The CLIC Physics Potential

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– on behalf of CLICdp –

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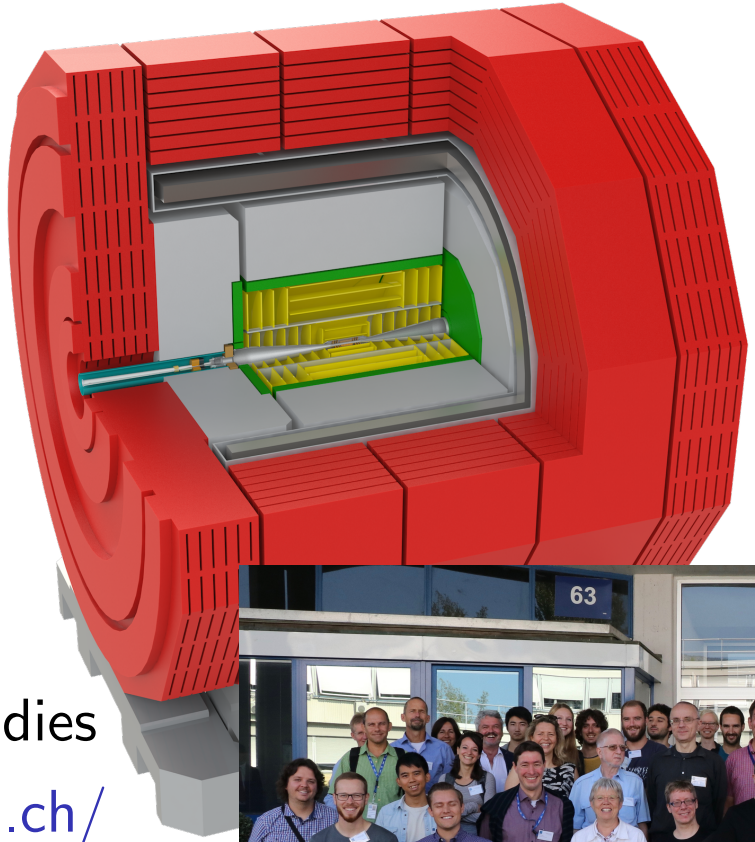
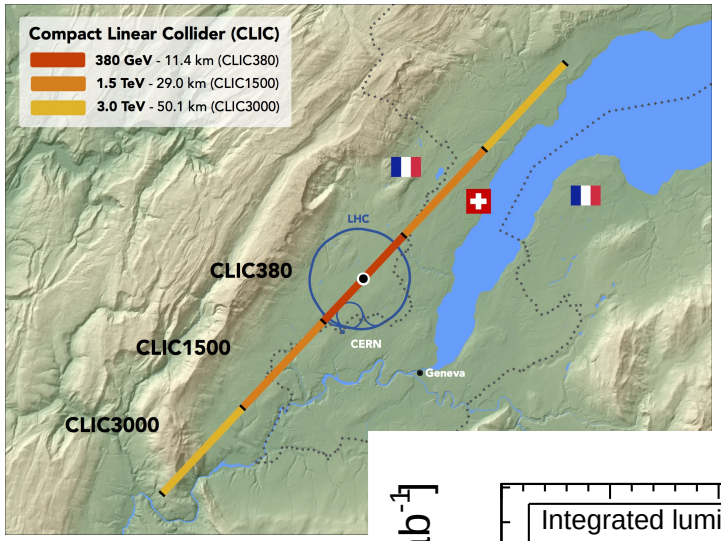
CLIC detector and physics (CLICdp)

- 30 institutions
- 18 countries
- Detector R&D and optimization
- Physics prospects and simulation studies

https://clicdp.web.cern.ch/



Physics at CLIC



CLIC 380 $\Rightarrow$ 1 ab^{-1}

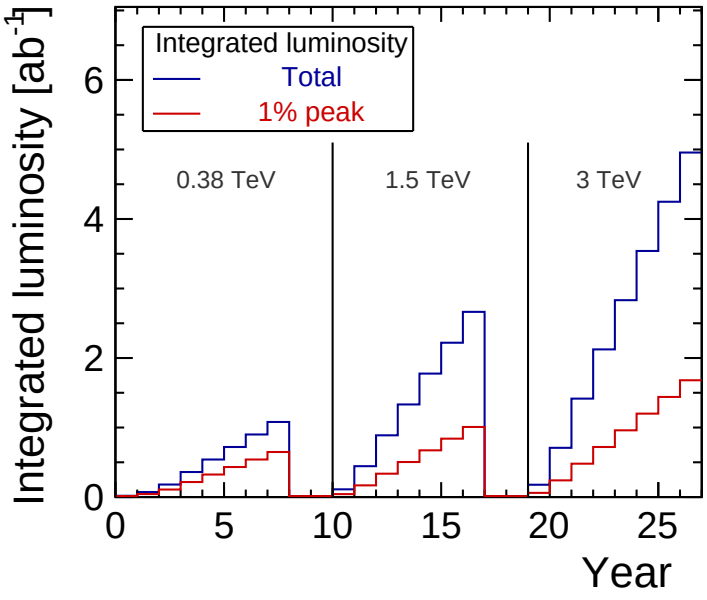
- Higgs decays and couplings
- Top-pair threshold
- Top-pair continuum

