A SPIN ON SAME-SIGN W BOSON PAIR PRODUCTION AT THE LHC

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MAIN MESSAGE OF THIS TALK:
Main message of this talk:

- Interparton correlations in the proton can be important
- Two-parton spin correlations can be measured at the LHC
PART I

INTERPARTON CORRELATIONS
THE PROTON STRUCTURE THROUGH A (PARTON-)PAIR OF GLASSES

Factorized cross section

\[
\frac{d\sigma_{DPS}}{\prod_{i=1}^{2} dx_i d\bar{x}_i} \sim \prod_{i=1}^{2} \int d^2 y H_i(q_i^2) \Phi_{DPS}(x_i, y) \bar{\Phi}_{DPS}(\bar{x}_i, y)
\]

Paver, Treleani (1982); Mekhfi (1985)
Diehl, Ostermeier, Schäfer, (2011)
THE PROTON STRUCTURE THROUGH A (PARTON-)PAIR OF GLASSES

Diagrammatic approach

\[
\Phi_{DPS} \sim \mathcal{F} \mathcal{T} \langle P | [\bar{q}(-\frac{1}{2}z_2)U_{[0,z_2]}q(\frac{1}{2}z_2)][\bar{q}(y - \frac{1}{2}z_1)U_{[y,z_1]}q(y + \frac{1}{2}z_1)] | P \rangle
\]

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Double parton correlator -> It naturally includes all the two-patron information an correlations
TYPES OF CORRELATIONS BETWEEN PARTONS INSIDE THE PROTON

The correlator describes quantum correlations, kinematical or mixed ones:

- Mehkfi, Artru (1985)
- Diehl, Ostermeier, Schäfer (2011)
- Manohar, Waalewijn (2012)
- Echevarria, Kasemets, Mulders, Pisano (2014)
- Rinaldi, Scopetta, Traini, Vento (2014)
- Ceccopieri, Rinaldi, Scopetta (2017)
- Kasemets, Scopetta (2017)
- Blok, Strikman (2017)
TYPES OF CORRELATIONS BETWEEN PARTONS INSIDE THE PROTON

The correlator describes quantum correlations, kinematical or mixed ones:

- Color
- Spin (polarization)
  - longitudinal
- Flavor interference
- Fermion number interference
- Between $y$ and $x_i$
- Parton type and $y$
- Between $x_i$
- ...

$(a + b) = (a' + b') \iff \begin{cases} a = a' \\ b = b' \end{cases}$

References:
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SPIN STRUCTURE

One can parametrize the $\Phi_{DPS}$ in terms of double parton distributions DPDs that contain parton polarization information.

$$f_{q_1,q_2} \sim \langle P| (\bar{q}_1 \Gamma_{q_1} q_1) (\bar{q}_2 \Gamma_{q_2} q_2) |P\rangle$$

The different Dirac matrices select quarks of different polarization:

$$\Gamma_q = \frac{1}{2} \gamma^+$$
$$\Gamma_{\Delta q} = \frac{1}{2} \gamma^+ \gamma_5$$
$$\Gamma_{\delta q}^j = \frac{1}{2} i \sigma^j \gamma^+ \gamma_5 \quad (j = 1, 2)$$
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AMOUNT OF QUARK POLARIZATION

The collinear DPS correlator is a diagonal operator. Some combination of functions have a probability interpretation.

In absence of transverse polarization:

\[ |f_{\Delta q \Delta q}| \leq f_{qq} \]

Partonic interpretation:
THE MODEL: MIX-TO-MAX POLARIZATION

\[ f_{\Delta q \Delta q}(x_1, x_2, y; Q_0) = (-1)^n f_{qq}(x_1, x_2, y; Q_0) \]

- \( n = 1 \) both quarks or antiquarks in the pair
- \( n = 2 \) mixed quark-antiquark in the pair
THE MODEL: MIX-TO-MAX POLARIZATION

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- \( n = 2 \): mixed quark-antiquark in the pair

- Bound saturated with mixed signs at the initial (low) scale + evolution with polarized dDGLAP

- Within what is allowed by the positivity bounds, we maximize the effects of polarization (mix-to-max scenario has the biggest impact on the final state distributions of all the other investigated correlations).

- Maximizing the correlation scenarios will help estimate if/when experiments can start detecting or constraining these correlation models.

- Other models are possible, e.g. \( n = 2 \) for all quarks and antiquarks.
SINGLE PDFS

All the DPDs are unknown, therefore we reduce them to single PDFs.

