# **Higgs boson coupling measurements** focus on HWW, HZZ, HHH

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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

### All the studies shown have been done in a contest of a 4 months M2 internship









# Inclusive affise

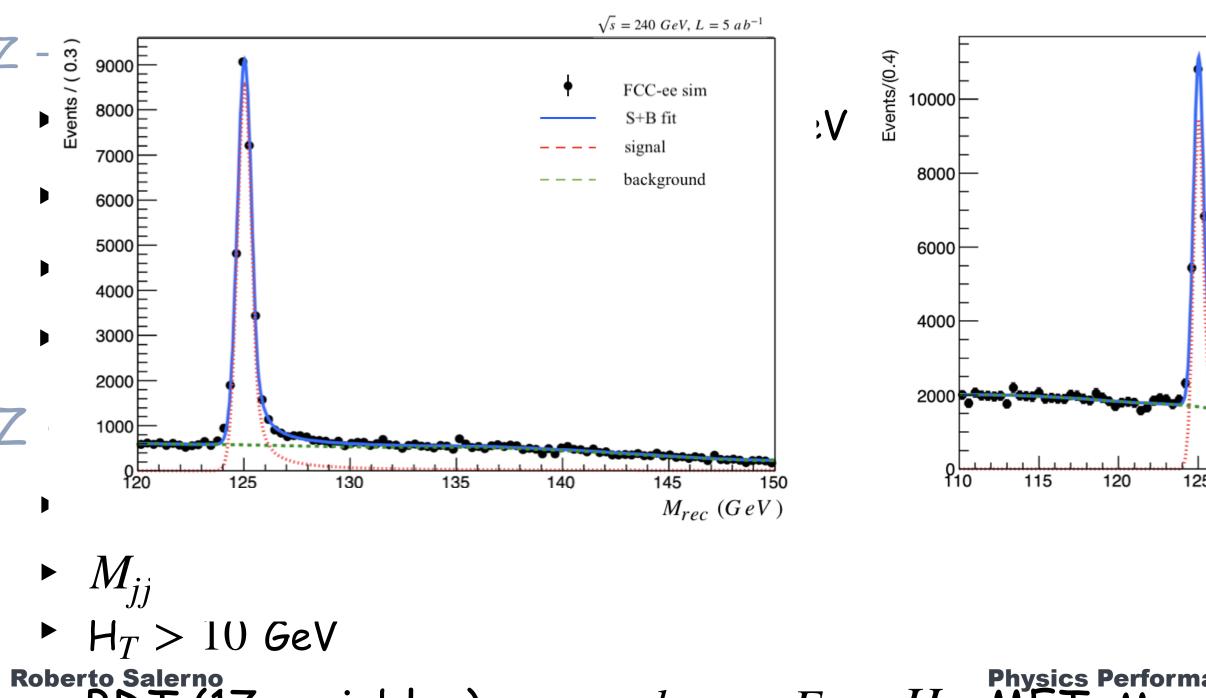
#### Minimu Exploited few Z decays "

▶ 120/110

## $Z \rightarrow \mu^+\mu^-$ (246/365 GeV)

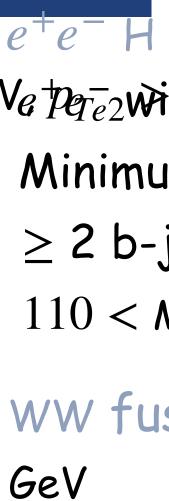
- $\mu^+\mu^-$  with  $p_{T\mu 1} > 20$  GeV,  $p_{T\mu 2} > 5$  GeV
- Minimum  $|M_{\mu^+\mu^-} M_Z|$
- ►  $80 < M_{\mu^+\mu^-} < 100 \text{ GeV}$  $120/110 < M_{rec} < 150 \text{ GeV}$

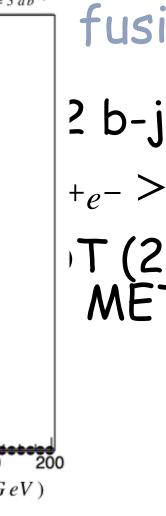
- $Z \rightarrow e^+ e^-$ 
  - $e^+e^-$  with
  - Minimur
  - $60 < M_{e^{-1}}$ 
    - $110 < M_{1}$



with $p_{T\mu 1} > 20$ GeV,	NARY,	$e^+e^-$ with $p$	$3eV)Z \rightarrow e$
with $p_{T\mu 1} > 20$ GeV,	$p_{T\mu 2} > 5 \text{ GeV}$	Alinimum $  M$	
$\lim_{\mu^+\mu^-} M_{\mu^+\mu^-} - M_Z  $	oil technig	Minimum   M	120  Com
$\mu^{+}\mu^{-}$ < 400 GeV	Individual	$100 < M_{e^+e^-} < 100$	120 Gev
$0 < M_{rec} < 150 \text{ GeV}$		$10 < M_{rec} <$	130 GeV
$Z(ee) \not\vdash e^+ e^- \vdash H$	→ bb (240-Ga	≥vþō Z(bl	b)H <sub>VBF</sub> : V
th $p_{Te1} > 10$ GeV, $p_T$	$e_2 > 5 \text{ GeV}$	$\geq$ 2 b-jets +	$p_{Tjj} > 60 \ G$
$ \mathbf{M}   \mathbf{M}_{e^+e^-} - \mathbf{M}_Z $		$M_{jj} > 45$ GeV	/
$_{e^+e^-} < 120 \text{ GeV}$		$H_T > 10 \text{ GeV}$	
$N_{rec} < 150$ GeV $10 < 1$	$M_{rec} < 150 ~G$ >	BDT (17 var	iables)
$\sqrt{s} = 240 \ GeV, \ L = 5 \ a b^{-1}$			$\sqrt{s} = 240 \ GeV, L = 5 \ d$
● FCC-ee sim	ion ( (c) 1000	FCC-ee sim	
——————————————————————————————————————	: <b>†\$ +</b> 6000	S+B fit	
background	GeV 5000	signal background	
	0 GeV 4000		
	j <b>y ar</b> j <sup>3000</sup>	and the second	
	n (3 1000		
25 130 135 140 145 15	0 0 20	40 60 80 100 1	 20 140 160 180
$M_{rec} (GeV)$	: <b>†S +</b>		$M_{rec} (Ge)$
• $M_{e^+e^-} >$	80 GeV		
N DNT (2	5 vaniables): A		

