Accessing λ at the LHC through HH production via VBS

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VBSCan WG1 meeting

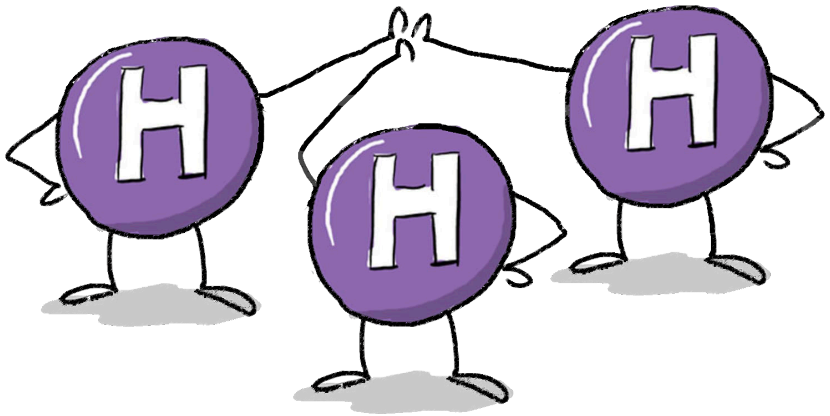
Based on [arXiv:1807.09736]

E. Arganda, **CGG**, M.J. Herrero

Introduction to the topic

Aim

- Measure accurately the Higgs self-coupling λ
- Understand the BEH mechanism
- Check BSM alternatives of λ



Current status and sensitivity at the LHC

- Studies focus on gluon gluon fusion (dominant) HH production

  See references [11-39] for theoretical studies and [40-46] for experimental searches in [arXiv:1807.09736]
- Different ggF channels considered (th. and exp.): $b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\bar{\tau}$...
- Current sensitivity: exp. global analysis constrains $\lambda \in [-5.0, 12.1]\ \lambda_{SM}$ at 95% C.L.

  [ATLAS-CONF-2018-043]

Future prospects at linear colliders

- e+e- linear colliders (ILC, CLIC) will allow for most precise λ_{SM} measurements

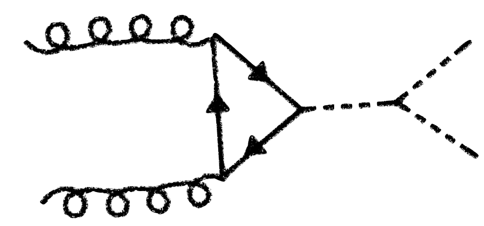
  [Abramowicz et al, Eur. Phys. J. C77 (2017) 475]
- Still far (and/or unknown) in the future!!

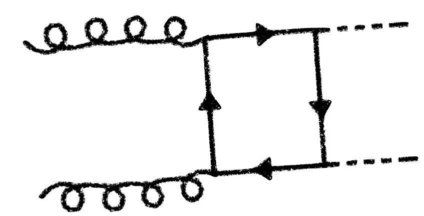
$$\Delta\lambda/\lambda = 40\% \;\; \text{at} \; \sqrt{s} = 1.4\,\text{TeV},$$
$$\Delta\lambda/\lambda = 22\% \;\; \text{at} \; \sqrt{s} = 3\,\text{TeV}.$$

Motivation

Is there an alternative to gluon gluon fusion to test λ?

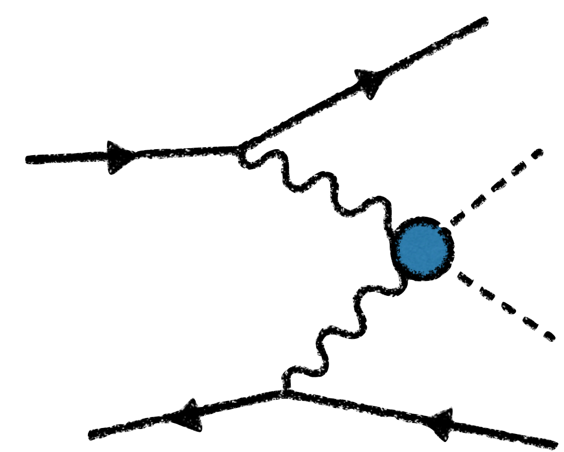
- Until today studies focus on gluon gluon fusion (ggF)





  - 👍 High rates
  - 👎 1-loop, top mass involved, big uncertainties

- Our proposal: focus on Vector Boson Scattering potential (VBS)



  - 👍 Tree level, no top physics involved,
    small uncertainties, heart of scalar interactions
    very characteristic kinematics
  - 👎 Lower rates

WARNING! All our LHC numerical results are provided at the parton level

Introduction - More on why VBS at the LHC

ggF: $gg \to HH$

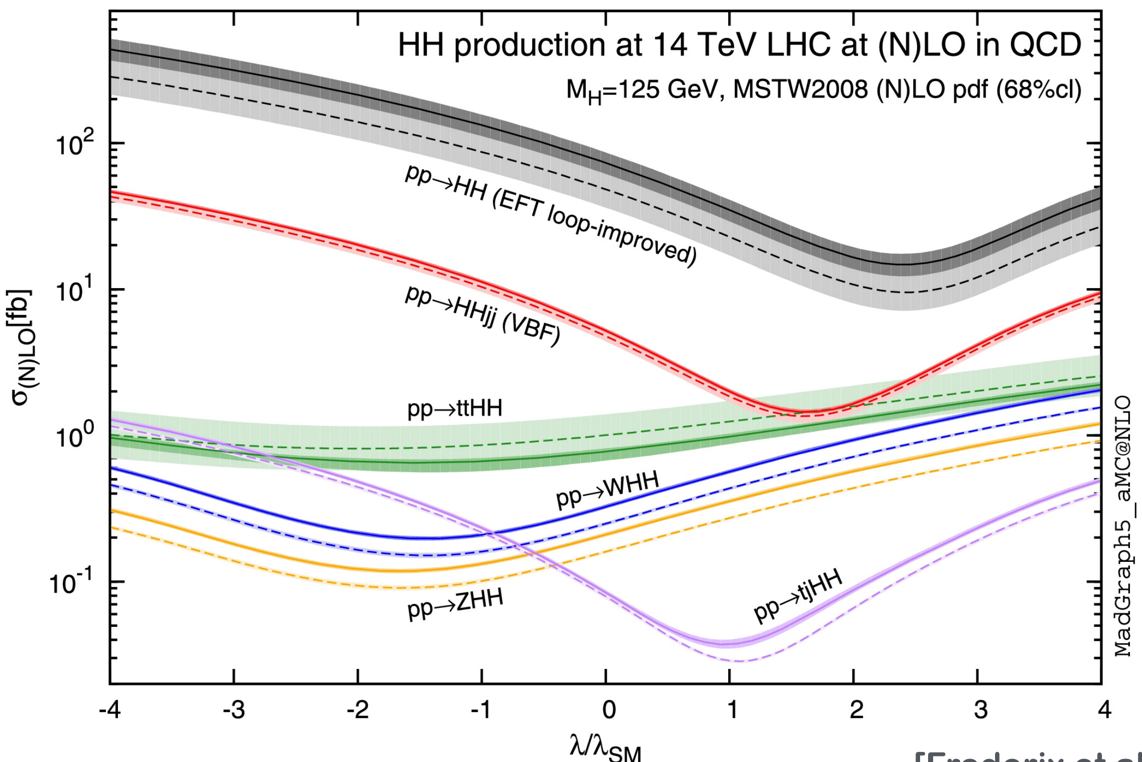
$$\sigma_{ggF}(14\ \text{TeV}, \kappa = \lambda/\lambda_{SM} = 1) \sim 32\ \text{fb}$$

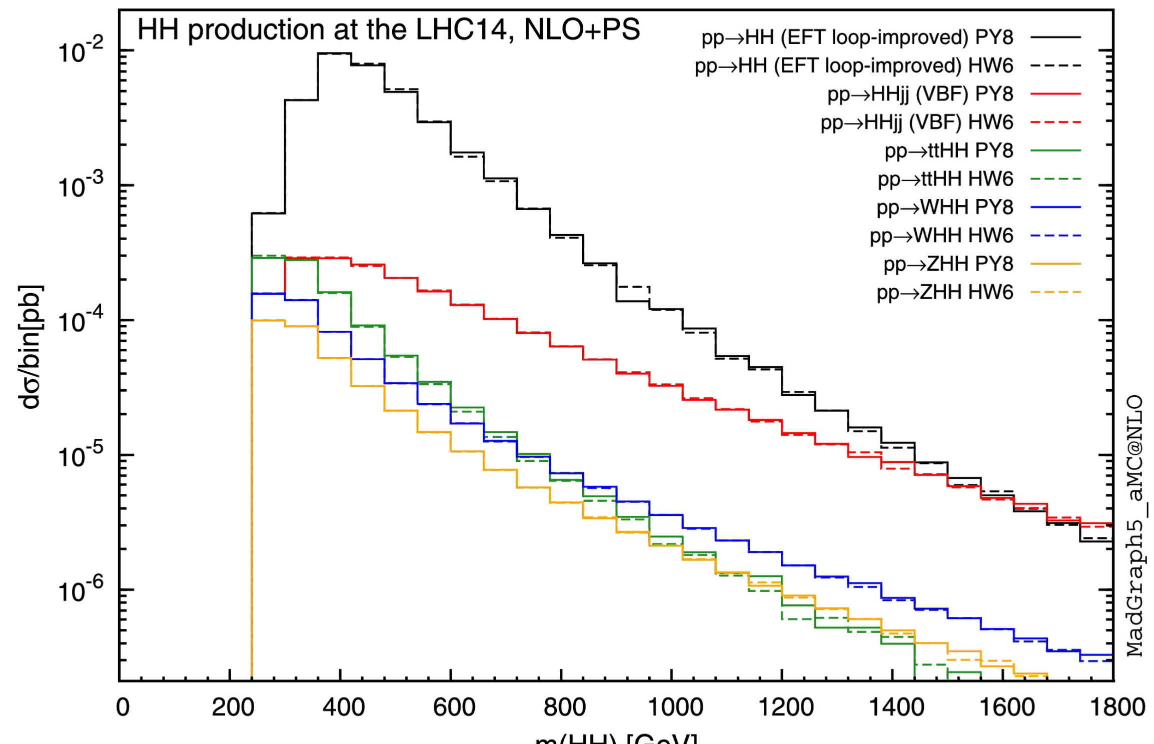
- 1-loop + Top mass uncertainties
- Big scale choice uncertainties
- Sizable NLO corrections
- Less specific kinematics
- Only sensitive to HHH coupling

VBS: $q_1q_2 \to HHq_3q_4$

$$\sigma_{VBS}(14\ \text{TeV}, \kappa = \lambda/\lambda_{SM} = 1) \sim 2\ \text{fb}$$

- Tree level + No top physics involved
- Small scale choice uncertainties
- Small NLO corrections
- Very characteristic kinematics
- Probes EWSB sector directly through $V_LV_L \to HH$ sub-scattering





[Frederix et al, Phys. Lett. B732 (2014) 142]

Introduction - More on why VBS at the LHC

ggF: $gg \rightarrow HH$

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VBS: $q_1 q_2 \rightarrow HH q_3 q_4$

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- Very characteristic kinematics
- Probes EWSB sector directly through $V_L V_L \rightarrow HH$ sub-scattering

ggF: $gg \rightarrow HHjj$?

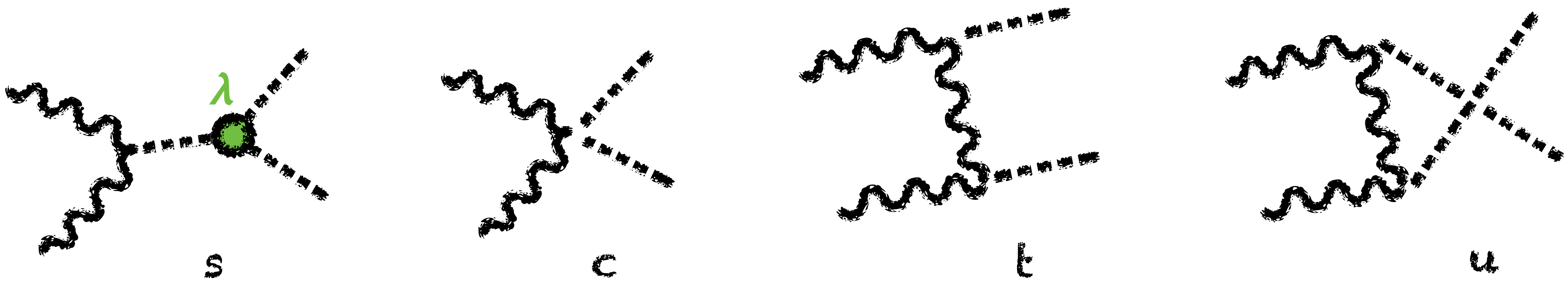
$\sigma^{\mathrm{HHjj}}_{\mathrm{ggF}}(14\ \mathrm{TeV}, \kappa = \lambda/\lambda_{\mathrm{SM}} = 1) \sim 5.5\ \mathrm{fb}$

- Contributes to our signal: “same” final state & sensitive to λ
- Larger above-commented uncertainties than VBS
- VBS selection cuts reduce cross section below pure VBS one
- More optimized VBS cuts suppose bigger reduction
- Not taken into account in the present work

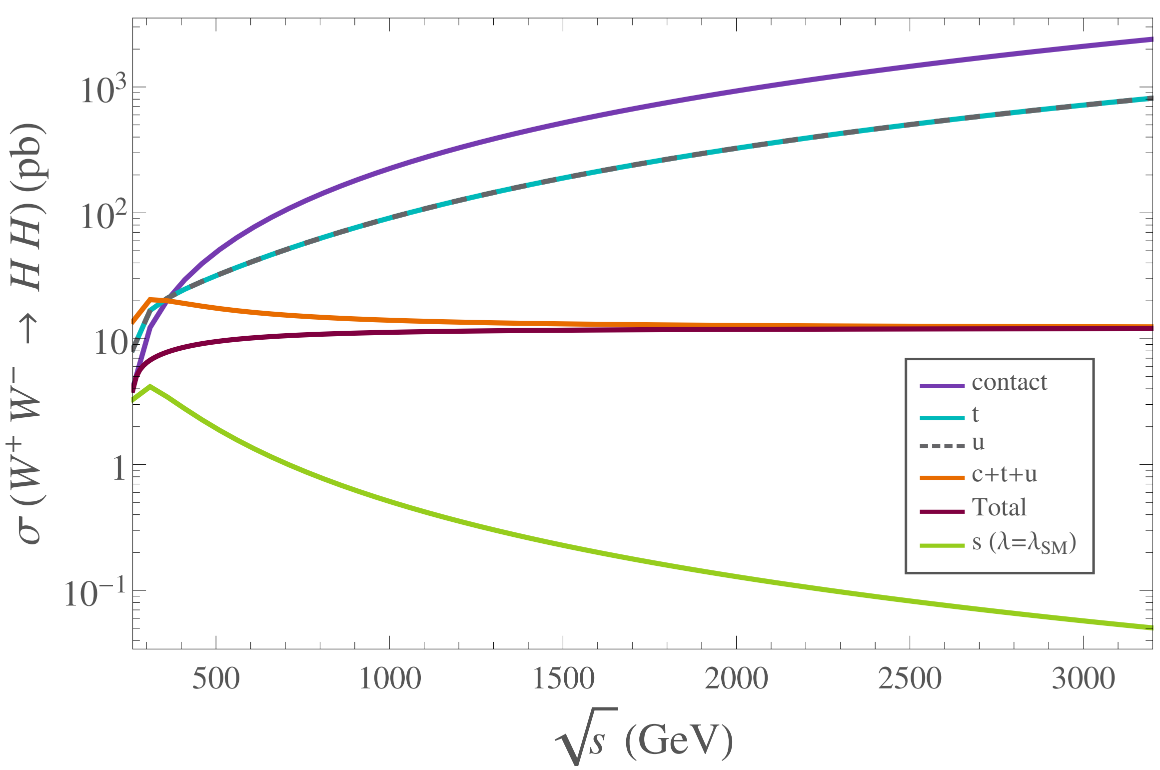
[Dolan et al, Phys. Rev. Lett. 112 (2014) 101802]
[Dolan et al, Eur. Phys. J. C75 (2015) 387]

