High Energy Jets

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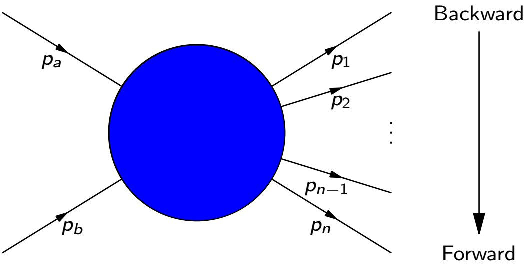
The High Energy Limit

Multi-Regge Kinematics



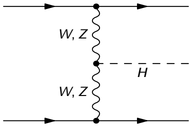
$$y_1 < y_2 < \cdots < y_{n-1} < y_n$$

High energy limit:

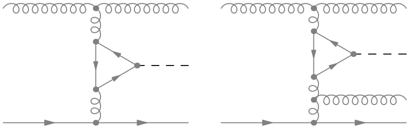
- All rapidity gaps large, all transverse momenta similar
- All outgoing invariant masses $\gg$ all $t-$channel momenta

Example: Higgs Boson Production With Jets

Weak Boson Fusion



Gluon Fusion



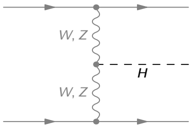
- Known at NNLO, $\sim 5\%$ correction

  [Cacciari, Dreyer, Karlberg, Salam, Zanderighi 2015; Cruz-Martinez, Gehrmann, Glover, Huss 2018]
- Probes couplings to W, Z bosons
- Widely separated jets, WBF cuts:

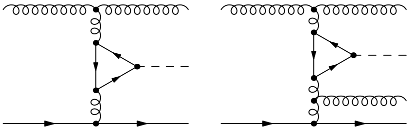
$$y_{j_1 j_2} > 2.8, \quad m_{j_1 j_2} > 400\,\text{GeV}$$

Example: Higgs Boson Production With Jets

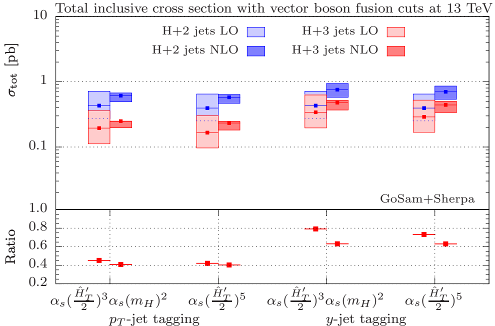
Weak Boson Fusion



Gluon Fusion

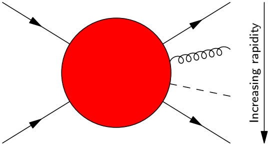


- Known at LO for $H + 2, 3$ jets, $m_t \to \infty$ is off by $\sim 2\%$ [Greiner, Höche, Luisoni, Schönherr, Winter 2016]
- $H + 2, 3$ jets known at NLO for $m_t \to \infty$. [Cullen et al. 2013]



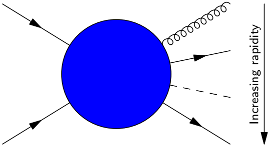
The High Energy Limit

FKL configurations [Fadin, Kuraev, Lipatov 1975–1977]:



- Maximum possible t-channel gluon exchanges
- Dominant contribution in high-energy limit

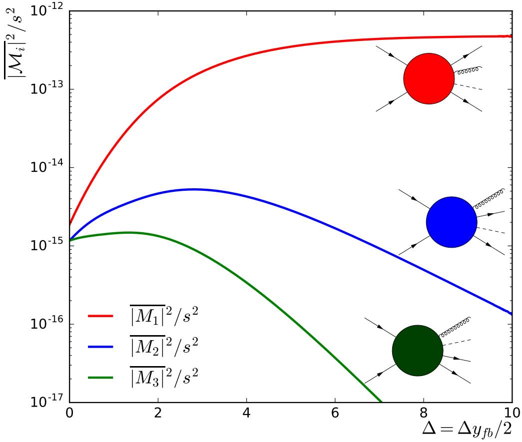
Non-FKL configurations:



- Less possible t-channel gluon exchanges
- Exponentially suppressed at large rapidities

The High Energy Limit

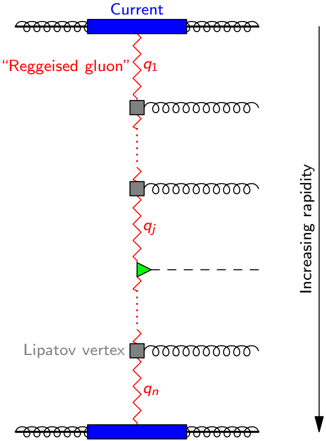
Scaling Behaviour



[Andersen, Hapola, Maier, Smillie 2017]

High Energy Jets (HEJ) resummation

FKL Matrix element [Andersen, Del Duca, Smillie, White 2008–2010]

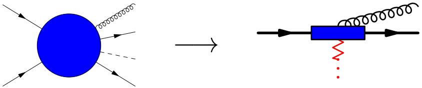


$$
\begin{aligned}
&\overline{\left|\mathcal{M}^{\text{HEJ}}_{f_1 f_2 \to f_1 \cdot g \cdot H \cdot g \cdot f_2}\right|}^2 = \\
&\frac{1}{4(N_C^2-1)} \left\| j_\mu V_H^{\mu\nu} j_\nu \right\|^2 \cdot \left(\frac{1}{t_j t_{j+1}}\right) \\
&\cdot \left(g_s^2 K_{f_1}(p_1^-, p_a^-) \frac{1}{t_1}\right) \\
&\cdot \left(g_s^2 K_{f_2}(p_n^+, p_b^+) \frac{1}{t_n}\right) \\
&\cdot \prod_{\substack{1\le k<j \\ j+1\le k<n}} \frac{-g_s^2 C_A}{t_k t_{k+1}} V_L(q_k, q_{k+1})^2 \\
&\cdot \prod_{i=1}^{n-1} \exp\left[\omega^0(q_{i\perp})(y_{i+1}-y_i)\right].
\end{aligned}
$$

High Energy Jets (HEJ) resummation

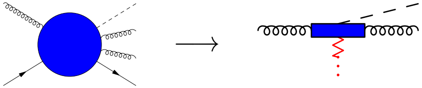
Unordered Emissions

Forward or backward gluon emission:



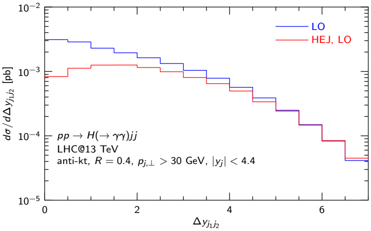
[Andersen, Hapola, Maier, Smillie 2017]

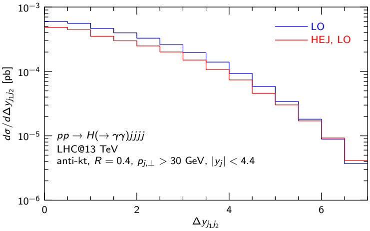
Forward or backward Higgs boson emission:



High Energy Jets (HEJ) approximation

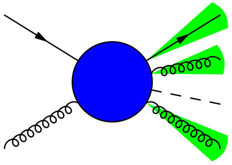
Comparison to fixed order

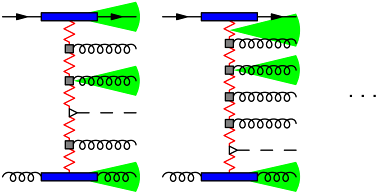




High Energy Jets (HEJ) resummation

Matching to leading order





Fixed-order FKL event
MadGraph, Sherpa, ...
$\sim |\mathcal{M}_{\text{LO}}|^2$

Resummation events
Keep Higgs + jet rapidities, shift jet $p_\perp$
$\sim |\mathcal{M}_{\text{HEJ}}|^2$

