

H+Dijets (or more) with High Energy Jets (HEJ)

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Multi-Jet Predictions for the Gluon-Fusion component of $H+(\text{di})\text{Jets}$

A different approach to resummation for multiple, hard, wide-angle emissions (and virtual corrections) in the **hard scattering**:

High Energy Jets

Implications for the GF component of $H+\text{jets}$ in the VBF region

The all-order perturbative $H + 2j$ cross section could in principle be calculated as:

$$\begin{aligned} \sigma_{H+2j} = & \sum_{f_a, f_b} \sum_{n=2}^{\infty} \left(\int \frac{d^2 \mathbf{p}_{1\perp}}{(2\pi)^3} \int_{y_{\min}}^{y_{\max}} \frac{dy_1}{2} \right) \left(\int \frac{d^2 \mathbf{p}_{n\perp}}{(2\pi)^3} \int_{y_{n-1}}^{y_{\max}} \frac{dy_n}{2} \right) \\ & \prod_{i=2}^{n-1} \left(\int \frac{d^2 \mathbf{p}_{i\perp}}{(2\pi)^3} \int_{y_{i-1}}^{y_{\max}} \frac{dy_i}{2} \right) \int \frac{d^3 p_{\gamma_1}}{(2\pi)^3 2E_{\gamma_1}} \int \frac{d^3 p_{\gamma_2}}{(2\pi)^3 2E_{\gamma_2}} \\ & \frac{|\mathcal{M}^{\text{reg}}(\{\mathbf{p}_i, \mathbf{p}_{\gamma_1}, \mathbf{p}_{\gamma_2}\})|^2}{\hat{s}^2} \\ & \times x_a f_a(x_a, Q_a) \cdot x_b f_b(x_b, Q_b) \cdot (2\pi)^4 \delta^4(\sum_{k=1}^n \mathbf{p}_{k\perp} + \mathbf{p}_{\gamma_1\perp} + \mathbf{p}_{\gamma_2\perp}) \mathcal{O}_{2j}(\{\mathbf{p}_i\}). \end{aligned}$$

The **only** which remains is to calculate virtual corrections, real emissions, subtraction terms etc. to any order in α_s .

Unfortunately, we cannot present a method for doing so¹.

But, **High Energy Jets (HEJ)** provides *approximations* to these terms, and then performs the relevant phase space integrals.

¹the margin is too small

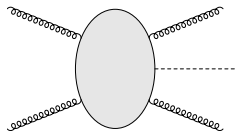
Regge theory: The matrix element $p_1 p_2 \rightarrow j_1 H j_2$ scales with the invariant masses raised to the spin of the exchanged particles:

$$\mathcal{M} \sim s_{1H}^{\alpha_1(t_1)} s_{2H}^{\alpha_2(t_2)} \gamma(t_1, t_2, s_{12}/(s_{1H}s_{2H})).$$

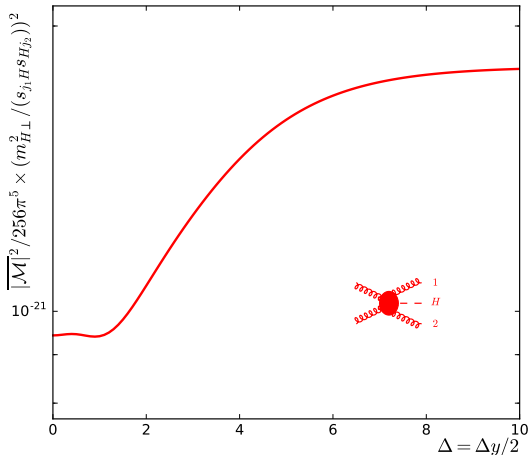
Q1: How do we make sense of this in QCD?

Q2: Does it even make sense in QCD?

