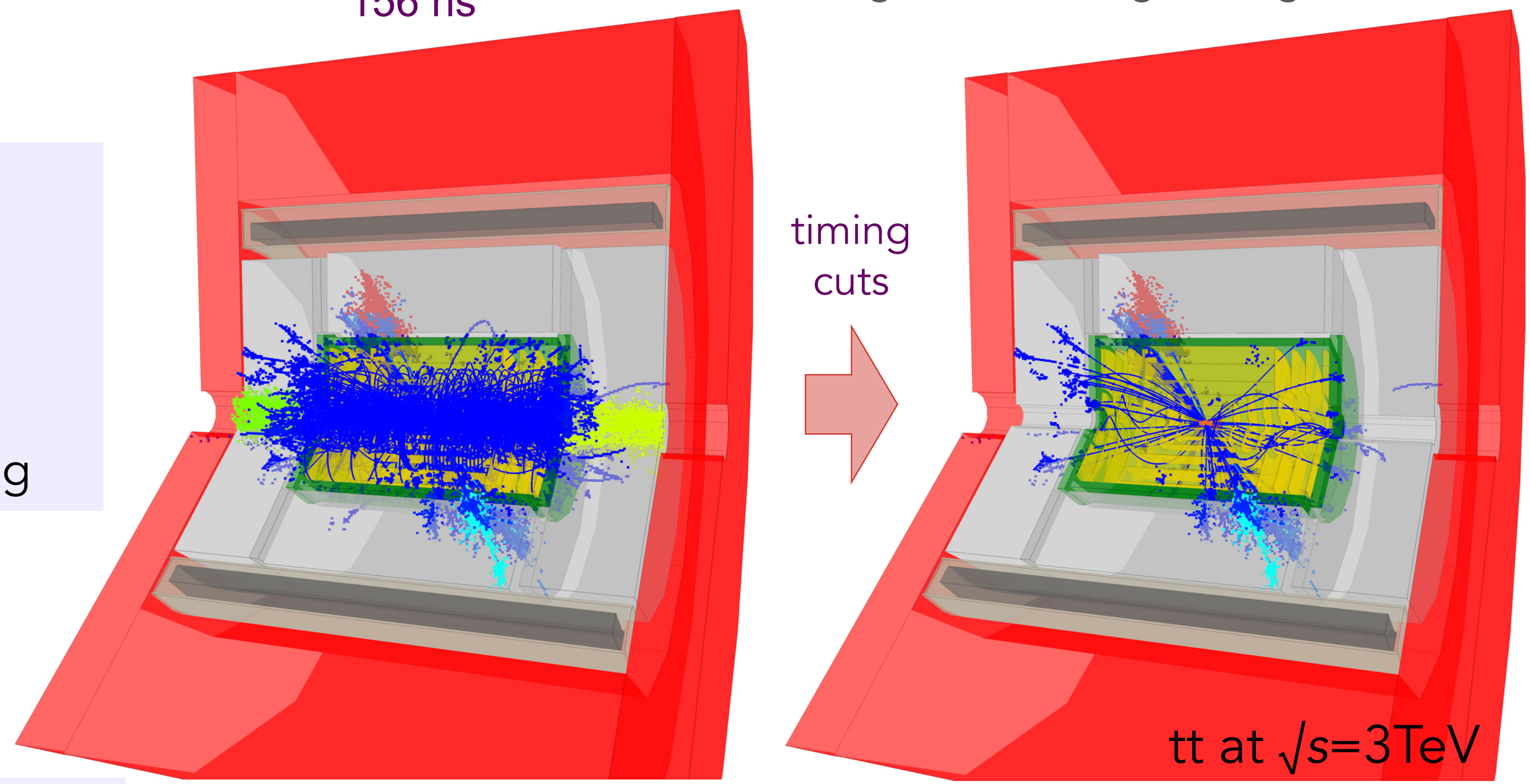
Collider environment



High bunch charge density
–> beam-related backgrounds
small effect at $\sqrt{s}$=380GeV
large effect at high energies

Precise timing required for beam background rejection

1ns in calorimetry,
5ns in vertexing/tracking



High precision:

- jet energy resolution
  - –> fine-grained calorimetry
- momentum resolution
- impact parameter resolution

$\sigma(E)/(E)$ ~ 3.5% for E>100GeV

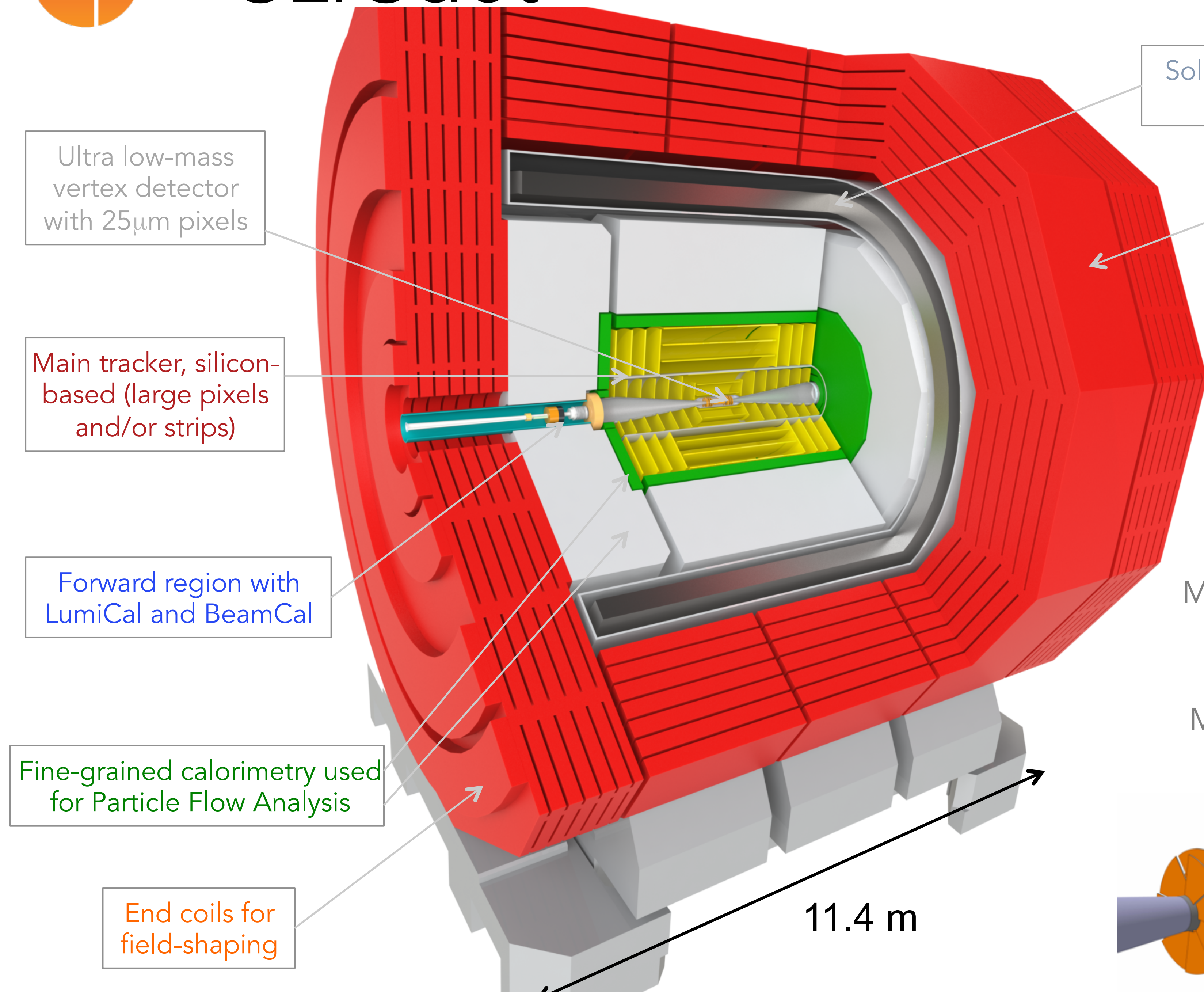
$\sigma(p_T)/p_T^2$ ~ 2x10^{-5} GeV^{-1}

$\sigma_{d0} \sim 5 \oplus 15/(p[\text{GeV}]\sin^{3/2}\theta)$ µm

CALICE / FCAL

CLICdp vertexing/ tracking programme

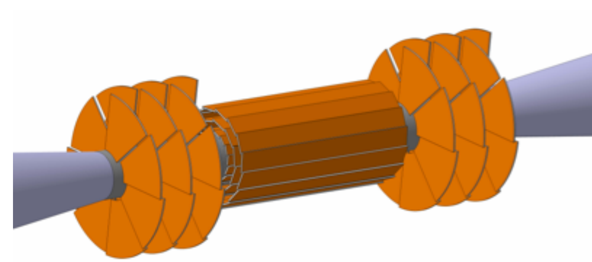
CLICdet



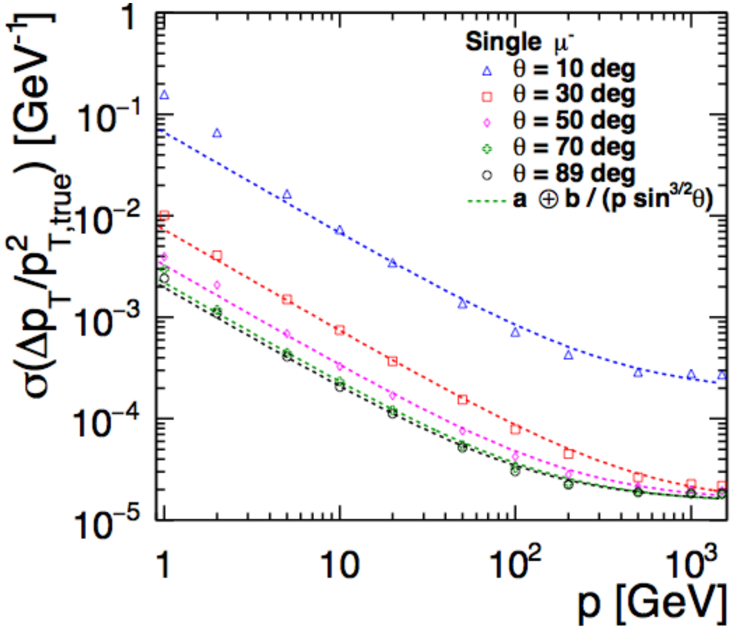
Triggerless readout

Tracker
spatial resolution: 7μm
Material: 1–2% X_0 / layer

Vertex detector
spatial resolution: 3μm
Material: 0.2% X_0 / layer
–> forced air cooling

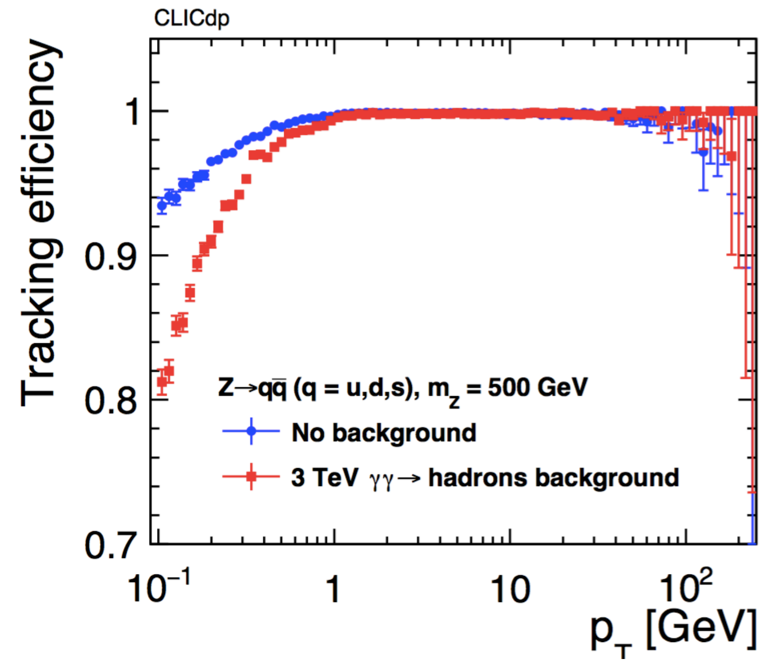


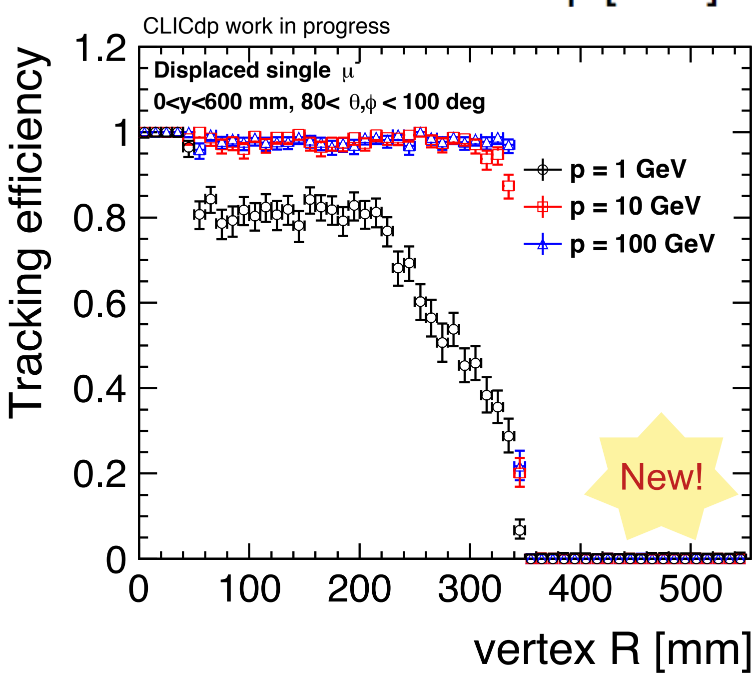
CLICdet Performance



performance goal: 2×10^{-5}

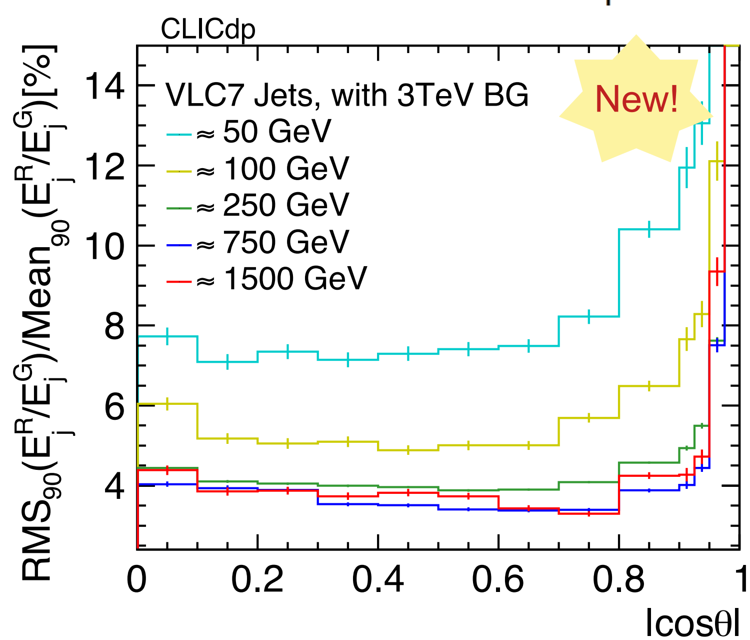
Characterization of detector model is now advanced





