Pair production of charged IDM scalars at high energy CLIC

J. Klamka, A. F. Żarnecki
Faculty of Physics, University of Warsaw

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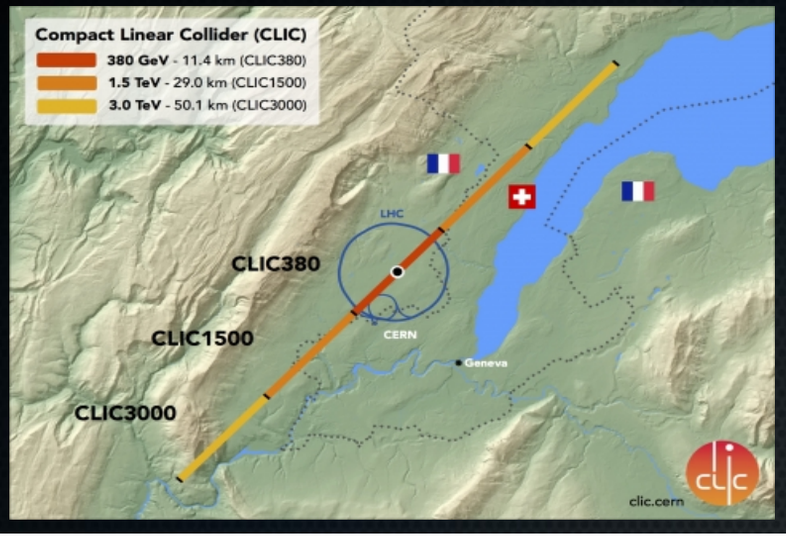
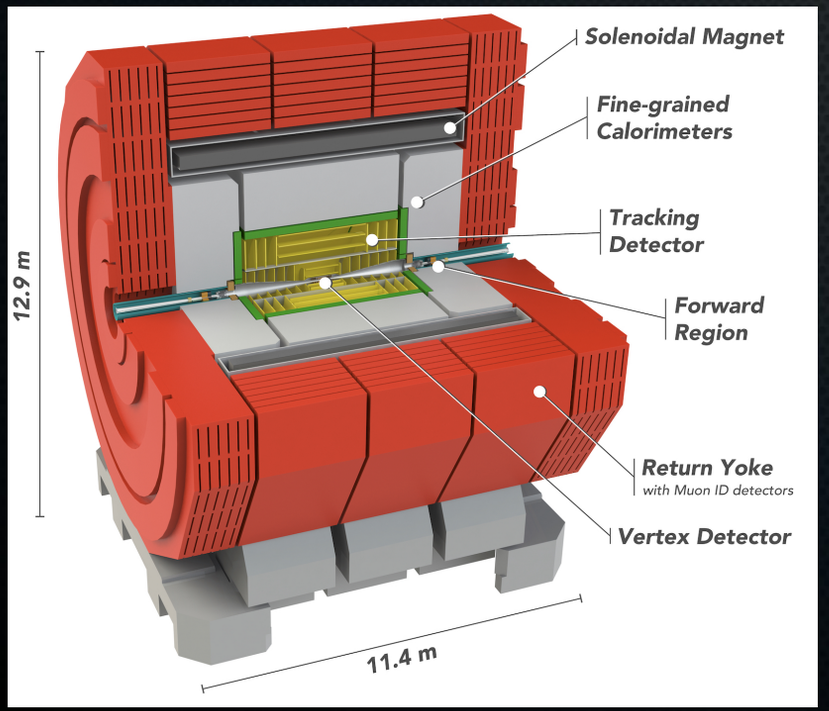
The Compact Linear Collider





- Proposed as the next large-scale installation at CERN

- Higgs and top physics programme running at 380 GeV

- Main goal at high energy stages: searching for BSM physics

The Inert Doublet Model

SM-like Higgs:

$$\phi_{SM} = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v + h + i\xi) \end{pmatrix}$$

„Higgs boson”: h

IDM Higgs:

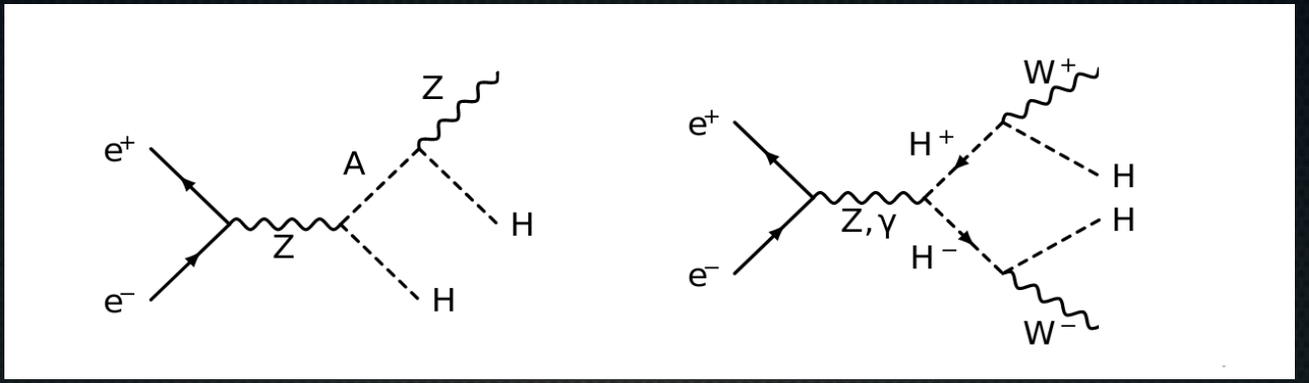
$$\phi_D = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA) \end{pmatrix}$$

New particles: $H^\pm, H, A$

- Additional scalars does not couple to fermions on tree level (Z_2 symmetry)
- The lightest of new particles is stable → **DM candidate**
- **5 free parameters** in the model with existing constraints

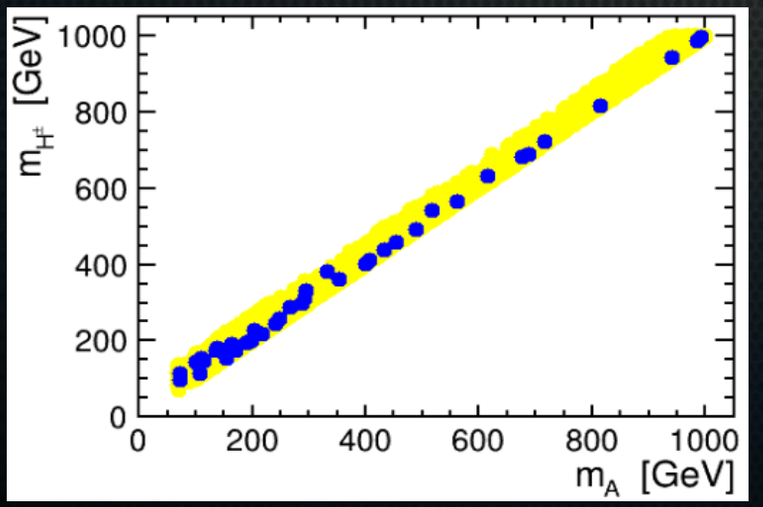
Benchmark points

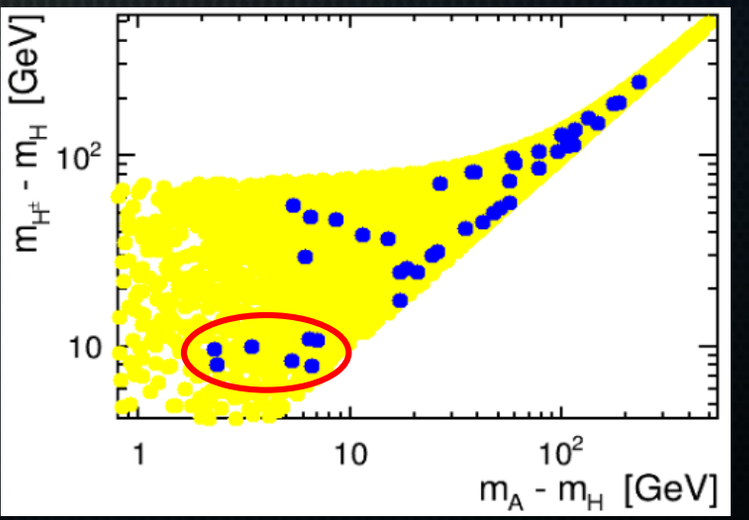
Considered 23 high-mass benchmark points from **JHEP 1812 (2018) 081, arXiv:1809.07712** for two production scenarios:



Mass difference affects virtuality of W boson!

