HEJ
Status Update

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   - FKL Contributions
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   - Finite Quark Mass Effects
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   - HEJ2.2(?): Improved Virtual Corrections
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An Introduction to HEJ

High Energy Jets

- A Partonic Monte Carlo Generator which aims to describe **high multiplicity events**.
- Provides perturbative predictions at LL accuracy ($\log(\hat{s}/\hat{t})$) with **resummation of hard corrections to all orders**.

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Multi Regge Kinematic (MRK) Limit

The MRK Limit:

large $\hat{s}$; small P_T ; **strongly ordered jet rapidities** $(\mathbf{y_j})$:

$$y_1 \ll y_2 \ll ... \ll y_i \ll .. \ll y_{n-1} \ll y_n$$

Some nice relations:

$$\begin{aligned} \hat{s}^2 &\sim -\hat{u}^2 \rightarrow large \\ \hat{t}_i &\sim -p_{\perp j_i}^2 \sim -p_\perp^2 \\ \log\left(\frac{\hat{s}_{ij}}{\hat{t}_{ij}}\right) &\approx |y_j - y_i| \end{aligned}$$

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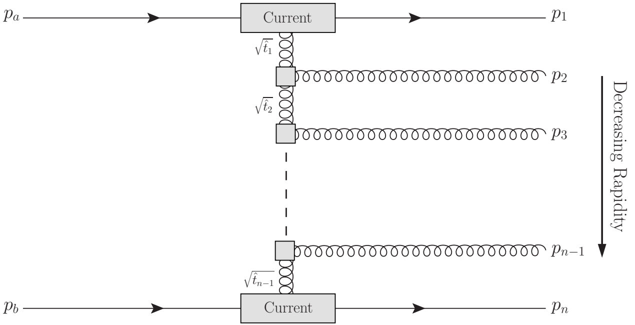
FKL Contributions

FKL configurations are the leading contributions in the MRK limit.

- $(2 \to n)$ amplitudes with strong rapidity ordering in final state
- **Internal jets** (by rapidity) required to be **gluons**



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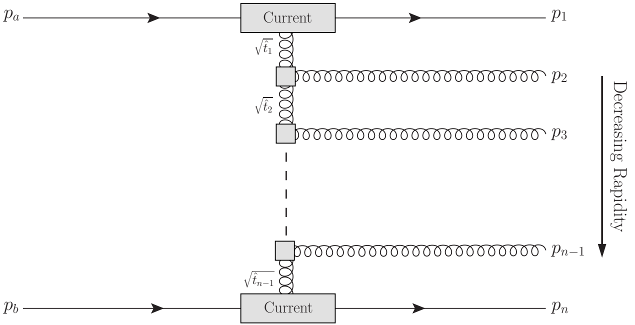

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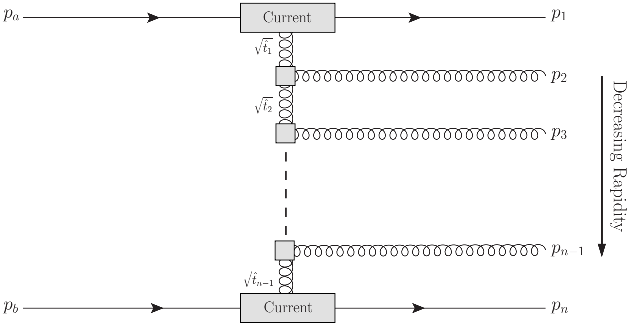

Resum via effective **Lipatov Vertices** and the **Lipatov Ansatz**.

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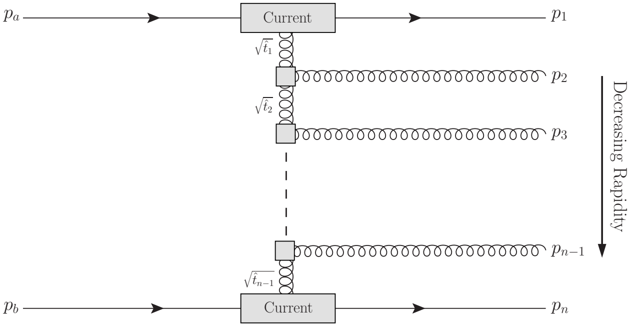
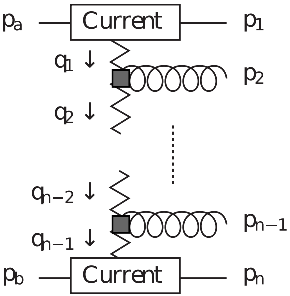


Resum via effective **Lipatov Vertices** and the **Lipatov Ansatz**.

