High Energy Jets

Status report

Marian Heil

IPPP, Durham

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Outline

1. Introduction
   - Motivation
   - Multi Regge limit
   - HEJ formalism
2. Results
   - Higgs + jets
   - W + jets
3. Summery & Outlook

Motivation

- parton shower: soft, collinear resummation & merging to ME

BUT large s/t: $\log(s/t) \sim \Delta y$ (MRK limit)

$\Rightarrow$ large logs, perturbative expansion breaks down

$\Rightarrow$ merging of high multiplicity guided by different log

$\Rightarrow$ HEJ: **resummation, matching & merging**

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currently implemented in `HEJ`:

- QCD ME with first order α_{EW} correction

$\Rightarrow$ all single gauge bosons production (γ, Z, W or h)

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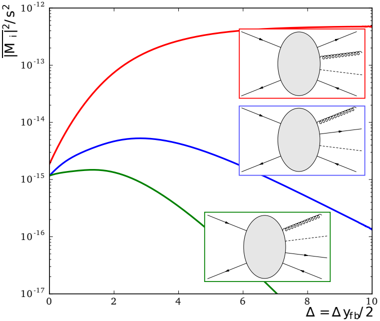
Dominant Contributions

Multi Regge theory

Limit for large t_1, t_2 with fixed s_{1H},s_{2H} and s_{12}

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

with α_i spin of exchange particle.



$\Rightarrow$ Gluon exchange dominant $\Rightarrow |\mathcal{M}|^2 \propto s_{j_1 j_2}^2 s_{j_2 H}^2 s_{j_3 H}^2$ (rapidity ordered, Fadin-Kuraev-Lipatov configuration)

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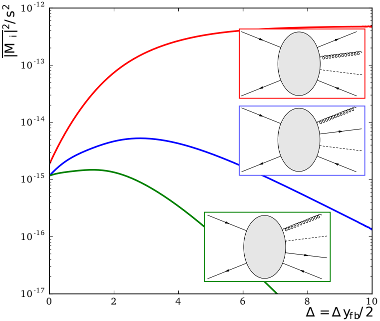

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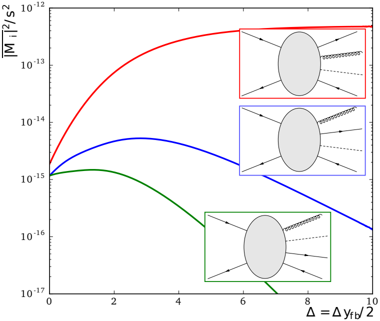

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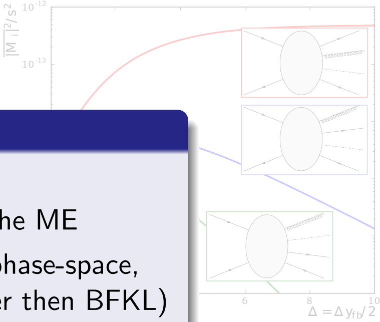
$\mathcal{M} \sim$

with α_i sp



The HEJ approximation is

- exact for large $\log(s/t)$
- systematic expansion of the ME
- *fast enough* to keep full phase-space, for any multiplicity (better then BFKL)

$\Rightarrow$ matchable to fixed-order ME

$\Rightarrow$ Gluon e

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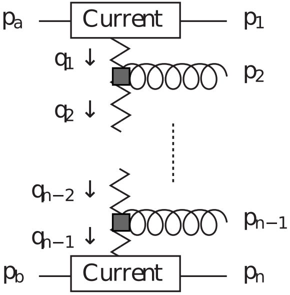
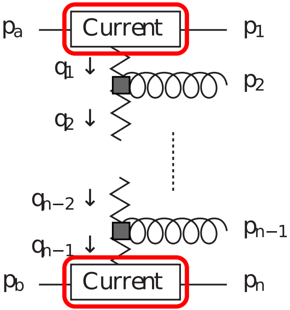
HEJ Matrix element



