

# Quark-flavor-violating Higgs decays at the ILC

**Alexander Helmboldt**

*Max-Planck-Institut für Kernphysik, Heidelberg*

in collaboration with Daniele Barducci  
based on [arXiv:1710.06657]



LCWS 2017, Strasbourg

26/10/17

INTERNATIONAL  
MAX PLANCK  
RESEARCH SCHOOL

PT  
FS FOR PRECISION TESTS  
OF FUNDAMENTAL  
SYMMETRIES



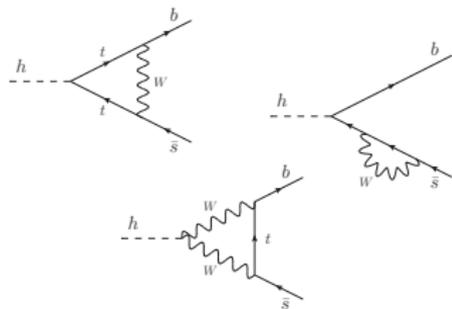
UNIVERSITÄT  
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ZUKUNFT  
SEIT 1386

# Motivation – Higgs decay $h \rightarrow bs$

- Quark-flavor-violating Higgs decays in the **Standard Model**

→ Loop and GIM suppressed

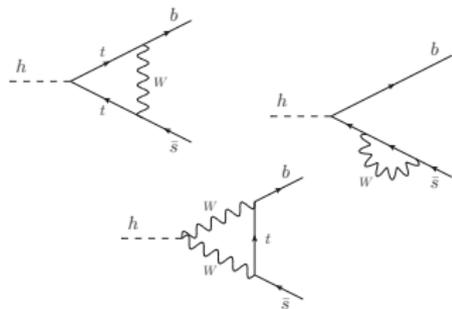
→ Branching ratio  $\mathcal{B}_{\text{SM}} = \mathcal{O}(10^{-7})$



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Any detection must necessarily be attributed to **New Physics!**

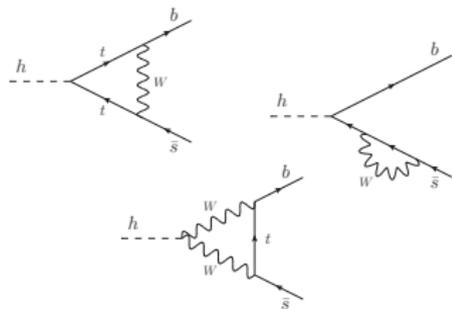


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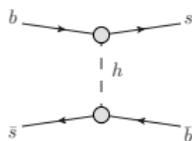
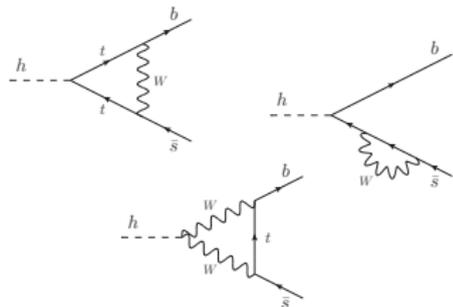


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$\rightsquigarrow \mathcal{B}(h \rightarrow bs) \lesssim \mathcal{O}(1\%)$   
(based on Harnik et al. '12)

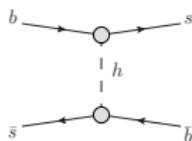
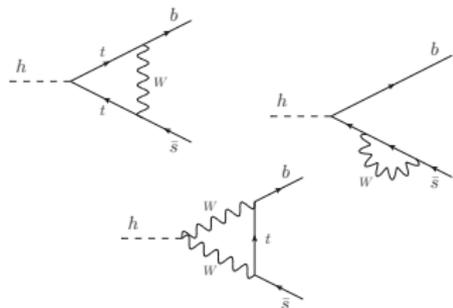
$\rightsquigarrow$  Cancellations may exist!  
(see e.g. recent 1710.04663)

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- **Direct** tests are complementary
  - Disentangle FCNC contributions
  - Measure values of couplings



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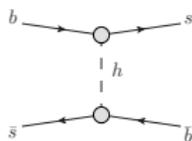
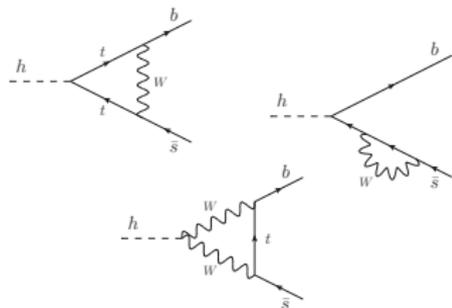
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- At LHC: too much QCD background



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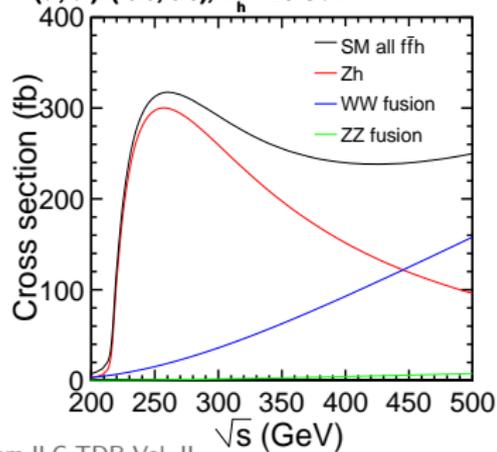
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$e^+e^-$  collider

much cleaner  
environment

## Higgs production

$P(e^-, e^+) = (-0.8, 0.3)$ ,  $M_h = 125$  GeV

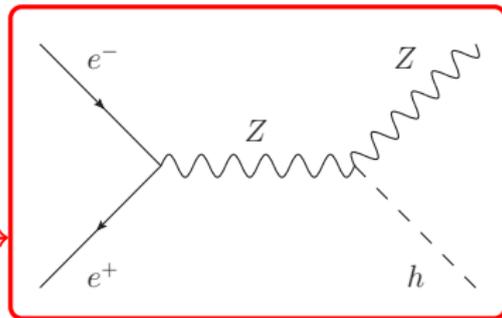
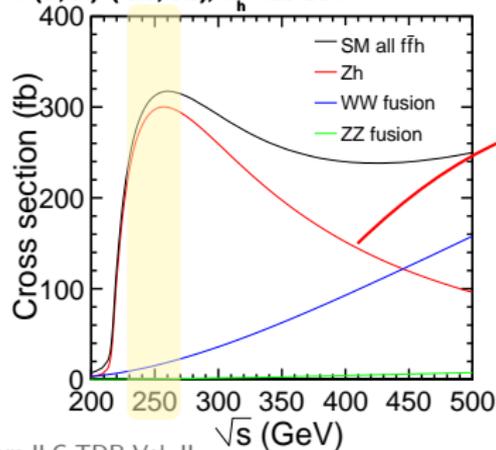


