Exotic Higgs Decay at FCC-eh

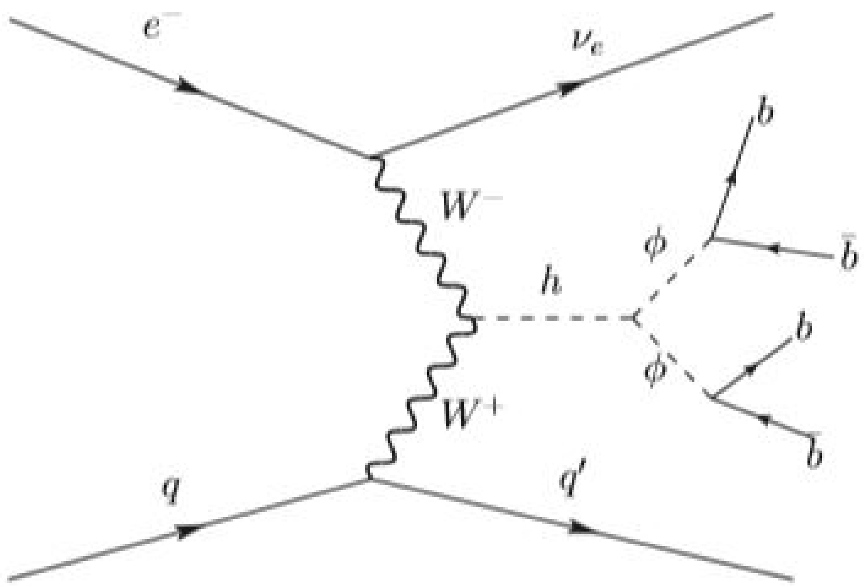
Uta Klein and Michael o'Keefe (MPHYTS project work, see draft version attached)

Decay Process

- Decay in question is Higgs to pair of scalar bosons, predicted by Next to Minimal Supersymmetric Model (NMSSM) [1]

- $Br(h \to \phi\phi) = 10\%$
- $Br(\phi \to b\bar{b}) = 100\%$
- $2M_b < M_\phi < M_h/2$
- M_ϕ =20-60 GeV in this study

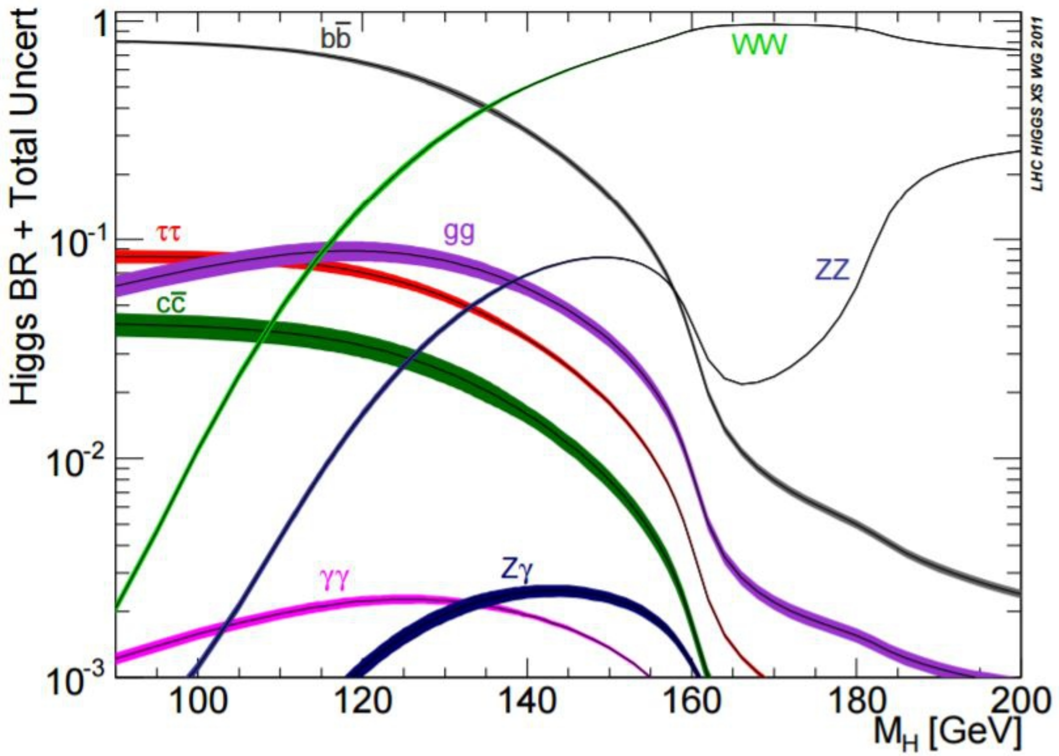
$$eq \to \nu_e h q' \to \nu_e \phi\phi q' \to \nu_e b\ \bar{b}\ b\ \bar{b}\ q'$$



