

Single and central diffractive production of open charm and bottom at the LHC

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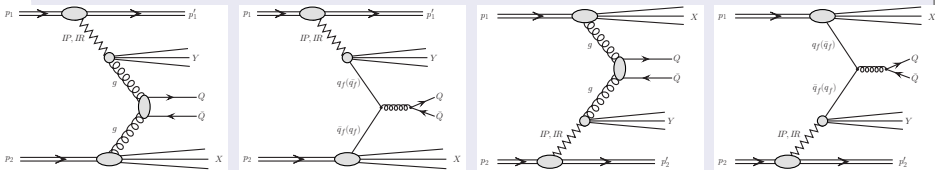
- Introduction
- Single and central diffraction
 - theoretical framework
 - diffractive production of $c\bar{c}$ and $b\bar{b}$
- Hadronization of heavy quarks
- Diffractive production of open charm and bottom
- Conclusions

Based on:

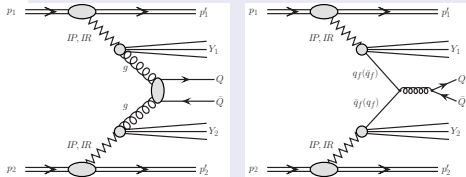
M. Łuszczak, R. Maciuła and A. Szczurek, arXiv:1412.3132

Single- and central-diffractive production of heavy quarks

single- diffractive production



central- diffractive production



- leading-order gluon-gluon fusion and quark-antiquark annihilation partonic subprocesses are taken into consideration
- the extra corrections from subleading reggeon exchanges are explicitly calculated

Theoretical framework

In this approach (**Ingelman-Schlein model**) one assumes that the Pomeron has a well defined partonic structure, and that the hard process takes place in a Pomeron-proton or proton-Pomeron (**single diffraction**) or Pomeron-Pomeron (**central diffraction**) processes.

$$\begin{aligned} \frac{d\sigma_{SD(1)}}{dy_1 dy_2 dp_{\bar{t}}^2} &= \frac{1}{16\pi^2 \hat{s}^2} \times \left[|\mathcal{M}_{gg \rightarrow Q\bar{Q}}|^2 \cdot x_1 g^D(x_1, \mu^2) x_2 g(x_2, \mu^2) \right. \\ &+ \left. |\mathcal{M}_{q\bar{q} \rightarrow Q\bar{Q}}|^2 \cdot \left(x_1 q^D(x_1, \mu^2) x_2 \bar{q}(x_2, \mu^2) + x_1 \bar{q}^D(x_1, \mu^2) x_2 q(x_2, \mu^2) \right) \right], \\ \frac{d\sigma_{SD(2)}}{dy_1 dy_2 dp_{\bar{t}}^2} &= \frac{1}{16\pi^2 \hat{s}^2} \times \left[|\mathcal{M}_{gg \rightarrow Q\bar{Q}}|^2 \cdot x_1 g(x_1, \mu^2) x_2 g^D(x_2, \mu^2) \right. \\ &+ \left. |\mathcal{M}_{q\bar{q} \rightarrow Q\bar{Q}}|^2 \cdot \left(x_1 q(x_1, \mu^2) x_2 \bar{q}^D(x_2, \mu^2) + x_1 \bar{q}(x_1, \mu^2) x_2 q^D(x_2, \mu^2) \right) \right], \\ \frac{d\sigma_{CD}}{dy_1 dy_2 dp_{\bar{t}}^2} &= \frac{1}{16\pi^2 \hat{s}^2} \times \left[|\mathcal{M}_{gg \rightarrow Q\bar{Q}}|^2 \cdot x_1 g^D(x_1, \mu^2) x_2 g^D(x_2, \mu^2) \right. \\ &+ \left. |\mathcal{M}_{q\bar{q} \rightarrow Q\bar{Q}}|^2 \cdot \left(x_1 q^D(x_1, \mu^2) x_2 \bar{q}^D(x_2, \mu^2) + x_1 \bar{q}^D(x_1, \mu^2) x_2 q^D(x_2, \mu^2) \right) \right], \end{aligned}$$

