Detector and Physics Status

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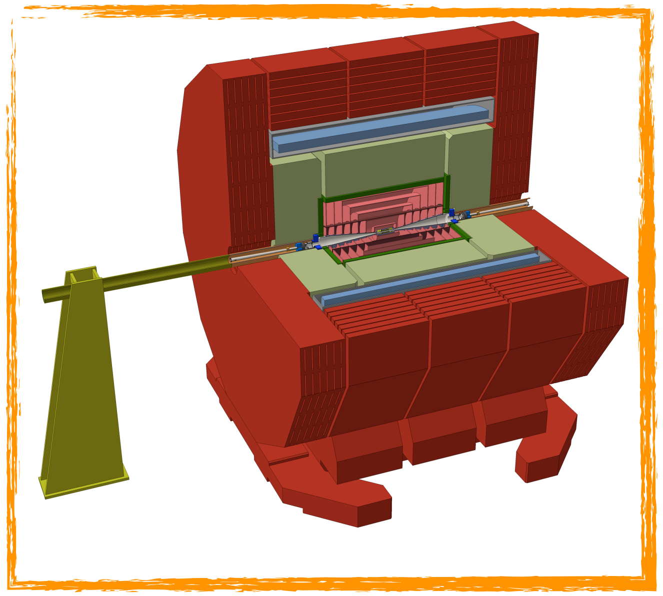
on behalf of the CLICdp Collaboration

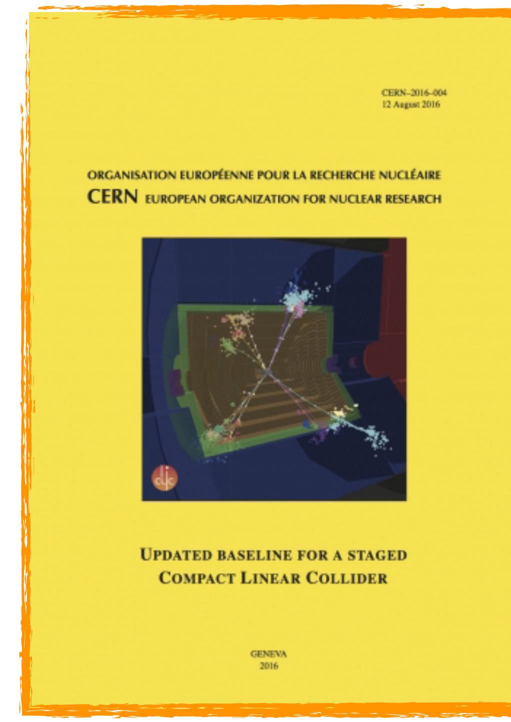
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

International Workshop on Future Linear Colliders
LCWS2016
5-9 DECEMBER, 2016
Aiina Center & MALIOS,
MORIOKA CITY, IWATE, JAPAN

Outline



- CLICdp introduction
- Updated baseline staging scenario
  arXiv:1608.07537

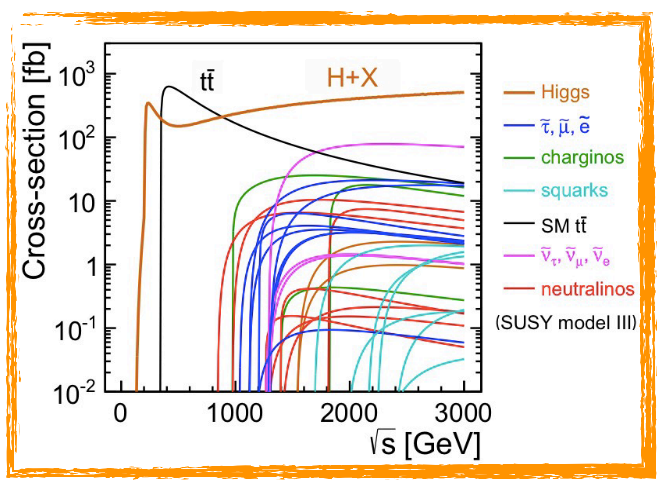


CERN-2016-004
12 August 2016

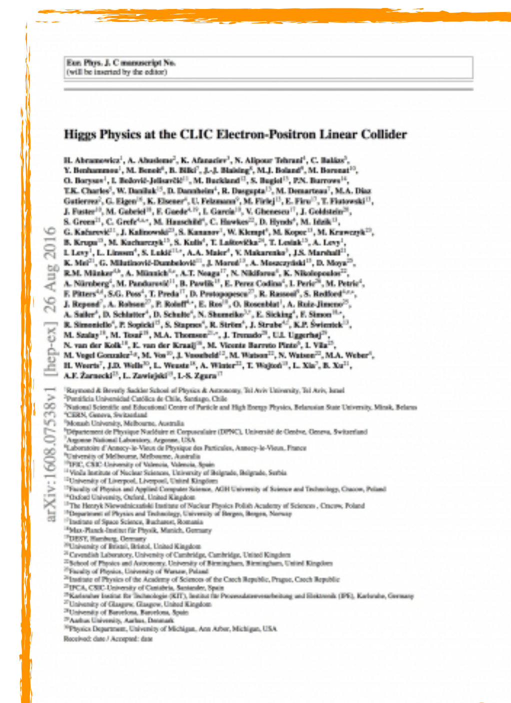
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

UPDATED BASELINE FOR A STAGED COMPACT LINEAR COLLIDER

GENEVA
2016



- New CLIC detector CLICdet
- Higgs physics overview
  arXiv:1608.07538



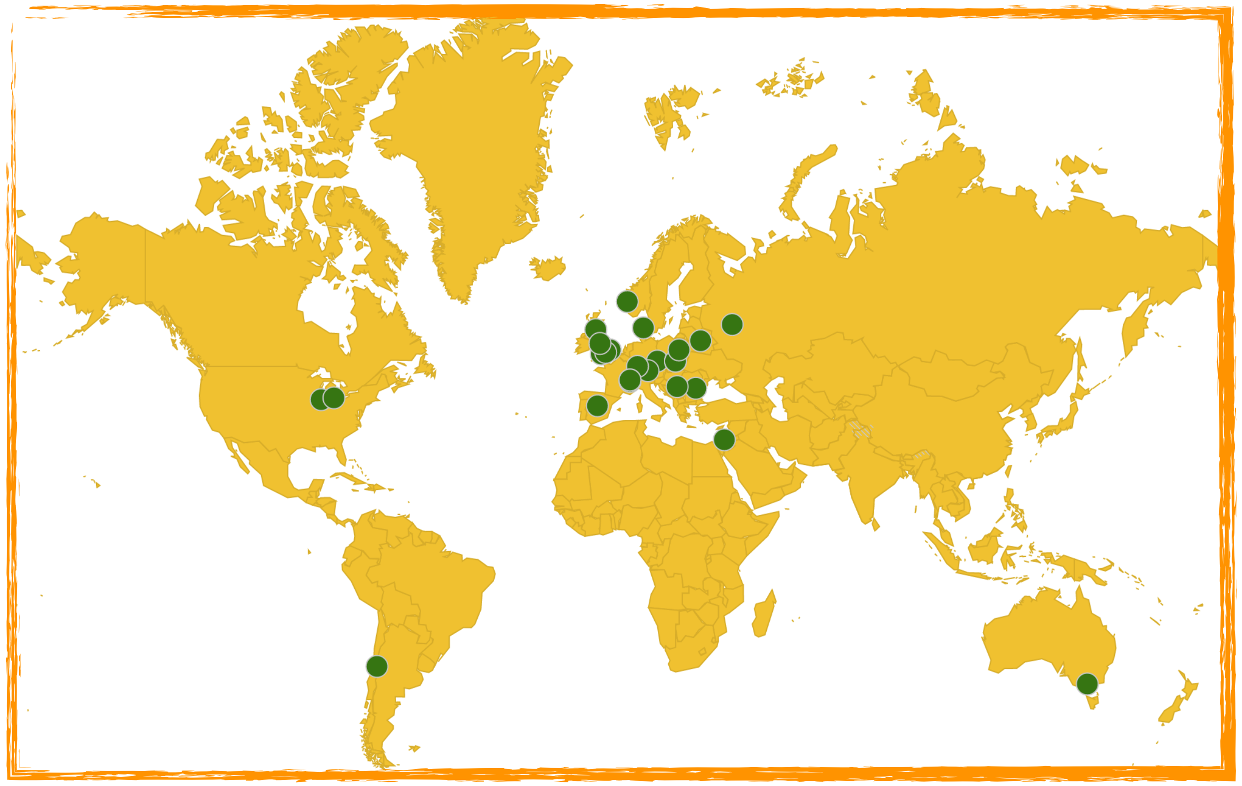
Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Higgs Physics at the CLIC Electron-Positron Linear Collider

arXiv:1608.07538v1 [hep-ex] 26 Aug 2016

CLICdp Collaboration

- CLICdp: CLIC Physics and Detector Study
  - 28 institutes from 17 countries
  - Physics prospects and simulation studies
  - Detector optimisation and R&D for CLIC detector



