XXVI International Workshop on Deep Inelastic Scattering and Related Subjects
Kobe (Japan), April 16th- 20th 2018

Exclusive measurements with CMS

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Outline

- Introduction

- CMS detector and forward instrumentation

- Exclusive $\pi^+\pi^-$ production at 7 TeV

- Exclusive $\Lambda$ production in pPb at 5.02 TeV
  [CMS FSQ-13-009]

CMS detector

**LHC Runs**

- **pp** 7, 8, 13 TeV
- **pPb** 5.02, 8 TeV

**Components:**
- EM and Hadron calorimeters
- Muon Chambers
- Inner tracker
- Pb (1.58 TeV)
- Proton (4 TeV)
- Hadron Forward calorimeter (HF): $2.9 < |\eta| < 5.2$ (10 m from IP)
- Beam Scintillator Counters BSC: $3.2 < |\eta| < 4.7$ (in front of HF)
- CASTOR calorimeter: $-6.6 < |\eta| < -5.2$ (14.4 m from IP, one side only)
- Forward Shower Counters FSC: $6 < |\eta| < 8$ (59-114 m from IP)
- Zero Degree calorimeter: $|\eta| > 8.1$ (140 m from IP)
Energy of scattered protons \(\approx\) beam energy (within a few \%) \(\rightarrow\) protons in the final state

Pomeron exchange (IP), Large Rapidity Gap (LRG)

If \(X \) = anything:

- Measure fundamental quantities of soft QCD
- Contributes significantly to pile-up, underlying event (SD \(\sim\) 15 mb, DD \(\sim\) 10 mb)

If \(X\) includes jets, W's, Z's:

- Hard processes, calculable in perturbative QCD
- Measure proton structure, QCD at high parton densities, discovery physics
...exclusive reactions

Study the reaction

$$pp \rightarrow p^{(*)}Xp^{(*)}$$

where numerous production mechanisms can contribute to produce the central system $X = e^+e^-, \mu^+\mu^-, \gamma\gamma, W^+W^-, ...$
Exclusive $\pi^+\pi^-$ production at 7 TeV
Experimental signature

Described in terms of Double Pomeron Exchange (DPE) at low scales or pertubatively in “CEP”

Low PU 2010 data @7 TeV, L ~ 505 μb⁻¹
Two opposite-sign pions with $p_T > 0.2$ GeV, $|y| < 2$
Exclusivity: no other tracks and no energy above thresholds in calorimeter

Monte Carlo Models:
PYTHIA 8C, PYTHIA 8 MBR, Dime for DPE
STARLight for fotoproduction
**Background estimation**

OS: Opposite Sign, *signal*
SS: Same Sign, *background*

Data driven background subtraction
looking at N of extra CAL towers above
noise threshold

$N_{\text{extra}} > 1$ well described by NBD between
2 and 10

Extrapolation of NBD to 0, 1 in OS
sample provides background estimation
Compared to predictions of
Dime and PYTHIA (DPE)
STARLight (rho photoproduction)

Beware: proton dissociation
NOT in the models
Central, exclusive production in pp

- Appears to be a universal, energy independent observation.
- Similar features observed at RHIC, Tevatron, LHC.

From Monday’s plenary by J. Nystrand
$d\sigma/dp_T$, $d\sigma/dy$

**Comparison**

**Compared to predictions of**

- **Dime** and **PYTHIA (DPE)**
- **STARLight** (rho photoproduction)

**Beware:** proton dissociation NOT in the models

Recent phenomenological developments, including continuum+resonances, indicate that data-model agreement can improve tuning IP-IP-f2 coupling

[P. Lebiedowicz, O. Nachtmann and A. Szczurek, PRD 93 (2016) 0504015]
Requirement of transverse momentum balance applied to reject background and select events of central exclusive production, \( pp \rightarrow ppX \) with \( X=\pi^+\pi^-, K^+K^- \), \( \pi^+\pi^-\pi^+\pi^- \), \( K^+K^-K^+K^- \), ...
Exclusive $Y$ production in $pPb$
Motivation

Ultraperipheral pPb collisions

Photon flux grows with the square of the charge, $Z^2$

Photoproduction process sensitive to gluon density squared in nucleon (nucleus)

$$\chi = (M_Y / W_{\gamma p})^2$$

Photonuclear cross-section shows power-law dependence with $W_{\gamma p}$

$$\sigma \propto W_{\gamma p}^\delta$$
Data

2013 pPb data @ 5.02 TeV, L ~ 33 nb⁻¹, UPC trigger with two muons
Dimuons with $p_T(\mu) > 3.3$ GeV, $|\eta| < 2.2$, $0.1 < p_T(\mu\mu) < 1$ GeV,
9.12 < $M_{\mu\mu}$ < 10.64 GeV, no extra tracks

STARLight for signal and QED continuum
Data-driven subtraction of proton-dissociation background
\[ \frac{d\sigma}{dt} \] fitted with an exponential function, provides info on the transverse profile of the interaction region.

**CMS Results**

\[ b = 4.5 \pm 1.7 \text{ (stat.)} \pm 0.6 \text{ (syst.) GeV}^{-2} \]

Data is in agreement with ZEUS measurements and consistent with predictions based on pQCD models.

**ZEUS for Y(1S)**

\[ b = 4.3^{+2.0}_{-1.3} \text{ (stat)} \]

Photoproduction cross section vs $W_{\gamma p}$

Cross section estimated by

$$\sigma_{\gamma p \rightarrow \Upsilon(1S)p} = \frac{1}{\Phi} \frac{d\sigma_{\Upsilon(1S)}}{dy}$$

$$W_{\gamma p}^2 = 2 \cdot E_p \cdot M_{\Upsilon} \cdot \exp(+/-y)$$

Cross-section corrected for muonic branching ratio, feed-down, upsilon (1S) fraction

A fit with power-law $A \times (W/400)^\delta$ to the CMS data

$$\delta = (0.96 \pm 0.43), A = 655 \pm 196$$

Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours LO pQCD predictions

ZEUS

$$\delta = 1.2 \pm 0.8$$

[PLB 680(2009) 4-12]
Summary

- **Exclusive $\pi^+\pi^-$**
  - Differential cross-sections above exclusive $\pi^+\pi^- + \rho$ photoproduction predictions for high-pt
  - The invariant mass spectrum shows some features not included in the purely non-resonant predictions

- **Exclusive $\gamma$ in pPb**
  - Data compatible with power-law dependence of $\sigma_{Y(1S)}(W_{\gamma p})$ and previous measurements by HERA and LHCb
  - $d\sigma/dt$ in agreement with earlier measurements and consistent with predictions based on pQCD models