Towards a Stage 1.3 / Stage 2 STXS extension for H+2j production

STXS finalization meeting of the LHCHWG2

14.12.2023

Based on: [2309.03146]

Leibniz Universität Hannover

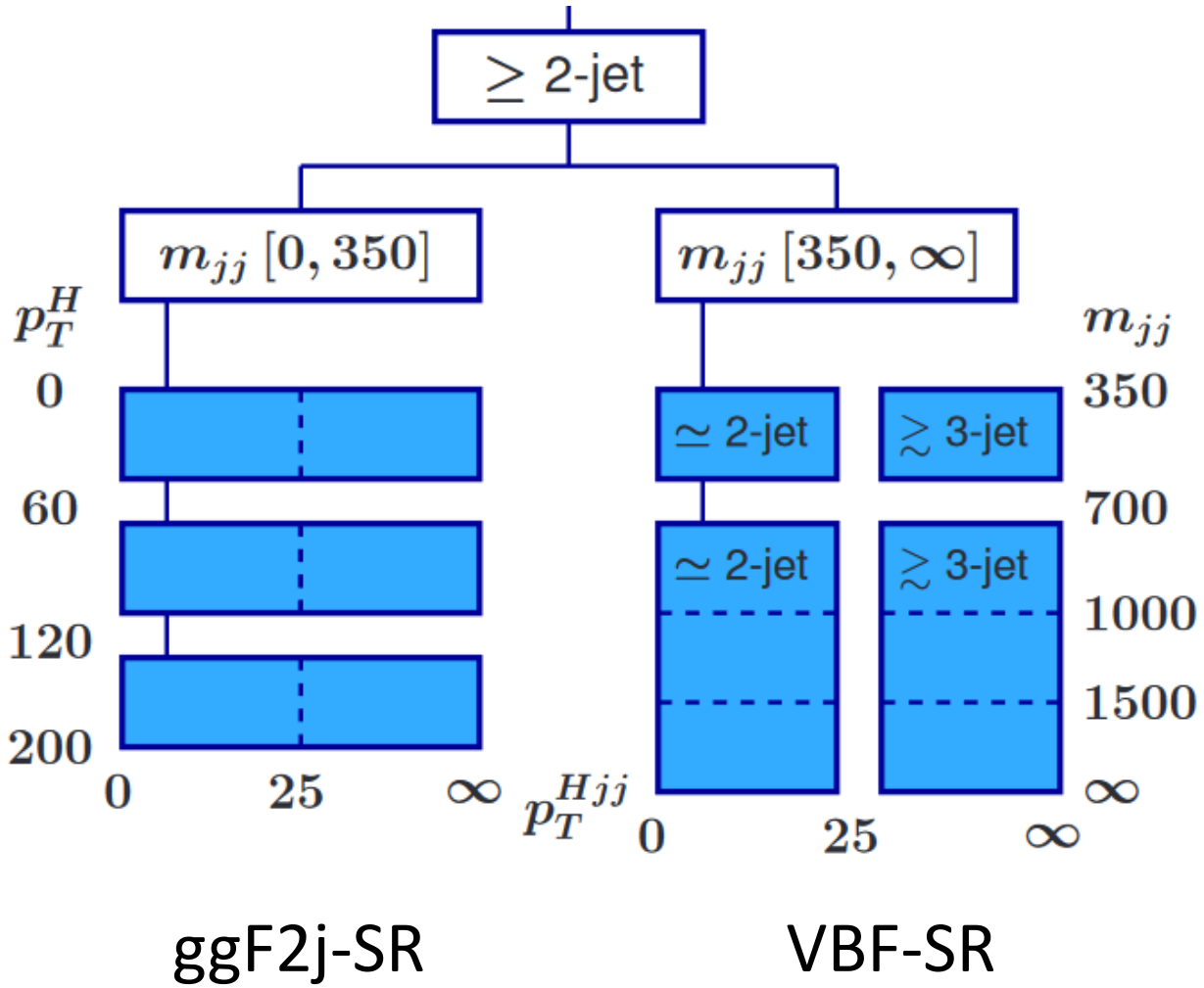
QuantumFrontiers Cluster of Excellence

PTB

BSM framework

- We used a classifier to separate events into a ggF2j- and a VBF-SR
- Not exactly STXS but m_{jj} is the most important variable for separation

⇒ Overlap should be large

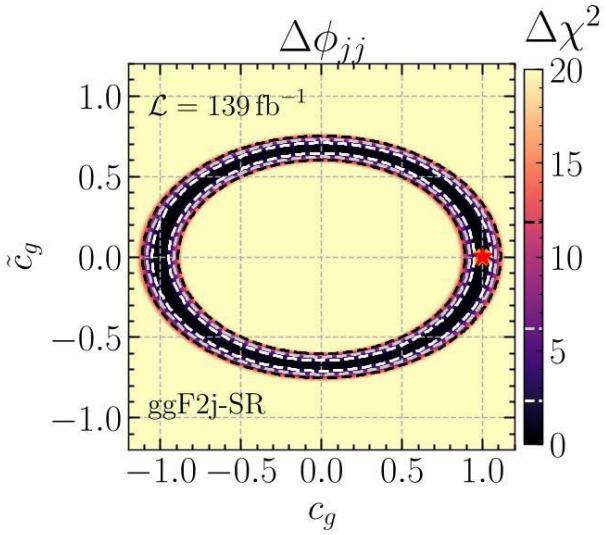


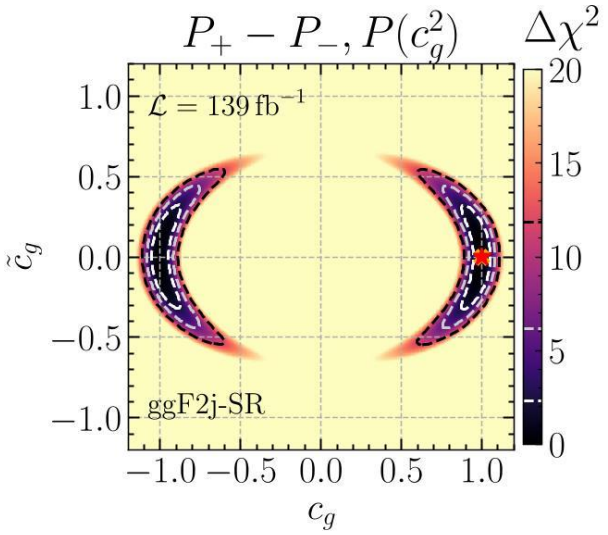
Expected limits

- We compare limits from a $\Delta\phi_{jj}$ separation alone to limits from a CP-even and a CP-odd classifier