Learning from SM subprocess VV→HH

Diagrams that contribute:



Reminder of main facts in the SM



- λ present only in s-channel
- Cross section dominated by $V_L V_L \to HH$
- λ contribution subleading in SM
- Main c+t+u cancellations lead to σ flatness at high $\sqrt{s}$
- Negative interference between λ diagram and the rest only relevant near HH threshold

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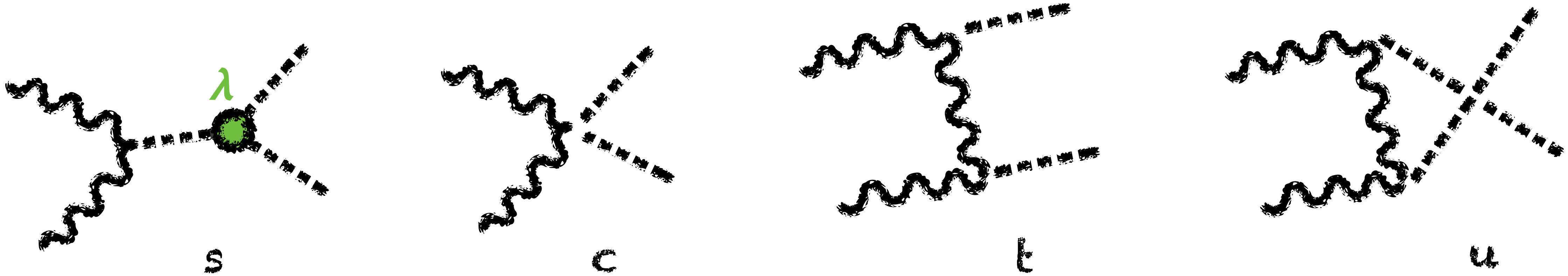

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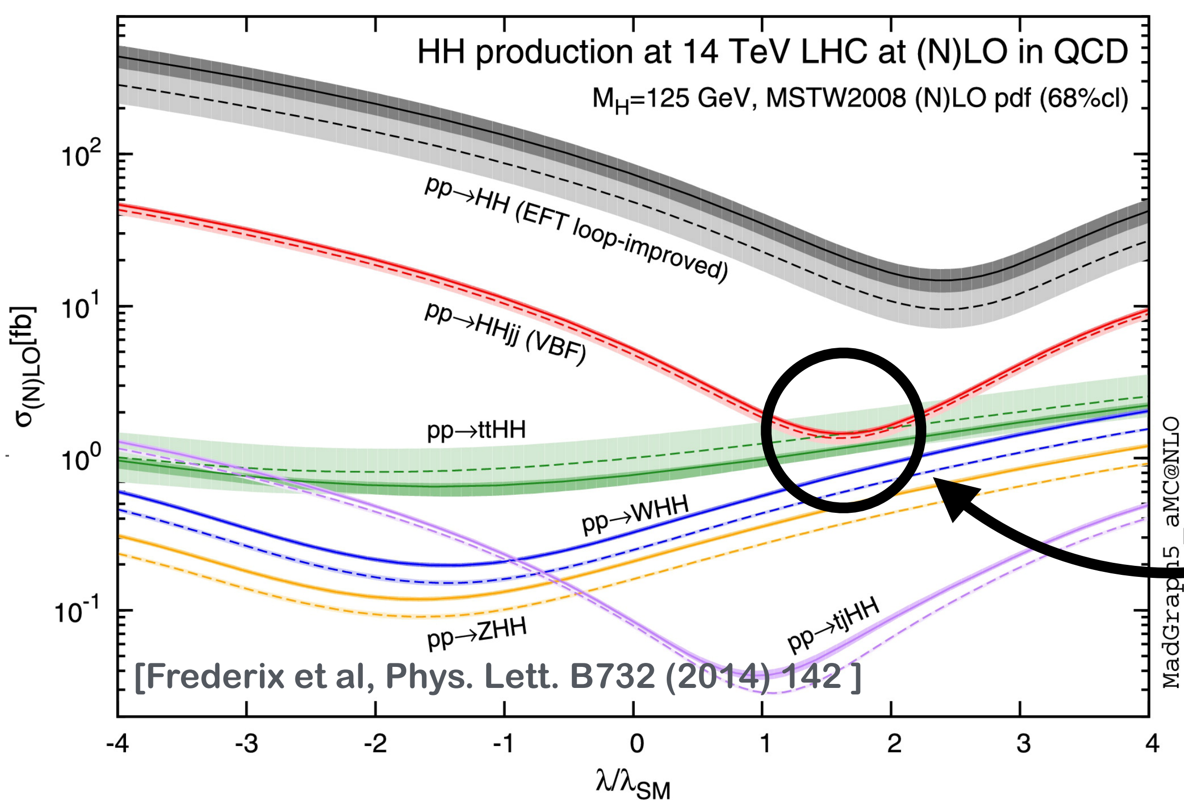

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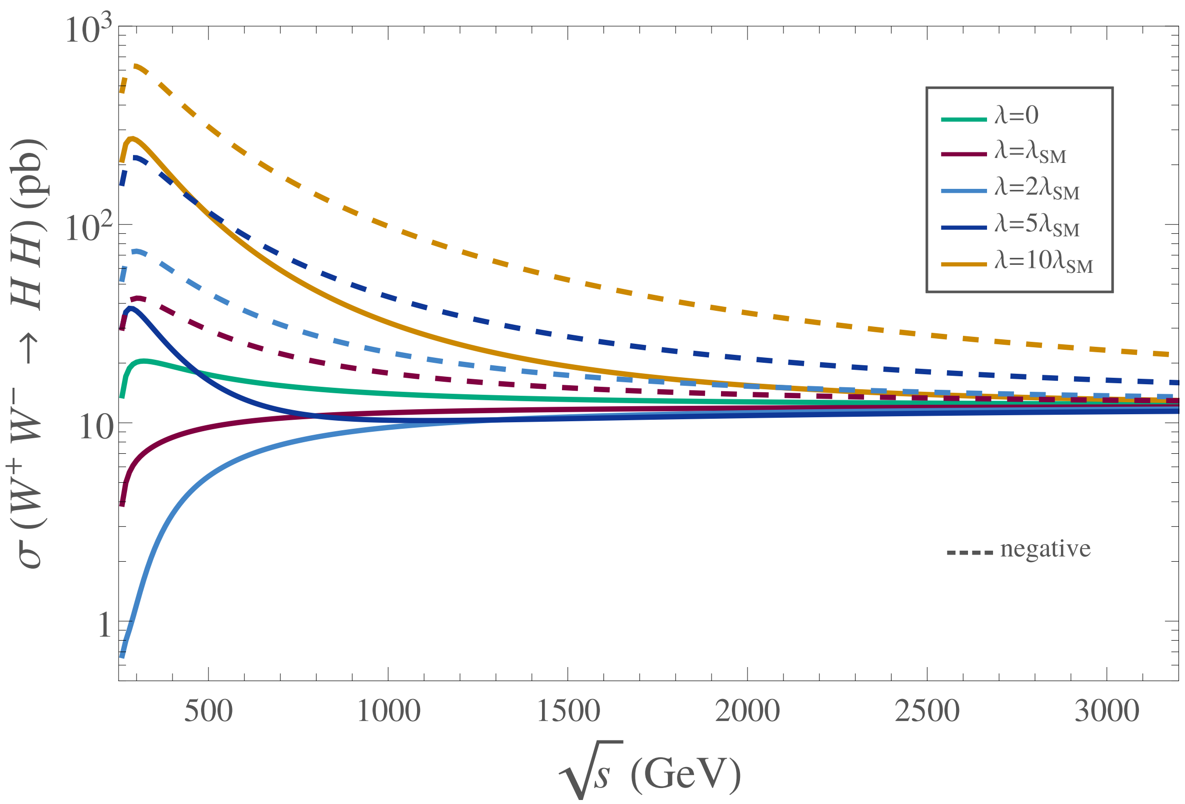
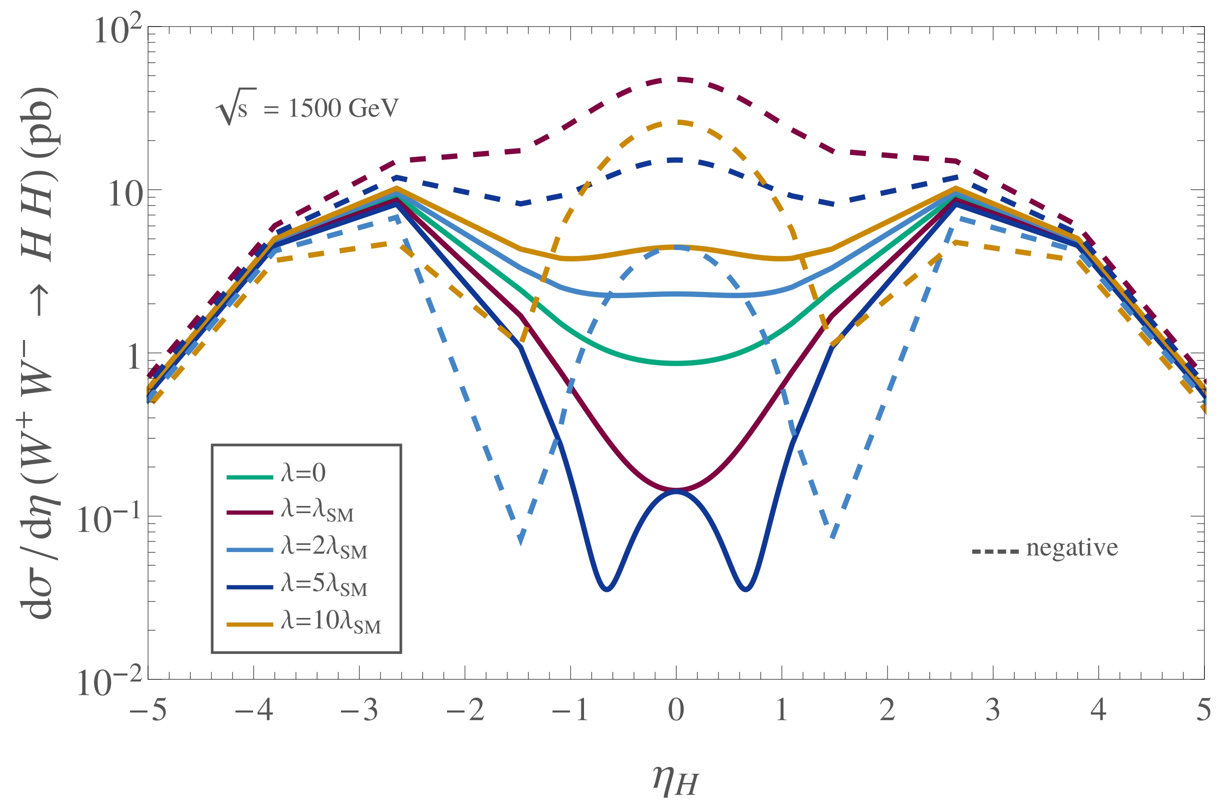
BSM distortions varying κ = λ/λ_{SM}

- We study $\lambda \in [-10,10]\ \lambda_{SM}$

- Energy and angular behavior change when varying λ





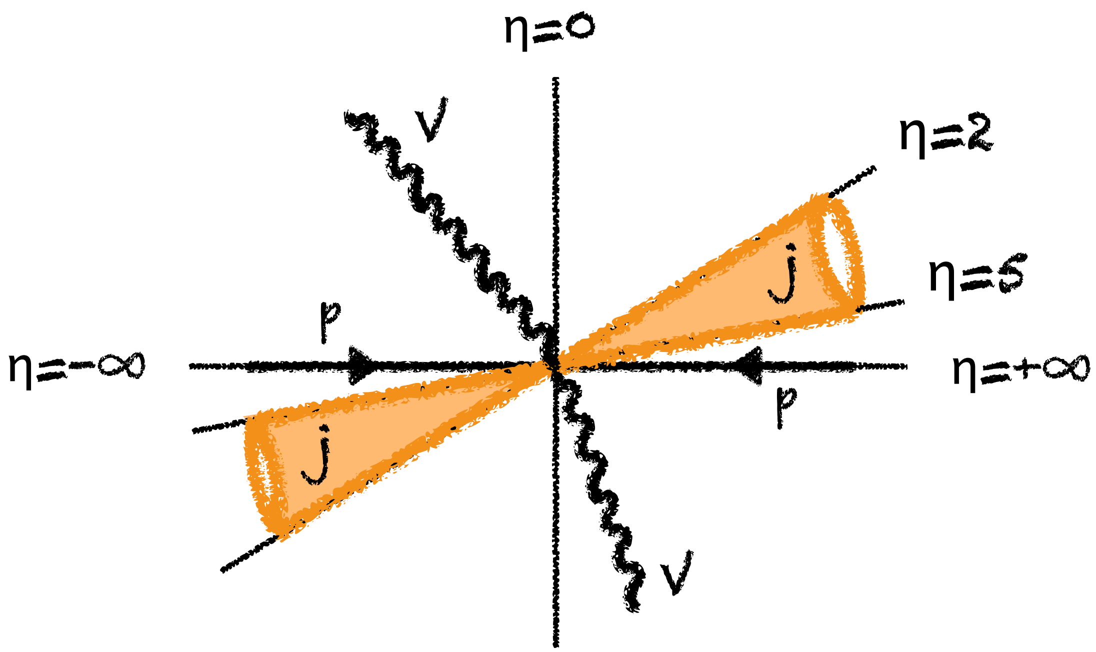
- $\lambda \neq \lambda_{SM}$ leads to sizable (exp. observable) deviations from the SM

