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# Exclusive production at the CMS experiment

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## On behalf of the CMS collaboration

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### Outline

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- Motivation
- Exclusive photoproduction of Upsilon in pPb collisions at √s = 5.02 TeV
  - estimate the t dependence of the cross-section
  - photonuclear cross-section

- → Exclusive production of massive electroweak boson pairs in pp collisions at  $\sqrt{s} = 7$  and 8 TeV
  - Search for exclusive  $\gamma \gamma \rightarrow W^+ W^-$
  - Limits on anomalous quartic gauge couplings

All Forward physics results at CMS https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ



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#### The CMS Experiment



#### Motivation: Exclusive upsilon photoproduction

- → The exclusive photoproduction of  $\Upsilon$  studied in pPb ultra peripheral collisions
- → Ions interact via photons, flux of photons  $\alpha$  Z<sup>2</sup>
- $\rightarrow$   $\gamma$  p: Dominant contribution,  $\gamma$  Pb: Small contribution
- Photoproduction process is sensitive to the gluon density squared in the nucleon (nucleus)

$$\frac{d\sigma_{\gamma p,A \rightarrow V p,A}}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG(x,Q^2)]^2$$

$$\sigma_{\gamma p \to \gamma p} = \frac{1}{b} \frac{d \sigma_{\gamma p, A \to V p, A}}{dt} \Big|_{t=0}$$

- → Probe gluon distribution in the proton at low x (10<sup>-4</sup> to 2\*10<sup>-2</sup>)  $x = (M_Y / W_{yp})^2$

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





#### **Exclusive upsilon production**

→ 2013 pPb data at 5.02 TeV with 32.6 nb<sup>-1</sup>

#### CMS-FSQ-13-009

- → Offline exclusive pPb →  $\Upsilon$  (γp) →  $\mu^+\mu^-$  signal selection
  - Invariant mass (μμ) : 9.12–10.64 GeV
  - Opposite-sign  $\mu\mu$  pair (final state) originating from commom primary vertex
  - No extra tracks at  $\mu\mu$  vertex to suppress non-exclusive background
  - Upsilon  $p_{\tau}: 0.1-1$  GeV to suppress QED and non-exclusive background
  - Upsilon |y| < 2.2 high muon finding efficiency



#### **Exclusive upsilon production**

Data compared to simulation (contains different contribution)

CMS-FSQ-13-009

- $\rightarrow$  Low p<sub>T</sub>: **QED** elastic background, estimated by **STARLIGHT**
- → High  $p_{\tau}$ : Non-exclusive background estimated from data
- **\rightarrow** STARLIGHT MC :  $\gamma$ Pb(small contribution) and  $\gamma$ p contribution reweighted



Good agreement betweem data and MC

Number of signal events estimated by subtracting all background contributions.

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#### Photoproduction cross section as a function of t

The differential cross section is calculated according to

$$\frac{d \,\sigma_{\rm Y}}{dt} = \frac{N_{sig}^{Unfolded}}{L \times \Delta t}$$

- N<sub>sig</sub>, the background subtracted, unfolded and acceptance corrected number of upsilon events in each | t | bin.
- $d\sigma/dt$  fitted with an exponential **→** function, provides the information on the transverse profile of the interaction region.



CMS-FSQ-13-009

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 $b = 4.3^{+2.0}$  (stat)

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#### Cross-section as a function of W

The cross-section is estimated by

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

- Rapidity distribution of  $\Upsilon(1S+2S+3S)$  used to estimate  $\sigma_{\gamma p}$ (1S) vs W<sub> $\gamma p$ </sub>
- The cross-section is corrected for muonic branching ratio, feeddown, upsilon (1S) fraction



#### Motivation: Exclusive electroweak boson pairs

- The exclusive production of W pairs is sensitive to anomalous quartic gauge couplings (aQGC)
- The electro-weak sector of Standard Model predicts QGC
- Any deviation from SM expections can reveal a sign of new physics
- → Objective: Measure SM cross section and look for aQGC.
- aQGC are introduced via effective Lagrangian

$$\mathcal{L}_{6}^{0} = \frac{-e^{2}}{8} \frac{a_{0}^{W}}{\Lambda^{2}} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W_{\alpha}^{-}$$
$$\mathcal{L}_{6}^{C} = \frac{-e^{2}}{16} \frac{a_{C}^{W}}{\Lambda^{2}} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W_{\beta}^{-} - W^{-\alpha} W_{\beta}^{+}) \cdot$$