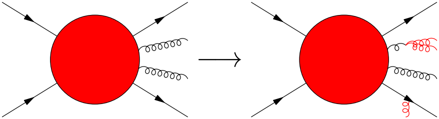
Final resummation event weight $\sim \frac{|\mathcal{M}_{\text{LO}}|^2 |\mathcal{M}_{\text{HEJ}}|^2}{|\mathcal{M}_{\text{HEJ, LO}}|^2}$

[Andersen, Hapola, Heil, Maier, Smillie 2018]

High Energy Jets (HEJ) resummation

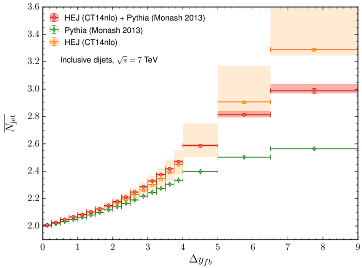
Matching to parton shower [Andersen, Brooks, Lönnblad 2018]

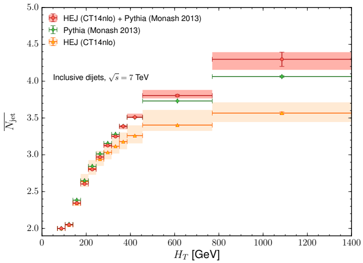
Add extra soft and collinear radiation



using *subtracted splitting function*

$$P^{\text{subtracted}} = P^{\text{PYTHIA}} - \frac{1}{2}\frac{1}{16\pi^2}\frac{\mathcal{M}_{n+1}^{\text{HEJ}}}{\mathcal{M}_{n}^{\text{HEJ}}}$$

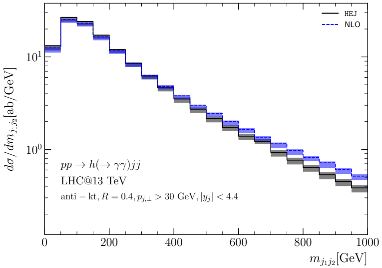


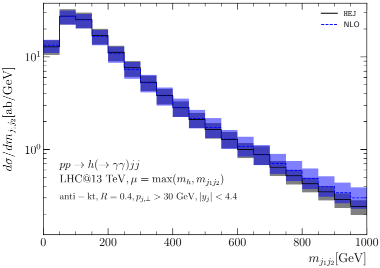


Results for Higgs+jets

[Andersen, Hapola, Heil, Maier, Smillie 2017–2018]

Invariant mass distribution

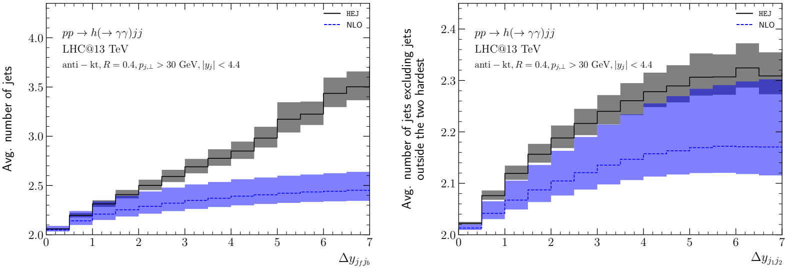




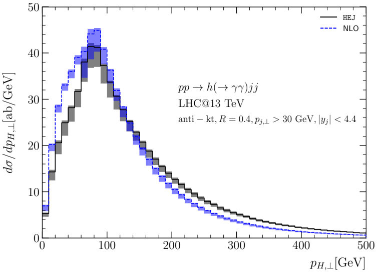
$\mu = H_T/2$ $\mu = \max(m_{j_1j_2}, m_h)$

