Searches for invisible scalar decays at CLIC

K.Mękała, A.F. Żarnecki, B. Grządkowski, M. Iglicki

Faculty of Physics, University of Warsaw

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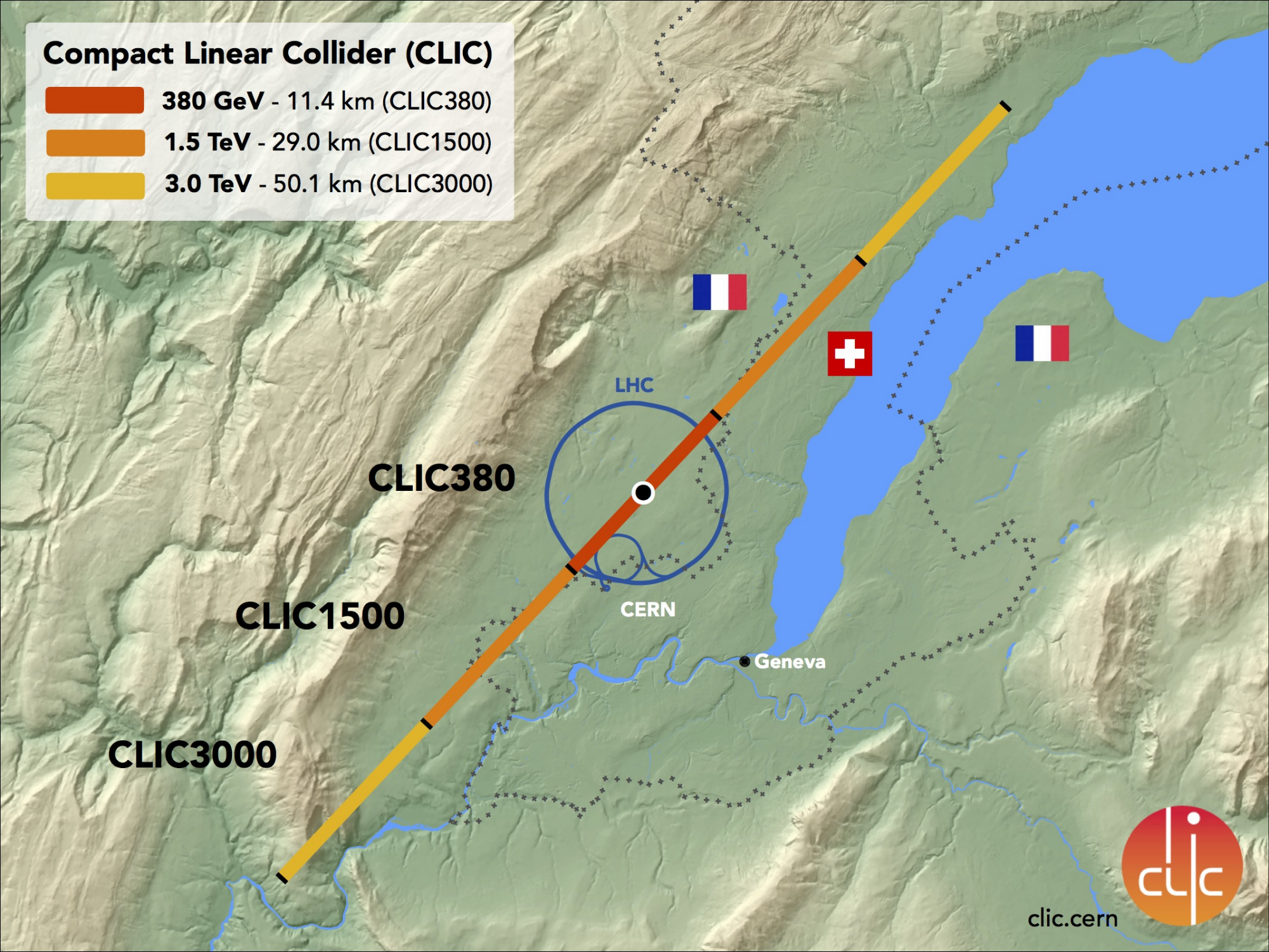
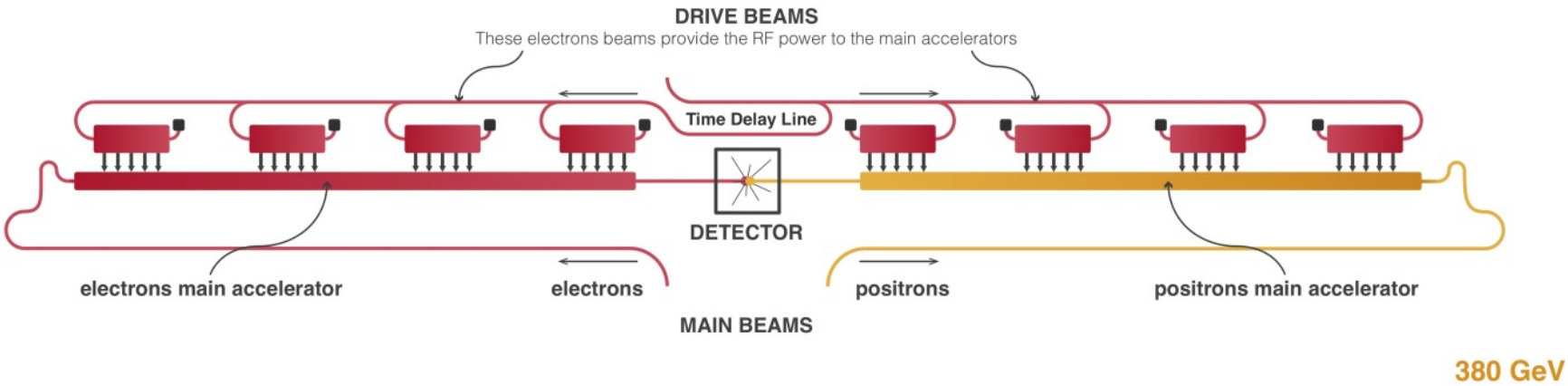

Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
clic.cern

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

Physics at e^+e^- colliders

Main research goals at CLIC:

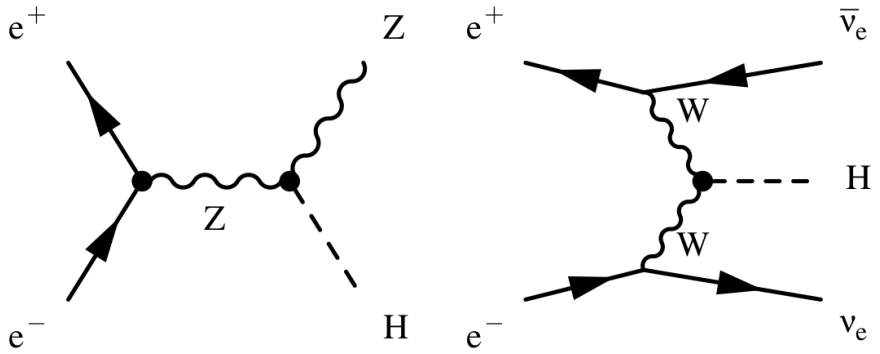
- Higgs boson production and decays
- top quark physics
- electroweak precision measurements
- Beyond the Standard Model searches

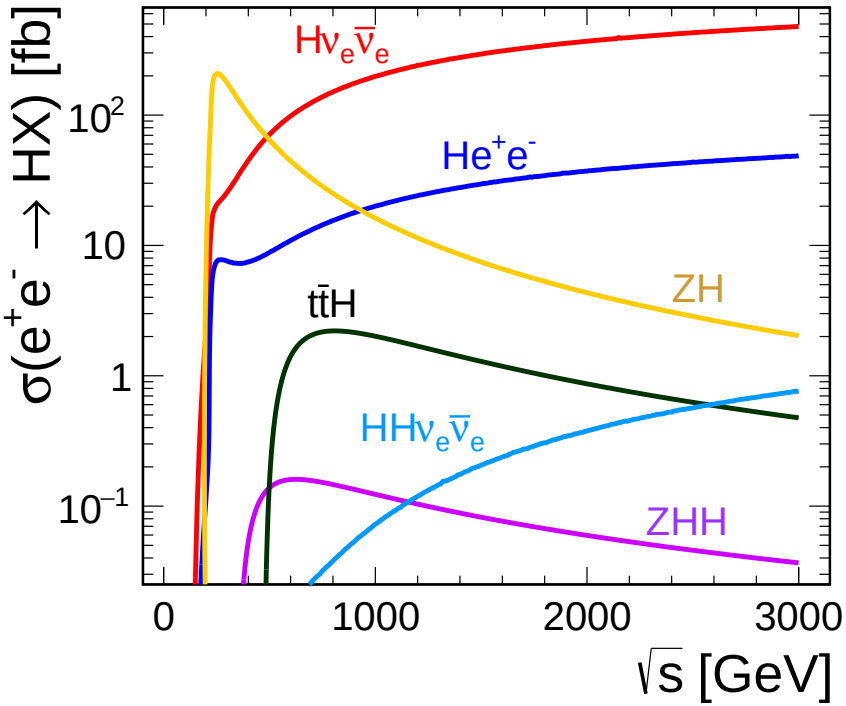
Higgs production

Two main Higgs production channels at CLIC:

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

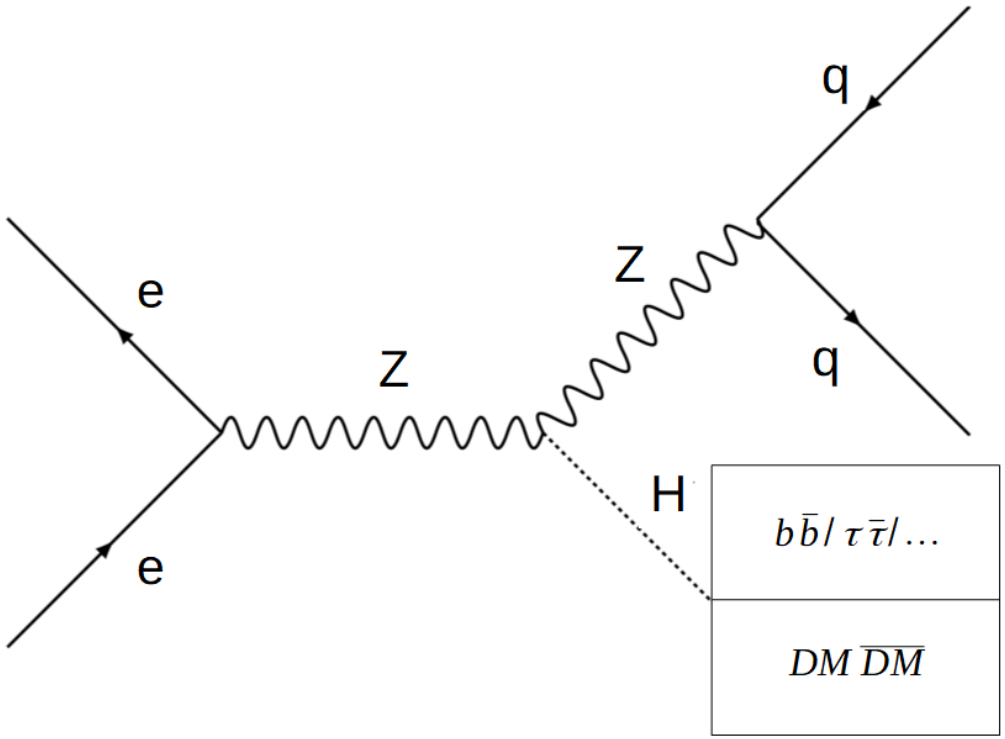
ZH channel allows for event selection independent on the Higgs decay channel $\longrightarrow$ sensitive also to invisible decays





