FACULTY OF PHYSICS
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Using Delphes for charged scalar search analysis at CLIC

ECFA Higgs Factories:
1st Topical Meeting on Simulation
2 February 2022

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Inert Doublet Model

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

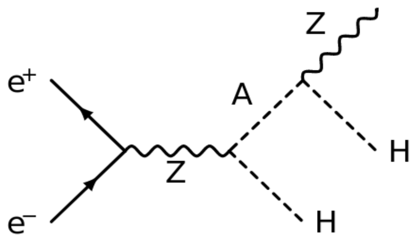
„Higgs boson”: h

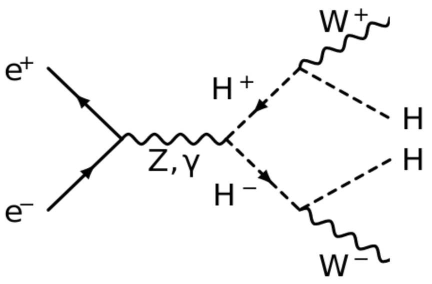
New scalars: $H^{\pm}$, H, A

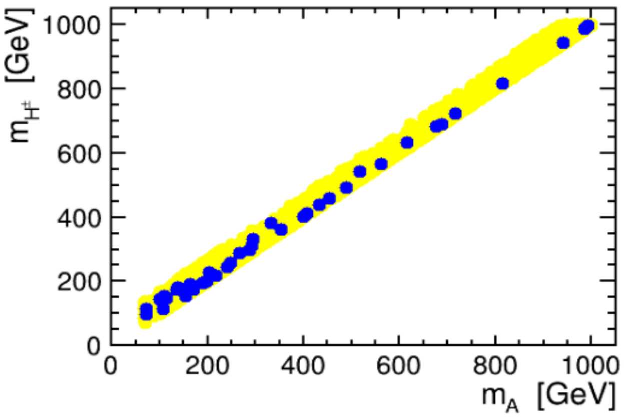
- Additional scalars do not couple to fermions on tree level (Z_2 symmetry)
- The lightest of new particles is stable → **DM candidate**
- **5 free parameters** in the model with existing constraints

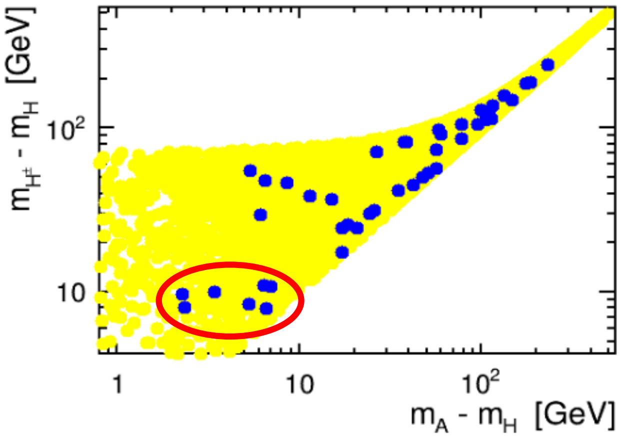
Inert Doublet Model

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





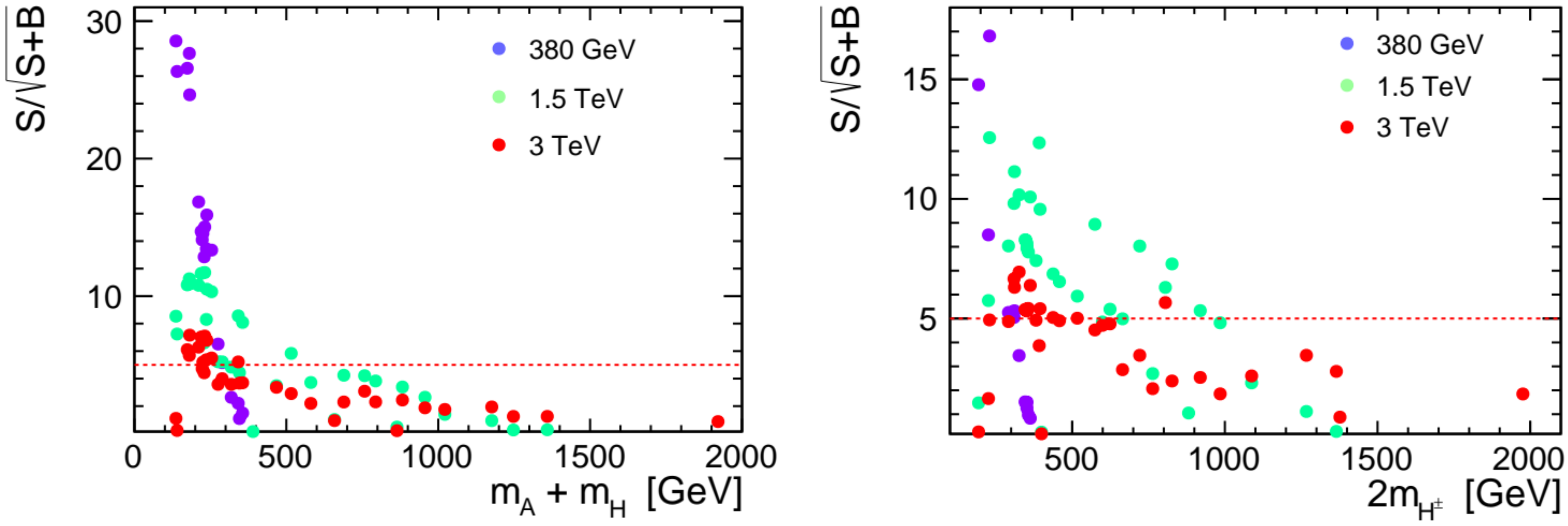




Mass difference affects virtuality of W boson!