Displaced track reconstruction

Achieve jet energy resolution target in presence of beam backgrounds



Vertex and Tracking R&D

Various sensor + readout technologies under study
for CLIC vertex + tracker detector

Highlights:

Good S/N from thin 50µm fully-depleted sensors,
satisfying CLIC time-stamping requirements

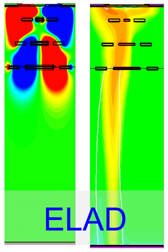
Sensor design with enhanced charge-sharing is underway

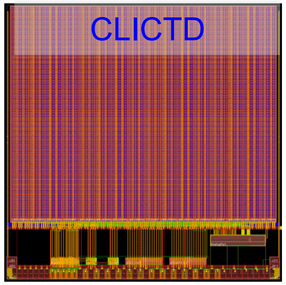
Good progress towards reducing detector mass with active-edge sensors
and through-Si interconnects

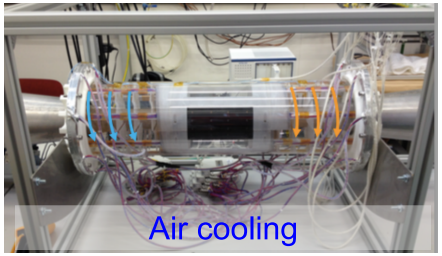
Promising results from fully integrated technologies;
CLIC-specific fully integrated designs underway (CLICTD, CLIPS)

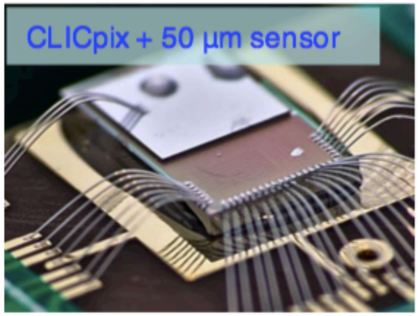
Feasibility of power-pulsing demonstrated
and power consumption specification met

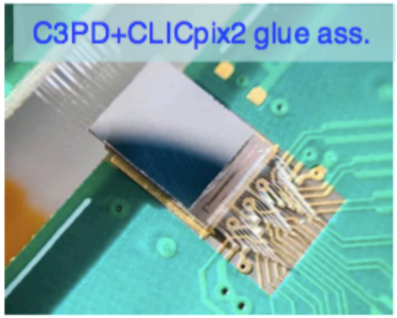
Feasibility of air cooling demonstrated in simulation & full vertex detector mockup

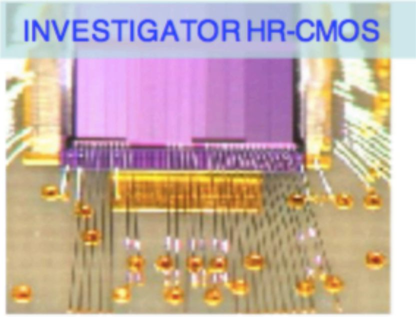












Accelerator challenges

Four challenges:

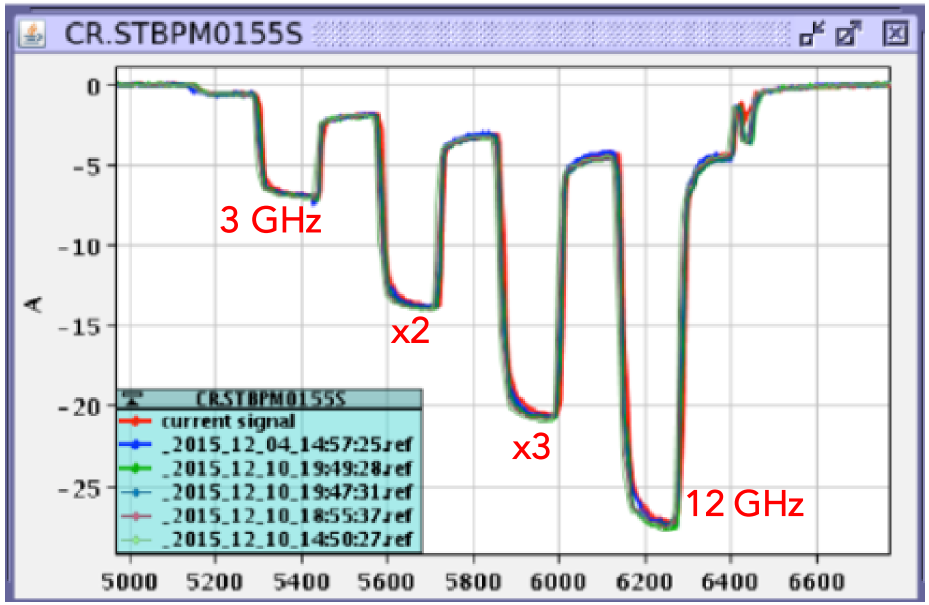
High-current drive beam bunched at 12 GHz

Power transfer + main-beam acceleration

~100 MV/m gradient in main-beam cavities

Alignment & stability

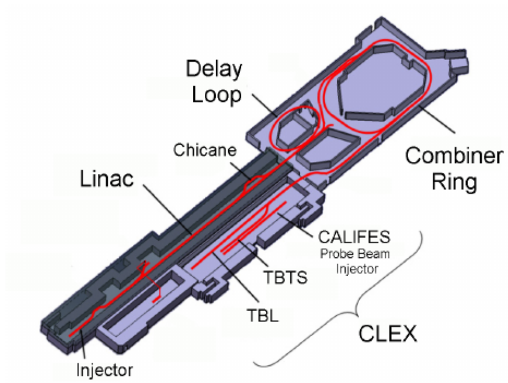
Drive beam quality:
Produced high-current drive beam bunched at 12GHz



28A

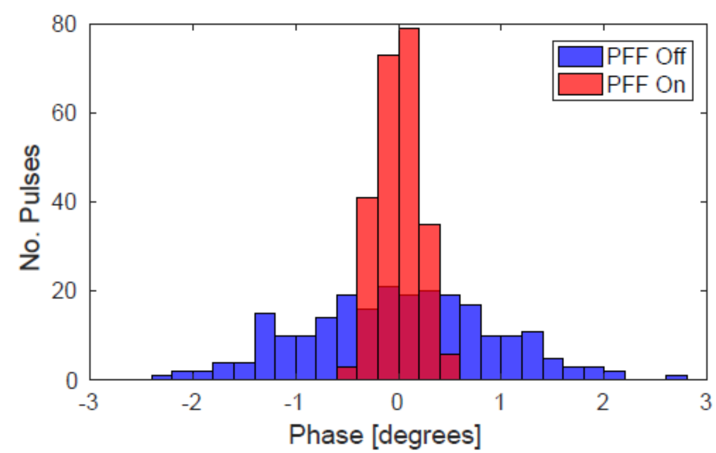
Current in combiner ring

Drive beam arrival time stabilised to CLIC specification of 50fs:



Examples of measurements from CLIC Test Facility, CTF3, at CERN.

CTF3 now the 'CERN Linear Electron Accelerator for Research' facility, CLEAR



Accelerator challenges

Demonstrated 2-beam acceleration

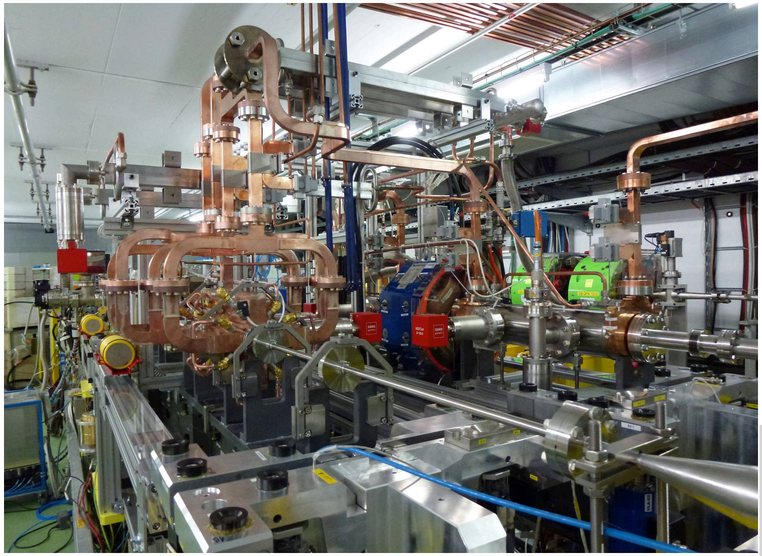
Four challenges:

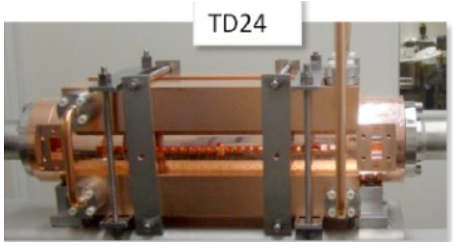
High-current drive beam bunched at 12 GHz

Power transfer + main-beam acceleration

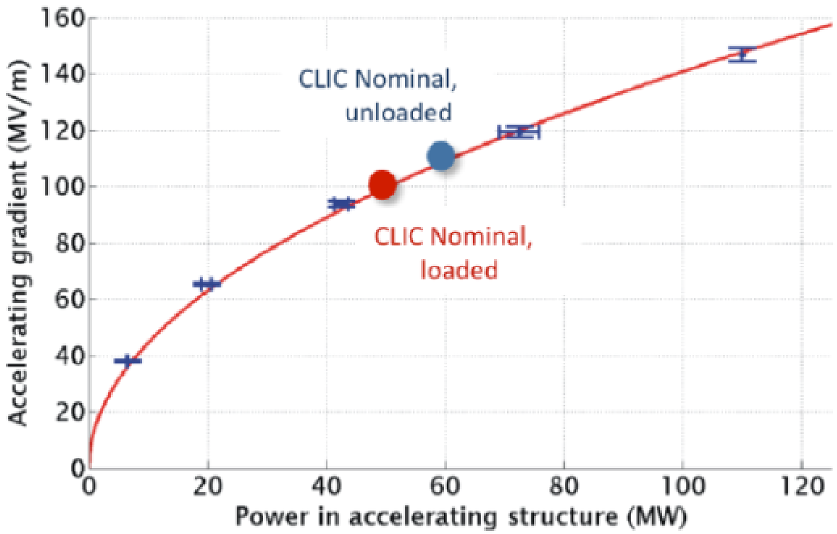
~100 MV/m gradient in main-beam cavities

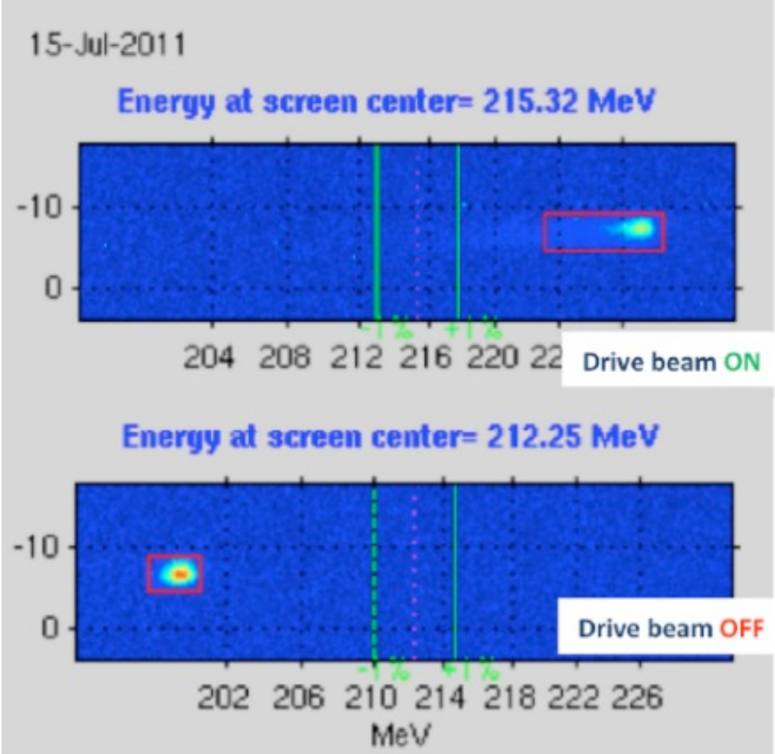
Alignment & stability





31MeV = 145MV/m





Accelerator challenges

X-band performance: achieved 100MV/m gradient in main-beam RF cavities

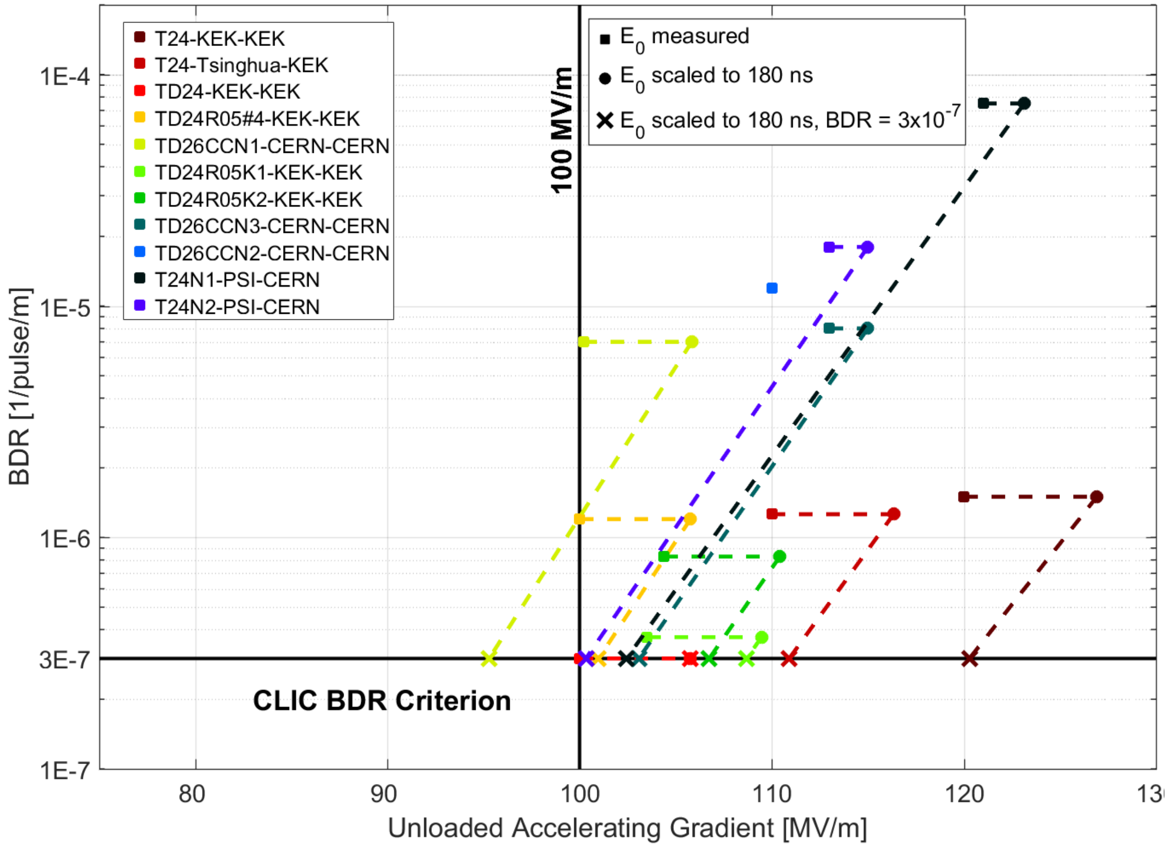
Four challenges:

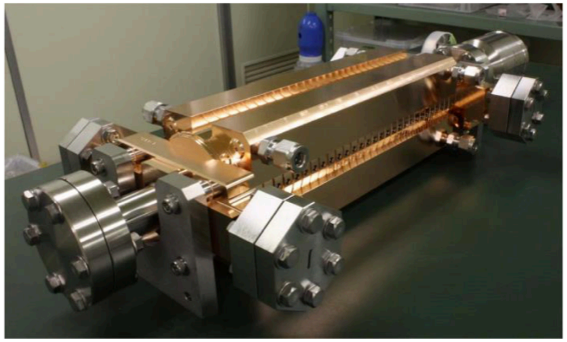
High-current drive beam bunched at 12 GHz

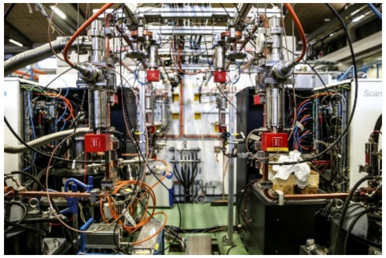
Power transfer + main-beam acceleration

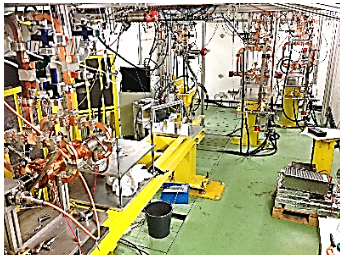
~100 MV/m gradient in main-beam cavities

Alignment & stability









Accelerator challenges

Nano-beams

Four challenges:

High-current drive beam bunched at 12 GHz

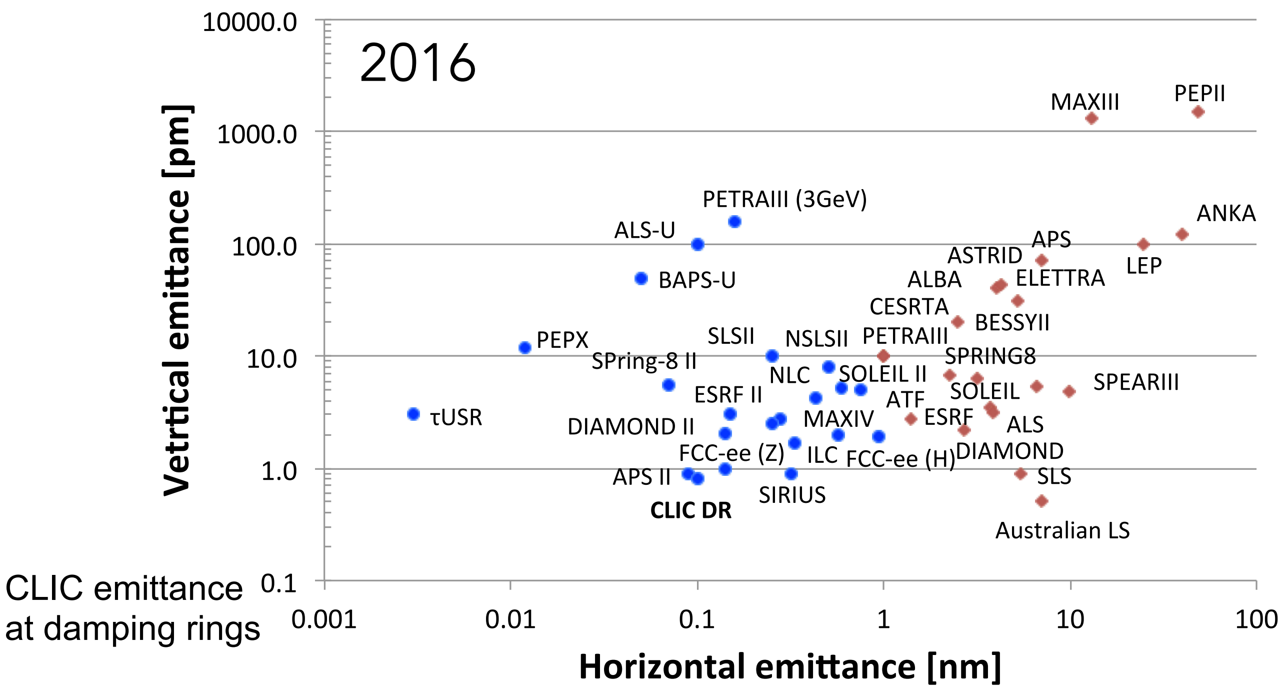
Power transfer + main-beam acceleration

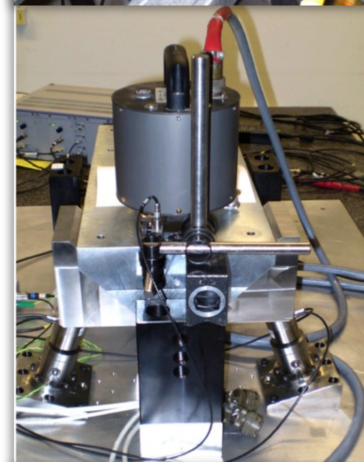
~100 MV/m gradient in main-beam cavities

Alignment & stability

The CLIC strategy:

- Align components (10μm over 200m)
- Control/damp vibrations (from ground to accelerator)
- Measure beams well – allow to steer beam and optimize positions
- Algorithms for measurements, beam and component optimization, feedbacks
- Tests in small accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)





Accelerator challenges

Nano-beams

Four challenges:

High-current drive beam bunched at 12 GHz

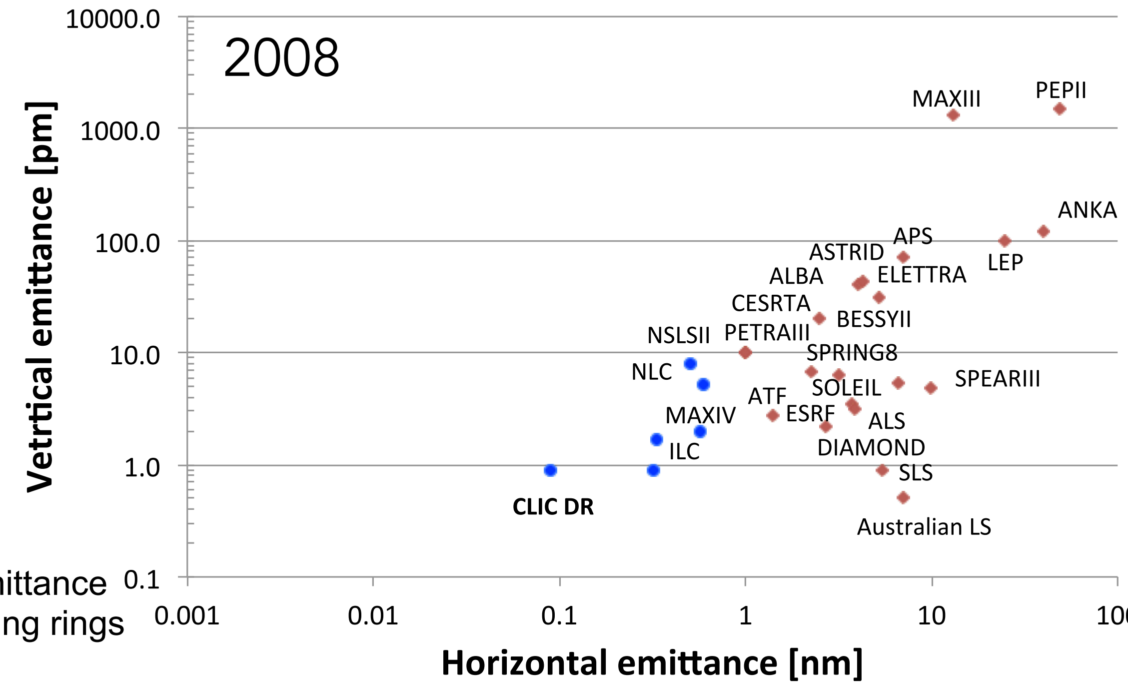
Power transfer + main-beam acceleration

~100 MV/m gradient in main-beam cavities

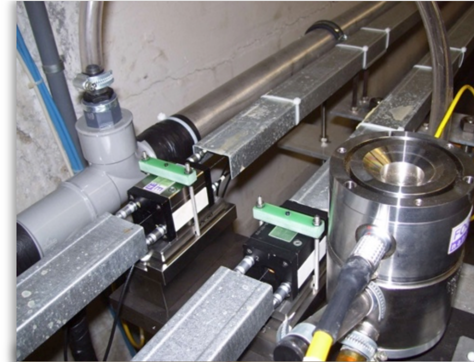
Alignment & stability

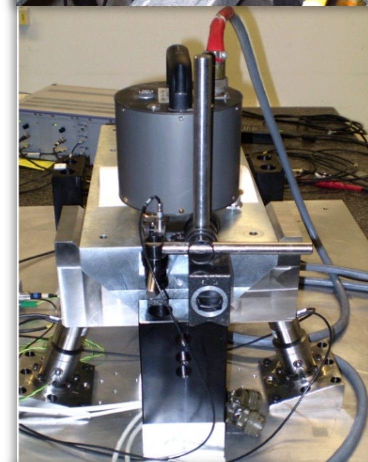
The CLIC strategy:

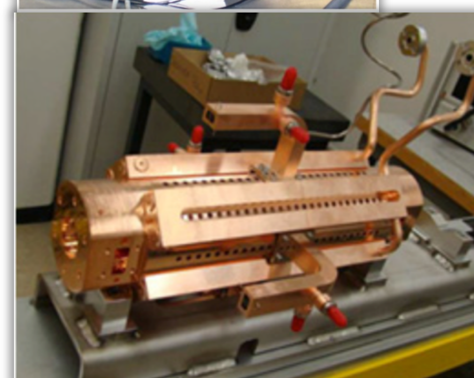
- Align components (10μm over 200m)
- Control/damp vibrations (from ground to accelerator)
- Measure beams well
  – allow to steer beam and optimize positions
- Algorithms for measurements, beam and component optimization, feedbacks
- Tests in small accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)



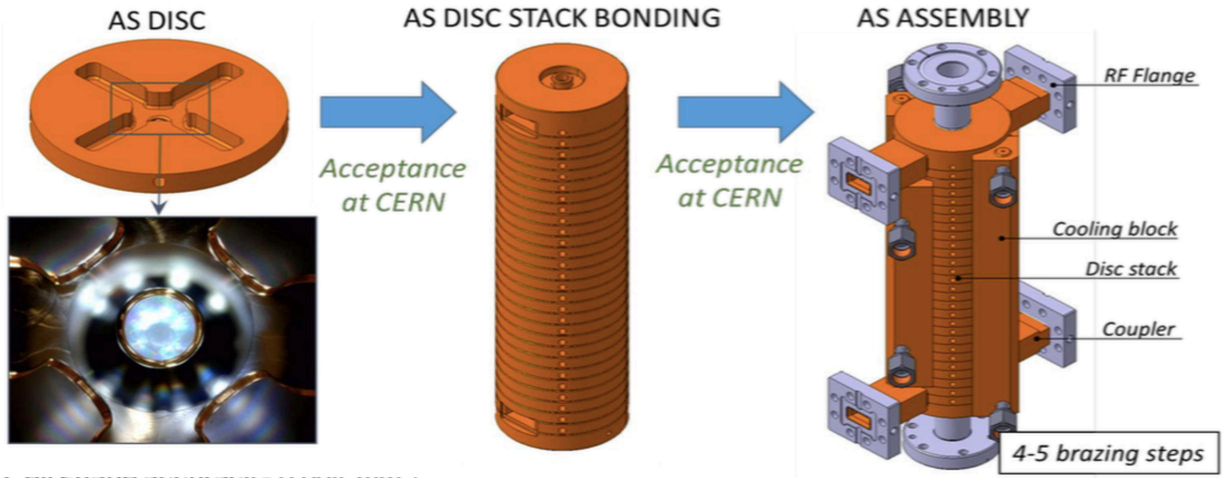
CLIC emittance at damping rings







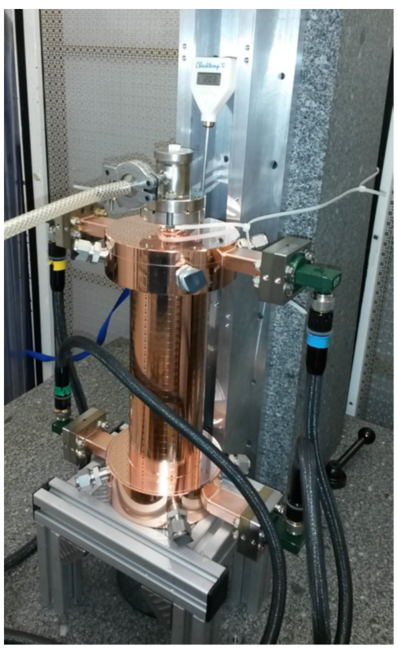
Towards industrialisation

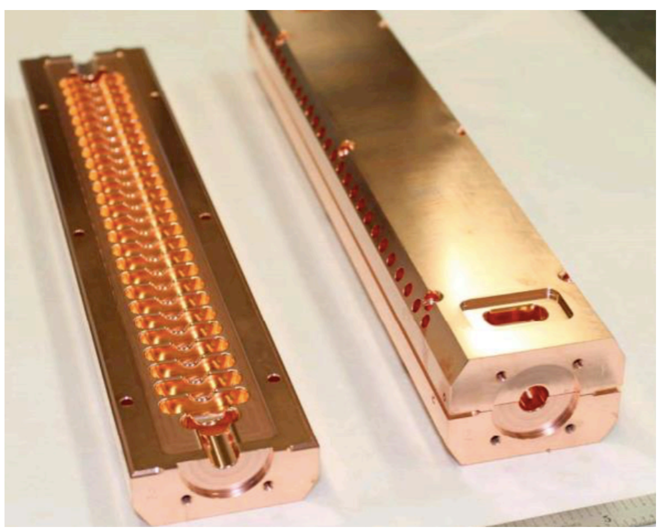


Investigating paths to industrialisation

Baseline manufacturing technique:
bonding and brazing

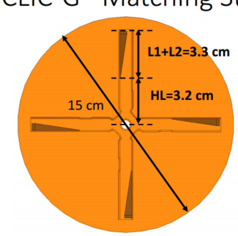
Alternatives:
brazing as for SwissFEL
machining halves





