The CLIC re-baselining document

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on behalf of the CLIC re-baselining editor team

CLIC workshop
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The CLIC re-baselining document

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Updated baseline for a staged Compact Linear Collider

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- Editors:
  Philip Burrows, Philippe Lebrun, Lucie Linssen, Daniel Schulte, ES, Steinar Stapnes, Mark Thomson
- Update of CLIC staging baseline
- Focus on initial energy stage
- Updated official CLIC figures
- Latest version always at this website
  http://esicking.web.cern.ch/esicking/ClicStagingBaseline/

Content of re-baselining document

Contents

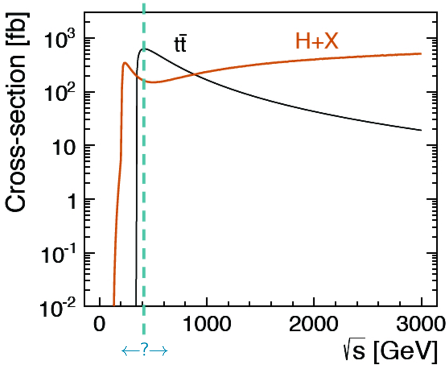
→ Physics considerations

→ Accelerator optimisation methodology

→ New staging baseline

Physics motivation of re-baselining

- CLIC is foreseen as staged machine with $\sqrt{s}$ from few-hundred GeV to 3 TeV

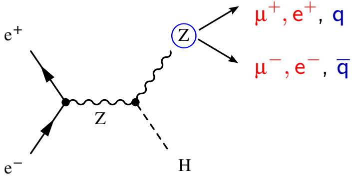


- 1^{st} stage
  - Guaranteed physics: **Higgs coupings + width** and **top**
  - Higgs discovered after CDR
  - $m_H = 125$ GeV
- Subsequent (2^{nd} and 3^{rd}) stages
  - Motivated by Higgs physics and new physics
  - → Potential discoveries at the LHC at 14 TeV
  - → Direct and indirect searches for beyond standard model physics

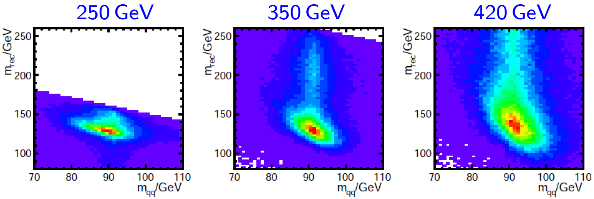
- Optimal $\sqrt{s}$ for 1^{st} stage is not at peak of HX and $t\bar{t}$ cross sections
  → luminosity and backgrounds can scale with centre-of-mass energy
  → theory uncertainties for $t\bar{t}$ can be larger close to on-set of $t\bar{t}$ production

Higgs recoil mass at $\sqrt{s} = 250/350/420$ GeV

- Accuracies of Higgs results governed by accuracy of **HZ coupling**
- HZ coupling in Z recoil mass measurement in first energy stage
- Hadronic channel ($\text{BR}_{Z\to q\bar{q}} \approx 70\,\%$) has largest impact
- Test three energies:



$$m^2_{\text{recoil}} = s + m^2_Z - 2E_Z\sqrt{s}$$



$\sqrt{s}$	σ(HZ)	$\Delta\,\sigma$(HZ)
250 GeV	136 fb	$\pm$3.65 %
350 GeV	93 fb	$\pm$1.80 %
420 GeV	68 fb	$\pm$2.63 %

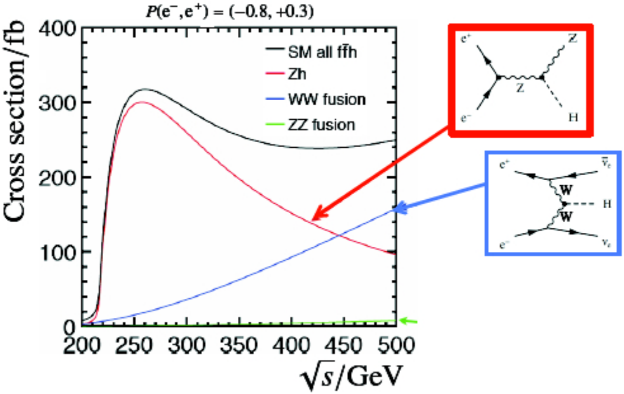
→ arXiv:1509.02853[hep-ex]

