DGLAP evolution at NLO accuracy in Parton Showers

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parton showers: reminder

prequel: parton showers vs. resummation calculations

- parton showers are approximations, based on leading colour, leading logarithmic accuracy, spin-averaged
- concentrate on parton shower $\longleftrightarrow$ compare with Q_T resummation

  (transverse momentum of Higgs boson etc.)
- parametric accuracy by comparing Sudakov form factors:

$$\Delta = \exp\left\{-\int \frac{\mathrm{d}k_\perp^2}{k_\perp^2}\left[A\log\frac{k_\perp^2}{Q^2} + B\right]\right\},$$

  where A and B can be expanded in $\alpha_S(k_\perp^2)$
- showers usually include terms $A_{1,2}$ and B_1 (NLL)

characterising parton showers

- paradigm: (quasi-)probabilistic description of multiple emissions in Markov-chain process, driven by Sudakov form factor

$$\Delta_{ij;k}(t_1, t_0) = \exp\left[-\int\limits_{t_0}^{t_1}\frac{\mathrm{d}t}{t}\int\limits_{z_0}^{z_1}\mathrm{d}z\,\alpha_S(\mu_R^2)\mathcal{K}_{ij,k}(t,z,\phi)\right]$$

- basically four ingredients in parton showers:
  - evolution variable t and splitting variable z
  - splitting kernels (must reproduce DGLAP kernels in collinear limit)
  - renormalisation scale μ_R and factorisation scale μ_F (for IS splittings)
  - kinematics to build splitting $p_{(ij)} + p_k \to p_i + p_j + p_k$

implementation in DIRE

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

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

- splitting functions including IR regularisation

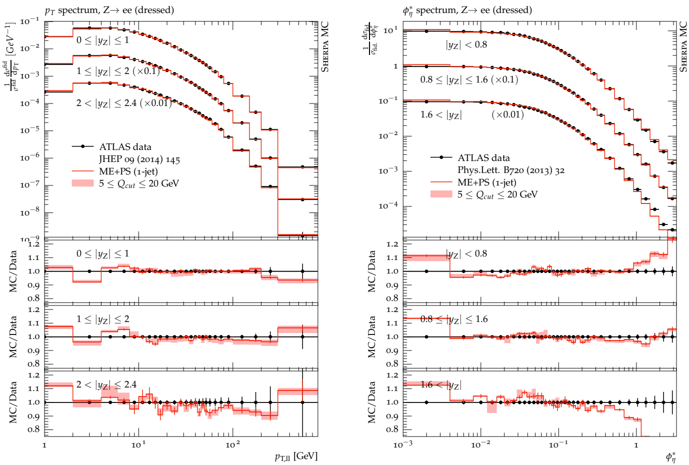
(a la Curci, Furmanski)

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

- 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

some parton shower fun with DY

(example of accuracy in description of standard precision observable)



implementing DGLAP @ NLO

towards higher logarithmic accuracy

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

- aim: reproduce DGLAP evolution at NLO

  include all NLO splitting kernels

- expand splitting kernels as

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

- 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. $q\to q'$), identifed as $1\to 3$
- new paradigm: two independent implementations

implementation details: $1 \to 2$ splittings

- problem: new pole structure $1/z$ appears
- in final-state shower: symmetrisation yields extra factor z

  (such a factor is present in IS shower)
- this factor accounts for $1/2$ typically applied to $g \to gg$
- include also $q \to gq$ splitting
- physical interpretation:
  - "unconstrained" (without) vs. "constrained" evolution

    (DGLAP evolution for fragmentation functions)
  - factor z explicitly guarantees (momentum) sum rules
  - it also identifies final state particle

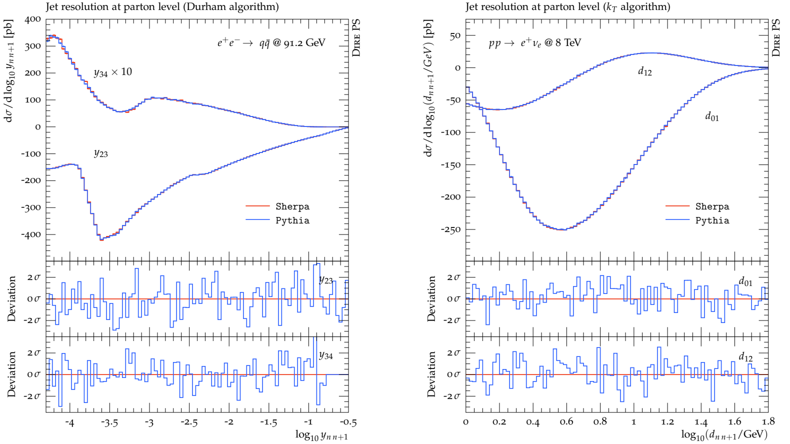
implementation details: $1 \to 3$ splittings

