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Higgs production through WBF and gluon fusion at the LHC

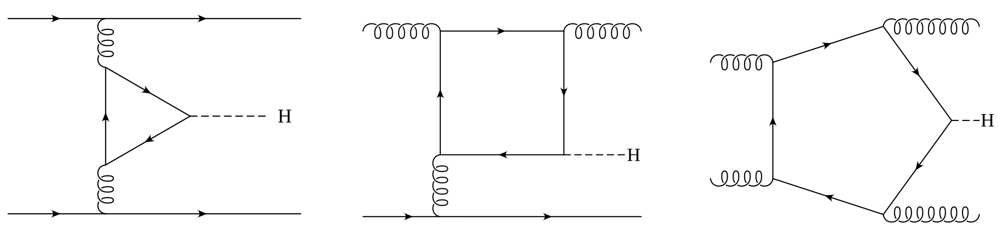
in collaboration with
the ALPGEN team (M.L. Mangano, M. Moretti, R. Pittau, A.D. Polosa)
V. Del Duca and D. Zeppenfeld

TeV4LHC, 20 October, Fermilab, 2005

Weak Boson Fusion will be an important channel for Higgs boson search at LHC and even more for the determination of its couplings to fermions and gauge bosons

Typical signature: $H + 2$ forward jets

Another possible contribution is Higgs production through gluon fusion with two additional jets, which is at one loop perturbative order but important because of $\mathcal{O}(\alpha_s)^4$ against $\mathcal{O}(\alpha_w^2)$ of WBF



(a) (b) (c)

V. Del Duca et al., *Phys. Rev. Lett.* 87 (2001) 122001

Since QCD $H + 2$ jets is a background to WBF for Higgs coupling studies, it is important to study the features of the two different processes

What is available in the literature:

- WBF at QCD NLO

  T. Han, G. Valencia and S. Willenbrock, *Phys. Rev. Lett.* 69 (1992) 3274
  T. Figy, C. Oleari and D. Zeppenfeld, Phys. Rev. **D68** (2003) 073005

- QCD production of $H + 2$ jets at LO in the limit $m_t \to \infty$ and keeping the complete m_t dependence

  V. Del Duca et al., *Phys. Rev. Lett.* 87 (2001) 122001
  V. Del Duca et al., Nucl. Phys. **B616** (2001) 367
  V. Del Duca et al., Phys. Rev. **D67** (2003) 073003

- LO calculation of $pp \to H + 3$ jets in the limit $m_t \to \infty$

  V. Del Duca, A. Frizzo and F. Maltoni, JHEP **0405** (2004) 064

- very recent improvement on calculation of virtual corrections to $H + 4$ parton processes, essential ingredient for the calculation of NLO corrections to $pp \to H + 2$ jets

  K. Ellis, W. Giele and G. Zanderighi, hep-ph/0506196

The parton level analysis carried out so far show particular features (such as a correlation in $\Delta\phi_{jj}$ between the tagging jets, see below) allowing to distinguish between WBF and gluon fusion production

On the other hand the picture could be changed once the higher order QCD radiation effects are taken into account. This is what has been found in the analysis by

K. Odagiri, JHEP **03030** (2003) 009

where the final state $H + 2$ jets has been generated starting from the kernel process $gg \to H$ and adding QCD radiation with `HERWIG` Parton Shower, i.e. neglecting exact matrix elements for hard QCD radiation

The situation can be improved if the combined information of matrix elements and Parton Shower can be used. This can be done for instance with the help of the `ALPGEN` event generator

M.L. Mangano, M. Moretti, F. P., R. Pittau, A.D. Polosa, JHEP **0307** (2003) 001

In ALPGEN v2.0 the effective coupling ggH in the limit $m_t \to \infty$ has been implemented at the Lagrangian level

M.A. Shifman, A.I. Vainshtein, M.B. Voloshin and V.I. Zakharov, Sov. J. Nucl. Phys **30** (1979) 711
J. Ellis, M.K. Gaillard and D.V. Nanopoulos, Nucl. Phys. **B106** (1976) 292

