ggF+jj Analysis

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DESY

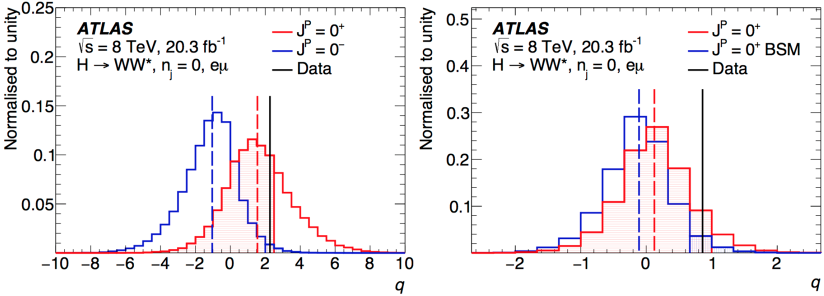
11 January 2018

Introduction

What did we measure in Run 1?

- cross sections
- couplings
- properties → based on hypothesis testing: Spin and CP

Always 0 or 1 jet



Introduction

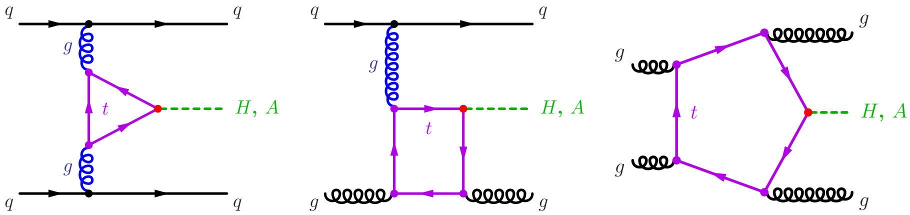
What do we want to measure?

- cross sections
- couplings
- properties: such as CP

Use effective Lagrangian as an example, but can apply same techniques to many other BSM models with large sets of parameters

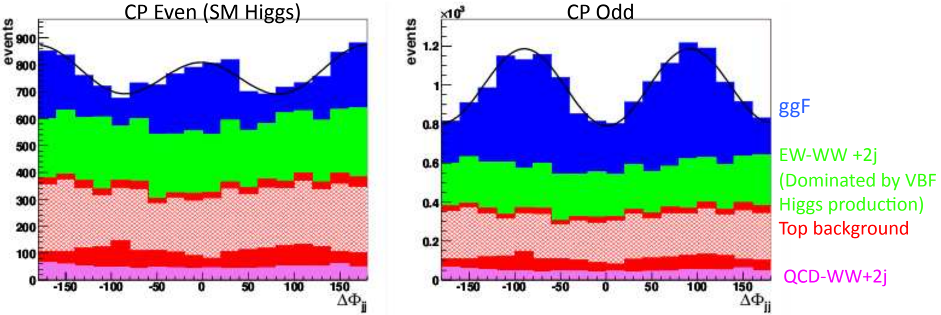
ggF+jj

Study in the H $\rightarrow$ WW $\rightarrow$ $l\nu l\nu$ channel.
Looking at gluon gluon fusion (ggF) with two jets.
Feynman graphs contributing to pp $\rightarrow$ Hjj



ggF+jj

- The SM CP even Higgs shows a modulation in $\Delta\phi_{jj}$
  the backgrounds and the VBF process are flat
- In the cases for a CP Odd or a CP mixed stat there is a different modulation
  - G. Klämke and D. Zepperfeld http://arxiv.org/pdf/hep-ph/0703202.pdf



Effective field theory framework implemented in Higgs Characterisation model

- Effective Lagrangian for the interaction of scalar and pseudo-scalar states with vector bosons

$$\begin{aligned}\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{SM} \left[\frac{1}{2} \tilde{g}_{HZZ} Z_\mu Z^\mu + \tilde{g}_{HWW} W_\mu^+ W^{-\mu} \right] \\ & - \frac{1}{4} \left[c_\alpha \kappa_{H\gamma\gamma} \tilde{g}_{H\gamma\gamma} A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} \tilde{g}_{A\gamma\gamma} A_{\mu\nu} \tilde{A}^{\mu\nu} \right] \\ & - \frac{1}{2} \left[c_\alpha \kappa_{HZ\gamma} \tilde{g}_{HZ\gamma} Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} \tilde{g}_{AZ\gamma} Z_{\mu\nu} \tilde{A}^{\mu\nu} \right] \\ & - \frac{1}{4} \left[c_\alpha \kappa_{Hgg} \tilde{g}_{Hgg} G_{\mu\nu}^a G^{a,\mu\nu} + s_\alpha \kappa_{Agg} \tilde{g}_{Agg} G_{\mu\nu}^a \tilde{G}^{a,\mu\nu} \right] \\ & - \frac{1}{4} \frac{1}{\Lambda} \left[c_\alpha \kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right] \\ & - \frac{1}{2} \frac{1}{\Lambda} \left[c_\alpha \kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + s_\alpha \kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu} \right] \\ & - \frac{1}{\Lambda} c_\alpha \left[\kappa_{H\partial\gamma} Z_\nu \partial_\mu A^{\mu\nu} + \kappa_{H\partial Z} Z_\nu \partial_\mu Z^{\mu\nu} + \kappa_{H\partial W} (W_\nu^+ \partial_\mu W^{-\mu\nu} + h.c.) \right] \Big\} \mathcal{X}_0\end{aligned}$$

Used in Run 1 (blue: first line, $\kappa_{HZZ}/\kappa_{AZZ}$ line, $\kappa_{HWW}/\kappa_{AWW}$ line)

Plan Run 2 (red: $\kappa_{Hgg}/\kappa_{Agg}$ line)

- Implemented in MADGRAPH5_AMC@NLO
- $\Lambda = 1\,\text{TeV}$, $\cos\alpha = \frac{1}{\sqrt{2}}$ fixed
- Define full coupling parameter as g_x (e.g. $g_{AWW} = s_\alpha \kappa_{AWW}/\Lambda$)

Analyses overview and plans in ATLAS

Plans for Run 2

- Perform combined studies of **many (all) parameters** in the matrix element
- Take **all correlations** between different operators into account
- Use constraining power from **rate & shape information**
- Combine results from different channels

→ Challenge: **large parameter space** (e.g. VBF H→VV 13 free parameters)

