Dijet azimuthal correlations in QCD hard processes

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DIS 2007
Munich, 17th April 2007

1 In collaboration with Andrea Banfi and Mrinal Dasgupta
Studies of **soft gluon radiation** and **non-perturbative effects** are vital for current and future colliders:

- Predictions for future colliders [LHC] (e.g. Higgs $Q_t$ spectrum).
- All-orders analytical resummations.
- Separating non-perturbative effects and underlying event from perturbative physics.
- Extracting non-perturbative parameters (coupling, pdfs).
- (Correct) tuning of Monte Carlos (HERWIG, PYTHIA, etc).
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Introduction
Examples of where we could go wrong

1. Non-global logs: numerically resummed for two-jet observables in the large $N_c$ limit to single-log accuracy:
   - $\mathcal{O}(1/N_c^2)$ neglected. Could be vital in some cases.
   - Three and four-jet observables unaccounted for.

2. Use of a jet algorithm affects resummation of non-global observables:
   - Reduces non-global logs.
   - Gives rise to additional logs.
     A. Banfi and M. Dasgupta, 2005
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Dijet azimuthal correlation is a valuable observable for these studies:

- Sensitive to jet algorithm and recombination scheme.
- Sensitive to soft and/or collinear gluon radiation and non-perturbative effects.
- Involves three or more jets (challenges our understanding of power corrections, resummation, clustering algorithm effects and non-global logs).
- Similar to dijet $\Delta p_t$ distribution.
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Introduction
Dijet azimuthal correlation

Jet 1

Jet 3

Jet 1

Jet 2

Jet 2

Jet 2

Jet 2

Three-jet event

Logarithmically enhanced

Soft and/or collinear emissions

Born event

\( \delta \phi_{\text{jets}} \)
Introduction
Dijet azimuthal correlation at DØ

Dijet azimuthal correlation recently measured by DØ

\[ \frac{1}{\sigma_{\text{dijet}}} \frac{d\sigma_{\text{dijet}}}{d\Delta\phi_{\text{dijet}}} \]

\[ p_T^{\text{max}} > 180 \text{ GeV} \quad (\times 8000) \]

\[ 130 < p_T^{\text{max}} < 180 \text{ GeV} \quad (\times 400) \]

\[ 100 < p_T^{\text{max}} < 130 \text{ GeV} \quad (\times 20) \]

\[ 75 < p_T^{\text{max}} < 100 \text{ GeV} \]

\[ \mu_r = \mu_f = 0.5 p_T^{\text{max}} \]

Figures showing data compared to NLO theory predictions.

V.M. Abazov, et al [DØ collaboration], 2004
Introduction
Comparison to NLOJET++

- NLO description is good when $\pi - \delta \phi_{jets}$ is large.
- Close to Born configuration ($\pi - \delta \phi_{jets} \to 0$) NLO results diverge.
- Soft and/or collinear logs + non-perturbative effects become enhanced.
- Needs resummation, power corrections and NLO matching.
- Same story in DIS. M. Hansson and L. Joensson, DIS 2006
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The observable
In the soft and/or collinear regime

\[ \Delta = \pi - \delta \phi_{\text{jets}}, \]

\( \delta \phi_{\text{jets}} \): difference in azimuth of outgoing jets.

Depends on jet recombination method:
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- **4-momentum addition** - used at DØ:
  \[ p^\mu_{\text{jet}} = \sum_{i \in \text{jet}} p^\mu_i \]
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\[ p_{\text{jet}}^{\mu} = \sum_{i \in \text{jet}} p_{i}^{\mu} \]

\[ \Delta \simeq \frac{1}{p_{t}} \sum_{i \notin \text{outgoing jets}} k_{t,i} \sin \phi_{i}, \]

\( p_{t} \): transverse momentum of outgoing jets.

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\( \implies \) non-global observable.
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\( \delta \phi_{\text{jets}} \): difference in azimuth of outgoing jets.

Depends on jet recombination method:

- **Average \( E_t \)-weighted azimuth** - used at HERA:
  \[ \phi_{\text{jet}} = \frac{\sum_{i \in \text{jet}} E_{t,i} \phi_i}{\sum_{i \in \text{jet}} E_{t,i}} \]
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\( \theta_{ij} = 1 \) if particle \( i \) belongs to jet \( j \).