This approximation has been shown to be very good for m_H and $p_j^T < m_t$

V. Del Duca et al., *Phys. Rev. Lett.* 87 (2001) 122001
V. Del Duca et al., Phys. Rev. **D67** (2003) 073003

The process $pp \to H + N$ jets ($N < 5$) has been introduced (and interfaced to the Parton Shower) with exact LO QCD matrix elements for up to N additional partons

Our aim is to study the effects of higher order QCD radiation (and eventually hadronisation) with the HERWIG Parton Shower on top of parton level events of the form $pp \to H + 2$ jets and $pp \to H + 3$ generated with ALPGEN

$m_H = 120$ GeV

Event selection:

$$p_\perp^j \geq 20 \text{ GeV}, \quad |\eta_j| \leq 5, \quad R_{jj} \geq 0.6$$
$$|\eta_{j1} - \eta_{j2}| \geq 4.2, \quad \eta_{j1} \cdot \eta_{j2} \leq 0, \quad M_{jj} \geq 600 \text{ GeV}$$

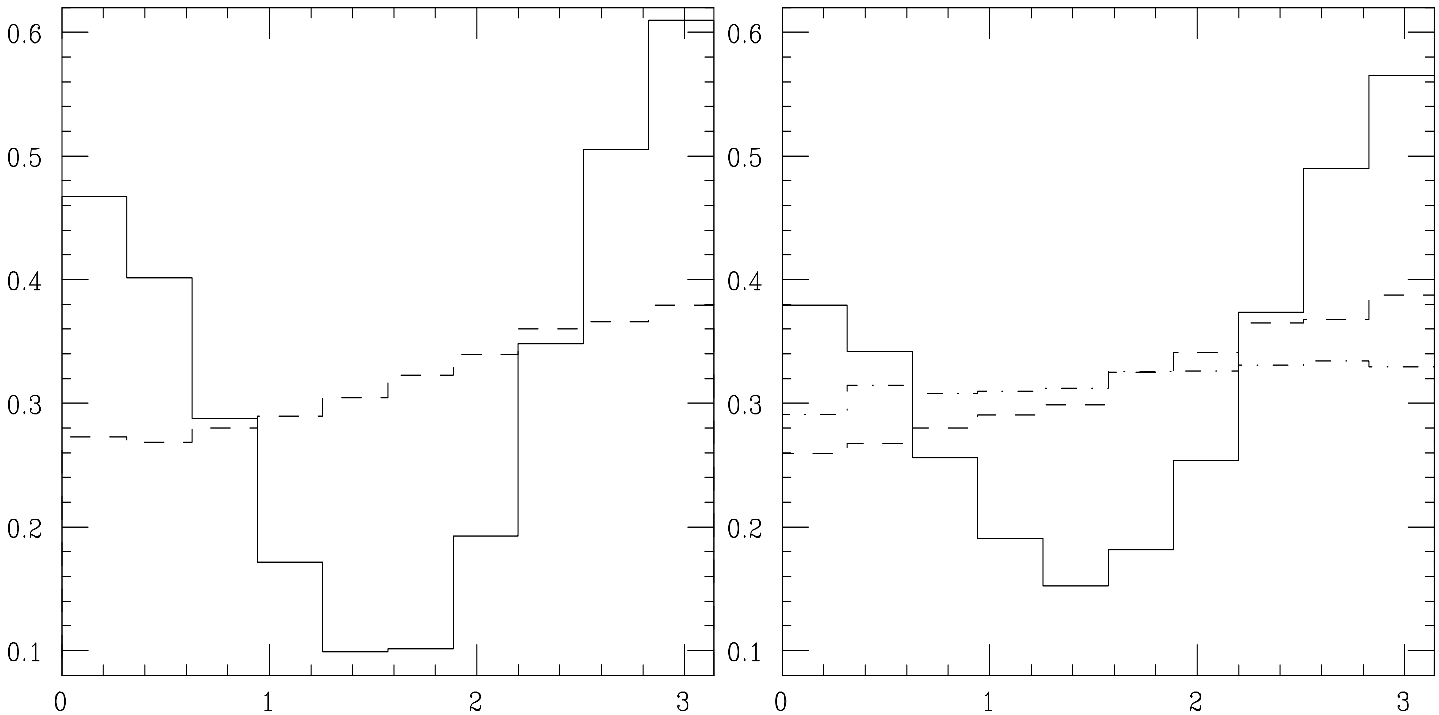
PDF set: CTEQ5L

Scales (affecting much more QCD Higgs productions than WBF):

$$\alpha_s^{2+N\text{jets}}(\mu_R) \rightarrow \alpha_s^2(M_H)\Pi_i \alpha_s(p_i^T)$$
$$\mu_F = (\Pi_i p_i^T)^{(1/N)}$$

Jets defined according to the routine `GETJET`, which uses a simplified version of the UA1 jet algorithm. Parameters for the jets as for the partons

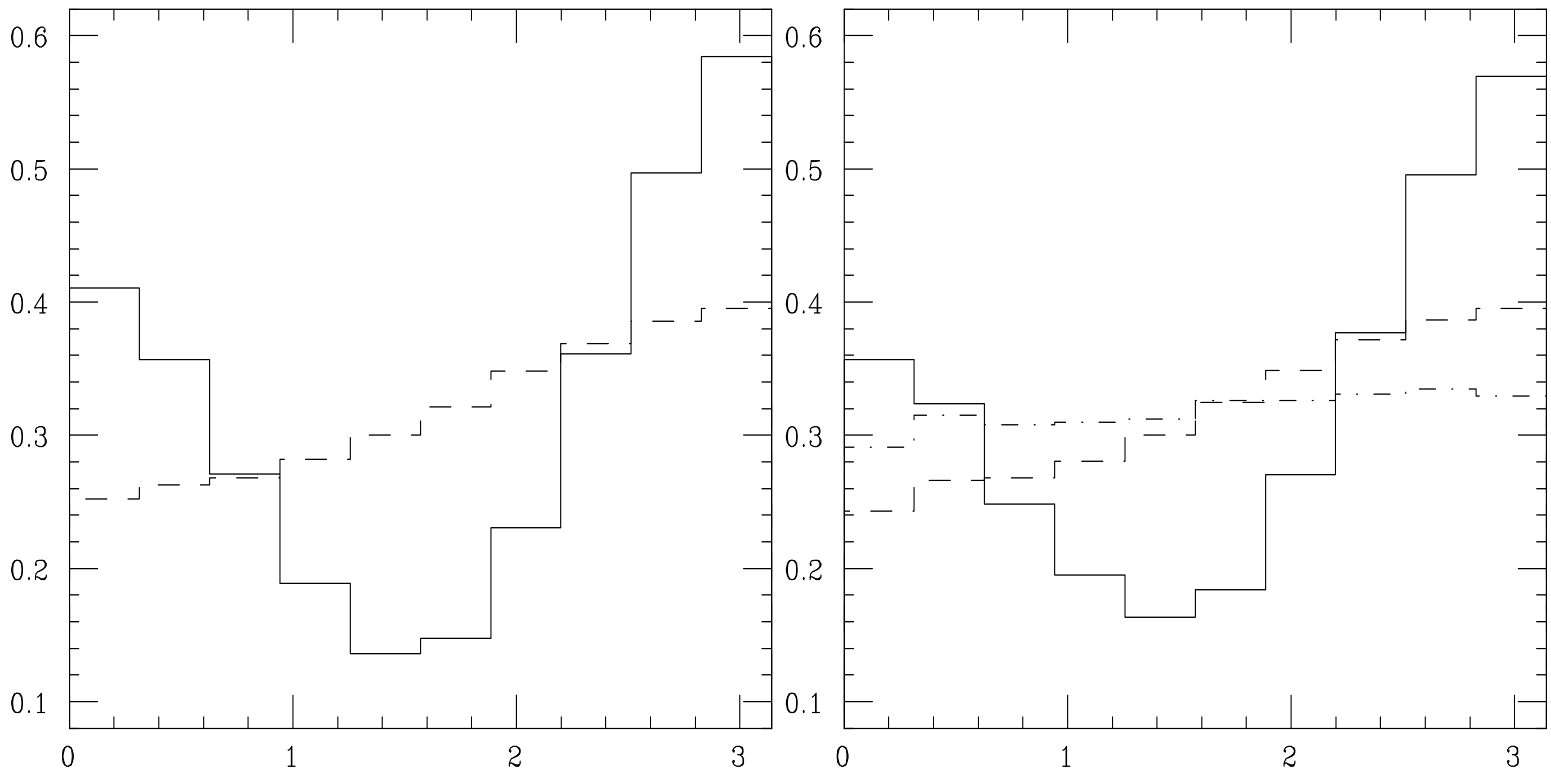
Azimuthal correlation between the tagging jets