Expected limits

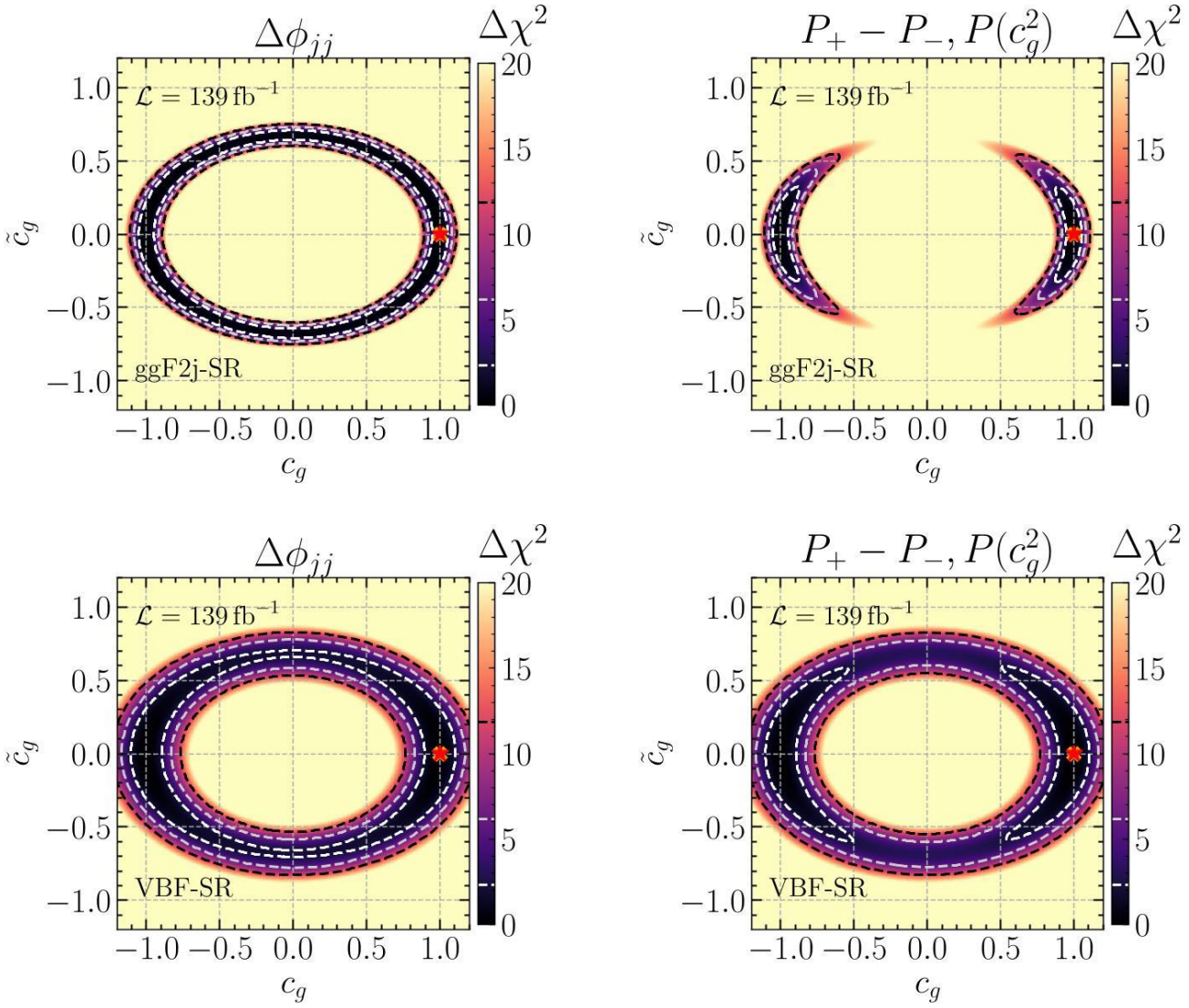
- We compare limits from a $\Delta\phi_{jj}$ separation alone to limits from a CP-even and a CP-odd classifier
- In the ggF2j-SR, the classifiers outperform $\Delta\phi_{jj}$ by a lot