We assume that (unpolarized distribution):

\[ f(x_1, x_2, y; Q_0) = f(x_1; Q_0) f(x_2; Q_0) G(y) \]

\[ \int d^2 y G^2(y) = \sigma^{-1}_{eff} \quad Q_0 = 1 \text{ GeV} \]
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KINEMATIC CORRELATIONS

- Evolution from the initial scale always creates (small) longitudinal correlations
- We investigated Additional phase-space factor \((1 - x_1 - x_2)^2(1 - x_1)^{-2}(1 - x_2)^{-2}\)
  These longitudinal correlations only minimally contribute wrt SPIN. Dedicated studies are necessary.
DPS theory in full glory

\[ \sigma_{DPS} \sim \frac{\sigma_1 \sigma_2}{\sigma_{eff}} \]
THEORY VS REALITY

Full richness of quantum and kinematic two-patron correlations in the $\Phi_{DPS}$

DPS theory in full glory

$$\sigma_{DPS} \sim \frac{\sigma_1 \sigma_2}{\sigma_{eff}}$$

Simplest possible approach is to assume that there are NO correlations of any types between the two partons inside the proton.
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PART II

IMPACT OF CORRELATIONS IN SAME–SIGN W BOSON PAIR PRODUCTION (SSW)
SAME SIGN W BOSON PAIR PRODUCTION (SSW)

Advantages

- It is initiated by quarks (we can study quark polarization)

- The W couples only with left-handed (right-handed) quarks (antiquarks) -> helicity flip is not allowed -> only *longitudinal* polarization of the quarks is directly accessed (no double transversity)

- The single parton equivalent is suppressed and it involves the production of two jets. This makes the signal clean.
Impact of Polarization in the Cross Section

Considering quark polarization, the expression for the cross section reads:

\[
\begin{align*}
\sim & \left(1 - \tanh \eta_{\mu_1}\right)^2 \left(1 - \tanh \eta_{\mu_2}\right)^2 \int d^2 y \left(f_{q_1 q_2} + f_{\Delta q_1 \Delta q_2}\right) \\
& \times \left(\frac{\bar{f}_{q_3 q_4}}{\bar{f}_{q_3 q_2}} + \frac{\bar{f}_{\Delta q_3 \Delta q_4}}{\bar{f}_{\Delta q_3 \Delta q_2}}\right) \\
& \times \left(\frac{\bar{f}_{q_1 q_4}}{\bar{f}_{q_1 q_2}} + \frac{\bar{f}_{\Delta q_1 \Delta q_4}}{\bar{f}_{\Delta q_1 \Delta q_2}}\right)
\end{align*}
\]

Longitudinal polarization changes both the size and the shape of the cross section.

\[\eta_{\mu} \rightarrow \text{muon pseudorapidity}\]
OUR “GOLDEN” OBSERVABLE – ASYMMETRY

\[ A = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+} \]

\(\sigma^-\)
Muons in \textit{opposite} hemisphere of the detector

\(\sigma^+\)
Muons in the \textit{same} hemisphere of the detector
OUR “GOLDEN” OBSERVABLE – ASYMMETRY

\[ A = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+} \]

- \( \sigma^- \): Muons in opposite hemisphere of the detector
- \( \sigma^+ \): Muons in the same hemisphere of the detector

Great observable from the theoretical point of view

\[ A = 0 \]

In the uncorrelated scenario the asymmetry must always be zero

\[ A \neq 0 \]

A value different from zero is a sign of parton correlation
MONTE CARLO EVENT GENERATORS FOR THE SIGNAL

- Herwig 7 is used to generate final-state distributions starting from our correlated parton level results.
- The default Herwig is re-weighted (more details in the upcoming paper by Cotogno, Kasemets, Myska 1812.xxx)

![Graph showing the comparison between different event generators.](image)
TAKING CARE OF THE BACKGROUND PROCESSES:

- $WWjj$: SPS equivalent to the DPS, the process is accompanied by two extra jets.

- $WZ/ZZ$ production in which one muon from the $Z$ decay is not detected.

- $tt$ production: can produce a pair of positively charged muons.
**TAking Care of the Background Processes:**

- $WW jj$: SPS equivalent to the DPS, the process is accompanied by two extra jets.
- $WZ/ZZ$ production in which one muon from the $Z$ decay is not detected.
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**Phase-Space Cuts**

\[
|\eta_i| < 2.4, \quad 25\text{GeV} < k_T^{\text{lead}} < 50\text{GeV}, \quad 15\text{GeV} < k_T^{\text{subl}} < 40\text{GeV}, \quad k_T^{\mu_3} < 5\text{GeV},
\]
\[
\not{E}_T > 20\text{GeV}, \quad dR(\mu_1, \mu_2) > 0.1, \quad k_T^{\text{jet}1} < 50\text{GeV}, \quad k_T^{\text{jet}2} < 25\text{GeV}
\]