Left: $\frac{1}{\sigma} d\sigma/d\phi_{jj}$ distribution at LO partonic level for the process $pp \to H + 2$ jets.
Solid line: QCD Higgs production; dashed line: WBF

Right: $\frac{1}{\sigma} d\sigma/d\phi_{j_1 j_2}$ distribution with Parton Shower (j_1 and j_2 are the leading p_T jets) on top of $pp \to H + 2$ jets generated events

Right: Dot-dashed line has been obtained generating $gg \to H$ with `HERWIG` and taking all jets from shower

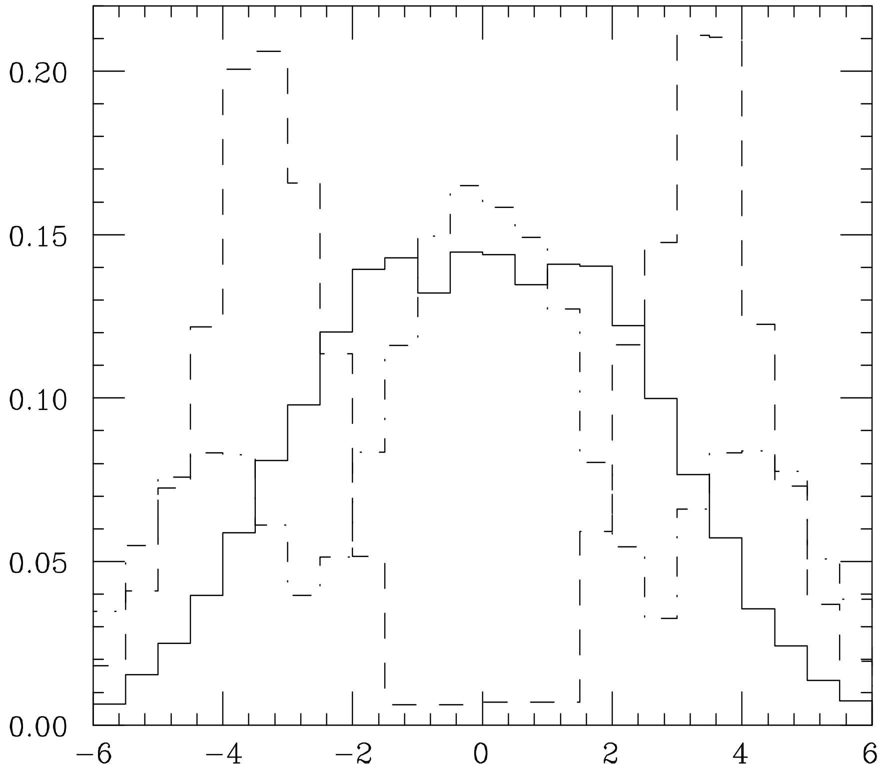


Left: $\frac{1}{\sigma} d\sigma/d\phi_{j_1 j_2}$ distribution at LO partonic level for the process $pp \to H + 3$ jets.
Solid line: QCD Higgs production; dashed line: WBF

