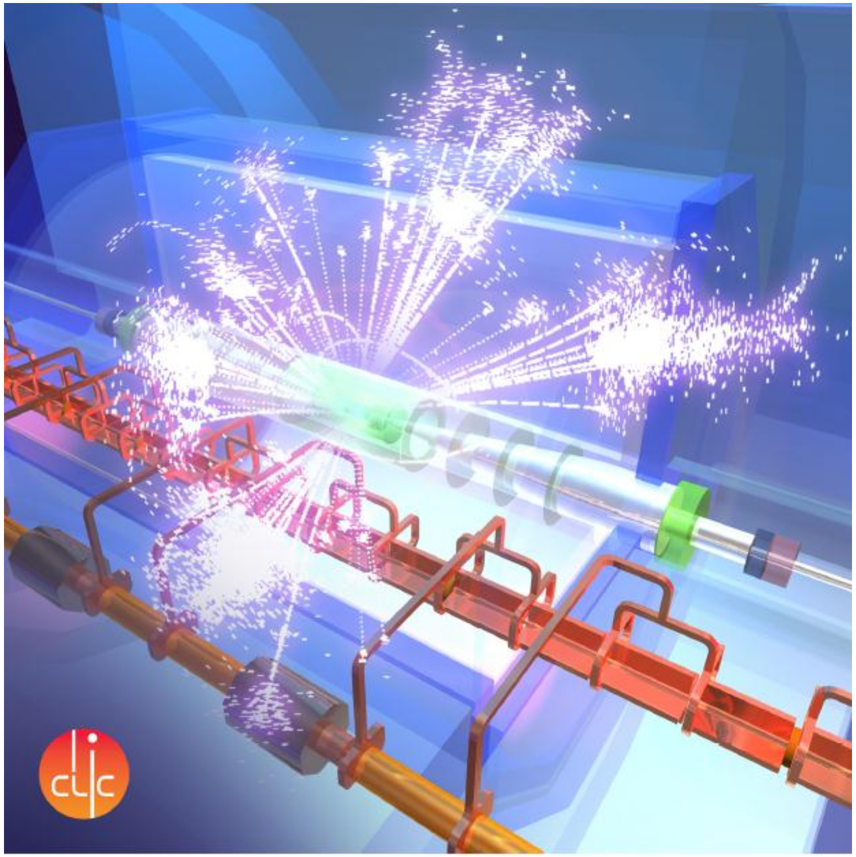
update on the CLIC studies



Lucie Linssen, CERN

on behalf of the CLIC physics and detector study

Recent CLIC documents…

- CLIC CDR (#3), The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale, ANL-HEP-TR-12-51, CERN-2012-005, KEK Report 2012-2, MPP-2012-115
  https://edms.cern.ch/document/1234246
- CLIC e^+e^- Linear Collider Studies, CLIC input to the update process of the European Strategy for Particle Physics: arXiv:1208.1402
- The Physics Case for an e^+e^- Linear Collider, LC input to the update process of the European Strategy for Particle Physics, ILC ESD-2012/4, CLIC-Note-949
- CLIC CDR (#2), Physics and Detectors at CLIC, ANL-HEP-TR-12-01, CERN-2012-003, DESY 12-008, KEK Report 2011-7, arXiv:1202.5940
- CLIC CDR (#1), A Multi-TeV Linear Collider based on CLIC Technology, JAI-2012-001, KEK Report 2012-1, PSI-12-01, SLAC-R-985, https://edms.cern.ch/document/1234244/

Outline

- CLIC layout at 3 TeV and 500 GeV
- CLIC accelerator, main achievements
- Motivation for energy staging
- Staging scenarios A and B, main features
- Scheduling, power and cost
- Results of benchmark studies
  - Higgs
  - top
  - SUSY
- CLIC strategy and objectives
- Physics and Detectors in next phase 2012-2016
- Summary and outlook

CLIC layout at 3 TeV

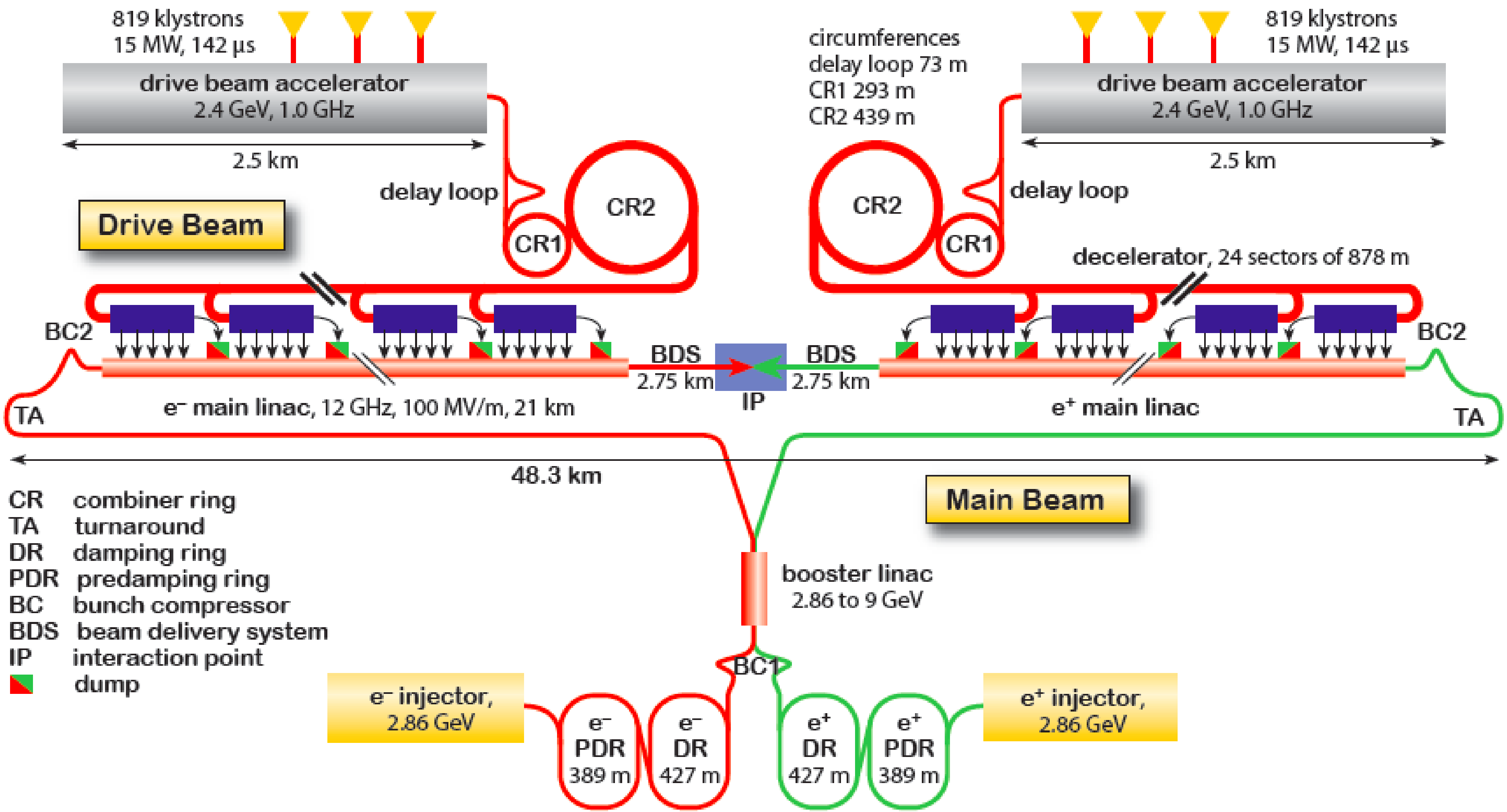


Fig. 3.1: Overview of the CLIC layout at $\sqrt{s} = 3$ TeV.

CLIC layout at 500 GeV

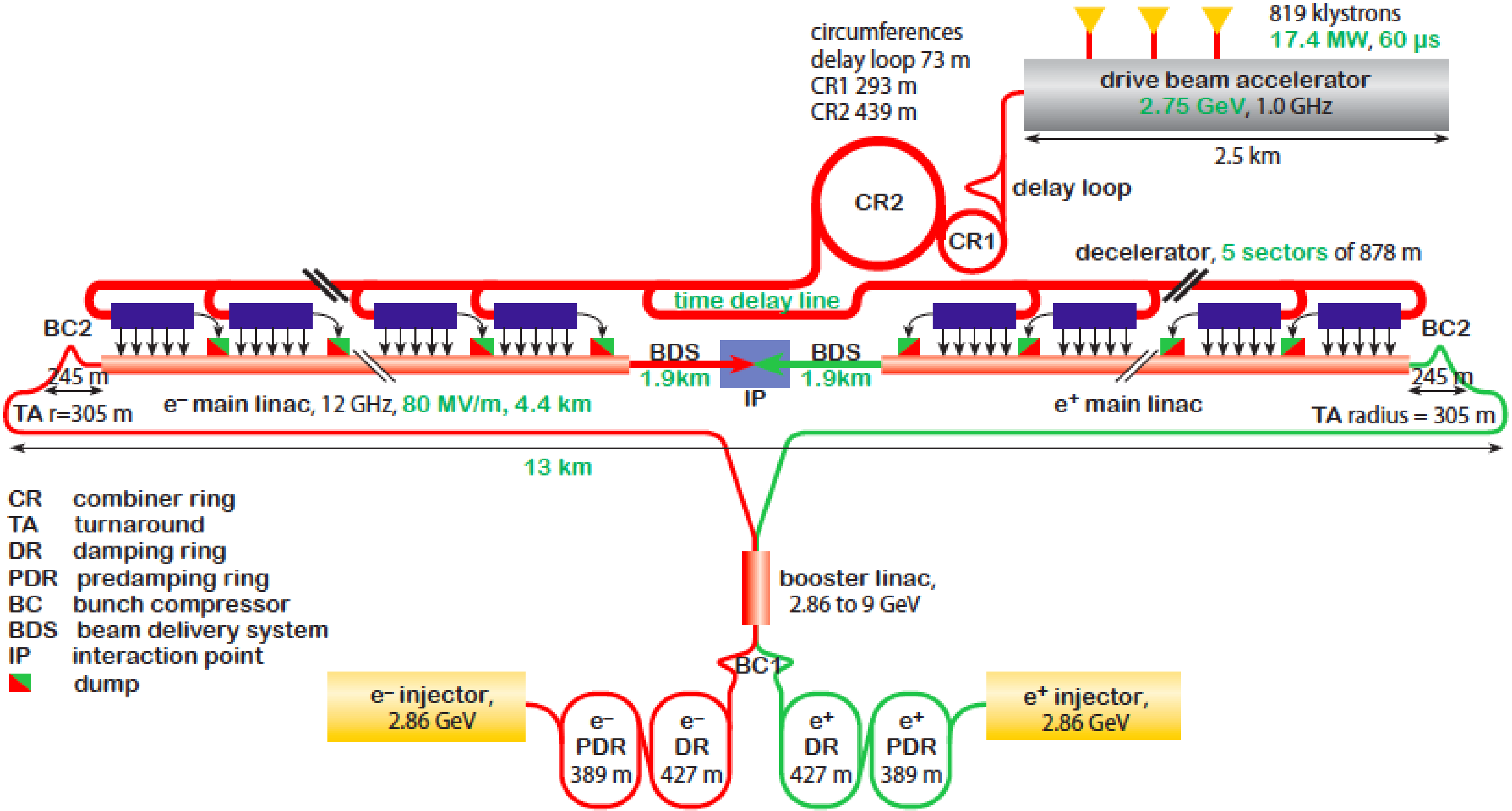


Fig. 3.2: Overview of the CLIC layout at $\sqrt{s}$ =500 GeV. (scenario A)

Main accelerator achievements

- **Drive beam generation**
  - High-current drive beam generated at CTF3
  - Achievements consistent with theoretically required tolerances
- **RF power production**
  - PETS tests => demonstrated feasibility with high power output at required pulse length and breakdown rate, incl. output power control
- **Drive beam deceleration**
  - Feasibility demonstrated through combination of simulations and tests with 9 PETS in CTF3, within tolerances. CTF3 tests with more PETS foreseen soon.
- **Accelerating structures**
  - Prototype structures tested at SLAC (thank you !) and KEK, achieved unloaded gradient >100MV/m at required breakdown rate
- **Two-beam acceleration**
  - Two-beam acceleration at above-nominal gradient achieved in CTF3
- **Generation and preservation of ultra-low emittances**
  - Simulations + various tests carried out on: damping ring, beam transport system, static imperfections, dynamic imperfections
- **Machine protection**
  - Issues addressed “by design” or detection/interlocks, based on LHC experience

