Parton Showering in SHERPA

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The parton shower implementation in DIRE

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

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

$$\kappa^2_{j,ik} = \frac{4(p_ip_j)(p_jp_k)}{Q^4} \quad \text{and} \quad z_j = \frac{2(p_jp_k)}{Q^2}\,.$$

- splitting functions including IR regularisation

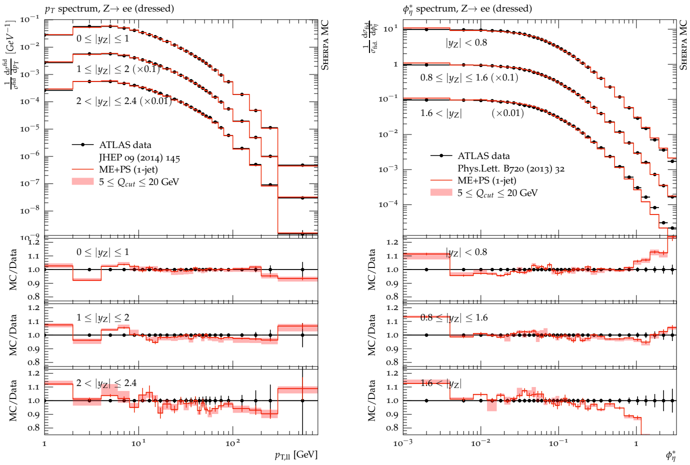
(a la Curci, Furmanski & Petronzio, Nucl.Phys. B175 (1980) 27-92)

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

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

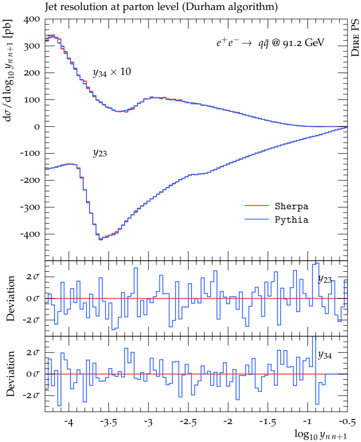
$$P(z,\,\kappa^2) \;=\; P^{(0)}(z,\,\kappa^2) \,+\, \frac{\alpha_S}{2\pi}\,P^{(1)}(z,\,\kappa^2)$$

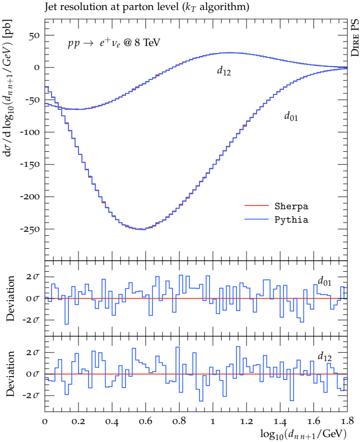
- aim: reproduce DGLAP evolution at NLO

  include all NLO splitting kernels

- three categories of terms in $P^{(1)}$:
  - cusp (universal soft-enhanced correction) (already included in original showers)
  - corrections to $1 \to 2$
  - new flavour structures (e.g. $q \to q'$), identified as $1 \to 3$
- new paradigm: two independent implementations

