LINEAR e^+e^- COLLIDER AT CERN

- Linear collider at CERN, first at 250 then at 550 GeV
- Possible further upgrades
- Replies to ESPP questions

12/02/2025 — NL ESPP
[indico]

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Nikhef

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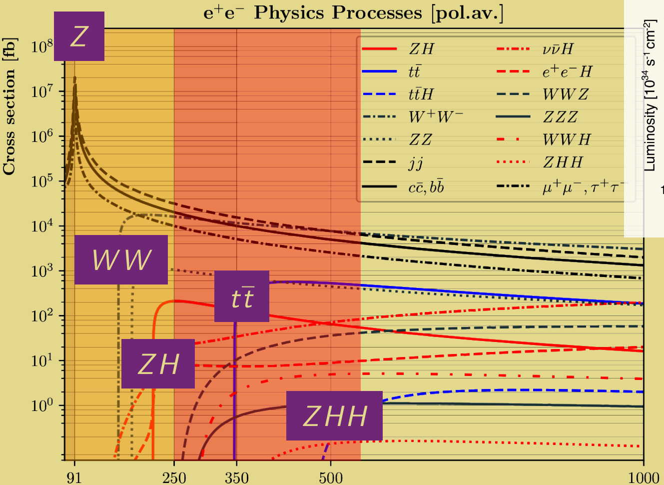
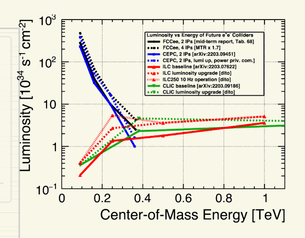
e^+e^- CROSS-SECTIONS



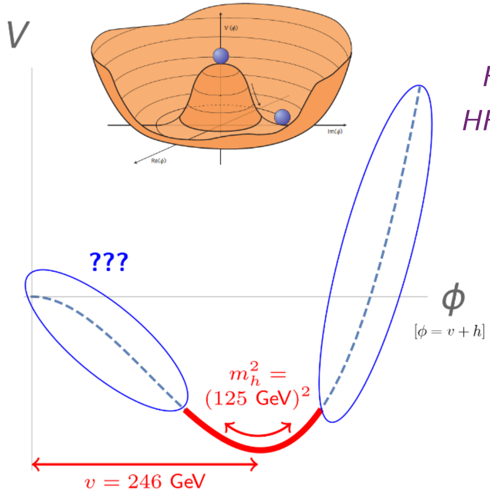
[B]

[J.R. Reuter]



Circular colliders are optimal at low $\sqrt{s}$. The higher you go, the better LC become.

Higgs potential

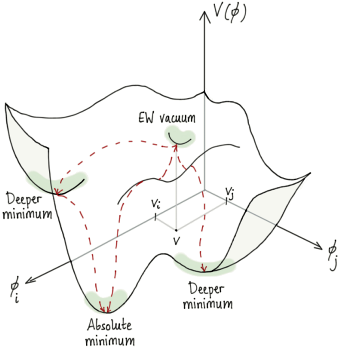


H: VEV $= 246$ GeV

HH: mass $= 125$ GeV

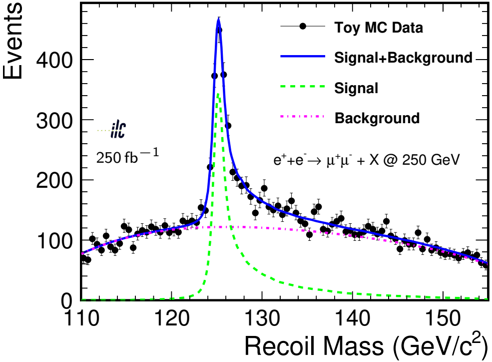
HHH: trilinear coupling unknown

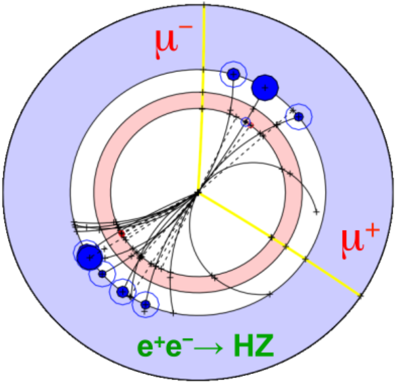
HHHH: quartic coupling unknown



Higgs couplings

With $\mathcal{O}(10^6)$ ZH events you can get an absolute measurement of the H coupling. LHC measurements are ratios.



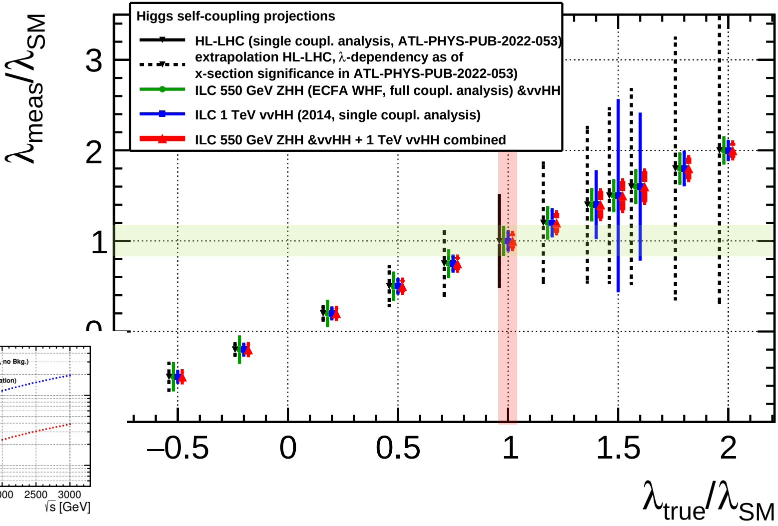


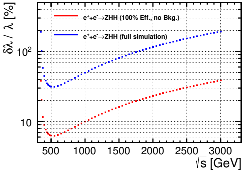
[indico]

