National Science Centre POLAND

FACULTY OF PHYSICS UNIVERSITY OF WARSAW

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Prospects for observing the charged IDM scalars at high energy CLIC

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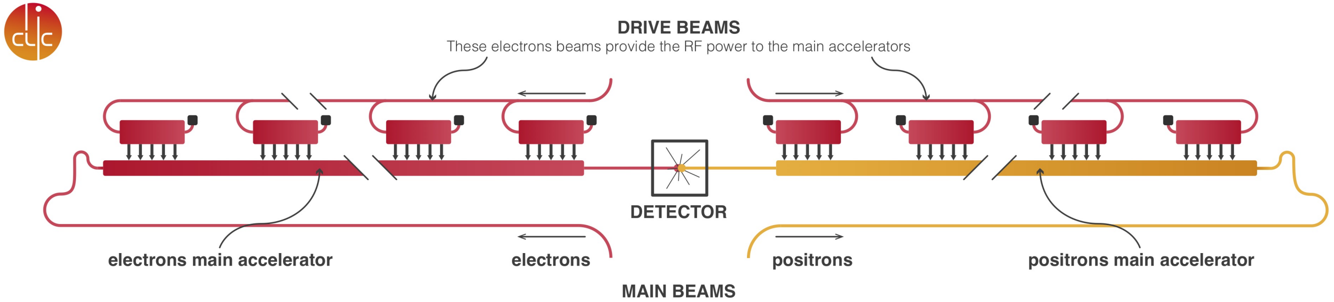
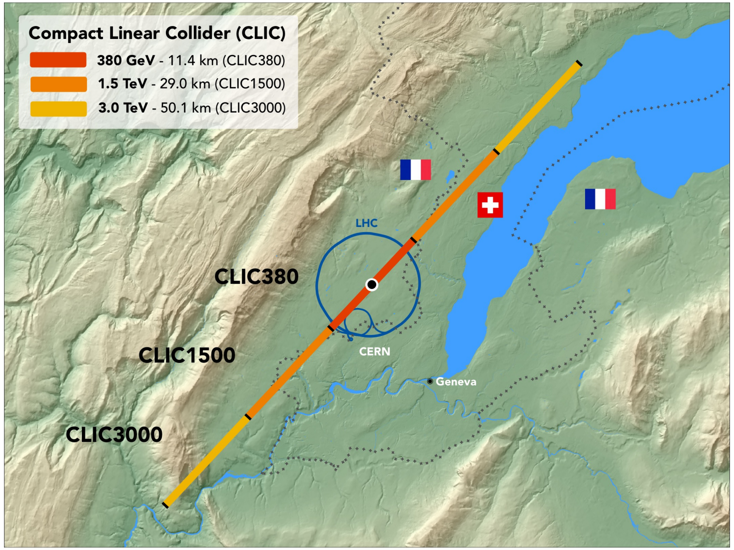
On behalf of the CLICdp Collaboration

