Combining Double Parton Distributions and Parton Showers

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Outline[1]

1. Introduction: double vs. single parton scattering

2. A parton shower using double parton distributions

3. Summary

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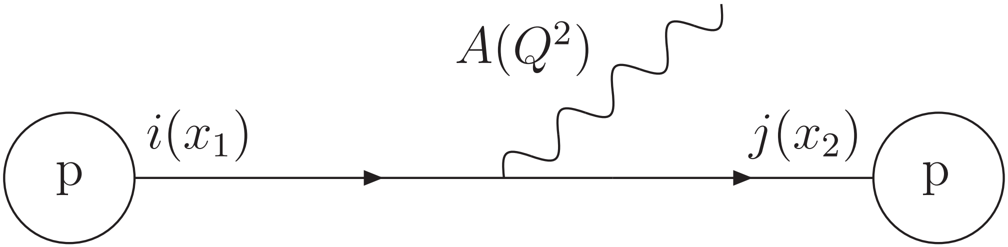
Double vs. single parton scattering

- 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).



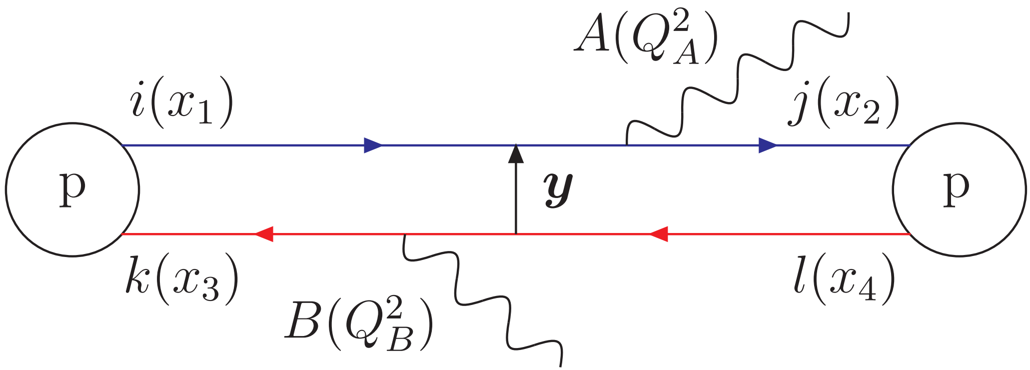
Double vs. single parton scattering

- Double parton scattering (DPS) [1710.04408]:

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

$$\int \mathrm{d}^2\boldsymbol{y}\, F_{ik}(x_1, x_3, \boldsymbol{y}, Q_A^2, Q_B^2) F_{jl}(x_2, x_4, \boldsymbol{y}, Q_A^2, Q_B^2).$$

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



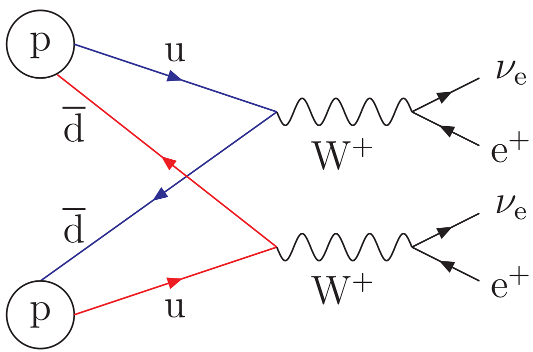
Why considering double parton scattering?

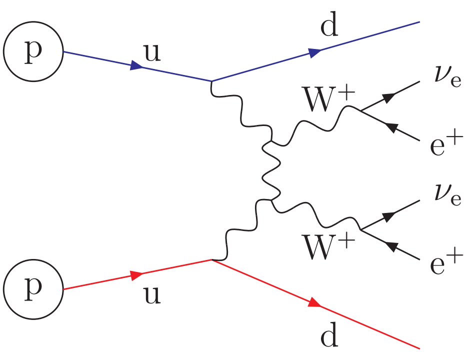
$\sigma^{\text{DPS}}_{(A,B)}/\sigma^{\text{SPS}}_{A+B} \sim \Lambda^2/Q^2$. But:

- In some very specific regions of phase-space [1111.0910]:

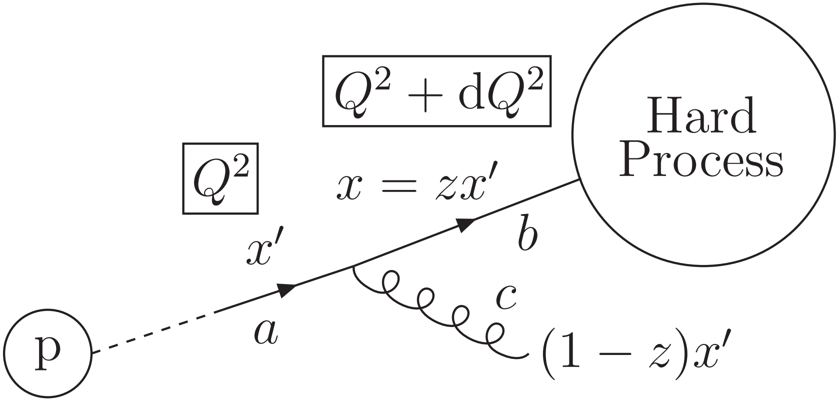
$$\frac{\mathrm{d}\sigma^{\text{DPS}}_{(A,B)}}{\mathrm{d}^2\boldsymbol{q}_A\mathrm{d}^2\boldsymbol{q}_B} \sim \frac{\mathrm{d}\sigma^{\text{SPS}}_{A+B}}{\mathrm{d}^2\boldsymbol{q}_A\mathrm{d}^2\boldsymbol{q}_B}$$

