Higgs boson coupling measurements

focus on HWW, HZZ, HHH

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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 not used (beam energy spread is not considered)
→ 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(μμ)H

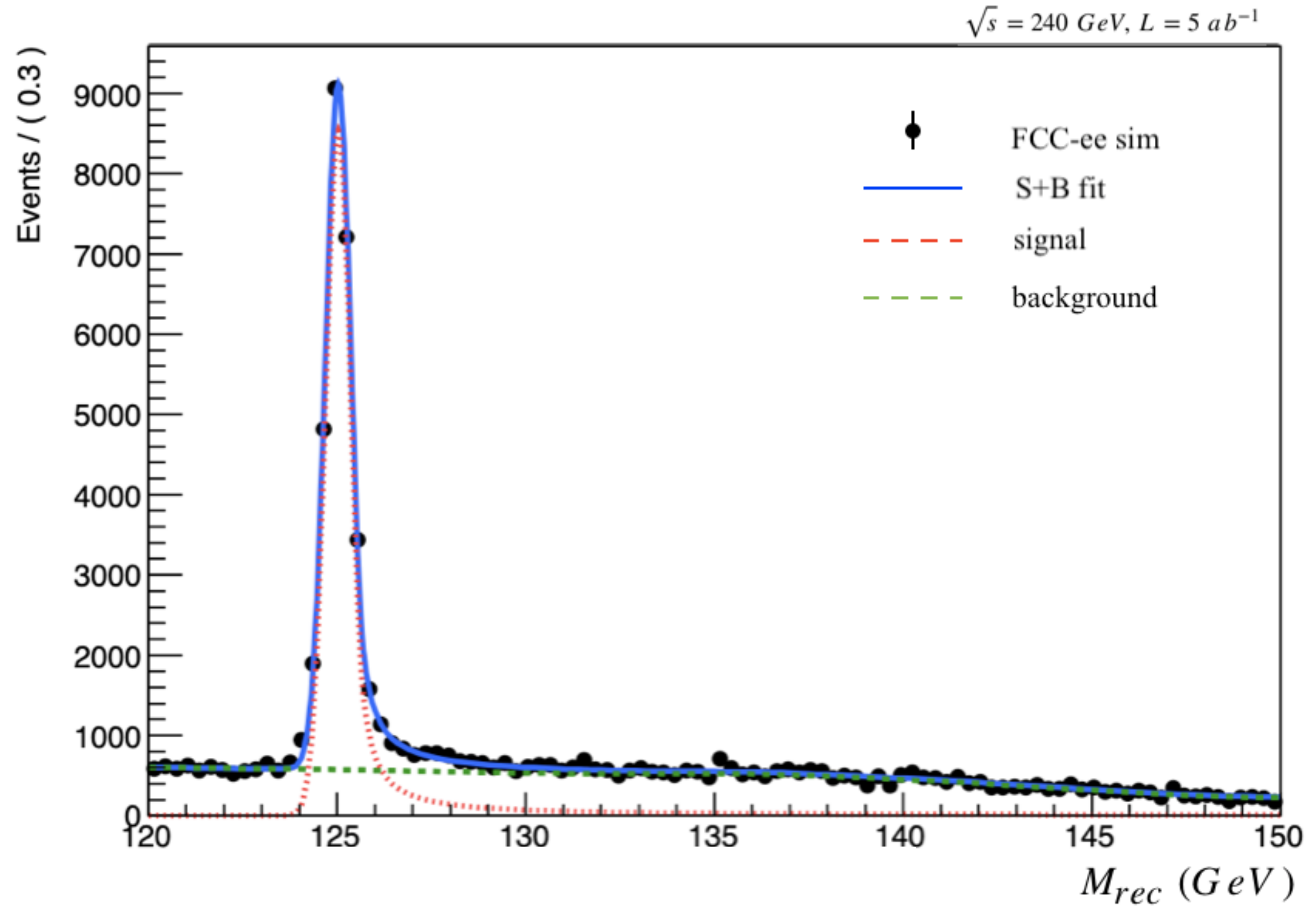
- $\mu^+\mu^-$ with $p_{T\mu1} > 20$ GeV, $p_{T\mu2} > 5$ GeV
- Minimum $|M_{\mu^+\mu^-} - M_Z|$
- $80 < M_{\mu^+\mu^-} < 100$ GeV

