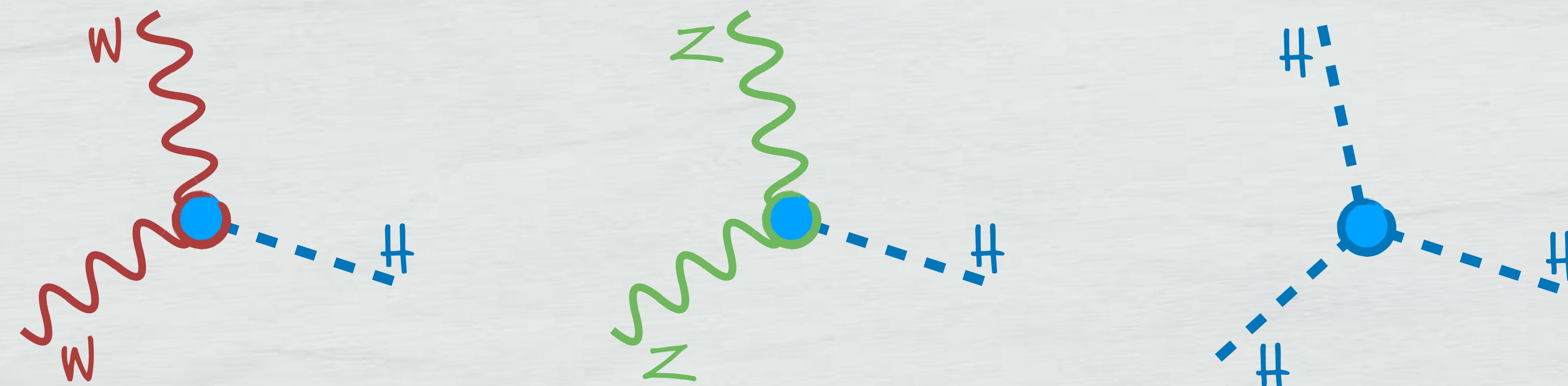


Higgs boson coupling measurements

focus on HWW , HZZ , HHH



Roberto Salerno

Foreword

All the studies shown have been done in a contest of a 4 months M2 internship that I have supervised.

The goal was to put in place a full analysis chain from the generation of the samples through the selection of candidates to the statistical analysis.

There are many caveats (results are on the optimistic side)

- The centrally produced samples are (yet) not used
- Not all the systematics uncertainties are included
- Only main backgrounds are considered, less selection cuts so higher signal efficiency



Inclusive analyses @240 GeV

Exploited few Z decays, using the recoil techniques

Z($\mu\mu$)H

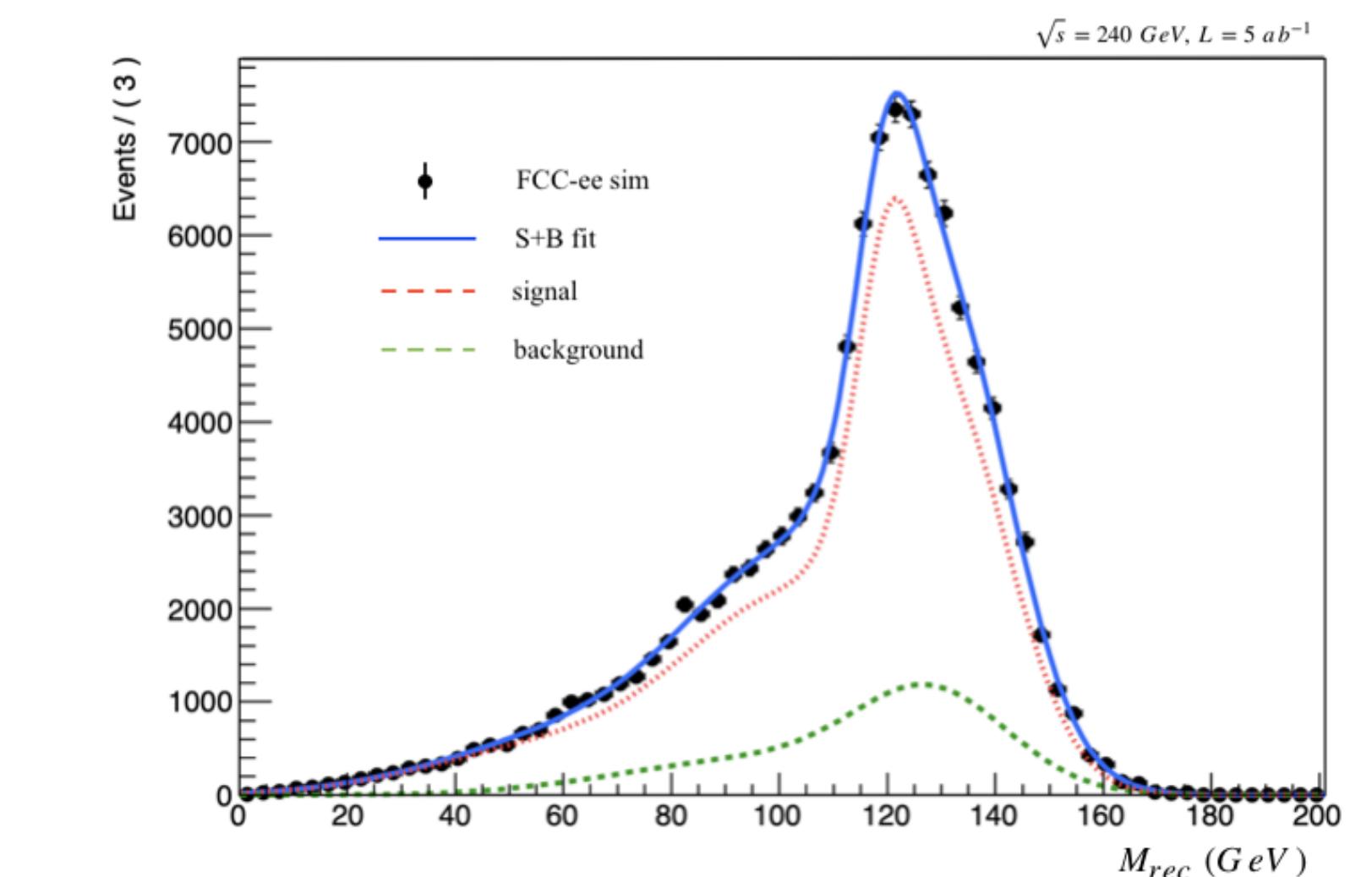
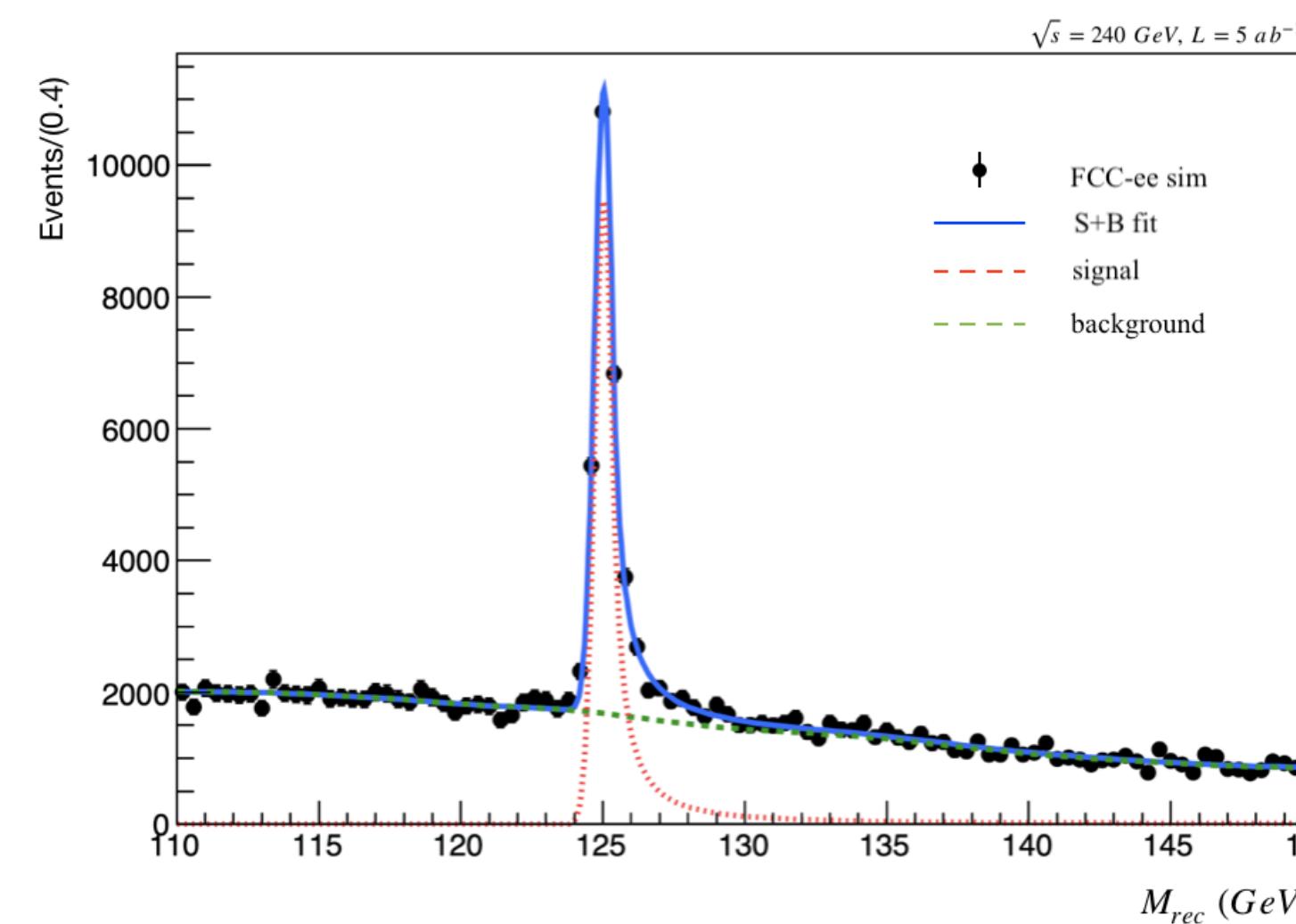
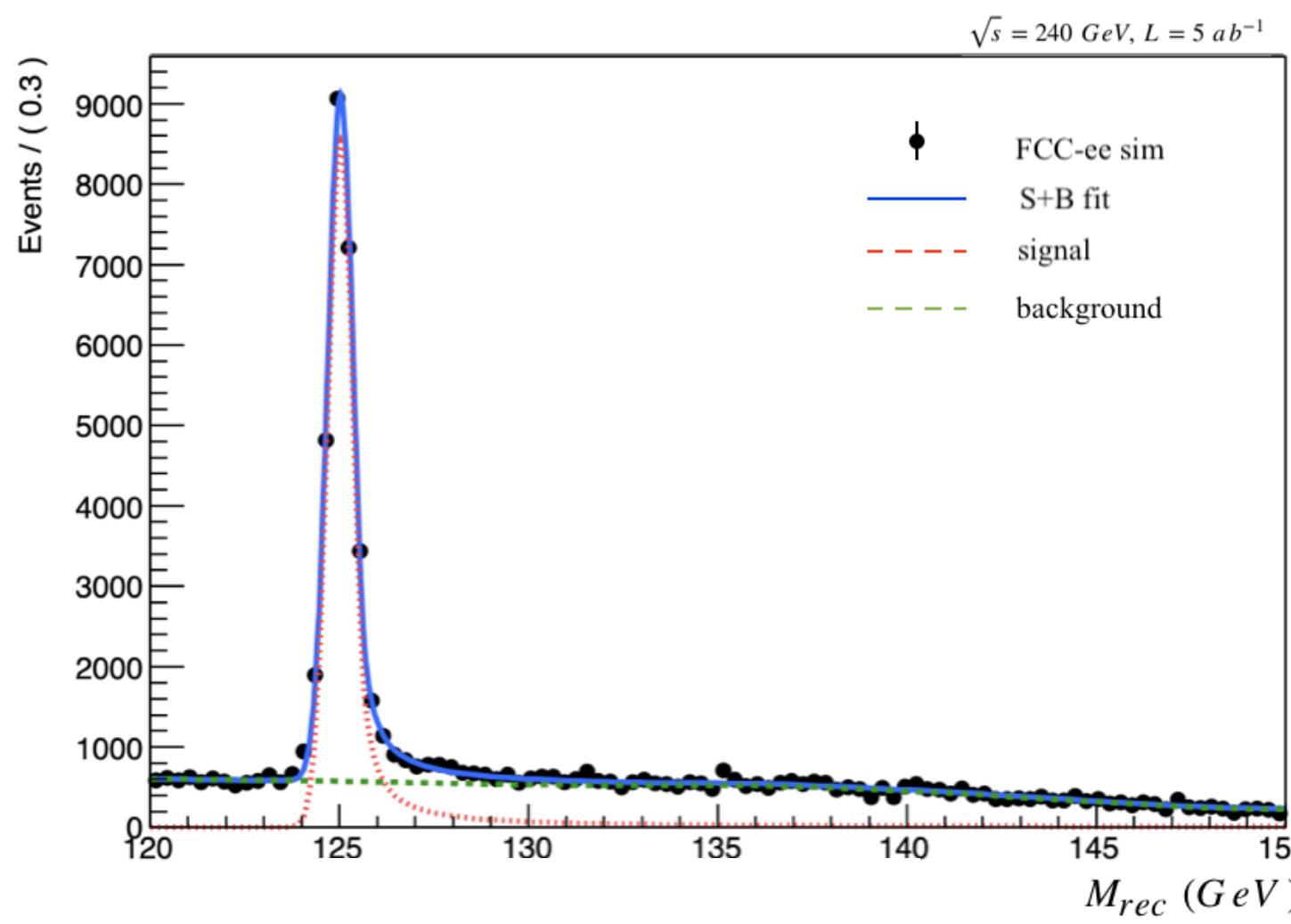
- $\mu^+\mu^-$ with $p_{T\mu 1} > 20 \text{ GeV}$, $p_{T\mu 2} > 5 \text{ GeV}$
- Minimum $|M_{\mu^+\mu^-} - M_Z|$
- $80 < M_{\mu^+\mu^-} < 100 \text{ GeV}$

