CMS RESULTS ON DIFFRACTION AND EXCLUSIVE PRODUCTION

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CONTENT

• Measurement of dijet production with a leading proton in proton-proton collisions at $\sqrt{s} = 8$ TeV

• Exclusive $\rho^0(770)$ photoproduction in ultra-peripheral pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

• Measurement of exclusive $\Upsilon$ photoproduction from protons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

• Evidence for light-by-light scattering & searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
First CMS-TOTEM measurement with tagged protons in low pile-up data at 8 TeV

Dijets in CMS, scattered proton in RP. Background: inclusive dijets in coincidence with random RP track from pileup or beam-background proton.

Matching: compare $\xi$ calculated from protons and from jets

$$\xi_{\text{CMS}} \cdot \xi_{\text{TOTEM}} < 0$$

Jet selection:
- $p_T > 40$ GeV, $|\eta| < 4.4$, $\xi < 0.1$ and $0.03 < |t| < 1$ GeV$^2$
DIFRACTIVE DIJET PRODUCTION

- Differential cross section as a function of $t$ and $\xi$:

$$\frac{d\sigma}{dt} \propto e^{-b|t|} \quad b = 6.6 \pm 0.6 \text{ (stat)} \pm 1.0 \pm 0.8 \text{ (syst)} \text{GeV}^{-2},$$

- Exponential fit in the region $0.03 < |t| < 0.45 \text{ GeV}^2$

- Total integrated cross section in kinematic region:

$$\sigma_{jj}^{pX} = 21.7 \pm 0.9 \text{ (stat)} \pm 3.0 \pm 3.3 \text{ (syst)} \pm 0.9 \text{ (lumi)} \text{nb}.$$
**Ratio of diffractive to inclusive dijets as a function of $x$.**

$$ R = \left( \frac{\sigma_{ij}^{X}}{\Delta \xi} \right) / \sigma_{ij} = 0.025 \pm 0.001 \text{(stat)} \pm 0.003 \text{(syst)} $$

Pythia8 DG: gap survival with Dynamic Gap model based on MPI shows good agreement with data

Comparison to CDF results: factor of ~3 suppression wrt to 1.96 TeV, larger contributions from rescattering processes

Region: $-2.9 < \log_{10} x < -1.6$
EXCLUSIVE RHO

- Exclusive vector meson photoproduction in ultra-peripheral pPb collisions (5.02 TeV): $\gamma p \rightarrow \rho^0(770)p$ in $\pi^+\pi^-$ decay channel

- Kinematics and event selection: $p_T > 0.4$ (0.2) GeV for lead. (sublead.) $\pi$, $|\eta| < 2.0$.
  exclusivity condition: calorimeter vetos including CASTOR, ZDC

- Main remaining backgrounds:
  non-resonant $\pi^+\pi^-$, $\rho^0(1700) \rightarrow 4\pi$,
  $\omega$ production, proton dissociation.

\[ CMS-PAS-FSQ-16-007 \]
**EXCLUSIVE RHO**

- Invariant mass and cross section as function of $W_{\gamma p}$:

  ![Graph 1](image1.png)

  **Fit invariant mass with Söding formula**

  Ratio of the nonres. to res. contributions:
  \[ |B/A| = 0.50 \pm 0.05 \text{ (stat); } 0.56 \pm 0.06 \text{ (stat) for } |t| < 0.5 \]
  
  H1: $0.57 \pm 0.09$ (stat) and ZEUS: $0.70 \pm 0.04$ (stat)

  ![Graph 2](image2.png)

  **Fit with**: $\sigma = \alpha W_{\gamma p}^{\delta}$, $\delta = 0.23 \pm 0.14 \text{ (stat) } \pm 0.04 \text{ (syst)}$

  Good agreement with HERA data and Regge theory (soft Pomeron)

  Integrated cross section:
  $11.2 \pm 1.4 \text{ (stat) } \pm 1.0 \text{ (syst) } \mu b$. 