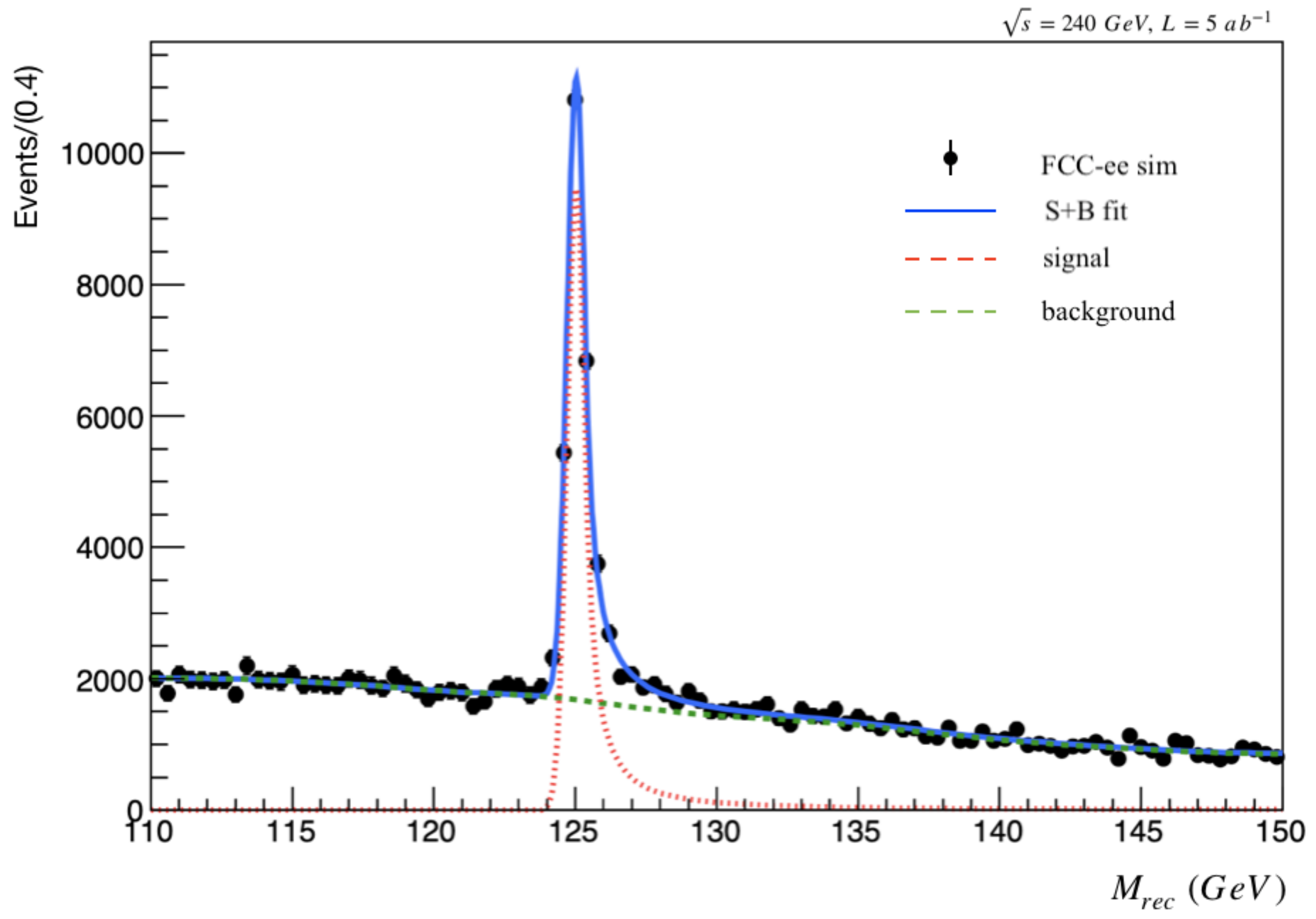
Z(ee)H

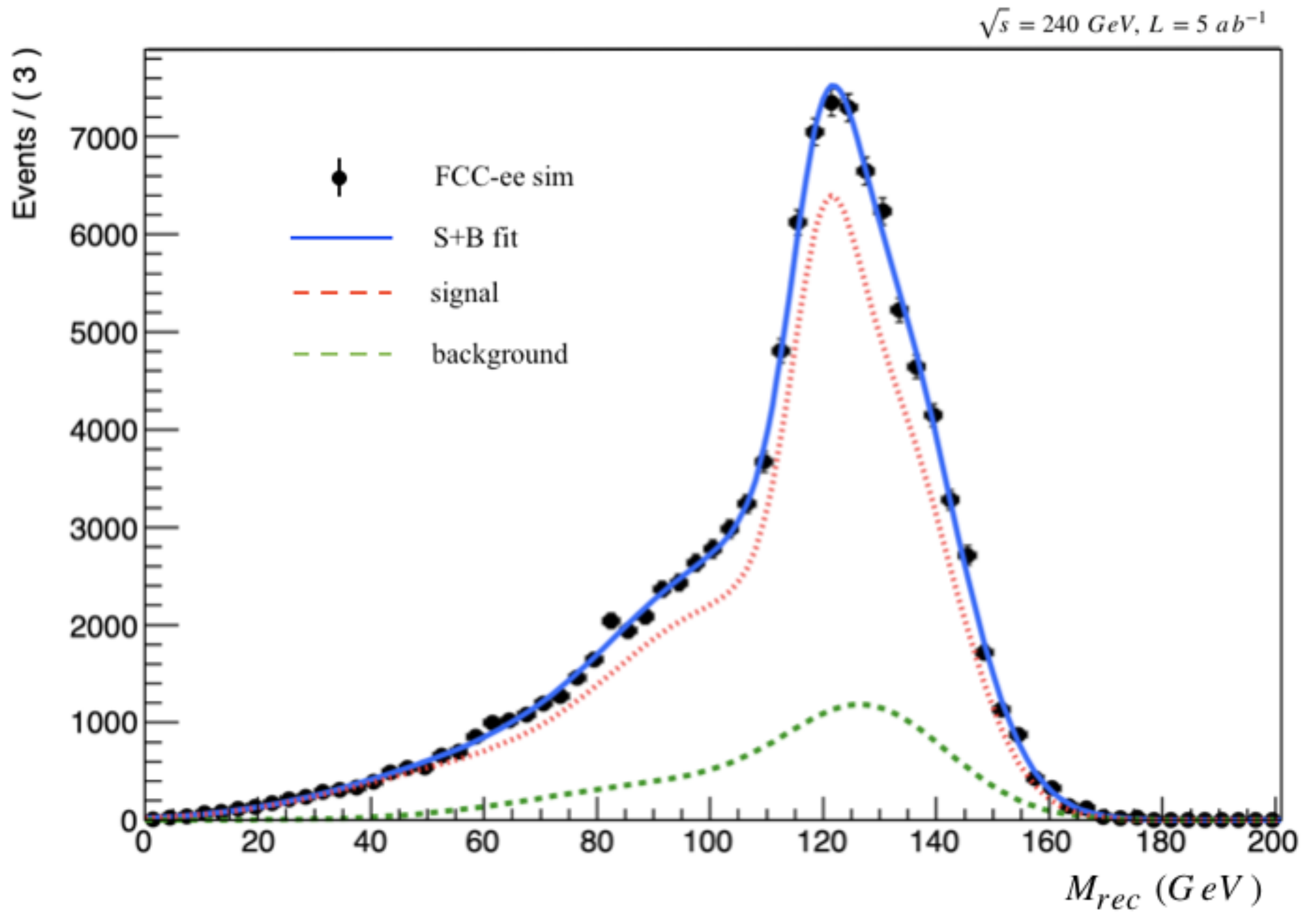
- e^+e^- with $p_{Te1} > 10$ GeV, $p_{Te2} > 5$ GeV
- Minimum $|M_{e^+e^-} - M_Z|$
- $60 < M_{e^+e^-} < 120$ GeV