[1] N. E. Bomark et al. A light NMSSM pseudoscalar Higgs boson at the LHC redux. JHEP 1502 (2015) 044, 2014, arXiv:1409.8393. We got the MG5 model from Chen Zhang et al.

Coupling of scalar to b's

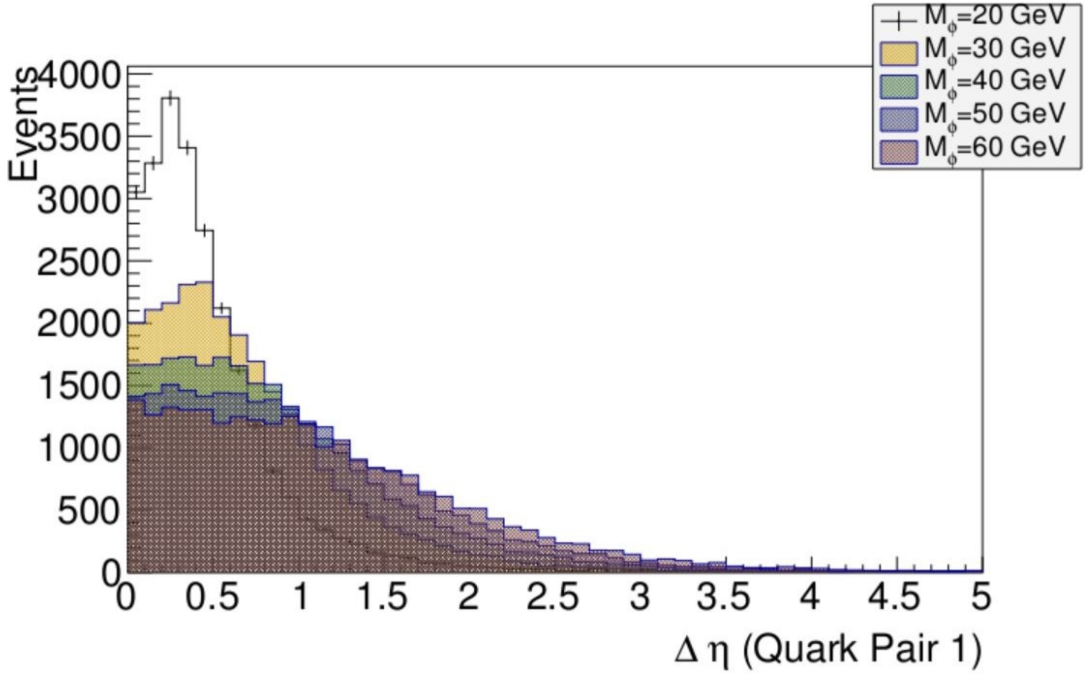
- The justification of using $Br(\phi \to b\bar{b}) = 100\%$ comes from the assumption that the scalar ϕ couples strongly to b's, similar to the Higgs [2]
- It is also assumed, like the Higgs, that ϕ has a narrow width resonance



[2] A. Denner; S. Heinemeyer; I. Puljak; D. Rebuzzi; M. Spira. Standard Model Higgs-Boson Branching Ratios with Uncertainties. Eur. Phys. J., C71:1753, 2011, 1107.5909.