(Hoeche & Prestel, 1705.00742)

- need to find parametrisation to fill three-body phasespace
- idea: use triple-collinear splitting functions
  but: $1 \to 3$ splittings emerge from successive $1 \to 2$ splittings
- subtract terms already present in parton shower at LO:
  - iterated spin-correlated $1 \to 2$ splittings
  - evolution of PDFs
- end result:
  - recover DGLAP kernels after partial integration
  - numerical integration of triple-collinear splitting functions to NLO DGLAP kernels

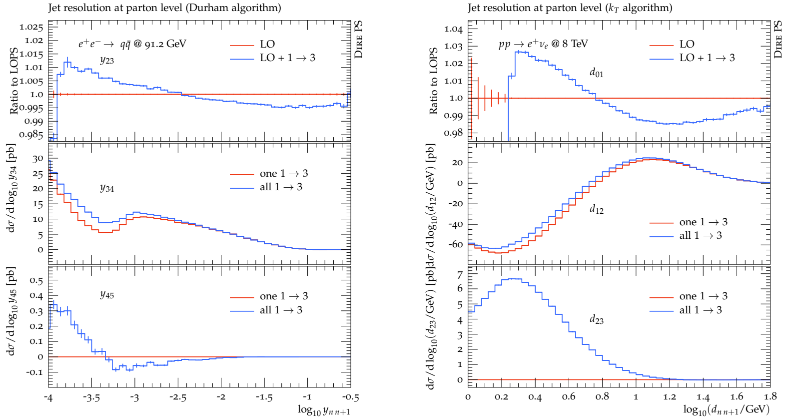
validation of $1 \to 3$ splittings

(Hoeche & Prestel, 1705.00742)



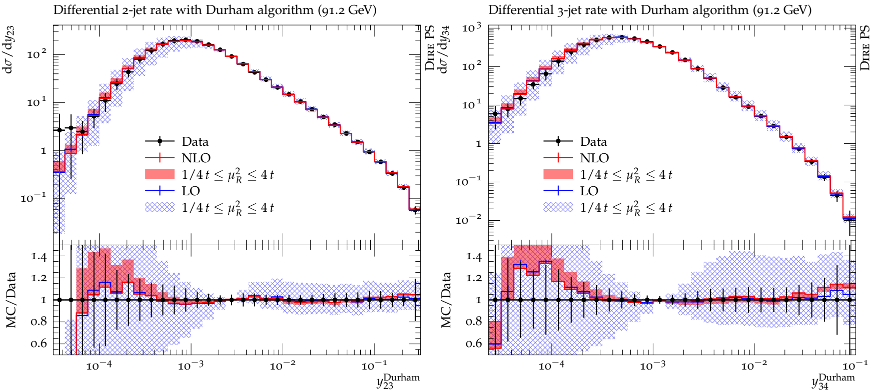
impact of $1 \to 3$ splittings

(Hoeche & Prestel, 1705.00742)



physical results: $e^- e^+ \to$ hadrons

(Hoeche, FK & Prestel, 1705.00982)