- Find optimal energy for first CLIC stage
  - Cross section decreases with $\sqrt{s}$
  - Absolute detector resolution degrades with $\sqrt{s}$
  - Background rejection improves with increasing $\sqrt{s}$

→ Optimum close to 350 GeV

Access to Higgsstrahlung and WW fusion

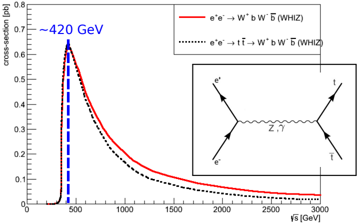
- For a comprehensive Higgs study in the first energy stage only, access to several Higgs production processes is advantageous

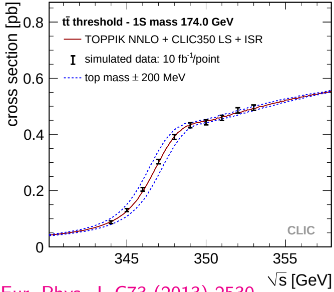


- Below $\sqrt{s} \sim 300$ GeV Higgsstrahlung dominates
- Above $\sqrt{s} \sim 500$ GeV, WW-fusion dominates

→ At $\sqrt{s} = 350$–450 GeV both processes contribute

Top physics





- At $\sqrt{s} > 350$ GeV, top pair production sets on
- Maximum at $\sqrt{s} > 420$ GeV, then cross section falls steeply (s-channel)

- High precision measurement of top mass from threshold scan with modest luminosity ($10\,\text{fb}^{-1}$/point) in addition to first energy stage

$\rightarrow$ $\delta m_t = 33$ MeV statistical uncertainty

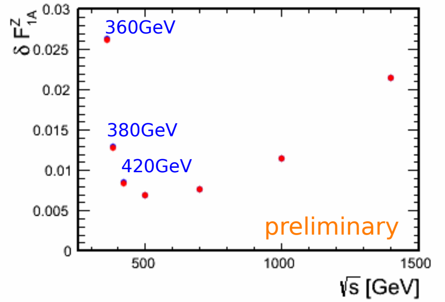
$\rightarrow$ Eur. Phys. J. C73 (2013) 2530

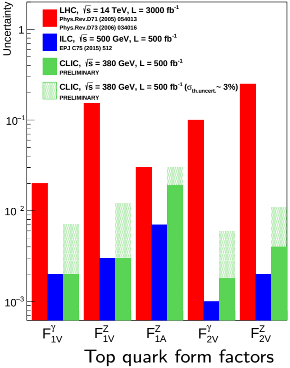
Top form factor measurement

→ Talk by Ignacio Garcia on Thursday

- Probe top vertex through cross section and forward-backward asymmetry (A_{FB})
  - Derive top form factors (F)
  - Expect deviations from SM expectations in form factors for BSM models

- Form factor uncertainty vs. $\sqrt{s}$ (500 fb^{-1} each)





- Reconstruction capability and impact of BSM on form factor increases with $\sqrt{s}$
- Theoretical uncertainty decrease with $\sqrt{s}$

→ Optimum close to 500 GeV (for fixed luminosity per $\sqrt{s}$)

Conclusion on CLIC first energy stage

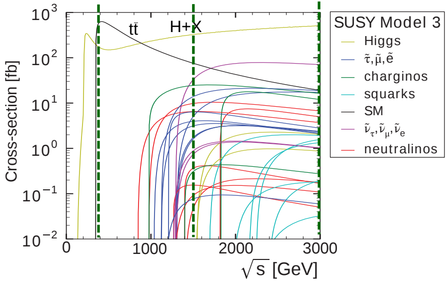
Find compromise for comprehensive physics programme of initial stage

