Simulating Double Parton Scattering with dShower

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Based on arXiv:1906.04669 (BC, JG and K. Ostrolenk)

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DPS theory developments

Many theoretical developments towards a better description of DPS:

- Correlations in spin, colour, flavour between partons

  Mekhfi, Phys. Rev. D32 (1985) 2380, Diehl, Ostermeier and Schafer (JHEP 1203 (2012)), Manohar, Waalewijn, Phys.Rev. D85 (2012) 114009

- DPS factorisation proof

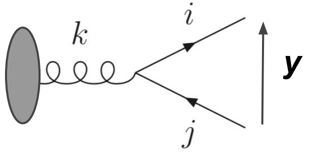
  Diehl, JG, Ostermeier, Plößl, Schafer, JHEP 1601 (2016) 076, Diehl, Ostermeier, Schafer, JHEP 1203 (2012) 089, Vladimirov, JHEP 1804 (2018) 045, Diehl, Nagar, JHEP 1904 (2019) 124

- Sum rules for double PDFs (dPDFs)

  JG, Stirling, JHEP 1003 (2010) 005, Blok, Dokshitzer, Frankfurt, Strikman, Eur.Phys.J. C74 (2014) 2926, Ceccopieri, Phys.Lett. B734 (2014) 79-85, Diehl, Plößl, Schäfer, Eur.Phys.J. C79 (2019) no.3, 253

- Proper treatment of the 1 → 2 splitting mechanism, with full ***y*** impact-parameter dependence + avoidance of double counting with SPS

  Diehl, JG, Schönwald, JHEP 1706 (2017) 083



- And more...

Experimental analyses of DPS

- Need to include those theoretical developments inside a tool that can **generate distributions in multiple variables**. Currently, machine-learning techniques are used by experimentalists.

- Usually, experimentalists turn to **Monte-Carlo event generators** to do this (e.g. Herwig, Pythia, Sherpa, …).

- But the DPS/MPI models in these generators are generally based on a simple picture of **independent scatters**. They do not include the latest theory developments (although Pythia has many nice improvements, see O. Fedkevych talk).

$$\sigma_{AB}^{DPS} = \frac{\sigma_A^{SPS}\sigma_B^{SPS}}{\sigma_{eff}}$$

Paver, Treleani, Nuovo Cim. A70 (1982) 215, Mekhfi, Phys.Rev. D32 (1985) 2371

- Would be useful to have an improved **Monte-Carlo model of DPS**, to make some of the recent theory developments accessible to **experiment analyses**.

⟶ **dShower**

BC, JG, K. Ostrolenk, JHEP11(2019)061, arXiv:1906.04669

Key features of dShower

- **Impact parameter *y*** fully included and **1 → 2 splitting mechanism** consistently incorporated.

- **Simultaneous shower evolution** of the two hard scatters guided by dPDFs: $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)$

- **Flexible framework**: user can plug in any dPDFs, provided they satisfy:
  1) Evolution according to double DGLAP.
  2) At small ***y***, the dPDFs are given by the perturbative 1 → 2 splitting expression (see slide 7).
  3) Approximately satisfy the momentum and number sum rules.

  Blok, Dokshitzer, Frankfurt, Strikman, Eur.Phys.J. C74 (2014) 2926, Ceccopieri, Phys.Lett. B734 (2014) 79-85, Diehl, Plößl, Schäfer, Eur.Phys.J. C79 (2019) no.3, 253

- Angular ordered shower evolution, as in Herwig.