Physics Performance meeting  $19/0B_{10}$  (25 variables):  $M_{e^+e^-}$ ,  $acol_{e^+e^-}$ ,  $acol_{jj}$ ,  $n_{bj}$ ,  $M_{jj}$ ,  $\eta_{a}$ ,



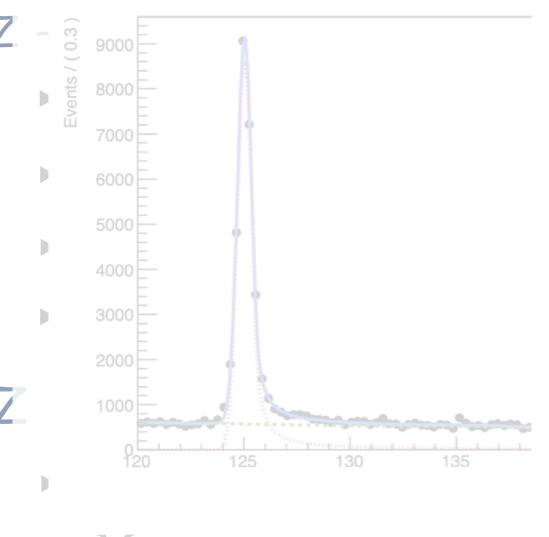




 $Z \rightarrow \mu^+\mu^-$  (246/365 Ge •  $\mu^+\mu^-$  with  $p_{Tu1} > 20$ 

• Minimum  $|M_{\mu^+\mu^-} - M$ 

►  $80 < M_{\mu^+\mu^-} < 100 \text{ Ge}$  $120/110 < M_{rec} < 150$ 

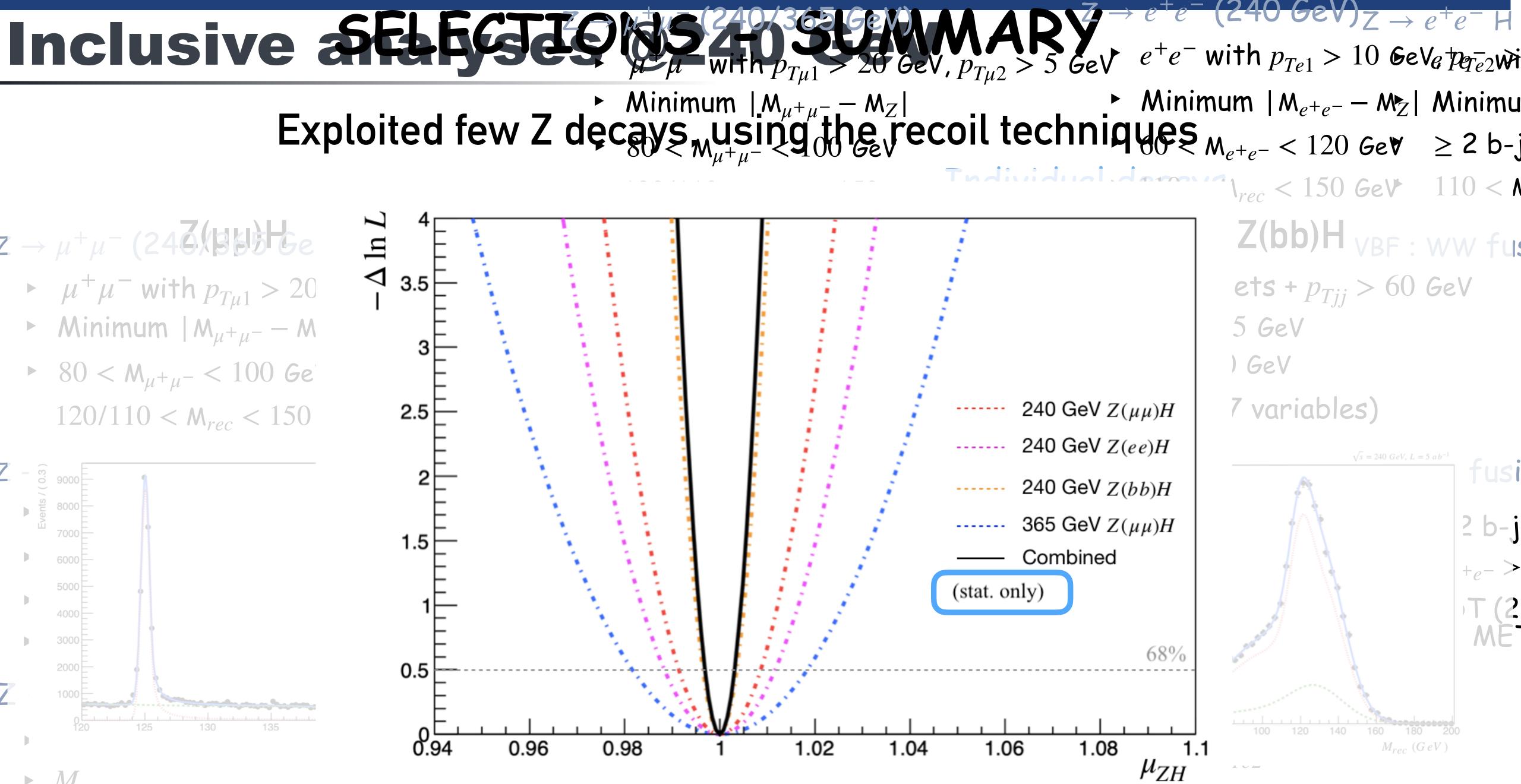


V

$$M_{jj}$$

$$H_T > 10 Ge$$

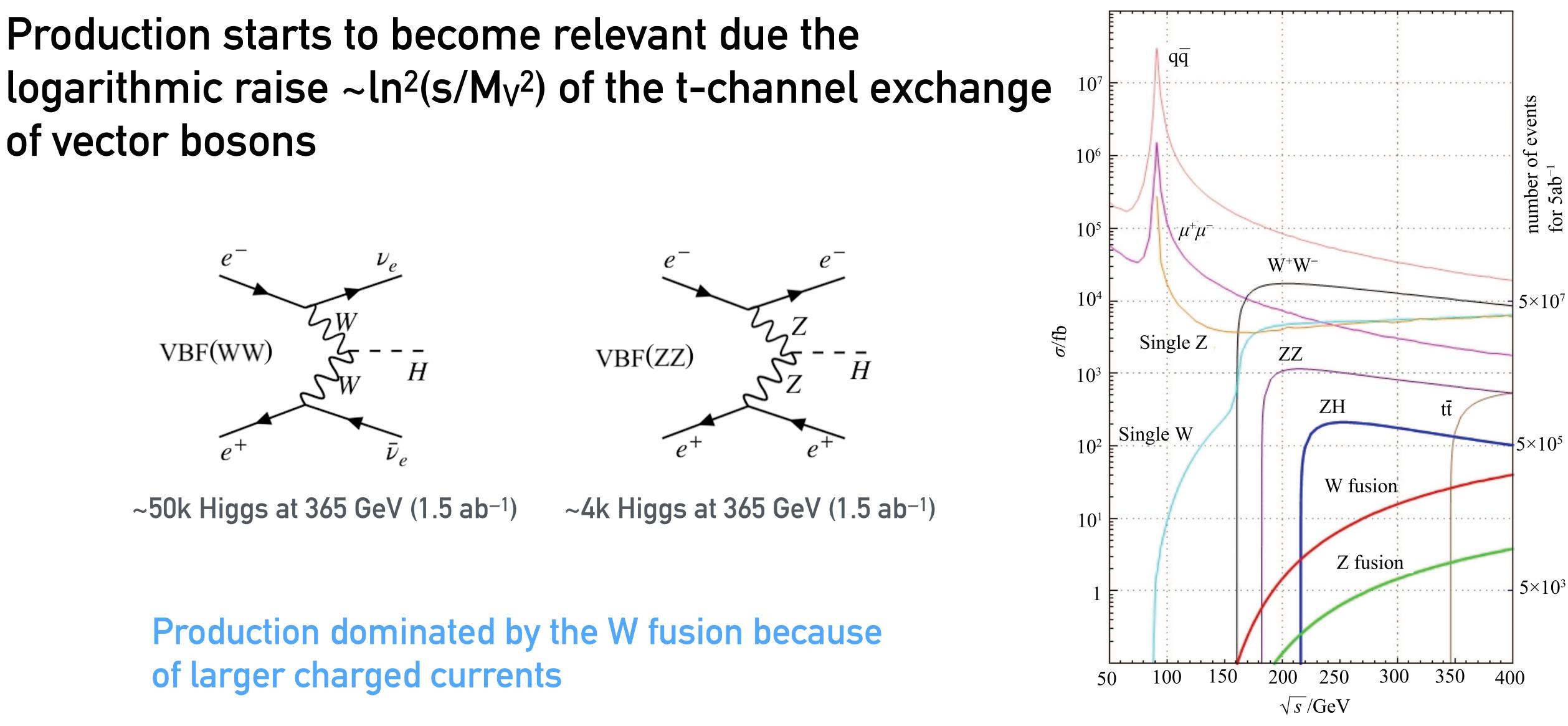
**Roberto Salerno** 



Physics Performance meeting 19/07 (25 variables):  $M_{e^+e^-}$ ,  $acol_{e^+e^-}$ ,  $acol_{ii}$ ,  $n_{bi}$ ,  $M_{ii}$ ,  $\eta_{A}$ ,

# Study the VBF production @365 GeV

## Production starts to become relevant due the of vector bosons



of larger charged currents

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

FCC-ee SIMULATION DELPHES |  $R - \phi$  view

Event: 17,  $\sqrt{s} = 240$  GeV  $e^+e^- \rightarrow \nu \bar{\nu} H(b\bar{b})_S$ 2 b-jets,  $|\eta_{ii}| < 3$ 