- Largest deviations near HH production threshold

Moving on to the LHC: pp → HHjj

Signal: prediction of $q_1q_2 \to HHq_3q_4$ events for given λ

VBS characterization of our signal



Extra jets identify VBS configurations among all contributing diagrams

Two opposite-side forward/backward jets with large pseudorapidity gap required

$$|\Delta\eta_{jj}| \equiv |\eta_{j_1} - \eta_{j_2}|$$

with large invariant masses

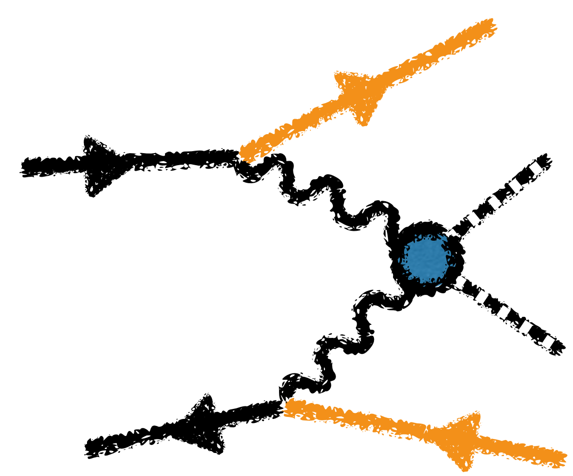
$$M_{jj}$$

Defining VBS selection cuts

Spoiler: more on this later

$$|\Delta\eta_{jj}| > 4$$

$$M_{jj} > 500 \text{ GeV}$$



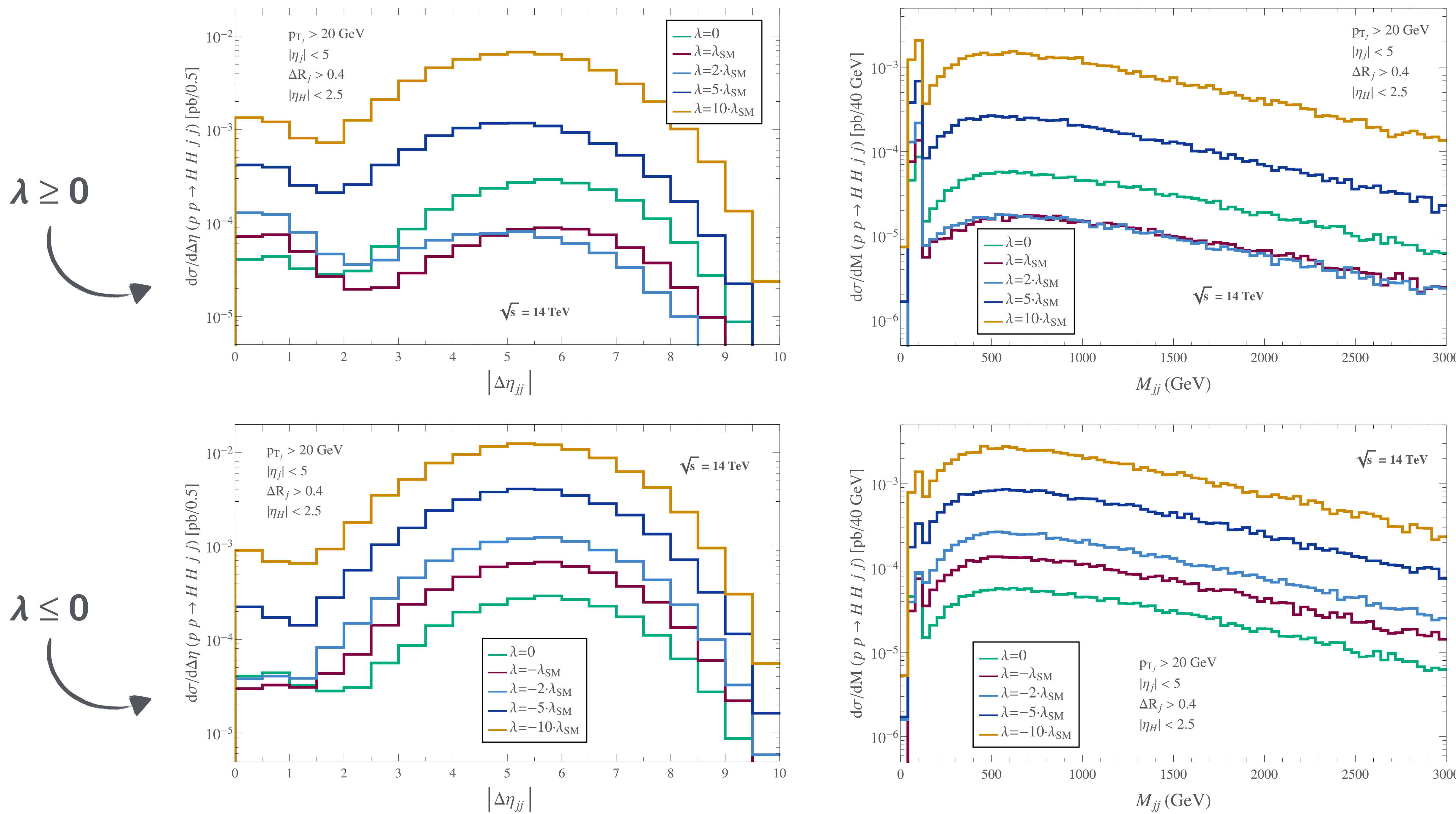
Basic detection cuts: $p_{T_j} > 20 \text{ GeV}, \quad |\eta_j| < 5, \quad \Delta R_{jj} > 0.4, \quad |\eta_H| < 2.5$

pp → HHjj characterization

All our LHC estimates are computed using MadGraph5

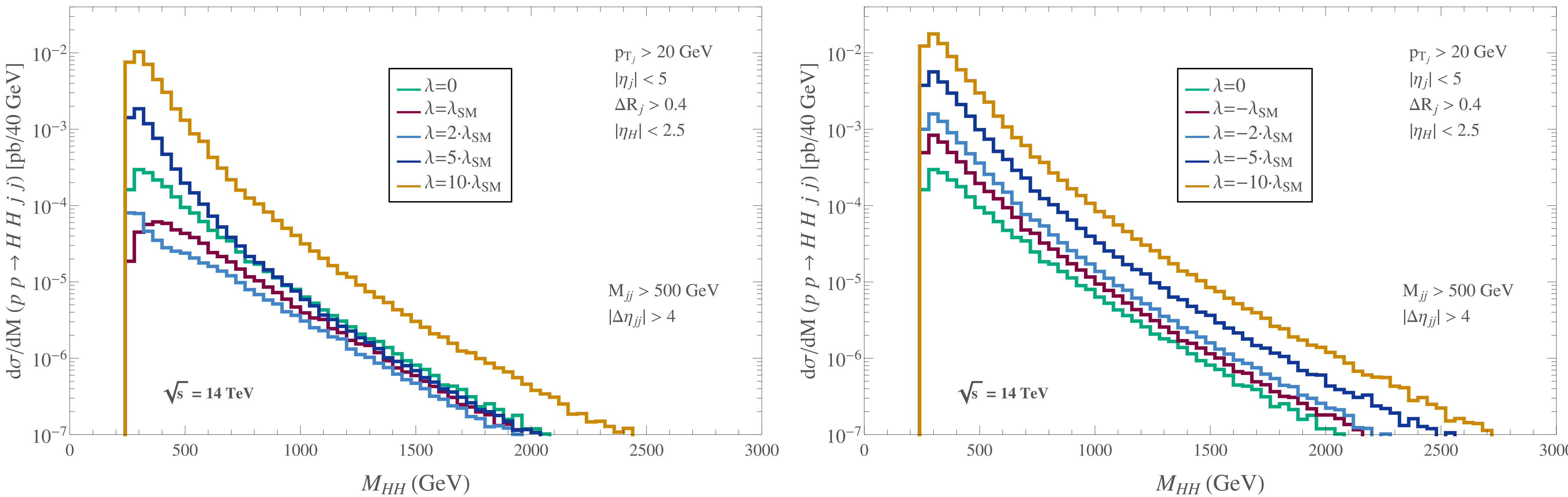
How VBS-dominated is our signal?

- **VERY!!!** 55-75% of $q_1q_2 \rightarrow HHq_3q_4$ events occur through VBS



Varying κ at the LHC in pp → HHjj

- pp → HHjj VBS-dominated → direct translation form subprocess results
- Visible deviations respect to the SM!!!



- Different sensitivity to $\lambda > 0$ and to $\lambda < 0$ remains
- Largest sensitivity still near HH production threshold

Our signal after Higgs decays

- HH production observed through Higgs decay products
- Two decays considered: $H \to b\bar{b}$ and $H \to \gamma\gamma$

$pp \to HHjj \to b\bar{b}b\bar{b}jj$ $(q_1 q_2 \to b\bar{b}b\bar{b}q_3 q_4)$

- **Highest rates** due to large $BR(H \to b\bar{b}) \sim 60\ \%$
- **Large backgrounds**

$pp \to HHjj \to b\bar{b}\gamma\gamma jj$ $(q_1 q_2 \to b\bar{b}\gamma\gamma q_3 q_4)$

- **Much cleaner** channel. Small and controlable backgrounds
- **Lower statistics** due to small $BR(H \to \gamma\gamma) \sim 0.2\ \%$

Our signal after Higgs decays

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Let us explore this one first!!

$pp \to HHjj \to b\bar{b}b\bar{b}jj$ $(q_1q_2 \to b\bar{b}b\bar{b}q_3q_4)$

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Identifying backgrounds in $pp \to b\bar{b}b\bar{b}jj$

multijet QCD $pp \to b\bar{b}b\bar{b}jj$

Estimated with MG5
Checked with AlpGen

- Dominant background by many orders of magnitude
- Additional selection cuts apart from VBS required?

+ ...

$\mathcal{O}(\alpha_S^3)$

$tt \to bW^+\bar{b}W^- \to b\bar{b}b\bar{b}jj$

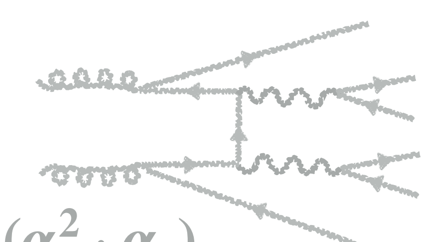
- CKM suppressed
- Radically different kinematics respect to VBS
- Under control

+ ...

$\mathcal{O}(\alpha^2 \cdot \alpha_S) \cdot |V_{qb}|^2$

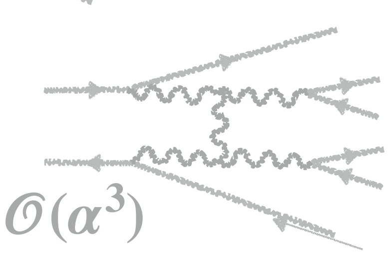
$pp \to ZZjj \to b\bar{b}b\bar{b}jj$ & $pp \to ZHjj \to b\bar{b}b\bar{b}jj$

- Take place in part through VBS configurations
- Additional selection cuts apart from VBS required?



+ ...

$\mathcal{O}(\alpha^2 \cdot \alpha_S)$



$\mathcal{O}(\alpha^3)$

Study of VBS cuts in pp → $b\bar{b}b\bar{b}jj$

- We analyze the fraction of events that satisfy different sets of VBS cuts
- Signal dominated by VBS topologies
- QCD background reduced in 1-1.5 orders of magnitude

Acceptance

$$\mathcal{A}_{\text{VBS}} \equiv \frac{\sigma(pp \to b\bar{b}b\bar{b}jj)|_{\text{VBS}}}{\sigma(pp \to b\bar{b}b\bar{b}jj)}$$

Set of VBS cuts	$\mathcal{A}_{\text{VBS}}^{\text{QCD}}$	$\mathcal{A}_{\text{VBS}}^{\text{Signal};\kappa=1}$
$\lvert\Delta\eta_{jj}\rvert > 4,\ M_{jj} > 500$ GeV	0.086	0.631
$\lvert\Delta\eta_{jj}\rvert > 4,\ M_{jj} > 600$ GeV	0.066	0.597
$\lvert\Delta\eta_{jj}\rvert > 4,\ M_{jj} > 700$ GeV	0.054	0.558
$\lvert\Delta\eta_{jj}\rvert > 3,\ M_{jj} > 500$ GeV	0.098	0.669
$\lvert\Delta\eta_{jj}\rvert > 3,\ M_{jj} > 600$ GeV	0.071	0.626
$\lvert\Delta\eta_{jj}\rvert > 3,\ M_{jj} > 700$ GeV	0.057	0.580

- Different sets give similar results → We stick to: $\lvert\Delta\eta_{jj}\rvert > 4$, $M_{jj} > 500$ GeV

Basic detection cuts: $p_{T_{j,b}} > 20$ GeV ; $\lvert\eta_j\rvert < 5$; $\lvert\eta_b\rvert < 2.5$; $\Delta R_{jj,jb} > 0.4$; $\Delta R_{bb} > 0.2$

