Sensitivity to new physics scenarios in invisible Higgs boson decays at CLIC

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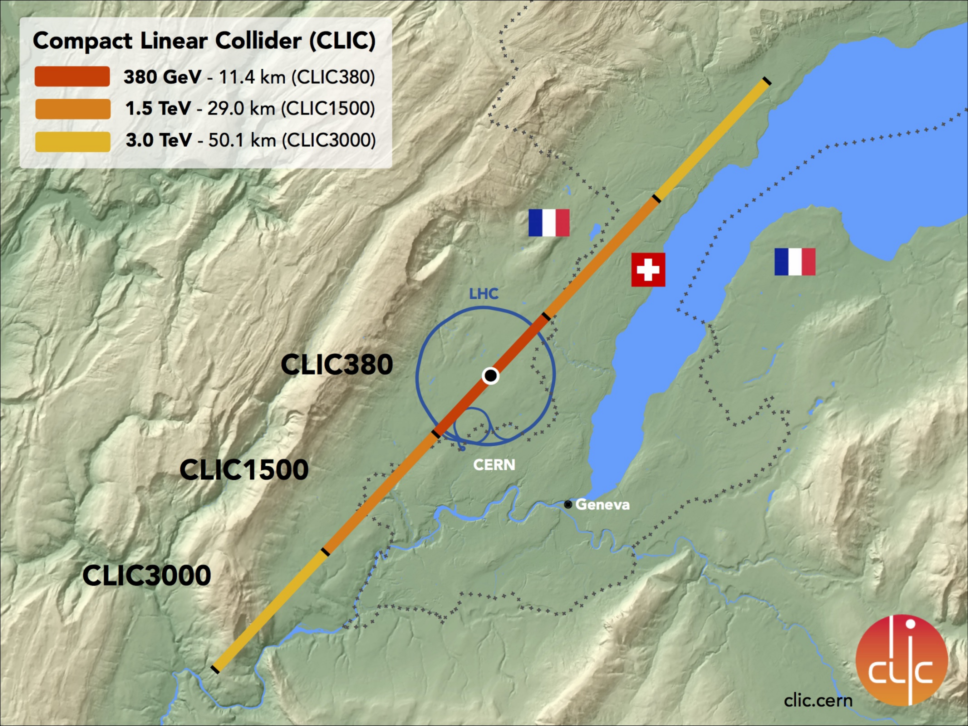


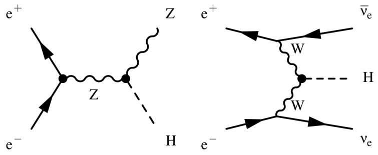
Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
clic
clic.cern

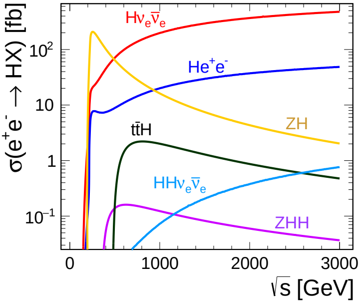
Compact Linear Collider (CLIC)

First stage @ 380 GeV

$\Rightarrow$ focus on studying Higgs boson and top-quark properties

Higgs production



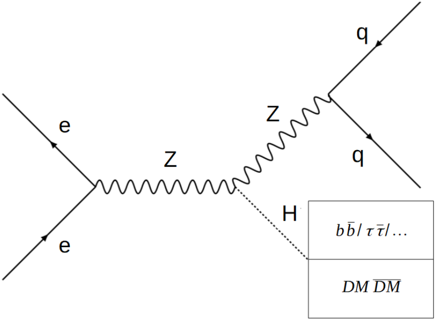


Higgs couplings to SM particles tested at % level

What about couplings (decays) to BSM states?