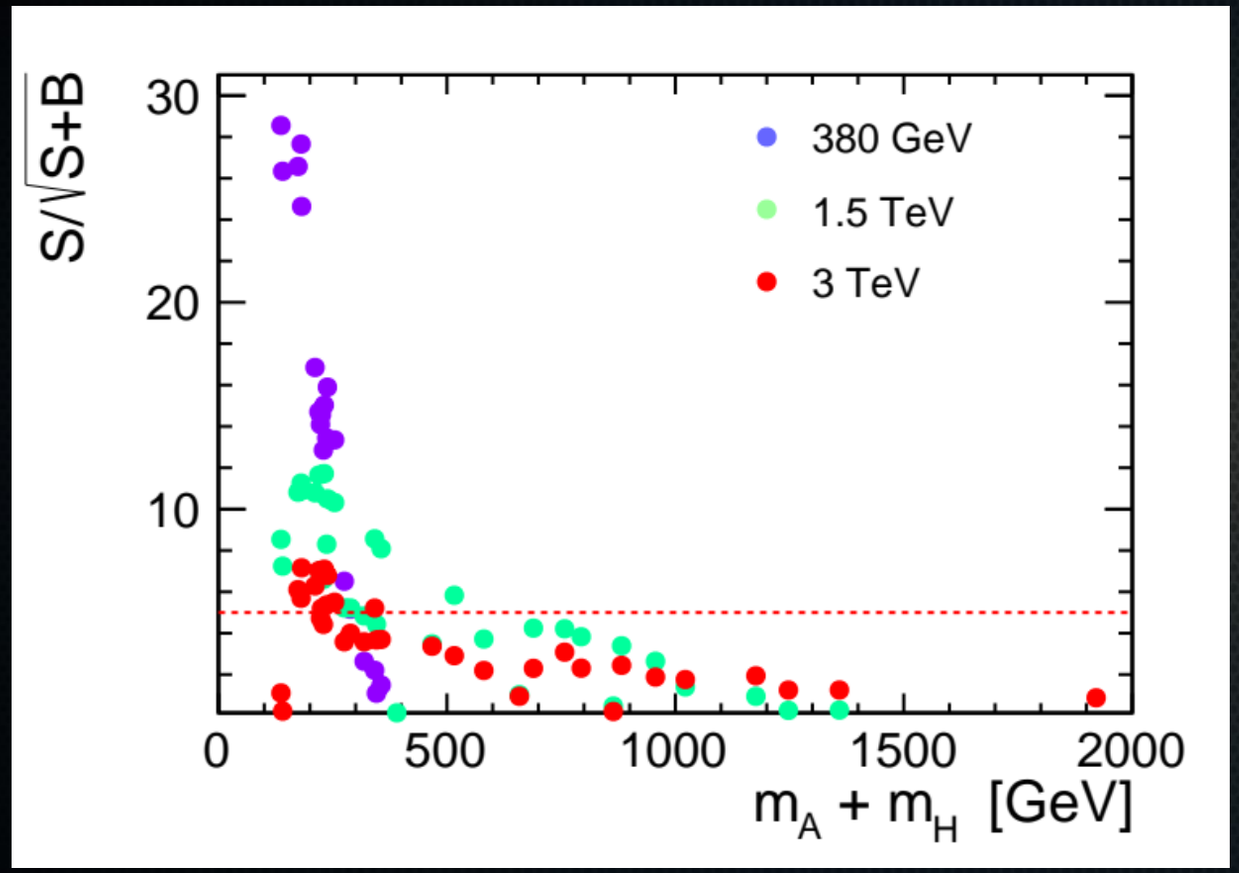
A.F. Żarnecki, ALPS2019

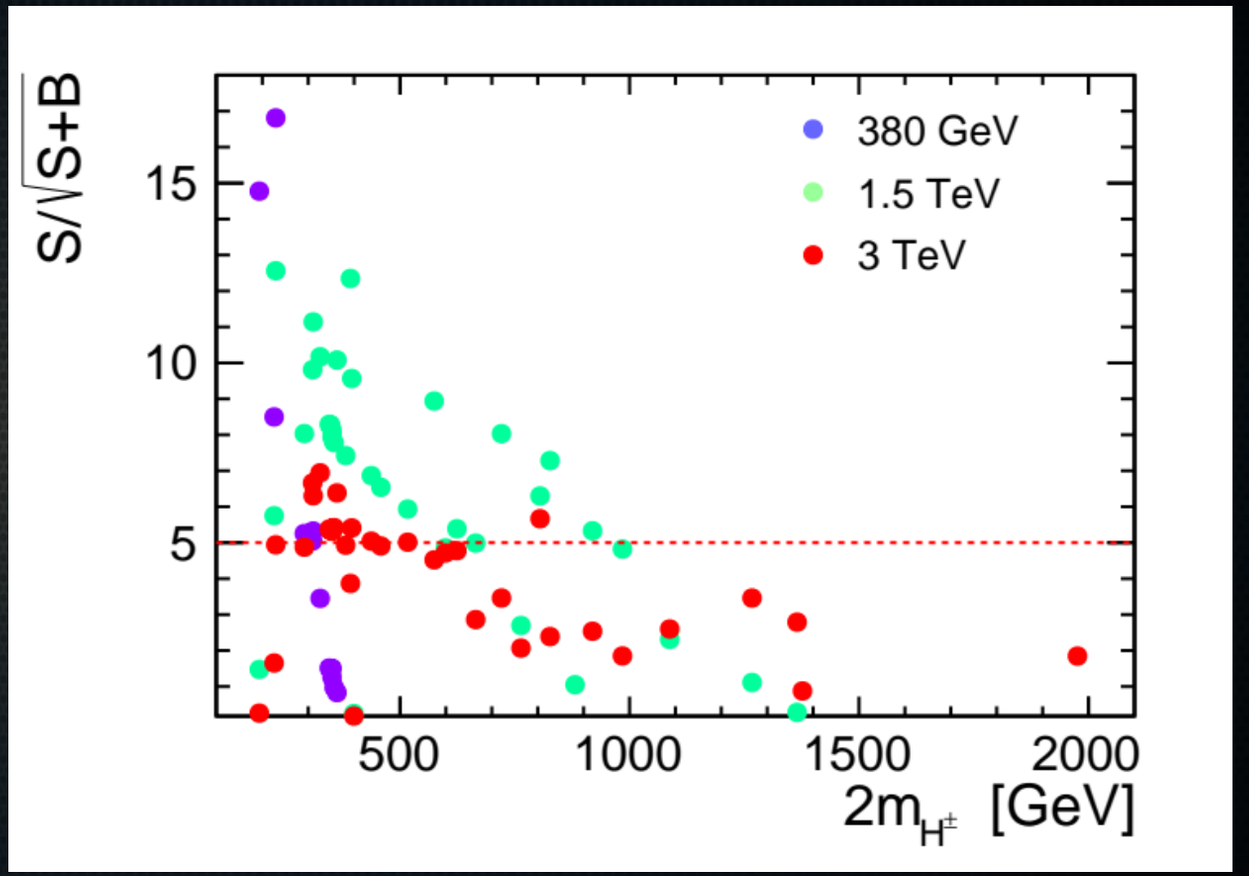




Strategy

IDM scalar production previously studied in leptonic channel (JHEP07 (2019) 053)

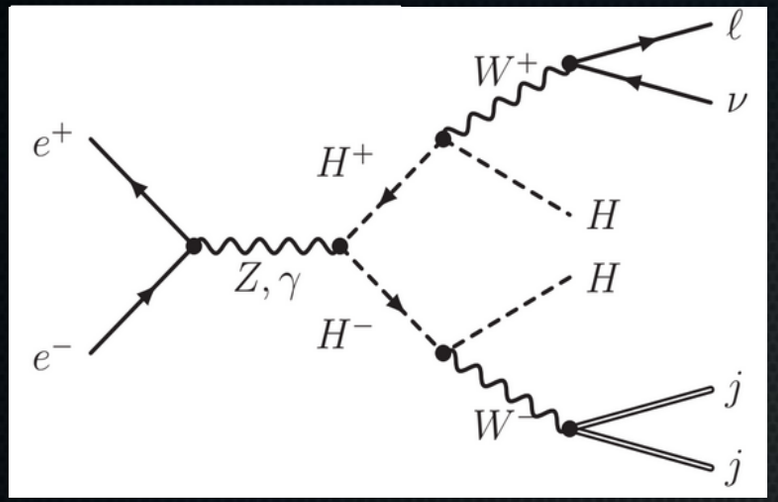




Discovery reach **limited** up to scalar masses ~250 GeV and ~500 GeV at 1.5 TeV and 3 TeV by production cross section