http://clicdp.web.cern.ch

CLIC Accelerator

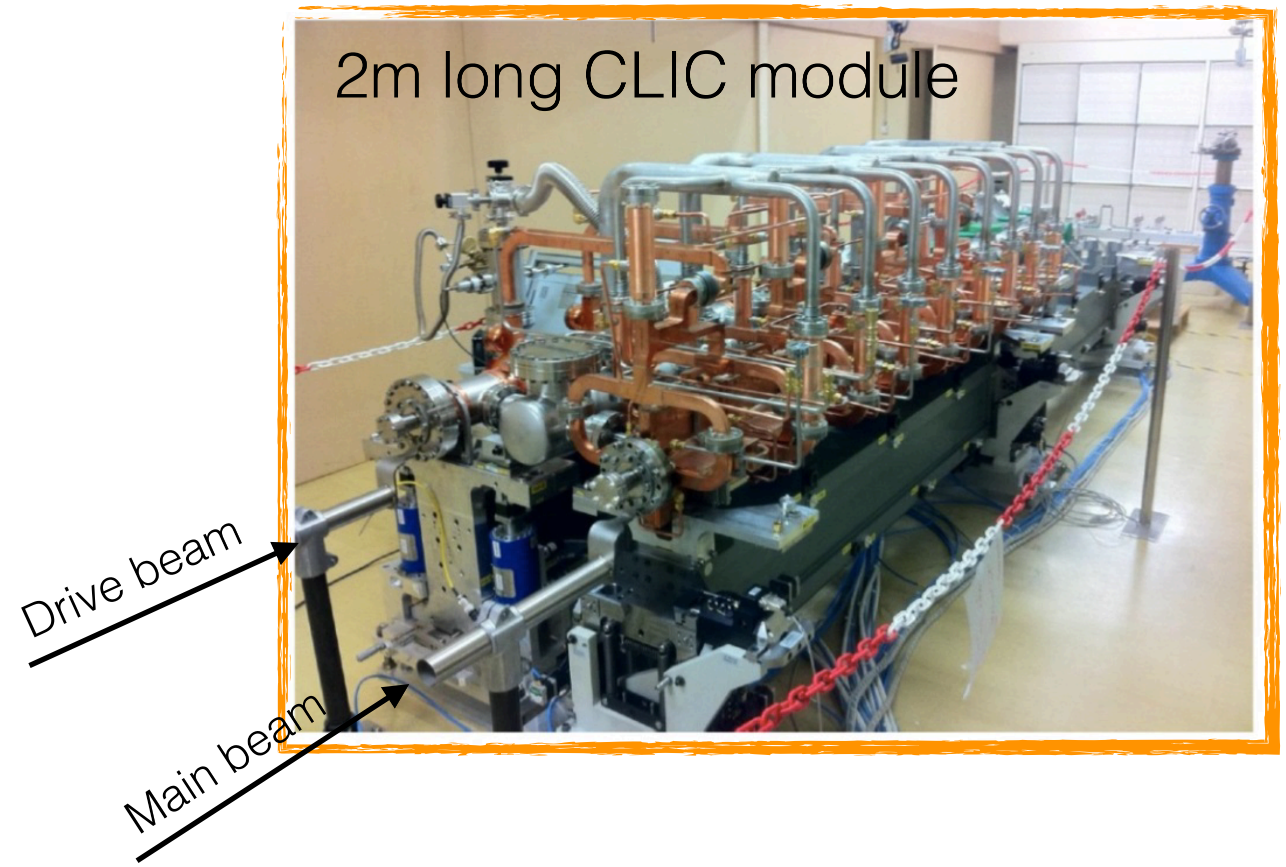
- High acceleration gradient at
  high frequency
  100 MV/m at 12 GHz
  Room temperature

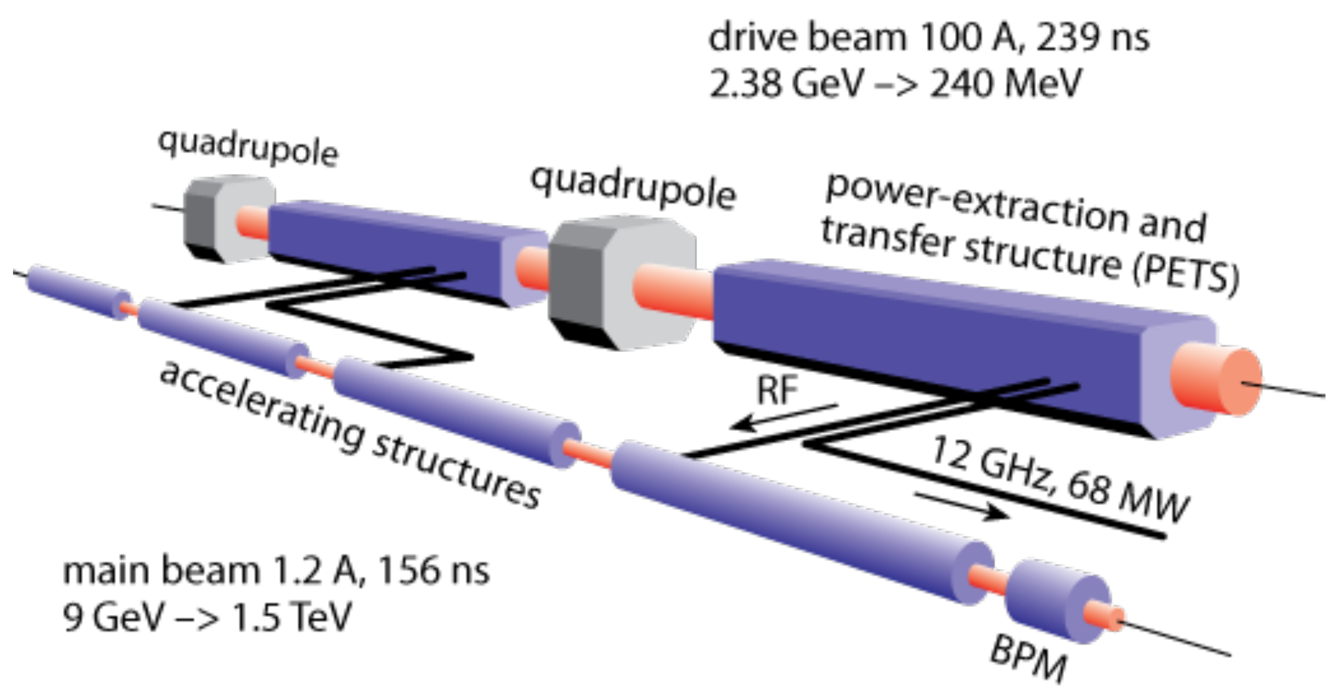
- Two-beam acceleration scheme:

  - Drive beam supplies RF power
    Low energy (2.4-240 GeV) and
    high current (100 A)
    12 GHz bunch structure

  - Main beam for physics
    High energy (9 GeV - 1.5 TeV)
    and low current (1.2 A)

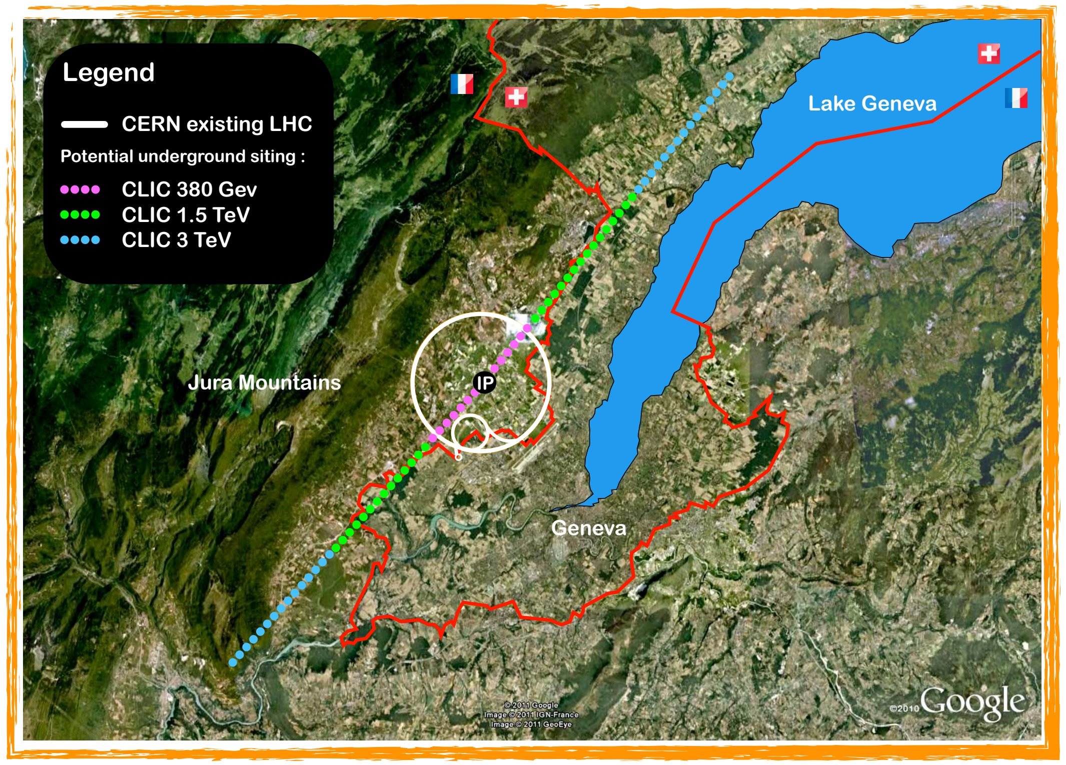
- 145 MV/m demonstrated in CTF3
  test facility