CLIC 1500 $\Rightarrow$ 2.5 ab^{-1}

- Exclusive top/electroweak interactions
- Higgs self-interaction

CLIC 3000 $\Rightarrow$ 5 ab^{-1}

- Vector-boson scattering
- Exploiting the BSM discovery potential

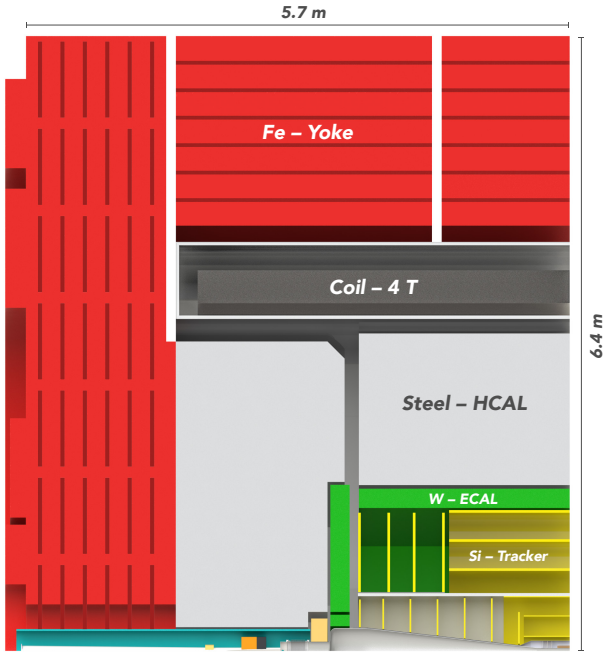


Polarization: e^- (± 80 %) / Lumi spectrum: via Bhabha scattering

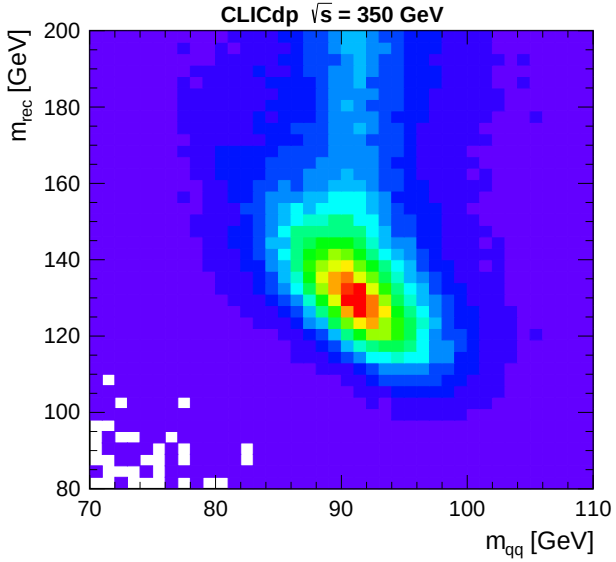
(arXiv:1812.01644)

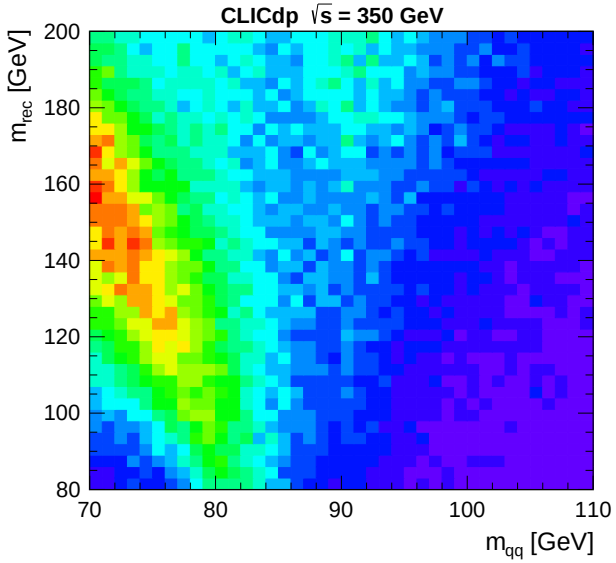
CLIC Detector (arXiv:1812.07337)

- Momentum resolution
  - ⇒ Higgs coupling to muons, leptons from BSM, ...
    $\sigma_{p_T}/p_T \sim 2 \times 10^{-5}$ GeV^{-1} above 100 GeV
- Jet energy resolution
  - ⇒ separation of W/Z/H di-jets
    $\sigma_E/E \sim 5\,\% \ldots 3.5\%$ for jets at 50 GeV ... 1000 GeV
- Impact parameter resolution
  - ⇒ b/c-tagging, Higgs couplings, ...
    $\sigma_{r\varphi} \sim a \oplus b\,/\,(p[GeV]\sin^{3/2}\theta)\,\mu$m
    with $a = 5\ \mu$m, $b = 15\ \mu$m
- Lepton identification efficiency $> 95\%$
- Angular coverage
  - ⇒ Vector-boson fusion, photon tagging
    Down to $\theta = 10$ mrad $(\eta = 5.3)$



Higgs Physics at 350 GeV: Recoil against hadronic Z





Higgs studies (EPJC 76 (2016) 72)

$e^-e^+ \to Z(\to jj)+X$ [1 ab^{-1}]

optimal sensitivity near 350/380 GeV:

$\sqrt{s}$ [GeV]	σ [fb]	$\Delta\sigma$ [fb]
250	136	2.6 %
350	93	1.3 %
420	68	1.9 %

(combine with $Z \to \ell\ell$)

$\Rightarrow$ fit

$\Rightarrow$ absolute normalization of all Higgs couplings

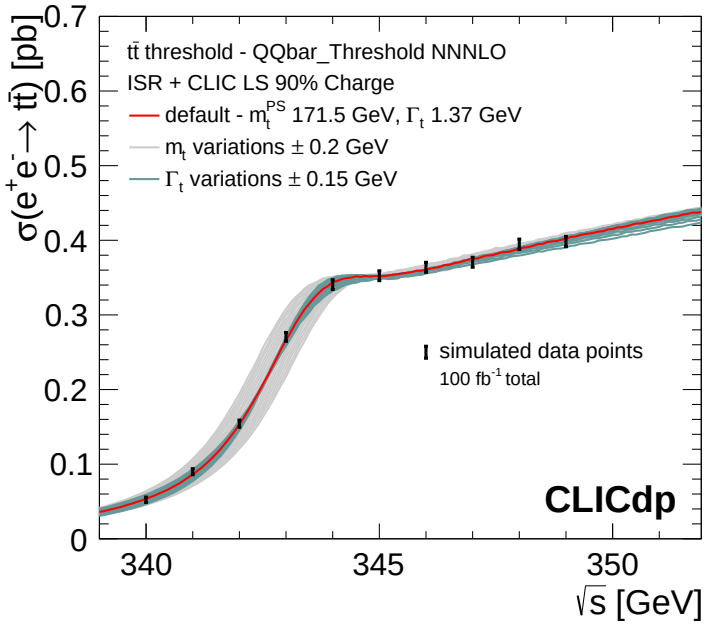
Higgs Physics at 350 GeV: Higgs-strahlung and WW fusion

