PROCEEDINGS OF SCIENCE

Search for magnetic monopoles with diphoton events at the LHC

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Magnetic Monopoles (MMs) are predicted in various theories of physics beyond the Standard Model. The introduction of MMs explains the electric charge quantisation and restores the symmetry in Maxwell's equations with respect to magnetic and electric fields. Despite intense experimental searches, they remain unobserved to date. The Large Hadron Collider (LHC) achieves energies never reached before, opening possibilities for the discovery of exotic particles in the TeV mass range. MMs direct production is explored in the specialised MoEDAL experiment. Investigating the $\gamma\gamma \rightarrow \gamma\gamma$ process is worthwhile as this channel allows the study of possible contributions from new particles, such as MMs. In this paper, we investigate the observability of virtual MMs in this channel at the LHC, in both ultra-peripheral Pb-Pb and pp collisions. Specifically, the reinterpretation of LHC Run 2 data has been performed in order to impose lower bounds on the MM mass. For this purpose, two different approaches have been used: Born-Infeld and Effective Field Theory.

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1. Motivation

The existence of MMs explains the discrete nature of the electric charge and symmetrises the Maxwell's equations with respect to magnetic and electric fields [1]. The MoEDAL experiment [2] explores the direct MM production, whilst MMs can be probed indirectly via a *box diagram* in which highly energetic photons are produced in photon fusion through a monopole–antimonopole loop [3], as depicted in Fig. 1.

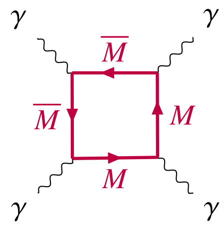

Figure 1: Monopole box diagram.

Loops of magnetic monopoles would contribute to light-by-light scattering, a process observed in the ATLAS [4] and CMS [5] experiments at the LHC in ultraperipheral heavy-ion collisions. In this work we consider Dirac, point-like, spin-½ monopoles with β-independent monopole–photon coupling. The final state of interest is a diphoton coming from central exclusive processes.

2. Central Exclusive $\gamma\gamma$ Production

The central exclusive production of diphotons in γ scattering in colliders can be described by

$$A + B \xrightarrow{\gamma\gamma} A + \gamma + \gamma + B,$$

where $A, B = p, \mathrm{Pb}$ are the incoming hadrons, scattered at a very small angle with respect to the beam, while the two final-states photons are detected and measured by the central detector [6].

In Pb-Pb collisions, soft γ spectra are produced in contrast to the pp collisions case in which a harder photon spectrum may be generated. Using *proton tagging*, we can reach much higher diphoton invariant masses. This consists in measuring the photon pair in the central detector and tagging the scattered intact protons with specific forward proton detectors. At the LHC, such detectors are the ATLAS Forward Proton detector (AFP) and the CMS-TOTEM Precision Proton Spectrometer (CT-PPS) situated symmetrically to the interaction points.

The first search for exclusive diphoton production in the $pp \to p(\gamma\gamma \to \gamma\gamma)p$ process via photon exchange has been performed by CT-PPS [7]. By employing the CMS and TOTEM detectors, the data were collected in 2016 with an integrated luminosity of $9.4\mathrm{fb}^{-1}$ and a center-of-mass energy of 13 TeV. No exclusive $\gamma\gamma$ event was found above the expected background.

3. Magnetic Monopoles in Effective Field Theory (EFT)

One of the ways to constrain the MM mass is the EFT approach. For $m \gg E$, the four-photon interactions can be described by dimension-8 local operators [8] in

$$\mathcal{L}_{4\gamma} = \zeta_1 F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2 F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu}, \quad (1)$$

where the $\gamma\gamma \to \gamma\gamma$ process can be induced by these local operators. In the case of loop of heavy charged particles with spin s, the $\zeta^{\gamma}_{1,2}$ couplings are expressed as

$$\zeta^{\gamma}_{i} = \alpha^2_{\mathrm{em}} Q^4 m^{-4} N c_{i,s}, \quad (2)$$

where m is the mass of the particle running in the loop, Q its charge, $c_{1,\frac{1}{2}} = -\frac{1}{36}$, $c_{2,\frac{1}{2}} = \frac{7}{90}$, Q the particle charge and in our case $N = 1$.

Projecting the results of the first exclusive $\gamma\gamma$ production search in proton-proton collision [7] on an effective dimension-8 extension of the Standard Model (SM), on the two anomalous four-photon coupling parameters have been constrained. More specifically, the limits at 95% CL are $|\zeta_1| < 2.88 \times 10^{-13}$ GeV^{-4} and $|\zeta_2| < 6.02 \times 10^{-13}$ GeV^{-4}. We use these data in order to impose lower bounds on the MM mass. Specifically, exclusion limits on MM mass as a function of Q in Dirac charge g_D units are reported in Fig. 2.