Z(bb)H

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





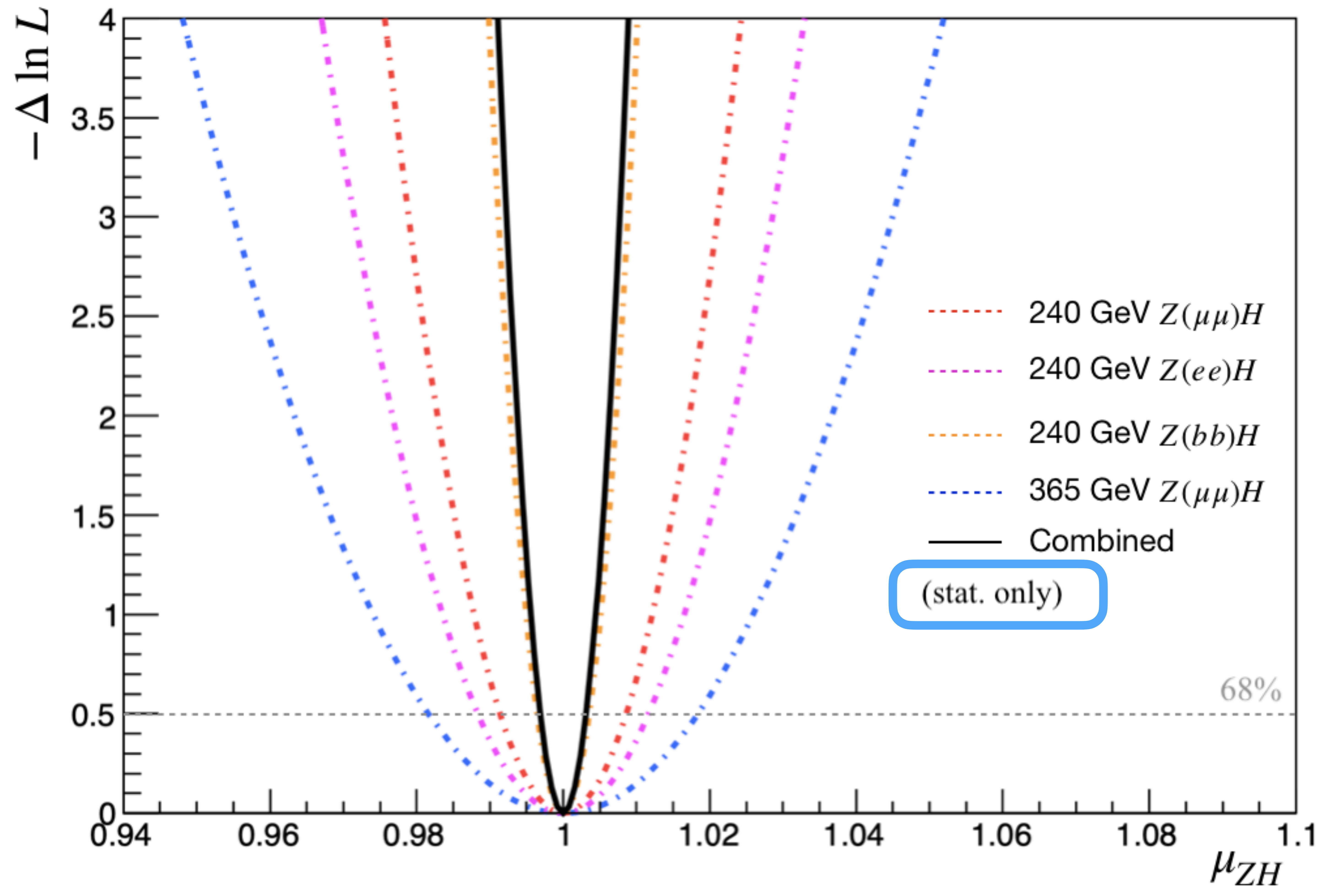


Inclusive analyses @240 GeV

Exploited few Z decays, using the recoil techniques

Z(μμ)H

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

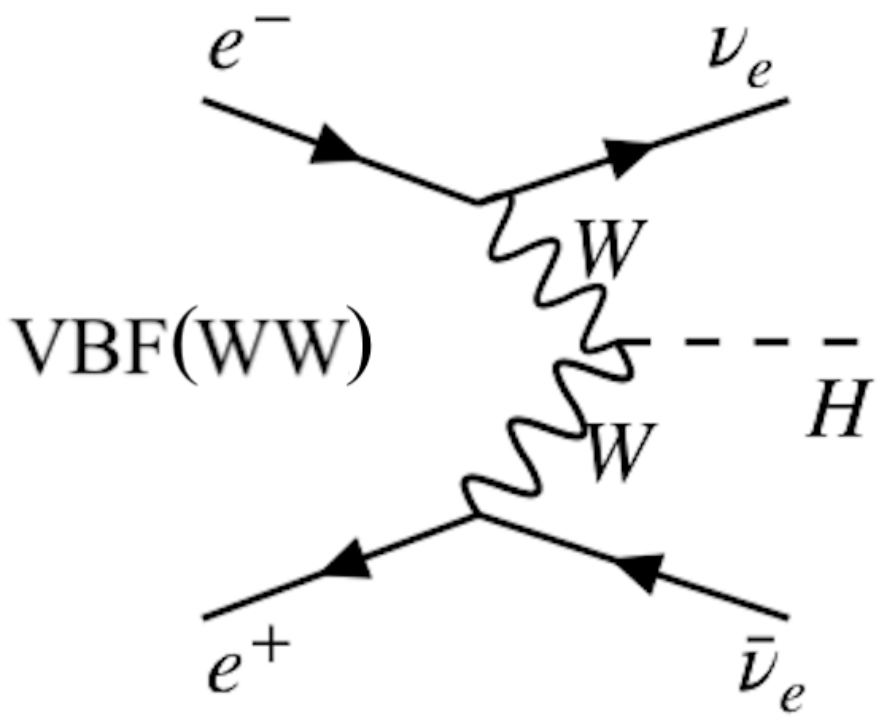


Z(bb)H

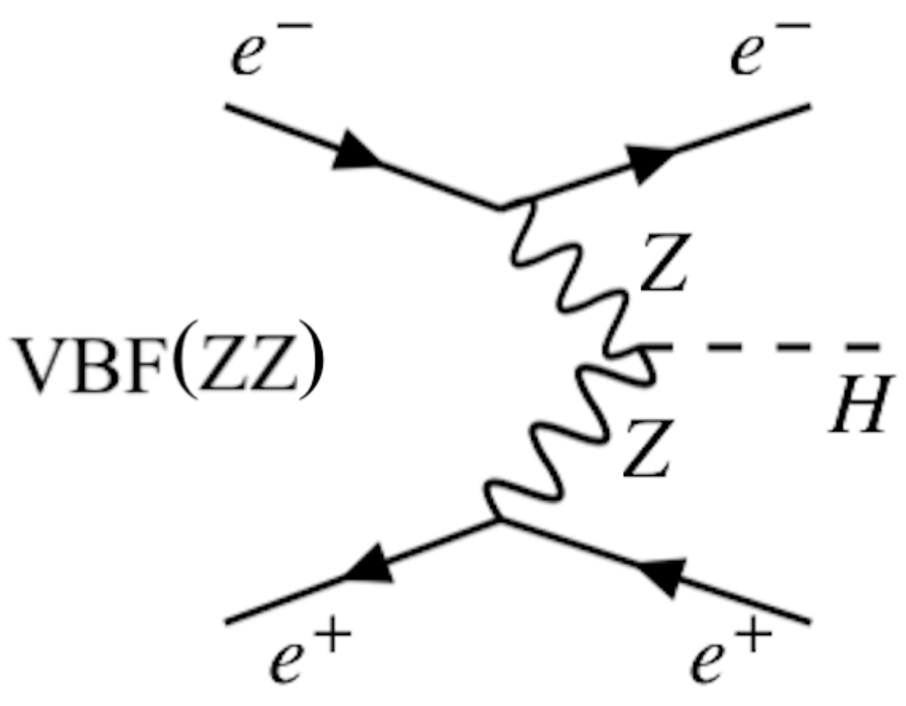
ets + $p_{Tjj} > 60$ GeV
5 GeV
) GeV
7 variables)

Study the VBF production @365 GeV

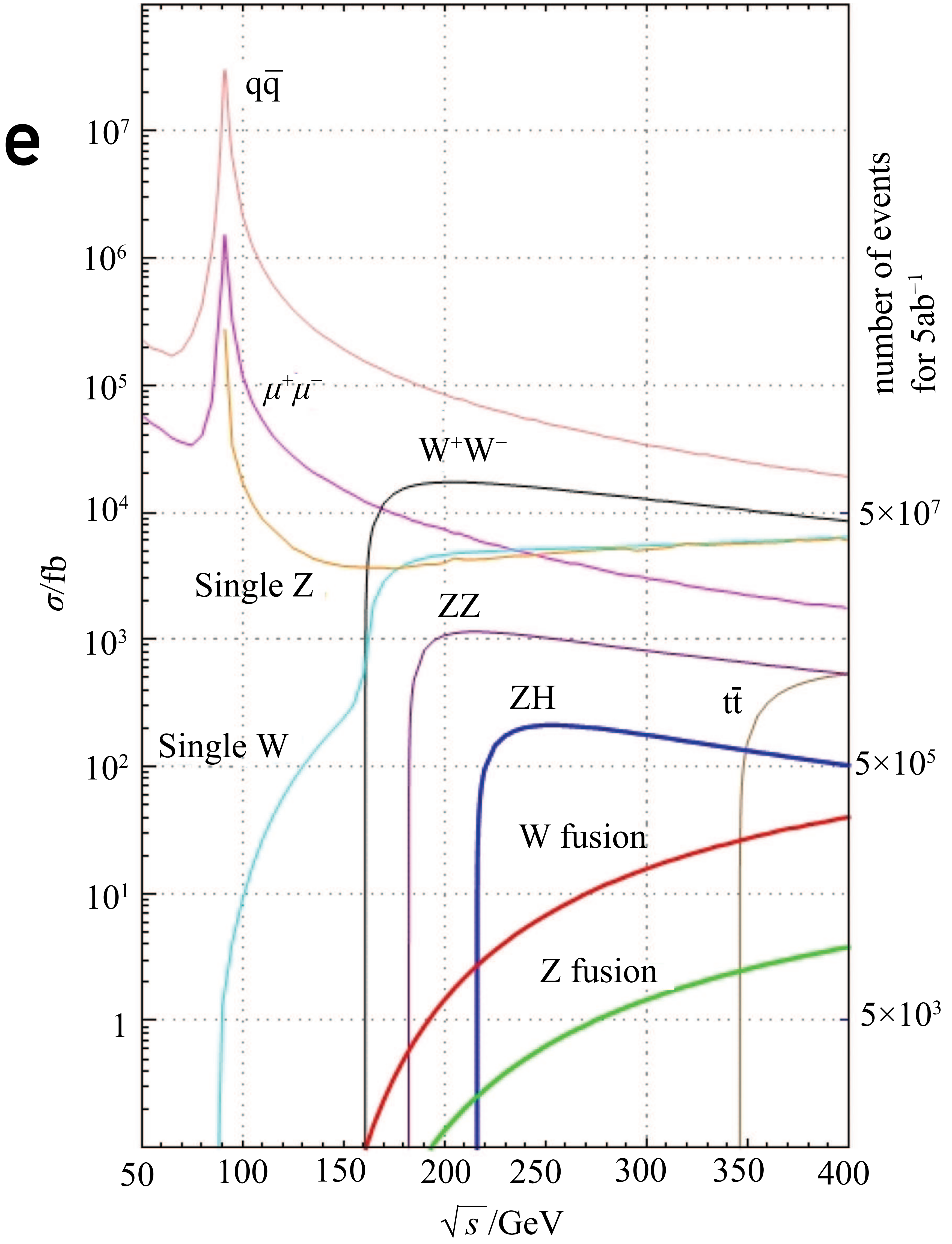
Production starts to become relevant due the logarithmic raise $\sim\ln^2(s/M_V^2)$ of the t-channel exchange of vector bosons



~50k Higgs at 365 GeV (1.5 ab^{-1})

