On the physics potential of ILC and CLIC

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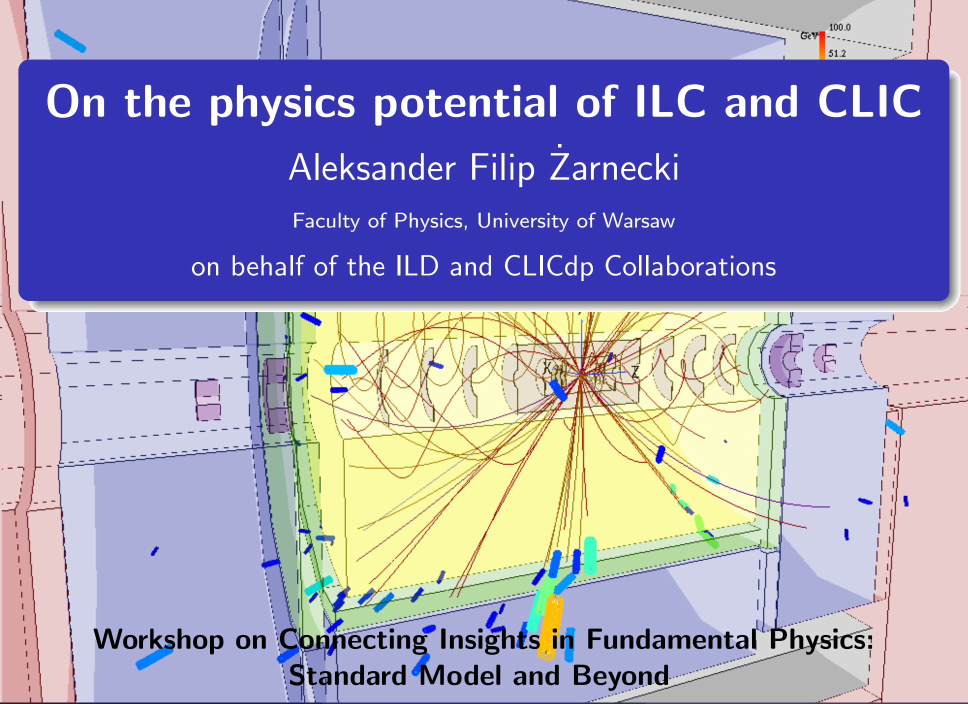
on behalf of the ILD and CLICdp Collaborations



Workshop on Connecting Insights in Fundamental Physics: Standard Model and Beyond

Outline

1. Colliders
2. Experiments
3. Higgs physics
4. Top-quark physics
5. BSM physics
6. Conclusions

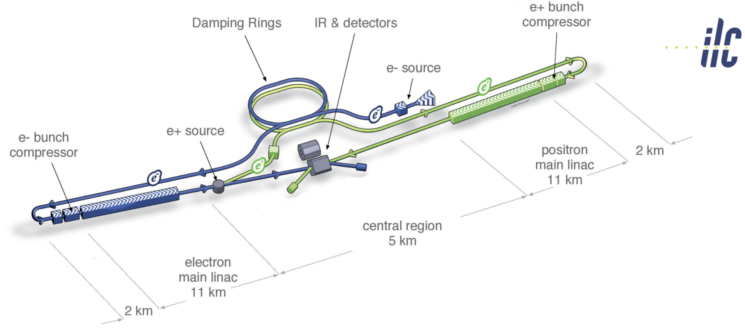
Focus on selected highlights, for more information refer to:

- ILC inputs to the European Strategy for Particle Physics Update + ILD contribution
- CLIC input to the European Strategy for Particle Physics Update


compositeness
hidden valley
stub tracks
self-coupling
Higgs
$V_{sr}(\phi) = rg\Lambda^3\phi$
neutral currents
lepton flavor violation
CLIC search
baryogenesis
dark matter
discovery
inert doublet
BSM
2HDM
precision
mono-photon
see-saw

Colliders

International Linear Collider



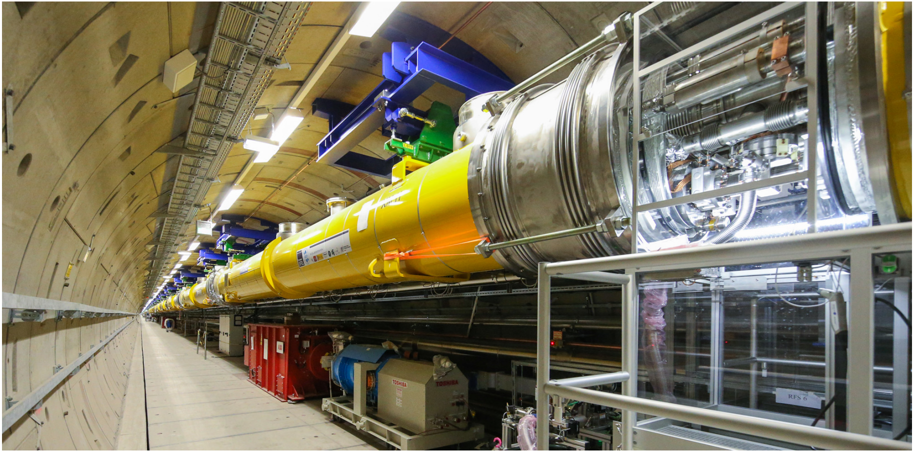
ILC Scheme | © www.form-one.de

Technical Design (TDR) completed in 2013 arXiv:1306.6328

- superconducting accelerating cavities
- 250 – 500 GeV c.m.s. energy (baseline), 1 TeV upgrade possible
- footprint 31 km
- polarisation for both e^- and e^+ (80%/30%)

E-XFEL first X-ray laser flashes in May 2017

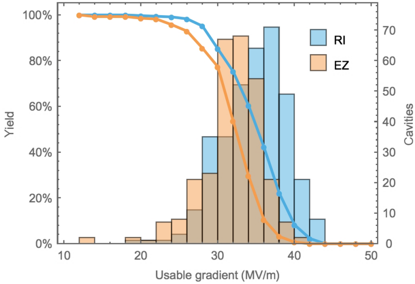
Largest ever accelerator prototype: ILC-250 arm in 1:7 scale (17.5 GeV)



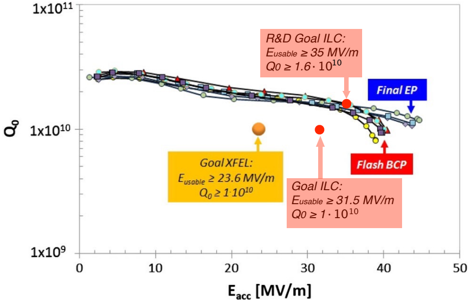
All construction issues verified. Full industrialization of cavity production.

International Linear Collider

Most E-XFEL cavities already meet ILC requirements



Cavity design and production optimisation studies still ongoing



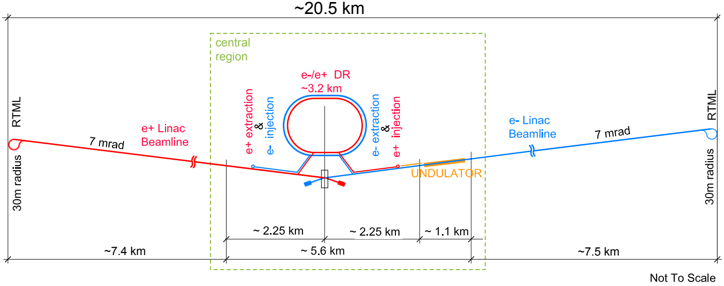
arXiv:1903.01629

ILC-250

The discovery of a Higgs Boson with a mass of 125 GeV opened the possibility of reducing ILC cost by starting at a centre-of-mass energy of 250 GeV with the possibility of future upgrades to 500 GeV or even 1 TeV.

arXiv:1711.00568

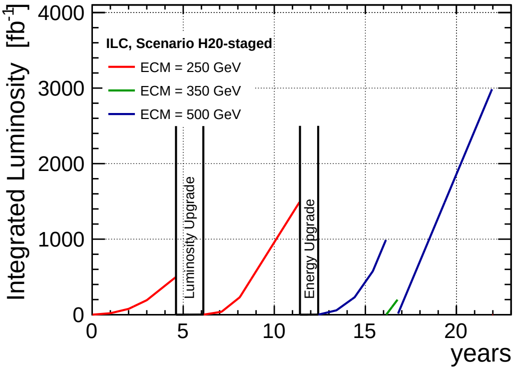
"Higgs-factory" layout 250 GeV optimal for Higgs production



arXiv:1903.01629

International Linear Collider

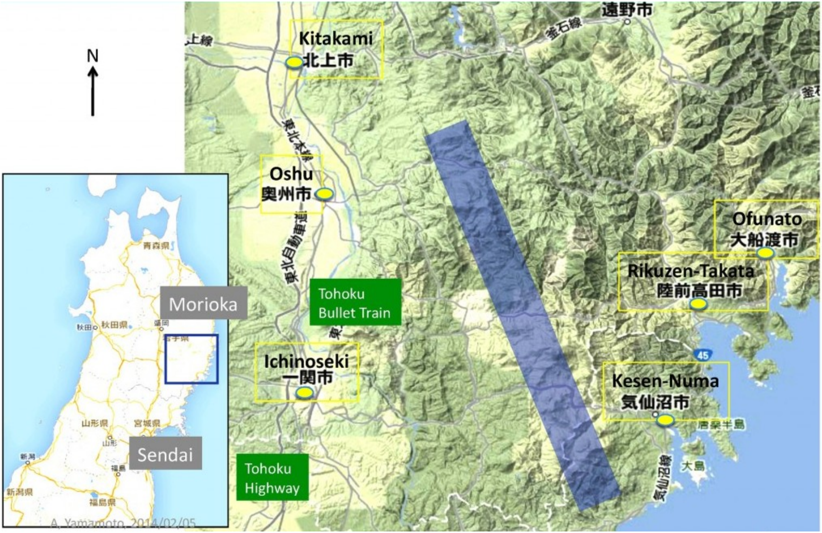
Baseline running scenario for staged ILC construction



arXiv:1903.01629

Total integrated luminosities same as in original H-20 proposal for ILC-500!