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





- Define the probability $\mathrm{d}\mathcal{P}_b = \mathrm{d}f_b(x, Q^2)/f_b(x, Q^2)$.



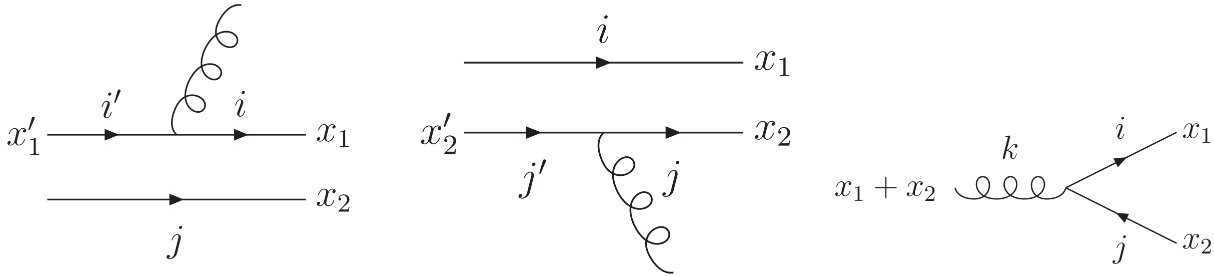
- Evolve downwards in Q^2 according to DGLAP equation:

$$\mathrm{d}f_b(x, Q^2) = \frac{\mathrm{d}Q^2}{Q^2} \sum_a P_{a\to bc}\left(\frac{x}{x'}\right) \otimes f_a(x', Q^2)$$

dDGLAP equation

- Write $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2) = f_{ij}(x_1, x_2, Q^2) F(\boldsymbol{y})$ [0910.4347].

$$\mathrm{d}f_{ij}(x_1, x_2, Q^2) = \frac{\mathrm{d}Q^2}{Q^2} \left(\sum_{i'} P_{i' \to i}\left(\frac{x_1}{x_1'}\right) \otimes f_{i'j}(x_1', x_2, Q^2) + \sum_{j'} P_{j' \to j}\left(\frac{x_2}{x_2'}\right) \otimes f_{ij'}(x_1, x_2', Q^2) + \frac{1}{x_1 + x_2} \frac{\alpha_s(Q^2)}{2\pi} P_{k \to ij}\left(\frac{x_1}{x_1 + x_2}\right) f_k(x_1 + x_2, Q^2) \right)$$



(a) (b) (c)

Parton shower with dPDFs

- As before, define a branching probability as $\mathrm{d}\mathcal{P}_{ij} = \mathrm{d}f_{ij}(x_1, x_2, Q^2)/f_{ij}(x_1, x_2, Q^2)$ [0408302].
- An angular-ordered parton shower is generated with the usual veto algorithm.
- dPDFs: GS09 set from J. Gaunt and J. Stirling [0910.4347].
  Single PDFs: MSTW 2008 set [0901.0002].
- Compare with the naive ansatz:

$$f_{ij}(x_1, x_2, Q^2) = f_i(x_1, Q^2) f_j(x_2, Q^2)(1 - x_1 - x_2)^p,$$

with $p = 0, 1, 2$.

Results – Number of emissions

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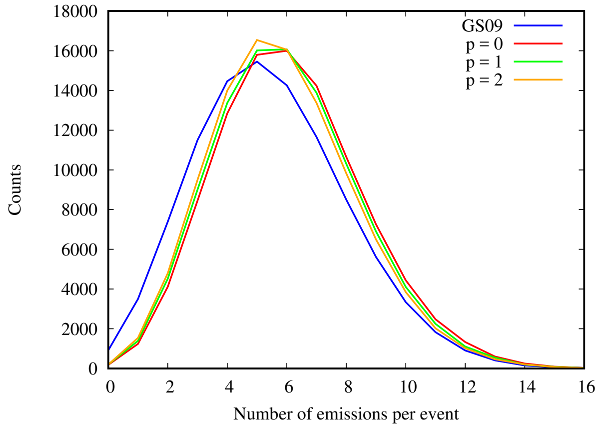

