



## Exclusive and Diffractive Physics with CMS

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- CMS experiment
- Exclusive Physics Process
  - Exclusive  $\gamma\gamma \to W^+W^-$
- Soft Diffraction Cross Sections
- Measurement of the Inelastic Proton-Lead Cross Section

All Forward Physics Results at CMS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ





#### • CMS experiment

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#### **CMS** Detector





| Weight: 14.000 ton. | Diameter: 15 m | Length: 21,6 m | Magnetic Field: 4 Tesla |





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## **Exclusive** $\gamma \gamma \rightarrow W^+ W^-$ **Production**



#### Motivations <u>CMS PAS FSQ-12-010</u>

- The measurements of the two-photon production of WW pairs are sensitive to Anomalous Quartic Gauge Couplings (AQGC).
- Previous exploratory studies ("exclusive" two-photon production of lepton pairs) indicated the potential for extending the experimental research limit beyond LEP results.
- Existing sensitivity studies performed in the scenario of Forward Detectors upgrade for CMS (Nucl.Phys.Proc.Suppl. |79-180 (2008) 257-264) and ATLAS (Phys. Rev. D81 (2010) 074003);



Published in the Journal of High Energy Physics as JHEP07(2013)116.

• These processes involve two triple coupling (TGC) vertices involving t-channel W boson exchange.

• Sensibility to TCG's and QGC's limited, given the LHC/LEP limits.



• 2011 data collected corresponding to an integration

• Criteria of Exclusivity: no extra tracks associated to

luminosity of 5.05 fb<sup>-1</sup> at 7 TeV (moderate: PU~10)

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electron-muon vertex

- SM region selection: N(extra tracks) 0 and  $pT(\mu e) > 30 \, GeV$
- $\gamma\gamma \rightarrow W^+W^-$ -search region: N(extra tracks) 0 and  $pT(\mu e) > 100 \, GeV$



#### CMS PAS FSQ-12-010





Exclusive  $\gamma \gamma \rightarrow W^+ W^-$  Production









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## Soft Diffraction Cross Sections

MC simulation:

- PYTHIA8-4C: diffraction with Schuler&Sjostrand model from PYTHIA6 (Tune 4C is additional scaling of SD and DD)

-PYTHIA8-MBR: diffraction with Minimum Bias Rockefeller model(http://indico.cern.ch/conferenceOtherViews.pyview=standard&confld=184925)

#### CMS-PAS-FSQ-12-005

- First measurement of the inclusive diffractive cross section
- Using Large Rapidity Gap (LRG) signatures
- SD and DD separated with CASTOR  $(-6.6 < |\eta| < -5.2)$ .





 $\frac{N^{data} - (N_{ND} + N_{SD} + N_{CD})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta \eta)_{bin}}$ 

DD (pp  $\rightarrow X$ )

CMS Preliminary, √s = 7 TeV, L = 16.2 µb<sup>-1</sup>



## Soft Diffraction Cross Sections



#### Rapidity gap cross section

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- Inclusive differential xsection for events with a largest forward rapidity gap
- Data has to be **corrected** for background of circulating beams and for bin migration and fake/miss events with the Bayesian unfolding method
- Unfolded and fully corrected differential cross section of the forward rapidity gap size
- Total systematic uncertainty is 20 % (shown with a green band)
- Good description using PYTHIA8-MBR



CMS-PAS-FSQ-12-005

## Soft Diffraction Cross Sections



#### **Comparison between CMS and ATLAS results**



Hadron level definition in each measurement: CMS and ATLAS

• The CMS results has a good agreement with ATLAS studies





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## UERJ CMS-FSQ-13-006

## Inelastic Proton-Lead Cross Section

# CMS



\*Phys. Rev. C 81, 025204

Measurement of Inelastic proton-lead cross section and comparison with model predictions: Glauber approach<sup>\*</sup> (implemented on MC generator HIJING) or Gribov-Regge framework (EPOS-LHC, QGSJETII-04)