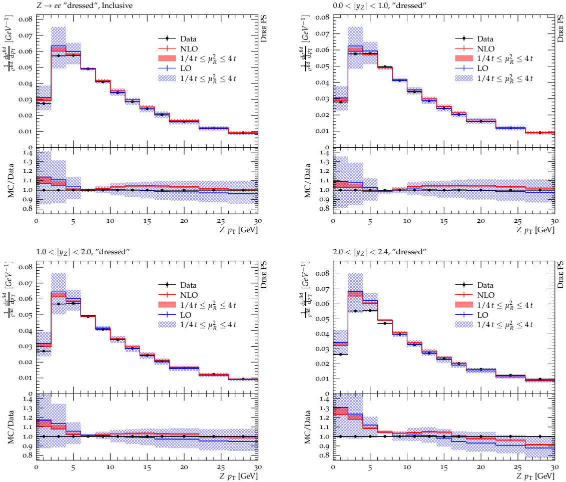
Validation of $1 \to 3$ splittings



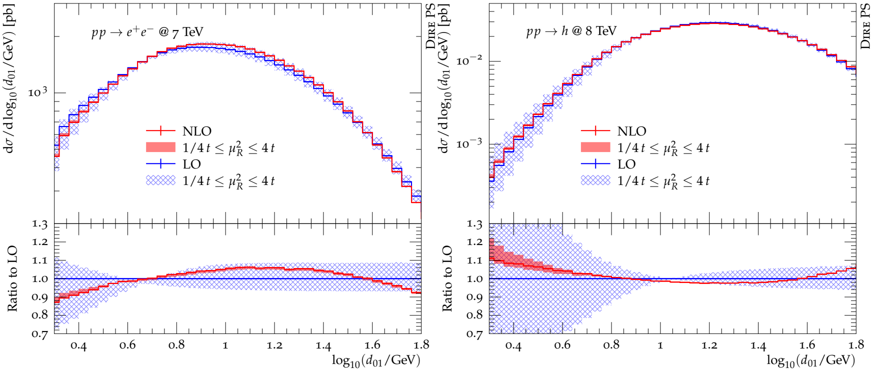


Physical results: DY at LHC

(untuned showers vs. 7 TeV ATLAS data)



Physical results: differential jet rates at LHC



Dealing with heavy quarks

- $g \to q\bar{q}$ beyond "shower-approximation" $\longrightarrow$ no soft gluon
- recent analyses showed problems in ll showers (see extra slides)
- heavy quarks also problemativ in initial state:
  no PDF support for $Q^2 \le m_Q^2 \longrightarrow$ 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 ⟷ SHERPA
- matching to NNLO/multijet merging at NLO ongoing work
- extension to include loop-corrections to $1to2$ 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 & Siegert, 1711.03497 (e^+e^- there, shower vs. CAESAR)

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

  $\longrightarrow$ 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

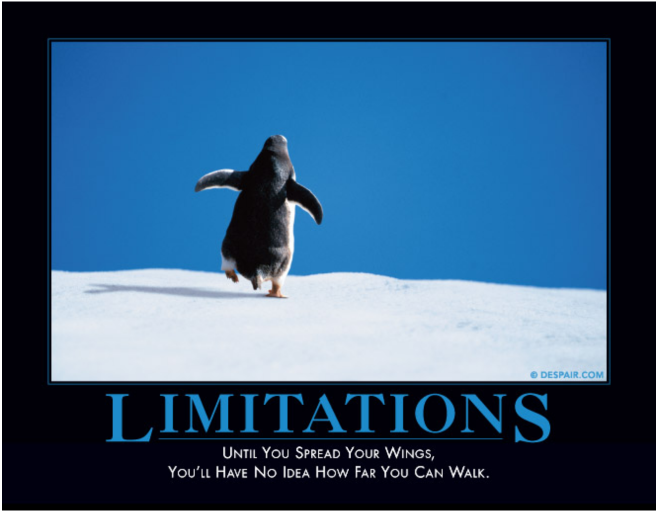
- non-perturbative effects: intrinsic $k_\perp$:
  - initial state partons "kicked": $\langle k_\perp\rangle \approx 1-2$ GeV

    (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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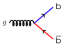
LIMITATIONS
Until You Spread Your Wings,
You'll Have No Idea How Far You Can Walk.

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

- parton showers geared towards collinear & soft emissions of gluons

(double log structure)

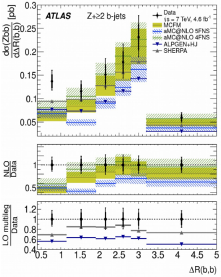


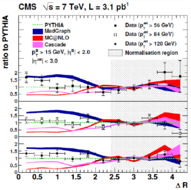
- $g \to q\bar{q}$ only collinear
- old measurements at LEP of $g \to b\bar{b}$ and $g \to c\bar{c}$ rate
- fix this at LHC for modern showers

(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 $B \to J/\Psi(\mu\mu) + X$ and $B \to \mu + X$
- use muons as proxies, most obvious observable $\Delta R(J\Psi, \mu)$