from ILC TDR Vol. II

# Signal at the ILC

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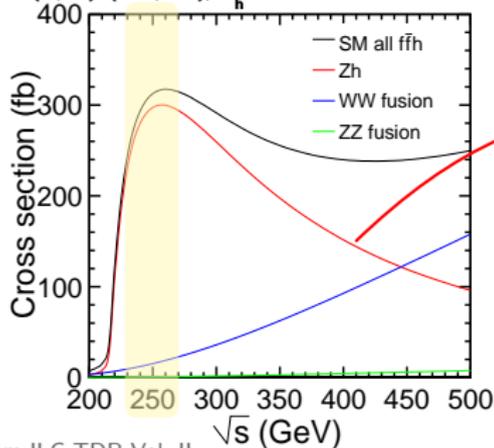


$$\sqrt{s} = 250 \text{ GeV}$$

# Signal at the ILC

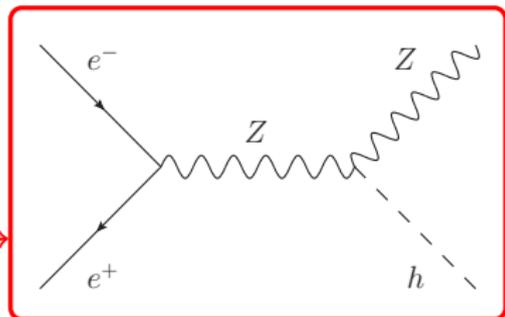
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from ILC TDR Vol. II

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Z decays

$\Rightarrow$  different signatures

$$B(Z \rightarrow \ell^+ \ell^-) = 6.73 \%$$

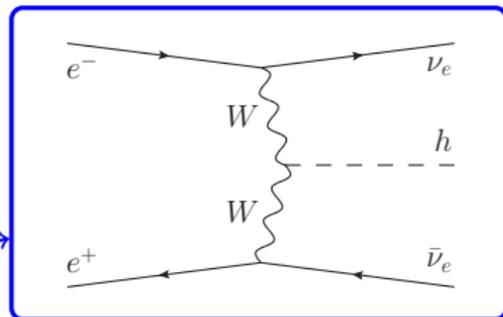
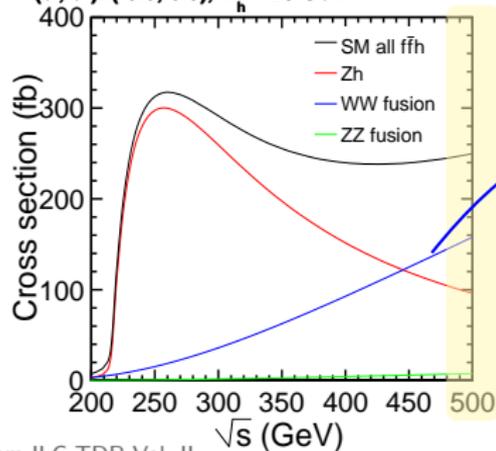
$$B(Z \rightarrow \bar{\nu} \nu) = 20 \%$$

$$B(Z \rightarrow \bar{q} q) = 70 \%$$

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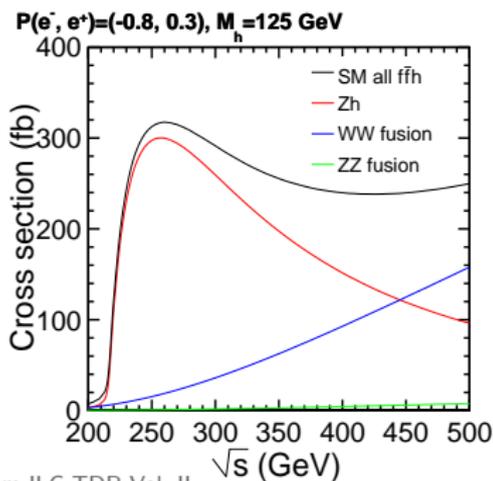
## Higgs production

$P(e^-, e^+) = (-0.8, 0.3)$ ,  $M_h = 125$  GeV



$$\sqrt{s} = 500 \text{ GeV}$$

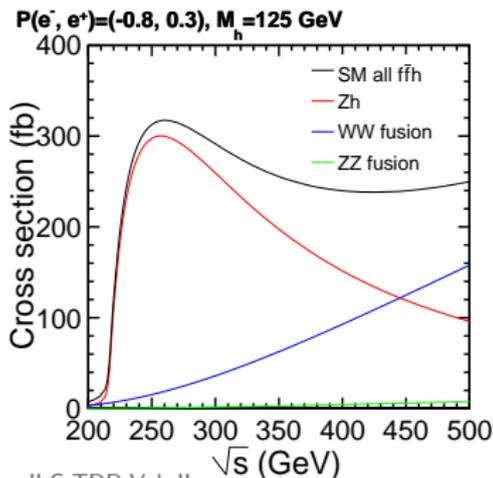
## Higgs production



## Investigated channels

- **hadronic** channel at 250 GeV
- **charged lepton** channel ( $e, \mu$ ) at 250 GeV
- **neutrino** channel at 250 GeV and 500 GeV

