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# The GS09 Double Parton Distribution Functions

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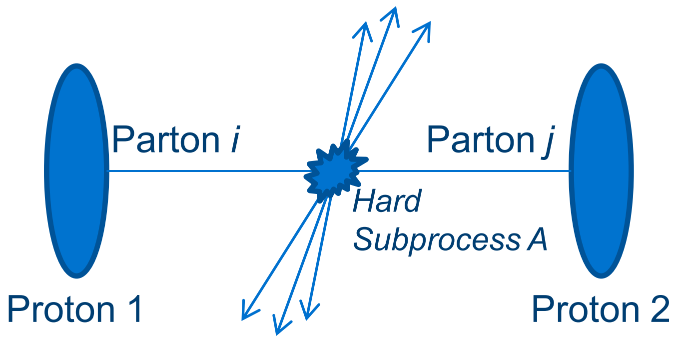
**Work performed in collaboration with W.J. Stirling (arXiv:0910.4347), and C.H. Kom, A. Kulesza and W.J. Stirling (arXiv:1003.3953).**

# Single vs. Double Parton Scattering

## Single Parton Scattering (SPS):

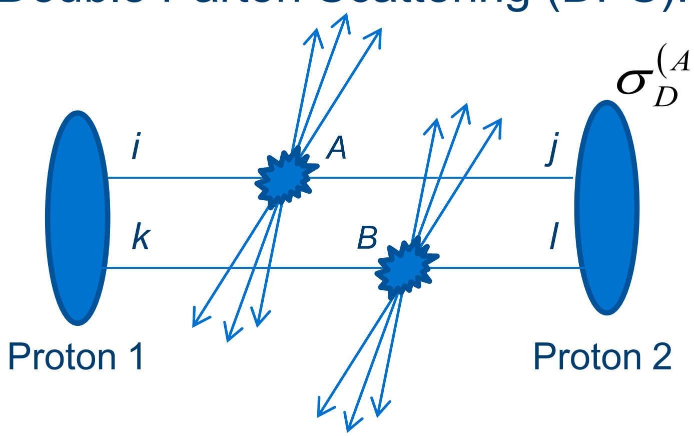



$$\sigma_S^{(A)} = \sum_{i,j} \int D_h^i(x_1;Q_A)\, D_h^j(x_1';Q_A)\, \hat{\sigma}_{ij}^A(x_1,x_1')\, \mathrm{d}x_1\, \mathrm{d}x_1'$$

(Single) Parton Distribution Functions

Hard subprocess cross section

## Double Parton Scattering (DPS):




Symmetry factor

**Double Parton Distribution Functions** (dPDFs)

$$\sigma_D^{(A,B)} = \frac{m}{2\sigma_{eff}} \sum_{i,j,k,l} \int D_h^{ik}(x_1,x_2;Q_A,Q_B)\, D_h^{jl}(x_1',x_2';Q_A,Q_B) \times \hat{\sigma}_{ij}^A(x_1,x_1')\, \hat{\sigma}_{kl}^B(x_2,x_2')\, \mathrm{d}x_1\, \mathrm{d}x_1' \mathrm{d}x_2\, \mathrm{d}x_2'$$

Factor related to correlations of partons in transverse space

# Why should we care about double parton scattering at the LHC?

Crudest approximation for dPDFs:

$$D_h^{ij}(x_1,x_2;Q_A,Q_B) \approx D_h^i(x_1;Q_A) D_h^j(x_2;Q_B)$$

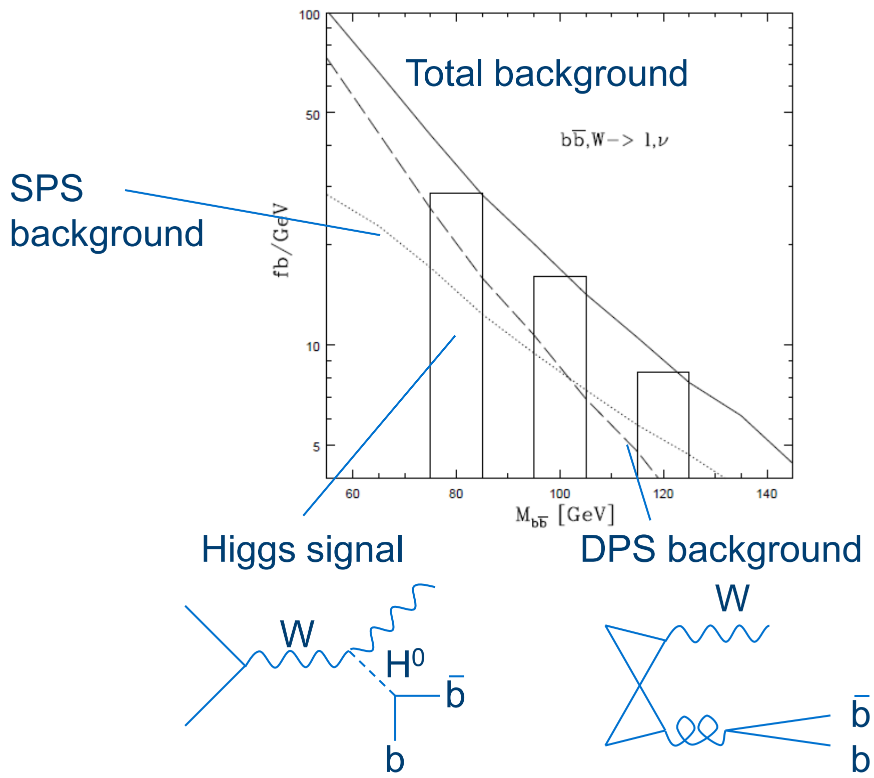
$$\Rightarrow \sigma_D^{(A,B)} \approx \frac{m}{2} \frac{\sigma_S^{(A)} \sigma_S^{(B)}}{\sigma_{eff}}$$

⇒DPS cross sections go like the product of SPS ones!
⇒DPS cross sections **grow faster with energy than SPS $\sigma$.**

DPS processes...

- provide significant backgrounds to Higgs and new physics signals.
- reveal information about the structure of the proton.

DPS background to Higgs + W production (Del Fabbro and Treleani, hep-ph/9911358,1999):

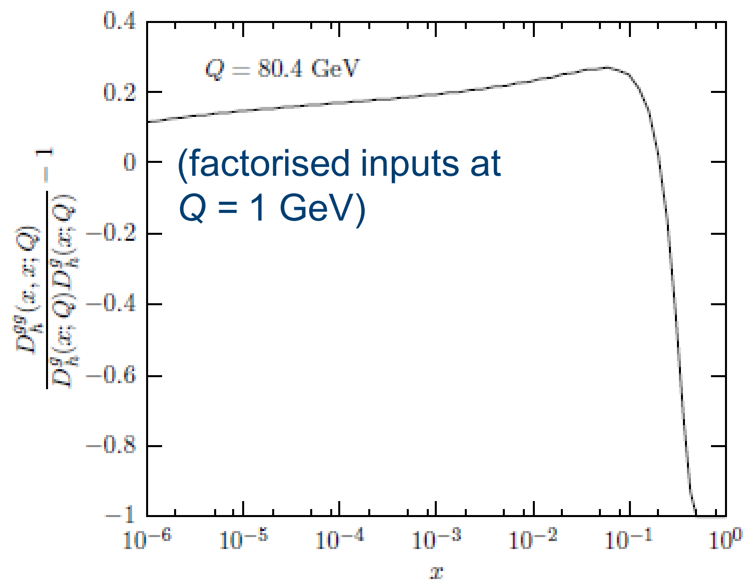


# What information do we have on the dPDFs?

**Experimental**: CDF/D0 investigations of DPS. Their findings are consistent with the factorised approximation for dPDFs (but low statistics & looking at sea quarks at low *x* only).

**Theoretical**: 'double DGLAP equation' describing the change in the dPDFs with factorisation scale, for the dPDFs with $Q_A = Q_B = Q$. (Kirschner, Phys.Lett.B84:266**,** 1979 and Shelest, Snigirev, and Zinovjev, Phys.Lett.B113:325**,**1982).

Crucial prediction of this equation: **pQCD evolution causes dPDFs to deviate from factorised forms!**




JG and Stirling, 0910.4347, 2009

# Input dPDFs

The most accurate approach to modelling the (equal scale) dPDFs is to use the double DGLAP equation along with some suitably chosen inputs at a low scale $Q_0$.

