Exclusive and diffractive physics results from CMS

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Outline

- Observation of inclusive (soft) diffraction at 0.9, 2.36 and 7 TeV
  *CMS PAS FWD-10-001, FWD-10-07*

- Hard diffraction
  - Diffractive dijets  *(new)*
    *CMS PAS FWD-10-004*
  - Energy flow and rapidity gaps at hard scale (W/Z events)

- Exclusive processes
  - \( \gamma \gamma \rightarrow \mu \mu \) production
    *JHEP 01:052, 2012*
  - \( \gamma \gamma \rightarrow ee \) and search for central exclusive \( \gamma \gamma \) production  *(new)*
    *CMS PAS FWD-11-004*
CMS detector

- Tracking
  \(|\eta| < 2.4, p_T \text{ down to } \sim 100 \text{ MeV}\)

- Calorimetry
  - Electromagnetic calorimeter \(|\eta| < 3.0\)
  - Hadronic calorimeter (HB, HE, HF) \(|\eta| < 5.0\)

- Muons
  \(|\eta| < 2.4, p_T > 3 \text{ GeV (barrel)}\)

- Forward detectors:
  - HF, hadron forward calorimeter (10m from IP) \(3 < |\eta| < 5\)
  - BSC, beam scintillator counters (in front of HF) \(3.2 < |\eta| < 4.7\)
  - CASTOR calorimeter (one side only) \(-6.6 < \eta < -5.2\)
  - ZDC (zero degree calorimeter) \(|\eta| > 8.1\)
Observation of soft diffraction

- Early CMS result based on dedicated runs (no PileUp) from 2009 and 2010 data
- Minimum-Bias trigger (hit in either of BSCs) + vertex
- Study activity in one of the forward calorimeters (HF)

Data compared to Pythia6, Pythia8 and Phojet with and without diffraction. At low HF energy deposits excess of data wrt non-diffractive MC. None of the models describe the features of the data.

\[ \sqrt{s} = 0.9 \text{ TeV} \]
\[ \sqrt{s} = 2.36 \text{ TeV} \]
\[ \sqrt{s} = 7 \text{ TeV} \]
Diffractive dijets

Measure hard diffractive process and compare to pQCD-based theory predictions (gap-survival probability at 7 TeV).

- Analysis based on 2010 data (2.7 nb⁻¹) with negligible PileUp
- Single-jet trigger, anti-kt 0.5, vertex.
- At least 2 jets with $p_T > 20$ GeV and $|\eta| < 4.4$
- Based on Particle Flow objects (tracking+calorimetry)

Large Rapidity Gap (LRG): require most forward (or backward) PF object in the event to satisfy $\eta_{\text{max}} < 3$ (or $\eta_{\text{min}} > -3$).

Corresponds to no individual energy deposit above 4 GeV in HF+ (or HF-). Rapidity gap of 1.9 units.

LRG data described by a combination of diffractive (POMPYT) and non-diffractive (PYTHIA6 Z2) samples

relative fraction from the fit to the data
Inclusive di-jet cross section extracted in 3 bins of $\xi$.

For single-diffractive events $\xi$ approximates proton fractional momentum loss.

\[ d\sigma_{jj} \over d\tilde{\xi} = N^i_{jj} \over L \cdot e \cdot A^i \cdot \Delta\tilde{\xi}^i \]

$\xi$ reconstructed from PF objects.
$\xi^+$ ($\xi^-$) corresponds to the gap on positive (negative) side.

Excess of events in low-$\xi$ region wrt non-diffractive PYTHIA6 and PYTHIA8 MC.

POMPYT and POMWIG (LO) diffractive MCs and NLO calculations from POMWEG, using diffractive PDFs, are a factor ~5 above the data in the lowest-$\xi$ bin.

Data/MC suppression factor is: 0.21 $\pm$ 0.07 (LO MC)
0.14 $\pm$ 0.05 (NLO MC).

After proton-dissociation correction, the ratio can be interpreted in terms of rapidity-gap survival probability of 0.12 $\pm$ 0.05 (LO MC) and 0.08 $\pm$ 0.04 (NLO MC).
Forward energy flow and rapidity gaps with W/Z events

Study of energy flow in the forward region. Diffractive component in W/Z sample.

- Analysis based on full 2010 dataset (36 pb\(^{-1}\))
- Only single-vertex events to suppress PileUp
- Selection for leptonic W/Z decays follows inclusive cross section measurements
  iso. lepton with \(p_T>25\) GeV and \(|\eta|<1.4\), \(E_{T,\text{miss}}>30\) GeV, \(m_T>60\) GeV

**LRG events**: events with no individual energy deposit above 4 GeV in one of HF. Rapidity gap of 1.9 units.

Wide range of (non-diffractive) predictions, tune dependent:
- Excess of gap events compared to PYTHIA6 D6T
- Deficit compared to PYTHIA6 Z2 and Pythia8.

