



Initial look at 2HDM+a scalar production at CLIC

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Introduction



2HDM+a

Simplified model: two Higgs doublets (h, H, A, H^\pm)
+ scalar mediator (a) + fermion DM (χ)

Proposed for studies at LHC, but interesting signatures also expected for e^+e^-

Masses below TeV scale still not excluded by LHC...

[1] M.Bauer, U.Haisch, F.Kahlhoefer, *Simplified dark matter models with two Higgs doublets: I. Pseudoscalar mediators*, JHEP (2017) 05, arXiv:1701.07427.

[2] T.Abe et al. (LHC Dark Matter Working Group), *Next-generation spin-0 dark matter models*, arXiv:1810.09420.



Introduction



Benchmark scenario

Tania Robens, private communication, May 2020

We consider benchmark scenario with:

- $m_H = 752.9$ GeV
- $m_a = 310.88$ GeV
- $m_A = 905.3$ GeV
- $m_{H^\pm} = 749.78$ GeV
- $m_\chi = 112.28$ GeV

Considered production channel:

$$e^+e^- \rightarrow H a$$

a is invisible (decays to $\chi\chi$), but H has $\sim 33\%$ chance to decay in $t\bar{t}$



Simulation



Top-quark pair-production events are expected to be selected with little background. Consider only two related background channels:

$$e^+e^- \rightarrow qW qW$$

consistent with $t\bar{t}$ production and decay
+ nonresonant contributions

$$e^+e^- \rightarrow qW qW \nu\nu$$

consistent with $t\bar{t}$ production in WW fusion process
+ nonresonant contributions



Simulation



Software framework

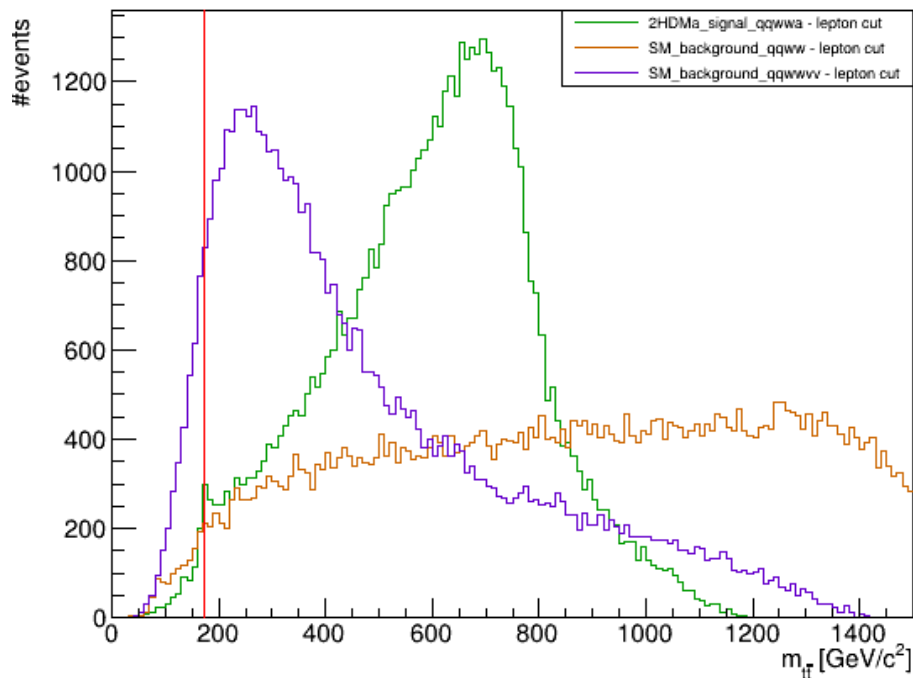
- signal and background events were simulated with WHIZARD 2.7.0
 - CLIC luminosity spectra included with CIRCE2
- Detector response simulated with DELPHES
 - Jet energy smearing due to overlay events NOT taken into account (DELPHES problem)

Cross section estimates (for 3 TeV, negative polarisation):