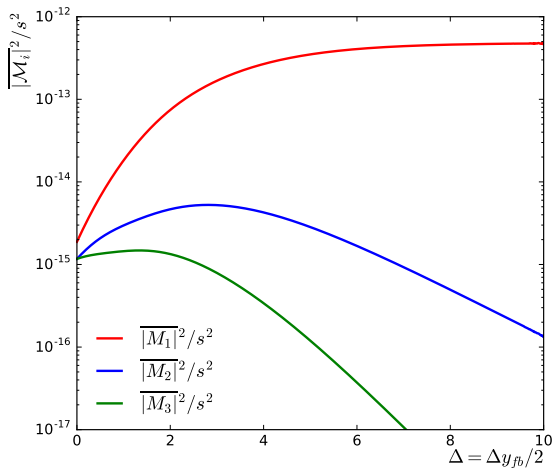
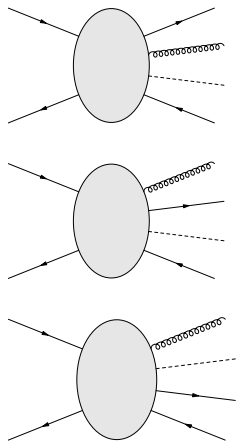
$|\mathcal{M}|^2$ does have the right behaviour



The full tree-level matrix element has the right scaling.

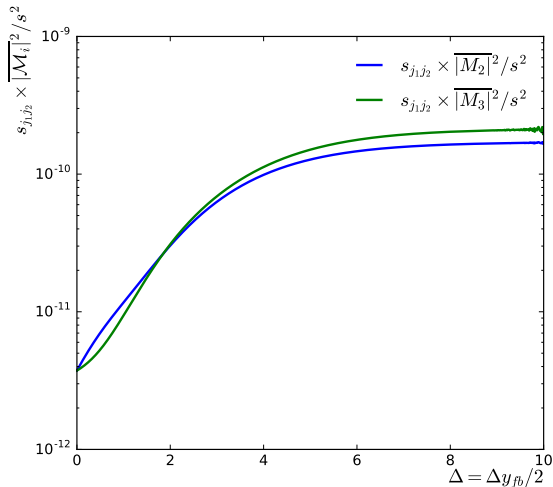
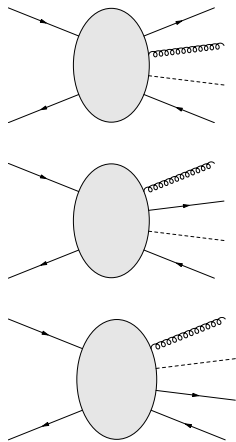


$|\mathcal{M}|^2$ does have the right behaviour



The “*t*-channel gluon-exchange” dominates

$|\mathcal{M}|^2$ does have the right behaviour



A t -channel quark exchange is suppressed by a power of $s_{j_1 j_2}$

Power expansion of \mathcal{M} : logarithmic control of σ

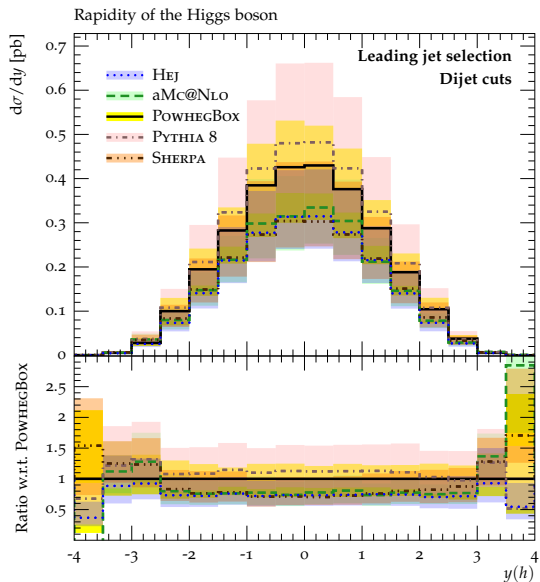
First set of sub-leading corrections included (1706.01002)