**Monte Carlo generators cannot describe the data.**

Fraction of gap events:

\[
W \rightarrow l\nu = 1.46 \pm 0.09 \text{ (stat.)} \pm 0.38 \text{ (syst.)} \%
\]

\[
Z \rightarrow ll = 1.60 \pm 0.25 \text{ (stat.)} \pm 0.42 \text{ (syst.)} \%
\]
Forward energy flow and rapidity gaps with W/Z events

Hemisphere correlation
Signed pseudorapidity of lepton, $\eta_l$:
positive - if gap and lepton on the same side
negative - if gap and lepton on the opposite side.

- Large asymmetry in model including W/Z production in single-dissociation diffraction (POMPYT)
- No significant asymmetry in non-diffractive PYTHIA W/Z samples, independent of the tune

Diffractive component in LRG W/Z sample:
from best with with PYTHIA (ND) and POMPYT (SD) MC

$$f_{SD} = 50.0 \pm 9.3 \text{ (stat.)} \pm 5.2 \text{ (syst.) \%}$$

First evidence of diffractive W/Z production at LHC
Exclusive $\gamma\gamma\rightarrow\mu\mu$ production

- Analysis based on full 2010 dataset (40 pb$^{-1}$)
- Di-muon trigger + tracking information (calorimeters not used)
- Vertex with 2 tracks, no other track within 2mm (track veto)
- Kinematic cuts: $\text{muon } p_T > 4 \text{ GeV, } |\eta| < 2.1$, $m(\mu\mu) > 11.5 \text{ GeV}$
- Back-to-back topology: $\Delta\phi > 162 \text{ deg.}, \Delta p_T < 1 \text{ GeV}$

QED process, accurate theory predictions:
- Complementary luminosity calibration.
- Control sample for other exclusive processes theoretically less certain (exclusive $\gamma\gamma$ or Higgs production).

Good agreement of kinematic distributions with LPAIR prediction

Dominant background – proton dissociation (uncertainty in modelling of low mass dissociated system)

Exclusivity defined by track veto retains efficiency with high PileUp! (~92% at PU=3)

JHEP 01:052,2012
Exclusive $\gamma\gamma\rightarrow\mu\mu$ cross section

Exclusive cross section and ratio to LPAIR prediction extracted from the fit to $p_T(\mu\mu)$ distribution.

Free parameters of the fit: signal yield, single proton-dissociation yield and the correction to the shape of the proton-dissociation sample (negligible).

Results of the fit:

$$\sigma = 3.38_{-0.55}^{+0.58} \text{ (stat.)} \pm 0.16 \text{ (syst.)} \pm 0.14 \text{ (lumi.) pb}$$

$$\text{ratio to MC} = 0.83_{-0.13}^{+0.14} \text{ (stat.)} \pm 0.04 \text{ (syst.)}$$

Consistent with expectations at ~ $1\sigma$. 

JHEP 01:052, 2012
$\gamma\gamma \rightarrow ee$ production and search for central exclusive $\gamma\gamma$ production

Exclusive $ee$ production – QED process (similarly to $\mu\mu$)
Exclusive $\gamma\gamma$ production – QCD process

- Analysis based on full 2010 dataset (36 pb$^{-1}$)
- Trigger: two electromagnetic objects. Offline: two high-quality electrons or photons.
- Exclusivity criteria: no additional tracks, no additional energy deposit in calorimeters (eff.=0.145±0.008)
- Kinematic cuts: $E_T > 5.5$ GeV, $|\eta| < 2.5$
- Back-to-back topology: $\Delta\varphi > 2.5$ rad

Exclusive $ee$:

17 candidates observed in data.
Background expectations: 0.84±0.28 (stat.)

Predicted by LPAIR:
16.5±1.7 (theory) ± 1.2 (stat.) (elastic and proton dissociation).

Very good agreement between data and LPAIR prediction.

Provides validation of experimental procedure for $\gamma\gamma$ search.

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CMS PAS FWD-11-004
Exclusive $\gamma\gamma$ production:

No events observed after all selections.

Upper limit on exclusive + proton dissociation production of $\gamma\gamma$ with $E_T > 5.5$ GeV, $|\eta| < 2.5$:

$$\sigma < 1.30 \text{ pb} \quad @95\% \text{ CL}$$

Results compared to prediction of ExHume MC with several LO/NLO PDF sets.

Poor statistics to test NLO calculations.

Probability of seeing 0 events wrt. MSTW08-LO prediction is 23%.
Summary

- CMS results presented on:
  - Soft diffraction at 0.9, 2.36 and 7 TeV
  - Diffractive dijets
  - Energy flow and rapidity gaps with W/Z events
  - Exclusive $\gamma\gamma \rightarrow \mu\mu$ production
  - Exclusive $\gamma\gamma \rightarrow ee$ and search for central exclusive $\gamma\gamma$ production

- Prospects:
  - Many new results expected - ongoing analyses with 2010/early 2011 data, possible low-pileUp runs in 2012
  - Only beginning to exploit the potential of forward detectors (CASTOR, ZDC, CMS, CMS+TOTEM common runs).

Stay tuned! And check the latest CMS results at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