Sensitivity to invisible scalar decays at CLIC

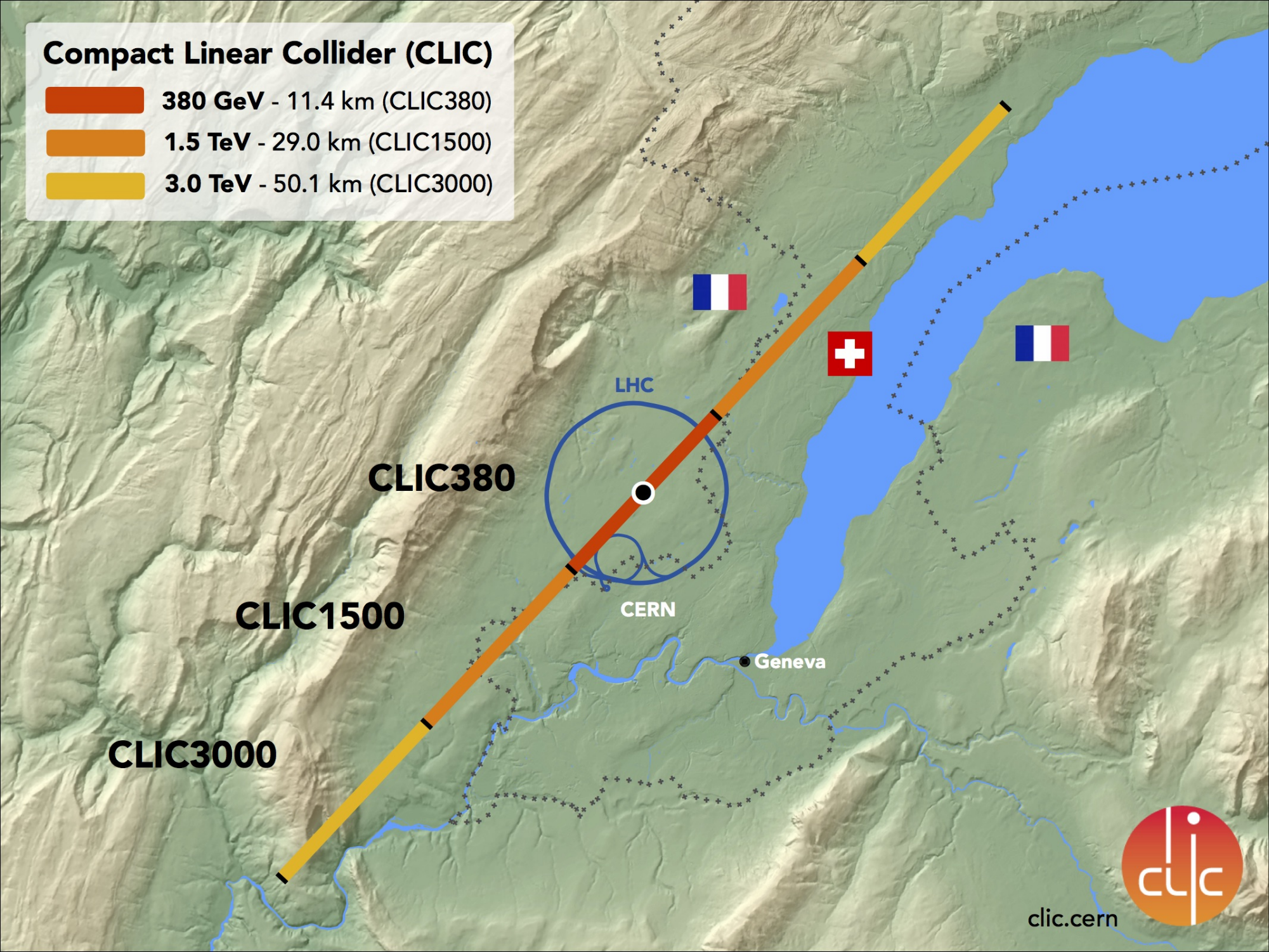
Krzysztof Mękała

Faculty of Physics, University of Warsaw

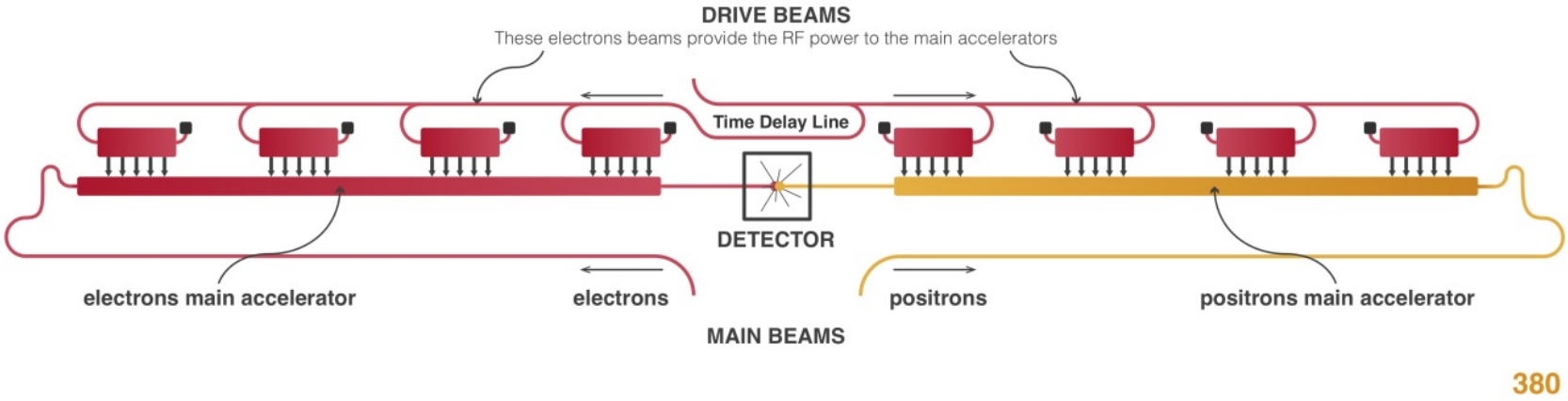
SUSY 2021

25.08.2021

Mekala, K., Zarnecki, A.F., Grzadkowski, B., Iglicki, M.,
Sensitivity to invisible scalar decays at CLIC,
Eur. Phys. J. Plus **136**, 160 (2021),
https://doi.org/10.1140/epjp/s13360-021-01116-5


