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Pair production of charged IDM scalars at high energy CLIC

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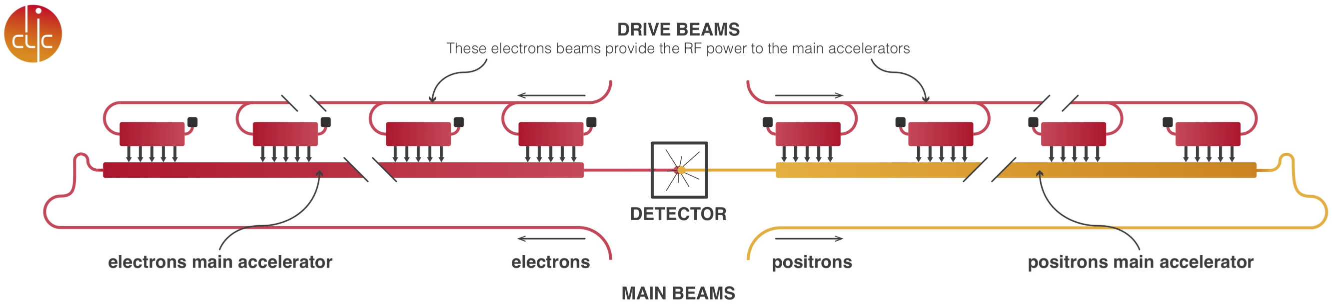
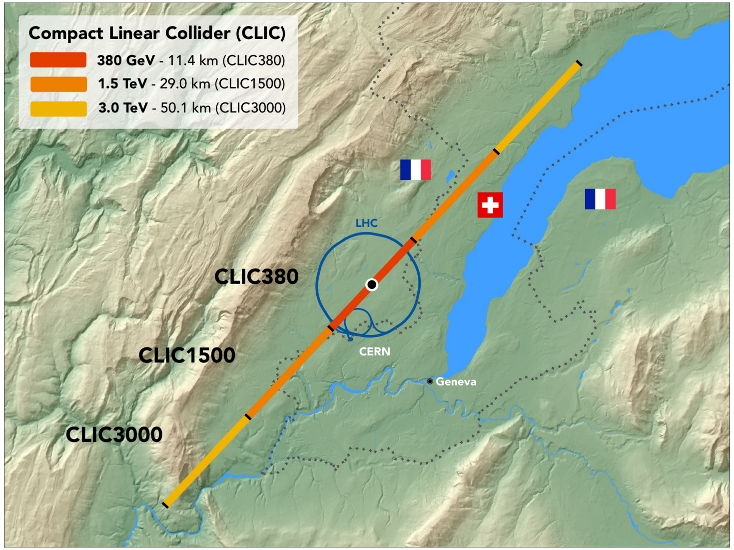
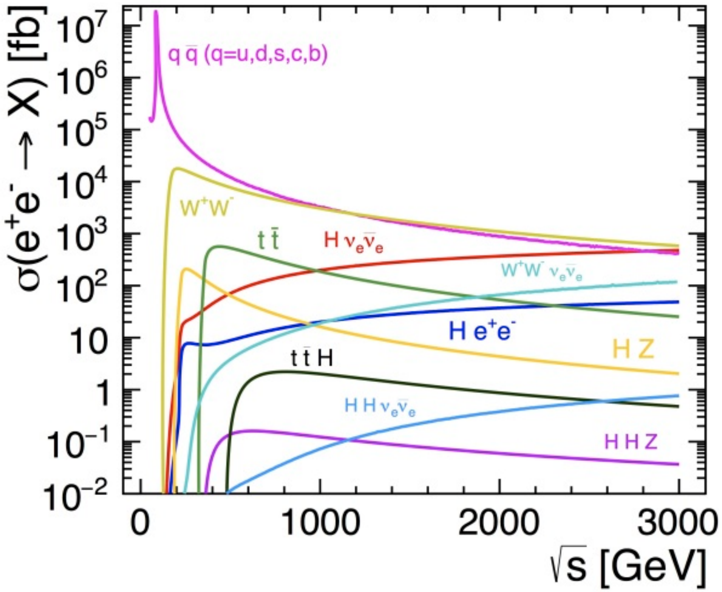
Compact Linear Collider





3 TeV

- Novel **two-beam** acceleration technique
- Normal-conducting technology
- High **100 MeV/m** gradient, **12 GHz** accelerating structures
- **±80% electron beam** polarisation
- Implementation in 3 energy stages



