# A new parton shower model for Sherpa

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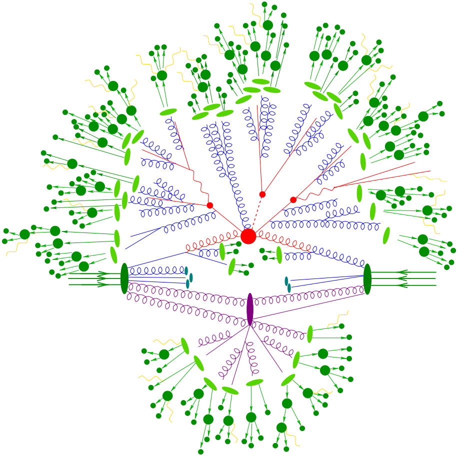
# Introduction

# Monte Carlo Event Generators

Event Generators crucial for collider physics

- Hard Process
- Parton Shower
- Underlying Event
- Hadronization
- QED FSR
- Hadron Decays



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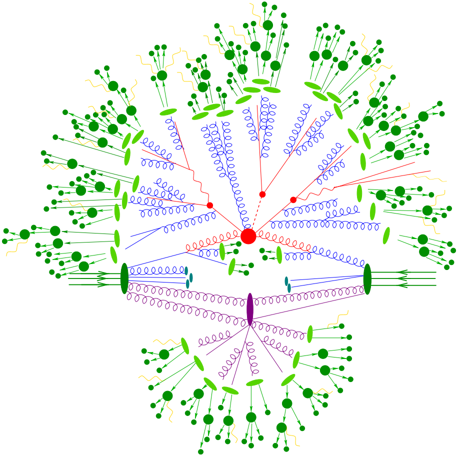
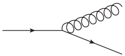


# Parton Shower

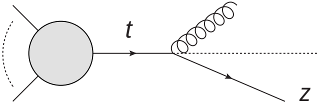
- Parton branching can occur in two ways


- observed


- unobserved

- Evolution conserves probability
- Decay probability for parton state in collinear limit

$$\rightarrow \frac{1}{n}\int_t^{Q^2} d\bar{t}\,\frac{d_{n+1}}{d\bar{t}} \quad \sum_{\text{jets}}\int_t^{Q^2}\frac{d\bar{t}}{\bar{t}}\int dz\,\frac{s}{2}P(z)$$

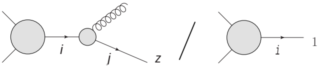


# Higher orders

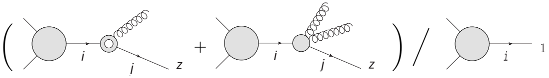
How to compute probabilities at higher orders
Interplay with NLO splitting functions

$$D^{(0)}_{ji}(z; \;\;) = \;\; _{ij} \;\; (1-z) \qquad \leftrightarrow$$


$$D^{(1)}_{ji}(z; \;\;) = -\frac{1}{"}P^{(0)}_{ji}(z) \qquad \leftrightarrow$$




$$D^{(2)}_{ji}(z; \;\;) = -\frac{1}{2"}P^{(1)}_{ji}(z) + \frac{0}{4"^2}P^{(0)}_{ji}(z) + \frac{1}{2"^2}\int_z^1 \frac{\mathrm{d}x}{x} P^{(0)}_{jk}(x)P^{(0)}_{ki}(z/x)$$

$\leftrightarrow$ 


Ability to simulate $P^{(1)}_{ji}$ fully differentially prerequisite to achieve NNLL accuracy for arbitrary observables

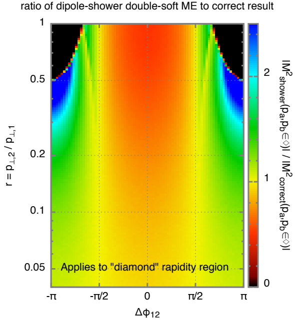
Soft and collinear limits schematically identical, but beware of soft/collinear overlap!

# The problem

# Recoil

Two problems in commonly used parton showers when compared to analytic NLL resummation:

- Angular correlations across multiple emissions due to recoil strategy and choice of evolution variable spoil formal accuracy
- Average color charge of initial $q\bar{q}$ dipole after radiation not reflected correctly




[Dasgupta, Dreyer, Hamilton, Monni & Salam, JHEP 09 (2018) 033]

Here: address kinematics problem

- Transverse recoil should not change hard partons
- Angles should be measured in frame of hard event

# The solution

# Momentum mapping

Use mapping where hard directions maintained *exactly*

Guideline: CS identified particle subtraction

[Catani  Seymour, Nucl.Phys.B 485 (1997) 291]

Collinear safety criterion

$$p_i \xrightarrow{p_i p_j \to 0} z\,\tilde{p}_i \;; \qquad p_j \xrightarrow{p_i p_j \to 0} (1-z)\,\tilde{p}_i$$

Splitting variable defined by

$$z = \frac{p_i n}{(p_i + p_j)n}$$

$n$ is an arbitrary auxiliary vector

$$\tilde{p}_i n \neq 0$$

# Momentum mapping

New vector $\tilde{K}$, sum of a subset of the momenta $\{\tilde{p}_a, \tilde{p}_a, \tilde{p}_1, \ldots, \tilde{p}_{j-1}, \tilde{p}_{j+1}, \ldots, \tilde{p}_n\}$

