Diffractive charm producttion
Measurement feasibility & discovery potential

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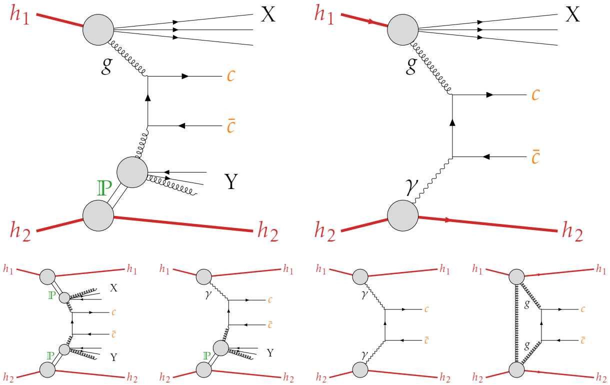
Physics Motivation:

Shed a Light on the Nature of Strong Colorless Exchange

- Mechanisms of diffractive production studied through the analysis of **open charm production**
- $c\bar{c}$ production – lowest-mass process involving **hard-scale**
- Probing the **nature of Pomeron**, testing alternative approaches (e.g. Soft Color Interaction)
- Testing the **factorization theorem**

- Diffractive events identified with **forward proton tag with AFP**



Unique class of events:

i) accessible within **perturbative QCD framework**,
ii) characterized by **high exepected cross-section**,
iii) possible to be studied in a clean, **low background** experimental environment – low pile-up

Models of diffraction

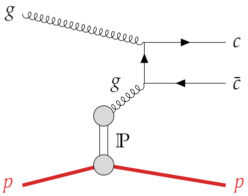
Resolved Pomeron

- Ingelman-Schlein
  + absorption corrections (S_G)
- Two-step factorization:
  Collinear factorization
  convolution of partonic subprocess and diffractive PDFs:

  $$d\sigma = f_i^D(x, Q^2, x_{\mathbb{P}}, t) \otimes d\sigma_{\text{sub}}(x, Q^2)$$

  Proton-vertex factorization
  Pomeron flux and its partonic structure:

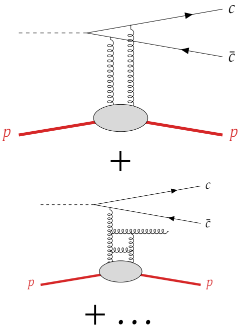
  $$f_i^D(x, Q^2, x_{\mathbb{P}}, t) = f_{\mathbb{P}/p}(x_{\mathbb{P}}, t) \cdot f_i(x/x_{\mathbb{P}}, Q^2)$$



Phys.Lett.B 152 (1985) 256-260
Eur.Phys.J.C18:167-179,2000
AIP Conf.Proc. 1105 (2009) 1, 248-251

Two-gluon exchange

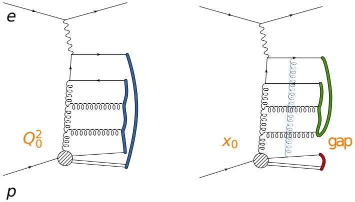
- **pQCD** framework applicable at sufficiently high p_T
- Dipole model ($\gamma \to q\bar{q}$)
- k_t factorization
- cross-section $\propto [x_{\mathbb{P}} G_g(x_{\mathbb{P}}, Q^2)]^2$



Phys.Lett.B 379 (1996) 239-248
Phys.Lett.B 386 (1996) 389-396
Phys.Lett.B 406 (1997) 171-177

Soft Color Interaction

- **Soft color exchange** may change the topology of the created color string
- Hard process remains unaffected
- Natural emergence of rapidity gaps
- Similar concept used in the Generalized Area Law model (soft color exchange happens between the strings)



Phys.Lett. B366 (1996) 371-378
Phys.Rev. D64 (2001) 114015

Phenomenology perspective

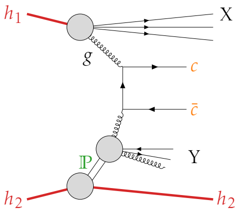
Specifics of **charm production**:

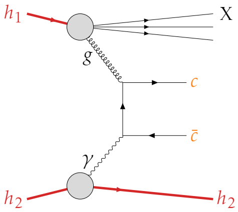
- At LHC, **large cross-sections** are expected from QCD.
  → background can be reduced with special, **low pile-up runs**
  → identification of diffractive events possible with **intact protons**
- Lesson from data on inclusive charm production:
  QCD LO collinear approach works rather poorly – higher order corrections are needed (e.g. k_t factorization).
- There exists a **wide range of model predictions** (next slides).

Discovery potential:

- Tests of **factorization theorem(s)**.
- Probing the **nature of the Pomeron**.
- **Measurement of diffractive charm production may pin down the mechanism of diffractive production – large differences in predicted cross-sections.**

Single Diffraction





1. Singe diffraction, $\mathbb{P}$-p process

$$\sigma(h_1 h_2 \to X Q\bar{Q} Y \,\llcorner\!\lrcorner\, h_2) = \int dx_1 \int dx_2 \;\; g_1(x_1, \mu^2) \;\; g_2^D(x_2, \mu^2) \;\; \hat{\sigma}(gg \to Q\bar{Q})$$

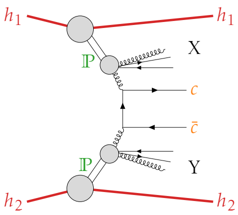
- The dominant contribution in SD processes at the LHC.
- Gay Ducati *et al.*, Phys.Rev.D 81 (2010) 054034
  14 TeV, Resolved Pomeron, $\sigma_{\gamma p} = 178$ μb ($R_{c\bar{c}} = 2.3\%$)
- Kopeliovich *et al.*, Phys.Rev.D 76 (2007) 034019:
  Dipole, Leading Twist Mechanisms
- Łuszczak *et al.*, Phys. Rev. D 91, 054024 (2015):
  Resolved Pomeron, 14 TeV, $|y| < 2.5$, $p_T > 3.5$ GeV, $D^0 + \bar{D^0}$, $\sigma_{\mathbb{P}p} = 3555$ nb.
- Łuszczak *et al.*, JHEP 02 (2017) 089:
  k_t-factorization, 13 TeV, $|y| < 2.1$, $p_T > 3.5$ GeV, $D^0 + \bar{D^0}$, $\sigma^{SD}_{\mathbb{P}p} = 3$–$4$ μb
- Siddikov *et al.*, Phys.Rev.D 102 (2020) 7, 076020:
  Dipole Model, 13 TeV, $R_{c\bar{c}}$=1.6% $\to \sigma_{\mathbb{P}p} \approx 135\mu$b
  predictions regarding charged particle multiplicity dependence

2. Single diffraction, γ-p process

$$\sigma(h_1 h_2 \to X Q\bar{Q} \,\llcorner\!\lrcorner\, h_2) = \int dx_1 \int dx_2 \;\; g_1(x_1, \mu^2) \;\; \gamma_2(x_2, \mu^2) \;\; \hat{\sigma}(\gamma g \to Q\bar{Q})$$

- Strong electromagnetic fields arising around the proton due to relativistic effects may interact directly with the partons inside the proton.
- Goncalves *et al*, Nucl.Phys.A 976 (2018) 33-45:
  13 TeV, $|y| < 10$, Dipole Model, $\sigma_{\gamma p} = 1030$ (b-CGC) — 1140 (IP-SAT) nb

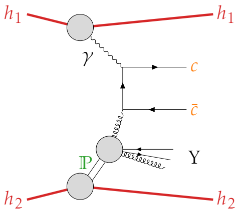
Central Diffraction



3. Central diffraction with double $\mathbb{P}$ exchange

$$\sigma(h_1 h_2 \to h_1 \sqcup X Q\bar{Q} Y \sqcup h_2) = \int dx_1 \int dx_2 \; g_1^D(x_1,\mu^2) \; g_2^D(x_2,\mu^2) \; \hat{\sigma}(gg \to Q\bar{Q})$$