→ New method to construct predictions for signal cross section and distributions

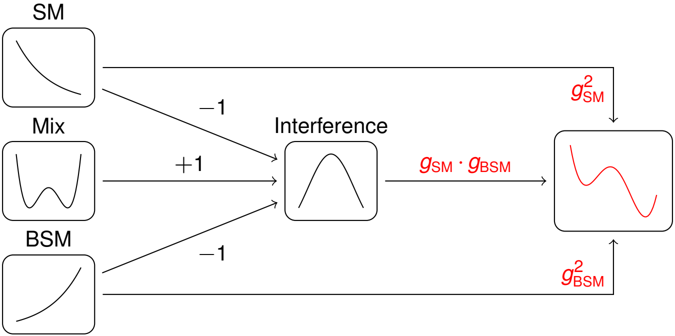
Morphing

→ ggF+jj in H → WW: 2 free parameters

Signal model construction in Run 2: Morphing

- **Morphing function** for an observable T_{out} at any coupling point $\vec{g}_{target}$ constructed from weighted sum of input samples T_{in} at fixed coupling points $\vec{g}_i$

$$T_{out}(\vec{g}_{target}) = \sum_{i=1}^{N_{input}} w_i(\vec{g}_{target}; \vec{g}_i) \cdot T_{in}(\vec{g}_i) \qquad \text{e.g. } T = \Delta\phi_{jj}$$



Example for 2 free parameters in one vertex

- Process with **two parameters** applied in **one vertex**: g_{SM} and g_{BSM}
- Matrix element can be **factorized**:

$$\mathcal{M}(g_{\text{SM}}, g_{\text{BSM}}) = g_{\text{SM}}\mathcal{O}_{\text{SM}} + g_{\text{BSM}}\mathcal{O}_{\text{BSM}}$$

$$|\mathcal{M}(g_{\text{SM}}, g_{\text{BSM}})|^2 = g_{\text{SM}}^2|\mathcal{O}_{\text{SM}}|^2 + g_{\text{BSM}}^2|\mathcal{O}_{\text{BSM}}|^2 + 2g_{\text{SM}}g_{\text{BSM}}\mathcal{R}(\mathcal{O}_{\text{SM}}^*\mathcal{O}_{\text{BSM}})$$

- **Distribution** of a kinematic observable **proportional to the matrix element squared**

$$T(g_{\text{SM}}, g_{\text{BSM}}) \propto |\mathcal{M}(g_{\text{SM}}, g_{\text{BSM}})|^2$$

- **3 generated distributions** needed to obtain distribution with arbitrary parameters
- E.g. generate MC events for $T(1,0)$, $T(0,1)$, $T(1,1)$

$$T_{in}(1,0) \propto |\mathcal{O}_{\text{SM}}|^2$$

$$T_{in}(0,1) \propto |\mathcal{O}_{\text{BSM}}|^2$$

$$T_{in}(1,1) \propto |\mathcal{O}_{\text{SM}}|^2 + |\mathcal{O}_{\text{BSM}}|^2 + 2\mathcal{R}(\mathcal{O}_{\text{SM}}^*\mathcal{O}_{\text{BSM}})$$

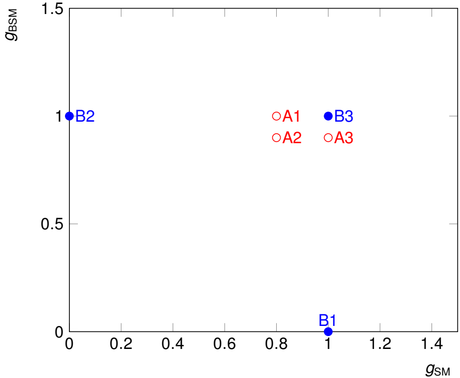
- Distribution with **arbitrary parameters** $(g_{\text{SM}}, g_{\text{BSM}})$

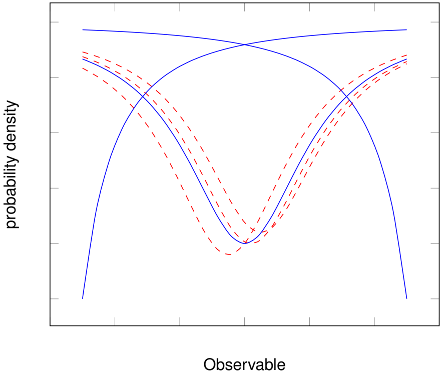
$$T_{out}(g_{\text{SM}}, g_{\text{BSM}}) = \underbrace{\left(g_{\text{SM}}{}^2 - g_{\text{SM}}g_{\text{BSM}}\right)}\, T_{in}(1,0) + \underbrace{\left(g_{\text{BSM}}{}^2 - g_{\text{SM}}g_{\text{BSM}}\right)}\, T_{in}(0,1) + \underbrace{g_{\text{SM}}g_{\text{BSM}}}\, T_{in}(1,1)$$

Choice of input parameters

- So far fixed parameters for input distributions: $T_{in}(1,0)$, $T_{in}(0,1)$, $T_{in}(1,1)$
- Aim to **generalise morphing** to have arbitrary g_i

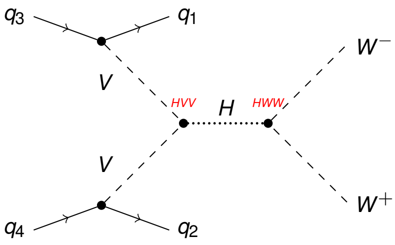
→ Can be chosen to **reduce statistical uncertainty**





Example: 13 free parameters for VBF H→ZZ process: 1605 samples

VBF H→WW example



- VBF H→WW process with **SM** (g_{SM}) and **2 BSM** operators (g_{HWW}, g_{AWW})

→ **15 samples** with different parameters needed

- 50k events generated for each sample
- Kinematic observable used: $\Delta\phi_{jj}$
- Only signal considered

VBF H→WW example: Samples

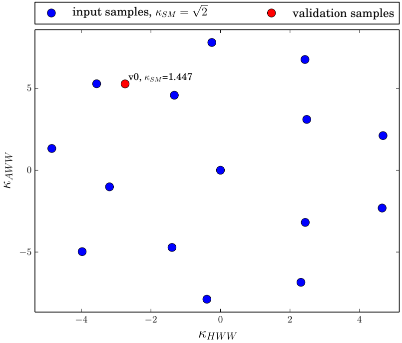
- Expect only **small deviations from SM**

→ $g_{SM} = 1$ for all input samples ($\Lambda = 1\,\mathrm{TeV}$, $\cos\alpha = \frac{1}{\sqrt{2}}$)

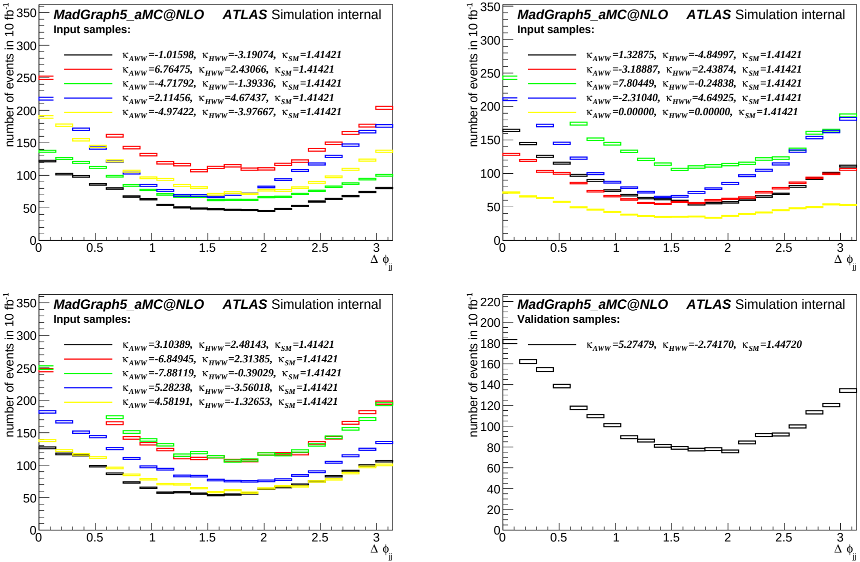
→ BSM parameter limits chosen such that $\sigma_{\text{pure BSM}} \sim \sigma_{SM}$