But what should the inputs look like? **Can we get any theoretical insight**?

First reaction - **NO**! A dPDF at any particular scale receives contributions from **non-perturbative physics**.

# The dPDF Sum Rules

Actually – **YES**, we can! We have shown that the following equalities (**sum rule equalities**) are preserved by double DGLAP:

$$\sum_{j_1} \int_0^{1-x_2} dx_1 x_1 D_h^{j_1 j_2}(x_1, x_2; t) = (1 - x_2) D_h^{j_2}(x_2; t)$$

$$\int_0^{1-x_2} dx_1 D_h^{j_{1v} j_2}(x_1, x_2; t) = \begin{cases} N_{j_{1v}} D_h^{j_2}(x_2; t) & \text{when } j_2 \neq j_1 \text{ or } \bar{j}_1 \\ (N_{j_{1v}} - 1) D_h^{j_2}(x_2; t) & \text{when } j_2 = j_1 \\ (N_{j_{1v}} + 1) D_h^{j_2}(x_2; t) & \text{when } j_2 = \bar{j}_1 \end{cases}$$

These equalities are no more than the statements of conservation of momentum and quark number for the dPDFs, and have an interpretation in terms of conditional probabilities.

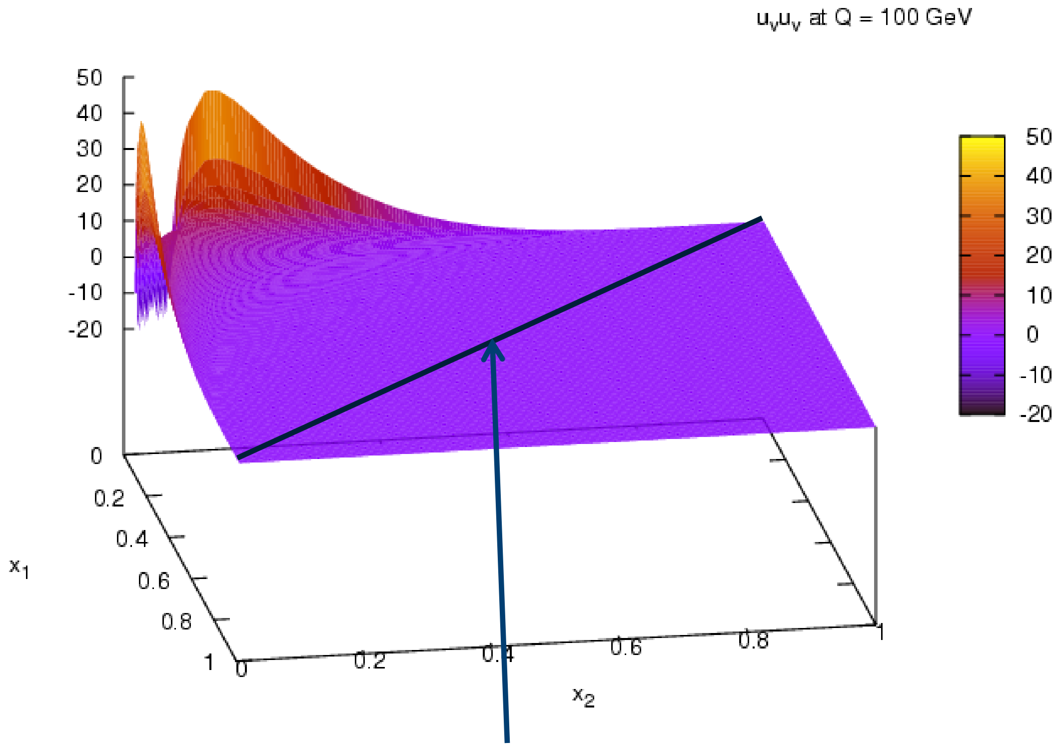
**The sum rules impose important constraints on the type of input dPDFs that are allowable.**

# The GS09 dPDFs

First set of publicly available LO equal-scale dPDFs (available from **HepForge**). Grid of dPDF values obtained by applying numerical double DGLAP evolution to certain inputs.

Inputs used at $Q_0$ = 1 GeV are based on products of MSTW2008LO single PDFs, but contain a number of **key features** to ensure that they approximately satisfy the sum rules.

