Simulating Double Parton Scattering

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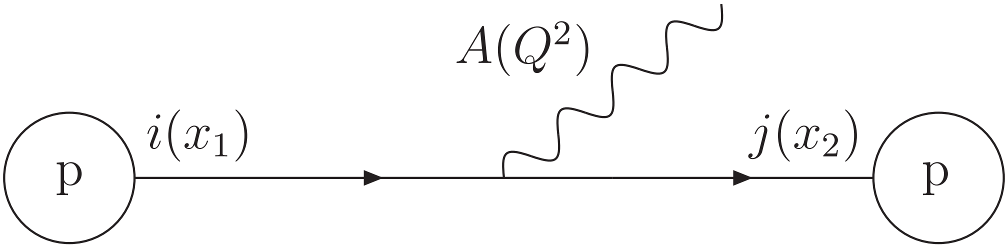
Double vs. single parton scattering

- Single parton scattering (SPS):

$$\sigma_A^{\text{SPS}} = \sum_{i,j} \int \mathrm{d}x_1 \mathrm{d}x_2 \, \hat{\sigma}_{ij\to A}(\hat{s} = x_1 x_2 s, Q^2) \, f_i(x_1, Q^2) \, f_j(x_2, Q^2).$$

- $f_i(x, Q^2)$: Parton Distribution Functions (PDFs).

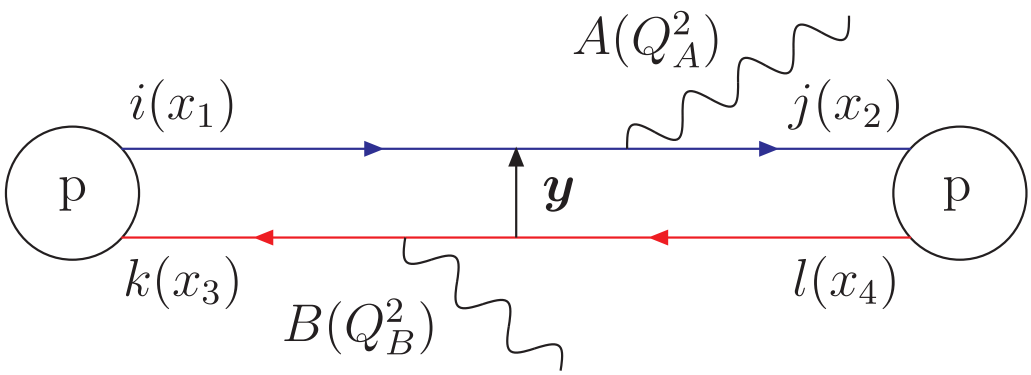


Double vs. single parton scattering

- Double parton scattering (DPS) [1111.0910, 1510.08696, 1702.06486, 1707.07606, 1812.09509]:

$$\sigma^{\rm DPS}_{(A,B)} = \sum_{i,j,k,l} \int {\rm d}x_1\, {\rm d}x_2\, {\rm d}x_3\, {\rm d}x_4\, \hat{\sigma}_{ij\to A}(x_1 x_2 s, Q_A^2)\, \hat{\sigma}_{kl\to B}(x_3 x_4 s, Q_B^2)$$
$$\int {\rm d}^2\boldsymbol{y}\, F_{ik}(x_1, x_3, \boldsymbol{y}, Q_A^2, Q_B^2) F_{jl}(x_2, x_4, \boldsymbol{y}, Q_A^2, Q_B^2).$$

- $F_{ij}(x_1, x_2, \boldsymbol{y}, Q_A^2, Q_B^2)$: dPDFs.



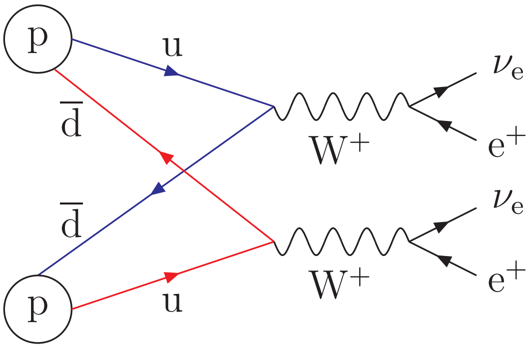
Why do we consider double parton scattering?