Strategy

Order of magnitude higher cross section expected for **semi-leptonic** channel

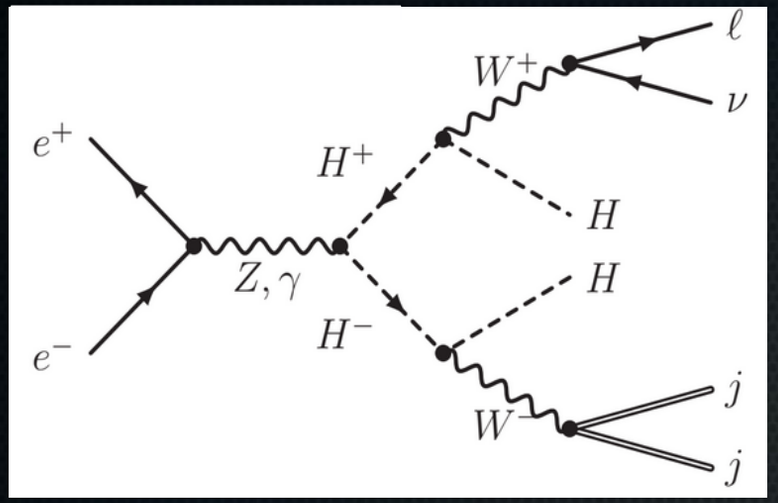


Expected **signature** of the final state:
One lepton: e or μ, and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

Strategy

Order of magnitude higher cross section expected for **semi-leptonic** channel



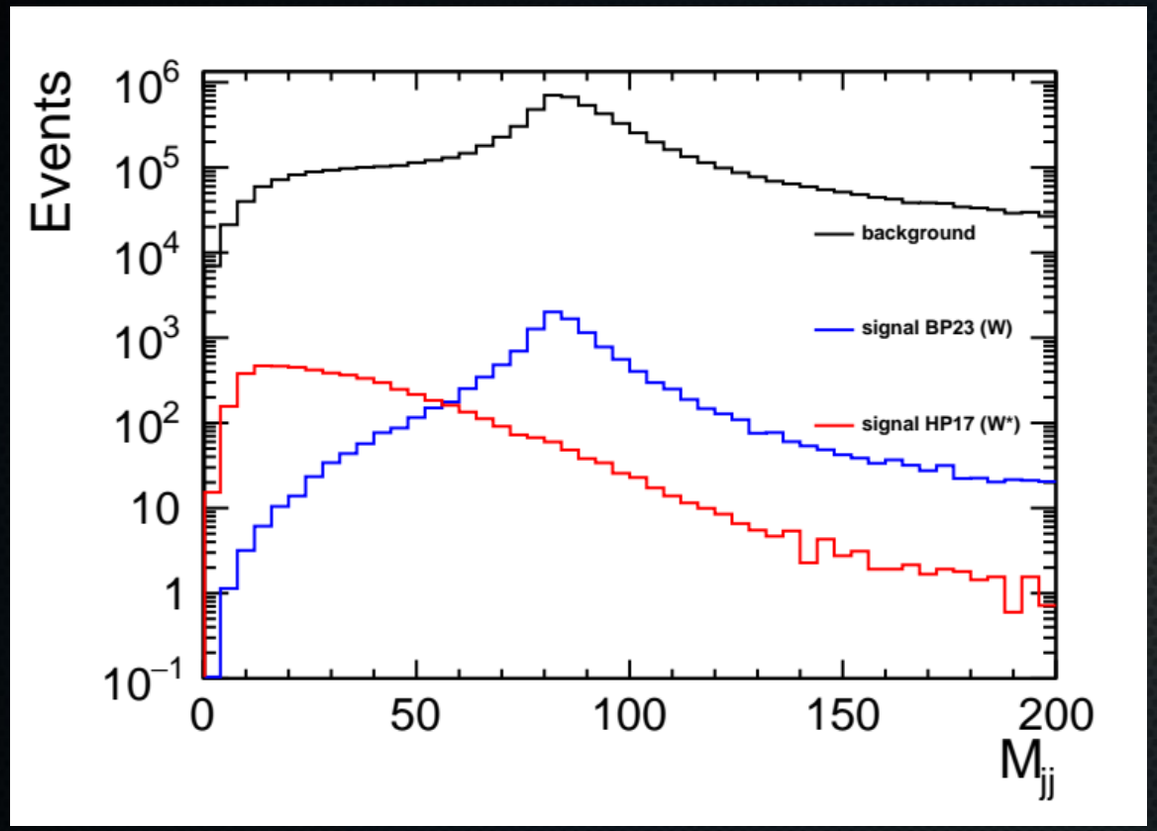
Expected **signature** of the final state:
One lepton: e or μ, and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

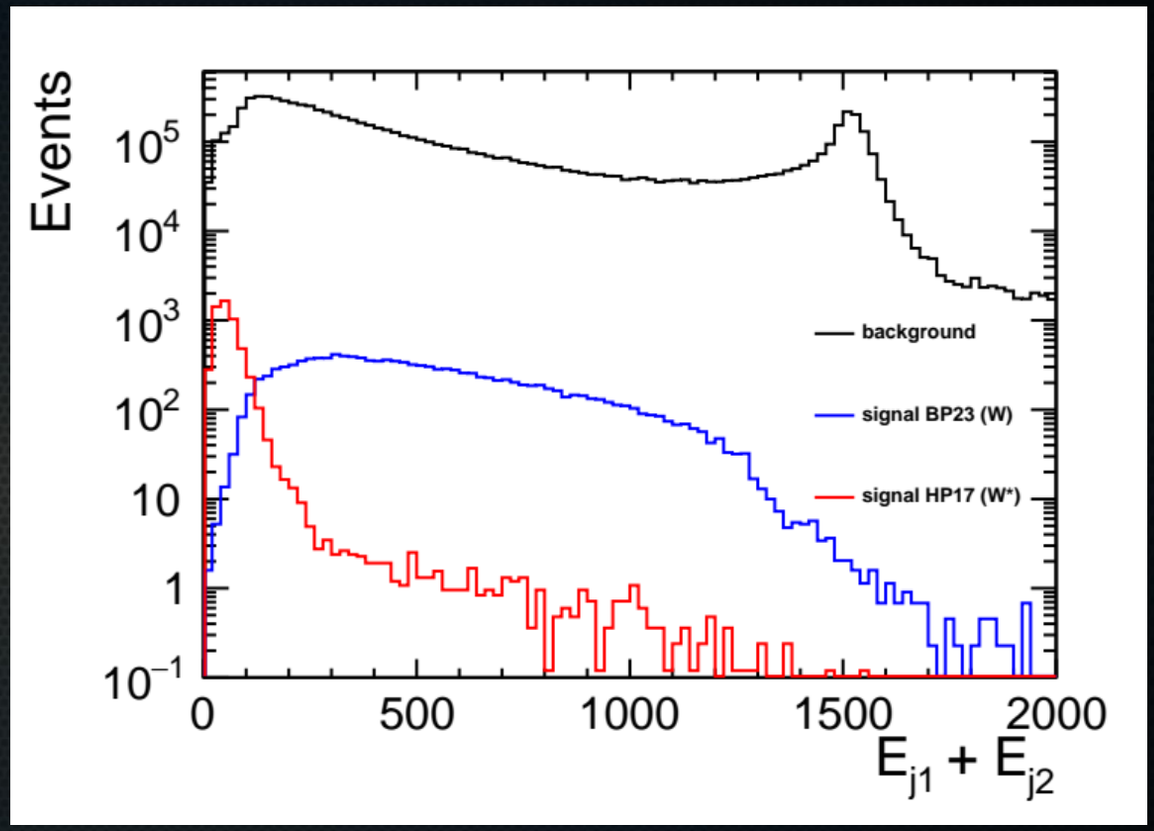
- Use CLIC beam spectra for **1.5 TeV (2000 fb^{-1})** and **3 TeV (4000 fb^{-1})**
- Generate samples with **Whizard 2.7.0**
- Use **Geant4** CLICdet model to simulate detector response for 5 scenarios

Extend to
all 23 benchmarks
with **fast simulation**

Scenarios with on-shell vs. off-shell $W^{+/-}$ (3 TeV)