380 GeV stage (1 ab^{-1}):

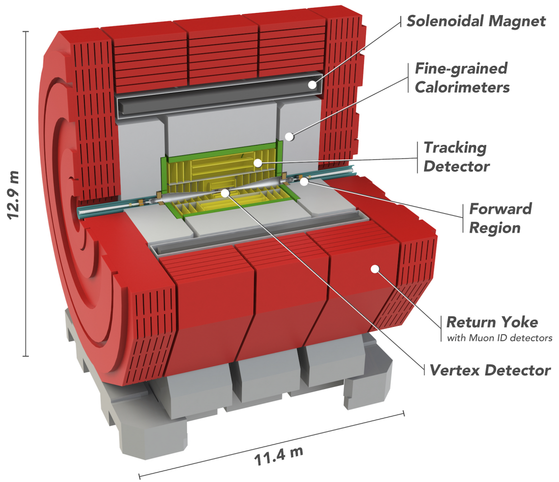
- presicion **Higgs** measurements
- presicion **top** measurements
- **top** threshold scan

1.5 TeV (2.5 ab^{-1}), **3 TeV** (5 ab^{-1}):

- **Higgs** self-coupling
- **top** Yukawa coupling
- more precision measurements: indirect **BSM** constraints

+ direct new physics searches at high energies

Dedicated **detector concept** optimised for **particle-flow** approach



Inert Doublet Model

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

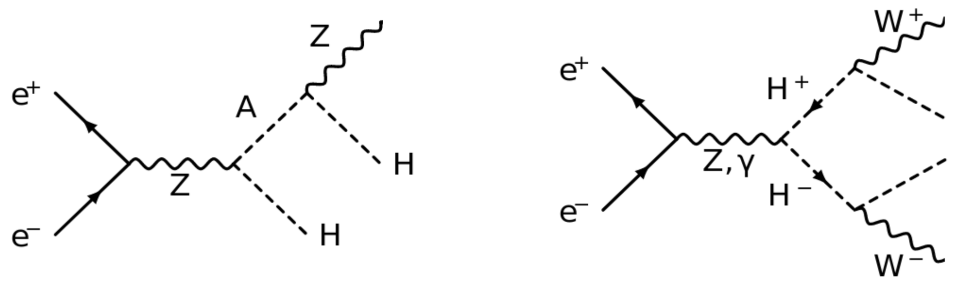
„Higgs boson”: h