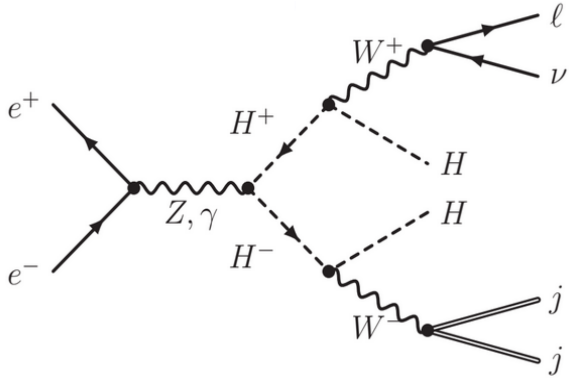
Strategy

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

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

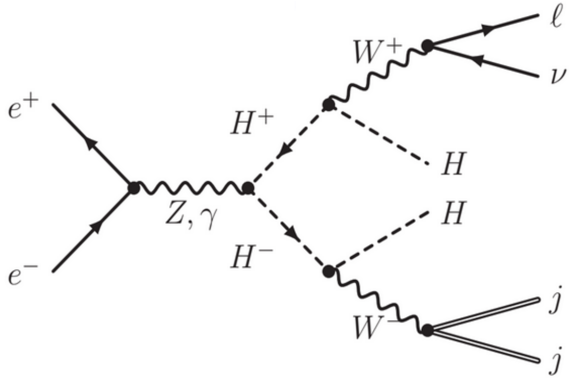


Expected signature of the final state:
One lepton: $e^{\pm}$ or $\mu^{\pm}$ and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

Strategy

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



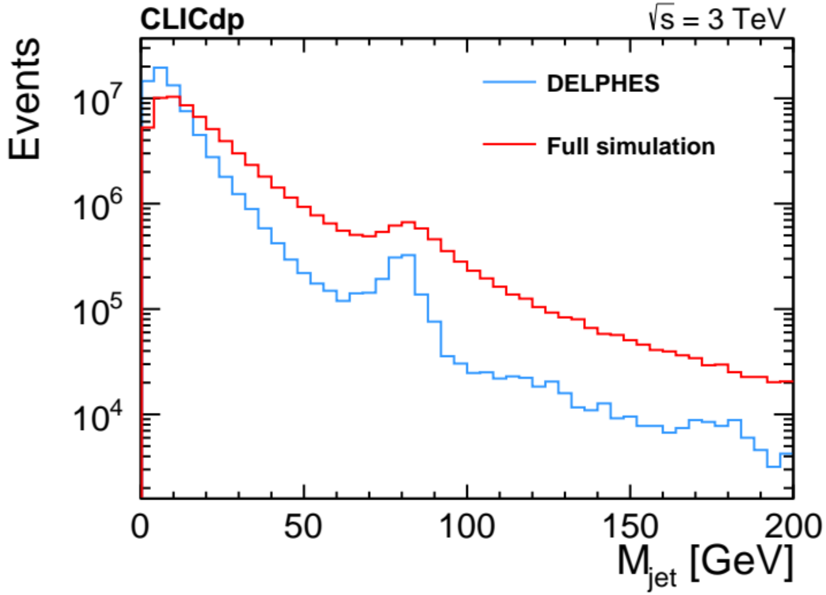
Expected **signature** of the final state:
One lepton: $e^{\pm}$ or $\mu^{\pm}$ and a **pair of jets**

cut-based preselection
+
multivariate analysis (BDTs)

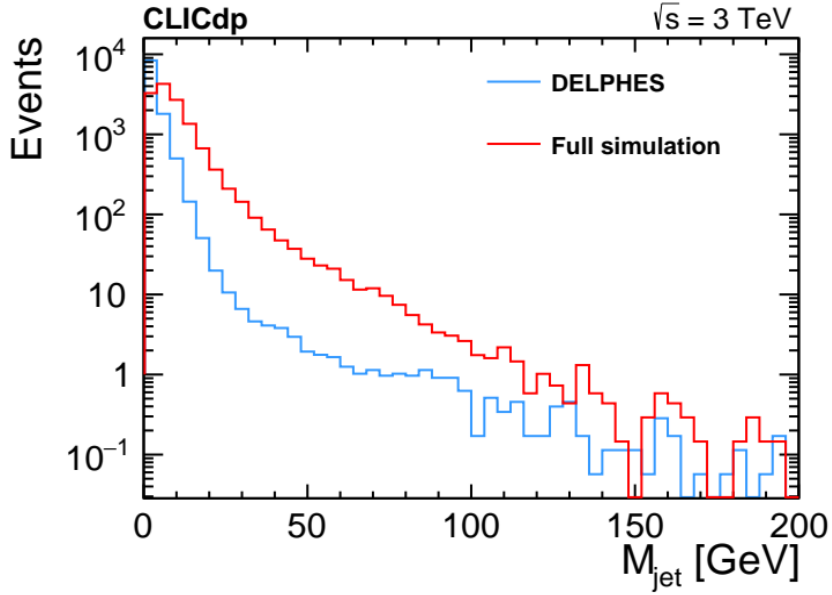
- Use CLIC beam spectra for **1.5 TeV (2000 fb^{-1})** and **3 TeV (4000 fb^{-1})**
- Generate samples with **Whizard 2.7.0**
- Use **Geant4** CLICdet model to simulate detector response for 5 scenarios

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

Delphes vs. Full simulation



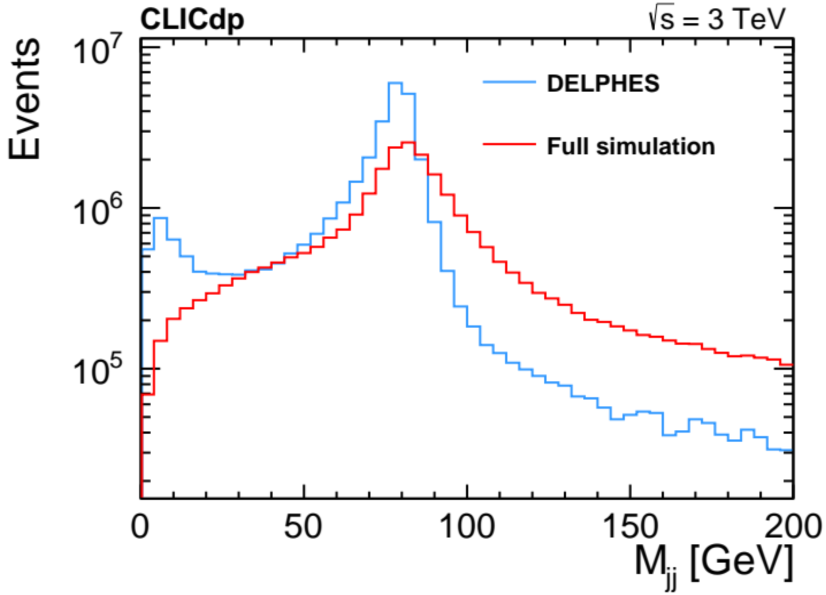
Background (qqlν)



