

Parton showering in SHERPA

Frank Krauss

Institute for Particle Physics Phenomenology
Durham University

p_{\perp}^Z and $p_{\perp}^W / p_{\perp}^Z$, CERN, 25.2.2018



The parton shower implementation in DIRE

(S.Höche & S.Prestel, Eur.Phys.J. C75 (2015) 461)

- evolution and splitting parameter ($((ij) + k \rightarrow i + j + k)$):

$$\kappa_{j,ik}^2 = \frac{4(p_i p_j)(p_j p_k)}{Q^4} \quad \text{and} \quad z_j = \frac{2(p_j p_k)}{Q^2}.$$

- splitting functions including IR regularisation

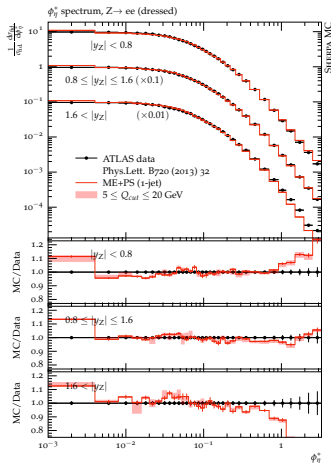
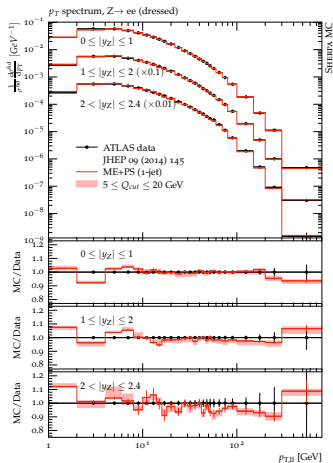
(a la Curci, Furmanski & Petronzio, Nucl.Phys. B175 (1980) 27-92)

$$\begin{aligned} P_{qq}^{(0)}(z, \kappa^2) &= 2C_F \left[\frac{1-z}{(1-z)^2 + \kappa^2} - \frac{1+z}{2} \right], \\ P_{qg}^{(0)}(z, \kappa^2) &= 2C_F \left[\frac{z}{z^2 + \kappa^2} - \frac{2-z}{2} \right], \\ P_{gg}^{s(0)}(z, \kappa^2) &= 2C_A \left[\frac{1-z}{(1-z)^2 + \kappa^2} - 1 + \frac{z(1-z)}{2} \right], \\ P_{gq}^{(0)}(z, \kappa^2) &= T_R \left[z^2 + (1-z)^2 \right] \end{aligned}$$

- renormalisation/factorisation scale given by $\mu = \kappa^2 Q^2$
- combine gluon splitting from two splitting functions with different spectators $k \rightarrow$ accounts for different colour flows

LO results for Drell-Yan

example of accuracy in description of standard precision observable – without tuning soft physics (intrinsic k_{\perp})



Including NLO splitting kernels

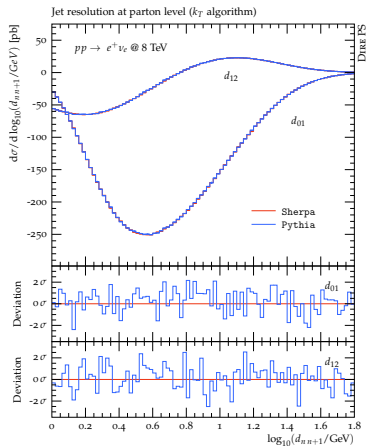
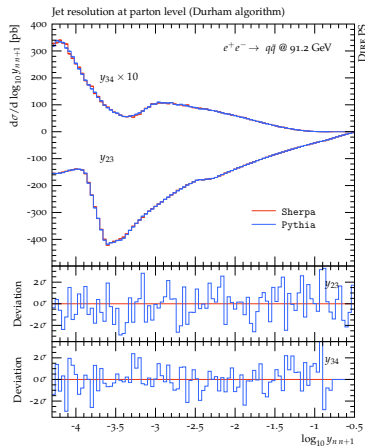
(Hoeche, FK & Prestel, 1705.00982, and Hoeche & Prestel, 1705.00742)

- expand splitting kernels as

$$P(z, \kappa^2) = P^{(0)}(z, \kappa^2) + \frac{\alpha_S}{2\pi} P^{(1)}(z, \kappa^2)$$

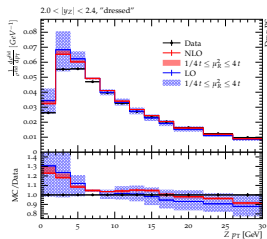
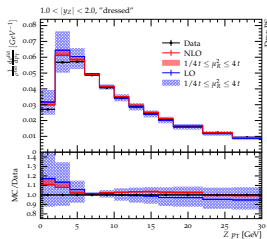
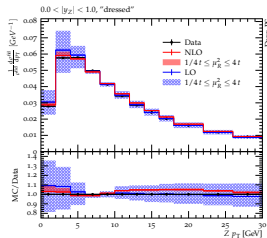
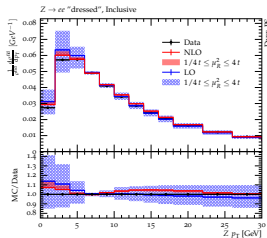
- aim: reproduce DGLAP evolution at NLO
include all NLO splitting kernels
- three categories of terms in $P^{(1)}$:
 - cusp (universal soft-enhanced correction) (already included in original showers)
 - corrections to $1 \rightarrow 2$
 - new flavour structures (e.g. $q \rightarrow q'$), identified as $1 \rightarrow 3$
- new paradigm: **two independent implementations**