Z(ee)H

- e^+e^- with $p_{Te 1} > 10 \text{ GeV}$, $p_{Te 2} > 5 \text{ GeV}$
- Minimum $|M_{e^+e^-} - M_Z|$
- $60 < M_{e^+e^-} < 120 \text{ GeV}$

Z(bb)H

- ≥ 2 b-jets + $p_{Tjj} > 60 \text{ GeV}$
- $M_{jj} > 45 \text{ GeV}$
- $H_T > 10 \text{ GeV}$
- BDT (17 variables)

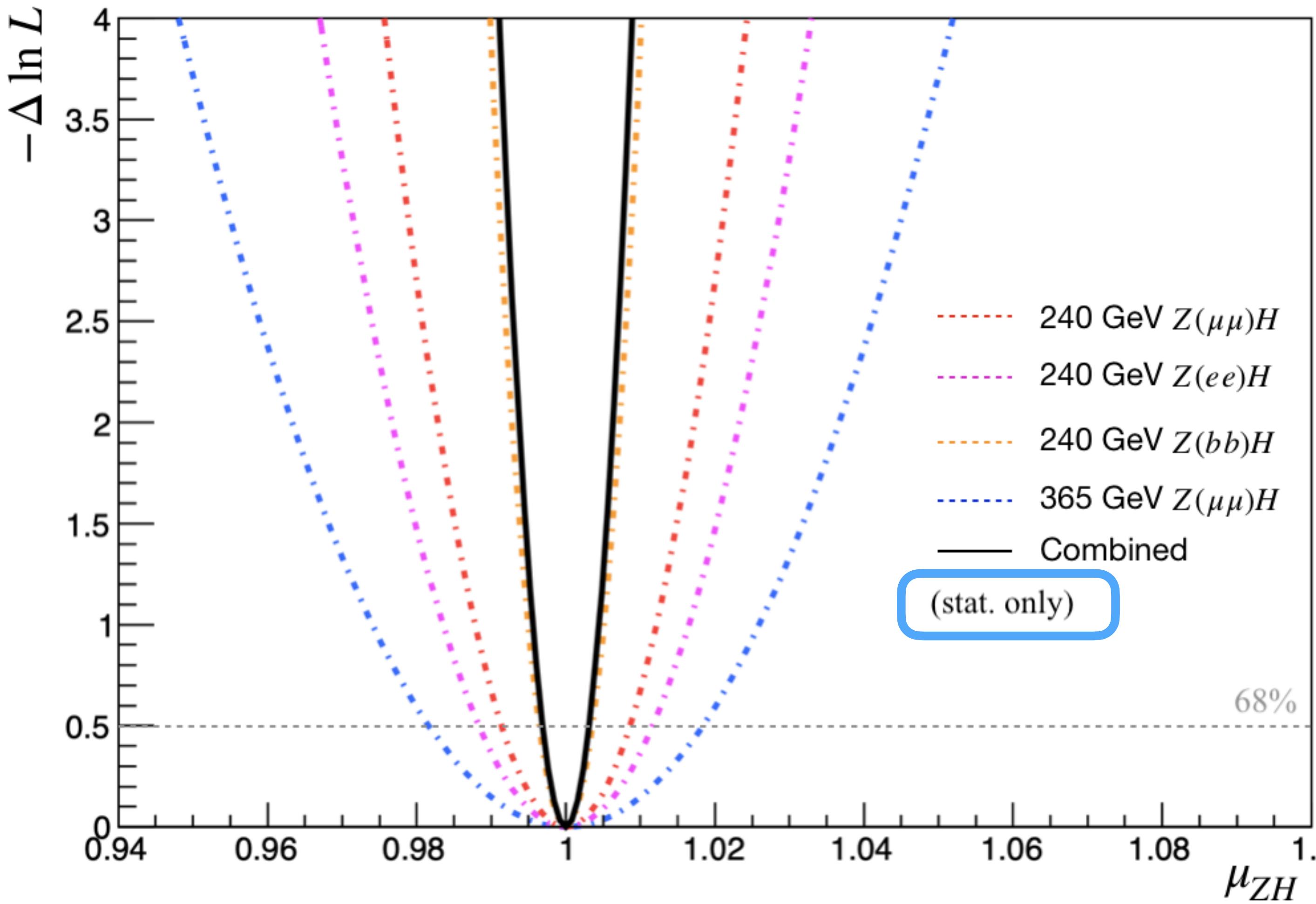
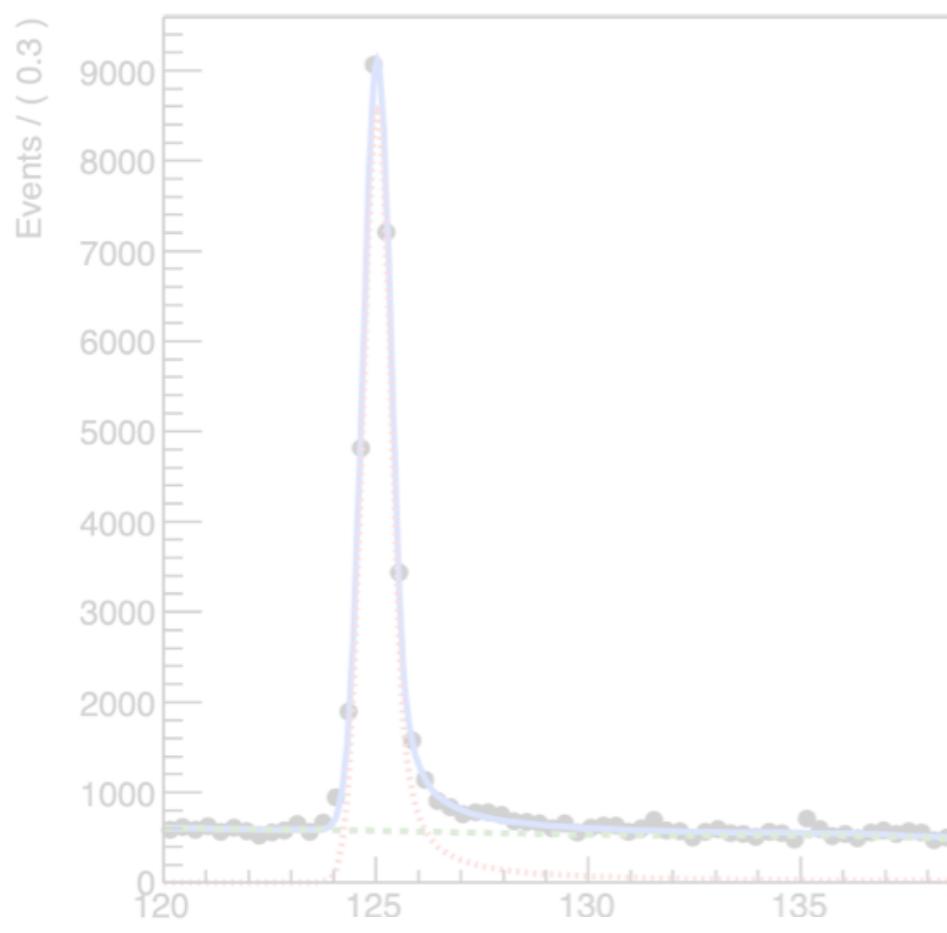


Inclusive analyses @240 GeV

Exploited few Z decays, using the recoil techniques

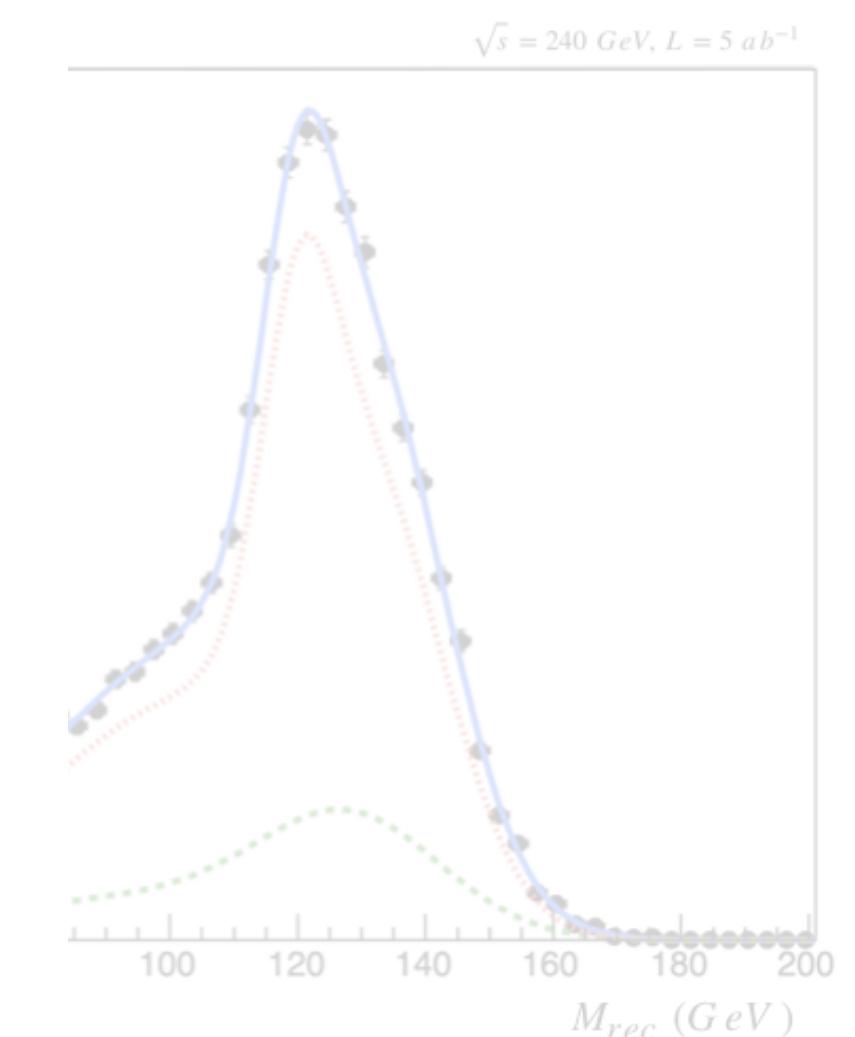
$Z(\mu\mu)H$

- $\mu^+\mu^-$ with $p_{T\mu 1} > 20$
- Minimum $|M_{\mu^+\mu^-} - M$
- $80 < M_{\mu^+\mu^-} < 100 \text{ GeV}$