Higgs self-coupling

Linear Collider Vision

Then go to 550 GeV





[Dawson, Maede, Ojalvo, Vernieri, arXiv:2209.07510]

Snowmass Higgs report

Precision on cubic Higgs coupling:

collider	Indirect-H	HH	combined
HL-LHC	100–200%	50%	50%
ILC_{250}/C^3_{250}	49%	–	49%
ILC_{500}/C^3_{550}	38%	20%	20%
FCC-ee	33%	–	33%
FCC-ee (4 IPs)	24%	–	24%
$CLIC_{380}$	50%	–	50%
$CLIC_{1500}$	49%	36%	29%
$CLIC_{3000}$	49%	9%	9%
FCC-hh	–	3.4–7.8%	3.4–7.8%
μ(3 TeV)	–	15–30%	15–30%
μ(10 TeV)	–	4%	4%

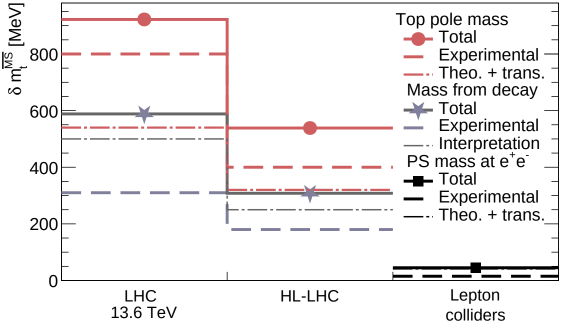
ILC with a 550 GeV gets to 20% precision.

LC@CERN: With double the luminosity get close to 10%

Top physics

Top physics:

- Mass
- Decays that are not allowed (in the SM)
- Decays to things that do not exist (in the SM)
- Other deviations, like *CPV*



Sounds a bit like LHCb, but at the top

Beam polarisation at e^+e^- colliders

Case	Effects	Gain
SM:		
top threshold	Improvement of coupling measurement	factor 3
$t\bar{q}$	Limits for FCN top couplings reduced	factor 1.8
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give access to S- and T-currents up to 10 TeV	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required
W^+W^-	Enhancement of $\frac{S}{B}$, $\frac{S}{\sqrt{B}}$	up to a factor 2
	TGC: error reduction of $\Delta\kappa_\gamma$, $\Delta\lambda_\gamma$, $\Delta\kappa_Z$, $\Delta\lambda_Z$	factor 1.8
	Specific TGC $\tilde{h}_+ = \mathrm{Im}(g_1^{\mathrm{R}} + \kappa^{\mathrm{R}})/\sqrt{2}$	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required
CPV in γZ	Anomalous TGC $\gamma\gamma Z$, γZZ	$P^{\mathrm{T}}_{e^-} P^{\mathrm{T}}_{e^+}$ required
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4 with RL
	Suppression of $B = W^+\ell^-\nu$	factor 1.7
Precision measurements of the Standard Model at GigaZ:		
Z-pole	Improvement of $\Delta \sin^2\theta_W$	factor 5–10
	Constraints on CMSSM space	factor 5
CPV in $Z \to b\bar{b}$	Enhancement of sensitivity	factor 3

Linear colliders can have polarised beams (typically 80%), which improves sensitivity compared to unpolarised beams, due to chirality in SM and (likely) BSM.

[Robson, Leonidopoulos, de Blas, Koppenburg, List, Maltoni, *et al.* [draft]]

ECFA Higgs/EW/Top Factory Report

350-page report due March 31. Draft on [CDS (open to $\mathcal{O}(10^3)$ participants)] .

DETECTOR DEVELOPMENT: Detector concepts (brief)

COMMON DEVELOPMENTS: was main aim of the study

HIGGS: Update of "Jorgen–Wouter" report [de Blas *et al.*, arXiv:1905.03764]

EW AND QCD: W mass, two-fermion physics, Z, WW differential, fragmentation...

TOP: $t\bar{t}$ threshold, t coupings, exotic decays

SMEFT: fits of EW/H/Top

BSM: Exotic scalars, LLPs, new gauge bosons, HNLs, SUSY, DM

FLAVOUR: V_{cb} and V_{cs} from W, V_{ts} from top

[B]

ILC

[indico]

LCF: LC FACILITY AT CERN

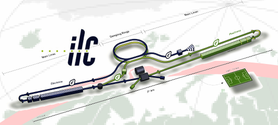
Linear Collider Vision

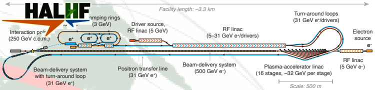
[B]

LCF: LC facility at CERN

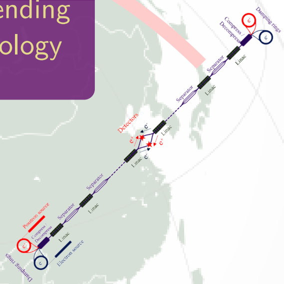
Linear Collider Vision

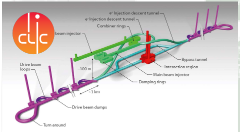
Much more than shipping ILC to CERN





Many upgrade options, depending on physics needs and technology readiness.





