Measurement of diffractive and exclusive processes with CMS

Ruchi Chudasama
On behalf of the CMS collaboration
Indian Institute of Technology - Bombay

ICHEP 2018
39th International Conference on High Energy Physics
5th July, 2018
CMS detector and forward instrumentation

Light-by-light scattering in PbPb at 5.02 TeV
CMS PAS FSQ-16-012

Inelastic pp cross section at 13 TeV
1802.02613, Accepted by JHEP

Dijet production with a large rapidity gap between jets in pp at 7 TeV

Outlook

The CMS-TOTEM Precision Proton Spectrometer and first physics results
Talk by Jonathan Hollar at 10 AM in this session

All FSQ Public results
Forward CMS detectors: $2.9 < |\eta| < 8.1$

- Hadron Forward Calorimeter (HF): $2.9 < |\eta| < 5.2$
- CASTOR calorimeter: $-6.6 < \eta < -5.2$
- Zero Degree calorimeter (ZDC): $|\eta| > 8.1$
Light by light scattering in PbPb UPC at 5.02 TeV
Elastic light-by-light ($\gamma\gamma \rightarrow \gamma\gamma$) scattering, a fundamental quantum-mechanical process.
- Difficult to observe due to tiny cross-section: $O(\alpha^4)$
- Indirectly observed in Delbruck scattering & photon splitting

Study of light-by-light (LbyL) at high invariant mass:
- Neat channel to study anomalous gauge couplings,
- Search for virtual contributions from BSM charged particles (SUSY, monopoles, axions,...)

Observed in electromagnetic interactions from p,Pb at the LHC

ATLAS measurement

Photon flux $\propto Z^2$, LbyL process highly favorable in PbPb collisions.

$\sigma(\text{fid}) = 70 \pm 20\,\text{(stat)} \pm 17\,\text{(syst)}\,\text{nb}$
$\sigma(\text{SM}) = 45 \pm 9\,\text{nb}$
Significance obs. (exp.): 4.4 (3.8)$\sigma$

Search for LbyL in PbPb UPC at 5.02 TeV

- **Trigger**
  - Luminosity: 390 μb⁻¹
  - 2 Electromagnetic shower with $E_T > 2$ GeV
  - One of the Hadron Forward empty

- **Event selection**
  - 2 photons, $E_T > 2$ GeV, $|\eta| < 2.4$, $m(\gamma\gamma) > 5$ GeV
  - Back-to-back 2 $\gamma$: $p_T(\gamma\gamma) < 1$ GeV, Aco: $(1-\Delta\Phi/\Pi) < 0.01$
  - Exclusivity: No track with $p_T > 0.1$ GeV
    - No extra neutral activity over $|\eta| < 5.2$

- **Background to LbyL**

  **Central exclusive production**
  - Generated with SUPERCHIC (pp scaled by $A^2 R_g^4$, $S^2 = 100\%$).
  - Normalized to data in Control region.
  - Reduced with acoplanarity cuts.

  **Exclusive QED**
  - $\gamma\gamma \rightarrow e^+e^-$
  - Generated with STARLIGHT
  - Hard-brem electrons, mis-identified as $\gamma$
  - Reduced with charged exclusivity
  - Only unconverted $\gamma$ for analysis

Ruchi Chudasama

CMS PAS FSQ-16-012
LbyL analysis redone with the same event selection criteria, except now requiring 2 exclusive opp-sign electrons, instead of exactly 2 photons.

Very good data-MC agreement over $m_{ee} \sim 5$-90 GeV.

Confirms quality of electron/photon reconstruction, validity of exclusive event selection criteria, as well as of MC predictions for PbPb UPCs.
**CMS PAS FSQ-16-012**

- **QED bkg:** \(1.1\pm0.6\) evts from STARLIGHT MC.

- **CEP + other residual bkg:** \(2.7\pm1.1\) evts normalized the CEP MC to data from acoplanarity tail (aco>0.02).

**Data:** 14 evts, \(N_{\text{sig}} = 11.1\pm1.1\), \(N_{\text{bkg}} = 3.8\pm1.3\) expected

The measured yields and kinematic distributions are in good agreement with the MC expectations (LbyL + QED + CEP + other)

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Data</th>
<th>LbyL MC</th>
<th>QED e^+e^- MC</th>
<th>CEP MC + other (normalized to data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged exclusivity</td>
<td>649</td>
<td>13.7 ± 1.4 (th)</td>
<td>9.8 ± 1.9 (stat)</td>
<td>21.9 ± 8.3 (stat)</td>
</tr>
<tr>
<td>Neutral exclusivity</td>
<td>107</td>
<td>13.3 ± 1.4 (th)</td>
<td>9.8 ± 1.9 (stat)</td>
<td>21.2 ± 8.1 (stat)</td>
</tr>
<tr>
<td>Diphoton (p_T &lt; 1) GeV</td>
<td>38</td>
<td>12.5 ± 1.3 (th)</td>
<td>9.0 ± 1.8 (stat)</td>
<td>17.5 ± 6.7 (stat)</td>
</tr>
<tr>
<td>Diphoton acoplanarity &lt; 0.01</td>
<td>14</td>
<td>11.1 ± 1.1 (th)</td>
<td>1.1 ± 0.6 (stat)</td>
<td>2.7 ± 1.1 (stat)</td>
</tr>
</tbody>
</table>
LbyL cross-section & signal significance