HEJ Matrix element



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

Processes $\Leftrightarrow$ currents, e.g. $\mathcal{S}_{f_1 f_2 \to f_1 H f_2} = j_\mu(p_1,p_a)V_H^{\mu\nu}(q_j,q_{j+1})j_\nu(p_b,p_n)$.

arxiv:1706.01002

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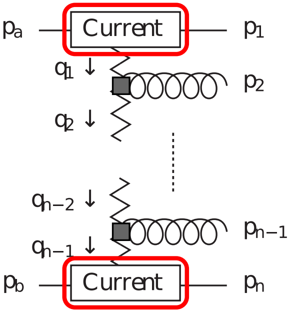

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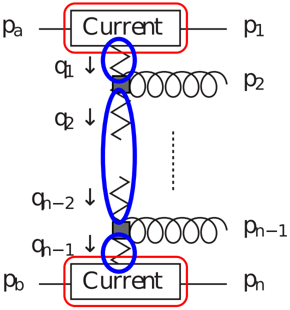

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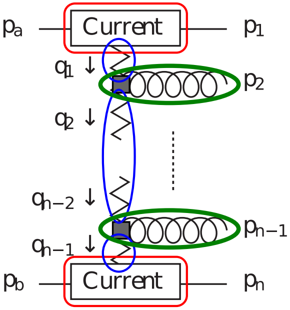

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Processes ⇔ currents, e.g. $\mathcal{S}_{f_1 f_2 \to f_1 H f_2} = j_\mu(p_1,p_a)V_H^{\mu\nu}(q_j,q_{j+1})j_\nu(p_b,p_n)$.

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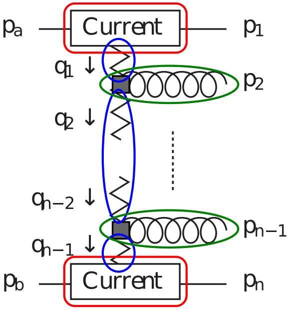

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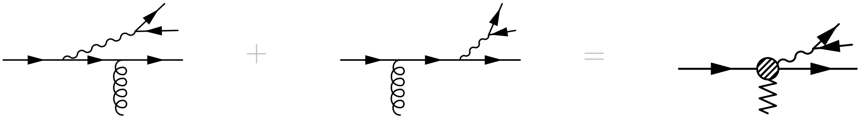

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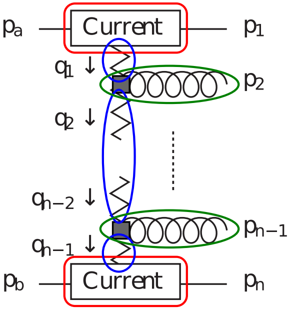

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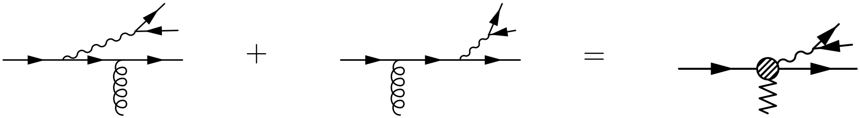

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HEJ2:

A complete* rewrite

What's new?

- Matching changed entirely
  - Start from Fixed Order input (Les Houches Format)
  - Add resummation particles for resummation event.
- Code organisation improvements (classes, namespaces.. etc)
- `HEJFOG`
- Usuable, referenced, consistent, updated documentation
  - Doxygen
  - Developer Manual
  - Sensible code comments
- Repository moved to Gitlab (Durham).
- Comprehensive Continuous Integration (feature coverage).