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.cern

CLIC accelerator

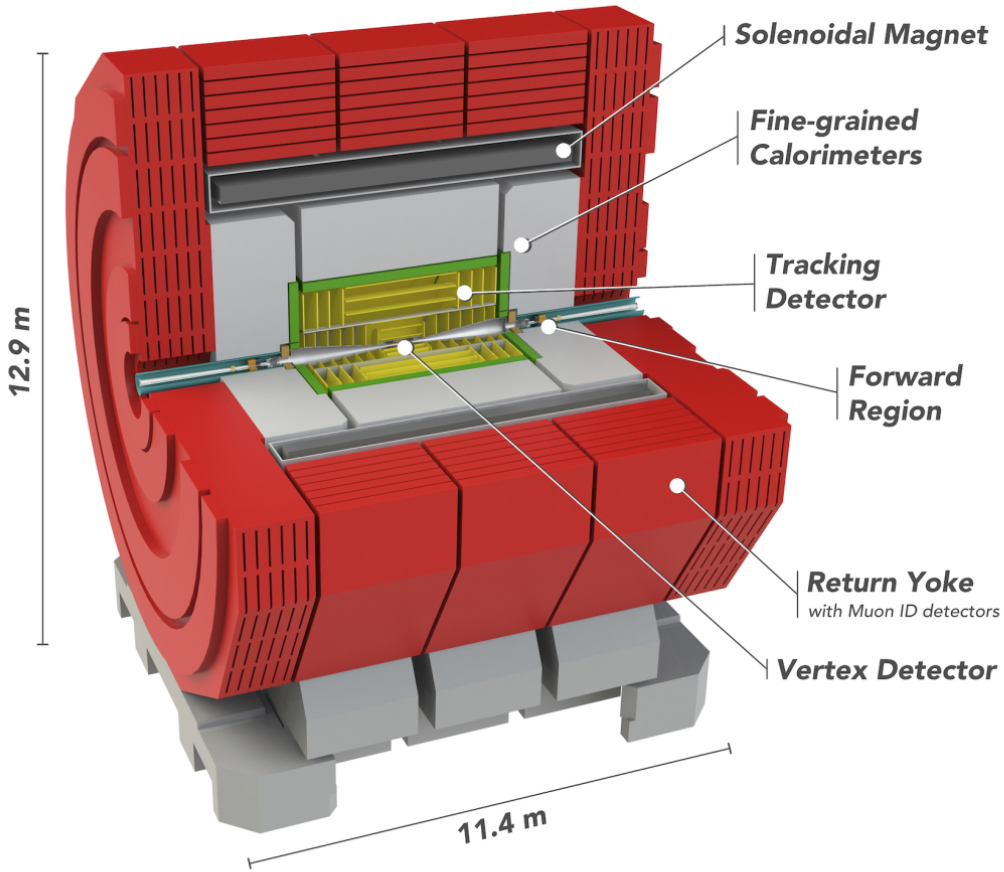


- two-beam accelerating system
- 3 stages: 380 GeV, 1.5 TeV and 3 TeV (11-50 km long)
- electron beam polarisation of 80%, positron beam unpolarised

for details see: arXiv:1812.07987

CLIC detector – CLICdet

Detector optimised for the Particle Flow Approach



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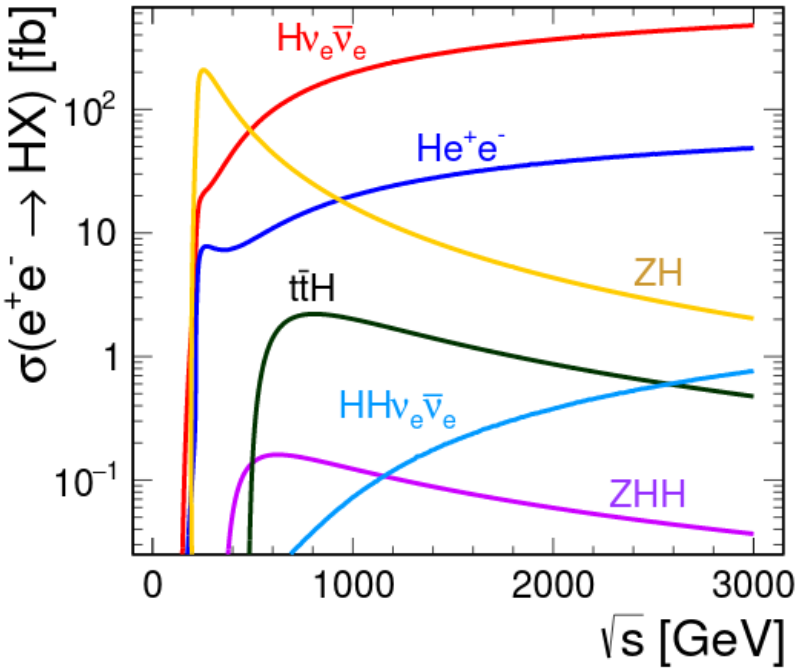
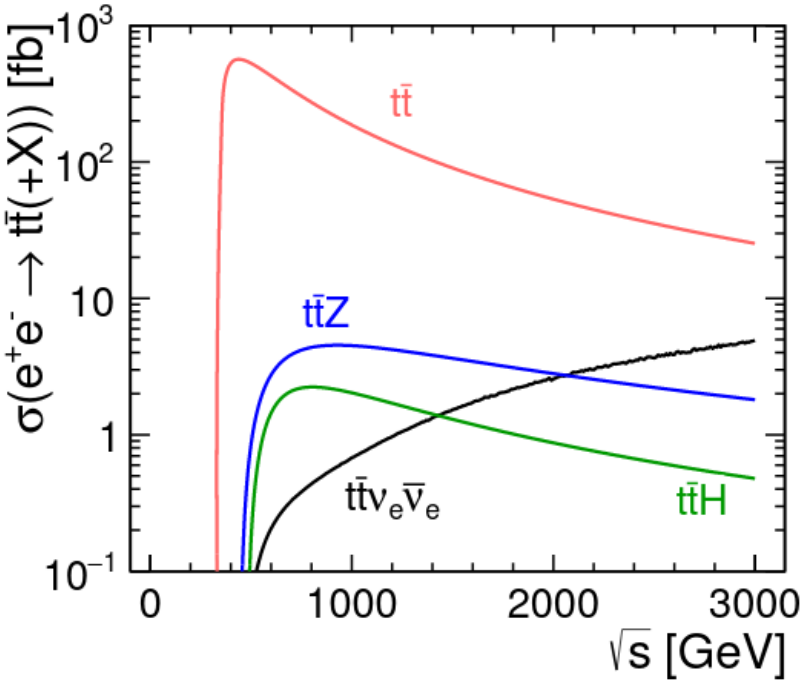
CLIC physics programme

3 stages, each of 7-8 years of running:

1. $\sqrt{s} = 380$ GeV, luminosity of 1 ab^{-1}:
   SM physics: Higgs boson and top quark

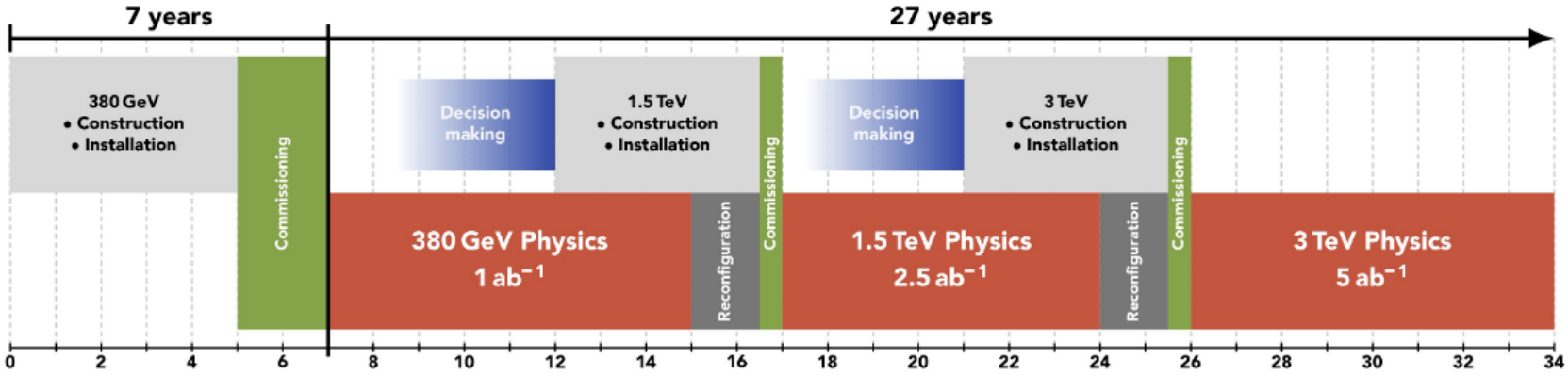




CLIC physics programme

3 stages, each of 7-8 years of running:

1. $\sqrt{s} = 380$ GeV, luminosity of 1 ab^{-1}:
   SM physics: Higgs boson and top quark
2. $\sqrt{s} = 1.5$ TeV, luminosity of 2.5 ab^{-1}:
   Higgs, top & Beyond the Standard Model physics
3. $\sqrt{s} = 3$ TeV, luminosity of 5 ab^{-1}:
   Higgs, top & Beyond the Standard Model physics