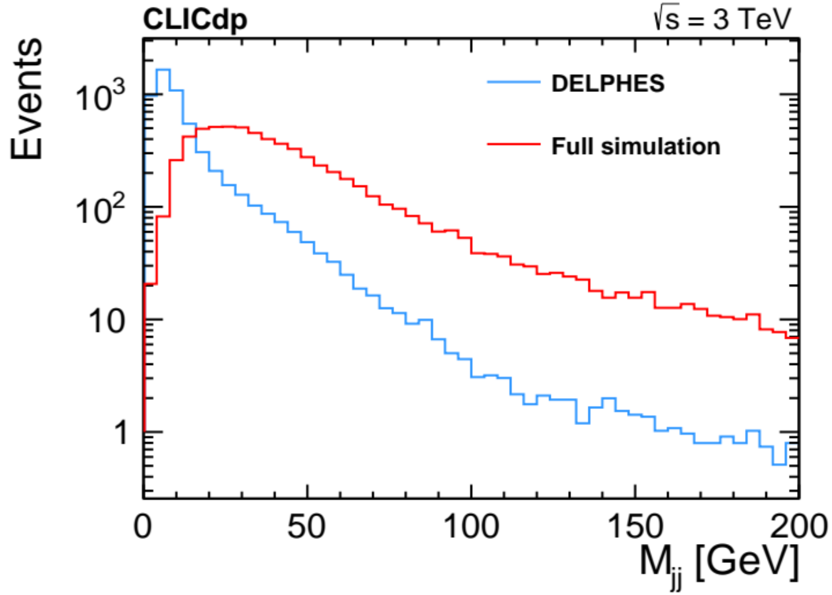
Signal (HP17)

Huge difference between Delphes and full simulation

Delphes vs. Full simulation



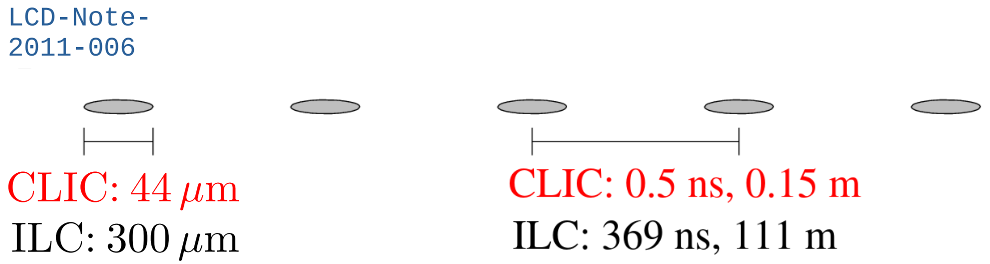
Background (qqlν)



Signal (HP17)

Very high disagreement for the dijet mass

Overlay events



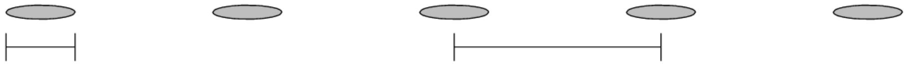
- Huge beam-induced background at CLIC

- $\gamma\gamma \to$ had. important for detector performance

- Timing cuts on PFOs to mitigate this backg.

Overlay events

LCD-Note-2011-006



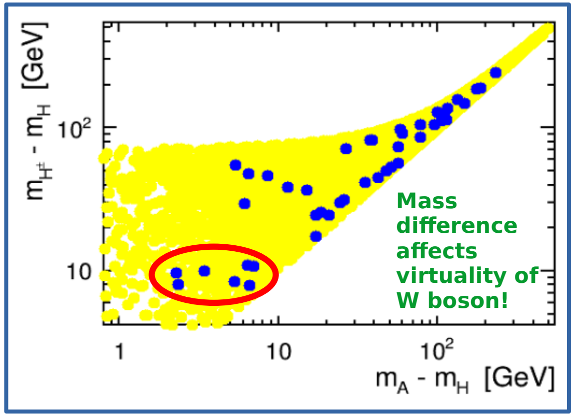
CLIC: 44 μm
ILC: 300 μm

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

– Huge beam-induced background at CLIC

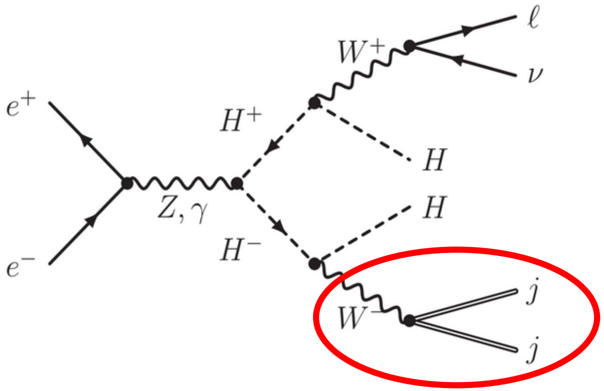
– $\gamma\gamma \to$ had. important for detector performance

– Timing cuts on PFOs to mitigate this backg.