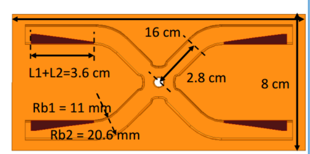
Target is structures that are
low-cost & easy-to-manufacture

CLIC-G* Matching Step



HL	32 mm	D2	5 mm
L1	31 mm	T2	5 mm
L2	2 mm	Mx	0.75 mm
D1	0.8 mm	Mz	1 mm
T1	0.6 mm	Tx	0 mm
		Tz	0.7 mm

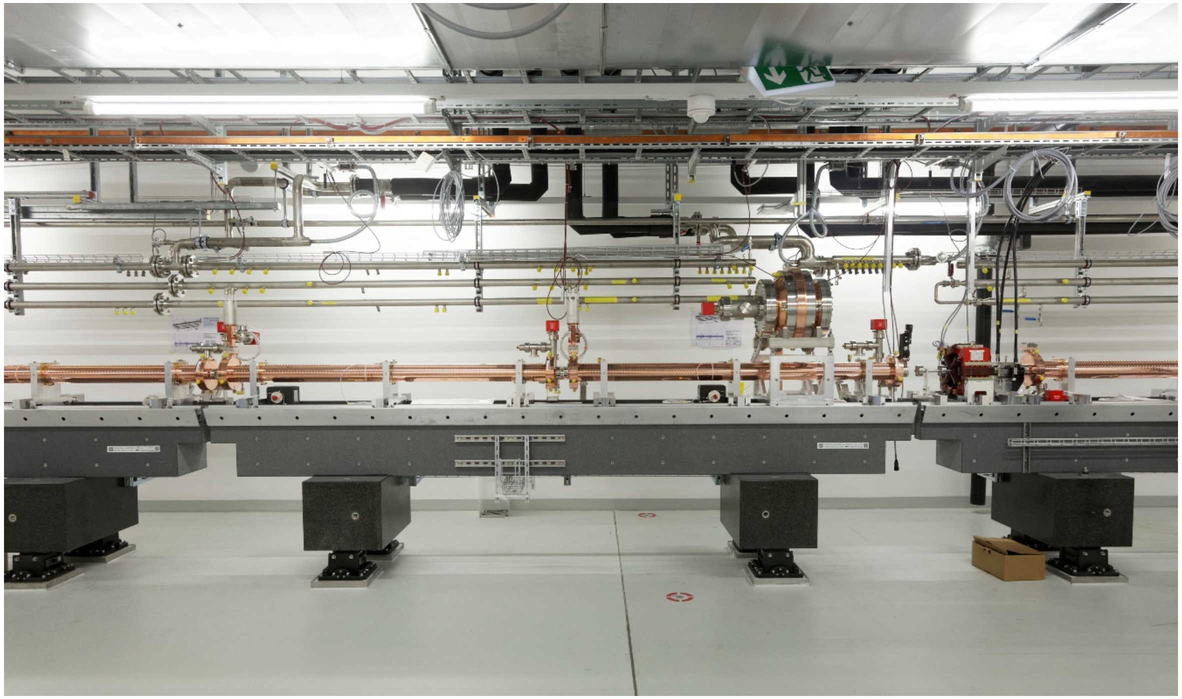
CLIC-G* Bend waveguide



		D2	5.2 mm
L1	34 mm	T2	4.8 mm
L2	2 mm	Mx	0.2 mm
D1	1 mm	Mz	1 mm
T1	1 mm	Tx	0 mm
		Tz	0 mm

SwissFEL – C-band linac

- 104 x 2m-long C-band structures
  (beam → 6 GeV @ 100 Hz)
- Similar μm-level tolerances
- Length ~ 800 CLIC structures
- Being commissioned

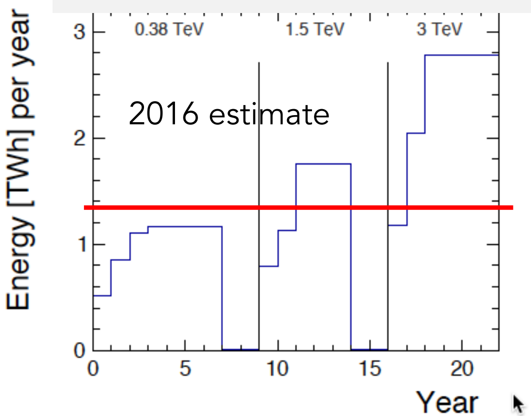


Power

Preliminary power consumption for 380GeV CLIC

Being updated for changes in design parameters, and using operating (not specification) values for RF power sources and magnet power supplies

CERN energy consumption 2012: 1.35 TWh



Total energy use will be updated once power consumption complete

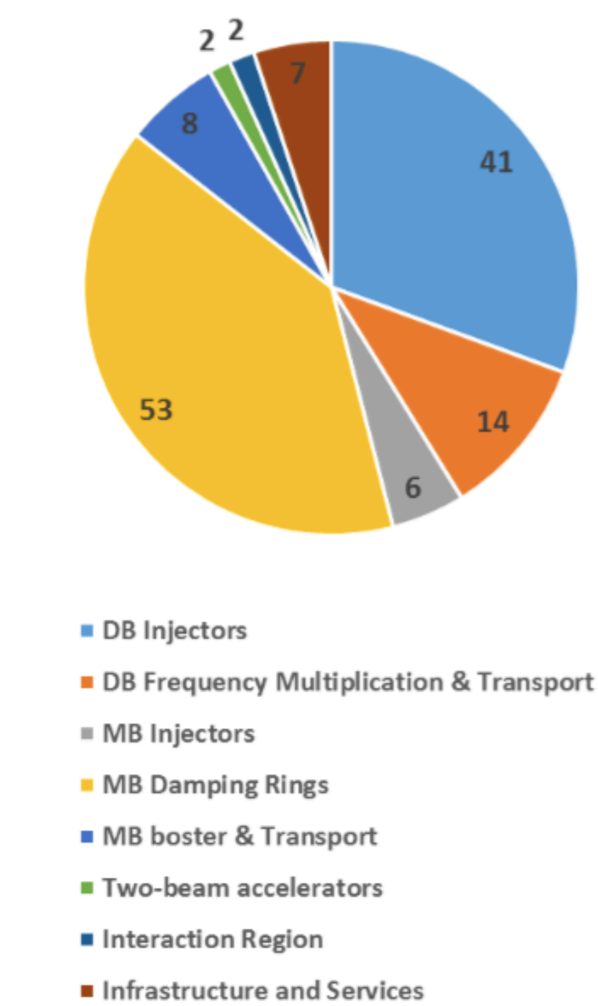
Included so far:

- Vacuum systems
- RF and RF power systems
- Magnet & magnet powering systems
- Beam instrumentation
- Active alignment and stabilization in ML and BDS
- Electricity

To be added:

- Experimental area
- Cooling & ventilation
- Safety systems
- Machine control & operational infrastructure

+~20–30%



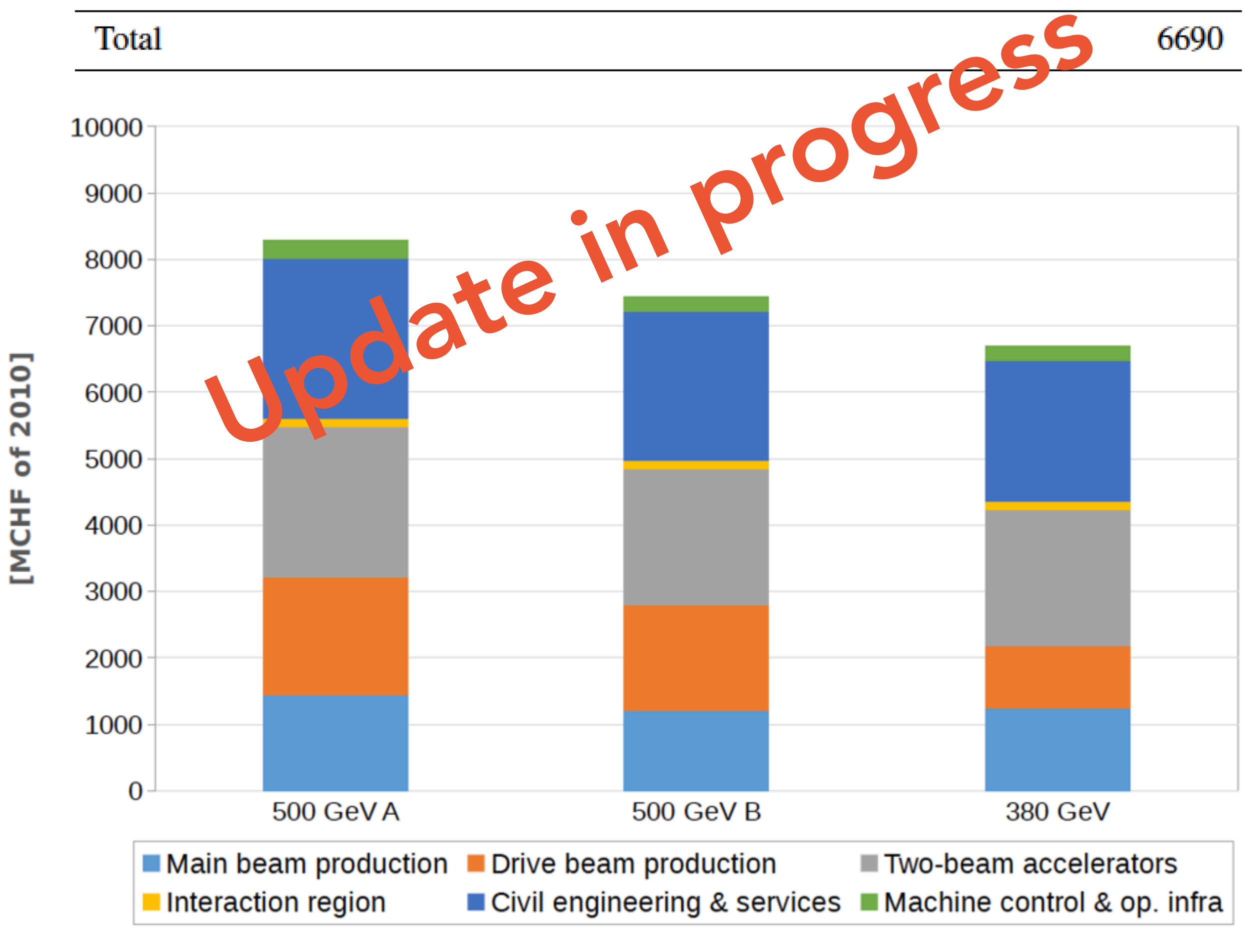
(Klystron-based option: 142 MW + ~20-30%)

Final power estimate will be ≲ 200MW (compared with 252MW in 2016)

Cost

Table 11: Value estimate of CLIC at 380 GeV centre-of-mass energy.

	Value [MCHF of December 2010]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Accelerator control & operational infrastructure	216
Total	6690



Machine has been bottom-up re-costed in 2018

Methods and costings validated at review on 7 November

Cost → ~6BCHF for initial stage
(to be finalised for ESU)

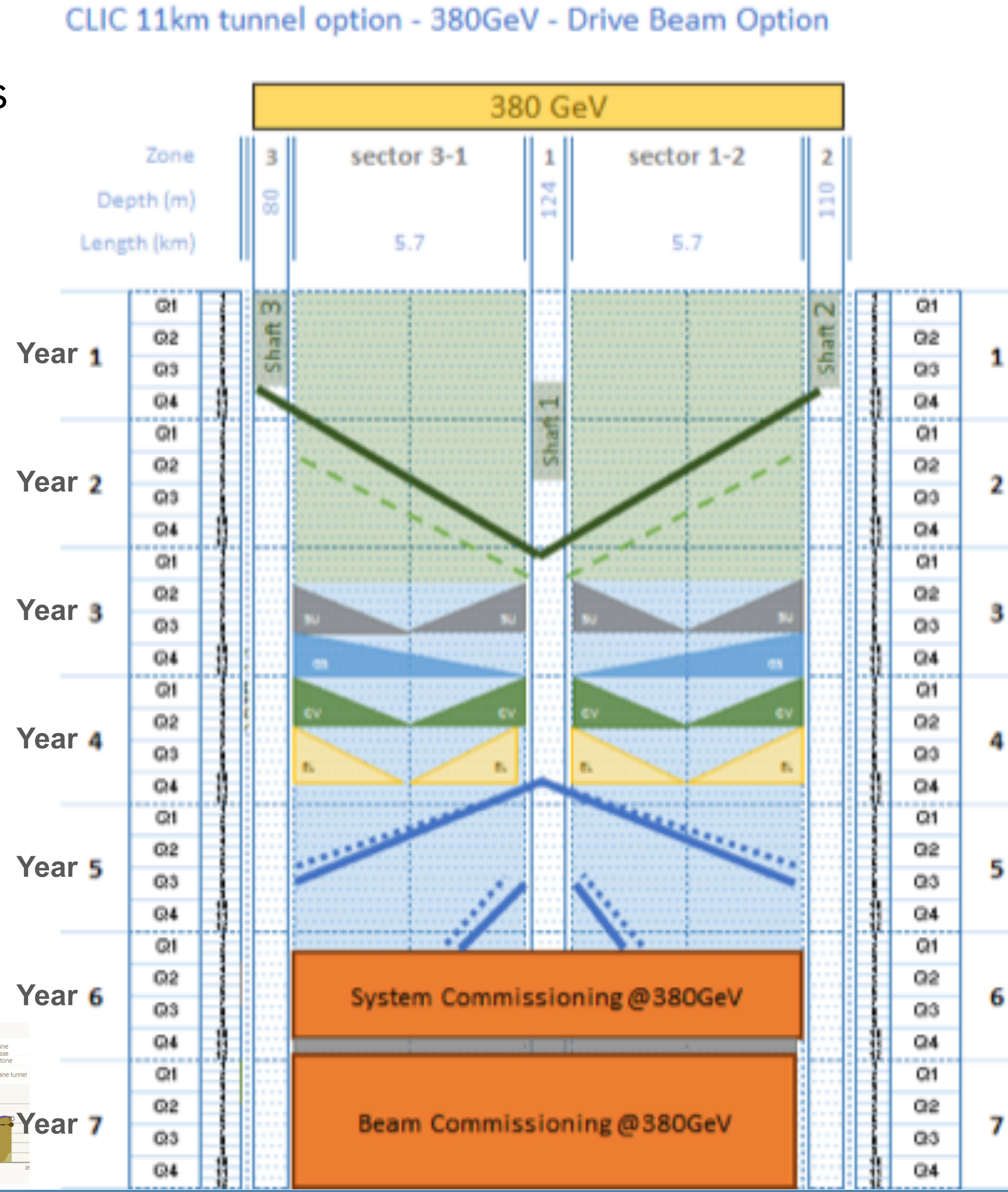
Schedule

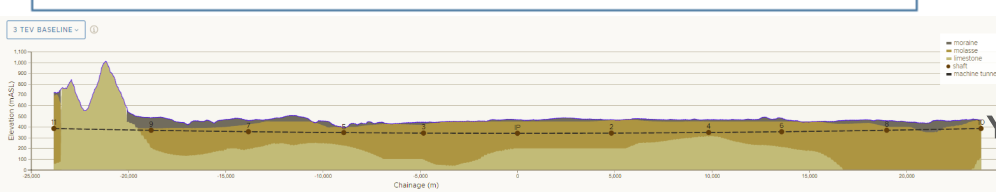
Updated schedule:
Construction + commissioning: 7 years