CMS-PAS-FSQ-16-007
**EXCLUSIVE RHO**

- Cross section as function of $|t|$:
  \[ |t| \approx p_T^2 \]

![Graph showing the differential cross section $d\sigma/dt$](image)

- Fit $b$ versus $W_{\gamma p}$:
  \[ b = b_0 + 2\alpha' \cdot \ln\left(\frac{W_{\gamma p}}{W_0}\right)^2 \]

Pomeron slope:
- CMS: $\alpha' = 0.48 \pm 0.33$ (stat) $\pm 0.12$ (syst) GeV$^{-2}$
- ZEUS: $\alpha' = 0.23 \pm 0.15$ (stat) $\pm 0.11$ (syst) GeV$^{-2}$
- Regge theory (soft Pomeron): $\alpha' \approx 0.25$ GeV$^{-2}$

Fit $|t|$ spectra with exponential:
\[ e^{-bt + ct^2} \]

$0.025 < |t| < 0.500$ GeV$^2$.

Good agreement with HERA data
EXCLUSIVE $\Upsilon$

- Exclusive vector meson photoproduction in ultra-peripheral pPb collisions (5.02 TeV): $\gamma p \rightarrow \Upsilon(nS)(n = 1, 2, 3)p$ in $\mu^+\mu^-$ decay channel

- Kinematics:
  $p_T^{\mu} > 3.3$ GeV; Di-muon system: $0.1 < p_T < 1$ GeV and $|\eta| < 2.2$.
  Exclusivity: no extra charged particles with $p_T > 0.1$ GeV & no activity in HF

- Backgrounds:
  QED: $\gamma\gamma \rightarrow \mu^+\mu^-$
  Proton dissociation (semi-exclusive)
  Inclusive
**EXCLUSIVE Υ**

- Cross section as function of $p_T^2$ and $W_{γp}$:

  Perform exponential fit:

  $b = 6.0 ± 2.1$ (stat) $± 0.3$ (syst) GeV$^{-2}$

Data sensitive to signs of saturation: new constraints on the evolution of gluon density at low $x$. 

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![Graph showing cross section as a function of $p_T^2$ and $W_{γp}$](image-url)


**LIGHT-BY-LIGHT SCATTERING**

- Elastic $\gamma\gamma \rightarrow \gamma\gamma$ scattering

  in PbPb collisions at 5.02 TeV
  fundamental QED/QCD process
  difficult to observe due to very small $O(\alpha^4)$ cross section
  sensitive to BSM physics (loop contributions, axions)

- Event selection:
  Two back-to-back photons: $E_T > 2$ GeV and $|\eta| < 2.4$.
  $P_{YY} < 1$ GeV, $m_{\gamma\gamma} > 5$ GeV
  Exclusivity: no tracks, no extra neutral activity.

- Backgrounds: CEP: $gg \rightarrow \gamma\gamma$ and QED: $\gamma\gamma \rightarrow e^+e^-$
**Light-by-Light Scattering**

- **Signal selection $A_\phi < 0.01$:**
  - Acoplanarity distribution:
    - Observed: 14 events
    - Expected: $11.1 \pm 1.1$ (th) signal
    - $4.0 \pm 1.2$ (stat) background events,
    - Significance: $4.1 \sigma$ (expected $4.4 \sigma$)

  ![Graph](image)

  ATLAS in a similar region: 13 candidates, expected background of $2.6 \pm 0.7$ events. NP 13 (2017) 852

\[
\sigma(\gamma\gamma \rightarrow \gamma\gamma)/\sigma(\gamma\gamma \rightarrow e^+e^-) = [25.0 \pm 9.6 \text{ (stat)} \pm 5.8 \text{ (syst)}] \times 10^{-6}
\]

Measured fiducial $\sigma(\gamma\gamma \rightarrow \gamma\gamma)$ cross section:

- $120 \pm 46$ (stat) $\pm 28$ (syst) $\pm 4$ (th) nb

Compare with theory: $138 \pm 14$ nb
LIGHT-BY-LIGHT SCATTERING

- Exclusion limits on Axion-Like Particles (ALPs):

possible narrow resonances in $\gamma\gamma$ mass spectra

Light-by-light scattering events treated as background.

Most stringent limits at low masses:
5-50 GeV for EM and 5-10 GeV for EW
SUMMARY

• Diffractive dijets with proton tag measured for the first time at the LHC at 8 TeV

• Results on exclusive vector meson photoproduction in pPb collisions at 5.02 TeV for $\rho^0(770)$ and $\Upsilon(nS)(n = 1, 2, 3)$: new input to constrain gluon densities

• Measurement of light-by-light scattering: set new limits on axion-like particle production