Subleading-N improved Parton Showers

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in collaboration with
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Motivation.

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Monte Carlo event generators are indispensable tools for collider phenomenology:

- account for the bulk of (soft/collinear) QCD radiation,
- include models for hadronization and multiple interactions,
- perform decays of unstable hadrons,
- finally deliver realistic, fully exclusive events.

Many improvements, particularly to include higher orders.

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This talk: Attempt to quantify the impact of subleading-N contributions.

Ultimately want to answer:

- Are they important at all?
- For which observables/phasespace regions?

Clearly state: *Subleading-N improved* instead of $N = 3$ *exact.*
Evolution at amplitude level hard to put into current MC frameworks.

Outline.

- Brief recaps of main ingredients.
- Colour matrix element corrections.
- Technicalities.
- Some first results.
- Conclusions and outlook.

Dipole factorization.

[Catani & Seymour, Nucl.Phys.B485:291-419,1997]

Tree-level matrix elements in singly-unresolved limits:

$$|\mathcal{M}_{n+1}(p_1, ..., p_{n+1})|^2 \sim \sum_{(ik)} \sum_{j \neq i,k} \langle \mathcal{M}_n(..., \tilde{p}_{ij}, ..., \tilde{p}_k, ...)| \mathbf{V}_{ij,k} | \mathcal{M}_n(..., \tilde{p}_{ij}, ..., \tilde{p}_k, ...) \rangle$$

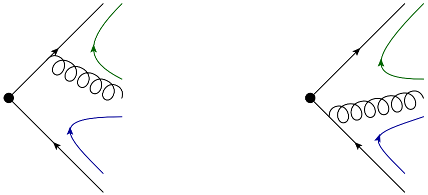
Neglecting spin correlations, **V** only contains colour correlations:

$$\mathbf{V}_{ij,k} = -V_{ij,k} \frac{\mathbf{T}_{ij} \cdot \mathbf{T}_k}{\mathbf{T}_{ij}^2}$$

Showers based on dipole factorization(s).

[Krauss & Schumann; Dinsdale & Weinzierl; Krauss & Winter; Giele & Skands; Gieseke & SP, ...]

$$P_{\tilde{ij} \to ij} \longrightarrow V_{\tilde{ij},\tilde{k} \to ij,k}$$



Evolution different from just $1 \to 2$: All 'dipoles' competing.
Momentum conservation locally in each branching.

Showers based on dipole factorization.

$p_\perp$-ordered CS type showers in detail: [SP & S. Gieseke, JHEP01(2011)024]

- Check Sudakov anomalous dimensions
  $\rightarrow$ LL and NLL coefficients ok, recoils power suppressed.
- Explicitly demonstrate coherent gluon emission
  $\rightarrow$ guaranteed by $p_\perp$ ordering, virtuality ordering *not* coherent.
- New prescription for initial state radiation
  $\rightarrow$ proper build-up of $p_\perp$ in hadronic collisions.

Implemented as add-on module to `Herwig++`.

Matrix element corrections.

Want hardest emission driven by exact real emission matrix element.

[e.g. Seymour, Comput.Phys.Commun.90:95-101,1995.]

Want n hardest emissions driven by exact real emission matrix elements.

[$\to$ merging – see work by CKKW, Lönnblad ...]

What it boils down to ...

$$P_{\text{parton shower}} \approx \frac{|\mathcal{M}_{n+1}|^2}{|\mathcal{M}_n|^2} \qquad \to \qquad \frac{|\mathcal{M}_{n+1}|^2}{|\mathcal{M}_n|^2}$$

Mind that this is an *exact* factorization at the level of cross sections.

Colour matrix element corrections.

Treat colour correlations along the lines of matrix element corrections.
For emission off a n-parton configuration:

$$V_{l,k\to ij,k} \to -V_{l,k\to ij,k} \times \frac{1}{|\mathcal{M}_n|^2}\langle\mathcal{M}_n|\frac{\mathbf{T}_l\cdot\mathbf{T}_k}{\mathbf{T}_l^2}|\mathcal{M}_n\rangle$$

Directly follows from the dipole factorization formula.

Algorithmic:

- Correct 'dipole' emission by colour matrix element corrections.
  $\to$ Not chains of dipoles, but all pairs.
- Calculate next amplitude from underlying dipole factorization.

Calculating the next amplitude.

From just soft gluon factorization:

$$|\mathcal{M}_{n+1}\rangle = \sum_l \frac{\epsilon^*(p_j)\cdot p_l}{p_j\cdot p_l}\mathbf{T}_l|\mathcal{M}_n\rangle$$

Instead use $|\mathcal{M}_n\rangle\langle\mathcal{M}_n|$ as the fundamental object:

$$|\mathcal{M}_{n+1}\rangle\langle\mathcal{M}_{n+1}| = -\sum_{(lk)} \frac{V_{l,k\to ij,k}}{\mathbf{T}_l^2}\ \mathbf{T}_k|\mathcal{M}_n\rangle\langle\mathcal{M}_n|\mathbf{T}_l$$

Allows to include collinear contributions.
Don't have to deal with explicit wavefunctions.