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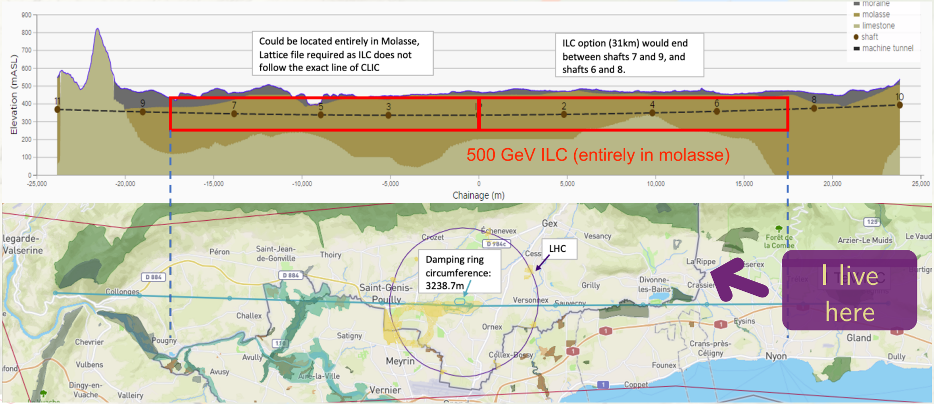

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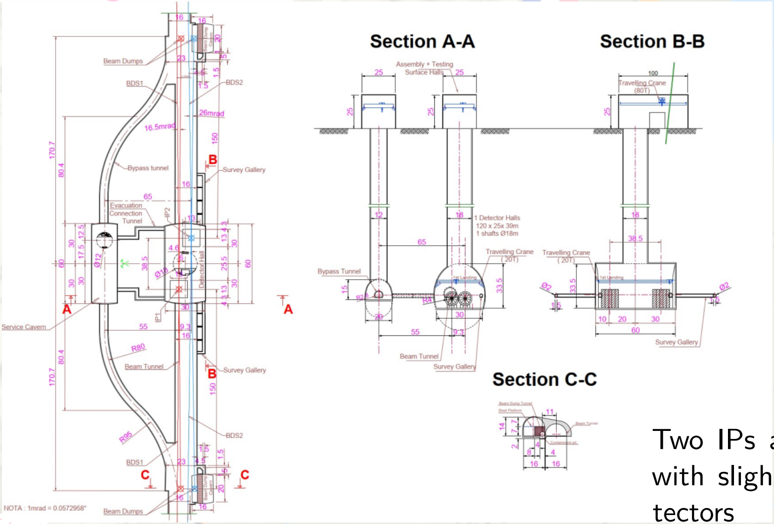
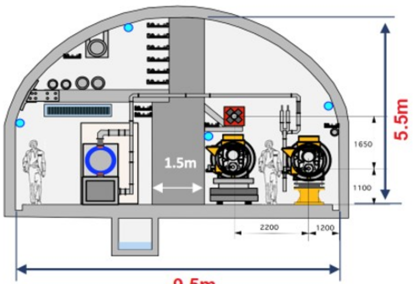


Two IPs are preferred, with slightly offset detectors

Location! Location! Location!

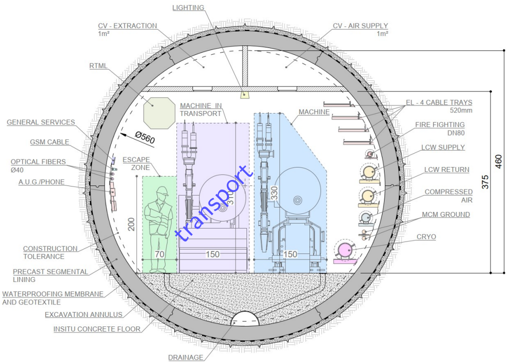
ILC Japan Typical Tunnel Cross Section

Arched 9.5m span. Tohoku region, Japan. (250GeV)



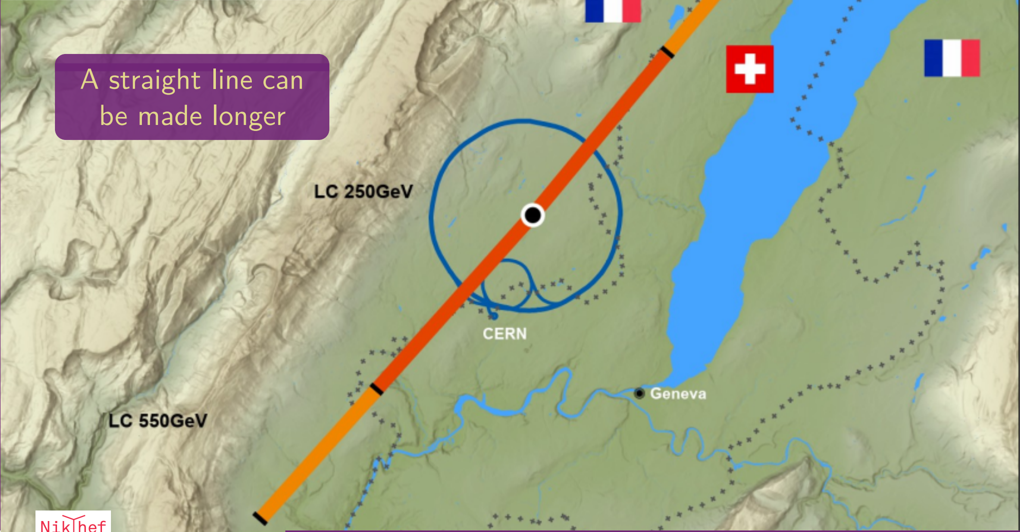
ILC Japan Cross section Implemented at CERN