Civil Eng.
- Tunnel excavation TBM Good rock
- Inner lining

Infrastr. + Machine Inst.
- Survey works
- General services installation
- CV Installation works
- Electrical installation and cabling
- Machine transport
- Machine Installation

- Commissioning period
- Physics

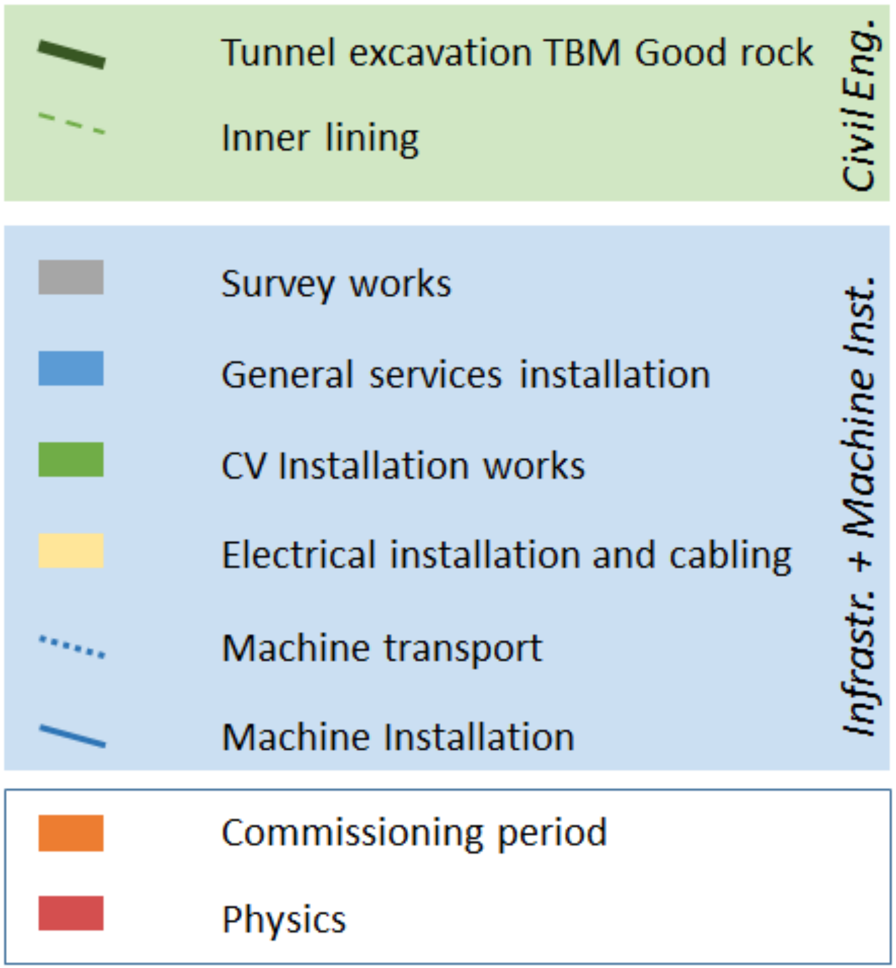


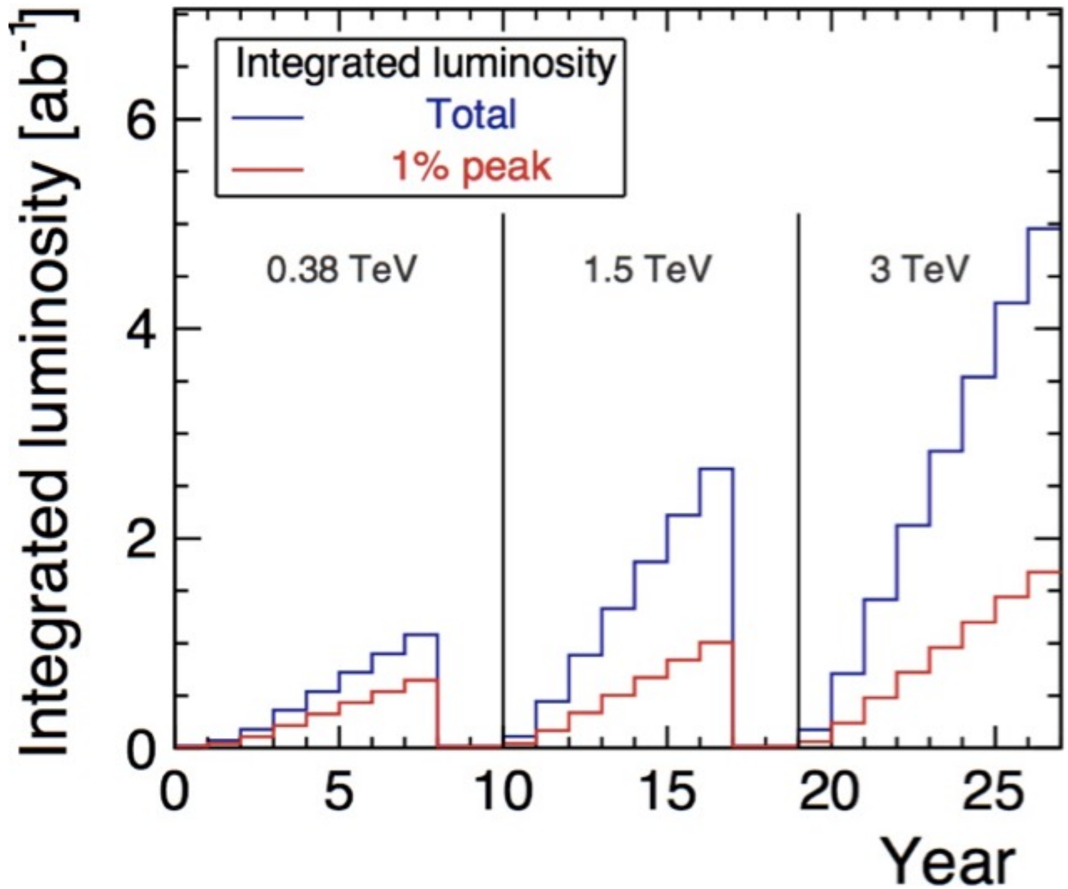


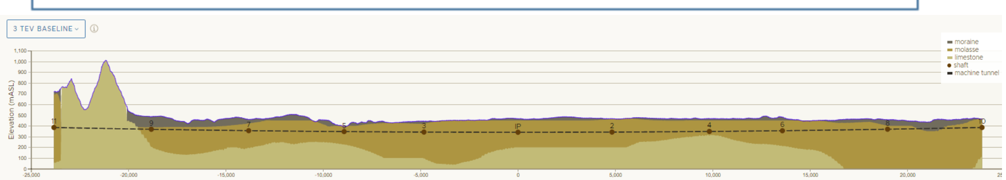
Schedule

Updated schedule:

Construction + commissioning: 7 years, followed by 25–30 year physics programme







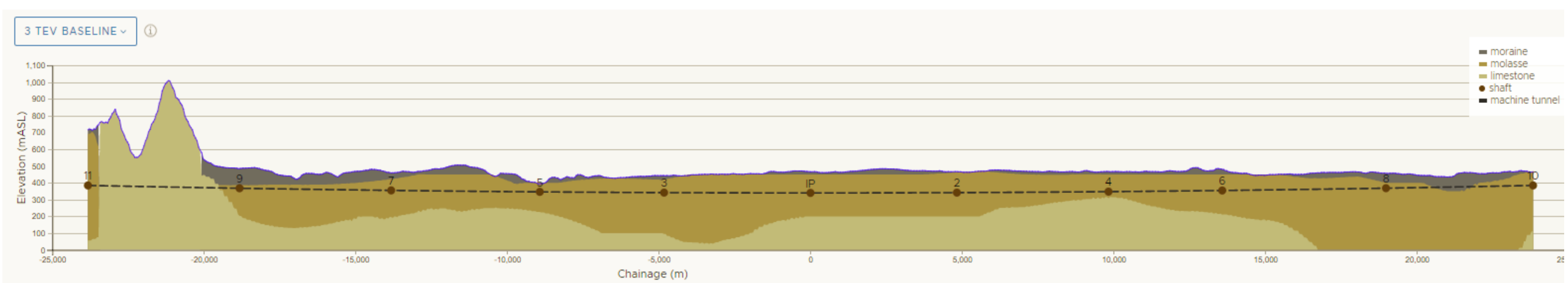
Next phase

2020–2025 Preparation Phase:

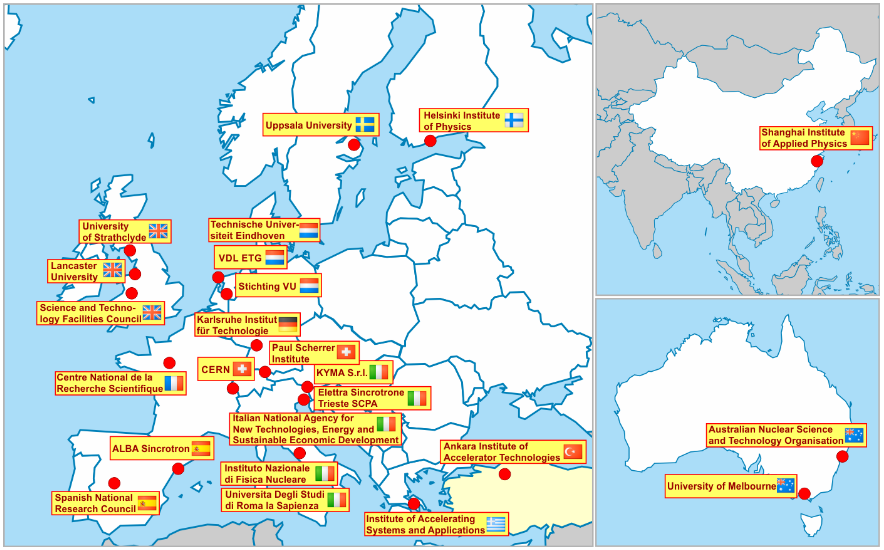
Finalisation of implementation parameters
Preparation for industrial procurement
Drive Beam Facility & other system verifications
Technical Proposal of the experiment
Site authorisation

2026 Construction start

Details	Purpose
Main linac modules	
Build ten prototype modules in qualified industries, two beam and klystron versions	Final technical design, qualify industry partners, verify performance
Accelerating structures	
Around 50 structures incl. for modules above	Industrialization, manufacturing and cost optimisation
Operating X-band test-stands, high efficiency RF	
X-band test-stands at CERN and collaborating institutes, cost optimized X-band RF	X-band component tests, validation and optimization, cost reduction and industrially available RF units
Technical components	
Magnets, instrumentation, alignment, stability, vacuum	Luminosity performance, costs and power, industrialization
Design&Parameters	
Beam dynamics studies, parameter optimization, costs, power	Luminosity performance, risk, costs and power reduction
Drivebeam studies	
Drivebeam front end optimisation and systemtests to around 20 MeV	Verification of the most critical parts of drivebeam concept, develop further the industrial capabilities for L-band RF systems



CLIC technology applications

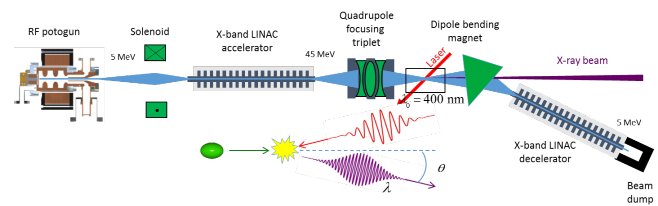


CompactLight

CLIC technology for different applications

- EU co-funded FEL design study
- SPARC at INFN-LNF
- …many other small systems…

INFN Frascati advanced acceleration facility EuPRAXIA@SPARC_LAB

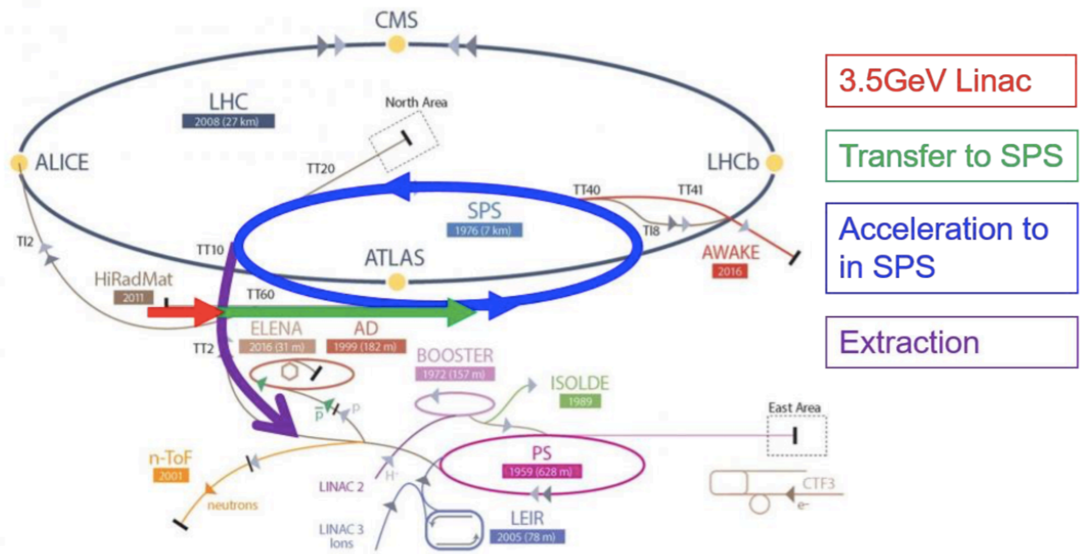


Eindhoven University led SMART*LIGHT Compton Source

Electron accelerator implementation at CERN

- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10

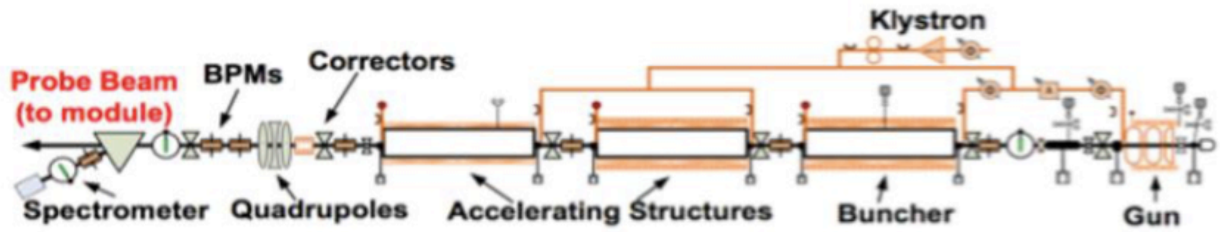
–> Potential experiment e.g. LDMX
Would fulfil many of CLIC accelerator next steps