## Higgs production



## Investigated channels

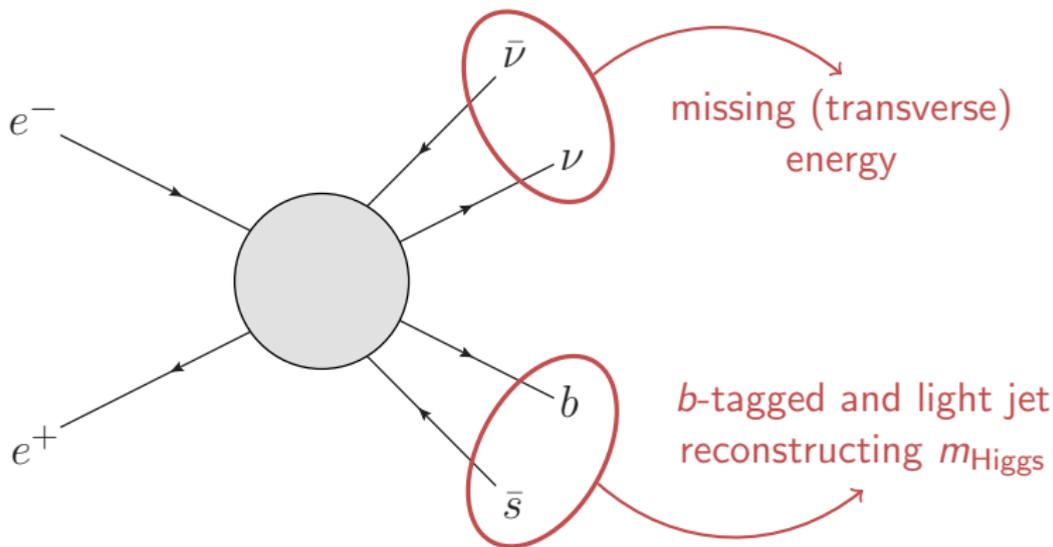
- **hadronic** channel at 250 GeV
- **charged lepton** channel ( $e, \mu$ ) at 250 GeV
- **neutrino** channel at 250 GeV and 500 GeV

gives best results  
→ **This talk**

For performance of other channels, see our paper.

# Signal at the ILC – neutrino channel

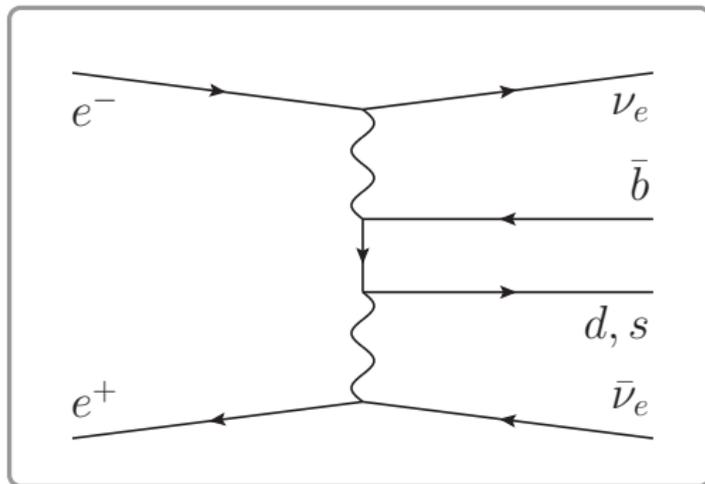
Signal process:  $e^+ e^- \rightarrow \bar{\nu} \nu bs$



Signal signature:  $e^+ e^- \rightarrow \cancel{E}_T + bj$

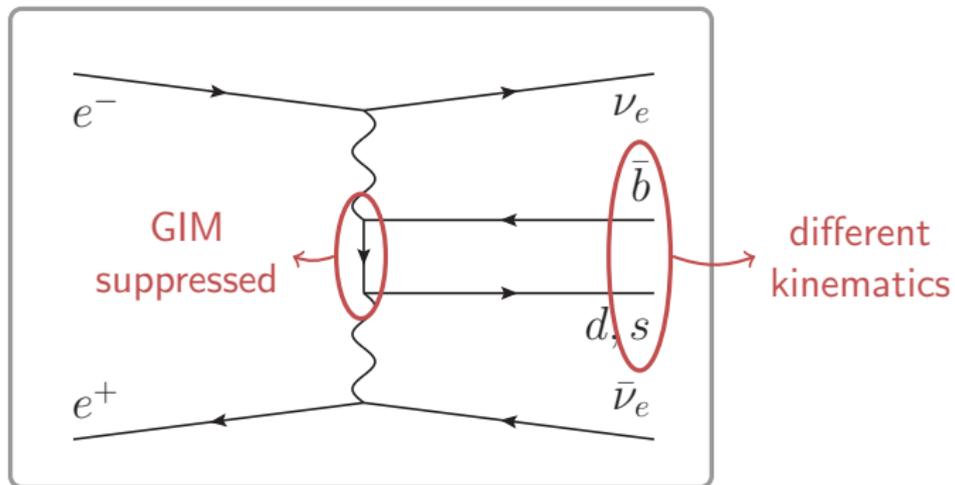
# Background – Standard Model

The process  $e^+e^- \rightarrow \bar{\nu}\nu bs$  exists in the Standard Model:



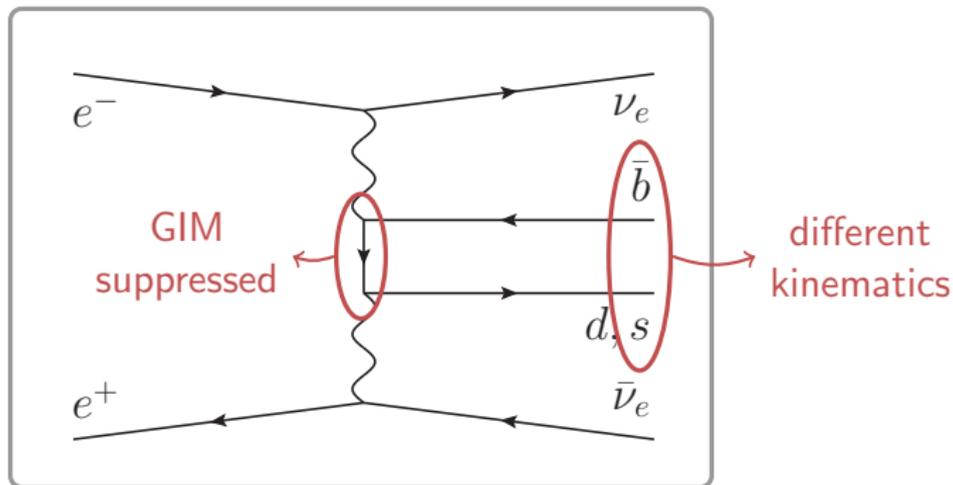
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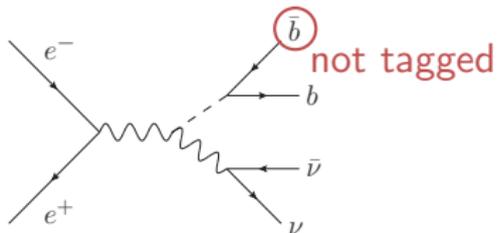
The process  $e^+e^- \rightarrow \bar{\nu}\nu bs$  exists in the Standard Model:



**BUT: Detector imperfections exist!**  
 $\Rightarrow$  other SM processes can mimic the signature

# Background – detector imperfections

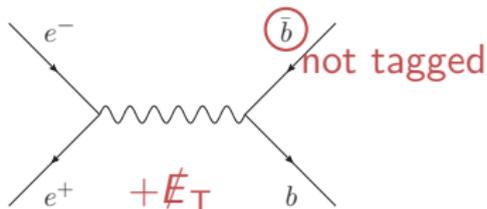
flavor  
mis-ID



*background reducible via:*

- jet flavor tagging
- two-jet invariant mass (for non-resonant case)

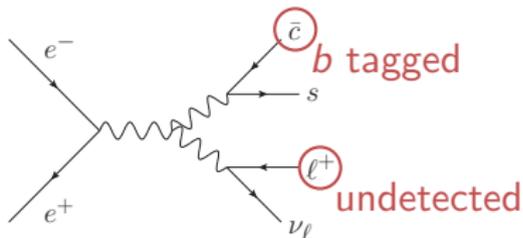
energy  
leakage



*background reducible via:*

- $\cancel{E}_T$  cut
- cut on  $\Delta\phi_{\text{jet}}$
- two-jet invariant mass

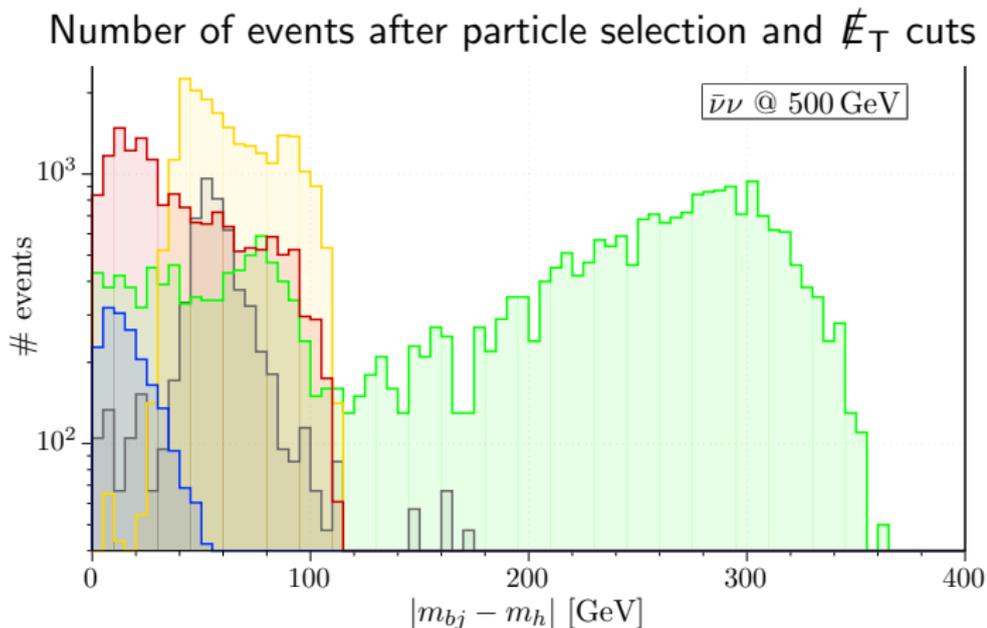
particle  
loss



*background reducible via:*

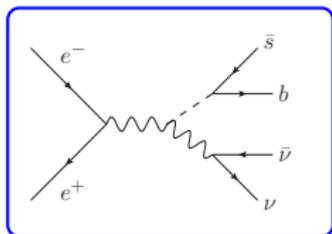
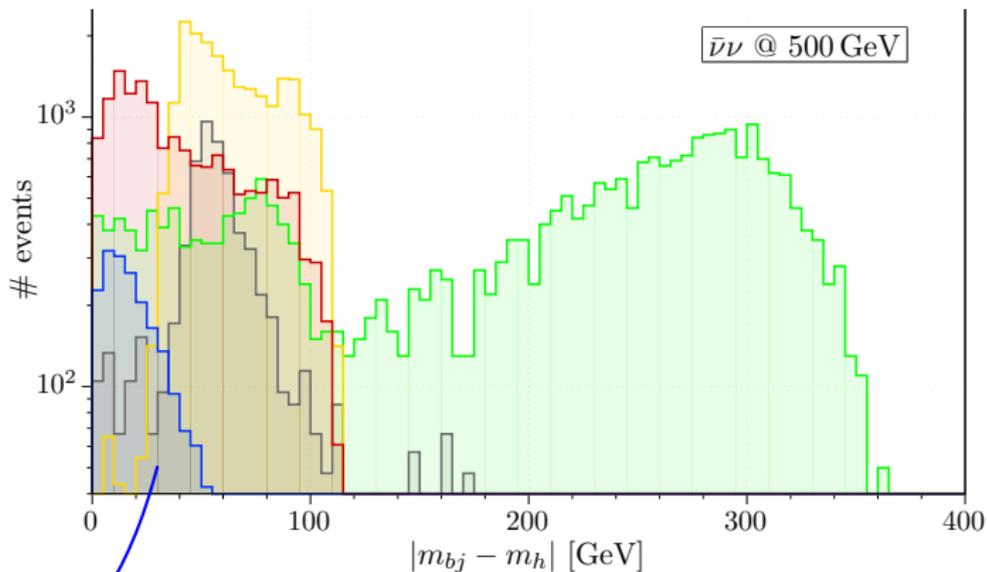
- cut on events with isolated leptons
- two-jet invariant mass