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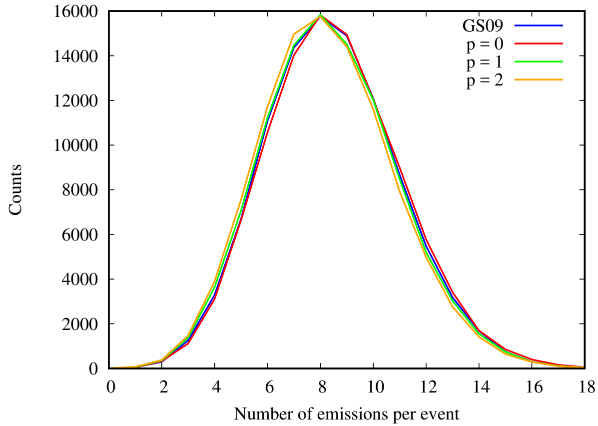
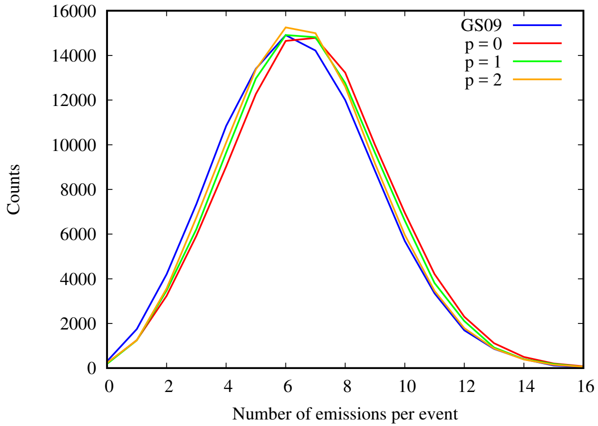


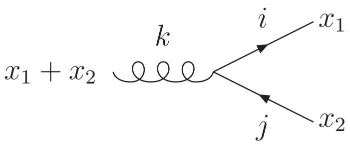
$s\bar{s}$



Results – Fraction of mergings

$f_{\text{mergings}}[\%]$	uu	gg	$s\bar{s}$
GS09	4.878	13.477	31.128
$p = 0$	6.396	13.248	27.943
$p = 1$	7.583	16.450	30.356
$p = 2$	8.358	19.091	32.302

Table 1: Fraction of events where the two branches have merged.



Summary

- Double parton scattering must be included to improve the precision of event generators. Combine dPDFs and parton showers.
- Use the $\boldsymbol{y}$-dependent dPDFs $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)$ (work in progress).
- Extension to two different energy scales Q_A^2 and Q_B^2?
- MPI models might benefit from a parton shower based on dPDFs.

Thanks for your attention!

Backup: Problems with the current model?

- In fact, using an inhomogeneous evolution equation with the standard veto algorithm is troublesome.
- Recall that unitarity and virtual corrections impose to use the probability:

$$\mathrm{d}\mathcal{P}_{ij}^{\mathrm{ISR}} = \underbrace{\mathrm{d}\mathcal{P}_{ij}}_{\text{naive probability}} \underbrace{\exp\left(-\int \mathrm{d}\mathcal{P}_{ij}\right)}_{\text{Sudakov factor}}.$$

- However, there is no virtual contributions to the inhomogeneous term of $\mathrm{d}\mathcal{P}_{ij}$.
- Solution: use $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2)$ instead which satisfies the homogeneous dDGLAP equation [1702.06486].

Backup: Sudakov form factor

- Radioactive decay : probability $N(t)$ that the nucleus remains after a time t.

$$\frac{\mathrm{d}N(t)}{\mathrm{d}t} = -c(t)\,N(t),$$

which leads to : $N(t) = \exp\left(-\int_0^t c(t')\mathrm{d}t'\right)$ and :

$$-\mathrm{d}N(t) = \underbrace{\mathrm{d}t\,c(t)}_{\text{naive probability of decay}} \underbrace{\exp\left(-\int_0^t c(t')\,\mathrm{d}t'\right)}_{\text{Sudakov factor}}$$

- Sudakov factor : probability that no decay has occurred before t.

Backup: dDGLAP equation

- Write $F_{ij}(x_1, x_2, \boldsymbol{y}, Q^2) = f_{ij}(x_1, x_2, Q^2) F(\boldsymbol{y})$. dDGLAP [0910.4347]:

$$\mathrm{d}f_{ij}(x_1,x_2,Q^2) = \frac{\mathrm{d}Q^2}{Q^2}\left(\sum_{i'}\int_{x_1}^{1-x_2}\frac{\mathrm{d}x_1'}{x_1'}\frac{\alpha_\mathrm{s}(Q^2)}{2\pi}P_{i'\to i}\left(\frac{x_1}{x_1'}\right)f_{i'j}(x_1',x_2,Q^2)\right.$$
$$+\sum_{j'}\int_{x_2}^{1-x_1}\frac{\mathrm{d}x_2'}{x_2'}\frac{\alpha_\mathrm{s}(Q^2)}{2\pi}P_{j'\to j}\left(\frac{x_2}{x_2'}\right)f_{ij'}(x_1,x_2',Q^2)$$
$$\left.+\frac{1}{x_1+x_2}\frac{\alpha_\mathrm{s}(Q^2)}{2\pi}P_{k\to ij}\left(\frac{x_1}{x_1+x_2}\right)f_k(x_1+x_2,Q^2)\right)$$