Virtual W → low **p, E** of decay products

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



Overlay events in Delphes

Adding pileup is possible in Delphes:

PileUp Merger module + binary **.pileup file**

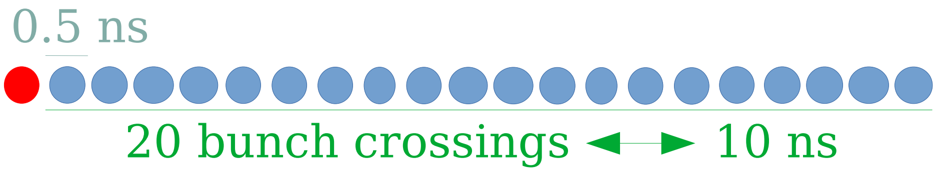
DELPHES
fast simulation

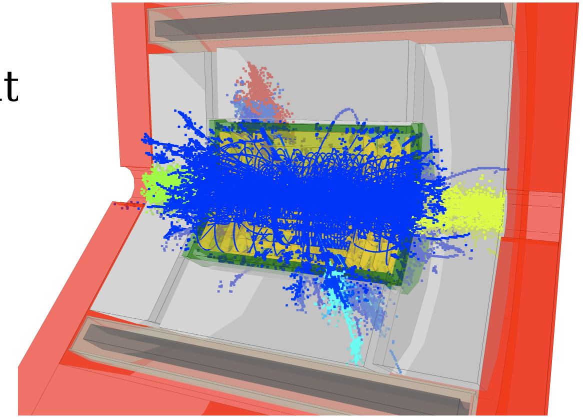
Not possible to apply timing cuts in Delphes model for CLIC

We use effective selection on the generator level

Timing cuts

In full simulation we have BXs from <u>10 ns</u> after the physical event





Timing cuts

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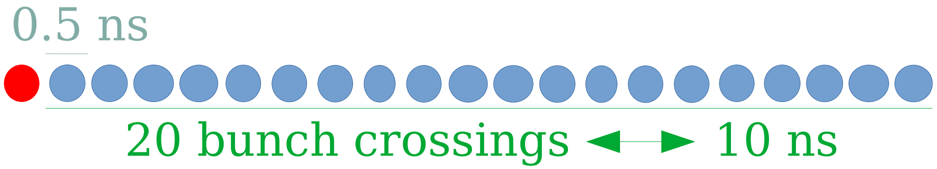
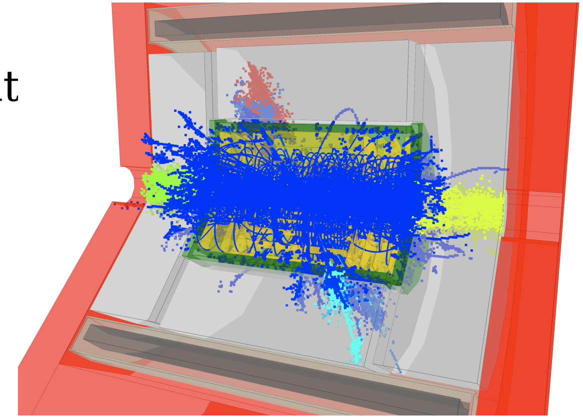
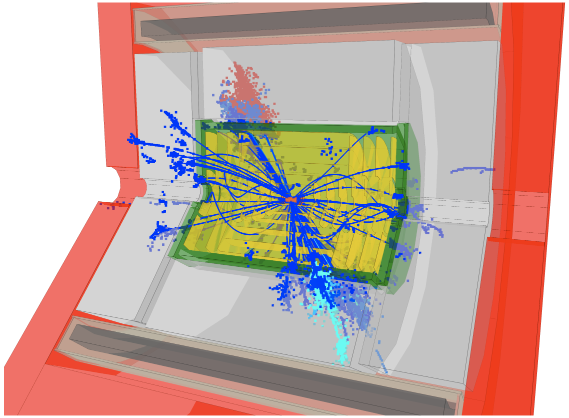




Additional timing cuts on PFOs to reduce $\gamma\gamma \rightarrow \text{had. backg.}$

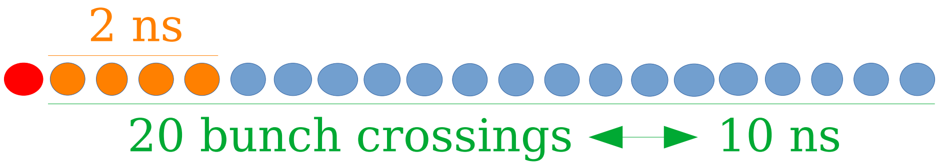
Example: Accept **tracks** with $p_T < 1$ GeV with $t < 2$ ns



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



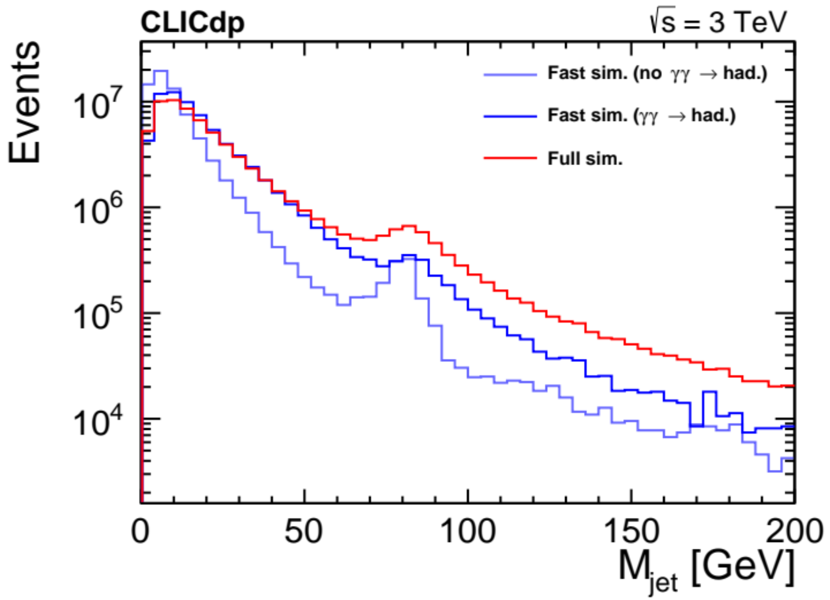
1. Take gen-level $\gamma\gamma \to \mathrm{had.}$ events in batches of N

