Double Parton Scattering.

A (very) brief introduction

December 3, 2019

A bit about myself.

About myself.

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Interests:

- going to concerts and collecting records
- riding my (motor)bike
- snowboarding (probably not much any more)
- recently started bouldering

Academic career:

- B. Sc. in Regensburg, 2010 - 2013
- M. Sc. in Regensburg, 2013 - 2015
  "Cancellation of Glauber gluon exchange in the double Drell-Yan process"
- PhD in Regensburg, 2015 - 2019
  "Double Parton Distributions - Perturbative splitting, sum rules and models"

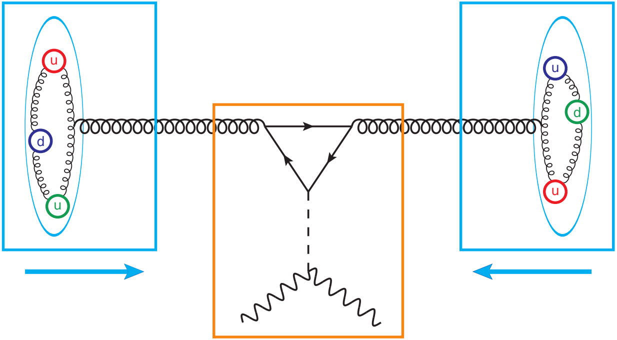
Research interests:

- double parton scattering and double parton distributions
- parton distributions in general
- perturbative QCD

Physics.

How to calculate cross sections for LHC physics?

The most important tool for the calculation of cross sections at the LHC is given by factorisation theorems for single parton scattering (SPS):



$$\sigma_{pp\to H\to ZZ} = f_i(x_1, Q^2) \otimes \hat{\sigma}_{ij\to H\to ZZ}(\hat{s} = x_1\bar{x}_1 s) \otimes f_j(\bar{x}_1, Q^2) \; + \underbrace{\mathcal{O}\left(\frac{\Lambda}{Q}\right)}_{\text{power corrections}}$$

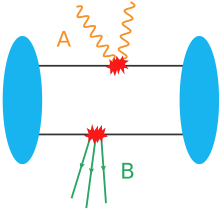
Neglecting power corrections?

As the accuracy of experimental data improves power corrections may no longer be negligible!

Precision of theoretical predictions has to keep up with the experiments, as possible signs of new physics could be missed!

One particularly interesting power correction is double parton scattering (DPS)

DPS is naturally associated with the situation where the final state can be separated into two subsets with individual hard scales

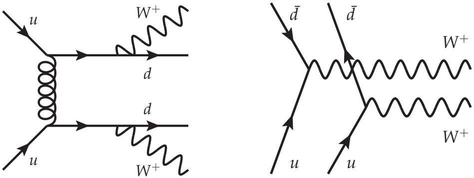


Why and/or when is DPS of interest?

Relevance of DPS

It can be shown that for final states differential in their transverse momenta DPS can be a leading contribution in some regions of phase space!

When production of a final states via SPS involves small coupling constants or higher orders in the coupling constants, DPS may also give a leading contribution (e.g. same sign WW).



DPS is not only interesting as a power correction to SPS, but also in its own right: access to information about 3D structure of protons and correlations between partons

A systematic description of DPS

Goal: proof of factorisation for DPS in close analogy to SPS!

Pioneering work in this direction already in the 1980's: Factorisation formula based on parton model picture [Politzer, 1980; Paver, Treleani, 1982; Mekhfi, 1985]

$$\sigma_{pp\to A,B} = \hat{\sigma}_{ik\to A}(x_1\bar{x}_1 s)\,\hat{\sigma}_{jl\to B}(x_2\bar{x}_2 s) \times \int \mathrm{d}^2\boldsymbol{y}\, F_{ij}(x_1,x_2,\boldsymbol{y};Q_1^2,Q_2^2)\, F_{kl}(\bar{x}_1,\bar{x}_2,\boldsymbol{y};Q_1^2,Q_2^2)$$

$F_{ij}(x_1,x_2,\boldsymbol{y};Q_1^2,Q_2^2)$ are (collinear) double parton distributions (DPDs)

Is it possible to extend the rigorous factorisation proofs from the SPS case to DPS?

YES! (for double Drell-Yan) [Diehl, Ostermeier, Schäfer, 2012; Diehl, Gaunt, Ostermeier, Plößl, Schäfer, 2016; Diehl, Nagar, 2019]

The problem with DPDs

As DPDs are genuinely non-perturbative quantities they have to be extracted either from fits to experimental data or calculated using lattice QCD.

An experimental determination of DPDs is difficult for three reasons

- larger number of (collinear, unpolarised) DPDs than PDFs (91 vs. 13)
- DPDs depend on more variables than ordinary PDFs
- DPS cross sections are small compared to SPS cross sections

LQCD provides a tool which in theory makes it possible to obtain the proton matrix elements in the definition of a DPD from first principles!

Problem: still a long way to go before a sensible determination of DPDs from lattice data is possible [Bali et al., 2018]

Solution: Construct physically motivated DPD models

How to obtain DPDs?.

Building DPD models

How to tell whether a DPD model is a good approximation for a real DPD?

DPD Sum Rules [Gaunt, Stirling, 2010]

$$\int_0^{1-x_1} \mathrm{d}x_2\, F_{ij_v}(x_1, x_2, \mathbf{\Delta} = 0) = \left(N_{j_v} + \delta_{i,\bar{j}} - \delta_{i,j}\right) f_i(x_1)$$

$$\sum_j \int_0^{1-x_1} \mathrm{d}x_2\, x_2\, F_{ij}(x_1, x_2, \mathbf{\Delta} = 0) = (1 - x_1) f_i(x_1)$$

$\longrightarrow$ Use these sum rules to construct a sum rule improved position space DPD model!

What I did during my PhD.

During my PhD I worked on three closely connected projects:

1. Proof of the DPD sum rules in QCD
   - the original DPD sum rule paper by Gaunt and Stirling glossed over the subtleties of renormalisation
   - we showed that the sum rules are valid for renormalised DPDs at all orders in the strong coupling
2. Building sum rule improved position space DPD models
   - we showed that the DPD sum rules can be used to constrain position space DPD models
   - in particular this highlighted the importance of the splitting contribution
3. Calculation of the two-loop splitting contribution to DPDs
   - we calculated the two-loop correction to the perturbative splitting part of a DPD
   - with this the last missing piece for NLO DPD models and DPS calculations is now known

What I plan to do during my Postdoc.

As a first project during my stay here at DESY I want to put the results of my PhD to use and finally calculate DPS cross sections:

- use the sum rule improved position space model DPDs in cross section calculations
- incorporate the NLO splitting into the DPD model
- help with the development of the ChiliPDF library for fast and precise renormalisation scale evolution of PDFs and DPDs

Besides this I am also part of the DFG Forschergruppe "Next Generation Perturbative QCD for Hadron Structure: Preparing for the Electron-Ion Collider".

- mostly concerned with TMD physics
- higher twist contributions to DPDs