Diffractive charm production at the LHC within k_t-factorization approach

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Outline

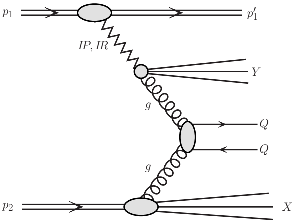
1. Introduction
2. Theoretical formalism
   - k_t-factorization in non-diffractive charm production
   - unintegrated diffractive gluon PDF
   - k_t-factorization in diffractive charm production
3. Numerical results
   - charm quark level
   - open charm meson

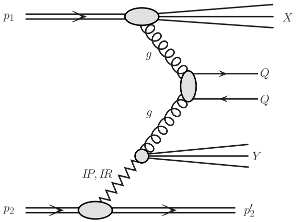
in collaboration with:

M. Łuszczak, A. Szczurek and M. Trzebiński

Diffractive production of open heavy mesons

- the subject discussed on Monday by M. Łuszczak
- theoretical predictions based on
  resolved pomeron model (Ingelman-Schlein approach)
  corrected by absorption effects in terms of gap survival probability
- diffractive collinear PDFs and LO collinear matrix elements

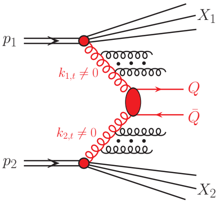




Extension of the theoretical model by adopting ***k_t*-factorization approach** as an effective way to:

- include higher-order corrections
- make kinematical correlation studies avalaible

Basic concepts of the k_t-factorization (semihard) approach



k_t-factorization $\longrightarrow$ $\kappa_{1,t}, \kappa_{2,t} \neq 0$ Collins-Ellis, Nucl. Phys. B360 (1991) 3;
Catani-Ciafaloni-Hautmann, Nucl. Phys. B366 (1991) 135; Ball-Ellis, JHEP 05 (2001) 053

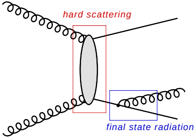
$\Rightarrow$ very efficient approach for $Q\bar{Q}$ correlations

- multi-differential cross section

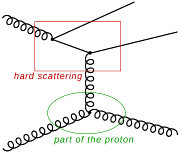
$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{i^* j^* \to Q\bar{Q}}|^2}$$
$$\times \; \delta^2 \left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t} \right) \mathcal{F}_i(x_1, \kappa_{1,t}^2) \, \mathcal{F}_j(x_2, \kappa_{2,t}^2)$$

- $\mathcal{F}_i(x_1, \kappa_{1,t}^2)$, $\mathcal{F}_j(x_2, \kappa_{2,t}^2)$ - unintegrated (k_t-dependent) gluon distributions
- **LO off-shell** $\overline{|\mathcal{M}_{g^* g^* \to Q\bar{Q}}|^2}$ $\Rightarrow$ Catani-Ciafaloni-Hautmann (CCH) analytic formulae or QMRK approach with effective BFKL NLL vertices
- major part of higher-order corrections effectively included

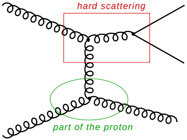
pair creation with gluon emission



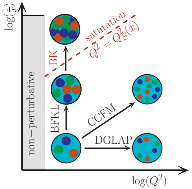
flavour excitation



gluon splitting



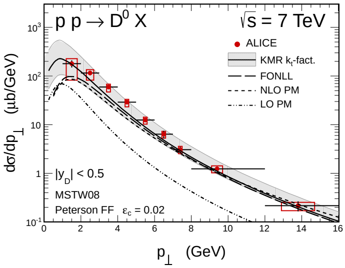
Unintegrated gluon distribution functions (UGDFs)

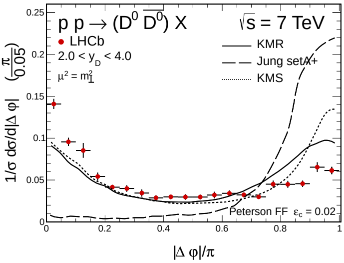


most popular models:

- Kwieciński, Jung (CCFM, wide range of x)
- Kimber-Martin-Ryskin (DGLAP-BFKL, wide range of x)
- Kwieciński-Martin-Staśto (BFKL-DGLAP, small x-values)
- Kutak-Staśto (BK, saturation, only small x-values)

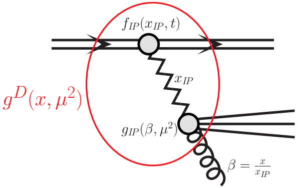
Lesson from non-diffractive charm production at the LHC:





- KMR UGDF works very well (single particle spectra and correlation observables)
- may be applied for hard diffractive processes

Model for diffractive UGDF



Resolved pomeron model (Ingelman-Schlein model):

- convolution of the flux of pomerons in the proton and the parton distribution in the pomeron
- both ingredients known from the H1 Collaboration analysis of diffractive structure function and diffractive dijets at HERA

First step $\Rightarrow$ diffractive collinear PDF:

$$g^D(x,\mu^2) = \int dx_{IP} d\beta\, \delta(x - x_{IP}\beta) g_{IP}(\beta,\mu^2)\, f_{IP}(x_{IP}) = \int_x^1 \frac{dx_{IP}}{x_{IP}} f_{IP}(x_{IP}) g_{IP}\left(\frac{x}{x_{IP}},\mu^2\right)$$

where the flux of pomerons: $f_{IP}(x_{IP}) = \int_{t_{min}}^{t_{max}} dt\, f(x_{IP},t)$

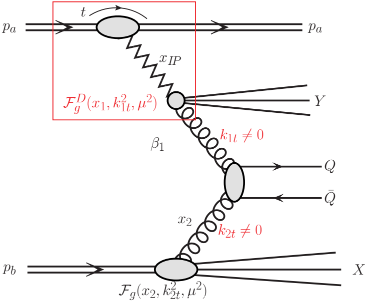
Second step $\Rightarrow$ diffractive unintegrated gluon within Kimber-Martin-Ryskin method:

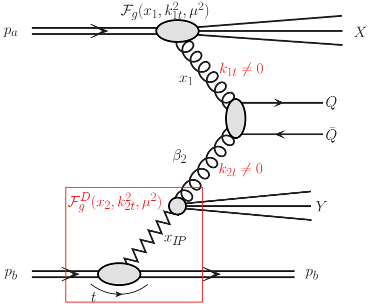
$$f_g^D(x,k_t^2,\mu^2) \equiv \frac{\partial}{\partial \log k_t^2}\left[g^D(x,k_t^2)\, T_g(k_t^2,\mu^2) \right] = T_g(k_t^2,\mu^2)\, \frac{\alpha_S(k_t^2)}{2\pi} \times$$

$$\int_x^1 dz \left[\sum_q P_{gq}(z) \frac{x}{z}\, q^D\left(\frac{x}{z},k_t^2\right) + P_{gg}(z)\frac{x}{z}\, g^D\left(\frac{x}{z},k_t^2\right) \Theta\left(\Delta - z\right) \right]$$

