Perturbative corrections to H+Dijets at High Energies

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Overview of Talk

Multi-Jet Predictions for the Gluon-Fusion component of H+(di)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+jets in the VBF region

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

$$\sigma_{H+2j} = \sum_{f_a,f_b} \sum_{n=2}^{\infty} \left(\int \frac{\mathrm{d}^2\mathbf{p}_{1\perp}}{(2\pi)^3} \int_{y_{\min}}^{y_{\max}} \frac{\mathrm{d}y_1}{2} \right) \left(\int \frac{\mathrm{d}^2\mathbf{p}_{n\perp}}{(2\pi)^3} \int_{y_{n-1}}^{y_{\max}} \frac{\mathrm{d}y_n}{2} \right)$$
$$\prod_{i=2}^{n-1} \left(\int \frac{\mathrm{d}^2\mathbf{p}_{i\perp}}{(2\pi)^3} \int_{y_{i-1}}^{y_{\max}} \frac{\mathrm{d}y_i}{2} \right) \int \frac{\mathrm{d}^3 p_{\gamma_1}}{(2\pi)^3\ 2E_{\gamma_1}} \int \frac{\mathrm{d}^3 p_{\gamma_2}}{(2\pi)^3\ 2E_{\gamma_2}}$$
$$\frac{\overline{|\mathcal{M}^{\mathrm{reg}}(\{p_i, p_{\gamma_1}, p_{\gamma_2}\})|}^2}{\hat{s}^2}$$
$$\times\ x_a f_{f_a}(x_a, Q_a)\ \cdot x_b f_{f_b}(x_b, Q_b) \cdot (2\pi)^4\ \delta^2\Big(\sum_{k=1}^{n} \mathbf{p}_{k\perp} + p_{\gamma_1\perp} + p_{\gamma_2\perp}\Big) \mathcal{O}_{2j}(\{p_i\}).$$

The **only bit** which remains is to calculate virtual corrections, real emissions, subtraction terms etc. **to any order in** α_s to form $|\mathcal{M}^{\mathrm{reg}}|^2$.
Unfortunately, we cannot present a method for doing so[1].
But, **High Energy Jets (HEJ)** provides *approximations* to all these terms, and the relevant phase space integrals can be performed.

[1] the margin is too small

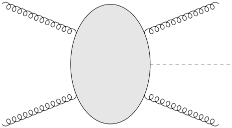
Ideas from before dawn of QCD…

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

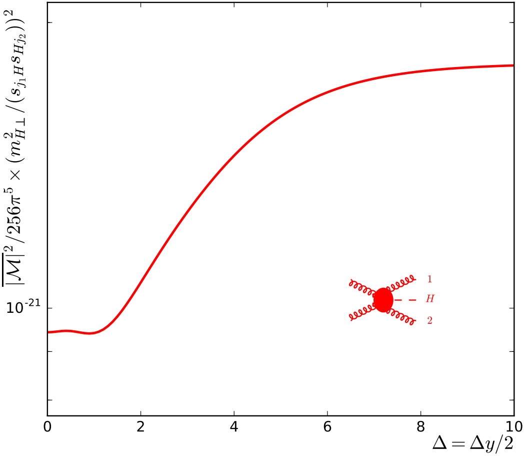
$$\mathcal{M} \sim \; s_{1H}^{\alpha_1(t_1)} \; s_{2H}^{\alpha_2(t_2)} \, \gamma\left(t_1, t_2, s_{12}/(s_{1H} s_{2H})\right).$$

Q1: How do we make sense of this in QCD?
Q2: Does it even make sense in QCD?