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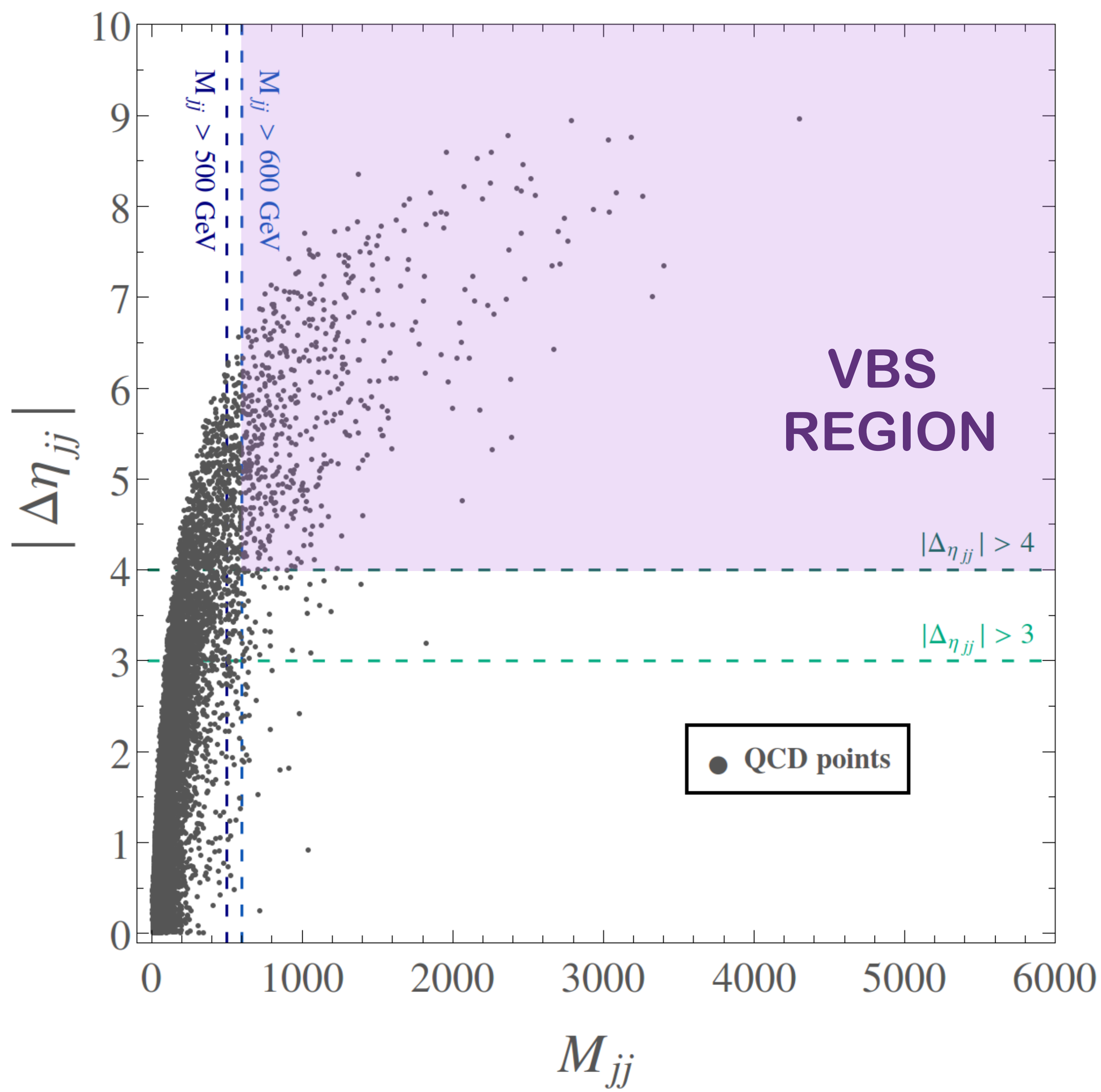
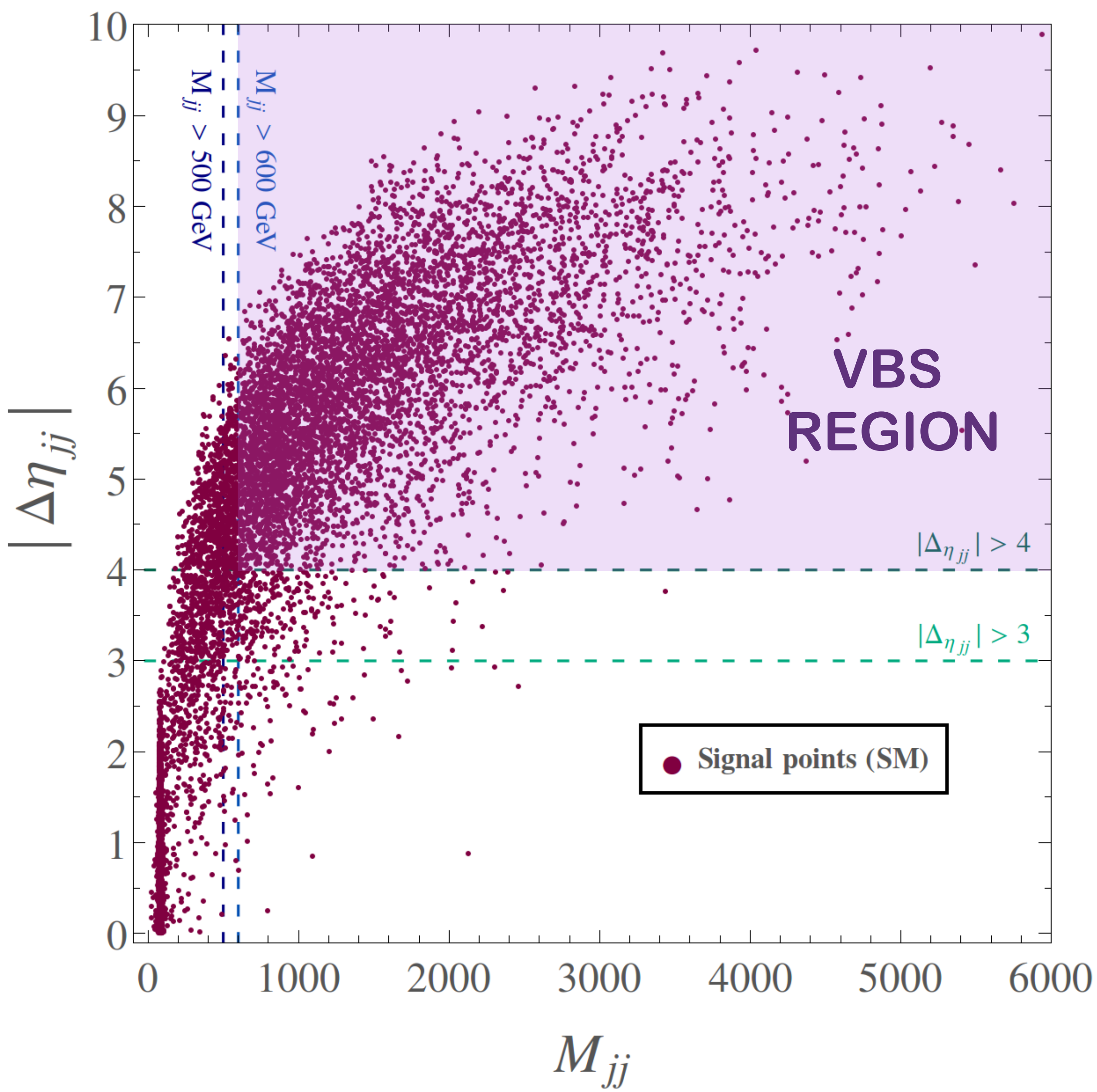
Signal and QCD background kinematics

Signal & QCD bkg populate different kinematical regions

Multijet QCD characterized by small $\Delta\eta_{jj}$ and small M_{jj}



Most of signal events in VBS kin. region

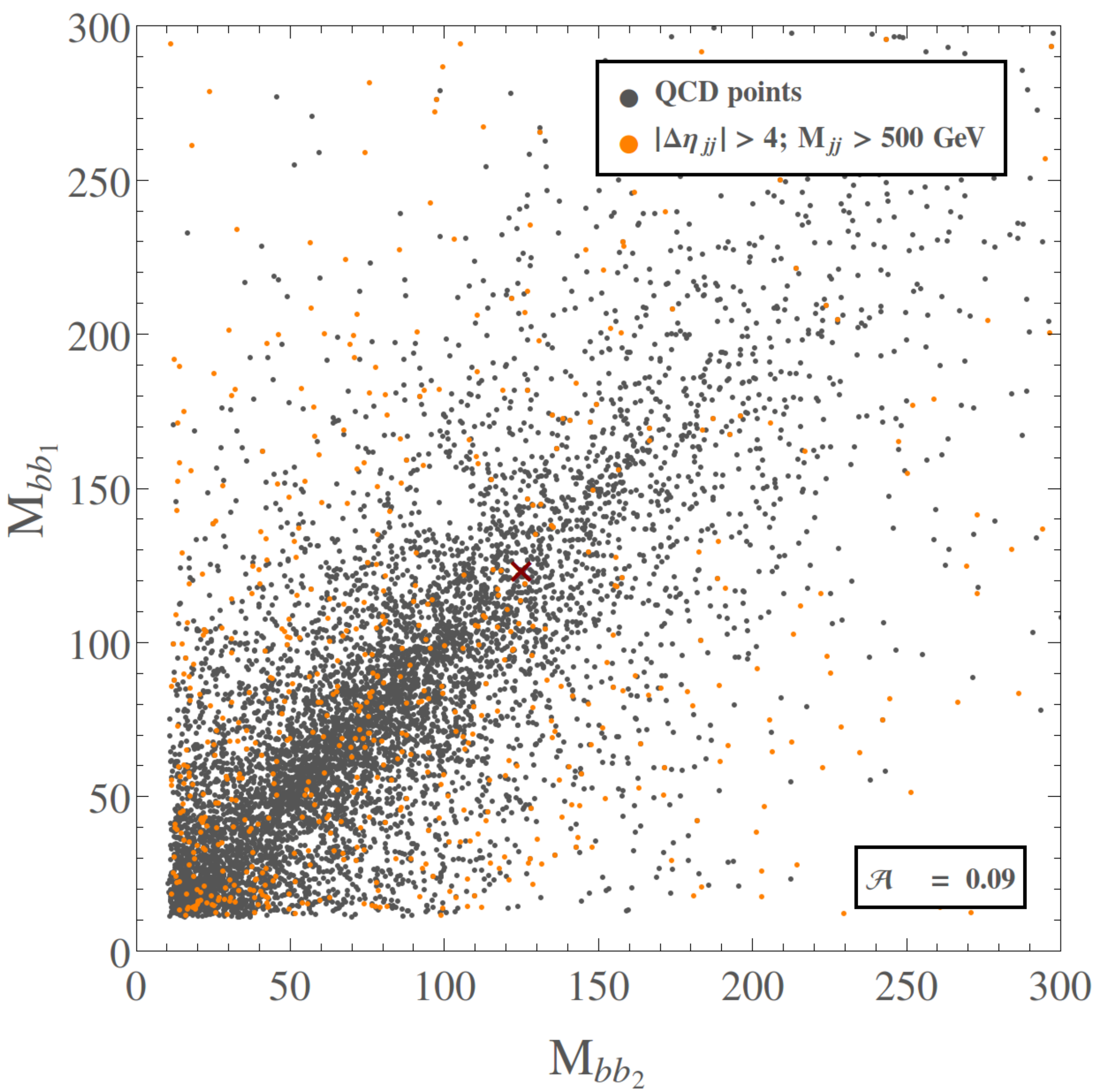


New cuts apart from VBS?

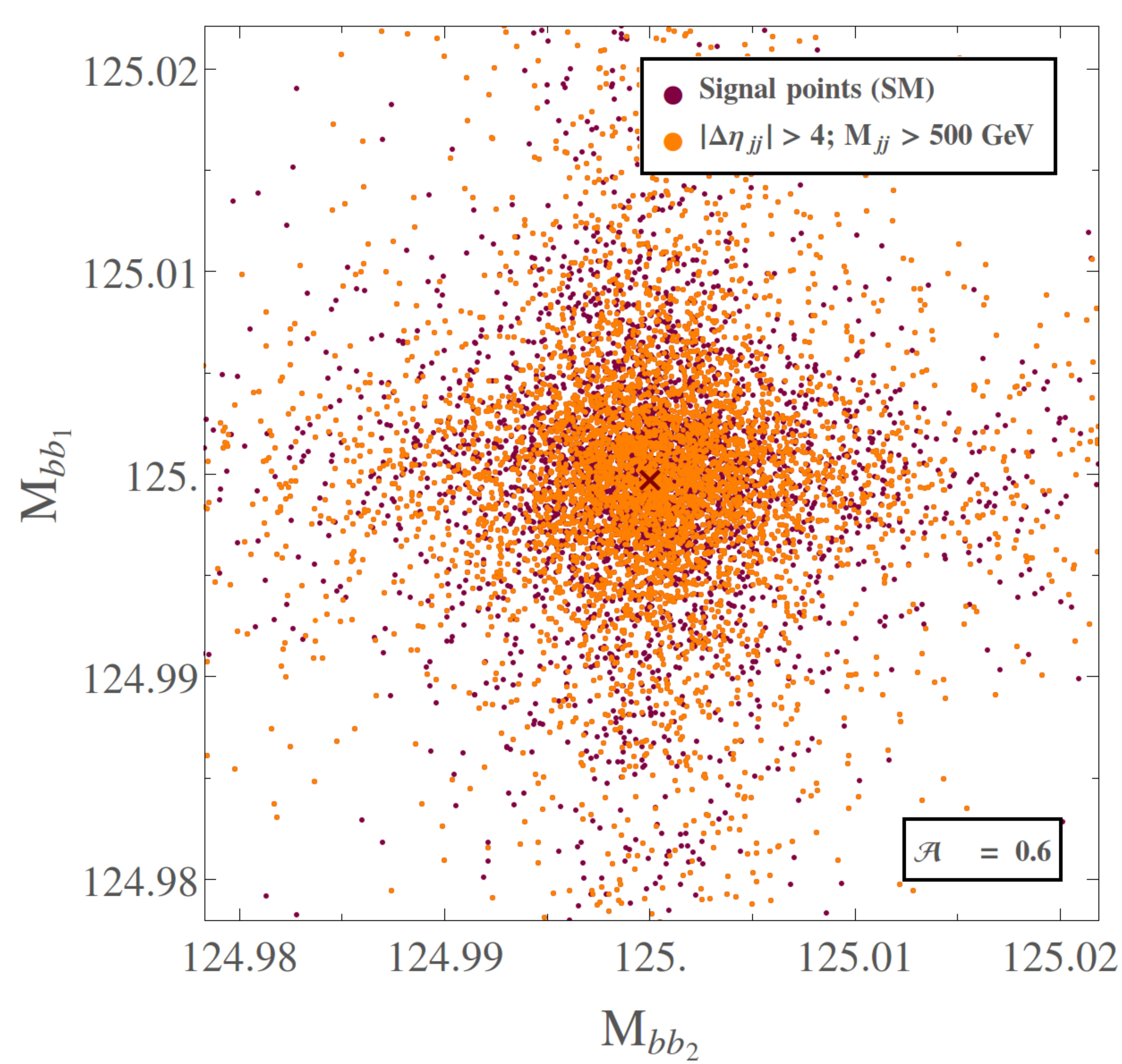
Profit from Higgs decays info

- b-quarks paired as HH candidates: pairing minimizing $|M_{bb1} - M_{bb2}|$

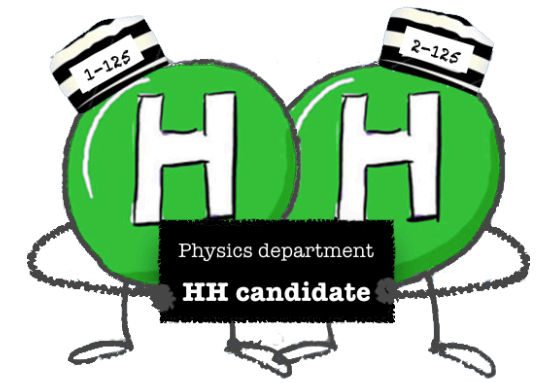
Multijet QCD background events lie mainly at low $[M_{bb1}, M_{bb2}]$



Signal events lie near $[M_{bb1}, M_{bb2}] \sim [M_H, M_H]$



HH candidate identification



b-quark pairs identified as HH decays

- **HH candidate cuts:**

  We follow recent cuts proposed by ATLAS [arXiv: 1804.06174] and CMS [CMS-PAS-HIG-16-026]