→ all other BSM parameters set to 0

- Scatter plot shows blue points in (g_{AWW},g_{HWW}) space used to generate **input samples**
- A **validation sample** is produced at the red point for cross-check
  - → **morphing** can reproduce the distribution there
  - → **fit** can reproduce the parameters from the validation sample



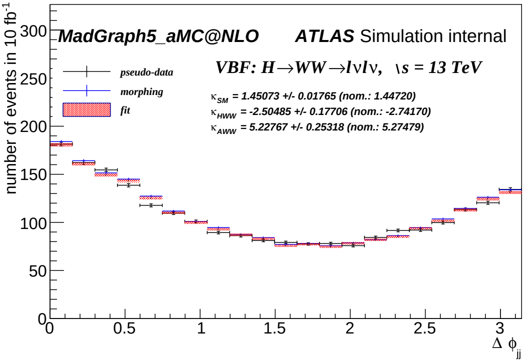
VBF H→WW example: Input and validation distributions



VBF H→WW example: Morphing and fit to validation sample

- Morphing and fit to validation distr. (pseudo-data)
- Validation and morphed distribution stat. independent
  - Agreement in morphing within MC stat. uncertainty
  - Fit results match nominal values within fit uncertainties
- **Sensitivity** on parameters shown in fit uncert.
- **Correlations** vary at different parameter point

	κ_{SM}	κ_{HWW}	κ_{AWW}
κ_{SM}	1.00	0.20	-0.95
κ_{HWW}	0.20	1.00	0.09
κ_{AWW}	-0.95	0.09	1.00



Generality of the method

- Morphing only requires that any differential cross section can be expressed as **polynomial in BSM couplings**
- Method can be used on **any generator** that allows one to vary input couplings
- Works on **truth** and **reco-level** distributions
- **Independent of physics process**
- Works on distributions and cross sections

Difficulties

From a theoretical viewpoint:

- Method in Effective Lagrangian: terms $\sim \frac{1}{\Lambda^2}$ from dim 6 operators included, but not from dim 8 operators
- Problematic to include dim-8 operators:
  - No generator available
  - Additional large set of coupling parameters
- Neglecting of quadratic terms not possible due to negative cross sections

From a experimental viewpoint:

- Separating ggF+jj from VBF
  - does not seem to interfere in a deconstructive way
- Reduction of backgrounds without chancing the shape of $\Delta\phi_{jj}$
  - Careful checks necessary

Summary

- Plan for Run 2: **Higgs coupling and properties measurements**
- Combine **rate and shape information** within effective Lagrangian framework
- New method for modelling BSM effects
  - continuous
  - analytical
  - fast

Backup

Comparison of methods

- **Needed:** MC samples covering wide range of values for coupling parameters
- Run 1 HWW and HZZ analyses: **Matrix Element Reweighting**
  (Event by event matrix element reweighting of one source MC sample with large statistics)

$$w(\vec{g}_{target}) = w(\vec{g}_i)\frac{|\mathcal{M}(\vec{g}_{target})|^2}{|\mathcal{M}(\vec{g}_{source})|^2}$$

ME Reweighting

For every configuration point

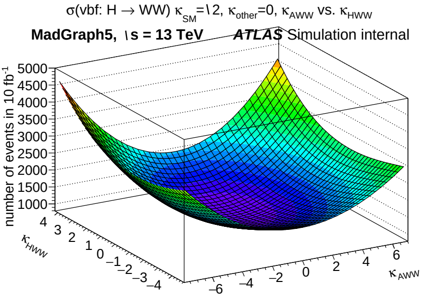
- rerun analysis
- write event weights to disk
- additional interpolation

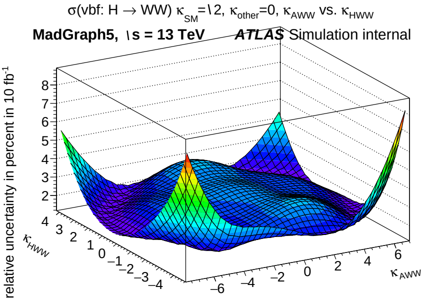
Morphing

- only calculates linear sums of coefficients
- all other inputs are pre-computed once
- computationally fast & convenient tool

- **Morphing function:** Instead of “matrix element reweighting” use morphing to obtain a distribution with arbitrary coupling parameters
- Can be applied directly and without change to
  - Cross sections
  - Distributions (before or after detector simulation)
  - MC events
- **Exact continuous analytical description of rates and shapes**
- Even possible to **fit** coupling parameters to data & derive limits

- Dependence of **stat. uncertainty** propagated in morphing function on generated input parameter grid
- Distribution of samples in parameter space **reduces** stat. uncertainty

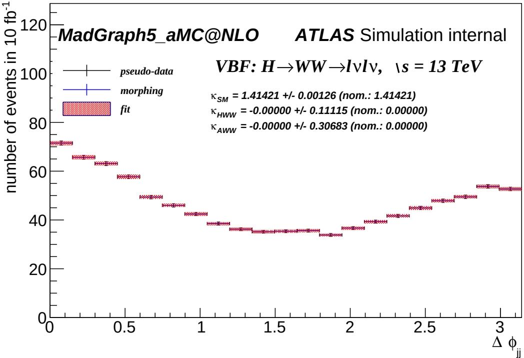




VBF H→WW example: Morphing and fit to SM input sample

- Morphing and fit to SM input distribution (pseudo-data)
- MC stat. uncertainty used
- Input and morphed distribution stat. dependent
  - perfect agreement in morphing
  - Post-fit parameters match exact nominal values
- **Sensitivity** on parameters shown in fit uncert.
- **Correlations** at SM point in table

	κ_{SM}	κ_{HWW}	κ_{AWW}
κ_{SM}	1.00	0.15	-0.23
κ_{HWW}	0.15	1.00	0.36
κ_{AWW}	-0.23	0.36	1.00



Example for 2 free parameters in one vertex: generalisation of input parameter

- Generalize to **arbitrary input parameters** $\vec{g}_i$ used to generate input distributions $T_{in}(\vec{g}_i)$

$$T_{in}(g_{\text{SM},i}, g_{\text{BSM},i}) \propto {g_{\text{SM},i}}^2 |\mathcal{O}_{\text{SM}}|^2 + {g_{\text{BSM},i}}^2 |\mathcal{O}_{\text{BSM}}|^2 + 2 g_{\text{SM},i} g_{\text{BSM},i} \mathcal{R}(\mathcal{O}^*_{\text{SM}} \mathcal{O}_{\text{BSM}}), \qquad i = 1, \ldots 3$$