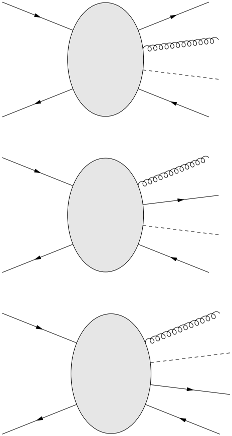
$|\mathcal{M}|^2$ does have the right behaviour

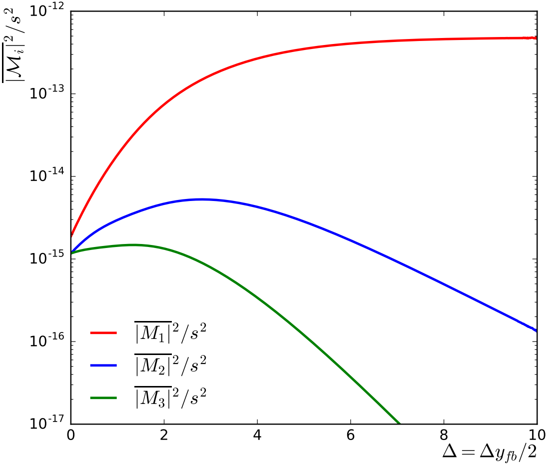


The full tree-level matrix element has the right scaling.



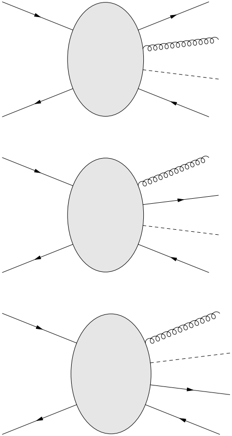
$|\mathcal{M}|^2$ does have the right behaviour

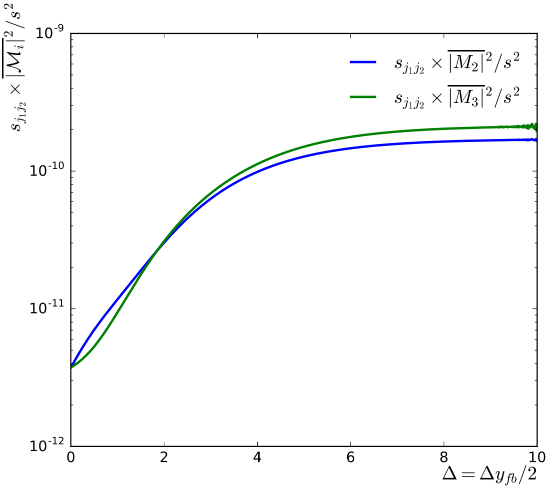




The "*t*-channel gluon-exchange" dominates

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





A t-channel quark exchange is suppressed by a power of s_{j1j_2}

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

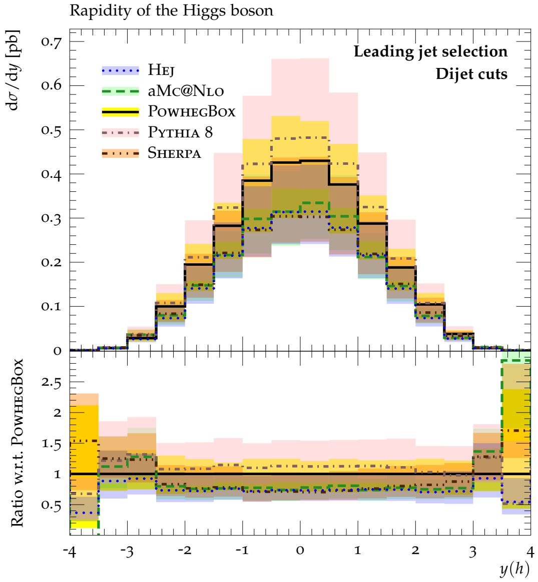
First set of sub-leading corrections included (1706.01002)