$$= \frac{1}{4\,(N_C^2-1)} \left\| S_{f_a f_b \to f_1 f_n} \right\|^2 \cdot \left(g_s^2\; K_{f_1}\; \frac{1}{t_1} \right) \cdot \left(g_s^2\; K_{f_n}\; \frac{1}{t_{n-1}} \right) \cdot \prod_{i=1}^{n-2} \left(\frac{-g_s^2 C_A}{t_i t_{i+1}}\; V^\mu(q_i, q_{i+1}) V_\mu(q_i, q_{i+1}) \right) \cdot \prod_{j=1}^{n-1} \exp\left[\omega^0(q_{j\perp})(y_{j+1} - y_j) \right]$$

Other processes: different $\left\| S_{f_a f_b \to f_1 f_n} \right\|^2$, e.g. additional h or unordered emission.



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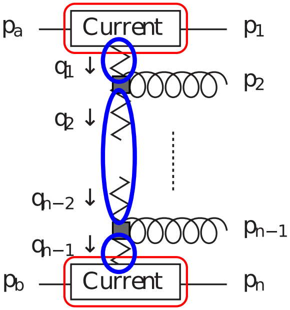

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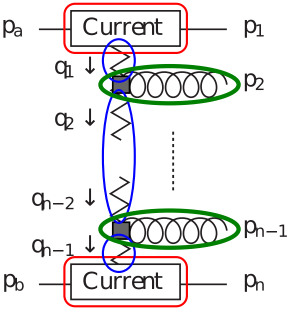

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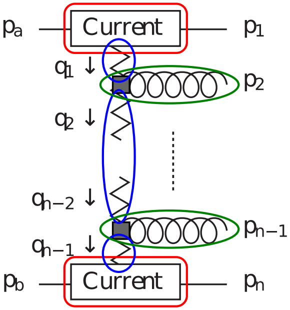

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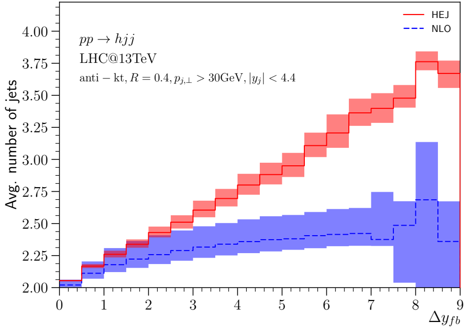
Average number of jets



- NLO leveling around $\Delta y_{fb} \sim 5$ and $\langle n_j \rangle \sim 2.4$

i.e. $h + 3j$ contribution comparable to $h + 2j$

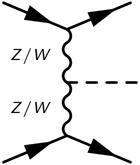
$\Rightarrow$ high multiplicities relevant, NLO insufficient

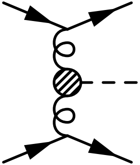
$\Rightarrow$ HEJ $\langle n_j \rangle \sim 3.7$ at $\Delta y_{fb} = 9$

$\Rightarrow$ large effect for any tagging on additional jet

- small quantum interference between WBF and gF for $h + jj$

$\Rightarrow$ Distinction between WBF and gF





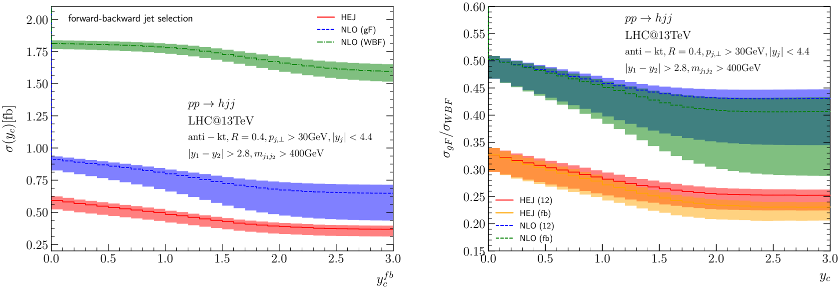
coupling:	h to Z/W (signal)	top-loop (background)
add. emission:	on external quark	on t-channel gluon