Expected limits

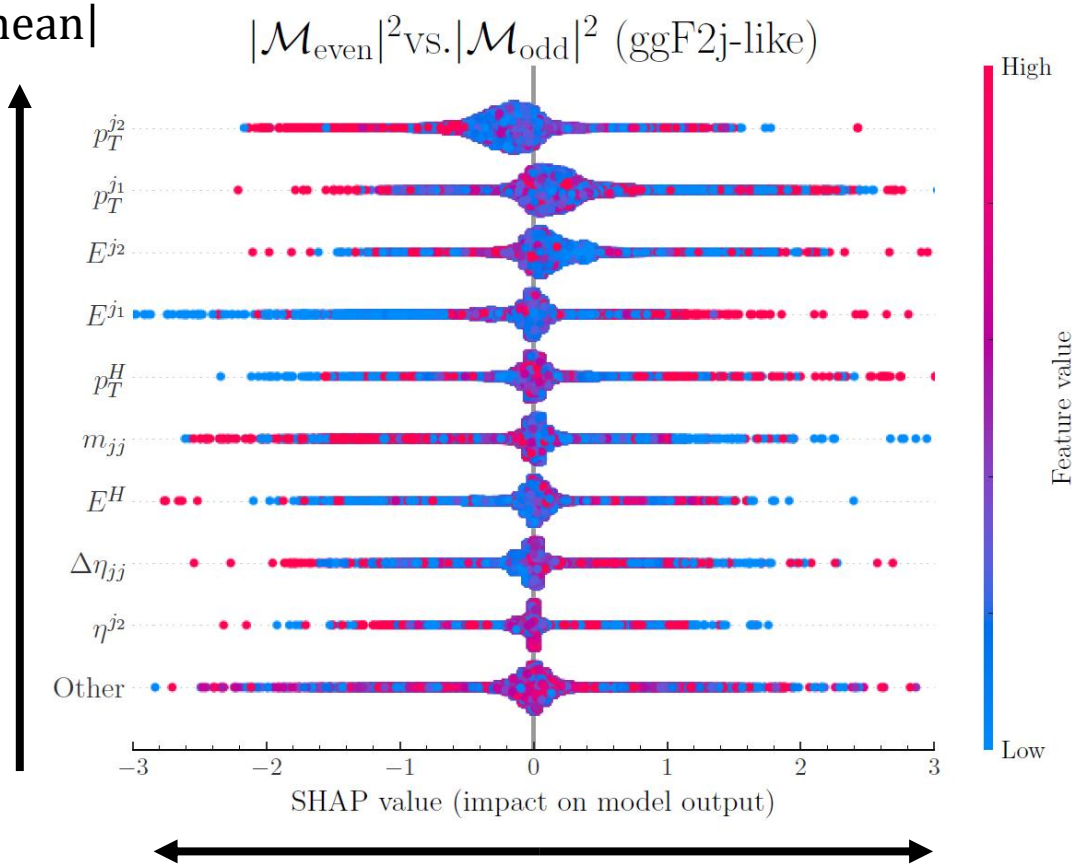
- We compare limits from a $\Delta\phi_{jj}$ separation alone to limits from a CP-even and a CP-odd classifier
- In the ggF2j-SR, the classifiers outperform $\Delta\phi_{jj}$ by a lot
- In the VBF-SR, $\Delta\phi_{jj}$ is a lot more important