Detector-Level Scalar Reconstruction

- Scalars were reconstructed on the basis of:
- Containing 4 b-tagged jets
- Minima in ΔM between each reconstructed djiet pair (using no further scalar mass assumption)
- Minima in Δη between each b-jet in each dijet pair (b's should originate from the same scalar, hence close in angular coordinates) -> motivated by parton-level studies, see right plot



Δη between b quarks in first scalar formed (parton level)

Scalar Reconstruction cont.

- The reconstruction of each $b\,\bar{b}$ pair should correspond to each scalar
- Then the addition of the 2 scalar pairs should correspond to a Higgs
- All jets in each event were looped over, and the pairs fulfilling the criteria on the previous slide accepted as scalar candidates
- Note that the initial dijet mass difference was set to 10, and the initial $\Delta\eta$ set to 2
- Each iteration with smaller differences than these were selected as the scalar candidate, resetting the differences below which we select scalar pairs

Dominant Backgrounds

- Dominant background processes expected to be charged current (CC)
- Primary source of 4b backgrounds considered were:
- $\bar{t} + multijet$
- $W/Z/h + multijet$
- $b\,\bar{b} + jets$

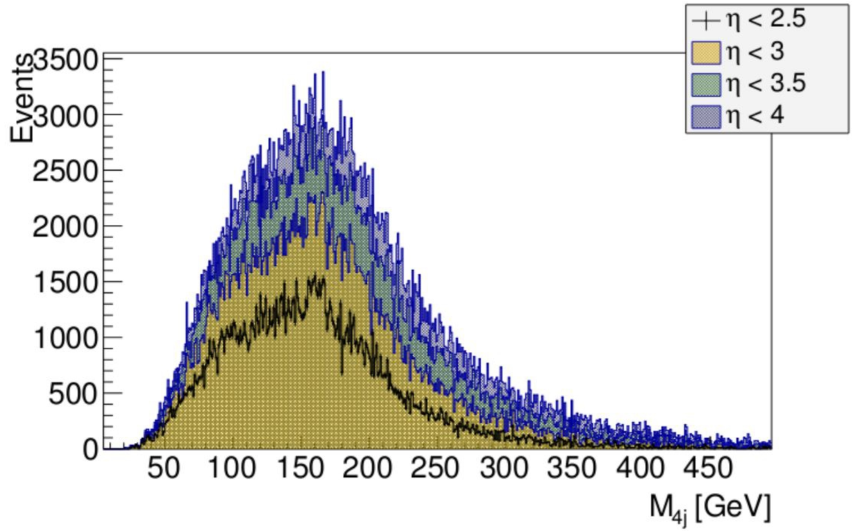
CC Top+Multijet Sample	all = g u c d s u~ c~ d~ s~ , ve vm vt ve~ vm~ vt~ ta- ta+ b b, ~ z w+ w- h t t~ pe- → b~ all all vl pe- → b all all vl	PT of Jets/b's/photons/charged leptons > 6.5 GeV η of Jets/b's/photons/charged leptons < 6.1 Min. ΔR between jets = 0.2 Min. Inv. Mass of Jet/bb~ pair = 8 GeV Beam Polarisation = 0	9683
CC Inclusive Single W/Z/h Production	p e- → vl w- j j / t~ t , w- → j j p e- → vl h j j , h → j j p e- → vl z j j , z → j j	PT of Jets/b's/photons/charged leptons > 6.5 GeV η of Jets/b's/photons/charged leptons < 6.1 Min. ΔR between jets = 0.2 Min. Inv. Mass of Jet/bb~ pair = 8 GeV Beam Polarisation = 0	3566
CC b b~ + 2j Production	all = g u c d s u~ c~ d~ s~ ve vm vt ve~ vm~ vt~ ta- ta+ b b~ p e- > b~ b all all vl	PT of Jets/b's/photons/charged leptons > 6.5 GeV η of Jets/b's/photons/charged leptons < 6.1 Min. ΔR between jets = 0.2 Min. Inv. Mass of Jet/bb~ pair = 8 GeV Beam Polarisation = 0	1120