ZH	Recoil mass distribution	m_H	78 MeV
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to \text{invisible})$	Γ_{inv}	0.4 %
ZH	$\sigma(ZH) \times \mathrm{BR}(Z \to \ell^+\ell^-)$	g^2_{HZZ}	2.7 %
ZH	$\sigma(ZH) \times \mathrm{BR}(Z \to q\bar{q})$	g^2_{HZZ}	1.3 %
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	0.61 %
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to c\bar{c})$	$g^2_{HZZ}g^2_{Hcc}/\Gamma_H$	10 %
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to gg)$		4.3 %
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to \tau^+\tau^-)$	$g^2_{HZZ}g^2_{H\tau\tau}/\Gamma_H$	4.4 %
ZH	$\sigma(ZH) \times \mathrm{BR}(H \to WW^*)$	$g^2_{HZZ}g^2_{HWW}/\Gamma_H$	3.6 %
$H\nu\bar{\nu}$	$\sigma(H\nu\bar{\nu}) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{HWW}g^2_{Hbb}/\Gamma_H$	1.3 %
$H\nu\bar{\nu}$	$\sigma(H\nu\bar{\nu}) \times \mathrm{BR}(H \to c\bar{c})$	$g^2_{HWW}g^2_{Hcc}/\Gamma_H$	18 %
$H\nu\bar{\nu}$	$\sigma(H\nu\bar{\nu}) \times \mathrm{BR}(H \to gg)$		7.2 %

Model-independent fit: $1\,\mathrm{ab}^{-1}$, no polarization (arXiv:1812.01644)

Top Physics at 350/380 GeV

Threshold scan (340 . . . 350 GeV): 10 steps, 100 fb^{-1} total
Continuum (380 GeV): top-coupling measurements



$\Delta m_t(\text{stat}) \approx 20 \ldots 30$ MeV
$\Delta m_t(\text{syst}) \approx 50$ MeV

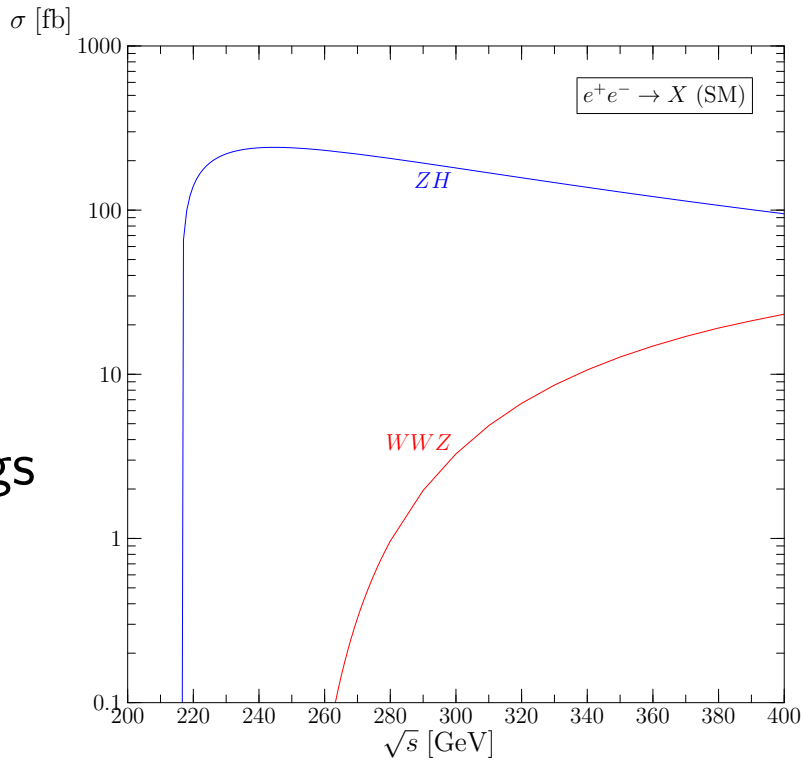
CLIC Top physics: arXiv:1807.02441

$\Rightarrow$ talk by Kacper Nowak

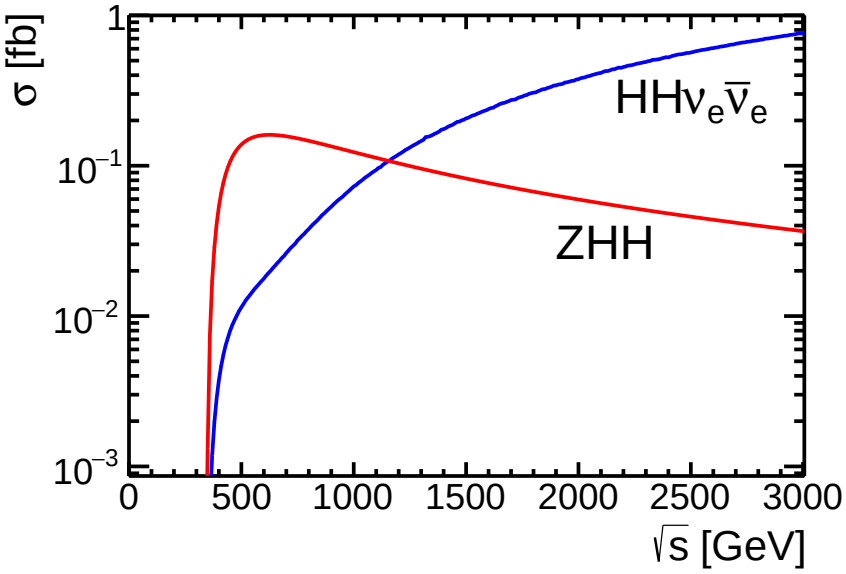
Electroweak Physics at 380 GeV: Triboson production

$e^- e^+ \to W^+ W^- Z \to 6f$

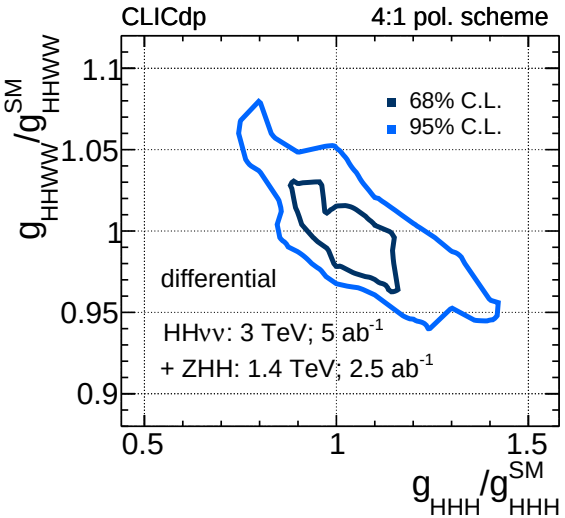
- 20k events (380 GeV, 1 ab^{-1})
- Triple + quartic gauge couplings
- Virtual Higgs exchange



Higgs Physics at 1500 and 3000 GeV: Self-coupling



Fit g_{HHH} and g_{HHWW}:



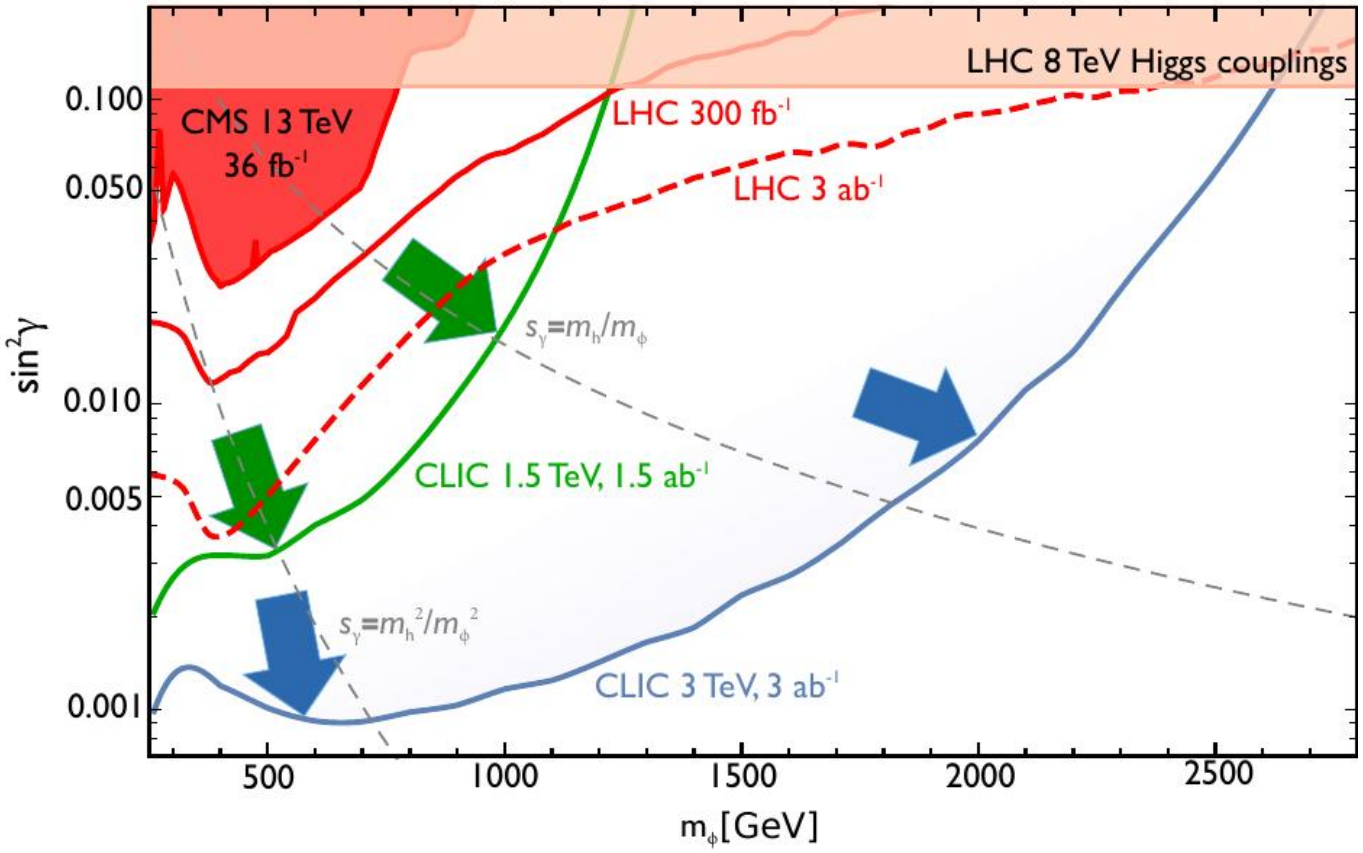
- $HH \to b\bar{b}b\bar{b}$ and $b\bar{b} + 4j$
- ZHH at 1.4 TeV
- $HH\nu\bar{\nu}$ at 3 TeV
- Full simulation, BDT analysis

Fit only g_{HHH}:

Analysis	Δg_{HHH} (68 % c.l.)
1.4 TeV only	$-34\,\% + 36\,\%$
1.4 and 3 TeV	$-7\,\% + 11\,\%$