$$\begin{aligned} \left| \overline{\mathcal{M}_{f_1 f_2 \rightarrow Hg f_1 \cdot g \cdot f_2}^{\text{HEJ}}} \right|^2 &= \frac{1}{4(N_C^2 - 1)} \left\| S_{qQ \rightarrow qQH}^{\text{uno}}(p_1, p_g, p_n, p_a, p_b, q_j, q_{j+1}) \right\|^2 \\ &\cdot \left(g^2 K_{f_1} \frac{1}{t_1} \right) \cdot \left(g^2 K_{f_2} \frac{1}{t_n} \right) \\ &\cdot \prod_{k=2}^j \left(\frac{-g^2 C_A}{t_{k_1} t_k} V^{\nu_k}(q_{k-1}, q_k) V_{\nu_k}(q_{k-1}, q_k) \right) \\ &\cdot \prod_{k=j+1}^{n-1} \left(\frac{-g^2 C_A}{t_k t_{k+1}} V^{\nu_k}(q_k, q_{k+1}) V_{\nu_k}(q_k, q_{k+1}) \right) \\ &\cdot \prod_{i=1}^{j-1} \exp[\omega^0(q_{i\perp})(y_{i+1} - y_i)] \cdot \prod_{i=j+2}^n \exp[\omega^0(q_{i\perp})(y_i - y_{i-1})] \\ &\cdot \exp[\omega^0(q_{j\perp})(y_H - y_j)] \cdot \exp[\omega^0(q_{j+1\perp})(y_{j+1} - y_H)] \end{aligned}$$

$$\begin{aligned}
\sigma_{H+2j}^{\text{resum, match}} = & \sum_{f_a, f_b} \sum_{n=2}^{\infty} \left(\int \frac{d^2 \mathbf{p}_{1\perp}}{(2\pi)^3} \int_{y_{\min}}^{y_{\max}} \frac{dy_1}{2} \right) \left(\int \frac{d^2 \mathbf{p}_{n\perp}}{(2\pi)^3} \int_{y_{n-1}}^{y_{\max}} \frac{dy_n}{2} \right) \\
& \prod_{i=2}^{n-1} \left(\int \frac{d^2 \mathbf{p}_{i\perp}}{(2\pi)^3} \int_{y_{i-1}}^{y_{\max}} \frac{dy_i}{2} \right) \int \frac{d^3 p_{\gamma_1}}{(2\pi)^3 2E_{\gamma_1}} \int \frac{d^3 p_{\gamma_2}}{(2\pi)^3 2E_{\gamma_2}} \\
& \frac{|\mathcal{M}_{\text{HEJ}}^{\text{reg}}(\{\mathbf{p}_i, \mathbf{p}_{\gamma_1}, \mathbf{p}_{\gamma_2}\}, \mu_R, \lambda)|^2}{\hat{s}^2} \times \left(\sum_{m=1}^{\infty} \mathcal{O}_{mj}^e(\{\mathbf{p}_i\}) w_{H+m\text{-jet}} \right) \\
& \times x_a f_a(x_a, Q_a) \cdot x_b f_b(x_b, Q_b) \cdot (2\pi)^4 \delta^2(\sum_{k=1}^n \mathbf{p}_{k\perp} + \mathbf{p}_{\gamma_1\perp} + \mathbf{p}_{\gamma_2\perp}) \mathcal{O}_{2j}(\{\mathbf{p}_i\}).
\end{aligned}$$

Calculates the leading and the first part of the sub-leading corrections.
The remaining Hjj and Hjjj σ is added with fixed order events.

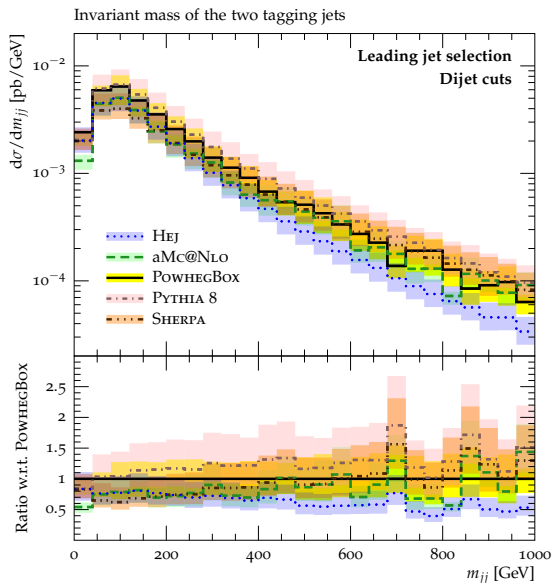
Les Houches Comparison of HJJ Predictions



Good agreement of inclusive Hjj -cross section and differential distributions (e.g. rapidity of the Higgs boson).