10 GeV

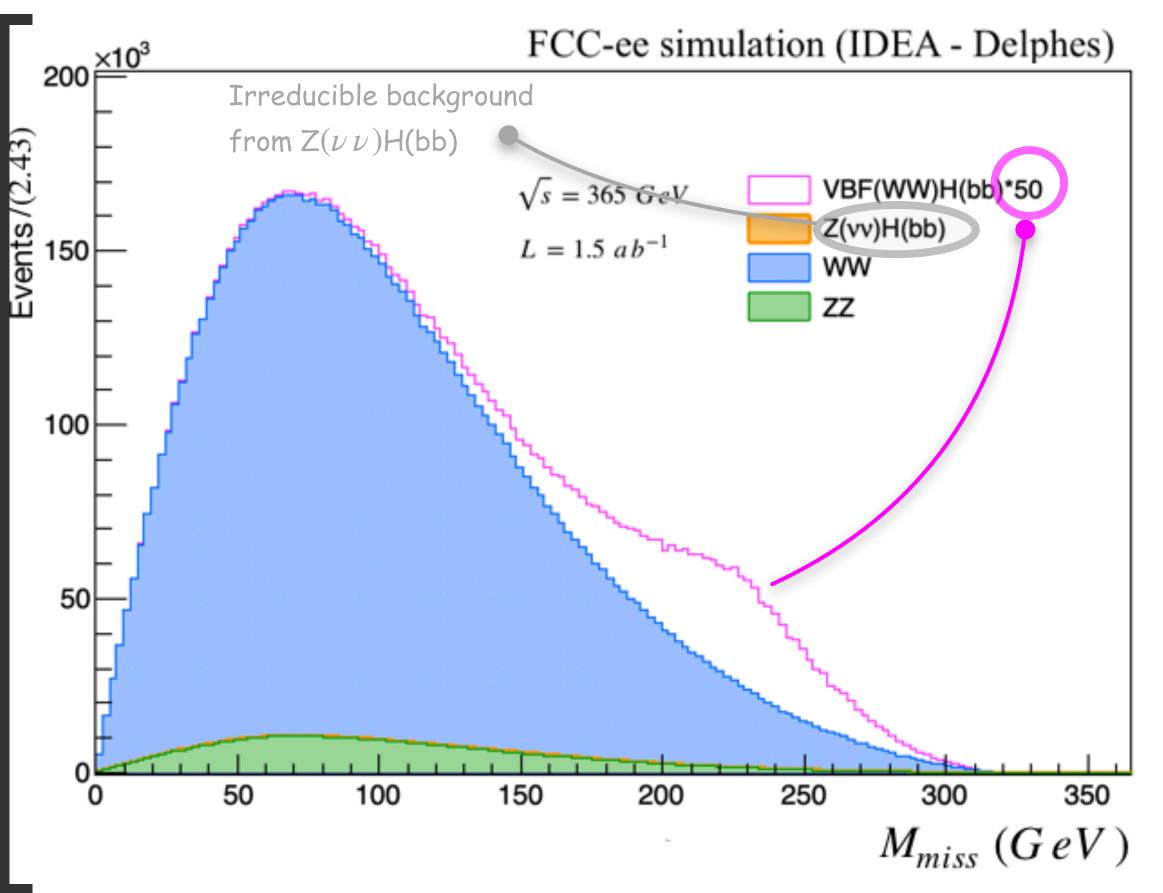
GeV

Deploy an adaptive BDT to further reduce the backgrounds → 17 input variables If a signal events Referent in the size of 1%, a maximum depth of 3

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**Physics Performance meeting - 19/07/21** 