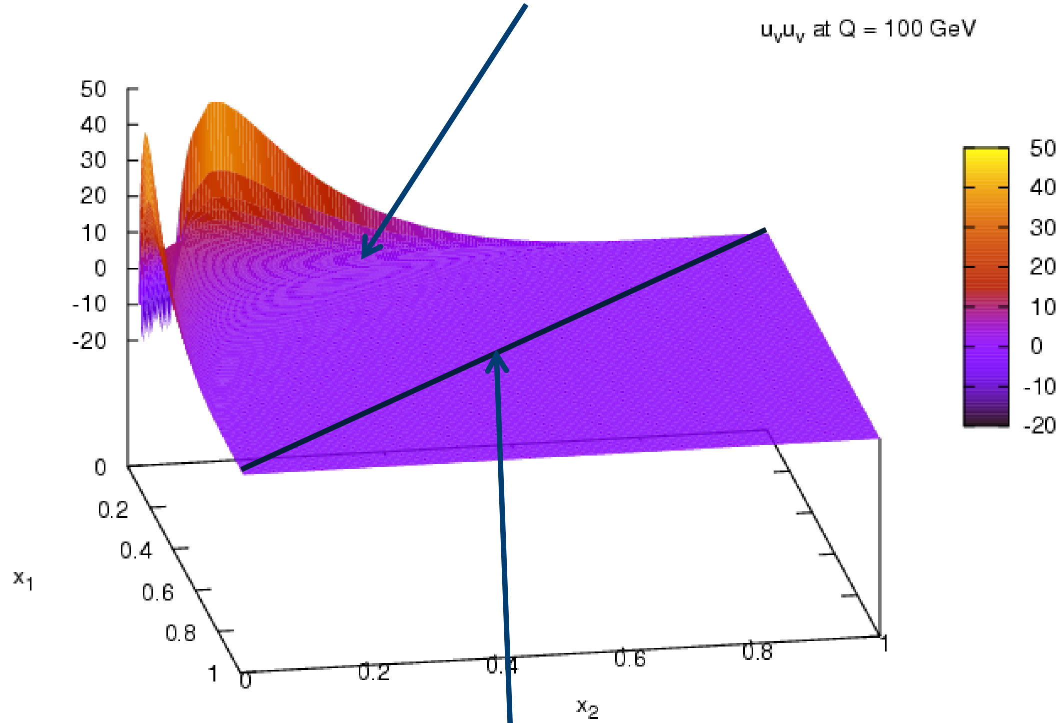
# The GS09 dPDFs




All dPDFs are suppressed near the kinematic boundary $x_1+x_2 = 1$ to take account of **phase space considerations**.

# The GS09 dPDFs

Terms have been added/subtracted from dPDFs to take account of **number effects**.