Variable importance – ggF2j-SR

Importance
~ |mean|

CP-even

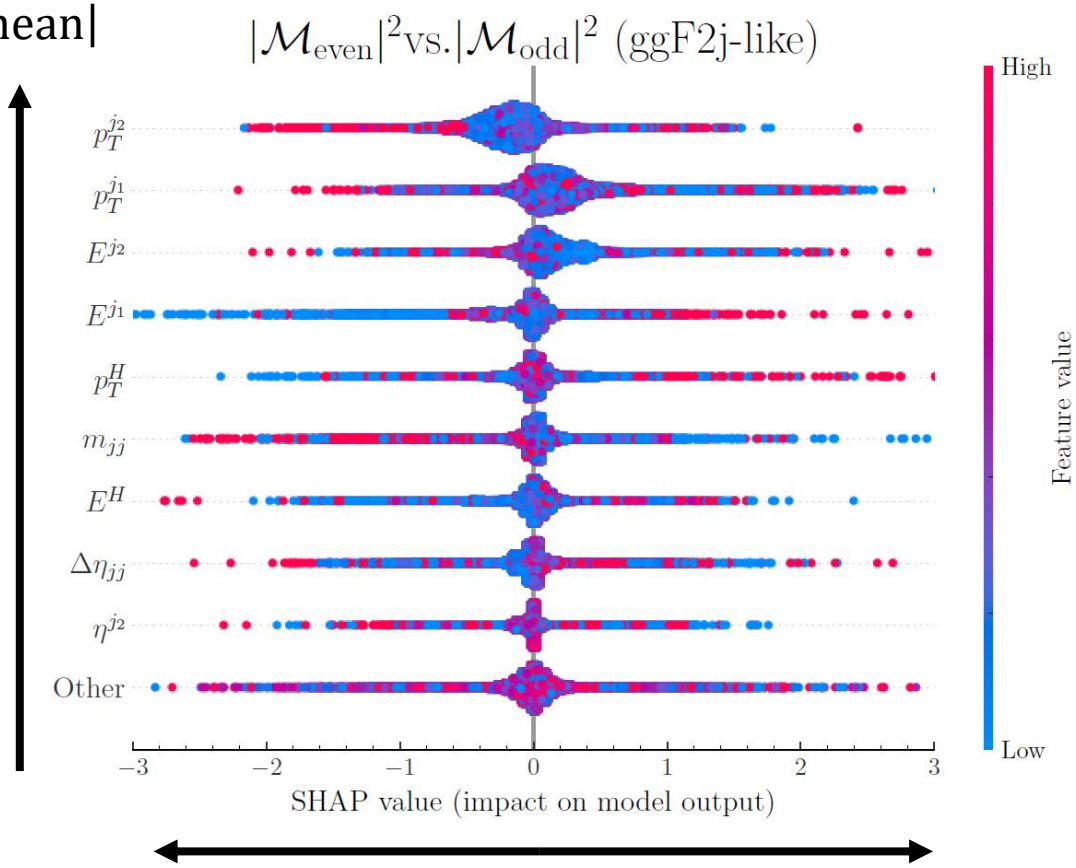


Impact of each event
1 dot = 1 event

Variable importance – ggF2j-SR

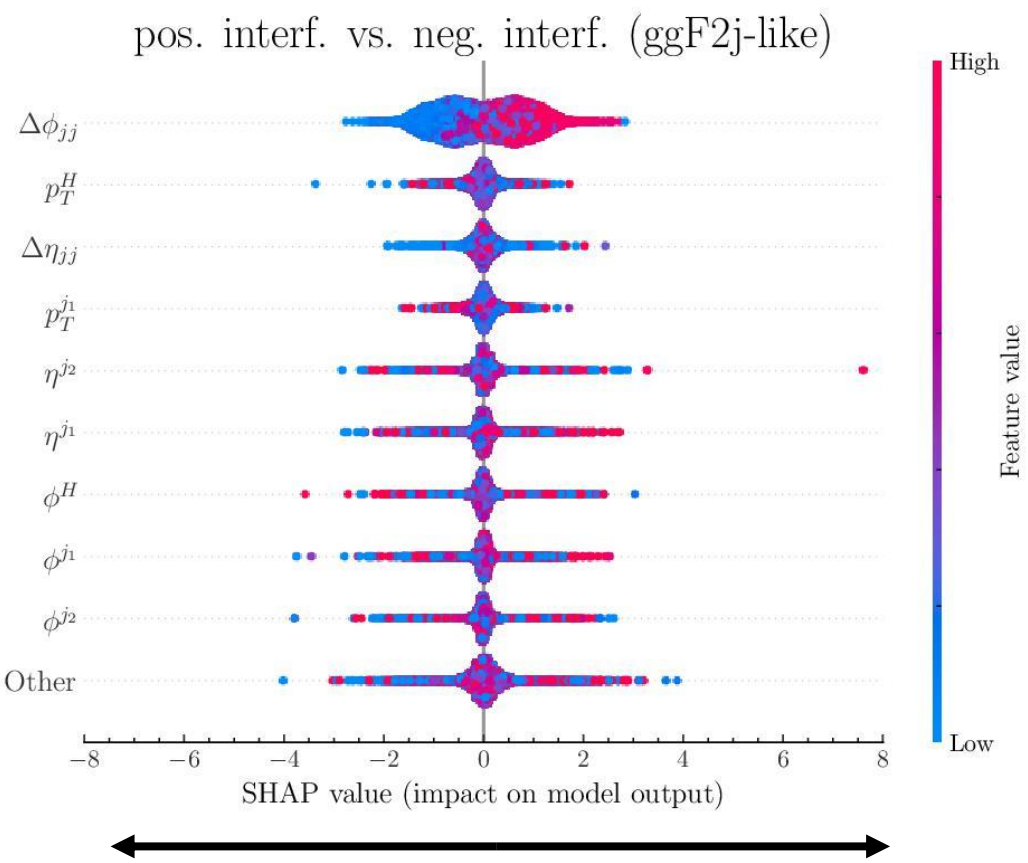
Importance
~ |mean|

CP-even



Impact of each event
1 dot = 1 event

CP-odd

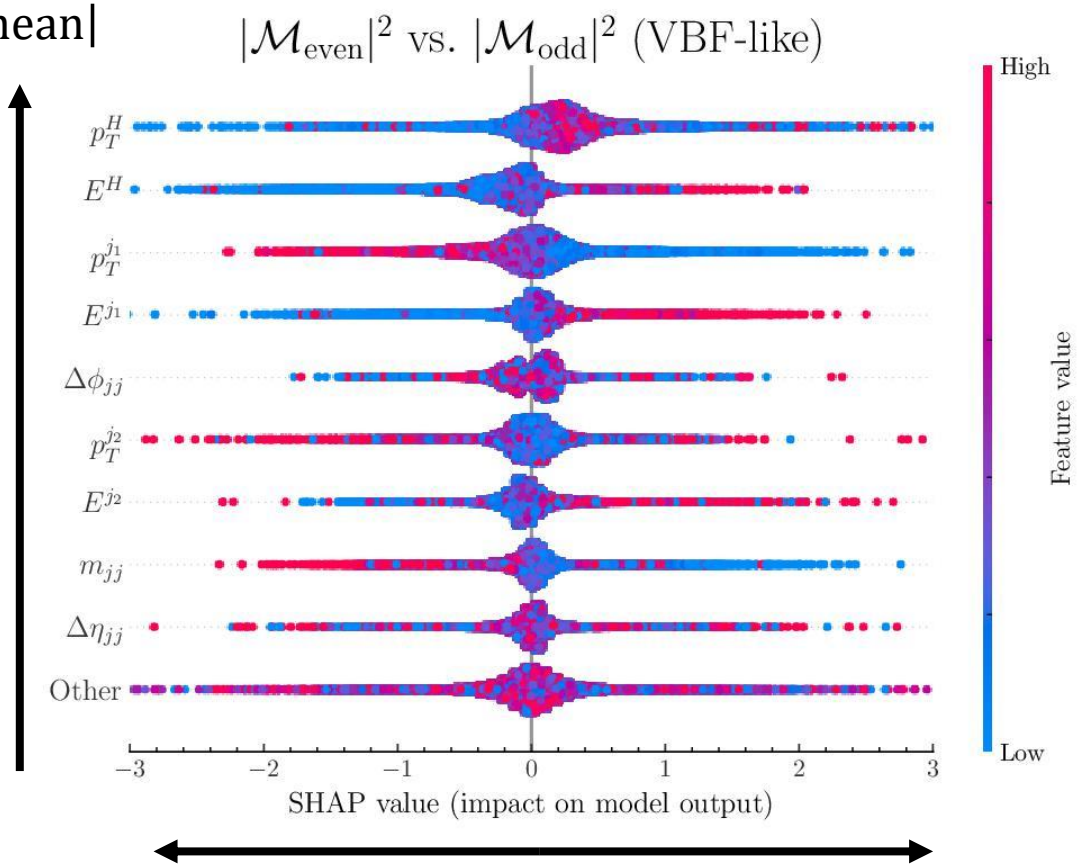


Impact of each event
1 dot = 1 event

Variable importance – VBF-SR

Importance
~ |mean|

CP-even

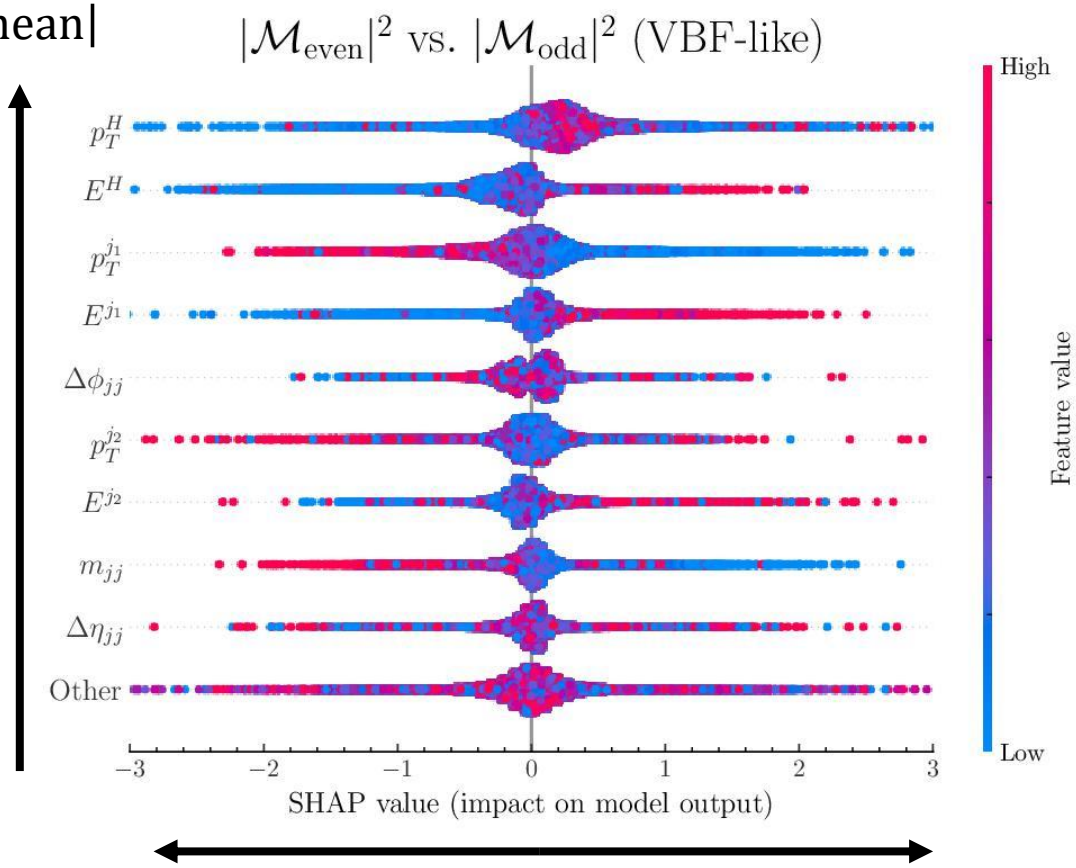


Impact of each event
1 dot = 1 event

Variable importance – VBF-SR