physical results: $e^-e^+ \to$ hadrons

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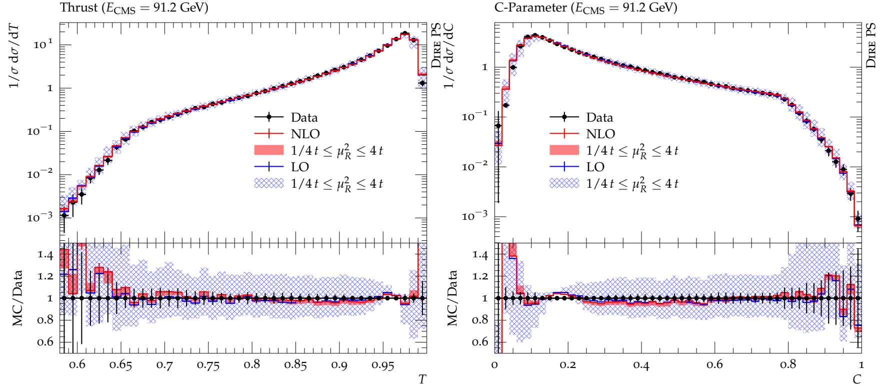
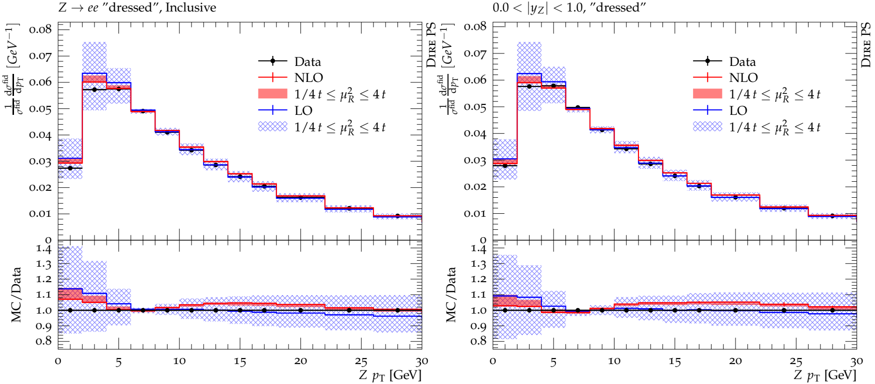


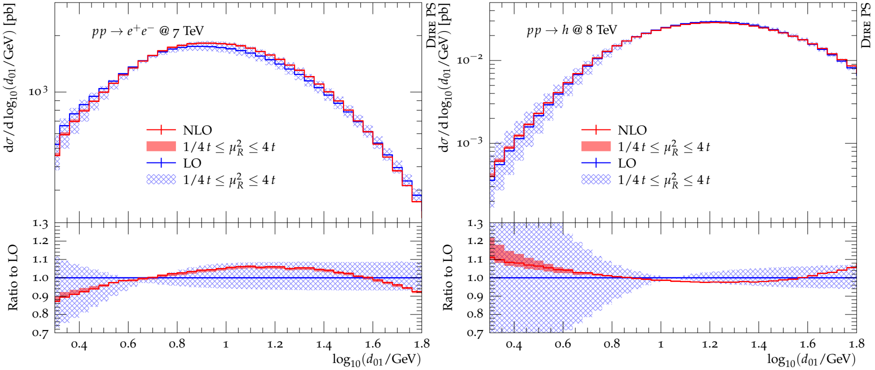
physical results: DY at LHC

(Hoeche, FK & Prestel, 1705.00982)



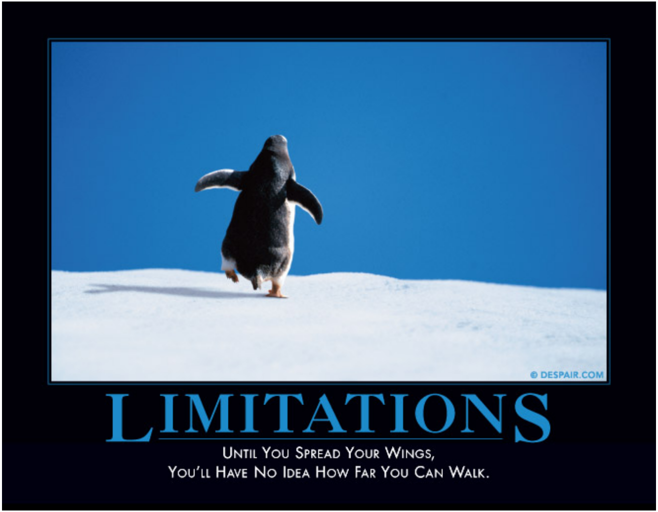
physical results: diff. jet rates at LHC

(Hoeche, FK & Prestel, 1705.00982)



summary & outlook

- implemented NLO DGLAP evolution into parton showers
  - (mild) re-formulation of FS parton showering
  - leads to inclusion of process–independent terms B_2 in Q_T resummation
  - lends itself to inclusion of full kineamtics of triple-collinear splitting functions
  - two independent realisations ("precision showering")
- next steps:
  - UN^{2}LOPS of multiple processes: $q\bar{q} \to V$, $gg \to H$, ...
  - include all triple-collinear splitting functions
  - check effect on jet shapes (boosted regime)
- science fiction: include multiple soft emissions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You'll Have No Idea How Far You Can Walk.