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

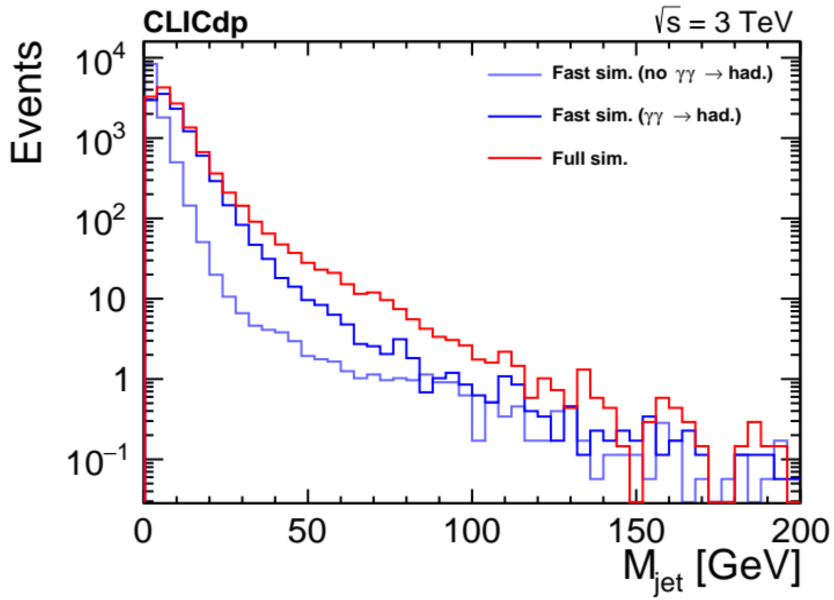
→ e.g. for $t < 2$ ns one can accept n=2 out of N=10

3. Overlay selected events on physical sample

$\gamma\gamma \to$ had. influence



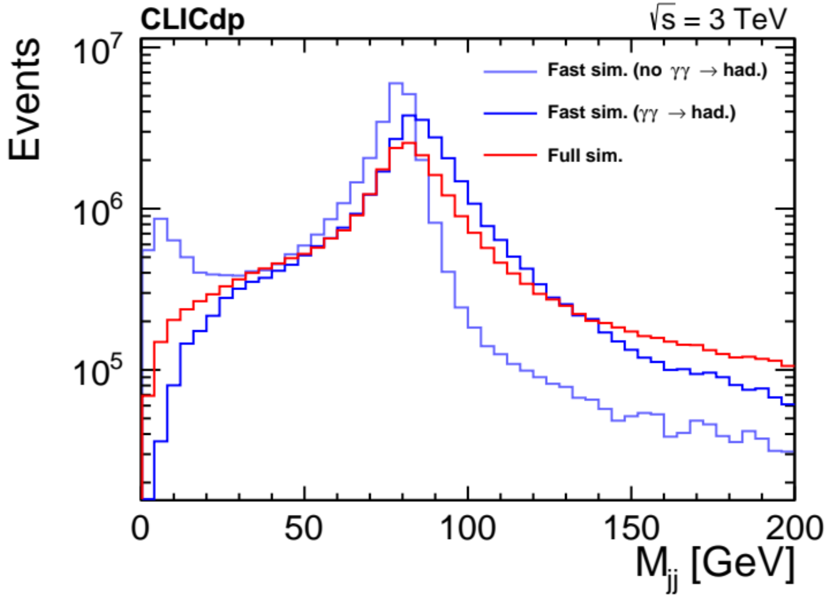
Background ($qql\nu$)



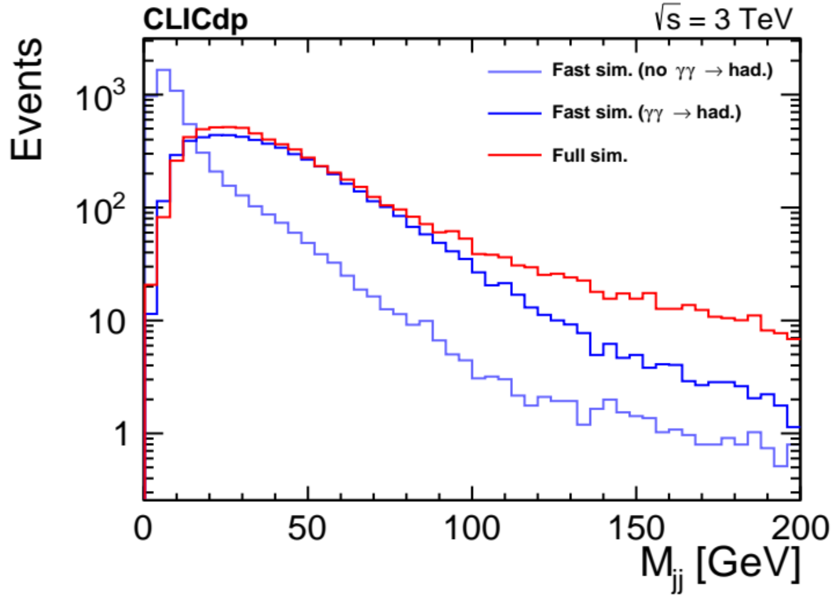
Signal (HP17)

Delphes with overlay similar to the full simulation!

$\gamma\gamma \rightarrow$ had. influence



Background ($qql\nu$)

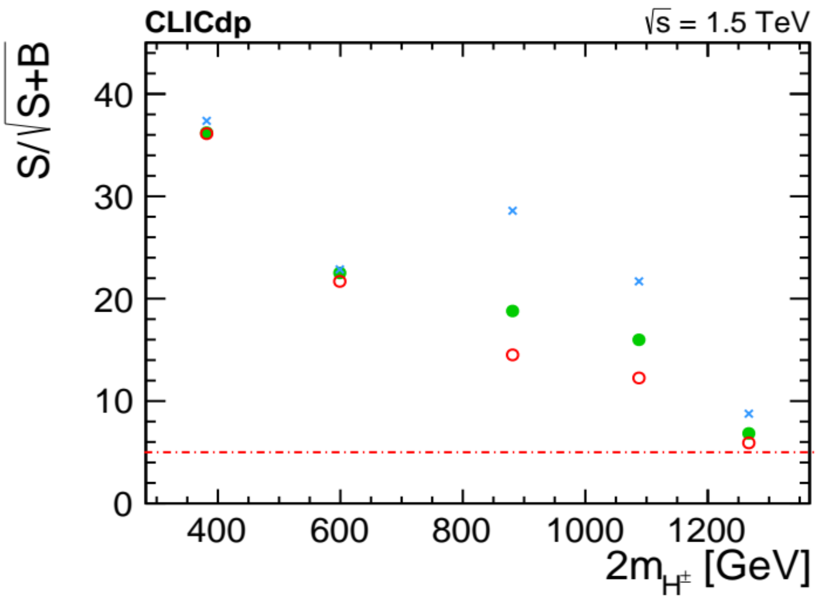


Signal (HP17)