# Background – important channels



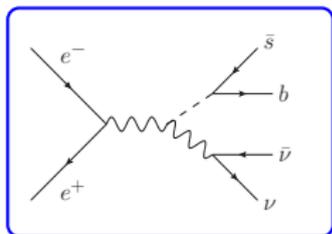
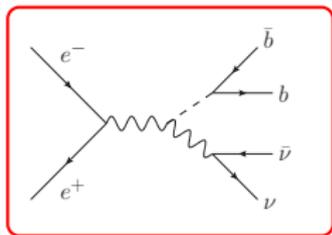
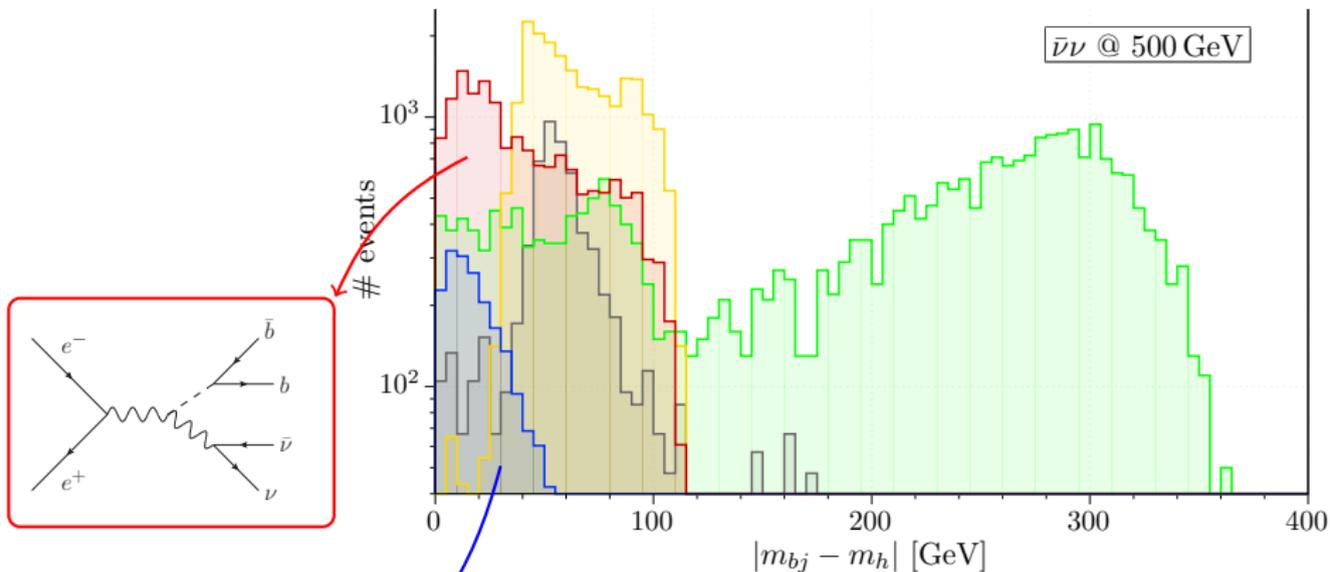
# Background – important channels