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

$$
\begin{aligned}
\sigma_{H+2j}^{\text{resum, match}} =& \sum_{f_a,f_b} \sum_{n=2}^{\infty} \left(\int \frac{\mathrm{d}^2\mathbf{p}_{1\perp}}{(2\pi)^3} \int_{y_{\min}}^{y_{\max}} \frac{\mathrm{d}y_1}{2} \right) \left(\int \frac{\mathrm{d}^2\mathbf{p}_{n\perp}}{(2\pi)^3} \int_{y_{n-1}}^{y_{\max}} \frac{\mathrm{d}y_n}{2} \right) \\
& \prod_{i=2}^{n-1} \left(\int \frac{\mathrm{d}^2\mathbf{p}_{i\perp}}{(2\pi)^3} \int_{y_{i-1}}^{y_{\max}} \frac{\mathrm{d}y_i}{2} \right) \int \frac{\mathrm{d}^3 p_{\gamma_1}}{(2\pi)^3\ 2E_{\gamma_1}} \int \frac{\mathrm{d}^3 p_{\gamma_2}}{(2\pi)^3\ 2E_{\gamma_2}} \\
& \frac{\overline{\left|\mathcal{M}_{\text{HEJ}}^{\text{reg}}(\{p_i, p_{\gamma_1}, p_{\gamma_2}\}, \mu_R, \lambda)\right|}^2}{\hat{s}^2} \times \left(\sum_{m=1}^{\infty} \mathcal{O}_{mj}^{e}(\{p_i\})\ w_{H+m-\text{jet}} \right) \\
& \times\ x_a f_{f_a}(x_a, Q_a) \cdot x_b f_{f_b}(x_b, Q_b) \cdot (2\pi)^4\ \delta^2\!\left(\sum_{k=1}^{n} \mathbf{p}_{k\perp} + p_{\gamma_1\perp} + p_{\gamma_2\perp} \right) \mathcal{O}_{2j}(\{p_i\}).
\end{aligned}
$$

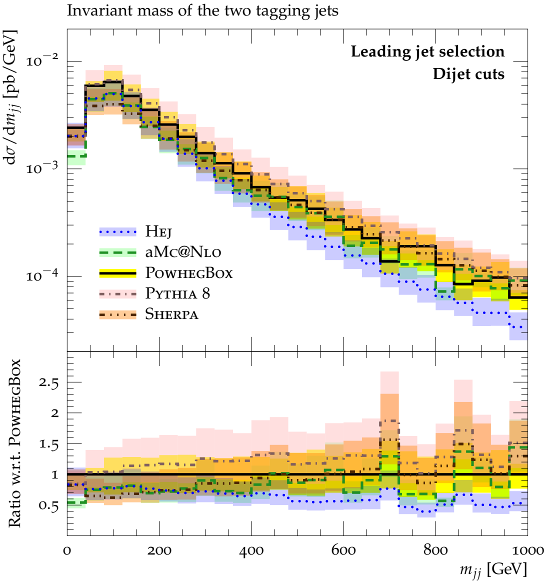
Calculates the leading and the first part of the sub-leading corrections. The remaining Hjj and Hjjj σ is added with fixed order events.

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

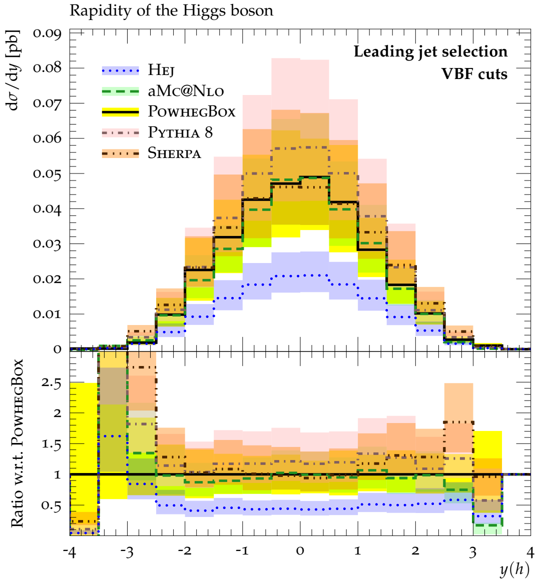


Differences arising at large invariant mass between the hard jets.
(as expected)