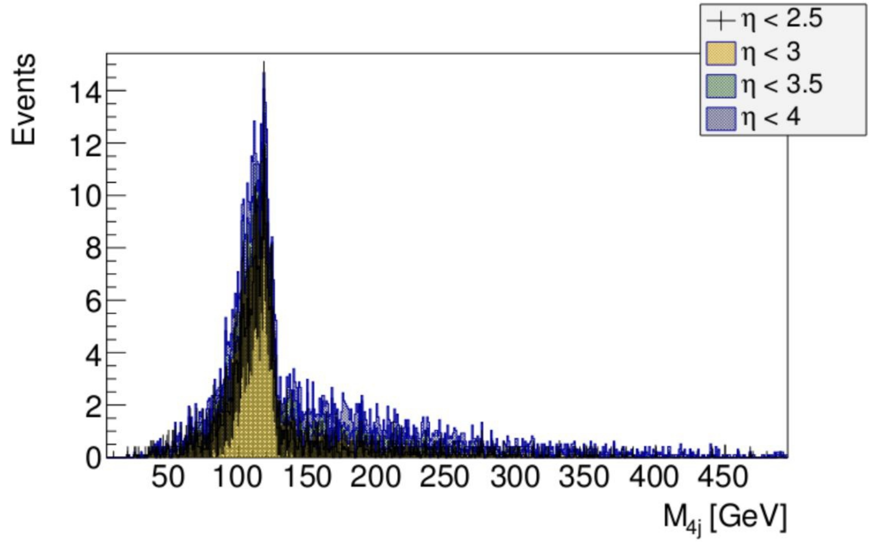
Other Backgrounds

- Other background samples that were considered:
- $t\,\bar{t} + jets$
- $t\,\bar{t}$ photoproduction
- It was found that the $t\,\bar{t}$ cross section was magnitudes smaller than the other backgrounds (7 fb) so neglected
- Photoproduction was qualitatively eliminated, assuming that the forward electron could be sufficiently tagged to vito photoproduction events

Cuts and efficiencies

- Anti-kt jet reconstruction algorithm used (with minimum separation=0.4)
- $PT > 8\ GeV$
- $\eta < 2.5$ (this produced significant reduction in top background, compared to markedly smaller reduction in signal background, could remove when using BDT?)
- PT and η dependent b-tagging efficiencies in the range of 64-85%
- Light quark mis-tagging rates of around 0.1% and charm mis-tagging rates of around 4%