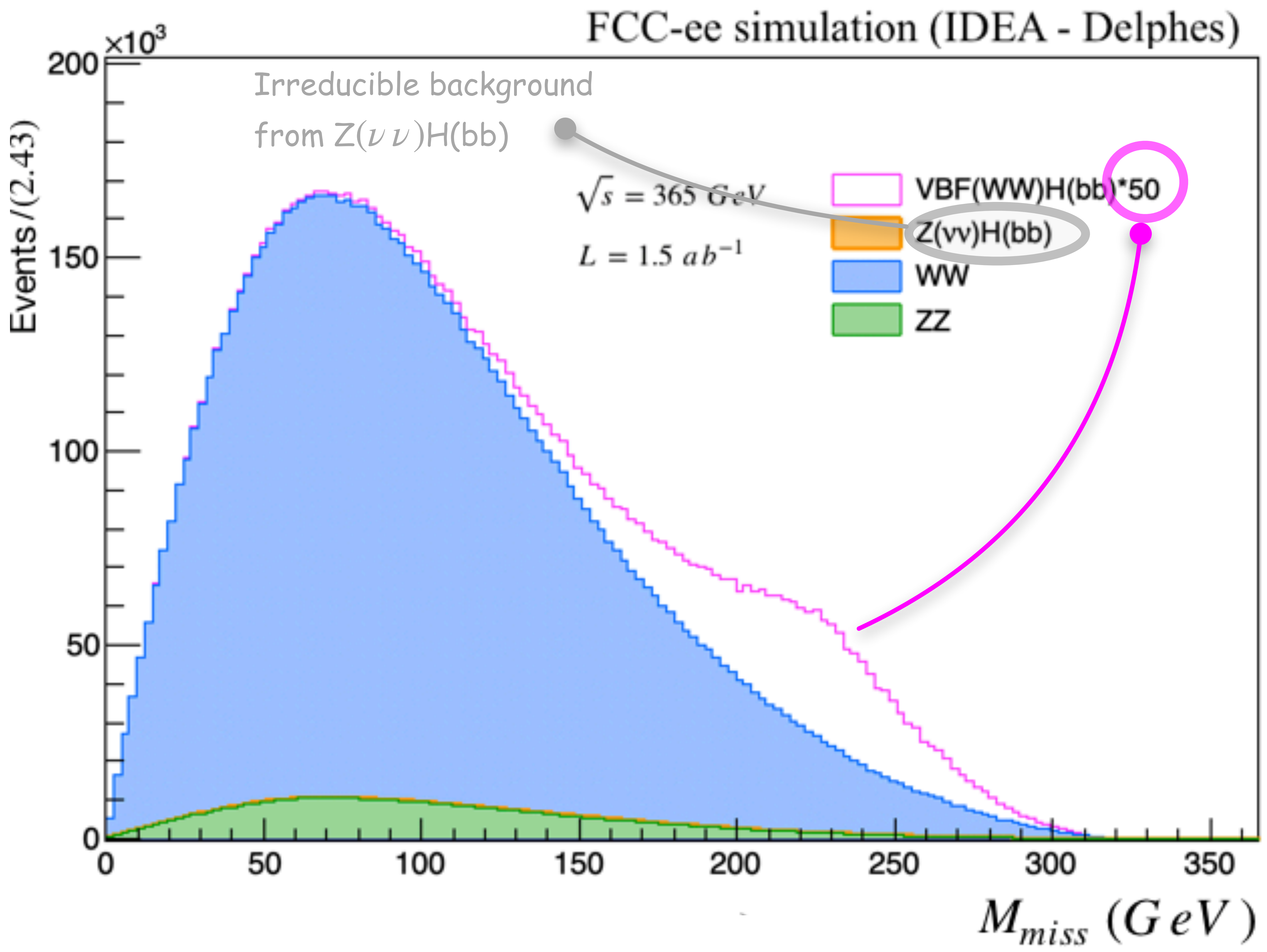


~4k Higgs at 365 GeV (1.5 ab^{-1})



Production dominated by the W fusion because of larger charged currents

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



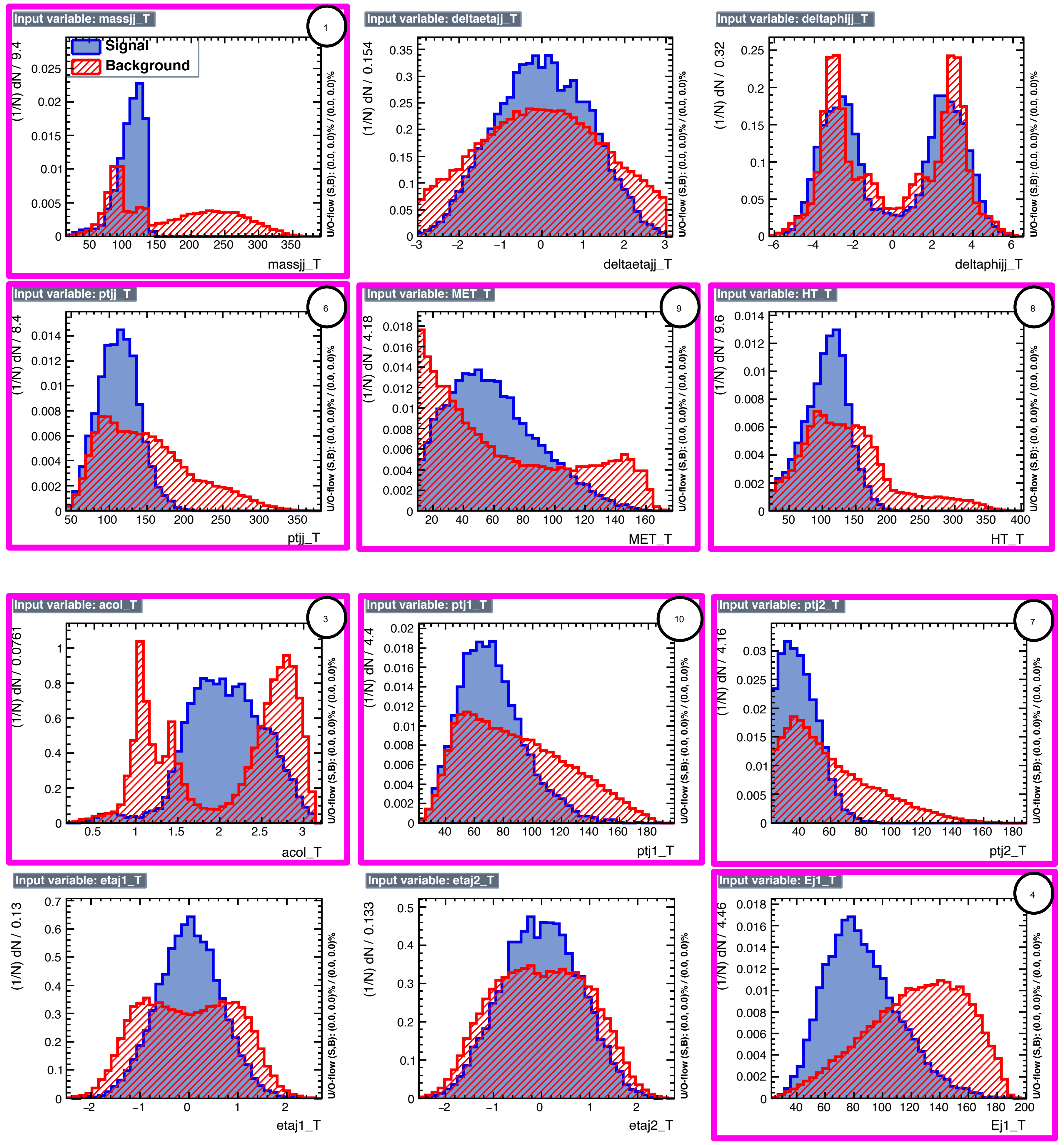
Preselection cuts

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

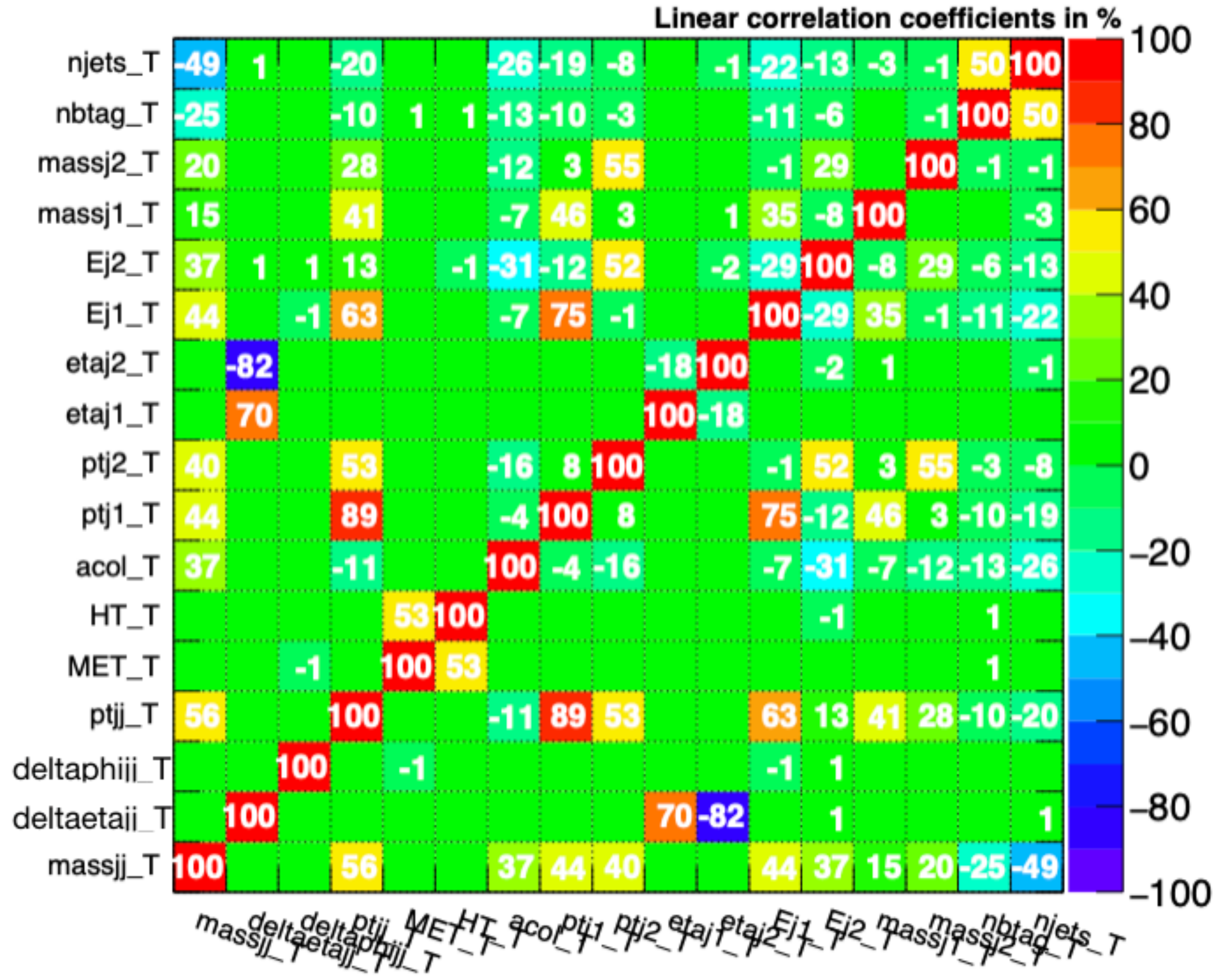
Deploy an adaptive BDT to further reduce the backgrounds