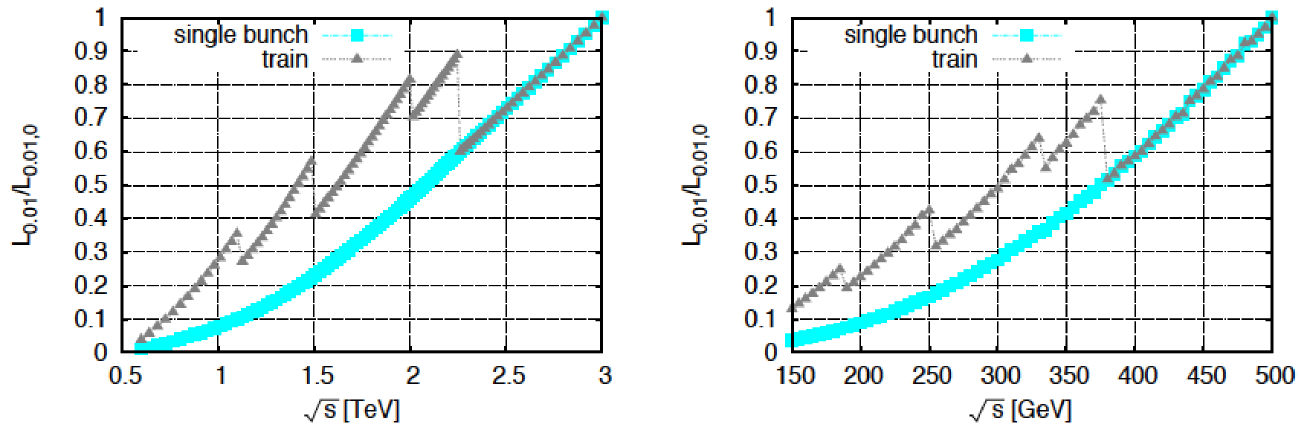
Motivation for energy staging (1)

CLIC physics potential:

- Precision measurements of standard model physics (e.g. Higgs, top)
- Direct searches for the production of new particles
- Sensitivity to effects of New Physics at higher mass scales via precision measurements

Making optimal use of the capacities (luminosity) of CLIC, this is best studied with a **collider built in a few successive energy stages**.

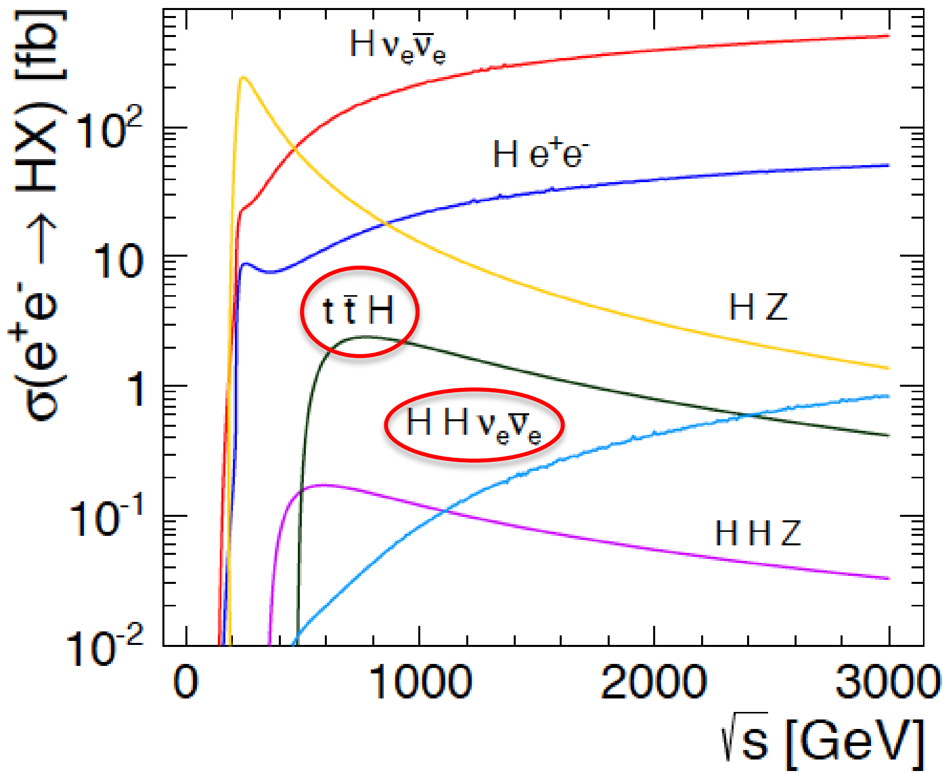
At each energy stage, the centre-of-mass energy can be tuned down by a factor ~3 with limited luminosity loss (e.g. for threshold scans).



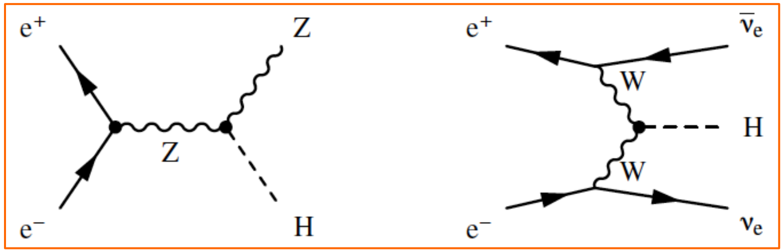
The optimal choice of the actual energy stages will depend on the physics scenario, driven by 8 TeV + 14 TeV LHC results.

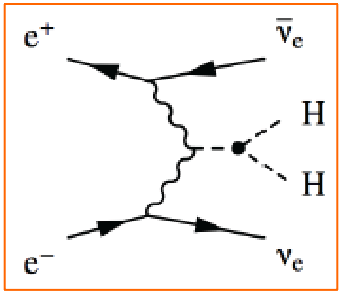
The scenarios presented are therefore **“just examples”, worked out illustrations**.

Motivation for energy staging (2)



Higgs physics

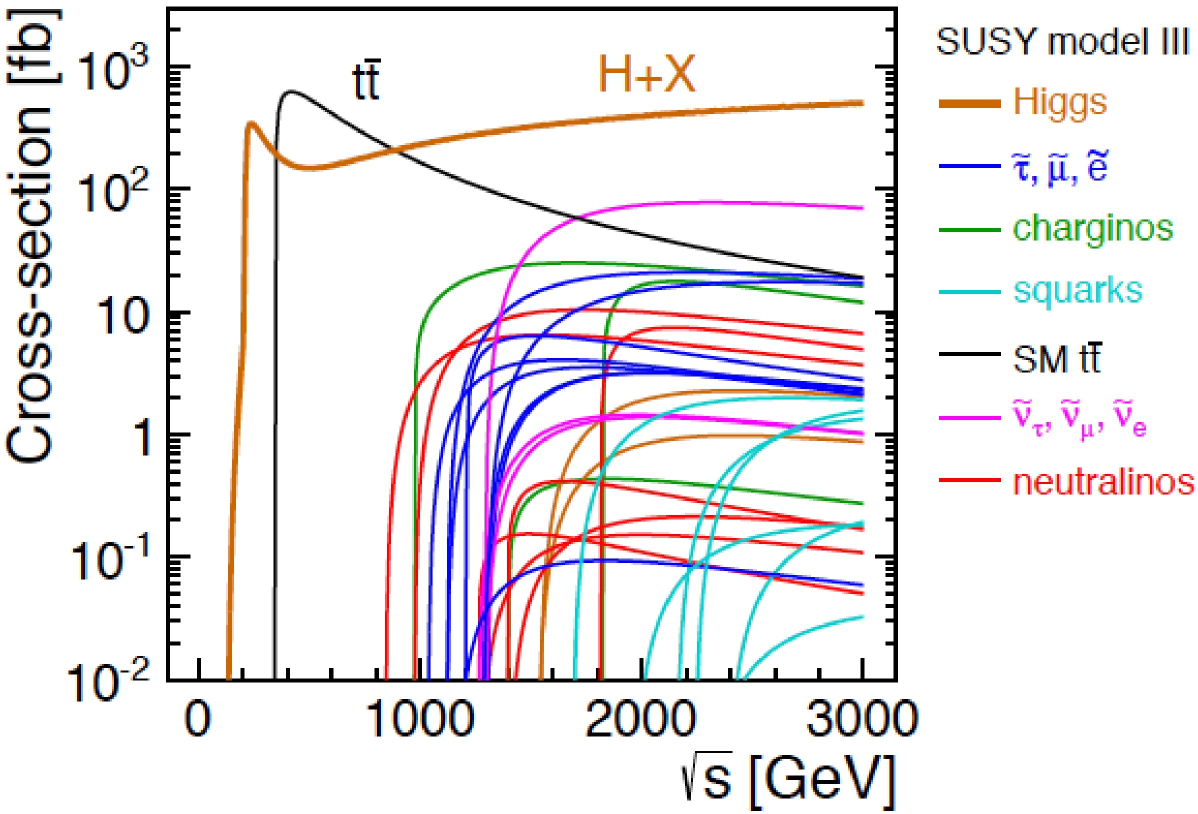




	350 GeV	500 GeV	1 TeV	1.5 TeV	3 TeV
$\sigma(e^+e^- \to ZH)$	129 fb	57 fb	13 fb	6 fb	1 fb
$\sigma(e^+e^- \to H\nu_e\bar{\nu}_e)$	30 fb	75 fb	210 fb	309 fb	484 fb
Int. $\mathcal{L}$	350 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	45,500	28,500	13,000	7,500	2,000
# $H\nu_e\bar{\nu}_e$ events	10,500	37,500	210,000	460,000	970,000

Available luminosity increases with √s !

Motivation for energy staging (3)



Stage 1: ~500 (350) GeV => Higgs and top physics
Stage 2: ~1.5 TeV => ttH, ννHH + New Physics (lower mass scale)
Stage 3: ~3 TeV => New Physics (higher mass scale)

SUSY models (*I, II, III*) used to illustrate physics (precision) capabilities

Staged approach, scenario A+B

A

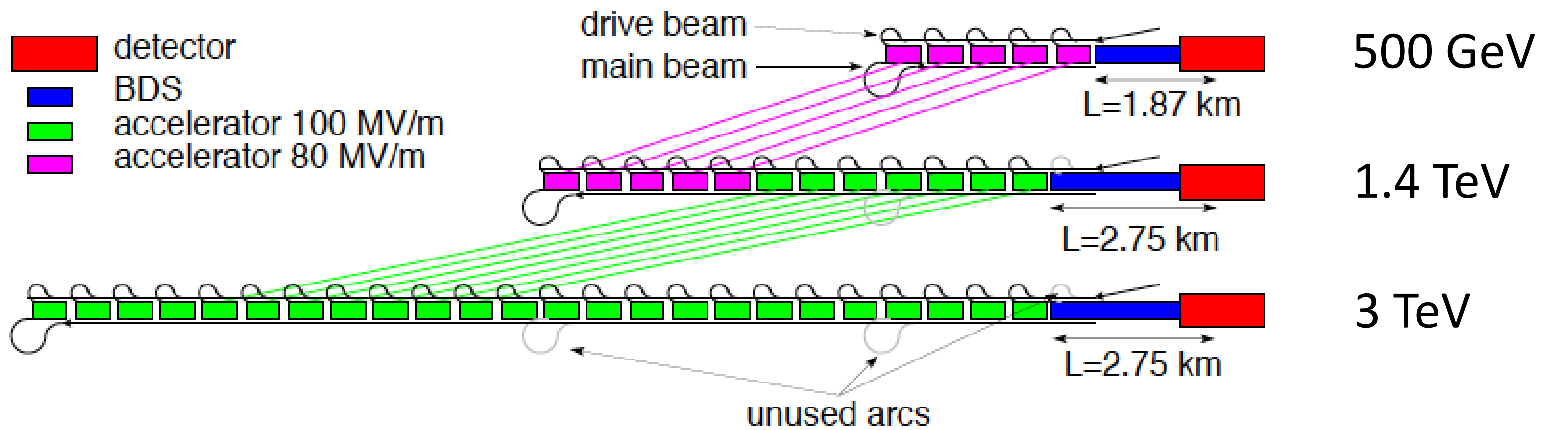


Fig. 3.5: Simplified upgrade scheme for CLIC staging scenario A. The coloured lines indicate the required movement of the modules from one stage to the next.