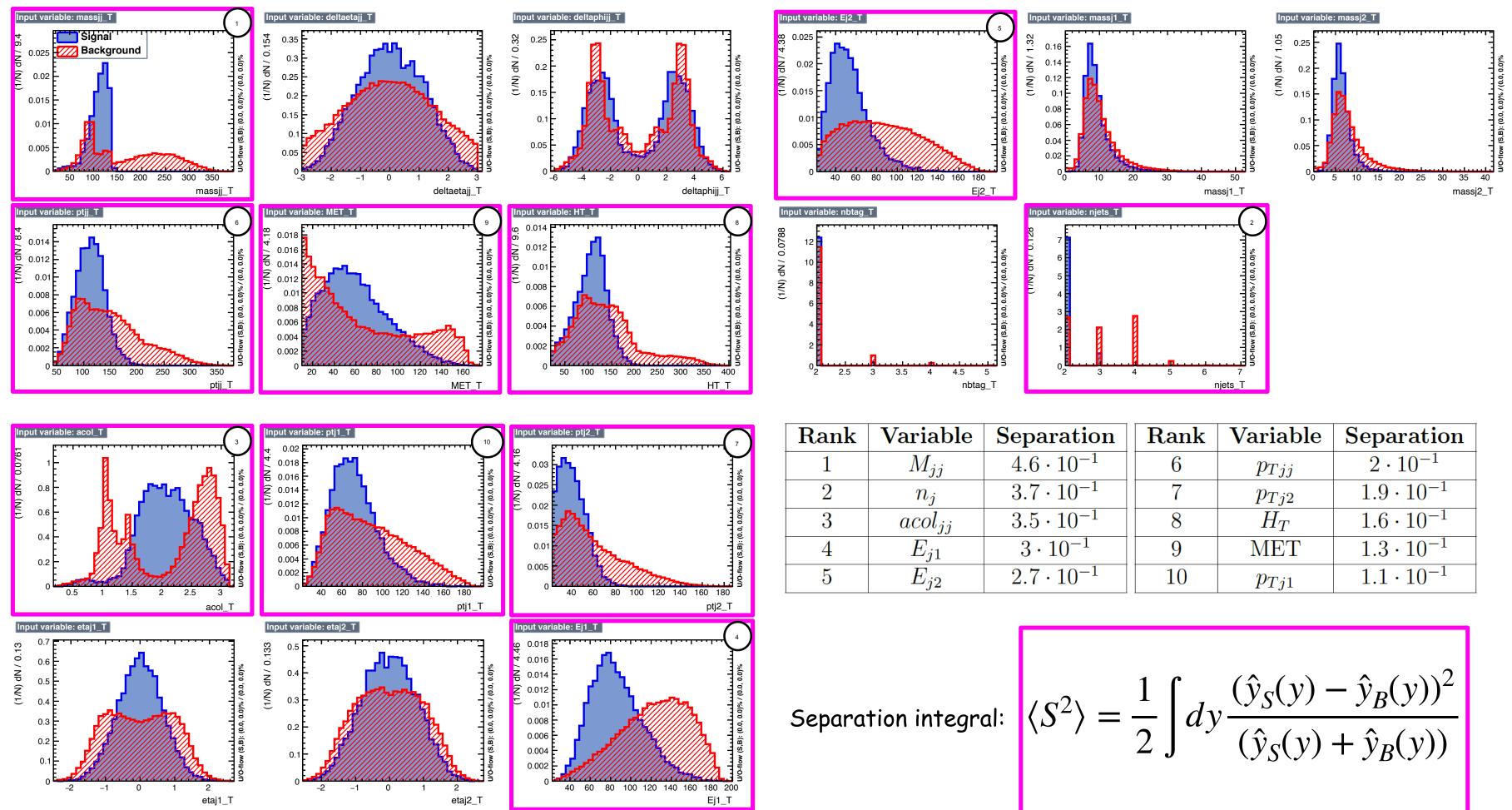




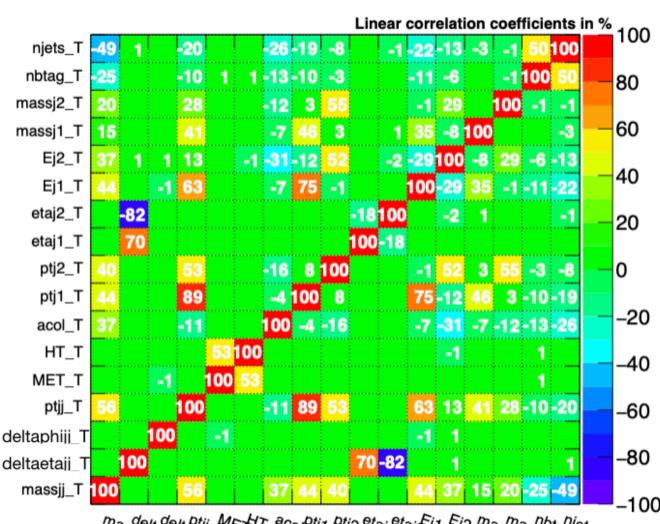




# RDT WB5538F65308B6-F68PUF6ARTABLES



#### **Correlation Matrix (signal)**



massentaenentij METHI acorpti prizetaj etaj Eij Eiz passijas potanjets T

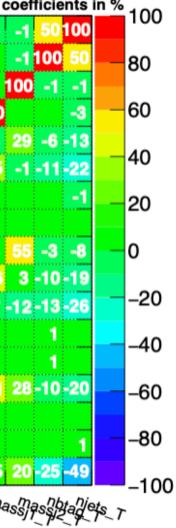
#### **Correlation Matrix (background)**

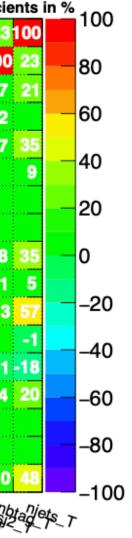
										Linear	corr	elati	ion c	coef	fici
njets_T	48			20	-18	-1	57	5	35		9	35		21	23
nbtag_T	10			4	-1		13	1	8			7	2	7	100
massj2_T	48			58	-4		35	45	63		28	41	23	100	7
massj1_T	24		-1	48	4		14	53	34		31	11	100	23	2
Ej2_T	76			50	-11	-1	52	28	68		9	100	11	41	7
Ej1_T	59			61	-3		43	66	43		100	9	31	28	
etaj2_T		-77								- <mark>17</mark> 100					
etaj1_T		75								100 <mark>-17</mark>					
ptj2_T	77			89	-8		58	67	100		43	68	34	63	8
ptj1_T	55			93	4		38	100	67		66	28	53	45	1
acol_T	88			51	-13	-1	100	38	58		43	52	14	35	13
HT_T	-1				8	100	-1					-1			
MET_T	-12			-1	100	8	-13	4	-8		-3	-11	4	-4	-1
ptjj_T	71			100	-1		51	93	89		61	50	48	58	4
deltaphiji_T			100										-1		
deltaetaji_T		100								<b>75</b> -77					
massjj_T	100			71	-12	-1	88	55	77		59	76	24	48	10
	-					1	-				~	~	-		

masseltaettatij METHI acol PHI PHIZ etaj Ptaj Eij Fiz Mass

Separation	Rank	Variable	Separation
$4.6 \cdot 10^{-1}$	6	$p_{Tjj}$	$2 \cdot 10^{-1}$
$3.7 \cdot 10^{-1}$	7	$p_{Tj2}$	$1.9 \cdot 10^{-1}$
$3.5 \cdot 10^{-1}$	8	$H_T$	$1.6 \cdot 10^{-1}$
$3 \cdot 10^{-1}$	9	MET	$1.3 \cdot 10^{-1}$
$2.7 \cdot 10^{-1}$	10	$p_{Tj1}$	$1.1 \cdot 10^{-1}$