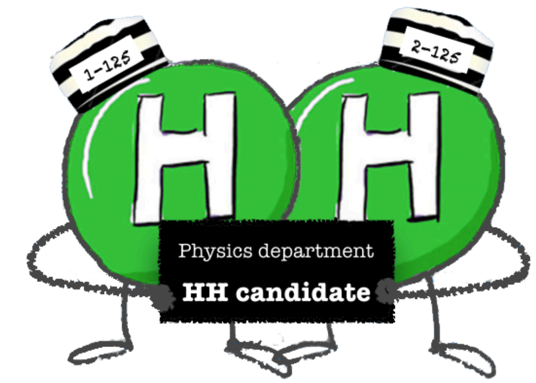
$$p_{T_b} > 35 \text{ GeV}$$

$$\hat{\Delta}R_{bb} \equiv \begin{cases} 0.2 < \Delta R_{bb^l} < \dfrac{653}{M_{4b}\,\text{GeV}} + 0.475\,;\;\; 0.2 < \Delta R_{bb^s} < \dfrac{875}{M_{4b}\,\text{GeV}} + 0.35\,,\; M_{4b} < 1250 \text{ GeV} \\ 0.2 < \Delta R_{bb^l} < 1\,;\;\; 0.2 < \Delta R_{bb^s} < 1\,,\; M_{4b} > 1250 \text{ GeV} \end{cases}$$

$$\hat{p}_{T_{bb}} \equiv p_{T_{bb^l}} > M_{4b}/2 - 103\,\text{GeV}\,;\;\; p_{T_{bb^s}} > M_{4b}/3 - 73\,\text{GeV}$$

$$\chi_{HH} \equiv \sqrt{\left(\frac{M_{bb^l} - m_H}{0.05\, m_H}\right)^2 + \left(\frac{M_{bb^s} - m_H}{0.05\, m_H}\right)^2} < 1$$

HH candidate identification



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Small angular separation between Higgs decay products

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[Mbb1, Mbb2] ~[MH,MH]

$$\chi_{HH} \equiv \sqrt{\left(\frac{M_{bb^l} - m_H}{0.05\, m_H}\right)^2 + \left(\frac{M_{bb^s} - m_H}{0.05\, m_H}\right)^2} < 1$$

Efficiency of the selection cuts

Combined HH candidate and VBS cuts

- **Signal mildly reduced**

Cut	σ_{QCD} [pb]	$\sigma_{ZHjj,ZZjj}$ [pb]	$\sigma_{\text{Signal};\kappa=1}$ [pb]
Basic detection cuts	602.72	0.028	$5.1{\cdot}10^{-4}$
$p_{T_b} > 35$ GeV	98.31	0.01	$3.0{\cdot}10^{-4}$
$\hat{\Delta}R_{bb}$	33.80	$6.3 \cdot 10^{-3}$	$1.1{\cdot}10^{-4}$
$\hat{p}_{T_{bb}}$	29.77	$5.8{\cdot}10^{-3}$	$9.0{\cdot}10^{-5}$
$\chi_{HH} < 1,$	$7.9 \cdot 10^{-2}$	$8.6{\cdot}10^{-6}$	$9.0{\cdot}10^{-5}$
VBS cuts in	$6.8 \cdot 10^{-3}$	$5.5{\cdot}10^{-6}$	$4.1{\cdot}10^{-5}$

Cuts subsequently applied

- Very reduced backgrounds!!!

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VBS cuts in	$6.8 \cdot 10^{-3}$	$5.5 \cdot 10^{-6}$	$4.1 \cdot 10^{-5}$

Cuts subsequently applied

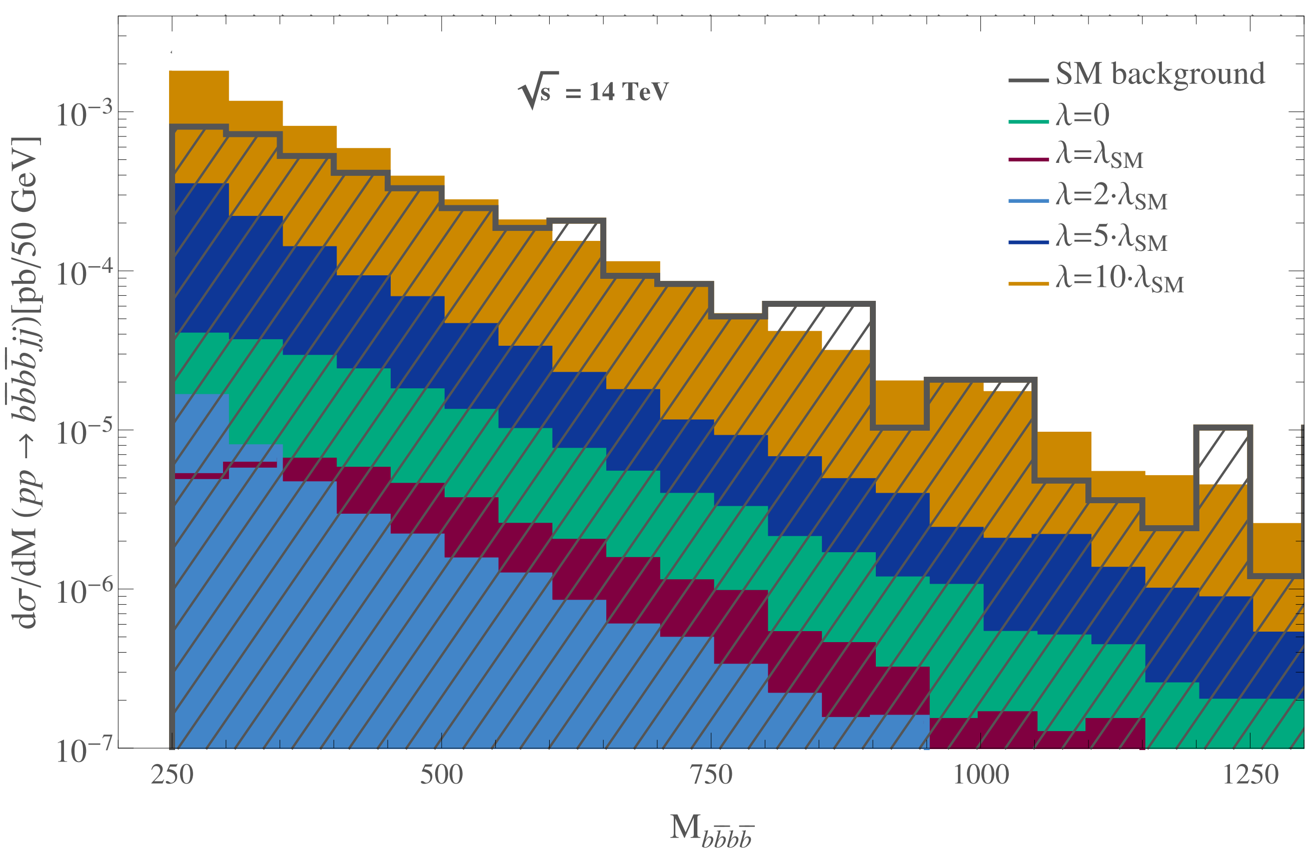
- Very reduced backgrounds!!!
- Total SM background: multijet QCD + ZZjj + ZHjj events leading to $b\bar{b}b\bar{b}jj$

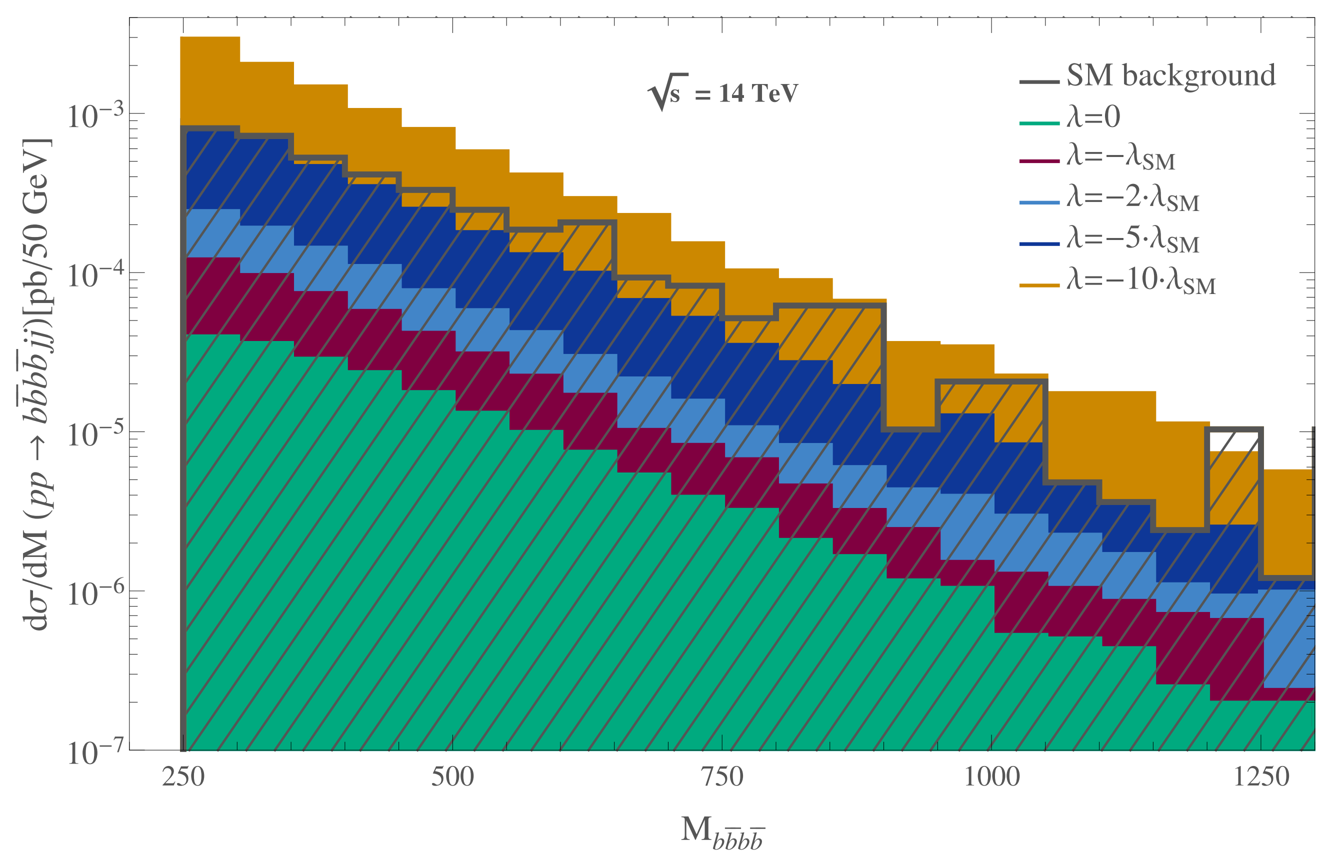
4b inv. mass distributions of $pp \to b\bar{b}b\bar{b}jj$

Signal = $q_1q_2 \to HHq_3q_4 \to b\bar{b}b\bar{b}q_3q_4$ (sensitive to λ)

SM Background = multijet QCD + ZHjj + ZZjj leading to $b\bar{b}b\bar{b}jj$

- Similar results as in $pp \to HHjj$ varying κ
- Clear deviations respect the background and the λ_{SM} prediction





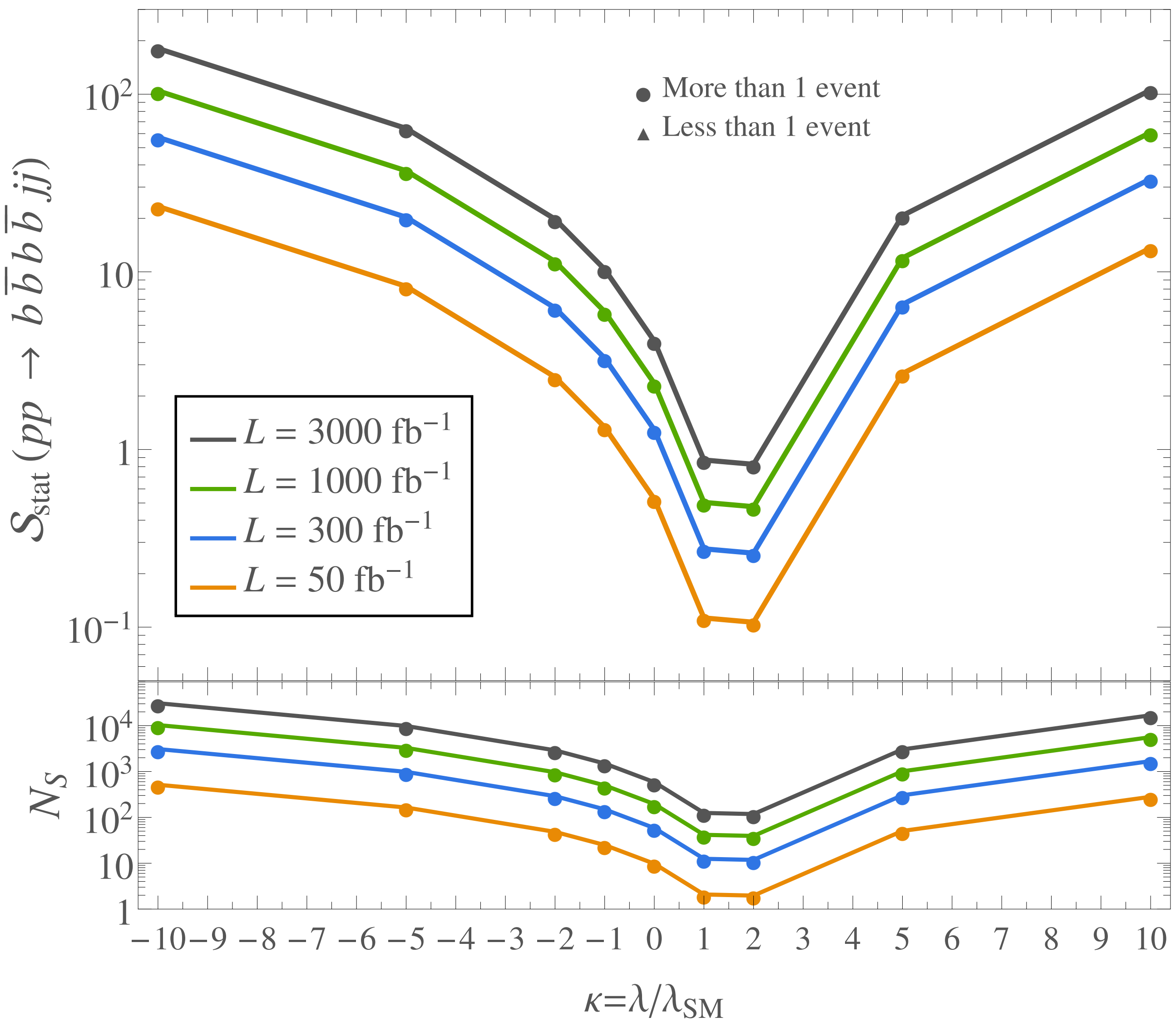
- Some predictions (κ = -10) even above backgrounds!