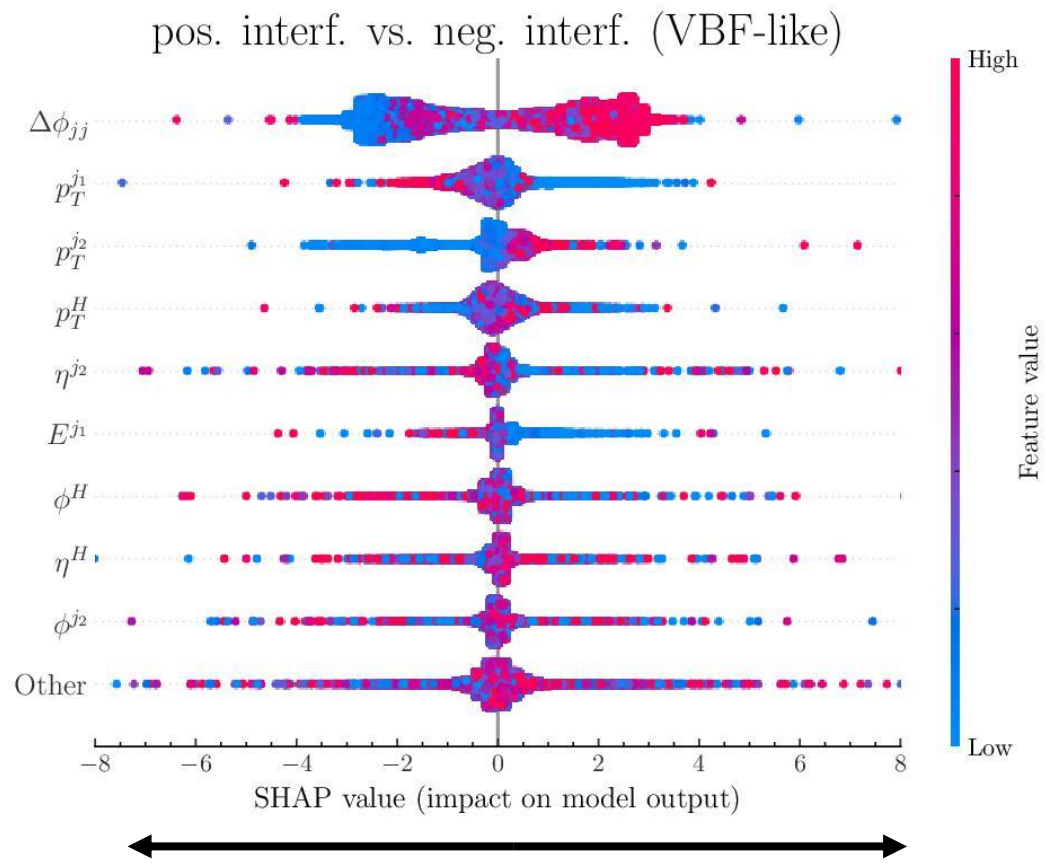
Importance
~ |mean|

CP-even



Impact of each event
1 dot = 1 event

CP-odd



Impact of each event
1 dot = 1 event

Conclusions

- $\Delta\phi_{jj}$ is the most important variable for interference effects
- In the ggF2j-SR (low m_{jj}), the interference effect has a low impact on the CP separation and $\Delta\phi_{jj}$ is therefore less important
- In the VBF-SR, we observe the opposite
- This study was conducted with $\mathcal{L} = 139\text{fb}^{-1}$, interference effects will become more important in the future