Candidate ILC site in Kitakami

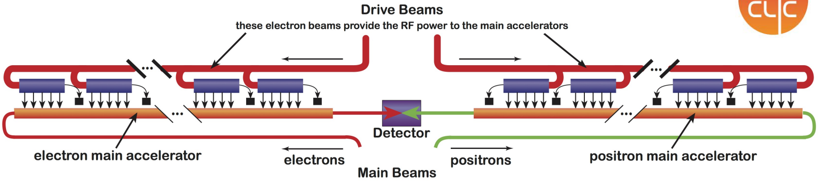


Candidate ILC site in Kitakami

Oshu City and panorama of the Kitakami mountains

Colliders

Compact LInear Collider



Conceptual Design (CDR) presented in 2012 CERN-2012-007

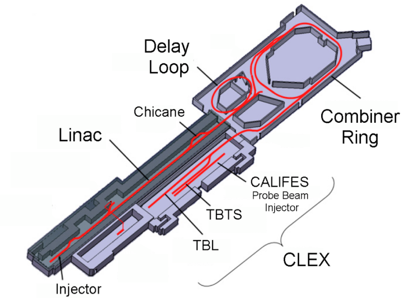
- high gradient, two-beam acceleration scheme
- staged implementation plan with energy from 380 GeV to 3 TeV
- footprint of 11 to 50 km
- e^- polarisation (80%)

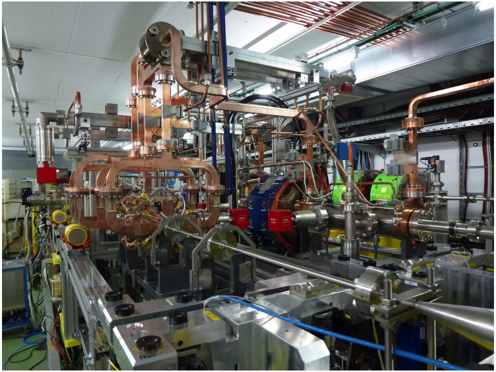
For details refer to arXiv:1812.07987

Compact LInear Collider

Novel acceleration technology required a lot of fundamental research

Studies completed at CLIC Test Facility 3 (CTF3: June 2003 - Dec 2016)

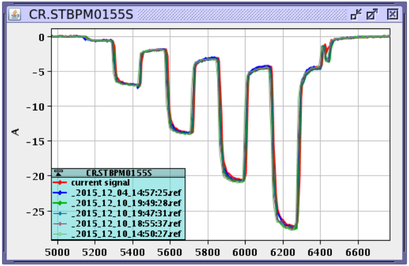




All key elements of the design verified

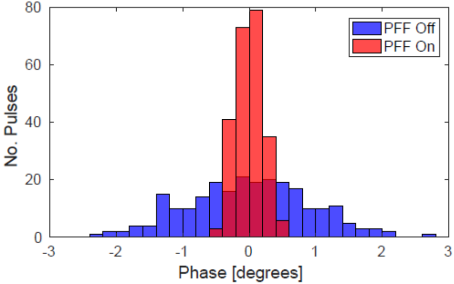
CTF3 test results

Drive beam bunch formation



current of 28 A reached

Phase locking for acceleration

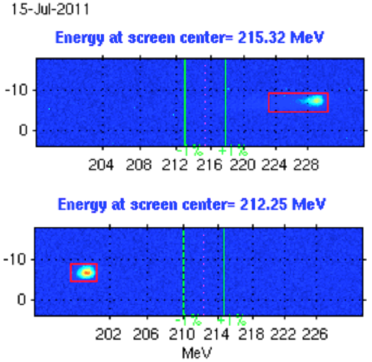


50 fs timing accuracy reached

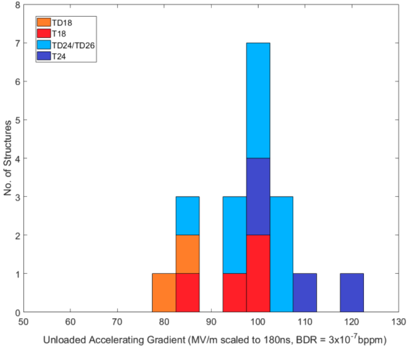
Steinar Stapnes, CLIC Workshop, January 2019

CTF3 test results

Energy gain in single cavity



Accelerating gradient for test cavities



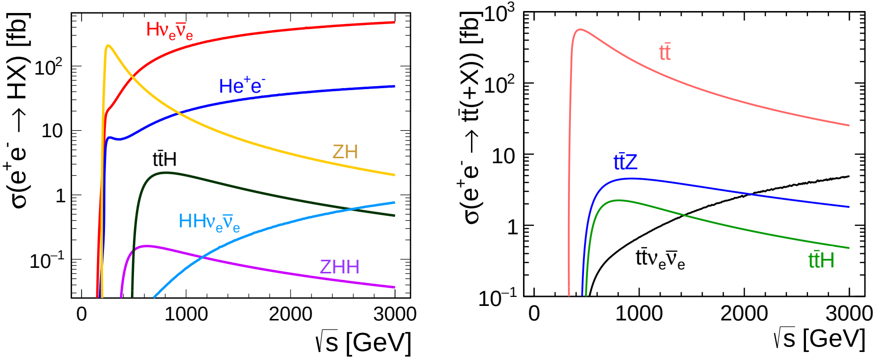
Steinar Stapnes, CLICdp Workshop, August 2019

CLIC running scenario

new baseline: CERN-2018-005-M

Three construction stages (each 7 to 8 years of running)
for an optimal exploitation of its physics potential

- $\sqrt{s} = 380$ GeV with $1\,\mathrm{ab}^{-1}$ including 100 fb^{-1} at $t\bar{t}$ threshold
  focus on precision Standard Model physics,
  optimised for **Higgs boson** and **top-quark** measurements



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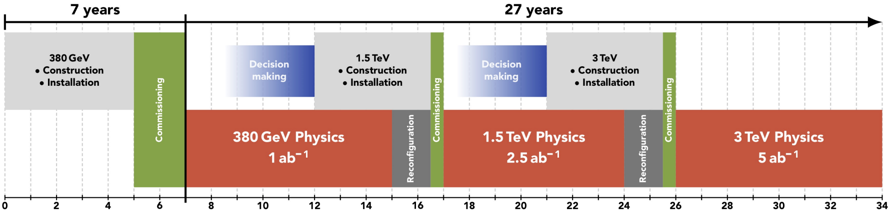
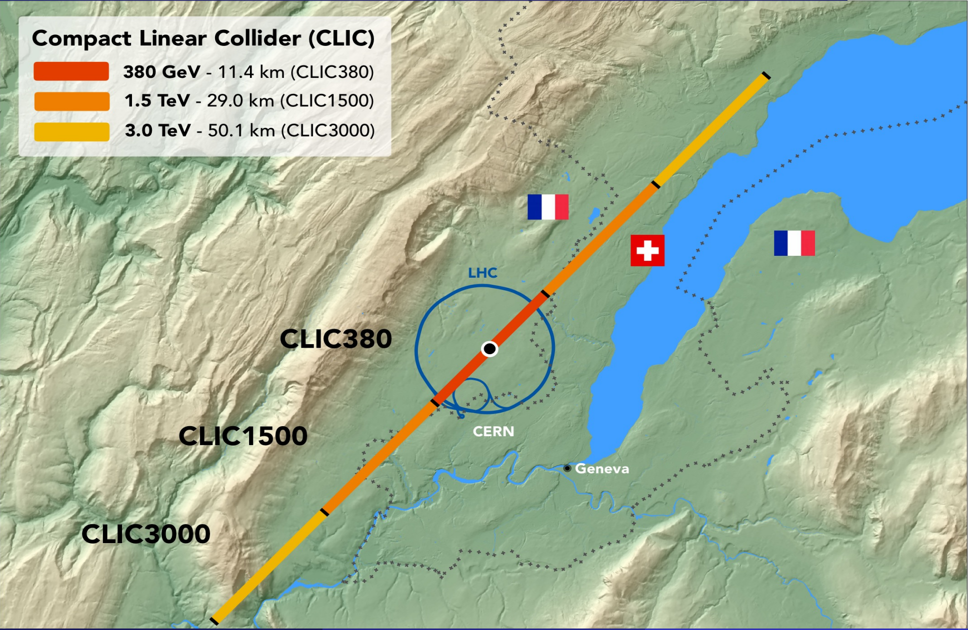
- $\sqrt{s} = 380$ GeV with $1\,\mathrm{ab}^{-1}$ including 100 fb^{-1} at $t\bar{t}$ threshold
  focus on precision Standard Model physics,
  optimised for **Higgs boson** and **top-quark** measurements
- $\sqrt{s} = 1.5$ TeV with $2.5\,\mathrm{ab}^{-1}$
- $\sqrt{s} = 3$ TeV with $5\,\mathrm{ab}^{-1}$
  focus on direct and indirect **BSM searches**,
  but also additional **Higgs boson** and **top-quark** studies



Colliders


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

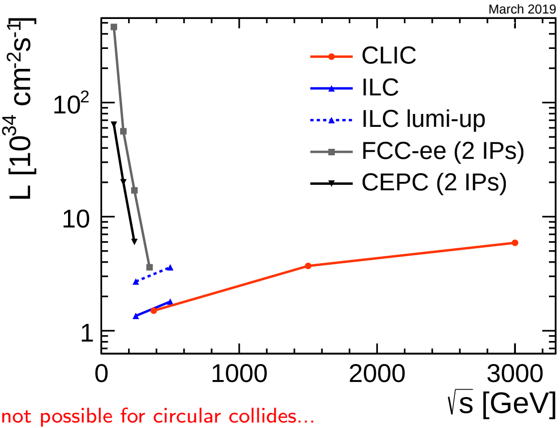
LC comparison   personal view

	ILC	CLIC
Technology	cold	worm
Acc. gradient	35 MV/m	72/100 MV/m
Initial energy	250 GeV	380 GeV
Final energy	500 GeV	3 TeV
Bunch spacing	300 ns	0.5 ns
Polarisation	e^- / e^+	e^-
Project timeline	22 years	27 years
Total luminosity	6.2 ab^{-1}	8.5 ab^{-1}

ILC: higher precision at low energies, CLIC: prospects for going $>$ 1 TeV
Running scenarios can be modified, depending on physics...

Comparison to other project

- $t\bar{t}$ threshold luminosity "per IP" similar for ILC/CLIC and FCC-ee
- much smaller construction cost and power consumption for LC!
- CLIC is the only e^+e^- project that can go into the TeV domain



Energy upgrade not possible for circular collides...

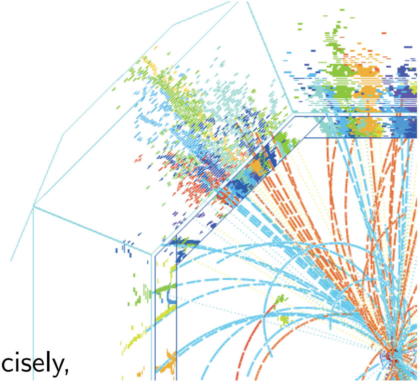
Experiments

Particle Flow concept

Jet energy resolution crucial for precision physics and background rejection

Typical jet composition:

- 60% charged particles
- 30% photons
- 10% neutral hadrons



Jet energy poorly measured in calorimeters, large flactuations.