Here everything shown in HEFT, but HEJ can use full m_t dependence

results from arxiv:1803.07977

Central jet veto

Veto event if jet with $\left|y_j - y_0\right| \leq y_c$, $y_0 = \frac{y_{t_1}+y_{t_2}}{2}$
tagging jets t_i: forward-backward (fb) or hardest (12)



- $20 - 30\%$ reduction of gF contribution
- only weak dependence on tagging

BUT large NLO scale dependence

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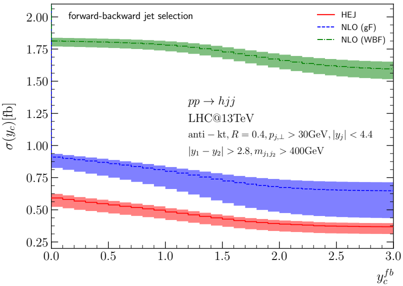

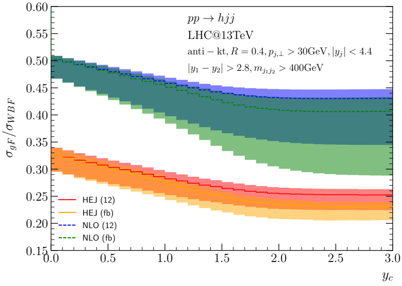

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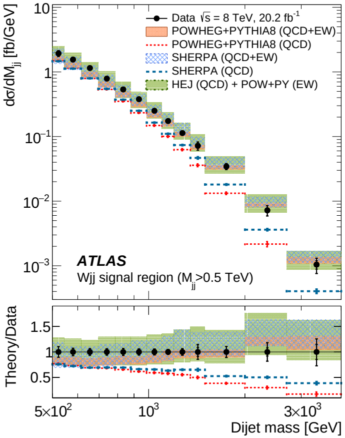
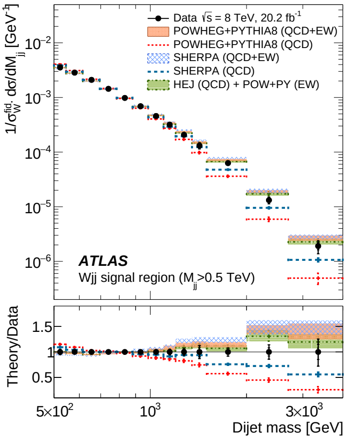
Wjj measurement (arXiv:1703.04362)





- HEJ scale uncertainty is systematic

⇒ significant improvement with (future) HEJ+NLO merging

Summery & Outlook

- NLO matching
- reversed HEJ

→ modfied matching, quicker, more flexible (`.lhe` file input)

→ released soon

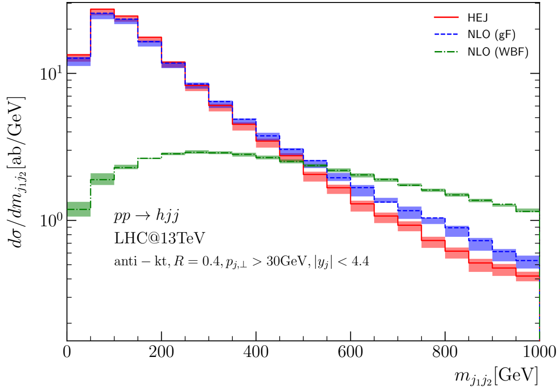
- HEJ & parton shower merging

→ CKKW-L like merging (two all order resummations)

→ released for PYTHIA8

- Include (more) sub-leading corrections to the HEJ ME

Thanks for your attention!

