Associated WD production at the LHC and double parton interactions

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P L A N O F T H E T A L K

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2. Theoretical framework. Comparison with ATLAS data.
3. Same-sign $W^{\pm}D^{\pm}$ states and double parton interactions
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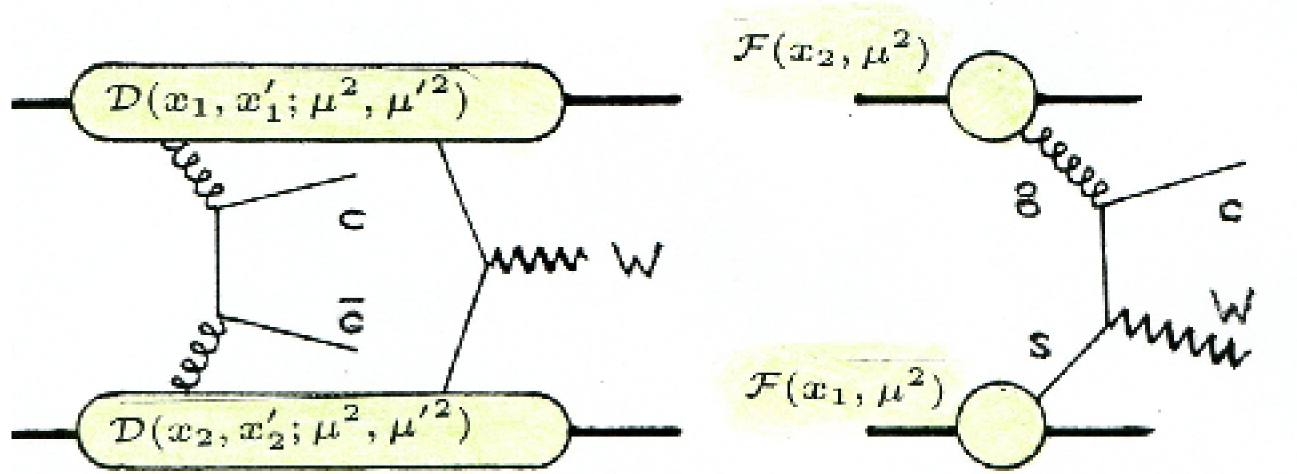
MOTIVATION

– A complex test of QCD and parton distributions
– An indicator of double-parton scattering



Our work was encouraged by the recent ATLAS measurent showing that there is enough statistics of WD events.

G. Aad *et al.* (ATLAS Collab.), JHEP 05, 068 (2014)

Attention was focused on the strange sea; to suppress other contributions (considered as background), only the difference between the opposite-sign (OS) and same-sign (SS) WD production cross sections was presented, $\sigma^{OS-SS}(WD)$. DPS is thus totally excluded.
On the contrary, we consider DPS as the most interesting part.

THEORETICAL FRAMEWORK

Standard QCD and Electroweak theory Feynman rules;

k_t-factorization with gluon spin density matrix $\overline{\epsilon^\mu \epsilon^{*\nu}} = k_T^\mu k_T^\nu / |k_T|^2$;
Advantage of having the initial state radiation corrections included in the form of k_t-dependent parton densities

L.V.Gribov, E.M.Levin, M.G.Ryskin, Phys. Rep. 100, 1 (1983)

KMR method to obtain unintegrated parton densities

M.A.Kimber, A.D.Martin, M.G.Ryskin Phys. Rev. D 63, 114027 (2001)

MSTW collinear parametrization taken as input

A.D.Martin, W.J.Stirling, R.S.Thorne, G.Watt, Eur. Phys. J. C 63, 189 (2009)

Running strong and electroweak coupling constants normalized to $\alpha_s(m_Z^2)$=0.118; $\alpha(m_Z^2)$=1/128; $sin^2\Theta_W = 0.2312$; c**-quark mass** m_c=1.5 **GeV;**

Factorization and renormalization scales $\mu_R^2 = \mu_F^2 = m_T^2(W) \equiv m_W^2 + p_T^2(W)$;

Peterson fragmentation function with $\epsilon = 0.06$
normalized to $f(c \to D) = 0.268$ **and** $f(c \to D^*) = 0.229$.

H.Jung, M.Kraemer, A.V.Lipatov, N.P.Zotov, JHEP 01, 085 (2011)

Comparison with ATLAS data

Measured and predicted cross sections (pb) in the fiducial region
$p_T(l) > 20$ GeV, $|\eta(l)| < 2.5$, $p_T(\nu) > 25$ GeV, $p_T(D) > 8$ GeV, $|\eta(D)| < 2.2$.

observable	Data	Theory
$Br^{W\to l\nu}\sigma^{OS-SS}(W^+D^-)$	**17.8**	**17.7**
$Br^{W\to l\nu}\sigma^{OS-SS}(W^-D^+)$	**22.4**	**19.5**
$Br^{W\to l\nu}\sigma^{OS-SS}(W^+D^{*-})$	**21.2**	**15.1**
$Br^{W\to l\nu}\sigma^{OS-SS}(W^-D^{*+})$	**22.1**	**16.8**

G.Aad *et al.* (ATLAS Collab.), JHEP 05, 068 (2014)

A reasonably good agreement is found. Now, having the theoretical approach justified, we can proceed to the Double Parton Scattering.