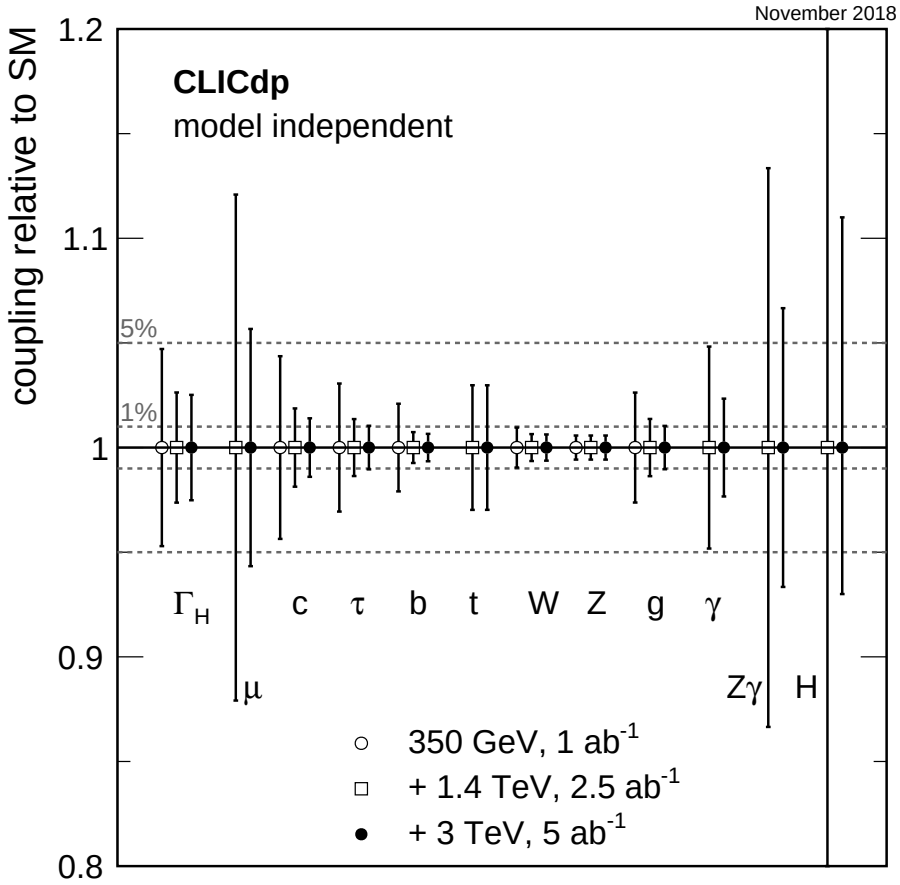
arXiv:1901.05897

Higgs Physics up to 3000 GeV: Resonances



Scalar singlet = resonance in $HH\bar{\nu}\nu$

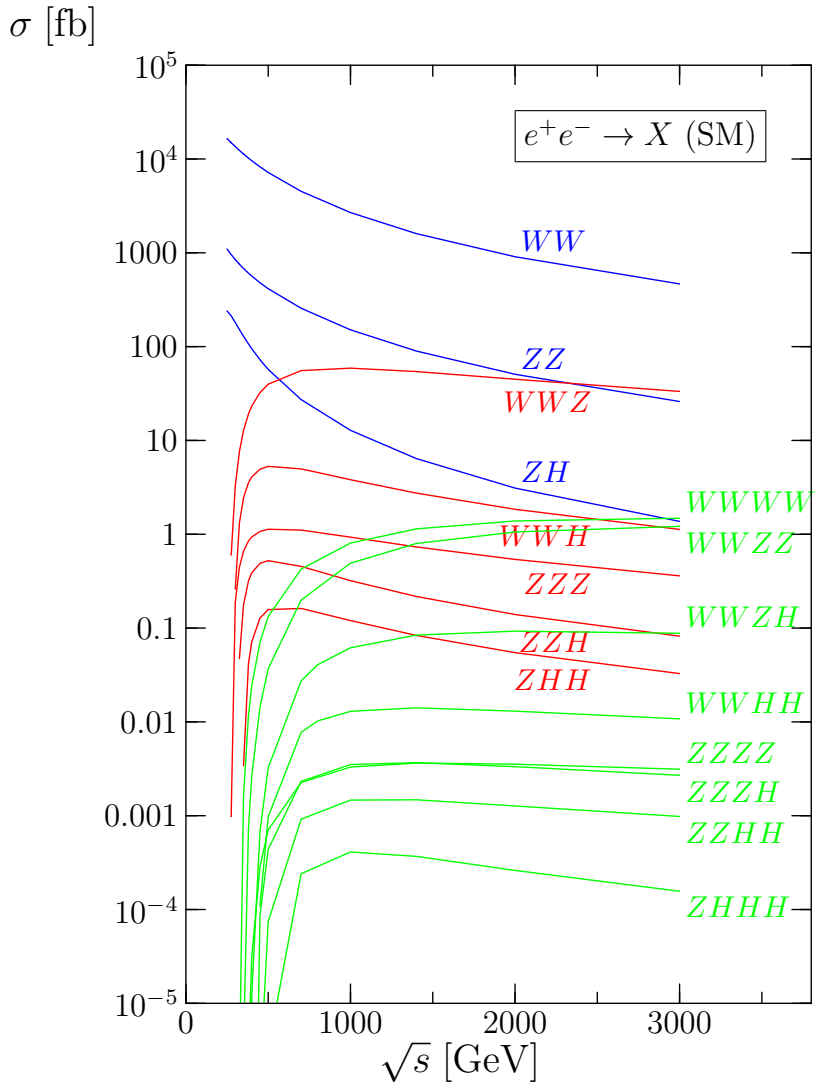
Higgs Physics combined: Higgs Couplings

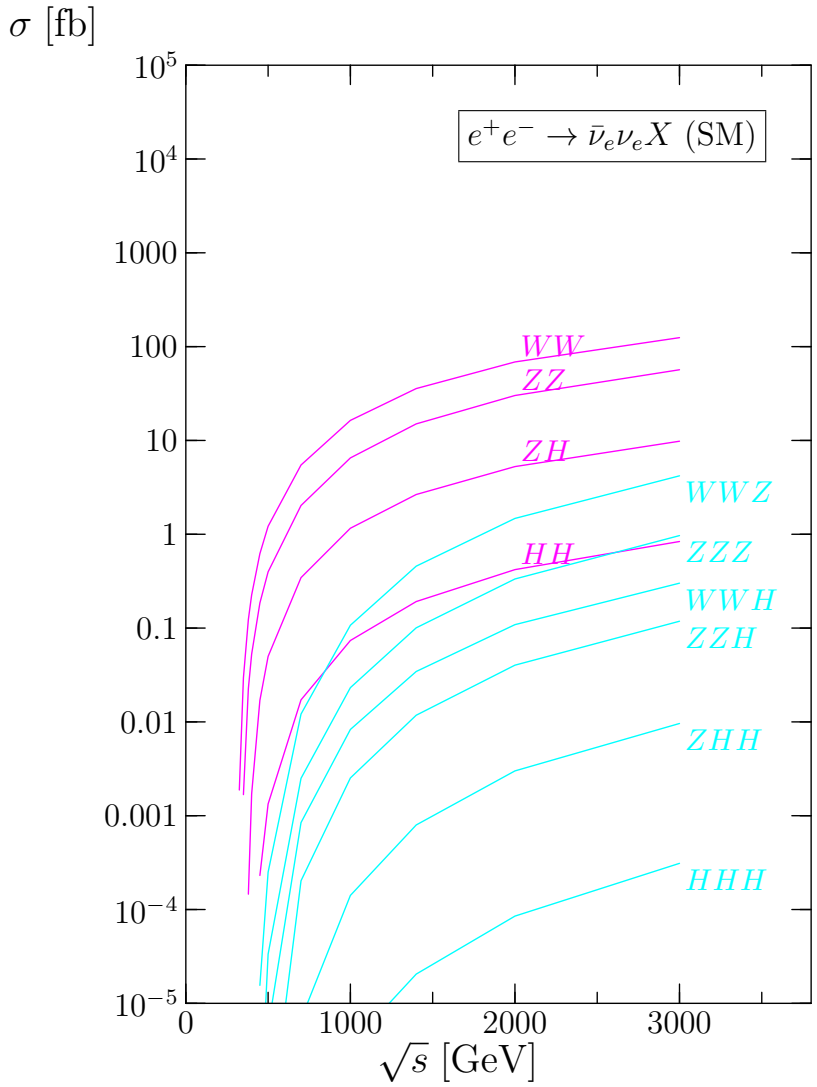


- Model-independent
- 11 parameters
- $\Delta\Gamma_H = 4.7\ \% \longrightarrow 2.5\ \%$
- Percent-level or better for all couplings

