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Exclusive production processes in CMS and TOTEM

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We discuss the most recent results from the CMS and TOTEM Collaborations on central-exclusive non resonant production of pions at low mass, the quasi-exclusive di-lepton production, the observation of $\gamma\gamma \to \tau\tau$, and the search for $\gamma\gamma WW$, $\gamma\gamma ZZ$ productions.

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In this short report, we will describe the most recent results from the CMS and TOTEM Collaborations on exclusive processes.

1. Central-exclusive non resonant production of pions at low mass

For the first time, the CMS and TOTEM collaboration measured the exclusive production of two pions $pp \to p\pi\pi p$ at high energy at the LHC by detecting [1] the two pions in CMS and tagging the intact protons in the TOTEM roman pot detectors located on both sides of the CMS detector at 213 and 220 m. Using a value of β^* of 90 m (that leads to a good acceptance of TOTEM to low mass diffraction), about 80 million events with two scattered protons and only two reconstructed central tracks were collected in 2028 [2]. Background can be controlled by matching the measurements of the protons in TOTEM and of the pions in CMS ($M_{pp} = M_{central}$, $y_{pp} = y_{central}$). Selecting events by requiring diproton and dipion p_x and p_y to match ($\Sigma_4 p_x \sim 0$ and $\Sigma_4 p_y \sim 0$, the sum extending on all protons and pions) ensures that the background is quite small and dominated by elastic events ($pp \to pp$) with inelastic pileup.

The studied distributions are as a function of the di-pion mass $m_{\pi^+\pi^-}$, the proton p_T and ϕ, the difference in azimuthal angle between the two protons. We focus on the non-resonant region $0.35 < m_{\pi\pi} < 0.65$ GeV. For the first time, the parabolic dependence in ϕ shown in Fig. 1 was observed at high LHC energies in different bins of p_T for each proton. Two channel models are favored and we observe a remarkable agreement with the DIME model [3].

2. Quasi-exclusive $\mu\mu$ and ee production

In order to measure quasi-exclusive $\mu\mu$ and ee production at the LHC, one detects two leptons in CMS and at least one proton in the Proton Precision Spectrometer (PPS) from CMS and TOTEM [4]. Dilepton production is dominated by photon exchange processes and the LHC is turned into a $\gamma\gamma$ collider at high energy. The flux of quasi-real photons is computed using the Equivalent Photon Approximation. The dilepton mass acceptance of PPS starts at about 400 GeV and we thus expect a very small number of double tagged events given the exclusive dilepton cross section. This is also why this measurement is performed at high luminosity using standard runs at the LHC (low value of β^*) and a luminosity of about 115 fb^{-1} collected in 2016-2018 is used for this analysis. The signal is either two leptons and two intact protons or two leptons and one intact proton (the other one being dissociated). The case when both protons are dissociated is considered as a background.

In Fig. 2 is shown the correlation between the ξ value measured using either the dilepton (ee and $\mu\mu$) in CMS or the protons in PPS on the left and right sides of the CMS detector. 17 (resp. 23) events are found with protons in the PPS acceptance and 12 (resp. 8) within a matching better than 2σ in the $\mu\mu$ (resp. ee) channel [5]. The significance is larger than 5σ for observing 20 events for a background of 3.85 ($1.49 \pm 0.07(stat) \pm 0.53(syst)$ for $\mu\mu$ and $2.36 \pm 0.09(stat) \pm 0.47(syst)$ for ee). This also shows that PPS works as expected and it validates all corrections on data such as the alignment method, the optics determination...