Number of events after particle selection and  $\cancel{E}_T$  cuts



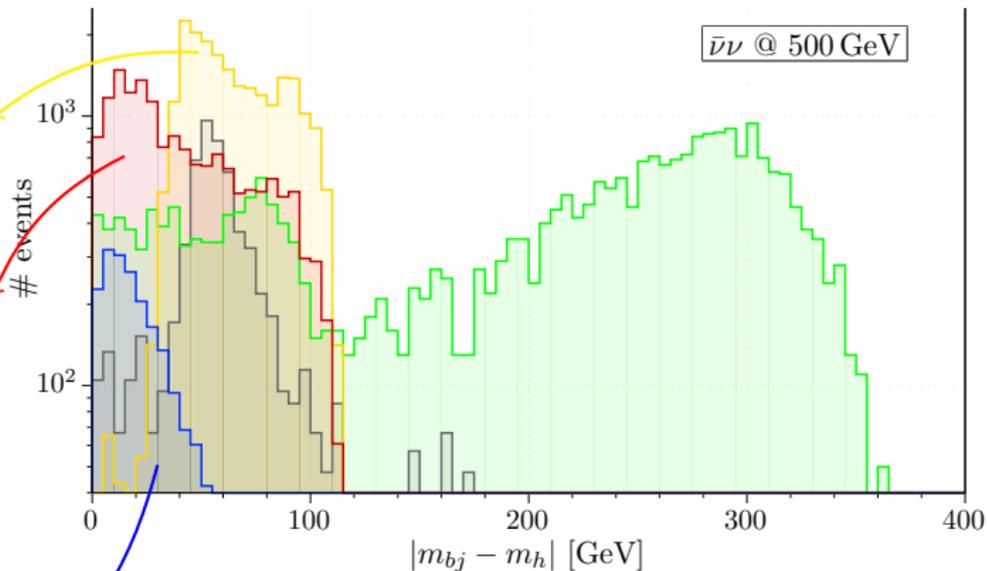
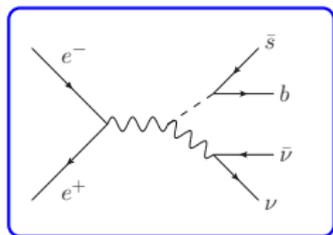
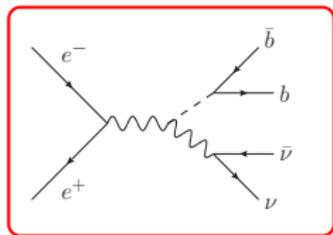
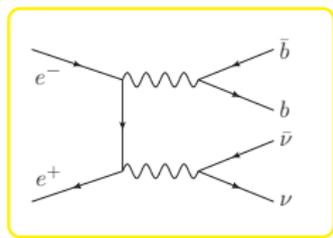
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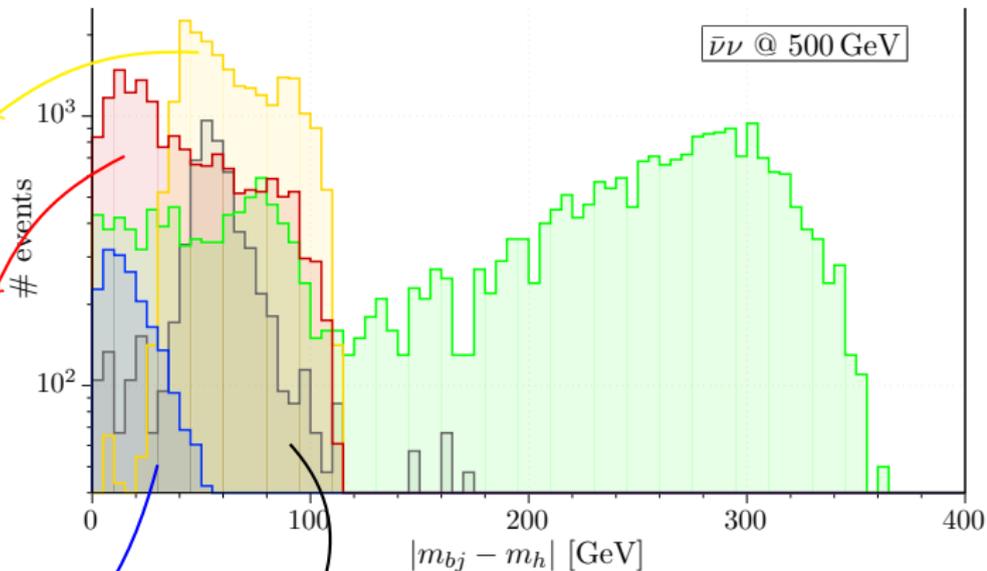
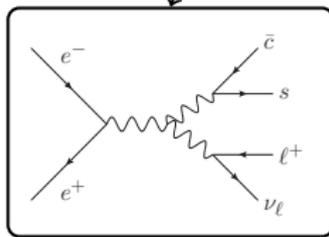
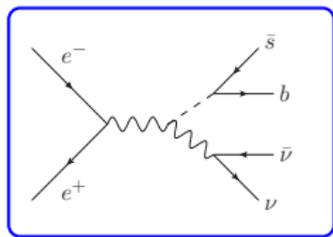
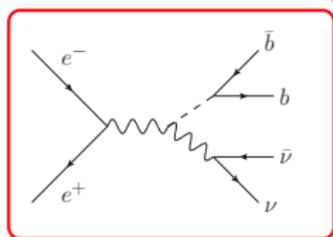
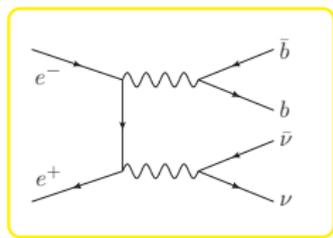
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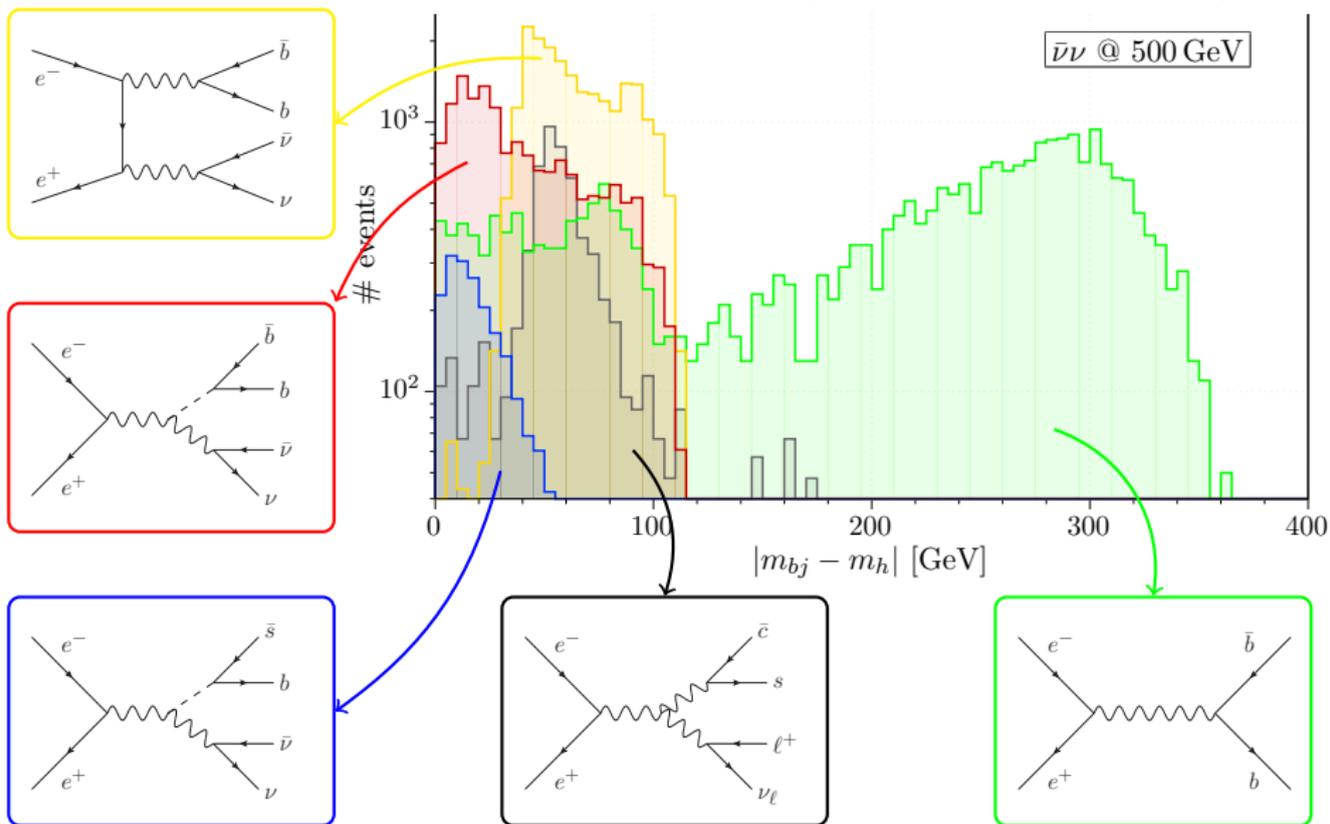
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# Selection of the signal

## Steps of our cut-based analysis

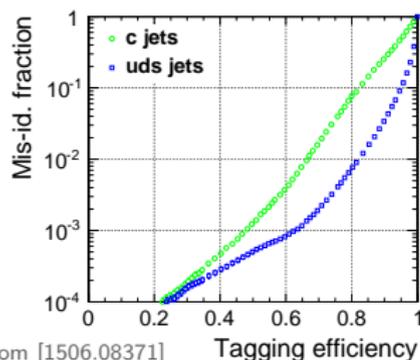
#	Cut description	Optimal value	Reduces background from
1.	events with exactly one $b$ and one light jet	–	mis-tagged events
2.	no events with isolated leptons	–	events with isolated leptons
3.	non-vanishing missing transverse energy	$\cancel{E}_T > 25 \text{ GeV}$	two-body final states
4.	invariant mass of jet pair	$ m_{bj} - m_h  < 25 \text{ GeV}$	non-resonant processes
5.	azimuthal distance of jet pair	$\Delta\phi_{bj} < 170^\circ$	two-body final states