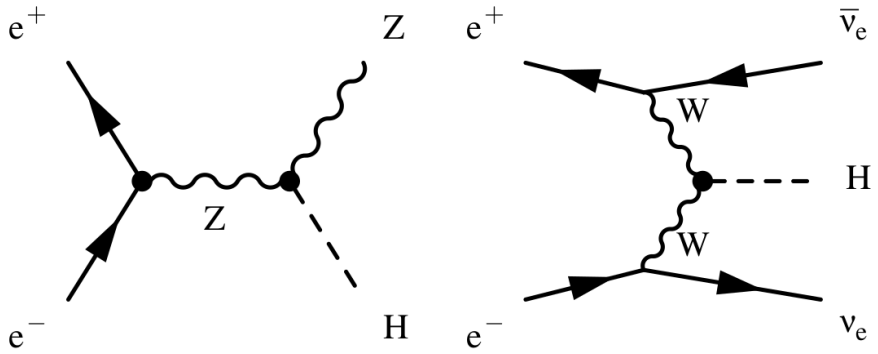


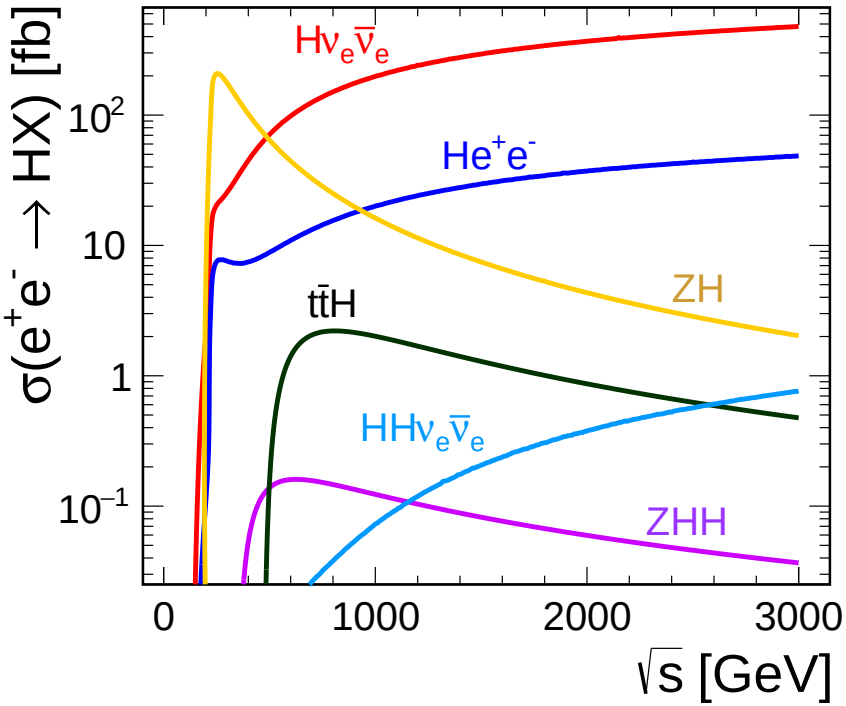
Higgs production

Two main Higgs production channels at CLIC:

- ZH production dominant at 380 GeV
- $H\nu\nu$ channel dominant at higher energy stages

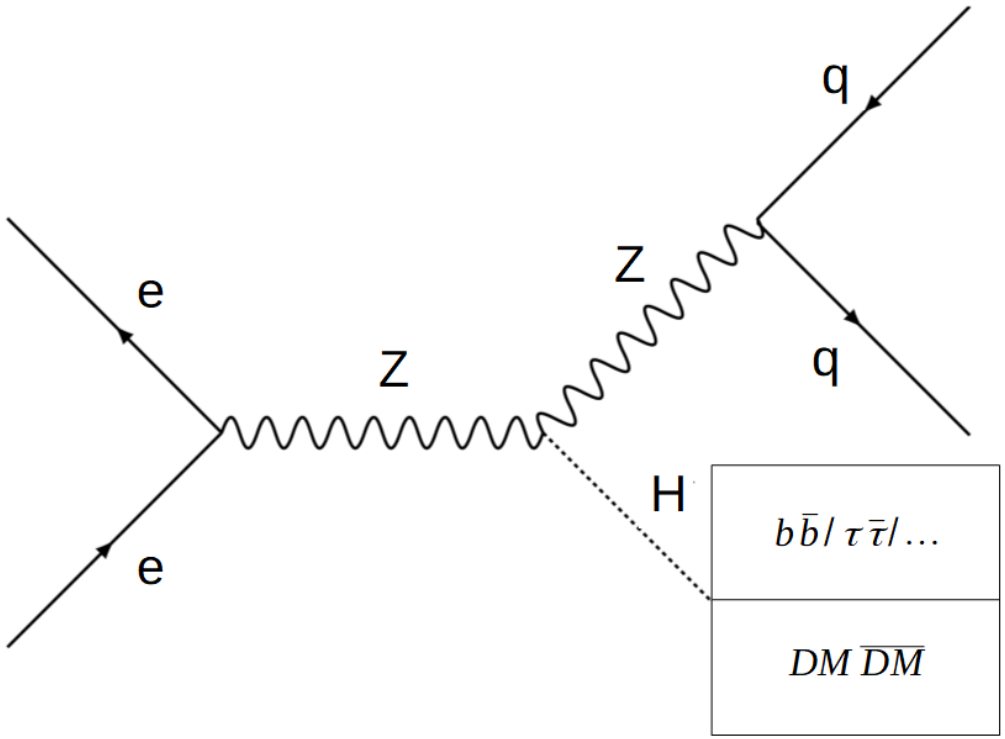
ZH channel allows for event selection independent of the Higgs decay channel $\longrightarrow$ sensitive also to invisible decays





Signal

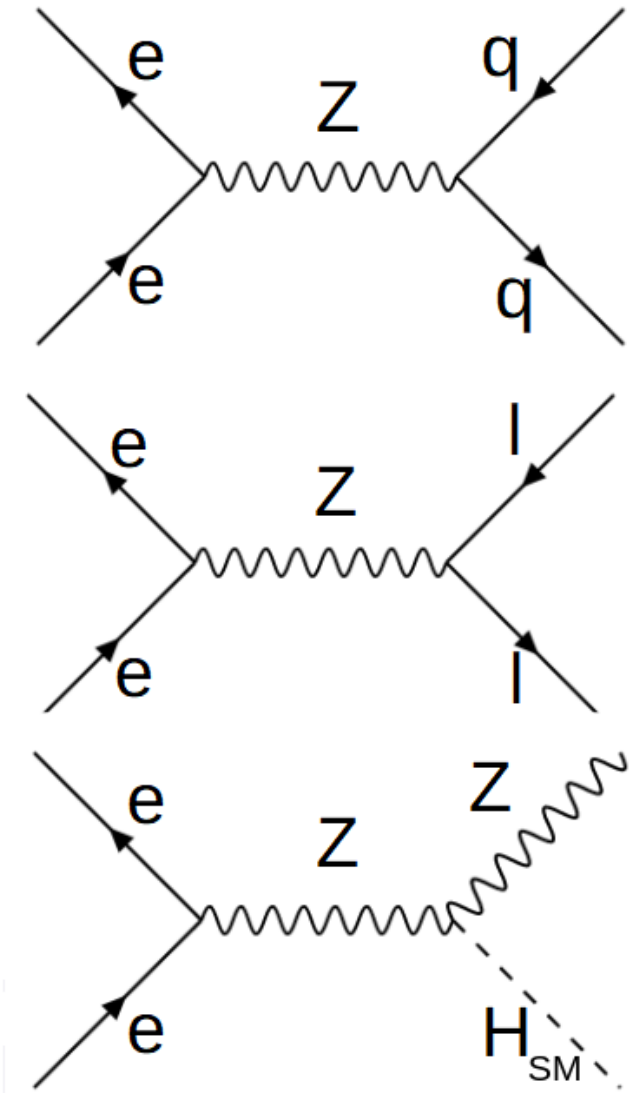
SM(-like) Higgs boson decay to invisible states (Dark Matter?)