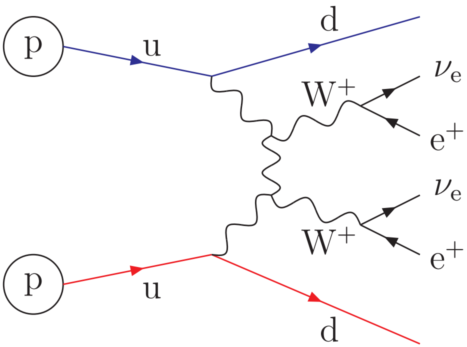
$\sigma^{\mathrm{DPS}}_{(A,B)} / \sigma^{\mathrm{SPS}}_{A+B} \sim \Lambda^2/Q^2$. But:

- For bosons with small transverse momenta [1111.0910]:

$$\frac{\mathrm{d}\sigma^{\mathrm{DPS}}_{(A,B)}}{\mathrm{d}^2\boldsymbol{q}_A \mathrm{d}^2\boldsymbol{q}_B} \sim \frac{\mathrm{d}\sigma^{\mathrm{SPS}}_{A+B}}{\mathrm{d}^2\boldsymbol{q}_A \mathrm{d}^2\boldsymbol{q}_B}$$

- SPS might be suppressed by a higher multiplicity of couplings:





dDGLAP equations

- Homogeneous equal-scale dDGLAP equations [1111.0910, 1702.06486]:

$$\mathrm{d}F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2) = \frac{\mathrm{d}Q^2}{Q^2} \left(\sum_{i'} P_{i' \to i}\left(\frac{x_1}{x'_1}\right) \otimes F_{i'j}(x'_1, x_2, \boldsymbol{y}, Q^2) + \sum_{j'} P_{j' \to j}\left(\frac{x_2}{x'_2}\right) \otimes F_{ij'}(x_1, x'_2, \boldsymbol{y}, Q^2) \right)$$

- Inhomogeneous term included inside $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)$ ($1/\boldsymbol{y}^2$ behaviour) [1702.06486].

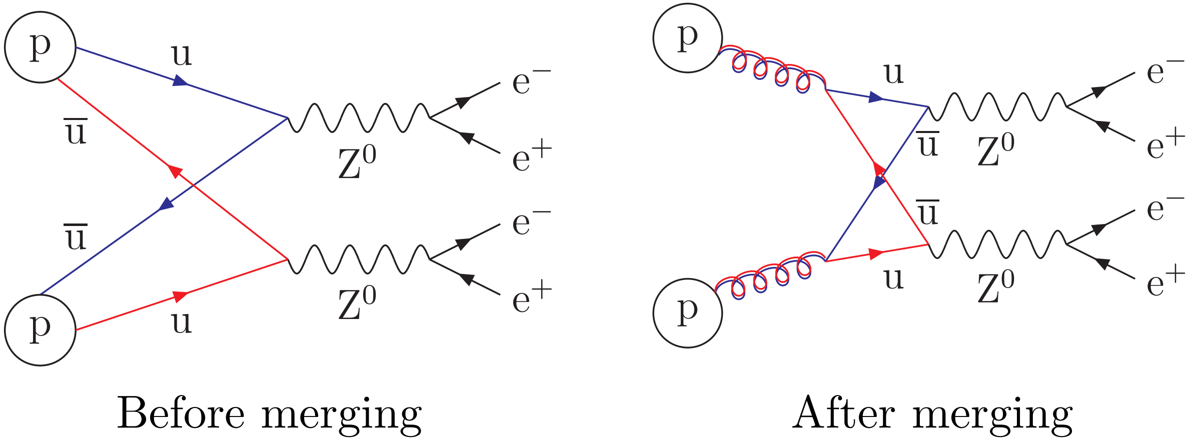
The simulation

- dShower: simulation based on the DGS framework, with $\boldsymbol{y}$-dependent dPDFs [1702.06486].
- Algorithm: [1906.04669]

1. Select two separate hard processes with the DPS cross section. A value for $\boldsymbol{y}$ is also selected.
2. Define the branching probability as $\mathrm{d}\mathcal{P}_{ij} = \mathrm{d}F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)/F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)$ (+ Sudakov) [0408302].
3. Simultaneous backward evolution of the two hard processes with an angular-ordered shower.