  Gieseke, Stephens, Webber, JHEP 0312:045,2003

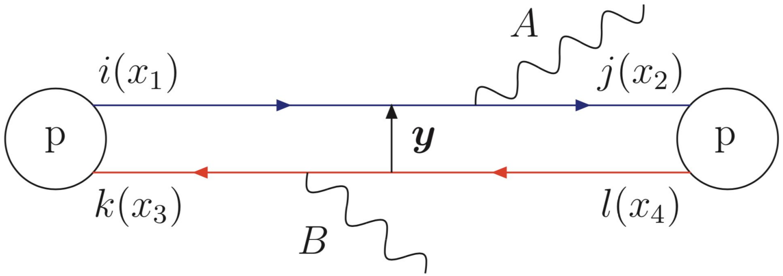
dShower algorithm

(1) Select the momentum fractions, the flavours and ***y*** according to:

$$\sigma^{\text{DPS}}_{(A,B)}(s) = \frac{1}{1+\delta_{AB}} \sum_{i,j,k,l} \int \mathrm{d}x_1\, \mathrm{d}x_2\, \mathrm{d}x_3\, \mathrm{d}x_4\, \hat{\sigma}_{ij\to A}(x_1 x_2 s, Q_h^2)\, \hat{\sigma}_{kl\to B}(x_3 x_4 s, Q_h^2)$$

$$\times \int \mathrm{d}^2\boldsymbol{y}\, \Phi^2(y\nu)\, F_{ik}(x_1, x_3, \boldsymbol{y}, Q_h^2)\, F_{jl}(x_2, x_4, \boldsymbol{y}, Q_h^2)$$

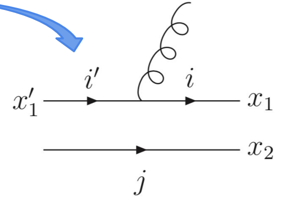
Cut-off of DPS for $y \lesssim 1/\nu \sim 1/Q_h$

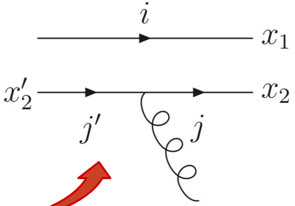


dShower algorithm

(2) Simultaneous **backward evolution** of the two hard scatters with an angular-ordered shower.

$$\mathrm{d}\mathcal{P}_{ij} = \frac{\mathrm{d}Q^2}{Q^2}\left(\sum_{i'}\int_{x_1}^{1-x_2} \boxed{\frac{\mathrm{d}x_1'}{x_1'}\,\frac{\alpha_\mathrm{s}(p_\perp^2)}{2\pi}\,P_{i'\to i}\left(\frac{x_1}{x_1'}\right)\frac{F_{i'j}(x_1',x_2,\boldsymbol{y},Q^2)}{F_{ij}(x_1,x_2,\boldsymbol{y},Q^2)}} + \sum_{j'}\int_{x_2}^{1-x_1} \boxed{\frac{\mathrm{d}x_2'}{x_2'}\,\frac{\alpha_\mathrm{s}(p_\perp^2)}{2\pi}\,P_{j'\to j}\left(\frac{x_2}{x_2'}\right)\frac{F_{ij'}(x_1,x_2',\boldsymbol{y},Q^2)}{F_{ij}(x_1,x_2,\boldsymbol{y},Q^2)}}\right)$$





Branching probability for the pair *ij*:

$$\mathrm{d}\mathcal{P}_{ij}^{\mathrm{ISR}} = \mathrm{d}\mathcal{P}_{ij}\underbrace{\exp\left(-\int_{Q^2}^{Q_h^2}\mathrm{d}\mathcal{P}_{ij}\right)}_{\text{“Sudakov factor” (survival probability)}}$$

dShower algorithm

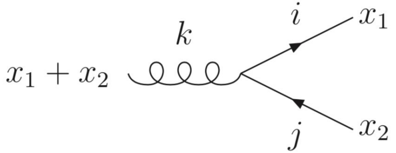
(3) **Merging phase**: at scale $Q = \mu_y \sim 1/y$ partons *i* and *j* **merge** with a probability defined as:

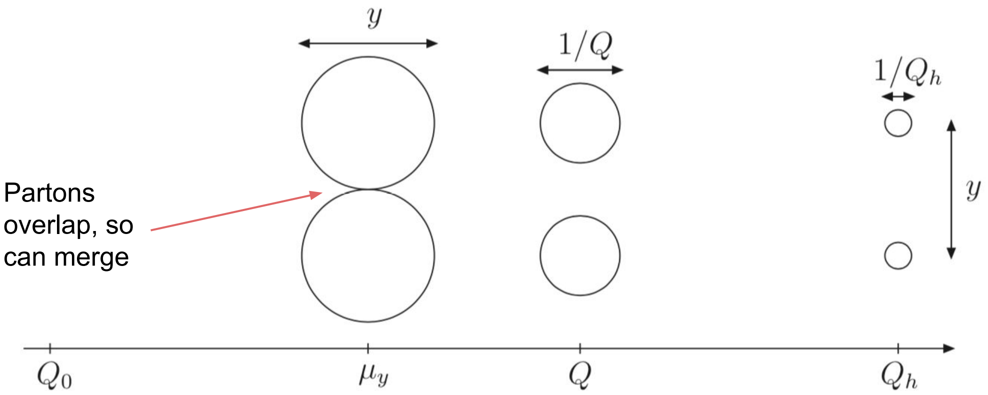
$$p_{\mathrm{Mrg}} = \frac{F_{ij}^{\mathrm{spl}}(x_1, x_2, \boldsymbol{y}, \mu_y^2)}{F_{ij}(x_1, x_2, \boldsymbol{y}, \mu_y^2)}$$

Perturbative 1 → 2 splitting expression:

$$\frac{1}{\pi y^2} \frac{f_k(x_1 + x_2, \mu_y^2)}{x_1 + x_2} \frac{\alpha_s(\mu_y^2)}{2\pi} P_{k \to i+j}\left(\frac{x_1}{x_1 + x_2}\right)$$

Total dPDF





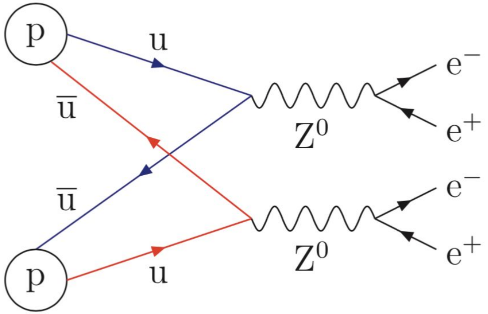
Partons overlap, so can merge

dShower algorithm

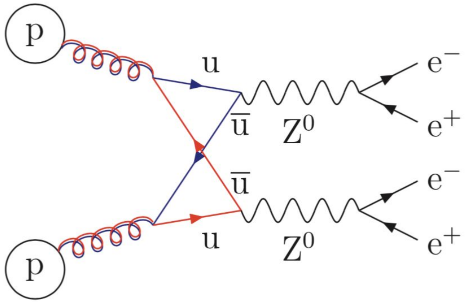
(4) After the merging phase, two possible paths:

i) No merging happened → continue with two-parton branching algorithm from (2), using only the “intrinsic” part of the dPDFs (no 1 → 2 splitting term).

ii) Merging occurred → evolve the mother parton with single shower.