arXiv:1812.01644

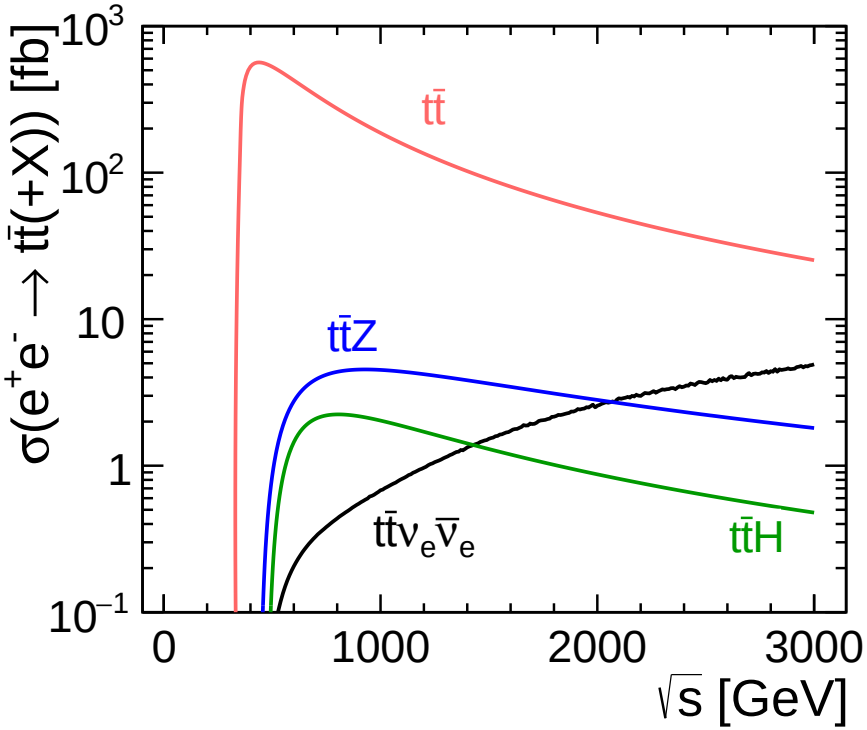
Electroweak Physics at 3000 GeV: The Rise of VBS





arXiv:1812.02093

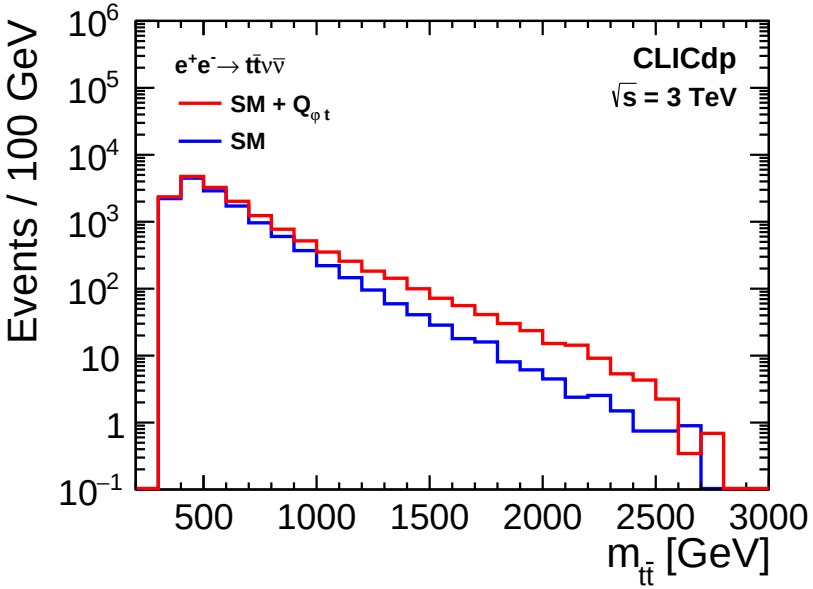
Top Physics at 3000 GeV



⇒ ttH, ttZ,...