Double Parton interactions

Two independent interactions $\hat{\sigma}^A$ and $\hat{\sigma}^B$ at a time:

$$\sigma^{\rm AB}_{\rm DPS} = \frac{1}{2}\sum_{i,j,k,l} \int \Gamma_{ij}(x_1, x_1'; \mathbf{b_1}, \mathbf{b_2}; Q^2, Q'^2)\hat{\sigma}^A_{ik}(x_1, x_2, Q^2)$$
$$\times\Gamma_{kl}(x_2, x_2'; \mathbf{b_1}-\mathbf{b}, \mathbf{b_2}-\mathbf{b}; Q^2, Q'^2)\hat{\sigma}^B_{jl}(x_1', x_2', Q'^2)$$
$$\times dx_1\, dx_2\, dx_1'\, dx_2'\, d^2b_1\, d^2b_2\, d^2b$$

with b_i being the impact parameters and Q^2 the probing scales

N. Paver, D. Treleani, Nuovo Cimento A 70, 215 (1982)

Further assumptions:
Decoupling of longitudinal and transversal variables

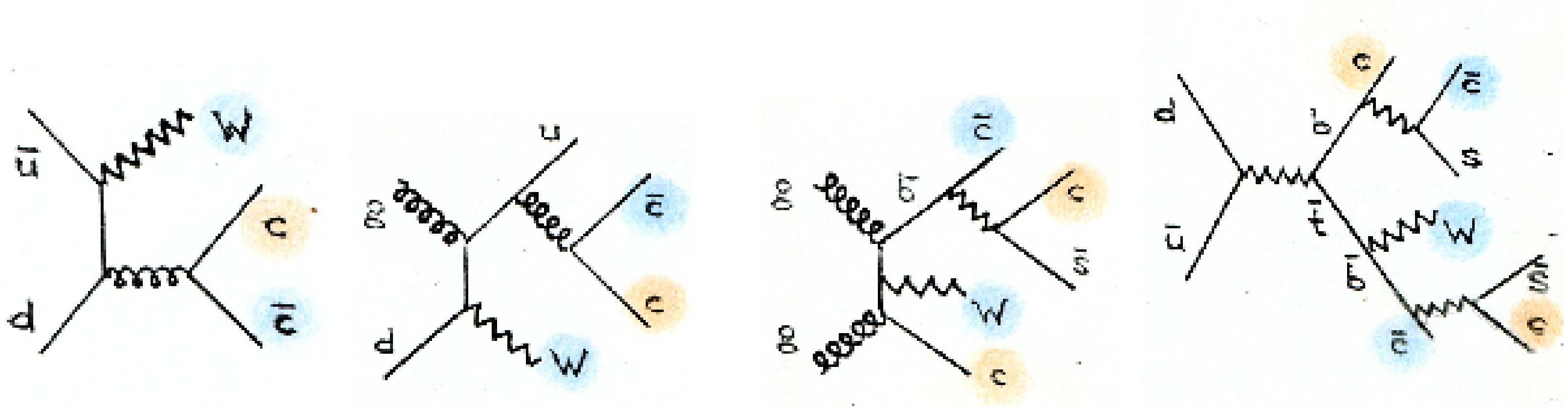
$$\Gamma_{ij}(x, x'; \mathbf{b_1}, \mathbf{b_2}; Q^2, Q'^2) = \mathcal{D}_{ij}(x, x'; Q^2, Q'^2) f(\mathbf{b_1}) f(\mathbf{b_2})$$

Factorization of parton distributions

$$\mathcal{D}_{ij}(x, x'; Q^2, Q'^2) = \mathcal{F}_i(x, Q^2)\mathcal{F}_j(x', Q'^2)$$

Result in $\sigma^{\rm AB}_{\rm DPS} = \frac{1}{2}\frac{\sigma^A_{\rm SPS}\sigma^B_{\rm SPS}}{\sigma_{\rm eff}}$ **with** $\sigma_{\rm eff} = 14.5\; mb$

SPS background in same-sign WD production



Direct contributions: gluon fragmentation

Quark-antiquark annihilation at $\mathcal{O}(\alpha_s^2\alpha)$:

$u+\bar{d}\to W^{+}+c+\bar{c}$ **or** $d+\bar{u}\to W^{-}+c+\bar{c}$

Quark-gluon scattering at $\mathcal{O}(\alpha_s^3\alpha)$:

$g+u\to W^{+}+d+c+\bar{c}$ **or** $g+d\to W^{-}+u+c+\bar{c}$

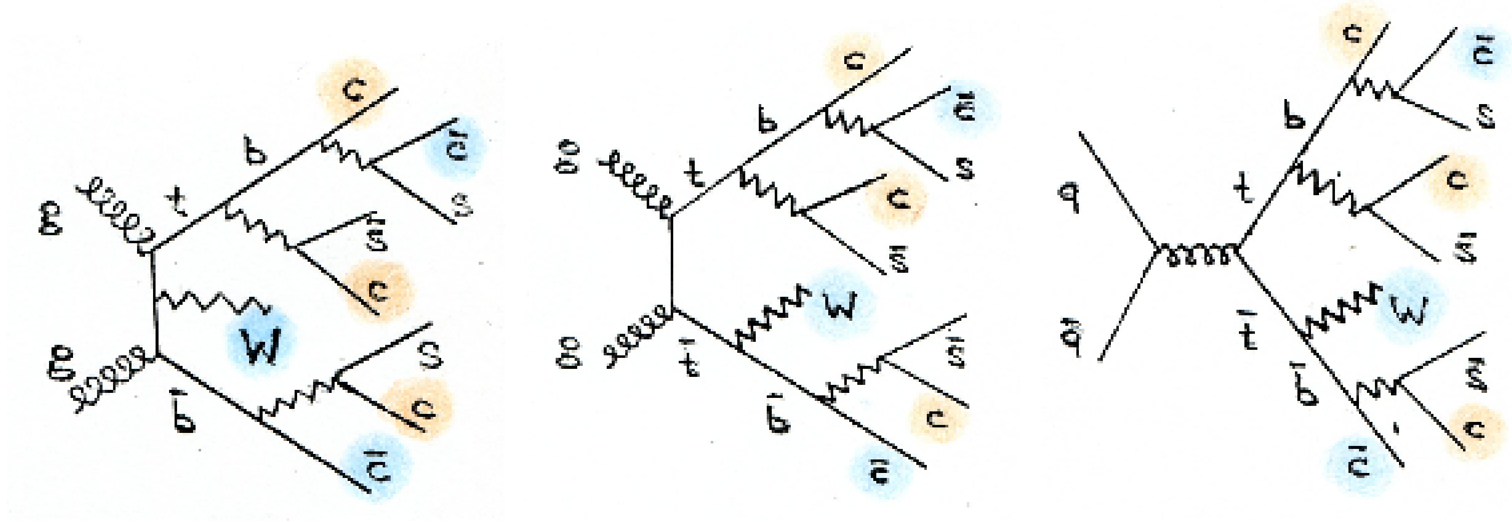
Indirect weak contributions:

$g+g\to W^{-}+c+\bar{b}$ **or** $g+g\to W^{+}+b+\bar{c}$

$u+\bar{d}\to t+\bar{b}$ **or** $d+\bar{u}\to \bar{t}+b$

$g+g\to W^{-}+t+\bar{b}$ **or** $g+g\to W^{+}+b+\bar{t}$

Production and decays of top-quarks



Indirect strong contributions:

$g+g \to t+\bar{t}$ and $q+\bar{q} \to t+\bar{t}$ followed by decay chain:
$t \to W^{+}+b$, $W^{+} \to c+\bar{s}$, $b \to c+X$ or $b \to c+\bar{c}+s$ (and charge conjugated).

Same-sign $W^{+}D^{(*)+}$ configurations may be formed by a W^{+} coming from t and a c coming from b coming from t, or a c coming from $\bar{b}$ coming from $\bar{t}$. Decay probabilities were taken from Particle Data Book.

K.A. Olive *et al.* ,Chin. Phys. C38, 090001 (2014)