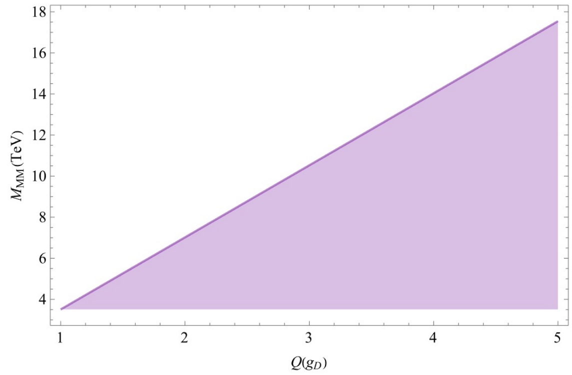

Figure 2: Exclusion limits (purple region) on MM mass as a function of Q in Dirac charge g_D units, by using limits on $\zeta^{\gamma}_{1,2}$ [7].

4. Magnetic Monopoles in Born-Infeld Theory

Another approach to constrain MMs is the Born-Infeld (BI) theory [9]. It was proposed to impose an upper bound on the electric field, by carrying out a nonlinear modification of the QED Lagrangian

$$\mathcal{L}_{\rm QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \longrightarrow \mathcal{L}_{\rm BI} = \beta^2\left(1 - \sqrt{1 + \frac{1}{2\beta^2}F_{\mu\nu}F^{\mu\nu} - \frac{1}{16\beta^4}(F_{\mu\nu}\tilde{F}^{\mu\nu})^2}\right), \tag{3}$$

where β is an unknown parameter with dimension of mass-squared. The SM modified by a BI theory of the hypercharge $U(1)_Y$ contains a finite-energy electroweak monopole solution M with mass

$$\mathcal{M}_{MM} = E_0 + E_1, \tag{4}$$

where $E_1 \sim 7.6$ TeV and $E_0 \simeq 72.8 M_Y$, with $M_Y = \cos\theta_W M$. Expanding (3) to fourth order in the electromagnetic field strength, it follows that for the coefficients ζ_1 appearing in (1) in terms of β [10]:

$$\zeta_1 = -\frac{1}{32\beta^2}, \quad \zeta_2 = \frac{1}{8\beta^2}. \tag{5}$$

In *pp collisions*, by considering results from the first search for exclusive diphoton from CMS-TOTEM [7] and (5), we conclude that

$$M > 675\ \text{ GeV} \Longrightarrow \mathcal{M}_{MM} \geq (7.6 + 72.8\cos\theta_W M) \simeq 50.92\ \text{TeV}. \tag{6}$$

This value is beyond the one that any current collider can reach. The leading-order cross-section for unpolarised $\gamma\gamma \to \gamma\gamma$ scattering, in BI theory and in the $\gamma\gamma$ centre-of-mass frame is [9]:

$$\sigma_{\rm BI}(\gamma\gamma \to \gamma\gamma) = \frac{1}{2}\int d\Omega \frac{d\sigma_{\rm BI}}{d\Omega} = \frac{7}{1280\pi}\frac{m_{\gamma\gamma}^6}{\beta^4}. \tag{7}$$

Taking into account last ATLAS [4] and CMS [5] data on the detection of $\gamma\gamma \to \gamma\gamma$ production in Pb-Pb collisions at $\sqrt{s} = 5.02$ TeV for 5 GeV $\leq m_{\gamma\gamma} \leq 100$ GeV, we constrain the BI parameter β and the associated magnetic monopole mass $\mathcal{M}_{MM}$, as shown in Fig. 3.

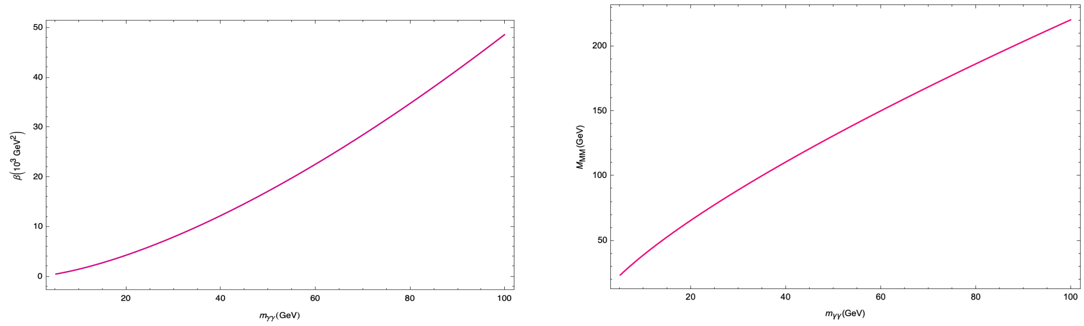

Figure 3: Born-Infeld parameter β(left) and MM mass $\mathcal{M}_{MM}$ (right) limits versus $m_{\gamma\gamma}$ in Pb-Pb collisions by using ATLAS and CMS data [4, 5].

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