- Higgs recoil mass measurement
  $\rightarrow$ $250\,\text{GeV} < \sqrt{s} < 420\,\text{GeV}$
- Higgs production via Higgsstrahlung and WW-fusion
  $\rightarrow$ $250\,\text{GeV} < \sqrt{s} < 450\,\text{GeV}$
- Top pair production
  $\rightarrow$ $\sqrt{s} > 350\,\text{GeV}$, maximum at $\sqrt{s} \approx 420\,\text{GeV}$
- Top as probe for BSM
  $\rightarrow$ $\sqrt{s} > 360\,\text{GeV}$
- Top not too close to threshold (theory uncertainties, boost)
  $\rightarrow$ $\sqrt{s} >> 350\,\text{GeV}$

$\rightarrow \sqrt{s} = 380\,\text{GeV}$

Proposed CLIC staging baseline

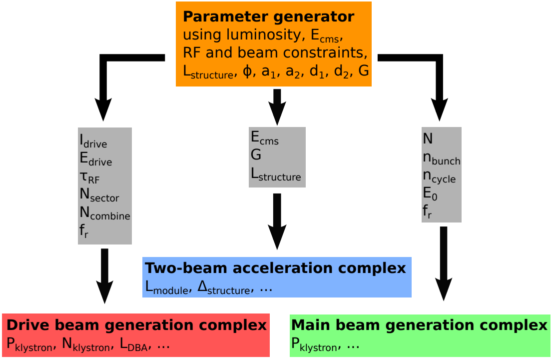
- CLIC energy stages defined by physics
- Proposed scenario
  1) $\sqrt{s} = 380\,\text{GeV}$
     - SM Higgs physics including total width measurement
     - Top precision measurements
     - New physics
  2) $\sqrt{s} = 1.5\,\text{TeV}$
     - New physics
     - $t\bar{t}H$, Higgs self coupling
     - Rare Higgs decays
  3) $\sqrt{s} = 3\,\text{TeV}$
     - New physics
     - Higgs self coupling
     - Rare Higgs decays



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

CLIC Accelerator Optimisation for $\sqrt{s} = 380\,\mathrm{GeV}$

- Accelerator structure design fixed by few parameters ($L_{\mathrm{structure}}$, Φ, ...)
- Find optimal parameter set for 380 GeV CLIC accelerator in parameter scan
- Evaluation tool exists, developed after CDR, based on methods already used in CDR
- Tested ~2 billion possible structures and resulting accelerator complexes based on these parameters

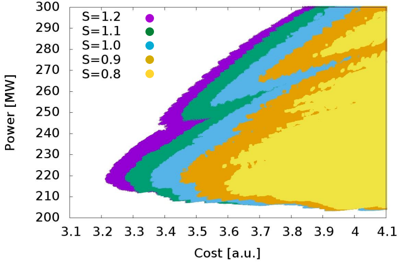


- All structures are checked for consistency with beam and RF constraints
- Gauging cost, power and luminosity (not including beam induced backgrounds)

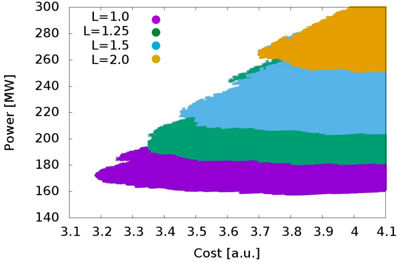
Example: Cost and power for 380 GeV

- Compared cost and power consumption for all resulting structures
  - Choice: fixed pulse length of 244 ns for all stages
  - Note: some accelerator components not included in cost and power, e.g. BDS, main beam injector