Signal

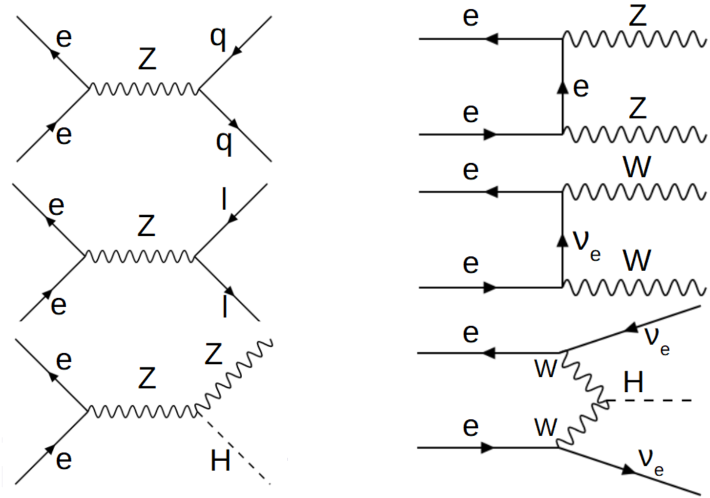
SM(-like) Higgs boson decay to invisible states (Dark Matter ?)



Signature of invisible Higgs decay:

- two jets consistent with hadronic Z decay   higher statistics
- missing energy-momentum consistent with production of invisible massive state of 125 GeV

Background processes considered



Simulation framework

- event samples generated with WHIZARD 2.7.0
  - Non-Higgs background: qq, ll, $qqqq$, $qqll$, $qql\nu$, $qq\nu\nu$
  - SM Higgs boson production: $H + qq$, $H + ll$, $H + \nu\nu$
    (with 100% SM decays)
  - Signal: $H + qq$ production with Higgs defined as stable

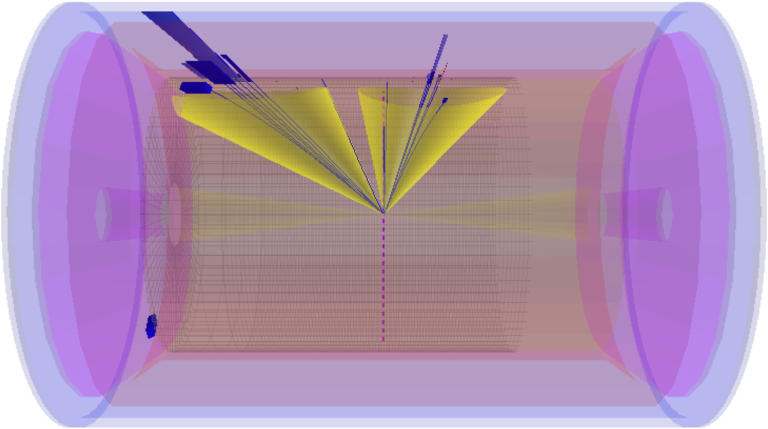
- CLIC energy spectra for **380** GeV
- CLIC integrated luminosity of **1000** fb^{-1} (unpolarised)
- detector simulation and event reconstruction with DELPHES, using modified[1] *CLICdet_Stage1* cards

Two jets reconstructed with VLC algorithm ($R = 1.5$, $\beta = \gamma = 1$)

[1] required to make Higgs invisible in the detector

Signature of $e^+e^- \to HZ \to jj + inv$

Two-jet events without electrons, muons, or isolated photons...



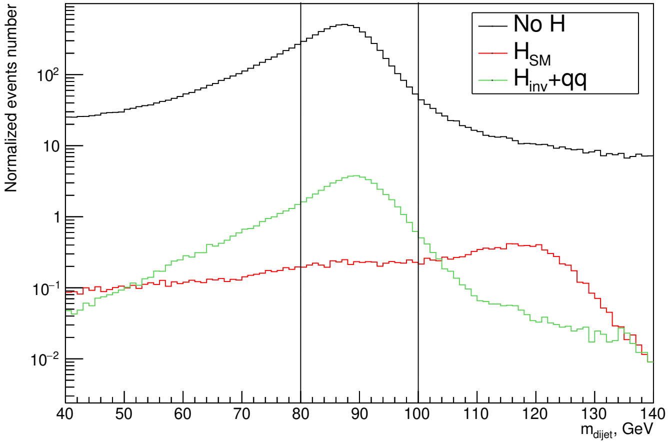
Preselection

Preselection cuts were used to select events with proper signature and kinematics consistent with invisible Higgs boson decay:

- Remove events with isolated electrons, muons or photons with energy above 2 GeV, 3 GeV and 5 GeV respectively
- Energy "lost" in jet clustering below 10 GeV
- Two-jet topology: $y_{23} < 0.01$ and $y_{34} < 0.001$
- Jet invariant mass: $80 < M_{jj} < 100$ GeV (Z mass)
- Dijet emision angle: $|\cos\Theta_{jj}| < 0.8$ (Z direction)

Preselection cut example

Di-jet invariant mass distribution with preselection cut indicated



Preselection

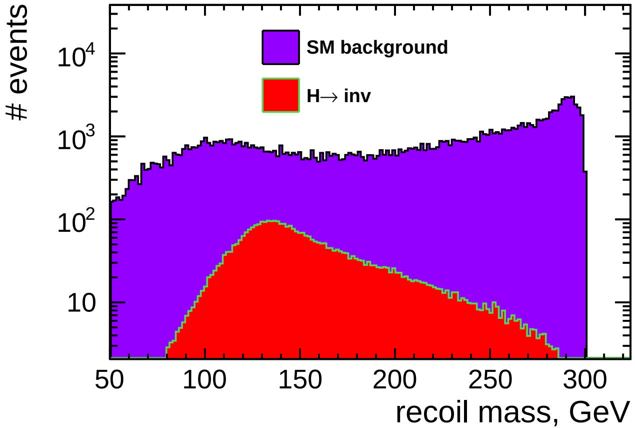
Efficiency of preselections cuts

Event class	*Efficiency*
Non-higgs background	**0.37%**
including $qq\nu\nu$	23%
$ql\nu$	0.68%
qq	0.087%
SM Higgs decays	**1.70%**
including $H + \nu\nu$	4.60%
$H + qq$ **invisible decays**	**47.0%**

Preselection

Recoil mass distribution after preselection cuts

For 1000 fb^{-1} collected at 380 GeV assuming BR(H→inv) = 10%

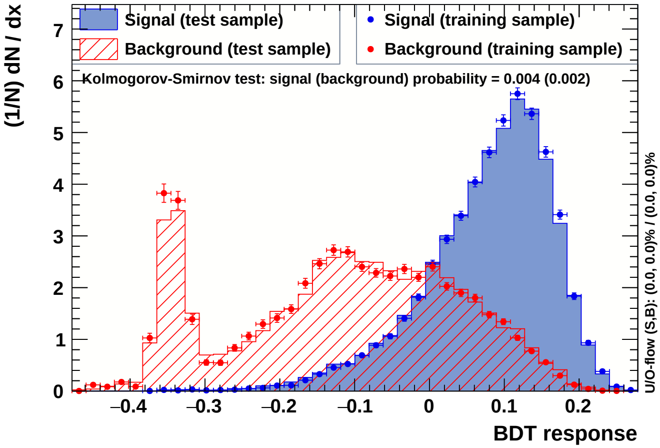


Selection

Final event selection based on the multivariate analysis.
Variables used as input for Boosted Decision Tree (BDT):

1. α_{jj} – angle between two jets in LAB frame
2. m_{jj} – dijet invariant mass
3. m^{miss} – missing mass
4. E_{jj} – dijet energy
5. p_t^{miss} – missing transverse momentum

Selection



Highest significance for invisible Higgs decays for BDT cut ~ 0.06

Results

95% C.L. limit expected for 1000 fb^{-1} collected at 380 GeV:

$$BR(H \to inv) \;<\; 0.86\%$$

Assuming **no excess** above predicted SM background is observed

CLICdp preliminary

Result consistent with the old study:
$BR(H \to inv) < 0.94\%$ expected for 500 fb^{-1} collected at 350 GeV
M. A. Thomson, The European Physical Journal C, 76(2):72