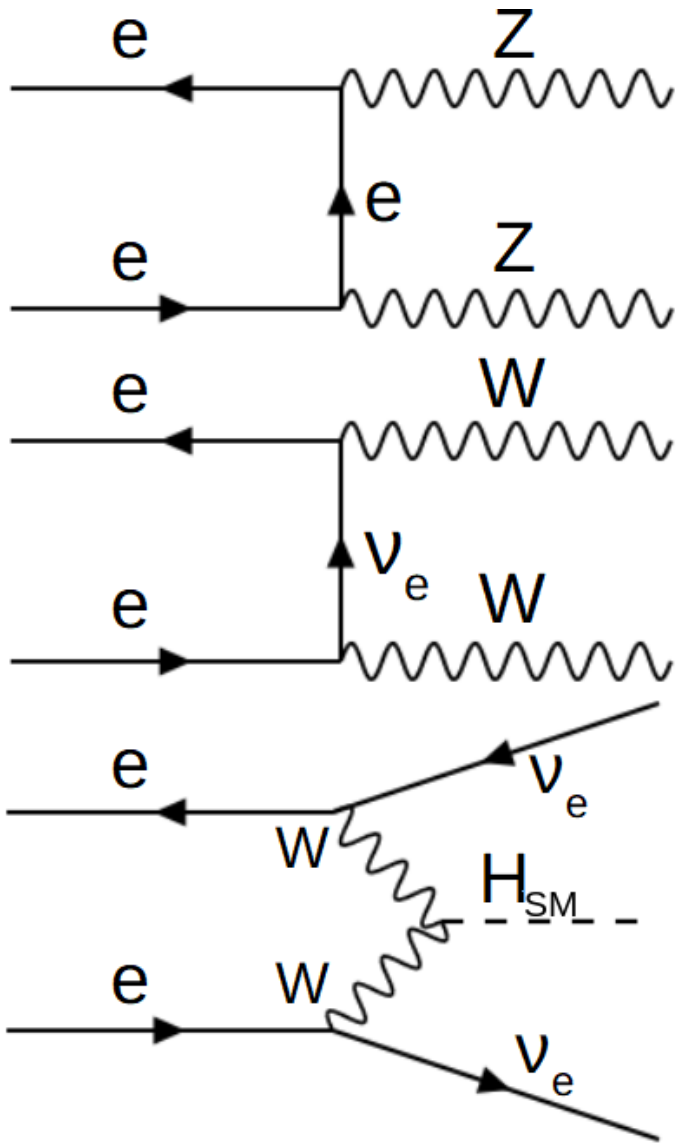


Signature of invisible Higgs decay:

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

Leading background processes



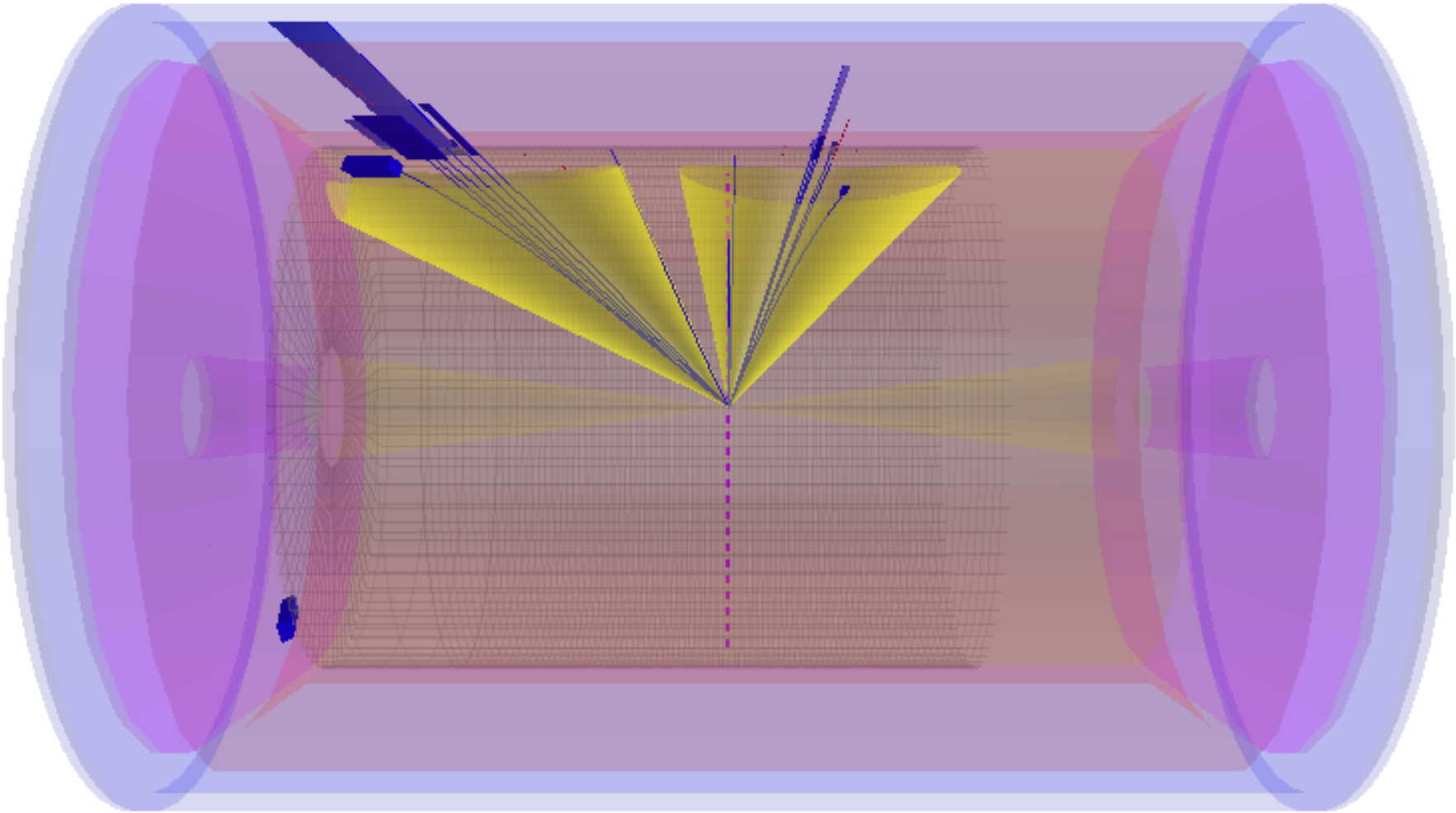


Simulation framework

- event samples generated with WHIZARD
  - signal: $H + qq$ production with Higgs defined as stable
  - SM Higgs boson production:
    $H + qq$, $H + ll$, $H + \nu\nu$ (with 100% SM decays)
  - non-Higgs background: qq, ll, $qqqq$, $qqll$, $qql\nu$, $qq\nu\nu$, $qql\nu\nu\nu$
  - beamstrahlung and EPA photon interactions:
    qq, $qq\nu$, $qqqq$, $qqll$, $qql\nu$, $qq\nu\nu$
- CLIC energy spectra for **380** GeV
- CLIC integrated luminosity of **1000** fb^{-1} (unpolarised)
- detector simulation and event reconstruction with DELPHES
  using modified *CLICdet_Stage1* cards (to make Higgs invisible in the detector)
- required topology: two jets reconstructed with the VLC algorithm
  ($R = 1.5$, $\beta = \gamma = 1$)