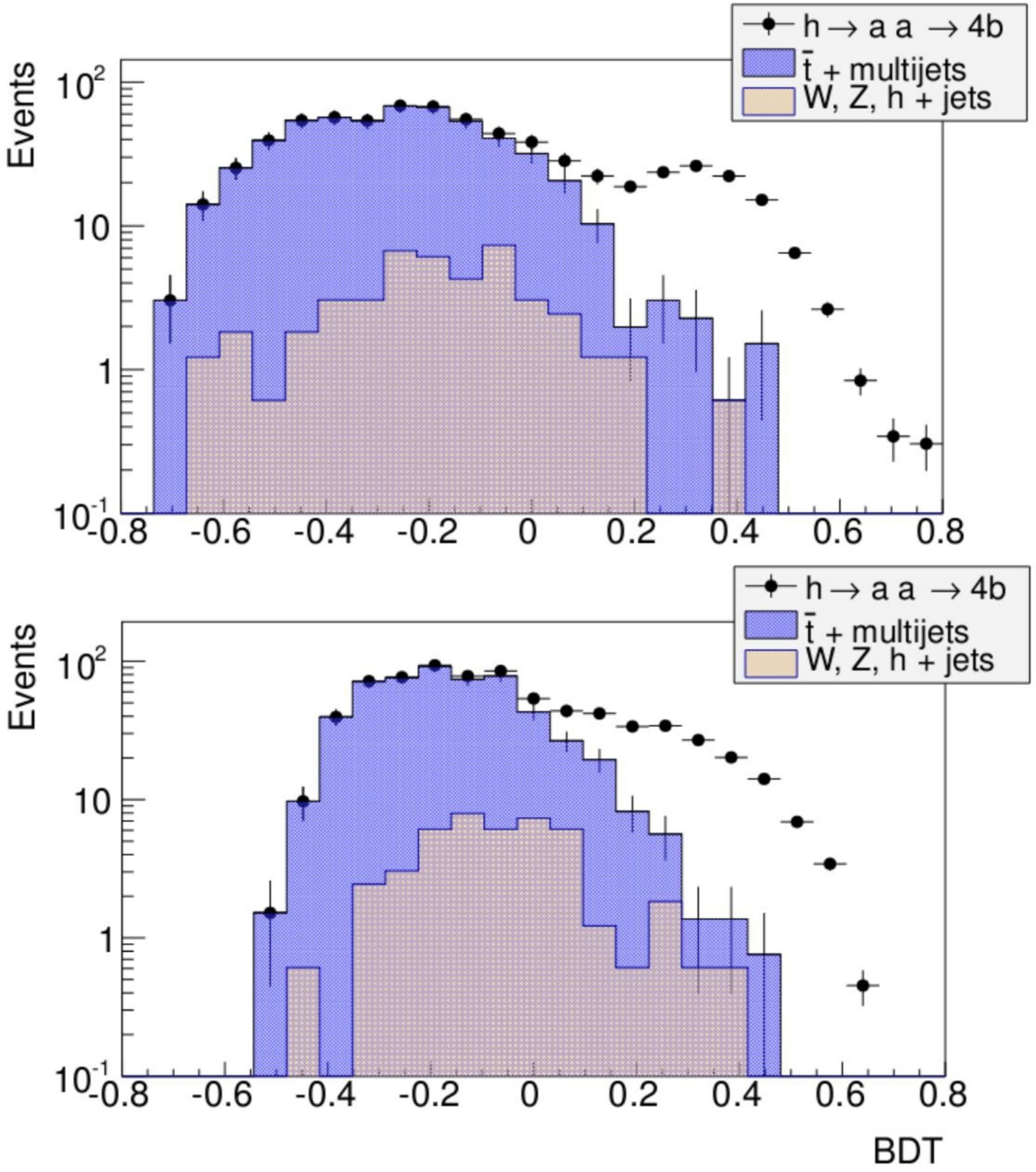




Cut flow for various η cuts for top background sample (top) and 20 GeV signal sample (bottom).

BDT Analysis

- BDT of 7 variables used:
- The difference in mass of the 4 first highest PT jets and the 3 first highest PT jets
- The invariant mass of the 4 jets chosen through the method of combinatorics
- The difference in mass between the two scalar candidates
- The missing energy
- The number of reconstructed jets
- The reconstructed HT (scalar sum of all pT)
- The difference in the ΔR between the two scalar candidates



BDT output for 20 GeV scalar (top) and 60 GeV scalar (bottom) with dominant CC backgrounds.