- Ansatz for **output distribution**

$$\begin{aligned} T_{out}(g_{\text{SM}}, g_{\text{BSM}}) = & \underbrace{(a_{11} {g_{\text{SM}}}^2 + a_{12} {g_{\text{BSM}}}^2 + a_{13} g_{\text{SM}} g_{\text{BSM}})}_{w_1} T_{in}(g_{\text{SM},1}, g_{\text{BSM},1}) \\ & + \underbrace{(a_{21} {g_{\text{SM}}}^2 + a_{22} {g_{\text{BSM}}}^2 + a_{23} g_{\text{SM}} g_{\text{BSM}})}_{w_2} T_{in}(g_{\text{SM},2}, g_{\text{BSM},2}) \\ & + \underbrace{(a_{31} {g_{\text{SM}}}^2 + a_{32} {g_{\text{BSM}}}^2 + a_{33} g_{\text{SM}} g_{\text{BSM}})}_{w_3} T_{in}(g_{\text{SM},3}, g_{\text{BSM},3}) \end{aligned}$$

Example for 2 operators in one vertex

- T_{out} should be equal to T_{in} for $\vec{g}_{target} = \vec{g}_i$

$$
\begin{aligned}
1 &= a_{11} g_{\text{SM},1}{}^2 + a_{12} g_{\text{BSM},1}{}^2 + a_{13} g_{\text{SM},1} g_{\text{BSM},1} \\
0 &= a_{21} g_{\text{SM},1}{}^2 + a_{22} g_{\text{BSM},1}{}^2 + a_{23} g_{\text{SM},1} g_{\text{BSM},1} \\
\ldots
\end{aligned}
$$

- Constraints in **matrix form**

$$
\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \cdot \begin{pmatrix} g_{\text{SM},1}{}^2 & g_{\text{SM},2}{}^2 & g_{\text{SM},3}{}^2 \\ g_{\text{BSM},1}{}^2 & g_{\text{BSM},2}{}^2 & g_{\text{BSM},3}{}^2 \\ g_{\text{SM},1} g_{\text{BSM},1} & g_{\text{SM},2} g_{\text{BSM},2} & g_{\text{SM},3} g_{\text{BSM},3} \end{pmatrix} = \mathbb{1}
$$

$$
\Leftrightarrow \qquad A \cdot G = \mathbb{1}
$$

- **Definite solution** $A = G^{-1}$ requires the samples to have parameters such that $\det(G) \neq 0$
- Very flexible in choosing the parameters for the input distributions

$\rightarrow$ Can be chosen to **reduce statistical uncertainty** in considered parameter space

General morphing and number of input distributions

- More complicated when processes share amplitudes between **production and decay**, for example VBF $H \to VV$
- General matrix element squared at **LO** & assuming **narrow-width-approximation** (ignoring the effect on the total width)
  $\Rightarrow$ **polynomials** of 2nd order in production and 2nd order in decay

$$T(\vec{g}) \propto |\mathcal{M}(\vec{g})|^2 = \underbrace{\left(\sum_{i=1}^{n_p+n_s} g_i \mathcal{O}_i\right)^2}_{\text{production vertex}} \cdot \underbrace{\left(\sum_{j=1}^{n_d+n_s} g_j \mathcal{O}_j\right)^2}_{\text{decay vertex}}$$

with number of parameters in **production vertex** (n_p), **decay vertex** (n_d) and **shared in vertices** (n_s)

- **Number of required input distributions** equal to number of different terms in expanded matrix element squared
  $\to$ dependent on process and considered parameters
  $\to$ N_{input} function of n_p, n_d and n_s
- Example: 13 free parameters for VBF H$\to$ZZ process:
  - $n_p = 4$ operators in production: $g_{\mathrm{HWW}}, g_{\mathrm{AWW}}, g_{\mathrm{H\partial W}}, g^*_{\mathrm{H\partial W}}$
  - $n_s = 9$ operators in both vertices: $g_{\mathrm{SM}}, g_{\mathrm{HZZ}}, g_{\mathrm{AZZ}}, g_{\mathrm{H\partial Z}}, g_{\mathrm{H\gamma\gamma}}, g_{\mathrm{A\gamma\gamma}}, g_{\mathrm{HZ\gamma}}, g_{\mathrm{AZ\gamma}}, g_{\mathrm{H\partial\gamma}}$
  - $n_d = 0$, no operators only in decay

$\to$ **1605 samples** needed!

$\to$ Reduction of considered operators favourable $\to$ see VBF study

Number of input distributions

$$N_{input} = \frac{n_p\,(n_p+1)}{2}\cdot\frac{n_d\,(n_d+1)}{2}+\binom{4+n_s-1}{4}$$
$$+\left(n_p\cdot n_s+\frac{n_s\,(n_s+1)}{2}\right)\cdot\frac{n_d\,(n_d+1)}{2}$$
$$+\left(n_d\cdot n_s+\frac{n_s\,(n_s+1)}{2}\right)\cdot\frac{n_p\,(n_p+1)}{2}$$
$$+\frac{n_s\,(n_s+1)}{2}\cdot n_p\cdot n_d+(n_p+n_d)\binom{3+n_s-1}{3}$$

with number of parameters in **production vertex** (n_p), **decay vertex** (n_d) and **shared in vertices** (n_s)

Propagation of statistical uncertainties

[noframenumbering]

- Morphing function for a bin in distribution

$$T_{out}^{bin}(\vec{g}_{target}) = \sum_i w_i(\vec{g}_{target}; \vec{g}_i) T_{in}^{bin}(\vec{g}_i)$$

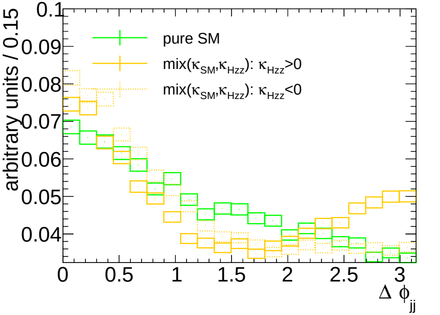
- For one input distribution, the bin content is calculated as follows

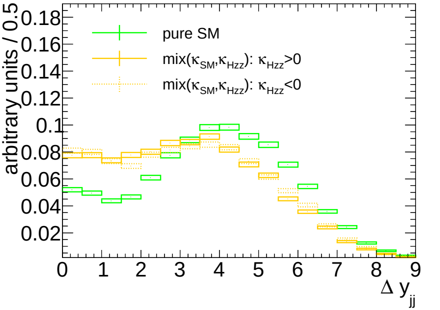
$$T_{in}^{bin}(\vec{g}_i) = N_{MC,in}^{bin}(\vec{g}_i) \cdot \sigma_{in}(\vec{g}_i) \mathcal{L} / N_{\mathrm{MC,in}}$$