- standard collinear MSTW08LO parton distributions (A.D. Martin, W.J. Stirling, R.S. Thorne and G. Watt)
- diffractive distribution function (diffractive PDF)

Theoretical framework

The diffractive distribution function (diffractive PDF) can be obtained by a convolution of the flux of pomerons $f_{\mathbf{P}}(x_{\mathbf{P}})$ in the proton and the parton distribution in the pomeron, e.g. $g_{\mathbf{P}}(\beta, \mu^2)$ for gluons:

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

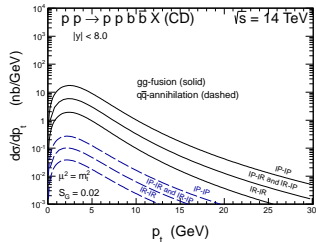
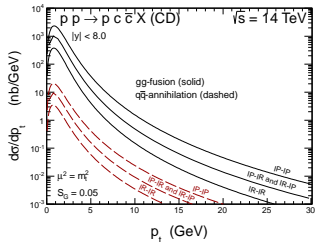
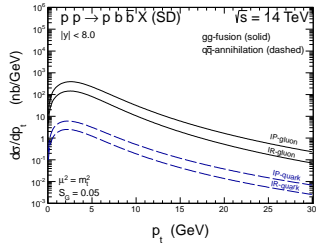
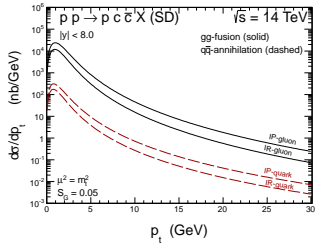
The flux of Pomerons $f_{\mathbf{P}}(x_{\mathbf{P}})$:

$$f_{\mathbf{P}}(x_{\mathbf{P}}) = \int_{t_{min}}^{t_{max}} dt f(x_{\mathbf{P}}, t),$$

with t_{min} , t_{max} being kinematic boundaries.

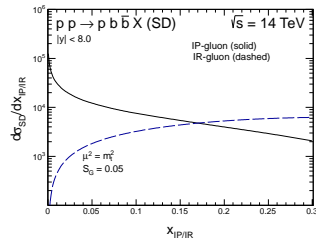
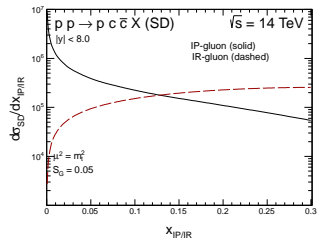
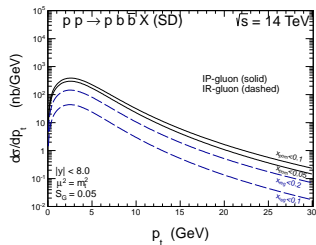
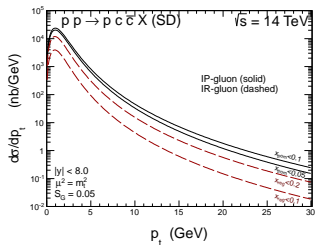
Both pomeron flux factors $f_{\mathbf{P}}(x_{\mathbf{P}}, t)$ as well as parton distributions in the pomeron were taken from the H1 collaboration analysis of diffractive structure function at HERA.