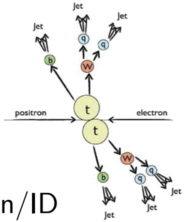
But we can measure:

- charged particle momenta very precisely,
- photon energy quite well,
- only neutral hadrons are a problem...

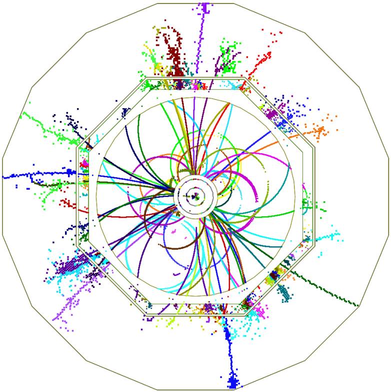
Detector Requirements

"Particle Flow" concept:
try to measure energy
particle by particle

Single particle reconstruction/ID
⇒ high calorimeter granularity



Benchmark reaction
$e^+e^- \to t\bar{t} \to 6j$



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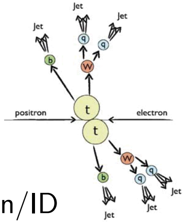

Single particle reconstruction/ID
$\Rightarrow$ high calorimeter granularity

Best energy estimate
for charged particles
$\Rightarrow$ precise momentum measurement

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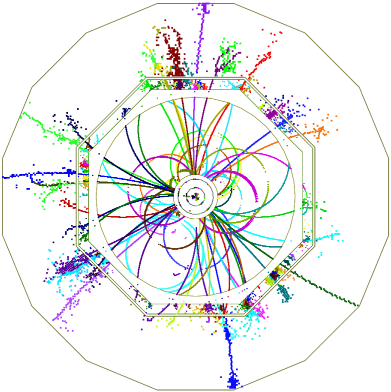

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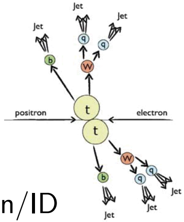

Single particle reconstruction/ID
$\Rightarrow$ high calorimeter granularity

Best energy estimate
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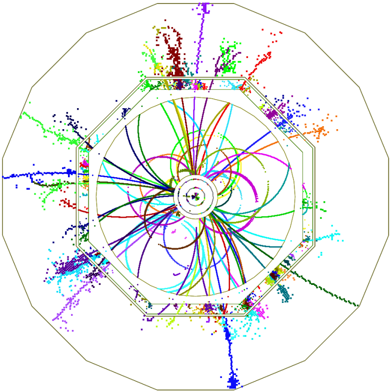
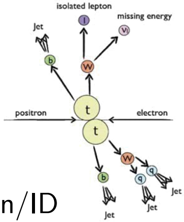
$\Rightarrow$ precise momentum measurement

Very efficient flavour tagging
$\Rightarrow$ high precision vertex detector

Benchmark reaction
$e^+e^- \rightarrow t\bar{t} \rightarrow 6j$



Detector Requirements



"Particle Flow" concept:
try to measure energy
particle by particle

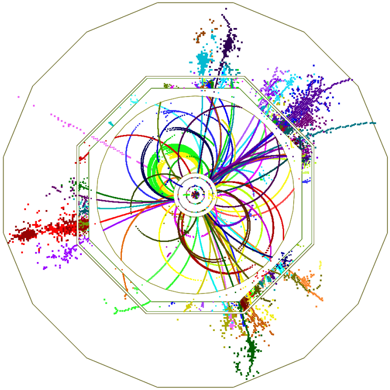
Single particle reconstruction/ID
$\Rightarrow$ high calorimeter granularity

Best energy estimate
for charged particles
$\Rightarrow$ precise momentum measurement

Very efficient flavour tagging
$\Rightarrow$ high precision vertex detector

Missing energy measurement
$\Rightarrow$ hermecity

Benchmark reaction
$e^+e^- \rightarrow t\bar{t} \rightarrow 4j + l + \nu$

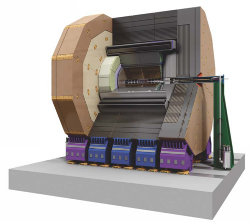


Detector Requirements same for ILC and CLIC

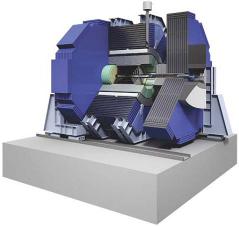
- Track momentum resolution: $\sigma_{1/p} < 5 \cdot 10^{-5}$ GeV^{-1}
- Impact parameter resolution: $\sigma_d < 5\mu m \oplus 10\mu m \frac{1\ \mathrm{GeV}}{p\ \sin^{3/2}\Theta}$
- Jet energy resolution: $\sigma_E/E = 3 - 4\%$ (for highest jet energies)
- Hermecity: $\Theta_{min} = 5$ mrad

Two detailed ILC detector concepts:

ILD



SiD



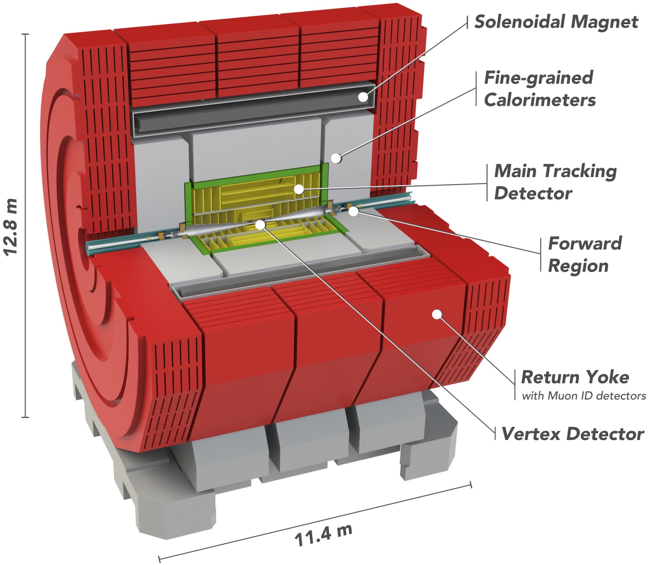
New CLIC detector model: CLICdet

Based on detailed simulation studies, detector R&D and beam tests.

Optimised for Particle Flow reconstruction

Full exploitation of physics potential from 380 GeV to 3 TeV

For details refer to arXiv:1812.07337



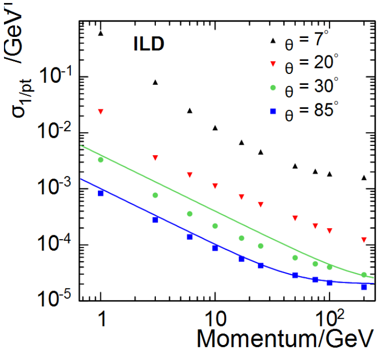
Detector performance

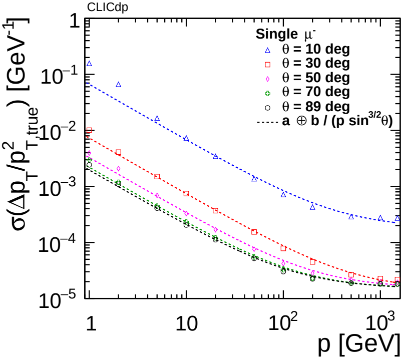
Track momentum resolution:

$$\sigma_{1/p} < 5 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$$

for high momentum tracks

p_T resolution for muons:





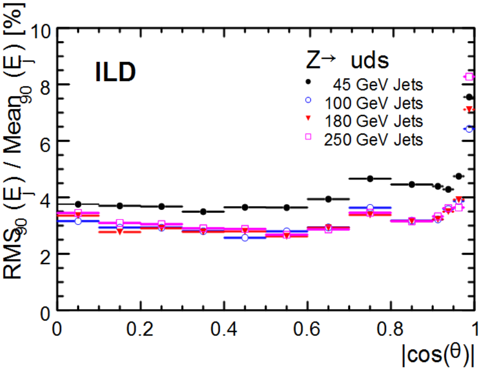
Detector performance

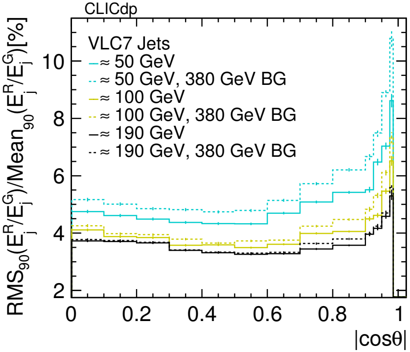
Jet energy resolution:

$$\sigma_E/E = 3 - 4\%$$

for high jet energies

Expected jet energy resolution based on particle flow reconstruction





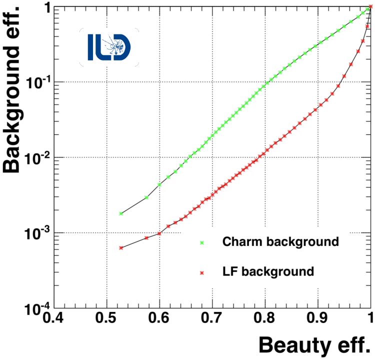
Detector performance

Impact parameter resolution:

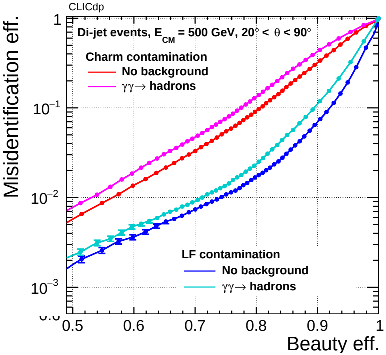
$$\sigma_d < 5\mu m \oplus 10\mu m \, \frac{1\ \mathrm{GeV}}{p\ \sin^{3/2}\Theta}$$