Interpretation

In Higgs-portal models, new scalars fields ϕ coupling to dark matter particles can mix with the SM Higgs field h resulting in two mass eigenstates:

$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

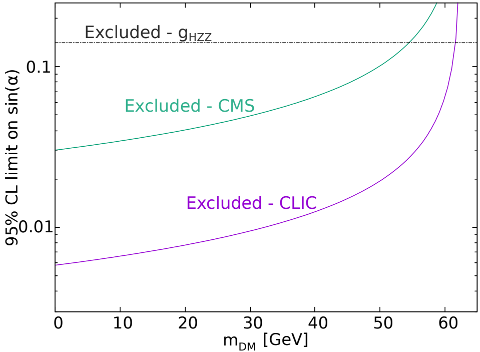
If $\alpha \ll 1$, h_1 is SM-like (the observed 125 GeV state),
but it can also decay invisibly via ϕ component (BR $\sim \sin^2\alpha$)

If h_2 is also light, it can be produced in e^+e^- collisions in the same way as the SM-like Higgs boson; invisible decays dominate.

We consider Vector-fermion dark matter model (VFDM) [arXiv:1710.01853]

Interpretation

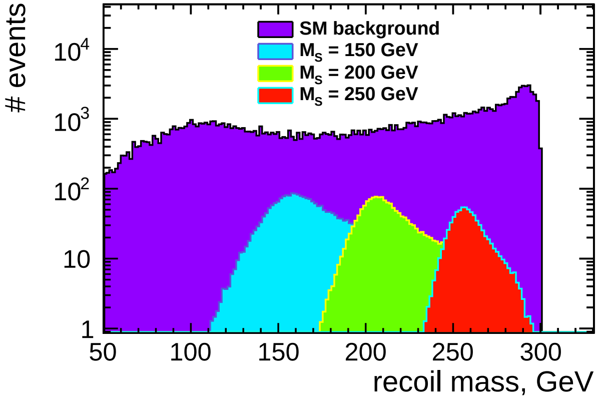
Limit on the invisible decays of the 125 GeV Higgs boson (h_1) can be interpreted in terms of the VFDM mixing angle limits.



Based on WHIZARD calculations assuming $g_X = 1$.

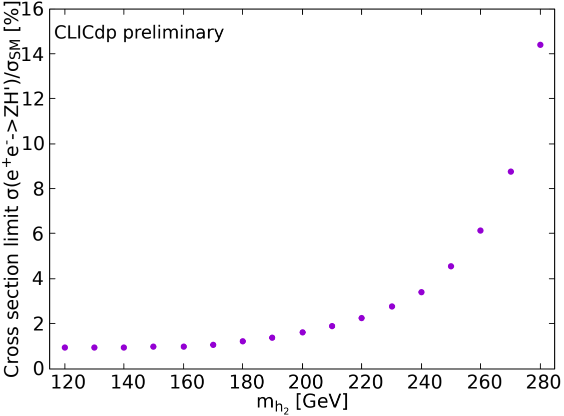
Limits on new scalar production

Same approach can be used to search for production of h_2 state in the process $e^+e^- \to Z\ h_2 \to qq + inv$



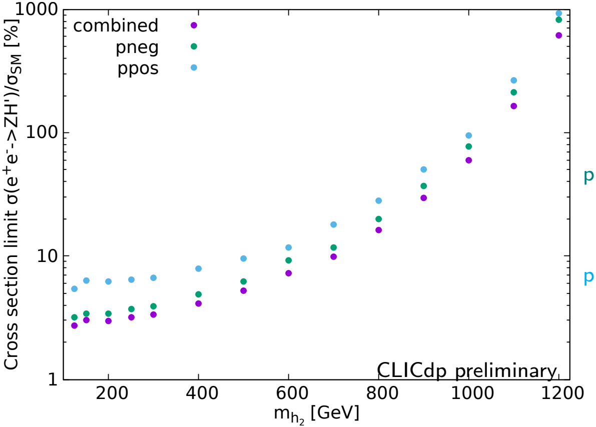
Limits on new scalar production

Expected limits on the h_2 production cross section, relative to SM, for $1000\,\mathrm{fb}^{-1}$ at 380 GeV assuming $\mathrm{BR}(\mathrm{h}_2 \to \mathit{inv}) \approx 100\%$