Merging

- The possibility to have mergings is included in the simulation (happens at the scale $Q^2 = 1/\boldsymbol{y}^2$):

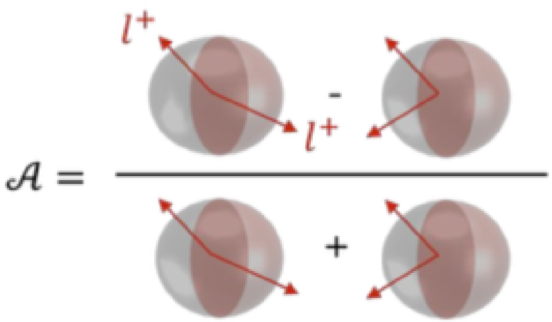


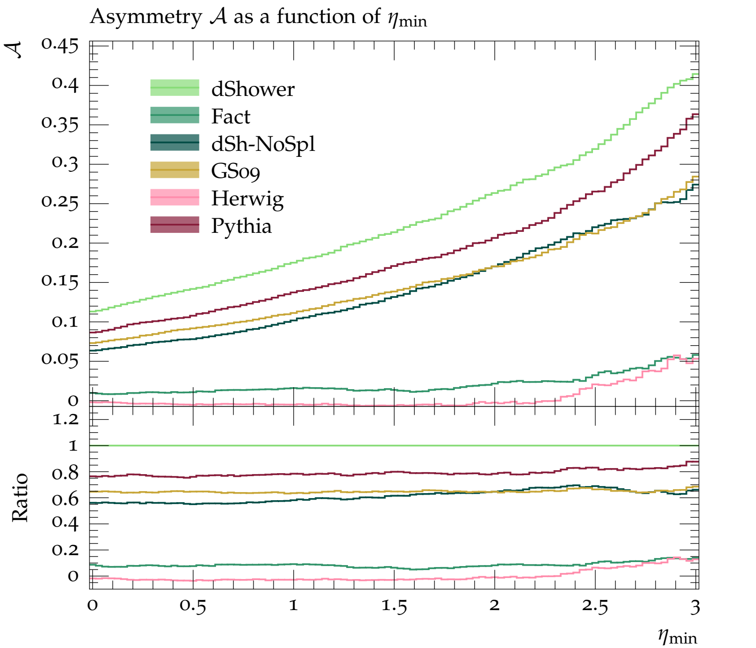
- But far from perfect (kinematics very difficult): much room for improvements!

Results – W^+W^+

- DPS: $W^+ \to e^+\nu_e \oplus W^+ \to \mu^+\nu_\mu$ (no SPS channel) [1906.04669].

Lepton pseudorapidity asymmetry, with $\eta_\mu, \eta_e > \eta_{\text{min}}$ [1003.3953, 1809.09024].





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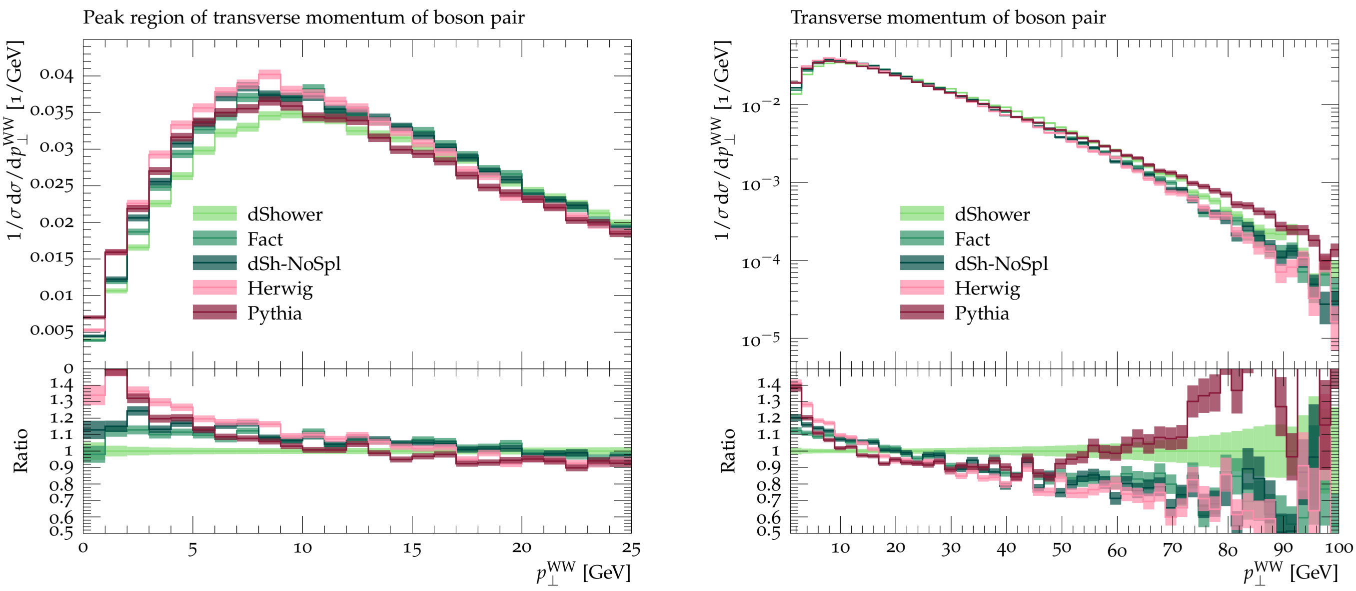