Variations within the uncertainty quoted for each calculation.

Les Houches Comparison of HJJ Predictions

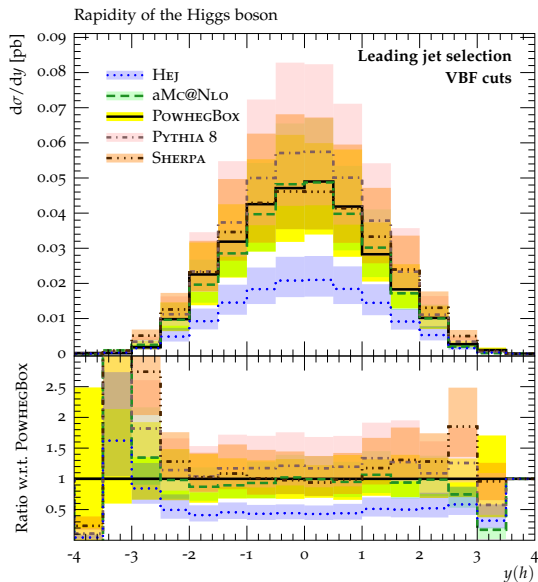


Differences arising at large invariant mass between the hard jets.
(as expected)

Vector-Boson-Fusion cuts select region of large m_{jj} .

(We will revisit large m_{jj} in W+Dijets).

Les Houches Comparison of HJJ Predictions



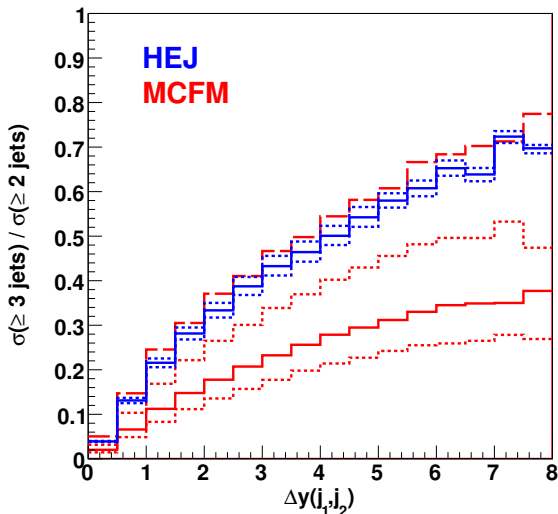
The difference in the distribution of m_{jj} (and Δy_{12}) induce a difference in the cross section after VBF-cuts.

The difference in behaviour between shower-approaches and HEJ appear at large rapidities and large m_{jj} - where HEJ resums virtual corrections that are not treated systematically in any of the other approaches.

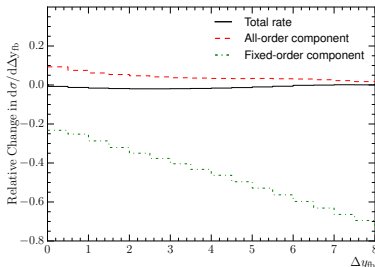
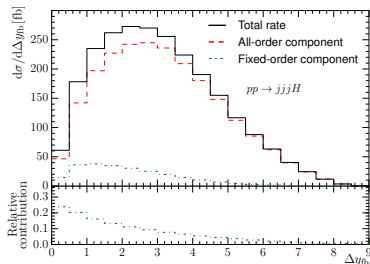
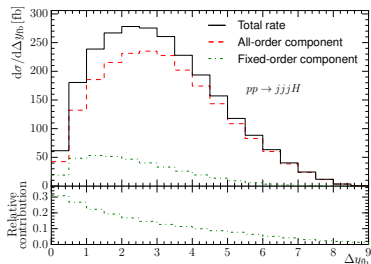
A Measure of the Impact of Higher Order Corrections

A measure of the significance of higher order perturbative corrections:
Require e.g. a Higgs boson and two jets at born level.
Calculate NLO. How frequently do we find 3 jets?
 $\Delta y \approx \ln \hat{s} / p_{\perp}^2$.