Right: $\frac{1}{\sigma} d\sigma/d\phi_{j_1 j_2}$ distribution with Parton Shower (j_1 and j_2 are the leading p_T jets) on top of $pp \to H + 3$ jets generated events

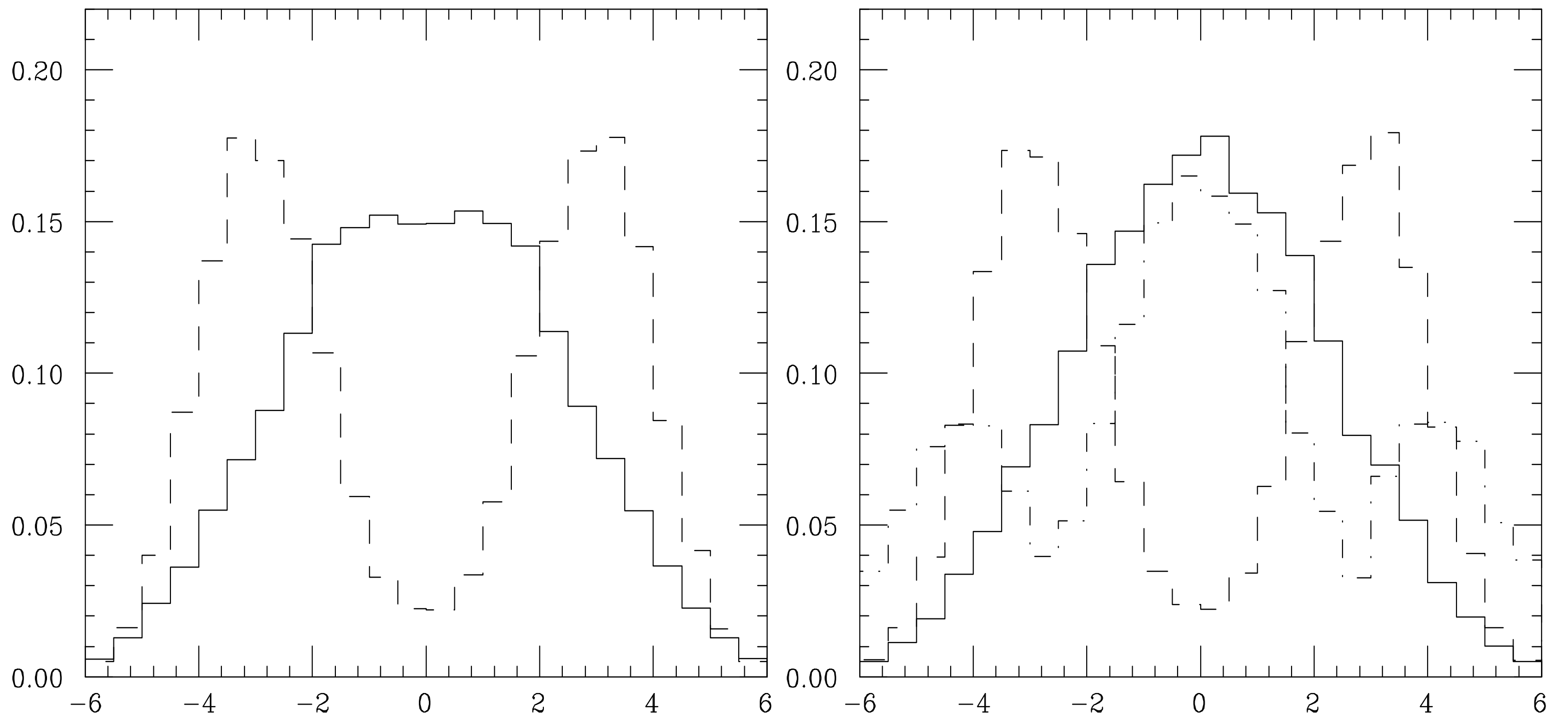
The presence of additional hard radiation doesn't change the $\Delta\phi_{jj}$ azimuthal correlation