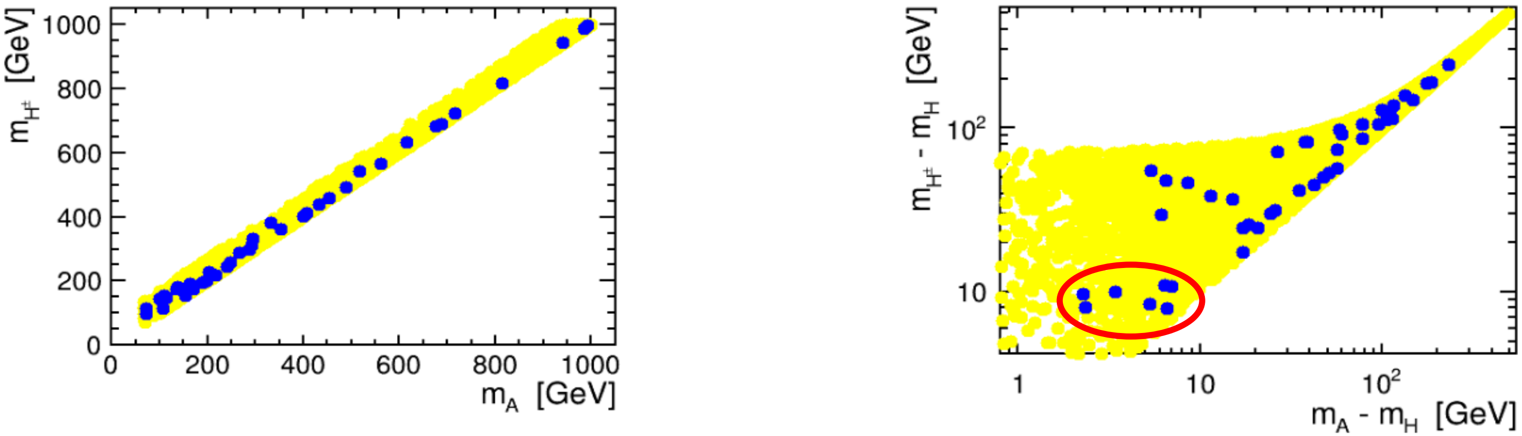
New scalars: $\mathrm{H}^{\pm}$, H, A

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

Inert Doublet Model

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

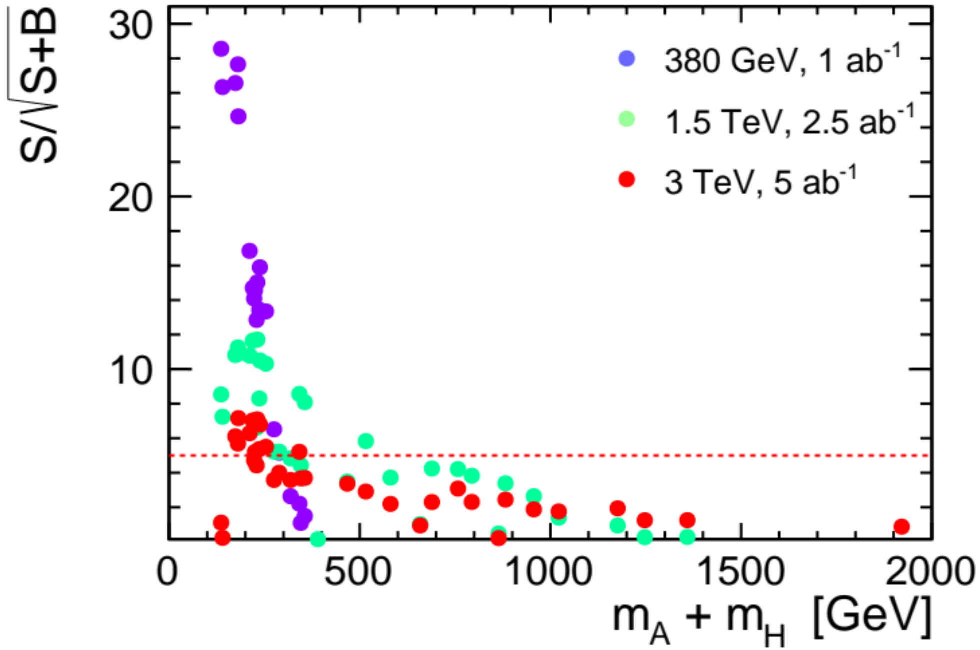


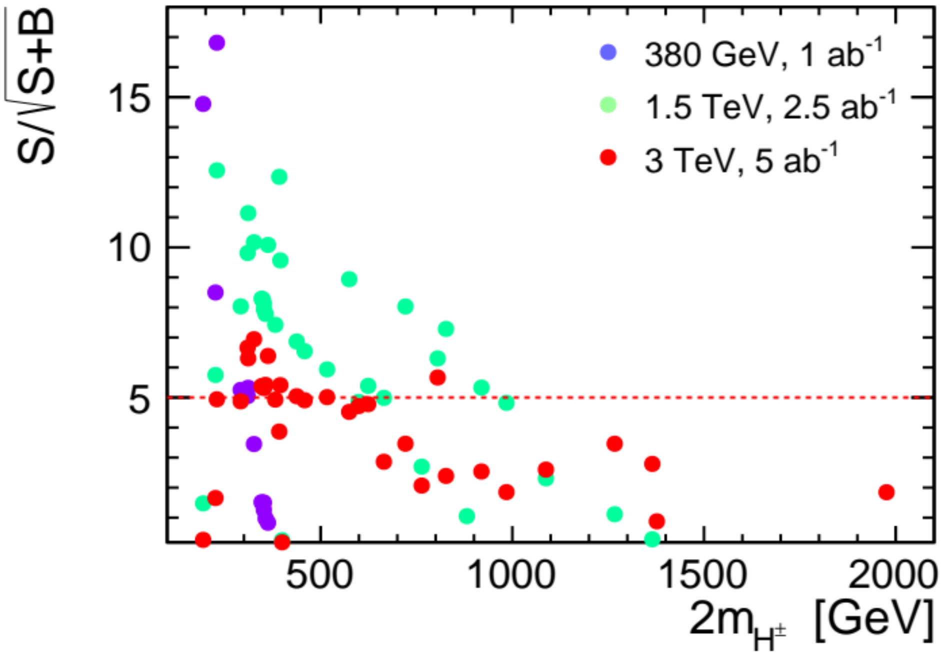


Mass difference affects virtuality of W boson!

Strategy

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

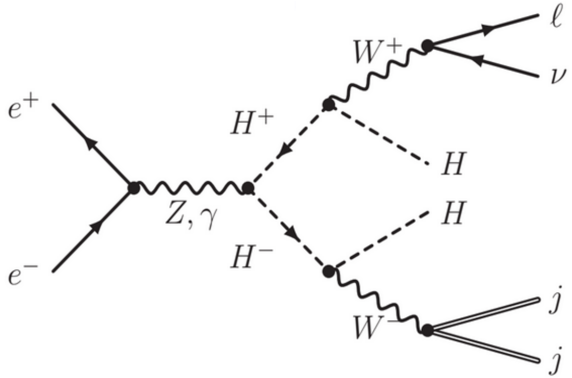




Discovery reach **limited** up to scalar masses ~250 GeV and ~500 GeV at 1.5 TeV and 3 TeV by production cross section