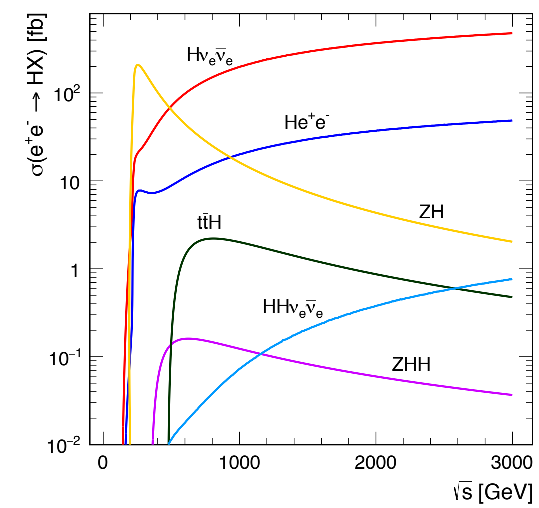
Updated baseline staging scenario

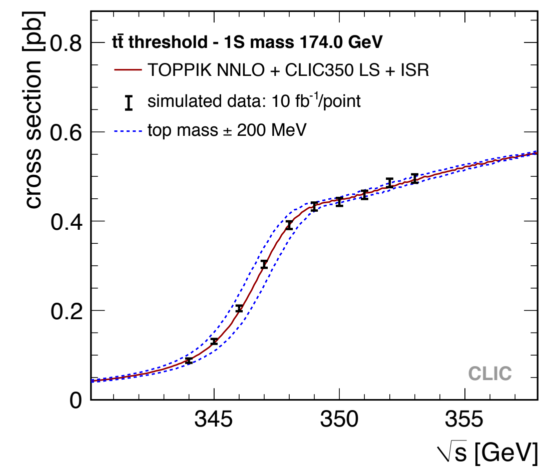
- CLIC CDR published in 2012
- Higgs mass not fully taken into account in choice of staging scenario
- Accelerator optimised for 3 TeV, with two low energy stages at 500 GeV and 1.4/1.5 TeV (not fully optimised)
- Comprehensive studies of performance, cost and power optimisation and further Higgs and top-quark physics studies lead to updated staging scenario
- **Rebaselining:**
  500 GeV -> **380 GeV**
  1.4/1.5 TeV -> **1.5 TeV**
  increased luminosity at **3 TeV**

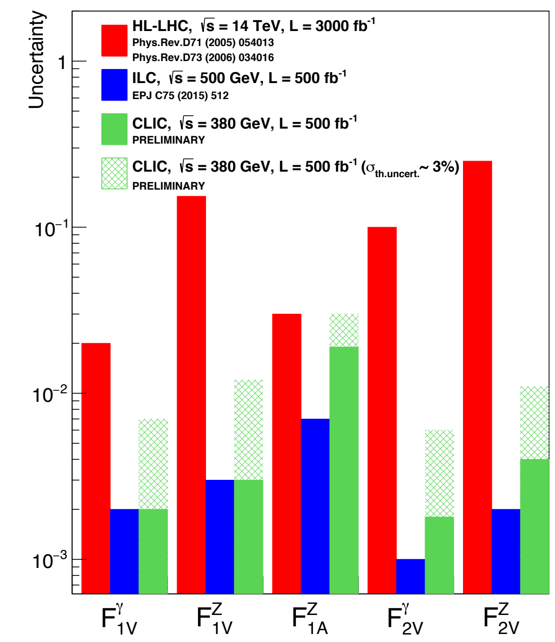


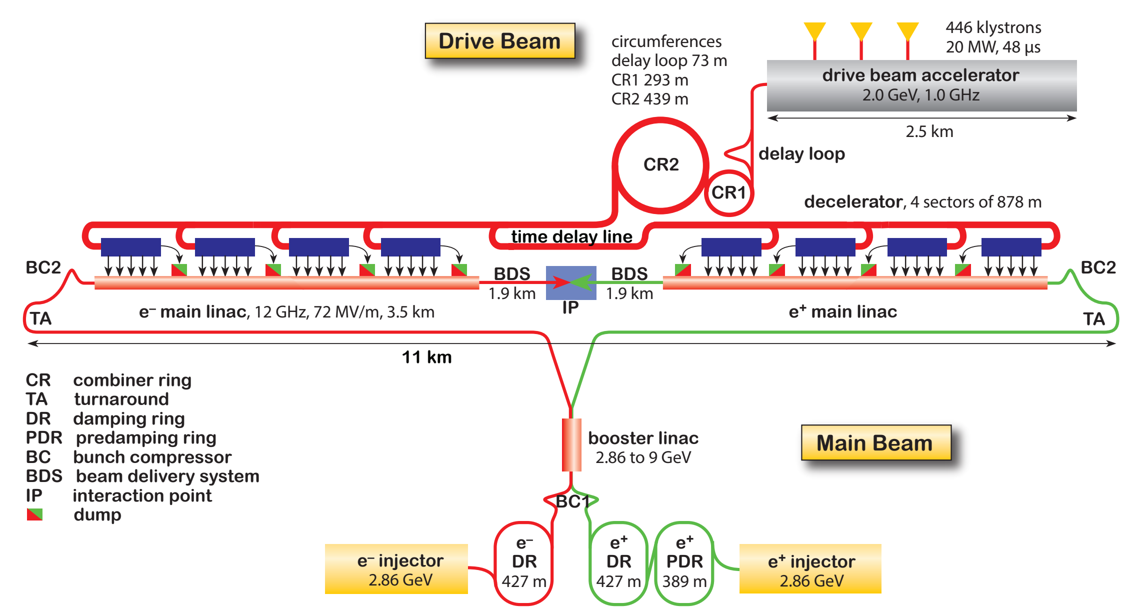
380 GeV

- **Higgs Physics**
  - Model independent measurement of gHZZ via Higgsstrahlung process to a precision of 0.8%
  - Together with WW fusion process gives access to total decay width and gHWW
  - Higgs mass to a precision of ~100 MeV
  - Best precision on cross-section around 350 GeV, precision of all Higgs couplings is limited by this uncertainty
- **Top Physics**
  - Top mass to a precision of ~50 MeV from threshold scan around 350 GeV
  - Top form factors precision at the percent level, above threshold boost helps accurate reconstruction
  - BSM in top sector best near the maximum cross-section near 420 GeV
- **380 GeV favourable for both Higgs and Top physics studies, supplemented with a top threshold scan around 350 GeV**
- **Accelerator**
  - Length: 11.4 km
  - Accelerating gradient: 72 MV/m
  - 1 drive beam complex