$\Rightarrow \Delta\phi_{jj}$ is a good candidate for an extended STXS binning

Backup

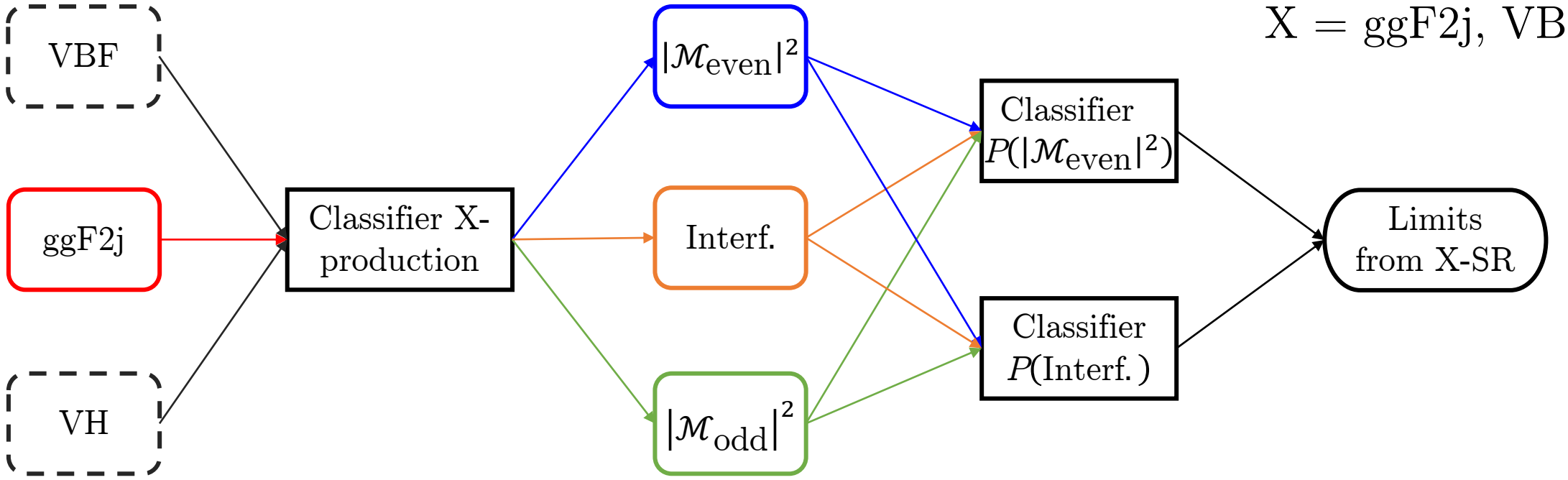
Cutflow

	Fraction of accepted events				
Applied cut	**ggF2j $\lvert\mathcal{M}_{\text{even}}\rvert^2$**	**ggF2j Interf.**	**ggF2j $\lvert\mathcal{M}_{\text{odd}}\rvert^2$**	**VBF**	**VH**
Initial events	100%	100%	100%	100%	100%
$N_j \geq 2, N_\gamma \geq 2$	48.1%	50.8%	48.1%	62.6%	49.8%
$100\text{GeV} \leq m_{\gamma\gamma}$ $m_{\gamma\gamma} \leq 140\text{GeV}$	47.8%	50.5%	47.9%	62.0%	49.4%
$p_T^{\gamma_1}/m_{\gamma\gamma} \geq 0.35$ $p_T^{\gamma_2}/m_{\gamma\gamma} \geq 0.25$	39.4%	40.9%	39.8%	50.0%	40.5%
$p_T^{j_1} \geq 30\text{GeV}$ $p_T^{j_2} \geq 20\text{GeV}$	38.6%	40.2%	38.6%	49.7%	39.9%
$\lvert\eta_j\rvert \leq 2.5$ $\lvert\eta_\gamma\rvert \leq 2.5$	22.9%	21.5%	22.7%	39.8%	31.2%
$p_T^H \leq 200\text{GeV}$ *	18.6%	18.4%	18.3%	34.4%	26.8%

* It is possible to relax this cut using $\text{FT}_{\text{approx}}$ → see Maltoni et al. ´14