5.6m Internal Diameter



Linear Collider Vision

A straight line can be made longer



1. LCF@CERN Parameters

- ⓐ The main stages of the project and the key scientific goals of each

  250 GeV: H studies in ZH ➜ Couplings to 2nd generation, Higgs width

  550 GeV: H self-coupling in ZHH, Top physics

- ⓑ Whether the ordering of stages is fixed or whether there is flexibility
  - ➜ Energy depends on installed cavities, so natural to increase 250 $\to$ 550.
  - But one could start at 550 ($!) and go down if needed. SCRF are flexible.

- ⓒ For each stage, the main technical parameters

  250 GeV: 5 years, 2 ab^{-1}

  550 GeV: 11 years, 4 ab^{-1} (short excursions to $t\bar{t}$ threshold)

- ⓓ The number of independent experimental activities and the number of scientists expected to be engaged in each.
  - ✔ Two detectors on different IPs ➜ Two collaborations
  - Beam dump possibilities, alike LUXE, SHiP . . .

[B]

1. LCF@CERN Parameters

Linear Collider Vision

a. The main stages of the project and the key scientific goals of each

250 GeV: H studies in ZH ➜ Couplings to 2nd generation, Higgs width

550 GeV: H self-coupling in ZHH, Top physics

b. Flexible upgrade possibilities

CLIC or C^3 and get to 2 or 3 TeV

ERLC Energy recovery to increase the luminosity 100×

HALHF Will plasma be ready? ➜ 10 TeV

It is important to be **flexible** as we do not know what will be found at 250–500 GeV, nor which technologies will be mature.

[B]

LCF@CERN: Length Options

	ILC-like	Upgrade	Upgrade 2	High-E	
Setup	SCRF			CLIC	C^3
Gradient	35 MV/m	50 MV/m		100 MV/m	120 MV/m
Tunnel	20.5 km				
Energy	250 GeV	380 GeV	550 GeV	1 TeV	1–2 TeV
Tunnel	27 km				
Energy	$\rightarrow$ 380 GeV	550 GeV	700 GeV	1.5 TeV	1.5–2.5 TeV
Tunnel	33.5 km				
Energy	250 GeV	550 GeV	1 TeV		
Maximum	550 GeV	700 GeV	1 TeV	$\geq$ 3 TeV	$\geq$ 3 TeV

Baseline to be defined:

- Cheapest option is just this

LCF@CERN: Length Options

Linear Collider Vision

	ILC-like	Upgrade	Upgrade 2	High-E	
Setup	SCRF			CLIC	C^3
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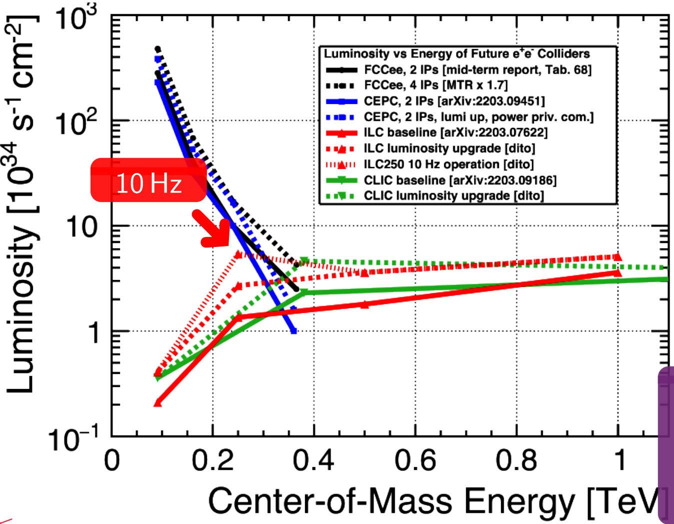
Tunnel	33.5 km				
Energy	250 GeV	550 GeV	1 TeV		
Maximum	550 GeV	700 GeV	1 TeV	$\geq$ 3 TeV	$\geq$ 3 TeV

Baseline to be defined:

- Baseline likely that: 33 km but run at 250–550 GeV.

LCF@CERN: Luminosity

Linear Collider Vision

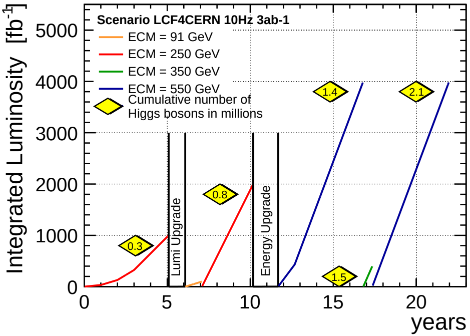


ILC luminosity was capped by requirements on wall power use

2. LCF@CERN Timeline

Linear Collider Vision

- The technically limited timeline for construction of each stage + scenario timelines
  - ➜ The ILC TDR dates from 2013 [TDR]. Timeline dominated by HL-LHC/budget, as FCC.
  - The local feasibility needs work. Aim to be ready for approval in < 5 years.
- The anticipated operational (running) time at each stage, and the expected operational duty cycle
  - ➜ There is flexibility
  - Could start at 550 GeV if CEPC covers region up to 350 GeV



[B]