Validation of $1 \rightarrow 3$ splittings

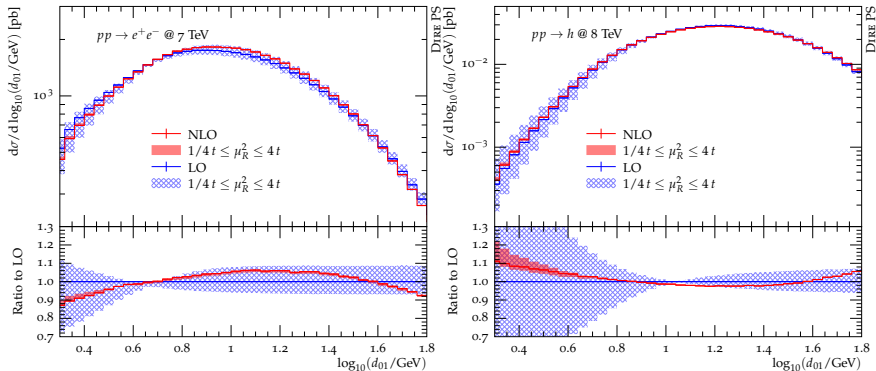


Physical results: DY at LHC

(untuned showers vs. 7 TeV ATLAS data)



Physical results: differential jet rates at LHC



Dealing with heavy quarks

- $g \rightarrow q\bar{q}$ beyond “shower-approximation” \rightarrow no soft gluon
- recent analyses showed problems in II showers (see extra slides)
- heavy quarks also problematic in initial state:
no PDF support for $Q^2 \leq m_Q^2 \rightarrow$ quarks stop showering
- possible solutions:
 - naive: ignore and leave for beam remnants (SHERPA)
 - better: enforce splitting in region around m_Q^2 (PYTHIA)
longrightarrow effectively produces collinear Q and gluon in IS

Summary

- implemented NLO DGLAP kernels into two independent showers
will allow cross checks/validation of NP effects
- cross-validated implementations PYTHIA \longleftrightarrow SHERPA
- matching to NNLO/multijet merging at NLO ongoing work
- extension to include loop-corrections to 1 to 2 straightforward
will allow to use triple-collinear splitting functions throughout
- future plans: soft-gluon emissions and non-trivial colour correlations
- in SHERPA: implement forced splittings for heavy quarks at threshold

Points for further investigation

- compare shower with analytic reummation

maybe in the spirit of Hoeche, Reichelt & Siebert, 1711.03497 (e^+e^- there, shower vs. CAESAR)

- compare two shower implementations in SHERPA, HERWIG, PYTHIA
- treatment of heavy flavours in IS:

→ forced transitions to gluons at/around mass threshold

(different in Z w.r.t. W production)

probably need to check y -dependence of flavour composition

- non-perturbative effects: intrinsic k_{\perp} :

- initial state partons “kicked”: $\langle k_{\perp} \rangle \approx 1 - 2 \text{ GeV}$

(usually parametrised by Gaussian and tuned to Z- p_{\perp})

- usually flavour-blind and x -independent

(non-default option of x -dependent in PYTHIA)

- mind the gap: accuracy vs. precision



LIMITATIONS

UNTIL YOU SPREAD YOUR WINGS,
YOU'LL HAVE NO IDEA HOW FAR YOU CAN WALK.

$g \rightarrow Q\bar{Q}$ — a systematic nightmare

- parton showers geared towards collinear & soft emissions of gluons

(double log structure)

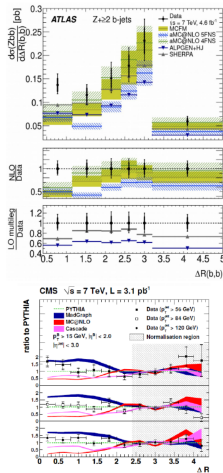


- $g \rightarrow q\bar{q}$ only collinear
- old measurements at LEP of $g \rightarrow b\bar{b}$ and $g \rightarrow c\bar{c}$ rate
- fix this at LHC for modern showers

(important for $t\bar{t}b\bar{b}$)

- questions: kernel, scale in α_S

(example: k_{\perp} vs. m_{bb})



- ATLAS measurement in $b\bar{b}$ production
- use decay products in $B \rightarrow J/\Psi(\mu\mu) + X$ and $B \rightarrow \mu + X$
- use muons as proxies, most obvious observable $\Delta R(J\Psi, \mu)$