Results for $c\bar{c}$ and $b\bar{b}$



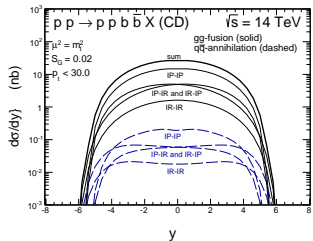
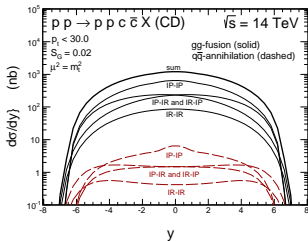
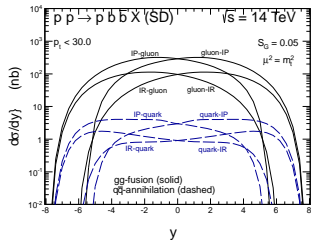
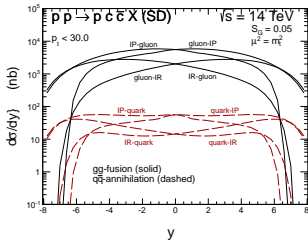
- the multiplicative factors are approximately $S_G = 0.05$ for single-diffractive production and $S_G = 0.02$ for central-diffractive one for the nominal LHC energy ($\sqrt{s} = 14$ TeV)

Results for $c\bar{c}$ and $b\bar{b}$



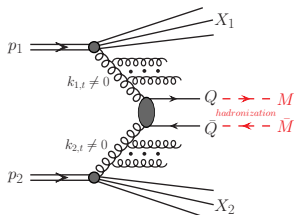
- in the case of pomeron exchange the upper limit in the convolution formula is taken to be 0.1 and for reggeon exchange 0.2 ($x_P < 0.1$, $x_R < 0.2$)
- the whole Regge formalism does not apply above these limits

Results for $c\bar{c}$ and $b\bar{b}$



- the individual single-diffractive mechanisms have maxima at large rapidities, while the central-diffractive contribution is concentrated at midrapidities. This is a consequence of limiting integration over x_P to $0.0 < x_P < 0.1$ and over x_R to $0.0 < x_R < 0.2$

Hadronization of heavy quarks



- phenomenology \rightarrow fragmentation functions extracted from e^+e^- data
- often used (older parametrizations):
Peterson et al., Braaten et al., Kartvelishvili et al.
- more up-to-date: charm nonperturbative fragmentation functions determined from recent Belle, CLEO, ALEPH and OPAL data:
Kneesch-Kniehl-Kramer-Schienbein (KKKS08) + DGLAP evolution!
- FONLL \rightarrow Braaten et al. (charm) and Kartvelishvili et al. (bottom)
GM-VFNS \rightarrow KKKS08 + evolution

- numerically performed by rescaling transverse momentum at a constant rapidity (angle)
- from heavy quarks to heavy mesons:

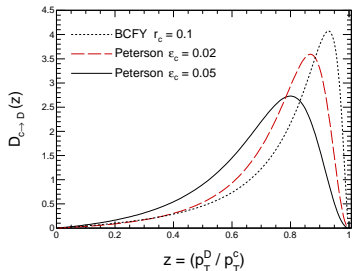
$$\frac{d\sigma(y, p_t^M)}{dyd^2 p_t^M} \approx \int \frac{D_{Q \rightarrow M}(z)}{z^2} \cdot \frac{d\sigma(y, p_t^Q)}{dyd^2 p_t^Q} dz$$

where: $p_t^Q = \frac{p_t^M}{z}$ and $z \in (0, 1)$

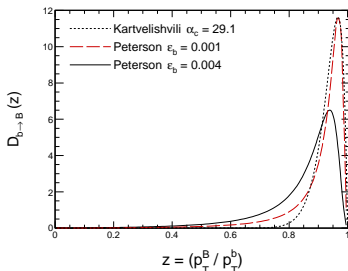
- approximation:**
rapidity unchanged in the fragmentation process $\rightarrow y_Q = y_M$

Fragmentation functions for heavy quarks

CHARM



BOTTOM



- default set: Peterson FF with $\epsilon_c = 0.05$ and $\epsilon_b = 0.004$ values extracted by H1, ALEPH and OPAL experiments
- Cacciari *et al.* (FONNL framework) \Rightarrow rather harder functions are suggested
BCFY FF with $r_c = 0.1$ and Kartvelishvili FF with $\alpha_b = 29.1$
our choice: Peterson FF with $\epsilon_c = 0.02$ and $\epsilon_b = 0.001$

Predictions of integrated cross sections for LHC experiments

TABLE I: Integrated cross sections for diffractive production of open charm and bottom mesons in different measurement modes for ATLAS, LHCb and CMS experiments at $\sqrt{s} = 14$ TeV.