Compact Linear Collider

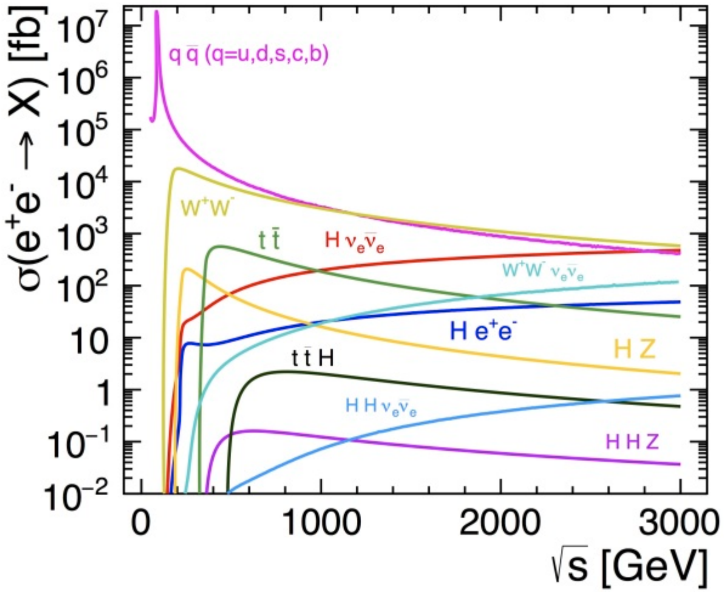


3 TeV



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

Compact Linear Collider



380 GeV stage:

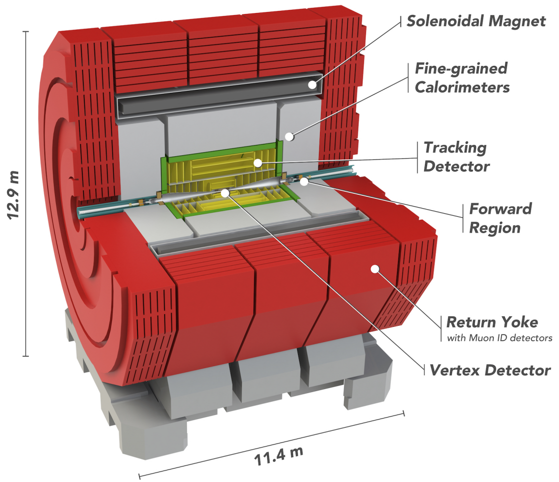
- presicion **Higgs** measurements
- presicion **top** measurements
- **top** threshold scan

1.5 TeV, 3 TeV stages:

- **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

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

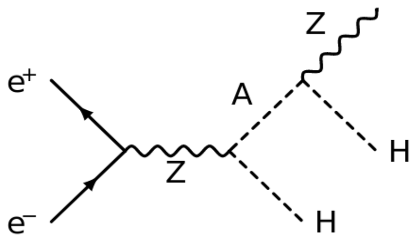
„Higgs boson”: h

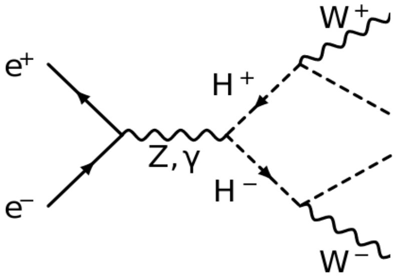
New scalars: $H^{\pm}$, H, A

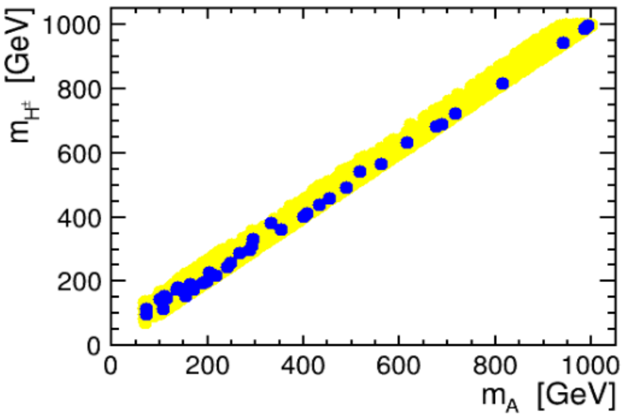
- Additional scalars do not couple to fermions on tree level (Z_2 symmetry)
- The lightest of new particles is stable → **DM candidate**
- **5 free parameters** in the model with existing constraints