Limits on new scalar production

Expected limits on the h_2 production cross section, relative to SM, for $2500\,\mathrm{fb}^{-1}$ at $1500\,\mathrm{GeV}$ assuming $\mathrm{BR}(h_2 \to inv) \approx 100\%$

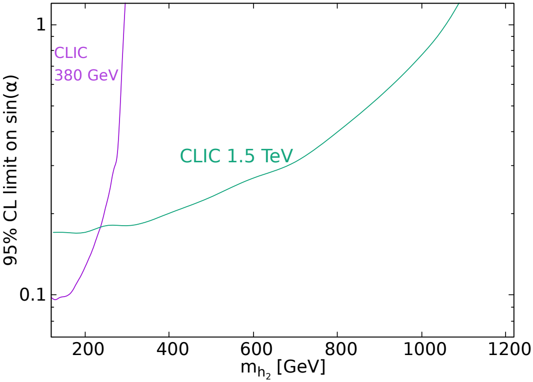


pneg:
$P(e^-) = -80\%$
$2000\ \mathrm{fb}^{-1}$

ppos:
$P(e^-) = +80\%$
$500\ \mathrm{fb}^{-1}$

The VFDM model

Expected limits on the production cross section can be translated within the VFDM model into limits on the mixing angle α.



Conclusions

1. Search for invisible Higgs boson decays based on the WHIZARD event generation and fast simulation with DELPHES.
2. CLIC running at 380 GeV can constrain the invisible decays of the SM Higgs boson to below 1%.
3. Results consistent with the previous study based on full simulation.
4. The study can be extended to search for extra scalars at CLIC operating at 380 GeV and 1.5 TeV.
5. Cross section limits can be translated to the limits on new physics model parameters.

References

H. Abramowicz et al.
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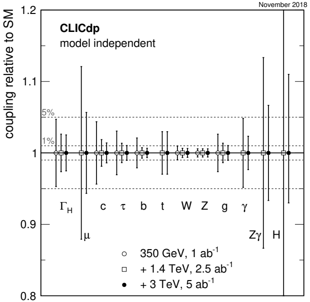
Model-independent measurement of the $e^+e^- \rightarrow HZ$ cross section at a future e^+e^--linear collider using hadronic Z decays.
The European Physical Journal C, 76(2):72, 2016.

BACKUP

Results of the model-independent fit to Higgs boson measurement at CLIC.

Parameter	Relative precision		
	350 GeV $1\,ab^{-1}$	+ 1.4 TeV + $2.5\,ab^{-1}$	+ 3 TeV + $5\,ab^{-1}$
g_{HZZ}	0.6 %	0.6 %	0.6 %
g_{HWW}	1.0 %	0.6 %	0.6 %
g_{Hbb}	2.1 %	0.7 %	0.7 %
g_{Hcc}	4.4 %	1.9 %	1.4 %
$g_{H\tau\tau}$	3.1 %	1.4 %	1.0 %
$g_{H\mu\mu}$	−	12.1 %	5.7 %
g_{Htt}	−	3.0 %	3.0 %
$g^{\dagger}_{Hgg}$	2.6 %	1.4 %	1.0 %
$g^{\dagger}_{H\gamma\gamma}$	−	4.8 %	2.3 %
$g^{\dagger}_{HZ\gamma}$	−	13.3 %	6.7 %
Γ_H	4.7 %	2.6 %	2.5 %