⇒ quartic couplings

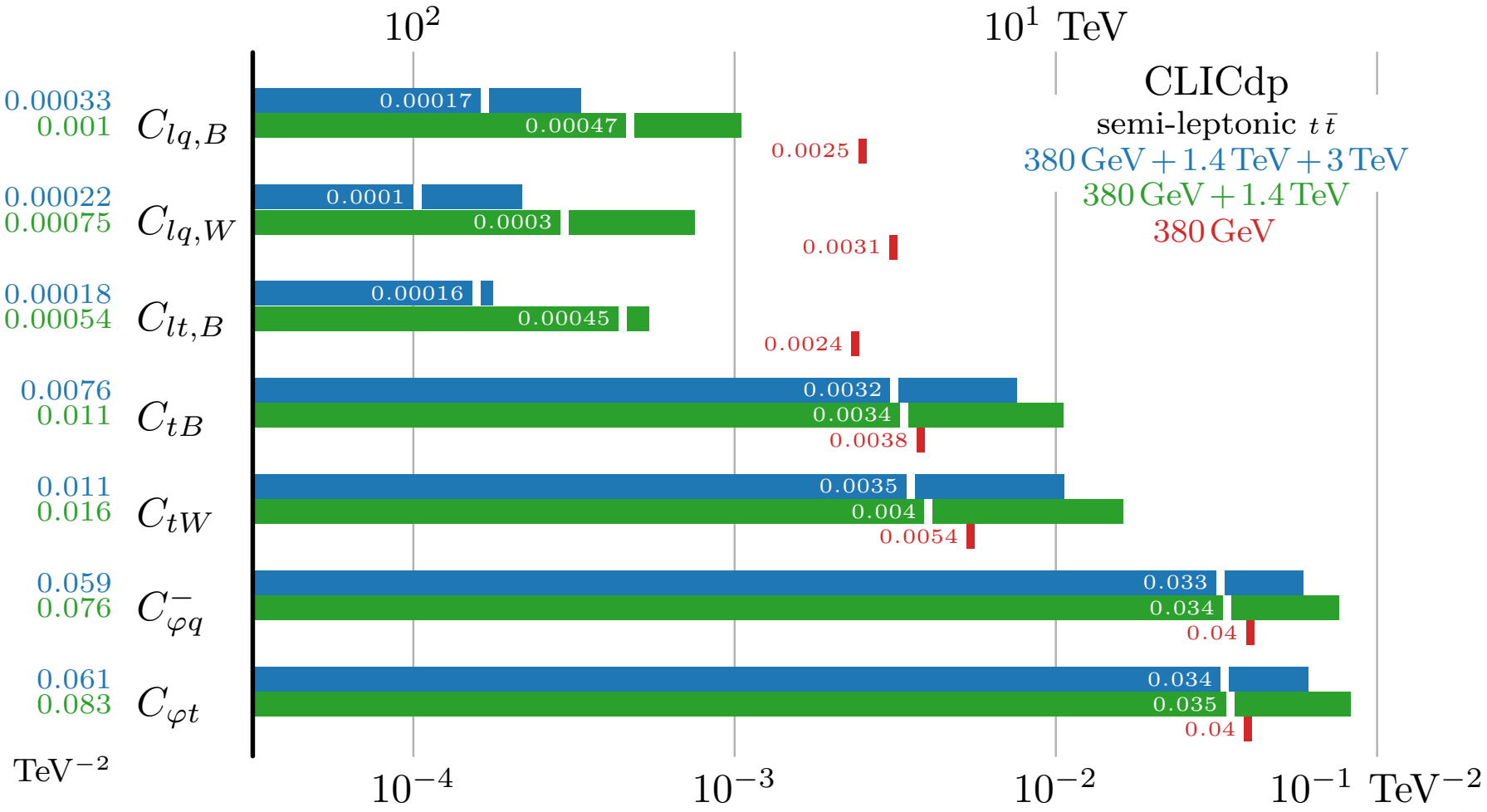
⇒ resonances



Vector-boson annihilation:
$WW \to t\bar{t}$

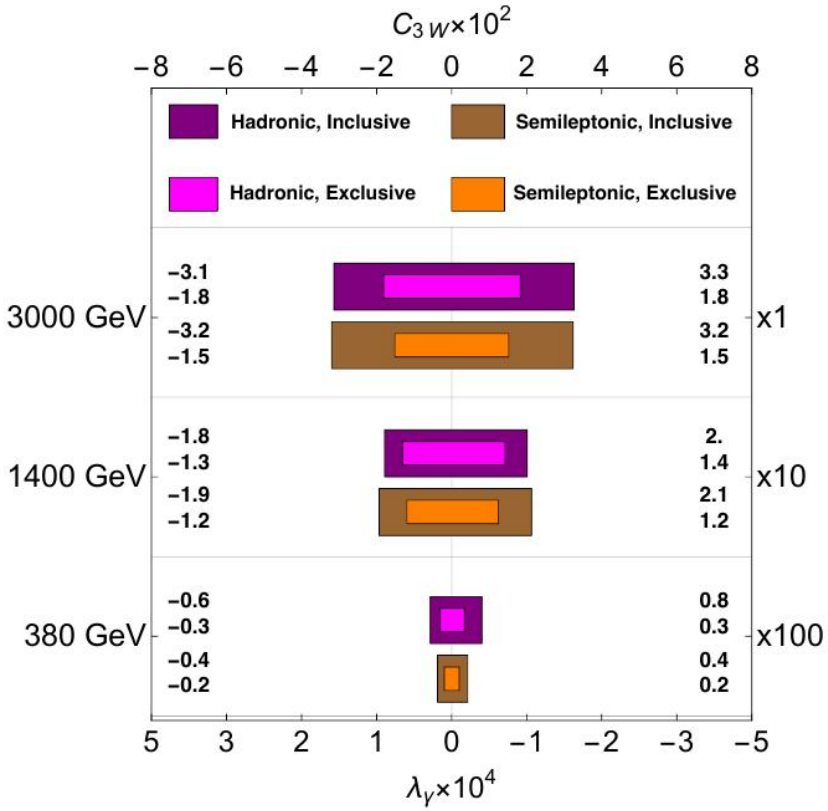
arXiv:1812.01644

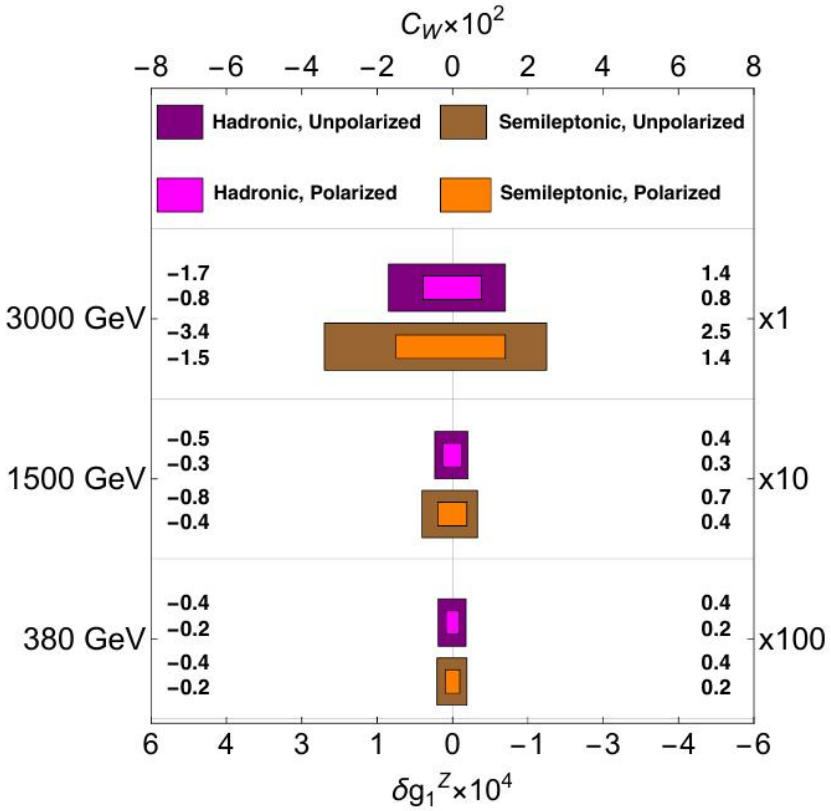
Top Physics combined



BSM Physics up to 3000 GeV: SMEFT (D=6) Coefficients

Process: diboson W^+W^-, angular analysis (arXiv:1812.02093)



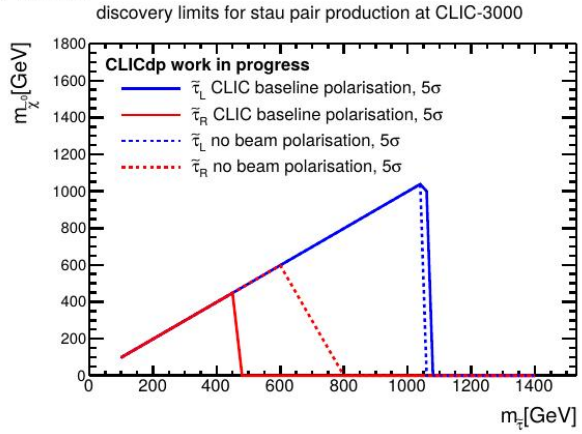


(Note scaling factors)