Di-jet mass

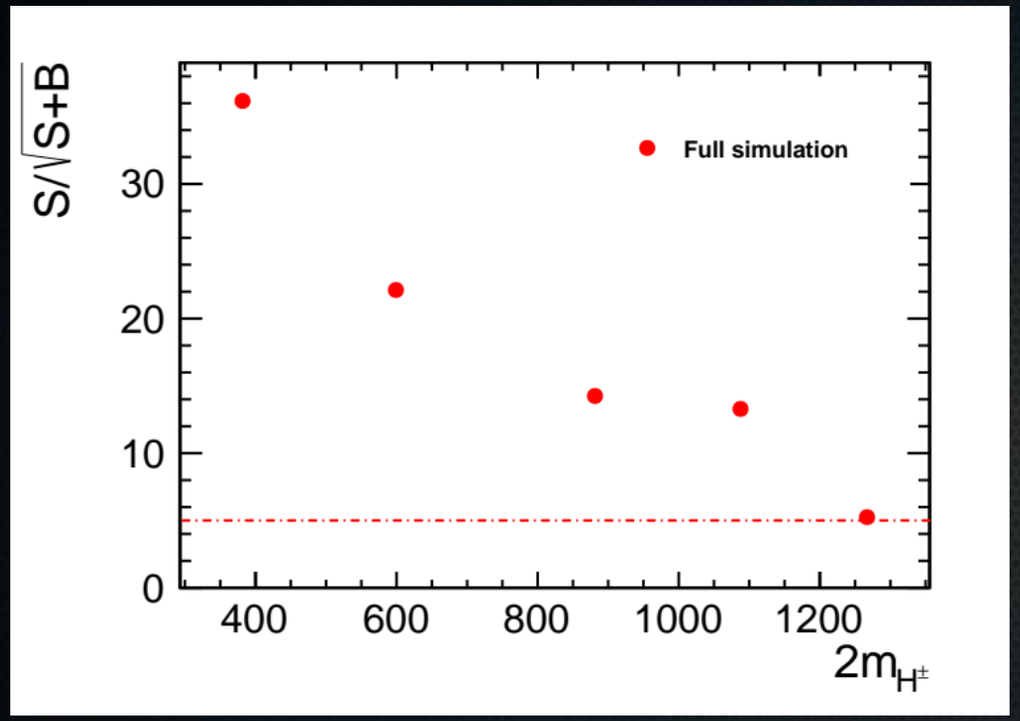


Di-jet energy

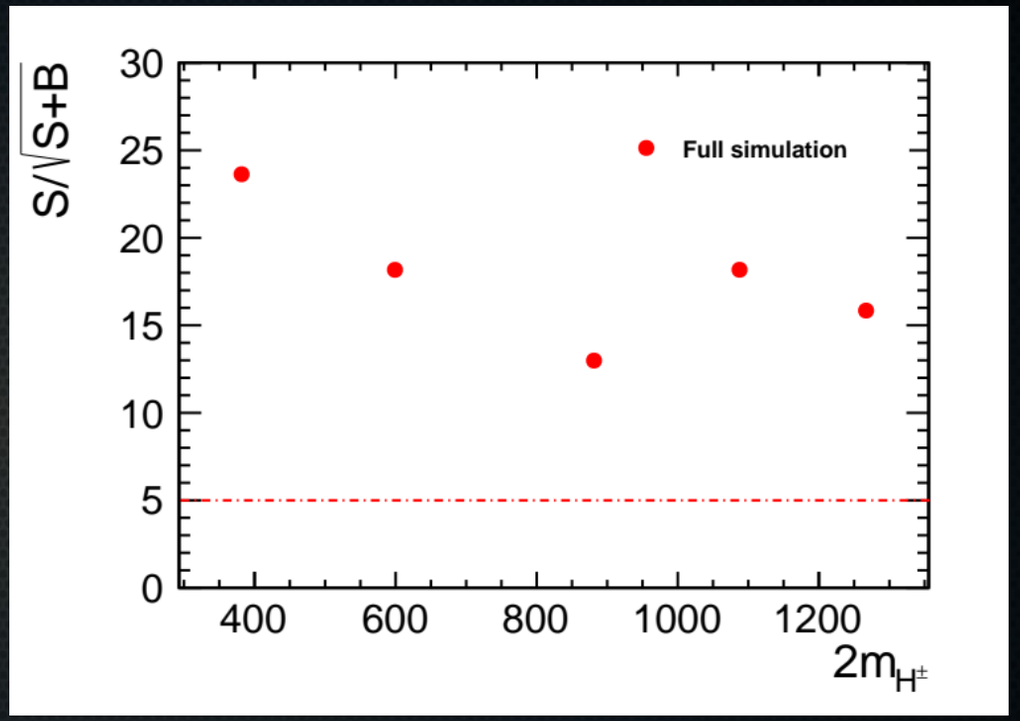
Huge difference between scenarios with large and small $m_{H^\pm} - m_H$

Full simulation results

1.5 TeV



3 TeV



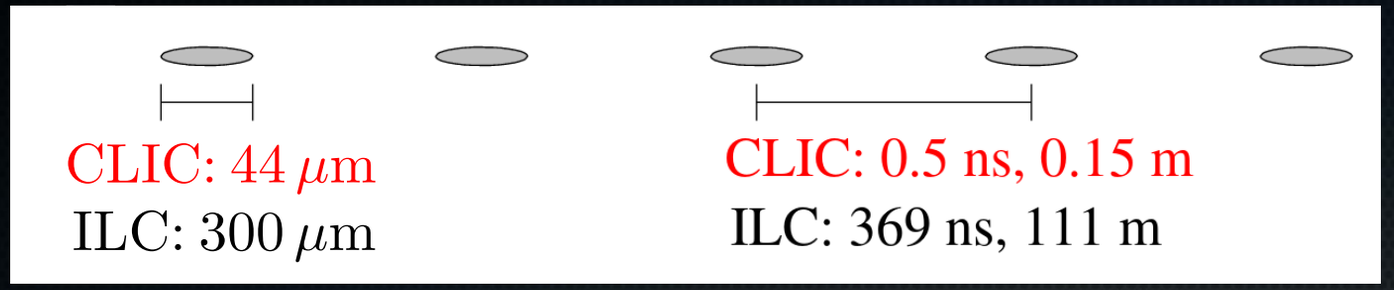
Note: MVA selection optimised for particular scenario!

Now extend to more scenarios using fast simulation and the same analysis methods!

DELPHES fast simulation

Overlay background

LCD-Note-2011-006



Virtual W

→ low **p, E** of decay products

→ **big influence of** $\gamma\gamma \to \mathrm{had.}$ **background!**

Huge beam-induced background at CLIC

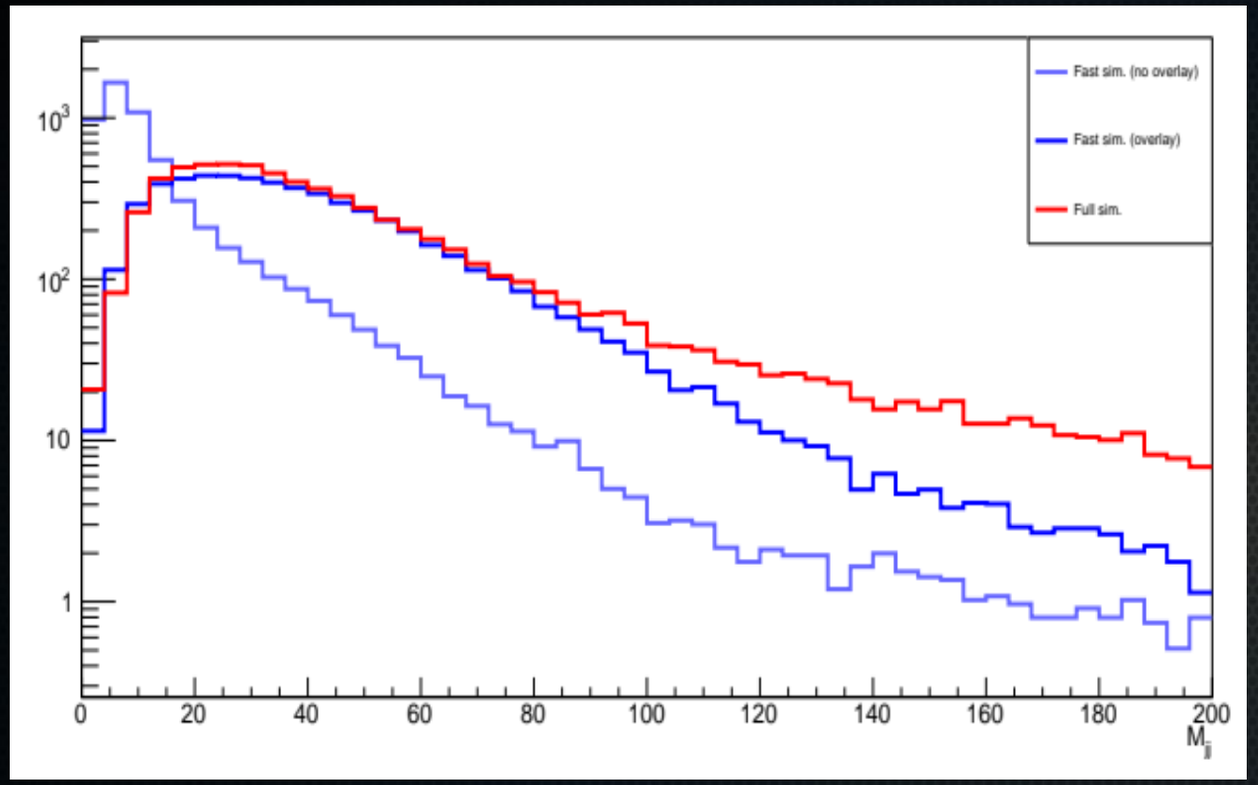
- $\gamma\gamma \to \mathrm{had.}$ important for detector performance

- Timing cuts on PFOs to reduce this bckg.