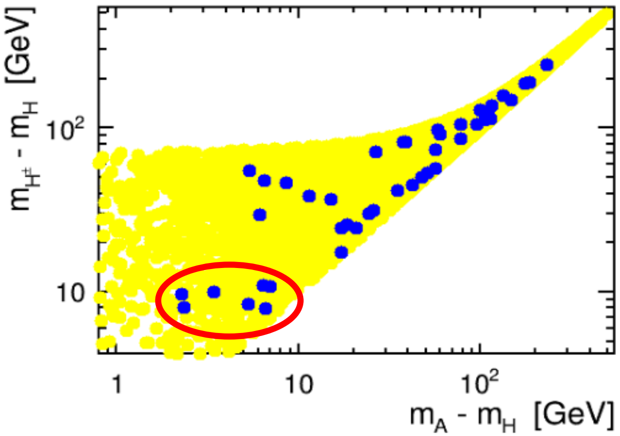
Inert Doublet Model

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





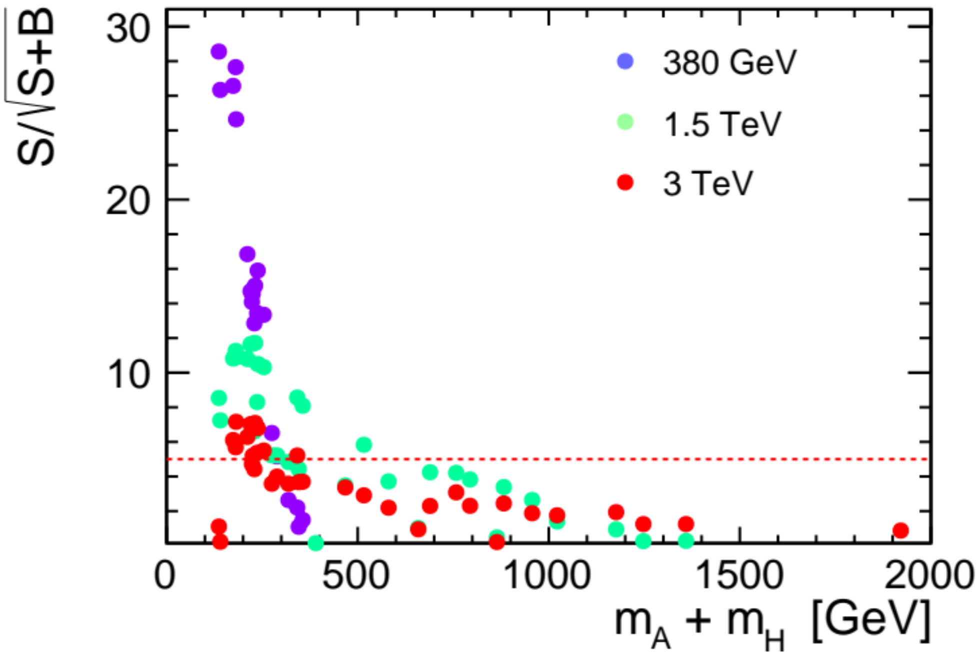


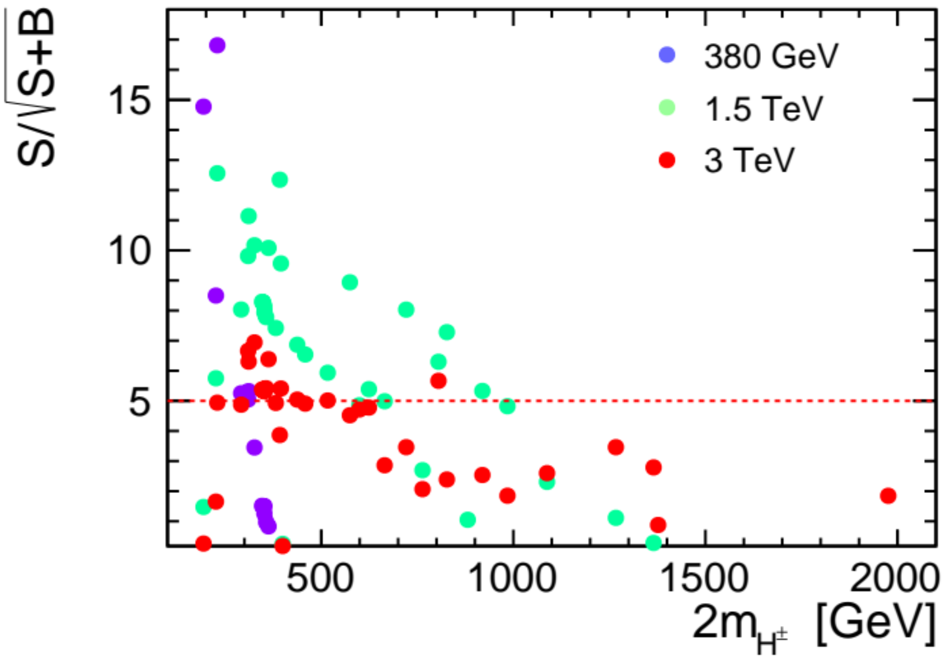


Mass difference affects virtuality of W boson!

Strategy

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

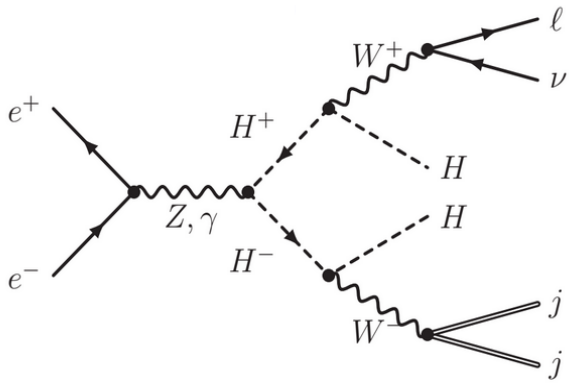




Discovery reach **limited** up to scalar masses ~250 GeV and ~500 GeV at 1.5 TeV and 3 TeV by production cross section

Strategy

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

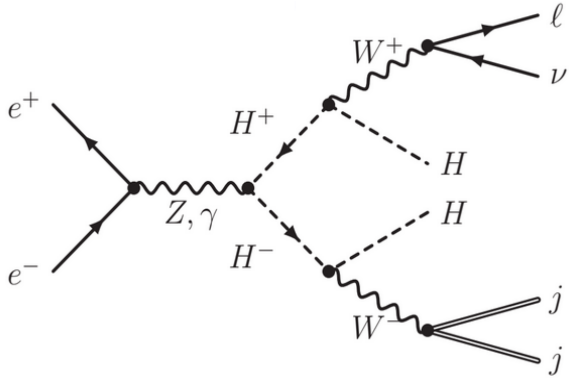


Expected **signature** of the final state:
One lepton: $e^\pm$ or $\mu^\pm$ and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