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





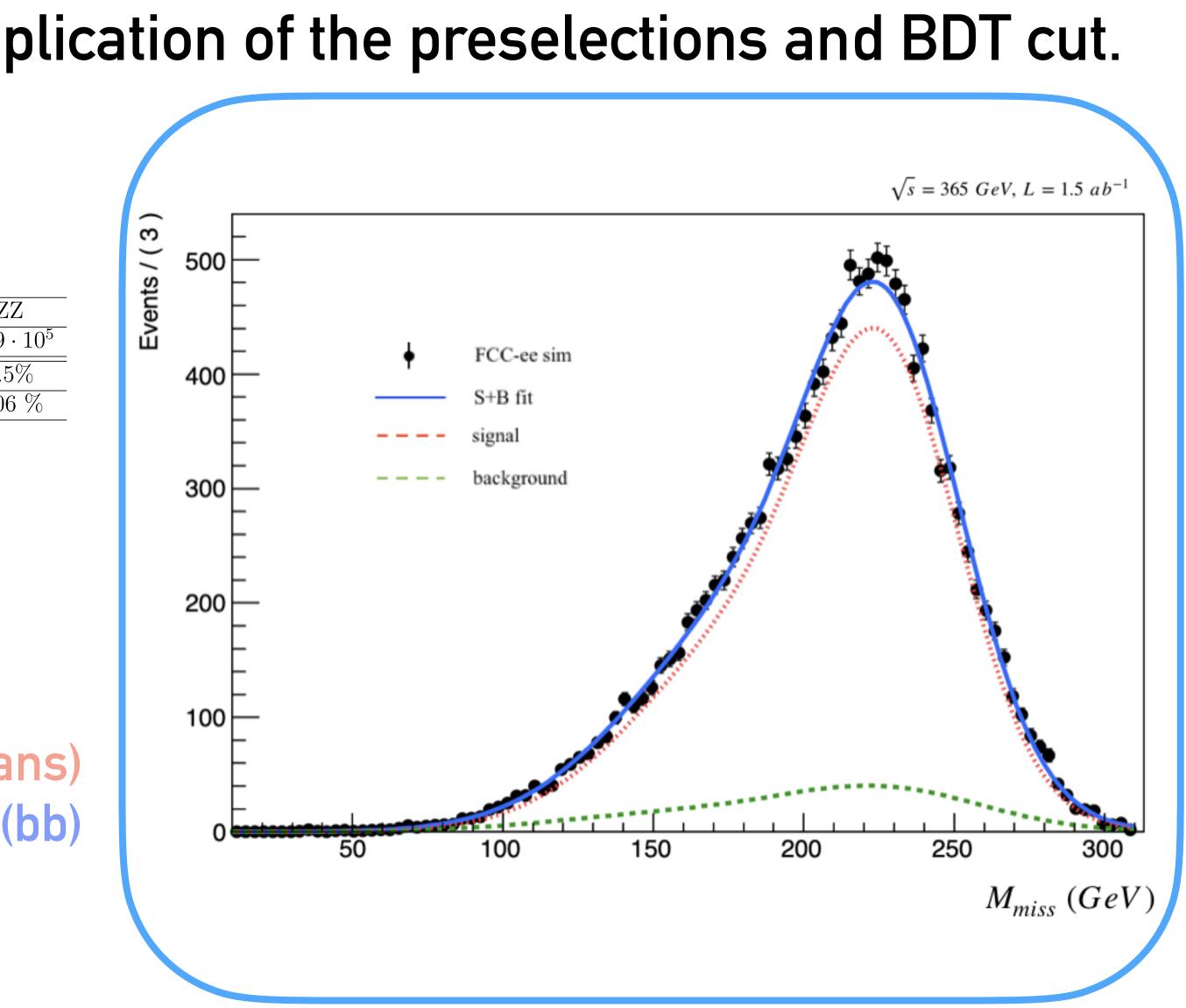


## After the BDT selection

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

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

#### Signal (convolution of 2 Gaussians) Irreducible background mainly from Z(vv)H(bb)

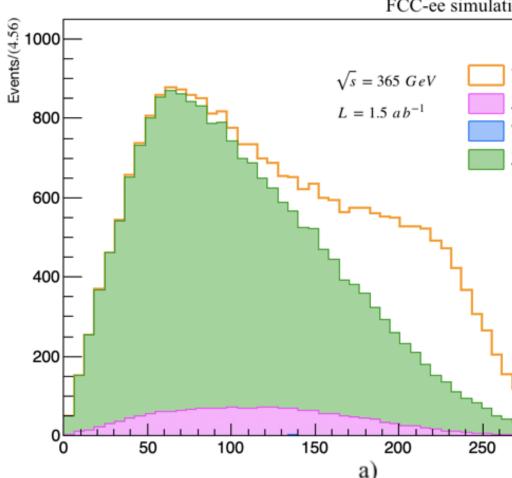




# Z boson fusion: ee→eeH(bb)

## **Preselection cuts**

# → 2 jets + 2 electrons → m<sub>ee</sub> > 80 GeV → MET > 10 GeV



#### BDT to further reduce the backgrounds

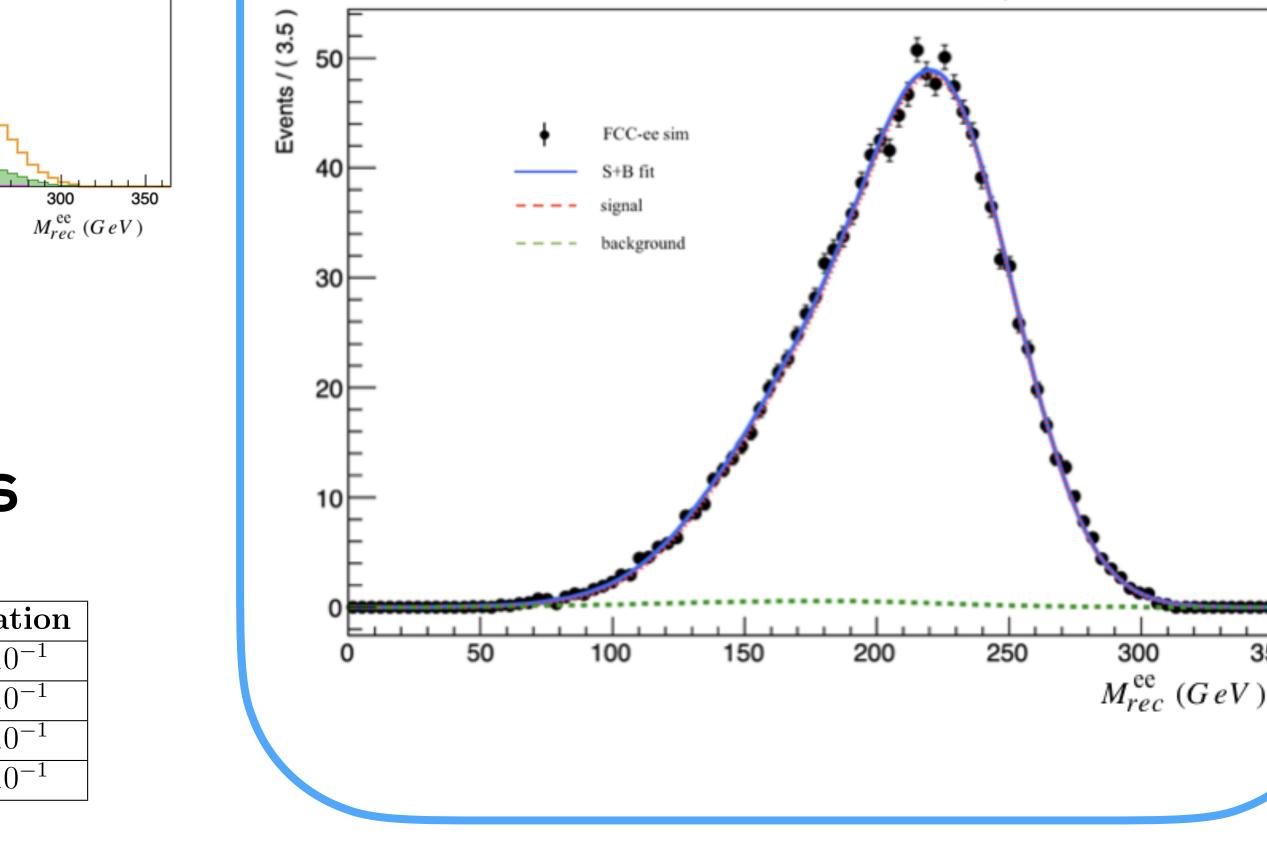
Rank	Variable	Separation	Rank	Variable	Separat
1	$M_{e^+e^-}$	$9.1 \cdot 10^{-1}$	5	$M_{jj}$	$3.8 \cdot 10$
2	$acol_{e^+e^-}$	$7.1 \cdot 10^{-1}$	6	$\eta_{e_2}$	$2.4 \cdot 10$
3	$acol_{jj}$	$7 \cdot 10^{-1}$	7	$E_{j1}$	$2.1 \cdot 10$
4	$n_{bj}$	$4.6 \cdot 10^{-1}$	8	$\eta_{j1}$	$1.4 \cdot 10$