B

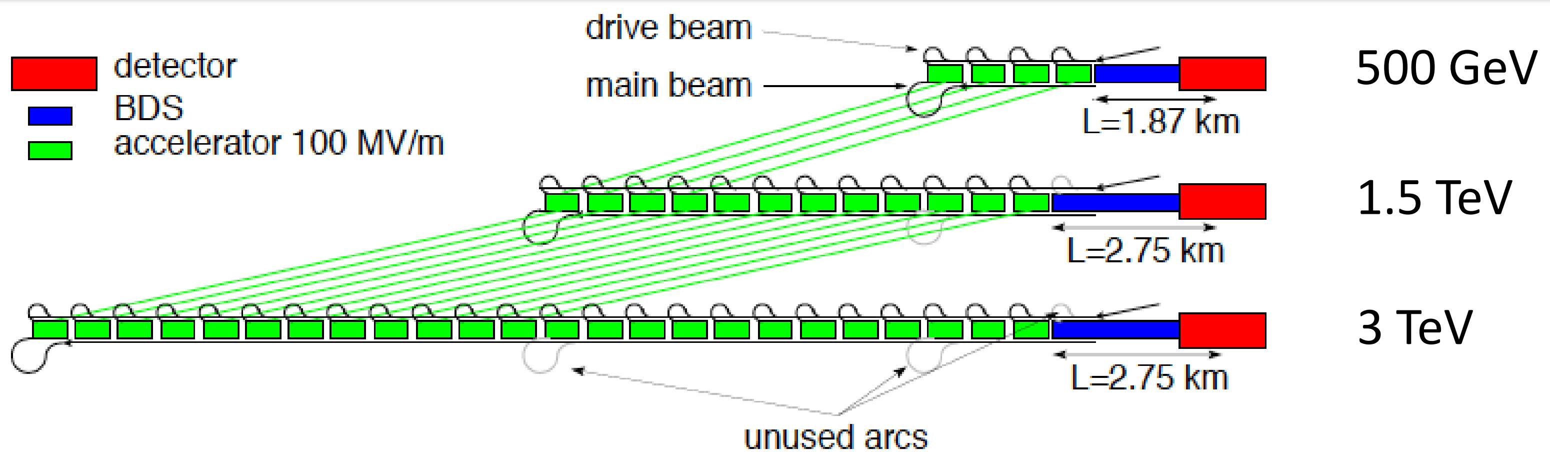


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Parameters, scenario A

Table 3.3: Parameters for the CLIC energy stages of scenario A.

Parameter	Symbol	Unit			
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δ_t	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	μm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	$\approx$ 60/1.5	$\approx$ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

Parameters, scenario B

Table 3.4: Parameters for the CLIC energy stages of scenario B.

Parameter	Symbol	Unit			
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δ_t	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	$10^{34}\ cm^{-2}s^{-1}$	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	$10^{34}\ cm^{-2}s^{-1}$	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	μm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	$\approx$ 60/1.5	$\approx$ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Integrated luminosity

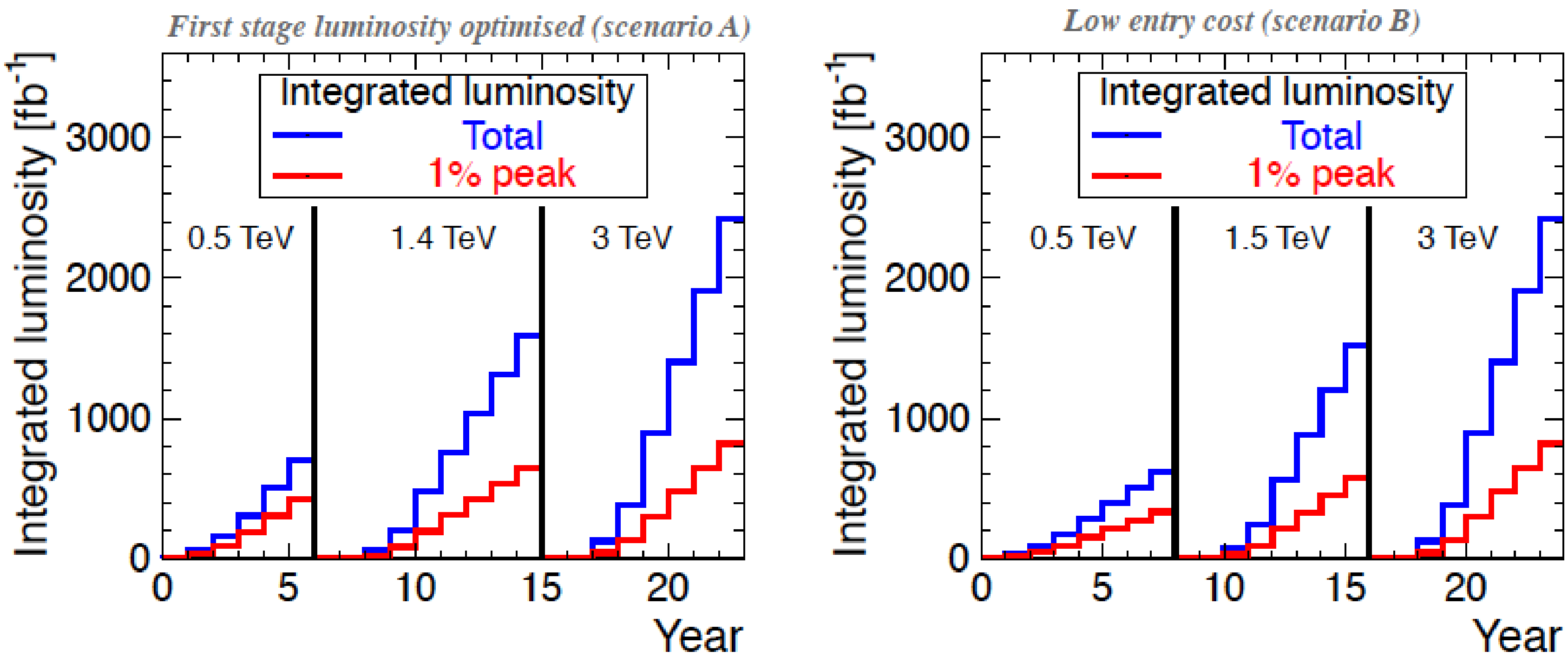


Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)
Target figures: >600 fb^{-1} at first stage, 1.5 ab^{-1} at second stage, 2 ab^{-1} at third stage

Scheduling of installation/operation

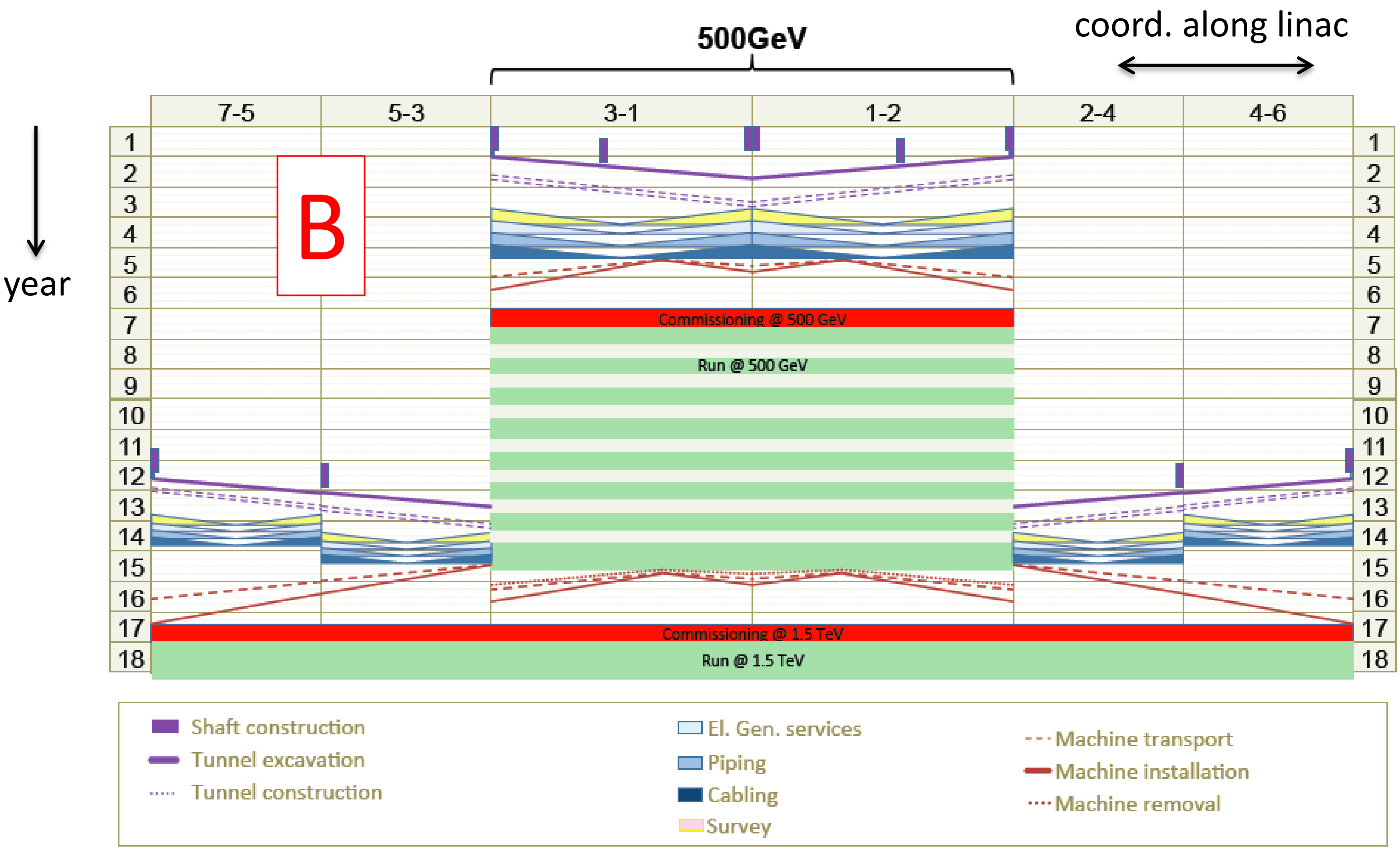


Fig. 5.4: Overall "railway" schedule for the first two stages of scenario B. The same conventions as in Figure 5.3 are used.