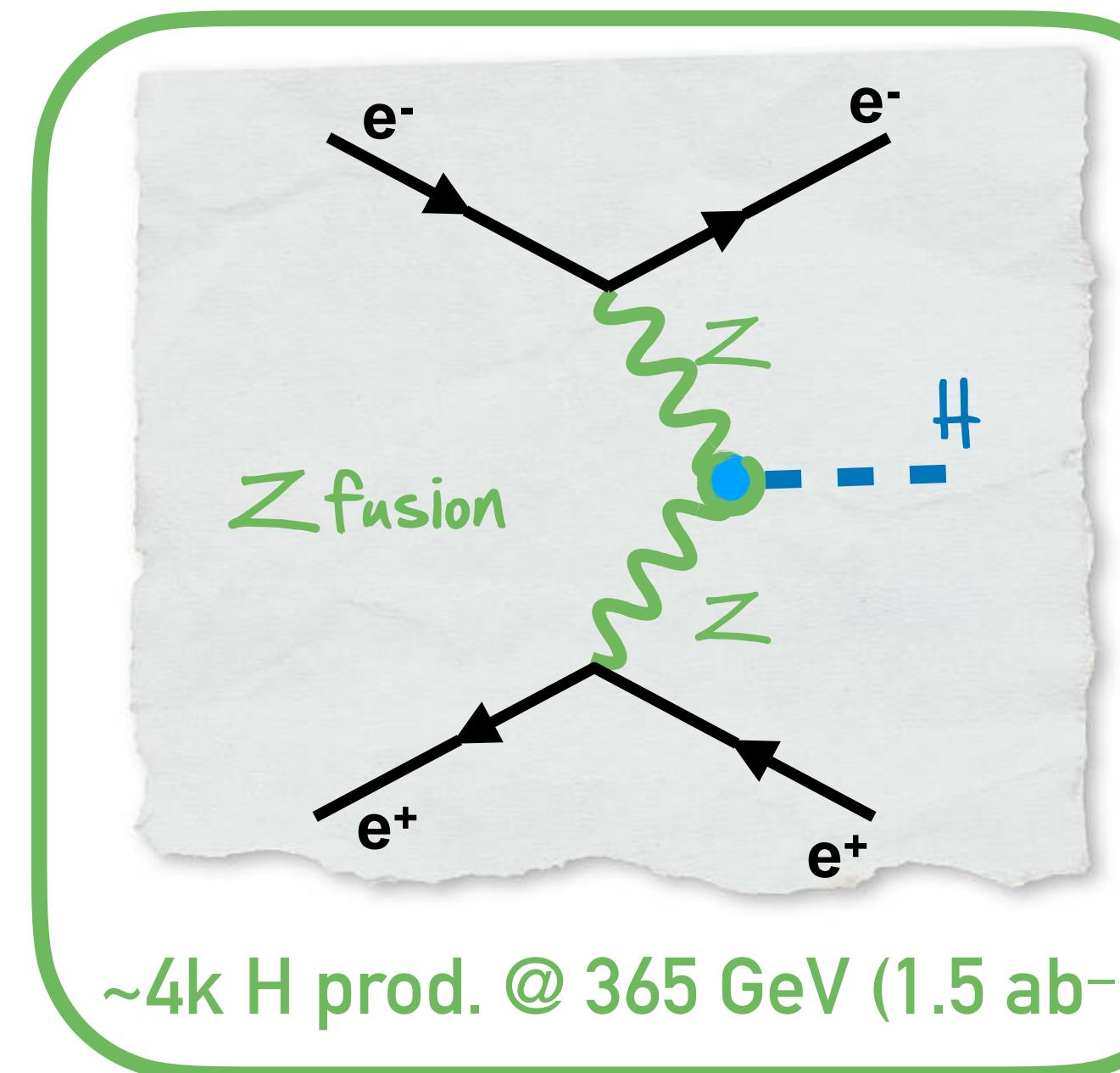
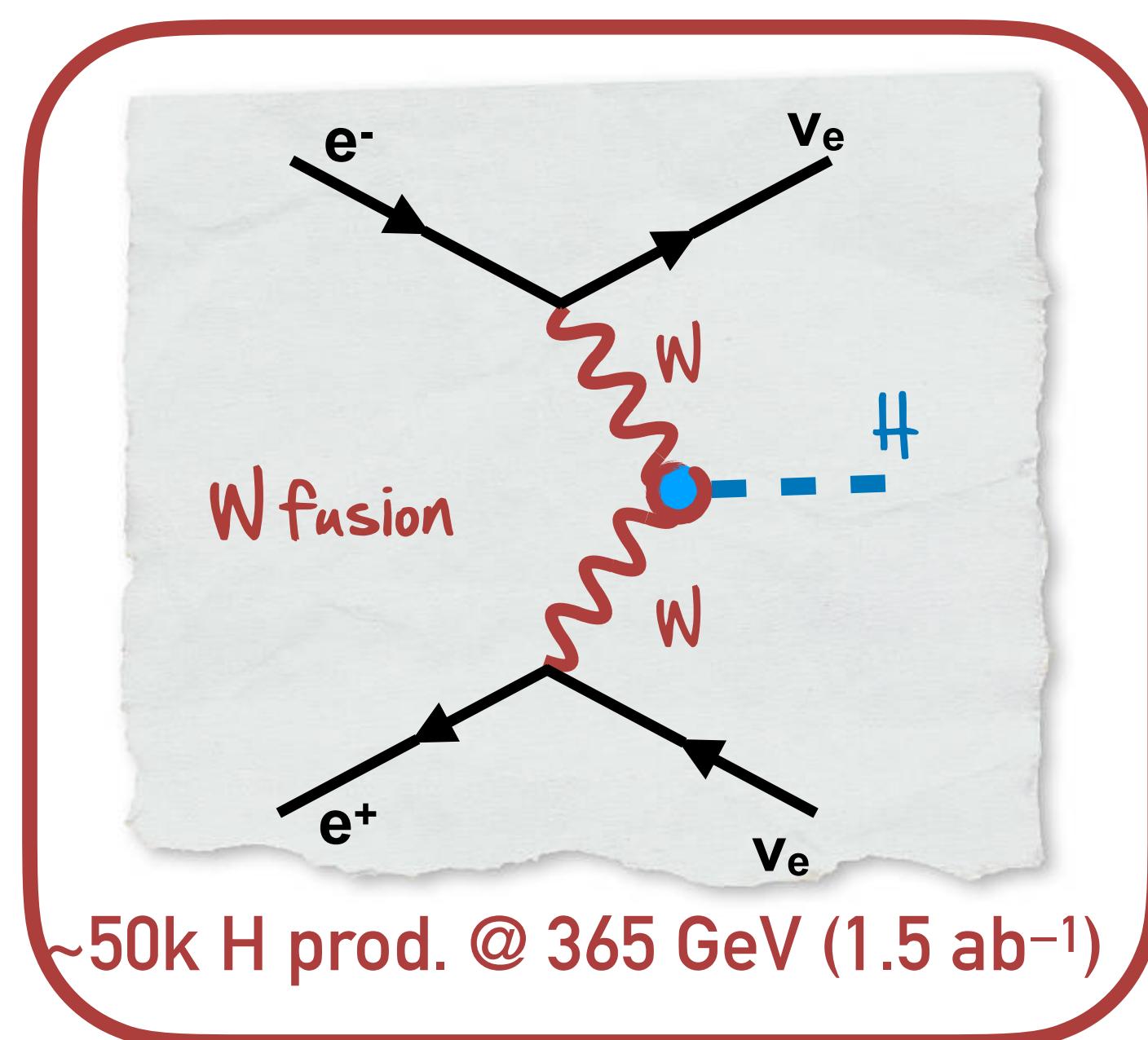
$Z(bb)H$

$\text{ets} + p_{Tjj} > 60 \text{ GeV}$
 5 GeV
 1 GeV
 7 variables)

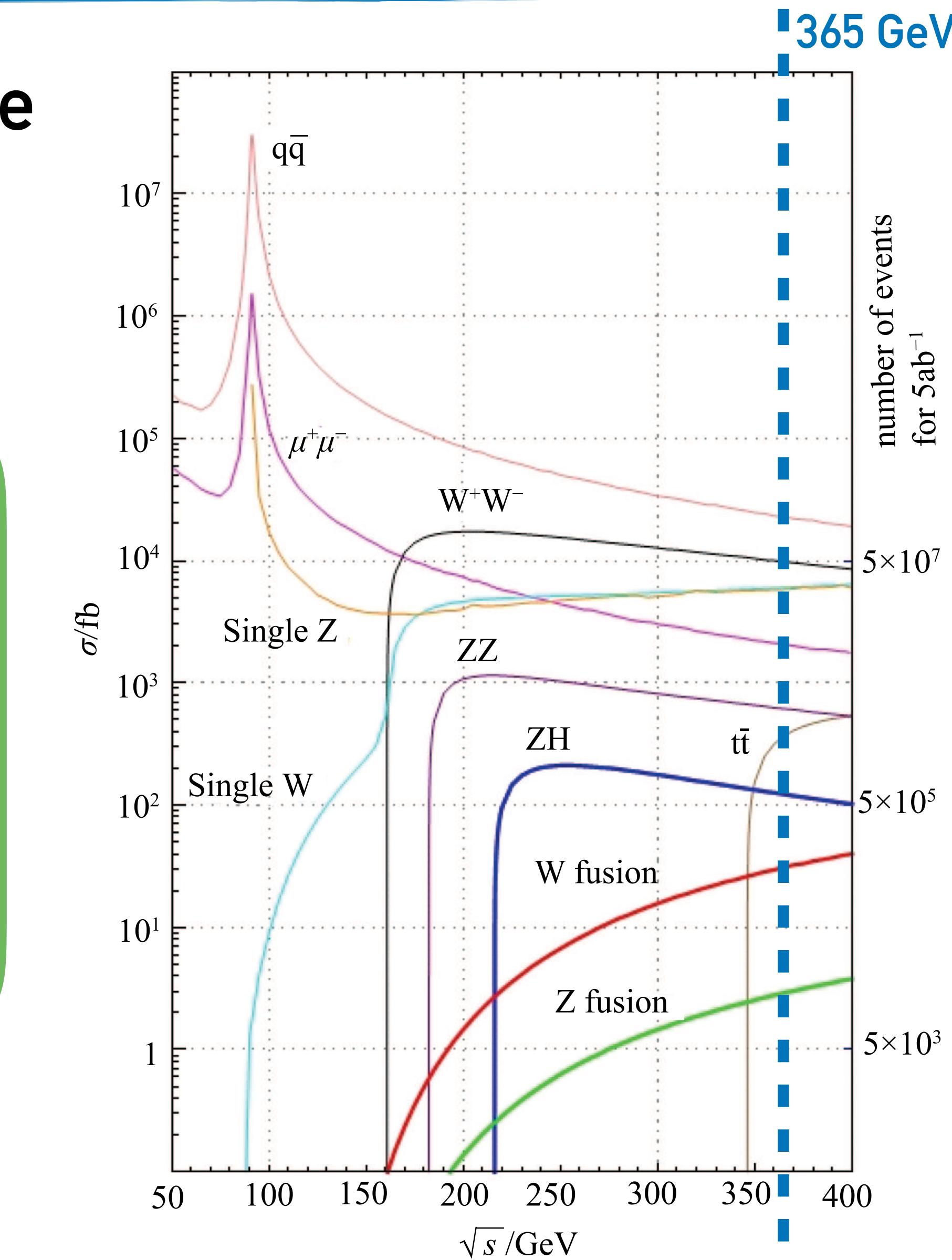


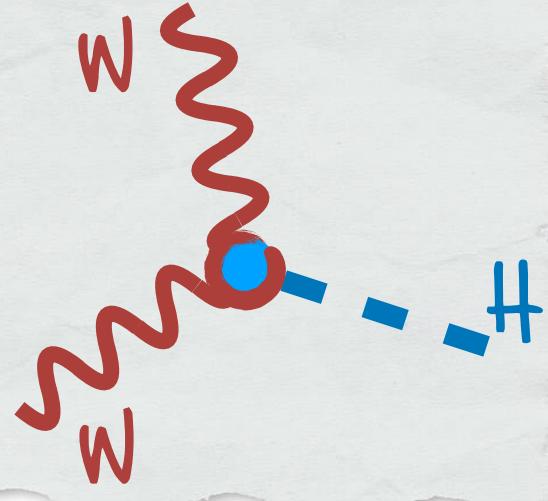
Study the VBF production @365 GeV

The production channel starts to become relevant due the logarithmic raise $\sim \ln^2(s/M_V^2)$ of the t-channel exchange of vector bosons