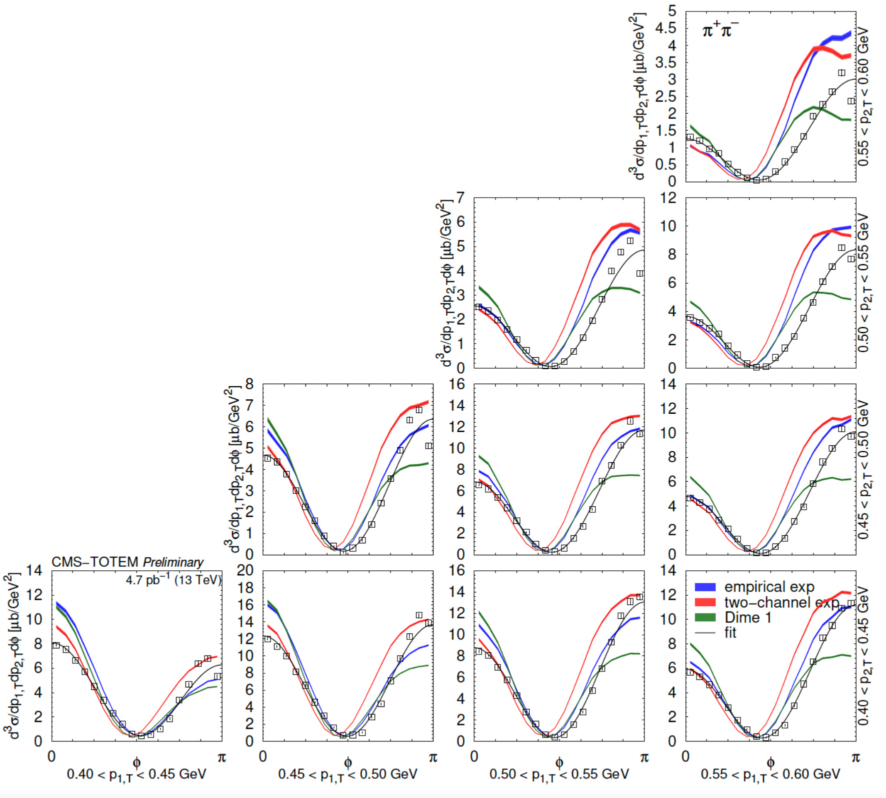

Figure 1: Measurement of the difference in azimuthal angle between the two intact protons in different $p_{1,T}$ and $p_{2,T}$ bins compared to different models.

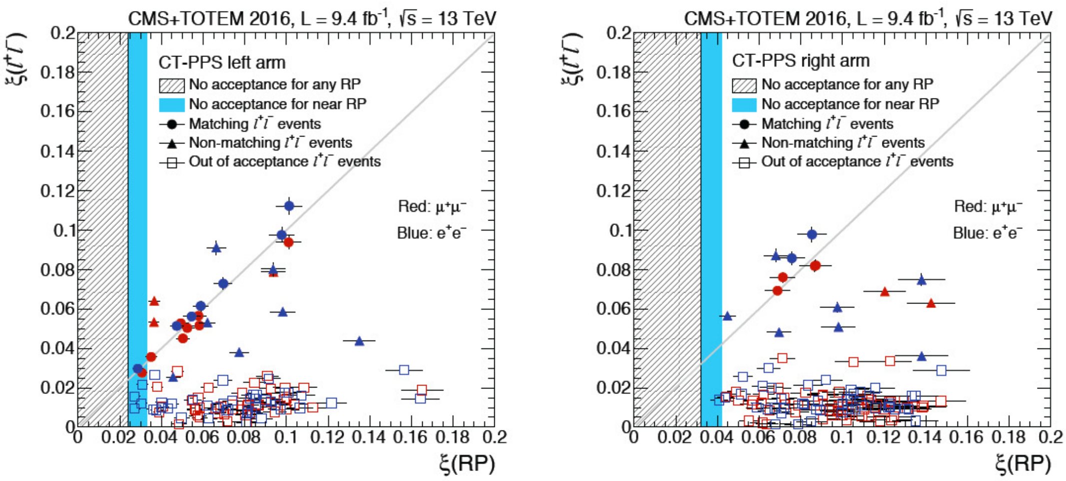

Figure 2: Correlation between the ξ measurements using the di-lepton or the proton information on both sides of the CMS detectors. The matching events within 2σ are shown in blue or red circles for di-electrons and di-muons respsctively.

3. τ electromagnetic moments from $\gamma\gamma \to \tau\tau$ events

τ (g-2) and the electric dipole moment d_τ can be probed from the $\gamma\tau\tau$ vertex. The idea is thus to measure the exclusive events $pp \to p\tau^+\tau^- p$ since this process includes two $\gamma\tau\tau$ vertices [6] and leads to constraints on the d_τ coupling for instance using an effective field theory approach. In the standard model, d_τ is very small but can be enhanced in beyond standard model theories.