- ➔ 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



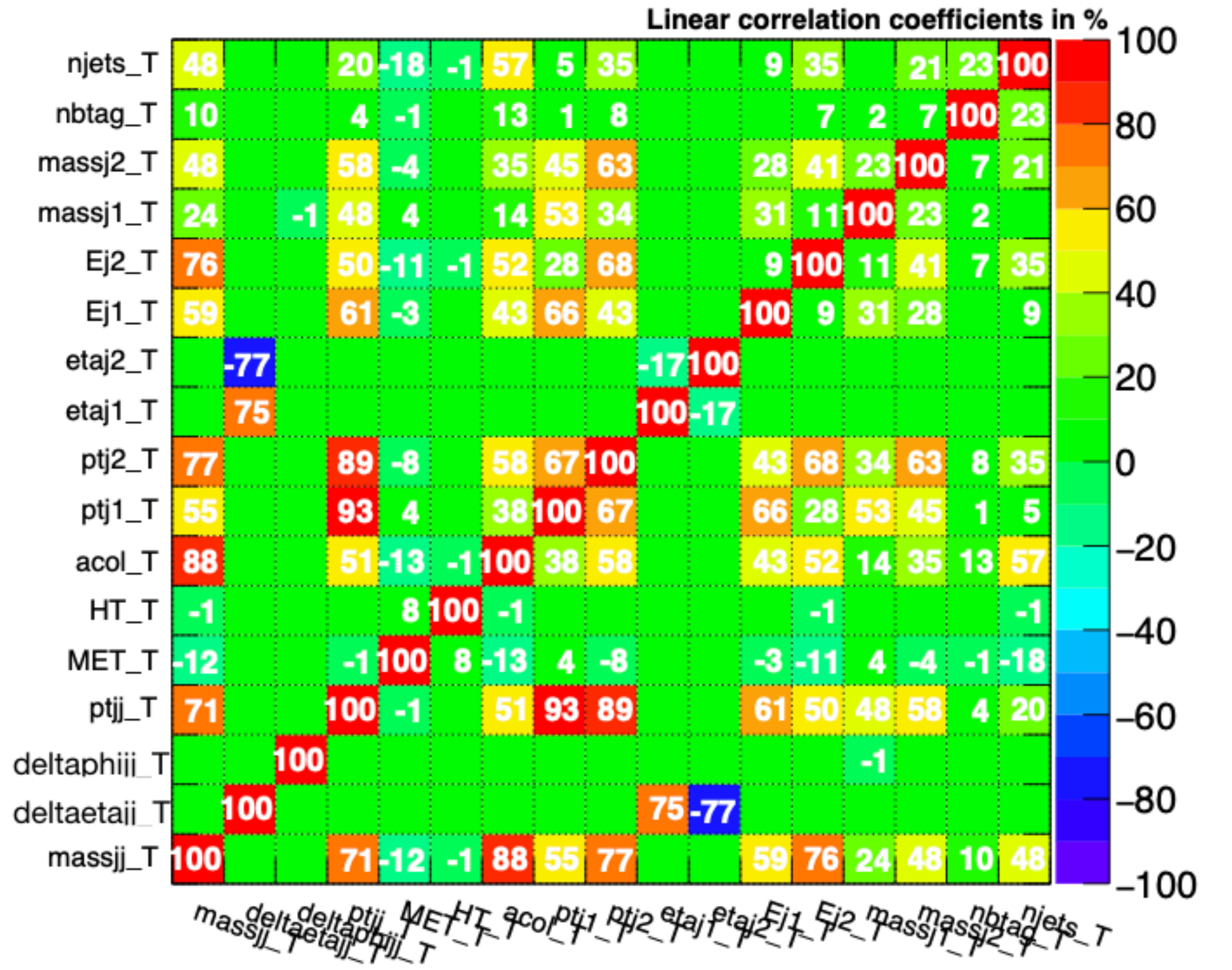
Correlation Matrix (signal)



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}	$1.1 \cdot 10^{-1}$

Correlation Matrix (background)

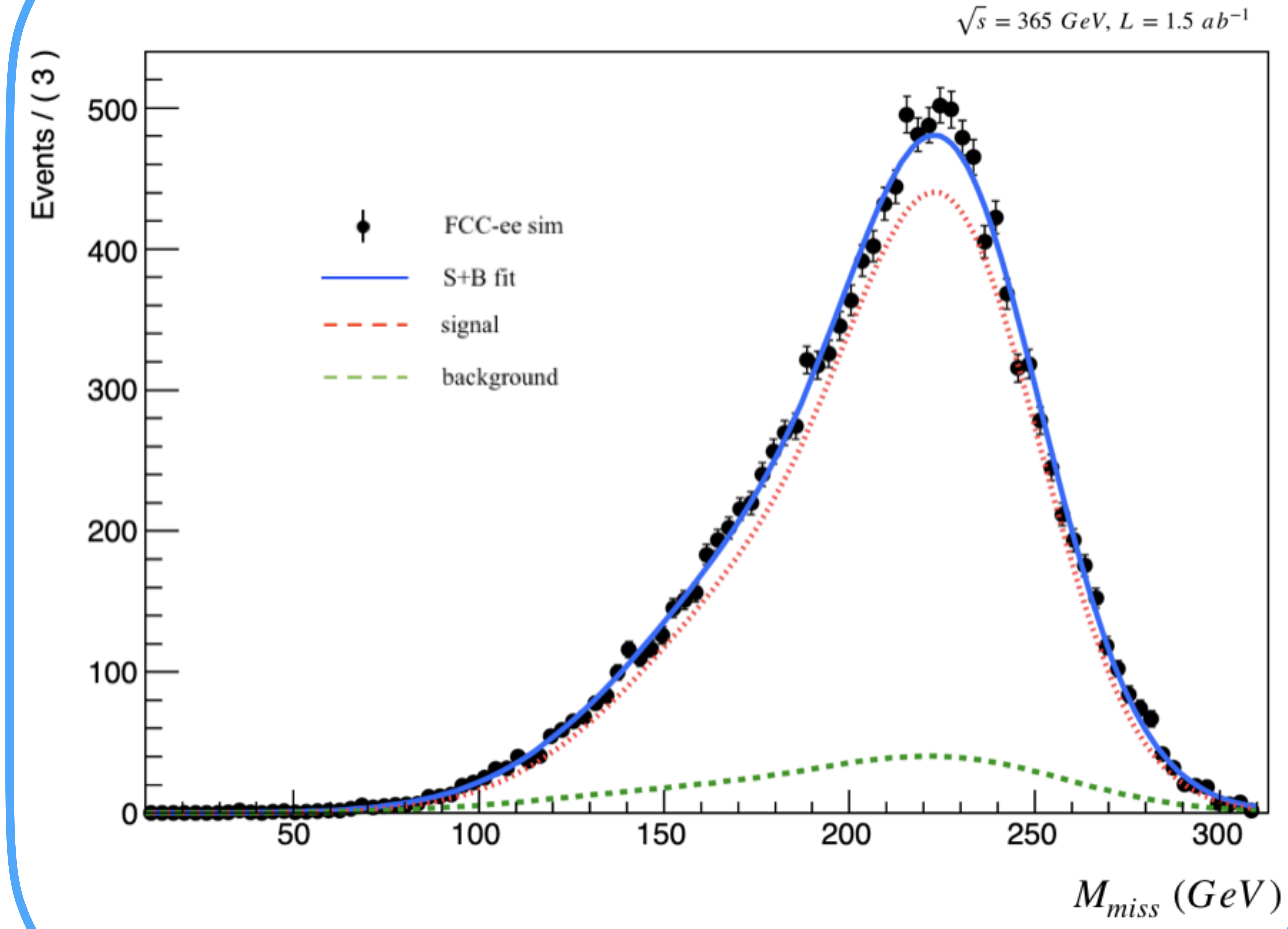


Separation integral: $$\langle S^2 \rangle = \frac{1}{2}\int dy \frac{(\hat{y}_S(y) - \hat{y}_B(y))^2}{(\hat{y}_S(y) + \hat{y}_B(y))}$$

After the BDT selection

Fit to the missing mass after the application of the preselections and BDT cut.