Production dominated by the W fusion because of larger charged currents

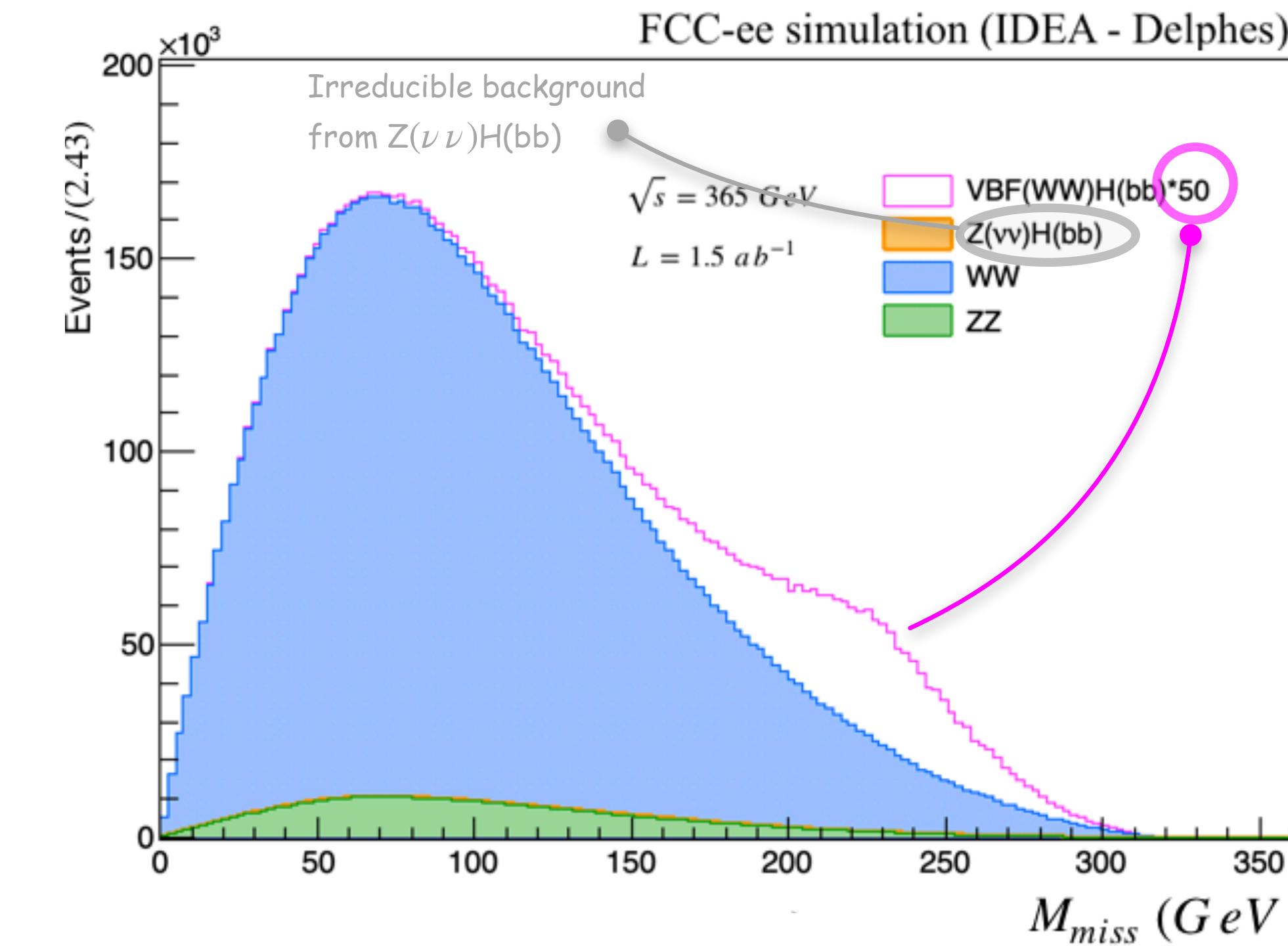




W boson fusion: $ee \rightarrow \nu_e \nu_e H(bb)$

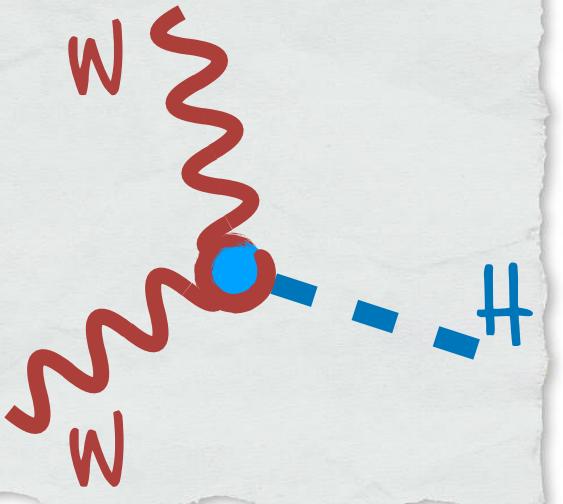
1. Preselection cuts

- 2 b-jets, $|\eta_{jj}| < 3$
- $H_T > 10 \text{ GeV}$
- MET $> 10 \text{ GeV}$

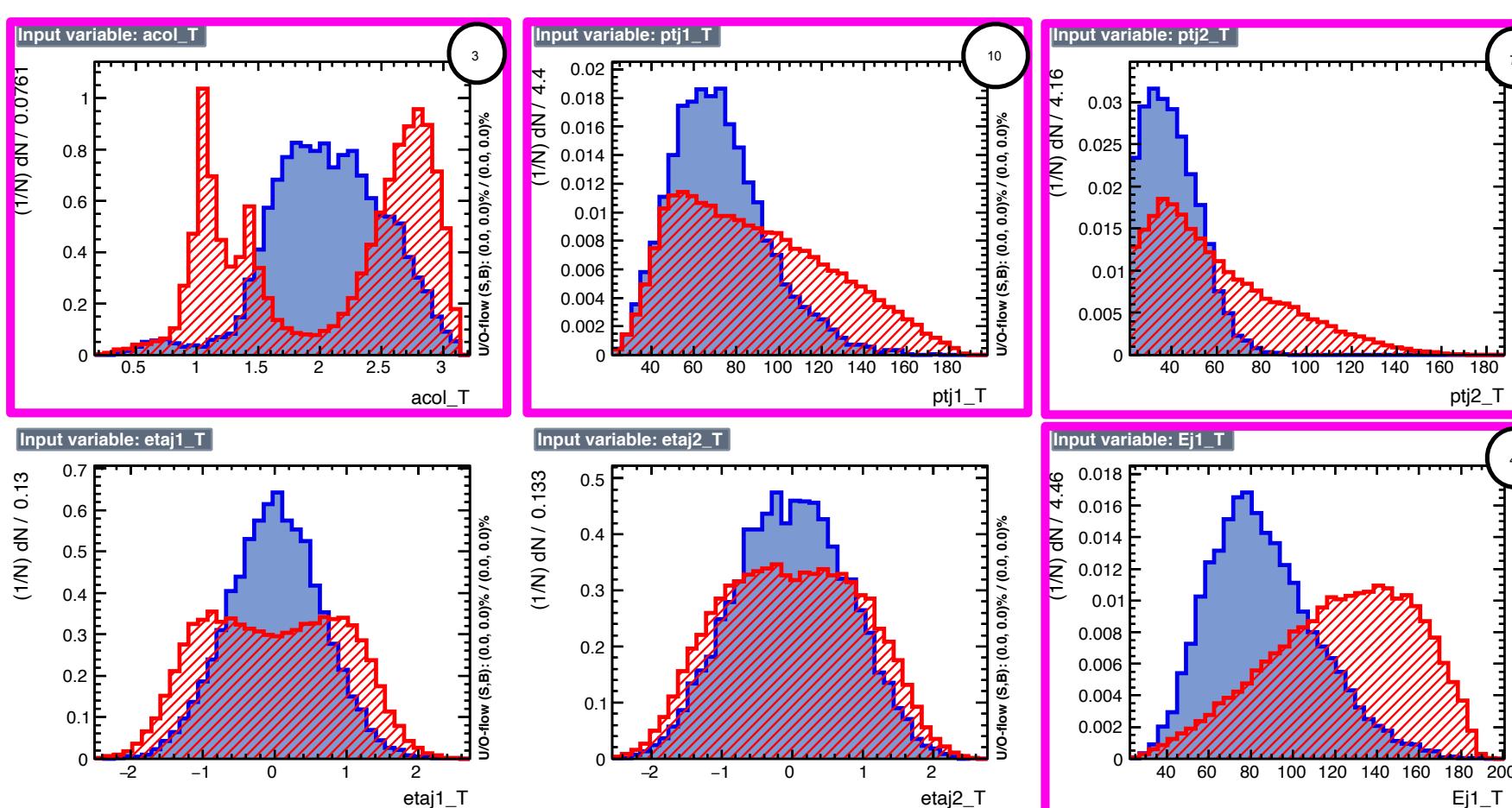
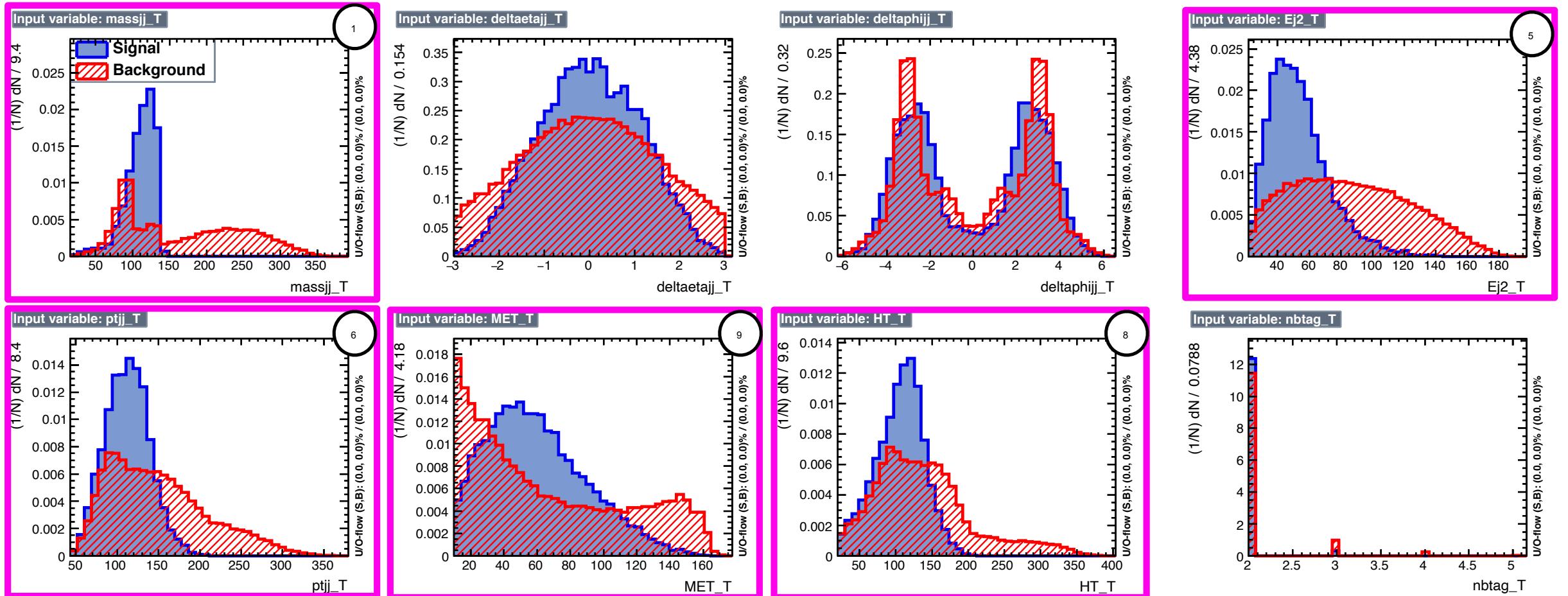


2. Adaptive BDT to further reduce the backgrounds

- 17 input variables
- trained with a 20k signal events and 100k background events
- 800 trees with a minimum node size of 1%, a maximum depth of 3