Signal

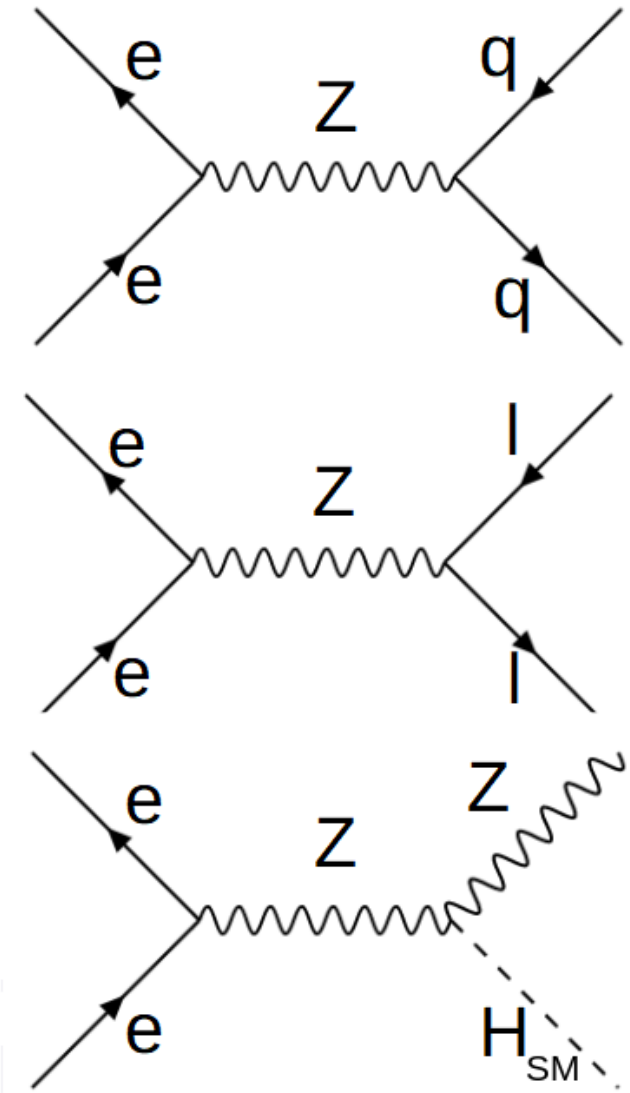
SM(-like) Higgs boson decay to invisible states (Dark Matter?)

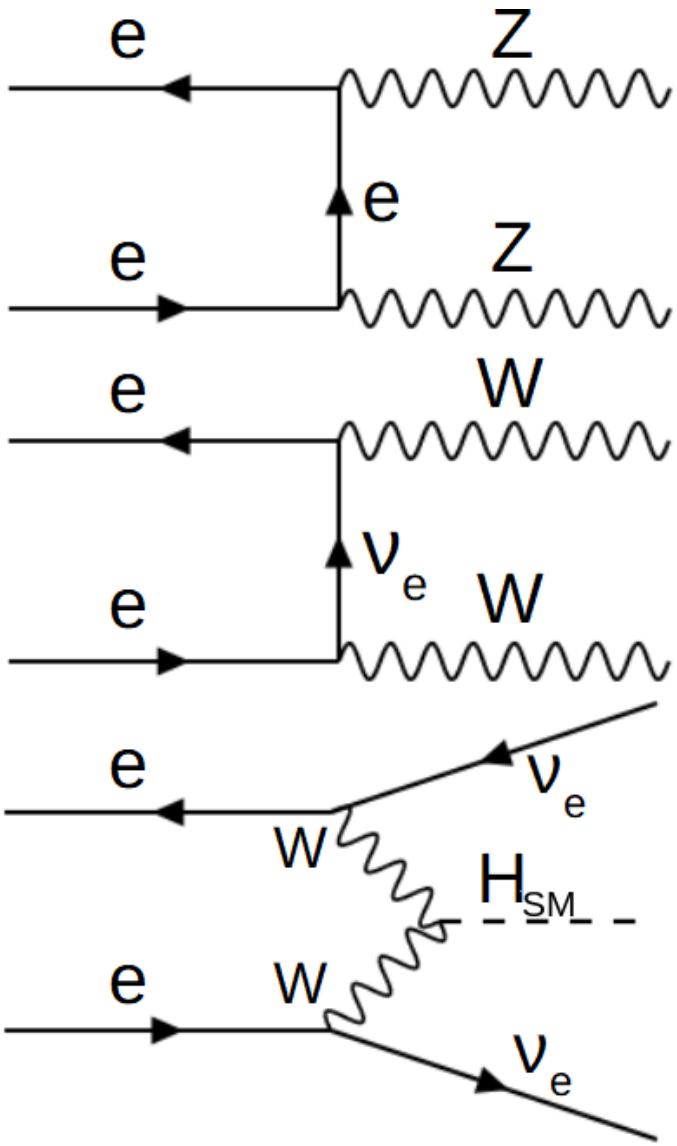


Signature of invisible Higgs decay:

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

Background processes considered



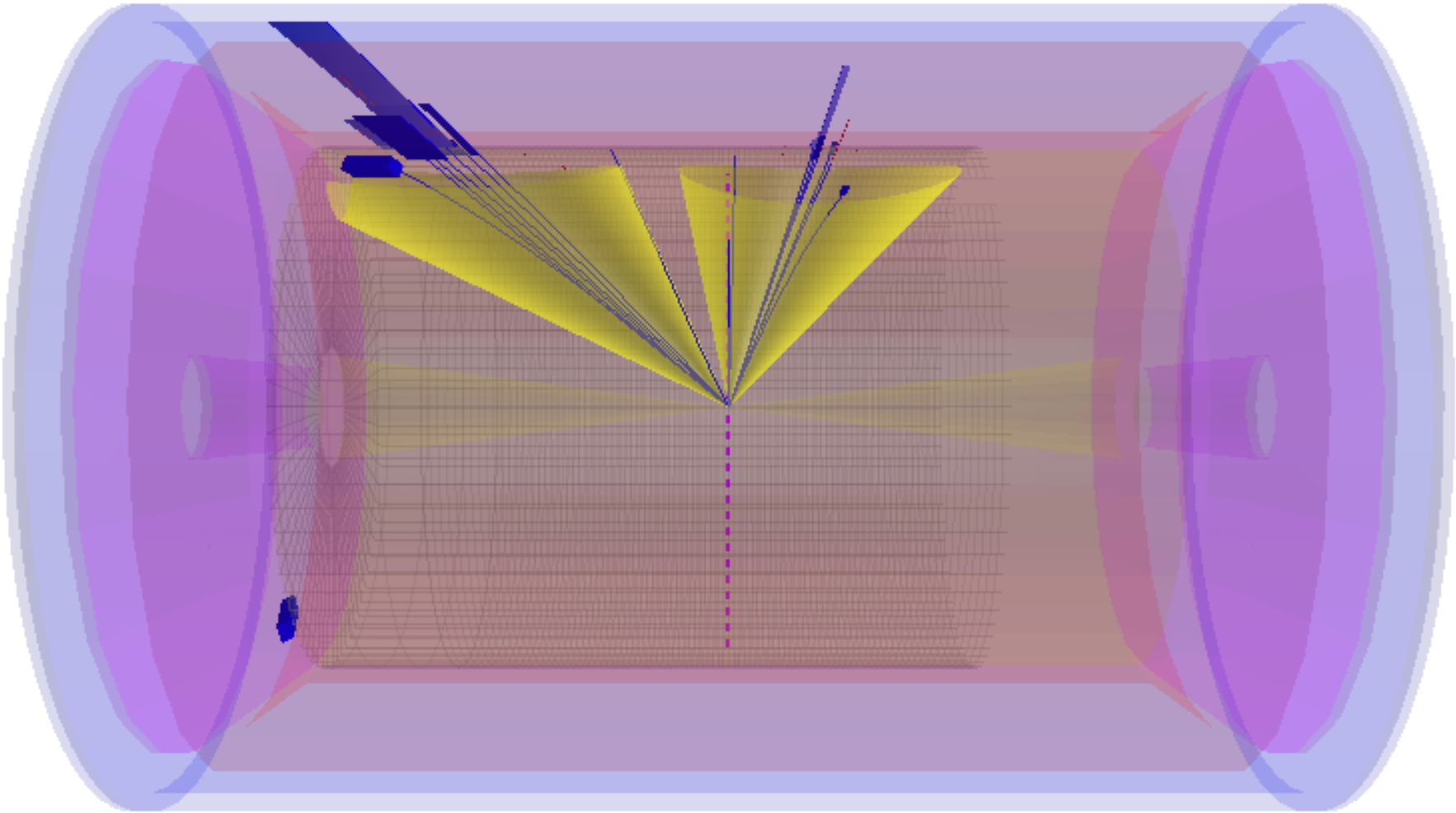


Simulation framework

- 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

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 $y_{34} < 0.001$
- Jet invariant mass: $80 < M_{jj} < 100\,\text{GeV}$ (Z mass)
- Dijet emision angle: $|\cos\Theta_{jj}| < 0.8$ (Z direction)