3. LCF@CERN Resources

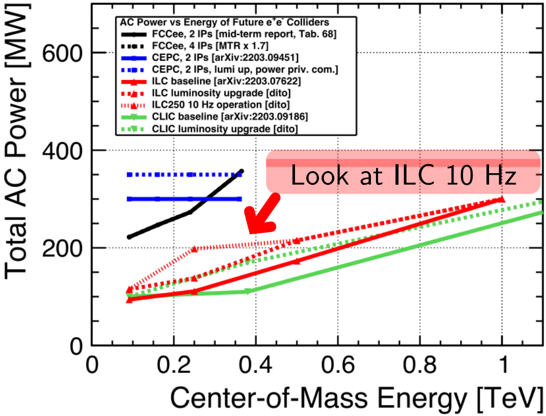
- a The capital cost of each stage in 2024 CHF
  - ➜ Being worked on.
- d Commentary on the basis-of-estimate of the resource requirements
  - ✔ Solid estimates for the Japanese proposal, converted to 2024 numbers: 6.8G$+2.2G$ (civil)
  - Expect about 10% lower numbers in CHF.
  - ➜ Being converted to CERN environment
    - ✔ Lab already there
    - ✗ different geology...

"*For prices in Switzerland, we do not give out numbers yet, but it is a fair statement to say that the exchange rate of 1 US$ =[0.9] CHF suggests that the expected price in swiss francs will be lower than in [$] by about 10%, but that detailed studies for the CERN site have not been concluded.*"

[B]

4. LCF@CERN Sustainability

- The peak (MW) and integrated (TWh) energy consumption during operation of each stage
  - ➜ 200–220 MW, which gives 0.7 TWh/y
  - ILC lumi was capped by requirements on wall power use



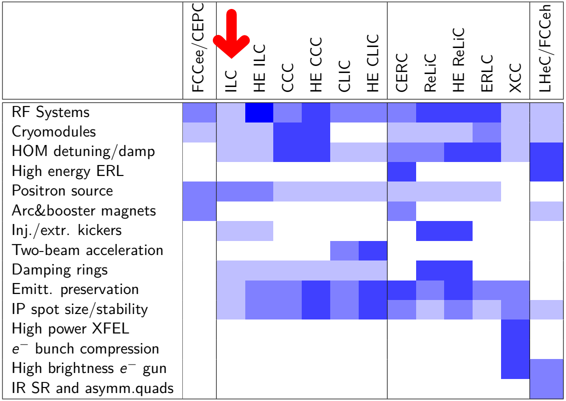
[B]

5. LCF@CERN Key Technology

Linear Collider Vision

ⓐ The key technologies needed for delivery that are still under development in 2024, and the targeted performance parameters of each development

➜ All good (positron source essentially needs an engineer)



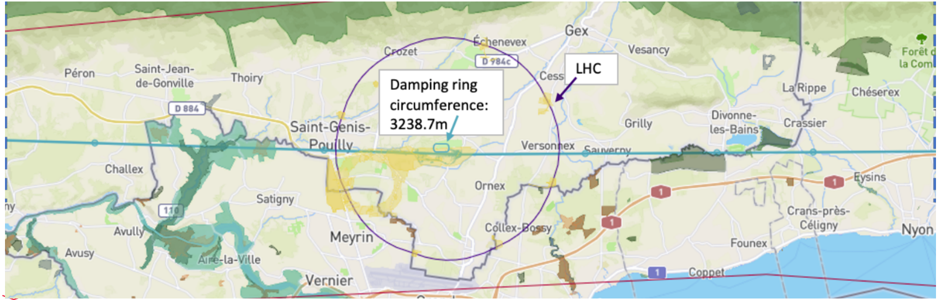
[Roser *et al.*, JINST 18 (2023) P05018, arXiv:2208.06030]

[B]

6. LCF@CERN Dependencies

Linear Collider Vision

- (a) Whether a specific host site is foreseen, or whether options are available
  - ➜ Topic of this talk: CERN. But no requirement on CERN's accelerator complex.
- (b) The dependencies on existing or required infrastructure
- (c) The technical effects of project execution on the operations of existing infrastructures at the host site



[B]

7. LCF@CERN Status

Linear Collider Vision

ⓐ A concise description of the current design / R&D / simulation activities leading to the project, and the community pursuing these

➜ There is a large linear collider community. LCF@CERN is just starting. Already 77 institutes involved (incl Nikhef) [sign]

- Workshop at CERN in January with 150 people (60 in room) [indico]

ⓑ Any other key technical information points in addition to those captured above, including references to additional public documents addressing the points above.

➜ Workshop slides [indico]

[B]

Conclusion

CERN should study the feasibility of a linear e^+e^- collider reaching energies up to 550 GeV to be operated after the LHC.

CERN should support R&D for future potential upgrades of such a collider, while being open to other options as demanded by physics and technological breakthroughs.

Now changing hats:
Long-term sustainability should be a guiding principle for the next large experimental facility and supported by international agreements.