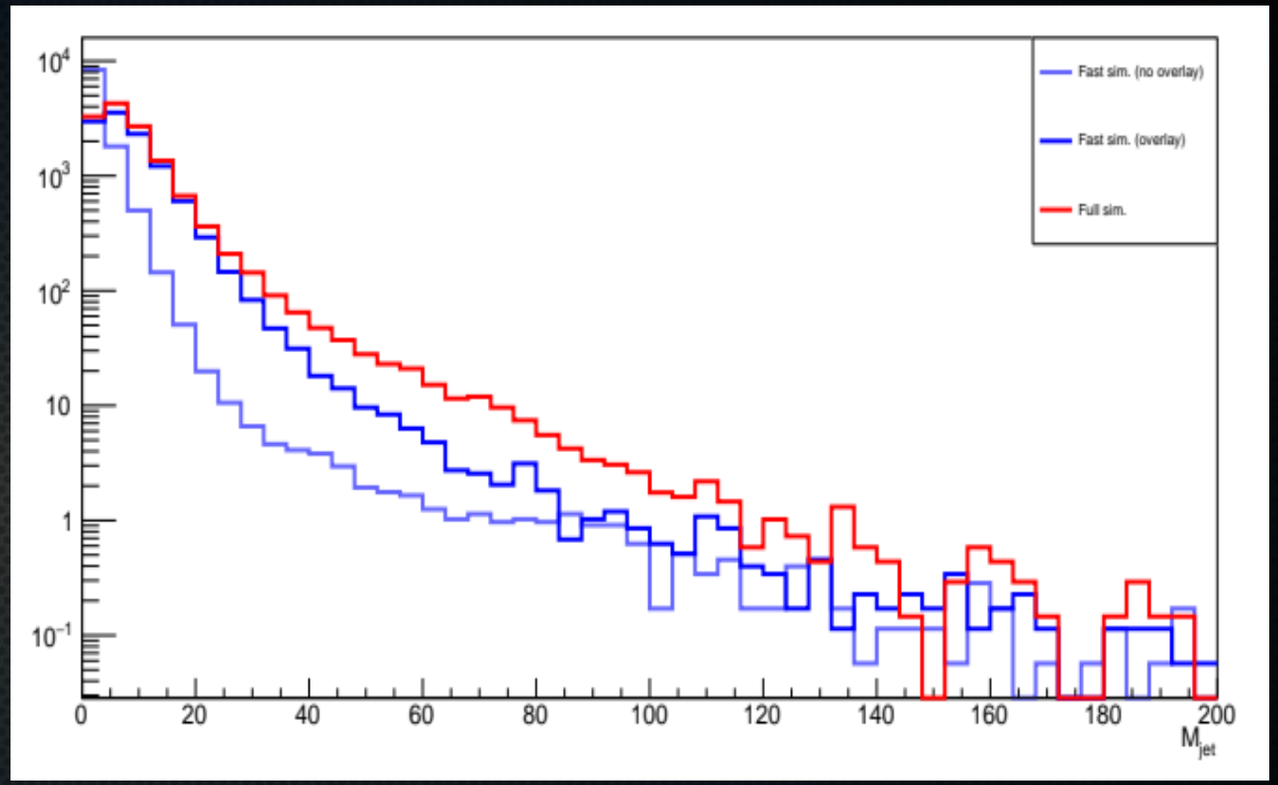
Timing cuts not implemented in Delphes model for CLIC

We include **overlay background** and apply **effective cuts** on the generator level

Influence of the overlay background (HP17 signal, 3 TeV)