- The uncertainty on that bin is $\sqrt{N_{MC,in}^{bin}(\vec{g}_i)}$
- The propagated statistical uncertainty is

$$\Delta T_{out}^{bin} = \sqrt{\sum_i w_i^2(\vec{g}_{target}; \vec{g}_i) N_{MC,in}^{bin}(\vec{g}_i) \cdot (\sigma_{in}(\vec{g}_i) \mathcal{L} / N_{\mathrm{MC,in}})^2}$$

- Highly **dependent** on
  - **input parameters** $\vec{g}_i$
  - desired **target parameters** $\vec{g}_{target}$


arbitrary units / 0.15
pure SM
mix(κSM,κHzz): κHzz>0
mix(κSM,κHzz): κHzz<0
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0 0.5 1 1.5 2 2.5 3
Δ ϕjj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pure SM
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mix(κSM,κHzz): κHzz<0
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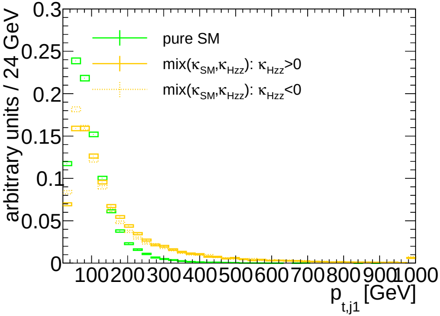
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0 1 2 3 4 5 6 7 8 9
Δ yjj


arbitrary units / 24 GeV
pure SM
mix(κSM,κHzz): κHzz>0
mix(κSM,κHzz): κHzz<0
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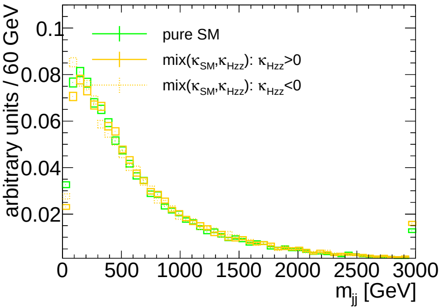
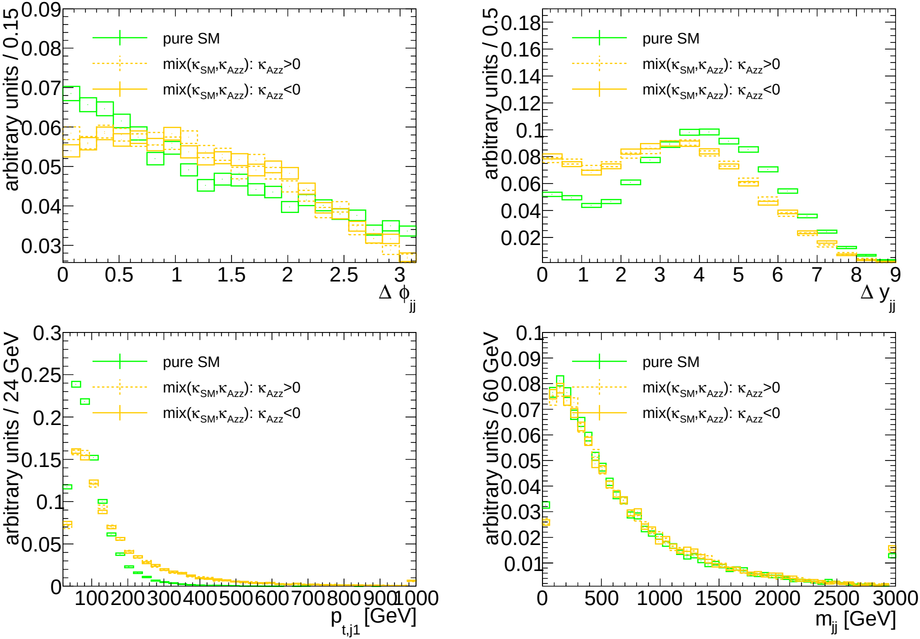
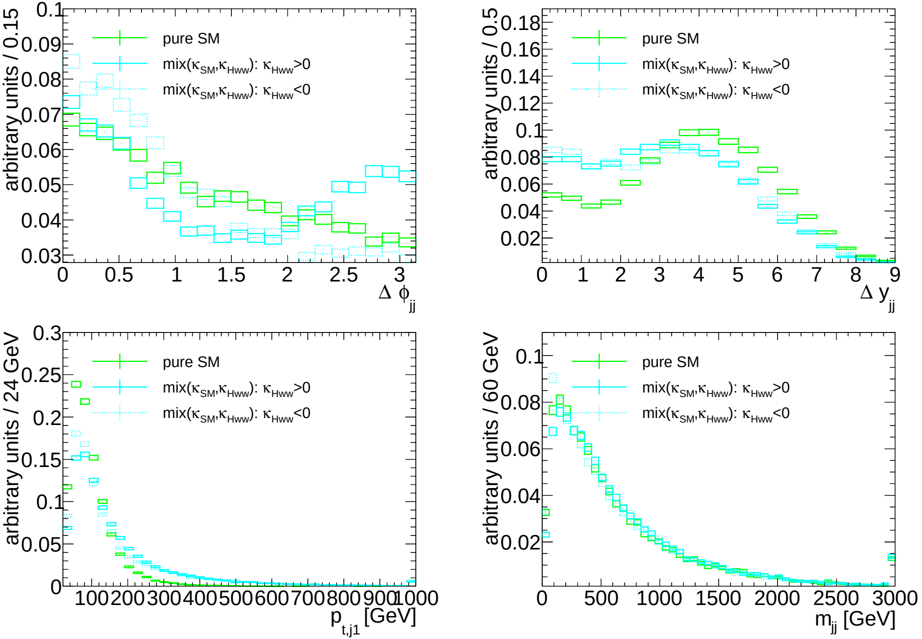
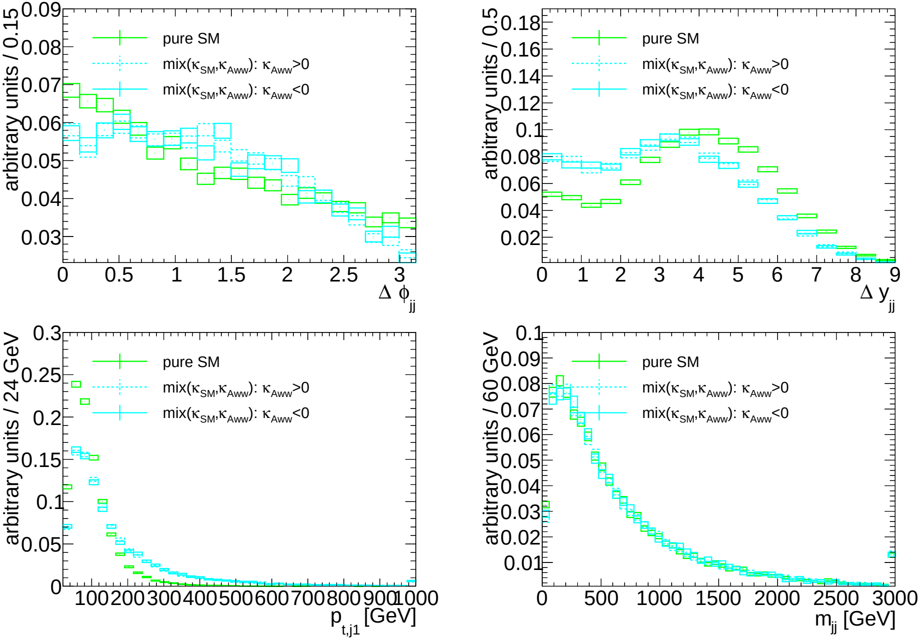
0.25
0.2
0.15
0.1
0.05
0
100 200 300 400 500 600 700 800 900 1000
pt,j1 [GeV]