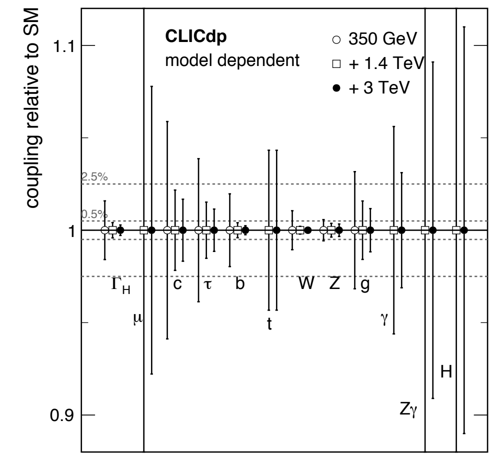


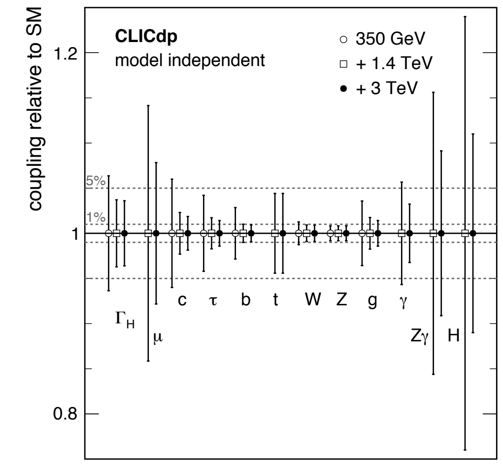


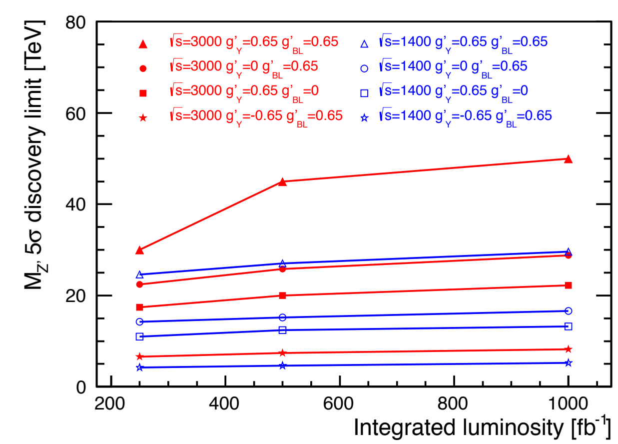


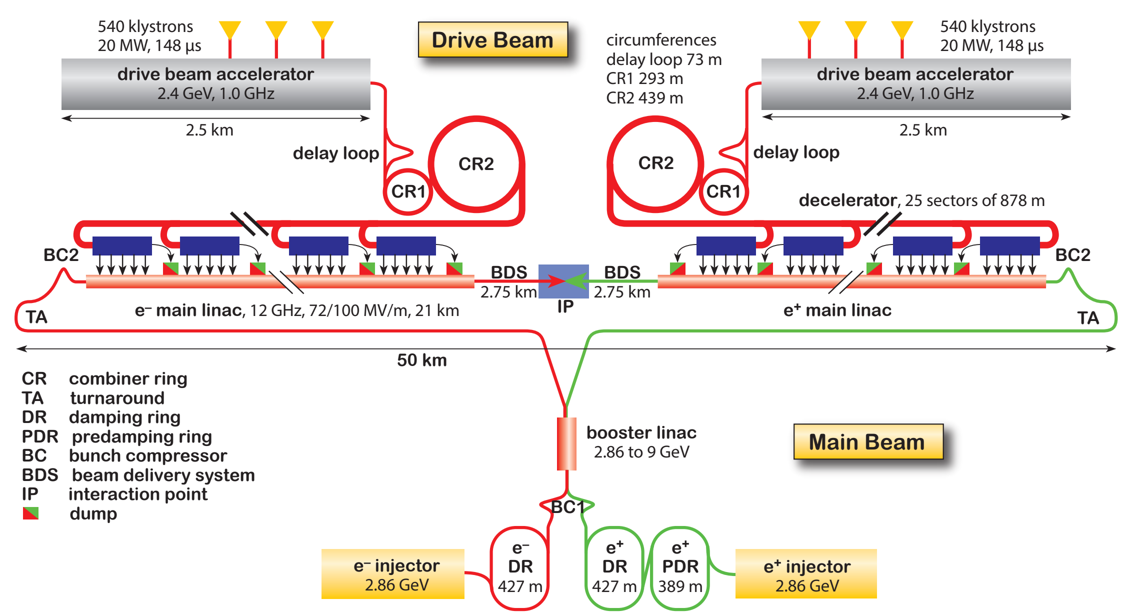
1.5 and 3 TeV

- **Higgs Physics**
  - WW-fusion and ZZ-fusion dominant
  - ~1% precision on the Higgs couplings to fermions and bosons
  - Higgs mass to ~32 MeV through H-> bb(bar) (1.5 and 3 TeV combined)
  - Top yukawa coupling through Higgs ee->ttH 4.1% statistical accuracy with 80% electron polarisation
  - Higgs self coupling through ee->HHnunu gives access to the coupling lambda to 10% precision (3 TeV)
- **BSM physics**
  - Direct searches: e.g. SUSY particle masses with 1% accuracy up to ~sqrt(s)/2
  - Indirect searches: deviations from SM predictions in Higgs and Top properties, or Z' via ee->mumu
  - Top sector: less statistical accuracy but improved reconstruction through boost and increased relative BSM contributions
- **Accelerator**
  - 3 TeV maximum envisioned energy
  - 1.5 TeV maximum energy for 1 drive beam complex
  - Length: 29.0 / 50.1 km
  - Accelerating gradient: 72 and 100 MV/m







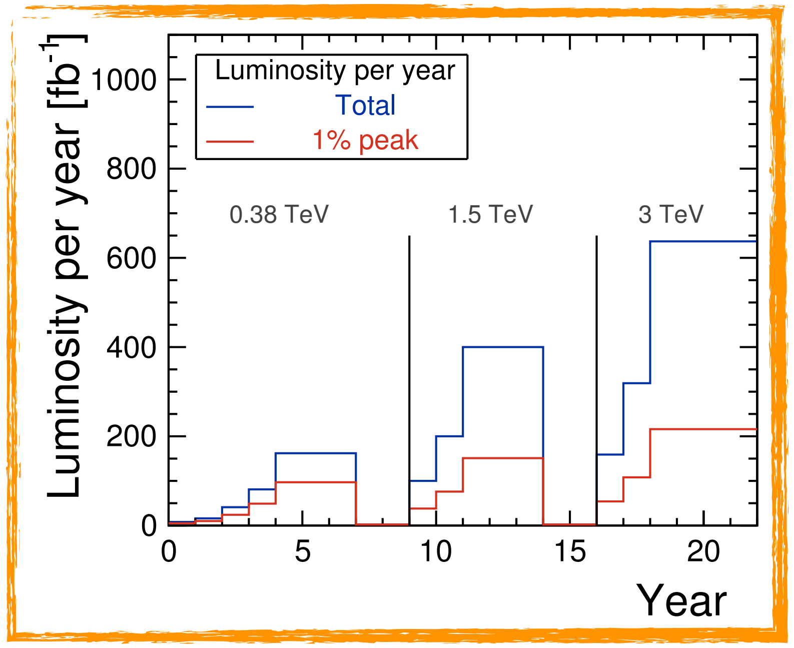


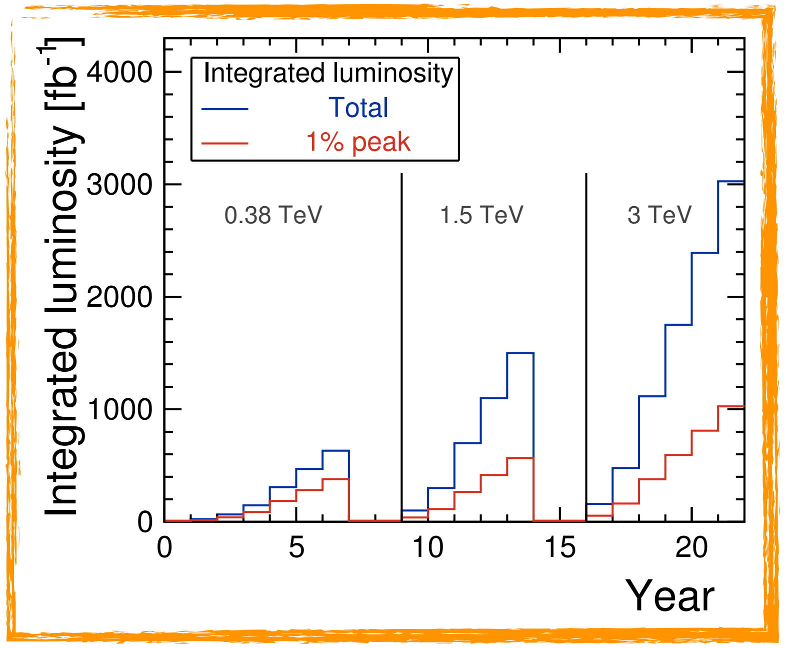
Baseline Staging Scenario

- Full programme will span 22 years
  - 5 to 7 years at each energy stage
  - 2 year upgrade periods between stages
  - Luminosity ramp up for each energy stage

Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{\mathrm{int}}$ (fb^{-1})
1	380 350	500 100
2	1500	1500
3	3000	3000

- Assume CLIC will operate for the equivalent of 125 days per year at 100% efficiency





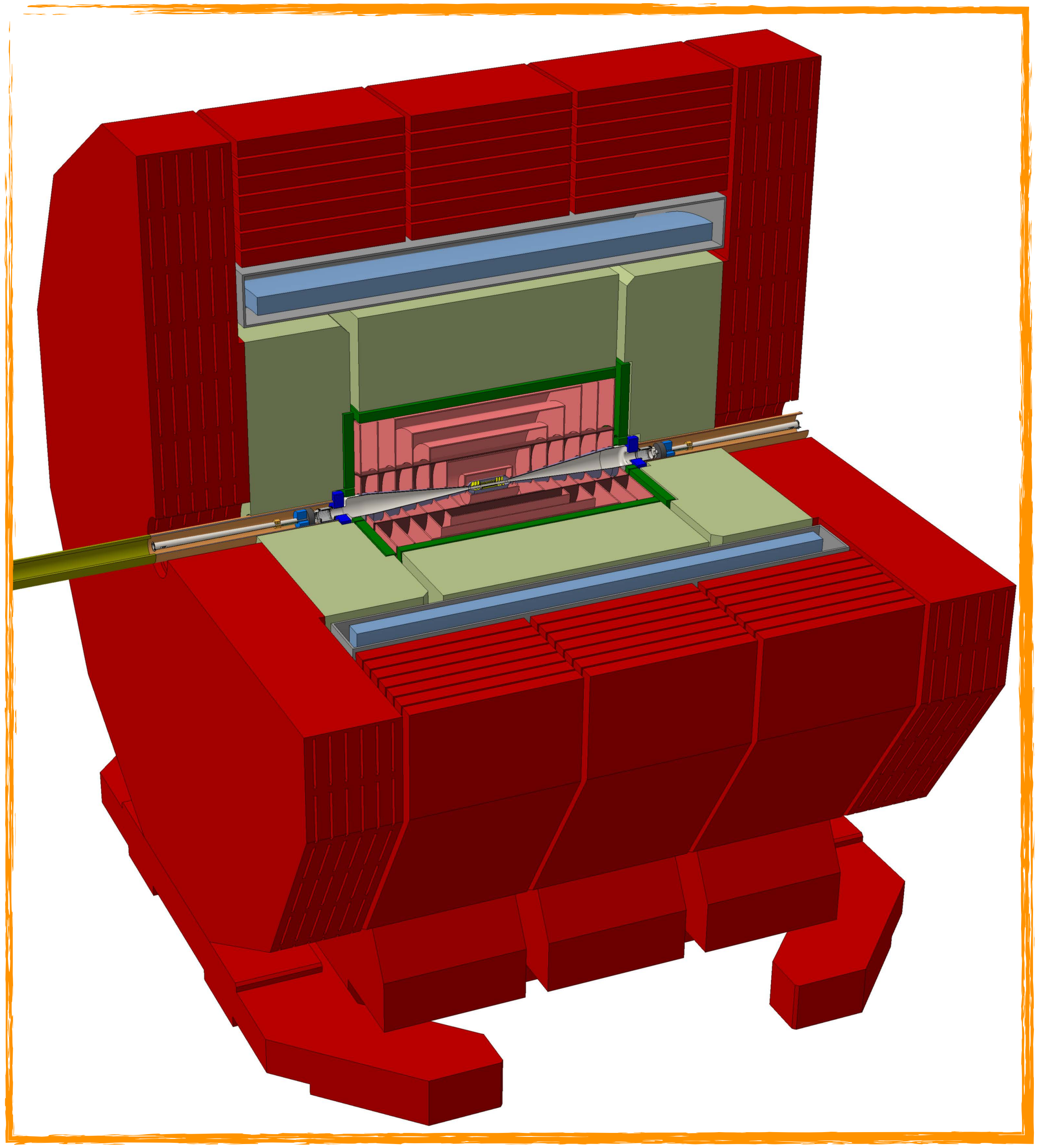
Post-CDR CLIC detector model

- Two detector models, CLIC_ILD and CLIC_SiD, were used in the CDR and for physics studies