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\[ \implies \text{Continuously global observable}. \]
Dijet azimuthal correlation in DIS

The resummed result

- Use average $E_t$-weighted azimuth method.
- Measure $\Delta$ between outgoing legs in hadronic CoM.

$$\sigma(\Delta) = \int \sigma_B dB \frac{2}{\pi} \int_0^\infty \frac{db}{b} \sin(b \Delta) e^{-R(b)},$$

$\sigma_B$: Born weight.
$R(b)$: Radiator, $R(b) = \lg_1(\alpha_s l) + g_2(\alpha_s l)$.

$l = \ln(be^{\gamma_E})$.

- $\lg_1(\alpha_s l)$ resums leading logs. Originate from soft-collinear emissions to all legs.
- $g_2(\alpha_s l)$ resums next-to-leading logs. Originate from soft wide-angle or hard-collinear emissions to all the legs.
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Dijet azimuthal correlation in DIS
The resummed result (preliminary)

\[ \Delta \sigma(\Delta) \]

Resummed
NLOJET++ NLO
\( x = 0.01 \)
\( Q = 20 \text{ GeV} \)

\[ \frac{1}{\sigma} \frac{d\sigma}{d\Delta} \]

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\( x = 0.01 \)
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Comparison to NLOJET++
MC vs resummation at $O(\alpha_s)$

Expansion of resummed result to $O(\alpha_s)$:

$$\frac{d\sigma^{(1)}(\Delta)}{dL} = h_{11} + 2h_{12}L,$$

$L = \ln(1/\Delta)$, $h_{ij}$: constants.
All logs controllable. Must fully agree with NLOJET++ in the logarithmically enhanced region.
Comparison to NLOJET++
MC vs resummation at $\mathcal{O}(\alpha_s)$

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Comparison to NLOJET++
MC vs resummation at $\mathcal{O}(\alpha_s^2)$

Expansion of resummed result to $\mathcal{O}(\alpha_s^2)$:

$$\frac{d\sigma^{(2)}(\Delta)}{dL} = 2h'_{22}L + 3h_{23}L^2 + 4h_{24}L^3,$$

NLOJET++ result at $\mathcal{O}(\alpha_s^2)$:

$$\frac{d\sigma_{\text{MC}}^{(2)}(\Delta)}{dL} = h_{21} + 2h_{22}L + 3h_{23}L^2 + 4h_{24}L^3 + \mathcal{O}(\Delta).$$

$h'_{22}$ and $h_{22}$ not the same (contain uncontrollable sub-leading logs).

$(d\sigma^{(2)}/dL)/L$ should give agreement for large values of $L$. 
Comparison to NLOJET++
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Expansion of resummed result to $\mathcal{O}(\alpha_s^2)$:

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MC vs resummation at $O(\alpha_s^2)$

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Comparison to NLOJET++

MC vs resummation at $\mathcal{O}(\alpha_s^2)$

![Graph showing comparison between NLOJET++ and resummation at $\mathcal{O}(\alpha_s^2)$](image)

- Expanded resummed NLO
- NLOJET++ NLO

$Q=20$ GeV

$x=0.01$
Matching

Back to the resummed result:

Need to combine NLO result with resummed result and remove double counted terms so as to achieve NLL+NLO accuracy. IN PROGRESS!
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Power corrections

Non-perturbative effects (hadronisation) enter the distribution through running of $\alpha_s$ below some scale $\mu_I$ ($\sim 2\text{GeV}$):

- Replace $\alpha_s$ with $\alpha_{\text{eff}}$ below $\mu$.
- Use

$$\frac{1}{\mu} \int_0^\mu \alpha_{\text{eff}}(k_t) dk_t = \alpha_0(\mu),$$

$\alpha_0$: non-perturbative parameter. $\alpha_0(2\text{GeV}) \approx 0.52 \pm 0.04$

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IN PROGRESS!
Future directions and conclusions

- Perform a **NLO matching** to NLOJET++ and calculate **power corrections**.
  - Study the hadron-hadron case (DØ) [Result analytically available for $E_t$-weighted recombination scheme].
  - 4-momentum addition recombination scheme.
  - Estimate the effects of non-global logs [may be insignificant] and clustering algorithm in the hadron-hadron case.
  - This is the first resummation for dijet azimuthal correlations.
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