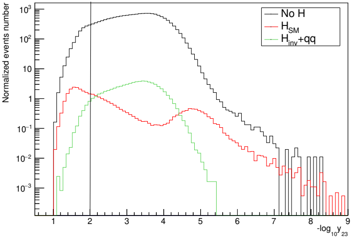


H. Abramowicz et al. Eur. Phys. J., C77(7):475, 2017.

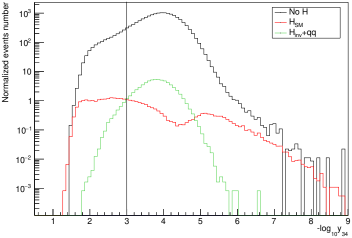
BACKUP

Preselection cuts on jet clustering resuts

2–3 separation ($-\log_{10} y_{23}$)



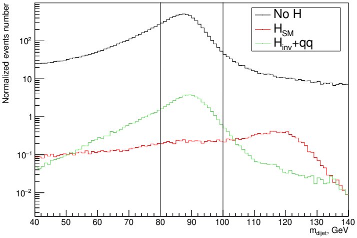
3–4 separation ($-\log_{10} y_{34}$)



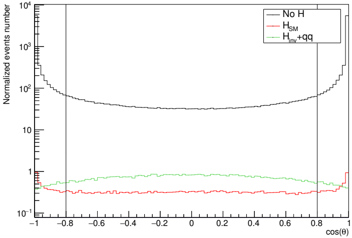
BACKUP

Preselection cuts on di-jet final state (Z boson)

Di-jet invariant mass

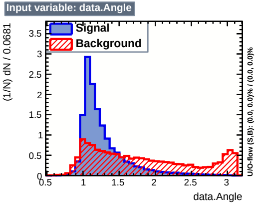


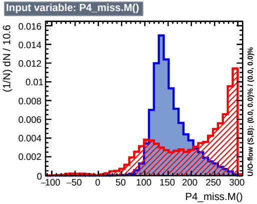
Di-jet emission angle

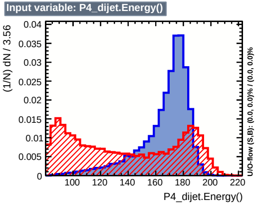


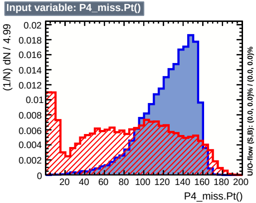
BACKUP

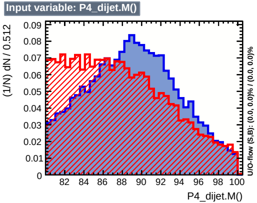
Input variables for multivariate analysis, for invisible decays of 125 GeV Higgs



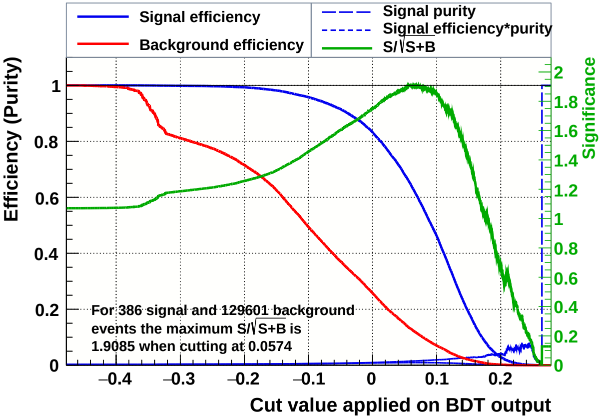








Signal significance as a function of the BDT cut
assuming BR(H→inv) = 1%



BACKUP

Final state	**Efficiency**	**N$_{pre}$**
Background		
$qq\nu\nu$	23,00%	72135
$ql\nu$	0,68%	37588
qq	0,087%	19234
$qqll$	0,043%	593
$qqqq$	0,0010%	51
In total:	0,37%	129601
SM Higgs decays		
$H_{SM} + \nu\nu$	4,60%	2515
$H_{SM} + ll$	0,017%	3
$H_{SM} + qq$	0,0057%	47
In total:	1,70%	2565
Invisible Higgs boson decays		
$H_{inv} + qq$	47,00%	38557