*some matrix element code is untouched

HEJ2:

Public Release

- HEJ2 Publically released!
  - https://hej.web.cern.ch/HEJ/
  - arxiv:1902.08430
- We also have a Docker Image!
  - https://hub.docker.com/r/hejdock/hepenv

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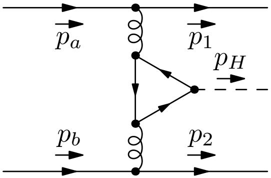
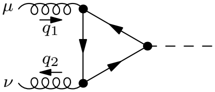
Finite quark mass effects

Simplest case: $qQ \to qHQ$

Higgs coupling factorises:



$\Rightarrow V_H^{\mu\nu}(q_1, q_2) =$



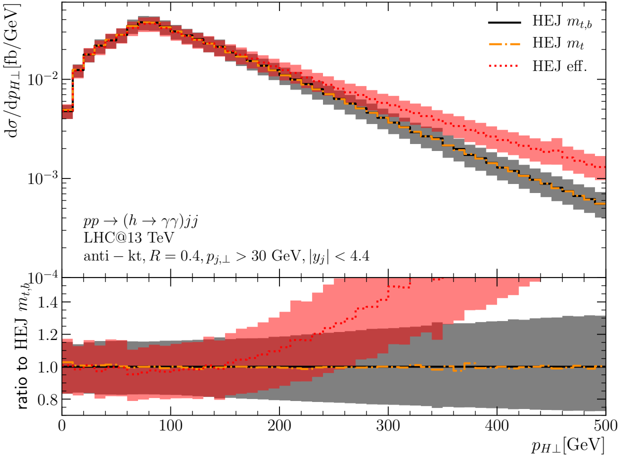
$$V_H^{\mu\nu}(q_i, q_{i+1}) = \frac{\alpha_s m^2}{\pi v}\left[g^{\mu\nu} T_1(q_i, q_{i+1}) - q_{i+1}^\mu q_i^\nu T_2(q_i, q_{i+1})\right]$$

$$\xrightarrow{m\to\infty} \frac{\alpha_s}{3\pi v}\left(g^{\mu\nu} q_i q_{i+1} - q_{i+1}^\mu q_i^\nu\right)$$

with form factors T_1 and T_2.

Higgs $p_\perp$

finite m_b



⇒ finite quark masses $\hat{=} -50\%$ at 350 GeV

⇒ no (visible) effect from finite m_b

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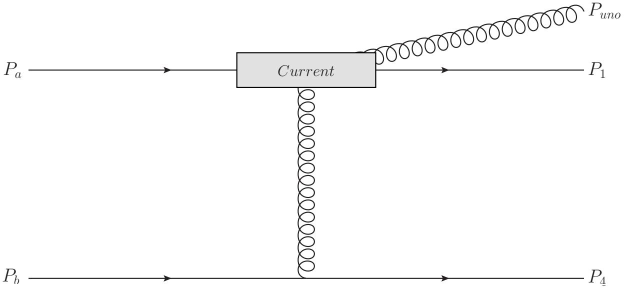
Subleading Processes
Unordered Contributions



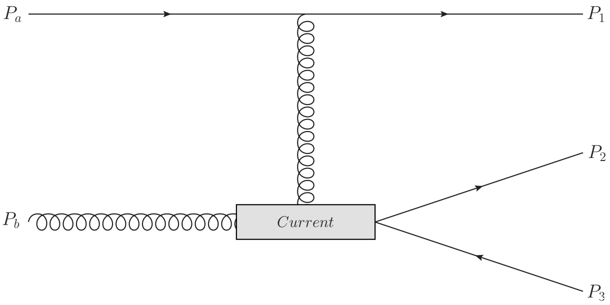
A gluon outside of FKL rapidity ordering is known as an **Unordered emission**.

In HEJ this is modelled as a modified current. Where we now allow that $y_{uno} \sim y_1$ and $y_1 >> y_2$. (QMRK Limit)

$$\mathcal{M}^{\text{uno}}_{qQ\to gqQ} \sim \frac{j^{\mu}_{\text{uno}}(p_a, p_1, p_{uno})j_{\mu}(p_b, p_2)}{\hat{t}}$$

Subleading Processes

Extremal $q\bar{q}$



The **Extremal qq̄** case is an incoming gluon splitting to $q\bar{q}$.

