Search for magnetic monopoles with diphoton events at the LHC

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Motivation

The existence of magnetic monopoles (MMs) [1] would

- explain the discrete nature of the electric charge (*Dirac Quantisation Condition*):

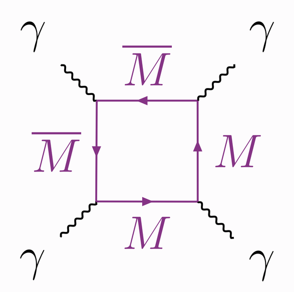
$$\alpha g = \frac{n}{2} e, \quad n \in \mathbb{Z}, \tag{1}$$

where $\alpha = \frac{e^2}{4\pi\epsilon_0} = \frac{1}{137}$ and $g = n g_D$ is the *magnetic charge*, being $g_D \equiv \frac{e}{2\alpha} = 68.5e$ the so-called *fundamental Dirac charge*

- symmetrise Maxwell's equations with respect to magnetic and electric fields.

Mass m and spin s are free parameters of the theory. In this work, we consider Dirac point-like MMs with spin-1/2 and beta-independent γ-MM coupling.

One of the MMs production mechanisms at colliders is via *box diagram* in which highly energetic photons are produced through a monopole-antimonopole loop [2].



MM loops would contribute to light-by-light scattering events and subsequently to additional production of diphoton final states. ATLAS and CMS collaborations observed this process at the Large Hadron Collider (LHC) in ultraperipheral heavy-ion collisions [3, 4].
Another mechanism of MM-induced diphoton events is the decay of a monopole-antimonopole bound state, the so-called *monopolium* [2].

Effective Field Theory

One of the ways we use to constrain the mass of MMs is the EFT approach.
Assuming $\Lambda_{NP} \gg E$, the $\gamma\gamma \to \gamma\gamma$ process can be induced by the pure photon dimension-8 operators in an effective Lagrangian [5]

$$\mathcal{L}_{4\gamma} = \zeta_1 F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2 F_{\mu\nu}F^{\nu\rho}F_{\rho\lambda}F^{\lambda\mu}. \tag{2}$$

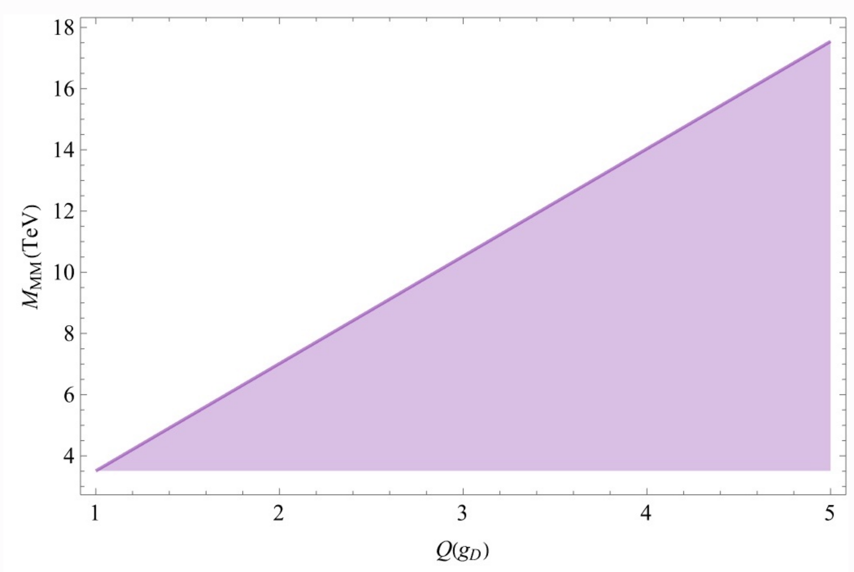
We are interested in loops from heavy charged particles. The contribution from a generic spin s particle to the $\zeta^{\gamma}_{1,2}$ couplings is

$$\zeta^{\gamma}_{i} = \alpha^2 Q^4 m^{-4} N c_{i,s} \tag{3}$$

with $c_{1,\frac{1}{2}} = -\frac{1}{36}$, $c_{2,\frac{1}{2}} = \frac{7}{90}$, Q the particle charge and in our case $N = 1$.
From the first search for exclusive $\gamma\gamma$ production via photon exchange in pp collisions at $\sqrt{s} = 13$ TeV performed by CMS-TOTEM [6], limits on the two anomalous four-photon couplings are set at 95% CL:

$$|\zeta_1| < 2.9 \cdot 10^{-13}\ \text{GeV}^{-4}, |\zeta_2| < 6.0 \cdot 10^{-13}\ \text{GeV}^{-4}. \tag{4}$$

We reinterpret these data corresponding to an integrated luminosity of 9.4 fb^{-1} in order to impose lower bounds on the MM mass. Specifically, exclusion limits (purple region) on MM mass as a function of Q in Dirac charge g_D units are reported in the following figure.

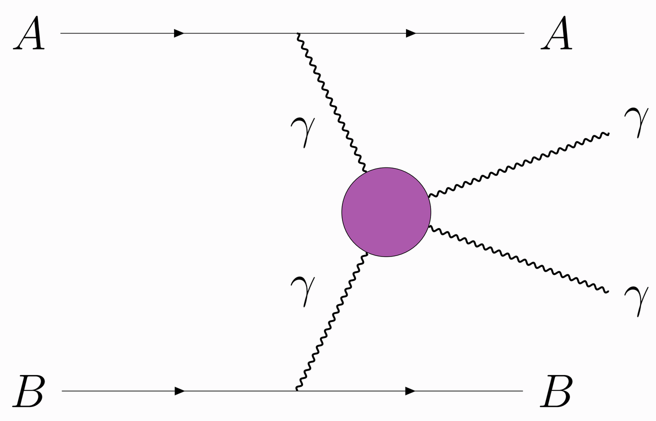


Exclusive $\gamma\gamma$ Production

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

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

where $A, B = p$, Pb are the incoming hadrons, scattered at a very small angle with respect to the beam and the final two-photon state is measured in the central detector [7].



