Diffractive production of open charm and bottom mesons at the LHC: theoretical predictions and experimental capabilities

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Plan of the talk

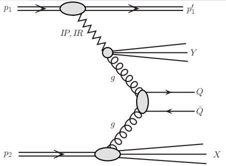
- Introduction
- Single and central diffraction
  - theoretical framework
  - diffractive production of $c\bar{c}$ and $b\bar{b}$
- Hadronization of heavy quarks
- Diffractive production of open charm and bottom
- Conclusions

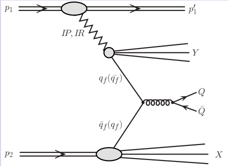
Based on:

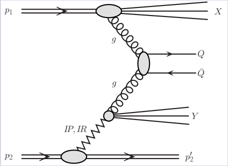
M. Łuszczak, R. Maciuła and A. Szczurek, Phys. Rev. D**91**, 054024 (2015), arXiv:1412.3132

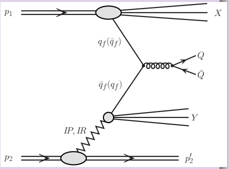
Single- and central-diffractive production of heavy quarks

single- diffractive production

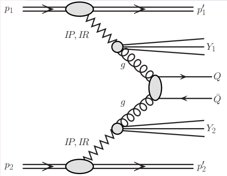


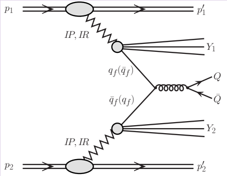






central- diffractive production





- leading-order gluon-gluon fusion and quark-antiquark anihilation 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.

$$\frac{d\sigma_{SD(1)}}{dy_1\, dy_2\, dp_t^2} = \frac{1}{16\pi^2 \hat{s}^2} \times \Big[|\mathcal{M}_{gg\to Q\bar{Q}}|^2 \cdot x_1 g^D(x_1,\mu^2) x_2 g(x_2,\mu^2)$$
$$+ |\mathcal{M}_{q\bar{q}\to Q\bar{Q}}|^2 \cdot \Big(x_1 q^D(x_1,\mu^2) x_2 \bar{q}(x_2,\mu^2) + x_1 \bar{q}^D(x_1,\mu^2) x_2 q(x_2,\mu^2) \Big) \Big],$$

$$\frac{d\sigma_{SD(2)}}{dy_1\, dy_2\, dp_t^2} = \frac{1}{16\pi^2 \hat{s}^2} \times \Big[|\mathcal{M}_{gg\to Q\bar{Q}}|^2 \cdot x_1 g(x_1,\mu^2) x_2 g^D(x_2,\mu^2)$$
$$+ |\mathcal{M}_{q\bar{q}\to Q\bar{Q}}|^2 \cdot \Big(x_1 q(x_1,\mu^2) x_2 \bar{q}^D(x_2,\mu^2) + x_1 \bar{q}(x_1,\mu^2) x_2 q^D(x_2,\mu^2) \Big) \Big],$$

$$\frac{d\sigma_{CD}}{dy_1\, dy_2\, dp_t^2} = \frac{1}{16\pi^2 \hat{s}^2} \times \Big[|\mathcal{M}_{gg\to Q\bar{Q}}|^2 \cdot x_1 g^D(x_1,\mu^2) x_2 g^D(x_2,\mu^2)$$
$$+ |\mathcal{M}_{q\bar{q}\to Q\bar{Q}}|^2 \cdot \Big(x_1 q^D(x_1,\mu^2) x_2 \bar{q}^D(x_2,\mu^2) + x_1 \bar{q}^D(x_1,\mu^2)\, x_2 q^D(x_2,\mu^2) \Big) \Big],$$

- 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:

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

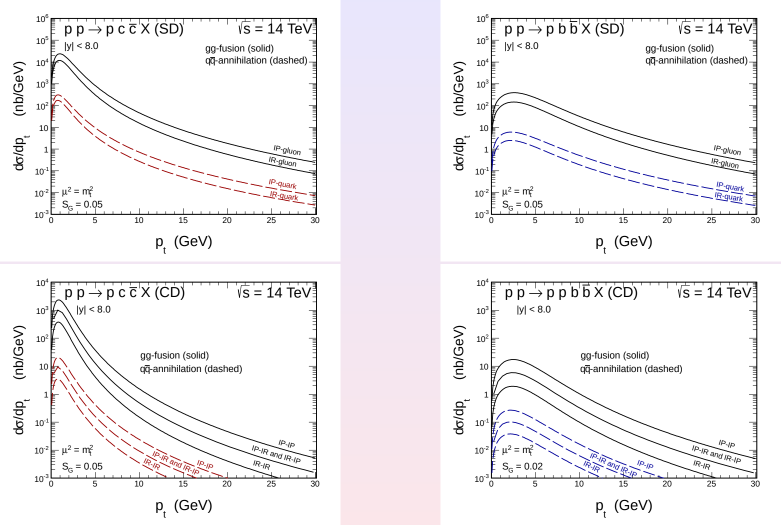
The flux of Pomerons $f_{\mathbf{P}}(x_{\mathbf{P}})$:

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

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

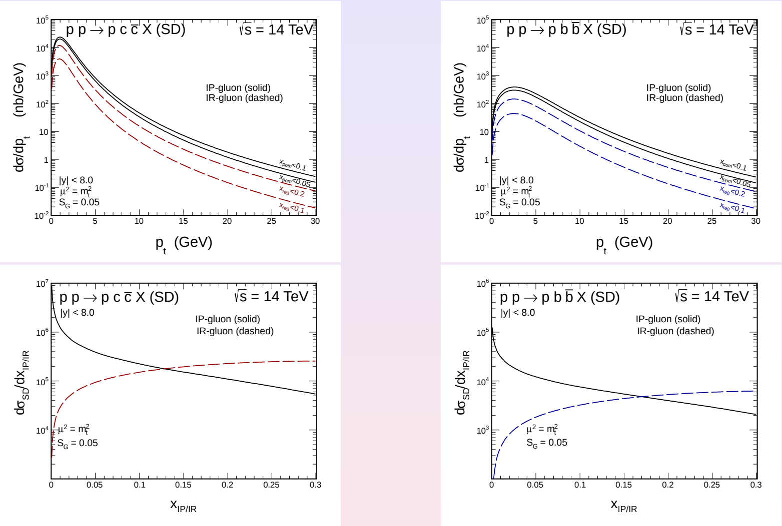
Both pomeron flux factors $f_{\mathbf{P}}(x_{\mathbf{P}}, t)$ as well as parton distributions in the pomeron were taken from the H1 collaboration analysis of diffractive structure function at HERA.

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



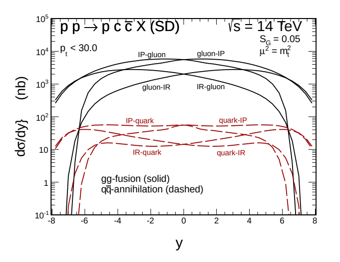
- the multiplicative factors are approximately $S_G = 0.05$ for single-diffractive production and $S_G = 0.02$ for central-diffractive one for the nominal LHC energy ($\sqrt{s} = 14$ TeV)

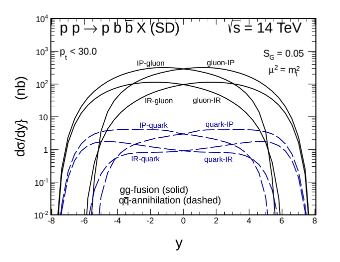
Results for $c\bar{c}$ and $b\bar{b}$

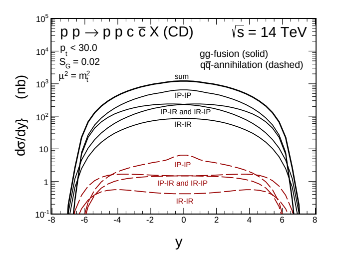


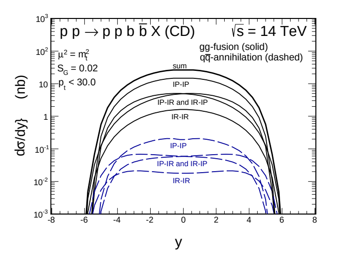
- in the case of pomeron exchange the upper limit in the convolution formula is taken to be 0.1 and for reggeon exchange 0.2 ($x_{\mathbb{P}} < 0.1$, $x_{\mathbb{R}} < 0.2$)
- the whole Regge formalism does not apply above these limits

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



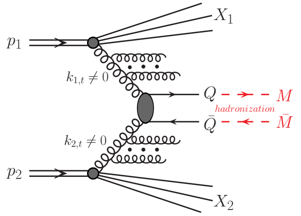






- the individual single-diffractive mechanisms have maxima at large rapidities, while the central-diffractive contribution is concentrated at midrapidities.
  This is a consequence of limiting integration over $x_{\mathbb{P}}$ to $0.0 < x_{\mathbb{P}} < 0.1$ and over $x_{\mathbb{R}}$ to $0.0 < x_{\mathbb{R}} < 0.2$