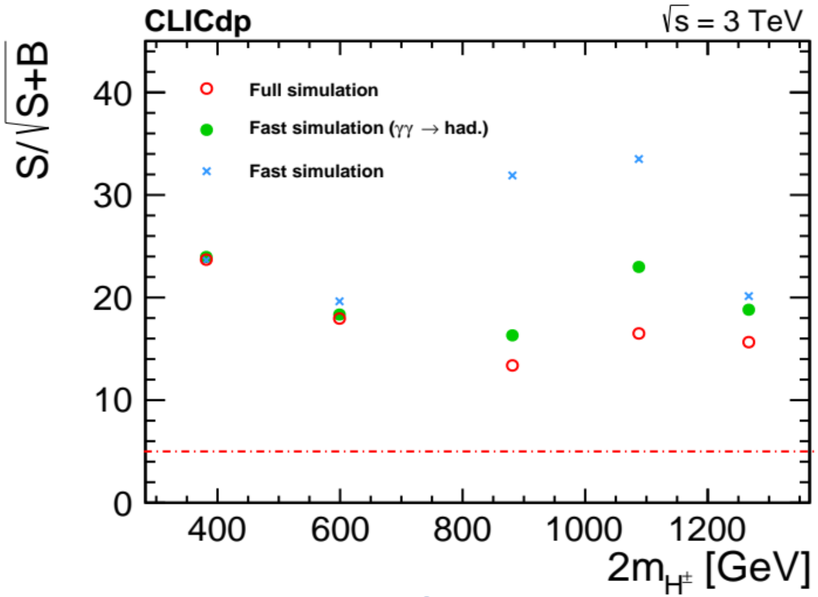
- In **HP17 scenario** $W^{+/-}$ is far off-shell
- **Delphes with overlay** performs much better

γγ → had. influence

Cut-based preselection + MVA with BDTs



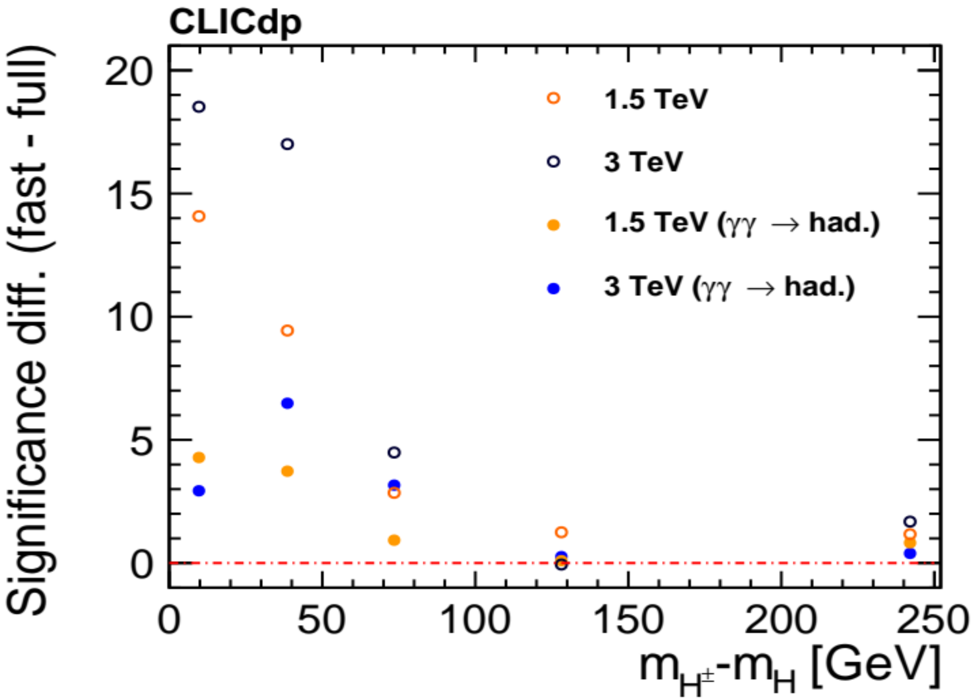
1.5 TeV



3 TeV

Selection **optimised** to particular scenario

$\gamma\gamma \rightarrow$ had. influence



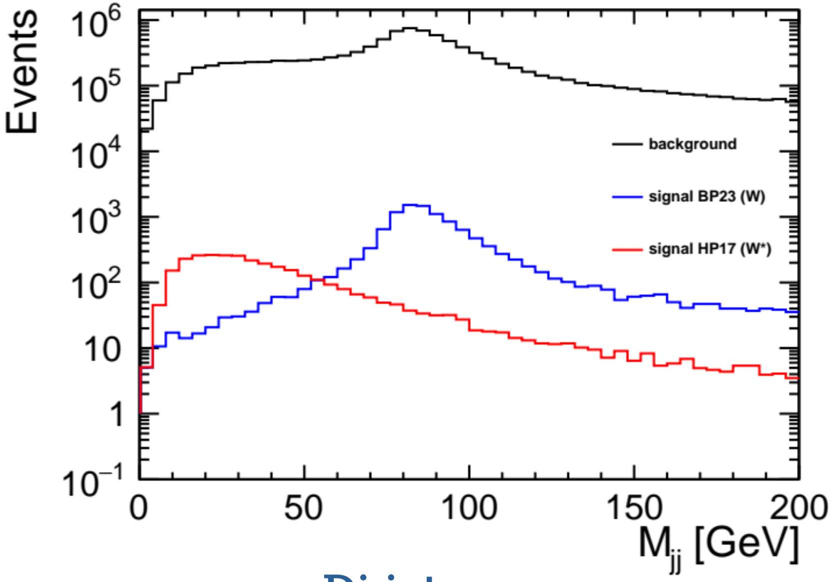
- Delphes with overlay much closer to the full simulation
- Scenarios with low mass difference are most influenced by overlay