Strategy

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



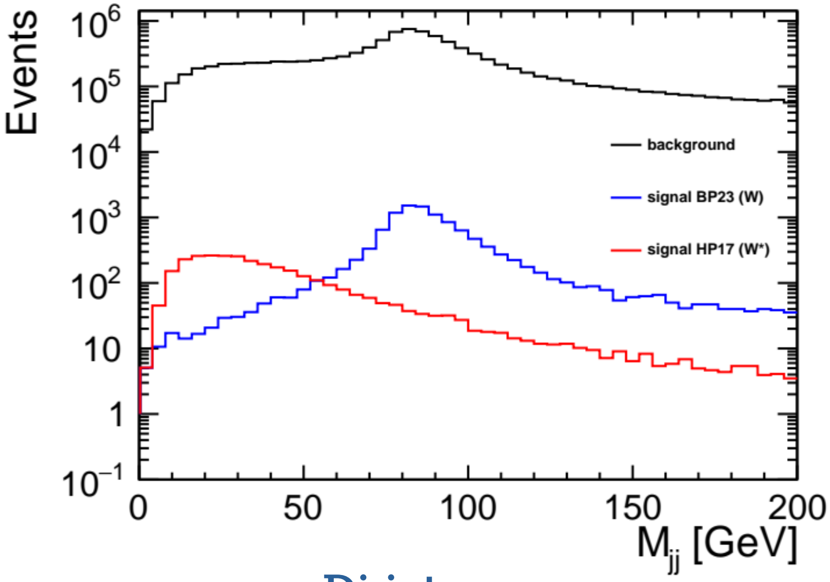
Expected signature of the final state:
One lepton: $e^{\pm}$ or $\mu^{\pm}$ and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

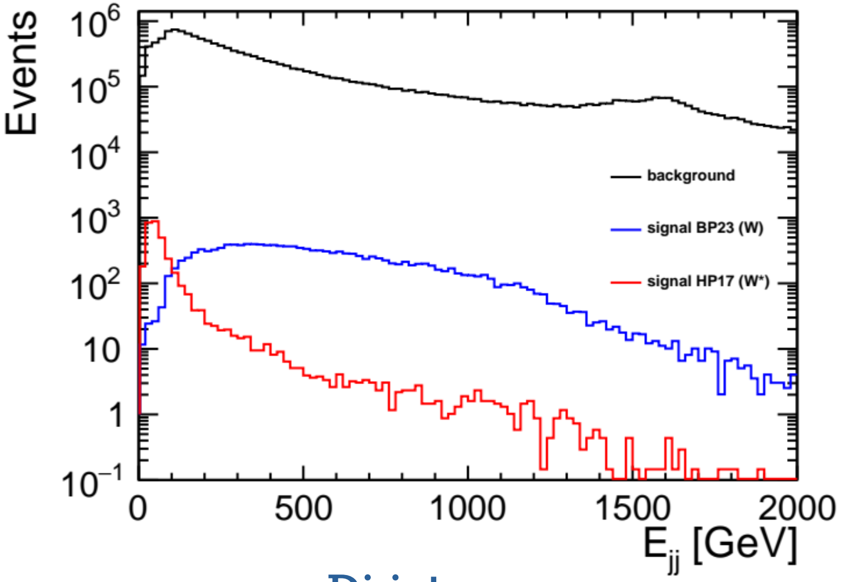
- Use CLIC beam spectra for **1.5 TeV (2000 fb^{-1})** and **3 TeV (4000 fb^{-1})**
- Generate samples with **Whizard 2.7.0**
- Use **Geant4** CLICdet model to simulate detector response for 5 scenarios