- Gay Ducati, *et al.*, Phys. Rev. C 83, 014903 (2011):
  14 TeV, Resolved Pomeron $\sigma_{\mathbb{P}\mathbb{P}} = 13.6\ \mu$b ($R_{c\bar{c}} = 0.17\%$)
- Łuszczak *et al.*, Phys. Rev. D 91, 054024 (2015):
  14 TeV, Resolved Pomeron, $|y| < 2.5$, $p_T > 3.5$ GeV, $D^0 + \bar{D}^0$, $\sigma_{\mathbb{P}\mathbb{P}} = 177$ nb.

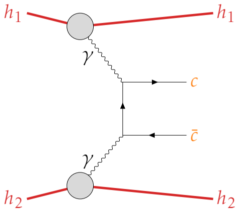


4. Central diffraction in $\gamma, \mathbb{P}$ exchange

$$\sigma(h_1 h_2 \to h_1 \sqcup Q\bar{Q} Y \sqcup h_2) = \int dx_1 \int dx_2 \; \gamma_1(x_1,\mu^2) \; g_2^D(x_2,\mu^2) \; \hat{\sigma}(\gamma g \to Q\bar{Q})$$

- Goncalves *et al*, Nucl.Phys.A 1000 (2020) 121862:
  pp @ 13 TeV, Exclusive, $|\eta| < 2.5$, Dipole Model
  $\sigma_{\gamma\mathbb{P}} = 83.2$–$117.9$ nb
- Goncalves *et al*, Phys.Rev.D 85 (2012) 054019:
  pp @ 14 TeV, Dipole Model, $\sigma_{\gamma\mathbb{P}} = 161$ nb
  pp @ 14 TeV, Resolved Pomeron, $\sigma_{\gamma\mathbb{P}} = 1208$ nb

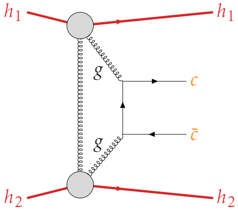
Central Diffraction (contd.)



5. Central exclusive production in the electromagnetic channel

$$\sigma(h_1 h_2 \to h_1 \sqcup Q\bar{Q} \sqcup h_2) = \int dx_1 \int dx_2 \;\; \gamma_1(x_1,\mu^2) \;\; \gamma_2(x_2,\mu^2) \;\; \hat{\sigma}(\gamma\gamma \to Q\bar{Q})$$

- The term $\hat{\sigma}(\gamma\gamma \to Q\bar{Q})$ is heavily suppressed due to presence of two EM vertices, thus it is not expected to contribute significantly to the signal measured experimentally.



6. Central exclusive production in the strong channel

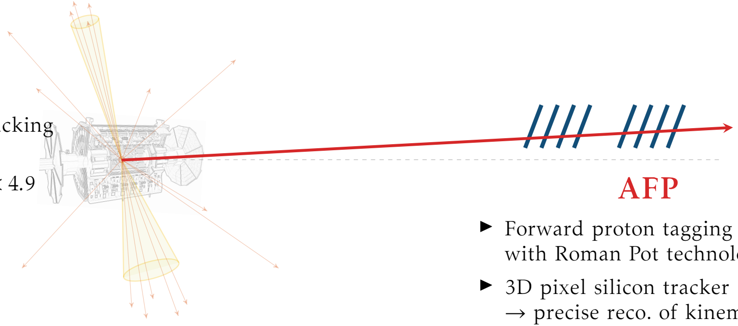
$$\sigma(h_1 h_2 \to h_1 \sqcup Q\bar{Q} \sqcup h_2) \propto \;\; \hat{\sigma}(gg \to Q\bar{Q})$$