Safety margin S for gradient



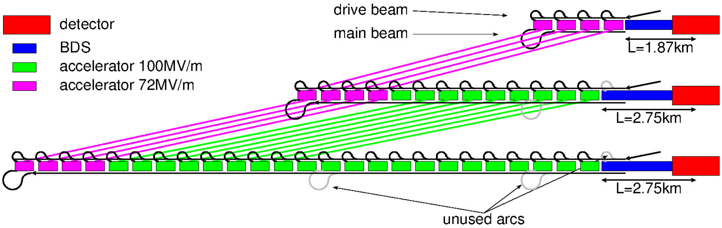
Luminosity target L



- Choice of safety margin 10% (S=1.1): only small impact on cost and power
- Cost and power increase with luminosity target (choice $L=1.5 \cdot 10^{34}cm^{-2}s^{-1}$: can reach $\mathcal{L}_{\text{int}} = 600\,\text{fb}^{-1}$ in 7 years)

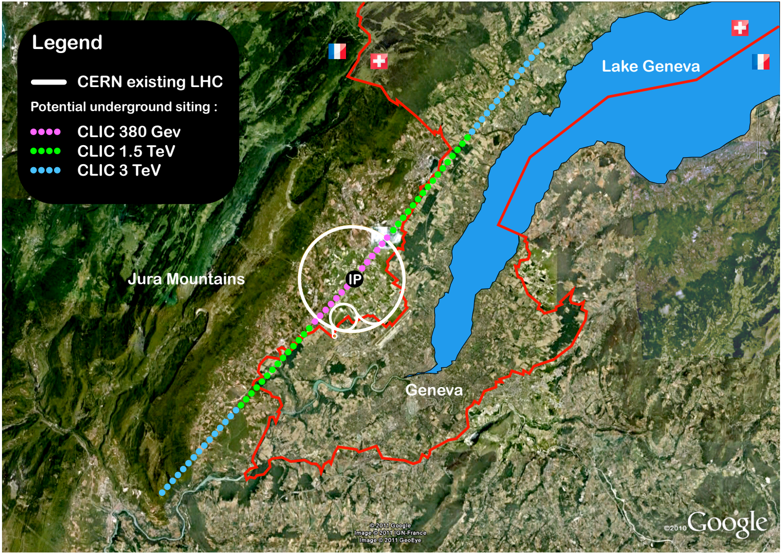
→ Most efficient structure: $G = 72\,\text{MV/m}$, similar to "CLIC_G"

Potential staging concept



- For the structures optimised for 380 GeV, staging scenario towards higher energy stages is available