- Measurement of the hadronic Inelastic xsec. by an event counting method
- Photo-nuclear collisions are excluded from measurement
- Equivalent-photon approximation handled by **Starlight** generator combined with DPMJET or PYTHIA

pp Inelastic Cross Section @ 7 TeV measured by several LHC experiments.



p-Air inelastic xsection with Pierre Auger Observatory @57TeV - Glauber model extended by inelastic screening to calculate pp xsection and large uncertainties

#### Phys. Rev. Lett. 109, 062002







➡EPOS-LHC xsec(diffractive) 1.12 to match ratio in data

→QGSJETII-04 is very similar but less for DD (1.15 xsec(diffractive) needed to get ratio seen in data)

➡HIJING does not have diffraction for pA included













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## Summary



- Measurement of the exclusive two-photon production of WW pairs in pp collisions at 7 TeV, based on samples of events collected during 2011 physics runs.
- Provide unique sensitivity to anomalous quartic couplings of the gauge bosons (AQCG). Extending the experimental reach by several orders of magnitude with respect to the best limits so far obtained at LEP.
- Inclusive SD and DD diffractive cross section measured at 7TeV. MC prediction are in agreements with data using several theoretical models.
- The differential cross section has been measured and as a function of the variable ( $\xi$ ) that approximates the momentum loss of protons in diffractive events.
- $\bullet$  Hadronic inelastic cross section measured with the CMS experiment in pPb collisions at 5.02 TeV





#### Extra Slides





### **General Information**



#### LHC Experiment







#### **CMS** Detector







#### Forward detectors









#### CMS PAS FSQ-12-010



 $\gamma\gamma \to W^+W^-$ 



#### CMS PAS FSQ-12-010













#### CMS PAS FSQ-12-010



Figure 45: Event displays of the two events passing all selection criteria with  $p_T(\mu^{\pm}e^{\mp}) > 30$  GeV.



## Exclusive production: $\gamma\gamma \rightarrow \mu^+\mu^-/e^+e^-$





CMS Experiment at LHC, CERN Data recorded: Fri Jul 30 01:43:39 2010 CEST Run/Event: 141956 / 304737217 Luni section: 546

MS



<u>CMS FWD-10-005</u> J. High Energy Phys. 01 (2012) 052



Exclusive two-photon events: 2 muons/electrons and nothing else

Main background to pure QED process from single and double proton dissociation processes, where the proton fragments in a low mass state

Standard candle for exclusive processes at the LHC

# CMS

# Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ production

Measurement restricted to well controlled kinematic region ( $p_T(\mu) > 4$ GeV,  $|\eta| < 2.1$ ,  $m(\mu\mu) > 11.5$ ), rejecting  $\Upsilon$  photo-production

Exclusivity condition requires a primary vertex with exactly 2 muons and no other track within 2 mm

Signal extracted with a binned maximum likelihood fit to the  $p_T(\mu\mu)$  distribution





$$\sigma \left( p + \mu \mu + p \right) = 3.38^{+0.58}_{-0.55} (stat.) \pm 0.16 (syst.) \pm 0.14 (lum.) \text{pb}$$

Largest systematics from track veto efficiency (data driven - pile-up sensitive)

Good agreement between data and LPAIR MC (signal and proton dissociation)

Potential for luminosity monitor at the LHC

## Exclusive $\gamma \gamma \rightarrow e^+e^-$ production



J. High Energy Phys. 11 (2012) 080





#### CMS-PAS-FSQ-12-005 Extra slides



## Soft Diffraction Cross Sections

#### **Experimental Topologies of Diffractive Events**

#### CMS-PAS-FSQ-12-005

•The topologies can be defined based on the position of the LRG in the central detector

•Forward gap is defined in terms of the highest or lowest pseudorapidity of PF object in the central detector for single dissociative events

•Double dissociative events: central gap is defined in terms of the closest-to-zero  $\eta$  of PF object on the positive or negative  $\eta$ -side of the central detector



 $\eta_{min}$ 

central<sub>i</sub>detector

central detector

level

ND

a)

SDI-type events will be treated in a control sample, while **SD2-type** events will be used to estimate the diffraction xsection





 $\eta_{max}$ 

true

level

ND