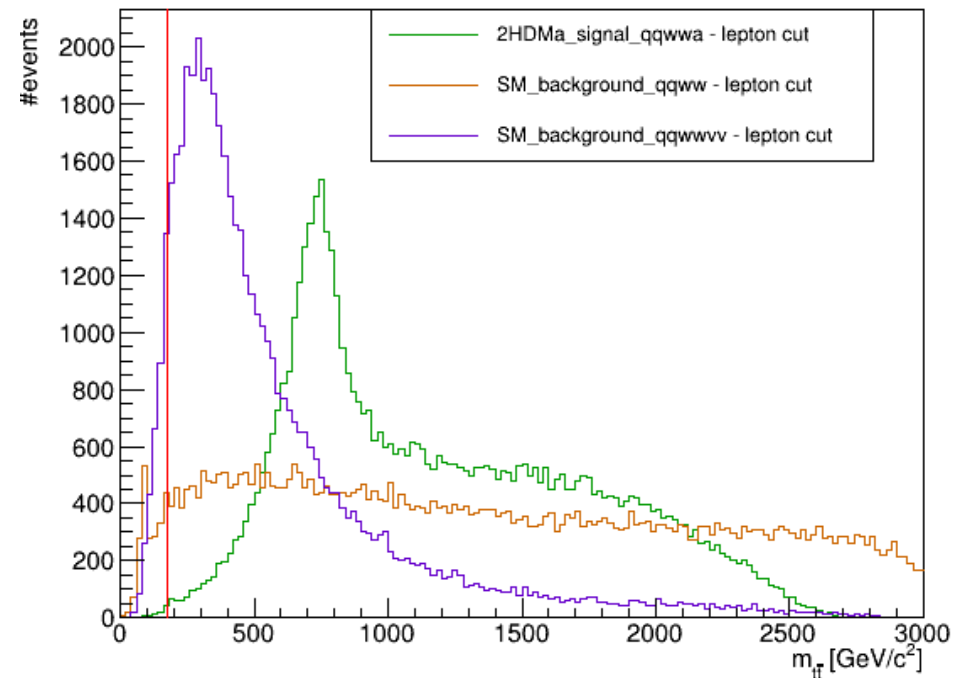
- $qW qW$ 141.86 fb
- $qW qW \nu\nu$ 10.44 fb
- $qW qW a$ 1.40 fb

Comparison of the kinematic distributions for the considered **signal** and background samples

1.5 TeV CLIC



3 TeV CLIC





Disclaimer



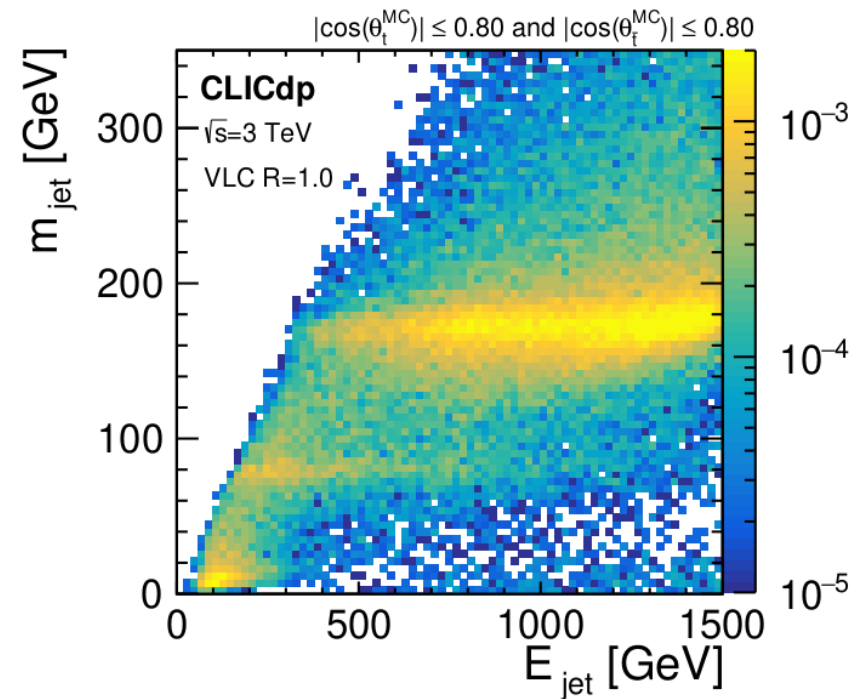
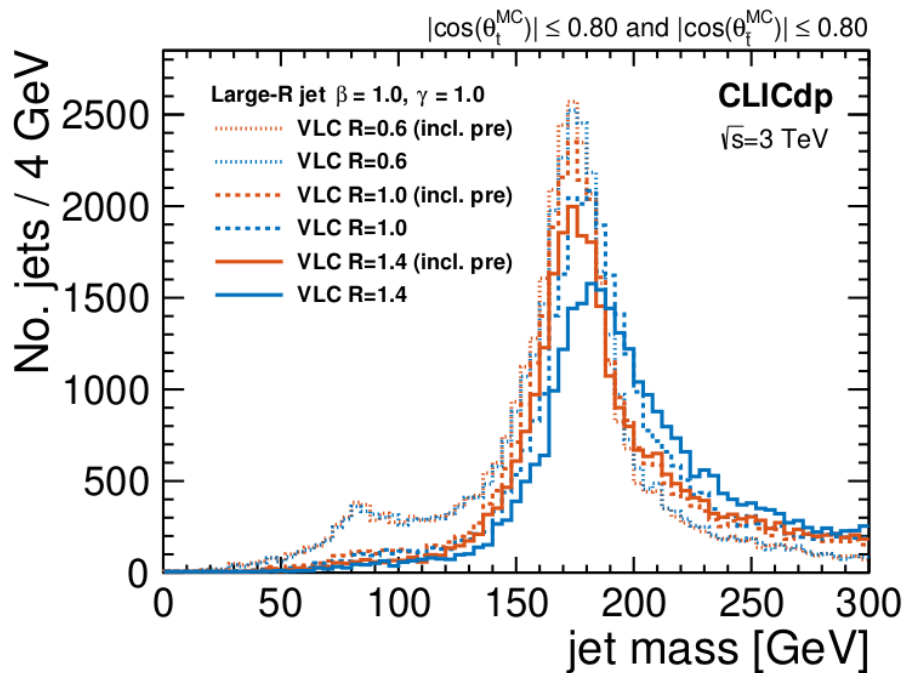
The aim of the presented study was to verify the feasibility of 2HDM+a observation at CLIC.

