$gg \rightarrow H + 2$ jets Theory Uncertainties in an MVA Setup

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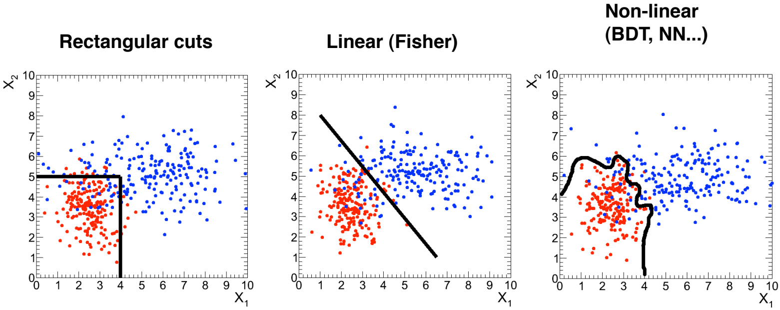
Talk overview

- The challenge of estimating ggF+2 jets uncertainties with an MVA selection
- Generalization of the Stewart-Tackmann procedure
- Implementation in the MVA Analysis: *Event-by-Event weights* or *Binned uncertainties*
- Comparison with pure MCFM and differences
- `C++` tool to use this

- Experimental situation: Want to achieve signal/background discrimination



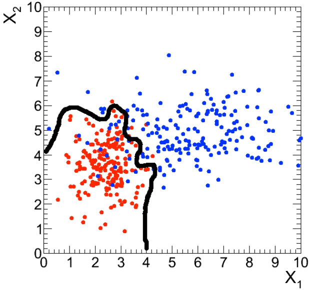
from Nicolas Chanon

- Multivariate analyses use supervised learning to combine a given set of input variables into one discriminating classifier.

→ Multivariate algorithms exploit correlations between variables better than rectangular cuts and achieve a better separation

ii. Uncertainties in a MVA Selection

- Scale uncertainties of rectangular cuts can readily be checked using MCFM Modulo the comparison of reco v true resolution of the cuts
- MVA selects non-linearly regions of phase-space:



  * Formidable challenge to select same region with MCFM
  * Our current method involves running MCFM for every working point

    Systematic scans cost a lot
  * Differential uncertainties would be highly desirable!

→ Propose Ansatz to generalize ST uncertainties to differential uncertainties

iii.a Recap of Stewart-Tackmann for $\Delta\phi_{H-jj}$ (See talk of S. Gangal for more details)

→ In ST procedure cross section divided as:

$$\sigma = \int_{\Delta\phi^{\text{cut}}}^{\pi} \frac{d\sigma}{d\phi} d\phi + \int_{0}^{\Delta\phi^{\text{cut}}} \frac{d\sigma}{d\phi} d\phi$$

* Exclusive 2jet cross section can be written as

$$\sigma_2(\Delta\phi > \Delta\phi^{\text{cut}}) = \sigma_{\geq 2} - \sigma_{\geq 3}(\Delta\phi < \Delta\phi^{\text{cut}})$$

$\sigma_{\geq 2}$: inclusive 2 jet cross section; $\sigma_{\geq 3}$: inclusive 3 jet cross section - here with cut on $\Delta\phi^{\text{cut}}$

* S/T: $\sigma_{\geq 3}(\Delta\phi < \Delta\phi^{\text{cut}})$ and $\sigma_{\geq 2}$ assumed uncorrelated, elaborated in arXiv:1107.2117

$$\Rightarrow \Delta_2^2(\Delta\phi > \Delta\phi^{\text{cut}}) = \Delta_{\geq 2}^2 + \Delta_{\geq 3}^2(\Delta\phi < \Delta\phi^{\text{cut}})$$

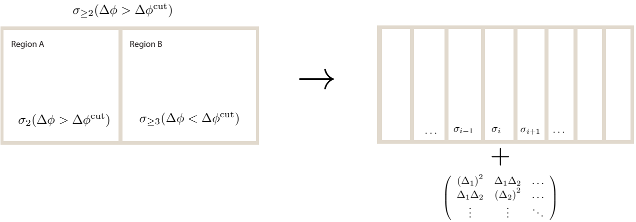
→ Correlation completely determined: $\{\sigma_{\geq 2}, \sigma_2, \sigma_{\geq 3}\}$

$$\begin{pmatrix} \Delta_{\geq 2}^2 & \Delta_{\geq 2}^2 & 0 \\ \Delta_{\geq 2}^2 & \Delta_{\geq 2}^2 + \Delta_{\geq 3}^2 & -\Delta_{\geq 3}^2 \\ 0 & -\Delta_{\geq 3}^2 & \Delta_{\geq 3}^2 \end{pmatrix}$$