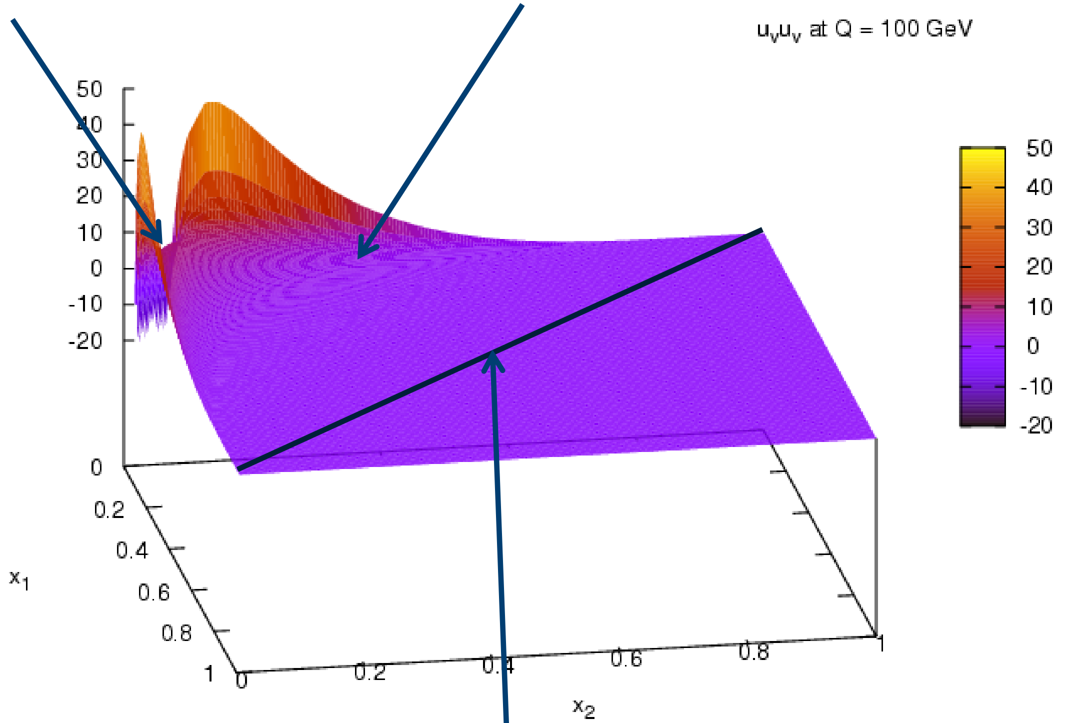



All dPDFs are suppressed near the kinematic boundary $x_1+x_2 = 1$ to take account of **phase space considerations**.

# The GS09 dPDFs

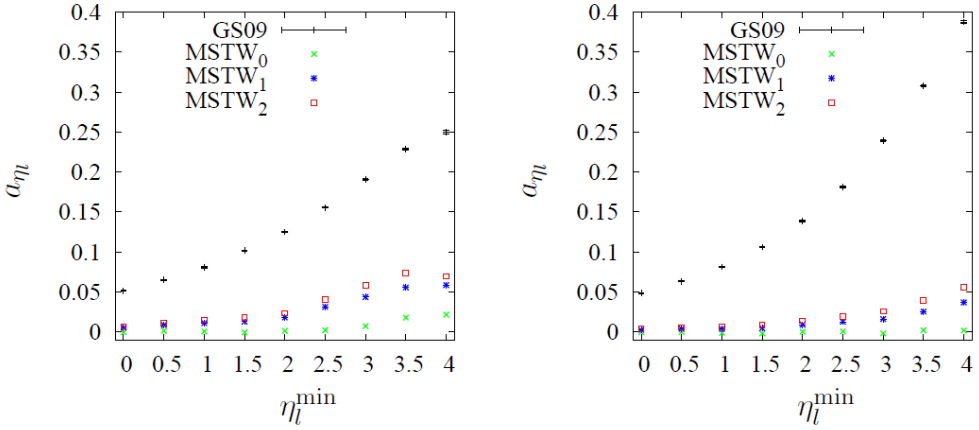
Terms have been added to the $j\bar{j}$ distributions to take account of $j\bar{j}$ **correlations**.

Terms have been added/subtracted from dPDFs to take account of **number effects**.




All dPDFs are suppressed near the kinematic boundary $x_1+x_2 = 1$ to take account of **phase space considerations**.

# Comparison of GS09 with factorised dPDFs




(a) Positively charged leptons (b) Negatively charged leptons

JG, Kom, Kulesza, Stirling, 1003.3953, 2010

Comparison in the context of a particular process – **equal sign W pair production.**

$$a_{\eta_l} = \frac{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) - \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) + \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}$$

$a_{\eta l}$ larger for GS09 due to number effect subtractions, especially for large $\eta_l^{min}$ (i.e. large *x*, where number effect subtractions have the largest impact).

# Future Work

Extend treatment to NLO!

- Need to compute $1 \rightarrow 2$ splitting functions at NLO (trivial at LO).
- Will need NLO coefficient functions for certain benchmark processes (e.g. equal sign WW production).

# Summary

- Important to understand DPS – will produce significant backgrounds and interesting signals at the LHC.
- For DPS predictions, require dPDFs. A ‘double DGLAP’ equation exists dictating the evolution of the equal-scale dPDFs, and we have derived the number and momentum sum rules for these quantities.
- We have produced the first publicly available set of LO equal-scale dDPFs. Sum rules used to guide construction of inputs at $Q_0$ = 1 GeV, and double DGLAP equation used to obtain dPDF values at other scales.
- Number and momentum correlations in GS09 dPDFs affect the signatures of DPS processes – but may be difficult to see this at LHC due to SPS background.