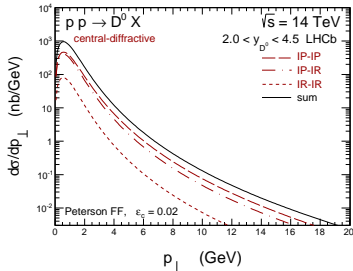
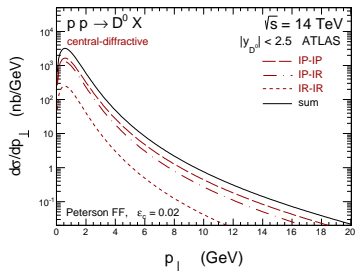
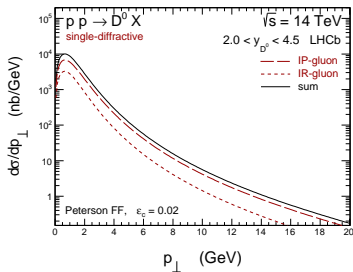
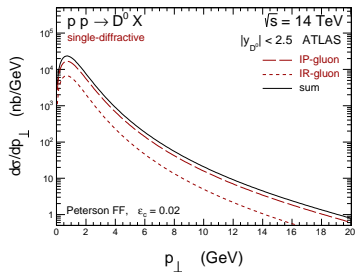
Acceptance	Mode	Integrated cross sections, [nb]		
		single-diffractive	central-diffractive	non-diffractive EXP data
ATLAS, $ y < 2.5$ $p_{\perp} > 3.5$ GeV	$D^0 + \overline{D}^0$	3555.22 (<i>IR</i> : 25%)	177.35 (<i>IR</i> : 43%)	–
LHCb, $2 < y < 4.5$ $p_{\perp} < 8$ GeV	$D^0 + \overline{D}^0$	31442.8 (<i>IR</i> : 31%)	2526.7 (<i>IR</i> : 50%)	1488000 ± 182000
CMS, $ y < 2.4$ $p_{\perp} > 5$ GeV	$(B^+ + B^-)/2$	349.18 (<i>IR</i> : 24%)	14.24 (<i>IR</i> : 42%)	$28100 \pm 2400 \pm 2000$
LHCb, $2 < y < 4.5$ $p_{\perp} < 40$ GeV	$B^+ + B^-$	867.62 (<i>IR</i> : 27%)	31.03 (<i>IR</i> : 43%)	$41400 \pm 1500 \pm 3100$
LHCb, $2 < y < 4$ $3 < p_{\perp} < 12$ GeV	$D^0 \overline{D}^0$	179.4 (<i>IR</i> : 28%)	7.67 (<i>IR</i> : 45%)	$6230 \pm 120 \pm 230$

- single-diffraction: $\frac{IR}{IP+IR} \approx 24 - 31\%$

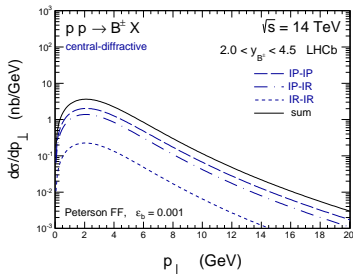
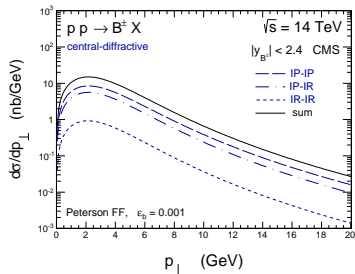
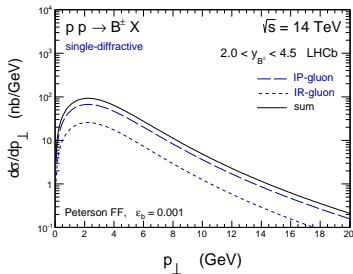
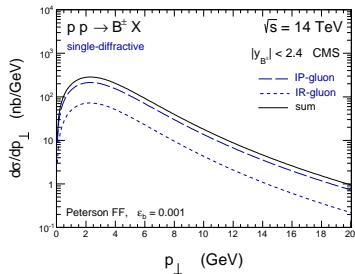
- central-diffraction: $\frac{IP\ IR+IR\ IP+IR\ IR}{IP\ IP+IP\ IR+IR\ IP+IR\ IR} \approx 42 - 50\%$