Sensitivity to λ in $pp \to b\bar{b}b\bar{b}jj$

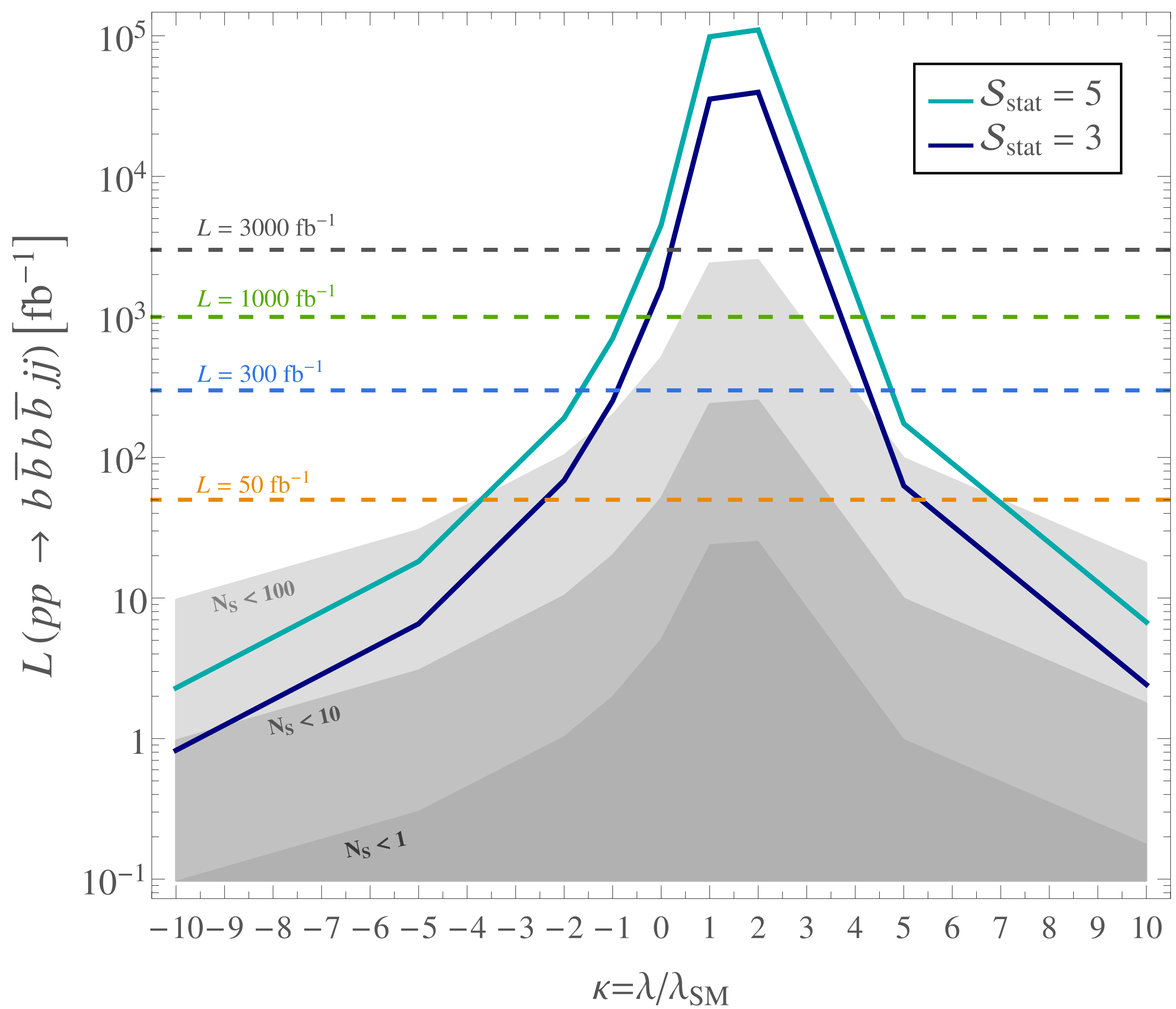
High sensitivity to BSM λ even for the lowest luminosities!!!

$$\mathcal{S}_{\text{stat}} = \sqrt{-2\left((N_S + N_B)\log\left(\frac{N_B}{N_S + N_B}\right) + N_S\right)}$$

Statistical significance for different λ values and different luminosities



Luminosity required to observe a λ value at 3σ and 5σ



Accesible values of λ in $pp \to b\bar{b}b\bar{b}jj$

Which λ intervals can we probe through VBS?

- We explore different luminosities
- Different sensitivities to $\lambda < 0$ and $\lambda > 0$ at 3σ (5σ)

$L\ [\mathrm{fb}^{-1}]$	50	300	1000	3000
$\kappa > 0$	$\kappa > 5.4\ (7.0)$	$\kappa > 4.3\ (4.8)$	$\kappa > 3.7\ (4.2)$	$\kappa > 3.2\ (3.7)$
$\kappa < 0$	$\kappa < -2.4\ (-3.8)$	$\kappa < -1.0\ (-1.7)$	$\kappa < -0.3\ (-0.8)$	$\kappa < 0\ (-0.2)$

- Very broad intervals probed even for low luminosities!
- For $L = 50\ \mathrm{fb}^{-1}$ similar results than current 95% C.L. sensitivity: $\kappa \in [-5.0, 12.1]$ *
- HL-LHC: able to test small deviations and be sensitive to all $\lambda < 0$ values

*WARNING!: Naive results. Hadronization and detector not taken into account

Our signal after Higgs decays

- HH production observed through Higgs decay products
- Two decays considered: $H \to b\bar{b}$ and $H \to \gamma\gamma$

$pp \to HHjj \to b\bar{b}b\bar{b}jj$ $(q_1 q_2 \to b\bar{b}b\bar{b}q_3 q_4)$

- **Highest rates** due to large $BR(H \to b\bar{b}) \sim 60$ %
- **Large backgrounds**

Time to explore this one!!

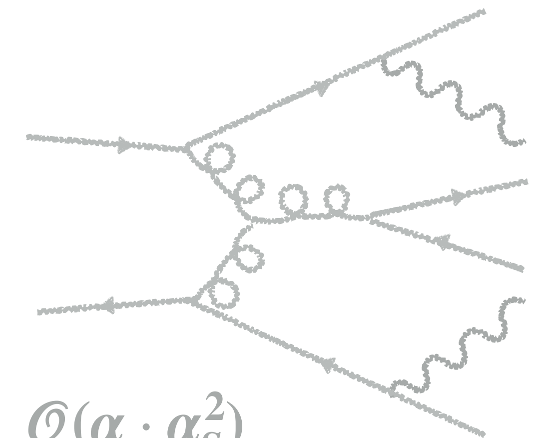
$pp \to HHjj \to b\bar{b}\gamma\gamma jj$ $(q_1 q_2 \to b\bar{b}\gamma\gamma q_3 q_4)$

- **Much cleaner** channel. Small and controlable backgrounds
- **Lower statistics** due to small $BR(H \to \gamma\gamma) \sim 0.2$ %

pp → bbγγjj backgrounds and selection cuts

mixed QCDEW pp→ $b\bar{b}\gamma\gamma jj$

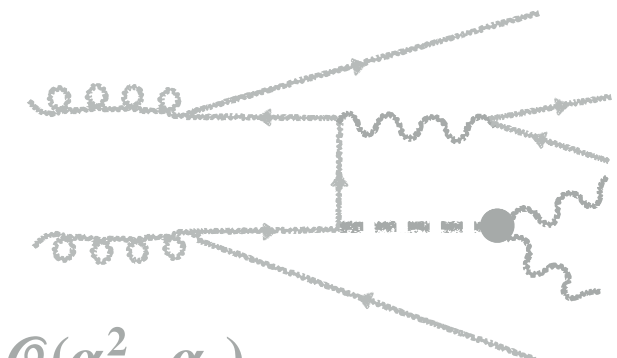
- **Dominant** background but easy to control
- **Additional** selection **cuts** apart from **VBS** required?



$\mathcal{O}(\alpha \cdot \alpha_S^2)$ + …

pp → ZHjj → $b\bar{b}\gamma\gamma jj$

- Take place **in part** through **VBS** configurations
- **Additional** selection **cuts** apart from **VBS** required?



$\mathcal{O}(\alpha^2 \cdot \alpha_S)$ + …

Selection cuts

VBS cuts + HH candidate $p_{T_{\gamma^l}}/M_{\gamma\gamma} > 1/3\,;\quad p_{T_{\gamma^s}}/M_{\gamma\gamma} > 1/4;\quad \chi_{HH} = \sqrt{\left(\frac{M_{bb}-m_H}{0.05\,m_H}\right)^2 + \left(\frac{M_{\gamma\gamma}-m_H}{0.05\,m_H}\right)^2} < 1$

VERY REDUCED BACKGROUNDS!

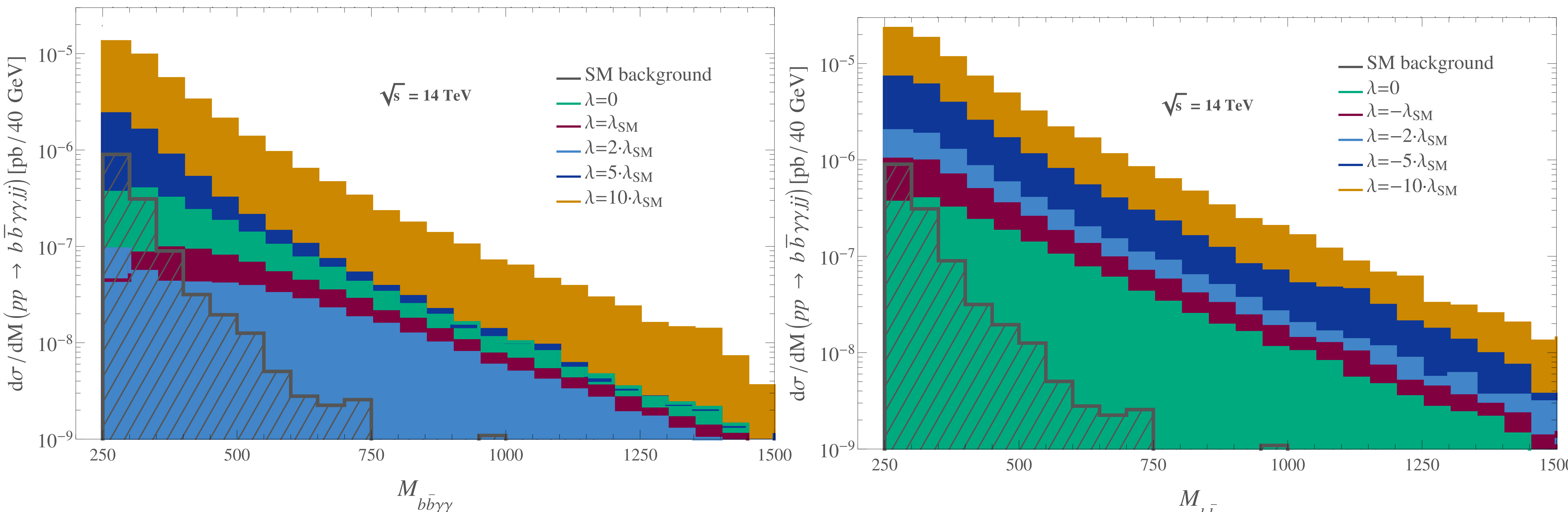
Basic detection cuts: $p_{T_{j,b}} > 20\text{ GeV}\,;\ p_{T_\gamma} > 18\text{ GeV}\,;\ |\eta_j| < 5\,;\ |\eta_{b,\gamma}| < 2.5\,;\ \Delta R_{jj,jb,\gamma\gamma,\gamma b,\gamma j} > 0.4\,;\ \Delta R_{bb} > 0.2, p_{T_{\gamma^l}}$

2b2γ inv. mass distributions of $pp \to b\bar{b}\gamma\gamma jj$

Signal = $q_1 q_2 \to HHq_3q_4 \to b\bar{b}\gamma\gamma q_3 q_4$ (sensitive to λ)

SM Background = mixed QCDEW + ZHjj events leading to $b\bar{b}\gamma\gamma jj$

- Similar results as in $pp \to HHjj$ and $pp \to b\bar{b}b\bar{b}jj$ varying κ with smaller rates
- Again clear deviations respect the background and the λ_{SM} prediction

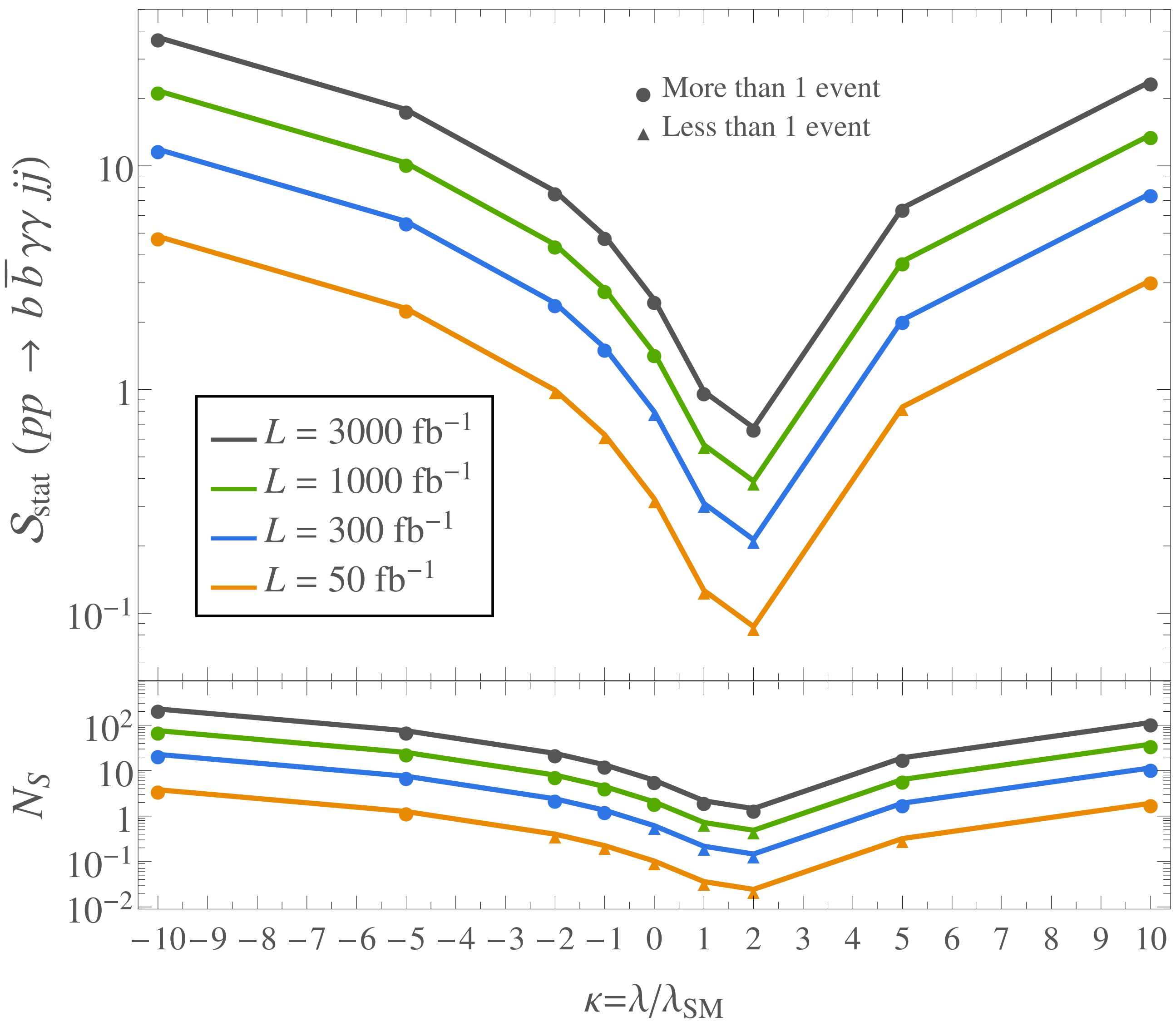


- Very reduced and steeper backgrounds
- All tested values of λ above background!