Technicalities.

Need colour basis for (in principle) arbitrary number of legs.

Working horse: `ColorFull`

- C++ implementation of trace basis algebra [M. Sjödahl, in preparation]
- Supplemented by `boost::blas` for efficiency
- Interfaced to `Matchbox` framework and dipole shower modules

[SP & S. Gieseke, arXiv:1109.6256]

The main MC algorithm can be extended to cope with the case at hand (negative splitting 'probabilities'). [SP & M. Sjödahl, arXiv:1109.6180]

Some first results.

Proof-of-concept sandbox: $e^+e^- \to$ jets.
Up to 6 improved gluon emissions.

Three scenarios considered to study systematics:

- $\mathbf{T}_i \cdot \mathbf{T}_j / \mathbf{T}_i^2$ exact, C_F exact: ‘full correlations’
- $\mathbf{T}_i \cdot \mathbf{T}_j / \mathbf{T}_i^2$ in large N, C_F exact: ‘large-N correlations’
- $\mathbf{T}_i \cdot \mathbf{T}_j / \mathbf{T}_i^2$ in large N, $C_F \to C_A/2$: ‘strict large-N correlations’

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Typical parton shower approximation.

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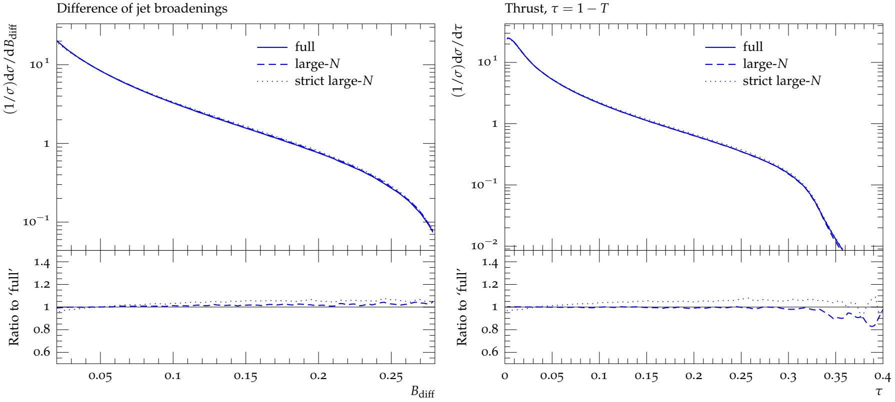

[preliminary]

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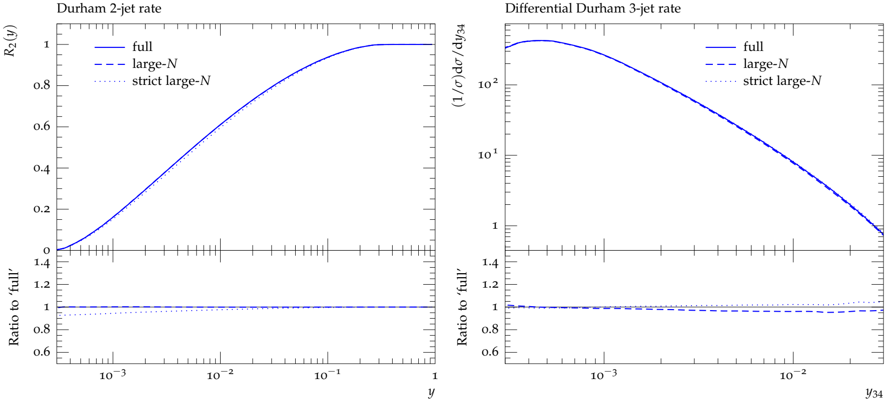

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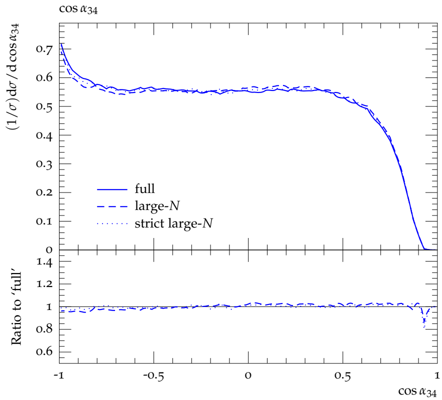

Still no large effects.

Construct dedicated 5, 6-jet observables (work in progress).

[preliminary]

Conclusions and outlook.

Algorithm to improve parton showers by subleading-N contributions.

Proof of concept implementation for $e^+e^- \to$ jets:

- Differences at the level of or below 5%
- Larger deviations for strict large-N limit with $C_F \to C_A/2$

Outlook:

- More significant effects expected in QCD $2 \to 2$.
- Combine with any number of large-N emissions downstream.
- Computationally less exhaustive algorithm possible?
- How should hadronization models be formulated?

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