Rapidity gaps survival: central-jet veto



$\frac{1}{\sigma}d\sigma/dy_{\rm rel}$ distribution with Parton Shower on top of $pp \to H + 2$ jets generated events; dashed WBF, solid QCD Higgs production, dot-dashed Parton Shower on top of $pp \to H$ generated events

$$y_{\rm rel} = y_3 - (y_1 + y_2)/2$$

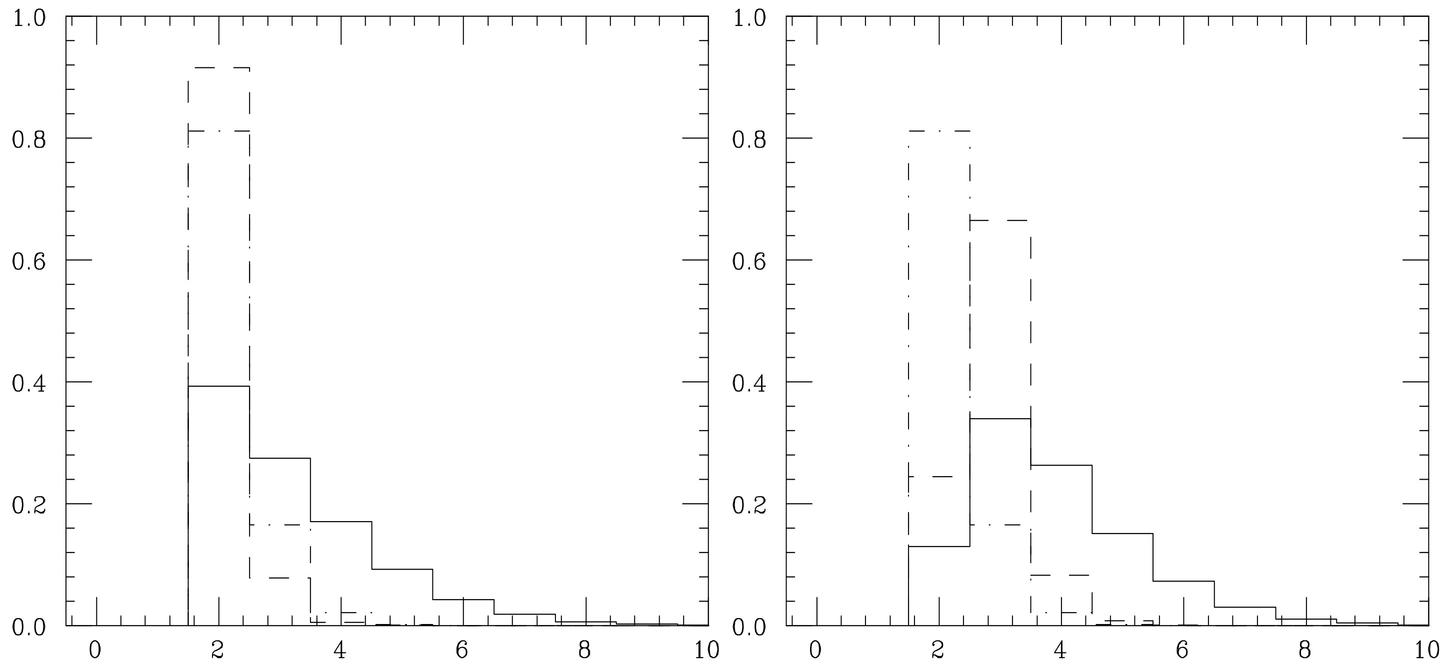


Left: $\frac{1}{\sigma}d\sigma/dy_{\rm rel}$ distribution at LO partonic level for the process $pp \rightarrow H + 3$ jets.
Solid line: QCD Higgs production; dashed line: WBF