Signature of $e^+e^- \longrightarrow HZ \longrightarrow jj + \mathit{inv}$

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

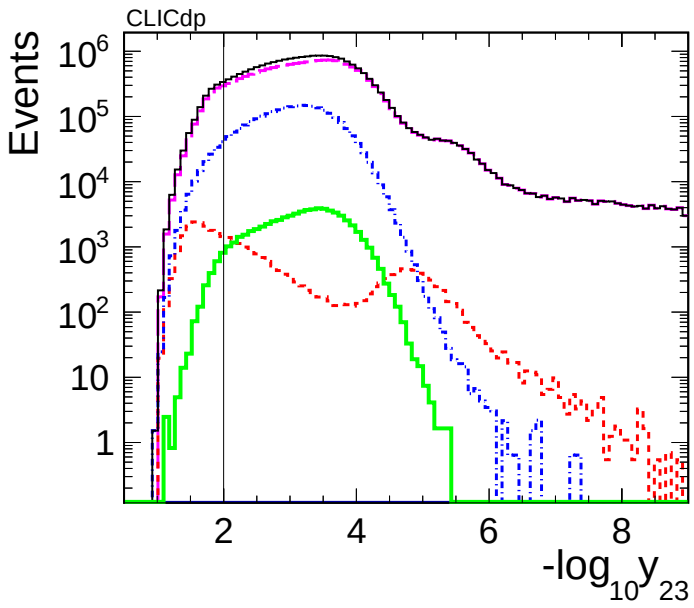


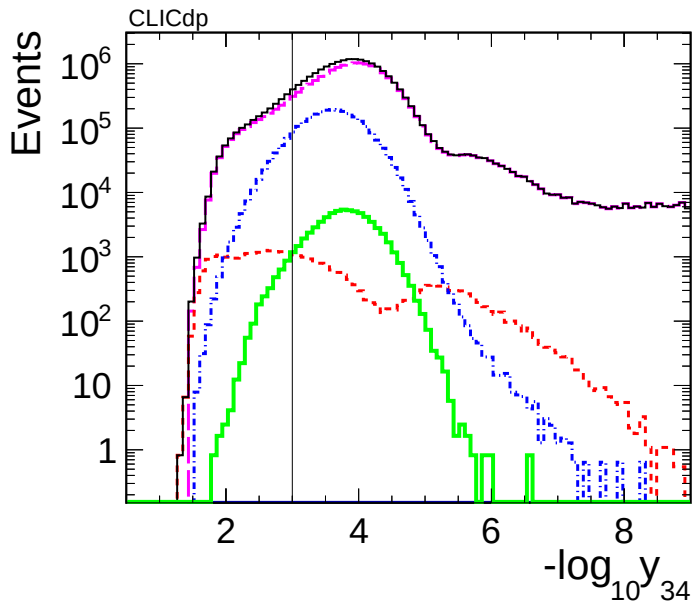
Preselection

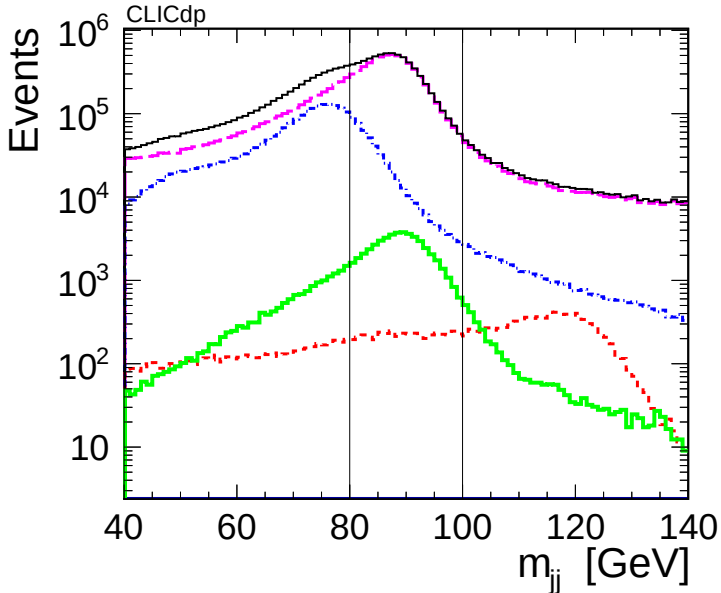
Preselection cuts were used to select events with proper signature and kinematics consistent with invisible Higgs boson decay:

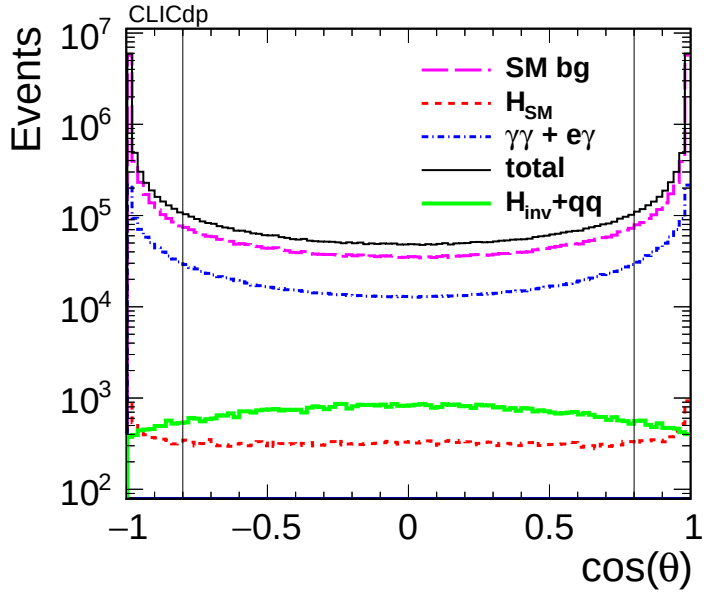
- No isolated electrons, muons or photons reconstructed with energy above 2 GeV, 3 GeV and 5 GeV respectively
- Energy "lost" in the jet clustering below 10 GeV
- At least 2 charged particles in each jet
- Two jet topology: $y_{23} < 0.01$ and $y_{34} < 0.001$
- Dijet invariant mass: $80 < M_{jj} < 100\,\text{GeV}$ (Z mass)
- Dijet emision angle: $|\cos\Theta_{jj}| < 0.8$ (Z direction)

Preselection cuts









Preselection efficiency

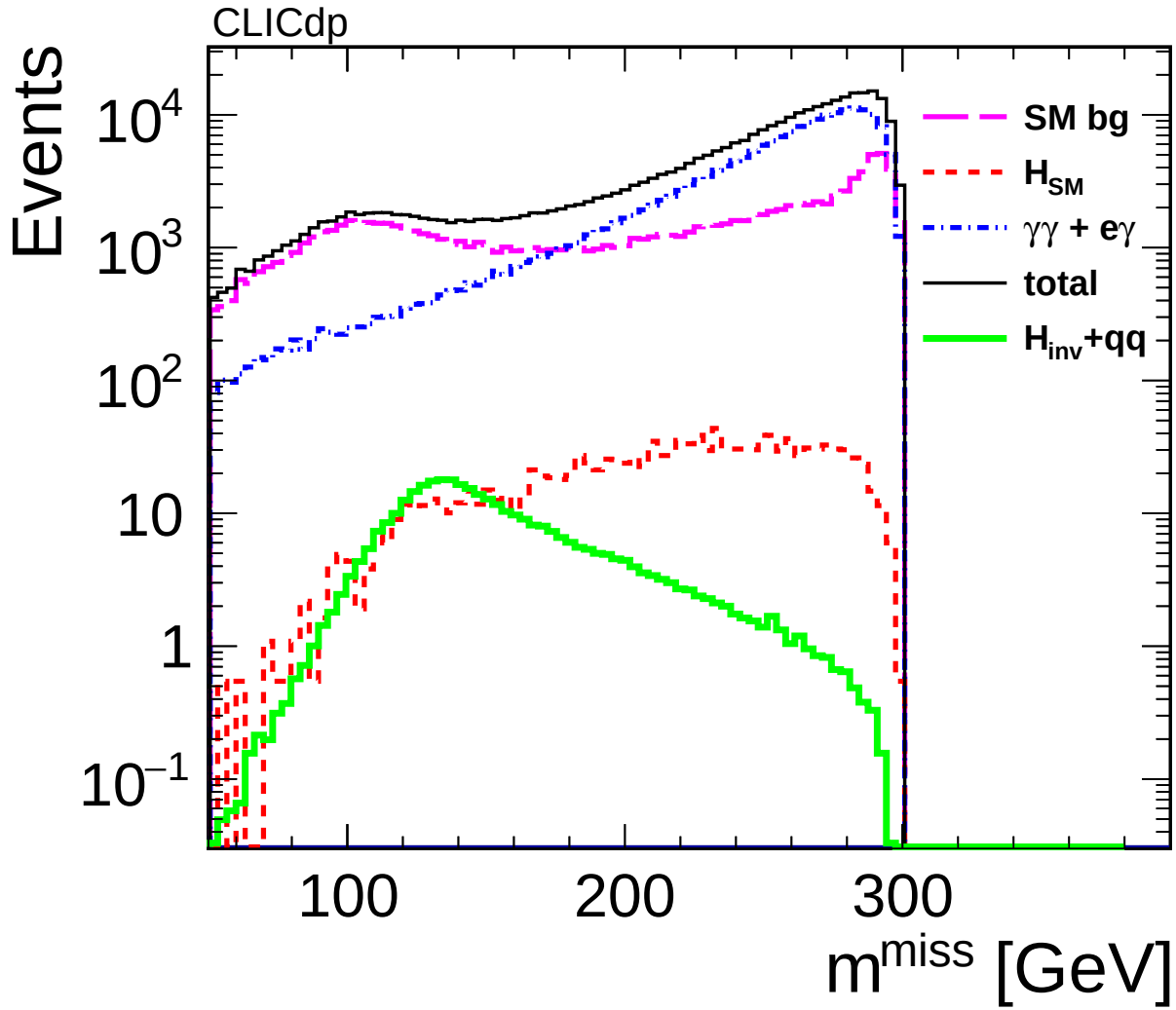
Event class	*Efficiency*	*Events expected at CLIC*
e^+e^- **bkg (non-Higgs)**	0.21%	115,398
leading channels:		
$qq\nu\nu$	20.47%	64,965
$qql\nu$	0.60%	33,065
qq	0.08%	16,684
$e\gamma$ **and** $\gamma\gamma$ **interactions**	5.11%	201,492
leading channels:		
$\gamma^{EPA}e^+ \to qq\nu$	6.20%	56,489
$\gamma^{EPA}e^- \to qq\nu$	6.32%	56,054
$\gamma^{BS}e^+ \to qq\nu$	6.68%	42,823
$\gamma^{BS}e^- \to qq\nu$	6.73%	42,707
SM Higgs decays	0.86%	1313
$H + qq$ **invisible decays**	43.56%	35,920