- $\frac{\text{single-diffractive}}{\text{non-diffractive}} \approx 2 - 3\%$ $\frac{\text{central-diffractive}}{\text{non-diffractive}} \approx 0.03 - 0.07\%$

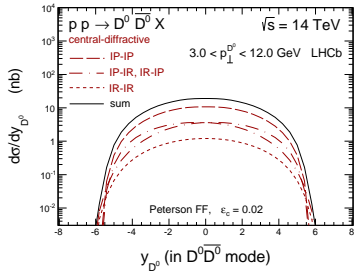
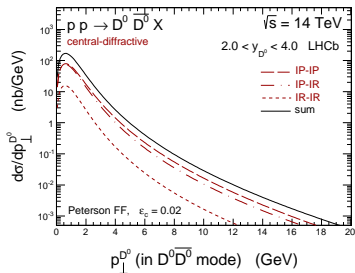
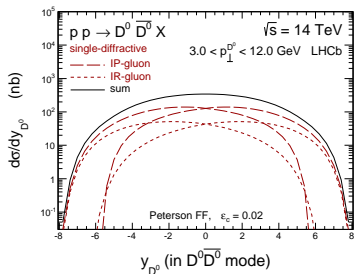
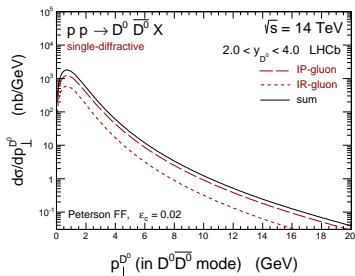
Results for D^0 mesons production



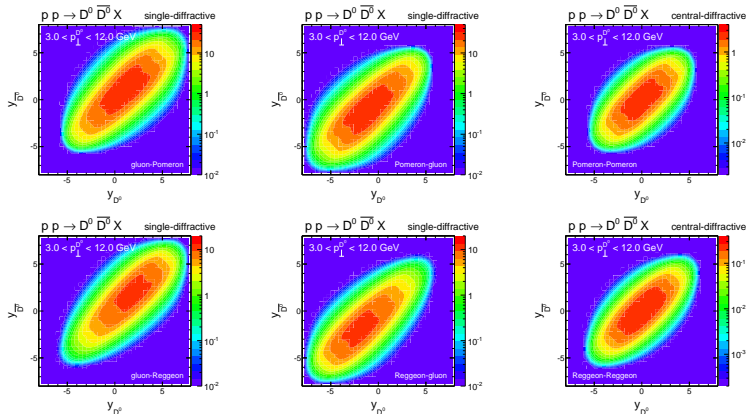
Results for B^\pm mesons production



Results for $D^0\bar{D}^0$ mesons production



Results



Double differential cross sections as a function of D^0 and \bar{D}^0 rapidities within the LHCb detector acceptance for single- (left and middle panels) and central-diffractive (right panels) production at $\sqrt{s} = 14$ TeV. The top and bottom panels correspond to the pomeron and reggeon exchange mechanisms respectively.

- Cross sections for single and central diffractive production of $c\bar{c}$ and $b\bar{b}$ have been calculated.
- Large and measurable cross section for charm single diffractive production.
- Cross sections for D^0 , B^\pm and $D^0\bar{D}^0$ mesons have been calculated for different experiments (cuts).
- LHCb wish to study such processes (G. Wilkinson).