Crucial for efficient flavour tagging

b-tagging @ ILC



b-tagging @ CLIC



Experiments

Detector performance

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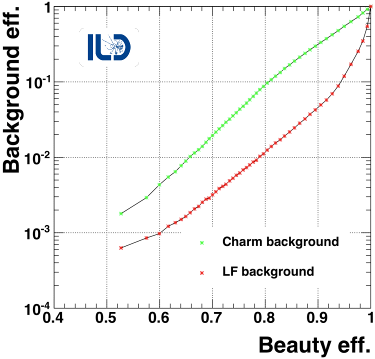
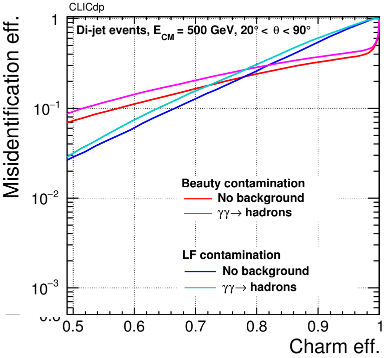
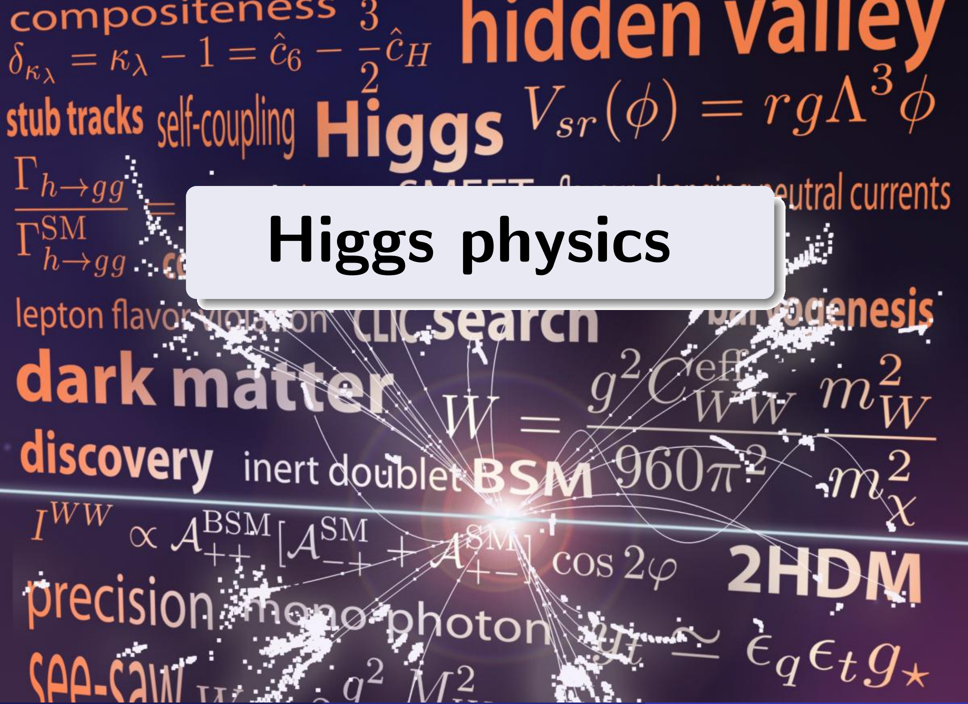


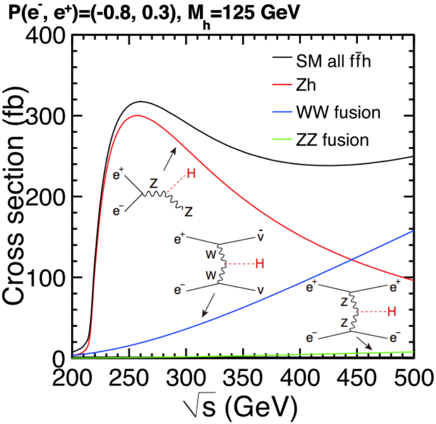
c-tagging @ CLIC





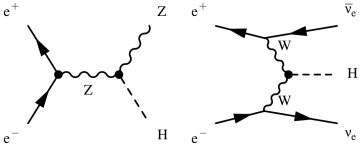
Higgs physics

Higgs production



Precision Higgs couplings measurements at 250/380 GeV

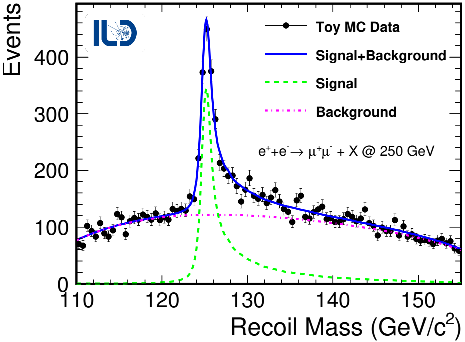
Profit from combining two production channels:



⇒ model independent analysis

Event reconstruction

In the ZH production channel (dominating below 450 GeV) we can use "Z-tagging" for unbiased selection of Higgs production events



We avoid any dependence on the Higgs decay channel!

Higgs physics

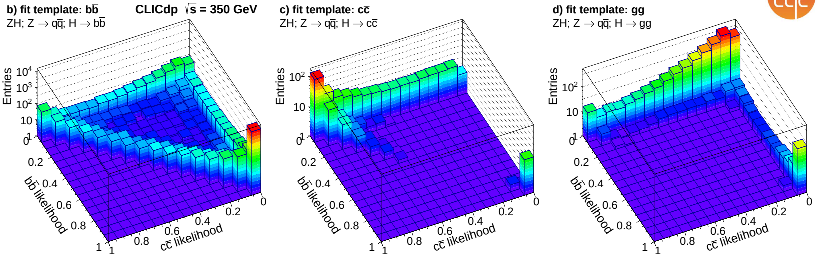
Decay reconstruction

CLIC study: arXiv:1608.07538

Recoil mass reconstruction in $e^+e^- \rightarrow ZH \Rightarrow$ unbiased selection

Clean environment $\Rightarrow$ unambiguous separation of different decay channels

Efficient b and c tagging:

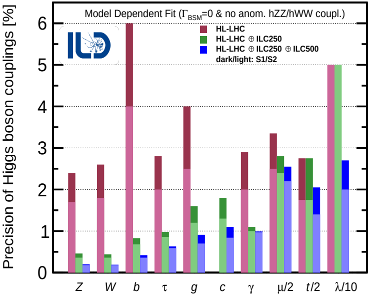


Prospects for direct measurement of $BR(H \rightarrow c\bar{c})$ and $BR(H \rightarrow gg)$

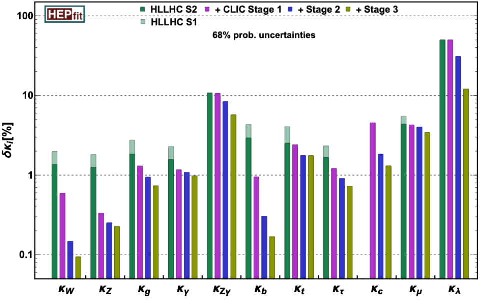
Higgs couplings

ILC/CLIC sensitivity to the different Higgs boson couplings
compared with the HL-LHC projections

Model-dependent analysis



arXiv:1903.01629



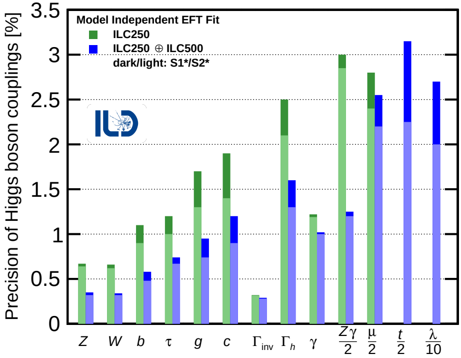
arXiv:1812.02093

Sub-percent level precision already at the first energy stages

Higgs couplings

ILC/CLIC sensitivity to the different Higgs boson couplings

Model-independent analysis



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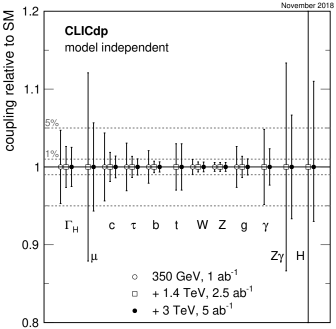
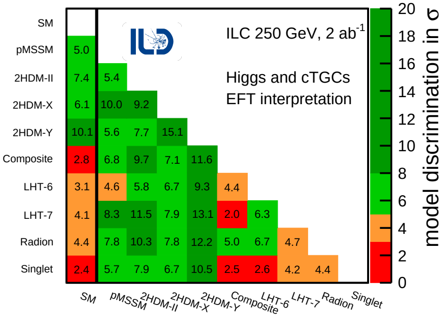


arXiv:1812.01644

BSM sensitivity

Precision of e^+e^- colliders allows to distinguish the SM expectations and other models from the global analysis of the Higgs boson couplings

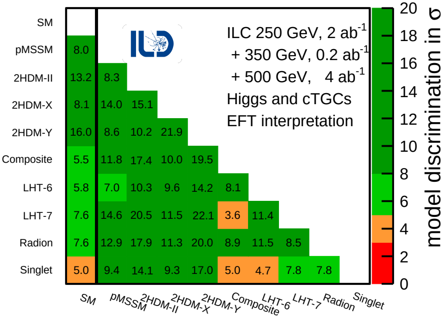


Significant ($> 5\sigma$) differences between most scenarios already at 250 GeV
All considered BSM scenarios can be identified at $\geq 5\sigma$ after full ILC programme (H-20)

arXiv:1710.07621

BSM sensitivity

Precision of e^+e^- colliders allows to distinguish the SM expectations and other models from the global analysis of the Higgs boson couplings

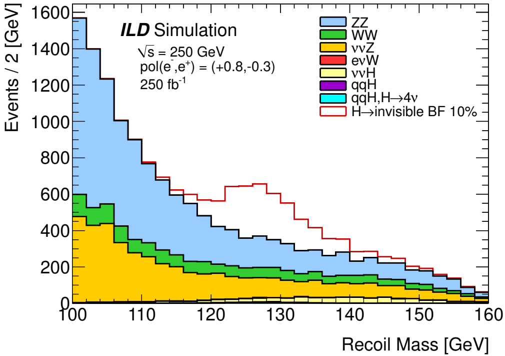


All considered BSM scenarios can be identified at $\geq 5\sigma$ after full ILC programme (H-20)

arXiv:1710.07621

Invisible decays

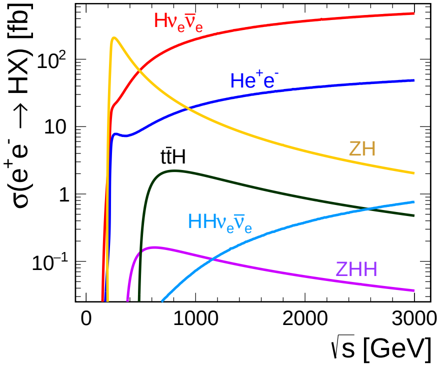
Recoil mass technique results also in high sensitivity to invisible Higgs boson decays



Expected 95% C.L. limit for $2\,\mathrm{ab}^{-1}$ collected at 250 GeV ILC: 0.23%

Yu Kato @ EPS-HEP 2019

Higgs production



New channels open above 500 GeV

- top Yukawa coupling
- Higgs self-coupling

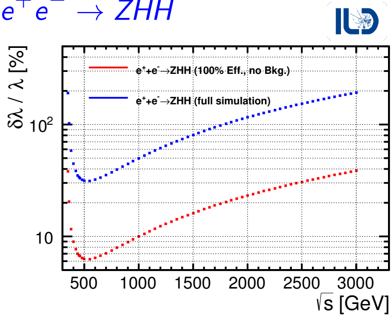
Even more Higgs bosons produced at TeV energies