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)	$3.05 \cdot 10^4$	$2.06 \cdot 10^4$	$1.61 \cdot 10^7$	$9.49 \cdot 10^5$
$n_{bj} \geq 2$, $\lvert\Delta\eta\rvert < 3$, HT > 20, MET > 10 GeV	47%	48%	0.09%	5.5%
BDTAda response ≥ 0.12	42 %	3.4 %	0.002 %	0.06 %



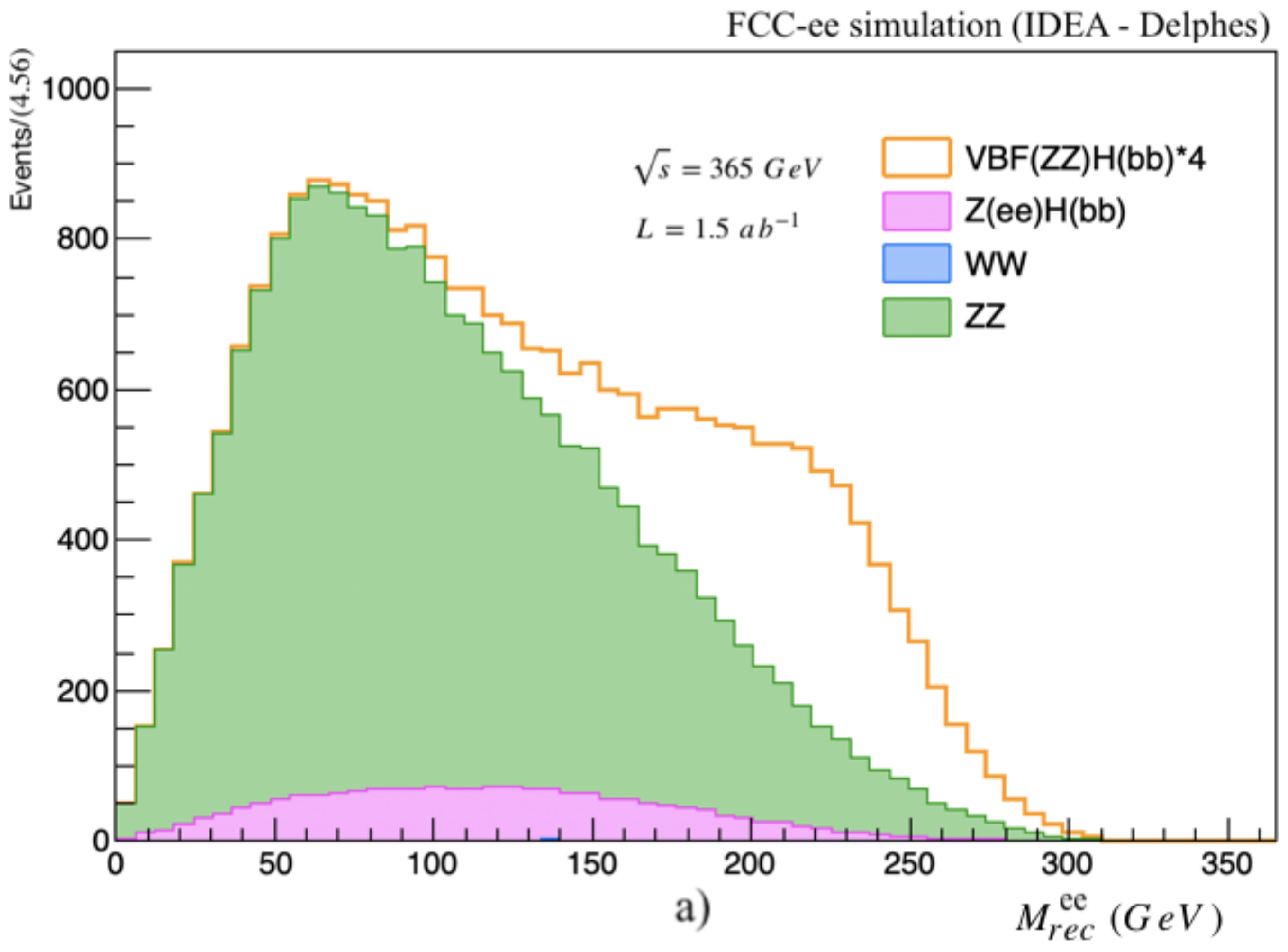
Signal (convolution of 2 Gaussians)

Irreducible background mainly from Z(νν)H(bb)

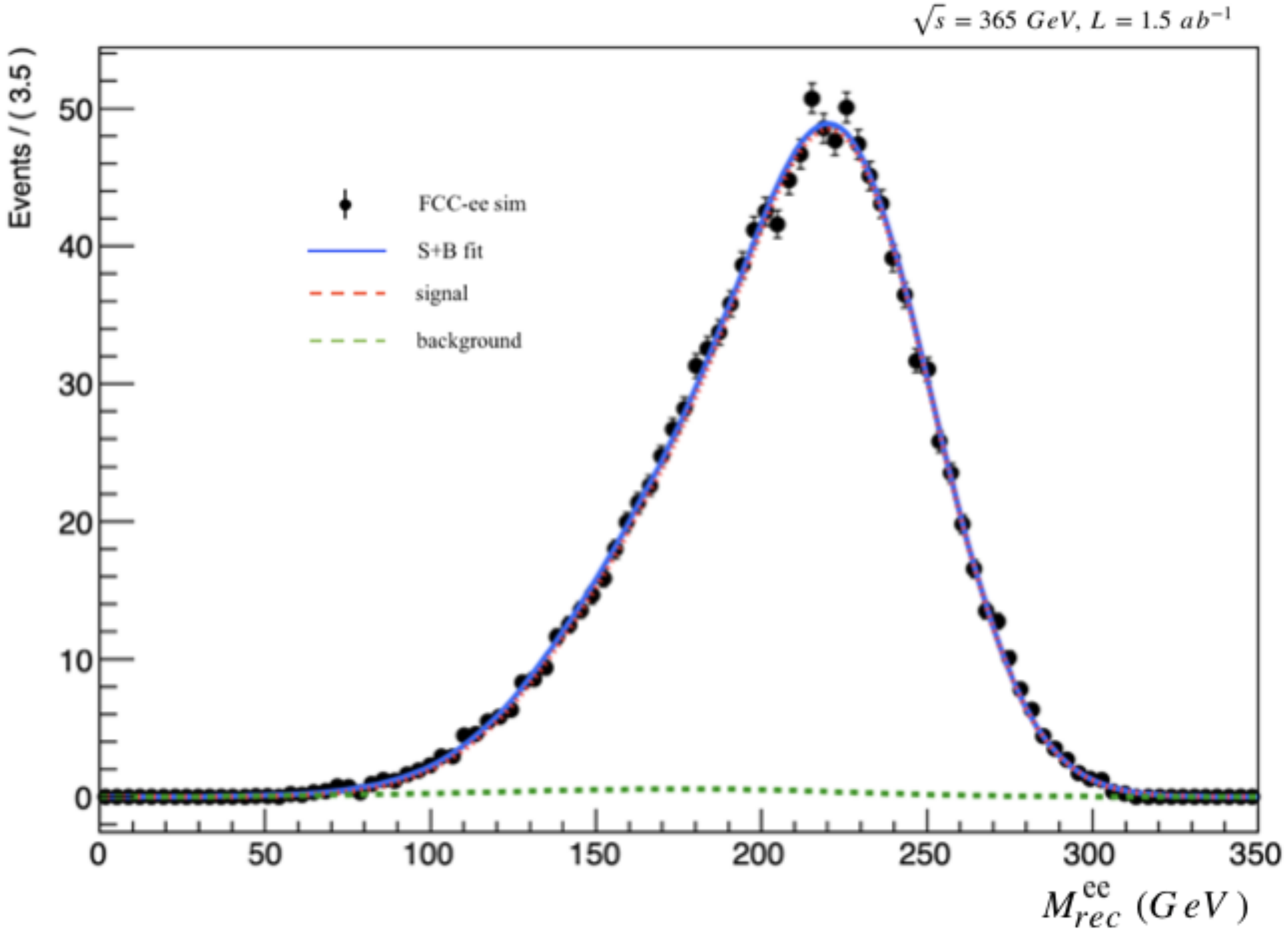
Z boson fusion: $ee \rightarrow eeH(bb)$