EoI to SPSC, autumn 2018: https://cds.cern.ch/record/2640784

CLEAR

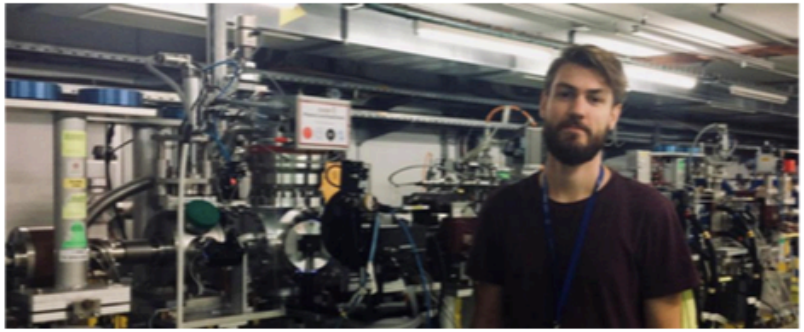
CERN Linear Electron Accelerator for Research



CALIFES beamline

80–220 MeV electrons
Bunch charge 0.01–1.5 nC

CLEAR started with beam in August 2017



Main activities:

CLIC & high-gradient X-band

Instrumentation R&D

VESPER irradiation test station
- Electronic components for space applications (with ESA)
- Medical applications (VHEE)
- Electronic components for accelerators and detectors

Novel techniques: plasma focusing and acceleration, THz radiation, dielectric structures

Open to proposals for user experiments

European Strategy Input

Updated Baseline for a Staged Compact Linear Collider ✓
arXiv: 1608.07537, CERN-2016-004

Higgs Physics at the CLIC Electron-Positron Linear Collider ✓
arXiv: 1608.07538, Eur. Phys. J. C77 (2017) 475

The optimised CLIC detector model CLICdet
CLICdp-Note-2017-001 ✓ and CLICdet detector validation note ✓

Top-quark physics at the CLIC electron-positron linear collider ✓
arXiv: 1807.02441, in journal review

CLIC Project Implementation Plan
2018

The CLIC Potential for New Physics
2018

Detector Technologies for CLIC
early 2019

Four new CERN Yellow Reports

CLIC 2018 Summary Report
2018

Official short ESU submissions (~10 pages):
1) CLIC project (accelerator + detector)
2) CLIC physics

Summary

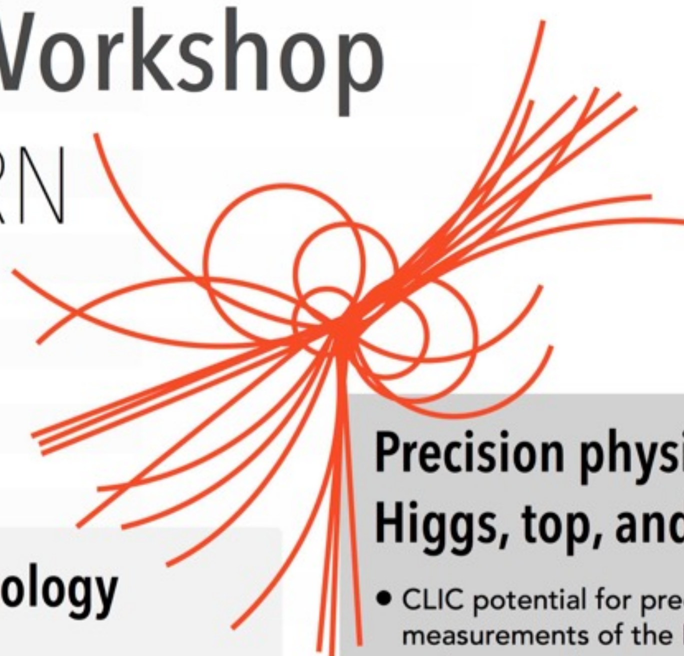
- CLIC is now a mature project, ready to be built
- The main accelerator technologies have been demonstrated
- The physics case is broad and profound
- The detector concept and detector technologies R&D are advanced
- The full project status will be presented imminently in a series of Yellow Reports

Thanks to all who provided material, including: Steinar Stapnes, Phil Burrows, Daniel Schulte, Walter Wuensch, Lucie Linssen, Andrea Wulzer, Roberto Franceschini, Jorge de Blas, Philipp Roloff

CLICWEEK2019

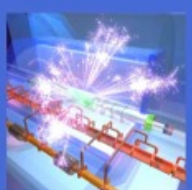
Compact Linear Collider Workshop

January 21 - 25, 2019 @ CERN



Accelerator technology, high-gradient structures, and low-emittance beams

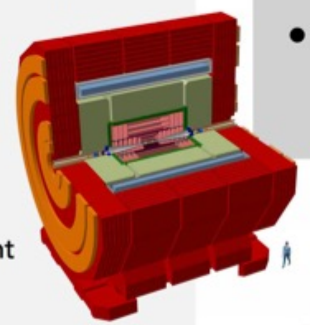
- Advanced radio frequency technologies: high-efficiency klystrons, pulse compressors, components, and accelerating structures



- Low emittance beams: beam dynamics, damping rings, beam delivery, instrumentation, alignment, stabilization
- Staged approach: from a 380 GeV Higgs/top factory to TeV energies

Detector technology and software

- Detector R&D: new prototype designs, simulation studies, and test-beam results for tracking detectors and calorimeters
- Software for detector geometry, simulation and reconstruction (DD4hep)
- Tracking and particle flow reconstruction
- Distributed data management and computing (iLCDirac)



Precision physics: Higgs, top, and BSM

- CLIC potential for precision measurements of the Higgs boson and top-quark properties, and the flavour sector
- Global interpretation using Standard Model effective field theory
- Signatures for direct discovery at CLIC, complementarity with indirect probes and hadron colliders

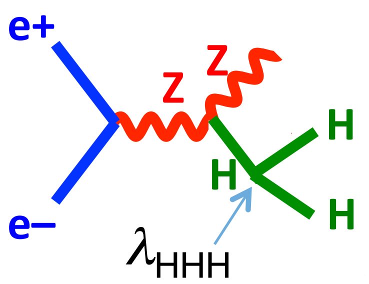
e^+e^- collisions at the energy frontier!

Learn more about CLIC here

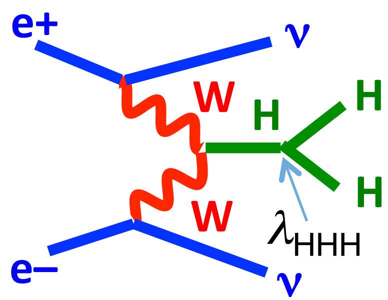
clicw2019.web.cern.ch

Backup

Higgs self-coupling



dominates around $\sqrt{s}$=500GeV



dominates at higher $\sqrt{s}$

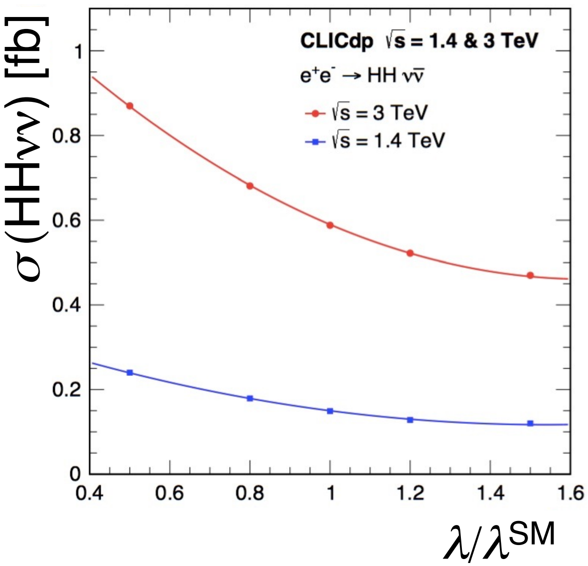
CLIC high-energy running required

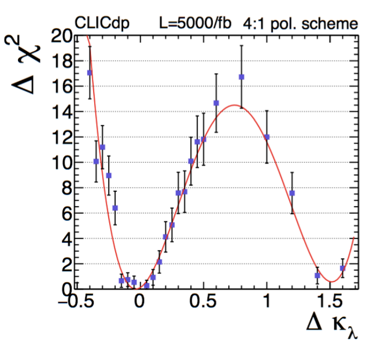
$\sqrt{s}$=1.4TeV, L=2.5ab^{-1} + $\sqrt{s}$=3TeV, L=5ab^{-1}

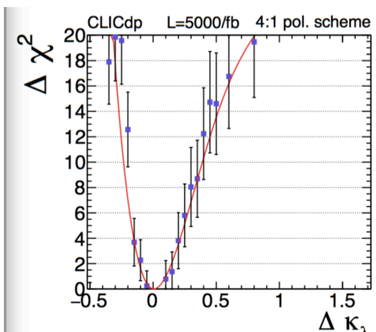
with (-80%,+80%) electron beam polarisation in ratio (80:20):

$\Delta\lambda/\lambda$ = 14% from cross-section measurements

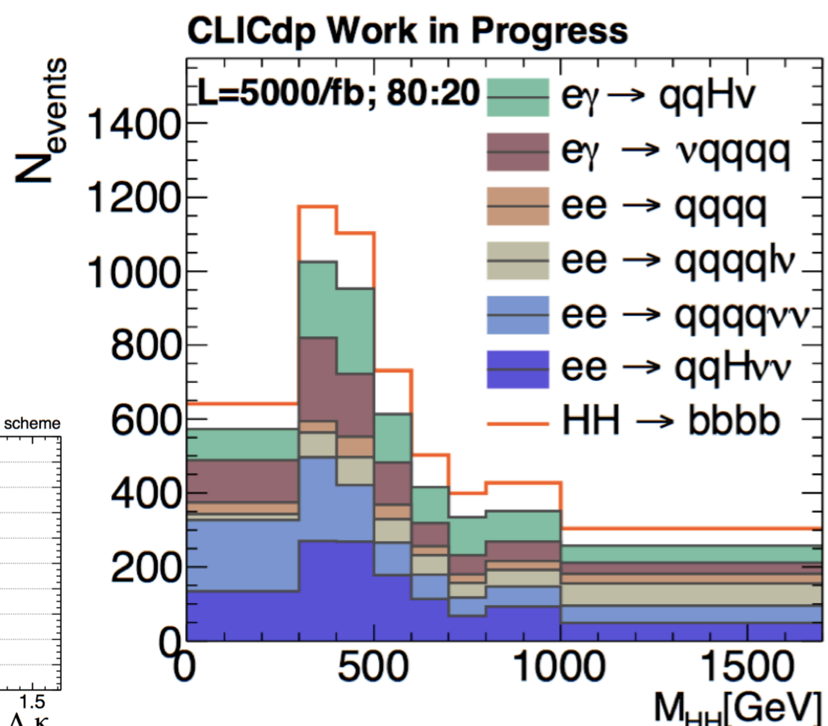
Based on Eur. Phys. J. C 77 475 (2017)







Additional information can be extracted from differential distributions e.g. *M*(HH) :



Expected CLIC 3TeV sensitivities:

without ZHH at 1.4TeV:

$\Delta\lambda/\lambda = {}^{+12\%}_{-7\%}$

including ZHH at 1.4TeV:

$\Delta\lambda/\lambda = {}^{+11\%}_{-7\%}$

New!