Strategy

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

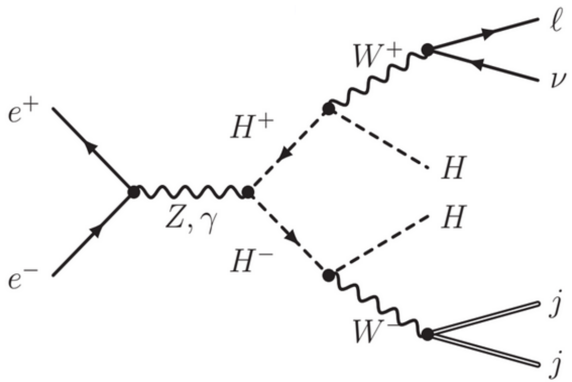


Expected **signature** of the final state:
One lepton: $e^{\pm}$ or $\mu^{\pm}$ and a **pair of jets**

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: $e^{\pm}$ or $\mu^{\pm}$ and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

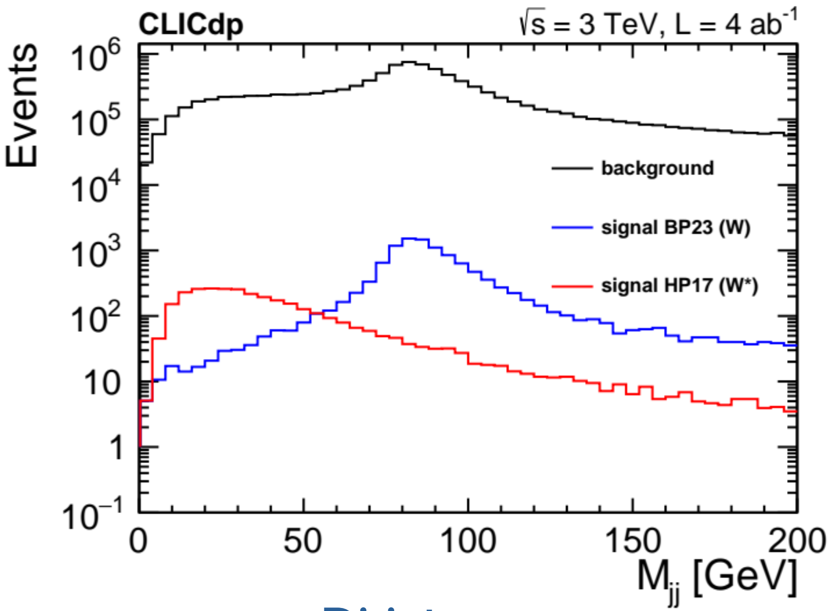
- Use CLIC beam spectra for **1.5 TeV (2000 fb^{-1})** and **3 TeV (4000 fb^{-1})**

→ assumed –80% e$^-$ beam polarisation statistics

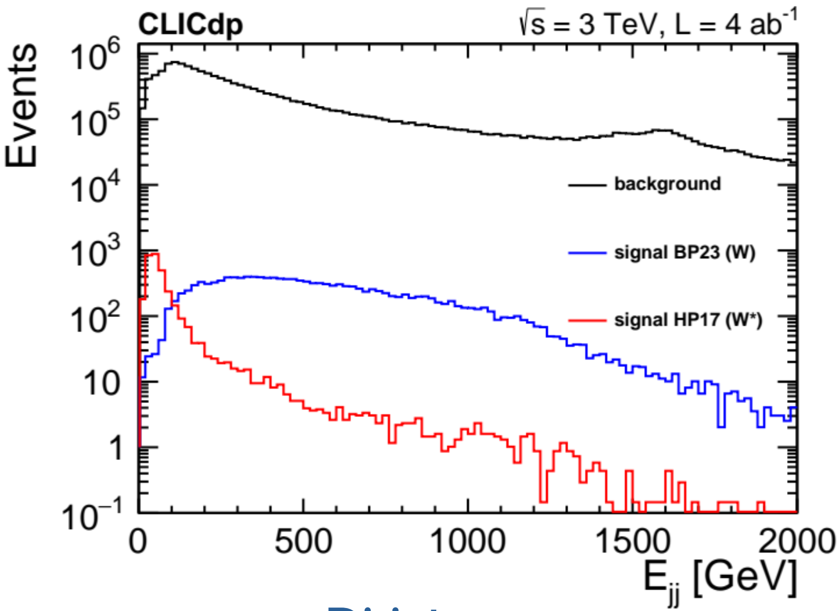
- Generate samples with **Whizard 2.7.0**
- Use **Geant4** CLICdet model to simulate detector response for 5 scenarios

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

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



Di-jet mass



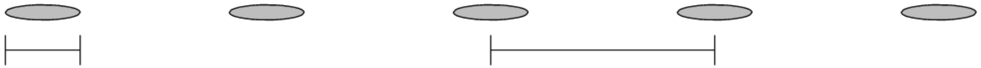
Di-jet energy

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

5 scenarios used in full simulation study selected to cover wide range of mass splittings