Preselection cuts

- ➔ 2 jets + 2 electrons
- ➔ $m_{ee} > 80$ GeV
- ➔ MET > 10 GeV



Fit to the recoil mass spectrum in after the BDT



BDT to further reduce the backgrounds

Rank	Variable	Separation	Rank	Variable	Separation
1	$M_{e^+e^-}$	$9.1 \cdot 10^{-1}$	5	M_{jj}	$3.8 \cdot 10^{-1}$
2	$acol_{e^+e^-}$	$7.1 \cdot 10^{-1}$	6	η_{e_2}	$2.4 \cdot 10^{-1}$
3	$acol_{jj}$	$7 \cdot 10^{-1}$	7	E_{j1}	$2.1 \cdot 10^{-1}$
4	n_{bj}	$4.6 \cdot 10^{-1}$	8	η_{j1}	$1.4 \cdot 10^{-1}$

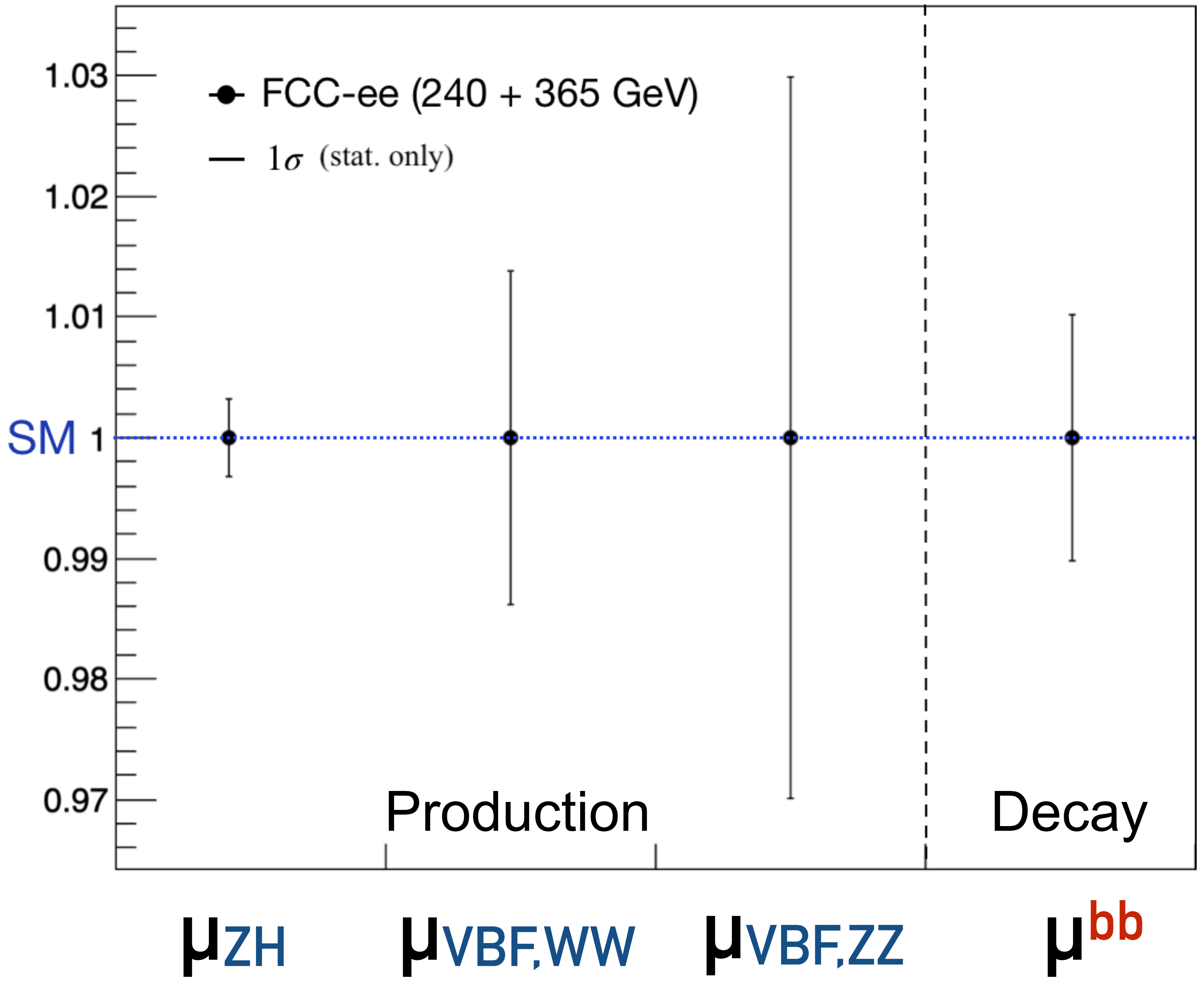
Combination of few orthogonal analyses

For each analysis the signal strength is parametrised as

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

Combining

- ➔ inclusive analyses : measure of μ_{ZH}
- ➔ an exclusive analysis Z(ll)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

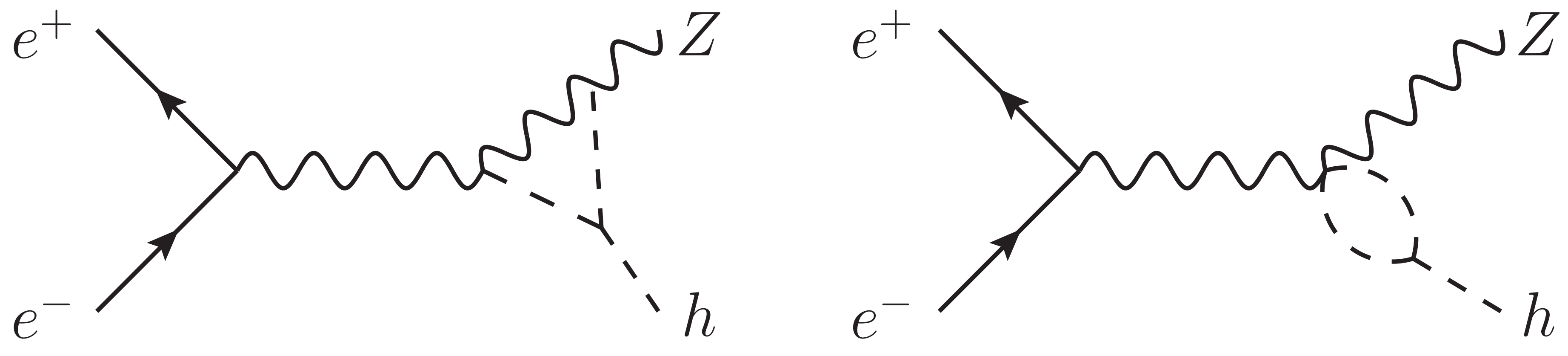
λ_{HHH} @ FCC-ee

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.

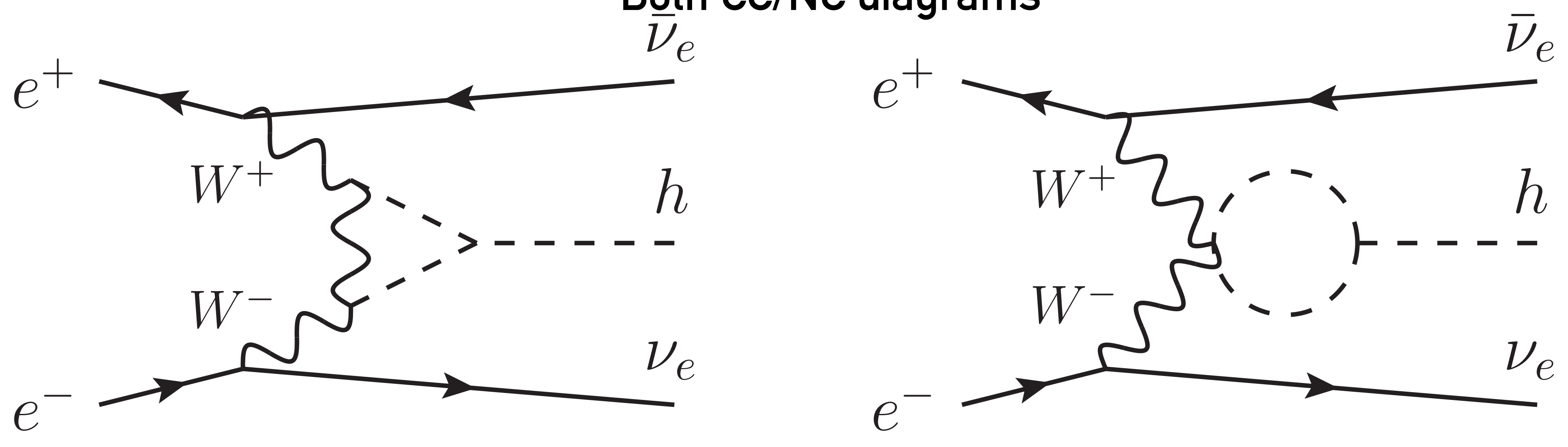
Linear correction to the vertex

ZH Higgsstrahlung

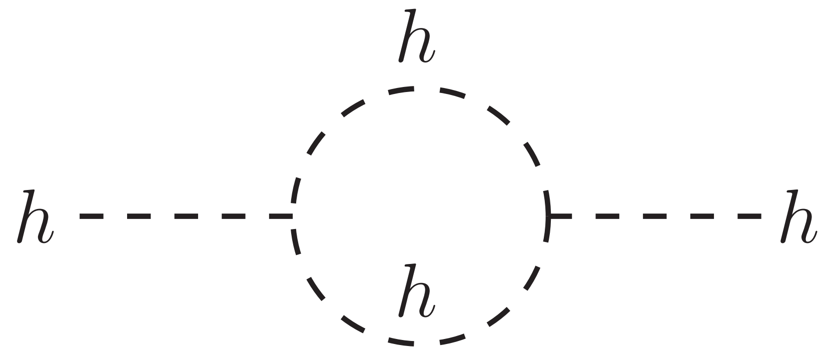


VBF processes

Both CC/NC diagrams



Quadratic corrections (wave function renormalisation)