Due to the time constraints, simplest possible analysis approach was used.

There are clearly many ways to improve it...

At high energy CLIC stages,
top quarks are produced with large boost

⇒ expect to observe massive “fat” jets



JHEP 11 (2019) 003

Require reconstruction of two “fat” jets (VLC, $R=1.5$)

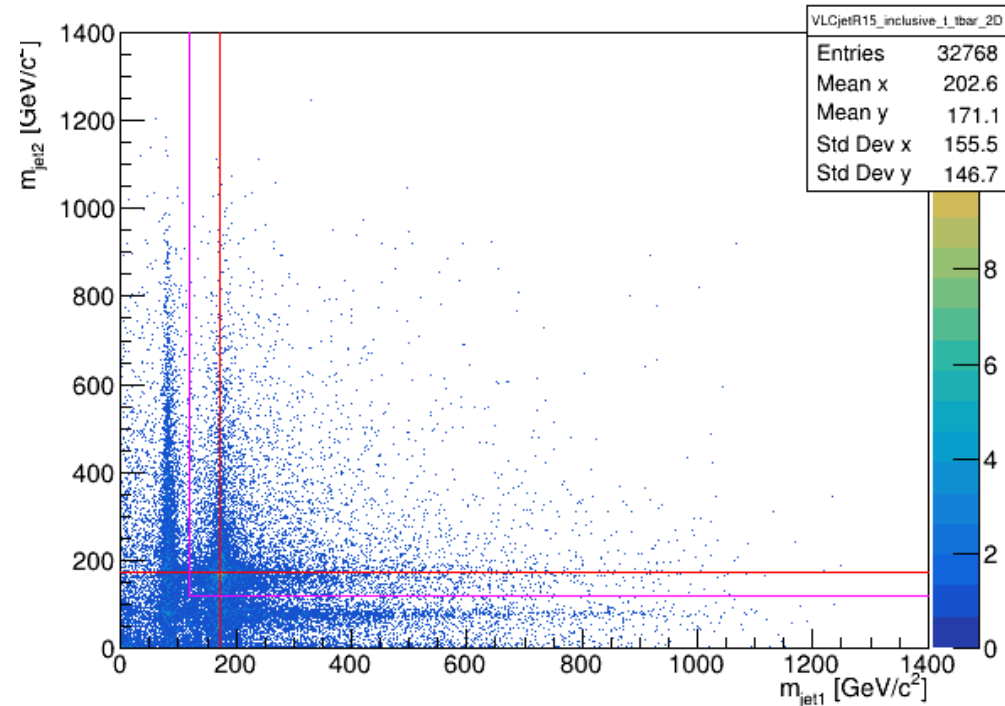
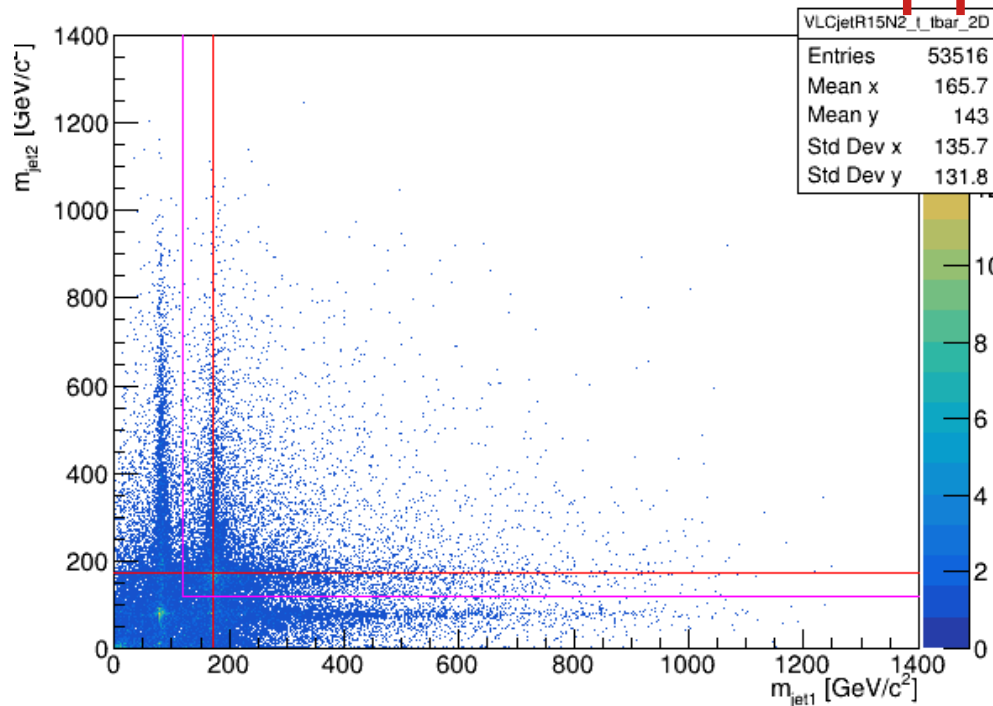
Events with isolated leptons or photons rejected.