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

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



Di-jet mass

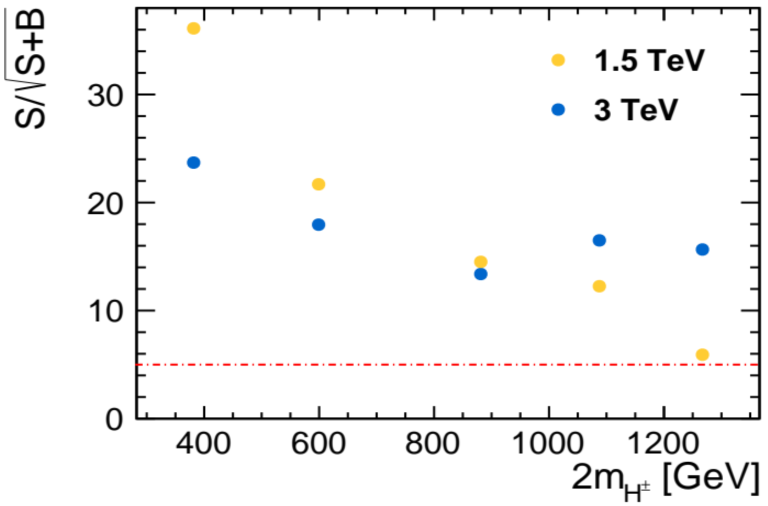


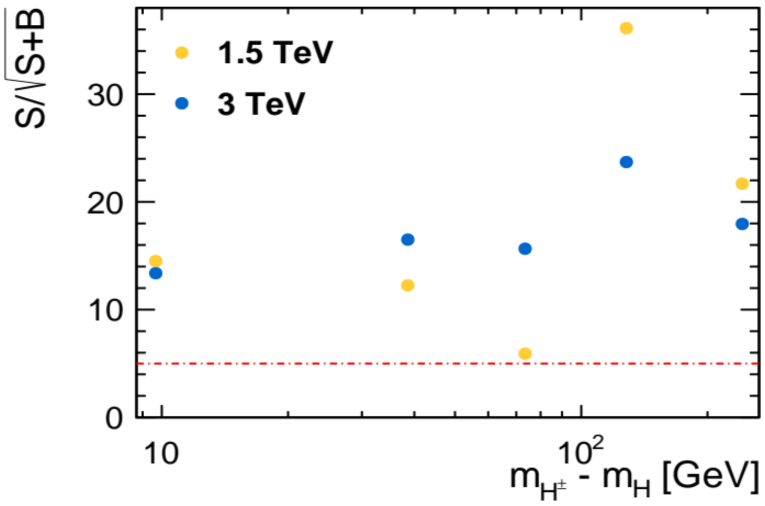
Di-jet energy

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

Full simulation results





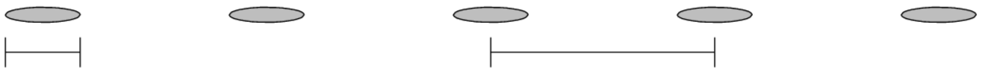
Note: MVA selection optimised for particular scenario!

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

DELPHES fast simulation

Overlay background

LCD-Note-2011-006



CLIC: 44 μm
ILC: 300 μm

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

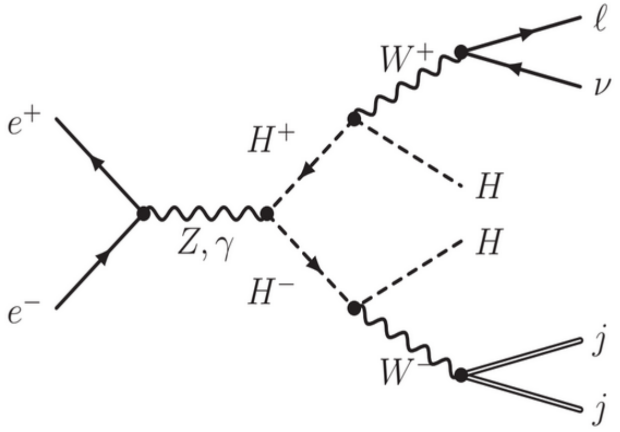
Huge **beam-induced backgrounds** at CLIC

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

Mitigation using timing cuts

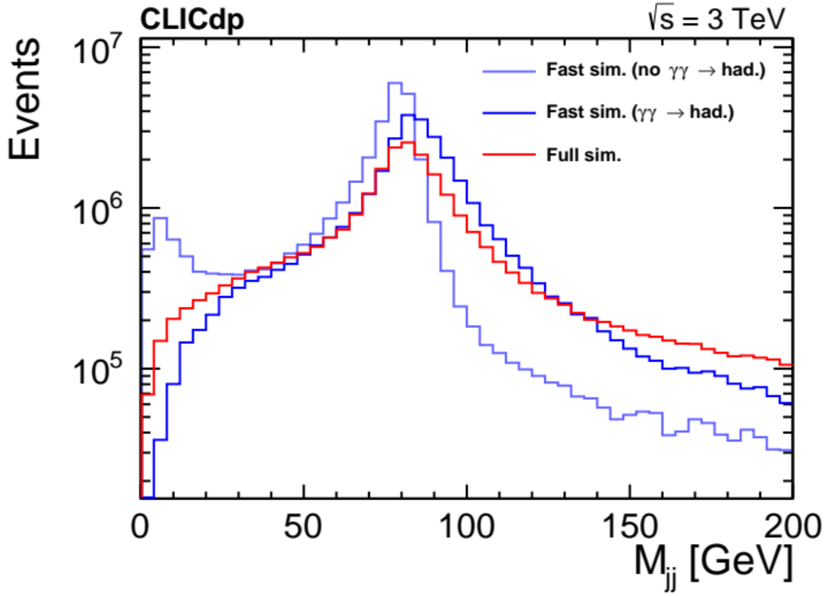
Timing cuts not existing in DELPHES CLICdet cards!