In PbPb collisions soft γ spectra are generated, in contrast with pp collisions in which it is possible to achieve much higher diphoton invariant masses by using the *proton tagging method*. 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 of the respective main experiments.

Born-Infeld Theory

Another approach to constrain MMs is the Born-Infeld (BI) theory [8].
It was proposed to impose an upper bound on the electric field, by carrying out a nonlinear modification of the QED Lagrangian

$$\mathcal{L}_{QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \longrightarrow \mathcal{L}_{BI} = \beta^2\left(1 - \sqrt{1 + \frac{1}{2\beta^2}F_{\mu\nu}F^{\mu\nu} - \frac{1}{16\beta^4}(F_{\mu\nu}\tilde{F}^{\mu\nu})^2}\right), \tag{5}$$

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

$$M_{\mathcal{M}} = E_0 + E_1, \tag{6}$$

where $E_1 \sim 7.6$ TeV and $E_0 \simeq 72.8 M_Y$, with $M_Y = \cos\theta_W M$.

- ***pp* collisions**

Expanding (5) to fourth order in the electromagnetic field strength, it turns out that the coefficients $\zeta_{1,2}$ appearing in (2) can be written in terms of β [9]:

$$\zeta_1 = -\frac{1}{32\beta^2}, \quad \zeta_2 = \frac{1}{8\beta^2}. \tag{7}$$

Reinterpreting results from the first search for exclusive $\gamma\gamma$ production in (4), we obtain

$$M > 675\ \text{GeV} \implies \mathcal{M}_{MM} \gtrsim (7.6 + 72.8\cos\theta_W M) = 50.9\ \text{TeV}. \tag{8}$$

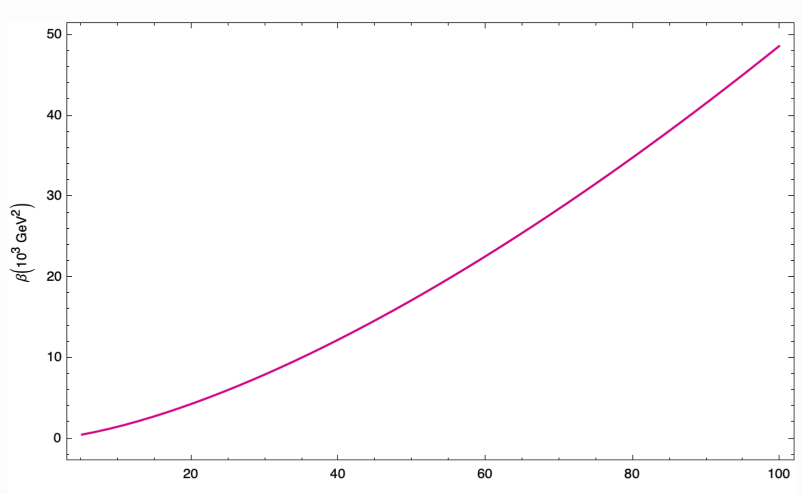
This value is beyond the reach of any current collider.

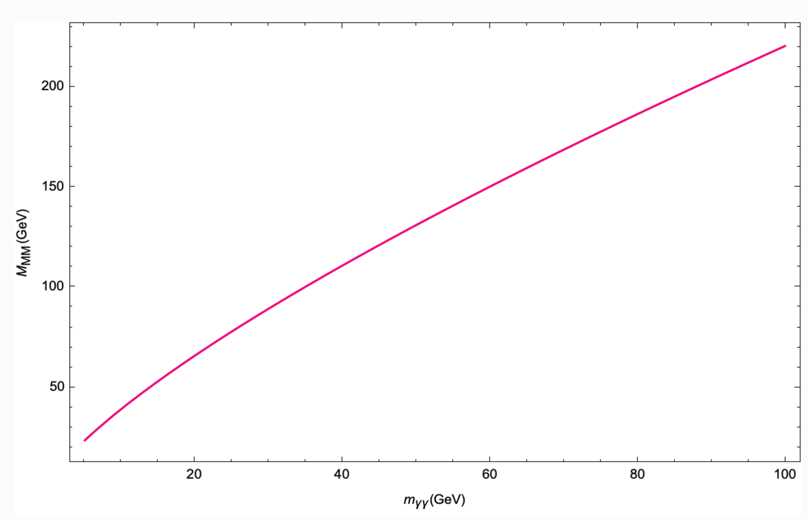
- **PbPb collisions**

In the BI scenario, the leading-order cross section for $\gamma\gamma \to \gamma\gamma$ process is given by [8]

$$\sigma_{BI}(\gamma\gamma \to \gamma\gamma) = \frac{1}{2}\int d\Omega \frac{d\sigma_{BI}}{d\Omega} = \frac{7}{1280\pi}\frac{m^6_{\gamma\gamma}}{\beta^4}. \tag{9}$$

Taking into account last ATLAS [3] and CMS [4] data about the detection of $\gamma\gamma \to \gamma\gamma$ production in PbPb 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 M_{MM}.
We plot both β and M_{MM} versus diphoton invariant mass $m_{\gamma\gamma}$.





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