- Maciuła *et al.*, Phys.Lett.B 685 (2010) 165-169:
  2 TeV: $R_{c\bar{c}} = 1\%$
- Gay Ducati, *et al.*, Phys. Rev. C 83, 014903 (2011):
  14 TeV: $\sigma_{\mathbb{PP}} = 0.53\ \mu$b ($R_{c\bar{c}} = 0.007\%$)

Measurement

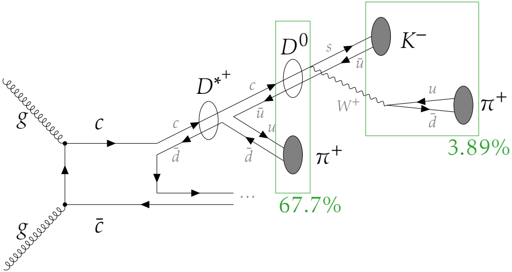
ATLAS

- Low-p_T charged particle tracking (down to 100 MeV)
- Calorimeter acceptance $|\eta| < 4.9$ (rapidity gaps)
- Dedicated triggers
- Advanced vertex & track reconstruction software



AFP

- Forward proton tagging with Roman Pot technology
- 3D pixel silicon tracker $\rightarrow$ precise reco. of kinematics
- Acceptance: $0.02 \lesssim \xi = 1 - E_{\text{proton}}/E_{\text{beam}} \lesssim 0.15$
- High efficiency, low background



Targeted decay modes:

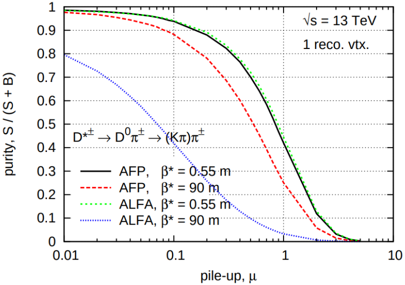
- $D^{*\pm} \rightarrow D_0\pi \rightarrow K\pi\pi$
- $D^{\pm} \rightarrow K\pi\pi$
- $D_s^{\pm} \rightarrow KK\pi$
- $\Lambda_C \rightarrow pK\pi$

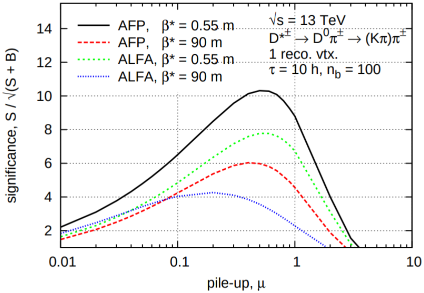
Measurement Feasibility

Excellent data to be studied:

- LHC Run 2 (2017):
  100 nb^{-1} at $\mu \sim 0.05$,
  500 nb^{-1} at $\mu \sim 0.3$,
  650 nb^{-1} at $\mu \sim 1$,
  150 pb^{-1} at $\mu \sim 2$.
- LHC Run 3 (2022):
  0.46 nb^{-1} at $\mu \sim 0.005$
  34.6 nb^{-1} at $\mu \sim 0.05$
  170 nb^{-1} at $\mu \sim 0.02$
- LHC Run 3 (2023):
  175 nb^{-1} at $\mu \sim 1$
  29 nb^{-1} at $\mu \sim 0.2$
  61 nb^{-1} at $\mu \sim 0.05$

- Feasibility studied with simulations (JHEP 02 (2017) 089)





- Dedicated triggers:
  track with min. $p_T = 2, 4, 6, 8$ GeV/c, single-side tag in AFP
  track with min. $p_T = 2, 4, 6, 8$ GeV/c, double-sides tag in AFP

First look at Pythia8 A3 simulation:

- The p_T spectrum of D mesons is quite soft – $\langle p_T \rangle \approx 2.5$ GeV/c for single diffraction
- Average number of charm hadrons with $|\eta| < 2.5$ is 1.77