Overlay background

LCD-Note-2011-006



CLIC: 44 μm
ILC: 300 μm

CLIC: 0.5 ns, 0.15 m
ILC: 369 ns, 111 m

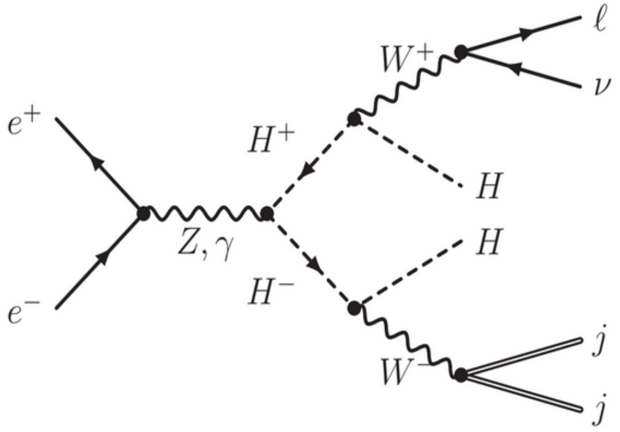
Huge **beam-induced backgrounds** at CLIC

$\gamma\gamma \to \boldsymbol{had.}$ most important (physics, performance)

Included in full sim., mitigated using timing cuts

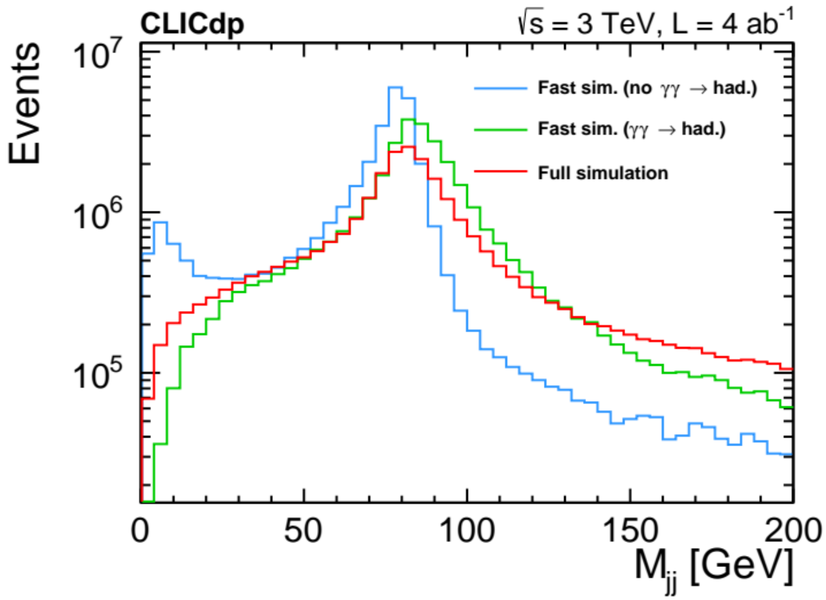
Timing cuts not included in Delphes CLICdet cards!