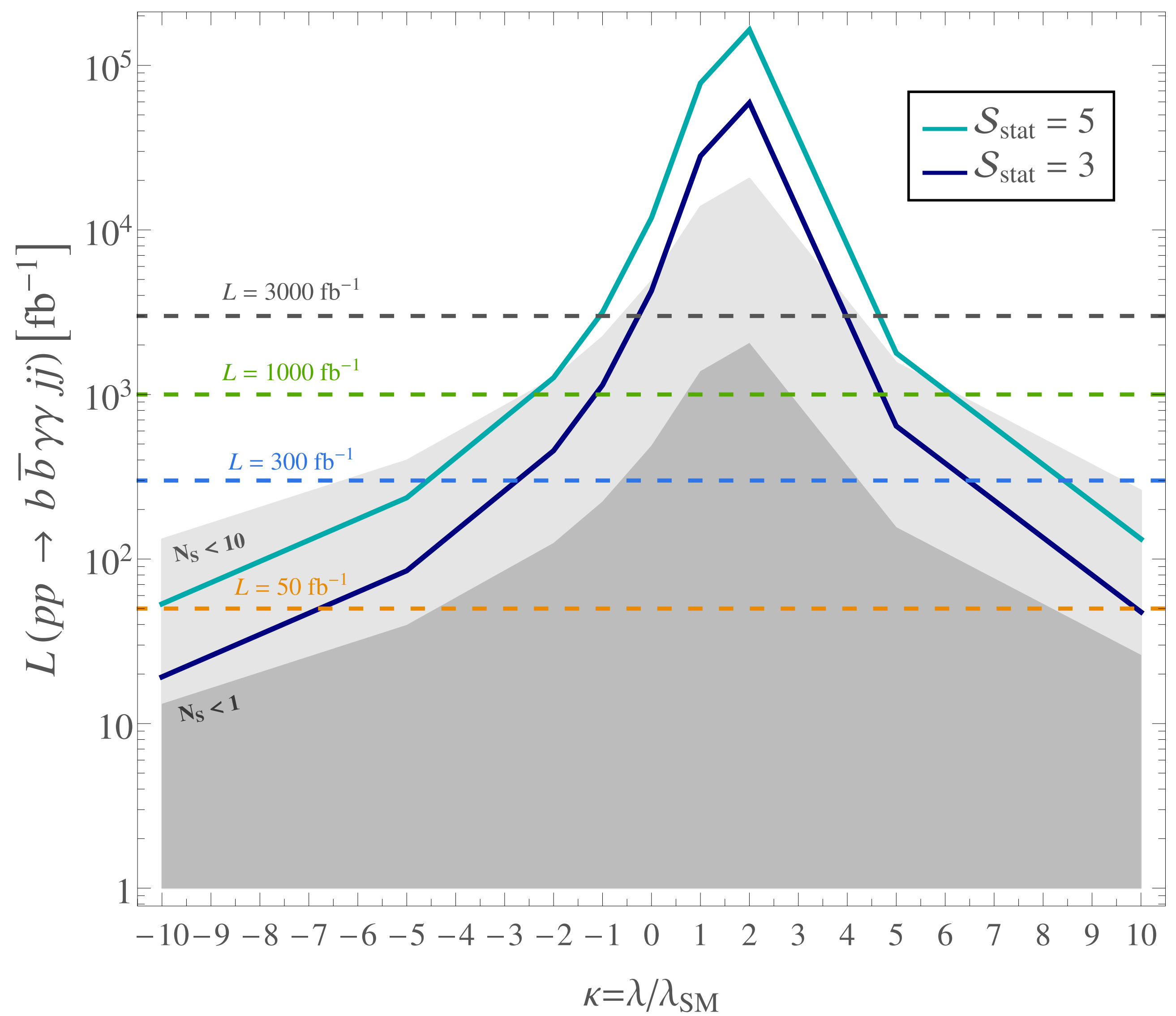
Sensitivity in $pp \to b\bar{b}\gamma\gamma jj$

Modest but interesting channel to probe the H self-coupling

Statistical significance for different λ values and different luminosities



Luminosity required to observe a λ value at 3σ and 5σ



Accesible values of λ in $pp \to b\bar{b}\gamma\gamma jj$

Which λ intervals can we probe through VBS?

- We explore different luminosities
- Different sensitivities to $\lambda < 0$ and $\lambda > 0$ at 3σ (5σ)

L [fb^{-1}]	50	300	1000	3000
$\kappa > 0$	$\kappa > 9.9$ (14.2)	$\kappa > 6.4$ (8.4)	$\kappa > 4.6$ (6.0)	$\kappa > 3.8$ (4.7)
$\kappa < 0$	$\kappa < -6.7$ (-10.0)	$\kappa < -2.7$ (-4.6)	$\kappa < -1.1$ (-2.3)	$\kappa < -0.2$ (-1.0)

- Very broad intervals probed except for low luminosities (not enough signal events)
- For $L \geq 300$ fb^{-1} similar results than current 95% C.L. sensitivity: $\kappa \in [-5.0, 12.1]$ *
- HL-LHC: Probe small deviations very efficiently in this channel

*WARNING!: Naive results. Hadronization and detector not taken into account

Conclusions

- Clear motivation: measure the H self-coupling through HH production
- Until now done via ggF ⟶ VBS has many advantages (although lower rates)

- We perform a devoted study of HH production via VBS at the LHC
- $pp \to HHjj$ ($q_1q_2 \to HHq_3q_4$) dominated by VBS configurations
- We give predictions for sensitivity in two decay channels after VBS and HH candidate selection
  - $pp \to b\bar{b}b\bar{b}jj$: large rates but large backgrounds

    High and promising sensitivities already for $L = 50\ \mathrm{fb}^{-1}$

    HL-LHC could probe small deviations: Up to $\kappa \sim 3$ for $\lambda > 0$ at 3σ; All studied values for $\lambda < 0$ at 3σ
  - $pp \to b\bar{b}\gamma\gamma jj$: small rates but very controlled backgrounds

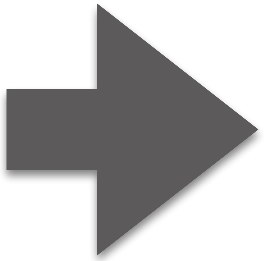
    Modest but interesting sensitivities. Need to go to $L \geq 300\ \mathrm{fb}^{-1}$

    HL-LHC could probe small deviations very efficiently
- Promising results deserve further study including hadronization and detector!!!

Take home message

VBS very optimal to probe the H self-coupling at the LHC!!!

Vector Boson Fusion



sensitivity

Conclusions

THANK YOU!!! :)

- Clear motivation: measure the H self-coupling through HH production
- Until now done via ggF ⟶ VBS has many advantages (although lower rates)

- We perform a devoted study of HH production via VBS at the LHC
- $pp \to HHjj$ ($q_1 q_2 \to HH q_3 q_4$) dominated by VBS configurations
- We give predictions for sensitivity in two decay channels after VBS and HH candidate selection
  - $pp \to b\bar{b}b\bar{b}jj$: large rates but large backgrounds

    High and promising sensitivities already for $L = 50\ \mathrm{fb}^{-1}$

    HL-LHC could probe small deviations:
    - Up to κ ~ 3 for $\lambda > 0$ at 3σ
    - All studied values for $\lambda < 0$ at 3σ
  - $pp \to b\bar{b}\gamma\gamma jj$: small rates but very controlled backgrounds

    Modest but interesting sensitivities. Need to go to $L \geq 300\ \mathrm{fb}^{-1}$

    HL-LHC could probe small deviations very efficiently
- Promising results deserve further study including hadronization and detector!!!

Back up slides

Features of sensitivity to λ at different $\sqrt{s}$

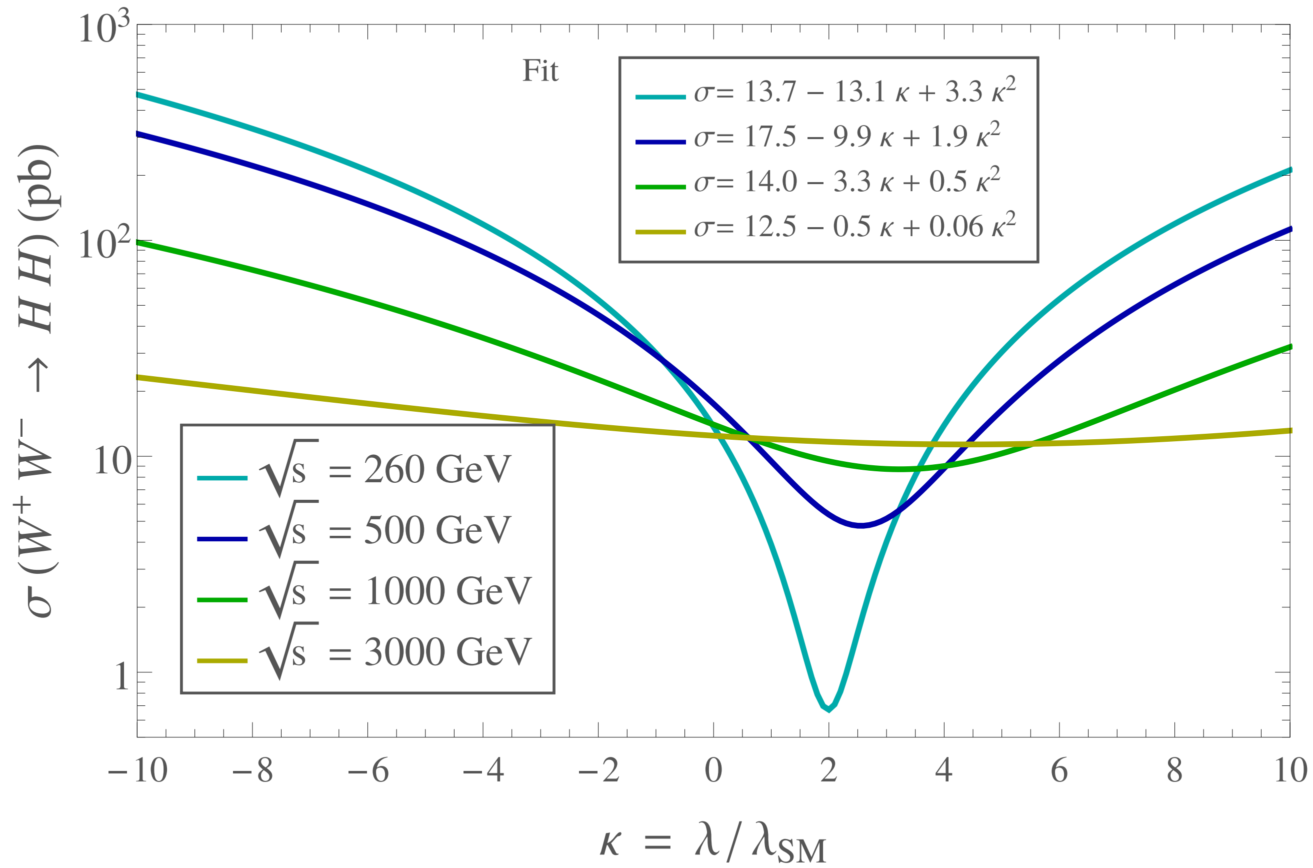
Interplay between diagrams

- $\lambda > 0$: negative interference
- $\lambda < 0$: positive interference

Sensitivity to $\lambda > 0$ and to $\lambda < 0$ different!

Better sensitivity for $\lambda < 0$ for same $|\lambda|$

Cancellations and analytical sensitivity to λ depend on energy and λ value



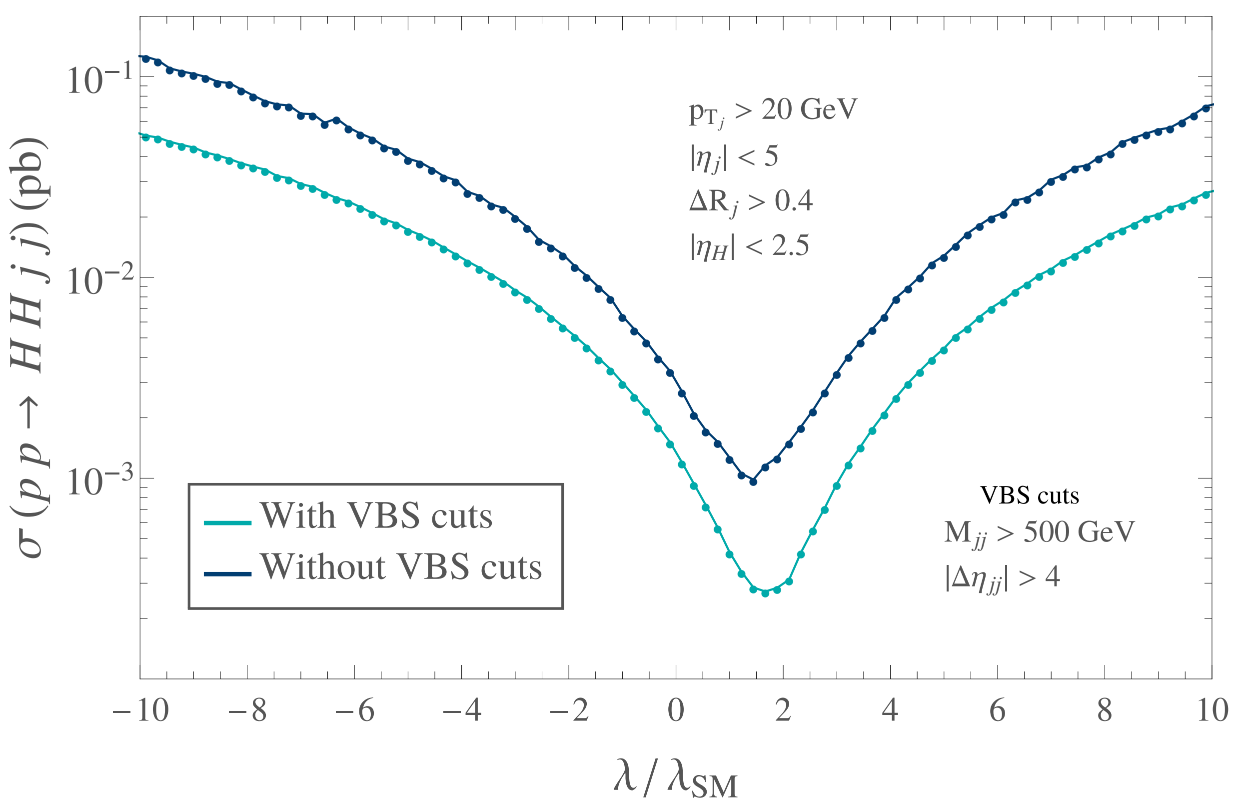
Highest sensitivity outside the interval around minimum