BDT variables and correlations

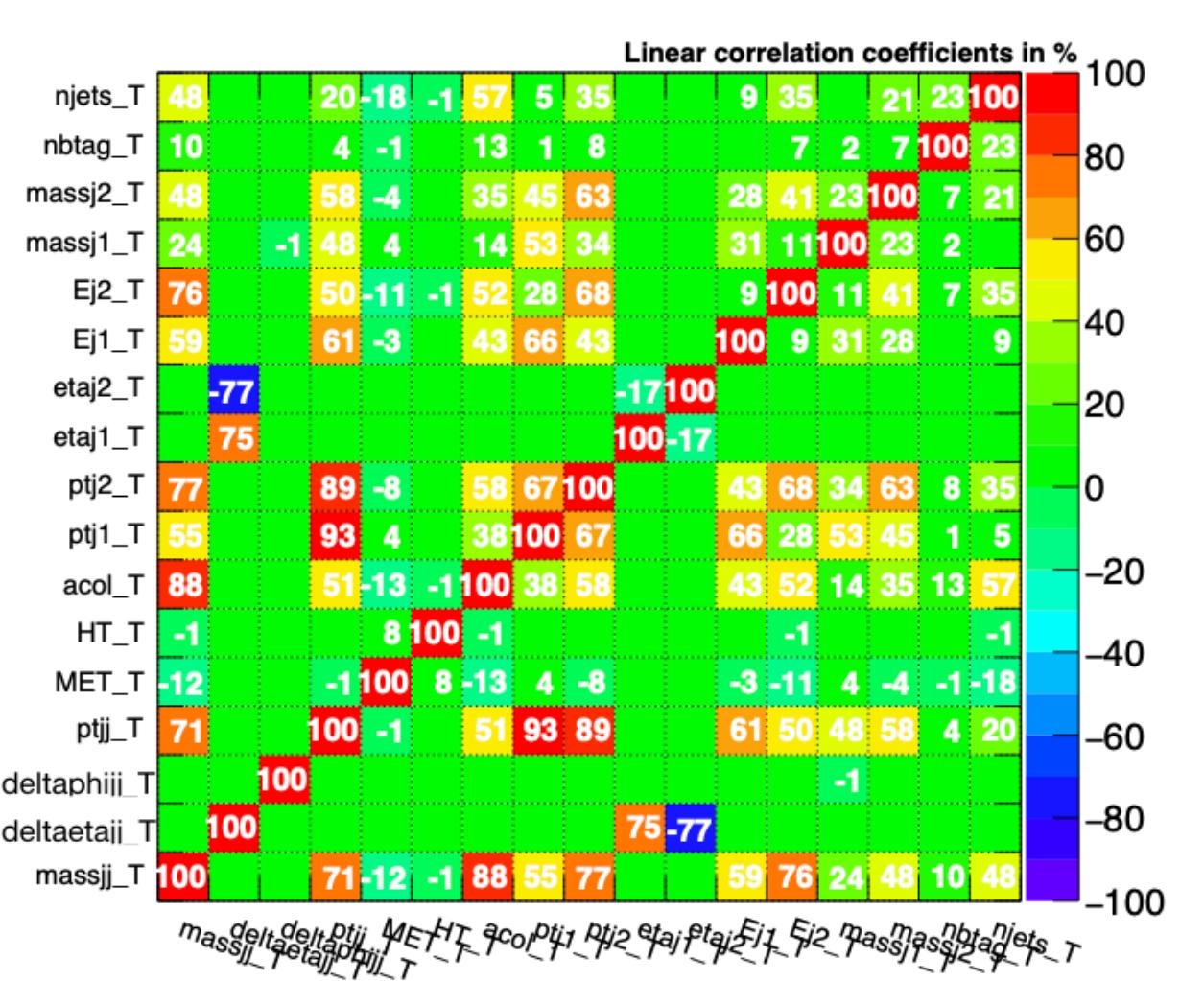
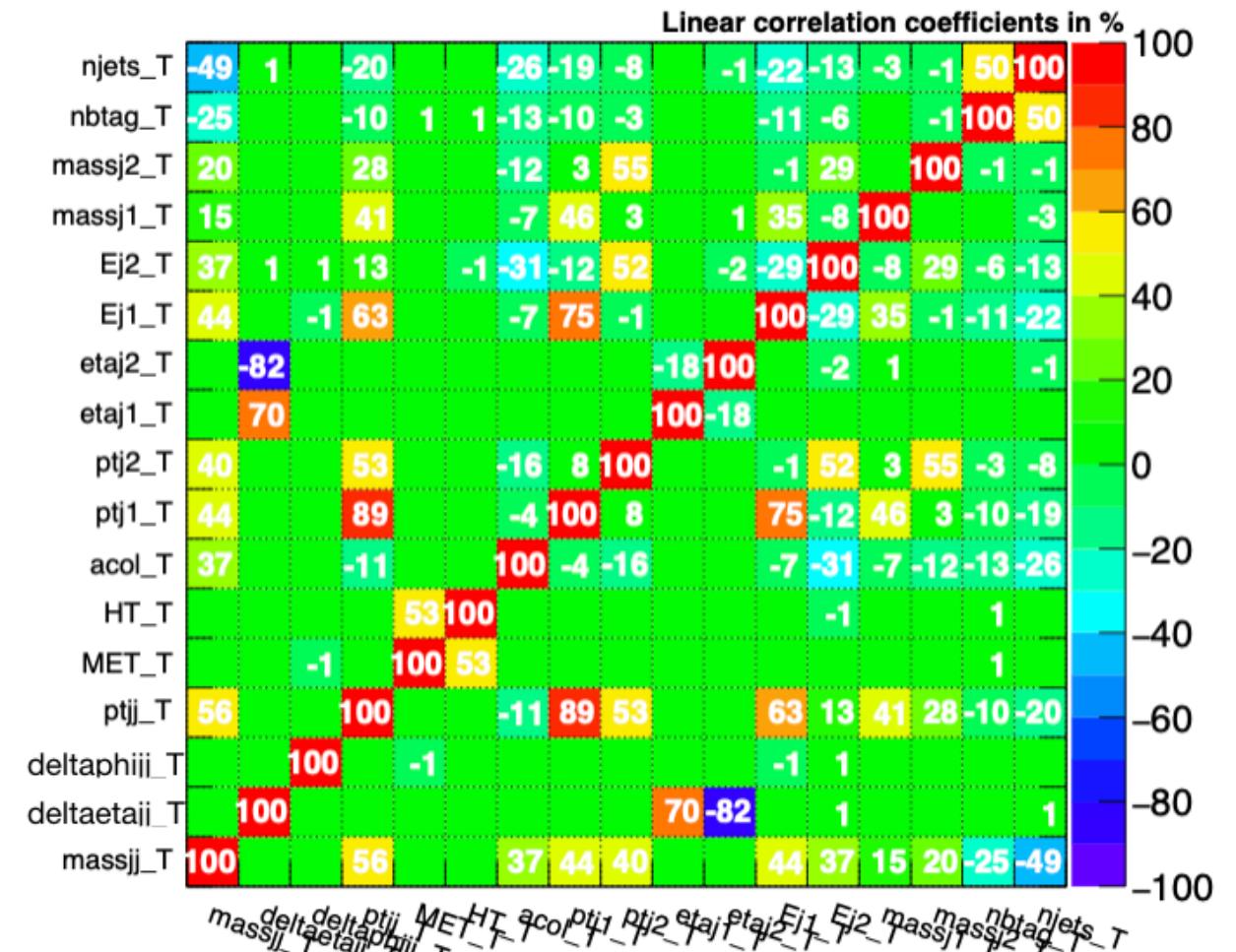


Rank	Variable	Separation
1	M_{jj}	$4.6 \cdot 10^{-1}$
2	n_j	$3.7 \cdot 10^{-1}$
3	$acol_{jj}$	$3.5 \cdot 10^{-1}$
4	E_{j1}	$3 \cdot 10^{-1}$
5	E_{j2}	$2.7 \cdot 10^{-1}$

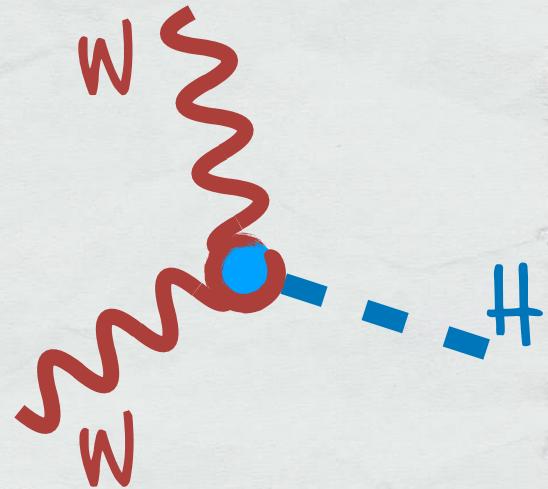
Rank	Variable	Separation
6	p_{Tjj}	$2 \cdot 10^{-1}$
7	p_{Tj2}	$1.9 \cdot 10^{-1}$
8	H_T	$1.6 \cdot 10^{-1}$
9	MET	$1.3 \cdot 10^{-1}$
10	p_{Tj1}	$1.1 \cdot 10^{-1}$

Separation integral:

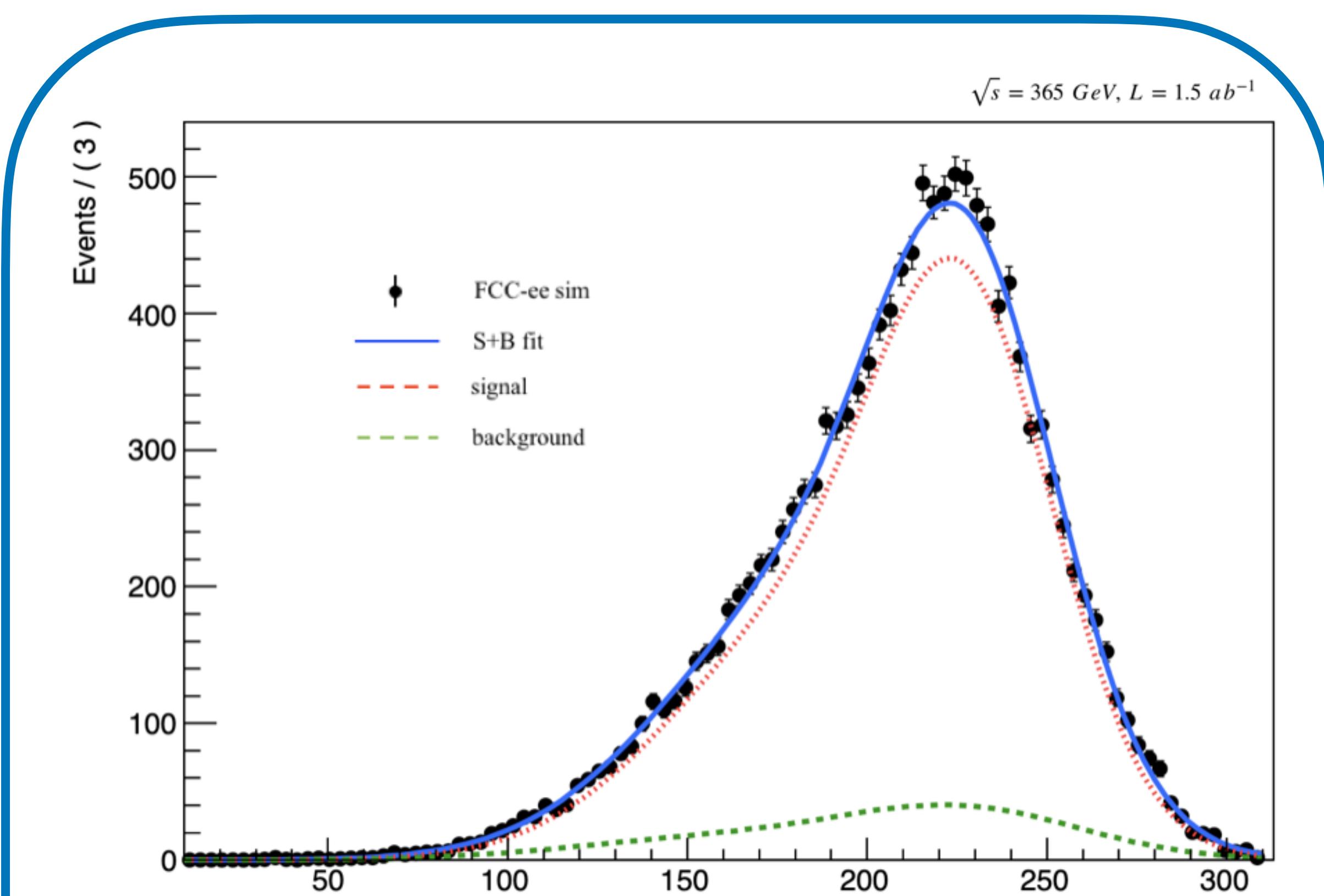
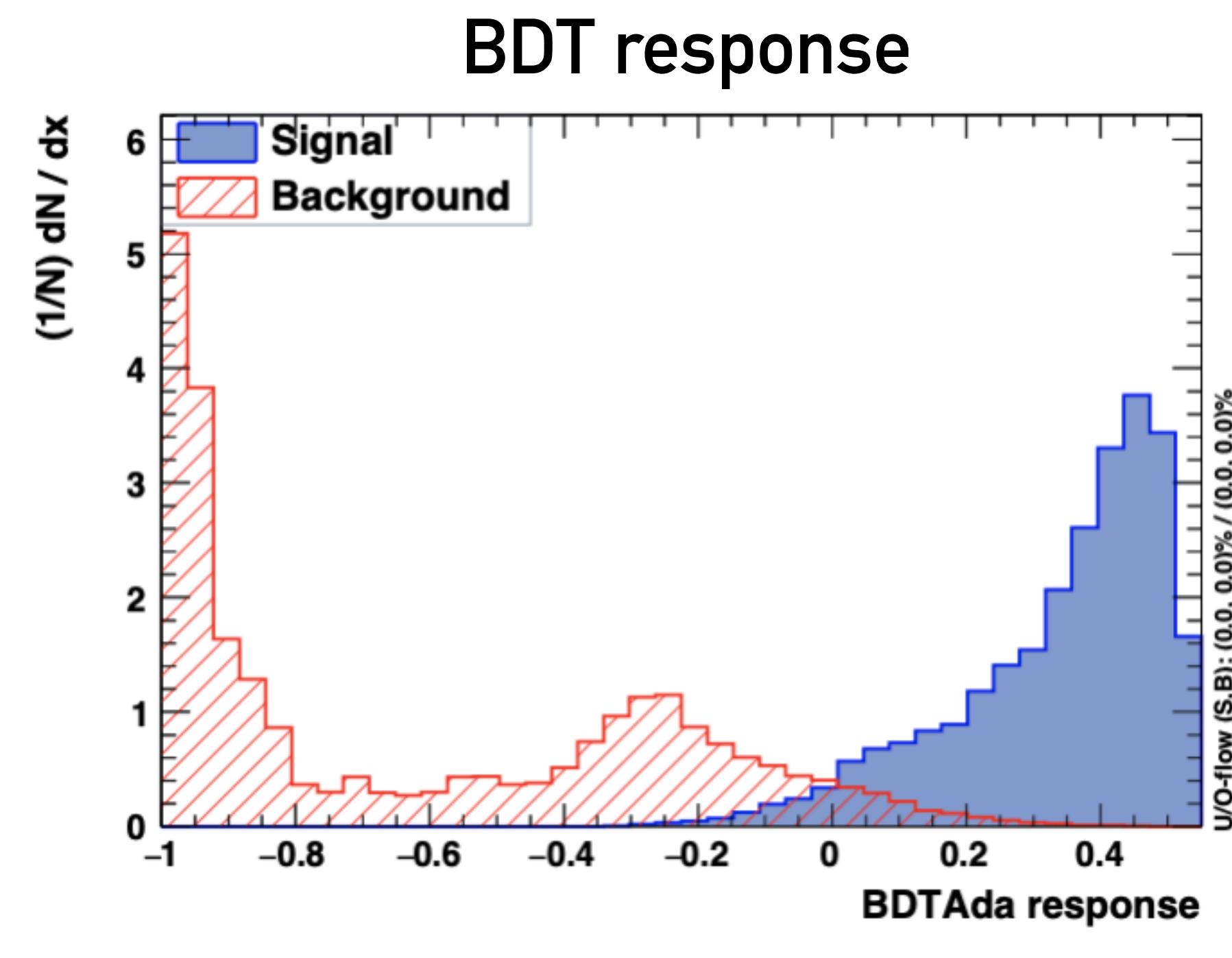
$$\text{I: } \langle S^2 \rangle = \frac{1}{2} \int dy \frac{(\hat{y}_S(y) - \hat{y}_B(y))^2}{(\hat{y}_S(y) + \hat{y}_B(y))}$$