- Ratio of LbyL to QED cross section, reduces uncertainties related to trigger, reconstruction efficiencies, and luminosity,

\[
R = \frac{\sigma_{\text{fid}}(\gamma\gamma \to \gamma\gamma)}{\sigma(\gamma\gamma \to e^+e^-, m_{e^+e^-} > 5 \text{GeV})} = \frac{N_{\gamma\gamma, \text{data}} - N_{\gamma\gamma, \text{bkg}}}{C_{\gamma\gamma}^{\text{data}}} \times \frac{C_{ee} \times A_{ee}^{\text{data}}}{N_{ee, \text{data}} \times P^{'}}
\]

\[
R = (25.4 \pm 9.6 \text{ (stat.)} \pm 6.0 \text{ (syst) } ) \times 10^{-6}
\]

- Fiducial LbyL cross section derived from R and QED $e^+e^-$ X-section from STARLIGHT = 4.82 ± 0.15 (th) mb

\[
\sigma_{\text{fid}}(\gamma\gamma \to \gamma\gamma) = 122 \pm 46 \text{ (stat) } \pm 29 \text{ (syst) } \pm 4 \text{ (th) } \text{nb},
\]

consistent with SM prediction: $\sigma(\text{fid}) = 138 \pm 14 \text{ nb}$.

- Compatibility of the data with background-only hypothesis, via profile-likelihood ratio of acoplanarity distribution:

LbyL significance: 4.1$\sigma$ observed (4.4$\sigma$ expected).
Inelastic pp cross section at 13 TeV
Total proton-proton (pp) cross section

Total pp cross section and its components

\[ \sigma_{\text{tot}} = \sigma_{\text{elastic}} + \sigma_{\text{inelastic}} \]

where

\[ \sigma_{\text{inelastic}} = \sigma_{\text{diff}} (\sigma_{SD} + \sigma_{DD} + \sigma_{CD}) + \sigma_{\text{non-diff}} \]

- Measurements of the pp cross sections provide valuable input for phenomenological hadronic interaction models and tuning of Monte Carlo (MC) event generators.
- Inelastic cross section required for the modeling of pileup.
Inelastic pp cross section at 13 TeV

The measured cross sections are smaller than those predicted by the majority of models for hadron-hadron scattering.

HF only

\[ \sigma(\xi > 10^{-6}) = 67.5 \pm 0.8 \text{ (syst)} \pm 1.6 \text{ (lumi) mb} \]

Relative cross section increase in %

<table>
<thead>
<tr>
<th>Data</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOS LHC</td>
<td>1.64 \pm 0.53</td>
</tr>
<tr>
<td>QGSJETII-04</td>
<td>1.76</td>
</tr>
<tr>
<td>PYTHIA 6 Z2* (SS)</td>
<td>2.36</td>
</tr>
<tr>
<td>PYTHIA 8 CUETP8M1 (SS)</td>
<td>1.74</td>
</tr>
<tr>
<td>PYTHIA 8 Monash (DL)</td>
<td>1.52</td>
</tr>
<tr>
<td>PYTHIA 8 MBR</td>
<td>3.83</td>
</tr>
<tr>
<td>PYTHIA 8 MBR</td>
<td>2.32</td>
</tr>
</tbody>
</table>

HF and CASTOR

\[ \sigma(\xi_X > 10^{-7} \text{ or } \xi_Y > 10^{-6}) = 68.6 \pm 0.5 \text{ (syst)} \pm 1.6 \text{ (lumi) mb} \]
Jet-gap-jet events in pp at 7 TeV
Two high $p_T$ jets separated by large rapidity gap, no charged particles produced in between.

- Diffractive process with Color Singlet Exchange (CSE)
- Described by BFKL approach

Event signature:

- Jet $p_T > 40$ GeV, $1.5 < |\eta| < 4.7$
- No charged particle with $p_T > 0.2$ GeV in $-1 < \eta < 1$

Charged multiplicity in the gap region $|\eta|<1$

- Clear excess of gap events over PYTHIA6 prediction in lower bins.
- Described by HERWIG (BFKL, Mueller-Tang model)

CSE fraction:

Ratio of background subtracted # of events for $N_{\text{track}} < 2$ to all events
- CSE fraction increases with jet energy (and rapidity separation Δη)
- A factor ~2 suppression w.r.t. to 1.8 TeV data
- Data compared with BFKL calculations with different implementations of the soft rescattering processes, none of the implementations is able to simultaneously describe all the features of the measurement.
Evidence of 4.1σ for light by light scattering: 14 evts, Nsig = 11.1±1.1, Nbkg = 3.8±1.3 expected

- Detailed measurements of inelastic cross sections across 11 units of pseudorapidity.
- With CMS-TOTEM data taking during special low pile-up and high-β* runs at 13 TeV: studies of diffractive processes with full proton kinematics. Sensitivity to anomalous gauge couplings and search for new resonances.
Evidence of $4.1\sigma$ for light by light scattering: 14 events, $N_{\text{sig}} = 11.1 \pm 1.1$, $N_{\text{bkg}} = 3.8 \pm 1.3$ expected.

- Detailed measurements of inelastic cross sections across 11 units of pseudorapidity.

- With CMS-TOTEM data taking during special low pile-up and high-$\beta^*$ runs at 13 TeV: studies of diffractive processes with full proton kinematics. Sensitivity to anomalous gauge couplings and search for new resonances.

Thank you!
Backup
Jet-gap-jet in pp at 7 TeV: CSE fraction

Ruchi Chudasama
• **LbyL analysis redone** with the same event selection criteria, except now requiring **2 exclusive opp-sign electrons**, instead of exactly 2 photons.

• Fit of acoplanarity distributions in data to the sum of two exponentials:
  - Low aco: Exclusive QED
  - High aco: non-excl. Backgds

• Purity: ratio of amplitudes of two expo. In Aco < 0.01
  \( P = 0.96 \pm 0.002 \)