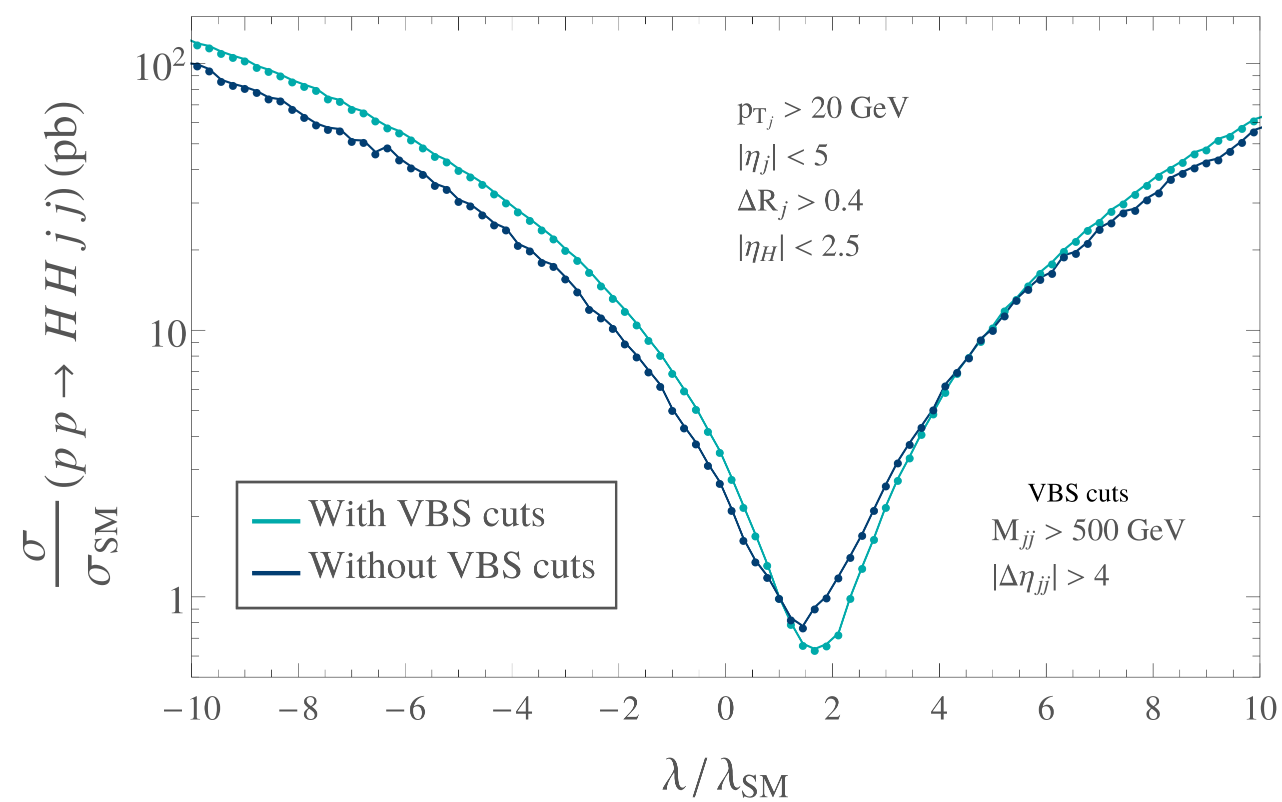
Largest cross section and sensitivity near the HH threshold

Sensitivity at the LHC vs subprocess

Does interference play the same role in pp → HHjj?

- Minimum appears in different place?
  - LHC cross section dominated by region close to HH threshold
  - Applying VBS cuts moves minimum
  - VBS selection improves sensitivity away from minimum



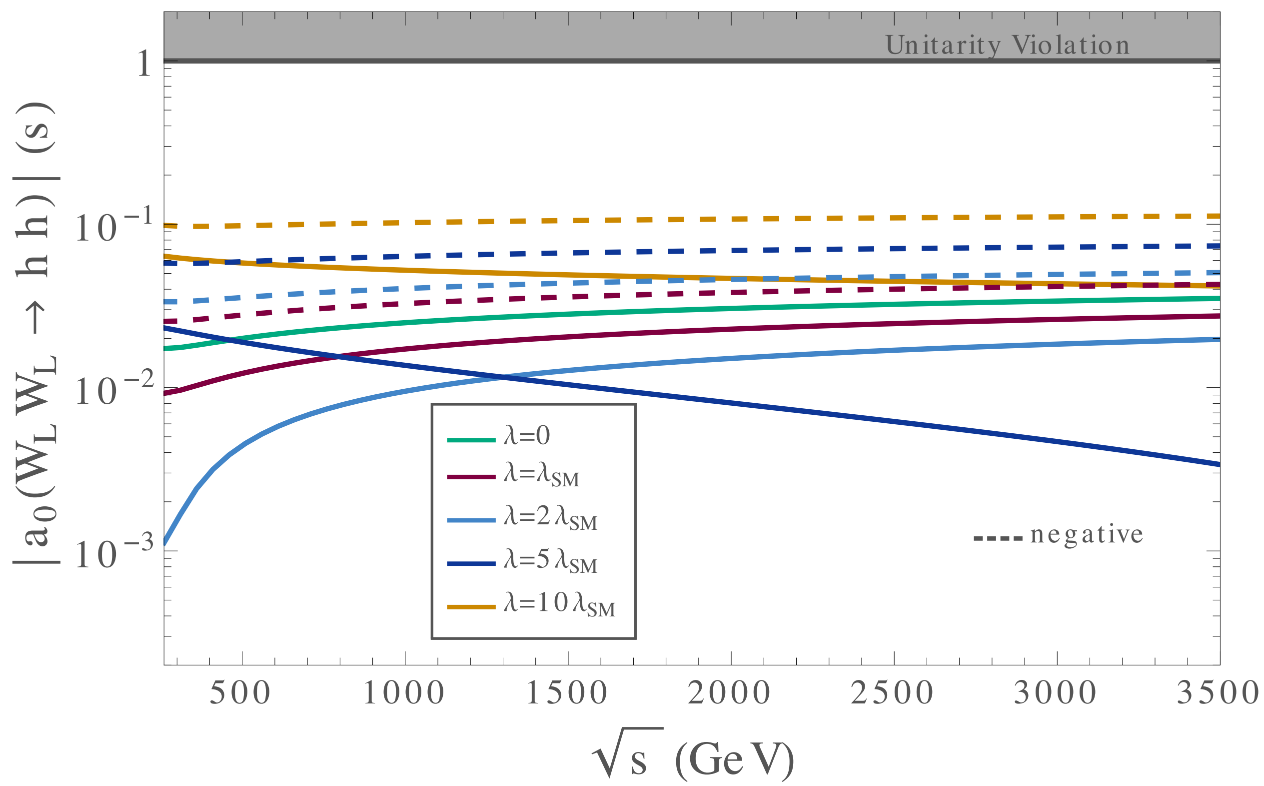


(No) Unitarity violation problems

- Definition of unitarity violation: absolute value of J^{th} (angular momentum) partial wave of VV → HH becomes 1

$$|a_J| = \left| \frac{1}{64\pi} \int_{-1}^{1} d\cos\theta \, A(VV \to HH)\, P_J(\cos\theta) \right| > 1$$

- We have checked that all our partial waves for $\lambda \in [-10,10]\ \lambda_{SM}$ are below 0.1
- No unitarity violation in this channel

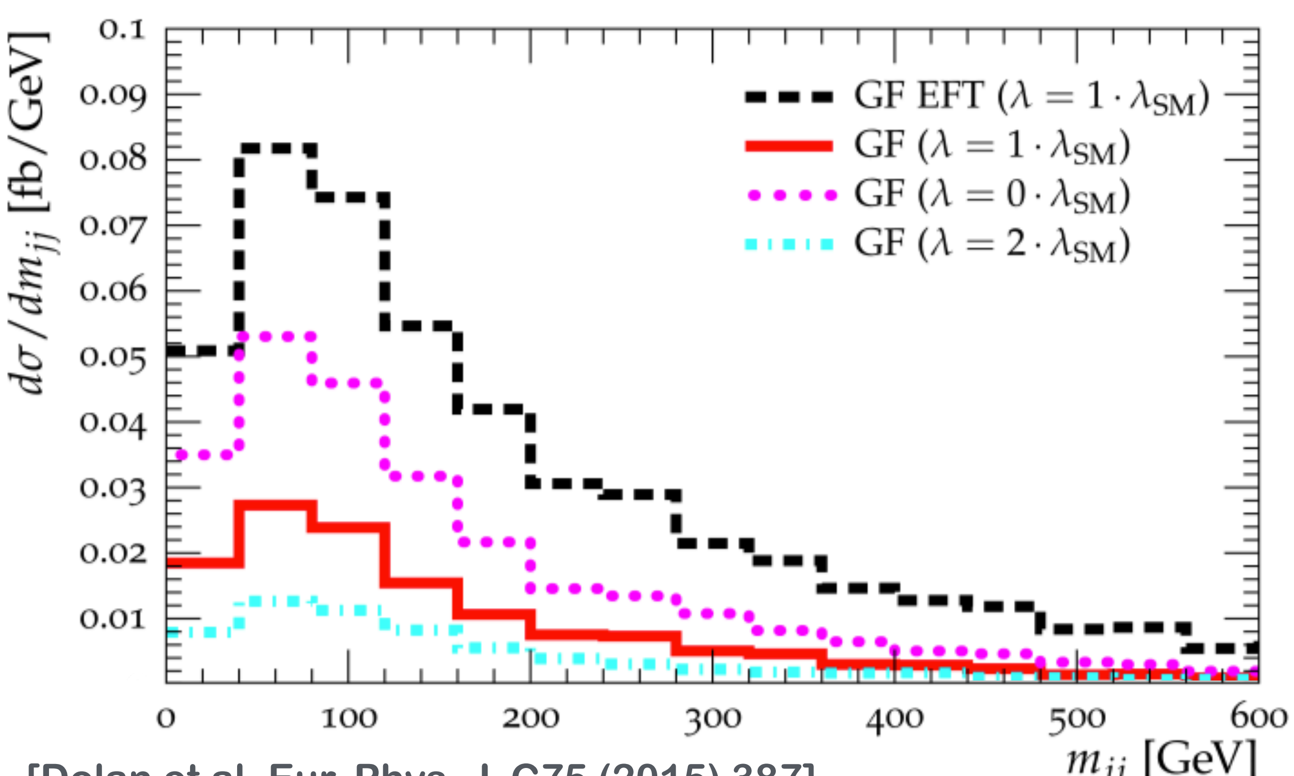


- Other channels such as HH HH might violate unitarity for κ ~7 values at low energies

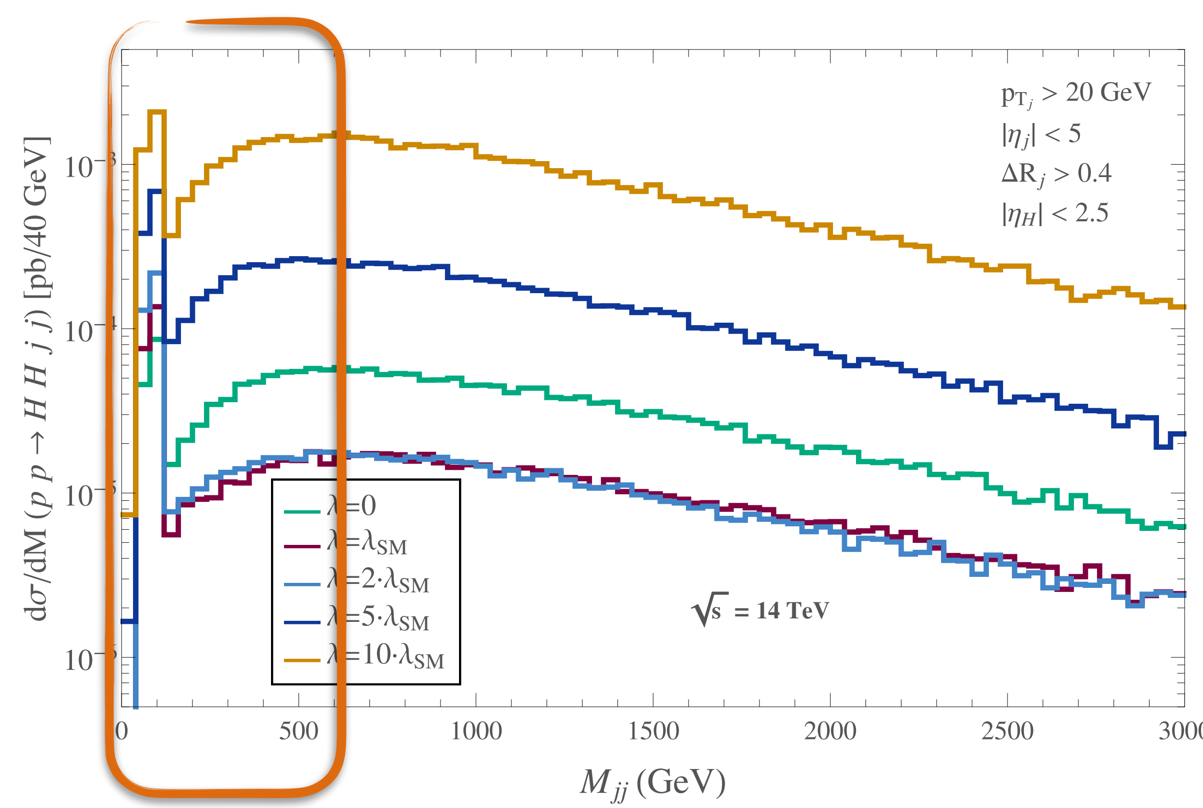
[Di Luzio et al, Eur.Phys.J. C77 (2017) no.11, 788]

“Pollution” from ggF HHjj production?

- Initial cross section twice as big as pure VBS
- After [Dolan et al, Eur. Phys. J. C75 (2015) 387] selection cuts based on $\Delta\eta_{jj}$ ggF amounts to 1/3 of VBS
- They also impose cuts on low M_{HH} masses near threshold where most of VBS signal lies
- More sophisticated VBS cuts, such as our M_{jj}, will improve this rate favoring VBS!!



[Dolan et al, Eur. Phys. J. C75 (2015) 387]



Comment on tagging efficiencies effects

- Results modified taking into account b and γ tagging efficiencies

Current values: b-tagging eff. ~ 70% γ-tagging eff. ~ 95%

	Number of events reduction	Significance reduction
bbbbjj	$N_{eff}/N \sim 0.25$	$S_{eff}/S \sim 0.5$
bbγγjj	$N_{eff}/N \sim 0.5$	$S_{eff}/S \sim 0.7$

- Examples of accesible values of λ for $L = 3000\ fb^{-1}$ with and without efficiencies

	κ > 0	κ > 0 (eff)	κ < 0	κ < 0 (eff)
bbbbjj	κ > 3.2 (3.7)	κ > 3.8 (8.7)	κ < 0 (-0.2)	κ < -0.6 (-1.0)
bbγγjj	κ > 3.8 (4.7)	κ > 4.7 (5.4)	κ < -0.2 (-1.0)	κ < -0.9 (-2.3)

- These efficiencies might improve! Easy way to apply the new ones!