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

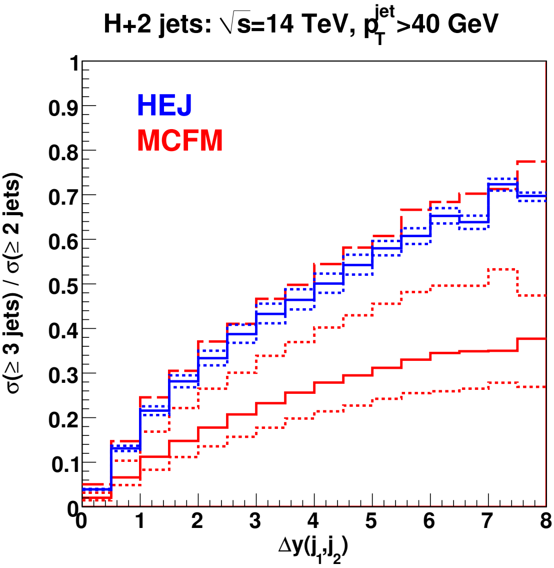


The difference in the distribution of m_{jj} (and Δy_{12}) induce a difference in the cross section after VBF-cuts.

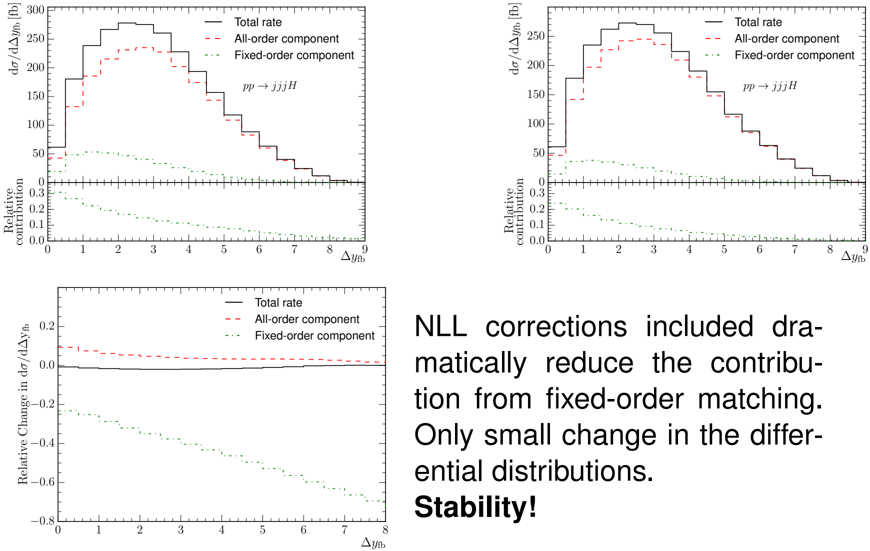
The difference in behaviour between shower-approaches and HEJ appear at large rapidities and large m_{jj} - where HEJ resums virtual corrections that are not treated systematically in any of the other approaches.

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?
$\Delta y \approx \ln \hat{s}/p_\perp^2$.



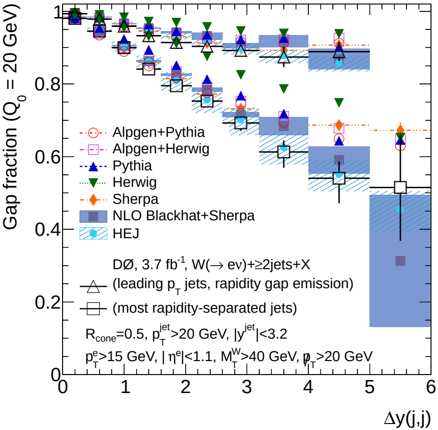
Stability of predictions assessed by including sub-leading logs