Right: $\frac{1}{\sigma}d\sigma/dy_{\rm rel}$ distribution with Parton Shower on top of $pp \rightarrow H + 3$ jets generated events

In WBF the emission of hard radiation starts to populate the central rapidity region but the shape of the parton level simulation is the same as after showering. For gluon fusion the third jet after showering is more likely to be emitted central in rapidity w.r.t. pure parton level

Jet multiplicity



Left: $\frac{1}{\sigma}d\sigma/dn_{\mathrm{jets}}$ distribution with Parton Shower on top of $pp \to H + 2$ jets generated events. Solid line: QCD Higgs production; dashed line: WBF; dot-dashed line: Parton Shower on top of $pp \to H$

Right: $\frac{1}{\sigma}d\sigma/dn_{\mathrm{jets}}$ distribution with Parton Shower on top of $pp \to H + 3$ jets generated events

While in WBF the number of jets is peaked at the number of final-state partons, a large part of the jets which pass the cuts in gg fusion originates from the parton shower

$$A_\phi = \frac{\sigma(\Delta\phi < \pi/4) - \sigma(\pi/4 < \Delta\phi < 3\pi/4) + \sigma(\Delta\phi > 3\pi/4)}{\sigma(\Delta\phi < \pi/4) + \sigma(\pi/4 < \Delta\phi < 3\pi/4) + \sigma(\Delta\phi > 3\pi/4)}$$

where $\Delta\phi$ is the azimuthal distance between the two tagging jets

A_ϕ for x partons + H f.s.	parton level	shower level
$A_\phi(0j - ggH)$		0.006
$A_\phi(2j - ggH)$	0.50	0.33
$A_\phi(3j - ggH)$	0.38	0.31
$A_\phi(2j - WBF)$	0.015	0.017
$A_\phi(3j - WBF)$	0.013	0.014

Work in progress to perform an inclusive analysis adding together samples with different jet multiplicities, without double counting and using proper reweighting of α_s, with MLM prescription for jet matching (now available in `ALPGEN v2.0`)

σ	fixed scale $\alpha_s(m_H)$	modified*	$\alpha_s^{\rm rew}$
$\sigma(2j-ggH)$	0.50(1) pb	0.73(1) pb	0.66(1) pb
$\sigma(3j-ggH)$	0.36(1) pb	0.44(1) pb	0.49(1)
$\sigma(2j-WBF)$	1.36(1) pb	1.41(3) pb	
$\sigma(3j-WBF)$	0.22(1) pb	0.26(1) pb	0.20(1)

*)

$$\begin{aligned} \alpha_s^{2+N{\rm jets}}(\mu_R) &\rightarrow \alpha_s^2(M_H)\Pi_i\alpha_s(p_i^T) \\ \mu_F &= (\Pi_i p_i^T)^{(1/N)} \end{aligned}$$

according to

V. Del Duca, A. Frizzo and F. Maltoni, JHEP **0405** (2004) 064

Possible check vs NLO calculation for WBF, for ggH will be possible in the future

Summary

- We proved the importance of the exact LO matrix element calculations for $H+$ jets final states in order to exploit all the correlations allowing to disentangle WBF from QCD Higgs production
- `ALPGEN v2.0` includes such processes with up to five jets in the final state
- While the use of the Parton Shower on the process $gg \to H$ can give unreliable results, once the complete matrix element for $H+$ jets is used, the shower doesn't alter the picture
- This has still to be proved when including hadronization *(work in progress)*
- A good integral quantity A_ϕ has been identified to distinguish between gluon fusion and WBF
- The use of exact matrix elements for $H+$ jets final state calls for a consistent matching between matrix elements and parton shower *(work in progress)*
- The availability of a NLO calculation would be useful in the study of the optimal scales