Selection of top-quark pair-production: $m_j > 120$ GeV

Exclusive with $N=2$

$qqww$

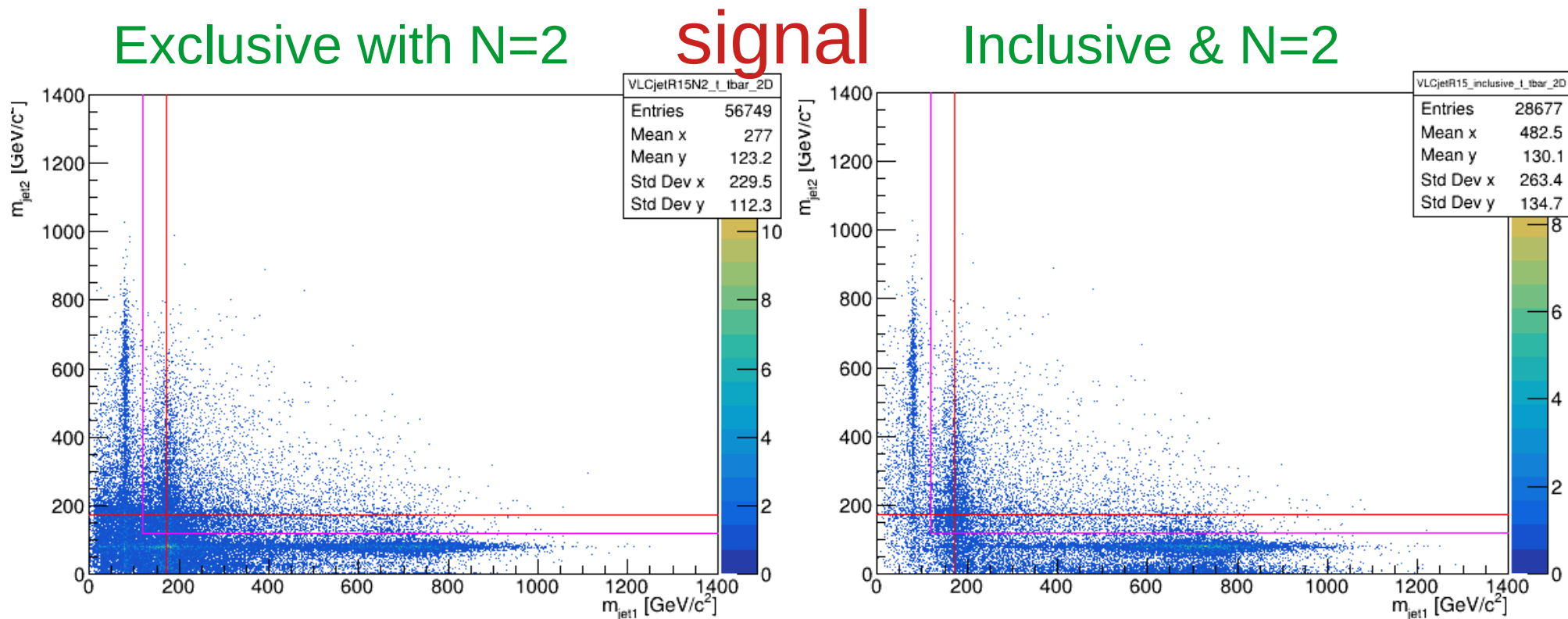
Inclusive & $N=2$



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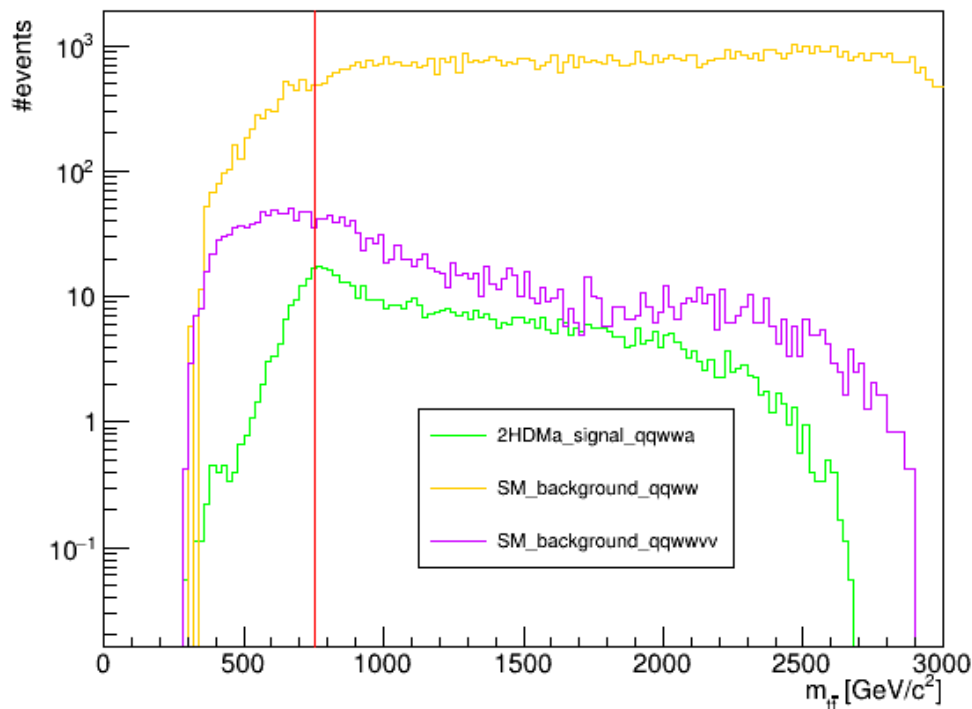