- A new optimised model, **CLICdet**, has been developed for the next round of benchmark studies

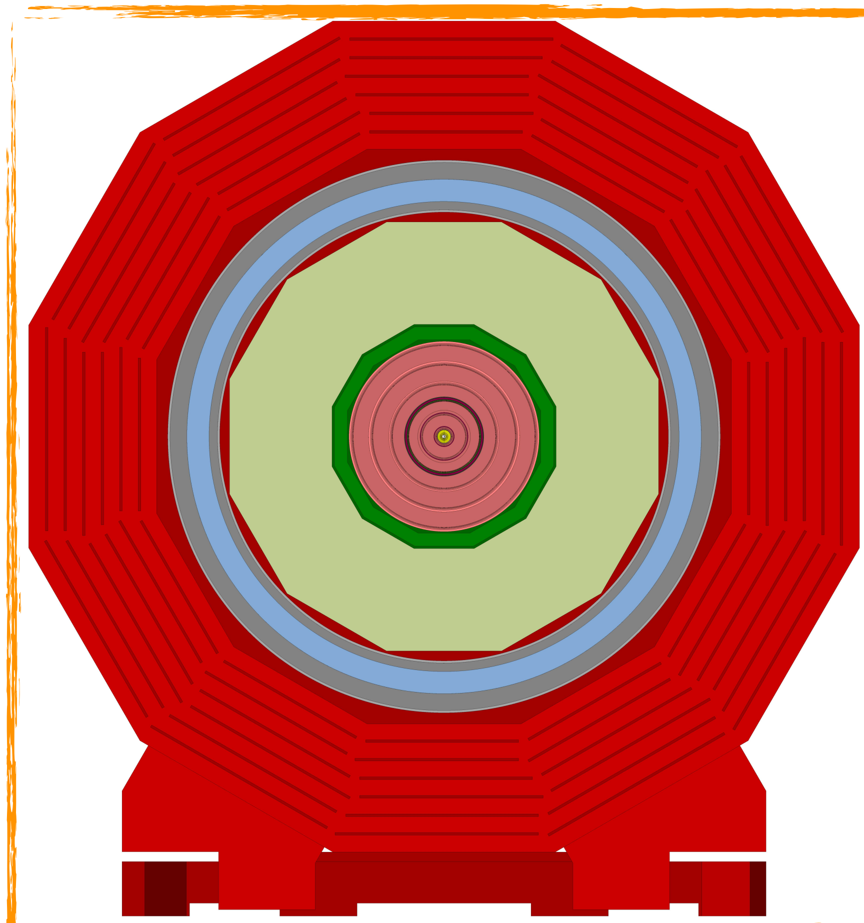
- Implemented in simulation/ reconstruction software in DD4Hep

- Document under collaboration review at the moment



A single detector at CLIC

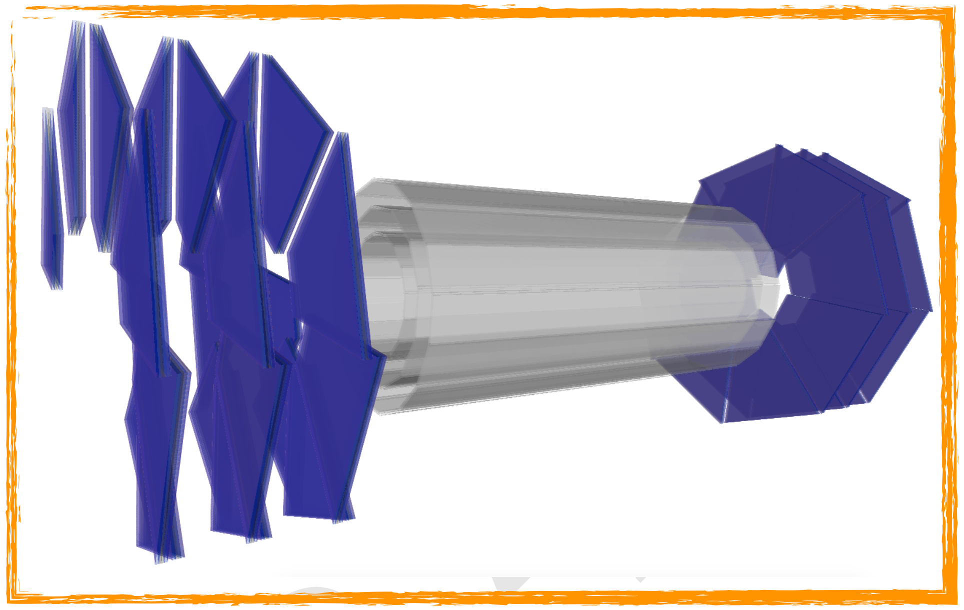
- Working hypothesis, can be revised if needed
- Considerations for a single detector:
  - two detector scheme is costly
  - loss of beam time in push-pull operation
  - small difference in physics reach between CLIC_SiD and CLIC_ILD
  - Conditions not favourable for a TPC at 3 TeV
- Magnet: 4 Tesla
- Return yoke:
  smaller outer radius due to less stringent requirements on stray fields
  thinner endcaps allow L* of 6 m
- Last quadrupole magnet (QD0) now outside of the detector at L* = 6 m, provides significantly better forward HCAL coverage

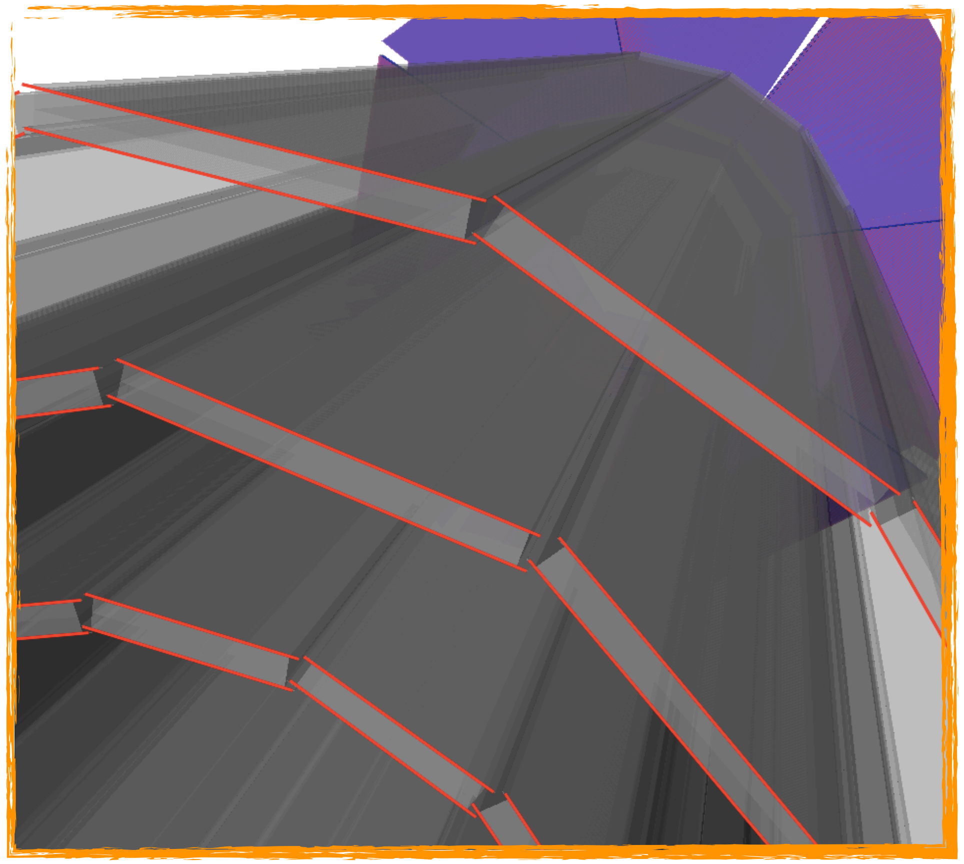


Concept	CLICdet	CLIC_ILD	CLIC_SiD
Vertex inner radius [mm]	31	31	27
Tracker technology	Silicon	TPC/Silicon	Silicon
Tracker half length [m]	2.2	2.3	1.5
Tracker outer radius [m]	1.5	1.8	1.3
ECAL barrel r_{min} [m]	1.5	1.8	1.3
ECAL barrel Δr [mm]	202	172	139
ECAL endcap z_{min} [m]	2.31	2.45	1.66
ECAL endcap Δz [mm]	202	172	139
HCAL absorber barrel / endcap	Fe / Fe	W / Fe	W / Fe
HCAL λ_I	7.5	7.5	7.5
HCAL barrel r_{min} [m]	1.74	2.06	1.45
HCAL barrel Δr [mm]	1590	1238	1177
HCAL endcap z_{min} [m]	2.45	2.65	1.80
HCAL endcap Δz [mm]	1590	1590	1595
Solenoid field [T]	4	4	5
Solenoid bore radius [m]	3.5	3.4	2.7
Solenoid length [m]	8.3	8.3	6.5
Overall height [m]	12.9	14.0	14.0
Overall length [m]	11.4	12.8	12.8
Overall weight [t]	8100	10800	12500