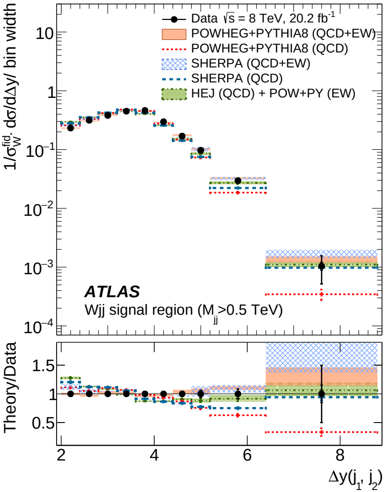


- gF: smaller values for $m_{j_1 j_2}$ (dominated by initial gluon)

$\Rightarrow$ *standard* cut: $m_{j_1 j_2} > 400$ GeV

$\Rightarrow$ after cuts: region where HEJ resummation becomes important

Backup slide: Wjj measurement Δy_{jj}



from arXiv:1703.04362

Backup slide: rHEJ matching

$$
\begin{aligned}
\sigma_{2j}^{\mathrm{resum,match}} = & \sum_{f_1,f_2} \sum_m \prod_{j=1}^m \left(\int_{p_{j\perp}^B=0}^{p_{j\perp}^B=\infty} \frac{\mathrm{d}^2\mathbf{p}_{j\perp}^B}{(2\pi)^3} \int \frac{\mathrm{d}y_j^B}{2} \right) (2\pi)^4\ \delta^{(2)}\left(\sum_{k=1}^m \mathbf{p}_{k\perp}^B \right) \\
& \times\ x_a^B\ f_a(x_a^B, Q_a^B)\ x_b^B\ f_b(x_b^B, Q_b^B)\ \frac{\overline{|\mathcal{M}^B|}^2}{(\hat{s}^B)^2} \\
& \times\ \overline{|\mathcal{M}_{\mathrm{HEJ}}^{tree}|}^{-2}\ \times (2\pi)^{-4+3m}\ 2^m \\
& \times\ \sum_{n=2}^\infty \int_{p_{1\perp}=.9p_{j,\perp}}^{p_{1\perp}=\infty} \frac{\mathrm{d}^2\mathbf{p}_{1\perp}}{(2\pi)^3} \int_{p_{n\perp}=.9p_{j,\perp}}^{p_{n\perp}=\infty} \frac{\mathrm{d}^2\mathbf{p}_{n\perp}}{(2\pi)^3} \prod_{i=2}^{n-1} \int_{p_{i\perp}=\lambda}^{p_{i\perp}=\infty} \frac{\mathrm{d}^2\mathbf{p}_{i\perp}}{(2\pi)^3}\ (2\pi)^4\ \delta^{(2)}\left(\sum_{k=1}^n \mathbf{p}_{k\perp} \right) \\
& \times\ \mathbf{T}_y \prod_{i=1}^n \left(\int \frac{\mathrm{d}y_i}{2} \right)\ \mathcal{O}_{mj}^e\ \left(\prod_{l=1}^{m-1} \delta^{(2)}(\mathbf{p}_{\mathcal{J}_l\perp}^B - \mathbf{j}_{l\perp}) \right)\ \left(\prod_{l=1}^m \delta(y_{\mathcal{J}_l}^B - y_{\mathcal{J}_l}) \right) \\
& \times\ x_a f_{a,f_1}(x_a, Q_a)\ x_b f_{b,f_2}(x_b, Q_b)\ \frac{\overline{|\mathcal{M}_{\mathrm{HEJ}}^{f_1 f_2 \to f_1 g \cdots g f_2}(\{p_i\})|}^2}{\hat{s}^2}\ \mathcal{O}_{2j}(\{p_i\}) \\
& \times\ \frac{(\hat{s}^B)^2}{x_a^B\ f_{a,f_1}(x_a^B, Q_a^B)\ x_b^B\ f_{b,f_2}(x_b^B, Q_b^B)}.
\end{aligned}
$$