**Theoretical Subtraction**
RAPIDITY OBSERVABLES SENSITIVE TO QUARK SPIN

- Product $\eta_1 \eta_2$, sum $\sum_\eta = |\eta_1 + \eta_2|$ and difference $\Delta_\eta = |\eta_1 - \eta_2|$ profiles and their slopes are sensitive to correlations.
RAPIDITY OBSERVABLES SENSITIVE TO QUARK SPIN

- Product $\eta_1 \eta_2$, sum $\Sigma_\eta = |\eta_1 + \eta_2|$ and difference $\Delta_\eta = |\eta_1 - \eta_2|$ profiles and their slopes are sensitive to correlations.

PHASE-SPACE CUTS + THEORETICAL SUBTRACTION
MEASURABLE AT THE LHC?

- Given that the background suppression is as effective as we assume, LHC can be sensitive to such values of the asymmetry in the near future.

| $|\eta_i|$ | $\sigma$ [fb] | $A_{\text{Mix-Pol}}$ |
|-----------|----------------|-----------------|
| > 0       | 0.51           | 0.07            |
| > 0.6     | 0.29           | 0.11            |
| > 1.2     | 0.13           | 0.16            |

![Graph showing significance vs. integrated luminosity for different channels](image-url)
**EFFECT ON THE RAPIDITY DISTRIBUTIONS: 2D PLOT**

\[
\frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Unp}} \\
\frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Mix-Pol}}
\]

Moreover, several different observables can be constructed from the rapidity distortion (more details can be provided...).
PART III

CONCLUSIONS
CONCLUSIONS

- In double parton scattering the the final states produced in the two hard interactions are not independent of each other because parton correlations play a role.

- In particular, quark spin correlations play a role in creating distortions and asymmetries in the final state distributions.

- W boson pair production at the LHC is a very promising process for the study of polarized double parton distributions.

- We identify a promising observable to detect and measure such quark spin correlations.

- Within some assumption on the possibility of subtracting the background we predict that the measurement can be performed at the LHC in the near future.

- Even a zero value for the asymmetry would put severe constraints and provide important information on the interparton correlations in the proton.
CONCLUSIONS

- In double parton scattering the final states produced in the two hard interactions are not independent of each other because parton correlations play a role.

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THANK YOU!
 COMMENTS

- The size of the DPDs is unknown so we need to search for a relative change in specific observables.

- Including polarization in different models can change the cross section up to 30%.

- Ranging between the several correlation scenarios (quantum and kinematic) the mix-to-max polarization scenario produces the largest asymmetry.

|   | Unp | Pos-Pol | Mix-Pol | Long-corr |
|---|-----|---------|---------|-----------|
| $A$ | 0.00 | -0.05  | 0.12    | 0.01      |
| $\sigma$ [fb] | 1.74 | 1.90    | 1.21    | 1.37      |
OTHER OBSERVABLES IN SSW
\[ \frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Unp}} \quad \frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Mix-Pol}} \]
\[
\frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Unp}} \quad \frac{d\sigma_{WW}}{d\eta_A d\eta_B} \bigg|_{\text{Mix-Pol}}
\]

\(\eta_B \, \text{"Slices"}\)
$\eta_B$ "Slices"
MIN-CORR

POS-POL

MIX-POL

LONG-CORR
SLICE-ASYMMETRY
\[ \Delta \eta = |\eta_1 - \eta_2| \]
\[ \sum \eta = |\eta_1 + \eta_2| \]
\[
\frac{d\sigma}{d\Sigma_\eta} \bigg/ \frac{d\sigma}{d\Delta_\eta}
\]

\[pp \rightarrow \mu^+ \mu^+, \sqrt{s} = 13 \text{ TeV}\]

Graph showing the distribution of $\rho_\eta = \Sigma_\eta = \Delta_\eta$ with different correlations:
- min-corr
- long-corr
- pos-pol
- mix-pol
IMPACT OF LONGITUNAL POLARIZATION

\[ f_{p_1p_2}(x_1, x_2, y; Q) = \tilde{f}_{p_1p_2}(x_1, x_2; Q) G(y), \]

\[ G(y) = 1 \]

Diehl, Kasemets (2012)
IMPACT OF LONGITUDINAL POLARIZATION

\[ f_{p_1p_2}(x_1, x_2, y; Q) = \tilde{f}_{p_1p_2}(x_1, x_2; Q) G(y), \quad G(y) = 1 \]

At values of $Q$ and $x$ typical of double $W$ production the contribution of the longitudinal part can be relevant! Worth to be investigated deeper…

Diehl, Kasemets (2012)