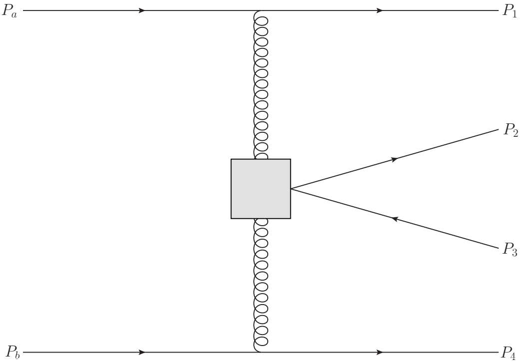
In HEJ use a a modified current (related by crossing symmetry to Uno case) in the scattering.

$$\mathcal{M}^{q\bar{q}}_{qg\to qQQ} \sim \frac{j^{\mu}_{q\bar{q}}(p_b, p_2, p_3) j_{\mu}(p_a, p_1)}{\hat{t}}$$

There are **5 possible diagrams** which contribute.

Subleading Processes

Central $q\bar{q}$



In the case a **Central $\mathbf{q\bar{q}}$** pair is produced, we use an effective vertex which fits the form:

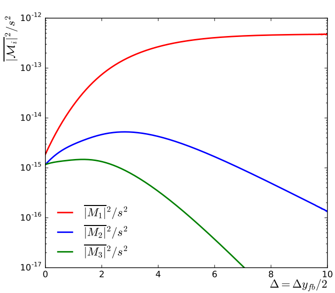
$$\mathcal{M}_{qq \to qQ\overline{Q}q} \sim \frac{\langle 1|\mu|a\rangle \, X^{\mu\nu} \, \langle 4|\nu|b\rangle}{\hat{t}_1 \, \hat{t}_3}$$

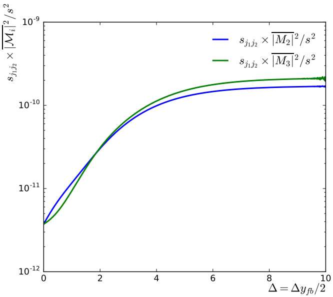
There are **7 possible diagrams** which contribute.

Scaling of the Matrix Elements

Higgs+3j: $qQ \to qgHQ$

Gluon Exchange (FKL) | Quark Exchange (Unordered) | Higgs Outside (Unordered)





In Multi Regge Theory:

$$|\mathcal{M}| \sim (\hat{s}_{j_ij_j})^{spin}$$

Swapping propagator (gluon $\to$ quark) suppresses ME by $(\hat{s}_{j_ij_j})^{1/2}$.

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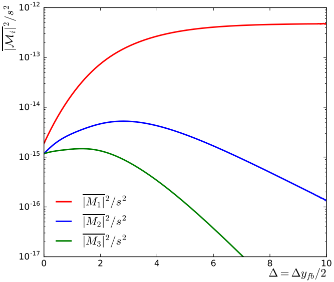

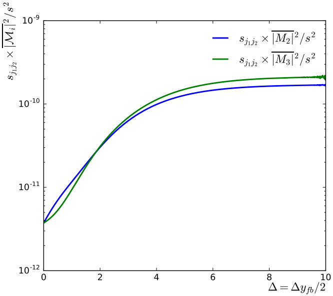

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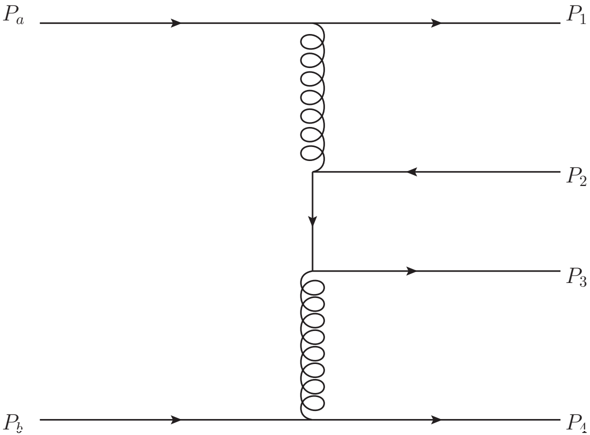
Reducing Dependence on Matching