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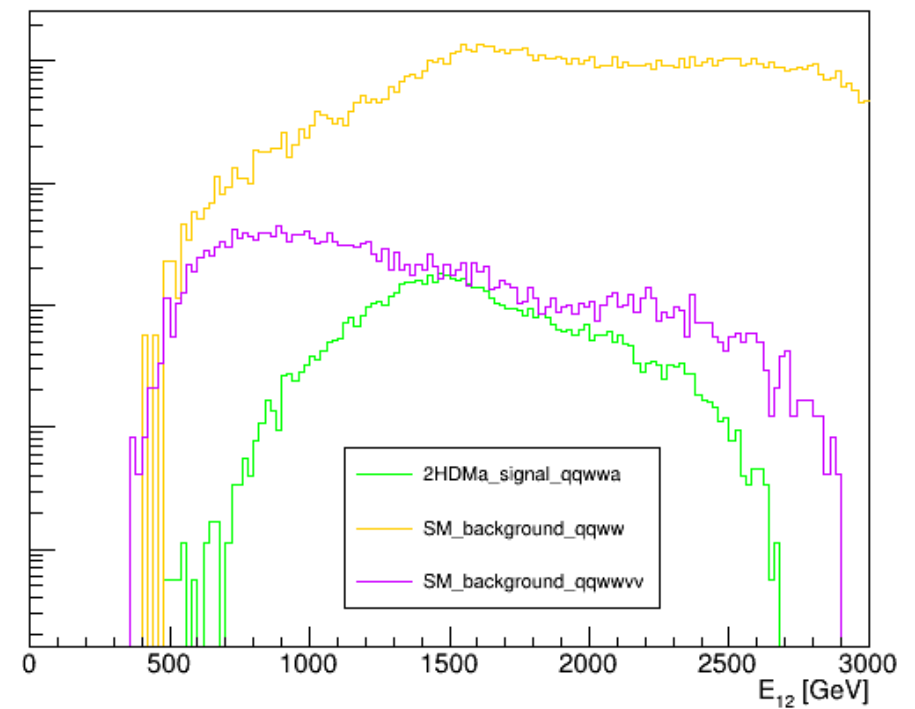
Expected signal and background distributions, after relative normalisation is taken into account