- rare decay channels

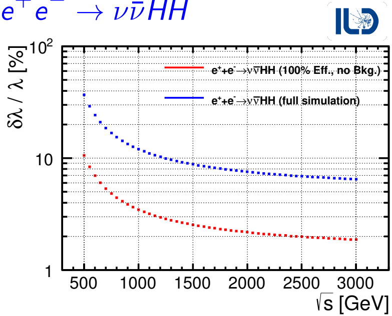
Higgs self-coupling

Estimated precision on the determination of Higgs self-coupling λ

$e^+e^- \to ZHH$



$e^+e^- \to \nu\bar{\nu}HH$



500 GeV optimal for measurement in *ZHH* channel:

27% uncertainty expected at ILC with 4 ab^{-1}

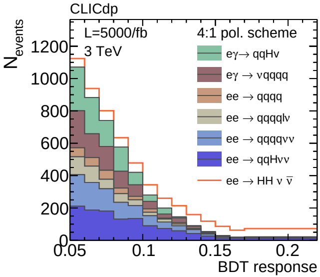
assuming the SM with only the trilinear Higgs coupling free

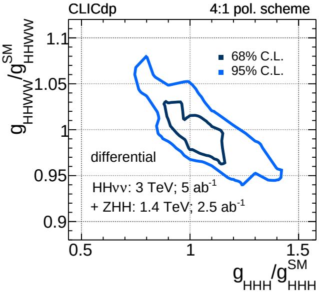
arXiv:1903.01629

Higgs self-coupling

arXiv:1901.05897

Extracted from the measurement of double Higgs boson production at CLIC, at energies of $\sqrt{s} = 1.5$ and 3 TeV.





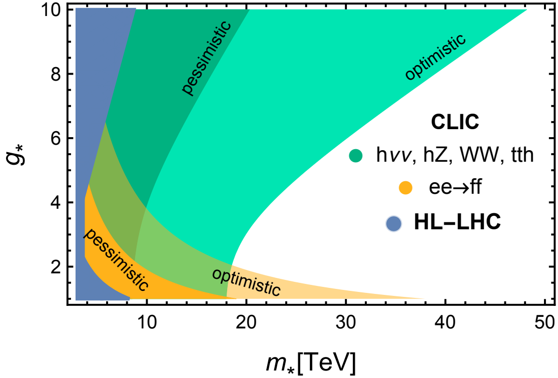
Both trilinear Higgs self-coupling and the quartic HHWW coupling can be constrained.

$$\delta\lambda/\lambda = -7\%/+11\% \qquad (68\%\ \text{C.L.})$$

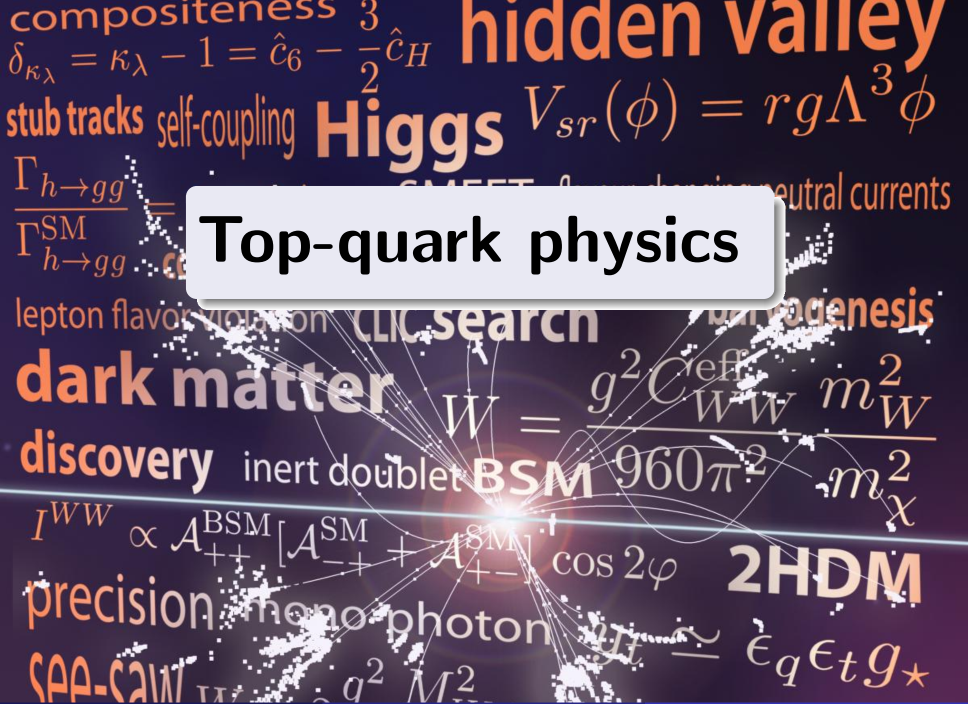
Looking for BSM effects

5σ CLIC discovery range for Higgs compositeness

compared to expected HL-LHC 2σ exclusions

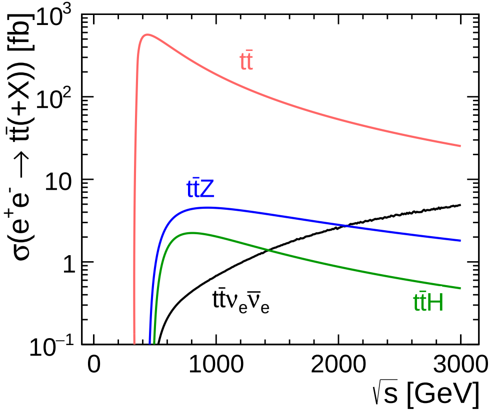


New physics effects can be discovered via precision Higgs measurements



Top-quark physics

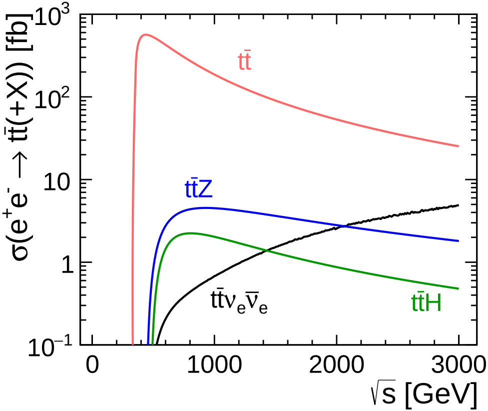
Processes of interest



Top pair-production at and above the threshold (350 GeV)

- top-quark mass
- electroweak couplings
- rare decays

Processes of interest



Top pair-production at and above the threshold (350 GeV)

- top-quark mass
- electroweak couplings
- rare decays

Additional processes open at high energies

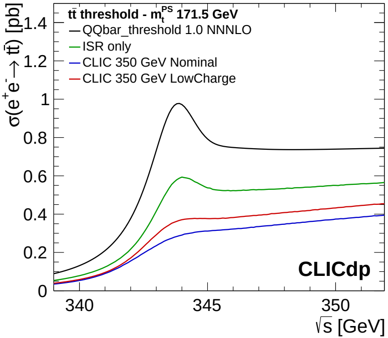
- top Yukawa coupling
- CP properties
- BSM constraints

Threshold scan

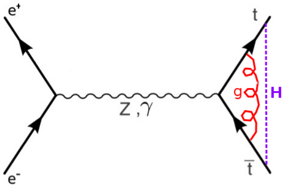
Top pair production cross section around threshold:

resonance-like structure corresponding to narrow $t\bar{t}$ bound state.

Very sensitive to top properties and model parameters:



- top quark mass m_t
- top quark width Γ_t
- strong coupling α_s
- top Yukawa coupling y_t



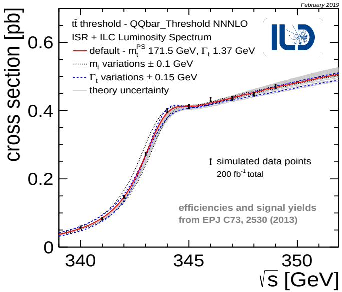
Significant cross section smearing due to luminosity spectra and ISR

Smearing due to luminosity spectra can be reduced by using dedicated running configuration

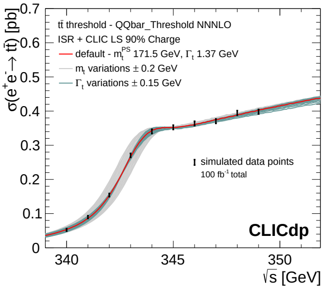
Threshold scan

Precision top mass measurement possible already with 100-200 fb^{-1}

Baseline scan scenario: 10 cross section measurements, 10-20 fb^{-1} each



arXiv:1903.01629



arXiv:1807.02441

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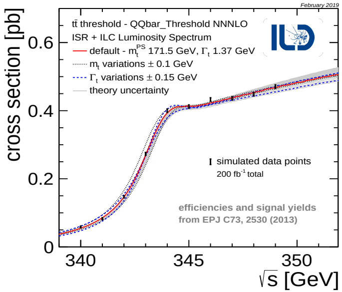

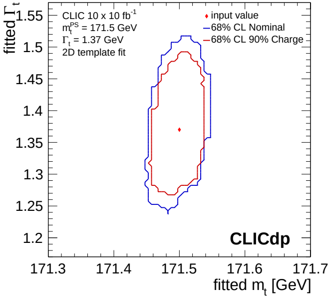

About 20 MeV uncertainty on mass expected from mass and width fit (2D)

Threshold scan

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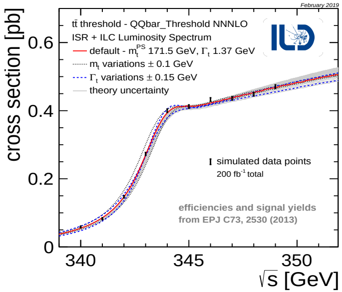
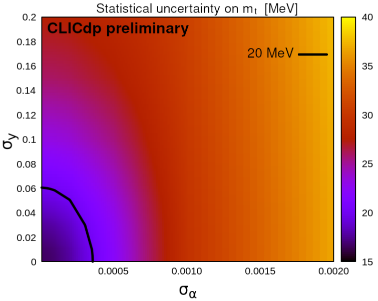




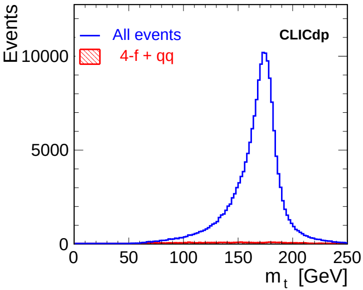
About 20 MeV uncertainty on mass expected from mass and width fit (2D)

However, α_s and top-quark Yukawa coupling need to be constrained from independent measurements. Total systematic uncertainty $\sim$ 50 MeV.