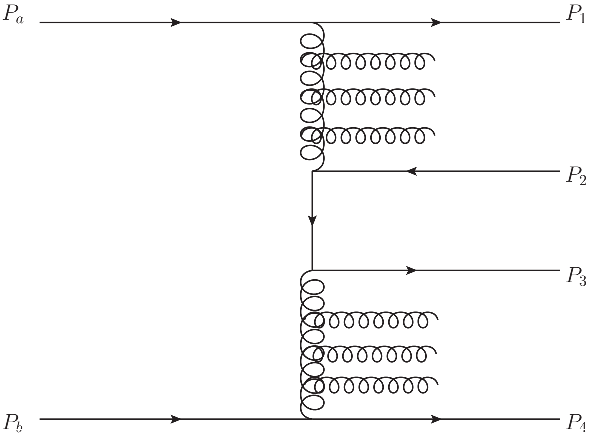
By Matching

α_s^4

Add Resummation

$(\alpha_s \Delta_y)^N$

Reducing Dependence on Matching



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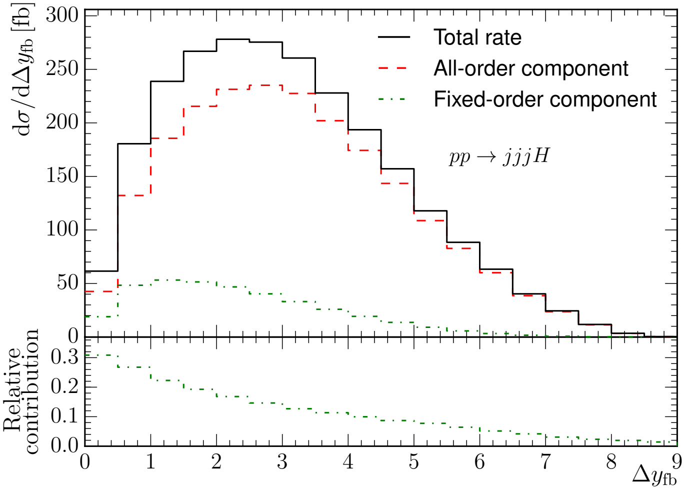
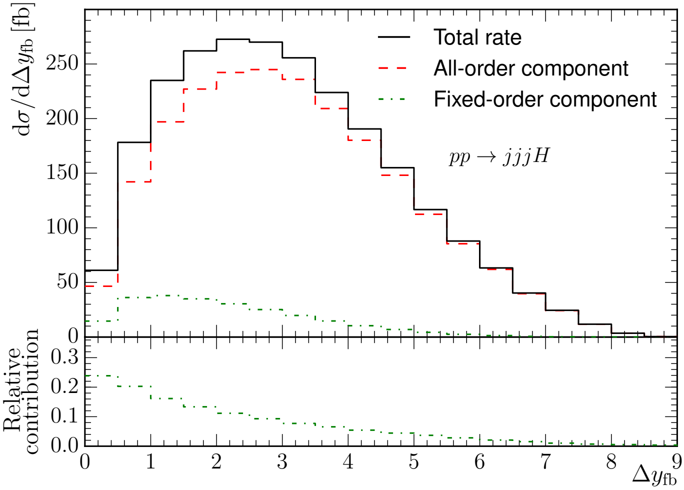
What Impact is Expected?