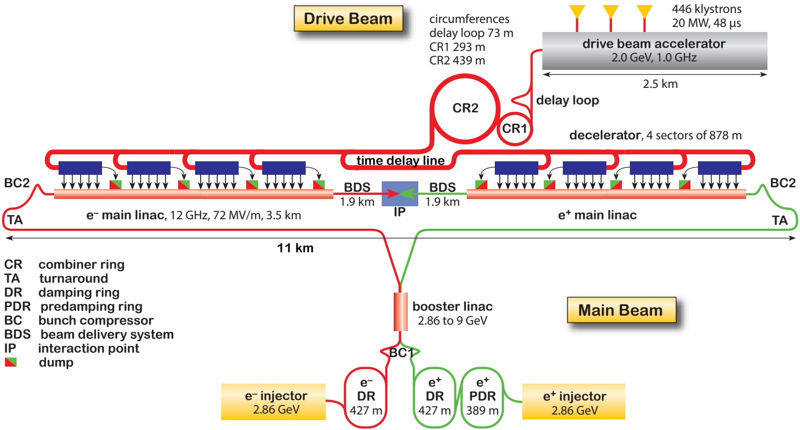
Updated CLIC footprint



Updated CLIC parameter table: Stage 1–3

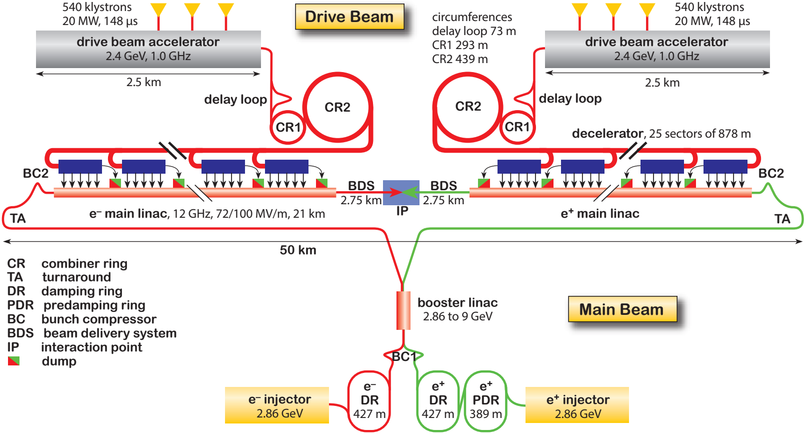
Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	$\Delta\, t$	ns	0.5	0.5	0.5
Pulse length	τ_{pulse}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathcal{L}$	10^{34} cm^{-2}s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathcal{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.9	1.4	2
Main tunnel length		km	11.4	29.0	50.1
Charge 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	—	660/20	660/20
Normalised emittance	ϵ_x/ϵ_y	nm	950/30	—	—
Estimated power consumption	P_{wall}	MW	252	364	589

New CLIC layout at 380 GeV



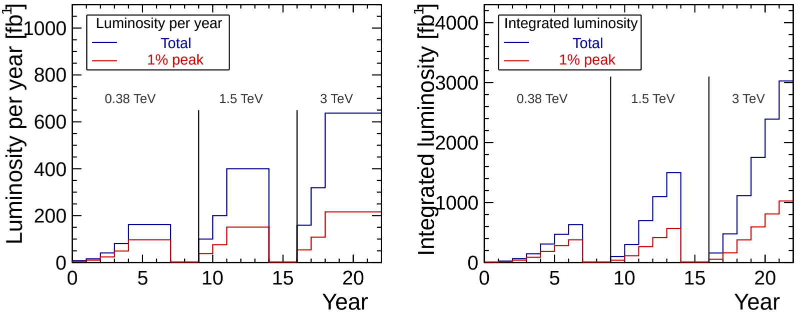
- Removed 1 e^--damping ring
- 11 km length (instead of 13 km at 500 GeV)
- 4 sectors (instead of 5 sectors at 500 GeV), ...

New CLIC layout at 3 TeV



- Removed 1 e^--damping ring
- 50 km length instead of 48 km
- 25 sectors instead of 24 sectors, …

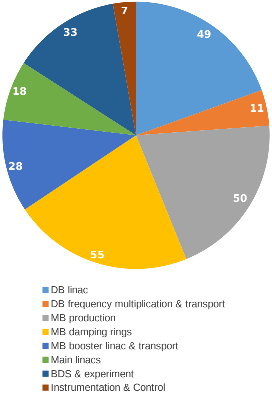
Updated luminosity development



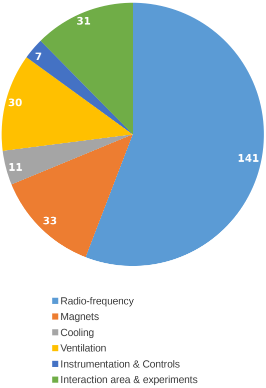
- CLIC programme of 22 years:
  7 years (380 GeV), 5 years (1.5 TeV), 6 years (3 TeV)
  interleaved by 2-years upgrade periods
- Luminosity ramp up of 4 years / 2 years
  (5%, 10%,) 25%, 50%, 100%

Updated power consumption at 380 GeV

per domain of the CLIC accelerator



per technical system



- CLIC power consumption at 380 GeV: $\sim$ 252 MW$_{\text{preliminary}}$ including all accelerator systems, services, experimental area and detector

(Note → Numbers scaled from CDR design at 500 GeV
→ To be repeated with detailed tech. description of 380 GeV CLIC)

Updated power consumption at all stages

- Current estimates of power consumption[1]