Di-jet mass

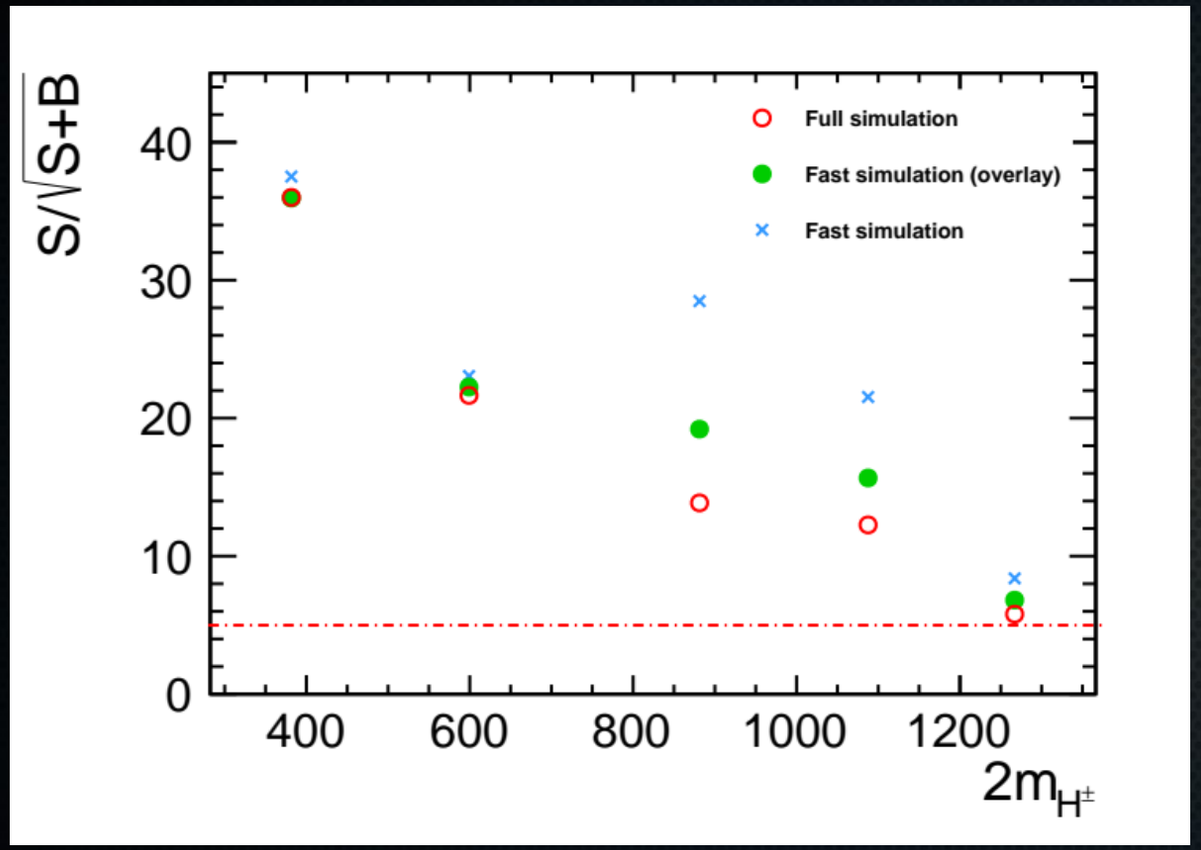


Single jet mass

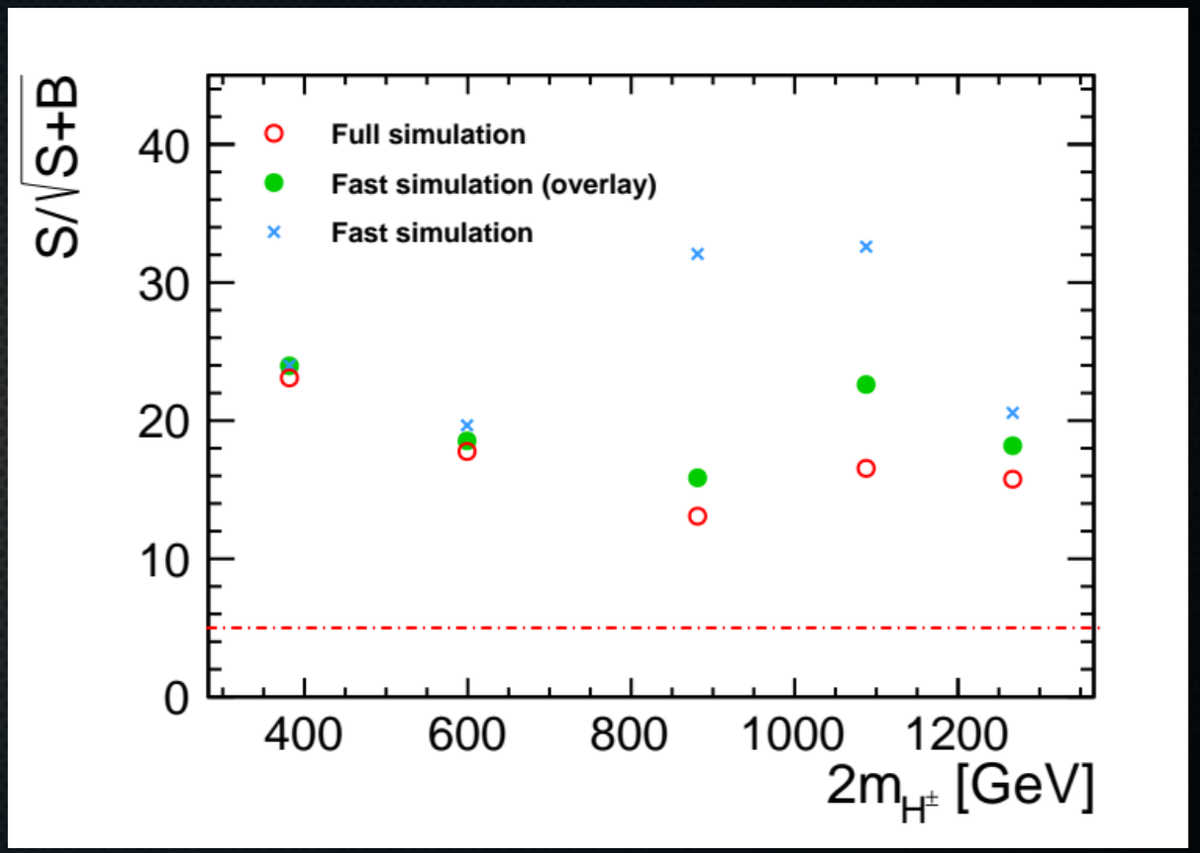
- In **HP17 scenario** $W^{+/-}$ is far off-shell
- **Delphes with overlay** much closer to full simulation results

Influence of overlay on the results

Cut-based preselection + MVA with BDTs



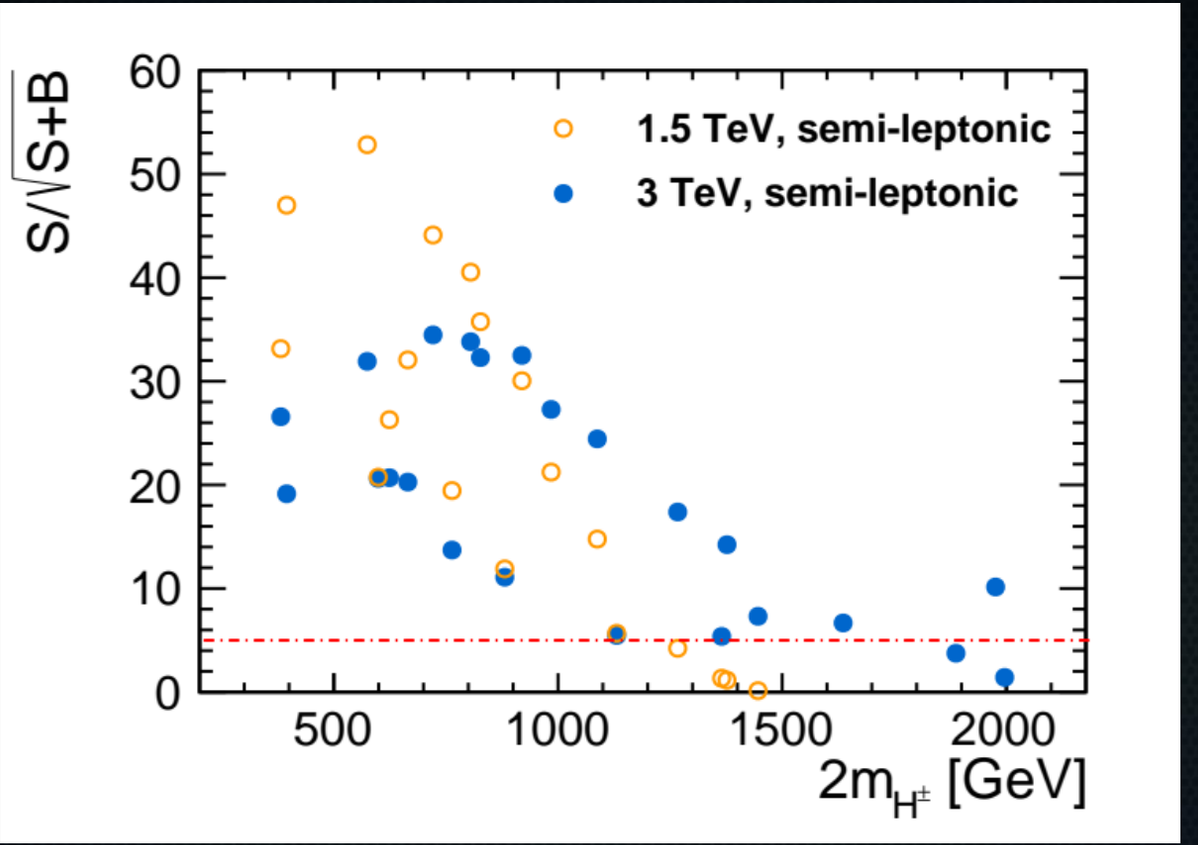
1.5 TeV



3 TeV

Selection still **optimised** to particular scenario

Final results (all scenarios)



- Two BDTs trained separately: for all scenarios with **off-shell** $W^{+/-}$ and for all scenarios with **on-shell** $W^{+/-}$

- Most benchmarks **above 5σ** discovery threshold

Summary

- Prospects for **discovery of charged IDM scalar** pair-production at high energy CLIC stages studied with **full** and **fast simulation**

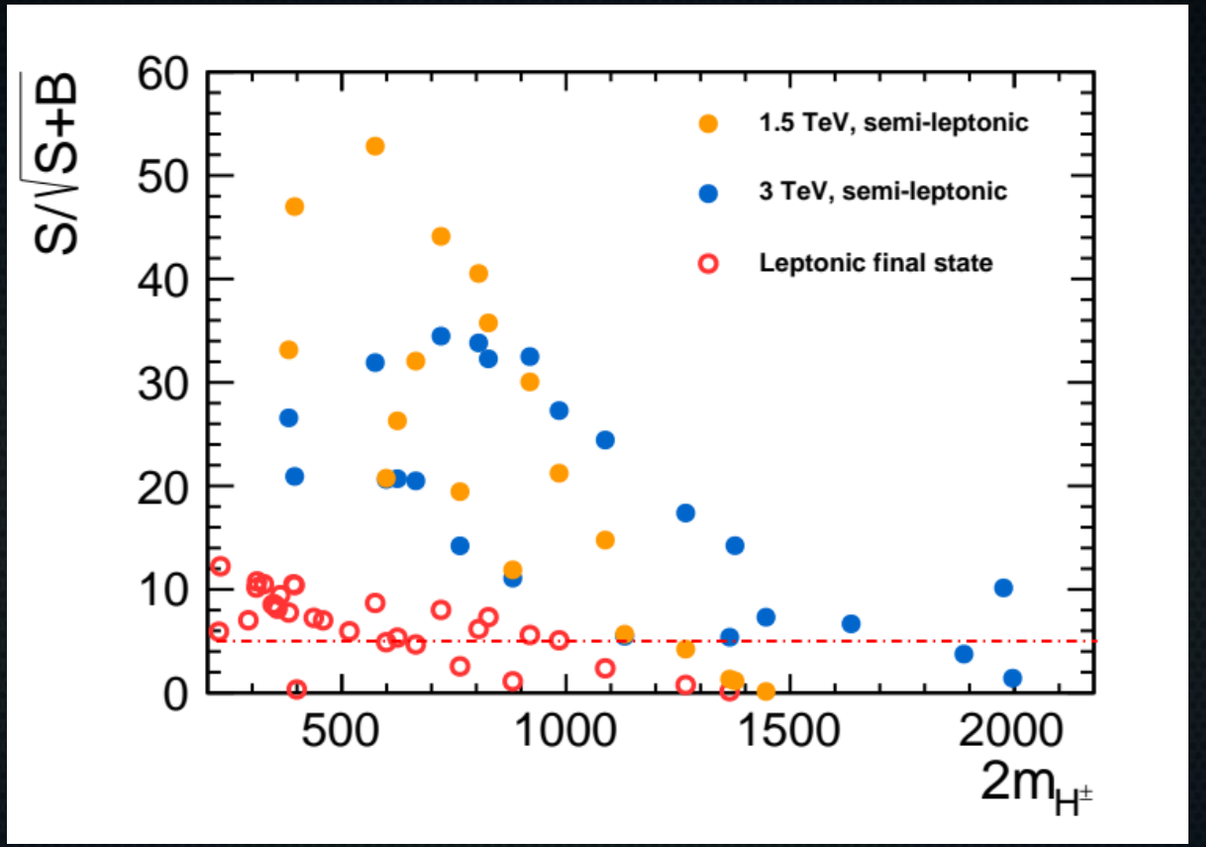
- CLICdet model for Delphes extended to include $\gamma\gamma \to \mathrm{had.}$ **overlay events**