$\to$ included in **approximate** way with **generator-level cuts**

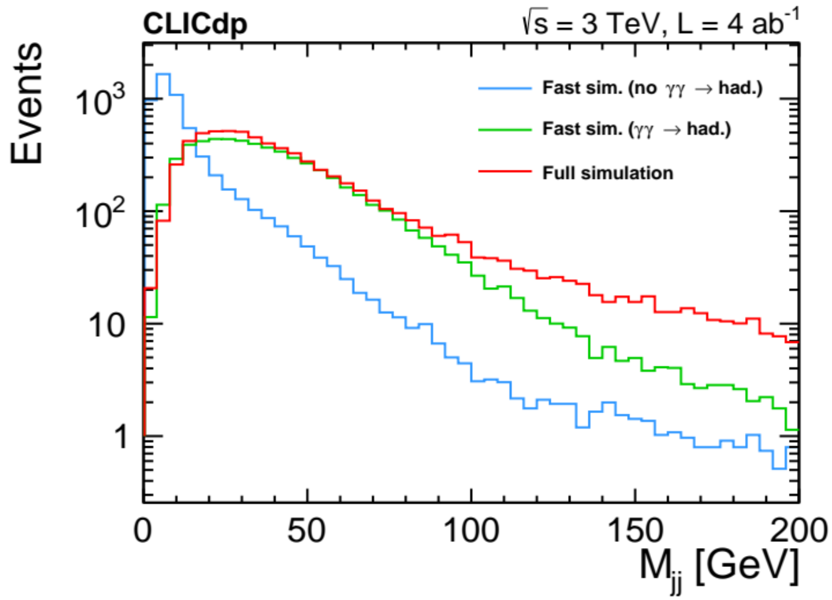


Influence on the reconstruction if W is virtual

$\gamma\gamma \rightarrow$ had. influence



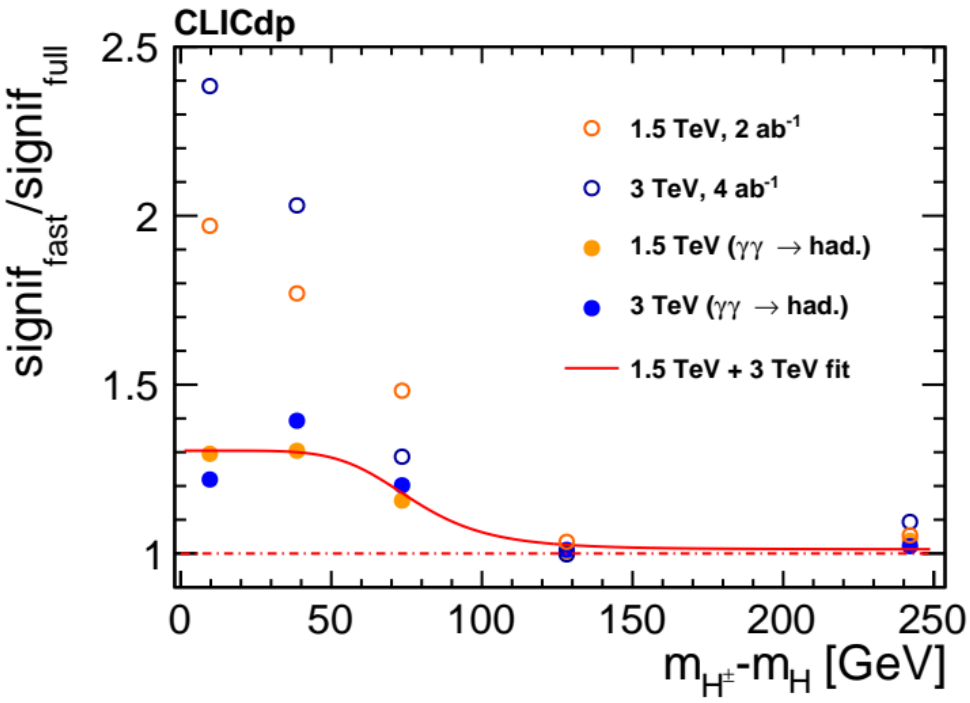
Background ($qql\nu$)



Signal (HP17)

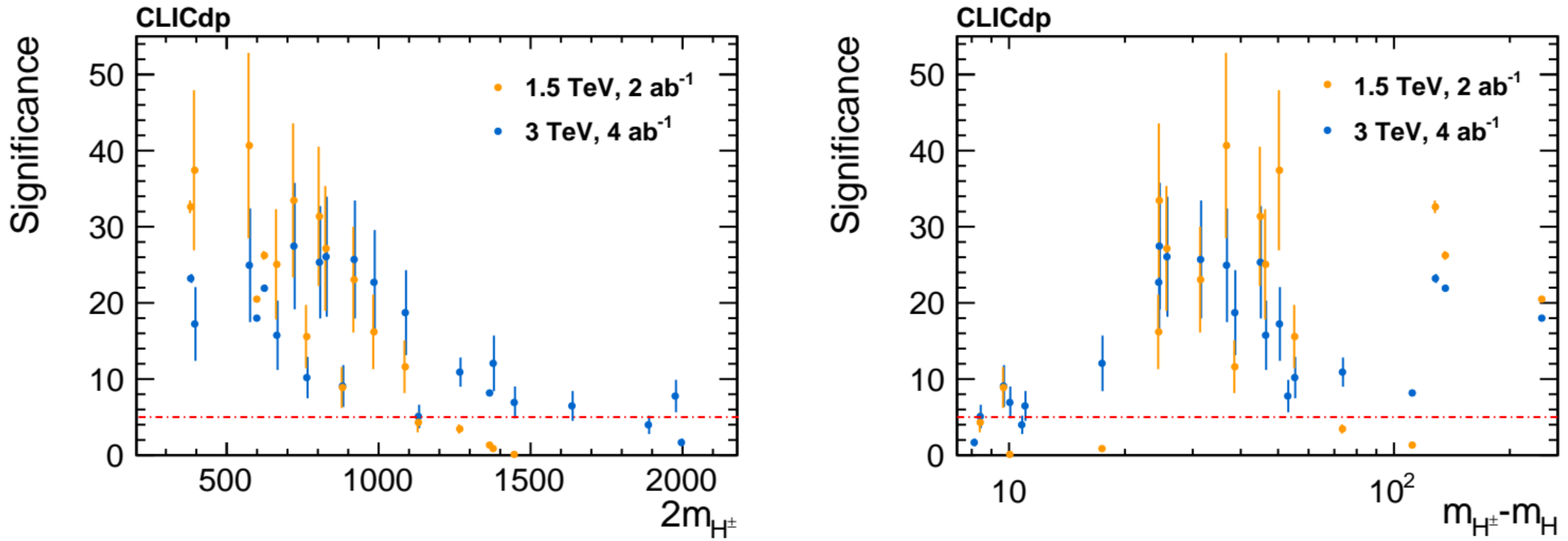
- In **HP17 scenario** $W^{+/-}$ is far off-shell
- **Overlay contribution in Delphes crucial** for reproducing full simulation results

$\gamma\gamma \rightarrow$ had. influence



- Residual difference between **full simulation** and **fast simulation** (with overlay included)
- **Dedicated correction** introduced, depending on the scalar mass difference

Results (Delphes + $\gamma\gamma \rightarrow$ had.)