Scheduling of installation/operation

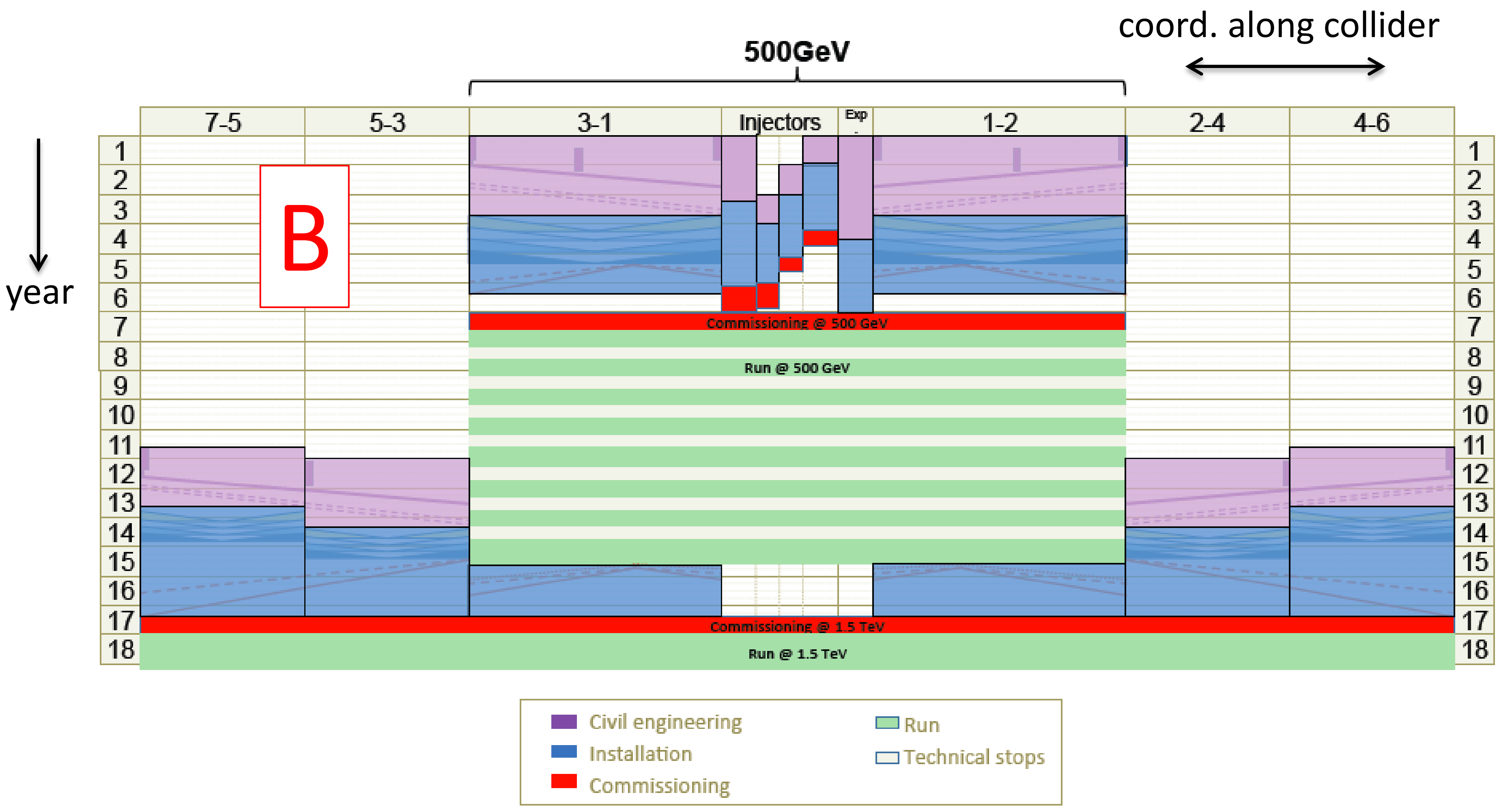


Fig. 5.6: Overall "railway" schedule for the first two stages of scenario B. The same conventions as in Figure 5.3 are used. Construction schedule for main-beam and drive-beam injectors, and for experimental area are shown in the centre.

Power

Table 5.1: Nominal power and efficiency for staging scenarios A and B, where $W_{main\ beam}$ is for the two main beams.

Staging scenario	$\sqrt{s}$ (TeV)	$\mathscr{L}_{1\%}$ ($cm^{-2}s^{-1}$)	$W_{main\ beam}$ (MW)	$P_{electric}$ (MW)	Efficiency (%)
A	0.5	$1.4 \cdot 10^{34}$	9.6	272	3.6
	1.4	$1.3 \cdot 10^{34}$	12.9	364	3.6
	3.0	$2.0 \cdot 10^{34}$	27.7	589	4.7
B	0.5	$7.0 \cdot 10^{33}$	4.6	235	2.0
	1.5	$1.4 \cdot 10^{34}$	13.9	364	3.8
	3.0	$2.0 \cdot 10^{34}$	27.7	589	4.7

Table 5.2: Residual power without beams for staging scenarios A and B.

Staging scenario	$\sqrt{s}$ (TeV)	$P_{waiting\ for\ beam}$ (MW)	$P_{shutdown}$ (MW)
A	0.5	168	37
	1.4	190	42
	3.0	268	58
B	0.5	167	35
	1.5	190	42
	3.0	268	58

Various options for improvement have been identified

CLIC, possible implementation

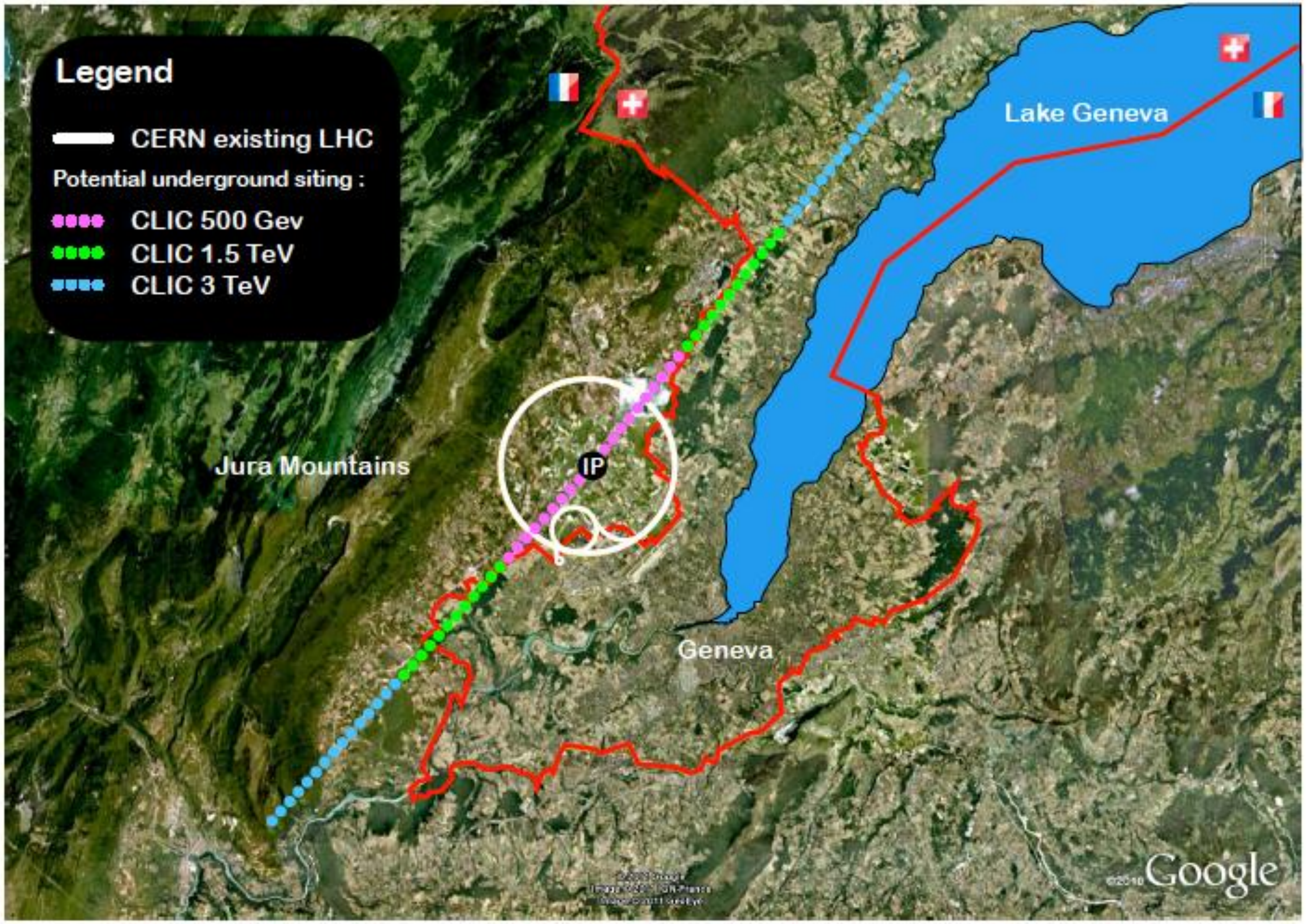


Fig. 7.2: CLIC footprints near CERN, showing various implementation stages [5].

The site specifications do not constrain the implementation to this location

CLIC accelerator cost

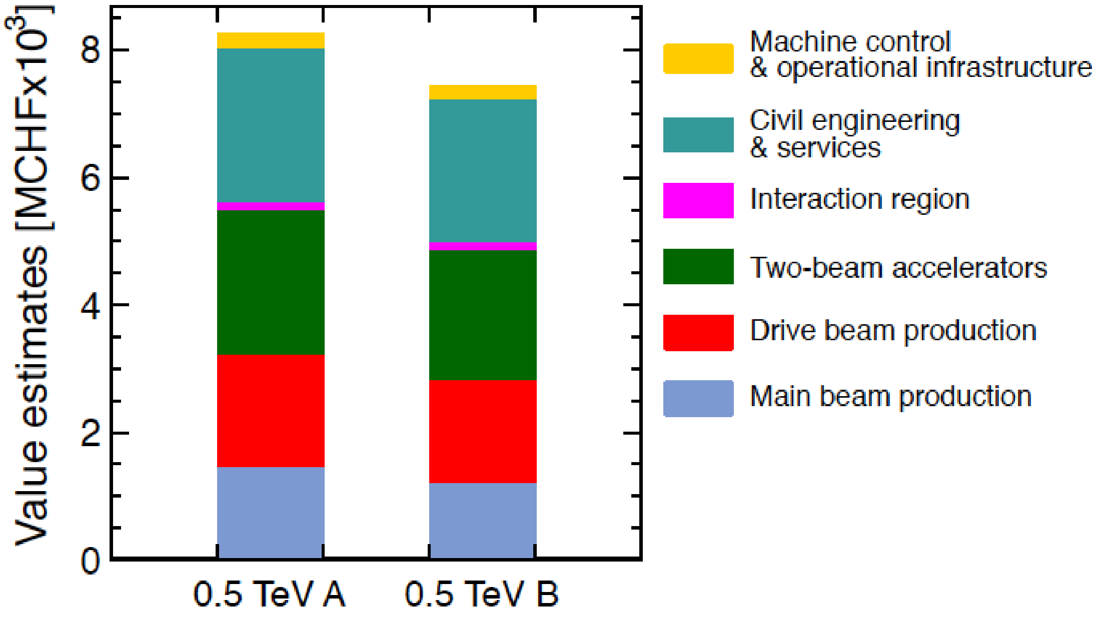


Fig. 5.8: Cost structure of the CLIC accelerator complex at 500 GeV for scenarios A and B.

500 GeV,
unit CHF,
excl. labour

Labour derived from LHC example (~1.9 FTE.year/MCHF) => 14100 FTE.years (scen. B)

Incremental cost (scenario B, 500 GeV => 1.5 TeV): 4 MCHF/GeV

Room for improvement (~10%) with current design, + additional possibilities from optimisation of energy staging