arbitrary units / 60 GeV
pure SM
mix(κSM,κHzz): κHzz>0
mix(κSM,κHzz): κHzz<0
0.1
0.08
0.06
0.04
0.02
0 500 1000 1500 2000 2500 3000
mjj [GeV]

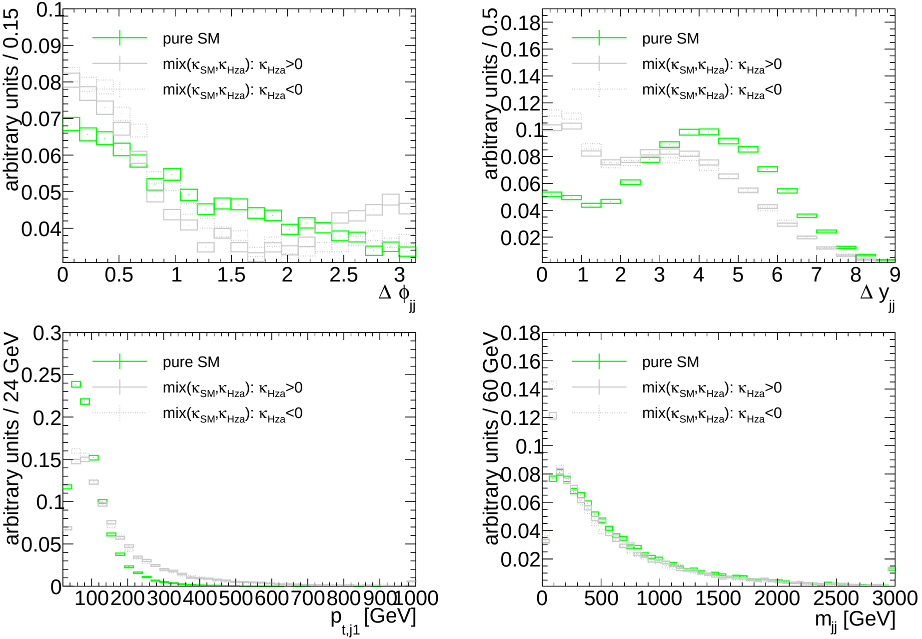

pure SM
mix(κ_SM,κ_Azz): κ_Azz>0
mix(κ_SM,κ_Azz): κ_Azz<0
arbitrary units / 0.15
Δ φ_jj
arbitrary units / 0.5
Δ y_jj
arbitrary units / 24 GeV
p_t,j1 [GeV]
arbitrary units / 60 GeV
m_jj [GeV]

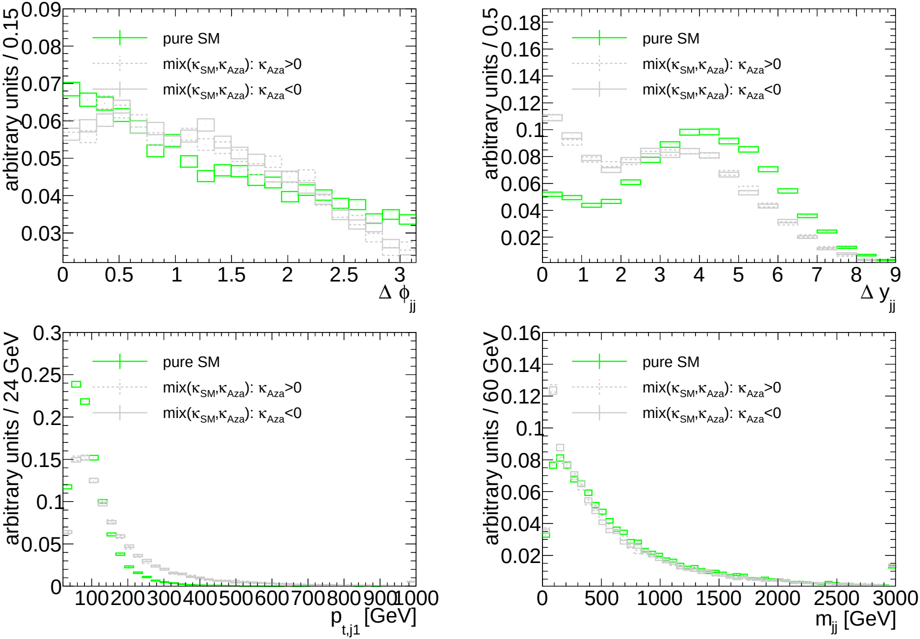


arbitrary units / 0.15
pure SM
mix(κSM,κHww): κHww>0
mix(κSM,κHww): κHww<0
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]

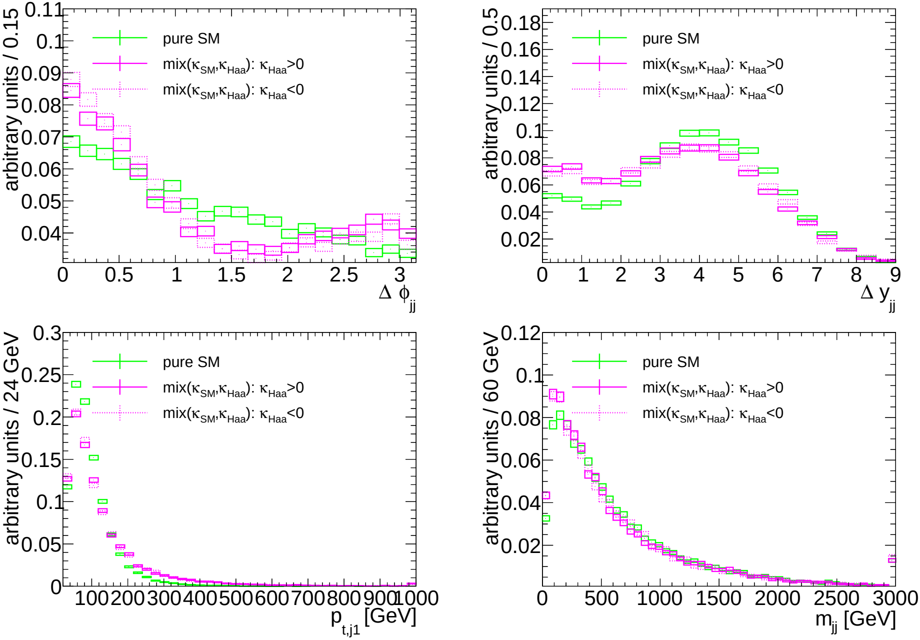


pure SM
mix(κSM,κAww): κAww>0
mix(κSM,κAww): κAww<0
arbitrary units / 0.15
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]