The experimental signature of the exclusive $\tau\tau$ events is the presence of two diffracted protons (that are not measured in this analysis), and two back-to-back opposite side τ leptons (acoplanarity < 0.015). Defining $Ntracks$ as the number of tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$ within a window of 0.1 cm around the di-τ vertex, excluding the tracks from the τ leptons, we expect $Ntracks = 0$, so no hadronic activity close to the di-τ vertex, The following decays of $\tau\tau$ are considered, $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$. In each di-τ final state, two signal regions are considered corresponding to $N_{tracks} = 0$ or 1 ($N_{tracks} = 0$ corresponds to about 50% of the signal and the inclusive backgrounds is reduced by about 1000 whereas $N_{tracks} = 1$ keeps about 25% of the signal bur leads to a larger background). In each of the categories, the visible invariant mass of the τ pair is fitted and signal appears at high mass.

After selection, the inclusive background (such as Drell-Yan production is found to be negligible. The elastic $\gamma\gamma \to \mu\mu, WW$ production is estimated from the $gammaUPC$ Monte Carlo [7], rescaled with a linear $m_{\mu\mu}$ dimuon mass function to match data. The N_{tracks} distribution is shown in Fig. 3 for signal (at low N_{tracks}) and background. This is the first observation of $\gamma\gamma \to \tau\tau$ in pp runs, and 5.3σ is observed (6.5σ expected).

This measurement is also sensitive to the τ electromagnetic moment a_τ and at large $m_{\tau\tau}$, the $\gamma\gamma \to \tau\tau$ cross section increases with both positive and negative variations of a_τ and the effect grows with $m_{\tau\tau}$. We this expect better BSM sensitivities in pp collisions than in $Pb - Pb$ interactions since a higher $m_{\tau\tau}$ mass region can be probed in pp runs. The constraint on the τ electromagnetic moments using an EFT approach is $a_\tau = 0.0009^{+0.0032}_{-0.0031}$ at 68% CL, $-0.0042 < a_\tau < 0.0062$ at 95% CL, improving previous constraints by a factor of about 5 as shown in Fig. 4.

4. Search for $\gamma\gamma WW$, $\gamma\gamma\gamma\gamma$ quartic anomalous couplings

The study of exclusive processes at the LHC such as $pp \to pWWp$, $pp \to pZZp$, $pp \to p\gamma\gamma p$, $pp \to p\gamma Zp$, $pp \to pt\bar{t}p$ allows to probe different quartic anomalous couplings with high precision [8, 9]. In addition, the standard model cross section for exclusive production of W boson pairs is quite high $\sigma_{WW} = 95.6$ fb ($\sigma_{WW}(W = M_X > 1TeV) = 5.9$ fb), and it should be possible to observe this process using 300 fb^{-1} of data.

The CMS collaboration performed the search for exclusive W boson pairs at high WW mass requesting the presence of two “fat" jets (radius 0.8), jet $p_T > 200$ GeV, 1126< m_{jj} <2500 GeV, the jets to be back-to-back ($|1 - \phi_{jj}|/\pi < 0.01$). The signal region is defined by the correlation between central WW system and proton information. No event was observed and the Limits on SM cross section was found to be $\sigma_{WW} < 67$fb (and $\sigma_{ZZ} < 43$fb) for $0.04 < \xi < 0.2$ [10]. New limits on quartic anomalous couplings were also found, $a_0^W/\Lambda^2 < 4.3\ 10^{-6}$ GeV^{-2}, $a_C^W/\Lambda^2 < 1.6\ 10^{-5}$ GeV^{-2}, $a_0^Z/\Lambda^2 < 0.9\ 10^{-5}$ GeV^{-2}, $a_C^Z/\Lambda^2 < 4.\ 10^{-5}$ GeV^{-2} with 52.9 fb^{-1}.