Preselection efficiency

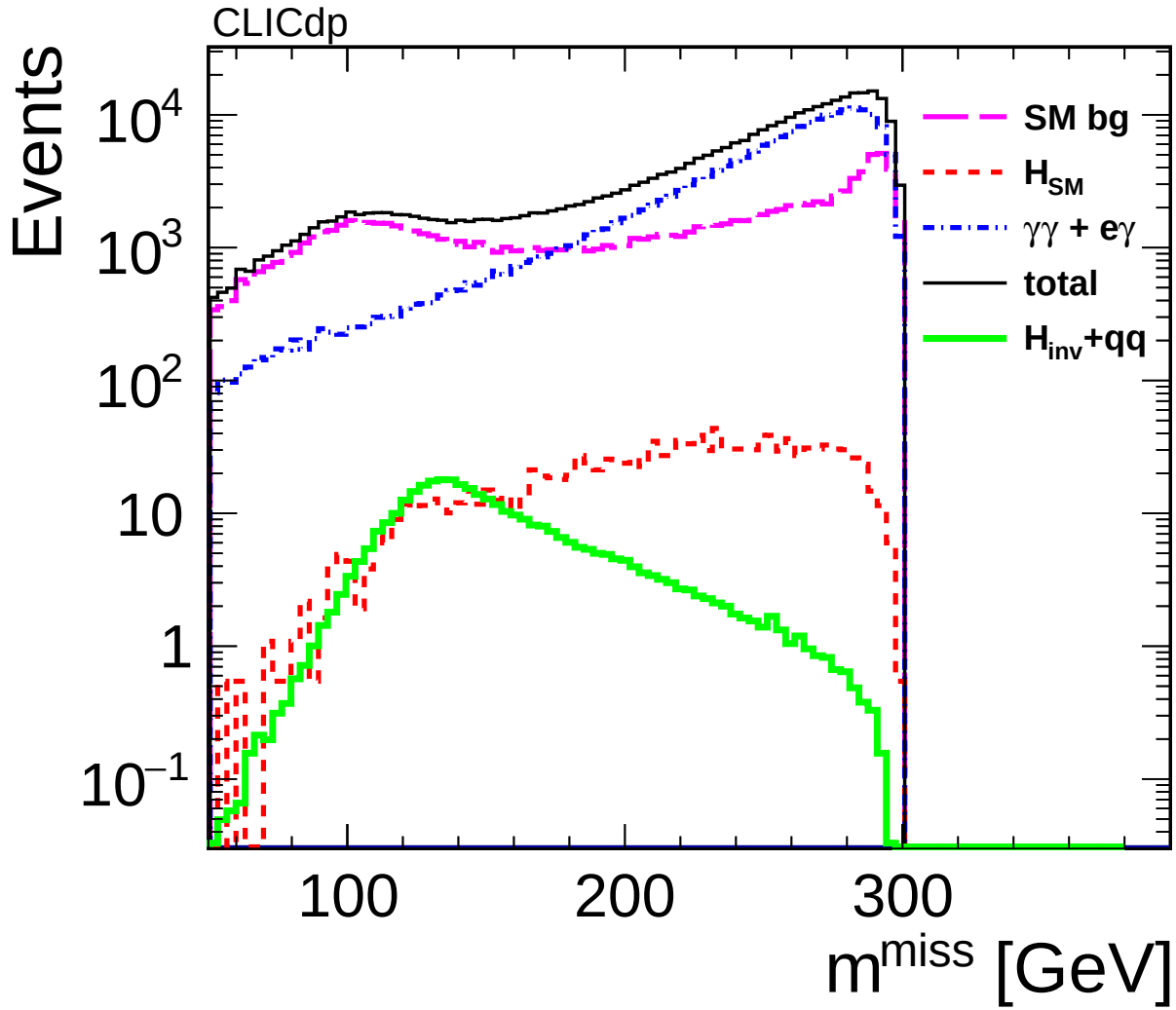
Event class	*Efficiency*	*Events after cuts*
e^+e^- backgrounds (non-Higgs)	0.21%	115,398
$e\gamma$ and $\gamma\gamma$ interactions	5.11%	201,492
SM Higgs decays	0.86%	1313
$H + qq$ invisible decays	43.56%	35,920

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

Preselection

Recoil mass distribution after preselection cuts

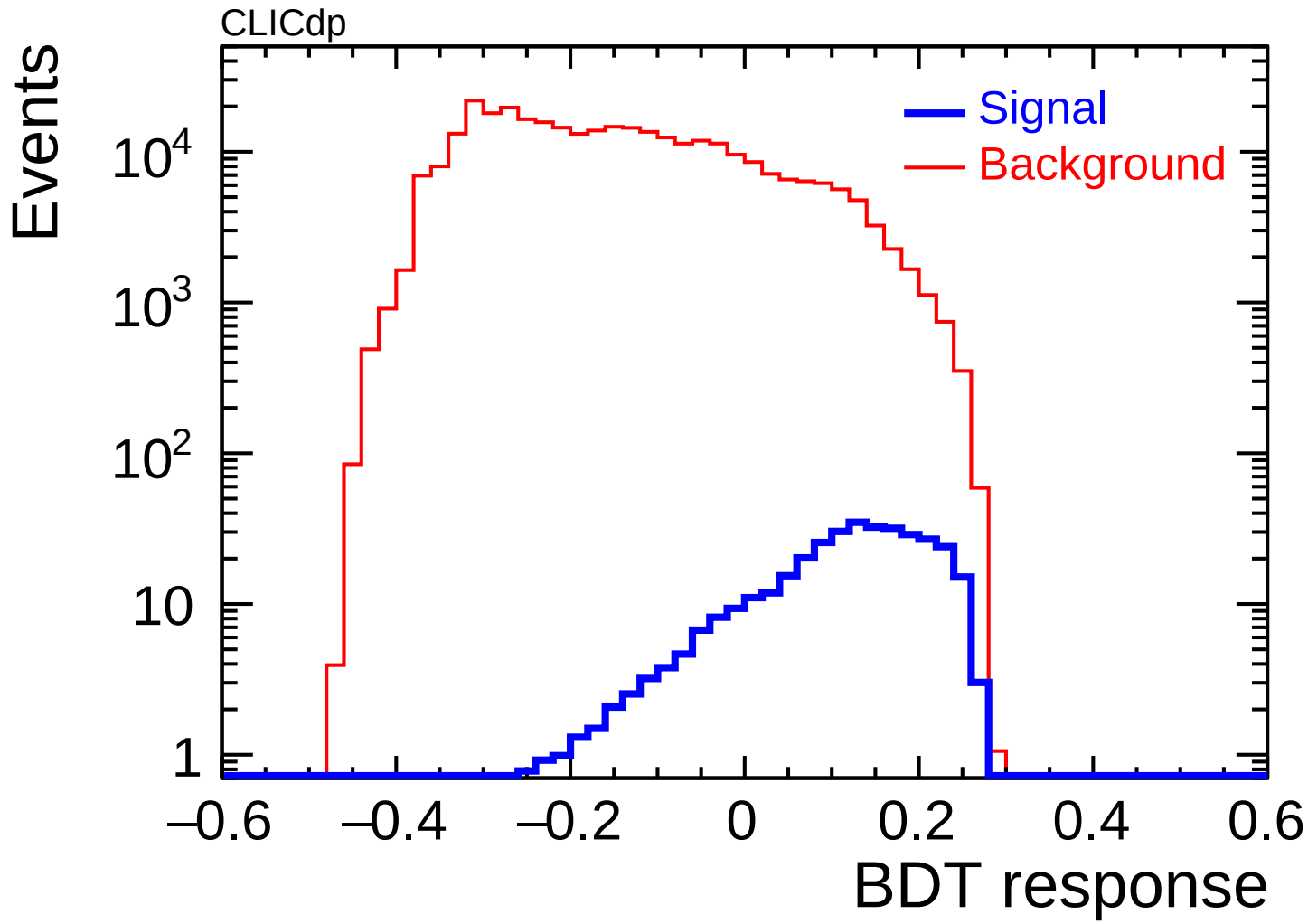
for 1000 fb^{-1} collected at 380 GeV, assuming BR(H→inv) = 1% for signal