- Two BDTs trained <u>separately</u> on the scenarios with off-shell $W^{+/-}$ and with on-shell $W^{+/-}$
- Conservative estimate of uncertainty: **100% uncertainty** on the applied correction
- Most scenarios **above 5σ** discovery threshold

Summary

- CLIC sensitivity to **charged IDM scalar** pair-production studied with **full** and **fast simulation**

- Impact of the $\gamma\gamma \rightarrow \mathrm{had.}$ **overlay events** crucial for the analysis. A method to include the overlay in CLICdet model for Delphes was developed

- Good agreement between full and fast simulation results (with overlay). **Dedicated correction applied** to take residual differences into account.

- Most IDM benchmark points, with scalar **masses** up to **1 TeV**, accessible at high-energy CLIC

Thank you!

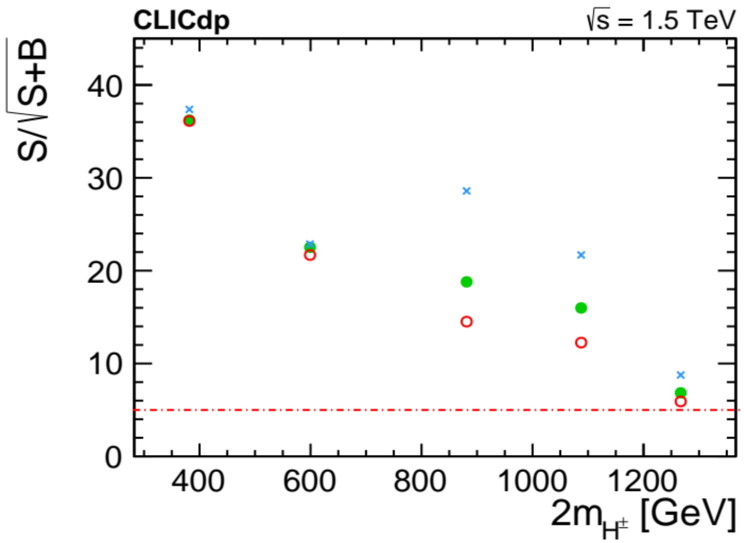
arXiv:2201.07146

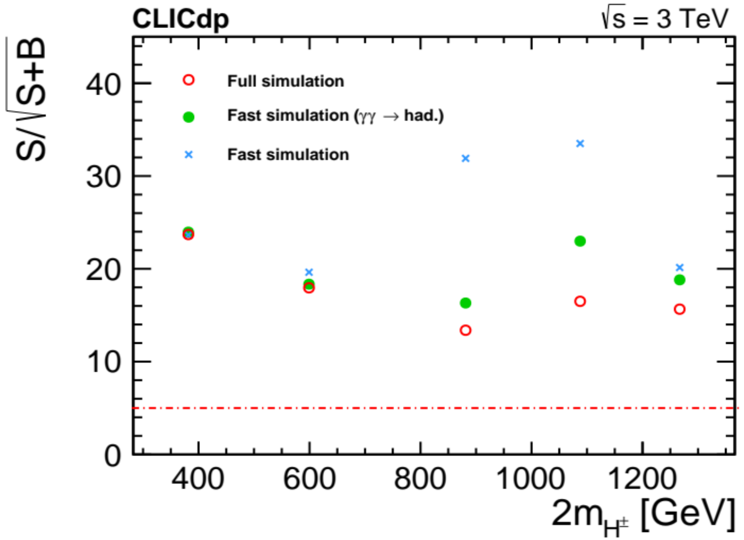
BACKUP

$\gamma\gamma \rightarrow$ had. influence

Cut-based preselection + MVA with BDTs

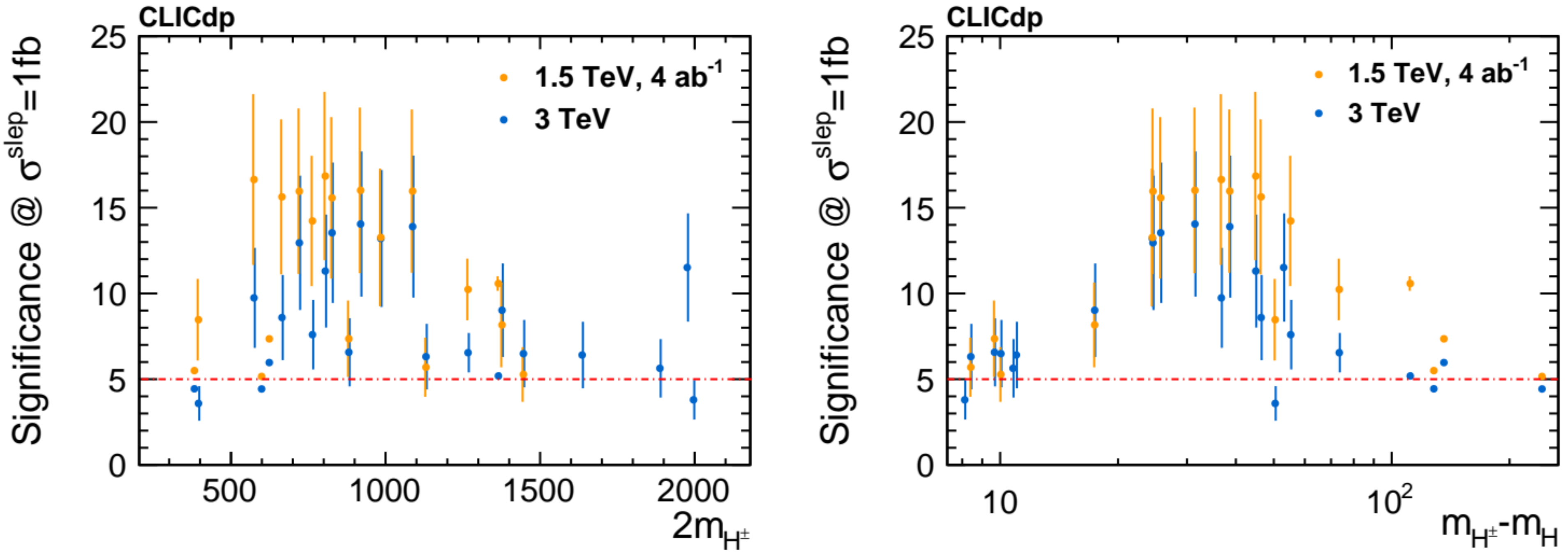
(MVA **optimised** to particular scenario)





- **Agreement** between fast and full simulation **significantly improved** when overlay taken into account in Delphes.