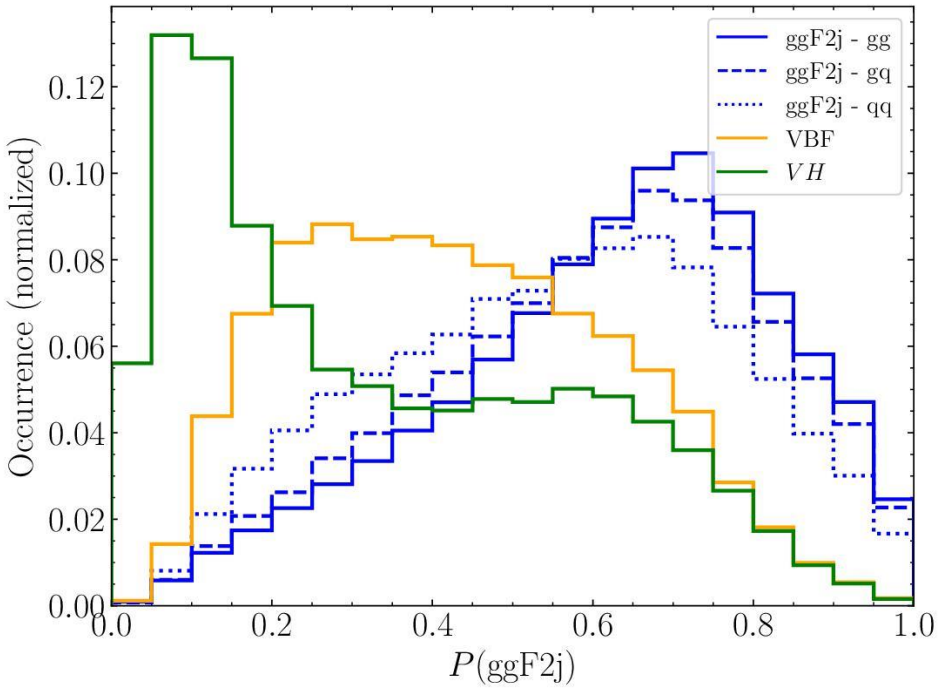
Analysis strategy

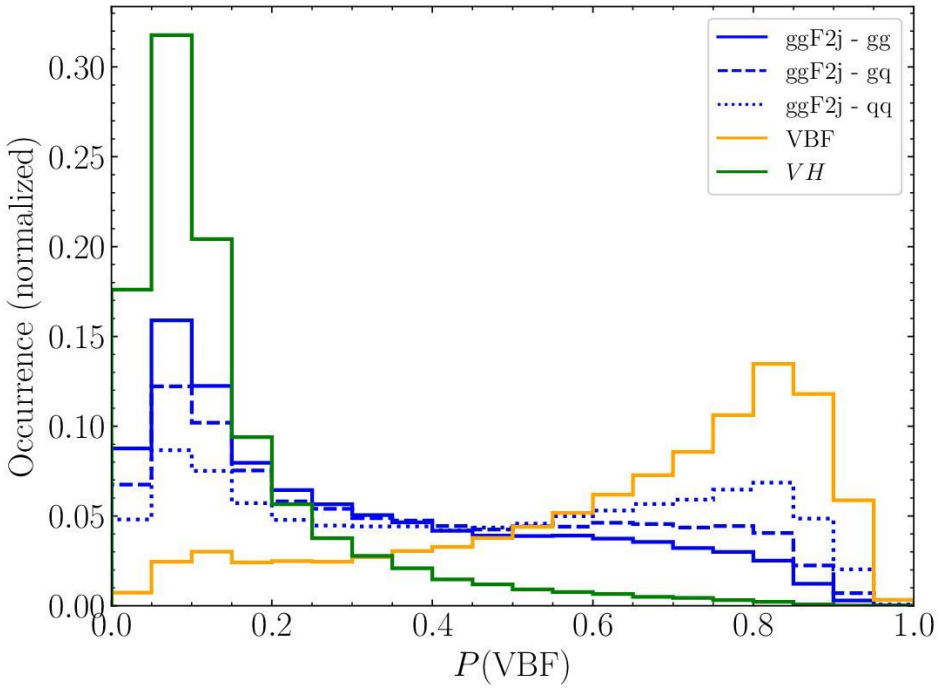
$$|\mathcal{M}_{\mathrm{ggF2j}}|^2 = c_g^2 |\mathcal{M}_{\mathrm{even}}|^2 + \underbrace{2 c_g \tilde{c}_g \mathrm{Re}[\mathcal{M}_{\mathrm{even}} \mathcal{M}_{\mathrm{odd}}^*]}_{\text{Interference}} + \tilde{c}_g^2 |\mathcal{M}_{\mathrm{odd}}|^2$$