Vertex detector

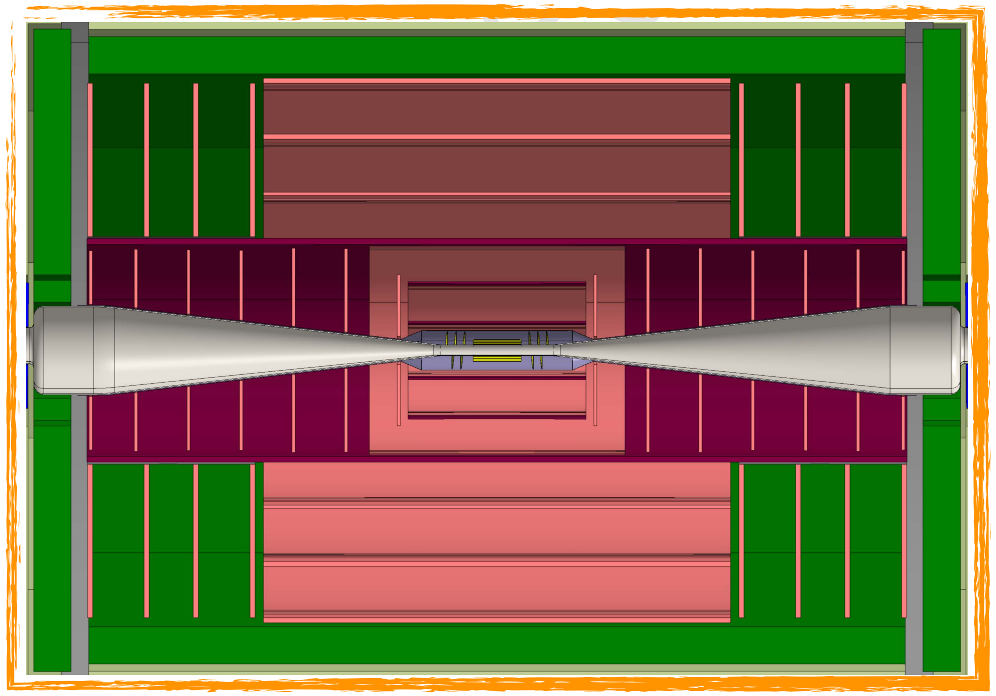
- Design driven by flavour tagging capabilities
- Cylindrical barrel, closed off by disks
  - Barrel: 3 double layers
  - Forward: 3 double segmented disks
  - Spiral layout enables efficient forced air flow cooling
- 0.2% X_0 per detection layer
- 25x25 μm^2 pixels
- Single point resolution ~3 μm

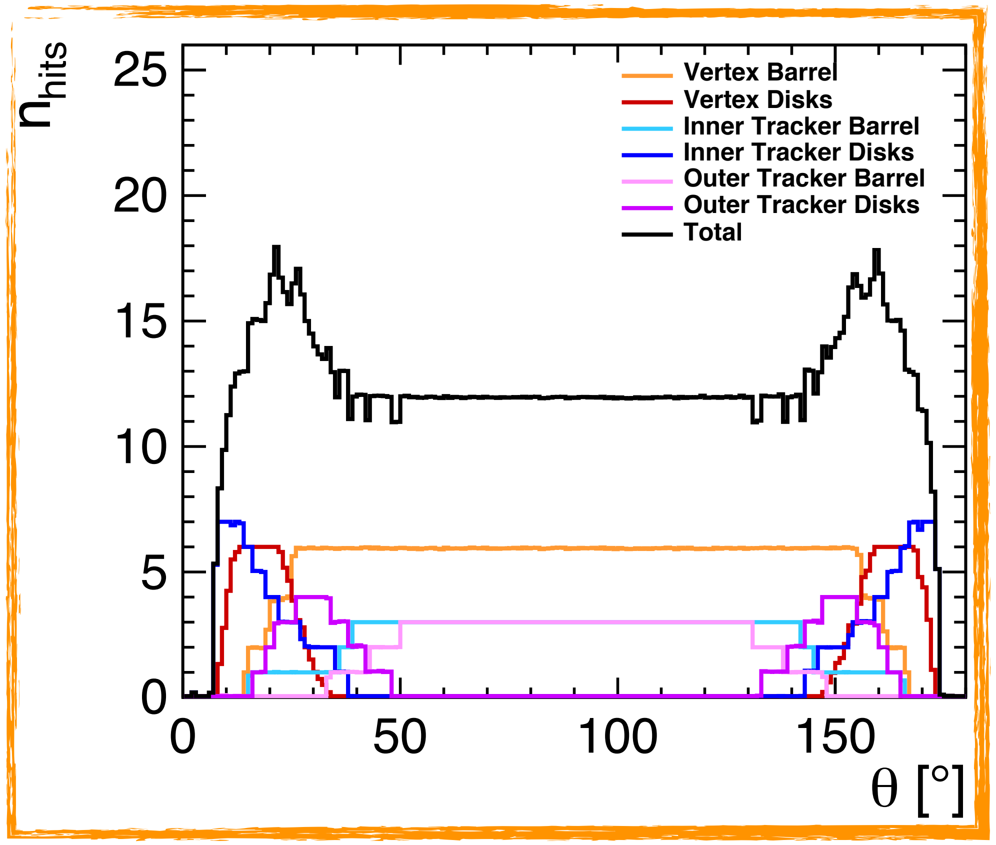




Silicon tracker

- All silicon tracker
    - Occupancy at 3 TeV too high for TPC (>30%)
- Radius: 1.5 m, Half length: 2.2 m
- Material budget: 1.1 -1.4 X_0 per layer
- Support structure enables tracking close to the beam pipe
- Inner tracker region: 3 barrel layers and 7 disks
- Outer tracker region: 3 barrel layers and 4 disks
- Larger tracker extended in particular in the forward coverage compared to CLIC_SiD