Hadronization of heavy quarks



- phenomenology → 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 → Braaten et al. (charm) and Kartvelishvili et al. (bottom) GM-VFNS → KKKS08 + evolution

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

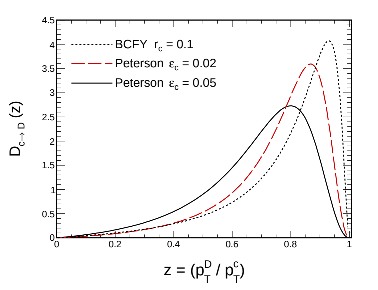
$$\frac{d\sigma(y, p_t^M)}{dy d^2 p_t^M} \approx \int \frac{D_{Q \to M}(z)}{z^2} \cdot \frac{d\sigma(y, p_t^Q)}{dy d^2 p_t^Q} dz$$

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

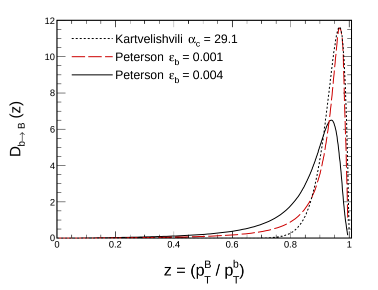
- **approximation:** rapidity unchanged in the fragmentation process → $y_Q = y_M$

Fragmentation functions for heavy quarks

CHARM



BOTTOM



- default set: Peterson FF with $\varepsilon_c = 0.05$ and $\varepsilon_b = 0.004$ 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 Kartvelisvili FF with $\alpha_b = 29.1$
  our choice: Peterson FF with $\varepsilon_c = 0.02$ and $\varepsilon_b = 0.001$

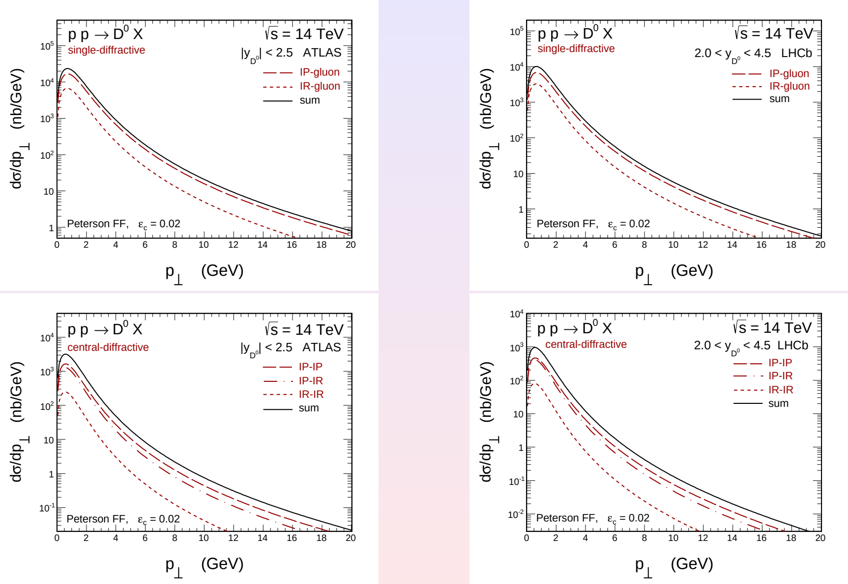
Predictions of integrated cross sections for LHC experiments

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.

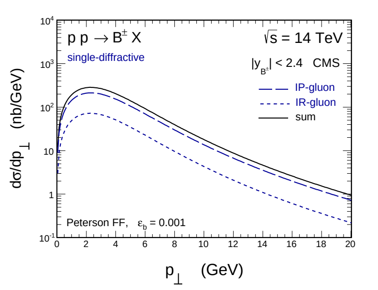
Acceptance	Mode	Integrated cross sections, [nb]		
		single-diffractive	central-diffractive	non-diffractive EXP data
ATLAS, $\|y\| < 2.5$, $p_\perp > 3.5$ GeV	$D^0 + \overline{D^0}$	3555.22 ($I\!R$: 25%)	177.35 ($I\!R$: 43%)	–
LHCb, $2 < y < 4.5$, $p_\perp < 8$ GeV	$D^0 + \overline{D^0}$	31442.8 ($I\!R$: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