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

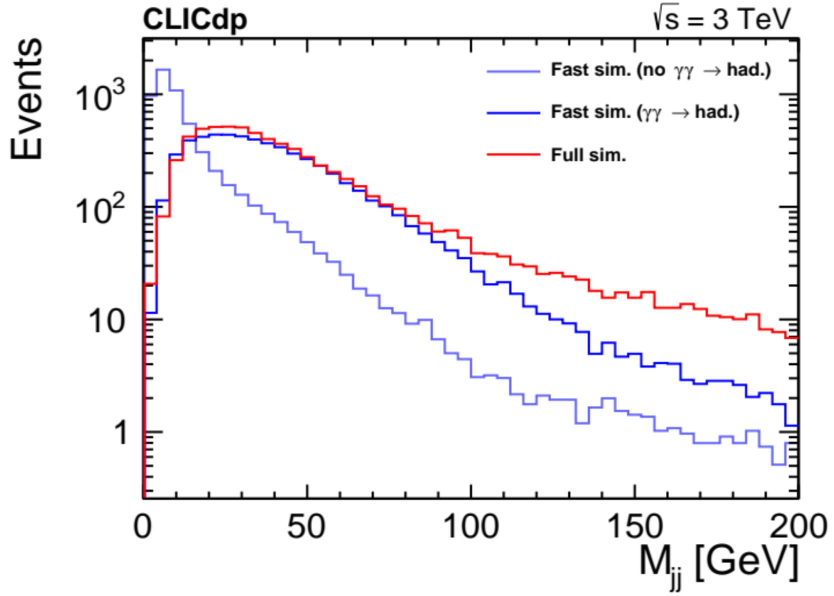


Influence on the reconstruction if W is virtual

$\gamma\gamma \to$ had. influence



Background ($qql\nu$)

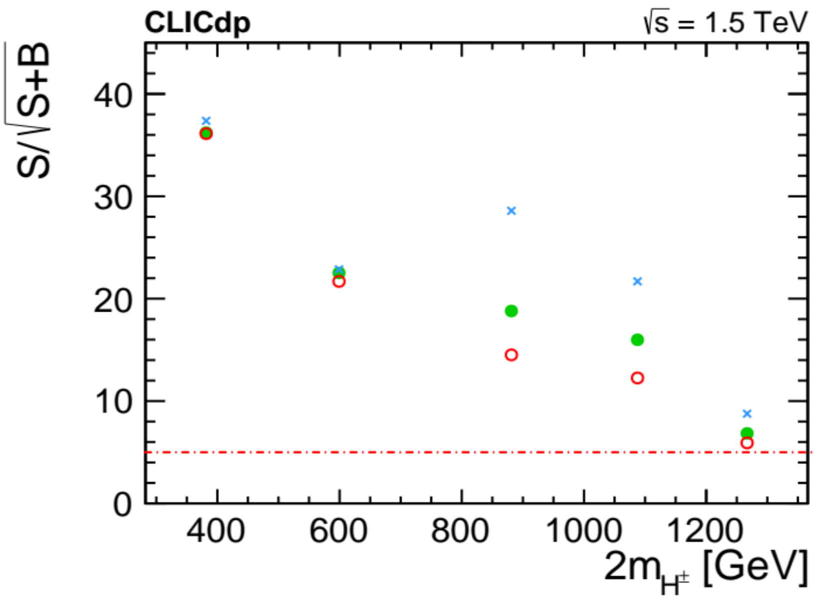


Signal (HP17)