- Charged IDM scalars with **masses** of up to **1 TeV** can be discovered at CLIC

Thank you!

BACKUP

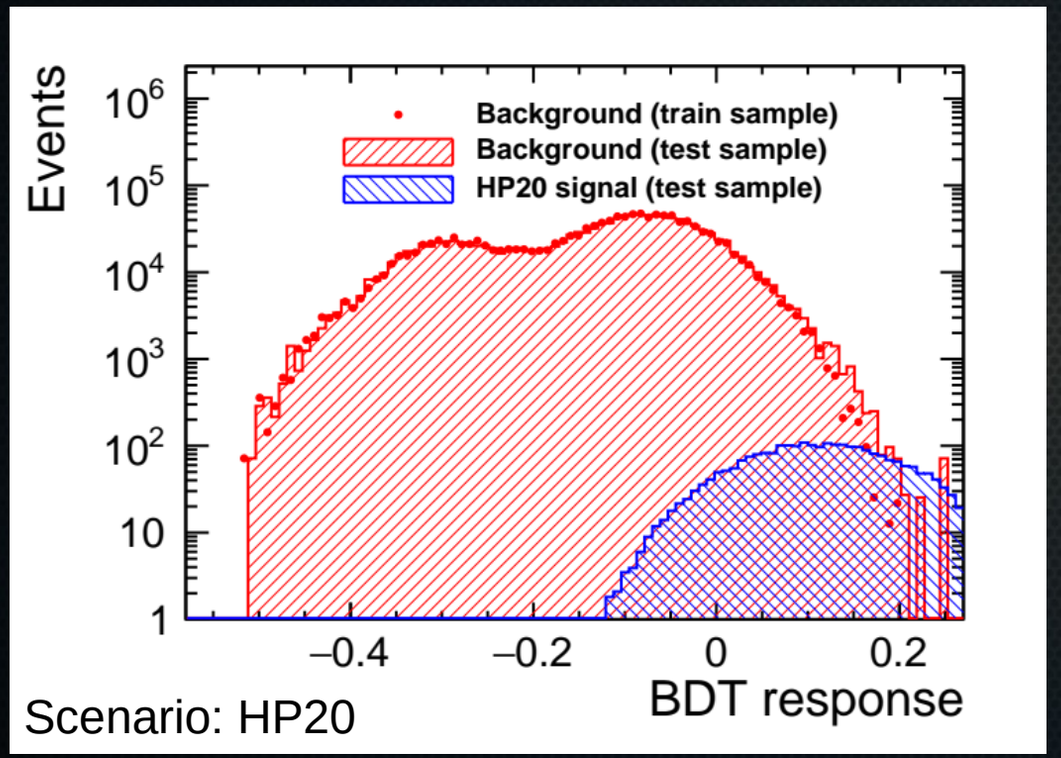
Final results with leptonic channel



Big improvement compared to leptonic channel

Event selection

After cut-based preselection → **Boosted Decision Trees**



- Machine learning method
- Decision tree cuts space and classifies events in its regions
- 1000 weak classifiers combined

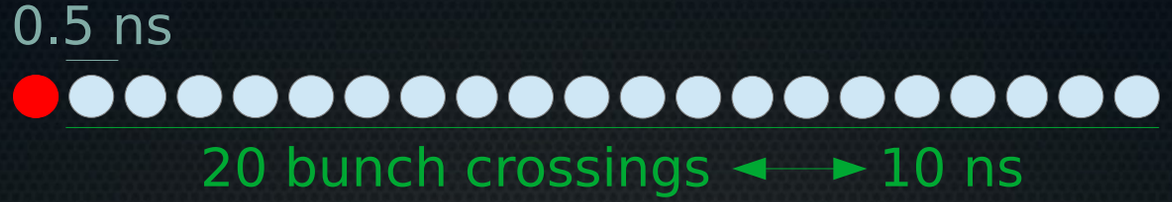
Input variables:

$M_{jj}, E_{jj}, \theta_{W^\pm},$
$E_j, p_T^j, \theta_j,$
$E_\ell, p_T^\ell, \theta_\ell,$
$\mathrm{MET}, M_{miss}, p_T^{\mathrm{utg}}, M_{\ell+miss}$
$\Delta\theta_{jW^\pm}, \Delta\phi_{jW^\pm}$

Selection optimised to particular scenario

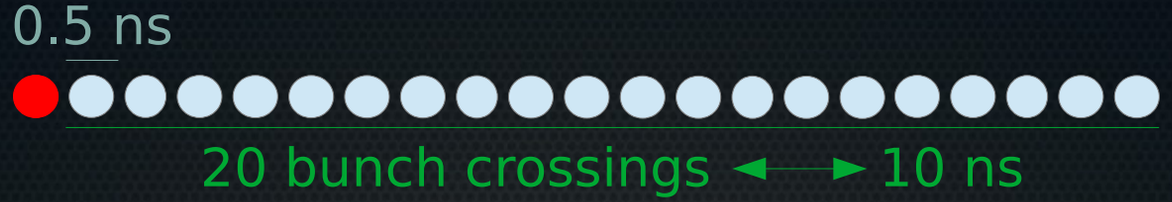
Approximate timing cuts

After timing cuts on **hits** in full sim.: 10 ns after physical event left



Approximate timing cuts

After timing cuts on **hits** in full sim.: 10 ns after physical event left

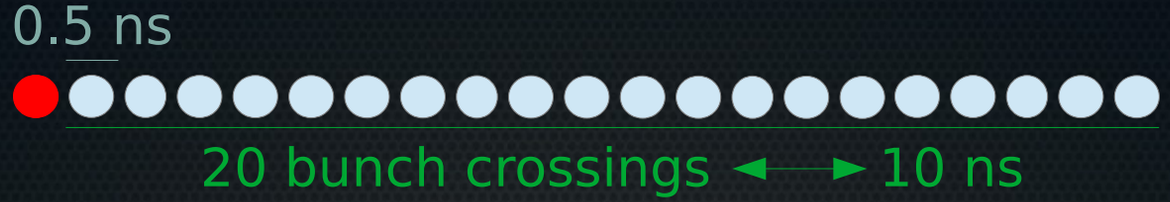


Additional timing cuts on PFOs to reduce $\gamma\gamma \to \mathrm{had.}$ backg.