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 1000 fb^{-1} collected at 380 GeV:

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

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 $e^+e^- \rightarrow ZH' \rightarrow qq + inv$

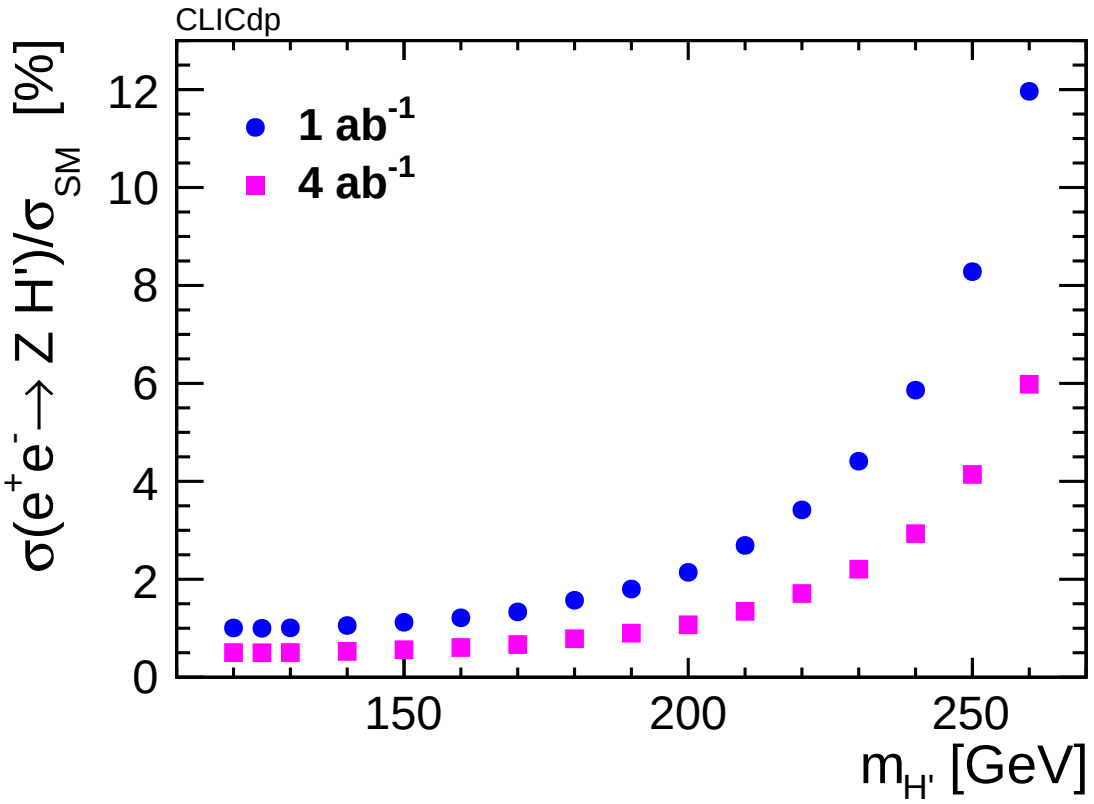
(H' generated in WHIZARD as SM-Higgs particle with a different mass)