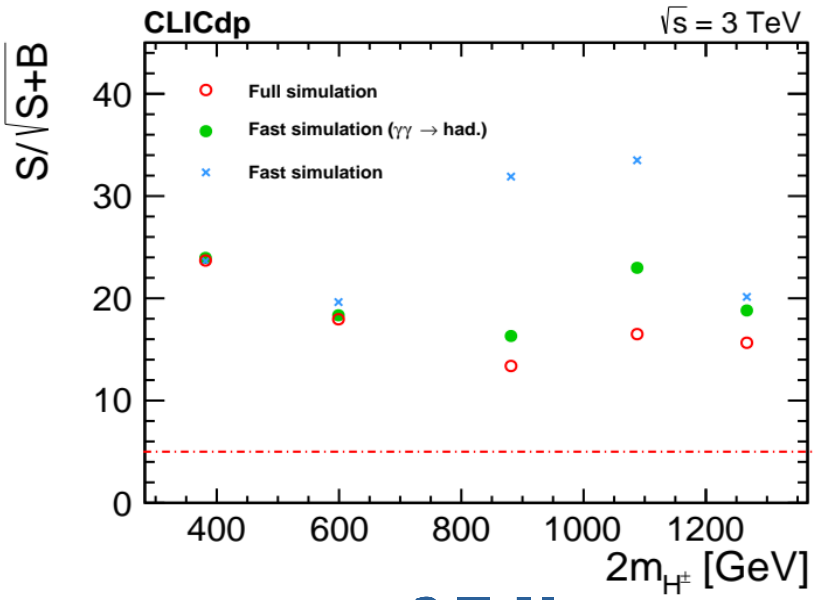
- In **HP17 scenario** $W^{+/-}$ is far off-shell
- **Delphes with overlay** performs much better