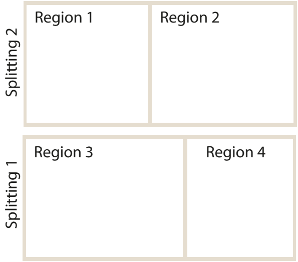
→ Obtain two 'Bins' which are anti-correlated with each other: $\{\sigma_2, \sigma_{\geq 3}\}$

iii.b Generalization of ST uncertainties to differential uncertainties

- **Generalization to differential uncertainties:** Optimally we want to adapt an established uncertainty scheme and convert them into something more differential. Input could be ST or other.



- **Can use ST method to predict uncertainties for many different cuts:**



i. Using different splittings one can formulate a number of boundary conditions for the total covariance between regions

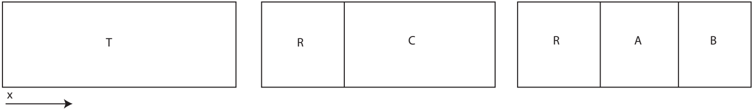
ii. Unknown parameters in covariance matrix scale as $\frac{1}{2}\left(n^2 - n\right)$

iii. Assume a model with decreasing correlations

$$\rho_{ij} \simeq 1 - \frac{1}{a}\left|\sigma_i - \sigma_j\right|$$

$\ldots \longrightarrow$ constraints on Covariance

iii.c Generalization of ST uncertainties to differential uncertainties



Sketch of a separation into three bins

* Repeating this for three bins: $\{\sigma_T, \sigma_R, \sigma_A, \sigma_B\}$

$$\begin{pmatrix} \Delta_T^2 & \Delta_T^2 & 0 & 0 \\ \Delta_T^2 & \Delta_R^2 & v_{CR} - v_{BR} & v_{BR} \\ 0 & v_{CR} - v_{BR} & \Delta_A^2 & v_{AB} \\ 0 & v_{BR} & v_{AB} & \Delta_B^2 \end{pmatrix}$$

ø The covariance matrix can be determined up to the correlation between regions A & B: v_{AB}

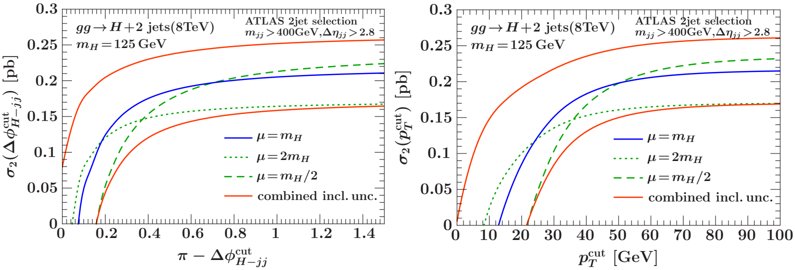
→ Ansatz with a model using decreasing correlations: $1 - \frac{1}{a}\left|\sigma_i - \sigma_j\right|$

→ Procedure can be generalized to n bins with $\frac{1}{2}\left(n^2 - n\right)$ model parameters.

Thanks to S. Gangal, F.J. Tackmann for help and providing inputs!

- Ideally one would want differential uncertainties in all variables of interest. I.e. in all variables that go into a MVA classifier
- Some variables are more relevant than others for the size of the overall $gg \to H{+}2$ jets uncertainties:

* MCFM Cumulant uncertainties for $\Delta\phi_{H-jj}$ and the recoil p_T of the Higgs + dijet system



Plots shown by F.J. Tackmann und S. Gangal (in October Meeting)

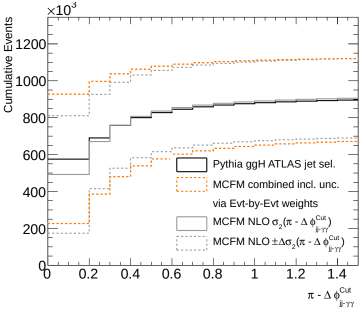
→ Results shown in the following use a single matrix in $\Delta\phi_{H-jj}$.