FCC-ee simulation (IDEA - Delphes)

VBF(ZZ)H(bb)\*4 Z(ee)H(bb) WW ZZ

# Fit to the recoil mass spectrum in after the BDT

 $\sqrt{s} = 365 \ GeV, L = 1.5 \ ab^{-1}$ 







## **Combination of few orthogonal analyses**

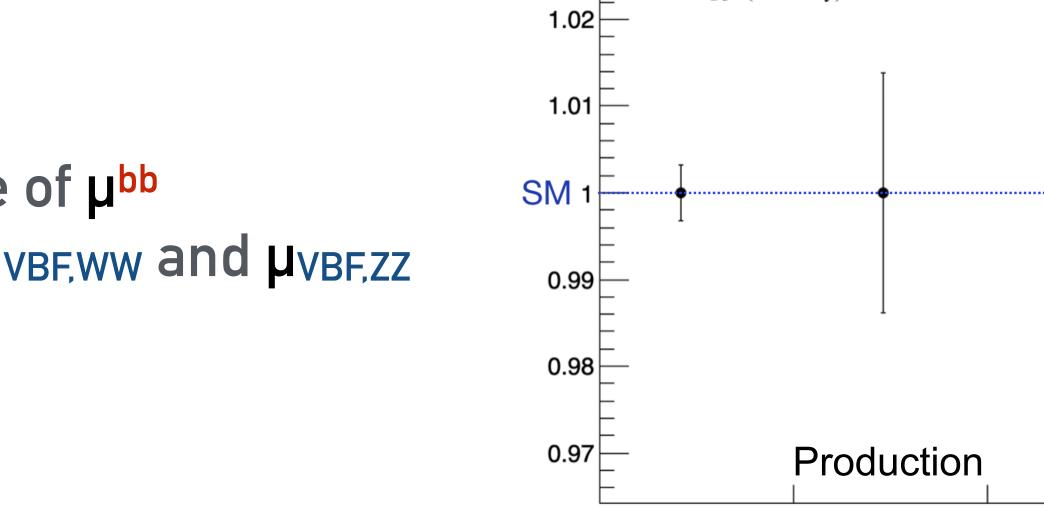
### For each analysis the signal strength is parametrised as

## Combining

- $\rightarrow$  inclusive analyses : measure of  $\mu_{ZH}$
- $\rightarrow$  an exclusive analysis Z(ll)H(bb) : measure of  $\mu^{bb}$
- $\rightarrow$  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

- $\mu_{i}^{f} = \frac{\sigma_{i} \cdot BR^{f}}{(\sigma_{i} \cdot BR^{f})_{SM}} = \mu_{i} \times \mu^{f}$

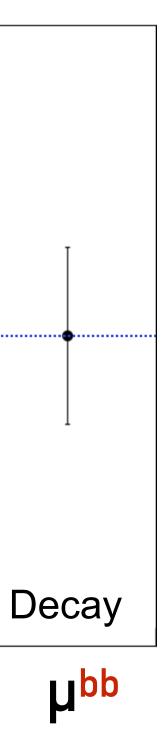


FCC-ee (240 + 365 GeV)

UVBF,WW

μzμ

 $1\sigma$  (stat. only)



