Exclusive Production at LHCb

LHCb Implications Workshop

Dan Johnson

CERN

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Overview

1. Central Exclusive Production (CEP) at LHCb
2. Results from run 1
3. Prospects for run 1 data
4. Extending LHCb’s rapidity coverage for next year
Interactions of the form $pp \rightarrow pEp$

**QED background:** $2\gamma$ exchange
- QED process with small proton form-factor corrections

**Pomeron exchange:**
- Pomeron is, at leading order, a pair of gluons in $++$ state

- **Photoproduction:** Photon-pomeron fusion
  - Probes gluon density at small values of proton’s momentum fraction, $x$
  - Perturbative calculations accessible for higher mass of $E$

- **Double pomeron exchange:** Pomeron-pomeron fusion
  - $E$ must be neutral $PC = ++$, no net flavour: $f_{0,2}, \chi_{c,b}, \gamma\gamma, JJ, H$
  - Low $M(E)$: spectroscopy studies. High $M(E)$: QCD and the pomeron
Experimental signature:

- ‘Exclusive’ candidate (e.g. $J/\psi \rightarrow \mu^+ \mu^-$) large rapidity gaps with respect to beam

At LHCb:

- Low pile-up
- Detection in pseudorapidity range $2 \rightarrow 5$
- Fully reconstruct and identify tracks from exclusive candidate
- Require no other detector activity
  - Implicitly require only one $pp$ interaction
  - Run 1 effective $L_{\text{int}}: \sim 600 \text{ pb}^{-1}$

Establishing the rapidity gap

- Require no other tracks reconstructed
- Require no $\gamma$ or $\pi^0$ activity in calorimeter
- Even beyond LHCb acceptance: exclusive candidate $p_T^2$ distribution
  - Regge theory implies exclusive candidate $\frac{d\sigma}{dt} \approx \exp(b_s t)$, where $t \approx -p_T^2 c^2$
  - Proton-dissociative background: similar exponential but with harder $p_T^2$
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Measurement: differential production cross-section (J Phys G41 055002)

\[ pp \rightarrow p(J/\psi \text{ or } \psi(2S) \rightarrow \mu^+\mu^-)p \]

Motivation

- Exchange of a photon and pomeron
- Calculable using pQCD, depends on gluon PDFs
- In LHCb rapidity range, probe \( x \) down to \( 5 \times 10^{-6} \)
- Sensitive to saturation effects
- Sensitive to odd-parity pomeron partner, ‘odderon’ (replacing photon)

‘Empty-detector’ signal and estimate of exclusivity

(a) Dimuon mass fit

(b) Example: \( J/\psi p_T^2 \) fit
1) Exclusive $J/\psi$ and $\psi(2S)$ production

**Interpretation**

- LO and NLO extrapolations from HERA data have been performed \(^1\)
- $J/\psi$ (left) and $\psi(2S)$ (right) data are superimposed: good agreement with NLO

\(^1\) JHEP 1311 (2013) 08
2) Double charmonium production

Measurement: production cross-section (J Phys G41 115002)

$$pp \rightarrow p(X)p, \; X = \{J/\psi J/\psi, J/\psi\psi(2S), \psi(2S)\psi(2S), \chi_{ci}\chi_{ci}\}$$

Motivation

- Exchange of two pomerons
- Cross-section and mass spectrum sensitive to exotics: e.g. glueballs or tetraquarks
- Relate cross section to calculated $$\sigma(gg \rightarrow J/\psi J/\psi)$$ using Durham model

‘Empty-detector’ signal

(c) Dimuon mass fit  
(d) Example: $$J/\psi J/\psi \; p_T^2$$ fit
Interpretation

- First observation of CEP for pairs of charmonium mesons
- Estimate of exclusive component in ‘empty-detector’ signal is $42 \pm 13\%$
- Measurement of $\sigma(J/\psi J/\psi) = 24 \pm 9 \text{pb}$ and $\frac{\sigma(J/\psi J/\psi(2S))}{\sigma(J/\psi J/\psi)} = 1.1^{+0.5}_{-0.4}$ in reasonably good agreement with subsequent theoretical calculation
- Observed $J/\psi J/\psi$ mass spectrum in good agreement with shape (independent of renormalisation/factorisation scales) from MSTW08LO (cf inclusive $J/\psi J/\psi$ mass spectrum).

\[\text{d}N/\text{d}M_{\psi\psi} \text{ [Events/GeV]}\]

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$^2$arXiv:1409.4785

$^3$PLB 707 52
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Ongoing analyses

Young field in LHCb, but maturing rapidly

Photoproduction

- Gluon PDF: natural to extend dimuon mass range (e.g. \( \Upsilon(1S, 2S, 3S) \)) where:
  - Heavier central system \( \Rightarrow \) pQCD
  - Probe very low \( x \)

\[(e) \ 37 \text{pb}^{-1} \ \text{dimuon mass spectrum} \]

Predictions exist for the \( \Upsilon \) CEP differential cross section:
Ongoing analyses

Pomeron pomeron fusion

- Di-meson production (e.g. $\pi\pi$, $KK$, $D\bar{D}$?)
- Heavy quark systems ($\chi_c, \chi_b, \ldots$)
  - Decaying to $\mu^+\mu^-\gamma$
  - Expect separation of $\chi_{c0,1,2}$ states using converted photons

Spectroscopy studies: $X(3872)$

- LHCb observed $1^{++}$ inclusively
- Can it be seen exclusively?

(f) $\mu^+\mu^-\gamma$ spectrum in 37pb$^{-1}$

(g) Inclusive $X(3872)$
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Biggest challenge currently is to establish the rapidity gap

High proportion (50% for $J_\psi J_\psi$ CEP) of ‘empty-detector’ signal where proton dissociation escapes down the beampipe

LHCb hopes for $\sim 5fb^{-1}$ during run II at low pile-up

Install scintillators either side of LHCb

Veto showers from high rapidity particles interacting with the beam-pipe elements
Simulated energy densities in first scintillator station

(h) Min-bias  
(i) Single-diffractive  
(j) CEP-like

- Each station must be sensitive to $\sim 100$ hits to effectively veto single diffractive events, while tolerating $\sim 2500$ hits/event in minimum bias operating conditions.
- Efficiency is good even for low energy particles, beyond geometric acceptance due to showering.
Installation and commissioning status

- Four of five stations installed and cabled
- Commissioning tests underway
- Read-out chain maturing
Summary

Exciting opportunities for CEP studies at LHCb

- **LHCb’s forward acceptance** provides unique window on CEP
- **Spectroscopy** in a very clean environment
- **QCD studies**
  - very low-$x$ gluon PDF
    - increased $\sqrt{s}$ allows probing of even lower $x$ (CEP $J/\psi \to x = 2 \times 10^{-6}$)
  - nature of pomeron
  - sensitivity to glueballs, odderons, tetraquarks
- **Run 1**:
  - published analyses: $J_\psi/\psi(2S)$ and double-charmonium CEP
  - many more analyses anticipated
- **Introduction of FSCs** for 2015 will greatly enhance LHCb’s CEP programme