Summary

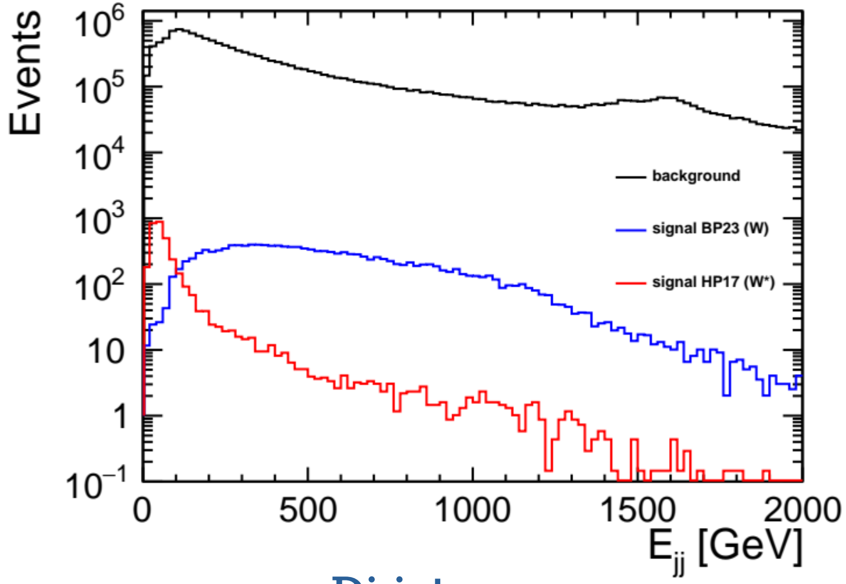
- Prospects for **discovery of charged IDM scalar** pair-production at high energy CLIC stages studied with **full** and **fast simulation**
- Impact of the $\gamma\gamma \to \mathrm{had.}$ **overlay events** crucial for the analysis
- A method to include this background in CLICdet model for Delphes was developed
- The approximate overlay modelling leads to **much more reliable predictions**

Thank you!