For 4000 fb-1 with negative electron polarisation @ 3 TeV CLIC

Top-pair invariant mass



Top-pair energy





Analysis



Signal-background discrimination and significance estimate with TMVA

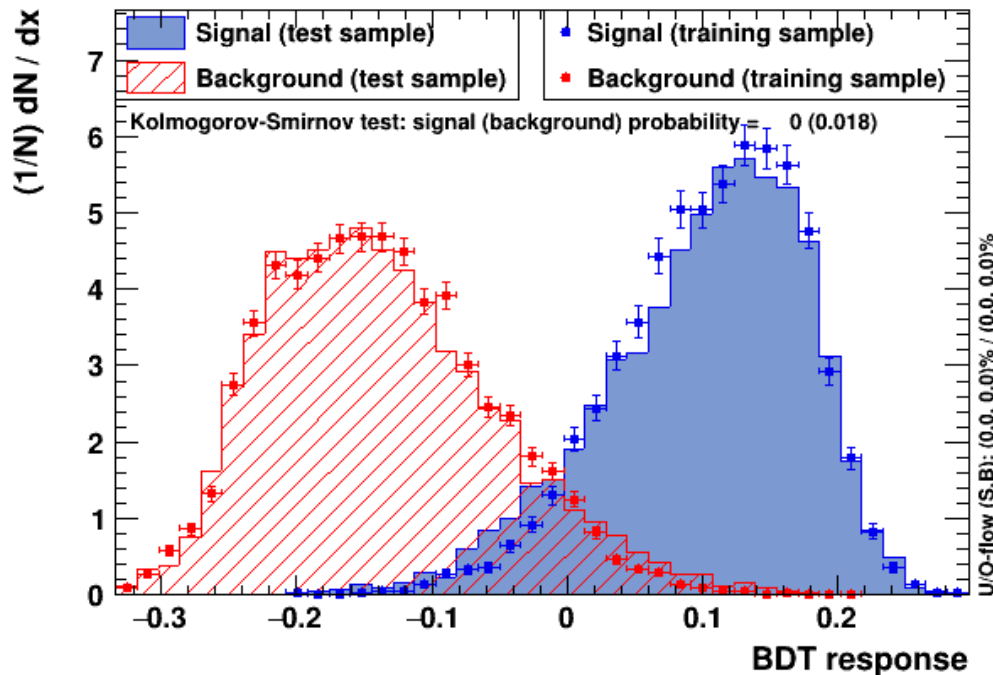
Following variables were used as input to BDT:

- jet parameters: mass, transverse momenta, energy, polar angle (x 2)
- angles between two jets
- reconstructed H mass, energy, angle and boost
- reconstructed a mass