[@koppenburg.ch] [patrick.koppenburg@nikhef.nl]


THE OTHER SIDE
Why do you need a reason?
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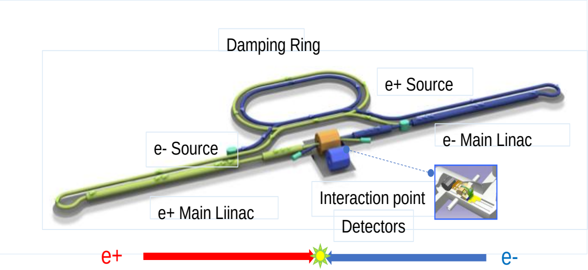
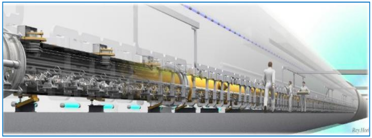
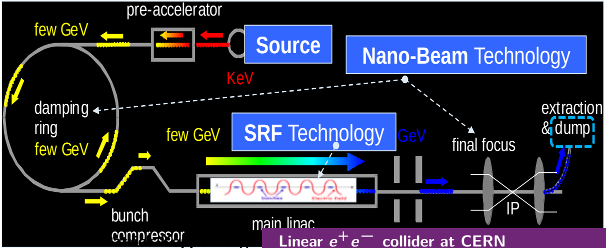
Backup

ILC and the Accelerator Technology



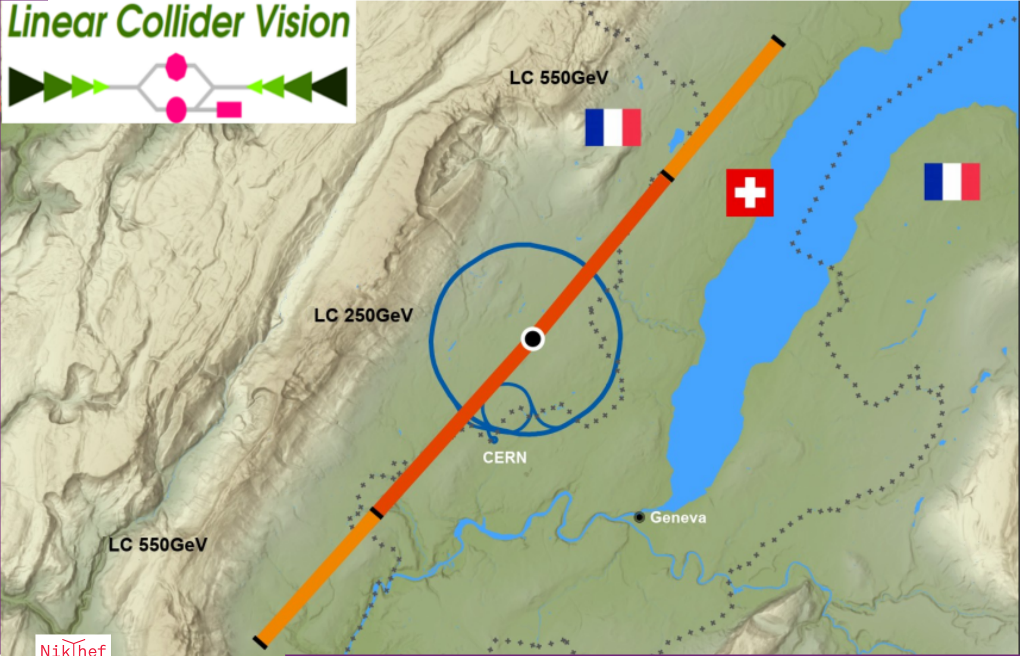


TDR was published in 2013 and SRF technology became matured by large-SRF accelerators (European XFEL, LCLS-II etc.).

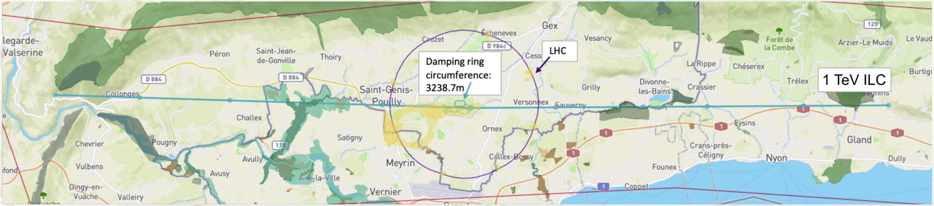


Parameters	Value
Beam Energy	125 + 125 GeV
Luminosity	1.35 / 2.7 x 10^{34} cm^2/s
Beam rep. rate	5 Hz
Pulse duration	0.73 / 0.961 ms
# bunch / pulse	1312 / 2625
Beam Current	5.8 / 8.8 mA
Beam size (y) at FF	**7.7** nm
SRF Field gradient	< 31.5 > MV/m (+/-20%) $Q_0 = 1 \times 10^{10}$
#SRF 9-cell cavities (CM)	~ 8,000 (~ 900)

Linear Collider Vision



Location! Location! Location!



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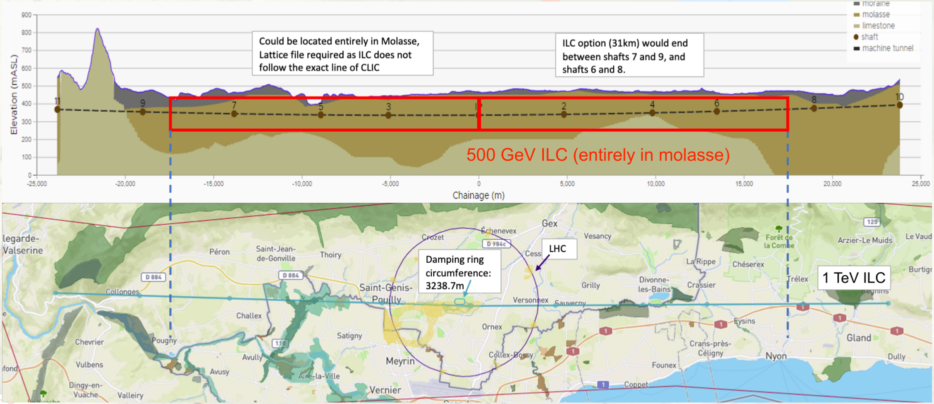