CLIC_ILD and CLIC_SiD concepts

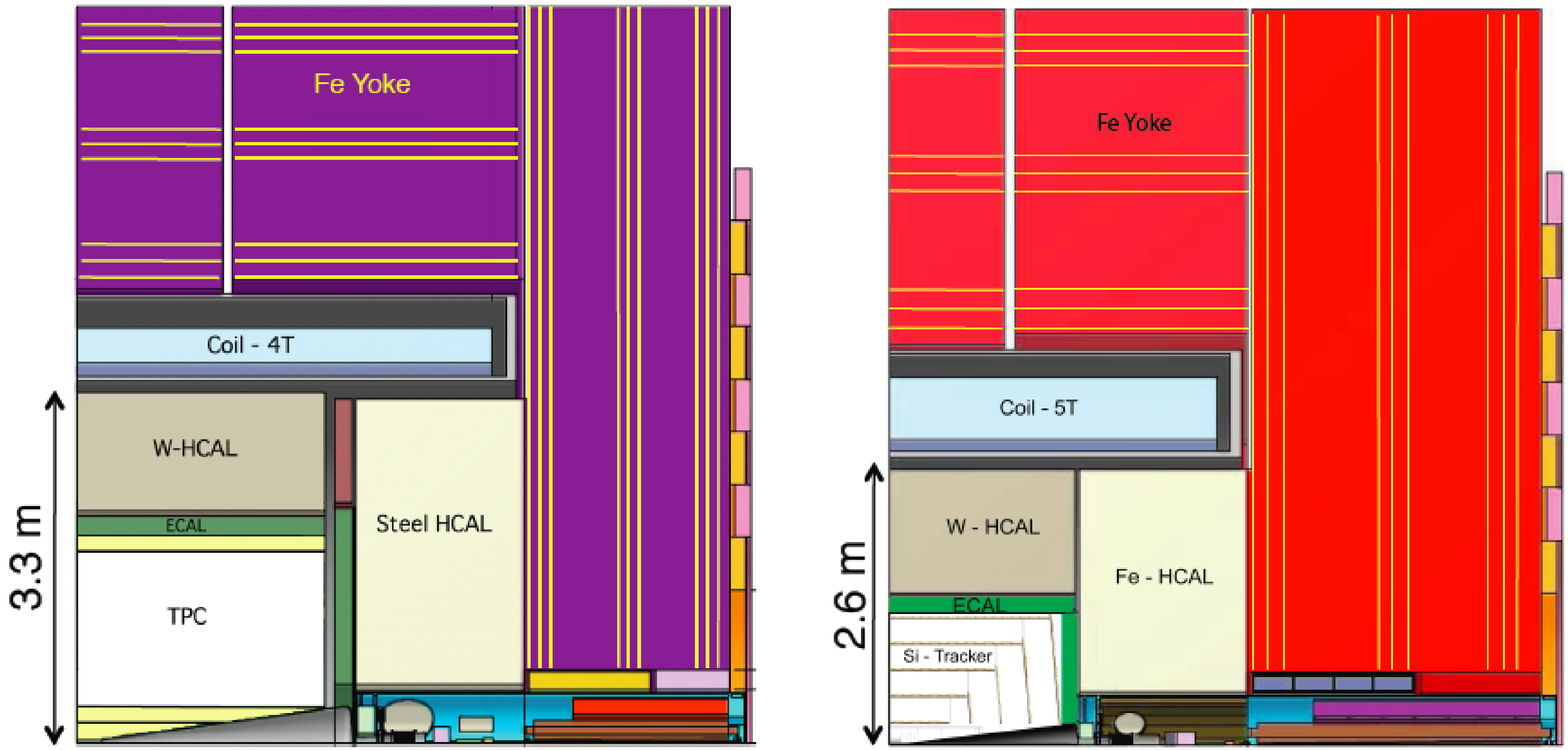
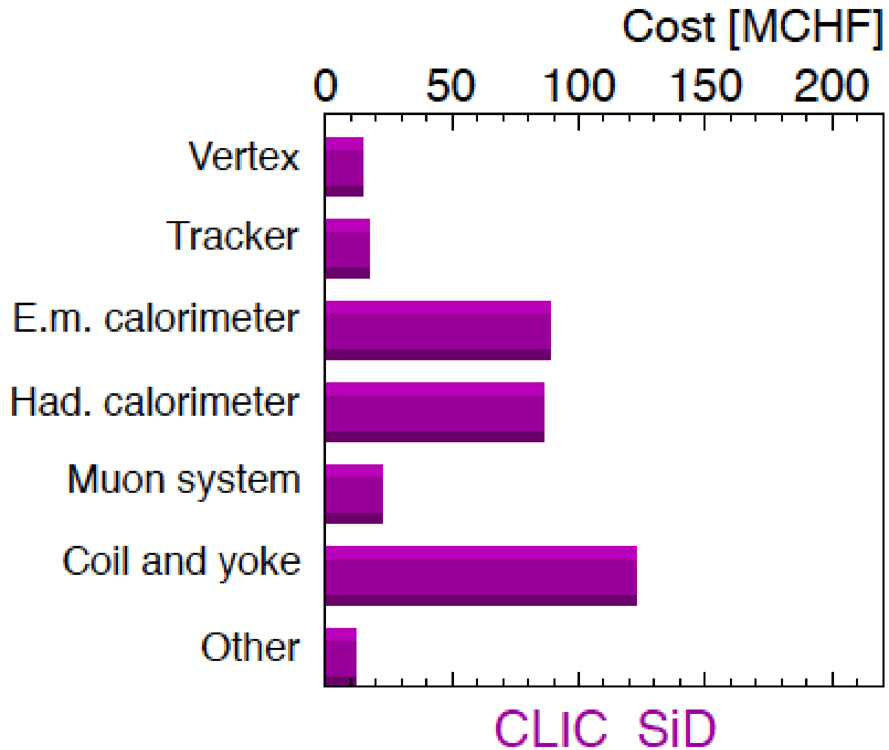


Fig. 4.2: Longitudinal cross section of the top quadrant of CLIC_ILD (left) and CLIC_SiD (right).

CLIC_SiD detector cost

	CLIC_SiD (MCHF)
Vertex	15
Tracker	17
Electromagnetic calorimeter	89
Hadronic calorimeter	86
Muon system	22
Coil and yoke	123
Other	12
Total (rounded)	360



CLIC_SiD detector concept optimised for 3 TeV, unit CHF, excl. labour

Results of Higgs benchmark studies

Table 6.1: Summary of results obtained in the Higgs studies for m_H =120 GeV. All analyses at centre-of-mass energies of 350 GeV and 500 GeV assume an integrated luminosity of 500 fb^{-1}, while the analyses at 1.4 TeV (3 TeV) assume 1.5 ab^{-1}(2 ab^{-1}).

Details will be presented at LCWS12 !

	Higgs studies for m_H =120 GeV							
	$\sqrt{s}$ (GeV)	Process	Decay mode	Measured quantity	Unit	Generator value	Stat. error	Comment
'12	350	SM Higgs production	$ZH \to \mu^+\mu^- X$	σ	fb	4.9	4.9%	Model independent, using Z-recoil
				Mass	GeV	120	0.131	
'12	500		$ZH \to q\bar{q}q\bar{q}$	$\sigma \times$ BR	fb	34.4	1.6%	$ZH \to q\bar{q}q\bar{q}$ mass reconstruction
				Mass	GeV	120	0.100	
'12	500		$ZH, H\nu\bar{\nu} \to \nu\bar{\nu}q\bar{q}$	$\sigma \times$ BR	fb	80.7	1.0%	Inclusive sample
				Mass	GeV	120	0.100	
'12	1400	WW fusion	$H \to \tau^+\tau^-$	$\sigma \times$ BR	fb	19.8	<3.7%	
	3000		$H \to b\bar{b}$			285	0.22%	
			$H \to c\bar{c}$			13	3.2%	
			$H \to \mu^+\mu^-$			0.12	15.7%	
'12	1400 3000	WW fusion		Higgs tri-linear coupling g_{HHH}			~20% ~20%	<= study still ongoing

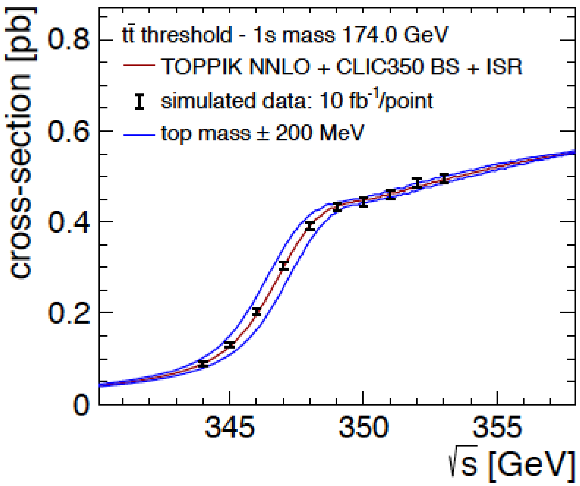
Results of top benchmark studies

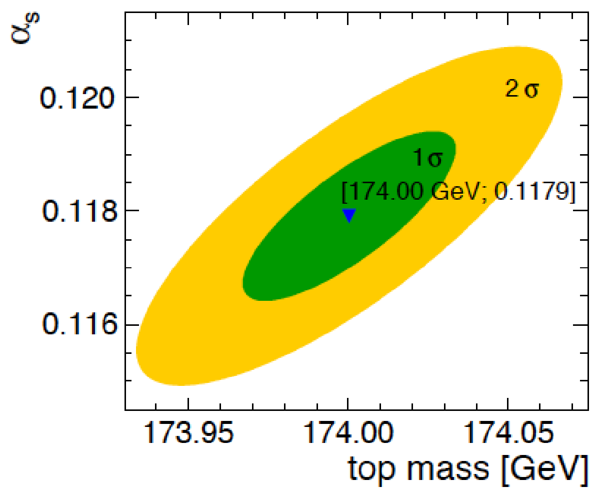
Table 6.2: Summary of full detector-simulation results obtained under realistic CLIC beam conditions in the top quark studies. The first (second) threshold scan contains 6 points (10 points) separated by 1 GeV and with 10 fb^{-1} of luminosity at each point.

Top studies

$\sqrt{s}$ (GeV)	Technique	Measured quantity	Integrated luminosity (fb^{-1})	Unit	Generator value	Stat. error	
350	Threshold scan	Mass	6×10	GeV	174	0.021	left
		Mass α_s	10×10	GeV	174 0.118	0.033 0.0009	right plot
500	Invariant mass	Mass	100	GeV	174	0.060	

'12





Results of SUSY benchmarks, 1.4 TeV

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
1.4 '12	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	σ	fb	1.11	2.7%
				$\tilde{\ell}$ mass	GeV	560.8	0.1%
				$\tilde{\chi}_1^0$ mass	GeV	357.8	0.1%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	5.7	1.1%
				$\tilde{\ell}$ mass	GeV	558.1	0.1%
				$\tilde{\chi}_1^0$ mass	GeV	357.1	0.1%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	5.6	3.6%
				$\tilde{\ell}$ mass	GeV	644.3	2.5%
				$\tilde{\chi}_1^\pm$ mass	GeV	487.6	2.7%
1.4 '12	Stau production	$\tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\tau}_1$ mass	GeV	517	2.0%
				σ	fb	2.4	7.5%
1.4 '12	Chargino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	III	$\tilde{\chi}_1^\pm$ mass	GeV	487	0.2%
				σ	fb	15.3	1.3%
	Neutralino production	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	487	0.1%
				σ	fb	5.4	1.2%

all results with L => 1.5 ab^{-1}

CLIC CDR Vol. 3

Results of SUSY benchmarks, 3 TeV

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
	Neutralino production	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%
3.0	Heavy Higgs production	$H^0A^0 \to b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
		$H^+H^- \to t\bar{b}b\bar{t}$		Mass	GeV	906.3	0.3%
				Width	GeV		27%

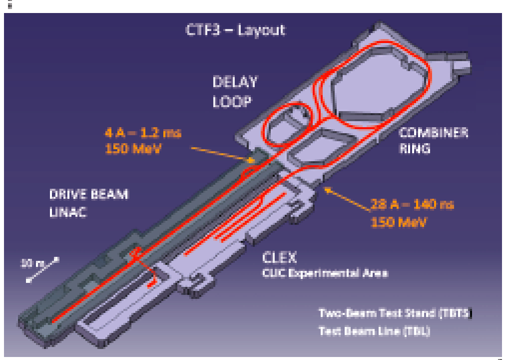
all results with L => 2 ab^{-1}

CLIC CDR Vol. 2

CLIC strategy and objectives

2012-16 Development Phase

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



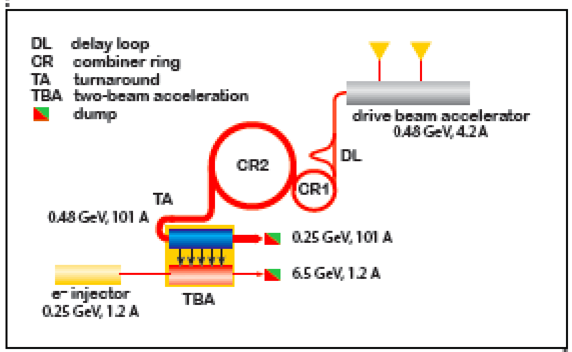
2016-17 Decisions

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

2017-22 Preparation Phase

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

Prepare detailed Technical Proposals for the detector-systems.