No merging

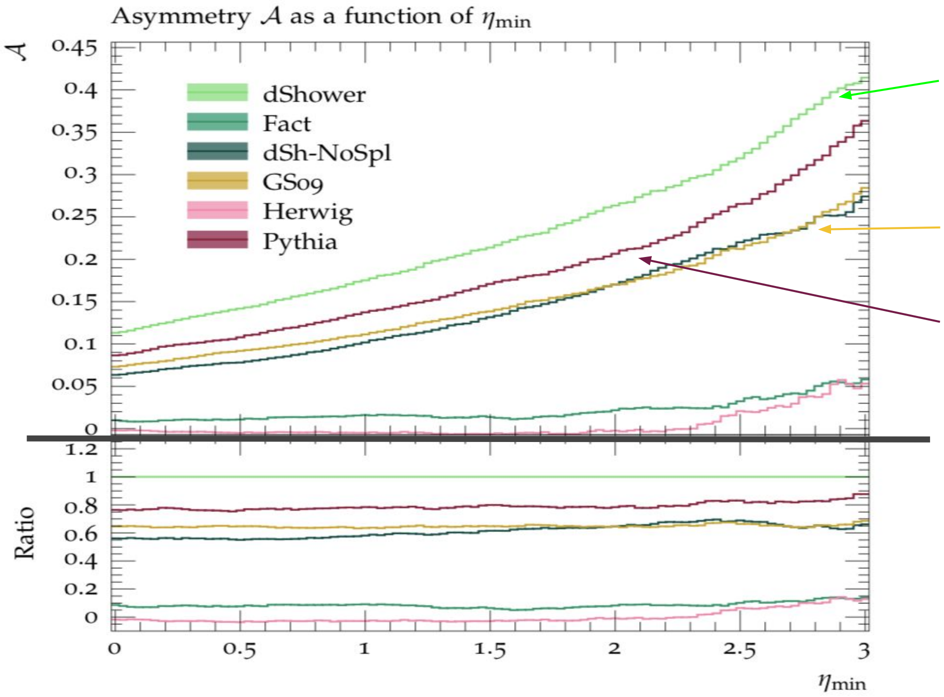


Double merging

Numerical results: asymmetry

Same-sign WW production via DPS: $W^+ \to e^+\nu_e \oplus W^+ \to \mu^+\nu_\mu$

No SPS process, three flavours, dPDF set from JHEP 1706 (2017) 083 (Diehl, JG, Schönwald).



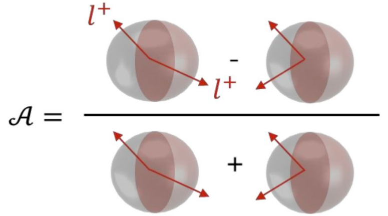
$1 \to 2$ splitting mechanism + valence number effects