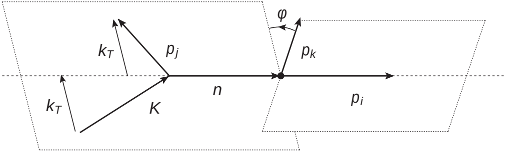
Shift ensuring momentum conservation

$$p_i = z\,\tilde{p}_i\;; \qquad n = \tilde{K} + (1-z)\,\tilde{p}_i$$

$\tilde{K}$ could be sum of lepton momenta in Drell-Yan

Now: find $K$ and $p_j$ such that $K^2 = \tilde{K}^2$ and collinear safe

# Momentum mapping




Variables

$$v = \frac{p_i p_j}{p_i \tilde{K}} \; ; \qquad = \frac{\tilde{K}^2}{2\tilde{p}_i \tilde{K}}$$

Now we can express $p_j$ and $K$:

$$p_j = (1 \quad z)\,\tilde{p}_i + v \quad \tilde{K} \quad (1 \quad z + 2 \quad )\,\tilde{p}_i \quad + k_?$$

$$K = \tilde{K} \quad v \quad \tilde{K} \quad (1 \quad z + 2 \quad )\,\tilde{p}_i \quad k_?$$

! collinear safe since $v$ / $E_j(1 \quad \cos \quad _{ij})$

$n$-frame and $K$-frame agree in soft limit

# Angular ordering

Angular ordering is approximation to soft coherence

Marchesini & Webber, NPB 310(88)461

Decompose Eikonal

$$w_{ik;j} = \frac{W_{ik;j}}{E_j^2}\ ; \text{ where } W_{ik;j} = \frac{1 \quad \cos \quad _{ik}}{(1 \quad \cos \quad _{ij})(1 \quad \cos \quad _{jk})}$$

Split into partial radiator functions

$$W_{ik;j} = \tilde{W}^{i}_{ik;j} + \tilde{W}^{k}_{ki;j}\ ;$$

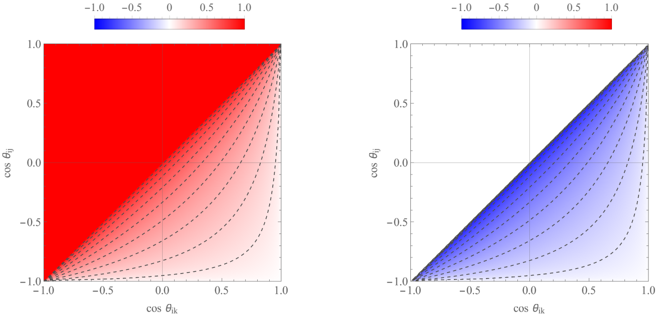
$$\tilde{W}^{i}_{ik;j} = \frac{1}{2} \quad \frac{1 \quad \cos \quad _{ik}}{(1 \quad \cos \quad _{ij})(1 \quad \cos \quad _{jk})} !$$

$$+ \frac{1}{1 \quad \cos \quad _{ij}} \quad \frac{1}{1 \quad \cos \quad _{jk}}$$

# Angular ordering

Azimuthal averaging ! negative and positive contributions cancel outside forward cone

$$\frac{1}{2}\int_0^{2} \mathrm{d}\;{}^{i}_{jk}\,\tilde{W}^{i}_{ik;j} = \frac{\tilde{I}^{i}_{ik;j}}{1 \quad \cos\;{}^{i}_{j}}\;;\;\tilde{I}^{i}_{ik;j} = \begin{cases} 1 & \text{if} \quad {}^{i}_{j} < {}^{i}_{k} \\ 0 & \text{else} \end{cases}$$

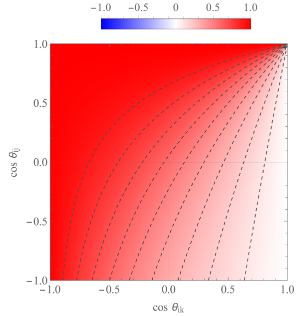



Azimuthal modulation needs to be included if observable sensitive to wide-angle soft effects (non-global logarithms)

# Alaric approach to soft coherence

Capture soft radiation pattern through partial fractioning of angular component of Eikonal

$$\bar{W}^{i}_{ik;j} = \frac{1 \quad \cos \quad _{ik}}{(1 \quad \cos \quad _{ij})(2 \quad \cos \quad _{ij} \quad \cos \quad _{jk})}$$




Advantage: strictly positive radiator, no dead zones

# Results

# Jet rates

# Event shapes

# Outlook

Full soft PS model given by

$$dP^{i}_{ik;j}(t;z;\ ) = d\ _{+1}(f\,\bar{p}g;p_j)\ \frac{s}{2}\ 2C_i\ w^{i}_{ik;j}$$

$$= dt\ dx\ \frac{d}{2}\ \frac{s}{2\ \ t}\ 2C_i\ \frac{(p_i p_k)(p_i n)}{(p_i p_j)(p_k n) + (\ p_k p_j)(p_i n)}$$

Note: Formalism actually Lorentz invariant

! extendable to initial state?

# Extension to initial state

Extension to initial state works the same as  nal state

! matches analytic resummation

# Outlook

Currently validating against criteria from

[Dasgupta, Dreyer, Hamilton, Monni, Salam & Soyez, 2002.11114]

$_s(M_Z) = 0{:}005$

Scheme similar to identi ed CS subtraction

! matching should be straightforward

ALARIC will become available as part of Sherpa

Include soft/collinear higher-order corrections

[Dulat, Gellersen, Höche & Prestel, 1705.00742, 1805.03757, 2110.05964]