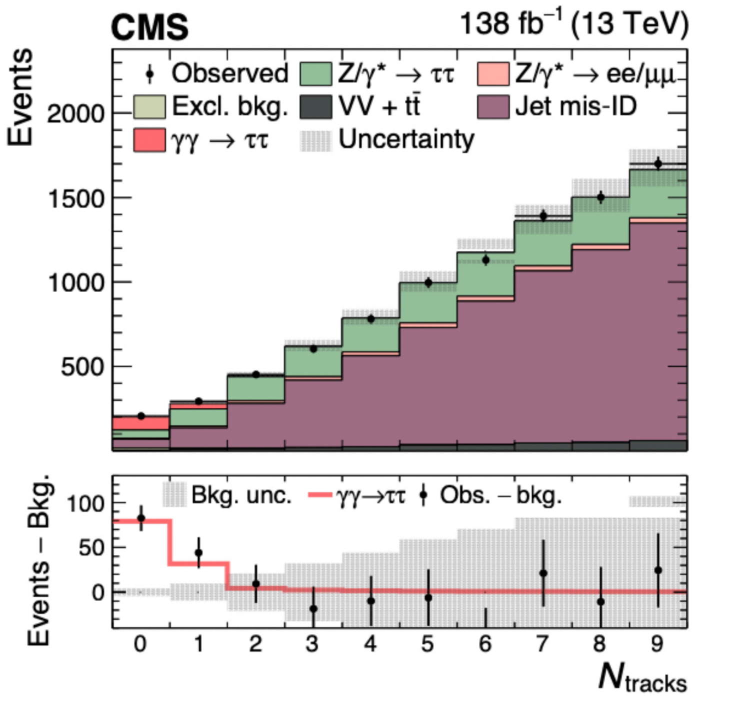

Figure 3: N_{tracks} distribution showing the first observation of $\gamma\gamma \rightarrow \tau\tau$. The signal appears at low N_{tracks} and the different background contributions dominate at high N_{tracks}. The bottom plot displays the signal minus background results.

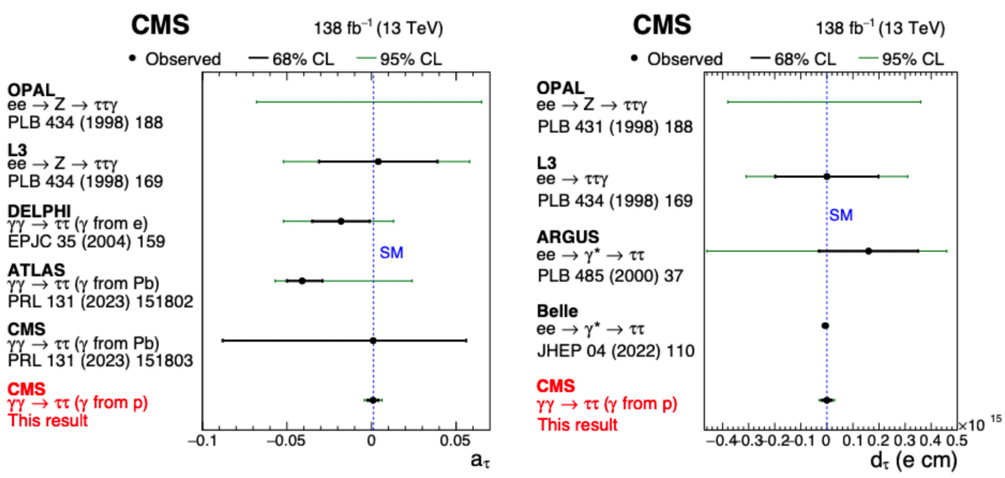

Figure 4: Constraint on the τ electromagnetic moments using an EFT approach and exclusive di-τ production, compared to results from previous experiments.

5. Coinclusion

In this short report, we discussed the most recent results from the CMS and TOTEM Collaborations on central-exclusive non resonant production of pions at low mass, the quasi-exclusive di-lepton production, the first observation of $\gamma\gamma \rightarrow \tau\tau$ (that leads to the best limit on the τ electromagnetic moments to date), and the search for $\gamma\gamma WW$, $\gamma\gamma ZZ$ production.

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