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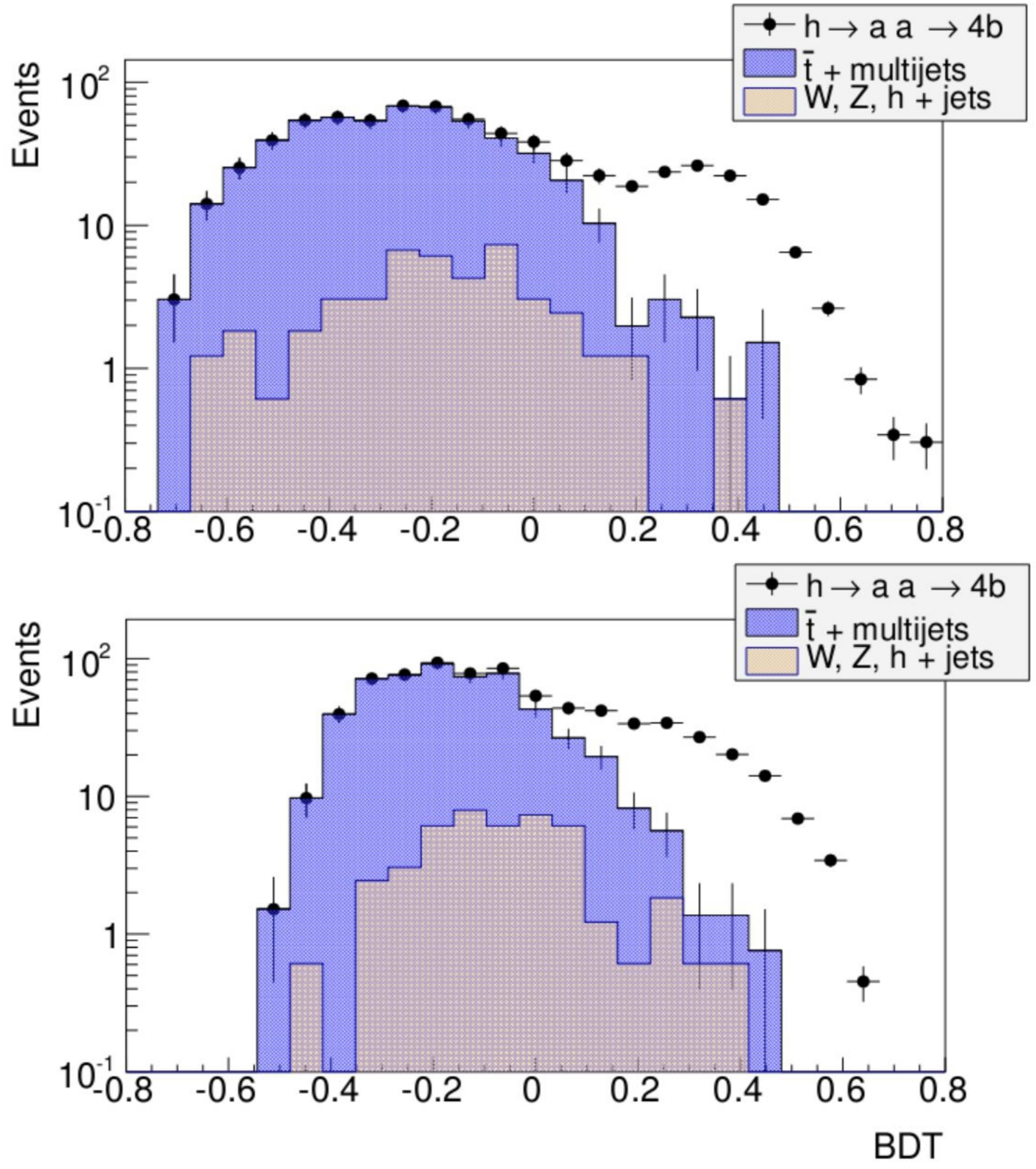
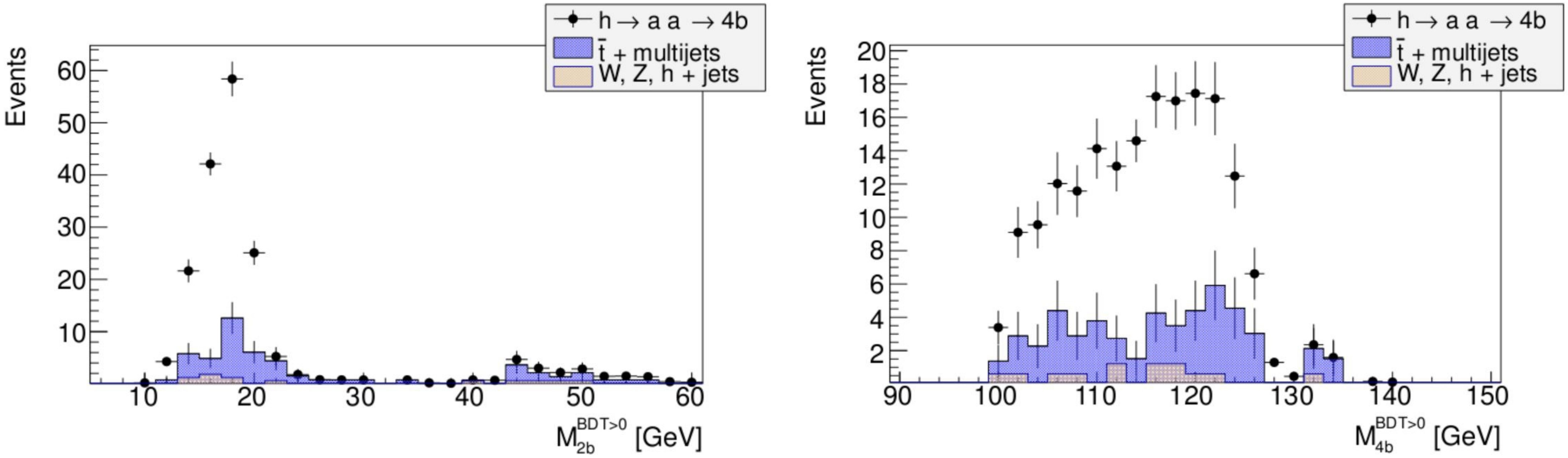
- The reconstructed HT (scalar sum of all pT)
- The difference in the ΔR between the two scalar candidates



