Looking for Magnetic Monopoles at LHC with di-photon events
In the limit $m \gg E$, one can describe the four-photon interactions using higher-dimensional local operators in an effective Lagrangian

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

S. Fichet and G. von Gersdorff, 1311.6815.

Four-photon anomalous quartic gauge coupling (dim-8 operators):

$$\zeta_{1,2} = \frac{a_1^{\gamma\gamma}}{\Lambda^4}$$
Effective Field Theory (EFT)

Four-photon couplings can be modified by loops of new particles or produced resonances that decay into two photons.

\[ \mathcal{L}_{4\gamma} = \zeta_1^\gamma F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2^\gamma F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu} \]

Loops of heavy charged particles

\[ \zeta_i^\gamma = \alpha_{em}^2 Q^4 m^{-4} N c_{i,s} \]

R. S. Gupta, Phys. Rev. D 85 (2012) 014006.

\[
c_{1,s} = \begin{cases} 
\frac{1}{288} & s = 0 \\
\frac{1}{36} & s = \frac{1}{2} \\
\frac{5}{32} & s = 1 
\end{cases}, \quad c_{2,s} = \begin{cases} 
\frac{1}{360} & s = 0 \\
\frac{2}{90} & s = \frac{1}{2} \\
\frac{27}{40} & s = 1 
\end{cases}
\]
**First search** for exclusive diphoton production at high mass with intact protons in p-p collisions (CMS-TOTEM)

NO exclusive $\gamma\gamma$ event is found above expected backgrounds
First search for exclusive diphoton production at high mass with intact protons in p-p collisions (CMS-TOTEM)

\[ \zeta_i = \alpha_{em}^2 Q_4 m^{-4} N c_{i,s} \]

\[ |\zeta_1| < 2.88 \times 10^{-13} \text{GeV}^{-4} (\zeta_2 = 0), \]

\[ |\zeta_2| < 6.02 \times 10^{-13} \text{GeV}^{-4} (\zeta_1 = 0). \]

\[ M_{MM} > 5.87 \text{ TeV} \]
Virtual Magnetic Monopoles in pp Collisions

**Born-Infeld Theory**

\[ \mathcal{L}_{QED} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \quad \rightarrow \quad \mathcal{L}_{BI} = \beta^2 (1 - \sqrt{1 + \frac{1}{2\beta^2} F_{\mu\nu} F^{\mu\nu} - \frac{1}{16\beta^4} (F^\mu_{\mu} F^{\nu}_{\nu})^2}) \]

with

\[ \tilde{F}^{\mu\nu} \equiv \frac{1}{2} \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma}, \]

and

\( \beta \) is an a priori unknown parameter with the dimension of \([\text{Mass}]^2\), i.e. \( \beta \equiv M^2 \)

One may also consider a Born-Infeld extension of the Standard Model in which the hypercharge \( U_Y(1) \) gauge symmetry is realised non-linearly (J.Ellis et al., 1703.08450)

where

\[ M_Y = \cos \theta_W M \]
The Standard Model modified by a Born-Infeld of the hypercharge $U(1)_Y$ theory contains a finite-energy electroweak monopole solution $M$, with mass

$$M = E_0 + E_1$$

$$E_0 = 72.8 M_Y,$$

$$E_1 = 7.6 \text{ TeV}$$

Expanding the Born-Infeld Lagrangian in inverse powers of $\beta$, it's possible to find operators of dimension-8 and higher in the effective field theory and thus make contact with previous one.

For this purpose, it is convenient to use the following representation of the 4-dimensional Born-Infeld theory

$$\mathcal{L}_{\text{BI}} \simeq - \beta^2 I_2 - \beta^2 I_4 (1 + \mathcal{O}(F^2))$$

where

$$I_2 = \frac{1}{4\beta^2} F_{\mu
u} F^{\mu\nu} - \frac{1}{8\beta^4} F_{\mu
u} F^{\nu\rho} F^{\rho\lambda} F_{\lambda\mu} + \frac{1}{32\beta^4} (F_{\mu\nu} F^{\mu\nu})^2$$
Expanding the following Lagrangian to fourth order in the electromagnetic field strength,

\[ \mathcal{L}_{A\gamma} = \zeta_1 F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} F^{\rho\sigma} + \zeta_2 F_{\mu\nu} F^{\nu\rho} F_{\rho\lambda} F^{\lambda\mu} \]

it turns the following expressions for the coefficients \( \zeta_{1,2} \) in terms of \( \beta \)

\[ \zeta_1 = -\frac{1}{32\beta^2} \quad \zeta_2 = \frac{1}{8\beta^2} \]

By reinterpretating results from first CMS-TOTEM research for exclusive diphoton production in p-p collisions (CMS-PAS-EXO-18-014) in which

\[ |\zeta_1| < 2.88 \cdot 10^{-13} \text{ GeV}^{-1}, \quad |\zeta_2| < 6.02 \cdot 10^{-13} \text{ GeV}^{-1} \]

we found

\[ M > 26 \text{ TeV} \implies M_{MM} \geq (7.6 + 72.8 \cdot \cos \theta_W M) \simeq 1.67 \cdot 10^3 \text{ TeV} \]
The leading-order cross-section for unpolarised light-by-light scattering, in Born-Infeld theory, by considering in the $\gamma \gamma$ centre-of-mass frame is

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

SM Light-by-Light scattering has been observed by ATLAS and CMS. Taking last ATLAS and CMS results (Run2) related to the detection of $\gamma \gamma \rightarrow \gamma \gamma$ production in Pb+Pb collisions at $\sqrt{s} = 5.02$ TeV, it turns out to be that the measured fiducial cross section

$$\sigma_{ATLAS} = 120 \pm 17(\text{stat}) \pm 13(\text{syst}) \pm 4(\text{lumi}) \text{ nb}, \quad \sigma_{CMS} = 120 \pm 46(\text{stat}) \pm 48(\text{syst}) \pm 12(\text{theo}) \text{ nb}$$

we found

$$M_{MM} = (7.6 + 72.8 \cdot \cos \theta_W M) \simeq 7.92 \text{ TeV} \quad \text{for} \quad m_{\gamma \gamma} = 5 \text{ GeV}$$

$$M_{MM} = (7.6 + 72.8 \cdot \cos \theta_W M) \simeq 10.24 \text{ TeV} \quad \text{for} \quad m_{\gamma \gamma} = 100 \text{ GeV}$$
New projects to start with:

- Prof. P.Q. HUNG (University of Virginia): Look for Long Lived Particles with MoEDAL-MAPP detector (Mirror fermions)

- Prof. M.A. Sanchis-Lopez (IFIC) and Redamy Perez Ramos (IPSA, LPTHE, Paris): Studying event shapes in e+e- collisions to detect New Physics (Hidden Valley)

Next conferences/Workshops:

- RED-LHC @IFT, Madrid (9-11 May 2022)

- ICHEP2022, Bologna (6-13 July 2022)
Thanks for your attention