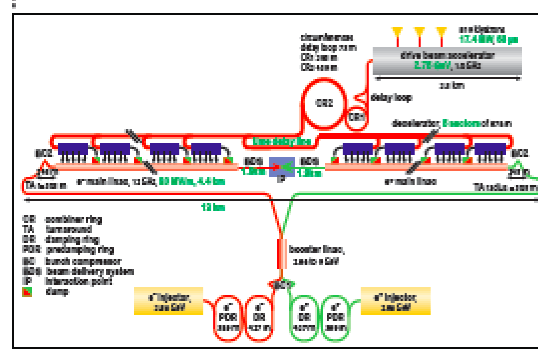
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Faster implementation possible, (e.g. for lower-energy Higgs factory): **klystron-based initial stage**

physics/detector objectives: 2012-2016

Implementation study and technical demonstration phase

Physics studies, following up on 8 TeV and 14 TeV LHC results

Exploration of SM physics (incl. Higgs, top) and reach for new physics

Adaptation of strategy for CLIC energy staging and luminosity levels

Detector optimisation

General detector optimisation + simulation studies in close relation with detector R&D

R&D: Implementation examples ***demonstrating the required functionality***

Vertex detector

Demonstration module, meeting requirements of high precision, 10 ns time stamp and ultra-low mass

Main tracker

Demonstration modules, including manageable occupancies in the event reconstruction

Calorimeters

Demonstration modules, technological prototypes + addressing control of cost

Electronics

Demonstrators, in particular in view of power pulsing

Magnet systems

Demonstrators of conductor technology, safety systems and moveable service lines

Engineering and detector integration

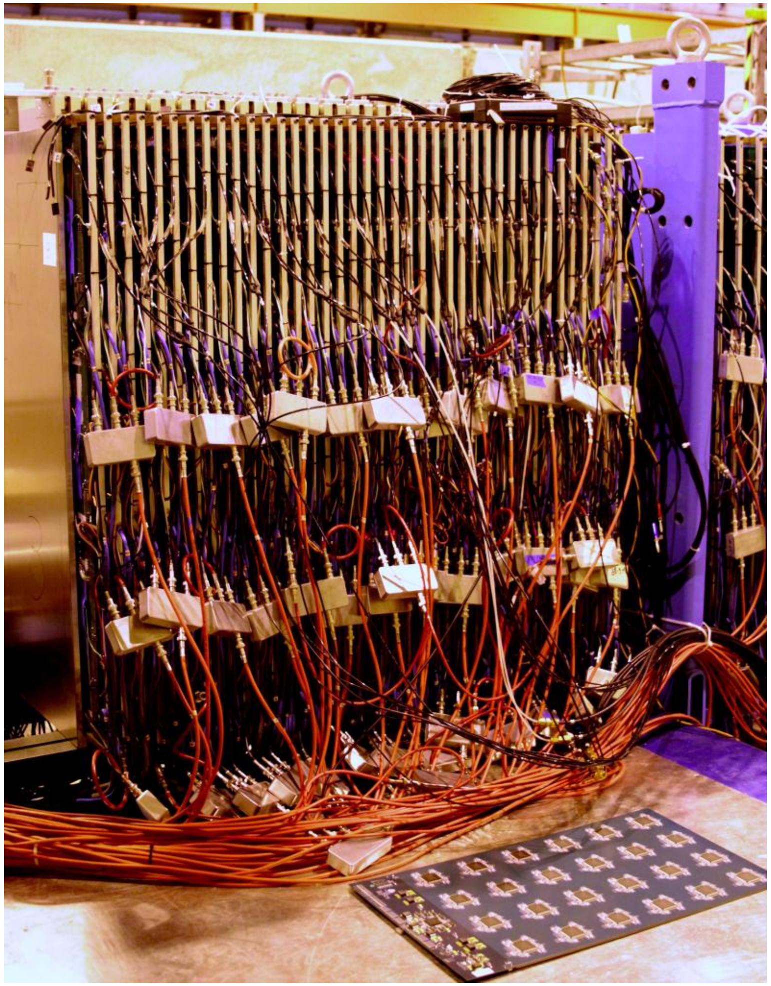
Engineering design and detector integration harmonized with hardware R&D demonstrators

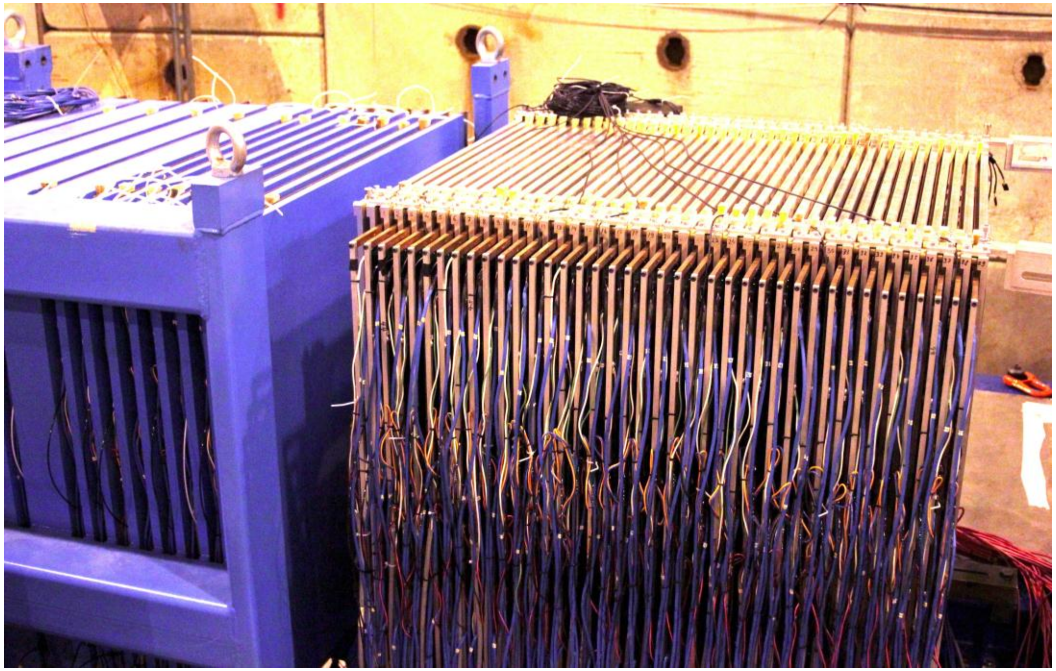
Lots of work in common with ILC !

Challenging detector technologies, considered feasible in a 5-year R&D program

Tungsten DHCAL tests (1)

HCAL tests with 10 mm thick **Tungsten absorber** plates,
Tests in 2012 with glass RPC (DHCAL) active layers, 1×1 cm^2 cells => digital readout



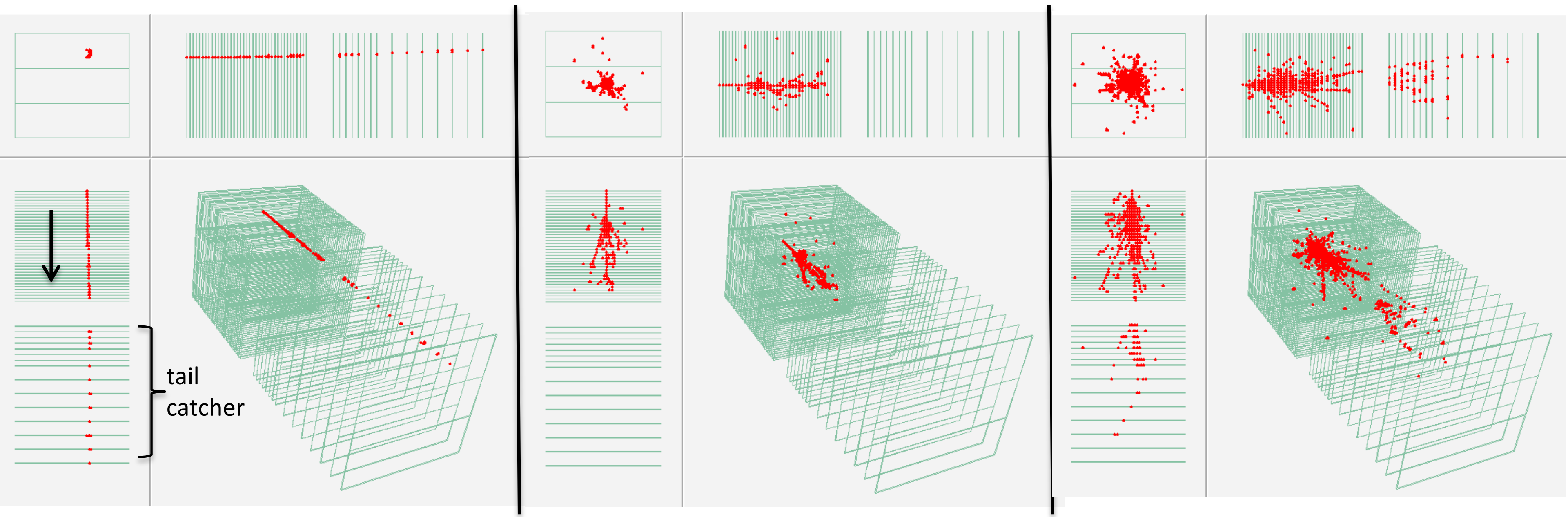


Successful beam tests at CERN: May –> August 2012

39 layers DHCAL + 15 layers tail catcher
(+ one strip of fast readout RPC after DHCAL)

Tungsten DHCAL tests (2)

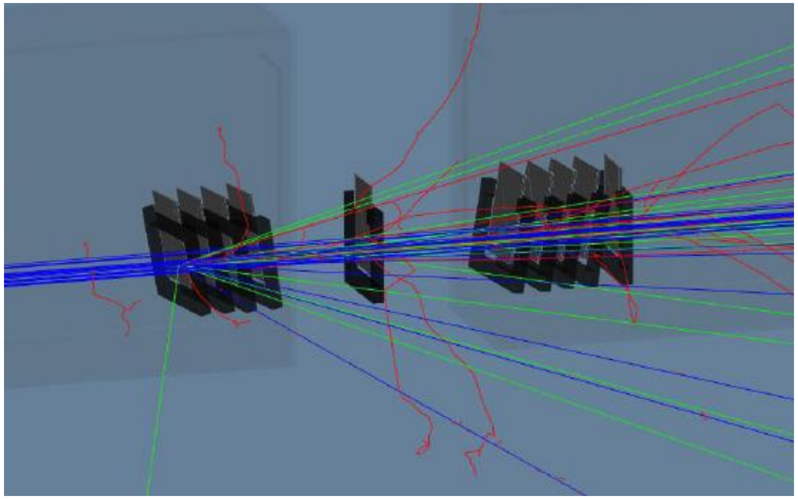
HCAL tests with 10 mm thick **Tungsten absorber** plates,
Tests in 2012 with glass RPC (DHCAL) active layers, 1×1 cm^2 cells => digital readout



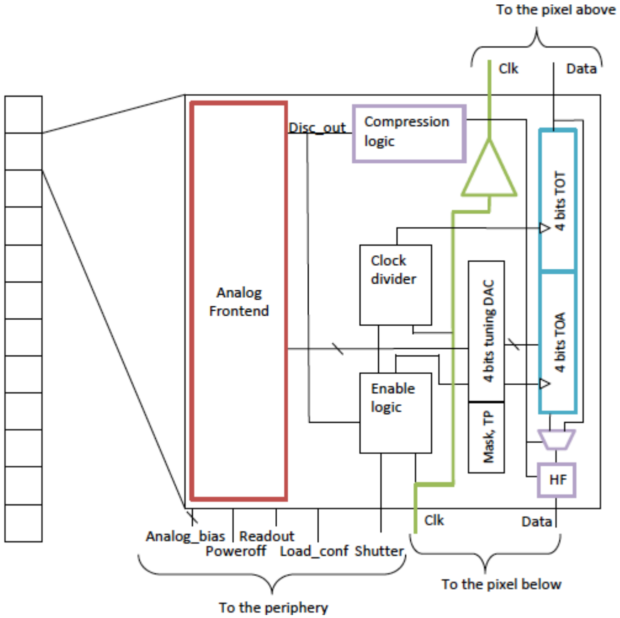
μ^+ at 10 GeV (PS) π^+ at 30 GeV (SPS) π^- at 210 GeV (SPS)

events are very clean !
tungsten is very dense (39 layers of 1 cm before tail catcher)