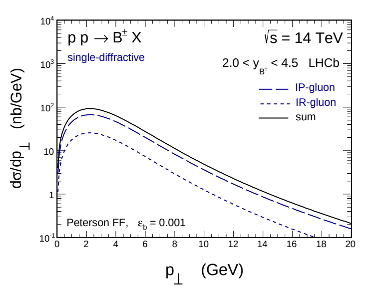
- single-diffraction: $\frac{I\!R}{I\!P + I\!R} \approx 24 - 31\%$
- central-diffraction: $\frac{I\!P I\!R + I\!R I\!P + I\!R I\!R}{I\!P I\!P + I\!P I\!R + I\!R I\!P + I\!R I\!R} \approx 42 - 50\%$
- $\frac{single-diffractive}{non-diffractive} \approx 2 - 3\%$ $\quad$ $\frac{central-diffractive}{non-diffractive} \approx 0.03 - 0.07\%$

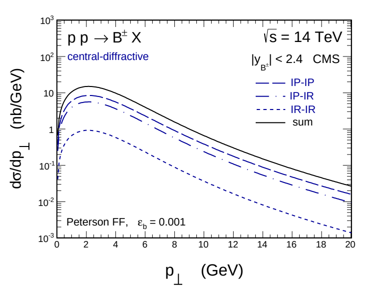
Results for D^0 mesons production

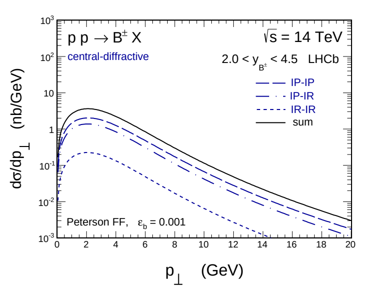


Results for $B^{\pm}$ mesons production

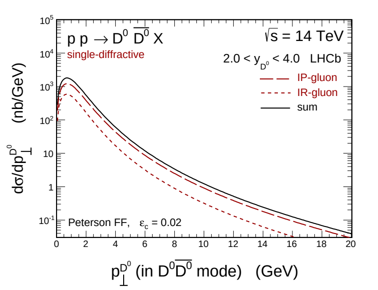


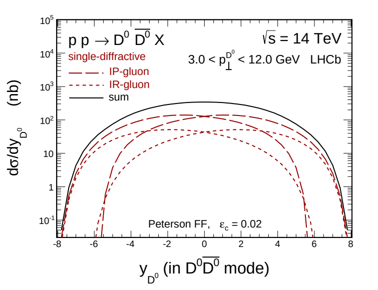


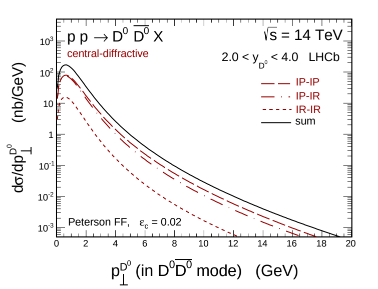


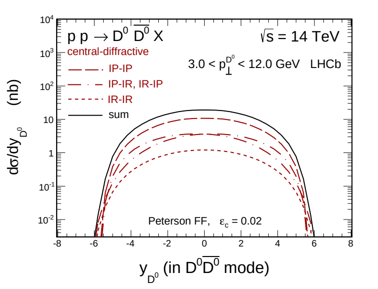


Results for $D^0\overline{D^0}$ mesons production

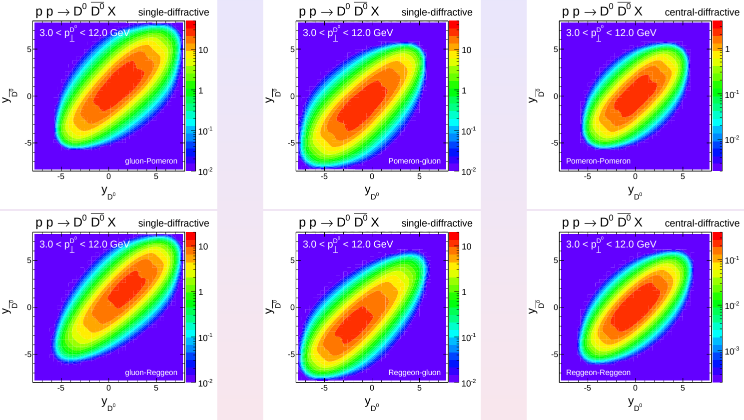








Results



Double differential cross sections as a function of D^0 and $\overline{D^0}$ 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.

Conclusions

- 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 $D^0\overline{D^0}$ mesons have been calculated for different experiments (cuts).
- LHCb wish to study such processes (G. Wilkinson).