Top-quark mass

Direct measurement

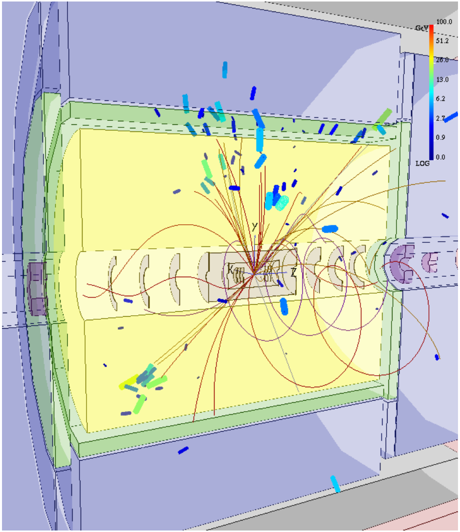
From reconstruction of hadronic top-quark decays



Statistical precision $\sim$ 30 MeV

Needs excellent control of JES
Large theoretical uncertainties

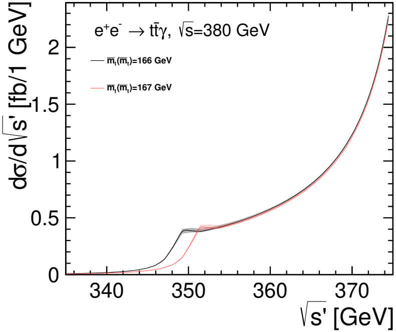
arXiv:1807.02441



Radiative events

$$e^+e^- \quad \rightarrow \quad t\ \bar{t} + \gamma_{ISR}$$

Threshold from reconstructed $t\bar{t}$ invariant mass distribution



M. Boronat et al., *Top quark mass measurement in radiative events at electron-positron colliders*, to be submitted.

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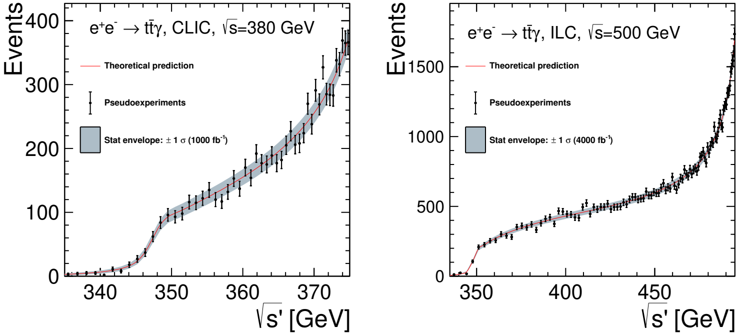

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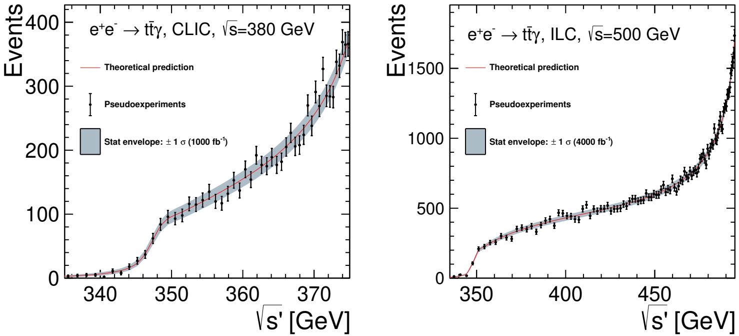
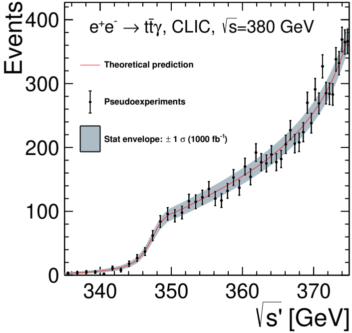


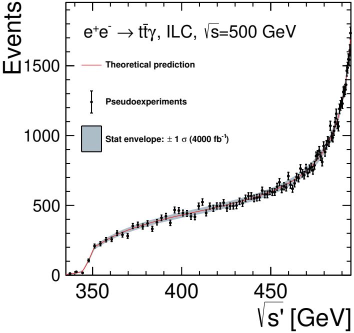
Statistical unc. on m_t: 90 MeV 110 MeV

Radiative events

$$e^+e^- \quad \rightarrow \quad t\,\bar{t} + \gamma_{ISR}$$

Threshold from reconstructed $t\bar{t}$ invariant mass distribution



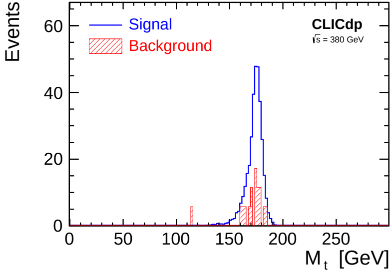


	CLIC	ILC
Statistical unc. on m_t:	90 MeV	110 MeV
Total unc.	110 MeV	150 MeV

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

Reconstructed $c\gamma$ invariant mass after BDT selection



arXiv:1807.02441

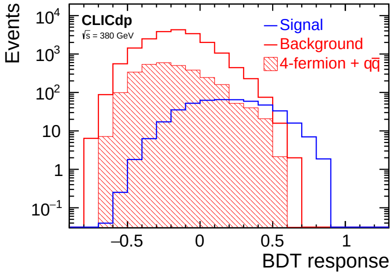
Limits expected for 1000 fb^{-1} collected at 380 GeV

$$BR(t \to c\gamma) \quad < \quad 2.6 \cdot 10^{-5}$$

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

Response distribution of the BDT for the $t \to cH$ selection



Limits expected for $1000\,\mathrm{fb}^{-1}$ collected at 380 GeV

$$BR(t \to c\gamma) \; < \; 2.6 \cdot 10^{-5}$$

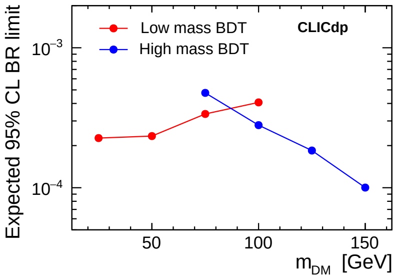
$$BR(t \to cH) \times BR(H \to b\bar{b}) \; < \; 8.8 \cdot 10^{-5}$$

arXiv:1807.02441

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

95% C.L. limits on $BR(t \to c\not{E})$ as a function of DM particle mass



arXiv:1807.02441

Limits expected for $1000\,fb^{-1}$ collected at 380 GeV

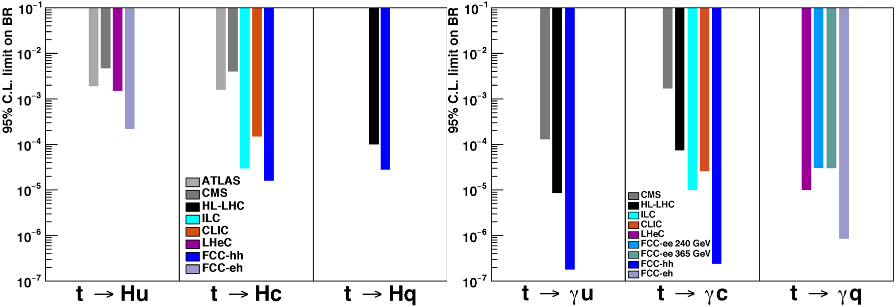
$$BR(t \to c\gamma) < 2.6 \cdot 10^{-5}$$

$$BR(t \to cH) \times BR(H \to b\bar{b}) < 8.8 \cdot 10^{-5}$$

$$BR(t \to c\not{E}) < 1.0 - 3.4 \cdot 10^{-4}$$

FCNC top-quark decays

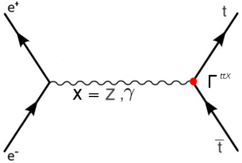
Comparison of expected limits:



For channels involving charm quark, only FCC-hh can compete with LC

Top-quark pair production

Pair production provides direct access to top electroweak couplings



Possible higher order corrections
⇒ sensitive to "new physics" contribution

New physics effects can be constrained through measurement of:

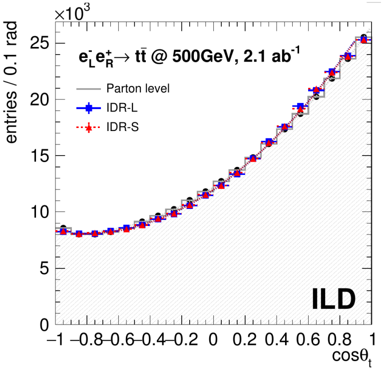
- total cross-section
- forward-backward asymmetry
- helicity angle distribution in top decays

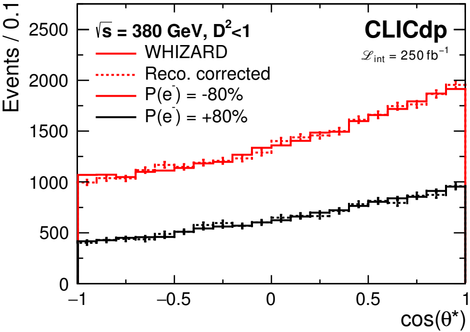
Additional constraints obtained by:

- using electron (and positron) beam polarisation
- measurements at different $\sqrt{s}$

Top EW couplings

Can be constrained from the measurements of top-quark pair-production cross sections and angular distributions

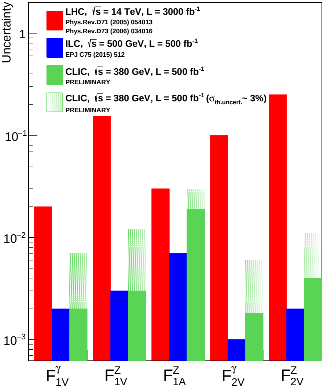




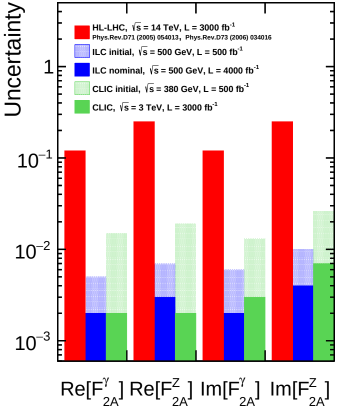
Top EW couplings

Expected sensitivity to electroweak couplings of the top quark

CP-conserving form factors



CP-violating form factors

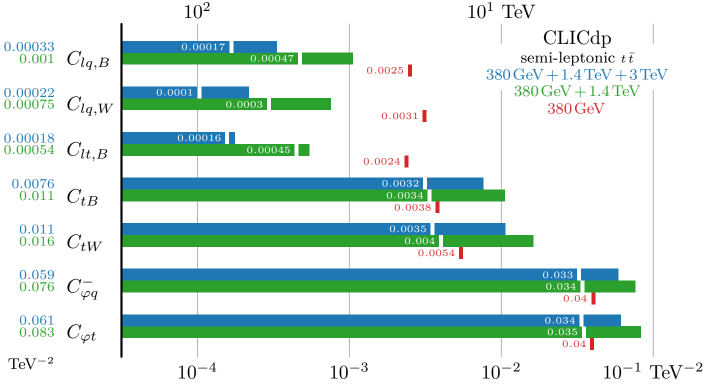


arXiv:1710.06737

Looking for BSM effects

Global EFT analysis of CLIC measurements involving top quark

Results based on statistically optimal observables arXiv:1807.02441



High energy CLIC can reach "new physics" scales in the 100 TeV range

BSM physics


compositeness
hidden valley
stub tracks
self-coupling
Higgs
neutral currents
lepton flavor violation
CLIC search
dark matter
discovery
inert doublet
BSM
2HDM
precision
mono-photon
see-saw