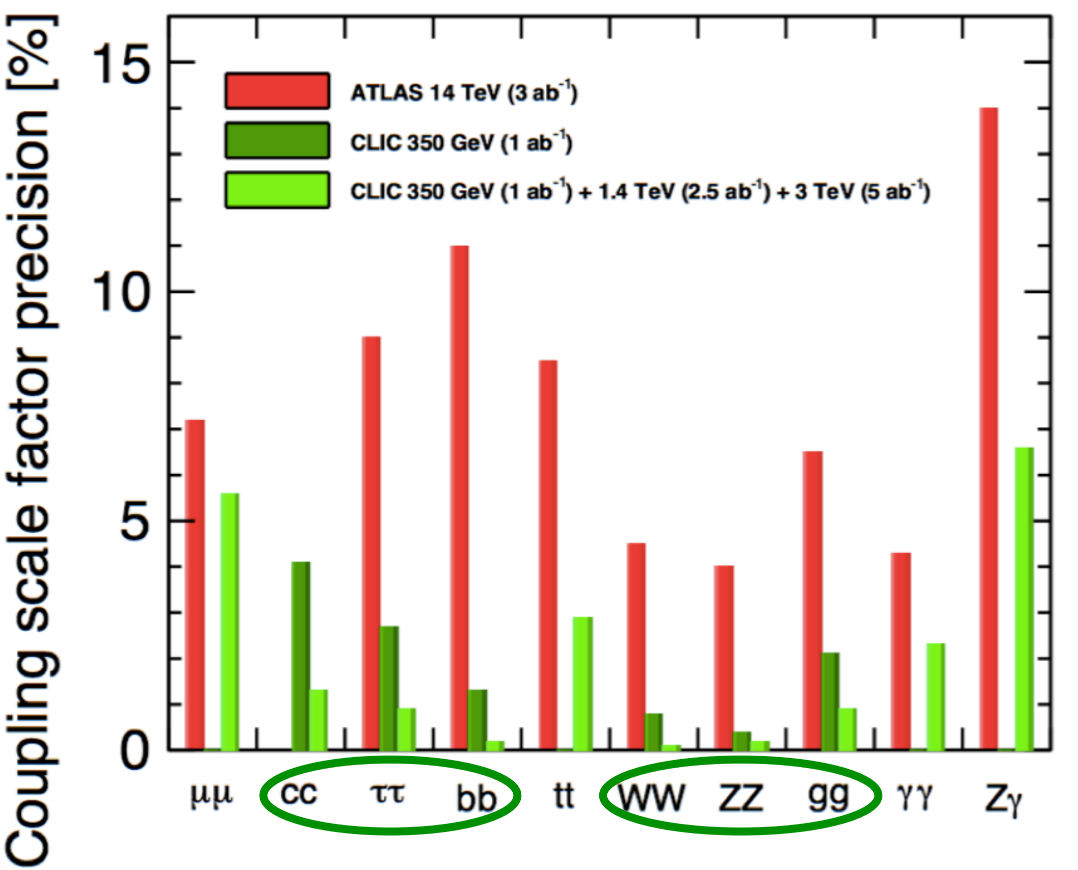
Higgs couplings

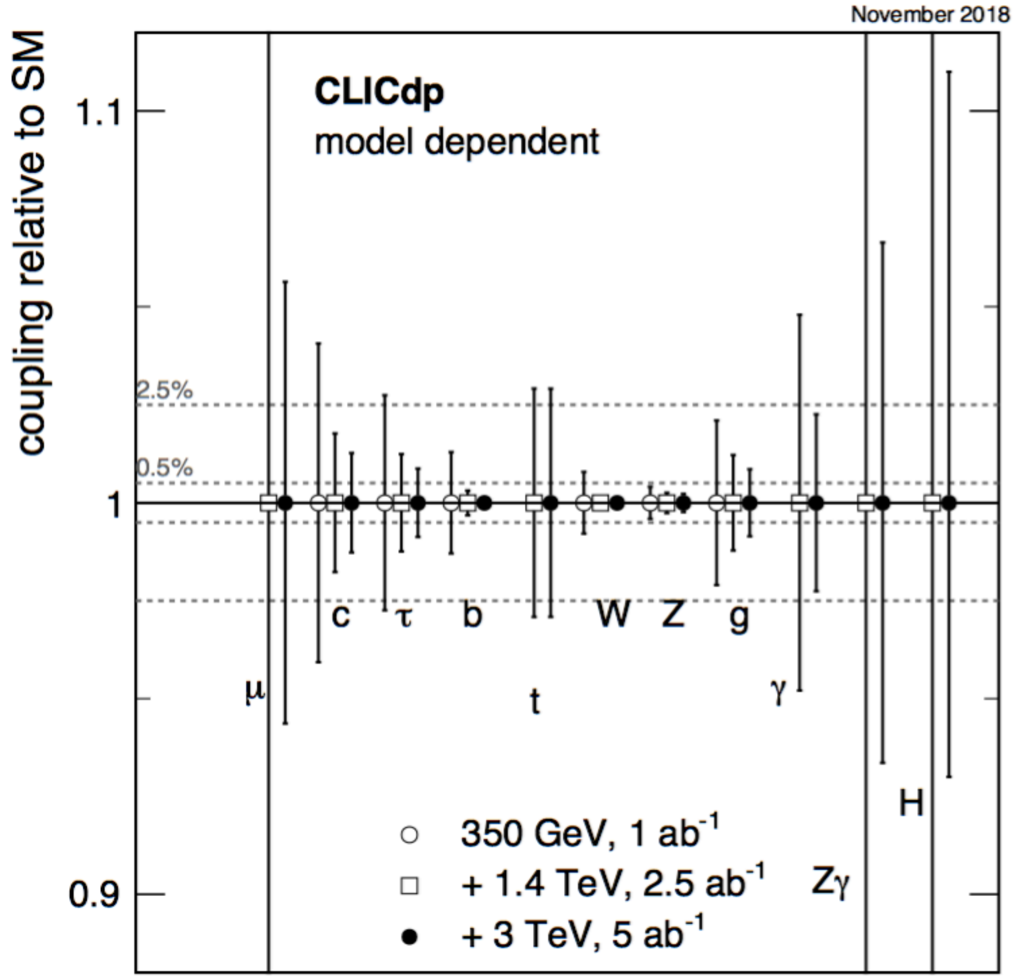
Model dependent fit:

$$\kappa_i^2 = \Gamma_i / \Gamma_i^{SM}$$

Only SM Higgs decays:

$$\frac{\Gamma_{H,md}}{\Gamma_H^{SM}} = \sum_i \kappa_i^2 \, BR_i$$





First CLIC stage is already significantly more sensitive than HL-LHC for several couplings
The full programme further enhances the precision

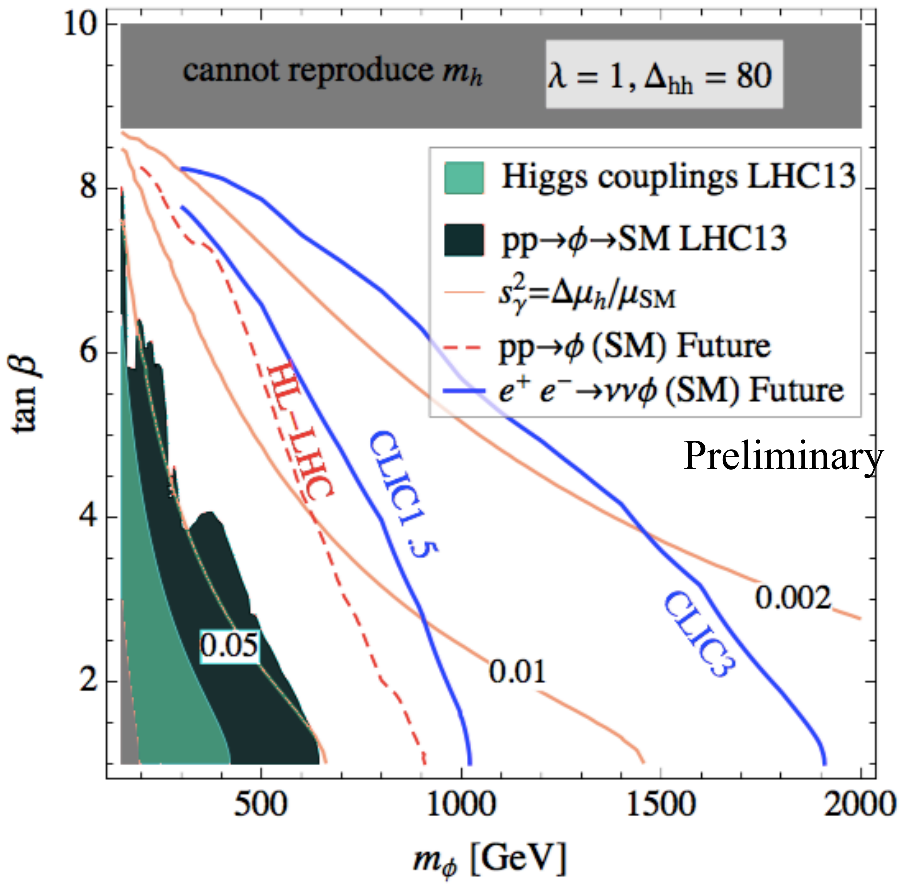
Based on Eur. Phys. J. C 77 475 (2017)
ATLAS-PHYS-PUB-2014-016

Model interpretations

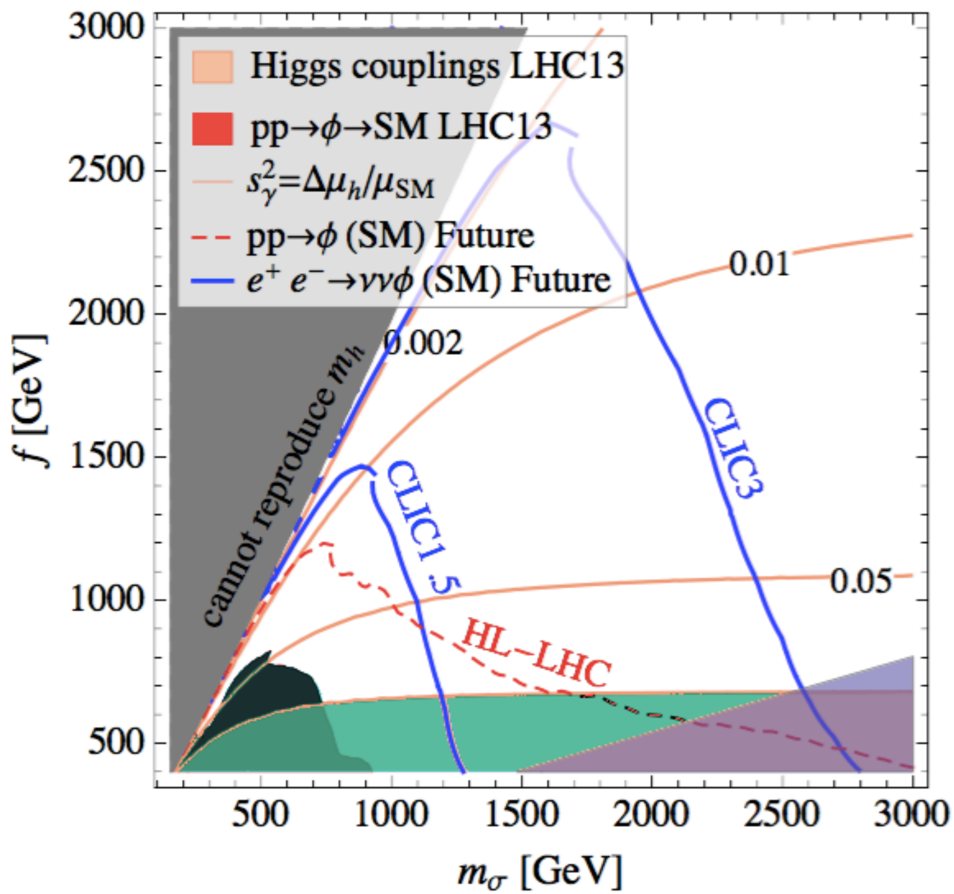
arXiv: 1807.04743 – Buttazzo, Redigolo, Sala, Tesi

Interpret in specific models:

NMSSM: assume h(125) and S are lightest NMSSM Higgses, then h–s mixing determined from masses and tanβ



Twin Higgs model:
S is SM singlet state from the twin sector; h–S mixing is of order *v*/*f*

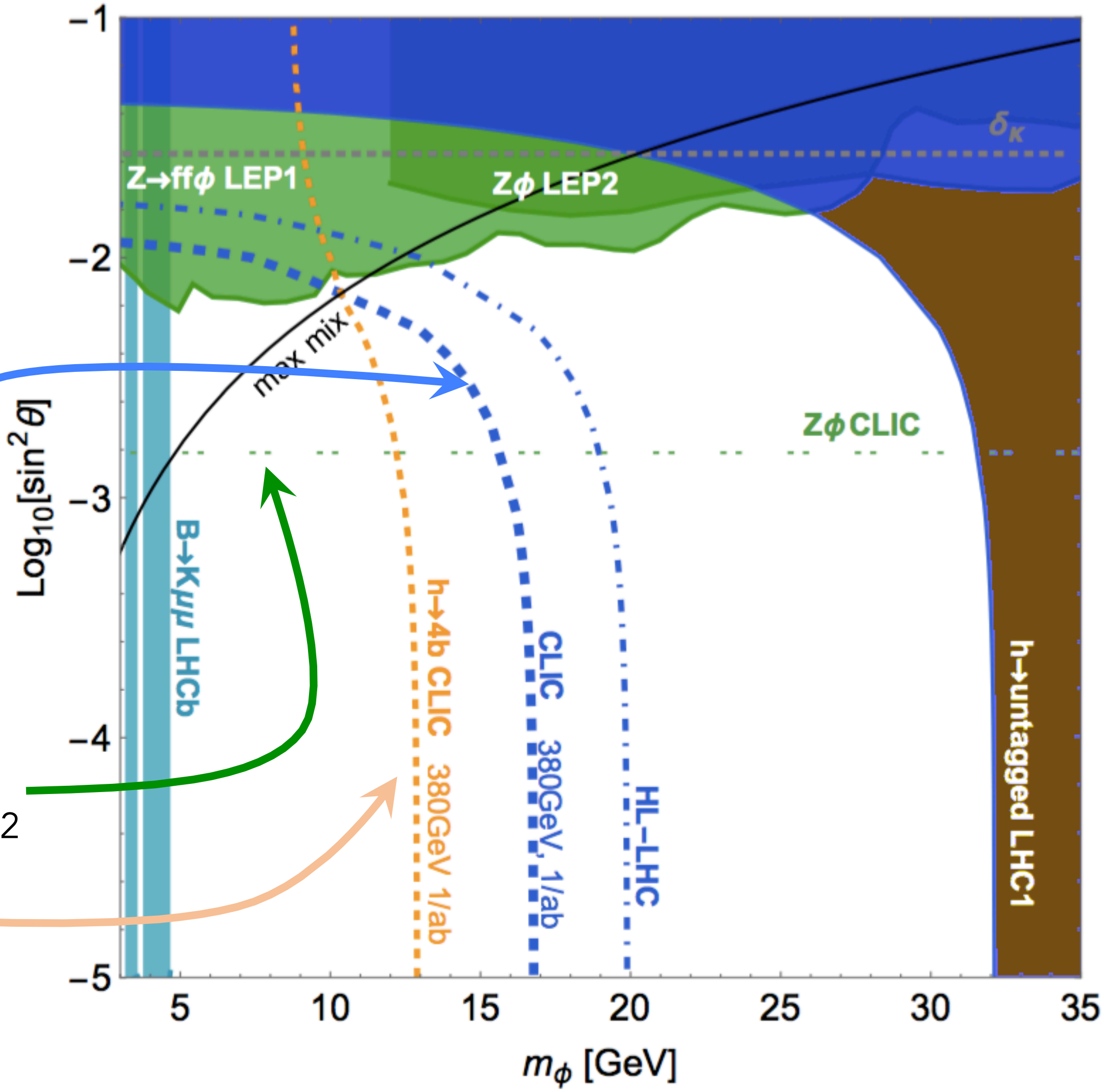


Light singlets and relaxions

arXiv: 1807.10842 – Frugiuele, Fuchs, Perez, Schlaffer

Relaxion ϕ stabilizes Higgs mass dynamically and addresses hierarchy problem / fine-tuning.

m_ϕ: sub-eV to tens of GeV
For masses in GeV range ϕ is short-lived
Dominant decay ϕ–>bb for m_ϕ>9GeV
Mixing angle θ



Higgs couplings global fit
BR(h–>untagged)