Limits on new scalar production – CLIC380

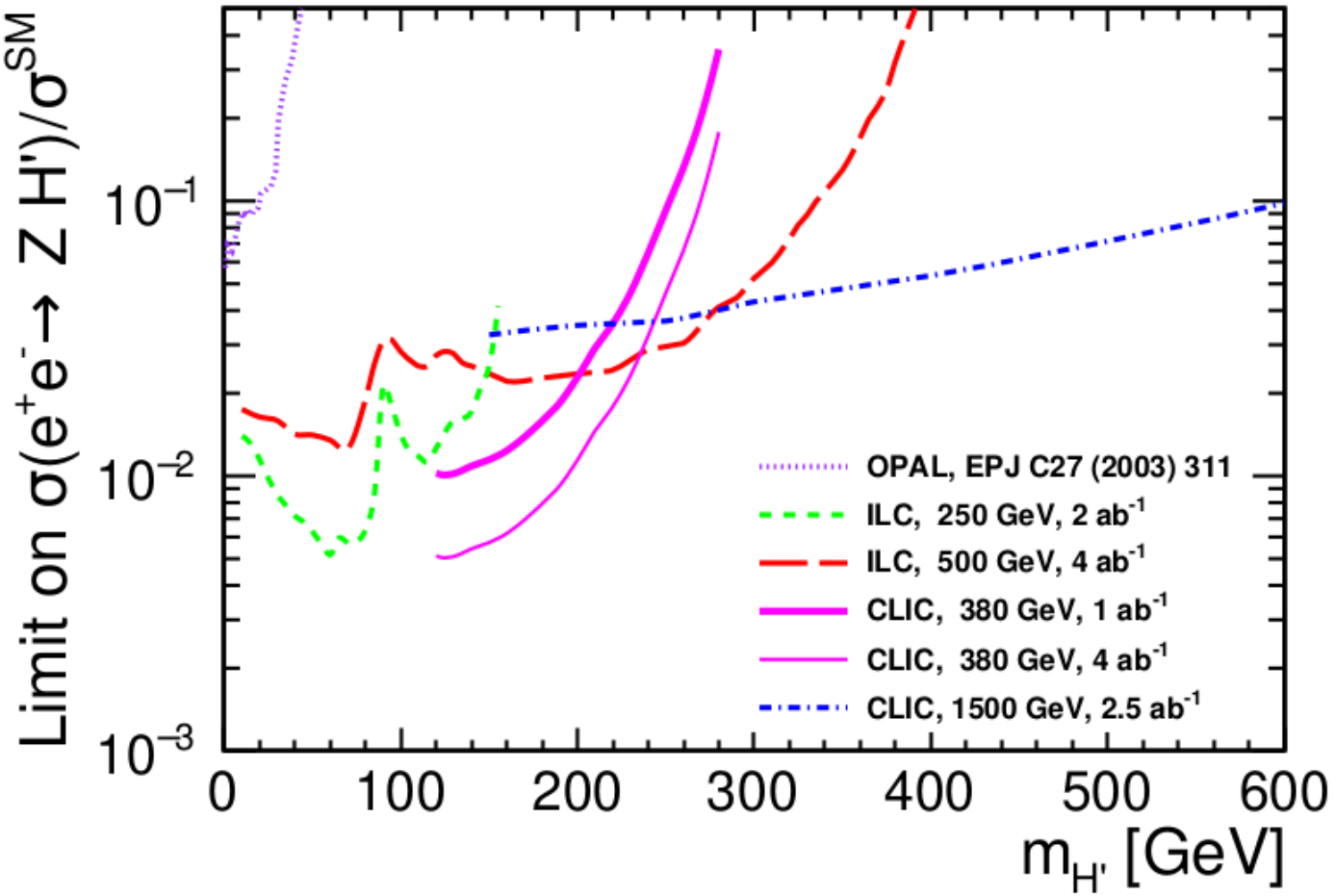
Same approach can be used to search for production of H' state in the process $e^+e^- \to ZH' \to qq + inv$

(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



Similar analysis performed also for CLIC1500.

Interpretation

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

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

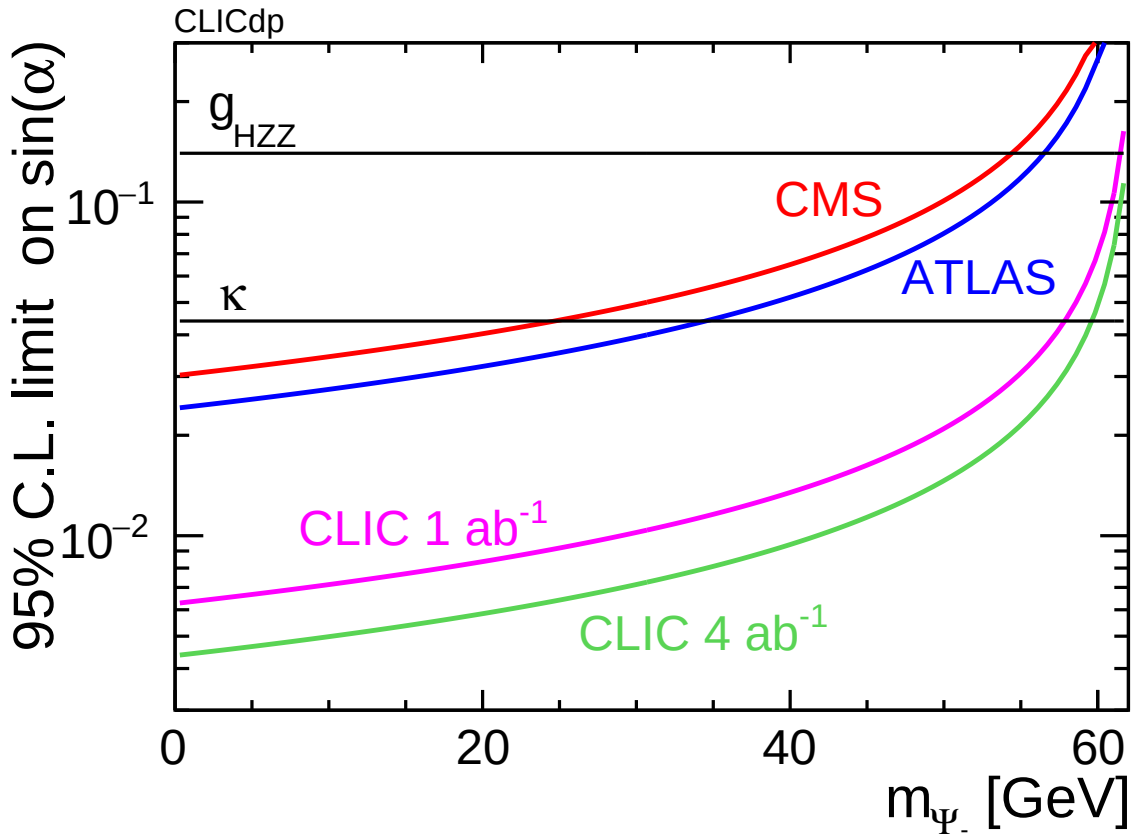
If $\alpha \ll 1$, H is SM-like (the observed 125 GeV state), but it can also decay invisibly via ϕ component (BR $\sim \sin^2\alpha$).

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 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 $g_X = 1$.