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

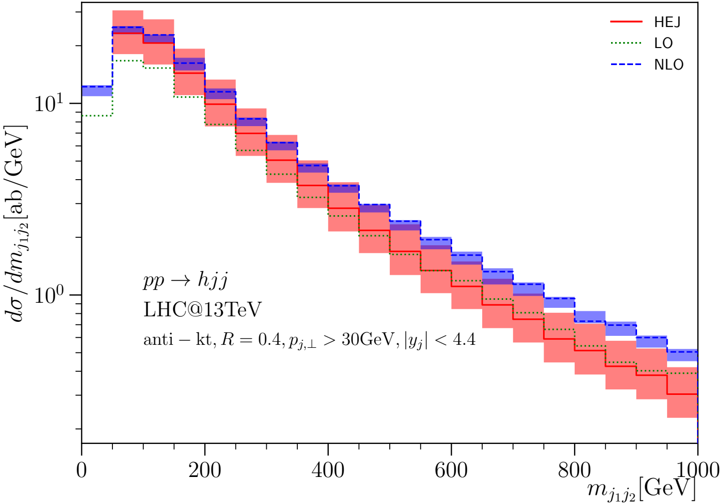
W+DiJets

Unique predictions made for W+jets, Z+jets, Dijets; these can be checked.



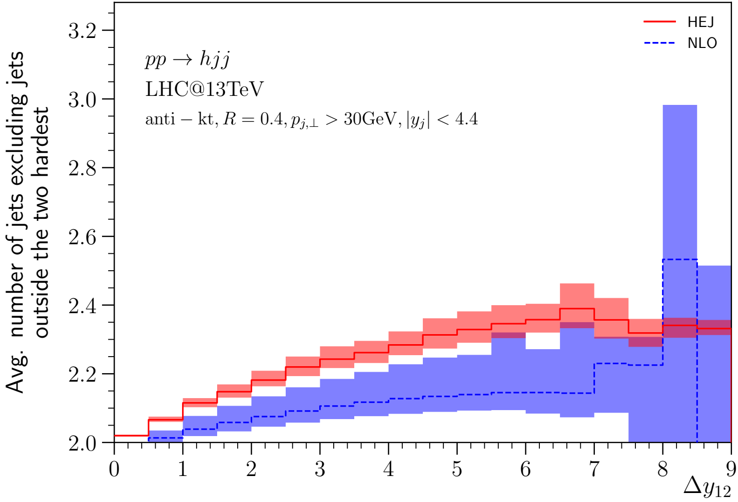
Gap fraction measured at D0 (arXiv:1302.6508)

H+DiJets



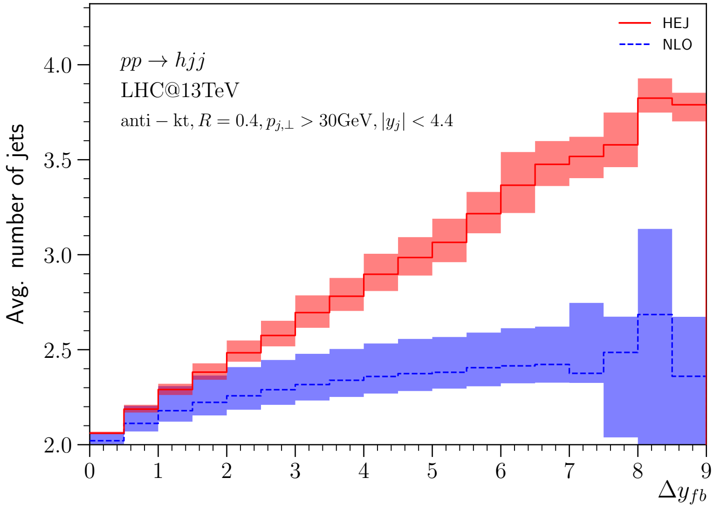
Steeper fall-off in $m_{j_1j_2}$ than NLO: cleaner VBF sample. arXiv:1706.01002

H+Dijets



Can we distriminate better by counting nuber of jets: arXiv:1706.01002

H+Dijets



Counting total hard number of jets vs. y_{fb} in the event is better discriminant between GF and VBF. Central jet veto? arXiv:1706.01002