H+2 jets: $\sqrt{s}=14$ TeV, $p_{\perp}^{\text{jet}} > 40$ GeV

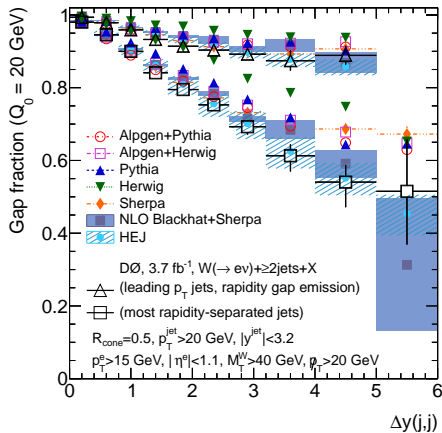


Stability of predictions assessed by including sub-leading logs

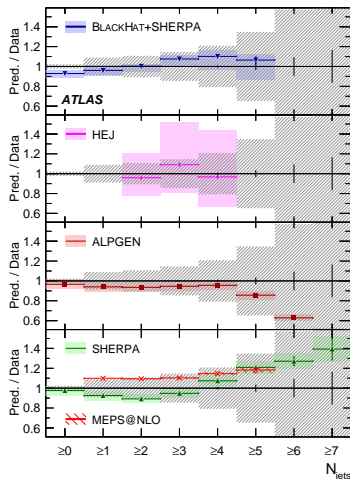
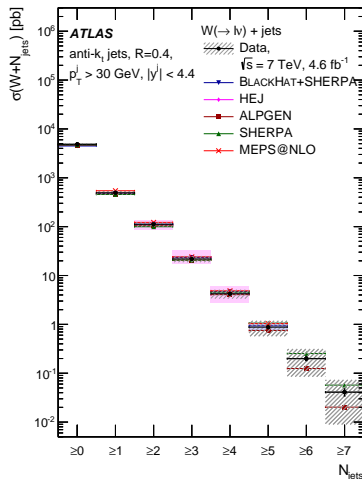


NLL corrections included dramatically reduce the contribution from fixed-order matching. Only small change in the differential distributions.

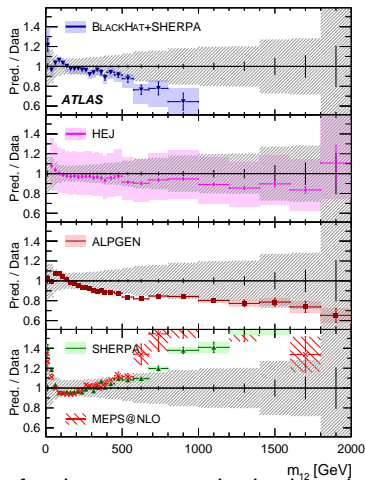
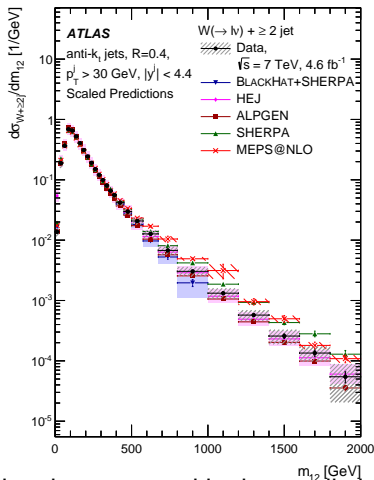
Stability!



Gap fraction measured at D0 (arXiv:1302.6508)



Good agreement between all predictions and data - on inclusive quantities.



There is a large spread in the predictions for the spectrum in the invariant mass between the two hardest jets. Here, the terms systematically dealt with in HEJ are important, and HEJ gives a good description.

Note: hjj interesting for $m_{jj} > 400 - 600\text{GeV}$.