# Anomalous coupling constant for quartic vertex $\Lambda$ : Scale for New Physics



#### Exclusive $\gamma \gamma \rightarrow W^+ W^-$ event selection

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- Exclusive production of W pairs  $pp \rightarrow p^{(*)}W^+W^-p^{(*)}$  $p^{(*)}$ : Elastic + Inelastic contributions
- → 2011 pp collision data at 7 TeV with 5.05 fb<sup>-1</sup>
- → 2012 pp collision data at 8 TeV with 19.7 fb<sup>-1</sup>
- → Offline exclusive  $\gamma\gamma \rightarrow W^+ W^-$  signal selection
  - Opposite-sign eµ pair (final state) originating from commom primary vertex
  - No extra tracks at eµ vertex to remove inclusive background
  - Invariant mass (eµ) > 20 GeV to get rid of any low mass resonances
  - $p_{\tau}(e\mu) > 30 \text{ GeV}$ to suppress DY and  $\gamma\gamma \rightarrow \tau^{+}\tau^{-}$
- Proton dissociation factor from exclusive μμ sample
  p<sub>τ</sub> (eμ) > 30 GeV SM , p<sub>τ</sub> (eμ) > 100 GeV aQGC





#### SM evidence at 7 and 8 TeV

#### SM signal region : N extra tracks =0 , $p_{\tau}(e\mu) > 30 \text{ GeV}$



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#### aQGC search and limit at 7 and 8 TeV

- Used shape of p<sub>τ</sub> (eµ) distribution to search for sign of anomalous quartic gauge couplings
- → p<sub>T</sub> (eµ) > 100 GeV used at
  7 TeV
- → Two bins at 8 TeV
  30 < p<sub>T</sub> (eµ) < 130 GeV and</li>
  p<sub>T</sub> (eµ) > 130 GeV
- Region outside solid line is excluded at 95% CL
- The most stringent limit so far, two orders of magnitude more stringent than LEP



Dimension-6 AQGC parameter	$7 \text{ TeV} (\times 10^{-4} \text{ GeV}^{-2})$	$8 \text{ TeV} ( imes 10^{-4} \text{ GeV}^{-2})$	7+8 TeV ( $\times 10^{-4} \text{GeV}^{-2}$ )
$a_0^{\rm W} / \Lambda^2 (\Lambda_{\rm cutoff} = 500 {\rm GeV})$	$-1.5 < a_0^W / \Lambda^2 < 1.5$	$-1.1 < a_0^W / \Lambda^2 < 1.0$	$-0.9 < a_0^W / \Lambda^2 < 0.9$
$a_C^W / \Lambda^2 (\Lambda_{\text{cutoff}} = 500 \text{GeV})$	$-5 < a_{C}^{W} / \Lambda^{2} < 5$	$-4.2 < a_C^W / \Lambda^2 < 3.4$	$-3.6 < a_C^W / \Lambda^2 < 3.0$

#### Summary

- Exclusive upsilon photoproduction
  - The first measurement of exclusive  $\Upsilon$  photoproduction in pPb collisions at 5.02 TeV
  - Data compatible with power-law dependence of  $\sigma(W_{_{\gamma p}})$ , disfavours LO pQCD predictions
  - The differential cross-section  $d\sigma/d|t|$  is in agreement with earlier measurements and consistent with predictions based on pQCD models
- → Exclusive  $\gamma \gamma \rightarrow W^+ W^-$ 
  - 2 events at observed at 7 TeV, 13 events observed at 8 TeV in SM region
  - The observed yields and kinematic distributions are consistent with the SM prediction, with a combined significance over the background-only hypothesis of  $3.4\sigma$
  - Search for aQGC- The most stringent limit so far, no indication of aQGC found.
- Probe lower x vaues with pPb 8 TeV collision
- → Expect more results in the future (13 TeV) with CT-PPS.