# Fast simulation setup

Module	Software	Remarks
LO event generation	Whizard 2.5.0/0'Mega	initial-state radiation, beamstrahlung
showering and hadronization	Pythia 8	final-state radiation
detector simulation	Delphes 3.4 with DSiD detector card	flavor tagging according to performance of the LCFIPlus package

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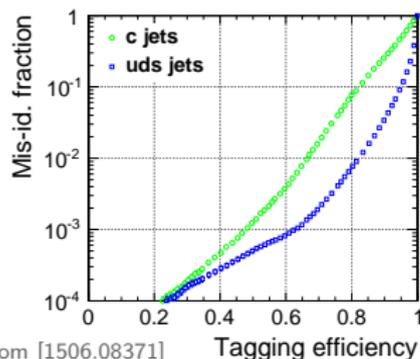
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tag	true $b$	true $c$	true $j$
$b$	0.80	0.08	0.01
$c$	0.17	0.70	0.10
$j$	0.03	0.22	0.89

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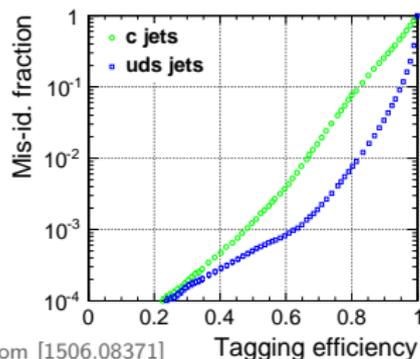
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taken from [1506.08371]

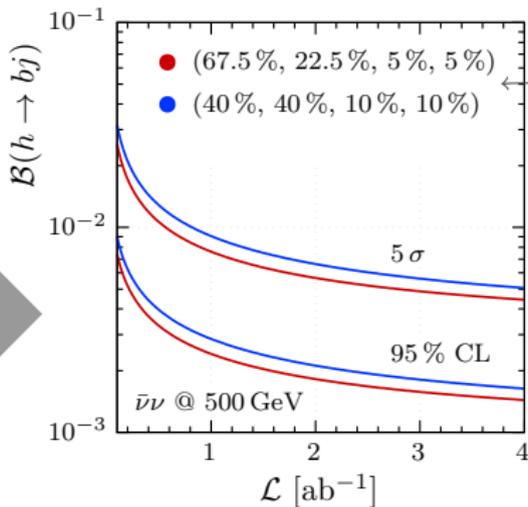
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# Results – bounds on $\mathcal{B}(h \rightarrow bj)$

## Specifications

- $\sqrt{s} = 500 \text{ GeV}$
- $\mathcal{P}(e^-) = \pm 0.8$
- $\mathcal{P}(e^+) = \pm 0.3$
- $\epsilon_{\text{syst}} \equiv \frac{\Delta B}{B} = 1\%$
- optimal cuts

$$z = \frac{S}{\sqrt{S + B + \epsilon_{\text{syst}}^2 B^2}}$$



(-+, +-, --, ++)

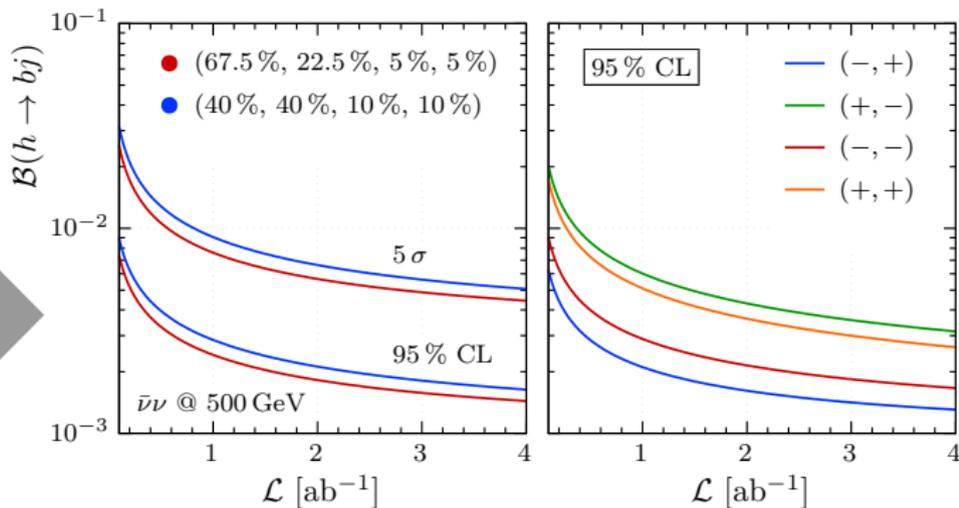
Polarization sharing  
from [1506.07830]

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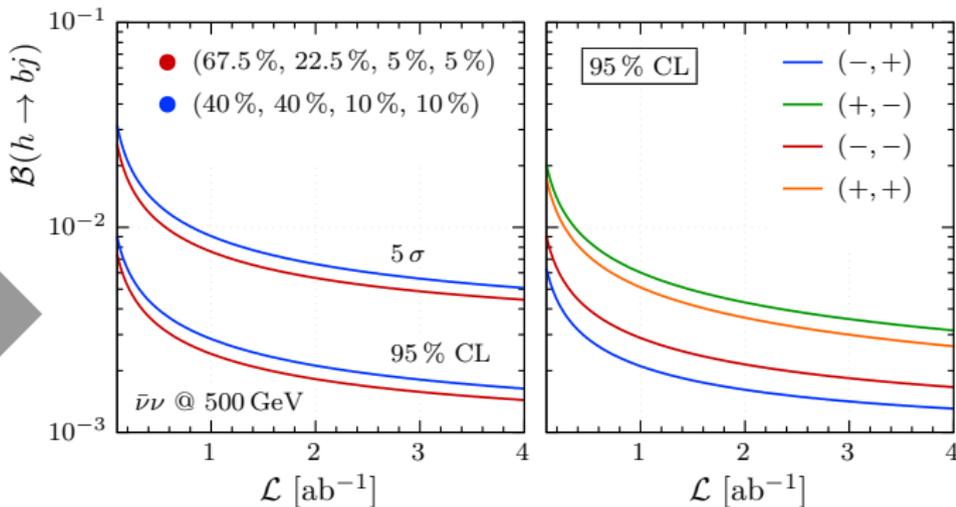