NUMERICAL RESULTS

Signal from Double Parton Scattering, pb

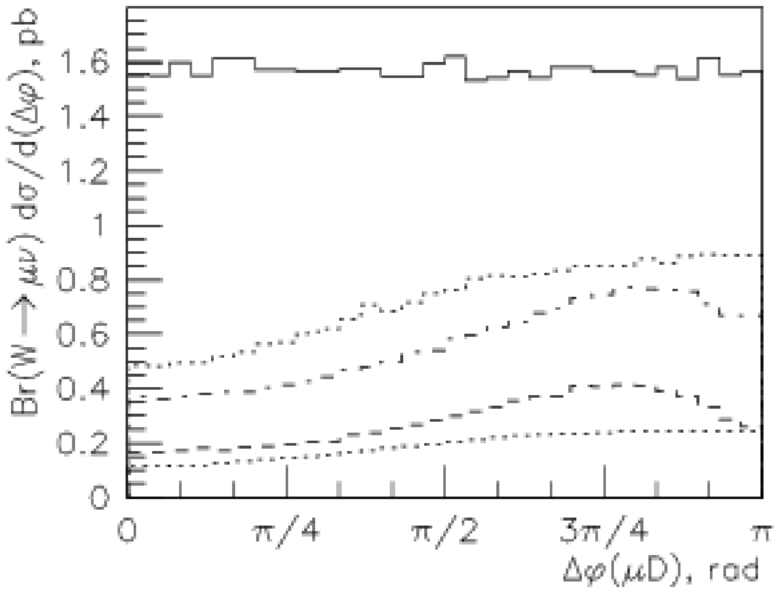
subprocesses	$Br\cdot\sigma(W^+D^+)$	subprocesses	$Br\cdot\sigma(W^-D^-)$
$u\bar{d}\to W,\ gg\to c\bar{c}$	**2.7**	$d\bar{u}\to W,\ gg\to c\bar{c}$	**1.9**

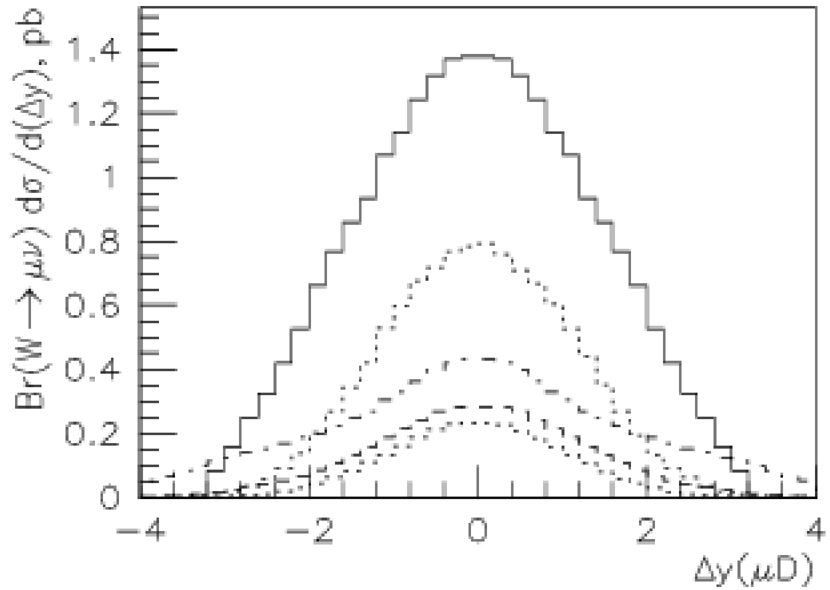
Background from Single Parton Scattering, pb

subprocess	$Br\cdot\sigma(W^+D^+)$	subprocess	$Br\cdot\sigma(W^-D^-)$
$u\bar{d}\to W c\bar{c}$	**0.41**	$d\bar{u}\to W c\bar{c}$	**0.29**
$gu\to W dc\bar{c}$	**1.0**	$gd\to W uc\bar{c}$	**0.7**
$gg\to t\bar{t}$	**1.1**	$gg\to t\bar{t}$	**1.1**
$q\bar{q}\to t\bar{t}$	**0.6**	$q\bar{q}\to t\bar{t}$	**0.6**
$u\bar{d}\to t\bar{b}$	**0.06**	$d\bar{u}\to b\bar{t}$	**0.04**
$gg\to W b\bar{c}$	**0.002**	$gg\to W b\bar{c}$	**0.002**

All indirect contributions can be rejected via observing a distanced secondary (b-decay) vertex. Then the DPS signal dominates over the SPS background.

Rapidity and transverse momentum correlations





solid = Double Parton Scattering;
upper dotted = $gg \to t\bar{t}$; **lower dotted =** $q\bar{q} \to t\bar{t}$;
dashed = $u\bar{d} \to W c\bar{c}$ **and** $d\bar{u} \to W c\bar{c}$;
dash-dotted = $gu \to W dc\bar{c}$ **and** $gd \to W uc\bar{c}$.

The distributions are all wide and flat because of large W mass.
All similar in shape; the kinematic correlations are not informative.

CONCLUSIONS

— Production of W bosons in association with charmed mesons in pp collisions at the LHC is considered. A reasonably good agreement with experimental data on $\sigma^{OS-SS}(WD)$ is observed.

— The consideration is extended to same-sign $W^{\pm}D^{\pm}$ configurations. After rejecting the b-decays, the DPS signal clearly dominates over the SPS background.

Thus, we come to an important conclusion that the production of same-sign $W^{\pm}D^{\pm}$ states can serve as a new indicator of double parton scattering.

Thank you for your attention!