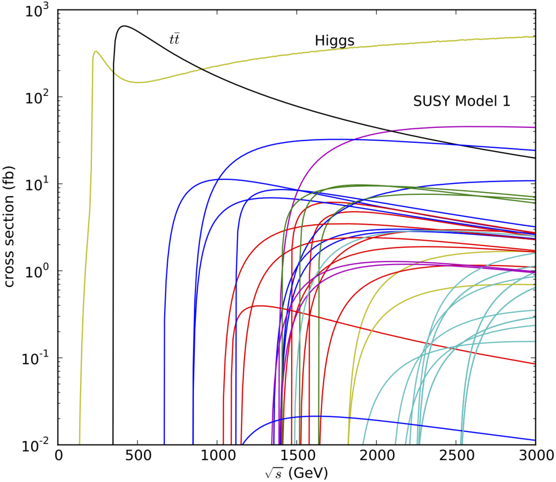
Two complementary approaches

Strong limits expected at HL-LHC for many scenarios.

Complementary searches at LC:

- direct searches
  models with weak couplings or soft signatures
- indirect searches
  high sensitivity

CLIC CDR



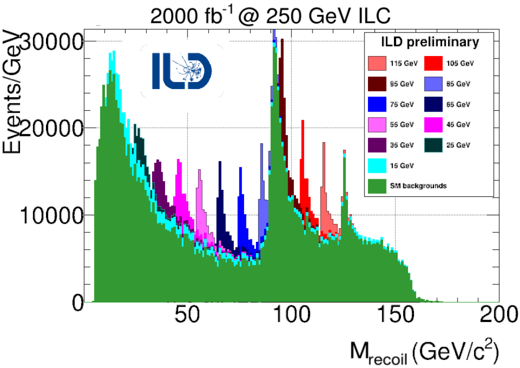
BSM physics

Search for new scalars

Many BSM models introduce extended Higgs sectors.

New scalars could be light, if their couplings to SM particles are small.

Search for production and invisible decays of new scalars: arXiv:1903.01629



$$e^+e^- \rightarrow Z\ S^0 \rightarrow \mu^+\mu^- + inv$$

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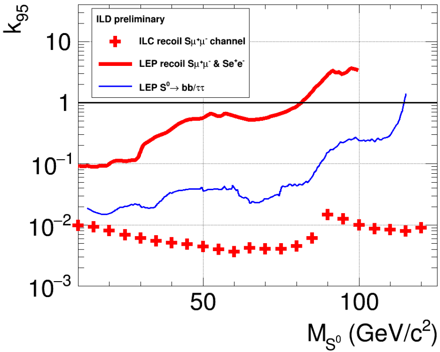

Significant improvement of LEP limits @ 250 GeV

Search for new scalars

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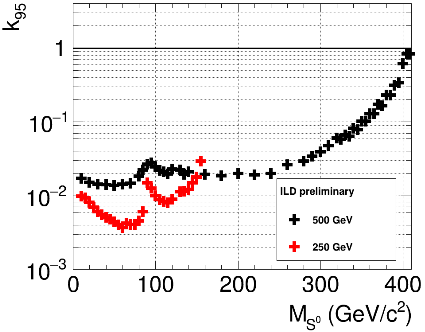
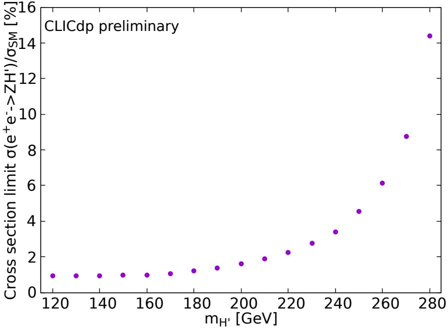
Search for production and invisible decays of new scalars:

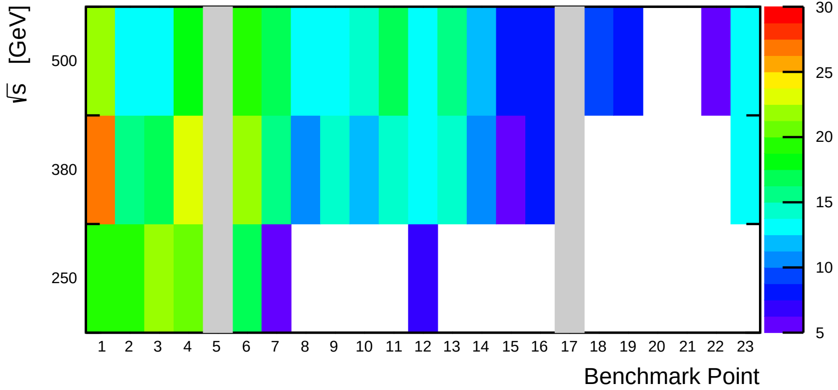




Extending to higher masses at ILC-500 and CLIC-380

Inert Doublet Model

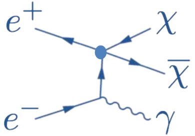
Scenarios with light inert scalars (DM candidates) still not excluded.
Many such scenarios can be probed at future e^+e^- colliders



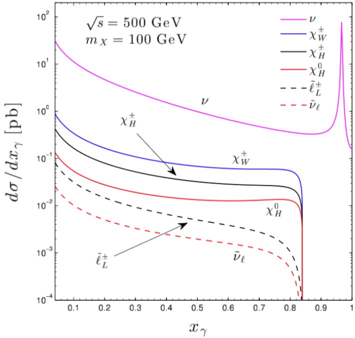
Benchmarks from arXiv:1809.07712

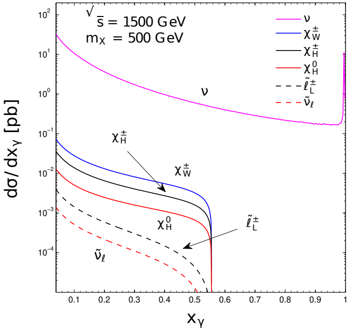
More details in a dedicated talk on Friday

Dark Matter searches



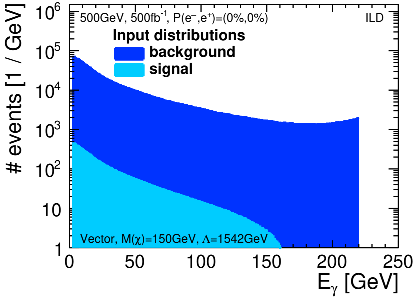
Production of Dark Matter possible in many scenarios.
In e^+e^- collisions, we can detect invisible final states by studying the ISR photon spectra





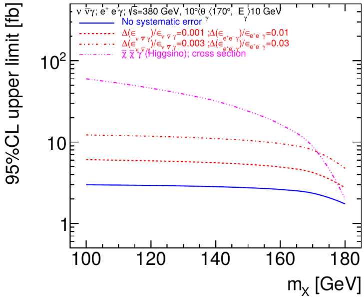
Dark Matter searches

Expected photon spectra (ILC500)



M.Habermehl, PhD Thesis

Cross section limits at CLIC380

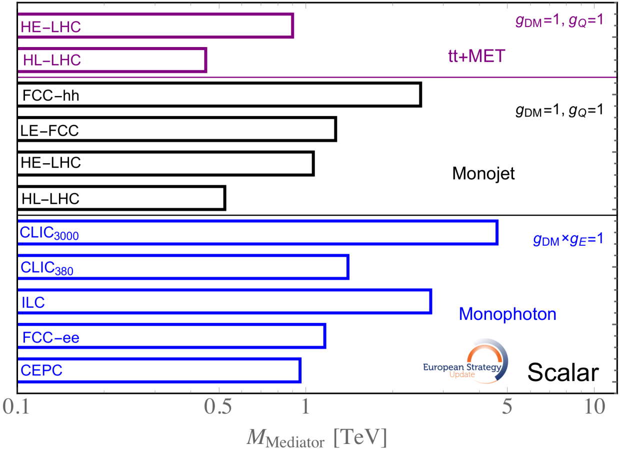


arXiv:1812.02093

Large background, but expected signal statistics is also large

Dark Matter searches

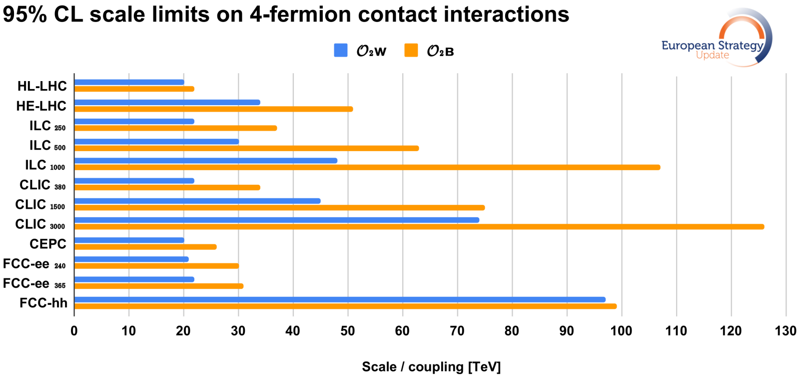
Comparison of extracted mediator mass limits



ILC/CLIC mass reach comparable with that of FCC-hh !!!