Simple valence number effects

Valence-sea scheme inside Pythia

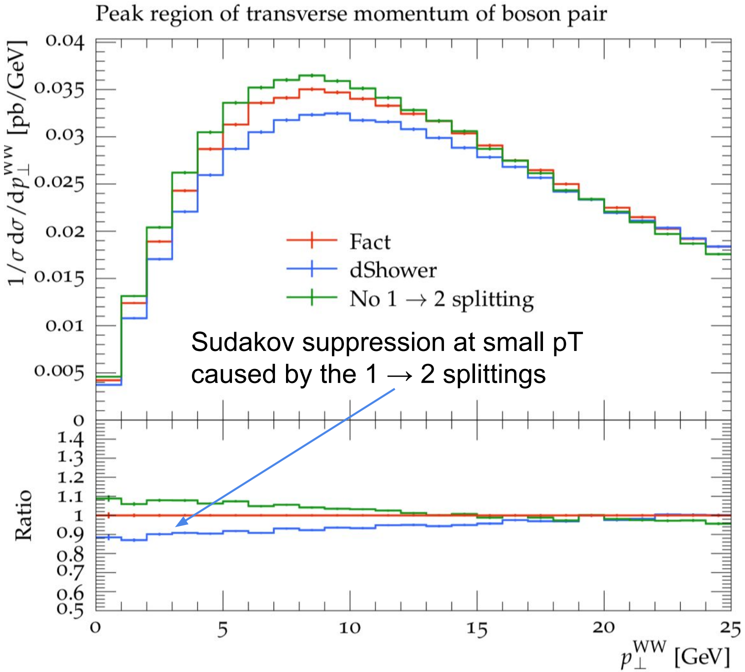
No parton-parton correlations

Lepton pseudorapidity asymmetry, with $\eta_\mu, \eta_e > \eta_{min}$

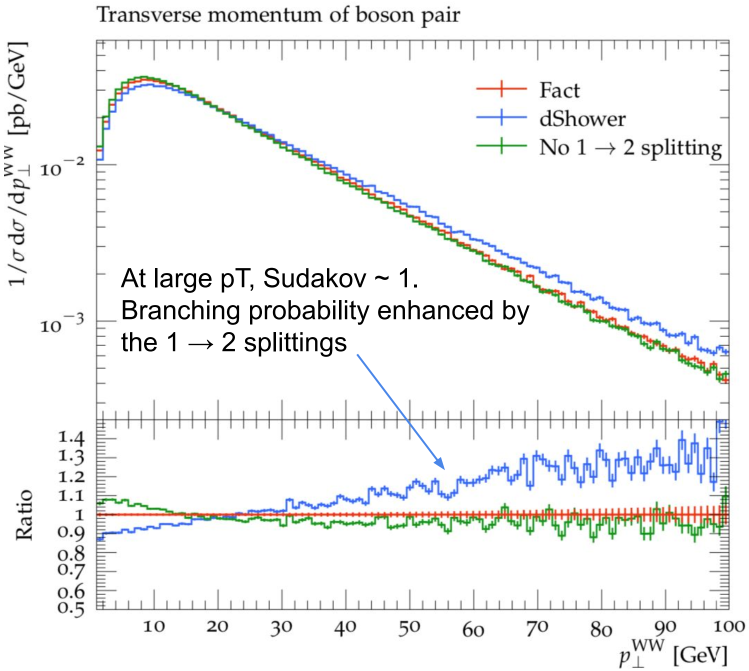


JG, Kom, Kulesza, Stirling, Eur. Phys. J. C69 (2010) 53-65, 2010

Numerical results: WW transverse momentum



Sudakov suppression at small pT caused by the 1 → 2 splittings



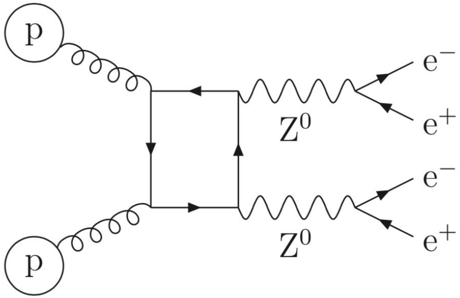
At large pT, Sudakov ~ 1. Branching probability enhanced by the 1 → 2 splittings

Branching probability for the backward branching g → dbar

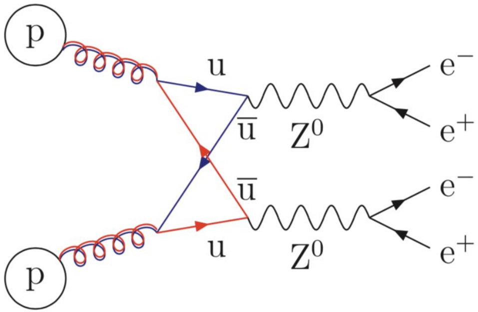
$$\sim \frac{1}{p_\perp^2} \boxed{\frac{gu}{\bar{d}u}} \exp\left(-\boxed{\frac{gu}{\bar{d}u}} \log^2\left(\frac{Q_h^2}{p_\perp^2}\right)\right)$$

Future work

- Implement procedure to **avoid double counting** between SPS and DPS, using ZZ and W+W- production as case studies.
  Diehl, JG, Schönwald, JHEP 1706 (2017) 083



SPS: loop induced



DPS + double merging

- Link to a hadronisation model: interface dShower with other event generators.

- Option to incorporate effects of longitudinal spin correlations.

Summary[1]

- **dShower** generates exclusive DPS events at parton level, with the **impact-parameter** dependence and the effects of the **1 → 2 splittings** fully taken into account.
- Any sensible set of dPDFs can be plugged into dShower → **high flexibility**.
- More developments coming.

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