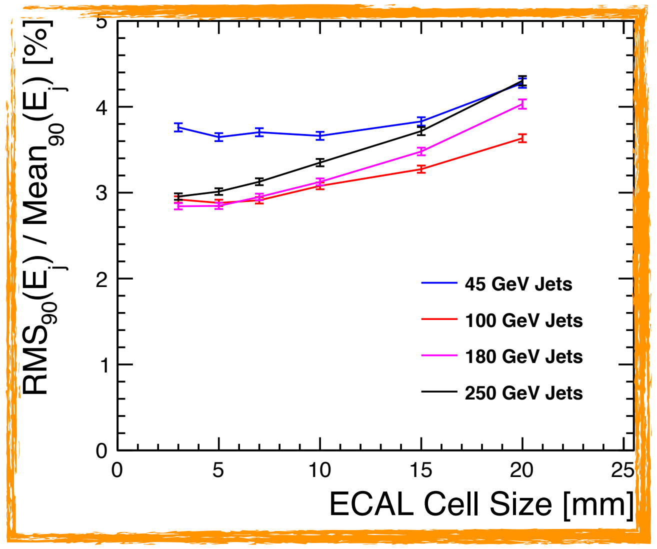


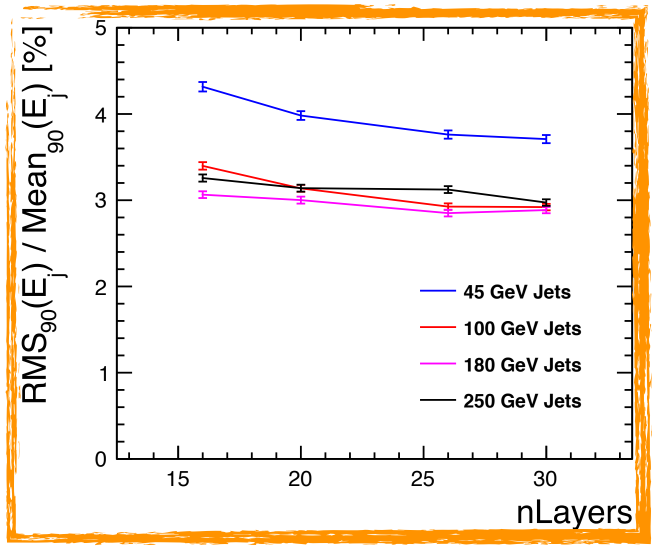


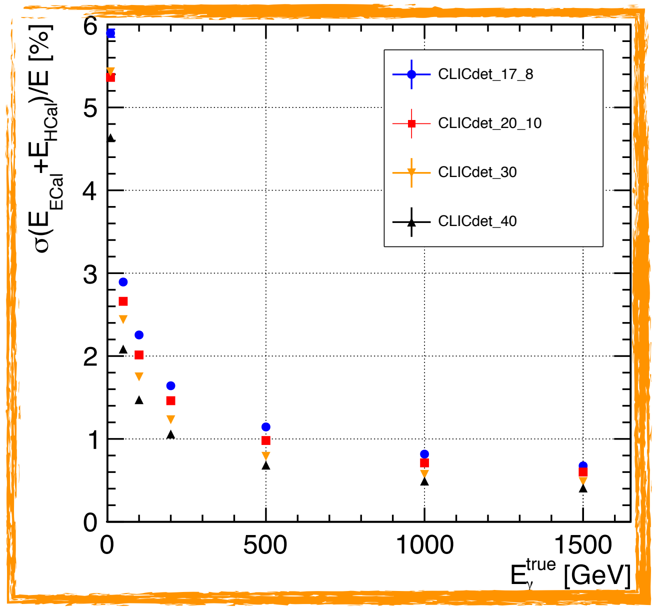
Silicon-Tungsten ECAL

- ECAL optimisation now also taking into account energy resolution for high energy photons
- Cell size 5x5 mm^2 optimal for jet energy resolution
- 40 layers of 1.9 mm tungsten optimal for high energy photons
- Material budget: 23 X_0
- Dimensions: R_{inner} 1.5 m, R_{outer} 1.7 m

See talk by Matthias Artur Weber on Wednesday at 13:50

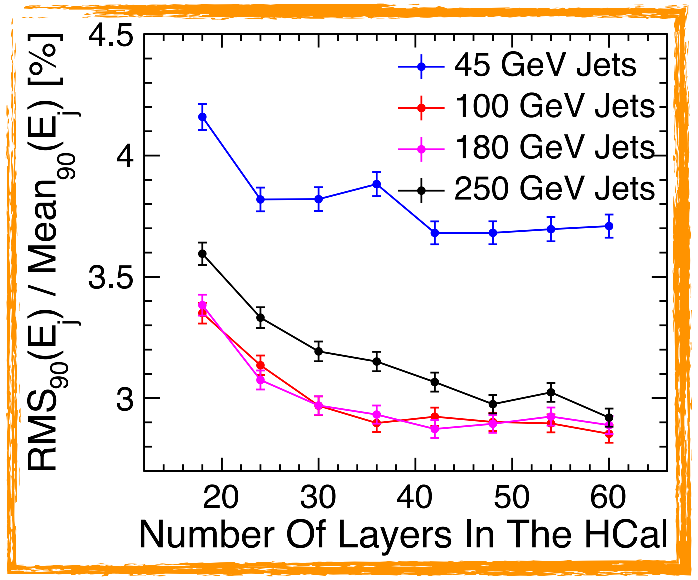


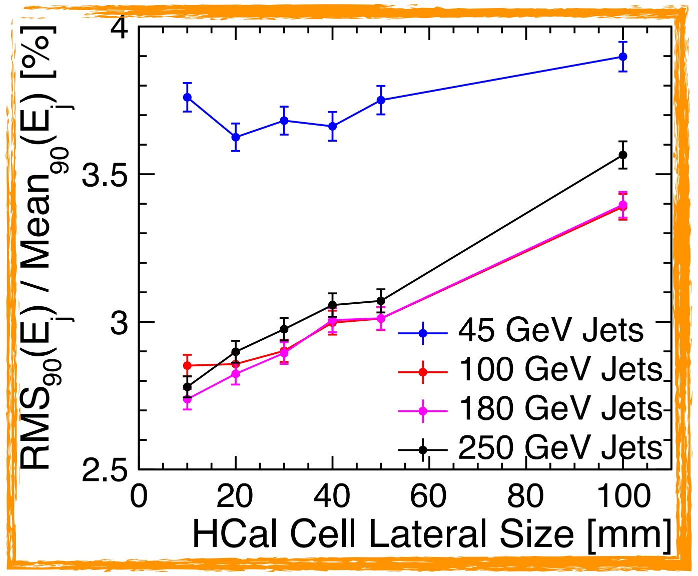


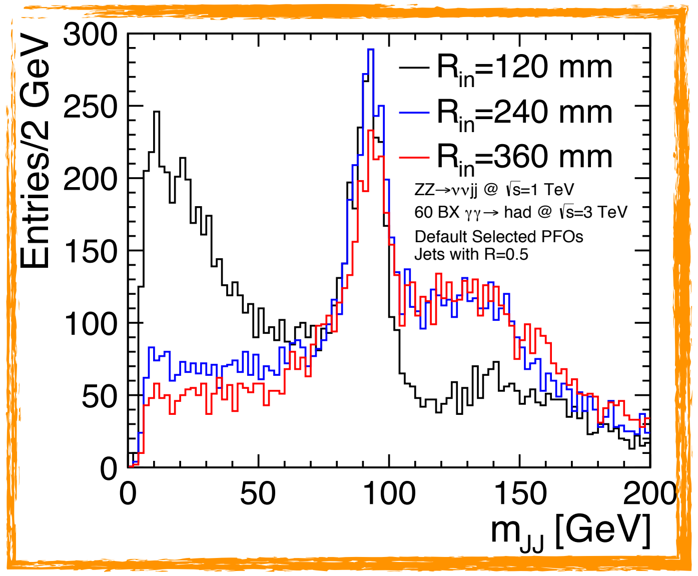


Scintillator-Steel HCAL

- Optimisation for jet energy resolution
- 60 layers of 19 mm thick steel and polystyrene scintillator tiles + SiPMs
- tile size 30x30x3 mm^3
- depth 7.5 λ_I
- Better forward coverage wrt the CDR, improves di-jet invariant mass