Final discrimination variable



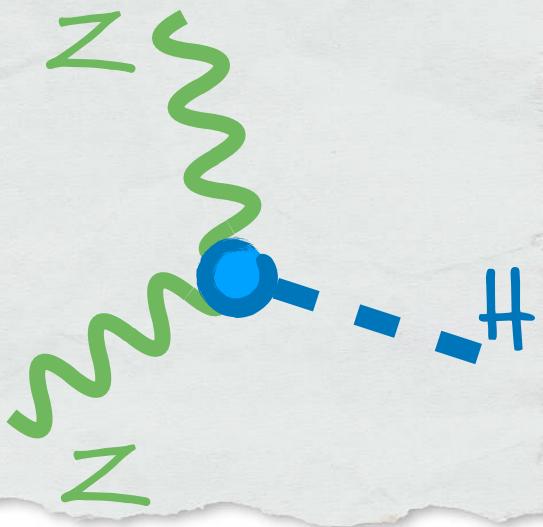
The missing mass after preselection and BDT cuts



MC samples	$\nu_e \bar{\nu}_e H(b\bar{b})$	$Z(\nu \bar{\nu}) H(b\bar{b})$	WW	ZZ
Number of events (normalized)	$3.05 \cdot 10^4$	$2.06 \cdot 10^4$	$1.61 \cdot 10^7$	$9.49 \cdot 10^5$
$n_{bj} \geq 2, \Delta\eta < 3, \text{HT} > 20, \text{MET} > 10 \text{ GeV}$	47%	48%	0.09%	5.5%
BDTAda response ≥ 0.12	42 %	3.4 %	0.002 %	0.06 %

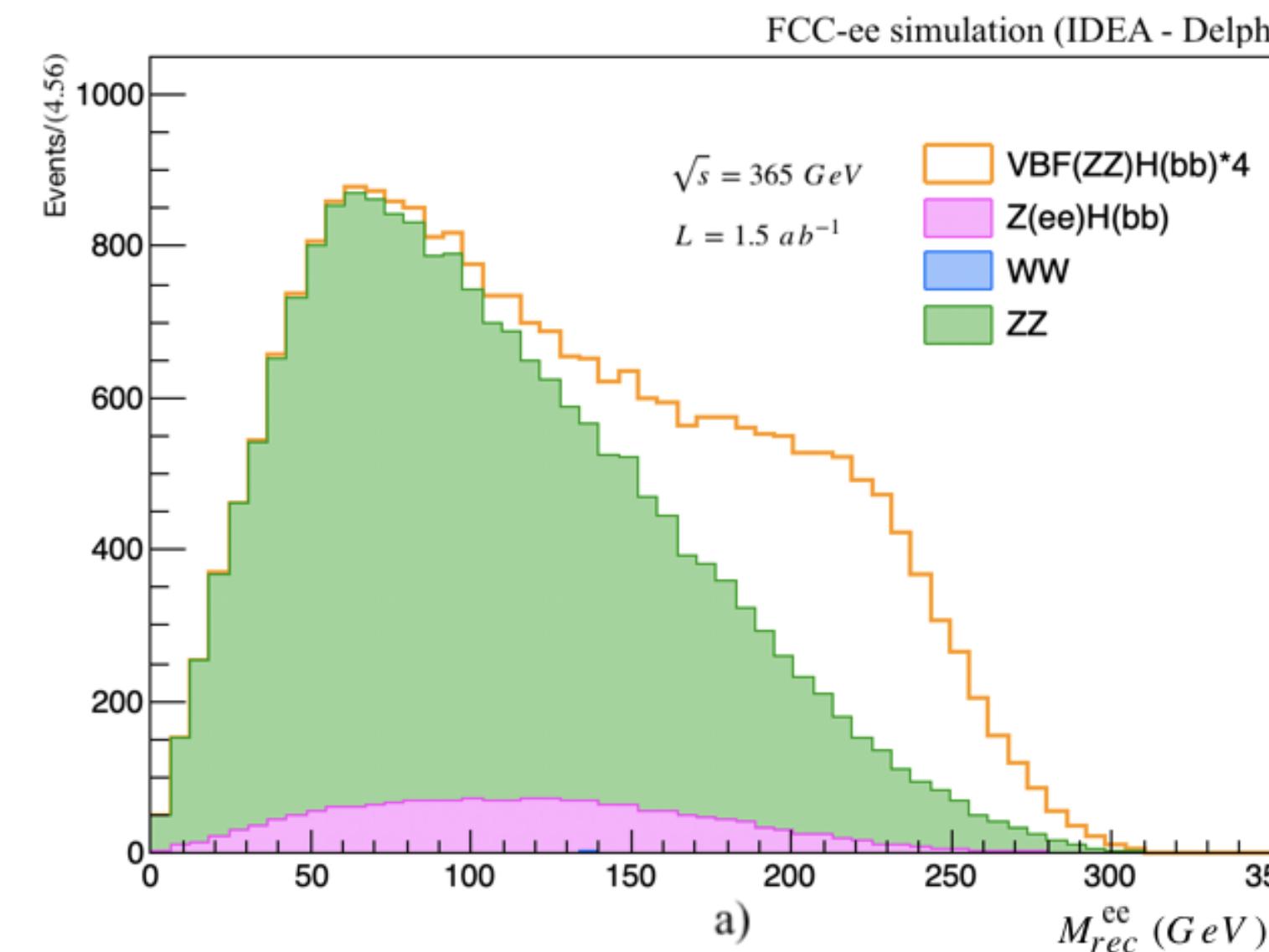
Signal (convolution of 2 Gaussians)

Irreducible background mainly from $Z(\nu\nu)H(b\bar{b})$



Z boson fusion: ee → eeH(bb)

1. Preselection cuts
 - 2 jets + 2 electrons
 - $m_{ee} > 80 \text{ GeV}$
 - MET > 10 GeV

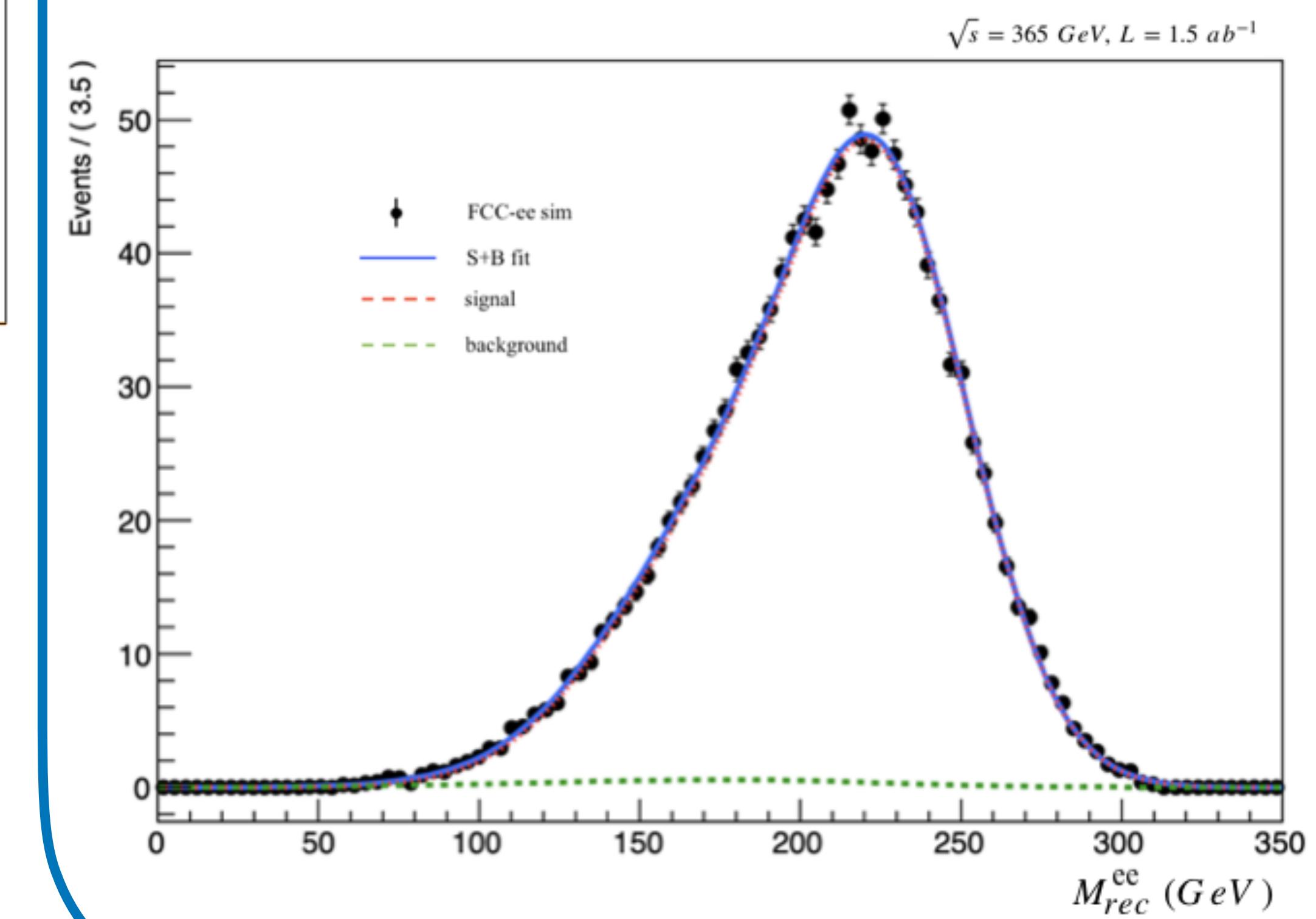


2. BDT to further reduce the backgrounds

Rank	Variable	Separation
1	$M_{e^+e^-}$	$9.1 \cdot 10^{-1}$
2	$acol_{e^+e^-}$	$7.1 \cdot 10^{-1}$
3	$acol_{jj}$	$7 \cdot 10^{-1}$
4	n_{bj}	$4.6 \cdot 10^{-1}$

Rank	Variable	Separation
5	M_{jj}	$3.8 \cdot 10^{-1}$
6	η_{e_2}	$2.4 \cdot 10^{-1}$
7	E_{j1}	$2.1 \cdot 10^{-1}$
8	η_{j1}	$1.4 \cdot 10^{-1}$