Z recoil: e^+e^- –> Zϕ –> Z+untagged
rescaling 1801.09662

e^+e^- –> Zh –> Z$\phi\phi$ –> Z+4f
rescaling 1612.09284

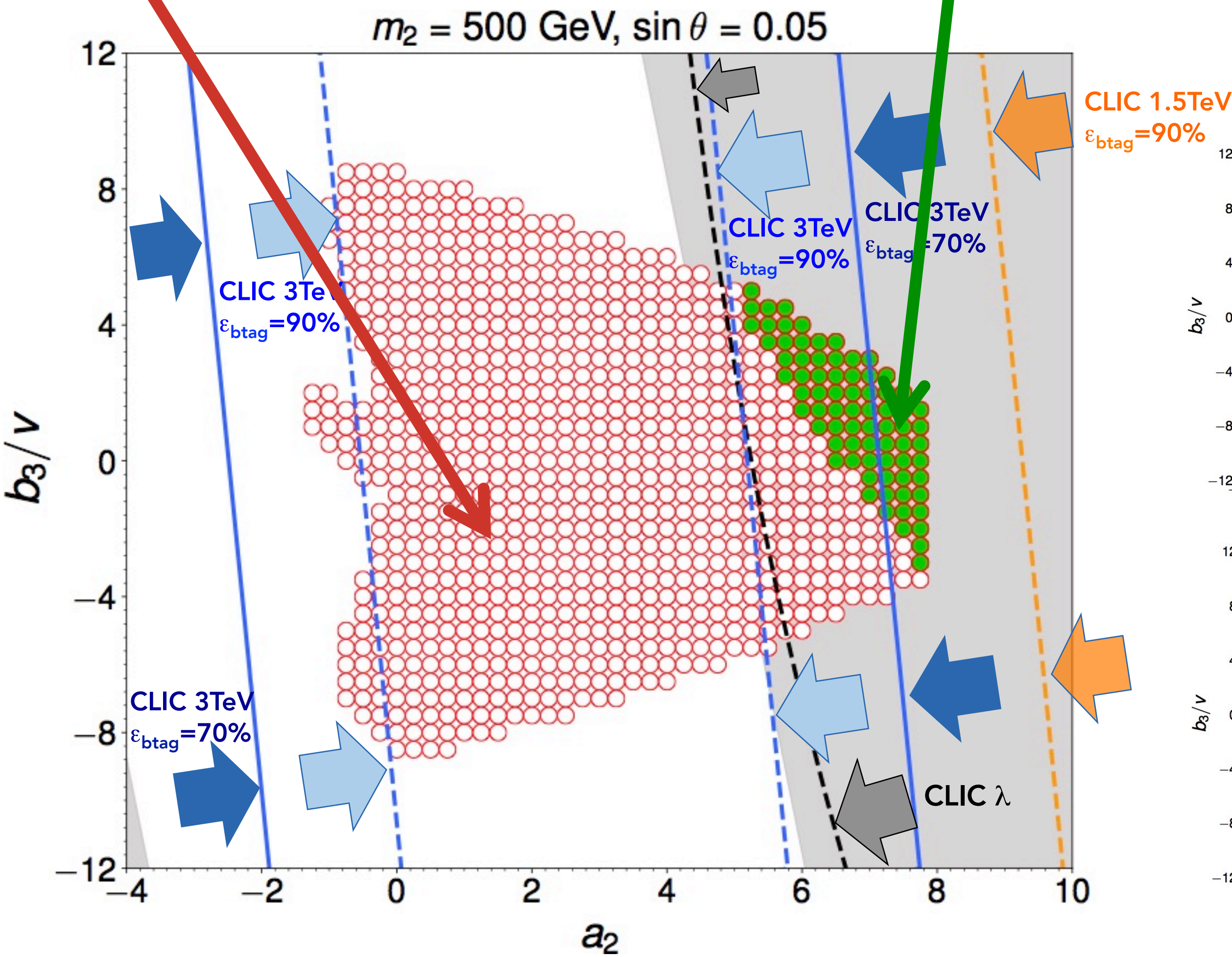
potential further gain from 3TeV

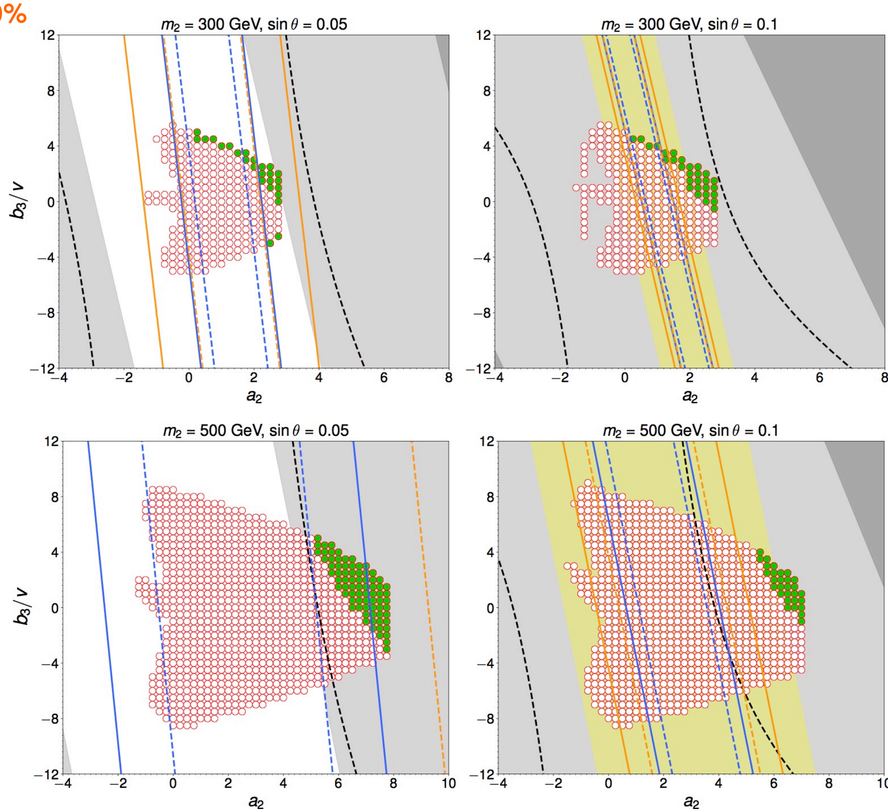
Baryogenesis

regions compatible w/ unitarity, perturbativity, and absolute stability of the EW vacuum

regions <u>also</u> compatible with baryogenesis

arXiv:1807.04284 No, Spannowsky

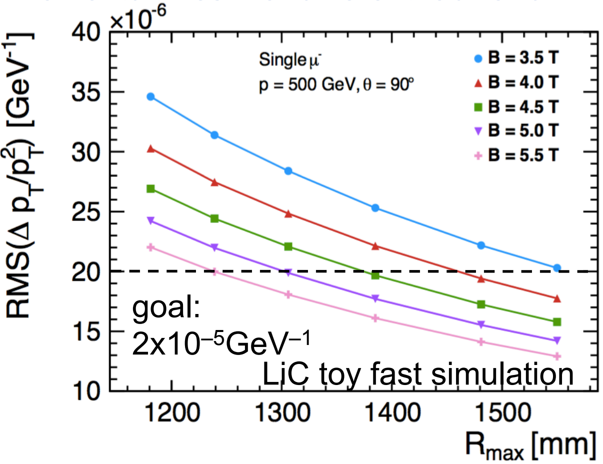




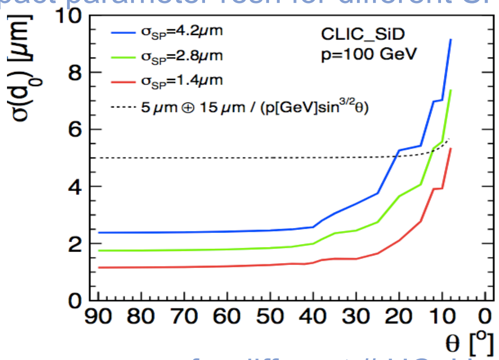
a_2 and b_3/v are parameters of the temperature-dependent effective potential; m_2 and θ are the singlet mass and mixing

Detector Optimization

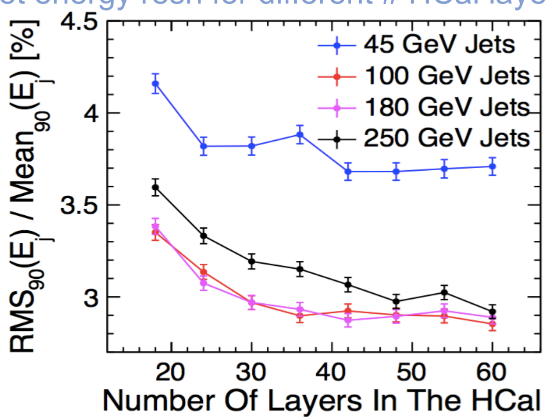
Momentum resn for different radii and B-fields



Impact parameter resn for different SP resns



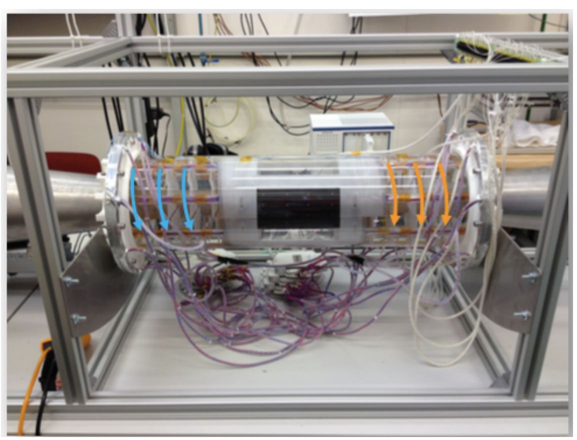
Jet energy resn for different # HCal layers

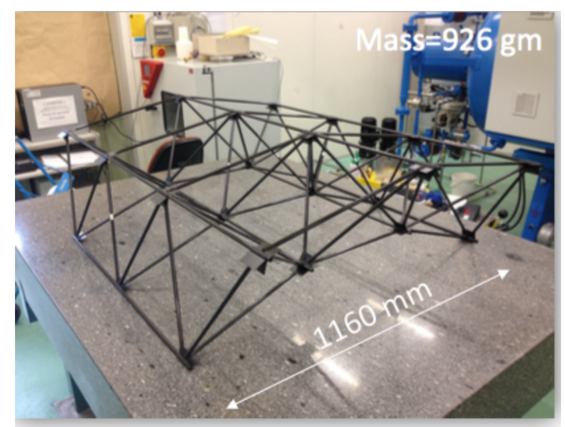


Many studies optimizing detector dimensions, spacings, granularities

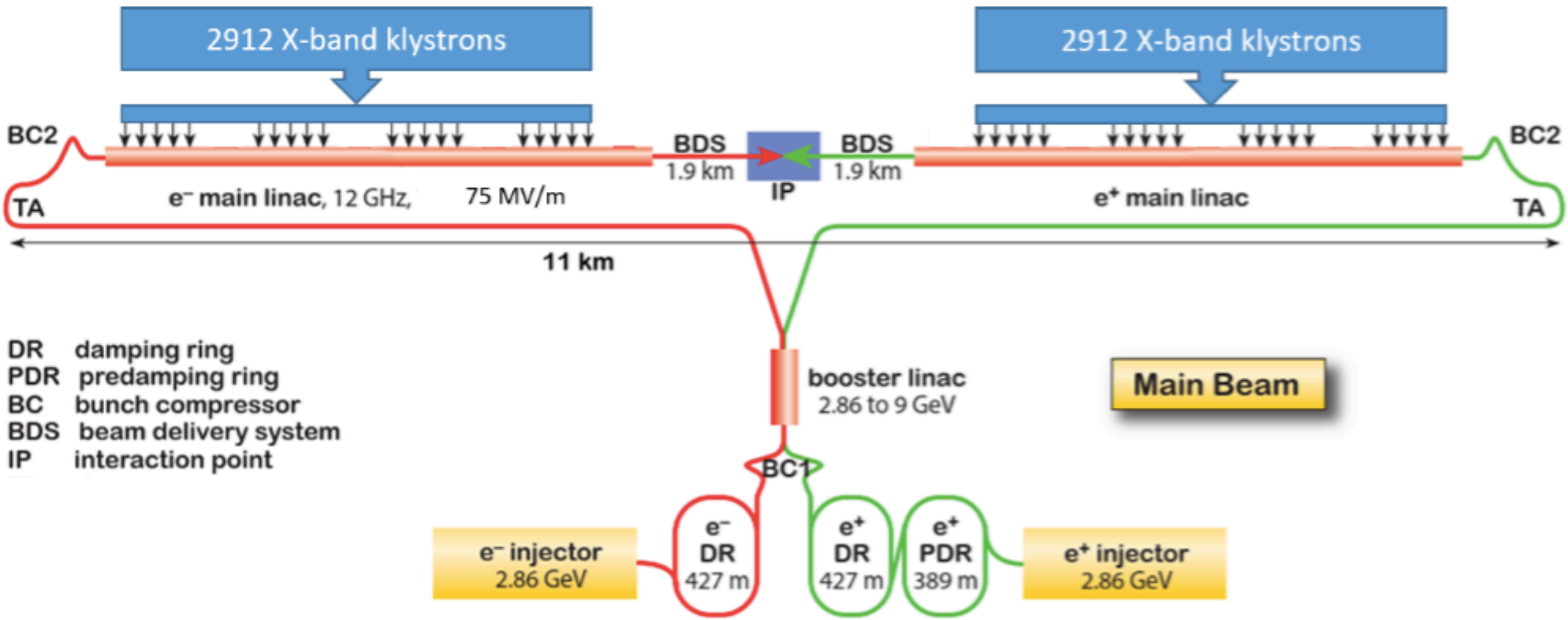
- Tracker spatial resolution: 7μm
  Material: 1–2% X_0 / layer
- Vertex detector spatial resolution: 3μm
  Material: 0.2% X_0 / layer
  –> forced air cooling

–> also informed by detector development, and full-scale cooling mockup and support structure development





380 GeV Klystron option



Next phase

Details	Purpose
Main linac modules	
Build ten prototype modules in qualified industries, two beam and klystron versions	Final technical design, qualify industry partners, verify performance
Accelerating structures	
Around 50 structures incl. for modules above	Industrialization, manufacturing and cost optimisation
Operating X-band test-stands, high efficiency RF	
X-band test-stands at CERN and collaborating institutes, cost optimized X-band RF	X-band component tests, validation and optimization, cost reduction and industrially available RF units
Technical components	
Magnets, instrumentation, alignment, stability, vacuum	Luminosity performance, costs and power, industrialization
Design&Parameters	
Beam dynamics studies, parameter optimization, costs, power	Luminosity performance, risk, costs and power reduction
Drivebeam studies	
Drivebeam front end optimisation and systemtests to around 20 MeV	Verification of the most critical parts of drivebeam concept, develop further the industrial capabilities for L-band RF systems