- $T_g(k_t^2,\mu^2)$ - Sudakov form factor

Single-diffractive cross section



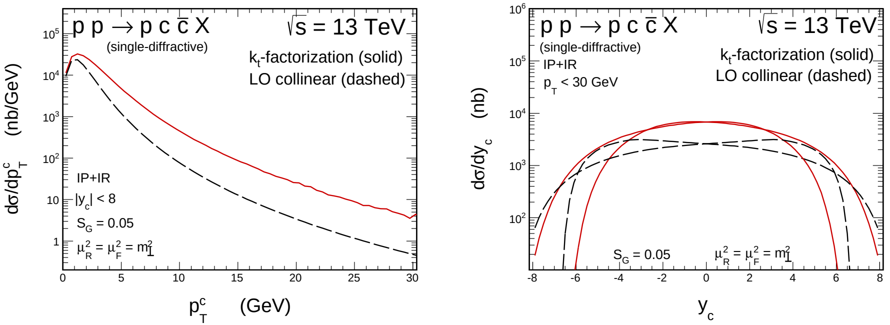


$$d\sigma^{SD(a)}(p_a p_b \to p_a c\bar{c}\, XY) = \int dx_1 \frac{d^2 k_{1t}}{\pi} dx_2 \frac{d^2 k_{2t}}{\pi}\, d\hat{\sigma}(g^* g^* \to c\bar{c}) \times \mathcal{F}_g^D(x_1, k_{1t}^2, \mu^2) \cdot \mathcal{F}_g(x_2, k_{2t}^2, \mu^2)$$

$$d\sigma^{SD(b)}(p_a p_b \to c\bar{c} p_b\, XY) = \int dx_1 \frac{d^2 k_{1t}}{\pi} dx_2 \frac{d^2 k_{2t}}{\pi}\, d\hat{\sigma}(g^* g^* \to c\bar{c}) \times \mathcal{F}_g(x_1, k_{1t}^2, \mu^2) \cdot \mathcal{F}_g^D(x_2, k_{2t}^2, \mu^2)$$

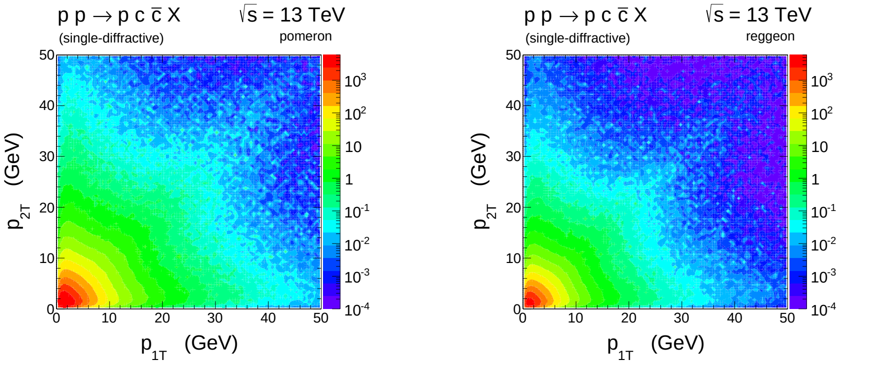
- $\mathcal{F}_g$ are the conventional UGDFs and $\mathcal{F}_g^D$ are their diffractive counterparts
- elementary cross section with off-shell matrix element $\overline{|\mathcal{M}_{g^* g^* \to c\bar{c}}(k_1, k_2)|^2}$
- influence of pomeron transverse momenta on initial gluon transverse momenta neglected, we assume: gluon $k_t >> p_T$ of pomeron (or outgoing proton) (work in progress)

LO Parton Model vs. k_t-factorization approach



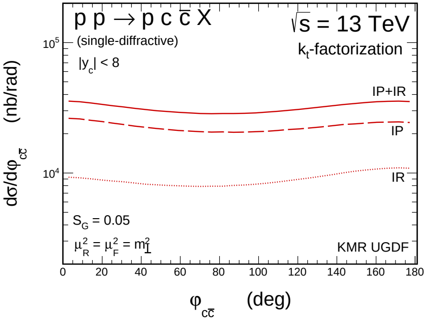
- significant differences between LO PM and k_t-factorization (similar as in the non-diffractive case)
- higher-order corrections very important

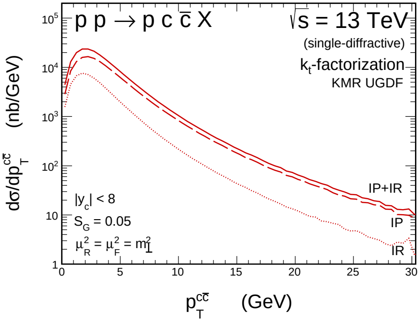
2Dim-distribution in transverse momenta of c and $\bar{c}$