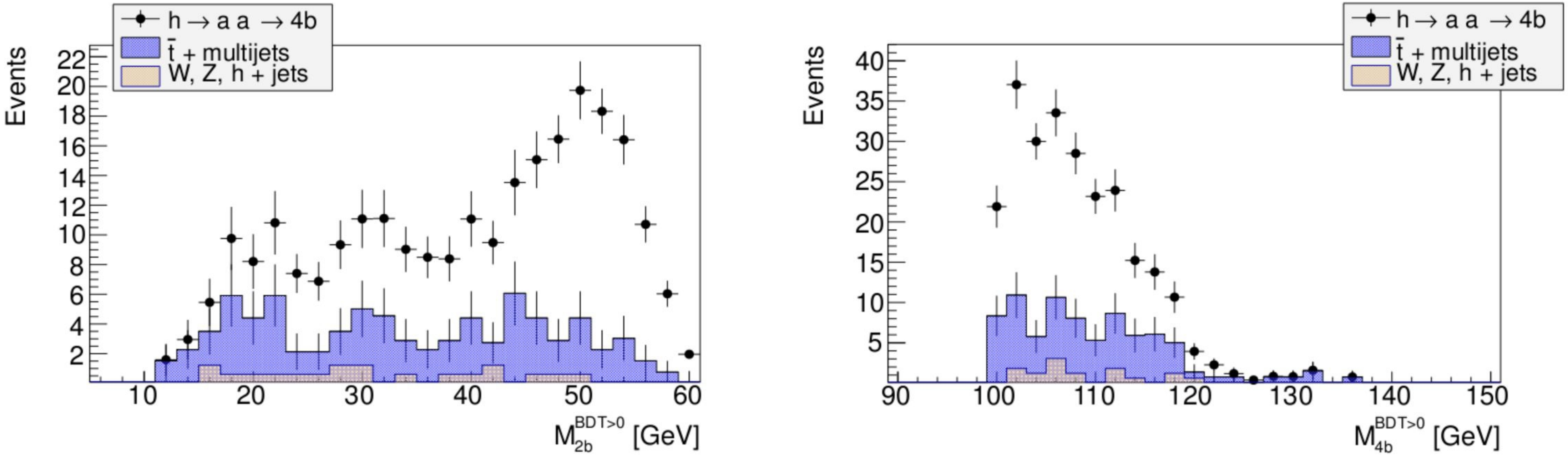
BDT output for 20 GeV scalar (top) and 60 GeV scalar (bottom) with dominant CC backgrounds.

20 GeV scalar/Higgs reconstructions



Invariant mass distributions for reconstructed 20 GeV scalar (left) and Higgs (right), with BDT > 0.

60 GeV scalar/Higgs reconstructions



Invariant mass distributions for reconstructed 60 GeV scalar (left) and Higgs (right), with BDT > 0.
Note: We didn't apply yet a scalar mass finding (left plot) to obtain best Higgs mass → current procedure is not biased w.r.t. any scalar assumption and thus delivers lower mass peak in 100-140 GeV Higgs mass window.