- Systematic differences remain - most likely due to underestimated background contributions.

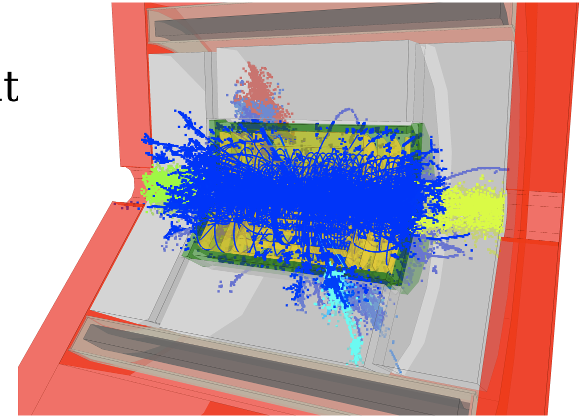
Results (σ^{slep} = 1 fb)



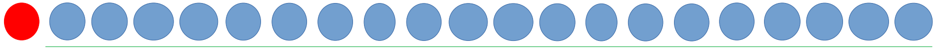
- Final results scaled to 1 fb for all benchmark scenarios, assuming 4 ab^{-1} luminosity at both energy stages
- No visible dependence on the scalar mass or the energy
  → the results depend on the signal cross section, not on the scalar mass

Timing cuts

In full simulation we have BXs from 10 ns after the physical event



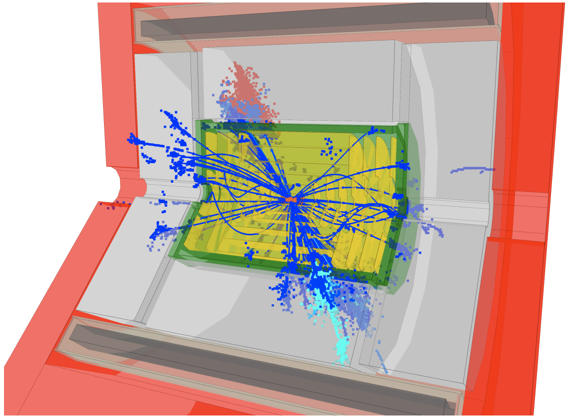
0.5 ns



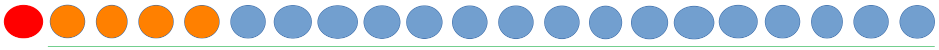
20 bunch crossings ⟷ 10 ns

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



2 ns



20 bunch crossings ⟷ 10 ns

Approximate timing cuts

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

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

1. Take gen-level $\gamma\gamma \rightarrow \mathrm{had.}$ events in batches of N

2. Accept specific particles with a **probability** t/10 ns, where a timing cut t corresponds to number n of BXs

→ e.g. for $t < 2$ ns one can accept n=2 out of N=10

3. Overlay selected events on physical sample