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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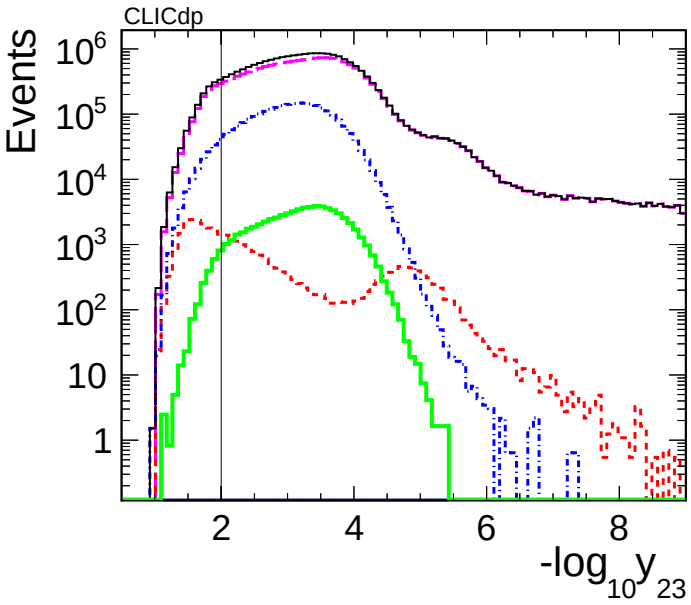
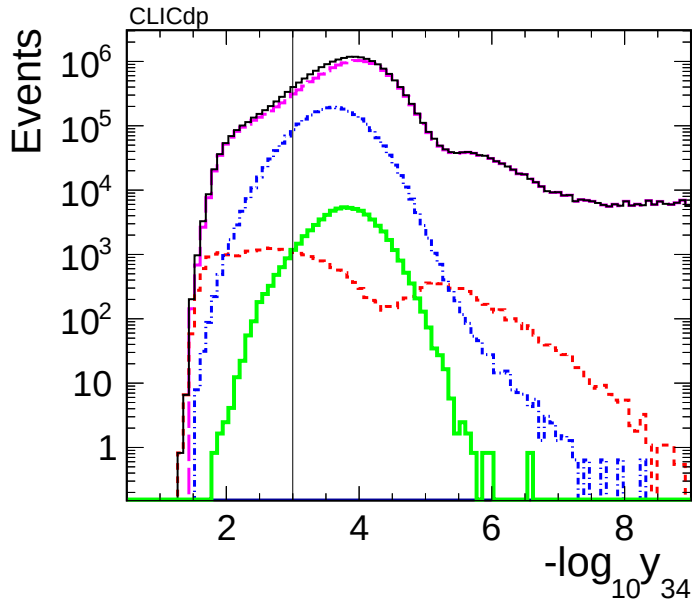
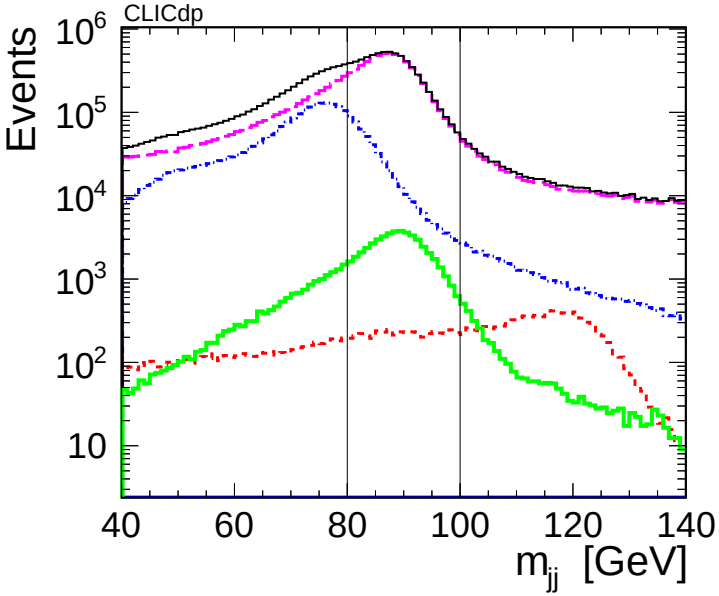
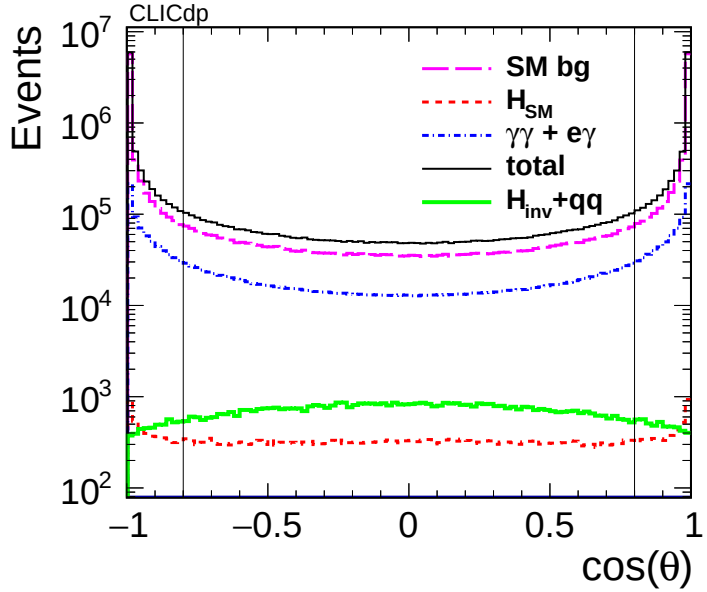
BACKUP: preselection cuts









BACKUP: limits on the mixing angle