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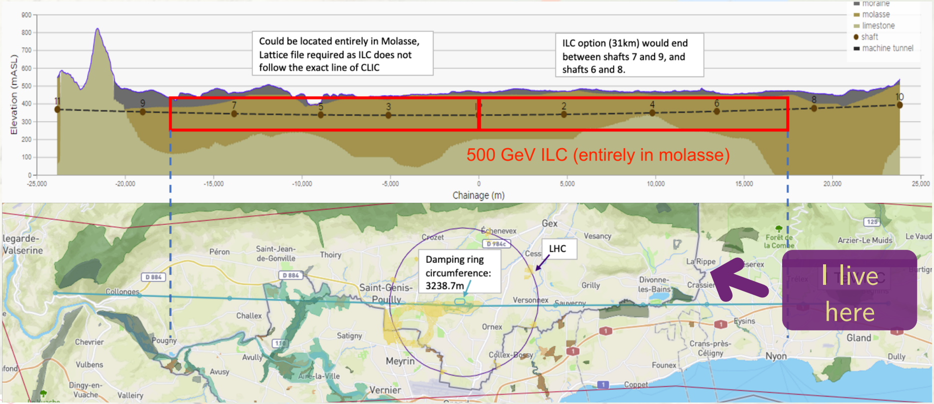

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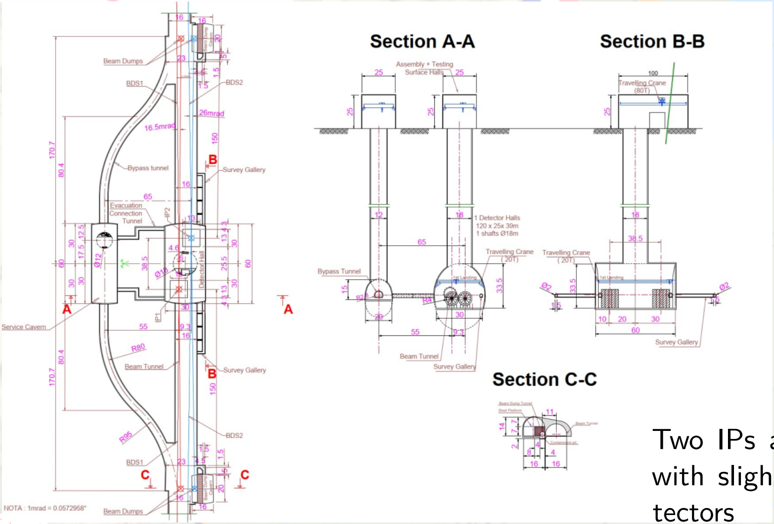

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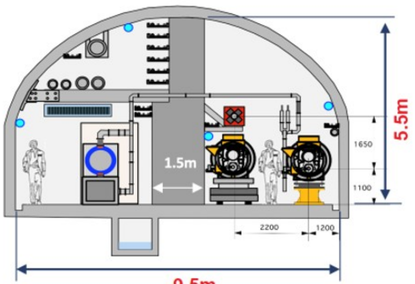
Arched 9.5m span. Tohoku region, Japan. (250GeV)



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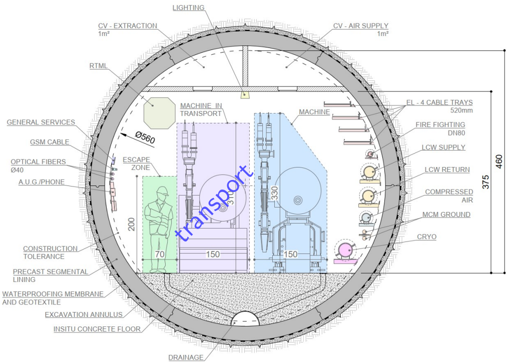
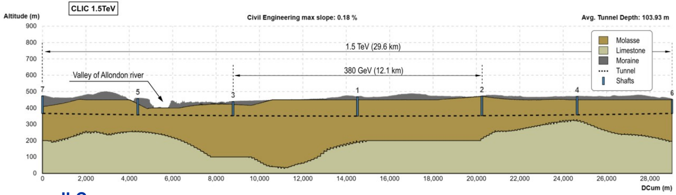
5.6m Internal Diameter



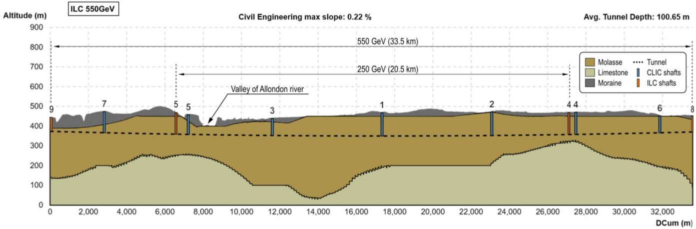
Location! Location! Location!