- transverse momenta of outgoing particles not balanced
- one p_t small and second p_t large $\Rightarrow$ configurations typical for NLO corrections (in the PM classification)

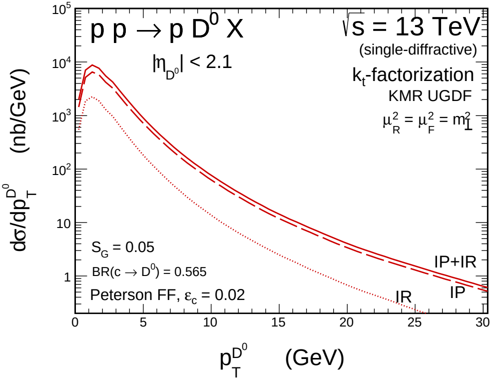
Correlation observables





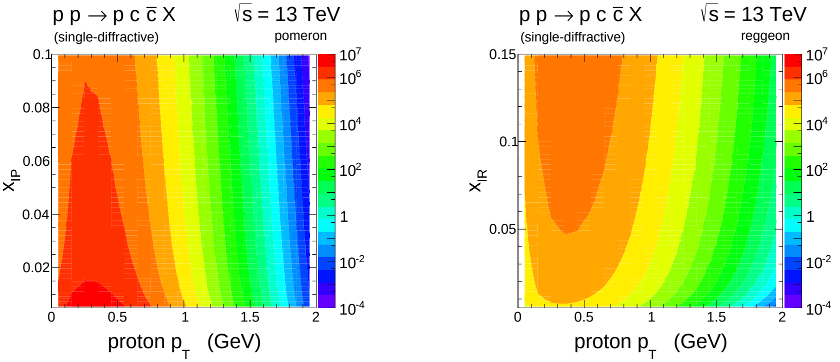
- azimuthal angle correlations ⇒ almost flat distribution
  (similar shape in the case of inclusive central diffraction (DPE))
- exclusive central diffractive events ⇒ much more correlated (peaked at π)
- quite large $c\bar{c}$ pair transverse momenta

D^0 meson transverse momentum spectra for ATLAS



- hadronization effects included via fragmentation function technique
- small reggeon contribution
  (becomes more important in the forward rapidity region, e.g. LHCb)

Proton-vertex variables



- the cross section concentrated in the region of proton p_T less than 1 GeV
- pomeron contribution ⇒ strong dependence on the minimal value of the x_{IP}

Integrated cross sections in nanobarns at $\sqrt{s} = 13$ TeV

- Exp. mode: $\frac{D^0 + \overline{D^0}}{2}$; ATLAS cuts: $p_T > 3.5$ GeV and $|\eta| < 2.1$
- BR($c \to D^0$) = 0.565

min. $x_P(x_R)$	parton-level σ_{tot} for $c\bar{c}$		D^0 meson with the ATLAS detector		
	pomeron	reggeon	pomeron	reggeon	$\frac{R}{P+R}$
0.005	71466.95	28239.61	3237.70	823.06	20%
0.01	59724.05	28059.41	2751.93	820.10	23%
0.015	51710.60	27795.48	2390.31	814.80	25%
0.02	45452.81	27456.82	2100.86	807.31	28%
0.025	40250.23	27049.62	1857.81	797.77	30%
0.03	35762.93	26578.13	1647.77	786.41	32%
0.035	31793.50	26045.35	1461.59	772.94	35%
0.04	28221.20	25453.78	1294.41	757.53	37%
0.045	24963.04	24806.25	1142.29	740.24	39%
0.05	21961.04	24103.46	1002.51	721.34	42%

- relatively high cross section: 2 – 3 μb (depending on minimal value of x_{IP})
- feasibility studies on the way (M. Trzebiński)

Conclusions

- sizeable cross section for single-diffractive production of open charm at the LHC calculated for the first time within the k_t-factorization approach
- useful model for unintegrated diffractive PDFs
- very important higher-order corrections and interesting azimuthal angle correlations in the case of inclusive diffractive charm production
- feasibility studies needed (on the way)

Thank You for attention!