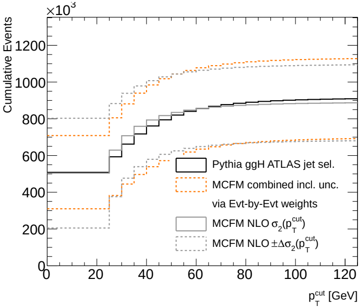
vi. Validation via cumulants

Non-trivial test: Matrix based on MCFM in $\Delta\phi_{H-jj}$ and assign uncertainties to Pythia $gg \to H$+2 jets (*with second jet from parton shower*);

- Cumulants for cuts on $\Delta\phi_{H-jj}$ and recoil p_T of the Higgs + dijet system:

  ATLAS jet selection applied; $m_{jj} > 400$ GeV$/c^2$, $\Delta\eta_j j > 2.8$





i. Reproduce MCFM uncertainties fairly well for $\Delta\phi_{H-jj}$ cuts.

   Observed differences are due to using MCFM uncertainties on the Pythia shape of $\Delta\phi_{H-jj}$.

ii. Reproduce MCFM uncertainties also well in recoil p_T; but we used $\Delta\phi_{H-jj}$ differential uncertainties as input!

v.a Event-by-Event weights *or* Binned Uncertainties

- Ideally: assign an uncertainty for the scale variations to each event.

Looked into two approaches: Event-by-Event weights and a binned approach:

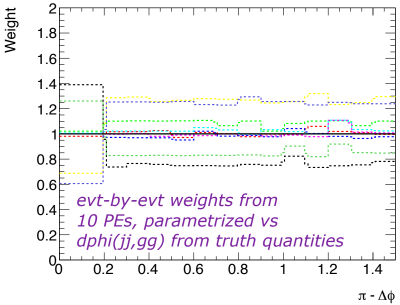
- Can be done by generating a set of pseudo-experiments from a sampling of the theory covariance.

i. For each pseudo-experiment we assign a weight to the event, based on it's $\Delta\phi_{H-jj}$, corresponding to the relative difference from the nominal cross section to the cross section of the pseudo-experiment in that given bin of $\Delta\phi_{H-jj}$.

ii. After applying a selection (MVA or cut based), the total uncertainty is retained by summing over all sets of weights,

$$\Delta_{\text{theory}} = \max_i \{ \sum_n w_n^i \}$$

where the sum runs over all remaining events and i denotes one set.



v.b Implementation via Event-by-Event weights

- The binned approach uses the binned $\Delta\phi_{H-jj}$ spectrum after the selection and results in the same uncertainties.

  The slight drawback is procedural: whereas the Event-by-Event uncertainties allow the determination of the uncertainties for arbitrary cuts once the weights are calculated, the binned version requires a reevaluation after every cut.

- Further cross checks and some general remarks

  * Check different Ansätze for correlations, impact of actual model seems small.
  * The matrix describes the evolution of the MCFM uncertainty in IR sensitive regions; if one is inclusive over these, the matrix reproduces the overall (inclusive) uncertainties.
  * Using several IR sensitive variables would require a more complex matrix, which covers the 2D phase space.

Comparison of Scale uncertainties:

Powheg+Pythia + Event-by-Event weights versus MCFM for ATLAS VBF Category:

$m_{jj} > 400$ GeV; $\Delta\eta_{jj} > 2.8$; $\Delta\phi_{H-\gamma\gamma} > 2.6$

MCFM	Our Method via Event-by-Event weights
25%	24.2 %

Differences in uncertainty entirely due to different shape of Powheg+Pythia v MCFM in $\Delta\phi_{H-jj}$

C++:

- We are currently writing a stand-alone C++ class which use the inputs from F.J. Tackmann und S. Gangal and calculates Event-weight or binned uncertainties.
- During initialization a set of pseudo-experiments is created from the theory Covariance
- Simple interface: one simply passes the truth $\Delta\phi_{H-jj}$ of the events before or after a cut to a function
- Can in principle be used by other channels and groups as well

Summary:

- We showed a method how the cumulative uncertainties can be transformed into differential uncertainties, using an underlying model for the correlations which cannot be determined from first principles.
- Using these differential uncertainties, one can determine the scale uncertainties of a non-linearly selected region of phase-space using sets of weights determined from pseudo-experiments generated by the theory covariance.
- The proposed method uses IR sensitive variables as a guideline for the overall uncertainty, which seems a reasonable approximation as long as one does not enter extreme regions of phase-space (e.g. very large m_{jj}).

  The shown results used $\Delta\phi_{H-jj}$, but the recoil p_T of the Higgs+dijet system is also a good variable.
- Allows consistent evaluation of scale uncertainties in the non-linear region of phase-space a MVA selects.