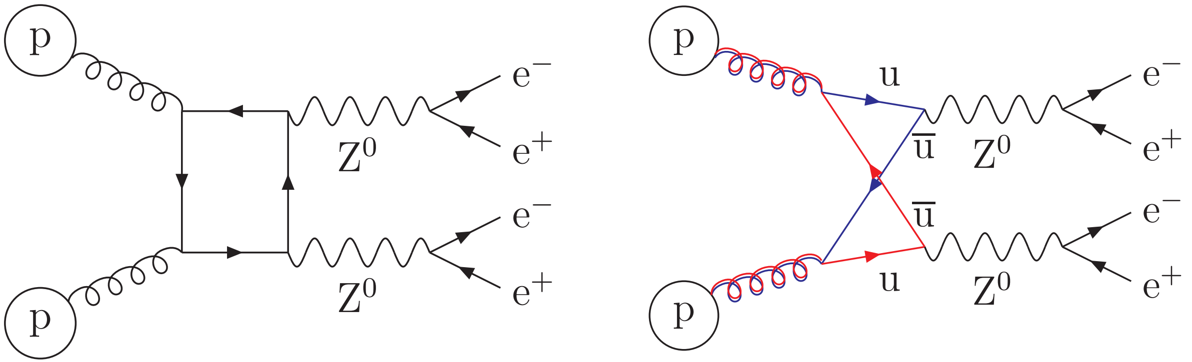
In the future

- Extension to include massive quarks in the shower: 3 flavours $\rightarrow$ 5 flavours.

- Interface the DPS simulation with the current event generators. How? – Input as Les Houches file which contains the parton-level DPS events.

In the future

- Combine SPS and DPS events: the example of Z^0Z^0 production.
- Problem: double counting between SPS and DPS + merging.



SPS: loop induced

DPS + merging

- A scheme was developed to remove the double-counting issues [1702.06486].

Summary

- dShower generates exclusive DPS events at parton-level, with the impact-parameter dependence fully taken into account.
- Any set of dPDFs which satisfies the DGS framework can be plugged into the simulation: high flexibility.
- Coming soon: possibility to interface the simulation with the current event generators.

Thanks[1]

Thanks for your attention!

[1] This work has received funding from the European Union's Horizon 2020 research and innovation programme as part of the Marie Skłodowska-Curie Innovative Training Network MCnetITN3 (grant agreement no. 722104).

Backup

- DPS: $W^+ \to e^+\nu_e \oplus W^+ \to \mu^+\nu_\mu$ (no SPS channel) [1906.04669].

Setup	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 14$ TeV
dShower	0.170 ± 0.002	0.718 ± 0.007
dSh-NoSpl	0.102 ± 0.001	0.451 ± 0.004
Fact	0.1571 ± 0.0001	0.6558 ± 0.0006
GS09	0.1364 ± 0.0001	0.6001 ± 0.0005
PYTHIA 8	0.1349 ± 0.0004	0.584 ± 0.002
DPS pocket formula	0.1585 ± 0.0004	0.660 ± 0.002

Table 1: Total DPS cross section in femtobarns [fb] for different setups and for different centre-of-mass energies $\sqrt{s}$. The statistical error is given.