Both Beamstrahlung and EPA photon interactions are considered for $e\gamma$.

Preselection

Recoil mass distribution after preselection cuts

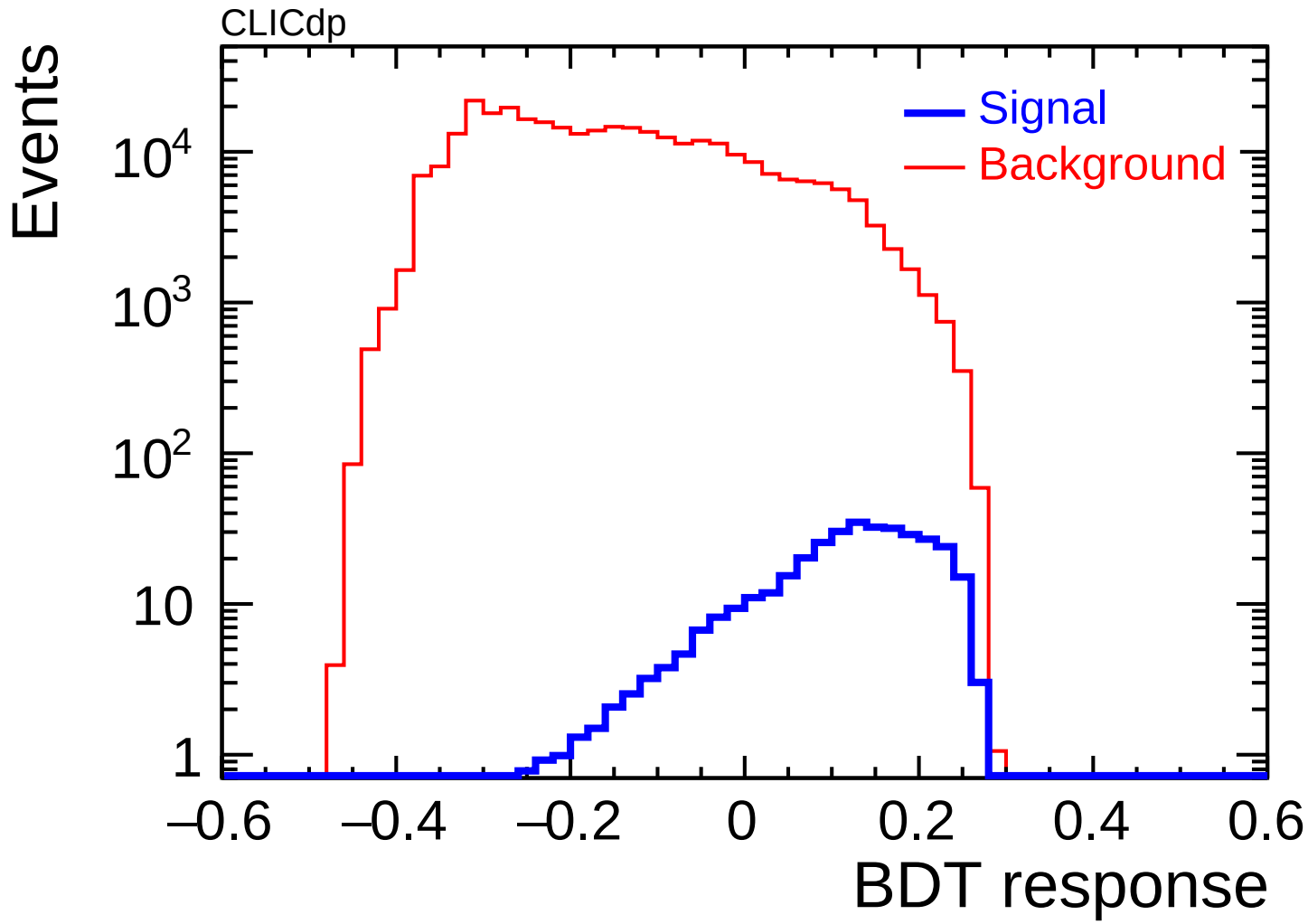
for 1000 fb^{-1} collected at 380 GeV, assuming BR(H→inv) = 1% for signal



Selection

Final event selection based on the multivariate analysis (5 variables).

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



Results

95% C.L. limit expected for 1 ab^{-1} (4 ab^{-1}) collected at 380 GeV:

$$BR(H \rightarrow inv) \quad < \quad 1.0\% \ (0.5\%)$$

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

Limits on new scalar production – CLIC380

Same approach can be used to search for production of H' state in the process $e^+e^- \rightarrow ZH' \rightarrow qq + inv$

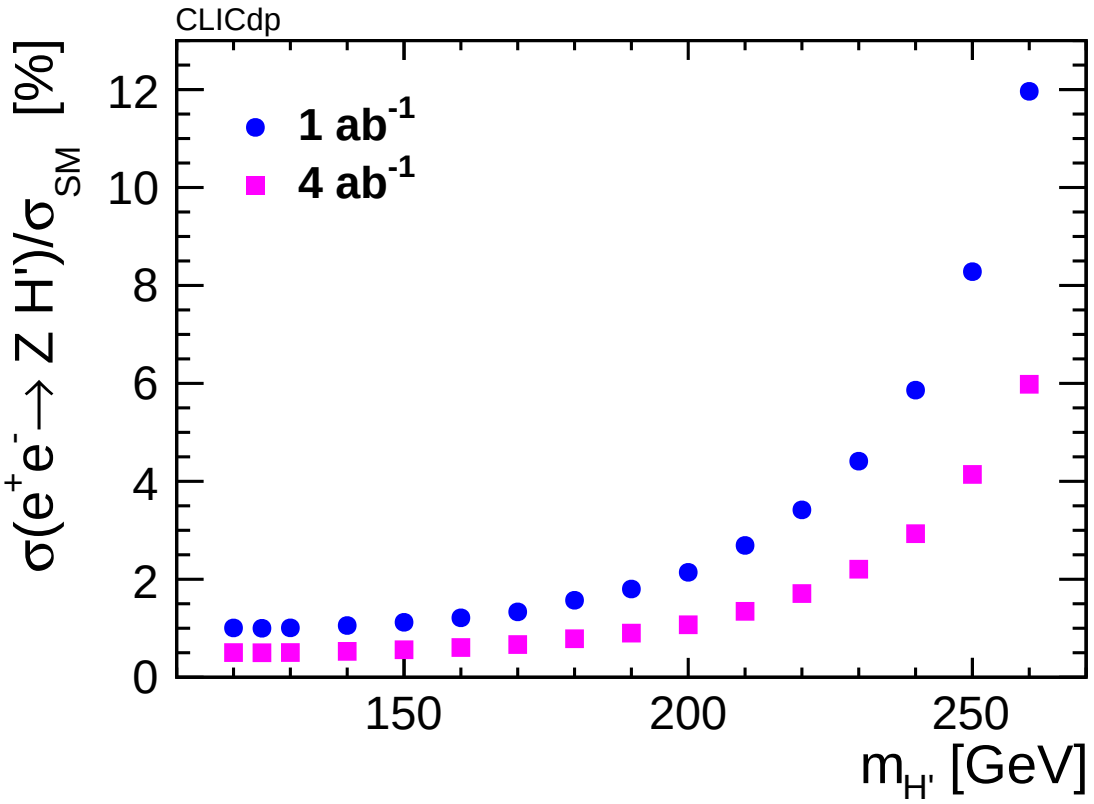
(H' generated in WHIZARD as SM-Higgs particle with a different mass)