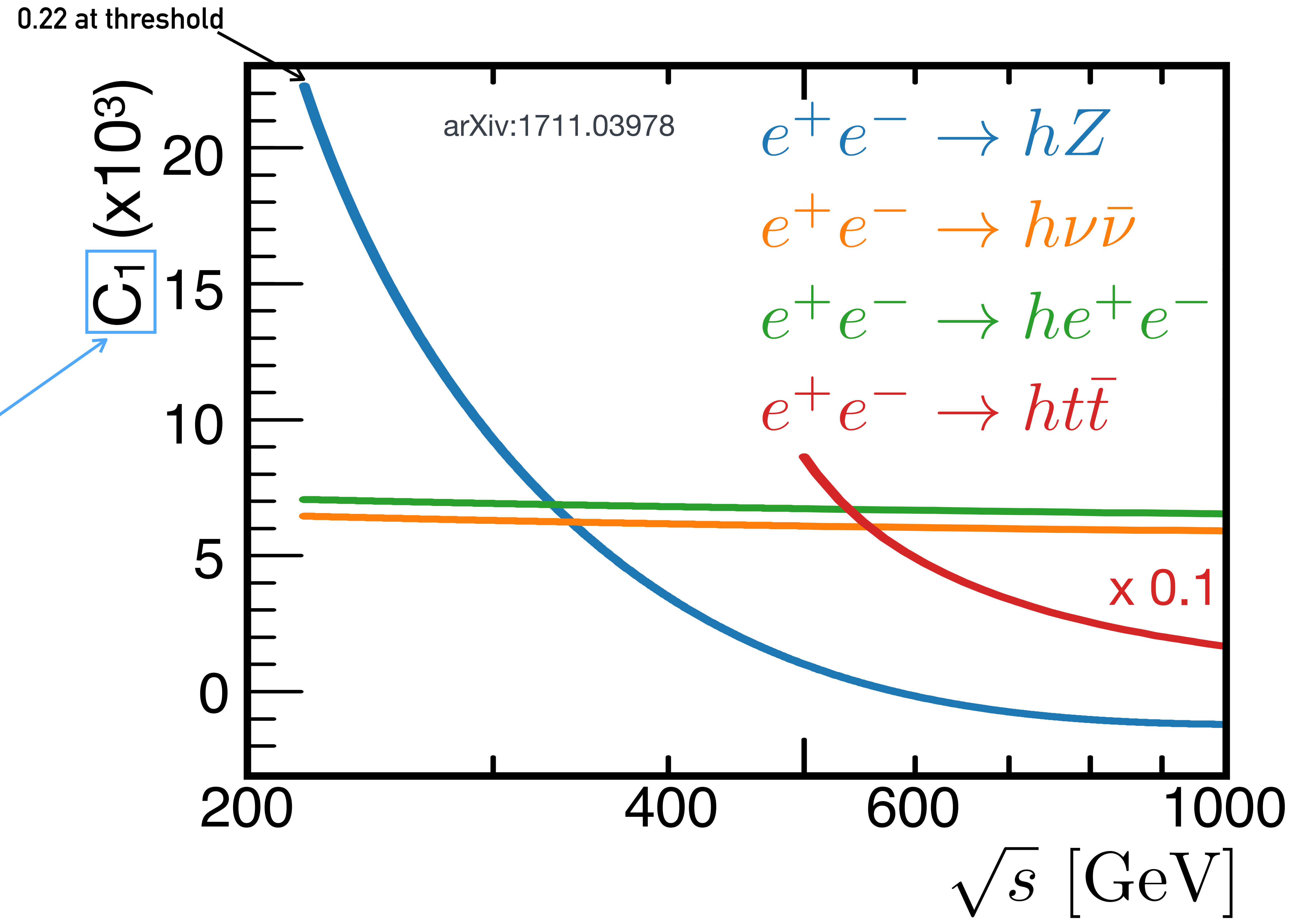
λ_{HHH} effect

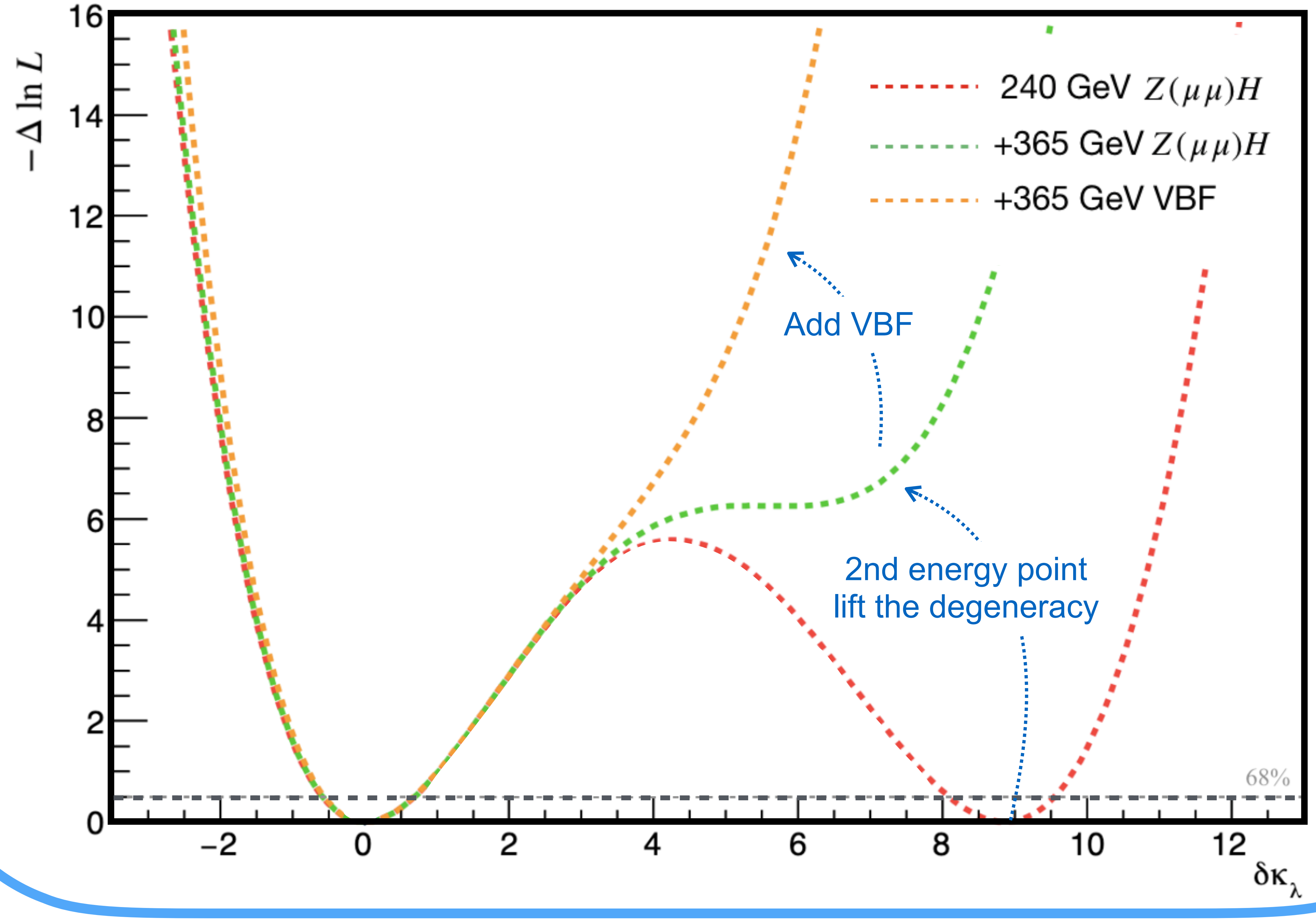
The NLO corrections to an observable Σ

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

Universal coefficient

Process dependent coefficient





Caveats :

1D fit with only $\delta\kappa_\lambda$ floating

σ(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 repeated using the centrally produced samples, add all the needed systematics, ….