σ_{HEJ} rescaled to σ_{NLO}

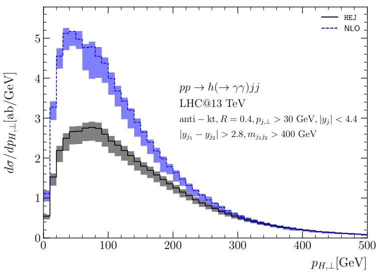
Jet multiplicity



Higgs transverse momentum distribution



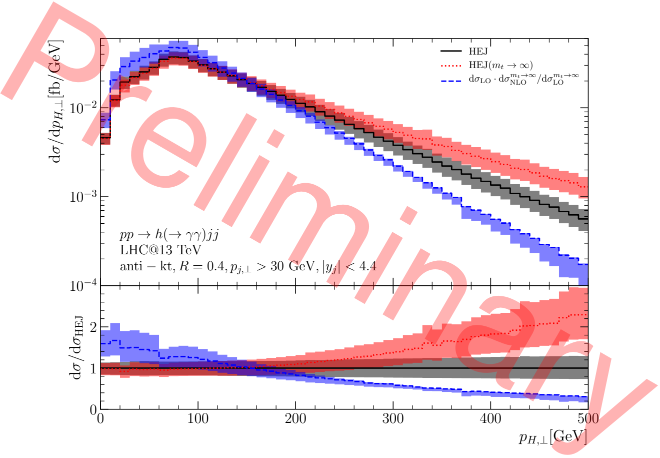
inclusive



WBF cuts

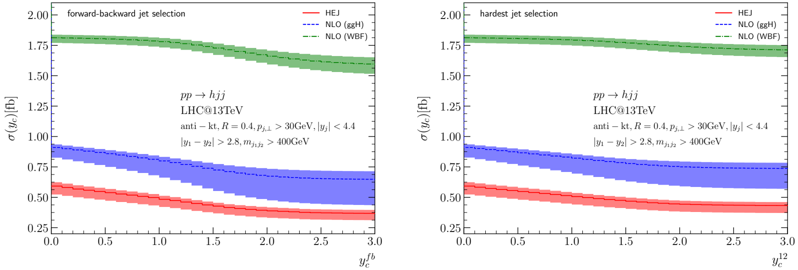
Higgs transverse momentum distribution

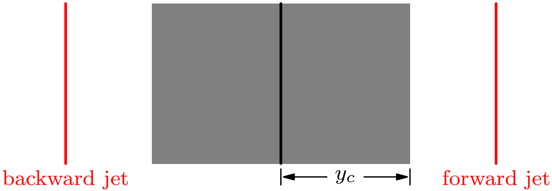
Quark mass effects



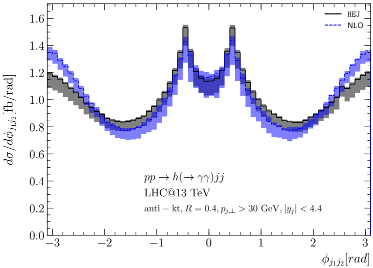
Jet veto efficiency

[Rainwater, Szalapski, Zeppenfeld 1996]





Angular separation



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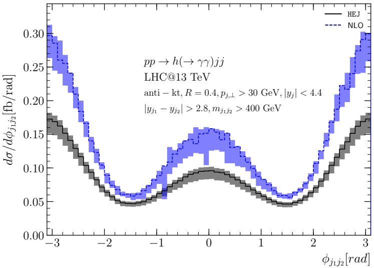

WBF cuts

Angular correlation $\Rightarrow$ CP properties of ggH coupling

Conclusion

- High Energy Jets (HEJ) provides all-order resummation for large rapidity spans
- Relevant for Higgs + jets in gluon fusion:
  Predictions differ significantly from NLO
- Other processes: W, Z/γ + jets

  [Andersen, Hapola, Smillie 2012; Andersen, Medley, Smillie 2016]

Work in progress:

- Quark mass effects in Higgs + jets
- Fixed-order matching at and beyond LO
- Subleading corrections
- Combination with parton showers
- Further processes

Backup

Comparison for W + jets

[arXiv:1703.04362]