$\gamma\gamma \rightarrow$ had. influence

Cut-based preselection + MVA with BDTs



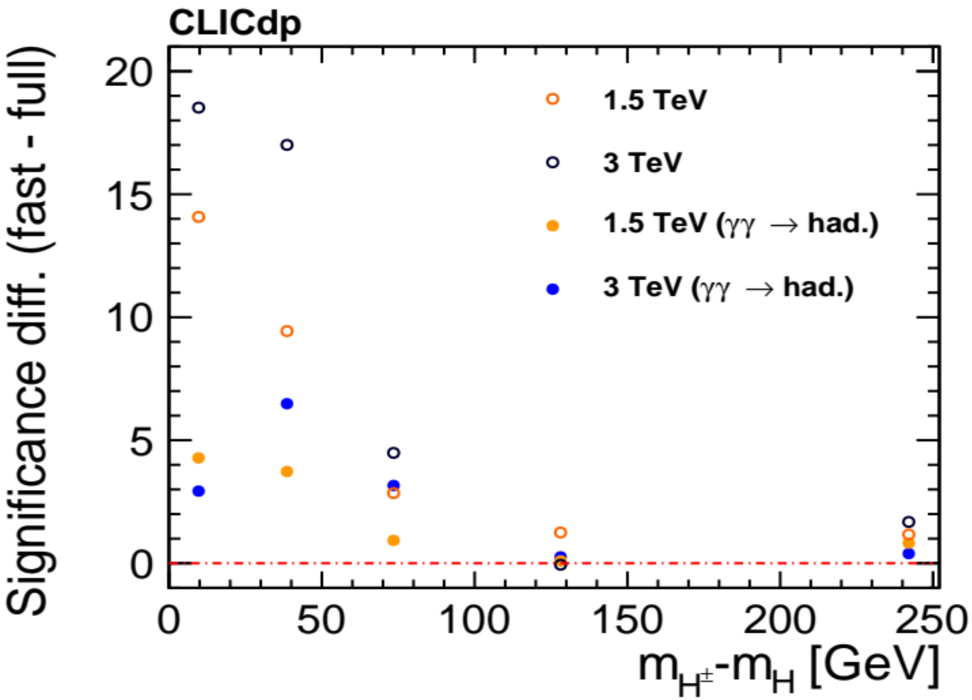
1.5 TeV



3 TeV

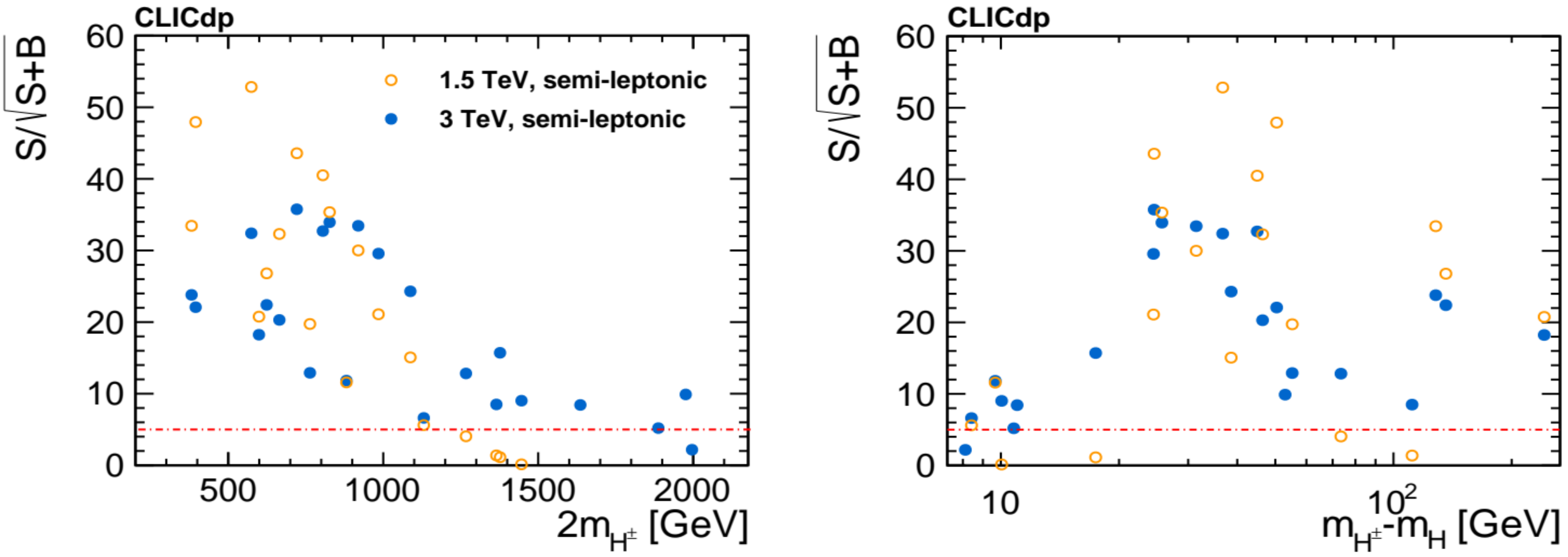
Selection **optimised** to particular scenario

$\gamma\gamma \rightarrow$ had. influence



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

Results



- 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

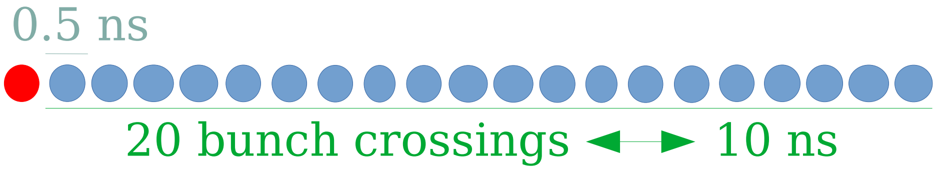
- Prospects for **discovery of charged IDM scalar** pair-production at high energy CLIC stages studied with **full** and **fast simulation**
- Impact of the $\gamma\gamma \to \mathrm{had.}$ **overlay events** crucial for the analysis
- A method to include this background in CLICdet model for Delphes was developed
- Charged IDM scalars with **masses** of up to **1 TeV** can be discovered at CLIC

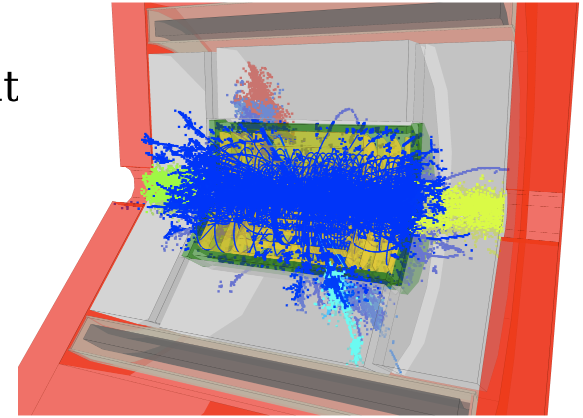
Thank you!

BACKUP

Timing cuts

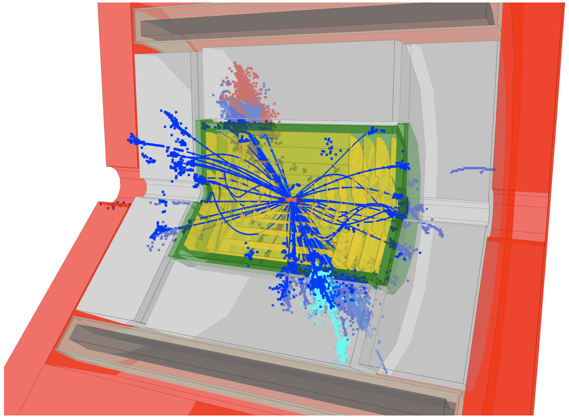
In full simulation we have BXs from 10 ns after the physical event





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

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



Approximate timing cuts

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 $\gamma\gamma \to \mathrm{had.}$ 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