BACKUP



Di-jet mass

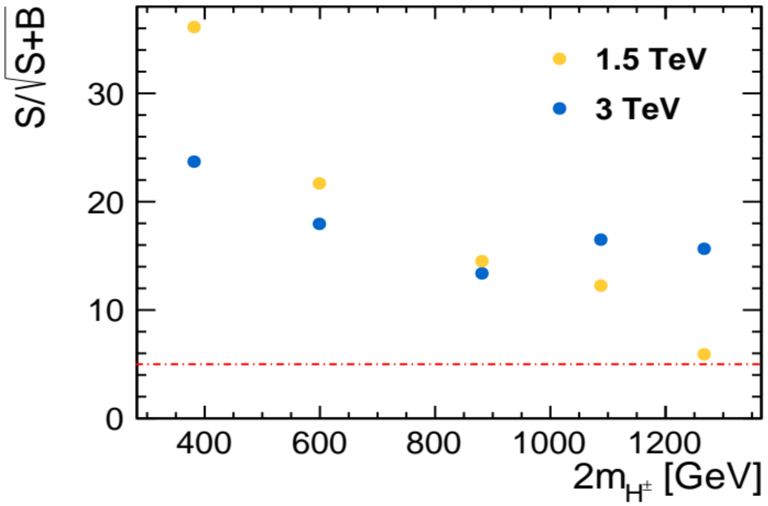


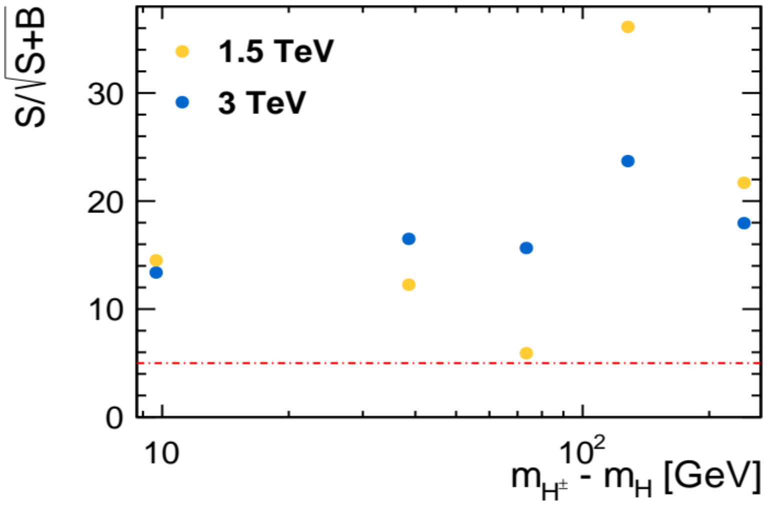
Di-jet energy

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



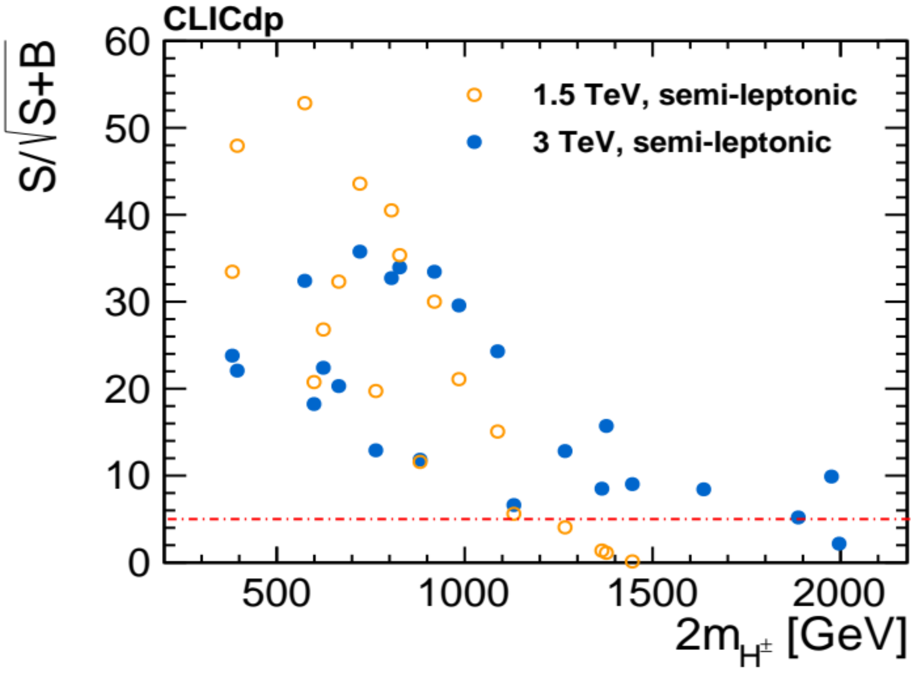


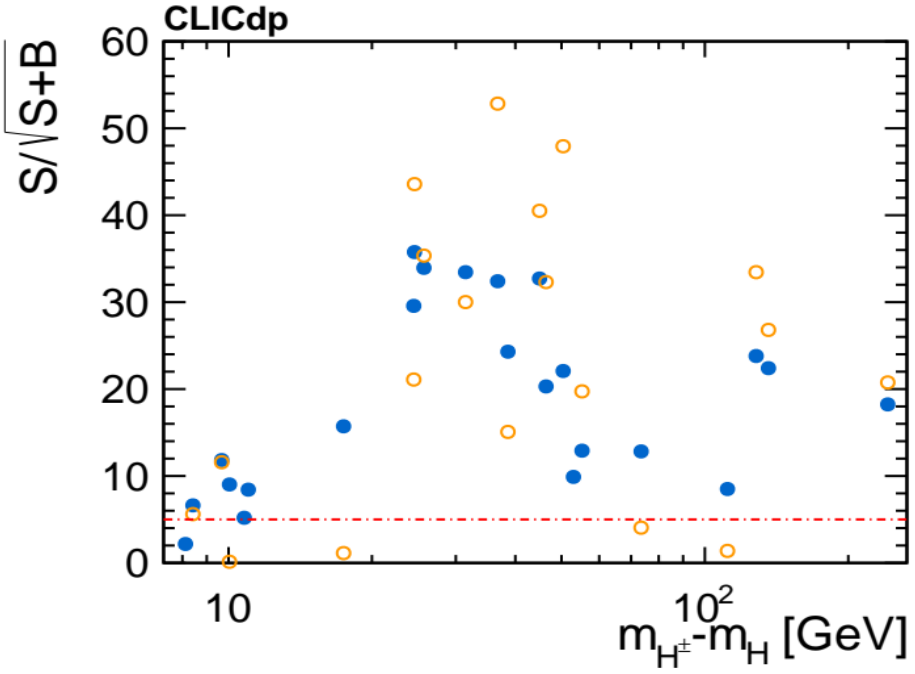
Note: MVA selection optimised for particular scenario!

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

DELPHES
fast simulation

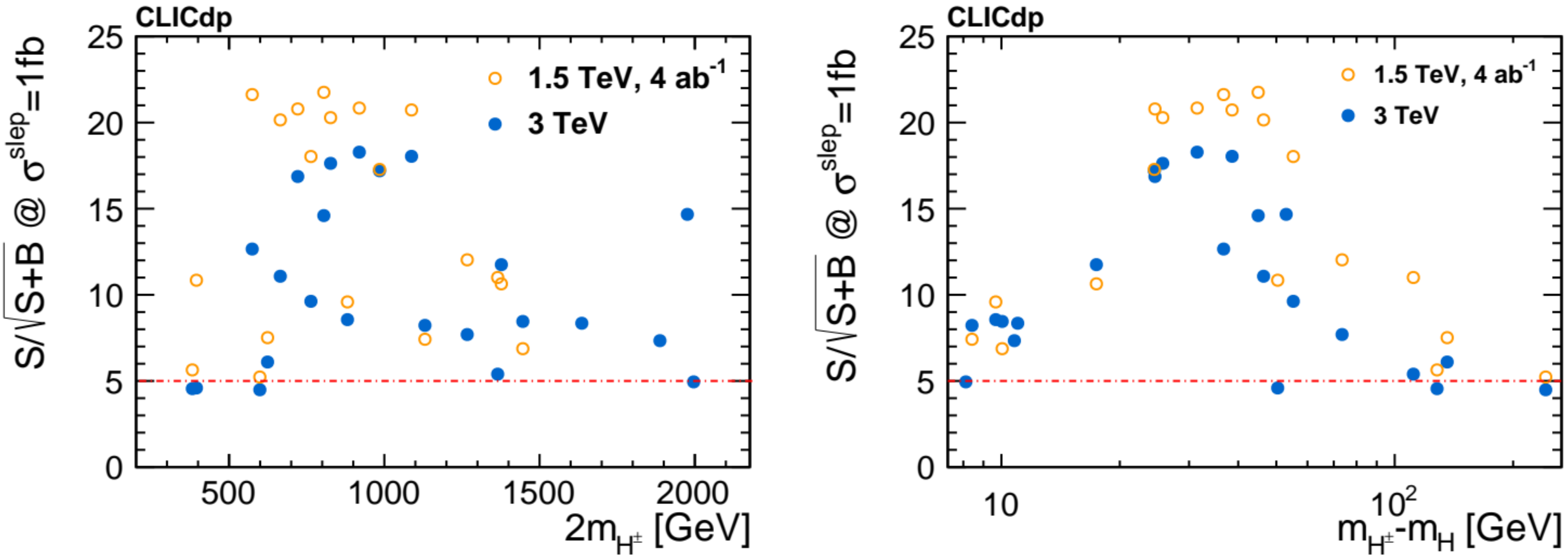
Results





- 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

Results (rescaled)



- 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