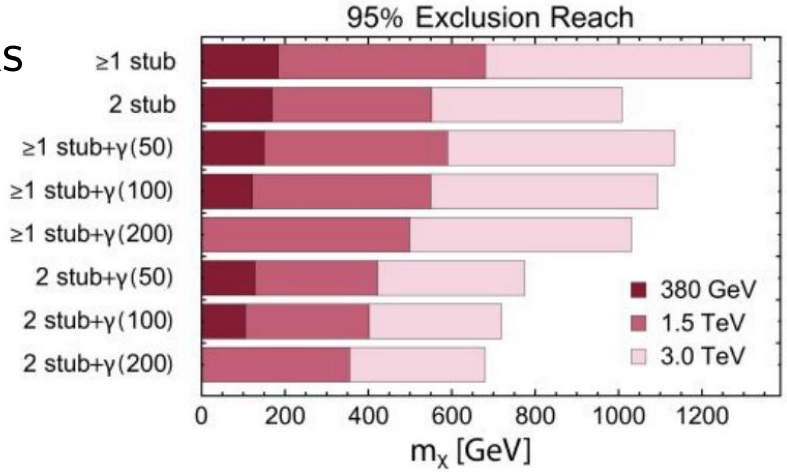
BSM Physics up to 3000 GeV: Discovery or Limits

- Low background, full final-state coverage
  - ⇒ pair-production limits determined by kinematics ($\sqrt{s}/2$) and available luminosity (5 ab^{-1})
- Example: stau pairs

5 σ limits:

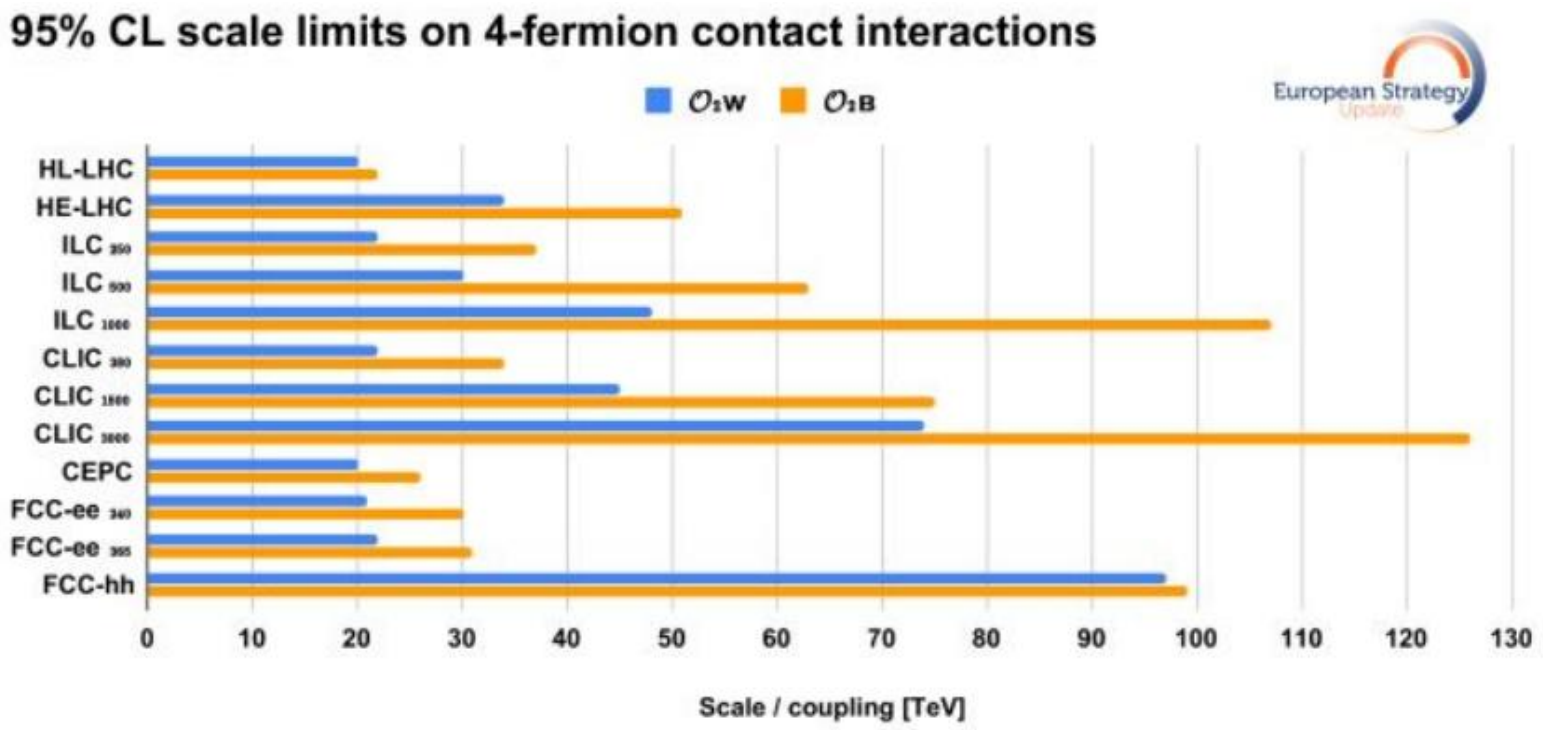


- Example: Higgsino DM, $\chi^{\pm}$ slightly heavier than χ^0
  - soft pions + disappearing tracks
  - ⇒ long-lived particles: talk by Ulrike Schnoor



BSM Physics up to 3000 GeV: Indirect Constraints

- SMEFT can be recast into limits on specific new-physics scenarios
- Straightforward: universal contact interactions



Read More:

- Higgs physics at the CLIC electron-positron linear collider
  (EPJC 76 (2016) 72, arXiv:1608.07538)
- Top-quark physics at the CLIC electron-positron linear collider
  (JHEP, arXiv:1807.02441)
- The CLIC Potential for New Physics
  (CERN Yellow Report, arXiv:1812.02093)
- The Compact Linear Collider (CLIC) - 2018 Summary Report
  (CERN Yellow Report, arXiv:1812.06018)
- Detector technologies for CLIC
  (CERN Yellow Report, arXiv:1905.02520)
- The Compact Linear e+e- Collider (CLIC): Accelerator and Detector
  (ESG Submission, arXiv:1812.07987)
- The Compact Linear e+e- Collider (CLIC): Physics Potential
  (ESG Submission, arXiv:1812.07986)