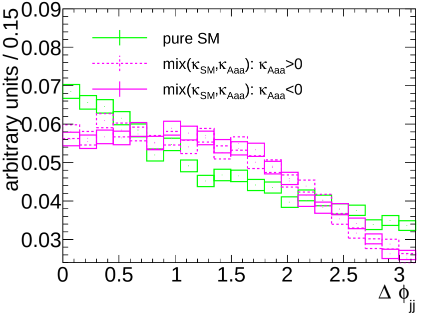

pure SM
mix(κSM,κHza): κHza>0
mix(κSM,κHza): κHza<0
arbitrary units / 0.15
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]

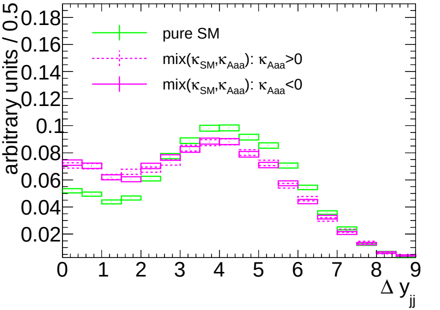


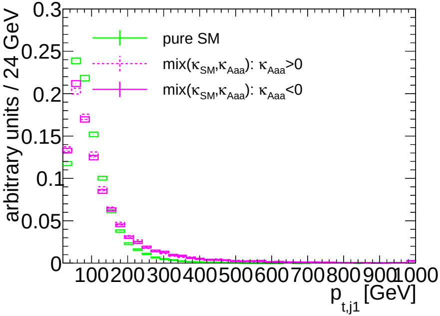
arbitrary units / 0.15
0.09
0.08
0.07
0.06
0.05
0.04
0.03
pure SM
mix(κSM,κAza): κAza>0
mix(κSM,κAza): κAza<0
0
0.5
1
1.5
2
2.5
3
Δ φjj
arbitrary units / 0.5
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
pure SM
mix(κSM,κAza): κAza>0
mix(κSM,κAza): κAza<0
0
1
2
3
4
5
6
7
8
9
Δ yjj
arbitrary units / 24 GeV
0.3
0.25
0.2
0.15
0.1
0.05
0
pure SM
mix(κSM,κAza): κAza>0
mix(κSM,κAza): κAza<0
100
200
300
400
500
600
700
800
900
1000
pt,j1 [GeV]
arbitrary units / 60 GeV
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
pure SM
mix(κSM,κAza): κAza>0
mix(κSM,κAza): κAza<0
0
500
1000
1500
2000
2500
3000
mjj [GeV]

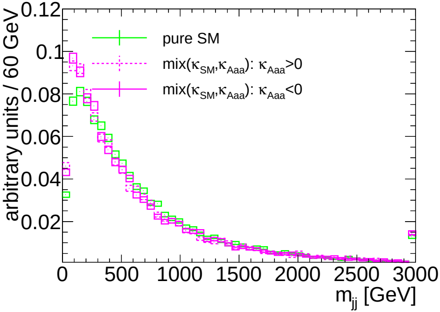


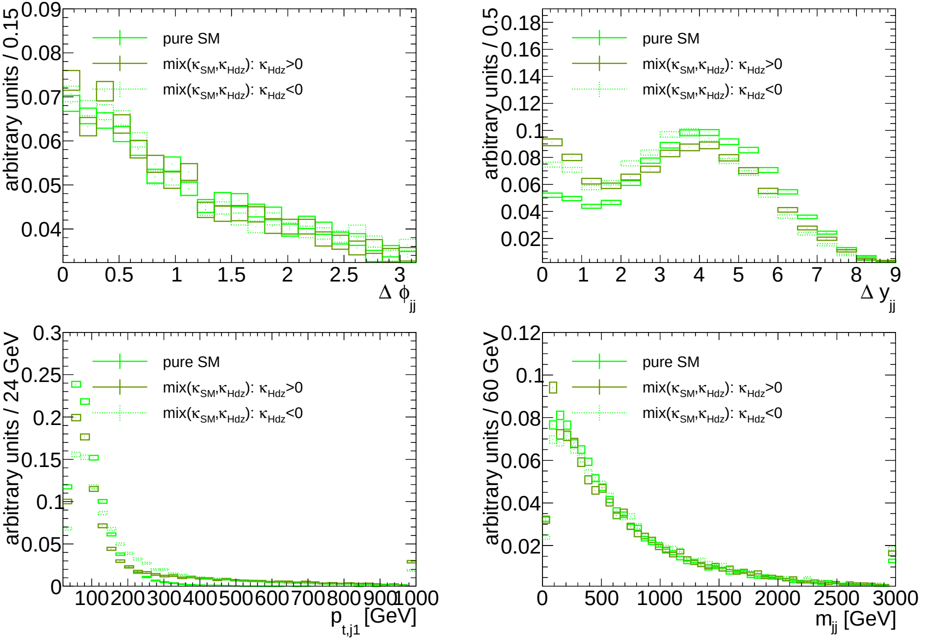
pure SM
mix(κSM,κHaa): κHaa>0
mix(κSM,κHaa): κHaa<0
arbitrary units / 0.15
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]