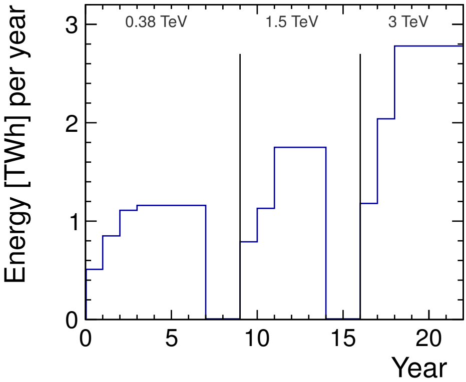
$\sqrt{s}$ [TeV]	P_{nominal}[MW]	$P_{\text{waiting for beam}}$[MW]	P_{stop}[MW]
0.38	252	168	30
1.5	364	190	42
3.0	589	268	58

- Potential power savings (not yet included here):
  - Re-design, possibly trading operation expenditure against investment costs
  - Lower current density in normal conducting magnets and cables
  - Use of permanent magnets → Talk by Jim Clarke on Wednesday
  - Reduction of heat loads to ventilation system (enhancement of water cooling)
  - Replacing normal-conducting by "super-ferric" magnets
  - Improving network-to-RF power conversion

→ estimated to be up to 30 MW at 380 GeV

[1]Note: 380 GeV numbers scaled from CDR, 1.5 TeV and 3 TeV numbers from CDR

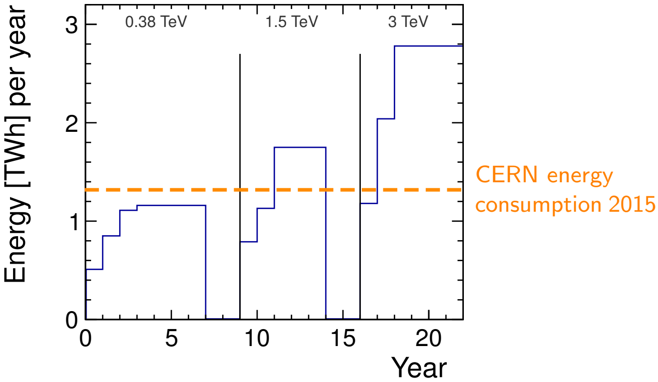
Yearly energy consumption



- Including reduced operation in the first years at each energy
- At 380GeV, a single positron target is used for the first three years (-10 MW with respect to nominal)

(Note → 380 GeV numbers scaled from CDR design at 500 GeV
→ To be repeated with detailed tech. description of 380 GeV CLIC)

Yearly energy consumption



- Including reduced operation in the first years at each energy
- At 380GeV, a single positron target is used for the first three years (-10 MW with respect to nominal)

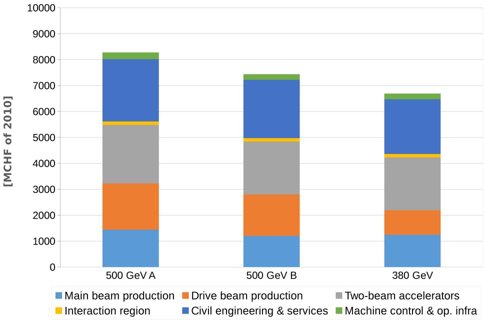
(Note → 380 GeV numbers scaled from CDR design at 500 GeV
→ To be repeated with detailed tech. description of 380 GeV CLIC)

Cost estimate for 380 GeV

- Full CLIC cost estimation including all contributions
- Use 2010 CHF for direct comparison to CDR estimates

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

Comparison to CDR values



- Full 380 GeV CLIC machine: $\sim$ 6.7 BCHF (2010)$_{\text{preliminary}}$ (+ 4 MCHF/GeV up to 1.5 TeV)

(Note → Numbers scaled from CDR design at 500 GeV
→ To be repeated with detailed tech. description of 380 GeV CLIC)

Summary

- CLIC re-baselining document close to final
  - Focus on initial energy stage at 380 GeV
  - 380 GeV cost: 6.7 BCHF(2010), power: 252 MW
  - Optimal accelerator structures close to CDR design "CLIC_G"
  - Update of official CLIC figures and tables
- Latest document version can be found at this website
  http://esicking.web.cern.ch/esicking/ClicStagingBaseline/
- Please check if you and your institute are already represented correctly in the author list and the acknowledgements
- Collaboration review will start soon