Results

- These results were obtained with an integrated luminosity of $100\ fb^{-1}$

Signal	σ (fb)	Δσ (fb)	Z*
20 GeV φ	1.30	0.13	14
60 GeV φ	1.68	0.16	14.7

*Significance

- Significance calculated according to [3]:

$$Z = \sqrt{2\left[(S+B)ln\left(1+\frac{S}{B}\right)-S\right]}$$

- Alternative calculations were obtained using:

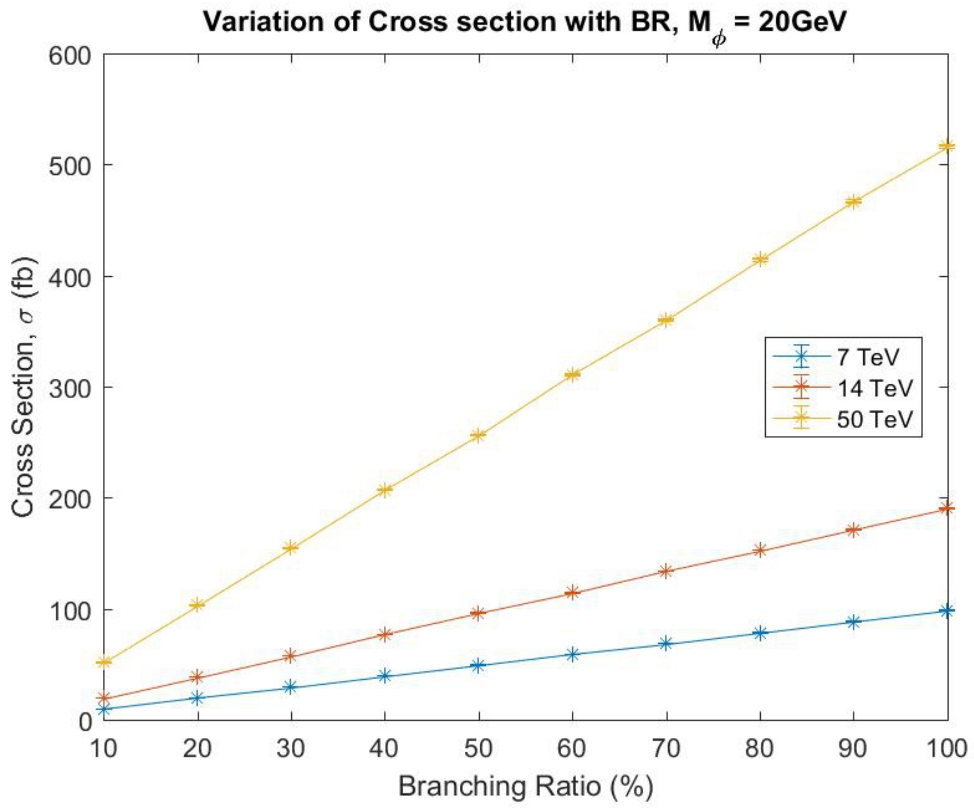
$$Z = \frac{S}{\sqrt{B}} \text{ and } Z = \frac{S}{\sqrt{S+B}}$$

- Equation to left results were roughly halfway between the two obtained using above equations

[3] Eq. 97 of G. Cowan; K. Cranmer; E. Gros; O. Vitells. Asymptotic formulae for likelihood-based tests of new physics. Eur. Phys. J., C71:1554, 2011, 1007.1727. [Erratum: Eur. Phys. J.C73,2501(2013)].

5σ discovery limit

- With an integrated luminosity of $1ab^{-1}$, the branching that obtained a 5σ significance was investigated
- This was found to be $Br(h \to \phi\phi) = 1\%$, with $Br\left(\phi \to b\,\bar{b}\right) = 100\%$
- Result obtained using linearity of cross section with branching ratio
- This is assuming the same cut flow for each branching option however, i.e. same cut flow for 1% branching as for 10%



Variation of cross section with branching ratio of $h \to \phi\phi$ (generator level).

Signal	σ (fb)	Δσ (fb)	Z
20 GeV φ	0.13	0.3	5.54
60 GeV φ	0.17	0.3	5.71

Outlook

- Exotic Higgs searches seem to be very promising at FCC-eh with a clear discovery potential
- To be explored still using a CL analysis: lower branching fractions than 1%
- To be studied: effect of extended b-tagging AND using BDT techniques
- Note: BDT can be further optimised: e.g. training conditions (c.f. Bsc project by Izzy Harris for Hcc at LHeC)