Example: Accept **tracks** with $p_T < 1$ GeV with $t < 2$ ns

Approximate timing cuts

After timing cuts on **hits** in full sim.: 10 ns after physical event left

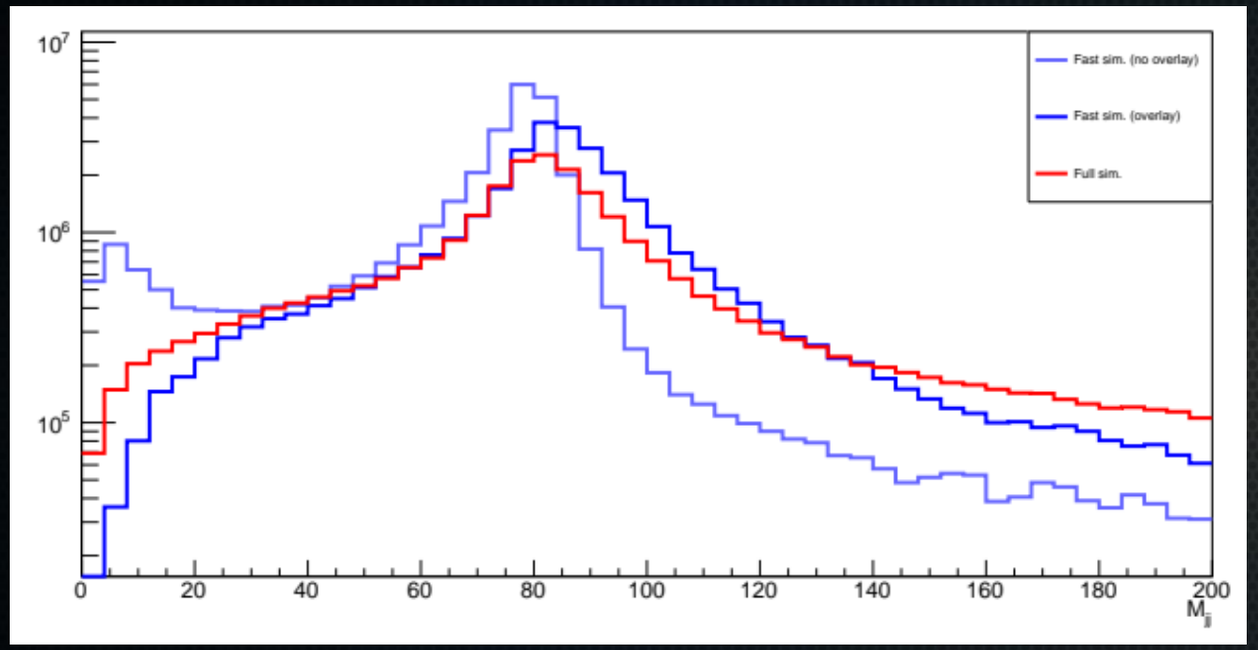


Additional timing cuts on PFOs to reduce $\gamma\gamma \to \mathrm{had.}$ backg.

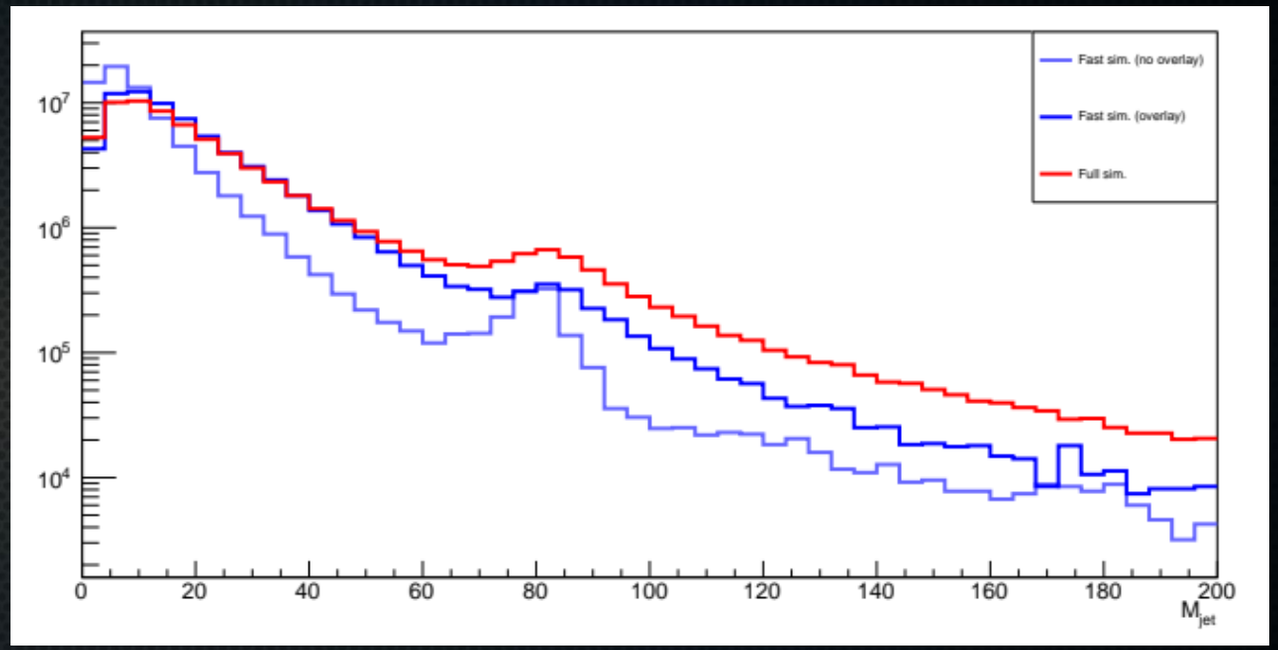
Example: Accept **tracks** with $p_T < 1$ GeV with $t < 2$ ns

1. Take gen-level gamma-gamma events in batches of 20
2. Accept specific particles from first N events
   - based on cuts from CLIC CDR
3. Overlay on physical sample

Influence of the overlay background (SM qqlv background, 3 TeV)



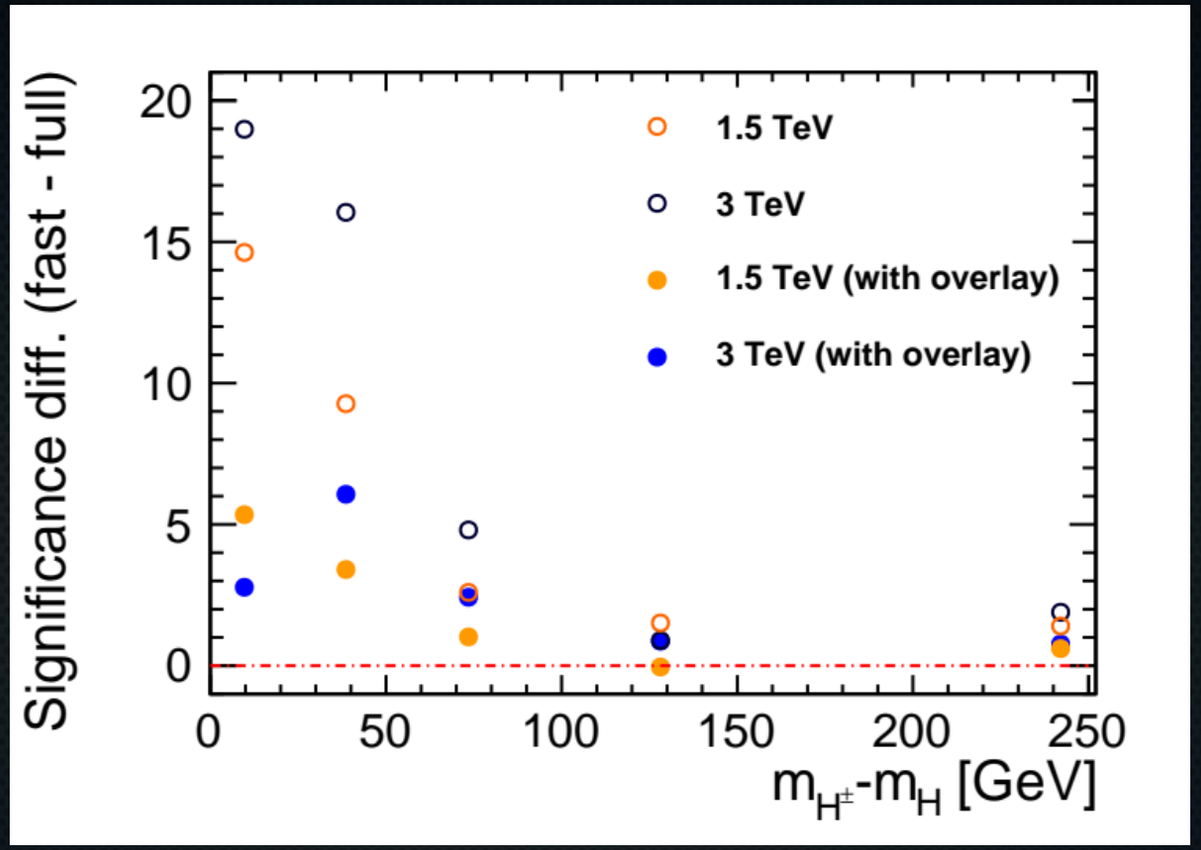
Di-jet mass



Single jet mass

Delphes with overlay similar to the full simulation!

Influence of overlay on the results



- Delphes with overlay much closer to the full simulation
- Scenarios with low mass difference are most influenced by overlay