Exclusive central diffractive production (ECDP): new results and key points

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LHC Working Group on Forward Physics and Diffraction
(16-17 December 2019, CERN)
ECDP kinematics and signatures

“HARD”

“SOFT”

\[ \phi \]

\[ \theta \]
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“HARD”

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1. Two final protons => Missing Mass Method
2. Large Rapidity Gaps ~ diffraction signature
ECDP regimes and theoretical approaches

Reggeon-reggeon
(Pomeron-Pomeron)
fusion
ECDP regimes and theoretical approaches

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M >> 1 GeV
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$M \gg 1 \text{ GeV}$

Resummations, PDFs, …
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Sudakov-like corr. (no “soft” radiation).

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IR, IP

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Possible final state “soft” interactions

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Resummations, PDFs, ...

< S^2 >

Unitarity => “soft surv. prob.”

IP-IP-IP, …, IR-IR-IR vertices

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IR, IP

M ~ 3-10 GeV

M ~ 1 GeV

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**ECDP key advantages**

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   * $d\sigma/dt$ $\rightarrow$ size and shape of the interaction region
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   * $d\sigma/dt$ $\rightarrow$ size and shape of the interaction region
5. Large cross-sections for low central masses
   (important for low luminosity runs)
ECDP: physics behind observables

Born term

Full result with all corrections

Spin-parity analyser

\[ \eta' \]

\[ f_1(1285) \]

\[ |t_1-t_2| < 0.1 \text{ GeV}^2 \]

\[ |t_1-t_2| > 0.2 \text{ GeV}^2 \]

\[ f_0(980) \]

\[ f_0(1500) \]

\[ f_2(1270) \]

\[ f_2(1950) \]

Figure 6: Results for the LHC energies. a) \( f_0(980), 0^{++} \); b) \( f_0(1500), 0^{++} \); c) \( f_2(1270), 2^{++} \); d) \( f_2(1950), 2^{++} \).
Size and shape of the interaction region

\[ \frac{1}{\sigma} \frac{d\sigma}{dt} \]
ECDP: physics behind observables

Size and shape of the interaction region

slope $B \sim R^2/2$

$\frac{1}{\sigma}\frac{d\sigma}{dt}$

elastic

ECDP

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Size and shape of the interaction region

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\[ \frac{1}{\sigma} \frac{d\sigma}{dt} \]

\[ s \uparrow, M_c \uparrow \]

ECDP: physics behind observables

ECDP

depend on different scales

elastic

ECDP

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Size and shape of the interaction region

\[ \text{slope } B \sim R^2/2 \]

Longitudinal size

\[ \Delta x_L > \frac{\sqrt{s}}{2\sqrt{\langle t^2 \rangle}} > -\langle t^2 \rangle \]

Depend on different scales

\[
\frac{1}{\sigma} \frac{d\sigma}{dt}
\]

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ECDP: physics behind observables

Size and shape of the interaction region

- slope $B \sim R^2/2$
- Dip position and depth $\Leftrightarrow \text{Re} \, T / \text{Im} \, T$

Depend on different scales

Longitudinal size

$$\Delta x_L > \frac{\sqrt{s}}{2\sqrt{\langle t^2 \rangle - \langle t \rangle^2}}$$

Graph showing the behavior of $1/\sigma$ with respect to $dt$, exhibiting different ECDP and elastic regions.
More sensitive variables = more exact verification

Born term $|M_B|^2 \sim e^{2B(t_1 + t_2)}$

Full result with all corrections

$t_1 + t_2$

$\delta^2 = (\Delta_1 - \Delta_2)^2 / 4.$
Low mass ECDP: di-pion continuum, interference with res.


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\[ \hat{F}_\pi = e^{(\hat{t}-m_{\pi}^2)/\Lambda_{\pi}^2} \]

STAR

\( \Lambda_{\pi}, \text{GeV} \)

5
4
3
1.6
1.2

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\[ \hat{F}_\pi = e^{\left(\frac{t-m_{\pi}^2}{\Lambda_{\pi}^2}\right)} \]

[CDF, CMS]

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CMS 7 TeV

\[ \frac{d\sigma}{dM_c}, \mu b/GeV \]
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\( \frac{d\sigma^{U}_{RF}}{dM_{c}} \), \( \mu b/GeV \)

\( M_{c}, \) GeV
Low mass ECDP: di-pion continuum, “soft surv. prob.”

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\( \frac{d\sigma}{dM_c}, \mu b/\text{GeV} \)

\( M_c, \text{ GeV} \)
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\[ \sigma_{\pi p} \]

\[ \sigma_{p^P (M^2; t)} \]
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\[ \sigma_{\pi p} \]

\[ \sigma_{pp}(M^2; t) \]

\[ \sigma_{pp}(M^2, t_1, t_2) \]
ECDP: reggeon-reggeon and reggeon-hadron interactions

\[ F_\theta \rightarrow \pi \]

\[ S \rightarrow t_1 \]

\[ T \rightarrow M \]

\[ \sigma_{\pi p} \]

\[ \sigma_{pp}(M^2; t) \]

\[ \sigma_{pp} \rightarrow \pi \pi \sim 0.1 \div 5 \text{ } \mu b \ll \sigma_{pp}^{tot} \sim 100 \text{ } \mu b \text{ , } M=1-3 \text{ } \text{GeV} \text{ , } t_{1,2}=-0.1 \text{ } \text{GeV}^2 \]
ECDP: very low $t$, Coulomb-nuclear interference

Elastic, very low $t$
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Elastic, very low t
ECDP: Odderon searches

\[ p \rightarrow \varphi, \omega, \Omega \rightarrow \varphi, \omega, J/\psi \rightarrow p \]
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\( \gamma \rightarrow \varphi, \omega, J/\psi \)
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\[ p \rightarrow C\text{-even state} \]

\[ (A, Z) \]
ECDP: Odderon searches

\( p \rightarrow \varphi, \omega, \Omega \rightarrow p \)  
\( p \rightarrow \gamma \rightarrow C\text{-even state} \rightarrow (A,Z) \)

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Monte Carlo generator for Exclusive Diffraction
Version 2.2 will be available soon
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Processes:
• elastic $p + p \rightarrow p + p$ at 7, 8, 13, 14 TeV
ECDP: simulation

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Processes:
• elastic \( p + p \rightarrow p + p \) at 7, 8, 13, 14 TeV
• ECDP \( p + p \rightarrow p + \text{Res.} + p \)

\( \text{Res.}: \)
\[ \eta_2(1645), \eta_0(1405) \text{ at } 13 \text{ TeV} \]
\[ \eta_0(958), f_1(1285), f_2(1270) \text{ at } 8 \text{ TeV} \]
\[ f_0(1500), f_0(1710), f_2(1950), f_2(2220) \text{ at } 8, 13 \text{ TeV} \]
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• ECDP $p + p \rightarrow p + \pi \pi + p$ at 7 TeV

Linked to Pythia 8 (to make resonance decays and hadronization) and also to ROOT and HEPMC output via Pythia interface
Summary: we need huge work in theory and experiment
We have the process ECDP with clear signature and tools (azimuthal, \( t \) and other vars. distributions) to obtain many important parameters: spin, parity, size and shape of the interaction region, dependence on different scales.

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- To clarify our understanding of Pomeron, Odderon, reggeons, and their interactions, we can extract hadron-reggeon and reggeon-reggeon cross-sections and also see additional processes where reggeons participate (Odderon-gamma, Odderon-Pomeron, …).
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- To study this process more deeply, we can use different kinematical modes, as in elastic scattering, for example, the region of interference of reggeon-reggeon and photon-photon processes.
Thank you