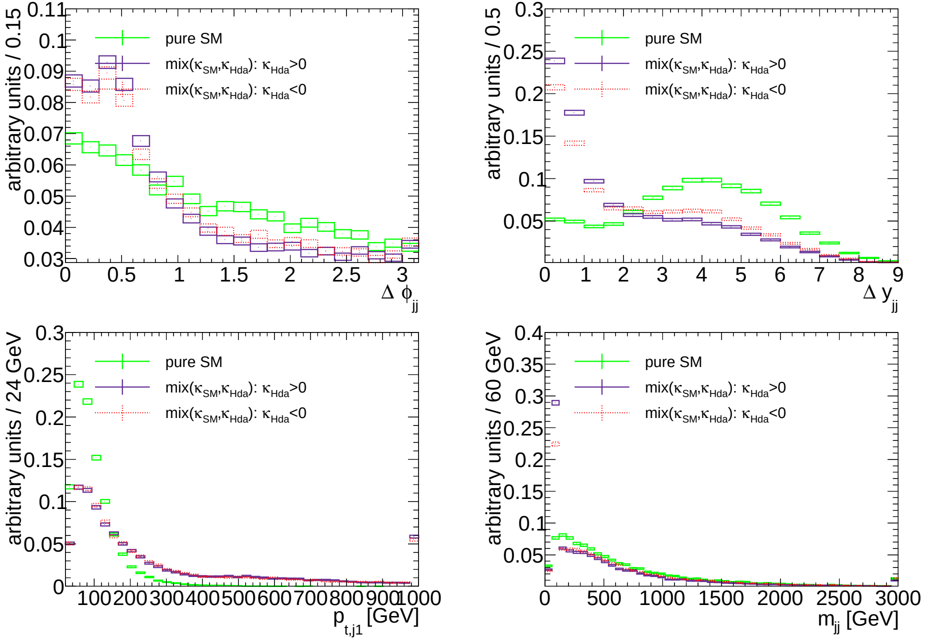

arbitrary units / 0.15
pure SM
mix(κSM,κAaa): κAaa>0
mix(κSM,κAaa): κAaa<0
Δ ϕjj


arbitrary units / 0.5
pure SM
mix(κSM,κAaa): κAaa>0
mix(κSM,κAaa): κAaa<0
Δ yjj

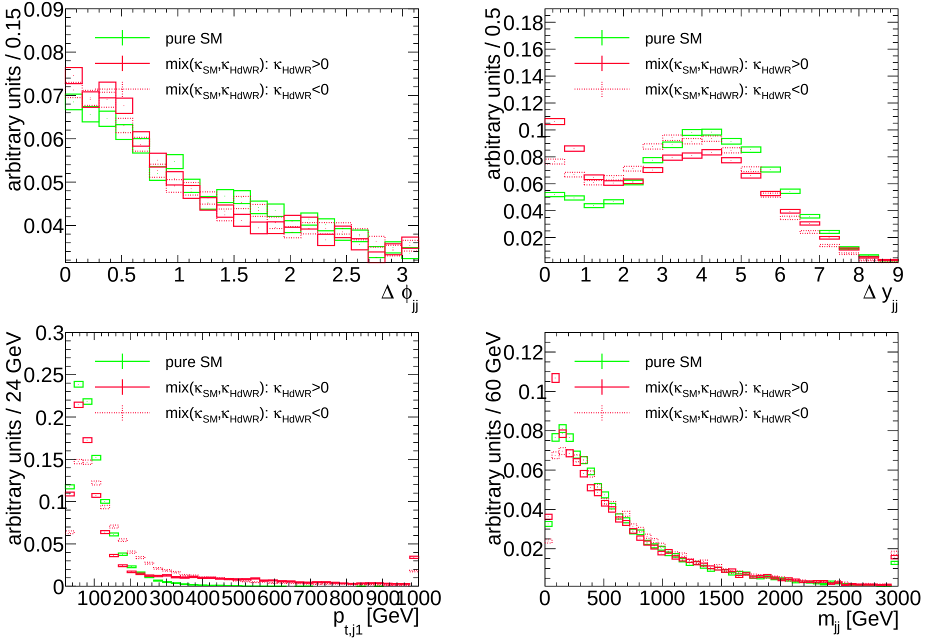

arbitrary units / 24 GeV
pure SM
mix(κSM,κAaa): κAaa>0
mix(κSM,κAaa): κAaa<0
pt,j1 [GeV]


arbitrary units / 60 GeV
pure SM
mix(κSM,κAaa): κAaa>0
mix(κSM,κAaa): κAaa<0
mjj [GeV]

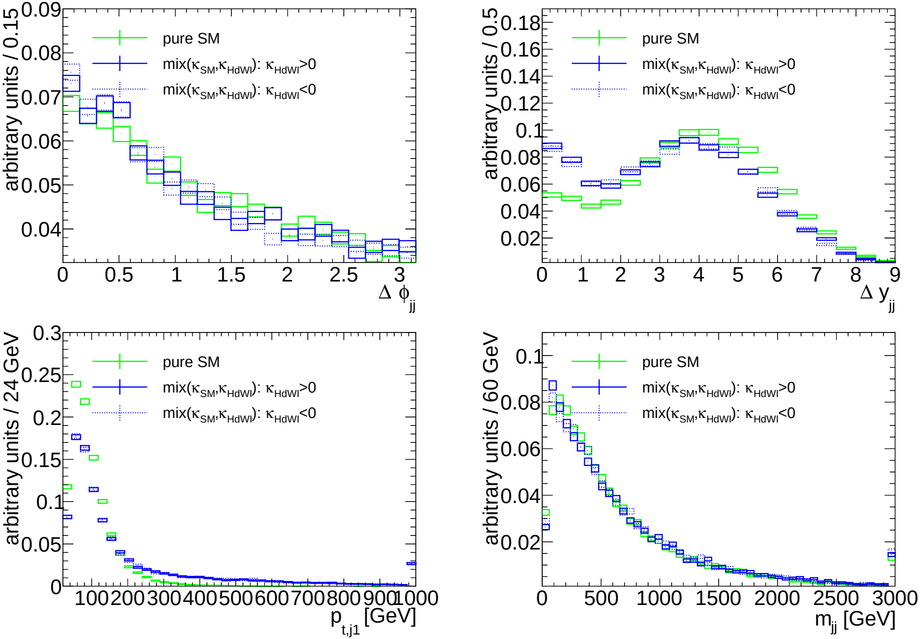

arbitrary units / 0.15
pure SM
mix(κSM,κHdz): κHdz>0
mix(κSM,κHdz): κHdz<0
Δ φjj
arbitrary units / 0.5
pure SM
mix(κSM,κHdz): κHdz>0
mix(κSM,κHdz): κHdz<0
Δ yjj
arbitrary units / 24 GeV
pure SM
mix(κSM,κHdz): κHdz>0
mix(κSM,κHdz): κHdz<0
pt,j1 [GeV]
arbitrary units / 60 GeV
pure SM
mix(κSM,κHdz): κHdz>0
mix(κSM,κHdz): κHdz<0
mjj [GeV]



arbitrary units / 0.15
pure SM
mix(κSM,κHda): κHda>0
mix(κSM,κHda): κHda<0
Δ φjj
arbitrary units / 0.5
pure SM
mix(κSM,κHda): κHda>0
mix(κSM,κHda): κHda<0
Δ yjj
arbitrary units / 24 GeV
pure SM
mix(κSM,κHda): κHda>0
mix(κSM,κHda): κHda<0
pt,j1 [GeV]
arbitrary units / 60 GeV
pure SM
mix(κSM,κHda): κHda>0
mix(κSM,κHda): κHda<0
mjj [GeV]



arbitrary units / 0.15
pure SM
mix(κSM,κHdWR): κHdWR>0
mix(κSM,κHdWR): κHdWR<0
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]



arbitrary units / 0.15
pure SM
mix(κSM,κHdWl): κHdWl>0
mix(κSM,κHdWl): κHdWl<0
Δ φjj
arbitrary units / 0.5
Δ yjj
arbitrary units / 24 GeV
pt,j1 [GeV]
arbitrary units / 60 GeV
mjj [GeV]