H+Jets FKL Only



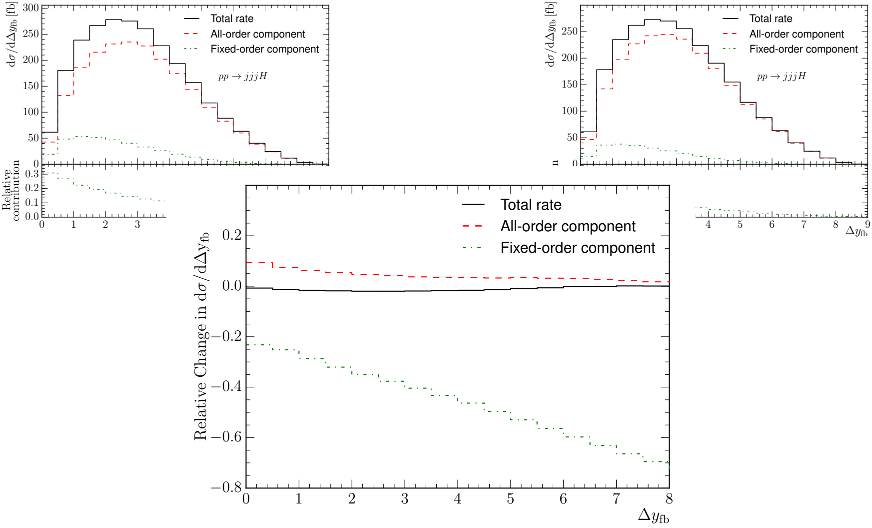
What Impact is Expected?

H+Jets Unordered Included

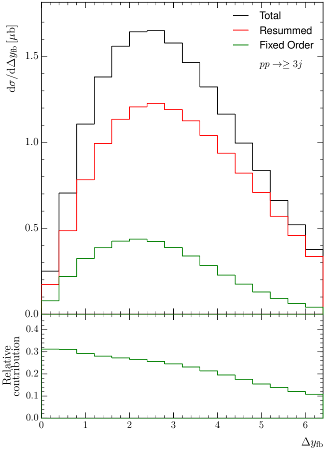


What Impact is Expected?

Change due to Unordered in Higgs+Jets

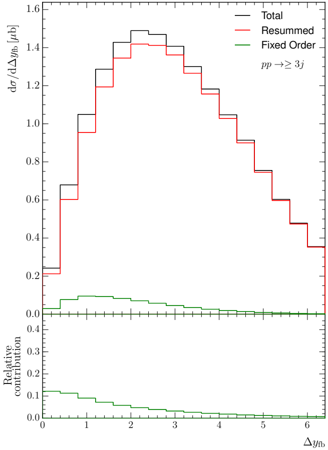


Pure Jets
FKL Only



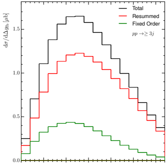
Pure Jets

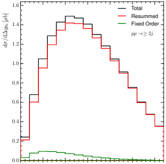
All subleading processes

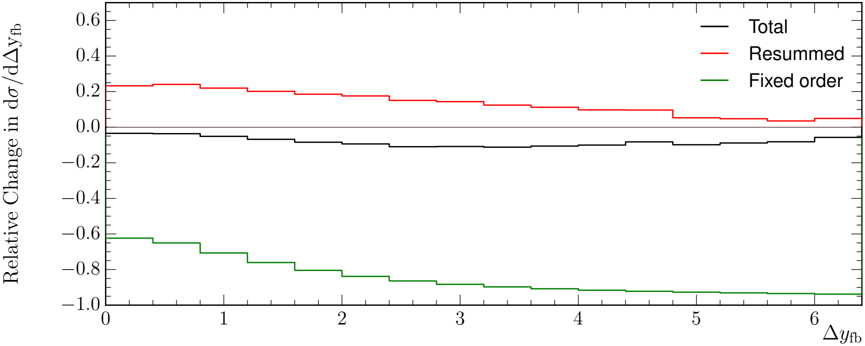


Pure Jets

Change due to Subleading Pieces







Ongoing Projects

- Improved Virtual Corrections
- Same Sign W
- HEJPYTHIA

Conclusions and Further Considerations

- Finite mass effects added for Higgs+Jets
- Added resummation for all sub-leading processes
- HEJ is now leading log accurate for all sub-leading processes
- Next steps for Next-to-Leading Log:
  - Virtual correction improvements
- Code rewrite/cleanup complete
- HEJ2 recently had a public release! + Docker image!
- Many ongoing exciting projects.

https://hej.web.cern.ch/HEJ/