Fit to the recoil mass spectrum in after the BDT



Combination of orthogonal analyses

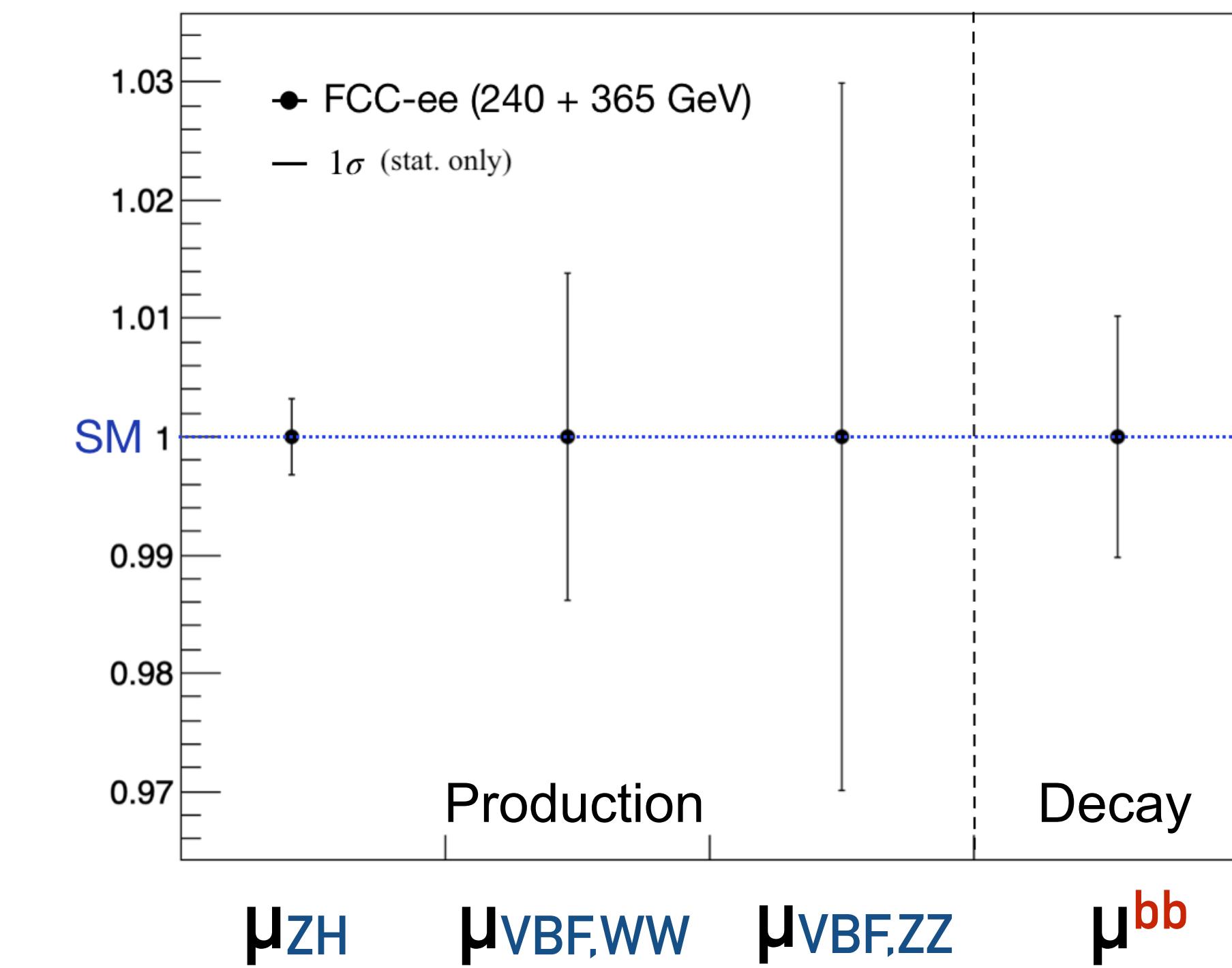
For each analysis the signal strength is parametrised as

$$\mu_i^f = \frac{\sigma_i \cdot BR^f}{(\sigma_i \cdot BR^f)_{SM}} = \mu_i \times \mu^f$$

Combining

- inclusive analyses : measure of μ_{ZH}
- an exclusive analysis $Z(l\bar{l})H(bb)$: measure of μ^{bb}
- two VBF analysis for $H(bb)$: measure of $\mu_{VBF,WW}$ and $\mu_{VBF,ZZ}$

This analysis can be easily extended with more decay channels



Does the Higgs boson interact with itself?

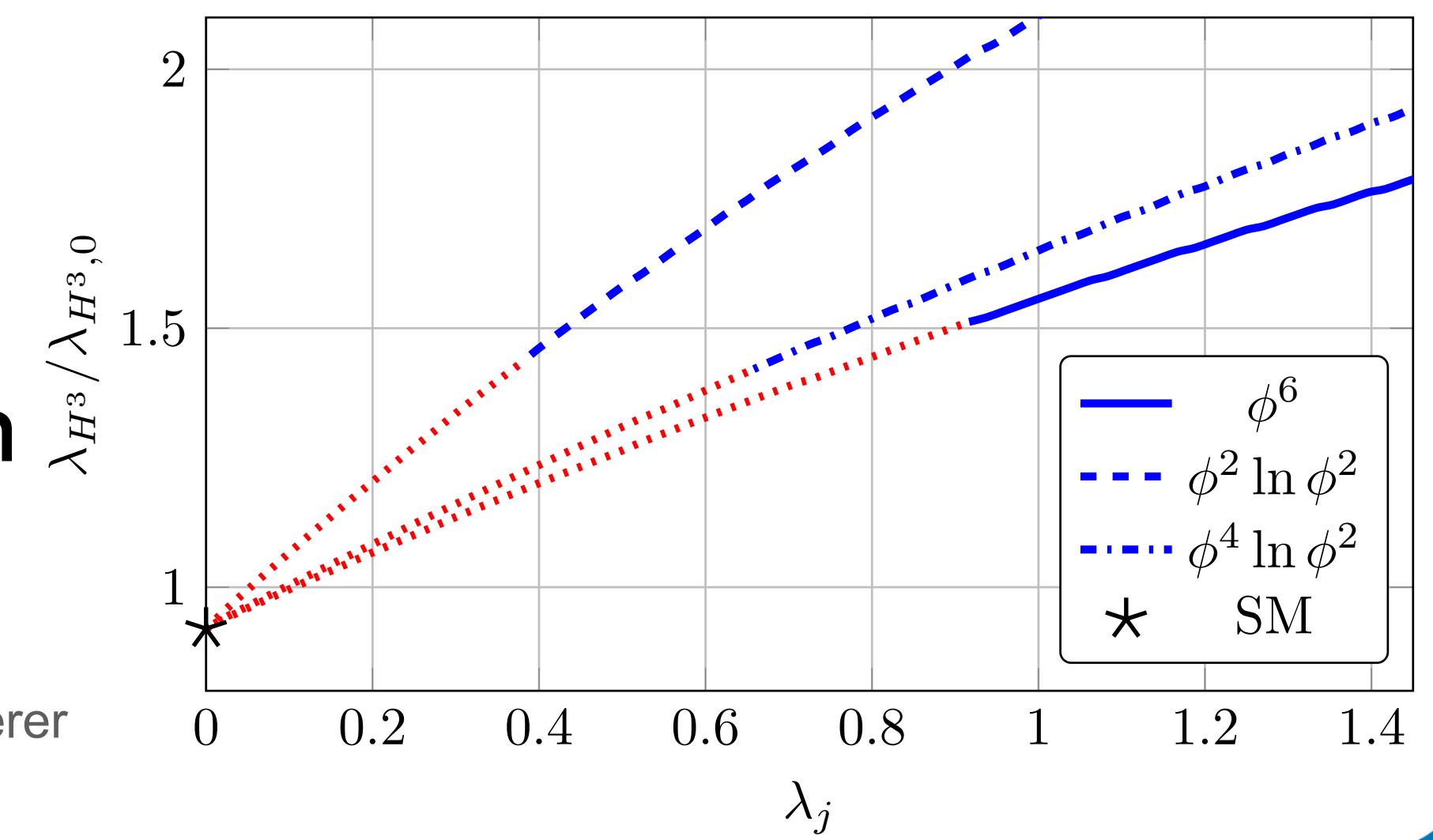
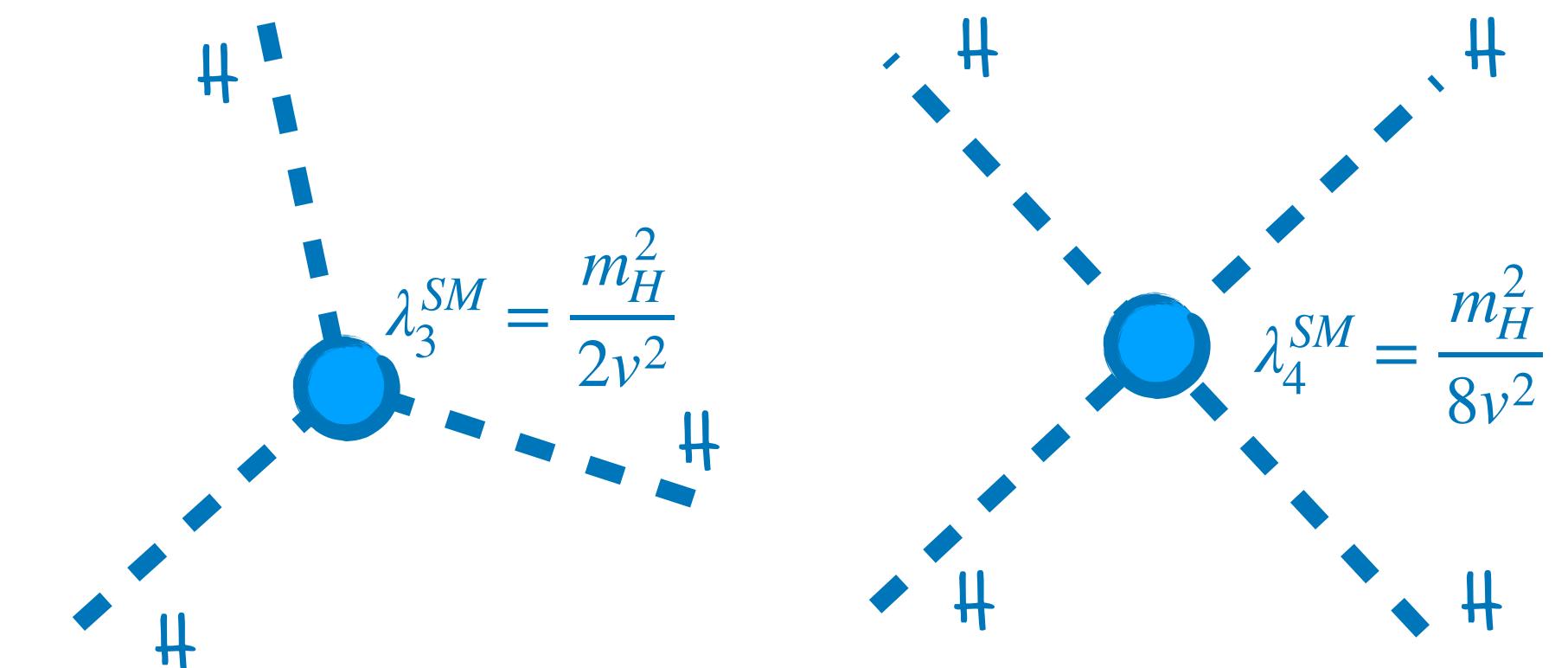
A self-interacting Higgs (as SM predicts) would be unlike anything yet seen in nature. All other interactions change particle identity.

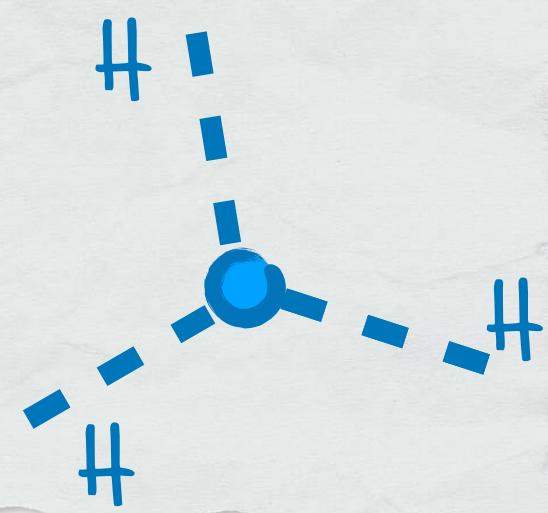
The Higgs boson cubic (λ_3^{SM}) and quartic (λ_4^{SM}) couplings are the keys to check the EWSB. The Higgs boson potential is :

$$\mathcal{L} \subset -\frac{m_h^2}{2}h^2 - \lambda_3^{SM}vh^3 - \lambda_4^{SM}h^4$$

Link with the cosmology

Deviation from SM Higgs boson self-coupling cause modified potential that **allows strong first-order electroweak phase transition** and hence an explanation of the observed matter vs anti-matter asymmetry!