Limits on new scalar production – CLIC380

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

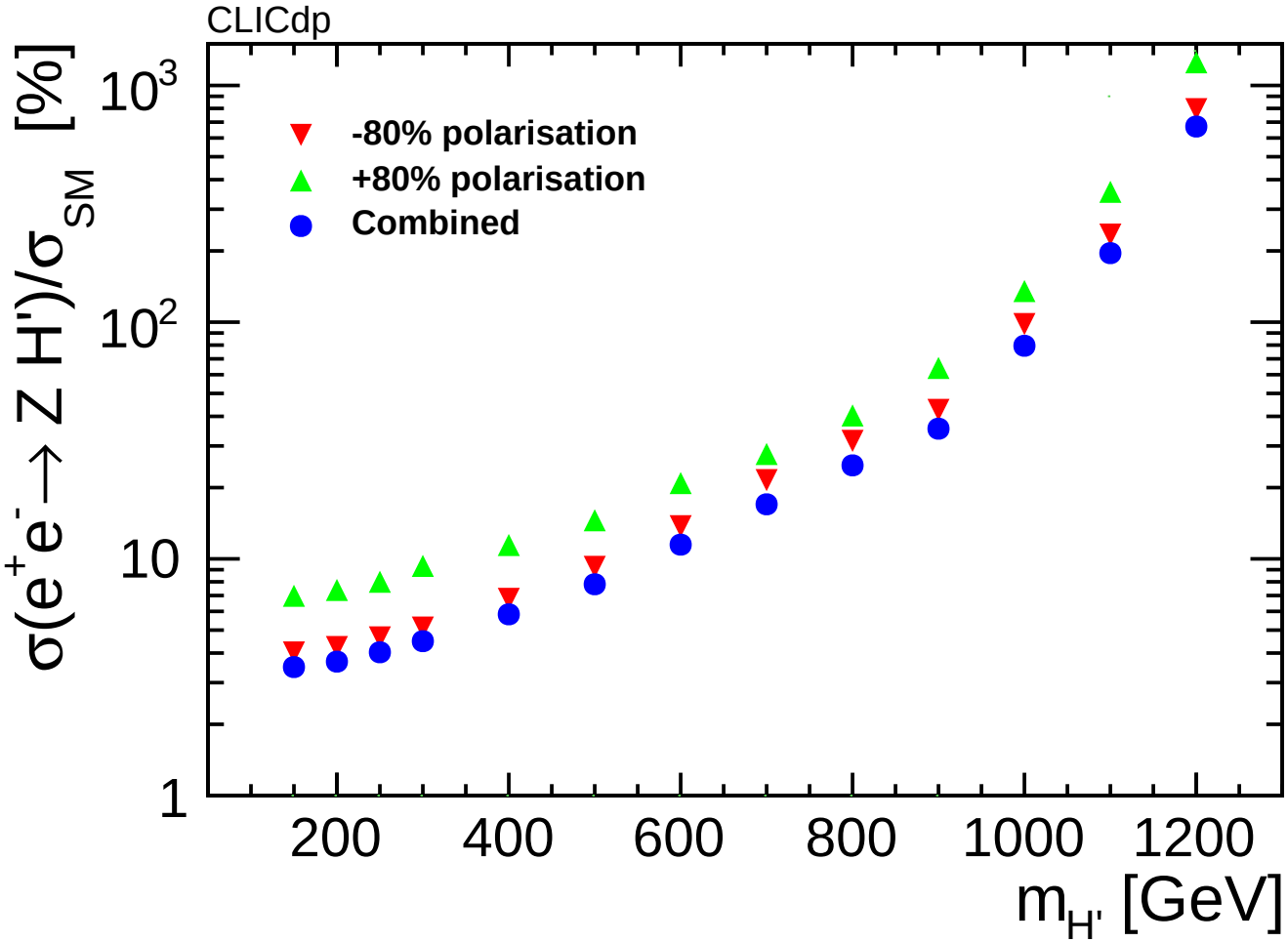
(H' generated in WHIZARD as SM-Higgs particle with a different mass)

Expected limits on the H' production cross section, relative to SM, for CLIC at 380 GeV, assuming BR($H' \to inv$) $\approx$ 100%:

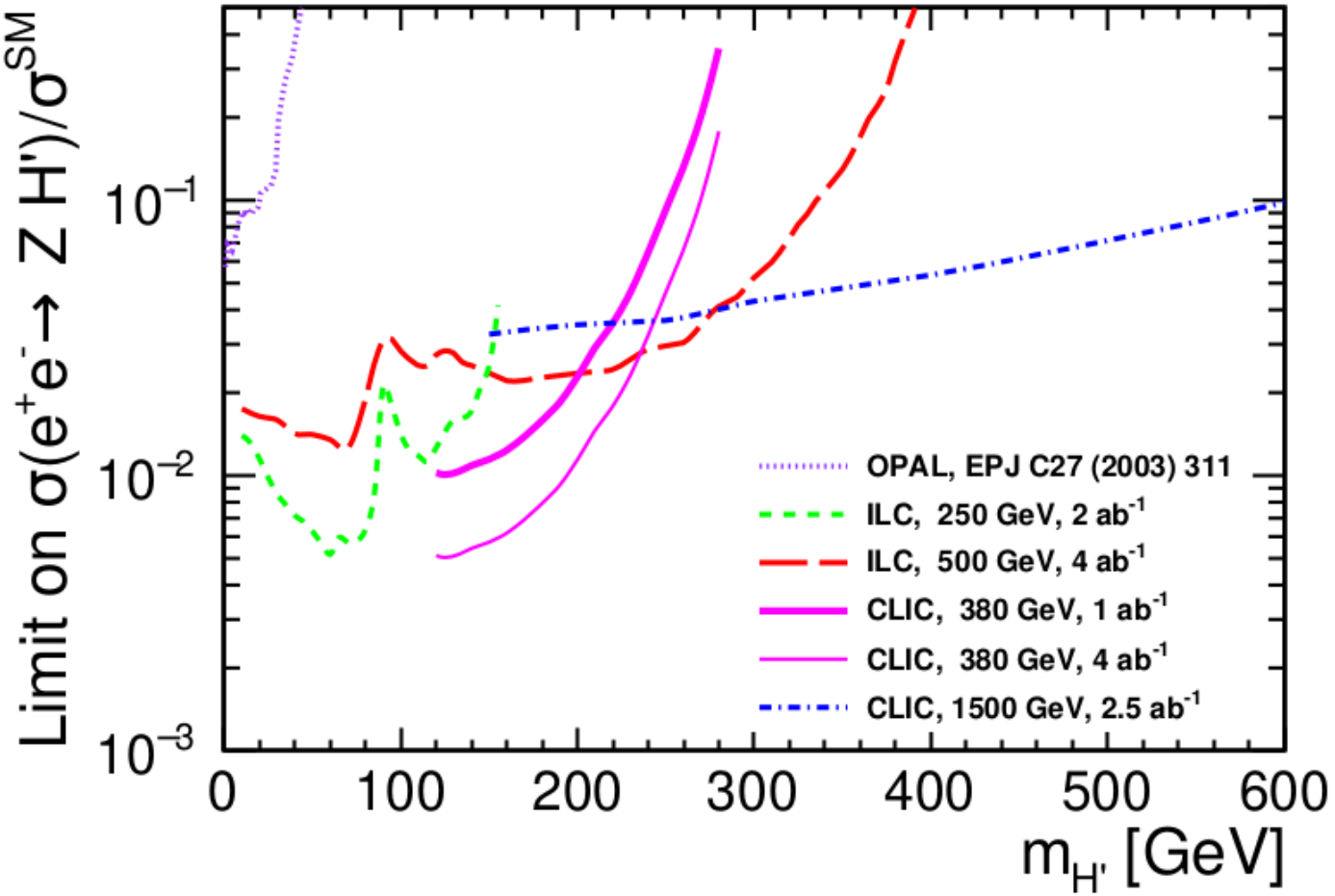


Limits on new scalar production – CLIC1500

Similar analysis can be performed for CLIC at 1.5 TeV (2500 fb^{-1}):