BDT training results for 3 TeV CLIC

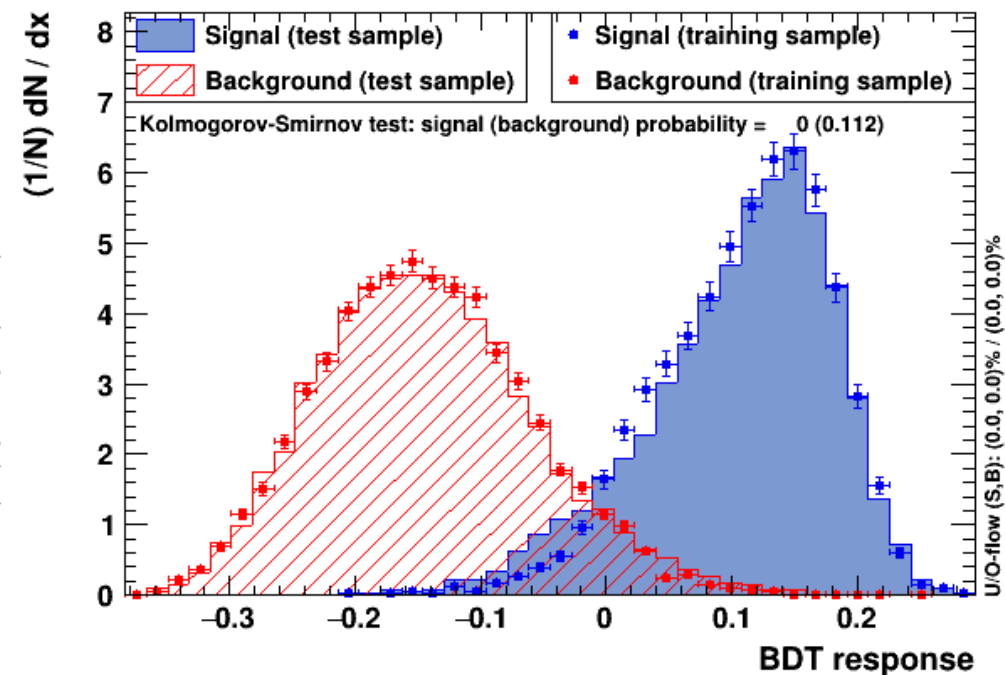
Negative electron polarisation

TMVA overtraining check for classifier: BDT



Positive electron polarisation

TMVA overtraining check for classifier: BDT



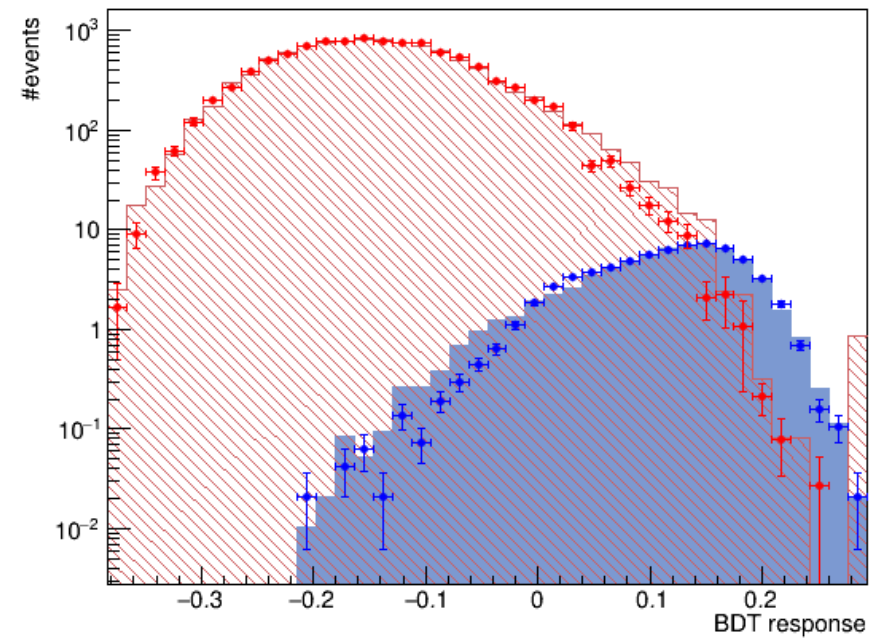
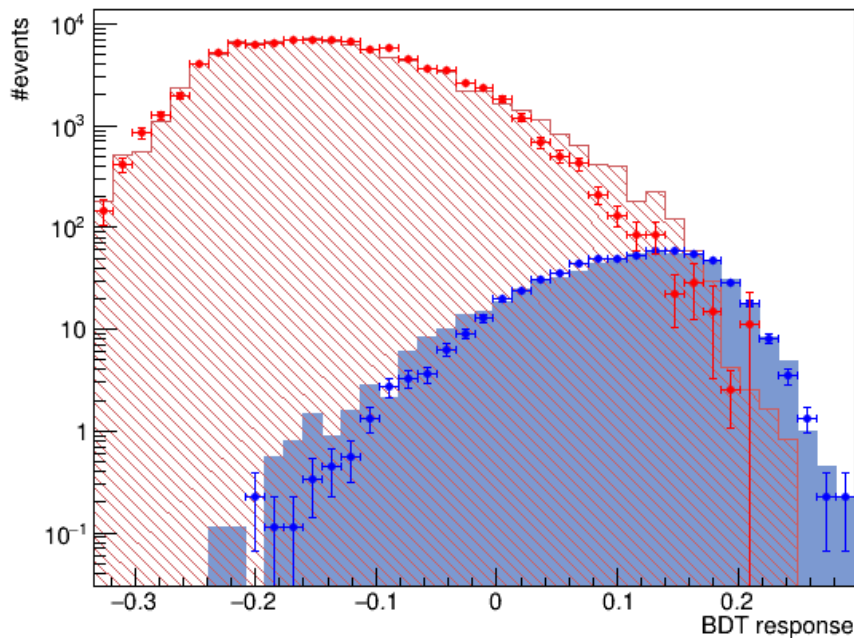


Results



BDT training results for 3 TeV CLIC

with signal and background normalised
to the expected data luminosity (4000/1000 fb⁻¹)