**UVBF,ZZ** 

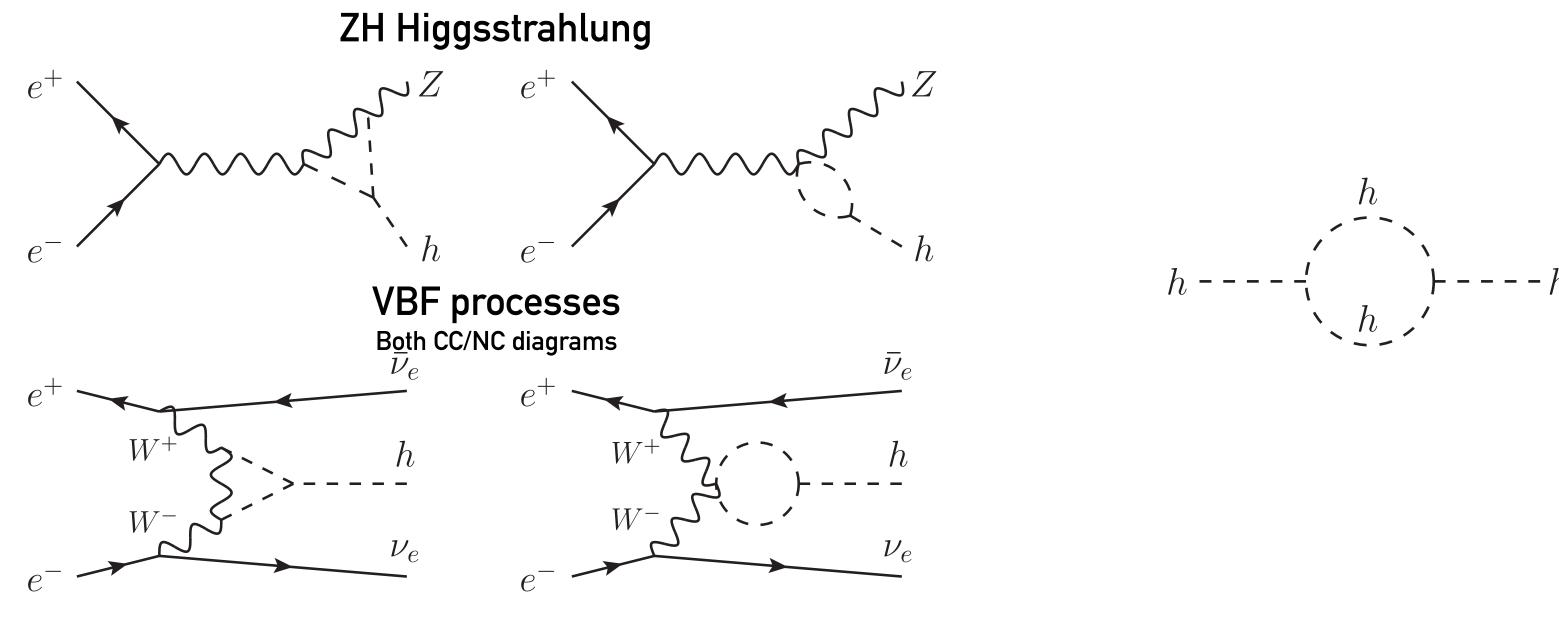




## Higher-order corrections to single-Higgs processes

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

Linear correction to the vertex

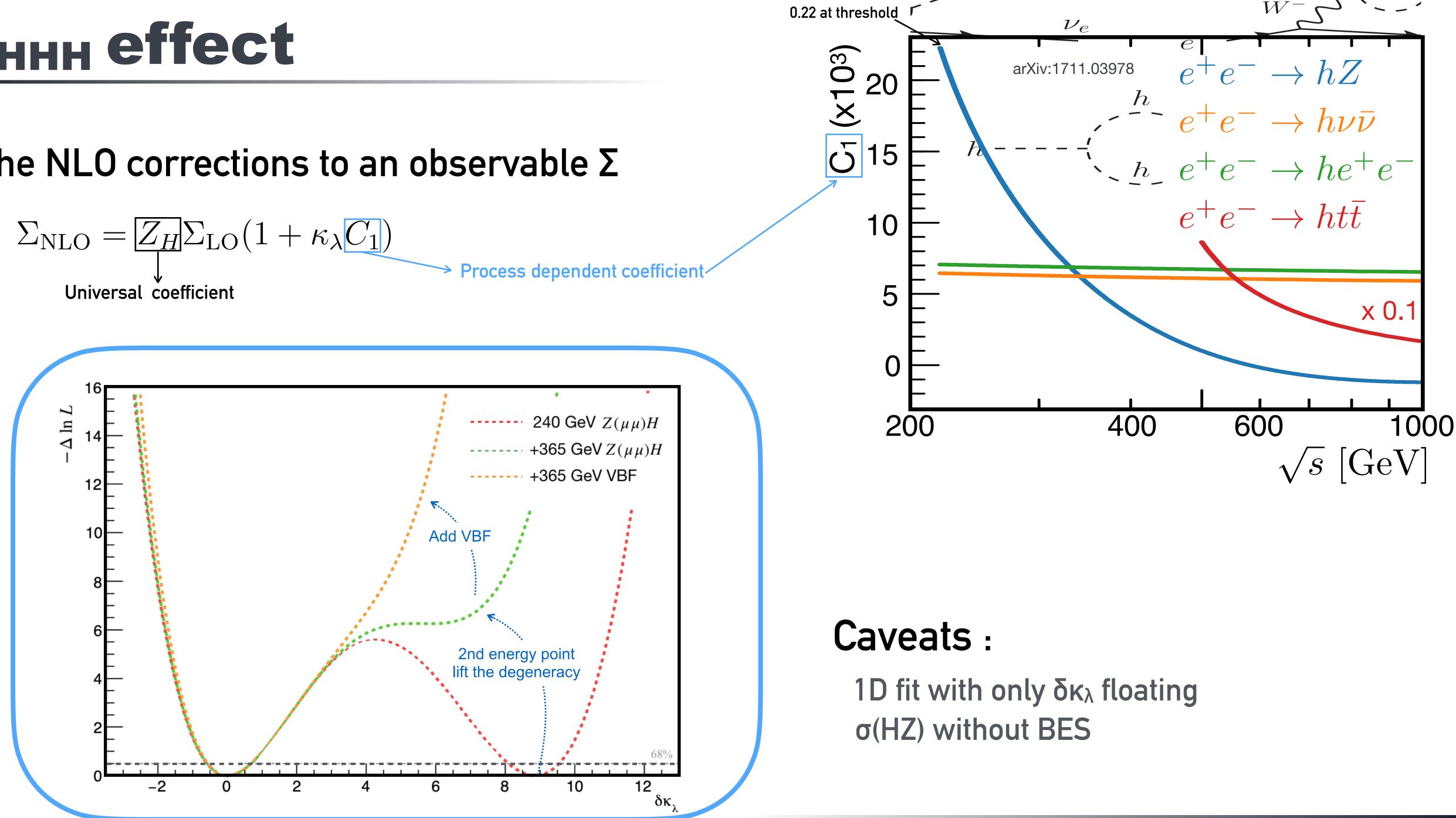


#### **Quadratic corrections** (wave function renormalisation)



## $\lambda_{HHH}$ effect

#### The NLO corrections to an observable $\Sigma$



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shown.

(HZZ, HWW, HHH) profiting of two energy points.

needed systematics, ....

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

- The analysis chain has been put in place to measure few Higgs boson couplings
- The analyses will repeated using the centrally produced samples, add all the