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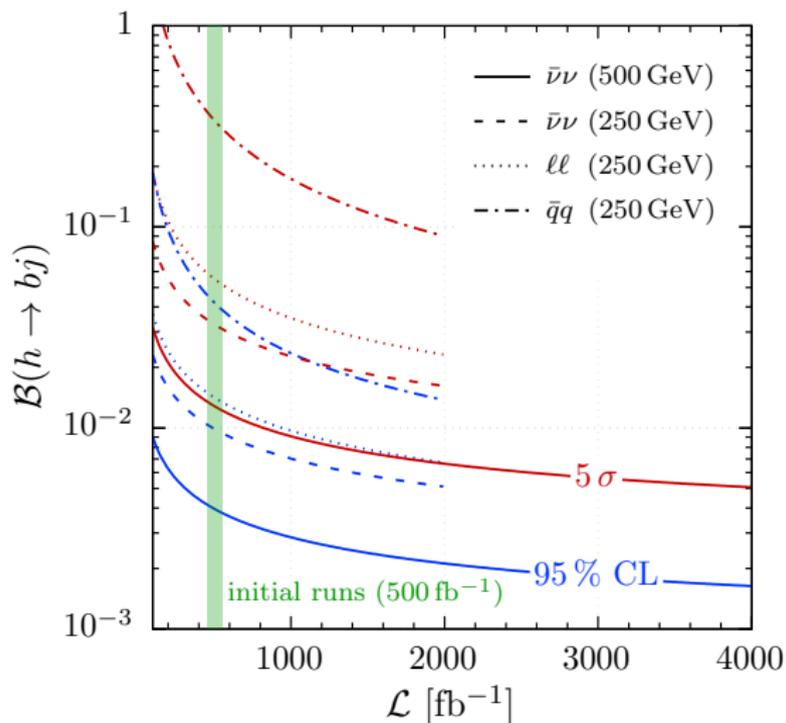
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## Expected performance

$\mathcal{L} [\text{ab}^{-1}]$	$\mathcal{B}_{95\%} [\%]$	$\mathcal{B}_{5\sigma} [\%]$
0.5	0.40	1.3
4.0	0.16	0.51

# Results – comparison of channels



# Summary

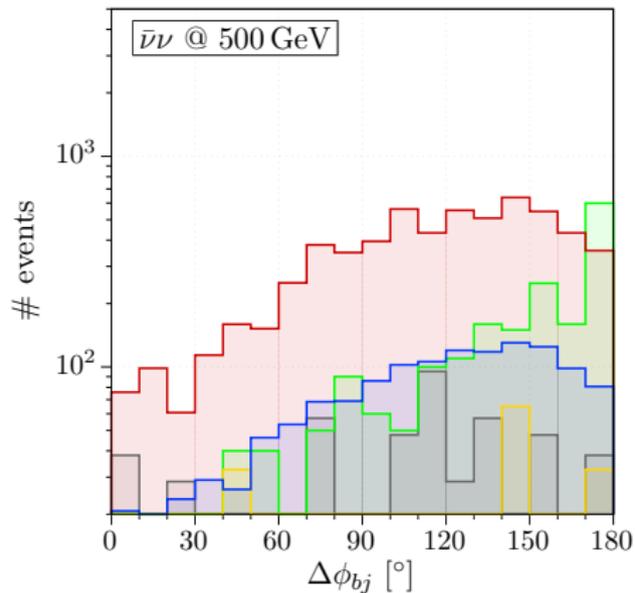
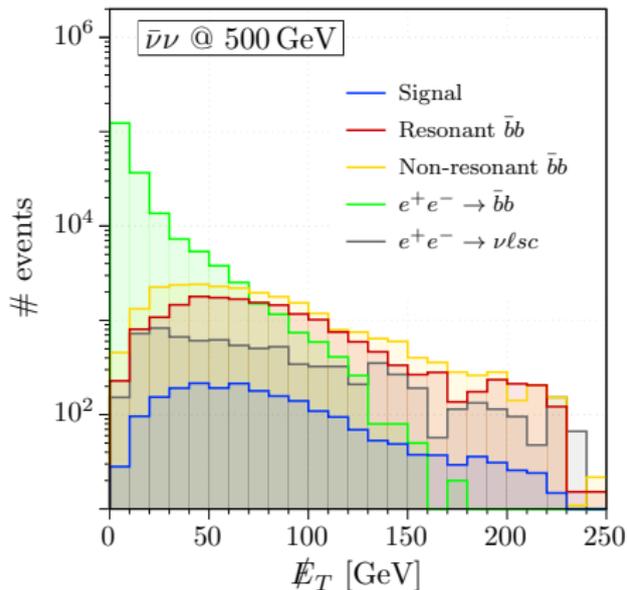
- First detailed study of the quark-flavor-violating Higgs decay  $h \rightarrow bs$  at a future  $e^+e^-$  collider.
- Most sensitive search signature is found to be  $e^+e^- \rightarrow bj + \cancel{E}_T$  at  $\sqrt{s} = 500$  GeV.
- The ILC at  $\sqrt{s} = 500$  GeV with  $4 \text{ ab}^{-1}$  of data is expected to exclude  $\mathcal{B}(h \rightarrow bj) \gtrsim 0.2\%$  at 95% CL.

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Thank you!

Backup

# Distributions – neutrino channel



# Cutflow table – neutrino channel

	Signal	$(\bar{\nu}\nu)\bar{b}b$	$(\bar{\nu}\nu)\bar{c}c$	$(\bar{\nu}\nu)jj$	$\nu_{\ell}sc$	$\nu_{\ell}du$
Exp.	2490	$7.5 \cdot 10^6$	$8.2 \cdot 10^6$	$2.3 \cdot 10^7$	$3.6 \cdot 10^6$	$3.6 \cdot 10^6$
Jet tag.	1147	$1.6 \cdot 10^5$	98 378	$1.6 \cdot 10^5$	$1.3 \cdot 10^5$	36 040
No $\ell$	1137	$1.6 \cdot 10^5$	97 545	$1.6 \cdot 10^5$	4092	1539
$\cancel{E}_T$	1040	37 247	20 224	23 285	3450	1217
$\Delta_{mh}$	695	4617	568	813	288	116
$\Delta\phi_{bj}$	655	3946	299	522	270	107

## Specifications

- $\sqrt{s} = 500 \text{ GeV}$
- $\mathcal{L} = 4 \text{ ab}^{-1} \dots$
- $\mathcal{B}(h \rightarrow bs) \simeq 0.73 \%$
- $\dots (40 \%, 40 \%, 10 \%, 10 \%)$
- optimal cuts