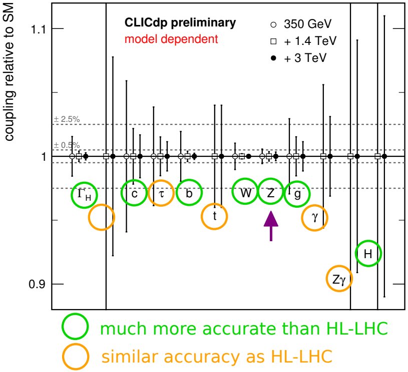
Backup

CLIC Higgs results for example staging scenario

- Studied Higgs physics potential of CLIC in staging scenario including 350 GeV (500 fb^{-1}), 1.4 TeV (1500 fb^{-1}) and 3 TeV (2000 fb^{-1})
- Combine results of studied Higgs production and decay channels in global fit → extract couplings and Higgs width

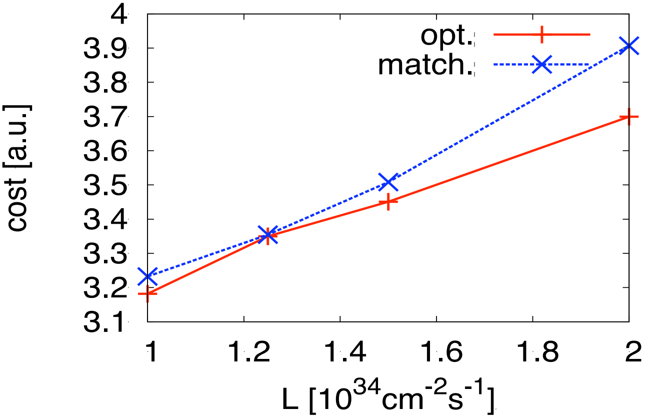
Based on results from full Geant4 detector simulations including backgrounds →

Assuming 80 % e^- beam polarisation at 1.4 TeV and 3 TeV



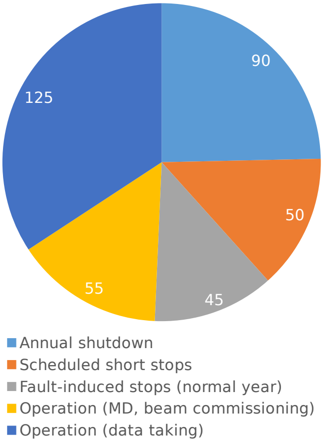
- Accuracies **governed by H-Z coupling** from H recoil mass measurement

Cost of initial stage



- Structures optimised for 380 GeV are similar in cost to those optimised for matching 3 TeV needs (+3% at $L = 1.5 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$)

Assumed operational scenario in “normal” years

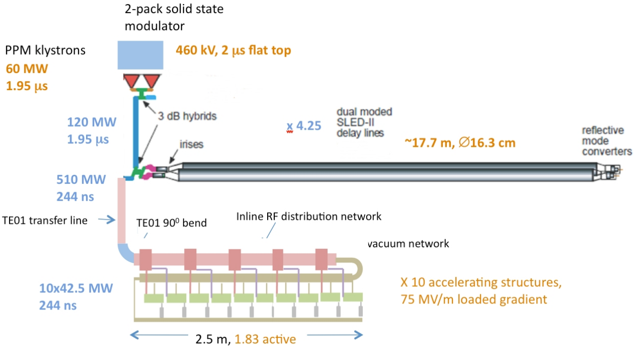


- 90-day annual shut-down
- 50 days of scheduled maintenance stops (1 day per week and 2 weeks every 2 months)

- Remaining 225 days
  - 45 days (20%) fault-induced stops
  - 180 days (80%) for operation
    - 55 days machine development and tuning runs
    - 125 days for physics data taking

Alternative klystron-based scenario

- At 3 TeV, drive-beam acceleration is more efficient and cost effective than klystrons
- At 380 GeV, X-band klystrons however interesting alternative



- Klystron-based CLIC concept for 380 GeV designed including
  - X-band klystrons
  - Pulse compressor
  - RF distribution system
  - Accelerating structures