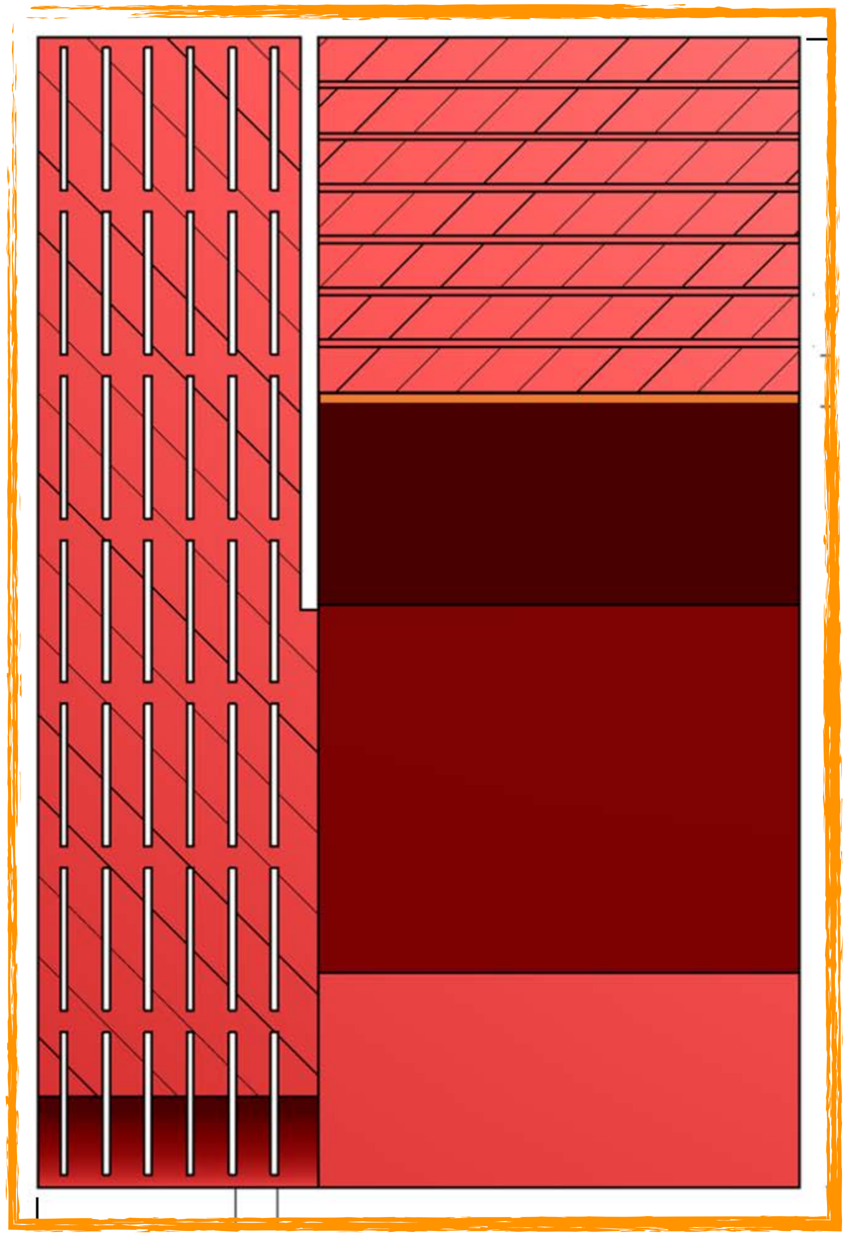






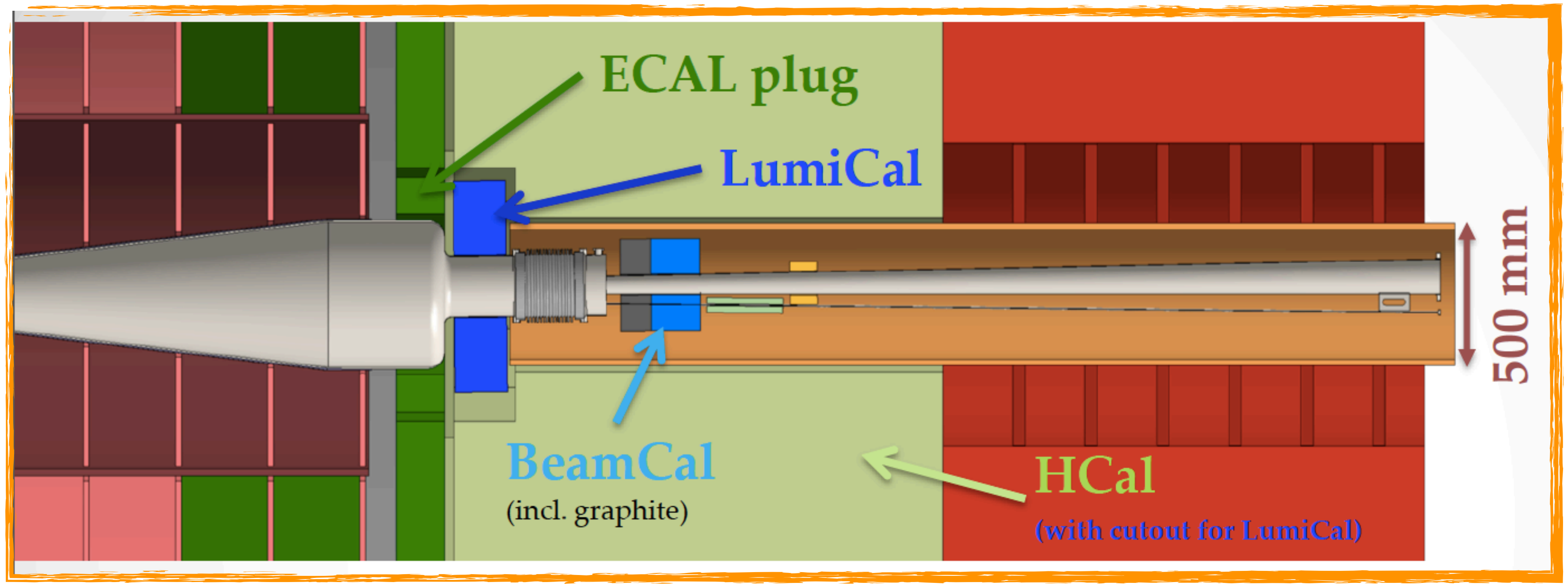
Muon system

- Smaller muon system due to thinner yoke
- Muon identification still sufficient
- 6 layers of RPC with 30x30 mm^2 cell size
  alternative: scintillator strips



Forward calorimeters

- Very forward region:
  - LumiCal for luminosity measurement (e+e- from Bhabha scattering)
    30 layers of 3.5 mm tungsten with 0.32 mm silicon sensors
  - BeamCal for monitoring of collisions
    30 layers of 3.5 mm tungsten with diamond sensors (radiation hard)
- Provide coverage for electrons and photons down to very small angles (10 mrad)
- Position and radii slightly changed wrt CLIC_ILD



Higgs physics paper

See talk by Philipp Roloff on Tuesday at 9 a.m

See talk by Mila Pandurovic on Wednesday at 14:20

- Overview of CLIC physics submitted to EPJC
- …..
- …..
- …..

Preparation for next European Strategy

- CLIC summary report
  - Updated baseline for a staged Compact Linear Collider
    CERN yellow report CERN-2016-004, arXiv:1608.07537
  - Higgs Physics at the CLIC Electron-Positron Linear Collider
    Submitted to EPJC, arXiv:1608.07538
  - The New Optimised CLIC detector model CLICdet
    Under Collaboration review
  - An overview of CLIC Top Physics
    Publication planned 2017

    See talks by Rickard Ström on Thursday at 15:50 and Filip Zarnecki on Tuesday at 9:40
  - Extended BSM studies
    Publication planned 2017/2018

    See talk by Philipp Roloff on Thursday at 10:40
  - CLIC R&D report (main CLIC technology demonstrators)
    Summary publications 2017+2018
  - Plan for the period ~2019-2025 in case CLIC is supported by the next strategy

Summary

- Rebaselining of **CLIC staging scenario** optimising both Higgs and Top physics program in first energy stage
    - 380 GeV, 1.5 TeV, 3 TeV
- New single CLIC detector model **CLICdet** based on optimisation studies in full detector simulations
- **Higgs physics overview paper** finalised and submitted
  Top physics overview and BSM physics overview being prepared
- Staged operation of CLIC offers an impressive energy frontier physics programme that reaches beyond the LHC.
  It is an excellent option for a post-LHC facility at CERN.

Backup slides

CLIC parameters

Table 9: Parameters for the CLIC energy stages. The power consumptions for the 1.5 and 3 TeV stages are from the CDR; depending on the details of the upgrade they can change at the percent level.

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} cm^{-2}s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}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	—	—
Estimated power consumption	P_{wall}	MW	252	364	589

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)

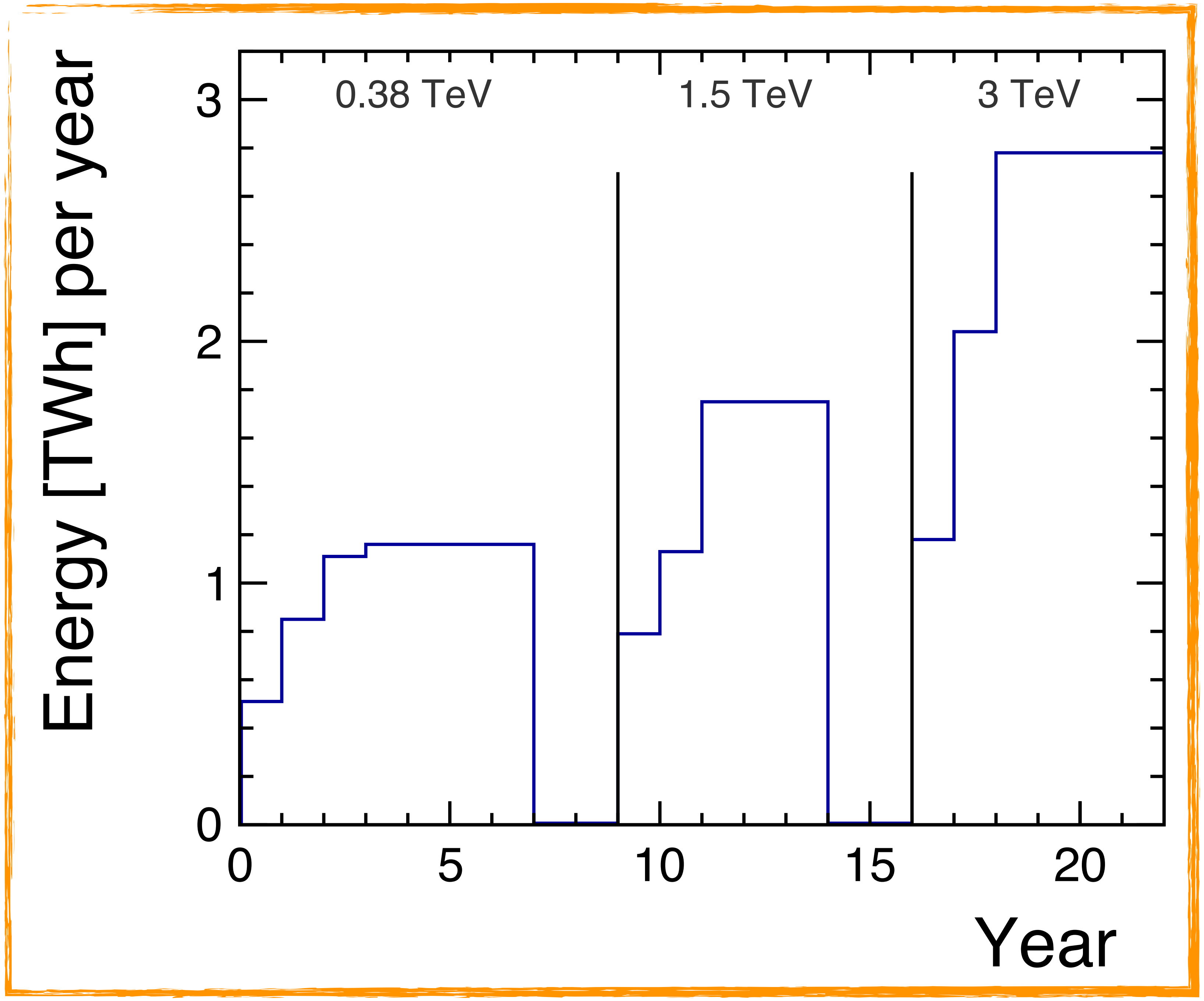
2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

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

CLIC energy consumption



Cost estimation for 380 GeV CLIC

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

Tracker radius

- Transverse momentum resolution, angular track resolution and jet energy resolution using particle flow benefit from a larger tracker radius