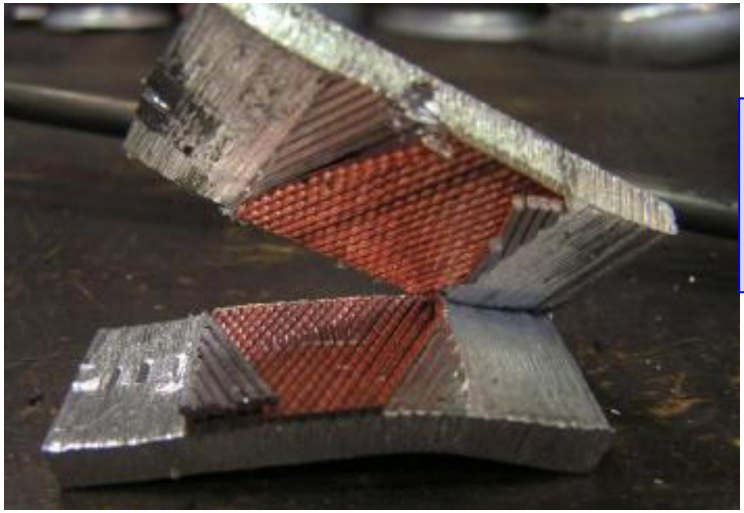
… and also



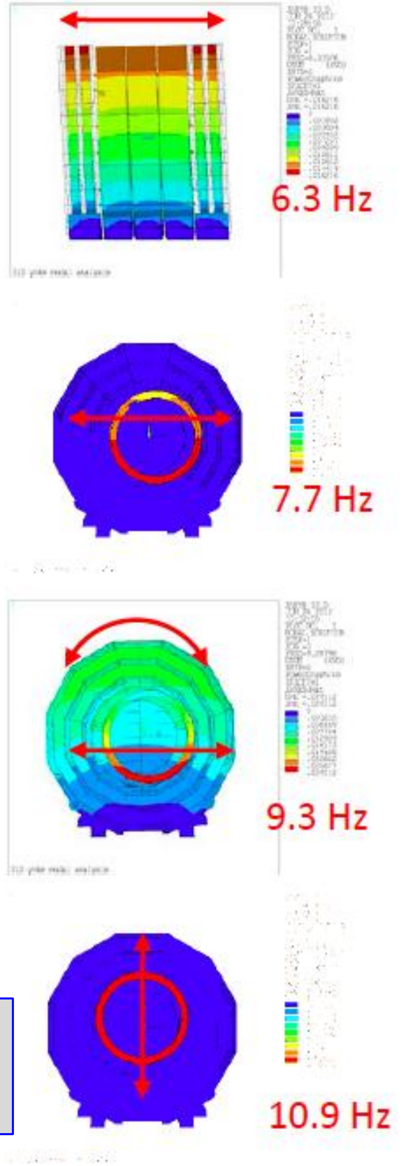
Simulations, lab test, beam test, power delivery studies with pixel assemblies



Pixel design, 65 nm technology



Extrusion test of reinforced conductor for solenoid



Seismic analysis CLIC-SiD yoke

summary and outlook

Summary of CLIC CDR studies

- CLIC accelerator feasibility demonstrated
- Feasibility of precision physics measurements demonstrated
- Staged implementation of CLIC => large potential for SM and BSM physics

Good progress with understanding detectors at CLIC

- Based on ILD and SiD concepts
- Detector requirements now well understood
- => challenging, but feasible through realistic R&D

Development program for the next CLIC phases

- Anticipating energy frontier machine choice 2016/2017
- Anticipating start of construction by 2022/2023

With many thanks
to all who contributed !
in particular acknowledging prior ILC SiD work

SPARE SLIDES

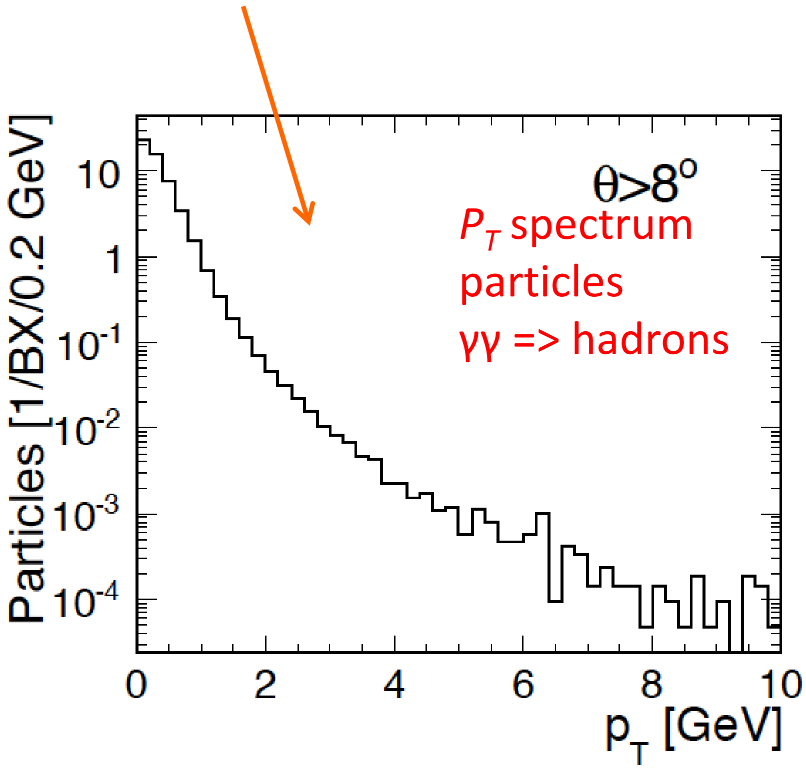
CLIC parameters, 3 TeV and 500 GeV

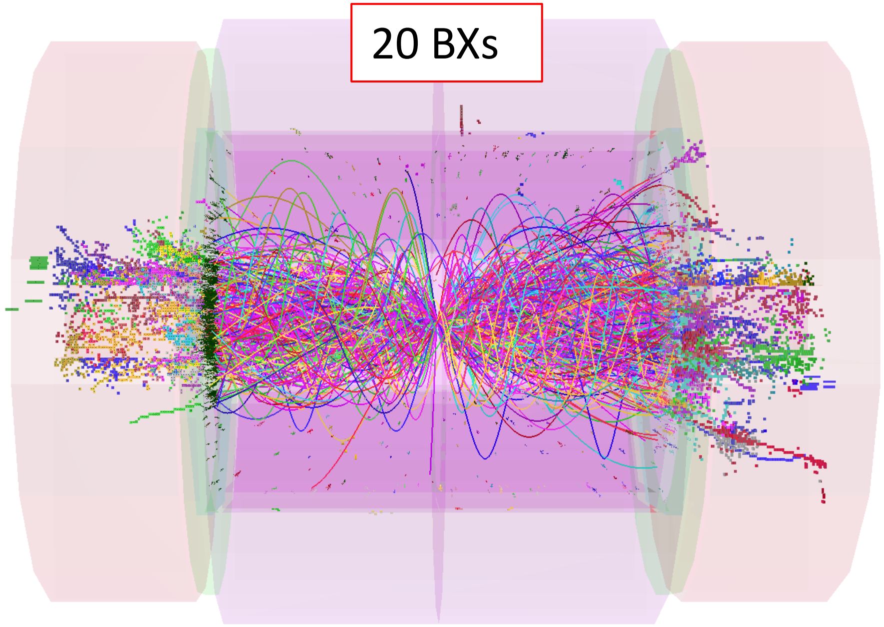
Table 3.1: Key parameters of the 3 TeV and 500 GeV designs.

Parameter	Symbol	Unit	500 GeV	3 TeV
Centre-of-mass energy	$\sqrt{s}$	TeV	0.5	3.0
Repetition frequency	f_{rep}	Hz	50	50
Number of bunches per train	n_b		354	312
Bunch separation	Δt	ns	0.5	0.5
Accelerating gradient	G	MV/m	80	100
Total luminosity	$\mathscr{L}_{total}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	2.3	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.4	2.0
Number of photons per electron/positron	n_γ		1.3	2.1
Average energy loss due to beamstrahlung	$\Delta E/E$		0.07	0.28
Number of coherent pairs per bunch crossing	N_{coh}		2×10^{-2}	6.8×10^{8}
Energy of coherent pairs per bunch crossing	E_{coh}	TeV	15	2.1×10^{8}
Number of incoherent pairs per bunch crossing	n_{incoh}	10^6	0.08	0.3
Energy of incoherent pairs per bunch crossing	E_{incoh}	10^6 GeV	0.36	23
Hadronic events per bunch crossing	n_{had}		0.3	3.2

impact of γγ → hadrons

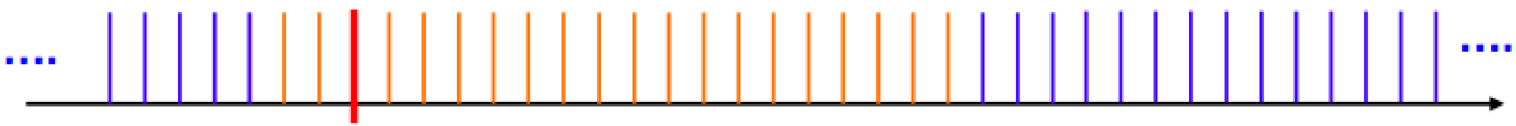
- Dominating background
- For entire bunch-train (312 BXs)
  - 5000 tracks giving total track momentum : 7.3 TeV
  - Total calorimetric energy (ECAL + HCAL) : 19 TeV
- Mostly low p_T particles





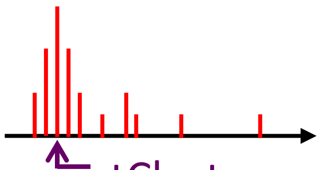
background suppression at CLIC

Triggerless readout of full train



t_0 physics event (offline)

- **Full event reconstruction + PFA analysis with background overlaid**
  - => physics objects with precise p_T and cluster time information
  - Time corrected for shower development and TOF
- **Then apply cluster-based timing cuts**
  - Cuts depend on particle-type, p_T and detector region
  - Allows to protect high-p_T physics objects



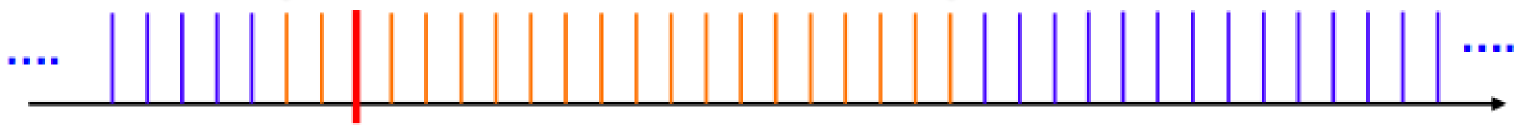
+

- **Use well-adapted jet clustering algorithms**
  - Making use of LHC experience (FastJet)

time window / time resolution

The event reconstruction software uses:

Subdetector	Reconstruction window	hit resolution
ECAL	10 ns	1 ns
HCAL Endcaps	10 ns	1 ns
HCAL Barrel	100 ns	1 ns
Silicon Detectors	10 ns	$10/\sqrt{12}$ ns
TPC	entire bunch train	n/a



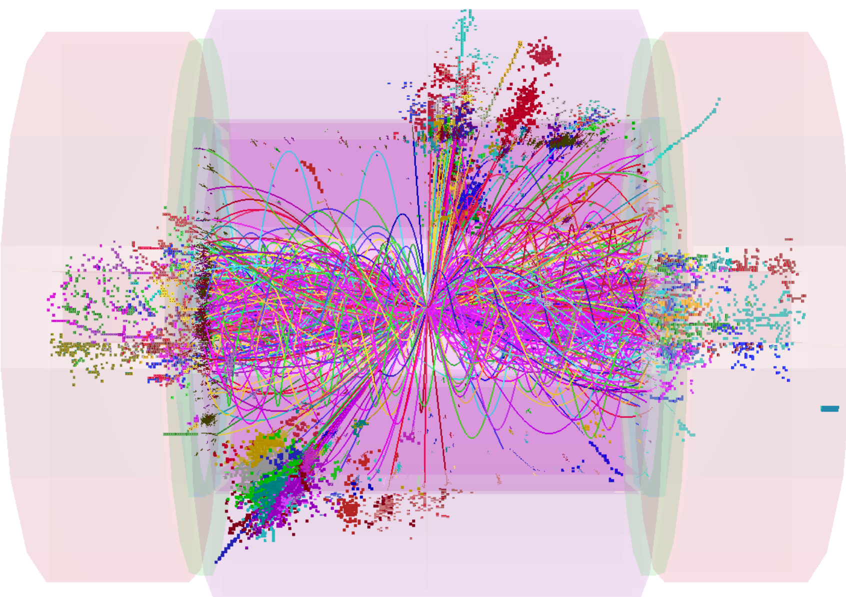
t_0 physics event (offline)