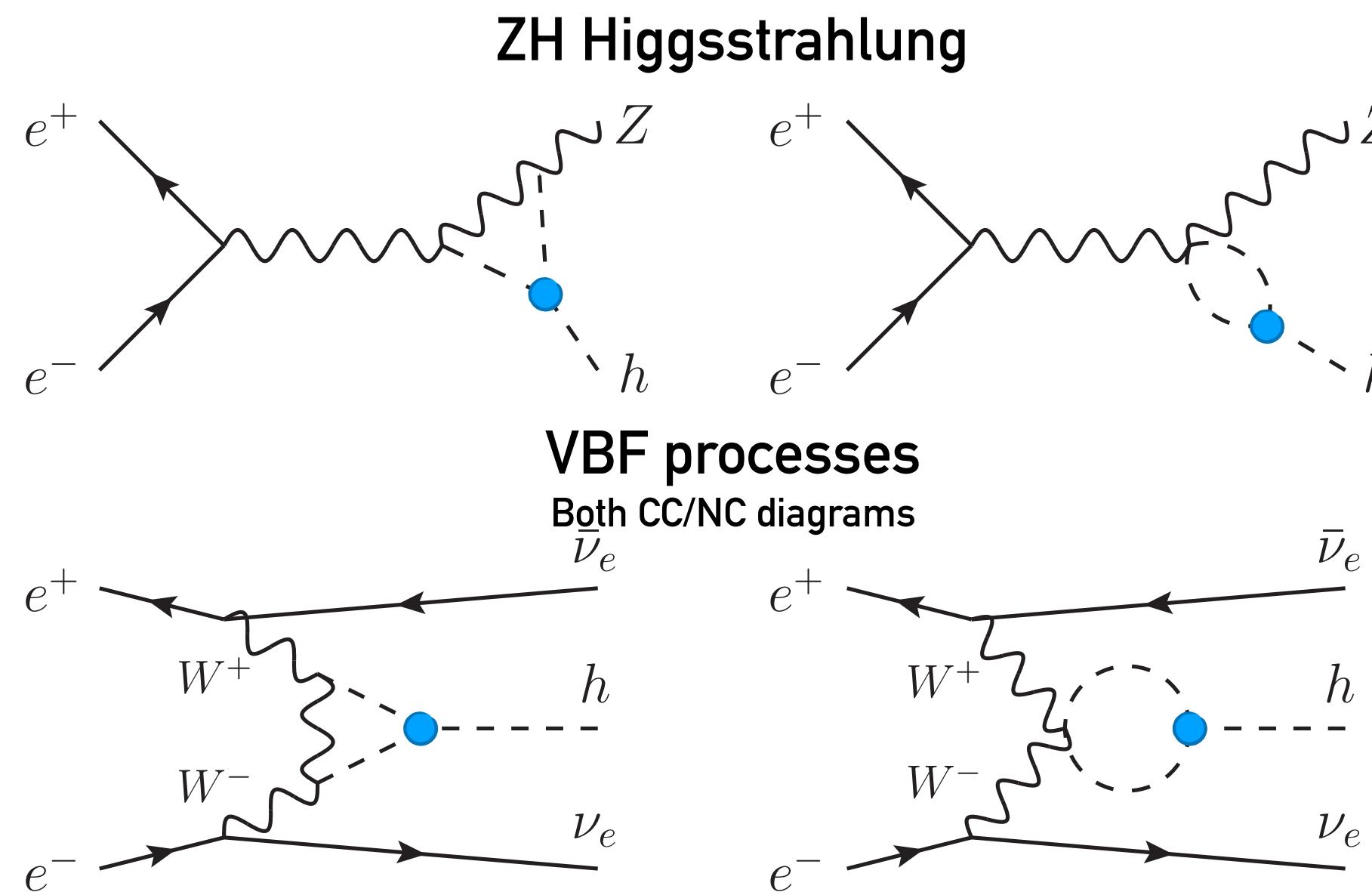




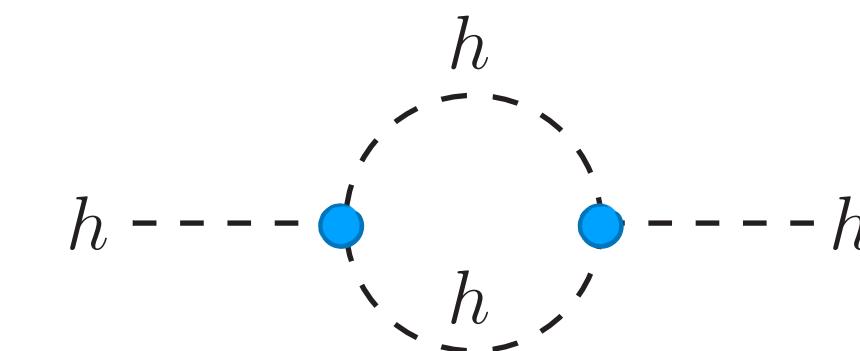
Higher-order corrections to single-Higgs processes

λ_{HHH} does not enter single-Higgs processes at LO but it affects both Higgs production and decay at NLO.

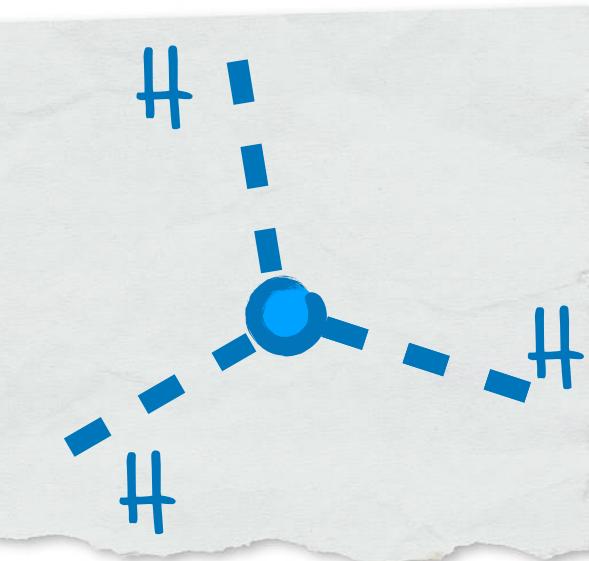
Linear correction to the vertex



Quadratic corrections
(wave function renormalisation)



λ_3 effect

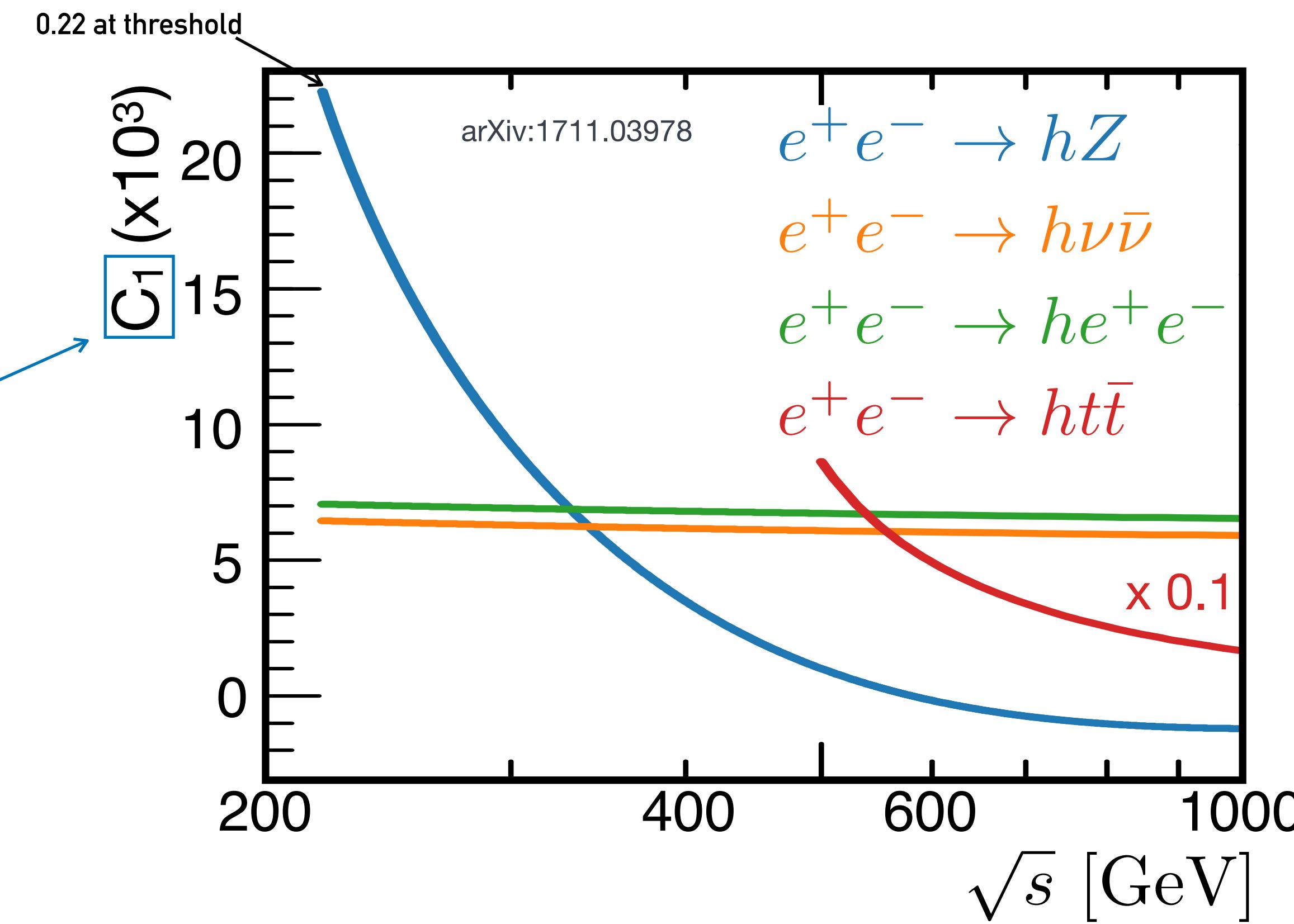
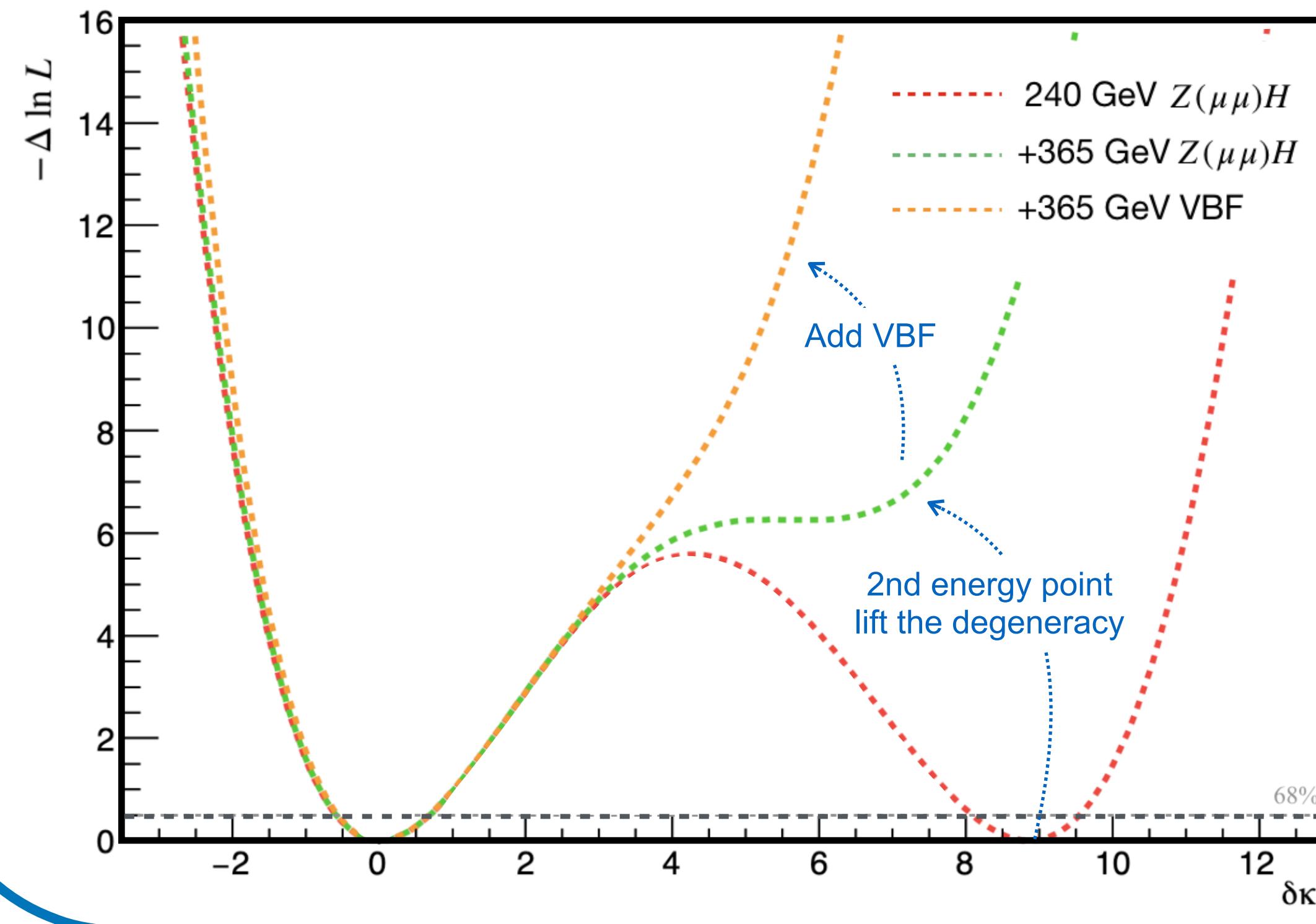


The NLO corrections to an observable Σ

$$\Sigma_{\text{NLO}} = \boxed{Z_H} \Sigma_{\text{LO}} (1 + \kappa_\lambda \boxed{C_1})$$

Universal coefficient

Process dependent coefficient



Caveats :

1D fit with only $\delta\kappa_\lambda$ floating
 $\sigma(\text{HZ})$ without BES

Conclusions

Preliminary results based on the work done during a M2 internship have been shown.

The analysis chain has been put in place to measure few Higgs boson couplings (HZZ, HWW, HHH) profiting of two energy points.

The analyses will be repeated using the centrally produced samples, add all the needed systematics,

More interested people are joining the effort.