Geological Profile

- CLIC



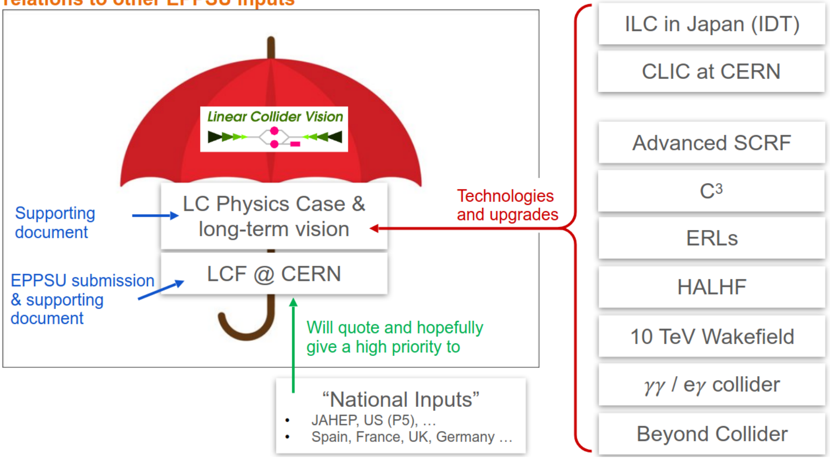
- ILC



- Ongoing Geographical study to optimise and share common shaft locations between CLIC and ILC.
- CLIC is symmetrical either side of the interaction region.
- ILC is not symmetrical either side of the interaction region.
- Shafts at 4&5 for both studies will be unified.
- It is easier to adapt the CLIC shafts to the ILC design due to the Cryo design constraints of the ILC.

LC Vision Documents

and their relations to other EPPSU inputs



[B]

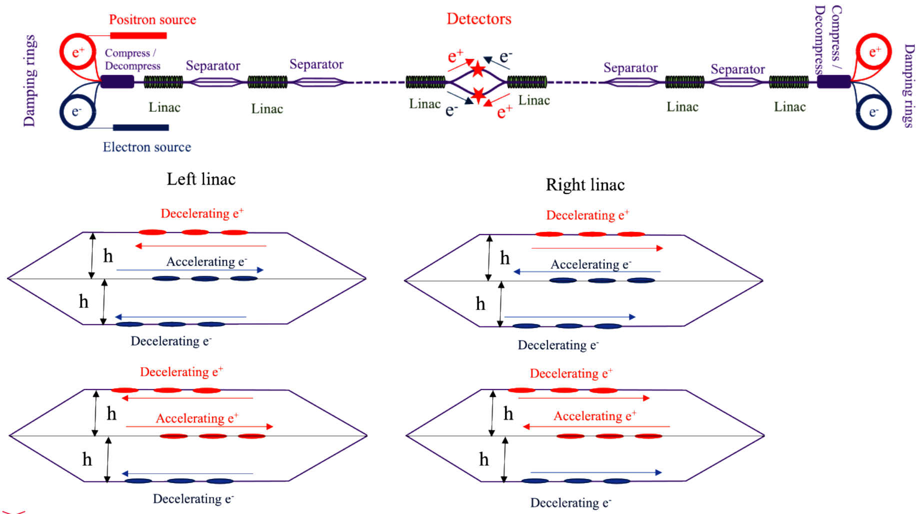
WW physics

With WW pairs one can measure

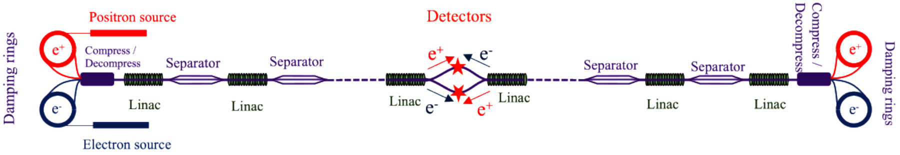
- The W mass ($0.5\,\mathrm{MeV}/c^2$ with a threshold scan
- $W \to \ell\nu$ BFs to 10^{-4}
- CKM matrix elements notably V_{cb}
- WW differential measurements useful for SMEFT
- Fragmentation functions relevant for H^0 and top physics

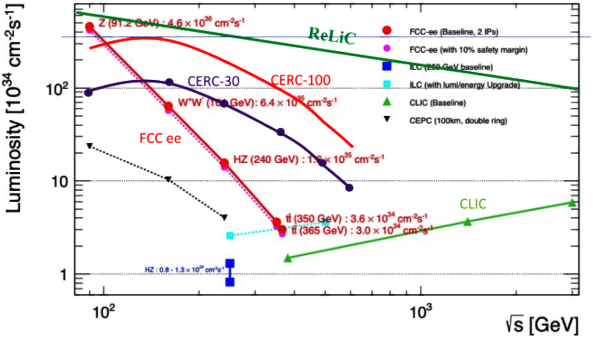
[Litvinenko *et al.*, arXiv:2203.06476]

ReLiC — recycling linear collider



ReLiC — recycling linear collider





"Needless to say, a detailed technical validation of this concept is needed."

[Robson, Leonidopoulos, de Blas, Koppenburg, List, Maltoni, *et al.* [draft]]

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- EW AND QCD: W mass, two-fermion physics, Z, WW differential, fragmentation. . .
- TOP: $t\bar{t}$ threshold, t coupings, exotic decays
- SMEFT: fits of EW/H/Top, Tera-Z
- BSM: Exotic scalars, LLPs, new gauge bosons, HNLs, SUSY, DM
- FLAVOUR: V_{cb} and V_{cs} from W, V_{ts} from top, V_{cb} from B_c^+, , rare b decays, precision τ physics

Linear e^+e^- collider at CERN: My take

1. A linear collider can be upgraded step-by-step, depending on available technologies and physics priorities
   - ➜ We do not need to, and should not, plan for the next 80 years
2. Lower luminosity than FCC below 200 GeV, but larger energy reach.

➜ Either way it's a bet on the future

[B]