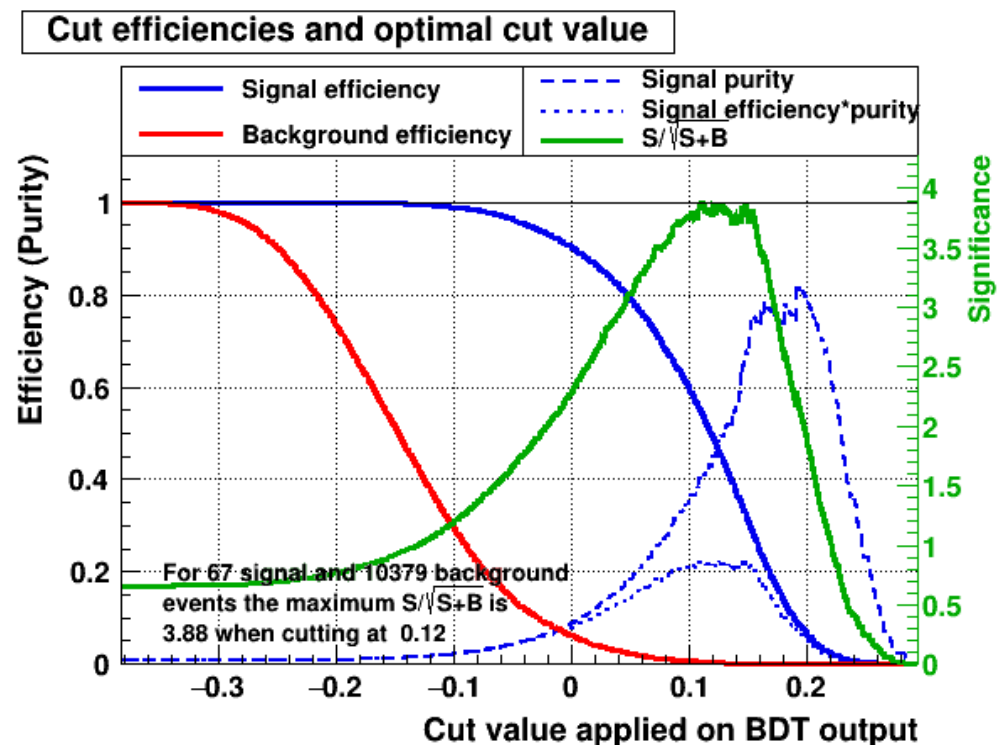
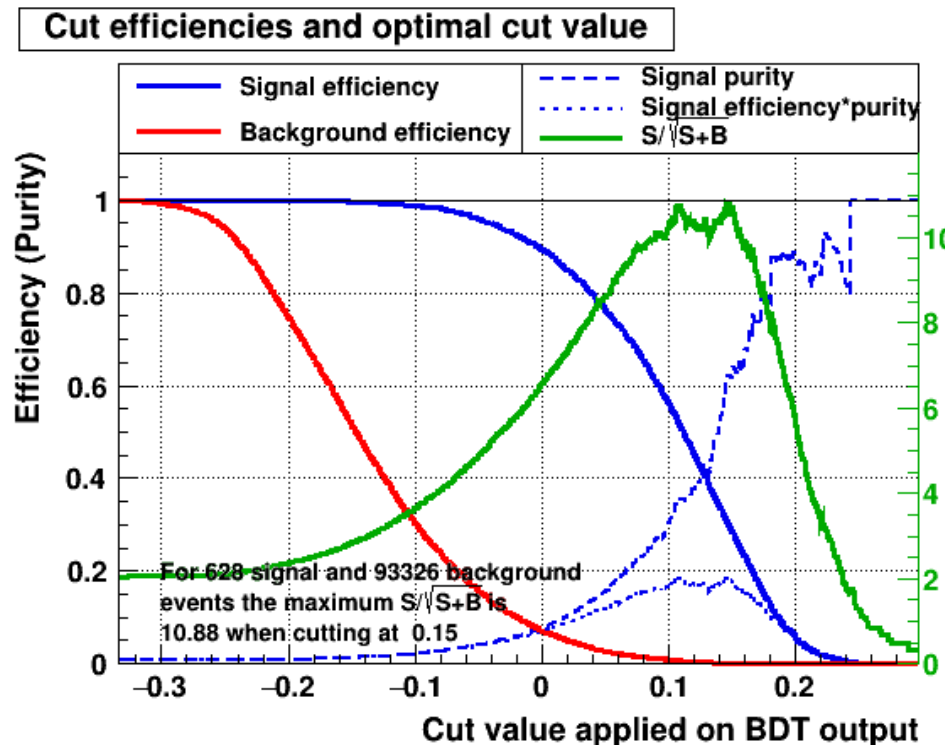


BDT training results for 3 TeV CLIC

Expected significance
for the expected integrated luminosity of 4000/1000 fb⁻¹

Negative electron polarisation

Positive electron polarisation

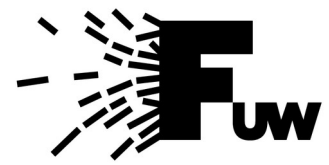




Conclusions



- Production of 2HDM+a scalars at high energy CLIC considered for the process:
$$e^+e^- \rightarrow H a \rightarrow t\bar{t} \chi\chi$$
- Only top-related background channels considered
- Most simplified analysis approach, based on “fat jet” reconstruction
- Final signal selection efficiency on 6-8% level
- Still, signal significance of $\sim 10 \sigma$ very promising
- Significance of only about 1.2σ at 1.5 TeV CLIC – too close to the production threshold



Thank you!