- Train a CP-even and a CP-odd classifier in a ggF2j-SR and a VBF-SR

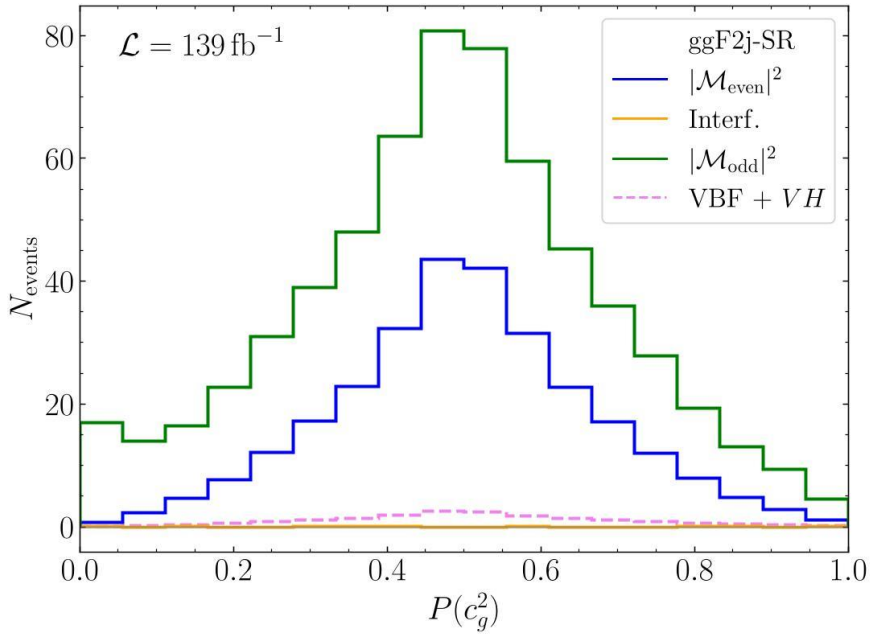
Signal regions

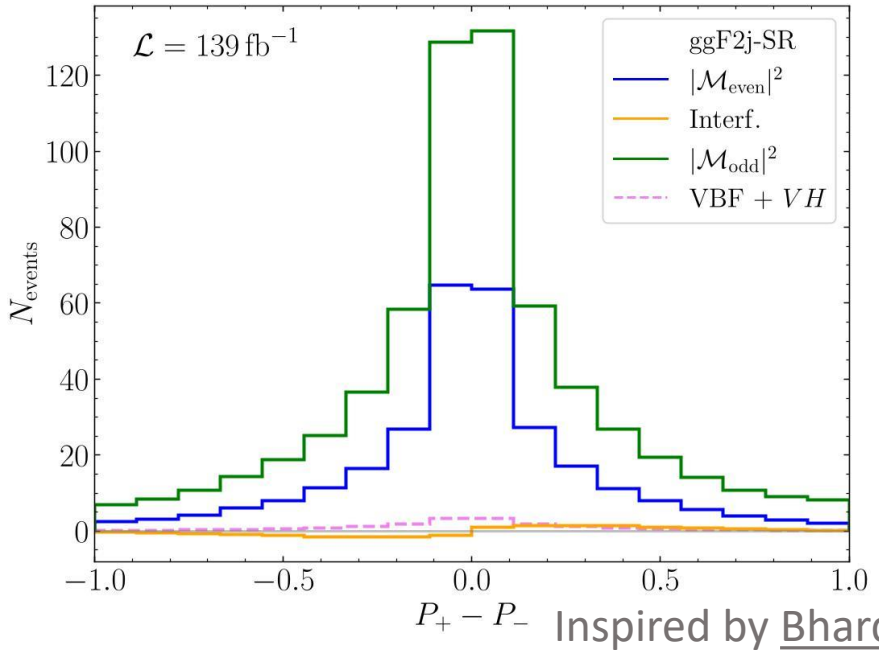




- Use $P(\mathrm{signal}) > 0.5$ as a cut to define signal regions
- ggF2j with $q\bar{q}$ initial state are identified as VBF-like more often
- ggF2j interference events are also identified as VBF-like more often

ggF2j signal region



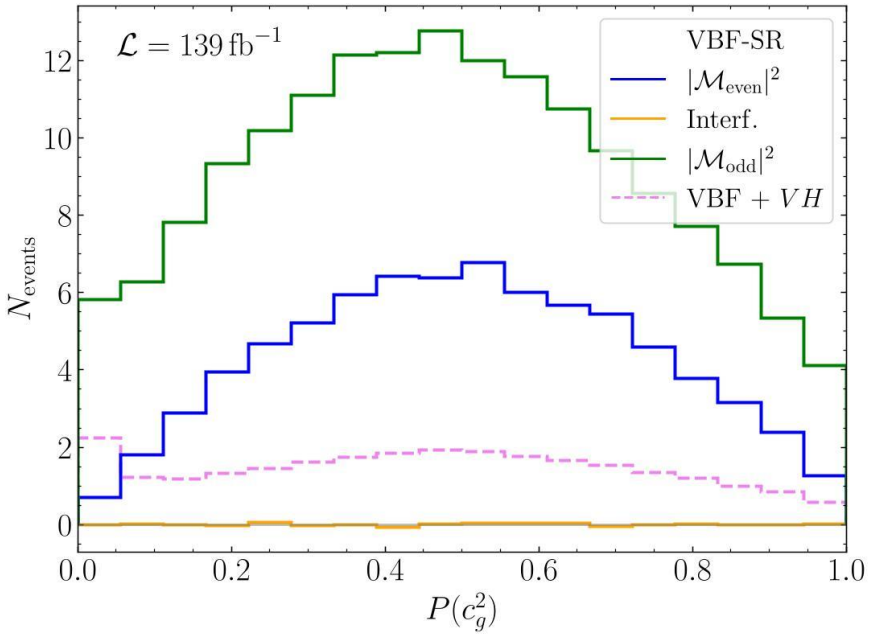


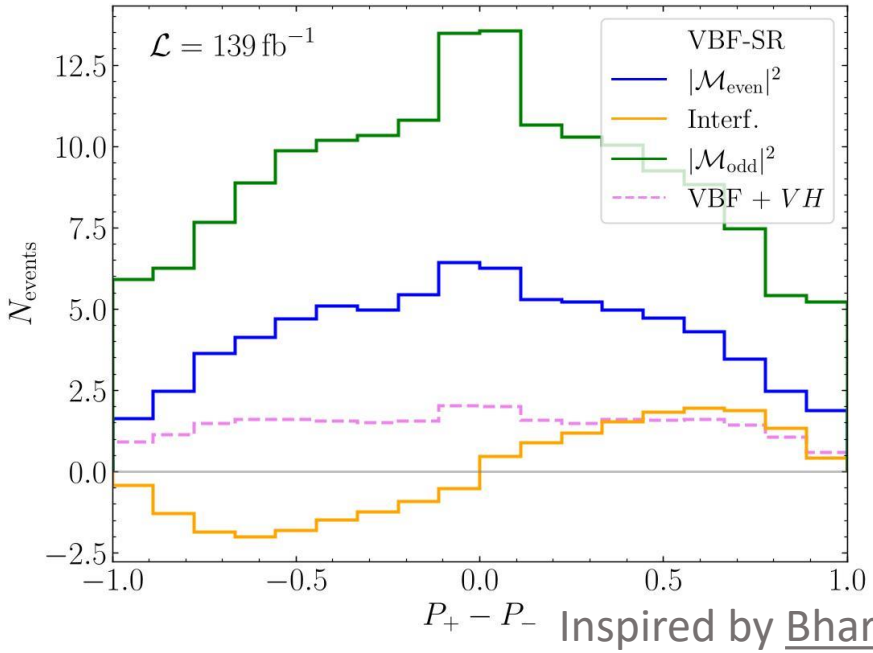
Inspired by Bhardwaj et al. `21

- $P(c_g^2)$ differentiates between $c_g^2|\mathcal{M}_{\mathrm{even}}|^2$ and $\tilde{c}_g^2|\mathcal{M}_{\mathrm{odd}}|^2$
- Kinematically very similar, but some separation in outer bins
- Interference term cancels out

- $P_+ - P_-$ differentiates between positive and negative interference
- Interference barely visible due to low cross section & looks more VBF-like
- CP-even terms are symmetric

VBF signal region





Inspired by Bhardwaj et al. `21

- $P(c_g^2)$ differentiates between $c_g^2|\mathcal{M}_{\mathrm{even}}|^2$ and $\tilde{c}_g^2|\mathcal{M}_{\mathrm{odd}}|^2$
- Less events than in ggF2j-SR, statistical fluctuations visible
- Wider peak around $P(c_g^2) = 0.5$

- $P_+ - P_-$ differentiates between positive and negative interference
- Interference much more pronounced due to overall lower events and their VBF-like kinematic