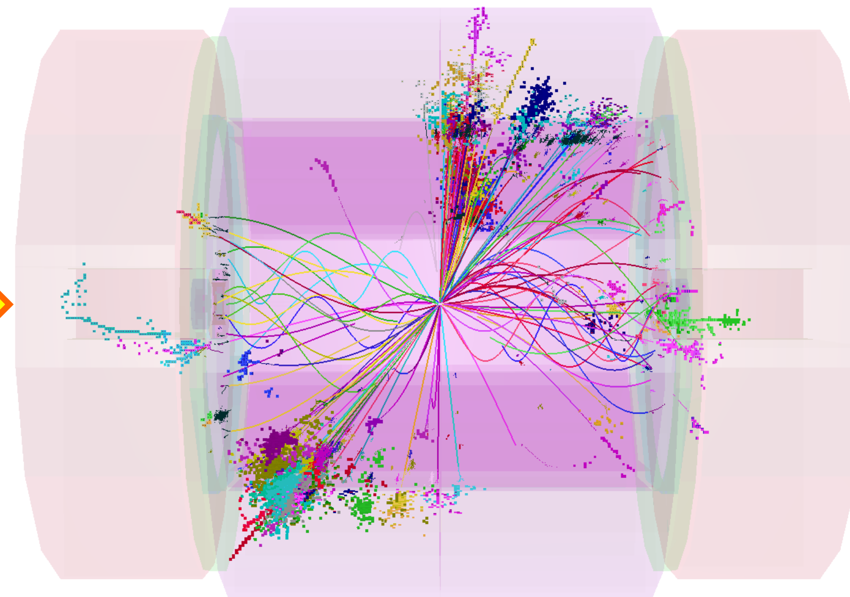
Translates in precise timing requirements of the sub-detectors

combined p_T and timing cuts

1.2 TeV

100 GeV





$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t} \rightarrow 8 \text{ jets}$$

1.2 TeV background in reconstruction time window

100 GeV background after tight cuts

PFO-based timing cuts

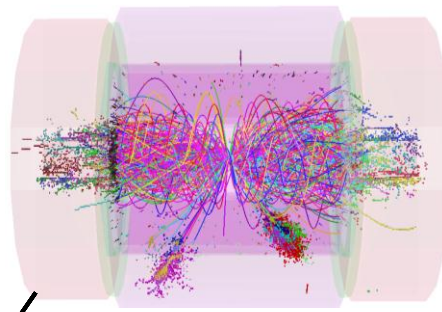
Region	p_t *range*	Time cut
Photons		
central ($\cos\theta \leq 0.975$)	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$ $0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$ $0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
Neutral hadrons		
central ($\cos\theta \leq 0.975$)	$0.75\ \text{GeV} \leq p_t < 8.0\ \text{GeV}$ $0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 2.5$ nsec $t < 1.5$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \text{GeV} \leq p_t < 8.0\ \text{GeV}$ $0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
Charged PFOs		
all	$0.75\ \text{GeV} \leq p_t < 4.0\ \text{GeV}$ $0\ \text{GeV} \leq p_t < 0.75\ \text{GeV}$	$t < 3.0$ nsec $t < 1.5$ nsec

- Track-only minimum p_t: 0.5 GeV
- Track-only maximum time at ECAL: 10 nsec

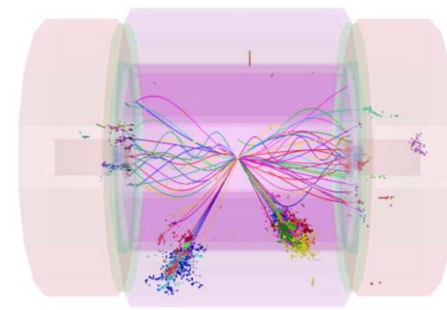
jet clustering (example)

e.g. $e^+e^- \rightarrow \tilde{q}_R \tilde{q}_R \rightarrow q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$

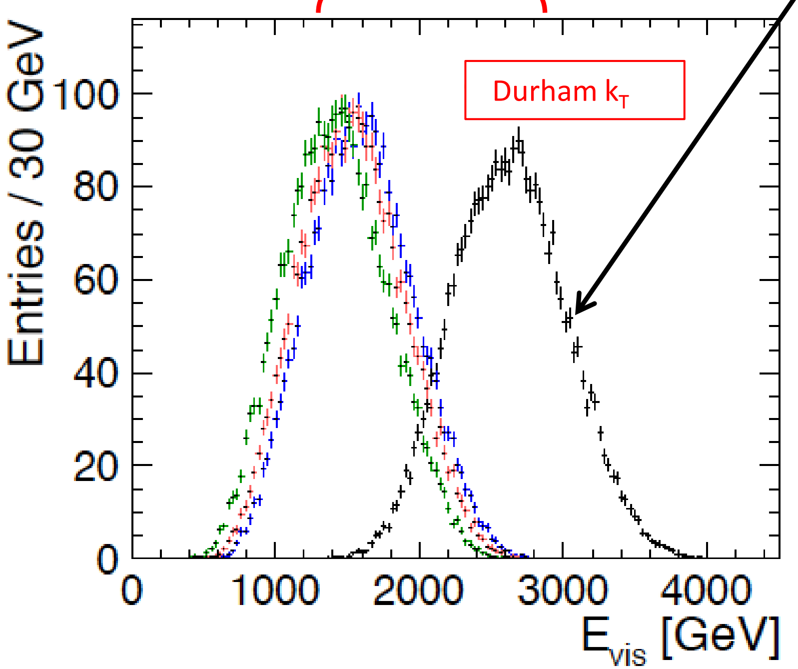
- for squark mass ~1.1 TeV
- two jets + missing energy

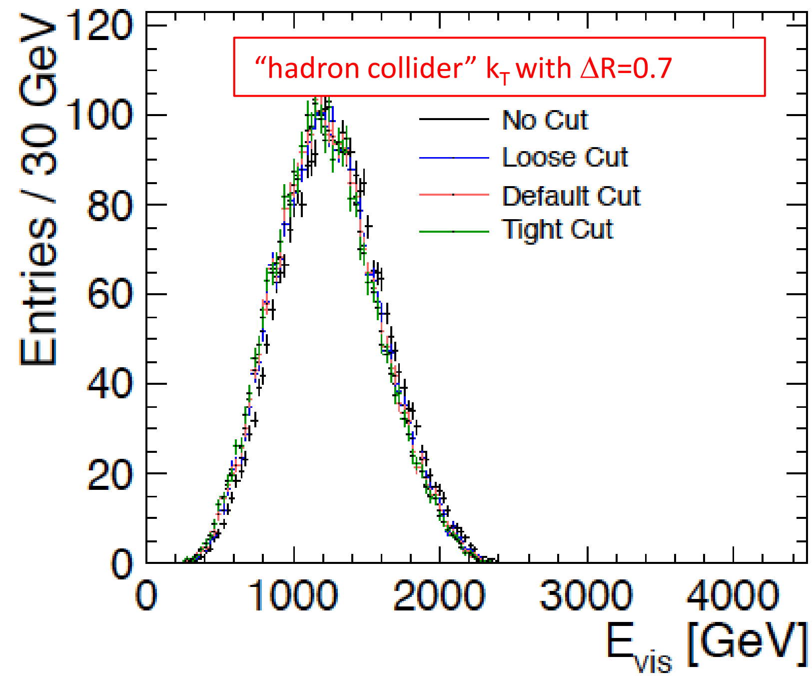


TIGHT timing



All particles clustered





Result of this detector benchmark study: $m_{\tilde{q}_R}$: $\pm 6\,\mathrm{GeV}$

detector benchmark studies for CDR

Six benchmark studies reported in the published CDR

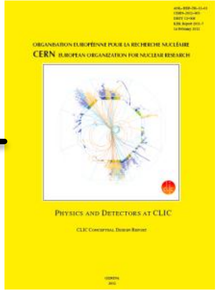
Full physics simulation and reconstruction studies with beam background overlay ($\gamma\gamma$ => hadrons):

3 TeV ($2\ ab^{-1}$)

- $e^+e^- \rightarrow h\nu_e\bar{\nu}_e$
- $e^+e^- \rightarrow H^+H^- / H^0A$
- $e^+e^- \rightarrow \tilde{q}_R\bar{\tilde{q}}_R$
- $e^+e^- \rightarrow \tilde{\ell}^+\tilde{\ell}^-$
- $e^+e^- \rightarrow \tilde{\chi}_i^+\tilde{\chi}_i^- / \tilde{\chi}_i^0\tilde{\chi}_i^0$

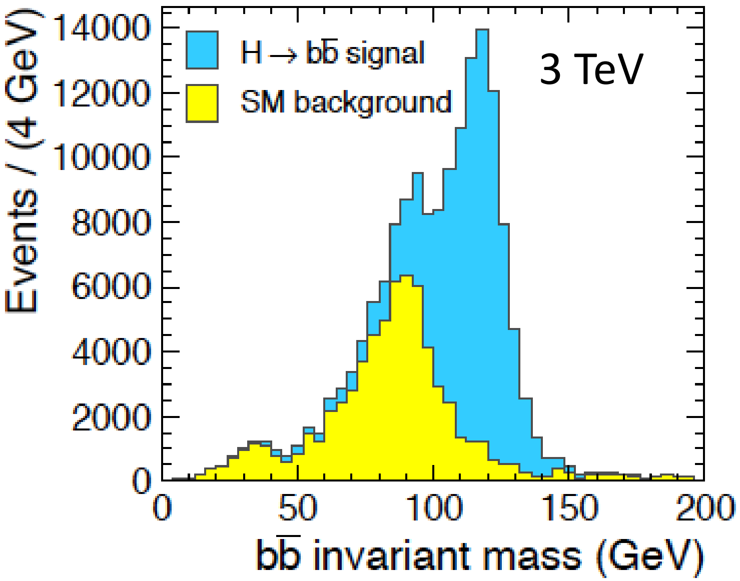
500 GeV ($500\ fb^{-1}$)

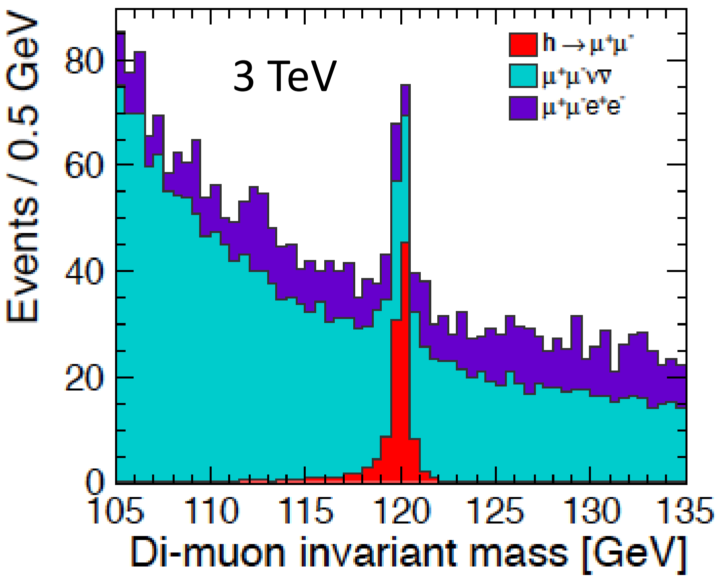
- $e^+e^- \rightarrow t\bar{t}$



SM Higgs

Full detector simulation/reconstruction with background overlaid at 3 TeV





$\sigma(h \rightarrow b\bar{b}) \rightarrow \pm 0.2\%$

$\sigma(h \rightarrow c\bar{c}) \rightarrow \pm 3\%$

$\sigma(h \rightarrow \mu^+\mu^-) \rightarrow \pm 15\%$

(statistical accuracies)

Preliminary studies of HH production indicate:

$\Delta\lambda/\lambda \leq 20\%$ at 1.4 TeV

$\Delta\lambda/\lambda \leq 25\%$ at 3 TeV

Direct probe of Higgs potential !