EFT analysis

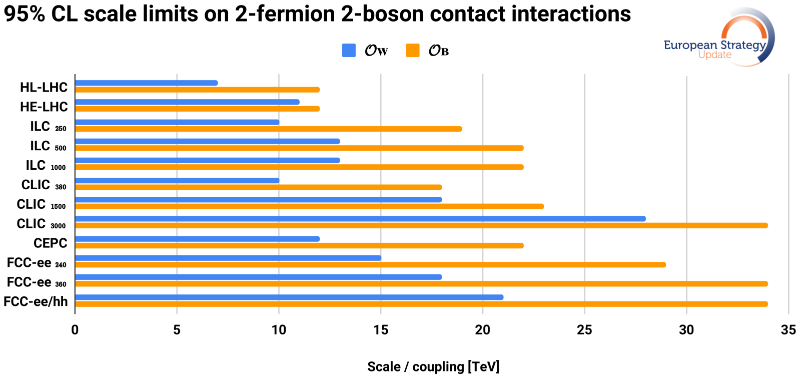
Summary of the sensitivity to SM-EFT operators from a global analysis of corresponding observables for different future colliders



ILC1000/CLIC3000 sensitivity exceeds that of FCC-hh

EFT analysis

Summary of the sensitivity to SM-EFT operators from a global analysis of corresponding observables for different future colliders

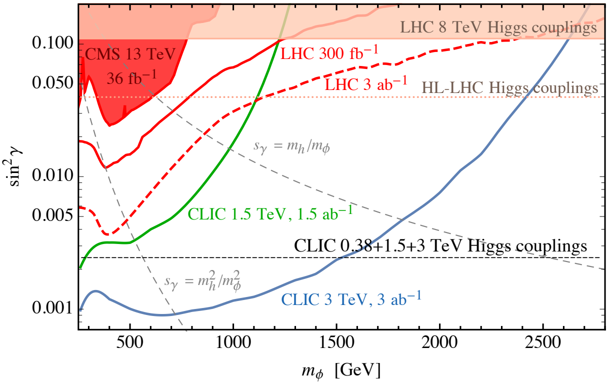


CLIC3000 sensitivity matches that of FCC-ee/hh

Direct searches

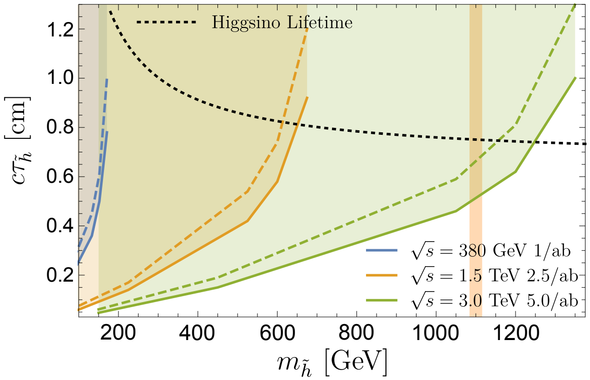
For many models, in particular those with exotic scalar sector or new Higgs bosons, CLIC direct and indirect reach can exceed that of HL-LHC.

Indirect and direct sensitivities to new heavy scalar singlets:



Direct searches

Search for dark matter using “disappearing tracks” signature @ CLIC



high sensitivity thanks to precision tracking and low background conditions

Conclusions

Conclusions

Physics potential of ILC and CLIC personal view

High Energy linear e^+e^- colliders offer rich and diverse research programme:

- precise determination of Higgs couplings
- precise determination of top-quark mass and other properties
- stringent constraints on many BSM scenarios from indirect searches
- prospects for direct observation of new physics in many scenarios

Physics potential of ILC and CLIC

personal view

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Conclusions

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As we have no hint for the actual BSM scenario, it is not possible to say which one, ILC or CLIC, has larger physics potential.

The two projects are to a large extent complementary!

From the physics point of view we should build both!


compositeness
hidden valley
stub tracks
self-coupling
Higgs
$V_{sr}(\phi) = rg\Lambda^3\phi$
neutral currents
lepton flavor violation
CLIC search
dark matter
discovery
inert doublet
BSM
2HDM
precision
photon
see-saw

Thank you!

ILC references

European Strategy submissions

- The International Collider. A Global Project — submission, arXiv:1903.01629
- The International Collider. An European perspective — submission
- The ILD Detector at the ILC — submission

Other reports

- The International Linear Collider Technical Design Report
  Volume 3.II: Accelerator Baseline Design — arXiv:1306.6328
- The International Linear Collider Technical Design Report
  Volume 4: Detectors — arXiv:1306.6329
- The Potential of the ILC for Discovering New Particles — arXiv:1702.05333
- Physics Case for the 250 GeV Stage of the International Linear Collider — arXiv:1710.07621
- The International Linear Collider Machine Staging Report 2017 — arXiv:1711.00568
- The role of positron polarization for the inital 250 GeV stage
  of the International Linear Collider — arXiv:1801.02840

CLIC references

Formal European Strategy submissions

- The Compact Linear e^+e^- Collider (CLIC): Accelerator and Detector, arXiv:1812.07987
- The Compact Linear e^+e^- Collider (CLIC): Physics Potential, arXiv:1812.07986

Yellow Reports

- CLIC 2018 Summary Report, CERN-2018-005-M, arXiv:1812.06018
- CLIC Project Implementation Plan, CERN-2018-010-M, arXiv:1903.08655
- The CLIC potential for new physics, CERN-2018-009-M, arXiv:1812.02093
- Detector technologies for CLIC, CERN-2019-001, arXiv:1905.02520

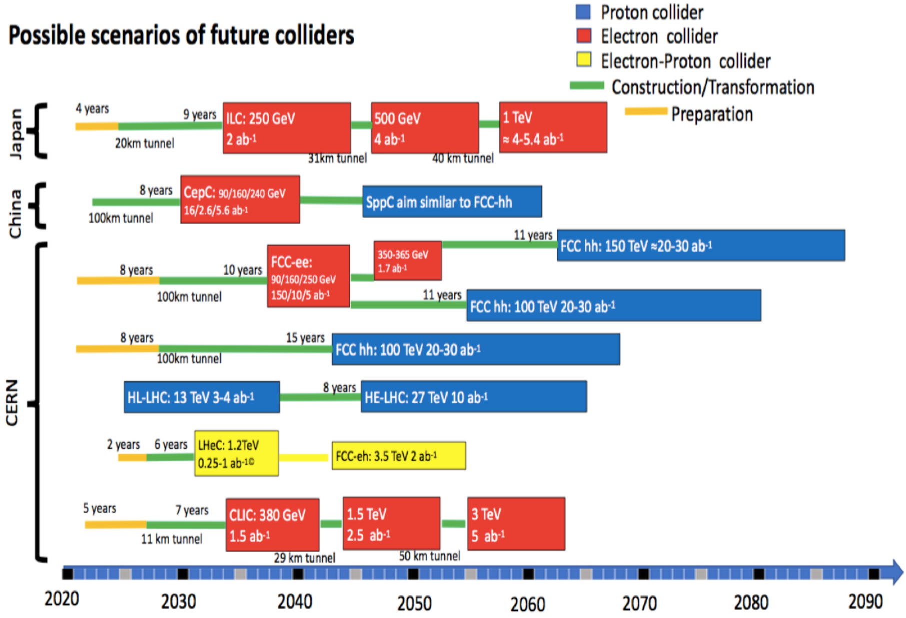
Journal publications

- Top-quark physics at the CLIC electron-positron linear collider arXiv:1807.02441
- Higgs physics at the CLIC electron-positron linear collider arXiv:1608.07538

Public CLICdp notes

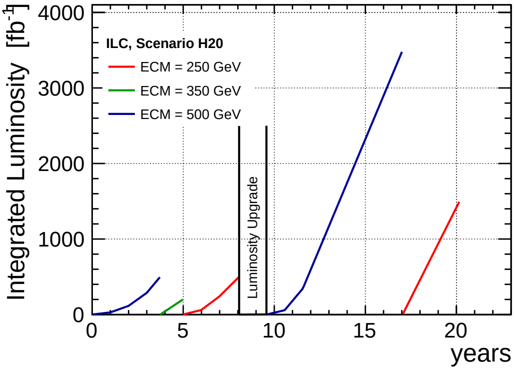
- Updated CLIC luminosity staging baseline and Higgs coupling prospects arXiv:1812.01644
- CLICdet: The post-CDR CLIC detector model CLICdp-Note-2017-001
- A detector for CLIC: main parameters and performance arXiv:1812.07337

Future collider timeline

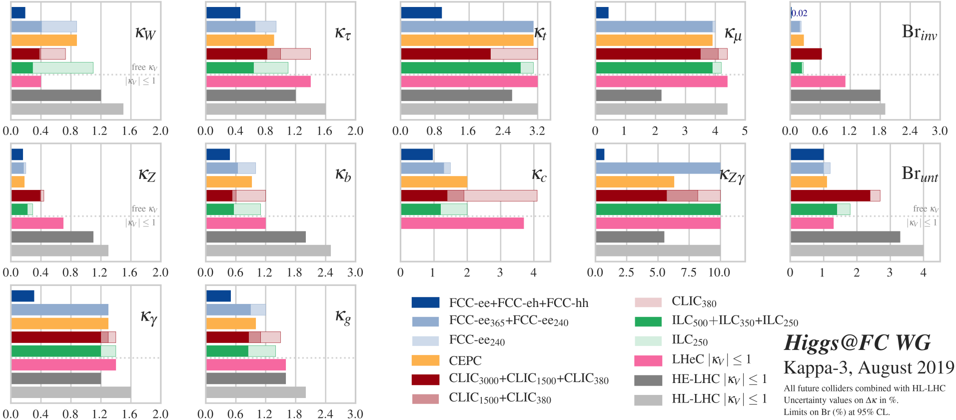


International Linear Collider

H-20 running scenario for ILC500



arXiv:1506.07830



κW
free κV
|κV| ≤ 1
0.0 0.4 0.8 1.2 1.6 2.0
κτ
0.0 0.4 0.8 1.2 1.6 2.0
κt
0.0 0.8 1.6 2.4 3.2
κμ
0 1 2 3 4 5
0.02
Br_inv
0.0 0.6 1.2 1.8 2.4 3.0
κZ
free κV
|κV| ≤ 1
0.0 0.4 0.8 1.2 1.6 2.0
κb
0.0 0.6 1.2 1.8 2.4 3.0
κc
0 1 2 3 4
κZγ
0.0 2.5 5.0 7.5 10.0
Br_unt
free κV
|κV| ≤ 1
0 1 2 3 4
κγ
0.0 0.4 0.8 1.2 1.6 2.0
κg
0.0 0.6 1.2 1.8 2.4 3.0
FCC-ee+FCC-eh+FCC-hh
FCC-ee365+FCC-ee240
FCC-ee240
CEPC
CLIC3000+CLIC1500+CLIC380
CLIC1500+CLIC380
CLIC380
ILC500+ILC350+ILC250
ILC250
LHeC |κV| ≤ 1
HE-LHC |κV| ≤ 1
HL-LHC |κV| ≤ 1
Higgs@FC WG
Kappa-3, August 2019
All future colliders combined with HL-LHC
Uncertainty values on Δκ in %.
Limits on Br (%) at 95% CL.