Limits on new scalar production



Interpretation

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

$$\begin{pmatrix} H \\ H' \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

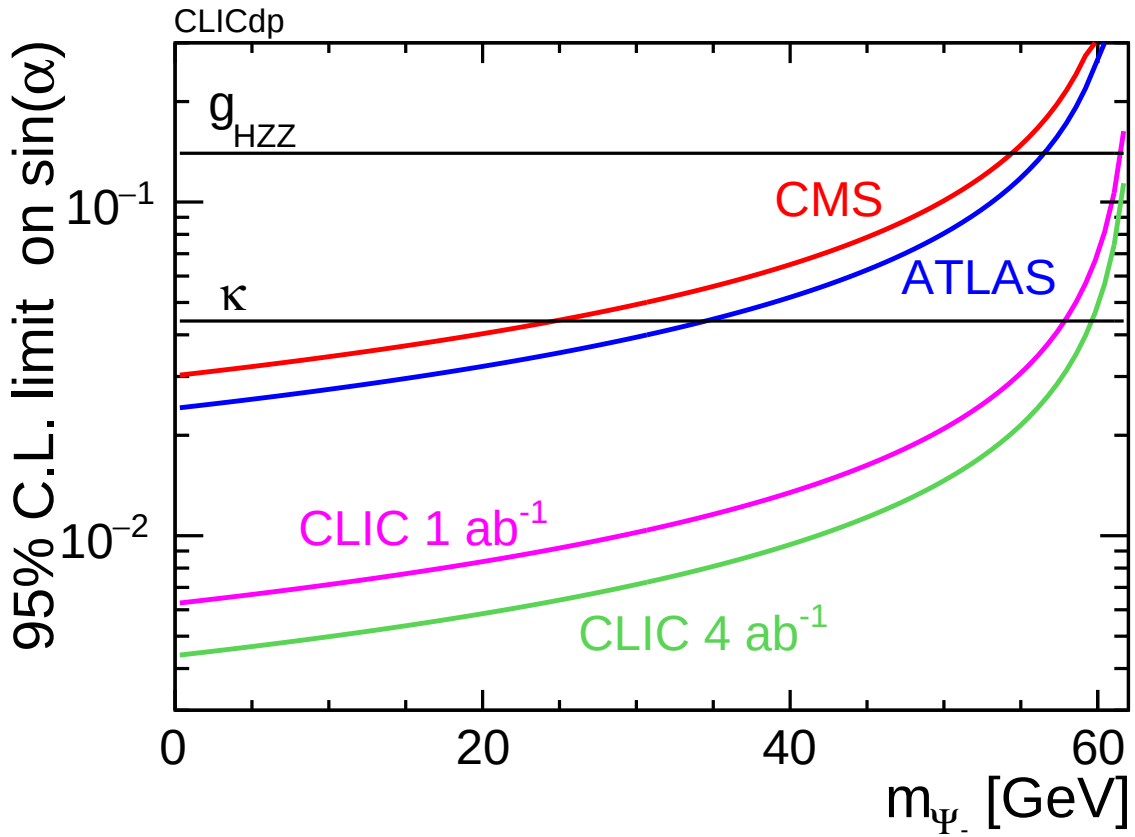
If $\alpha \ll 1$, H is SM-like (the observed 125 GeV state), but it can also decay invisibly via ϕ component (BR $\sim \sin^2\alpha$).

If H' 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 the Vector-fermion dark matter model (VFDM) [arXiv:1710.01853]

Interpretation

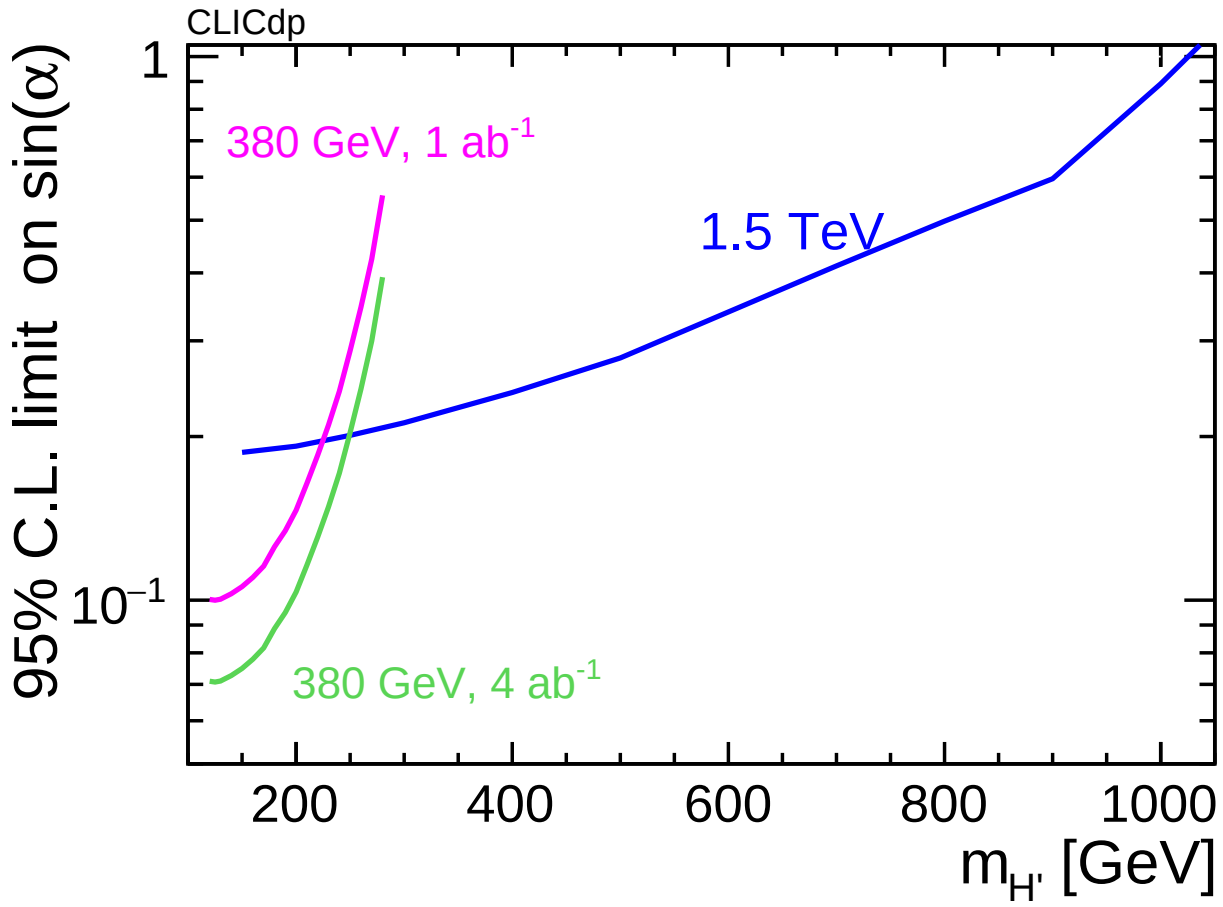
Limit on the invisible decays of the 125 GeV Higgs boson (H) can be interpreted in terms of the VFDM mixing angle limits.



Based on WHIZARD calculations assuming $g_X = 1$.

The VFDM model

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



Conclusions

1. We searched for invisible Higgs boson decays using WHIZARD event generation and fast simulation with DELPHES, including γ-induced background.
2. CLIC running at 380 GeV (lum. 1 ab^{-1}) can constrain the invisible decays of the SM Higgs boson to 1%.
3. The study can be extended to search for extra scalars at CLIC operating at 380 GeV and 1.5 TeV.
4. The results can be interpreted in terms of mixing angles of Higgs-portal models.

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URL https://doi.org/10.1140/epjc/s10052-016-3911-5.

BACKUP: BDT variables

Variables used as input for the Boosted Decision Trees (BDT) method:

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